Canada and the Thirty Meter Telescope Project

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The choice of Canadians to join with Caltech, the University of California and AURA (the Association of Universities for Research in Astronomy – the US astronomy consortium) to create the Thirty Meter Telescope (TMT) Project is based on our direct, and to various degrees ongoing, engagement with all extremely large telescope (ELT) projects. The TMT is the leading project, unique in having three published preliminary studies and successfully having raised US$63M to undertake joint detailed design prior to construction. TMT is well matched to Canadian interests, and technically and financially positioned to achieve the scientific impact and other benefits to Canada that a project of this magnitude demands. The Canadian project continues to emphasize a strategy that will give us flexibility as we rapidly move toward the construction start in 2009.

Overview of TMT origins

The Canadian Large Optical Telescope Project is a major element of the Long Range Plan (LRP) for Astronomy in Canada. The scientific excitement of diffraction limited (nearly "space quality" images) ELTs became quickly apparent in the late 1990's with the discovery of extra-solar planets, dark energy, and the many aspects of formation of planets, stars and galaxies that were beyond the reach of any existing telescope. At the same time the technical and financial feasibility of ELTs became apparent with technical breakthroughs in Adaptive Optics and the success of the segmented-mirror W. M. Keck telescope, built by Caltech and the University of California.

An importance piece of Canadian context results from the early 1980's 8m telescope era. At that time the absence of a clear overall Canadian national astronomy plan and a fragmented Canadian funding system lead to slow engagement in these telescopes. The outcome has been diminished scientific and economic benefits at no real cost saving. The Long Range Plan for Astronomy, developed in 1999 and reviewed and updated in 2004, now provides a powerful and balanced plan which urges full Canadian engagement in ELTs from the outset. The ongoing success of our current TMT engagement has been the result of the adoption of this strategy and the timely arrival of financial support from Canadian funding agencies and international partners.

The Canadian Large Optical Telescope project began in 2000, supported by an NSERC International Opportunities Fund (IOF) grant and internal funds within NRC-HIA. Canadian scientists and engineers participated in a series of meetings with all the major telescope organizations in North America, Europe and contacts with Australia and various Asian nations. In 1999 the current Canada-France-Hawai Telescope (CFHT) partners undertook a set of design studies to consider ways of renewing that facility. However, the costs were beyond the CFHT partnership alone. In about 2000 North American groups and European groups firmed up their different technical approaches. The primary mirrors of all next generation telescopes will be "segmented", that is, created by carefully aligning many smaller, relatively low cost, mirrors. The Europeans argued that it was possible to step from the existing 8-10m telescopes to a telescope as large as a 100m. North Americans were interested in eventually building a 100m class telescope, but believed that a 30m class telescope was a necessary step to reduce risk and costs. The requirement to provide near “space quality” (i.e. images limited only by the fundamental physics of the diffraction of light waves) is an exceptional technical challenge for existing telescopes, and doubly so for a segmented mirror ELT.

Caltech and UC initiated a design study, the California ELT (CELT) in 2000. At about the same time AURA began to look at the value of a 30m “MAXAT” which evolved into the Giant Segmented Mirror Telescope concept, GSMT. Canada initiated the Very Large Optical Telescope project, VLOT, primarily using LRP support through NRC-HIA. Each of these groups spent $2-3M exploring technical, scientific and partnership options. The groups independently reached similar solutions.

Canadians had a series of informal discussions with the CELT partners in 2002, which was then presented as the preferred partnership in the Canada Foundation for Innovation (CFI) proposal of May 2003 and more formally in the October 2003 face-to-face CFI review with a delegation co-lead by Presidents Birgenau (Toronto) and Piper (UBC). The CFI proposal requested $125M to support the design and first construction phases of Canada’s participation in an expanded CELT partnership. The proposal was submitted May 29, 2003 through the University of Toronto as the CFI host institution for the fifteen supporting universities of ACURA, The Association of Canadian Universities for Research in Astronomy. ACURA signed a letter of intent with Caltech and the University of California, in parallel with a similar letter from AURA, to undertake a joint detailed design of a telescope as a first step toward construction and operation. These letters were signed on June 11, 2003, thereby initiating the Thirty Meter Telescope (TMT) project.

Deciding Factors for TMT

The reasons for selecting the TMT project over other possibilities were compelling and continue to gain force. The depth of our knowledge of other projects is illustrated by the invitation to the TMT Canada Project Director to review the status of all projects at IAU Symposium 232, *The Scientific Requirements for Extremely Large Telescopes,* held in Cape Town, 14-18 November 2005 and the active participation of the HIA Director General in an ongoing series of international astronomy funding agency discussions on major astronomy facilities.

