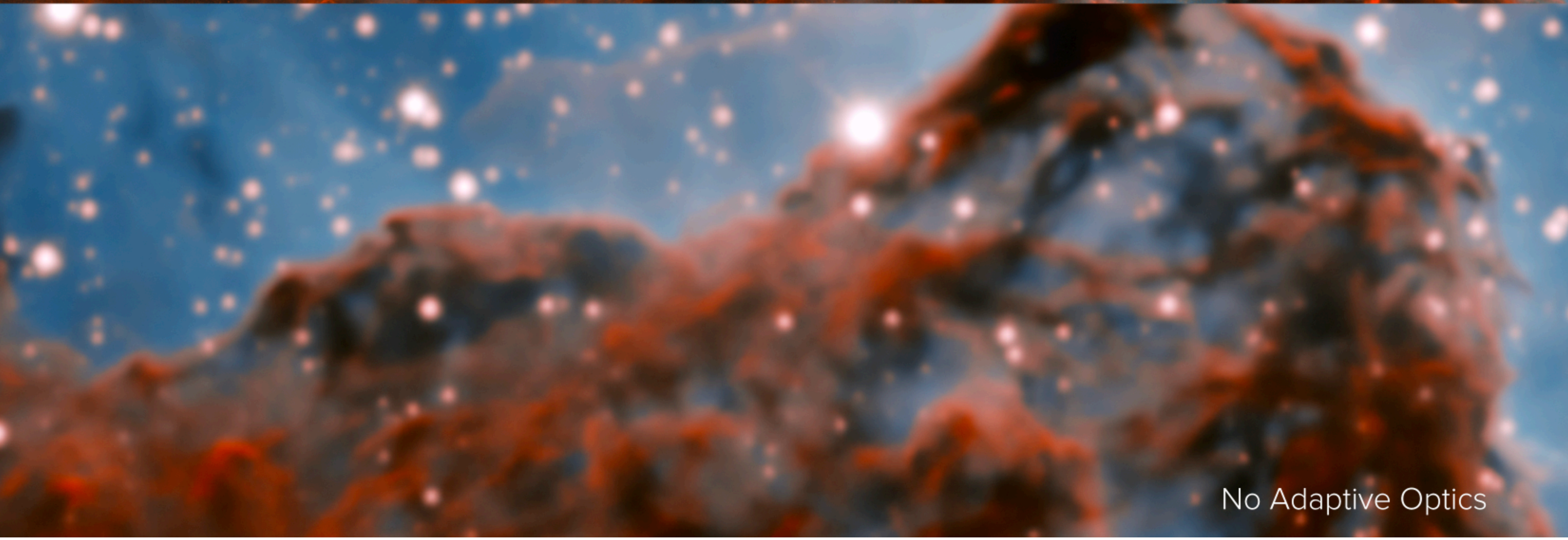
Adaptive Optics

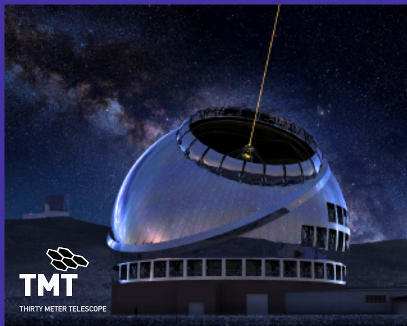


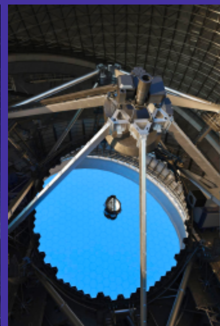
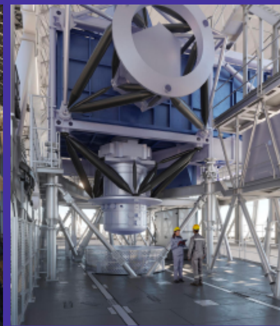
US EXTREMELY LARGE TELESCOPE PROGRAM

TMT THIRTY METER TELESCOPE

NOIRLab

GIANT MAGELLAN TELESCOPE



Adaptive Optics

The US Extremely Large Telescope Program (US-ELTP) is a joint endeavor of NSF's NOIRLab, the US national center for optical astronomy, and the organizations building two of the next generation of extremely large telescopes, the Giant Magellan Telescope and the Thirty Meter Telescope. This collaboration will lead to revolutionary astronomical discoveries and provide full-sky access to all US astronomers.

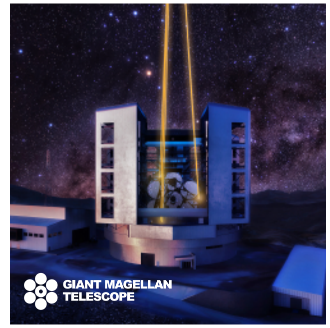
While constructing ground-based telescopes at the most ideal locations minimizes many factors that may distort images, atmospheric blurring effects cannot be completely removed by location or altitude alone. Different layers in Earth's atmosphere, have various temperatures and densities that interfere with the light we see, causing stars to twinkle. Engineers and scientists design software and technology that measure the distortion caused by Earth's atmosphere hundreds to thousands of times a second. Another system responds to the measured distortions by deforming the shape of specialized telescope mirrors, counteracting the blurring effects. This technology is called **adaptive optics**.

