

THE LOWELL OBSERVER

Issue 130 | 2023 no. 3

SOLVING THE PLANET FORMATION RIDDLE:

Untangling Signals from Stellar Activity and Giant Planets

By Shih-Yun Tang, PhD Student, Department of Physics & Astronomy, Rice University;
Research Assistant, Lowell Observatory

The study of planet formation is not just a topic of scientific curiosity but is also fundamental to questions about life in our universe. To understand the process of planet formation, it is necessary to focus on planets still in their developmental phases, particularly those known as "hot Jupiters". These giant objects, ranging from half to thirteen times the mass of Jupiter, complete an orbit around their host star in less than ten days. Investigating the formation mechanisms

of hot Jupiters provides critical insights into the processes that might lead to the emergence of habitable worlds.

However, the journey toward identifying the formation mechanisms of nascent hot Jupiters is fraught with challenges, the most prominent of which is the high stellar activity exhibited by young stars which typically display extensive starspots.

CONTINUED ON PAGE 11



The turbulent atmosphere of a hot, gaseous planet known as HD 80606b is shown in this simulation based on data from NASA's Spitzer Space Telescope. Photo: NASA/JPL-Caltech/MIT/Principia College

IN THIS ISSUE

Remembering Ted Bowell 3

Slipher Bros Inducted into High School Hall of Fame 4

Disaster Preparedness in the Archives 5

Capital Campaign Ended 6

Staff Profile: Michael Sweaton 7

For the Kids: Native American Symbols 8

How to Look into the Future of Lowell Observatory

By Dr. Christoph Keller, Director of Science

You may have heard it through the grapevine: the science and tech teams have been busy thinking about what facilities we need to enable world-leading science at Lowell Observatory over the coming decades. This is not an easy task, but it is a crucial one because funding and building new facilities for

planetary science and astronomy easily take a decade or even more. In the following I describe the process that we followed to come to our Science and Technology Vision and Strategy, which will be released soon.

CONTINUED ON PAGE 11

EXECUTIVE DIRECTOR'S UPDATE



By Dr. Jeff Hall

This Observer contains an article by Lisa Actor about completion of the \$53.6M capital campaign for the Astronomy Discovery Center (ADC). We did it – with our deepest appreciation to so many of our

supporters who made it possible! With the campaign completed, the ADC will open in its full incarnation next year. I'm thrilled and gratified, for a target of \$53.6M for an institution our size is a lofty – some might say almost impossible – bar.

But we've done it before. Back in 2007, when former Director Bob Millis was searching for partners to join us in a future facility now known as the Lowell Discovery Telescope (LDT), reactions ranged from amazement to, among a few more cynical folks, eye-rolling that a little non-profit was crazy enough to try to build its own 4-meter telescope. There was also former Trustee Bill Putnam's reaction in 2000, when he received a consultant's report that we could not come even close to finding the funds needed for the project: Bill promptly tossed the report in the trash, asserting that we would build the telescope anyway (using more colorful terms than I recount here).

The song East Bound and Down from the classic movie Smokey and the Bandit, a delightful earworm from the late great Jerry Reed, contains the lyrics "We gonna do what they say can't be done." As we did with LDT, so we are doing again today with ADC, albeit with more refined purposes than bootlegging beer. I increasingly think of LDT and ADC not as separate facilities, but as equal and complementary manifestations of our mission, which is to better understand the cosmos and to communicate that understanding to everyone, professional and general audiences alike. And so we shall. •

TRUSTEE'S UPDATE



By W. Lowell Putnam

I hope you enjoy this issue of the Observer. It certainly covers a wide range of topics, and yet all of them reflect on how much is being done at Lowell. Because we are an active research institution, we need to look ahead to the future to plan what facilities we need, and we need to keep bringing in new scientists as well. Because of the work that has been done by prior astronomers, we have a rich history of discoveries, and the stories of the people and effort that went into making them. And, along the way, we have had the opportunity to engage with many people about many of these topics in person and in writing.

All of that shows up in this issue, and it is because of our supporters - past, present and into the future - that we can continue to do all of this.

