SKA1 Scientific Use Cases

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1 Introduction

1.1 Purpose of the Document

Here, we present a series of sample use cases that highlight some of the scientific objectives that could be enabled by phase 1 of the SKA (SKA1). This set consists of examples that include a broad range of scientific applications requiring the frequency coverage of SKA1-LOW and SKA1-MID ([AD3]), as well as the extended high frequency coverage that could be enabled by the advanced instrumentation programme band 6 receivers (beyond 15 GHz; [RD6]). These are intended to serve as examples, and should not be regarded as a substitute for the system level 1 requirements document.

The majority of these science use cases are fully consistent with the SKA1 baseline design ([AD3]). A small subset of these request analysis techniques or observing capabilities not currently in the Level 1 requirements, but have been considered through the engineering change proposal (ECP) process. For these cases, the ECP number is indicated in the 'Preconditions' section.

1.2 Scope of the Document

The science use cases presented here are by no means meant to identify specific surveys or projects that are guaranteed to be carried out with SKA1, nor are they intended to highlight the highest priority science cases. They should be used as a reference for science and engineering staff involved in the design, construction and operations activities.

2 Scientific Use Cases

2.1 A sensitive measurement of the power spectrum of 21cm brightness temperature fluctuations and tomographic cubes during the EoR and the Cosmic Dawn

PROJECT DETAILS	
Title	A sensitive measurement of the power spectrum of 21cm brightness temperature fluctuations and tomographic cubes during the EoR and the Cosmic Dawn
Principal Investigator	J. Kepler
Co-Authors	The EOR Team
Time Request	7,500 hrs

FACILITY		Preconditions
x	SKA1-LOW	An archive should be available to store time and frequency averaged, calibrated visibilities with <10 kHz spectral resolution and <10 second time resolution (TBD; e.g. Yatawatta et al. 2013) and spectral line data cubes with a resolution of <5 kHz for at least five years in order to collate the data acquired throughout the duration of the survey (TBD). TBD% of the antennas in the spiral arms should be available.
	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
x	SKA1-LOW	On-sky time 7,500 hrs total, split as 2500 hrs DEEP, 2500 hrs MEDIUM, 2500 hrs SHALLOW, leading to a total of 15,000 hrs of accumulated data assuming a two-beam capability with 150MHz bandwidth

		each.
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
x	Normal	These observations should be scheduled at night when local RFI is at a minimum. The autumn months may be preferable when the nights are longer and the ionosphere will be more stable after sunset. Dynamic scheduling is required based on ionospheric monitoring to assign best nights to DEEP fields, followed by MEDIUM and SHALLOW.
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
x	Commensal	**with Continuum SWG SKA1-LOW survey**
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Survey consists of three tiers – SHALLOW, MEDIUM, DEEP. DEEP: Total observing time 2500hrs using two beams of 150MHz bandwidth to acquire 1000 hrs on each of 5 fields in the frequency range 50-250MHz. Total sky coverage ~100 sq.deg. MEDIUM: Total observing time 2500hrs using one beam of 300MHz band to acquire 50 hrs on each of 50 fields in frequency range 50-350MHz. Total sky coverage ~1000 sq.deg.

SHALLOW: Total observing time 2500hrs using two beams of 150MHz band to acquire 10 hrs on each of 500 fields in frequency range 50-250MHz. Total sky coverage ~10,000 sq.deg. SHALLOW might be conducted in drift scan mode (TBD). MEDIUM band allows for HI intensity mapping of unresolved galaxies at redshifts 3-7 for cosmology and to probe the transition from pre- to post-reionization phase. DEEP field requires the quietest ionospheric conditions and times with minimal Milky Way emission. Observations should be started a few hours (TBD) after the sun has set to maximize the probability of a stable ionosphere. Each observation should be carried out for 3 to 8 hours, depending on scheduling constraints and the outcome of quality assessment checks. These observations should be scheduled at night when local RFI is at a minimum and the ionosphere is largely at rest. Long nights (>8hr) are preferred, but compromises might have to be made to minimize the effect of the Milky Way in the Southern Hemisphere. The Continuum SWG SKA1-LOW survey is designed to be commensual with these EoR observations. Commensual continuum observations will help provide a point source model for EoR foreground removal.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**x**	Stokes I
	YY	x	Stokes Q
	XY	x	Stokes U
	YX	x	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The Cosmic Dawn and the Epoch of Reionization (EoR) that occurred sometime during the first 800 million years after the big bang remains one of the least understood periods in the Universe. Optical and infrared spectroscopic probes of star-formation in galaxies quickly become limited during the EoR, due to scattering and absorption of Lyman Alpha photons in the neutral intergalactic medium along the line of sight. Redshifted 21cm line emission will become the most important probe of galaxy and structure formation during these early times, and the SKA will be the most sensitive instrument for characterizing the power spectrum of

brightness temperature fluctuations and for the first time directly make tomographic data cubes of the actual fluctuations out to the redshifts when the first galaxies formed. Here, we suggest a survey strategy to make both tomographic data-cubes, measure the power spectrum of 21cm brightness temperature fluctuations from z~25 to z~3, and if discovered use high-z radio sources to measure the HI forest at very high resolution. A 5 degree diameter field is sufficient to allow the sample variance on the power spectrum measurements to be ~3% on scales of one degree or less (Mellema et al. 2013), but multiple windows might be necessary to control systematics and reduce sample variance even further, especially on larger scales. Note: for a review of the science goals see Mellema et al. 2013 and Koopmans et al. (2015). *The SKA Phase 1 System (Level 1) Specifications document (Dewdney et al. 2013) shall be taken as the main reference unless stated otherwise.*

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
	x	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	DEEP: Five deep fields each with a FoV of 20 sq. degrees located in low (intensity and polarization) Galactic foreground regions (TBD). MEDIUM: 50 fields each with a FoV of 20 sq. degrees located in low (intensity and polarization) Galactic foreground regions (TBD). SHALLOW: 10,000 sq.deg. survey of essentially full sky within ~20 deg of zenith (TBD). Possibly conducted in drift scan mode. DEEP and MEDIUM fields are not necessarily contiguous to improve cosmic variance/control for systematics by checking agreement between fields. DEEP and MEDIUM fields will be chosen based on available results SKA precursors in the southern hemisphere (e.g. MWA and PAPER) and SKA commissioning observations in order to minimize the impact of the sky temperature (i.e. a cold region is needed), to minimize Galactic polarization in the field and to minimize leakage of sources and the Milky Way in the far field (via the beam sidelobes). A snapshot survey (few-	

	min integration) with SKA1-LOW preceding SHALLOW would help to cover the full observing band.	
Positions of targets	TBD.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………..]
	x	NO
Time Critical?		YES [details: ……………………………………..]
	X	NO
Integration time per target (hrs)	DEEP: 1000 hrs, MEDIUM: 50 hrs, SHALLOW: 10 hrs.	
Average peak flux density (Jy or Jy per beam)	Unresolved point sources within the large field of view are typically 5 Jy/beam or brighter at 110 MHz in the wide fields covered by one SKA-low pointing (e.g. Intema et al. 2011; Yatawatta et al. 2013). Fields on even brighter (100Jy or more) could potentially be chosen for precise in-field calibration purposes. In general no single HI line will be detected with high significance, except in cases of HI-absorption against very bright radio source at redshifts of the CD/EoR era, if discovered.	
Range of peak flux densities (Jy or Jy per beam)	See above	
Expected polarised flux density (expressed as % of total)	Brightness temperatures in polarized emission up to several Kelvin are expected on all angular scales (arcminutes and larger) in most chosen fields. On ~5 arcminute scales this corresponds to a few mJy, on degree scales this could be hundreds of mJy. Compact sources might also be polarized at the few percent level, corresponding to tens of mJy for the brightest sources. Post-calibration polarization leakage should be less than 10^{-4} such that polarized foreground leave <<1 mK of residual Tb in the images, i.e. well below the expected CD/EoR signals (Asad et al. 2015).	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	DEEP fields focus on HI line emission over frequencies (50-250MHz) corresponding to redshifts 4.7-27. Two beams required each of 150 MHz (freq. spread over the 200MHz window TBD; see below). MEDIUM fields cover the full band 50-350MHz corresponding to redshifts 3-27. One beam. SHALLOW fields focus on HI line emission over frequencies (50-250 MHz) corresponding to redshifts 4.7-27. Two beams required of 150MHz each. DEEP and SHALLOW may benefit from picket fence observing with contiguous central frequency band and narrow outrigger bands offset in frequency to better characterize smooth continuum foregrounds.
Total Bandwidth (MHz)	2 x 150 MHz (DEEP and SHALLOW), 300 MHz (MEDIUM)
Minimum and maximum frequency over the entire range of the setup (MHz)	50-350 MHz
Spectral resolution (kHz)	Maximum permitted by the correlator: ~4.6 kHz. (required for RFI flagging)
Temporal resolution (in seconds)	~3 sec (corresponding to ionospheric fluctation time scales)

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	N/A
Maximum baseline required (km)	N/A
Primary beam size (sq degrees)	N/A
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	
Required rms (Jy) (if polarisation products required	

define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	X	n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	The highest angular resolution will be 6-7 arcseconds at 110 MHz (approximately 65 km maximum baseline) for sky and ionospheric modelling, calibration and compact- source foreground subtraction. CD/EoR science will be done largely on core resolution of ~1 arcminute and larger.	
Maximum baseline required (km)	65km or array maximum baseline (sky modelling, ionosphere, foreground subtraction). Core ~km (EoR imaging/power spectrum)	
Mapped image size (degrees)	See earlier	
Required pixel resolution (arcseconds)	~6 arcsec (foreground imaging), ~1 arcmin (EoR)	
Number of image channels	~65536	
Channel width (kHz)	~4.6kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	~1 microJy per 1 MHz bandwidth at 150MHz (e.g. Mellema et al. 2013) resulting in ~ 1mK brightness temperature.	
Dynamic range within image per channel (if polarisation products required define for each)	>2.5x10^6	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin)	

(single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Directionally dependent gain calibration should be used to take into account direction-dependent effects associated with wide-field imaging at low frequencies (Bhatnagar et al. 2008; Yatawatta et al.).
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Reprocessing will be required multiple times, updating the sky/calibration models and improving low-level RFI excision.
Data products	RFI flagging on raw highest resolution (1sec-4.6KHz) data. Calibrated visibilities with <10 kHz spectral resolution and <10sec seconds of time averaging (TBD). Different levels of averaging can be stored. A spectral line (tomographic) cube with 0.1 MHz spectral resolution will result. A two-dimensional power spectrum of the coherently added visibilities (power in both k-parallel and k- perpendicular modes should be measured; e.g. Beardsley et al. 2013). Higher-order statistics will be derived. Imaging will be done in the DEEP field. HI absorption line spectra will be inferred from the DEEP data (or dedicated high-z radio source observations).

Description of pipeline	Calibrated visibilities will first be subjected to an optimized flagging analysis and then averaged to ~10 kHz and ~10 sec (TBD; e.g. Yatawatta et al. 2013) spectral resolution. Directionally dependent calibration will be done using these data-cubes, using increasingly more complex sky models. This sky model will be removed and from the residual data- cubes the smooth FGs will be removed using different techniques. From these data set (a combination of all observing epochs) a three-dimensional power spectrum will be measured (e.g. Bowman et al. 2009; Parsons et al. 2013). The visibility data should also be combined and imaged with a weighting that is inversely proportional to the system temperature squared (TBD), and a final spectral line data cube with 0.1 MHz resolution should be generated. The tomographic data cubes with S/N>3 will also be studied in detail and compared to simulations.
Quality assessment plan & cadence	Amplitude and phase coherence quality assessment test at 20 minute intervals. An initial pipeline calibrated spectral line data cube image should be generated and the noise calculated as a function of frequency.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of scheduling block.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
The data analysis for this experiment will need to build on the experience gained from current EoR detections experiments using the GMRT, MWA, LOFAR and PAPER.

REFERENCES

Asad et al. (2015), *Polarization leakage in Epoch of Reionization windows: I. LOFAR observations of the 3C196 field*, MNRAS, 451, 3709

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Intema, H. et al., 2011, *Deep Low Frequency Observations of the NOAO Bootes field*, A&A, 535, 13

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2.2 Global EoR with SKA1-LOW

PROJECT DETAILS	
Title	**Global EoR with SKA1-LOW**
Principal Investigator	**N. Udaya Shankar[1],**
Co-Authors	**Mayuri Sathyanarayana Rao[1], Saurabh Singh[1], Ravi Subrahmanyan[1] (1- Raman Research Institute, India)**
Time Request	Commissioning Time (100 hr), On-sky integration (12 X 24 hr), TBC

FACILITY		Preconditions
X	SKA1-LOW	A Compact Array of 64 Outrigger antennas (Half the number of SKA1-Low stations) that are interspersed amongst core stations of SKA1-Low. The signal transport and correlator configuration is required to provide: 1. Correlation products between outriggers and core SKA1-low stations. 2. Correlation products between the SKA1-Low stations. 3. Correlation products between outriggers themselves. **4.** Autocorrelation spectra of outriggers.

		An engineering change proposal (ECP150021) was assessed to determine the viability of implementing these preconditions. This ECP has been rejected due to changes in the LOW design.
	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
X	SKA1-LOW	~400 hr
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
X	Custom Experiment	1. The autocorrelation spectra of outriggers would serve as a measurement set for global redshifted 21-cm signal from reionization. 2. The calibration set is derived from the visibility products measured by three different types of 2-element interferometers with: a) SKA stations as interferometer elements, b) Outriggers as interferometer elements, and **c)** Outriggers and SKA stations as interferometer elements.
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
The observations will be carried out in a drift scan mode in a set of sessions in which the SKA stations will be phased towards different directions spanning the meridian.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	X	Stokes Q
	XY	X	Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
A key science for SKA is the interferometer imaging of spatial-temporal fluctuations in the hydrogen ionization fraction and spin temperature as a diagnostic of the Epoch of Reionization (EoR). The global EoR signal, which is outside the purview of the SKA observing in interferometer mode, provides the mean departure of the 21-cm brightness temperature from the ambient CMB and the critical zero-spacing measurement vital for establishing the base level of the fluctuations. We propose placing a compact array of outrigger elements, interspersed between core stations of SKA1-low, to enable detection of the global EoR as a supplement to the EoR key science. The outrigger elements are to be wideband and frequency-independent to minimize the leakage of spatial structures to the frequency domain. The autocorrelations of the outrigger elements would form the measurement set for the global EoR. The visibilities measured between outriggers and SKA stations would provide the global sky model and calibration set required for precise calibration of the mode-coupling, primary beam and bandpass of the outriggers. The autocorrelations of and ultra-short baselines between the outriggers would image structures larger than those that can be imaged by SKA1-low and provide a supplement to all-sky continuum imaging.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	Not applicable	
Positions of targets	Not applicable	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)		
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)		
Expected polarised flux density (expressed as % of total)		

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (X_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	150 MHz
Total Bandwidth (MHz)	200 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	50 to 250 MHz
Spectral resolution (kHz)	10 kHz (RFI mitigation requirement)
Temporal resolution (in seconds)	100 ms (RFI mitigation requirement)

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	

Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	12 arcmin	
Maximum baseline required (km)	0.6 km	
Mapped image size (degrees)	20^0 (Null to Null station beam width at 50 MHz, the lowest operating frequency)	
Required pixel resolution (arcseconds)	120 arcsec	
Number of image channels	~2k channels	
Channel width (kHz)	100 kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	NA	
Dynamic range within image per channel (if polarisation products required define for each)	NA	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	1. Standard SKA high dynamic range imaging. 2. Broadband full polarisation calibration including bandpass calibration. 3. Solving for the beam patterns of the outriggers. 4. RFI mitigation.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Flag data acquired with TEC greater than 5 units (TBC).
Data products	• 1. Multi-channel visibilities measured between

	SKA stations. 2. Multi-channel visibilities measured between SKA stations with outriggers. 3. Multi-channel visibilities measured between outriggers. 4. Autocorrelation spectra of outriggers. These four will lead to 1. Improved Global Sky Model including large scale structures beyond the imaging capabilities of SKA 1-low. 2. Global EoR spectrum.
Description of pipeline	• 1. Standard SKA high dynamic range full polarisation imaging pipeline. 2. Bandpass, Polarimetric and primary beam calibration of outriggers.
Quality assessment plan & cadence	Standard; at the end of each session of observation.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	At completion of the full project.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
1. Design, Development and commissioning of outrigger antennas and associated electronics. 2. Design of the array configuration for outriggers and their placement relative to the SKA core stations. 3. Signal transport considerations for carrying outrigger signals to the central correlator building. 4. Interfacing the outrigger signals to the SKA correlator. 5. Operating the correlator in a mode that measures all possible visibility products within the total array consisting of SKA stations and outriggers, as well as the autocorrelation spectra of signals from outriggers. 6. An assessment of data acquisition rates and procurement of storage requirements. 7. Pipelines to process the measurement and calibration data sets to produce the science deliverables (Global EoR signal and GSM with large scale structure).

REFERENCES
1. Subrahmanyan, R., Shankar, U.N., Pritchard, J.,& Vedantham, H.K., 2015, Advancing Astrophysics with the Square Kilometre Array (AASKA14), 14 2. Dewdney, P. E., Turner, W., Millenaar, R., McCool, R., Lazio, J., Cornwell, T. J., 2013, SKA1- System baseline design.

2.3 A blind HI 21-cm absorption line survey at 3<z<6 (200 – 350 MHz) using SKA1-LOW

PROJECT DETAILS	
Title	**A blind HI 21-cm absorption line survey at 3<z<6 (200 – 350 MHz) using SKA1-low**
Principal Investigator	**HI galaxy science working group**
Co-Authors	**HI galaxy science working group**
Time Request	5000 hrs (Commensal with SKA1-low EoR survey)

FACILITY		Preconditions
X	SKA1-LOW	Spectral resolution of 4.6 kHz over 200 – 350 MHz.
	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
X	SKA1-LOW	5000 hrs
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE	Details

(as defined in Concept-of-Operations)		
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
We observe 50 unique pointings with SKA1-low, commensally with the EoR experiment covering 50 – 200 MHz. Each pointing is observed for 100 hrs covering 200 – 350 MHz with a spectral resolution of 4.6 kHz to search for HI 21-cm absorption towards sources brighter than 10 mJy at 3<z<6. This use case covers requirements for the deep 21-cm absorption line survey that can be carried out commensally with the EoR experiment. The dynamic range requirements and pipeline processing steps specified here will also apply to a shallower (less integration time per pointing but covering much larger area) absorption line survey.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX	**X**	Stokes I
X	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
HI 21-cm absorption line surveys towards bright continuum radio sources can be used to trace the evolution of cold atomic gas associated with normal and active galaxies (Morganti et al.

2015). This project will use the capabilities of SKA1-low to search for cold atomic gas at 3<z<6 towards sources brighter than 10 mJy. The observations will be sensitive to column densities of ~10^{19}cm^{-2} gas with a temperature of 100 K. Besides revealing the evolution of cold atomic gas cross-section of galaxies in an unbiased way, the population of high-z quasars discovered through this survey will be used to constrain quasar luminosity function and its impact on the IGM at high redshifts.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	50 pointings	
Positions of targets	TBD *(To be aligned with the SKA1-low EoR experiment)*	
Rapidly changing sky position? (e.g. comet, planet)		YES [details:]
	X	NO
Time Critical?		YES [details:]
	X	NO
Integration time per target (hrs)	100 hrs per pointing	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)		
Expected polarised flux density (expressed as % of total)	N/A	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*

Central Frequencies (MHz) (including redshift, observatory correction)	275 MHz (corresponds to z=4.17 for redshifted HI 21-cm line)
Total Bandwidth (MHz)	150 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	Minimum: 200 MHz; Maximum: 350 MHz
Spectral resolution (kHz)	4.6 kHz (~ 5 km/s at 275 MHz)
Temporal resolution (in seconds)	'standard' (or shortest possible as required for RFI mitigation)

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	0.07 arcmin at 275 MHz (corresponding to 65 km baselines)	
Maximum baseline required (km)	65 km	
Mapped image size (degrees)	Full FoV	
Required pixel resolution (arcseconds)	0.6 arcseconds	
Number of output channels	3 (each corresponding to 50 MHz BW to yield continuum images at 225, 275 and 325 MHz)	
Output bandwidth (minimum and maximum frequency - MHz)	(see above)	
Required rms (Jy per beam) (if polarisation products required define for each)	Stokes I: 0.4 uJy/beam (For BW = 150 MHz, T_{int} = 100 hrs and A_e/T_{sys} at 275 MHz for the rebaselined design)	
Dynamic range within image (if polarisation products required define for each)	> 10^6 assuming brightest source to be ~1 Jy	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	0.07 arcmin at 275 MHz (corresponding to 65 km baselines, or maximum allowed by configuration) .
Maximum baseline required (km)	65 km (or maximum of configuration)

Mapped image size (degrees)	Full FoV	
Required pixel resolution (arcseconds)	0.6 arcseconds	
Number of image channels	37500	
Channel width (kHz)	4 kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	Stokes I: 0.08 mJy/beam/channel	
Dynamic range within image per channel (if polarisation products required define for each)	10^4 (assuming brightest sources of ~1 Jy)	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)	**N/A**	
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
	X	5%
		10%

		20-50%
		n/a

DATA ANALYSIS	
Procedures required	• RFI mitigation and flagging • Gain calibration • Wide-field wideband interferometric imaging including correction for direction dependent effects (Bhatnagar et al. 2013) • Continuum subtraction • Doppler correction
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Only calibrated visibilities, continuum source model and image cubelets or spectra extracted towards >10 mJy sources will be archived. Therefore, reprocessing of calibrated visibilities will be required to derive more information, as needed.
Data products	• Stokes I continuum visibility datasets and images at 225, 275 and 325 MHz. • Stokes I spectral-line cube over 200 – 350 MHz with 4 kHz resolution. • Cubelets and spectra towards all the sources brighter than 10 mJy in the FoV, along with the RFI flags applied to the data. • Continuum source and spectral line catalogs.
Description of pipeline	The visibility dataset for each observing run will be subjected to the following: • RFI mitigation and flagging • Gain calibration • Generate continuum visibility dataset • Generate continuum image (AWProjection, Self-calibration and correction for direction dependent effects) • Apply the self-calibration solutions and direction-dependent corrections to the spectral line visibility dataset • Subtract continuum from the line dataset • Doppler correct (CVEL) line dataset • Generate stokes-I spectral-line cube for full FoV at 4.6 kHz resolution • Deconvolve channels with line detections, if needed.

	After the quality assessment, the calibrated continuum and spectral line visibilities to be combined with the data from other observing runs to generate `final' stokes-I spectral-line cube(s).
Quality assessment plan & cadence	For every observing run: check gain solutions, bandpass calibration, direction dependent corrections, and frequency-dependent flagging applied to the data.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	None.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Strategies to combine calibrated line datasets from different observing runs need to be tested.

REFERENCES
• Bhatnagar et al. 2013, ApJ, 770, 91 • Morganti et al. 2015, Proceedings of Advancing Astrophysics with the Square Kilometre Array (AASKA14). 9 -13 June, 2014

2.4 SKA1 All-Sky HI Survey

PROJECT DETAILS	
Title	**SKA1 All-Sky HI Survey**
Principal Investigator	**Oort**
Co-Authors	**HI-Galaxy SWG**
Time Request	**10,000 hrs**

FACILITY		Preconditions
	SKA1-LOW	
•	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
•	SKA1-MID Band 2	10,000
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)	Details

•	Normal	Mosaic observations
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
•	Commensal	Continuum, polarisation, cosmology
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
A hemispheric band-2 HI survey will require at least 20,000 fields to obtain uniform sensitivity at z=0. Each field needs to be observed for a total of 30 mins, and will require multiple visits to ensure a good synthesised beam.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
•	XX (for flagging)	•	Stokes I (final cubes required to be in Stokes I)
•	YY (for flagging)		Stokes Q
•	XY (for RFI mitigation)		Stokes U
•	YX (for RFI mitigation)		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
A hemispheric survey will be a major legacy survey of the SKA1-mid facility. An HI survey will complete the census of gas-bearing galaxies in the Local Group down to the faintest limits, and thereby help our understanding of galaxy formation processes. It will allow precise measurements of the effect of environment (density, intra-group gas, tidal fields etc) on global quantities such as the HI mass function, as well as at a detailed local level through processes such as stripping and stimulated star formation. This will permit important, and accurate, measurements of galaxy evolution processes at the current epoch and (for the more massive galaxies, or with stacking techniques) over the past 2-5 billion years. The survey will also be a stringent test of ΛCDM by mapping the structure and motions of galaxies and determining whether their growth rate matches GR predictions. This survey will detect HI in over 550,000 galaxies to a mean redshift of 0.06 at a resolution of 15”, with a 5-σ column density sensitivity of 2×10^{20} cm^{-2}. The shorter baselines will permit high sensitivity observations of the Galactic Plane and Magellanic Clouds, whilst the longer baselines will allow absorption-line measurements against background continuum sources in order to probe: (a) associated

absorbers; (b) intervening absorbers; and (c) the Galactic and Magellanic ISM. The large time requirement means that such a survey will likely only be possible in commensal mode. However, as discussed at the 2015 Stockholm KSP meeting, there is a very close match between the HI requirements and those of the continuum, magnetism and cosmology SWGs.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	1	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	20,000	
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	•	NO
Time Critical?		YES [details: ……………………………………….]
	•	NO
Integration time per target (hrs)	0.5	
Average peak flux density (Jy or Jy per beam)	2 mJy	
Range of peak flux densities (Jy or Jy per beam)	0-10 mJy	
Expected polarised flux density (expressed as % of total)	0%	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (X)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1180 MHz

Total Bandwidth (MHz)	500 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	950 – 1430 MHz
Spectral resolution (kHz)	15.3 kHz
Temporal resolution (in seconds)	2 sec for imaging (only baselines <10 km are useful); 0.14 sec for absorption spectra

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	15 arcsec
Maximum baseline required (km)	10 km (150 km for HI absorption and commensal science)
Mapped image size (degrees)	1
Required pixel resolution (arcseconds)	3 arcsec (0.2 arcsec for HI absorption, but only towards bright continuum sources)
Number of image channels	32,768

Channel width (kHz)	15.3 kHz (also require zoom mode channels of 0.5 kHz over 1416–1424 MHz to cover galactic HI)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	0.9 mJy (Stokes I)	
Dynamic range within image per channel (if polarisation products required define for each)	100:1 spatial DR 10,000:1 spectra DR (continuum subtraction)	
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	RFI mitigation, flagging, calibration, continuum subtraction, widefield imaging, mosaicing, source-finding and source parameterisation
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Likely processing issues: • Large data volumes • Widefield images with non-coplanar baselines • Accurate primary beam for mosaicing • Flagging of RFI • Requirement to search cubes multiple times (source detection). • Requirement to stack at a given set of coordinates
Data products	Stokes I data cubes; image cut-outs; spectra; minicubes; catalogues
Description of pipeline	• Collect visibilities on multiple days • Apply barycentric correction • Apply flagging • Calibrate visibilities • Peel strong continuum sources • Subtract remaining continuum sources using global sky model • Make daily cubes at multiple resolutions for each pointing • Combine cubes (and beams) for individual pointings in the image domain • Residual polynomial continuum subtraction in image domain • Linear mosaicking of multiple fields, followed by cutouts in RA, Dec, Freq • Multiscale deconvolution of strongest sources
Quality assessment plan & cadence	• Inspect RFI occupancy plots • Examine rms and histogram of pixel values in daily cubes. • Compare flux densities of known sources in daily cubes.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	On completion of observations and data reduction

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
For science and legacy purposes, it would be preferable to expand the survey to 3-π steradians. However, column density sensitivity are also important, and these would suffer if the survey became too shallow.

REFERENCES
Staveley-Smith, L., Oosterloo, T., 2015, POS(AASKA14), 167

2.5 Deep Galactic and Magellanic HI Survey

PROJECT DETAILS	
Title	**A Deep Galactic HI survey**
Principal Investigator	**HI galaxy science working group**
Co-Authors	**HI galaxy science working group**
Time Request	4500

FACILITY		Preconditions
	SKA1-LOW	
	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
X	SKA1-MID Band 2	4500
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
There are two components, Galactic plane (2500 hours) and Magellanic Clouds (1500 hrs). These could be commensal with any Band 2 survey of Galactic plane or MCs, provided availability of a 8 MHz spectral zoom at 1420 MHz.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX	**X**	Stokes I
X	YY	X	Stokes Q

X	XY	X	Stokes U
X	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
These observations will obtain high spectral resolution across the frequency range of Galactic and Magellanic HI with the band 2 of SKA1-MID. This survey complements the large-area Galactic HI sky survey. A Galactic HI survey will provide a legacy data set providing information about the cold-gas properties of galaxies, which, in synergy with multi-wavelength, multi-archive large area data, will provide significant insight into galaxy evolution. This will provide particular insight into the resolved components of the Interstellar Medium and structure of the Milky Way Atomic hydrogen in the interstellar medium is mainly found in two phases: a warm phase (WNM) with a temperature of several 1000 K and a cold phase (CNM) with a typical temperature of 100 K. While the line widths of the WNM are at least 20 km/s, due to the low temperature of the CNM, the thermal width of the HI line of the of the CNM can be smaller than 1 km/s. Therefore, in order to properly resolve the HI spectral line of the CNM, and to be able to do a proper kinematical analysis, a velocity resolution of ~0.1 km/s (0.5 kHz) is needed. Inclusion of full polarimetric information will allow full HI Zeeman analysis for magnetic field measurements. The high spectral resolution is only required over limited bandwidth. This is because, due to beam smearing effects, detailed studies of the CNM are only feasible for Galactic HI and in galaxies at very low redshift. The overall bandwidth needed has to be wide enough to cover the total velocity range of the atomic hydrogen in our Galaxy, with enough extra frequency space so that the data contain adequate line-free channels to define the continuum properly. Therefore, a velocity range of at least ~1500 km/s (~8 MHz) is required.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	1200	

Positions of targets	Galactic Plane, Magellanic Clouds	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	2.3 hrs per point (Galactic Plane) to 15 hrs per point (Magellanic Clouds)	
Average peak flux density (Jy or Jy per beam)	50 Kelvin for emission. Absorption towards 100 mJy sources.	
Range of peak flux densities (Jy or Jy per beam)	1 – 150 Kelvin for emission. Absorption towards 10 mJy to 10 Jy sources.	
Expected polarised flux density (expressed as % of total)		

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1420 MHz (rest frequency of atomic hydrogen line)
Total Bandwidth (MHz)	8 MHz at high spectral resolution (3 concatenated 4 MHz zoom bands as described in ECP 140009 (approved and implemented). Plus continuum (coarse channelized data).
Minimum and maximum frequency over the entire range of the setup (MHz)	1416 MHz – 1424 MHz
Spectral resolution (kHz)	0.5 kHz (equivalent to ~0.1 km/s velocity resolution)
Temporal resolution (in seconds)	'Standard' 5s

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	

Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	
Required rms (Jy per beam) (if polarisation products required define for each)	

Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	10 – 20 arcsec	
Maximum baseline required (km)	10 km	
Mapped image size (degrees)	100 sq deg	
Required pixel resolution (arcseconds)	~2 arcsec	
Number of image channels	16,000	
Channel width (kHz)	0.5 kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	0.5 – 1 mJy	
Dynamic range within image per channel (if polarisation products required define for each)	1000:1	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Flagging, calibration in full Stokes (I,Q,U, and V),
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	Fully calibrated I, Q, U and V cubes at full spectral resolution.
Description of pipeline	Calibrated visibilities will first be subjected to an optimized flagging analysis. The visibility data should be imaged with robust weighting. Spectral line data cubes from different observing runs should be

	combined by taking into account a weighting which is inversely proportional to the noise in each cube. One should also consider gridding the UV data so that new data can be combined in this grid as it is observed. A similar approach is adopted for the VLA CHILES survey (Fernandez et al. 2013).
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Prefer to operate commensally with other projects interested in same targets.

REFERENCES
HI Presentations at the "Advancing Astrophysics with the SKA" science meeting in Sicily, 2014.

2.6 Medium-Deep HI Imaging Survey

PROJECT DETAILS	
Title	**Medium-Deep HI Imaging Survey**
Principal Investigator	**Oort**
Co-Authors	**HI galaxy science working group**
Time Request	2000 hours

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	2000 hours
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	Desirable if commensal with magnetism/continuum observations (i.e. all 4 polarisations would be needed)
X	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
This survey will consist of repeated observations to a total observing time of 3000 hours of a single pointing on the sky. Night time observations preferred to avoid solar interference.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX	X	Stokes I
X	YY		Stokes Q
X	XY (for RFI mitigation)		Stokes U
X	YX (for RFI mitigation)		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
This survey is the medium-deep layer of a 'wedding cake' tiered strategy to observe HI in galaxies from 0<z<0.8. This tier covers 20 deg^2 in band 2. These surveys will enable the study of many science topics including, but not limited to: • Studies of the mass properties of galaxies: the cosmic neutral gas density and HI mass function as a function of redshift and environment • Studies of the environment: gas inflow and removal from galaxies • Angular momentum and kinematics of galaxies: scaling relations between galaxy properties and the evolution of the Tully-Fisher relation.

‘TARGETS’ OF OBSERVATIONS		
Type of observation (what defines a ‘target’)		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	One deep field	
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………..]
	X	NO
Time Critical?		YES [details: ……………………………………..]
	X	NO
Integration time per target (hrs)	Total 2000 hours (individual observations of 4-8 hours)	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)	4e-5 - 2 Jy/beam.	
Expected polarised flux density (expressed as % of total)	0	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1185 MHz
Total Bandwidth (MHz)	470 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	950 – 1420 MHz (band 2)
Spectral resolution (kHz)	12.4 kHz
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	Various from 5 - 30 arcsec
Maximum baseline required (km)	150 km
Mapped image size (degrees)	20 degrees
Required pixel resolution (arcseconds)	1 arcsec
Number of image channels	65536

Channel width (kHz)	12.4 kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	4e-5 Jy	
Dynamic range within image per channel (if polarisation products required define for each)	~1e5	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	RFI flagging, calibration, continuum subtraction, data combination to created integrated deep cube (uv and image domain), cube imaging, mosaicing, source-finding, source parametrization,
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Likely processing issues: - Large data volumes - Widefield images with non-coplanar baselines - Accurate primary beam for mosaicking - RFI flagging - Requirement to search cubes multiple times (source detection) - Requirement to stack signals from a given set of coordinates
Data products	Calibrated, imaged, continuum subtracted datacubes; image cut-outs, spectra, moment maps, catalogues
Description of pipeline	- Collect visibilities on multiple days - Apply barycentric correction - Apply flagging - Calibrate visibilities - Peel strong continuum sources - Polynomial continuum subtraction - Make daily cubes at multiple resolutions for each pointing - Combine cubes (and beams) for individual pointings in the image or uv domain - Residual continuum subtraction in image domain - Linear mosaicking of multiple fields, followed by cutouts in RA, Dec, Freq - Multiscale deconvolution of strongest sources
Quality assessment plan & cadence	- Examine rms and histogram of pixel values in daily cubes.

	- Compare flux densities of known sources in daily cubes.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of scheduling block and pipeline reduction

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Observing parameters depend sensitively on array configuration and receiver sensitivity.

REFERENCES
Blyth et al, 2015, POS(AASKA14), 128 Meyer et al, 2015, POS(AASKA14), 131 Obreschkow et al., 2015, POS(AASKA14), 138 Staveley-Smith & Oosterloo, 2015, POS(AASKA14), 167

2.7 An all-sky absorption survey at z~1 - 3

PROJECT DETAILS	
Title	**An all-sky HI absorption survey at z ~ 1-3**
Principal Investigator	**HI galaxy science working group**
Co-Authors	**HI galaxy science working group**
Time Request	1000 hrs

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	1000
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	

	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY

POLARISATION PRODUCTS REQUIRED: *BEAMFORMER (__) or CORRELATOR (X)*			
x	XX		Stokes I
x	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Blind spectral line surveys toward bright continuum sources in the distant Universe provides a powerful means of identifying gas-rich galaxies at high-redshift through their 21cm HI absorption signature in the form of intervening absorption systems and allow studies of the ISM in galaxies. Similarly, the associated absorption seen against AGN gives valuable information on the interaction of the AGN with the surrounding ISM, which is very relevant for studying the feedback mechanisms for galaxy formation. For both purposes, this redshift range is largely unexplored and SKA1 gives the first real opportunity to study these issues. This project aims to conduct a blind survey with band 1 (350 to 1050 MHz) on SKA1-MID to search for redshift HI absorption line systems over the redshift range, $0.35 < z < 3.0$. Such a survey will provide an unbiased sample of gas-rich objects in the distant Universe and the role of cold gas in AGN.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	x	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets		
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	x	NO
Time Critical?		YES [details: ……………………………………….]
	x	NO
Integration time per target (hrs)	20 minutes per target	

Average peak flux density (Jy or Jy per beam)	+100 mJy at 600 MHz
Range of peak flux densities (Jy or Jy per beam)	100-3000 mJy
Expected polarised flux density (expressed as % of total)	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	full band from 350 to 1050 MHz
Total Bandwidth (MHz)	700 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	350-1050 MHz
Spectral resolution (kHz)	15 kHz
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
	x	5%
		10%

		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	~1 arcsec at 1000 MHz	
Maximum baseline required (km)	120 km	
Mapped image size (degrees)	full primary beam (4 degrees at 350 MHz)	
Required pixel resolution (arcseconds)	0.2 arcsec	
Number of image channels	65000	
Channel width (kHz)	10 kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	~ 5mJy per 8 km/s channel	
Dynamic range within image per channel (if polarisation products required define for each)	>100	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	
Mapped image size (degrees)	
Number of image channels	
Channel width (kHz)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	

Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Standard imaging After initial flagging, the data should be processed by the both the spectral line and continuum pipelines. Some time averaging is likely to be acceptable since the target will be at the phase center.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	ii) Continuum image with 30% bandwidth (multi-frequency synthesis) centered at 600 MHz. This will be used to check the total flux density of the background source which should further be logged in a public database for future sky-model reference
Description of pipeline	Standard spectral line and continuum imaging pipelines

Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES

2.8 Cosmic Web: The extended environment of galaxies and the IGM

PROJECT DETAILS	
Title	**Cosmic Web: The extended environment of galaxies and the IGM**
Principal Investigator	**J.H. Oort**
Co-Authors	**HI galaxy science working group**
Time Request	~5000 hours (100 hrs per target)

FACILITY		Preconditions
	SKA1-LOW	
	SKA1-MID	X

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	100 hrs
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	Continuum & Spectral Imaging
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Because of the low surface brightness, short baselines are crucial. Night-time observations are preferred to avoid solar interference.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX	**X**	Stokes I
X	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Numerical simulations predict that the matter distribution in the Universe forms a Cosmic Web of extended structures and gaseous filaments. This Cosmic Web is thought to play an important role in both the growth and the depletion of the gas reservoir in galaxies. To learn more about these large-scale structures and the role they play in the evolution of the gas content of galaxies, the extended environment of galaxies has to be observed. Due to the UV background, it is expected that the HI column densities of most of this Cosmic Web is (well) below ~10^{19} cm^{-2} and to detect the Cosmic Web, column density sensitivities of below ~10^{18} cm^{-2} are needed at resolutions of ~ 1 arcmin. SKA1-Mid offers the first real possibility to achieve this and may bring a breakthrough in this area. A pre-selected sample of ~50 galaxies will be observed for ~100 hours each to study the Cosmic Web in different environments and for different galaxy types.

‘TARGETS’ OF OBSERVATIONS		
Type of observation (what defines a ‘target’)	X	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets		
Positions of targets	~50 target spread over full LST range	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	100	
Average peak flux density (Jy or Jy per beam)	This varies per object, on short baselines the HI flux can be ~5Jy	
Range of peak flux densities (Jy or Jy per beam)	The expected noise is ~0.02 mJy/beam over 24.2 kHz. Peak line flux in is ~100 mJy/beam	
Expected polarised flux density (expressed as % of total)	NA	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1410MHz
Total Bandwidth (MHz)	>32 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	~1393 to ~1425 MHz
Spectral resolution (kHz)	~15 kHz (~3 km/sec)
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	

Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	Various: ~20 arcsec, 1 arcmin and 3 arcmin	
Maximum baseline required (km)	~3km	
Mapped image size (degrees)	~1.5 degrees	
Required pixel resolution (arcseconds)	~5 arcsec, ~15 arcsec and ~45 arcsec	
Number of image channels	~2000	
Channel width (kHz)	15 kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	~0.02-0.05 mJy/beam (depending on weighting)	
Dynamic range within image per channel (if polarisation products required define for each)	1e5	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Standard imaging procedures with image cubes at multiple resolutions. Addition of single dish data for imaging.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	Image cubes, moment maps, images of the PSF
Description of pipeline	Calibrated visibilities will first be subjected to an optimized flagging analysis. The visibility data should be imaged with robust weighting. Spectral line data cubes from different observing runs should be

	combined by taking into account a weighting which is inversely proportional to the noise in each cube. One should also consider gridding the UV data so that new data can be combined in this grid as it is observed. A similar approach is adopted for the VLA CHILES survey (Fernandez et al. 2013).
Quality assessment plan & cadence	After every observing run (approximately 10 hours)
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	upon completion of scheduling block and pipeline reduction

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES
Braun, R & Thilker, 2004 A&A 417, 39T De Blok, W.J.G. et al, 2014, A&A 569A, 58D Carignan, C., et al. 2013, AJ, 146, 48 Oosterloo et al. 2007, AJ, 134, 1019 Pisano, D.J. 2014, AJ 147, 48P Popping, A. et al. 2009 A&A 504, 15P Popping, A. et al, 2015, AASKA14, 132

2.9 Deep HI Imaging Survey

PROJECT DETAILS	
Title	**Deep HI Imaging Survey**
Principal Investigator	**Oort**
Co-Authors	**HI galaxy science working group**
Time Request	3000 hours

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	3000 hours
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	Desirable if commensal with magnetism/continuum observations (i.e. all 4 polarisations would be needed)
X	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
This survey will consist of repeated observations to a total observing time of 3000 hours of a single pointing on the sky. Night time observations preferred to avoid solar interference.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX	X	Stokes I
X	YY		Stokes Q
X	XY (for RFI mitigation)		Stokes U
X	YX (for RFI mitigation)		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
This survey is the deep layer of a 'wedding cake' tiered strategy to observe HI in galaxies from 0<z<0.8. This tier covers a single pointing in band 1. These surveys will enable the study of many science topics including, but not limited to: • Studies of the mass properties of galaxies: the cosmic neutral gas density and HI mass function as a function of redshift and environment • Studies of the environment: gas inflow and removal from galaxies • Angular momentum and kinematics of galaxies: scaling relations between galaxy properties and the evolution of the Tully-Fisher relation.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
	X	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	One deep field	
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ………………………………………..]
	X	NO
Time Critical?		YES [details: ………………………………………..]
	X	NO
Integration time per target (hrs)	Total 3000 hours (individual observations of 4-8 hours)	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)	1e-5 - 1 Jy/beam.	
Expected polarised flux density (expressed as % of total)	0	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	825 MHz
Total Bandwidth (MHz)	450 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	600 – 1050 MHz (full band 1)
Spectral resolution (kHz)	10.7 kHz
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	

Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	Various from 2-20 arcsec	
Maximum baseline required (km)	200 km	
Mapped image size (degrees)	3 degrees	
Required pixel resolution (arcseconds)	0.5 arcsec	
Number of image channels	65536	
Channel width (kHz)	10.7 kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	1e-5 Jy	
Dynamic range within image per channel (if polarisation products required define for each)	1e5	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	RFI flagging, calibration, continuum subtraction, data combination to created integrated deep cube (uv and image domain), cube imaging, source-finding, source parametrization,
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Likely processing issues: - Large data volumes - RFI flagging - Requirement to search cubes multiple times (source detection) - Requirement to stack signals from a given set of coordinates

Data products	Calibrated, imaged, continuum subtracted datacubes; image cut-outs, spectra, moment maps, catalogues
Description of pipeline	- Collect visibilities on multiple days - Apply barycentric correction - Apply flagging - Calibrate visibilities - Peel strong continuum sources - Polynomial continuum subtraction - Make daily cubes at multiple resolutions for each pointing - Combine cubes (and beams) for individual pointings in the image or uv domain - Residual continuum subtraction in image domain - Multiscale deconvolution of strongest sources
Quality assessment plan & cadence	- Examine rms and histogram of pixel values in daily cubes. - Compare flux densities of known sources in daily cubes.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	Upon completion of scheduling block and pipeline reduction

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Observing parameters depend sensitively on array configuration and receiver sensitivity

REFERENCES
Blyth et al, 2015, POS(AASKA14), 128 Meyer et al, 2015, POS(AASKA14), 131 Obreschkow et al., 2015, POS(AASKA14), 138 Staveley-Smith & Oosterloo, 2015, POS(AASKA14), 167

2.10 **Medium-Wide HI Imaging Survey**

PROJECT DETAILS	
Title	**Medium-Wide HI Imaging Survey**
Principal Investigator	**Oort**
Co-Authors	**HI galaxy science working group**
Time Request	2000 hours

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	2000 hours
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	Desirable if commensal with magnetism/continuum observations (i.e. all 4 polarisations would be

		needed)
X	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
This survey will consist of repeated observations to a total observing time of 3000 hours of a single pointing on the sky. Night time observations preferred to avoid solar interference.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX	X	Stokes I
X	YY		Stokes Q
X	XY (for RFI mitigation)		Stokes U
X	YX (for RFI mitigation)		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
This survey is the medium-wide layer of a ‘wedding cake’ tiered strategy to observe HI in galaxies from 0<z<0.8. This tier covers 400 deg^2 in band 2. These surveys will enable the study of many science topics including, but not limited to: • Studies of the mass properties of galaxies: the cosmic neutral gas density and HI mass function as a function of redshift and environment • Studies of the environment: gas inflow and removal from galaxies • Angular momentum and kinematics of galaxies: scaling relations between galaxy properties and the evolution of the Tully-Fisher relation.

‘TARGETS’ OF OBSERVATIONS		
Type of observation (what defines a ‘target’)		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	One deep field	

Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	Total 2000 hours (individual observations of 4-8 hours)	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)	1e-4 - 2 Jy/beam.	
Expected polarised flux density (expressed as % of total)	0	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1185 MHz
Total Bandwidth (MHz)	470 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	950 – 1420 MHz (band 2)
Spectral resolution (kHz)	10.7 kHz
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	
Maximum baseline required (km)	
Primary beam size (sq degrees)	

Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	
Required rms (Jy per beam) (if polarisation products required define for each)	
Dynamic range within image (if polarisation products required define for each)	

Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	Various from 10 - 60 arcsec	
Maximum baseline required (km)	200 km	
Mapped image size (degrees)	400 degrees	
Required pixel resolution (arcseconds)	2 arcsec	
Number of image channels	65536	
Channel width (kHz)	10.7 kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	1e-4 Jy	
Dynamic range within image per channel (if polarisation products required define for each)	~1e5	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	

Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	RFI flagging, calibration, continuum subtraction, data combination to created integrated deep cube (uv and image domain), cube imaging, mosaicing, source-finding, source parametrization,
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Likely processing issues: - Large data volumes - Widefield images with non-coplanar baselines - Accurate primary beam for mosaicking - RFI flagging - Requirement to search cubes multiple times (source detection) - Requirement to stack signals from a given set of coordinates
Data products	Calibrated, imaged, continuum subtracted datacubes; image cut-outs, spectra, moment maps, catalogues

Description of pipeline	- Collect visibilities on multiple days - Apply barycentric correction - Apply flagging - Calibrate visibilities - Peel strong continuum sources - Polynomial continuum subtraction - Make daily cubes at multiple resolutions for each pointing - Combine cubes (and beams) for individual pointings in the image or uv domain - Residual continuum subtraction in image domain - Linear mosaicking of multiple fields, followed by cutouts in RA, Dec, Freq - Multiscale deconvolution of strongest sources
Quality assessment plan & cadence	- Examine rms and histogram of pixel values in daily cubes. - Compare flux densities of known sources in daily cubes.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	Upon completion of scheduling block and pipeline reduction

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Observing parameters depend sensitively on array configuration and receiver sensitivity.

REFERENCES
Blyth et al, 2015, POS(AASKA14), 128 Meyer et al, 2015, POS(AASKA14), 131 Obreschkow et al., 2015, POS(AASKA14), 138 Staveley-Smith & Oosterloo, 2015, POS(AASKA14), 167

2.11 High spatial resolution imaging of the HI in nearby galaxies

PROJECT DETAILS	
Title	**High spatial resolution imaging of the HI in nearby galaxies**
Principal Investigator	**H. van de Hulst**
Co-Authors	**HI galaxy science working group**
Time Request	300 hr

FACILITY		Preconditions
	SKA1-LOW	
	SKA1-MID	X

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	

	SKA1-MID Band 2	300 hr
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	Continuum & spectral imaging
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
x	XX		Stokes I
x	YY		Stokes Q

	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The transformation of gas into stars is one of the most important processes in galaxy evolution. Understanding the conditions that determine the efficiency of this process, and the associated physics, is the goal of many observational and theoretical studies. They also form important input into numerical computer models of galaxy formation and evolution. A complete understanding requires knowledge of these processes over a large range in scales: from galaxy-sized scales where gas is transported from the disk of the galaxy into the halo and back, via kpc-sized scales where gas clouds are coalescing and sub-kpc scales where neutral gas cools and forms molecular gas in GMCs, to parsec scales where individual stars are formed. The recent completion of ALMA is now, for the first time, enabling high-resolution studies of the star-forming molecular ISM in external galaxies over a large range of spatial scales and in a range of environments. The SKA will provide a similar, revolutionary step forward in the study of the non-molecular ISM. High spatial and spectral resolution observations of the neutral ISM in nearby galaxies will provide crucial information on the physics leading to star formation, the effects star formation in turn has on the ISM in the form of feedback processes, and the importance of various cold and warm phases in regulating star formation and with that galaxy evolution. The powerful combination of SKA and ALMA will lead to the most complete picture possible of the physics of the ISM and its connection with star formation. Detailed understanding of these processes is also immediately relevant for studies of high-redshift galaxies, where conditions in the ISM are more extreme, and a detailed description of the local ISM processes is a pre-requisite for interpreting the high-redshift data.

‘TARGETS’ OF OBSERVATIONS		
Type of observation (what defines a ‘target’)		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	1 (M83)	
Positions of targets	13h37m01s -29d51m56s	

Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	300	
Average peak flux density (Jy or Jy per beam)	M83 in HI is a very extended source. On shortest baselines, the HI flux is ~5 Jy	
Range of peak flux densities (Jy or Jy per beam)	Expected noise 0.013 mJy/beam over 24.2 kHz. Peak line flux in image ~ 100 mJy/beam	
Expected polarised flux density (expressed as % of total)	N/A	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1418 MHz (513 km/s)
Total Bandwidth (MHz)	> 20 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	1408- 1428 MHz
Spectral resolution (kHz)	~2 kHz (~ 0.5 km/s) (spectral zoom mode) and ~ 0.5 Mhz (continuum)
Temporal resolution (in seconds)	standard

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	
Maximum baseline required (km)	
Primary beam size (sq degrees)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	

Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a ‘support image’ in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	
Required rms (Jy per beam) (if polarisation products required define for each)	
Dynamic range within image (if polarisation products required define for each)	

Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	Various: 2, 5, 15, 45, 90 arcsec	
Maximum baseline required (km)	~30 km	
Mapped image size (degrees)	~1.5 degree	
Required pixel resolution (arcseconds)	~0.5	
Number of image channels	>10000	
Channel width (kHz)	~2 kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	~0.01 mJy/beam	
Dynamic range within image per channel (if polarisation products required define for each)	Image dynamic range: 10^5. Given the large flux on short baselines, the bandpass stability on these baselines has to be 10^6 over the timescale between bandpass calibrations. Self-calibration (time dependent, frequency independent) can be done on the continuum of this observation obtained from the broad band continuum . The requirement to have enough sensitivity to calibrate the spectral data on the shortest baselines sets the total bandwidth requirement of >100 MHz	
Absolute flux scale calibration		1-3%
	x	5%

		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Apart from standard processing: joint deconvolution of mosaic; Multi-scale deconvolution; Addition of single-dish data for imaging

Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	Data cubes, Total HI image, velocity field, velocity dispersion map. At various resolution (2,5,15,30,60 arcsec)
Description of pipeline	Calibrated visibilities will first be subjected to an flagging analysis. The visibility data should be imaged with robust weighting and with several tapers. Spectral line data cubes from different observing runs should be combined by taking into account a weighting which is inversely proportional to the noise in each cube. One should also consider gridding the UV data so that new data can be combined in this grid as it is observed. A similar approach is adopted for the VLA CHILES survey (Fernandez et al. 2013).
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
These observations require the spectral zoom mode, i.e. a spectral window of ~ 20 MHz with high spectral resolution (order 2 kHz) and a broad continuum band with low spectral resolution (0.5 MHz)

REFERENCES

2.12 **Probe the role of black holes in galaxy evolution**

PROJECT DETAILS	
Title	**Probe the role of black holes in galaxy evolution**
Principal Investigator	**I. Prandoni (on behalf of Continuum WG)**
Co-Authors	**Continuum Science Working Group**
Time Request	8,500 + 2,100 hours (TBC based on actual performance)

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
X	SKA1-MID Band 2	Wide Tier: 6000 hours Deep Tier: 1500 hours Ultra-deep: 1000 hours (TBC)
	SKA1-MID Band 3	
	SKA1-MID Band 4	
x	SKA1-MID Band 5	Deep Tier: 1500 hours Ultra-deep: 600 hours (TBC)

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
3 Tiers at Band 2: Wide tier: 1000 sq deg to 1 muJy/beam rms, 0.5 arcsec resolution Deep tier: 10 sq deg to 0.2 muJy/beam rms, 0.5 arcsec resolution Ultra-deep tier: 1 sq deg to 0.05 muJy/beam rms, 0.5 arcsec resolution 2 Tiers at Band 5: Deep tier: 1 sq deg to 0.3 muJy/beam rms, 0.1 arcsec resolution (overlapping Deep tier at Band 2) Ultra-deep tier: 0.008 sq deg (1 pointing) to 0.04 muJy/beam rms, 0.1 arcsec resolution

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	X	Stokes Q
	XY	X	Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The goal of this project is to probe galaxy-AGN co-evolution and AGN feedback as a function of cosmic time, stellar/black-hole mass, galaxy morphology and environment, through a multi-tier, multi-frequency survey. Several questions await to be answered: what is the relative importance of the two accretion/ feedback modes - *fast* or *quasar* mode typically associated to Radio Quiet (RQ) AGN and *slow* or *radio* mode typically associated to (low excitation/power) Radio Loud (RL) AGN - as a function of galaxy mass and epoch; which role is played by the environment; what drives these processes. Deep radio surveys can detect RQ AGN, and therefore can probe the *entire* AGN population, and not only the tiny (10%) RL AGN fraction. The advantage of radio over e.g. X-ray/optical studies is that radio emission is not affected by gas obscuration and/or dust extinction. This means that the radio band is sensitive to all types of AGN, and not biased towards unobscured samples. This also includes low power RL AGNs, typically hosted by otherwise quiescent galaxies, thought to be the main drivers of the radio-mode feedback. In addition SKA can provide sub-arsec spatial resolution. This is an advantage over mid/far infrared surveys, as it mitigates the confusion problem, it allows the identification of the host galaxies in crowded, deep fields, and, combined with spectral and polarization information, it helps with the source classification.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	3 fields/tiers, of varying depth and size.	
Positions of targets	Target fields will be selected in coordination with other deep multi-wavelength surveys. The ultra-deep tier could be selected to be away from bright radio sources.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	6000 hours (wide tier B2), 1500 hours (deep B2), 1000 hours (ultra-deep B2),1500 hours (deep B5), 600 hours (ultra-deep B5) (TBC)	

Average peak flux density (Jy or Jy per beam)	Wide tier B2: 5 uJy Deep tiers: ~1 uJy Ultra deep tiers: 0.25 – 0.3 uJy
Range of peak flux densities (Jy or Jy per beam)	Wide tier: 5 uJy to 2 Jy Deep tiers (B2/B5): 1/1.5 uJy to 500/100 mJy {*} Ultra-deep tiers (B2/B5): 0.25/0.2 uJy to 100/10 mJy {*} {*} The maximum flux densities refer to random fields. It will be lower as we will likely select fields free from bright sources to help with the dynamic range requirement
Expected polarised flux density (expressed as % of total)	1 – 50%

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Band 2: 1360 MHz Band 5: 9200 MHz
Total Bandwidth (MHz)	Band 2: 810 MHz Band 5: 2x2500 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	1000
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	
Maximum baseline required (km)	
Primary beam size (sq degrees)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	
Required rms (Jy)	

(if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	Band 2: 0.5 arcsec Band 5: 0.1 arcsec
Maximum baseline required (km)	150 km (see required angular resolution)
Mapped image size (degrees)	1-1000 sq. degr.
Required pixel resolution (arcseconds)	Band 2: 0.125 arcsec Band 5: 0.025 arcsec
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	950 – 1760 MHz (full Band 2) 7000 – 12000 MHz {*} {*} the observing time calculation assumes this set-up. We may want to go to the highest frequency as possible, if sensitivity allows it, to maximise resolution. Alternatively we may decide to choose two well separated 2.5 GHz wide bands (fi 4.6-7.1 GHz and 11.3-13.8 GHz) to get a good frequency lever arm for spectral studies
Required rms (Jy per beam) (if polarisation products required define for each)	Wide tier B2: 1 muJy/beam Deep tier B2: 0.2 muJy/beam

	Ultra-deep tier B2: 0.05 muJy/beam Deep tier B5: 0.3 muJy/beam Ultra-deep tier B5: 0.04 muJy/beam	
Dynamic range within image (if polarisation products required define for each)	Wide tier: 2 million Deep tier: 1-2 million {*} Ultra-deep tier: 1-2 million {*} {*} It can be mitigated with a clever choice of fields	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%

		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Multi-frequency multi-scale synthesis imaging
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	High dynamic range required. This will require not only self-calibration but also advanced imaging techniques to remove direction dependent effects (e.g. time-dependent/3D primary beam) such as peeling, A-W projection. For the ultra-deep fields we may want a high-wind flag and on-the-fly pointing measurements+correction.

