Australian Membership of the Giant Magellan Telescope Project

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Introduction

This proposal argues that the astronomical community should strategically invest approximately $5M of NCRIS funds in the Giant Magellan Telescope project.

While this document is addressed primarily to this community, it has been written to take account of NCRIS priorities and criteria. The proposal looks ahead to required future funding, most probably directly from Federal funds as a 'Landmark' facility. This means that broader issues than purely scientific ones are addressed; funding on the scale of an ELT will depend on substantial benefits to industry and education. Many questions are unresolved, and are not explored in this brief paper; the aim is to engage the enthusiasm of the community, and initiate debate leading to the resolution of these questions.

Background

Extremely Large Telescopes (ELTs) are the future of optical and infrared astronomy.

Australia has an opportunity now to join the Giant Magellan Telescope project. GMT will be a 21-25 metre (collecting area – angular resolution equivalents) telescope costing approximately US$550M. The partners are a consortium of major US research institutions and the Australian National University. The project is currently entering the Design Development Phase (DDP). If the final design review in 2009 is successful, construction will then begin, with the goal of achieving first light in 2016.

Access to an ELT is one of the key objectives of the Australian Astronomy Decadal Plan, and fits into its strategy of maintaining access to world-class facilities for a community that will continue to contribute across all of astronomy at the highest international level.

Science Case

The GMT science case is defined by the intersection of its community's scientific aspirations and the unique capabilities of the telescope and its instruments. Some of these capabilities draw largely on the dramatic gains in angular resolution promised by adaptive optics, while others rely entirely on the enormous light grasp offered by the collecting area of the seven primary mirror segments and the wide field of view of the survey instruments. In this sense GMT strikes a finely tuned balance between the promise of developing technology and the demonstrated power of telescopes with large collecting areas.

The science that we can currently predict will emerge from GMT is exciting and fundamental, and fully justifies its construction. However experience shows that the most important scientific discoveries made by each generation of new and more powerful telescopes have been unexpected ones. Indirect benefits also emerge from the development of new technologies.

The science goals that will be addressed by GMT range over the whole of astronomy and important areas of fundamental physics, and match Australian ambitions:

- Star and planet formation
- Stellar populations and chemical evolution
- The nature of dark matter and dark energy
- The evolution of galaxies and intergalactic matter
- Black hole growth
- The first stars and galaxies

In each of these areas the GMT can make critical contributions, often in synergy with facilities working at other wavelengths or in survey domains.

The full science case is on the GMT web site at www.gmto.org/sciencecase/, but some examples follow.

Stellar populations: The enormous collecting area of the GMT will open a new window on stellar astrophysics and chemical evolution within galaxies spanning a broad range of Hubble types and evolutionary histories. The increased sensitivity compared to current 8m class telescopes will allow determinations of abundance patterns in RGB stars in Local Group galaxies and extreme metal-poor stars in Local Group dwarfs, gravities and abundances in giants beyond the Local Group and a wide range of other studies in fundamental stellar astrophysics. Diffraction-limited imaging and multi-object spectroscopy via IFUs will improve our understanding of star formation histories, and dynamical evolution in dense star clusters and other confusion-limited environments.

Galaxy evolution, black holes and first light: The GMT wide-field optical spectrograph will allow tomographic studies of the IGM and reveal the interplay between galaxy evolution, star formation and the heating and enrichment of intergalactic matter. The great sensitivity of the GMT will allow us to use faint AGN and compact galaxies as background sources, achieving much denser sampling of the IGM than is possible with current QSO based studies. Spectroscopy with the near-IR MOS will allow dynamical and chemical evolution studies of galaxies at $1 < z < 5$ with statistically valid samples, while diffraction-limited IFU spectroscopy will allow detailed dissection of individual systems. Similar techniques will allow extensions of black hole – bulge mass studies to intermediate and high redshifts, probing the era of quasar growth. The GMT high-resolution spectrographs will probe the reionization epoch using $z > 6$ AGN discovered in large-area near-IR imaging surveys. Lastly, by working at intermediate resolution in the near-IR, the GMT will complement JWST studies of first light.

