THE LOWELL OBSERVER Issue 124 | 2022 no. 1

THE LUCY MISSION

By Dr. Will Grundy, Planetary Scientist

**Editor's note – Last October, NASA's Lucy spacecraft lifted off from the Kennedy Space Center in Florida atop an Atlas V rocket. Dr. Grundy, along with hundreds of engineers and fellow scientists on the Lucy team, witnessed the launch and now look to the future when Lucy will explore several of Jupiter's Trojan asteroids.*

As a member of the Lucy science team since 2014, I helped define the science goals for the mission and spell out the technical capabilities required to accomplish those goals, and then helped convince NASA that the mission was achievable and worth the cost. Post-launch, our work continues with planning the various spacecraft activities, and eventually, analyzing the data collected and sharing the results with the world.

I also have a second Lucy role as the instrument scientist for the infrared spectral instrument. The instrument scientist works to ensure that the instrument can do everything the science team needs it to do and that the team is equipped with the tools and knowledge to interpret the data the instrument produces.

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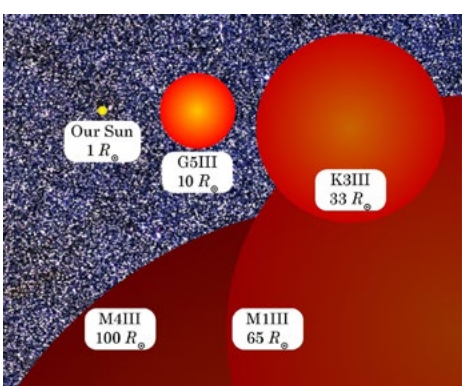

Gerard van Belle Heads Unprecedented Star Survey that Details Physical Characteristics of Giant Stars

By Kevin Schindler, Historian/PIO

In a study that is by far the most accurate of its kind, a team of scientists led by Lowell Observatory's Dr. Gerard van Belle has now directly measured the temperatures and sizes of 191 giant stars. The results were published in a 310-page paper that the authors anticipate will serve as a standard reference for years to come. One application of the study involves clarifying the ultimate fate of the Sun.

A giant star is a type of star that is much larger and brighter than other stars

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DIRECTOR'S UPDATE

March 2022 marks the two-year anniversary of our closing our public program as the COVID-19 pandemic began surging around the world—a dubious milestone to be sure, but perhaps one for which it appears we might finally be emerging for good into full operations.

The team has been exemplary during this wild two-year ride. Our researchers have kept the discoveries and results coming and have excelled at winning grants to support their work. By mid-2020, the technology team had figured out pandemic protocols to let us operate our telescopes safely, minimizing our observing downtime. The outreach and marketing teams quickly pivoted to excellent online programming. And it looks like we may at last be at the end of our labyrinthine path from full shutdown to full reopening of our onsite visitor programs.

Lots of other things have had to happen as well, including obtaining badly needed PPP funds, managing the ever-shifting COVID policies and providing guidance for staff who contracted the illness, and just watching out for the physical plant while Mars Hill was, for all intents and purposes, deserted.

Everyone has played an important role in getting Lowell through the last two years—including our many friends around the world who have continued to support us so generously. We greatly appreciate it.

The time since March 2020 has been wearisome for me personally, as I know it has also been for so many on the team. I'm so grateful for everyone's perseverance and dedication to the institution: we're stronger now than we were two years ago, and you are why. •

TRUSTEE'S UPDATE

As this issue shows, the breadth and depth of research at the observatory continues to grow. Even the excavation for the new visitor center let us discover more about the geology of Mars Hill itself!

Sustaining long-term research studies has always been a key mission for the observatory. It is what allowed Carl Lampland to do his research in the 1900's and is a core component of the giant star survey work recently completed by Gerard van Belle and his team.

Equally important to Percival was the ability to engage with non-scientists and excite them about this kind of work. COVID certainly impacted our ability to do that these past two years, but our visitor program has re-opened and I would encourage you to come up on Mars Hill and see all that is going on, both on the campus and in the skies. We have not been idle during this period and there is a lot to take in.

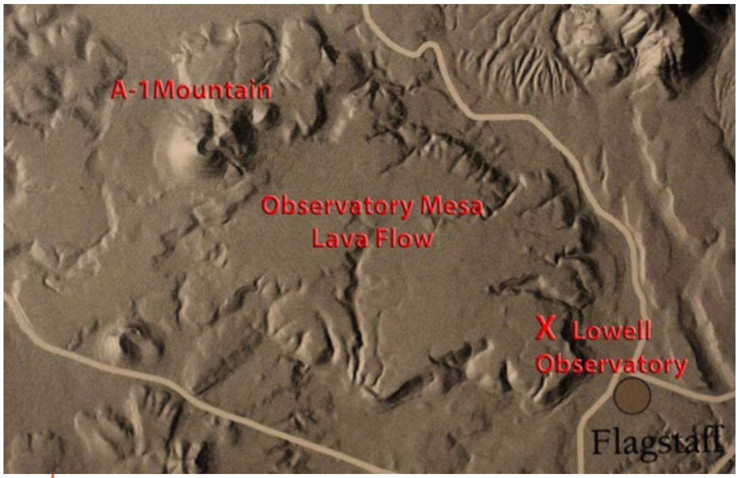
And encourage your friends to come visit as well! •

ADC Update *By Dave Sawyer, Technical Project Manager*

Things are back in full swing at the Astronomy Discovery Center site following a snow delay. The concrete contractor has completed the footings of the building. The photo to the right shows the crew pouring the footing for the elevator shaft along with a footing for a large steel support column visible behind the elevator pit. As you might imagine from this photo, the ADC footings have pretty much depleted the stock of steel rebar in the Flagstaff area. Following completion of the footings is work on the masonry block for the elevator shaft and building stem walls.

