



xNTD and the Path towards the SKA

Lister Staveley-Smith

School of Physics, University of Western Australia, M013, Crawley, WA 6009, Australia

Abstract. The CSIRO-led eXtended New Technology Demonstrator (xNTD) will test key SKA technologies whilst delivering exciting science outcomes in the fields of HI surveys, gaseous evolution, galactic magnetism, pulsars and transients. The xNTD and its sister telescope, the MIT-led Low Frequency Demonstrator (LFD), build on technologies developed by the Sydney University SKA Molonglo Prototype (SKAMP) and the CSIRO New Technology Demonstrator (NTD). The science and technology goals for the xNTD are outlined, and the implications for SKA science and technology development are discussed. The xNTD is at least an order of magnitude faster for HI surveys than existing instruments, making it a powerful instrument for gathering data on large samples of galaxies with the aim of complementing extensive infrared and optical surveys, and pushing the redshift range for the detection of substantial numbers of galaxies to $z \sim 0.5$. Together, the xNTD and LFD are excellent demonstrations of SKA science and technology over a significant fraction of the SKA frequency range.

1. Introduction

The Square Kilometre Array (SKA) is an ambitious scientific project designed to tackle fundamental problems in cosmology, galaxy formation, planet formation, as well as to perform stringent tests on the theory of general relativity. The scientific case for the SKA, as outlined in Carilli & Rawlings (2004), and as updated in these proceedings, is both powerful and extensive. It is therefore an expensive instrument which has many competing scientific requirements. However, it is expected that extensive use of new technologies, particularly in the signal processing domain, will allow the SKA to deliver high performance at moderate cost for a wide range of these requirements.

To aid the development of new radio telescope technologies, and to perform measurements not possible with existing radio telescopes, several groups have embarked on SKA demonstrators. Most of these are described in these proceedings. Some, such as the xNTD, SKAMP and the Karoo Array Telescope (KAT), are very much aligned with SKA development. Others, such the Allen Telescope Array (ATA) and Dutch LOFAR telescope, were developed for science goals that are, in part, different from the SKA but which nevertheless incorporate technologies that are cutting-edge and well-aligned with SKA technology requirements.

In this paper, I summarise recent Australian contributions to the SKA project concentrating, in particular, on the goals of the xNTD project and the technology contributions of the NTD and SKAMP projects.

2. Existing Australian SKA Demonstrators

For the last five years, a substantial amount of Australian effort has gone into development of new technologies for radio astronomy, with significant funding from the Major National Research Facility (MNRF) scheme and from

CSIRO. The following are some of the key developments in SKA-related technology development that have occurred:

- The development of wide bandwidth (4 to 8 GHz) FPGA-based FX spectrometers for the Mopra millimetre telescope and the Compact Array. The Mopra spectrometer has already been commissioned; commissioning for the Compact Array Broadband Backend (CABB) is expected in 2008.
- The development of a new SKAMP correlator (see below) of lower bandwidth, but designed to cope with a much larger number of antenna bay inputs. A continuum prototype has already produced astronomical fringes and images.
- Development of phased array line-feed modules for SKAMP.
- Disk-based recording systems for VLBI and the development of a software correlator available as a national facility at the Swinburne supercomputer. The first global VLBI experiment to use disk-based recorders and software correlation involved telescopes in Australia, South Africa, USA and Japan, and used three different recording formats (Horiuchi et al. 2006).
- Development and deployment of high frequency Indium Phosphide low-noise amplifiers for the Mopra telescope and the Compact Array. These devices offer high performance, but are reliable and cheap to replicate.
- Development of RF-CMOS ‘receiver-on-a-chip’ technology, essential for mass production of receiver electronics on large- N , small- D arrays and on Focal Plane Arrays.
- Design and prototyping of a lightweight Luneberg lens as an alternative to parabolic dish technology. Although found not suitable for SKA purposes, commercial applications are possible.



Fig. 1. The eastern antenna of the New Technology Demonstrator (NTD) located in Marsfield, Sydney. The NTD is a single-baseline interferometer designed to test Focal Plane Array (FPA) technology.

- Installation of the 2×14 -m New Technology Demonstrator, equipped with an ASTRON THEA tile (see below).
- Deployment of a radio frequency trailer at the Australian SKA candidate site at Mileura station.

2.1. New Technology Demonstrator (NTD)

The NTD consists of two 14-m antennas located at the CSIRO site in Marsfield for the main purpose of testing Focal Plane Array (FPA) technology in an interferometer (O’Sullivan 2006). For initial tests, two antennas from the decommissioned Fleurs Synthesis Telescope (Batty et al. 1986) were transported to Marsfield. One of the antennas was fitted with a THEA tile from ASTRON (Bij de Vaate & Kant 2002). First fringes were obtained in mid-2006, and first beam-formation was achieved later in 2006.