My thanks to all of you who have helped make that happen. •

ADC Construction Update

By Dave Sawyer, Technical Project Manager

Aside from a brisk pace of ongoing activities installing ducting, electrical, plumbing, and interior walls, there has been a big push to get the electrical service connected and the building weather tight before winter sets in. The electrical service infrastructure on campus required upgrades to overhead lines coming up Mars Hill and switch cabinets added near the Clark Dome and overflow parking area to accommodate the ADC and future expansion. These upgrades are now complete and APS is scheduled to energize service to the building soon. Up on the roof, the slab for the Skylight Terrace, which includes a hydronic ice melt system and in-floor induction loops for hearing assistance, has been poured and the Dark Sky Planetarium is being prepped to pour in the coming month. The roofing over all other areas is complete and the exterior walls on the roof level are being framed, sheathed and readied for stucco siding.



View of the Skylight Terrace looking north as the concrete slab is poured.

REMEMBERING TED BOWELL

As reported in the last issue of the Lowell Observer, longtime Lowell scientist Dr. Edward Leonard George "Ted" Bowell passed away peacefully in Flagstaff on August 21, 2023.

Ted was born in London, United Kingdom on November 26, 1943. While he initially thought he might want to be a musician or writer, he soon chose astronomy for his career path. As he later recalled, "Being an astronomer must be fun because one could stay up late at night and therefore wouldn't have to get up early in the morning."

Ted earned a doctorate in astrophysics from the University of Paris in 1973.

That same year, Dr. Bill Baum, then serving as Director of the Planetary Research Center at Lowell Observatory, offered him a job that involved the photographic study of planets. Thus began Ted's career at Lowell, which lasted nearly 38 years until his retirement in 2011.

While Ted spent much of his early time at Lowell studying planets, he eventually turned his attention to asteroids. Initially using the 13-inch Lawrence Lowell Telescope—the instrument that Clyde Tombaugh used to discover Pluto—he began searching for these small celestial bodies. From 1979-1988, he led a survey that resulted in the discovery and naming of more than 600 such bodies.

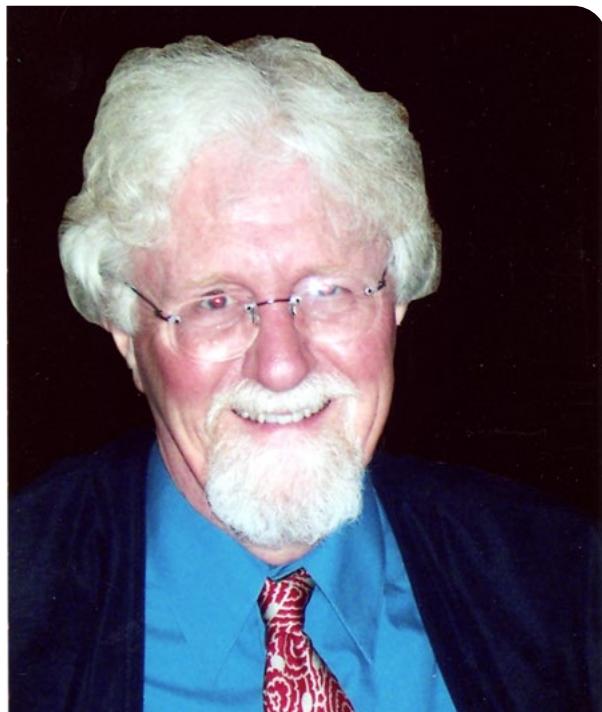
Years later, in 1993, he embarked

By Kevin Schindler, Historian & PIO

on a new project to search for asteroids and comets that orbit close to Earth (called Near-Earth Objects, or NEOs). Generally referred to as LONEOS, for Lowell Observatory Near-Earth-Object Search, this study lasted until 2008. Under Ted's direction, LONEOS discovered more than 21,000 asteroids (more than 200 of these are NEOs) and 40 comets.

Far from being a one-dimensional scientist, Ted was known

among friends and colleagues for his love of gourmet food and wine. A master of sauces, he liked to say, "When I'm not busy in astronomy, I'm busy in gastronomy." At Lowell Observatory parties, his table was always the most ebullient—partly because of Ted's good cheer, partly because of the extraordinary wine he personally selected for his tablemates. He once bought a car based on the size of the back cargo compartment, so he could maximize the number of cases of wine he could transport.



