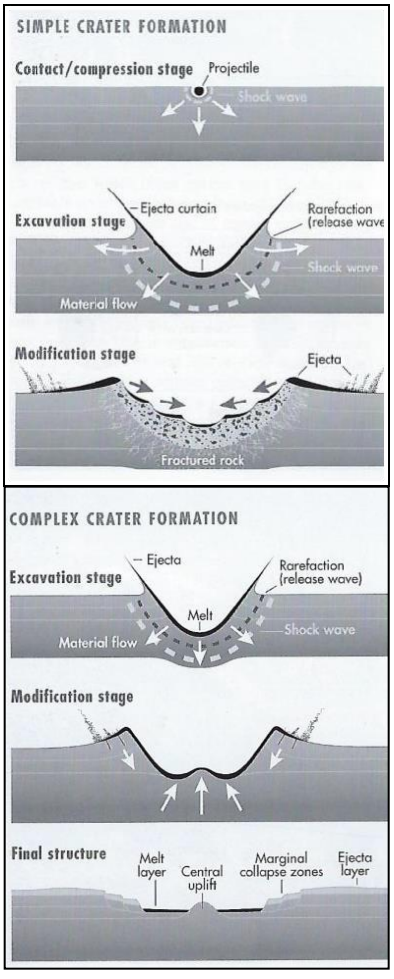
ASTRONOMY – A NEW APPROACH TO AN OLD HOBBY

by Art Storbo, February 2021

Background. My interest in astronomy began with my first job after high school when I worked at Boeing as a draftsman on the Minuteman missile, 1961-1963. I had read all the books in my home- town library about the nascent U.S. space program and astronomy, but I didn't own a telescope as I was saving money for college. My mentors at Boeing pointed me to civil engineering, and the next 45 years of school and work left me little time for astronomy. Sharon and I watched the Apollo moon landings beginning in 1969; and like others at the time, we bought a small 4" refractor telescope. We learned of the Hubble Space Telescope's myopic vision and fix in the 1990s. We followed the Space Shuttle program and saw the next-to-last Shuttle launch at Cape Canaveral in 2011. We got by with binoculars and our 4" scope as our kids grew up, observing our Moon, Jupiter and its moons, and Saturn and its rings. Tame stuff, though, and the often-cloudy weather in western Washington was a problem. Owning more sophisticated equipment could not cure that. Reading *Sky and Telescope* magazine helped with news andadvice for amateur astronomers. It and more books provided me with a basic astronomy education.

In time, we acquired larger telescopes – a 5" refractor and, in 2008, a 9-1/4" reflector, also two hydrogen-alpha solar scopes for looking at the sun. From the 1980s, we had attended star parties in SunRiver, OR. These events were hosted by amateurs (including us) who furnished their own telescopes for the public to peer through while getting a short lecture on the object seen. We learned that distant galaxies, nebulae, globular clusters, quasars, double stars, and other objects were often beyond the interest/understanding of the general public. And if we showed them the Moon in our telescope, we had the most popular viewing line. Along the way, we watched our share of meteor showers, lunar eclipses, comets, and sunspots, often from Ellensburg, WA, and other areas where the skies are usually clear.



More Astronomy. On retirement in 2008, I took a 5-credit class in astronomy at Bellevue College to see what I had missed in self-study. Not much, I found. I did my term paper on geology and impact craters of the Moon; that earned me an "A" for the class. The Moon had been my favorite observing target because, as a civil engineer, I understood dirt and rocks better than deep space. Understanding crater formation is relevant not only to the Moon but to planets like Earth. Earth has more than 200 known craters surviving

erosion and plate tectonics, without which it would look much like our Moon.

After visits to Kitt Peak Observatory, Meteor Crater, and Lowell Observatory (LO), all in AZ, plus others, we became dues-paying members of LO in 2010. But observing was still a lonely hobby, as few of our friends would stay up half the night just to look at the 'boring' dark sky. To us, acquiring knowledge was as much fun as observing in the hobby of astronomy.

