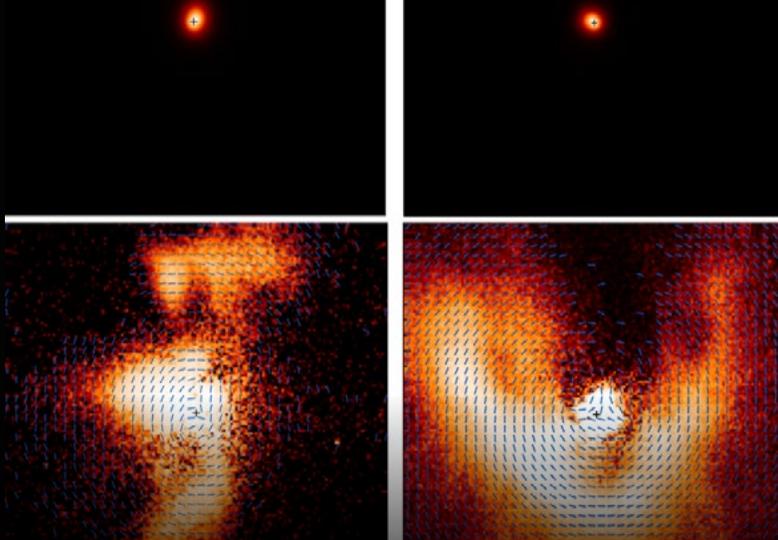


T-Tauri

MWC147



Seeing Dust around Stars: Measuring the linear polarization of light (direction and magnitude of light wave oscillation) allows us to remove the star and see dust around stars. The images were recorded at the 4.2-meter William Herschel Telescope in the Canary Islands with the Extreme Polarimeter instrument that Dr. Keller and his group built in The Netherlands. The upper images are regular intensity images that show only the star because the intensity of the dust around these stars is too weak to be seen directly. The lower images show the polarized light, which only comes from the dust. On the left is T Tauri, a young triplet of roughly solar-mass stars that just formed from the surrounding cloud of dust and gas, and on the right is MWC 147/HD259431, a young, much more massive star also surrounded by dust.



THE LOWELL OBSERVER

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Fun With Photons

By Dr. Christoph Keller,
Director of Science

**Editor's Note – Lowell Observatory is pleased to welcome Dr. Christoph Keller as our new Director of Science. In this article he reviews his research interests. For more about Dr. Keller, see his Staff Highlight on page 7.*

Over the last three decades, I have worked on a range of topics including the Sun and stars, exoplanets, and planetary atmospheres. I have been involved in research in planetary science and exploration (Mercury exosphere, Venus atmosphere, instrument studies for missions to the Moon, Mars, Jupiter, and Saturn), stellar magnetic fields, and biomedical imaging. My experience ranges from numerical simulations to observations to challenging laboratory experiments, and with approaches

from theoretical physics to cutting-edge technology developments.

I started my scientific career studying the Sun at ETH Zurich in my home country, Switzerland, and taking the first images of magnetic fluxtubes, highly concentrated magnetic areas outside of sunspots that had been predicted to exist in the early 1970s. During a decade at the National Solar Observatory

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Youngest Asteroid Pair Detected

By Dr. Nick Moskovitz, Planetary Astronomer

With the catalog of known minor planets in the solar system recently growing to more than one million bodies, it is inevitable that unusual and interesting objects are found. In that vein, a pair of extraordinary asteroids were the topic of a recent publication by an international

team including several researchers at Lowell. This pair of objects challenge our understanding of asteroid evolution and suggest a surprising recent history.

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EXECUTIVE DIRECTOR'S UPDATE



I was walking home past the Steele Visitor Center a week ago and found myself remembering that when I first came to Lowell, the SVC site was a forest and the central walk up to the Slipper Building was the staff parking

lot. It seemed like an upheaval when the SVC was built, but today it's a campus staple just like the Clark. Likewise, I easily recall the water tanks near the Pluto dome, but the GODO already seems like it always belonged there, bringing our guests closer to the beauty of the Universe than perhaps we've ever been able to do. And it was a staff-wide reprogramming of neurons a few years ago to start saying LDT (Lowell Discovery Telescope) instead of DCT (Discovery Channel Telescope)!

Below is a picture showing the current status of the next big evolution on campus: the Astronomy Discovery Center. It seems like another massive upheaval for now, but I know that not long after opening in mid-2024, it will quickly become another familiar part of our physical ensemble, just as the Steele will settle easily into its new role as an education and conference facility.

Perhaps "normality" is whatever you're first presented with – having been born and raised in southside Virginia, the landscapes and climate of Arizona still seem a bit weird to me even after 30 years of living here. It's been fun to watch Mars Hill evolve over those decades and to watch new groups of staff come on board into new normals, steadily pushing the institution forward to its next big thing, whether LDT, ADC, or future technical and instrumentation facilities.

Changes always come with tension and stress, but they're healthy, and in that regard, Lowell is seeming healthy indeed. •

TRUSTEE'S UPDATE



I am regularly surprised and pleased at how things continue to change at Lowell Observatory and yet, how many things remain the same. As this issue of the *Observer* shows, we are welcoming many new people on staff, and saying goodbye (at least

for now) to others. Meanwhile our mission of science and communication continues and the addition of someone like Dr. Christoph Keller will help guide our research mission into the future.

