21st Century Astronomy

- JWST: 2021
- ALMA: operational
- SKA: 2028
- KM3NeT: 2020s
- ELT: 2027
- CTA: 2025
- LIGO/VIRGO: operational/++
- ATHENA: 2032
The Dawn of the Universe
Cosmic Dawn

Planck (ESA) (2009-2013)

Observed radio waves from cosmic microwave background
First Light

ESA’s Planck Mission showed us a snapshot of the Universe: at ~400,000 years of age
Dark Ages, Cosmic Dawn & Reionization

Snapshot at ~400,000 years

Dark Ages: HI traces dark matter and so allows precision cosmology

- First objects form and radiate (eg stars, galaxies, black holes etc)

Reionization:
- Feedback from these changes IGM (eg heating/ionizing, metals, shocks etc)
- Universe reionizes and becomes transparent (first galaxies, stars etc become visible)

Credit: Leon Koopmans
Dark Ages, Cosmic Dawn & Reionization

Snapshot at ~400,000 years

SKA will observe Hydrogen to make a movie of the Dawn of the Universe

Credit: Leon Koopmans
What might SKA Observe?

Simulation: "Swiss cheese effect". Growing bubbles of ionized material sitting in sea of hydrogen, over ~1 billion years

(Alvarez et al, UToronto)
Gravitational Waves
Pulsars
Testing General Relativity in extreme environments

5.757451924362137(2) ms (Verbiest et al. 2008) = 2 attoseconds ($10^{-18}$) seconds uncertainty!

(c) M.Kramer
SKA will detect all pulsars in Milky Way

- ~30,000 normal pulsars
- ~2,000 millisecond pulsars
- ~100 relativistic binaries
- pulsar – Black Hole binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

• Probe General Relativity to its breaking point
• Direct detection of gravitational waves passing through the Galaxy
SKA will detect all pulsars in Milky Way:

- ~30,000 normal pulsars
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SKA will detect: Super-Massive Black Hole mergers and Primordial Gravitational Waves
The SKA Observatory
What is SKA?

• A global collaboration to design, build and operate the next-generation radio astronomy observatory

• A treaty has been signed and now ratified to establish the SKA Observatory: a new Inter-Governmental Organisation for astronomy and fundamental science with a 50+ year lifetime

• 15 countries engaged in partnership at this time

• It will consist of:
  • An array of 197 dishes in South Africa
  • An array of ~132,000 antennas in Australia
  • Global HQ in the UK
  • 2 Data processing centres (AU and ZA) and a global network of Regional Centres delivering science-ready data to end users

• Governments working to provide ~€1.99B for 2021-2030, will cover construction and first 10 years of operations.
The SKA Observatory is being established as an Intergovernmental Organisation, taking over from the SKA Organisation. It will undertake the construction and operation of the SKA telescopes.

One Observatory
Two Telescopes
Three Continents
Karoo SKA site

MeerKAT: Operational

Radio-quiet

- Johannesburg
- Cape Town

~600km
Murchison SKA site

~600km • Perth

ASKAP: Operational

Radio-quiet

MWA: Operational

Exploring the Universe with the world's largest radio telescope
SKA Phase 1

3 sites (AUS, RSA, UK-HQ)
2 telescopes (LOW, MID), one Observatory (SKAO)
Construction: 2021-2027/8 (Science commissioning 2024+)

**SKA1-Low**: 512 x 256 low-freq dipoles, 50 - 350 MHz
65 km baselines (11” @ 110 MHz)
Murchison, Western Australia

**SKA1-Mid**: 133 x 15m + 64 x 13.5m dishes, 0.35 - 15 GHz
150 km baselines (0.22” @ 1.7 GHz; 34 mas @ 15 GHz)
Karoo, South Africa

SKA Phase 2: 2500 dishes across Africa; 1,000,000 antennas across Australia
## Cost estimate