	In addition there is the need to produce images at varying resolutions. Highest resolution for source classification; matching resolution for spectral studies (Band 2/Band 5, and/or SKA-LOW). It would be useful to get variability information as well. This requires observations taken with a months/year cadency, imaged separately. Note however that when coadding those images to get the final requested depth, imaging problems may arise at the variable sources.
Data products	Stokes I,Q,U,V images or gridded visibilities (see ISSUES below)
Description of pipeline	Advanced imaging pipeline, incorporating A-W project and possibly peeling, to produce high dynamic range continuum maps.
Quality assessment plan & cadence	Check flux densities and positions against existing radio continuum surveys in the same area, whenever possible.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	Upon completion of 10-20% (TBD) of each tier

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Dynamic ranges of ~ million are required for this use case. However, if this dynamic range is not achieved around bright sources those areas could be masked in the final image. The current SDP plan of co-adding images to get deeper is unlikely to produce high dynamic range images. This needs to be explored further, but we may need to request gridded visibilities as data products, rather than images. Similarly it is unlikely that image convolution can produce good results. Gridded visibilities would allow us to get images at varying resolution, performing the appropriate tapering in the UV plane.

REFERENCES
Smolcic et al. 2015 (New SKA Book) Mc Alpine et al. 2015 (New SKA Book)

2.13 Radio mode feedback in clusters of galaxies

PROJECT DETAILS	
Title	**Radio mode feedback in cluster of galaxies**
Principal Investigator	**Mamta Pandey-Pommier**
Co-Authors	**Alastair Edge, Harald Ebeling, Huub Rottgering + Science working group members**
Time Request	7000 hrs

FACILITY		Preconditions
X	SKA1-LOW	Deep Observations in imaging (compact and VLBI) mode
X	SKA1-MID	Deep Observations in imaging (compact and VLBI) and spectral line mode

RECEIVER(S) REQUIRED		Time (hrs)
X	SKA1-LOW	1000 hours at 0.05–0.35 GHz (imaging observations)
X	SKA1-MID Band 1	2000 hours at 0.35 –1.05 GHz (imaging and spectral line observations)
X	SKA1-MID Band 2	2000 hours at 0.95 –1.76 GHz (imaging and spectral line observations)
	SKA1-MID Band 3	
	SKA1-MID Band 4	
X	SKA1-MID Band 5	2000 hours at 4.6 –8.5 GHz (Band 5a) and 8.3 –15.3 GHz (Band 5b)

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	-The project would be carried out in SKA1 LOW, SKA1 MID Band 1, 2 and 5 (compact array and VLBI) imaging observation mode -The project would be carried out in SKA1 MID Band 1, 2 and 5 spectral line observation mode (HI and extragalactic non-HI) -Commensal with deep field searches for cold gas (HI and molecular line emission) in galaxies at Band 1, 2 (HI emission and absorption projects) and

		Band 5 emission line surveys -Commensal with galaxy clusters survey at SKA VLBI, SKA LOW, SKA MID 1, 2 and 5 projects
X	Collaborative & Coordinated	Coordinated with non-thermal and thermal SFHU, galaxy cluster and AGNs survey
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Deep observations of 7000 hours at: SKA LOW (0.05–0.35 GHz) imaging (compact array and VLBI mode), Pointed observations of 1000 hrs, 20 microJy, 10-1.5 arsec resolution for compact array SKA MID Band 1 (0.35–1.05 GHz) and 2 (0.95 –1.76 GHz)- imaging (compact array and VLBI mode), Pointed observations of 2000 hrs at Band 1 & 2, 1-100 microJy, 0.6-0.28 arsec resolution for compact array and 0.04-0.07 arcsec, ~1 microJy for VLBI mode SKA MID Band 1 (0.35–1.05 GHz) and 2 (0.95 –1.76 GHz)- spectral line (HI), Pointed observations of 2000 hrs, 0.6 arsec resolution for imaging and 0.2 arcsec for absorption, absorption survey frequency resolution 200 MHz-1750 MHz, 10-4 KHz SKA Band 5 (4.6–15.3 GHz)- imaging and spectral line (extragalactic non-HI eg. CO, HCN, HCO+ lines redshifted to 10-14 GHz range), Pointed observations of 2000 hrs (1000hrs in imaging and 1000hrs in spectral line mode), 0.3 microJy, 0.05 arsec resolution in compact array mode

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX		Stokes I
X	YY		Stokes Q
X	XY		Stokes U
X	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Radio mode feedback in brightest Cluster Galaxies (BCGs) play an important role in heating the intracluster medium and counteract the cooling of the intracluster gas within the dynamically inactive cool-core (CC) clusters (Fabian 1994). This scenario is further supported by the discovery of X-ray cavities, created by the radio jets, and the presence of filamentary reservoirs of cooling flows (Dunn 2006, Edge et al. 2001). Thanks to the high sensitivity of SKA1-LOW and mid arrays, a discovery of roughly 1000s of a new population of radio mini halos and halos are expected out to z = 1.5 in clusters, as compared to the current pathfinders (Cassano et al. 2015). With this proposal, we propose to carry out a survey on CC clusters in (0<z<1.5) to: 1- study the impact of cooling and AGN feedback on star formation activities in CC clusters as well as distant (0<z<6) lensed galaxies behind CC clusters by using the Band 1 and 2 HI (imaging and spectral) emission and absorption data (Edge et al. 2001, Pandey-Pommier et al. 2019) 2- investigate the properties of low surface brightness emission around the central BCG e.g. mini halos (Ferreti et al. 2012, Giacintucci et al. 2014, Pandey-Pommier et al. 2015), study their spectral energy distribution and ages over a broad frequency range using SKA1-LOW, Band 1 and 2 arrays 3- disentangle the core and possibly jet emission from the surrounding diffuse structure, using the high-resolution SKA VLBI data at SKA LOW, Band 1 and 2 4- use the Band 5 spectral line data to identify the redshift of gravitationally lensed distant (5<z<10) radio sources behind CC clusters emitting (redshifted) CO, HCN, HCO+ spectral lines.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	X	Individual pointing per object
		Individual fields-of-view with multiple objects

	X	Maps through multiple fields of view
		Non-imaging pointing
Number of targets	Deep survey with up to 100 targets (of varying size) at Band LOW, 1, 2 and 5 with 10 hours per target per band	
Positions of targets	Target field will be sleceted in coordination with multi-wavelength (MSE,ALMA,eRosita,PLANCK) survey	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	7000 hrs with 10 hrs per target distributed as follows -1000 hours deep observations at Band LOW -2000 hours deep observations at Band 1 -2000 hours deep observations at Band 2 -2000 hours deep observations at Band 5	
Average peak flux density (Jy or Jy per beam)	Band LOW - 20 microJy Band 1&2 - 1-100 microJy Band 5 - 0.3 microJy	
Range of peak flux densities (Jy or Jy per beam)	Band LOW - 100 microJy - a few 100 of mJy Band 1&2 - 5 microJy- a few 10s of mJy Band 5 - 1 microJy- a few 10s of mJy	
Expected polarised flux density (expressed as % of total)	1-50%	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	LOW- 130 MHz Band 1- 825 MHz Band 2- 1410 MHz Mid Band 5
Total Bandwidth (MHz)	LOW - 150 MHz Band 1- 450 MHz Band 2- 810 MHz Band 5- 5000 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	Full Band
Spectral resolution (kHz)	Band 1- 10.7 KHz (HI) Band 2- 15 KHz (HI) Band 5- 2000 KHz (non-HI)
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	
Maximum baseline required (km)	
Primary beam size (sq degrees)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	
Required rms (Jy) (if polarisation products required define for each)	
Dynamic range (if polarisation products required define for each)	

Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	LOW - 10-1.5 arsec Band 1&2 - 0.6-0.28 arcsec Band 5 - 0.05 arcsec Targets have varying size from roughly 2- 40 arcmin
Maximum baseline required (km)	150 km for compact array and 1000 km(or maximum possible) for VLBI observations
Mapped image size (degrees)	1-1000 sq.degree
Required pixel resolution (arcseconds)	LOW - 2 arsec (1/4 of angular resolution) Band 1&2 -0.125 - 0.025 arcsec Band 5- 0.01 arcsec
Number of output channels	Maximum
Output bandwidth (minimum and maximum frequency - MHz)	Full band
Required rms (Jy per beam) (if polarisation products required define for each)	LOW - 20 microJy Band 1&2 - 1-100 microJy Band 5- 0.3 microJy/beam

Dynamic range within image (if polarisation products required define for each)	10^5 - 10^6	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	-For HI imaging and absorption survey 0<z<6, 200 MHz-1750 MHz, -Primary beam- 0.2 arcsec for absorption and up-to 0.6 arcsec for imaging -PSF FWHM- 1-20 arcsec - For non-HI, 0.3 arcsec
Maximum baseline required (km)	50 km for compact array
Mapped image size (degrees)	100 %
Required pixel resolution (arcseconds)	-For HI- 0.2 arcsec -For non HI- 0.1 arcsec
Number of image channels	Standard
Channel width (kHz)	Band 1- 10.7 KHz Band 2- 15 KHz Band 5- 2000 KHz
Required rms (Jy per beam per channel) (if polarisation products required define for each)	-For HI- 5 mJy per 8 km/s channel -For non HI- 1.7microJy per 100km/s

Dynamic range within image per channel (if polarisation products required define for each)	>100	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)	~20 mas (1000 km or maximum VLBI baselines) Targets have varying size from a few up to 30 mas	
Mapped image size (degrees)	max 0.05 degrees	
Number of image channels	Standard	
Channel width (kHz)	Standard	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	1 micro Jy	
Dynamic range within image per channel (if polarisation products required define for each)	>50 for primary target ~1000 for calibrators	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Multi frequency synthesis imaging at SKA LOW, SKA MID Band 1, 2 and 5. Standard spectral line (HI and non-HI) data processing of Band 1 , 2 and 5 Multi-resolution clean, tapering, Direction dependent gain calibration.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	High dynamic range, self-calibrated and removal of direction dependent calibration effects, RFI flagging, bright source peeling and A-W projection
Data products	Gridded visibilities, calibrated and direction dependent correction applied continuum images at continuous frequency band, spectral index maps, and spectral line data cubes, moment maps
Description of pipeline	Advanced imaging pipeline for SKA LOW, SKA MID Band 1, 2 and 5, incorporating A-W projection and peeling to produce high dynamic range images. Standard VLBI imaging pipeline for SKA LOW, SKA MID Band 1, 2
Quality assessment plan & cadence	Standard data quality and calibration checks, Source position and spectral index verification with SKA precursors and SKA LOW, SKA MID Band 1,2 and 5 data
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	Upon completion of 10-20% of the observations.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

Imaging and spectral line observations. Dynamic range of 10^6 is required in these observations to detect the faint diffuse emission as well as the lensed structures. High resolution imaging to to resolve structures at milliarcsec. Commonalities with HI and SKA VLBI Procedural details of the data analysis will be built based on our experience of data analysis from LOFAR, VLA, ATCA, GMRT, JVLA.

REFERENCES
1.Cassano, R., Bernardi, G., Brunetti, G., et al. 2015, Advancing Astrophysics with the Square Kilometre Array (AASKA14), 73 2.Dunn, R. & Fabian, A. 2006 MNRAS 373, 959 3. Edge, A. C., 2001, MNRAS, 328, 762 4.Fabian, A. 1994 ARA&A 32, 277 5.Feretti, L., Giovannini, G., Govoni, F., & Murgia,M. 2012, A&A Rev.„ 20, 54 6.Giacintucci, S., Markevitch, M., Venturi, T. et al., 2014, ApJ781 7.Pandey-Pommier, M.; Richard, J.; et al.; 2015, SF2A conference 8.Pandey-Pommier, M.; Richard, 2019, Habilitation thesis

2.14 Distant Universe via Cluster Lensing in the SKA era

PROJECT DETAILS	
Title	Distant Universe via Cluster Lensing in the SKA era
Principal Investigator	Mamta Pandey-Pommier
Co-Authors	Rob Beswick + J. Wagg + M. T. Sargent + Continuum science working group
Time Request	6000 hours (TBC)

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	Observations to be arranged jointly with the SKA VLBI array

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
X	SKA1-MID Band 1	Deep observations of 2000 hours at 0.35 –1.05 GHz (imaging and spectral line observations)
X	SKA1-MID Band 2	Deep observations of 2000 hours at 0.95 –1.76 GHz (imaging and spectral line observations)
	SKA1-MID Band 3	
	SKA1-MID Band 4	
X	SKA1-MID Band 5	Deep observations of 2000 hours at 4.6 –8.5 GHz (5a) and 8.3 –15.3 GHz (5b)

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	

X	Commensal	-The project would be carried out in SKA1-MID Band 1, 2 & 5 observation compact array and VLBI imaging mode -The project would be carried out in SKA1-MID Band 1,2 and Band 5 observation in spectral line mode (HI and extragalactic non-HI) -Commensal with deep field searches for cold gas (molecular line emission) in galaxies at Band 5, SKA VLBI Gravitational lensing project and HI emission and absorption projects
X	Collaborative & Coordinated	Coordinated with non-thermal and thermal SFHU
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Deep observations of 6000 hours at: SKA MID Band 1 (0.35 –1.05 GHz) and 2 (0.95 –1.76 GHz)- imaging (compact array and VLBI mode), Pointed observations of 2000 hours, 1-100 microJy, 0.6-0.28 arsec resolution for compact array and 0.05-0.1 arcsec, ~1 microJy for VLBI mode SKA MID Band 1 (0.35 –1.05 GHz) and 2 (0.95 –1.76 GHz)- spectral line (HI), Pointed observations of 2000 hours, 1-100 microJy, 0.6 arsec resolution for imaging and 0.2 for absorption, Absorption survey frequency resolution 200 MHz-1750 MHz, 10-4 KHz SKA Band 5 (4.6–15.3 GHz)- imaging (1000 hours) and spectral line (1000 hours, extragalactic non-HI eg. CO, HCN, HCO+ lines redshifted to 10-14 GHz range), Pointed observations, 0.3 microJy, 0.05 arsec resolution

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX		Stokes I
X	YY		Stokes Q
X	XY		Stokes U
X	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Clusters are a unique tool to probe matter distribution and gas interaction around the dense regions in the cosmic web as well as, galaxy evolution and star formation from the epoch of cosmic noon where the bulk of star formation occurred up to the reionization, in the distant Universe (z~10), thanks to the Gravitational lensing technique. SKA will transform our understanding of the Universe via cluster lensing technique, particularly at radio wavelengths where the number of known radio-emitting lensed galaxies are scarce from z > 1 (McKean 2014). The technical requirements and main scientific goals of the proposed SKA1 survey on lensing clusters are provided below: -Continuum imaging (0.2–0.6 arcsec, and 3 µJy/beam sensitivity) and spectral line (HI) survey for 4000 hours on lensing clusters at SKA1-MID Band 1 & 2 (+ VLBI with 5-10 milliarcsec and a sensitivity of ~1 microJy) to study the matter distribution, discover a new population of background lensed galaxies (0 < z <6) via imaging, provide higher angular resolution images of star-forming galaxies with SKA VLBI and study the impact of the extreme cluster environment on the atomic gas (HI) reservoirs. -For lensed galaxies at 5 < z <10, continuum imaging and spectral line observations for 2000 hours in Band 5 with 0.05-0.1arcsec to not only provide insights on the thermal (free-free) emission from star-forming galaxies dominating over synchrotron emission beyond ~10 GHz, but also the cold molecular gas reservoirs (CO, HCN, HCO+, etc.) (Carilli & Walter 2013, Condon 1992, Murphy et al. 2003, Wu et al. 2005) that trace the sites of on-going star formation.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	X	Individual pointing per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view

		Non-imaging pointing
Number of targets	Deep survey on up to 100 targets (of varying size) at Band 1, 2 and 5 with 10 hrs/ target/ band/observation mode	
Positions of targets	Target field will be selected in coordination with multi-wavelength (Optical/IR) survey	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………..]
	X	NO
Time Critical?		YES [details: ……………………………………..]
	X	NO
Integration time per target (hrs)	-2000 hours deep observations at Band 1 -2000 hours deep observations at Band 2 -2000 hours deep observations at Band 5 Total 6000 hours	
Average peak flux density (Jy or Jy per beam)	Band 1&2 - 1-100 microJy Band 5 - 0.3 microJy	
Range of peak flux densities (Jy or Jy per beam)	Band 1&2 - 5 microJy up to a few mJy Band 5 - 1 microJy up to a few 10s of mJy	
Expected polarised flux density (expressed as % of total)	1-50%	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Band 1- 825 MHz Band 2- 1410 MHz

	Mid Band 5
Total Bandwidth (MHz)	Band 1- 450 MHz Band 2- 810 MHz Band 5- 5000 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	Full Band
Spectral resolution (kHz)	Band 1- 10.7 KHz (HI) Band 2- 15 KHz (HI) Band 5- 2000 KHz (non-HI)
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%

		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	Band 1&2 - 0.6-0.28 arcsec Band 5 - 0.05 arcsec Targets have varying size from roughly 2- 40 arcmin	
Maximum baseline required (km)	150 km for compact array and 1000 km(or maximum possible) for VLBI observations	
Mapped image size (degrees)	1-1000 sq.degree	
Required pixel resolution (arcseconds)	Band 1&2 -0.125 arcsec Band 5- 0.01 arcsec	
Number of output channels	2500	
Output bandwidth (minimum and maximum frequency - MHz)	Full band	
Required rms (Jy per beam) (if polarisation products required define for each)	Band 1&2 - 1-100 microJy Band 5- 0.3 microJy/beam	
Dynamic range within image (if polarisation products required define for each)	10^5 -10^6	
Absolute flux scale calibration	X	1-3%
		5%

		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	-For HI Imaging and absorption survey 0<z<6, 200 MHz-1750 MHz, -Primary beam- 0.2 arcsec for absorption and up-to 0.6 arcsec for imaging -PSF FWHM- 1-20 arcsec - For non-HI emission, 0.3 arcsec	
Maximum baseline required (km)	50 km for compact array	
Mapped image size (degrees)	100%	
Required pixel resolution (arcseconds)	-For HI- 0.2 arcsec -For non HI- 0.1 arcsec	
Number of image channels	Standard	
Channel width (kHz)	Band 1- 10.7 KHz Band 2- 15 KHz Band 5- 2000 KHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	-For HI- 5 mJy per 8 km/s channel -For non HI- 1.7microJy per 100km/s	
Dynamic range within image per channel (if polarisation products required define for each)	>100	
Absolute flux scale calibration		1-3%
	X	5%

		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)	~20 mas (1000 km or maximum VLBI baselines) Targets have varying size from a few up to 30 mas	
Mapped image size (degrees)	max 0.05 degrees	
Number of image channels	Standard	
Channel width (kHz)	Standard	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	1 micro Jy	
Dynamic range within image per channel (if polarisation products required define for each)	>50 for primary target ~1000 for calibrators	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Multi frequency synthesis imaging Standard spectral line (HI and non-HI) and continuum data processing of Band 1 , 2 and 5
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	High dynamic range, self-calibrated and removal of direction dependent calibration effects, bright source peeling and A-W projection
Data products	Gridded visibilities, calibrated and direction dependent correction applied continuum images at continuous frequency band, spectral index maps, and spectral line data cubes, moment maps
Description of pipeline	Advanced imaging pipeline, incorporating A-W projection and peeling to produce high dynamic range images. Standard imaging pipeline for SKA band 1, 2 and 5, SKA VLBI
Quality assessment plan & cadence	Standard data quality and calibration checks, source position and spectral index verification with SKA precursors and SKA MID Band 1,2 and 5 data
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of 10-20% of the observations.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Dynamic range of 10^6 is required in these observations to detect the faint lensed structures. High resolution imaging to resolve structures at milliarcsec scale. Commonalities with HI and SKA VLBI SKA Band 1, 2 observations in imaging and spectral line observation modes. Procedural details of the data analysis will be built based on our experience of data analysis from LOFAR, VLA, GMRT, EVN.

REFERENCES
Carilli, C & Walter, F, 2013, ApJ, 770, 91 Condon, J.J., 1992, ARA&A, 30, 575 McKean, J., Jackson, N., et al., 2015, AASKA14, 84 Murphy, M. T., Webb, J. K., et al., 2003, MNRAS, 345, 609 Wu, J., et al. 2005, ApJ, 635, L173

2.15 **Studying the Sunyaev Zel'dovich effect in Galaxy clusters with the SKA**

PROJECT DETAILS	
Title	Studying Sunyaev Zel'dovich effect in Galaxy clusters with the SKA
Principal Investigator	Mamta Pandey-Pommier
Co-Authors	Keith Grainge, Yvette Perrott+ SWG members
Time Request	3000 hours (TBC)

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	Deep observations in imaging mode

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
X	SKA1-MID Band 1	500 hours at 0.35 –1.05 GHz (imaging observations) on a sample of clusters with multiwavelength (X-ray/PLANCK) coverage
X	SKA1-MID Band 2	500 hours at 0.95 –1.76 GHz (imaging observations) on a sample of clusters with multiwavelength coverage
	SKA1-MID Band 3	
	SKA1-MID Band 4	
X	SKA1-MID Band 5	2000 hours at 8.3 –15.3 GHz (5b) on a sample of clusters with multiwavelength coverage

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	

	Commensal	
	Collaborative & Coordinated	Band 1, 2 and 5
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Deep observations of 2000 hours at: SKA MID Band 1 (0.35 –1.05 GHz) and 2 (0.95 –1.76 GHz)-imaging, Pointed observations of 1000 hrs at both the bands with 5 hrs per cluster, 1-100 muJy/beam, 0.6-0.28 arsec resolution SKA Band 5 (4.6–15.3 GHz)- imaging, Pointed observations of 2000 hrs with 20 hours per cluster, 10-20 arsec low resolution imaging and 3 muJy/beam for the observations of substructures. Night time observations to avoid RF interference and map low surface brightness sources with short baselines.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX		Stokes I
X	YY		Stokes Q
X	XY		Stokes U
X	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The next decade will see a step-change in our observational capacities for especially rare high-redshift (z > 0.6) clusters from new X-ray instruments (eROSITA, Athena) and SZ-capable, arc minute resolution sub-mm observatories (Simons Observatory, CMB-S4) (Grainge et al. 2015, Ade et al. 2014). The SKA occupies a unique niche amongst these instruments due to its Band 1, 2 & 5 capabilities (0.35-15.3 GHz, 100-3 microJy/beam rms noise) and spatial resolution (0.6-20 arcsec) that offers the possibility of detailed characterization of dynamics and imaging of substructures in high-redshift clusters. With this proposal, we aim to - 1-detect and characterize the redshift-independent bulk SZ thermal signal using the shorter baseline data at Band 5, allowing the observation of clusters in a single pointing, using a large primary beam. Simulations show SKA observations can constrain the pressure profile at small and intermediate radius, in the context of the GNFW model (Nagai et al. 2007). 2-exploit the longer-baseline Band 5 data to investigate the detailed substructure of high-redshift clusters including pressure discontinuities, AGN bubbles, and investigate the formation process underway in high-redshift clusters. 3-use the longer baseline Band 5 data, in conjunction with the Band 1 & 2 data, to investigate the diffuse non-thermal emission from the intracluster medium (ICM) and give insights into the impact of the extreme cluster environment on galaxy evolution 4-trace the bulk radio velocity motions via the kinematic SZ effect, in conjunction with other high-resolution SZ data at higher frequencies such as AtLAST and ALMA (Diego et al. 2015).

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	X	Individual pointing per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointing
Number of targets	Band 1,2 and 5 deep survey with multiple (approx. 100) targets of a few arcmin in size	

Positions of targets	Target field will be selected in coordination with multi-wavelength (X-ray/mm/sub-mm) survey	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
		NO
Time Critical?		YES [details: ……………………………………….]
		NO
Integration time per target (hrs)	- roughly 5 hrs per target at each band with a total 1000 hours observations at Band 1&2 - deep observations of 20 hrs per cluster with a total of 2000 hours at Band 5	
Average peak flux density (Jy or Jy per beam)	Band 1&2 - 1-100 microJy Band 5 - 3 microJy/beam for substructure detection	
Range of peak flux densities (Jy or Jy per beam)	Band 1&2 - 5 microJy- a few 10s of mJy Band 5 - 1 microJy- a few mJy Band 5- ~ 1 uJy-30 uJy for substructures at z = 1.5	
Expected polarised flux density (expressed as % of total)	1-50%	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Band 1- 825 MHz Band 2- 1410 MHz Mid Band 5
Total Bandwidth (MHz)	Band 1- 450 MHz Band 2- 810 MHz Band 5- 5000 MHz

Minimum and maximum frequency over the entire range of the setup (MHz)	-Full Band for Band 1 & 2 -Due to satellite RFI and the SZ signal dependence we will use the upper part of Band 5b
Spectral resolution (kHz)	
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	Band 1&2 - 0.6-0.1 arcsec Band 5 -0.05 arcsec (max.). Low resolution uv-tapered images of 10-20 arcsec will be produced to detect arcmin scale thermal signal, while higher-resolution images will be used to remove contaminating radio sources	
Maximum baseline required (km)	From 5 km at Band 5 to 150 km at Band 1&2	
Mapped image size (degrees)	A few sq.degrees	
Required pixel resolution (arcseconds)	Band 5- 0.025 arcsec	
Number of output channels	128 at Band 5 and maximum possible at Band 1 & 2	
Output bandwidth (minimum and maximum frequency - MHz)	Full band	
Required rms (Jy per beam) (if polarisation products required define for each)	Band 1&2 - 1-100 microJy/beam Band 5- 0.3 microJy/beam	
Dynamic range within image (if polarisation products required define for each)	10^5 - 10^6	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	
Mapped image size (degrees)	
Number of image channels	

Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Synthesis imaging Standard continuum data processing at Band 5
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	High dynamic range, calibrated and removal of direction dependent calibration effects at Band 1&2, bright source peeling and A-W projection at at Band 1&2
Data products	Gridded visibilities, calibrated and direction dependent correction applied continuum images at continuous frequency band, spectral index maps,
Description of pipeline	Advanced imaging pipeline, incorporating A-W projection and peeling to produce high dynamic range images. Standard imaging pipeline for SKA Band 5
Quality assessment plan & cadence	Standard data quality and calibration checks, Source position and spectral index verification with SKA MID Band 1, 2 & 5 data

Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of 10-20% of the observations.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Dynamic range of 10^5-10^6 is required in these observations to detect the faint non-thermal emission, SZ diffuse signals, as well are sharp merger regions with the possible presence of bright radio sources Commonalities with SKA Band 1, 2 survey on galaxy clusters

REFERENCES
Ade, P. A. R., Aghanim, N., et al. 2014, A&A, 571, AA20 Diego, J. M., Broadhurst, T., Molnar, S. M., et al. 2015, MNRAS, 447, 3130 Grainge, K., Borgani, S., et al. 2015, ASKA14CONF, 170 Nagai, D., Vikhlinin, A., & Kravtsov, A. V. 2007b, ApJ, 655, 98

2.16 SKA Low Multi-tiered Continuum Survey

PROJECT DETAILS	
Title	**SKA Low Multi-tiered Continuum Survey**
Principal Investigator	**Nick Seymour**

Co-Authors	**Continuum Science Working Group**
Time Request	7,500 hours (TBC)

FACILITY		Preconditions
X	SKA1-LOW	
	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
X	SKA1-LOW	Shallow Tier: 2,500 hours Mid Tier: 2,500 hours Deep Tier: 2,500 hours
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	

X	Commensal	**With EoR observations**
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
This survey is designed to be commensal with the planned 3-tier EoR experiments with the data product being derived in coordination with the EoR team and SDP in order to conduct the science described below and to provide the best foreground model for the EoR observations. We estimate that the depth/resolutions listed here will not be confusion limited, but there is a sharp trade-off between these two parameters and it will be sensitive to the final configuration. The total times listed above assume the EoR experiment uses 2 beams simultaneously. Shallow Tier: 10,000deg^2 drift scan, 15uJy/bm at 200MHz, 10 arcseconds resolution Medium Tier: 1,000deg^2 pointed, non-contiguous scan, 8uJy/bm at 200MHz, 10 arcseconds resolution Deep Tier: 100deg^2 pointed, non-contiguous scan, 2.6uJy/bm at 200MHz, 10 arcseconds resolution

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Radio surveys provide perhaps the best tracer of star formation and AGN, activity, as well as clusters, over cosmic time, being unaffected by dust. A survey with SKA LOW would be able to measure with unprecedented accuracy the evolution of star forming galaxies and AGN over cosmic time. The large volumes probed by a multi-tiered survey would allow the effects of stellar/black hole mass, environment, AGN mode to be disentangled across most of cosmic time, z<6.

At low radio frequencies SFGs and AGN display a wide range of spectral energy distributions (SED) as revealed by surveys from MWA and LOFAR (~75% deviate from a pure power-law). A diverse range of spectral curvatures is observed which relate to their underlying physical processes (e.g. age and physical extent of starburst, radio-jet age etc). As such these observations would complement those planned with SKA MID providing both broad-band (50-1000 MHz) radio SEDs for most sources and detection of steep spectrummed sources not seen in surveys at higher frequencies. Commensal with the planned EoR observations we can conduct a shallow (10,000deg^2, 15uJy/bm rms), medium (1,000deg^2, 8uJy/bm rms) and deep (100deg^2, 2.6uJy/bm rms) survey at 50-350MHz and a resolution of ~10arcseconds. The EoR program proposes two simultaneous beams for observations, reducing the overall observing time to 7,500 hours.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	3 tiers of varying areas and depths	
Positions of targets	Target fields will be selected in conjunction with other deep multi-wavelength surveys and the EoR consortium.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	5,000\Nbeam hours per tier, where Nbeams is the number of beams the EoR observations require. Estimated to be 2 beams.	
Average peak flux density (Jy or Jy per beam)	Shallow tier: 60uJy Medium tier: 30uJy Deep tier: 10uJy	
Range of peak flux densities (Jy or Jy per beam)	Shallow tier: 60uJy – 24Jy Medium tier: 30uJy – 12Jy	

	Deep tier: 10uJy – 2Jy
Expected polarised flux density (expressed as % of total)	<1%

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	130MHz
Total Bandwidth (MHz)	150MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	75-225 MHz
Spectral resolution (kHz)	1000 (averaged from EoR data resolution)
Temporal resolution (in seconds)	standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%

		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	0.1666 (i.e. 10 arcseconds)	
Maximum baseline required (km)	80km	
Mapped image size (degrees)	Wide (50 to 10,000)	
Required pixel resolution (arcseconds)	2	
Number of output channels	~11 frequency bands with delta(nu)/nu~0.1, varying from ~8MHz to ~21MHz	
Output bandwidth (minimum and maximum frequency - MHz)	75-225MHz	
Required rms (Jy per beam) (if polarisation products required define for each)	Shallow tier: 15uJy/beam Medium tier: 8uJy/beam Deep tier: 2.6uJy/beam	
Dynamic range within image (if polarisation products required define for each)	0.5 million for each tier	
Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	
Mapped image size (degrees)	
Number of image channels	
Channel width (kHz)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	
Dynamic range within image per channel	

(if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Mutli-frequency multi-scale synthesis imaging, MFS cleaning and A-W projection
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	High Dynamic Range, Ionospheric Corrections, Self-calibration
Data products	Stokes I images, in 11 bands with delta(nu)/nu~0.1. Catalogues of radio sources both per band and list driven from a high frequency, high sensitivity wide-band image.
Description of pipeline	Advanced imaging pipeline, incorporating A-W projection, peeling etc.
Quality assessment plan & cadence	Flux scales and positions checked against known radio surveys such as MWA/GLEAM and future low-nu surveys from MWA or an early all-sky survey with SKA-LOW. No constraints on cadence.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	Upon a fractional completion of each tier (TBD)

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
- coordination with EoR and mid frequency observations - high dynamic range - advanced ionospheric corrections

REFERENCES

2.17 Probing the evolution of non-thermal components in Galaxy Clusters

PROJECT DETAILS	
Title	**Probing the evolution of non-thermal components in galaxy clusters**
Principal Investigator	**Rossella Cassano**
Co-Authors	**Continuum Science Working Group, G. Brunetti, M. Gitti, L. Feretti & T., Venturi**
Time Request	2 years (TBC)

FACILITY		Preconditions
X	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
X	SKA1-LOW	2 years (TBC)
	SKA1-MID Band 1	
X	SKA1-MID Band 2	2 years (TBC)
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	Can be commensal with the EOR (SKA1-LOW), magnetism and cosmology (SKA1-MID)
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
2 tier surveys SKA1-LOW wide-field survey: 3π sr to 20 μJy/beam rms, 10” resolution SKA1-MID wide-field survey: 3π sr to 4 μJy/beam rms, 2-5” resolution

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	**X**	Stokes Q
	XY	**X**	Stokes U
	YX	**X**	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Radio observations of galaxy clusters (GCs) are a unique probe for the presence of non-thermal components, relativistic particles and magnetic fields, in the Intra-Cluster-Medium (ICM), through the detection of Mpc-scale central Radio Halos (RH) and peripheral Relics in merging clusters, and central Mini-Halos (MH) in more relaxed cool-core GCs. The existence of these components open fundamental questions about their origins as well as their impact on the (micro-)physics of the ICM and on the process of formation of GCs. Relics are likely produced by mechanisms of particle (re-) acceleration in large-scale shocks, while RH probably trace gigantic turbulent regions in the ICM, where particle are re-accelerated during mergers. MH could be produced by the re-acceleration of relativistic electrons by gas sloshing turbulent motion and/or by secondary electrons. SKA1 surveys will explore the formation and evolution of non-thermal sources in a new range of cluster masses and redshifts, allowing firm test of the current theoretical hypothesis. We propose two continuum all-sky surveys with SKA1-LOW and SKA1-MID (band 2), to: - perform a complete census of non-thermal radio sources in GCs up to z~1 and down to cluster masses ~10^{14} M_{sun}; - discovery ~2500 RH, of which 1000 with ultra-steep radio spectra (α>1.5, S~ν-α); - detect for the first-time “off-state” hadronic halos in more relaxed clusters - discovery ~1000 new radio relics and ~600 MH up to z~1; - study the radio power - cluster mass correlations (scatter, evol. with z)

‘TARGETS’ OF OBSERVATIONS		
Type of observation (what defines a ‘target’)		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view

		Non-imaging pointings
Number of targets		
Positions of targets	All-sky (~36.000 sq degrees visible from sites).	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………..]
	X	NO
Time Critical?		YES [details: ……………………………………..]
	X	NO
Integration time per target (hrs)	Without overheads: - SKA1-MID Band 2: ~0.5 h - SKA1-LOW: ~5.5 h Note that, for SKA1-MID, we have considered 30% BW for spectral index studies within the band (i.e. 4 μJy/beam sensitivity per sub-band). The exposure times thus reduces by a factor ~3.3 when considering the whole BW. For SKA-LOW we have adopted a conservative approach, taking into account the steep decrease in sensitivity starting below ~110 MHz, i.e., we have considered the worst possible sensitivity at the lowest frequency (75 MHz) in the selected band. The adopted BW is 150 MHz.	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)		
Expected polarised flux density (expressed as % of total)	Up to few tens of %	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1360 MHz for SKA1-MID 150 MHz for SKA1-LOW

Total Bandwidth (MHz)	810 MHz for SKA1-MID 150 MHz for SKA1-LOW
Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	2000 kHz (for commensality with magnetism)
Temporal resolution (in seconds)	standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	5 arcsec with SKA1-MID 10 arcsec with SKA1-LOW	
Maximum baseline required (km)	~30 km at the central frequency indicated for SKA1-MID ~50 km at the central frequency indicated for SKA1-LOW	
Mapped image size (degrees)	~1 degree (for mapping large-scale structures at low z)	
Required pixel resolution (arcseconds)	1-1.2 arcsec with SKA1-MID 2-2.5 arcsec with SKA1-LOW	
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)	950 – 1760 MHz (full Band 2) for SKA1-MID 100–300 MHz for SKA1-LOW	
Required rms (Jy per beam) (if polarisation products required define for each)	SKA1-MID: 5 muJy/beam SKA1-LOW: 20 muJy/beam	
Dynamic range within image (if polarisation products required define for each)	10^5 - 10^6	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	

Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%

		20-50%
		n/a

DATA ANALYSIS	
Procedures required	The larger number of short baselines available for SKA1-LOW and MID configurations is ideal to image diffuse extended emission. Advanced calibration and processing techniques are required to obtain deep and high-fidelity images especially at low frequency, where direction dependent effects (DDE) should be taken into account. Multi-frequency synthesis imaging, multi-resolution clean, tapering will be performed. In order to enhance the sensitivity to diffuse sources and to properly measure the fluxes of the intra-cluster radio emission, a widely adopted strategy is to: a) produce high resolution images (to identify the radio galaxies in the cluster and to subtract their emission from the uv-data), b) produce low resolution images by tapering the uv-subtracted data.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	If the high-resolution and low-resolution maps (for low resolution: point source subtracted and tapered) will not be available as an output of the pipeline, we will need a post-reprocessing step requiring visibilities. Tests need to be developed to evaluate if gridded visibilities would be enough, with the weighting scheme adopted in the general pipeline.
Data products	High- and low-resolution multi-frequency maps, produced as described above, otherwise visibilities are necessary (see above) Full-Stokes images for commensality with magnetism.
Description of pipeline	<u>Advanced imaging pipeline, incorporating A-W project and possibly peeling, to produce high dynamic range continuum maps.</u> Based on the LOFAR experience, direction dependent calibrations seem to be crucial for detecting low-surface brightness radio sources with SKA1-LOW.
Quality assessment plan & cadence	Check flux densities and positions against radio continuum surveys such as EMU (for SKA1-MID, band 2) and the GMRT TGSS/MWA (for SKA1-LOW).
Latency (Desired time lag between observation commencement and data being available in the archive.	

e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of 10-20% (TBD) of each tier

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
We restate here that to image the diffuse extended emission and provide accurate measurements of the diffuse flux densities, the point source subtraction is required (see the . Data Analysis/Procedures Required Section.)

REFERENCES

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2.18 Studying AGN in TGSS Fields with SKA1-MID

PROJECT DETAILS	
Title	**Studying AGN in TGSS Fields with SKA1-MID**
Principal Investigator	**Preeti Kharb and C. H. Ishwara-Chandra**
Co-Authors	**SKA continuum survey science working group**
Time Request	10,000 hours

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
X	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	

	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**x**	Stokes I
	YY	**x**	Stokes Q
	XY	**x**	Stokes U
	YX	**x**	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The 150 MHz survey with the TIFR GMRT Sky Survey (TGSS) when completed, is expected to detect approximately 2 million radio sources in the north-south hemisphere accessible to the GMRT, India (declination +90 to –55 degrees). GHz frequency observations of the TGSS fields with SKA will separate diffuse radio emission from clusters of galaxies, relics/halos in galaxy clusters and active galactic nuclei (AGN) – the diffuse emission from all but AGN is likely be resolved out with SKA1-MID. Observations with the SKA1-MID band-5 will identify the “cores”, “jets”, “hotspots” and “lobes” in active galaxies. The low frequency GMRT images, as well as those from the all sky SKA1-LOW survey, will reveal the presence of diffuse lobe emission in radio galaxies and low redshift Seyfert galaxies, possibly identifying multiple AGN activity episodes through the presence of additional steep-spectrum lobes (e.g., Kharb et al. 2006; Hota et al., 2011). These episodes will constrain the AGN activity duty cycle and their presence will provide insights into jet formation and propagation inside varying galactic environments. SKA1-MID will therefore prove invaluable to utilize the full potential of the 150 MHz TGSS and SKA1-LOW datasets, providing an unprecedented resource to the astronomy community at large.

‘TARGETS’ OF OBSERVATIONS		
Type of observation (what defines a ‘target’)		Individual pointings per object
	x	Individual fields-of-view with multiple objects

		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	~10,000 pointings to image interesting targets, with 29 arcmin^2 FoV.	
Positions of targets	Assorted 0.5% of all ~2 million TGSS sources.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	x	NO
Time Critical?		YES [details: ……………………………………….]
	x	NO
Integration time per target (hrs)	In each FoV, to reach a sensitivity of 3–4 μJy/beam we need ~1 hour integration time, assuming a bandwidth of 2 × 2500 MHz.	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)		
Expected polarised flux density (expressed as % of total)	3–8 percent	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	9.2 GHz
Total Bandwidth (MHz)	2 × 2500 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	Maximum permitted by the correlator.
Temporal resolution (in seconds)	Default

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)	~0.1 arcsecond at 5 GHz	
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)	2×2500 MHz (maximum)	
Required rms (Jy) (if polarisation products required define for each)	3–4 μJy	
Dynamic range (if polarisation products required define for each)	~10^6	
Absolute flux scale calibration		1-3%
	x	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	~0.1 arcsecond at 5 GHz
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	2×2500 MHz (maximum)

Required rms (Jy per beam) (if polarisation products required define for each)	3–4 μJy	
Dynamic range within image (if polarisation products required define for each)	~10^6	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Direction dependent gain calibration, multi-frequency multi-scale synthesis should be taken into account, which are important for wide-field, wide-bandwidth imaging at these high frequencies.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Re-processing is needed, we would need calibrated visibilities to make images at several different resolutions.
Data products	Data output should have undergone i. RFI flagging and other bad data flagging ii. calibrated visibilities with a few KHz resolution (highest channel-resolution is preferred) should be made available.
Description of pipeline	Calibrated visibilities will be • first subject to scrutiny of bad data, and

	then multi-frequency, multi-scale imaging would be performed, an important step for wide-field, wide-bandwidth imaging at high frequencies.
Quality assessment plan & cadence	Stability of amplitude and phase, both as a function of time as well as a function of frequency on time scales of 20–30 min.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	We will prefer data be made available once a scheduling block and pipeline reduction is complete, i.e. after 24 hr time block.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Procedural details of the data analysis will be built based on our experience of data analysis from WSRT, VLA, ATCA, LOFAR, GMRT, JVLA, etc.

REFERENCES

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2.19 **An all sky survey across the SKA1-LOW**

PROJECT DETAILS	
Title	**An all sky survey across the SKA1-LOW**
Principal Investigator	**P. Kharb & D.V. Lal (coordinators) for the SKA-India team**
Co-Authors	Team comprises of experts in science, including theorists and technical aspects, with huge experience in imaging with VLA, WSRT, JVLA, GMRT, Lofar and MWA. Technical support from S. Bhatnagar and R.V. Urvashi (NRAO, USA) is also available.
Time Request	~8,000 hrs (tentative!)

FACILITY		Preconditions
x	SKA1-LOW	
	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
x	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
x	Normal	

	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
If the `drift-scan' mode is available, we would use it to make all-sky images; i.e., we point the primary beam to one declination and let the sky drift. Depending on the primary beam width, we cover a 6–8 hours in hour-angle each day for a given pointing. Since this is a low frequency imaging, we will prefer night time observing to minimize scintillations and ionospheric disturbances. Therefore, we request observing sessions separated by three months to cover the whole sky during the night observing and we would revisit the sky for a second round of observing in the next season.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	X	Stokes Q
	XY	X	Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The SKA1-LOW survey will provide us with detailed, deep image of the total intensity and polarisation imaging of the entire sky. The survey complements deep field images at high frequencies and it will permit to tackle following science aspects at high and low redshifts:
(i) understanding the origin of radio-FIR correlation, (ii) the evolution of magnetic fields in AGN, relics, bridges connecting clusters, filamentary structures of the cosmic web, etc., (iii) environments of AGNs, Fanaroff-Riley dichotomy and radio-loud–radio-quiet divide, (iv) the role of diffuse radio emission (halos and relics), jets and bubbles blown by SMBH/AGN in galaxy clusters and interplay between them, (v) discovering head-tail radio galaxies and use them as tracers of cluster potential, (vi) search for diffuse, low surface brightness radio emission in field radio galaxies, which

	probably fades as rapidly as high frequency synchrotron emission,
(vii)	discovering giant radio galaxies and use them as barometers to understand warm-hot inter-galactic medium,
(viii)	inverse-Compton emission from lobes of high-z radio galaxies,
(ix)	search for inverse-Compton ghosts (also called radio-ghosts),
(x)	search for gravitational lensing candidates and using them to put constraints on the cosmological parameters, and
(xi)	nature of radio sources at μJy levels and radio source count.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	x	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	~500 pointings to cover whole sky, with the FoV of each pointing being 72 deg^2 (~36,000 deg^2 of total sky visible).	
Positions of targets	All visible part of the sky (~36,000 deg^2)	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	x	NO
Time Critical?		YES [details: ……………………………………….]
	x	NO
Integration time per target (hrs)	In each FoV, to reach a sensitivity of ~1 μJy/beam, we need about 16 hour integration time; assuming a bandwidth of 300 MHz, T_{sys} = 250 K at 150 MHz, 1.3*10^5 LPDs and A_eff = 0.25*λ^2 of each LPD.	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)		
Expected polarised flux density (expressed as % of total)		

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	200 MHz (SKA1-LOW band)
Total Bandwidth (MHz)	300 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	Maximum permitted by the correlator
Temporal resolution (in seconds)	Default

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)	A few arcsecond at 350 MHz	
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)	~1 μJy (the confusion noise estimate at 150 MHz for an arcsec^2 beam is also ~1 μJy)	
Dynamic range (if polarisation products required define for each)	~10^6	
Absolute flux scale calibration		1-3%
	x	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	A few arcsecond at 350 MHz	
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)	Maximum allowed, i.e. 300 MHz	
Required rms (Jy per beam) (if polarisation products required define for each)	~1 μJy per 1 MHz bandwidth at 350 MHz	
Dynamic range within image (if polarisation products required define for each)	$\sim 10^6$	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of image channels	

Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Direction dependent gain calibration, and multi-frequency, multi-scale synthesis should be taken into account, which are important for wide-field, wide-bandwidth imaging at low frequencies.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Re-processing is needed, we would need calibrated visibilities to make images at several resolutions.
Data products	(i) RFI flagging and other bad data flagging, (ii) calibrated visibilities with a few KHz resolution (highest channel-resolution is preferred)
Description of pipeline	Calibrated visibilities will be (i) first subject to scrutiny of bad data, (ii) then the direction dependent calibration will be performed, and (iii) finally, multi-frequency, multi-scale imaging would be performed, an important step for wide-field, wide-bandwidth imaging at low frequencies.
Quality assessment plan & cadence	Stability of amplitude and phase, both as a function of time as well as a function of frequency on time scales of 20–30 min.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	We will prefer data be made available once a scheduling block and pipeline reduction is complete, i.e. typically after the 24 hours time block.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Procedural details of the data analysis will be built based on our experience of data analysis from upgraded-GMRT at low frequencies. As mentioned earlier, our team comprises of experts in science, including theorists and technical aspects, with huge experience in imaging with VLA, WSRT, JVLA, GMRT, Lofar and MWA. Technical support from S. Bhatnagar and R.V. Urvashi (NRAO, USA) experts in this field is also available.

REFERENCES
i. SKA-India science book (ver. 1), available at http://www.ncra.tifr.res.in:8081/~tirth/SKA-India/booklet.pdf ii. Bagchi, J. et al. 2006 Sci. 314, 791 iii. Basu, A. et al. 2015 ApJ 803, 51 iv. Begelman, M.C. & Nath, B. 2005 MNRAS 361, 1387 v. Dwarakantha, K.S. & Udaya Shankar, N. 1990 JApA 11, 323 vi. Fanaroff, B.L. & Riley, J.M. 1978 MNRAS 167, 31P vii. Ishwara-Chandra, C.H. et al. 2010 MNRAS 405, 436 viii. Kale, R. & Dwarakanath, K.S. 2012 ApJ 744, 46 ix. Kharb, P. et al. 2008 ApJS 174, 74 x. Krishna, Gopal- et al. 2014 MNRAS 443, 2824 xi. Lal, D.V. & Rao, A.P 2004 A&A 420, 491 xii. More, S. et al. 2013 MNRAS 430, 747 xiii. Sharma, P. et al. 2014 MNRAS 443, 3463 xiv. Shastri, P. 201 A&AT 20, 281 xv.

2.20 Extended diffuse radio sources in galaxy clusters with SKA1-MID band 5

PROJECT DETAILS	
Title	**Extended diffuse radio sources in galaxy clusters with SKA1-MID band 5**
Principal Investigator	**Ruta Kale**
Co-Authors	**SKA continuum survey science working group**
Time Request	500 hours

FACILITY		Preconditions
	SKA1-LOW	
x	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
x	SKA1-MID Band 5	500 hours

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
x	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**x**	Stokes I
	YY	x	Stokes Q
	XY	x	Stokes U
	YX	x	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The generation and sustenance of diffuse radio sources in galaxy clusters in the form of radio halos, relics and mini-halos are long standing puzzles. Observations and simulations have indicated strongly that turbulence and shocks in the intra-cluster medium can amplify magnetic fields and make relativistic electrons in addition to those created by hadronic collisions. The generation mechanism behind these sources and ageing impacts their spectra, more critically in the higher frequency side due to their dependence on the square of the energy of the emitting electron. The location of the break in the spectrum has implications to the effectiveness of turbulent re-acceleration and shock acceleration. In addition, rotation measure synthesis is needed to understand the magnetic field properties along the line of sight. The SKA1-MID is the first telescope that can provide the critical short baselines for imaging extended sources in the frequency band 5–13 GHz. We propose to survey all the known radio halos, relics and mini-halos in the Band 5 (4.6–13.8 GHz, full polar mode) of SKA1-MID with unprecedented sensitivities with the aim of constraining the theoretical models and the three dimensional structure of magnetic fields in the intra-cluster medium. Our sample comprises of targets with angular sizes less than 10 arcminutes keeping in mind the shortest baseline spacing of 25 m expected with the SKA1-MID.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	X	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	~100	
Positions of targets	Assorted.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	In each target per pointing, to reach a sensitivity of 2–3 μJy/beam we need 4–5 hours integration time; assuming a bandwidth of 2 × 2500 MHz, 10 arcsec resolution and 2/3 (~133) antennae are in ~1 km core.	
Average peak flux density (Jy or Jy per beam)		

Range of peak flux densities (Jy or Jy per beam)	
Expected polarised flux density (expressed as % of total)	3–8 percent

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	9.2 GHz
Total Bandwidth (MHz)	2×2500 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	Maximum spectral resolution permitted by the correlator.
Temporal resolution (in seconds)	default

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)	~10 arcsecond at 5 GHz	
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)	2×2500 MHz (maximum)	
Required rms (Jy) (if polarisation products required define for each)	2–3 μJy	
Dynamic range (if polarisation products required define for each)	~10^5	
Absolute flux scale calibration		1-3%

	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	~10 arcsecond at 5 GHz	
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)	2×2500 MHz (maximum)	
Required rms (Jy per beam) (if polarisation products required define for each)	2–3 μJy	
Dynamic range within image (if polarisation products required define for each)	$\sim 10^5$	
Absolute flux scale calibration		1-3%
	x	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	
Mapped image size (degrees)	
Number of image channels	
Channel width (kHz)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	
Dynamic range within image per channel	

(if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Multi-frequency, multi-scale synthesis should be taken into account; important for wide-bandwidth imaging of our extended targets.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Re-processing is needed, we would need calibrated visibilities to make images at several different resolutions.
Data products	Data output should have undergone iii. Flagging: RFI, bad data, in time and frequency flagging, etc. iv. calibrated visibilities with a highest channel-resolution should be made available.
Description of pipeline	Calibrated visibilities will be • subject to scrutiny of bad data, and then multi-frequency, multi-scale imaging would be performed, an important step for wide-bandwidth imaging.
Quality assessment plan & cadence	Stability of amplitude and phase, both as a function of time as well as a function of frequency on time scales of ~30 min.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	We will prefer data be made available once a scheduling block and pipeline reduction is complete, i.e. after 24 hr time block.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Procedural details of the data analysis will be built based on our experience of data analysis from WSRT, VLA, ATCA, GMRT, JVLA, etc.