In the past 10 years Lowell Observatory has gone from an annual budget of \$6 million with 80 employees to a budget for 2022 of nearly \$20 million and 150 employees. So it should come as no surprise that we are restructuring the organization to better serve our mission. In addition to having a new Director of Science, we have also created a new position of Chief Operating Officer. Dr. Amanda Bosh is taking on that role, and her many years of work at Lowell will help with the transition to this new management structure. This is designed to support the increases in both science research and outreach that are occurring.

All of this would not be happening without the encouragement, support, and contributions of all of you. Thank you for helping to make the Observatory such a success! •

ADC Update

By Dave Sawyer, Technical Project Manager

Masonry work is well underway as seen in the adjoining photo. The exterior block walls along the northern hemisphere of the building have reached the second-floor level, where work on them will pause while the under-slab plumbing and electrical utilities are installed. The towering structures in the foreground are part of the scaffolding set up for building the elevator shaft.



3RD ANNUAL I HEART PLUTO FESTIVAL

By Kevin Schindler, Historian/PIO

This year's I Heart Pluto Festival ran from February 12-21 and included more than 70 events and activities. A Visit Arizona Initiative Grant from the Arizona Office of Tourism provided major funding and The Runway Nightlife and Eats served as event sponsor. The Festival featured presentations by 16 scientists, an art show, products by local partners, educational programs and tours at Lowell, a VIP tour, and even ongoing coverage by the Northern Arizona DX Association (ham radio operators). Shown here is the label of Mother Road Brewing Company's Lowell Lager featuring the iconic image of Percival Lowell at the 24-inch Clark Telescope. •



"A Night of Discovery" panel discussion at the Orpheum Theater headlined this year's I Heart Pluto Festival. From left to right, Alden Tombaugh (son of Pluto discoverer Clyde Tombaugh), Dr. Cathy Olkin (Southwest Research Institute and holding monitor showing her colleague Dr. Alan Stern, who joined the discussion remotely), moderator Dr. Jeff Hall (Lowell Observatory), Dr. Donald Johanson (Institute of Human Origins), Christa Sadler (One New Education), and host Kevin Schindler (Lowell Observatory).



Recent Publications

Claytor, Z., van Saders, J., Llama, J., Sadowski, P., Quach, B., Avallone, E., 2022, ApJ, 927, 219, <https://iopscience.iop.org/article/10.3847/1538-4357/ac498f>

Archer, H., Hunter, D., Elmegreen, B., Cigan, P., Jansen, R., Windhorst, R., Hunt, L., Rubio, M., 2022, AJ, 163, 141, <https://iopscience.iop.org/article/10.3847/1538-3881/ac4e88>

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 http://www2.lowell.edu/users/tac/bio/dct_ref_pubs_et al.html

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

Moving On



Dr. Kathryn Neugent first came to Lowell Observatory in 2008 as part of the MIT/Wellesley Field Camp program and returned in 2009 as a summer REU student working with Dr. Phil Massey. Since then, she has worked with Dr. Massey on massive star research.

Long-time Lowell research associate Dr. Kathryn Neugent has accepted two prestigious postdoctoral fellowships: one is the Center for Astrophysics Fellowship administered by the Smithsonian Astrophysics Institute with Harvard, and the other the NASA Hubble Fellowship, which she will also be taking to Harvard. Together these will give her a five-year position, allowing her to continue to expand her studies of massive stars and forge new collaborations. The position also gives her access to the Magellan and MMT telescopes.

Our graduate student Lauren Biddle was offered and accepted a postdoctoral position at the University of Texas at Austin with Dr. Brendan Bowler to work on high-contrast imaging of young exoplanets with the Hubble Space Telescope.

Another of our graduate students, Catherine Clark, has accepted a postdoctoral position in the NASA Exoplanet Exploration Program office at the Jet Propulsion Laboratory. She'll start in Pasadena, California, this August.

Support Lowell While Shopping on Amazon

You can support Lowell Observatory by using the smile.amazon.com link when making your purchases and we will receive donations from Amazon.

Here's how it works:

- Go to smile.amazon.com
- Enter "Lowell Observatory" as your charity

Amazon will donate 0.5% of your eligible purchases to Lowell. We receive quarterly distributions which totaled almost \$1,000 last year.

STUDYING THE EVOLUTION OF WOLF-RAYET STARS

By Erin Aadland, PhD Student



Erin Aadland standing in front of the Magellan Baade 6.5-meter Telescope at Las Campanas Observatory in Chile. This telescope was used for the majority of the observations used in this project.

For my dissertation, I've been evaluating whether the WO-type stars are more chemically evolved than the WC-type stars. To do this, I modeled the spectra of six WC-type stars and two WO-type stars in the Large Magellanic Cloud to determine their physical properties. The Large Magellanic Cloud is the perfect location to look at these stars since the distance is well known which allows us to determine their luminosities. The modeling software produces a spectrum from values that we input for the chemical abundances, luminosity, mass-loss rate, etc. This model spectrum is then compared to our observations.

