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TELESCOPE WARS

Old grudges between three teams of astronomers have threatened the survival of ground-based astronomy's boldest, biggest projects

By Katie Worth

For 15 years three competing groups of astronomers have chased a single dream: to build the grandest telescope on earth. The stargazing behemoths they aim to build would be three times larger than the world's current largest optical telescopes, powerful enough to take pictures of planets circling other stars and to peer across the breadth of the universe, gazing back in time nearly to the big bang.

This dream observatory comes in three versions: the Giant Magellan Telescope (GMT), developed by a consortium including the Carnegie Institution for Science; the Thirty Meter Telescope (TMT), developed by the California Institute of Technology, the University of California system and others; and the European Extremely Large Telescope (E-ELT), developed by the European Southern Observatory (ESO). Building all three would cost nearly $4 billion, but so far the world has balked, leaving each project short on cash and hustling for more. There could have been at least one giant telescope gazing at the heavens today; instead partially built hardware awaits delivery to barren construction sites.

All three telescopes are likely to limp across the finish line of their race and begin operations sometime in the 2020s, albeit behind schedule and over budget.

Illustration by Alex Nabaum

Katie Worth is a reporter at *Frontline*, a television production of WGBH in Boston. She spends a lot of time thinking about politics, science and their myriad intersections.

How did this happen? How did three separate projects with common goals come to be fighting one another for funding? And what has prevented them from joining forces to minimize the chance of their collective failure?

These questions have been asked repeatedly, including by a bewildered national panel considering two of the telescopes for federal funding. Dozens of scientists interviewed for this story pondered what might have been if instead of three ventures, there had been one or two. Nearly all agreed that humankind would be much closer to building the next, greatest generation of observatories if competing groups of astronomers had not spurned repeated chances to collaborate. That competition started in the first decades of the 20th century and has been sustained across the years by personality conflicts, miscommunications, competing technologies and an expanding universe of bitterness.

THE BIG DEAL

THE STORY BEGINS IN 1917, when an ambitious astronomer and observatory director named George Ellery Hale unveiled something entirely new to science, a 100-inch optical telescope.

In the world of telescope construction, size matters: the larger a telescope's mirror, the farther it sees. The new telescope, perched on Mount Wilson in what was then still a dark-skied Los Angeles County, dwarfed all others on earth. Its revolutionary size rapidly produced revolutionary results. Edwin Hubble used it to discover that our galaxy is but one among many and then to gather evidence that the universe is expanding.

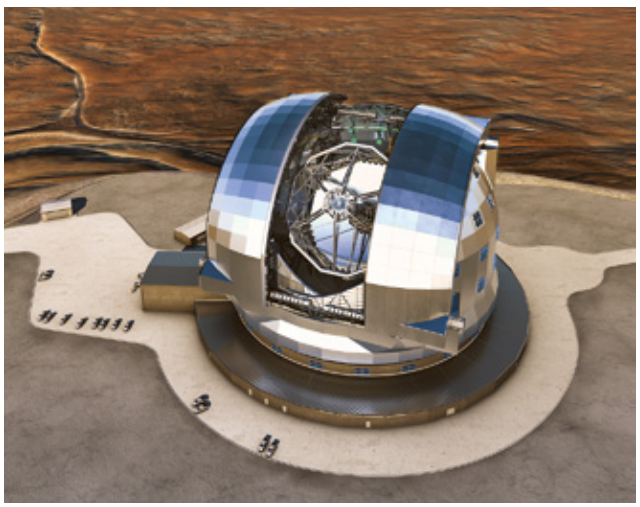
But Hale was not satisfied. He wanted a 200-inch telescope.

The 100-inch one was built and run by what was then called the Carnegie Institution of Washington, a charity created by steel baron Andrew Carnegie. Carnegie was not prepared to spend millions more on a new telescope, so Hale slyly pitched the project to an organization funded by Carnegie's rival, oil magnate John D. Rockefeller. In 1928 Rockefeller personally approved Hale's 200-inch telescope, eventually providing it with a $6-million grant—at the time, the largest sum ever donated to a scientific project.

There was a catch: the astronomers at the Carnegie Institution were the only ones in the world with the expertise to build the new telescope, but Rockefeller would not fund his old rival's charity. "It was just not going to happen," says historian Ronald Florence, who wrote *The Perfect Machine,* a book about the 200-inch telescope. "So that sets up the pool shot for problems."

