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Features Astrochemistry

How the Giant Magellan Telescope got its mirrors

The powerful instrument promises to reveal the cosmos in greater detail than ever before. To accomplish this feat, engineers had to make the world's largest mirrors

by **Fionna Samuels**

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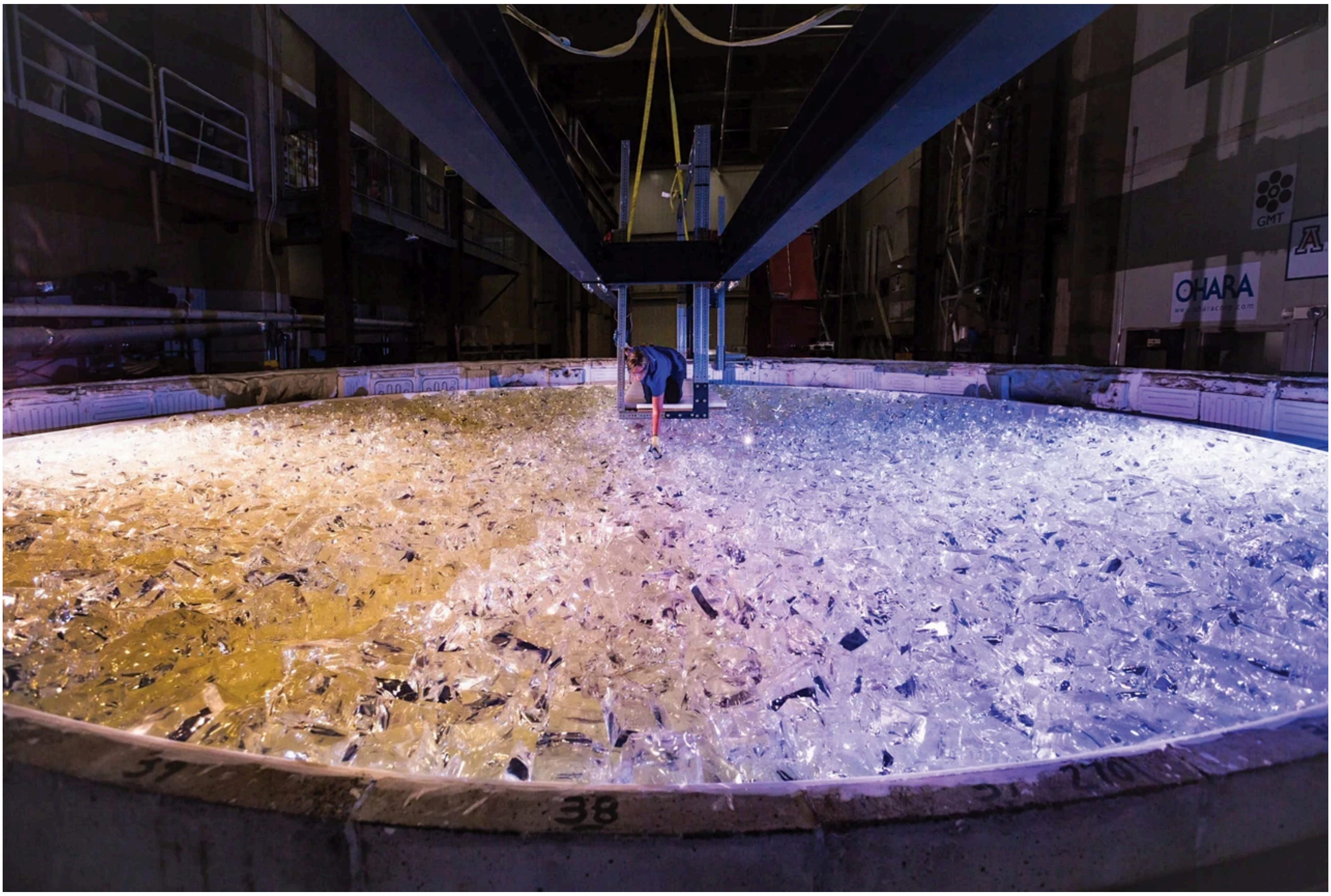


To build the Giant Magellan Telescope, engineers constructed seven massive mirrors, the largest mirrors in the world. Each one began as thousands of glass chunks carefully placed by hand (shown). | Credit: Giant Magellan Telescope – GMTO Corporation

Since time immemorial, humans have sought to understand the cosmos. Ancient civilizations traced the movement of stars by eye, passing down their observations through written and oral histories. The light-focusing lenses of the first telescopes brought planets and distant galaxies into focus and changed our understanding of our place in the universe.