We found that the strong oxygen feature in the WO-type stars, O VI 3811,34, was insensitive to the oxygen abundance and the WO-type stars actually have similar oxygen abundances to the oxygen-rich WC-type stars! However, the WO-type stars do have a higher carbon and lower helium content than the WC-type stars. This actually shows that the WC-type stars are indeed more chemically evolved since as He-burning continues in the core of the star, helium will be converted into carbon.

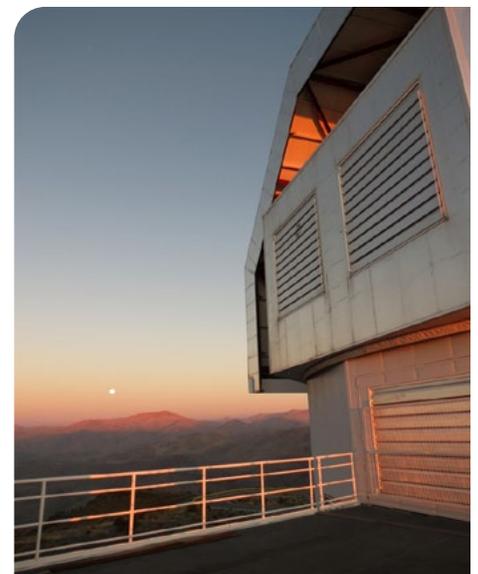
This results in quite an interesting outcome since theoretical evolutionary models cannot predict the chemical abundances that we observed for the WO-type stars. Instead, theoretical models predict a higher carbon and oxygen abundance. This is possibly due to the uncertainty in the reaction rate of oxygen. When working with our collaborators who developed the evolutionary models, we found that if we used a reaction rate that is 3 times smaller, we could reproduce the WO-type stars! •

I came to Lowell to start my PhD with Dr. Phil Massey four years ago. When I arrived, we sat down to discuss possible dissertation projects and decided on investigating a long-lasting question in massive star evolution about Wolf-Rayet stars. Wolf-Rayet stars are massive stars that have an extended stellar atmosphere, meaning that instead of their spectrum showing absorption lines like our Sun does, they actually have strong, broad emission lines similar to a planetary nebula. The outer hydrogen layers have been stripped away, revealing their He-burning cores.

Wolf-Rayet stars are split into two subtypes based on their optical spectrum. The WN-type (the nitrogen sequence) has nitrogen and helium in its spectrum, while the WC-type (the carbon sequence) has carbon, helium, and a little bit of oxygen. There are a few Wolf-Rayet stars that have been classified into WO-type (oxygen sequence) stars. These stars have spectra almost identical to the WC-type stars, but have a stronger oxygen feature: O VI 3811,34. This oxygen line is in the blue part of the optical spectrum and is due to oxygen missing five of its electrons. This strong oxygen line has led many astronomers to think that the WOs have a higher oxygen abundance and are thus more chemically evolved than the WC-type stars. As stars evolve, carbon and helium react to produce oxygen. Therefore, oxygen is one sign that a star is further evolved.

As stars evolve, carbon and helium react to produce oxygen. Therefore, oxygen is one sign that a star is further evolved.

While on the mountain, there were beautiful sunsets and amazing moonrises.



McCann Family Bench

By Stephen Riggs, Senior Philanthropy Manager

In 2021, Terrence McCann, a key member of the team of telescope observers, photographers, and scientific illustrators that studied the Moon through the 24-inch Clark Telescope and created maps of the lunar surface for the Apollo Moon landing missions, passed away. His family recently made a gift of a bench in his memory to commemorate the vital work he and the others did to help make the Apollo project a success.



The McCann Family Bench is located just to the south of the 24-inch Clark dome, with a stunning view of Flagstaff.

Journey to Pluto Science Show by Resi Baucce, Public Program Supervisor

Prepare for launch in our latest addition to Lowell programming, the Journey to Pluto science show!

The 20-minute science show imagines a manned mission to the outer reaches of our solar system, posing a series of challenges and obstacles that must be taken into account for space travel, and demonstrating solutions to these problems. For example: space missions are very long and fuel is very expensive, so how do we go as fast as possible using as little fuel as possible? In the show, our educators pose this question and then demonstrate angular momentum and discuss how we can use our understanding of physics to get a gravity assist—using the gravity of a planet to slingshot us further into space at a higher speed. This is how the New Horizons spacecraft reached Pluto in 2015 at record speeds, and would likely be how a manned mission would choose to make the most of their resources.

Our story goes a little further as we then pose some additional questions to our audience. If Pluto doesn't have as much atmosphere as Earth, can we still land our spacecraft with a parachute? What will the atmospheric pressure on Pluto be like? If there's less atmosphere, will we be able to hear one another talk? How cold will it be, and how will we stay warm? What might we discover when we land on Pluto?

While Journey to Pluto was written for family audiences, the material is highly adaptable to fit the wide backgrounds of Lowell's diverse guests and can be adjusted for younger children, or a more adult audience, depending on who we see in our audience that night.