ADC Sits Atop Ancient Lava Flow

By Dr. Kent Colbath, Geologist and Advisory Board Member



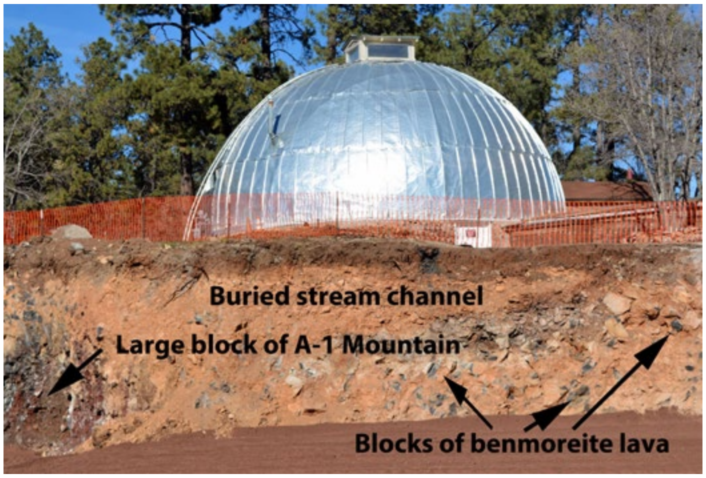


Image (left): A digital elevation model of Observatory Mesa. | Image (right): Excavation face of the ADC site, near the Lampland Dome.

On your next visit to Lowell Observatory pay attention as you drive west along Santa Fe Avenue from downtown Flagstaff.

At the point where Santa Fe transitions to Mars Hill Road you'll notice an abrupt increase in slope, followed by a couple of switchbacks as you drive to the top of Observatory Mesa, which stands 150 feet above the downtown area. Why the steep slope? In this short drive from downtown you've traversed the front of a gigantic lava flow that erupted from the A-1 Mountain vent northwest of town approximately 330,000 years ago. The flow covers roughly 10 square miles, and is composed of a volcanic rock called benmoreite, which is intermediate in silica composition and high in alkalis, especially sodium, compared to other lavas.

Recent blasting and excavation on the mesa for the new Astronomy Discovery Center afforded me a unique opportunity to examine a fresh exposure of fourteen feet of rock and soil on the top of this ancient lava flow. At first glance, this exposure appeared to be an incoherent mess. Aside from the distinctive organic soil horizon on the top of the flow, and a buried stream channel beneath the Lampland Dome, there wasn't much obvious structure to be seen. After four visits to the excavation face, one with the able consultation of Dr. Nancy Riggs, the volcanologist at Northern Arizona University (no relation to the observatory's Stephen Riggs), I think I can offer a coherent explanation of what was exposed in the excavation.

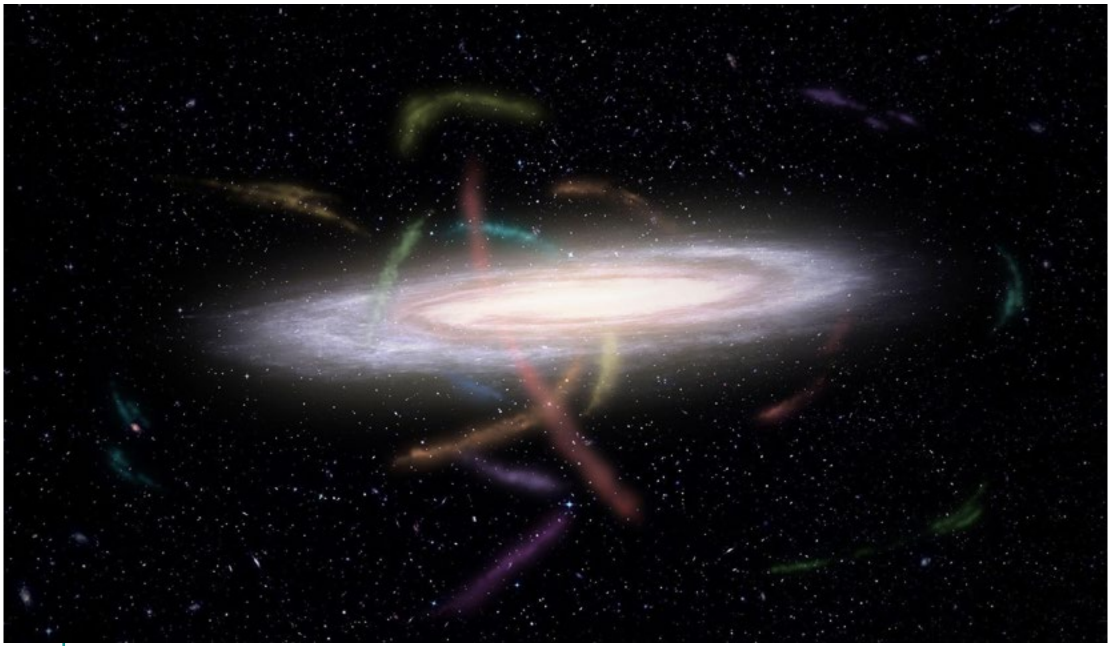
The top of the lava flow is mostly a large pile of volcanic rubble. There are blocks of dark gray benmoreite that preserve flow banding, but the banding is not consistent from one block to the next. The blocks are separated by rinds of clay minerals developed during 330,000 years of weathering, much of it under wetter and colder conditions than we see today. Of particular interest are large patches of red, weathered, volcanic rock which appear markedly different from the other blocks. Dr. Riggs made a persuasive case that these are actually pieces of the A-1 Mountain cinder cone volcano that broke loose and tumbled down onto the top of the lava flow, where they were carried on a lava conveyor belt to their current location, over three miles away, at what is now the observatory.

From a practical standpoint the discrete blocks of material separated by soil presented challenges to the construction crew, and required more work to stabilize the foundation of the new building that was originally anticipated. On the science side, viscosities of erupted lavas vary by eight orders of magnitude, from hot, runny flows of Kilauea clocked at 15 mph, to volcanic dome eruptions with lava so viscous they require time-lapse photography to visualize. Most modern eruptions tend toward one of these two end members, but somehow the Observatory Mesa flow was smack in the middle.

The A-1 Mountain volcano is extinct, so there is no concern about a new flow covering the Mesa and our favorite observatory. There is geophysical evidence that there is still liquid magma at the base of Earth's crust to the northeast of Flagstaff, however, and the odds of another eruption occurring within the next ten thousand years are fairly high. Perhaps there are more blocky benmoreite lava flows to come! •

NEW STUDY CASTS LIGHT ON DARK MATTER, FORMATION OF MILKY WAY

Compiled by Kevin Schindler, Historian/PIO



Artist's representation of our Milky Way Galaxy surrounded by dozens of stellar streams. These streams were the companion satellite galaxies or globular clusters that are now being torn apart by our galaxy's gravity.

