TMT

BUILDING THE **GATEWAY** TO THE UNIVERSE

THIRTY METER TELESCOPE

CONTENTS

On the cover
Artist's concept of the Thirty Meter Telescope. The unique dome design optimizes TMT's view while minimizing its size. The louvered openings surrounding the dome enable the observatory to balance the air temperature inside the dome with that of the surrounding atmosphere, ensuring the best possible image with the telescope. ***Photo-illustration: Skyworks Digital***

BUILDING THE

GATEWAY

TO THE UNIVERSE

THE STORY OF TMT IS THE HISTORY OF THE UNIVERSE

The Thirty Meter Telescope (TMT) will take us on an exciting journey of discovery. The TMT will explore the origin of galaxies, reveal the birth and death of stars, probe the turbulent regions surrounding supermassive black holes, and uncover previously hidden details about planets orbiting distant stars, including the possibility of life on these alien worlds.

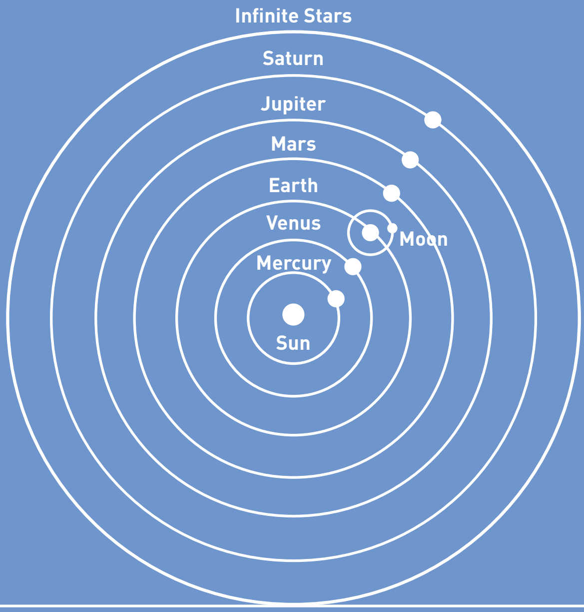
Photo-illustration: Dana Berry

Research in astronomy has revealed exciting details about our place in the cosmos. Through careful observations of objects in the Solar System, scientists were able to unravel the true relationship among the planets, Earth, Moon, and the Sun. Later discoveries with larger and more powerful telescopes revealed that our Solar System was part of a larger galaxy made up of billions of stars, which itself was part of an expanding Universe filled with billions of other galaxies.

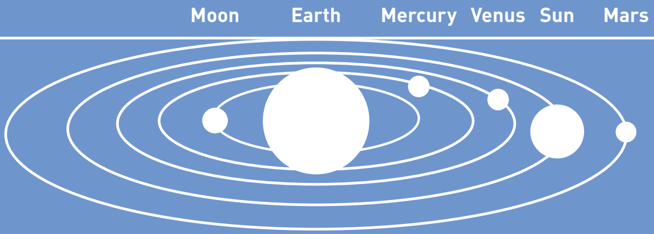
The Orion Nebula, located approximately 1,350 light-years from Earth, is a massive cloud of dust and gas. The image contains more than 100 proto-planetary disks, regions of active star and planet formation. The Thirty Meter Telescope, with its infrared capabilities, will be able to probe deeply into star-forming regions to study the conditions that lead to new solar systems.
Image courtesy of HubbleSite

The Heliocentric Solar System

From our vantage point, Earth appears to be at the center of a vast celestial sphere. It took centuries of careful scientific observations to reveal that the Sun is at the center of the Solar System. In the early 1600s, Johannes Kepler devised a series of laws that explained the motion of planets around the Sun, including the fact that planets travel in an ellipse rather than a perfect circle. A few years later, Galileo's observations of the moons of Jupiter and the phases of Venus provided supporting evidence for the heliocentric model of the Solar System. Eighty years later, Sir Isaac Newton showed that the motion of planetary bodies was governed by the same forces that pulled objects to the Earth, validating the work of Kepler and Galileo.

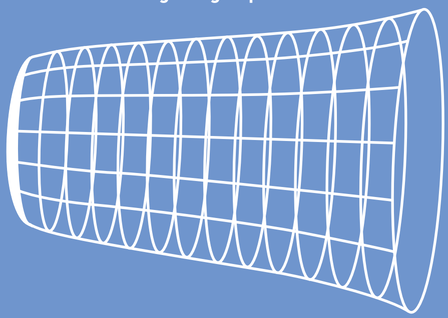


Heliocentric



Geocentric

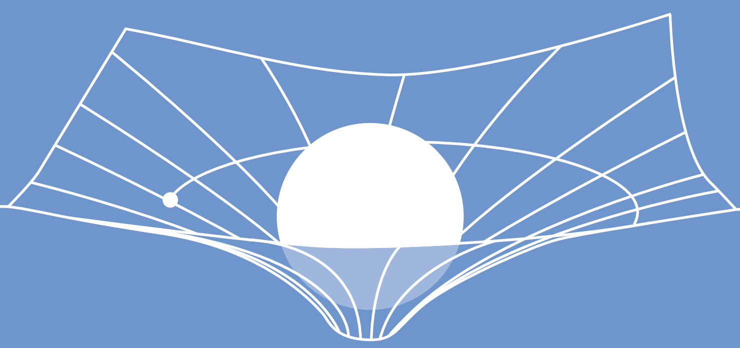
Big Bang Expansion

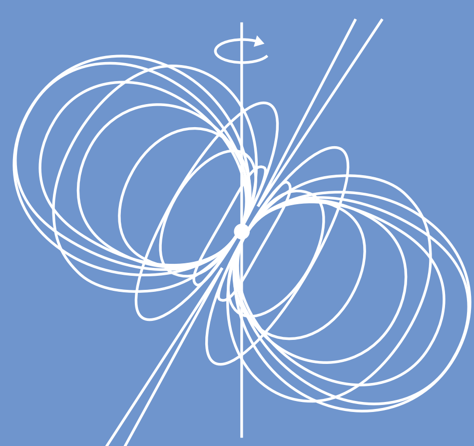


Big Bang and the Expansion of the Universe

Albert Einstein's equations of general relativity suggested that the Universe was either expanding or contracting, an idea that Einstein initially rejected. By studying the redshift of distant galaxies, Edwin Hubble found evidence that Einstein's initial equations were correct. Hubble discovered that distant galaxies were indeed rushing apart. This led to our modern understanding of cosmology and the Big Bang theory. Later, Arno Penzias and Robert Wilson detected a faint microwave "hiss" coming from all areas of the sky. This was the predicted afterglow of the Big Bang.