The sole purpose of the NTD is for technology demonstration. It is not expected that much astronomical science will be obtained because of the small aperture and its location in the interference-rich Marsfield area. However, it is a powerful test-bed for the xNTD and will enable the testing of better FPA technologies prior to implementation in a remote environment.

A picture of the eastern antenna, prior to the deployment of the FPA is shown in Fig. 1.

2.2. SKA Molonglo Prototype (SKAMP)

The Molonglo Observatory Synthesis Telescope (MOST) is a powerful widefield survey instrument (Bock et al. 1999) which was initially modified from the Molonglo Cross in 1978, and has been the subject of several upgrades since. The latest SKAMP project involves upgrades to feed, signal transport and correlator technology. These upgrades are complementary to those being developed in

the NTD project and emphasise differing aspects of SKA technology research, such as the feasibility of using cylinders for polarimetry, and the design of correlators with massive numbers of antennas (or antenna bays).

Although some of the design goals of SKAMP are not as ambitious as in other demonstrators, the scientific return of this demonstrator will be great, due to the massive area of the telescope – some $18,000 \text{ m}^2$, or 2% of the SKA area. Science goals include: HI absorption at high redshift; HI emission deep fields to $z = 0.3$ and beyond; high- z galaxies and OH megamasers; diffuse Galactic polarisation; and establishing a dense grid of rotation measures to explore Galactic and extragalactic magnetic fields.

3. Future Australian-hosted SKA demonstrators

The current generation of Australian radio telescopes and technology demonstrators is based at sites which have levels of RFI that, even with active RFI cancellation, would make it difficult to achieve the high levels of sensitivity required to achieve some of the SKA science goals. Future generations of instruments are therefore planned for Western Australia. With its extremely low population density, WA has many sites that are remarkably free from RFI. Measurements of a representative site at Mileura Station, west of Meekatharra confirm this, and have led to a high Australian site ranking by the International SKA Steering Committee.

To utilise these remarkably RFI-free sites, and to test the feasibility of remote operation on such sites, it is planned to build the next generation of Australian radio telescopes in Western Australia, close to recently tested sites.

3.1. eXtended New Technology Demonstrator (xNTD)

The xNTD is intended to be a mid-frequency telescope, (<http://www.atnf.csiro.au/projects/ska/xntd.html>) able to use the technologies developed in the NTD project, but having a much larger collecting area such that it will be able to produce world-class scientific outcomes. Currently, the technology of choice is FPAs located at the prime focus of an array of 12 to 15-m class antennas (see Fig. 2), with a nominal frequency range of 0.7 to 1.8 GHz. However, many technological challenges remain to be solved, even after NTD, for xNTD to be successful. These challenges include low-cost antennas, integrated receivers, correlation, data transmission and post-correlation processing, remote operation and the logistics of handling vast data volumes.

Assuming a total collecting area close to that of the Parkes 64-m antenna, Johnston (2006) lists some of the expected science outcomes which include: a massive HI galaxy survey ($\sim 500,000$ galaxies to $z \approx 0.2$); a continuum and polarisation survey ($\sim 600,000$) rotation measures; characterization of the transient radio sky; and a new pulsar survey. These goals are somewhat astounding given the limited scope of the xNTD array (0.3% of the SKA collecting area). They are mainly possible through



Fig. 2. An artist’s impression of the xNTD (or SKA) antennas, fitted with Focal Plane Arrays (FPAs). Image courtesy of CVA Film and Television, Perth.

the wide field-of-view of the FPA/antenna combination which allows deep integrations to be made of massive areas of sky (30-40 deg² planned).

If we define the ‘survey speed’ Q of a radio telescope as inversely proportional to the time taken to achieve a uniform sensitivity S across a given (large) solid angle of sky, and over a given bandwidth B then, when comparing different telescopes, $Q \propto \Omega(A/T)^2$ where Ω is the instantaneous field of view, A is the total collecting area, and T is the receiver temperature.

In the case of the xNTD, this gives rise to an improvement in Q by a factor of 26 over the Parkes telescope with its low-noise 21cm multibeam receiver (Staveley-Smith et al. 1996)! A summary of the speed comparison of xNTD with other existing, and other planned radio telescopes is shown in Table 1, reproduced from Johnston (2006). Note that Johnston also includes minor factors which account for antenna and correlator efficiency.

Although the parameters for xNTD as summarised above, and used in Table 1, are likely to shift significantly, the Table does illustrate the enormous power of the new technology.

