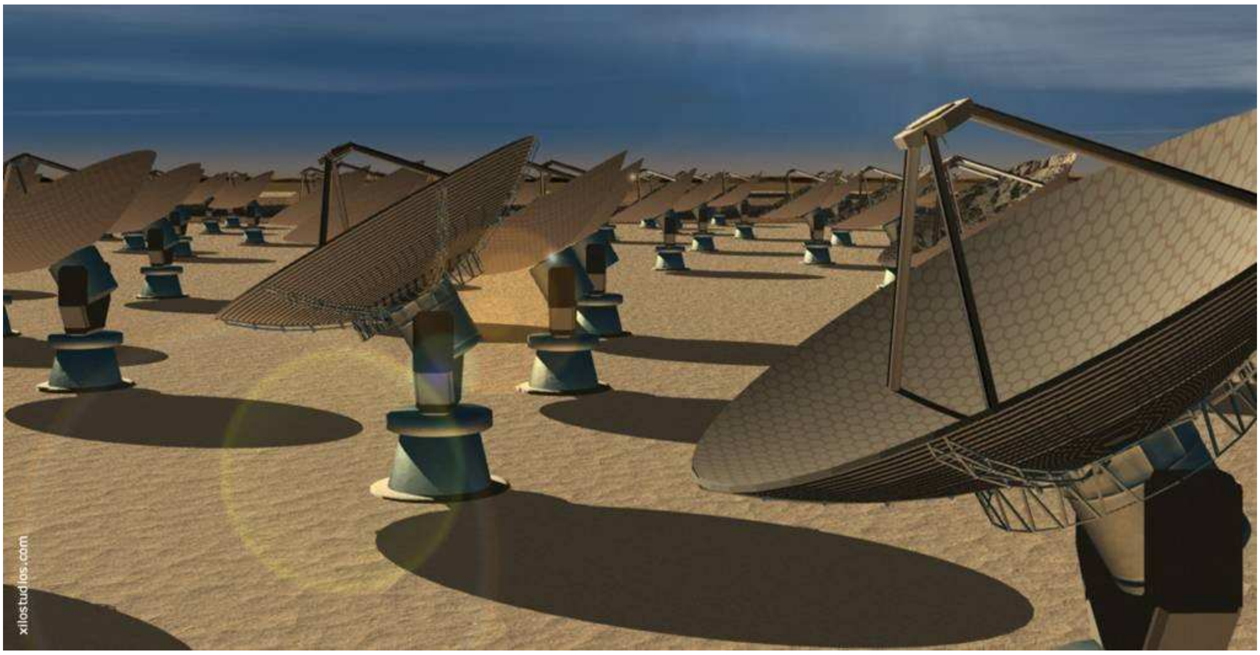

SKA TECHNOLOGIES ROADMAP
Review of Australian SKA-related R&D
and Industry Opportunities

An Australian Government Initiative
AusIndustry

SKA
SQUARE KILOMETRE ARRAY

Australian SKA Industry Cluster Mapping is
Supported by AusIndustry under its Industry Cooperative Innovation Program (ICIP)
In collaboration with CSIRO and Australian Industry

Report Purpose

The Square Kilometre Array (SKA) will be the world's 'next generation' radio astronomy telescope. The SKA will form part of a whole suite of astronomical facilities, spanning the entire electromagnetic waveband which will operate through to the middle decades of the 21st century. However, the technological requirements to realise the SKA require technological innovation and complex system integration on a challenging scale.

As a result of the SKA's demand for new technology, there is significant interest from industry on two fronts: (1) that the SKA build contracts will be significant, and (2) that the potential adoption of SKA-developed technologies into adjacent markets might also prove lucrative. Industry activity has been particularly notable in Australia, and can be attributed to the leading role played by Australia, primarily through CSIRO, in the international SKA project, the development of a complete end-to-end demonstrator radio telescope (ASKAP – formerly known as the eXtended New Technology Demonstrator (xNTD)) in WA at the Australian SKA candidate site and last but not least, the promotion of an early-phase formation of an Australian SKA Industry cluster.

This roadmap sets out the R&D plans within the ASKAP project and other SKA-related R&D, and discusses the technological trends imbedded in the project.

The SKA is an international project, and therefore it provides an opportunity for Australian companies, of all sizes, to cooperate in early-phase R&D: There are always concerns on the potential outcomes from any *juste retour* arrangement from the international funding arrangements. At this stage of the SKA project, the funding and procurement is not yet agreed, and so no one can predict what these arrangements will be. However it is clear that it will be the owners of the core IP who will benefit from the eventual SKA contracts – whether via direct contracts or cross-licence arrangements.

The specification and design for the SKA will not be defined until 2008-09. Helping set this specification will be the outcomes from SKA "pathfinder" projects, of which ASKAP is one. In this report we discuss the R&D towards ASKAP, much of which tackles direct SKA technological challenges, to highlight the potential for industry engagement.

This report is intended for external stakeholders regarding both the ASKAP and the SKA projects, and is primarily directed to Australian industry. It describes ASKAP project technology readiness, scope and implementation timescales, and discusses where benefits may arise from R&D, as a justification of future investment.

Technology Mapping Outcomes

This report has been compiled to

- *Identify and promote beneficial collaboration between CSIRO (& other partners) and Australian industry – either fostering existing capabilities or growing them,*
- *Ensure Australian industry is well-placed to bid for eventual SKA contracts*
- *Aid Australian industry in exploiting the IP developed within ASKAP R&D, outside of radio astronomy*
- *Foster and increase collaborative R&D in related technologies*

Disclaimer

This document has been compiled in good faith to present an accurate picture of the technologies under development for CSIRO's SKA pathfinder project, and to the best of its ability report on how these may be incorporated into the longer-term international SKA project. The reader is reminded that these are highly-experimental, technical projects, and the nature of the R&D is such that details will change. Before making any commercial or investment decisions related to these projects, the reader is advised to consult the latest project material.

Authorship & Acknowledgements

The authors wish to thank the Department of Industry, Tourism and Resources through its AusIndustry Industry Cooperative Innovation Programme for part-funding of the Australian SKA industry cluster project, of which this report is one deliverable. The significant support, both financial and professional input, of the Australian SKA Industry Cluster core sponsor members is also acknowledged in developing this report.

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Australian SKA Industry Cluster

Since late 2005, the Australian SKA Industry Cluster Consortium comprising Boeing, Cisco Systems, BAe Systems, RFS, Raytheon, Tenix, RLM, CSIRO, AEEMA, RF Technologies and Global Innovation Centre have been working collaboratively to provide a strong industry foundation for the 'mega-science' Square Kilometre Array (SKA) initiative. The consortium has since been increased with a number of new members that have expressed a keen interest in the challenges and opportunities inherent in the complex task to design and build the next world's radio-telescope and its earlier 'demonstrators'. The current cluster consortium members' logos are included on the final page of this report and their advice and support in all of the ASKAP-related activities is gratefully acknowledged.

The formation of the Consortium, with its associated industry-led Cluster activities, recognizes the necessity for early and ongoing Australian industry engagement with SKA. Current objectives, supported by the above organisations and AusIndustry's Industry Cooperative Innovation Program (ICIP), include the identification of projects/prototypes suitable for SKA Cluster development as well as formulation of a technology roadmap (this report) and investment profile. The Australian SKA industry capability study has been completed and launched in February 2007. This initial version contains more than 100 Australian companies with SKA-related expertise. Copies can be downloaded from the ASKAP project pages at www.atnf.csiro.au/projects/ska/industry.html and also from the AEEMA electronics industry web pages at www.aeema.asn.au.

The SKA is a project approved under the Australian Government's Electronics Industry Action Agenda led by the Australian Electrical and Electronic Manufacturers Association (AEEMA).

Contents

Executive Summary

Australia has a defined pathway to realise SKA technologies, concentrating on the development and build of a new radio telescope at the Australian SKA candidate site, located in Murchison Shire in mid-west WA. This major new facility with a current budget of AUD 100M – comparable to the build of the Australia Telescope Compact Array radio telescope, will demonstrate the operation of a range of new technologies which are demanded by the SKA – both in operational capability and cost-specification terms.

This document sets out the technology roadmap for ASKAP and SKA-related technologies and identifies opportunities for industry involvement during the ASKAP project lifecycle, as per the current (Q1 2007) project plans. At this stage of the SKA project, it is difficult to predict which technologies will be selected, and furthermore international procurement and funding arrangements have yet to be determined. However it is clear that early engagement in the ASKAP project technologies will stand Australian industry in good stead – and allow further development, perhaps beyond radio astronomy to suitable adjacent markets.

This document considers each major component of the end-to-end ASKAP system and discusses the R&D, timeline and the likely method(s) which will be used to obtain the system's requirements (e.g. CSIRO ATNF bespoke build, open procurement, collaborative R&D, etc).

Defining ASKAP - Australia's SKA pathfinder

Until 2007, the CSIRO SKA demonstrator project was known as the eXtended New Technology Demonstrator - 'xNTD'. This has since been renamed to 'ASKAP' – the Australian SKA Pathfinder telescope.

