Australian SKA Concept Demonstration Activities

A Submission to the International SKA Director
by the Australian SKA Consortium

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Australian SKA Concept Demonstration Activities

1. Overview

Australia's SKA concept demonstration activities are aimed at demonstrating several key technologies highlighted by the SKA IEMT report of October 2003, i.e.

- Low-cost manufacturing methods for both concentrators and dense aperture arrays
- Sensitive, cheap, highly-integrated uncooled receivers
- Efficient and inexpensive broadband phased arrays
- Scaleable signal processors – including correlators – that demonstrate processing power, flexibility and connectivity issues
- Demonstration of interference mitigation techniques.

In addition, the Australian SKA concept demonstration program aims to explore and demonstrate issues associated with siting a next-generation radio telescope on a remote, very radio-quiet site, and will demonstrate the feasibility of a remote Australian site for the SKA.

The Australian SKA concept demonstration program is funded mainly by a Major National Research Facilities (MNRF) Program grant from the Australian Government, and by matching funds from CSIRO, Australian universities, the Australian Research Council, the Government of Western Australia, Australian Government departments, and industry. The Australian SKA R&D effort has a total budget of order A$35 million (~US$25 million) for the five-year period 2003-7, of which A$18 million comes from the MNRF grant and the remainder from other sources (including the salaries of those involved in the development work).

The concept demonstration program we outline below is already fully funded, with one exception. Additional Australian funding for the SKA New Technology Demonstrator (NTD) at a radio-quiet site (see Section 2.5), is currently being sought from CSIRO, the State Government of Western Australia and the Australian Research Council. The program is being put together in collaboration with MIT in the US, who plan to seek funds from NSF for the program as a continuation of their design and prototyping work on an array at low frequencies and its science objectives. This is based on the selection of WA as the optimum site for low-frequency astronomy by an international site evaluation process.

A project plan for the NTD program will be prepared by July 2004 and presented to the IEMT in time for discussion at the 2004 SKA meeting.

The main themes of the Australian SKA concept demonstration program are:

- Development of infrastructure and connectivity at a remote, radio-quiet site, and investigation of optimum signal processing techniques in a radio-quiet environment
- Demonstration of wide-band continuum and spectral-line imaging over extremely wide fields of view at frequencies up to 1.4 GHz

- Demonstration of scaleable signal processing, including powerful new correlators for existing telescopes
- Development of a sensitive, cheap, wide-band line feed as required by the cylindrical reflector SKA concept.

The Australian astronomy community considers it important that our SKA demonstration program also delivers new scientific capabilities, and to some extent this is also a requirement of our funding under the MNRF scheme. The science goals of the facilities to be built under the Australian demonstrator program are discussed briefly at the end of this report.

In 2003, Australia submitted white papers for two SKA concept designs: the Cylindrical Reflector and Luneburg Lens. Most of the Australian demonstrator program is not tied to any particular antenna concept, but we will continue technology development and prototyping for the Cylindrical Reflector SKA concept, with particular emphasis on demonstrating an efficient (uncooled) wide-band line feed and an ultra-wide (>50 square degree) field of view below 1.4 GHz. A review of the Luneburg Lens development program is scheduled for mid-2004, and (based on results to date) the likely outcome is that technical development of the Australian Luneburg Lens SKA concept proposal will not be further progressed at the moment. Commercial applications for Luneburg lenses will continue to be explored and developments in other areas embodied in the Australian Luneburg lens proposal will continue.

2. Australian SKA Concept Demonstration Project Plans

2.1 MMIC Development

Summary

This program will deliver components for inclusion in the various SKA demonstrators including the Australia Telescope Compact Array Broadband Backend (CABB), the SKA Molonglo Prototype (SKAMP), the NTD, and in other enhancements of ATNF instrumentation. These components will include high-speed digital devices for data sampling and transmission, broadband low noise microwave amplifiers and integrated receiver and beam-forming systems.

The program will support a number of Monolithic Microwave/Millimeter-wave Integrated Circuit (MMIC) fabrication runs, using technologies such as Gallium Arsenide (GaAs), Indium Phosphide (InP), Silicon Germanium and RF-CMOS.

