A broad brush overview of AIP science with the SKA

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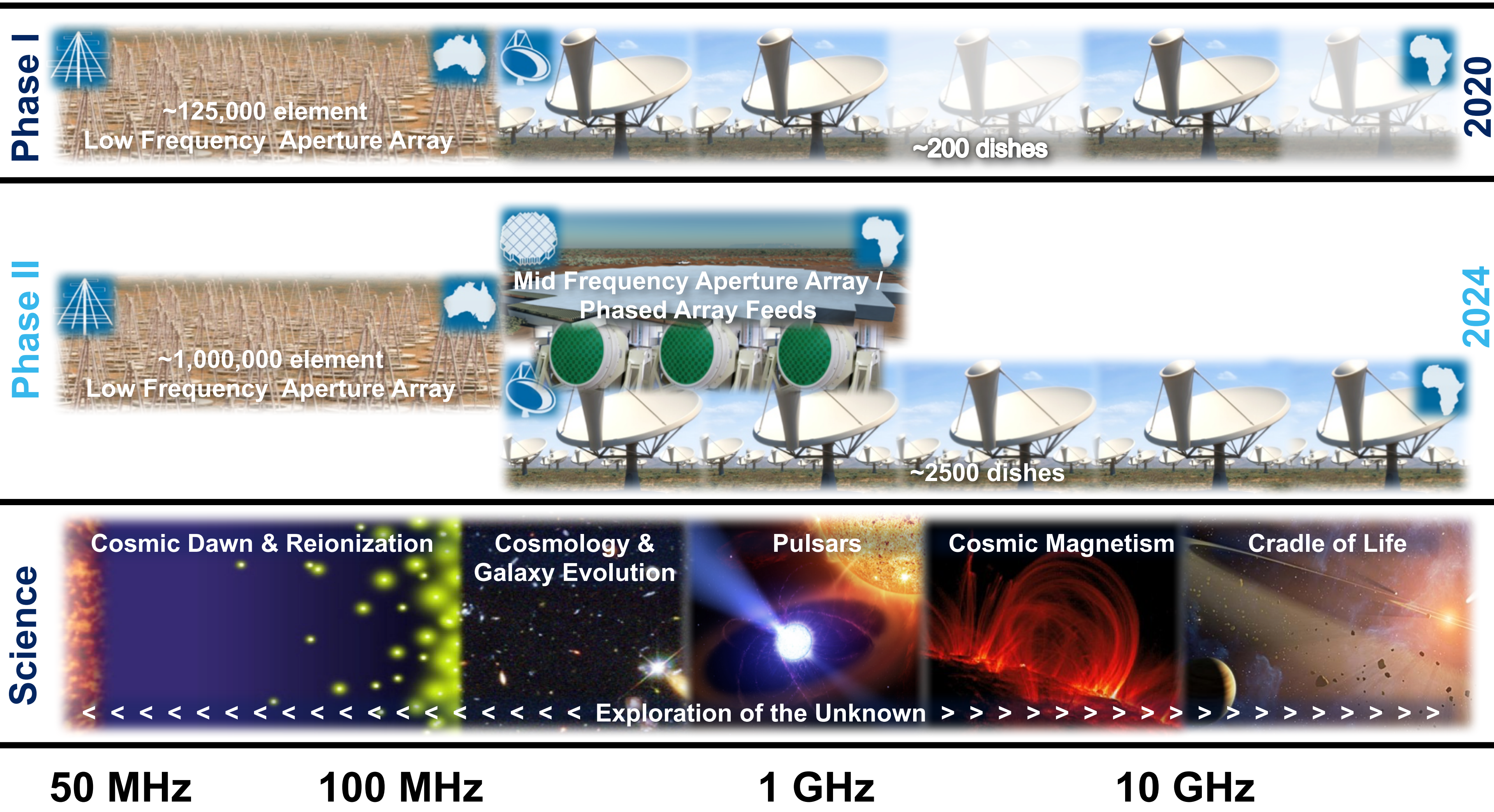
AIP meeting, ASTRON
June 8 - 9, 2017

Overview of the SKA

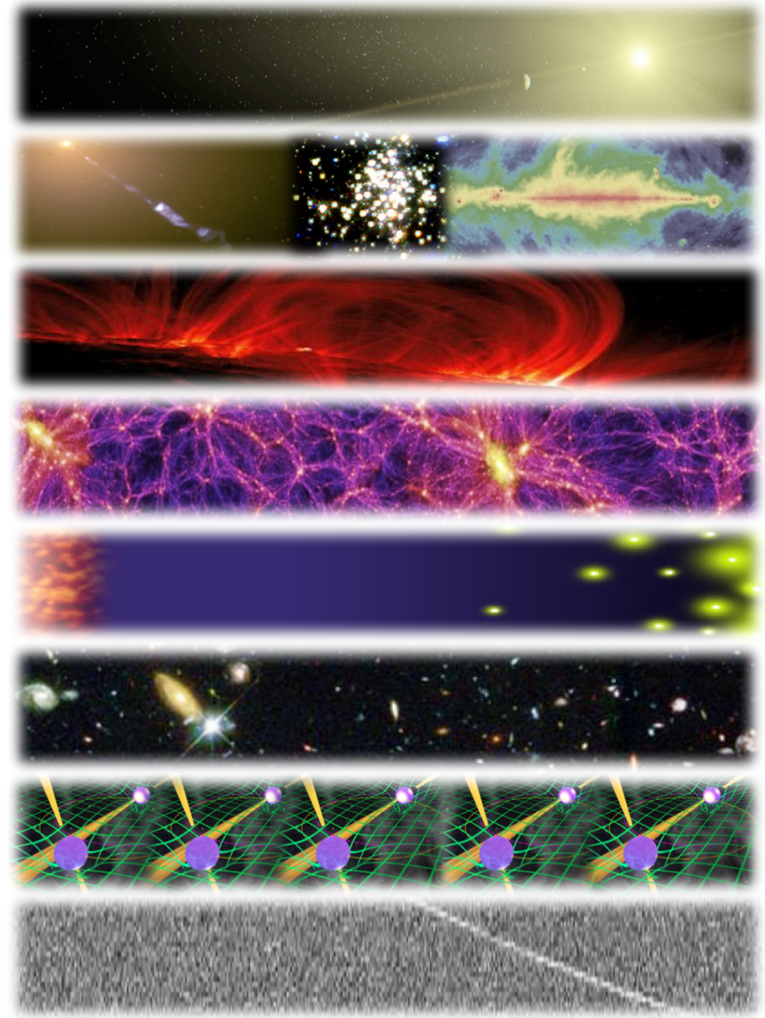


Outline

- science working group activities
- SKA1 high priority science goals
- science with the full SKA