ASKAP and the Wide Field Array (WFA, formerly known as LFD) form a complete SKA demonstrator, covering the key frequency ranges ~80 MHz to ~2 GHz.

ASKAP is an international collaboration between Australia (CSIRO) and Canada (NRC) to build an array capable of high dynamic range imaging and using wide-field-of-view phased array feeds in the cm-waveband. A related collaboration with South Africa will provide common software systems for ASKAP and the Karoo Array Telescope (meerKAT).

This document considers only the R&D towards ASKAP led by CSIRO ATNF.

ASKAP Key Challenges

Many challenges exist within the ASKAP project. The highest-impact areas where the project is seeking more engagement and input from external parties are –

1. Infrastructure: most efficient phased development of the site including energy-supply options

2. Data transport: the development of scalable infrastructure to get TB's of data from the remote site to Geraldton and Perth – includes options for network storage en route.

3. Phased array feeds: design, modelling and testing of phase array feeds suitable for radio astronomy

4. Low noise receivers: low-cost (large-N), ultimately the development of the entire 'receiver on chip' solution – CMOS design expertise.

5. Design and build techniques for 12-m diameter radio astronomy antennas – at low unit cost and with minimal on-site commissioning.

More discussion of the technical requirements is given in the later sections of this document.

The International SKA Project – an Australian perspective

The Square Kilometre Array (SKA) is the world's 'next generation' radio astronomy telescope project. It is designed as a spatially-distributed system (radio interferometer) providing huge gains in sensitivity compared to today's largest radio telescopes. With the capability of detecting very weak radio signals from distant objects in space, SKA will enable astronomers to answer many important questions about the Universe and fundamental physics, including the nature of dark matter, dark energy and the origins of life.

The SKA is a major international project, recognised as one of the future 'mega-science facilities' by the OECD. It has a total projected build budget of €1.5 billion, an operating budget estimated at €100M p.a. and a lifetime of order 50 years. Development of the project is managed via a consortium of 24 world-renowned institutions from 17 nations. CSIRO's Australia Telescope National Facility (ATNF) has assumed the leadership role in Australia, building on its strong tradition in radio astronomy and instrumentation. Australia, primarily through CSIRO ATNF, plays a strong role in the international partnership developing SKA and is host to one of the two potential SKA sites (i.e. mid-west WA). See www.skatelescope.org and www.atnf.csiro.au/projects/ska

The SKA project has been under development for about 15 years, and covers a range of R&D activities undertaken either singly, or jointly, by the international partners. The functional specification of the SKA is driven by the key science experimental requirements which are defined *today*, as well as the need to build a powerful, flexible and responsive system possible. The current timeline for the international project is shown below.

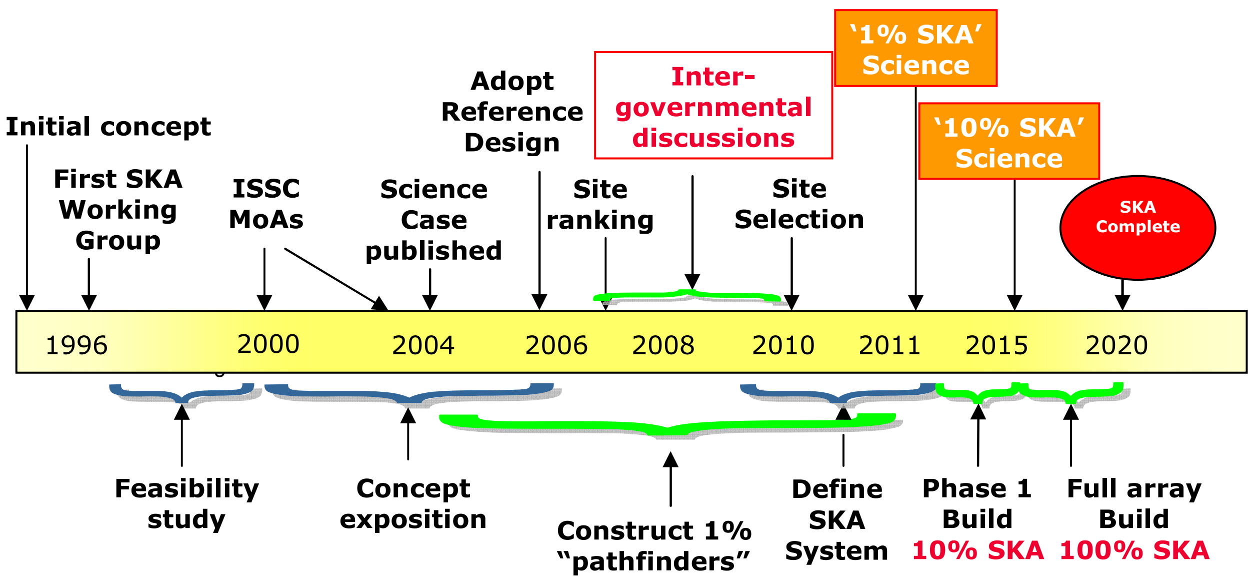

Figure: SKA Project Timeline

At the time of this report's preparation (2007 Q1) the SKA project is in the 'construct 1% pathfinder' phase: this is a phase in which national and regional projects are undertaking major R&D projects to build significant-size facilities to test key technologies which will contribute to the selection of the SKA technologies. Australia's decision on what to build for this phase and why is discussed in the next section. Other (international) pathfinder projects are outlined in Appendix A.

The pathfinders and SKA design studies are significant projects in their own right and will lay the foundation for much scientific and technical progress towards the SKA.

A Snapshot of Australian Astronomy

Forefront astronomical research is primarily driven by technology, relying on the development of increasingly more sensitive telescopes and instrumentation. Astronomy isn't unique in this respect, but it is one of a number of scientific endeavours (particle physics, atmospheric sciences, etc) which drive a wide range of technologies, from the development of mm-size highly-integrated, low-power circuits to sophisticated low-noise, wide-band receiver systems, and through to fast computer algorithms to process the resultant gigabytes of data. These sciences and their technologies co-evolve – the specification of scientific goals 'pushes the envelope' of the available technologies which in turn are underpinned by fundamental science.

Astronomy is an attractive science: it excites the general public and also offers industry a "show casing" opportunity for technologies which otherwise might be closed off due to secrecy or other sensitivities (e.g. defence). Astronomy is a benign, ethically-neutral activity, being an observational-based science which cannot dictate nor affect the object(s) of the experiment.

Australia has several world class centres developing astronomical instrumentation, most notably the Anglo Australian Observatory (optical/IR), the Research School of Astronomy & Astrophysics, ANU (RSAA-ANU, Optical/IR) and CSIRO Australia Telescope National Facility (radio/sub-mm). These groups cover a wide spectrum of technical capabilities – theoretical and applied – including optical design, grating and photonics design, electronic and mechanical engineering, systems engineering and integration, telescope control systems, graphics simulation and software. These groups are increasingly dependent on close relationships with universities, observatories, government laboratories, industrial partners, and industrial research networks. These links are essential to the R&D programs for a number of reasons, including

- Access to new ideas,
- Access to state-of-the-art lab facilities & expensive software packages,
- Attracting excellent students and engineers,
- Opening new avenues for research funding - e.g. through DITR[1] and DEST[2]'s Innovation Access Program.

[1] Department of Industry, Trade & Resources

[2] Department of Education, Science & Training

Australian astronomical research has a long and illustrious history, backed up by the development of novel and ground-breaking instrumentation at radio, microwave and optical wavelengths: e.g. the Parkes HI multi-beam receiver (CSIRO-ATNF 1997), the two degree field instrument (2dF, AAO 1998) and the near-infrared integral field spectrograph for Gemini (NIFS, AUD $4M, RSAA 2004). Not only do these instruments generate contracts for similar instruments for other international telescopes - e.g. ALFA (HI multibeam) on the Arecibo telescope (Cornell University) 2004 and FLAMES/Ozpoz on the VLT – an adaption of AAO 2dF technologies - but they can also spawn new companies as discussed in the PMSEIC report 'Technology Transfer' section 7 (June 2004). An outstanding case of this was the Australian start-up Radiata, whose fundamental capabilities can be traced to R&D at CSIRO Radiophysics (Matthews and Frater[3]), also discussed in Appendix B.

Astronomy Applications & Industry links

Radio astronomy emerged from the invention and application of Radar during World War II, from which Australia maintained a strong commitment to radio astronomy instrumentation. To some limited extent, links forged between radio astronomy and electronics companies, particularly in the early days of the subject, helped foster a modest number of competitive Australian companies.

Increasingly, astronomical facilities are based on information processing and telecommunications technologies (ICT) –extending from the ultra-fast processing chips at the front-end of the receiver system to sophisticated imaging algorithms at the end-user (astronomer) interface. Astronomy provides a demanding development environment for state-of-the-art devices, systems and algorithms.