The program currently includes the following specific components:

- An initial establishment period, where processes and techniques are investigated. This includes the procurement of suitable design tools and the setting up of contracts with integrated circuit fabricators in order to obtain detailed design information for processes of interest
- The development of wide-band LNAs, below 10GHz, using the Northrop Grumman (formerly TRW) InP process

- The development of ultra wide bandwidth amplifiers (>40GHz) as driver amplifiers for high bit rate digital photonic data transport, using the InP process
- The development of integrated receivers for a low frequency (<2GHZ) phased array antenna, using a RF-CMOS process
- The development of wideband low frequency LNAs using SiGe or GaAS processes.

Major Milestones

Date	Milestone
September 2004	Submit designs for integrated receiver prototypes
January 2005	Submit InP designs for fabrication
March 2005	Submit designs for integrated receiver assemblies
July 2005	First integrated receivers available for testing
July 2006	Final devices available for integration into demonstrators

Program Budget (from 2003/04)

Budget (A$k)	2003/04	2004/05	2005/06	2006/07
Total	795	935	900	330

2.2 Signal processing, connectivity and software correlators

Summary

This program (in which Swinburne University is the lead institution) will demonstrate:

1. Disk-based data buffering, fibre-based data transport, and real-time software correlation of long baseline interferometer data

Disk-based baseband recording systems have been developed and have been deployed to 5 Australian radio telescopes. These recorders have been used to buffer and transfer baseband data to a real-time software correlator for VLBI observations. It is planned to use this system with Gbps data links between at least 3 Australian telescopes (up to 400 km baselines), to demonstrate different data transfer protocols, buffering requirements, and processing algorithms of relevance to the SKA.

2. Precision pulsar timing using baseband processing in software

The Caltech Parkes Swinburne Recorder 2 (CPSR2) has been developed for precision pulsar timing studies and as a prototype instrument for pulsar studies using the SKA. CPSR2 is a cluster of 30 dual-processor server-class Dell PCs that collects 1 Gbps of baseband data from the Parkes radio telescope. The cluster processes these data in near real-time, including coherent de-dispersion of the pulsar signal. CPSR2 timing is proving to be extremely accurate on even low-flux radio pulsars.

In addition, a similar cluster of machines is being installed at the Australia Telescope Compact Array and will demonstrate pulsar timing observations using a phased array (6 antennas). The suitability of using phased arrays for pulsar timing, versus single dishes, will be explored.

Major Milestones

Date	Milestone
Dec 2002	Coherent Dedispersion system Operational
July 2004	Software correlator operational
July 2005	Fibre-based eVLBI demonstrated
July 2006	Real-time eVLBI routinely available
July 2007	eVLBI and pulsar (single dish and phased array) studies complete

Program Budget (from 2003/04)

Budget (A$k)	2003/04	2004/05	2005/06	2006/07
Total	400	300	300	300

2.3 Australia Telescope Compact Array Broadband Backend (CABB)

Summary

This program will demonstrate and investigate new signal processing technologies and their application to the SKA. It will deliver, by mid-2006, a new broadband backend system for the Australia Telescope Compact Array (ATCA) at Narrabri. The maximum bandwidth of the instrument will be increased from the current 128MHz to 2GHz, a factor of 16 improvement. This will improve the continuum sensitivity of the ATCA by at least a factor of four as well as providing a greatly enhanced spectral line performance, particularly at the higher observing frequencies.

Major Milestones

Date	Milestone
January 2002	Commencement of project – conceptual design
July 2005	Commencement of installation at Narrabri
July 2006	ATCA operational with new backend
January 2007	Broadband ATCA tied array operational

Program Budget (from 2003/04)

Budget (A$k)	2003/04	2004/05	2005/06	2006/07
Total	1053	1707	1807	300

2.4 The SKA Molonglo Prototype (SKAMP) program

Summary
This project is a joint venture between the University of Sydney and CSIRO, with the overall goal of upgrading the Molonglo telescope to be a world-class spectral line instrument, while at the same time developing technologies relevant to SKA. The new NTD project (see Section 2.5) will link closely with SKAMP and plans are being put in place to accelerate key elements of the SKAMP project, such as the linefeed development. Full details of resulting changes to the SKAMP Program deliverables will be available with the Project Plan for the NTD, due to be completed by July 2004.

The outcome from the SKAMP project will be a sensitive telescope equipped with a 2048 channel spectrometer capable of operating continuously over the frequency range 300-1400 MHz, with an instantaneous operating bandwidth of about 50MHz. The field of view will be several square degrees. The new technologies to be demonstrated are:

- Implementation of a wideband feed operating over the whole frequency range (this is the biggest technical challenge)
- Two stage beam-forming to give extremely wide fields of view
- Digital filter-banks operating at speeds above 100 M samples/sec
- The correlation of a large number of antenna stations providing high fidelity imaging and polarization capabilities
- Control, monitoring and data handling of approximately 100 antennas as a step towards the SKA
- Implementation of RFI mitigation strategies.

