Air and Space this Week

Item of the Week

ASTRONOMY IN CHILE

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I recently had the pleasure of a visit to Chile, where among other things, I was able to visit two of the large astronomy observing sites there, as well as some other astronomy-related places. More than half of ground-based astronomical research worldwide is presently conducted utilizing telescopes of various types in Chile, and that percentage will increase significantly as observatories and telescopes presently under construction come on-line in the coming years. There is no question that the future of ground-based astronomy will be located primarily in Chile!

INTRODUCTION: THE EARLIEST DAYS

THE GILLISS EXPEDITION

The earliest-known account of an astronomical observation being made in Chile dates back to 1582, when Pedro Cuadrado Chavino observed a total solar eclipse in the city of Valdivia, and used an early Greek technique to determine the city's latitude. In the modern era, a scientific mission led by Lt. James Melville Gilliss and organized by the U.S. Navy, came to Chile in 1849 to make measurements of the positions of Venus and Mars to determine the Earth-Sun distance.

Lt. Gilliss had an interesting career. He joined the U.S. Navy at age 15 as a midshipman, made several training cruises, and passed the necessary exams to become a "passed midshipman" in 1833. He requested and received leave to continue his studies, but was recalled to service as an assistant at the Navy's Depot of Charts and Instruments in 1836. The DoCI was responsible for the Navy's navigational tools, and at the time was headed by Lt. Charles Wilkes. Gilliss proved to be an excellent astronomical observer and was promoted to officer-in-charge of the DoCI in 1837, where he began researching techniques to determine longitude from celestial observations.

Gilliss was promoted to Lieutenant in February, 1838, and took command of the DoCI when Lt. Wilkes was assigned to lead the famous U.S. Exploring Expedition of 1838-1842. Gilliss then began a series of astronomical observations that would result in the publication of the first star catalog created in the U.S. (1846). At the same time, he lobbied strongly and successfully for the establishment of the U.S. Naval Observatory, securing the necessary funds from Congress in 1842. He supervised the building of the observatory and brought the necessary instruments

from Europe; the USNO was operational by October, 1844. For disreputable reasons, Gilliss was not named USNO Director as he should have been, but he finished up his star catalog and secured the funding necessary from Congress to mount the aforementioned expedition to Chile in 1848, to more precisely measure to Earth-Sun distance using the parallax method (see here for how that method has been used to determine the distance to the stars). The expedition started in August, 1849 and returned in November, 1852. It was a rousing success. The observatory Gilliss built, and its instrumentation, were left behind to form the nucleus of astronomical research in Chile.

Gilliss would go on to lead to other scientific expeditions prior to the Civil War. The person inserted as USNO Director instead of Gilliss turned coat and went South, and Gilliss was named has his replacement in 1861. He *became a founding member of the National Academy of Science* and was promoted to Captain in 1862. His career flourished further until his unexpected and too-soon death on February 9, 1865. He was only 53.

The James Melville Gilliss Building in Washington DC houses the offices of the USNO and the Oceanographer of the Navy; the Library at the USNO is named for him, as were two U.S. Navy ships, a minesweeper built in 1945 and an oceanographic research vessel in 1962.

THE NATIONAL ASTRONOMICAL OBSERVATORY

The Chilean government purchased the observatory and instruments from the Gilliss Expedition and established the NAO. The initial site, Santa Lucia Hill in downtown Santiago, proved increasingly unsatisfactory, as did several other sites tried in succession. Finally, in 1956, the NAO was moved to its final site, Cerro Calán. I had the pleasure of visiting there, and had a nice tour with one of the NAO professors. The site suffers from increasingly-severe light pollution, and the equipment installed there dates from the early 20th Century, so Cerro Calán is not a location of present-day astronomical research, however, it remains a very important educational and training facility, part of NAO's effort to develop home-grown astronomers and experts in astronomy infrastructure.

INTERREGNUM

The first half of the 20th Century saw considerable growth of observational astronomy, particularly in the United States. The largest refracting telescope ever built, the 40" at Yerkes Observatory in Wisconsin, came on line in 1897. The 60" telescope at Mt. Wilson outside LA, funded by Andrew Carnegie and built by George Ellery Hale, was completed in 1908 after many trials and tribulations. The 100" Hooker Telescope was built at Mt. Wilson, seeing "First Light" on November 1, 1917. These were colossal engineering feats, especially considering the level of technology prevailing at those times.

Hale was not finished raising money for observatories, however. Astronomy and LA were outgrowing the Mt. Wilson site; a larger telescope at a better site was necessary. He would find a sponsor in the Rockefeller Foundation in the late 1920s, scouted sites (settling on Mt. Palomar between LA and San Diego), oh, and helped found Cal Tech along the way. The 200"

construction had some glitches, including the failure of the mold during the first attempt to pour the mirror at Corning Glass Works (I grew up in the Corning area and often visited the Corning Museum of Glass, where at the time the failed mirror blank was on prominent display.).