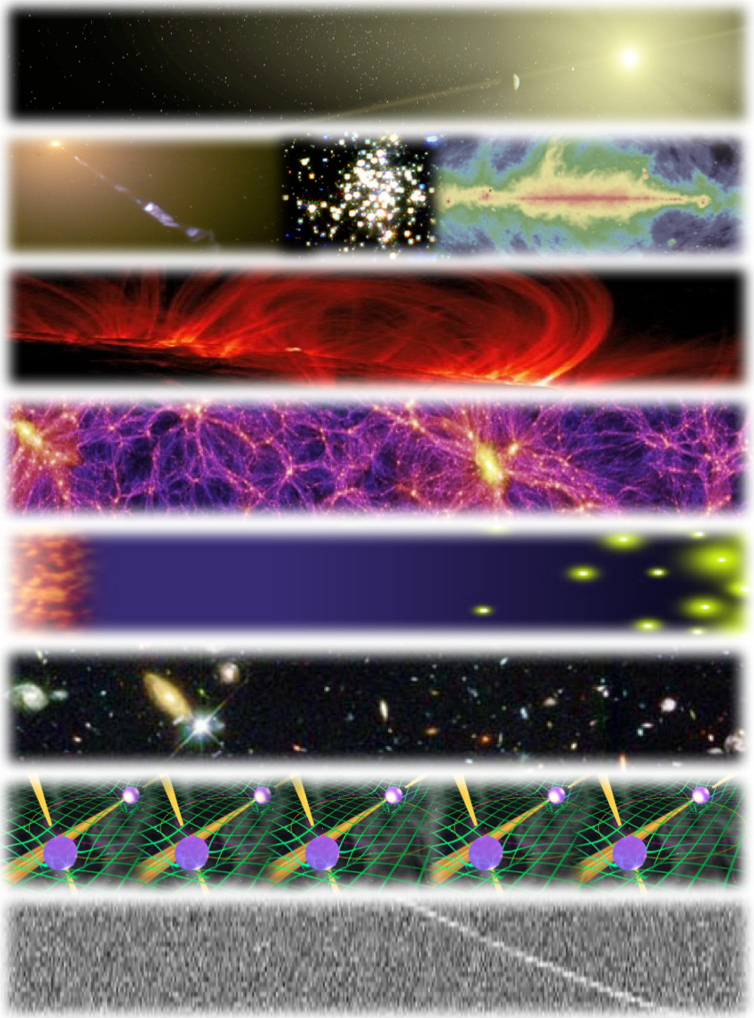
The Science Working Groups

- **Astrobiology ("The Cradle of Life")**
  - *Working Group Chairs:* Andrew Siemion (US) and Di Li (China)
- **Extragalactic Continuum**
  - *Working Group Chairs:* Minh Huynh (AU) and Rosella Cassano (IT)
- **Cosmic Magnetism**
  - *Working Group Chairs:* Ann Mao (NZ) and Russ Taylor (SA)
- **Cosmology**
  - *Working Group Chairs:* Mario Santos (SA and PT) and Xuelei Chen (China)
- **Epoch of Reionisation & the Cosmic Dawn**
  - *Working Group Chair:* Jonathan Pritchard (UK)
- **Extragalactic Spectral Line (non-HI)**
  - *Working Group Chairs:* Rob Beswick (UK) and Francoise Combes (France)
- **HI Galaxies**
  - *Working Group Chairs:* Erwin de Blok (SA) and Martin Meyer (NL)
- **Our Galaxy**
  - *Working Group Chairs:* Grazia Umana (IT) and Mark Thompson (UK)



The Science Working Groups

- **Pulsars ("Strong field tests of gravity")**
  - *Working Group Chairs:* Ben Stappers (UK) and Andrea Possenti (IT)
- **Solar, Heliospheric and Ionospheric Physics**
  - *Working Group Chairs:* Divya Oberoi (IN) and Eduard Kontar (UK)
- **Transients**
  - *Working Group Chair:* Michael Rupen (CA) and J.-P. Macquart (AU)



Science update: cost control project

- SKAO generate an initial ranking of cost control options in order of perceived scientific impact (based on HPSOs)

