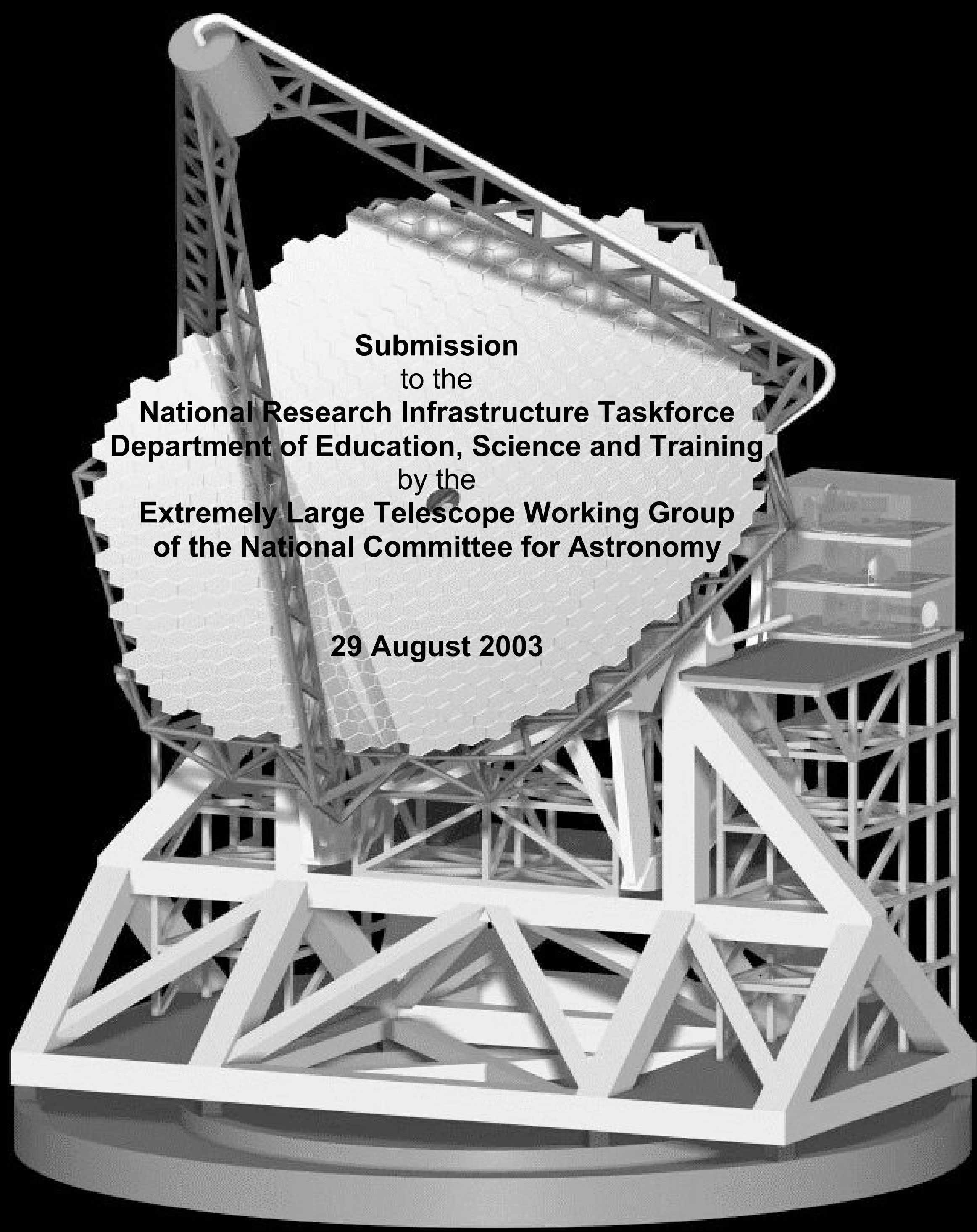
Research Infrastructure for a Future Large Optical Telescope



Submission
to the
National Research Infrastructure Taskforce
Department of Education, Science and Training
by the
Extremely Large Telescope Working Group
of the National Committee for Astronomy

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Summary

Access to telescopes across the electromagnetic spectrum is needed to sustain a broadly-based astronomical research community, but Australia's share of the premier optical telescopes has declined dramatically in recent years. Access to an optical/infrared Extremely Large Telescope (ELT) is essential to the future of Australian astronomy. Such front-rank facilities leverage access to other front-rank facilities.