Ted had a style all his own and was known among both colleagues and friends for his colorful shirts, European shoes, and silk ties.



During a solar eclipse in Turkey in 2006, Ted combined his passions for astronomy and wine, using a wine bottle to make his observations.

He even found a way to combine his scientific pursuits with his love for wine, naming asteroids he discovered after Randall Grahm—vintner of Bonny Doon Vineyard—and the village of Barolo—a favorite wine region in Italy.

Above all, Ted was charming, generous, caring, kind, genuine, and humorous—a person that brings smiles to all who knew him and whose spirit will forever shine. •

SLIPHER BROTHERS INDUCTED INTO FRANKFORT HIGH SCHOOL HALL OF FAME

By Kevin Schindler, Historian & PIO

Around northern Arizona, the Slipher name is associated with astronomy. In Frankfort, Indiana, the name is connected to farming. In late July, the two identities converged as longtime Lowell Observatory astronomers—and brothers—

V.M. and E.C. Slipher were posthumously inducted into their high school hall of fame in Frankfort.

V.M. graduated from Frankfort High School in 1897 and E.C. followed suit four years later. They both attended Indiana University, and both then spent their entire professional careers as astronomers at Lowell Observatory. They both also made significant contributions to their field; among so many other things, V.M. first observed the expanding nature of the universe while E.C. revolutionized photography techniques for studying the planets. In addition to their research, they both also served as director of Lowell Observatory (V.M. for several decades) and both served the Flagstaff community (E.C. even served as mayor at one time).

While these contributions are well established in Flagstaff, they were a footnote at best in Frankfort. That is, until the brothers' grandnephew, Clark Slipher, contacted Frankfort High School a few years back. He shared the story of V.M. and E.C. and how much they impacted astronomy, and this ultimately led to July's induction into the Frankfort High School Hall of Fame.

As guests of Clark and his wife Diane, Lowell's Philanthropy Manager Sherry Shaffer and I traveled to Indiana for the festivities. The induction took place during the community's annual Hot Dog Festival. Frankfort High is home of the Hot

When V.M. and E.C. Slipher attended Frankfort High School, it was in this building, nicknamed "Old Stoney". The high school has since moved, and Old Stoney now houses Frankfort city offices and the Clinton County Historical Society and Museum.

Dogs, the mascot being a fierce-looking dachshund (if one can imagine such a thing).

On the morning of the induction ceremony, we explored the home where V.M. and E.C. grew up (the house and surrounding farmland is still owned by the family), nestled around hundreds of acres of corn and soybean fields. In a cosmically delightful coincidence, to get to the house of the future astronomers, one turns at the drive-thru restaurant named...wait for it...the Milky Way.

In looking around the farmland, one cannot help but see the connection between farming and astronomy, at least how the Slipthers practiced it. Farming requires patience, long hours of work, and a fair bit of tinkering with equipment to keep it running. Astronomy requires the same attributes, and the Slipthers adapted their propensity to tinker with farm equipment to doing the same with telescopes, cameras, and other scientific equipment. This trait allowed them to revolutionize techniques for gathering astronomical data.