A number of beneficial points as to why industry might collaborate with astronomy projects can be put forward:

- The opportunity to engage the creativity of the best professionals to achieve imaginative projects in a networked, cooperative project: e.g. transfers skill, open new markets, attract and retain key engineers.
- The ability to finesse leading-edge technologies and techniques for extremely demanding applications with technologically-sophisticated users who will support riskier, cutting-edge solutions.
- The ability to generate and share information with R&D partners in a benign commercial environment.
- To be able to publicise project outcomes freely – unlike e.g. defence systems, and to use this publicity as an attractor for other contracts and personnel.
- High visibility from being associated with an innovative, international mega-science project which will have ongoing impact.

[3] Creating and Exploiting Intangible Networks: How Radiata was able to improve its odds of success in the risky process of innovating, M Matthews & R Frater, Nov 2003, Case study prepared for the Science and Innovation Mapping Study (DEST: http://www.dest.gov.au/mapping/case_studies.htm).

- The potential to engage in very early phase R&D for multi-million dollar-projects, almost all of which are cross-discipline – engineering, systems and computing
- The opportunity to 'smooth' the continued employment of talented engineers and scientists, where system integration companies (which may have a strong role within the SKA project) are reliant on large-$, but 'lumpy', defence contracts.

Countering the last point, though, are periods where the skilled labour force is fully employed due e.g. to a combination of large contracts, a commodities boom, etc, so that any 'new' project like the SKA finds itself in stiff competition for key skills: this isn't insurmountable, but will require consideration.

The astronomy-industry link also strongly benefits the scientific community, recognising that it

- provides consultative networks
- focuses research on industry needs
- provides a greater understanding of current and future demands (market knowledge)
- facilitates additional funding and resources
- provides an impartial and objective contribution to the development of project concepts
- assistance in management of the applied science projects
- enables the direct "commercialisation" of research.

Furthermore, ensuring the continuity of a skilled workforce, both in astronomical community and in industry is vitally important to a small technology economy such as Australia. Astronomy has similar skills as industries such as defence, communications. An example of which can be found in the burgeoning wireless communication industry – there are challenges meeting the world-wide demand for qualified radio-frequency (RF) systems engineers: Radio astronomy is one potential training ground for such individuals, with a proportion of undergraduate and graduate affiliates returned to industry with strong technical and scientific skills. At present there is a particular need for RF engineers having a background in advanced technologies such as RF CMOS - exactly the same areas which need to be developed for ASKAP and other SKA engineering programs. ASKAP projects are already combining the know-how from industry and radio astronomy to produce next-generation, high performance systems suitable for use in radio astronomy as well as other domains.

The technologies spawned by astronomy are not always obvious – some examples are discussed elsewhere in this document and many diverse opportunities have already been identified within the SKA project, e.g. if the SKA is sited in Australia, it will have a wide impact, including

- facilitate improvements in community infrastructure in remote areas
- extend Australia's fibre optic network
- provide supplementary communications capacity
- expand communications bandwidth ex Australia
- significantly develop antenna and communications technology

- encourage further development of low cost renewable energy including solar, wind and geothermal power generation and hydrogen storage technologies
- stimulate parallel communications research
- develop low cost antennas which may be useful in other applications

The flow-on benefits from these dot points are not identified or quantified here – but are only recorded to show that there are many benefits and potential industry ‘links’ which extend beyond the telescope technologies themselves.

For Australian companies, the highly networked astronomical community provides a direct route to potential international customers and also to like-minded companies in specialist fields of engineering. For example, the infrastructure component alone for the SKA is expected to be in the order of €400 M and it too has potential spin-off applications: for example Steensenvarmig (Australia) see a particular challenge in developing the type of distributed system that would be required for the SKA: These must have a green ‘soft-footprint’, low RFI, being energy efficient and able to operate in a remote, standalone mode. “This has interesting potential applications beyond just astronomy. A facility with standalone energy source which is secure and reliable, green, high-tech, smart and restorable may be developed into an economically-viable venture in itself. There are potential markets internationally in health, defence, police, customs, communications, mining, tourism, indigenous communities etc. Specialised, but potentially highly successful business niche” [4]

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[4] SKA industry benefits submission from Mr Dan MacKenzie, Director, Steensenvarming, January 2005

Australia's SKA Pathway

Australia plays a leading role in the international SKA project and has done so since its inception. The ASKAP radio telescope is an ambitious technology demonstrator for the SKA, incorporating key technologies which have yet to be proved. A prototype system, based on a 2-antenna interferometer, known as the New Technology Demonstrator (NTD) was funded from the Major National Research Facilities (MNRF) 2001 program. The NTD provides a test-bed for the initial development of a range of focal plane array receivers (FPAs). Building on the NTD outcomes, ASKAP will use FPAs, providing a new wide-field radio telescope to the National Facility in 2011/12. ASKAP received major funding as part of CSIRO's "Science Investment Process" (SIP), from the 'Australian Astronomy' bid to the Federal Government initiative "National Collaborative Research Infrastructure Strategy" (NCRIS) and most recently from the May 2007 Federal Budget. ASKAP has attracted collaborators and further funding from international partners.

CSIRO ATNF has been gathering data on the radio frequency environment in mid-west WA for many years and has determined that the spectral occupancy of the spectrum is extremely low in many locations – most notably extending through the FM band (90 – 110 MHz). An attractive site for a wide range of radio astronomy observations has been identified and in March 2007 the WA Government announced the creation of a 'Radio Astronomy Park' to support the development of radio astronomy in WA.

In developing SKA-related technologies, expertise is being drawn from 2 CSIRO divisions – Australia Telescope National Facility (ATNF), and the ICT Centre, as well as a developing relationship with Canada through the Herzberg Institute of Astrophysics (HIA) Dominion Radio Astrophysical Observatory (DRAO).

ASKAP overview

ASKAP sets out to demonstrate a wide-field-of-view 'mini station' solution for the SKA. ASKAP will be based on modest-sized antennas (dishes, each of ~12-m diameter) each equipped with focal plane array receivers. If this particular solution were selected for the SKA then ASKAP would need to be scaled up by a factor of about 500 to achieve the full SKA collecting area – i.e. 120 distributed stations each comprising of order 400 antennas – but note that these numbers are subject to future SKA system design considerations. ASKAP is unique in providing a wide field of view instrument using the small dish focal plane array concept (SD-FPA), using all-digital beamforming.

ASKAP Specification

ASKAP is designed as a fast survey instrument to take full advantage of the wide field-of-view capability of focal plane phased arrays. The science goals for ASKAP continue to refine the exact specification. The ASKAP science case can be found at www.atnf.csiro.au/projects/mira/science.html

The specification for ASKAP is:

- Total collecting area ~3500 m^2, from 30-45 antennas, each 12-m diameter, forming up to 990 baselines
- System temperature of 50 K

- Frequency range 0.7 to 1.8 GHz
- Instantaneous bandwidth 300 MHz
- At least 30 independent beams, each of ~1 sq degrees, yielding ~ 30 sq degrees FoV at 1.4 GHz
- Maximum baseline ~8km
- Full cross-correlation of all antennas

Scaling ASKAP to SKA

The table below shows the some projected data rates for ASKAP with 30 antennas, if scaled up to 10% SKA, and then as full SKA;

	ASKAP 1% Pathfinder	**SKA – 10% Pathfinder**	**SKA**
Number 12 m dishes	**30 - 45**	**~500**	**~5000**
Frequency Range	**0.7 – 2 GHz**	**0.3 – 10 GHz**	**0.3 – 22 GHz**
Number of receivers	**8,000**	**200,000**	**1,000,000**
Bandwidth	**0.3 GHz**	**2 GHz**	**4 GHz**
DSP Processing	**800 Top**	**40 Pflop**	**400 Pflop**
Computer Processing	**1 Tflop**	**5 Pflop**	**50 Pflop**

ASKAP Technology Objectives

To achieve the ASKAP specification as above, the technological goals are to develop

1. 10x10 dual polarisation FPA receivers operating over the frequency range 700-1800 MHz, one in each of 30 parabolic reflector antennas
2. RFI and spectral line ripple cancellation using the receiver (FPA) response
3. RF and IF beam-forming to give extremely wide fields of view.
4. High polarization purity
5. Correlation of large number (of order 30) independent beams
6. Wide band operation with low RFI levels
7. Proof of infrastructure in remote desert environment (power supply, on-site data transport)

A number of aspects of the above technologies and techniques would also have commercial application.

As a result of ASKAP being an entire new array, opportunities exist for companies to get involved with this new telescope with specialist expertise in areas such as

- ICT hardware & software (control systems, modelling and simulation systems)
- ICT data management, distributed data processing & networking systems
- RF devices & RFI mitigation (EMC)
- Systems integration and ICT design, fabrication and test
- Remote infrastructure operations and maintenance
- Scheduling, operations and maintenance of complex distributed systems
- Engineering (R&D, design and analysis and fabrication)
- Telecommunications systems
- Antenna design and manufacture
- Receiver feed systems and integrated receivers
- High-speed digital fibre link and signal processing systems
- High performance computing and image processing
- Site management and planning
- Energy systems and storage
- Environmental Services

The ASKAP project team has a high profile within the SKA project and associated international development programs e.g. EU FP6 RadioNet (PHAROS), FP6 EU SKADS, NASA DSAN, and these are described in Appendix A.

