NATIONAL COLLABORATIVE

RESEARCH INFRASTRUCTURE STRATEGY

Investment Plan

For the research capability

Radio and optical astronomy

v2.2

August 23 2006

Version	Date	Comments
1.0	31 June	Initial version distributed to community for comments
1.1	7 July	Progress report submitted to NCRIS
1.2	31 July	Included summary section and section on data management
2.0	17 August	Revised investment profile based on NCRIS feedback. Revised contributions from proponents.
2.01	18 August	Minor editing of infrastructure cases
2.02	19 August	Inclusion of further items on GMT and AAO regional benefits
2.03	21 August	Addition of input from Governance WG
2.04	22 August	Further edits from proponents
2.1	23 August	Further edits from proponents
2.2	24 August	Financial tables included, updated organization charts

INSTRUCTIONS

Purpose

This Investment Plan is to be completed in respect of funding to support Australian research infrastructure under the National Collaborative Research Infrastructure Strategy (NCRIS).

Guidance on issues related to the development of this Investment Plan can be found in the NCRIS Roadmap and NCRIS Investment Framework.

GST

The Department will not provide funding to cover any amounts of GST incurred by any Party to the Investment Plan in circumstances where the applicant is entitled to claim input tax credits for those GST amounts. Therefore, budget figures should be the GST exclusive costs of all items in respect of which any Party is entitled to an input tax credit.

Confidential Information

No confidential information should be included in this Investment Plan.

If it is considered necessary to provide certain confidential information to the Department or the NCRIS Committee in association with this Investment Plan, then only a non-confidential summary explaining the nature and ownership of the information should be provided in Attachment J. DEST will then contact relevant parties to obtain access to the confidential information in an appropriate manner.

Consideration of Investment Plans

Investment Plans will only be considered by the NCRIS Committee and DEST if they have been prepared by the Facilitator identified for the relevant NCRIS Research Capability.

CONTENTS

PART ONE – FACILITATOR'S DECLARATION

I, [Facilitator's name], confirm that I have prepared this Investment Plan in accordance with the NCRIS principles as set out in the NCRIS Investment Framework.

………………………………………..
Signed

Brian J Boyle
………………………………………..
Name

7 September 2006
………………………………………..
Date

PART TWO - OVERVIEW

Details of the organisation that will contract with the Commonwealth:

Organisation Name:	**Astronomy Research Australia Ltd**
Ultimate parent organisation *(if appropriate):*	
Organisation Type *(please select one of the following)* - Higher Educational institution; - Australian Government research institution; - State or territory research institution; - Private sector research organisation; - Other (Please state)	
Contact Officer *(name and position held)*:	
Phone number:	
Fax number:	
Email Address:	
Website:	
Physical Address:	
Postal Address for all correspondence*:*	

Details of all other organisations that will contribute resources to this Investment Plan:

Organisation Name:	
Organisation Type *(please select one of the following)* - Higher Educational institution; - Australian Government research institution; - State or territory research institution; - Private sector research organisation; - Other (Please state)	
Contact Officer details (please include Name, Position, Phone Number and Email Address):	

Organisation Name:	
Organisation Type *(please select one of the following)* - Higher Educational institution; - Australian Government research institution; - State or territory research institution; - Private sector research organisation; - Other (Please state)	
Contact Officer details (please include Name, Position, Phone Number and Email Address):	

Organisation Name:	
Organisation Type *(please select one of the following)* - Higher Educational institution; - Australian Government research institution; - State or territory research institution; - Private sector research organisation; - Other (Please state)	
Contact Officer details (please include Name, Position, Phone Number and Email Address):	

Funding Summary:

Table 1: Outline of the overall funding (GST exclusive) for the Investment Plan:
Table 2: Summary of the contributions to be made by each participant organisation:

(Tables 1 and 2 combined, as Table 2 is basically a sub-total that feeds in to Table 1)

Organisation		2006/07	2007/08	2008/09	2009/10	2010/11	Total
NCRIS	Cash	$3,433,500	$8,684,067	$8,821,600	$14,781,853	$9,278,980	$45,000,000
	Total	$3,433,500	$8,684,067	$8,821,600	$14,781,853	$9,278,980	$45,000,000
ANU	In-kind	$1,300,000					$1,300,000
	Total	$1,300,000					$1,300,000
Members	Cash	$60,000	$164,300	$174,158	$184,605	$195,681	$778,744
	Total	$60,000	$164,300	$174,158	$184,605	$195,681	$778,744
ARC	Cash		$867,000	$889,000	$911,000	$933,000	$3,600,000
	In-kind	$2,222,243	$936,543				$3,158,786
	Total	$2,222,243	$1,803,543	$889,000	$911,000	$933,000	$6,758,786
CSIRO	In-kind	$3,920,000	$6,280,000	$7,630,000	$7,330,000	$4,840,000	$30,000,000
	Total	$3,920,000	$6,280,000	$7,630,000	$7,330,000	$4,840,000	$30,000,000
GSKA MNRF	In-kind	$4,614,655					$4,614,655
	Total	$4,614,655					$4,614,655
UNSW	In-kind	$62,500	$125,000				$187,500
	Total	$62,500	$125,000				$187,500
WA Govt	In-kind		$2,000,000	$4,500,000	$3,500,000		$10,000,000
	Total		$2,000,000	$4,500,000	$3,500,000		$10,000,000
Total		$15,612,898	$19,056,910	$22,014,758	$26,707,458	$15,247,661	$98,639,685

Table 3: Breakdown of expenditure (the totals should match those in Table 1):

Type	2006/07	2007/08	2008/09	2009/10	2010/11	Total
Expense - International Access	-$6,464,898	-$3,423,210	-$3,766,000	-$3,828,666	-$3,121,833	-$20,604,607
Expense - Operating	-$3,878,000	-$3,185,033	-$5,088,092	-$5,116,792	-$4,647,161	-$21,915,078
Expenses - Capital	-$5,270,000	-$11,200,000	-$13,130,000	-$17,730,000	-$8,790,000	-$56,120,000
Grand Total	-$15,612,898	-$17,808,243	-$21,984,092	-$26,675,458	-$16,558,994	-$98,639,685

Additional Tables

Table 4: Breakdown of revenue per facility and organisation

Facility	Funding		2006/07	2007/08	2008/09	2009/10	2010/11	Total
6.19% Gemini	ARC	Cash		$867,000	$889,000	$911,000	$933,000	$3,600,000
		In-kind	$2,142,243	$936,543				$3,078,786
		Total	$2,142,243	$1,803,543	$889,000	$911,000	$933,000	$6,678,786
	GSKA MNRF	In-kind	$2,074,655					$2,074,655
	Total		$2,074,655					$2,074,655
	NCRIS	Cash		$3,168,334	$3,219,666	$3,273,666	$1,214,500	$10,876,166
		Total		$3,168,334	$3,219,666	$3,273,666	$1,214,500	$10,876,166
Total			$4,216,898	$4,971,877	$4,108,666	$4,184,666	$2,147,500	$19,629,607
AAO	NCRIS	Cash	$950,000	$2,720,000	$2,800,000	$2,500,000	$1,050,000	$10,020,000
		Total	$950,000	$2,720,000	$2,800,000	$2,500,000	$1,050,000	$10,020,000
Total			$950,000	$2,720,000	$2,800,000	$2,500,000	$1,050,000	$10,020,000
ARA	Members	Cash	$60,000	$164,300	$174,158	$184,605	$195,681	$778,744
		Total	$60,000	$164,300	$174,158	$184,605	$195,681	$778,744
	NCRIS	Cash	$183,500	$237,140	$243,340	$249,593	$255,886	$1,169,459
		Total	$183,500	$237,140	$243,340	$249,593	$255,886	$1,169,459
Total			$243,500	$401,440	$417,498	$434,198	$451,567	$1,948,203
Gemini additional	GSKA MNRF	In-kind	$2,540,000					$2,540,000
		Total	$2,540,000					$2,540,000
Total			$2,540,000					$2,540,000
GMT	ANU	In-kind	$1,300,000					$1,300,000
		Total	$1,300,000					$1,300,000
	NCRIS	Cash	$1,300,000					$1,300,000
		Total	$1,300,000					$1,300,000
Total			$2,600,000					$2,600,000
GMT/ PILOT/8m	NCRIS	Cash		$358,593	$358,594	$358,594	$358,594	$1,434,375
		Total		$358,593	$358,594	$358,594	$358,594	$1,434,375
Total				$358,593	$358,594	$358,594	$358,594	$1,434,375
MIRA	CSIRO	In-kind	$3,920,000	$6,280,000	$7,630,000	$7,330,000	$4,840,000	$30,000,000
		Total	$3,920,000	$6,280,000	$7,630,000	$7,330,000	$4,840,000	$30,000,000
	NCRIS	Cash	$500,000	$1,700,000	$2,200,000	$8,400,000	$6,400,000	$19,200,000
		Total	$500,000	$1,700,000	$2,200,000	$8,400,000	$6,400,000	$19,200,000
	WA Govt	In-kind		$2,000,000	$4,500,000	$3,500,000		$10,000,000
		Total		$2,000,000	$4,500,000	$3,500,000		$10,000,000
Total			$4,420,000	$9,980,000	$14,330,000	$19,230,000	$11,240,000	$59,200,000
PILOT	ARC	In-kind	$80,000					$80,000
		Total	$80,000					$80,000
	NCRIS	Cash	$500,000	$500,000				$1,000,000
		Total	$500,000	$500,000				$1,000,000
	UNSW	In-kind	$62,500	$125,000				$187,500
		Total	$62,500	$125,000				$187,500
Total			$642,500	$625,000				$1,267,500
Grand Total			$15,612,898	$19,056,910	$22,014,758	$26,707,458	$15,247,661	$98,639,685

Table 5: Breakdown of expenditure per facility

Facility	Transaction Type	2006/07	2007/08	2008/09	2009/10	2010/11	Total
6.19% Gemini	Expense - International Access	-$3,924,898	-$3,423,210	-$3,766,000	-$3,828,666	-$3,121,833	-$18,064,607
	Expense - Operating	-$292,000	-$300,000	-$312,000	-$324,000	-$337,000	-$1,565,000
	Total	-$4,216,898	-$3,723,210	-$4,078,000	-$4,152,666	-$3,458,833	-$19,629,607
AAO	Expense - Operating	-$600,000	-$1,000,000	-$1,000,000	-$1,000,000	-$500,000	-$4,100,000
	Expenses - Capital	-$350,000	-$1,720,000	-$1,800,000	-$1,500,000	-$550,000	-$5,920,000
	Total	-$950,000	-$2,720,000	-$2,800,000	-$2,500,000	-$1,050,000	-$10,020,000
ARA	Expense - Operating	-$243,500	-$401,440	-$417,498	-$434,198	-$451,567	-$1,948,203
	Total	-$243,500	-$401,440	-$417,498	-$434,198	-$451,567	-$1,948,203
Gemini additional	Expense - International Access	-$2,540,000					-$2,540,000
	Total	-$2,540,000					-$2,540,000
GMT	Expense - Operating	-$2,600,000					-$2,600,000
	Total	-$2,600,000					-$2,600,000
GMT/ PILOT/8m	Expense - Operating		-$358,593	-$358,594	-$358,594	-$358,594	-$1,434,375
	Total		-$358,593	-$358,594	-$358,594	-$358,594	-$1,434,375
MIRA	Expense - Operating		-$1,000,000	-$3,000,000	-$3,000,000	-$3,000,000	-$10,000,000
	Expenses - Capital	-$4,420,000	-$8,980,000	-$11,330,000	-$16,230,000	-$8,240,000	-$49,200,000
	Total	-$4,420,000	-$9,980,000	-$14,330,000	-$19,230,000	-$11,240,000	-$59,200,000
PILOT	Expense - Operating	-$142,500	-$125,000				-$267,500
	Expenses - Capital	-$500,000	-$500,000				-$1,000,000
	Total	-$642,500	-$625,000				-$1,267,500
Total		-$15,612,898	-$17,808,243	-$21,984,092	-$26,675,458	-$16,558,994	-$98,639,685

Project Description

In no more than five pages, please provide a summary of the Investment Plan that addresses the recommendations of the NCRIS Roadmap and the Investment Criteria set out in the NCRIS Investment Framework.

<u>Alignment with NCRIS roadmap</u>

The NCRIS roadmap states:

> For Australia to remain a major international contributor to astronomy it is essential that we continue to have a strong presence in leading-edge international infrastructure, both the current and next generations. Australia also needs to maintain the domestic infrastructure which constitutes the bulk of observing capacity for Australian astronomers.

This balanced strategy is implemented in this plan by investing in the following domestic and international optical and radio infrastructure, identified as highest priorities in the communities strategic plan *New Horizons: The Australian Astronomy Decadal Plan 2006-2015.* These are:

- Anglo-Australian Observatory
- Gemini telescopes (6.19% share of the two 8m-diameter telescopes)
- Mileura International Radio Array (MIRA): A pathfinder for the Square Kilometre Array (SKA)
- Additional access up to the equivalent of 15% of an 8m-class telescopes including the effective 12.4% from Gemini
- Design and development for the next generation of optical/infrared telescopes; the Giant Magellan Telescope (GMT) and PILOT.

These reflect the strategic infrastructure priorities laid out in the NCRIS roadmap viz.

> The Australian astronomy community has identified its priorities for infrastructure investment in the *Australian Astronomy Decadal Plan 2006-2015*. Consistent with that plan, the Committee considers that the priority areas for NCRIS investment in optical and radio astronomy should be (in no specific order):
> - Additional support for the Anglo-Australian Observatory (AAT optical/infrared telescope);
> - Delivery of the Square Kilometre Array (SKA) *Phase 1* radio telescope facility; and
> - Access to the equivalent of 20% of an 8m-class telescope through the existing Gemini partnership and through new telescope and instrument agreements.

The plan also proposes the strategic investments to be made in the next-generation of optical/IR facilities to provide valuable options in the future development of any case for Landmark-scale infrastructure in this domain as recommended by the NCRIS committee in the strategic roadmap viz.

> The Committee considers the National Committee of Astronomy's recommendation that a Giant Magellan Telescope Landmark Facility Committee be established by relevant government, business and academy partners to work towards Australian participation in the GMT consortium has merit and encourages the parties to consider it.

Excellence in Australian research: NCRIS Investment Criterion 1

Astronomy is one of Australia's highest impact sciences (*Australian Science and Technology At a Glance*, DEST, 2004), with internationally acknowledged strengths in ground-based optical and radio astronomy, backed by theory and computation. In the past decade, Australian astronomers have played leading roles in major discoveries, including the acceleration of the universe and the existence of dark energy, a new type of galaxy, a unique double pulsar, and planets orbiting other stars. The impact of Australian astronomy has risen significantly compared to the rest of the world over the past 5 years. Over the period 1994-98, papers with Australian authors received an average of 5.5 citations (cf. world average 5.0); by the period 1998-2002, this had risen to 9.9 citations (cf. world average 6.8) [Source: *Australian Astronomy Decadal Plan 2006-2015*, adapted from *ANU Capabilities and Performance Statement 2004*]. This has been driven by the capability's access to world-class infrastructure, principally the 3.9m optical/IR Anglo-Australian Telescope, the radio telescopes of the Australia Telescope National Facility and, more recently, the twin 8m Gemini optical/IR telescopes.

Each of the components of this plan offers Australian astronomy either an internationally *unique capability* in some valuable sense (e.g. the AAO as the world's fastest survey spectroscopy machine, PILOT as one of the world's most sensitive mid-infrared telescopes) or access to a *world-best facility* (Gemini now, MIRA in five year's time, GMT in 10 years and SKA in 15 years). The combined suite of facilities encompassed by this research capability addresses both fundamental (dark matter and dark energy) and exciting (black holes and planets) topics in astronomy and physics.

Access policies and capacity to promote collaboration: NCRIS Investment Criterion 2

The principles of merit-based time assignment and effective data management systems are embedded in the infrastructure proposed in this investment plan. These are already, or will be, facilitated by integrated proposal and data management systems, including WWW-based telescope-time application and peer-review procedures, comprehensive on-line archives, availability of pipeline data-reduction tools and researcher access to reduced data products and catalogues.

In astronomy, forefront science can only be done in cooperation with scientists from around the world and scientists working in different wavelength regions. The substantial benefits that accrue from such linkages include access to cutting-edge data and technologies, leveraging of the scientific funding of larger nations, and increased international collaboration.

Australian astronomy has a strong culture of international linkage – it leads the nation in the fraction of publications produced with international collaborators, its on-shore facilities are in high demand from international users, and all its new facilities proposed in this plan will be built with international partners:

- 77% of Australian astronomy papers over the past decade have international co-authors;
- 40% of the users of Australian national facilities come from overseas;
- 33% of Australian astronomy citations arise from international astronomy facilities to which Australia makes no financial contribution (cf. ~5% of Australian astronomy spending devoted to international facilities).

Facility Ownership and Management Structure: NCRIS Investment Criterion 3

A central component of the plan is the establishment of a single Governance body for the management of the NCRIS investment; Astronomy Research Australia Ltd (ARA). ARA is constituted to provide effective, broad-ranging oversight of the NCRIS program, with an expert Board capable of taking the strategic decisions over the period of the NCRIS plan.

ARA will give the Australian government a single point of accountability, initially in the governance of any NCRIS investment in astronomy, and potentially growing to include other items of national infrastructure for astronomy.

ARA will contract the day-to-day operation of the domestic facilities (AAT, MIRA) to existing Australian organizations (AAO, CSIRO respectively). Both have a long-standing record of world's-best practice in the operation of astronomical infrastructure. ARA will contract the management of the Australian Gemini Office to AAO, while the signatory for the Gemini Agreement with the international agencies/organisations will remain the ARC-DEST.

In the long term, ARA may provide a comprehensive solution for the funding and management of national astronomy facilities, simplifying the complex existing arrangements while offering sufficient versatility to interface Australia with the next generation of international facilities. As such, the long-term rationalisation of the infrastructures supporting Australian astronomical research potentially enabled by the establishment of ARA may prove to be one of the most valuable outcomes of the NCRIS process. Although this investment plan proposes that the ARA costs be shared between NCRIS and the members, the long-term sustainability may be best guaranteed by members contributing a significantly larger fraction, up to 100%, as ARA grows over the 2006-11 period.

Implementation Strategy and Effective Business Case: NCRIS Criterion 4

Within its $45M indicative envelope, the investment plan proposes significant investment in MIRA ($19.2M), AAO ($10M) and Gemini ($6.9-10.6M). Further, it proposes initial limited (~$1M) investment in a PILOT design study and in the first year of the design and development phase (DDP) for GMT. The plan also proposes a number of strategic options (up to $5M) in the optical domain. This includes further investment in the GMT DDP, PILOT construction and/or additional 8m time.

The breadth of this plan reflects the maturity of the field's science and infrastructure, and the comprehensive stock-taking and strategising of the Decadal Plan process. The 'conditionality' of the strategic options in the plan is a rational and prudent response to the inevitable uncertainties of a 5-year plan, particularly one with international linkages.

In particular, the astronomy capability views the initial PILOT and GMT investments as central to the success of this 'strategic options' strategy. Information obtained from these studies will enable ARA to most effectively evaluate the option (or combination of options) that will maximise the scientific return to the capability and economic/social return to the country.

The plan maps out the long-term evolution of a carefully structured set of major facilities. These facilities have individual lifetimes of decades, from original concept, through design, construction, operation and revitalisation, to ultimate decommissioning. For the health of Australian astronomy we need to be supporting facilities at all stages of this lifecycle, as indeed this plan does. Specifically, the plan provides for the revitalisation of the AAO, on-going operation and access for Gemini (and perhaps other 8m telescopes), the design and development for GMT, PILOT and MIRA, and the construction of MIRA (and, perhaps, PILOT); it also foreshadows the decommissioning of the AAT and de-scoping of existing radio facilities by the time GMT and SKA come into operation.

The proposed infrastructure enables a broad range of scientific investigations and supports the research of essentially the entire optical and radio astronomy community, as well as having important applications in other science areas such as space science and ICT. The strategy has been developed with a clear recognition that Australia's role in international astronomy will be limited by access to funds and it is very much in the interests of the wider Australian community that the available funds be directed for maximum impact and value. This has involved sober assessment of those areas in which Australia can be most competitive[1], the development of a

1 . This has involved the explicit de-priotisation of investment in space-based astronomy and in certain major international facilities such as the Atacama Large Millimetre Array.

vision of how Australia can exploit these areas of competitive advantage to the benefit of all astronomy – and turning this into an explicit strategy for the future.

The 5-year financial plan is secured by strong commitment of funding from a range of co-investors, and by a planning process designed to ensure adequate flexibility to deal with the uncertainties inherent in this type of infrastructure planning. This approach will allow ARA to respond to changing information – on costs, feasibility, value and revenues – to ensure maximum value is obtained from the NCRIS and co-investment funds while managing key risks. Use of options-based principles for planning and managing the strategy – in a manner analogous to the earlier work done on the SKA Business Case – ensures that risk management is integrated into the investment process and that the flexibility exists to respond to risks and opportunities as they emerge.

Key elements of the strategy – especially in relation to MIRA, PILOT and GMT – are in fact sound investments in information options on which longer term planning for the next generation of large facilities can be based.

