# THE SQUARE KILOMETRE ARRAY

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## *ABSTRACT*

The Square Kilometre Array (SKA) is the future centimeter- and meter-wavelength telescope with a sensitivity about 50 times higher than present instruments. Its Key Science Projects are (a) Astrobiology including planetary formation within protoplanetary disks; (b) Testing theories of gravitation using an array of pulsars to search for gravitational waves and relativistic binaries to probe the strong-field regime; (c) The origin and evolution of cosmic magnetism, both within the Galaxy and in intergalactic space, via an all-sky grid of magnetic field measurements; (d) The end of the Dark Ages, involving searches for a neutral hydrogen signature, the first supermassive black holes, and the first metal-rich systems; and (e) A hydrogen census to a redshift $z \geq 1$ from which to study the evolution of galaxies, dark matter, and dark energy. The SKA will operate at wavelengths from 1.2 cm to 3 m (0.1–25 GHz), providing milliarcsecond resolution at the shortest wavelengths. Its instantaneous field of view will be about 1° (20 cm wavelength), with many simultaneous beams on the sky. The Reference Design is composed of a large number of small dish antennas, building upon an original US proposal. In order to obtain these capabilities at a reasonable cost, significant engineering investments are being made in antennas, wideband feeds and receivers, and signal processing; aperture arrays (phased feeds) are also being investigated in Europe for the lower frequencies. Candidate sites are in Argentina, Australia, China, and South Africa, with a short list of acceptable sites anticipated late in 2006.

***Keywords:*** ***instrumentation: radio telescopes, instrumentation: interferometers, astrobiology, gravitation, magnetic fields, large-scale structure of universe, cosmology: observations***

## 1. INTRODUCTION

Over the past few decades, astronomers observing at radio wavelengths have made a series of discoveries that have helped set the stage for much of modern astronomy. Objects or processes discovered include non-thermal radiation, radio galaxies, quasars, the cosmic microwave background, cosmic evolution, pulsars, gravitational lensing, cosmic masers, molecular clouds, evidence for dark matter, and extrasolar planetary systems.

Astronomy in the 21st century is likely to be increasingly multi-wavelength, requiring a balanced portfolio of facilities available to probe issues ranging from fundamental physics to the origin and evolution of the Universe to the structure of the Milky Way Galaxy to the formation and distribution of planets and perhaps even life itself. Currently under development by an international consortium, the Square Kilometre Array (SKA) is a centimeter- and meter-wavelength telescope envisioned as being one of a suite of new, large telescopes for the 21st century. In its capabilities, particularly with a sensitivity of 50 to 100 times that of current instruments, the SKA will make a revolutionary break from today's radio facilities.

Here we provide an overview of the SKA, starting with the science and continuing with a description of the Reference Design and project timeline and concluding with a discussion of the site selection process and current management structure.

## 2. SCIENCE

The original motivation for the SKA was as a telescope capable of studying the evolution of the atomic hydrogen content of the Universe, with the nominal goal of constructing a telescope capable of detecting the neutral hydrogen (H I) emission from a Milky Way-like galaxy at a redshift $z \sim 1$. Such an instrument would require a substantial increase in sensitivity. Originally proposed in the early 1990s, a series of meetings throughout the 1990s began to focus the discussions on the desired capabilities for a next-generation radio telescope and the technology needed to obtain its construction. It was recognized quickly that such a telescope would be far more powerful than simply being able to detect H I emission.

Throughout 2003 and 2004 a series of meetings and workshops was held to define and refine the science case for such a telescope. The goal was to identify fundamental physics and astronomical questions that either required radio observations or could be done uniquely only at radio wavelengths. Attended by astronomers from all over the world, these meetings culminated with the SKA Science Case (Carilli & Rawlings 2004). The SKA Science Case highlights 5 Key Science Projects as well as a host of additional problems that could be investigated with the SKA. Here we summarize these Key Science Projects.

