The Square Kilometre Array:
Timeline to SKA Phase 1, Key Science Projects, and UK involvement

An overview talk prepared by the UKSKASC
May 2015
The Square Kilometre Array (SKA)

The SKA is a next-generation radio interferometer:

- 3 telescopes, on 2 sites
- Collecting area > 5 km² on baselines up to 3000 km
- Frequency range 50MHz - 14GHz
- Expected cost: >1.5 billion Euros

Compared to current instruments, SKA will be:

- ~100x more sensitive
- ~10⁶x faster surveying the sky

SKA uses innovative technologies

- Major ICT project…
SKA Phase 1

SKA Phase-1 is the first phase of the SKA project:

- builds on technologies of “precursors”, ASKAP, MeerKAT & MWA, along with “pathfinders” such as LOFAR, eMERLIN, eEVN

SKA Phase 1 has an agreed budget cap of €650 million

- UK contribution: £100M. UK role ~18-19%

Original baseline design didn’t fit within the budget cap

- a ‘re-baselining’ process went on during 2014/15
  - Science Working Groups developed high-priority science cases
  - SKA project office + Science Review Panel (SRP) rated these
  - SKA project office costed various new baseline options
  - SRP assessed impact of each of these on high-priority science
  - Science & Engineering Advisory Panel assessed project risks
  - SKA Board considered advice and approved new baseline design
New baseline SKA Phase 1

SKA Phase 1 baseline design:

- **SKA1-Mid (South Africa)**
  - 200 15m dishes (inc. 64 MeerKAT dishes)
  - Three frequency bands:
    - Band 1: 350-1050 MHz
    - Band 2: 950-1760 MHz
    - Band 5: 4600 -13800 MHz
  - Maximum baseline ~150 km

- **SKA1-Low (Australia)**
  - 130,000 low-frequency antennas
  - 50MHz – 350 MHz
  - Max. baseline 65km

- **Construction 2018-2022**
- **Early science from ~2020**
SKA Sensitivity

SKA1 raw sensitivity ($A_{\text{eff}}/T_{\text{sys}}$):
- At low frequency
  - SKA1-Low: $\sim 8 \times$ LOFAR
- At high frequency
  - SKA1-Mid: $\sim 5 \times$ JVLA

SKA1 survey speed:
- At low frequency
  - SKA1-Low: $\sim 135 \times$ LOFAR
- At high frequency
  - SKA1-Mid: $\sim 60 \times$ JVLA

SKA Phase 2 will be 1-3 orders of magnitude higher still.
SKA Timeline

Critical steps on the timeline to SKA are:

- **2012:** Site decision made
- **2013-2016:** Pre-construction: detailed design
  - 11 technical work packages
  - Worked on by project office and international consortia
- **March 2015:** SKA Phase 1 baseline design finalised
- **2015-2018:** Establishment of Key Science Projects
- **2016-2017:** Ratification of agreements
- **2018-2022:** SKA Phase 1 construction
  - Early science exploitation from ~2020
- **2022-2028:** SKA Phase 2 (full SKA) construction
SKA Science

SKA will tackle an exceptionally wide range of science:

- Neutral hydrogen in the universe from cosmic dawn until now
- Evolution of galaxies; AGN; dark matter; dark energy
- Star formation and the cradle of life
- Fundamental forces: pulsars, general relativity, gravitational waves
- Origin and evolution of cosmic magnetism
- Transients: new phenomena

There are currently 8 Science Working Groups (SWGs) within SKA with at least two further SWGs in the process of being set up.

- see following slides for a summary of each, and UK contacts
- these are not closed shops: anyone can request to join
  - members are actively involved in developing and shaping SKA1
- these are not (proto) key science projects
- Scope for lots more science that falls outside these SWGs
Epoch of Re-ionization / Cosmic Dawn

UK contact: Jonathan Pritchard (Imperial; SWG Chair)

Key Science Goal: map neutral hydrogen in intergalactic medium at z=6-27 (Universe 100Myr-1Gyr old)

• 3D imaging of ionized regions during re-ionization
• Power spectrum measurements to constrain X-ray emission and SFR of first galaxies via spin-temperature fluctuations
• 21cm forest towards radio bright high-z sources e.g. Quasars probes small scale structures
• Cosmology from density field, weak lensing, thermal history
• Uses SKA-Low:
  – 50-250 MHz sees 21cm line at z=5-27.
• 10 arcmin res. resolves HII bubbles on 20deg² FoV
• Target ~1mK fluctuations or ~10mK max contrast
Fundamental Physics with Pulsars

