Exploring the Universe with the world’s largest radio telescope

Phase I: 2020
- 250,000 element Low Frequency Aperture Array
- 254 dishes
- 96 survey enabled dishes

Phase II: 2024
- >250,000 element Low Frequency Aperture Array
- 2500 dishes

Mid Frequency Aperture Array

Science
- Cosmic Dawn & Reionization
- Cosmology & Galaxy Evolution
- Pulsars
- Cosmic Magnetism
- Cradle of Life

 Frequencies:
- 50 MHz
- 100 MHz
- 1 GHz
- 10 GHz
The Science Working Groups

- **Astrobiology (“The Cradle of Life”)**
  - *Project Scientist:* Tyler Bourke
  - *Working Group Chair:* Melvin Hoare

- **Continuum**
  - *Project Scientist:* Jeff Wagg
  - *Working Group Chairs:* Nick Seymour & Isabella Prandoni

- **Cosmic Magnetism**
  - *Project Scientist:* Jimi Green
  - *Working Group Chairs:* Melanie Johnston-Hollitt & Federica Govoni

- **Cosmology**
  - *Project Scientist:* Jeff Wagg
  - *Working Group Chair:* Roy Maartens

- **Epoch of Reionisation & the Cosmic Dawn**
  - *Project Scientist:* Jeff Wagg
  - *Working Group Chair:* Leon Koopmans

- **HI Galaxies**
  - *Project Scientist:* Jimi Green
  - *Working Group Chairs:* Lister Staveley-Smith & Tom Osterloo

- **Pulsars (“Strong field tests of gravity”)**
  - *Project Scientist:* Jimi Green
  - *Working Group Chairs:* Ben Stappers & Michael Kramer

- **Transients**
  - *Project Scientist:* Tyler Bourke
  - *Working Group Chair:* Rob Fender
The Work Package Consortia

- Project Scientist: Jimi Green
- Project Scientists: Jeff Wagg & Tyler Bourke
- Project Scientist: Tyler Bourke

- Project Scientist: Jeff Wagg
- Project Scientists: Jimi Green & Tyler Bourke
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- Project Scientist: Tyler Bourke
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- Project Scientist: Tyler Bourke
- Project Scientists: Jeff Wagg & Tyler Bourke
How does SKA1 baseline redefine state-of-art?

<table>
<thead>
<tr>
<th></th>
<th>JVLA</th>
<th>MeerKAT</th>
<th>SKA1-mid</th>
<th>ASKAP</th>
<th>SKA1-survey</th>
<th>LOFAR-NL</th>
<th>SKA1-low</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aeff/Tsys</strong></td>
<td>m²/K</td>
<td>265</td>
<td>321</td>
<td>1630</td>
<td>65</td>
<td>391</td>
<td>61</td>
</tr>
<tr>
<td><strong>Survey FoV</strong></td>
<td>deg²</td>
<td>0.14</td>
<td>0.48</td>
<td>0.39</td>
<td>30</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td><strong>Survey Speed FoM</strong></td>
<td>deg² m⁴ K⁻²</td>
<td>0.98×10⁴</td>
<td>5.0×10⁴</td>
<td>1.0×10⁶</td>
<td>1.3×10⁵</td>
<td>2.8×10⁶</td>
<td>2.2×10⁴</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>arcsec</td>
<td>1.4</td>
<td>11</td>
<td>0.22</td>
<td>7</td>
<td>0.9</td>
<td>5</td>
</tr>
</tbody>
</table>

**A_{eff}/T_{sys}:**

- 6xJVLA
- 6xASKAP
- 16xLOFAR

**Survey Speed:**

- 100x
- 22x
- 270x
SKA1 “2nd generation” configurations

- SKA1-LOW possible configuration of core and remote spiral

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SKA1 “2nd generation” configurations

- SKA1-MID possible configuration of core and remote spiral

Exploring the Universe with the world’s largest radio telescope
SKA1 “2nd generation” configurations

- SKA1-SUR possible configuration of core and remote spiral

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SKA1 performance as function of scale

- Configuration optimisation for broad performance “sweet-spot”
SKA Key Science

- Strong-field Tests of Gravity with Pulsars and Black Holes
  Phase 1 headline science
- Galaxy Evolution, Cosmology, & Dark Energy
  Phase 1 headline science
- Emerging from the Dark Ages and the Epoch of Reionization
  Phase 1 headline science
- The Cradle of Life & Astrobiology
- The Origin and Evolution of Cosmic Magnetism

With design philosophy of *Exploration of the Unknown*
Cosmic Origins
Probing the early universe with the 21cm HI Line

Neutral Hydrogen 21 cm spin-flip transition provides probe of neutral intergalactic medium before and during formation of first stars

$\nu = 1420 \text{ MHz}/(1 + z)$

$\lambda = 21 \text{ cm} \ (1 + z)$

$T_b (\text{mK})$
• Detecting EoR structures in imaging mode (as distinct from statistically) on 5 arcmin scales with 1 mK RMS
• Probing the Cosmic Dawn statistically or possibly even imaging in ultra-deep

Exploring the Universe with the world’s largest radio telescope
Finding all pulsars in the Milky Way...