### 2.1. Astrobiology: The cradle of life

The focus of this Key Science Project is to observe the process of planet formation in the dusty disks around young stars. The heuristic picture of planetary assembly is that it begins in a disk composed of dust and gas. The initial dust grain size is probably sub-micron, comparable to that for interstellar dust particles. Within the proto-planetary disk, the dust grains begin to "stick" together. As they do so, they decouple from the disk gas and begin to interact gravitationally. The dust grains continue to accrete, forming "pebbles," then "boulders," and finally planetismals. One difficulty with this scenario is that, given their kinetic energies, how dust grains accrete to form "pebbles" rather than destroying each other is not clear. Probing this crucial regime of planet formation requires observations at wavelengths comparable to the size of the particles, so on scales of order 1 cm. With its high frequency capabilities (observations to 25 GHz or 1.2 cm wavelength), the SKA will be positioned uniquely to probe the assembly of planets. Moreover, it is planned for the SKA to be able to obtain milliarcsecond resolution. At the distance of nearby star forming regions (~ 150 pc, e.g., Taurus, Ophiucus, and Chamaeleon), 1 AU subtends an angle of approximately 7 milliarcseconds. Thus, the SKA will be able to resolve the inner portions of proto-planetary disks. For a solar-mass star, the orbital period at a distance of 1 AU is 1 year, so the SKA will even be able to make synoptic observations of the inner regions of proto-planetary disks, potentially assembling "movies" of planet formation.

In addition, a number of large (> 10 atom) prebiotic molecules are being discovered in interstellar space. Typical transition frequencies for these molecules lie in the 10 to 20 GHz range, and the expectation is that even larger molecules would have transitions at lower frequencies. The SKA will search for these prebiotic molecules and explore the extent of organic chemistry and the precursors of life in interstellar space. Finally, detecting transmissions from another civilization would provide immediate and direct evidence of life elsewhere in the Universe. With its sensitivity, not only will the SKA probe deeper into the Galaxy than any previous survey, for the first time it will enable searches for unintentional emissions or "leakage" at power levels comparable to that of terrestrial TV transmitters.

### 2.2. Strong Field Tests of Gravity using Pulsars and Black Holes

The focus of this Key Science Project is to conduct a census of the Galaxy for radio pulsars and identify those objects best suited for probing strong field gravity within the context of theories of gravity such as general relativity (GR). Current estimates are that the Milky Way Galaxy contains about 20,000 rotation-powered radio pulsars beamed in our direction. The sensitivity of the SKA will be such that it should be able to detect all of these pulsars (Figure 1). Observations of a particular pulsar, PSR B1913+16, have already provided an indirect detection of the gravitational radiation predicted in GR (as well as the 1993 Nobel Prize in Physics). However, the Galaxy should contain a number of systems capable of providing even more stringent tests. After completing the census of pulsars, observations with the SKA will focus on high precision timing observations of these pulsars, with an aim toward two aspects of GR.

First, population studies of neutron stars and radio pulsars suggest that there should be at least one pulsar-black hole binary system and potentially as many as 100 in the Galaxy. The pulses from a pulsar can be considered to form a clock. As a black hole is the most compact object that should exist, a clock in its environment would provide stringent tests of various predictions of GR. At a basic level, the pulsar timing will reveal the properties of the black hole companion, such as its mass and angular momentum, in a manner similar to how pulsar timing observations have measured the mass of both components in double neutron star systems. High precision timing will allow higher order tests to be conducted, such as tests of the "no-hair" theorem that predicts that a black hole is described entirely by its mass, angular momentum, and electric charge, and which also predicts a simple relation between its angular momentum and quadrupole moment. Other tests that could be conducted include searching for possible violations of the strong equivalence principle or evidence for gravitational theories beyond GR (e.g., tensor-scale theories). An important aspect of this search is the Galactic center. The supermassive black hole in the Galactic center should contain a number of pulsars in orbit about it, pulsars which have escaped detection because current instruments do not have the requisite sensitivity at the frequencies (> 10 GHz) required to mitigate the severe interstellar scattering effects along the line of sight.