Credit: James Josephides and S5 Collaboration

Astronomers, including Lowell's Dr. Kyler Kuehn are one step closer to learning the properties of dark matter enveloping our Milky Way Galaxy, thanks to a new map of twelve streams of stars orbiting within our galactic halo.

Understanding these so-called stellar streams is very important for astronomers. As well as revealing the dark matter that holds the stars in their orbits, they also tell scientists about the formation history of the Milky Way, revealing that it has steadily grown over billions of years by shredding and consuming smaller stellar systems.

"We are seeing these streams being disrupted by the Milky Way's gravitational pull, and eventually becoming part of the Milky Way. This study gives us a snapshot of the Milky Way's feeding habits, such as what kinds of smaller stellar systems it 'eats'. As our Galaxy is getting older, it is getting fatter." said University of Toronto's Ting Li, head of an international team of collaborators that includes Dr. Kuehn.

The team initiated a dedicated program—the Southern Stellar Stream Spectroscopic Survey (S5)—to measure the properties of stellar streams. These streams are the shredded remains of neighboring small galaxies and star clusters that are being torn apart by our own Milky Way. Unlike previous studies that have focused on one stream at a time, S5 measures multiple streams.

The properties of stellar streams reveal the presence of the invisible dark matter of the Milky Way. "Think of a Christmas tree", said team member Geraint F. Lewis of the University of Sydney. "On a dark night, we see the Christmas lights, but not the tree they are wrapped around. But the shape of the lights reveals the shape of the tree," he said. "It is the same with stellar streams – their orbits reveal the dark matter."

A crucial ingredient for the success of S5 were observations from the European Gaia space mission. "Gaia provided us with exquisite measurements of positions and motions of stars, essential for identifying members of the stellar streams" said team member Sergey Koposov of the University of Edinburgh.

As well as measuring their speeds, the astronomers can use these observations to work out the chemical compositions of the stars, giving a clue about where they were born. "Stellar streams can come either from disrupting galaxies or star clusters," said team member Alex Ji of the University of Chicago. "These two types of streams provide different insights into the nature of dark matter."

According to Li, these new observations are essential for determining how our Milky Way arose from the featureless universe after the Big Bang. "For me, this is one of the most intriguing questions, a question about our ultimate origins," Li said. "It is the reason why we founded S5 and built an international collaboration to address this".

The S5 collaboration has not only built on the work of earlier scientists, but branched out into entirely new science. Kuehn says, "Understanding the characteristics of a dozen separate stellar streams is a significant

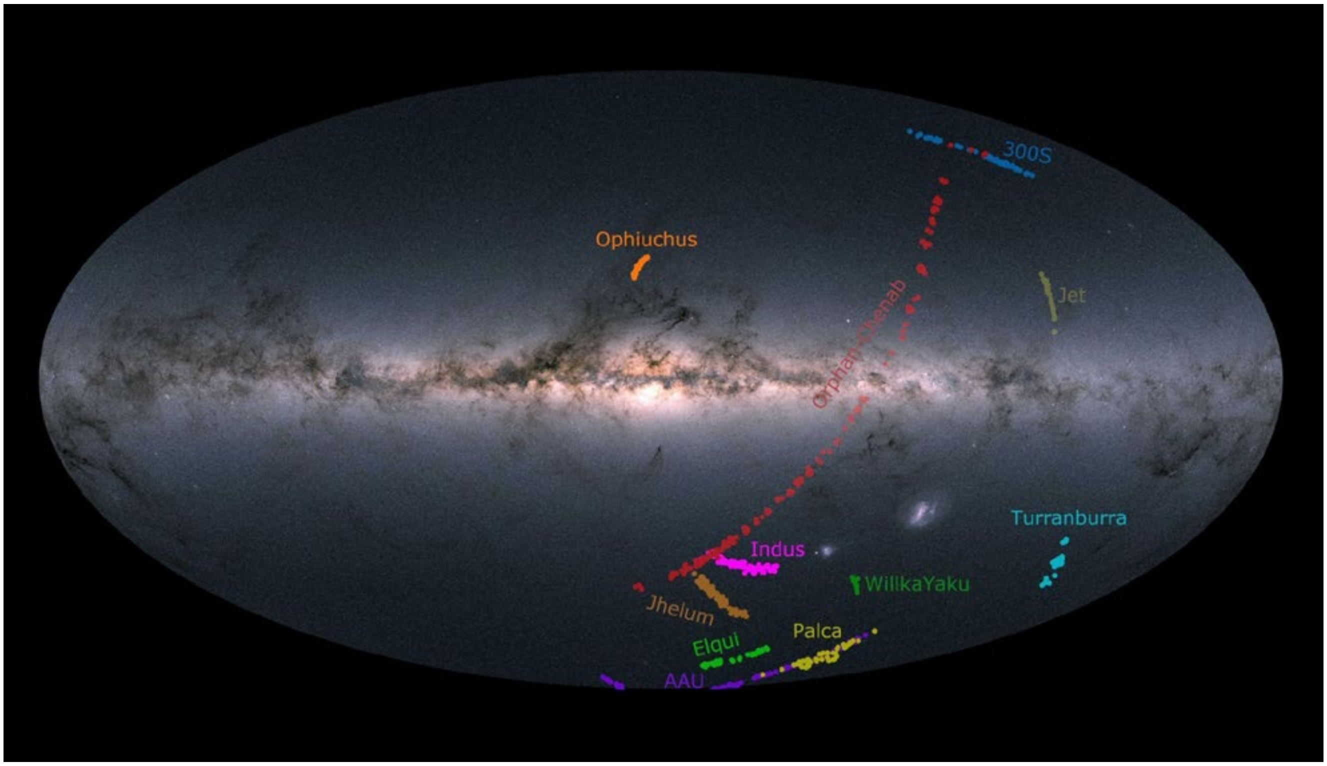
Celebrating 10 Years of the Lowell Discovery Telescope

By Kevin Schindler, Historian/PIO

Time flies when you're having fun! No one knows this better than our scientists who explore the cosmos with the Lowell Discovery Telescope (LDT). A decade has passed since the LDT began revealing the secrets of the universe, and the observatory is celebrating this 10th anniversary with a monthly livestream series. On the third Thursday of each month in 2022, from 7-8pm MST, scientists, engineers, and telescope operators will take viewers on a tour of the LDT, looking at the research done with it and at how the facility works.

