2 GMT OVERVIEW

2.1 Introduction

The GMT Consortium has begun to design and build the first of the next generation, extremely large telescopes. The GMT is based firmly on the heritage of the highly successful Magellan telescopes, which, thanks to their superb site and excellent design, routinely produce the sharpest images of the current generation of ground-based large telescopes. The GMT will continue in this tradition, and will offer sharp images over wide fields in natural seeing, and with seeing enhanced by ground layer adaptive optics. In addition, the GMT will routinely produce diffraction-limited images with powerful adaptive optics systems designed into the telescope. The GMT will be a powerful tool for addressing the key astrophysical problems of its era, beginning in approximately a decade.

Our goal in this document is to lay out a technical description of the GMT and our performance goals for the telescope, its instruments, adaptive optics system, and support facilities at a conceptual design level. We hope that we have captured some of the excitement and inspiration that we have felt working together on the GMT Project as well as presenting a comprehensive technical discussion.

2.2 GMT Consortium

The GMT Consortium has formed around a nucleus of the Partners in the highly successful Magellan Project. The twin Magellan Baade and Clay 6.5 meter telescopes, located at Las Campanas in Chile, have a well-deserved reputation for superb image quality, successful innovation, cooperative decision making, and cost-effective operations. The GMT Consortium has the goal of carrying this successful Magellan model into the era of extremely large telescopes.

There are five Magellan Partners: the Observatories of the Carnegie Institution of Washington, Harvard University, the Massachusetts Institute of Technology, the University of Michigan, and the University of Arizona. For the GMT Consortium, these institutions have been joined by the Smithsonian Institution, Texas A&M University, The Australian National University and The University of Texas at Austin. Harvard University and the Smithsonian Astrophysical Observatory (SAO) are partners in the Center for Astrophysics, and SAO and the University of Arizona jointly operate the 6.5 meter MMT Observatory. The University of Texas operates McDonald Observatory and jointly operates the 9.2 meter Hobby-Eberly Telescope. The Australian National University operates the Mt. Stromlo and Siding Spring Observatories. The GMT Consortium will consider the addition of other institutions to the GMT Project subject to the review of the GMT Board.

Collectively, the institutions in the GMT Consortium support an impressive breadth of astrophysical research and draw upon front-rank scientific and engineering talent with considerable experience in the design of large astronomical telescopes, adaptive optics systems, and instruments.

2.3 GMT Heritage

As the current generation of very large telescopes (6.5 to 10 meter) has shown, there is more than one way to build a large telescope. About the only feature that is common to this generation of telescopes is an alt-azimuth mount. As we approach the design of extremely large telescopes (ELTs) we can add an additional point of agreement: no one wishes to tackle the casting and transportation of a 20+ meter diameter primary mirror. All agree that ELTs will use segmented primary mirrors. The choice of primary mirror segment size becomes a key design issue.

More than one astronomer has suggested that choosing a segment size is a straightforward cost-minimization problem. Designers of large telescopes recognize the imperative of minimizing costs while maintaining excellent optical performance. However, it is very difficult to determine a true cost minimum along the segment size curve. As the primary segment size grows from one to eight meters, there are discontinuous changes in the technologies available to cast, polish, and support the segments. It is one thing to understand in principle how to address a technical problem and another to understand exactly how long the solution will take and how much it will cost.

The uncertainty about the schedule, cost, and technical performance associated with primary segment size has led us to look for approaches to designing an ELT that draw upon the collective experience of the GMT Consortium. Our experience has been with casting, polishing, and supporting large, structured, borosilicate mirrors. This type of primary mirror has been used for the 6.5 meter converted MMT, the 6.5 meter Baade and Clay Telescopes, and the twin 8.4 meter LBT.

The MMT and Magellan Telescopes have now been in operation for several years and the design goals for the large borosilicate mirrors have been achieved in many seasons of observing. These telescopes produce superb images that are limited by atmospheric seeing, and not by the telescope optics. The thin sections of the large borosilicate mirrors and forced air cooling allow these mirrors to rapidly equilibrate with the surrounding air.

In addition to dozens of person-years of experience with operating telescopes with large borosilicate mirrors, we have the benefit of several generations of design development in many key technical areas. The Steward Observatory Mirror Laboratory (SOML) has cast four 6.5 meter mirrors, and three 8.4 meter mirrors (including the first GMT off-axis segment), with no failures. In continuous production with the equipment already in place, the SOML is able to produce one polished 8.4 meter mirror per year, a rate sufficient for the GMT schedule. This successful experience and powerful infrastructure lies behind our decision to use 8.4 meter segments for GMT.