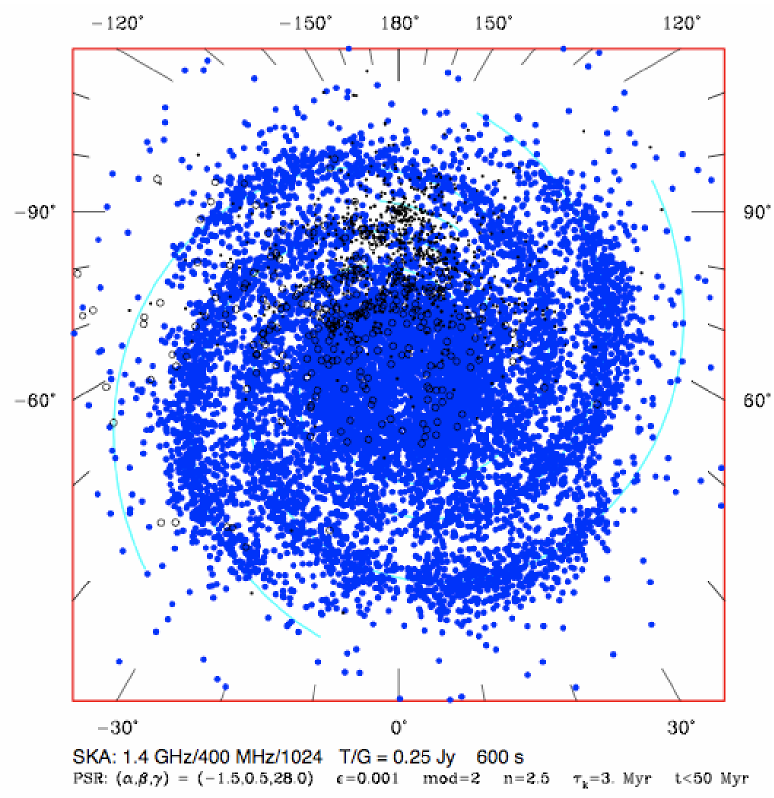

**Figure 1. Illustration of the expected increase in the known pulsar population after the advent of the SKA. The black dots indicate the locations of the currently known pulsars projected onto the Galactic plane, the cyan lines indicate the assumed spiral arms, and the blue dots indicate the locations of pulsars that the SKA would be capable of detecting. Their locations are the result of a Monte Carlo simulation, based on the currently known population. The Galactic center is at the center of this figure and the axes indicate Galactic longitude. (Figure courtesy of J. Cordes)**

Second, the SKA is expected to discover a network of millisecond pulsars across the sky. With their exquisite timing stability, millisecond pulsars form among the most accurate clocks available. Effectively, this network of millisecond pulsars (the pulsar timing array) can serve as a many-armed gravitational wave detector, searching for timing distortions due to the passage of very long-frequency gravitational waves (~ nHz). Generally, cosmic sources are expected to produce a spectrum of gravitational waves, and the SKA pulsar timing array will probe a regime in which gravitational waves may have been produced either by cosmic strings or during the initial inflationary epoch of the Universe.

Finally, a small number of pulsars emit so-called “giant pulses,” the strengths of which are orders of magnitude larger than the typical pulse. With the SKA sensitivity, numerous giant pulse-emitting pulsars in nearby galaxies will be detected, and the SKA may be able to reach to the Virgo cluster of galaxies, the nearest large cluster.

### 2.3. The Origin and Evolution of Cosmic Magnetism

The focus of this Key Science Project is an all-sky grid of magnetic field measurements from which to probe the role and origin of the magnetic field in the Galaxy, galaxy clusters, and intergalactic space. Electromagnetism is one of the most accurate physical theories, and it is clear that magnetic fields fill intracluster and interstellar space, affect the evolution of galaxies and galaxy clusters, contribute significantly to the total pressure of interstellar gas, are essential for the onset of star formation, and control the density and distribution of cosmic rays in the interstellar medium. Nonetheless, fairly basic questions remain about the origin and evolution of cosmic magnetic fields. A radio wave propagating through a magnetized plasma undergoes Faraday rotation, providing the SKA with a unique probe on cosmic magnetic fields.