A replica of a cryovolcanic explosion, using liquid nitrogen and boiling water.

Demonstrations include experimenting with sound, dropping a feather in a vacuum chamber, flash freezing flowers with liquid nitrogen, a replication of a cryovolcano, and a number of additional interactive elements designed to get young volunteers out of their seats and involved hands-on in problem solving the challenges of space travel.

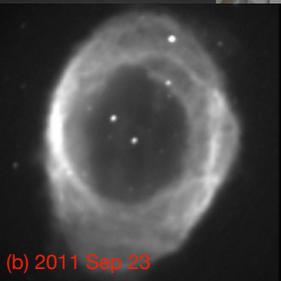
Journey to Pluto is the latest in a series of new programs for the public here at Lowell, designed in anticipation of the upcoming Astronomy Discovery Center and its Universe Theater. It follows Colors of the Cosmos, which was added last fall, and will be followed by the upcoming show Betsy the Electron. Guests who are returning for the first time since 2020 will likely recognize old favorites in our demonstrations mixed with new narratives, new activities, and multimedia elements meant to engage curious learners of all backgrounds and learning styles.

The Journey to Pluto science show made its debut at the 2022 I Heart Pluto Festival and entered our standard nightly programming on April 1. •

A DECADE OF THE LOWELL DISCOVERY TELESCOPE

By Dr. Stephen Levine, Astronomer/LDT Scientist

(a) 2011 Sep 01



(b) 2011 Sep 23



(c) 2012 Apr 03

(a) The first image taken with the test camera. (b) Image of the Ring Nebula in Lyra (M57), a planetary nebula showing nice structure in the ring of gas and dust. (c) The barred spiral galaxy Messier 109 is over 80 million light years away and here we clearly see its central bulge, prominent bar and spiral arms. The background image is a picture taken from the Nasmyth platform of the LDT looking past the top end of the telescope out the dome slit at the almost full Moon just after sunset.

It is now ten years since the Lowell Discovery Telescope (LDT) first focused light onto a detector.

In that time, the 4.3-meter (169-inch) diameter telescope has matured into a versatile workhorse in the optical and near infrared for all six of the partners (Lowell, Boston University, University of Maryland/GSFC, University of Toledo, Northern Arizona University, and Yale).

The very first image from the LDT was taken with a small test camera on the night of September 1, 2011. The telescope was not finished; it did not yet have its secondary mirror. The image was fuzzy, and not round, but it brought light close enough to focus to give us confidence that the telescope would work. Within three weeks, we had improved the operation of the primary mirror support system to the point where stellar images were nice and round as in the adjoining image of the Ring Nebula in Lyra. In early 2012, we installed the secondary mirror. Official first light through the now fully assembled telescope was on the night of April 3rd, 2012. One of the first objects that we imaged was a barred spiral galaxy in Ursa Major, best known as Messier 109.

Scientific observations began almost immediately, mixed in with work to commission the telescope. Observing ramped up so that on January 1, 2015, LDT formally went into full science operations. The LDT design included optimizations for following fast-moving solar system objects and that has made it possible to track near-Earth objects and active asteroids, to do twilight observations of Mercury's exosphere, and to directly measure the sizes of trans-Neptunian objects.

The combination of flexible scheduling and the EXPRES high resolution spectrograph (built by Yale) at LDT has put the facility at the cutting edge in the search for Earth-mass planets orbiting low-mass stars. EXPRES is even used during the day, when light from a small solar telescope is fed into it, making it possible to study our Sun as an analog for other stars potentially hosting planets.

Because of both flexible scheduling, and availability of up to five instruments at all times, LDT can be used for multiple programs each night and is also well suited for Target of Opportunity observations. These are observations that can interrupt another program with only a few minutes notice to follow up unpredictable, time critical transient events like new supernovae, and the detection of gravitational wave events caused by things like black hole mergers. Observers have the flexibility to respond in real time to changing conditions and unexpected alerts.

Another important design consideration for the LDT was to minimize unwanted stray light from reaching the focal plane. This has made it possible to look for very faint signatures of star formation in the outer edges of some of the smallest galaxies that would otherwise be lost in the background light. It also makes it possible to search for very faint diffuse structures between galaxies in clusters, and around comets in our own Solar System.

By virtue of being a partnership, LDT has also encouraged collaboration between members of the different institutions. Starting with the first refereed publication in 2013, there are now more than 170 refereed publications based on data taken at LDT, including more than 40 in 2021 alone. For an up to date list of research from LDT, see <https://confluence.lowell.edu/display/LDTOI/LDT+Scientific+and+Technical+Publications>.

In the near future, LDT is looking forward to the next generation of instruments that will keep our research at the forefront of discovery. The first such instrument will be the Rapid infrared IMAgeR Spectrometer (RIMAS), currently being built at GSFC and designed to follow up explosive transient objects like gamma-ray bursts. •

Dr. Christoph Keller

by Madison Mooney, Content Marketing Specialist

Accomplished astronomer, professor, and author Dr. Christoph Keller joined Lowell Observatory as the Director of Science in early 2022. His research expertise includes exoplanets, solar and stellar magnetic fields, aerosols and trace gasses in planetary atmospheres as well as innovative optical instruments for astronomy, remote sensing and biomedical imaging.