To tune in, visit **lowell.edu/a-decade-of-exploration**

The Lowell Discovery Telescope dome is nestled beneath a star-spangled sky. | Credit: Joe Llama

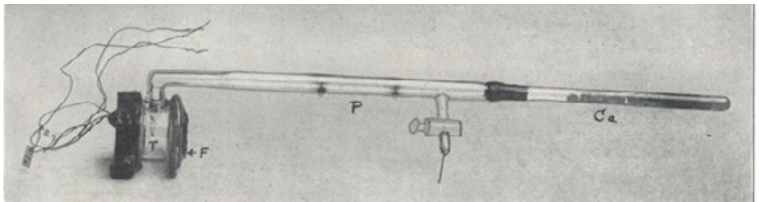


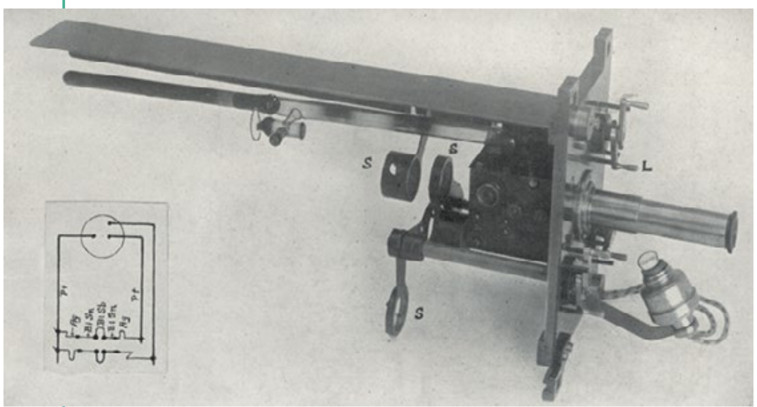
Location of the stars in the dozen streams as seen across the sky. The background shows the stars in our Milky Way from the European Space Agency's Gaia mission. The AAT is a Southern Hemisphere telescope so only streams in the Southern sky are observed by S5. | Credit: Ting Li, S5 Collaboration and European Space Agency

accomplishment, and there will be plenty more results to come from S5. We're learning a lot about these streams from our observations, and in the not-too-distant future, we expect to use them to measure important properties of the Milky Way itself—including its total mass and the way that dark matter is spread out through our galaxy." •

THE SCIENTIFIC LEGACY OF THE 42-INCH LAMPLAND TELESCOPE

By Dr. Joseph Marcus, Advisory Board Member





At the core of the radiometer were thermocouples (T) inside an evacuated container (top). Planetary radiation passed through a fluorite (F) window, striking tiny (< 0.5 mu), lampblack-coated tin receivers (the "dot" symbols at the U-shaped junctions of bismuth and antimony wires at bottom, inset). This heated the blackener, inducing a tiny thermoelectric current between the dissimilar metals (antimony and bismuth) that was amplified by a galvanometer ("circle" symbol, inset) located in the dome's adjoining silvering room. In the fully-mounted assembly (bottom), cutoff "transmission screens" (S) could be interposed in the light path by levers (L) to parse the radiation signal into wavebands in the visible and infrared. Both images from Lowell Observatory Bulletin No. 85 (1923).

At its commissioning in 1909, the Lowell Observatory 42-inch Clark Telescope was the third-largest silver-on-glass reflector in the world, surpassed only by the 60-inch reflectors at Mt. Wilson and Harvard. Staff astronomer Carl Otto Lampland (1873-1951) would be its primary user. He photographed the planets, their satellites, comets, variable stars, and nebulae, including nearly 1000 plates of Hubble's variable nebula, and the variable nebulosities surrounding the stars R Aquarii and Nova Persei 1901. He used it in 1911-1913 to search for Percival Lowell's "Planet X," and, after Clyde Tombaugh discovered Pluto in 1930, to obtain precise positions to determine the orbit. But of all Lampland's work with this telescope, none was as significant as his radiometry of the planets—the measurement of their light and heat. From these measures, the temperatures of the planets were derived for the first time.

The Lampland reflector and its radiometer reflect the observatory's long-held practice of taking risks with new technologies.

The powerful, state-of-the-art 42-inch was uniquely suited for this task. Reflecting telescopes transmit light from in advance of the visible region (0.4 to 0.7 mu wavelength) to deep in the infrared beyond 20 mu. Refractors are ill-suited because their glass lenses do not transmit radiation beyond 8 mu. The planets of our solar system radiate much of their heat beyond 8 mu.

To do radiometry, Lampland collaborated with William Weber Coblentz (1873-1962), the pioneering infrared physicist at the National Bureau of Standards in Washington, D.C. Coblentz built exquisitely sensitive "stellar radiometers" which he had deployed on the 36-inch Crossley reflector at Lick Observatory to measure the heat of the stars in 1914. He brought these inventions to Lowell Observatory, which offered better observing conditions with its drier atmosphere, and Lampland hooked them to the 42-inch. Together they radiometrically measured the planets during Coblentz's visits in 1921, 1922, 1924, and 1926.

Their results were pathbreaking. They determined that Jupiter was not a star (up to then many astronomers thought that Jupiter was incandescent). They found that Venus unexpectedly radiated heat equally from its day and night sides. They determined that Mars was clement for life, with noontime equatorial temperatures up to 21 °C (70 °F). But the huge dawn-to-dusk temperature swings they found meant that the Martian atmosphere must be very thin. Their numerous high-impact publications in the 1920s burnished the reputation of the observatory. By 1929, Lampland's visit to Princeton earned coverage in *The New York Times*.