At the same time, both MIRA and PILOT are seen as extremely valuable infrastructure in their own right that are deliverable within the time-frame of NCRIS. Involvement in the design phase of GMT will also build capability in relevant industries and academic departments, which may later be exploited in the construction and operational phases of the telescope.

From the perspective of international leverage, the $45m NCRIS investment yields access to $632m [##need to check this figure] in infrastructure proposed over the 5-year period 2006-11. The NCRIS investment critically enables the Australian astronomers to surmount the participation hurdle in international programs and consequently exploit the investments made by other partners in such large-scale infrastructure. The minimum required scale for competitive user facilities in the 21^{st} century means that dollars invested in an international collaborative project will often yield better value for money than dollars invested in a nationally-based one.

It has been possible to establish the longer term viability of the investments with a high degree of confidence. This is based on financial commitments already made; on high levels of wider interest in access to these infrastructure assets that are, and will be for a long time to come, state-of-the-art; and on the presence of active markets in trading access rights that offer both risk coverage and opportunities to expand involvement where justified. For these very large infrastructure assets, we have had to assume that a form of continuing government involvement would be available beyond 2011.

PART THREE – RESEARCH INFRASTRUCTURE

In this part, you are required to show how the proposed infrastructure facilities meet NCRIS Investment Criterion 1, ie:

> **An investment plan must result in excellent research infrastructure that addresses the national requirements of the relevant capability area described in the NCRIS Roadmap.**

In addressing the criterion, you should fully address:

- all issues relevant to Criterion 1 that are identified in the NCRIS Roadmap; and
- the requirements of Section 3.1 of the NCRIS Investment Framework 'Content of Investment Plans'.

This part should detail all infrastructure that is to be funded by this Investment Plan, including any elements that relate to Platforms for Collaboration.

The assets that will be funded by this Investment Plan should be detailed in Attachment A.

……………………………………………………………………………………..

National Requirements – the Australian Astronomy Decadal Plan 2006-15

The Australian astronomy community has been characterized over the last decade by coherent strategic planning across all wavelength bands and sub-disciplines, exemplified by the unified plan for major optical and radio facilities funded under the MNRF-2 program. In 2005, the Australian astronomical community mapped out its strategic vision in *New Horizons: A Decadal Plan for Australian Astronomy 2006-15*. The Decadal Plan identifies the national requirements relating to astronomy and proposes a strategic roadmap that addresses these requirements and is well supported across the astronomy community. Although the Decadal Plan pre-dates the finalisation of the NCRIS process, the strategic aims of both the Decadal Plan and the NCRIS process are highly aligned. This includes a strong focus on world-class science outcomes and on a national, collaborative (integrated) approach to achieving those outcomes, and equal emphasis on laying the foundations for the infrastructure of next decade in the optical and radio domains. NCRIS funding has a central role to play in delivering the Decadal Plan strategy, and the infrastructure investments proposed in this Investment Plan are consistent with the strategy proposed in the Decadal Plan.

National Requirements – the NCRIS context

- Infrastructure is a critical component of an observationally led capability such as astronomy. In this area, the Decadal Plan highlighted the following key strategies.
    - A strong focus on engagement in international collaborations
    - Investment in the next generation of front-rank infrastructure in both optical and radio astronomy.
    - Maintain appropriate investment levels in existing world-class infrastructure until new infrastructure is available, followed by reprioritisation of resources.

National Requirements - Science Focus

The primary focus of most astronomy research – and the proposed application of the research infrastructure for which NCRIS support is being sought – is knowledge derived for its own sake.

Knowledge of the universe is a public good, one in which there is substantial interest and which provides cultural value, perhaps the greatest being the inspiration of young minds to think scientifically and to enter scientific and engineering careers. While we have identified scope for significant tangible benefits from the proposed infrastructure investment, we are not arguing that this should constitute the primary rationale. We are proposing support for truly excellent science directed at the most fundamental questions about our universe.

The Decadal Plan sets out, and discusses, nine big questions yet to be satisfactorily answered, where the emerging tools of modern astronomy have good prospects for making a major contribution:

- What is the nature of the dark energy and dark matter that appears to make up about 95% of the universe?
- How and when did the first stars form in the early universe?
- How are galaxies assembled and how do they evolve?
- Is our understanding of gravity correct?
- How do the super-massive black holes in the cores of galaxies work?
- What is the origin and evolution of cosmic magnetism?
- How do stars and planetary systems form?
- How common are planetary systems and conditions suitable for life?
- How do stars produce and recycle the elemental building blocks of life?

All these questions are concerned with the basic conditions that shape, and have shaped, us and the world in which we live. The same astronomy that probes the limits of our universe is also probing the limits of our understanding of many of the laws of physics and the very nature of matter and energy. The suite of infrastructure proposed for investment will enable Australian astronomers to continue to make world-leading contributions to answering these questions.

National Requirements - International focus

The Investment Plan focus is on a small group of major research infrastructure investments that will support Australia continuing to play a key role at the forefront of international astronomy. Astronomy is a truly international science that is now highly dependent on internationally funded and operated major infrastructure facilities. Sophisticated systems for sharing costs and for managing access to ensure that the best science is undertaken by the best scientists – with appropriate technical support in, and development of, the facilities – have been developed by the international astronomy community[2]. Over the past 30+ years, the Anglo-Australian Telescope has been an Australian-based example of this approach in optical astronomy, while the ATNF has served as the exemplar in radio astronomy for almost 20 years. Closely analogous systems apply to the Gemini telescopes and are planned for the Giant Magellan Telescope, the Antarctic PILOT telescope and the Mileura International Radio Array (MIRA).

The principles embodied in these systems closely parallel the vision developed in the NCRIS Roadmap – in relation to both the collaborative design and development of facilities and the basis on which access is provided.

Several principles have been central to the development of the investment proposition set out in this document:

- A predominant consideration through the strategy development has been its focus on supporting *excellence in science* – internationally competitive, involving deep international collaboration and in many cases operating at the world leading edge – in astronomy.
- The strategy also recognises the scientific and economic benefits of combining support for Australian facilities, with obtaining access to large international facilities at the best off-shore sites. Thus we can maintain Australia's high international standing in astronomical science across many wavelength bands.

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[2] 77% of Australian astronomy papers over the past decade have international co-authors (New Horizons: A Decadal Plan For Australian astronomy 2006-2015, Australian Academy of Sciences)

- We focus on areas where Australia has an established presence and capability in international astronomy of a very high order, and thus real competitive advantage
- Excellence in the skill set is a central element of competitive advantage in a field that is increasingly competing for access to facilities located around the world. Australia has in the past proven highly competitive in this way, and a key element of the strategy is designed to maintain this competitive advantage. These skills include those relevant to the cost-effective delivery of capability to telescopes via smart instrumentation and data capture and analysis capabilities.
- In two items of proposed infrastructure, one currently more developed than the other, Australia appears highly competitive in the *location* of prospective new facilities:
    - A next generation radio telescope, the Mileura International Radio Array (MIRA), capable of internationally competitive science breakthroughs, and with good prospects for enhancing Australia's competitive advantage for siting the proposed Square Kilometre Array facility in Australia. The strategy has been designed to deliver a major upgrade to Australian radio astronomy capability while being consistent with the cost-effective/risk-mitigated option of progressive upgrading of the investment out to the full SKA. The strategy maximizes Australia's prospects for playing a leading role in the technology development in SKA in addition to being selected as the site for this facility.
    - The first major Antarctic optical/infrared telescope, with Australia well placed to support such a facility in the Australian Antarctic Territory, with the viability of this strategy having been enhanced recently with the construction of airport facilities.
- Involvement through NCRIS in the GMT design phase will provide opportunities to showcase existing R&D infrastructure within Australian industry, in high-technology areas where there is increasing international activity and contract opportunities. In this context, Australian astronomy is most useful tool for the nation, due to the discipline's strong international links in the areas of interest. International exposure through the GMT DDP process will create enhanced opportunities for Australian industry to win contracts in ELT design and construction, both through the GMT itself, and, in addition, other ELT projects under consideration. .
- The GMT offers opportunities for Australian business both in niche high technology areas, and also in high-level technology integration, project management and systems engineering; winning contracts in these areas, which are Australian strengths, will expand capability through involvement in a challenging international project. Thus the initial modest investment proposed through NCRIS has the potential to return substantially enhanced benefit to Australian R&D capability and the economy. In this Investment Plan, we propose investment in the first year of the GMT DDP as a priority item for expenditure. This will provide Australian industry and academia with the resources required to coordinate and demonstrate Australian R&D capability in the area of ELT design and development. Such investment is also necessary to inform future decisions about further GMT engagement, both in the .current design phase and hence in the ensuing construction phase, for which funding will have to be sought beyond the NCRIS process.

The strategy will deliver the collective capability to continue to compete and contribute at the leading edges of international astronomy, while ensuring that the full range of capabilities Australia offers in relation to future astronomy – from sites for telescopes, through main instrument design and other instrumentation through to the planning and execution of great science using the instruments – is able to compete on merit. Under these circumstances, we fully expect Australia to continue to 'punch well above its weight class' in astronomy for many years to come.

The strategy as developed does offer very substantial opportunities for leverage. NCRIS investment will make significant contribution to building Australia's case as a location for, and designer and builder of, future very large astronomy facilities that will draw on international funding.

Australian scientists will gain access to internationally leading-edge facilities that are only made possible by the level of contribution of funds from other countries, and by the ability of Australian institutions to bring considerable additional resources to both the planning and the use of the facilities[3]. There are now very large size economies in both optical and radio astronomy. The strategy is designed to exploit these economies and the commitment of other countries and other institutions to this major area of research to deliver a dramatic increase in the capability of the facilities to which Australian astronomy has access. The prospects for NCRIS investment in radio astronomy are already attracting substantial state and international interest in co-investment in the MIRA facility.

The budgeting describes the extent to which other funding sources are sought even for the specific infrastructure items within the NCRIS funding program. Just as importantly, these facilities will add greatly to the strength of the case for even wider leverage in relation to future investments in the SKA, in the Giant Magellan Telescope and in a much larger Antarctic telescope. In two of these three cases, the chances of an Australian location being chosen by the international consortia is substantial – which is likely to increase the effective level of leverage in relation to total Australian benefits. In the third (GMT), an Australian consortium of industry and academia has already formed to coordinate bids that could bring substantial return to the Australian economy, both in overseas investment, intellectual property and international exposure.

National Requirements – Likely Demand and Encouraging Collaboration

The benefits that accrue from the international linkages that are an essential component of modern astronomy are substantial, and include access to cutting-edge international instruments, data and technologies, leveraging the scientific funding of larger nations, and increased international collaboration. Australian astronomy has a strongly developed culture of international linkage – astronomy leads the nation in the fraction of publications it produces with international collaborators, Australian astronomers use international facilities, its on-shore facilities are in high demand from international users, and almost all its next-generation facilities will be built with international partners.

The main national optical/infrared facilities for Australian astronomers - Gemini and AAT - have typically been over-subscribed by factors of between 2 and 3 over the past few years; these are considered healthy factors for competitive facilities by international standards.

In the case of the AAT, this demand level under-predicts future Australian requirements because it does not take into account the demand for large-scale observing programs that until recently had been not been fully explored. The AAO's announcement of opportunity for Large Observing Programs starting in 2006 resulted in requests for 1500 nights over the next 3 years – i.e. these programs alone over-subscribe the telescope by a factor of 1.5. Together with the current level of demand for smaller programs, these large programs will maintain the future over-subscription on the AAT remain at around its current level even as the Australian share of AAT time increases from 50% to 100% over the next 4 years. Demand would be further stimulated by the new AAT instrument funded by NCRIS, which will provide new capabilities that address the needs of Australian astronomers in a broad range of fields. The unique capabilities of the full AAT instrument complement, particularly in the area of wide-field survey spectroscopy, will also encourage international collaborations and provide Australian astronomers with leverage for collaborative access to other countries' facilities.

In the case of Gemini, the current over-subscription rate is close to the point of being self-limiting – i.e. astronomers would like more access but do not find it worthwhile to submit additional, or larger, observing proposals when the over-subscription exceeds a factor approaching 4. This has been demonstrated by the increased level of demand on the occasions that there have been one-off opportunities for Australian astronomers to access additional time on Gemini or other 8m telescopes – the amount of available time has increased, but the over-subscription factor has remained roughly constant. Demand for Gemini time is only likely to become stronger as Gemini

[3] 33% of Australian astronomy citations arise from international astronomy facilities to which Australia makes no direct financial contribution (ibid.)

introduces new and more capable instrumentation; the next generation of "Aspen" instruments is expected to offer powerful new capabilities (very high resolution imaging and massively multiplex spectroscopy) that are not otherwise available to Australian astronomers. These instruments will address fundamental science questions (specifically, the formation of planets, the origin of the Galaxy, and the nature of dark energy) that will be tackled by international collaborations in which Australia will play a significant, and in some cases leading, role.

For MIRA, the unique combination of fast mapping speed with high angular resolution ensures that the mid-frequency component of MIRA will provide a surveying capability at least ten-fold greater than any existing radio telescope. National and international demand for this telescope is likely to significantly exceed recent over-subscription rates on the Australia Telescope Compact Array (approximately 2:1). Within its first year of operation MIRA will produce a catalogue of HI emission in more than 500,000 galaxies to unprecedented redshifts, while simultaneously cataloguing 10 million continuum sources in the deepest all-sky continuum survey to date. Previous catalogues, such as the HIPASS HI galaxy catalogue and particularly the Northern VLA Sky Survey (NVSS) continuum catalogue, are among the most highly cited astronomy papers of the past decade (from Astrophysical Data Service citations). All indications are that with the increasing concentration of large telescopes (including ALMA) in the southern hemisphere, catalogues with at least an order of magnitude more sources will carry similar weight. The low-frequency component of MIRA will be opening up an unexplored frequency range and the new science that will be possible with the instrument should ensure that it is in high demand. There are many Australian institutions already participating to develop the initial stages of this instrument, which will ensure a trained community able to exploit the instrument when it becomes available through NCRIS funding.

The GMT and PILOT components of the astronomy plan are aimed at meeting the expected demand for vastly more capable facilities in the next decade, addressing many of the nine Big Questions of the Decadal Plan. GMT offers Australia an appropriate level of participation in the next generation of 'Extremely Large Telescopes', capable of sensitivities 7 times those of existing 8m telescopes with 3 times the resolving power. When complete, GMT will be one of only two or three Extremely Large Telescopes in the world, capable of imaging extra-solar planets in their own and reflected light, detecting many of the large black holes in the Universe, and mapping the web of diffuse material that accounts for the lion's share of the normal baryonic material in the Universe. PILOT offers a parallel path that seeks to exploit the potential of Antarctica as the world's best observing site. The development of Antarctica as a site for future generations of ELTs (or equivalent facilities) is a strategic driver for investment in pathfinder facilities such as PILOT. Both GMT and PILOT will be international collaborations: GMT with leading US institutions, such as Harvard, MIT, Texas and Arizona and PILOT with major European institutions. Differing fractional contributions by Australia are being contemplated for PILOT and GMT. These projects are quite different in scope, and share will not be the only factor that informs the desired level of participation.

National Requirements - Industry and Education Links

Education

Astronomy provides a popular and useful training ground for students of all levels, and Australia's national astronomy facilities provide a valuable educational role within Australia. As Australia's major national optical facilities, the AAO and Gemini support the training of a large fraction of Australian astronomy graduate students: over the past five years, AAO facilities and staff have contributed to the training of 56 research students: 31 PhD students, 8 Honours undergraduates and 17 Summer Scholars; over the past three years, Gemini has contributed to the training of 18 research students: 16 PhD students and 2 Honours undergraduates. As Gemini matures, the number of Australian students using its facilities is increasing rapidly. Over calendar years 2001-2005, the CSIRO Australia Telescope National Facility supported the training of 51 PhD students, 3 Masters students and 38 ATNF Summer Scholars.

A study of the subsequent careers of these students carried out as part of the *Australian Astronomy Decadal Plan*, found that for the period 2000–04, some 70% of PhD graduates in astronomy and astrophysics took their first job in astronomy; of these, a further 70% (i.e. 50% of the total) took their first job overseas. The remaining 30% are distributed between teaching, industry and commerce in Australia and non-astronomy jobs overseas (the latter being approximately 10% of the total). Only a very small proportion are unemployed for any significant period. The 30% of students who leave astronomy for other employment, together with the low unemployment rate, reflects the inherent saleability of an astronomy PhD, whose skills in areas such as complex data analysis, information technology and innovation are highly applicable in business and finance. A number of the technology- and engineering-oriented students have gone on to apply their skills in high-tech industrial companies.

Industry

The optical astronomy facilities that are proposed for support by NCRIS have a diverse set of links with industry. The astronomical instrumentation programs that form part of the AAO, Gemini and PILOT components involve links to a number of high-technology firms, including Auspace (Mitchell, ACT), Prime Optics (Eumundi, QLD), Electro-Optical Systems (Queanbeyan, NSW), BAE Systems Australia Ltd (Adelaide, SA), Broens Engineering (Sydney, NSW), Laserdyne (Brisbane, QLD), Connell Wagner and Sinclair Knight Merz.

An important opportunity for expanding links with industry, and for providing Australian companies with international opportunities for developing their technological expertise and showcasing their skills, lies with the Design Development Phase of the GMT project. A GMT Industry Working Group has been formed, including EOS, Auspace, Sinclair Knight Merz and VIPAC (Adelaide, SA), to map the capabilities of Australian industry to the requirements of the GMT project and identify companies with suitable expertise in areas of the project that Australia is seeking to contribute. Working on the GMT project is likely to involve Australian companies in cutting-edge technologies in areas such as complex technology integration, systems engineering, smart optics and control systems and provide them with new connections to leading US technology firms and customers. The GMT project will also provide strong educational and research links to some of the best US universities. An example of less conventional transfer of knowledge is that commercialization of a hydrodynamical code, originally developed in Australia for the study of double stars, for use in motion picture animation – including in scenes from The Lord of the Rings.

In addition to PILOT's role in astronomy, it could also have an important application in extending searches for satellite debris in low-earth orbit. Dome C's geographic location is close to optimum for detection of polar orbiting and high-inclination satellites and debris, and the long duration of twilight at high latitudes greatly increases the observability of such objects. This is a "space environment" issue of growing importance, with some 100,000 objects between 1 cm and 10 cm in diameter posing an ever-increasing risk to the space industry. Successful trial observations by PILOT in this mode could lead to the rapid deployment of a PILOT clone dedicated to debris tracking, or a potential long-term role for PILOT once astronomers have moved on to larger telescopes. Such an application is vitally important to the space insurance industry and creates important opportunities for private sector co-investment.

The technological and engineering effort and capability needed to support radio astronomy is driving:

- close links between radio astronomy and ICT developments in signal processing
- developments in remote operations, and
- national and international bandwidth upgrades to communications infrastructure.

Due to its extreme demands for sensitivity and data processing power, future radio astronomy technology represents transformational technology for ICT. Involvement in future radio astronomy R&D will link Australia's technologists to the most innovative in the world in these areas, and provide a unique training ground for tomorrow's technicians. 80% of work cited in patents as inspiration for the patents is basic academic research.

The Australian Electronics Industry Action Agenda has been established in recognition of the need to assist and update the Australian electronics industry. In June 2005 the Electronics Industry Action Agenda Implementation Group endorsed the SKA as a signature project. With support from AEEMA (the Australian Electrical and Electronic Manufacturers' Association), an "SKA cluster mapping project" has been developed to identify the potential benefits for Australian industry from the SKA-related projects and SKA-related R&D. The radio astronomy projects in Australia are identified as a more stable revenue stream than variable Defence contracts, and so the radio astronomy work can provide a relatively more stable business environment – a pre-requisite to successful innovation.

Five SKA cluster events have already been held; in Sydney, Perth, Geraldton (to a large local audience) and more recently Brisbane and Adelaide Over 200 company representatives have attended these meetings. Awareness and interest of Australian industry has been raised, with more organisations (eg HP, GHD, SA Government, CMD) seeking to join the SKA cluster. The Western Australian Government has signalled its intention to be part of the Cluster.

Public Understanding of Science

Astronomy is a vital part of the science culture of all mankind. It tells us what we know of where we, and our planet, fit into the physical environment of the Universe. A person deprived of the broad outlines of astronomical knowledge is as culturally handicapped as one never exposed to history, literature, music or art. Astronomy enriches the intellectual lives of millions. The recent high level of public interest in the International Astronomical Union's definition of a planet provides a prime example of this strong cultural impact.

In today's world marketplace, a competitive nation needs its entire population to have a basic level of scientific literacy. As a visual science, easily accessible to amateur observers, astronomy is a particularly effective educational tool and stirs scientific curiosity in thousands of young people every year. Some of these go into astronomy research, but many more take their interest in science into other areas of endeavour, enriching whatever field they work in.

