Strategic Investment in

Australian Research Infrastructure

A Submission to:

The National Research Infrastructure Taskforce
Department of Education, Science and Training
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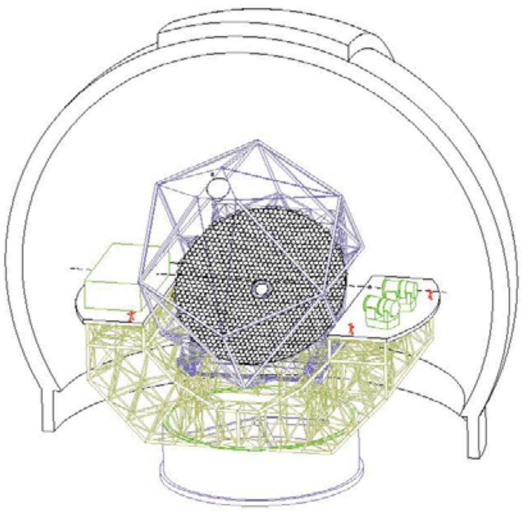

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A Philosophy of this Submission

Given the nature of the submitting institution and the professional experience of its author, many specific issues will be addressed within the context of astronomical research and the long, rich history of excellence at the Research School of Astronomy and Astrophysics (RSAA) at the Australian National University (ANU), which operates the Mount Stromlo (MSO) and Siding Spring (SSO) Observatories. The internationalism of astronomy, its reliance on (and generation of) technical advance, its ability to excite the minds of the young to enter scientific disciplines across several fields, and its world-class reputation in Australia, combine to make astronomy an excellent case study for the funding of research infrastructure. Many policy issues addressed in this submission will be discussed more generally, and have global applicability beyond astronomy. Here, the author will bring to bear not only her experience as Director of the RSAA, but also experience as a scientific researcher in astronomy and physics on three continents, and as a Program Director at the National Science Foundation in the United States.

B Executive Summary

Australia urgently requires a mechanism to respond rapidly but responsibly to developing opportunities for major capital investment in very large, long-term research infrastructure. Such investment should include the costs of exploration, design, construction, and full operation.

Early involvement, a phased program of funding, and a competitive winnowing process will ensure the best scientific, technological and financial returns. In order to successful management a wide range of programs at various stages of development, a large fund for very major infrastructure should be developed and sustained.

All large research infrastructure projects should be held to similar high standards of accountability, risk management and budgetary controls throughout the phased process. With phased funding, the opportunity to cease funding at any point up to and including construction is maintained. Assessment criteria should be developed for each successive stage. Suggested funding stages are:

- Phase I: Exploration
- Phase II: Conceptual Design and Development
- Phase III: Detailed Design
- Phase IV: Construction and Operations
- Phase V: Periodic Review (5 yr)
- Phase VI: Eventual, but Gradual Decommissioning

Provision should be made for funding multiple projects at a variety of stages at any given time. In this way, a total spend profile can be managed through a natural and necessary culling process, especially within the first three stages. Furthermore, major infrastructure investment would be assessed on the basis of well-developed and rigorously tested proposals that could be fully supported with confidence.

Phase IV should include clear assessment of the amount and source of operational costs, which should be considered part of the overall program commitment. Assessment of long-term projects should consider whether an appropriately trained and appropriately large Australian user base will be in place at the time of completion.

Australia should invest most heavily in projects where Australia has specific needs and/or strengths. Without this, Australia runs the risk of becoming indistinguishable and thus mediocre in all fields of endeavor. On the other hand, broad investment at its "GDP share" level over a wider variety of research infrastructures will allow the flexibility required to ensure that Australia is able to shift directions and adapt as Australian and world research needs evolve.

C Specific Issues

C.1 Australia's Future Research Infrastructure Needs

C.1.1 Australia's Research Infrastructure Strengths and Gaps

- **University-based astronomy is a national and international research strength.** Mount Stromlo (MSO) and Siding Spring (SSO) observatories are part of the Research School of Astronomy and Astrophysics (RSAA) at the Australian National University (ANU), and are examples of ANU's national leadership in providing research infrastructure that benefits not only the excellent researchers in its own institution, but those across Australia and overseas. *For more than three decades ANU's leading-edge research facilities have supported Australian and international optical/infrared astronomical communities.* In 2002, for example, over 120 non-ANU astronomers used RSAA telescopes; 77 of these were from overseas. Astronomy students from universities across Australia use and are trained on ANU telescopes.

