Square Kilometer Array

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<www.skatelescope.org>
COBE DMR Microwave Sky at 53 GHz
The Big Bang Space Time
A rich history of discovery

- Many discoveries over the past 50yr
  - Pulsars
  - Microwave Background
  - Cosmic Evolution
  - Dark Matter in galaxies
  - Quasars
  - Jets + Superluminal motion
  - Gravitational Radiation
  - Aperture Synthesis
  - Cosmic Masers
  - Giant Molecular Clouds

The Discovery of Pulsars
Radio provides unique information about the Universe

Non-thermal processes: quasars, pulsars, jets
Radio provides unique information about the Universe

Tracer for Cosmic Magnetic Fields
“What are the basic properties of the fundamental particles and forces?”

Neutrinos, Magnetic Fields, Gravity, Gravitational Waves, Dark Energy

“What constitutes the missing mass of the Universe?”

Cold Dark Matter (e.g. via lensing), Dark Energy, Hot Dark Matter (neutrinos)

“What is the origin of the Universe and the observed structure and how did it evolve?”

Atomic hydrogen, epoch of reionization, magnetic fields, star-formation history……

“How do planetary systems form and evolve?”

Planet Formation, Astrobiology, Radio flares from exo-planets……

“Has life existed elsewhere in the Universe, and does it exist elsewhere now?”

SETI
What Is the Reionization Era?
A Schematic Outline of the Cosmic History

- The big bang: The universe fills with ionized gas.
- The universe becomes neutral and opaque. The dark ages start.
- Galaxies and quasars begin to form. The reionization starts.
- The cosmic renaissance. The dark ages end.
- Reionization is complete. The universe becomes transparent again.
- Galaxies evolve.
- The solar system forms.
- Today: Astronomers figure it all out!
Top Priorities for a New Generation Radio Telescope

- Detect and image neutral hydrogen in the very early phases of the universe when the first stars and galaxies appeared – “epoch of re-ionisation”

- Locate 1 billion galaxies via their neutral hydrogen signature and measure their distribution in space – “dark energy”

- Origin and evolution of cosmic magnetic fields – “the magnetic universe”

- Time pulsars to test description of gravity in the strong field case (pulsar-Black Hole binaries), and to detect gravitational waves

- Planet formation – image Earth-sized gaps in proto-planetary disks
What instrument do we need?
A radio telescope with

- sensitivity to detect and image atomic hydrogen at the edge of the universe \(\rightarrow\) very large collecting area
- fast surveying capability over the whole sky \(\rightarrow\) very large angle field of view
- capability for detailed imaging of the structures of the planetary gaps and how they change \(\rightarrow\) large physical extent
- a wide frequency range to handle the science priorities
Key Technical Specifications

• **collecting area** of order 1 million square meters, array of ~5000 dishes each ~12 meters in diameter

• **frequency range** 100 MHz – 25 GHz

• **large instantaneous field of view** 1 sq. deg. at 1.4 GHz

• **configuration**
  • 20% of total collecting area within 1 km diameter,
  • 50% of total collecting area within 5 km diameter,
  • 75% of total collecting area within 150 km diameter,
  • 100% of total collecting area within 3000 km from array core.
SKA Poster

Big Bang
Evolving galaxies
First astronomical objects
Probing the early Universe
Gravitational radiation
Pulsar
Adaptive nulling
Gamma-ray burster
SETI
Adaptive nulling
Future Sensitivity

HST

SKA 2020
Radio provides unique information about the Universe.

Neutral Hydrogen
Was Einstein Right?

Pulsars
Collapsed stars with extreme physical properties

Pulsars: Cosmic Lighthouses

High Gravity Field
200000xSun

Most accurate clocks known
10^{-9}sec
Surveys with Parkes, Arecibo & GBT.

Simulated & actual pulsars shown

Yield ~ 1000 pulsars in ALFA survey
SKA pulsar survey
600 s per beam
\(\sim 10^4\) psr’s
The Cradle of Life

- Test conditions for life elsewhere in the Universe
  - Image proto-planetary disks
  - Search for Extraterrestrial intelligence
Today’s hot new issues are tomorrow’s old issues.

The excitement of the SKA will be not in the old questions it will answer but in the new questions it will raise!
SKA science book

Science with the Square Kilometre Array,

eds: C.Carilli, S.Rawlings,

www.skatelescope.org
Concepts

- China KARST
- Canadian aerostat
- US Large N
- Antenna designs: India, US.
- Australia: Luneburg Lenses and Cylinders
- Dutch Fixed Planar Arrays
The Netherlands
NxArecibo

Karst region for array of large Arecibo-like Telescopes

D > 200 m
LAR Prototyping

- Focal Plane Array package covering 0.7-1.4 GHz
- RF Feed design
- Beam forming
- Reflector actuators

Instrument Package

- GPS antenna
- Anemometer
Multiple Feeds And Beams
Why parabolic dishes?
- experience
- sky coverage
- frequency coverage

U.S. Consortium Concept
Synthesis Array
Large N/Small D

Why large N?
- collecting area
- dynamic range
- baseline diversity
- snapshot mode
- self-calibration
- RFI excision

Why small D?
- field-of-view
- minimizes cost
Reference Design

- small dishes + smart feeds
- aperture arrays on the “innovation path” + EoR array (0.1-0.3 GHz)

Wide-angle radio camera + radio “fish-eye lens”

Inner core

Station
SKA – not just antennas

- **High speed data transport**
  - Tb/s from EACH station on scales of hundreds of km
  - 100 Gb/s trans-continental and trans-oceanic links
  - Longest links will rely on telcos and research networks
    - Need government initiatives for affordable access

- **Signal processing**
  - Peta-ops per second
  - Need highly scaleable solutions

- **Post-processing, information management**
  - New super-computer architectures
  - Archive and sharing of data will be a major challenge

- **Infrastructure**
  - Civil, electrical (power, …), communications

- **Operations and support**
SKA as e-science

E-science:
Global collaboration in key areas of science, and the next generation of infrastructure that will enable it.
GOVERNANCE

SKA was “born global”; >50 institutes in 17 countries actively involved.