Site prep at Palomar began in 1935, and the basic dome structure was completed by 1939, just in time for the telescope to be installed. The telescope and the observatory were named for Hale. All facilities were completed after WWII, and the Hale was dedicated on June 3, 1948. Edwin Hubble took the first "official" photo with the new telescope. It remained the largest telescope in the world until 1993, producing front-line astronomical research for decades.

The War years, and the Depression in between, were not kind to Chilean astronomy…

ASIDE: WHAT MAKES CHILE SUCH A GOOD OBSERVING PLACE?

There are four reasons that Chile is the up-and-coming spot for conducting ground-based astronomical research.

The first is that northern Chile's weather is ideal for astronomy. The offshore Humboldt Current brings cold water directly off Chile's west coast. Its low temperature suppresses humidity, and rain shadowing by coastal mountains adds to the lack of rain potential. Skies are clear over the western Andes as a consequence, allowing most nights to be suitable for observing. Further, the low humidity (and high elevation) allows seeing into the near infrared, where a lot of astronomical data reside.

The second is suitable observing sites at high altitude. Height means not only IR use, but also lower atmospheric turbulence, "good seeing" in astronomical parlance. You can get above much of the atmosphere and most of any atmospheric haze.

The third is government support for the development of the necessary infrastructure to support large observatories. Chile learned early-on that astronomical research means money, jobs, and the prospect for additional partnering.

The fourth is support of the local populations. Elsewhere, indigenous groups can regard mountaintops as religious sites, and protest vigorously if an observatory is proposed. This is true at Mauna Kea and at Mt. Graham in Arizona, and elsewhere, but not in Chile. The locals support observatories, and as we shall see, have found ways to promote astro-tourism as a way to increase the local standard of living.

CERRO TOLOLO INTER-AMERICAN OBSERVATORY

I doubt there is a more-fitting name for an astronomical observatory anywhere in the world than Cerro Tololo, because "Tololo" in Quechuan, the language of the Inca, means "The Edge of the Abyss!"

Most permanent astronomical observatories built prior to WWII were in the northern hemisphere. They had no counterparts that could see southern skies; 30% or so of the celestial sphere was "astronomica incognito." That all changed in the 1960s. Astronomers, particularly

those in Europe, realized that having a major observing site somewhere well south of the Equator would be most desirable. The search was on for a satisfactory site, and Cerro Tololo in the Chilean Andes was determined to be the best place.

A 4-meter telescope, later named for the second CTIO Director, Victor Blanco, was the first built at Cerro Tololo, completing in 1974. Now the astronomical community had a wonderful telescope with a full view of southern skies! Additional telescopes would come to the "Edge of the Abyss" in the following years, to the point that the summit of Cerro Tololo could no longer accommodate them. So CTIO expanded to the next peak over, Cerro Pachón, which, because it is a few hundred feet higher, is even edgier abyss-ward. The Southern Astrophysical Research Telescope and the Gemini South telescope (the twin of Gemini North on Mauna Kea) have been at Pachón for a number of years, and the Vera Rubin Observatory, with the Simonyi giant camera, is presently under construction there.

As if the seeing conditions weren't good enough at Tololo, astronomers have found a way to warp the main mirror of their telescopes slightly to compensate for observed turbulence - in real time! This amazing development was pioneered in part in Chile; the Gemini North/South telescope pair helped lead the way.

THE PLAYERS

Building, maintaining, and operating large observatories in the Andes requires a lot of money and supporting infrastructure, more than a single university, government, or patron could alone accommodate. Professional astronomy in Chile is managed by four consortium-type organizations.

CATA (Centro Astropisica y Technologias Afines)

CATA is the Chilean organization dedicated to astronomical research and public outreach. They manage the CNO and other Chilean astronomical assets and play an important role in helping the other three consortia with observatory site selection and acting as a liaison with local government and organizations. They help ensure Chilean astronomers have telescope access, and work to see that Chilean students receive the education and training necessary to both conduct research and to support the research efforts of others.

AURA (Association of Universities for Research in Astronomy)

AURA has three main subdivisions, the National Solar Observatory, the Space Telescope Science Institute, and NOIRLab (formerly the National Optical Astronomy Observatory). The principal facility of the NSO is the Daniel K. Inouye Solar Telescope on Maui, the most sophisticated solar telescope ever built. The STScI manages the data from the *Hubble Space Telescope*, and NOIRLab is the National Science Foundation's Center for Ground-based Optical Astronomy.