- **Canberra bushfires had severe, but recoverable consequences for astronomy.** As has been well-reported, the 2003 bushfires destroyed all the observational and technological infrastructure on Mount Stromlo. *Current plans call for the re-establishment of the two primary research telescopes lost in the fires with modern equivalents that should surpass their predecessors in key aspects.* Notably, the 50-inch Great Melbourne Telescope will be replaced with a state-of-the-art, fully-robotic SkyMapper telescope, capable of carrying out the just-initiated Stromlo Southern Sky Survey, the first digital all-sky survey of the Southern Skies, at substantially greater speeds than any telescope in the world. (The size of a telescope refers to the diameter of its collecting area, or mirror.) Placing the telescope on the dark site of Siding Spring will ensure greater longevity for the telescope and the ability to link the large data-flow telescope to the new IT infrastructure partially funded by the Systemic Infrastructure Initiative (SII) grant. The largest telescope on Stromlo, the 74-inch, will be replaced with a compact and fully-robotic telescope specializing in bright-sky astronomy and high-resolution spectroscopy of variable objects. In addition, its versatile, multi-purpose design will enable this new "Phoenix" to serve as a training facility for astronomy and engineering students, a test-bed for new technologies, and a public outreach telescope near the nation's capital.

- **Stromlo astronomical instrumentation capabilities continue to be world class.** Despite the destruction of the workshops and technical facilities at Mount Stromlo, the ANU has kept a multi-million dollar contract to build Australia's first instrument for the international twin 8m Gemini telescope program, of which Australia is a partner. By working with local industry, RSAA expects to rebuild the nearly-completed NIFS instrument by the end of 2004. Furthermore, Stromlo won a second Gemini contract to build the flagship instrument for Gemini South: an adaptive optics imager, which will produce images comparable in sharpness to those from the Hubble Space Telescope. *That the second, 6 million dollar, GSAOI contract was verified after the fires is a testament to the intellectual strength and reputation of the RSAA in* *astronomical instrumentation*. The internationally competitive bid was won against fierce competition from the National Optical Astronomy Observatory of the United States.

- *The primary costs of reconstruction of ANU's Mount Stromlo observing and technology facilities is expected to come from insurance, but to maintain the most important of these at a state-of-the-art level will require the Commonwealth funding already provided (7.3M$), and quite likely an additional injection of funds as well.*

- **Investment in astronomy can be investment in science literacy.**
  Astronomy captures public imagination and excites curiosity and fascination for science in our youth. As a cross-disciplinary "origins" topic, astronomy stimulates broader interest in science. The major astronomical research facilities of Australia are icons of Australian scientific endeavor and achievement, and as such attract large numbers of the public each year in the form of tourists and organized school groups. The visitors are not only the young scientists of tomorrow, but also the young educators, entrepreneurs and public servants. *Flagship astronomy projects can and have served as beacons for whole generations, as evidenced by the launch of the first man-made satellites in the late 1950s and the lunar landings in the early1970s.* The young South African government has shown exceptional vision in funding the 10m diameter optical/infrared Southern Africa Large Telescope as a symbol to its people and to the world, of its intention to flourish in a technologically advanced and outward-looking human community.

- **Telescopes operating at different frequencies are required to understand the full cosmic symphony.**
  Depending on their temperature, physical state, and surroundings, objects in the Universe emit radiation at different frequencies. No single telescope can provide complete understanding, just as listening to a single instrument, playing over a narrow range of audio frequencies can result in the appreciation for a symphony. As in many disciplines, a variety of research infrastructure is required to make progress on the most fundamental questions, especially as we begin to realize how interconnected are all the physical processes in nature. *Australian investment should concentrate on those wavelengths at which Australian astronomy is most scientifically productive and has unique advantages, while allowing some access to facilities at other frequencies as well.*

- **Telescopes of different sizes support differing scientific needs.**
  A range of facilities of differing size (and cost) is essential to match need to availability. Large astronomical infrastructure is expensive, but necessary for solving problems involving the faintest and smallest objects in the universe. Smaller facilities are used to develop research programs for larger facilities, to supplement data obtained on larger facilities, and to train research students in an environment that is more hands-on and less time-critical than on larger, more expensive facilities. For certain applications, continuous access to a facility can be as important as size of the collecting area. Telescopes are long-lived, with many having useful scientific

lifetimes as long as 40-50 years. A large component of their capability is defined by their instrumentation, which can be upgraded regularly to keep them competitive. *Support for continued enhanced instrumentation is thus an integral, and cost-effective method to reap the benefits of initial capital investments in telescopes.*

- **Ironically, there are now more 8m than 4m telescopes in the world.**
  Australia has 50% access to the 4m-class Anglo-Australian Telescope and 6% access to the twin 8m-class Gemini telescopes in Hawaii and Chile.
  As a minor partner in the international Gemini Observatory, Australia has been able to "punch above its weight" with respect to contracts for instrumentation, but the scientific impact has been limited primarily to observing programs that require only a very small number of nights. Furthermore, this undesirable situation limits Australian involvement and control of the facility. *Even when scaled by Gross Domestic Product, other comparable astronomical countries in the world (Canada, United Kingdom, The Netherlands) have larger access to 8m-class facilities, and to space and other astronomical programs to which Australia has no access.*