REFERENCES
1. Prandoni, I & Seymour N. arXiv:1412.6512 2. Cassano, R. et al. 2015, aska, Conf. E, 73 3. Cassano, R & Brunetti, G., 2005 MNRAS 357, 1313 4. Cassano, R. et al. arXiv:1412.5940 5. Gitti, M. et al. arXiv:1412.5664 6. Kale, R. et al., 2013 A&A 557, 99 7. Kale, R. & Dwarakanath, K. S., 2010 ApJ 718, 939

2.21 Measuring the Star formation History of the Universe (thermal processes)

PROJECT DETAILS	
Title	**Measuring the Star Formation History of the Universe (thermal processes; science goal #37)**
Principal Investigator	**E. J. Murphy & M. T. Sargent**
Co-Authors	Continuum science working group
Time Request	3000 hours (TBC)

FACILITY		Preconditions
	SKA1-LOW	
✓	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
✓	SKA1-MID Band 5	Deep Tier: 2000 hours Ultra-deep: 1000 hours (TBC)

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
✓	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
(✓)	Commensal	commensal with deep field searches for high-z molecular line emission
(✓)	Collaborative & Coordinated	coordinated with non-thermal SFHU (Science Goal #37)
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
2 tier survey. Deep tier: 1 sq deg to 0.3 μJy/beam rms, 0.05-0.1 arcsec resolution Ultra-deep tier: 30 square arcminutes to 0.04 μJy/beam rms, 0.05-0.1 arcsec resolution

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	✓	Stokes I
	YY	✓	Stokes Q
	XY	✓	Stokes U
	YX	✓	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Observations at ~10 GHz provide insights on the ISM properties at high redshift, where they probe rest-frame wavelengths where thermal (free-free) dominates over synchrotron emission. Additionally, resolutions of order 0.05-0.1" enable mapping of the distribution of star formation within galaxies, and morphologically separate out AGN contributions for unbiased measurements of star formation rates (SFRs). By including all polarization products this high-resolution data will further make it possible to distinguish between nuclear starbursts and AGN based on the degree of polarization of their emission. - The “deep” tier will detect SFR ~100 M□/yr galaxies out to z□3 (rest-frame 40 GHz for robust SFR estimates); will resolve SFR>100 M□/yr galaxies on sub-kpc (□0.1") scales out to z~0.5. - The “ultra-deep” tier will (a) detect SFR ~50 M□/yr galaxies out to z~6 (same as ultra deep Tier at 1 GHz in their rest-frame 70 GHz emission), providing a robust SFR indicator; (b) resolve SFR>100 M□/yr galaxies on sub-kpc (~0.1") scales out to z~1; (c) will resolve SFR>100 M□/yr galaxies on kpc (□0.2") scales out to the peak of the cosmic star formation rate density (z□2; rest-frame 30 GHz, also typically dominated by free-free emission)

‘TARGETS’ OF OBSERVATIONS		
Type of observation (what defines a ‘target’)		Individual pointings per object
		Individual fields-of-view with multiple objects
	✓	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	Two-tiered survey (varying depth & size)	
Positions of targets	Target fields will be selected in coordination with other deep multi-wavelength surveys. The ultra-deep tier should be selected to be away from bright radio sources.	

Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	✓	NO
Time Critical?		YES [details: ……………………………………….]
	✓	NO
Integration time per target (hrs)	2000 hours (deep), 1000 hours (ultra-deep) (TBC)	
Average peak flux density (Jy or Jy per beam)	Deep tier: 0.01-0.1 mJy Ultra deep tier: 2-20 μJy	
Range of peak flux densities (Jy or Jy per beam)	Deep tier: 1.5 μJy to 50 mJy Ultra-deep tier: 0.2 μJy to ~5 mJy	
Expected polarised flux density (expressed as % of total)	1 – 50%	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (✓ _)*	
Central Frequencies (MHz) (including redshift, observatory correction)	11500
Total Bandwidth (MHz)	5000
Minimum and maximum frequency over the entire range of the setup (MHz)	9000-14000
Spectral resolution (kHz)	2000
Temporal resolution (in seconds)	standard

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	
Maximum baseline required (km)	
Primary beam size (sq degrees)	
Number of output channels	

Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	0.05-0.1 arcsec
Maximum baseline required (km)	130 km
Mapped image size (degrees)	Deep tier: 1 square degree Ultra deep tier: 30 square arcminutes
Required pixel resolution (arcseconds)	0.013-0.025 arcsec
Number of output channels	2500
Output bandwidth (minimum and maximum frequency - MHz)	9000-14000 MHz (band 5)
Required rms (Jy per beam) (if polarisation products required define for each)	Deep tier: 0.3 muJy/beam Ultra-deep tier: 0.04 muJy/beam
Dynamic range within image (if polarisation products required define for each)	Approx. $10^{5.5}$,both for the deep & ultra-deep tier in Stokes I. Approx. $10^{3.5}$ – $10^{4.5}$ for Stokes Q, U & V (assuming about 10% polarization).

Absolute flux scale calibration	✓	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	

Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Multi-frequency synthesis imaging.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	High dynamic range required. This will require not only self-calibration but also advanced imaging techniques to remove direction dependent effects (e.g. time-dependent/3D primary beam) such as peeling, A-W projection.
Data products	Stokes I images. Catalogue of radio source components.
Description of pipeline	Advanced imaging pipeline, incorporating A-W projection and possibly peeling, to produce high dynamic range continuum maps.
Quality assessment plan & cadence	Check radio source positions against SKA-precursor radio continuum surveys and band 2 SKA continuum survey(s), check spectral indices against band 2 SKA continuum survey.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections	Upon completion of 10-20% (TBD) of each tier.

using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
1) Dynamic ranges of ~$10^{5.5}$ are required in the deepest tier of this use case. However, if this dynamic range is not achieved around bright sources those areas could be masked in the final image. 2) An alternative tuning strategy could be to place the upper 2.5 GHz sideband at the upper edge of band 5, while the lower sideband would be located well below 10 GHz in order to facilitate spectral index measurements for bright sources. In such a case the Advanced Imaging Pipeline should be able to produce both images of the individual sidebands and of both sidebands together (for maximal sensitivity/bandwidth). For the latter, the Advanced imaging pipeline should be able to produce equally good results as would be the case for two adjacent 2.5 GHz sidebands.

REFERENCES
Murphy et al. 2015, "The Astrophysics of Star Formation Across Time at >10 GHz with the Square Kilometre Array" (SKA Science Book) Prandoni & Seymour 2015, "Revealing the Physics and Evolution of Galaxies and Galaxy Clusters with SKA Continuum Surveys" (SKA Science Book)

2.22 Measuring the star formation history of the Universe

PROJECT DETAILS	
Title	**Measuring the star formation history of the Universe**
Principal Investigator	**Minh Huynh**
Co-Authors	**Continuum Science Working Group**
Time Request	8,000 hours (TBC)

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
X	SKA1-MID Band 2	Wide Tier: 4000 hours Deeo Tier: 2000 hours Ultra-deep: 2000 hours (TBC)
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	**Could be commensal with HI, Polarisation and cosmology surveys.**
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
3 tier survey. Wide tier: 1000 sq deg to 1 muJy/beam rms, 0.5 arcsec resolution Deep tier: 10 sq deg to 0.2 muJy/beam rms, 0.5 arcsec resolution Ultra-deep tier: 1 sq deg to 0.05 muJy/beam rms, 0.5 arcsec resolution

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (<u>X</u>)*			
	XX	**X**	Stokes I
	YY	X	Stokes Q
	XY	X	Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The goal of this project is to trace the build of stars from the local universe to z ~ 3 - 4. Radio luminosities provide a much more reliable tracer of star formation rate than optical/UV luminosities, especially at high redshift where the latter are strongly affected by dust extinction. In addition radio interferometric images can have much higher (sub-arcsec) angular resolution than the confusion-limited infrared satellites (Spitzer, Herschel), allowing a probe of much fainter and higher redshift galaxy populations. In its phase 1 SKA will allow us to go factors 10-100x deeper/wider than pathfinders and JVLA in Band 2. A tiered approach such as that proposed here will open up the study of star formation in a variety of environments at z ~ 1 as well as detecting SFR > 10 Msun/yr galaxies at z ~ 3 - 4.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view

		Non-imaging pointings
Number of targets	3 fields/tiers, of varying depth and size.	
Positions of targets	Target fields will be selected in coordination with other deep multi-wavelength surveys. The ultra-deep tier could be selected to be away from bright radio sources.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	4000 hours (wide tier), 2000 hours (deep), 2000 hours (ultra-deep) (TBC)	
Average peak flux density (Jy or Jy per beam)	Wide tier: 5 muJy Deep tier: 1 muJy Ultra deep tier: 0.25 muJy	
Range of peak flux densities (Jy or Jy per beam)	Wide tier: 5 muJy to 2 Jy Deep tier: 1 muJy to 1 Jy Ultra-deep tier: 0.25 muJy to 1 Jy	
Expected polarised flux density (expressed as % of total)	1 – 50%	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1360 MHz
Total Bandwidth (MHz)	810 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	1000
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	0.5 arcsec
Maximum baseline required (km)	90 km (see required angular resolution)
Mapped image size (degrees)	Wide
Required pixel resolution (arcseconds)	0.125 arcsec
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	950 – 1760 MHz (full Band 2)

Required rms (Jy per beam) (if polarisation products required define for each)	Wide tier: 1 muJy/beam Deep tier: 0.2 muJy/beam Ultra-deep tier: 0.05 muJy/beam	
Dynamic range within image (if polarisation products required define for each)	Wide tier: 400,000 Deep tier: 1 million Ultra-deep tier: 4 million	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%

		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Multi-frequency synthesis imaging.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	High dynamic range required. This will require not only self-calibration but also advanced imaging techniques to remove direction dependent effects (e.g. time-dependent/3D primary beam) such as peeling, A-W projection
Data products	Stokes I,Q,U,V images. Catalogue of radio source components.

Description of pipeline	Advanced imaging pipeline, incorporating A-W project and possibly peeling, to produce high dynamic range continuum maps.
Quality assessment plan & cadence	Check flux densities and positions against radio continuum surveys such as EMU.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of 10-20% (TBD) of each tier

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Dynamic ranges of ~ million are required in the deepest tier of this use case. However, if this dynamic range is not achieved around bright sources those areas could be masked in the final image. Note also that while Stokes I is all that is strictly required for this case, Q, U, and V are included in data products as they are essentially for free, and full Stokes increases commensality.

REFERENCES

2.23 Structure formation and energy balance in the ISM and IGM at high redshifts

PROJECT DETAILS	
Title	Structure formation and energy balance in the ISM and IGM at high redshifts
Principal Investigator	**Fatemeh Tabatabaei, Masoumeh Ghasemi**
Co-Authors	**Mark Sargent, Eric Murphy, Keith Grainge, Rob Beswick, and the SKA continuum survey science working group**
Time Request	~5600+1400+4600 hours (TBD)

FACILITY		Preconditions
	SKA1-LOW	
✓	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
✓	SKA1-MID Band 1	Wide: 5600 h Deep: 1400 h Ultra-deep: 4600 h
✓	SKA1-MID Band 2	As proposed in use case 2.22
	SKA1-MID Band 3	
	SKA1-MID Band 4	
✓	SKA1-MID Band 5	As proposed in use case 2.21

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
✓	Normal	

	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
(✓)	Commensal	Could be commensal with cosmology, HI, and Magnetism SWGs
(✓)	Collaborative & Coordinated	Coordinated with thermal and non-thermal SFHU (HPSO #37 & 38)
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY

Covering the mid-radio SED at different depths and FOV at as many frequency as possible. These include the available SKA1-MID Bands 1, 2, & 5. The observing procedures for Bands 2 and 5 are the same as those proposed in the Star Formation History use cases 3.19 and 3.20. We consider here Band1 as well. We note that the FoVs should overlap as much as possible at different Bands (not necessarily equal). 3 Tiers at Band 1: Wide tier: 1000 sq deg to 1.5 muJy/beam rms, 0.7" resolution, 5600 hours total observing time (~9h per pointing for Npoint=2340x(lambda/D)^2=633 at 770MHz) Deep tier: 10 sq deg to 0.3 muJy/beam rms, 0.7" resolution, 1400 hours (~200h per pointing for Npoint=7 at 770MHz) Ultra-deep tier: >1 sq deg to 0.075 muJy/beam rms, 0.7" resolution, 4600 hours (~4600 h per pointing, Npoint=1 through entire B1) (These calculations are consistent with Band2, taking into account a spectral index of 0.7. Set ups for other two Bands are as follows. 3 Tiers at Band 2: Wide tier: 1000 sq deg to 1 muJy/beam rms, 0.5" resolution Deep tier: 10 sq deg to 0.2 muJy/beam rms, 0.5" resolution Ultra-deep tier: 1 sq deg to 0.05 muJy/beam rms, 0.5" resolution 2 Tiers at Band 5: Deep tier: 1 sq deg to 0.3 muJy/beam rms, 0.1" resolution Ultra-deep tier: 0.008 sq deg (1 pointing) to 0.04 muJy/beam rms, 0.1" resolution) These surveys will consist of repeated observations to the proposed total observing time of a single pointing on the sky. Particularly for Band 1, night time observations preferred to avoid solar interference. Because of the low surface brightness, short baselines are crucial.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
✓	XX	✓	Stokes I
✓	YY	✓	Stokes Q
✓	XY	✓	Stokes U
✓	YX	✓	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
We study the formation and evolution of structures inside and surrounding galaxies, the ISM and IGM at high-redshifts (up to z~2.5 including the epoch of star formation). The radio continuum (RC) emission, particularly its non-thermal component, provides a dust-unbiased tracer of energetic processes in the ISM (Tabatabaei et al. 2018). To understand how star formation and galactic structures evolve over cosmic time, it is important to know how the pressure & energy balance in the ISM/IGM changes with z. This can best be studied through resolved MID-RC SEDs of galaxies helping us to disentangle the thermal and non-thermal processes in the ISM & IGM (Tabatabaei et al. 2017). The SKA1-MID surveys at Bands 1, 2, and 5 provide a significant frequency range to study the MID-RC SEDs and to shed light on this important topic. Simulations show that the MID-RC SED of normal star forming galaxies becomes flatter with redshift z indicating that these particles are more energetic at higher redshifts. The thermal fraction of the radio continuum emission also changes with redshift: It increases monotonically with z or shows a small maximum around z ~ 1 depending on the SFR evolution. The thermal and non-thermal RC maps of galaxies simulated at high redshifts show the possibility to detect spiral arms up to z~1 at an SKA resolution of 0.6". At z~2, the ISM in the inner vs outer disks in normal galaxies such as M51 will be detected at S/Ns>10 of the ultra-deep tier. In the deep tier, the mean ISM can be detected at > 3σ level up to z = 2 in the M51-like galaxies, while such detection is only possible up to to z = 1 in the NGC6946-like galaxies assuming no galaxy-size-evolution (Ghasemi & Tabatabaei et al. submitted).

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	✓	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	1000	
Positions of targets	3 fields/tiers, of varying depth and size for Band 1 Target fields will be selected in coordination with the SFH B2 & 5 surveys. The ultra-deep tier should be selected to be away from bright radio sources.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ………………………………………..]

	✓	NO
Time Critical?		YES [details: ……………………………………….]
	✓	NO
Integration time per target (hrs)		Wide tier: **5600 hours** total observing time (~9h per pointing for Npoint=2340x(lambda/D)^2=633 at 770MHz) Deep tier: **1400 hours** (~200h per pointing for Npoint=7 at 770MHz) Ultra-deep tier: **4600 hours** (~4600 h per pointing, Npoint=1 through entire B1)
Average peak flux density (Jy or Jy per beam)	Band 1: Wide tier: 7.6 uJy Deep tier: ~1.5 uJy Ultra deep tier: 0.4 – 0.5 uJy	
Range of peak flux densities (Jy or Jy per beam)	Wide tier: 7.5 uJy to 3 Jy Deep tier: 1.5 uJy to 750 mJy {*} Ultra-deep tier: 0.35 uJy to 150 mJy {*} {*} The maximum flux densities refer to random fields. It will be lower as we will likely select fields free from bright sources to help with the dynamic range requirement	
Expected polarised flux density (expressed as % of total)	1-50%	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (✓ _)*	
Central Frequencies (MHz) (including redshift, observatory correction)	B1-sb1: 415 MHz B1-sb2: 565 MHz B1-sb3: 770 MHz
Total Bandwidth (MHz)	540 MHz if using sb1,2,3 only: B1-sb1 350-480 MHz B1-sb2 480-650 MHz B1-sb3 650-890 MHz *B1- sb4 890 -1050 MHz *Note: B-sb4 has overlaps w B2*
Minimum and maximum frequency over the entire range of the setup (MHz)	350-890 MHz

Spectral resolution (kHz)	Can be coordinated with the HI or line surveys
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	~ 0.009 - 0.017arcmin

Maximum baseline required (km)	150 km	
Mapped image size (degrees)	>1 - 1000 sq. deg.	
Required pixel resolution (arcseconds)	1/4 of angular res. (0.14”-0.2”)	
Number of output channels	Can be coordinated with HI or line surveys	
Output bandwidth (minimum and maximum frequency - MHz)	350-890	
Required rms (Jy per beam) (if polarisation products required define for each)	Wide tier: 1.5 muJy/beam Deep tier: 0.3 muJy/beam Ultra-deep tier: 0.075 muJy/beam	
Dynamic range within image (if polarisation products required define for each)	Wide tier: 2 million Deep tier: 1-2 million {*} Ultra-deep tier: 1-2 million {*} {*} It can be mitigated with a clever choice of fields	
Absolute flux scale calibration	✓	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of image channels	

Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%

		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Multi-frequency, multi-scale synthesis should be taken into account
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	High dynamic range required. This will require not only self-calibration but also advanced imaging techniques to remove direction dependent effects (e.g. time-dependent/3D primary beam) such as peeling, A-W projection. Producing images at varying resolutions might be needed.
Data products	Stokes IQUV fits images or cubes and gridded visibilities as it helps to get images at varying resolution, performing the appropriate tapering in the UV plane. Catalogue of radio source components.
Description of pipeline	Advanced imaging pipeline, incorporating A-W projection and possibly peeling, to produce high dynamic range continuum maps.
Quality assessment plan & cadence	Check radio source positions against SKA-precursor radio continuum surveys and band 1 SKA continuum survey(s), check spectral indices against band 1 SKA continuum survey.

Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of 10-20% (TBD) of each tier.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES
Ghasemi-Nodehi & Tabatabaei et al., *Evolution of radio continuum emission on kpc scales with SKA, submitted* Tabatabaei et al. 2018, *Discovery of massive star formation quenching by non-thermal effects in the center of NGC1097*, 2018, Nature Astronomy, 2, 83 Tabatabaei et al., 2017, *The Radio Spectral Energy Distribution and Star Formation Rate Calibration in Galaxies,* 2017ApJ, 836, 185

2.24 Cosmological Weak Lensing in the Radio Band

PROJECT DETAILS	
Title	**Cosmological Weak Lensing in the Radio Band**
Principal Investigator	
Co-Authors	**Ian Harrison, Michael Brown, Prina Patel**
Time Request	10,000 hours

FACILITY		Preconditions
	SKA1-LOW	
	SKA1-MID	Production of gridded visibilities with high spectral and time resolution *or* images made with an imaging algorithm that will preserve source ellipticity to 1 part in 10^4. Baselines to give resolution of at least 0.5" across 900 to 1.5GHz frequency range (>100km). This SDP capability was assessed through an engineering change proposal (ECP150007), and approved.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
X	SKA1-MID Band 2	10,000
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	
X	Collaborative & Coordinated	**Can be part of general wide area continuum/HI survey, contingent on required integration time and sky area.**
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	X	Stokes Q
	XY	X	Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
This survey has the potential to open a new window on cosmology with weak lensing, being the first survey in the radio band to have galaxy number densities (≥2 arcmin^{-2}) and survey area (1-5000 deg^2) high enough to provide cosmological constraints competitive with the best optical experiments. Performing weak lensing in the radio has a number of unique advantages, potentially overcoming systematics which would otherwise become the limiting factor in our ability to do precision measurement of the Dark Energy equation of state using optical and NIR weak lensing. The deterministic and well-characterised beam of radio interferometers can greatly assist with the suppression of shear systematics due to PSF anisotropies; the extra polarisation information (Brown & Battye 2011) and spectral information (Voigt et al 2012, Morales 2006) provide opportunities to remove the contaminating intrinsic alignments of galaxies and correct for frequency dependence in the PSF. In addition, by covering the same region as the Dark Energy Survey (DES) cross-correlation of overlapping galaxy samples can increase effective number counts and remove wavelength-dependant systematics (Patel et al 2010). By probing the muJy flux populations around 1 GHz, we expect to be measuring emission from star-forming galaxies with median redshift z~1, providing extra redshift bins with which to perform weak lensing tomography and hence a longer lever arm with which to measure the evolution of the accelerating expansion.

‘TARGETS’ OF OBSERVATIONS		
Type of observation (what defines a ‘target’)		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
	X	Non-imaging pointings
Number of targets	13,333 pointings of 0.375 deg^2 to make up 5000 deg^2	
Positions of targets	Science maximised by overlapping with matched optical survey, DES, for cross-correlation studies. To consist of 5000 deg^2 bounded by -60 < RA < 105, -65 < DEC < 3. This area consists of SPT, Viking, Round 82 and Stripe 82 regions. This area should also be probed by (potentially commensal) HI survey for source redshift information.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	~1 hour per pointing	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)		
Expected polarised flux density (expressed as % of total)	~1-10% polarisation fraction expected for the star forming galaxies usable for weak lensing.	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (X)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1100
Total Bandwidth (MHz)	300MHz +

Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	30
Temporal resolution (in seconds)	0.5

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	

Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	0.5 arcsec
Maximum baseline required (km)	150
Mapped image size (degrees)	1 degree
Required pixel resolution (arcseconds)	0.1 arcsec
Number of image channels	6000
Channel width (kHz)	30
Required rms (Jy per beam per channel) (if polarisation products required define for each)	2 muJy
Dynamic range within image per channel	10^6

(if polarisation products required define for each)		
Absolute flux scale calibration	X	1-3%, driven by requirements of commensal galaxy survey and necessity for removal of bright contaminating sources.
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Flagging, broadband calibration in full Stokes (I, Q, U and V), extremely high-fidelity wide-field broadband imaging, mosaicking, source finding, source classification, measurement of source ellipticities.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Weak lensing requires measurement of star-forming galaxy shapes with biases of less than 0.01% in source ellipticity, requiring minimal bandwidth and time smearing and deep removal of bright contaminating sources.
Data products	Deconvolved images in I, Q, U, V for source finding and calibration. Require either access to gridded visibilities (see SKA ECP150007) for weak lensing shape fitting or an imaging pipeline capable of preserving source ellipticities to the level required for cosmic shear weak lensing.
Description of pipeline	Collect visibilities over multiple pointings. Apply flagging Calibrate visibilities Remove strong contaminating sources Mosaicking of multiple pointings in wide-field images Source identification Classification of star-forming galaxy sources EITHER: Image-plane measurement of source ellipticities contingent upon imaging quality OR: UV-plane measurement of source ellipticities through modelling of the gridded visibilities
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the	Science will be performed using the whole survey region at once, so data availability should be at the end of a scheduling block or the completion of the project.

fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Principal issue TBD is method of shape measurement to be used. Will either require extremely high fidelity imaging (in the sense that ellipticities of galaxies do not become biased) or UV-plane source modelling. This is being actively investigated in the radioGREAT programme. Also requires knowledge of muJy flux star forming galaxies, their number densities, size distributions and polarisation properties. These are being investigated on SKA pathfinder surveys e-MERGE and SuperCLASS, with results due in the next year.

REFERENCES

Morales, 2006, *A Technique for Weak Lensing with Velocity Maps: Eliminating Ellipticity Noise in H I Radio Observations*, ApJ 650, 1, L20. arXiv:astro-ph/0608494

Patel et al, 2010, *Radio weak gravitational lensing with VLA and MERLIN*, MNRAS, 401, 4, 2572. arXiv:0907.5156

Brown & Battye, 2011, *Polarization as an indicator of intrinsic alignment in radio weak lensing*, MNRAS 410, 3, 2057. arXiv:1005.1926

Voigt, Bridle, Amara et al, 2012, *The impact of galaxy colour gradients on cosmic shear measurement*, MNRAS, 421, 2, 1385. arXiv:1005.5595

Brown, M., Bacon, D., Camera, S., et al., 2015, *Weak Lensing with the Square Kilometre Array,* Advancing Astrophysics with the Square Kilometre Array (AASKA14), 23, arXiv:1501.03828

Harrison & Brown, 2015, *Gridded Visibilities to Enable Precision Cosmology with Radio Weak Lensing*, arXiv:1507.06639

2.25 **All-Sky Rotation Measure Grid Survey**

PROJECT DETAILS	
Title	**All-Sky Rotation Measure Grid Survey**
Principal Investigator	**Magnetism Science Working Group**
Co-Authors	**Magnetism Science Working Group**
Time Request	**7500 Hours**

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	Full-Stokes IQUV image cubes at a spectral resolution of 1 MHz should be archived, if resources allow. If Rotation Measure Synthesis (and other polarimetric analysis tools) is included in SDP, then RM cubes (and derived image and catalog products such as Faraday moment maps and source properties) should also be stored and accessible.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
X	SKA1-MID Band 2	7500 h
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	With Legacy Reference Continuum Survey from the Continuum SWG #4 described by Prandoni, & Seymour (2015).
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
From Braun et al. (2019), the FoV diameter for Band 2 at 1400 MHz is 60 arcminutes. Separating fields by that angular size, we require 30,000 pointings. Also from Braun et al. (2019), the continuum sensitivity is expected to be 4 uJy/beam for a 15 minute observation and with 2” resolution. See also the discussion in Heald et al. (2020, Galaxies, 8. 53). 1 MHz channels corresponds to a maximum recoverable RM of approximately 8450 rad/m^2 and this is expected to be adequate for most of the sky, despite the possibility of missing a rare population of exciting sources. A stretch goal for SDP and/or SRC data products is capability for RMs up to a few times 10^5 rad/m^2 from cubes with “fine resolution” (13.4 kHz) spectral resolution, at least for a limited range of sky area, but this is considered to be non-essential for the all-sky survey and all science goals except the discovery of unknowns.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (_) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	**X**	Stokes Q

	XY	**X**	Stokes U
	YX	**X**	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
All-Sky RM Grid Cosmic magnetism has been a key SKA science driver since the early planning phases of the project, including an early "RM Grid" concept. The SKA holds great promise because of the central importance of meter- and centimeter-wavelength radio observations for the study of cosmic magnetism. The study of cosmic magnetism spans diverse astrophysical domains, and magnetic fields within the corresponding observational targets range over a wide variety of scales, from Mpc down to sub-pc. Overarching these detailed studies are two common questions: 1) what is the origin and evolution of magnetic fields throughout the Universe? and 2) how do magnetic fields illuminate and influence the physical processes in different objects? The SKA will probe magneto-ionic media in many different environments including the large-scale structure of the Universe and the intergalactic medium, large-scale jets and outflows from AGN, the formation and evolution of galaxies and stars, and the properties of the interstellar medium. The greatest challenge to addressing these issues has been a lack of deep, broad bandwidth polarimetric data over large areas of the sky. The SKA will radically improve this situation via an all-sky polarisation survey that delivers both high quality polarisation imaging in combination with observations of 2-3 million extragalactic rotation measures.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	30,000 pointings	
Positions of targets	All-Sky	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO

Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	15 minutes per pointing (using sensitivity estimates from Braun et al 2019)	
Average peak flux density (Jy or Jy per beam)	N/A	
Range of peak flux densities (Jy or Jy per beam)	N/A	
Expected polarised flux density (expressed as % of total)	N/A	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (X)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1355 MHz
Total Bandwidth (MHz)	Full bandwidth of Band 2: 810MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	950; 1760 MHz
Spectral resolution (kHz)	13.4 kHz, to be averaged later to 1 MHz
Temporal resolution (in seconds)	N/A

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	N/A
Maximum baseline required (km)	N/A
Primary beam size (sq degrees)	N/A

Number of output channels	N/A	
Output bandwidth (minimum and maximum frequency - MHz)	N/A	
Required rms (Jy) (if polarisation products required define for each)	N/A	
Dynamic range (if polarisation products required define for each)	N/A	
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	Image in all Stokes at 2" resolution; another set of image cubes to be constructed at (5-10") resolution to maximize sensitivity to extended structures
Maximum baseline required (km)	150 km for legacy value, but expecting to use Bmax ~40 km for our primary 2" imaging
Mapped image size (degrees)	All-Sky
Required pixel resolution (arcseconds)	0.4 arcsec
Number of output channels	1
Output bandwidth (minimum and maximum frequency - MHz)	810 MHz
Required rms (Jy per beam) (if polarisation products required	Stokes QUV broadband sensitivity: 4 uJy/beam

define for each)		
Dynamic range within image (if polarisation products required define for each)	Stokes I: 30 dB Stokes Q,U: 25 dB Stokes V: 20 dB	
Absolute flux scale calibration	x	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	Continuum cubes in all Stokes at 2” resolution; another set of image cubes to be constructed at (5-10”) resolution to maximize sensitivity to extended structures	
Maximum baseline required (km)	150km (see maximum baseline required in the continuum section)	
Mapped image size (degrees)	All-Sky	
Required pixel resolution (arcseconds)	0.4”	
Number of image channels	810	
Channel width (kHz)	1MHz = 1000 kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	Per-channel rms 114 uJy/beam Required for IQUV	
Dynamic range within image per channel (if polarisation products required define for each)	Stokes I: 23 dB Stokes Q,U: 18 dB Stokes V: 13 dB	
Absolute flux scale calibration	**X**	1-3%

		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)	N/A	
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	- On-axis continuum and polarization calibration across band 2: broadband bandpass, gain, leakage and polarization angle calibration. - Primary beam correction across

	broadband in Stokes I and characterization & correction of off-axis polarization across broadband - Stokes I: wideband, wide-field imaging - Stokes QUV: 1MHz channel maps - RM Synthesis
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	For some areas of sky we may require higher spectral resolution to recover higher RMs
Data products	- Stokes IQUV spectral-cubes at 1-MHz resolution - A catalogue of polarized sources - Faraday depth sub-cubes - A catalogue of Faraday rotation of sources detected in the Faraday depth cube
Description of pipeline	Flagging, broadband full-Stokes calibration, primary beam correction in Stokes IQUV, wideband widefield Stokes I imaging, Stokes IQUV image cube imaging, RM Synthesis, Producing catalogues
Quality assessment plan & cadence	Cadence flexible to match the Legacy Reference Continuum Survey from the Continuum SWG #4 described by Prandoni, & Seymour (2015).
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Time lag is not expected to be a major science driver, but: - Calibrated UV data and wideband Stokes I image should be available soon after observations. - Stokes IQUV image cubes should be available on an intermediate time scale - Final mosaiced full-sensitivity data-cube and catalogues to be available at the completion of the full project

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
We may want to enable binning in lambda^2 space instead of cubes in frequency space Broadband linear polarization deconvolution algorithms are still in development and have not yet proven to be fully fit-for-purpose (at least in cases where |RM|>>0)

REFERENCES
Braun et al. (2019) https://ui.adsabs.harvard.edu/abs/2019arXiv191212699B/abstract Heald et al. (2020) https://ui.adsabs.harvard.edu/abs/2020Galax...8...53H/abstract Johnston-Hollitt et al. (2015) https://ui.adsabs.harvard.edu/abs/2015aska.confE..92J/abstract Prandoni & Seymour (2015) https://ui.adsabs.harvard.edu/abs/2015aska.confE..67P/abstract

2.26 Rotation Measure Synthesis in Targeted Fields

PROJECT DETAILS	
Title	**Rotation Measure Synthesis in Targeted Fields**

Principal Investigator	**George Heald**
Co-Authors	**Cosmic Magnetism SWG**
Time Request	40h per target

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	An archive should be available that will store full-polarization image cubes at the specified spectral resolution. The archive should be able to link, for a given target field, the separate Band 1 and Band 2 data products and run Rotation Measure Synthesis (and/or other complementary spectropolarimetric packages) on the joined dataset. Both the frequency cubes and the RM cubes should be stored in this archive. A mechanism should be available to determine the temporal variation of the ionospheric Faraday rotation per station.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
X	SKA1-MID Band 1	20h per target
X	SKA1-MID Band 2	20h per target
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	The observations of a given target field do not have a time-critical nature, but

		the full cumulative dataset is needed for final data processing.
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
The observations should be performed during stable ionospheric conditions to avoid substantial depolarization within the observing band due to locally induced Faraday rotation. Nighttime observations are preferred but not required as long as the Sun is far from the target field and not producing strong bursts.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (_) or CORRELATOR (x)*			
	XX	**X**	Stokes I
	YY	**X**	Stokes Q
	XY	**X**	Stokes U
	YX	**X**	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
A highly sensitive probe of the internal structure of magnetoionized media (e.g. the ISM of galaxies, ionized bubbles and diffuse emission regions in the Milky Way, clusters, AGN jets) is the partial depolarization of synchrotron radiation from inside the emitting volume. Different configurations of magnetic field and ionized gas within the beam cylinder of the telescope lead to changes in the observed, highly frequency-dependent polarization degree. The results of spectro-polarimetric observations are tied to physical structure in the ISM or ICM through comparison with detailed modeling, supplemented with the use of techniques including but not limited to Rotation Measure Synthesis. The target sources are diffuse structures, so this Use Case makes use of both high surface brightness sensitivity and angular resolution.

The observations will provide superb leverage on the internal ordered and random structure of the gas and magnetic fields in the target sources, uniquely probing the three-dimensional gas and magnetic field structures on small scales.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	**X**	Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	Tens	
Positions of targets	Variable	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs,mins,secs as appropriate)	40h	
Average peak flux density (Jy per beam)	The primary targets are extended sources, usually with relatively low flux density (down to the detection limit), but bright point sources with flux densities in the range 1-10 Jy will be present in typical fields.	
Range of peak flux densities (Jy per beam)	See above.	
Expected polarised flux density (expressed as % of total)	Varies strongly and rapidly within the bandwidth of interest. This is the central observational characteristic of interest for this Use Case.	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (x)*	
Central Frequencies (MHz) (including redshift, observatory correction)	This project aims to recover the full depolarization spectrum, necessitating the use of the full combined Band 1 and Band 2 (350-1760 MHz).
Total Bandwidth (MHz)	1410 MHz
Spectral resolution (kHz)	400 kHz, allowing the detection of Faraday RMs up to ~1000 rad/m2 with little bandwidth depolarization per channel. This specification is driven by the low-frequency (350 MHz) end of the bandwidth.
Temporal resolution ('dump' time in s or 'standard')	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS
N/A

IMAGING CONSIDERATIONS (continuum – single channel of full bandwidth)	
Required angular resolution (arcsec) (single value or range)	1-5" Higher angular resolution decreases beam depolarization, while lower angular resolution increases sensitivity to diffuse low surface brightness regions.
Required image size (arcsec) (single value or range)	Typically 1800"-7200" for extragalactic targets, but larger areas requiring mosaicing for Galactic targets
Required rms (Jy per beam) (if polarisation products required define for each)	For Stokes Q,U: to be imaged in separate channels (see below), leading to a broadband sensitivity of 250 nJy/beam rms For Stokes I: 500 nJy/beam rms
Dynamic range within image (if polarisation products required define for each)	For Stokes Q,U: typically up to ~10^5 For Stokes I: 10^6-10^7
Absolute flux scale calibration	1-3%

	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)			
Required angular resolution (arcsec) (single value or range)	1-5” Higher angular resolution decreases beam depolarization, while lower angular resolution increases sensitivity to diffuse low surface brightness regions.		
Required image size (arcsec) (single value or range)	Typically 1800”-7200” for extragalactic targets, but larger areas requiring mosaicing for Galactic targets		
Number of image channels	1750 (Band 1) + 2025 (Band 2) = 3775		
Channel width (kHz)	400 kHz		
Required rms (Jy per beam per channel) (if polarisation products required define for each)	Stokes Q,U: 15 μJy/beam per channel		
Dynamic range within image per channel (if polarisation products required define for each)	Stokes Q,U: typically up to ~10^3		
Absolute flux scale calibration			1-3%
		X	5%
			10%
			20-50%
			n/a

DATA ANALYSIS	
Procedures required	- Correction for ionospheric Faraday rotation - Broadband full-polarization calibration, including excellent bandpass correction

	- Widefield, broadband imaging in Stokes I including determination of spectral index/curvature and the use of A-projection - In Stokes Q,U,V: imaging of individual 400 kHz channels - Rotation Measure Synthesis (optionally including RM-CLEAN) and other supplementary spectropolarimetric techniques TBD (e.g. Q,U fitting)
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	RM Synthesis can only be performed once all data for both bands are collected and imaged in Q,U channels. Stokes V channels are also required to assess and incorporate the variance across the full bandpass.
Data products	- Stokes I image(s) and corresponding source catalogues including spectral index/curvature information - Cubes of Stokes Q,U,V at full spectral resolution - Output cubes (Q, U, and P) from RM Synthesis (typical cubes will have 2000 planes to recover the full range of accessible RMs while Nyquist sampling the resolution element in Faraday depth) - Catalogue of polarized sources detected in RM cubes
Description of pipeline	Flagging, broadband polarization calibration, wideband imaging, spectral line imaging, and creation of RM cubes through the joint use of RM Synthesis and other supplementary spectro-polarimetric analysis techniques
Quality assessment plan & cadence	TBD

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Optimal procedures for analysing spectro-polarimetric datasets, including the use of Rotation Measure Synthesis, are still being actively studied within the community and improvements are often identified. A detailed and flexible RM pipeline needs to be defined taking into account the best available knowledge, potentially initially based on the POSSUM pipeline but allowing for future enhancements (hence the generally applicable need to retain the Q,U(,V) frequency cubes in addition to RM cubes).

REFERENCES

References for RM Synthesis and related techniques: Brentjens & de Bruyn 2005, A&A 441, 1217 [RM Synthesis fundamentals] Farnsworth et al 2011, AJ, 141, 191 [Q,U fitting] Frick et al 2010, MNRAS 401, 24 [wavelet-based RM Synthesis] Heald et al 2009, A&A 503, 409 [RM deconvolution] Li et al 2011, A&A 531, 126 [compressive sensing as applied to RM Synthesis] O'Sullivan et al 2012, MNRAS 421, 3300 [Q,U fitting]

2.27 Deep Fields and Cosmic Magnetism

PROJECT DETAILS	
Title	**Deep Fields and Cosmic Magnetism**
Principal Investigator	**Russ Taylor**
Co-Authors	**Cosmic Magnetism WG, D. Ryu**
Time Request	8210 hours

FACILITY		Preconditions
	SKA1-LOW	
X		This use case combines Band 2 and Band 3 for a very broad band

	SKA1-MID	(950 – 3050 MHz) deep polarization survey.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
X	SKA1-MID Band 2	4360
X	SKA1-MID Band 3	3850
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I

	YY	**X**	Stokes Q
	XY	**X**	Stokes U
	YX	**X**	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Deep surveys with the SKA1 mid-band array offers the opportunity to systematically explore the polarization properties of the µJy source population. In total intensity this population will be dominated by star forming and normal galaxies to intermediate redshifts, and low-luminosity AGN to high redshift. The broad bandwidth of the combined mid-bands span the Faraday thick and thin regime, allowing study of the intrinsic polarization properties, and depolarization from embedded and foreground plasmas. We will detect polarized emission from star forming and normal galaxies to high redshift (Stil et al. 2009, Taylor et al. 2014) to explore the emergence and evolution of magnetic fields in disk galaxies and its relation to cosmic star formation history. We will study the evolution of magnetic properties of AGN in relation to redshift, host galaxy and environment. The sensitivity and bandwidth will allow Faraday Rotation Measures measurements with accuracy better than 1 rad-m^{-2} down to polarized flux densities of 1.5 µJy. The angular correlation of RM will be measured on scales of arc minutes and precision of a few rad-m^{-2}, the regime where fluctuations from primordial magnetic fields are expected to create detectable signal distinct from the Galactic foreground (Kolatt, 1998; Akahori & Ryu, 2010).

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	40 in band 2, and 40 in band 3 (mosaic pointings).	
Positions of targets	This will be commensal with deep continuum survey fields. The target field will be selected in coordination with complementary multi-wavelength deep imaging data.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO

Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs,mins,secs as appropriate)	110 hours in band 2, 96 hours in band 3	
Average peak flux density (Jy per beam)	a few micoJy/beam.	
Range of peak flux densities (Jy per beam)	0.38 microJy/beam to 10 mJy/beam in polarized flux density.	
Expected polarised flux density (expressed as % of total)	1-50%	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (__)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1360 (band 2), 2530 (band 3)
Total Bandwidth (MHz)	808 (band 2), 1403 (band 3)
Spectral resolution (kHz)	1000
Temporal resolution ('dump' time in s or 'standard')	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS

IMAGING CONSIDERATIONS (continuum – single channel of full bandwidth)	
Required angular resolution (arcsec) (single value or range)	1.0 arcsec
Required image size (arcsec) (single value or range)	108000 (band 2), 36000 (band 3)
Required rms (Jy per beam)	75 nJy per beam in each band

(if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)	10^6 in Stokes I, 10^5 in polarization	
Absolute flux scale calibration	**X**	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcsec) (single value or range)	1.0 arcsec	
Required image size (arcsec) (single value or range)	108000 (band 2), 36000 (band 3)	
Number of image channels	1000 (band 2), 2000 (band 3)	
Channel width (kHz)	1000	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	2.3 microJy/beam (band 2), 3.3 microJy/beam (band 3). Required per polarization.	
Dynamic range within image per channel (if polarisation products required define for each)	10^4 in Stokes I, 10^3 in polarization.	
Absolute flux scale calibration	**X**	1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS

Procedures required	Polarization imaging over the broad band width will require integration of multi-frequency synthesis with RM/Faraday synthesis (i.e. RM synthesis integrated into the wide-band multi-frequency synthesis, Fourier inversion, deconvolution and imaging). This is required to recover the full u-v coverage in polarization, provide wide-band, total intensity and polarization and images with identical u-v response functions and, account for frequency-dependent source response in polarization over the wide band during synthesis.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	RM cubes from polarization multi-frequency synthesis as well as standard channelized Stokes cubes in I,Q, U, and V for analysis of complex Faraday dispersion cases.
Description of pipeline	The pipeline to image products will consist of two parallel tracks. Standard channelized I,Q, U, V image cube production applying narrow band but direction dependent polarization corrections over the as part of the deconvolution (e.g. full Stokes A-W projection). In addition we require a mode to directly create a Faraday dispersion image cube (e.g. an RM synthesis cube) through a combined Faraday de-dispersion and multi-frequency synthesis process.
Quality assessment plan & cadence	

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Knowledge of the instrumental polarization over the full field of view to within 0.1%. An optimal approach to joint Faraday de-dispersion and multi-frequency synthesis has not yet been developed or implemented. It is part of the Ph.D. project of a current graduate student in the project team and will be investigated within the cosmic magnetism working group.

REFERENCES
Here you can include a list of references to published or supplementary material. When

possible, please include references to justify sensitivities, required angular resolution, data analysis procedures required, etc. Akahori, T. and Ryu, D. 2010, ApJ, 723, 476. Brentjens and de Bruyn, 2005, A&A, 441, 1217. Heald et al 2009, A&A 503, 409. Kollatt, T. 1998, ApJ, 495, 564. Stil. J.M., Krause, M., Beck, R. and Taylor, A.R. 2009, ApJ, 693, 1392. Taylor, A.R., Bhatnagar, S., Condon, J., et al. 2014, BASI, in press.

2.28 High-frequency polarised emission of nearby galaxies

PROJECT DETAILS	
Title	High-frequency polarised emission of nearby galaxies
Principal Investigator	Rainer Beck
Co-Authors	Cosmic Magnetism WG, R.-J. Dettmar, A. Fletcher, V. Heesen, C. Horellou, M. Krause, E. Schinnerer, D. Sokoloff, F.S. Tabatabaei
Time Request	1000 h (on-source)

FACILITY	Preconditions

	SKA1-LOW	
	SKA1-MID	Band 4 (2.8-5.2 GHz) is optimal to reach the science goals. Band 5 (4.6-13.8 GHz) is preferred if Band 4 is delayed.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	1000 h (on-source)
	SKA1-MID Band 5	1000 h (on-source) (alternatively)

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	Mosaicing needed for the largest galaxies
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
>8 h observation runs per galaxy needed to achieve good uv coverage (5 h for M33 due to low elevation). Sources should be at least 30 degrees from the Sun. Nighttime observations

preferred.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	X	Stokes Q
	XY	X	Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Magnetic fields are an important ingredient in galaxy evolution and of the structure of the ISM, but their origin, evolution and fundamental production mechanisms are far from being understood. SKA1 will provide significant progress. *A galaxy survey of diffuse polarised emission that we propose will allow us to identify the saturation mechanism for the galactic dynamo and to derive the relationships between the strength of the turbulent and regular fields and star formation, gas density, rotation and outflows that can be used in galaxy evolution models. This requires polarisation observations of a sample of galaxies at a moderate spatial resolution (a few 100 pc).* *High-resolution polarisation observations in the very nearest galaxies with small and moderate inclinations with high spatial resolution (better than 10 pc) are the clue to measure the properties of turbulent fields. We wish to understand the coupling between cold gas and magnetic fields and how gas motions are affected. We also need to know whether this coupling persists in the vicinity of spiral and bar shocks and to test the idea that these are important sites of cosmic-ray acceleration. Gas inflows into central regions are possibly magnetically controlled.* *With high-resolution polarisation observations in edge-on galaxies we will investigate how magnetic fields govern the transport of the relativistic cosmic rays, relevant to the ignition, ejection and regulation of galactic outflows and winds, which in turn are pivotal in shaping the structure of halo magnetic fields. Strongly coupled to this is the origin and amount of "galaxy feedback" into larger-scale structures (groups, clusters, IGM) that the magnetised galactic outflows can produce.* *We wish to observe a large-enough sample of nearby galaxies, including the nearest galaxies accessible with SKA, with at least 5" resolution, sufficient to resolve spatial scales of ~1 pc in LMC/SMC, ~20 pc in M33 and ~100 pc otherwise. In order to be mostly free of Faraday depolarization and measure intrinsic polarisation angles, Band 4 (or Band 5) of SKA1-MID is needed.*

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	x	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	23	
Positions of targets	2 Irregulars: LMC, SMC (pointings on selected regions) 7 Spirals: M33 (~20 pointings), M74, NGC300, 1808, 1566, 2997, Circinus 7 Barred: M83 (3 pointings), NGC1097, 1313, 1365, 1512, 1672, 2442 7 Edge-ons: M104, NGC55, 253 (5 pointings), 1532, 3628, 4666, 4945 (3 pointings)	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………..]
	x	NO
Time Critical?		YES [details: ……………………………………..]
	x	NO
Integration time per target (hrs)	1 h on-source per pointing (LMC, SMC, M33), 10 h on-source per target and pointing (other galaxies)	
Average peak flux density (Jy or Jy per beam)	10^-4 per 5" beam for extended galaxies	
Range of peak flux densities (Jy or Jy per beam)	10^-5 – 10^-3 per 5" beam for extended galaxies, up to 1 Jy for background sources	
Expected polarised flux density (expressed as % of total)	5 – 20	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (X_)*

Central Frequencies (MHz) (including redshift, observatory correction)	4 GHz
Total Bandwidth (MHz)	2380
Minimum and maximum frequency over the entire range of the setup (MHz)	2800 – 5180 (Band 4) 4600 – 9600 (Band 5)
Spectral resolution (kHz)	1000
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support

image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	0.02 – 0.08	
Maximum baseline required (km)	20 km	
Mapped image size (degrees)	0.3 - 1	
Required pixel resolution (arcseconds)	0.2	
Number of output channels	1024	
Output bandwidth (minimum and maximum frequency - MHz)	2800 – 5180 (Band 4) 4600 – 9600 (Band 5)	
Required rms (Jy per beam) (if polarisation products required define for each)	6 10^-7 (I, Q, U) for LMC, SMC, M33, 2 10^-7 (I, Q, U) for the other galaxies	
Dynamic range within image (if polarisation products required define for each)	10^6 (I), 10^4 (Q and U)	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of image channels	
Channel width (kHz)	

Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS

Procedures required	Bandpass calibration, full polarization calibration, wide-field broadband imaging, online RM Synthesis with limited RM resolution and field size
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Q, U and V data cubes should be stored for reprocessing
Data products	Images in Stokes I and V, data cubes in Stokes Q, U and V, images of average RM, average spectral index and of spectral curvature, catalog of polarised sources with RMs and intrinsic polarisation angles
Description of pipeline	Flagging, broadband calibration in full Stokes, wide-field imaging, self-cal, RM Synthesis
Quality assessment plan & cadence	TBD
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of scheduling block and pipeline reduction

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES

Beck, R., Bomans, D., Colafrancesco, S., et al. 2015, Advancing Astrophysics with the Square Kilometre Array, (AASKA14) 94

2.29 Polarised emission in cosmic-web filaments

PROJECT DETAILS	
Title	**Polarised emission in cosmic-web filaments**
Principal Investigator	**Annalisa Bonafede**
Co-Authors	**SKA magnetism working group,** **Franco Vazza (Hamburg Uni); C. Gheller (CSCS); Marcus Brüggen (Hamburg Uni); C. Ferrari (OCA Nice).**
Time Request	4200 h

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
X	SKA1-MID Band 1	4200 h

	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
To avoid RFI and minimise ionospheric variations, observations should be conducted when the source is at more than 10 degrees from the Sun. We ask for 2 MHz channel resolution in order to be sensitive to Faraday Rotations up to 1000 rad/m^2 at 600 MHz.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	X	Stokes Q
	XY	X	Stokes U

	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The aim of this science case is to detect the cosmic web in polarisation. The existence of a cosmic web, through which matter accretes onto galaxy groups and clusters is predicted by the LambdaCDM cosmological model but so far only a couple of indirect tentative detections have been claimed (e.g. Planck Collaboration 2013a). *As matters accretes onto galaxy clusters, powerful shock waves develop along intergalactic filaments. These shock waves accelerate particles, provided that magnetic fields are already present there. So far, nothing is known about magnetic fields in these environments.* *Using the cosmological simulations by Vazza et al. (2012) we have predicted the emission that SKA-1 will be able to detect. We assume a conservative magnetic field with 5% energy of the thermal energy, and a polarisation fraction of 30%, as detected in the low-Mach number shocks within the virial radii.* *We find that the polarised cosmic-web can be best detected by SKA-1 MID Band1 at z=0.4 - 0.5 with a sensitivity of 0.2 microJy/beam (3'' beam). At z<0.4 and z>0.5 the emission will be filtered-out and suppressed by cosmological dimming, respectively.* *Short baselines are crucial to such experiment. Provided that the observations will not be dynamical-range limited, the emission is detectable also in total intensity.*

'TARGETS' OF OBSERVATIONS	
Type of observation (what defines a 'target')	We have selected from the Planck (Planck Collaboration, 2013b) and MACS catalogs (Ebeling et al. 2007) the two most massive galaxy clusters in the redshift range 0.4 < z < 0.5, and having a declination < -10 degrees. We also checked that they are out of the Galactic plane (|b| > 30deg) in order to avoid the contamination from the Galactic foreground. Massive galaxy clusters are believed to form at the intersection of cosmological filaments, hence observations centred on massive clusters are the perfect targets for our scientific goals. We want to cover a large field of view around each target to maximise our chances of detecting the largest possible number of filaments. The field of view of SKA-1 MID Band1 is 1.4 square degrees. With 8 pointings per target we will image a region of 3.3x3.3

	degrees around each target, corresponding to 73x73 Mpc at z=0.5, wide enough to trace the cosmic web over tens of Mpc. The selected targets are the fields around RXJ1347.5-1145, z=0.45 MACS J2214-1359, z=0.48
Number of targets	2
Positions of targets	**RXJ1347.5-1145:** RA=13h47m30.6s DEC=-11d45m10s **MACS J2214-1359:** RA=22h14m57.4s DEC= -14d00m11s
Rapidly changing sky position? (e.g. comet, planet)	YES [details: ……………………………………….] **X** NO
Time Critical?	YES [details: ……………………………………….] X NO
Integration time per target (hrs)	2100 h per target (SKA1-MID Band 1)
Average peak flux density (Jy or Jy per beam)	The targets are extended sources with low flux density (the average peak flux density is 7 microJy/beam) but in the field bright point sources will be present, with peak flux densities up to 10 Jy.
Range of peak flux densities (Jy or Jy per beam)	For the targets we expect peak flux densities in the range 0.9 Jy/beam down to the detection limit (0.6 microJy/beam)
Expected polarised flux density (expressed as % of total)	> 30%, which is the average polarisation of radio emission caused by low-Mach number shocks in the cluster outskirts. In the cosmic web shocks with higher Mach numbers are expected, which should lead to a higher polarisation fraction.To be conservative we have taken 30% into account in our time calculations.

