AAO CASE FOR NCRIS FUNDING

1 THE AAO AND THE DECADAL PLAN

The role for the AAO envisioned by the *Australian Astronomy Decadal Plan 2006-2015* is to be the Australian national observatory for optical and infrared astronomy, with the following specific responsibilities:

1. Operating the AAT throughout the decade 2006-2015 as Australia's major on-shore optical/infrared telescope facility.
2. Keeping the AAT at the forefront of astronomical research by developing at least one major new instrument for the telescope.
3. Supporting Australia's involvement in other optical/infrared facilities in which there is a national interest.
4. Maintaining Australia's strength in astronomical technology and instrumentation.
5. Providing a focus and infrastructure for astronomical research.

The AAO component of the NCRIS proposal is focussed on realising these decadal goals through three measures: refurbishment of the AAO's infrastructures to ensure the efficient operation of the AAT; construction of a new AAT instrument to maintain the productivity and impact of the telescope; and support for the AAO's core instrumentation technology team to spearhead and leverage Australia's involvement in other existing and new facilities in which there is a national interest, and which may also be part of the NCRIS astronomy capability. The case developed here is based on the AAO's submission to the DEST review of the AAO (http://www.aao.gov.au/press/AAOsubmissionDESTreview.pdf), modified only by DEST's subsequent advice that NCRIS is the only route for additional funding for the AAO.

2 CURRENT CAPABILITIES

The mission of the Anglo-Australian Observatory (AAO) is to provide world-class optical and infrared observing facilities to enable excellent science, and to be a world leader in astronomical research and in the development of innovative telescope instrumentation. The AAO is currently an equal partnership between Australia and the UK, but over the next four years the UK will gradually withdraw and Australia will take the dominant role. The AAO will become wholly Australian from July 2010.

The AAO's main facility is the 4-metre Anglo-Australian Telescope (AAT), the largest optical/infrared telescope in Australia. Australia's share of the AAT is currently 50%, but will increase to ~66% in 2006-7, ~80% in 2007-8 and 100% from 2010-11. Together with Australia's 6.2% share in the twin 8-metre Gemini telescopes, the AAT provides the major national observing capability for optical/infrared astronomy. *Allowing for the differences in aperture and share, the AAT and Gemini each provide approximately 50% of this capability.*

The Decadal Plan goals include supporting the growth of the Australian share of the AAT from 50% to 100%, and increasing the effective share of an 8-metre telescope from 12.4% to 20%. If these goals are realized, Australia's combined access to 4-metre and 8-metre telescopes will increase by 80% by 2011, with the AAT accounting for 55% of this capability.

3 REFURBISHING AAO INFRASTRUCTURES

Large optical telescopes can remain operational and productive for many years. The AAT was dedicated in 1974, and has operated effectively for over thirty years. The telescope was designed using proven, appropriate technology and built to a very high standard, resulting in a versatile, reliable and stable platform. The telescope, its mounting and dome have no fundamental issues likely to present major problems for the next twenty years. However the supporting infrastructure (such as encoding, drive and control systems) is reaching the end of its lifecycle, and a planned program of refurbishment and replacement is essential to ensure that the AAT continues to deliver the high levels of reliability and performance for which it is renowned, and which have played such an important part in its high productivity.

The AAO therefore commissioned a detailed study of the long-term maintenance issues for its facilities. The consulting firm Strategic Facility Services (SFS) carried out this study with expert assistance from members of the AAO's staff. It led to the report *A Long-Term Maintenance Plan for the AAO Facilities at Epping and Siding Spring* (summarised in the AAO's submission to the DEST review, section 2.9 and Appendix D). The Long-Term Plan includes the spending profiles required to refurbish and maintain the AAT, the site workshop and the Epping headquarters facility in optimal working order for the coming decade.

The SFS report grades risks into five categories depending on their probability of occurrence and the severity of the consequences. SFS define category 1 high-risk/high-probability issues as those that would make the facility unusable, with immediate high risk to operations, security, heath and safety, property damage, and significant cost implications; category 2 medium-risk/high-probability issues are those causing major disruption to service capability, with risk to health and safety or property, and high cost implications or financial losses. The bottom-line cost of the program needed to address just these two highest-risk categories is $4.162M, and is dominated by refurbishment and upgrades to the AAT (76%), with lesser amounts for the site workshop (21%) and the Epping facilities (3%) – see *Table 1*.