- **Australia's access to large optical/infrared telescopes is inadequate.**
  Australian astronomers' disadvantage in access to large aperture optical/infrared telescopes is further exacerbated by its current lack of involvement in the design and implementation of the next generation of telescopes of this type, the 20-100m class Extremely Large Telescopes (ELT). The National Committee for Astronomy has recently recognized this gap, and has instituted a national working group to accelerate Australian understanding and involvement in worldwide ventures. Equal, significant access to ELT would allow Australia to be fully involved in the design, development, construction, operation, and management of such facilities in an area of clear strength and international recognition. Futhermore, it would allow Australian researchers to define significant new research directions, rather than following the lead of majority partners, thereby maximizing both scientific and technical return to Australia of participation in the partnership. Leadership in the development and use of ELT is a key part of the RSAA's strategic plan. *It is essential to stress that Australia is already beginning to suffer due to an inability to recruit some of the best young talent in astronomy because of its relatively minor access to large telescopes, and its perceived unwillingness to invest sufficiently in ELT.*

C.1.2 Research Trends, Emerging Technologies, and Stakeholders

- **Trends in the study of exoplanets and the distant Universe require ELT.**
  The faintest and extremely small detail of objects in the very distant Universe and planets and planetary systems in our own Galaxy require the light collecting power of Extremely Large Telescopes and the spatial resolution of adaptive optics for comprehensive study and understanding. These cosmic origin questions are the driving force behind the international astronomical community's response to development of next generation of optical/infrared telescopes. Australia must

participate in this activity in order to maintain its strong position in international astronomical research over the next two decades.

- **ELTs of the future rest on existing technology plus complex, adaptive optics.** Future optical/infrared Extremely Large Telescopes will be more sophisticated versions of telescopes already available within Australia, with the exception that they will use complex adaptive optics systems that are not currently available within Australia and for which Australia has limited expertise at the moment. Future ELT will also use sophisticated instrumentation that simultaneously measures more objects in more complex ways than existing Australian facilities, although Australian expertise in building these instruments is well-poised to contribute to the larger facilities. Australia's limited experience in adaptive optics (the correction of image blur due to an intervening medium, such as the Earth's atmosphere) must be addressed immediately, not only because of the importance of this key technology to all ground-based optical-infrared astronomy of the future, but also because of its importance in the fields of ophthalmology, laser machining, and defence. *Australia needs to increase its expertise in adaptive optics in order to address the challenges for designing, constructing, and operating such systems on Extremely Large Telescopes, and to take a leading role in this emerging technology for a variety of sectors, including industry, which has already indicated its interest.*

- **Networking, intellectual and electronic, are key to future research strength.** These facilities are being upgraded through a 5.6 M$ Systemic Infrastructure Initiative (SII) grant to improve instrumentation, increase the bandwidth to the observatories and many Australian institutions, and provide remote observing capabilities for all Australian users. *Although the ANU receives no special operational funds to support national use of ANU observatories, the Commonwealth SII grant is a key ingredient in supplying necessary hardware enhancements accessible to all Australian astronomers.*

C.2 The Commonwealth's Research Infrastructure Funding System

C.2.1 Strengths of Current Funding System

- **The current funding system is competitive.**
  It provides a formal mechanism whereby a group of researchers can put a case for major funding to an informed group for objective consideration.

- **The current funding scheme is regular.** Researchers can plan to prepare and submit funding requests at essentially regular intervals, thereby allowing forward plans to be made and proposals prepared ahead of time. In the case of MNRF and CRC rounds, this interval of several years is not sufficiently responsive to developing opportunities.

C.2.2 Weaknesses of Current Funding System

- **Insufficient, competitive funds are available for major infrastructure.** For example, ELT investment comparable to the level being considered by the Canadian government, namely 20% involvement in a 30m optical/infrared telescope or 50% involvement in a 20m telescope, will cost approximately $A250-300M in design, development and construction costs over ten years. A comparable amount, over a somewhat longer time frame, may be required for significant involvement in SKA-like facilities. However, the current funding scheme for large infrastructure (MNRF) would consider $A20M over five years a large grant. (Some SKA design studies are already being funded by the MNRF.)