An ELT will address some of the outstanding problems in astrophysics and will require an investment at least as large as previous Australian investments in major telescope facilities. An ELT will demand close collaboration between astronomers and industry and would be available to all Australian astronomers on the basis of competitive, peer-reviewed procedures. Australia has the astronomical user base and skills for exploiting an ELT, and expertise in most of the enabling technologies (a census of relevant skills in Australian industry is in progress). Adaptive optics is identified as a critical technology for an ELT where Australia should build up its expertise.

The greatest weakness of the present funding system for research infrastructure is that the level of available funding is inadequate for major facilities on an international scale. Other issues that need to be addressed are the integration of operating costs and associated research activity in the funding of major facilities. Desirable features of a new funding system include: flexibility in dealing with a wide range of funding models and international collaborative arrangements; a multi-stage competitive winnowing of proposals, based on scientific merit and performance; long-term funding for successful proposals. Matching funding from industry should be encouraged but not required. The fullest technological and financial return comes from early investment, and seed funding for involving industry at an early stage would be valuable.

International collaborations in major facilities are essential to Australian astronomy, and bilateral collaborations offer many advantages given a suitable partner. A mixed ownership/access strategy across a range of facilities is likely to best meet astronomers' needs. The preferred model for an ELT is part-ownership, since owning a share of the facility provides many more advantages than proportionate access.

Context

This submission is made by the Extremely Large Telescope Working Group (ELTWG) set up by the National Committee for Astronomy (NCA) of the Australian Academy of Science. The ELTWG is tasked by the NCA with exploring opportunities for Australian participation in projects to build an extremely large optical/infrared ground-based telescope (an ELT).

The members of the working group are Dr Matthew Colless (ANU, Chair), Dr Sam Barden (Anglo-Australian Observatory), Dr Tim Bedding (U.Sydney), Prof. Warrick Couch (UNSW), Prof. Brad Gibson (Swinburne University of Technnology), Dr Jon Lawrence (UNSW), Dr Peter McGregor (ANU), Prof. Penny Sackett, (ANU) and Dr Chris Tinney (Anglo-Australian Observatory).

The contact for the ELTWG is Dr Matthew Colless, Mount Stromlo Observatory, Canberra (phone: 02-6125-8030; email: colless@mso.anu.edu.au). Further information about the ELTWG and its activities can be found at http://www.mso.anu.edu.au/ELT/.

This submission considers the research infrastructure needed for a future large optical telescope. Such a telescope will be a high priority for Australian astronomers in the coming decade, and this submission focuses on the infrastructure issues that are specifically relevant to realizing this particular major research facility. This submission is complementary to, and should be read in conjunction with, other submissions from the astronomical community that deal more generally with research infrastructure issues.

In this context, the following sections address the various issues raised in the Invitation for Submission.

1 Australia's Future Research Infrastructure Needs

1.1 Australia's Astronomical Infrastructure Strengths and Weaknesses

- **Access to telescopes across the electromagnetic spectrum is needed to maintain a broadly-based astronomical research community in Australia.**
  Modern astrophysical research requires observations across the whole electromagnetic spectrum, and astronomers need to be able to access optical, infrared, radio, X-ray and other radiation bands in order to obtain a complete picture of the universe. The broader the range of facilities Australian astronomers can access, the greater the scientific grasp their research will have. Given limited resources, the most effective strategy is to focus investment in telescopes at wavelengths that are particularly important to Australian research and where Australian astronomers have historical strengths, while providing some level of access to telescopes at other wavelengths. Observational astronomy in Australia has historically been concentrated on optical/infrared and radio wavelengths, which together have provided the foundation for Australia's outstanding research record in astronomy. Within optical astronomy, telescopes with a range of sizes are needed: large telescopes are required for studying the smallest and faintest objects while smaller telescopes provide survey and training facilities.