Star and planet formation: Using its adaptive secondary the GMT will image massive exoplanets around nearby stars with separations between 0.5 and 5 AU. Extreme Adaptive Optics techniques in the 1-2.5micron windows will allow exoplanet and debris disk imaging via reflected light. Contrast levels in the 10^7-10^9 range should be obtainable on angular scales from 50 to 500mas. Nulling interferometry will allow thermal IR imaging of young planets in star forming regions in Taurus, Orion and other young stellar populations in the southern hemisphere. Additional techniques for exoplanet studies include transit spectroscopy, reflected light spectroscopy, proper motion studies and radial velocity reflex-motion probes of low-mass stars and brown dwarfs. Diffraction-limited imaging in the near- and mid-IR will allow the GMT to determine the initial mass function in crowded regions and to probe star formation over a wide range of physical conditions. The near-IR high-resolution spectrometer will allow detailed studies of the chemistry of protostars and young T-Tauri stars.

The GMT Opportunity

Astronomy is a world-class fundamental science in Australia, and is strongly driven by observation. If the nation is left out of the ELT era this status will inevitably be lost. With GMT, TMT and OWL having all held their conceptual design reviews the ELT era has already begun, and there are strong arguments for Australia to participate now.

Demand for ELT access will be intense in Australia in 2020, when at least two 20-30-m telescopes will exist, and we must plan for that now. A share in GMT would keep Australian astronomers at the forefront of international astronomical research for the next two decades. GMT is well matched to future Australian requirements and will do outstanding science. It is a judicious step forward based on established technologies, with less cost and risk than other ELT projects. A given Australian investment therefore buys a larger share of GMT and provides more observing time. The GMT funding model is flexible, giving Australia options for investing in the project and trading cash and in-kind contributions. The GMT consortium values Australia for both its research strength and its technological capabilities, as evidenced by the welcome extended to the ANU.

No other ELT project offers participation to Australia on terms as suitable as the GMT. By entering the project at a significant level and at an early stage, Australia can influence GMT's scientific agenda and technical direction, and maximize the benefits to astronomers and the Australian companies and institutions involved in construction. Through this cutting-edge project, Australian scientists, engineers and industries will develop and showcase valuable intellectual property and enter collaborations with international technology leaders. GMT will be a high-profile flagship facility attracting young Australians into scientific careers and bringing top researchers home from abroad. Membership of the GMT consortium would open the prestigious GMT institutions to exchanges of students and researchers.

It is a strategic objective for the optical/IR community to be "second to none" in share amongst the partners in any ELT project that Australia joins. The GMT has nine members so this is an achievable objective with a reasonably-sized share.

Based on these arguments, the ELT Working Group narrowed its focus to GMT from early 2005. Australians have served as observers on the Science Working Group, the Project Scientists' Working Group, and the Board. A consortium of interested industrial partners has focused on specifically GMT opportunities, as has fund-raising and lobbying.

The GMT Project – Background and Status

The GMT Project began as collaboration between a group of leading US educational and research institutions. The U.S. members are: the Carnegie Institution of Washington, University of Arizona, Harvard University, Smithsonian Astrophysical Observatory, Massachusetts Institute of Technology, the University of Michigan, The University of Texas at Austin, and Texas A&M University. These institutions developed, and currently operate, the two Magellan 6.5 m telescopes at Carnegie's Las Campanas Observatory in Chile. Collectively the group has a long history of building and operating forefront astronomical optical/infrared telescopes stretching back over a century. Recent projects in addition to the Magellan telescopes include the Multiple Mirror Telescope (MMT) and its conversion to a single 6.5 m primary; the Large Binocular Telescope (LBT) currently nearing completion on Mount Graham; the 10m Hobby-Eberly Telescope (HET) at McDonald Observatory; and the 10m Southern Africa Large Telescope (SALT).

The GMT telescope combines seven 8.4-metre diameter mirrors to make a telescope with 4.6 times the light-gathering power and 2.5 times the resolving power of the largest existing telescopes. The design utilizes the largest monolith mirrors that can be made today and an adaptive secondary that is an achievable extension of the technology already in use on other telescopes built by GMT consortium partners. The first of the off-axis mirrors has been cast and figuring will start soon. The Gregorian configuration and the optically adaptive secondary mirror result in a relatively wide field of view with extremely sharp imaging capabilities. The GMT structure is also designed to minimize the scattering and emission of optical and infrared light in order to achieve the lowest possible levels of background light. Using the combined figure of merit called 'light-grasp' (the product of the collecting area and field of view divided by the image size), the GMT will be 30 times more powerful than today's best telescopes.

The GMT site will probably be at Las Campanas, an established site with the outstanding image quality, dark skies and high fraction of clear nights that makes Chile an excellent location for large telescopes. The scientific opportunities afforded by locations near the Atacama Large Millimetre Array (ALMA) and other major current and proposed astronomical facilities make Chile even more attractive as a site. A southern-hemisphere site is complementary to existing and future Australian facilities.