UK contact: Ben Stappers (Manchester; SWG Co-Chair)

Key Science Goals: identify and use pulsars for strong-field tests of gravity, and gravitational wave detection

• Cosmic census for pulsars:
  – Galactic population of pulsars, magnetars, etc.
  – Pulsars in galactic centre, globular clusters, external galaxies (giant pulses)

• Fundamental physics:
  – Tests of theories of gravity, including BH properties
  – Detection and study of gravitational waves
  – Properties of super-dense matter

• Relativistic plasma physics (magnetospheres)

• Study interstellar medium, Galactic magnetic field.

• Uses multi-beaming on SKA1-Low and SKA1-Mid

>15,000 pulsars with SKA1
HI and Galaxy Evolution

UK contact: Steve Eales (Cardiff)

Key Science Goals: resolved studies of HI emission in and around galaxies out to z~1 (lookback time ~8Gyr)

• High spatial resolution (<500pc) studies of the ISM in nearby galaxies
  – physics of the ISM and star formation: synergies with ALMA
• Survey cold gas content of galaxies and their environments across most of cosmic time (period when cosmic star formation rapidly declined)
  – resolved studies to z~1; unresolved studies to z~2
  – cf. multi-wavelength properties: key input to galaxy evolution models
• Targeted HI absorption studies out to highest redshifts
• Low column density gas around nearby galaxies: galaxy/IGM interface
• Uses deep integrations with SKA1-Mid

[Image: NGC 6964: same scale]
Cradle of Life

UK contact: Melvin Hoare (Leeds; previous SWG Chair)

Key Science Goal: How do planets like Earth form and nurture life?

• Map the growth of dust grains in the terrestrial planet forming zone
  – How does dust overcome growth barriers that dominate cm-size regime?
  – Shape of the grain size distribution up to and around cm-size
• Detect auroral emission & characterise magnetic fields of exoplanets
  – strength, orientation, rotation periods
• Detect pre-biotic molecules in pre-stellar cores out to 100pc
• Map sub-structure and dynamics of nearby clusters of forming stars
• Constraints on EUV-driven photo-evaporation of proto-planetary discs
• SETI surveying of nearby stars
• Use high frequency band-5 of SKA1-Mid (>10 GHz)
• Needs highest angular resolution
Cosmology

UK contact: Filipe Abdalla (UCL) (+ others)

Key Science Goals: high precision tests of cosmological models

• HI intensity mapping survey to map 3D matter distribution on largest scales out to z~3
  – tests of non-Gaussianity, and of modified gravity on super-horizon scales
  – use power spectrum, baryon acoustic oscillations, redshift-space distortions and topology for high precision test of GR and dark energy

• Precision measurement of Cosmic Dipole & comparison with CMB

• Map the dark Universe with a radio weak-lensing survey

• Radio gives different systematics to optical/ IR
  – combination stronger than each separately

• Needs high sensitivity over 0.3-1.2 GHz

• Carried out in parallel with deep surveys
Radio Transients

UK contact: Rob Fender (Oxford; previous SWG Chair)

Key Science Goals: Extreme astrophysics: stellar explosions, black holes and neutron stars.

- Discover and monitor all transients and variables in all data streams
  - Understand the fundamental physics
  - Using luminous events as cosmological probes
- Fast radio bursts
  - unexplained coherent bursts at cosmological distances
- Tidal disruption events
  - accretion of star by supermassive black hole
- Accreting binaries, flare stars, novae, kilonovae, supernovae, etc.
- Requires commensal, low-latency real-time interrogation of data & fast, global alerts
Cosmic Magnetism

UK contact: Anna Scaife (Manchester)

Key Science Goals: Understand the origin, evolution and influence of cosmic magnetic fields

• Use diffusion synchrotron, diffuse polarisation, rotation measure grids, Faraday tomography, Zeeman splitting
• Magnetic fields in the Milky Way
  – large and small scales; turbulent and coherent structure
• Magnetic fields in nearby galaxies
  – structure, impact, origin, evolution of B-fields
• Large-scale structure
  – magnetic fields in galaxy clusters & cosmic web
• Requires wide frequency coverage and good polarisation purity
Continuum Surveys