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (X)*	
Central Frequencies (MHz) (including redshift, observatory correction)	600 MHz
Total Bandwidth (MHz)	550 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	2 MHz
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	3" - 10" -30"	
Maximum baseline required (km)		
Mapped image size (degrees)	25.2 e3" x 25.2e3"	
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)	I: 0.22 microJy/beam (beam of 3" x 3") Q and U: 0.15 microJy/beam V: 0.22 microJy/beam	
Dynamic range within image (if polarisation products required define for each)	I:10^{6-7} Q and U: 10^5	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	3" - 10" - 30"
Maximum baseline required (km)	
Mapped image size (degrees)	25.2 e3" x 25.2e3"
Required pixel resolution (arcseconds)	
Number of image channels	250

Channel width (kHz)	2 MHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	I: 3.5 microJy/beam (beam of 3” x 3”) Q and U: 2.5 microJy/beam V: 3.5 microJy/beam	
Dynamic range within image per channel (if polarisation products required define for each)	I:10^6 Q and U: 10^5	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Reprocessing is not critical, but would allow these observations to be used for many other scientific purposes. Cubes of Q and U are needed, because they permit us to reprocess the data using different techniques, complementary to RM synthesis. A work by Sun et al. (2015) shows that complementary techniques are required to better map the complexity of the Faraday structures.
Data products	We request I, Q, U and V images at full resolution (3" beam), at intermediate resolution (10") and at low resolution (30" beam). Sampling this range of resolution is crucial because we will not know the Faraday fluctuations ahead of time. The intermediate and low resolution images would be obtained by tapering down the long baselines in order to gain sensitivity to the diffuse emission. To avoid internal and bandwidth depolarisation, Rotation Measure Synthesis algorithm (see Brentjens and de Bruyn, 2005) should be run on the final products (hence, RM cubes should be stored). We also request the image-cubes in Q, U, and V to be stored, to run the Rotation Measure Synthesis and complementary algorithm afterwards.
Description of pipeline	The pipeline should calibrate the data (polarisation calibration is required too), create a Faraday dispersion image cube (e.g. through the RM synthesis algorithm), and release image-cubes of the field of view at the three requested resolutions.
Quality assessment plan & cadence	The pipeline should calibrate the data (polarisation calibration is required too), create a Faraday dispersion image cube (e.g. through the RM synthesis algorithm), and release image-cubes of the field of view at the three requested resolutions. Although not critical for this Use Case, discrete sources and the filaments would appear as Faraday thin and Faraday thick sources, respectively, we would benefit from the existence of a procedure to subtract the discrete sources emission from the diffuse emission of the filaments.

	In particular, this would give us the chance of studying and characterising the total intensity emission of the filaments in more detail, achieving a better understanding of the underlying magnetic field.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES

Brentjens and de Bruyn, 2005, Astronomy and Astrophysics, Volume 441, Issue 3, October III 2005, pp.1217-122.

Ebeling et al., 2007, The Astrophysical Journal, Volume 661, Issue 1, pp. L33-L36.

Planck Collaboration 2013a, Astronomy & Astrophysics, Volume 550, id.A134, 16 pp.

Planck Collaboration 2013b, Astronomy & Astrophysics

Sun. *et al. 2015, The Astrophysical Journal 2015, Volume 149, p. 60.*

Vazza et al., 2012, Monthly Notices of the Royal Astronomical Society, Volume

421, Issue 4, pp. 3375-3398.

Vazza et al. 2015, Astronomy and Astrophysics Volume 580, id.A119, 18 pp.

2.30 Fast Transients

PROJECT DETAILS	
Title	**Fast Transients**
Principal Investigator	**Evan Keane (as author of this draft)**
Co-Authors	
Time Request	Up to all of the available observing time: commensal observations piggy-backing on all observing projects.

FACILITY		Preconditions
	SKA1-LOW	500 Tied-array beams from core, to be searched with the single pulse search pipeline within the CSP.PSS.

		Transient buffers, capable of approximately 5 minutes of data storage.
	SKA1-MID	1500 Tied-array beams from core, to be searched with the single pulse search pipeline within the CSP.PSS Transient buffers, capable of approximately 30 seconds of data storage.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	Up to 100% of time used on LOW
	SKA1-MID Band 1	Up to 100% of time used at this band on MID
	SKA1-MID Band 2	Up to 100% of time used at this band on MID
	SKA1-MID Band 3	Up to 100% of time used at this band on MID
	SKA1-MID Band 4	Up to 100% of time used at this band on MID
	SKA1-MID Band 5	Up to 100% of time used at this band on MID

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	**X**
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
The observing strategy is to run the CSP.PSS single pulse search pipeline at all times (on both MID and LOW) on the tied-array beam-formed data, piggy-backing all observations,

commensally. The search of the tied-array beam-formed will focus on the Stokes I data, but 4 polarisations will be formed. When fast transients are detected the transient buffer systems can be recorded for offline reconstruction of the full signal (rate of buffer dumping to be defined by observer, and practical considerations). This is a commensal observing mode. This is a non-imaging observing mode. Piggy-backing all observations maximises the time on sky, and so enables identification of the rarest, and most scientifically interesting events. It is practical because: (a) There are fast transients which are cosmological (off the Galactic plane) and Galactic (in the Galactic plane), i.e. it is always useful to commensally search for fast transients, regardless of the target the SKA is pointing towards; (b) single pulse searches operate at lower power than the full acceleration search for pulsars with CSP.PSS so it is feasible, power-wise, to do this.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (X) or CORRELATOR (_)*			
X	XX		Stokes I
X	YY		Stokes Q
X	XY		Stokes U
X	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Searching for Fast Radio Bursts (fast transients of cosmological origin, seen far from the Galactic plane) is one of the High Priority Science Objectives of Phase 1 of the SKA. These can be used for cosmological studies of dark energy, for studying the intergalactic medium ("weighing the missing baryons"), investigating magnetic fields and studying the energetic environments in which FRBs are created. This is elaborated in detail in an SKA science chapter by Macquart et al. (see references for details). In addition to the FRBs there are a plethora of high time resolution transients to be discovered in the Galactic plane. To boost the discovery rates we need to maximise (a) sensitivity, (b) field-of-view and (c) observing time. The first two are done by default with the SKA and the third is achieved by observing commensally at all practical times. As such the strategy for obtaining a complete picture of the transient radio sky with the SKA fits in perfectly with commensal observing of all targets the SKA will look at. As such we describe here typical use case parameters and considerations to make this a reality with the SKA.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects

		Maps through multiple fields of view
	X	Non-imaging pointings
Number of targets	Commensal observations of, up to, all targets observed by the SKA, with both MID and LOW	
Positions of targets	Anywhere in the primary beam. Galactic and non-Galactic.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	The data is not integrated as in imaging. The highest time resolution (as per the PSS acceleration search criteria) must be maintained to resolve the fast transient signals. The data rate is determined by the number of candidates output per unit time.	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)		
Expected polarised flux density (expressed as % of total)	From 0 to 100%	

OBSERVATIONAL SETUP : *BEAMFORMER (X) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	As per the observing setup that is being piggy-backed.
Total Bandwidth (MHz)	LOW: 100 MHz for search, full band for transient buffer dumps. MID: 300 MHz for search , full band for transient buffer dumps. Note that, as per pulsar searching, fast transient searches can trade beams for bandwidth, i.e. form 2 x 300-MHz tied-array beams on the same point of sky each with different observing frequencies

	to effectively have 1 x 600-MHz tied-array beam, or any such possible combination as chosen by the observer.
Minimum and maximum frequency over the entire range of the setup (MHz)	Minimum: 50 MHz Maxiumum: top frequency of band 5
Spectral resolution (kHz)	Same as for pulsar search. LOW: approx. 12 kHz MID: approx. 73 kHz Note: Depends strongly on observing frequency. Should be sufficiently high resolution so as not have dispersion smearing in one channel. Smearing in a channel is given by: tsmear = 4149 seconds * (DM/(pc/cm^3)) * ((f_bottom_of-channel/MHz)^-2 - (f_top_of_channel/MHz)^-2) tsmear must be << tsamp.
Temporal resolution (in seconds)	Same as for pulsar search, 64 microsec (MID) or 128 microsec (LOW)

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	Approximately Wavelength/D, where D ranges from ~2 km to ~20 km and the wavelength is whatever the piggy-backed observations are operating at.
Maximum baseline required (km)	20 km (same as PSS and PST requirements)
Primary beam size (sq degrees)	Approximately Wavelength/D, where D is the dish diameter (on MID) or the station size (on LOW)
Number of output channels	Same as per pulsar search, i.e. 4096 (MID) or 8192 (LOW) As above, depends strongly on observing frequency.
Output bandwidth (minimum and maximum frequency - MHz)	LOW Minimum: ~50 MHz Maximum: ~300 MHz MID Minimum: ~300 MHz

	Maximum: entire bandwidth of band in use	
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
	X	10% (no worse than)
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%

		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	
Mapped image size (degrees)	

Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	CSP.PSS's single pulse search pipeline SDP pipeline to assess fast transient candidates sent from CSP to SDP. TM Infrastructure to send alerts of transient detections
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Data that is highly affected by RFI may not be usable for science. Due to the observe-all-the-time strategy observations cannot be redone, and are simply lost science wise if the RFI contamination is too severe. However, such RFI contaminated data will be useful for characterising the high time resolution RFI environment and its time variability on each site.
Data products	Somewhat reduced resolution (i.e. typical PSS resolution) time-frequency-Stokes data cubes around the transient events. Searched for initial detection and useful for quick looks. Nyquist-sampled voltage dumps around the transient events. Used for full reconstruction of the transient signal offline. Depending on the dispersion measure and observing band the signal could last up to ~30 seconds (for MID)

	or ~5 minutes (for LOW) so the data blocks dumped will be of this size.
Description of pipeline	CSP.PSS single pulse search pipeline (threshold searching across range of dispersion measure trials and pulse widths, cross-beam coincidence-ing, RFI filtering, neural network assessment, etc.) CSP then sends ~1 candidate/10s/beam to SDP, roughly 3.68 GB every 10 seconds (LOW) or 1.23 GB every 10 seconds (MID).
Quality assessment plan & cadence	Neural network assessment of candidates.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	This should be limited by the duration of the events, and at worst a few seconds after the detection of the signal at the lowest observing frequency in use, to enable rapid alerts to other instruments to be issued as appropriate. Ideally it should be limited by the dispersion sweep duration of the fast transient across the observing band. This is being run at Parkes Due to the observe-all-the-time strategy the project does not have a natural start, finish or break point. Results should be produced in real time.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
The ‘trigger rate’ for the transient buffers need to be decided. For example do would probably not wish (even if it were possible) to do that for every transient event, most likely much less often. This can simply be decided by (a) what is possible, resource wise as an upper limit on the frequency of these triggers, and (b) by the observer. It should be a user option to say “I only want signals which are S/N > 50 and no more than ~1 per 10 minutes” or something to that effect, as desired.

REFERENCES
“Fast Transients at Cosmological Distances with the SKA”, AASKA14, Chapter 55, 2015. URL: http://pos.sissa.it/archive/conferences/215/055/AASKA14_055.pdf

2.31 **Transient searches during wind-stow**

PROJECT DETAILS	
Title	**Transient searches during wind-stow**
Principal Investigator	**Rob Fender, Patrick Woudt**
Co-Authors	**The SKA Transients SWG**
Time Request	N/A

FACILITY	Preconditions	
	SKA1-LOW	
		When wind stowed

	SKA1-MID	

RECEIVER(S) REQUIRED	Time (hrs)	
The system should be able to operate on any and all receivers for which normal imaging modes are available	SKA1-Mid	This is **effectively** an entirely commensal proposal and so costs no additional telescope time
	SKA1-MID Band 1	X
	SKA1-MID Band 2	X
	SKA1-MID Band 3	X
	SKA1-MID Band 4	X
	SKA1-MID Band 5	X

OPERATIONAL MODE (as defined in Concept-of-Operations)	Details	
	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	**All**
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
The aim of this use case is to suggest that during wind-stow periods at SKA1-Mid, when the telescopes would be pointed at (or near to) the zenith, data are still

recorded and analysed for transients (both in real time using the commensal systems described in other use cases and in more detail and depth by some transients team t.b.d.)

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
All available	XX		Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Transients science, associated with the most extreme astrophysics in the present day universe, is likely to be one of the highest impact areas of SKA science. As outlined in the accompanying use case ***Near real time commensal image plane transient searches*** *we would like to search all data streams all of the time to look for transient and variable events. This use case is to draw attention to the possibility of continuing to take data during periods of wind-stow. Although the data may be less than optimal, if wind-stow is an appreciable fraction of SKA1-MID, then this could turn into a valuable survey at the zenith. We note that current estimates for the Karoo site indicate that wind stow periods may be ~5% of the time, a significant fraction (we do not have information for the Boolardy station).*

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	All normal imaging data streams	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets		

<table>
<tr><td></td><td colspan="2"></td></tr>
<tr><td>Positions of targets</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Rapidly changing sky position?
(e.g. comet, planet)</td><td></td><td>YES [details: ………………………………………….]</td></tr>
<tr><td></td><td>NO</td></tr>
<tr><td rowspan="2">Time Critical?</td><td></td><td>YES [details: ………………………………………….]</td></tr>
<tr><td></td><td>NO</td></tr>
<tr><td>Integration time per target
(hrs)</td><td colspan="2"></td></tr>
<tr><td>Average peak flux density
(Jy per beam)</td><td colspan="2"></td></tr>
<tr><td>Range of peak flux densities
(Jy per beam)</td><td colspan="2"></td></tr>
<tr><td>Expected polarised flux density
(expressed as % of total)</td><td colspan="2"></td></tr>
</table>

It is not straightforward to place our requirements within the standard boxes of the template form, hence most of them are outlined in the text boxes below.

DATA ANALYSIS	
Procedures required	We propose that data continue to be taken by SKA1-Mid when they are wind-stowed, as an additional "free" search for transients and variables. Wind stow is estimated to be up to 5% at the Karoo site, so this is a significant amount of observing time.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	As a default, the observing mode adopted could simply be that of 10 second images being processed by the commensal imaging system described in use case "*Near real time commensal image plane transient searches".*

Data products	As per commensal imaging (at minimum)
Description of pipeline	As per commensal imaging (at minimum)
Quality assessment plan & cadence	Our goal would be that this system was operating on one second cycles (or faster – see commensal imaging use case), with a latency between data acquisition and image analysis of less than ten seconds (in agreement with the L0 requirements).

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
We have been in discussion with the MeerKAT team about implementing such a mode on that telescope, where wind-stow is estimated to be ~5% of the time (which we assume to be the same for SKA1-Mid). The team has been very positive about this and plan to implement it (at present). We note that the wind-stow pointing may not necessarily be directly to the zenith, and that we should assume that the data will be of lower quality than those take at other times. *It is not clear to us if processing those data will in any way require additional resources* (we expect not at any significant level).

REFERENCES
We refer the reader to the Transients Science Assessment Workshop report, which has been circulated to the SPO and the SWGs, and is available on request from Rob Fender (rob.fender@astro.ox.ac.uk).

2.32 Near-real-time image-plane searches for radio transients

PROJECT DETAILS	
Title	**Near-real-time image-plane searches for radio transients**
Principal Investigator	**Rob Fender, James Miller-Jones**
Co-Authors	**J-P Macquart, Michael Rupen**
Time Request	100% commensal

FACILITY		Preconditions
	SKA1-LOW	A similar system should be implemented on SKA1-LOW, but the figures considered here are for -MID.

	SKA1-MID	This use case is primarily written with SKA1-MID in mind

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	(Potentially)
	SKA1-MID Band 1	Potentially any SKA1-MID band
	SKA1-MID Band 2	Potentially any SKA1-MID band
	SKA1-MID Band 3	Potentially any SKA1-MID band
	SKA1-MID Band 4	Potentially any SKA1-MID band
	SKA1-MID Band 5	Potentially any SKA1-MID band

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	**X**
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
This use case describes our clearest ideas at present about a realisable strategy for searching, in near-real-time, image-plane data from SKA phase 1, for transients and variables. The idea is that with a significant but limited additional

resource, compared to the original baseline design, SKA phase 1 could automatically find and report radio transients to the wider community on timescales comparable to the variability timescales of the event itself, which could range from seconds to days. This would be sufficient for it to become a major source of astrophysically-interesting transients for the broader astrophysical community, much as wide-field gamma-ray and optical searches are today, and LSST will be in the future. This will maximise the scientific output of the SKA telescope. The new considerations have been driven by discussions with the SDP group which suggested that data transport / storage was the major issue with earlier strawman plans.

1. We assume that SKA is able to deliver 60k x 60k pixel images on a timescale of 1.2 second with >100 channels and full Stokes parameters. We propose that on this cycle timescale Transient-searching software (perhaps a later version of the 'TraP' [Swinbank et al. 2015]) will locate transient candidates. Following discussions with the SDP group, we propose that 'postage stamps' of 1k x 1k pixels are stored around each transient candidate. Regions, rather than 'hot' pixel values, are required in order to e.g. identify and reject (correlated) noise. It seems that it is impossible to store the full-field (3.6 Gpix) images, even with some highly-averaged spectral resolution (e.g. 100 channels), on this timescale. The searching software should connect to an additional software suite which can make initial classifications (perhaps, e.g. based on variability timescales, see Pietka, Fender & Keane 2015) and report automatically to the global community, thereby maximising the science. We believe we understand how to do the alerting (via VOEvents). NB it is possible that the 1.2 sec full image could be made with less than full angular resolution; one arcsec localisation would be comparable to current optical transients surveys.

The observatory/observer may wish to place postage stamps on known interesting rapid-variable sources in the field, so the option to pre-set some monitoring regions is desirable.

2. We estimate (very approximately) that, setting a high false-transients threshold (e.g. max 10% false positives), we might have of order 10 events per day.

3. For the event on which we trigger, we would request the postage stamp area around the transient candidate for the full duration of the current observation (maybe typically a few hr), at the full 1.2sec time resolution. We note that for a typical 6hr observation, for a transient event found mid-observation, we would have the full spectral and temporal resolution data to inspect afterwards (for a limited time). These data could also be used to see if there is variable HI absorption towards an event, which could potentially act as a distance constraint (Fender & Oosterloo 2015).

4. We estimate the total data rate for these ~10 events per day, at full time resolution, with 100 channels, with all 4 Stokes parameters, to be about 1 TB/day.

5. We propose that these data be transferred to a Transients 'staging area' of total data capacity ~1 PB, which would be managed by humans, where it would need

to be 'flushed' at an average rate of ~1TB/day (i.e. comparable to the input rate in [4.] above). Heavy averaging to e.g. 1-10 spectral channels could possibly be used as an intermediate compression step, following initial analysis but before flushing, since most transients are not expected to show interesting spectral feature.

6. We assume that there is also a 'live' staging area in which full data products would be stored for a few hours, which could be frozen in the event of extremely high priority events being detected.

7. In parallel to the high-time-resolution searches, we propose that images also be made and searched for on logarithmically-increasingly timesteps. This will no more than double the total data rate.

8. Finally, as an additional resource, we propose that heavily averaged (e.g. 10 minutes, two channels, coarser pixel scale by a factor ~2) images be stored on a timescale of perhaps 10 minutes in order to provide a long-term imaging record of the sky which can be later searched by 3rd parties.

We suggest this may be a 'central' rather than 'Transients' SKA data product in a 'core' archive.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**x**	Stokes I
	YY	x	Stokes Q
	XY	x	Stokes U
	YX	x	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The key scientific goal of this use case is to discover and report radio transients to the wider astronomical community as rapidly as possible. The case for doing this has been elaborated in e.g. Fender et al. (2015), parts of which were ranked by the SKA Science Review Panel as key science for SKA phase 1. Large numbers of radio transients at GHz frequencies have been independently predicted for SKA1 by Metzger, Williams and Berger (2015).

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	x	Individual pointings per object
	x	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	Not directly applicable – suggesting one interesting target per postage stamp zone.	
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	x	NO
Time Critical?		YES [details: ……………………………………….]
	x	NO (not in the traditional sense)
Integration time per target (hrs)	Commensal	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)		
Expected polarised flux density (expressed as % of total)		

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Commensal
Total Bandwidth (MHz)	

Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	For stored data products on transients, relatively few spectral channels required.
Temporal resolution (in seconds)	1.2 sec and upwards (logarithmically)

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a ‘support image’ in the case of VLBI observations)	
Required angular resolution (arcmin)	Main driver is localisation of transients to

(single value or range)	~1 arcsec necessary for optical follow-up	
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)	~1	
Number of output channels	10-100	
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3% (ideally)
		5% (desirable)
	x	10%(min. acceptable)
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of image channels	
Channel width (kHz)	
Required rms (Jy per beam per channel)	

(if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Please see incorporated lengthier description, which

	has been developed together with SDP.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	Images / postage stamps on a range of temportal/spatial/spectral scales.
Description of pipeline	See text.
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Latency should be of order the timescale of the event itself – ie. Very short for seconds-minutes timescale events, but progressively longer for slower events. This is motivated by the desire to alert the broader community to an event while it is still occurring.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Rate of transient candidates detected **per day** is highly uncertain, and if too large could strain/break the proposed procedures. Who and how will a long-term image/lightcurves archive be established? Rapid flagging will need to be efficient, and yet at the same time there is the risk that flagging could remove transients (this has been explored for e.g. LOFAR and AMI). Will need some work to understand how best to automatically flag these data.

REFERENCES
Fender et al., Proceedings of Science (arXiv:1507.00729): *Transient Astrophysics with the Square Kilometre Array* Fender R. & Oosterloo T., MNRAS, 451, L75 (2015): *Neutral Hydrogen Absorption towards Fast Radio Bursts* Metzger B,D., Williams P.K.G., Berger E., ApJ, 806, 224 (2015): *Extragalactic Synchrotron transients in the era of wide-field radio surveys. I. Detection rates and light curve characteristics* Pietka, Fender & Keane, MNRAS 446, 3687, (2015): *The variability time-scales and brightness temperatures of radio flares from stars to supermassive black holes*

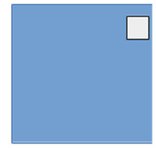
Swinbank et al., Astronomy & Computing, 11, 25 (2015): *The LOFAR Transients Pipeline*

SUPPORTING FIGURE

Cannot store full image every 1.2 sec → Store regions around transient candidates

60k x 60k pixels
10 channels
4 Stokes
4 bytes
3.6Gpix * 10 * 4 * 4
~6TB/1.2 sec

Impossible to store
Use instead “postage stamps” (PS) with 1000 x 1000 pix →
1Mpix * 10 * 4 * 4
~0.2 GB/1.2sec/PS



Full image is searched on each 1.2 sec cycle (with e.g. 'TraP-SKA') for Transients, postage stamps (POS) around transient candidate(s) are stored

If, on average, there is one PS being recorded at any given time, all the time → 14TB/day

Approximately (maximally) double this rate for logarithmically-stored images (2.4, 4.8. 9.6s..)

At this rate a 1 PB Transients staging area would be able to hold ~35 days' data

Thoughts on storing some averaged images in a central archive as a record:

In parallel, we store full image every 10 minutes, with only two channels, resolution reduced by a factor of two, Stokes I only → 0.9Gpix * 1 * 4 * 144 → ~0.5 TB/day

2.33 Short Monitoring Observations of Many Sources at Multiple Bands with Pre-defined Cadences

PROJECT DETAILS	
Title	**Short Monitoring Observations of Many Sources at Multiple Bands with Pre-defined Cadences**
Principal Investigator	**Michael Rupen**
Co-Authors	**Transient science working group**
Time Request	Many few-second to few-minute observations

FACILITY		Preconditions
X	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
X	SKA1-LOW	0.001-0.01
X	SKA1-MID Band 1	0.001-0.01
X	SKA1-MID Band 2	0.001-0.01
X	SKA1-MID Band 3	0.001-0.01
X	SKA1-MID Band 4	0.001-0.01
X	SKA1-MID Band 5	0.001-0.01

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	Cadenced observations, not on a fixed schedule
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	**Sometimes**

COMMENTS ON OBSERVING STRATEGY
Primary goal is efficient use of very short (seconds to minutes) observations of individual objects. This requires (1) standard setups (to allow group calibrations), including standard spectral lines (e.g., HI/OH absorption), and (2) dynamic scheduling which includes source positions, cadence, and required SNR/sensitivity. Use of sub-arrays for simultaneous multi-band observations would also be useful, but observing efficiency would require the ability to rapidly (within a few seconds) form and dissolve sub-arrays. See various descriptive sections below for further details. One possible approach would be to simply have a list of sources to be monitored with preferred observing bands, cadences, and sensitivities (SNR and noise level). [Note that some of these sources may come automatically from outside inputs, e.g., when some satellite reports that an X-ray binary on a PI's approved list has gone into outburst.] When prompted, the scheduler selects sources from the list according to cadence and weather, then groups possible sources by position. Looking at the amount of available time the scheduler then creates an SB with one standard correlator/receiver setup for all sources per band (and hence one flux/bandpass calibrator per band), and chooses nearby groups of sources to fill up the available time. Each source is observed long enough to achieve the indicated SNR if possible (as determined by real-time SDP results – assuming this is possible), or the noise level (mJy/bm) if not; the latter thus gives the maximum observing time spent on each source. Ideally "IF" statements would allow for the detection of the source at a certain level in one band, which could then trigger (1) observations at other bands or with other setups; (2) a change in the required cadence; (3) a change in the scientific priority; and/or (4) an automatic alert sent to other telescopes, SKA1 schedulers, the PI, and/or the astronomical community as a whole.

More sophisticated scheduling might also consider uv-coverage, to allow more reliable difference imaging in analysing flux variations. This requires some analysis, both for the general case, and possibly as a function of individual source fields, if SDP is sophisticated enough to allow this.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	X	Stokes Q
	XY	X	Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The sensitivity of SKA1 (e.g., 6 microJy/beam in 1sec for SKA1-Mid in band 5) makes even extremely short observations scientifically interesting. Here we consider the special case of monitoring observations, exploring the new frontier of time-domain astrophysics. SKA1 like many SKA precursors has made the time-domain a high priority; for this to be meaningful, observations of variable sources must be made easy and productive. Current instruments are limited in part by sensitivity, but also by relatively crude scheduling algorithms, with each source or type of source the subject of a separate proposal, and the corresponding scheduling blocks (SBs) written by the individual PIs. Apart from the inconsistencies which inevitably result (in calibration, observing frequency, etc.) there is an enormous overhead: because monitoring often requires very little time on-source, monitoring SBs are usually dominated by move time and calibration, and this huge loss of efficiency (up to 80% for observations of mJy sources with the VLA) will become even worse for more powerful instruments. Further, dynamic scheduling algorithms either ignore cadence or treat it very crudely, making it very hard to obtain well-sampled light curves without enormous PI overhead in rapidly reducing current observations and carefully planning the submission of new SBs. The SKA can make a huge advance in this field by building variable source observations into its plans from the start, making high-quality monitoring observations as easy and simple as the sensitivity of the telescope allows. Applications range from radio monitoring of astronomical explosions (e.g., X-ray binaries, novae, supernovae, gamma-ray bursts, and tidal disruption events) to probes of the medium along the line-of-sight (e.g., extreme scattering events) to the basic physics of intrinsically variable sources (e.g., active galactic nuclei, flare stars, brown dwarfs, HII regions, stars with star spots).

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	X	Individual pointings per object
	X	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	Many	
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?	X	YES [details: ……………………………………….]
		NO
Integration time per target (hrs)	0.001-0.01	
Average peak flux density (Jy per beam)	0.1 mJy to Jy (lower limit set by sensitivity)	
Range of peak flux densities (Jy per beam)	0.1 mJy to Jy (lower limit set by sensitivity)	
Expected polarised flux density (expressed as % of total)	0.1-100%	

OBSERVATIONAL SETUP : *BEAMFORMER (X) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	
Total Bandwidth (MHz)	
Spectral resolution (kHz)	
Temporal resolution ('dump' time in s or	

'standard')	
OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (X)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Should cover full observing band in one setting
Total Bandwidth (MHz)	As much as possible
Spectral resolution (kHz)	1 km/s-ish on a few key lines (for absorption)
Temporal resolution ('dump' time in s or 'standard')	

NON-IMAGING SPECIFIC CONSIDERATIONS		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (continuum – single channel of full bandwidth)	
Required angular resolution (arcmin) (single value or range)	As high as possible but difference imaging should allow interesting results even at poor spatial resolution
Single Field-Of-View or mapped image size (degrees)	Single field-of-view in most cases
Required rms (Jy per beam) (if polarisation products required define for each)	Thermal noise for a few second to few minute observation – note that we are interested in *variability* so images with huge spatial dynamic range are usually not needed
Dynamic range within image (if polarisation products required define for each)	10s to 100s:1

Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Single Field-Of-View or mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	
Single Field-Of-View or mapped image size (degrees)	

Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Snapshot imaging. Checks for variability between epochs Comparisons of variability between sources within the same field-of-view Checks for association of variable sources with a priori positions and/or source catalogs
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Ideally would combine many snapshot observations of the same field in deriving variability of a point source within that field. Should be able to compare variability of all sources within the field, and derive relative changes in one source compared to all others in the field (i.e., derive relative photometry based on all sources in the field).
Data products	One or more of the following: 1- Flux density (full Stokes) of target source

	within the field 2- location of any previously-unknown source within the field 3- Maximum variable source flux density within some radius of the target location 4- Most probable variable source given an a priori estimate of the position (e.g., a map of a priori location probability) 5- Astrometry (with error bars) of all sources in the field, with special emphasis on new sources and variable sources
Description of pipeline	This depends to some extent on the scheduling procedure (e.g., do we require very similar uv-coverage for each epoch?), which in turn depends on the results of simulations. NOTE THAT IDEALLY WE WOULD SAVE THE UV-DATA TO ALLOW COMBINATION OF MULTIPLE EPOCHS. Assuming the uv-coverage is different enough between epochs that we cannot difference visibilities directly, the pipeline might run something like this: 1-Auto-flagging 2-Derive and apply basic calibration (flux, phase, bandpass) 3-Make basic (full-Stokes) images, deriving spectral variations if appropriate given the SNR. If any source is strong enough to detect 10%-ish absorption, check for such absorption for appropriate spectral lines (e.g., HI at 1420 MHz). 4- Compare the resulting images to those from previous epochs, deriving estimates of variability for all sources in the field. Derive true upper limits for any non-detections, based on a priori positional uncertainties. 5 - Check for sources (especially variable ones) within the a priori position (with error bar) of the source of interest. Report the likelihood that each detected radio source is actually the source of interest, for those more likely than some threshold value, and always for at least one source. 6 - Return flux densities for definite detections

	to TM if that might influence the on-going observations (e.g., SB might say "Take a 30min HI absorption spectrum if 20cm flux density is > 1 Jy", or "Observe source in all other bands if first band returns flux density > 50 mJy at >99% probability"). Place flux densities in data base, which may influence observing cadence or other parameters for future SBs. 7 - Raise alerts as appropriate (e.g., PI requests immediate notification when flux density > 100 mJy, or VLBI is triggered if > 1 Jy within X days of explosion, or HST observes when certain conditions are met). Note that this assumes a point source. Some variable sources are resolved (e.g., relativistic jets from X-ray binaries), and there should be another pipeline for those, allowing for moving sources and deriving proper motions for those. The pipeline should in any case derive astrometry (including error bars) for all the sources, especially the target(s) of interest and any new sources which have just appeared (and hence may be associated with a variable core). Note the overlap of the proposed pipeline with John Swinbank's LOFAR transient pipeline (TRaP) software.
Quality assessment plan & cadence	The most obvious quality check is to compare flux densities for other sources in the field, to see that most stay within the bounds appropriate to background sources (e.g., mean change in flux density across the field should be consistent with zero). One would also check positions and polarization fractions of those sources. This would in general be an excellent check of the whole system. Quality checks (e.g., light curves of background sources) should be reported to all PIs for observations sharing various calibrations, to allow a more general evaluation of whether the data are any good (remember that a given PI may only get one second of data, esp. if she shares a phase calibrator with five other sources each with an independent PI – this might really happen near the Galactic Center, for instance!).

	Observing cadence is specified by the observer, and could depend on past and current flux densities. The next observations might be requested on any timescale from immediate (e.g. flare stars) to minutes or hours (e.g., very fast microquasars) to years (e.g., large HII regions), and would typically be evenly spaced or logarithmic since some fiducial date (that date could in some cases be derived from the radio light curve itself).

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Main requirement is dynamic scheduling which allows for efficient short observations of many sources with user-defined cadences and criteria, as discussed above. This includes the desire for either sophisticated SB functions (cf. Tim Cornwell's vision of SBs as multi-parameter function calls) or the automated real-time generation of observing scripts. A further requirement is the definition of standard observing setups for each band. Further, the scheduler must either merge sources across multiple scientific proposals into a single scheduling block, or allow very short (seconds to minutes) SBs which share a common flux, polarization, and bandpass calibration. Finally, the scheduler should allow for frequent updates of observing priorities, possibly on timescales of a minute or so. Data analysis pipeline should return results very rapidly (of order a minute) both internally (to the scheduler) and externally (to the PI). The pipeline results may also lead to internal and/or external alerts, as described above. Ideally this would include comparison to previous results and generation of long-term radio light curves (with real error bars generated and retained throughout). The data analysis pipeline might also try for automatic source identification, e.g. with LSST catalogs, associating variable radio sources with optical or other counterparts. The proposal tool should allow for simple and easy proposals to handle time-critical phenomena – e.g., SN1987A has just gone off, observe ASAP and continue with this cadence. Proprietary periods for such proposals may be much shorter than for "standard" observations, and could in fact be zero (no proprietary period).

Ideally one could form and destroy sub-arrays within a single "administrative" (schedulable) sub-array[1], to allow simultaneous observations of a single bright source at multiple bands. Rapid sequential observations are an acceptable substitute in most cases, if this is not possible.

[1] Here I use "administrative sub-array" to mean a set of antennas which is scheduled together. I'm asking that one be allowed to split up this set of antennas into multiple sub-sub-arrays which would all be controlled by the same observing project, to allow truly simultaneous observations at multiple bands. This would have significant implications for TM however!

REFERENCES

2.34 **Young Stellar Cluster Deep Field**

PROJECT DETAILS	
Title	**Young Stellar Cluster Deep Field**
Principal Investigator	**M. Hoare**
Co-Authors	**Cradle of Life Team**
Time Request	1000 hours

FACILITY		Preconditions
	SKA1-LOW	
	SKA1-MID	Needs VLBI for one of the science goals. Some aspects would benefit from Band 5+.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	1000 hours

OPERATIONAL MODE (as defined in Concept-of-Operations)	Details

	Normal	
	Fixed schedule (give cadence)	125 x 8 hour visits to build up the 1000 hours in total. 4 epochs of 8 hours each spread evenly over about one year will be done with VLBI for parallax and proper motion measurement. This would need to be repeated 4 times at each 3 month period to cycle around the number of VLBI targets within the single field of view. The other 105 epochs of 8 hours would be spread out with a logarithmic distribution of cadence over 2-3 years.
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Observations toward one field-of-view where we cover the low-mass star forming cluster ρ Oph A in the L1688 cloud in Ophiuchus. This single pointing contains seven class I and seven class II sources with the 6' field of view in Band 5 (Gutermuth et al. 2009). A total of 1000 hrs of integration time in SKA1-mid Band 5 would allow us to map the dust continuum at a resolution of up to 35 mas or 3.6 au at the 120 pc distance of the rho Oph complex. This will probe grain growth through the cm-size regime both in the terrestrial and Jovian planet forming zones at either side of the snow line. Simultaneously we will conduct a search for pre-biotic molecules in the cool outer regions of the disk on 100 au or arcsecond scales. Simulations show that we should be able to detect the faint emission of simple amino acids such as glycine, as well as to characterise the chemistry of its precursors, which also show a collection of transitions at centimetre wavelengths and are expected to be more abundant than glycine. We will simultaneously conduct time monitoring of flaring emission due to magnetic activity from the YSOs in the field of view and study the polarization and variability in any ionized jet emission associated with the YSOs. Some epochs will be jointly observed in VLBI mode so that we determine the 6D position-velocity structure of a subset of the sources in the cluster to test cluster formation models.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX		Stokes I
	YY		Stokes Q
	XY		Stokes U

	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The earliest stage of the planet formation process is the growth of dust grains from micron through millimetre to centimetre sizes. Sensitive cm-wave studies are the only way to fill the large gap in our understanding of the early growth of grains through the cm-size regime (Testi et al. 2014). SKA1-mid equipped with Band 5 receivers provides the resolution and sensitivity to map out the progress of these processes in the nearest systems. Radial variations in grain growth (Perez et al. 2012) can be studied both inside and outside the snow line – the traditional boundary between rocky and gas giant planet formation. Asymmetries in the disk can also reveal processes that assist grain growth (Perez et al. 2014). The deep field observation also enables a simultaneous very deep search for the building blocks of life such as amino acids in the outer regions of the actual disks where planets are forming. The detection of glycine in these regions, where incorporation onto comets and delivery onto terrestrial planets is possible, would represent a major milestone in Astrobiology. We will also simultaneously study the ionized jets and 6D phase structure of the young cluster to test star formation models.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
	X	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	1 field of view	
Positions of targets	The core of the rho Ophiuchus A cluster at RA=16:26:24 Dec=-24:23	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?	X	YES [details: Timing of the VLBI measurements and cadence for variability studies makes the relative timing of the epochs important but not the absolute timing.]
		NO
Integration time per target	1000 hrs toward one field-of-view	

(hrs)	
Average peak flux density (Jy or Jy per beam)	Average continuum flux density at 13 GHz is 0.2 μJy per 35 mas beam over the whole disk. Integrated flux is about 0.3 mJy over a 1.5 arcsec diameter disk. Line intensities of ~0.05-0.2 K in a 3”-beam for the glycine lines around 13GHz.
Range of peak flux densities (Jy or Jy per beam)	Peak continuum is about 10 μJy per 35 mas beam. Intensity drops to below a 3σ detection at around a radius of 0.5 arcsec from the centre of the disk. Glycine lines could be much weaker if freeze out onto grains is more than assumed.
Expected polarised flux density (expressed as % of total)	Flaring systems can be highly circularly polarized (~30%) and will be bright. Synchrotron components in the ionized jets can be linearly polarized at around the 10% level. The jets are brighter than the disc and so this should be easily detectable. The dust emission from the disk is polarized at around the 1% level at mm wavelengths and could be less at cm wavelengths.

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (X)*	
Central Frequencies (MHz) (including redshift, observatory correction)	One of the 2.5 GHz bands will be centred at 12.5 GHz to cover the continuum from 11.3 to 13.8 GHz. We will deploy two 256 MHz wide zooms centred on the brightest glycine lines at: 12.613 GHz and 13.477 GHz. The other 2.5 GHz band will be centred at 7.4 GHz and cover the 6.2 to 8.7 GHz continuum. This will allow frequency overlap with the VLBI dishes operating at 6.7 GHz with up to 1 GHz bandwidth. We will deploy two 256 MHz wide zooms centred on other glycine lines around 6.8 and 8.5 GHz.
Total Bandwidth (MHz)	5 GHz
Minimum and maximum frequency over the entire range of the setup (MHz)	6.2 GHz to 13.8 GHz
Spectral resolution (kHz)	In the 256 MHz zoom modes each with 16k channels each channel will be 16 kHz giving a velocity resolution ranging from 0.7 to 1.5 kms^{-1} sufficient for detecting lines with widths of around 0.8 kms^{-1}. In the rest of the continuum the 5000 x 1

	MHz channels only gives a velocity resolution of about 25 kms^{-1} which is insufficient to remove line contamination or study radio recombination lines in the jets.
Temporal resolution (in seconds)	The maximum dump time of 1.4 seconds is sufficient for the variability studies of flaring stars.

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin)	0.035 arcsec at 13 GHz

(single value or range)	
Maximum baseline required (km)	150 km
Mapped image size (degrees)	800 arcsec. Need to image the entire primary beam (and probably several sidelobes), to model the (time-variable) extragalactic background sources.
Required pixel resolution (arcseconds)	0.012 arcsec
Number of output channels	20 x 256 MHz wide channels covering full 5 GHz observed to derive the spectral index maps.
Output bandwidth (minimum and maximum frequency - MHz)	256 MHz
Required rms (Jy per beam) (if polarisation products required define for each)	80 nJy/beam
Dynamic range within image (if polarisation products required define for each)	Of order 10^5 to account for background sources in the field of view at the 10 mJy level.

Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	3”, corresponding to the whole disk where the emission is expected to arise.
Maximum baseline required (km)	2 km
Mapped image size (degrees)	~20 facets of 30 arcsec each centred on a PPD target within the fov.
Required pixel resolution (arcseconds)	1”

Number of image channels	4 x 16348
Channel width (kHz)	15.6 kHz
Required rms (Jy per beam per channel) (if polarisation products required define for each)	57 μJy/beam per 15.6 kHz channel. This is equivalent to an rms of 30mK over two channels needed to detect the glycine lines at around the 5σ level.
Dynamic range within image per channel (if polarisation products required define for each)	100

Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	1 milli-arcsecond (it's VLBI!)
Mapped image size (degrees)	3 arcsec
Number of image channels	1
Channel width (kHz)	1 GHz
Required rms (Jy per beam per channel) (if polarisation products required define for each)	4 μJy in each 8 hour epoch
Dynamic range within image per channel (if polarisation products required define for each)	1000

Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%

		n/a

DATA ANALYSIS	
Procedures required	To calibrate the continuum and reach the high continuum dynamic range in the presence of background sources of order 10 mJy the full field of view will need to be imaged and perhaps a few sidelobes. Over the 1000 hour integration many of these background sources (and also other T Tauri type stars in the cluster) will also vary. Once a suitable calibration has been achieved on the continuum this can be transferred to the spectral data. To fully search the spectrum for pre-biotic molecules, it is desirable that the full spectrum (4 x 256MHz total bandwidth with 64k channels) is provided. This implies large data rates and large data cubes. However, only a small fraction of the total field of view needs to be imaged in spectral mode just around the targets of interest. Multiple lines from other more abundant complex organic molecules (COMs) will likely be detected simultaneously. Appropriate software exists to assist in the identification of all molecular lines detected within the observations (e.g. XCLASS, Comito et al. 2005, or Weeds, Maret et al. 2011).
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	High wind speed data should be flagged. Reprocessing will be needed to refine the calibration and interpretation. After regions with strong lines have been identified then line-free regions of continuum can be defined in order to better determine the spatial variation of the continuum spectral index. May also find new sources in the deep continuum map that were not known about a priori and that will be re-examined for line emission
Data products	Continuum image and spectral index map for the full field of view. Spectral data cubes around ~20 small fields of interest. VLBI continuum maps around ~15 very small

	fields of interest. Time resolved continuum data around ~20 sources of interest.
Description of pipeline	TBC
Quality assessment plan & cadence	TBC
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	For the continuum and spectral line imaging this will be about 24 hours up completion of each 8 hour scheduling block. Similarly for the VLBI datasets. For the time variability studies this will be a few seconds.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
VLBI capability needs to be available and to be used simultaneously with imaging with the full SKA1-Mid array. If 4 VLBI beams are assumed then we would put 1 VLBI beam on a calibrator and the other 3 on targets in the single field of view for a single 8 hour epoch. Assuming there are about 15 VLBI targets within the field of view then we would like to use 5 x 8 hour VLBI

runs to cycle around all the targets. This would then need to be repeated three more times at around 3 month intervals to measure the parallax and proper motions. Am also currently checking if the AVN dishes will be able to do a 1 GHz VLBI bandwidth around 6.7 GHz – note that our VLBI is continuum mode not using the methanol maser line at 6.7 GHz as low-mass YSOs do not exhibit this line.

The current 1 MHz resolution of the 5000 continuum channels when zoom modes are deployed is not sufficient to study the recombination lines. We will submit an ECP to allow a trade off between channels in the zooms and continuum channels. For instance if we dropped one of the zooms we could use those 16k channels on the continuum which would then give a resolution of about 10 kms^{-1} which is sufficient for recombination lines. Note that there are about 22 RRLs across the whole 5 GHz of continuum bandwidth, but only about 5 of these would fall within the zooms deployed. Hence, we would be missing an opportunity to double the S/N in the recombination lines by stacking them all.

For the time variability studies then at present we have indicated that we would search down to the dump time scale of 1 arcsecond for fast flaring events. Given that the data cannot all be stored I presume that this is similar to slow transient searching mode where you have a few hours to look for and store the data around the transient objects. Given that the transient objects are bright non-thermal sources then they are likely to be also bright enough for VLBI. So there is a mode whereby during the runs with VLBI we would want to search the first half an hour or so of the imaging data to see if new VLBI targets have appeared and if so then switch a VLBI target beam onto them perhaps.

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2.35 The stellar neighbourhood

PROJECT DETAILS	
Title	The stellar neighbourhood (Stars, Planets and Civilisations)
Principal Investigator	Philippe Zarka & Cradle of Life Science Working Group
Co-Authors	Joe Lazio, Gregg Hallinan, Andrew Siemion, Soobash Daiboo, Tara Murphy, David Kaplan, Melvin Hoare, Di Li, Grazia Umana, Leon Koopmans, et al.
Time Request	750 hours (2500 hours in step 2)

FACILITY		Preconditions
x	SKA1-LOW	Full array, forming 8 beams per observation (4 pointing directions x 2 bands of ~37.5 MHz)
	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
x	SKA1-LOW	750 hours x 8 beams
?	SKA1-MID Band 1	*750 hours, optional*
?	SKA1-MID Band 2	*750 hours, optional*
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
x	Fixed schedule (give cadence)	~Daily
	Time-critical override	
	Custom Experiment	
	Commensal	
x	Collaborative & Coordinated	With “Our Galaxy”: study of all nearby stars, brown dwarfs, low-mass stars, white dwarfs
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
The purpose is to search (CMI) radio emissions from all exoplanets, brown dwarfs and other low-mass stars in the Solar neighbourhood, in 2 consecutive steps : within 10 pc, then within ~25 pc. Jupiter’s bursts at 30-40 MHz would reach a few tens of μJy at 10 pc range, a sensitivity achievable in ~1 hour × 20 MHz with SKA-Low. Intrinsic burstiness and beaming anisotropy makes Jupiter detectable ~10% of the time by an Earth-based observer. These characteristics govern the definition of the observations below. Step 1: Observe all stars within 10 pc, i.e. ~250 stars including 35 known exoplanets (potentially many more), with the following methodology : - SKA-Low, imaging, in V & I or 4 Stokes (CMI emission expected in V-Stokes, where images are not confusion-limited) - temporal & spectral resolution of final products : Δt ~ 5 – 10 sec, Δf ~ 0.1 – 1 MHz - 1 beam 50-87.5 MHz (FoV ~30 sq. deg.) + 1 beam 300-337.5 MHz (FoV ~2 sq. deg.) per target => 4 targets observable in parallel with 8 beams × 37.5 MHz - 12 hours per target, following a multi-epoch scheme permitting to cover/sample orbital periods from a few hours to a few weeks This will result in a total of **750 hours** of observation (250/4×12). As we will be interested in the center of the FoV, direction-independent calibration will probably be sufficient, allowing us to reach 10 μJy (in the 300-337.5 MHz band) to 50 μJy (in the 50-87.5 MHz band) sensitivity with a fast imaging pipeline. This makes Jupiter emission or Solar type II bursts detectable at ≤10 pc range. Optionally, we may want also SKA-Mid observations on the same targets (Bands 1, 2), ~3 hours per target with the full array, in order to explore with very high sensitivity potentially

higher magnetic field emitters (unipolar inductors, WD-planet systems …) SETI observations will be performed on beamformed raw voltages acquired in parallel. After interference elimination, sensitivities to ~10^{10} W Equivalent Isotropic Radiated Power can be reached, nearing the highest power leakage transmitters from Earth. Step 2: Extend to a large fraction of the stars within 25 pc, i.e. ~10× more targets. At 4 hours / target, this will result in a total of **~2500 hours** of observation (~2500/4×4). NB1 : For defining the target lists, we will use the RECONS database (http://www.recons.org/) and the SIMBAD database (http://simbad.u-strasbg.fr/simbad/). These databases may be more complete when actual observations will be defined. We will test (with the SWG « Our Galaxy ») spectral type distribution and samples completeness. NB2 : At Step 2, the number of observations in the band 50-87.5 MHz actually constitutes a full survey of the sky in this band, so that the strategy will be optimized as Key Observation #3.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	X	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Cyclotron-Maser emission is the most intense radio emission from Planets, and has been detected from Brown Dwarfs and Low-mass stars. Its detection is expected to bring unique information about exoplanets and star-planet plasma interactions (involving FGKM stars as well as White Dwarfs), opening the news fields of comparative exo-magnetospheric physics and extrasolar space weather, and about auroral-like radio emissions from brown dwarfs and low-mass stars. For exoplanets, detection will give a unique access to magnetic field strengths and tilts (and thus to planetary interior structure), rotation periods (and thus spin-orbit coupling), orbit inclination, and existence of exo-moons, and it has implications on the planet's habitability. For both exoplanets and low-mass stars, detection will permit to elucidate the type or « engine » in operation : star-planet interactions (stellar wind control – V,B,ρ –, triggering by CME, magnetic reconnection, unipolar induction), auroral-like currents in stellar environments. The expected sensitivity will also permit to detect radio emissions from stellar coronal mass

ejections (CME, analog to Solar type II bursts), that may in turn trigger exoplanetary radio emissions, and from magnetic binaries with star-planet-like interaction. The proposed targets and observations are ideally adapted to SETI commensal studies, probing leakage radiation from Kardashev 0-1 civilizations on nearby planets.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	X	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	~250	
Positions of targets	All sky (~isotropic). For defining the target lists, we will use the RECONS database (http://www.recons.org/) and the SIMBAD database (http://simbad.u-strasbg.fr/simbad/). These databases may be more complete when actual observations will be defined.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	x	NO
Time Critical?		YES [details: ……………………………………….]
	x	NO
Integration time per target (hrs)	12	
Average peak flux density (Jy or Jy per beam)	10 – 50 µJy	
Range of peak flux densities (Jy or Jy per beam)	Tens to hundreds of µJy, highly variable	
Expected polarised flux density (expressed as % of total)	Up to 100% (V)	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	2 beams per target: 50-87.5 MHz & 300-337.5 MHz
Total Bandwidth (MHz)	37.5 MHz per beam
Minimum and maximum frequency over the entire range of the setup (MHz)	50 – 350 MHz
Spectral resolution (kHz)	~100 kHz
Temporal resolution (in seconds)	5 – 10 sec

NON-IMAGING SPECIFIC CONSIDERATIONS (for SETI)		
Required angular resolution of a tied array beam (arcmin)	~0.1 to 0.5, as provided by full array	
Maximum baseline required (km)	~65	
Primary beam size (sq degrees)	1.3° to 6.5° (FoV ~2 to 30 sq. deg.)	
Number of output channels	Raw voltages with maximum resolution in each frequency band	
Output bandwidth (minimum and maximum frequency - MHz)	50-87.5 MHz & 300-337.5 MHz	
Required rms (Jy) (if polarisation products required define for each)	N/A	
Dynamic range (if polarisation products required define for each)	N/A	
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	x	n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a ‘support image’ in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	~0.1 to 0.5, as provided by full array	
Maximum baseline required (km)	~65	
Mapped image size (degrees)	1.3° to 6.5° (FoV ~2 to 30 sq. deg.)	
Required pixel resolution (arcseconds)	~10 pixels per PSF	
Number of output channels	375 channels per 37.5 MHz band	
Output bandwidth (minimum and maximum frequency - MHz)	50-87.5 MHz & 300-337.5 MHz	
Required rms (Jy per beam) (if polarisation products required define for each)	10 – 50 μJy	
Dynamic range within image (if polarisation products required define for each)	$>10^5$ in I, V	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of image channels	

Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Flag RFI
Data products	Images in I & V stokes per 0.1 – 1 MHz band every 5 to 10 sec. Possible post-integration at ~1 min.
Description of pipeline	Fast & simple direction-independent calibration & imaging in I & V Sokes
Quality assessment plan & cadence	?
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	Typically 24 hours

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
SWG « Our Galaxy » : There is strong commensality of this observation with a wide study of all nearby stars, brown dwarfs, low-mass stars, white dwarfs. While searching for signature of

a planet, we will :

- study the stellar radio coronae
- detect/study radio flares (multi-epoch observations, high temporal resolution) and characterize their typical behaviour (occurence rate, duration..) [currently ~420 radio detected stars]
- comparison stellar flares with solar-type magnetic activity
- look for evidences of rotational modulation of the radio emission.

Stellar studies are also a strong motivation to extension to SKA-Mid. No detail has been provided here for observations in Band 1 & 2 with SKA-Mid. TBD with "Our Galaxy" SWG.

REFERENCES

- Hallinan et al., Magnetospherically driven optical and radio aurorae at the end of the stellar main sequence, Nature 523, 568-571, 2015.
- Siemion et al., Searching for Extraterrestrial Intelligence with the Square Kilometre Array, SKA science book, 27-42, 2015.
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- and references therein.

2.36 SKA unveiling heavy carbon chains chemistry in OMC-2, the closest analogue to our Sun's birth environment

PROJECT DETAILS	
Title	**SKA unveiling heavy carbon chains chemistry in OMC-2, the closest analogue to our Sun's birth environment**
Principal Investigator	**Eleonora Bianchi**
Co-Authors	**Cradle Of Life Team**

Time Request	~ 1000 hours

FACILITY		Preconditions
	SKA1-LOW	
x	SKA1-MID	Band 5b frequency coverage in 2 windows 2.5 GHz broad (9 -11.5 GHz and 13-15.5 GHz) + four narrower zoom windows on selected lines. Some aspects would benefit from Band 5+.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
X	SKA1-MID Band 5	~1000 hours

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	Yes
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	

	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
We will observe the Orion molecular cloud (OMC) 2 region, an active, star-forming filament with a rich population of young protostars, and considered the closest analogue to our Sun's birth environment. The angular resolution of 0.5" (corresponding to ~ 200 au) will allow us to characterize the chemistry of heavy carbon chains on unprecedented scales towards different sources. The large field of view will allow us to probe different regions of the cloud characterized by different high energy particles irradiation, shedding light on the chemical processes at the origin of the warm carbon chain chemistry sources (WCCC; Sakai & Yamamoto 2013). This will perfectly complement the already performed ALMA surveys of complex organic molecules, probing the hot corino sources. A total observing time of 1000 hr will give a rms of 19 μJy/beam in 2x80.6 kHz channels. We will use the broad spectral window in combination with four narrower zoom windows targeting selected spectral lines. This will allow us to obtain the complete census of heavy carbon chains at an unprecedented combination of sensitivity and spatial resolution. The angular resolution could be reduced down to the Solar System scale (beam ~ 0.1"-0.2" or ~ 40-80 au) in case of the operational SKA sensitivity in Band 5 will reach a few μJy.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX	**X**	Stokes I
X	YY		Stokes Q
X	XY		Stokes U
X	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
In the last years a striking chemical diversity has been identified around Sun-like protostars. In particular, major differences have been observed in the chemistry of hot corinos (enriched in complex organic molecules, e.g. Ceccarelli et al. 2007) and the WCCC (*Warm Carbon Chain Chemistry*) sources (enriched of unsaturated small carbon chains, with less than about five C-atoms: e.g. Sakai & Yamamoto 2013). The origin of this diversity is unclear and it may be related to environmental conditions at

the epoch of dust icy mantles formation. Moreover, very few is known so far about the presence and the evolution of large carbon species (e.g. chains with more than seven C-atoms) which cannot be properly investigated at mm wavelengths. Yet, heavy C-species might have a crucial role in the heritage of organic material from the pre- and proto- stellar phase to the objects of the newly formed planetary system, like asteroids and comets (e.g. Mumma & Charnley 2011).