The scope of ASKAP can be compared with that of the Australia Telescope Compact Array (ATCA) built in the late 1980s, being similar in terms of time-scale and cost. However, there are many differences in terms of maturity of technologies, environmental factors, number of antennas, data transport issues with the result that ASKAP is a far more ambitious endeavour. A number of CSIRO ASKAP senior staff were involved in the development of the ATCA, and lessons learned from that experience are being reviewed.

ASKAP 5-year Project Plan

The following diagram provides a roadmap, showing the various projects leading to the operational ASKAP in 2012. A brief description of these projects is also provided. It should be noted that:

- The forerunner NTD project provides some key deliverables to ASKAP by mid-2007 – mostly in the development of the FPA design and characterisation
- A new antenna will be installed at Parkes during 2007 to provide a “testbed” to allow further development of FPA technology. Parkes has a better RFI environment than Marsfield. Use will also be made of the 64 m antenna at Parkes for interferometer experiments.
- Alternative antenna designs for ASKAP will be developed and evaluated during 2007

- A 6-antenna system is planned for commissioning at the ASKAP site before the build of the full system: It is envisaged that much will be learnt from the initial system to enable an optimised ASKAP to be built.
- Each of the sub-projects (indicated by a coloured bar in the figure below) provides deliverables to the Parkes testbed, the 6-antenna system and the full ASKAP.

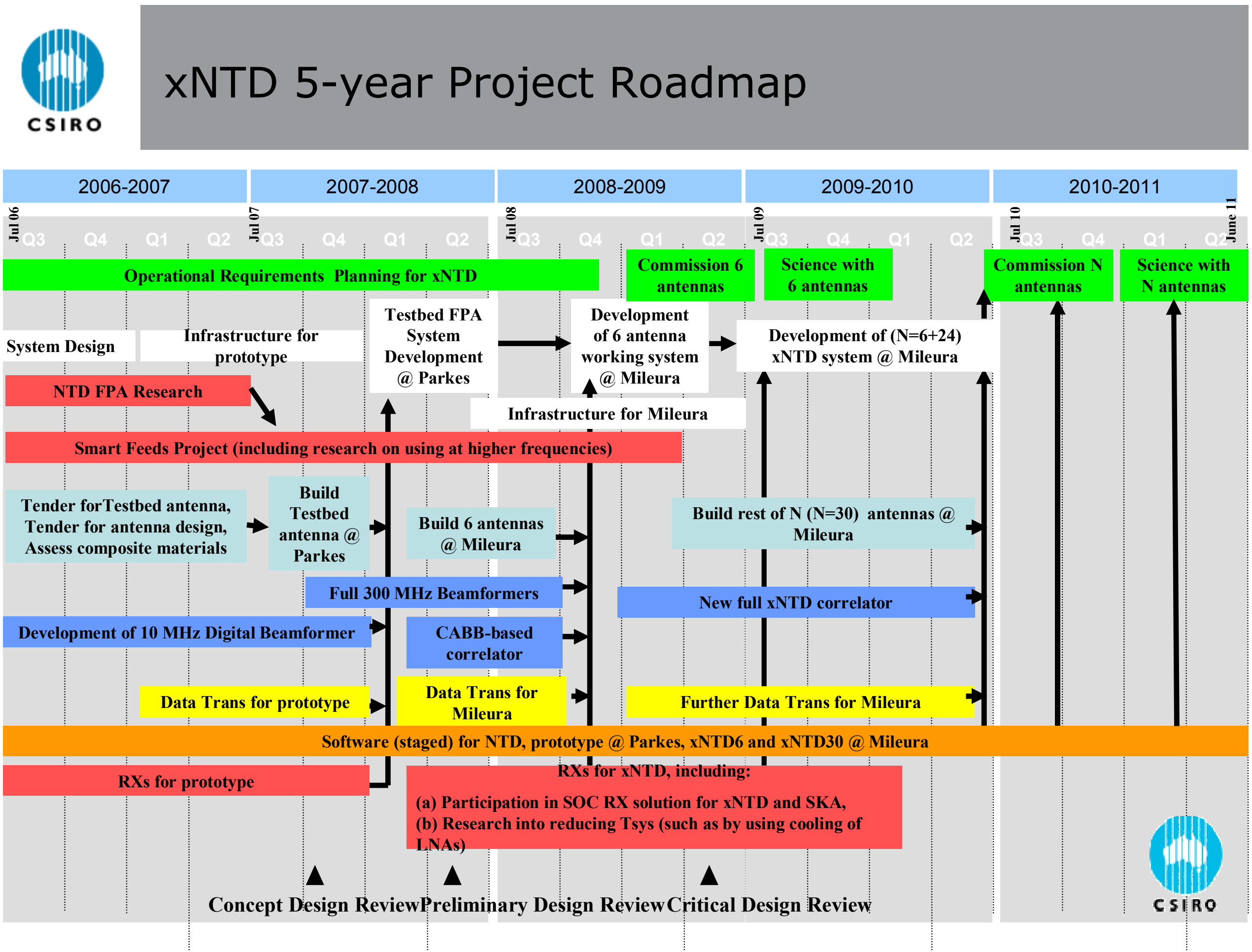

Figure: 5-year roadmap (under revision, in particular this version refers to xNTD): Included here to provide indication of project streams and development timescales.

Road Mapping Process & Methodology

ASKAP Technology development plans

In the following sections we describe the scope and timescales for each subproject within the development of ASKAP

For each internal component we discuss

- The sub-project scope, deliverables and goals.
- Approach to the R&D, including potential for industry collaboration(s) and potential for using commercial-off-the-shelf (COTS) components-
- Expected warranties, operational lifetime and associated issues
- Overlap with activities within other CSIRO divisions, international partners etc.

Cutting across all of the ASKAP sub-projects, there are two major decision points:

1. Whether the Tsys performance of the FPA receiver can be achieved with no cooling systems, or if options for cryogenic cooling of the receivers will have to be incorporated.

2. How to achieve high dynamic range imaging from the FPA + antenna system – critical factors being the optimal specification of the focus, mount and feed rotation mechanisms to match the FPA performance.

A. ASKAP SYSTEM DESIGN, INFRASTRUCTURE AND INTEGRATION PROJECT

This project oversees the development of the infrastructure for ASKAP, overall project planning and communication within the ASKAP project. The project includes

- Project planning, ensures regular communication and documentation between project teams, including the coordination between ASKAP and other local and international projects, including technical contributions to ISPO, SKAMP, SKADS, PHAROS and PREPSKA.
- Modelling ASKAP system cost and performance aspects to allow optimisation. Under subcontract to ISPO this model will be extended to a general purpose cost and performance model for the reference SKA system design.
- Investigating interference mitigation algorithms and techniques.
- The operations model for the telescope.
- During 2007, to install the infrastructure at Parkes for the new FPA test bed antenna
- Coordination with WA entities for the development of ASKAP infrastructure.

Potential for Industry Participation

Collaboration in areas covering system models, cost option modelling, specialist infrastructure (i.e. standalone control buildings), power backup systems etc are welcome.

CSIRO would encourage the formation of one or more 'industry working groups' e.g. for (i) infrastructure (power, development strategy) (ii) operations and maintenance… etc.

B. ASKAP ANTENNAS & CONTROL SYSTEMS

The cost-spec for the ASKAP antennas requires low-cost, low-power and low-manpower build antennas on a scale not previously realised. The challenge for ASKAP is to specify, design and deliver

1: A FPA test-bed antenna at Parkes by Q4 2007

2: A small number of antennas to push the FPA development into the mega-data issues of array operation, by Q4 2009

3: The complete ASKAP in WA by Q3 2010 which

- meet the cost-spec for the ASKAP antennas
- investigate novel antenna solutions which go some way towards realising the cost-spec for the SKA: this requires a reduction of approximately a factor of 2.5 cost reduction compared to the ASKAP target of $300k per antenna, built at site.

This project will also develop antenna control systems software to support each of the 3 stages of antenna development described above.

