CHICAGO-3 DISCUSSION DOCUMENT

A Plan for Implementing the Square Kilometer Array

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Purpose

This document is intended to stimulate discussion within the US community about implementation of the Square Kilometer Array (SKA) in advance of activities for the astronomy and astrophysics decadal survey, assumed to commence in mid 2008.

The International SKA Program

Rather than a single instrument, the International SKA Steering Committee (ISSC) views the SKA as a *Program* that addresses all the primary scientific goals that have driven the SKA concept.[1] Specifically, these are

1. **Probing the dark ages**
2. **Galaxy evolution, cosmology and dark energy**
3. **Strong-field tests of gravity using pulsars and black holes**
4. **The origin and evolution of cosmic magnetism**
5. **The cradle of life**

In addition to these specific science programs, the unprecedented new capabilities of the SKA will enable *exploration of the unknown* that undoubtedly will add to the long radio astronomy tradition of important, unexpected discoveries.

The ISSC has recognized[2] that technology solutions to SKA scientific specifications map into three frequency bands defined nominally as: low: $\lesssim 0.3$ GHz; mid: ~ 0.3 to ~ 3 GHz; and high: $\lesssim 3$ to 25 GHz, with eventual frequency boundaries to be determined through ongoing technology development. Recognizing that pathfinder arrays and technology development will influence other deployment decisions for the SKA, the ISSC has also resolved to (a) support a phased development of the SKA that progresses from pathfinder telescopes to the first 10% of the SKA (designated Phase 1) that will have a restricted frequency range, to the full SKA with the full frequency range; (b) initially focus Phase 1 on the mid-band frequencies, while retaining an option to add collecting area at less than 300 MHz, based on the outcomes of existing observational facilities and developments in the theory of the Epoch of Reionization (EoR); and (c) use the Phase 1 results to guide the development and construction of the full SKA.

The description and status of the three frequency bands is as follows:

1. **Low-frequency Array:** $< 0.1 - 0.3$ GHz to cover EoR studies of redshifted hydrogen and other science areas. This array will comprise dipole antennas organized in tiles and will be a follow-on to pathfinder arrays: the Low Frequency Array (LOFAR), the Long Wavelength Array (LWA), the Mileura Widefield Array (MWA), and the Precision Array to Probe Epoch of Reionization (PAPER). The design of this array must await detection of the EoR signal in order to optimize full-imaging capability, and the array necessarily must be on a very radio-quiet site. US investment in this band is ongoing and is anticipated to be substantial in the next decade.
2. **Mid-frequency Array:** $0.3 - X$ GHz with X of at least 3 GHz and possibly higher. This too will include hydrogen science in the form of a billion-galaxy redshift survey, gravity studies using pulsars, cosmic magnetism, the transient universe, and the search for extraterrestrial intelligence (SETI). Pathfinder arrays include the Allen Telescope Array (ATA), the Australia SKA Pathfinder (ASKAP), and Meer-Karoo Array Telescope (MeerKAT). The first 10% of the SKA is highly likely to be concentrated in this band, with Phase 1 (see above) construction commencing in the next decade.
3. **High-frequency Array:** $X' - 25$ GHz with X' chosen to provide some overlap with the mid-frequency array. High-frequency science supports the view that the upper frequency should extend above 25 GHz. SKA/high will cover "Cradle of Life" science — including synoptic imaging of protoplanetary disks on sub-AU length scales, complex molecules, and SETI — and high-redshift detection of the first metals (CO) on targets that will complement those studied with ALMA and EVLA at radio wavelengths and JWST in the IR. High-frequency capability requires further technology development in order to bring down costs on precision reflectors, mounts and wide-band processing. Detailed design, including sensitivity requirements, can await science results from EVLA and ALMA.

The SKA program is being developed under an international, four-year (2008-2011) technology development and design project with US contributions from the NSF-funded SKA Technology Development Project (TDP). Deliverables and decisions are being defined jointly with the Preparatory SKA (PrepSKA) project funded by the European Commission.

[1] "Science with the Square Kilometre Array," 2004, eds. C. Carilli & S. Rawlings, New Astronomy Reviews, Vol. 48, 979–1563
[2] ISSC Resolution, "Phased Implementation of the SKA" (March 2007)

A US View of the SKA Program

The following points address the deployment and development plan of the international SKA Program from a US viewpoint:

1. The US is committed to the international development of the SKA Program as defined by the ISSC (see previous page). US personnel have played significant roles in the SKA program to date and we expect this to continue. International collaboration is the only realistic avenue of achieving this ambitious project, both scientifically and financially. We endorse the scientific goals of the SKA, which could revolutionize astronomy.

2. All parts of the SKA Program — low, mid and high — should be available to world-wide astronomers on an open skies basis. This will assure the best science return from this large international investment.

3. Within the baseline SKA Program — three arrays covering different frequency ranges — it is not clear that the best scientific return would be achieved by siting all three arrays at the same site. The two identified candidate sites are scientifically excellent for SKA-low and SKA-mid, but a higher altitude site would yield better science return for SKA-high, including options for possibly extending the frequency range well above 25 GHz to maximize complementarity with ALMA, enhance observations of CO in high-z galaxies, and increase sensitivity to thermal radiation from stars and disks. As one example, it might prove attractive to develop SKA/high in a way that leverages significant existing EVLA/VLBA infrastructure in New Mexico. The final decision on sites for all three frequency bands will be made by future international consensus based on science, cost, and international politics and funding.

4. In this picture, the EVLA and ATA are pathfinders for SKA/high at present. Further technology development on SKA/high needs to be pursued on the international level along with SKA/low and SKA/mid.

5. We expect US participation in the SKA program to sum to one third of the total effort, with US funding being substantial in all phases of SKA development, possibly with different weightings in the three bands. Work on the SKA/low and SKA/mid arrays will probably be emphasized in the early years of the SKA program, with SKA/high construction commencing later in the decade after technology development is complete. The US portion of the construction cost of the full SKA (excluding site preparation costs and contingencies) is currently estimated to be $500-700M. US funding requires vetting through the US decadal survey mechanism and other protocols for acquiring funds from the US National Science Foundation (NSF) or other US Government agencies.

6. The total integrated cost of the SKA Program is currently a major issue. The combined cost of the SKA/low and SKA/mid arrays, based on current requirements, is likely to reach the ceiling anticipated by the ISSC and relevant funding agencies for funding that may be available next decade. However, further SKA/high technology development is warranted in the next decade to reduce costs and increase capability and to define a construction plan beginning late next decade and continuing in the following decade. In addition, further assessment of scientific specifications for SKA/high is needed; it is conceivable that SKA/high science can be achieved with sensitivity at the level of 0.1 to 0.2 square kilometers.

Recommendations: In summary, we suggest that the US community's proposal to the decadal committee concerning the SKA should emphasize that:

1. The only realistic road to the full SKA is international and the US community endorses the international community's concept of the SKA, a 3-array multistage program that would result in transformational contributions to many of the most important problems in astrophysics, astrobiology and fundamental physics;

2. Completion of the full SKA in the upcoming decade is inconsistent with the projected time scale for the availability of major funding from the NSF and perhaps other international funding agencies. Therefore, although SKA/low and SKA/mid might be completed in the coming decade, much of the construction of the SKA/high array might more realistically occur in the following decade;

3. The international SKA program should give serious consideration to exploring the relative scientific and cost advantages of placing SKA/high at a different site from the SKA/low and SKA/mid arrays, possibly using a higher SKA/high site to extend the SKA to frequencies above 25 GHz for increased science return.