Recent pilot surveys have been performed to unveil the large carbon chains reservoir in few Solar precursors, discovering a plethora of complex C-chains species, using the 100m Green Bank Telescope (e.g. Bianchi et al. in prep.; GOTHAM and ARKHAM projects, McGuire et al. 2020, Burkhardt et al. 2021), and the 40m Yebes antenna (QUIJOTE survey, Cernicharo et al. 2021).

Some examples are C_4H, C_6H, HC_7N, HC_9N, C_3S, and, cyclic hydrocarbons such as c-C_9H_8 and o-C_6H_4. A fundamental step ahead in Astrochemistry is to **unveil with SKA, the C-chains reservoir at small angular scales,** where planetary systems are forming. In particular, this project will shed light on the origin of the chemical diversity observed in Solar-System precursors and on how it affects the composition of the forming planetary systems. These observations will be possible only thanks to the combination of high angular resolution and sensitivity provided by SKA.

This project will be highly complementary to several astrochemical surveys at mm- and submm- wavelengths, performed with IRAM-30m (e.g., ASAI survey; Lefloch et al. 2018), IRAM-NOEMA (e.g., SOLIS; Ceccarelli et al. 2017) and ALMA (e.g., FAUST, Bianchi et al. 2020; PILS, Jorgensen et al. 2016), which obtained the chemical census of complex organic molecules in Solar System precursors. In this respect, the SKA project represents a major step ahead. On the one hand, it will overcome several limitations related to (sub-) mm-observations, such as dust opacity and line confusion, providing new insights on the envelope/disk structure. On the other hand, it will unveil a new chemistry of complex C-chain species allowing us to unravel their formation mechanism in space, "top-down" (destruction of PAHs) vs "bottom-up" (the growth from the atomic C).

In summary, SKA will complement our understanding of complex species expected to play a major role in the emergency of life, acting as the backbone of relevant biological molecules, such as proteins, RNA and DNA.

We will observe the Orion molecular cloud (OMC) 2 region, at a distance of 393±25 pc (Grossschedl et al. 2018). OMC-2 an active, star-forming filament with a rich population of young stars and disks (Shimajiri et al. 2008, 2011, 2015; López-Sepulcre et al. 2013b; Kainulainen et al. 2017; Tobin et al. 2019). OMC-2 contains several star forming regions, among which the FIR 4 region, which is a well-studied proto-stellar cluster, permeated by a flux of high energy cosmic-ray-like particles (Ceccarelli et al. 2014; Fontani et al. 2017; Osorio et al. 2017; Favre et al. 2018; Ceccarelli et al. 2019). **This elevated dose of energetic particles** is very similar to that experienced by the young Solar System, which was formed in a crowded cluster of stars (Adams 2010, Lichtenberg et al. 2019). For these reasons OMC-2 FIR4 is considered as one of the closest analogues of the environment in which our Sun may have formed and thus ideal in **pursuing a chemistry that resembles that of our early Solar System.**

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
	X	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	1	
Positions of targets	The OMC-2 FIR 4 cluster RA=05 :35 :27.0 Dec=-05 :09 :56.8 The field of view of 6.7' will cover the whole OMC-2 star forming region	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	1000 hrs towards one field-of-view	
Average peak flux density (Jy or Jy per beam)	~ 0.1-0.5 mJy/beam from Tobin et al. 2019	
Range of peak flux densities (Jy or Jy per beam)	From 0.05 to 1.9 mJy/beam	
Expected polarised flux density (expressed as % of total)		

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	We will use the 5b receiver. We will use two 2.5 GHz spectral band to cover the frequency ranges from 9.0

	to 11.5 GHz and from 13.0 to 15.5 GHz. We will add four narrower zoom windows targeting selected spectral lines for kinematics.
Total Bandwidth (MHz)	5 GHz
Minimum and maximum frequency over the entire range of the setup (MHz)	9 GHz to 15.5 GHz
Spectral resolution (kHz)	80.6 kHz spectral resolution, corresponding to 1.9 kms^{-1} + 4 zoom windows with 0.2 kms^{-1}
Temporal resolution (in seconds)	Not required

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%

		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	0.5 arcsec corresponding to ~200 au (down to 0.1-0.2 arcsec depending on operational sensitivity)

Maximum baseline required (km)	150 km	
Mapped image size (degrees)	6-7 arcmin to map the whole OMC-2 region	
Required pixel resolution (arcseconds)	0.125 arcsec	
Number of image channels	62k	
Channel width (kHz)	80.6 kHz corresponding to 1.9 km/s at 12.5 GHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	27 μJy/beam per 80.6 kHz channel.	
Dynamic range within image per channel (if polarisation products required define for each)	1000	
Absolute flux scale calibration		1-3%
		5%
	x	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	
Mapped image size (degrees)	
Number of image channels	
Channel width (kHz)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	

Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	We expect several emission lines from carbon-chain molecules and complex organic molecules (McGuire et al. 2020, Bianchi et al. in prep). Line-free channels will be identified in order to produce continuum maps and to subtract the continuum emission to produce line cubes. Line identification will be performed using the major spectral databases (Jet Propulsion Laboratory molecular database, Pickett et al. 1998; Cologne Database for Molecular Spectroscopy, Müller et al. 2005). For the species for which the collisional coefficients are calculated, a non-LTE Large Velocity Gradient analysis will be performed to derive the gas physical properties (column density and temperature). For the other species they will be derived using the LTE approximation. In order to have a precise determination of the gas properties, it is desirable to have as many transitions as possible for each molecular species, covering a broad range of upper level energy. This will require that the full spectrum is provided, implying large data rates and large data cubes.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Some reprocessing may be required.

Data products	Continuum images and spectral data cubes around ~ 30 protostellar objects.
Description of pipeline	TBC
Quality assessment plan & cadence	TBC
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	At completion of the full project

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES
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2.37 Selected Sample of of Known Exoplanets, Brown Dwarfs and Low Mass Stars

PROJECT DETAILS	
Title	Selected sample of Known Exoplanets, Brown Dwarfs and Low Mass Stars (Stars, Planets & Civilisations)
Principal Investigator	Philippe Zarka & Cradle of Life Science Working Group
Co-Authors	Joe Lazio, Gregg Hallinan, Andrew Siemion, Soobash Daiboo, Tara Murphy, David Kaplan, Melvin Hoare, Di Li, Grazia Umana, Leon Koopmans, et al.
Time Request	1500 hours

FACILITY		Preconditions
x	SKA1-LOW	Full array, forming 8 beams per observation (4 pointing directions x 2 bands of ~37.5 MHz)
	SKA1-MID	

RECEIVER(S) REQUIRED	Time (hrs)

x	SKA1-LOW	1500 hours x 8 beams
?	SKA1-MID Band 1	*Optional*
?	SKA1-MID Band 2	*Optional*
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
x	Fixed schedule (give cadence)	~Daily
	Time-critical override	
	Custom Experiment	
	Commensal	
x	Collaborative & Coordinated	With “Our Galaxy”: study of stars, brown dwarfs, low-mass stars, white dwarfs. With “Transients”, list of targets (coordinates of known exoplanets and low-mass stars) → alerts.
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
The purpose is to search (CMI) radio emissions from a list of known Exoplanets, Brown Dwarfs and Low-mass stars, established from existing observations (from GMRT, LOFAR, UTR-2, and including ongoing/near-future exoplanet findings from GAIA, TESS, ESPRESSO, ESO-VLT/NGTS, PLATO …) and selected from theoretical considerations (hot Jupiters – especially with optical SPI signatures –, planets orbiting bright X-UV stars or strongly magnetized stars, …) at the time of the proposal. Many of these targets will be at a distance >25 pc and thus not covered by Key Observations #1. Outputs from Key Observations #1 & #3 may also feed the target list. Jupiter’s bursts at 30-40 MHz would reach a few tens of μJy at 10 pc range, a sensitivity achievable in ~1 hour × 20 MHz with SKA-Low. Intrinsic burstiness and beaming anisotropy makes Jupiter detectable ~10% of the time by an Earth-based observer. These characteristics govern the definition of the observations below.

The same observational setup as Key Observation #1 will be used : - SKA-Low, imaging, in V & I or 4 Stokes (CMI emission expected in V-Stokes, where images are not confusion-limited) - temporal & spectral resolution of final products : Δt ~ 5 – 10 sec, Δf ~ 0.1 – 1 MHz - 1 beam 50-87.5 MHz (FoV ~30 sq. deg.) + 1 beam 300-337.5 MHz (FoV ~2 sq. deg.) per target => 4 targets observable in parallel with 8 beams × 37.5 MHz - 20 hours per target, following a multi-epoch scheme permitting to cover/sample orbital periods from a few hours to a few weeks We will again use 2 beams (× 37.5 MHz) per target, i.e. 4 targets observable in parallel. The choice of the frequency ranges will depend of what is known from previous observations. For exoplanets, it is likely to be the ranges 50-87.5 and 87.5-125 MHz. For stars, we will likely stick to 50-87.5 and 300-337.5 MHz. Characterization of the source will require a longer observation time per target than Key Observations #1. With ~20 hours per target (distributed according to the known periodicities of the system – orbital period, stellar rotation …) and a list of order of 300 targets & using the 8 beams of SKA-Low, this will result in a total of **1500 hours** of observation (300/4×20). SKA-Mid observations may additionally be required in some cases. SETI observations will again be performed on beamformed raw voltages acquired in parallel to imaging. Optionally, we may want also SKA-Mid observations on the same targets (Bands 1, 2). SETI observations will be performed on beamformed raw voltages acquired in parallel.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	x	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX	x	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Cyclotron-Maser emission is the most intense radio emission from Planets, and has been detected from Brown Dwarfs and Low-mass stars. Its detection is expected to bring unique information about exoplanets and star-planet plasma interactions (involving FGKM stars as

well as White Dwarfs), opening the news fields of comparative exo-magnetospheric physics and extrasolar space weather, and about auroral-like radio emissions from brown dwarfs and low-mass stars. For exoplanets, detection will give a unique access to magnetic field strengths and tilts (and thus to planetary interior structure), rotation periods (and thus spin-orbit coupling), orbit inclination, and existence of exo-moons, and it has implications on the planet's habitability. For both exoplanets and low-mass stars, detection will permit to elucidate the type or « engine » in operation : star-planet interactions (stellar wind control – V,B,ρ –, triggering by CME, magnetic reconnection, unipolar induction), auroral-like currents in stellar environments. The expected sensitivity will also permit to detect radio emissions from stellar coronal mass ejections (CME, analog to Solar type II bursts), that may in turn trigger exoplanetary radio emissions, and from magnetic binaries with star-planet-like interaction. The proposed targets and observations are ideally adapted to SETI commensal studies, probing leakage radiation from Kardashev 0-1 civilizations on nearby planets.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	x	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	~250	
Positions of targets	All sky (~isotropic). For defining the target lists, we will use the http://exoplanet.eu database, at the time of observation.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………..]
	x	NO
Time Critical?		YES [details: ……………………………………..]
	x	NO
Integration time per target (hrs)	20	
Average peak flux density (Jy or Jy per beam)	10 – 50 μJy	
Range of peak flux densities	Tens to hundreds of μJy, highly variable	

(Jy or Jy per beam)	
Expected polarised flux density (expressed as % of total)	Up to 100% (V)

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	2 beams per target: 50-87.5 MHz & 300-337.5 MHz
Total Bandwidth (MHz)	37.5 MHz per beam
Minimum and maximum frequency over the entire range of the setup (MHz)	50 – 350 MHz
Spectral resolution (kHz)	~100 kHz
Temporal resolution (in seconds)	5 – 10 sec

NON-IMAGING SPECIFIC CONSIDERATIONS (for SETI)		
Required angular resolution of a tied array beam (arcmin)	~0.1 to 0.5, as provided by full array	
Maximum baseline required (km)	~65	
Primary beam size (sq degrees)	1.3° to 6.5° (FoV ~2 to 30 sq. deg.)	
Number of output channels	Raw voltages with maximum resolution in each frequency band	
Output bandwidth (minimum and maximum frequency - MHz)	50-87.5 MHz & 300-337.5 MHz	
Required rms (Jy) (if polarisation products required define for each)	N/A	
Dynamic range (if polarisation products required define for each)	N/A	
Absolute flux scale calibration		1-3%
		5%

		10%
		20-50%
	x	n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	~0.1 to 0.5, as provided by full array	
Maximum baseline required (km)	~65	
Mapped image size (degrees)	1.3° to 6.5° (FoV ~2 to 30 sq. deg.)	
Required pixel resolution (arcseconds)	~10 pixels per PSF	
Number of output channels	375 channels per 37.5 MHz band	
Output bandwidth (minimum and maximum frequency - MHz)	50-87.5 MHz & 300-337.5 MHz	
Required rms (Jy per beam) (if polarisation products required define for each)	10 – 50 μJy	
Dynamic range within image (if polarisation products required define for each)	>10^5 in I, V	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	

Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%

		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Flag RFI
Data products	Images in I & V stokes per 0.1 – 1 MHz band every 5 to 10 sec. Possible post-integration at ~1 min.
Description of pipeline	Fast & simple direction-independent calibration & imaging in I & V Sokes
Quality assessment plan & cadence	?
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Typically 24 hours

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
SWG « Our Galaxy » : There is strong commensality of this observation with a wide study of all nearby stars, brown dwarfs, low-mass stars, white dwarfs. While searching for signature of a planet, we will : - study the stellar radio coronae - detect/study radio flares (multi-epoch observations, high temporal resolution) and characterize their typical behaviour (occurence rate, duration..) [currently ~420 radio detected stars] - comparison stellar flares with solar-type magnetic activity - look for evidences of rotational modulation of the radio emission. Stellar studies are also a strong motivation to extension to SKA-Mid. No detail has been provided here for observations in Band 1 & 2 with SKA-Mid. TBD with "Our Galaxy" SWG. SWG « Transients » : As for LOFAR, our KSP will provide a list of targets (coordinates of known exoplanets and low-mass stars) to include in the transients pipeline, that shoud result in alerts if/when a transient is detected at a position matching a candidate in this list. All frequency bands are interesting, circular polarization is of special interest.

REFERENCES
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2.38 Galactic water masers and ammonia: science at 20 GHz and beyond

PROJECT DETAILS	
Title	**Galactic water masers and ammonia: science at 20GHz and beyond**
Principal Investigator	**Andrew Walsh**
Co-Authors	**Milky Way SKA focus group**
Time Request	1000 hours

FACILITY		Preconditions
	SKA1-LOW	
	SKA1-MID	This program is contingent on SKA1-MID being able to cover frequencies up to 25GHz. Lowest frequency considered is 22GHz.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5(req: Band5+)	1000

OPERATIONAL MODE	Details

(as defined in Concept-of-Operations)		
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Mosaicked observations of many fields to cover the Galactic Plane visible from SKA. Highest priority would be a 2-degree wide strip along the mid-Plane from latitudes 300 to 40. Approximately one hour of integration time per field would result in a simultaneous spectral line sensitivity of 0.3 K rms in a 0.1 km/s channel and 15” beam and continuum sensitivity of 1.2 mJy in a 0.3” beam. The spectral line sensitivity is sufficient to detect ammonia emission from a typical star forming cloud with total mass 90 solar masses across to the far side of the Galaxy in lower energy ammonia transitions: (1,1), (2,2) and (3,3). Simultaneously observe water masers at 22GHz.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX		Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Ammonia is an excellent tracer of dense gas at the critical density threshold for star formation (Lada et al. 2010). It reliably traces quiescent gas, since it does not suffer from freeze-out onto dust grains in the coldest regions. It is an excellent thermometer between 15-400K, when multiple transitions are combined. It also has hyperfine components, allowing optical depth to be measured. This survey will obtain a complete inventory of star formation across our Milky Way Galaxy with sensitivity and spatial resolution to detect and resolve a single core of 90 solar masses and size ~0.05pc. Water masers are excellent tracers of both star formation and evolved stars in our Galaxy. They can be used to identify outflows and shock fronts, trace circumstellar shells and understand the timeline of high mass star formation.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	Mosiacing along the Galactic plane	
Positions of targets	Galactic coordinates: l=300-40, |b|<2	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	1	
Average peak flux density (Jy or Jy per beam)	30mJy	
Range of peak flux densities (Jy or Jy per beam)	There will be a large range, given that we will include masers. Expected range from 100mJy to 500Jy	
Expected polarised flux density	Not significant	

(expressed as % of total)	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Ammonia (1,1) through to (6,6): 23694-25056MHz; water maser: 22235MHz
Total Bandwidth (MHz)	2x2.5GHz
Minimum and maximum frequency over the entire range of the setup (MHz)	22200-25100MHz
Spectral resolution (kHz)	3.2kHz channels needed for ~0.1km/s velocity resolution
Temporal resolution (in seconds)	Not important

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%

		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	0.3 arcsec	
Maximum baseline required (km)		
Mapped image size (degrees)	200 square degrees in total	
Required pixel resolution (arcseconds)	0.05	
Number of output channels	32	
Output bandwidth (minimum and maximum frequency - MHz)	20000 – 25000	
Required rms (Jy per beam) (if polarisation products required define for each)	0.0012 Jy/beam	
Dynamic range within image (if polarisation products required define for each)	10000	
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	0.3 arcsec
Maximum baseline required (km)	
Mapped image size (degrees)	200 square degrees

Required pixel resolution (arcseconds)	0.05 arcsec	
Number of image channels	16k	
Channel width (kHz)	0.1	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	120 mJy/beam per channel	
Dynamic range within image per channel (if polarisation products required define for each)	10000	
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%

		n/a

DATA ANALYSIS	
Procedures required	To enable a contiguous survey, calibrate the continuum and reach high dynamic range against bright sources in the fields, the full primary beam will need to be imaged. Zoom windows need to be placed on one water maser line at 22235MHz and five ammonia lines between 23694 and 25056MHz.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Need to be able to process (or reprocess) line and continuum data with different setups: to improve brightness temperature sensitivity for ammonia the data need to be tapered to a 15-20” beam and to maintain angular resolution for continuum the data need to be processed without tapering.
Data products	Continuum maps and spectral index maps. Spectral line cubes (extracted around each line, or around the range of Galactic velocities) for both water and ammonia lines.
Description of pipeline	
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds'	Upon completion of scheduling block and pipeline reduction.

for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
This work requires availability of SKA1-MID up to 25.1GHz. ie. Band 6 ([RD6])

REFERENCES
Lada, C. J., Lombardi, M. & Alves, J. F., 2010, ApJ, 724 68

2.39 **Anomalous H2CO absorption in the Galactic Plane**

PROJECT DETAILS	
Title	**Anomalous H2CO absorption in the Galactic Plane**
Principal Investigator	**Mark Thompson**
Co-Authors	**Our Galaxy SWG**
Time Request	~2000 hours

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	Band 5 is required to observe the 4.8 GHz H2CO line and the higher frequency continuum up to 9.8 GHz. Highly desirable for WBSPF AIP Band B or an extension to Band 5 to cover the 14.4 GHz line so as to use the line ratios as a densitometer. Elsewhere in this use case 'setup 1' refers to the first scenario, 'setup 2' to the second.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
X	SKA1-MID Band 5 (or 5+ AIP)	~2000 hours

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Mosaicked observations of many fields to cover the Galactic Plane visible from SKA. Highest priority would be a 2-degree wide strip along the mid-Plane from latitudes 300 to 40. Approximately one hour of integration time per field would result in a simultaneous spectral line sensitivity of 0.1 K rms in a 0.1 km/s channel and 20” beam and continuum sensitivity of 400 nJy in a 0.3” beam. The spectral line sensitivity is sufficient to detect H2CO in absorption against the CMB and the continuum sensitivity to detect stellar radio emission from winds, coronae and magnetospheres. Simultaneously in continuum mode we will be able to resolve and detect at least 75 radio recombination lines from H, He and C. The channel resolution required for recombination lines is 160 kHz, and so native continuum resolution is more than sufficient for these lines – as long as the native continuum resolution is not reduced to 1 MHz when zoom windows are used. In practice 16384 channels will not be required for each zoom window for the H2CO spectroscopy and so these channels could be used to increase the continuum resolution to adequately study radio recombination lines. Follow-up targeted observations of the 14.4 GHz H2CO line will be made toward 4.8 GHz detections to enable the measurement of the gas volume density via the H2CO line ratio. With integration times of an hour per pointing we would be able to measure densities from ~$10^{2.5}$ to 10^6 cm^{-3}. The deployment of the Advanced Instrumentation Programme Band 5+ would be needed to cover this line, unless the frequency range of band 5 were extended to 15 GHz. These observations would also provide high frequency continuum, RRLs, plus the 12.2 CH3OH maser line.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	X	Stokes Q

	XY	X	Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Measuring the density of molecular gas is a difficult process involving many techniques that rest upon different assumptions, from the CO-H2 X-factor to the dust emissivity coefficient. The studies upon which the Schmidt-Kennicutt relation is determined on Galactic and extra-galactic scales use a variety of density tracers with many different systematics that result in errors around an order of magnitude (e.g. Krumholz 2014). However there is one important distance-independent tracer of molecular gas that can be used without systematics to determine the molecular *volume* density to within 0.2 dex. This is anomalous absorption of formaldehyde (H2CO) against the cosmic microwave background (Palmer et al 1969). The ratio of the two ground state transitions at 4.8 and 14.4 GHz directly depends upon the gas volume density (Ginsburg et al 2012). This absorption is faint and has to date been difficult to detect, but the SKA offers the potential to transform this technique into a method of wide-area molecular gas density measurement for the Milky Way. Simultaneously with such a wide-area Galactic Plane survey, it will be possible to acquire deep continuum imaging at 4.8 and 14.4 GHz, plus maps of over 70 RRLs from H, He and C, and serendipitous 6.7 and 12.2 CH3OH maser studies.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	x	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	500 fields for 4.8 GHz line, 500 assumed for 14.4 GHz line	
Positions of targets	Evenly spaced along the Galactic mid-Plane from l=300 to l=40 (RA 12h25 to 19h00), to enable at least half-beam sampling at 4.8 GHz.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]

	X NO
Integration time per target (hrs)	~1-2
Average peak flux density (Jy or Jy per beam)	See below
Range of peak flux densities (Jy or Jy per beam)	There will be a high dynamic range in flux density of objects along the Plane from compact HII regions with few mJy to Jy fluxes at 5 GHz, to stellar sources with few micro-Jy fluxes.
Expected polarised flux density (expressed as % of total)	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (X)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Continuum from 4.6 to 9.6 GHz Zoom bands on: H2CO lines at 4.8 GHz and 14.4 GHz CH3OH line at 6.7 GHz Recombination lines across the band
Total Bandwidth (MHz)	2 x 2.5 GHz to simultaneously cover a range of continuum frequencies for spectral index measurements, and also to cover the widest range of recombination lines.
Minimum and maximum frequency over the entire range of the setup (MHz)	4600 – 9600 MHz setup 1 14200 – 19200 MHz Band 5+ setup 2
Spectral resolution (kHz)	1.6 kHz channels needed for 0.1 km/s velocity resolution at 4.8 GHz - hence at least two zoom bands required for CH3OH and H2CO
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	

Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	0.3" for continuum & maser lines
Maximum baseline required (km)	100
Mapped image size (degrees)	Need to image entire primary beam of 0.39 deg^2
Required pixel resolution (arcseconds)	FWHM/3
Number of output channels	For continuum purposes, band could be averaged into ~200 MHz channels for spectral index. Ideally for recombination lines the native resolution (65k channels) would be required, needing repeat observations or extension to the zoom mode capability.
Output bandwidth (minimum and	4600 – 9600 MHz setup 1

maximum frequency - MHz)	14200 – 19200 MHz Band 5+ setup 2	
Required rms (Jy per beam) (if polarisation products required define for each)	400 nJy/beam for continuum (I)	
Dynamic range within image (if polarisation products required define for each)	At least 10^6 to account for bright Galactic confusing sources	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	15” for H2CO lines at 4.8 & 14.4 GHz	
Maximum baseline required (km)	100	
Mapped image size (degrees)	Need to image entire primary beam of 0.39 deg^2 at 4.8 GHz	
Required pixel resolution (arcseconds)	5”	
Number of image channels	16384 in zoom window (although can be reduced by binning or dropping channels at the edge of the zoom window)	
Channel width (kHz)	0.1 km/s velocity resolution required at 5 GHz – 1.6 kHz channels	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	0.73 mJy/beam	
Dynamic range within image per channel (if polarisation products required define for each)	100	
Absolute flux scale calibration		1-3%

	x	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	To enable a contiguous survey, calibrate the continuum and reach high dynamic range against bright sources in the fields, the full primary beam will need to be imaged. As the Radio Recombination lines (RRLs) are widespread throughout the band, the full frequency range needs to be processed (but not necessarily at native resolution - 10 km/s channels are sufficient, i.e. 160 kHz at 4.8 GHz and 480 kHz at 14.4 GHz). Zoom windows need to be placed on at least two important transitions in the 4.8 GHz (H2CO plus 6.7

	GHz CH3OH) and 14.4 GHz band (H2CO plus possibly 12.2 GHz CH3OH).
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Need to be able to process (or reprocess) line and continuum data with different setups: to improve brightness temperature sensitivity for H2CO the data need to be tapered to a 15-20" beam; and to maintain angular resolution for continuum the data need to be processed without tapering. The full continuum bandwidth must be processed at 160 or 480 kHz resolution to enable the radio recombination lines to be resolved.
Data products	Continuum maps and spectral index maps generated from recombination line-free channels. We envisage 10 separate 0.5 GHz continuum sections across the 5 GHz bandwidth. Recombination line cubes (extracted around each line, or around the range of Galactic velocities). Cube of H2CO emission at 4.6 and 14.4 GHz, and line ratio maps/cubes.
Description of pipeline	
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours),	Upon completion of scheduling block and pipeline reduction

to 'at completion of the full project'.)	

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
The value of the H2CO absorption study is in the measurement of the ratio between the 4.8 and 14.4 GHz lines. This ratio directly depends upon the H2 *volume* density and so *both* lines at 4.8 and 14.4 GHz must be observed. Currently the 14.4 GHz line lies just outside the Level 1 specification for Band 5 and so to enable this technique to be used would require a slight extension to the current Band 5 range or the deployment of the Band 6 Advanced Instrumentation Project in Phase 1 [RD6]. Also, the current level 1 specification for the correlator states that when zoom windows are used the default continuum band resolution drops of 1 MHz channels. This is not sufficient to observe Radio Recombination lines in continuum mode – these lines require at least 10 km/s channels (160 kHz at 4.8 GHz and 480 kHz at 14.4 GHz). Conversely, the full 16384 channels are not required for 0.1 km/s resolution in zoom windows that cover the full range of Galactic velocities (+/- 300 km/s) and so these channels could be used to increase the continuum resolution without affecting the zoom window science.

REFERENCES
Ginsburg, A., Darling, J., Battersby, C., Zeiger, B., & Bally, J., 2011, ApJ, 736, 149 Krumholz, M., 2014, *Physics Reports* 539.2 (2014): 49-134. Palmer, P., Zuckerman, B., Buhl, D., & Snyder, L.E., 1969, ApJL, 156, L147

2.40 **Pre-biotic Molecules in Solar-System Precursors**

PROJECT DETAILS	
Title	**Pre-biotic Molecules in Solar-System Precursors**
Principal Investigator	**Izaskun Jimenez-Serra**
Co-Authors	**Cradle of Life Working Group**
Time Request	~1000 hrs

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	Frequency coverage from 12.6 GHz to 13.5 GHz in four zoom windows of 64 MHz each, targeting four lines of glycine. This science will greatly benefit from Band 6 since the glycine lines are factors ~4-8 brighter between 18.5 and 22 GHz than at 13GHz.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
X	SKA1-MID Band 5	~1000 hrs

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	Yes
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Pointed observations toward the L1689B pre-stellar core, where several complex organic molecules have recently been detected (Bacmann et al. 2012). A total of ~1000 hrs of integration time in SKA1-mid Band 6 would be needed to detect the faint emission of simple amino acids such as glycine in this pre-stellar core, as well as to characterise the chemistry of its precursors which also show a collection of transitions at centimetre wavelengths and are expected to be more abundant than glycine. This time estimate is optimized for the detection of glycine.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX	**X**	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Complex organic molecules have been traditionally found in hot regions around new-born stars (the so-called “hot cores” or their low-mass counterparts the “hot corinos”). Whether these complex molecules are related to the building blocks of life (as e.g. amino acids) is a big open question. It is not fully understood either how these molecules are formed (grain-surface versus gas chemistry). Recently, the detection of complex molecules in starless dense cores and pre-stellar cores, characterized by very low temperatures (10 K), or in extended regions around hot cores/corinos with low-excitation temperatures have challenged our understanding of the interstellar chemistry. The emission of complex organic molecules is spread over many transitions. At low temperatures (10 K), the peak of this emission is shifted toward low frequencies, hence making SKA a prime instrument to trace this emission in starless/pre-stellar dense cores. Here, we focus on the detectability of the simplest amino acid, glycine, toward a low-mass pre-stellar core, i.e. a core in the verge of gravitational collapse. The detection of glycine, and of its precursors, in these cores represents a major milestone in Astrochemistry and Astrobiology, providing a unique opportunity to characterise the pre-biotic chemistry at the earliest stages of Solar-type Systems. Although glycine shows a collection of transitions at millimetre wavelengths, we stress that observations at centimetre wavelengths carried out by SKA1-mid Band 5 (12.6 to 13.5 GHz), or even better by SKA1-mid Band 5+ (between 18.5 and 22 GHz), will be essential to provide reliable identifications of these lines thanks to the increasing frequency span between transitions at longer wavelengths, which prevents line blending and line confusion.

‘TARGETS’ OF OBSERVATIONS		
Type of observation (what defines a ‘target’)	x	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	1 pointing toward 1 object (the L1689B pre-stellar core)	
Positions of targets	alpha(J2000)=16:34:48.300, delta(J2000)=-24:38:04.000	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………..]
	X	NO
Time Critical?		YES [details: ……………………………………..]
	X	NO
Integration time per target (hrs)	~1000 hrs toward the L1689B pre-stellar core	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)	~0.1-0.2 mJy/beam for the lines between 12.6 and 13.5 GHz. These fluxes correspond to peak intensities of	

	~5-10 mK in a 12”-beam. If Band 5+ were available, the flux of the glycine lines between 18.5 and 22 GHz would range between 0.5 and 0.8 mJy/beam in a 12”-beam, making it easier the detection of this amino acid.
Expected polarised flux density (expressed as % of total)	None

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Glycine lines for Band 5 = 12613.2, 12912.9, 13253.9 and 13477.1 MHz. Glycine lines for Band 6 = 18860.2, 18918.1, 19972.7, 20365.4, 21724.4 and 21745.2 MHz Note that with Band 6 we could cover two more lines of glycine with only four 64 MHz wide windows
Total Bandwidth (MHz)	4 zoom windows x 64 MHz = 256 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	Band 5: Minimum frequency = 12581 MHz Maximum frequency = 13509 MHz Band 6: Minimum frequency = 18828 MHz Maximum frequency = 21777 MHz
Spectral resolution (kHz)	4 kHz, i.e. ~0.09 kms-1 at 13 GHz or ~0.05 kms-1 at 22 GHz.
Temporal resolution (in seconds)	Not required

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%

		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	~12 arcsec, which corresponds to few thousand AU scales, needed to image the expected extended emission of glycine and other COMs.
Maximum baseline required (km)	0.5 km for Band 5 or 0.3 km for Band 6
Mapped image size (degrees)	3-3.5 arcmin = 180-210" so that the full structure of the core is mapped from the densest parts to the outer envelope with Av < 3 mag (up to distances of ~30000 AU at 150 pc).
Required pixel resolution (arcseconds)	~4 arcsec
Number of image channels	4 x 16384, i.e. all channels available. This is needed to resolve the narrow lines (linewidths ~0.3-0.4 kms-1)
Channel width (kHz)	4 kHz. This corresponds to ~0.09 kms-1 at 13 GHz or ~0.05 kms-1 at 22 GHz.
Required rms (Jy per beam per channel) (if polarisation products required define for each)	At 13 GHz, the rms is expected to be ~85 uJy/beam within a 12"-beam across two channels (i.e. for a velocity resolution of ~0.2 kms-1). Since the sensitivity has dropped by 30% after rebaselining, this rms would not allow the detection of glycine.

	However, if the frequency coverage of Band 5 were extended up to 23 GHz (Band 6), the glycine lines between 18.5 and 22 GHz would be detected with S/N>5-9, assuming a similar noise level.	
Dynamic range within image per channel (if polarisation products required define for each)	100	
Absolute flux scale calibration		1-3%
		5%
	x	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Lines from other more abundant complex organic molecules (COMs) are expected to be detected simultaneously (note that methyl formate and dimethyl ether have already been detected toward the L1689B pre-stellar core; see Bacmann et al. 2012). Appropriate software will be needed to assist in the identification of all lines within the observations (see e.g. Weeds in CLASS and XCLASS in CASA; Comito et al. 2005; Maret et al. 2011). Since we require a high spectral resolution in this experiment to resolve the lines, the final images will need to be constructed with all channels available per window. This implies large data rates and large data cubes.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	

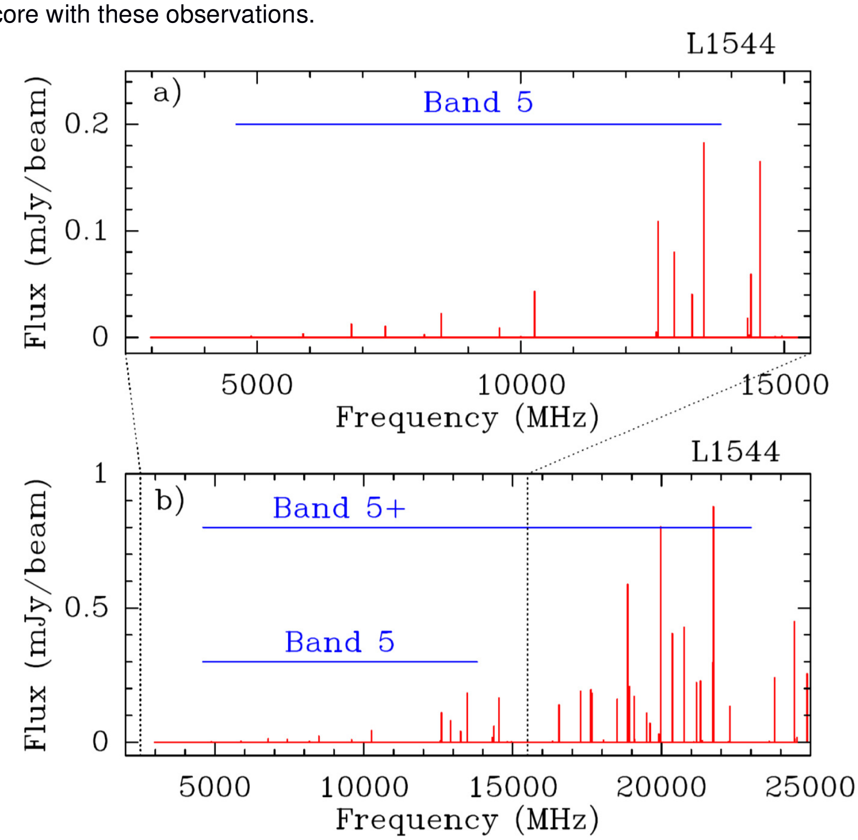
Data products	Individual datacubes centered at the frequency of every glycine line. Datacubes of every 64 MHz window will need to be obtained to check for the lines from other COMs that will be imaged simultaneously.
Description of pipeline	
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	At completion of the full project

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Collisional coefficients of glycine and other complex organic molecules with H2 or He will need to be calculated. As recently shown by Faure et al. (2014), some of these lines may form under non-LTE conditions and therefore, they may be affected by weak masing effects.

REFERENCES

Bacmann et al. (2012), A&A, 541,L12
Belloche et al. (2008), A&A, 482, 179
Belloche et al. (2013), A&A, 559, 47
Bernstein et al. (2002), Nature, 416, 401
Caselli et al. (2012), ApJ, 759, L37
Comito et al. (2005), ApJS, 156, 127
Faure et al. (2014), ApJ, 783, 72
Jimenez-Serra et al. (2014), ApJ, 787, L33
Maret et al. (2011), A&A, 526, 47
Munoz-Caro et al. (2002), Nature, 416, 403

We attach the predicted spectrum of glycine obtained for a low-mass pre-stellar core, L1544, for which its internal physical structure is well-constrained. The proposed target of this science use case (L1689B) has a similar physical structure to L1544, and therefore these results can be extrapolated to L1689B. The frequency range shown in the Figure cover the SKA Band 5 and Band 5+. The velocity resolution used in the simulations is ~0.2 kms-1. The physical and kinematic structure of the core is taken from Caselli et al. (2012). We assume a solid glycine abundance of 2E-8 on ices, i.e. of the same order as those derived in laboratory experiments of UV irradiated interstellar ice analogues (Munoz-Caro et al. 2002; Bernstein et al. 2002). We also consider that glycine is photo-desorbed (by secondary FUV photons) from ices together with water in pre-stellar cores. We assume a constant gas phase glycine abundance across the core of ~8E-11. This abundance is estimated by scaling down the solid abundance of glycine on ices by the fraction of solid water that has been FUV photo-desorbed in L1544. Our predictions are shown in the Figure below. We note that an abundance of ~8E-11 would be the lowest abundance of glycine that could be detected with this experiment. The expected linewidth of the glycine emission is ~0.3 kms-1. Other complex organics such as the precursors of the glycine chemistry – e.g. amino acetonitrile or methyl formate - are expected to be factors of ~100 more abundant than glycine (Belloche et al. 2008, 2013), and thus they will be readily detected in the L1689B pre-stellar core with these observations.



2.41 Determining the origin of dust and gas in a prototypical debris disk

PROJECT DETAILS	
Title	**Determining the origin of dust and gas in a prototypical debris disk**
Principal Investigator	**Asunción Fuente**
Co-Authors	**Pablo Riviére-Marichalar, Cristina García Miró and The Cradle of Life SWG**
Time Request	1500 hours

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	Band 2 (HI, OH), Band 4 (CH), Band 5b (Continuum, OH, CH)

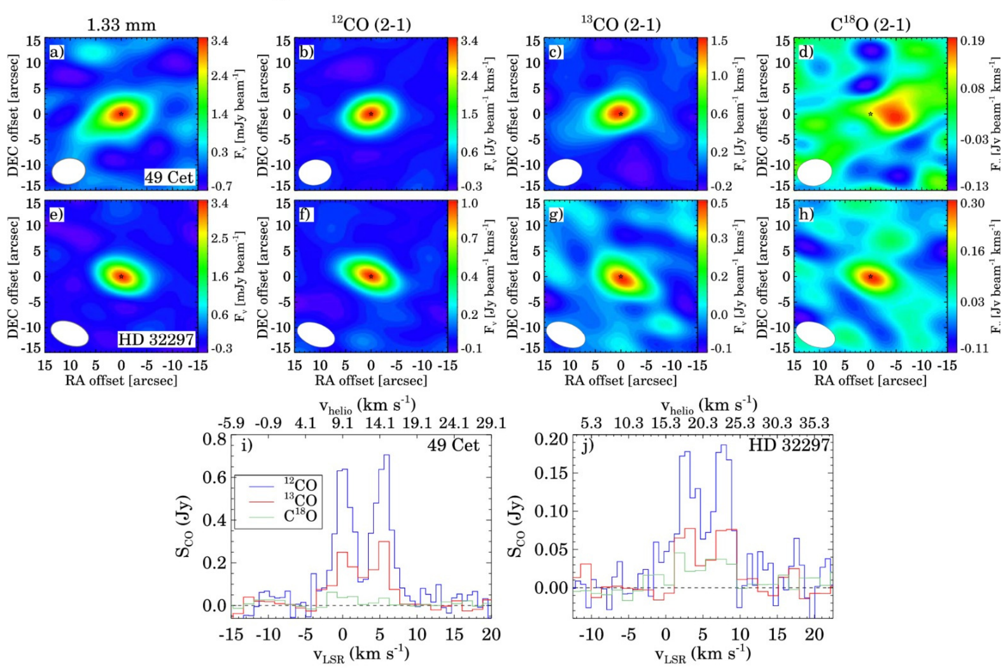
RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	500
	SKA1-MID Band 3	
	SKA1-MID Band 4	500
	SKA1-MID Band 5	500

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
x	Normal	Yes
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
The dust continuum emission would be measured using Band 5. Only atoms and simple molecules are expected to be detected in the gas-poor debris disks. We target the HI line at 21 cm to probe the atomic gas. Two different sets of lines are selected for OH and CH to probe warm and cold gas, respectively. We propose to use the OH lines at 1.6 GHz and the CH lines at 3.3 GHz to trace cold gas at a temperature <50 K. The warm gas at 150 K will be better traced with the higher excitation OH lines at 13.4 GHz and CH lines at 14.8 GHz.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX	x	Stokes I
X	YY		Stokes Q
X	XY		Stokes U
X	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Debris disks are tenuous dusty disks that differ from their predecessors in many ways. Dust grains in these disks are second generation. i.e., are formed by collisional grinding of previously formed planetesimals (Wyatt 2008, Krivov 20109). Recently, significant amount of gas has been detected in some young (typically 10– 40 Myr old) debris disks (Moór et al. 2017). The origin of the gas in these systems is debated. It has been suggested that these stars harbor hybrid disks where the dust has secondary origin while the gas is predominantly primordial, the remnant of the original disk. We propose to investigate the dust and gas properties of the prototypical young debris disk HD 32297, that has been recently imaged with ALMA in continuum emission at 1.3mm and CO, showing one of the highest CO-mass/dust-mass ratio (see Figure below, Moór et al. 2019). We propose to observe the continuum emission in Band 5 to characterize the dust properties. In addition, we will carry out spectroscopic observations to investigate the origin of the gas. The ratio between the HI mass and those of CH and OH are expected to be different in a primordial disk than in the gas produced by planetesimals collisions. Several lines of OH and CH will be observed in order to probe the cold and warm gas. HD 32297, as a specially gas-rich debris disk, can be used as a template for future debris disks observations that could be extend to a potencial sample of 12 debris disks with similar characteristics.



‘TARGETS’ OF OBSERVATIONS		
Type of observation	x	Individual pointings per object

(what defines a ‘target’)		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	HD32297 (template source). The project could be extended for a potential sample of 12 debris disks.	
Positions of targets	RA(J2000): 05:02:27.43 Dec(J2000): +07: 27:39.68	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………..]
	x	NO
Time Critical?		YES [details: ……………………………………..]
	x	NO
Integration time per target (hrs)	1500 hours in total towards one field of view.	
Average peak flux density (Jy or Jy per beam)	The estimated continuum flux in Band 5b is 2 microJy in a beam of 0.06”. Line intensities of 0.05 K in a 5” beam for Band 5b, ~0.5 K in a 5” beam for Band 4 and ~5 K in a 5” beam for Band 2.	
Range of peak flux densities (Jy or Jy per beam)		
Expected polarised flux density (expressed as % of total)		

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Band 5b centred at 12.5 GHz. We will use two 2.5 GHz spectral bands to cover the frequency ranges from 10 to 15 GHz for continuum studies. We will add two narrower zoom windows centred at 13.44 GHz and 14.76 GHz targeting the OH and CH lines. Band 4: one spectral window centred at 3.33 GHz Band 2: two spectral windows centred at 1.420 GHz and 1.667 GHz
Total Bandwidth (MHz)	Band 5b: 5 GHz for the continuum and two spectral windows of 100 MHz Band 4: 2380 MHz for continnum and one spectral window of 50 MHz Band 2: 810 MHz for continuum and two spectral windows of 25 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	Band 5b : Continuum : 10 GHz -15 GHz. Spw1: 13.4 GHz – 13.5 GHz Spw2: 14.7 GHz – 14.8 GHz Band 4 : Continuum: 2.8 GHz – 5.2 GHz Spw1: 3.30 GHz – 3.35 GHz Band 2 : Continuum: 0.95 GHz – 1.76 GHz Spw1: 1.654 GHz – 1.670 GHz Spw2: 1.407 GHz – 1.432 GHz
Spectral resolution (kHz)	Band 5b: 6 kHz for the spectral windows centred at the OH and CH lines. This spectral resolution provides a velocity resolution of ~0.13 km/s at 13.5 GHz, which allows to fully resolved the profile of the gaseous lines with typical linewidths of ~1 - 5 km/s Band 4: 3 kHz for the spectral windows, that provides a velocity resolution of ~0.37 km/s at 3.3 GHz Band 2: 1.5 kHz for the spectral windows that provides a velocity resolution of ~0.3 km/s at 1.5 GHz

Temporal resolution (in seconds)	Not required

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	Band 5b- continuum Range of angular resolution: 0.06"- 5"
Maximum baseline required (km)	~90 km

Mapped image size (degrees)	Band 5b: 0.1 degree (for single pointing)	
Required pixel resolution (arcseconds)	Band 5 : 0.01”	
Number of output channels	25 x 200 MHz wide channels covering full 5 GHz to derive spectral index maps using standard imaging mode resolution (13440 Hz).	
Output bandwidth (minimum and maximum frequency - MHz)	10 GHz – 15 GHz	
Required rms (Jy per beam) (if polarisation products required define for each)	Band 5: 0.1 microJy/beam to detect fluxes of 2 microJy/beam with S/N>10	
Dynamic range within image (if polarisation products required define for each)	~ 10^5	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	Band 5b: 0.06”- 5” Band 4: 0.5” - 5” Band 2: 0.5” - 5” 1 arcsec = 72 au
Maximum baseline required (km)	~90 km
Mapped image size (degrees)	Band 5b: 0.1 degree Band 4: 0.2 degree Band 2 : 1 degree
Required pixel resolution (arcseconds)	Band 5b: 0.01” Band 4: 0.1” Band 2: 0.1”
Number of image channels	16384

Channel width (kHz)	Band 5b : 6 kHz Band 4: 3 kHz Band 2: 1.5 kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	Band 5b: 30 microJy in a beam of 5" x 5" to detect lines of 0.05 K with S/N~5 around 13.5 GHz Band 4: 20 microJy in a beam of 5" x 5" around 3.3 GHz to detect lines of 0.5 K with S/N ~5. Band 2: 40 microJy in a beam of 5" x 5" around 1.5 GHz in a beam of 5"x 5" to detect lines of 5 K with S/N~5. The requested sensitivities will allow to detect the OH and CH lines assuming column densities of $\sim 10^{14}$ cm^{-2}. For comparison, the average N(CO) is $\sim 5x10^{17}$ cm^{-2}.	
Dynamic range within image per channel (if polarisation products required define for each)	$\sim 10^3$	
Absolute flux scale calibration		1-3%
		5%
	x	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	
Mapped image size (degrees)	
Number of image channels	
Channel width (kHz)	

Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	It is necessary to have the image of the whole of field of view in order to detect the presence of any other continuum and /or spectral emitting source in the field.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	High wind speed data should be flagged. Reprocessing will be needed to refine the calibration and interpretation. After regions with strong lines have been identified then line-free regions of continuum can be defined in order to better determine the spatial variation of the continuum spectral index.
Data products	Continuum image and spectral index map of the full disk with a spatial resolution of 5 au. Spectral data cubes of the OH and CH lines to probe the physical conditions and the chemistry of the gas.
Description of pipeline	TBC
Quality assessment plan & cadence	TBC

Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	At completion of the scheduling block and pipeline reduction.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

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2.42 **Technosignature Searches**

PROJECT DETAILS	
Title	Technosignature searches
Principal Investigator	S. Croft
Co-Authors	J. Tarter, M. Garrett, J. Lazio, C. Ng, I. Morrison, P. Zarka, A. Siemion, D. Price
Time Request	Commensal, plus 100 hours as primary user

FACILITY		Preconditions
X	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
X	SKA1-LOW	
X	SKA1-MID Band 1	
X	SKA1-MID Band 2	
X	SKA1-MID Band 3	
X	SKA1-MID Band 4	
X	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)	Details

	Normal	
	Fixed schedule (give cadence)	
X	Time-critical override	Occasional overrides to follow up candidates and / or targets of opportunity
	Custom Experiment	
X	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
This use case requires access to raw voltages and / or tied array voltage beams for commensal searches for technosignature candidates. A dedicated SETI backend requires access via multicast ethernet to appropriate signal spigots, before any RFI excision is performed. This backend will produce dynamic spectra at frequency resolutions as fine as 1 Hz, and time resolutions as fine as 1 second, for input to Doppler drift search algorithms. The raw data streams themselves could also be searched with non-beam-formed interferometric or visibility-based approaches. Searches can also be performed using image cubes, although these normally provide lower frequency resolution than is optimal, and are produced after RFI has been excised (potentially removing bona fide technosignatures). Small amounts of dedicated primary-user time would also be required for follow-up of interesting signals (either from SKA, or other telescopes) or for observations of targets of high interest. This would consist of additional beamformed observations and / or images where appropriate. Imaging parameters are not specifically listed below, but in general, high frequency resolution and good sensitivity are desirable. VLBI, where available, can help with signal localization and RFI rejection, as can techniques such as cyclostationary imaging.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (X) or CORRELATOR (_)*			
	XX	X	Stokes I
	YY	X	Stokes Q
	XY	X	Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Searches for technosignatures (indicators of technology developed by extraterrestrial life), otherwise known as SETI, are a key component of astrobiology, and complement the SKA's search for life's building blocks as part of the Cradle of Life science goal. Biosignature searches are generally only possible in a handful of nearby systems with current technologies, whereas some kinds of technosignatures are detectable to much larger distances. Detecting technosignatures has implications for a fundamental biological question, as it would demonstrate that the transition from single-celled life to complex organisms is not unique to the Earth, whereas if biosignature searches succeed, but technosignature searches fail, it would suggest that technological life is rare. Technosignature searches have been deployed on SKA precursors and pathfinders (including MWA and MeerKAT), and the technology and techniques used can inform their execution on SKA. Searches can largely be performed commensally, without impacting other users of the telescope. Signal detection algorithms running in real time on dedicated hardware can trigger voltage dumps of signals of interest. As outlined (Siemion et al. 2015) in the SKA Science Book, the SKA has the potential to place some of the most stringent limits to date (comparable to Earth-like civilizations on planets around nearby stars) on the prevalence of technosignatures.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	X	Individual pointings per object
	X	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
	X	Non-imaging pointings
Number of targets	Many	
Positions of targets	All available sky	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………..]
	X	NO (usually, although some targets are not sidereal)
Time Critical?		YES [details: ……………………………………..]
	X	NO (usually commensal, occasional overrides)
Integration time per target (hrs)	0.1 - 1	

Average peak flux density (Jy or Jy per beam)	From sensitivity limit to ~Jy
Range of peak flux densities (Jy or Jy per beam)	From sensitivity limit to ~Jy
Expected polarised flux density (expressed as % of total)	0 – 100%

OBSERVATIONAL SETUP : *BEAMFORMER (X) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Should cover full band in one setting
Total Bandwidth (MHz)	Maximum available
Minimum and maximum frequency over the entire range of the setup (MHz)	Full range
Spectral resolution (kHz)	0.001 (achieved by performing FFT with dedicated SETI search hardware)
Temporal resolution (in seconds)	1

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	Smaller beams desirable for stellar targets, larger for tiling extended objects
Maximum baseline required (km)	Varies
Primary beam size (sq degrees)	Default
Number of output channels	Billions (few Hz resolution required) – implemented in commensal SETI hardware
Output bandwidth (minimum and maximum frequency - MHz)	Full available band
Required rms (Jy) (if polarisation products required define for each)	Best available, but, because of generally commensal nature, set by parameters of “parent observation”
Dynamic range (if polarisation products required	Best available, but, because of generally commensal nature, set by parameters of “parent observation”

define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
	X	20-50% (or better)
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	n/a	
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	See "comments on observing strategy" above.	
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	See "comments on observing strategy" above.
Mapped image size (degrees)	
Number of image channels	
Channel width (kHz)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	
Dynamic range within image per channel	

(if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Searches require access to raw voltage data, critically before RFI excision is performed. Voltages should be multicast and then ingested by dedicated hardware that performs searches for signals of interest. Searches for narrow-band signals and broad-band pulses, as well as other anomalies will be performed. RFI rejection can be accomplished by comparison with other beams. Voltage dumps are triggered for signals of interest.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Critical that data is *not* flagged for RFI before delivery to the technosignature search pipeline.
Data products	Beamformed raw voltages, and dynamic spectra with frequency resolution of a few hertz, will be produced by the SETI backend. Approximately 1 PB per year of data on signals of interest will be added to the archive.
Description of pipeline	Raw voltages are delivered as multicast packets over ethernet to GPU-accelerated compute servers (e.g. as described by MacMahon et al. 2018) that perform detection in the raw voltage data, and / or FFT to generate spectrograms that are searched for

	narrowband Doppler-drifting signals, pulses, or other anomalies. Existing pipelines are in use at a variety of radio telescopes including MWA and MeerKAT, and will be further developed and expanded for SKA.
Quality assessment plan & cadence	No known technosignatures are available as test signals, but a variety of proxies (particularly pulsars and deep space probes) can be used to test pipelines end-to-end, in addition to artificial signal injection and recovery.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Data should be delivered to a dedicated SETI backend in near-real-time. Subsets of the data around signals of interest should be delivered to the archive as soon as practicable.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Access to the raw voltages, before flagging, is essential for technosignature searches.