The tool by which the SKA will probe cosmic magnetic fields is an all-sky Faraday rotation measure survey. In contrast to current magnetic field measurements, which number of order 1500, the SKA is expected to be able to measure the Faraday rotation measure toward of order $2 \times 10^7$ extragalactic sources (and perhaps all 20,000 pulsars in the Galaxy). This all-sky grid will provide a typical separation of about 90 arcseconds between magnetic field measurements.

With this grid, a detailed picture of the Galactic magnetic field will be produced, and similar measurements will be used to probe the fields in nearby galaxies. Such a detailed model for galactic magnetic fields in turn can discriminate between various origins for magnetic fields in galaxies, whether the fields are in some sense primordial or were generated at later times by a dynamo action (e.g., a so-called $\alpha$-$\Omega$ dynamo).

For relatively nearby clusters of galaxies, the grid of magnetic field measurements will be sufficiently dense to probe the field within the clusters themselves, in contrast to the current situation in which only properties averaged over many clusters can be determined. A detailed view of the magnetic field structure within clusters will in turn allow probes of the interaction between magnetic fields and the hot, X-ray emitting gas as well as the interplay between various “heating” mechanisms for a cluster (e.g., mergers, radio jets from active galactic nuclei near the center of clusters) and the cooling provided by the X-ray emission.

Finally, with the deepest SKA observations, magnetic field measurements at high redshift ($z > 2$) will be possible. Complementing the field measurements in nearby galaxies, observations of the field in distant galaxies may trace directly the enhancement of the field by a dynamo (or illustrate that a dynamo is not responsible for the origin of the field). Also, the SKA all-sky grid will allow searches for any intergalactic magnetic field (i.e., one outside of clusters and permeating intergalactic space as a whole). Such an intergalactic magnetic field may have played a role in the assembly of large-scale structure and the formation of the “cosmic web.”

### 2.4. Probing the Dark Ages

The focus of this Key Science Project is the first luminous objects in the Universe and their formation. At a redshift around 1100, the Universe became largely neutral as protons and electrons combined to form the first hydrogen atoms and the photons that we now see as the cosmic microwave background began free streaming across the Universe. Today the Universe is largely ionized. The epoch of reionization of the Universe is dated to $z \approx 6$ to 10 from observations of the highest redshift quasars detected in the Sloan Digital Sky Survey and the analysis of the Wilkinson Microwave Anisotropy Probe (WMAP) observations. The interval from a redshift of about 1100 to the epoch of reionization is known as the Dark Ages. The redshift of the epoch of reionization is so large that only observations at wavelengths longer than 1 micron are useful, and the SKA will play a key role in probing two aspects of the end of the Dark Ages.

First, as the first structures form and the first stars and quasars begin to illuminate their surroundings, they should heat the surrounding hydrogen gas. Its excitation will decouple from the temperature of the cosmic microwave background, and a complex, time-dependent patchwork of (highly redshifted) hydrogen emission or absorption on the sky is predicted to result. The simplest result is that Strömgren spheres will be formed around the first stars, the first quasars, or both. More complicated scenarios involve the heating of the hydrogen gas as it collapses even before the first stars form. The current constraints on the redshift at the epoch of reionization indicate that the 21-cm (1420 MHz) emission from the remaining neutral hydrogen will be visible at wavelengths between about 1.5 and 2.3 meters (frequencies between about 130 and 200 MHz). The goal of the SKA is to detect this highly-redshifted neutral hydrogen emission or absorption, which in turn will constrain the formation of the first structures.

Second, the SKA will detect and study these first luminous objects. The spectrum of a typical radio-loud active galactic nucleus steepens toward high frequencies; the redshifted spectrum of such an object consequently will be even steeper. A sensitive, moderate resolution search for objects with steep, non-thermal spectra is therefore an effective filter for potentially quite distant active galactic nuclei, including the first to appear at the end of the Dark Ages. As active galactic nuclei are thought to be powered by supermassive black holes, effectively the SKA will be searching for some of the first black holes in the Universe. A complementary goal to the search for neutral hydrogen emission is to conduct a search for neutral hydrogen absorption in the spectra of these first radio-loud quasars. Finally, carbon monoxide (CO) emission has been detected from some of the most distant currently known radio-loud quasars. The presence of “metals” such as carbon and oxygen in objects at redshifts near 6 is potentially problematic. The time scale for these elements to be produced in the first stars and then distributed is uncomfortably close to the age of the Universe at that time, meaning that it is not clear that there would have been enough time for CO to have been formed. The shorter-wavelength capabilities (~ 1.5 cm) of the SKA will be used to conduct even more sensitive searches for CO emission from distant, radio-loud objects and constrain the time scales on which the first stars would have had to form, fuse these elements, then disperse them back to the surrounding medium.