WS / Origin	Description	LOW / MID / COMMON	Science Implication	Science Impact
5.39	INFRA_SA Renewable energy to outer dishes	MID	None	1
5.34	Maximise use of code produced during Pre-Construction	COMMON	None	1
5.38	Simplify DDBH LOW	LOW	None	1
5.38	Simplify DDBH MID	MID	None	1
5.25.2	Reduce PSS-MID: A, 750 nodes to 500 nodes	MID	Likely none, or small reduction of pulsar search parameter space.	1
5.25.2	Reduce PSS-LOW: A, 250 nodes to 167 nodes	LOW	Likely none, or small reduction of pulsar search parameter space.	1
5.35	Reduce CBF-MID: Freq. Slice variant of CSP design vs. MeerKAT-based design	MID	None	1
5.19	MID Frequency and Timing Standard: SaDT solution vs. MeerKAT-based solution	MID	None	1
5.36	MID SPF Digitisers: DSH solution vs. MeerKAT-based solution	MID	None	1
5.26 / 5.29	LOW RPF: Early Digital Beam Formation vs. Analogue Beam Formation	LOW	None	1
2	LOW Antenna: Log Periodic Design vs. Dipole Design	LOW	None of the current designs meet the L1 requirements	3
8	SDP- HPC: Deploy 200 Pflops (rather than 260 Pflops)	COMMON	Lower allowed duty cycle for HPC-intensive observations.	2
5.24.3	Reduce Bmax MID from 150 to 120 km: Case A, remove 3 dishes, but keep infra to 150km	MID	Reduction of maximum achievable resolution by 20%, although can be partially recovered with data weighting and longer integration times.	2
5.24.2	Reduce Bmax MID from 150 to 120 km: Case B, remove infra, but add dishes to core	MID	Reduction of maximum achievable resolution by 20%, although can be partially recovered with data weighting and longer integration times.	2
			Reduction of maximum achievable	

Science update: SKA Science Assessment Teams

1. Impact on EoR/CD of changes to SKA1-Low maximum baseline length
   - **Emma Chapman (UCL, Chair),** Sarod Yatawatta (ASTRON), Gianni Bernardi (SKA-SA), George Heald (CSIRO), Jeff Wagg (SKAO Support)
2. Required timing accuracy to enable successful precision pulsar timing science
   - **Andrea Possenti (INAF, Chair),** Ingrid Stairs (UBC), Ben Stappers (UMan), Scott Ransom (NRAO), Willem van Straten (AUT), Evan Keane (SKAO Support)
3. Impact of SKA-Low antenna optimised frequency coverage
   - **Chiara Ferrari (ObsCoAz, Chair)**, Leon Koopmans (UGroningen), James Aguirre (UPenn), Annalisa Bonafede (INAF), Jason Hessels (UAmsterdam), Divya Oberoi (NCRA), Philippe Zarka (ObsPM), Francesco de Gasperin (ULeiden), Anna Bonaldi (SKAO Support)

Science update: SKA Science Town Hall Meeting

- Preliminary reports from the three Science Assessment Teams

- Preliminary Science Assessments from each SWG / FG which:
  1. Endorse or suggest reordering of items in the cost savings measures list
  2. Affirm or not the transformational science capability of the cost-capped observatory

- Q&A opportunities with very constructive discussion

- Some outcomes:
  - agreement that some reduction of longest baselines on LOW can be tolerated by EoR/CD science (~49km)
  - double hits to continuum science in the case of both LOW and MID (reduced bandwidth combined with reduction of maximum baseline and number of feeds) → no longer transformational. Needs revision.
  - reduction of PSS capabilities not worth cost savings

SKA1 Science Objectives

- Arranged by SWG
- Arbitrary order of SWG groups
- SWG priority order within each group

Science Goal	SWG	Objective	SWG Rank
1	*CD/EoR*	Physics of the early universe IGM - I. Imaging	1/3
2	*CD/EoR*	Physics of the early universe IGM - II. Power spectrum	2/3
3	*CD/EoR*	Physics of the early universe IGM - III. HI absorption line spectra (21cm forest)	3/3
4	*Pulsars*	Reveal pulsar population and MSPs for gravity tests and Gravitational Wave detection	1/3
5	*Pulsars*	High precision timing for testing gravity and GW detection	1/3
6	*Pulsars*	Characterising the pulsar population	2/3
7	*Pulsars*	Finding and using (Millisecond) Pulsars in Globular Clusters and External Galaxies	2/3
8	*Pulsars*	Finding pulsars in the Galactic Centre	2/3
9	*Pulsars*	Astrometric measurements of pulsars to enable improved tests of GR	2/3
10	*Pulsars*	Mapping the pulsar beam	3/3
11	*Pulsars*	Understanding pulsars and their environments through their interactions	3/3
12	*Pulsars*	Mapping the Galactic Structure	3/3
13	*HI*	Resolved HI kinematics and morphology of ~10^10 M_sol mass galaxies out to z~0.8	1/5
14	*HI*	High spatial resolution studies of the ISM in the nearby Universe.	2/5
15	*HI*	Multi-resolution mapping studies of the ISM in our Galaxy	3/5
16	*HI*	HI absorption studies out to the highest redshifts.	4/5
17	*HI*	The gaseous interface and accretion physics between galaxies and the IGM	5/5
18	*Transients*	Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State	=1/4
19	*Transients*	Accessing New Physics using Ultra-Luminous Cosmic Explosions	=1/4
20	*Transients*	Galaxy growth through measurements of Black Hole accretion, growth and feedback	3/4
21	*Transients*	Detect the Electromagnetic Counterparts to Gravitational Wave Events	4/4
22	*Cradle of Life*	Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc	1/5
23	*Cradle of Life*	Characterise exo-planet magnetic fields and rotational periods	2/5
24	*Cradle of Life*	Survey all nearby (~100 pc) stars for radio emission from technological civilizations.	3/5
25	*Cradle of Life*	The detection of pre-biotic molecules in pre-stellar cores at distance of 100 pc.	4/5
26	*Cradle of Life*	Mapping of the sub-structure and dynamics of nearby clusters using maser emission.	5/5
27	*Magnetism*	The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields	1/5
28	*Magnetism*	Determine origin, maintenance and amplification of magnetic fields at high redshifts - I.	2/5
29	*Magnetism*	Detection of polarised emission in Cosmic Web filaments	3/5
30	*Magnetism*	Determine origin, maintenance and amplification of magnetic fields at high redshifts - II.	4/5
31	*Magnetism*	Intrinsic properties of polarised sources	5/5
32	*Cosmology*	Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales.	1/5
33	*Cosmology*	Angular correlation functions to probe non-Gaussianity and the matter dipole	2/5
34	*Cosmology*	Map the dark Universe with a completely new kind of weak lensing survey - in the radio.	3/5
35	*Cosmology*	Dark energy & GR via power spectrum, BAO, redshift-space distortions and topology.	4/5
36	*Cosmology*	Test dark energy & general relativity with fore-runner of the 'billion galaxy' survey.	5/5
37	*Continuum*	Measure the Star formation history of the Universe (SFHU) - I. Non-thermal processes	1/8
38	*Continuum*	Measure the Star formation history of the Universe (SFHU) - II. Thermal processes	2/8
39	*Continuum*	Probe the role of black holes in galaxy evolution - I.	3/8
40	*Continuum*	Probe the role of black holes in galaxy evolution - II.	4/8
41	*Continuum*	Probe cosmic rays and magnetic fields in ICM and cosmic filaments.	5/8
42	*Continuum*	Study the detailed astrophysics of star-formation and accretion processes - I.	6/8
43	*Continuum*	Probing dark matter and the high redshift Universe with strong gravitational lensing.	7/8
44	*Continuum*	Legacy/Serendipity/Rare.	8/8