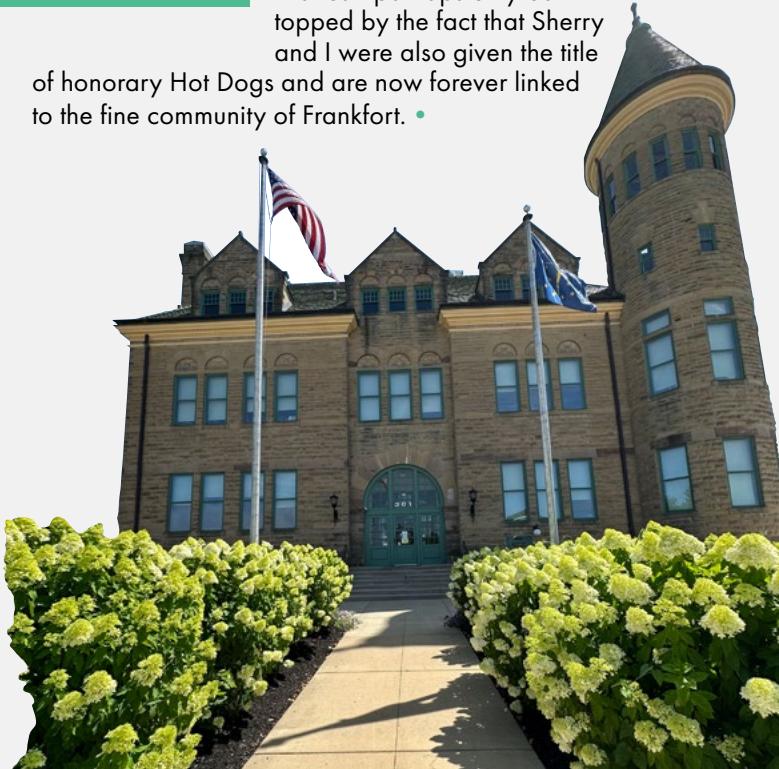
After this morning journey through the Breadbasket of America, we participated in a podcast produced by the local library, and then headed over to the high school for the induction ceremony, where I had the honor of speaking on behalf of the Slipthers. We then adjourned to a local pizza parlor, joined by some three dozen members of the Slipher family.

Sherry and I were honored to represent Lowell Observatory and Flagstaff in what now feels like a sister city and pleased the Hoosier community now celebrates the groundbreaking research conducted by two native sons 1600 miles away. That can perhaps only be topped by the fact that Sherry and I were also given the title

of honorary Hot Dogs and are now forever linked to the fine community of Frankfort. •



Diane Slipher, Sherry Shaffer, Kevin Schindler, and Clark Slipher stand at the center of the Milky Way.



Messrs. Brian A. Skiff & Edward Bowells,
Lowell Observatory,
Flagstaff,
Arizona
U.S.A.

18th April 1990

Dear Bri. & Ed.

This is just a short note to thank you for naming that lump of rock Ringo.

It gives me great pleasure to think that there's something in the heavens that will be rolling on after I've gone.

Next time could you make it a planet, or a sun, or a moon, or a galaxy, or, if you are not too busy, maybe a black hole!

Kind regards,



Ringo Starr

Treasures from the Archives

By Lauren Amundson, Librarian & Archivist

This treasure is absolutely fab! In 1990, Beatles drummer Ringo Starr sent a letter to Lowell Observatory astronomers Brian Skiff and Dr. Ted Bowell thanking them for naming an asteroid after him (4150 Starr). The letter resided in Brian's personal files until this summer, when he transferred it to the Archives so we could display it for the Asteroids, Comets, Meteors Conference reception at Lowell. Brian and Ted also named asteroids after Paul McCartney, John Lennon, and George Harrison.

Disaster Preparedness in the Archives

By Lauren Amundson, Librarian & Archivist

With the increase in natural disasters such as wildfires, hurricanes, and flooding caused by climate change, archivists must be ready more than ever to prepare for and respond to these challenging situations. Lowell Observatory's location on the edge of a Ponderosa pine forest makes it especially vulnerable to wildfires. In the archives, we have spent the past several years developing a written disaster response and recovery plan, attending workshops and webinars, prioritizing collections for evacuation and salvage, and creating disaster recovery supply caches. We are also a member of the Northern Arizona Heritage Response Consortium, a group of local archives, libraries, and museums dedicated to assisting one another in the event of a disaster.

A disaster can be something relatively small, like a broken pipe or a leak. This spring, after a winter with record snowfall, we experienced minor flooding in two of our basement vaults. Luckily, we were able to avoid damage to collections by using a wet vacuum to clean up the water and running fans for several days to dry out the rooms. Mold can start to grow within 24 to 48 hours, so it's important to start circulating air as quickly as possible. We also make sure that collections are stored at least six inches off the floor, and we use wireless water and temperature/humidity monitors.

