Breaking Ground Now: **Next-Gen Giant Telescopes**

A new generation of larger, faster and more far-reaching telescopes is poised to revolutionize our understanding of the universe.

The Thirty Meter Telescope is illustrated at night on its proposed site in Mauna Kea, with the laser-guide-star system illuminated.

TMT Observatory Corporation

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The largest telescope on Earth is currently the Gran Telescopio Canarias in the Canary Islands of Spain, which was built in 2009 with an aperture of 10.4 m. This 10-m design will hold the record for another four to eight years, but a new crop of next-generation telescopes now under construction will make a technological leap in instrumentation and size – some to 30 and 40 m. And that will change everything.

Upon its scheduled completion in 2022, the Thirty Meter Telescope (TMT) will be one of the largest telescopes in the world. Conceived in 2003 by the Association of Canadian Universities for Research in Astronomy, the California Institute of Technology, and the University of California, the TMT project consortium now includes Japan, India and China. In July, after years of preparation and instrument development, the TMT project collaboration announced the start of the observatory construction phase on the Mauna Kea site in Hawaii.

The TMT will be a wide-field Ritchey-Chrétien *f*/1 telescope with a 30-m-diameter hyperboloidal primary mirror made up of 492 segments (each measuring 1.44 m in diameter), along with secondary and tertiary mirrors.[1] Following in the footsteps of its predecessor Keck, the TMT's segmented design will use sensors, actuators and control systems to carefully position each segment so that the entire assembly behaves like a single monolithic mirror.

With its wide 20-arcmin field of view, the $1.47 billion (in 2012 base-year dollars) TMT will be the world's most advanced and capable ground-based observatory for optical, near-infrared and mid-infrared wavelengths. First-light instruments on TMT will include the Wide-Field Optical Spectrometer and Imager (WFOS), the Near-IR Integral Field Spectrograph and Imager for AO (adaptive optics) corrected images (IRIS), and a Near-IR Multislit Spectrograph and Imager for AO-corrected images over a 2-arcsec field (IRMS). The TMT's science goals will be to study faint quasars and early galaxies to gather information about the evolution of the universe, and to provide finer details of objects in the solar system and around other stars.