Lampland continued radiometry into the early 1940s. But paralyzed by perfectionism, he never published further results, despite Coblentz's nagging. He made the first infrared observations ever of a comet in 1927, but only published an abstract. In 1984, Lowell Observatory Director Art Hoag fished these out of the Archives and found them to be eminently usable, as have I (see https://www.aspbooks.org/publications/471/181.pdf). Lampland's entries in 16 voluminous radiometry logbooks remain untapped save for a handful from 1924 and 1926. Most of the data he and Coblentz reduced and published preceded the logbooks and appear lost. But help is on the way! Last year, Archives volunteers John and Linda Spahn inventoried the logbooks, and volunteer Karen Kitt is now digitizing them using the new, donor-funded Zeutschel scanner, to make the observations available to the astronomical community.

The Lampland reflector and its radiometer reflect the observatory's long-held practice of taking risks with new technologies. The Lowell Discovery Telescope (LDT) and its fabulous instrument cube are only the latest examples of this successful high-risk, high-reward strategy. •

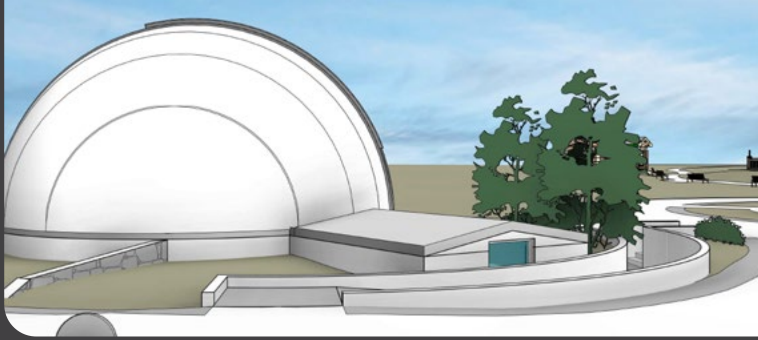
Help Save the Lampland Dome

By Sherry Shaffer, Philanthropy Manager

The pioneering scientific work done in the Lampland Dome was described on page 6. To preserve this integral piece of Lowell's history, we are now looking to restore the facility. Time and usage have taken their toll on the once stately Carl Lampland Dome. Situated on the path from the future Kemper and Ethel Marley Foundation Astronomy Discovery Center (ADC) to the rest of campus, the dome is now an eyesore and unfit for public use.

For years, and despite the design issues, the Lampland Dome was a research workhorse until the telescope's mirror was shattered in 1964. It then became a shop and a pottery studio, and even the silvering room became a greenhouse. Over time, the canvas exterior was replaced with aluminum sheeting (earning the nickname, the "Jiffy Pop Shop/Dome"), the telescope was removed, foam insulation was sprayed over the beautiful interior, and a loft was built. The exterior grounds got piled up with detritus and tools; somehow, a bathtub even made its way to the dome's yard.

The budget to restore the dome to its former splendor and convert it to an exhibit that showcases Lowell's innovative past is $600,000. The dome was at risk of demolition until a handful of generous donors stepped up to save it. We now have nearly half of the funds raised, so demolition appears less likely.



Top: Artist rendering of planned refurbishment of Lampland Dome, as seen from the ADC.

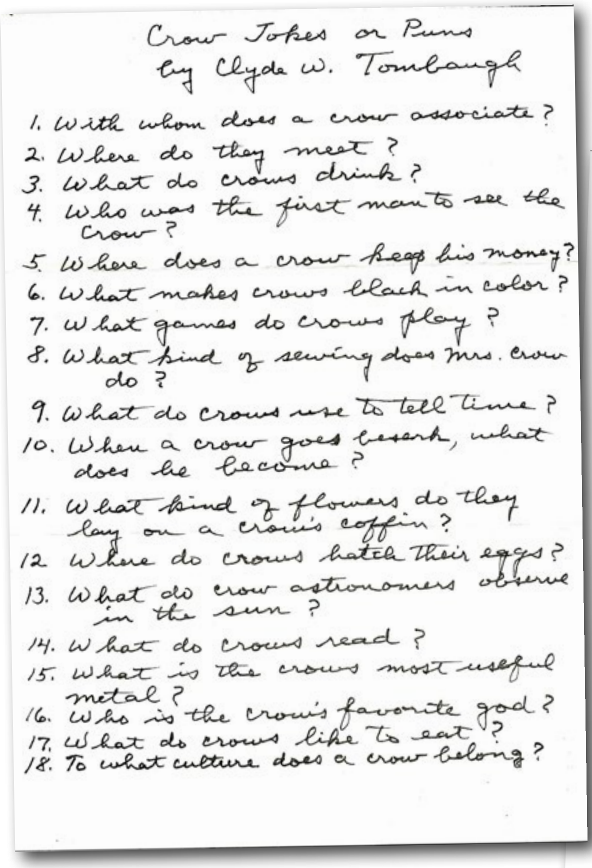
Bottom left: Historic picture of the Lampland Dome, date uncertain.

Bottom right: The Lampland Dome as it currently stands.

Help us preserve this important piece of Lowell Observatory's pioneering history. Call Sherry Shaffer at 928.714.7777 or email sshaffer@lowell.edu to make your gift and save the Lampland Dome from being erased and forgotten.

