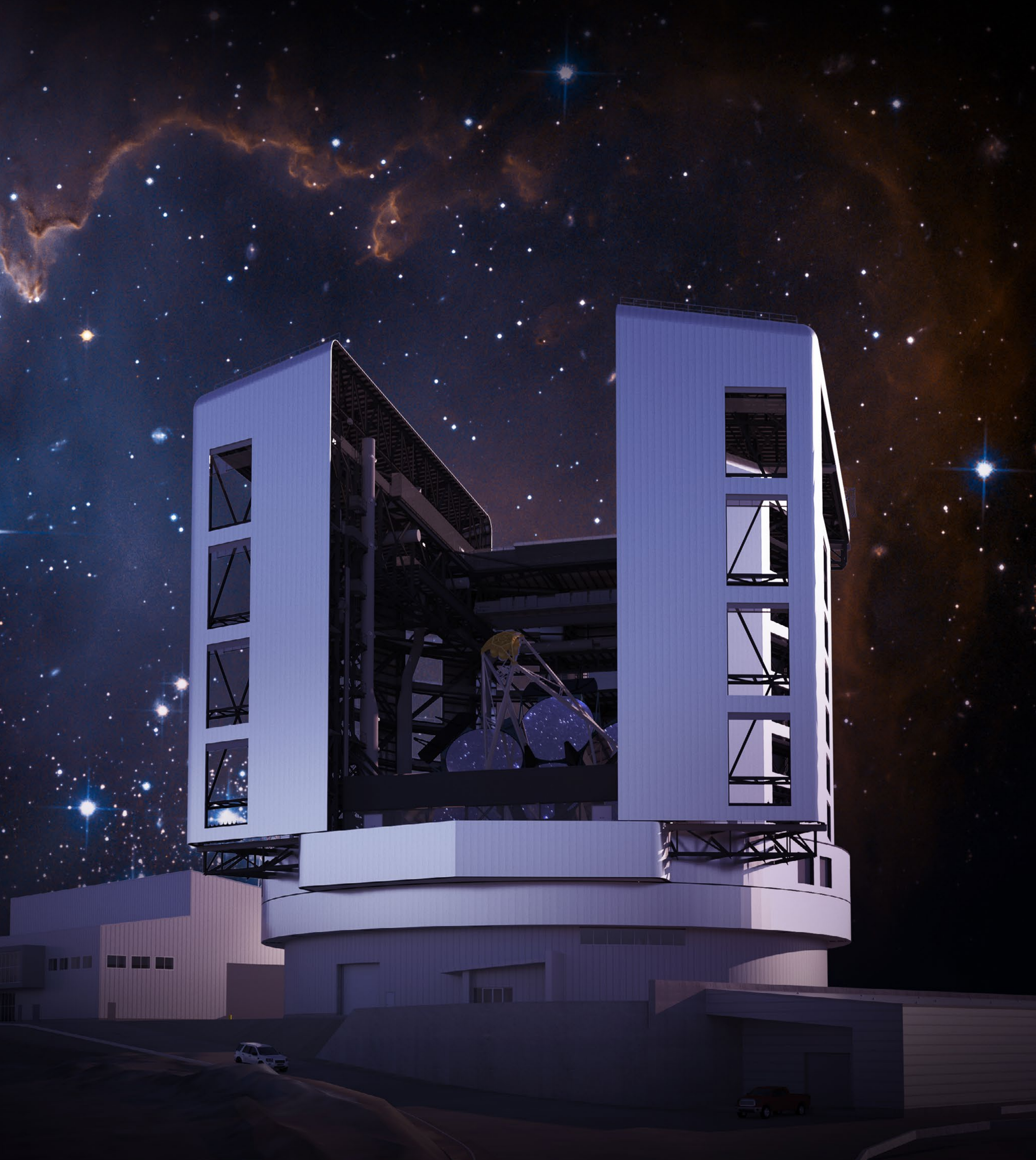
GIANT MAGELLAN TELESCOPE

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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EXECUTIVE SUMMARY

The Giant Magellan Telescope is poised to become the first in a new generation of "Extremely Large Telescopes." When it becomes operational in the late 2020s, 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 first two completed mirrors meet all of the 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 Vera C. Rubin Observatory (formerly 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.