2.4 GMT Science Case, Science Requirements, and Instruments

We have engaged in building GMT because observations enabled by its huge collecting area and by images ten times sharper than Hubble Space Telescope will significantly advance our understanding of the Universe. The GMT Science Working Group has explored open issues in five key areas of astrophysics, and has described the considerable impact that GMT is expected to make. These areas of research are: (1) the nature of dark matter and dark energy, (2) the first stars and galaxies, (3) star and planet formation throughout cosmic time, (4) the evolution of galaxies and their stellar populations, and (5) the growth of black holes. The most recent National Research Council Decadal Survey identified a very similar set of high priority research themes, and endorsed the construction of an extremely large telescope like GMT. Many of these same themes also appear in the Department of Energy/National Science Foundation/NASA report "Connecting Quarks with the Cosmos."

The GMT Science Working Group (SWG), following their review of scientific priorities for GMT, has set forth specific goals for GMT's performance and has defined a suite of candidate first-light instruments capable of making the critical observations. The SWG describes six instruments, three and a half of which operate at the seeing limit; the remaining two and half require adaptive optics (AO). The seeing-limited instruments include a wide-field optical spectrograph, a wide-field infrared (0.9-2.5 μm) imaging spectrograph, a high-dispersion optical spectrograph, and the 1.1-2.4 μm module of the high-dispersion infrared spectrograph. The AO-fed instruments include a high-resolution near-infrared (0.9-2.5 μm) imager, a 2-35 μm imaging spectrograph, and the 3-5 μm module of the high-dispersion infrared spectrograph.

Figure 2-1 is a simulation demonstrating the power of GMT with adaptive optics.

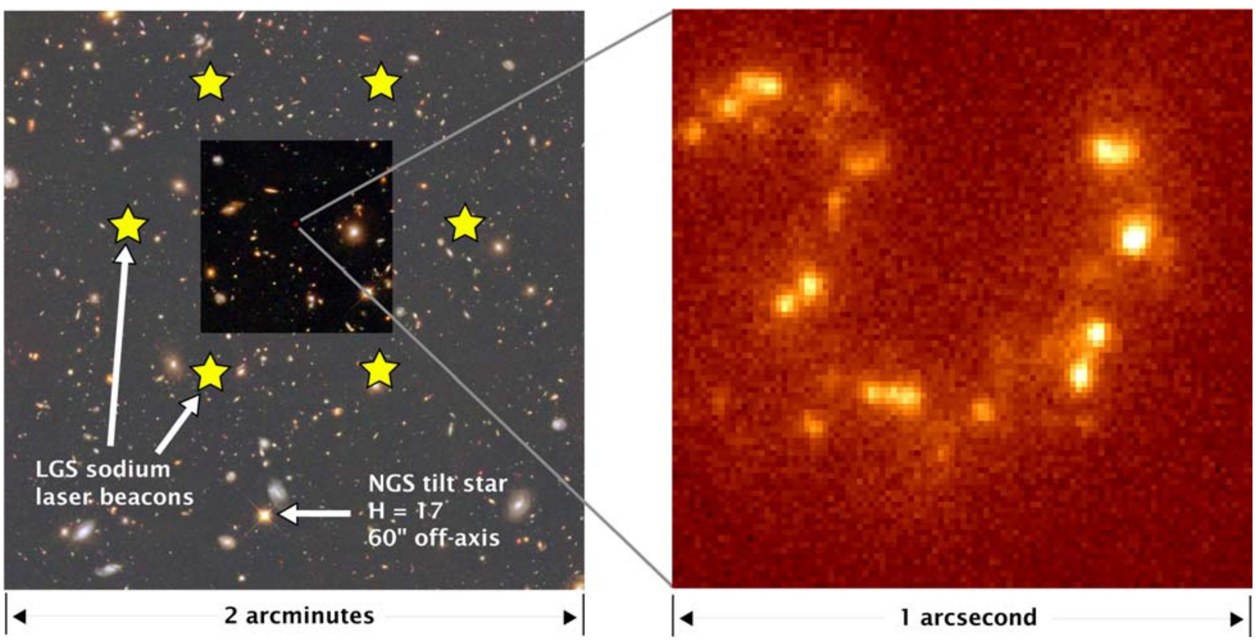

Figure 2-1. **(***Right***)** A simulated one hour GMT image of a starburst galaxy at z = 1.4, demonstrating the GMT's 0.016″ H band resolution with adaptive optics, ten times the resolution of HST. This simulation is based on an Hα image of NGC 3089 at a detector plate scale of 0.010″ per pixel. This narrow band image is centered at the redshifted Hα wavelength of 1.58 μm. (*Left*) The full field of the GMT AO imager is 40″ across, with an area 1600 times larger than the detail to the right. The positions of the constellation of laser guide star (LGS) beacons and the natural guide star (NGS) used to recover tip-tilt information are indicated.