Table 1 - Components of long-term maintenance plan

Item	Cost
AAT telescope, dome and systems	$3,157,000
Site workshop building and facilities	$860,000
Epping headquarters buildings	$145,000
Total	**$4,162,000**

4 AAOMICRON – A NEW INSTRUMENT FOR THE AAT

The Decadal Plan recognises that the AAT requires a major new instrument in order to remain a frontline facility throughout the coming decade. The recently commissioned AAOmega multi-object spectrograph provides a dark-time capability for the AAT that will be world-leading until the planned WFMOS spectrograph becomes available through Gemini in about 2012. However the main existing bright-time instruments (IRIS2 and UCLES) are less competitive in international terms, even though they will remain useful workhorses for some years to come. Ideally, therefore, the AAT needs a bright-time instrument for the latter part of the coming decade that will have unique capabilities and serve the scientific needs of a broad swathe of the Australian community. One new instrument concept that meets these requirements is described here, together with an outline of the science it could accomplish.

The concept is a fibre-fed near-infrared spectrograph, called AAOmicron, complementing the AAOmega fibre-fed optical spectrograph. AAOmicron builds on existing excellence and innovative developments: the AAT's established international superiority as a spectroscopic survey telescope, the highly successful investment in the 2dF fibre positioner and wide-field corrector, and the new sky-suppression fibres being developed at the AAO, which offer huge sensitivity gains for ground-based NIR observations. Table 2 gives the top-level instrument parameters for AAOmicron.

Table 2 - Summary of AAOmicron instrument concept

Field of view	2 degrees
Number of fibres	>200
Multiplex	>200 (or >100 with beam switching)
Angular size of fibres	~2 arcsec
Spectral coverage	0.85–1.7 microns (z, J and H bands)
Spectral resolution ($\lambda/\Delta\lambda$)	>3500 (>1000 with sky suppression)
Spectral resolution (FWHM)	~3 pixels
Total system throughput	>10% within the z, J and H bands

Science with AAOmicron. A wide-field near-infrared (NIR) spectrograph offers enormous potential to Australian astronomers. Such an instrument is a powerful tool for understanding the high-redshift universe: star-formation, galaxy merging and galactic nuclear activity all peaked at early times in the history of the universe, and it is crucial that we extend our current detailed optical observations to the near-infrared, to study the highly redshifted spectral lines that are needed to fully understand the physics at work. A NIR spectrograph is also an ideal tool for probing the cool and dusty universe, encompassing the star-forming regions in our own Galaxy, some of the end products of stellar evolution, low-mass stars and sub-stellar objects. Table *3* (below) summarises some of the scientific objectives of AAOmicron, and how it engages the big questions highlighted in the Decadal Plan, in terms of both 'key' and 'supporting' investigations. A more detailed science case for AAOmicron can be found in the AAO's submission to the DEST review (Appendix G).

Table 3 – Science investigations with AAOmicron

Investigation	**Key**	**Support**
The distribution of galaxies in the early universe	✓	
The nature of dark energy	✓	
The formation and evolution of galaxies	✓	
The nature of active galactic nuclei	✓	
Star-formation processes		✓
Low mass stars and unbound planets		✓
High mass stars, planetary nebulae and supernova remnants		✓
Spectroscopic follow-up of NIR imaging surveys	✓	✓

The most exciting science from new instrumentation cannot always be planned in advance. Deep near-infrared imaging surveys, both ongoing and planned, will undoubtedly reveal new mysteries and questions to be answered. Understanding the physical processes at work in our universe generally requires spectroscopic observations to reveal the chemical make-up of the bodies we observe, their temperatures, interactions, emission mechanisms, redshifts and much more. AAOmicron will provide Australian astronomers with a uniquely powerful facility for a very broad range of astronomical research over the coming decade.