Our supply caches contain items that we can use in case of a small-scale disaster: mops, freezer paper, sponges, plastic sheeting, box fans, newsprint, flashlights, gloves, safety glasses, bankers boxes, and paper towels. If we experience a larger event, such as a fire or widespread

water damage, we will utilize the services of Belfor Property Restoration. Belfor restores books, manuscripts, magazines, maps, blueprints, audiovisual materials, magnetic media, and photographic materials that have had water, fire, and/or smoke damage. We also have a large restaurant-grade freezer in our Putnam Collection Center that we can use to freeze wet books or paper until Belfor arrives with its equipment.

As collections stewards, it's difficult for us to imagine the loss of irreplaceable documents, photographs, and artifacts. We must remember that life safety always takes priority before collections assessment and salvage can begin. Planning, practicing various scenarios, and working in collaboration with our local first responders and fellow cultural institutions are all important steps in disaster preparedness. It's not a matter of if, but when something happens, and we need to be as ready as possible to protect our history. •



Librarian/Archivist Lauren Amundson poses with some of the items in the Archives' disaster supply cache.

WE DID IT TOGETHER!

Thanks to 500+ Lowell Supporters, Our Capital Campaign Has Ended

By Lisa Actor, Chief Philanthropy Officer



Artist rendering of the Kemper and Ethel Marley Foundation Astronomy Discovery Center.

After seven years, we closed our capital campaign on June 30, 2023, with \$58 million raised to achieve our vision to be the premiere public astronomy destination in the world.

The New Horizon's Pluto fly-by in 2015 caused the observatory's visitor program to explode. By Spring 2016, we were on track for 100,000 yearly guests, overwhelming our Steele Visitor Center. To address what was a "good problem to have," Executive Director Jeff Hall invited renowned planetarium and science center planners, Ian McLennan and Bill Peters, to help us plan to expand our visitor program.

"Should we build a planetarium?" We asked the experts. Our discussions resulted in the plans for an Astronomy Discovery Center with a unique, two-story theater, a rooftop, open-to-the-sky planetarium —featuring Flagstaff's dark night skies—and interactive exhibit galleries.

Since the discovery center would take years to realize,

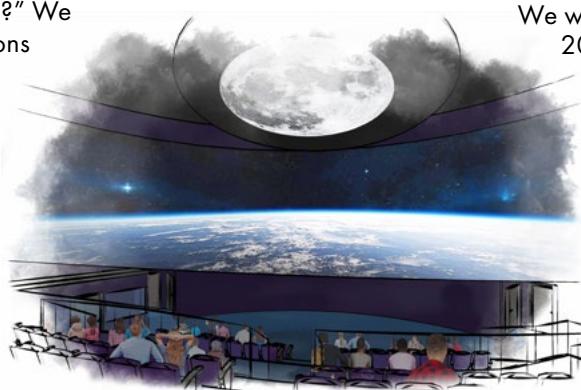
Advisory Board Chair Mike Beckage advised the Lowell leadership to act sooner to alleviate the long wait times for telescope viewing. In 2017, we planned for an observing plaza with six permanently mounted telescopes: the Giovale Open Deck Observatory (GODO). Fundraising took off, and we dedicated the GODO in Fall 2019.

Fundraising for a new visitor center began, in earnest, before the GODO was complete. By August 2019, the naming gift for the Kemper and Ethel Marley Foundation Astronomy Discovery Center (ADC) was committed for what we thought was a \$29 million facility. As the plans came together, we realized we needed to elevate the Dark Sky Planetarium above the treetops, increase the size of the main astronomy gallery, and switch out a projection system for an LED screen in the Lowell Universe Theater. These changes added \$10M to the ADC price tag.

In August of 2022, thanks to hundreds of generous supporters, we were within \$1 million of the \$39 million goal when the final bids came back from our subcontractors. Covid-related economic issues had escalated the total ADC costs by 36%, to over \$53 million.

Lowell supporters came through in 2023, with many of our lead donors giving an additional 36% on top of their already generous commitments for the facility. Over 200 Lowell supporters committed an additional \$1 million to meet a generous million-dollar challenge. And with the help of Arizona District 7 Representative David Cook, the State of Arizona committed the last \$5.6 million.

