Square Kilometre Array – Instrument and Science Overview

Robert Braun
SKA Science Director
14th January 2014
Great Observatories for the coming decades

E-ELT optical/IR

Construction approved
Great Observatories for the coming decades

Atacama Large Millimetre Array (ALMA): mm/submm
Chajnantor Plateau @ 17,000 ft
Early science now
Inaugurated on 13th March 2013
Great Observatories for the coming decades

James Webb Space Telescope: due for launch in 2018
Great Observatories for the coming decades

Square Kilometre Array: radio
Construction start 2017/18
Specialised “experiments”

EUCLID: ~€1B, lau

LSST: ~$750M, operational ~2020
Exploring the Universe with the world’s largest radio telescope

Phase I: 2020
- 250,000 element Low Frequency Aperture Array
- 50 MHz
- Cosmic Dawn & Reionization
- Science

Phase II: 2024
- >250,000 element Low Frequency Aperture Array
- 100 MHz
- 1 GHz
- Cosmic Dawn & Reionization
- Science

96 survey enabled dishes
254 dishes
2500 dishes

Cosmic Magnetism
Cradle of Life
Cosmology & Galaxy Evolution
Pulsars
Exploring the Universe with the world’s largest radio telescope

Phase I: 2020

- 250,000 element Low Frequency Aperture Array
- 254 dishes

Science
- 96 survey enabled dishes
- Cosmic Dawn & Reionization
- Pulsars
- Cosmic Magnetism
- Cradle of Life
- Cosmology & Galaxy Evolution

Frequency Bands:
- 50 MHz
- 100 MHz
- 1 GHz
- 10 GHz
How did we choose the site?

- **Sydney**: population 4 million
- **Narrabri**: population 4000
- **Mileura**: population 4
How did we choose the site?

Background Radiation at 131.0 MHz (mV/m)

Exploring the Universe with the world’s largest radio telescope
Shire of Murchison:

- 50,000 km$^2$; size of the Netherlands
- 0 gazetted towns
- 29 sheep/cattle stations
- 110 population => 0.002 km$^{-2}$
The Science Working Groups

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

- **Galaxy Evolution – 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

- **Galaxy Evolution – HI**
  - 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 Scientist: Jeff Wagg & Tyler Bourke

Project Scientist: Tyler Bourke

Project Scientist: Jimi Green

Project Scientists: Jeff Wagg & Tyler Bourke

Project Scientist: Tyler Bourke

Project Scientist: Jeff Wagg

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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>A_{eff}/T_{sys}</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>

\[
\frac{A_{\text{eff}}}{T_{\text{sys}}}:
\begin{align*}
6 & \times \text{JVLA} \\
6 & \times \text{ASKAP} \\
16 & \times \text{LOFAR}
\end{align*}
\]

**Survey Speed:**
\[
\begin{align*}
100 & \times \text{JVLA} \\
22 & \times \text{ASKAP} \\
270 & \times \text{LOFAR} \\
280 & \times \text{JVLA}
\end{align*}
\]
Survey speed comparison

Survey Speed ($m^2/K\, \text{deg}^2$)

Frequency (GHz)

SKA1
SKA2
LOFAR
JVLA

Exploring the Universe with the world’s largest radio telescope
SKA1: facility versus “experiment”

- Configuration optimisation for broad performance “sweet-spot”
SKA1 configurations

• SKA1-LOW possible configuration of core and remote spiral

Exploring the Universe with the world’s largest radio telescope
SKA1 configurations

• SKA1-MID possible configuration of core and remote spiral

Exploring the Universe with the world’s largest radio telescope
• SKA1-MID configuration: still scope for adjustment of 3km -> 30+ km
SKA1 configurations

- SKA1-SUR possible configuration of core and remote spiral

Exploring the Universe with the world’s largest radio telescope
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*
Neutral Hydrogen 21 cm spin-flip transition provides probe of neutral intergalactic medium before and during formation of first stars.

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

\( \lambda = 21 \text{ cm} \ (1 + z) \)
HI surveys of the EoR/Cosmic-Dawn Universe

• 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
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 ~50% 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):
  
  \[
  S = 0.5 - 1.3 \text{ Jy}, \Delta t = 1 - 6 \text{ msec}, \text{DM} = 550 - 1100 \text{ cm}^{-3} \text{ pc}
  \]

- Estimated event rate: $1 \times 10^4 \text{ sky}^{-1} \text{ day}^{-1}$

- Completely unknown origin, possibly at cosmological distances

Exploring the Universe with the world’s largest radio telescope
• Integration of \( \approx 50 \) 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
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
Cosmology with SKA1: Complementarity with Euclid

• Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect

• Achieving 2 $\mu$Jy rms would provide $\approx$4 galaxies arcmin$^{-2} (>10\sigma)$

• Almost uniform sky coverage of $3\pi$ 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
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

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 WigglesZ $10^{5.2}$ galaxies with $<z> \approx 0.6$
- Major contribution to BAO science, complementary systematics versus Opt/IR
Cosmology with SKA1: complementarity with optical

- Correlation functions of HI detections demonstrate much lower bias and excellent prospects for Redshift-space distortion measurements once interesting sample sizes are achieved with SKA1

(Papasterigis et al. 2013) ALFALFA HI versus SDSS blue and red samples

- Correlation functions of HI detections demonstrate much lower bias and excellent prospects for Redshift-space distortion measurements once interesting sample sizes are achieved with SKA1

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 (2020+5?) 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
3 Engineering Change Proposal (ECP)

3.1 What is an ECP?

An ECP expresses the need for a permanent change of one or more Configuration Items. The rationale for a change could be one or more of the following:

- Functional/Performance improvement or correction
- Change of interfaces
- New requirements
- A change in schedule and/or costs above a certain threshold (TBD)

The ECP process is the formal way to evaluate and to assess possible impacts that a proposed change will have on:

- Schedule,
- Performance,
- Full lifecycle cost,
- Interfaces to other Elements or the external world.

According to their impact, ECPs are classified as either Minor, Major or System Level, based on an evaluation by the SKA Chief System Engineer, SKA Architect & SKA Project Manager and following guidelines provided by the SKA Configuration Control Board (see below).
SKA1 Change Process

**Figure 1:** The normal ECP work flow.

1. Need for a permanent change identified, ECP definition and scope formalised by joint action between Consortium PM (if from a Consortium) or Element Project Manager (if from outside a Consortium) and the initiator. A complete and procedurally satisfactory ECP is then submitted to the Configuration Manager. Any proposal for Fast Track processing is agreed.

2. First technical/managerial assessment, EPM recommendation for classification (System Level/Major/Minor), Fast Track status and follow up (Accept, Reject, ask for a CRB).

3. Based on EPM recommendation, CCB goes either for a final decision (System Level/Major/Minor, Accepted/Rejected) or to follow up with a detailed analysis. If a final decision is reached, step 4 and 5 are skipped.


5. Final decision of the CCB on CRB recommendation. (If CCB unsatisfied, return to CRB for further work, return to step 4).

6. Decision recorded by CM and transmitted to initiator for implementation. Implementation is then monitored until completion criteria are met, the Chairman of the CCB signs it off and the CM archives the whole record.
SKA1 Change Process

Figure 2: The ECP work flow diagram.
Thank you

www.skatelescope.org