- **Australia's access to premier optical telescopes has declined dramatically in recent years**.
  Australia currently has a 50% share in the 4m-class Anglo-Australian Telescope and a 6% share in the twin 8m-class Gemini telescopes in Hawaii and Chile. A decade ago, when 4m-class telescopes were the premier optical/infrared facilities, Australia had a 4.5% share of the world's best optical telescopes. Today, now that 8m-class telescopes are the premier facilities, Australia has only a 1.0% share of the world's best optical telescopes. This is below Australia's 1.2% share of the global GDP, and well below the GDP-scaled level of access available to astronomers in the UK, Canada, the Netherlands and other countries with which Australian astronomers had until recently competed on a level footing. Moreover, this comparison neglects the fact that Australia only has significant investments in ground-based optical and radio telescopes; it has no significant investment in facilities at other wavelengths or in space-based astronomy. This significant decline in relative access to premier facilities will inevitably lead to a decline in the front-rank research that can be done by Australian astronomers unless the trend is reversed.

- **Access to an optical/infrared Extremely Large Telescope is essential to the future of Australian astronomy.**
  Optical and infrared astronomy lies at the heart of astronomical research because: (i) most of the radiation in the universe is emitted in these bands; (ii) they are rich in spectral features that carry a wealth of astrophysical information; (iii) the Earth's atmosphere is transparent at optical and near-infrared wavelengths, allowing ground-

based telescopes in these bands. Two of the most important measures of a telescope's capability are its collecting area (which determines the faintest objects it can detect) and its resolution (which determines the smallest objects it can discern). Both of these quantities are related to the size of the telescope (given by the diameter D of the main mirror): the collecting area goes as D^2 and the resolution as D; in fact, for some particular cases of interest the figure of merit for a telescope can increase with size as fast as D^4 or even D^6. Thus the capabilities of the next generation of ELTs (with D=20-100m) will far outstrip even the largest telescopes today (with D=8-10m). These performance gains are not simply quantitative: an ELT will be able to do qualitatively new science because the quantitative performance gains push its performance over physical thresholds, allowing observations of previously inaccessible and extremely important phenomena (e.g. the properties of planets around other stars, the formation of the very first stars, and the origin of supermassive black holes). ELTs will define the leading edge of optical/infrared astronomy a decade from now. If Australian astronomers do not have access to an ELT they will be unable to compete internationally, and astronomy will be reduced from one of the powerhouses of Australian basic research to a second-rate, niche-oriented field.

- **An ELT will be a major facility requiring an investment comparable to previous Australian investments in large astronomical telescopes.**
  The conceptual design studies for ELTs carried out by a number of groups around the world concur in estimating the capital cost of a 30-metre ELT at around $1 billion, with an annual operating cost of roughly $100 million. The initial project plans estimate that the construction of an ELT will take about a decade from the initial design phase through to first light. An Australian share of 10% of a 30m (corresponding to 25% of a 20m or perhaps 5% of a 100m) would therefore require a capital investment of the order of $100 million and operational funding of order $10 million per year (large telescopes have useful lifetimes of at least 25 years). An ELT is therefore a major research facility. Such an investment is in line with Australia's previous investments in major astronomical facilities: the construction cost of the Anglo-Australian Observatory (built in 1973) was $43 million (in 2003 $'s, scaling by GDP), and that of the Australia Telescope National Facility (built in 1988) was $86 million; both facilities have annual running costs of order 10% of their capital costs.

1.2 National Research Priorities, Emerging Industries & Research Trends

- **Astronomy contributes to the National Research Priority "frontier technologies for building and transforming Australian industries".**
  Observational astronomy is a technology-driven science, which works at the frontiers of high technology. It can and does develop new technology – recent examples include CCD detectors, now pervasive in medical imaging, and adaptive optics, which has very wide applications in areas from ophthalmology to missile targeting. An ELT will critically depend on adaptive optics, pushing the technology into new

developments. It will also demand extremely high-precision control systems, novel lightweight mirror technologies and a range of other frontier technologies that can only be developed through collaborations between astronomers and industrial partners.

- **An ELT will address some of the outstanding problems in astrophysics.**
  The two most exciting new areas in astronomy are the study of the origins of the universe – the formation of the first stars and galaxies – and the properties of exoplanets – planets around other stars. A number of reviews by the various international ELT programs have clearly demonstrated that an ELT will powerfully contribute to our understanding of these two fields and many others – e.g., the GSMT Science Working Group report to the US National Science Foundation (http://www.aura-nio.noao.edu/), the CELT Green Book (http://celt.ucolick.org/) and the European Southern Observatory OWL project (http://www.eso.org/projects/owl/).