Hale came up with a solution: Rockefeller would give the telescope money as a gift to Caltech, which had just been established only two miles (three kilometers) from Carnegie's observatory headquarters in Pasadena, Calif. Caltech was still so embryonic that it did not employ a single astronomer, let alone an astrophysics department. Nevertheless, the Rockefeller Foundation funded Caltech's construction of Hale's new telescope and the Palomar Observatory in San Diego County, which housed it. Hale believed Carnegie's leaders would find working on such a magnificent stargazing tool irresistible and would lend their expertise to design and construct the new telescope.

Hale was mistaken. According to Florence, the deal enraged the Carnegie Institution's president, John Merriam, who saw it as an unforgivable deceit. He worked to scuttle the project, refusing to allow Carnegie scientists to help and pressuring the Rockefeller Foundation to walk away. Desperate, Hale called on the diplomat Elihu Root, an old friend of both Rockefeller and Carnegie. Root swayed Merriam, who at last signed on to the project.



But the discord was only beginning: Merriam was still angry and tried for years to wrest control from Caltech, Florence says, until the institutional distrust became mutual and profound.

After Merriam retired, the warring charities at last formed an uneasy truce. The Rockefeller Foundation approached its astronomical adversaries with a deal: Caltech would own the telescope when it opened its 16-foot eye in 1949, but Carnegie would operate it.

COURTESY OF L. CALCADA *European Southern Observatory*

IN BRIEF

Three extremely large telescopes are currently under construction and slated to begin operations in the 2020s.

Each telescope will boast a primary mirror around 30 meters in diameter. Such gigantic mirrors will allow astronomers to study the cosmos with unprecedented, revolutionary clarity.

Despite such great scientific potential, the projects all have funding troubles, leading critics to wonder why astronomers are simultaneously building three giant telescopes rather than just one or two. The answer lies in an old rivalry that traces back to the first large telescopes of the early 20th century.

The fragile relationship between the institutions inevitably spilled into science, especially after the identification of "quasi-stellar objects"—quasars—in the early 1960s by Dutch-American astronomer Maarten Schmidt. Although they at first seemed to be dim stars in the sky, further studies showed quasars to be shining with almost unthinkable brilliance from the far distant universe. The mysterious objects quickly became astronomy's sexiest subject, and Caltech and Carnegie researchers vied for time on the world's largest telescope to study them, sometimes resorting to "junior high–level pettiness," Florence says.

In 1979, after half a century of tensions, Caltech finally sought to end its strained shared custody of Palomar. The split did not go well and proved intensely personal. The late Allan Sandage, Carnegie's legendary astronomer, who had achieved his life's work at Palomar, refused to set foot in the observatory again. "It was the kind of divorce where you had to choose the husband or the wife," Florence says. "There was no staying friends with both."

To most astronomers, jumping from a 10-meter telescope to a 100-meter one was absurdly ambitious. But a 30-meter telescope seemed viable, to the consternation of Gus Oemler, then the observatories director at Carnegie. He remembers waking up to Caltech's announcement and feeling sick. "We were struggling to finish the Magellan telescopes, which were finally going to give us some kind of parity with Caltech after many years, and suddenly they were starting the next phase."

After much debate, Carnegie pitched Caltech on a collaboration. Both sides were hesitant, but the boards of each institution thought it was time to traverse the freeway and the old grudge that separated them. "We recognized it would be kind of crazy to have two giant telescopes centered on two institutions within two miles of each other," says Carnegie astronomer Alan Dressler.

So on June 21, 2000, two scientists from Caltech—the late astronomer Wal Sargent and the late Tom Tombrello, then the physics chair—and two from Carnegie—Oemler and Dressler—met to discuss a partnership.

GLASS GARGANTUANS: The Thirty Meter Telescope (*above left*) and the Giant Magellan Telescope (*above right*) will be about the same size; the larger European Extremely Large Telescope (*opposite page*) will boast a nearly 40-meter mirror.

COURTESY OF THIRTY METER TELESCOPE (*left*); COURTESY OF GIANT MAGELLAN TELESCOPE ORGANIZATION (*right*)

CONFLICTING DESIGNS

OVER THE NEXT TWO DECADES the institutions trod separate paths. In the 1990s Caltech partnered with the University of California to unveil the twin 10-meter Keck telescopes on Mauna Kea in Hawaii, using what was then a novel segmented mirror design in which many small mirrors created one larger, light-gathering aperture. Their risk paid off: the design worked beautifully, and their astronomers enjoyed years of scientific preeminence before anyone else built something competitive. Meanwhile Carnegie stuck with the older, single-mirror technology but ventured into the Southern Hemisphere, constructing the twin 6.5-meter Magellan telescopes in the Atacama Desert in northern Chile.