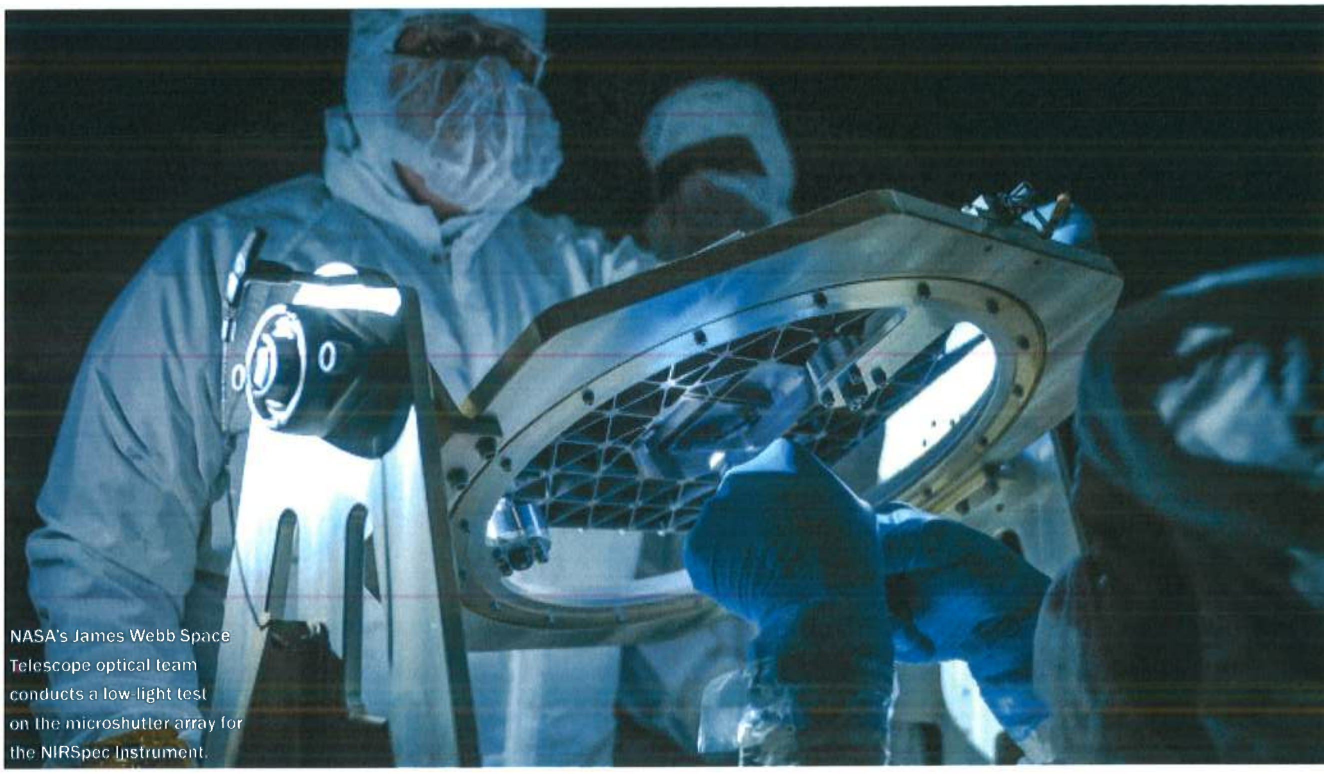
A European scope in Chile

With a primary mirror measuring a whopping 39.3 m, the $1.3 billion European Extremely Large Telescope (E-ELT) – which will see first light in 2024 – will be even bigger than Hawaii's Thirty Meter Telescope. Indeed, it will be the largest optical and infrared telescope in the world by far, probably for decades to come. Planned by the European Southern Observatory, which includes 14 European countries and Brazil, the telescope will be located high atop Cerro Armazones in the Atacama Desert in northern Chile, where site construction began on June 20 this year. When E-ELT is completed, it will be able to gather 15 times more light than today's largest telescopes.[2] Its resolution will be close to the theoretical diffraction limit, nearly four times sharper than that of today's best telescopes.

Like TMT, the massive E-ELT primary mirror will be a honeycomb design incorporating 798 individual hexagonal segments, each measuring 1.45 m across. The E-ELT's unique optical design includes five mirrors total: three anastigmatic mirrors (primary M1, secondary M2 and tertiary M3) and two flat mirrors (M4 and M5). The first three mirrors fold the optical path to a workable length and direct the incoming light to two flat mirrors that direct the beam to the foci. The AO corrections on existing telescopes are usually done after the focal point in the optical path, whereas the AO corrections in the E-ELT design happen before the focal point, said astronomer Dr. Jochen Liske in the E-ELT Programme Science Office in Garching, Germany. The M4 is a thin, flexible AO mirror with thousands of actuators that deform it every few mil-

European Southern Observatory

The future E-ELT observatory dome, 100 m in diameter, sits in contrast to four current 25-m-high Very Large Telescope units and the Colosseum in Rome.



NASA's James Webb Space Telescope optical team conducts a low-light test on the microshutter array for the NIRSpec Instrument.

NASA/Chris Gunn

liseconds to compensate for atmospheric interference. This design enables more accurate, real-time wavefront control in the optical path.

As the "biggest eye on the sky," E-ELT will able to quickly obtain extremely precise observations of all kinds of things, such as extrasolar planets and recession velocities of distant objects in the early universe. "The E-ELT measurements would give us an entirely new, direct and model-independent handle on the expansion history of the universe, and may therefore help us to figure out the nature of the acceleration," Liske said. "There won't be anything comparable to the E-ELT when it sees first light in 10 years."

JWST

The long-awaited James Webb Space Telescope (JWST) began its planning stage in 1996, and despite congressional delays and budget overtopping, NASA claims the project is on budget and on track for launch in 2018. Designed to replace the Hubble Space Telescope, it isn't just the next-generation space telescope; it's the end-all, be-all telescope, according to project veterans.

At 6.5 m in diameter, its primary mirror is three times as big as Hubble's. While that might not sound impressive next to the E-ELT's 39.3-meter primary mirror, the JWST's location in space will make a big difference. The telescope will be located 1.5 million km from Earth at the L2 halo orbit, an orbital position where the combined gravitational pull of the Earth and sun exactly cancel the centrifugal effects of the orbit. Besides having zero atmospheric distortion, it will have no thermal effects to deal with, either. The entire telescope will be a very cold 40 K, the ambient temperature of the surrounding space environment.

"We will be able to see objects so faint, a person could name the photons as they hit the detector," said a JWST project scientist based at Ball Aerospace in Boulder, Colo. "The background light of a ground-based telescope would make it impossible to pick out such faint and distant objects."

JWST will have several special instruments that will enable observations at wavelengths ranging from 600 nm (in the visible orange region) to 28.5 µm (mid-IR). This fall, the NASA optical team is conducting low-light tests on Webb's Near Infrared Spectrograph, an instrument developed to obtain information on more than 100 objects simultaneously over a 9-arcmin^2 area via an innovative microshutter array.[3] The microshutter array has 250,000 shutters that open and close individually. The MEMS (microelectromechanical systems) design will be the first spectrograph of its kind in space.