Now scientists are turning to a new class of fantastically large telescopes to study space in mindboggling detail, greater than ever before. Governed by an international consortium of research institutions, the Giant Magellan Telescope (GMT) is one such beast. Destined to study the skies from Chile's Atacama Desert, it entered the final design stage last summer.

“Telescopes get bigger because you want to collect a lot of light, fast,” says Rebecca Bernstein, chief scientist for the GMT project. More light means sharper, brighter images. The heart of this new behemoth will comprise seven primary mirrors, each a whopping 8.4 m in diameter, larger than any other single telescope mirror.

Together, they'll create a light-collecting surface 25.4 m across designed to channel the faint glow of distant celestial bodies into an array of instruments that promise to revolutionize astronomy and enable scientists to study the chemical composition of exoplanets with higher precision than ever before.

Only one place in the world is capable of building the large, lightweight mirrors for the GMT: the Richard F. Caris Mirror Laboratory at the University of Arizona. Peek behind the scenes to see how these giant mirrors were made.

The Giant Magellan Telescope is expected to collect its first images in the 2030s. The telescope will use seven giant mirrors as its primary reflective surface, as seen in this artist's rendering. | `Credit: Giant Magellan Telescope – GMTO Corporation`

The making of a massive mirror

It’s fairly easy to find the Richard F. Caris Mirror Lab. Simply set a course for the Casino del Sol football stadium and you’ll find the entrance tucked beneath the eastern bleachers. Its unassuming entrance belies an impressive interior.

“It’s basically a gigantic hangar,” says Buell Jannuzi, director of the University of Arizona’s Steward Observatory, home of the mirror lab. The concrete pillars that provide structural support for the stadium above are also the perfect mounts for the cranes that workers use to transfer mirrors in progress. As a mirror is made, it is moved from one end of the lab to the other.

Engineers in the lab have found one method to be the best for making large mirrors: spin casting.

Every material used in the lab is carefully chosen to ensure that casting goes smoothly. The GMT’s giant mirrors began as thousands of pieces of solid borosilicate glass carefully placed into a massive honeycomb mold built within a furnace mounted on a turntable.

The mold is made of two heat-tolerant ceramic materials. For the floor and walls, "we use a castable silicon carbide. It's kind of like cement," says Hubert "Buddy" Martin, a project scientist at the mirror lab. But silicon carbide reacts strongly with melted glass, producing so many bubbles of carbon dioxide that the glass practically foams.

Credit: Giant Magellan Telescope - GMTO Corporation

To prevent a reaction, the lab workers line the silicon carbide with hexagonal boxes made from a ceramic fiber called alumina silica. “There’s 1,700 of them for an 8.4 m mirror,” Martin says. The hexagons remain embedded in the glass after it cools and solidifies. But the ceramic material is “so much softer and weaker than the glass, we can remove it just by blasting it with high pressure water,” he says. The empty honeycomb leaves the mirror 80% hollow and makes it incredibly lightweight for its size.

Lab founders chose a borosilicate glass formulation for its ability to flow while molten and to maintain its solid shape even with temperature variations. Since the lab cast its first mirror in 1984, engineers have sourced the material from a single optical glass company, Ohara.

“We picked that glass in part because it used to be one of the most abundant glasses,” says director Jannuzi. “Now we’re the only people buying it.” In fact, they tested a different brand of borosilicate at least once, but it did not perform as well.

Credit: Giant Magellan Telescope - GMTO Corporation

The glass arrives from Ohara in chunks, giving it an edge over competitors. “All the surfaces of the glass chunks are fracture surfaces. They’ve never been in chemical contact or intimate contact with any other material,” Martin says. When they melt together, there will be no trace that they’ve ever been apart.