REFERENCES
Lebofsky, M., et al. 2019, *The Breakthrough Listen Search for Intelligent Life: Public Data, Formats, Reduction, and Archiving*, PASP, 131, 124505 MacMahon, D. H. E., et al. 2018, *The Breakthrough Listen Search for Intelligent Life: A Wideband Data Recorder System for the Robert C. Byrd Green Bank Telescope*, PASP, 130, 044502 Siemion, A. et al. 2015, *Searching for Extraterrestrial Intelligence with the Square Kilometre Array,* PoS (AASKA14) 116

2.43 Commensal Core-Collapse Supernova searches with the SKA

PROJECT DETAILS	
Title	Commensal Core-Collapse Supernova searches with the SKA
Principal Investigator	M.A. Pérez-Torres (IAA-CSIC)
Co-Authors	A.Alberdi (IAA-CSIC), R.J. Beswick, P. Lundquist, R. Herrero-Illana, C. Romero-Cañizales, S. Ryder, M. della Valle, J. Conway, J.M. Marcaide, S. Mattila, T. Murphy, E. Ros
Time Request	

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	1000 sq. deg, rms=1.6 uJy/b per epoch (assumes 0.6 hr net time per epoch), 1.0 GHz nominal freq.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
X	SKA1-MID Band 2	~4700 hr (after 2 yr)
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	Commensal observations with the Radio Continuum surveys. Total area: 1000 sq deg; single pointing FoV: 1.4 sq deg Angular resolution: 0.8 arcsec Sensitivity: 1.6 uJy/b per epoch (assumes 0.6 hr net time) 715 pointings to cover 1000 sq deg Total time: ~4700 hr
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
These observations will be commensal with the radio continuum surveys. Given the proposed surveys, the one that best fits our needs is a relatively deep survey (1.6 uJy/b per epoch) of 1000 sq. deg with SPF1. This is mainly due to the expected number of visits (11), which is realistically to carry out within one, or two years, as the total net time is ~4700 hr (or about 7800 hr, which is close to the total number of available hours for useful SKA time within one year). Although our preferred observing frequency would be 1.7 GHz, this project can be easily accommodated at 1.0 GHz, as the number of visits warrants a very good monitoring of each region of the sky imaged by the survey. This fact is a winning factor over strategies that only consider 1, or 3 visits at most of the same pointing field.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	X	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Optical searches of Core Collapse Supernovae (CCSN) miss a significant fraction of them due to dust obscuration; CCSN radio searches are thus more promising for yielding the complete, unobscured star-formation rates in the local universe. The SKA yields the possibility to piggyback for free in this area of research by carrying out commensal, widefield, blind transient survey observations. SKA1 should be able to (blindly) discover several hundreds of CCSNe in just one year. SKA, with an expected sensitivity ten times that of SKA1, is expected to detect CCSNe in the local Universe by the thousands. Therefore, commensal SKA observations could easily result in an essentially complete census of all CCSNe in the local universe, thus yielding an accurate determination of the volumetric CCSN rate. In addition, some specific, relevant questions that will be tackled by those observations include the following: i) Unveiling the hidden CCSN population and the true volumetric CCSN rate in

the local universe; ii) Probing the SN-CSM interaction for all CCSN types, from the relatively faint Type IIP to the extremely radio bright Type IIn SNe; iii) Bridging the gap between Type Ibc SNe and (long) Gamma-ray bursts; iv) Typing CCSNe from their radio behaviour. A systematic monitoring could permit us to type CCSNe from their radio light curves; v) Correlating optical and radio properties. This will be possible by, e.g., making a combined, commensal use of wide-field surveys programmed at radio wavelengths with SKA, and at optical wavelengths with, e.g., the LSST or similar telescopes. The most interesting cases will be subject of targeted, monitoring observations with these and other facilities.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	Our targets are CCSNe; our expectations based on the SKA1-MID sensitivity numbers is that over 600 CCSNe will be detected in just the 1st year of observations. After 2 years, assuming that's the time to complete the survey, this number will be double, reaching a booming >= 1200 CCSNe.	
Positions of targets	Commensal	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	0.6 hr per visit, as programmed for the deep continuum survey of 1000 sq. deg.	
Average peak flux density (Jy or Jy per beam)	It depends on the supernova type and its distance. With SKA1-MID, SN Ib/c (peak luminosity 20×10^{26} erg/s/Hz) can be detected above 5 sigma up to 457 Mpc; SN IIb/IIL (peak luminosity 0.5×10^{26} erg/s/Hz) up to 323 Mpc; SN IIP (peak luminosity 100×10^{26} erg/s/Hz) up to 72 Mpc; SN IIn up to 1022 Mpc.	
Range of peak flux densities (Jy or Jy per beam)	From tens of μJy/b to mJy/b.	
Expected polarised flux density (expressed as % of total)		

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1,000
Total Bandwidth (MHz)	500 MHz

Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	Does not apply
Temporal resolution (in seconds)	Does not apply

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)	Does not apply	
Maximum baseline required (km)	150 Km	
Primary beam size (sq degrees)	FoV of 1.4 deg^2.	
Number of output channels	Standard	
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)	1.6 uJy/ per visit, as per programmed survey	
Dynamic range (if polarisation products required define for each)	>= 5 to ascertain variability with respect to proceeding epochs.	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	
Required rms (Jy per beam) (if polarisation	

products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	
Mapped image size (degrees)	
Number of image channels	
Channel width (kHz)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	
Dynamic range within image per channel	

(if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Requires well established policies on commensality. A research program on the study of nearby galaxies (local U/LIRGs) is a clear program for commensal observations. Any radio survey with a good angular resolution (~0.8 arcsec) and covering a large field of view (>= 1000 deg^2) is appropriate for the project. The high angular resolution is required in order to resolve out most of the background galaxy luminosity and detect the supernova events.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	The data should be stored for comparison among the different visits to each field.
Data products	Standard SKA1-MID interferometer data. The area covered by the observations after one year is of the order of 1000 deg^2
Description of pipeline	Real-time Imaging pipeline results of the SKA1-mid interferometer data. Once the first images for each field have been obtained, a check of the image in the next visits is required in order to identify new compact sources. A kind of automatic comparison of the images should we established in order to produce an alert message.
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	We are contemplating ≥5 visits to each field within a year. The data should be available on the archive until all the visits have been performed and the data have already been compared.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
A combined, commensal use of wide-field surveys programmed at radio wavelengths with SKA, and at optical wavelengths with, e.g., the LSST or similar telescopes can be considered.

REFERENCES
Perez-Torres, M. A., Romero-Cañizales, C., Alberdi, A., & Polatidis, A. 2009, A&A, 507, L17 Perez-Torres, M. A., Alberdi, A., Romero-Canizales, C., & Bondi, M. 2010, A&A, 519, L5 Perez-Torres, M. A., Alberdi, A., Beswick, R. et al. 2015, in PoS(AASKA14)060 Perez-Torres, M. A., Alberdi, A., Herrero-Illana, R. et al. 2015, in Spanish SKA White Book" arXiv:1506.03474

2.44 **An OH maser search in the Magellanic Clouds**

PROJECT DETAILS	
Title	**An OH maser search in the Magellanic Clouds**
Principal Investigator	**Sandra Etoka**
Co-Authors	**ExtraGalactic Spectral Line Science Working Group**
Time Request	2500 hours

FACILITY		Preconditions
	SKA1-LOW	

X	SKA1-MID	
	SKA1-SURVEY	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
X	SKA1-MID Band 2	2500
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	
	SKA1-SURVEY Band 1	
	SKA1-SURVEY Band 2	
	SKA1-SURVEY Band 3	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Mosaic observations of the 80 deg^2 covering the Small and Large Magellanic clouds in the 4 ground-states OH maser lines down to a sensitivity of 0.1 mJy with a bandwidth covering a LSR velocity range of -450 to +450 km/s. Since it is a search for (faint) maser emission, a coarse velocity resolution of 3.9 kHz per channel (i.e. ~0.7 km/s) is used to favour sensitivity. Follow up observations of positive detections would then be done with a channel resolution 10 times finer, to enable source identification and confirmation. This can be done in a commensal way thanks to Spectral Zoom windows.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	**X**	Stokes Q
	XY	**X**	Stokes U
	YX	**X**	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Ground-state OH maser emission is commonly found in regions were stars are born as well as towards evolved stars. Evolved stars are generally strongest in the 1612-MHz satellite line. While the 4 lines can be observed towards star forming regions, the mainlines at 1665 & 1667 MHz are the most commonly observed. The study of this maser emission has many applications, including the determination of magnetic field strengths from polarisation measurements, studies of stellar kinematics using the precisely determined radial velocities, and distance determinations from VLBI astrometry. Only a small number of maser sources with luminosities similar to their Galactic analogues are known outside the Milky Way. Late-type star evolution and the star formation process may differ in galaxies with other metallicity environments. Due to their proximity, the Magellanic Clouds with their low-metallicity environment are the first galaxies to address. A complete unbiased search of the maser population in the Local Group will provide a tool to study these differences.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings

Number of targets	18 FoVs to cover the LMC and SMC combined	
Positions of targets	Magellanic Clouds	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	14.25 hours (to reach a sensitivity of 0.1 mJy per channel)	
Average peak flux density (Jy per beam)		
Range of peak flux densities (Jy per beam)		
Expected polarised flux density (expressed as % of total)		

OBSERVATIONAL SETUP : *BEAMFORMER (X) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	These observations require 3 Spectral windows (SpWs) to observe the 4 ground-state OH maser lines. One centred at 1612.231 [SpW1], one centred at 1666.4 for the 1665.402 & 1667.359 lines [SpW2] and one at 1720.530 MHz [SpW3].
Total Bandwidth (MHz)	8 MHz per spectral window
Spectral resolution (kHz)	3.9 kHz (i.e., ~0.7 km/s)
Temporal resolution ('dump' time in s or 'standard')	standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Absolute flux scale calibration		1-3%

		5%
		10%
		20-50%
	X	n/a

IMAGING CONSIDERATIONS (continuum – single channel of full bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Single Field-Of-View or mapped image size (degrees)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	X	n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	0.3 arcsec
Single Field-Of-View or mapped image size (degrees)	The entire FoV (0.49 deg^2) per mosaic
Number of image channels	2048 channels for each of the 3 Spectral Zoom Window
Channel width (kHz)	3.9 kHz

Required rms (Jy per beam per channel) (if polarisation products required define for each)	0.1 mJy	
Dynamic range within image per channel (if polarisation products required define for each)	1000	
Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Single Field-Of-View or mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	X	n/a

DATA ANALYSIS	
Procedures required	Spectral line & wide-field calibrations

Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Flag data for antennas off-source GPS data will be useful for atmospheric calibration
Data products	Spectral line data cubes in full Stokes
Description of pipeline	
Quality assessment plan & cadence	

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Need spectral Zoom mode (ECP approved)

REFERENCES
Etoka, S., et al. 2015, AASKA14, 125, "OH masers in the Milky Way and Local Group galaxies in the SKA era"

2.45 Radio Recombination Lines and Star Formation

PROJECT DETAILS	
Title	**Radio Recombination Lines and Star Formation**
Principal Investigator	**Pamela Klaassen**
Co-Authors	**Our Galaxy SWG**
Time Request	

FACILITY		Preconditions
	SKA1-LOW	
x	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
x	SKA1-MID Band 5	2000

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
x	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Mosaiced observations in each band covering a 1-2 deg strip along the observable Galactic plane (@ 10 arcsec resolution to ensure detection of new sources without worrying about beam dilution). 200 sq.deg: 740 hrs to 0.1 K sensitivity at 10arcsec (5GHz) at a spectral resolution of 1 km/s Followup on detections at < 1 arcsec (ideally 0.1arcsec) to resolve even the smallest (youngest) HII regions Per pointing: 750 hrs to 0.2 K sensitivity at 1 arcsec (5 GHz) at a spectral resolution of 5 km/s. do this for two key targets to start (in-depth study of more regions with SKA2) From line free channels, spectral energy distributions of the HII regions can be derived.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**x**	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
All of the star forming HII regions in our Galaxy (out to 20 kpc, at a luminosity threshold of 10^4 L_sun) are known from the RMS survey (Lumsden et al. 2013). Most even the densest HII regions become optically thin at frequencies greater than 5 GHz, at which point RRLs become detectable. Observing RRLs from ~H110a to ~H60a probes a wide range of physical parameters within star forming HII regions. With detections of multiple lines, we can accurately quantify: 1) electron temperature 2) electron density 3) electron pressure (from collisional broadening) 4) emission measure at a variety of optical depths (since it only takes a subset of lines to measure these quantities). This gives the 3D internal structure of HII regions. This then tells us about what kinds powering sources are responsible for the HII regions, their sizes and distributions within the HII region (in combination with modelling of the derived density, temperature, etc. gradients within the HII region).

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	x	Individual pointings per object
	x	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	<100	
Positions of targets	Galactic Plane	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ………………………………………..]
	x	NO
Time Critical?		YES [details: ………………………………………..]
	x	NO
Integration time per target (hrs)		

Average peak flux density (Jy or Jy per beam)	
Range of peak flux densities (Jy or Jy per beam)	
Expected polarised flux density (expressed as % of total)	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (X_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Band centre
Total Bandwidth (MHz)	Full band
Minimum and maximum frequency over the entire range of the setup (MHz)	Full band
Spectral resolution (kHz)	16-83 kHz (1 km/s)
Temporal resolution (in seconds)	N/A

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	
Maximum baseline required (km)	
Primary beam size (sq degrees)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	
Required rms (Jy) (if polarisation products required define for each)	
Dynamic range (if polarisation products required define for each)	

Absolute flux scale calibration		1-3%
	x	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a ‘support image’ in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	See spectral considerations	
Maximum baseline required (km)	See spectral considerations	
Mapped image size (degrees)	See spectral considerations	
Required pixel resolution (arcseconds)	See spectral considerations	
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	0.166 arcmin (10arcsec) 0.1 arcmin (< 1arcsec)	
Maximum baseline required (km)	15 km @ 5 GHz, 3 km @ 25 GHz	
Mapped image size (degrees)	200	
Required pixel resolution (arcseconds)	< 1arcsec (for spatial zooms)	
Number of image channels		
Channel width (kHz)	16 kHz @ 5 GHz, 83 kHz @ 25 GHz (1 km/s)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	6uJy @ 5 GHz, 0.16 mJy @ 25 GHz (1 K km/s)	
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
	x	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	
Mapped image size (degrees)	
Number of image channels	
Channel width (kHz)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	

Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	
Description of pipeline	
Quality assessment plan & cadence	
Latency (Desired time lag	Upon completion of scheduling block and pipeline

between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	reduction

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES
Lumsden et al. 2013ApJS 208 11L

2.46 The physics of the CNM through low-frequency Radio Recombination Lines

PROJECT DETAILS	
Title	The physics of the CNM through low-frequency Radio Recombination Lines
Principal Investigator	J. B. R. Oonk
Co-Authors	Our Galaxy SWG
Time Request	1000

FACILITY	Preconditions	
X	SKA1-LOW	Observing and resolving Radio Recombination Lines (RRL) associated with cold CNM gas in the Milky Way requires zoom windows with spectral resolutions varying from about 0.5 to 2 kHz
	SKA1-MID	

RECEIVER(S) REQUIRED	Time (hrs)	
x	SKA1-LOW	1000
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)	Details	
x	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
60-350 MHz observations to cover 420 deg2 of the inner Galactic Plane (b+-2 deg, l=300-40 deg) visible from SKA-LOW, 64 deg2 of the Large Magellanic Cloud and 16 deg2 of the Small Magellanic Cloud. Approximately 8 hours of integration time per field would result in a 5 sigma peak spectral line sensitivity of 0.1-1 K in a 1 kHz channel with a 3 arcmin beam. This spectral line sensitivity is sufficient to detect carbon radio recombination lines (CRRL), stacked in sets of 9 lines, on 3 arcmin scales. In addition we will also be able to detect the corresponding hydrogen radio recombination lines (HRRL) that are always redshifted by 150 km/s as compared to the corresponding carbon line. The full SKA-LOW frequency range contains 243 alpha lines and 306 beta lines from carbon, and the same amount from hydrogen, for a redshift z=0. Observing a large span in frequency is necessary to constrain the CRRL emission models (e.g. Oonk et al. 2015 PoS(AASKA14)139). To to this end, and to spectrally resolve the CRRL line profiles associated with the coldest clouds, we aim to observe with 4 spectral windows, each having 16384 channels, centered at 332 MHz (32 MHz bandwidth), 142 MHz (16 MHz bandwidth), 96 MHz (8 MHz bandwidth) and 64 MHz (8 MHz bandwidth). This will allow us to obtain at least 5 alpha line stacks (each containing between 9 and 14 lines) and 5 beta line stacks (each containing between 11 and 18 lines). A beamformer for SKA1-LOW would be highly desirable as the Galactic plane and Magellanic Clouds RRL survey time in the current design is completely dominated by the small beam at the higher frequency part of the band. Conducting the survey in limited frequency chunks with more beams could reduce the total survey time by at least a factor 2.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX	X	Stokes I
X	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The SKA will transform our understanding of the role of the cold, atomic gas in galaxy evolution. The interstellar medium (ISM) is the repository of stellar ejecta and the birthsite of new stars and, hence, a key factor in the evolution of galaxies over cosmic time. Cold, diffuse, atomic clouds are a key component of the ISM, but so far this phase has been difficult to study, because its main tracer, the HI 21 cm line, does not constrain the basic physical information of the gas (e.g., temperature, density) well. The SKA opens up the opportunity to study this component of the ISM through a complementary tracer in the form of low-frequency carbon radio recombination lines (CRRL). These CRRLs provide a sensitive probe of the physical conditions in cold, diffuse clouds. The SKA allows for efficient surveys of the sky, that will revolutionize the field of low-frequency recombination line studies. By observing these lines we will be able determine the thermal balance, chemical enrichment, and ionization rate of the cold, atomic medium from degree-scales down to scales corresponding to individual clouds and filaments in our Galaxy and the Magellanic Clouds (e.g. Oonk et al. 2015 PoS(AASKA14)139). Here we focus solely on the CRRL spectroscopic case. However, in addition the proposed observations will also be valuable for studies of free-free absorption (continuum imaging) and magnetic fields (if additional polarisation products are included) neither of which we will treat here.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	X	Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	Galactic Plane: 210 (limited by the 332 MHz beam).	

	Magellanic Clouds: 40 (limited by the 332 MHz beam).	
Positions of targets	Galactic Plane: evenly spaced along the mid-Plane. Magellanic Clouds: 4x4 and 8x8 deg2 mosaics	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	8	
Average peak flux density (Jy or Jy per beam)	See below	
Range of peak flux densities (Jy or Jy per beam)	There will be a high dynamic range in flux density of objects along the Plane from very diffuse, low-level extended continuum emission to compact HII regions and bright supernova remnants. The continuum flux densities range from about 1 Jy to about 1000 Jy per beam.	
Expected polarised flux density (expressed as % of total)	The RRL line emission is not expected to be highly polarized, although the underlying continuum emission can be.	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	332, 142, 96 and 64 MHz.
Total Bandwidth (MHz)	32+16+8+8 = 64 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	60 (minimum) 350 (maximum) MHz
Spectral resolution (kHz)	1.95, 0.98, 0.49 and 049 kHz
Temporal resolution (in seconds)	N/A

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a ‘support image’ in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	

Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	1.5-10
Maximum baseline required (km)	2
Mapped image size (degrees)	>2 (depends on frequency)
Required pixel resolution (arcseconds)	20
Number of image channels	16384, 16384, 16384, 16384
Channel width (kHz)	1.95, 0.98, 0.49 and 0.49 kHz
Required rms (Jy per beam per channel) (if polarisation products	See below

required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)	The spectral dynamic range, i.e. the variation from channel image to channel image for a flat source should be better than 1e-4 in optical depth. I.e. for a source with 10 Jy/beam this corresponds to 1 mJy/beam.	
Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	We need to calibrate the continuum and reach high dynamic range against bright sources in the fields, the full primary beam will need to be imaged. The RRLs will be observed in 4 zoom windows centered around 332, 142, 96 and 64 MHz. The full frequency range within these zoom windows needs to be processed at the native resolution.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Need to be able to process (or reprocess) line and continuum data with different setups: to improve brightness temperature sensitivity for extended versus compact sources.
Data products	Recombination lines cubes (which could be extracted around the different lines) and associated continuum maps at a variety of frequencies.
Description of pipeline	Flagging, averaging, bandpass and amplitude calibration. Continuum (self-)calibration and creation of continuum images for each of the 4 zoom windows. Transfer of the continuum calibration to the line data followed by line imaging and line cube creation.
Quality assessment plan & cadence	Step1: Continuum data can be used to assess ionospheric conditions and imaging data quality. Step 2: Spectral RMS and dynamic range of spectra can be used to assess spectral data quality. Given the dynamic sky at low frequencies automatic quality assessment will need to be carried out for each observation.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of scheduling block and pipeline reduction.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
1) The exact frequency setup for the zoom windows may be refined at a later stage. This will likely also depend on the results from the ongoing LOFAR-CRRL survey (PI: Oonk). 2) Given the large change in the size of the station beam with frequency for SKA-LOW, a beamformer would be highly desirable, as it will allow us to decrease the required observing time for this project by observing with multiple beams in smaller frequency chunks. For an effective survey one should aim for bandwidth/central_frequency < 2. This would reduce the survey time by at least factor 2. 3) More flexibility in the zoom windows would allow for a much better sampling of CRRLs as a function of quantum number (or equivalently frequency). In particular using many more, but much narrower contiguous spectral windows with similar channel widths (i.e. 0.5-1.95 kHz) in frequency would allow for a much better selection of CRRLs as a function of frequency and we would also be able to select many more CRRLs for the same total number of channels (or equivalently bandwidth).

REFERENCES
1) Oonk et al. 2015 PoS(AASKA14)139

2.47 Probing the physical conditions of the CNM in galaxies through low-frequency radio recombination lines

PROJECT DETAILS	
Title	Probing the physical conditions of the CNM in galaxies through low-frequency Radio Recombination Lines
Principal Investigator	J. B. R. Oonk
Co-Authors	Extragalactic (non-HI) Spectroscopy SWG

Time Request	2 yrs (as part of a continuum survey)

FACILITY	Preconditions	
x	SKA1-LOW	A full 2 pi steradian survey, with 8 hr pointings, of the 50-350 MHz sky visible from SKA-LOW is only feasible (time-wise) if a beamformer becomes part of the design.
	SKA1-MID	

RECEIVER(S) REQUIRED	Time (hrs)	
x	SKA1-LOW	17500 (2yrs)
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)	Details	
x	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
x	Commensal	**part of continuum survey**

	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
50-350 MHz observations to cover the 2 pi steradian sky visible from SKA-LOW. Approximately 8 hours of integration time per field would result in a 5 sigma point source sensitivity of 0.2 to 2 mJy/beam in a 30 km/s channel with a 3 arcmin beam. This spectral line sensitivity is sufficient to detect carbon radio recombination lines (CRRL), stacked in sets of 9 lines, from extragalactic sources with a flux density above 0.2 to 2 Jy/beam (depending on frequency). In addition we will also be able to detect the corresponding hydrogen radio recombination lines (HRRL) that are always redshifted by 150 km/s as compared to the corresponding carbon line. Spectral zoom windows are not required for extragalactic CRRL observations as turbulent broadening of the gas, within a spatial resolution element for SKA-LOW, will in most cases be large enough that the line emission will not be diluted along the spectral axis when observing a full 300 MHz window with 4.58 kHz resolution. It is important to observe a large contiguous bandwidth, to (i) enable a redshift independent search for the lines and (ii) constrain the CRRL emission models (e.g. Oonk et al. 2015 PoS(AASKA14)139). The full SKA-LOW frequency range contains 243 alpha lines from carbon, and the same amount from hydrogen, for a redshift z=0. For a redshift z=2 the number of alpha lines decreases from 243 to 168. This extragalactic RRL survey would be a natural product of a 2 pi steradian, deep, wide-band, continuum survey, as it does not require special spectral setups. A beamformer for SKA1-LOW would be highly desirable as the extragalactic RRL survey time in the current design is completely dominated by the small beam at the higher frequency part of the band. Conducting the survey in limited frequency chunks with more beams could reduce the total survey time by at least a factor 2.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
x	XX	**X**	Stokes I
x	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The SKA will transform our understanding of the role of the cold, atomic gas in galaxy evolution. The interstellar medium (ISM) is the repository of stellar ejecta and the birthsite of new stars and, hence, a key factor in the evolution of galaxies over cosmic time. Cold, diffuse, atomic clouds are a key component of the ISM, but so far this phase has been difficult to study, because its main tracer, the HI 21 cm line, does not constrain the basic physical information of the gas (e.g., temperature, density) well. The SKA opens up the opportunity to study this component of the ISM through a complementary tracer in the form of low-frequency carbon radio recombination lines (CRRL). These CRRLs provide a sensitive probe of the physical conditions in cold, diffuse clouds. The SKA allows for efficient surveys of the sky, that will revolutionize the field of low-frequency recombination line studies. By observing these lines we will be able determine the thermal balance, chemical enrichment, and ionization rate of the cold, atomic medium. A 2 pi steradian survey, consisting of 8 hr pointings, would enable us to search and detect CRRLs in up to 1e5 galaxies, spanning a redshift range from z=0 to 5. Additionally we will be able to spatially resolve these CRRL, on arcmin scales, in up to 100 nearby galaxies (e.g. Oonk et al. 2015 PoS(AASKA14)139).

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
	X	Maps through multiple fields of view
		Non-imaging pointings
Number of targets	<5000 (depends on availability of beamformer)	
Positions of targets	2 pi steradian survey (mosaic)	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	8	

Average peak flux density (Jy or Jy per beam)	See below
Range of peak flux densities (Jy or Jy per beam)	There will be a high dynamic range in flux densities for objects within large fields of view. In our case we are only interested in objects with a flux density greater than 0.1 Jy at 350 MHz. So the range of interest is from 0.1 to about 1000 Jy.
Expected polarised flux density (expressed as % of total)	The RRL line emission is not expected to be highly polarized, although the underlying continuum emission can be.

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	200
Total Bandwidth (MHz)	300
Minimum and maximum frequency over the entire range of the setup (MHz)	50 (minimum) 350 (maximum) MHz
Spectral resolution (kHz)	4.58
Temporal resolution (in seconds)	N/A

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	
Maximum baseline required (km)	
Primary beam size (sq degrees)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	
Required rms (Jy) (if polarisation products required define for each)	

Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%

		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)			
Required angular resolution (arcmin) (single value or range)	1.5-10		
Maximum baseline required (km)	2		
Mapped image size (degrees)	>2		
Required pixel resolution (arcseconds)	20		
Number of image channels	65536		
Channel width (kHz)	4.58		
Required rms (Jy per beam per channel) (if polarisation products required define for each)	See below		
Dynamic range within image per channel (if polarisation products required define for each)	The spectral dynamic range, i.e. the variation from channel image to channel image for a flat source should be better than 1e-4 in optical depth. I.e. for a source with 10 Jy/beam this corresponds to 1 mJy/beam.		
Absolute flux scale calibration		1-3%	
		5%	
	X	10%	
		20-50%	
		n/a	

IMAGING CONSIDERATIONS (VLBI)

Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	We need to calibrate the continuum and reach high dynamic range against bright sources in the fields, the full primary beam will need to be imaged. The RRLs will then be searched for by a cross-correlation techniques. The full frequency range needs to be processed at the native resolution.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	For nearby galaxies we need to be able to process (or reprocess) line and continuum data with different setups: to improve surface brightness sensitivity for extended versus compact structures.

Data products	Recombination lines cubes (which could be extracted around the different lines) and associated continuum maps at a variety of frequencies.
Description of pipeline	Flagging, averaging, bandpass and amplitude calibration. Continuum (self-)calibration and creation of continuum images. Transfer of the continuum calibration to the line data followed by line imaging and line cube creation.
Quality assessment plan & cadence	Step1: Continuum data can be used to assess ionospheric conditions and imaging data quality. Step 2: Spectral RMS and dynamic range of spectra can be used to assess spectral data quality. Given the dynamic sky at low frequencies automatic quality assessment will need to be carried out for each observation.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of scheduling block and pipeline reduction.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
1) Given the large change in the size of the station beam with frequency for SKA-LOW, a beamformer would be highly desirable, as it will allow us to decrease the required observing time for this project by observing with multiple beams in smaller frequency chunks. For an effective survey one should aim for bandwidth/central_frequency < 2. This would reduce the survey time by at least factor 2. 2) A low frequency spectroscopic survey of RRLs in extragalactic sources does not require long baselines and is not confusion limited for long exposures with only the core. However, continuum calibration at low frequencies, a necessary step before line imaging can be done, may require baselines beyond the core SKA-LOW. Experience obtained with SKA pathfinders and precursors together with the SKA-LOW design after rebaselining is complete will have be taken into account to assess this.

3) From a scientific point, if sufficient sensitivity is available on baselines >2km in the final design of SKA-LOW then it will be very exciting to be able to localize the CRRLs in extragalactic sources on sub-arcmin scales. This will have to be investigated once the rebaselining process has finished. 4) For a 50-350 MHz, 2 pi steradian, survey of the SKA-LOW sky, with 8 hr pointings, to be carried out over a time span of about 2 yrs a beamformer we have assumed that a beamformer with at least 3 simultaneous beams will be available and that the full survey will be done in atleast three sub-surveys with each covering 100 MHz bandwidth (50-150, 150-250,250-350 MHz).

REFERENCES
1) Oonk et al. 2015 PoS(AASKA14)139

2.48 Survey of star-formation and accretion activities in nearby galaxies

PROJECT DETAILS	
Title	**Survey of star-formation and accretion activities in nearby galaxies**
Principal Investigator	**R.Beswick**
Co-Authors	**E. Brinks, M. Perez-Torres, A. Richards, S. Aalto, A. Alberdi et al (on behalf of ex-gal continuum SWG)**
Time Request	1.5hrs per target per band ~2 to 3 band/freqs, few 100-1000 sources Total = ~3000-4500 (TBC) – some fraction to be commensal

FACILITY		Preconditions
	SKA1-LOW	

X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
X	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
X	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	**Some elements are likely to be observed commensally with other projects/surveys**
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Targeted survey of sample of galaxies. Elements can be tied with other wide-area surveys to reduce observing overheads, in some bands. But for full coverage of a statistically viable sample some specific targeted pointing maybe required.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (_) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Primary goal of this project is to provide high sensitivity (few uJy/bm rms) and high resolution (sub-arcsec) imaging of a statistically robust sample of many 100s-1000 nearby (<100Mpc) individual galaxies across all available frequency ranges of the SKA. The high resolution and sensitivity will allow the physics of star-formation and accretion (both nuclear and extra-nuclear) to be catalogued across the full gambit of galaxy environments in the local Universe. This will provide the cornerstone to our understanding of these processes in a sample that is both close enough to be resolved on physically important scales, whilst remaining diverse in environment, activity levels, and cover a range of galaxy evolutionary stages. Project to utilise both broad band continuum observation across multiple bands (characterise a resolves SED for both galaxies and individual constituent parts. Also exploit simultaneous line searches (molecular/atomic/RRL) thus require piggy backs zoom SPW. - Observations may be achievable to some degree in a commensal manner with other pointed observations or wide area surveys - Observations may be broken into multiple snapshots to make commensal with transient searches.

‘TARGETS’ OF OBSERVATIONS		
Type of observation (what defines a ‘target’)	X	Individual pointings per object
	X	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	Few hundred to 1000	
Positions of targets	Targets selected from sample defined from multi-	

	wavelength studies with appropriate distance limitations.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
		NO
Time Critical?		YES [details: ……………………………………….]
	X	NO → observe in multiple epoch to allow variability search
Integration time per target (hrs)	~1.5hr per band (Total 1.5*[2or3 bands]*1000[targets]=3000-4500hrs) TBD	
Average peak flux density (Jy or Jy per beam)	Wide range Target specific/dependent – Jy – ~100uJy	
Range of peak flux densities (Jy or Jy per beam)	From few tens uJy/bm- few 100mJy/bm	
Expected polarised flux density (expressed as % of total)	1-30% - Typically few%	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	~1GHz, ~4GHz, ~8GHz (+upto 25 via AIP) – Ideally many freq (minimum 2-3)
Total Bandwidth (MHz)	700MHz, 1000MHz, 2*2.5GHz
Minimum and maximum frequency over the entire range of the setup (MHz)	Most sensitive range available per band, Some line specific tuning (esp Bands 2 & 5)
Spectral resolution (kHz)	Line zooms required (line dependent – more required for masers band) ~10kHz
Temporal resolution (in seconds)	N/a

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	N/A
Maximum baseline required (km)	150+km

Primary beam size (sq degrees)		
Number of output channels	Standard for continuum (wide field) + multiple zoom bands with channel width from 0.5-20km/s depending on lines	
Output bandwidth (minimum and maximum frequency - MHz)	Maximum available	
Required rms (Jy) (if polarisation products required define for each)	1-2uJy/bm	
Dynamic range (if polarisation products required define for each)	Few 100,000:1 (target dependent)	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	0.6-0.1arcsec (max available in all bands used)
Maximum baseline required (km)	>150km
Mapped image size (degrees)	~0.4 (target specific)
Required pixel resolution (arcseconds)	Nyquist
Number of output channels	1000
Output bandwidth (minimum and maximum frequency - MHz)	Max available
Required rms (Jy per beam) (if polarisation products required define for each)	

Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	0.6-0.1arcsec	
Maximum baseline required (km)	>150km	
Mapped image size (degrees)	0.4 (target specific)	
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)	~10kHz (targeted line/band dependent)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	MFS imaging, Multiscale imaging, Separate full resolution spectral line imaging for specific bands Polarsiation calibration.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	Time dependent images, spectral cubes (specific freqs), RM synth??
Description of pipeline	

Quality assessment plan & cadence	Cadence of return field observations is flexible within periods of <1yr (caution against variability) but may be useful for commensal observations with transient searches if observing time is spread over a period of 12mnths.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	Upon block completion. (maybe ASAP for transient searches – different use case (e.g. see Perez-Torres)

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Obvious scope of commensal overlap with other SWG areas, in particular - 1) ex-gal H1 2) ex-gal spectral lines 3) transients 4) polarisation

REFERENCES
Beswick et al, 2015, in PoS(AASKA14)070

2.49 Survey of star-formation and accretion activities in nearby galaxies – megamaser subsection

PROJECT DETAILS	
Title	**Survey of star-formation and accretion activities in nearby galaxies - megamaser subsection**
Principal Investigator	**R.Beswick**
Co-Authors	**E. Brinks, M. Perez-Torres, A. Richards, S. Aalto, A. Alberdi et al (on behalf of ex-gal continuum SWG)**
Time Request	1.5hrs per target per band ~2 to 3 band/freqs, few 100-1000 sources Total = ~3000-4500 (TBC) – some fraction to be commensal

FACILITY		Preconditions
	SKA1-LOW	
X		

	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	few tens
	SKA1-MID Band 2	few tens
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	**Some elements are likely to be observed commensally with other projects/surveys**
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Targeted survey of sample of galaxies. Elements can be tied with other wide-area surveys to reduce observing overheads, in some bands. But for full coverage of a statistically viable sample some specific targeted pointing maybe required.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	X	Stokes Q
	XY	X	Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Primary goal of this project is to provide high sensitivity (few uJy/bm rms) and high resolution (sub-arcsec) imaging of a statistically robust sample of many 100s-1000 nearby (<100Mpc) individual galaxies across all available frequency ranges of the SKA. The high resolution and sensitivity will allow the physics of star-formation and accretion (both nuclear and extra-nuclear) to be catalogued across the full gambit of galaxy environments in the local Universe. This will provide the cornerstone to our understanding of these processes in sample that is both close enough to be resolved on physically important scales, whilst remaining diverse in environment, activity levels, and cover a range of galaxy evolutionary stages. Project to utilise both broad band continuum observation across multiple bands (characterise a resolves SED for both galaxies and individual constituent parts. Also exploit simultaneous line searches (molecular/atomic/RRL) thus require piggy backs zoom SPW. - Observations may be achievable to some degree in a commensal manner with other pointed observations or wide area surveys - Observations may be broken into multiple snapshots to make commensal with transient searches. The SKA will be able both to resolve and to measure Zeeman splitting in OH megamasers. This will provide a comparison between the magnetic and kinetic/hydrostatic energy densities in circumnuclear star formation environments.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	X	Individual pointings per object
	X	Individual fields-of-view with multiple objects
		Maps through multiple fields of view

		Non-imaging pointings
Number of targets	Few hundred to 1000 few test objects for initial megamaser studies	
Positions of targets	Targets selected from sample defined from multi-wavelength studies with appropriate distance limitations.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………..]
	X	NO
Time Critical?		YES [details: ……………………………………..]
	X	NO
Integration time per target (hrs)	~1.5hr per band (Total 1.5*[2or3 bands]*1000[targets]=3000-4500hrs) TBD	
Average peak flux density (Jy or Jy per beam)	Wide range Target specific/dependent – Jy – ~100uJy megamasers ~few (tens) mJy continuum (line) peaks)	
Range of peak flux densities (Jy or Jy per beam)	From few tens uJy/bm- few 100mJy/bm Megamasers need to resolve structure down to 10 uJy;	
Expected polarised flux density (expressed as % of total)	1-30% - Typically few% Megamasers 1% (may be higher at finer resolution)	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	~1GHz, ~4GHz, ~8GHz (+upto 20 via AIP) – Ideally many freq (minimum 2-3)
Total Bandwidth (MHz)	700MHz, 1000MHz, 2.5GHz
Minimum and maximum frequency over the entire range of the setup (MHz)	Most sensitive range available per band, Some line specific tuning (esp Bands 2 & 5)
Spectral resolution (kHz)	Line zooms required (line dependent – more required for masers band)

	~10kHz
Temporal resolution (in seconds)	N/a

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)	N/A	
Maximum baseline required (km)	150+km	
Primary beam size (sq degrees)		
Number of output channels	Standard for continuum + zoom bands	
Output bandwidth (minimum and maximum frequency - MHz)	Zoom 8 or 16 MHz B1; 16 MHz B2, continuum max. convenient	
Required rms (Jy) (if polarisation products required define for each)	1-2uJy/bm	
Dynamic range (if polarisation products required define for each)	Few 100,000:1 (target dependent) Polarization: >300:1 (1000:1 ideal including in autocorrelations)	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	0.6-0.1arcsec (max available in all bands used)

Maximum baseline required (km)	>150km	
Mapped image size (degrees)	~0.4 (target specific)	
Required pixel resolution (arcseconds)	Nyquist	
Number of output channels	1000	
Output bandwidth (minimum and maximum frequency - MHz)	Max available..	
Required rms (Jy per beam) (if polarisation products required define for each)	Megamasers ~100 uJy	
Dynamic range within image (if polarisation products required define for each)	few 100 - 1000	
Absolute flux scale calibration		1-3%
	x	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	0.6-0.1arcsec
Maximum baseline required (km)	>150km
Mapped image size (degrees)	0.4 (target specific) Megamasers <1arcmin
Required pixel resolution (arcseconds)	At least 3 pixels per synthesised beam
Number of image channels	
Channel width (kHz)	~10kHz (targeted line/band

	dependent)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	Imaging: 1 mJy (small sample) in ~25 km/s channels; 100s uJy for larger sample. Low spatial res. or autocorrelations, similar sensitivity in 0.5 or 1 km/s channels	
Dynamic range within image per channel (if polarisation products required define for each)	few 100 - 1000 for all Stokes	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
	X	5%

		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	MFS imaging, Multiscale imaging, Separate full resolution spectral line imaging for specific bands Polarsiation calibration.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	Time dependent images, spectral cubes (specific freqs), RM synth??
Description of pipeline	
Quality assessment plan & cadence	Cadence of return field observations is flexible within periods of <1yr (caution against variability) but may be useful for commensal observations with transient searches if observing time is spread over a period of 12mnths.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to	Upon block completion. (maybe ASAP for transient searches – different use case (e.g. see Perez-Torres)

‘at completion of the full project’.)	

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Obvious scope of commensal overlap with other SWG areas, in particular - 1) ex-gal H1 2) ex-gal spectral lines 3) transients 4) polarisation a) Zeeman chapter b) Maser chapter

REFERENCES
Beswick et al, 2015, in PoS(AASKA14)070

2.50 Imaging the dense molecular gas in quasar host galaxies during the reionization epoch

PROJECT DETAILS	
Title	Imaging the dense molecular gas in quasar host galaxies during the reionization epoch
Principal Investigator	**M. Sargent**
Co-Authors	K. Knudsen, J. Wagg

Time Request	TBC (100) hrs

FACILITY		Preconditions
	SKA1-LOW	
✓	SKA1-MID	No MeerKAT antennas would be used since these would not have the higher frequency band 5 capabilities.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
✓	SKA1-MID Band 5	Approx. 100 hours (TBC). The observations are aimed at detecting and imaging the HCN, HCO+ and HNC lines redshifted to 12.84, 12.93 and 13.14 GHz, respectively.

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
✓	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
(✓)	Commensal	commensal with deep continuum surveys in band 5 (esp. ‘Measuring the Star Formation History of the

		Universe (thermal processes; science goal #37)')
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
We expect that 4 to 8 hour duration observations will be necessary to complete this project, depending on the scheduling constraints and the outcome of quality assessment checks.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	✓	Stokes I
	YY	✓	Stokes Q
	XY	✓	Stokes U
	YX	✓	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The most common tracer of the star-forming molecular gas in high-redshift galaxies is molecular CO line emission observed at submm-to-cm wavelengths (Carilli & Walter 2013 for a review). Although the high-J transitions of CO (J=4-3, 5-4, etc.) are excellent tracers of dense gas, other molecules with critical densities for excitation in excess of 10^4 cm-3, such as HCN, have been widely surveyed in the nearby Universe (e.g. Gao & Solomon 2004a, b). The luminosity in the HCN J=1-0 line emission has been shown to follow a tight correlation with infrared luminosity over decades in luminosity, with a power-law slope close to 1 (e.g. Wu et al. 2005). This tells us that the gas traced by HCN is closely linked with sites of on-going star-formation. Previous studies of redshifted emission from the low-J tracers of HCN (88.63 GHz rest-frame) as well as HCO+ and HNC (89.19 and 90.66 GHz rest-frame) have been limited by the sensitivity of past facilities at cm-wavelengths. With phase I of the SKA it is now possible to detect and image these lines out to the epoch of reionization at z~6. Here, we propose to image the J=1-0 transitions of HCN, HCO+ and HNC in a FIR luminous quasar host galaxy at z=5.9 with a FIR luminosity ~2.E+13 Lsun. The expected linewidths based on previous CO emission line observations is 500km/s FWHM. The continuum emission will also be measured to constrain the observed-frame 3-mm wavelength emission, which will be comprised of a combination of free-free, synchrotron and thermal dust emission.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	✓	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	One quasar host galaxy at z=5.9 with a FIR luminosity ~2.E+13 Lsun.	
Positions of targets	RA: 20h54m06.5s DEC: -00d05m14.8s (J2000)	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	✓	NO
Time Critical?		YES [details: ……………………………………….]
	✓	NO
Integration time per target (hrs)	Approx.. 100 hrs (TBC)	
Average peak flux density (Jy or Jy per beam)	Within the full field of view, the brightest source is likely to be less than ~1 mJy per beam at 13 GHz measured over a 500 MHz bandwidth (e.g. Davies et al. 2010), and 30-40% brighter at 10 GHz measured over 2.5 GHz of bandwidth.	
Range of peak flux densities (Jy or Jy per beam)	10 μJy (e.g. HCO+) to 20 μJy (HCN) (assumes HCN/IR ratios as in Gao & Solomon (2004b) and, e.g, HCO+/HCN ratios as in Riechers et al. (2006) or Papadopoulos (2006))	
Expected polarised flux density (expressed as % of total)	Unknown	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (✓ _)*	
Central Frequencies (MHz) (including redshift, observatory correction)	MID band 5, no MeerKAT antennas. We are proposing to observe line emission from HNC, HCO+ and HNC at redshifted

	frequencies of 12.84, 12.93 and 13.14 GHz. A ~500 MHz IF covers all three lines described but in the interest of max. commensality with, e.g., the thermal SFHU project, we would use the full available bandwidth of 2.5 GHz for both IFs to measure also the thermal emission from the QSO host galaxy and/or further galaxies in the field-of-view. The upper IF would extend to the upper end of the band 5 tuning range, the lower IF would be placed adjacent to it (or a central frequency optimized for maximal commensality with band 5 continuum surveys).
Total Bandwidth (MHz)	5000
Minimum and maximum frequency over the entire range of the setup (MHz)	9000-14000
Spectral resolution (kHz)	2000 (Identical to spectral resolution required by band 5 continuum surveys commensal with this project. The according velocity resolution of the molecular lines is ~40-50 km/s and would allow a sampling of the line with multiple channels. For a sufficiently bright line the measured line profile/width should allow basic dynamical modelling of the system.
Temporal resolution (in seconds)	standard

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	
Maximum baseline required (km)	
Primary beam size (sq degrees)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	
Required rms (Jy)	

(if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	0.3" beam size	
Maximum baseline required (km)	~50 km	
Mapped image size (degrees)	Full field-of-view (~30 square arcminute).	
Required pixel resolution (arcseconds)	~0.1 arcsec	
Number of output channels	2500	
Output bandwidth (minimum and maximum frequency - MHz)	9000-14000 MHz (band 5+)	
Required rms (Jy per beam) (if polarisation products required define for each)	The sensitivity for this experiment is driven by the spectral line science case, although we note that the sensitivity to the continuum emission at 10 GHz calculated over the 2.5 GHz of bandwidth is expected to be ~73 nJy per beam.	
Dynamic range within image (if polarisation products required define for each)	Approx. 10^4.	
Absolute flux scale calibration	✓	1-3%
		5%

		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	0.3" beam size	
Maximum baseline required (km)	~50 km	
Mapped image size (degrees)	Single-field covering central ~1 arcminute (corresponds to a physical scale of ~354 kpc at z=5.9) of the full-of-view. (If possible a spectral data cube covering the full field-of-view would be desirable for blind line searches – see comment under "Data Analysis -> data products" below.)	
Required pixel resolution (arcseconds)	~0.1 arcsec	
Number of image channels	1250	
Channel width (kHz)	2000	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	The brightest emission line we expect to detect is HCN J=1-0, which should have a peak flux density of 25 microJy per beam if the source is unresolved (ie. >1 arcsecond beamsize) or 12.5 microJy at our proposed resolution of 0.3 arcseconds where the emission will be spread over two beams (e.g. Walter et al. 2004). We require an rms of ~1.7 microJy per 100km/s channel, in order to ensure >~5-sigma detections of the HCN line emission over the central line channels.	
Dynamic range within image per channel (if polarisation products required define for each)	n/a	
Absolute flux scale calibration		1-3%
		5%

		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Standard spectral line and continuum data processing of band 5 data will be required (e.g. Rau et al. 2009 and references therein).
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Standard
Data products	We require both continuum images over the entire field-of-view and 2 MHz (~50km/s) spectral line data

	cubes over the central 1 arcmin squared. If data volumes are not prohibitive we would like to extend the coverage of the spectral data cubes to the entire field-of-view.
Description of pipeline	Continuum Images and spectral line data cubes can be co-added using a weighting that depends on the rms.
Quality assessment plan & cadence	The phase coherence should be checked regularly (10 to 20 minute intervals) by the astronomer at the telescope. At the end of an observing block, an initial pipeline calibrated spectral line data cube image should be generated and the noise calculated as a function of frequency to verify that the thermal noise level is being reached.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of the full project and reduction.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
These observations depend on the deployment of the band 5/6 receiver suite on SKA1 MID.

REFERENCES
Bhatnagar, S. et al. 2008, *Correcting direction-dependent gains in the deconvolution of radio interferometric images*, A&A, 487, 419 Bhatnagar, S. et al. 2013, *Wide-field wide-band Interferometric Imaging: The WB A-Projection and Hybrid Algorithms,* ApJ, 770, 91 Carilli, C & Walter, F. 2013, *Cool gas in High-redshift Galaxies,* ARA&A, 51, 105 Davies, M. L. et al. 2010, *10C Survey of Radio Sources at 15.7 GHz: II – First Results*, arXiv:1012.3659 Dewdney, P. et al. 2013, *SKA Phase 1 System (Level 1) Specifications*, SKA-OFF.SE.ARC-SKO-SRS-001-A, Revision 1 Gao, Y & Solomon, P. 2004a, *HCN Survey of Normal Spiral, Infrared-luminous, and Ultraluminous Galaxies*, ApJS, 152, 63 Gao, Y & Solomon, P. 2004b, *The Star Formation Rate and Dense Molecular Gas in Galaxies*, ApJ, 606, 271 Perley, R., *High Dynamic Range Imaging,* from *Synthesis Imaging in Radio Astronomy II,* ASPC, Vol 180, p. 275 Riechers, D., et al. 2006, *First Detection of HCO^+ Emission at High Redshift*, ApJL, 645, 13 Rau, U., et al. 2009, *Advances in* Calibration *and Imaging Techniques in Radio Interferometry*, IEEEP, 97, 1472 Wagg, J. et al. 2015, “Enabling the next generation of cm-wavelength studies of high-redshift molecular gas with the SKA” (SKA Science Book) Walter, F. et al. 2004, *Resolved Molecular Gas in a Quasar Host Galaxy at Redshift z=6.42*, ApJ, 615, 17 Wu, J., et al. 2005, *Connecting Dense Gas Tracers of Star Formation in our Galaxy to High-z Star-Formation,* ApJ, 635, L173

2.51 Detecting hydrogen radio recombination emission lines from high-z quasars with SKA-MID

PROJECT DETAILS	
Title	**Detecting hydrogen radio recombination emission lines from high-z quasars with SKA-MID**
Principal Investigator	**Serena Manti**
Co-Authors	**Simona Gallerani, Andrea Ferrara, Gianni Bernardi**
Time Request	200 hrs

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	Band 4 (2.8 to 5.18 GHz) and Band 5 (4.6 to 13.8 GHz). The possibility of choosing high observing frequencies (from ~3 to ~14 GHz) with SKA-MID is optimal to reach our goal.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
X	SKA1-MID Band 4	100 hrs
X	SKA1-MID Band 5	100 hrs

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Numerous observations show that z ~ 6 quasars are powered by super-massive black holes (SMBHs) rapidly grown up to a mass M ~ 10^{10} M_{sun} in less than 1 Gyr, depending on still uncertain initial black hole seeds (e.g. Ferrara et al. 2014). The lower mass ancestors (10^{6-8} M_{sun}) of these SMBHs have never been detected so far, possibly because they are enshrouded by a thick cocoon of gas and dust heavily absorbing their optical/X-ray radiation (e.g. Comastri et al. 2015).

The transparency of dust to radio photons makes Radio Recombination Lines (RRLs) a promising tool for detecting obscured high-z quasars (e.g. Manti et al. 2015), and SKA-MID a perfect instrument to monitor the formation of the earliest AGNs. A necessary first step is to detect RRLs in high-z quasars and to understand the process that determines the RRL emission in these sources, namely spontaneous emission and/or stimulated emission due to a non-thermal background radio continuum (Shaver 1978).

Thus, we propose to observe Hnα emission lines in a z=6.31 quasar (J1030+0524). We compute the expected RRL flux density for lines detectable in correspondence of two significative SKA-MID frequency ranges (Fig. 1, left) and considering the cases with and without stimulated emission (Fig. 1, right). This experiment will confirm or not the potential of SKA to detect (obscured) SMBH ancestors, a kind of process that would revolutionize our understanding of the galaxy-black hole formation mechanisms.

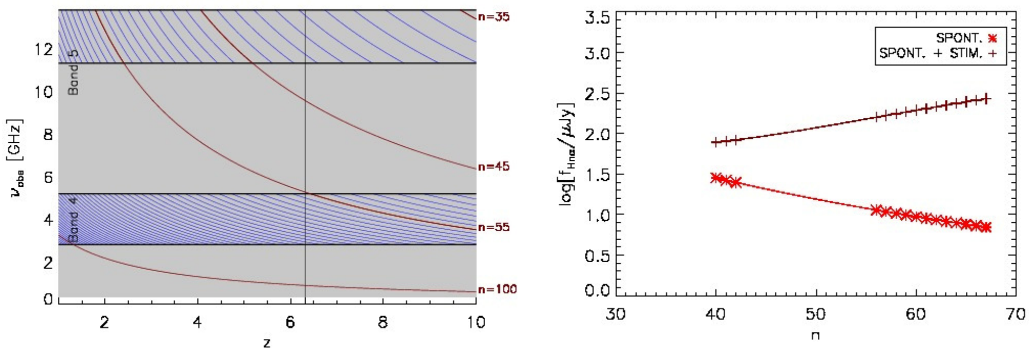

Figure 1. ***Left*: Hydrogen RRL observed frequencies as a function of redshift, in the selected SKA-MID frequency ranges. The black vertical line corresponds to the redshift of the target (z=6.31). *Right*: logarithm of fHnα versus n, a) considering only spontaneous emission (red curve) and b) including the maximum stimulated contribution from the radio continuum (HII region with electron temperature $T_e=10^3$ K; electron density $n_e=10^5$ cm^{-3}) (purple curve). Red asterisks and purple crosses correspond to the quantum numbers detectable in the selected MID frequency ranges at z=6.31. Calculations are based on the work by Manti et al. (2015).**

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	X	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	One quasar: J1030+0524, at z=6.31	

Positions of targets	RA: 10h30m27.1s DEC: +05d24m55.0s (J2000)	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	200 hrs	
Average peak flux density (Jy or Jy per beam)	The average peak line flux density is ~110 µJy and ~55 µJy in the MID Band 4 and 5 respectively.	
Range of peak flux densities (Jy or Jy per beam)	~7-270 µJy in the MID Band 4; ~25-85 µJy in the MID Band 5.	
Expected polarised flux density (expressed as % of total)	TBD	

OBSERVATIONAL SETUP : *CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	We are observing redshifted Hnα line emission over the entire MID Band 4 frequency range and a selected frequency range (11.3-13.8 GHz) in the MID Band 5, in correspondence of redshift z=6.31
Total Bandwidth (MHz)	2380 MHz for Band 4, 2500 MHz for Band 5 (to simultaneously detect more spectral lines)
Minimum and maximum frequency over the entire range of the setup (MHz)	Min: 2800 MHz, Max: 13800 MHz
Spectral resolution (kHz)	
Temporal resolution (in seconds)	

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	

Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	0.003-0.0007
Maximum baseline required (km)	120
Mapped image size (degrees)	20 arcmin
Required pixel resolution (arcseconds)	0.01
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	Min: 2800 MHz, Max: 13800 MHz
Required rms (Jy per beam) (if polarisation products required define for each)	2 μJy/beam

Dynamic range within image (if polarisation products required define for each)	N/A	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Standard
Data products	Visibilities

Description of pipeline	Standard
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	at completion of the full project

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES
Comastri A., Gilli R., Marconi A., Risaliti G., Salvati M., 2015, eprint (arXiv:1501.03620) Ferrara A., Salvadori S., Yue B., Schleicher D., 2014, MNRAS, 443, 2410

Gordon M. A., Sorochenko R. L., 2002, Astrophysics and Space Science Library, Vol. 282. Kluwer Academic Publishers, Dordrecht

Manti S., Gallerani S., Ferrara A., Feruglio C., Graziani L., Bernardi G., 2015, MNRAS, submitted

Rule E., Loeb A., Strelnitski V. S., 2013, ApJ, 775, L17

Shaver P. A., 1978, A&A, 68, 97

Wang R. et al., 2007, AJ, 134, 617

2.52 All sky pulsar surveys with SKA1-LOW and SKA1-MID

PROJECT DETAILS	
Title	All sky pulsar surveys with SKA1-LOW and SKA1-MID
Principal Investigator	N. Copernicus
Co-Authors	The pulsar team
Time Request	5200 hrs

FACILITY		Preconditions
x	SKA1-LOW	Approximately 5100 x 2 pointings for Galactic latitudes greater than 5 degrees at declinations less than 30 degrees. Beams are assumed to be hexagonally tiled in triangular planes using 35-m stations.
x	SKA1-MID	Approximately 6000 x 2 pointings with SKA1-MID Band 1 and 4500 x 2 pointings with SKA1-MID Band 2. Band 1 will be used for an all-sky survey at declinations between 30 and 45 degrees. Band 2 will be used for a survey of Galactic latitudes less than 10 degrees at declinations less than 30 degrees. This assumes we use a hexagonal tiling of rectangles, with dishes located out to a ~475m radius from the centre of the array, with enough receivers operational to ensure a filling factor (collecting area / baseline^2) of 0.3 or greater.