### 2.5. Galaxy Evolution, Cosmology, and Dark Energy

The focus of this Key Science Project is a deep survey for H I emission from galaxies. The SKA will detect easily the H I emission from galaxies at the modest redshift of 1, and, in reasonable integration times, it will be able to probe to $z \sim 3$. Detecting the H I emission from potentially more than one billion galaxies, this SKA survey will be a crucial tool for explicating various aspects of cosmic evolution.

The SKA H I survey will provide a three-dimensional map of the Universe at least out to $z \approx 1.5$. In turn, this survey will yield the galaxy power spectrum as a function of redshift, from which acoustic oscillations, also as a function of redshift, can be determined. Crudely, these acoustic oscillations can be considered to be a standard ruler. The SKA experiment will determine the change in the apparent angular size of these acoustic oscillations as a function of redshift. When combined with measurements of the size of these oscillations seen in the cosmic microwave background, we obtain a measure of the cosmic evolution of the Universe. In particular, the influence of dark energy from the time of the formation of the cosmic microwave background to $z \sim 1$ can be probed, thereby constraining the equation of state of the Universe. Crucially, the accuracy of measurements of this sort depends upon the total number of objects detected. The large sample size of the SKA surveys will provide unparalleled precision.

More generally, neutral hydrogen is the raw material from which stars form. There is increasing evidence that star formation peaked at redshifts of about 1 to 2. The SKA will be able to probe the evolution of neutral hydrogen through this crucial point in the assembly of galaxies.

Other avenues that the SKA can explore include weak lensing and an improved determination of the Hubble constant. The same survey that provides the galaxy power spectrum will also provide information about the shapes of many galaxies. Weak lensing is the distortion in the appearances of galaxies seen through the gravitational potentials of foreground objects. Its importance is that it can provide constraints “orthogonal” to those provided by acoustic oscillation measurements. The SKA also will conduct a survey for water masers in the disks surrounding supermassive black holes at the centers of galaxies. The exemplar of such a water maser-bearing disk is that in NGC 4258. In contrast to the present situation in which only a small number of such objects are known, the SKA has the potential to detect hundreds, potentially thousands of such systems, thereby increasing the precision of Hubble constant measurements by at least an order of magnitude. Not only is determining the Hubble constant important in and of itself, the precision to which the Hubble constant is known can also be a limiting factor for some of the dark energy experiments described above.

### 2.6. Discovery space

The history of science has shown that new technologies lead to discoveries. The field of radio astronomy itself is an excellent example of this phenomenon. Celestial radio emission was discovered serendipitously by Karl Jansky during his investigations into the sources of static in long-distance radio transmissions. As mentioned above, since its discovery, observations at radio wavelengths have laid much of the groundwork for modern astronomy, including the discovery of non-thermal emission processes, quasars, the cosmic microwave background, pulsars, masers, and extrasolar planetary systems. Moreover, many of these discoveries were themselves serendipitous. With its unparalleled sensitivity, the SKA will undoubtedly make a series of unexpected discoveries.

## 3. REFERENCE DESIGN

Soon after the original goal of the SKA was described, a variety of possible concepts for realizing it were introduced. Initial proposals for the elements comprising the array included large apertures (> 100 m diameter), small apertures (~ 10 m diameter), refracting globes (“Luneberg lenses”), and tiles of phased arrays. Over the past several years, initial design and prototyping efforts have focussed the design, as described in *The Square Kilometre Array: An Engineering Perspective* (Hall 2005) and have led to the recently adopted Reference Design.