The accessibility of astronomy gives it a high public profile. This awareness and interest by the community makes it particularly valuable in demonstrating science in action. Astronomy's appeal makes it a valuable way in which to engage and educate students and the public about science and technology. As a recent example Dr Fred Watson (AAO), was the 2006 winner of the Eureka Prize for Promoting Understanding of Science

By exciting young people's interest in the Universe and how we study it the astronomical community and educators can take an important role in strengthening scientific education and skills in Australia. NCRIS funding for new astronomical facilities will lead to many new exciting technologies and discoveries. Experienced, well-supported educators can use these to produce stimulating educational case studies. Relevant, engaging examples support the effective teaching of science and technology and will help promote careers in these fields. As an example, the Australia Telescope National Facility is running in 2006-7 a high-school astronomy education program called 'Wildflowers in the Sky' in Mid West schools in Western Australia. The regional impact of the radio astronomy NCRIS infrastructure provides a mechanism to take relevant science education to regional areas.

National Requirements – Links to other sciences.

Astronomy has always had application over a wide range of science areas. For example, our calendar, timekeeping and much of our mathematics came from astronomy. Radio astronomers led the development of low-noise radio receivers that made possible the satellite communications industry. Image-processing techniques developed by astronomers are now part of the medical imaging systems that allow non-invasive examination of patients' internal organs.

Working with the proposed NCRIS infrastructure will stretch and develop the skills of the most capable young scientists and engineers at the PhD and post-doc level. There is an outstanding precedent for this: the Fleurs radio telescope of the University of Sydney, which was a new kind of telescope in its time. For two decades this was a focus for the PhD programs for engineers and scientists, numbers of whom went on to work in areas of technology such as chip design and wireless networks. David Skellern and John O'Sullivan, two of the moving forces behind the Radiata company sold to Cisco Systems for $600 million in 2001, both completed PhDs using Fleurs, and spent many more years working on radio telescopes and their associated technology.

Astronomical tools and techniques are regularly transferred to medicine, industry, defence and environmental science. For example, a medical tool that arose from X-ray astronomy, the portable Low Intensity X-ray Imaging Scope (Lixiscope), is now one of NASA's largest sources of royalties. It is widely used in neonatology, out-patient surgery, diagnosis of sports injuries, and clinics in developing countries. [Source: US Astronomy decadal review.]

In the area of software alone, astronomical techniques for reconstructing 3-D images from one- and two-dimensional images have been applied to imaging for CT scans, magnetic resonance imaging, and positron emission tomography.[i] Other image processing software (IRAF and AIPS), developed by the US National Radio Astronomy Observatory, NASA and others, has been applied to cardiac angiograms, monitoring neutron activity in the brain, studying automobile crashes and testing aircraft hardware. Adaptive optics, a technology fundamental to the GMT and already being implemented at Gemini, is in use in laser machining, defence, and medicine, through, for example, enhanced retinal imaging and diagnostic techniques.

ICT, for which Australia is recognised as having particular strength, is currently the critical enabling technology and is a major contributor to national productivity and growth. Powerful next-generation telescopes will generate databases containing terabytes (10^{12} bytes) or even petabytes (10^{15} bytes) of data. Finding patterns in this data will require new software tools. But other fields of science and business will need the same tools to let thousands of distributed users put complex queries to multiple catalogues and image databases. Because astronomy does not have the problems associated with protection of individual privacy, it has been able to solve the same kind of problems in database querying that will be useful to the medical profession in, for example, searching epidemiological data.

The recent Defence Electronic Systems Sector Strategic Plan (Department of Defence, 2004) incorporates an industry analysis that concludes that, over coming years, an average of about AUD1,000m per annum in locally sourced military electronics system work will be required, along with a substantial demand, at around AUD700m, for on-going local support (possibly declining slowly with increasing system reliability). This constitutes a substantial slice of local demand for electronics sector expertise. The local acquisition is heavily weighted towards electronic systems integration – where the analogy with the integration requirements of the SKA project is strong.

The report identifies industrial capabilities that will be needed to support the Defence programs as including: "photonics, monolithic microwave integrated circuits, artificial intelligence, electro-optics, radio frequency (RF) engineering, radar technologies, data fusion, safety critical software systems, and space-based communications." The overlap with the skill base needed for the astronomy NCRIS infrastructure is considerable. Astronomy can be a valuable and steady training ground for technicians for important industry R&D sectors.

The MIRA project will be working directly with approaches to handling very high speed networking, interpretation of large volumes of data and management of geographically diverse radio communications facilities. Historical precedent suggests high prospects for achieving some significant breakthroughs. Examples such as Radiata and the earth station antennas[4] point to a

[4] Anderssen, Harvey, and Matthew Hampton (1991), *Analysis of CSIRO Industrial Research: Earth Station Antennas.* Research Paper 6, Bureau of Industry Economics. Study inferred a benefit-cost ratio for Australia of 2 at a 10% discount rate.

track record in capturing enough of the benefits of at least some of these developments to more than justify their costs.

Companies are already expressing interest in these technologies through the industry-led Australian SKA Cluster Mapping Project.

The fields of Earth Science and Physics also will benefit from these NCRIS investments, particularly in the Gemini and GMT capabilities that will enable our own Solar System to be placed into the larger, diverse, context of planetary systems throughout the Galaxy.

Space weather is another vital area where the astronomy infrastructure has the potential to benefit other sciences. Coronal mass ejections and the flares with which they are associated can play havoc with satellites, communication links and power grids, can endanger astronauts, and are responsible for the polar light shows known as auroras. These "space weather" effects can be predicted, but not well. Sometimes, the ejected material is deflected by the Earth's magnetic field and Earth is shielded. Other times, the shield fails and widespread damage can ensue – the difference is due to the magnetic properties of the ejected material. If we are to improve the predictions and provide reliable advance warning of adverse space weather, we must measure the magnetic field which permeates the material when it is ejected by the sun and travels in the heliosphere. Until now, we have had no way to make that measurement until it is near Earth. The low-frequency component of MIRA will enable scientists to deduce the all-important magnetic field properties. This is a crucial measurement of enormous scientific and commercial value for all sciences that use space technology, as it would provide advance notice about the space weather effects on Earth well ahead of the time of impact of the plasma burst.

PILOT, and telescopes at Dome C that evolve from PILOT, are well situated to perform "dual use" observations of the upper atmosphere. For example, hydroxyl (OH) measurements from Dome C would be a byproduct of PILOT's routine near-IR observations and would give valuable data on stratospheric temperatures at polar latitudes, which in turn are a key ingredient of climate models. In addition to incidental measurements of atmospheric parameters, a small fraction of PILOT time could be dedicated to specific observations, for example, studies of stratospheric ozone and trace gases that are crucial for climate change modeling.

In addition, the orbital decay rates of low-earth-orbit space debris discovered by PILOT are a good measure of the density of the upper atmosphere. This in turn is a function of solar activity, providing vital clues links about "space weather" that are of considerable environmental significance.

Regional/State Benefits

Infrastructure longevity is an important factor in considering the long-term nature of the benefits to the country of NCRIS-funded infrastructure. Next-generation telescopes are planned to have a 50+ year lifetime, returning benefits to the partner countries until at least 2070.

MIRA

The MIRA project has potential for boosting employment and wider economic activity in a remote region in Western Australia. Were the SKA to be sited in Australia, it is highly likely significant economic benefit would be delivered into the regions where the stations are to sited. Thus, by increasing the chances of Australia being selected as the SKA site, MIRA brings substantial additional benefit to regional Australia in general and WA in particular.
The effects of MIRA itself are likely to be both positive and substantial in regional terms, based on:

- the scale of the project;
- the infrastructure requirements of the facility and the likely need for on-site assembly of antenna arrays;
- post commissioning demands for significant on-going support and operation of the facilities;
- on-going regional scope for joint use of infrastructure such as broadband;

- opportunities for planning other regional activities to exploit the synergies, including tourism (although not at the core site to main radio quietness);
- the sensitivity of small regional economies to quite modest changes in activity levels.

Of course, small, remote regional communities are likely also to be limited in their scope for responding to some of these opportunities. CSIRO, in partnership with other groups, has initiated industry briefing sessions and high-school education activities to raise awareness and capability. Furthermore, the need to accommodate and support an influx of workers would create its own demands on the regional facilities and businesses. The ongoing needs to operate and maintain the facilities should imply long-term demands for goods and services that could sustain some economic growth.

Specific opportunities, where there should be local supplier advantage, have been identified in relation to:

- site construction, especially buildings and footings but possibly extending to some role in the on-site assembly of antennas;
- employment from tourism, including for indigenous communities.
- It is appropriate to recognise that increased activity and throughput in remote regions could translate into efficiencies for governments in ensuring minimal social infrastructure – or could allow the standards of such facilities to be raised cost effectively. Similarly, commercial services into the region could be encouraged;
- extension of local accommodation facilities, and wider social facilities, to meet the increase in the workforce during the construction phase and to meet the longer term stable demands of the facility;
- trenching for the broadband system.

The WA Government is seeking to gradually diversify the economic base of the State away from mining to a range of other activities including in ICT and system engineering and support to Defence. These three sectors (which all overlap) lie at the heart of the technology and engineering effort and capability needed to support radio astronomy. A unique advantage that the location of radio telescopes in WA will give to the State is that it will provide an alternative (and relatively constant) revenue stream to a number of small-medium enterprises (SMEs) especially, which otherwise would struggle to survive in the lumpy investment space of Defence. When the latter point is combined with the current and worsening national (indeed global) skills shortage in these and associated high tech. industries, continuity of business becomes one of the major factors in staff retention. A relatively more stable business environment is a pre-requisite to successful innovation. Thus the NCRIS funded infrastructure and new developing market in WA can go to the heart of the future economic health and well-being of the State, In addition, the communications infrastructure that will be needed to support radio astronomy will genuinely allow the State Government of WA to think differently about regional development within the State.

<u>PILOT</u>

The Tasmanian Polar Network is an industry association set up to promote Tasmanian industry capability, and can be expected to lead efforts to capture the maximum return for the state's economy from the expansion of activities at Dome C following the construction of PILOT. Because PILOT is itself a pathfinder for future large international telescopes at Dome C (in fact, "PILOT" is an acronym for "Pathfinder for an International Large Optical Telescope"), Australian investment at these earliest stages of the Dome C Station positions the country to reap future benefits from the ongoing logistical support of the station.. This opportunity is consistent with the Tasmanian government's stated vision for Hobart to become *"…recognized globally as the world's pre-eminent gateway to the Antarctic…".* Already, Antarctic-related activities contribute $90m/year to the Tasmanian economy. The world currently spends about $1billion per annum on polar activities, suggesting major growth potential for Tasmania's Antarctic support industries.

Construction of PILOT as an Australian-led project would showcase Australia's capacity for deployment of advanced scientific infrastructure to Antarctica, creating enhanced opportunities for Hobart to become the Antarctic gateway of choice for the Antarctic programs of other countries in preference to the alternative ports of Christchurch and Cape Town.

AAO

Educational
The site of the AAO close to the Warrumbungle National Park sees a large number of visitors to the park being exposed to the concepts and operations of astronomy. The Siding Spring Observatory is one of the most accessible professional observatories in the World. During each year large numbers of school students from across NSW come to Coonabarabran to further their study regime including astronomy.

Regional Environment Plan
The Warrumbungle Shire Council has been a partner with the Observatory in developing the first Regional Plan dealing with light emissions. These lighting codes have raised awareness of the environmental value of dark skies and the importance of energy conservation, and have been used as the basis for models of lighting controls internationally.

Direct Economic Benefit
Coonabarabran town has a population of nearly 3000 people which is recognised as a critical level of sustainability. It is a busy town centre providing services and amenity for the region of approximately 7500 people and the passing traffic along the Newell Highway. The contribution that the $2 million per annum wages alone generated into the local economy by AAO staff is vitally important to the future of Warrumbungle Shire.

Social
Staff and their families contribute to the social fabric of the region. The excellent reputation of the schools and health services is a direct result of the calibre of scientific and support staff at the AAO.

Tourism
Coonabarabran has since 1994 branded itself as the Astronomy Capital of Australia. This has been a very successful marketing and promotional campaign, as demonstrated by recent Central NSW (CNSW) Regional Tourism Organisation visitor experience and product development research1. For example:

- 17% of visitors to Central NSW spend time in Coonabarabran, of whom 94% stay at least one night
- 74 % of the visitors to Coonabarabran go to Siding Spring Observatory and 70% go to the Warrumbungle National Park
- The key market opportunities for Coonabarabran are the Compatriots and Wanders, who spend on average $111 and $132 per day respectively.

Ref: Central NSW Tourism Business Prospectus – Coonabarabran (2003) PacALLIANCE (Australia) Pty Ltd & Environmetrics Pty Ltd

Coonabarabran is capturing a higher number of visitor nights which reflects the destinational nature of the area and variety of activities available

More so than any other local government area in Central NSW region, offering the prospective tourist a degree of involvement was identified as an opportunity for Coonabarabran. The educational outreach of the AAO is clearly a critical aspect of the tourism product on offer in the Warrumbungle Shire.

On average 32,000 visitors call into the Coonabarabran Visitor Information Centre per annum. This is a Council funded facility, which is operated by 3 full time and 2 part time staff and supported by an annual combined Tourism and Economic Development promotions budget of $60,000.

Proposed Package - a balanced suite of infrastructures

The investment portfolio is balanced across a small number of infrastructure items, providing a balance of support for existing facilities and developing options to invest in future facilities.

The investment strategy is viewed by the astronomy community as a *package*, with strong synergies available through the cross-spectrum features (higher and lower frequency radio, infrared and optical) of the proposed package and through the coherent whole-of-astronomy-community support that has emerged from the planning processes.

In respect of a number of the major questions to which the proposed infrastructure will be applicable, there will be growing scope to exploit these cross-spectrum synergies, especially those available from the next generation of much larger radio and optical instruments, to deliver a fuller understanding of the phenomena being observed. None of the leading countries in astronomy has focused on one part of the spectrum at the expense of the others – astronomy is advancing using a range of types of instruments whose costs are such that sharing the costs of individual instruments internationally allows access to the package of instruments appropriate to addressing the major questions in astronomy.

In terms of the Decadal Plan and the desire to host the SKA, this package character of the proposal takes on even greater significance. International perceptions of Australia's commitment and capability across the spectrum have a major impact on international perceptions of Australia as a suitable site for the SKA. This influence arises through a combination of considerations, ranging from true technical and scientific synergies, through to assessment of depth of commitment to a project with a very long planned life. It represents a clear differentiator relative to the most likely alternative site – and perceptions that Australian commitment across the spectrum may be diminishing could be expected to reduce substantially Australia's prospects for being chosen to host the SKA.

The 2005 DEST business case for Australian involvement in the SKA, including the possibility of being chosen as the host site, emphasised the value of preserving this hosting option. Indicatively, using the same parameter settings used then, a plausible reduction in Australia's prospects of being selected from 1:2 to 1:3 would entail a (very conservative) reduction in expected net economic benefits to Australia of the order AUD200M (NPV) – with the consistent conservatism used throughout the options modelling suggesting the true cost could be substantially higher. However, the costs to Australian astronomy and perceptions of Australia's position in astronomy, and the value of Australian involvement in this major international project, would we believe be very much greater than these tangible benefits alone. These strategic considerations are appropriately included in the assessment of alternative funding packages for this round of NCRIS.

NCRIS funding is required for maintaining access to existing optical world-class facilities, both on-shore (AAO) and off-shore (Gemini). In the radio astronomy domain, support for existing national facilities is provided through CSIRO, and it is proposed that this support be to some extent re-directed to the new infrastructure.

Infrastructure investment in the design phase of GMT and in PILOT is developing options for possible engagement in future large-scale optical facilities and for maximising Australia's ability to compete in the next stages of optical and infrared astronomy. This represents a sound approach to the considerable challenges inherent in planning for such complex instruments. The GMT is already well-developed. It has just passed a Conceptual Design Phase, culminating in a 700-page public document that has passed international peer-review by a panel of experts. In the case of PILOT, preliminary studies of the winterising of a commercial 2.4 metre telescope can now be followed by a detailed design phase. As is discussed further in Attachment K, the nature of the science and its required infrastructure and the rapidly changing technologies really dictate that a level of adaptive strategy is going to be a sound part of any cost effective strategy for delivering these types of infrastructure.

While this NCRIS proposal concerns funding over the next 5 years, this strategy is about building Australian capacity to contribute at the leading edge of astronomy over many years to come. Astronomy is characterised by very rapid rates of technological development that becomes embodied in very large infrastructure projects that can take over a decade to roll out. It is not possible to operate in this environment on the basis of deterministic planning, built around currently available technologies.

Major astronomy facilities are well suited to adaptive development that incorporates modern principles for large investment planning and roll-out under uncertainty, and sensible investments in reducing project uncertainty and in providing access to evolving technologies are an inherent part of a sound infrastructure roll-out strategy. New technologies can be incorporated into facilities during and after roll-out, provided that the design has built in scope for such flexibility. Attempting to build to a rigid strategy is not cost effective.

One of the major attractions to participation in these projects, and associated leverage of funds, lies in the opportunities to participate in leading edge technology development with application to the facility and with possibilities for substantial wider industry and application spin-offs from these technologies. Australian involvement in an adaptive project development maximises the scope for Australia being part of the technology development, and being able to benefit from the skills and IP that follow. Adaptive management of risks and opportunities offers scope for much better cost management without jeopardising long term objectives for the facility – while also retaining the opportunity of pushing out the value of the project as a result of technology developments that occur across the planning and roll-out phases.

To realise our ambitions we will use a range of funding sources. To manage the potential conflict here, we have constructed a package of funding sources directed at different elements of the overall infrastructure need, reserving for NCRIS funding those elements that do fit clearly within the NCRIS criteria. For the above reasons, it will be appropriate that this package be capable of adaptation to new information. However, all elements for which NCRIS funding is sought are investment in infrastructure and infrastructure options. Relevant research elements will be the subject of leverage from other countries and institutions, and these have been factored into the overall budgeting.

The major elements of this proposed investment package are:

<u>The Anglo-Australian Observatory (AAO)</u>

- The Anglo-Australian Telescope (AAT) is widely acknowledged to have been the most productive telescope for Australian researchers over the past decade. The AAT accounted for 15% of all Australian astronomy citations over the past eight years.
- Over the next four years the UK will gradually withdraw from the AAO, and by mid-2010 Australia will have sole ownership of the AAT and all the other assets of the observatory. The Decadal Plan envisages that the AAO will expand its role in the delivery of research outcomes to the Australian astronomical community by evolving into the national optical/infrared observatory.
- NCRIS investment of AUD10M is required to maintain the AAT as a world-class facility available to Australian researchers over the next decade.
- This investment will accomplish two major goals: (i) AUD4.1M will be used to refurbish the AAT to allow it to operate reliably and efficiently throughout the coming decade.
  (ii) AUD5.9M will be used to construct a new instrument to offer world-leading capabilities to Australian researchers and to sustain very high levels of scientific productivity and impact.

<u>Gemini and large telescope access</u>

- The funding of Australia's existing 6.19% share of Gemini and the local support infrastructure costs will involve joint investment from NCRIS and by the Australian Research Council (ARC).
- The ARC is Australia's signatory to the International Gemini Agreement and hence has ultimate responsibility for Australian participation in Gemini. As such it wishes to continue providing funding support and will do so through its Linkages Infrastructure and Equipment Fund (LIEF) scheme.
- The total cost of Gemini "operations" associated with Australia's 6.19% share is AUD10.5M over the NCRIS period. The ARC is expected to contribute AUD3.6M of this; the remaining AUD6.9M is a priority item for NCRIS funding.
- Australia is also required to contribute its share of the cost of Gemini's "Aspen" instrumentation program, which will equip the telescopes with the next generation of state-of-the-art instruments over the next 5 years. The scope of this program is currently under review (because of uncertainties in the funding available from major partners) to the extent that the required investment of NCRIS funding could range from AUD0.0 – 3.7M. Since Australia is required to meet this commitment whatever its final value should be, it is also a priority item for NCRIS funding. However, its uncertainty means that the total priority funding for Gemini (to cover "operations" and "Aspen") can, at this stage, only be quoted as a range – from AUD6.9M to AUD10.6M.
- A stated goal of the Decadal Plan is to increase access to large telescopes for Australian astronomers to a level corresponding to a 20% share in an 8-metre telescope over the coming decade. As a first step towards this goal, AUD1.9M in NCRIS funds is requested to acquire additional access (over and above the 12.4% access provided by Australia's 6.2% share in the two Gemini telescopes) to large telescopes to provide Australian astronomers with the equivalent of a 15% share in an 8-metre telescope. This additional share is a 'strategic-option' priority for NCRIS funding. It is dependent on its strategic priority, as determined by ARA, relative to the other options in the program.

