The Square Kilometre Array - An Australian Perspective

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The Square Kilometre Array (SKA) is a next-generation radio telescope expected to be completed by 2015. With 1 million square metres of effective collecting area, it will be 100 times as sensitive as the biggest present-day telescopes and deep-space network earth stations.

The extraordinary sensitivity of the SKA will enable astronomers to see to great distances, corresponding to a time only 1 million years after the Big Bang. With these observations it will be possible to see the formation of the first structures, such as galaxies and stars. Unlike today's Universe, where material is re-cycled continuously in complex cycles of explosions and collapses, the early Universe is pristine, giving cosmologists and astrophysicists their clearest glimpses of the formative processes and, by extension, the best clue about the eventual fate of the cosmos. Many early Universe studies will be unique to the SKA and flow from its capacity to see the weak, highly Doppler-shifted, quasi-CW, radio emission from hydrogen - the most abundant element in the Universe.

Of course, a telescope as powerful as the SKA has an almost limitless number of other applications, and a particularly important one is the study of pulsars in the Milky Way and nearby galaxies. Pulsar observations have already given us the best checks of General Relativity and SKA observations will allow still better tests of our fundamental physical laws. The observations also offer the promise of detecting the ultra-low frequency gravitational radiation which may permeate the Universe.

Table 1 shows some technical goals for the SKA and, apart from the enormous sensitivity, one of the most exciting prospects is the the capacity to observe many parts of the sky simultaneously, with perhaps 100 separate beams. Many astronomy, radio science and space communications programs will be conducted simultaneously - a huge improvement in effective information rate and efficiency compared with current instruments.

Table 1 - SKA Major Specifications

Parameter	**Design Goal**
Sensitivity	Effective Area/System Temperature = 2×10^4 m^2K^{-1} (or 68 dB K^{-1})
Frequency range	f = 0.2 to ≥ 12 GHz
Number of simultaneous beams	~ 100
Field of view	1 degree square at 1.4 GHz
Angular resolution	0.1 arcsecond at 1.4 GHz
Instantaneous bandwidth	0.5 + (f/5) GHz
Number of spectral channels	10^4

To achieve its performance goals within a $1 billion budget, SKA designers plan to exploit the convergence of radio and computing technologies. Despite formidable challenges in antenna and RF engineering, the SKA will be largely a software defined telescope, with many functions previously performed in dedicated hardware being allocated to general-purpose computers or programmable signal processing engines.

Australia has a lead role in an 11-member international SKA collaboration. Recently, an Australian SKA Consortium Committee was established, with the intention of co-ordinating research in this country and making the world aware of the advantages which Australia offers as an SKA host. Many of these advantages flow from our low RF interference levels, technological sophistication, and political stability. Australian researchers have, in fact, been the first to begin site tests in earnest and first results from rural Western Australia are encouraging. These tests will be extended to other parts of the continent as funding permits.

There are many concepts for the SKA, with ideas ranging from a collection of very large reflectors built in natural land depressions (like the Arecibo radio telescope) to many thousands of small satellite TV receiving dishes. Whatever the actual antenna element, the overall SKA layout may look something like that shown in Figure 1. Hundreds of stations equivalent in collecting area to perhaps a 100 m dish will be distributed across a 2000 km extent, the largest station separations giving the angular resolution needed to distinguish the many new radio sources detected by the SKA.

Perhaps the most novel suggestion for collecting elements has come from CSIRO researchers. Figure 2 shows an SKA station based on Luneburg Lens antennas, the operation of which is depicted in Figure 3. While CSIRO and its industry partners are addressing formidable materials issues governing cost and RF loss, the Luneburg Lens approach promises wideband, high-efficiency, multi-beaming across a large fraction of the sky.

To verify electro-magnetic design and analysis techniques and software, CSIRO has recently obtained a 0.9 m diameter lens from a Russian manufacturer. Figure 4 shows this lens under test. While first results are excellent, mass production of the antennas will require new low-cost artificial dielectrics; these materials have many other applications in electro-magnetic engineering and a number of manufacturing approaches are now being developed in Australia.

