Annexure A to Participation Deed

Outline statement of work, deliverables, and schedule of MNRF payments to the University of Sydney.

SKA Molonglo Prototype Project Plan

Project Leader: Anne Green, Sydney University
Participating Organisation:

- *Sydney University*
- *CSIRO ATNF*
- *CSIRO ICT*

Executive summary

In line with the priorities identified in the 2001 mid-Term Review of Australian Astronomy, to develop enabling technologies to strengthen Australia's case to host the SKA, this project is a joint venture between the University of Sydney and CSIRO, entitled the SKA Molonglo Prototype (SKAMP) project. Its overall goal is to upgrade the Molonglo telescope to be a world-class spectral line instrument, at the same time developing technologies of relevance to SKA. It has the following specific aims:

1. Demonstrate SKA-relevant technologies, particularly relating to ultra-wideband line feeds for cylindrical geometry antennas, wide field-of-view imaging and high-speed digital signal processing.
2. Provide a new low frequency spectral-line facility in the southern hemisphere, building on the existing Molonglo Observatory Synthesis Telescope (MOST), which is owned and operated by the University of Sydney.
3. Undertake supervision and training of postgraduate students as an essential contribution to producing scientists and engineers to design and use the next generation telescopes.

Not all of the SKAMP project is included in this MNRF project.

1 Overview

1.1 Context and Significance

Both the location and the technology for the next-generation Square Kilometre Array (SKA) telescope are still to be decided. Australia has an excellent case for being selected as the site of the SKA. To help capture a share of the $2b SKA program for Australian industry, we need to use the current MNRF program to demonstrate a credible concept for the technology of the SKA itself. The SKAMP project provides the opportunity to test and evaluate the cylindrical reflector concept for the SKA, and to lead into the next stage of advanced prototypes, which will be an excellent strategic pathway to gaining funding for a full SKA in 2010-12. A second major outcome for the SKAMP project will be the commissioning of a powerful new low-frequency facility for radio astronomy in Australia.

Funding received from the ARC Research Networks, the RFI mitigation project and the development with industry of an ultra-wideband feed system for a cylindrical antenna are all external to the MNRF program. However, the research objectives and outcomes are all well-aligned with no duplication of resourcing. In addition, ARC funding has been received for 2004 – 2006 to support the operation of MOST with the science goals of studying the properties and history of star formation in the Milky Way Galaxy. This project will run in parallel with the SKAMP development and will complement the project by providing simultaneous images for close comparison and verification of positions and flux densities.

2 Scope of the SKAMP Project

The outcome from the SKAMP project will be a sensitive telescope equipped with a 2048 channel spectrometer, operating continuously over the frequency range 300—1400 MHz, with an instantaneous operating bandwidth of about 50MHz. The potential angular resolution of the telescope will range from 26 to 126 arcsec (provided that the entire length of the telescope is fitted with the new feed structure), with a sensitivity of between 0.02 and 1 mJy/beam. 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 LOFAR and the SKA

To achieve these outcomes, the project has been divided into five stages, which can proceed largely in parallel.

Stage I – a continuum correlator (partially included in this MNRF project)

The first stage of the project is the construction and installation of a 96 station continuum correlator, with 3 MHz of bandwidth centred at 843 MHz (the current operating frequency of the MOST). This system will be used with the existing front-end feeds and signal pathway of the MOST. The goal is to prove high dynamic range imaging with correlation processing, in parallel with the existing data acquisition systems. Simultaneous observations will allow precise verification of the new signal pathway and continuation of the current science programs, the Sydney University Molonglo Sky Survey (SUMSS) and the Galactic Plane Survey. All of Stage I is included in the MNRF project with the exception of the hardware and software design of the correlator, which will be funded from a University of Sydney Sesqui R&D grant.

Stage II – a spectral-line correlator (included in this MNRF project)

The second stage of the project is the development and construction of a 2048 channel spectral-line correlator, centred on 843 MHz. This stage will use the existing ring antennas (which determine the 30 MHz bandwidth for this stage of the project) with a new local oscillator, timing, signal distribution, and full optic fibre feeds to each of the 88 independent bays of the telescope. It is planned to digitise the signal at the telescope focal plane using an integrated circuit for the mixers, RF filters and samplers. A new 2048 channel polyphase filterbank will input to the correlator, which is a scaled-up version of the Stage I correlator. The entire 1.6 km of the cylindrical reflector will be fitted with new mixers and samplers for one low-noise amplifier (LNA) per independent bay. The present restriction to one hand of circular polarization will remain for this stage. For operation of the MOST under its previous configuration, 4 LNAs are added together for the illumination of a bay. The configuration for Stage II will reduce the effective collecting area of the telescope. However, the consequent reduction in sensitivity is largely offset by the ten-fold increase in instantaneous bandwidth.