Verification of General Relativity
Einstein's theory of general relativity states that gravity results from massive objects bending the fabric of space-time. The more massive an object, the more space and time curve around it. This curved space-time could be detected, Einstein reasoned, by observing the path that light takes as it passes by a very massive object, such as the Sun. Sir Arthur Eddington, during a solar eclipse in 1919, tested this prediction by measuring how the Sun bent light from a distant star, changing the star's apparent position on the sky.





Multi-wavelength Astronomy
While trying to locate the source of static in trans-Atlantic radio signals, engineer Karl Jansky detected radio waves coming from the center of the Milky Way Galaxy. Following up on Jansky's discovery, Grote Reber built the first radio telescope and made the first radio maps of the sky. This work paved the way for the entire field of multi-wavelength astronomy, which enabled the discovery of pulsars, the cosmic microwave background radiation, and other important contributions to astronomy and physics. Today, astronomers study the Universe across the entire electromagnetic spectrum, from faint radio waves to high-energy gamma rays.

GRAND CHALLENGES OF ASTRONOMY

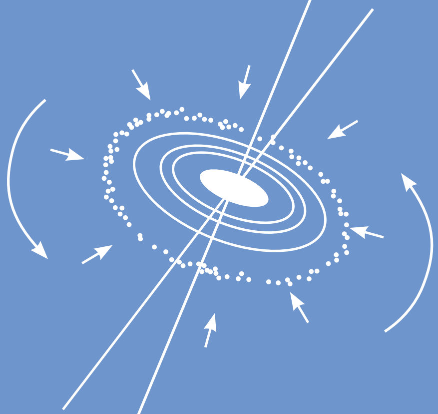
Building on breakthrough discoveries and remarkable innovations in telescope design, astronomers have now set their sights on bigger questions and more challenging research.

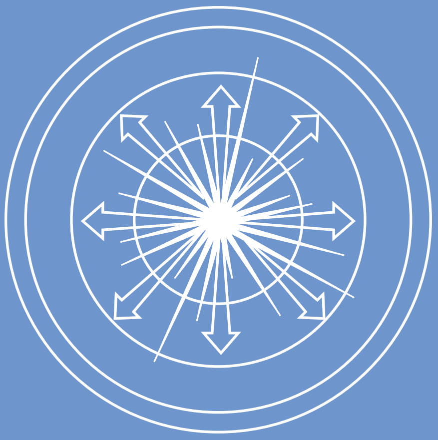
Today's cutting-edge telescopes, however, are reaching their limits as they probe further into space in an effort to find the faintest stars and observe the most distant galaxies.

To continue this journey of exploration, engineers, astronomers, and project specialists are working to build the Thirty Meter Telescope (TMT), the highly anticipated, next-generation observatory for the astronomical community. With TMT, we will study the Universe as never before, finding answers to many of the grand challenges of science.

This Hubble Deep Field image covers a speck of the sky only about the width of a dime as seen 75 feet away, yet it contains more than 1,000 galaxies at various stages of evolution. The individual objects, however, appear pixilated and blurry. TMT, with its greater resolution and sensitivity, will image objects like these in stunning clarity, revealing new details and prompting new discoveries.

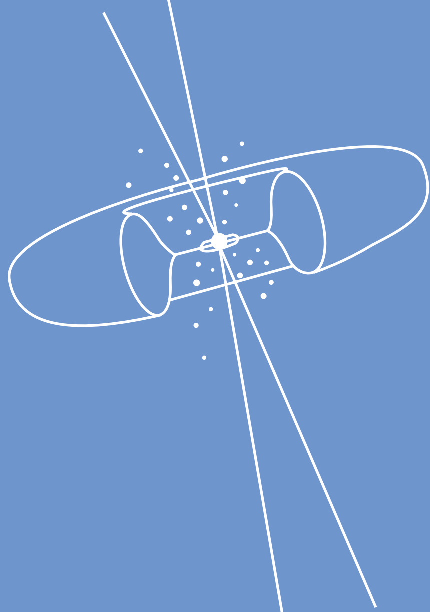
Can the first stars and galaxies tell us how our galaxy came to be?
By studying the most distant galaxies, TMT also will be peering back in time to when the Universe was much younger and the formation of stars in galaxies was much more spectacular than it is today. By studying the Universe when it was just a fraction of its current age, astronomers hope to understand the history of galaxy formation and how the earliest structures evolved into spectacular spirals like our own Milky Way.





Will dark energy shape how the Universe will end?
For decades, astronomers assumed that the expansion of the Universe was slowing. Scientists studying distant galaxies and supernovae were surprised to discover, however, that the Universe is actually expanding faster and faster. Astronomers have named this unknown force “dark energy.” By studying the most distant objects, astronomers hope TMT will shine more light on this mysterious repulsive force, how it affects normal matter, and what part it will play in the ultimate fate of the Universe.

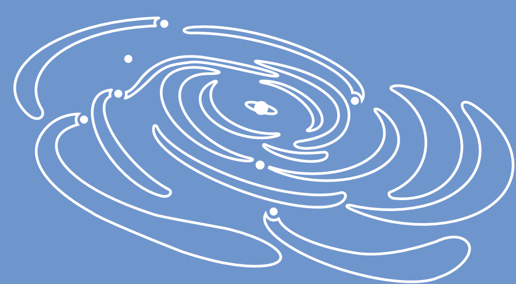
What and where is dark matter?
All the matter we can see in the Universe is not nearly enough to keep galaxies from flying apart or to bind clusters of galaxies together. Astronomers believe that there is another invisible “dark matter” that suffuses the cosmos in a web-like scaffolding, providing the gravity and mass necessary to give the Universe its shape. The greater sensitivity of TMT will enable astronomers to better map the distribution of dark matter and uncover clues to its composition.



How do supermassive black holes influence the evolution of galaxies?
Imagine a place where giant stars swarm at fantastic speeds around an invisible point millions of times more massive than our Sun. That turbulent region has actually been found at the center of our galaxy. Recent studies with the Keck 10-meter telescope have revealed stars racing around what we now know to be the Milky Way's supermassive black hole. With TMT, astronomers will be able to study ten times the number of stars currently seen and learn more about the chaotic environment near one of the Universe's most extreme objects.

Once highly speculative, there is now overwhelming evidence for the existence of black holes—infinitely dense objects that warp space so severely that nothing, not even light, can escape their grasp. Lurking at the center of the Milky Way and perhaps all other galaxies are black holes many millions of times more massive than the Sun.

How do dust and gas become stars and planets?
Stars and planets form out of vast clouds of dust and gas. For reasons we don't fully understand, areas of these clouds begin to collapse under gravity, forming protoplanetary disks, the infant stage of new solar systems. Astronomers will use TMT to determine when these clouds form stars, their masses, and what fraction has planetary systems.



Is there life elsewhere in the Universe?
If the same conditions that gave rise to life on Earth existed on other planets, then the Universe could be teeming with life. Directly detecting life would be extremely challenging, but TMT will be able to detect planets within a star's "habitable zone," where liquid water could exist. TMT also will be able to study the chemical make-up of alien atmospheres to see if they could support life as we know it.