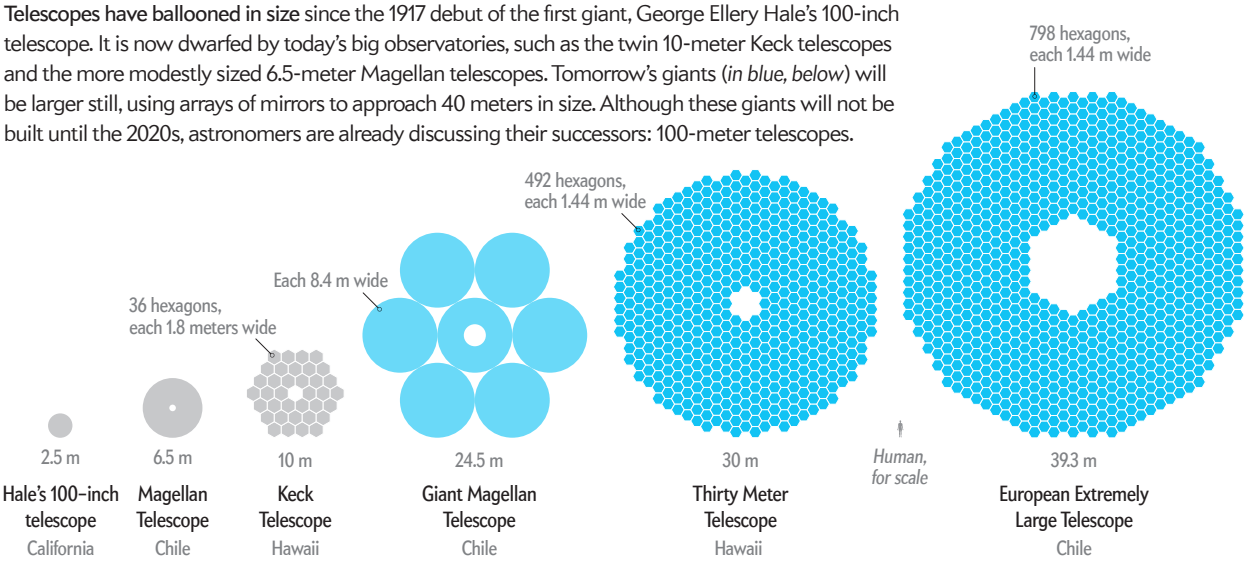
Carnegie was just completing these telescopes in 1999 when Caltech and the University of California announced their intention to build a 30-meter telescope. The ESO, an intergovernmental organization of astronomers throughout Europe, was already toying with something even more ambitious—a 100-meter (and appropriately named) OverWhelmingly Large Telescope.

By all accounts, that discussion went terribly. The meeting was tense, disjointed and plagued by misunderstanding. Both Wendy Freedman, who would later become director of the Carnegie Observatories, and Richard Ellis, now a senior scientist at the ESO, who was then on the verge of replacing Sargent as Caltech's Palomar Observatory director, spoke to all four men immediately after the meeting and heard a different story from each: Dressler felt that the Caltech men were not taking Carnegie's proposal seriously, whereas Tombrello mistakenly believed that Carnegie did not have serious money to contribute. Oemler said Sargent sat in icy silence through most of the meeting. Sargent later said he was worried about upsetting Caltech's then delicate relationship with the University of California. But Sargent had not explained that concern during the meeting, Ellis says, so "of course, the Carnegie people were offended."

The next day Tombrello sent an e-mail "to summarize our rambling discussion." Caltech was not interested in working with Carnegie on the telescope for the time being, Tombrello wrote, al-

Big, Bigger, Biggest

Telescopes have ballooned in size since the 1917 debut of the first giant, George Ellery Hale's 100-inch telescope. It is now dwarfed by today's big observatories, such as the twin 10-meter Keck telescopes and the more modestly sized 6.5-meter Magellan telescopes. Tomorrow's giants (*in blue, below*) will be larger still, using arrays of mirrors to approach 40 meters in size. Although these giants will not be built until the 2020s, astronomers are already discussing their successors: 100-meter telescopes.



though he would not exclude the possibility if the work got expensive. The Carnegie astronomers felt condescended to and insulted. The nascent collaboration died, and the long tradition of acrimony between the institutions grew longer.

That meeting is now a part of giant telescope lore. Ellis is one of many astronomers who wonder what might have happened had the meeting gone differently.