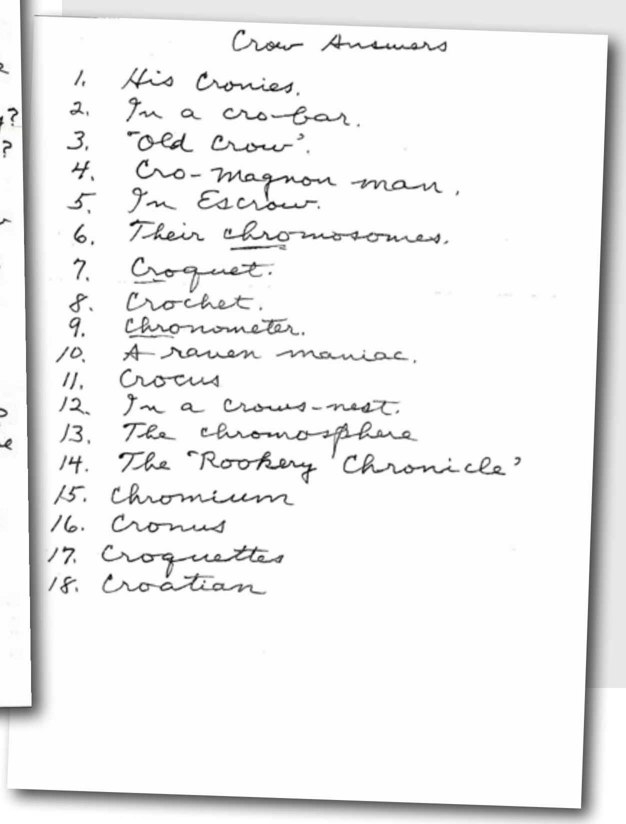
Clyde Tombaugh Crow Jokes

Pluto discoverer Clyde Tombaugh was known for his puns that brought groans from listeners of all ages. His crow puns were especially notorious. Periodically, Lowell staff members are asked about them or people who knew Clyde recall them with a wince. Here, then, is a list of his crow jokes, courtesy of the New Mexico State University Archives & Special Collections.



Crow Jokes or Puns
by Clyde W. Tombaugh

1. With whom does a crow associate?
2. Where do they meet?
3. What do crows drink?
4. Who was the first man to see the crow?
5. Where does a crow keep his money?
6. What makes crows black in color?
7. What games do crows play?
8. What kind of sewing does Mrs. Crow do?
9. What do crows use to tell time?
10. When a crow goes berserk, what does he become?
11. What kind of flowers do they lay on a crow's coffin?
12. Where do crows hatch their eggs?
13. What do crow astronomers observe in the sun?
14. What do crows read?
15. What is the crow's most useful metal?
16. Who is the crow's favorite god?
17. What do crows like to eat?
18. To what culture does a crow belong?



Crow Answers

1. His Cronies.
2. In a cro-bar.
3. "Old Crow".
4. Cro-Magnon man.
5. In Escrow.
6. Their chromosomes.
7. Croquet.
8. Crochet.
9. Chronometer.
10. A raven maniac.
11. Crocus
12. In a crows-nest.
13. The chromosphere
14. The 'Rookery Chronicle'
15. Chromium
16. Cronus
17. Croquettes
18. Croatian

DISPATCHES FROM THE UNIVERSE

NIGHT VISION

By Dr. Michael West, Astronomer

Snowy owls are native to the Arctic. Occasionally, however, they descend as far south as the United States, delighting birdwatchers there.

Much of the fascination with snowy owls comes from their appearance. Although their sharp beaks and talons can rip a rodent to pieces, their round faces and plush plumage give the impression of a cuddly critter rather than a powerful predator.

But it's their oversized eyes that are most alluring. A snowy owl's head is about the size of a human hand, yet their eyes are as large as ours, giving them an expression that seems equal parts surprise, disdain, and monk-like inner peace. It's not surprising that they're often depicted as wise creatures or that J.K. Rowling chose a snowy owl, Hedwig, to accompany Harry Potter on his adventures.

Those large eyes are an adaptation for hunting. Packed with light-sensitive rods, they allow the owl to pinpoint prey in the dim light of the long arctic nights. For them, the night sky must be spectacular. A person with normal vision can see thousands of stars on a moonless night, far from city lights. But a snowy owl can see so much more.

Some migratory birds are even known to use the stars for navigation. In a classic series of experiments in the 1950s, ornithologist Franz Sauer showed that European warblers, which migrate mainly at night, orient themselves by the positions of the stars. Similarly, scientist Stephen Emlen showed that Indigo Buntings recognize the north-south direction from the apparent rotation of the night sky around the North Star.

We humans, too, have long used the stars for practical purposes. Our ancestors navigated the seas, created calendars, planted crops, and celebrated holidays based on the rising and setting of the constellations.

But we also look at the stars in ways of no practical use at all, driven only by a sense of wonder and curiosity. Ralph Waldo Emerson wrote: *"If the stars should appear one night in a thousand years, how would men believe and adore; and preserve for many generations the remembrance of the city of God which had been shown! But every night come out these envoys of beauty and light the universe with their admonishing smile."*

It's easy to imagine that snowy owls, with their walnut-sized brains, are focused only on survival in their harsh arctic home. For them, the stars might be nothing more than ambient lighting in their search for food.

But I like to think that maybe the owl's wise expression reflects much more. Perhaps, like us, they've glimpsed something sublime in the heavens. •

Pluto Circle Event Celebrates Mars

Dr. William Sheehan and Jennifer Putnam entertained Pluto Circle participants with stories of Mars.

Lowell Observatory hosted the 2021 Pluto Circle event virtually this past August. Linguist/historian Jennifer Putnam—daughter of observatory Sole Trustee W. Lowell Putnam—and Dr. Bill Sheehan talked about the human fascination surrounding Mars. During the live YouTube stream, we learned about Percival Lowell's studies surrounding Mars, including his correspondence with Giovanni Schiaparelli, an Italian astronomer.

Contact membership@lowell.edu or 928.255.5059 if you wish to learn about the Pluto Circle and other membership levels.

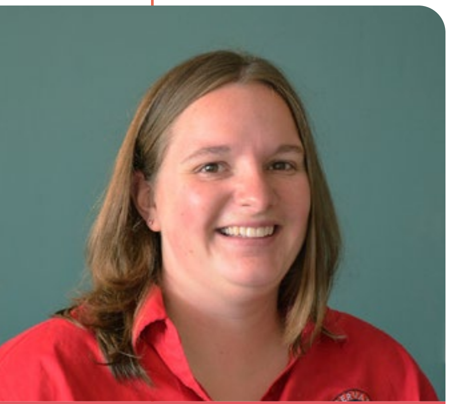
Employee & Team of the Year

By Madison Mooney, Content Marketing Specialist

2021 was a year filled with trials and tribulations for the world at large, and Lowell Observatory was no exception.

At Lowell's annual Employee Recognition event in December, one team and one employee were awarded for going above and beyond in their roles.

Public Program Manager Sarah Burcher was named Employee of the Year for her outstanding leadership of Lowell's public outreach programs throughout 2021. "No department at Lowell has been more upended by COVID-19 than our outreach programs, which were completely shut down at the start of the pandemic, and now once again as Omicron rolls through," says Lowell director Jeff Hall. "Sarah Burcher has done a fabulous job keeping the staff together, developing programs through our gradual re-opening, and keeping everything going to the greatest extent possible since our March 2020 closure."