UK contact: Matt Jarvis (Oxford) (+ others)

Key Science Goals: Cosmic history of star formation & black hole accretion

- Deep and wide surveys for optimal synergy with multi-wavelength datasets to maximise synergies. Wide-ranging science goals:
  - star formation history of the Universe
  - history of black hole accretion
  - AGN feedback
  - diffuse non-thermal emission in clusters
  - strong gravitational lenses
  - radio continuum from the cosmic web
  - first galaxies and black holes
- Builds on high sensitivity / survey speed
- Focus on SKA1-Mid surveys, in parallel with HI and cosmology surveys

![Cosmic star-formation history](image)
New Science Working Groups

There are two more newly-established science working groups

• **The Milky Way Galaxy**
  - Key Science Goals: studies of Milky Way ISM and molecular clouds; nearby clusters; star-forming regions;
  - UK contact: Mark Thompson (Hertfordshire; SWG co-chair)

• **Extragalactic Spectral Lines**
  - Key Science Goals: (non-HI) extragalactic spectral line studies
  - UK contact: Rob Beswick (Manchester; SWG coordinator)

One further SWG is in the process of being set up:

• **Solar and Heliospheric Physics**

Other science working groups may be established in the future.

For more information on SKA Science Working Groups see https://www.skatelescope.org/swg-terms-of-reference/
Key Science Projects

The SKA Board has approved the development of Key Science Projects for SKA Phase 1

- In total, between 50 and 70% of the observing time on SKA-1 over a 5-yr period is expected to be dedicated to KSPs

Key Science Projects should satisfy one or more of:

- substantially address key science objectives identified for SKA-1
- require large allocations (>1000 hr) over 1-5 years
- require substantial dedicated or customised observatory resources

Current plan is that observatory will define a list of notional KSPs, but prospective KSP teams will self-organise and propose specific projects, and these proposals will be reviewed.

- KSP PIs and membership are expected to be balanced across member states in accordance with member contributions
“SKA Phase 1 Key Science Goals”

As part of the “re-baselining” procedure to finalise the Phase 1 SKA design, 13 key science goals were identified by the Science Review Panel, in combination with the SWGs.

• This is effectively a first-draft list of the “notional KSPs”

<table>
<thead>
<tr>
<th>Science Goal</th>
<th>SWG</th>
<th>Objective</th>
<th>SWG Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CD/EoR</td>
<td>Physics of the early universe IGM - I. Imaging</td>
<td>1/3</td>
</tr>
<tr>
<td>2</td>
<td>CD/EoR</td>
<td>Physics of the early universe IGM - II. Power spectrum</td>
<td>2/3</td>
</tr>
<tr>
<td>4</td>
<td>Pulsars</td>
<td>Reveal pulsar population and MSPs for gravity tests and Gravitational Wave detection</td>
<td>1/3</td>
</tr>
<tr>
<td>5</td>
<td>Pulsars</td>
<td>High precision timing for testing gravity and GW detection</td>
<td>1/3</td>
</tr>
<tr>
<td>13</td>
<td>HI</td>
<td>Resolved HI kinematics and morphology of <del>10^10 M☉ sol mass galaxies out to z</del>0.8</td>
<td>1/5</td>
</tr>
<tr>
<td>14</td>
<td>HI</td>
<td>High spatial resolution studies of the ISM in the nearby Universe.</td>
<td>2/5</td>
</tr>
<tr>
<td>15</td>
<td>HI</td>
<td>Multi-resolution mapping studies of the ISM in our Galaxy</td>
<td>3/5</td>
</tr>
<tr>
<td>18</td>
<td>Transients</td>
<td>Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State</td>
<td>=1/4</td>
</tr>
<tr>
<td>22</td>
<td>Cradle of Life</td>
<td>Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc</td>
<td>1/5</td>
</tr>
<tr>
<td>27</td>
<td>Magnetism</td>
<td>The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields</td>
<td>1/5</td>
</tr>
<tr>
<td>32</td>
<td>Cosmology</td>
<td>Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales.</td>
<td>1/5</td>
</tr>
<tr>
<td>33</td>
<td>Cosmology</td>
<td>Angular correlation functions to probe non-Gaussianity and the matter dipole</td>
<td>2/5</td>
</tr>
<tr>
<td>37 + 38</td>
<td>Continuum</td>
<td>Star formation history of the Universe (SFHU) – I+II. Non-thermal &amp; Thermal processes</td>
<td>1+2/8</td>
</tr>
</tbody>
</table>