- **Major funding is ad hoc or tied to a rigid, long-term cycle.** The consequence is that some projects are not adequately weighed against alternatives, while other collaborative opportunities are lost because of the unavailability of timely funding. As an example, the international dynamic of ELT partnerships has changed dramatically over the last six months. The University of California (UC), the California Institute of Technology (Caltech), and the National Optical Astronomy Observatory (NOAO) have agreed to undertake collaborative design studies for a single Thirty Meter Telescope (TMT). Caltech has obtained $US17.5M from the Moore Foundation (Intel), and UC have requested a similar amount. NOAO are seeking $US35M from the National Science Foundation. Canada, which has expressed a strong desire to collaborate with Australia, has agreed to collaborate with the TMT group on design studies, and has submitted to the $C1,000M Canadian Innovation Fund for $C125M. European members of the European Southern Observatory (including the UK) are collaborating with non-ESO European countries in a EU Framework proposal for ELT design study funding. *In the absence of both funding and a formal funding mechanism, Australia is not yet being treated as a serious contender for partnership.*

- **A matching fund requirement is unworkable for major infrastructure.** The requirement for matching funds severely limits the scope of proposals made to existing funding mechanisms, with the unintended result that whole classes of excellent research are not proposed. In other research areas, the ability of the university system to identify matching funds has become saturated to the point where further applications of any sort are extremely difficult. This problem is exacerbated at the higher funding levels of truly major research infrastructure.

- **No specific, long-term mechanism exists to fund operating costs.** Major research infrastructure is expected to have a lifetime of order 20-30 years. Operating costs are not funded in existing schemes; even the MNRF provides funding over a fixed period of only a few years. The situation with Australia's involvement in the Gemini telescopes is particularly strained and artificial: the ARC must be approached each year for Australia's annual operating costs. Infrastructure operating costs should be identified in the original proposal and factored into the decision to support particular proposals. Operating costs of major facilities will be large; for the proposed share of an ELT mentioned above, for example, operating costs would be approximately $A10M/yr.

- **No clear mechanism to support a vibrant user community.** A vibrant user community is essential to reap the research rewards of investment in major scientific infrastructure. *It is inconsistent to fund major research while at the same time allowing the research personnel base of the country to erode due to severe increases in training loads among the higher education sector*. Proposals for major infrastructure should be required to include on-going budgets to support facility users, skills investment, student training, and public outreach. *In addition, it is crucial to stress that investment in theoretical science, in its people and infrastructure, must be supported in concert with experimental and observational facilities*.

C.2.3 An Improved Funding System for Large Research Infrastructure

- **Fund projects based on potential to yield high scientific return for investment.** For any Commonwealth-funded research infrastructure, the emphasis should be on the ability to deliver scientific knowledge as outputs, not on shorter-term, secondary criteria. Consideration should be given to whether an appropriately trained and appropriately large Australian user base will be in place at the time of completion.

- **Establish a funded system intended to stretch over decades.**
All of the relevant timescales for good investment are long: the time to plan and develop large, long-term research infrastructure, the useful lifetime of such facilities, and the lead time from scientific discovery and innovation to large financial and social benefit it brings. Major infrastructure investment must be a considered process and infrastructure development is frequently a protracted process. It is therefore appropriate that funding of major research infrastructure should occur regularly but on a timescale that is responsive to changing international circumstances. The MNRF program occurs on a timescale that is too long and too erratic to form the basis of responsible planning.

- **Provide funding at all levels, but from a single, identified, managed source.**
Inherent in the system should be a provision to fund multiple projects at different phases at any given time. In this way, the total spend profile of the large research infrastructure fund can be managed into the future through a natural and necessary culling process.

- **Do not attempt to pick winners; let the winners identify themselves.**
By using a staged system to fund, reassess, and cull projects at a variety of critical key times, the best projects can be identified more naturally, and with increasing certainty as the project is poised to enter the most expensive phases. Funding assessment should be competitive. Those projects and groups capable of delivering early progress against reasonable criteria are more likely to continue to do so with the larger sums required to carry a project to completion. *Adequate investment in the early development and design stages of several projects, and requiring success to continue to the next stage, is good investment strategy that will save more money in the long term than it spends on less worthy projects that are not carried to completion.*

- **Initiate a large number of exploratory projects; fund construction of only a few.** For example, several stages of funding might be considered, each with different assessment criteria, and increasing in the total funding available:
  - Phase I: Exploration
  - Phase II: Conceptual Design and Development
  - Phase III: Detailed Design
  - Phase IV: Construction and Operations

  At any given point in time, several projects would be funded at each stage. Only a small number of projects would advance to the subsequent stage. This would require a large total fund to be identified and managed over a long period of time. Individual phases for individual projects may have durations of many years. *Estimates of the total project cost and schedule should be rigorously maintained over these phases.*

- **Yearly opportunities to request funding can be sufficient.** If funding is available for any phase at any given time, annual calls for proposals should be sufficient to respond quickly to new opportunities while fostering appropriate competitiveness and review and allowing sufficient time for adequate bid preparation. Note that it would not be expected that a given project would bid annually, rather that there be a yearly opportunity for new projects, or projects moving to a new stage, to be considered.