MIRA

- NCRIS funding of AUD19.2M is requested for radio astronomy infrastructure for construction of a world-leading next-generation radio telescope, the Mileura International Radio Array (MIRA) at Mileura – the proposed central site for the SKA should it proceed in Australia.
- The MIRA builds on existing commitments to the CSIRO-funded extended New Technology Demonstrator, and the NSF- and Australian- funded Low Frequency Demonstrator (LFD) at Mileura. NCRIS funding will enable the enhancement and integration of these two facilities into a powerful next-generation radio telescope according to the international SKA Reference Design.
- The MIRA also builds on commitment by the Government of Western Australia to establish a Radio Astronomy Park at Mileura, to protect the site for the purpose of radio astronomy, and to provide infrastructure support to a level of AUD4.2M. The funding sources for the MIRA include CSIRO (~AUD30M), the US National Science Foundation (USD4.9M), Harvard University (USD0.5M), the USAFOSR (USD0.3M). In addition, an MOU is currently being prepared between CSIRO and Herzberg Institute of Astrophysics to further develop MIRA over the coming 5 years. The Australian and South African SKA teams are collaborating on software development for MIRA and the South African Karoo Array Telescope. NCRIS funding may also leverage further international investment. Recent discussions at the International Astronomical Union meeting in Prague have led to agreement to develop an MOU between China and CSIRO to supply the FAST radiotelescope – the largest (500m-diameter) single dish telescope in the world – with technologies developed for MIRA (focal-plane arrays, digital signal processing). This MOU could also from the basis for future scientific collaboration between China and Australia for joint science programs with FAST and MIRA. This would add to the scientific capability of both infrastructures, particularly if the telescopes can be directly linked by broadband infrastructure. In addition, the LFD partners are in discussion with the Raman Research Institute (India) about possible partnership in the LFD.

- ARC LIEF grants and other sources may be used to support specific University research outputs of the LFD program
- The indicative timetable involves construction commencing in 2007, integration of the Australian-funded portion of LFD into MIRA on an access by merit basis in 2010 and full commissioning in 2011. Some operating costs would be expected to come from international partners.
- Operating costs for the MIRA post-2011 would be partially sourced from re-prioritisation of existing resources within ATNF.
- Access for Australian researchers would be handled through a Time Assignment Committee managed through CSIRO ATNF using the existing merit-based approach.

PILOT

- The PILOT program involves the detailed design, construction and operation of a 2.4-metre optical/infrared telescope at Concordia Station, Dome C, in the Australian Antarctic Territory. PILOT is the first stage of a development path that provides the option of engagement in larger facilities in Antarctica, consistent with the high priority given Antarctic astronomy in the Decadal Plan and the Australian Extremely Large Telescope (ELT) Working Group Roadmap (2005).
- The initial timetable indicates a detailed design phase beginning in 2007, with a design review to occur after 12 months. NCRIS funding is requested for this detailed design phase for PILOT of AUD1.0M.
- Substantial additional investment is expected from the European partners and from Australian institutions. Preliminary discussions have already been held with overseas partners and these discussions are likely to lead to firm agreements by the time of completion of the Design Review.
- The construction phase of PILOT would follow the satisfactory completion of the design review, and would be funded through a combination of NCRIS, Australian University and European resources. NCRIS resources of up to AUD5M are requested for a significant share in the construction of PILOT, as a ‘strategic option’ priority. This would be contingent of the success of the design study and evaluation by ARA of its strategic priority, relative to other options in the NCRIS program.
- Maximising the level of funding for PILOT in the construction phase is important for maximising Australian influence over aspects of logistical support to maximise economic return to Australia.
- The design, construction and operation of PILOT will be managed by a PILOT Board that is responsible to the Astronomy Research Australia Board, and to its European counterpart.
- Access to PILOT for end users will ultimately be managed via the existing Australian Time Allocation Committee (ATAC).

The Giant Magellan Telescope (GMT)

- Enabling access to the next generation of extremely large telescopes for all Australian astronomers is a high priority item of the Decadal Plan. The Giant Magellan Telescope is a 25-metre telescope, plans for which are being developed by a consortium of some of the most global and high profile research institutions in the USA and the Australian National University. GMT has been chosen by the Australian ELT Working Group as the best matched of the next generation of extremely large aperture optical telescopes to Australian astronomers’ scientific requirements and technical capabilities. The expected total capital cost of the GMT is USD550M.
- There are strong indications that the legal agreement currently being drawn up to form the partnership will favour early investment reaping larger influence and share than later investment.
- The GMT project is now entering its Design Development Phase (DDP), which will cost USD56M. Early entry to this next-generation facility will allow Australian astronomers to help set the scientific agenda through opportunities to participate in the design of the telescope and instruments, and will allow Australian industry to compete effectively for, and maximally benefit from, the technological developments and construction contracts.

- The criteria for successful involvement by Australia in the design phase include satisfactory definition of science goals, winning of design contracts by industry and academia, healthy financial and governance arrangements for the project, and effective use of Australian membership in science popularization and outreach.
- NCRIS funding of AUD4.8M would (with matching funds from the ANU) secure ground floor Australian membership at the 10% level in the consortium for the Design Development Phase. In the priority list for NCRIS, it is proposed that AUD 1.4M be allocated to secure Australian participation in the critical first year of the design phase; with ANU contributions, this will mean that there is a substantial Australian involvement in the project, equally weighted between NCRIS and ANU sources. The funding required for the final two years of the DDP is strategic option; a decision will be made about further involvement, based on the extent to which GMT involvement has been a success in relation to other options, as judged by the criteria given above.
- During this phase, Australian astronomers would, in partnership with government and industry, establish a GMT Landmark Facility Committee (a suggestion commended in the NCRIS strategic roadmap) to develop the business case for Australian participation in the construction and operation of the GMT, based on engagement with, and first outcomes from, the DDP.
- Following commissioning in 2017, telescope time on the GMT would be divided amongst partners in proportion to their investment. Each partner would allocate that time as they saw fit; in the case of Australian time, it would be allocated competitively on merit through the well-established national procedures for allocating telescope time.

NCRIS Funds and Funds Management

NCRIS funding will be managed by a new peak body to be established with appropriate legal status, Astronomy Research Australia Ltd (see section 5), that will allocate NCRIS funds to the various infrastructures according to agreed timelines and subject to satisfactory progress through critical review points. ARA will have some ability to re-prioritise and re-allocate funds to adapt to changing international circumstances. Decision points will be necessary for allocation of funds in the optical astronomy area.

Depending on results from the first year of the GMT DDP, the one-year PILOT design study, and the level of NCRIS funds remaining, decisions will be made whether to support one of these infrastructures or additional 8-metre telescope access in subsequent years of the NCRIS funding cycle.

AUD1.17M of NCRIS funds will be required to support the ARA Office over the life of NCRIS. This investment offers good value via the scope it will provide for adaptive management of the overall investment in order to maximise the value of the infrastructure options. ARA will give the Australian government a single point of accountability, initially in the governance of any NCRIS investment in astronomy, and potentially growing to include other items of national infrastructure for astronomy. ARA is discussed in substantially more detail in the context of the proposed governance arrangements, in Part 5.

Investment Portfoilo

The overall $45M investment portfolio may be summarized as follows:

Governance	AUD1.17M
Base Level	
Gemini (2 x 6.19%) share	AUD6.95-10.65M[5]
MIRA	AUD19.20M
AAO	AUD10.02M
GMT DDP Year 1	AUD1.30M
PILOT Design	AUD1.00M
Strategic Options	AUD1.58-5.28M
Increased access to 8m (15% share)	[up to ~AUD2M]
GMT DDP Years 2&3	[up to ~AUD3M]
PILOT construction	[up to ~AUD5M]

In this portfolio we have explicitly recognized the current uncertainty in the cost of Australia's 6.19% Gemini share (discussed in more detail in the risk management section: Attachment G). Within the $45m envelope, this uncertainty is reflected in the resources available to the strategic options.

These strategic options are not discretionary expenditures; they are options in the sense used in the economic and investment literature. This investment proposal recognises substantial uncertainties and risks and a strategy has been developed to manage these risks and ensure maximum value. That appropriately means we do not now commit to a deterministic strategy.

We propose to start with some strategic investments designed to reduce the uncertainties and we then adapt the detail of the investment mix, in the light of this information, to ensure maximum value. It is for this reason that we have also proposed an initial one-year investment in the GMT DDP, alongside the PILOT design that was identified by the NCRIS committee as a high priority item.

The process for deciding on the changed mix in the light of fresh information will be embodied in criteria to be used by ARA and these will, where appropriate, include formal consultation with NCRIS. Failure to build flexibility in this package of investments would limit the scope for return to the community.

The sum available to the strategic options would be fixed by the investment necessary to maintain Australia's 6.19% share of Gemini. The criteria applied to investment decisions between the options themselves would focus on the strategic, scientific and technical returns to Australia and to the capability. It would include consideration of:

- the construction costs for PILOT (and the consequent level of Australian participation in PILOT);
- the evidence of influence in the design of GMT (and the tangible return to Australian industry);
- the requirement to access capabilities on other 8m-class optical telescope unlikely to be provided by any scale back in the Gemini 2nd generation instrumentation program.

[5] These amounts reflect the uncertainty in Australia's required contribution to Gemini's "Aspen" instrumentation program, which is currently under review by the Gemini Board and could range from AUD0.0 – 3.7M.

PART FOUR – ACCESS AND PRICING

In this Part, you are required to show how the arrangements for the proposed infrastructure meet NCRIS Investment Criterion 2, ie:

> **An investment plan must result in research infrastructure that is accessible by researchers on the basis of merit, at reasonable prices, and that encourages collaboration in research.**

In addressing the criterion, you should fully address:

- all issues relevant to Criterion 2 that are identified in the NCRIS Roadmap; and
- the requirements of Section 3.2 of the NCRIS Investment Framework 'Content of Investment Plans'.

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Access to the various infrastructure components of this investment plan would be via the existing well-established time assignment mechanisms, already identified as exemplars of best-practice access policies by the NCRIS committee[6]. Access to all – both existing and proposed – infrastructure would be co-ordinated via the AAO Australian Time Assignment Committee (for the optical/IR) and the ATNF Time Assignment Committee (for the radio). This is consistent via the Decadal Plan strategy of having AAO and ATNF act as the national observatories for optical/IR and radio astronomy respectively. Initiated by the proposed NCRIS Governance body, the capability may in future look towards combining the time assignment committees to foster yet further cross-capability collaboration. For the present, the existing structure works well and provides transparent merit-based access for all researchers to the major Australian astronomical facilities.

AAT

Applications for access to the Anglo-Australia Telescope (AAT) are made to a single bi-national time assignment committee - the Anglo-Australian Time Assignment Committee (AATAC), which ranks all proposals for observing time on the AAT, from both Australian and UK astronomers, on the basis of scientific merit and technical feasibilty, and assigns each successful proposal an appropriate number of nights observing time.

The Australian members of AATAC are appointed by the AAT Board, based on the recommendations of a 3-person appointment committee comprising the Australian Gemini Board member, the senior Australian AAT Board member, and the President of the Astronomical Society of Australia. The members of AATAC are a subset of the members of the Australian Time Assignment Committee (ATAC) that awards access to all Australian national optical astronomy facilities.

Calls for proposals are made twice a year, and proposals are submitted via a WWW-based application systeem. All researchers, irrespective of nationality, are able to apply. Full secretarial support for the proposal submission and review process is provided by the AAO. Technical evaluation and scheduling of the proposals is also carried out by the AAO.

No charge is made to users of the facility allocated time under this process. Basic costs associated with travel/accomodation to carrry out the observations at the AAT are provided by the AAO, although some costs are borne by the users. Data archive/management costs are borne by the

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[6] Based on the document *Guidance on access and charging issues* submitted to the NCRIS facilitators' meeting 9 June 2006.

Observatory. All data is freely available to the international scientific community via a WWW-based archive, following a proprietary period of 18 months.

Gemini

Applications for access to the Australian share of the Gemini Telescopes are made to a single national time assignment committee - the Australian Time Assignment Committee (ATAC), which ranks all Australian proposals for observing time on Gemini, on the basis of scientific merit and technical feasibilty, and recommends an appropriate number of nights observing time to each successful proposal. These successful proposals are then passed on to the Gemini international TAC (on which Australia has a representative) to make the final scheduling recommendations, taking into account possible multi-partner participation programs (each national TAC having provided its assesement of the scientific merit of any particular program) and any program conflicts/duplication. The ITAC is careful to maintain appropriate partner-share balance in its final assembly of the telescope schedule.

Applications for observing time on the Gemini Telescopes are made via a WWW-based application form. Call for proposals are made twice a year. Full sectarial support for the proposal submission and review process is provided by the AAO, as a component of its contribution to the Australian Gemini Project Office.

No charge is made to users of the facility allocated time via this process. Time on the Gemini telescopes is awarded on both a 'classical' and 'queue' basis. Observers who are granted classical time are expected to travel to the telescope to conduct the observations, and bear the costs associated with this. Observers awarded queue time will have their observations conducted for them and the resultant data distributed to them.

Data archive/management costs are borne by the observatory. All data is freely available to the international scientific community via a WWW-based archive, following a proprietary period of 18 months.

Additional 8m Time

Any further 8m time on a telescope other the Gemini would be accessed via ATAC in exactly the same fashion as defined above. Indeed, time of the Magellan optical/IR facility (accessed via MNRF funds) is currently ranked and allocated via ATAC.

PILOT

The Australian share of time on PILOT would also be accessed via ATAC in exactly the same fashion as for Gemini and other 8m telescopes.

MIRA

During the term of the NSF grant (2006-10), when the mid-frequency (xNTD) component of MIRA will be under construction, the use of the low-frequency (LFD) component is already clearly laid out by the international LFD consortium, with the key science projects, international science collaboration teams, and campaign-mode style of operations determined. There are well-defined mechanisms for interested groups to apply to join science collaboration teams. Australian institutions are already members of the teams and so can participate in the science experiments of the LFD during the term of the NSF grant. . Australian LFD participants are forming an Australian LFD consortium to coordinate participation in governance of the LFD, and construction and operation of the LFD during this early phase.

When MIRA is fully commissioned (in ~2011), it is intended that applications for observing time on at least the Australian-funded fraction of the MIRA facility (either the extended New Technology Demonstrator or Low Frequency Demonstrator) would be made via a single Time Assignent Committee, which will operate along similar lines to the exising Australia Telescope National Facility Time Assignment Committee (TAC). It is likely that a fraction of Australian MIRA time will be targeted towards major survey-oriented key science projects. Time will be allocated to teams for these projects on the basis of merit. It is likely that there will also be time available for innovative shorter-timescale experiments and observations, also on the basis of merit.

Currently, the ATNF TAC reviews proposals for the Australia Telescope Compact Array, the Parkes radio telescope, the Mopra radio telescope, the Long Baseline Array and the Tidbinbilla antenna (5% science access via host coutry agreement). The TAC ranks all proposals received for observing time on these telescopes, on the basis of scientific merit and technical feasibilty, and assigns each successful proposal an appropriate amount of observing time.

The TAC is appointed by the ATNF Steering Committee and comprises Australian researchers principally from outside the ATNF. Applications to the TAC are made via a WWW-based application form. Call for proposals are made twice a year, and proposals are submitted via a WWW-based application system. All researchers, irrespective of nationality, are able to apply. Full secretariat support for the proposal submission and review process is provided by the ATNF.

No charge is made to users of the facility allocated time via this process. Users are expected to cover costs associated with travel/accomodation to carrry out the observations at the telescopes. Data archive/management costs are borne by the observatory. All data are freely available to the international scientific community via a WWW-based archive, following a proprietary period of 18 months.

Data Management and Access

Through its many-decade history of operating national and international-scale access with broad merit-based user access, the astronomy capability has developed sophisticated tools for the entire data management pipeline, including reduction, storage, archive and retrieval. Data management systems are built into the operating costs of facilities. Observatories typically own the data acquired by researchers and have the responsibility to both provide the data to the user in an accessible format and maintain a data archive accessible to all researchers.

The data archive is maintained at the infrastructure in question (either at the remote Observatory, the city-based laboratory or both). In some cases (e.g. AAO) a copy of the archive is also maintained overseas.

Observers may obtain their own copy of the data either by attending the facility in person - 'classical' mode e.g. AAO, ATNF, Gemini, by observing remotely over the network (e.g. ATNF), or by receiving disk media from observations carried out in service mode by observatory staff (e.g. AAO, Gemini).

Similar models of data ownership and curation as proposed for the new NCRIS infrastructure. For PILOT, users will obtain data conducted by service observations and sent to Australia via satellite. MIRA users will conduct observations over broadband links. GMT users will conduct their observations through a mix of service and 'classical' mode. Data curation for MIRA will occur at a science centre based either in Geraldton or Perth, serving data product volumes of 400Tb/yr. Operating costs for these infrastructures have been factored into the post-2011 operating costs for these facilities. Data curation will include the provision of processed data products via WWW-based archive to the broad astronomical community on request following the appropriate proprietary period for the science team that obtained the data. It will also include the Federation of data products into the broader International Virtual Observatory (see below). This will further enable Australian scientists to leverage access to data products from infrastructure that Australia does not directly contribute to.

The AAO typically generates about 400 Gb of raw astronomical data each year. All this data is archived available on the web (see http://www.aao.gov.au/archive/) after an 18-month proprietary period. The AAO provides pipeline software packages that are optimized for the rapid analysis of the data produced by the various instruments on the AAT, so that (in general) users of the facility are able to leave the telescope with at least the initial, instrument-specific, reductions of the data already completed.

The ATNF generates and maintains a number of data products. About 1.5 Tb of raw astronomical are recorded and archived each year, and made available to the astronomical community after a proprietary period of 18 months. An important component of this is the ATOA (Australia Telescope Online Archive) that comprises Compact Array data available on the web (http://www.atnf.csiro.au/observers/data.html). In addition, the ATNF maintains and serves to the scientific community datasets derived from major sky surveys conducted with the Facility's instruments. In total the ATNF maintains an archive that currently comprises about 15 Tbytes of raw data and 1Tbyte of sky survey data products. A number of instrumental upgrades to the facility will increase the data volume by an order of magnitude over the next three years.

The ATNF also provides a suite of data reduction software optimised for its radio astronomy data. This software is made available as part of the ATNF Compute Facility and is also available for download to users' home institutions. In preparation for future telescopes, techniques are being developed that make use of 1Gbit/s links to ATNF telescopes and remotely located supercomputers. These techniques are already yielding very high sensitivity high-resolution radio images of the sky, but involve the temporary storage and management of 200 Tbyte datasets. The data volumes expected from radio telescopes currently under design necessitate an integrated approach to collection, transport, reduction and archiving of data.

As well as archiving the raw data produced by the telescopes, the AAO and ATNF also manage several large databases of refined data resulting from some of the major imaging and spectroscopic surveys. These datasets are mostly interfaced to the main international data-mining services, such as the NASA Extragalactic Database (NED; US) and the Centre de Données astronomiques de Strasbourg (CDS; France).

The Gemini Observatory distributes and archives the data obtained on its telescopes through the *Gemini Science Archive* (GSA) which is operated and managed by the Canadian Astronomy Data Centre (CADC) in Victoria, BC, Canada. The GSA is both a sophisticated repository for observational data and its associated metadata (which aids in the characterization of the science data), as well as an integral part of Gemini’s observatory- and partner-wide dataflow operations. In future, it will also link the Observatory and its users to the International Virtual Observatory.

As data are collected by the instruments on the Gemini telescopes, they are streamed to the GSA at CADC. The average ingestion time for such data is ~30 minutes. This includes on-line ingestion validation and verification at the telescope, electronic transfer (via a Virtual Private Network link from Hawaii and Chile), and ingestion into the GSA. Gemini investigators can then access their data electronically via the Principal Investigator Electronic Transfer and Distribution system within the GSA. This system provides a direct, almost real time conduit between the Observatory’s data taking operations and the users. It also means that users have quick access to a number of processed data products, in addition to the raw data. This access is made available through a password-protected area on the GSA site, and given the swift data transfer and ingestion process, data can be downloaded and scrutinized in less and hour after the data are taken. The proprietary period for all such Gemini data is 18 months. The total amount received by Australian astronomers each year will be of order 0.5Tb.

The GSA also provides for direct and ready access to all Gemini data, once it becomes non-proprietary. This involves the use of the web-based Data Retrieval Facility (http://www2.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/gsa), which allows archive users to request and receive archival data as well as preview some types of data. It has the added functionality of being able to perform archival searches on the basis of object name and position, and science program number.

While the GSA is specific to Gemini, very similar data access and archival facilities are in operation at other 8m telescope facilities, with very much the same arrangements applying should access be forthcoming through NCRIS.

The international astronomical community also has free access to the Astrophysics Data System (ADS); a NASA-funded project which maintains a comprehensive bibliographic database containing more than 4.8 million records. The main body of data in the ADS consists of searchable bibliographic record and full-text scans of much of the astronomical literature, both accessible via a WWW-based interface. The ADS also provides access and pointers to a wealth of external resources, including electronic articles, data catalogs and archives.

The existing national facilities (AAO, ATNF, Gemini) also have strong links with the Australian Virtual Observatory project (Aus-VO; http://aus-vo.org/), which is part of the International Virtual Observatory Alliance (IVOA; http://www.ivoa.net/) formed in June 2002. These virtual observatories are the next-generation astronomical data management systems, and the IVOA aims to facilitate the international coordination and collaboration necessary for the development and deployment of the tools, systems and organizational structures necessary to enable the utilization of astronomical archives as an integrated and interoperating virtual observatory.

The goal is to achieve for astronomical data the transparency of the World Wide Web, and a long-term goal is a computational Grid. The VO concept already has a high priority in most national astronomy programs. Peter Quinn, the previous Head, Data Management and Operations Division of the European Southern Observatory in Garching, Germany, has taken up a Western Australian Research Fellowship in Radio Astronomy from August this year. Peter has agreed to lead the Aus-VO effort, and the enhanced international links will benefit the astronomy VO activity in Australia, especially in WA where the NCIRS radio astronomy research infrastructure is to be sited.