A BRIEF HISTORY OF ASTRONOMY AND TELESCOPES

From Galileo Galilei's first stunning discoveries about our solar system to Edwin Hubble's detection of the expansion of the Universe, new technologies have paved the way to new knowledge. TMT will carry on this legacy, which stretches back more than 400 years.

1608

Lens maker Hans Lippershey is credited with making the first telescopes.

1609

Galileo was among the first people to use the telescope for studying the heavens, discovering the moons of Jupiter, mountains and craters on Earth's Moon, and the phases of Venus.

1611

Johannes Kepler proposes advantages of using two convex lenses in a telescope.

1668

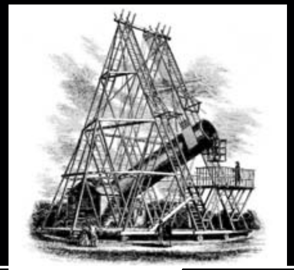
Isaac Newton is credited with building the first practical reflector telescope.

1672

The Cassegrain reflector telescope was designed by Laurent Cassegrain.

1733

Chester Moore Hall produces the first achromatic lens for a refracting telescope, helping to correct for the different refractive properties of different wavelengths of light.



1789

William Herschel creates the 49 inch reflecting telescope.

1845

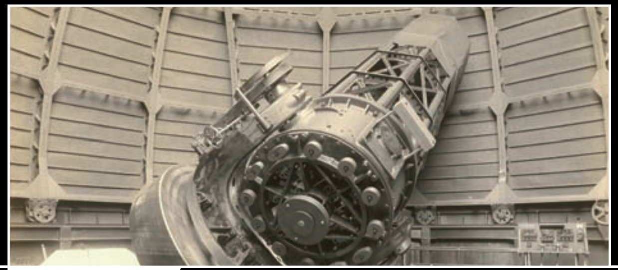
Lord Rosse's 72-inch Newtonian reflecting telescope, known as the Leviathan of Parsonstown, was the first to discover the spiral form of galaxies (then known as nebulae).

1888

The Lick Observatory and its 36-inch refractor telescope becomes the first mountaintop observatory.

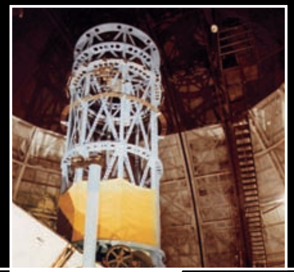
1897

The 40-inch refractor lens for the Yerkes Observatory is developed. It is the largest refractor lens created.



1908

The 60-inch reflector telescope is built atop Mount Wilson near Pasadena, California.



1917

Also atop Mount Wilson, the famous 100-inch Hooker telescope is built. It is with this instrument that Edwin Hubble discovers that the nebulae studied by Lord Rosse are actually separate galaxies, apart from our Milky Way.

1918

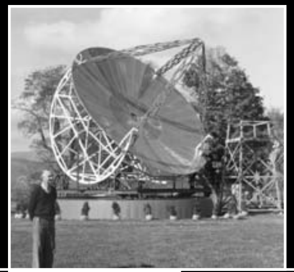
The 1.8 meter Plaskett Telescope is commissioned near Victoria, British Columbia.

1933

Fritz Zwicky, by analyzing Doppler velocities in the Coma galaxy cluster, proposes the existence of "dark matter" as providing the gravitational force necessary to hold galaxy clusters together.

1933

Karl Jansky discovers radio waves emanating from the center of the Milky Way Galaxy.



1937

Grote Reber built the first radio telescope and used it for the first systematic survey of radio waves from the sky.

1948

The 200-inch Hale reflector at Mount Palomar achieved "first light," becoming the world's premier observatory, and continues to produce important scientific results.

1964

Arno Penzias and Robert Wilson detect the predicted cosmic microwave background radiation, providing overwhelming support for the Big Bang theory.

1970s

Vera Rubin, working with Kent Ford, finds evidence for dark matter in the unexpectedly high orbital velocity of stars in the outer reaches of spiral galaxies.

1979

The Canada-France-Hawaii located on Mauna Kea in Hawaii becomes operational.

1990

The Hubble Space Telescope is launched.

1993

The first of the twin Keck Telescopes, which pioneered the segmented mirror design, began scientific observations on Mauna Kea in Hawaii; Keck II began observations in 1996. Jerry Nelson, who pioneered Keck's design, is now the project scientist for the Thirty Meter Telescope.

1998

The European Very Large Telescope array (VLT) achieves first light. The VLT consists of four Unit Telescopes with mirrors 8.2 meters in diameter and four movable 1.8 meter diameter Auxiliary Telescopes.

1998

Two separate groups hunting distant supernovae discovered several that were dimmer than they were supposed to be, suggesting that the expansion of the Universe was accelerating.

1999

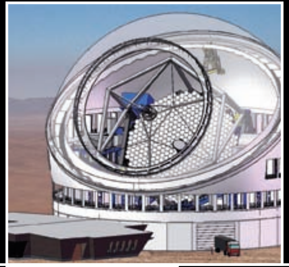
The Japanese Subaru telescope begins operations on Mauna Kea.

2000

The twin multinational Gemini telescopes, one on Mauna Kea, the other on Cerro Pachón in Chile become operational.

2000

The Astronomy and Astrophysics Survey Committee recommends as its highest priority ground-based initiative for this decade, construction of a 30-meter aperture Giant Segmented Mirror Telescope.

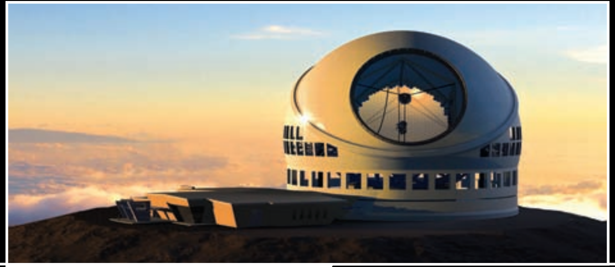


2003

Project partnership among Caltech, the University of California, and the Association of Canadian Universities for Research in Astronomy is created to design and build a 30-meter class, segmented mirror telescope.

2009

TMT selects Mauna Kea as the preferred site for the telescope, completes its design and development phase, and moves into early construction.



PRESENT

TMT begins full-scale polishing of the 1.4-meter mirror blanks that will make up the primary mirror, and develops many of the essential prototype components for the telescope.