GIANT MAGELLAN TELESCOPE

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.

The GMT is designed to have an operational lifespan of 50 years or more and 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.

BACKGROUND:
GMT Rendering
GMTO

TOP TO BOTTOM:
Palomar 200-inch disc
Palomar 200-inch mirror
Palomar Observatory/California Institute of Technology

Large Binocular Telescope
LBT Observatory/Enrico Sacchetti

Very Large Telescope (VLT) Mirror
European Southern Observatory

Roger Angel inspects GMT Mirror Segment 1
GMTO/Ray Bertram

SCIENCE DRIVERS

The design for the GMT is driven by a set of key requirements that flow from a high-level science vision. This science vision is described in the 2018 edition of the GMT Science Book. It 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 Exoplanets

The GMT's sensitivity, resolution, and spectroscopic capabilities will enable us to understand the origins of the wide range of planetary systems we see in the galaxy around us. We will be able to measure the physical properties of those planets to learn if they contain life and to compare our solar system to its neighbors.

Building Galaxies from Cosmic Gas

With the GMT we will be able to map the vast volume of space that lies between galaxies, as well as the material surrounding galaxies. The GMT's resolution will also enable us to peer into the hearts of galaxies to understand how their stars and central black holes process gas.

Birth and Death of Stars

Using infrared light, the GMT will unveil forming stars in stellar nurseries across the Milky Way, allowing us to see the complex process of star formation with new clarity. The GMT will also probe the physics of the vast diversity of stellar explosions throughout the cosmos, searching for the chemical elements that are cast into space when a dying star explodes.

Galaxy Formation and Evolution

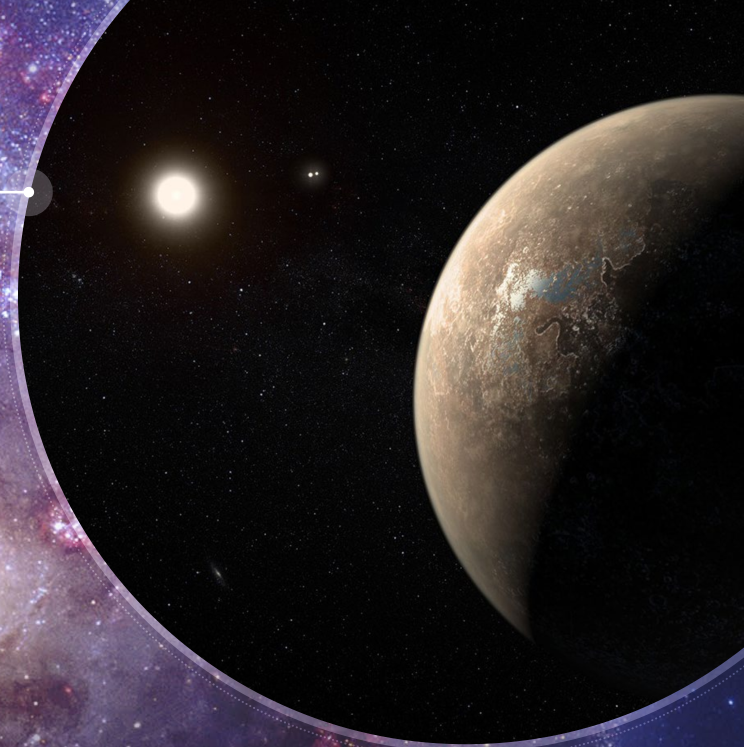
The GMT will be able observe very faint stars in the nearest galaxies, allowing us to explore the complex formation and evolution of galaxies like our own. Additionally, GMT's tremendous light-gathering power will allow us to measure the smallest and faintest galaxies ever observed, to reveal the internal workings of galaxies across the entirety of cosmic history.