Will JWST be worth the estimated $8.7 billion price tag? Absolutely, say NASA experts – to the extent that astronomy textbooks will need heavy updating.

LSST and GMT

Two other long-awaited next-generation telescopes are the Large Synoptic Survey Telescope (LSST) and the Giant Magellan Telescope (GMT). For its 10-year-long survey of the entire sky, LSST's 8.4-m mirror isn't as impressive as those of other upcoming scopes; the big deal is its digital camera – the world's largest, at 3.2 billion pixels. The LSST project will produce 30 terabytes of data each night, creating a database of 100 petabyes – and bringing optical astronomy into the petascale era.[4] In August, LSST got the go-ahead to begin construction on Cerro Pachón, Chile, and is scheduled for completion in 2019. For a billion-dollar price tag over its 10-year life, LSST will focus on problems such as dark energy, galaxy formation and hazardous asteroid identification, among others.

Another next-gen giant, the GMT will have a segmented design like TMT and E-ELT, except the individual mirrors will number only seven, albeit seven of the largest ever to be cast, each measuring 8.4 m.[5] When combined, the telescope will be 25.4 m in diameter. Also like TMT and E-ELT, the giant telescope is expected to come online at Las Campanas Observatory in the Chilean Andes in 2022. Astronomers will use the scope to search other planets for telltale signs of life, to probe the formation of stars and galaxies shortly after the big bang, and to explore dark matter and dark energy.

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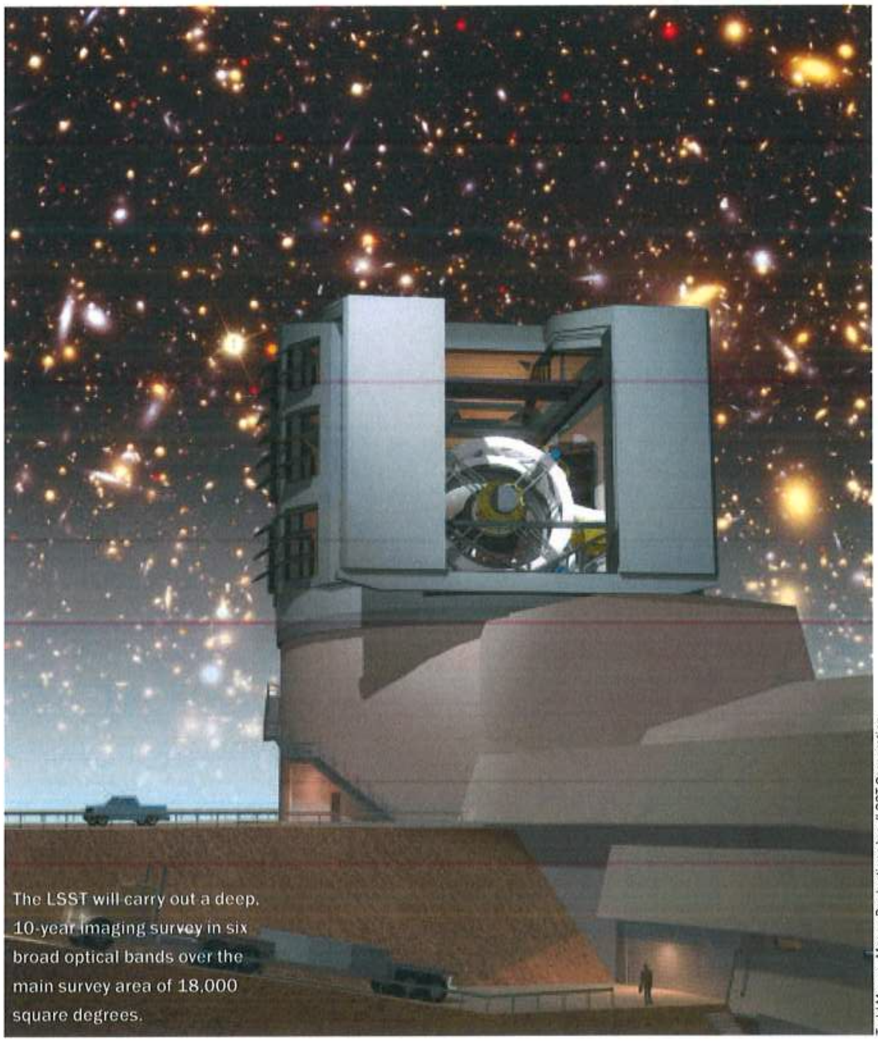

The LSST will carry out a deep, 10-year imaging survey in six broad optical bands over the main survey area of 18,000 square degrees.

Todd Mason, Mason Productions Inc./LSST Corporation

The Giant Magellan Telescope in Chile will combine seven of the largest mirrors ever cast, each weighing roughly 20 tons.

GMTO Corporation