The GMT webpage provides further information on the telescope design, enclosure, instruments and site selection – see www.gmto.org.

The GMT schedule is planned to have five main phases: Conceptual Development 2003-2005 (now complete), Design Development 2006-2009, Construction 2010-2016, Commissioning 2015- 2016 and Operations from 2016 onward. Partners sign up for one phase of the project at a time. Although the expectation is that partners will continue through to the end of the project in order to realize the full benefits, signing up for any one phase is not a formal commitment to subsequent phases.

The GMT partners have already funded the Conceptual Design Phase of the telescope. An international panel examined this design over three days in February 2006, and approval was given for the project to proceed to the Design Development Phase. Even before this, the partners had cast the first of the off-axis 8-m mirrors, regarded as one of the highest technical risk items in the project.

Partner Rights and Access

The rights of a partner investing in the GMT include partial ownership of the telescope and guaranteed observing access proportional to the investment made. Partners also are able to nominate a member of the GMT Board of Directors. The precise terms of partnership for the Design Development, Construction and Commissioning Phases are being negotiated now by the foundation partners as part of the legal agreement that will establish the GMT Corporation. It is expected that this document, which should be finalized before the end of 2006, will reward early investment. Consideration will be given to institutions that do not wish to become partners, but rather participants, by contributing only to operational costs.

Access to the GMT will depend on the level of a partner's contribution. Each partner will allocate its share as it sees fit: in Australia, via the usual ATAC telescope time allocation procedures. All Australian astronomers would have access to the GMT based on the scientific merit of their observing proposals.

NCRIS Proposal

This is a proposal to allocate NCRIS funds so Australia can join the GMT Design Development Phase.

The ANU has become a foundation partner by paying the entry fee into the GMT project. It expects to help shape and eventually sign the agreement that will form the GMT Corporation and set conditions for partnership in the Design Development Phase. The current expectation is that partners will each agree, upon signing this agreement, to use best efforts to raise between 5% and 10% of the funding for the DDP, which is currently expected to cost US$ 56M. This means that the ANU will commit to raising its share from sources other than NCRIS.

A high benefit-to-cost option for Australia would be to leverage the investment already made by ANU by adding NCRIS funding to that raised by ANU to form a single Australian partner share in the DDP. In this way, two membership fees would not need to be paid, the early investment benefits in partner share would be realized, and Australia would be able to exert considerable influence on the design and science of the GMT and its instruments.

A 5% Australian open-access GMT share in the DDP from NCRIS, if combined with the ANU entry fee, would cost approximately $3.8M. In addition, $200K per annum would be needed to support an Australian Project Office (see below).

Joining the GMT at this stage will have the following benefits:

1) As an early joiner, Australia will have the maximum opportunity to influence designs and specifications to suit scientific needs.
2) Both the industrial and academic sectors should capture high-value and high-status work, and have the best opportunities both for training and for international exposure and synergy.
3) The nation will be positioned to join the construction phase of a telescope that meets its needs and where its industries can compete for major international contracts.
4) A generation of young astronomers will have been developing their science in an environment where an ELT is a present reality, enhancing their international awareness and competitiveness.
5) In outreach, a demanding and exciting technology project with full Australian participation will be a strong selling point to encourage more students in the sciences and engineering.
6) Joining early means that costs are spread out; late joiners will face a substantial one-off entry fee.

Canada has made a success of its membership of TMT, both by winning major industrial contracts and by taking scientific and technical leadership in several areas of the project. This shows what can be done by joining early, and shows what can be lost by delay. See http://hia-iha.nrc-cnrc.gc.ca/atrgv/tmt_e.html for details of Canada's achievements.

Cost Summary

Project Phase	Total Cost USD	Cost of share AUD	Notes
Preliminary Phase			Fully funded and winding down now with successful CoDR.
Joining Design Development Phase	--	--	Membership fee paid by ANU.
Design Development Phase	56M$	3.8M$	At 5% share and exchange rate 1.3; requested from NCRIS
Australian Project Office	--	800K$	Will not count towards share in GMT; requested from NCRIS
Construction Phase	Approx 550M$	Approx 110M$	Indicative 15% share, domestic costs included; subject of Landmark bid around 2008-9
Operations phase	Approx 20M$	Approx 4M$	Indicative 15% share

Risks and Risk Reduction

The risks of participating in the GMT DDP are:

1) The GMT project is unable to raise the funds for the construction or indeed the design phase.
2) Australia joins the design phase but is unable to raise the money to join the construction phase.
3) The design or construction phase encounter insuperable technical problems, or management control is lost and the costs or timescales blow out of control.
4) The GMT project merges with another ELT project, as a result of US or international political or funding considerations.