Cosmology and the Dark Universe

The GMT will offer new ways to challenge our understanding of the physical laws that govern the universe. By exploring the extreme environments in the cosmos, we will refine the properties of dark matter and dark energy to further our understanding of the structure and contents of the universe.

First Light and Reionization

The GMT will enable detailed spectroscopy of the first objects that formed in the universe. Working in concert with the next generation of space observatories and radio telescopes, the GMT will help us understand how the first sources of light formed and how they changed the early universe.



Historical experience shows that large increases in light-collecting area have opened new observational discovery space and have led to unanticipated breakthroughs. This fact alone is a key driver for the next generation of telescopes.

BACKGROUND:
Antennae Galaxies NGC 4038-4039
NASA, ESA, and Hubble Heritage Team (STScI/AURA)

TOP TO BOTTOM:
Artists impression, planet orbiting Proxima b
ESO/M. Kornmesser

Pandora's Cluster — Abel 2744
NASA, ESA/J.Merten and D. Coe

SN 1987A
NASA, ESA/P.Challis & R. Kirshner

Hubble Frontier Field Galaxy Cluster
NASA, ESA/L. Infante

Cosmic Web
Phil Mansfield (U Chicago) and Benedikt Diemer (ITC, Harvard)

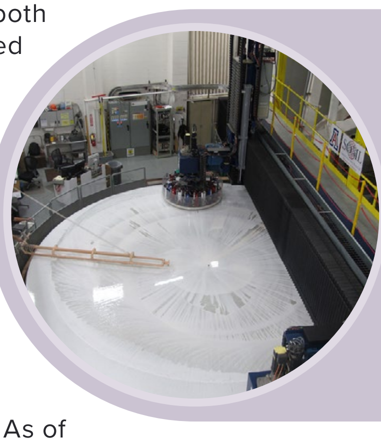
CORE TECHNOLOGY

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

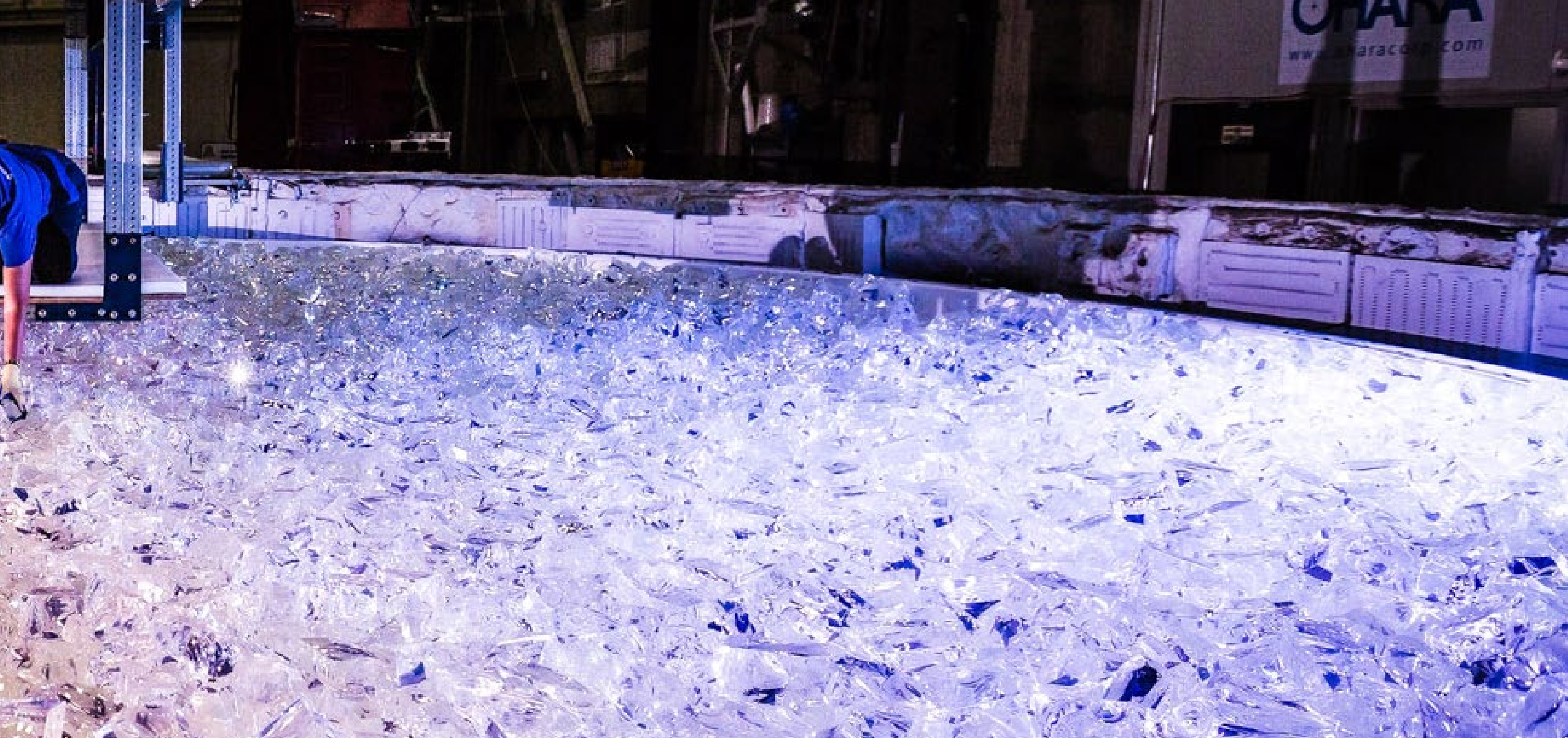
The GMT mirrors are developed at the University of Arizona's Richard F. Caris Mirror Laboratory. The mirrors are made from a high-tech glass that maintains its shape to very high precision as the temperature changes in response to varying ambient conditions at the observatory site. The glass behind the 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.