SKA1 High Priority Science Objectives

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18	*Transients*	Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State	=1/4
22	*Cradle of Life*	Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc	1/5
27	*Magnetism*	The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields	1/5
32	*Cosmology*	Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales.	1/5
33	*Cosmology*	Angular correlation functions to probe non-Gaussianity and the matter dipole	2/5
37+38	*Continuum*	Star formation history of the Universe (SFHU) – I+II. Non-thermal + Thermal processes	1+2/8

SKA1 High Priority Science Objectives

- Arranged by SWG
- Arbitrary order of SWG groups
- Priority order within each group
- most science goals benefit from survey speed below 1420 MHz

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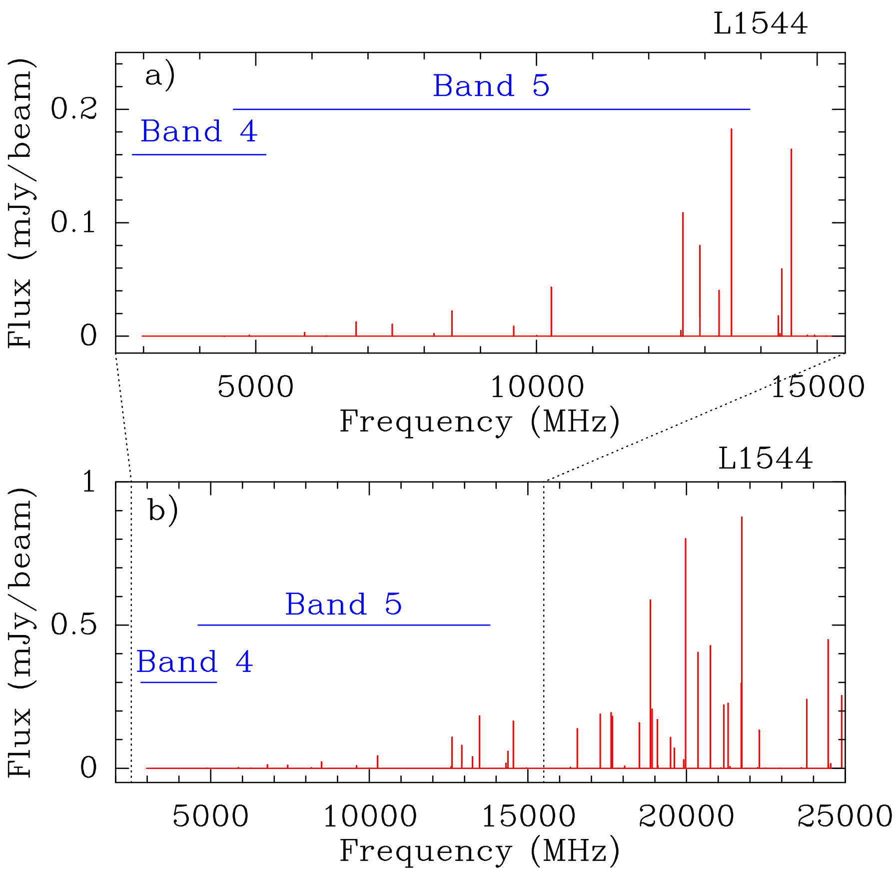
- Broad bandwidth at high frequencies not included in the original baseline design, but scientific interest exists in new SWGs (ExGal spectral lines, Our Galaxy) and Cradle of Life

Complex organics

Holy Grail of Pre-biotic Astrochemistry
– detection of amino acids in the gas phase, e.g., Glycine NH_2CH_2COOH

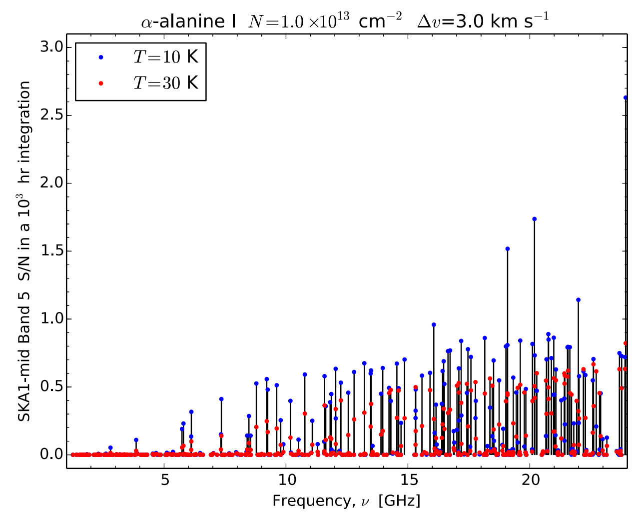


Protoplanetary disk – beam matched to disk size (~few arcsec)

Firm detections in meteorites (e.g. Ehrenfreund+2001) and comets (Elsila+2009)

Not (yet) detected in the ISM

Colds cores and disks – frozen onto grains?

