STRENGTH IN NUMBERS

by Katie Neith

Caltech builds on past successes to help create the world's most powerful telescope.

Since its inception, Caltech has been dedicated to undertaking big, risky projects, particularly in the area of exploring our universe. Astronomer George Ellery Hale, one of the men credited with molding the Institute into a world-class science and engineering college, was the primary creative force behind the famed Palomar Observatory. Now, nearly 70 years after the groundbreaking 200-inch Hale Telescope—then the world's largest—saw first light on that Southern California mountaintop, Caltech, along with the University of California and a group of international partners, is again leading the way toward the construction of what will be the world's most advanced ground-based telescope, the Thirty Meter Telescope, or TMT.

"Thinking big and taking on the world's largest astronomical telescopes is something we've been doing since the 1920s—it's in our blood, in some sense," says astronomer Shri Kulkarni, director of Caltech Optical Observatories.

Like those observatories that have come before, he says, TMT is an ambitious project of incredible scope, a project that both has been and will be years and years in the making. Alone, the still-ongoing process of planning and developing TMT has taken over a decade. It's estimated that constructing the telescope, building its instruments, and getting all of its mechanical systems online will take another eight years. The site where TMT will be built was blessed in the traditional Hawaiian manner October 7, and first light is currently planned for the early 2020s.

So why has Caltech taken on a leadership role in such a time-intensive challenge? The answer, like the project, is complex.

TMT is not being developed from scratch, but, at least figuratively, will be built on the shoulders of giants—the two 10-meter telescopes at the W. M. Keck Observatory (WMKO). The Keck telescopes were also a project in which Caltech played a large role, and the achievements seen there have shaped plans for TMT.

"The 200-inch telescope at Palomar was a huge success, and the Keck telescopes were just as great an accomplishment. TMT is the next step," says Kulkarni.

"There are no serious technical challenges with TMT; they were all solved in the building of Keck," adds astronomer Judith Cohen, who worked extensively on the WMKO and is a member of the TMT science advisory committee.

The twin Keck telescopes currently stand as the world's largest optical and infrared telescopes. Perched proudly on the summit of Mauna Kea in Hawaii—the same site that in 2013 was officially approved to become TMT's home—the Keck Observatory was the first to piece together segments of reflective glass to form one giant primary mirror. While the two Keck telescopes have 36 hexagonal pieces for each of their mirrors, TMT will use 492.

"The sensitivity gains of TMT over Keck will range from about a factor of 10 to a factor of 100, depending on what you are trying to do," says astronomer Chuck Steidel, who has been part of the TMT project since its inception. "As we found with Keck, such gains in sensitivity result in all kinds of new scientific discoveries that are not written down in your initial research goals."

One of the really striking things that astronomers have found with Keck, Steidel notes, is that the scientific justifications astronomers gave in the original proposal for the observatory, to convince funders to support the project, now sound so mundane compared to what those telescopes actually revealed—everything from the information that helped demote Pluto from the status of planet, to conclusive proof that the center of our galaxy harbors a supermassive black hole to the discovery and characterization of the most distant galaxies, going back to when the universe was only 10 percent of its current age.

And once these powerful instruments start gathering the kinds of data you couldn't have dreamed up, Steidel says, anything is possible.

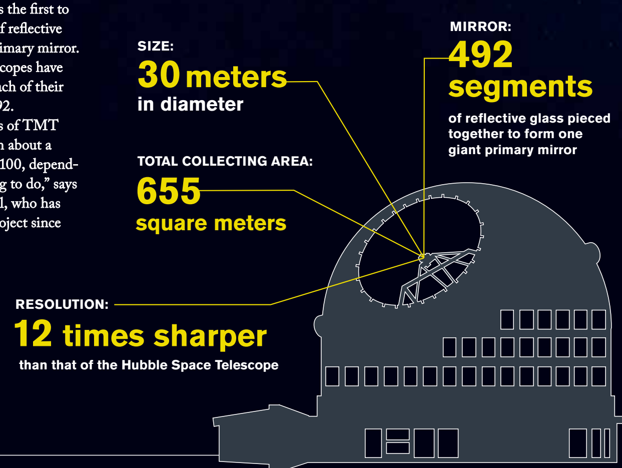
"You start experimenting, trying out observations that would have been impossible using previous equipment, and all of a sudden you have a huge number of new discoveries," he notes. "I expect that's going to happen with TMT."