1.3 Collaborative Use of Research Infrastructure

- **An ELT will be available to all Australian astronomers.**
  Time on all Australian telescopes is accessible via a competitive process open to all Australian astronomers, with some time also available to international astronomers. Any Australian share in an ELT would be accessible in the same way. Note that although time on many international astronomical facilities (e.g. the Hubble Space Telescope) can be accessed in the same way, there is no guarantee that this will be the case in future (e.g. time on the Gemini telescopes is only available to astronomers in the partner countries).

- **An ELT will demand close collaboration between astronomers and industry.**
  Any appreciable Australian share in the design and construction of an ELT will demand close collaboration between astronomers and industry due to the scale of the project and the wide array of necessary technological inputs.

1.4 Developments in Enabling Technologies

- **The critical technology for an ELT is adaptive optics.**
  Although the existing conceptual designs for ELTs push the envelope in a wide range of technologies from complex control systems to lightweight support structures, the central critical technology is adaptive optics. Adaptive optics allow the the blurring effects of the atmosphere to be corrected so that an ELT can operate at (or close to) the limiting resolving power set by the primary mirror size. Without such adaptive optics, ELTs cannot fully realize their potential. The requisite technology is currently under development in a number of countries, and certainly appears feasible. Australia needs to develop its capacity in this field in order to fully participate in an ELT project and because adaptive optics will be a critical component of all future ground-based telescopes.

- **Australia has expertise in other enabling technologies for an ELT.**
  Australia does have front-rank expertise in other enabling technologies for an ELT, with examples including large-scale light-weight civil engineering projects, complex real-time control systems, large multi-object spectrographs and other instrumentation technologies. An active effort is currently underway to chart the full extent of the relevant expertise within Australian industry.

1.5 Necessary Skills

- **Australia has the essential astronomical skills for an ELT.**
  Australian astronomers are already working in the fields to which an ELT will most likely contribute, including cosmology, galaxy formation and exoplanet studies. They have experience on the current generation of 8m-class telescopes through Gemini, although the limited amount of time available means that the community does not possess the breadth or depth of experience possessed by astronomers in countries with greater access to such facilities. Nonetheless, Australian astronomers have managed to win contracts to build a number of instruments for 8m-class telescopes (including Gemini and the European Southern Observatory's Very Large Telescope), and have established an outstanding reputation in large telescope instrumentation.

- **A census of relevant skills in Australian industry is in progress.**
  The ELT Working Group is currently beginning a census of the skills available in Australian industry that will be relevant to an ELT. The already-known skills base is impressive, but it is expected that a comprehensive census will significantly broaden the areas of relevant expertise and may turn up some particular examples of world-leading technological capabilities that were previously unappreciated.

2 The Commonwealth's Research Infrastructure Funding System

2.1 Strengths and Weaknesses of Current Funding System

- **The scale of available funding is inadequate for major research infrastructure.**
  Astronomers won the largest single grant ($23M for Gemini and SKA development) in the last Major National Research Facilities round, where the total available funding was $125M. However a modest share in an ELT would cost at least $100M; other future astronomical projects (e.g. the Square Kilometre Array radio telescope) require comparable investments. At present, the two major US ELT programs are each seeking half of US$70M to fund a joint ELT design effort; this is the first 10% of the expected total cost of their ELT. Meanwhile the Canadian ELT program is seeking C$125M from the C$1000M Canadian Innovation Fund as the first step towards their own significant share in an ELT program. As these examples show, unless there is a very significant increase in the overall level of funding for research infrastructure, Australia will not be participating in astronomical facilities that would

truly be considered ‘major’ on the international scale. In the short term, the absence of any visible mechanism for obtaining funding at this level means that Australia is not considered a serious player by the international ELT projects that are evaluating potential partners.

2.2 Balancing Investment between Acquisition and Operation

- **Operating costs must be included in the funding of major facilities.**
  At present the funding programs do not in general supply the operating costs of major facilities, and the lack of an integrated view of research funding means that facilities can obtain capital investment without a secure source of operational funding. This is in fact the case for Australia’s share in the Gemini telescopes, for which running costs must be obtained from the ARC on an annual basis in an *ad hoc* arrangement. For larger facilities like an ELT, such arrangements are untenable – it will be essential to source long-term operating costs at the same time as the capital investment in such projects.