Technical overview. The heart of AAOmicron will be a replica of the successful AAOmega spectrograph, modified to operate at near-infrared wavelengths (0.85-1.7 microns). To minimise costs and development risks, AAOmicron will share major system components with AAOmega including the 2dF corrector and positioner, the fibre bundle, and as much of the spectrograph design as possible (although some significant modifications will be required in order to operate at near-infrared wavelengths). The common components and shared design will allow the AAO to rapidly and cost-effectively build an instrument that would otherwise be unfeasibly expensive, and start delivering key science as soon as 2010.

Although AAOmicron may initially need to use standard optical fibres, an exciting and relatively low-cost option is to use the sky-suppressing fibres that are currently being developed by the AAO. These fibres block unwanted background light from OH lines in Earth's atmosphere, enabling a huge gain in sensitivity over current NIR spectrographs. AAOmicron would be the first system in the world to use this revolutionary technology.

Competitiveness. Wide-field multi-object optical spectrographs are extraordinarily powerful and versatile instruments: there is no major observatory in the world today without such an instrument, and they are invariably one of the highest-demand capabilities. With the growing significance of the high-redshift universe and the cool, dusty universe as fields of astronomical study, the near-infrared regime is rapidly becoming as important as the optical. At present, however, there are no genuinely wide-field multi-object NIR spectrographs in operation, and only one under construction – the FMOS instrument for the Subaru 8-metre telescope. Because of the wide range of science they can address, the demand for such instruments is going to be extremely high. AAOmicron will be only the second wide-field multi-object NIR spectrograph in the world, the first to which Australian astronomers will have as-of-right access, and in some important aspects will out-perform FMOS.

Even without sky-suppression fibres, AAOmicron will be highly competitive: it has 16 times the field of view and the same instrumental throughput as FMOS, so although Subaru's aperture is 4 times that of the AAT, AAOmicron's AΩ product (the figure of merit governing survey speed) will be 4 times that of FMOS. For large-area surveys, therefore, AAOmicron will be the most powerful NIR spectrograph in the world. With sky-suppression fibres, which reduce the night-sky background emission by factors of 20-30, AAOmicron will also be able to reach fainter objects faster than FMOS. The AAT will then again have a unique, world-leading instrument, which, in combination with AAOmega, offers outstanding scientific potential for Australian astronomers.

Estimated cost. The estimated cost to design, build, commission and operate AAOmicron is summarised in Table 4. The total estimated cost is $5.9M, including overheads and contingencies of 10% for materials and 20% for labour. This figure is based on the known cost of AAOmega, from which AAOmicron is derived, and so is more robust than usual at this stage of an instrument's development; this is reflected in the modest levels of contingency allowed for in the estimate.

Table 4 - Cost estimates for AAOmicron

Functional Area	Materials	Labour
Project management	-	$410,000
Instrument design & optics	$230,000	$410,000
Mechanical	$140,000	$1,130,000
Electronics (incl. detector)	$750,000	$910,000
Software	-	$870,000
Contingency	$120,000	$930,000
Total	**$1,240,000**	**$4,660,000**
Grand Total	**$5,900,000**	

5 CORE INSTRUMENTATION TECHNOLOGY TEAM

The AAO has an international reputation for developing innovative technology and implementing it in unique and powerful astronomical instruments. The success of the AAO's instrumentation program depends on two key factors: (i) giving creative scientists and engineers time and resources to explore such technologies and identify effective ways to exploit them for astronomical research; (ii) having the organisational agility to rapidly translate technological advances into operational instruments.

The AAO is proposing to move to a more flexible model for its instrumentation group, dividing it into two components: a core group and project teams. The core group of permanent staff would comprise the critical mass of instrument scientists and engineers essential to developing innovative instrument technologies, providing conceptual designs for new instrumentation, and leading the construction phases of instrument projects. The project teams will be hired on fixed-term contracts using funding obtained for specific instrumentation projects. This model will allow the AAO to provide Australian astronomers with world-class instruments on the national and international facilities in which Australia participates, and potential leverage on other projects in which Australia may take an interest.