3.1.1. HI Surveys

One of the prime uses for xNTD will be for HI surveys of varying depths. An all-sky HI survey with an integration time of around a year will be able to detect around half a million galaxies out to modest redshift of ~ 0.2 . Deep surveys in a single xNTD ‘pencil beam’ will detect fewer galaxies per unit of integration time, but will be able to detect substantial numbers of galaxies to redshifts of at least 0.5. These surveys go well beyond the 5000 galaxies detected by HIPASS (Meyer et al. 2006; Wong et al. 2006). The science drivers for such enormous samples include:

- Measurement of the HI mass function of galaxies, and its evolution from lookback times of ~ 5 Gyr to the present. Neither semi-analytic models or the current

- sparse ultraviolet and radio observations, are able to constrain the gas evolution of galaxies particularly well.
- Measurement of the large-scale structure traced out by gas-rich galaxies in order to locate the preferred sites for enhanced gas accretion and depletion, and to measure the ‘bias’ factor and its evolution with time for gas-rich galaxies.
- By overlapping with other recent and planned optical/IR surveys such as SkyMapper, SLOAN and 2MASS, important complementary information on the redshifts, neutral hydrogen content and internal dynamics of large galaxy samples will be provided.

With a limited total aperture, it is important to carefully optimise the xNTD antenna configuration. The SKA concept of having large amounts of collecting area distributed on all scales, from zero to many thousands of kilometres, is not available to a small demonstrator with a few dozen antennas. From the perspective of HI surveys alone, Staveley-Smith (2006) considers the competing requirements of shallow and deep surveys. Based on the desire, for surveys, to have a synthesised beam which is larger than the galaxy size (for optimum sensitivity), and on the desire, for studying galaxy properties, to have a high angular resolution (to aid identification and reduce confusion), a compromise of 30 arcsec is proposed. For such an array, with a Gaussian ‘natural’ beam to minimise sidelobes, this corresponds to a maximum baseline of around 2 km at a redshift of 0.2, or a frequency of 1.2 GHz.

3.2. Low Frequency Demonstrator (LFD)

The LFD is an MIT-led instrument designed to operate at the low-frequency end of the SKA spectrum, 80–300 MHz, using phased array technologies. Unlike the xNTD, where the phased arrays are placed at the foci of parabolic dishes, the LFD uses tiles of crossed dipoles placed on the ground as in Fig. 3. Each tile consists of a 4×4 array of dipoles.

The LFD will consist of approximately 500 tiles distributed in an array of diameter 1.5 km and having around 1% of the SKA collecting area. Such an array has enormous potential for the statistical detection of the intergalactic medium at the epoch of reionization (Morales et al. 2006), the study of solar outbursts and space weather (Salah et al. 2006), the study of diffuse Galactic emission, and the detection of transient radio sources.

The LFD will be constructed close to the Australian candidate SKA site, and close to the xNTD. Together, the two arrays are likely to be extremely useful in demonstrating the scientific potential of new technologies, the quality of the Australian candidate SKA site, and the feasibility of remote operation of complex instruments in such a location.

Table 1. A comparison of the ‘survey speeds’ (see text for definition) of different telescopes at 21cm from Johnston (2006). The higher the survey speed, the shorter it takes to execute a survey over a given solid angle of sky to a given sensitivity. The survey speed depends mainly on the total area of the array (which in turn is derived from the diameter of each element and the number of array elements N), the system temperature T_{sys} and the field of view (FOV).

Telescope	Diameter m	N	T_{sys} K	FOV deg ²	Speed (Q)
xNTD ^a	12-15	20-30	50	41	124
Parkes 21cm multibeam	64	1	22	0.58	4.8
ATCA	22	5(6)	35	0.38	0.6
VLA	25	27	33	0.29	7.4
GMRT	45	20(30)	70	0.09	1.8
Arecibo ALFA	300	1	35	0.014	22
ATA	6.1	350	50	5.0	126

^aFollowing Johnston (2006), xNTD line speed is calculated for a nominal array consisting of 20 dishes diameter of 15m.



Fig. 3. An antenna ‘tile’ from the Mileura Widefield Array – Low Frequency Demonstrator (LFD), early deployment array. Each LFD tile consists of a 4×4 phased array of crossed dipoles. Image courtesy of the LFD Early Deployment team.

4. xNTD/LFD Timeline and the SKA

Critical to timely development of the SKA is the timescale of the development of SKA technologies contained in the Australian and other international demonstrator projects. As of 2006, the timeline for LFD/xNTD and SKA developments is as follows:

2006	SKA reference design SKA site ranking
2007	LFD prototype
2008	LFD commissioning SKA preliminary design review
2009	6-antenna xNTD SKA site selection
2010	xNTD commissioning
2010	SKA Phase 1 construction begins
2014	Science with SKA Phase 1
2020	Full SKA operation

At this stage of early development, there are many uncertainties in the above timeline (for updates, see <http://www.skatelescope.org>). However, the timeline indicates the small amount of time between the development of the demonstrators and the start of construction of the SKA. In order for the SKA to be successful, not to be delayed, and to learn as much from the demonstrators as possible, it is important that the Australian, and other international demonstrators, are deployed as rapidly as possible, and with as much shared development as possible.

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