- **Identify and fund adequate operating costs before the construction phase.** Adequate operating costs are essential to the success of major research infrastructure and should be considered in the design of a project. By the time of assessment for the construction phase, operation should be clearly studied and costed, so that it forms part of criteria against which funding decisions will be based. Operations should include all costs: personnel, information technology, maintenance, renewal and refurbishment, reporting, management, training, and outreach.

- **Apply consistent, high standards of project management**. Although individual milestones will differ widely across the large range of large research infrastructure projects that will be considered, all should be held to similar standards of external (international) assessment, accountability, and risk management.

- **Periodically reassess funded projects, allowing for eventual decommissioning.** Although large research infrastructure should have a long lifetime, its continued success would be more effectively ensured with critical assessment at moderately long (5 year) intervals. Such reviews could include provision for enhanced or renewed facilities, but within the context of the total fund available for all large national research facilities. It is vital that such reviews are held to international standards. *Over time, it will be necessary, as a matter of principle and practicality to decommission some projects in order to allow new infrastructure to develop in a timely way.* An adequate decommissioning phase should be put in place to allow a shift to new mechanisms and infrastructure and to enable smooth redistribution of skilled personnel and expertise.

C.2.4 Integration with research funding & collaboration among stakeholders

- **The ARC Discovery Projects program works well for funding research.** Where major infrastructure is available, established Australian scientists are creative in its exploitation and can seek funding through the ARC Discovery Projects program for associated general research. A shortcoming of the ARC Discovery Projects program is the tendency to partially fund projects, which are then unable to achieve their goals.

- **Major infrastructure should include support for early-career researchers.** Growing pressures on university staff are directly responsible for reducing the time academics can commit to research. Funding for major infrastructure should include a component for supporting early-career researchers during the life of the facility. For example, the Space Telescope Science Institute in the USA supports a prestigious Hubble Fellowship program.

- **Allow researchers to decide between acquiring major infrastructure or obtaining access through collaboration.** Different solutions will be appropriate in differing research environments. A prescriptive and global approach to acquisition and collaboration would be too restrictive. Australia has been very successful in obtaining access to international infrastructure through collaboration. However, there is a sense in the international community that Australia does not pay it way. *Australia must acquire its own major infrastructure in research areas in which it has the greatest strengths, so that it directly controls research in these fields, returns to the international community as much as it takes, and capitalizes on early investment in critical technologies.*

- **Large ad hoc requests should be directed to an annual competitive process.** As noted above, a balanced system of staged funding would allow the progressive development of funding proposals so that large ad hoc funding requests would be avoided. Only well developed proposals would qualify for major funding.

- **Collaborative use of research infrastructure can be fostered explicitly.** Major infrastructure requires a diverse user base and should be accessible to the broadest possible user base. By including collaboration in the competitive assessment process at each stage of funding for large research infrastructure, this goal can be achieved.

C.3 Acquisition, Development & Operation of Research Infrastructure

C.3.1 Emerging Approaches to Acquisition, Development, and Operation

- **Early engagement Is essential scientifically and financially.**
  The next generation of astronomical telescopes are complex and costly machines, challenging existing technologies in many areas. New technologies are being developed to allow their cost-effective construction through international collaborative efforts. Countries investing in these developments are evolving their industries to meet these challenges and will procure lucrative construction contracts while developing spin-off benefits. Australia needs to participate at an early phase in these developments to reap the full rewards of these investments and to develop and foster the scientific expertise simultaneously that will enable Australian scientific leadership once the facility is in place. Staged funding is appropriate so that separate funding proposals are prepared at successive design phases.

C.3.2 Skills to Use and Operate Major Research Infrastructure

- **On-shore training and development facilities are vital.**
  The facilities at Siding Spring Observatory are ideal to train early-career researchers in the skills needed to use and operate larger astronomical facilities. SSO is operated by the ANU in a university environment that trains the next generation of Australian astronomers. The skills developed in using these facilities are directly transferable to larger facilities, such as the Gemini telescopes and future Extremely Large Telescopes. The hands-on experience obtained by Australian students and post-doctoral fellows in this environment makes them highly sought after in the international astronomical community. Similarly, an active instrument development program for these telescopes is essential in developing the expertise and technologies needed to attract major international instrumentation contracts for larger facilities. Indeed, *all recent major contracts obtained by Australia's highly successful astronomical instrumentation groups can be traced back to earlier prototype instruments developed for our domestic facilities.*

C.3.3 Innovative Financing Mechanisms

- **Collaborative investment by industry should not be a requirement.**
  Major infrastructure should be funded for the scientific return it will provide to the nation. Industrial return should be valued highly, and industrial or state investment in major infrastructure might be viewed favorably in a competitive assessment process, but should not be viewed as essential or allowed to drive the long-term scientific needs of the Commonwealth. *More appropriately, the Commonwealth should set its own goals independently, and then encourage State, local and industrial co-investment through incentives to those sectors.* This would also release Universities

from a growing and unmanageable level of matching fund requirements to fund the basic research that will eventually benefit all national sectors.