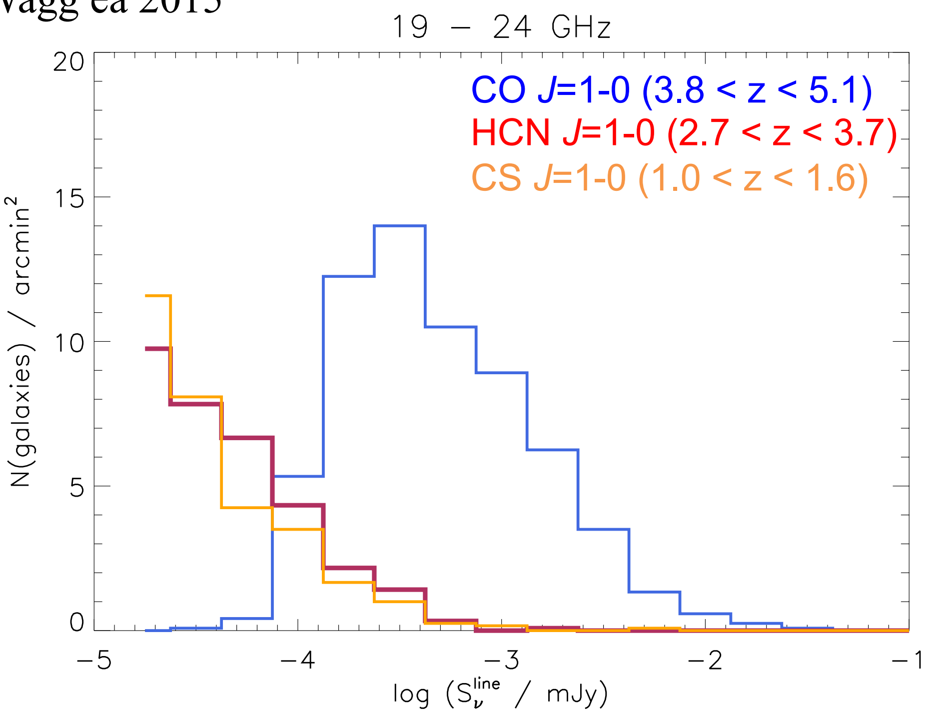


Hoare+, Codella+, Testi+ 2015

High-redshift molecular gas

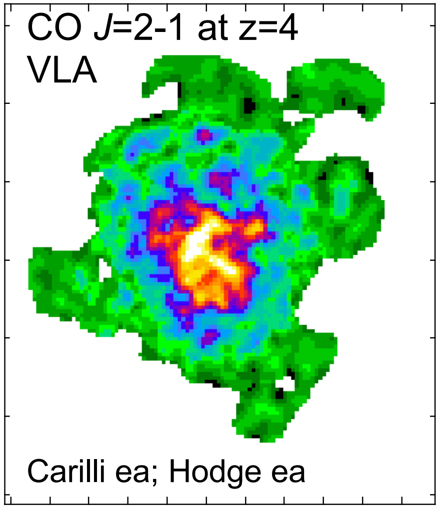
– Molecular gas (CO, CS, HCN, HCO+) content of galaxies that existed during the first half of the age of the Universe

Wagg ea 2015



- Blind surveys enabled by broad bandwidth

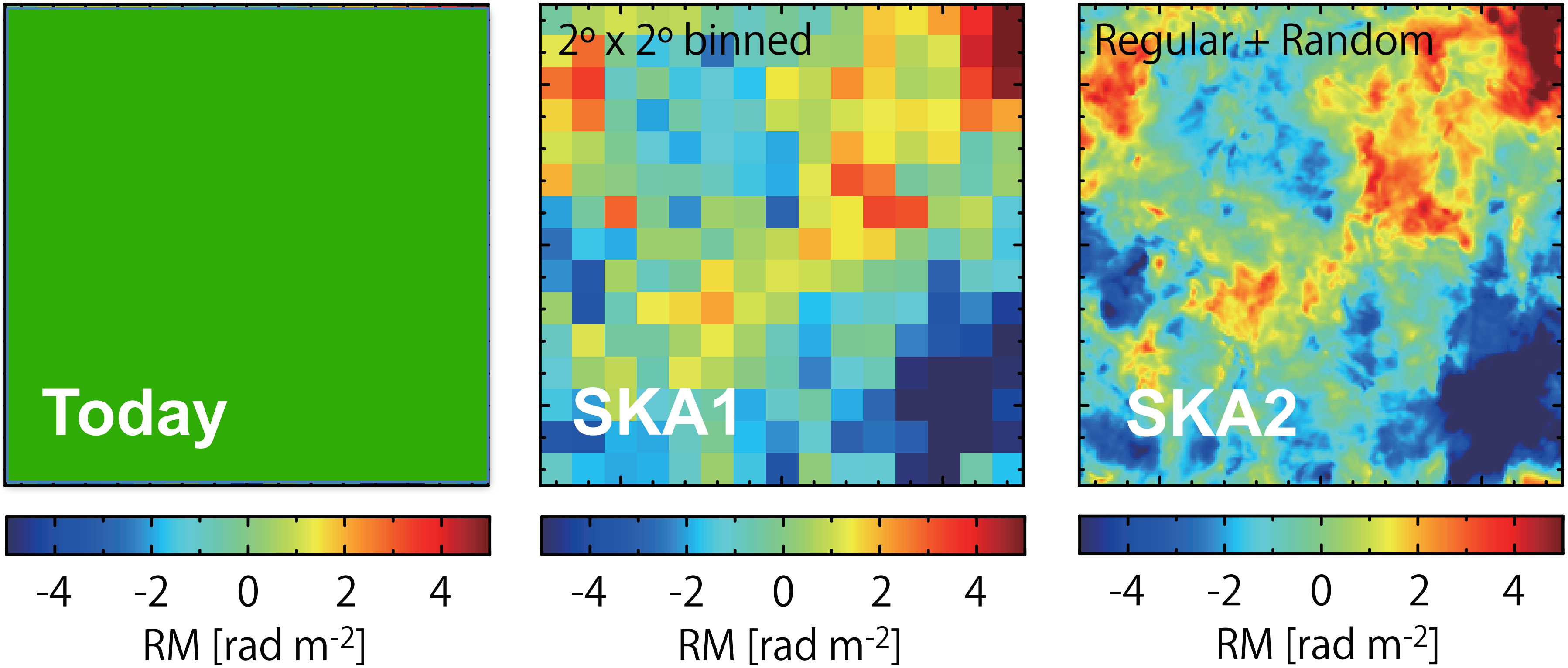
- molecular (=H_2) gas: CO J=1-0
  dense gas: HCN/HCO+/HNC
- (total) cold molecular gas masses
- dense molecular gas fractions