NOIRLab manages the Kitt Peak National Observatory in Arizona and the Community Science and Data Center, which provides software systems, user services, and development initiatives for users of the AURA observatories. NOIRLab manages the Cerro Tololo Observatory, both

components of the International Gemini Observatory, and the Vera Rubin Observatory under construction on Cerro Pachón. The VRO is scheduled to be completed in 2025. Its main light-gathering power is the Simonyi Survey Telescope, with an 8.4-meter diameter mirror, but what really is special about it is that it will use the largest digital camera ever built, a 3.2 giga-pixel array. It has an enormous field of view, and will allow deep surveys with but a short time between looks, allowing the detection of rapid changes. It will also be an important tool in the investigation of the nature of dark matter. For a summary of the camera's capabilities, see here; for info on the VRO, see here. [FYI: Charles Simonyi, a software expert and Microsoft's employee #40, funded the construction of the telescope/camera. He was the guy behind the development of both MS Word and MS Excel. Like NASM patron, Steven F. Udvar-Hazy, he grew up behind the Iron Curtain and Space for him, represented freedom from an early age. He's the only person who has paid to be a tourist at the ISS twice.]

CARNEGIE INSTITUTION FOR SCIENCE

The Carnegie Institution continued its strong support for astronomical research. It built and operates the Las Campanas Observatory (LCO) complex on Cerro Las Campanas. The LCO actually predates CTIO, at least operationally; its 40" Swope Telescope saw First Light in 1971. The du Pont 100" telescope was completed in 1977, and the twin Magellan Telescopes, each with a 6.5-meter mirror, saw First Light in 2000 and 2002. One of the MTs is named for famed astronomer Walter Baade, the other for financial sponsor Landon T. Clay. The Magellan Telescopes have additional financial and operational support from a consortium that includes the University of Arizona, Harvard, the University of Michigan, and MIT. I had a wonderful tour of the Clay Telescope, led by the LCO Director himself, Dr. Leopoldo Infante. He gave a great tour, and the facility is absolutely amazing!

LCO is also the site for the Giant Magellan Telescope, a behemoth that will use a cluster of seven mirrors, each 8.4 meters across. All seven mirrors have been cast, six of which have been fully-completed and are in storage awaiting transportation to Chile and installation in the GMT. The giant mounting is presently being fabricated by Ingersoll Machine Tools and MT Mechatronics; its delivery to the observatory site is scheduled for late 2025. Site prep is well underway, and First Light is expected in 2029. For more information on the seventh mirror, see here; for more on the GMT, see here.

A separate company, GMTO, was formed to oversee and coordinate the construction of the GMT. There are many members of the GMT consortium, including the Harvard-Smithsonian Astrophysical Observatory.

The European Southern Observatory

European astronomers also have had a long interest in Chilean observing sites. They operate four separate facilities: La Silla, Paranal and nearby Cerro Amazones, and the Atacama Large Millimeter-Submililmeter Array (ALMA) radio telescope.

The La Silla Observatory has two main telescopes, the 3.6-meter Telescope, which focuses on exoplanets and astro-seismology (yes, stars do have "star-quakes" detectable from Earth!), and

the New Technology Telescope, which also was a pioneer in adaptive optics like the Gemini scopes were.

Paranal is the home of the Very Large Telescope (astronomers are at times as bad as geologists at coming up with cool names for things). It has four mirrors, each 8.4-meters in diameter that can operate as an interferometer, which gives superb resolution. It has been in full operation for almost two decades, and has produced a lot of good science.

Cerro Amazones, near Paranal, is the site of the Extremely Large Telescope, now under construction. The ELT will have a segmented mirror with adaptive optics, and a surface area larger than a regulation basketball court.

ALMA is the largest radio telescope complex in the world. It was built in part to study young star systems where planets are in the process of formation. One of the first high-resolution images acquired by ALMA was of HL Tauri, 480 light-years distant. It is surrounded by a protoplanetary disc, with gaps where planets are likely forming. The accretion of particles within the disc causes polarization of light they emit, and with ALMA's resolution capability and HL Tauri being rather "close" to us, it could be studied in unprecedented detail. For a summary of this work, see here; for the abstract of the paper in *Nature*, see here.

Astronomers recently used ALMA to examine a supernova remnant called LHA 120-N49 in the Large Magellanic Cloud. They report that the expanding shockwave from the ~4800-year-old supernova is heating the material in the interstellar medium in the vicinity of the explosion site. For more on this work, see: https://phys.org/news/2023-11-alma-molecular-clouds-supernova-remnant.html.

Another team of astronomers used ALMA to observe the star R Leporis, a star in its last stage of life, over 1500 light-years from Earth. They are examining a ring/shell of gas being blown off R Leporis into surrounding interstellar Space. The study is important in its own right, but it also serves as a test of maximizing the resolution of the ALMA system of antennae. For a summary of this work, see: https://www.sciencedaily.com/releases/2023/11/231115113925.htm.