Major Milestones

Date	Milestone
Dec 2004	Completion of design for spectral-line correlator and polyphase filter bank. Commissioning of continuum correlator.
Dec 2005	Commissioning of spectral-line correlator
Dec 2006	Production and installation of broadband phased-array line-feed systems
Jun 2007	Commissioning tests on full system

Program Budget (from 2003/04)

The total funding for the SKAMP project (including A$230k spent in 2002/3 and A$300k in additional funding for line-feed development from outside the MNRF program) is A$2.1 million.

Budget (A$k)	2003/04	2004/05	2005/06	2006/07
Total	402	502	457	298

2.5 SKA New Technology Demonstrator (NTD) on a remote, radio-quiet site

Summary

The aim of this program (in which the CSIRO ATNF is the lead institution) is to deliver an SKA technology demonstrator with a collecting area of up to 3000 square metres, plus supporting infrastructure, located at the representative candidate Australian SKA site at Mileura Station in WA. There will be significant complementarity between the SKAMP and NTD projects, and production of a detailed project plan and budget for the NTD is still in progress. The Project Plan is being developed in collaboration with MIT in the USA as part of their continuation of previous array work at low frequencies. The joint aim is development of a wide Field-of-View low-frequency radio astronomy technology demonstrator on an optimum radio-quiet site. The WA technology demonstrator will be designed to be upgradeable to a larger collecting area if additional funds become available in the future.

The specific aims of the NTD are to demonstrate:

- Antenna, receiver, and backend technology to support wide field-of-view (FoV), wideband radioastronomy
- An operational facility at a remote radio-quiet site and the establishment of a radio-quiet reserve, to demonstrate the unique opportunities for radio science in an extremely low RFI environment
- Data processing/transport over long distances, and continent-wide and international connectivity
- Remote energy provision for SKA

- Environmental conditioning of radio astronomy equipment on a semi-arid remote site.

Major Milestones

Date	Milestone
July 2004	Project Plan completed
2007	Complete NTD

Program Budget (from 2003/04)

The project has current funding of A$3.5M, although formal approval from the Australian Government Department of Education, Science and Training and the Australian Astronomy Board of Management will be required to change the NTD program from its current goal of a demonstrator sited at Narrabri to a demonstrator sited in Western Australia. This approval will be sought in July 2004, when a full project plan/risk assessment is in place. Additional Australian funding is being sought for this program from CSIRO (through its Major Cross-Divisional Program initiative), the State Government of Western Australia and the Australian Research Council.

MIT plans to seek funds from the US National Science Foundation to enable their maximum participation in the joint development. ATNF and MIT are also exploring collaboration with other groups on this program.

2.6 Luneburg Lens development and testing

Summary

This program is investigating new materials technology for the mass production of spherical lenses with diameters of the order of a few metres, and is aiming towards a major project review in mid-2004. The program has completed development and testing of a prototype 1m lens. Based on the present results, the likely outcome of the review is that the Australian Luneburg lens proposal will not be progressed further at the moment as an SKA proposal. The project will seek funding for commercial exploitation of the technology and other areas embodied in the Australian Luneburg lens proposal will continue to be developed.

Major Milestones

Date	Milestone
Dec 2003	Delivery of prototype 1m lens to CSIRO test range in Sydney
April 2004	Complete test report on prototype lens
June 2004	Project review

Program Budget (from 2004)

Budget (A$k)	2004/05
Total	155

2.7 Development and testing of techniques for RFI mitigation

Summary

2.7.1 ATNF Developments

A large FoV with wide bandwidth and low angular resolution at the lower SKA frequencies is a combination of every aspect of radio telescope engineering science that is vulnerable to external interference. Hence it is essential that we not only demonstrate the value of an extremely radio quiet site, but also that we can demonstrate cost effective interference mitigation at such a site. We have ongoing funded activities in adaptive RFI mitigation in both the pre and post detection domain, and with both arrays and single dishes. These studies include real implementations on operating radio telescopes. We are also evaluating the design consequences in terms of cost to implementation. For this aspect it is essential to investigate radio quiet sites since the RFI mitigation that will still be needed for SKA will be cheaper and more effective.