The Reference Design comprises both a set of specifications, informed by the Key Science Projects, as well as a concept for realizing those specifications. Table 1 summarizes key aspects of those specifications, where $A_{eff}/T_{sys}$ is the ratio of the effective collecting area to the system temperature (i.e., sensitivity). The Reference Design also provides nominal guidance on the distribution of the collecting area: 20% of the collecting area should be within a 1-km diameter region centered on the selected core site (see below), 50% should be within 5 km of the core site, 75% within 150 km, of the core, with the remainder on maximum baselines of about 3000 km from the array core.

**Table 1. Key SKA Reference Design Specifications**

| **Frequency range** | 0.1–25 GHz |
|---|---|
| **$A_{eff}/T_{sys}$** | |
| 0.1–0.3 GHz | 5000 $m^2$ $K^{-1}$ |
| 0.3–10 GHz | 20000 $m^2$ $K^{-1}$ |
| 10–25 GHz | 10000 $m^2$ $K^{-1}$ |

The Reference Design also emphasizes that, contrary to the popular notion of a telescope being the collecting area (a mirror or a reflecting parabolic dish), the most complex aspect of the SKA will be the data transmission and central processing facility. Radio signals will be fed to this central processing facility by one of three "front-end" collectors, in a manner analogous to that of an optical telescope in which the mirror feeds visible-wavelength photons to one of a number of "back-end" instruments. The three front-end collectors are:

- An array of small-diameter antennas with "smart feeds": The diameter is of the order of 10 meters, and the feeds comprise phased arrays in the focal planes of the antennas for frequencies between 0.3 and 3 GHz, and wide-band feeds at higher frequencies up to 25 GHz.
- Aperture array tiles in the core of the array: This innovative technology provides a "radio fish-eye lens" for all-sky monitoring in the frequency range 0.3 up to 1 GHz and multiple independent field observations.
- An Epoch of Reionization array: Operating in the ≤0.1 to 0.3 GHz range, it will be located in the core of the array. This array will make use of broad-band dipoles similar to those developed for the Low Frequency Array (LOFAR), the Milurea Wide-field Array (MWA), and the Long Wavelength Array (LWA), and will be constructed as part of the second phase of the SKA.

One of the motivations for this multiple front-end design is that the technology required to cover the full 0.1 to 25 GHz frequency range cannot be obtained by a single collector design. Figure 2 illustrates how the core region of the SKA might look.

**Figure 2. The SKA core. In the foreground are wide-field aperture arrays. In the background are parabolic antennas outfitted with "smart feeds." (Figure courtesy of the International SKA Project Office)**

The goals of the Reference Design are both to focus the engineering and science efforts around the world in order that the project be in a position to start construction of the telescope in about 2011 and to provide the basis for detailed costing of the array. It is expected that the Reference Design will mature, as various demonstrator and pathfinder projects underway around the world refine the technology.

## 4. PROJECT TIMELINE

Six major phases of technological development (and their status or anticipated milestones) have been identified within the project:

- **Feasibility**: Completed based on experience from existing radio interferometers and strawman designs.
- **Preliminary design and technology development**: Prototyping of antenna technologies and design studies of all other aspects of the SKA architecture including general site dependencies, occurring over the interval 2000 to 2007.
- **Advanced design and prototype arrays**: Construction of regional and national technology demonstrators and science-capable 1% SKA pathfinder telescopes, occurring over the interval 2005 to 2010.
- **Full system design**: leading to Phase I construction, with Phase I having approximately 10% of the full SKA sensitivity: 2008–2011.
- **Phase I construction**: leading to an initial operations capability and full array design fine-tuning: 2011–2014.
- **Complete construction**: the full SKA with the final operations capability: 2014–2020.

Currently the project is in the transition phase between preliminary design and technology development to the advanced design and prototype array phase. Major demonstrator and pathfinder facilities are under construction in Australia, Europe, South Africa, and the United States and construction is expected to begin shortly on a facility in China.

Important major milestones foreseen in the near future include the evaluation of potential sites with a selection of a short list of acceptable sites occurring in the third quarter of 2006, and an international review of the SKA design in the fourth quarter of 2007.