An important complementary line of research involves refinement of phased array antenna concepts. Phased arrays are an integral part of CSIRO's thinking so far as focal surface arrays ("radio retinas") for Luneburg Lenses are concerned. However, if lens costs prove too high, the arrays themselves may be viable as SKA primary receptors. This option is currently being explored by Dutch and Australian workers. The main challenges relate to making efficient, wideband, elements with low manufacturing cost and negligible area projection and scan blindness effects.

Where does Australian SKA research stand? Recently, groups from the CSIRO, University of Sydney and Swinburne University of Technology were successful in obtaining SKA funding of order $18M under the Federal Government's Major

National Research Facilities (MNRF) scheme. Half of this amount will in fact be supplied by the main proponents themselves, and by initial research partners such as Advanced Nano Technology P/L, CEA Technologies P/L and the WA Government.

The aim of the funding is to enable Australia to build technology demonstrators suitable for evaluation by international assessors in the period 2005-2007, the same timeframe for choosing an SKA site. The proposed "smart" demonstrators make full use of existing, advanced, radio telescopes operated by CSIRO and the University of Sydney. Proof of new radio science concepts in the context of an operational telescope confers great advantages and should compensate for a lower demonstrator budget than that of complementary international projects, such as the privately-funded Allen Telescope Array in the USA.

While initial, independent, studies of the SKA project show the economic viability of a projected $100M Australian investment, simple studies to date have not accounted for the huge potential returns in areas such as national infrastructure, technology R&D, and human resource development. An obvious infrastructure example flows from Figure 1 (and the associated trans-continental separation of some additional antennas). SKA station-to-station optical fibre links will have large spare capacity and offer selected regions great advances in communications infrastructure. Similarly, looking at the benefit/cost ratios of previous astronomy projects, such as the Australia Telescope to, for example, the satellite earth station industry, makes it clear that a project as ambitious and novel as the SKA has much to contribute to the technology base of the Nation.

More information on the SKA, including a booklet outlining some of the engineering challenges, is available on the Web at http://www.atnf.csiro.au/SKA The booklet also gives a brief overview of new, commercially interesting, Australian research in areas such as active RF interference mitigation techniques; wideband, low-noise, amplifiers based on monolithic microwave ICs; and fast (8 Gs s^{-1}) signal quantizers. As the SKA project gains momentum, the Australian consortium is keen to forge alliances with commercial and other partners interested in sharing R&D opportunities flowing from this exciting endeavour. One national science and engineering symposium was held in February 200 and a second gathering is scheduled for October; details will be posted on the Web site as they become available.