2.5 Technical Overview

2.5.1 Primary Segments and Optics

GMT is designed around the primary mirror segments that SOML can produce. As shown in Figure 2-2, GMT uses a single on-axis segment surrounded by six identical off-axis segments. The primary mirror array spans just over 25 meters at its widest point, and GMT will have an effective collecting area of ~380 m^2. With a Gregorian secondary producing a final focal ratio of f/8, GMT will have a focal plane scale of 1 mm $arcsec^{-1}$.

GMT is designed from the outset around adaptive optics (AO) with the goal of producing diffraction limited images at 1 μm and longer wavelengths. The segmented deformable secondary mirror, based on the adaptive secondary mirror pioneered at the MMT, will be the first element in all GMT AO systems. GMT will use aplanatic Gregorian optics, analogous to Ritchey-Chretien optics in a Cassegrain telescope.

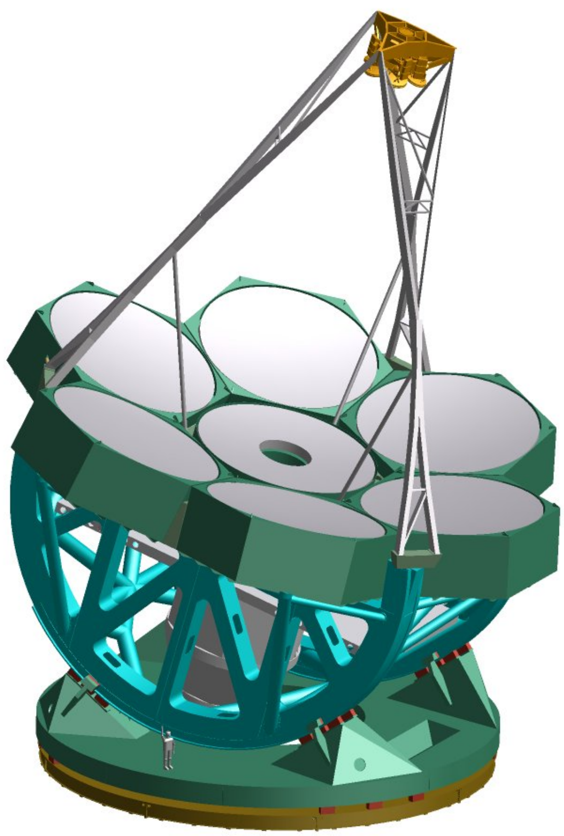

Figure 2-2. CAD model of the GMT. The seven primary mirrors are part of a single parent surface.

The stressed lap technology developed at the SOML allows us to consider extremely fast and aspheric primary segments, an important consideration in designing a compact and stiff structure. As telescopes become larger and larger, their lowest resonant frequencies drop, rendering them increasingly vulnerable to wind disturbance. Since we are aiming at diffraction limited performance, designing a high-performance structure is imperative. GMT's primary focal ratio of ~f/0.7 breaks new ground for a large optical telescope. This fast focal ratio is possible with existing technology because the stressed lap is capable of bending sufficiently to polish the off-axis segments.

The major new challenge is testing GMT's six aspheric, off-axis segments during polishing. Any ELT using a segmented, aspheric primary requires precise optical tests of the figure of off-axis segments. The GMT design has the advantage of requiring only a single optical test for all six off-axis segments, rather than the dozens of different tests required with small segments. Nonetheless, the GMT Project is intent upon reducing the technical risk still further by casting (now complete, see Figure 2-3) and polishing a complete off-axis segment very early in the project.

Figure 2-3. The first 8.4 m off-axis primary mirror blank for GMT in the Steward Observatory Mirror Laboratory.