Credit: Giant Magellan Telescope - GMTO Corporation

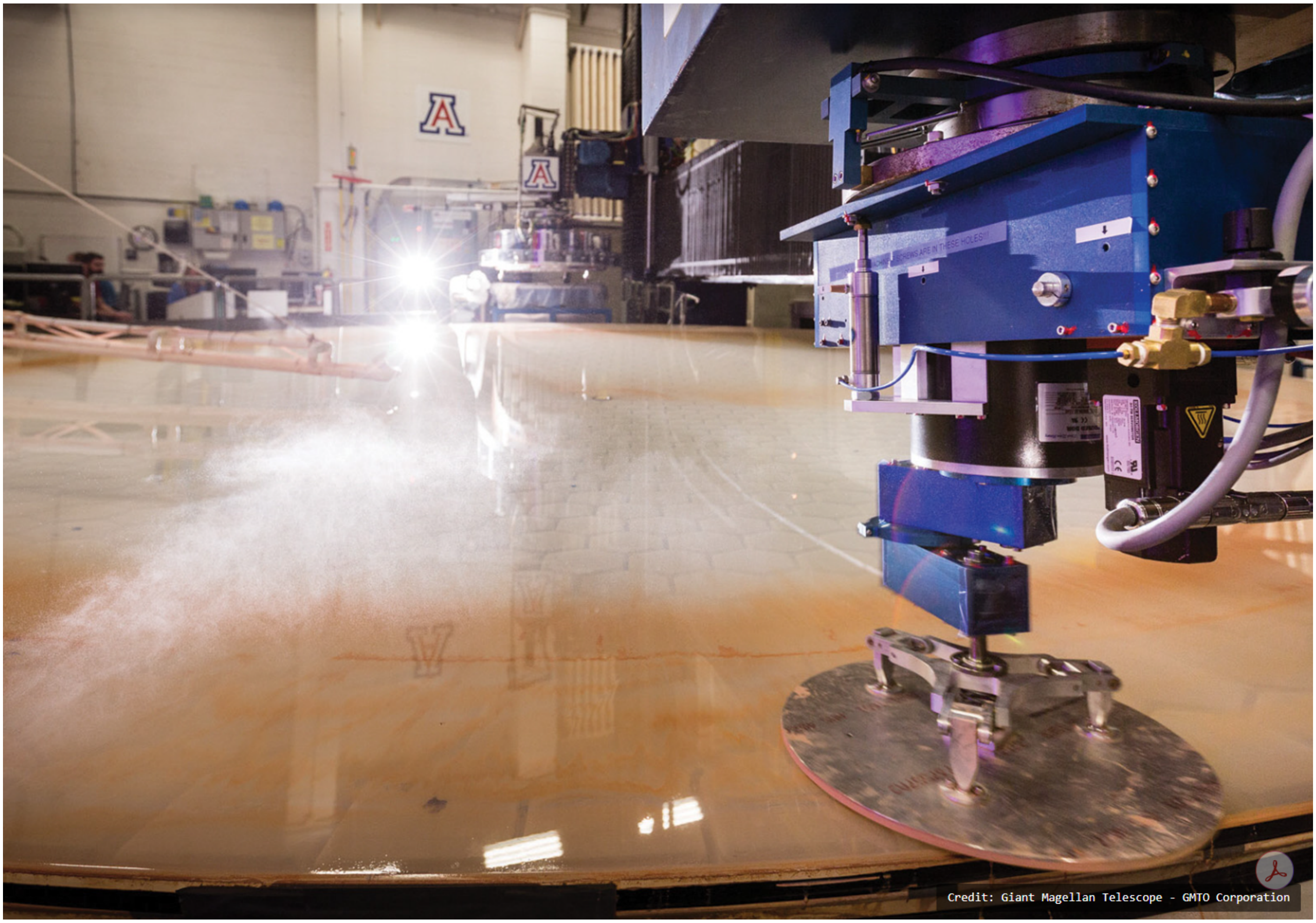
After cleaning the glass pieces and placing them into the mold by hand, workers close the furnace and turn up the heat. The turntable starts spinning as the glass softens and will continue as the glass melts completely then cools, forming a solid mirror.

Spin casting may seem like extra effort, but it’s actually a time-saver. The ideal telescope mirror has a concave, parabolic shape that is designed to focus collected light to a point above the mirror. “The centrifugal force gives you the right curvature,” Martin says. It’s not a perfect surface, but it takes far less effort to create it by spinning than by grinding.

Credit: Giant Magellan Telescope - GMTO Corporation

With the basic form cast, the mirror is moved to a polishing station, where it can stay for more than a year.