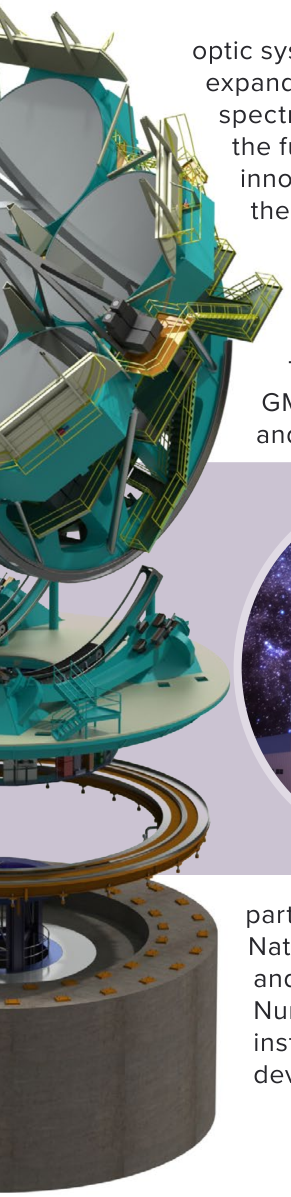


The challenge associated with making the large off-axis primary mirror segments was identified as the greatest technical risk to the program. As a risk mitigation and technical demonstration effort, the first off-axis mirror was cast in 2005. As of March 2020, two mirrors are complete, three others are under production, and materials for segments 6 and 7 are in hand.

Scientific Instruments

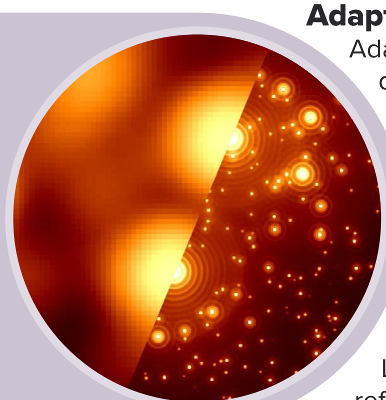
Scientific instruments – primarily cameras and spectrographs – capture, reformat, and record the light collected by the telescope so that it can be used for scientific investigations. Scientists within the GMT community have selected a first-generation suite of instruments that will allow them to carry 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 final design and construction is being carried out by MT Mechatronics and Ingersoll Machine Tools.