## 5. SITE SELECTION

An expensive, complex and large instrument like the SKA must be located on the best possible site. A Request For Proposals was issued by the International SKA Steering Committee (ISSC) on 2004 September 1, after pre-proposals were received and analyzed. By the deadline of 2005 December 31 for final proposals, the ISSC had received 4 official proposals to host the SKA. These are being evaluated by various committees and by an external independent committee. The ISSC plans to develop a short list of acceptable sites by the end of the third quarter in 2006. Following the ISSC's evaluation, it is expected that a negotiation process between the ISSC, various governmental agencies around the world that might fund the SKA, and the potential host country itself would commence and last until a site is selected. The candidate host countries are:

- **Argentina**: The proposed core site is at an elevation of 2600 meters in the region located in a National Park with mountain chains on the east and west of the site and with distant stations extending into southeast Brazil.
- **Australia**: The core site is located in the Mid-West region of Western Australia on a flat desert-like plain at an elevation of about 460 meters. The most distant stations will be located in New Zealand.
- **China**: The core site is located in the Karst region of Guizhou in southwest China. This region contains many depression regions of limestone.
- **South Africa**: The core site is located at an elevation of about 1000 meters in the Karoo area of the arid Northern Cape Province, with distant stations in Ghana, Kenya, Madagascar, and Mauritius.

The SKA site bids are being analyzed using the following major evaluation principles: (1) The ability to maximize the science return; (2) The construction and operational costs; and (3) Physical and political issues. The specific criteria being used to evaluate the proposals include:

1. The quality of science to be delivered, which depends upon
   a) The presence of radio frequency interference (RFI) over both the short and long term and protection issues including the establishment of radio quiet zones;
   b) The possibility to configure the array configuration in an optimum manner; and
   c) Ionospheric and tropospheric conditions.
2. Infrastructure, climatic, and costing issues, which depend upon
   a) The climate at the site;

  - b) Physical site characteristics for stations;
  - c) Impact of land-use and urban centers;
  - d) Existing infrastructure;
  - e) Data interconnects (specificallyincluding connections with fiber optics); and
  - f) Cost—both capital and operational.

3. National attributes related to the SKA site, which include
  - a) General economic and political issues;
  - b) Government and departmental interaction; and
  - c) Support for astronomy in general and the SKA facility in particular by the host country.

In addition to the detailed proposals, the International SKA Project Office commissioned independent RFI measurements contracted with the ASTRON research institute (the Netherlands). Figure 3 shows RFI measurements being conducted at one of the candidate sites (South Africa). These independent measurements on each proposed site were performed with the same instruments and analyzed with the same software for direct comparisons of the levels of RFI. The RFI results have been analyzed by an expert international committee.

**Figure 3. The SKA RFI monitoring project at the candidate South African site. (Figure courtesy of R. Millenaar)**

## 6. MANAGEMENT

The current SKA project is governed by a Memorandum of Agreement (MoA), which was signed in 2004; Figure 4 shows the management structure established under that MoA. Institutes signing the MoA ("Collaboration in the Development of the SKA") include consortia of institutions (universities and research institutes) engaged in radio astronomical research in Australia, Canada, Europe, and the United States, individual institutes in China and India, and the National Research Foundation in South Africa.