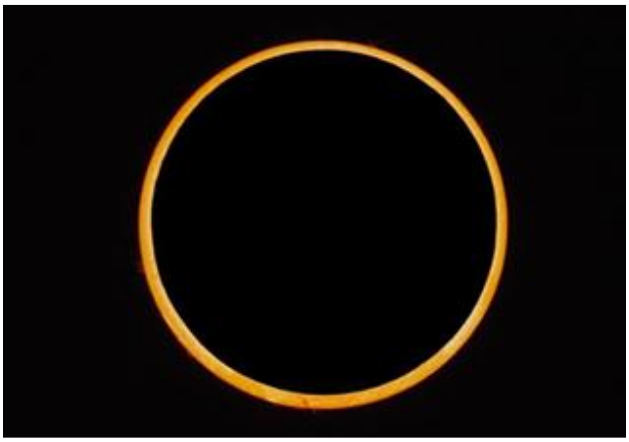
We loved travel, adventure, and history; and we enjoyed meeting people We had visited prehistoric Stonehenge observatory with our British friends whom we met on the Trinidad water project in 1978.

While living in Norway in 2003, we saw wonderful auroras. In Sweden, we saw the Siljan Ring, at a 32-mile-diameter, the largest meteor crater in Europe. And we observed a transit of Mercury in 2006.

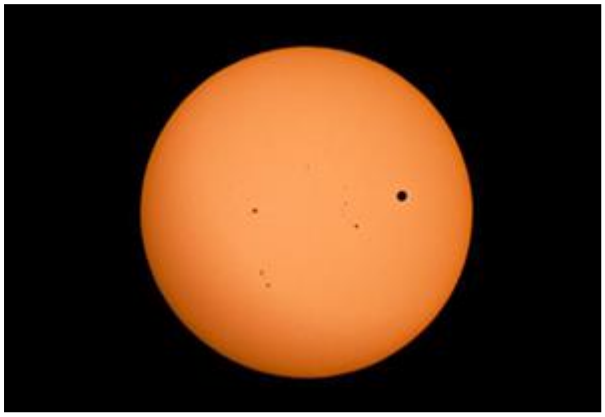
Then in 2012, our astronomy hobby really took off. In May that year, we watched a solar eclipse in Susanville, CA. Events like this require careful planning. We arrived a full day early and drove around the area to select an observing site, then we followed the sun through the path it would take the next day to verify continued visibility. If the weather forecast wasn't to our liking, we still had time to drive farther east. People came from all over the west coast to see this eclipse.

In June 2012, we visited Keck Observatory in Hawaii with a group led by the editor of *Sky and Telescope* magazine. Our main purpose was to watch a transit of Venus – when planet Venus crosses the face of the Sun in our direct line of sight. This event happens only twice in 121 years, the second transit occurring 8 years after the first. Here we learned something valuable – it was better to observe through other peoples' equipment and avoid the hassle of transporting our own equipment with risk of damage, especially to remote locations like cold, windy Mauna Kea.

Sharon with Dale (RDD) and Karen Cannon, observing the annular eclipse, Susanville, CA, 2012.



Annular eclipse of the Sun, from Susanville, CA, 2012. Relative Moon and Sun distance from Earth determines whether the Sun is partially or totally obscured.



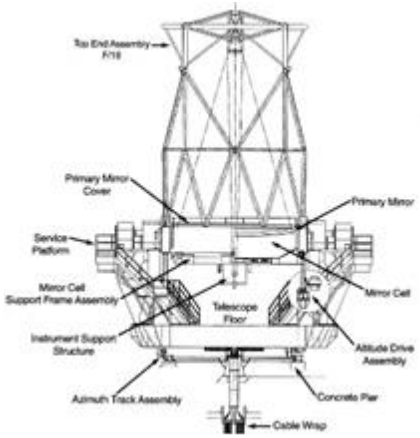
Planet Venus (large black dot to right) transits the Sun, June 5, 2012. Smaller spots are sunspots. Venus was 52 million miles distant, and the Sun 93 million miles. Photo by David Buchla, as displayed on the 36" flat screen in the back of the van next to Sharon.

Sharon at the eyepiece of tour-operator's telescope atop 13,800-ft Mauna Kea, transit of Venus, June 5, 2012. Total transit time was 6 hours and 40 minutes.

Art and Sharon Storbo meet Neil Armstrong, 2012.