"When you look back on that moment—what a tragedy," he says. "With a few phone calls and a bit of diplomacy, we could have brought Carnegie in. And had we brought them in, we'd probably have a telescope by now."

Garth Illingworth, an astronomer at the University of California, Santa Cruz, says there remained "just enough residual resentment and unhappiness" from the old rivalry to derail a constructive conversation. "You just think, jeez, why wasn't there a little adult supervision in the room to help these folks to get over this?" he adds.

DIVIDED THEY FALL

AFTER THIS FAILED DÉTENTE, the rivalry only expanded. Caltech and the U.C. system developed the TMT, to be constructed next to the Keck telescopes in Hawaii. Meanwhile Carnegie designed the GMT, a 24.5-meter telescope, to cap its Las Campanas Observatory in Chile. Around the same time, the Europeans scaled down their dreams from overwhelmingly large to merely extremely large and planned the construction of the 39-meter E-ELT in Chile.

The three projects scoured the globe for financing, sometimes searching in the same places. Pony up money, the typical pitch went, and your astronomers will be guaranteed telescope time. Canadian astronomers, for instance, were courted by both the Carnegie group and the Caltech-U.C. teams and chose the latter. Harvard University was also wooed by both but committed to Carnegie. At least once, the two American teams awkwardly ran into each other in an airport as they traveled to meetings with the same potential partners. And the Europeans were not above the fray: they initially secured support from Brazil, whose president agreed to join the ESO and underwrite a major chunk of the E-ELT. But fractured Brazilian politics stalled the agreement. Carnegie has taken advantage of the E-ELT's woes: in July 2014 the University of São Paulo joined the GMT project, and according to Dressler, GMT leadership hoped the Brazilian government would soon follow, although that has not turned out to be the case.

The most sought-after partner of all has been the U.S. government, which could open its strongbox of federal funding to finance a giant telescope and provide access for all American astronomers. In 2000 the Astronomy and Astrophysics Decadal Survey, a once-a-decade national panel that guides U.S. federal funding, had declared a next-generation giant telescope the country's highest priority in ground-based optical astronomy.

With this endorsement, the National Science Foundation began discussing a partnership with the Caltech-U.C. TMT project in 2003. But within months GMT astronomers wrote a letter saying the deal would unfairly favor the TMT. The letter was effective: the NSF balked, unwilling to take sides in the increasingly divisive politics of top-tier optical astronomy.

In reality, there was not much federal money to provide anyway, according to NSF senior adviser Wayne Van Citters. But the feud did not help, he says: "We needed the community to come together and decide which one they wanted to do. We couldn't possibly do both."

The community, for its part, tried repeatedly to do just that, but the efforts proved fruitless. European astronomers discussed collaborations with both their rivals but ultimately only agreed to share technology insights. And in 2007, at the insistence of their boards, TMT and GMT leaders held several coldly cordial meetings to discuss ways they might work together. Nothing came of it.

The situation confounded panel members of the 2010 decadal survey, who questioned why the U.S. astronomy community was

SCIENTIFIC AMERICAN ONLINE View past, present and future giant telescopes at ScientificAmerican.com/dec2015/giants

Graphic by Daisy Chung

being asked to support two separate American-led large optical telescopes. In the end, they backed neither, kicking the projects to the bottom of the priority list and effectively quashing federal funding for another 10 years.

Rivalry is hardly rare in science: brilliant minds are often accompanied by big egos with a penchant for clashing. Sometimes feuds can yield innovation; other times they can turn the high-minded pursuit of discovery into a series of petty personal conflicts. Some disciplines have successfully convinced potential rivals to join forces: High-energy physicists work in massive international ensembles on particle accelerators. Radio astronomers have collaborated on their field's largest next-generation tool, the $1.4-billion Atacama Large Millimeter/submillimeter Array.

In contrast, optical astronomy in the U.S. has been riven with competition. Italian-American astronomer and Nobel laureate Riccardo Giacconi described it in a July 2001 speech to the National Academy of Sciences as a sociological problem.

To historian W. Patrick McCray of the University of California, Santa Barbara, who wrote *Giant Telescopes,* a book about the American optical astronomy community, what is striking about the enmity between Caltech and Carnegie is its longevity: they have been bickering over large telescopes since 1928. "You just think, Have you people learned nothing?" McCray says.