2.3 Integrating Infrastructure Funding and Research Activity Funding

- **Major research infrastructure funding needs to be closely integrated with research activity funding.**
  Investment in major research infrastructure will only return its full value if there is appropriate funding of associated research activities. This requires there to be a proportionate user community in the first instance, but also that this community’s research be supported in suitable ways. In the case of an ELT, this means funding research activities that directly use the telescope (e.g. observational research projects, travel to the facility) and also activities that indirectly support its full exploitation (theoretical research, conferences, student training, public outreach).

2.4 Balancing Acquisition of Infrastructure and Access to Facilities

- **Owning a share of a facility provides much more than proportionate access.**
  Although access to an ELT is the fundamental requirement, it is worth emphasizing that owning a share in an ELT provides many advantages over merely having the equivalent access. This can be illustrated with a hypothetical but plausible example from the Gemini partnership. Australia currently has a 6% share of Gemini, which returns not only 6% of the time available on the telescopes, but also means that approximately 6% of instrumentation contracts will be placed in Australia. This ownership share also gives Australia one seat on the 14-member Gemini Board, which determines policy for the facility. In principle Australia could buy time (but not share) from another partner – this would increase the level of access, but would not increase Australia’s say in running the facility or increase the funds which Australia could expect to recover in instrumentation contracts. Owning a share thus provides a much fuller engagement with the facility, returning significant value in both scientific and financial terms. The most likely model for participation in an ELT, as for most

modern ground-based astronomical facilities, is that the owners share in the facilities in proportion to their investment, with access to the facility for non-partners at the partners' discretion.

- **A mixed ownership/access strategy is likely to best meet astronomers' needs.**
  As noted above, Australian astronomers need access to a variety of facilities in order to be competitive. At the same time, they need to take leading roles in a few major facilities in order to remain in the front rank. These conflicting needs can best be met by a mixed strategy in which some low level of access is provided to facilities of all types at minimal cost while major investment is focused on a few high-priority facilities. Some facilities, including many satellite observatories, allow access to all comers based purely on competitive proposals; other types of facility (and this likely will include major new ground-based facilities like ELTs) will retain the lion's share of access for the owners.

2.5 Infrastructure Timescales and the Funding Cycle

- **Major infrastructure funding programs must be flexible and long-term.**
  The variety of forms that major research infrastructure can take, and the variety of ways in which it can be realized (particularly when international collaborations are involved), means that the funding mechanism must be as flexible as is consonant with competitive equity. The natural timescales for major projects are long – for an ELT the design and construction phase will take about a decade and the operational phase will probably last a few decades. Such a project needs some guarantee of long-term funding support, subject to continual and rigorous performance monitoring. On the other hand, opportunities for involvement in such projects, especially opportunities for international collaborations, can emerge on short timescales and may require relatively rapid responses. At present Australian infrastructure programs tend to have short total durations and long proposal cycles, which is precisely the opposite of what is needed.

2.6 Prioritizing Large Funding Requests

- **Major research infrastructure must be funded competitively.**
  Previous major astronomical facilities (e.g. the Anglo-Australian Observatory in the optical and the Australia Telescope National Facility in the radio) have been funded via *ad hoc* arrangements. Although these facilities have in fact proven highly successful, *ad hoc* funding fails to provide accountability, equity and cross-disciplinary balance; it can also be wasteful and slow. A competitive process for assessing and funding major research infrastructure is greatly to be preferred to *ad hoc* funding arrangements.

- **Matching funding should not be an essential measure of merit.**
  A rigidity in many current programs is a requirement for a high minimum level of matching funding. While matching funding from other sources is clearly highly

desirable, the availability of matching funding varies enormously from field to field, and it should not be taken as a essential measure of a proposal's merit.

- **Long-term funding for major facilities should involve multi-stage winnowing.** The funding system should support many concept studies, fewer design studies and fewer projects still should be taken to construction and operation stages. At every transition threshold there should be a competitive winnowing of the projects under consideration. For example, appropriate stages for reconsideration of an ELT proposal would be (i) feasibility studies and the formation of international partnership(s); (ii) conceptual design and technology development; (iii) detailed design and award of the main construction contracts; (iv) construction and initial operations (v) continuing operations, phase-out and termination. At every stage the project budget and business model would be refined and the whole project reviewed before it passed (if successful) to the next stage.