A Closer Look

Almost since the WMKO telescopes saw their first light, TMT has been the dream child of astronomers imagining what they might do next.

"Very early on, we decided to get involved with the University of California [UC] system—our partners in Keck—in developing a concept for an even larger telescope," says astrophysicist Tom Soifer, a TMT board member since 2010 who is currently chair of the Division of Physics, Mathematics and Astronomy at Caltech.

Back then, that concept went by the name of CELT, or the California Extremely Large Telescope. Caltech and the UC participated in a technical and scientific study—asking what it's possible to do with a telescope of that size and considering what its most important areas of study should be—that served as the foundational argument for pursuing TMT.



"A number of the Caltech astronomy faculty were engaged in those questions and concluded that taking on this project was, indeed, an immensely exciting opportunity," says Soifer. "The only issue was money, so that was really what drove the project."

TMT was made possible thanks to the vision of the Gordon and Betty Moore Foundation, which provided funding for the development of the design of TMT beginning in 2004, followed by grants for early construction, with the foundation's support totaling $140 million to date.

"Nothing would have happened if it wasn't for Gordon Moore and the Moore Foundation," Steidel says.

"The Moores came in at the beginning when it was a very risky move," adds Cohen. "I'm sure they were well aware that this whole thing could have foundered, and they've been very patient in keeping faith that it will all happen."

Caltech alumnus and astronomer Jerry Nelson (BS '65), principal designer and project scientist for the Keck telescopes and winner of the Kavli Prize in Astrophysics for his work with giant telescopes, has helped secure further funding by pointing out that TMT isn't going to be quite the financial risk it would otherwise be.

"Jerry gave this provocative colloquium in 2000 where he claimed that we had broken the cost curve with Keck. In other words, we built a bigger telescope without its price increasing too fast compared to previously existing telescopes—meaning that it was a good value relative to the scientific benefit—and that to try for something bigger would really just be a scaling up of proven technologies," remembers Cohen.

Further bolstering the astronomer's case for another giant telescope was the National Academy of Sciences' 2001 decadal survey, which listed the construction of a 30-meter segmented-mirror telescope as its top recommendation for the advancing of ground-based astronomy and astrophysics.

In 2003, a scientific advisory committee—made up of representatives from partner institutions and the broader astronomy community—met for the newly named TMT, and Nelson was named project scientist. The aim of this committee was to "help match the technical goals of TMT with the demands of the scientific community for a next-generation observatory," according to Steidel. In other words, if you're going to build a really big telescope, you need to make sure it's going to help you answer your most interesting and difficult questions.

"TMT will be able to significantly further our search for early galaxies."

Caltech's scientists believe TMT will be able to do just that. After all, Steidel says, with big scopes comes exponentially bigger science. A telescope's ability to gather light and see faint, faraway objects increases with the area of the primary mirror, and the telescope's ability to resolve details increases with the mirror's diameter.

Uncharted Territory

A 30-meter mirror, then, should be able to tackle fundamental and currently unanswered questions regarding cosmological issues, including the birth of stars and galaxies, the composition and expansion of the universe, and the characteristics of exoplanets.

Right now, astronomers are tantalizingly close to seeing the formation of the first galaxies, but TMT will provide the sensitivity to reach that goal. This is because the sheer size of the TMT primary mirror's collecting area will allow researchers to see objects that are, at a minimum, 10 times fainter than those currently observable via the Keck telescopes, according to Cohen. Maximum gains may be closer to a factor of 100.

"But even 10 is pretty good!" she says. "That will get us back toward the earliest galaxies and give us the ability to study them in much more detail than we can now."

Where Cohen really sees TMT shining, however, is in adaptive optics, or AO. This technology works to correct distortions, such as blurriness, that can happen when light from an astronomical object travels through Earth's atmosphere. It's what you see happening when a star appears to flicker in the night; AO takes out the twinkle. "Imaging of exoplanets—those outside our solar system—should be absolutely fabulous with a 30-meter telescope," she says.