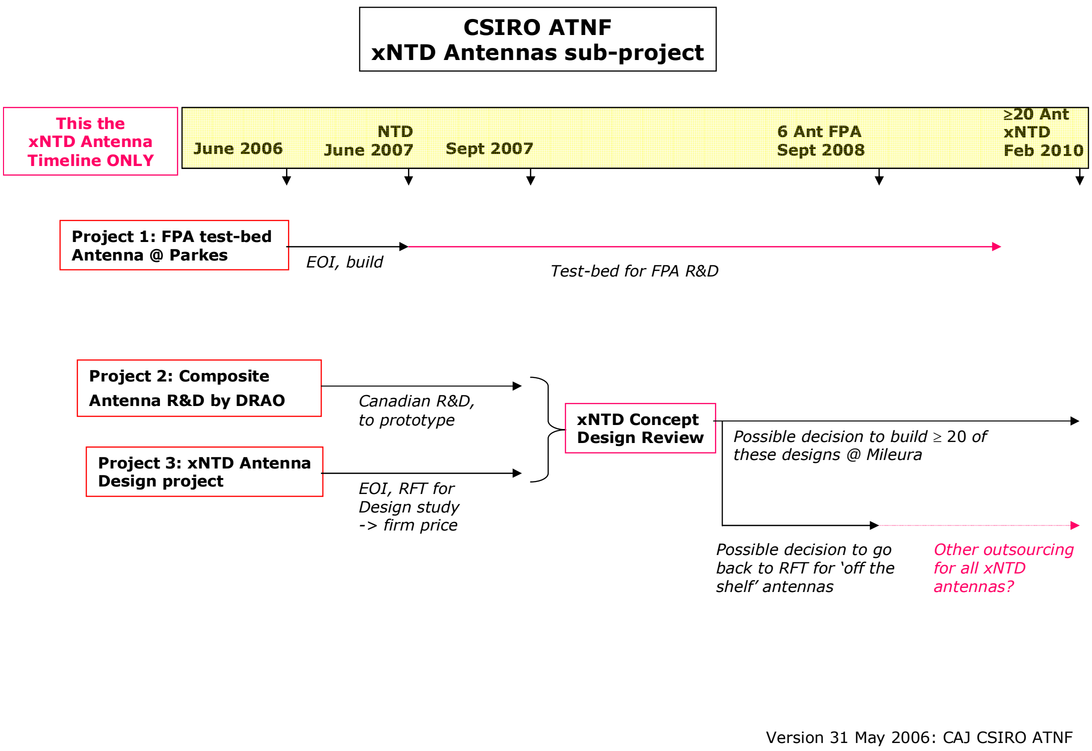

Figure: Project work flow for the ASKAP antennas

B.1.1 Procurement of FPA test-bed antenna at Parkes

The procurement of a "commercial off-the-shelf" antenna is underway to provide a new antenna at the Parkes Observatory site. This antenna does not match the ASKAP specification and the requirement for ultra-cheap or novel construction has been relaxed. This antenna will be built and commissioned during Q4 2007, and for the next 2-3 years it will be used to test novel FPAs in the relatively RF-quiet environment at the Parkes Observatory.

At this stage of the overall project, it is not anticipated that this antenna has any relationship to the 30 or more antennas that will eventually form ASKAP.

Potential for Industry Participation

None currently – the open tender process was completed through AusTender Q4 2006.

B.1.2 Development of prototype carbon composite antenna by DRAO team

The SKA development group at the Dominion Radio Astrophysical Observatory (DRAO) in Canada have developed a novel technique of forming monolithic antenna dishes from carbon fibre which appears promising for the ASKAP and SKA requirements.

The DRAO group will develop and test a 10-m diameter prototype reflector by 30 September 2007 at Penticton. There is continuous on-going collaboration and liaison between the ASKAP antenna team and DRAO to oversee progress and eventual RF performance of this prototype.

Potential for Industry Participation

None has been identified at this stage as the composite reflector needs fully prototyping and testing. There is possible involvement regarding larger-scale manufacturing if this option is adopted as the ASKAP antenna solution, in which case the opportunity will be as part of the whole ASKAP antenna solution (see B.1.3 below).

B.1.3 ASKAP antenna design project

This project will design complete antenna solutions for ASKAP. Whilst the general specification and budget for the ASKAP antennas are set, fundamental decisions around the type of mount (equatorial or alt-az), sky coverage, computing complexity, reflector type (i.e. if the DRAO composite is viable, then its low weight offers a number of new avenues) are intertwined and these are being incorporated into the work of this project.

Potential for Industry Participation

Some fundamental specifications for the ASKAP antennas can only be set once the FPA is reasonably well-developed – expected sometime around late 2007. Given the required flexibility in the specification we are welcoming industry participation in the antenna designs on a co-investment basis at this stage. At present there is a collaboration involving Connell Wagner and Tenix, both working on a range of design options for antenna mounts, reflectors and backup structures in concert with ATNF and DRAO. When the final design decisions are made – focus (prime or secondary) and the value of f/D (set by the illumination of the FPA) we expect to undertake a manufacturing study for the selected design(s) and then tender for the build of the first few ASKAP antennas in mid 2008.

Alternative designs to meet the ASKAP cost-spec are welcome from parties external to the work of the antenna design project. The project team would appreciate advance notice of any submission in time for the antenna CDR (provisionally tabled for January 2008).

CSIRO encourages the formation of industry working group around the antenna design issue: note also that there is an active collaborative project with Tenix and Connell Wagner that can be extended for new members.

Antenna Control systems

These will be developed in-house by CSIRO and any antenna solution is not expected to provide these.

C. ASKAP SMART FEEDS PROJECT

This project will develop the focal plane array (FPA) for ASKAP. Successive versions of FPAs will tested on the test-bed antenna at Parkes before the final design for ASKAP is selected.

An additional goal of the project effort is to build the skills which will enable the development of improved smart feeds for more general use within radio astronomy: This may ultimately lead to operation at higher frequencies (10 GHz and above), development of designs where cryogenic cooling of the receivers improves Tsys, and also to improve system aspects such as use of beamformer weights to adaptively correct for reflector distortions and pointing.

Scope

The smart feed project as outlined will work closely with the ASKAP receiver project, but does not directly include this aspect in the project. It is anticipated that the LNA design requirements can be sufficiently decoupled from the smart feed electromagnetics.

The project activities include

- Electomagnetic design and modelling
    - Improved array designs and in particular, improved LNA coupling designs
    - Modelling tool development including integration of commercial tools with locally developed tools
    - Modelling of actual array to be prototyped including details of PCB and connector structures (Q3-4 2007)
- Array mechanical design
    - Designs for low cost manufacture, eg PCB array structures which can be easily assembled.
    - Enclosure design – weight, strength, thermal, moisture ingress, etc

- Array system design
    - Development of performance criteria and measures for improved array
    - Beamformer optimisation and requirements
- Prototype Manufacture and Integration
    - Array prototype manufacture
    - Integration with receiver and optical fibre data transmission.
- Testing on Parkes interferometer
    - Interferometric measurement of element beams
    - Demonstration of beamformed efficiency and system temperature
- Design modifications and re-test (if necessary)
- Manufacture FPAs for first phase of ASKAP
- Manufacture FPAs for the full ASKAP array

The targets are to attain
- Efficiency after beamforming in the range 60-75%
- Tsys (after beamforming) of 50K
- FOV of 30 sq degrees at 1.8 GHz
- A frequency range of 700 MHz to 1.8 GHz with stretch target to extend to 2.5 GHz.

Potential for Industry participation

Project R&D is not yet advanced enough to determine what industry participation might be useful or attractive. However we encourage interested parties to contact the project for updates and discussions at any time.

D. ASKAP RECEIVERS PROJECT

Receivers are a major component of ASKAP. Each FPA will require of order 200 individual receivers. These receivers will need to be situated near the focus of the antennas, probably within the focal plane array enclosure. The Low-Noise Amplifier (LNA) will need to be closely integrated with the antenna feeds. The project will pursue a solution based on RF CMOS.

For the quantities involved, RF-CMOS Receiver-on-a-chip implementation becomes attractive, and for further progression towards SKA, this approach will be mandatory. To maximise the benefit of ASKAP, it is necessary to look at numerous approaches to reduce the system temperature Tsys, such as cooling of (just) the LNAs.

Scope

This project focuses on the receiver component and works closely with the Smart Feed project in particular for detailed specifications and requirements.

- LNA Design methods – new design methods and design tools for LNA optimisation are necessary to account for differences in noise/power/array match due to array coupling
    - Methods and techniques
    - Software tools
- Differential LNA measurement and testing methods – non-50 ohm systems with differential inputs present new challenges for measurement and testing
    - Test jigs
    - Measurement techniques
- ASKAP prototype LNA development – when Smart Feed design is sufficiently advanced, carry out detailed LNA design
    - design
    - protoype and test
    - manufacture
- Receiver down-converter – discrete wide band design
- Integrated receiver/down-converter investigations. This will also include the investigation of RF-CMOS alternatives.

Potential for Industry Participation

This ASKAP project is actively seeking industry collaborators, both domestic and with international groups. There is a substantial amount of commercial expertise in the development of RF-CMOS technology in Australia including the embryonic “Australian Microelectronic Product Realisation Centre’ with which we hope to develop the ‘receiver on chip’ solution. This particular project is large and therefore any interested party is encouraged to discuss co-investment/collaborative activities as soon as possible.

E. ASKAP DIGITAL SYSTEMS PROJECT

This project develops the digital systems for ASKAP. The so-called ‘smart feeds’ approach relies upon a phased array of feeds producing signals that are immediately digitised for subsequent beamforming, frequency channelisation and correlation.

ASKAP requires a digital beamformer and correlator. The most cost effective solution for these systems is to use Field Programmable Gate Arrays (FPGAs). The latest generation of FPGAs will be lower power and cost than current devices and importantly will include, on chip, the interfaces for high speed serial links. As the designs will occupy a number of card cages, serial links are needed for inter-card cage connections. The devices will thus allow a significant simplification of the designs as the number of FPGAs and other logic on the boards will be considerably reduced. However, from past experience, there are risks in using frontier technology chips which will need to be continually assessed. The project plan incorporates peer assessment of alternative solutions, with consequent decision points and milestones.