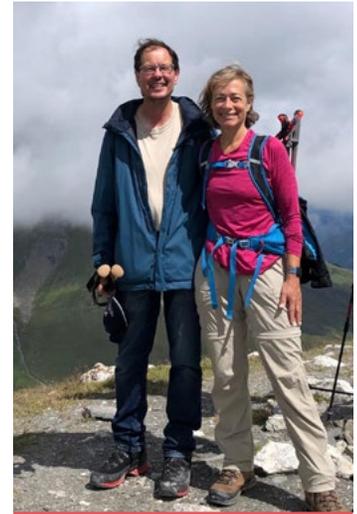
Christoph brings to this new position 17 years of experience as a professor of Experimental Astrophysics at Leiden and Utrecht universities, and prior to that, a decade as a research astronomer at the National Solar Observatory (NSO) in Tucson. NSO allowed him to focus his attention on the Sun and make new discoveries about the magnetic field of our nearest star. At Utrecht and Leiden, Christoph broadened his areas of interest. He has worked on a variety of exciting projects from building instruments to finding exoplanets to using astronomical techniques to do everything from measuring air quality to detecting fetal brain waves.

Christoph has authored or co-authored more than 350 publications and received the Friedrich Wilhelm Bessel award for outstanding research in astrophysics. He is a world-leading expert in high-accuracy polarimetry for astronomy and environmental sensing with the world's

largest telescopes and the latest space instruments for climate science.

Today, Christoph works to provide the ideal environment for Lowell researchers to continue making groundbreaking astronomical discoveries. After living the last 17 years in the Netherlands, Christoph, his wife Renny, their youngest child Vi; two small dogs, Baggins and Trixie; and four cats: Minoes, Voxel, Pixel and Jack, are returning to the United States, excited by all that Flagstaff has to offer. To get from there to here, however, is an enormous undertaking—from the logistical: selling their home, packing up, getting a moving company to ship their things (“We’ve learned a lot about cargo ships in the last weeks,” Renny remarks) to the social: moving so far away from their two older children, Phillip and Lily, and saying goodbye to dear friends.

We are pleased to welcome Christoph and his family to Lowell! •



Christoph and Renny



Credit: Dr. Joe Llama

Celebrating 10 Years of the LDT

By Kevin Schindler, Historian/PIO

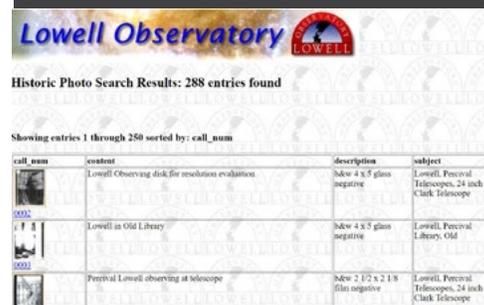
Lowell Observatory is celebrating the 10th anniversary of LDT First Light with a monthly livestream series. On the third Thursday of each month in 2022, from 7-8pm MST, scientists, engineers, and telescope operators will take viewers on a tour of the LDT, looking at the research done with it and at how the facility works.

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

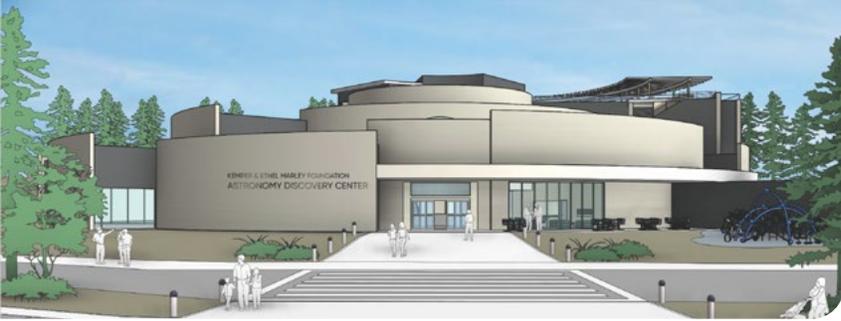
New Digital Archives Platform

By Lauren Amundson, Librarian/Archivist

To provide better access to our digital archives, we are migrating our online collections to new software called ArchivEra. Our current system is twenty-five years old and its design and structure are terribly outdated. ArchivEra offers a customizable public portal, intuitive searching, hosted cloud storage, and a suite of backend administrative tools. We successfully raised the funds for the new software during our 2021 Fall Appeal and cannot wait to share our collections with you!



The old archives website.



Funding in 2021 helped Lowell Observatory move forth with construction of the Astronomy Discovery Center, set to open in 2024.

Fundraising Review

By Stephen Riggs, Senior Philanthropy Manager

2021 was another stellar year for fundraising at Lowell Observatory.

Generous donors contributed \$17,605,100 to fund the Marley Foundation Astronomy Discovery Center (ADC), astronomical research, the Lampland dome restoration, the Steele Learning Center, Native American Astronomy Outreach Program, the Percival Lowell Trust, endowment funds in the Lowell Observatory Foundation, and general operations...as well as many other projects and programs. This marks three consecutive years in which gifts surpassed \$10 million.