Later in 2012 came an invitation to LO's "first-light" celebration of its new Discovery Channel Telescope (DCT), in 2020 renamed the Lowell Discovery Telescope (LDT). Neil Armstrong was to be the keynote speaker at the 600-person fund-raising banquet, $125 a plate, in Flagstaff, AZ. We jumped at the opportunity, and we also bit on the extra $1,000 required donation to meet Neil in person. Sharon knew there was no one on the face of the planet who I'd like to meet more than Neil. Among the 200 people in the reception and photo line, we got about 2 minutes of face time with him. Then after dinner, in his typical nonchalant fashion, Neil gave a fine hour-long illustrated talk about the complexities and drama of his landing on the Moon.

On a subsequent trip to LO in 2013, we got a personal tour of the LDT and the Navy Precision Optical Interferometer (NPOI). To me, an engineer, these were fascinating instruments ($50M^{+} apiece); and we could get close to them and talk to astronomers and operators. Here we learned of LO's public outreach program aimed at bringing astronomy to the public and we began making an annual donation to their Director's Outreach Network (DON). This earned us a privilege few get – to travel every second year (at our expense) to big-time observatories somewhere in the world in company of astronomers, who opened doors we wouldn't normally get through.



Typical configuration of a large reflecting telescope.

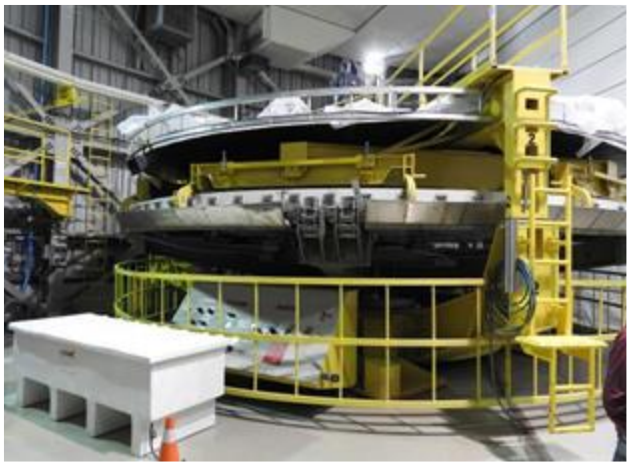
Son Jeff (6'-2"), at center, standing next to the 8.1m (26.5ft) diameter Gemini South telescope.

Chile, 2016. The first of these trips came in 2016, to visit observatories in Chile, S.A. Sharon had recently undergone a knee replacement, so our son Jeff went with me. After landing in Santiago and a day of sightseeing, our group of 22 was bussed first to Gemini South at 8,000 ft elevation in the Andes Mtns (Gemini North is at Mauna Kea, Hawaii). Gemini is owned and operated jointly by the U.S, Canada, Chile, Brazil, and Argentina.

The Gemini South telescope has a configuration typical of most of the world's large reflecting telescopes – separate drives for azimuth (compass direction) and altitude (elevation up from horizon), with the entire assembly mounted on a large concrete pier founded in solid rock. Incoming light hits the primary mirror at the bottom of the mirror frame, which by its parabolic or hyperbolic shape reflects the light into the much smaller secondary mirror at the top of the frame, from where it is reflected again to the instrument packages below the center hole in the primary mirror. These large telescopes may weigh hundreds of tons. The telescope is housed in a dome for weather protection. The dome rotates to match telescope azimuth, and a section across the top of the dome opens to accommodate telescope altitude.

Gemini telescope mirrors are cleaned and recoated every 5 years. This is an intriguing and delicate operation that requires the mirrors to be removed from the frame and transported to the washing machine where dust and bird poop are removed.
The secondary mirror is small, easy to handle; but a single-piece primary mirror 6 inches thick (glass) may weigh 25 tons and must be handled very carefully. The mirrors are washed with soap and water, and then given an acid rinse to remove the old silver coating. The mirror is recoated in another machine before being replaced in the telescope frame. In the recoating machine, the mirror is held in a vacuum chamber where 10 microns of pure silver, atomized by electric arc, are uniformly distributed over the mirror surface. Gemini South uses silver coating to obtain mirror reflectivity of 99 percent, better than the 98 percent achieved with aluminum coating used by most observatories. However, silver oxidizes (tarnishes) more quickly and requires weekly washing in situ in the telescope frame. There is no "polishing" of themirror – absolutely nothing is allowed to touch its surface. Gemini South saw first light in 2001 at a construction cost of $300M.