$L_{IR} \sim 10^{12}\ L_\odot$
$M_{dyn} \sim 5\times10^{11}\ M_\odot$
$M_{H2} \sim 10^{11}\ M_\odot$
$t_{univ} \sim 2.2$ Gyr

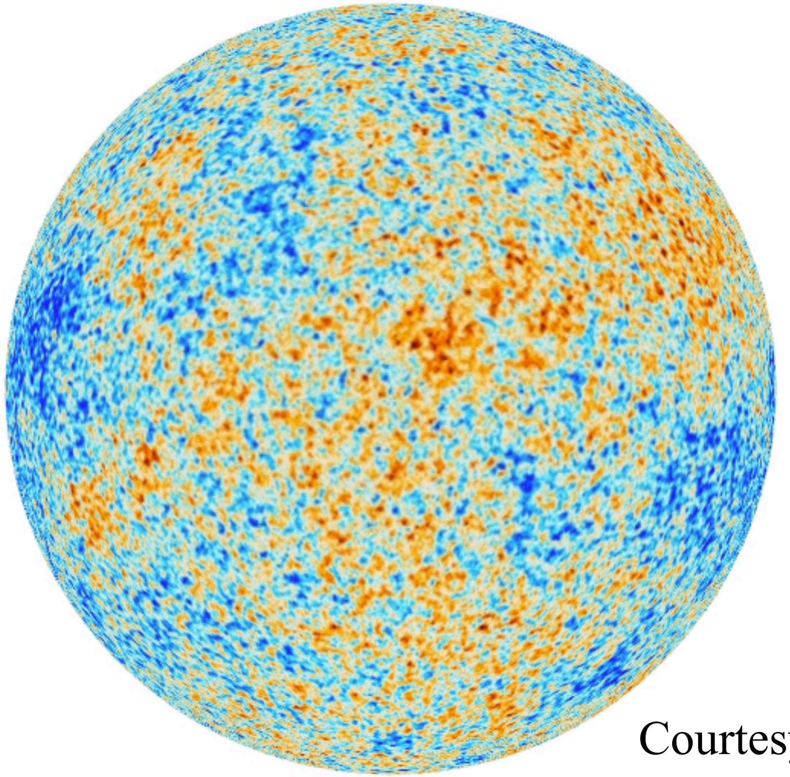
similar sensitivity to HCN *J*=1-0 at z~4 with SKA2 in 1000h

The all-sky rotation measure grid



- 3D magnetic tomography of the Galaxy and distant universe; from current 1 RM deg^{-2}, SKA1: 300 deg^{-2} to SKA2: 5000 deg^{-2}
  (Johnston-Hollitt et al. 2015)

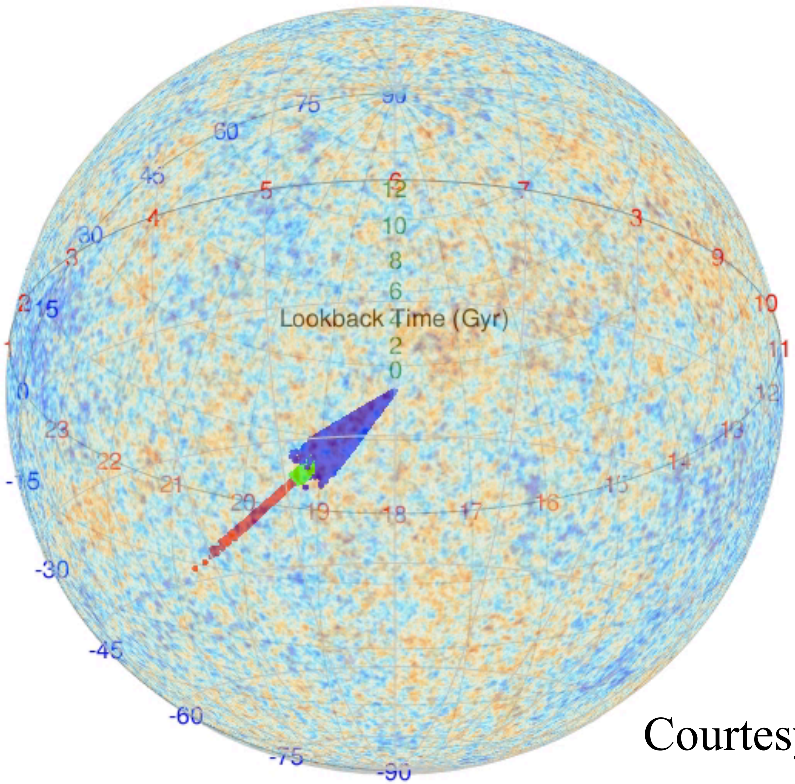
HI Galaxy Surveys with SKA



Courtesy of M. Meyer, UWA

- Gas content and kinematics of galaxies
- Cosmology over wide fields (100s to 1000s of sq. degrees) – talk by Alkistis
- Samples: ~10^4 (current) to ~10^9 with full SKA