<table>
<thead>
<tr>
<th>Design Baseline</th>
<th>Sept 2020 submitted</th>
<th>Provided through annual contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Value (€M) (Aug 2020)</strong></td>
<td>Capital cost of construction (€M)</td>
<td>Construction Support Budget (€M)</td>
</tr>
<tr>
<td></td>
<td>1054</td>
<td>228</td>
</tr>
</tbody>
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### SKA-1 Total Costs (€M)

- **Construction (Capital)**
- **Construction Support**
- **Operations/Business Enabling**
- **Observatory Development**
- **TOTAL**

![SKA-1 Total Costs (€M)](image-url)
SKA HQ: Jodrell Bank, UK

HQ of one of the world’s largest scientific facilities. Acts as a nexus for world radio astronomy.
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HQ of one of the world’s largest scientific facilities.
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Current status
Key Milestones

- August 2019: The Netherlands ratifies the SKA Observatory Treaty;
- December 2019 – March 2020: successful SKA1 critical design review;
- March 2020: successful operations review;
- April 2020: successful, external, cost audit;
- June 2020: South Africa ratifies;
- July 2020: successful business-enabling review;
- September 2020: Australia ratifies;
- September 2020: the SKA Board endorses the SKA1 Construction Proposal (CP) and the Observatory Establishment and Delivery Plan (OEDP);
- December 2020: Italy, Portugal and the United Kingdom ratify;
Rome, signed 12 March 2019
London, ratified 16 December 2020
Hardware prototypes

• All Observatory elements have hardware prototypes in various stages of testing and preparation for manufacturing.

• Dish: new drive system installed 2 weeks ago, testing underway

• AAVS2: much simulation, testing, characterization etc, summarized in SPIE paper “A prototype model for evaluating SKA-LOW station calibration”

• Testing programme for 2021 focused on prep for construction.
Data Flow through SKA

• For planning the observing programme of the SKA, the SDP becomes a schedulable resource of the telescope.

~8 Tb/s ~5 Tb/s ~350 PB/yr
SKA Regional Centres (SRCs)

700 PB/yr

LOFAR
23PB

Uploads to
Google
100PB

Uploads to
Facebook
180PB

SKA Phase1 Science Archive
700PB
India’s role
Proud history of radio astronomy, within DAE
Indian participation in SKA

Collaborating Institutes in India

Technologies developed

1. **Telescope Manager**: end-to-end observatory management system, with sophisticated algorithms and software, suitable for management of any complex, distributed system. Prototype version being deployed at NCRA's GMRT observatory, which is SKA pathfinder facility.

2. **Wideband radio frequency and optical fibre systems**: these have been developed by the teams from NCRA as part of the upgrade of the GMRT, a SKA pathfinder facility.

3. **High speed digital signal processing modules**: these have been developed by RRI for the MWA project – a SKA precursor facility, and also by NCRA for the upgraded GMRT – a SKA pathfinder facility.
Societal impact of the SKA
Societal benefits of the SKA

UN Sustainable Development Goals
Impacts of radio astronomy

Radio astronomy is intimately linked to many technological breakthroughs, including:

- The invention of WiFi;
- Magnetic Resonance Imaging (MRI);
- Reference systems for space navigation and GPS;
- High-precision monitoring of tectonic plate movements;
- Low-noise amplifiers for use in radar, telecommunications and remote sensing;
- Space tracking;
- Voluntary distributed computing for citizen-science (e.g. SETI@Home)
- DARA & DARA Big Data
Timeline

• Q1 2019: Treaty signing
  - Covid-19

• Q1/Q2 2019: Major reviews
  - Covid-19

• Q3 2020: CP/OEDP endorsed by SKA Org Board
  - Covid-19

• Q4 2020: SKA Observatory exists
  - Covid-19

• 1st SKA Observatory Council Meeting (January 2021)

• Q2 2021: SKA Observatory Council to approve start of construction

• Q3 2021: Construction activity begins ($T_0$)

• Q3 2024/5: Science Commissioning starts, community involved

• 2028: SKA1 construction complete; start of full operations
2020 – a year to remember (or forget) for many reasons

2021 – a year to celebrate the birth of the SKA Observatory