Stage III - increase the tuning range (included in this MNRF project, with the exception of the line feed design)

The third stage of the project will produce a 300—1400 MHz continuous spectral line capability, although the instantaneous bandwidth will be limited to about 50 MHz (by the bandwidth associated with the signal processing). This will not compromise the proof of concept for the SKA demonstration, as a new contiguous broadband line feed will be developed and installed on a section of the array as the key new technology (this feed development is funded by the ARC and is not part of this MNRF). What fraction of the 1.6 km is converted is still to be decided. The feeds will be combined in 8-element sections, with two new low cost LNAs for every element, for full polarisation capability, to minimize the system noise. It is proposed that the beam-forming, low cost LNAs and digitization circuits will be combined into a sandwich structure, located behind the line feeds, up on the telescope structure. Detailed designs for this stage are under development and may be changed to capitalize on new technologies released to the commercial market. There is also close collaboration with the element combination developments being undertaken at CSIRO.

Stage IV – develop new solutions for transferring broadband digital data (not included in this MNRF project)

SKAMP will trial high-speed, fibre-linked data acquisition as a testbed for both the advanced SKA prototype and for the planned LOw Frequency ARray (LOFAR). To expedite the linkages and promote the advancement of skills across countries and disciplines, we have submitted an application for seed funding under the new ARC Research Networks initiative. The fibres themselves will have already been installed under phase II of the project, and what is being developed in this project is novel digitisation, optoelectronics, and broadband data transfer techniques.

Stage V – RFI mitigation (not included in this MNRF project)

For a telescope as sensitive as the SKA, the growing levels of radio frequency interference (RFI) across much of the radio spectrum have to be tackled. Smart solutions in RFI mitigation are required, and the challenge for the SKAMP project of the planned siting of the operational Headquarters of the Defence Department only a few kilometres from the telescope has provided the impetus for a joint research project. The success of this RFI mitigation project will be an important test for astronomers to manage the interface with Australia's national interests. We will seek funding from Defence and elsewhere to establish a small research group to develop mitigation tools over the period 2004-2006.

2 Goals

The goal of the SKAMP project is to build a new low frequency spectral-line facility onto the existing MOST. This will be achieved from the design and construction of a 2048 channel spectrometer, polyphase filter-banks and dual-stage beam-forming systems, and a wideband line feed, to enable observation of the sky continuously over the frequency range 300 – 1400 MHz.
The project will also train young engineers for next generation radio telescopes.

3 Major milestones

The goals and milestones are listed under Section 4 in the Table showing timelines and budgets.

4 Timelines and budget

Each section in this Table represents the achievements anticipated for each year of the project. Each row within a section details particular goals and milestones. The last three columns show respectively the in-kind contribution and the cash contribution from the University of Sydney, and the cash that the SKAMP project will use from the MNRF program.

Milestones associated with the ARC Discovery Grant to develop a wideband feed, and the relevant associated funds, are not given in the following Table as they are not directly part of the MNRF program. The funds for this and a related University of Sydney Sesqui R&D Grant (2002) are listed in the Annual Financial reporting under "Other Sources".

Year	**Date**	**Stage**	**Milestones & Goals**	**Contrib.** In-kind ($'000s)	**Contrib.** Cash ($'000s)	**MNRF** Contrib. ($m)
02/03	Jul 2002 Sep 2002 Jan 2003 Mar 2003 Jun 2003	I I III II	Appoint SKAMP Site Manager Design concept for continuum correlator Specify wideband feed project Build infrastructure & isolate signal pathway Update SKA scope of project document	127.5	90.0	0.0
03/04	Dec 2003 Mar 2004 May 2004 Jun 2004 Jun 2004	I I II I	Test continuum correlator design Appoint RF Engineer Design concept for spectral-line correlator Fringes from 96-station continuum correlator Update SKAMP scope of project document	131.0	90.0	220.0
04/05	Sep 2004 Dec 2004 Mar 2005	II II II	Complete design for spectral line correlator Design for polyphase filterbank complete Design concept for LO/IF & samplers			

	May 2005 Jun 2005 Jun 2005	II II	Filters and correlator boards manufactured Optic fibre installation implemented Update SKAMP scope of project document	134.5	90.0	210.0
05/06	Sep 2005 Oct 2005 Dec 2005 Jun 2006 Jun 2006	III II II III	Design concept for beam-formers Digital signal to central control room Commission spectral line correlator Prototype feed & front end designed, tested Update SKAMP scope of project document	134.5	90.0	298.7
06/07	Sep 2006 Dec 2006 Apr 2007 Jun 2007 Jun 2007	III V III III	Build prototype feed Document on RFI strategies complete Production & installation of feed systems Commissioning tests on full system Update SKAMP scope of project document	67.0	90.0	10.0

5 Key personnel

Key personnel for the SKAMP project are as follows:
Dr Anne Green, Director of Molonglo Observatory and Senior Lecturer in the School of Physics at the University of Sydney. Dr Green is the leader of the SKAMP project with overall responsibility for management and direction. Time allocation 0.25 FTE

Dr Michael Kesteven, Senior Research Scientist at CSIRO, Australia Telescope National Facility. Dr Kesteven is the Senior Project Manager and has been co-ordinating overall system design and implementation. Time allocation 0.1 FTE.

