The Square Kilometre Array

Introduction

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UK Science Director SKA Organisation
What is the Square Kilometre Array (SKA)

• Next Generation radio telescope – compared to best current instruments it is ...
What is the Square Kilometre Array (SKA)

- Next Generation radio telescope – compared to best current instruments it is ...
  - $\sim 100$ times sensitivity
  - $\sim 10^6$ times faster imaging the sky
- More than 5 square km of collecting area on sizes 3000km
What is the Square Kilometre Array (SKA)

- Next Generation radio telescope – compared to best current instruments it is ...
  - ~100 times sensitivity
  - ~ $10^6$ times faster imaging the sky
  - More than 5 square km of collecting area on sizes 3000km

- Will address some of the key problems of astrophysics and cosmology (and physics)

- Builds on techniques developed here in the UK
  - It is an interferometer

- Uses innovative technologies...
  - Major ICT project
  - Need performance at low unit cost
Mid frequency array and mid-frequency aperture array
Low-frequency aperture array and survey array
Phased Aperture array for 40 – 650 MHz
Phased Aperture array: 3 million antennas
Specifications SKA2

• Next generation cm-wave radio interferometer
  • 50 MHz – 24GHz continuous frequency coverage
  • Full polarization coverage with > 32000 configurable spectral channels
• Sensitivity ~ 50 times the JVLA
  • > 1 GHz A/T ~ 10000 m²K⁻¹ → 0.35 μJy in 1 min at 1.4 GHz
  • 120 MHz A/T ~ 4000 m²K⁻¹ → ~ 1 μJy in 1 min at 120 GHz
• Resolution up to 10 mas at 1.4 GHz
  • Baselines to 3000 km
• Excellent surface brightness sensitivity
  • Very compact core
    ➢ 20 % of collector within 1 km diameter core
    ➢ 50 % of collector within 5 km diameter core
• Very high survey speed
  • ~ 200 sq-degrees FoV below 1 GHz
  • 1 sq-degree at 1.4 GHz or 20 sq-degrees with Phased Array Feeds
SKA Key Science Drivers

**ORIGINS**
- Neutral hydrogen in the universe from the Epoch of Re-ionisation to now
  - When did the first stars and galaxies form?
  - How did galaxies evolve?
  - Role of Active Galactic Nuclei
  - Dark Energy, Dark Matter
- Cradle of Life

**FUNDAMENTAL FORCES**
- Pulsars, General Relativity & gravitational waves
- Origin & evolution of cosmic magnetism

**TRANSIENTS (NEW PHENOMENA)**
SKA: A Leading Big Data Challenge for 2020

Antennas

Digital Signal Processing (DSP)

To Process is HPC
2020: 100 PBytes/day
2028: 10,000 PBytes/day
Over 10’s to 1000’s kms

Transfer antennas to DSP
2020: 20,000 PBytes/day
2028: 200,000 PBytes/day
Over 10’s to 1000’s kms

HPC Processing
2020: 300 PFlop
2028: 30 EFlop

High Performance Computing Facility (HPC)
Major Advances

• Major international review March 2011 – green light to go ahead with Detailed Design (90m Euros – 120m Euros available)

• SKA is now a legal entity (December 2011), company limited by guarantee [UK, NL, Aus, NZ, RSA, It, Canada, China, Sweden, Germany, India]

• Global HQ in UK

• Site decision and decision on SKA structure

• UK commitment:
  – £19m to design
  – £100m to SKA1 construction (18.5% of total cost)
SKA Implementation
SKA Phase 1 Implementation

SKA1_Mid_Dish

SKA1_Survey

SKA1_Low
• Formal inclusion of precursors and use of infrastructure leads to implementation options which offer scientific advantage

<table>
<thead>
<tr>
<th></th>
<th>RSA</th>
<th>ANZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precursor</td>
<td>MeerKAT</td>
<td>ASKAP</td>
</tr>
<tr>
<td>A/T</td>
<td>m²/K</td>
<td>260</td>
</tr>
<tr>
<td>Survey speed</td>
<td>m⁴/K²/deg²</td>
<td>5 x 10⁴</td>
</tr>
<tr>
<td>Power Installed</td>
<td>MVA</td>
<td>7 + 3.75</td>
</tr>
<tr>
<td>Data lit</td>
<td>Gb/s</td>
<td>10</td>
</tr>
<tr>
<td>Additional data</td>
<td>k€/ 10 Gb/s</td>
<td>280</td>
</tr>
<tr>
<td>Power recurrent cost per MW</td>
<td>M€/yr</td>
<td>5 - 10</td>
</tr>
</tbody>
</table>

• SKA1 Baseline has SKA1_Low and SKA1_Dish consisting of 250 15m SKA dishes
• Can achieve SKA Phase 1 sensitivity requirement utilising MeerKAT + 190 SKA Dishes
• Incorporating ASKAP + 60 SKA Dishes equipped with Phased Array Feeds gives a enhanced science return over baseline
• SKA1_Low has 250,000 dual-polarization antennas
## SKA1 Redefining Radio Astronomy

<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$<em>{eff}$/T$</em>{sys}$</strong></td>
<td>m$^2$/K</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey FoV</td>
<td>deg$^2$</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>Survey Speed FoM</td>
<td>deg$^2$ m$^4$/K$^{-2}$</td>
<td>0.98×10$^4$</td>
<td>5.0×10$^4$</td>
<td>1.0×10$^6$</td>
<td>1.3×10$^5$</td>
<td>2.8×10$^6$</td>
<td>2.2×10$^4$</td>
</tr>
<tr>
<td>Resolution</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>

