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Square Kilometer Array Science Working Group
Question 2 of "The Magnificent 8"

What is the case for multiple independently-steerable FoVs?"

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Preamble:

The innovation of the SKA is the combination of large field of view (FoV) with orders of magnitude increase in sensitivity along with a rich pallette of operating modes that can exploit both of these characteristics. Currrent SKA specifications[1] call for a 1 deg^2 FoV at 1.4 GHz, increasing to $\sim$ 200 deg^2 at 0.7 GHz. The number of *separate* FoVs is one with full sensitivity, ten in sub-arrays and a goal of four separate FoVs with full sensitivity. Here we discuss the scientific need for multiple FoVs. There is not yet a compelling need for multiple FoVs at full SKA sensitivity. An exception *may* be the follow-up timing observations of pulsars, the number of which will be very large. However, further simulations of the process by which pulsars are discovered and then timed are needed in order to assess the throughput needed to make the pulsar KSP feasible.

Definitions:

Following the initial discussion on this topic in the Groningen SKA meeting in August 2002, we first define the large number of types of beams that enter the discussion:

Primary Beam: response of an individual antenna element. For a dual-antenna system (e.g. a paraboloid + feed antenna) this is the net angular response at a single focal point. For a single element of an aperture array, this would be the basic response of that element.

Station Beam = the synthesized beam of a *station* built up from primary elements.

SKA Beam = synthesized beam of the entire SKA.

Field of View (FoV) = the primary beam $\times$ delay beam (or equivalent), i.e. the usable, instantaneous patch of solid angle that can be analyzed.

For aperture arrays, the FoV spec is much smaller than the intrinsic beam width of the tiles. Multibeaming is therefore much more flexible in this design and it is possible to simultaneously sample regions of the sky separated by $\gg 1$ deg and using the entire collecting area of the SKA. Other designs may achieve large solid-angle coverage through use of multiple-beam systems at the focal point of a primary reflector (e.g. through use of focal-plane-sampling arrays or multiple feed antennas). In our definition of primary beam (above), we would consider each pixel of a multiple beam system of this type to be a single FoV. While this differs from usage of the term in optical and other contexts, it is useful for the SKA because a single FoV defined this way indeed would form the boundaries of the analyzed field of view in, say, a VLBI observation.

Core-Array Beam = the synthesized beam from elements within a central core array.

Key Science Projects that need a core-array beam include EoR studies, HI detection of galaxies, molecular line studies, and blind surveys for pulsars, transients and SETI.

[1] SKA Science Requirements: Version 2, SKA Memo 45, D. L. Jones

It is useful to define the core-array beam because elements within the core-array can be phased together or correlated individually rather than by first phasing them into station beams. Additionally, and most importantly, it is only for the core array that one can hope to sample the *entire* FoV of ~ 1 deg at 1.4 GHz.

Discussion of Multiple FoV Needs for Different Key Science Projects

At some level, all science areas would benefit from multiple, simultaneously-available FoVs because they would effectively provide larger solid angle coverage and hence, greater survey throughput. However, the FoVs specified in SKA Memo 45 already take into account throughput requirements for the KSPs. The key question for the present document is the simultaneity of multiple FoVs, especially if they are widely separated, for example, by tens of degrees on the sky. Such coverage can always be gotten through subarray capability at less than full sensitivity. So the real issue is: what science areas require multiple, widely separated FoVs at full sensitivity?

1. The Cradle of Life

The three components of the Cradle of Life (imaging of protoplanetary disk evolution, inventories and chemistry of biomolecules, and the search for signals from extraterrestrial intelligence [SETI]) do not require simulaneous, widely spaced FoVs at full sensitivity. Anti-coincidence tests of RFI are crucial for SETI and thus SETI would benefit from the capability. However, multiple-site observations are at least as important for anti-coincidence tests and would most likely involve less-than-full sensitivity.

2. Strong-Field Tests of Gravity Using Pulsars and Black Holes

The topic of this document was discussed at the recent (2005 August) Pulsar SKA/KSP Project Workshop at the ATNF[2]. Discussion of the pulsar KSP requires us to distinguish between the three observational components: searching, timing and astrometry using long baselines. Briefly, the workshop discussion lead to the following assessment:

- *Searching:* Multiple FoVs are not essential but would be useful in terms of increasing survey throughput.
- *Timing:* Precision timing is needed at a frequency of about 2 GHz. FoVs separable by 10 to 45 deg are desireable or required depending on simulations for simultaneous multiple pulsar timing. Note that this is an efficiency issue, but efficiency may be so low that the KSP is not feasible (keeping in mind that $\sim 10^4$ pulsars will be discovered in the search and these will all require follow-up timing of some sort in order to identify objects that will warrant long-term timing. For many objects, it may be possible to use subarrays for getting multiple FoVs. Simulations are required to really answer the question. Conducting the needed simulations is an action item.
- *VLBI astrometry:* Multiple FoVs are not necessary.

3. The Origin and Evolution of Cosmic Magnetism

There is no apparent need for simultaneous, multiple FoVs.

[2]See report "Summary of a Workshop on the SKA held at CSIRO/ATNF," (J. M. Cordes and M. Kramer) http://www.astro.cornell.edu/∼cordes/PSR-KSP/

4. Galaxy Evolution, Cosmology and Dark Energy with the SKA

The massive surveys that comprise much of this KSP require large solid angle coverage and in fact drive the requirement stated in SKA Memo 45 for frequencies below 1 GHz and down to about 0.4 GHz. However, there is no apparent requirement for multiple, widely spaced FoVs. The third component of this KSP consists of VLBI observations of water masers. The nominal high-frequency FoV will suffice.

5. Probing the Dark Ages with the SKA

The three components of this KSP are (1) high-z HI observations to detect the IGM during the reionization stage; (2) Detection of the first CO molecules in galaxies; and (3) surveying radio continuum emission from the first waves of star formation. The solid-angle requirements for each of these areas are already included in the SKA specifications of SKA Memo 45. Separate, simultaneous multiple FoVs are not needed to accomplish the science.

6. Exploration of the Unknown

The SKA will probe vast new regions of parameter space owing to its specified coverage of the frequency, time and spatial domains. Entirely new classes of objects are almost certain to be discovered. Transient sources represent one broad area in which the SKA will unveil new sources. A key factor for surveys of transients is instantaneous solid-angle coverage. As with the KSPs, any increase in the instantaneously sampled solid angle will improve survey throughput. Searches for fast transients require continuous dwelling on maximal solid angle, whereas slow transients (by definition) are those that can be surveyed through raster-scanning of the sky. In either case, there is no compelling requirement for simultaneous, multiple FoVs. As for SETI (see above), anti-coincidence tests for RFI will be a necessary feature of transient searches and could benefit from multiple FoVs. But without further knowledge of the luminosity function for transients, it is not clear that such multiple FoVs would *require* full sensitivity and thus can be made using subarrays of the SKA.