2.5.2 Instrument Accommodations

GMT offers two types of instrument mounting as shown in Figure 2-4. Smaller instruments can be placed on a rotating instrument platform, and fed with a fold mirror. These instruments are always available for rapid deployment. The initial suite of adaptive optics instruments will be placed on this platform, with the exception of a ground layer adaptive optics-fed near-IR spectrograph. Placing mid-IR instruments and a feed for a high resolution optical spectrograph on this platform will allow flexible scheduling to respond to current observing conditions.

Larger instruments are placed at the direct Gregorian focus. Instruments weighing 25 tons with diameters exceeding six meters can be accommodated at the direct Gregorian focus. We describe wide-field optical and near IR spectrographs that would be mounted at the direct focus.

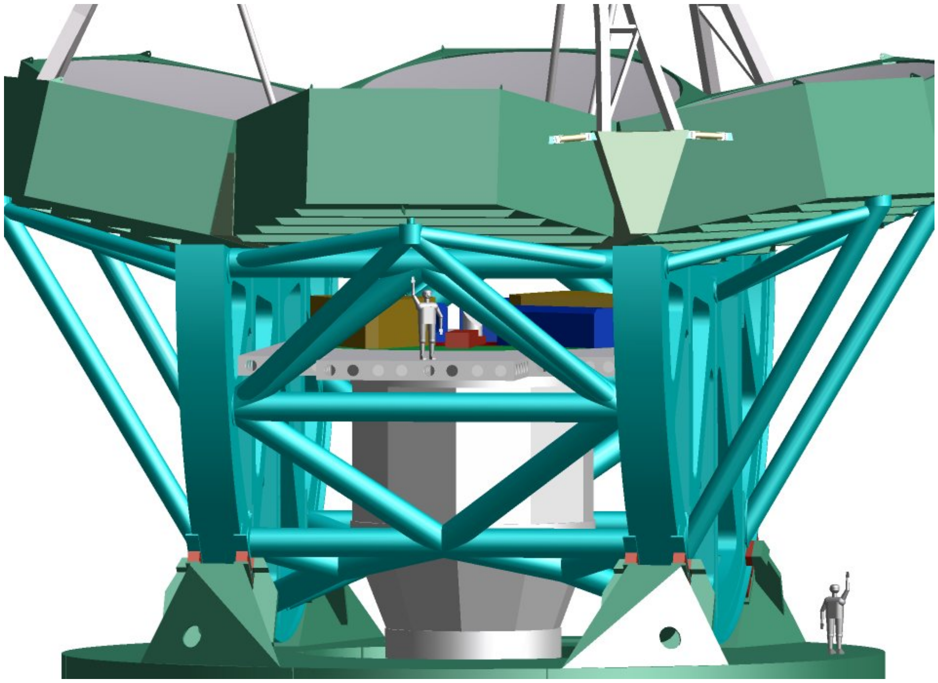

Figure 2-4. A view of the GMT from the side. The rotating instrument platform houses adaptive optics wavefront sensors and smaller instruments, including those fed by adaptive optics. A large instrument at the straight Gregorian focus is also shown.

2.5.3 GMT Operating Modes

The baseline GMT is designed to allow five observing modes, two in natural seeing and three with adaptive optics. In natural seeing, the GMT's aplanatic Gregorian design provides a field of view 8′ in diameter with (geometric) image aberrations less than 0.1″ RMS diameter. With a refractive corrector/ADC, a field of view 20′ in diameter with (geometric) image aberrations less than 0.1″ RMS diameter is available at wavelengths shorter than 1 μm.

Three adaptive optics operating modes are planned for the baseline GMT, all using the adaptive secondary mirror to provide the wavefront correction. The adaptive optics wavefront sensors are mounted on the GMT's instrument platform and can be used with any instrument mounted at the appropriate location. The three baseline adaptive optics modes are:

(1) Ground layer adaptive correction for wavelengths between 0.9 and 2.5 μm, covering an 8′ diameter field of view at the direct Gregorian focus;

(2) Laser tomography adaptive optics providing high Strehl correction across a 1′ to 4′ diameter field of view at wavelengths between 0.9 and 25 μm, and with excellent sky coverage, at the folded Gregorian focus on the instrument platform;

(3) Extreme contrast adaptive optics optimized for the detection of planetary disks and young, hot planets at wavelengths between 1 and 5 μm, provided by specialized wavefront sensors in dedicated instruments mounted on the instrument platform.