RECEIVER(S) REQUIRED		Time (hrs)
x	SKA1-LOW	1700 hrs (|b| > 5 degrees at declinations < 30 deg., 600 s pointings)
x	SKA1-MID Band 1	2000 hrs (all-sky at declinations between 30 and 45 deg., 600 s pointings)
x	SKA1-MID Band 2	1500 hrs (|b| < 10 deg. at declinations < 30 deg., 600 s pointings)
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
x	Normal	Non-imaging processing/Pulsar Search Engine

	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Observations will be made with beams sampling the entire sky at the Nyquist rate. To improve efficiency (in confirming sources), observations will be made through two passes. Different regions of the sky will be covered at different frequencies, to balance the speed of the survey and interstellar propagation effects, with one region covered by both SKA1-LOW and SKA1-MID Band 2. This is essential for achieving good comparisons between the survey performance to be used in population simulations. On SKA1-LOW, simulations of the pulsar yield show that it is worthwhile going beyond the 600-s integration time up as far as 1800 s, i.e. we don’t reach the luminosity limit before integrations of 600 s.

POLARISATION PRODUCTS REQUIRED : BEAMFORMER (__) or CORRELATOR (X)			
	XX	X	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Detect all the pulsars in the Galaxy (beamed towards us) to the sensitivity afforded by an observing programme of two years on sky. This is a non-imaging programme ('NIP') using the pulsar search engine. All-sky coverage is needed to detect the variety of pulsars required for timing and other science programmes. The observing is divided between SKA1-LOW and SKA1-MID. The SKA1-LOW survey will cover the entire visible sky at declinations < 30 degrees with |b| > 5 degrees. This will optimize the speed of the survey. SKA1-MID will cover the entire visible sky with declinations between 30 and 45 degrees using band 1 (~800 MHz) and with declinations < 30 degrees and |b| < 10 degrees using band 2 (~1400 MHz), to minimise the affects of scattering. There will be an overlap in sky coverage between SKA1-LOW and SKA1-MID at declinations < 30 degrees and 5 < |b| < 10 degrees, providing confirmations and measurements of spectral indices.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
	x	Non-imaging pointings
Number of targets	Tied-array beams to adequately sample primary beam with 500 search beams with SKA1-LOW and 1500 search beams with SKA1-MID (approximately equivalent to Nyquist sampling ~80% of the primary beam). Pointings to cover whole sky.	
Positions of targets	Multiple targets within whole sky visible with SKA1-LOW and SKA1-MID (total of 35,000 square degrees).	
Rapidly changing sky position? (e.g. comet, planet)		YES[details: ………………………………………..]
	x	NO
Time Critical?		YES[details: ………………………………………..]
	x	NO

Integration time per target (hrs)	600 s
Average peak flux density (Jy or Jy per beam)	Unknown
Range of peak flux densities (Jy or Jy per beam)	Unknown
Expected polarised flux density (expressed as % of total)	Unknown

OBSERVATIONAL SETUP : BEAMFORMER (x) or CORRELATOR ( )	
Central Frequencies (MHz) (including redshift, observatory correction)	Centre frequencies of ~300 MHz for SKA1-LOW and ~800 MHz and ~1400 MHz for SKA1-MID. Note ideal frequencies still to be determined.
Total Bandwidth (MHz)	Approxinately 100 MHz bandwidth for SKA1-LOW and 300 MHz bandwidth for SKA1-MID
Minimum and maximum frequency over the entire range of the setup (MHz)	Approximately 150 MHz to 1700 MHz
Spectral resolution (kHz)	Approximately 12 kHz for SKA1-LOW and 74 kHz for SKA1-MID
Temporal resolution (in seconds)	Approximately 100 microsec for SKA1-LOW

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	N/A
Maximum baseline required (km)	N/A

Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)	N/A	
Dynamic range (if polarisation products required define for each)	N/A	
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	x	n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	N/A
Maximum baseline required (km)	N/A
Mapped image size (degrees)	N/A
Required pixel resolution (arcseconds)	N/A
Number of output channels	N/A
Output bandwidth (minimum and maximum frequency - MHz)	N/A
Required rms (Jy per beam) (if polarisation products required	N/A

define for each)		
Dynamic range within image (if polarisation products required define for each)	N/A	
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	x	n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	N/A	
Maximum baseline required (km)	N/A	
Mapped image size (degrees)	N/A	
Required pixel resolution (arcseconds)	N/A	
Number of image channels	N/A	
Channel width (kHz)	N/A	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	N/A	
Dynamic range within image per channel (if polarisation products required define for each)	N/A	
Absolute flux scale calibration		1-3%
		5%
		10%

		20-50%
	x	n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)	N/A	
Mapped image size (degrees)	N/A	
Number of image channels	N/A	
Channel width (kHz)	N/A	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	N/A	
Dynamic range within image per channel (if polarisation products required define for each)	N/A	
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	x	n/a

DATA ANALYSIS	
Procedures required	Calibration information provided to enable that the beams be added coherently to within a few % of the maximum gain. This solution should also be stable. Polarisation calibration required for the transients. RFI mitigation on antenna/station basis in the

	beamformer. [All the following required procedures will be part of the 'Pulsar Search Engine' but are listed here for completeness] RFI mitigation, incoherent de-dispersion, single-pulse searching, time domain and frequency domain acceleration searching, forming power spectra, thresholding, detection, and subsequent folding of candidate signals to create diagnostic plots.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Able to drop antenna/stations dynamically and adjust weights appropriately either for RFI or other reasons. All others within the pulsar search engine.
Data products	A candidate list, for each candidate from the periodicity search: Sky position, pulse-average, total intensity, flux density, period, dispersion measure, pulse archive, DM – SNR data, and three 3-dimensional data cubes {DM – TIME – SNR; Pulse Phase – Frequency Channel – Intensity; Pulse Phase – subintegrations – Intensity}. A candidate list, for each candidate from the single-pulse search: Sky position, DM, SNR, time, width.
Description of pipeline	See Stappers et al. whitepaper in CSP Technical proposal.

Quality assessment plan & cadence	Includes amplitude, phase, polarisation, dispersion measure, period and acceleration, flag tables, and candidate statistics including single-pulse statistics. Also RFI statistics will be very important.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of scheduling block and pipeline reduction is generally ok. However, most data products should be available for inspection with a lag of approximately one "pointing" if in pulsar search mode. Some data products, like transients and new pulsar updates should be available immediately to enable rapid follow up if required.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES
Kramer & Stappers, 2015, "Pulsar Science with the SKA", PoS(AASKA14)036, "Advancing Astrophysics with the Square Kilometre Array". Keane et al., 2015, "A cosmic census of radio pulsars", PoS(AASKA14)040, "Advancing Astrophysics with the Square Kilometre Array".

2.53 Deep targeted searches for radio pulsars in and around the Milky Way

PROJECT DETAILS	
Title	**Deep targeted searches for radio pulsars in and around the Milky Way**
Principal Investigator	**Andrea Possenti, Pablo Torne (as main authors of this document)**
Co-Authors	**The pulsar science working group *et al.***
Time Request	1000 hours spread over 5 years and different frequency bands [e.g., 400 hours for Globular Cluster searches and 600 hours for other targets such as unassociated Fermi-LAT sources, supernova remnants, Magellanic Clouds, M31, and "radio-quiet" pulsars]. Values here and below are estimates that are strongly motivated by our aim to improve upon the sensitivity limits of current and planned projects at other major facilities (see e.g. Hessels et al. 2015).

FACILITY		Preconditions
X	SKA1-LOW	Usable for certain targets
X	SKA1-MID	The preferred array for majority of the targets

RECEIVER(S) REQUIRED		Time (hrs)
X	SKA1-LOW	For regions with low interstellar medium effects, the LOW array could provide a higher sensitivity
X	SKA1-MID Band 1	For targets with not-so-strong interstellar medium effects this band may be more sensitive because of

		the typically steep spectra of pulsars in the radio band
X	SKA1-MID Band 2	This will be the preferred band for this science case as it typically offers the best compromise between interstellar medium effects and the achievable sensitivity to pulsar searches.
X	SKA1-MID Band 3	Searches for pulsars behind extremely-scattered regions may require this band, but these cases are expected to be rare (e.g., searches in young supernovas or globular clusters located in the Galactic bulge, and those very close to the Galactic plane)
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	Non-imaging processing
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
The plan is to use the pulsar timing beams (anywhere from 1 to 16, to suit the characteristics of a specific target) to cover the area of interest and output data in the dynamic spectrum mode, with observing parameters (bandwidth, sampling time, number of polarisations and number of [coherently de-dispersed] frequency channels) compatible with the maximum data transfer rates from the PST to the SDP and subsequently to the SRC. The pulsar search engine is not expected to have the computational capabilities for dealing with a full processing of the data from these long observations. Thus, PST will be used for

generating the aforementioned dynamic spectrum mode data; then the data will be transferred to the SRC network for the whole subsequent processing. These targeted searches are expected to fit into a standard scheduling strategy without special time constrains. PIs will provide the area to cover, the number of beams to sample it, the frequency band to use, and the required sensitivity. Scheduling blocks could then be created from this information. This is a non-imaging project, however parallel acquisition of interferometric data by the whole array will be welcome.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (X) or CORRELATOR (_)*			
	XX	X	Stokes I
	YY	X	Stokes Q
	XY	X	Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Independent but highly complementary to the all-sky pulsar survey proposed for the SKA (Science use case 2.52), several specific regions of the Galaxy of particular interest like Globular Clusters, unassociated Fermi-LAT sources, supernova remnants or neutron stars without radio emission yet detected, justify deep observations to increase the sensitivity to weak pulsars. Despite their usually fainter radio flux, these pulsars offer the possibility to provide unique insights about their astrophysical environment (e.g. the hosting globular cluster, the supernova remnant) and unique constraints about the radio emission mechanisms (for unassociated Fermi-LAT and TeV sources and for the radio-quiet neutron stars). Within the Globular Clusters, one could also find some exceptional systems which are not expected elsewhere in the Galaxy (e.g. double millisecond pulsars, pulsars orbiting an intermediate mass black-hole) or the formation of which could be significantly favoured in a Globular Cluster (e.g. ultra-fast spinning pulsars or very heavy neutron stars). In addition, the SKA will offer the potential to discover additional pulsars in the Magellanic clouds, and for the first time radio pulsars in a set of nearby galaxies, enabling a better modelling of neutron star populations outside our own Galaxy and the study of the local inter-galactic medium.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
	X	Non-imaging pointings
Number of targets	Hundreds of different targets/regions. Some of these will be point-like, but some can extend up to several arcminutes squared.	
Positions of targets	Milky Way disk and halo, and a few external nearby galaxies	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ………………………………………]
	X	NO
Time Critical?		YES [details: ………………………………………]
	X	NO
Integration time per target (hrs)	Typically, between 30 minutes and a few hours per target	
Average peak flux density (Jy or Jy per beam)	N/A – Searches are designed to reach a certain sensitivity level, depending on the target	
Range of peak flux densities (Jy or Jy per beam)	Targeted sensitivity in the micro Jansky order	
Expected polarised flux density (expressed as % of total)	Up to 100% linear, tens of % circular	

OBSERVATIONAL SETUP : *BEAMFORMER (X_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Central frequencies of each band
Total Bandwidth (MHz)	Maximum available per band
Minimum and maximum frequency over the entire range of the setup (MHz)	

Spectral resolution (kHz)	Depends on the frequency band
Temporal resolution (in seconds)	32 microseconds desirable, however 64 microseconds acceptable

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)	Nyquist sample the FoV	
Maximum baseline required (km)	Depends on target. The aim is to fully sample the target area with the maximum sensitivity, assuming the availability of up to 16 tied-array beams. Very small targets will allow the use of long baselines (up to the available maximum value), whereas Globular Clusters and Supernova Remnants will likely require smaller maximum baselines, typically of order 1 km	
Primary beam size (sq degrees)	N/A	
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)	Depends on target	
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a ‘support image’ in the case of VLBI observations)	
Required angular resolution (arcmin)	

(single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of image channels	
Channel width (kHz)	
Required rms (Jy per beam per channel)	

(if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Flux and polarisation calibration, flag RFI, produce

	dynamic spectrum mode data. Since the PSS machine is not expected to have the computational power to deal with the required long integrations, the data will have to be transferred to the SRC network for all the steps of the successive processing
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	Dynamic spectrum mode data, with the usual set of associated metadata and observational parameters
Description of pipeline	The data will be processed by the PST in dynamic spectrum mode, and sent through the SDP to the SRC. Once the data has been packed in to the dynamic spectra data products, no additional processing will be required until the data reaches the SRC.
Quality assessment plan & cadence	The methodology can be tested by applying it to a known pulsar
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Within a few days of the completion of a scheduling block, the data should be made available in the SRC system for their processing.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Depending on limitations of durations of scheduling blocks, long observations (hours) may needed to be split into several blocks. But they need to be executed consecutively and with the minimum possible gaps between them because the computational costs of searching for accelerated pulsars scales roughly with the cube(!) of the integration time. The requirement to periodically re-phase the array during long observations (depends on the frequency and maximum baseline, and so particularly relevant for observations with SKA-low) will result in unavoidable gaps in data recording, but it is important to ensure synchronisation of the data (e.g. by zero-padding the times when the array is being re-phased) so data can be suitable for sensitive searches.

REFERENCES

Kramer and Stappers 2015, PoS (AASKA14), “Pulsar Science with the SKA”

Tauris et al. 2015, PoS (AASKA14), “Understanding the neutro star population with the SKA”

Keane et al. 2015, PoS (AASKA14), “A Cosmic Census of Radio Pulsars with the SKA”

Watts et al. 2015, PoS (AASKA14), “Probing the neutron starinterior and the Equation of State of cold dense matter with the SKA”

Hessels et al. 2015, PoS (AASKA14), “Pulsars in Globular Clusters with the SKA”

2.54 Pulsar Timing with the SKA

PROJECT DETAILS	
Title	**Pulsar Timing with the SKA**
Principal Investigator	**Michael Kramer, Gemma Janssen as authors of this document**
Co-Authors	**PSWG**
Time Request	1420 hrs over 5 yrs on SKA1-LOW; 5300 over 5 years on SKA1-MID. All time estimates below are averages and estimates.

FACILITY		Preconditions
X	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
X	SKA1-LOW	900 (follow-up); 520 (PTA MSPs)
X	SKA1-MID Band 1	450 (follow-up Slow); 580 (follow-up MSP); 260 (PTA MSPs)
X	SKA1-MID Band 2	1350 (follow-up Slow); 1750 (follow-up MSP); 780 (PTA MSPs)
X	SKA1-MID Band 3	
	SKA1-MID Band 4	
X	SKA1-MID Band 5	130 (Galactic Centre)

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
X	Fixed schedule (give cadence)	Resolving + monitoring (2 weeks)
	Time-critical override	
X	Custom Experiment	Full orbit for specific binaries
X	Commensal	For SKA-low: searching and timing
	Collaborative & Coordinated	
X	Sub-arrays required	Optional depending on source

COMMENTS ON OBSERVING STRATEGY

Timing serves two purposes: i) Resolving: identifying interesting pulsars from a pool of newly discovered pulsars (to be included in other experiments like pulsar timing arrays) and ii)the Monitoring of pulsars that are included in specific experiments such as gravitational wave detection or gravity tests.

Resolving:

- all discovered pulsars need to be timed for a sufficient time to characterise their usefulness. That requires initial resolving observations, where new sources are timed several times in the initial few days, after which the cadence can be decreased to weekly observations. Later, monthly observations up to 12 months should suffice (note that astrometry observations with VLBI can shorten this time, sufficiently accurate positions may also already be available from search/confirmation observations for many of the slower pulsars)
- new pulsars in binaries require additional resolving observations to determine their orbital parameters. The requirements will depend on the orbital period and eccentricity of the binary.
- once new pulsars are characterised they will be passed on to high-precision timing (monitoring) observations on SKA1-MID or SKA1-LOW depending on their suitability for the KSPs, or referred to other telescopes for further monitoring, or be included in other timing programs, such as those proposed in the magnetospheres UseCase.

Monitoring:

- known pulsars suitable to be included in a pulsar timing array (Janssen et al. 2015) need to be timed with a cadence from one to two weeks. Pulse jitter may be the determining factor for observing time, allowing the possibility to sub-array for increased efficiency
- pulsars in short-period binary systems (Shao et al. 2015) may need to be tracked regularly over the full orbit with full sensitivity (coherently added array). The length of the observing time is given by the orbital period.

• high precision timing observations require fully calibrated polarisation information. For low – precision timing observations, total power is sufficient • high precision timing observations require observations in multiple observing bands to measure and mitigate delays due to the ISM, the required bands are pulsar-specific. A combination of SKA1-MID bands and SKA1-LOW will be used. • SKA1-LOW may be able to time most pulsars off the Galactic plane. Pulsars in the Galactic plane require Band2/3 observations. • Pulsars in the Galactic Centre require Band5 observations (Eatough et al. 2015).

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (X) or CORRELATOR (X)*			
X	XX		Stokes I
X	YY		Stokes Q
X	XY		Stokes U
X	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Pulsar timing is used to derive a wide range of science (Kramer & Stappers 2015). The arrival time of pulses is measured to high precision and monitored over a large time span to be able to compare the TOAs with predictions based on a model. The timing model contains information on the rotational parameters of the pulsar, its astrometric parameters, binary parameters as well as a basic response to the delaying effects of the interstellar medium. Any deviations from the predictions based on the timing model will represent the impact of intrinsic or extrinsic effects to the pulsar signal due to e.g. changing interstellar weather or propagating gravitational waves. Main goals from pulsar timing observations with SKA1 • detect GWs: correlate the arrival times of a set of highly stable MSP, and derive a common signal (Janssen et al. 2015). • test theories of gravity by measuring relativistic effects in binaries (Shao et al. 2015) • Follow-up timing of newly discovered sources (Keane et al. 2015) • study ISM by observing at multiple frequencies (Han et al. 2015) The SKA1 will improve on all aspects and goals of pulsar timing by the increased sensitivity, cadence and the number of pulsars that can be observed on a regular basis. Moreover, with the closely linked planned pulsar survey observations many useful new pulsars will be discovered (Keane et al. 2015).

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
	X	Non-imaging pointings
Number of targets	Up to ~11000: ~9000 Slow pulsars; 1500 MSPs; 50 PTA targets (estimates only) these will be distributed, in some cases across the lifetime of the pulsar search projects/KSPs.	
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?	Y	YES [details: depending on source..]
		NO
Integration time per target (hrs)	Depending on source, 3 – 300min	
Average peak flux density (Jy or Jy per beam)	Depending on source	
Range of peak flux densities (Jy or Jy per beam)	Depending on source	
Expected polarised flux density (expressed as % of total)	Up to 100%	

OBSERVATIONAL SETUP : *BEAMFORMER (X) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Centre frequencies of bands
Total Bandwidth (MHz)	Max available bandwidth
Minimum and maximum frequency over the entire range of the setup (MHz)	

Spectral resolution (kHz)	Nyquist (baseband)
Temporal resolution (in seconds)	Nyquist, < 100 ns

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)	N/A	
Maximum baseline required (km)	Up to 10 km to give sufficient sensitivity	
Primary beam size (sq degrees)	N/A	
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)	>300 MHz, up to 2.5 GHz, i.e. maximum available bandwidth at Band 5 for GC observations	
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
	▯	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a ‘support image’ in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	

Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%

		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Incoherently and coherently dedispersed time series of sub-array beams. RFI mitigation and full polarisation calibration should be possible. Frequency resolution (sub-banding required).
Processing considerations	

(e.g. flag high wind speed data, reprocessing required?)	
Data products	Pulse phase-resolved observations supporting the product of the number of phase bins, channel and polarisation products up to 262,144 (e.g. 1024 x 32 x 4). Providing pulsar phase bin widths with a time resolution of better than 10us. Subbands required.
Description of pipeline	Coherent dedispersion, RFI mitigation, Polarisation calibration, folding of all Stokes parameters
Quality assessment plan & cadence	Depending on source
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	It should be possible to switch between observing bands within 30 sec.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Each data sample shall be traceable to a time code with an accuracy better than 10 ns over a period of 1 observation to 10 years for each individual Pulsar timing observation Cross polarisation ratio for Pulsar timing shall be at least 15 dB over the whole observing bandwidth within the half power beam width Accurate pointing for the beams using accurate phase solutions.

REFERENCES
Eatough et al. 2015, AASKA(045) Han et al. 2015, AASKA(041) Janssen et al. 2015, AASKA(037) Keane et al. 2015, AASKA(040) Kramer & Stappers 2015, AASKA(overview) Paragi et al. 2015, AASKA(143) Shao et al. 2015, AASKA(042)

2.55 Galactic Centre Pulsar Survey

PROJECT DETAILS	
Title	A high frequency pulsar survey of the Galactic centre with SKA1-MID
Principal Investigator	R. P. Eatough
Co-Authors	the pulsar team
Time Request	6 -11 hrs x3 (for each frequency), per session - TBC

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	TBD

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
X	SKA1-MID Band 3	6 -11 hrs - TBC
X	SKA1-MID Band 4	6 -11 hrs - TBC
X	SKA1-MID Band 5	6 -11 hrs - TBC
	SKA1-SURVEY Band 1	
	SKA1-SURVEY Band 2	
	SKA1-SURVEY Band 3	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
X	Normal	Non-imaging processing/ Pulsar Search Engine/ raw voltage dumps
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
	Commensal	

	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Survey region: The target pulsars, i.e. those that can be used to probe the space-time of Sgr A* will lie within less than an arcsecond of this object. Pulsars up to a few arcminutes (e.g. 10'-15') from Sgr A* can be used for probing the origins of the extreme ionised and magnetised interstellar medium in the Galactic Centre, and should also be observed. To cover this region, and to rule out false positive pulsar candidates, a number of simultaneous synthesised beams should be used. **Survey integration time and repetition:** The proposed survey region is small, and as such sensitivity can be improved by performing a small number of long integrations (e.g. the order of hours). This is also beneficial for the detection of any putative relativistic binary pulsar systems as all orbital phases are covered in a single observation. Multiple passes (separated by months to years) are proposed since pulsars in binary systems or orbiting Sgr A* may precess into the line of sight on these time-scales. **Observing set-up and frequencies:** Fast sampled multi-channel pulsar search data (ideally for all four Stokes parameters to measure Faraday Rotation) should be taken at each observing frequency. Alternatively, raw voltages from a small number of beams could be acquired in order to perform "coherent dedispersion" which would improve sensitivity to narrow pulses (see ECP140036). The latter might not be necessary for band 5 observations. Based on the observed scattering in the Galactic Centre magnetar, PSR J1745-2900 (Spitler et al., 2014), the frequencies covered by bands 3, 4, and 5 should be used to detect the full range of pulsar spin periods. Note, Faraday rotation might become an important discriminator for real pulsars in the absence of dispersion at higher frequencies.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (X) or CORRELATOR (__)*			
	XX	**X**	Stokes I
	YY	**X**	Stokes Q
	XY	**X**	Stokes U
	YX	**X**	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
This survey aims to discover pulsars towards the Galactic Centre, and orbiting Sgr A*. In order to overcome interstellar scattering toward the Galactic Centre (which smears out the pulses from pulsars), and to retain sensitivity to all pulsar spin periods, these observations must be done at frequencies from 2.4 to 9 GHz, with high spectral and temporal resolution. The science aims (see Eatough et al., 2014) will be to: measure the mass of Sgr A* to a precision of 1 solar mass; measure the spin of the central Black Hole, testing the "cosmic censorship conjecture"; measure the quadrupole moment of the central Black Hole, testing the "no-hair theorem"; place limits on the dark matter content in the Galactic Centre; map the magnetized and ionized interstellar medium in the immediate vicinity of the supermassive Black Hole, giving insight into the accretion process onto this object (Eatough et al., 2013).

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
	X	Non-imaging pointings
Number of targets	Tied array beams to adequately sample primary beam with 1500 search beams (approximately equivalent to Nyquist sampling ~80% of the primary beam). Pointings to ~0.25 degrees of the Galactic Centre	
Positions of targets	Multiple targets within ~0.25 degrees of Galactic Centre.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………..]
	X	NO
Time Critical?		YES [details: ……………………………………..]
	X	NO
Integration time per target (hrs,mins,secs as appropriate)	TBCs	

Average peak flux density (Jy per beam)	TBD
Range of peak flux densities (Jy per beam)	TBD
Expected polarised flux density (expressed as % of total)	Up to 100%

OBSERVATIONAL SETUP : *BEAMFORMER (X) or CORRELATOR (__)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Centre frequency of 2.4, 4 and 9 GHz. Note ideal frequencies still to be determined.
Total Bandwidth (MHz)	>300 MHz
Spectral resolution (kHz)	In the range 300 to 3000 kHz
Temporal resolution ('dump' time in s or 'standard')	64 microsec

NON-IMAGING SPECIFIC CONSIDERATIONS		
Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (continuum – single channel of full bandwidth)	
Required angular resolution (arcsec) (single value or range)	N/A (non-imaging processing)
Required image size (arcsec) (single value or range)	N/A (non-imaging processing)
Required rms (Jy per beam)	N/A (non-imaging processing)

(if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)	N/A (non-imaging processing)	
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	X	n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcsec) (single value or range)	N/A (non-imaging processing)	
Required image size (arcsec) (single value or range)	N/A (non-imaging processing)	
Number of image channels	N/A (non-imaging processing)	
Channel width (kHz)	N/A (non-imaging processing)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	N/A (non-imaging processing)	
Dynamic range within image per channel (if polarisation products required define for each)	N/A (non-imaging processing)	
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	X	n/a

DATA ANALYSIS

Procedures required	[All will be part of the 'Pulsar Search Engine'] RFI mitigation, incoherent de-dispersion, time domain and frequency domain acceleration processing, forming power spectra, thresholding and detection
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	All within the pulsar search engine
Data products	A candidate list, with for each candidate: Sky position, pulse-average, total intensity, flux density, period, dispersion measure, pulse archive, DM – SNR data, and three 3-dimensional data cubes {DM – TIME – SNR; Pulse Phase – Frequency Channel – Intensity; Pulse Phase – subintegrations – Intensity }. Possibly raw voltages (see ECP140036).
Description of pipeline	See Stappers et al. whitepaper in CSP Technical proposal.
Quality assessment plan & cadence	Includes amplitude, phase, polarisation, dispersion measure, period and acceleration, flag tables, candidate statistics. Also RFI statistics will be very important.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
- Will single extended integration times (i.e. many hours) be possible? - For this kind of targeted survey, can the data be stored and processed offline? The data analysis could be more sophisticated than for the all sky pulsar survey, due to the reduced data volume. - What are the available bandwidths in each frequency band? - Can all 4 Stokes parameters be taken in pulsar search mode? - Will it be possible to dump the raw voltages from a small number of beams in order to perform coherent dedispersion.

REFERENCES
Spitler et al., 2014, 780L, 3S Eatough et al., SKA science book chapter, “Radio Pulsars in the Galactic Centre” Eatough et al., 2013, Nature, 501, 391E

2.56 Understanding the magnetospheres of pulsars using single pulses

PROJECT DETAILS	
Title	**Understanding the magnetospheres of pulsars using single pulses**
Principal Investigator	**Aris Karastergiou (as main author of this draft)**
Co-Authors	
Time Request	~300 h/telescope/ year (considerations: X pulses from Y pulsars every Z days, e.g X=[50000 for MSPs and 4000 for slow pulsars], Y=60 [60 pointings using subarrays, of a population of 25 MSPs and 300 slow pulsars]. Z=30 [24 epochs]

FACILITY		Preconditions
X	SKA1-LOW	Dual polarization, tied array beams from core.
X	SKA1-MID	As with LOW.

RECEIVER(S) REQUIRED	Time (hrs)

X	SKA1-LOW	100% of time request
X	SKA1-MID Band 1	100%, in sub-array mode (depends on policy for multi-frequency obs)
X	SKA1-MID Band 2	100%, in sub-array mode
X	SKA1-MID Band 3	100%, in sub-array mode
X	SKA1-MID Band 4	50%, in sub-array mode (longer integrations on pulsars with flatter spectra)
X	SKA1-MID Band 5	20%, in sub-array mode (is in band 4)

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
X	Fixed schedule (give cadence)	~ monthly
	Time-critical override	
	Custom Experiment	
	Commensal	**Fast transient searches could be carried out commensally**
	Collaborative & Coordinated	
X	Sub-arrays required	**widest band observations**

COMMENTS ON OBSERVING STRATEGY
If possible, it would be very useful to sometimes record the coherent data allowing for offline coherent dedispersion and other coherent processing steps (e.g. cyclic spectroscopy) to extract the most information from the data possible. (Relies on dynamic spectrum mode, see ECP150011)

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX		Stokes I
X	YY		Stokes Q
X	XY		Stokes U
X	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The objective of this Use Case is to understand how pulsar magnetospheres produce the polarized radio emission that we observe and how magnetospheric processes affect the rotational properties of pulsars. The sensitivity of the SKA will significantly increase the numbers of pulsars with high S/N single pulses. Simultaneous, multi-frequency observations of targeted pulsars,using the sub-array capability, will allow us to trace frequency-dependent polarization profiles, building a clear picture of the emission structure of the magnetosphere. With this Use Case we will understand the mechanism that sets the observed polarization, which will also then allow us to determine the main parameters of each pulsar's geometry. This will also allow us to disentangle magnetospheric effects from effects caused by propagation in the interstellar medium. Of particular importance is the population of MSPs that we propose to monitor. In particular, it has been shown in slow pulsars that their magnetospheric behaviour can be correlated to spin irregularities. With SKA, we will have the opportunity to study individual pulses from a significantly larger population than the currently available (~3) to understand the origins of this behaviour. This will also give us the opportunity to study the differences between MSP and slow pulsar magnetospheres, and provide geometry information.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	X	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	50 per 416h proposal	
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ………………………………………..]
	X	NO

Time Critical?		YES [details: ……………………………………….]
	X	NO
Integration time per target (hrs)	4000 rotations per slow pulsar (~2000s) 50000 per MSP (500s).	
Average peak flux density (Jy or Jy per beam)	~0.1 mJy continuum equivalent flux density	
Range of peak flux densities (Jy or Jy per beam)	~0.01 – 10 mJy continuum equivalent flux density	
Expected polarised flux density (expressed as % of total)	0-100%	

OBSERVATIONAL SETUP : *BEAMFORMER (X) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	TBD
Total Bandwidth (MHz)	Full bandwidth per band
Minimum and maximum frequency over the entire range of the setup (MHz)	Full extent of available bands; i.e. for LOW 50MHz to 350 MHz; for MID 350 MHz (bottom of Band 1) to 13.8 GHz or 23 GHz (top of Band 5)
Spectral resolution (kHz)	Coherent data
Temporal resolution (in seconds)	Native resolution

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	NA
Maximum baseline required (km)	NA
Primary beam size (sq degrees)	NA
Number of output channels	>512 for Stokes data
Output bandwidth (minimum and maximum frequency - MHz)	Full bandwidth available; Sub-arrays as mentioned above.

Required rms (Jy) (if polarisation products required define for each)	It is more reasonable to specify a required number of periods (Periods given in time request)	
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration	X	1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%

		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	
Mapped image size (degrees)	
Number of image channels	

Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Flux calibration, RFI mitigation, polarization calibration, RM determination and removal
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	Coherent voltage data for MSPs at least. Stokes data would be useful for fast data analysis.
Description of pipeline	Minimal online processing. For offline processing: dspsr for dedispersion and detection, PSRCHIVE style tools for calibration, RFI mitigation and single pulse processing.
Quality assessment plan & cadence	The data will be assessed within 48 h to evaluate whether the observations need repeating

Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	24 hours after completion of each epoch.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES
Kramer & Stappers, 2015, "Pulsar Science with the SKA", PoS(AASKA14)036, "Advancing Astrophysics with the Square Kilometre Array". Karastergiou et al., 2015, "Understanding pulsar magnetospheres with the SKA", PoS(AASKA14)038, "Advancing Astrophysics with the Square Kilometre Array". Tauris et al., 2015, "Understanding the Neutron Star Population with the SKA", PoS(AASKA14)039, "Advancing Astrophysics with the Square Kilometre Array".

2.57 Parallax measurement of Southern hemisphere pulsars

PROJECT DETAILS	
Title	**Parallax measurement of Southern Hemisphere pulsars**
Principal Investigator	**A. Deller on behalf of the Pulsar SWG**
Co-Authors	**The pulsar astrometry team**
Time Request	800 hours

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	800
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE	Details

(as defined in Concept-of-Operations)		
	Normal	
X	Fixed schedule (give cadence)	8 epochs over 18 months per source, 50 sources (spread in RA, but concentrated in the plane and towards the Galactic Centre).
	Time-critical override	
	Custom Experiment	
	Commensal	Commensal fast transient observations could make use of the voltage data to follow up candidates.
X	Collaborative & Coordinated	Simultaneous availability of Long Baseline Array including Hartebeestok, EVN antennas, African VLBI Network antennas, and SKA1-MID
	Sub-arrays required	Subarrays may be requested for some targets

COMMENTS ON OBSERVING STRATEGY
Observations will need to be fixed time, scheduled using SKA-VLBI access agreements, in order to enable the other elements of the VLBI array to participate. In order to sample the parallax signature most effectively, epochs will ideally be observed within +/- 1 week of the optimal time, which depends on their right ascension. Some grouping of target sources is likely to be possible. Subarrays may be used for some bright targets (for which the full sensitivity is not required), enabling a separate SKA1-mid observation to take place while just a few antennas are used for SKA-VLBI. The assumed configuration of other participating VLBI stations is 5-10 25m-class stations + ASKAP; unless subarrayed, SKA1-mid dominates the sensitivity. Band 2 (for observations at 1.2-1.7 GHz) would be used for almost all cases if only bands 1/2/5 are available; for some bright and/or strongly scattered pulsars, observations at higher frequency may be preferred (band 5 at 8 GHz; if bands 3 and 4 became available, then observations at 2.3 or 4.8 GHz would be useful in more cases than band 5). More details are given in Paragi et al. (2015). Primary output from the SKA-VLBI antennas is N VLBI data streams (where N is 1,2,3, or 4) that are centred on a target and one or more calibrator sources. Normal interferometer data should be produced from the antennas participating in SKA-VLBI observations, to provide absolute amplitude calibration. Every attempt should be made to ensure that the gain of the SKA1-mid voltage beams are as stable as possible, since these will likely be used to refine the pulsar ephemeris for the target

pulsars (unless the pulsar timing backend at SKA1-mid can run in parallel to VLBI observing, which would be an even better solution).

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY	X	Stokes Q
	XY	X	Stokes U
	YX	X	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Parallax measurements of millisecond pulsars to obtain precision astrometry (position, proper motion and parallax), which will be used to improve the pulsar timing model for the system. This will enable improved strong-field tests of gravity, one of the key SKA science goals (Shao et al., 2015). Other science benefits include studying the neutron star equation of state and better modeling the Galactic electron density distribution (Han et al. 2015, Tauris et al. 2015, Janssen et al. 2015). As shown below, the precision of SKA1-VLBI astrometry on a typical pulsar target will be comparable to the best possible precision with GAIA, and for “bright” sources (≥ 0.5 mJy) it will be possible to approach a parallax error of ~3 micro-Jy, several times better than GAIA’s best (Paragi et al., 2015). The necessary astrometric accuracy (and hence required S/N ratio on target) will depend on the distance to each individual system. Here we take 30 micro-arcseconds per epoch as a fiducial value, sufficient to yield a parallax accuracy of 10 micro-arcseconds and hence a distance accurate to 1% at 1 kpc / 10% at 10 kpc. Assuming a VLBI beam size of 6 mas, attaining 30 micro-arcsecond per-epoch accuracy requires a S/N ratio of 100. The required on-source time then depends on the target brightness; we have used 100 microJy as a fiducial value and assumed a pulse duty cycle of ~10% (meaning the “gated equivalent” flux density of 3x higher, or 300 microJy), which means a noise value of 3 micro-Jy is required – this will take 2 hours on-source. Some sources will require longer, many will not need this much time.

‘TARGETS’ OF OBSERVATIONS		
Type of observation (what defines a ‘target’)		Individual pointings per object
	X	Individual fields-of-view with multiple objects

		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	50	
Positions of targets	Spread in RA and declination, but concentrated at lower Galactic latitudes for all but the closest pulsars. In Galactic longitude, many targets will be close to 0 degrees.	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?	X	YES to be observed close to desired dates for good sampling of parallax extrema
		NO
Integration time per target (hrs)	16 hours per source (8 x 2 hours per observation)	
Average peak flux density (Jy or Jy per beam)	100 microJy (assumed pulse duty cycle ~10%, corresponding to an equivalent peak flux density of 300 microJy after pulsar gating)	
Range of peak flux densities (Jy or Jy per beam)	60 microJy minimum (would take 6 hours per obs), ~few mJy maximum (no longer sensitivity-limited, could be as short as 30 min per observation)	
Expected polarised flux density (expressed as % of total)	Varies depending on source up to close to 100%; not important for the science case.	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (X)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1.6 GHz
Total Bandwidth (MHz)	500 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	1250-1750 MHz

Spectral resolution (kHz)	Standard continuum standard spectral resolution, e.g. 0.5 MHz
Temporal resolution (in seconds)	Standard continuum temporal resolution, e.g. 1 s
OBSERVATIONAL SETUP : *BEAMFORMER (X) or CORRELATOR ( )*	
Central Frequencies (MHz) (including redshift, observatory correction)	1.6 GHz
Total Bandwidth (MHz)	500 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	1250-1750 MHz
Spectral resolution (kHz)	16, 32, 64 or 128 MHz bands ("VDIF" VLBI output format).
Temporal resolution (in seconds)	Nyquist sampled

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	May be observation specific, but by far the most common case will be ~0.05 arcmin (by going to the maximum baseline practical before re-phasing starts to become a problematic overhead).
Maximum baseline required (km)	In the most common case, ~15 km or so. Needs to be user-selectable on a per-observation basis to allow control over the tied array beam size (in some cases, a shorter max baseline and hence larger tied array beam will be desirable to fit several targets into a single beam) and how frequently the array needs to be recalibrated.
Primary beam size (sq degrees)	0.5
Number of output channels	Depends on the output subband bandwidth. For a default case of 32 MHz bands, this equates to 16 subbands x 2 polarisations.
Output bandwidth (minimum and maximum frequency - MHz)	Minimum 16 MHz, maximum 128 MHz (set based on the capabilities of the other VLBI antennas participating.)
Required rms (Jy) (if polarisation products required	Not directly applicable.

define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	0.01-0.1.	
Maximum baseline required (km)	Set to the same value as is used for the formation of the VLBI beam, so typically ~15 km. If the more distant stations can also be included, that is welcome, but not required.	
Mapped image size (degrees)	1	
Required pixel resolution (arcseconds)	0.5 (for the canonical case of 15 km max baseline)	
Number of output channels	10 (to provide basic spectral index information for sources in the field)	
Output bandwidth (minimum and maximum frequency - MHz)	1250-1750 MHz	
Required rms (Jy per beam) (if polarisation products required define for each)	3e-6 for a typical observation of ~2 hour	
Dynamic range within image (if polarisation products required define for each)	100,000 to 500,000	
Absolute flux scale calibration		1-3%

	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (milliarcseconds) (single value or range)	5-10
Mapped image size (arcseconds)	5 (set by the tied array beam size of SKA1-

	mid)	
Number of image channels	10	
Channel width (kHz)	50,000	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	Typically ~10e-6 (depends on the pulsar brightness and hence observation time. Most stringent case will approach 5e-6)	
Dynamic range within image per channel (if polarisation products required define for each)	100,000	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Correlator: standard Beamformer: Will use standard VLBI techniques.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Production of flag table covering timeranges where beamformer sum is not present (e.g., slewing) or corrupted (e.g., due to failed antenna). Production of estimated system temperature table for beamformer sum, for use in VLBI processing.
Data products	Correlator: standard Beamformer: VDIF baseband data (includes metadata eg time stamps. Description of VDIF standard is available at http://vlbi.org/vdif/)
Description of pipeline	Correlator: standard Beamformer: Realtime data transport to VLBI correlator (could be in Perth, Hobart, Europe…) this requires 20 Gbps link for realtime correlation. Alternative is recording to harddisk on-site or in

	Geraldton or Perth.
Quality assessment plan & cadence	Records of delays, phases, fringe rates, amplitude calibration corrections that can be used to estimate sensitivity and compared to nominal values. Feedback will be supplied after VLBI correlation and analysis, and should be provided for every observation. The time to VLBI correlation will dominate the lag between observation and the provision of feedback – the quality assessment should be an integral part of the correlation process.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	For the VLBI data itself, obviously this needs to be available in real time. For the commensal SKA1 imaging, this can be upon completion of the scheduling block and pipeline reduction

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Most importantly, agreements covering the proposing and scheduling of VLBI observations need to be made. The LBA, EVN, GMRT and EAVN are all potential partners for VLBI observing and expertise. The location of the VLBI correlator and hence the manner in which SKA1-mid baseband data is transported to the correlator (via high-speed network in real time, buffer + slower than real-time network, network partway + transportable media hybrid, …) remains to be determined. The availability of other VLBI-capable antennas in Africa has the potential to strongly influence the available uv coverage for VLBI observations (which although not directly critical for point-source astrometry, does impact the ability to model calibrator sources and minimise source

structure effects). The production of flag and system temperature tables for use during VLBI data reduction has not yet been planned and will need to be addressed during the commissioning period.

REFERENCES
Paragi Z., et al., 2015, AASKA2014, 143 Shao L., et al., 2015, AASKA2014, 42 Han J., et al., 2015, AASKA2014, 41 Tauris T. M., et al., 2015, AASKA2014, 39 G., et al., 2015, AASKA2014, 37

2.58 Galactic Structure using maser parallax measurements

PROJECT DETAILS	
Title	**Galactic Structure using maser parallax measurements**
Principal Investigator	**Simon Ellingsen**
Co-Authors	**Andreas Brunthaler, Huib van Langevelde, Hiroshi Imai**
Time Request	1500 hours

FACILITY		Preconditions
	SKA1-LOW	

X	SKA1-MID	100% of SKA1-mid collecting area phased up, simultaneous availability of LBA (Long Baseline Array), AVN (African VLBI Network) and EVN (European VLBI Network) antennas.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
X	SKA1-MID Band 5	1500

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
X	Fixed schedule (give cadence)	4 epochs over a 1-2 year period close to the date where the parallax signature is largest (March and September)
	Time-critical override	
	Custom Experiment	
	Commensal	
X	Collaborative & Coordinated	Simultaneous availability of Long Baseline Array (Australia), African VLBI Network and European VLBI Network antennas with 6.7 GHz receiver capability
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Scheduling commensal with VLBI network. At least 4 phased beams required, 3 for calibrators,

1 for target. For some targets up to 10 beams could be utilized if available. Observe International Celestial Reference Frame (ICRF) sources. Primary output is VLBI-formatted beamformed data, normal imaging data should be taken in parallel. Sources need to be observed at 4 epochs spread over 18-24 months at times when the parallax signature is greatest.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Parallax measurements of interstellar masers can provide accurate (4% at 8 kpc) distances to the population of young, high-mass star formation regions which define the spiral arms. This project will measure parallax distances to 300 southern sources to obtain a southern sample equivalent to those currently being obtained in the northern hemisphere. These observations will produce the most accurate measurements to date of the basic Galactic parameters such as the radius and speed of rotation of the solar system about the Galactic centre and also of the distances to the individual star formation regions. We are seeking an astrometric accuracy of 5 µas from 4 epochs of observing, which provides distances accurate to 1% for sources at 2 kpc (the nearest spiral arm), falling to 5% at 10 kpc. We will select 6.7 GHz methanol maser targets with a peak flux density greater than 0.7 Jy and a background quasar stronger than 0.5 mJy within the SKA1-mid FoV. A single epoch astrometric accuracy of 10 µas (to achieve 5 µas over 4 epochs) requires an SNR of 60, hence an RMS noise level in the continuum images of 8 µJy/beam. This requires 1 hour on-source per field per epoch.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
	1.	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings

Number of targets	300 6.7 GHz methanol masers covering a range of Galactic longitudes and LSR velocities.	
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	1.	NO
Time Critical?	X	YES [details: Observations required near the equinoxes to maximise the amplitude of the parallax signal. Time window is of the order of 4 weeks]
		NO
Integration time per target (hrs)	60 minutes per field per epoch.	
Average peak flux density (Jy or Jy per beam)	0.5 mJy for in-beam background quasar.	
Range of peak flux densities (Jy or Jy per beam)	Expect 3 sources per field stronger than 0.15 mJy	
Expected polarised flux density (expressed as % of total)	Small, few percent maximum	

OBSERVATIONAL SETUP : *BEAMFORMER (X) or CORRELATOR (X)*	
Central Frequencies (MHz) (including redshift, observatory correction)	6666 – 6672 MHz
Total Bandwidth (MHz)	500 MHz (dual polarization)
Minimum and maximum frequency over the entire range of the setup (MHz)	Exact values not important, but will utilise as large a spread in bandwidth as can be accommodated by the receiver/backend hardware to obtain optimal calibration of the zenith tropospheric delay
Spectral resolution (kHz)	2 kHz for 2 MHz around maser frequency, standard continuum for full 500 MHz band
Temporal resolution (in seconds)	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)	0.1 arcseconds or larger	
Maximum baseline required (km)	N/A, phasing of full array	
Primary beam size (sq degrees)	0.015 square deg (SKA1-mid 6.7 GHz FoV)	
Number of output channels	2048 channels per VLBI baseline per pol product	
Output bandwidth (minimum and maximum frequency - MHz)	500 MHz (preferably 6.4 – 6.9 GHz, but exact range not important as long as it includes the 6.7 GHz methanol line).	
Required rms (Jy) (if polarisation products required define for each)	8 μJy $beam^{-1}$	
Dynamic range (if polarisation products required define for each)	60:1	
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a ‘support image’ in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	0.015 arcmin
Maximum baseline required (km)	N/A, phasing of full array
Mapped image size (degrees)	N/A VLBI imaging
Required pixel resolution (arcseconds)	N/A VLBI imaging
Number of output channels	1024
Output bandwidth (minimum and	500 MHz (preferably 6.4 – 6.9 GHz, but exact range not important as long as it includes the 6.7

maximum frequency - MHz)	GHz methanol line).	
Required rms (Jy per beam) (if polarisation products required define for each)	8 μJy beam^{-1}	
Dynamic range within image (if polarisation products required define for each)	60:1	
Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	0.015 arcmin	
Maximum baseline required (km)	N/A, phasing of full array	
Mapped image size (degrees)	N/A VLBI imaging	
Required pixel resolution (arcseconds)	N/A VLBI imaging	
Number of image channels	1024	
Channel width (kHz)	2.2	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	1.2 mJy/beam	
Dynamic range within image per channel (if polarisation products required define for each)	600:1 – 6000:1 (depending on source)	
Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%

		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)	1.2 milliarcseconds (8000 km VLBI baselines at 6.7 GHz)	
Mapped image size (degrees)	1 arcsecond for each phased-array beam (one for maser), remaining on background calibrator targets within FoV	
Number of image channels	1024 (maser) / 1024 (calibrators)	
Channel width (kHz)	2.2 kHz (maser) / 500 kHz (calibrators)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	1.2 mJy beam^{-1} (maser) / 8 μJy beam^{-1} (calibrators)	
Dynamic range within image per channel (if polarisation products required define for each)	600 – 6000:1 (maser) / 60:1 (continuum)	
Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Correlator: standard Beamformer: Will use standard VLBI techniques
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Flag data for antennas off-source
Data products	Correlator: standard Beamformer: VDIF baseband data (includes metadata

	eg time stamps. Description of VDIF standard is available at http://vlbi.org/vdif/)
Description of pipeline	Correlator: standard Beamformer: Streaming of data to appropriate VLBI correlator. Data rate for phased SKA-mid is 4 Gbps per beam, although project could utilise higher data rates, if they were available. Data from outstations (LBA, AVN etc) also to be streamed to VLBI correlator site.
Quality assessment plan & cadence	Records of delays, phases, fringe rates.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of scheduling block and pipeline reduction.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Requirements for this project are very similar to those for "Parallax measurements of southern hemisphere pulsars". Specifically, an accurate frequency standard (e.g. hydrogen maser) at each VLBI site. For in-beam calibration it is desirable if as many VLBI sites as possible have the same FoV as the SKA1-mid antennas, this technique is more complicated for a heterogeneous VLBI array. For heterogeneous arrays with some larger diameter (smaller FoV) antennas in-beam phase calibration will only be possible for a subset of sources where suitable calibrators are within the FoV of the larger antennas.

REFERENCES

2.59 **Exploration of the dynamics of the Galactic Bulge**

PROJECT DETAILS	
Title	**Exploration of the dynamics of the Galactic Bulge using OH maser parallax measurements**
Principal Investigator	**Hiroshi Imai**
Co-Authors	**Gabor Orosz, Ross A. Burns, Naoteru Goda, Tahei Yano, Yoshiyuki Yamada, Naoko Matsumoto**
Time Request	2000 hours

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	70% of SKA1-MID collecting area phased up, simultaneous availability of LBA (Long Baseline Array), AVN (African VLBI Network) and EVN (European VLBI Network) antennas.
	SKA1-SURVEY	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
X	SKA1-MID Band 2	2000
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	
	SKA1-SURVEY Band 1	

	SKA1-SURVEY Band 2	
	SKA1-SURVEY Band 3	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
X	Fixed schedule (give cadence)	4 epochs over a 1-2 year period close to the date where the parallax signature is the largest (March and September)
	Time-critical override	
	Custom Experiment	
X	Commensal	Pulsar astrometry towards the Galactic Centre
X	Collaborative & Coordinated	Simultaneous availability of Long Baseline Array (Australia), African VLBI Network and European VLBI Network antennas with 1.6-1.7 GHz receiver capability
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Scheduling commensal with VLBI networks. At least 4 phased beams required, 3 for calibrators, 1 for target. For some targets up to 10 beams could be utilized if they were to become available. Need to observe International Celestial Reference Frame (ICRF) sources. Primary output is VLBI-formatted beamformed data, normal imaging data should be taken in parallel. Sources need to be observed at 4 epochs spread over 18-24 months at times when the parallax signature is greatest (March and September).

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**X**	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Parallax measurements of circumstellar and interstellar hydroxyl masers can provide reliable (relative uncertainty ~10% at 8 kpc) distances to evolved stars and massive young stars in the Galactic Bulge. This project will measure parallax distances and proper motions of 500 sources to sample these stars in the 6-dimensional phase space (X, Y, Z, V_X, V_Y, V_Z), free from interstellar extinction. The kinematic information will be used for elucidating the dynamics of the inner Galactic bulge in order to understand the co-evolution of the central massive black hole with the bulge. We are seeking an astrometric accuracy of 20 µas from each of 4 observation epochs using in-beam astrometric technique. This will provide distances accurate to 10% for sources at 10 kpc (behind the bulge). We will select 1.6 GHz hydroxyl maser targets with a peak flux density greater than 0.3 Jy and a background quasar brighter than 2.0 mJy within the SKA1-MID FoV. A single epoch astrometric accuracy of 20 µas (to achieve 10 µas over 4 epochs) requires an SNR of 300, hence an RMS noise level in the maser and continuum images of 0.9 mJy/beam and 6.7 µJy/beam, respectively. This requires 1 hour on-source per field per epoch.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
	X	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	500 1.6 GHz hydroxyl masers	
Positions of targets	Within +/- 2 degrees of Galactic longitude and latitude	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	X	NO
Time Critical?	X	YES [details: Observations required near the equinoxes to maximise the amplitude of the parallax signal. Time window is of the order of 4 weeks]
		NO
Integration time per target (hrs)	1 hour per field per epoch.	
Average peak flux density	2.0 mJy for in-beam background quasar.	

(Jy per beam)	
Range of peak flux densities (Jy per beam)	Expect 3 sources per field stronger than 0.15 mJy
Expected polarised flux density (expressed as % of total)	Small, few percent maximum

OBSERVATIONAL SETUP : *BEAMFORMER (X) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1480 MHz (maser lines at 1612, 1665, 1667, 1720 MHz)
Total Bandwidth (MHz)	500 MHz (dual polarization)
Spectral resolution (kHz)	1 kHz for 0.5 MHz around maser frequency, standard continuum for full 500 MHz band
Temporal resolution ('dump' time in s or 'standard')	Standard

NON-IMAGING SPECIFIC CONSIDERATIONS		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	X	n/a

IMAGING CONSIDERATIONS (continuum – single channel of full bandwidth)	
Required angular resolution (arcmin) (single value or range)	0.015 arcmin
Single Field-Of-View or mapped image size (degrees)	0.48 degree (SKA1-MID 1.6 GHz FoV)
Required rms (Jy per beam)	6.7 μJy beam^{-1}

(if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)	300:1	
Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	0.015 arcmin	
Single Field-Of-View or mapped image size (degrees)	0.48 degree (SKA1-MID 1.6 GHz FoV)	
Number of image channels	1024	
Channel width (kHz)	1.0	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	0.9 mJy beam^{-1}	
Dynamic range within image per channel (if polarisation products required define for each)	300 : 1 (depending on source)	
Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)	12 milliarcseconds (3000 km VLBI baselines at 1.6 GHz)	
Single Field-Of-View or mapped image size (degrees)	1 arcsecond for each phased-array beam (one for maser), remaining on background calibrator targets within FoV	
Number of image channels	1024 (maser) / 1024 (calibrators)	
Channel width (kHz)	1.0 kHz (maser) / 500 kHz (calibrators)	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	0.9 mJy beam^{-1} (maser) / 6.7 μJy beam^{-1} (calibrators)	
Dynamic range within image per channel (if polarisation products required define for each)	300:1	
Absolute flux scale calibration		1-3%
		5%
	X	10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Correlator: standard Beamformer: Will use standard VLBI techniques
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Flag data for antennas off-source GPS data will be useful for atmospheric calibration
Data products	Correlator: standard Beamformer: VDIF baseband data (includes metadata eg time stamps. Description of VDIF standard is available at http://vlbi.org/vdif/) Moderate channel spacings (0.5 - 8 MHz) are suitable for cross correlation between the SKA1-MID and other stations with channel spacing compatibility.