*25% of Australian citations over the past decade arose from infrastructure to which Australia did not directly contribute (e.g. Hubble Space Telescope, ESO Very Large Telescope)

Source: New Horizons: A Decadal Plan for Australian Astronomy (2006-15)

PART FIVE – OWNERSHIP AND MANAGEMENT

In this Part, you are required to show how the ownership and management arrangements for the proposed infrastructure meet NCRIS Investment Criterion 3, ie:

> **An investment plan must include a facility ownership and management structure that will result in the efficient and effective operation of the infrastructure**

In addressing the criterion, you should fully address:

- all issues relevant to Criterion 3 that are identified in the NCRIS Roadmap; and
- the requirements of Section 3.3 of the NCRIS Investment Framework 'Content of Investment Plans'.

Any company constitution, memorandum of understanding or other agreement relating to entities that will own or operate the NCRIS facilities should be provided in Attachment B if available. Otherwise, a detailed description should be provided of the arrangements that are proposed to be implemented.

Organisation charts explaining the relationships between entities involved in the project, or showing the management structure within relevant organisations should be provided in Attachment C.

Where possible, curriculum vitae for key personnel (maximum of 2 pages per person) involved in the management of the NCRIS facilities should be provided in Attachment D.

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The major elements of this strategy involve international cooperation in the funding, planning, construction, prioritisation of access and operation of major facilities. Many of these facilities will not be solely Australian owned and there will be international ownership and governance arrangements suited to such facilities.

In this section we summarise the characteristics of these arrangements, as a backdrop to the proposed arrangements for appropriate governance in respect of the investment from NCRIS that is sought here.

The governance model proposed here seeks to be consistent with the principles outlined in the Astronomy Decadal Plan i.e. that of a peak body for Australian astronomy, linking into international organizations as appropriate. While the model has been finalised in time for NCRIS governance, if successful, it could be enlarged over time to incorporate further elements of Australia's national and international optical and radio astronomy infrastructure. The model is in itself a piece of infrastructure.

Proposed NCRIS Governance

The Decadal Plan called for a new piece of astronomy infrastructure; a peak body to coordinate Australia's astronomical activities. Consistent with this strategy it is proposed to create a public company limited by guarantee called "Astronomy Research Australia Limited" (ARA), which will be responsible for the governance of any NCRIS investment in the capability. ARA will be owned by a consortium of universities and other research organisations. ARA's mission would be:

to act on behalf of the astronomical community of Australia to promote excellence in astronomical research through advocacy and efficient management of programs and facilities.

ARA will give the Australian government a single point of accountability, initially in the governance of any NCRIS investment in astronomy, and potentially growing to include other items of national infrastructure for astronomy. ARA will be a management company, and will contract suitable organisations to build and operate national infrastructure for astronomy.

To become a member of ARA, an institution would have to satisfy the ARA board that it has goals consistent with the ARA mission, and pay an annual membership fee. Each institutional member of ARA will appoint a member representative to attend the annual general meeting of ARA. These member representatives could as easily be DVC-Rs or university financial officers as astronomers. Indeed, it would important to get a mix of people and expertise. The member representatives elect Board members from nominations via a nominating committee assembled by the members

The Board of Directors will consist of seven individuals with an appropriate breadth of expertise in astronomy, management and finance. As a possible example, the Board of Directors may consist of four astronomers chosen for their research expertise and their balanced views of the strategic needs for the astronomy community, and three non-astronomers. The appointment of the Board, including the Chair, will be approved by formal vote of the member representatives (one vote per member institution).

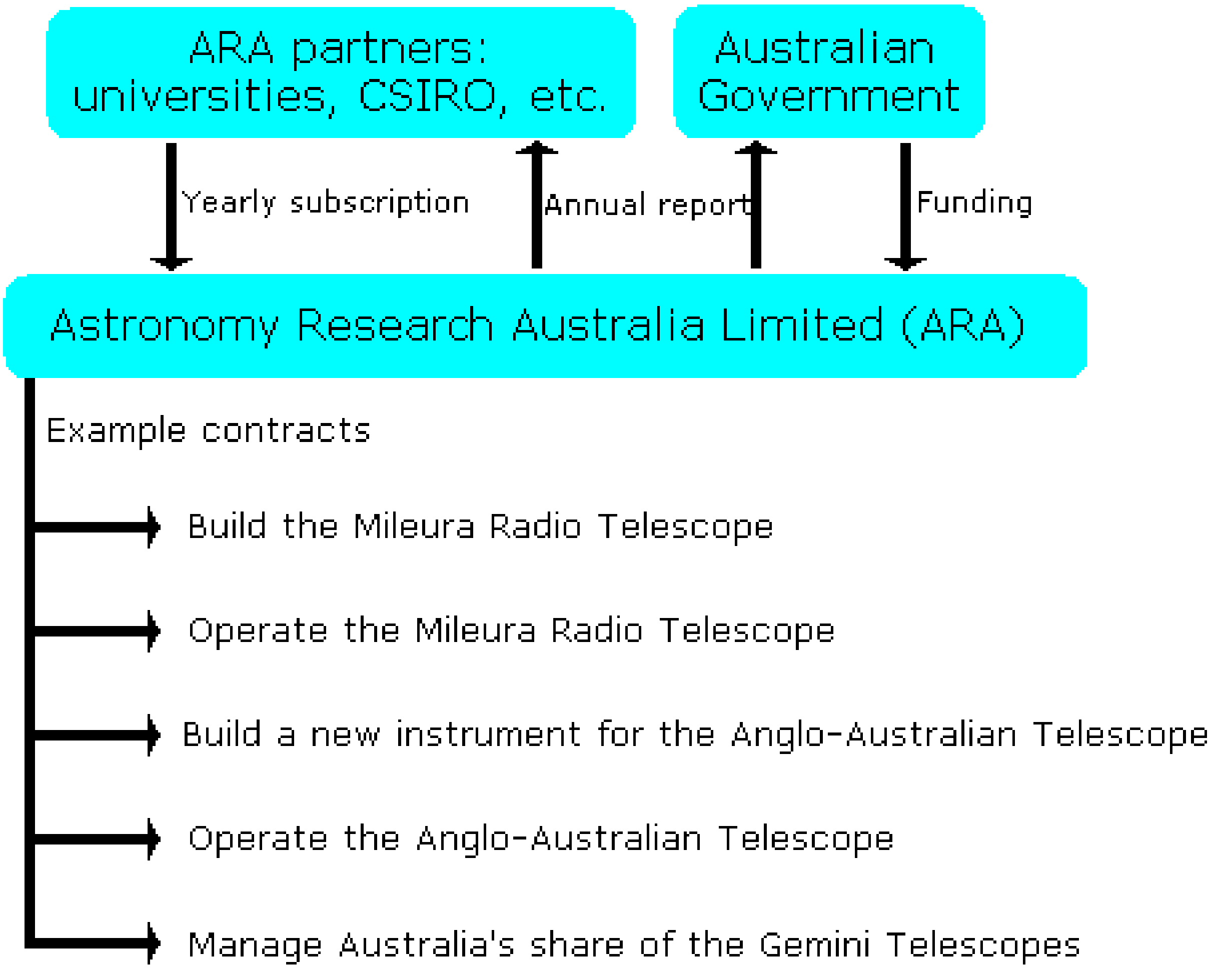
The principal role of the Board is to progress the mission of ARA. Consequently, the Board members are not in any sense representatives of their institutions or other employers. Consistent with this role, the Chair and members of the Board would be paid a fee for attending each Board meeting. Given the small size of the astronomy community in Australia, the member representatives have a duty to ensure the independence of the directors and in casting their votes for directors they will need to consider possible conflicts of interest that would impede the directors' ability to discharge their fiduciary duties. Membership terms of the Board will be staggered so as to ensure both continuity and rotation.

ARA will have a budget for 1 to 1.5 FTE staff to implement its strategy. Responsibilities of these staff will include financial management, and oversight of the programs under ARA's contractual arrangements, reporting to the Board on their status. The Board would meet quarterly to receive these reports, set strategic goals, approve financial allocations, etc. The staff could also play an advocacy role of behalf of the mission of ARA with government, industry, the university sector, etc.

Within the NCRIS context, it is presumed that ARA would contract with DEST to carry out the approved programs in the NCRIS Business Plan. The funding of ARA would come from the NCRIS grant and from the annual memberships fees. The expectation would be that approximately 2% of the NCRIS program allocation would be used in this way to support the governance structure, a percentage that is at the lower end of international best practice.

ARA would use the NCRIS grant to contract relevant organisations to deliver particular components in the Business Plan, in accordance with project milestones and subject to satisfactory performance. Performance would be monitored independent of the institutions and organisations and reported to the ARA Board. The Board receives these reports and acts appropriately. In the longer term, ARA could take ownership of all of Australia's national astronomy facilities, and contract the operation of these facilities to the relevant organisations. The timeline for these longer term changes will undoubtedly vary from facility to facility, for example:

- ARC is currently the signatory Australian organization for the Gemini Partnership with funding flowing through a Trust Fund held by the University of Sydney, but this arrangement will be changed by June 2007 so that future funding for Gemini flows through ARA
- The AAT Board is the governing body for the AAO until the end of the current AAT Agreement in June 2010. ARA is potentially a suitable organization to take over the role of the AAT Board when the AAO reverts to wholly Australian ownership in mid-2010.



The Board would take advice from existing advisory structures e.g. from the AAT Board for AAT/AAO activities, the Australian Gemini Steering Committee for Gemini and 8m issues, from the Australia Telescope Steering Committee for radio astronomy matters and from other similar steering and advisory committees as appropriate.

Below we describe the relationship between the funding routes, or governance bodies and operating organisations for the infrastructures proposed in this investment plan. Consistent with the strategies outlined in the Decadal Plan, we would envisage the AAO and ATNF increasingly acting as the National Optical and National Radio Observatories respectively in operating these infrastructures (or the Australian component of these infrastructures) and the corresponding access via their existing time assignment committees.

Operation of AAO and Gemini
The AAT and Gemini are the existing optical/infrared national facilities. For the AAO, funding flows directly from the Australian and UK funding agencies (DEST and PPARC), and NCRIS funding through ARA. From 2010, all Australian Government funding to the AAO could flow through ARA, which could take over the role of the AAT Board. For Gemini, both the NCRIS funding and the ARC LIEF funding will flow to ARA; most of the funds are then paid directly to the Gemini Observatory as Australia's subscription to the partnership. A small amount will be paid to AAO, which will manage the Australian Gemini Office, providing support to Australian users of the Gemini telescopes and running the telescope time allocation process on behalf of the community.

Development of GMT

The tangible reward for partners in the GMT project is that they receive a share of the telescope in proportion to their integrated investment over time. These shares are tradable assets amongst the partners. In the Australian context, ARA and ANU will both be purchasing share in GMT during the design phase, although these shares will be separately owned.

The goal would be for NCRIS and the ANU to each provide half of the amount required for a combined 10% involvement in the Design and Development Phase (DDP) of the GMT project. Currently, ANU is a signatory member of the GMT Project; when NCRIS monies flow from ARA to GMT, these arrangements will be revisited to appropriately reflect the ARA-ANU partnership. In making decisions relating to GMT DDP matters, special arrangements will be made to ensure that the ANU and the ARA Board carry weights proportional to their investments. Like all other partners in the GMT project, Australia would have two representatives and one vote on the GMT Board. Assuming approximately equal investments from NCRIS and ANU, one of the two Australian members of the GMT Board would be appointed by the ARA Board, and the other would be appointed by the ANU, with the ARA Board and ANU each approving both nominees. Should Australian involvement in the GMT be supported by national funding for the subsequent construction and operation phases of GMT, this symmetry would likely be broken, so that new arrangements would need to be made. The ANU may consider selling its share, in which case its membership would be through ARA as for other institutions."

Overall management of the GMT project resides with the GMT Project Office at the Carnegie Observatories in Pasadena, California, which will award the contracts for the design and development work during the DDP. ARA will contract an Australian GMT Project Office to assist Australian industry and astronomical institutions in winning GMT project contracts, and provide top-level management of those contracts placed with Australian institutions.

Development of PILOT
PILOT is proposed to be a 50/50 Australian/European partnership. On the Australian side, PILOT will be funded by ARA; on the European side, it may be funded by the EU's Framework Program through ARENA. The ARA Board and ARENA appoint equal numbers of members to the PILOT Board, which will be responsible for the overall management of the project. During the design phase, the work packages being carried out by Australian industry and astronomical institutions are managed by the Australian PILOT Project Office, while those carried out by European industry and astronomical institutions may be managed by the European PILOT Project Office.). This arrangement is adequate for the design phase, but it is envisaged that the construction and operations phases would each need to be contracted to a single organization, which might be AAO, ESO or another entity.

Development and Operation of MIRA
MIRA will be sited on the WA Government-owned Radio Astronomy Park (RAP) being created at Mileura Station by the Government of Western Australia. Enabling infrastructure for the RAP is being provided by the Government of WA.

LFD Component

During the term of the USA NSF grant (2006-10), progress of the LFD project will be reviewed by an international LFD Board. The LFD Board has 3 US and 4 Australian representatives. There will also be a Steering Committee, the executive arm of the Board. The Steering Committee will have 2 US and 3 Australian representatives. The LFD project is to be managed, in this first phase, by the Project Office at MIT Haystack Observatory. Decisions by the Project Office regarding design, future directions and operations of the LFD will be guided by advice from the international LFD Steering Committee and, if necessary, the Board. Site operation of the LFD during the term of the NSF grant will be the responsibility of the Australian LFD Site Manager, Professor Mervyn Lynch from Curtin University. NCRIS funding during this early stage will provide infrastructure for LFD to enable expansion of LFD beyond 2010, linking LFD into MIRA and opening of the Australian share of LFD time to other users.

The Australian LFD community is forming an Australian LFD consortium, comprising Australian research institutions contributing to LFD construction and contributing to LFD research and development. The consortium will select members to be on the international LFD governing bodies. Applications have been made to the ARC to support University-based scientific R&D on LFD during this first stage.

One member of the Australian LFD consortium will contract with the WA Government on behalf of the Australian consortium for access to the RAP for the LFD (Lead member). The Lead member of the Australian LFD consortium will enter a Consortium Agreement with other members of the Australian LFD consortium. The Consortium Agreement will establish an appropriate level of control over the future directions and use of the LFD for the Australian LFD consortium members.

<u>xNTD Component</u>

Funding for the xNTD will come from CSIRO, ARA (courtesy of the NCRIS grant) and possibly other international partners. ARA or CSIRO will contract with the WA Government for access to the RAP for the xNTD component of MIRA. CSIRO will construct and operate the xNTD component of MIRA.

International partners may also contribute to the building and operation of the xNTD component of MIRA. A contract will be drawn up to enable the international partners to maintain an appropriate level of control over the future directions and use of the xNTD component.

<u>Mileura International Radio Array (MIRA)</u>

By 2010, at the completion of the current NSF grant for LFD, it is the joint intention of the international partners that LFD phase 2 will include upgrading user support for the LFD and significantly integrating LFD into MIRA to enable cost-effective operation of at least the Australian portion of LFD as a user facility. This is consistent with NSF guidance, assuming success of the first LFD phase.

At the end of the NCRIS funding cycle, MIRA will continue to be managed and operated as an international facility. Australia's share of the operational funding could come from the existing funding to operate the Australia Telescope, through re-prioritisation. It is expected that the international partners would also contribute a share of the operating costs.

<u>Landmark Infrastructure</u>

ARA could also be responsible for the development of any astronomy 'landmark' infrastructure proposals e.g. GMT or SKA construction.

PART SIX – IMPLEMENTATION STRATEGY AND BUSINESS CASE

In this Part, you are required to set out an implementation strategy and business case for the proposed infrastructure showing how these arrangements meet NCRIS Investment Criterion 4, ie:

> **An investment plan must include an implementation strategy and business case that will result in the efficient implementation and effective ongoing financial management of the infrastructure.**

In addressing the criterion, you should fully address:

- all issues relevant to Criterion 4 that are identified in the NCRIS Roadmap; and
- the requirements of Section 3.4 of the NCRIS Investment Framework 'Content of Investment Plans'.

A strategy for the implementation of the Investment Plan should be provided in Attachment E.

A financial plan including projected financial statements should be provided in Attachment F.

A risk management strategy should be provided in Attachment G.

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Purpose

This Section sets out the proposed implementation and business strategy, reflecting the information requirements set out in Part 3.4 of the NCRIS Investment Framework. Further detail is provided in a series of attachments:

- Attachment E sets out the implementation strategy, including timelines;
- Attachment F sets out the financial plan – both during the NCRIS process and beyond and incorporates projected financial statements
- Attachment G sets out the detail of the risk management strategy;

Context

Important aspects of this strategy, and more generally of modern astronomy investments, require particular attention to:

- Almost all major new investments are done via international consortia – allowing access to size economies, cost and risk sharing and providing the basis for international collaboration involving the best scientists doing the best science in the world.
    - This creates opportunities for Australian scientists to contribute at the leading edge of international technology and research.
    - Even though Australia is a small country we can make valuable contributions and gain enormously from exposure to large-scale international enterprises
- These efforts are truly collaborative, involving commitment to up-front investment, to the prior and on-going development and provision of key technologies and to participation in science teams working on the major questions in astronomy.
    - It is important to recognise that this is quite different from arrangements simply to buy time in major facilities – the commercial analogy is far more closely aligned to that of a joint venture.
    - For the three major new facilities for which NCRIS funding is sought, Australia has taken a key foundation role.

- In relation to MIRA and PILOT, Australia has taken the lead role and both would be located on Australian territory; MIRA is also seen as pivotal in building the case for Australia being the site of the much larger SKA project.
- Nominal shares held by Australia in a project can seriously misrepresent the infrastructure access delivered, because of the very large size economies delivered. In astronomy, smaller systems do not simply involve less output at higher unit cost – they involve a fundamental loss of capability, in terms of the data that can be gathered and the questions that can be probed.
- These infrastructure projects are big – not just by the standards of science infrastructure, but even by the standards of general industry infrastructure. The SKA project, as a credible extension from the MIRA infrastructure project, is likely to involve a direct capital cost of the order of $2B and substantial operating and upgrade costs ($100M/yr) extending over decades. The GMT is envisaged as growing to a project with a capital cost of around US$550M and ongoing operating costs of the order of US$32M per annum. While the PILOT project being led by Australia is planned to be of modest size, its primary rationale lies in building the capability to underpin a much larger international investment
- For the GMT strategy, Australia is also involved from the start, at this crucial stage in the concept development – a stage that will shape the capability of the facility for decades to come. This will have a decisive impact on Australian industry's level of involvement in the project. Australian academic capabilities in integral field spectrographs, fibre optics, focal plane access, turbulence profiling and adaptive optics instrumentation have already been identified by the international GMT consortium as relevant to the GMT; Australian industrial strengths are also well-matched to various areas of the project, as has been discussed earlier.

Strategic Assessment

Background

Every major item of infrastructure proposed here (including strategic options) had, even before the NCRIS process gained traction, been the subject of detailed assessment of needs and appropriate responses, both within the Australian astronomy community and with prospective international partners. The Decadal Plan has provided strong guidance and focus to these strategic assessments and has played a role in firming up the industry view of the package of infrastructure needs that has now been further developed in this NCRIS proposal.

The NCRIS processes have delivered a high degree of coherence in the community's views as to the strategic role of each item of infrastructure. This extends to a good understanding of the major questions to be addressed, of the areas in which these infrastructure investments and Australian skills are likely to be able to be competitive, and the way in which the facilities will underpin the progressive evolution of an astronomy capability well beyond the current NCRIS timetable – including strategies in respect of the SKA, the GMT and Antarctic astronomy.

A major business case for Australian engagement with the SKA, with MIRA incorporated into the early strategy on the basis of both its own science merit and its contribution to improving Australia's ability to compete to host the SKA, has already been developed for DEST. It is available to the NCRIS assessment process. Core capability has been identified enabling Australia to shape the technological solution to the telescope design, a comprehensive proposal to site the SKA in Australia has been developed, and key alliances are being built.

Similar processes are now well underway in relation to the GMT– though, for good reason, without plans to have the instrument located in Australia. The nine members have already invested over US$15M in the project, and a high-risk technical issue, relating to the large optics, is being resolved with the successful casting of the first of the 8m off-axis mirrors. A full conceptual design review, using a distinguished international panel, was completed in February – leading to commitment to the full design phase, with the legal agreement for this phase now being finalised.

The project is being run by a Board (with two members from each partner) that instructs the Project Manager and Project Office.

The AAO has just been the subject of a major review (ee http://www.dest.gov.au/ sectors/science_innovation/policy_issues_reviews/reviews/anglo_aus.htm)[7], and this process involved detailed business planning by AAO.

Gemini is now a mature operating facility, offering state-of-the-art optical capabilities; the strategic issues relate to Australian access and to Australia's role in future instrumentation to extend its capabilities.