Public Program Manager Sarah Burcher

The Native American Astronomy Outreach Program (NAAOP) was named Team of the Year, for their tireless dedication to bringing the wonders of the cosmos to communities that were hit the hardest by the pandemic. "We chose the Native American Astronomy Outreach Program in honor of Dr. Deidre Hunter, who handed off leadership of the program this year after 25 years," says Jeff. "It has grown into one of our marquee outreach programs and creates a wonderful connection between Lowell and our neighboring Native American population. We look forward to seeing it grow further under Todd Gonzales's leadership." •

Poster session are one of the many ways participants show off what they've learned through the NAAOP program.

Star Stuff: A Space Poddity

Lowell Observatory is proud to present its very first podcast: *Star Stuff*! This bi-weekly, 45-minute "space poddity" will focus on making astronomical science and space exploration fun and accessible to wide audiences using humor, facts, and casual banter. Marketing Manager Cody Half-Moon will sit down together to discuss astronomy, planetary science, and space exploration via news articles, movie reviews, audience questions, pop culture discussions, and guest speakers.

The first official episode of *Star Stuff* was released in January 2022 and all episodes are available to listen to at lowell.edu/discover/starstuff/. After you listen, we want to know what you think. Send your comments, questions, and suggestions for our podcasters to info@lowell.edu. And of course, don't forget to subscribe to *Star Stuff: A Space Poddity* on Spotify, Apple Podcasts, or wherever you like to listen.

NSF Awards Funding to Audrey Thirouin

Dr. Audrey Thirouin was awarded a three-year research grant from the National Science Foundation in the amount of $352,538. Her project, Resonant Contact Binaries in the Trans-Neptunian Belt, will study these relics from our solar system's birth, providing new insights into the formation and evolution of planetary systems around other stars as well. Dr. Scott Sheppard (Carnegie Institution for Science) is co-Principal Investigator.

For the Kids

By Education Manager Todd Gonzales and longtime observatory supporter Joe Simms

PLANETS OF THE SOLAR SYSTEM

DOWN

1. This is a cold rocky planet with five moons. It was the last to be discovered in 1930 and is now known as a dwarf planet.

2. This is a gas planet that has rings of dust and rock orbiting its equator that can be observed through a telescope or binoculars.

3. This cold gas planet has an icy atmosphere with its own faint set of rings and is the third largest planet.

ACROSS

4. This planet is known as the red planet because of its rusty soil color having its day (time to rotate) 24 hours plus and is about half the size of Earth.

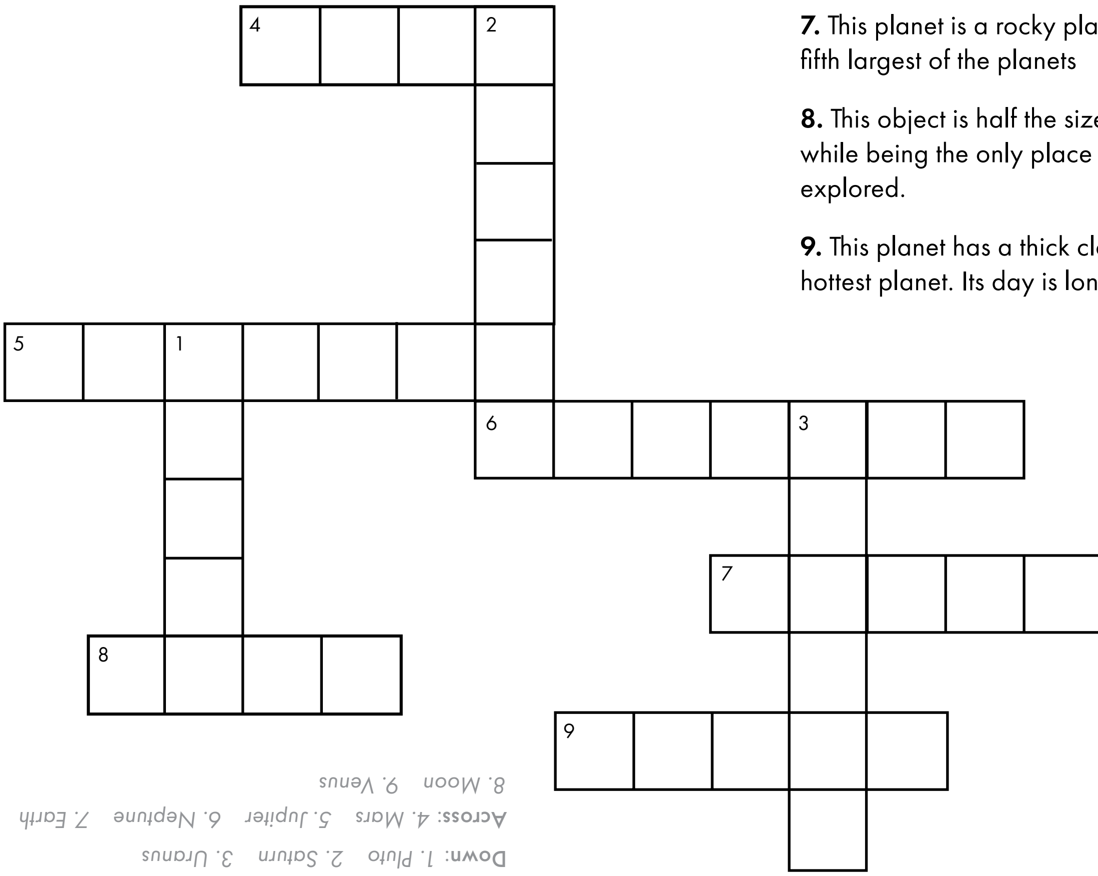
5. This is the largest planet with the shortest day (about 10 hours) and has a giant storm called the great red spot.

6. This is a gas planet having the strongest winds in the solar system, and was discovered with math before it was seen in a telescope.

7. This planet is a rocky planet with liquid water and is the fifth largest of the planets

8. This object is half the size of Mars having no atmosphere while being the only place where humans have landed and explored.