Each antenna will have a digital beamformer which will take in ~100 dual polarisation baseband signals each of 300MHz bandwidth. These will be digitised and processed by a first stage polyphase filterbank. This will reduce the fractional bandwidth of each channel to less than 1%. Thus, across each band the beamforming weights can be approximated by a single complex number.

The beamformer will accept analogue baseband data or digitised data via optical fibre, the choice will be chosen by the Data Transmission project. The beamformer will process this data to generate ~30 beams with the data for each beam channelised to a resolution suitable for spectroscopic observing. The data generated is then transported on a separate Signal and Data transport system to the correlator. The correlator calculates full Stokes parameters for all beams, channels and baselines. The beamformer will be controlled by a computer that is part of the Antenna and Control system. The output from the correlator goes to the Computing system which will also provide control signals and monitor the operation of the correlator.

The data from the first polyphase filterbank passes through a cross-connect system consisting of cable routed between the modules as well as back plane routing in the first stage polyphase filter bank modules. The purpose of this is to ensure that each of the beamformer boards has data for all inputs for the particular frequency band that it processes, where each band will be ~10 MHz.

On the beamformer boards all ~30 beams are calculated using a simple weight and sum procedure. At the same time a subset of the correlations between the input signals is calculated for calibration purposes. Also on the beamformer board is a second stage polyphase filterbank which decimates the data to the frequency resolution needed for spectral line observing. The resolution is limited by memory but with the use of cheap DRAM the full bandwidth can be decimated to the finest required resolution (~5kHz). In the correlator, coarser frequency resolution will be obtained by channel averaging and it is hoped that building a system with a single internal frequency resolution will save considerable time in programming and configuring the correlator.

The data from each beamformer is then coarsely quantised (15 levels) and transported to a central correlator. The data is physically cross-connected (possibly via optical links) at the correlator so that each correlation module receives from all antennas for a subset of the beams and frequency channels. An interface board may be needed to house the optical receivers and format the data for the correlator. The correlator board itself is envisioned to be a modified version of the SKAMP correlator. With modification being increased input bandwidth and a change of the FPGAs to the latest (and cheapest) devices.

In building and commissioning the hardware a full first stage filterbank system will be built (hardware and firmware) together with the cross connect. A "CABB"[5] or a similar high capacity processing board will then be used to prototype the beamformer firmware at the added cost of a simple Rear Transition Module (RTM) to interface the data. This can be used to test beamforming with actual antenna data.

[5] CABB = Compact Array (ATCA) broadband backend system developed 2005-2007

While the firmware is being developed the beamformer board itself will be designed and one built to validate the system, followed by commissioning of a full beamformer at Parkes and then at the ASKAP as the array is built.

Potential for Industry Participation

This project is closely aligned to the development of a beamformer/correlator system for the University of Sydney's "SKAMP" project at the Molonglo Radio Telescope. The development of beamformers and correlators are as specialised astronomy systems, even so, there is scope for industry participation although details have not yet been determined. Any interested parties are encouraged to contact the project team for further details and to explore options for collaboration.

F. ASKAP COMPUTING PROJECT

This project will develop the software systems for ASKAP which includes scheduling of observations, monitor and control of the telescope during observations, processing of observations into scientifically useful data products, and archiving of data products.

The list of processes to be controlled synchronously within ASKAP is larger than that usually associated with a synthesis telescope, such as the ATCA, where processing and archiving are usually performed asynchronously ("off-line"). This reflects the operational model of ASKAP whereby the immediate result of observing is a scientifically useful data product in the form of images and/or catalogues. A major consideration for ASKAP is that the data rate from the observations will be large, so it is unlikely that more than 24 hours of 'raw' data will be stored.

The project covers the development of systems for

- Campaign-style observing in the first instance, such as a year-long continuum and HI emission survey of the entire visible sky, together with transient detection. Software to support substantial observing of individual targets is specifically excluded from the initial deliverables.

- Firmware for the operation of telescope subsystems is excluded (assumed to be provided under other ASKAP projects), although some support for the SNMP interface may be provided under this project.

- Development of specific analysis capabilities such as catalogue construction is in scope. However (as noted in the first dot point above), the development of a fully general analysis package for processing ASKAP and KAT observations (based on MIRIAD or AIPS++, for example) is excluded.

The major components to be produced are considered to be subsystems, e.g. architecture & design, archive, calibration and imaging methods, central processor, configuration design, infrastructure, management, simulation monitor & control: These map to work packages to be performed in collaboration with the South African KAT project computing team.

The components will be delivered, deployed, and tested on a sequence of telescope platforms, including the KAT Production Equivalent Demonstrator (Jan 2007), the Parkes FPA test antenna (late 2007), an equivalent at Hartebeestock (Sept 2007), a small ASKAP array (2009), the KAT (Dec 2009), and ASKAP (2012). In addition, builds of the entire system will be delivered in some form every three to four months.

The telescope software will be similar to that developed for LOFAR ("model-based") where a model of the entire telescope is kept in a database. The primary connection of devices to the database is via a demonstrated and mature solution – SNMP v3: SNMP is widely used for the control and monitoring of network attached devices, using a hierarchical namespace. Commercial and open-sources tools are available for many needs, such as logging and graphing of devices.

All telescope subsystems (antennas, receivers, beamformers, correlator, central processor, archive, computers, disk drives, weather station) will be accessed in this way, which may require development of specific drivers.

Data processing into scientific data products occurs in the Central Processor – a computing system of architecture appropriate to the data processing needs. Initial analysis indicates that for ASKAP, this will be a relatively large (of order of a few thousand elements) cluster for data parallel reduction such as processing spectral channels, plus a smaller scale shared memory computer for algorithm parallel reduction such as continuum imaging.

Data products are staged to the archive as they become available, and are accessed principally via the archive. The data volumes may be very large (many TB per hour, depending on the details of the telescope such as baseline length), and so it is not yet clear what will be retained in the archive. Initial analysis into catalogues (continuum, spectral, time) will be performed on the Central Processor, but may be repeated later offline if resources are available.

Potential for Industry Participation

The development of astronomical software to process raw observed data into astronomical images is highly specialised, and therefore it will be developed 'in house' by a team of Australian and South African scientific programmers. However there are aspects of the total computing systems required for ASKAP and the SKA which could be developed in collaboration with external parties – e.g.

1. Evaluation of using special computational elements in clusters. The kernel of the astronomical processing algorithm, which involves gridding irregularly-sampled data onto a regular grid, can probably

be implemented in any of a number of specialized processors - Cell, GPU, stream processors, FPGA. There are potential computational cost savings and any solution would have to be integrated into the central processor (cluster or supercomputer).

2. Very large inexpensive data storage systems: require 3 levels of response - fast access for online processing, medium for the last few days' data, and slower for general backup. The anticipated data rate amounts to perhaps 10-50 PB per year. The current model is to reduce the data to simple catalogs and only keep these: However, if the cost of storage could be substantially reduced, we would keep the raw data – with the advantage of potentially better science output.

3. Collaboration technologies - how to successfully enable collaborative work across distributed teams – both in the development and operational phases of a project. The challenge is that the team is non-uniform- some interact across limited bandwidth: Ideally we would like to 'simulate' whiteboards, person-to-person interactions and group videocons, tele-presence.

G. ASKAP DATA TRANSMISSION AND SIGNALLING PROJECT

This project develops the signal distribution and data interconnectivity systems for ASKAP and includes the data transport from the telescope site to a major network link.

As ASKAP could be configured as either an interferometer or single phased array dish (sum of 30 antennas), both phase coherent receiver and signal processing systems are required.

The project will also make available access to site frequency standards and arterial data transport systems for use by other arrays, experiments and facilities sharing the telescope site.

Antenna specific hardware and subsystems will be tested in the NTD Sydney (as appropriate) and outfitted into the FPA test-bed antenna at Parkes as part of the test and development phase.

The project has separate work packages for local oscillator, signal transmission and data transport. The following lists the main steps for the data transmission signals

- Optical transmission of signals from apex of antenna to pedestal room of antenna. RF over multimode fibre (or alternatives)
- Optical transmission hardware for 160Gbps digital data between each antenna and the central site building.
- Optical transmission hardware for distribution local oscillators to (and from) antennas.
- Development of central building LO synthesizers and roundtrip phase measurement system.
- Development of Station Master Reference system.
- Optical transmission hardware for the Operations Centre 40Gbps link including the 1GE WAN.

- Optical transmission hardware and network modules for the 1GE antenna monitor and control LAN.
- Installation of the Operations Centre multi-core fibre cable and repeater huts.

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Potential for Industry Participation

We are interested in hearing from potential industry collaborators or suppliers who can offer solutions for any of the steps outlined above

1. solutions for the transmission of data from the receiver to the beamformer (dot point 1)
2. provision of broadband fibre connections to Geraldton & Perth.

There is a separate briefing paper on the data transport requirements in progress: copies of this can be requested from the project team. In the mean time interested parties are encouraged to discuss their expertise with the team members.

H. ASKAP OPERATIONAL PLANNING

ASKAP will be sited in a radio-quiet zone and the challenge is to ensure that all systems developed at the site preserve this status. The initial (possibly, 6 antenna array) is scheduled to be commissioned in 2009 and the full ASKAP will be commissioned in 2011/12. The correlator is also to be located at the ASKAP site, with fibre taking the correlated data off-site for archiving and processing.