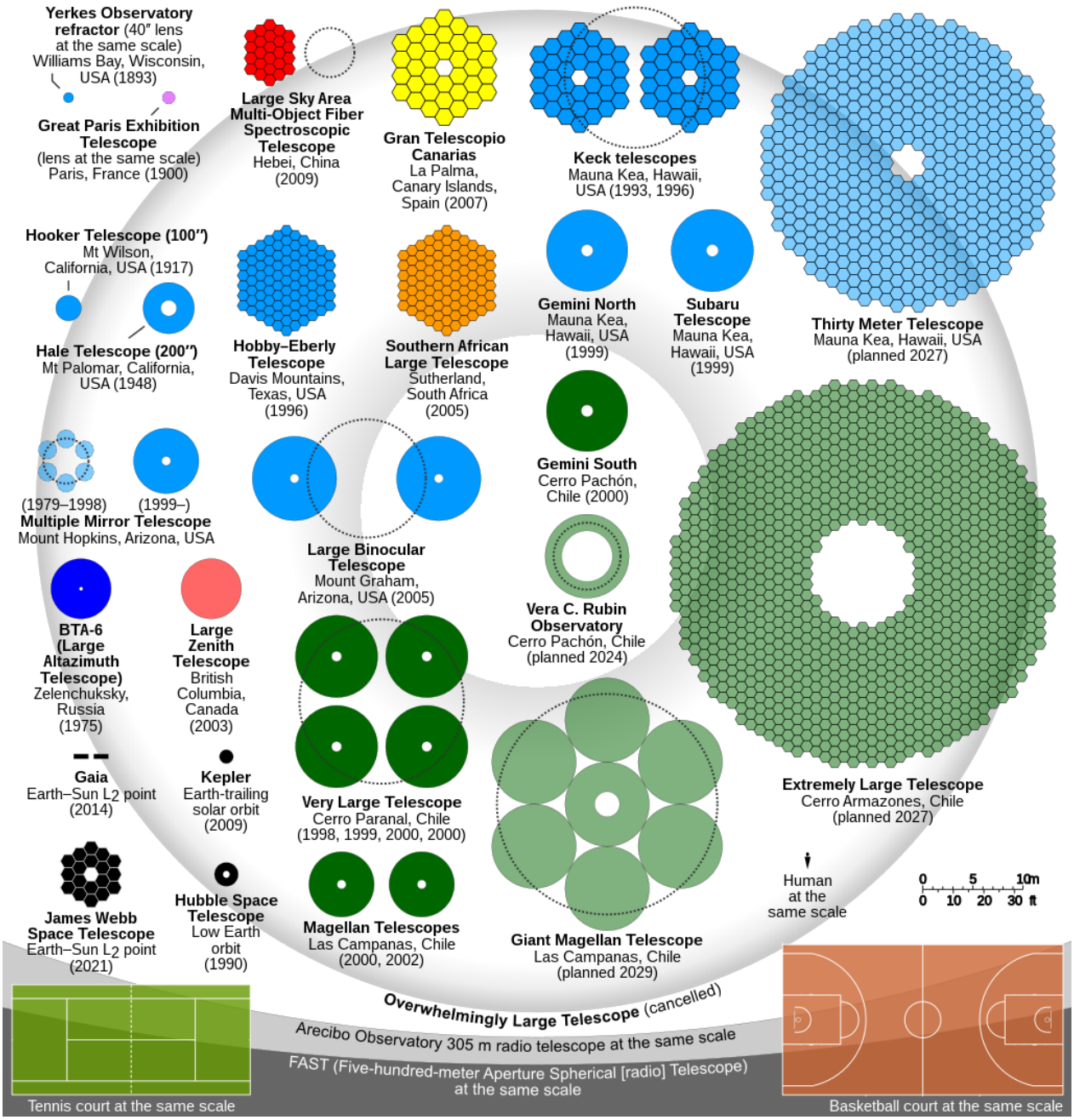
ALMA is difficult to work on, since it lies at an altitude of 18,000 feet!

TOURISM OBSERVATORIES

The dark skies of Chile are attracting increasing numbers of tourists interested in seeing southern celestial features, often as part of a larger tour that showcases Chile's interesting history, amazing scenery, and excellent wines. A number of communities and private companies have built observatories with reasonably-large and capable telescopes, not for research, but for attracting tourists. I visited three such on my recent visit to Chile, and they were an important addition to the overall enjoyment of the trip.

COMPARISON OF TELESCOPE MIRRORS

Check out the figure below to see how much telescope optics have expanded over the years. I got it from Wikipedia, but it's all over the Internet; I could find no original source to credit.



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