3 Acquisition, Development and Operation of Infrastructure

3.1 Emerging Approaches

- **The fullest technological and financial return comes from early investment.** Because ELTs are extremely expensive they will be managed like the correspondingly expensive major space programs. In particular, this will mean that the design phase will be extremely detailed and prolonged, that many aspects of the design will be frozen in relatively early in the project, and that the major contractors will also be identified early-on. Thus in order to gain the fullest technological and financial return on its investment in an ELT, Australia will need to join an international ELT program at the earliest possible stage. Joining late will mean shipping funds off-shore to pre-determined overseas contractors rather than recovering the funding for Australian industry. If the earliest concept design and technology development phases of the project are missed, then so are the major knowledge-transfer gains from participating with international collaborators on the technological challenges of an ELT.

3.2 Fostering Strategic Decision Making

- **Major research infrastructure should be based on strategic planning.** The astronomical community follows a decadal process of reviewing its goals and needs and then setting out a strategic plan to achieve these ends. This process is facilitated by the National Committee for Astronomy. Major research infrastructure should be supported at a national level by the strategic planning processes of the relevant discipline(s). Support for grass-roots strategic planning would materially assist in the development of Australia's research infrastructure.

3.3 Collaboration between Governments and Industry

- **Seed funding for involving industry at an early stage would be valuable.**
  Because of the long-term nature of major research facilities, industry is often hesitant to get involved at the early stages. Funding support to identify relevant industry partners and involve them in the earliest phases of developing the concepts and technology leading towards a major facility would be most valuable.

3.4 Skills to Use and Operate Major Research Infrastructure

- **To fully exploit a long-term major research facility requires appropriate training of the next generation of researchers.**
  The long-term nature of a major facility like an ELT means that many of its first users are still at school and some of its eventual users may not yet be born. Training future researchers at all levels of the education system therefore needs consideration and encouragement. A successful major facility will often draw suitable people into the research field, but once there they need appropriate support. Student internships and early-career programs associated with a particular facility are widely recognized as efficient ways of supporting tomorrow's leading research workers.

3.5 Innovative Financing Mechanisms

- **Matching funding by industry should be encouraged but not required.**
  The primary function of research infrastructure is to enable research of intrinsic value. Additional goals such as fostering industry or technology should be valued but secondary. Consequently, funding support for research infrastructure from industry or other sources should be encouraged, and included in any comparison of competing proposals, but it should not be a primary (still less, essential) requirement for research infrastructure programs.

- **Australia needs to develop a private philanthropic sector for funding research.**
  The current largest optical telescopes in the world, the two Keck 10m telescopes in Hawaii, were largely funded by a massive donation by the W.M.Keck Foundation, a private philanthropic trust. Likewise, Caltech has recently secured US$17.5M from the Moore Foundation, founded by Gordon Moore of Intel, for the design phase of the CELT telescope project, and it expects to secure much larger sums for the eventual construction of this 30m telescope, which is currently envisaged as a 50/50 public/private venture. Australia lacks a comparable level of private philanthropic investment in research other than medical research, and any moves to encourage the growth of this sector would have enormous long-term benefit for Australian science.

4 Domestic Research Infrastructure Collaboration and Access

4.1 Current and Future Models for Domestic Collaboration and Access

- **Australia's share of an ELT will be available to all Australian researchers.**
  All existing major Australian telescopes (the Anglo-Australian Observatory, the Gemini telescopes and the ATNF radio facilities) are national facilities open to all Australian researchers on the basis of competitive, peer-reviewed scientific proposals. This general approach is common to all major astronomical facilities world-wide. In some international partnerships, like Gemini, each partner has a national time allocation committee that assigns its own share of time on the facility, with an international committee merging the national recommendations. In other cases, such as the European Southern Observatory, time is assign by a single international committee, with guidelines ensuring each country obtains its fair share. Both methods have pros and cons, but both are in successful use. An ELT in which Australia owned a share would probably adopt one or other of these approaches, either of which would ensure that all Australian researchers had merit-based access to the telescope.