A BRIEF HISTORY OF ASTRONOMY AND TELESCOPES

TMT

Images: Bell Labs, Andrew Dunn, European Southern Observatory, Gemini Observatory, Keck Observatory, Vadim Kurland, Lick Observatory, Todd Mason, Matthew Mew, NRAO/AUI, Subaru Observatory

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THIRTY
METER
TELESCOPE
MAUNA KEA
HAWAII
SELECTED AS
PREFERRED SITE
FULLY INTEGRATED
LASER GUIDE STAR
ADAPTIVE
OPTICS
FULL SUITE OF
INSTRUMENTS
TMT
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UNLOCKING NEW **FRONTIERS**

To capture the sharpest images and produce the best science, astronomers need more than an extraordinary telescope; they also need an equally extraordinary location with just the right atmospheric qualities.

After a rigorous five-year campaign that spanned the entire globe, TMT scientists found such a site, Mauna Kea, a dormant volcano in Hawaii that rises nearly 14,000 feet above the surface of the Pacific Ocean.

This site, which is above approximately 40 percent of Earth's atmosphere, has a climate that is particularly stable, dry, and cold. All of which are important characteristics for clear seeing.

This mountain in Hawaii is also home to some of today's most powerful telescopes, including the Gemini North Telescope, the Canada-France-Hawaii Telescope, the Subaru Telescope, and TMT's forerunners the twin Keck telescopes.

Sunset at Mauna Kea with a dome of one of the observatories shown in silhouettes against a cinder cone. ***Photo courtesy of Keck Observatory***

THE SCIENCE AND TECHNOLOGY OF TMT

Today's cutting-edge telescopes are making startling discoveries about new planets, interacting galaxies, and the incredibly powerful death throes of supermassive stars at the edge of the observable Universe. To maintain this exciting pace of discovery, astronomers and engineers are pushing the boundaries of today's technology while simultaneously creating the innovations that will make TMT the most advanced and capable telescope on Earth.

Photons from space rain down on Earth much the same way that rain falls to Earth. Faint, distant objects gently drizzle photons, while bright nearby objects provide a deluge of light. The bigger the aperture, or mirror of a telescope, the more photons it can collect.
Photo-illustration: Todd Mason

TMT, with its 30-meter (nearly 100-foot) diameter mirror, will have nine times the light-gathering power of today's best telescopes. When compared to the Hubble Space Telescope, TMT will have 156 times the collecting area and more than 10 times its resolution at certain wavelengths.

TMT will use a segmented primary mirror, which was successfully pioneered on the Keck telescopes. This design is essential for extremely large telescopes. A single 30-meter diameter mirror would be too large to build and transport. TMT's smaller segments, less than two meters across, can be more easily made, transported, and replaced if necessary.

Evolution of the Primary Mirror
A larger primary mirror enables a telescope to see fainter objects and to create an image with much finer detail.

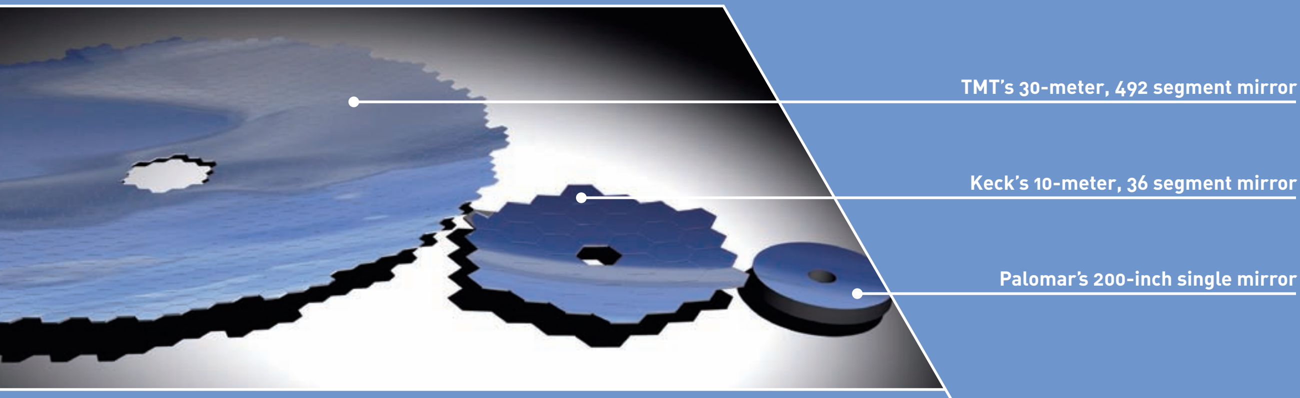
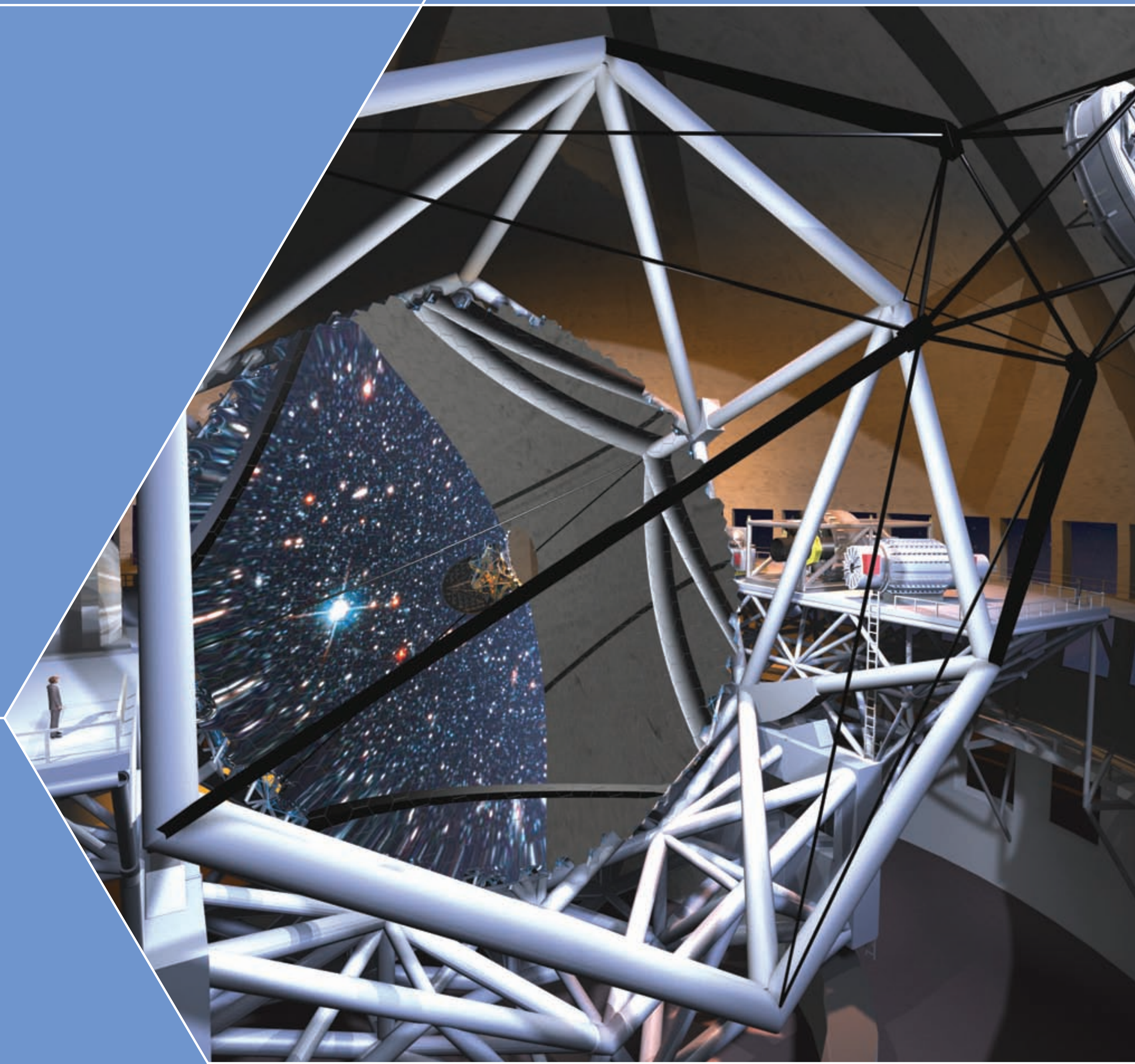