We will celebrate YOU in November 2024, when we officially open the Kemper and Ethel Marley Foundation Astronomy Discovery Center. Watch for opening celebration dates next year. •



Artist rendering of the Lowell Universe Theater screen

The ADC Endowment Fund: An Enduring Investment in Discovery and Awe

The ADC will be an exciting place to learn about the cosmos. With its high-tech amenities, it will be expensive to maintain and operate. We're raising a \$7 million endowment that will support technology upgrades, theater programs, exhibits, and more over the life of the ADC. The Lowell Observatory Foundation will manage the ADC Endowment Fund.

We have more features in the ADC for you to sponsor. Now that construction funding is complete, your gifts will help build the ADC endowment. Thank you! To learn how you can help, contact Lisa Actor at lactor@lowell.edu.

Star Stuff: Season 2

By Madison Mooney, Content Marketing Specialist

STAR STUFF

A LOWELL OBSERVATORY PODCAST



Star Stuff: A Space Poddity is winding down on Season 2. Host Cody Half-Moon continues to explore the cosmos with new special guest stars, plus a few fan favorites. Start your interstellar journey

on your favorite listening platform today. All Season 2 episodes are now recorded on video as well, so you can watch them on YouTube.

Host Cody Half-Moon and returning guest Dean Regas on a recent episode titled "Life Beyond Our Solar System."



Listen now at lowell.edu/starstuff

Members-Only Facebook Page

By Emma Wood, Membership Assistant

The Lowell Observatory Member Community Facebook group is a space where members can meet and discuss topics of shared interest, as well as stay up to date on astronomical events. Every week members can expect to receive a Sky Report on the next week's astronomical events, courtesy of Stellar Vista Observatory. On top of that, members regularly share interesting articles, stories, beautiful pieces of astrophotography, astronomy memes, and more. Join now to become an engaged part of the Lowell Observatory Member Community!

facebook.com/groups/lowellobservatorymembers

Give the Gift of Membership

Give the universe as a gift! Elevate someone's sense of wonder and curiosity by gifting a Lowell Observatory membership. Members receive free admission to Lowell, a 10% discount in the gift shop, invitations to member-only events, and much more.

Learn more at
lowell.edu/membership



Michael Sweaton LDT Electrical Engineer

By Madison Mooney, Content Marketing Specialist

STAFF PROFILE

LDT Electrical Engineer Michael Sweaton started working at the Lowell Discovery Telescope in August of 2011. His principal responsibility as Electrical Engineer is ensuring that the telescope is operational for nightly observing sessions. He and his team triage an ever-growing list of projects aimed at improving the telescope's operation and optimizing maintenance tasks.

One of Michael's favorite parts of his job is having the ability to enjoy the view from the top of the mesa on which the LDT sits, an 8,000-foot cinder cone volcano. On a professional level, he enjoys the satisfaction of knowing that he's a small but integral part of something much bigger: a mission to unravel the mysteries of the universe.

In his time away from the LDT, Michael enjoys birdwatching with his wife, playing racquetball, riding his electric motion trials motorcycle, and building e-bikes. He also enjoys playing a good practical joke on his coworkers. Whether or not his coworkers enjoy these practical jokes played on them is unknown!



Native American Symbols

From petroglyphs to pottery and clothing, Native Americans have recorded stars, comets, the weather and their surroundings. Below are symbols used amongst multiple tribes that can still be found today in jewelry, clothing, and other arts. Note some symbols share multiple meanings from different tribes, such as the Life Steps symbol. The symbol can represent deities, clouds, mountains, and growth. The storm cloud may be followed by zig-zag lines representing lightning.

Make your way through the maze starting from the arrowhead and ending at the medicine wheel. Stop at every symbol listed below. Some symbols included in the maze are not labeled below; feel free to research their meaning.