Notable for 2021 was the large number of donors to the Annual Fund, whose gifts broke previous records. Membership, too, exceeded goals in spite of COVID-related closures for part of the year. All of these gifts have allowed us to begin construction on the ADC, acquire a new one-meter research telescope for our Anderson Mesa facility (see story on this page), and offset income gaps caused by the lengthy closures. Notable, too, were two very generous bequests. Thank you for your outstanding generosity and support of the observatory's mission in 2021! •

New 1-meter Telescope at Anderson Mesa

by Hannah Rounds, Corporate & Foundation Philanthropy Manager

The Peggy and Eric Johnson Telescope will be a new robotic 1-meter facility at Lowell's Anderson Mesa site. It will replace the 31-inch telescope which served Lowell astronomers well for 57 years. Following site testing in December, the planning team determined that an existing dome could be retrofitted for the new facility. The team chose PlaneWave as the telescope vendor and Teledyne Instruments for the primary imager. The goal is to have all components assembled and operational before the end of 2022.

The Anderson Mesa research site, where the 1-meter Peggy and Eric Johnson Telescope will be located.



Hunting for Meteorites

On March 12-13, Dr. Nick Moskovitz led a group that included Lowell's Dr. Teddy Kareta, Sam Hemmelgarn, Cecilia Siqueiros, Jason Sanborn, Dr. Larry Wasserman, Dr. Danielle Adams, and Kevin Schindler on a search for meteorites in the Navajo Nation, about 30 miles east of Gallup, New Mexico. The search was motivated by a bright fireball captured on January 11 by the LO-CAMS meteor cameras. While no meteorites were found, the effort was an important step in refining search techniques for meteorites.

Sam Hemmelgarn, Mason Hemmelgarn, Nick Moskovitz, and Larry Wasserman search for meteorites.

Credit: Tom Polakis

WEIGHT ON DIFFERENT PLANETS

The measurement of our body weight is really the measurement of the force of gravity on the mass of our bodies. Because each planet has a different gravitational pull, you, a pet, or a favorite object might weigh different on other planets. To calculate this, you will need:

- 1) Your weight measurement on Earth. (It is okay to use the weight of a pet or favorite object)
- 2) Scratch paper and pencil. (You may use an adult and/or calculator if you have not learned your multiplication tables yet.)

You will be multiplying your weight by the gravitational force of each of the planets. (The gravitational force of Earth will be 1.0. So your weight multiplied by 1.0 is what you weigh on Earth).

Practice:

We cannot stand on the Sun but if we could, the Sun's gravitational pull near its surface is **27.9 times** stronger than Earth's. How much do you or your object weigh if you could measure weight on the Sun?

27.9 x _____ lbs. = _____ lbs. (lbs. is the symbol for pounds)

For example, if you weighed 90lbs on Earth, then you would weigh 2,511 pounds on the Sun! (27.9 x 90).



Now try these:

Rocky Planets

Mercury: 0.38 x _____ lbs. = _____

Venus: 0.91 x _____ lbs. = _____

Mars: 0.38 x _____ lbs. = _____

Icy Planet

Pluto: 0.06 x _____ lbs. = _____

Gas Planets

Jupiter: 2.34 x _____ lbs. = _____

Saturn: 1.06 x _____ lbs. = _____

Uranus: 0.92 x _____ lbs. = _____

Neptune: 1.19 x _____ lbs. = _____

Which object do you or your object weigh the most on?

Which one do you or your object weigh the least on?

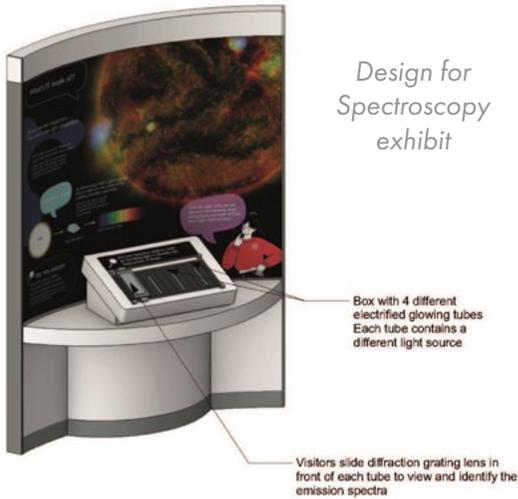
Bonus Question!

What would the weight of you or your object be on the Moon?

(Hint: The Moon's gravitational pull is 1/6 of the Earth's.)
1/6 = 0.17

AN INTERN'S CHANCE TO GIVE BACK

by Lisa Actor, Chief Philanthropy Officer



When they created the Geile Charitable Foundation, Bob and Sharon Geile hadn't anticipated their grandson, Logan Bayer, becoming a physicist nor the value that knowledge would bring to their family foundation.

Last summer, members of their family met with the Lowell philanthropy team to discuss support for the Kemper and Ethel Marley Foundation Astronomy Discovery

Center (ADC). By the end of the meeting, Bob knew they needed Logan's input. Logan stepped up. In December, he recommended that his family support two important exhibits in the ADC's new Astronomy Gallery: "Spectroscopy" and "Where have my atoms been?"