C.4 Domestic Research Infrastructure Collaboration and Access

C.4.1 Current and Emerging Approaches to Domestic Collaboration

- **ANU astronomical facilities are available to all Australian researchers.** Telescope time is assigned principally on the basis of scientific merit by a time allocation committee having national representation. Having direct control of our own facilities means that time can be allocated in a flexible way that appropriately supports student training and strategic use of the facilities, while maintaining a generally competitive environment. This process has worked extremely well for decades. Effectively, these facilities are operated as a national facility, but without the operating budget typical of a national facility. Consequently, the level of user support that can be offered is of necessity inferior to that experienced at other national facilities, which is less than ideal.

- **New ANU initiatives will continue this trend of domestic collaboration.** The ANU was recently awarded a Systemic Infrastructure Initiative grant to improve the instrumentation, electronic data transfer and remote access of its facilities to all Australian users. The Stromlo Southern Sky Survey, which will commence if appropriate funding for the SkyMapper telescope to replace the destroyed Great Melbourne can be identified, will provide a huge data mine to all astronomers.

- **Gemini Observatory telescopes are available to all Australian researchers.** Telescope proposals are assessed on the basis of scientific merit by an Australian assessment committee having national representation. An international time allocation committee managed by the Gemini Observatory then allocates time. This process works well. Individual countries cannot unduly influence the outcome to meet perceived national needs.

- **Australia lacks a National Gemini Project Office to promote its involvement.** All other Gemini partner countries have established National Gemini Project Offices with a full-time scientific staff that coordinates, promotes, and manages each country's Gemini involvement. The Australian Government has chosen not to fund an Australian National Gemini Project Office. Consequently, Australia's scientific involvement with Gemini is distributed. Funds to support an Australian Gemini Project Scientist and a minimal project office must be requested annually from the ARC and participating universities. Instrumentation contracts with the Gemini Observatory must be negotiated directly with Australian universities, placing all the associated financial risk on these individual institutions. *The situation is unsatisfactory, and unsustainable into the era of Extremely Large Telescopes.*

- **The tyranny of distance still impedes effective, close domestic collaboration.**

Funding mechanisms should recognize and address this uniquely Australian barrier to collaboration by supporting travel funds and video conferencing to enhance researcher mobility, especially among early-career researchers. The contrast with Europe and America is marked; Australia is characterized by isolated centers, while other research communities are characterized by frequent, fruitful interaction.

C.4.2 Role of Industry in Domestic Collaboration

- **Industrial collaboration requires rapid response.**
  Industry demands immediate returns to immediate issues, which is not a feature of current scientific research. In our experience, industry interest declines rapidly if the timescale to procure funding extends beyond approximately three months. This is compounded when the low success rate of research funding requests is also considered. Faster response mechanisms such as the Innovation Access Program are required to attract significant industry involvement. Response times for ARC Discovery Projects and Linkage Projects are unattractively long.

- **Industry is disillusioned with Governments that do not fund major infrastructure.**
  Our early experience in attracting industry involvement in an Australian 20-30m optical/infrared telescope (ELT), indicates that companies are skeptical of the Government's commitment to fund major research infrastructure. Many have been involved in a number of such projects over the last 25 years that have come to naught because of insufficient Government funding. We perceive that industry is looking for a real commitment from Government, beyond rhetoric, to support major research infrastructure before it makes further strong commitment from its own sector.

- **Major infrastructure investment can directly benefit Australian industry.**
  We are actively defining ways in which Australia industry can become involved in international research and development in preparation for the construction of 20-30m optical/infrared telescopes. Australia has an excellent reputation in these areas. International teams are extremely enthusiastic about Australian involvement, and about design ideas already developed in Australia. A challenge is to identify Australian industries that are already involved in relevant areas, or that can expand and evolve into relevant areas over the next decade. This task is severely manpower limited. We would welcome the opportunity to work more closely with Government to foster these developments.

C.4.3 Prioritization of Access to Facilities

- **Merit should determine access to major research infrastructure.**
  It is to be expected that demand will exceed capacity on any worthwhile major research infrastructure. Access should be managed in a way that maximizes the scientific productivity of the facility to Australian researchers. Scientific merit as judged by a peer group is the best way of achieving this outcome. International use

of Australian research infrastructure should be permitted, and indeed encouraged to foster the sharp, competitive Australian science. Australia is too small on the world scene, however, to support a dominant international user community on its facilities.