Photo-illustration: Todd Mason



The enclosure for TMT is a unique design and it will be the first item to be built on Mauna Kea. The floor upon which the telescope structure will be mounted is larger than 10 tennis courts.
Photo-illustration: Todd Mason

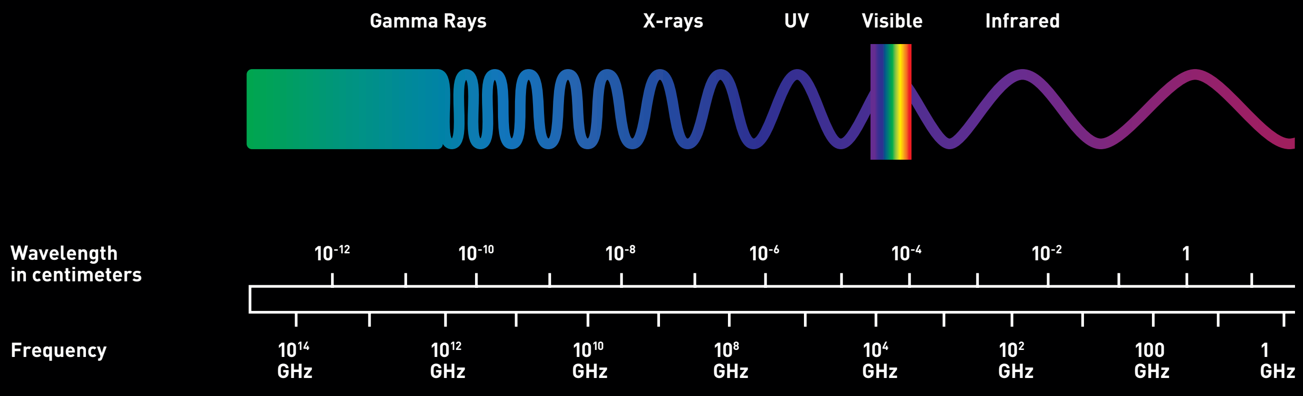
To find the earliest galaxies, probe stellar nurseries, and image planets as they are forming, astronomers need to see beyond visible light and into the realm of the infrared.

Infrared is the portion of the spectrum just beyond the red we see with our eyes. It is where many of TMT's key science questions will be answered.

As light from the most distant galaxies travels billions of light-years across the expanding Universe, it becomes stretched, or shifted, to longer, redder wavelengths. The TMT will be able to see and study this infrared light, which will help us better understand the origin and evolution of the Universe.

Infrared light, with its longer wavelengths, can also more easily pass through murky interstellar clouds. This will enable the TMT to look in on the birth of stars and the formation of planets.

The Electromagnetic Spectrum



The spectrum of our Sun (below) was generated by data recorded at Kitt Peak National Observatory. The dark lines indicate absorption of certain wavelengths of light by chemical elements within the Sun. Similar techniques can be used to detect chemical elements present in other stars.
Image credit: N.A. Sharp, NOAO/NSO/ Kitt Peak FTS/AURA/NSF

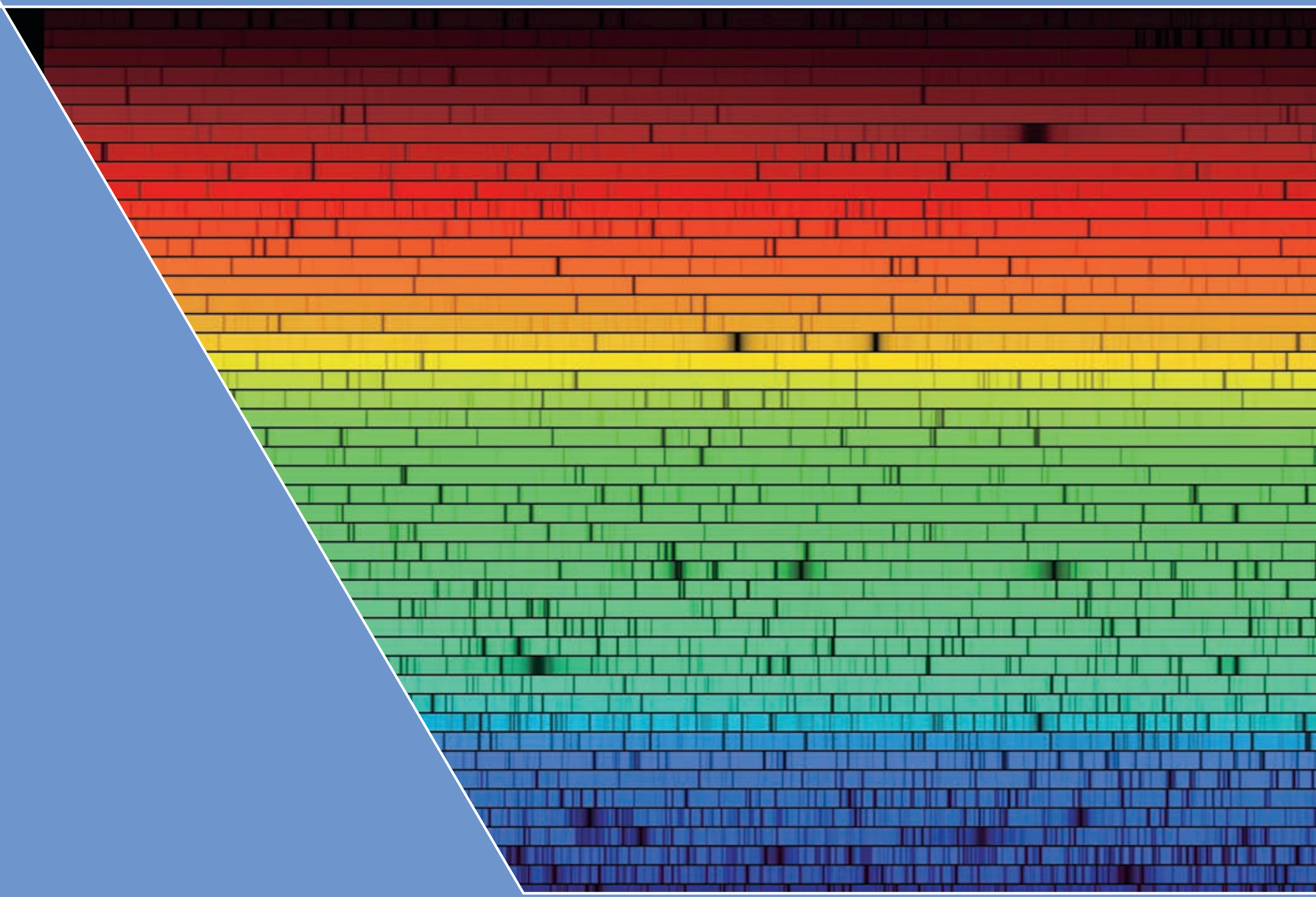
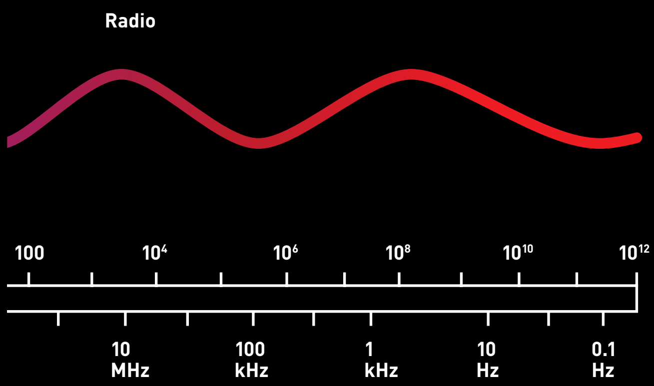