This core group provides a number of crucial advantages: (i) It guarantees continuity of the AAO's instrumentation program, free from the threat of extinction due to the substantial (and increasing) stochasticity and granularity of instrument project funding. (ii) It allows the AAO to continue to generate the intellectual capital that provides it with a vital edge in an increasingly competitive and globalised market for astronomical instruments. (iii) It safeguards the core competencies required to generate new business by developing concepts and proposals for Australian and overseas instrumentation opportunities (see §7.5.2 of the AAO's submission).

The combination of security and flexibility provided by this model offers the best strategy for sustaining the AAO's world-renowned instrumentation program in a challenging environment. *For the five years of the NCRIS program, the core instrumentation group could be maintained by the funding provided for the new AAT instrument plus an additional $4.4M.* The technical effort supported by this investment would be directed towards a number of strategically important projects: the new AAT instrument; realisation of the revolutionary potential of OH-suppression fibres; development of other new technologies (starbugs, honeycombs, tunable filters, photonic spectrographs and more–see §4.2 of the AAO's submission to the DEST review); and, critically, design and engineering effort in developing new initiatives such as GMT and an Antarctic telescope.

6 ACCESS AND DEMAND

Access. The Anglo-Australian Time Assignment Committee (AATAC) awards access to the AAT on the basis of the scientific merit of the proposals submitted. Time is accounted against the Australian and British shares of the telescope in proportion to the number of Australian and British astronomers on successful proposals (with collaborators from other countries counting *pro rata* against the Australian and British shares).

The open-access policy of the AAT is based on encouraging the very best scientific research and international collaborations. It is in accord with the standard practice of most major international astronomical facilities, and the time provided to overseas astronomers on the AAT is repaid many times over by Australian astronomers' access to international facilities (such as the NASA space observatories and the national facilities of the USA and Europe).

Demand. The over-subscription factor for the AAT (the ratio of nights requested to nights available) has been fairly constant over the past five years at around 2.4. The number of Australian users of the AAT (including AAO users) is currently 40-50 per semester. There are also large numbers of users from the UK and other countries, reflecting increasing levels of international collaboration. Approximately equal amounts of time on the AAT are currently going to Australian (including AAO) users, UK users and other international users. The Australian share of time will evolve from the current 50% to about 66% in 2006-7 and about 80% from then until the AAT becomes a wholly Australian facility in 2010.

The likely impact of AAOmicron on demand for the AAT can be estimated from the impact of its optical counterpart, AAOmega, which increased the overall demand for dark time on the AAT by 40%. The large observing program proposals for AAOmega on their own overfilled the current semester, and together sought to use all the dark time on the telescope for the next 4 years. As both instruments offer capabilities that are unique in the world, both enable a wide range of science, and both are suited to ambitious observing programs addressing major questions, the demand for AAOmicron is likely to be at least as high as for AAOmega.

7 EXPECTED OUTCOMES

The refurbishment of the AAO's facilities and the provision of a powerful new instrument for the AAT will allow the AAO to continue to provide excellent research infrastructure for Australian astronomers and maintain Australia's strong international reputation in the field.

Productivity and impact. The most recent bibliometric analysis (Trimble, Zaich & Bosler, 2005, PASP, 117, 111; Trimble et al., 2006, Nature, 439, 250) compares astronomical facilities on the basis of productivity (number of papers) and impact (number of citations) using papers published in 2001. The main conclusions relating to the AAO were that the AAT is still, as it was a decade ago, *the* most productive and highest impact 4-metre class telescope in the world; that it was the third-ranked optical telescope of *any* size by total citations; and that it was fourth over *all* astronomical facilities by citations per paper. These figures (supported by other analyses) show that the AAO provides an internationally excellent and cost-effective facility that is being exploited effectively by its user community.

While it is difficult to forecast the productivity and impact of a new instrument, AAOmicron builds on the great success of the 2dF instrument and the demonstrated demand for its successor, AAOmega. In fact AAOmicron is a more significant step forward than AAOmega, since it opens up the almost virgin territory of wide-field near-infrared spectroscopy, exploring a new realm of observations that has hitherto been inaccessible. Such advances into fresh territory have historically led to some of the most fruitful new discoveries in astronomy.