The strategic value of a functioning Antarctic instrument has been determined by world-leading Australian work in site characterisation – the PILOT process is directed more at practical implementation issues, and the staged approach by the consortium is designed to minimize risks while pursuing this opportunity to open up a new area of astronomy.

There are also extremely important linkages across the whole package. Australia's active involvement in astronomy as a whole is likely to be a key ingredient in its ability to compete to locate the SKA here. Construction of MIRA would enhance Australia's competitiveness in relation to the SKA technology package. The PILOT project, being led by Australia and being based on Australian territory, would add substantially to Australia's wider credentials in optical/infrared astronomy – including its plans to compete to supply next generation instruments to the Gemini telescopes and its influence in the planning for the GMT. Commitment to the GMT itself makes a strong statement about Australia's commitment to the medium-term future of astronomy – in relation to important fields of inquiry beyond the capabilities of Gemini and away from the area of special value of Antarctic astronomy.

At the same time, the strategy has been developed with a clear recognition that Australia's role in international astronomy will be limited by access to funds and it is very much in the interests of the astronomy community, and the wider Australian community, that the available funds be directed for maximum impact and value. This has involved sober assessment of those areas in which Australia can be most competitive, and those areas where investment will bring maximum benefit to Australia. It has involved the explicit de-prioritisation of investment in space-based astronomy and in major international facilities such as the Atacama Large Millimetre Array (ALMA)

These considerations of competitiveness have necessarily included non-astronomy as well as astronomy benefits for Australia, with two key components being of particular importance:

- Australian competitiveness in delivering key innovations as part of solutions to key technology challenges.
- Australian competitiveness in location; for both PILOT and MIRA, Australia can offer superb sites, thus maximising returns to the country, including through benefits flowing to two relatively disadvantaged regions in Australia..

<u>The Vision for the Investment Package</u>

The proposed investment package is designed to allow Australia to participate, and in a range of areas play a leading role, in delivering a transformational change in the capabilities of international astronomy, and in our associated understanding of the universe. The combination of dramatic increases in aperture/collecting area, exploitation of observing conditions in Antarctica and inland Australia, and technological lead in specialist areas, will ensure maximum return to the Australian economy and society.

- MIRA offers an order of magnitude increase in effective collecting area for Australian radio astronomy, to a design that complies with the International SKA Reference Design – and

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[7] This plan has been prepared without access to the report of the review committee, which remains confidential.

would be a key component in establishing the viability and cost effectiveness of this new approach to radio astronomy.
    - Progression to the full SKA would mean an overall 100-fold increase in effective collecting area relative to anything else available in the world.
- PILOT is being planned to explore the optical to mid-infrared window on the sky, by allowing larger instruments to take advantage of the superb seeing conditions and low infrared background in Antarctica.
- The GMT will have an effective aperture of nearly 25-metres, offering an order of magnitude increase in collecting area relative to the largest optical telescopes, such as Gemini, that are now in service.
    - Early Australian participation, especially participation as a national as opposed to single institutional partner, would give Australia negotiating power greater than its share in seeking access to the high value work – paralleling Canadian success in this way in relation to the Thirty-meter telescope project.
    - Securing a substantial share in GMT would secure a key for Australia in the future of optical astronomy that will inevitably move to this new class of optical telescope.
- The AAO and Gemini elements of the strategy are directed at ensuring maximum value is obtained from the existing facilities and skills. These elements will maintain the core of Australian capability in optical astronomy and take advantage of the industry and science opportunities associated with the demands of emerging instruments and technologies.
    - Access to, or assurance of future access to, the next generation of optical facilities (GMT and Antarctica) could add greatly to the incentives for building careers in astronomy and encourage the skills to be focussed on gaining maximum advantage from this group of facilities.

A key feature of the proposed investment is that it will be supporting not just a crucial role for Australia in providing transformational astronomical research, but may in fact underpin a central role for Australian-based facilities that are the best of their type in the world, and largely Australian-developed instruments, that operate at the leading edge of this quest. The instruments, and the information generated from these infrastructure facilities, will be available to the international astronomy community, ensuring that the very best use is made of the facilities, and ensuring strong intellectual links between Australia and the best international research and educational institutions.

<u>Key Value Drivers for the Strategy</u>

Australia has a proud history of major contribution to astronomy. Citation-based impact assessments have long suggested that Australia 'punches above its weight class' and suggest its competitiveness has been growing strongly over the past 10 years. Australian astronomy has a strong recent record of real industrial and wider economic spin-offs – in large part reflecting the discipline's heavy reliance on leading edge data capture, processing and analysis capability and the extent to which gaining value from the major facility investments has been dependent on on-going investment in adaptation and extension of capability through new and often innovative instrumentation, stronger networking and smarter software.

The primary focus of most astronomy research – and the proposed application of the research infrastructure for which NCRIS support is being sought – is knowledge derived for its own sake. We view knowledge of the universe as essentially a public good, one in which there is substantial interest. While we have identified scope for significant tangible benefits from the proposed infrastructure investment, we are not arguing that this should constitute the primary rationale. We are proposing support for truly excellent science, based around Australian contribution to international science ventures involving the best scientists and science in the world and directed at the most fundamental questions about our universe.

This certainly does not deny the scope for future practical – potentially world-changing – application of some of this astronomy knowledge. This has certainly been true historically. Astronomy is in fact an enormous physics laboratory – indeed the only such laboratory capable of observing the laws of physics in operation since the formation of the universe – on time and spatial scales not otherwise accessible. Recent discoveries are already feeding into serious challenges for mainstream views of the laws of physics and will almost certainly feed future changes. Australian astronomy and astronomers have been playing key roles in these developments.

A clear example of this lies in the recent major Australian contributions to identifying dark energy – now recognised as the major constituent of the Universe, yet is poorly understood. Indeed, the observed value of dark energy is 10^{120} times greater than that predicted by current theories. Further observations with AAT, Gemini, MIRA and ultimately the SKA and GMT will extend this work, gaining a better understanding of dark energy and helping shape the laws of physics. It is likely that work with significant prospects for helping bridge a discrepancy in current theories as large as this will flow through into new insights of practical as well as cultural value.

We believe that efforts to force the astronomy endeavour to be justified solely or mainly in terms of more tangible returns – and especially in the same terms that might be applied to industry-oriented R&D and research infrastructure – would prove seriously distorting and would erode Australia's capability and contribution to this science. It would work to the disadvantage of an area of science where Australia is seriously competitive as a leader in key areas of a multinational science endeavour. By the same token, as was discussed earlier, we recognise the value of these tangible as well as less tangible (but not less important) values and the strategy is heavily geared towards Australian engagement that favours these spin-offs from areas in which Australia has competitive advantage.

Our reading of the NCRIS roadmap is quite consistent with this interpretation. The rationale set out in the Roadmap is that:

- "Astronomy is one of Australia's highest impact sciences. Australian astronomers have played leading roles in recent major discoveries, including the acceleration of the universe, the existence of dark energy, a new type of galaxy, a unique double pulsar, and planets orbiting other stars. Our high international standing in astronomy helps support public interest in science and provides powerful evidence to the rest of the world of Australia's scientific and technological capacity. Astronomy is a rapidly evolving field in which continued investment is essential in order to keep pace with global developments."
- "Development of infrastructure for astronomy involves significant collaboration with industry and generates technological spin-offs. Early investment in new projects is crucial to securing the most valuable elements of these technology development programs and maximising the spin-off benefits for Australia."

The first of these points recognises this primary cultural value, and Australia's demonstrated capacity to contribute at the highest level. Further evidence of our track record in influencing astronomy internationally was documented in the Decadal Plan. The second point recognises that pursuing these central cultural goals need not be at the expense of good innovation and economic contribution and this argument is developed in more detail below.

We stress the main thrust of the case presented here for a major NCRIS investment in astronomy lies with a combination of:

- Australia's track record in the field, and the evidence of strengthening competitiveness and recent discoveries of major importance;
- Strong technology and research trends that imply that Australia's competitiveness could decline rapidly without significant investment in new infrastructure and in extending the life of existing facilities still capable of making major contributions to leading edge science;
- The fact that the sector is well organised and has developed, and signed off on, an affordable, coherent strategy that will allow Australia to build its capability to maintain, and in selected areas expand, its competitiveness, to continue to deliver excellent science off the back of a quantum leap in instrument capabilities over the next few years.
    - This demonstrated ability for a coordinated sector response is strongly supportive of NCRIS objectives and provides good evidence of the ability of the community to

follow through in taking full advantage of the opportunities that would be created by the proposed research infrastructure and associated access arrangements.

Interest in astronomy extends well beyond the astronomy community. There is wide public interest, typically starting in childhood and characterised by the wide media interest in the new discoveries and by the significant popular science coverage on television, in books etc. Stars and planets – and recent Australian successes in discovering over 20 new planets is relevant here – are highly accessible, and of interest to, to the general public. The rate at which our 'model' of the universe is evolving, the strangeness of the models that are emerging and the notion that space stands at the frontier for future exploration are all factors underpinning wider community interest.

Tangible benefits – Options for Australia

By far the most appropriate paradigm for looking at the tangible benefits is that of *option value* – recognising the value that lies in the prospects for delivering valuable outcomes in the future. This is a modern, state-of-the-art paradigm for valuing investments that incorporate high levels of risk – and is therefore discussed in more detail in the explicit discussion of risk management. The options view is about securing access to upside opportunities as well as covering downside risks – and astronomy investments offer significant upside value to the Australian community.

- Australia's competitiveness in siting major facilities has a substantial option value – via the prospects for investment into Australia from other project participants.
- This was clearly indicated through the analysis undertaken last year by ACIL Tasman, developing the business case for Australian participation in the SKA project.
  - That analysis pointed to a substantial value for the option to be the selected site, even after taking into account significant risks to the project proceeding, to Australia being the chosen site etc.
- The gross option value of the tangible benefits from Australian participation was conservatively valued at around $130m (present value basis) – before attributing any value to the astronomy outcomes seen as the primary rationale for the investment.
  - This option value takes into account risk-weighting for the chance that Australia is not selected as the site. The *potential* tangible value was in fact conservatively estimated to be just under $250m (present value basis).
  - The option value of these tangible benefits alone exceed by around $30m the total assessed risk-weighted cost of participation in the SKA venture.
- The same option modelling pointed to the 'opportunity cost' of any developments that lower Australia's being chosen as the site.
  - Halving Australia's prospects from those assumed would drop the value of the option by about $30m (present value basis) – in return for a risk-weighted cost saving of around $10m. We stress that inclusion of the value of the astronomy and other intangible benefits would imply a much greater net cost than is indicated by these tangible figures.
  - A corollary is that our proposed commitment, supported by NCRIS funding, to proceed with the MIRA radio telescope development in WA will, in addition to the direct science benefits from this order of magnitude improvement over current Australian radio astronomy capability, deliver significant additional value via an increase in the value – to the Australian economy – of Australia's SKA options.
- It is important also to recognise that Australia's on-going involvement in a major capacity in optical and infrared astronomy, including the maintenance of capability and reputation but extended by our clear commitment to remaining at the visionary edge of astronomy in key niches across the spectrum will add directly to two key groups of options:
  - It too enhances Australia's prospects for locating the SKA, being part of a broad technical capability, supporting cross-spectrum research and perceptions by the international astronomy community of national commitment to these programs.
  - Clear evidence of on-going commitment across appropriate areas of astronomy, coupled with what is implied for maintenance of local capability in astronomy and astronomy instrumentation and technologies can be expected to add significantly to the likelihood of Australia being selected to site the SKA.

- Even more directly, it becomes a key part of Australia's competitiveness for the siting of an Antarctic optical instrument. The proposed PILOT program, for which NCRIS funding is sought, is expected to add significantly to the strength of Australia's case – while also enhancing the wider value, and perceptions of value, in Australia's Antarctic research activities.
    - In addition to being able to offer a suitable site, Australia is particularly well-placed to bring to bear its proximity to the site in offering support during construction and operation, its established presence in the Antarctic Territory with a major science program and the associated logistical support, including air and sea links, its experience in construction, facilities operation and science in Antarctica and explicit relevant technical skills in relation to remote power generation, robotics, and harsh-environment engineering.
- In respect of the GMT, we noted earlier that a key benefit of serious engagement now in the design phase – and indeed of serious national engagement that can be delivered through NCRIS involvement – is the scope this offers for Australia to have influence that is disproportionately large relative to its formal share.
    - In the 'politics' of these international science consortia, it is greatly to the advantage of a project to have a 'national' partner.
    - Canada has assumed this role in relation to the Thirty-Meter Telescope and has consequently won a large volume of the high-intellectual value work, despite being a minor participant.
    - Australia is well-placed to offer the GMT project highly relevant industrial expertise in areas such as control systems, vibrational analysis, fluid dynamics, systems engineering and project management – as well as its direct science capabilities in instrumentation and the relevant astrophysics.
- Finally, as was recognised in the roadmap, it is in the nature of modern development of astronomy facilities that the major opportunities to share in the opportunities for industry collaboration and technology develop accrue to those who establish early participation in the emerging projects and especially to those who bring to the projects high prospectivity approaches to addressing the key technology and cost challenges.

The Decadal Plan, supported by this NCRIS proposal, is pitched strongly at securing these opportunities through early and influential involvement in the project planning and by bringing specific technology as well as site location strategies to the table.

<u>Exploiting competitive advantage</u>
The dominant trend in creating leading edge infrastructure in astronomy – in optical/IR and in radio – is towards substantial expansion the receiving areas of the telescopes, to deliver greater resolution, combined with wider data capture, analysis and interpretation capabilities. In the case of optical/IR, a limitation on the relationship between resolution and telescope diameter has been removed, through the introduction of adaptive optics to reduce any atmospheric distortions. In the case of radio astronomy, the trend is towards networking receiving instruments located across very large areas – characterised by the SKA proposal, but already reflected in substantial national and international networking of established instruments.

These trends are creating increasingly demanding requirements for site location. For optical/infrared instruments, high altitude, low moisture and low light conditions are strongly favoured. For radio instruments, access to large stretches of radio-quiet land, ideally capable of having the radio quietness locked in for the life of the instrument, is important. In all cases, access to sound local infrastructure and the technical capabilities needed to support a high technology investment are requirements.

Ultimately, the core capability needed for excellent astronomy lies, as with other areas of science, with the people and their skills. Excellence in the skill set is a central element of competitive advantage in a field that is increasingly competing for access to facilities located around the world. Australia has in the past proven highly competitive in this way, and a key element of the strategy is designed to maintain this competitive advantage. These skills include those relevant to the cost-effective delivery of capability to telescopes via smart instrumentation and data capture and analysis capabilities.

Key planks of the strategy include support for Australia's efforts, based on cost-effectiveness principles, for being the site for the SKA and, if proven appropriate, for the first large optical instrument investment in Antarctica. Note that the immediate investment case is not seeking funding for either of these proposals – both of which involve longer time scales than the current round of NCRIS and neither of which is yet proven. The role in support of these efforts seen for NCRIS is in contributing to two new instruments – MIRA in WA and PILOT (subject to successful further investigations) on the high plateau of the Australian Antarctic Territory. These facilities would:

- greatly enhance Australian and international capability in these two areas;
- provide prototyping capabilities suited to assessing and, if appropriate, refining the plans for the SKA and larger Antarctic instruments;
- contribute to Australia's capability, and wider perceptions of this capability, to compete to be the preferred site for the main instruments;
- be suited to networking and integration into the SKA and Antarctic astronomy capability – adding to both the value of the options built into these instruments, and to their expected economic lives.

The strategy also incorporates commitments to excellence in science in relation to instruments located, or likely in the future to be located, elsewhere – notably in Chile and Hawaii, where Australia has a well established set of relationships to provide a firm basis for such developments. Included here, in a manner analogous to the long term options being secured for radio and Antarctic astronomy, would be the development of options for serious engagement with the next generation (and beyond) of ELTs. As was argued earlier, Australia is able to offer competitive skills across a broad range of the capabilities that will be needed for this next generation of instruments as well as to ensure that maximum value is obtained from the established instruments.

More fundamentally, the strategy offers the collective capability to continue to compete and contribute at the leading edges of international astronomy, while ensuring that the full range of capabilities Australia offers in relation to future astronomy – from sites for telescopes, through main instrument design and other instrumentation through to the planning and execution of great science using the instruments – is able to compete on merit. Under these circumstances, we fully expect Australia to continue to 'punch well above its weight class' in astronomy for many years to come.

Cost effective leverage

Astronomy is a truly international science that is now highly dependent on internationally funded and operated major infrastructure facilities. From an NCRIS perspective, there are real strengths in this. The need for such facilities, and their high cost, has created the need to develop sophisticated systems for sharing costs and for managing access to ensure that the best science is undertaken by the best scientists – with appropriate technical support in the facilities. Over the past 30 years, the Anglo-Australian Telescope has been an Australian-based example of this approach in optical astronomy, while the ATNF has served as a similar example for almost 20 years. Closely analogous systems apply to the Gemini telescopes and are planned for the Giant Magellan, the Antarctic PILOT and the SKA facilities.

The principles embodied in these systems closely parallel the vision developed in the NCRIS Roadmap – in relation to both the collaborative design and development of facilities and the basis on which access is provided.

The Australian astronomy community welcomes the NCRIS program as an important source of funding critical to its Decadal Plan and to ensuring that Australia is able to maintain and build its excellence and competitiveness in this major area of international science.

The strategy as developed does offer very substantial opportunities for leverage, in the sense of Australian scientists gaining access to internationally leading-edge facilities that are only made possible by the level of contribution of funds from other countries, and by the ability of Australian institutions to bring considerable additional resources to both the planning and the use of the facilities. There are now very large size economies in both optical/IR and radio astronomy. The strategy is designed to exploit these size economies and the commitment of other countries and other institutions to this major area of research to deliver a dramatic increase in the capability of the facilities to which Australian astronomy has access. The same strategy will underpin on-going value in aging but still productive facilities in Australia, including the AAO, and the Siding Spring, Parkes, Narrabri and Mopra facilities.

A feature of the continued effective operation of these facilities, supported where appropriate by new instruments, is that they will allow optimisation of operating strategy for the future telescopes. This flows from the demonstrated value of these processes in delivering wider field of view surveys that can support short-listing of targets for the larger, and more time-constrained and expensive to operate, instruments.

<u>Options-based planning as an integral part of the Business Case</u>

As discussed above, cost effective investment in major astronomy infrastructure is necessarily done on an adaptive basis, precluding rigid deterministic roll-out strategies. The proposed investment plan embodies latest thinking – based around the principles of risk-based investment planning and management with a strong emphasis on *maximising the value of the options* created through the process. This is a logical extension of the thinking and options modelling already used in the ACIL Tasman business case for the SKA, and discussed above. Specific option-based planning tools will assist the community and the government in managing the process to deliver greatest value.

As with most options-based planning, these approaches are expected to allow significant savings – through the avoidance of unnecessary investments – and the achievement of growth in the value of outputs via the efficient redirection of these funds and through the identification of more valuable ways of developing the infrastructure package over time.

This flexibility is a strength of the strategy. The financial plan set out below is predicated on an NCRIS budget of $45m, not because of a shortage of high value applications for funds in excess of that level but because of feedback from the NCRIS Committee of likely funding levels for the Astronomy Capability.

The proposal has inherent cost uncertainty – discussed further in relation to risk management below and in Attachment G. Furthermore, aspects of it – notably the PILOT strategy – mean that some costs are linked, even within the next 5 years, to outcomes from the first stage investment. It is in fact here that the potential cost of the $45m NCRIS budget constraint becomes quite apparent.

Major elements of the investment package – both this constrained package and the communities preferred and less constrained package, are quite ‘lumpy’. Construction of PILOT, if it proceeds, is estimated to cost Australia around $5m. Managing within the NCRIS limit to ensure the flexibility is retained to allocate funds to PILOT construction, if proven to be appropriate, places its own constraints on the form and timing of other elements of the package.

Similarly, achieving the desired goal of a total 10% Australian share in the GMT Design Development Phase, based on the success of the first stage of engagement, can only be realised if sufficient flexibility is maintained in the strategic options part of the overall NCRIS package. A total NCRIS commitment of $2.8M is required to maintain Australia’s 10% share (with ANU) during Years 2 and 3 of the DDP.

There are inevitable compromises in this process, but great care has been taken to assemble a mix of core and optional investment elements that work within the constraints as cost effectively as possible.

PILOT Stage 1 will build valuable infrastructure assets in the form of an improved understanding of the engineering requirements for Antarctic astronomy, detailed design drawings for Stage 2 if this still looks cost effective, and ultimately in contributing to a substantially larger international facility, with greatly expanded capability. Stage 1 is an investment in information options as part of a sensible strategy for rolling out astronomy infrastructure in Australia's Antarctic Territory.

The strategy certainly allows for the possibility that the best use of resources beyond Stage 1 may be redeployment to bring forward some other elements of the package and deferral of the next stage in Antarctica – this is just sound planning strategy, underpinned by the options paradigm. The planned diversion of resources would be to high value uses, already identified in the Decadal Plan but tentatively delayed because of the budget constraint. Bringing the other elements forward can be expected to deliver fundamental benefits – for example in the form of elevated prospects for an expanded role in delivering the high-intellectual value work for the GMT as was discussed earlier. This is the flip side of the 'opportunity cost' of the funds constraints that apply and to which the strategy has been adapted.

