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The Square Kilometre Array

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Abstract. The Square Kilometre Array (SKA) is a global project to design and construct the next-generation international radio telescope operating at metre to cm wavelengths. The SKA will be an interferometric array with a collecting area of up to one million square metres and maximum baseline of at least 3000 km, and is designed to address fundamental questions in cosmology, physics and astronomy. The key science goals range from the epoch of re-ionization, dark energy, the formation and evolution of galaxies and large-scale structure, the origin and evolution of cosmic magnetism, strong-field tests of gravity and detection of gravity waves.

The SKA project is now entering a final design for an SKA Observatory to begin to be built in the latter half of this decade that will include facilities in South Africa and Western Australia. The SKA design relies on advances in several technologies that will be prototyped over the next few years, and demonstrated for astronomical observations on SKA precursor telescopes. Scientific operations of the first 10% scale phase of the SKA is targeted for 2020.

Keywords. instrumentation: interferometers, techniques: interferometric, radio continuum: general

1. Introduction

The Square Kilometre Array (SKA) is a next-generation radio telescope for the metre to centimetre wavelength regime. The SKA conceptual design was developed by a consortium of institutions in 22 countries, including Argentina, Australia, Brazil, Canada, China, France, Germany, India, Italy, The Netherlands, New Zealand, Poland, Portugal, Russia, South Africa, Sweden, United Kingdom and the United States. The project is now entering the detailed design phase with participation at time of writing of 10 countries, with a target to begin construction of the first phase of the telescope around 2016.

The SKA will be an interferometric array with a collecting area of order one million square metres, providing a sensitivity about 50 times higher than the largest currently existing radio telescopes. Taking advantage of technology developments in radio frequency devices and digital processing it will achieve a sky imaging capacity 10,000 times faster than our current best imaging radio telescopes. The science case for the SKA has been under development for over a decade, e.g. Taylor (1999), Carilli & Rawlings (2004). The major leap in our ability to observe the universe enabled by the SKA will advance a broad range of modern astrophysics. The SKA science community has identified five key science areas where the SKA is targeted to make transformational advances in questions of fundamental importance in physics and astrophysics.

- *Strong-field tests of gravity using pulsars and black holes*: Surveys will detect tens of thousands of new pulsars including binary systems, some potentially with black hole companions. The sensitivity of the SKA will allow ultra-precise timing of pulsar signals. Thousands of millisecond pulsars will be detected; the most stable will form a pulsar timing array for detection and study of gravitational waves.

Table 1. Target SKA development and construction timeline

Time	Phase
2008 - 2011	Conceptual design (preparatory phase)
2011	Establish SKA organization for pre-construction
2012	Site decision
2012 - 2016	Detailed design (Pre-construction phase)
2016 - 2020	SKA phase 1 construction
2020	SKA phase 1 science operations
2020 - 2024	SKA phase 2 construction
2024	Science operations with full SKA

- *The origin and evolution of cosmic magnetism.* Surveys of polarization properties of the sky will yield measures of polarized synchrotron radiation arising from relativistic particles interacting with magnetic fields. Faraday Rotation Measure synthesis will be possible for more than 10^8 polarized extragalactic radio sources out to cosmological distances, allowing the evolution of magnetic fields in galaxies to be traced over cosmic time, and providing a sensitive probe of the magnetic cosmic web that may be associated with the formation of large-scale structure.
- *Probing the Dark Ages*: At its lowest frequencies the SKA will probe the structure of the neutral universe during the "dark ages" before the first "objects" were formed, as well as the subsequent epoch of reionization.
- *Galaxy evolution and cosmology.* Atomic hydrogen emission will be detectable in normal galaxies to high redshift, providing measure of the cosmic evolution of HI and star formation. Radio continuum tracing star formation will be detectable to arbitrary redshift and the wide-field of view capability will trace out the large scale distribution of galaxies to high z, allowing precise studies and determination of the equation of state of dark energy.
- *The conditions for and existence of life elsewhere in the Universe*: Sub-AU imaging of thermal emission will trace the process of terrestrial planet formation and probe the dense proto-planetary environments for pre-biotic molecules that are the building blocks of life. The raw sensitivity and field of view of the SKA will allow leakage radiation to be detected from potential civilizations in planetary systems around millions of solar type stars.

Complete and current information about the SKA can be found at the project web site http://www.skatelescope.org, and a detailed description of the SKA can be found in Schilizzi *et al.* (2010).

2. The Square Kilometre Array

2.1. *SKA technology and timeline*

The timeline for the SKA project is shown in Table 1. The SKA project completed a conceptual design effort in 2011 with contributions from over 60 institutes in 20 countries. Achieving a design of the scale and scope of the SKA telescope has relied on advances in the costs and capabilities of a range of technologies, including:

- high performance, low-cost reflector antennas
- wide-field of view focal and aperture plane array receiver systems,
- broad-bandwidth receivers and digital transport and processing devices

Application of many of these technologies for astronomy will be demonstrated over the next few years. For example, focal-plane phased-array receiver systems and composite manufactured antennas, are under development as part of the SKA precursor telescopes being constructed at the two SKA sites, ASKAP in Western Australia (Deboer 2009)

Figure 1. Rendering of a prototype SKA 15-m composite material antenna under construction at the Dominion Radio Astrophysical Observatory in Penticton, Canada. The offset design optimizes for high dynamic range imaging by minimizing radiation scattered into feed. The focal structure will accommodate both single-pixel and focal-plane phased-array feed systems. (Image Credit: National Research Council of Canada, Canada/US-TDP SKA Dish Verification Project)

and MeerKAT in South Africa (Jonas 2009). These telescopes will begin astronomical observations by 2014/15. Focal-plane phased array systems are also being installed on the Westerbork Synthesis Radio Telescope (Verheijen 2008) to provide a factor of 25 increase in field of view. Low-frequency aperture plane array systems are achieving operational status for astronomy on the LOFAR facility (Vermeulen 2012).