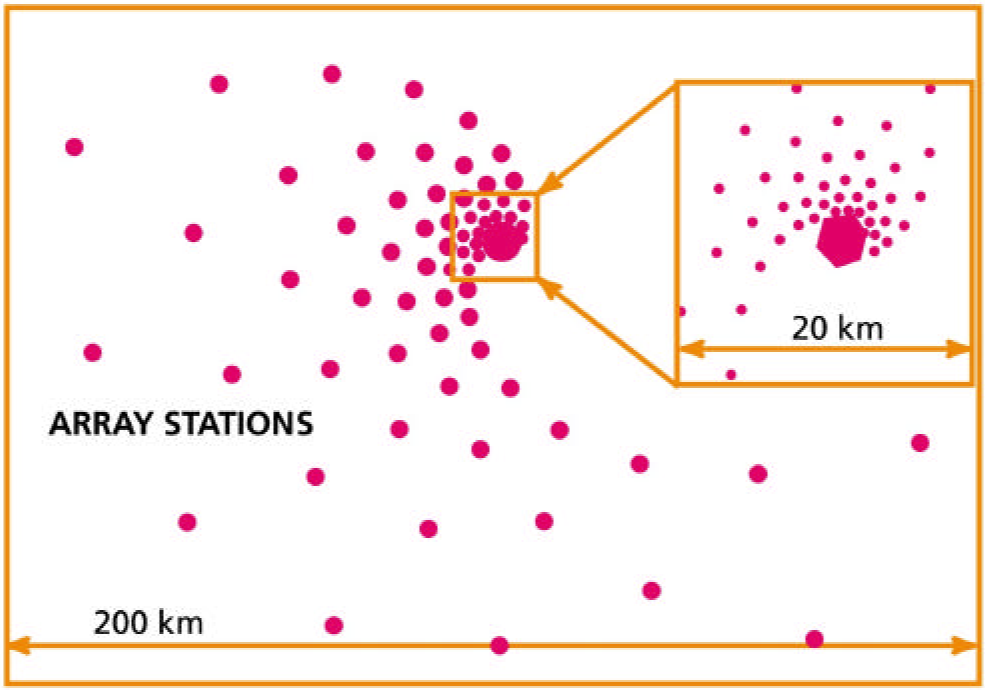


Figure 1. A possible layout for the SKA. The central core of the instrument will be quite dense: half the antennas will be within the central 2 km. A few very distant stations, located up to 2000 km from the central site, will also be included. The "log-spiral" configuration shown is economical to connect and gives good astronomical imaging performance.

Credit: Ben Simons, Sydney VisLab

Figure 2. Artist's impression of an SKA station composed of 400 Luneburg Lens antennas, each 5 m in diameter. The station has the same collecting area as a 100 m diameter dish, but can form many simultaneous, widely-spaced, beams on the sky. More than 100 such stations would be required for the SKA.