2.5.4 GMT Enclosure

The highest point of the approximately cylindrical GMT enclosure is 65 meters above ground level. The rotating portion of the enclosure is 50 meters high and 55 meters in diameter. The telescope rotates independently from the enclosure, and is able to rotate 360º inside the enclosure without interference. The rotating portion of the enclosure is mounted on a base structure about 15 meters tall. A set of horizontal shutters at the top of the rotating portion of the enclosure and a set of vertical shutters along its face are opened to allow access to the sky. The shutter openings can be controlled to minimize wind loads during high winds. A series of windows distributed over the rotating portion of the enclosure can be opened to increase ventilation. A large overhead crane at the top of the rotating portion of the enclosure is available for telescope construction and maintenance. The enclosure is shown in Figure 2-5.

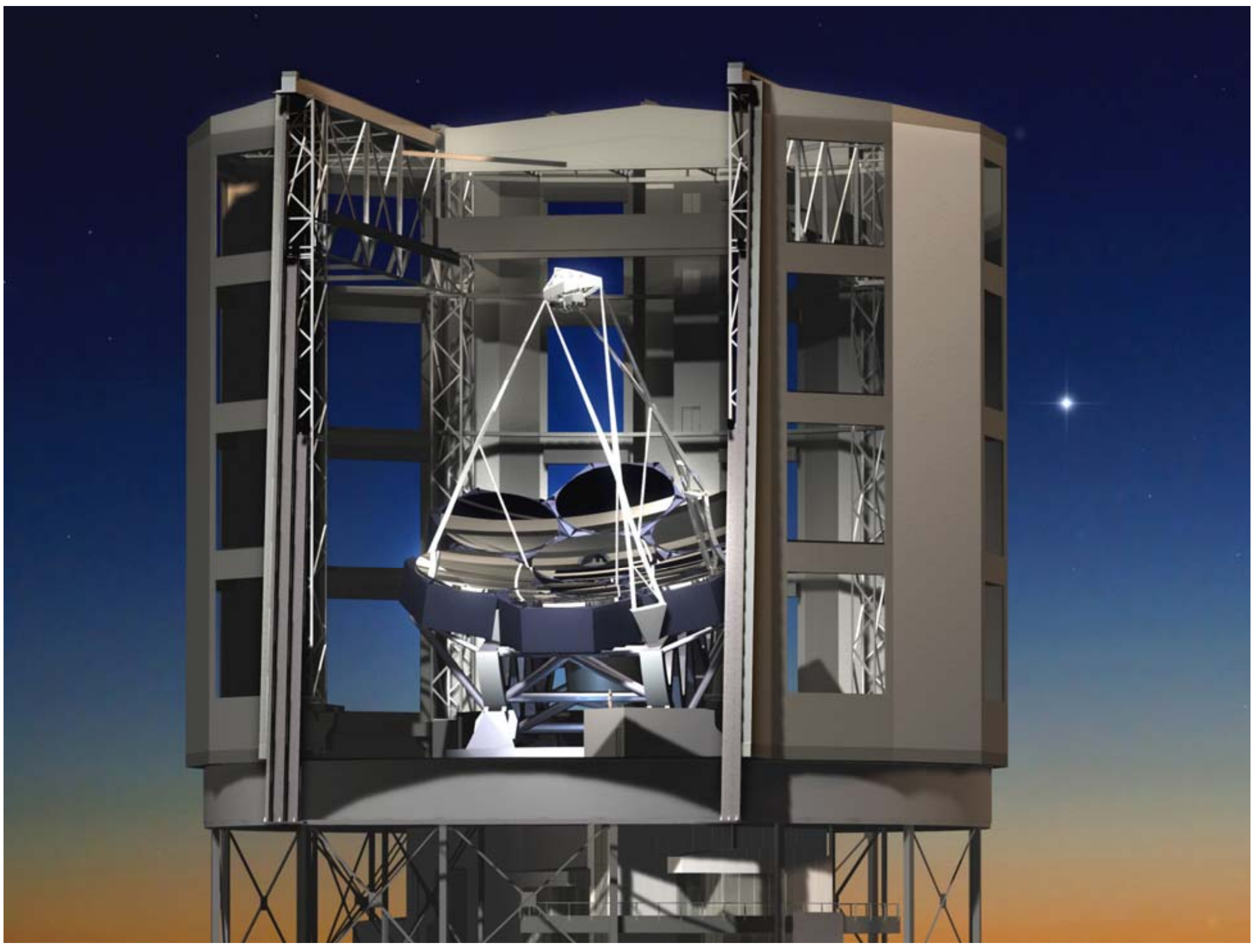

Figure 2-5. An artist's rendering of GMT in its enclosure. The front shutters have been removed to allow a clearer view of the GMT.