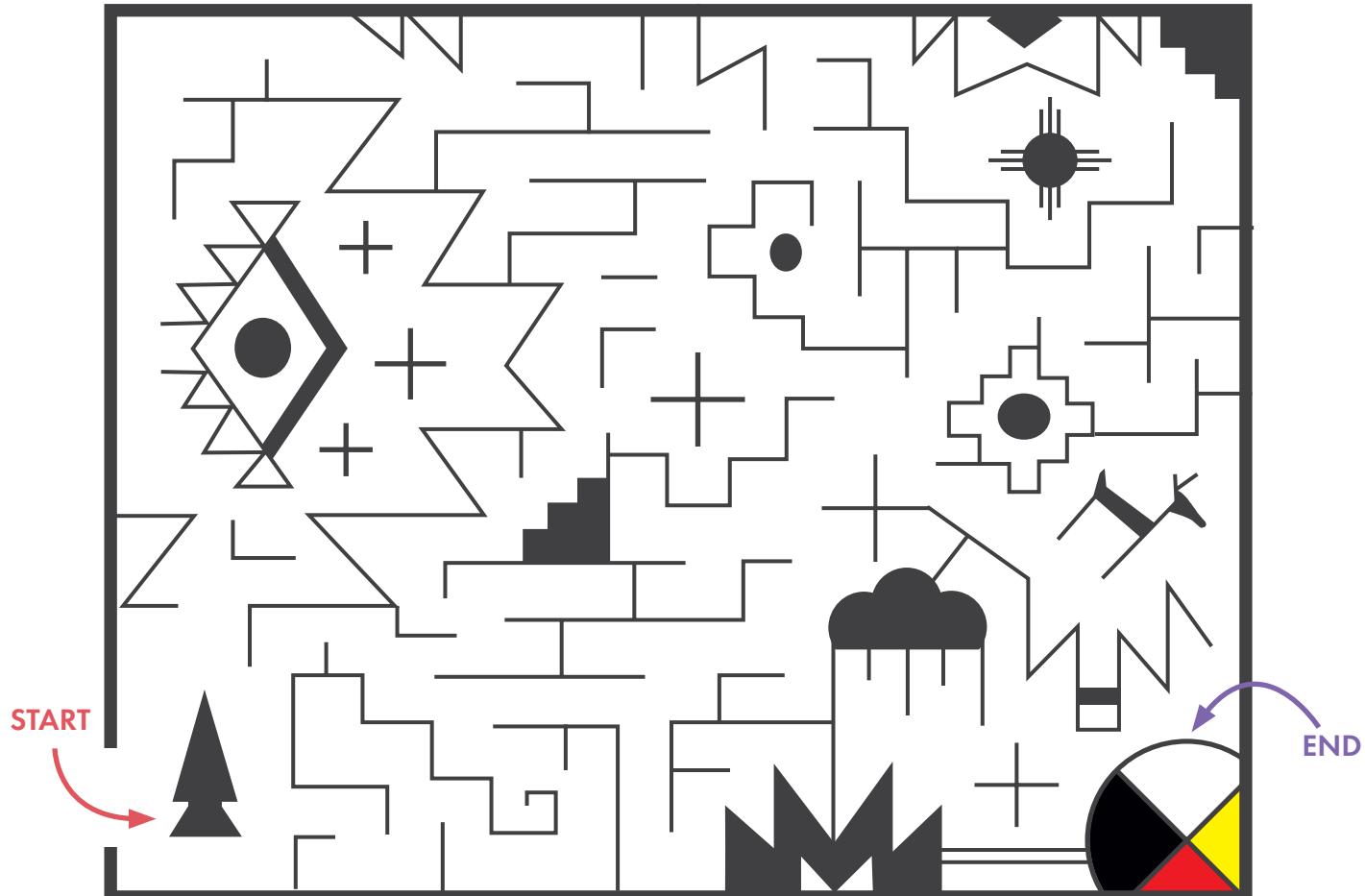
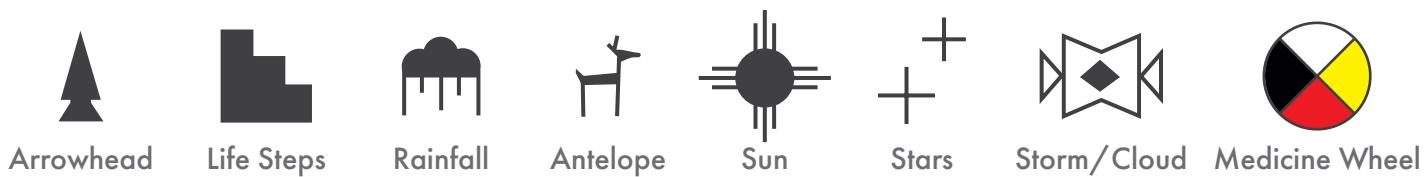
Try pronouncing these words in Navajo as you go through the maze.