- ~30,000 normal pulsars
- ~2,000 millisecond psrs
- ~100 relativistic binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

• Timing precision is expected to increase by factor ~100
• Rare and exotic pulsars and binary systems: including PSR-BH systems!
• Testing cosmic censorship and no-hair theorem
• Current estimates are that ~75% of entire Galactic population in reach of SKA1

Exploring the Universe with the world’s largest radio telescope
The transient radio sky

A Population of Fast Radio Bursts at Cosmological Distances
D. Thornton et al.
Science 341, 53 (2013);
DOI: 10.1126/science.1236789

- Four celestial “FRB” events now detected (after first “Lorimer” burst):
  S = 0.5 – 1.3 Jy, Δt = 1 – 6 msec, DM = 550 – 1100 cm⁻³ pc
- Estimated event rate: 1x10⁴ sky⁻¹ day⁻¹
- Completely unknown origin, possibly at cosmological distances

Exploring the Universe with the world’s largest radio telescope
A daily SKA1 all-sky transient survey

- Integration of ≈50 seconds per position
- Sensitivity for 2 msec bursts is 160x worse: 27 mJy, 8 mJy rms
- Computing strategy most still be developed for such a mode!
- Predicted FRB detections: 5 per day, with localisation to a fraction of arcsec

Exploring the Universe with the world’s largest radio telescope
Cosmology with SKA1: Integrated Sachs-Wolfe effect

• Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect: correlation of foreground source populations with CMB structures

Exploring the Universe with the world’s largest radio telescope
Cosmology with SKA1: Complementarity with Euclid

- Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect
- Achieving 2 μJy rms would provide ≈4 galaxies arcmin⁻² (>10σ)
- Almost uniform sky coverage of 3π sr is exceptional
- Major enhancement over Euclid alone

Exploring the Universe with the world’s largest radio telescope
Cosmology with SKA1: Weak Gravitational Lensing

- Constraining the Dark Energy Equation of State with Weak Gravitational Lensing

Exploring the Universe with the world’s largest radio telescope
Cosmology with SKA1: Complementarity with Euclid

- Constraining the Dark Energy equation of state with a weak gravitational lensing measurement of cosmic shear
- Achieving 1 \( \mu \text{Jy} \) rms would provide \( \approx 6 \) galaxies arcmin\(^{-2} \) (>10\( \sigma \))
- PSF is excellent quality circular Gaussian from about 0.6"
- Major enhancement in DE Figure-of-Merit

Euclid +SKA1 lensing
\( \sigma_w=0.03 \)
\( \sigma_\gamma=0.017 \)

Exploring the Universe with the world’s largest radio telescope
Cosmology with SKA1: Baryon Acoustic Oscillations

- Constraining Dark Energy models with redshift-resolved BAO measurements

(Blake & Moorfield)
A wide-field HI emission survey for BAO and $\Omega_{\text{HI}}(z)$

- Detect $10^{7.1}$ galaxies $<z> \approx 0.3$, $10^{5.1}$ galaxies $<z> \approx 1$
- Density $\approx 2500$ galaxies deg$^{-2}$, 1 arcmin$^{-2}$
- Compare SDSS: $10^{6.2}$ galaxies with $<z> \approx 0.1$ over 15,000 deg$^2$
- Compare WigglersZ $10^{5.2}$ galaxies with $<z> \approx 0.6$
- Major contribution to BAO science, complementary systematics versus Opt/IR

Exploring the Universe with the world’s largest radio telescope
An **SKA2** HI emission survey for precision Cosmology

• Detect $10^{8.9}$ galaxies with $<z> \approx 1$, $10^{7.9}$ with $<z> \approx 2$
• Compare Euclid target of $10^8$ spectra with $<z> \approx 1$
• **SKA2** will provide an unrivaled capability for precision cosmology!

Exploring the Universe with the world’s largest radio telescope
SKA Key Science

• Strong-field Tests of Gravity with Pulsars and Black Holes
  Unique GR constraints, major contributions in Phase 1 and Phase 2
• Galaxy Evolution, Cosmology, & Dark Energy
  Cutting edge contributions in non-Gaussianity and Dark Energy
  Complementarity to Euclid, LSST in Phase 1 (reduced systematics)
  Unmatched performance in Phase 2 (Billion Galaxy Surveys)
• Emerging from the Dark Ages and the Epoch of Reionization
  Unique EoR imaging capability in Phase 1
  Reaching to Cosmic Dawn in Phase 2
• The Cradle of Life & Astrobiology
• The Origin and Evolution of Cosmic Magnetism

With design philosophy of *Exploration of the Unknown*

Unmatched prospects (complement to LSST) in Phase 1 and Phase 2

Exploring the Universe with the world’s largest radio telescope
Continuum Surveys with SKA1:

• All-sky surveys for Integrated Sachs-Wolfe, magnetism, Galactic sources, local Universe

Exploring the Universe with the world's largest radio telescope
Continuum Surveys with SKA1:

- Medium-wide surveys for weak lensing, galaxy evolution $z < 1$
Continuum Surveys with SKA1:

- Deep surveys for resolved morphology of $z > 1$ galaxies

Exploring the Universe with the world’s largest radio telescope
High Frequency Imaging with SKA1:

- Targeted imaging of line and continuum fields

Exploring the Universe with the world’s largest radio telescope
High Frequency Imaging with SKA1:

- Targeted imaging of line and continuum fields

Exploring the Universe with the world’s largest radio telescope