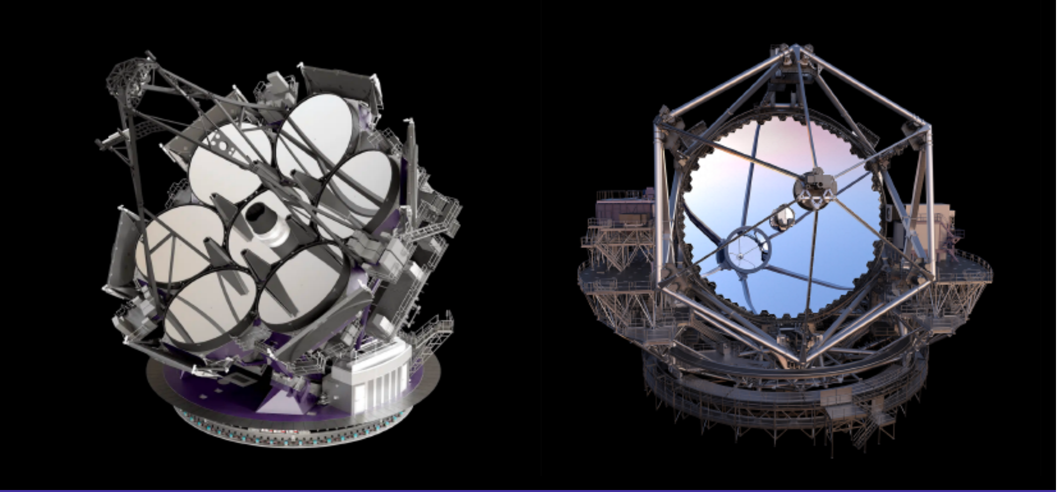
Exoplanet System Formation

US EXTREMELY LARGE TELESCOPE PROGRAM

TMT THIRTY METER TELESCOPE

NOIRLab

GIANT MAGELLAN TELESCOPE



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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.

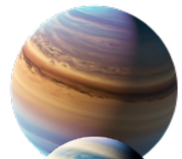
Planets orbiting other stars than the Sun, or *exoplanets*, are among the most interesting yet difficult objects to observe. Relative to their host stars, exoplanets are small, extremely dim, and close to their much brighter hosts. The study of exoplanets is a relatively new field in astronomy: the first planet outside our Solar System was discovered only in 1992. New instruments on the ground, and more importantly new missions in space, have contributed greatly to the discovery of exoplanets, confirming the 5000th exoplanet in 2022. These powerful new capabilities have excelled at discovering planets, but cannot fully characterize them. As a result, there is still much we don't know about the demographics of exoplanets and the processes by which they form and evolve. The Thirty Meter Telescope and the Giant Magellan Telescope will revolutionize exoplanet science with their extreme sensitivities and advanced imaging and spectroscopic capabilities. These telescopes will provide powerful exoplanet characterization capabilities and greatly expand the types of planets we can discover and study in detail.

The exoplanets discovered to date can roughly be broken down into four main categories: gas giants, Neptunians, super-Earths, and terrestrial. Most discovered Neptunians, and similar smaller planets called Mini-Neptunes, have short orbital periods and are the most common type of planet discovered to date, while giant planets are potentially less common but may provide key information about the process of planet formation. The US-ELTP telescopes will discover a broader range of planets that will help us determine what the true exoplanet census looks like. They will also explore the compositions of these planets, allowing astronomers to unravel why and how planets form around some stars but not others, deepening our understanding of planet and star formation.

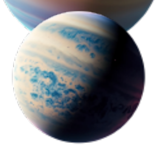
To understand the true variety of exoplanets and how these systems formed, planet-forming disks of dust and gas surrounding stars, especially Sun-like stars, need to be explored. These younger systems tend to be more distant from Earth than the mature exoplanetary systems, making them difficult to study. The fine **spatial** and **spectral resolution** of the Giant Magellan Telescope and the Thirty Meter Telescope will allow astronomers to probe the innermost regions of the disks of gas and dust where planets form. Analyzing the densities and dynamics of these disks will lead to a better understanding of how gas and dust are distributed over time, what causes planets to migrate closer to or farther from their host stars, and how disk compositions help determine planet constitution. Studying these disks will reveal the relationship between the origins of early-forming planets with the properties of mature planets and their stars.

The US-ELTP telescopes will also track the abundances of chemical species, including carbon and oxygen, within the protoplanetary disks to better understand the processes that form rocky planets like Earth and identify systems that would likely host planets within habitable zones. A habitable zone is the area around a star in which a planet's temperature allows liquid water to exist on its surface. Too hot and any water on the planet is turned to steam; too cold and the water remains solid ice. The location and extent of the habitable zone are influenced by various factors including the size, temperature, and distance of its host star. The Thirty Meter Telescope and Giant Magellan Telescope will allow us to explore the origins of Earth-like planets and gain insight into our own Solar System and the prospects for life elsewhere in the Galaxy.

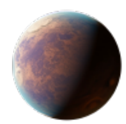
Exoplanet Types



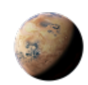
Gas Giant
Planets that exceed 10 Earth masses and with radii several times that of Earth are considered gas giants. They are predominantly composed of hydrogen and helium.



Neptunian
Neptune-like planets are similar in size to Neptune, while Mini-Neptunes are slightly smaller. Neptunians often have thick clouds and can be icy or considered warm if they orbit close enough to their star. Mini-Neptunes have rocky cores and thick atmospheres.



Super-Earth
Planets between 1 and 10 Earth masses yet are lighter than ice giants like Neptune. Super-Earths are typically composed of hydrogen and helium, but can also have a rocky surface.



Terrestrial
Terrestrial or rocky planets are typically composed of silicon, oxygen, or metals and are about the same size as Earth or smaller. They typically form without a significant atmosphere.

Vocabulary

Spatial Resolution — The ability to distinguish a feature at one location from another
Spectral Resolution — The ability to distinguish between fine wavelength intervals

About the Images

Front: An artist's impression of an exoplanet forming in a disk of a newly formed star. The Thirty Meter Telescope and the Giant Magellan will deepen our understanding of planet and star formation. *Credit: NOIRLab/NSF/AURA/P. Marenfeld*

Back: The large mirror of the Thirty Meter Telescope (left) and seven of the world's largest mirrors of the Giant Magellan Telescope (right) will provide the necessary power to observe and explore faint, distant exoplanets that will help us understand planetary formation and evolution. *Credits: TMT International Observatory; GMTO Corporation*

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