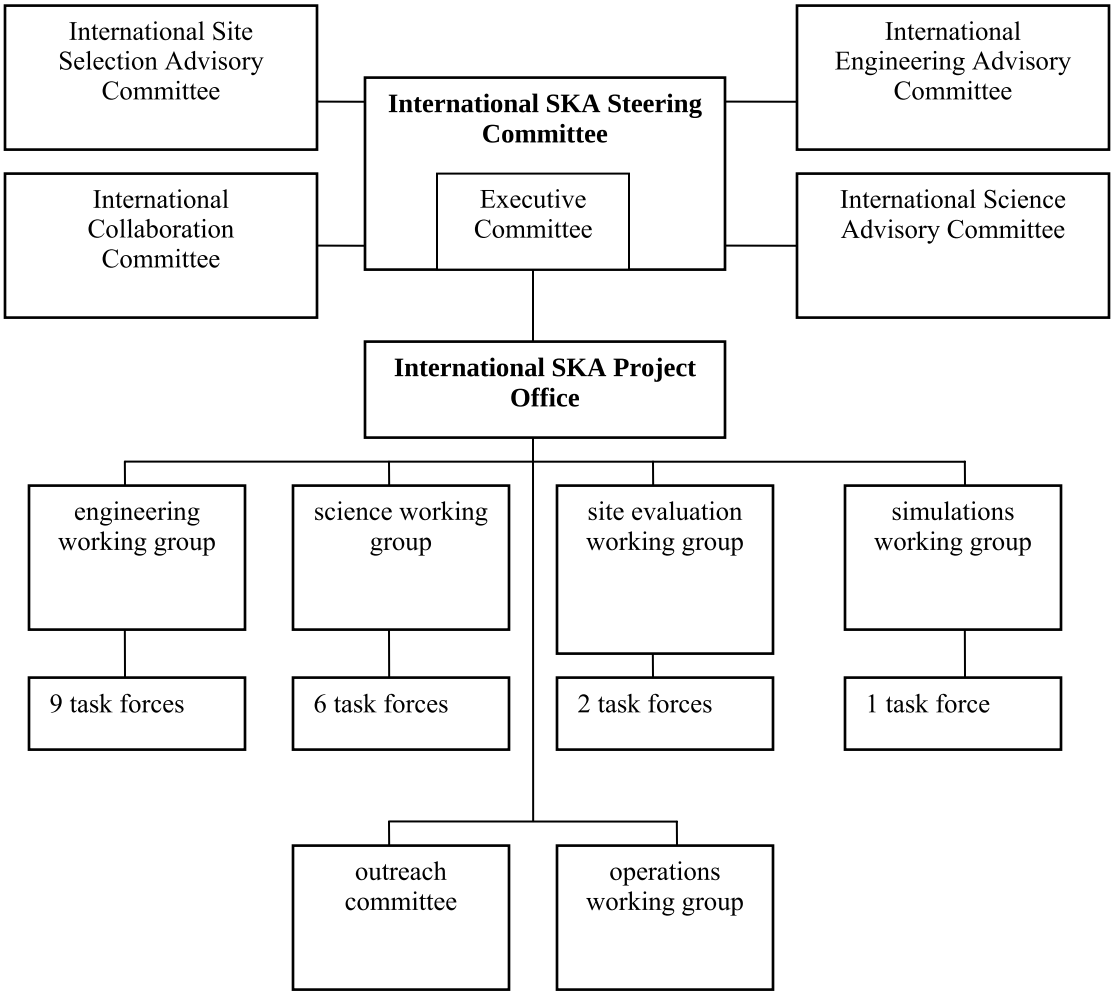

**Figure 4. The current SKA management structure. (Figure courtesy of the International SKA Project Office)**

The International SKA Steering Committee is charged with the overall decision making, oversight, and promotion of the SKA and is composed of 21 representatives. Current membership on the ISSC is apportioned so that 1/3 of the members are from European institutions, 1/3 are from U.S. institutions, and 1/3 are from institutes in other nations that have signed the MoA. The ISSC receives recommendations from external advisory panels; currently members for only the International Site Selection Advisory Committee and International Engineering Advisory Committee have been named .

Reporting to the ISSC is the International SKA Project Office (ISPO), staffed currently by a Director and Project Engineer. The ISPO is responsible for the coordination and leadership of the various projects underway worldwide and assists the ISSC with various management responsibilities. Reporting to the ISPO are a number of Working Groups focussing on the science of the telescope, its engineering, simulating its performance, evaluating the site bids, operational models for the telescope, and education and public outreach.

The current MoA expires at the end of 2006. It is expected that a more intensive phase of design, development, and initial construction will result, requiring a modified management structure. Discussions about the future management structure are underway.

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References

Carilli, C., and Rawlings, S. 2004, *Science with the Square Kilometre Array* (Elsevier: Amsterdam)

Hall, P. J. 2005, *The Square Kilometre Array: An Engineering Perspective* (Springer: Dordrecht)

Square Kilometre Array, http://www.skatelescope.org/