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.

THE ASTRONOMICAL LANDSCAPE

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 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

By 2030, Chile will host more than half of the light grasp in the world. Located in one of the highest and driest locations on earth, in Chile's Atacama Desert, the GMT will have spectacular conditions in which to undertake cutting-edge astronomy for more than 300 nights a year. 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.

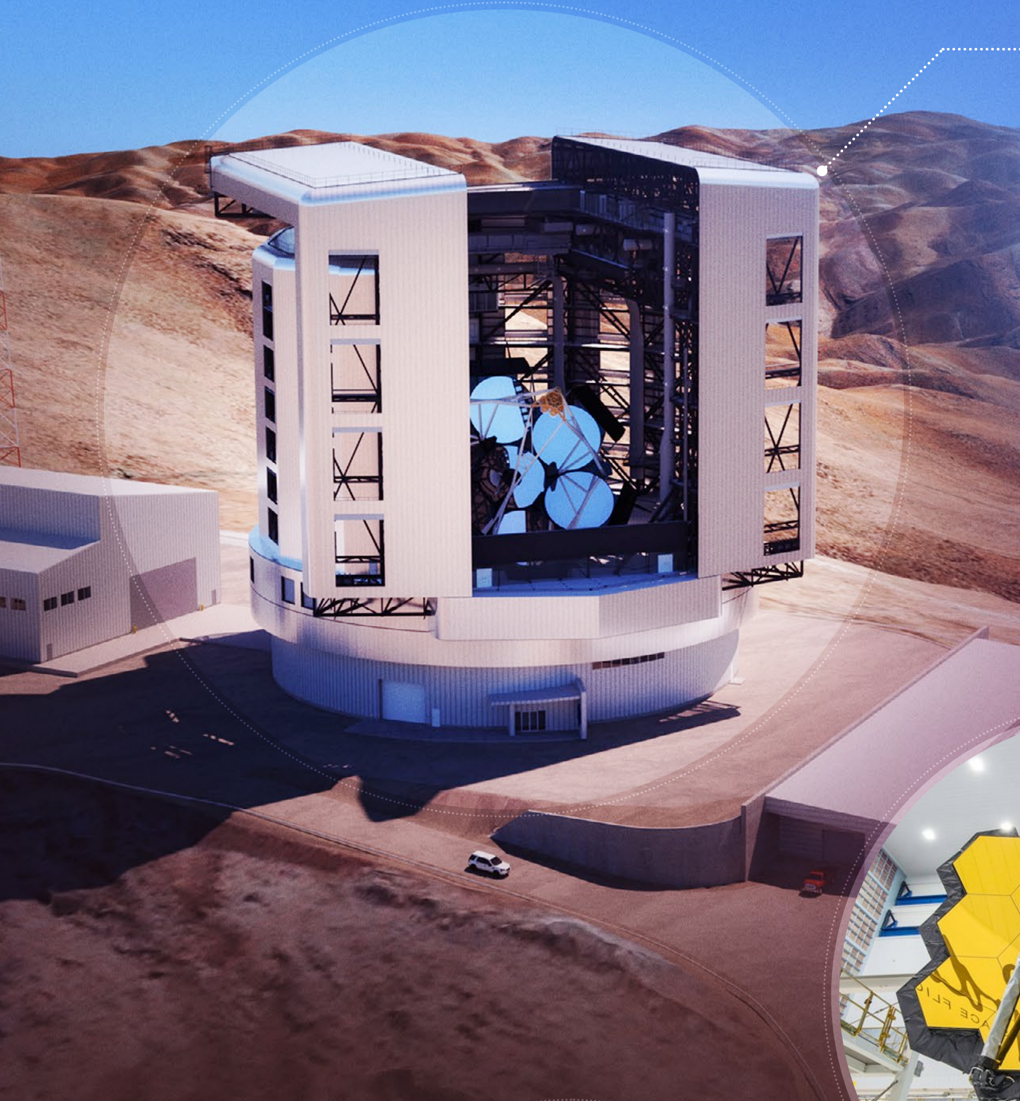
Global ELT Effort

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.