Large Gregorian instruments not in use are stored in a separate building approximately 40 meters from the GMT enclosure. A set of rails carry instrument and mirror cell transportation vehicles between the enclosure and facilities building. The instrument and mirror cell transportation vehicles protect the instruments and mirrors from inclement weather. A staging area for instruments is provided at the base of the enclosure. A large instrument lift mounted in the center of the telescope pier lifts instruments to the direct Gregorian focus for mounting. The instrument lift is also used to move the central primary mirror in its cell between the observing floor and the base of the enclosure. The off-axis primary mirrors are removed from the telescope and lowered through a hatch with the overhead crane. Aluminizing equipment is located in the facilities building.

A control room, observer facilities, and equipment rooms are provided in the non-rotating base of the GMT enclosure.

2.6 Site Selection

The GMT Consortium is fortunate to have access to a superb developed site in the southern hemisphere: Las Campanas Observatory. The internal GMT site selection effort is currently concentrating on characterizing several possible GMT sites on the Las Campanas property. The principal shortcoming of Las Campanas is that its altitude (~2500 m) is too low to achieve very low background and very high transparency at wavelengths longer than 3 μm. We have begun a program to monitor the precipitable water vapor above Las Campanas for at least two years. It may be possible to meet the GMT Consortium's needs by scheduling mid-infrared observations during dry periods. If not, GMT will consider higher altitude, dryer sites. A promising Chilean site at ~4500 m is currently being tested by the NOAO New Initiatives Office.

The GMT Consortium would like to choose a site for GMT that would allow expansion to a second GMT if additional partners come forward. The original Magellan Project grew to include a second 6.5 meter telescope when it became clear that additional institutions wished to join the project. At least one of the potential GMT sites, Las Campanas Peak, allows room for a second GMT as shown in Figure 2-6.

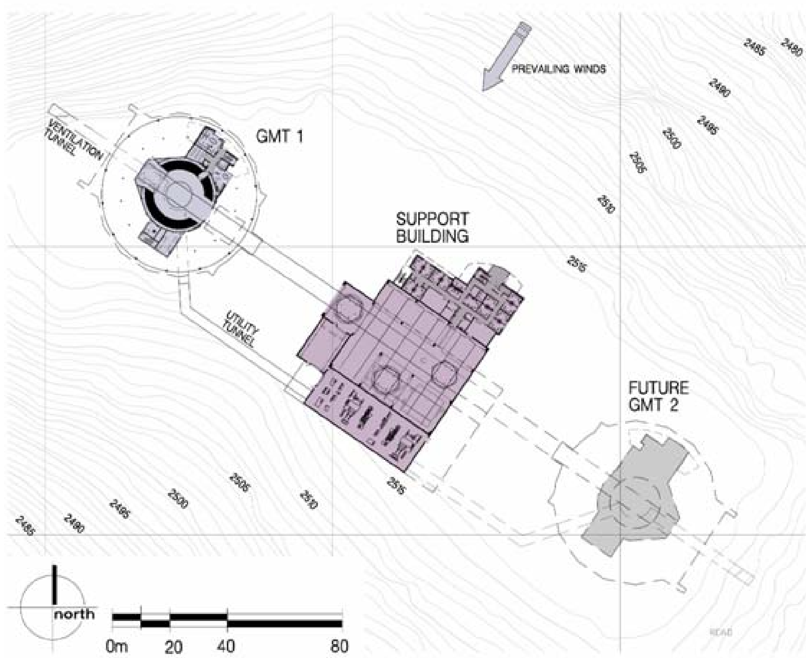

Figure 2-6. Possible siting of two GMTs on Cerro Las Campanas.

2.7 Project Status and Development Plan

The GMT Project has been divided into four phases: (1) Conceptual Design, (2) Design Development, (3) Construction, and (4) Commissioning and Operations. This review marks the nominal end of the Conceptual Design. If approval to proceed to Design Development is recommended by the Conceptual Design Review Committee, and granted by the GMT Board, the scope of the project will widen significantly. At the beginning of the Design Development, a more formal GMT Project structure will be established, and a Project Office will be created to oversee the GMT design.

Start of science operations with the full complement of mirrors is projected to be early in 2016.