SQUARE KILOMETER ARRAY PROJECT: CONCEPTS AND TECHNOLOGIES

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Insights into the future research needs of astronomy have led radio astronomers to study the concept of a next generation of radio telescopes that will outperform today's radio telescope instruments in many aspects. In particular a three-decade frequency range, greatly improved sensitivity and angular resolution that matches the capabilities of planned instruments in other frequency domains, are challenges that are now being investigated. In parallel, the organization of the project is taking form. This presentation aims at an update of these activities, the concepts and the technologies that are being examined and among which will be selected in 2005.

INTRODUCTION

To detect and study normal galaxies in the early Universe, shortly after the Big Bang creation event, a new generation of astronomical telescopes is required. At cm to m wavelengths, within technological reach is a facility with sufficient sensitivity that normal galaxies may be detected at such great distances that the look-back time approaches the total age of the Universe. In this case, the evolution over all of cosmic time of gas, of star production, of the large-scale distribution of galaxies and of unseen matter, as well as such exotica as massive black-holes will be made available for empirical investigation. The sensitivity increase required is a factor of about a hundred over existing radio telescopes. This increase must be achieved by increasing the total collecting area to about a million square meters, leading to the name, Square Kilometer Array (SKA), for the facility.

The SKA project is being pursued as a global cooperation from the outset. Some 23 astronomical institutes in 14 countries are currently participating in an effort to formulate the detailed scientific specifications and carry out the necessary technical R&D. An international steering committee coordinates these activities.

The design goals, proposed scientific research program, and reports of workshops and organizational meetings are available on the project's international web site: http://www.skatelescope.org . The telescope is foreseen as a general-purpose facility capable of addressing the main scientific issues of the day at the relevant frequencies. In addition to greatly increased sensitivity, the scientific case calls for up to three decades of essentially continuous frequency coverage.

This exceedingly wide coverage is desired both to make possible the investigation of phenomena as a function of cosmic redshift (i.e. to determine empirically their evolution over cosmic time) and to ensure that a diversity of physical phenomena may be studied at unparalleled sensitivity. The design will also be optimized for the detection and study of transient radio sources, which are expected to be of increasing scientific importance. Finally, an important desideratum is that observations with SKA will have an angular resolution that provides complementary information to aid the interpretation of observations with the most advanced telescopes at other frequencies. This requirement leads to a total extent for the array of several hundreds to several thousands of kilometers depending on frequency.

Five substantially different technical concepts have been proposed for SKA, all of which are technically feasible and each of which offers technical, operational or cost advantages. A combined total of about M€ 50 is being expended for these studies. The remainder of this contribution summarizes these concepts, considers their distinctive properties and provides web addresses where additional information is to be found.

TECHNICAL CONCEPT DEVELOPMENT

To achieve the desired angular resolution, the total aperture of the SKA will be sampled sparsely. Individual antennas or clusters of antennas (termed 'stations') will be positioned across this aperture. These stations will be connected to a central processing unit by high-capacity glass fiber. The five concepts for the station antennas are being examined in detail by institutes around the world. These activities are being coordinated and evaluated by the International SKA Steering Committee (ISSC), which proposes to make a selection, or alternatively conclude that a hybrid construction is desirable, in 2005. The final choice of concept may also be closely involved with the selection of the location of the central portions of the array, which is therefore planned for the same period.

The five station concept development efforts may be summarized as follows:

1. Each station consists of a large reflecting surface installed in a naturally occurring depression, with the receiver system suspended from pylons at the edge of the depression. The Beijing Astronomical Observatory is pursuing this option, calling it the KARST (Kilometer square Radio Synthesis Telescope) project. A karst limestone region in Guizhou province in southwest China has been identified as suitable for the entire SKA and a pilot project to build a single antenna of this type is being planned (the Five hundred meter Aperture Spherical Telescope, FAST, project, to be the largest single dish antenna in the world). FAST will have an active mirror surface and an innovative mechanical system for controlling the positioning of the prime focus receiver system. More information is given at http://data.bao.ac.cn/bao/LT/ .

2. Each station consists of a large reflecting surface installed on nominally flat ground, with the receiver system suspended from an aerostat. The Dominion Radio Astrophysical Observatory is pursuing this option, calling it the Large Adaptive Reflector (LAR) project. The reflecting surface will be active and the aerostat will support a wide band array antenna feed system. Prototype systems are under development, with the aerostat recently having undergone its first flight. More information may be found at http://www.drao.nrc.ca/science/ska/ .

3. Each station is a cluster of coupled, small parabolic dish reflecting antennas, each of which is equipped with a feed and receiver system. Studies of this concept are being made at the SETI Institute and the Univ. of California's Radio Astronomy Laboratory. Six-meter Gregorian dishes are being designed for a fully operational prototype, the Allen Telescope Array. More information may be found at http://www.seti.org/science/ata.html . Studies are also being made at the National Centre for Radio Astronomy, Pune, which aim to build on the lessons learned during the construction of the Giant Meter Radio Telescope (GMRT). This design employs tensioned wires on a truss system to maintain the desired shape of the reflecting surface and promises to be very inexpensive at the expense of high-end frequency coverage. More information may be found at http://dhruva1.ncra.tifr.res.in/ska/ .