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

6 x JVLA
100 x JVLA

Survey Speed:

1 x JVLA
22 x JVLA
550 x LOFAR
SKA Timeline

- **2020**: Early science SKA\(_1\)  
  - **2022**: Full Operations SKA\(_1\)

- **2022-2028**: Construction of Full SKA, SKA\(_2\)  
  - €1.5B

- **2017-2022**: 10% SKA construction, SKA\(_1\)  
  - €650M

- **2012**: Site selection

- **2013 - 2016**: Pre-Construction: 3 yr Detailed design and production Readiness  
  - €90M

- **2008 - 2012**: System design and refinement of specification

- **2000 - 2007**: Initial concepts stage

- **1995 - 2000**: Preliminary ideas and R&D
Work Packages in the PEP

1. System
2. Science
3. Maintenance and support /Operations Plan
4. Site preparation
5. Dishes
6. Aperture arrays
7. Signal transport
8. Data networks
9. Signal processing
10. Science Data Processor
11. Monitor and Control
12. Power
# Work Packages in the PEP

1. System
2. Science
3. Maintenance and support /Operations Plan
4. Site preparation
5. Dishes

<table>
<thead>
<tr>
<th>Work Package</th>
<th>Leader(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Aperture arrays</td>
<td>ASTRON (lead), UK, Itals, ICRAR (Aus)</td>
</tr>
<tr>
<td>7. Signal transport</td>
<td>UK (lead)</td>
</tr>
<tr>
<td>8. Data networks</td>
<td>UK (lead)</td>
</tr>
<tr>
<td>9. Signal processing</td>
<td>Canada (lead) … UK</td>
</tr>
<tr>
<td>10. Science Data Processor</td>
<td>UK (lead), AU (CSIRO…), NL (ASTRON…)</td>
</tr>
<tr>
<td>11. Monitor and Control</td>
<td>South Africa SKA, Industry (Intel, IBM…)</td>
</tr>
<tr>
<td>12. Power</td>
<td></td>
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</tbody>
</table>
SKA₁ & SKA₂ will have much higher sensitivity & survey speed than existing instruments.
### Nominal SKA1 Sensitivity

<table>
<thead>
<tr>
<th>Telescope</th>
<th>Band (GHz)</th>
<th>Frequency (GHz)</th>
<th>Bandwidth (MHz)</th>
<th>Integration Time (s)</th>
<th>FoV (deg^2)</th>
<th>Sensitivity in 12 hrs (mJy)</th>
<th>Sensitivity in 1000 hrs (micro Jy)</th>
<th>Sensitivity in 1000 hrs (nJy)</th>
</tr>
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<tbody>
<tr>
<td><strong>Mid</strong></td>
<td>0.35 - 1.05</td>
<td>0.7</td>
<td>500</td>
<td>1</td>
<td>1.4</td>
<td>0.10</td>
<td>0.47</td>
<td>51.8</td>
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<tr>
<td></td>
<td>0.95 - 1.76</td>
<td>1.4</td>
<td>500</td>
<td>1</td>
<td>0.375</td>
<td>0.06</td>
<td>0.29</td>
<td>31.4</td>
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<td></td>
<td>1.65 - 3.05</td>
<td>2.4</td>
<td>1000</td>
<td>1</td>
<td>0.125</td>
<td>0.05</td>
<td>0.25</td>
<td>27.5</td>
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<tr>
<td><strong>Low</strong></td>
<td>50 - 450</td>
<td>50</td>
<td>20</td>
<td>1</td>
<td>39</td>
<td>3.53</td>
<td>17</td>
<td>1862</td>
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<tr>
<td></td>
<td>110</td>
<td>50</td>
<td>1</td>
<td>8</td>
<td>0.32</td>
<td>1.5</td>
<td>169</td>
<td></td>
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<tr>
<td></td>
<td>160</td>
<td>50</td>
<td>1</td>
<td>3.8</td>
<td>0.29</td>
<td>1.3</td>
<td>152</td>
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<td></td>
<td>220</td>
<td>100</td>
<td>1</td>
<td>2</td>
<td>0.19</td>
<td>0.93</td>
<td>102</td>
<td></td>
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<tr>
<td></td>
<td>300</td>
<td>100</td>
<td>1</td>
<td>1.1</td>
<td>0.19</td>
<td>0.89</td>
<td>97</td>
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<tr>
<td><strong>Survey</strong></td>
<td>0.35 - 0.9</td>
<td>0.63</td>
<td>500</td>
<td>1</td>
<td>63</td>
<td>0.56</td>
<td>2.7</td>
<td>296</td>
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<td>0.65 - 1.67</td>
<td>1.2</td>
<td>500</td>
<td>1</td>
<td>18</td>
<td>0.25</td>
<td>1.2</td>
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<td>1.5 - 4.0</td>
<td>2.8</td>
<td>1000</td>
<td>1</td>
<td>3.25</td>
<td>0.32</td>
<td>1.5</td>
<td>170</td>
</tr>
</tbody>
</table>
SKA Board has decided on cot-capped SKA1 – 650m Euros
Current estimates from design consortia exceed this for complete telescope
Design work to reduce costs ongoing, but expect to need to rebaseline SKA1
Science Review Panel: SWG chairs + Board nominations