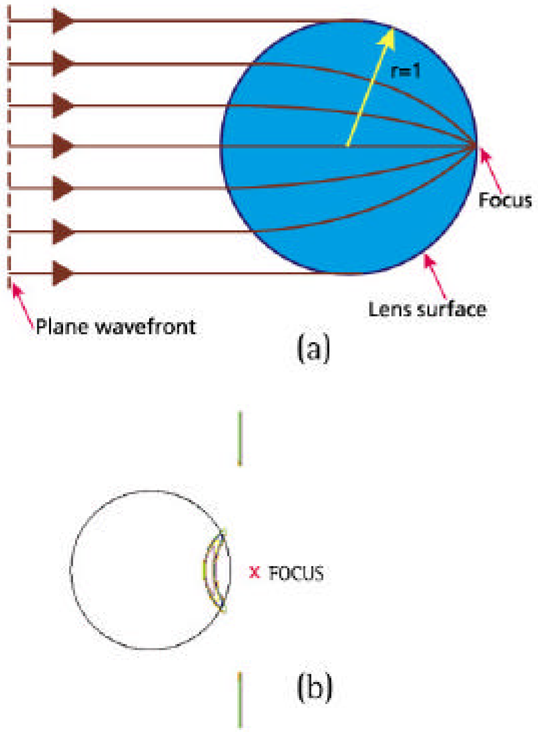
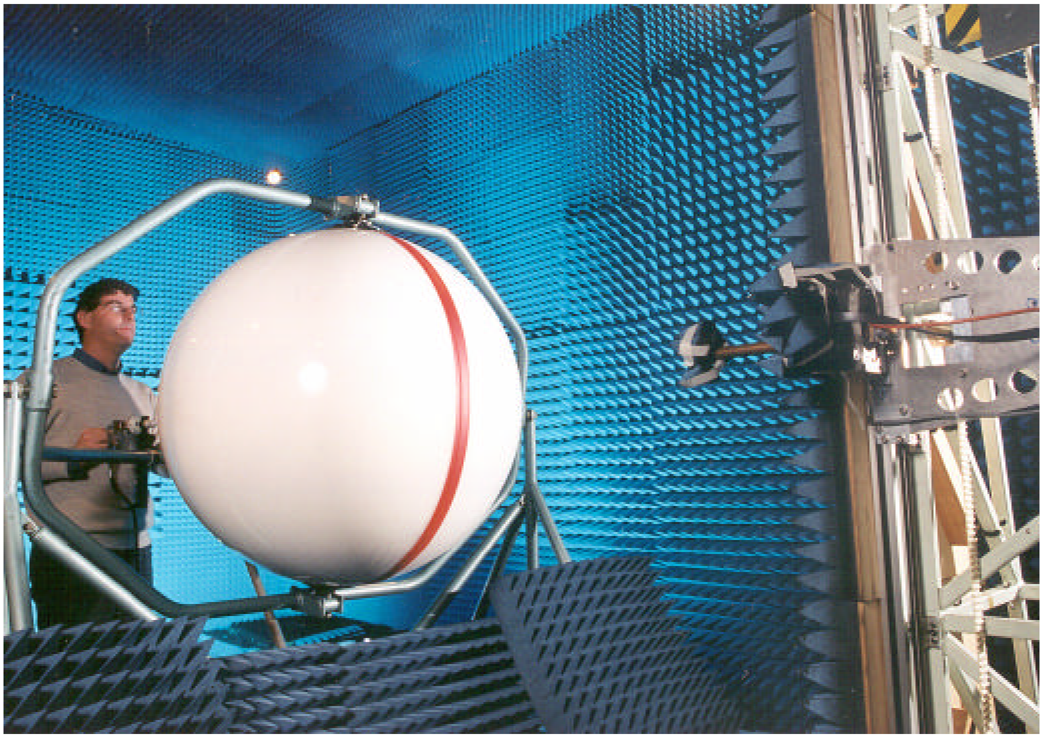
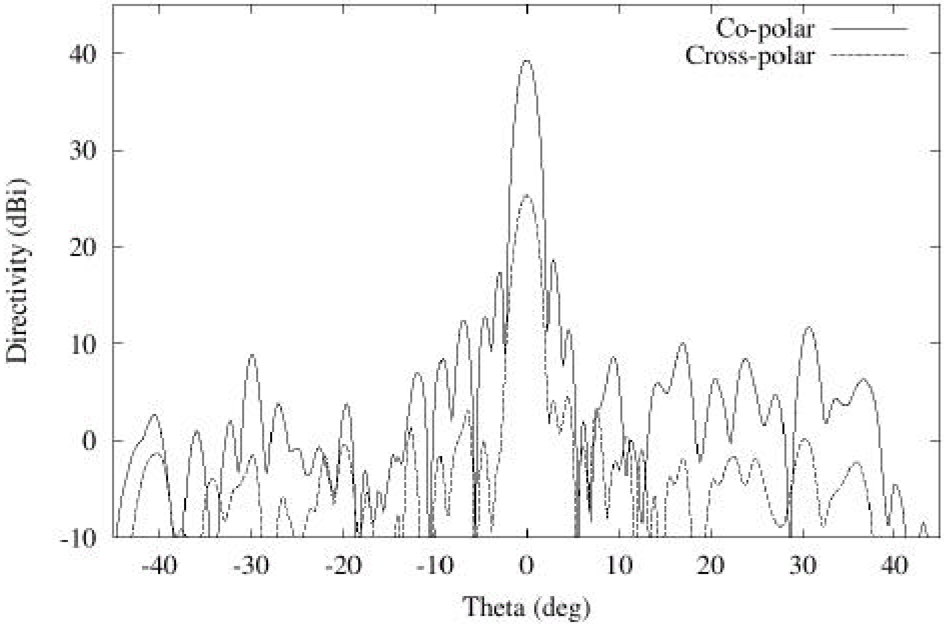


Figure 3. (a) Luneburg Lens beam forming. The lens has a radially-graded refractive index producing, in the classical case, a focus on the surface. (b) Focussing action of a 1 m lens on 600 ps gaussian pulse (1/T ~ 1.7 GHz) incident from the left. Note the retardation of the wavefront in the central region of highest refractive index. In this case the focus is displaced from the surface, making feed arrangements somewhat easier. (FDTD electric field image courtesy A. Parfitt, CTIP).



Credit: David Smyth

(a)



(b)

Figure 4. (a) 0.9 m diameter Luneburg Lens made by Konkur Ltd, a Moscow company, under test at CSIRO's near-field test chamber, in Sydney. (b) First derived far-field pattern obtained using a consumer-grade satellite TV feed at 12.75 GHz.