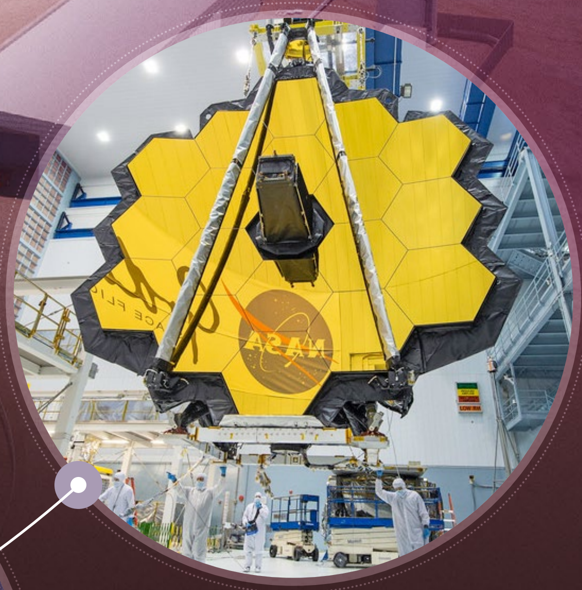
Rubin Observatory, ALMA, JWST

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 Vera C. Rubin Observatory (formerly LSST). The Rubin Observatory will begin its 10-year sky survey in 2022, and we expect the GMT to be in a position to work with the Rubin Observatory 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.



The GMT Site

The Project team conducted an extensive survey of potential sites within Carnegie's Las Campanas Observatory (LCO) property, selected due to Carnegie's legal title to the land, its excellent "seeing" conditions (atmospheric stability), good weather, and dark skies. The GMT site—Las Campanas Peak—was selected in 2011 on the basis of its excellent image quality and large summit area.