“It’s easy to make the surface shiny and reflective,” Martin says. “But for an astronomical telescope, polishing means making the surface accurate, giving it the right shape to a small fraction of wavelength.” Depending on the wavelength of light being measured, any series of dips or bumps on the surface that are larger than 10-20 nm will blur the image. For scale, a single red blood cell lying flat on the mirror would create a bump about 100 times as large.



Credit: Giant Magellan Telescope - GMTO Corporation

The polishing work is performed by a programmable machine. The tool’s long arm sweeps polishing pads of various sizes, from 5 to 60 cm in diameter, across the surface. “It’s a continuous process of removing glass from the surface,” Martin says. “We never do anything to add glass.”

This approach makes it vital to precisely measure the mirror’s surface before each round of polishing. It’s a job for the lab’s laser interferometer. The tool illuminates the entire surface of the mirror and measures the reflected light. The test compares how the mirror actually reflects light to how a perfect mirror would reflect light, showing the engineers where glass needs to be removed.

Excavation of the Giant Magellan Telescope site on Las Campanas Peak at the southern edge of Chile's Atacama Desert is already complete. | Credit: Giant Magellan Telescope – GMTO Corporation

“We polish for 80–100 h then test, back and forth, between the polishing machine and the test equipment,” until the shape is perfect, Jannuzi says.

In the first sweep, the lab engineers use a coarse diamond wheel that grinds millimeters of glass from the mirror’s surface. As the surface is worn away, they switch to finer abrasives, typically metal oxides, to remove less glass with each pass. The final polish leaves the surface of the mirror accurate to within 10–20 nm and ready to be coated with a uniform layer of aluminum only 100 nm thick.

To date, the lab has cast all seven GMT mirrors and polished three, Jannuzi says. The mount for the mirrors is being built in Illinois, and the observatory site in Chile has been excavated. From an engineering perspective, everything is on track for the GMT to be operational in the 2030s, Jannuzi says. Many individuals and institutions have invested in the telescope, “but we still need Congress to say, ‘Yes, we want the National Science Foundation to partner in this,’ ” he says.