The SKA builds on these technology advances. The new international SKA Organization has now begun a final detailed design phase (the so-called pre-construction phase) targeted to end in 2016. This phase will see prototypes of SKA technologies. For example, Figure 1 shows a rendering of a prototype SKA 15-m composite dish antenna that will be constructed in early 2013 at the Dominion Radio Astrophysical Observatory in Canada. The primary outcomes of the pre-construction work will be a construction ready design for the first phase of the SKA and an assessment of technical readiness of advanced instrumentation options for SKA phase 2. The full SKA will consist of $\sim$3000 15-m parabolic antennas distributed over an area with baselines extending to several thousand kilometres and operating up to a radiation frequency of 10 GHz. In addition, aperture-plane phased arrays will be used up to baselines of a few hundred kilometres to observe large areas of the sky instantaneously at low frequencies, from 70 MHz up to at least a few hundred MHz and potentially as high as a GHz.

SKA phase 1 will provide a sub-set of the full SKA capabilities, chosen to target at high priority two key science areas: pulsars and gravity, and the evolution of hydrogen from the dark ages to the present epoch. Phase I will have approximately 10% of the collecting area of the full SKA and will extend to baselines of a few hundred kilometres. The Phase 1 SKA Observatory will consist of three separate receptor arrays: an array of 250 dish antennas equipped with single-pixel feeds operating in the GHz range, an array of 90 dish antennas with focal-plane phased-array feeds operating from 0.7 - 1.8 GHz, and a low-frequency sparse aperture-plane phased array operating from 70 - 450 MHz.

Table 2. Summary of the dual-site deployment plan for the SKA Observatory Facilities

SKA Phase 1 Deployment 2016-2020	
Phase 1 low-frequency aperture plane array	Western Australia
90-element sky survey dish antenna array with focal-plane phased-array feeds	Western Australia
250-element high-sensitivity dish antenna array with single-pixel feeds	South Africa
SKA Phase 2 Deployment 2020-2024	
Phase 2 low-frequency aperture plane array	Western Australia
3000-element dish antenna array with FPA and single-pixel feeds	Southern Africa
Mid-frequency dense aperture array[1]	South Africa

Notes: [1] Deployment of dense aperture plane array receptors for SKA Phase 2 is contingent on technical readiness.

2.2. *The SKA observatory sites*

Following extensive technical studies, beginning in 2008, of proposed SKA sites in Australia/New Zealand and Southern Africa, the SKA Organization formally adopted a dual site option for the SKA in 2012. This option leverages the significant investment in infrastructure developments in both Western Australia and South Africa to provide an enhanced SKA phase I observatory. The distribution of the SKA observatory facilities for Phase I and Phase 2 is shown in Table 2. The 250-element high-sensitivity dish array will be constructed by adding 190 antennas to the MeerKAT located in the Karoo Desert in northern South Africa. In Western Australia the ASKAP telescope with focal-plane array feeds will be built out from 36 to 90 antennas, providing a power sky survey telescope for continuum and atomic hydrogen line emission. Western Australia will also host the first phase of the sparse aperture plane array for instantaneous all-sky imaging of high redshift HI and transient detection. These facilities provide complementary capabilities that are a major advance on current telescopes and together advance key science questions related to the epoch of re-ionization, transients, pulsars and gravity, and galaxy evolution.

Phase 2 of the SKA will see the extension of the dish array to baselines of several thousand kilometres through Southern Africa and the build out of the low-frequency spare aperture plane array in Western Australia to its full collecting area early in the next decade. En-route to the distributed long-baseline remote stations for SKA Phase 2, a group of African nations is advancing the development of a network of antennas for an African VLBI network.

3. Conclusion

The Square Kilometre Array project is moving into a final detailed design and technology demonstration phase that will lead to the deployment of the first 10% of the SKA at sites in Western Australia and South Africa during the latter part of this decade. The sensitivity, field-of-view, broad-frequency range and imaging capabilities of this first phase of the SKA will begin a transformational advance over a broad range of astrophysics. Optimization for studies of pulsars, extreme gravity and gravitational waves, and of the evolution of neutral hydrogen are guiding the engineering design of SKA phase 1 - an important milestone on the pathway to the full SKA science operations in the decade to follow.

Figure 2. The Phase 1 SKA Observatory will consist of dish and sparse aperture plane array technologies. Two dish antenna arrays, a high-sensitivity array equipped with single-pixel feeds in South Africa will operate up to 3 GHz and a second survey instrument with focal-plane phased arrays in Australia will image large instantaneous fields of view from 0.7 - 1.8 GHz. A separate low-frequency sparse aperture plane array at the Western Australia site, operating down to 70 MHz, will allow sensitive observations of highly redshifted neutral hydrogen emission. (Image credit: SKA Organization/Swinburne Astronomy Productions.)

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