The Square Kilometer Array: How will you use it for Communications and Navigation?

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DESCANSO Seminar
May 17, 2001
Presentation Purpose

- Inform the JPL community of the Radio Astronomy community’s plans to build a radio telescope with a square kilometer of collecting area -- the Square Kilometer Array (SKA)
- Begin developing mission concepts and other applications for a major breakthrough in tracking station performance
- Develop the case for NASA/JPL participation in the planning, development, and implementation of the SKA
Largest Full-sky Antenna Size vs. Time

![Graph showing the largest full-sky antenna size over time from 1970 to 2010. The size increases significantly from 1970 to 2000 and remains relatively stable from 2000 to 2010.]
Number of Antennas Arrayed vs. Time

![Bar chart showing the number of antennas arrayed over time from 1975 to 2010. The x-axis represents the years (1975, 1980, 1985, 1990, 1995, 2000, 2005, 2010), and the y-axis represents the number of antennas arrayed (ranging from 0 to 400). The chart indicates a significant increase in the number of antennas arrayed after 2000, with a major peak in 2010.]
The Very Large Array
Arraying requires adjusting the phase delay between antennas to “focus” the array

1. **Geometric Delay** is obtained from known antenna locations

2. **Propagation and Instrument Delay** are dynamic and different for each antenna
   - \( N(N-1)/2 \) baselines to correct \( N \) antenna phases
   - Observe radio source with known position and solve for optimum antenna phase delays
   - Array can then use even weak in-beam sources to stay “phased”
What is the Square Kilometer Array (SKA)?

A large aperture array of antennas with a collecting area of a square kilometer

- An array of antennas providing 100 times the sensitivity of today’s best single aperture antennas
- Up to 100 simultaneous, independent fields of view (beams)
- High angular resolution
- 0.15 GHz to 22 GHz continuous frequency range
- Recommended by the Decadal Review
- Planned completion in 2015
The SKA

An Artist’s Conception
The SKA
Example Array Geometry
SKA Applied to Radio Astronomy

- PROBE THE STRUCTURE OF THE UNIVERSE BEFORE THE DAWN OF GALAXIES (highly red shifted 21-cm radiation from the intergalactic media prior to re-ionization)
- CHART THE FORMATION AND EVOLUTION OF GALAXIES FROM THE EPOCH OF FORMATION (CO at z > 3.5; history of star formation at early epochs, unaffected by obscuration)
- PROBE DARK MATTER WITH GRAVITATIONAL LENSING (very wide field of view and extremely well defined point spread function)
- INVESTIGATE ACTIVE GALACTIC NUCLEI (huge increase in VLBI sensitivity; H$_2$O megamasers give distances and black hole masses)
SKA Applied to Radio Astronomy

Continued

• UNDERSTAND THE PHYSICAL MECHANISMS THAT GIVE RISE TO PLANETARY SYSTEMS (imaging of protostellar jets & proto-planetary disks; imaging stellar surfaces; planet detection via stellar astrometry)

• DETECT RADIO AFTERGLOWS FROM GAMMA-RAY BURSTS (rapid sub-arcsecond positions; expansion of fireball or jet)

• DETECT LONG-PERIOD GRAVITATIONAL WAVES (simultaneous timing of multiple pulsars; can detect ultra-massive black hole binaries anywhere in the Universe)
# SKA vs. DSN 70m Stations at X-band

<table>
<thead>
<tr>
<th></th>
<th>SKA</th>
<th>70m</th>
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<tbody>
<tr>
<td>G/T (dBi)</td>
<td>94+</td>
<td>74</td>
</tr>
<tr>
<td>delta f/f @10s</td>
<td>&lt;1 E-13</td>
<td>&lt;1 E-13</td>
</tr>
<tr>
<td># beams</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>EIRP (comm)*</td>
<td>165+ dBm</td>
<td>145 dBm</td>
</tr>
<tr>
<td>EIRP (radar)**</td>
<td>181+ dBm</td>
<td>161 dBm</td>
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* 2W transmitters on 10,000 elements
** 50W transmitters on 10,000 elements
Uplink Phasing Steps

1. **Pre-pass**, use satellite power monitor to phase transmitters
   Calibrate atmosphere with in-beam radio source

2. **During tracking**, correct phase changes by observing in-beam natural radio source
SKA Applied to Deep Space Communications

- Use SKA to increase data rate by a factor of 100+
  - Enhanced science observations
    - Movies instead of images
    - More complete target coverage
      - MRO will only image 1 - 2% of Mars at the highest resolution
    - High resolution, multi-spectral imaging
      - Current instrument produce ~ 100 more data than link capacity
    - Enhanced SAR mapping
  - New science enabled
    - ?
  - New missions enabled
    - Hostile environments with limited spacecraft life
    - Multi-channel HDTV for Robotic Outposts, piloted missions
    - Interstellar probe missions
SKA Applied to
Deep Space Communications

