GIANT MAGELLAN TELESCOPE
Transforming Our Understanding of the Universe
GMT Founder Institutions
The Giant Magellan Telescope project consists of an international consortium of leading universities and science institutions. Founder institutions include:

Arizona State University
Astronomy Australia Limited
Australian National University
Carnegie Institution for Science
FAPESP – The São Paulo Research Foundation
Harvard University
Korea Astronomy and Space Science Institute
Smithsonian Institution
Texas A&M University
The University of Texas at Austin
University of Arizona
University of Chicago

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The Giant Magellan Telescope is poised to become the first in a new generation of “Extremely Large Telescopes.” When it becomes operational in the first half of the next decade, the GMT will open new discovery space and address key questions in astrophysics, cosmology, and the study of other worlds.

The GMT uses seven of the largest astronomical mirrors that can be manufactured to form a single coherent optical system capable of producing images ten times sharper than the Hubble Space Telescope. The mirrors are made at the University of Arizona’s Richard F. Caris Mirror Laboratory. The GMT’s off-axis mirrors are the most challenging large optics ever produced, and the completed first mirror meets all of its specifications.

The GMT will be located at Las Campanas Observatory in the Chilean Andes, an ideal location with dark and clear skies. The Las Campanas site was purchased by the Carnegie Institution in 1969, and it has been established as a premier observatory site for nearly 50 years.

The GMT will work in synergy with a number of facilities on the ground and in space, particularly those accessing the southern hemisphere. It will be poised to leverage the power of the Large Synoptic Survey Telescope (LSST), an instrument located 100 km south of Las Campanas that will map the entire sky every few nights to find transient objects, small bodies in the outer solar system, and distant supernovae.

The GMT project is being developed by a nonprofit Delaware corporation (GMTO) that is governed by a master agreement among the Founder institutions. GMTO is recognized by the government of Chile as a tax exempt and partially immune international organization.

The project passed a number of rigorous independent reviews before entering into the Construction Phase in 2015.
The Giant Magellan Telescope is one of a new generation of ground-based “Extremely Large Telescopes” designed to provide unprecedented clarity and sensitivity for the observation of astronomical phenomena. The GMT will leverage cutting-edge optical technology to combine seven mirrors to form a coherent optical system capable of achieving ten times the angular resolution of the Hubble Space Telescope in the infrared region of the spectrum. GMT will embark on a mission of discovery to explore the origins of the chemical elements, the formation of the first stars and galaxies, and the mysteries of dark matter and dark energy. The GMT will also characterize conditions in planets orbiting other stars.

Poised to be the first Extremely Large Telescope to begin operations, and designed to have an operational lifespan of 50 years or more, the GMT will provide a powerful tool for generations of leading researchers.

**History of the Project**

Development of the GMT concept began in the early 2000s in the context of the successful suite of 8m-aperture telescopes operating in Chile, Hawaii, and the southwestern U.S. In the 1980s two technologies were developed for the production of individual mirrors larger than 5 meters in diameter. One approach, developed by Corning in the U.S. and Schott in Europe, used a ceramic-like material that does not change shape as its temperature varies. This material was used to make thin mirrors for...
the European Very Large Telescope and the twin Gemini 8m telescopes. The alternate approach, developed at the University of Arizona, built on the heritage of the Palomar mirror to make large and stiff honeycomb mirrors from a glass that can be molded into complex shapes. Large Arizona mirrors are in operation at the MMT, the Large Binocular Telescope, and the twin Magellan telescopes.

The design for the GMT grew from a series of discussions between Carnegie, Arizona, Smithsonian, and others regarding the next logical step beyond 8-10m telescopes. The outstanding image quality delivered by the Magellan telescopes using the Arizona mirrors was the deciding factor in selecting the structured, honeycomb mirror technology and the Las Campanas site.
The design for the GMT is driven by a set of key science requirements derived from a high-level science vision document, *Scientific Opportunities with the Giant Magellan Telescope*. This aligns to a high degree with the scientific priorities identified in the National Research Council’s 2000 and 2010 decadal surveys of astronomy and astrophysics.

**Properties of Extrasolar Planets**
The GMT will help us understand the masses, structure, composition, and diversity of planets around other stars, including planets in the habitable zone—those on which water is in the liquid state. Precision spectroscopy will allow detection of Earth-mass planets and will probe the atmospheric composition of exoplanets to search for signs of biomarkers.

**Stellar Populations & Cosmic Chemistry**
All atoms heavier than lithium were formed inside stars or in supernova explosions. Precision spectrographs on the GMT will allow us to probe the chemistry of the oldest stars in the Milky Way and nearby galaxies to understand conditions in the early universe.
Galaxy Formation and Evolution

Galaxies took on their present spiral or elliptical shapes and structures in the last 8 billion years or so. With the GMT, we will observe the formation and assembly of galaxies from smaller units in the first few billion years after the Big Bang.

Dark Matter, Dark Energy, and Fundamental Physics

GMT will examine the properties of dark matter, and the question of just how dark it truly is, by probing its structure through gravitational lensing and studies of the motions of stars in dark matter-dominated galaxies.