C.5 Processes for International Collaboration and Access

C.5.1 Demand for Two-Way International Collaboration

- **International collaborations are essential to Australian leading-edge science.** Australian research contributes to a global effort that far exceeds Australian involvement. Consequently, all Australian research should have an international as well as national audience. International collaboration is then essential, fruitful, and unavoidable.

- **Long-term international collaborations must be based on equal partners.** Effective collaborations are those in which partners have similar goals and each pay their own way. If collaborations fail to meet these criteria, natural mechanisms should be allowed to take effect that will dissolve ineffectual partnerships and create new ones. To be viewed as an attractive partner internationally, Australia needs to demonstrate a long-term commitment to major research infrastructure through regular, stable, and suitably large funding programs, that are further supported by adequate research funding through the ARC that fully funds successful projects to completion.

- **Bilateral collaborations are a powerful mechanism for some projects.** Bilateral arrangements commit countries at senior levels to the success of the venture where their goals are seen to be aligned for the near to long-term future in a given major facility. It also facilitates close collaboration between the two international communities to their mutual benefit. Such arrangements have served the Australian astronomical community extremely well, as exemplified by the Anglo-Australian Observatory. This highly successful model should inform Australia's involvement in the next generation of 20-30m diameter optical/infrared Extremely Large Telescopes.

C.5.2 Improving Competitive Success Rate

- **Familiarity with facility capabilities greatly enhances competitive success rate.** A cost-effective solution to achieving detailed familiarity is for the funding system to support the operation of local "project offices" that manage scientific access to each international facility at a fraction of the cost of actually maintaining the facility. Each "project office" would maintain a scientific staff with specific interest in the use of the international facility. These staff would also inform and promote the facility to the wider Australian community and assist them in developing competitive applications for the use of the facility. This successful model has been adopted by all partner countries in the Gemini Observatory except Australia, to our detriment.

- **Early engagement increases scientific, technological and economic competitiveness.**
  Early engagement in the explorative research, detailed design and construction phases of major research infrastructure allows a substantial competitive edge. Leading, rather than following international developments will allow Australia to influence the science that will be done in international collaborations, build the necessary scientific and technological skills sets, attract and hold the best young researchers to exploit the potential of new facilities, and allow industrial returns and spin-offs from international projects to flow back to Australia. When done well, these returns can far exceed Australia's per capita "share".

C.5.3 Prioritising Access to Australian Research Infrastructure

- **Access should be merit-based with measured international access.**
  As with most major national facilities, Australian research using its major infrastructure benefits from measured access by the international community, either directly, or through collaboration. As a small country, however, Australia cannot support completely open access to facilities that it solely funds. Time allocation should be on the basis of scientific merit, but with sensitivity to the broad issue of maintaining a viable Australian user community in the long term. In practice, all international research facilities find a subjective balance between the needs of serving both national and international research communities.

C.5.4 Major Barriers to Access to Overseas Research Infrastructure

- **The lack of sustained, large infrastructure funding is deleterious to Australia.**
  The largest of the new facilities for astronomy are too large to be funded by Australia alone, and thus require international partnership. *Without a visible, long-term mechanism for funding large scale, collaborative projects, including their infrastructure costs, Australia is often disregarded as a serious potential partner.* Significant access to these facilities is likely to be on a partnership basis only, as evidenced by the Gemini Observatory, the European Southern Observatory, and all new ELT development plans. The new radio-millimetre wave ALMA facility is another example.

- **Sufficient travel funds are required to initiate and maintain collaborations.**
  Many modern astronomical facilities will be remotely-operated, and include large data transfers, making the Virtual Observatory a reality. This will reduce travel costs associated with the direct use of the facilities, but not the need for international visits to foster scientific collaborations after the facility is completed, and to build the collaborations, information exchange, and relevant technical expertise in the development and design stages. Such travel funds, if managed well, will have benefits that far outweigh costs by providing enhanced competitiveness in scientific, technological and industrial returns.

D Relevant Summary of Submitting Institution

The **mission** of ANU's Research School of Astronomy and Astrophysics is to:

- *Advance the observational and theoretical frontiers of astronomy and its enabling technologies*
- *Provide national and international leadership*
- *Train outstanding scientists*

Selected **recent achievements** of the institution include:

- In 2002, six RSAA astronomers were among the top 32 **most highly-cited scientists in Australia**, making the RSAA the most represented department in the country in any scientific discipline. In 2003, five RSAA astronomers were among the 40 top-cited Australian scientists. The majority of these highly-cited publications depend on the collection and interpretation of optical-infrared data.

- Through international competitive awards totaling more than $10 million over the last four years, the RSAA is **building Australia's first two instruments for the Gemini 8-m telescopes**. ANU is the only institution in the world to have been awarded two such contracts.

- **ANU observatories are open to all Australian researchers and students**, providing and maintaining a significant national resource.