We are also active in pursuing the political and social aspects of protecting the radio quiet environment at the demonstrator site.

2.7.2 Swinburne University Developments

Using the disk-based baseband recorders and clusters of PCs at both the Parkes radio telescope and the Australia Telescope Compact Array, we will undertake RFI surveys of both sites. We will aim to record baseband data from both single dishes and arrays and demonstrate a hierarchy of RFI mitigation techniques.

Major Milestones

Date	Milestone
July 2004	Demonstration of simulated RFI processing with software correlator
July 2005	RFI surveys at Parkes and ATCA complete
July 2006	Implementation of real-data RFI mitigation techniques with software correlator
July 2007	Real-time correlation of ATCA data with RFI mitigation

2.7.3 Overall Program Budget (from 2003/04)

This funding is largely from sources outside the MNRF program, in particular from the Australian Research Council through the award of Federation Fellowships to Profs Ron Ekers and Dick Manchester.

Budget (A$k)	2003/04	2004/05	2005/06	2006/07
Total	200	200	200	200

3. Collaborative work with international SKA partners

3.1 ATNF participation & links with projects PHAROS (EU FP6 RadioNet) and EMBRACE (EU FP6 SKADS)

The EU FP6 RadioNet project "PHAROS" will develop and test a generic prototype phased array receiver operating between 4 and 8 GHz suitable for use on a wide range of telescopes. The FPA will initially be tested on one of the Westerbork Array telescopes, and subsequently on the JBO 76m Lovell telescope. In the PHAROS contract we have left open the option for ATNF to build a similar FPA and test it on the Parkes (or other) telescope, with the ultimate aim of developing it into a useful user instrument. Another option for us is to have the EU PHAROS FPA to be shipped to Australia to be tested on Parkes or some other Australian infrastructure.

ATNF has committed 19.3 person months effort to PHAROS and is a self-financing partner within the EU project. ATNF has applied for funds from DEST's Innovation Access Programme (IAP) to support the collaborative work. The funding request is for A$210,000 and the outcome will be known in July 2004.

ATNF has committed manpower to SKADS in line with the SKA/NTD development activities already underway – e.g. signal processing, integrated systems development, site and infrastructure studies etc, providing key background 'enabling' technologies. Within SKADS are options for ATNF to be more heavily involved with the EMBRACE array. However the funding, manpower and logistics of this are yet to be determined.

3.2 International collaboration on developing a remote, radio-quiet site

As mentioned earlier, ATNF is exploring collaborations with overseas groups (most notably MIT) in progressing the establishment of a low-frequency and wide-field radio astronomy demonstrator in Western Australia. This extends already very productive collaboration between MIT and Australian groups on SKA simulations research and development.

3.3 Opportunities for international collaboration on SKA software

We note that software development and testing is likely to account for a significant fraction of the cost of most SKA demonstrators, and urge the IEMT to investigate ways in which these costs could be reduced by collaboration between groups. For example, to what extent could the control software currently being developed for ALMA be modified to work for SKA and SKA demonstrators?

4. Collaborative work with Australian industry

The Australian SKA community is working with a number of industry partners on SKA R&D, for example:

- Argus Technologies (Australia) Pty. Ltd. specialise in antennas for mobile communications. They are collaborating on the development of a wideband phased array feed for cylindrical reflectors, carrying out development and testing of prototype array elements.
- Connell Wagner consulting engineers have made a significant contribution to SKA site development and to the Luneburg lens project, and are further contributing to the development of the NTD in the areas of mechanical design and energy.
- CEA Technologies Pty. Ltd. develop advanced phased array systems, and are partners in the MNRF program with significant expertise in the manufacture of modular antenna arrays.
- Advanced Powder Technology Pty. Ltd. are manufacturers of specialist nano-powders who have supplied advanced materials to the Luneburg lens development program.

5. Science goals of the Australian SKA demonstrators

In general, the science returns from the Australian SKA demonstrator program will come from adding new capabilities to existing telescopes, rather than from building large amounts of collecting area. The reasons for this are economic – the total collecting area of existing Australian radio telescopes is almost 6000 m^2 for the national-facility telescopes (2300 m^2 for the ATCA and 3200 m^2 for the Parkes dish) and 18,000 m^2 for the Molonglo telescope (which currently operates in a narrow band centred at 843 MHz). To build an equivalent or larger amount of new collecting area (say 25,000 m^2) would cost at least A$12 million, even at the low cost envisaged for the SKA (of order US$500 per square metre if the goal is to build a one million square metre telescope for US$1 billion and the antenna cost is assumed to be half the total budget).