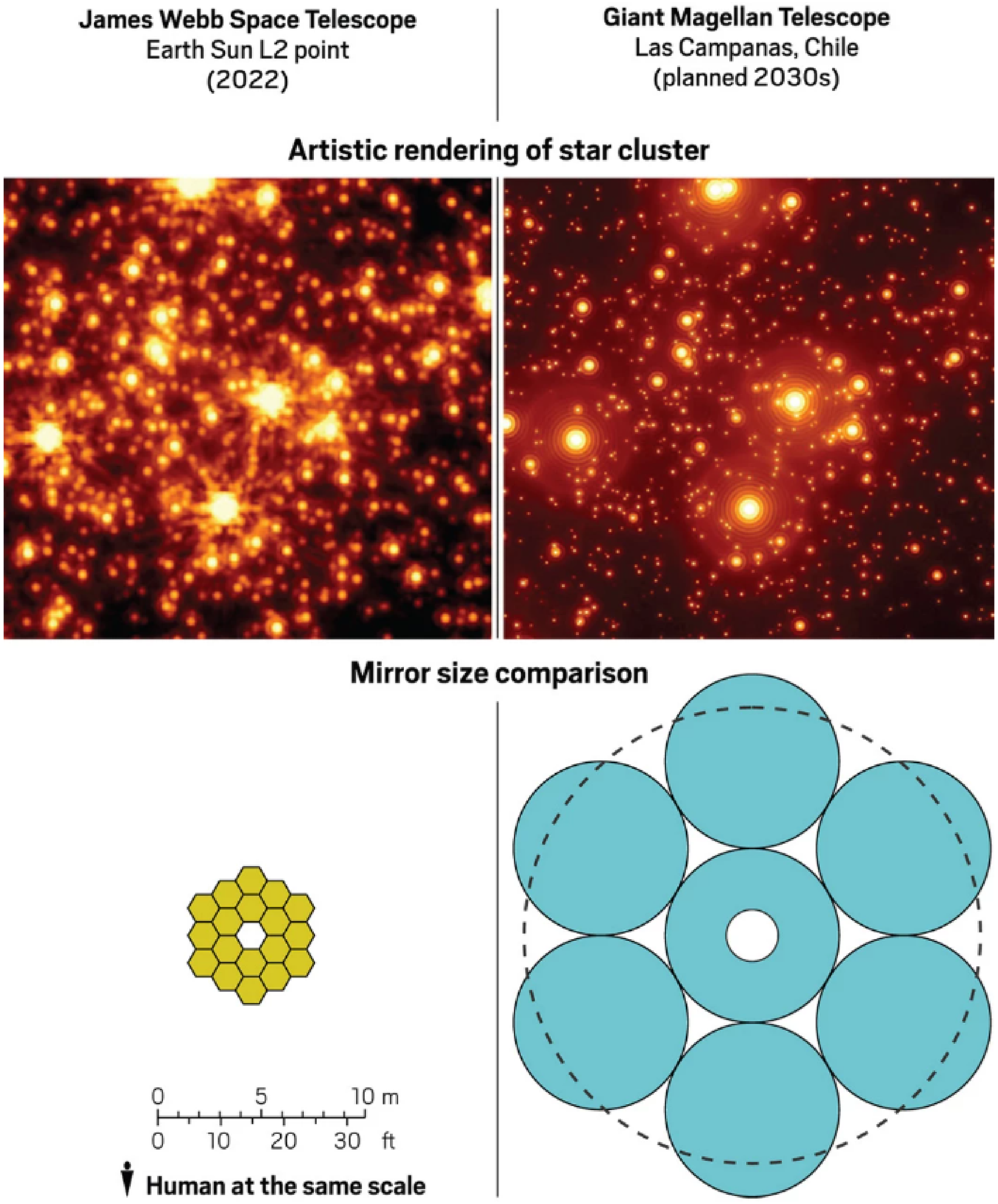
Beyond big mirrors

Mirror size is only one aspect of a powerful telescope. Engineers must also consider the behavior of light, especially when it travels through air.

Scientists have sent telescopes into space to avoid the problems air causes. For example, the James Webb Space Telescope (JWST) sports the largest primary mirror ever launched into space. With no atmosphere to contend with, the light it collects is unfiltered and undistorted by air. Still, the JWST is diffraction limited; the size of its primary mirror determines how well a telescope can differentiate two closely spaced objects.

Interstellar imaging gets a glow-up

When the Giant Magellan Telescope is operational, scientists expect it to produce much sharper images than those from the James Webb Space Telescope (JWST). To illustrate the difference, researchers generated renderings of a star cluster imaged by JWST (top, left) and the Giant Magellan Telescope. The seven primary mirrors of the Giant Magellan Telescope (bottom, right) create a reflective surface with a diameter about four times as large as that of JWST, so the ground-based telescope will have about four times as much resolving power at the same wavelength. In practice, this will enable scientists to distinguish objects that are very close to each other, such as exoplanets that closely orbit their stars.



Credit: Rob Bryson/C&EN/Giant Magellan Telescope – GMTO Corporation

It’s easier to build big on the ground. Back on Earth, the GMT’s primary mirror will dwarf that of the JWST, increasing its resolving power. But for the GMT to reach its full potential, researchers will need to correct the distortions in light caused by Earth’s atmosphere. In other words, they must remove a star’s twinkle.

The telescope will use adaptive optics to accomplish this feat. Light collected by the primary mirror will travel to seven curved, meter-wide secondary mirrors that act as a single reflective surface. Magnets will cover the back of each mirror. “Those magnets are on little actuators,” chief scientist Bernstein says. The mirrors are only a few millimeters thick, and the scientists can “push and pull on each point so that the mirror can literally wiggle.”

By carefully controlling how the mirrors wiggle, the scientists can remove ripples in the light caused by the atmosphere.

The secondary mirrors will direct the corrected light through a hole in the center of the primary mirror and into the instruments housed beneath. One instrument has been designed to search for exoplanets that today’s telescopes struggle to see: cool planets that orbit close to their star. Such planets are expected to be similar to Earth.

Another will collect spectra from these planets’ atmospheres, and scientists will analyze the signals in search of biosignatures. “The resolution and the sensitivity we’ll be able to get won’t be matched by another telescope for decades in space,” and at least a decade on the ground, Bernstein says. This precision comes from the incredible control the engineers will have over the way the light enters the instruments.

“To say that it’s state of the art is an understatement,” she adds. “It’s beyond state of the art.”

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