HI Galaxy Surveys with SKA1: 1k hours



Red – single pointing Band 1
Green – 20 sq. deg. Band 2
Blue – 400 sq. deg. Band 2

Courtesy of M. Meyer, UWA

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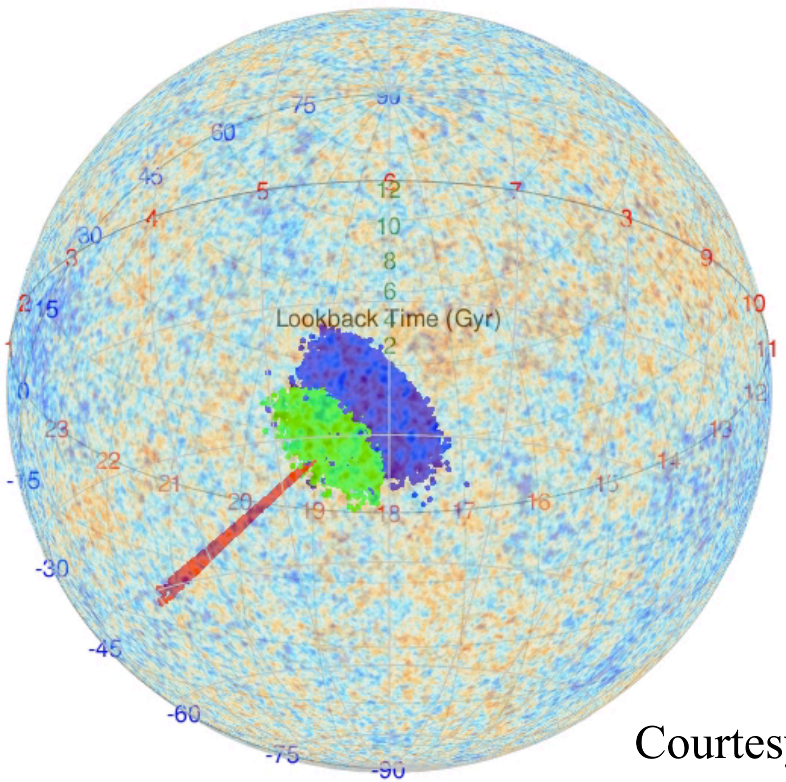
HI Galaxy Surveys with SKA1: 10k hours

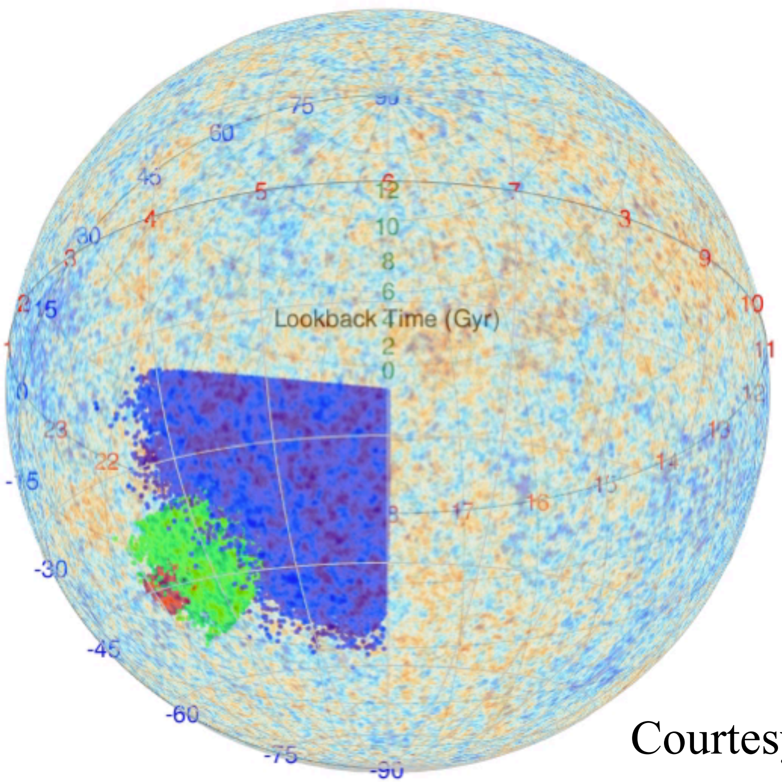


Red – single pointing Band 1
Green – 5000 sq. deg. Band 2
Blue – 20000 sq. deg. Band 2

Courtesy of M. Meyer, UWA

- Gas content and kinematics of galaxies
- Cosmology over wide fields (100s to 1000s of sq. degrees) – talk by Alkistis
- Samples: ~10^4 (current) to ~10^9 with full SKA