But rivalry alone does not explain the state of affairs. There were rational reasons to work on separate telescopes, notes astronomer Ray Carlberg of the University of Toronto, which is part of an association involved with the TMT project. Initially astronomers believed there would be money for all three, and giant telescopes in both the Northern and Southern hemispheres would ensure full coverage of the entire sky. "The world had just built quite a few eight- and 10-meter telescopes, and it didn't seem unreasonable to have a bunch of these big ones," Carlberg says. By the time it was clear that Caltech could use Carnegie's help, Carnegie was too deeply invested in its own project to abandon it.

TOO MANY TELESCOPES

ON THE BIG ISLAND OF HAWAII, a corner of Mauna Kea's immense summit has been flattened to make way for the TMT. The telescope's 30-meter mirror, the diameter of the U.S. Capitol Dome, will be composed of a honeycomb of 492 hexagonal, 1.44-meter segments, all housed in an 18-story structure on the dormant volcano. The project has been granted land-use permits, although it still faces vocal opposition and legal challenges from some native Hawaiians and environmentalists. To help pay for the $1.5-billion endeavor, Caltech and the U.C. system have secured international partnerships with India, China, Japan and Canada. They are still searching for an additional $270 million; the project's current best guess for its telescope's debut is sometime in the early 2020s.

Eleven blocks from the TMT's Pasadena headquarters, Carnegie and its partners are coaxing the 24.5-meter GMT into life. It will consist of seven 8.4-meter mirrors, with six mirrors arranged like flower petals around one in the center—an approach very different from, and incompatible with, the smaller, more numerous hexagonal mirrors of the TMT. Four mirrors have already been cast at a laboratory at the University of Arizona. The more modest size and design come with a more modest cost: just under $1 billion. Carnegie has enlisted the support of universities from South Korea, Australia and Brazil, as well as several domestic universities. They have raised roughly half the money needed to build the telescope at its construction site within the Las Campanas Observatory. If all goes as planned, the GMT will begin collecting light by 2022.

A 12-hour drive up the Pan-American Highway from Las Campanas is Cerro Armazones, the desert mountain where the E-ELT will one day perch. The site was initially scoped out by TMT astronomers, who spent years monitoring the atmosphere above Cerro Armazones for transparency and turbulence before concluding they preferred to build in the Northern Hemisphere instead; the Europeans took advantage of that groundwork and claimed Armazones for their own project. Today a newly paved road leads to the mountain's bald scalp, which has been shaved with dynamite and heavy machinery into a soccer-field-sized flattop. Visible to the east of the mountain, the firmament meets the 6,723-meter Andean volcano Llullaillaco, where the Inca once sacrificed children to the gods. It and the rest of the arid panorama fade at nightfall, making way for a playground of stars overhead.

With a mirror 39 meters wide, the E-ELT will be the grandest next-generation telescope of all. Like the TMT, the E-ELT will have a segmented design, but instead of 492 hexagonal mirrors, it will boast 798. In December 2014 the ESO voted to move forward with first-phase construction. A second phase has not yet been funded. The E-ELT's leadership plans for the telescope to begin stargazing in 2024, for a total construction cost of €1.1 billion.

Once constructed, the three telescopes will have synergistic strengths, says the E-ELT's Roberto Gilmozzi. The E-ELT will specialize in zooming in to provide high-resolution images of small regions of the sky; the GMT will excel at wide-field astronomy. And the TMT will be located in a different hemisphere, observing a different sky.

Gilmozzi, like most other astronomers interviewed for this story, thinks that had there been two telescopes instead of three, both might be nearing completion by now, at a cost hundreds of millions of dollars less. "If you don't consider the problem of finding the money, it's wonderful to have more than one," he says. "Scientifically speaking, I could use 100 telescopes if I could afford to build them."

Unfortunately, building telescopes is just the first step. Neither the GMT nor the TMT currently has enough money to sustain operations once it is constructed. Both hope the federal government will eventually step in to assist, but Van Citters says it is not clear how much money the government will be able to contribute. The telescopes are each expected to cost tens of millions of dollars a year to operate. "That's enough to give people nightmares," McCray says.

Even so, the problem of too many telescopes has a silver lining: the world could one day have three giant eyes gazing at the cosmos. This would be a big win for science, McCray says. "If this situation is a tragedy, it's a tragedy with a small 'T.'" SA

MORE TO EXPLORE

Giant Telescopes: Astronomical Ambition and the Promise of Technology. W. Patrick McCray. Harvard University Press, 2004.

FROM OUR ARCHIVES

Giant Telescopes of the Future. Roberto Gilmozzi; May 2006.
Origami Observatory. Robert Irion; October 2010.
Star Wars. Michael West; Forum, July 2015.

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