BACKGROUND:
Giant Magellan Telescope
GMTO, M3

TOP TO BOTTOM:
James Webb Space Telescope
NASA/Desiree Stover

ALMA
ESO,NAOJ, NRAO/C. Padilla

Vera C. Rubin Observatory
Rubin Obs./NSF/AURA

BUDGET & TIMELINE

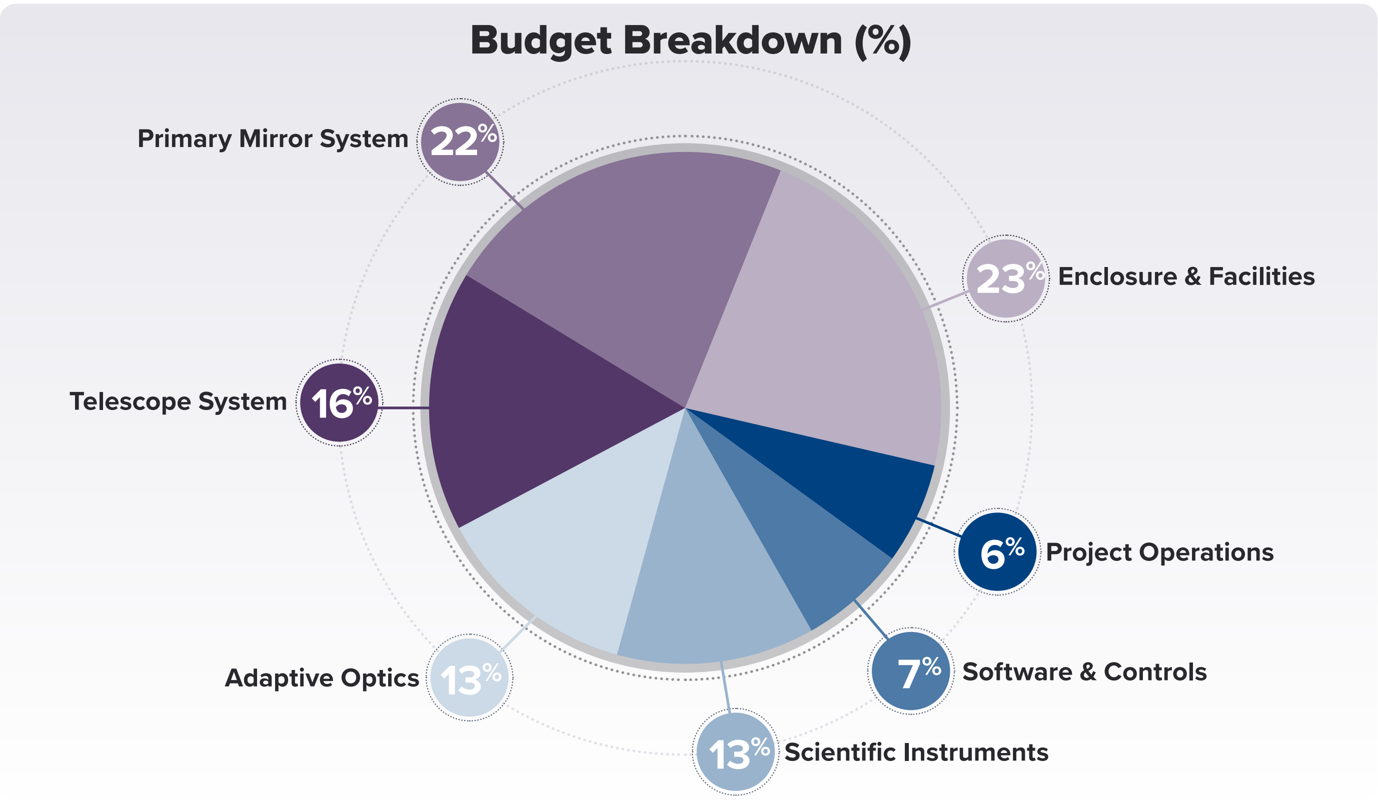
Budget

The GMTO's 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



Former President of Chile, Michelle Bachelet
Alex Ibañez, Chile's Prensa Presidencia

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.

Integrated Baseline Review

In 2019, GMTO completed a rigorous, external Integrated Baseline Review (IBR) of GMTO's total project cost and schedule. The IBR review committee was composed of a distinguished group of experts. In the review committee's final report, the top-level conclusion was that the Project Team can deliver the GMT.

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. Accomplishments to date include: completion of hard rock excavation for the telescope and enclosure, extensive site infrastructure, completion of two of seven of GMT's giant primary mirror segments (with three other primary mirror segment already cast and in varying stages of finishing), and a contract to fabricate the mount assembly, our largest procurement to date valued at approximately $135M. The mount assembly will be fabricated in the United States.

An excellent project team has been assembled, and project management has produced and vetted a comprehensive plan for the work. With sufficient funding, the GMT will see first-light in early 2029 and construction complete in 2030.

Federal Relations

The GMT and the Thirty Meter Telescope projects are working with the NSF's National Optical-Infrared Astronomy Research Laboratory as part of the U.S. Extremely Large Telescope Program. This Program's goal is to strengthen scientific leadership by the U.S. community-at-large through access to extremely large telescopes in the Northern and Southern Hemispheres. This two-hemisphere model will provide the U.S. science community with greater and more diverse research opportunities than can be achieved with a single telescope, and hence more opportunities for leadership. The audience for this endeavor is the U.S. research community as represented by the 2020 Decadal Survey, and the National Science Foundation.

GMTO CORPORATION

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 12 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 Corporation

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***


GIANT MAGELLAN TELESCOPE
GMTO CORPORATION
COMMUNITY BANK
24 HOUR FITNESS
OEWAVES
SIERRA LOBO, INC.
PNC TREASURY MANAGEMENT
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