Both the Thirty Meter Telescope and the Giant Magellan Telescope have been designed from the beginning with state-of-the-art, built-in advanced adaptive optics capabilities. In normal operation, the telescopes will deliver images at infrared wavelengths that are up to 12 times sharper than those of the *Hubble Space Telescope* and more than 4 times sharper than those of the *James Webb Space Telescope*. The combination of ground-based and space-based telescope systems is highly complementary. Ground-based telescopes must compensate for Earth's atmosphere unlike space telescopes, but can provide a greater range of data with a broader variety of instruments, with comparable and sometimes even greater precision.

Guide Stars

Adaptive optics systems need bright reference sources, called guide stars from which to measure the atmospheric deformations. A **natural guide star** is a bright object, usually a star, close to the object being studied. The natural guide star may be the science target itself if it is bright enough. The information measured from the natural guide star is used to correct for the distortion caused by the atmosphere. The same adjustments that are made to correct the natural guide star's image are then made to the object under study.

Sometimes there aren't any bright natural guide stars close to the object of study. In this case, an 'artificial star' is created using a laser. Directing a laser to a layer of sodium atoms in Earth's atmosphere, located about 90 kilometers (56 miles) above the surface, causes the sodium to emit light, creating what is known as a **laser guide star**. The adaptive optics system then uses the observed distortions of the image of the laser guide star to correct the image of the object of study in the same way it does with a natural guide star. Both US-ELTP telescopes will use multiple laser guide stars to produce sharper images over a wider field of view than can be done with single guide stars.




Thirty Meter Telescope Adaptive Optics

The Thirty Meter Telescope adaptive optics system will support three science instruments and use a combination of six laser guide stars and three natural guide stars. The highly specialized adaptive optics system will correct for distortions at two different heights in the atmosphere. This ability, called multi-conjugate adaptive optics, provides the highest available image resolution over a wide field of view. Two highly specialized mirrors will adjust their shape and correct for the distorting effect of Earth's atmosphere about 1000 times per second. The system will use a minimal number of optical surfaces and contain a refrigerant unit to actively cool all optical elements to −30 degrees Celsius to reduce even the slightest heat that could distort the mirrors. Other adaptive optics modes will come in the future to provide additional capabilities with different resolutions and fields of view.

Giant Magellan Telescope Adaptive Optics

The adaptive optics system for the Giant Magellan Telescope includes six laser guide stars and seven adaptive secondary mirrors that hang above the giant primary mirrors' light path (second image from right). Each adaptive secondary mirror is paired and aligned with one of seven primary mirrors. The flexible glass-like secondary mirrors are 2 millimeters thick and can reshape their surface 2000 times per second to keep up with the constantly changing atmosphere (image far right). The telescope has three adaptive optics observing modes. One important mode is called ground layer adaptive optics, which corrects for turbulence lower in the atmosphere, providing improved image quality and sensitivity. This system allows the Giant Magellan Telescope to achieve better-than-atmospheric seeing over the widest field of view of any extremely large telescope.

Vocabulary

Adaptive Optics — Adaptive optics uses nearby bright stars or artificial stars and special sensors to measure the distortion caused by the atmosphere and deformable mirrors to correct it
Natural Guide Star — A bright reference star close to the object of interest, used to measure and correct the atmospheric distortion of light
Laser Guide Star — Artificial reference star generated by directing a laser into the atmosphere used to measure and correct the atmospheric distortion of light

About the images

Front: A comparison of the (top) western wall of the Carina Nebula taken by the 8-meter Gemini South telescope of the International Gemini Observatory and an image of the same region without adaptive optics (bottom) taken at the Cerro Tololo Inter-American Observatory with the Víctor M. Blanco 4-meter Telescope. *Credit: International Gemini Observatory/CTIO/NOIRLab/NSF/AURA*

Back: Purple Panel: (left to right) A digital artistic rendering of the Thirty Meter Telescope at night, propagating its laser to form laser guide stars for its adaptive optics system. A view of the Thirty Meter Telescope primary mirror and top-end, showing components of the laser launch system. A digital rendering of the adaptive optics system (blue box with associated structure) on the Thirty Meter Telescope with an instrument receiving the light mounted on the bottom. *Credit: TMT International Observatory*

Back: White Panel: (left to right) Artist's conception of the lasers that will be used on the Giant Magellan Telescope. The structure of the Giant Magellan Telescope primary and secondary optics. The adaptive secondary mirror is used to perform adaptive optics. *Credit: GMTO Corporation*

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