Image source: NASA Jet Propulsion Laboratory

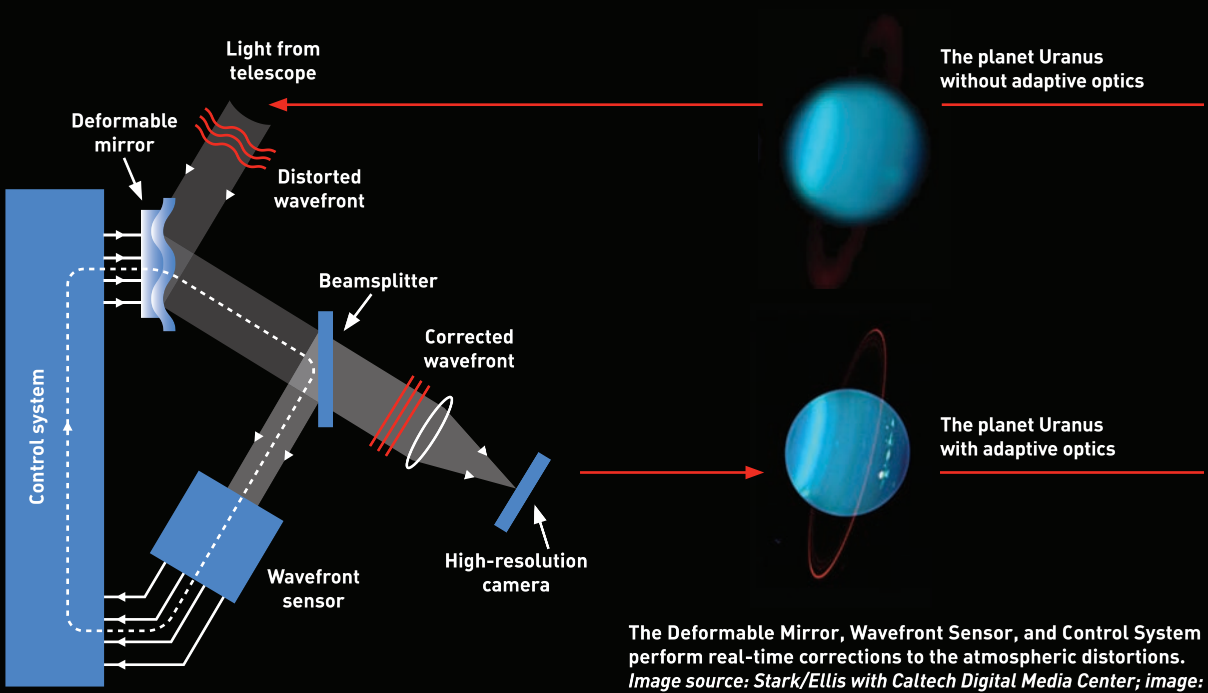


The Electromagnetic Spectrum
Though astronomical images reveal important and often stunning features, much of the science we learn comes from studying the light and analyzing the spectrum of an object. That is why each of TMT's first light instruments will be equipped with a spectrometer.

Like a prism, spectrometers separate light into its different colors or wavelengths. Information gained by studying the unique signatures of these spectra will enable astronomers to probe the structure and composition of the interstellar medium, the chemistry of stars and galaxies, and even measure cosmic distances by observing how far that light has been red-shifted due to the expansion of the Universe.

Earth's atmosphere is like a vast ocean, with waves, currents, and layers of different density. Turbulence in this ocean of air bends and blurs light that passes through it, giving stars their distinctive twinkling appearance. Though captivating when looking at the night sky, this twinkling severely limits the quality of astronomical observations. TMT's adaptive optics system will correct for this blurring, revealing stars and galaxies as crisply as if the telescope were in space.

The telescope will do this by shining lasers high into Earth's atmosphere to create artificial "guide stars." By continuously monitoring these points of light, the TMT will measure the turbulence of the atmosphere in real time. The telescope will then counter the blurring by making hundreds of microscopic adjustments each second to a small, pliable mirror. The result will be a sharper image and better science.