The essence of the risk in (1) to (3) is that Australian astronomers do not get a telescope, despite investing a significant fraction of the funds available. In the case of (2), the share could be on-sold. In the case of (4) that investment would presumably be intact, but would correspond to reduced access.

The U.S. institutions involved in GMT are some of the richest in the country and have a good track record. The project methodology aims to develop technically risky areas to the review stage as soon as possible, rather than marching the whole schedule forward in a 'success-oriented' way. The risky areas are primarily optics fabrication, sensing and control within the active telescope, detectors, and the management of an extremely complex project.

The risk reduction strategy for Australia is twofold. One part is vigorous involvement in the project, and deployment of strong Australian expertise. Control engineering and project management are examples of such expertise. The other part is to ensure that Australia benefits in a continuous way throughout the DDP. Aspects would include ensuring a steady flow of work back to Australian industry and academia, maximizing synergy and IP generation amongst Australian participants, and capitalizing on the opportunities for outreach and student training in partnership with some of the strongest research and educational institutions in the US. This set of tasks will require a strong Australian Project Office, charged with ensuring that the GMT project is a success for Australia year on year. This proactive, outcomes-oriented approach will also increase the likelihood of a successful bid for Federal funds to support ‘Landmark’ status and the construction phase.

Although substantial overall national benefit can be secured even if the project stops or Australian participation ceases, there is no doubt that astronomy as a discipline in Australia is exposed to a risk. In the DDP the flow-back to astronomy specifically (as opposed to Australia as a whole) will not be in proportion to the investment. The benefit of the investment, in the form of purely astronomical research, comes later.

Australian GMT Project Office

A strong project office will be needed in Australia to manage risks effectively, and secure the maximum national benefit over the Design Development Phase. The Australian GMT Project Office would be responsible for

1. Communicating Australian science, governance and technical priorities to the GMT Project Office in Pasadena.
2. Disseminating information from the GMT Project Office, including tender documents and calls for instrument proposals, to Australian stakeholders (interested academic and research institutions, industry and government).
3. Acting as an advocate for Australia in publicizing the nation’s capability to contribute to the design and construction of GMT.
4. Acting as the facilitator for putting together strong consortia that can secure high-value contracts and reap maximum Australian advantage from partnership.
5. Providing a technical focus for review of GMT specifications and progress.
6. Publicizing the GMT within Australia and organizing appropriate outreach.

The estimated cost is based on 1.5 FTE, office, computing and travel costs.

Governance

The GMT Partnership Agreement will be concluded by the start of the design phase. This Agreement will establish the non-profit corporation that will own the GMT facility and be responsible for completing the design, constructing the observatory, and operating it for the benefit of the partners. The Agreement will define the overall governance of the project and, among other things, specify:

1) the scope of the project;
2) the organizational and administrative structure;
3) the responsibilities and duties of Officers, key appointees and the Science Advisory Committee;
4) the funding and budgeting process during construction and operations;
5) how contributions to the capital and operations cost of the project translate into project shares and time on the telescope; and
6) how instruments are to be provided.

Governance principles will need to be developed, defining the way in which NCRIS monies for the Australian Project Office will be used, and how NCRIS investment in the DDP will translate into Australian share of the GMT.

Beyond the Design Phase

Looking ahead, it is clear that an enterprise the size of GMT construction cannot be afforded from normal continuing funds. The NCRIS committee recognized this by awarding GMT participation ‘Landmark’ status. A special bid to the Federal government will have to be prepared during the middle years of the DDP, including a detailed business case that is informed in detail by the experience during the DDP.

Since construction will start in early 2010 on the present schedule, a Landmark bid will have to be prepared to enter the FY2009-10 budget cycle. This bid would need to be ready by late 2008. For an indicative 15% share, the bid would be for roughly $110M, spread over 8-10 years.

The current estimate of the cost of the Operations Phase is US$20M per year, or about $4M per year for a 15% Australian share. This is an affordable sum if we assume that the NCRIS level of funding for the astronomy capability indicates how much may be expected from the taxpayer in the long term.