In terms of operations, some of the issues being addressed are:

- Who runs ASKAP? It will most probably be run by the CSIRO ATNF as a National Facility, along similar lines as the current ATCA at Narrabri, using the mechanisms that are already in place, e.g. time-assignment committees, user committees, booking facilities, etc. A key issue to be addressed related is that ASKAP will be sited in WA whereas the ATNF is presently situated on the east coast of Australia.
- Who can use it, and how is time to be allocated? The culture of Australian radio astronomy favours an open-access peer-review system.
- Where are data processed, and who is responsible for providing the software to do so? There should be no need for users to travel to WA to process their data. Several scenarios are being discussed, including having processing centres located at various alternative sites, e.g. Geraldton, Perth, Sydney.
- How is the operations scheduled, and what is the mode of user interaction with the instrument?
- What do we do with the archives?
- How do we maintain the instrument, and where would the maintenance staff be based?
- How do we interact with other instruments on site, such as the LFD?
- What are the operating and maintenance costs, and how are they funded?

- How do we commission ASKAP? Commissioning time will be considerable, but it is important that good science be generated early in the life of the instrument.

As at Q4 2006, work has begun on developing a strawman operational model. This work is being led by Ray Norris (CSIRO) The strawman operational model is intended to be a starting point for a wider discussion by non-ATNF stakeholders.

Potential for Industry Participation

A draft operational plan has been prepared and we will be inviting comments and input from industry in due course.

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ASKAP Smart Feeds – Dr John O'Sullivan

ASKAP Project Scientist
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APPENDIX A:

Related International Radio Astronomy Projects - International Links & Benefits

In this section we present brief descriptions of other projects, related to SKA R&D, worldwide.

International SKA Project Office (ISPO)

Project leader Richard Schilizzi, ISPO Office currently hosted by ASTRON, Netherlands

ISPO coordinates the activities of the international SKA consortium and oversees the planning for the eventual SKA facility.

More information: www.skatelescope.org

APERTIF

Project leader Wim van Cappellan, ASTRON, Netherlands.

APERTIF is a project to equip the Westerbork synthesis radio telescope with FPA. The FPA specification is similar to that for ASKAP.

More information: www.nwo.nl/projecten.nsf/pages/2300132562 and

www.skatelescope.org/SKAmeeting_Paris/pdf/APERTIF.pdf

EU FP6 RadioNet PHAROS

Project leader Jan Geralt bij de Vaate, ASTRON, Netherlands.

RadioNet is an integrated infrastructure initiative (I3) within the EC's Sixth Framework Program. PHAROS is one of 3 technology development programs within RadioNet, and is developing a prototype 5-7 GHz FPA. The FPA is based on Vivaldi architecture with an RF backend.

More information: www.radionet-eu.org

EU FP6 SKADS

Project leaders Andrew Faulkner, Jodrell Bank Observatory, University of Manchester ("2-PAD") and
Parbhu Patel, ASTRON, Netherlands ("EMBRACE")

The EU SKA Design Study ("SKADS") is a design study within the EC's Sixth Framework Program. The design study includes the development of an aperture tile array demonstrator ("EMBRACE") and also the development of a prototype, digital, aperture tile array ("2-PAD").

More information: www.skads-eu.org

EU FP7 PREPSKA

Project leader Phil Diamond, Jodrell Bank Observatory, University of Manchester

A proposal is in preparation for a full international preparatory study for the SKA. Funding will be for 4 years from Jan 2008. Australia, Canada, USA and South Africa are non-EU partners. PREPSKA will see the development of governance and operational structures as well as lead to the siting and technology selections in 2011.

The South Africa KAT Project

Project Manager Anita Loots,

The South Africa SKA project team's SKA prototype is named the Karoo Array Telescope ("KAT" and "meerKAT"), based on modest-size antennas (~15-m diameter) and horn cluster feeds.
More information: www.ska.ac.za

MWA or Low Frequency Demonstrator ("LFD")

Project leader Colin Lonsdale, MIT, USA
The MWA will be a new radio telescope based on crossed-dipole antennas (see picture of prototype below) which will operate in the 80 – 240 MHz range. The MWA will be co-located with ASKAP, to share infrastructure.
More information: www.haystack.mit.edu/ast/arrays/mwa

Image: prototype LFD antennas in WA Q3 2006.

USA Technology Development Program (TDP)

Project leader Jim Cordes, Cornell University, USA
The USA SKA TDP is a funding proposal to the NSF to cover a range of SKA-related R&D.

The low frequency Array "LOFAR"

Project leader Marco de Vos, ASTRON, Netherlands
LOFAR is funded by the Dutch government in the BSIK programme for interdisciplinary research for

improvements of the knowledge infrastructure of the Netherlands. It comprises an array of sensor networks, including antennas for radio astronomy, to cover the frequency range 30 – 240 MHz.
More information: www.lofar.org

The Allen Telescope Array "ATA"

Project Leader Leo Blitz

The Allen Telescope Array (ATA) is a joint project by the SETI Institute and the Radio Astronomy Laboratory at the University of California, Berkeley to construct a Radio Interferometer for astronomy and for simultaneous searching for extra-terrestrial intelligence.
More information: www.seti.org/site/pp.aspx?c=ktJ2J9MMIsE&b=179290

NASA JPL Deep Space Array Network (DSAN)

Project leader Mark Gatti, JPL CalTech

There are strong synergies between the next-generation DSN array and the SKA project: both are designed as low-element cost, large array systems, with multi-beam capabilities and collecting area of order 1 square km, although there are obvious differences (DSN requires uplink/transmit whereas SKA does not).
More information: dsnarray.jpl.nasa.gov

APPENDIX B

Radio Astronomy Technology Diffusion

On the international scale, astronomical tools and techniques have successfully been transferred to medicine, industry, defence and environmental science. For example, the Low-Intensity X-ray Imaging Scope (Lixiscope) has its origins in X-ray astronomy and is now one of NASA's largest sources of royalties. Astronomical data imaging techniques have been adopted for reconstructing 3-D images from CT scans, MRI (magnetic resonance imaging) and position emission tomography, for medicine, material science and other applications. Specific software developed for astronomy (e.g. IRAF and AIPS, developed by NRAO) have been applied to cardiac angiograms, monitoring neutron activity in the brain, studying car crash scenarios and testing aircraft hardware. The FORTH computer language, developed by NRAO, was commercialised and subsequently used to control systems in the space shuttle, Argo submersible vehicle, quality control of Kodak film production and extensively used in hand-held computers systems.

More generally, radio astronomy has driven

- the development of very low-noise receivers over a large frequency range (10's MHz to 100's GHz) with noise temperatures as low as 1 K per GHz. These have had wide application.
- the development of mm-thermography for medical application (~45 GHz)
- the detection of cancers at cm wavelengths (~10 GHz) with modern radiometers and using a method of mini-aperture synthesis (interferometry)
- the detection of forest fires via microwave radiation
- earthquake forecasting via very long baseline interferometry (VLBI) techniques
- the determination of many geophysical quantities including continental drift, polar shifting, latitude measurements, the variation of the earth's rotation and the fixing of the fundamental celestial reference frame
- the development of remote sensing to detect characteristics of the Earth's atmosphere
- weather monitoring via radiometers
- surveying of the ozone layer depletion via mm spectroscopy.

Astronomy-industry case histories

ATCA antenna development

An example of successful 'technology' transfer from an Australian project is found in the ATCA project. From the outset, the ATCA was always to be built in Australia and have high Australian content. The ATCA was developed from 1982 onwards, as a bicentennial project complete and operational in 1988.The total value of the Australian-supplied content is of order 90% of all components[6]: A key development for the ATCA included the design of the antenna dishes as shaped parabolas with high efficiency through to microwave frequencies (> 100 GHz).

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[6] No reliable reference or figure has been sourced for this %

Connell Wagner has been involved in supporting CSIRO both in the build, and subsequent development of the ATCA, and more recently on the major surface upgrade of the Parkes Telescope for the NASA Jupiter mission (Galileo) in 1995.

The expertise gained by Connell Wagner (and its forerunners and partner companies) has enabled them to win contracts for[7]

- the Australian Defence Satellite Communication Station in Geraldton (4 x 26 m diameter antennas)
- the Perth International Telecommunications station (1 new 20 metre and 1 refurbished 27.5 metre antenna)
- communications antennas in Australia, (6 x 18 metre diameter, not designed by CW, project management only) two in Vietnam and one in Cambodia
- numerous other smaller communications antennas

The early experience with the ATCA design and development enabled Connell Wagner to grow relationships with Aussat and Overseas Telecommunications Commission (OTC) leading to Satellite Earth Stations around Australia for Aussat and the OTC earth station at Oxford Falls. Subsequently Connell Wagner has developed a strong relationship with Optus of providing a wide range of management, design and consulting services on over 3500 sites for their GSM network and over 1000 sites for other mobile carriers around Australia.