The **Scientific Alignment** of the TMT partnership with the goals of the Canadian astronomical research community is very strong. There is complete agreement to the focus on major problems in cosmology and the formation of galaxies, stars and planets and the resulting scientific capability requirements. Major telescopes continue to be multi-purpose facilities which will support an evolving set of scientific programs and instrumentation over their lifetimes. Decisions made at the outset of the project will emphasize some capabilities over others—it is important to Canadian scientists that areas that we judge to be important are realized within the design. Since the scientific capability of a diffraction limited telescope rises as the diameter of the primary mirror to the forth power, the larger the mirror the better. However, the risks and costs rise with aperture as well. The choice of approximately 30m was established in independent preliminary studies to be a project “sweet spot”: 30m is large enough to address the pressing scientific questions motivating the construction of new, large telescope and, while extremely challenging, is deemed to be within current technological capabilities.

A newly powerful cost-benefit argument for “big is better” is that for diffraction limited images, the science return per unit time is proportional to the primary mirror diameter, D, to the fourth power, rather than D^2 as for “natural seeing” telescopes. Costs have traditionally scaled approximately as $D^{2.7}$. Therefore the cost-benefit equation now clearly encourages building as big as possible to maximize the scientific return on the investment. In addition, there are significant costs of site, management and operation that do not strongly depend on aperture, so are more diluted in a larger telescope. A number of aspects of the system complexity grow as D^4, which increases the risk to performance or timely delivery. The realisation that diffraction limited imaging is attainable on an ELT, at a cost that is within the reach of more than one existing major telescope organizations, has made construction inevitable.

The **Timeliness** of a 30m class telescope as the centerpiece of the Canadian astronomical facilities strategy meshes will with the arrival of Canadian access to the Atacama Large Millimeter Array (ALMA) and the James Webb Space Telescope (JWST) in about 2012. Current 8m class telescopes cannot reach the fainter sources already visible in pre-cursor mm-wave and space telescopes. The TMT plans to be operational in 2015 to reap the scientific benefits of being the first next-generation optical instrument with the needed sensitivity and scientific scope. In TMT we are building on the heritage of the Keck telescopes (the only fully operational segmented mirror telescopes, and ones in which Canadian industry played a role) and the Gemini telescopes, in which Canada is a partner.

Technical Readiness is currently being firmly established through a US$63M detailed design study. The work includes the most extensive site testing ever undertaken, novel wind flow modelling, new structural designs, new techniques for optics and instrumentation studies. The project will have a full conceptual design and a cost capped project price (with options for descopes and enhancements) in the fall of 2006.

Canadian industry is actively involved in the telescope and instrument design and is positioned to play a critical role in the construction of the telescope. Canadians have expertise in the design and construction of large telescope domes, as well as in optical instrumentation and other technologies critical to the success of the TMT. The TMT provides Canadian industry with an opportunity to maintain its leadership and retain critical technical expertise on-shore. The project has already served to generate a prominent profile for Canadian technology in other ELT projects and their suppliers around the world . Canada’s role in the TMT project is structured to capture maximum economic benefit to Canada. This is a position that would be difficult to capture in other ELT projects, and arises from early and close cooperation between the scientific community and the private sector on the TMT project.

The **route to future telescopes** larger than 8m in aperture is universally understood to require the development of a primary mirror composed of segments consisting of anywhere from 1m to 6m in size. TMT is the sole project using small aspheric segments. A proposed 20m class project, the Giant Magellan Telescope (GMT), is based on 8m disks with substantial gaps between them. Our own studies found that the GMT configuration would lead to scientific compromises and would likely be more expensive (based on estimates from a commissioned study by the French optical firm, SAGEM). The European OWL project proposes to use small spherical segments similar to those envisioned for the TMT. The resulting spherical mirror then demands a massive corrector system (of order in size of an 8m telescope) to give useful images.