Description of pipeline	Correlator: standard Beamformer: Streaming of data to appropriate VLBI correlator. Data rate for phased SKA1-MID is 4 Gbps per beam, although project could utilise higher data rates if available. Data from outstations (LBA, AVN etc) also to be streamed to VLBI correlator site.
Quality assessment plan & cadence	Records of delays, phases, fringe rates

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Requirements for this project are very similar to those for "Parallax measurements of southern hemisphere pulsars". Specifically, an accurate frequency standard (e.g. hydrogen maser) at each VLBI site. For in-beam calibration it is desirable if as many VLBI sites as possible have the same FoV as the SKA1-MID antennas, this technique is more complicated for a heterogeneous VLBI array. For such arrays with some larger diameter (smaller FoV) antennas in-beam phase calibration will only be possible for a subset of sources where suitable calibrators are within the FoV of the larger antennas.

REFERENCES

Ellingsen, S., et al. 2014, SKA Science Use Case, "Galactic Structure using maser parallax measurements"

Ptolemy, C., and the SKA Pulsar Team, 2014, SKA Science Use Case, "Parallax measurements of southern hemisphere pulsars"

Etoka, S., et al. 2015, AASKA14, 125, "OH masers in the Milky Way and Local Group

galaxies in the SKA era"

2.60 Resolving ultra-relativistic outflows in Gamma-Ray Bursts (Supernovae, Tidal Disruption Events etc.) with SKA-VLBI

PROJECT DETAILS	
Title	**Resolving ultra-relativistic outflows in Gamma-Ray Bursts (Supernovae, Tidal Disruption Events etc.) with SKA-VLBI**
Principal Investigator	**Zsolt Paragi**
Co-Authors	**Alexander van der Horst, Miguel Pérez-Torres** for the VLBI working group
Time Request	5x3 hours (for VLBI monitoring of a single target at 5 epochs)

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	Forming multiple tied-array beams, monitored for phasing-up stability, shadowing and individual antenna data quality. Standard VLBI data format output, parallel local interferometer data products, VLBI data streaming (real-time e-VLBI or buffering+electronic shipment), and flexibility to target of opportunity observations as well as accurate calibration of the tied-array beams are required as well.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	

	SKA1-MID Band 4	
X	SKA1-MID Band 5	5x3 hours

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
	Fixed schedule (give cadence)	
X	Time-critical override	SKA-VLBI observations triggered either from another instrument (X-ray, optical or radio detection of a GRB afterglow), or directly from an SKA1- mid detection.
	Custom Experiment	
X	Commensal	Possibly, with SKA1-MID transient follow-ups
X	Collaborative & Coordinated	Will have to coordinate the SKA-VLBI observations with radio observatories.
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Rapid turnaround of results during the first epoch is essential, where the selection of best calibrators will be finalized. Later it will help define the best monitoring strategy.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (X) or CORRELATOR (_)*			
X	X (or RCP)		Stokes I
X	Y (or LCP)		Stokes Q
	XY		Stokes U
	YX		Stokes V

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
X	XX (linear products may be used by SDP for phasing-up the array / calibrating the beam-formed data)	**X**	Stokes I (total intensity and polarization maps from the simultaneous SKA1-MID array data have immediate scientific value)
X	YY	**X**	Stokes Q
X	XY	**X**	Stokes U
X	YX	**X**	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
[This example describes a Target of Opportunity project to follow up an extragalactic transient with SKA-VLBI, in this case a GRB.] We propose to observe nearby and bright gamma-ray bursts (redshift up to ~ 0.15) with SKA1-VLBI at 5 epochs within 1 month. Typical radio afterglow of a GRB is at the 100 μJy level within a day – few days after discovery. The radio afterglows initially have an inverted spectrum, indicating that they are still optically thick at GHz frequencies, and the flux density is expected to rise further. Milliarcsecond resolution data are highly valuable, because the only GRB for which the expansion was reliably measured with the VLBI technique is GRB 030329. Our goal is to probe the expansion of the blast wave on shorter timescales than for GRB 030329, allowing us for the first time to probe the ejecta while it is still in the ultra-relativistic phase. The excellent resolution and sensitivity of total intensity SKA-VLBI imaging will allow us to detect a source size of <50-250 μas (for resolution range 0.6-3 mas, and SNR>50), or ejecta proper motion in the 10 μas/month regime. In addition, full-Stokes SKA1-MID interferometer data will allow us to probe polarization in the afterglow (~0.1% level for a 1 mJy source, close to the expected peak of the emission). These measurements will provide important constraints on theoretical models of ultra-relativistic outflows.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
	X	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings

Number of targets	4 – primary target (~>100 µJy) plus minimum 1, ideally at least 3 ~>1 mJy calibrators	
Positions of targets	All within a single FoV of individual SKA1-MID dishes	
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………………..]
	X	NO
Time Critical?	X	YES [details: details: Target of Opportunity requiring rapid response within a few days]
		NO
Integration time per target (hrs)	Minimum on-source integration time is 3 hours. (all targets simultaneously). One could obtain useful science data down to 1 hour integration time (especially on brighter targets), but ideally we would prefer a longer integration to build up *uv*-coverage. There may be some additional time required for setting up realtime e-VLBI.	
Average peak flux density (Jy or Jy per beam)	~10^{-3} Jy/beam peak brightness (at maximum)	
Range of peak flux densities (Jy or Jy per beam)	~10^{-4} – 10^{-2} Jy/beam peak brightness	
Expected polarised flux density (expressed as % of total)	1%	

OBSERVATIONAL SETUP : *BEAMFORMER (X) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	8,400 MHz (choice of 5,000–13000 MHz)
Total Bandwidth (MHz)	512 MHz / polarization (equivalent of 4 Gbit/s/beam for 2-bit sampling)
Minimum and maximum frequency over the entire range of the setup (MHz)	Central frequency ±256 MHz
Spectral resolution (kHz)	Minimum 500 kHz
Temporal resolution (in seconds)	Standard Nyquist sampling (VLBI data integration time will be 1-2s at the VLBI

	correlator; these spectral and time resolutions will allow several arcsec FoV for each target)

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (* ***X*** *)*	
Central Frequencies (MHz) (including redshift, observatory correction)	8,400 MHz (choice of 5,000–13000 MHz)
Total Bandwidth (MHz)	2380 MHz (maximum available)
Minimum and maximum frequency over the entire range of the setup (MHz)	See above
Spectral resolution (kHz)	500 kHz
Temporal resolution (in seconds)	10s

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)	N/A	
Maximum baseline required (km)	4 km core	
Primary beam size (sq degrees)	>0.01	
Number of output channels	N/A	
Output bandwidth (minimum and maximum frequency - MHz)	512 MHz per polarization	
Required rms (Jy) (if polarisation products required define for each)	N/A	
Dynamic range (if polarisation products required define for each)	N/A	
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%

		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	0.03 (200 mas)	
Maximum baseline required (km)	150 km	
Mapped image size (degrees)	0.05 (20 arcsec)	
Required pixel resolution (arcseconds)	0.05 arcsec	
Number of output channels	4760	
Output bandwidth (minimum and maximum frequency - MHz)	2380 MHz	
Required rms (Jy per beam) (if polarisation products required define for each)	3×10^{-7} Jy/beam; assuming all telescopes	
Dynamic range within image (if polarisation products required define for each)	300 – I, 30 – Q/U/V (for primary target)	
Absolute flux scale calibration	**X**	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	

Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin) (single value or range)	10^{-3} arcsec (0.6-3 mas, depending on obs. frequency, VLBI array config., data weighting)
Mapped image size (degrees)	Up to 5x5 arcsec per beam□(typically 1x1 arcsec is sufficient when the source position is known at the sub- arcsecond level)
Number of image channels	1024; eventually averaged down to ~32
Channel width (kHz)	500 kHz => 16-32 MHz
Required rms (Jy per beam per channel) (if polarisation products required define for each)	1.5–□□×10^{-6} Jy/beam.□Note this sensitivity is achievable with SKA1-MID plus the EVN for example. We assumed 81% of SKA1- MID core (inner 4 km) is phased-up, providing a rebaselined SEFD of 5 Jy.

Dynamic range within image per channel (if polarisation products required define for each)	>50 for primary target ~1000 for calibrators	
Absolute flux scale calibration	**X**	1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Requires well established policies on how SKA1-MID will respond to outside triggers, how target of opportunity SKA1-MID results (and what details of the results, e.g. flux densities only or coordinates as well) are published in public domain, what groups will be eligible to initiate ToO observations on SKA1-MID, whose responsibility will be to coordinate the SKA-VLBI observations (proposing group or SKA) etc.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Beam-formed data degradation due to shadowing and/or cross-talk should not be underestimated. Will likely need a real-time monitoring system of what telescopes contribute to the beam-formed data. SEFD estimates should accurately reflect the situation when part of the array does not contribute to beam-formed data.
Data products	We indicated above that we need both beam-formed data for SKA-VLBI, and simultaneous SKA1-MID interferometer data. The latter will be extremely valuable for total flux density and polarization monitoring of the target, and at the same time for the accurate calibration of the VLBI data products, by measuring total flux densities of the calibrators in the field. (Note for VLBI we do not have primary flux density calibrators, therefore the calibration of the individual telescopes is usually based on measured Tsys, and a-priori assumed telescope gain; having VLBI targets with accurately known flux densities at the epoch of observation will help VLBI calibration.) The primary science goal depends highly on the

	amplitude calibration of all VLBI components, because we want to measure a source size that is a fraction of the beamwidth. As for polarization, the beam-formed SKA-VLBI data are expected to be in the RCP+LCP format. Conversion from the X, Y linear polarization products may alternatively occur in the VLBI correlator. However, SDP should then provide calibration information in (near) real-time.
Description of pipeline	(Near-) real-time imaging pipeline results (of the SKA1-MID interferometer data) after each epoch will be crucial in the decision mechanism on how to proceed with the following epochs.
Quality assessment plan & cadence	The beam-formed products will be streamed (either real-time, or after buffering) to a VLBI correlator centre, that will give feedback on the VLBI data products in either real-time, or ideally within 1-2 days. Cadence of the monitoring observations may depend on both the total flux density evolution and the apparent source size. The primary goal is to obtain the first epoch within 1-2 days of the initial radio detection, to have additional 4 epochs within a month. Observations on much longer timescales may be considered later, based on the results.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.	As for the scientific evaluation of the SKA1-MID data, after completing the project, as soon as possible. However, as noted above, conversion of linear-to-circular polarization of the beamformed data relies on SKA1-MID calibration information, to be provided near real-time.

ISSUES TO BE DETERMINED/RESOLVED

(Here you should include any additional information that needs to be resolved before this science can be carried out)

- To get practically thermal noise limited data on the primary target, having ~>1 mJy compact calibrator(s) in the FoV is a basic requirement for this observation, i.e. multiple-beam capability is a must. □

- It is likely that we will not have information on the compactness of mJy sources in the ToO field, therefore we may not know in advance where the additional beams should point to. Various solutions to this include a) pre-selection of flat-spectrum sources in the first hour of the first epoch observation from the SKA1-MID correlation data; these will be best candidates b) alternatively, if this is real-time e-VLBI, then pre-selection can be based on compactness check from the VLBI data c) form a large number of beams (>10) and use the data from the small fraction of compact sources. In case of a) and b) one may want to spend more time at the very first epoch (and use less for the rest). □

- One limitation of using large dishes in the VLBI array is that their individual FoV may be significantly smaller than the separation of SKA1-MID beams, i.e. they will have to nod between calibrator and target in a traditional phase-referencing style. If calibrators are to be selected “on-the-fly”, this will mean that the observing schedule will also have to be modified for nodding telescopes. In case of Effelsberg 100m, the calibrator will have to be within a few arcminutes of the target to avoid nodding. □

- The N number of SKA1-MID beams will add to the number of data-streams to be correlated. For N~4-5, this will not be a critical extra load. □

- The ideal observing frequency is a trade-off between resolution and FoV, that will limit the availability of “in-field” calibrators. Lover part of Band 5 will still work; at higher frequencies using a single SKA1-MID beam and frequent source switching with all telescopes may be the solution. □

- If the observations are real-time e-VLBI, part of the observing time will have to be spent on “clock-searching” and setup before science observations can start. □

- As mentioned earlier, SKA1-VLBI observations will require coordination with other telescopes. Note since we need long (8000–10000 km) baselines in both N-S and E-W directions, this will constrain the joint visibility of the target and therefore the GST limits when the observations can be carried out.

- The negative effects of rebaselining is offset by assuming more telescopes in the SKA-VLBI array. The sensitivity gained this way, and the realistic possibility of >5 GHz observations with SKA1-MID (thus better resolution) means that we maintain our original goals of accurate source size determination below ~100 μas level.

REFERENCES

The physical implications of GRB VLBI observations, both in general and in the specific case of GRB 030329 are discussed in the following paper. This also explains how VLBI results relate to radio flux measurements, light curves at other frequencies, and the overall picture:

Granot, J., van der Horst, A.J., 2013, PASA, 31, e008

Here is an example of a real-time e-VLBI + regular VLBI observation of a transient source in a series of Target of Opportunity monitoring experiments. This demonstrates why nearby calibrators are essential, but also the feasibility of searching suitable calibrators during the first epoch that can be used at subsequent epochs. Ideally, SKA1 would do this at the beginning of the first epoch:

Paragi, Z., van der Horst, A.J., Belloni, T. et al., 2013, MNRAS, 432, 1319

The first VLBI paper on GRB 030329, so far the only afterglow that has been resolved with VLBI. Note this source was 10x brighter (10 mJy at peak) than the typical GRB for which we drafted our science case, i.e. for GRB 030329 type events the SKA-VLBI would do even better. The lower resolution of 3 mas (Band 3) will only provide useful constraints if the target is exceptionally bright (SNR>>50, ζ_{min}<<250 μas), like GRB 030329:

Taylor, G.B., Frail, D., Berger, E., Kulkarni, S.R., 2004, ApJ, 609, L1

For estimating the minimum detectable proper motion, we assumed the source localization accuracy of beamsize/(2xSNR). For the minimum resolvable angular size, we used the approximation ζ_{min}~0.6xSNR$^{-0.5}$, see:

Martí-Vidal, I., Pérez-Torres, M., Lobanov, A., 2012, A&A, 541, A.135

We note that this GRB example is very similar to the case of resolving relativistic outflows from tidal disruption events, or from mildly relativistic (GRB-) supernovae – the latter will be seen in larger numbers at much closer distances (z~0.05, or ~100 Mpc).

2.61 **Adding high angular resolution to SKA surveys through wide-field-VLBI technique**

PROJECT DETAILS	
Title	**Adding high angular resolution to SKA surveys through wide-field-VLBI technique**
Principal Investigator	**Marcello Giroletti**
Co-Authors	**Zsolt Paragi, Tuomas Savolainen, Iván Agudo, SKA-VLBI-science Working Group**
Time Request	500-2000

FACILITY		Preconditions
	SKA1-LOW	
X	SKA1-MID	Forming multiple beams; standard VLBI data format output; VLBI data streaming; coordination with EVN, AVN, LBA

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
X	SKA1-MID Band 2	500-2000
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	

	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
X	Commensal	**the project would be carried out in combination with the SKA1-MID surveys thanks to simultaneous correlation and beam-forming of the data**
X	Collaborative & Coordinated	VLBI network such as LBA, AVN, EVN will provide time and correlation facilities, which requires coordination
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
We envisage two possible strategies, one that can only be applied to a deep field, and a second one that is applicable to both a deep and a wide-field survey: **1.** *(blind survey)* the goal is to image with high angular resolution the entire 0.5deg x 0.5deg central area of a SKA1-MID deep field. The deep survey itself will be carried out with a total time of ~1000 SKA1-MID hours on a single 1deg^2 field. At the same time, multiple beams would be formed, and each of them would be correlated with the simultaneous data taken by the coordinated VLBI dishes. The multiple beams are iteratively formed on several pointing positions in order to cover as large as possible an area. With 4 beams, it is reasonable to cover the central 0.5deg x 0.5deg; with more beams (eg. 16), it would be possible to cover the entire deep field (in a balanced trade off with sensitivity). **2.** *(targeted survey)* in this complementary strategy, the VLBI data are only taken on a target list that is iteratively compiled as the SKA1-MID survey goes on. Beams are not formed with the goal of mapping the entire field at high angular resolution but only to correlate the data around catalogued sources. In the early sky visits, beams are formed and VLBI-correlated with phase centres on the relatively brighter sources, in the later observations fainter source fields are added. This strategy would then be applicable to both the deep and the wide SKA1-MID survey; in the latter case, the coverage would be limited to what actually feasible on the VLBI networks, with an approach similar to what carried out in the mJive project (Deller&Middelberg 2014)

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (X)*			
X	RCP standard VLBI input		Stokes I

X	LCP standard VLBI input		Stokes Q
			Stokes U
			Stokes V
POLARISATION PRODUCTS REQUIRED : *CORRELATOR (X)*			
X	XX		Stokes I
X	YY		Stokes Q
X	XY		Stokes U
X	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The study of galaxy evolution over cosmic time is a topical area of activity for the SKA. The addition of sensitive long baselines to the continuum surveys carried out with the SKA will provide fundamental clues on the nature of the radio sources detected in the surveys themselves and described in Prandoni & Seymour (2015). In particular, brightness temperature can be used to discriminate between AGN activity and star formation. This will further provide an efficient method to select AGNs over a broad range of cosmic times and a tool to study the feedback processes between supermassive black holes and their host galaxy as they merge and evolve through cosmic time. Both radio quiet (yet not radio silent) and radio loud AGNs will be detected. Other science area that would greatly benefit are the search for dual/multiple supermassive black holes (Deane et al. 2015), intermediate mass back holes (e.g. Mezcua et al. 2014) and the study of LIRG/ULIRG.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
	X	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
	X	Non-imaging pointings

Number of targets	2000 for the deep field	
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ………………………………………..]
	X	NO
Time Critical?		YES [details: ………………………………………..]
	X	NO
Integration time per target (hrs)	0.5	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)		
Expected polarised flux density (expressed as % of total)		

OBSERVATIONAL SETUP : *BEAMFORMER (X) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	1400
Total Bandwidth (MHz)	500
Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	1000
Temporal resolution (in seconds)	Nyquist sampling

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	
Maximum baseline required (km)	1 (for blind survey), 4 (for targeted survey)
Primary beam size (sq degrees)	

Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)	6-7 microJy/beam	
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	standard for reference surveys with SKA1-MID Band 2 and above
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	
Required rms (Jy per beam) (if polarisation products required define for each)	

Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	n/a	
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%

		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)	5 milliarcsec	
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)	5-6 uJy/beam	
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
	X	5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Correlator: standard Beamformer: standard VLBI techniques

Processing considerations (e.g. flag high wind speed data, reprocessing required?)	correlation with very long baselines, wide-field VLBI imaging
Data products	Beamformer: VDIF baseband data (includes metadata eg time stamps. Description of VDIF standard is available at http://vlbi.org/vdif/)
Description of pipeline	
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Beam-formed data should be available for VLBI correlation. Electronic transfer of the data to the VLBI correlator could be done "a posteriori" or ideally (as will likely become standard practice at the SKA1 operational epoch) in real time. For our strategy #2 approach, the target list needs to be updated as the SKA1-MID survey makes progress, so regular updates would be necessary; for a deep 1000hr pointing, this means every few days, for the wide shallow 3pi survey, once per month would be sufficient.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
a) Conversion from linear to circular polarisation. It should be tested whether the post-correlation conversion as with ALMA works also here. b) The number of tied array beams available for VLBI.

REFERENCES
Deane, R., Paragi, Z., Jarvis, M., et al. 2015, aska.conf, 151 Deller, A. T., Brisken, W. F., Phillips, C. J., et al. 2011, PASP, 123, 275 Deller, A. T., & Middelberg, E. 2014, AJ, 147, 14 Garrett, M. A., Wrobel, J. M., & Morganti, R. 2005, ASPC, 340, 600 Lenc, E., Garrett, M. A., Wucknitz, O., Anderson, J. M., & Tingay, S. J. 2008, ApJ, 673, 78 Mezcua, M. 2014, evn..conf, 2 Middelberg, E., Deller, A., Morgan, J., et al. 2011, A&A, 526, A74 Middelberg, E., Deller, A. T., Norris, R. P., et al. 2013, A&A, 551, A97 Morgan, J. S., Mantovani, F., Deller, A. T., et al. 2011, A&A, 526, A140 Paragi, Z., Godfrey, L., Reynolds, C., et al. 2015, aska.conf, 143

2.62 **Shocks waves, CMEs, Type II bursts**

PROJECT DETAILS	
Title	Shocks waves, CMEs, Type II bursts
Principal Investigator	Jasmina Magdalenic
Co-Authors	Peter Gallagher, Dalmiro Maia, Iver Cairns, Habeeb Allawi, Christophe Marque and the Solar team
Time Request	

FACILITY		Preconditions
	SKA1-LOW	50 – 350 MHz
	SKA1-MID	Band 1: 400 – 1000 MHz

RECEIVER(S) REQUIRED	Time (hrs)

	SKA1-LOW	Monitoring/target of opportunity observations
	SKA1-MID Band 1	Monitoring/target of opportunity observations
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	Triggered observations; 24 hours in advance. Observations near the local noon are prefered
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
To minimize projection effects, the observations should be triggered when the sunspot group with the complex photosperic field configuration (beta-gamma-delta) appears at the east solar limb, or when it is (closed to) approaching to the west solar limb.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**Yes**	Stokes I
	YY	Yes	Stokes Q

	XY	Yes	Stokes U
	YX	yes	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Radio emission produced by non-thermal electrons accelerated at the shock wave front, so-called type II radio bursts are a well-known, and in many aspects unique, means to study the propagation of shock waves in the solar corona and heliosphere. We propose to study coronal type II radio bursts using the new and unique observational capabilities of SKA. Scientific objectives addressed by this project include determination of the relative positions of the metric type II burst sources and the coronal mass ejection (CME) possibly driving the shock, estimation of the shock wave characteristics (e.g. amplitude, the Alfven Mach number, and the Alfven speed) using the type II band split, and tracing the fast electron beams accelerated at the shock front. Recent LOFAR observations of shock signatures show unusually strong fragmentation of the radio emission within the envelope of type II burst, and indicate that the fine structures of the type II burst are not fully resolved. The unique capability in terms of time, frequency and spatial resolution, as well as simultaneous observations of dynamic spectra and imaging of SKA will bring a new view on the physics of the shock associated radio emission.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	One target only – Sun.	
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [Tracking Sun. …………………..]
		NO
Time Critical?		YES [details: ………………………………………..]
		NO
Integration time per target (hrs)		
Average peak flux density	Sun is an intense source with thousands of Jansky during	

(Jy or Jy per beam)	the quiet conditions and by orders of magnitude more for eruptive events.
Range of peak flux densities (Jy or Jy per beam)	about 3*10^4 – 3*10^7 Jy (3 – 3000 sfu)
Expected polarised flux density (expressed as % of total)	0 – 20 % usually with occasional fine structures up to about 50 – 100 %

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	
Total Bandwidth (MHz)	SKA-Low and SKA-Mid Band 1
Minimum and maximum frequency over the entire range of the setup (MHz)	40–350 LOW 400 – 1000 MID
Spectral resolution (kHz)	5 -10 kHz
Temporal resolution (in seconds)	0.0005 – 0.001 s

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%

		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin)	

(single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)	depending on frequency SKA1-LOW 0.5'–1.0' & SKA1-MID < 0.5'	
Mapped image size (degrees)	?	
Number of image channels		
Channel width (kHz)	150 - 200 kHz,	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	Sun is an intense source with thousands of Jansky during the quiet conditions and order of magnitude more for eruptive events.	
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%

		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	
Description of pipeline	
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling	at completion of the full project

block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES

2.63 **Study of spatially and spectrally resolved MHD waves with solar radio bursts**

PROJECT DETAILS	
Title	Study of spatially and spectrally resolved MHD waves with solar radio bursts
Principal Investigator	Valery Nakariakov, Sergey Anfinogentov, Giuseppe Nistico, Alexey Kuznetsov
Co-Authors	The Solar and Heliosphere Team
Time Request	Monitoring

FACILITY		Preconditions
	SKA1-LOW	X

	SKA1-MID	X

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	Monitoring
	SKA1-MID Band 1	Monitoring
	SKA1-MID Band 2	Monitoring
	SKA1-MID Band 3	Monitoring
	SKA1-MID Band 4	Monitoring
	SKA1-MID Band 5	Monitoring

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
	Fixed schedule (give cadence)	around local noon, daily
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Observing modes of interest to the proposal are: (i) Interferometric Mode; We need to resolve the spatial location of different fine spectral structures in solar Type-III and Type-IV radio bursts for the largest possible off-limb field of view, e.g., from the solar centre, up to 3 R_sun off-limb in the radial direction, and of about 0.5_R_sun in the transverse direction, with 1 R_sun = 1000”. At the solar limb, the field-of-view should include a

pronounced active region. The location of the active region will be determined before the observation, in the optical or EUV band, and updated daily. At different distances from the limb the main emission is determined by the local electron plasma frequency, thus covering the range from several GHz (SKA1-MID) to several tens of MHz (SKA1-LOW). For typical slow magnetoacoustic waves, the wavelength is 40 Mm (~60", for the sound speed of about 0.2 Mm and the period of 200 s), so the required minimal angular resolution is 10" (reachable with both SKA1-MID and SKA1-LOW). For typical fast magnetoacoustic waves, the wavelength is 10 Mm (~13", for the Alfven speed of 1 Mm/s and period of 10 s - the transverse Alfven transit time across a typical plasma waveguide of 10 Mm width), reachable with SKA1-MID. The required time resolution is about 0.1 s or better, allowing us to resolve the spectral evolution in Type-III and -IV bursts. In both instruments (SKA1-MID and SKA1-LOW) we need the intensity and polarisation signals, and highest possible spectral and time resolution.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (X) or CORRELATOR (X)*			
	XX	**x**	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX	x	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Interaction of non-thermal electrons produced in flares with solar coronal plasmas leads to the excitation of coherent radio bursts. Detected with the sufficient spectral resolution, the bursts provide us with the diagnostics of the local electron concentration (e.g., Type-III bursts) and the magnetic field (e.g., the double plasma resonance responsible for zebra-patterns and fiber-bursts in Type-IV bursts). Both these quantities are perturbed by magnetohydrodynamic (MHD) waves, and hence modulate the radio emission. Coronal MHD waves are intensively studied in EUV and soft-X-ray bands in the context of coronal heating and seismology. Preliminary results show that, e.g., zebra-pattern wiggles are associated with magnetoacoustic oscillations. Further progress in coronal MHD wave studies is limited by time resolution of available instruments, and also by their off-limb field-of-view. Both issues will be revolutionised by SKA. We aim to - detect magnetoacoustic waves in open coronal structures as modulation of Type-III bursts (the frequency drift will give the snapshot of density modulation by the waves), and study the wave evolution up to large (> 0.3 R_sun) heights; - study spatial locations of ZP stripes and their evolution caused by sausage oscillations; - detect guided fast magnetoacoustic wave trains, assessing fine filamentation of coronal plasma.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	x	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	1	
Positions of targets	The region of interest should begin at the solar centre and cover the radial distances up to 3 R_sun from the solar centre. For example, it should be a box with the diagonal of 4000”. The region of interest must include one or more pronounced active regions, predetermined 1 or 2 days before the observation.	
Rapidly changing sky position? (e.g. comet, planet)	x	YES [Following the Sun]
		NO
Time Critical?	x	YES [Observations must be done during the local day time, preferably around the midday to minimise the effect of the signal integration along the ionosphere.]
		NO
Integration time per target (hrs)		
Average peak flux density (Jy or Jy per beam)	At least 10,000 Jy as the quiet Sun level, and up to higher for radio bursts.	
Range of peak flux densities (Jy or Jy per beam)	Up to 10^{10} Jy (in a major solar flare).	
Expected polarised flux density (expressed as % of total)	0-100%	

OBSERVATIONAL SETUP : *BEAMFORMER (x) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	All frequencies of SKA1-LOW and SKA1-MID, with the central frequencies coinciding with the central frequencies of

	these instruments.
Total Bandwidth (MHz)	Total widths of LOW and MID.
Minimum and maximum frequency over the entire range of the setup (MHz)	Bandpass of LOW and MID (e.g. 50 MHz - 5 GHz)
Spectral resolution (kHz)	10 kHz in LOW, and 100 kHz in MID
Temporal resolution (in seconds)	0.1 s, but 1 s can be used for some classes of MHD wave phenomena too.

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	0.1 arcmin at least, ideally 1"
Maximum baseline required (km)	
Mapped image size (degrees)	1 (the diagonal of the region-of-interest)
Required pixel resolution (arcseconds)	Ideally 1" or better, minimal requirement is 5".
Number of image channels	Maximum possible

Channel width (kHz)	Narrowest possible	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	???	
Dynamic range within image per channel (if polarisation products required define for each)	10^4 (from 10^5 Jy to 10^9 Jy in a typical flare)	
Absolute flux scale calibration		1-3%
	x	5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Data will be analysed using pre-written routines to create spectral-imaging data.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Only those time intervals that will have the total radioflux exceeding a certain threshold (i.e. the time intervals of radio bursts) will be kept for detailed analysis. Initially the selection of these intervals will be performed manually using spectrograms of the full Sun (without spatial resolution).
Data products	Imaging spectroscopy maps of the regions-of-interest, including potentially flaring solar active regions, at as many wavelength as possible, at 0.1 s time cadence, constructed during the manually identified radio bursts.
Description of pipeline	N/A
Quality assessment plan & cadence	The data will be manually inspected for solar activity. Data where the Sun is not active will not be kept to minimise the data storage requirements. The data inspection will be carried out on the daily basis.
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of scheduling block.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Selection of the target for the observation will be performed manually a few (1-2) days before the observation. This time lag between the identification of the target and the observation

should be consistent with the observational time management routine.

REFERENCES
Observational detections of MHD wave phenomena described in the scientific description: [1] Ofman, L, Nakariakov, V.M., De Forest, C.E., Slow Magnetosonic Waves in Coronal Plumes, Astrophys. J. 514, 441, 1999 [2] Yu, S., Nakariakov, V.M., Quasi-periodic Wiggles of Microwave Zebra Structures in a Solar Flare. Astrophys. J., 777, 159, 2013 [3] Kuznetsov, A.A. Generation of Intermediate Drift Bursts by Magnetohydrodynamic Waves in the Solar Corona, Solar Phys. 237, 153, 2006 [4] Kuznetsov, A.A. Superfine Temporal Structure of the Microwave Burst on 21 April 2002: What Can We Learn about the Emission Mechanism?, Solar Phys. 253, 103, 2008 [5] Nisticò, G.; Pascoe, D. J.; Nakariakov, V. M., Observation of a high-quality quasi-periodic rapidly propagating wave train using SDO/AIA, Astron. Astrophys. 569, 12, 2014

2.64 Observations of flaring loops in the solar corona with SKA1-MID

PROJECT DETAILS	
Title	Observations of flaring loops in the solar corona with SKA1-MID
Principal Investigator	Alexey Kuznetsov, Eduard Kontar
Co-Authors	*The Solar and Heliosphere Team*
Time Request	Monitoring

FACILITY		Preconditions
	SKA1-LOW	

	SKA1-MID	X

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	Monitoring

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
	Fixed schedule (give cadence)	2-6 hours daily, preferably around midday
	Time-critical override	
	Custom Experiment	
	Commensal	
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
Observing modes of interest to the proposal are: (i) Interferometric Mode. We need interferometric imaging observations covering the entire solar disk at high frequencies (5 GHz and higher). The observations should provide the highest possible angular

(1'' or better) and spectral (100 frequency channels or more) resolution. The time resolution of 1 s or better is required. Since the solar flares are infrequent and unpredictable, we need continuous monitoring observations – at least 2 hours daily. The data fragments without flares will be then discarded to minimize the data storage requirements. Preferably, the observations should be performed around a local noon to minimize the ionospheric interference.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
	XX	**x**	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX	x	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Solar flares and the accompanying coronal mass ejections are the main drivers of the space weather. In addition, solar flares are a unique space laboratory allowing us to study various aspects of plasma physics. Radio emission of the flares is an important diagnostic tool, because it is highly sensitive to the parameters of plasma, magnetic field and energetic particles. In particular, the emission in the microwave range (~5 GHz and above) is produced mainly due to the incoherent gyrosynchrotron mechanism, which is relatively simple and well-studied at the micro-level. Inferring the emission source parameters from the radio observations requires using the forward-fitting methods, when the simulated emission from a 3D coronal model is compared with observations. In turn, this requires *(i)* observations with high angular resolution and *(ii)* simultaneous imaging observations at many frequencies. The SKA1-MID Band 5 (4.6-13.8 GHz, with planned extension up to 24 GHz in SKA2) observations are perfectly suited for the flare diagnostics. Using these observations and the gyrosynchrotron simulation tools, we will be able to reconstruct the physical parameters in the solar flaring loops with unprecedented accuracy and reliability.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	x	Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
		Non-imaging pointings
Number of targets	1	

Positions of targets	Centred on the Sun.	
Rapidly changing sky position? (e.g. comet, planet)	x	YES [the Sun]
		NO
Time Critical?	x	YES [Observations must be done during the day; preferably, around a local noon to minimize the ionospheric interference]
		NO
Integration time per target (hrs)	2 hrs	
Average peak flux density (Jy or Jy per beam)	10^7 Jy	
Range of peak flux densities (Jy or Jy per beam)	10^4 – 10^9 Jy	
Expected polarised flux density (expressed as % of total)	0-100%	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (x)*	
Central Frequencies (MHz) (including redshift, observatory correction)	9200 MHz
Total Bandwidth (MHz)	9200 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	4600-13800 MHz
Spectral resolution (kHz)	92000 kHz (92 MHz) or better
Temporal resolution (in seconds)	1 s or better

NON-IMAGING SPECIFIC CONSIDERATIONS	
Required angular resolution of a tied array beam (arcmin)	
Maximum baseline required (km)	

Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	
Required rms (Jy per beam) (if polarisation products required define for each)	
Dynamic range within image (if polarisation products required define for	

each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	0.015 arcmin (1 arcsec)	
Maximum baseline required (km)	15 km	
Mapped image size (degrees)	0.6	
Required pixel resolution (arcseconds)	1 arcsec	
Number of image channels	> 100	
Channel width (kHz)	< 92000 kHz	
Required rms (Jy per beam per channel) (if polarisation products required define for each)	1000 Jy for each polarization	
Dynamic range within image per channel (if polarisation products required define for each)	10^5 for each polarization	
Absolute flux scale calibration	X	1-3%
		5%
		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)	
Required angular resolution (arcmin)	

(single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Data will be analysed using pre-written routines to create spectral-imaging data.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	RFI flagging.
Data products	1. Imaging spectroscopy maps of the Sun with the above-mentioned angular and spectral resolution, and sub s (or better) cadence. 2. Total (spatially unresolved) dynamic spectra of the solar radio emission with the above-mentioned spectral and temporal resolution.
Description of pipeline	N/A
Quality assessment plan & cadence	The data will be manually inspected for solar activity. Data where the Sun is not active will not be kept to minimise the data storage requirements. The data inspection will be carried out on the daily basis.
Latency (Desired time lag	

between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of scheduling block.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES
The methods of analyzing the multifrequency imaging radio observations, as well as the requirements to an instrument, are discussed in the following papers: 1. Nita, G.M., Fleishman, G.D., Kuznetsov, A.A., Kontar, E.P., Gary, D.E., Three-dimensional Radio and X-Ray Modeling and Data Analysis Software: Revealing Flare Complexity, Astrophys. J., 799, 236, 2015. 2. Kuznetsov, A.A., Kontar, E.P., Spatially Resolved Energetic Electron Properties for the 21 May 2004 Flare from Radio Observations and 3D Simulations, Solar Phys., 290, 79, 2015.

2.65 Imaging the inner heliosphere and Space Weather

PROJECT DETAILS	
Title	**Imaging the Inner Heliosphere and Space Weather**
Principal Investigator	**Richard Fallows, Liu Lijia**

Co-Authors	
Time Request	Monitoring

FACILITY		Preconditions
	SKA1-LOW	Science can be achieved with system as currently designed.
	SKA1-MID	Science can be achieved with system as currently designed.

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	Monitoring
	SKA1-MID Band 1	Monitoring
	SKA1-MID Band 2	Monitoring
	SKA1-MID Band 3	Monitoring
	SKA1-MID Band 4	Monitoring
	SKA1-MID Band 5	Monitoring

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
x	Normal	
	Fixed schedule (give cadence)	
x	Time-critical override	
	Custom Experiment	

x	Commensal	Dedicated imaging+beamformed observations
	Collaborative & Coordinated	
x	Sub-arrays required	Simultaneous use of spare outlying stations to record beamformed data individually per station.

COMMENTS ON OBSERVING STRATEGY
Use spare stations for dedicated beamformed observing. Use core stations for dedicated imaging+beamformed observing.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
x	XX	**x**	Stokes I
x	YY	x	Stokes Q
x	XY	x	Stokes U
x	YX	x	Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Solar wind conditions are the principle driver of the space weather environment around the Earth and other planets. Our increasing reliance on electronic technology, and the susceptibility of aspects of that technology to conditions in the Earth's magnetosphere, means that the monitoring of space weather assumes increasing importance. In recent years the study of interplanetary scintillation has matured and is now an important technique used to ascertain global solar wind conditions in the inner heliosphere. The direction of the interplanetary magnetic field is an essential parameter in the prediction of space weather impact on the environment around Earth, but observation before spacecraft measurements at the L1 point have proved challenging. A technique to accomplish such observation is the use of Faraday Rotation. Observations using pulsars in close proximity to the Sun have been taken with LOFAR for this purpose. A more interesting line of research is to use a Galactic polarised background to “image” the Faraday Rotation across a wide field of view. Whilst analysis using both techniques is on-going, it has the potential to be a very fruitful

line of research with important implications for the prediction of the effect on Earth of space weather events.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	x	Individual pointings per object
	x	Individual fields-of-view with multiple objects
		Maps through multiple fields of view
	x	Non-imaging pointings
Number of targets		
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………….]
	x	NO
Time Critical?	x	YES [details: Daytime…………………….]
		NO
Integration time per target (hrs)	> 5 minutes	
Average peak flux density (Jy or Jy per beam)	Depends on target and objectives (scintillation/pulsar/imaging)	
Range of peak flux densities (Jy or Jy per beam)	Depends on target and objectives (scintillation/pulsar/imaging)	
Expected polarised flux density (expressed as % of total)	Depends on target and objectives (scintillation/pulsar/imaging)	

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	Depends on the observing frequency

Total Bandwidth (MHz)	Depends on the observing frequency
Minimum and maximum frequency over the entire range of the setup (MHz)	Depends on the observing frequency
Spectral resolution (kHz)	
Temporal resolution (in seconds)	0.01 s (scintillation), Nyquist sampled (pulsar)

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
	x	5%
		10%
		20-50%
	x	n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a ‘support image’ in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	x	n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of image channels	

Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	x	n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	x	n/a

DATA ANALYSIS	
Procedures required	Pulsar pipeline (pulsar observations) Stokes I dynamic spectra (scintillation) standard EoR processing (imaging)
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	
Data products	Full band dynamic spectra for beamformed scintillation data, Stokes I standard pulsar pipeline data products Calibrated visibilities with no time averaging.
Description of pipeline	
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of pipeline reduction.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES

2.66 **Turbulent Structures in the Ionosphere**

PROJECT DETAILS	
Title	**Turbulent Structures in the Ionosphere**
Principal Investigator	**Fallows, Richard et al**
Co-Authors	**SHI team**
Time Request	commensal/monitoring

FACILITY		Preconditions
	SKA1-LOW	Science can be achieved with system as currently designed.
	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	commensal/monitoring
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
x	Normal	
	Fixed schedule (give cadence)	
	Time-critical override	
	Custom Experiment	
x	Commensal	Imaging+beamformed observing including the ability to record beamformed data individually per station
	Collaborative & Coordinated	
x	Sub-arrays required	Simultaneous use of spare outlying stations to record beamformed data individually per station.

COMMENTS ON OBSERVING STRATEGY
Two-fold strategy: 1. Use data (imaging and/or beamformed) of scheduled observations; 2. Use spare stations for dedicated beamformed observing.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
x	XX	**x**	Stokes I
	YY		Stokes Q
	XY		Stokes U
	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
Observations from the LOFAR and MWA instruments are demonstrating that the mid-latitude ionosphere is not necessarily the quiet and benign entity often thought. Regular beamformed ionospheric scintillation observations with LOFAR show that the scintillation is present, to a greater or lesser degree, almost continually at the low frequencies. Fallows et al (2014) presented the first observations of "scintillation arcs" due to the ionosphere, hitherto only observed in observations of interstellar scintillation (Stinebring et al, 1999), leading to the possibility of determining the altitudes from which the scintillation originates. Loi et al (2015) presented, using regular imaging data from the MWA, the first observations showing density ducts between the plasmasphere and the ionosphere. These ducts were aligned with the Earth's magnetic field and are likely due to Whistler waves. Further observations demonstrated more widely the mapping of small-scale density structures which can be achieved from such analyses. This mapping could ultimately be used to model the resulting scintillation pattern seen in dynamic and power spectra. Broadband observations of the scintillation enable analysis which cannot be achieved via the usual satellite measurements. This includes: – Understanding the turbulence energy cascade and instability mechanisms in the ionosphere. – Refinement of scattering models.

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')	x	Individual pointings per object
	x	Individual fields-of-view with multiple objects

	x	Maps through multiple fields of view
	x	Non-imaging pointings
Number of targets		
Positions of targets		
Rapidly changing sky position? (e.g. comet, planet)		YES [details: ……………………………………..]
	x	NO
Time Critical?		YES [details: ……………………………………..]
	x	NO
Integration time per target (hrs)	> 5 minutes	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)		
Expected polarised flux density (expressed as % of total)		

OBSERVATIONAL SETUP : *BEAMFORMER (_) or CORRELATOR (_)*	
Central Frequencies (MHz) (including redshift, observatory correction)	
Total Bandwidth (MHz)	
Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	100 kHz
Temporal resolution (in seconds)	<= 1 second

NON-IMAGING SPECIFIC CONSIDERATIONS

Required angular resolution of a tied array beam (arcmin)		
Maximum baseline required (km)		
Primary beam size (sq degrees)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy) (if polarisation products required define for each)		
Dynamic range (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	x	n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)	
Required angular resolution (arcmin) (single value or range)	
Maximum baseline required (km)	
Mapped image size (degrees)	
Required pixel resolution (arcseconds)	
Number of output channels	
Output bandwidth (minimum and maximum frequency - MHz)	

Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	x	n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)		
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%

	x	n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)		
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
	x	n/a

DATA ANALYSIS	
Procedures required	Standard imaging/beamformed pipeline data reduction. Beamformed data should be integrated to a time resolution of 0.1s to reduce data quantity.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	

Data products	Full band dynamic spectra for beamformed data, Stokes I Calibrated visibilities with no time averaging and no ionospheric calibration applied for the imaging data.
Description of pipeline	Standard imaging pipeline, without any ionospheric calibration.
Quality assessment plan & cadence	
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to 'at completion of the full project'.)	Upon completion of pipeline reduction.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)

REFERENCES
Fallows, R. A., et al. "Broadband meter wavelength observations of ionospheric scintillation.", *Journal of Geophysical Research: Space Physics* 119 (12), 2014 Loi, Shyeh Tjing, et al. "Real time imaging of density ducts between the plasmasphere and ionosphere.", *Geophysical Research Letters,* 2015 Stinebring, D. R., et al. "Faint scattering around pulsars: probing the interstellar medium on solar system size scales.", *The Astrophysical Journal Letters,* 549(1), 2001

2.67 High Precision Air Shower Detection

PROJECT DETAILS	
Title	**High Precision Air Shower Detection**
Principal Investigator	**T. Huege**
Co-Authors	**J. Bray, S. Buitink, C.W. James, A. Nelles**
Time Request	None (fully commensal)

FACILITY		Preconditions
Y	SKA1-LOW	Particle detector array (external instrument) operating in core. >= 5 core stations deployed and operating.
	SKA1-MID	

RECEIVER(S) REQUIRED		Time (hrs)
	SKA1-LOW	
	SKA1-MID Band 1	
	SKA1-MID Band 2	
	SKA1-MID Band 3	
	SKA1-MID Band 4	
	SKA1-MID Band 5	

OPERATIONAL MODE (as defined in Concept-of-Operations)		Details
	Normal	
	Fixed schedule (give cadence)	

	Time-critical override	
Y	Custom Experiment	Requires particle detector for triggering
Y	Commensal	No targeting requirement
	Collaborative & Coordinated	
	Sub-arrays required	

COMMENTS ON OBSERVING STRATEGY
We will use a particle detector array (external instrument, to be constructed) to identify cosmic ray interactions in the atmosphere above the SKA-low core. The detector array will generate a trigger to read out antenna-level data from the TPM buffers for the time of particle detection [7]. We expect one trigger on average per minute, and will return 50 microseconds of baseband (unchannelised) data (X and Y pol) for each event, for at least one in every four antennas. More details are laid out in [6]. Since we use individual antennas we have no requirements on pointing, and our data is pre-beamformer and pre-correlator. We can thus be fully commensal with any/all SKA-Low observations, and have no requirements on data products below. We plan to operate commensally 100% of the time.

POLARISATION PRODUCTS REQUIRED : *BEAMFORMER (__) or CORRELATOR (X)*			
N/A	XX		Stokes I
N/A	YY		Stokes Q
N/A	XY		Stokes U
N/A	YX		Stokes V

SCIENTIFIC DESCRIPTION (max 200 words)
The radio emission generated by extensive air showers following an interaction of a high-energy cosmic ray (>10^16 eV) in the atmosphere has proven to be a powerful technique to measure cosmic rays, their energy and their mass composition. The observational signatures are non-repeating nanosecond-scale pulses, with a characteristic broadband frequency-spectrum peaking below 100 MHz. LOFAR has already been used very successfully to record air showers and currently provides the best precision of the measurement of the distance of the air shower maximum, which is a proxy for the mass of the primary cosmic ray. SKA-LOW will vastly improve air-shower measurements over LOFAR both in terms of instantaneous bandwidth and number of antennas, resulting in superior sensitivity and accuracy, thereby potentially revealing unexpected information about the air shower development and mass-composition sensitive parameters. Furthermore, the higher density and improved antennas will provide a lower energy threshold. More details are provided in [1,2,6].

'TARGETS' OF OBSERVATIONS		
Type of observation (what defines a 'target')		Individual pointings per object
		Individual fields-of-view with multiple objects
		Maps through multiple fields of view
	X	Non-imaging pointings
Number of targets	All-sky (non-beamformed)	
Positions of targets		
		YES [details: ……………………………………..]

Rapidly changing sky position? (e.g. comet, planet)		NO
Time Critical?		YES [details: ……………………………………..]
		NO
Integration time per target (hrs)	We plan to operate for 10 years, fully commensal.	
Average peak flux density (Jy or Jy per beam)		
Range of peak flux densities (Jy or Jy per beam)		
Expected polarised flux density (expressed as % of total)	100%, all expected pulses are fully polarized.	

OBSERVATIONAL SETUP : *BEAMFORMER (__) or CORRELATOR (_)* ***N/A***	
Central Frequencies (MHz) (including redshift, observatory correction)	200 MHz
Total Bandwidth (MHz)	300 MHz
Minimum and maximum frequency over the entire range of the setup (MHz)	
Spectral resolution (kHz)	300,000 (i.e. single channel)

Temporal resolution (in seconds)	0.00000000167 (Nyquist rate ~1.67 ns)

NON-IMAGING SPECIFIC CONSIDERATIONS		
Required angular resolution of a tied array beam (arcmin)	N/A	
Maximum baseline required (km)	1 (core only)	
Primary beam size (sq degrees)	N/A	
Number of output channels	1	
Output bandwidth (minimum and maximum frequency - MHz)	50-350 MHz	
Required rms (Jy) (if polarisation products required define for each)	Poorly defined for our science case	
Dynamic range (if polarisation products required define for each)	At least 8 effective bits (12 bits strongly preferred), as the measured amplitude scales with the energy of the cosmic ray	
Absolute flux scale calibration		1-3%
	x	5%
		10%

		20-50%
		n/a

IMAGING CONSIDERATIONS (CONTINUUM. This includes the specifications for a 'support image' in the case of VLBI observations)		
Required angular resolution (arcmin) (single value or range)	N/A	
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of output channels		
Output bandwidth (minimum and maximum frequency - MHz)		
Required rms (Jy per beam) (if polarisation products required define for each)		
Dynamic range within image (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%

		10%
		20-50%
		n/a

IMAGING CONSIDERATIONS (spectral – multiple channels of narrow bandwidth)		
Required angular resolution (arcmin) (single value or range)	N/A	
Maximum baseline required (km)		
Mapped image size (degrees)		
Required pixel resolution (arcseconds)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%

		20-50%
		n/a

IMAGING CONSIDERATIONS (VLBI)		
Required angular resolution (arcmin) (single value or range)	N/A	
Mapped image size (degrees)		
Number of image channels		
Channel width (kHz)		
Required rms (Jy per beam per channel) (if polarisation products required define for each)		
Dynamic range within image per channel (if polarisation products required define for each)		
Absolute flux scale calibration		1-3%
		5%
		10%
		20-50%
		n/a

DATA ANALYSIS	
Procedures required	Step 1: return 50 microseconds of buffered antenna-level data from trigger Step 2: remove narrow-band RFI [if needed] Step 3: search for antenna-level pulses Step 4: perform initial time/direction fit, estimate shower core position Step 5: reduce data from 50 us to 5 us around burst Step 6: store data and perform detailed offline reconstruction.
Processing considerations (e.g. flag high wind speed data, reprocessing required?)	Recording of environmental parameters is appreciated.
Data products	Baseband X/Y data from each antenna
Description of pipeline	Pipeline is currently operational for data from other experiments (LOFAR [4], etc.) and will be adapted to SKA needs. This will be done by the High Energy Cosmic Particles Focus Group.

Quality assessment plan & cadence	Cadence: approx. 1 trigger every 1 minute (on average, with a Poissonian distribution) [6] Quality assessment plan: identify antennas with unusual/missing signal, log and search for ongoing anomalies in instrument response. [3]
Latency (Desired time lag between observation commencement and data being available in the archive. e.g. This could range from 'a few seconds' for transient detections using the fast imaging pipeline, to 'upon completion of scheduling block and pipeline reduction' (approximately 24 hours), to ‘at completion of the full project’.)	Technically: upon completion of the scheduling block (not time critical). However: given we expect triggers - on average - once every minute, we would prefer to process the data as it is coming in, and hence an availability of ~30 seconds would be preferred. But a solution involving keeping the antenna-level data in some internal buffer for instance, and being made available to us after 24 hr, would be satisfactory.

ISSUES TO BE DETERMINED/RESOLVED (Here you should include any additional information that needs to be resolved before this science can be carried out)
Antenna-level buffering needs to be implemented, and the duration of the buffers must be determined. We expect that we need 10 ms to form the trigger by the particle detector array. In addition, the buffers need to account for the time delay arising from transmitting the trigger through the SKA system. Construction of particle detector array. Proto-types have been tested at LOFAR and the MWA [5], demonstrating functionality and RFI/EMI-quietness, but the final design has yet to be approved and construction has to be started. Time delay between trigger generation and transmission and TPM buffers being stopped for read-out needs to be determined (must be shorter than buffer duration!) Mechanism for buffer data return must be implemented.

REFERENCES

[1] S.Buitink et al. Performance of SKA as an air shower observatory, *PoS* ICRC2021 (2021) 415

[2] T.Huege et al. Ultimate precision in cosmic-ray radio detection — the SKA, *EPJ Web Conf.* 135 (2017) 02003

[3] A. Nelles et al., Applications of antenna-level buffering, Arxiv: 1906.09066

[4] P.Schellart, A.Nelles. S.Buitink et al. Detecting cosmic rays with the LOFAR radio telescope, *Astron.Astrophys.* 560 (2013) A98

[5] J.D. Bray et al. The SKA Particle Array Prototype: The First Particle Detector at the Murchison Radio-astronomy Observatory, *Nucl.Instrum.Meth.A* 973 (2020) 164168

[6] ECP-150010 - "Enabling detection of cosmic ray air showers with SKA-low"

[7] ECP-170036 - "SKA1-Low Custom Experiment Port: Event capture at antenna level for custom experiments and diagnostics"

A References

A.1 Applicable Documents

Applicable documents The following documents are applicable to the extent stated herein. In the event of conflict between the contents of the applicable documents and this document, **the applicable documents** shall take precedence.

[AD1] *Observatory Establishment and Delivery Plan*

[AD2] Braun, R., et al. 2019, *Anticipated Performance of the Square Kilometre Array – Phase 1 (SKA1)*, arXiv:1912.12699

[AD3] Dewdney, P., et al. 20XX, *SKA1 System Baseline Design,* Rev. XX

[AD4] *SKA Phase 1 System (Level 1) Requirements Specification*, Rev. XX

A.2 Reference documents

The following documents are referenced in this document. In the event of conflict between the contents of the referenced documents and this document, **this document** shall take precedence.

[RD1] 2015 Science Book

[RD2] SKA-SCI-PRI-002-AppendixA, SKA1 Science Priority Outcomes

[RD3] SKA1 Scientific Use Cases, Revision 3

[RD4] SKA-OFF.AG.CNF-SKO-TN-001-1, SKA1 Configurations

[RD5] Radio Source Confusion Document, Condon et. al. 2012, ApJ 758, 23.

[RD6] Conway et al. 2020, *SKA1 Beyond 15 GHz: The Science case for Band 6,* Memo 20-01

LIST OF ABBREVIATIONS

AD .... Applicable Document

RD .... Reference Document

SKA..................... Square Kilometre Array

SKAO .... SKA Observatory

DOCUMENT HISTORY

Revision	Date Of Issue	Engineering Change Number	Comments
F	2014-02-25		Draft
G	2014-02-25		Draft
03	2016-03-11		Released
04	2021-12-07		Release

DOCUMENT SOFTWARE

	Package	Version	Filename
Word processor	MS Word	Office 365	SKA-TEL-SKO-0000015-04_Science_UseCases
Block diagrams			
Other			

ORGANISATION DETAILS

Name	SKA Observatory
Registered Address	Jodrell Bank Lower Withington Macclesfield Cheshire, SK11 9FT, UK
Fax	+44 (0)161 306 9600
Website	www.skao.int