4. Each station is a cluster of radio *lenses*, based on the Luneburg lens concept and incorporating movable array antenna feeds, is being studied at CSIRO. This construction shows promise of being no more expensive that the small parabolic dish antennas but allowing at the same time simultaneous, full gain, multiple beams across the sky. Pilot lens antennas are being built and tested. More information may be found at the web-site: http://www.atnf.csiro.au/projects/ska/ .

5. Each station consists of an array of integrated antenna panels. Each panel consists of a collection of simple, all-sky antennas coupled such that beams are formed and steered electronically on the sky. A single panel may be considered to function as a number of parabolic dish antennas, each of which is independently steerable with full gain across the sky. This concept is the most advanced of those under investigation and has arisen from two considerations: (a) to move as far as possible to a fully electronic antenna, thereby moving onto a cost-curve that (unlike the other designs) should continue to decrease with time for the foreseeable future; and (b) to exploit fully the unique features of radio signal detection, whereby interferometric signal combination may occur after signal registration, and copies of the signal come essentially noise-free. The European SKA Consortium is pursuing this concept and a series of demonstrator antennas has been constructed at ASTRON. A fully operational low frequency telescope (LOFAR) that incorporates many of the relevant system design features is being developed at ASTRON, MIT and NRL. More information may be found at the respective web-sites: http://www.astron.nl/ska/ and http://www.lofar.org .

EVALUATION OF CONCEPTS

As practical experience is gained with the pilots and prototypes currently under development, the different design concepts may be compared for functionality, cost and commercial interest. Several tentative conclusions have already been reached.

The first three concepts are clearly the most mature. The first two (large, fixed, active antennas) also show the most promise of being able to provide the desired frequency coverage in a single antenna concept. All three concepts suffer from the high cost of steel and movable mechanical structures, although if the cost of cryogenic refrigeration of the first stage amplifier can be greatly reduced the third concept (array of small dishes) may be an interesting way along the road to affordability possibly at the expense of the lowest frequency range. The first concept suffers from limited sky coverage and is restricted in any case to the few places in the world where large approximately spherical depressions occur naturally (although the Guizhou site area extends over several hundred kilometres). Both of the first two concepts require additional R&D to demonstrate adequate controllability and stability of the positioning and focusing of the receiver sub-systems. Finally, an important disadvantage of all of the first three concepts is their inability to provide many simultaneous and independently steerable measurement beams over the sky, thereby greatly reducing operational efficiency for many scientific problems.

The radio lens approach addresses most of these problems. For example, by employing multiple, independently positioned receivers on the focal surfaces of the individual lenses, it should be possible to provide multi-beaming over the sky. Several important risk areas remain to be investigated, however, including the uncertain cost of manufacturing, the attenuation through the lens at the higher frequencies, and the mechanical support of the large dielectric spheres (which are likely to weigh over a thousand kilograms each).

While the most advanced, the fifth concept is also the least mature. Fully electronic beam formation provides the greatest signal processing flexibility and most scope for true multi-beam operation and adaptive interference suppression [e.g. ref. 1]. Unfortunately, these advantages are accompanied by large uncertainties deriving from the need to highly integrated design. That is, very large numbers of element antennas are required and the necessary cost reduction, to be achieved by integration onto silicon of both the front-end and subsequent processing electronics, remains to be demonstrated. In addition, the design does not lend itself easily to modular upgrade in the future. While in principle feasible, the initial non-recoverable R&D costs promise to be substantial. On the other hand, the concept is readily adaptable to commercial exploitation and may expect to benefit from the substantial R&D currently under way in the telecom and information technology sectors. The cost of manufacturing is likely to scale as the highest frequency squared, leading to consideration of employing this concept for the lower frequency range of the SKA – for research on neutral hydrogen in the early Universe, say, where the signal processing advantages are perhaps also the most needed.

ORGANIZATIONAL ISSUES

Two issues relating to the international organization of the SKA project are currently being addressed.

First, the requirement for access to the radio spectrum across a wide and essentially contiguous range of the radio spectrum conflicts with the plans of the global satellite personal telecommunications industry greatly to increase the number of communications satellites in low Earth orbits. The various down-links of such systems could become a major problem for the SKA if there are multiple constellations of satellites filling the sky at any given time. The matter has received the attention of governments and the OECD is sponsoring a Task Force on Radio Astronomy and the Radio Spectrum that has brought together satellite telecom experts, astronomers and government spectrum regulators to seek a solution. The Task Force expects to make its recommendations to governments in mid-year 2002.

Second, large research infrastructures similar to the SKA have previously been realized on a national basis or through regional cooperation. The organizational structures for a truly global project are not yet in place. Following discussions with government science policy experts at the Global Science Forum of the OECD, the ISSC proposes to submit simultaneously late in 2003 to all participating governments a management plan for the project and a proposal to begin discussions of how the project can best achieve its organizational goals.

References:

[1] A. van Ardenne, B. Smolders, G. Hampson; "Active Adaptive Antennas for Radio Astronomy; results of the initial R&D program toward the Square Kilometre Array", Proc. SPIE Conf. 4015 Radio Telescopes. Ed. H. Butcher, Munich, March 2000.