Financial Feasibility: Although challenging, the combined resources of the TMT partners are considered sufficient to build and operate the telescope. The Gordon and Betty Moore Foundation in California has provided an initial grant of US$35M to the Caltech and UC partners in TMT and is expected to be a key supporter in the construction phase. Caltech and UC operate the W. M. Keck Observatory, with its two co-located 10m telescopes in Hawaii, and Canada and AURA currently operate the two 8m telescopes of the Gemini Observatory, one in Chile and the other in Hawaii. Based on this experience, it is reasonable to assume that the operating costs for such large facilities, including ongoing scientific renewal, is about 10% of the initial capital costs. Our 25% share of TMT is thus estimated to require an annual contribution of about $25M. This is a factor of three greater than the projected annual cost to Canada of supporting its 15% interest in Gemini; however, the TMT will offer Canadian astronomers a scientific gain of a factor of between 11 and 75, depending on the instruments used. To put this into a broader perspective, the present annualized expenditure on ground-based astronomy in Canada is about $40M. The assumption of TMT operating costs a decade from now will increase this total to about $55M to $60M (in current dollars). This is viewed as a modest increment for the scientific return to what is seen as one of Canada's strongest scientific communities and, as documented in the LRP Report, would still leave Canada well below the *per capita* expenditures on astronomy of our sister G8 nations.

Competitive Position: The two main competing projects are the European ELT effort and the GMT. Neither of them has yet raised the same amount of money or has undertaken the same level of technical evaluation as has TMT. Both of those projects are in the position of reacting to the leadership position that TMT has established.

The European ELT project is aimed at a 60m-100m ground-based optical telescope. This is a factor of 6 to 10 larger than the largest of the current generation of telescopes and is obviously an ambitious attempt to break the historical pattern, extending over more than century, whereby optical telescopes grow by approximately factors of two in aperture with successive generations. The TMT will be the first telescope designed to operate in the diffraction limit from the outset. The diffraction limit requires greater precision with greater aperture imposing considerable technical challenges. The costs of non-diffraction limited telescopes have empirically been found to scale roughly as the $D^{2.7}$ "Meinel Law". Using a cost of about US$200M for an 8m telescope with a retrofitted adaptic optics system (AO) (from VLT and Gemini costs), a 30m telescope would then cost US7000M. Enough work has been done that the TMT Board has confidence, based on extensive technical study, that a 30m class telescope can be built for US$700M or less (formally US500M with a reserve of US$200M). The “scale-breaking” cost savings result from lessons learned from the 8m telescopes and ongoing developments in optics, electronics and computerization.

Canadian scientists continue to interact with their European colleagues and we intend to follow the 60+m ELT developments. It is our belief that to realize an ELT project of this scope will necessarily require a pooling of all international resources, perhaps within a framework not unlike that of ALMA. We concur that an ELT is a future step for ground-based optical astronomy, but we also believe that it is very far beyond the present scientific and technical horizon.

The GMT is a competing project based at the Carnegie Observatories in Pasadena. The partners in that project are US universities and allied institutions. The principle partners presently operate the twin 6.5m Magellan telescopes in Chile and the 6.5m MMT in Arizona. The partners are Carnegie Observatories, Harvard University, SAO, MIT, Texas, Texas A&M, Michigan and the University of Arizona. Arizona runs the Mirror Lab (now in a new arrangement) which has proposed to make the GMT mirrors. The GMT concept is to provide a partially filled aperture consisting of 7 large 8m discs and arranged on a common, steerable mount. The effective aperture of the GMT is approximately 22m. The GMT group is undertaking design studies largely using existing staff, as compared to TMT’s separate project office with its own staff. In a bold move, GMT is casting a demonstration 8m off-axis aspheric mirror. At an early stage, the Canadian LOT project worked together with Harvard and Carnegie in a precursor to GMT. Although our design studies concluded that a 20m telescope was scientifically acceptable, the ~50% filled GMT large-disk aperture would produce inferior images compared to a mirror filled with small hexagonal segments and that all available information pointed to significantly higher costs for the large disks. The Canadian LOT Steering Committee has accepted the argument that a 25% share of a 30m was more scientifically useful than a 40% share of a 20m. Moreover, in 2001 the partnership arrangement that GMT offered was not suitable, as Canada would have been restricted to one of six equal shares. Although we wish the GMT all possible success and believe it can meet the ambitions of its members, the GMT project, as presently constituted, would not be suitable for Canadian participation.

Summary

The conclusion is very clear. The TMT project started first, is technically the most advanced, is the best funded, is on the path to future telescopes and has a partnership of public and private well matched to Canadian interests. Canada is extraordinarily well positioned as a leader through its partnership position in TMT. Canada last took such a strong position about 40 years ago for the project that produced CFHT. The benefits to Canada of that strong position will span our scientific, educational, industrial and economic interests.