From Gemini South, we could see construction of the 6.5m-LSST (renamed the Vera C. Rubin Observatory) on another mountain top 3/4-mile away, to be completed by 2021. This telescope's 3-billion-pixel camera will scan the entire southern sky weekly to create a 3-dimensional cosmic map in the search for dark matter and dark energy. It will also detect and track potentially hazardous asteroids.



The mirror washing machine at Gemini South.

We next went to Paranal, north of Santiago, where the ESO (European Southern Observatory), a consortium of 16 European countries and Chile, operates an array of telescopes known as the VLT, or Very Large Telescope, at 8,000 feet in the Atacama Desert. It comprises four 8.2-m fixed telescopes and four 1.8-m moveable telescopes, plus others offsite. These telescopes can work independently or in combination. Combinations function like an interferometer; more about that below in discussion of the NPOI at LO.
Like Gemini, Paranal has similar servicing equipment for mirror cleaning and recoating.

The mirror recoating machine at Gemini South.

Based on Gemini South construction cost, Paranal must have cost about $1.6B. It is said to be the most productive telescope facility in the world, generating more than 1,000 professional papers per year.

At Paranal, we had the opportunity to talk to telescope operators in the control center, like we had done at Keck in Hawaii. To be an operator at any of these large telescope facilities requires a minimum PhD in astronomy or physics. Being a telescope operator is often an early step in the career path of an astronomer. Each of the eight Paranal telescopes is operated by a 4-person team. Night shifts are generally 12 hours, including an hour startup and an hour shutdown. Astronomers with allotted time on a telescope may choose to come to Paranal to work directly with the operators or they may remain remote with data transmitted electronically to their home location, a world-wide practice. Acquiring time on any telescope is a competitive process; the telescope committee decides who gets time based on the merits of submitted proposals (and applies to the Hubble Space Telescope as well). Time is often scheduled months, even years, ahead, and can result with no time if the weather is bad on the night allotted.

ESO's VLT (Very Large Telescope) complex at Paranal.

The VLT comprises four 8.2m fixed telescopes and four 1.8mmoveable telescopes that travel on tracks in the foreground.

From Paranal, we bussed north and east for 6-1/2 hours toSan Pedro de Atacama, a quaint old town at 7,900 feet among the Andes Mtns towering to 19,000 feet in the eastern part of Chile near its border with Argentina and Bolivia. En route, we passed the Chuquicamata copper mine near Calama. At a half mile deep and 2 to 3 miles across, it is the world's largest open pit mine. The next day, we went by bus to altiplano lakes Miscanti and Minigues at 14,000 feet. We saw salt flats, smoking Lascar Volcano, and at 16,000 feet, the ALMA (Atacama Large Millimeter/ submillimeter Array) radio telescopes. Comprising 66 dishes of 12-m and 7-m diameters, ALMA is the world's largest radio telescope array. We were only able to see ALMA from the highway that day, as we had not spent enough hours at altitude to meet prescribed acclimatization requirements for a site tour. The thin, dry air provides superb night vistas of the southern sky; but it was difficult to recognize familiar constellations upside down from the positions as we see them in the northern hemisphere, amid far more stars than we had ever seen before.

ALMA radio telescopes under Atacama Desert dark sky. This Internet photo also shows the magnificent Milky Way.

LO Advisory Board. After the Chile trip, Sharon and I were invited in 2017 to join the advisory board (AB) at LO. The 30+ members of the AB have no authority in business decisions and day-to-day operations of LO; they function more like a citizens advisory committee. Their main responsibility is in helping LO share the fascinating science of astronomy with the public. To that end, we and two other couples are the eyes and ears of LO in the Seattle area. We help arrange venues for LO astronomers who come to Seattle for presentations. Through our contacts with local astronomy clubs, schools, and the public, we encourage persons interested in astronomy to visit LO in Arizona.
We relay to LO suggestions on ways to improve public outreach, the second most important element in LO's mission after pure scientific research. We also watch for potential donors to LO's public outreach program.

Giovale Open Deck Observatory, completed in 2019.