As Tony Barry states “Connell Wagner has always valued its relationship with CSIRO and in a broader sense the science community. This relationship is one through which the co-dependence of engineering and the sciences has flourished. In 1995 Connell Wagner was presented with a copy of the Sir Ian McLennan Achievement for Industry Award made to CSIRO's Dr Bruce Thomas for "contributions to and development of the antennas design industry in Australia' which "recognises the part played by Connell Wagner Pty Ltd in the development".”

The contract value of the ATCA antenna spin-off alone has more than recovered the build cost of the ATCA ($50M) according to the study by the Bureau of Industry Economics[8]. The benefit-to-cost ratio for the antennas built for export has been assessed at 4.6:1. Around 20 earth station antennas for satellite communications have been built based on CSIRO expertise – most in Asia and the Pacific rim.

Another company that directly benefited from early R&D towards the ATCA was Austek Microsystems. Austek manufactured an array of 5000 signal processing chips for the correlator.

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[7] A Barry, NSW Director of Connell Wagner Pty Ltd

[8] DITAC, Aug 1991: Analysis of CSIRO Industrial Research: Earth Station Antennas

Thus the development phase of the ATCA clearly illustrated how Government funding of basic research stimulated industry. However, the benefits are not only from the initial R&D phase of facilities or instrumentation: There are also spin-off benefits to Australian industry during the operational phase of major facilities due to the necessity of maintaining sophisticated facilities and upgrading: An example of this would be the US-based SETI Institute who required a specialised wideband receiver for their project (AUD $2M) contracted from ATNF and Radiophysics (now ICTC). Projects such as this have a high international profile and wide impact, such that the SETI receiver contract generated orders for similar instruments for other international telescopes.

The development of new astronomical instrumentation is an opportunity for industry to engage in leading-edge R&D – which is particularly attractive to companies which rely on creating new markets. Industry may not make significant money from the development of astronomical devices, but the R&D often provides the basis of profitable technologies and future contracts as illustrated by Connell Wagner's experience.

Other Australian case histories

What follows is a snapshot of Australian companies either stemming from, or using technologies developed within Astronomy:

Austek Microsystems – founded 1984 semiconductor startup, Austek Microsystems. Following a first-round financing of $US 6.7 million in 1984, the company developed the world's first single-chip cache controller and other complex logic chips used by PC manufacturers in the U.S, Asia, and Europe, as well as the first asynchronous logic VLSI chip. Austek Microsystems Pty. Ltd. was a company founded to commercialize a break-through design technology developed by CSIRO through their VLSI Programme. Developments also included a floating-point arithmetic processor chip for an American computer company, samples of signal processing chips for Japan and the world's first single-chip cache controller operating at 20 MHz and to augment the performance of 80386-based computer systems.
Austek Microsystems went on to develop chip used in the Cochlear implant.

Lake Technology Corporation

In the late 1980s, the CSIRO Division of Radiophysics and Austek Microsystems co-developed digital signal processing technology for the development of new chips. Two engineers, Brian Conolly and David McGrath, saw a business opportunity in the technology in audio applications, and founded Lake DSP in 1991. (The company was renamed Lake Technology Limited when it later listed on the Australian Stock Exchange.)

Lake Technology's first customer was Bose, the well-known US audio company, which contracted Lake Technology to explore the development of digital audio signal processing products. The products developed under the contract were acoustic research tools which are still marketed to acoustic laboratories in Japan, the USA and Europe.

With the support of a Commonwealth industry R&D grant, Lake Technology developed the Huron Simulation tools, a package of software-based signal processing systems over the period 1993-6. These tools are suited to a range of virtual reality applications, such as virtual teleconferencing, interactive simulation of the acoustic qualities of buildings at the design stage, multi-player games and location-based entertainment for amenities such as theme parks.

The simplicity of the technology means that it can be incorporated in several consumer products. It is also easily implemented in a wide range of digital processing chips, thus opening the door to its use in most situations where headphones are used and leading to the development of the process known as Dolby Headphone.

Dolby Headphone allows people to listen to computer models of room acoustics and experience the sound as if they were present in the space being simulated. In 1997, Lake Technology began to market the headphone surround sound technology. In 1998, Dolby agreed to commercialise the technology as "Dolby Headphone". Singapore Airlines launched the technology in April 1999 for its in-flight entertainment. Lake Technology has subsequently licensed the technology to Qantas, Lufthansa and Cathay Pacific.In the eleven years since inception, Lake Technology has grown to a company employing more than 25 staff and listed on the Australian Stock Exchange in December 1999.

In December 2001, Dolby Laboratories acquired a strategic shareholding in the company, the first such investment by this world-leading company. This is expected to give rise to further licencing opportunities in the future and validates the quality of Lake's audio technology.

Accusound Pty Ltd started designing and manufacturing loudspeakers in 1984 based on the A4 chip designed for audio applications by the CSIRO radiophysics team working on the FFT and VLSI projects. They are now highly successfully developing and selling mid-range speaker systems.

AUSSAT Australia's national satellite company, now Optus Communications Pty. Ltd. provides a wide range of domestic services to the entire continent and its offshore islands. Services include direct television broadcast to homesteads and remote communities, high-quality television relays between major cities, and voice applications for urban and remote areas. In 1993 "Aussat" developed an L-band tracking satellite antenna as a joint project with CSIRO. When "Aussat" became "Optus" work was stopped on this project, although CSIRO continued development to a commercial product.

Radiata is the most successful Australian start-up whose origin lies in radiophysics research. The basic research into realising wireless LAN communications were developed in the 1990s and earlier radio research by many groups worldwide including CSIRO radiophysics and the Department of electrical engineering at Macquarie University. CSIRO funded the development based around 60 GHz given the expertise gained from radio astronomy and microwave landing systems, and developed a broadband wireless system based on the fast-fourier transform and coded orthogonal frequency division multiplexing (CODFM). A US patent (applicable to the ‘802.11a’ standard for WLANs – but also the .11g and .11j standards) was granted in 1995 (O’Sullivan et al, CSIRO). Radiata was formed in 1997 to meet the demand for 5-GHz based wireless LANS. Radiata was purchased by Cisco in 2000 for AUD 567M. The interaction with CSIRO radiophysics continued, with research into indoor radio propagation and antennas in particular.

Auspace Ltd was set up in the 1980s by a group of electronics engineers from Mount Stromlo Observatory (now RSAA), ANU, Having worked on the Starlab project (Australia-Canada-USA joint project) they pooled expertise in electronic cameras and spectrum scanners. Auspace now makes hardware for earth-observation satellites and telecommunications, has been the prime contractor for the re-build of the Gemini NIFS instrument (following the RSAA bushfire) and is a wholly owned subsidiary of EADS Astrium. Ausspace built FEDSAT. Two key personnel have background in astronomy, total workforce ~35, annual revenue ~$7M. About 40% of work from overseas.

Electro Optic Systems Pty Limited (EOS), based in Queanbeyan is a world leader in space research, having adopted the technologies for optical astronomical telescopes for satellite-ranging systems. EOS also now focus on the development of new technologies in space navigation and tracking, employing engineers in electronics, lasers, opto-mechanical and software development. 2 of 3 CEOs have astro background, 3/8 senior managers are astro background out of total of ~85 employees. Annual revenue ~$25M. About 95% of work comes from overseas.

Connell Wagner – already discussed

Poseidon Scientific Instruments The search for gravity waves by the University of Western Australia has led to new commercial technologies. One is an ultra-stable microwave oscillator, now licensed to an Australian company, Poseidon Scientific Instruments (PSI) and through it to US defence contractors. PSI launched as a technology consultancy with close links to university research (UWA) in 1988. In the early 1990's, Jesse Searls, the founder and managing director, recognized the potential of a unique technology then under research at UWA. At the heart of the technology is a high-quality sapphire-loaded cavity resonator which allows low noise signals to be generated directly at microwave frequencies. In 1993, the unique technology and cutting edge performance of the Poseidon oscillators quickly drew the attention of many of the world's largest and most sophisticated defense contractors. PSI’s signal generators were selected and designed into defense systems because they provided a strategic advantage that no other technology could match. In 1996, PSI's first commercially available low noise signal generator was introduced, with a "Shoebox" sized oscillator following in 1998. This totally Australian technology enables systems developers to build radars which can see many times further, with much higher resolution or with much lower system weight and cost than could be achieved with established technologies.

CSIRO Industrial Physics has unique expertise and capability to produce the precision optics (mirrors and beam splitters) required for NASA's LIGO and SIM missions (see http://www.tip.csiro.au/IMP/Optical/customers.htm). This expertise grew out of its work on solar astronomy (1970s) and the Sydney University Stellar Interferometer (1980s) – both of which required high-performance polished surfaces.

Altium Ltd Develops and sells electronic design automation (EDA) software used to design electronic products under MS windows. Sydney HQ, has 270-employees, 2 key top personnel with astro background. Annual revenue ~A$50M, 98% of its business is with overseas customers. Dave Warren of Altium was keen that the Sydney Univ group use Altium's FPGA routing/programming software (Protel) for the SKAMP project. There were discussions between Altium & Tim Adams which triggered some amendments/improvements in the software.

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