HI Galaxy Surveys with full SKA: 10k hours

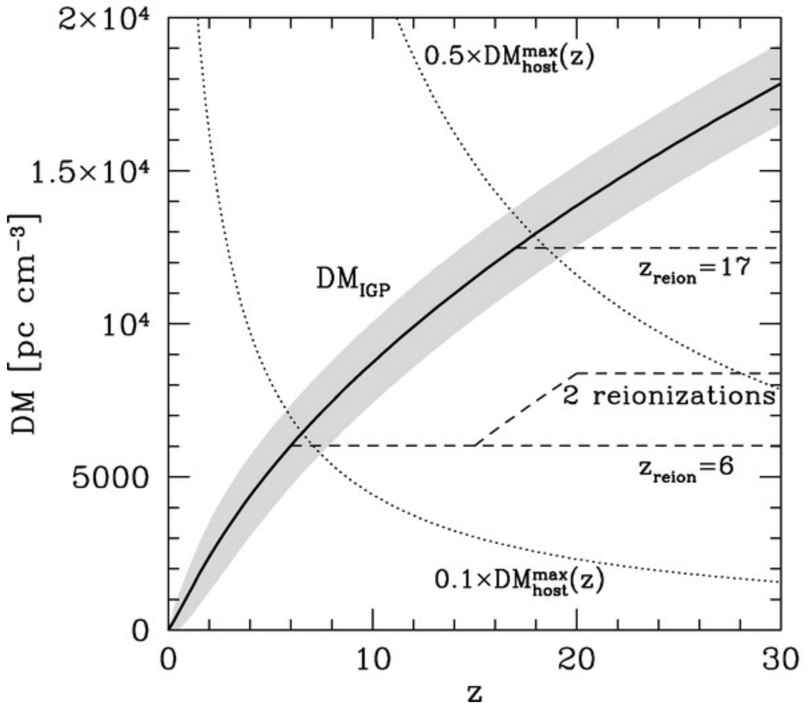


Red – 60 sq. deg. Band 1
Green – 600 sq. deg. Band 2
Blue – 6000 sq. deg. Band 2

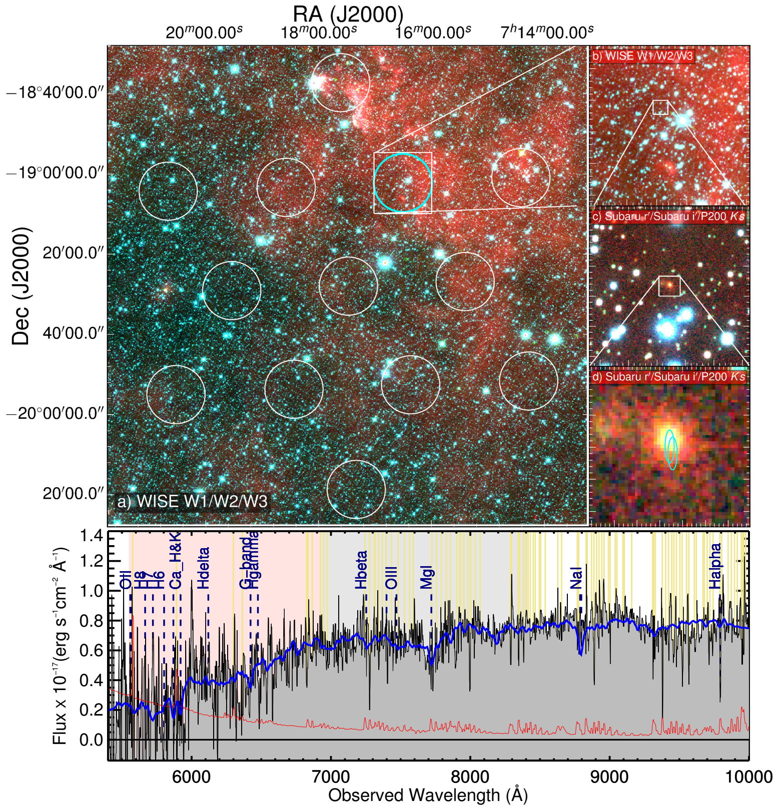
Courtesy of M. Meyer, UWA

- Gas content and kinematics of galaxies
- Cosmology over wide fields (100s to 1000s of sq. degrees) – talk by Alkistis
- Samples: ~10^4 (current) to ~10^9 with full SKA

Fast Radio Bursts as a cosmological probe



(Ioka 2003)



(Keane et al. 2016)

- SKA1: (~1000) of spectroscopically identified FRBs may provide a means of probing the missing baryons
- number of transients will scale linearly with FoV – talks by Petroff and Broderick

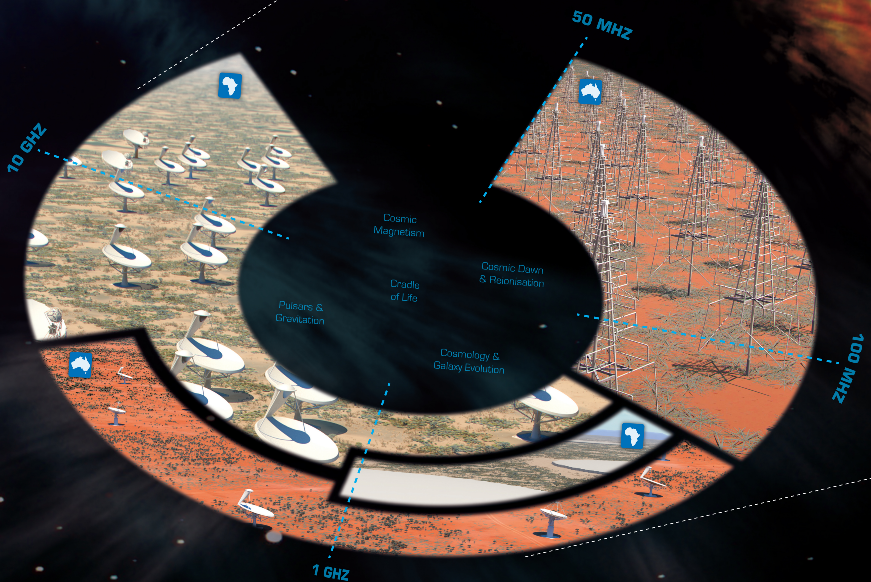
Summary

- Excellent engagement with the broad scientific community
- Design changes and cost control options have significant input from SWGs
- Full SKA (technology) science desires are likely to prioritize mid-frequency survey speed and broad bandwidth at high frequencies (>10 GHz)
- *Recommend that AIP consortia review the SKA science book*

SKA Science

The SKA will revolutionise our understanding of the Universe and the laws of fundamental physics

http://astronomers.skatelescope.org/



Credits and acknowledgements: Djorgovski et al, (Caltech) (EoR image); Casey Reed (Pulsar image); NASA/JPL-Caltech/SSC (Galaxy evolution image-NGC 3190 Field); NASA/Stanford-Lockheed Institute for Space Research's TRACE Team (Cosmic Magnetism image-Sun's Corona); NASA/JPL-Caltech (Cradle of life image)