Soifer looks to TMT for help in answering what he thinks is the ultimate question: "Is there life on other planets like there is on Earth?" Runners-up, he says, include fundamental questions of physics like "What is dark energy?"—the hypothetical form of energy responsible for the accelerating expansion of the universe—and "What is dark matter?"—referring to mass that appears to be missing from the universe.

"TMT will also address the key question of when galaxies first formed," adds Richard Ellis, who served on the TMT board during the formative years of the project. "We have used our current facilities, like Hubble and Keck, to their limits in this important quest and are close, we believe, to finding the first generation of stellar systems when the universe was barely a few percent of its current age. With the combination of its large aperture and exquisite angular resolution, TMT will be able to significantly further our search for early galaxies."

Kulkarni, for his part, hopes to use TMT to look at gamma-ray bursts, which are massive, brilliant explosions of electromagnetic radiation that have been observed in distant galaxies. When a gamma-ray burst begins, he says, he will be able to scan the skies near the burst with TMT to get an infrared spectrum and will be observing the young universe when it was barely 100 million years old.

"With TMT one could even imagine taking pictures of other solar systems 30 light-years away," says Kulkarni. "This may be within reach for us—just imagine!"

He says the things TMT is expected to do will be possible simply because no one is trying to reinvent the wheel with this telescope.

"Caltech, as an educational and research institute, will be able to draw upon the top experts in the world, and that will only enrich the project."

"We are taking all the technologies and lessons learned from Keck, Palomar, and other projects so that the instruments we are designing for TMT receive the benefit of all previous generations of instruments," says Kulkarni. "We're not spending millions of dollars on something that may or may not work. We know it works—the Keck telescopes work every night—so we're really benefiting from our past experience."

In fact, the goal of TMT is to achieve the best resolution of the telescope—something that typically takes months on a new telescope—from day one, says Steidel. For his own research, he is looking forward to using TMT to better explore how galaxies formed in the young universe and how they have evolved to the present day. TMT will allow astronomers to both map out the distribution of galaxies and the tenuous gas between them, as well as to "dissect," using extremely high spatial resolution, what is going on within individual galaxies.

"Who knows what we're going to find when things can be dissected at that level," he says. "What we call the 'discovery space'—or things we will be able to see with TMT—becomes huge."

Scope of Impact

The TMT project is not just huge in size and potential astronomical power but also in the breadth of its collaboration. In addition to Caltech and UC, the TMT collaboration now includes national institutes of Japan, China, and India, along with the Associated Canadian Universities for Research in Astronomy.

"This project is unique in that it is a multinational, public/private project," says Soifer. "I don't know of any collaboration, in any field of science, that is anywhere near as large as TMT and that has governments, a state university, and a private university attached. We really are breaking totally new ground in that sense."

Kulkarni, who played a large outreach role in promoting TMT in his native India to convince that nation to join the project, says that because of the cultural differences between the various members of this partnership, the collaborative process has been a lot more work than most people had expected. Nonetheless, he thinks it is worth it.

"All the leadership has been taken by the private sector, that is, private philanthropy has funded and seeded this project, but the bulk of the money for construction and operation will come from international governments," Kulkarni explains. "In a way, that can be an ideal thing—private funding can usually move things quickly and then government is very good at maintaining support.

"I think some partners are a bit surprised that this small institute in Southern California can be a legitimate partner," he notes, "but we've proven ourselves with our history, our track record. As leaders of a global project, we've become plugged into the best of the best scientists in each of these countries. Caltech, as an educational and research institute, will be able to draw upon the top experts in the world, and that will only enrich the project."

Steidel agrees, adding that he sees TMT as a way to help expand the field of astronomy around the globe.