- International Science Advisory Committee
- International Collaboration Working Group
- International SKA Steering Committee
  - Executive Committee
- International Engineering Advisory Committee
- International Site Selection Advisory Committee
- International SKA Project Office
  - Engineering Working Group: 8 task forces
  - Site Evaluation Working Group: 2 task forces
  - Science Working Group: 6 task forces
  - Simulations Working Group: 1 task force
  - Outreach Committee
  - Operations Working Group
International SKA Steering Committee (ISSC to SSEC)

21 members representing 11 countries

– 7 European (2 UK, France, Germany, 2 Netherlands, Italy)
– 7 United States
– 2 Canada
– 2 Australia
– 2 Asia (China, India)
– 1 South Africa
– Observers from Japan, Russia
**SKA: How much will it cost?**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>4400 x 12 m antennas</td>
<td>$ 660 M</td>
</tr>
<tr>
<td>Receivers</td>
<td>170</td>
</tr>
<tr>
<td>Data transmission</td>
<td>40</td>
</tr>
<tr>
<td>Civil costs (central site)</td>
<td>65</td>
</tr>
<tr>
<td>Civil costs (outer configuration)</td>
<td>135</td>
</tr>
<tr>
<td>Signal processing</td>
<td>80</td>
</tr>
<tr>
<td>Computing hardware</td>
<td>80</td>
</tr>
<tr>
<td>Software development (660 man years)</td>
<td>50</td>
</tr>
<tr>
<td>Non-recurring engineering</td>
<td>60</td>
</tr>
<tr>
<td>Contingency (20%)</td>
<td>270</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$1,610 M</strong></td>
</tr>
</tbody>
</table>
Who is going to Pay for it?

• Plan 1
  – U.S. 1/3
  – Europe 1/3
  – RoW (Canada, Australia, Asia, Africa) 1/3

• Plan 2:
  – North America 40%
  – Europe 40%
  – RoW (including Japan) 20%
Number of Active Participants in SKA Committees, Working Groups and Task Forces

- China: 105
- India: 24
- South Africa: 16
- Canada: 8
- Australia: 11
- Europe: 60
- USA: 81

Percentages of Active Participants in SKA Committees, Working Groups and Task Forces

- China: 33%
- India: 33%
- South Africa: 8%
- Canada: 4%
- Australia: 5%
- Europe: 20%
- USA: 27%
Where will the SKA be built?

• Northern (infrastructure) vs Southern (Galactic Center) hemisphere
• RFI environment
• Troposphere stability (high desert site)
• Ionospheric stability
• Political issues
• Preliminary proposals
  – U.S., Australia, South Africa, Argentina, Brazil, China
• Decision - Oct. 2006 (short list of acceptable sites)
ISSC SHORT LISTED
CORE SITES

SOUTH AFRICA

AUSTRALIA
SKA configuration
Western Australia example

200km
Australia
Site selection

Sydney: population 4 million

Narrabri: population 4000

Mileura: population 4
South Africa + 7 countries
South Africa
RFI Measurements
NATIONAL ATTRIBUTES

• Political and economic structure and stability
• Entry visas to all
• Ease of government interactions
• Import/export issues and taxes
• Access to foreign companies
• Land claims
• General support of science and technology
• Academic astronomy population
• Availability of engineers and technical personnel
POSSIBLE OUTCOMES

1) Winner takes all

2) Win-Win
   SKA-LO in one country
   SKA-MID in the other country

   Most of the SKA in one country
   A mega-station in the other country

   Dishes in one country
   Aperture arrays in the other country
   (Some science duplications ??)

NOTE: Cost duplications ? And issues with all Win-Win models.
SKA IN THREE FREQUENCY BANDS

--SKA LOW  100 MHz TO 300 MHz

--SKA MID  300 MHz TO 10 GHz

--SKA HIGH  10 GHz TO 25-35 GHz
US SKA CONSORTIUM
FOUNDED IN 1999
To promote the future of radio
astronomy in the US universities
and research centers, and to
coordinate the SKA activities in
the US
US SKA Consortium
Chair: Yervant Terzian (Cornell)
Vice Chair: Joseph Lazio (NRL)

Caltech/JPL
Cornell/NAIC
Harvard/Smithsonian
MIT/Haystack
NRAO
NRL

SETI Institute
University of Illinois
University of New Mexico
University of Wisconsin
UC Berkeley
Virginia Tech
SKA timeline

- Reference Design selected
- Sites short-listed
- External Engineering Review of design
- Early Science SKA mid+low
- SKA(mid+low) Construction & Commissioning
- Production Readiness Review
- SKA-mid+low Complete
- Review Hi-freq SKA Design

Timeline:
- 06 | 08 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |

- Initial SKA specs
- Prod’n Readiness & System Verif’n
- SKA mid+low Construction & Commissioning
- Concept design for SKA-hi
- System design for SKA-hi
- EC-FP7: PrepSKA
  - System design
  - Funding
  - Governance
  - Site Seln
- Costed SKA low+mid designs complete