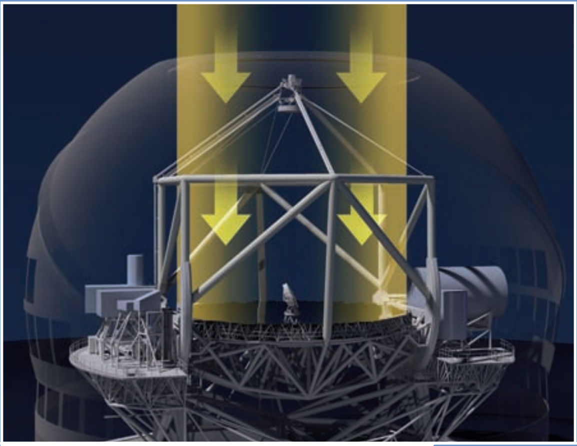
The Deformable Mirror, Wavefront Sensor, and Control System perform real-time corrections to the atmospheric distortions. ***Image source: Stark/Ellis with Caltech Digital Media Center; image: Sandbox Studio; Uranus images: Michael Bolte and Keck Observatory***

Gemini North adaptive optics image of Jupiter and its two red spots (which appear white because this is a near-infrared image; in visible light they appear reddish). By using adaptive optics, this image from the ground rivals the quality of images from space.

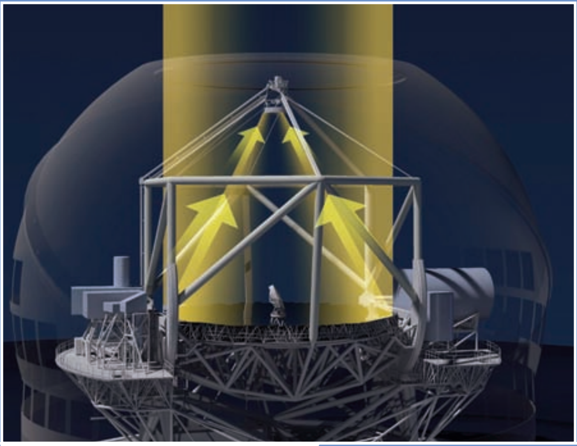
In many ways, TMT will be a vastly more powerful version of an amateur reflecting telescope. Light from distant objects will be collected and concentrated by a primary mirror (Mirror Path 1). The light will then travel to a secondary mirror (Mirror Path 2), which will reflect it back down to a third mirror (Mirror Path 3). From there, however, the similarity ends as TMT's light will be directed—not to an eyepiece—but to an adaptive optics system and a powerful suite of scientific instruments located around the telescope (Mirror Path 4). This special configuration will make TMT very nimble, allowing astronomers to do more science in less time.

When the TMT begins its research mission, it will have three very powerful scientific instruments. These "first-light" instruments, which include two infrared spectrometers and one optical spectrometer, will provide unparalleled science and imaging capabilities, taking full advantage of TMT's sensitivity and resolution.

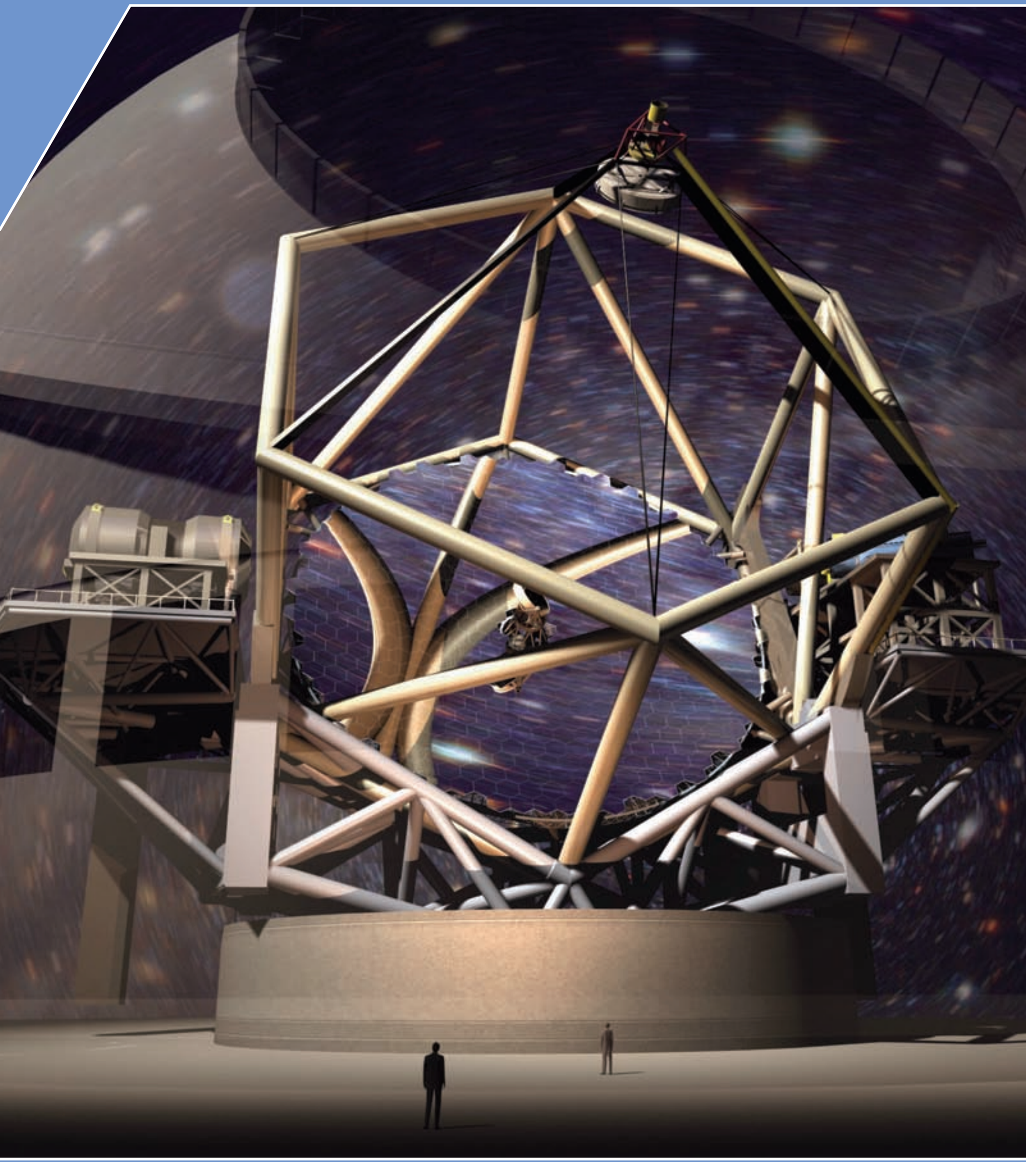
TMT's Light Path Configuration



Mirror Path 1



Mirror Path 2



TMT's First Light Instruments

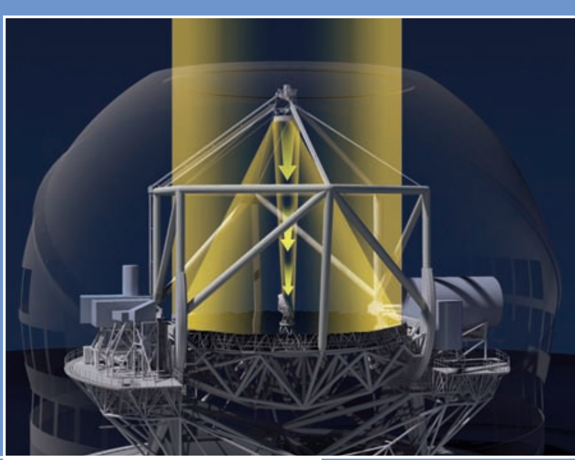
Wide Field Optical Spectrometer (WFOS)
will study and make images of objects in visible light