Mr Duncan Campbell-Wilson, Site Project Manager and Officer-in-Charge at the Molonglo Observatory. Mr Campbell-Wilson is responsible for telescope operation and maintenance and for integration of the new signal pathway into and parallel with the present telescope system. He will also oversee sections of the project and the time allocation is 1.0 FTE. The technical officers at the MOST are funded by an ARC Discovery Grant to operate and maintain the facility. They will also contribute to the building and maintenance of SKAMP.

Dr John Bunton, Senior Engineer at CSIRO, Telecommunications & Industrial Physics. Dr Bunton is an Advisor and System Specialist who has played a major role in the design of the correlator and the beamforming electronics. It is anticipated that his role will increase. He will co-supervise the work of Mr Tim Adams. Time allocation 0.1 FTE.

Dr Andrew Parfitt, Leader of the Space & Satellite Communications Systems, CSIRO Telecommunications & Industrial Physics. Dr Parfitt is an antenna expert who is co-supervising the PhD student Mr Martin Leung. He will also have a supervisory role with the Research Associate appointment on the feed development project as he is a co-PI on the Grant. Time allocation 0.1 FTE.

Dr Bevan Jones, Managing Director of Argus Technologies Australia P/L. Dr Jones is the industry partner on the ARC Linkage grant and will be responsible for feed prototype building and testing and some co-supervision of the PhD student. Cylindrical antennas are core business for Argus Technologies. Time allocation 0.1 FTE.

There is a contribution on an informal basis from School of Physics staff, principally on scientific issues: *Prof Richard Hunstead, Dr Simon Johnston, Dr Elaine Sadler* From the CSIRO, Australia Telescope National Facility, there will be additional input from members of the ATNF SKA team, including *Prof Ron Ekers, Dr Frank Briggs* (located in Canberra) and *Dr Peter Hall*. Some external scientific and technical advice will be sought from other members of the SKA consortium, *Prof John Dickey* (U. Minnesota), the Dutch phased array team.

The project has a training capacity and student projects include:

- *Martin Leung* PhD student (wideband feed development)
- *Aaron Chippendale* PhD student (high dynamic-range imaging and configuration simulations)
- *Tim Adams* future PhD student & now Research Assistant (correlator & polyphase filterbank design and construction)

There will also be additional research and technical appointments made for the project:

- Research Associate funded by the ARC Linkage grant (*Dr Sergey Vynogradov)* to study the theoretical options for an ultra-wideband low frequency feed system.
- RF Engineer, funded by the MNRF program and located at the Molonglo Observatory, to design and build the beam-forming sections of the front-end and to implement the signal transport system.
- Project engineer and system software co-ordination, based in Sydney and working closely with Dr Kesteven. Funding for this position (externally to the MNRF) is being negotiated.

6 Issues

Technical risk

Much of the MNRF program funding for this project is for production and implementation of complex systems from components designed in separately funded sub-projects or commercially available at competitive costs. Cost effectiveness is a crucial aspect of the success of the SKAMP project. The most high-risk part of the project arises from the sub-project to develop an ultra wideband feed for a cylindrical antenna. The success of the SKAMP project will not be compromised if the full technical specifications are not achieved in a single feed element. The goals of the project may still be achieved if the feed system is constructed in several contiguous elements (each of modest bandwidth) or if somewhat less than the entire 1.6 km of the existing telescope is fitted with a new low frequency feed.

Defence Department Headquarters
In late 2002 it was announced that a new Operational Headquarters of the Defence Department was to be constructed only a few kilometres from the Molonglo telescope. Radio signals from this new building have the potential to interfere with the operation of the upgraded telescope, and could be a potential threat to this MNRF project. The Defence Department are working with Sydney University to explore options to remove or mitigate the effects of the interference. Options include funding a joint research project to develop radio frequency interference mitigation techniques over the period 2004-2006.