An exception is the proposed NTD, the Australian antennas for which, at 1.4 GHz, will have a collecting area similar to the Parkes radio telescope, but a much wider field of view (50 deg^2 at 1.4 GHz, compared to 0.06 deg^2 for the Parkes primary beam and 0.8 deg^2 for the 13-beam Parkes Multibeam receiver at the same frequency). The NTD's high survey speed, made possible by its wide field of view, will make it a valuable new facility for the astronomy community as well as an SKA technology demonstrator.

The new broadband correlator for the ATCA will provide a powerful capability for both imaging and spectral-line work over a broad frequency range (1-100 GHz). Its main science goals include deep continuum surveys in targeted areas and surveys for C0 1-0 line emission from high-redshift galaxies.

The SKAMP project will provide a new low-frequency spectral-line facility in the southern hemisphere, building on the existing Molonglo Observatory Synthesis Telescope (MOST). The main science goal is the study of high-redshift HI as seen in absorption against background radio galaxies and quasars. SKAMP is also likely to be a powerful survey instrument for pulsar searches and Galactic science.

A prime science goal for the NTD is an all-sky HI emission-line survey of galaxies out to a redshift of z~0.07 (or about three times the typical redshift detected by the Parkes HI multibeam survey). The NTD survey should detect up to 100,000 galaxies in one year of observing, and would be well-matched in depth to the optical 6dF Galaxy Redshift Survey of the entire southern hemisphere (6dFGS) currently being carried out with the AAO Schmidt telescope. The fast mapping speed of the NTD also allows a galactic HI survey to be made. A deep HI survey at intermediate Galactic latitudes would complement the completed Galactic plane survey, with the aim of studying the disk-halo interaction and searching for high velocity clouds.

With a large collecting area in the west of the continent, the NTD could be combined with the existing eastern Australian radio telescope antennas to carry out eVLBI, with a sensitivity of 11 μJy/beam in 12 hrs for imaging.

High-resolution observations of pulsars would yield up to 100 proper-motion measurements. A pulsar survey is envisaged to exploit the wide FoV capability of the NTD. The sensitivity per unit time would be 2-3 times better than the Parkes multibeam survey, which should allow the NTD to uncover of order 1000 new pulsars.

The scientific goal of the signal processing, connectivity and software correlator demonstration program is to develop a VLBI array of at least three Australian telescopes that will transfer and correlate data in real time. This system will ultimately provide a factor of three sensitivity increase over the current Australian VLBI system, and will have a very short response time. The scientific goals of this system are therefore: to investigate transient phenomena such as GRBs and X-ray binary systems; undertake high-sensitivity, high-resolution surveys of compact extragalactic radio sources; and perform novel pulsar VLBI observations that are not possible with any other VLBI system in the world

6. Budget summary for the Australian SKA concept demonstration program

We provide here a summary of the currently-funded Australian concept demonstration program. As noted earlier, the main source of funds is the A$18.4 million (including cash and in-kind matching funds from the partner institutions) MNRF grant awarded for SKA research and development.

Other funding comes from a variety of sources, including ~$1 million which flows from grants awarded by the Australian Research Council (for RFI studies and development of a prototype wide-band line feed) and in-kind funding provided by industry partners like Connell Wagner (mainly for infrastructure-related projects). Since it was not possible to provide a complete audit of all funding on the timescale required for this report, we simply note that the MNRF grant is our major source of funding and give an outline of how we plan to spend this money (with items rounded to the closest A$0.1 million).

Past Expenditure 2002-3

Luneburg lens development and testing	A$ 2.0 million
Site surveys and RFI testing	A$ 0.8 million

Planned Expenditure 2004-7

MMIC development	A$ 3.0 million
ATCA broadband backend	A$ 4.9 million
NTD	A$ 3.5 million
SKAMP	A$ 1.7 million
Swinburne-based projects	A$ 2.1 million
Luneburg lens 2004	A$ 0.2 million
EU collaboration	A$ 0.2 million

Total A$ 18.4 million

7. Contact details and web pages

This report has been compiled by a subcommittee of the Australian SKA Consortium Committee comprising:

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The web page for the Australian SKA Consortium (ASKAC) is at www.askac.org. The current ASKAC Chair is Dr Bob Frater, and the Executive Secretary is Dr Michelle Storey (Michelle.Storey@csiro.au).