As Logan explained, "Light provides an immense amount of information about our past, present, and future. Unlocking some of the secrets light holds requires the use of spectroscopy (i.e. looking at the fingerprints of elements through light). To illuminate some of the underlying mystery of light and spectroscopy, the Geile Foundation voted to fund the Spectroscopy exhibit."

"Complementing the Spectroscopy exhibit, Where Have Your Atoms Been? seemed to fit the niche perfectly," added Logan. "Through spectroscopy, we know all elements which form life stem from the end-of-life processes of stars (along with mergers of black holes and neutron stars). The ability for someone to explore that they may be older than they look (in terms of their atoms) is quite exciting."

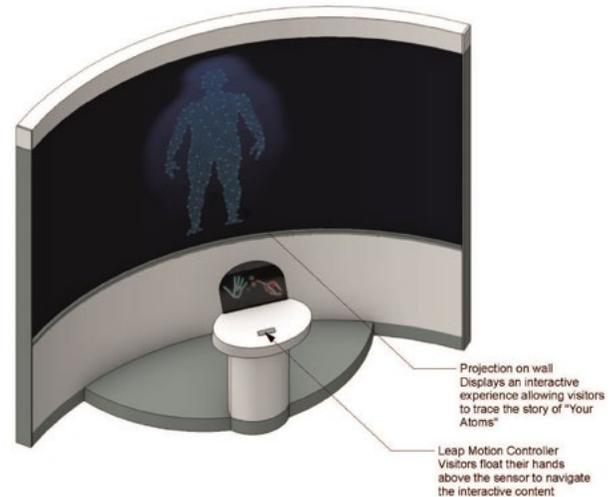
In 2018, as a senior in high school, Logan got his start as

an intern at Lowell Observatory working with Executive Director Dr. Jeff Hall on solar variations studies.

The eight months Logan spent with Hall were formative for his future. "Dr. Hall laid the foundation for developing my intense work ethic, diligence, intuition, communication, and many, many more attributes which I use daily," he said. "Working with Dr. Hall solidified my choice to pursue Physics. Naively, before working with Dr. Hall, I struggled with the prospect of exploring Physics in college as I wanted to find a field which directly impacted people. Little did I know, Physics always applies to people."

During the internship, Hall invited Logan to accompany him to the Sun-Climate Symposium in California. "To say the experience was amazing would be an understatement," said Logan. "A more apt descriptor for the experience of the conference and the internship in general would be lifechanging!"

Logan is a senior at Gonzaga University, where he is pursuing a BS in Physics. We are grateful for his and his family's philanthropy. •



The Where Have Your Atoms Been? exhibit will allow guests to trace the story of atoms in their bodies.

Supporter Feedback

Compiled by Heather Craig, Marketing Operations Specialist

Google Review

We took two of the tours (Lowell overview and Pluto) and our guide – Curtis – was phenomenal. He knows his stuff and kept the tone light and fun. He answered every one of the 50+ questions asked by visitors with passion and insight – he clearly loves his job. Highly recommended if you have any interest in astronomy!

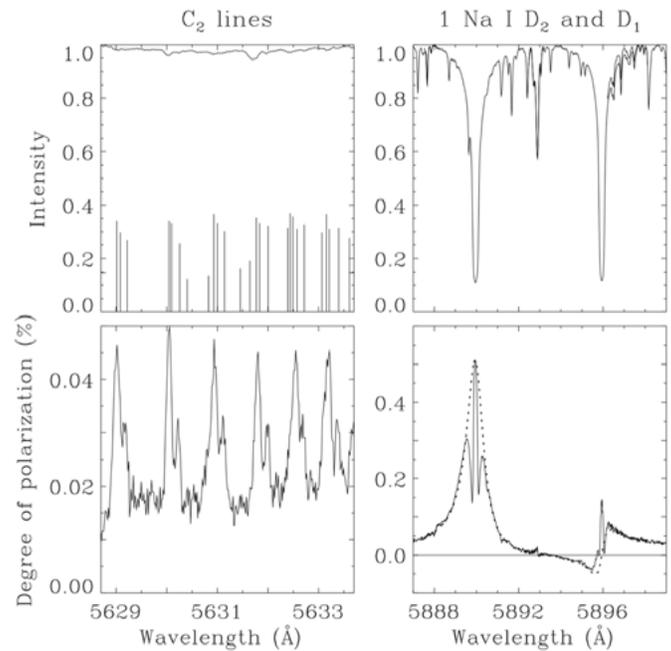
Great adventure for my little space lover (age 7). We enjoyed the live presentations/videos as well as self-guiding to see the different telescopes. Staff were all really helpful, kind, informative and fun to talk with. Also, never been in such a reasonably priced gift shop!!

in Tucson, I pioneered ultra-sensitive polarimetry, the measurement of the direction of oscillations of the light waves, which revealed intriguing quantum-mechanical effects, the presence of molecules, and turbulent magnetic fields in the solar atmosphere. In addition, I led the effort to build the SOLIS VSM instrument, which provides the best ground-based, full-disk measurements of the strength and direction of solar magnetic fields.