7 Project Plan

Year 2002-2003
The first year of the project will be spent on conceptual design of the 96 station continuum correlator, Stage 1 of the SKAMP project. Since the correlator design is based on programmable chips, there is a conjunction of hardware and software design. Tools used are Protel and Xilinx.
The company now producing Protel (Altium) are interested in offering technical support for the project, which is at the limit of the capability of their products.
Another part of the initialisation of the project is the construction of essential infrastructure at the MOST site. A parallel signal pathway is designed to enable ongoing science programs to proceed without interruption and to provide essential calibration and verification of the new system. The appointment of the Site Project Manager (Mr Duncan Campbell-Wilson) has occurred. This is a 5 year appointment. He has supervised the infrastructure changes and has designed and built part of the signal pathway (delay boards and fringe rotators). Other personnel are listed in Section 5. Design costs for correlator and feed project are externally funded.

Year 2003-2004
The second year of the project will see the completion of the narrowband continuum correlator board, comprising 21 Field Programmable Gate Arrays (FPGAs), to preserve maximum flexibility in the design. Salary costs of correlator designer (Mr Timothy Adams) will be borne externally. The board will be manufactured externally and tested in Sydney. Control software and data acquisition software will be tested. The design concept for the spectral-line correlator will be completed. It is the expectation that a scaled up version of the first board will be the foundation of the new design. Commissioning test on the continuum correlator will be carried out. An RF engineer, to work at the MOST site, will be appointed to build and manage the front end architecture. This appointment is ongoing for 4 years. PhD student Aaron Chippendale will conduct imaging and simulation experiments as part of his thesis project.

Year 2004-2005
The third year of the project will be spent in designing the 2048 channel polyphase filterbank and completion of the spectral-line correlator. The modification needed to provide the 30 MHz bandwidth front end will be designed by the RF engineer. It is expected that the digitisation will occur out on the telescope. This will simplify the transport of signals via optic fibre to the control centre. Implementation of a full fibre-fed network to all 1.6 km of the telescope will be undertaken during the year.

Year 2005-2006
The fourth year of the project will see the commissioning of the spectral-line correlator backend and the completion of the design for the two stages of beam-forming. Evaluation of the spectral imaging capability and the dynamic range achieved will be conducted by Aaron Chippendale as part of his PhD thesis. His project also includes an experiment on the Epoch of Reionisation, carried out at the Australia Telescope National Facility. The prototype of the ultra-wideband feed will be built, and the integrated system of LNAs, mixers and potentially samplers, will be completed. The major tasks will be to prepare the telescope feed structures and build the front end receivers, packaging commercial LNAs and mixers with digitisers.

The final feed design and development will be funded by an ARC Linkage Project, and the construction of the final production feeds funded by the MNRF. The cost of this, as is appropriate for an experimental, cutting-edge design, is uncertain. We expect that 500m of line feed will be installed in the telescope, but an unexpectedly high production cost may mean that a smaller section will be installed. While this will not compromise the ability of SKAMP to be a prototype demonstrator, it may constrain some scientific programs which require the highest sensitivity available with full area coverage, and so in that case additional funding will be sought from other sources.

Year 2006-2007
The final year of the project will focus on building and commissioning the chosen prototype feed. The PhD student Martin Leung will complete his thesis this year. The selected feed and integrated amplifier/mixer/sampler will be built and installed at the telescope. The full signal pathway will be connected. Commissioning test will be undertaken on the 50 MHz instantaneous bandwidth system, operating over a wide range of frequencies.

8 Intellectual Property and Commercialisation

Relationship agreements exist for all the MNRF participants. It is expected that the collaborators in the SKAMP project will develop significant IP connected with wide field of view imaging, high speed digital correlation of signals and techniques associated with a cylindrical reflector array. The IP generated is to be freely shared by all partners in the collaboration for the purposes of the research. In addition, IP agreements exist for the project to develop a wideband dual polarisation feed system, between the University of Sydney, CSIRO and Argus Technologies. Agreements will be negotiated for follow-on projects such as the advanced SKA prototypes

Foreground IP will be reviewed regularly to check for patentable material and commercialisation opportunities. Participants will be free to publish and present material, with the appropriate acknowledgements, in relevant research forums, in accordance with University stipulations.

9 Education and Outreach

The SKAMP project has substantial training opportunities. Postgraduate degree projects already underway or planned include:

- PhD to develop ultra wideband feed (Martin Leung),
- PhD to study RFI mitigation (Daniel Mitchell)

- PhD to study high dynamic range imaging and configuration simulations (Aaron Chippendale),
- PhD or traineeship to design polyphase filterbank (potentially Tim Adams),
- PhD and Honours projects to exploit the science goals investigating the neutral hydrogen structures and galaxy populations at redshifts equivalent to the hydrogen line at a radio frequency near 843 MHz.

10 Key Performance Indicators

The key performance indicators for this project are:

- the milestones achieved on time and on budget,
- the successful completion of the PhD programs associated with this project
- the number of scientific publications reporting the results from the operation of the SKAMP facility.