Infrared Imaging Spectrometer (IRIS)
will study and make images of objects in exquisite detail as they appear in infrared light

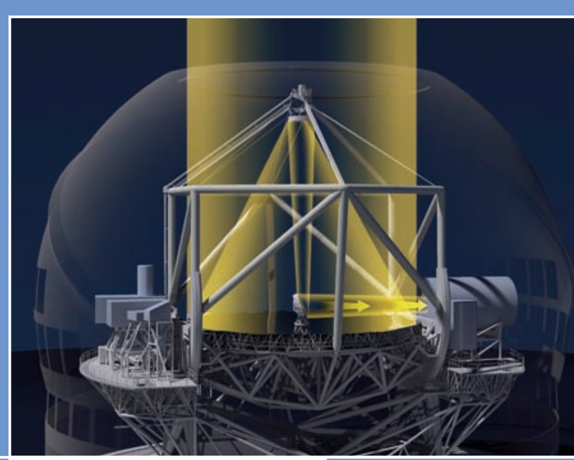
Infrared Multi-object Spectrometer (IRMS)
will analyze infrared light from many objects simultaneously

Photo-illustration: Todd Mason

Photo-illustrations: Dana Berry



Mirror Path 3



Mirror Path 4

TECHNOLOGY, INNOVATION, AND SCIENCE

The Thirty Meter Telescope will take advantage of the most successful technologies from today's most advanced telescopes. These technologies include adaptive optics, a segmented primary mirror, and three state-of-the-art scientific instruments at first light, creating a superior tool for science.

Photo-illustration: Todd Mason

TURNING STARLIGHT INTO INSIGHT

In the coming decades, TMT will explore the great mysteries of the Universe: black holes at the center of galaxies, assembly of the first galaxies and their evolution, birth and death of stars, and planets around distant stars. However, the most intriguing may be the questions we cannot foresee. It is by probing the unknown that TMT will reach its full potential, taking astronomers and the public on new journeys of exploration.

Image: HubbleSite

Design and typography: Sandbox Studio, Chicago

The Thirty Meter Telescope Project is an international partnership among the California Institute of Technology, the University of California, and the Association of Canadian Universities for Research in Astronomy, joined by the National Astronomical Observatory of Japan, the National Astronomical Observatories of the Chinese Academy of Sciences, and the Department of Science and Technology of India.

Acknowledgements
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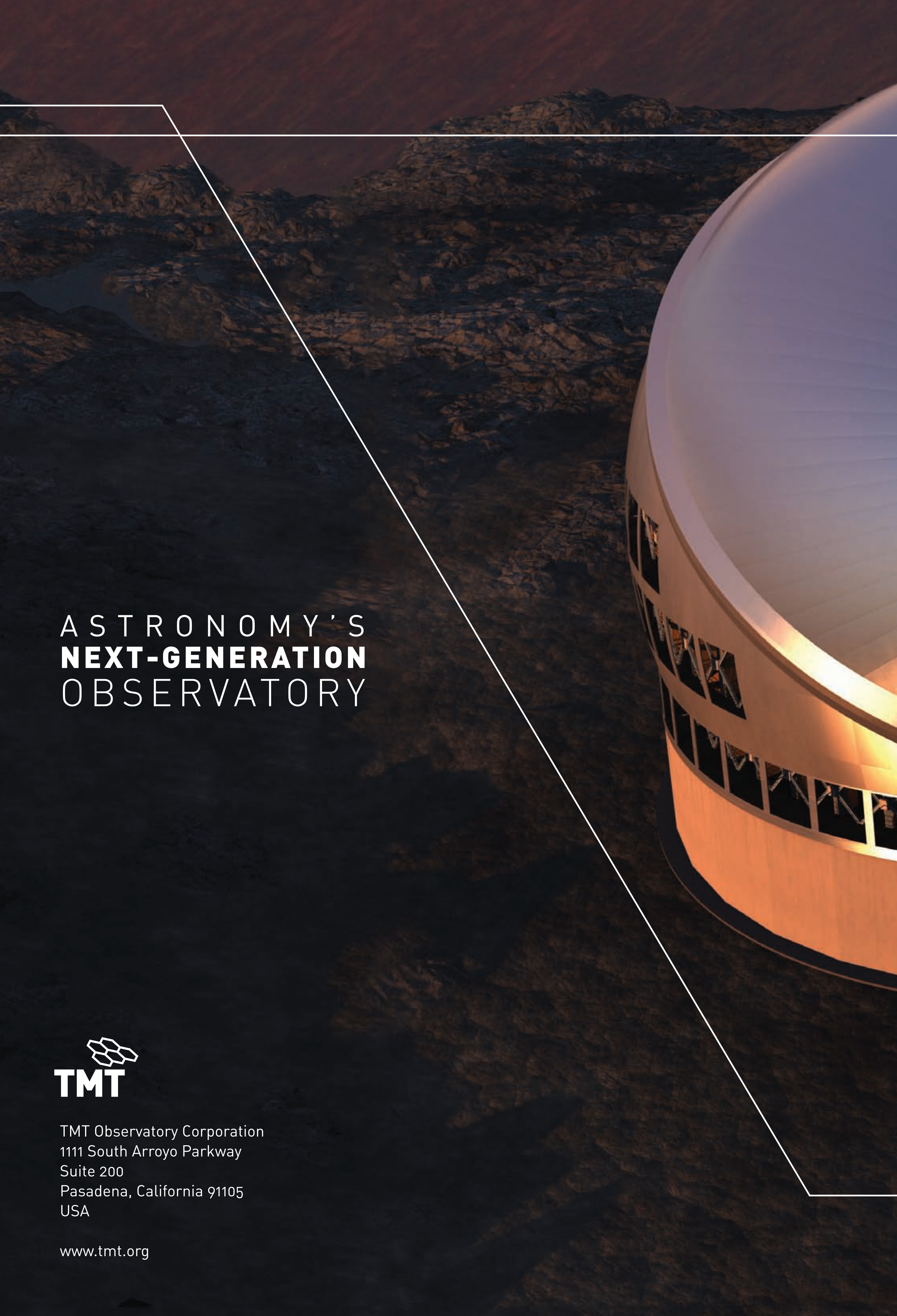

ASTRONOMY'S
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