More generally, the astronomy community clearly recognises that the strategic options that have been identified, especially PILOT Construction and GMT engagement, are not scientifically interchangeable. In terms of the Australian and international astronomy endeavours, they are in fact strongly complementary – and the trade-off involved as a result of funding constraints is difficult and costly. However, the process is designed to ensure that the ARA Board will be able to make decisions at the appropriate time be based on the best available information.

These concepts are absolutely central to the rationale for the PILOT and GMT strategies – both of which are essentially about securing infrastructure options relevant to the next generation of technologies – but also have a lot to offer in respect of the MIRA investment (of value in its own right and for the SKA options it supports) and for the AAO and Gemini strategies, that are again of value in their own right and are expected to provide valuable support for Australia's role in the next generation of large astronomy projects.

This approach feeds into the financial plan and the risk management strategy,

Role of NCRIS Funds

The following comments apply to the role of NCRIS funds in the overall international infrastructures to which NCRIS funds will be applied::

Gemini

- o Gemini delivers to Australia a capability that would be impossible with Australian funds alone
- o Australia has specific capabilities to offer the consortium – in instrument design as well as in use of the main instruments – that could lead to a loss of value of outputs from this collaboration without NCRIS investment

GMT

- o NCRIS funding would allow Australian participation to be a 'national', as opposed to institutional engagement. This doubles influence and involvement, and build momentum towards a bid for funding for the construction phase..
- o A corollary is that NCRIS funding – if feasible within the difficult trade-offs needed across the 'optional' elements of this investment package – could secure a disproportionate level of Australian involvement in delivering the industrial and technical package need to construct the GMT.
- o Furthermore, from the point of view of Australian astronomy, exclusion from the early stages of the next generation of optical instruments means that these instruments will not necessarily be aligned with the Australian astronomy's priorities and strengths, will not be designed or built here, and may not be directly available to Australian astronomers when they are operational.

AAO, MIRA and PILOT

- o It is unambiguously clear that the proposed science infrastructure will not proceed without strong Australian involvement, and this clearly requires significant funding from NCRIS.
- o Other sources of Australian funds have been incorporated to the maximum extent judged feasible.
- o These initiatives are all being driven by Australia – using NCRIS investment as a catalyst – but can then command significant funds from other sources.
- o LIEF investment may also be brought to bear on targeted University research outcomes, both early on in the development of these infrastructures and, following their elevation to 'national facility' status made possible with NCRIS investments through investment in additional instrumentation and other items of infrastructure.

Detailed financial plan

Financial planning has involved a range of steps:

- Preparation of detailed budgets for each of the key initiatives included in the strategy – the 'Strategic Options' items as well as Priority items
  - o based on the best information now available;
  - o based around firm and highly prospective commitments from other parties; and
  - o inclusive of reasonable contingencies so that the costs can reasonably be interpreted as estimates of expected cost
- Identification of flexibility inherent in the 'Strategic Options' components, and to an extent in the detail of the Priority components; and
  - o development of an overall package that includes all items.
  - o "Weights" have emerged from the options model, and from the requirement to 'cut the cloth to fit' – they can be interpreted as attaching to the individual components a likelihood of exclusion or scaling back to allow the total package to be delivered within $45m envelope. In most cases, we expect this to imply deferral beyond the 5 years, rather than cancellation, of these package components. Deferral itself may have significant impact on Australia's ability to particpate in, and derive benefit from, the international projects that make up the options component.

- Effectively, these allow modelling of a total package in which details of the final composition can only be determined cost effectively after the investment process starts.

With these elements, it is possible to compose 'whole of package' budgets, inclusive of this risk weighting.

 # Tables4&5 from section 2 to be included here

Attachment E provides much greater disaggregation of these tables, and discusses the basis on which the cost estimates have been reached.

Implementation – Timelines and institutional arrangements

To be completed

Operations beyond 2011

The above budgets, the options based approach to flexible planning and the risk management strategy discussed below, and in Attachment G and the proposed governance arrangements all support the view that this strategy has excellent prospects for financial viability through to 2011.

The extensive experience that Australian astronomy has in the management of large infrastructure facilities, such as those operated by AAO and ATNF; the analogous established experience in relation to overseas infrastructure, such as through the Gemini Consortium; and the fact that senior management bringing this experience will be heavily involved in the proposed investment process; all add to the confidence with which this can be asserted.

Revenues beyond 2011 are not as certain for some of the package components. In each case, operating costs inclusive of periodic normal replacement and upgrade requirements have been estimated – based on extensive experience with these types of facilities.

Realistically, for at least some elements – such as continued operation of AAO beyond 2011 – it is necessary to assume that some form of successor to NCRIS will be available, or else the facility will need to close. The AAT is expected to have a scientific lifetime extending at least to 2015; the AAO - as the national optical/infrared observatory - is envisaged to have a continuing long-term role.

For Gemini access, block funding through something like NCRIS is also a necessary assumption for operations to continue beyond 2011. There is no great financial risk involved here – there is a market in access to Gemini, as is discussed in Appendix G and, with warning, Australia should be able to withdraw. There would however be much wider and more concerning risks for Australian astronomy.

For MIRA, CSIRO ATNF has already indicated a willingness to assume responsibility for operating costs beyond 2011 – though the strategy will involve looking to incorporation of MIRA into an Australian-based SKA strategy, with funding for that being dealt with as a separate major investment item, as was noted in the NCRIS Roadmap.

None of the GMT DPP or PILOT stages have any costs projected beyond 2011.

Should work proceed to construction of PILOT, completion is planned during the life of the NCRIS process. However, there will then be an operational facility with an ongoing need for support. The Concordia Station at Dome C is jointly operated by the French and Italian National Antarctic Programs and costs approximately €4.5m per annum. There are planned to be six scientists working year-round at Concordia, so if one of these is assigned to PILOT it would be reasonable to attribute one sixth of the total operational cost of the facility to PILOT – or AUD 1.2m/annum.

Coinvestment by the UNSW in a PILOT ‘Science Centre” will provide scientific support staff to ensure that Australian astronomers can use the telescope to its full potential, while operation of the telescope itself and data curation would be the responsibility of the (fully Australian owned) Anglo-Australian Observatory.

ATTACHMENT A LIST OF ASSETS

The nature, ownership, value and expected date of acquisition of significant assets should be recorded.

To be included later

ATTACHMENT B CONSTITUTION / MEMORANDUM OF UNDERSTANDING

Any company constitution, memorandum of understanding or other agreement relating to entities that will own or operate the NCRIS facilities should be provided if available. Otherwise, a detailed description should be provided of the arrangements that are proposed to be implemented.

Draft ARA constitution currently in a separate document.

To be included here before 8th September 2006.

ATTACHMENT C ORGANISATION CHARTS

Organisation charts explaining the relationships between entities involved in the project, or showing the management structure within relevant organisations should be provided.

Gemini and AAO

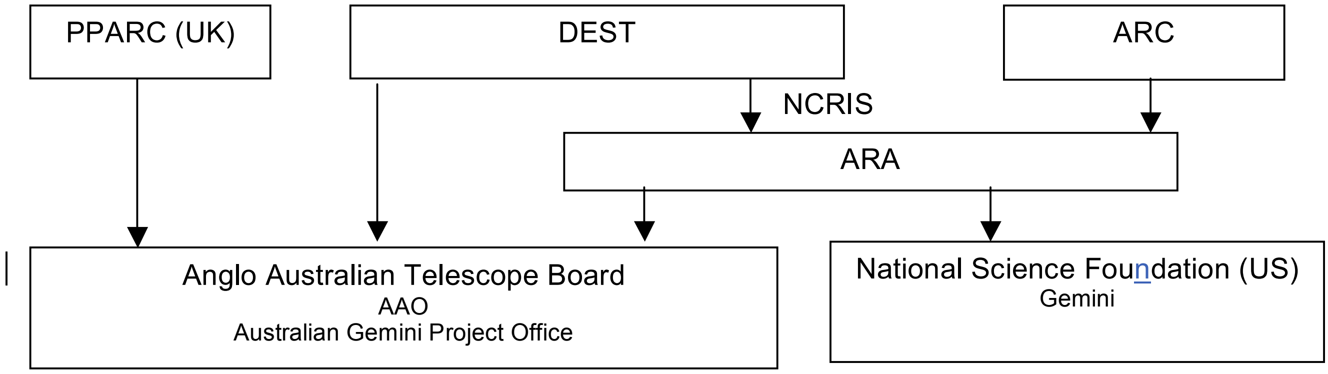
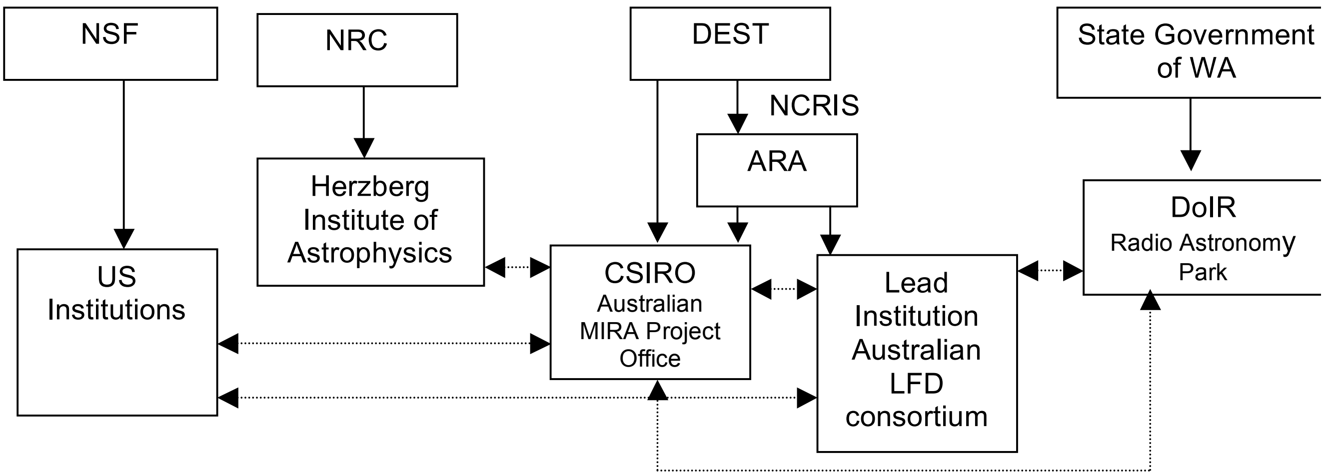


Figure x: Cash flow between legal entities for the AAO and the Australian share of Gemini

Notes:

- While the AATB continues to operate as a separate entity with UK involvement, the governance for both the AAO and Gemini Telescopes will involve both ARA and the AATB. The AATB will be directly responsible for AAO operations, AAO instrumentation development, and the Australian Gemini Office which facilitates access to Gemini for Australian astronomers.
- The NSF in the USA is responsible for Gemini Operations. The NSF has the Gemini Board to manage the Gemini Observatory, and Australia has one seat on that board.

MIRA



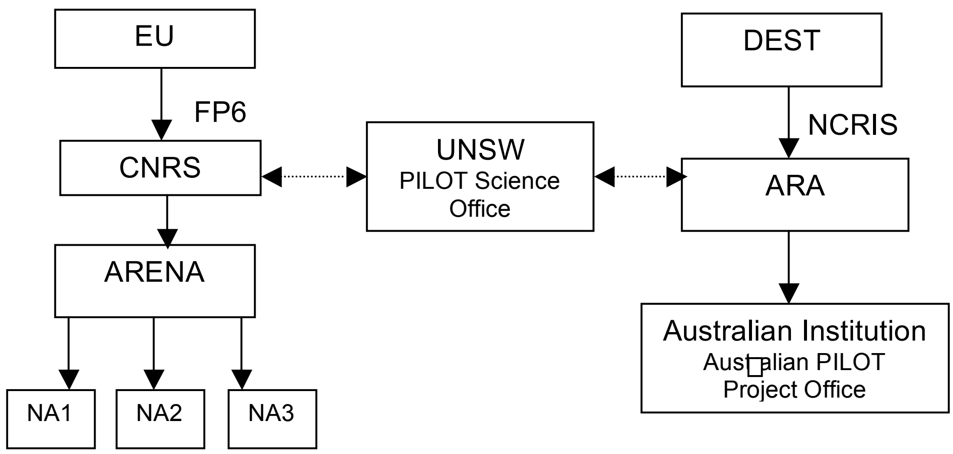
Dotted lines indicate MOUs

Figure x: Cash flow between legal entities for MIRA

Notes:

- CSIRO also makes in-kind co-investment to xNTD component of MIRA.
- Australian MIRA project office will contract with Australian Universities, institutions and industry to deliver work packages/components of MIRA as appropriate.
- The relationship between CSIRO, and DoIR as managers of the Radio Astronomy Park, may be established by an MOU. The agreement to site MIRA on the RAP will be established between DOIR and the relevant lead agencies.
- Overseas institutions may contribute to xNTD portion of MIRA.
- A Lead Agency of the Australian LFD Consortium (currently University of Melbourne) manages LFD portion of MIRA. The Lead Agency has applied for ARC funding to support construction of LFD.
- US institutions build US portion of LFD (funds from NSF, MIT, AFOSR, CFA-Harvard)
- ANU is also a signatory to the LFD MOU, but as a separate member from the Australian LFD consortium (omitted from the above diagram simply for clarity).
- CSIRO or Australian Lead Agency integrates LFD into MIRA using NCRIS resources.
- WA Govt, through DOIR support Radio Astronomy Park.

PILOT

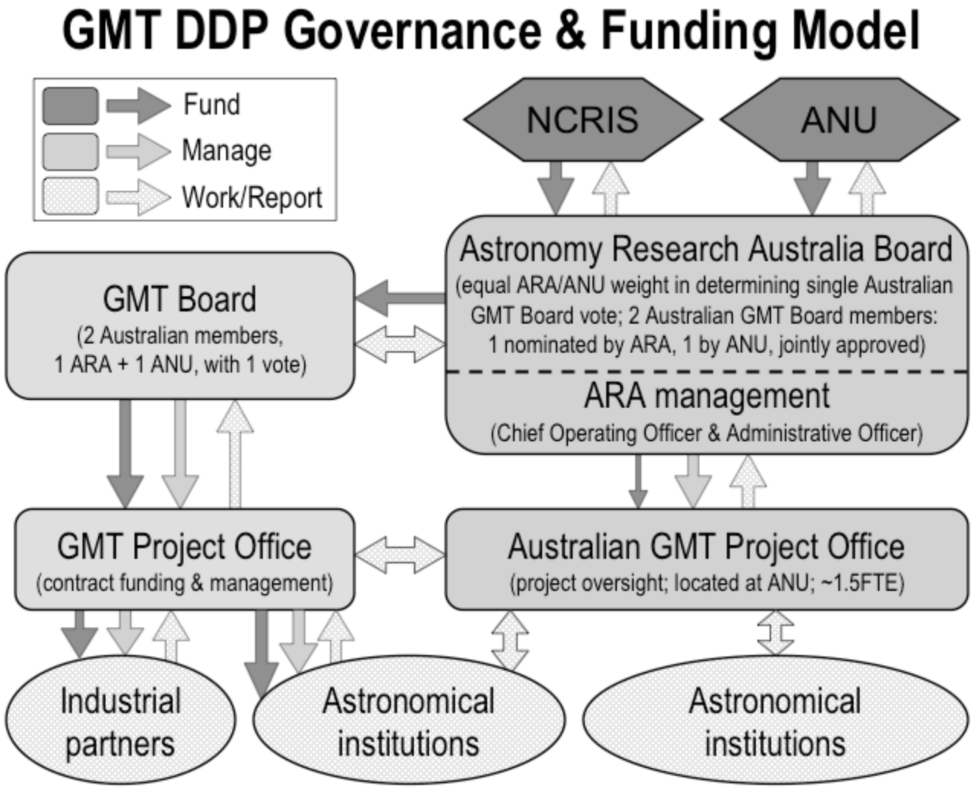


Dotted lines indicate MOUs

Figure x: Cash flow between legal entities for PILOT

Notes

- CNRS is the French Centre National de la Recherche Scientifique, and is the contracting agency to the European FP6 program on behalf of ARENA.
- ARENA is the FP6 "Coordinating Activity" for Antarctic Astronomy. It stands for Antarctic Research; a European network for Astronomy.
- ARENA is funded for three years, beginning in 2006.
- The Australian Project Office will manage, and allocate funding to, a series of work packages within Australian industry and academia, leading to the production of a detailed design for the Critical
- Design Review of the project by ARA.
- This cash flow chart is appropriate for Stage 1 of PILOT. If PILOT proceeds to the construction and operational phases, it will be desirable for a single PILOT Board to be created, with equal European and Australian representation.
- The Australian PILOT Project Office would be established by ARA within an existing Australian institution with a good track record in the management of large projects.


GMT DDP Governance & Funding Model
Fund
Manage
Work/Report
NCRIS
ANU
Astronomy Research Australia Board
(equal ARA/ANU weight in determining single Australian GMT Board vote; 2 Australian GMT Board members: 1 nominated by ARA, 1 by ANU, jointly approved)
ARA management
(Chief Operating Officer & Administrative Officer)
GMT Board
(2 Australian members, 1 ARA + 1 ANU, with 1 vote)
GMT Project Office
(contract funding & management)
Australian GMT Project Office
(project oversight; located at ANU; ~1.5FTE)
Industrial partners
Astronomical institutions
Astronomical institutions

ATTACHMENT D CURRICULUM VITAE FOR KEY PERSONNEL

Where possible, curriculum vitae for key personnel (maximum of 2 pages per person) involved in the management of the NCRIS facilities should be provided.

Chair of Board, Executive Officer

ATTACHMENT E IMPLEMENTATION STRATEGY

To be completed

ATTACHMENT F **ARA FINANCIAL STATEMENTS**

A financial plan including projected financial statements should be provided as specified in Section 3.4 of the NCRIS Investment Framework

Budget – Statement of Financial Performance

	2006/07	2007/08	2008/09	2009/10	2010/11	Total
Revenue						
ARA members	$60,000	$164,300	$174,158	$184,605	$195,681	$778,744
ARC		$867,000	$889,000	$911,000	$933,000	$3,600,000
NCRIS	$3,433,500	$8,684,067	$8,821,600	$14,781,853	$9,278,980	$45,000,000
Total	$3,493,500	$9,715,367	$9,884,758	$15,877,458	$10,407,661	$49,378,744
Expenses						
International Access		-$2,486,667	-$3,766,000	-$3,828,666	-$3,121,833	-$13,203,166
Operating	-$2,143,500	-$2,060,033	-$2,088,092	-$2,116,792	-$1,647,161	-$10,055,578
Profit / Loss	$1,350,000	$5,168,667	$4,030,666	$9,932,000	$5,638,667	$26,120,000

Budget – Statement of Cash Flows

Cash Flow	2006/07	2007/08	2008/09	2009/10	2010/11	Total
Cash inflow	$3,493,500	$9,715,367	$9,884,758	$15,877,458	$10,407,661	$49,378,744
Cash outflow	-$3,493,500	-$8,466,700	-$9,854,092	-$15,845,458	-$11,718,994	-$49,378,744
Net cash flow	$0	$1,248,667	$30,666	$32,000	-$1,311,333	$0
Cash at start of period	$0	$0	$1,248,667	$1,279,333	$1,311,333	
Cash at end of period	$0	$1,248,667	$1,279,333	$1,311,333	$0	

Budget – Statement of Financial Position

	30-Jun-07	30-Jun-08	30-Jun-09	30-Jun-10	30-Jun-11
ASSETS					
Cash	$0	$1,248,667	$1,279,333	$1,311,333	$0
Total current	$0	$1,248,667	$1,279,333	$1,311,333	$0
AAT instrument	$350,000	$2,070,000	$3,870,000	$5,370,000	$5,920,000
LFD	$0	$0	$0	$2,300,000	$4,600,000
PILOT DDP	$500,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000
xNTD	$500,000	$2,200,000	$4,400,000	$10,500,000	$14,600,000
Total non-current	$1,350,000	$5,270,000	$9,270,000	$19,170,000	$26,120,000
Total assets	$1,350,000	$6,518,667	$10,549,333	$20,481,333	$26,120,000
LIABILITIES					
Total liabilities	$0	$0	$0	$0	$0
Equity					
Total Equity	$1,350,000	$6,518,667	$10,549,333	$20,481,333	$26,120,000

ATTACHMENT G RISK MANAGEMENT STRATEGY

Background

Any large infrastructure project entails risks – invariably in relation to cost estimates and revenues, commonly in relation to technical and legal matters, changing 'markets' and changing technological possibilities. There can also be risks of dispute within consortia.

Both this proposed NCRIS investment strategy, and the wider Decadal Plan Strategy, involve large, high cost investments in long-lived research infrastructure assets – with substantial on-going operating, maintenance and upgrade costs, as well as up-front capital costs. Both of financial necessity and to ensure greatest value is extracted from the assets, the investment and access will be international in nature. The technologies underpinning astronomical research are developing rapidly, as is the underlying science. A corollary of the latter is that there is particularly high uncertainty regarding the particular way in which the infrastructure will be deployed in the future, and how it will need to be modified over time to maintain its value and relevance.