First Light and Reionization

Some 400,000 years after the Big Bang, electrons and protons combined to form the first atoms. The universe remained dark for the next 50 to 100 million years, until it was lit up by energy released by the first stars, accreting black holes, and galaxies. The GMT will help us probe this “first light” era in which the first stars and galaxies formed.
Principal Elements of the GMT

The GMT is designed around technology developed over the past decades, augmented with state of the art detector systems, precision positional measurement systems, and advanced opto-mechanical devices.

**Primary Mirrors**

The GMT mirrors are developed at the University of Arizona’s Richard F. Caris Mirror Laboratory. The mirrors are made from a high-tech glass that maintains its shape to very high precision as the temperature changes in response to varying ambient conditions at the observatory site. The glass behind the front surface is structured to be both rigid and 85% lightweighted compared to a solid mirror. The front surface is shaped and tested with advanced polishing tools and multiple optical tests.

The challenge associated with making the large off-axis primary mirror segments was identified as the greatest technical risk to the program. As a risk mitigation and technical demonstration effort, the first off-axis mirror was cast in 2005. As of May 2017, five mirrors are under production, and materials for segments 6 and 7 are in hand.

**Scientific Instruments**

Scientific instruments – primarily cameras and spectrographs – capture, reformat, and record the light collected by the telescope so that it can be used for scientific investigations. Scientists within the GMT community have selected a first-generation suite of instruments that will allow them to carry out the highest priority scientific programs. The selected instruments are primarily spectrographs – optical devices that disperse the light into its constituent colors. Two of the spectrographs for GMT will operate in the visible region of the spectrum, while the other two are sensitive to infrared light. For each wavelength region, teams have designed a “high resolution” spectrograph for precision work and a “survey spectrograph” that is optimized for very faint sources. An advanced fiber-optic system using tiny robotic positioners will expand the capabilities of most of the GMT spectrographs by allowing...
them to access the full field of view provided by GMT’s innovative optical design. Lastly, but first on the sky, a simple commissioning camera will allow the GMT team to characterize the performance of the telescope and will produce the first scientific data.

The first scientific instruments for the GMT are being developed by scientists and engineers at partner institutions, particularly the Smithsonian, Australian National University, Texas A&M University, and The University of Texas at Austin. Numerous scientists at the other partner institutions participate in the instrument development teams.

**Telescope Mechanical Structure**

The telescope mount stands 36 meters above the observing floor and spans nearly 48 meters from the base of the pier foundation to the top of the secondary mirror support system. The telescope is a two-axis altitude-azimuth system that allows for a compact high-performance structure. The optical support structure moves on two nearly frictionless bearings that use hydrostatic pressure to float the telescope on a film of oil just 50 microns thick. The telescope mount is under procurement.

**Adaptive Optics System**

Adaptive Optics (AO) compensates for the distortions introduced by the Earth’s atmosphere using deformable optical elements. The GMT adaptive optics system will allow the telescope to produce images limited only by the diffraction of the primary mirror array. The GMT AO system builds on the deformable mirror technology that was developed for the MMT and Large Binocular Telescope and was refined for the Magellan Telescopes and the European VLT.

**Enclosure & Site Infrastructure**

The 22-story enclosure, or “dome,” has a large number of retractable doors that can open at night to allow airflow, which ensures that the interior nighttime temperature matches the ambient temperature with high precision. The enclosure design is nearing completion.
Global ELT Effort

Three ELT projects are underway around the world. In addition to the GMT, a consortium of governmental organizations in Canada, Japan, China, and India have partnered with the University of California and Caltech to design and build the Thirty Meter Telescope (TMT) based on the small-segmented mirror architecture of the Keck Telescopes.

The European Southern Observatory (ESO), a consortium of European governments, is planning a telescope in Chile called the European ELT (E-ELT). It too uses a large number (~1,000) of small mirror segments to form a 39 meter primary mirror array.

LSST, ALMA, JWST

The GMT and other ELTs will work in synergy with other ground-based telescopes such as the Atacama Large Millimeter/Submillimeter Array (ALMA) and the Large Synoptic Survey Telescope (LSST). The LSST will begin its 10-year sky survey when the GMT has first light, and we expect the GMT to be in a position to work with the LSST to make breakthrough discoveries. Follow-up work by the GMT will also complement space telescopes, including the James Webb Space Telescope, in the same way that 8m-class ground-based telescopes such as the Gemini and Keck telescopes currently work in concert with the Hubble Space Telescope.

GMT Advantage

One might expect that the scientific return from a telescope is entirely determined by the size of its primary aperture. In practice, a number of factors influence the scientific productivity of an astronomical telescope, including collecting area, image quality, and field of view on the sky. Many scientific programs require observations of large numbers of individual celestial objects.
objects that are faint compared to the glow of the night sky. A telescope that produces both sharp images, and thus high contrast with the sky, and a wide field of view can optimize the impact of its primary collecting area. GMT has an ideal combination of sharp images, when used in its standard mode or with a range of adaptive optics modes and, thanks to its compact optical system, a relatively wide field of view.

