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This artist's rendering shows the Extremely Large Telescope in operation on Cerro Armazones in northern Chile. The telescope will use lasers to create artificial stars high in the atmosphere.

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The Era of Monster Telescopes

Matters of money, engineering and sheer geometry may end the construction of ever larger astronomical telescopes

BY PHIL PLAIT

CONSIDER THIS: astronomers think of the Hubble Space Telescope as small. That might surprise you because after three decades' worth of images from Hubble with depth and detail most ground-based telescopes couldn't achieve, popular conception holds that the telescope must be one of the biggest ever built.

But its mirror is only 2.4 meters wide. That's not terribly large. Even the newer James Webb Space Telescope (JWST), now capturing images that evoke gasps the same way Hubble's do, has a mirror that's 6.5 meters wide, which puts it in medium-to-big territory in the minds of astronomers. Of course, these telescopes were launched into space on rockets, a process that puts its own limits on how hefty a scope can be. On Earth there are telescopes far larger: the Very Large Telescope in Chile has an 8.2-meter mirror, and the twin Keck Telescopes in Hawaii are each a gargantuan 10 meters wide. Several enormous telescopes are currently under construction, including the Giant Magellan Telescope (which has seven 8.4-meter mirrors, equivalent to a single mirror more than 22 meters across) in Chile and the Thirty Meter Telescope in Hawaii.

Right now the beefiest telescope under construction is the European Southern Observatory's Extremely Large Telescope, or ELT, which, after its completion in 2028, will be a staggering 39 meters across. It will be by far the largest visible- and infrared-light telescope on—or off—the planet.

ELT may as well be the biggest that will ever be built. The reasons boil down to cost (unsurprisingly), engineering and the implacability of geometric laws.

That last factor is decisive in limiting the size of jumbo telescopes. Astronomers sometimes call telescopes "light buckets" because they collect light falling through space like a bucket in the rain collects water. The bigger the bucket, the more rain you collect. Faint objects drizzle very little light that reaches Earth. A bigger telescope collects more light, so in principle it can see

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fainter objects, more distant galaxies and more ancient stars. After centuries of observations, we've seen most of the bright objects in the sky, so the astronomical frontier now is in seeking out the dimmer ones.

Bigger telescopes have another advantage: they have better resolution, meaning the ability to see fine details. Doubling a telescope's width enables it to detect details half as wide, revealing distant galaxies as more than just tiny smudges.

For these reasons, astronomers always want larger telescopes. The problem is that past a certain size (roughly eight meters wide), a monolithic, single-piece telescope mirror is very difficult to cast, polish and use—building a structure just to support such an object's immense weight is prohibitive. A telescope mirror's area is the square of its diameter, so a 10-meter telescope will have four times the area (and about four times the volume and therefore the weight) of one that is five meters wide.

To overcome this hindrance, astronomers have turned to segmented mirrors, effectively combining several relatively small mirrors into one larger one. These are generally hexagonal in shape because hexagons can be tiled into large arrays easily; JWST uses just such an arrangement. Small motors in the back tip and tilt these segments to ensure that they combine as precisely as possible. Even better, these mirrors can be quite thin and can deform their shape on demand to overcome the blurring induced by Earth's atmosphere. The air is a boiling mass of gaseous soup, distorting and dispersing light coming from the cosmos (this phenomenon is why stars twinkle). But with highly sophisticated sensors and actuators, a special mirror in the light path can be deformed within milliseconds to correct this turbulence, sharpening the telescope's resolution. Ground-based telescopes routinely employ this "adaptive optics" technique to get images as sharp as Hubble's and JWST's.

This approach is what allows ELT to be so huge. Besides an adaptive optics mirror, the main mirror's 798 individual mirror segments, each 1.4 meters wide, have multiple automatically controlled systems to keep them aligned.

The system is understandably expensive; the total baseline cost for ELT is estimated at about $1.5 billion in 2023 dollars. The engineering of this immense beast is cutting-edge as well. It requires a vast dome 80 meters high and 88 meters across and a foundation equipped with shock absorbers to cushion it against vibrations.

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These parameters are why ELT may be one of the largest ground-based telescopes, if not the largest, ever built. It's possible something incrementally bigger could be constructed someday, but anything significantly larger will cost several times more and come with commensurately larger engineering headaches. In fact, ELT started out as an idea called OWL—the OverWhelmingly Large Telescope—that would have been a Brobdingnagian 100 meters wide; after much review, a panel of astronomers decided a more modest 39 meters would be sufficient.

Do we need bigger telescopes? ELT was sized to match the scientific needs of the astronomical community. Those included directly imaging nearby exoplanets—including Earth-size worlds at the right distance from their stars to have liquid water—and seeing back to the era of the universe in which the very first galaxies were born. Bigger telescopes could do more, but at the moment, ELT is at the forefront of astronomy. It may lay the groundwork, literally, for even larger future telescopes, but their time hasn't yet come.

Such a future could be delayed for other reasons. Astronomers might instead turn to a decades-old technique called interferometry, whereby observations from radio telescopes large distances apart are combined to mimic the resolution of a much larger telescope. The Event Horizon Telescope, which has observed the central black hole in the Milky Way, as well as that of the galaxy M87, is a radio interferometer. It combines telescopes across Earth, effectively making an observatory the size of our entire planet.

Sounds great, but there are two problems with interferometry for visible-light observations. One is that it is limited by the area of the individual telescopes used, so seeing faint sources—a critical aspect of astronomical observations—is still an issue. The other is the difficulty of combining the observation scales with the frequency of the light detected because visible-light frequencies can reach far, far higher than those of radio waves. Visible-light interferometry has been achieved with telescopes close together—the Very Large Telescope Interferometer uses four eight-meter telescopes a few dozen meters apart from one another. Longer baselines are possible, but they're extremely challenging, requiring nanometer-scale measurement precision. If visible-light interferometry is eventually possible with longer baselines, however, it will ease the need for an even larger telescope than ELT.

Given all that, would astronomers want a larger telescope if it became possible? Yes, obviously. And one might cost less than a far smaller, though nimbler, space telescope.

Perhaps future technologies will be discovered that can overcome some of the barriers to creating a gigantic visible-light telescope. We might build observatories on the moon, for example, where lower gravity and a lack of atmosphere offer a tremendous advantage over earthbound instrument settings. A radio telescope a kilometer across, nestled in a lunar crater, has been proposed for the far side of the moon, free from earthly interference. Although radio telescopes are far easier to construct than visible-light ones, if we're positing building such behemoths on the moon, one that can detect visible light is something to consider. It's a dream, but technologies have a way of turning dreams into reality.

Never say never. ELT may be the biggest ever built and might hold that record a long, long time—but perhaps not forever. ●