With my move to the Netherlands, I shifted my research towards exoplanets and remote sensing of planetary atmospheres, and my latest endeavors have been at the interface of astrophysics, planetary science and Earth science. I am fascinated by the opportunities offered by combining the knowledge of our own solar-system bodies with that of far-away exoplanetary systems to ultimately understand life on Earth and in the universe. In this context, Lowell Observatory is a particularly attractive institute because of the research interests of the scientific staff in solar-system science and astronomy as well as the close connections with NAU, the USGS Astrogeology Science Center and Lowell's university partners.

Recent successes of my group at Leiden University included the first computer model for the light curve of the disintegrating exoplanet Kepler 1520-b. In 2019, we managed to record the first spectra of exoplanets around PDS70 that are still forming using MUSE at the Very Large Telescope in Chile and laser-guide stars. In 2021, we obtained the first linear-polarization signals from exoplanets, which we interpreted as signals from circumplanetary disks.

My research on astronomical instruments also led to successes in other fields. My efforts in adaptive optics (AO) allowed my group to overcome long-standing wavefront-sensing challenges in microscopy and successfully demonstrated AO correction of tissue-induced aberrations in microscopy, which opens up the possibility to non-



The Second Solar Spectrum: Measurement of intensity and polarization close to the solar limb. Polarization reveals polarized spectral lines due to carbon-2 molecules on the left; the spectral lines are not visible in the regular intensity spectrum (expected location of spectral lines are shown with vertical lines in the upper panel), but they show up in polarization. The figures on the right show the famous two sodium lines in the orange part of the spectrum. The complex, completely different polarization spectrum below is due to quantum-mechanical effects. Explaining all the polarized details in this sodium spectrum has taken theoreticians 25 years.

invasively image cancer cells. Our novel SPEX technology measures polarization without any moving parts in a single exposure. This ultimately led to SPEX-airborne, which flies on the NASA ER-2, a modified U-2 spy plane, and SPEXone for NASA's PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) satellite. And thousands of citizen scientists in the Netherlands and all over Europe measured aerosols with the smartphone-based iSPEX. •

The near-Earth objects (NEOs) designated 2019 PR2 and 2019 QR6 (hereafter PR2 and QR6) were discovered in August of 2019. They are respectively 1 km and ½ km in size, and were immediately flagged as interesting because their orbits around the Sun are extremely similar. In fact, no other pair of NEOs come close to having such similar orbits. This discovery raised fundamental questions: are these two objects related or are they coincidentally in close proximity? If related, when and how did they come into their current configuration? Our team set out to answer these questions through a combination of observations, computer models, and digging through data archives.

To answer whether these objects are related, the 4.3-m Lowell Discovery Telescope (LDT) was used to measure their reflectance properties. We found that the colors of

these objects are unusually red, a trait rare amongst NEOs and more common amongst comets and objects in the outer solar system beyond Jupiter. Finding two NEOs with nearly identical orbits around the Sun and with similar rare colors strongly suggests that they originated from the separation of a common parent body.

To find out when these objects separated, the team wanted to rewind the clock to look at how the distance between them may have changed in the past. Modeling this backwards evolution is a straightforward process, but there was a problem. Since PR2 and QR6 were newly discovered, their orbits were not well defined and thus any backwards inference of their positions was poorly constrained. Improving the orbits required a longer baseline of data. Luckily, analysis of archival images

from the Catalina Sky Survey at the University of Arizona revealed faint, previously unreported detections of both objects from October of 2005. These added detections provided the means to construct an orbital history.

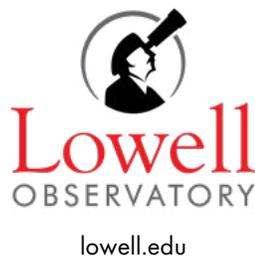
When propagating the positions backwards, it was found that these objects came close to one another, but not close enough for any scenario in which they originated from a single parent body. No matter how these calculations were run, their distance relative to one another came out too large. So, taking inspiration from the unusual comet-like colors, the models were run assuming that these asteroids once experienced comet-like outgassing. It turned out that such activity provided just enough extra thrust to bring these objects together. Even more surprising was that this convergence happened just 300 years ago. This suggests an extraordinarily recent event, representing a separation age 100 times younger than any other asteroid pair in the solar system.

This study revealed intriguing features of this asteroid pair, however with every question answered, more have arisen. We still do not know the nature of the process in which these objects separated. We do not understand the evolutionary pathway for a comet to become an asteroid in a mere (by solar system standards) 300 years. Although these objects are moving away from the Earth and won't be observable again until 2033, in the mean time we can look forward to the discovery of other unexpected objects that will challenge our understanding of the definitions and relationships of small bodies in the solar system. •

Front cover image: Artist rendition of an asteroid pair, shortly after separation. Over millennia these objects will drift apart and become harder to identify. At 300 years old, the asteroid pair 2019 PR2 and 2019 QR6 are the youngest found to date. Credit: UC Berkeley/SETI Institute

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