Continued

• Use SKA to reduce spacecraft mass, cost, power
  – Smaller RPA’s, less power, smaller solar arrays
    • Exciter output (20 mW) through an HGA could produce meaningful data rates at Mars -- 10s of kbps
  – Smaller, lower gain antennas, reduced antenna pointing requirements
  – Lower mass spacecraft could enabled missions using solar sails or other low impulse propulsion
  – Decrease the need for gravity assists, shortening interplanetary cruise and decreasing operations costs
SKA Applied to
Deep Space Communications

Continued

• Use SKA to support multiple spacecraft simultaneously
• Use SKA for in situ communications where comm/nav networks are unavailable
• Use small sub-arrays, “dial-up” needed aperture,
  – Near-Earth post-launch support
  – Interplanetary Cruise for navigation data acquisition with low rate telemetry
• Use SKA to support of spacecraft in distress
SKA Applied to Deep Space Navigation

• Use SKA to obtain real-time plane-of-sky spacecraft position simultaneously with Doppler and range
  – Provides valuable independent and complementary data to add to Doppler and range
    • ~50 nanoradian accuracy with 20 km array baselines, 10 minute integration
    • ~5 nanoradian accuracy with 500 km array baselines, 10 minute integration
    • Approach trajectories tend to be plane-of-sky
  – Large field-of-view expands spacecraft-spacecraft “delta DOR” and in some cases spacecraft-target opportunities
  – Near real-time access allows plane-of-sky measurement use in “terminal” navigation for landers and for spacecraft rendezvous
SKA Applied to Deep Space Navigation

Continued

• Uplinks with different frequencies from different sub-arrays could allow spacecraft autonomous plane-of-sky position determination
SKA Applied to
Entry, Descent, and Landing (EDL)

• Factor of 100 increase in sensitivity could allow meaningful data rates over low - medium gain antennas
• Combination of high resolution angle data with Doppler and range allows real-time monitoring of spacecraft location
• Tone communication with tumbling spacecraft
SKA Applied to Radio Science

• Radio Occultation
  – higher resolution ionospheric, atmospheric and ring profiles
  – detection of tenuous atmospheres (Pluto) and rings
  – Probe deeper into thick atmospheres
  – Horizontal “tomography” of atmospheres and rings using multiple beams

• Gravity fields and celestial mechanics
  – Combination of angle measurements with Doppler puts tighter constraints on spacecraft trajectory models and gravity fields

• Bi-static radar
  – near-backscatter bistatic studies of icy surfaces

• 3D in-situ plasma measurements with multiple spacecraft
SKA Applied to Planetary Radar

• New targets
  – Range and image all the known solid body planets, major satellites and rings in the Solar System
  – Target smaller asteroids, further away
    • Improve the ephemerides of more Earth crossing asteroids
  • Better radar images
    – Image the Saturnian satellites with the same SNR as current Martian images

• Interferometric radar measurements
  – More numerous baselines

• Detection of spacecraft to ~2,000,000 km
The SKA - Other NASA Benefits

- Graceful degradation, downtime for maintenance
- Potential site diversity
- Arrays are less susceptible to RF interference
- Use of SKA requires no new development of spacecraft communications hardware
- Develop mutually constructive partnerships with the Radio Astronomy community
- Acquire and maintain core capabilities in signal processing and telecommunications within TMOD, JPL, NASA.
The SKA as a Tool for Deep Space Communications, Navigation, and Science

Technical Challenges

• Phase-arraying thousands of signals
  – Need to find economical way to scale current signal combining architectures

• Uplink arrays
  – Need to develop prototype uplink array concepts

• Need to develop low cost, mass production of antennas and electronics
  – Terrestrial communications applications are leading the way

• Develop wideband, very low noise receivers and feeds
  – ATA has 0.5 to 11 GHz instantaneous bandwidth; would like 2 to 40 GHz for SKA.
SKA as an element of the DSN

Open Issues

• A Square Kilometer Array will eventually be built
  – Will NASA, JPL, DSMS help make it happen?
  – How will the NASA flight projects and other DSMS users use it? *How will you use it?*
SKA as an element of the DSN

Next Steps

⇒ Collect mission concepts and other applications for a major breakthrough in tracking station performance
⇒ Develop the case for NASA/JPL participation in the planning, development, and implementation of the SKA
  • Secure NASA funding and agreements for DSN participation in the SKA consortium
  • Procure prototype antennas and electronics
  • Demonstrate ranging and uplink capabilities using arrays
  • Develop more detailed array life cycle cost estimates
The SKA Applied to Landscape Design
Conclusions

• A large array of antennas is the **only** technology that promises orders of magnitude increase in sensitivity (G/T) at RF

• A large array like the SKA will be built based on its enormous potential for radio astronomy. NASA participation will:
  – make it happen sooner
  – allow deep space missions and other current users of the DSN to utilize the array’s enormous potential

• In order to maintain its status as a preeminent provider of services to the space exploration community, the DSN must actively participate in the development and implementation of the SKA