9. This planet has a thick cloudy atmosphere and is the hottest planet. Its day is longer than its year.



Down: 1. Pluto 2. Saturn 3. Uranus
Across: 4. Mars 5. Jupiter 6. Neptune 7. Earth
8. Moon 9. Venus

Supporter Feedback

Compiled by Heather Craig, Marketing Operations Specialist

Lowell Rocks and Haley the tour guide is the best! They have new scopes and lots of new tricks. Go if you haven't been in a few years. Worth it!"

Google Review

We thoroughly enjoyed the Expanding Universe tour. It was informative and engaging. We loved seeing through the telescopes. It was awesome!

Facebook Review

Amazing tour at night. The tour guide was very knowledgeable and spent a lot of time pointing out constellations. We spent a good amount of time in the viewing area outside looking through the various telescopes. Amazing and clear view of Saturn and Jupiter in those telescopes! The glowing rocks on the ground made it easy to see where we were going outside and they looked pretty awesome!

Google Review

THE LUCY MISSION | CONTINUED FROM PAGE 1

Lucy's mission is to explore several of Jupiter's Trojan asteroids: Eurybates, Polymele, Leucus, Orus, Patroclus, and Menoetius. Visiting multiple objects enables Lucy to assess their diversity as well as the characteristics they have in common. The Trojans are irregularly-shaped objects up to about 100 miles in size that share Jupiter's orbit around the Sun. Many thousands of them occupy two broad swarms, one ahead of Jupiter in its orbit and the other trailing behind. These swarms cluster around Jupiter's leading and trailing Lagrange points, refuges where small bodies can reside stably over the age of the solar system. Lucy will be able to visit both groups, thanks to its eccentric orbit. Its perihelion (closest approach to the Sun) corresponds to Earth's orbit while its aphelion (greatest distance from the Sun) is out at the distance of Jupiter and the Trojans. The trick is that the Lucy spacecraft is to orbit the Sun every six years, while Jupiter and the Trojans take 12 years to complete their orbits. Lucy's quicker orbit enables it to visit the leading swarm during its first aphelion in 2027-2028 followed by the trailing swarm during its second aphelion in 2033.

What's special about the Trojan asteroids? They are planetesimals—planetary building blocks left over from the formation of the giant planets. Having remained in cold storage in their stable orbits ever since, they are effectively

Image (above): Some of the Lucy team visits the spacecraft during final integration at Lockheed Martin Space Systems in Littleton, Colorado. Grundy is 4th from the left. At center in a pale shirt is Donald Johanson, co-discoverer of the *Australopithecus afarensis* fossil Lucy in 1974.
Credit: Dustin Volkel, Lockheed Martin

Image (front cover): Artist's portrayal of Lucy flying past a Trojan asteroid. Lucy's most prominent features are its two huge solar panel arrays, each about 24 feet across. Their size enables Lucy to operate on solar power out at the Trojan swarms despite sunlight there being 25 to 30 times fainter than at Earth. The silvery cone-shaped component is the high gain antenna that permits communication with Earth (also visible at top right of the other image). | Credit: Southwest Research Institute

fossils from the era of planet formation.

The Lucy spacecraft is named for the famous *Australopithecus afarensis* fossil that provided key insights into the evolution of humans, much as we expect this spacecraft to do for the formation of the giant planets. No Trojan asteroid has previously been visited by a spacecraft. Fascinating surprises are in store whenever a new population is first explored, so stay tuned for an exciting voyage! You can follow along and learn much more at http://lucy.swri.edu. •

STAR SURVEY | CONTINUED FROM PAGE 1

of similar temperatures. In 1997, a team of astronomers began making high-precision measurements of such stars using the Palomar Testbed Interferometer in California. They continued collecting data through 2008, when the facility closed.

The Palomar work was supplemented with observations by both professional and amateur astronomers using telescopes at Lowell Observatory, as well as a privately owned telescope. While this type of study has been done before, none come close in terms of scale or accuracy. Van Belle said, "At best, every other study is only half this size, in terms of the number of stars."

In evaluating the resulting data, the team determined temperatures at an accuracy two to four times higher than in previous studies. Van Belle explained, "This means that if you tell me what color a star is or if you tell me what type of star it is, I can tell you its temperature and be much more confident in that."

The data set has many potential applications. For instance, knowing a star's size allows astronomers to infer the sizes of planets detected around them, and higher precision measurements allow for more accurate size estimates.

A closer-to-home application involves the Sun. Increasingly accurate measures of the sizes and temperatures of giant stars can challenge, guide, and improve the models that scientists create to predict stars' life cycles. The Sun will turn into a giant star in about five billion years—when it swells 10 to 100 times its current size—and this newest data will help clarify its ultimate fate, as well as give insight into its current physical processes.

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Recent Publications

Aadland, E., **Massey, P.**, Hillier, D., Morrell, N., 2022, ApJ, 924, 44, The Physical Parameters of Four WC-type Wolf-Rayet Stars in the Large Magellanic Cloud: Evidence of Evolution

Dr. Stephen Levine has created a listing of research utilizing the 4.3-meter Lowell Discovery Telescope. It is based on the Astrophysics Data System (ADS) and is updated regularly. See **https://jumar.lowell.edu/confluence/display/LDTOI/LDT+Scientific+and+Technical+Publications**

Levine has also put together a list of work by Lowell Observatory staff that is also updated regularly: http://www2.lowell.edu/users/tac/bio/Lowell_Annuals.html

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Van Belle pointed out that this type of long-term research project is typical of Lowell Observatory. "This is very much in Lowell's blood," he said. "It's very hard to do this work anywhere else—we have our own telescopes and control the time. We have it in our DNA to support long-term projects."

The research was supported by NASA, the National Science Foundation, and Lowell Observatory's Slipher Society. The paper was published in *The Astrophysical Journal* https://iopscience.iop.org/article/10.3847/1538-4357/ac1687. •

Front cover image: A giant star is a type of star that is much larger and brighter than other stars of similar temperatures. In 1997, a team of astronomers began making high-precision measurements of such stars using the Palomar Testbed Interferometer in California. They continued collecting data through 2008, when the facility closed.

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