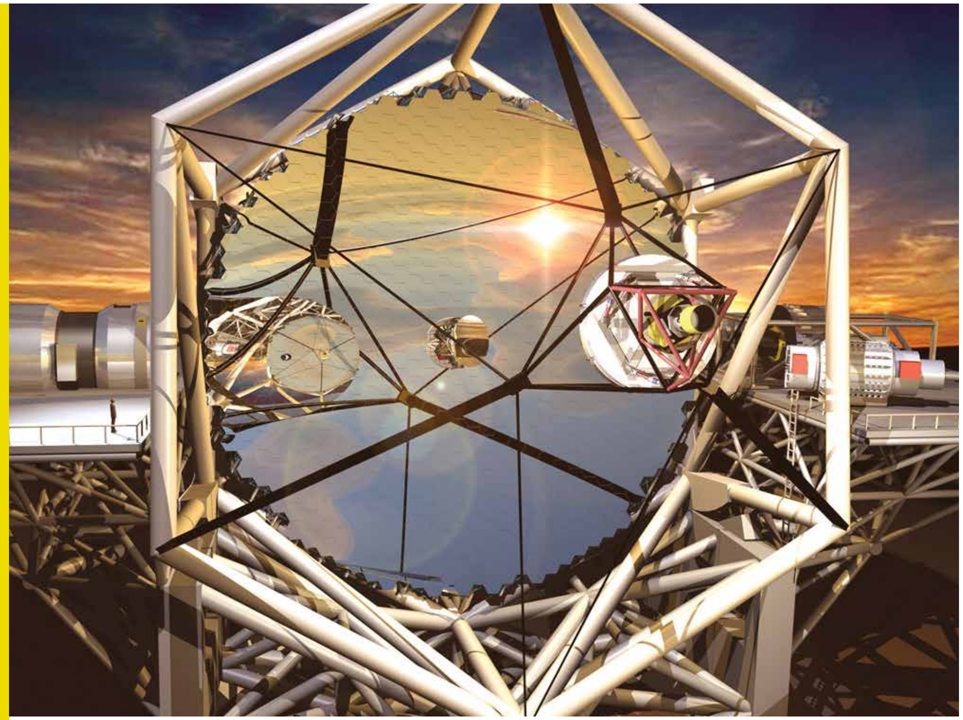
"It will be exciting to develop new ties and collaborations with scientific communities that we haven't worked with before," he says. "The potential for these collaborations is huge."

The project team has also worked with the people of Hawaii to earn the trust needed for permission to build TMT on Mauna Kea.

That's especially important because Mauna Kea is the best site for TMT. In fact, it's the premiere site in the Northern Hemisphere for any type of ground-based astronomy due to its stable atmosphere, lack of city lights, and cold and dry climate, all of which are ideal for optimal sky gazing. The fact that Caltech, along with many of the project's partners, has other observatories there is also useful, says physicist Edward Stone, who has been vice chair of the board of directors for TMT and is now the TMT executive director.

"There is creative synergy among the different capabilities offered by the telescopes that share the Mauna Kea site, and TMT would be the crown jewel," he explains.

"We'll have the world's largest telescope, an amazing site in Mauna Kea, and 10th-generation instruments—we're at the top," adds Kulkarni.



And the top is exactly where he and his colleagues would like to stay.

"Caltech has been blessed with having access to the world's biggest, ground-based telescopes ever since the opening of the 200-inch Hale Telescope in 1948, and that's been a key attractor to Caltech," Soifer says. "It's been the foundation from which we've built one of the world's great astronomy programs. I see TMT as essential to maintaining that leadership." E&S

Judith Cohen is the Kate Van Nuys Page Professor of Astronomy.

Richard S. Ellis is the Steele Family Professor of Astronomy.

Shri Kulkarni is the John D. and Catherine T. MacArthur Professor of Astronomy and Planetary Science, and director of Caltech Optical Observatories.

Tom Soifer is a professor of physics, the director of the Spitzer Science Center, and the Kent and Joyce Kresa Leadership Chair of the Division of Physics, Mathematics and Astronomy.

Chuck Steidel is the Lee A. DuBridge Professor of Astronomy.

Edward C. Stone is the David Morrisroe Professor of Physics and vice provost for special projects. He is project scientist for the Voyager mission and served as director of the Jet Propulsion Laboratory from 1991 to 2001.

An artist's rendering of TMT (above) shows the telescope without its protective domed enclosure.