The optical configuration chosen for the GMT makes it very compact and gives GMT a distinct performance edge by enabling compact instruments. This provides advantages in terms of optical design options, technical performance (e.g. throughput and spectral resolution), mechanical performance, operational issues (swapping and handling instruments), and cost.

Southern Migration of Astronomy Assets

Chile will host more than half of the light grasp in the world by 2025. The Chilean sites are dark and provide a view of the galactic center directly overhead. Features of the Southern Sky also include some of the brightest star clusters and views of the nearest neighboring galaxies.

Chile has emerged as an extraordinary host for the astronomy community with one of the most stable, prosperous economies in the region and an excellent infrastructure in terms of power distribution, roads, and communication. The Chilean government actively collaborates with the astronomy community to protect astronomical sites from various forms of pollution.
**Budget**
The total GMT Project capital budget was capped by the GMTO Board in 2014. The project cost estimate is derived from a resource-loaded schedule and individual cost estimates for procurements and services. The cost can be broken down as shown in the chart below.

**Top-Level Schedule**
For purposes of planning and budgeting, the GMT Project is, and has been managed through, four Project Phases:

1. Conceptual Design Phase
2. Design Development Phase
3. Construction/Commissioning Phase
4. Operations Phase
Conceptual Design
The Project conducted its first substantial external review in 2006. At this Conceptual Design Review, the basic concept, science drivers, and support infrastructure for GMT, including a conceptual level budget and timeline, were reviewed by an external panel of experts. Following a favorable report from the review panel, the project transitioned from the Conceptual Design Phase to the Design Development Phase.

Conceptual designs for the first generation of scientific instruments were developed in the 2006-2011 timeframe by teams at the Founder institutions. Six instrument concepts were developed under contract from GMTO. Each of the instruments underwent a conceptual design review by an outside panel of experts. Following those reviews, a high-level scientific panel, the GMT Instrument Development Advisory Panel, provided a ranked set of priorities for the Project and GMTO Board in early 2012.

Design Development
In 2013 the Project team brought designs for each of the major subsystems to sufficient maturity that Preliminary Design Reviews (PDRs) were conducted for the Enclosure and Site Facilities, the Adaptive Optics System, and the Telescope System. A System Level Preliminary Design Review of the integrated Observatory design was held in January 2014. The System Level PDR was quickly followed by an independent management and cost review. All review panels returned positive reports with a strong recommendation by the System Level PDR panel that the project proceed to the construction phase.

Construction/Commissioning
The Project Office submitted a construction plan to the GMTO Board in July 2014. GMTO announced the beginning of construction in June 2015 following the Founders’ commitment of more than $500M.

The GMT site was leveled in 2012, clearing a total surface area equivalent to four football fields. Geotechnical testing was conducted through three 60-meter deep borings on the summit. The properties of the summit rock were analyzed, and the design for the telescope pier was updated accordingly. GMTO held a groundbreaking ceremony in November 2015, and on-site work is currently underway, beginning with the build-out of site infrastructure.

The Project is scheduled to achieve first-light with a subset of the primary mirrors in 2023, with full operations beginning around 2026.
501(c)(3) Tax Exempt Status
The GMTO Corporation is a standalone non-stock nonprofit U.S. (Delaware) corporation created to execute the development and operation of the Giant Magellan Telescope facility on behalf of a consortium of academic and research institutions.

The GMTO is a 501(c)(3) organization recognized by the U.S. Internal Revenue Service and the State of California as a charitable organization exempt from most taxes.

GMTO Corporation is currently governed by 11 Founder institutions that act through Founder Representatives and a Board of Directors nominated and elected by the Founders, with additional Directors as determined by the Board and elected by the Founders. The GMTO Corporation is subject to Delaware, California, U.S., and Chilean Law, the Third Amended and Restated Founders’ Agreement dated October 1, 2015, and the Bylaws, adopted in 2008.

Status in Chile
GMTO has an agreement with the University of Chile, which sets forth GMTO’s provisions to provide observing time to astronomers at Chilean universities. GMTO has been recognized through a presidential decree as an “international organization” in Chile, giving it tax advantages and a high degree of legal immunity.

GMTO Organization
GMTO Corporation has its offices in Pasadena, CA and Santiago, Chile and employs approximately 100 people between the California and Chile offices but will grow as construction ramps up. We expect to host more than 200 contract employees in Chile at the peak of construction.

If you'd like to learn more visit GMTO.org
FOUNDER INSTITUTIONS

The GMT project is an international consortium of leading universities and scientific institutions:
Arizona State University • Astronomy Australia Ltd • Australian National University • Carnegie Institution for Science
FAPESP – São Paulo Research Foundation • Harvard University • Korea Astronomy and Space Science Institute
Smithsonian Institution • Texas A&M University • The University of Texas at Austin
University of Arizona • University of Chicago