4.2 Barriers, Opportunities and the Role of Industry

- **Government investment in major research infrastructure directly benefits Australian industry.**
  The ELT Working Group is currently mapping the capabilities of Australian industry that are relevant to an ELT. It is expected that this exercise will identify many small to medium-sized technology companies with skills and expertise that would be applicable to an ELT. If these SME's were to participate in the various phases of an government-funded ELT project they would benefit through the opportunity to develop leading-edge technology, knowledge and skill transfers from international collaborators and the showcasing of their capabilities in a prestigious, high-profile project.

- **Timescale is a major barrier to industrial involvement.**
  The short timescales on which most small to medium companies operate are a barrier to their involvement in large-scale, long-term projects such as an ELT. Possible ways around this problem include seed funding for industry involvement at the early stages of such projects, and the involvement of large companies as `umbrella' organizations willing to make longer-term investments and shelter smaller companies which act as sub-contractors.

4.3 Initiating Opportunities for Collaboration and Access

- **Seed funding for involving industry at an early stage would be valuable.**

As noted above, funding support to identify relevant industry partners and involve them in the earliest phases of developing the concepts and technology leading towards a major facility would be a very effective means of initiating collaborations.

4.4 Prioritization of Access to Facilities

- **Merit should determine access to major research infrastructure.**
  As noted in the discussion of access models above, scientific merit is, and should be, the only factor in determining the access of astronomers to an ELT or any other major facility. On premier facilities like an ELT, demand always greatly outstrips supply, and only the best of the best proposals can be supported. The current method of evaluating merit by peer review is, as Winston Churchill said of government by democracy, “the worst system apart from all the others”.

5 Processes for International Collaboration and Access

5.1 Demand for Two-Way International Collaboration

- **International collaborations are essential to Australian astronomy.**
  Astronomy is one of the most internationalized of all the sciences, and international collaboration has long played a part in Australian research. The two major optical telescopes in which Australia shares are both international collaborations – the Anglo-Australian Observatory is a bi-national collaboration, while the Gemini Partnership involves seven countries. The scale of an ELT demands that Australia participate as part of an international collaboration.

5.2 Role of Bilateral Collaboration/Access

- **Bilateral collaborations offer many advantages given a suitable partner.**
  The advantages of bilateral models are that they are tightly focused and can be completely symmetrical, which is a very good basis for collaboration and simplifies management. Australian astronomy has a very successful example of a bilateral collaboration in the Anglo-Australian Observatory, which has been a major contributor to Australian and British optical astronomy for nearly 30 years. This highly successful model would be suitable if, for example, Australia wished to own half a relatively small ELT (say, 20-25m) in partnership with a country with comparable astronomical capabilities (e.g. Canada or Japan).

5.3 Improving Chances of Success for Competitive Access

- **The preferred model for ELT is part-ownership.**
  By owning part of an ELT, Australia guarantees its share of access. Further, the earlier the stage at which Australia becomes a stakeholder in an ELT project, the greater the benefits (see above).

- **Front-rank facilities leverage access to other front-rank facilities.**
  For facilities where Australia does not own a share and have as-of-right access, the most effective way of gaining access is to have leading-edge facilities of your own which can be used as leverage. This leverage can be realized by a direct access trade, by enhancing the competitiveness of research proposals to the other facility, or through synergistic collaborations with international researchers.

5.4 Prioritizing Access to Australian Research Infrastructure

- **Access should be based on scientific merit judged by peer review.**
  See above.

5.5 Major Barriers to Accessing Overseas Research Infrastructure

- **Travel funds are a significant barrier.**
  Funding for access to overseas research facilities is currently available through the Access to Major Research Facilities program. However an Australian share in an ELT would include appropriate funding for researchers to take up their competitively-awarded time allocations as part of its operating costs. This model is followed for British astronomers using the AAO, and by European astronomers using the VLT. It is expected, however, that an ELT would in large part (perhaps primarily) function in service mode, so that astronomers would not need to be physically present to carry out their observations. This would minimize travel costs and increase efficiency, although placing a greater load on the local ELT staff to carry out observations.

5.6 Transforming International Collaboration via Information Technology

- **Information access is becoming more common than physical access.**
  The model for accessing overseas facilities is rapidly changing, from direct physical access to IT-based information access through an intermediate operative layer. As noted above, this may be the standard operational model for an ELT and offers considerable benefits.