- The RSAA has **Australian astronomy's only active Fellow of the Royal Society**, one of three ARC Federation Fellows in astronomy (another is an adjunct professor), 2 Fellows of the Australian Academy of Science, and 2 Associates of the Royal Astronomical Society.

- The RSAA is **Australia's largest grouping of astronomers** and offers its most comprehensive set of undergraduate and graduate courses. The RSAA has **trained many of the world's astronomical leaders** residing in the United States, Europe, Asia, Africa, and Australia.

- Five of Australia's nine prestigious Hubble Fellows were ANU-trained, making the **RSAA the second most successful non-US institution in Hubble Fellowship awards.** The first is Cambridge, which has six.

E Two-Page Curriculum Vitae of Submitting Author

Penny D. Sackett

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Born: 28 February 1956, Lincoln, Nebraska U.S.A.
Citizenship: U.S.A.
Residence: Australia (Permanent)

Education:

1984	Ph.D., University of Pittsburgh, Physics *Thesis: Scale Parameters for Finite Temperature Actions of Lattice Gauge Theories Coupled to Fermions*
1980	M.S., University of Pittsburgh, Physics
1978	B.S., University of Nebraska-Omaha, Physics
1978	Teaching certification (K-12), Physics and Mathematics, Univ. of Nebraska-Omaha

Distinctions and Honors:

2003	Elected International Associate of the Royal Astronomical Society
2002	Harley Wood Lecturer, Astronomical Society of Australia
2000	Athena Lecturer, St. Andrews University
1998	University of Groningen Teaching Award (Onderwijsprijs)
1992-1994	J. Seward Johnson Fellow, Institute for Advanced Studies, Princeton, NJ
1981-1982	O.H. Blackwood Award for Excellence in Teaching, Univ of Pittsburgh, PA
1979-1981	Andrew Mellon Fellowship, University of Pittsburgh, PA
1978	Summa Cum Laude, University of Nebraska-Omaha, NE
1978	Most Outstanding Physics Student, University of Nebraska-Omaha
1978	Most Outstanding Mathematics Student, University of Nebraska-Omaha
1974-1978	Dean's List, University of Nebraska-Omaha, NE
1974-1978	Nebraska Regent's Scholarship, University of Nebraska-Omaha, NE
1974-1978	National Merit Scholarship, University of Nebraska-Omaha, NE

Recent Professional Appointments:

2002-present	Director, Research School of Astronomy and Astrophysics,

	and the Mt. Stromlo and Siding Springs Observatories, Australian National University, Canberra, Australia
2001-2002	Chaired Professor of (Extra)Galactic Optical/Infrared Astronomy, Kapteyn Astronomical Institute, Univ of Groningen, NL
1998-2000	Associate Professor with tenure (Universiteits Hoofd Docent), Kapteyn Astronomical Institute, Univ of Groningen, NL
2000	Visiting Member, Institute for Advanced Study, Princeton, NJ, USA
1999	Visiting Scientist, Anglo-Australia Observatory, Epping, Australia
1995-1997	Assistant Professor with tenure (Universiteits Docent), Kapteyn Astronomical Institute, Univ of Groningen, NL
1995-1997	Visiting Research Member, School of Natural of Sciences, Institute of Advanced Study, Princeton, NJ, USA
1992-1994	Research Member and J. Seward Johnson Fellow, Institute of Advanced Study, Princeton, NJ, USA
1991-1992	Program Director, Education, Human Resources & Special Programs, Division of Astronomical Sciences, National Science Foundation, Washington, DC, USA

Recent Local, National & International Service and Membership:

2003-present	Elected University Research Committee, Australian National University, Canberra, AU
2002-present	National Committee for Astronomy (NCA), Subcommittee of the Australian Academy of Science
2003-present	NCA Task Force on Extremely Large Telescopes (ELT)
2002-present	Representative to Association of Universities for Research in Astronomy (AURA) (ANU is one of six, elected, non-US participants in AURA)
2002-present	Australian Gemini Steering Committee
2002-present	Board of Management for the Australian Astronomy Major National Research Facility Award
2002-present	Academic Board, Australian National University
1995-2002	Principal Investigator, International PLANET Collaboration
2001-2002	Science Advisory Committee for the Square Kilometer Array (SKA)
2001-2002	Curriculum Advisory Committee for Astronomy, Kapteyn Astronomical Institute
2000-2002	European Southern Observatory (ESO) Programmes Committee
2000-2001	Chair, Stars and Planets Panel for European ELT Working Group
1998-2002	Co-Investigator and Member of Dutch Science Team for Wide Field OmegaCAMera for the VST on Paranal
1996-1998	ESO Working Group on ExtraSolar Planets
1996-1998	Facilities Program Committee for the Netherlands Organization for Scientific Research