The 24" Clark refractor, used in early 1960s to map the Moon prior to Apollolandings, reconditioned for public use.

From what we have seen, astronomers do a better job of informing the public of their accomplishments than civil engineers do, in part because the astronomy industry depends on public support of their research. We have made a new circle of friends on the AB, all of whom have a passion for astronomy and public outreach. Kent Robinson, a former CH2M manager who only recently passed away, was on the AB when we came onboard. Other AB members include the editor of *Astronomy* magazine; a member of the Barringer family who owns and operates Meteor Crater; Alan Stern (principal investigator of New Horizons); and numerous retired scientists, educators, and financial experts.

LO Facilities and Astronomers. LO is a research facility located in Flagstaff, AZ, at elevation 7,000 feet. Funded by private donations, NASA grants, telescope rental, and visitor fees. It has an interesting history of astronomical discovery spanning 125 years. It has clear skies, a spacious campus atop Mars Hill, and is near Northern Arizona University (NAU) and the U.S. Naval Observatory with its 1.55-m (61") reflector. Established in 1894, LO first became known for the study of "canals" on planet Mars by its founder, Percival Lowell, who installed the 24" Clark telescope in 1896. In 1912-1914, V.M.Slipher discovered that light from distant galaxies is red-shifted, proving that the universe is expanding.

In 1930, the planet Pluto was discovered at LO; other discoveries have been made in subsequent years. In late 2019 LO fulfilled one of its goals of public outreach when the GODO (Giovale Open Deck Observatory) came online, featuring a retractable roof/wall structurehousing six state-of-the-art telescopes for public use. See Glovale Open Deck Observatory. Until Covid-19 halted such public gatherings, LO was drawing 100,000 visitors per year. By 2023, LO plans to have a new visitor facility, the Astronomy DiscoveryCenter (ADC) with latest high-tech public displays and education on the science of astronomy.

LO has been a real adventure for us. We have toured all of LO's historic telescopes, the 24" Clark, the Pluto Dome, their state-of-the-art 4.3-m LDT, the NPOI, and others. The LDT, completed in 2012, is used primarily by LO astronomers but is also available to other astronomers with time on a competitive basis. It has similar service equipment to that shown above for Gemini and Paranal. We have met many of the staff – astronomers, operators, mechanics, and educators who lead public tours.

The LO astronomers always amaze us with their ingenious scientific and engineering talents. If a specific instrument isn't made by commercial suppliers, they design and build what they need themselves. Through public and private gatherings, we've found these astronomers and planetary scientists are some of the brightest people we know. Will Grundy was surficial geologist on the New Horizons flyby of Pluto in 2015. He tells about the fascinating geology of Pluto, much colder than Earth, where frozen water ice makes up much of the hard bedrock supporting softer ices of CO_2, nitrogen, and methane. He has shown us his cold lab at NAU where he can create temperatures down to -250°C. Alan Stern was the mastermind of the New Horizons project for more than 20 years. His stories recount building, testing, permitting (New Horizons instrumentation and communication systems are nuclear-powered), launch, navigation, and travel of the spacecraft on its 9-year journey to Pluto, and its highly successful fly-by and photography. Jeff Hall, director of LO, specializes in stellar activity, sunspots, and the sun's effects, cyclical and otherwise, on Earth's weather. He is also active in dark skies preservation efforts, a growing concern for all astronomers.

The Pluto Dome, where Clyde Tombaugh discovered Pluto.

Clyde Tombaugh's 13" astrograph used to find Pluto.

Gerard van Belle manages the NPOI, a unique facility operated in partnership between LO and the U.S. Navy.
First known as the Navy Prototype Optical Interferometer, it was built in 1994 to test the principals of interferometry with visible light, after radio wave interferometry had proven so successful. Like ESO radio telescopes at Paranal, the NPOI uses two to six telescopes in combination. Interferometry is the process of synthesizing streams of light from multiple telescopes, which in combination "see" as well as a single telescope of diameter equal to the multiple telescope separation distance.

The NPOI has 9 fixed telescope positions on each of 3 arms 120° apart and 250 meters long.


One of NPOI's 27 siderostats and lizard head telescopes.