Research students. The AAO is not a PhD-awarding institution, but makes two types of contribution to student research: providing data for theses and co-supervision for students. Over the five-year period 2001-05, 46 students used the AAT to obtain data for their PhD research: 19 from Australia and 27 from other countries. Over the same period, AAO staff co-supervised 22 Australian PhD students. Altogether, AAO staff and facilities have contributed to training a total of 31 PhD students over these 5 years. In addition, AAO staff have co-supervised the Honours projects of at least 8 Australian undergraduates and hosted another 17 Australian undergraduates as Summer Scholars (most of whom go on to astronomy PhDs, with about half carrying on to postdoctoral research positions). A significant number of today's established Australian astronomers went through the AAO studentship program.

With the Australian share of the AAT doubling from 50% to 100%, and with increasing numbers of astronomy undergraduates and postgraduates at many universities, the AAO's contribution to research training is likely to increase over the next five years. The value of that training will be increased by the enhanced research facilities proposed here.

Other outcomes. The AAO is leading an international consortium of 7 institutions that is competing for the contract to build the Wide-Field Multi-Object Spectrograph (WFMOS), a US$60M instrument that is a joint project of the Gemini and Subaru observatories. WFMOS is driven by two major science programs, one to study the nature of the dark energy and the other to unravel the formation of the Milky Way. AAOmega and AAOmicron are highly complementary forerunners of WFMOS, and will allow the Australian astronomical community to position itself to fully exploit the scientific potential of WFMOS when it becomes available in about 2012. The construction of AAOmicron also makes full use of the team that constructed AAOmega, and provides a valuable bridge to WFMOS, the next planned project.

8 RISKS, CONSEQUENCES AND MITIGATION

Table 5 summarises the top-level risks to the AAO's capabilities, their consequences for the Australian astronomical community, and the mitigation measures that might be adopted.

Table 5 - Risk analysis for the AAO

Risks	Possible consequences	Mitigation measures
Failure of essential but aging infrastructure at the end of its lifecycle	1. Irrecoverable damage to AAT 2. Severe disruption of AAT observing programs 3. Poorer service & reliability 4. Cost of repairs greater than cost of preventive maintenance 5. Demoralised operating staff	1. Implement long-term plan for maintaining & refurbishing facilities, focussing on high-risk/highly-likely issues; <u>OR</u> 2. Seek funding for repairs as and when needed; live with loss of observing facilities
AAT maintains current instrument suite for the remainder of its lifetime	1. AAT lacks unique capabilities in latter part of decade 2. AAT supports less science and smaller user community 3. AAT under-used & low-impact 4. Harder to attract good staff	1. A major new instrument for the AAT with broad appeal and unique capabilities to address big questions; <u>OR</u> 2. Minor upgrades to existing instrument suite
AAO instrumentation program depends entirely on project-specific funding	1. Erosion of intellectual capital 2. Competitive advantage lost 3. No technical support for new projects (e.g. GMT, Antarctic) 4. Eventual extinction of instrument program	1. Adopt core team/project team model with ongoing funding for core team; <u>OR</u> 2. Seek continuous flow of new instrument projects and relinquish R&D capability

9 SUMMARY: OVERALL NCRIS FUNDING PROFILE

The costs of the maintenance program and new instrument are summarised in Table 1 and Table 4. The overall funding profile over the period of the NCRIS program is given in Table 6 below. The funding profile for the refurbishment program follows the Long-Term Maintenance Plan, while that for the new instrument is designed to deliver AAOmicron to the AAT in 2010, and that for the core instrument team maintains constant funding for the permanent staff.

Table 6 - NCRIS funding profile for AAO infrastructure ($M)

	2006-07	2007-08	2008-09	2009-10	2010-11	Total
Refurbishment	0.9	0.9	0.9	0.8	0.6	**4.1**
New AAT instrument	0.5	1.5	1.5	1.4	1.0	**5.9**
Core instrument team	0.0	0.9	0.9	0.9	1.7	**4.4**
Total	**1.4**	**3.3**	**3.3**	**3.1**	**3.3**	**14.4**