As was argued in Section 6, we believe strongly that the NCRIS processes need to recognise and value the *strategy flexibility* that has emerged as the sound approach to delivering the best and most effective science where these types of uncertainty arise – and that has been built into this astronomy strategy.

To a large extent, the uncertainty and risks that need to be managed (and exploited) stem from recent successes of these large international collaborations – successes in both driving innovation to deliver rapidly expanding capability and in demonstrating striking success in implementing these technologies and in delivering an understanding of the universe that is now improving exponentially.

Two of the major science innovations driving this success – and two areas where Australian science has been active – are:

- The development of credible technological strategies – including packages incorporating the xNTD and other ICT technologies in which Australia is playing a key development role – to enable a radio telescope of the scale of the SKA, with its two orders of magnitude improvement in collection area, to be seriously planned.
    - The MIRA proposal includes the first 'production' deployment of the xNTD technology in a major instrument. This is expected to add substantially to prospects for this technology being taken up by the SKA consortium and to Australia's prospects for hosting the SKA – reducing 2 key risks associated with the overall astronomy strategy and the prospects for large tangible benefits from the NCRIS investment.
- The development of adaptive optics that has made practical the development of very large land based optical telescopes, because of the ability now available to adjust for atmospheric distortion.
    - Without this development, the shape of the astronomy strategy would be strikingly different – with much less emphasis on expanding aperture, possibly with a greater emphasis on improved instrumentation for existing instruments but with nothing like the capability improvement now possible, and probably with expectations of a diminishing role for terrestrial optical astronomy.
    - but the international community has focused on resolving this problem and has set in train the development of a land-based telescope strategy for the next few decades that is set to deliver a massive improvement in precision and in the power offered to address the big questions.

The way that the development of these capabilities, and their subsequent translation into revised international astronomy strategy, provide major examples of how these types of risks can be (and will continue to be) managed in astronomy while pushing out, and funding, major advances in the research infrastructure.

More generally though, what is proposed here is a major collaborative investment effort. There are technical risks to be managed, alongside of financial and legal risks. The need for coordination across a range of Australian institutions, but in the case of some of the infrastructure across international consortia, creates management risks for long-lived asset investments as well as offering powerful checks and balances, substantial risk spreading and even supporting a potential market for trading in consortium membership which in itself offers an important form of risk management.

Key Risks Needing Management

Specific risks that have been the focus of this risk management strategy include:

- Technical risks associated with science and engineering issues yet to be resolved but where, for reasons outlined earlier, it is not usually cost effective to wait till all such issues have been resolved before commencing work on these large infrastructure projects.
    - These are naturally greatest for the most innovative new elements of the package – PILOT, GMT and MIRA, but in principle apply to all components given the necessary commitment to on-going innovation.
- Associated uncertainty that flows from the ‘lumpiness’ of some of the possibilities – notably but not only PILOT Construction – where uncertainty about whether it will make sense for this to proceed creates a need for budget management across the package to ensure that maximum value can be derived from the available funds.
- Cost uncertainty in the components of the strategy, beyond the technical uncertainties, due to uncertainties about project detail and cost;
    - Every large infrastructure project involves such uncertainties – and in general the greater the innovation, or the special environment in which the project is to be located, the greater these uncertainties.
    - They need not all be downside risks, but avoiding this requires careful management.
    - These uncertainties are typically managed in planning stages through contingencies, but this on its own creates a risk of not being able to get full value out of a constrained budget, because of the level of contingency involved.
    - This class of uncertainty is again likely to be greatest for the most innovative projects – where contingency to cover ‘scope creep’ to deal with unanticipated problems can be substantial, with a corresponding risk of underutilisation.
- Cost uncertainty attributable to exchange rate risks.
    - Again, these can involve upside as well as downside.
    - Commercial mechanisms are available for managing these risks, but they are not costless.
    - These risks are likely to be greatest for projects involving high levels of inputs from overseas – again tending to be the innovative new collaborative ventures, in contrast, for example, to the on-going operation of the AAO. Gemini subscription rates are denoted in US dollars and therefore also involve a significant risk to be managed.
- ‘Market risks’ associated with the possibility that demand for access to the facilities could fall, reducing the scope for deriving revenues from the associated access charges.
- ARA and associated ‘joint venture’ risks.
    - The proposal will have ARA responsible for the sound management of a large budget – over $50m over 5 years and with scope for influence over a substantially larger total budget.
    - ARA will involve a shareholding spanning a somewhat diverse range of Australian organisations, with the potential for divergence in expectations and demands of the company – as with commercial joint ventures.

  - There may be important issues of IP ownership and of ARA decisions that might be subject to legal challenge.
  - Risks that need to be addressed range from inadequacies in governance and legal through to fracturing of the business model.
- Associated risks to sustainability of funding beyond 2011.

Strategy

Against this background, important elements in the overall risk management include:

- The governance arrangements that will apply to the management of the proposed NCRIS investment, as documented in Part 5 of the application. These include reporting and accountability; performance and risk monitoring; and response strategies; adaptive planning; and allocation of responsibilities in respect of specific risk elements.
  - Substantial progress has already been made in implementing these arrangements through ARA, with the strong support of all key participants. This progress is reported in detail in Part 5 of the submission and again in Attachment E.
  - These arrangements include specific safeguards to protect the interests of the Commonwealth.
  - The long-standing success of international collaboration arrangements in delivering and maintaining these large infrastructure projects is another source of confidence in the containment of risks, further reinforced by the extensive experience that Australian astronomy has with such arrangements – experience that will be incorporated into ARA as well as the participant Australian organisations.
- The high levels of international leverage incorporated in the strategy.
  - These have the dual effects of limiting the exposure of NCRIS and other Australian astronomy infrastructure investment (and allowing this investment to be spread over a more diverse 'portfolio' of such investments) and the valuable counterchecks provided by all the other participants in vetting the true value of the proposed investments and their management.
  - As was noted above, these also create a true market in level of consortium participation. This is explicit in the option, identified as part of the strategy, for Australia to expand its participation in the Gemini Consortium.
  - In principle, this international diversity of participation also opens opportunities for internally managing exchange rate risks – subject to appropriate i9nternal arrangements for sharing of the risks.
- The presence of established arrangements for access to major astronomy research infrastructure, including for the AAO and Gemini, and existing Australian experience with ATNF – and the track record of these arrangements in dealing with changing demands and consortium membership and shares; and
  - international acceptance and support for these arrangements as a basis for moving forward with consortia planning for new facilities.
- The fact that these infrastructure facilities are being designed for maximum flexibility over the planned operating lives – flexibility to accommodate new instruments and uses, and to switch to alternative functions in the future as later generation instruments become available.
- Reinforcing the last point, strong reliance throughout the implementation strategies on cautious project development with an eye to managing risks using state-of-the-art methods for planning, rolling out and managing long-lived investments under high uncertainty.
  - This incorporates strong elements of options-based planning – designed to manage downside risks while keeping access to upside opportunities, and with a very strong emphasis on the value of flexibility in the investments in skills and infrastructure.
  - A major example of this in relation to the Decadal strategy is the options model prepared as part of the SKA business case – with its demonstrated value in guiding major strategic investment decisions and in valuing the ability to reduce uncertainties before making irreversible commitments. This model was discussed further in Part 6.

  - The MIRA project is in fact an integral part of the SKA options strategy.
  - A precisely analogous options approach is proposed for the PILOT project, avoiding irreversible commitment to major capital costs until a detailed design study and risk analysis have been completed. This is a strategic investment in better information to manage the risks of inappropriate investment. In this context, we see the risks of not properly assessing the option of a major optical instrument in Antarctica as being as relevant to risk management as the risk of commiting to the construction of such an instrument prematurely.
- The package character of the proposed investments – covering internationally competitive capability across the spectral range. This alone offers substantial flexibility for adapting the investment emphasis over time, based on the insights and technologies then available, and offers strong prospects for Australia being an important participant in major outcomes from international astronomy, regardless of where they fall.
- Structure of the proposed package – across both high priority (core) investment elements and a package of strategic options to be managed in the basis of emerging information on project costs, from PILOT Stage 1, from the Gemini Consortium and from the GMT Consortium.
  - The priority elements of the package (composed of AAO, MIRA, Gemini at current levels, Pilot Design, GMT DDP and Governance) has been costed at between $40..1mand $43.5m, inclusive of planning contingencies. The variation relates to the current uncertainty over the level of investment required from the Gemini partners for the "Aspen" instrumentation program, as discussed below.
  - The package of strategic options, composed of PILOT Construction (up to $5m, GMT DDP Years 2&3 (up to $3.2m) and Additional 8m Access (up to $2m) provides substantially flexibility to adapt the total NCRIS spend to ensure greatest value, inclusive of the information provided by the PILOT Stage 1 process – while also affording significant management of other financial risks.
- Sustainable funding beyond 2011 and the strategies that will be implemented ahead of that time to secure adequate and appropriate funding consistent with the objectives of the infrastructure investment.
  - We anticipate that a sound case will emerge from this NCRIS round for a continuing function for a facility analogous to NCRIS. At the same time, it will be important that the strategy be robust enough to deal with loss of this source of funds.
  - Then international leverage built into the infrastructure projects, coupled with the above risk-based planning and management tools, offers a solid starting point, but sound risk management will incorporate significant pre-emptive strategy directed at maintaining Australian funding where appropriate.

Beyond this, there are, for reasons flagged above, stark differences between different components of the investment package in their vulnerability to some of these risks; in some cases there are substantial upside opportunities as well as risks. This creates scope for managing the risks of the portfolio by exploiting this diversity of risk exposure. The creation of ARA and the central management of the block of funds for the 'package' create real scope for doing this and focusing on maximising the value obtained from the package despite the uncertainties and risks.

Management of Aspen instrumentation program risks and opportunities

The Gemini "Aspen" instrumentation program seeks, over the next five years, to equip the Gemini telescopes with the next generation of state-of-the-art instruments. This bold and ambitious program is both high risk and expensive (with a total cost of US$75M) but, if successful, will make the Gemini Observatory a world-leader in observational optical/infrared astronomy. A key component to this program and one that is critical to catering for Australia's scientific and instrument building ambitions, is the Wide Field Multi-Object Spectrograph (WFMOS) instrument, which will provide the only capability for conducting high multiplexed spectroscopy over a wide field on an 8m-class telescope.

At the present time, the funding of the Aspen program by the Gemini partners remains uncertain, with a number of key decision points being reached in the next 12-18 months that will determine the fate of the program and its final scope. The most critical factor in this regard is the ability of the major partners in Gemini – the US, UK and Canada – to secure their funding commitments to the program. So far, they have only been able to commit 40% of their full funding share over the first two years of the program, with no certainty that this shortfall will be made up and their full commitments for the final three years of the program will be found. As such, the options that will be faced over the next 15 months and the decisions that the Gemini Board will likely have to make in each case are as follows:

Decision points	Scenarios	Likely outcome
Nov 2006 Board meeting	(a)No immediate new funding forthcoming from Gemini partners	Lifetime of Aspen program extended beyond 5 years; proceeding with WFMOS further postponed.
	(b)Significant new funding found by major partners for 1st two years (and beyond)	Full Aspen program resumes including design studies for WFMOS instrument
May 2007 Board meeting	(c)Subsequent to (a), still no new funding commitments from major Gemini partners	Major de-scope of Aspen program with total funding envelope and partner contributions renegotiated; the most expensive instrument, WFMOS, almost certain to be cancelled; Australia would need to assess worth of any future involvement in program.
Nov 2007 Board meeting	(d)Subsequent to (b), WFMOS design studies completed and show it to be technically unfeasible and/or too expensive	Decision made not to proceed with WFMOS, but to continue with rest of Aspen program at a level commensurate with committed funding. Australia would need to assess future involvement
	(e)Subsequent to (b), major partners unable to find full funding for remainder of program	As for (c).
	(f)Subsequent to (b), all partners able to commit funding for full program, and WFMOS design studies show it to feasible and affordable	Proceed with full Aspen program.

The key implications of this decision-making process for the investment of NCRIS funding and the operation of ARA in managing these uncertainties in respect of the "Gemini 6.19% component can be summarized as follows:

- While the future and scope of the Aspen program are currently uncertain, there will be full clarity by the end of 2007 – meshing well with PILOT Stage 1 and key decisions in respect of the strategic options.
- One of three scenarios is likely to emerge, each with the following approximate likelihoods and costings:
  - Full program proceeds (20%) – A$3.7M
  - Program proceeds at a descoped level (40%) – A$1-2M
  - Program is cancelled (40%) – no cost.
- Given the delays suffered already in the program, it will almost certainly extend beyond 5 years, should it proceed.

These indications point to a high likelihood that funding available for managing the strategic options will be of the order of $5m, and possibly as high as $6.2m – with scope for some additional discretion within the NCRIS time period as a result of the likelihood of slippage in the timing of the Aspen program.

Technical risks

As was noted earlier, these vary substantially across elements of the package. The AAO and Gemini elements in the package are well-defined, relate largely to continued operation of facilities for which there is established experience – and technical risks are likely to be modest.

This does not mean they will be negligible – new instrumentation is planned for both facilities. However, new instrument development will be handled through a cautious staged development with clear scope for abandoning the strategy at each step; and the option to defer development and implementation will be retained as a means of managing cost risks. These risks are well-suited to options-based management that has been incorporated into the strategy.

For the Gemini participation, Australian risks are limited by the extent of our share in the Consortium and by the presence of an active market in shares – though clearly the proposed investment strategy also recognises that this low shareholding is also limiting the benefits to Australian participation.

For PILOT and GMT technical risks are being tightly managed through a staged options approach – with initial funding only sought for participation in the detailed design phases. This represents sound risk management, while retaining access to the upside opportunities of success in demonstrating feasibility and cost justification. PILOT Design and GMT DPP Year 1 both involve modest initial investments in these information infrastructure options in relation to the next generation of optical facilities.

PILOT Stage 2 will only proceed after Stage 1, subject to conclusions to emerge from that Stage and subject to a sound business case that then determines the most cost effective application of then uncommitted ARA funds, across the set of optional strategies. All these decisions can be taken against the background of what is then known of the total risks of the strategy, and the affordability of the construction proposal.

Similar principles will apply to GMT, with progression to GMT DPP Years 2&3 being subject to Year 1 outcomes and the associated business case. Phase 2 is still seen as a modest investment in creating the information options that can maintain Australia's ability to choose to be part of this next generation project through to the critical decision point at the start of the construction phase.

Conceptually, MIRA has similar elements. It is part of a much larger venture, and will have a key role to play in managing risks associated with the SKA prospect. However, MIRA will also be a leading edge facility in its own right – even if the SKA project were not to proceed or were to be located elsewhere. MIRA will provide an order of magnitude improvement in Australia radio astronomy capability and will incorporate a range of state-of-the-art features – including the planned implementation of the Australian xNTD technology as an SKA demonstrator and again of value in its own right.

A lot of work has gone into planning for both the SKA and MIRA – and the SKA business case has mapped pout the options-based management of xNTD and MIRA technical risks. Beyond the specialist technologies to be demonstrate, the scale of MIRA represents normal incremental extension of existing radio cluster capabilities, so that other technical risks are well within normal ranges.

The costs and risks of MIRA are to be shared internationally.

<u>Exchange rate risks</u>

Cost estimates discussed above have been developed based on an AUD/USD exchange rate of 0.75. This is broadly consistent with current levels and with interest rate trends in Australia and the US. However, over the life of the NCRIS program, there remains significant uncertainty and a risk to be managed

Of the high priority items, Australian-based activities account for over 75% of the formal costs, and this brings with it substantial natural hedging. MIRA will involve significant imported content, though this is likely to come from diverse sources, providing some hedge against unilateral strengthening of the USD.

Of the strategic options, PILOT Construction should offer substantially greater natural hedging relative to GMT and additional Gemini access. The flexibility of ARA in relation to these strategic options offers some flexibility here – but this will be limited by the performance of PILOT Stage 1.

A level of residual exchange rate risk will remain. There will be upside as well as downside elements to this, but sound management of the risk will be required. Financial hedging strategies (e.g. an exchange rate collar) have been ruled out by DEST.

<u>Other cost uncertainty</u>

The Australian and the international astronomy communities are highly experienced in managing the deployment of large engineering infrastructure projects. All planning has been predicated on the application of mainstream planning and engineering principles and has drawn on the experience of analogous projects in Australia and/or elsewhere. Participation by international consortia applies additional checks on project governance and pressures to contain costs – at least within the recognised politics of the management of these consortia.

The major 'new project' element in the package is MIRA (with the possibility of the PILOT Construction project after detailed design and feasibility assessment – but PILOT will be a relatively small facility, limiting the scope for cost blow-out in absolute terms).

The budgets for these investments incorporate contingencies to allow for both price rises and for scope creep. They are not based around highly optimistic assumptions. On the other hand, individually, they do not present worst-case cost outcomes – to base the planning for the whole portfolio in case-by-case worst case estimates would create its own risks – of serious underutilisation of the already constrained financial resources.

Instead, the budgets as developed represent estimates of the expected cost of the individual items and sum to a realistic estimate of the expected cost of the portfolio, if all items were to be pursued. As such, these estimates include possible overs and unders, and the cost risk for the portfolio as a whole will be significantly less than the cost risk for the individual elements.

A possible exception to this diversification benefit is the risk of systemic cost blow-out – driven by rising international materials and energy costs. This is a risk inherent in all infrastructure projects and one that can only be handled through hedge instruments (use of derivative products to lock in prices) and/or integration into the strategy of substantial flexibility in the form of deferral and, if necessary, abandonment options, and options to redirect resources in directions less affected by unexpected cost pressures.

These approaches have been integrated into the strategy as follows:

- The risks of major systemic cost blow-out are greatest for the new projects – with established facilities still offering some natural hedge within the portfolio, and limiting the need for, and level of compromise in, exercising the other options.

- Overall risks of serious damage to the planned strategy within the 5-year period has been assessed as very low.

'Market' risks

##Should be able to argue that these are very small – all the more so given the level of innovation in some of the projects and the proven track record and value of the survey operations. Referring here to demand for access to these facilities and associated revenue streams.

Australia's ability to acquire additional 8m time will be tied to the market in 8m access at the time. This access cannot be guaranteed now – other possible than through acquisition of a put option with a current shareholder – but the nature of this market is such as to suggest that this should not be a major risk. The risk is further mitigated by the flexibility built into the strategy.

Joint venture risks

##Key inputs once implementation arrangements are agreed. Includes consideration of staging of membership – and ability to operate in the meantime – responsibilities for costs etc if choose to exit and processes for managing how these evolve over time.

Further details of the flexibility inherent in components

##Include here a component by component discussion of the flexibility inherent in the proposal:
- *As a source of portfolio flexibility to accommodate cost changes and cases emerging for Stage/Phase 2 investments.*
- *Incorporating a discussion of scope for and costs of spreading the investment beyond the 5 years.*
- *Incorporating scale back opportunities to deliver most benefits at lower cost.*
- *Incorporating scope for rapid up-scaling should the case and/or funds emerge.*

Apart from the obvious strategic value, this discussion could be a powerful way of pushing the case that the budget constraint has high cost – helping NCRIS build the case for flow-on funding and possibly for reaching early agreement on their being a replacement instrument. Knowledge of this would immediately increase the value of the options, by lowering one uncertainty.

ATTACHMENT H LETTERS OF COMMITMENT

Letters of commitment should be provided by all parties that have committed any form of assistance or resources to the implementation or operation of this Investment Plan.

The letters should commence in the following fashion:

Dr Mike Sargent AM
Chair
NCRIS Committee
C/- Department of Education, Science and Training
GPO Box 9880
CANBERRA ACT 2601

Dear Dr Sargent

I am writing to confirm the commitment of [name of organisation] to participating in the operation and management of the research infrastructure, and providing the financial and other support, as specified in the National Collaborative Research Infrastructure Strategy Investment Plan for [name of research capability area].

………

Yours sincerely,

ATTACHMENT I FURTHER INFRASTRUCTURE NEEDS

The nature and value of research infrastructure that is required for this capability area, but not included in this Investment Plan should be detailed.

The following provides a table of optical and radio infrastructure in Australia not included in the NCRIS proposal. It ranges from National Facilities (ATNF) to University PhD training telescopes. All are deemed required for maintaining the capability over the NCRIS period.

##To be completed as outlined in Progress Report, include unresesourced strategic options and GMT landmark.

ATTACHMENT J CONFIDENTIAL INFORMATION

No confidential information should be included in this Investment Plan.

If it is considered necessary to provide certain confidential information to the NCRIS Committee in association with this Investment Plan, then a non-confidential summary explaining the nature and ownership of the information should be provided in this Attachment. DEST will contact relevant parties to obtain access to the confidential information in an appropriate manner.

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[i] U.S. DEPARTMENT OF COMMERCE,
National Telecommunications and Information Administration [Joseph P. Camacho], Radio Astronomy Spectrum Planning Options, NTIA Special Publication 98-35 (1998), Appendix B, applications of astronomical techniques,
http://www.ntia.doc.gov/osmhome/reports/pub9835/Raspapnd.htm .