NPOI was originally equipped with fixed siderostats (20" mirrors) that track the object and reflect its light to "lizard head" telescopes by which the light beam is narrowed for transmission through evacuated tubes to the beam-combining facility, a complex operation that corrects for Earth'srotation and orbital movement. Recent additions include three 1-m moveable telescopes. For more details, see Navy Precision Optical Interferometer.

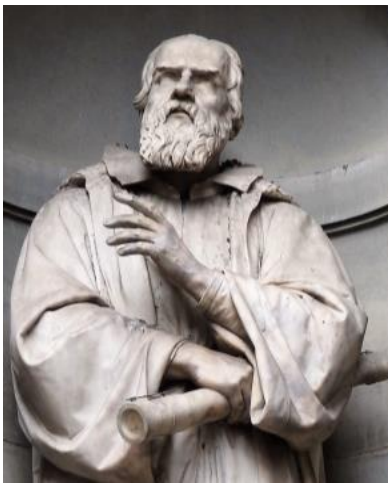
LO's premier telescope, the LDT, is the fifth largest telescope in the continental U.S. Its 6,700-pound, 4"-thick single-piece mirror is equipped with active optics to compensate for gravityand temperature deformations. Its instrument cube can accommodate five different instruments recording simultaneously. Virtually all observations are recorded or transmitted electronically to a screen; no one squints through an eyepiece anymore. LO has a fully equipped instrument and machine shop, staffed by five technicians who keep existing equipment operating smoothly and build new instrumentation when needed. For more on the LDT and its instrumentation, see the following websites: Lowell Discovery Telescope andLowell.edu.

Art under the LDT mirror frame, rotated down so we could see the primary mirror.

Lowell Discovery Telescope.

UK, Germany, Italy, 2018. Our second overseas astronomy trip,in 2018, featured the history of astronomy. It began with a tour of England's Royal Observatory at Greenwich, where we stood on the line of zero longitude, saw the UK's 1893 Great Equatorial Telescope (28" refractor) and learned about John Harrison's 1760 invention of the chronometer, an accurate clock essential to determining longitude for navigation at sea as well as world-wide astronomy. Then we visited Stonehenge, mankind's best-known early-day observatory, and learned about its construction some 4,500 years ago.

Great Equatorial Telescope, UK.



Galileo with his 2" scope.

Astronomy on Tap, Seattle.

In Germany, we visited Heidelberg Observatory where we saw more historic telescopes, then the Max Planck Institute where we learned how astronomers and agencies like NASA collaborate world-wide in their research. In Milan, Italy, we visited Brera Observatory and Museum, where we saw Giovanni Schiaparelli's 1865 Merz 218-mm refractor and his historic correspondence with Percival Lowell from the early 1900s. In Florence at the Galileo Museum, we saw Galileo Galilei's 2-inch telescope with which he verified in 1610 his deduction that the Earth moves, by watching the motion of Jupiter's large moons.

Canary Islands, Spain, France, 2020. This trip, featuring more world-class observatories, was postponed to 2022 because of Covid-19.

Events closer to home. In recent years, we have helped LO with local events. For example, in 2017, we shared telescopes at the Great American Eclipsein Madras, OR. In 2019, we helped LO arrange their annual Seattle lectures to coincide with the Museum of Flight's week-long celebration of the 50th anniversary of Apollo 11's landing on the Moon. This year, the annual AB meeting was held virtually because of Covid-19 restrictions. As a substitute for public visits to the campus, LO has developed a series of weekly live-streaming events – Cosmic Coffee, Meet an Astronomer, and Interactive Stargazing. See Interactive Stargazing.

They have also produced single livestreams for events like the Great Conjunction in December 2020. Part of our "job" is to provide feedback on as many of these events as we have time to watch. These live-streams are archived at You-Tube so they can be easily accessed later by anyone. They form a library of sorts for teachers' and students' use as supplemental schoolwork. Closer yet to home, we did a presentation at Bellevue's Eastside Astronomical Society, observed a transit of Mercury, saw Comet NEOWISE and the recent Perseid meteor shower, and, until March of 2020, enjoyed the monthly Astronomy on Tap held by UW students at Peddler Brewery in Ballard.
A great hobby!

Part of LO audience at Museum of Flight, July 2019.

Storbo family helping LO with public event at Madras, OR.