Table 2. List of highest priority SKA1 science objectives, grouped by SWG, but otherwise in arbitrary order.
Key Science Projects

The details of KSPs will be established over a series of meetings from 2015-2017, beginning at:

- Stockholm meeting, 25-29 Aug 2015

The aims of these meetings are to:

- Further develop KSP concepts, and review the first-draft notional KSP list developed in the re-baselining process.
- Support development of potential KSP collaborations
- Maximise potential for commensality of observations
  - to achieve all key science in a 5-yr period, the same observations will need to serve multiple KSP groups, each with limited data rights for specific science objectives.

Attendance of this, or any other, KSP workshop is not a pre-requisite for KSP participation or leadership.
Input to Stockholm Meeting

Registration for the Stockholm meeting is now closed, but if you wish to input views you can pass them to any attendee:

- **Participants listed online:**

- **In particular, 4 members of UK SKA Science Committee will be attending and are happy to pass on views of UK interest**
  - Mark Birkinshaw (Bristol)
  - Jonathan Pritchard (Imperial)
  - Anna Scaife (Manchester)
  - Mark Thompson (Hertfordshire)
Global SKA Structures

Current country members:
- Australia
- Canada
- China
- Germany (until 06/15)
- India
- Italy
- Netherlands
- New Zealand
- South Africa
- Sweden
- UK
- Others joining soon…

SKA Office: 50
Design consortia: > 350
# Pre-construction Work Packages

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)</td>
</tr>
<tr>
<td>10. Science Data Processor</td>
<td>UK (lead), AU (CSIRO ), NL (ASTRON ), South Africa SKA, Industry (Intel, IBM )</td>
</tr>
<tr>
<td>11. Monitor and Control</td>
<td></td>
</tr>
<tr>
<td>12. Power</td>
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</table>
SKA Headquarters

SKA Headquarters have been located at Jodrell Bank during the development phase. Recent board decision is that they will remain there during the operational phase:

- Secures UK involvement
- UK will lead inter-governmental negotiations
- UK SKA efforts coordinated by (UK) SKA Programme Board
  - aligned with stakeholders: BIS, SKA Board, University of Manchester.
UK SKA Structures

UK SKA Board Members
  John Womersley (STFC)
  Paul Alexander (Cambridge)

UK SKA Programme Board
  (BIS, UK PIs, Univ. Manc, Board Members, Committee Chairs)

- UK SKA Industrial Committee
  - UK Industry Community

- UK SKA Oversight Committee
  - 5 Universities + National labs

- UK SKA Science Committee
  - UK Science Community
UKSKASC

The UK SKA Science Committee has been established to:

- engage the UK science community
- provide a platform for discussion and dissemination of critical SKA science issues
- collate, summarise and present the views of the UK Science Community to the UK SKA board members

See our webpage at:

- http://www.stfc.ac.uk/ukskasc
  - contains useful science links to SKA documents & descriptions
  - contains list of UKSKASC members

Next community meeting:

- Manchester, on 4th November 2015
  - more details and registration form on UKSKASC webpage soon
How to get involved / Having a voice

You can get involved in SKA now, and input your views:

• Through the Science Working Groups:

• By getting involved in the development of Key Science Projects
  – too late now for the August Stockholm meeting, but this is only the first of several planned meetings so keep an eye open for more

• By passing your views through your the SKA contact person at your institute, or any member of the UKSKASC
  – UKSKASC chair is Philip Best (Edinburgh); pnb@roe.ac.uk

• By coming along to UK SKA Community Meetings
  – next one in Manchester on 4th November 2015
  – see www.stfc.ac.uk/ukskasc for more info & to register
Summary

• The SKA will be an extremely powerful facility for an exceptionally broad-range of science.

• SKA Phase 1 will be built on a timescale of 2018-2022

• The first stages of designing Key Science Projects are just beginning: these will be widely open, so please get involved

• You can find out more, and input your views, by coming along to the forthcoming UK SKA Community Meeting
  – Manchester, 4/11/2015
  – see www.stfc.ac.uk/ukskasc for more information / registration