Left – **nishtł' ajígo** (nish-thah-jih-goh)

Up – **deego** (deh-goh)

Right – **nish' nájígo** (nish-nah-jih-goh)

Down – **yaago** (yah-goh)



Your Gifts Make All the Difference at Lowell Observatory!

By Sherry Shaffer, Philanthropy Manager

Your contributions are important to us whether it's one dollar or one million dollars. As an independent non-profit we couldn't do everything we do without our generous donors. We are extremely grateful to you who support our mission—thank you!

2023's inflation and lingering COVID effects made this year tighter than we anticipated. But with your help, we're making it work and continuing with all our research, outreach, and projects. You made the difference; thank you!

This year, your gifts brought the story of the Sykes brothers to life in the Putnam Collection Center. Kids learned about our universe through school trips and summer camps. The new one-meter telescope was installed and the instrument team is working on the remote software. Your support makes it all happen!

At the end of each year, we ask that you consider a gift to our annual fund. We can't always predict what will impact the budget (record-breaking snow wearing out our snow blowers, for example) so we often have some gaps that the annual fund helps to fill. Your gifts of all sizes—via check,



In 2023, Lowell's annual fund helped the observatory maintain the equipment necessary for operating the observatory, including snow removal vehicles.

credit card, donor advised fund, IRA qualified distribution, stock, or cash—will help us complete 2023 in the black.

You are the reason we keep going year after year. We can't thank you enough. •

Contact our philanthropy team if you need help donating. Write to donate@lowell.edu or call **928.268.2924**

A Look Back at Our Member Events

By Shannon Gonzales, Membership Manager

In the past year, the membership program has tried its hand at monthly events. Talks by knowledgeable astronomers and educators enlightened and inspired. Captivating astronomical viewings sparked joy and curiosity. Engaging webinars with some of Lowell's favorite figures brought forth intriguing questions from all over. Throughout, it was our members' unwavering support that made each event a success. As we look forward, we do so with gratitude for the connections forged and the memories created. Here's to another year of growth, learning, and unity with our remarkable member community. We look forward to seeing you at the next event!

"The Universe in Motion" member preview.



Dr. Jennifer Hanley Granted Tenure

By Dr. Christoph Keller, Director of Science

On August 24, Dr. Jennifer Hanley was granted tenure with a corresponding promotion from Assistant Astronomer to Astronomer. Tenure at Lowell Observatory means that the observatory intends to continue the employment indefinitely provided that the performance continues to be satisfactory and the institution does not encounter a financial emergency. The tenure committee, consisting of all tenured scientists at Lowell Observatory and six external reviewers, were unanimous in their assessment of Jennifer as a staff member who successfully brings together theory, laboratory experiments, and observations covering a broad range of topics; the science community recognizes her as a leader in those areas. Jennifer obtained a significant number of grants and has been highly successful in integrating students into her research. Her services to the community and the observatory are much appreciated. Congratulations, Jennifer!



Eclipse Over Texas: Live From Waco to Celebrate April 8, 2024 Total Solar Eclipse

By Kevin Schindler, Historian & PIO

On April 8, 2024, a total solar eclipse will be visible from a narrow path running from Mexico to Canada. Texas will be an ideal viewing spot, and Lowell Observatory is teaming with The City of Waco, Baylor University, and Warner Brothers Discovery on a public event, Eclipse Over Texas 2024: Live from Waco. This will include an onsite celebration at Baylor University's McLane Stadium in Waco, as well as virtual programming that people around the world may view.

Eclipse Over Texas 2024: Live from Waco will consist of a full day of presentations by astronomers and educators, interactive activities, and telescope viewing. Warner Brothers Discovery will broadcast the event on their linear and digital networks. All of this will center around the eclipse: the Sun will begin to be eclipsed at 12:20pm CDT. The Sun's surface will gradually be covered until totality sets in at 1:38pm CDT. This will last for four minutes and 11 seconds, at which point the Sun will begin its gradual move out of the Moon's shadow.

Waco sits in the middle of the path of totality. This, combined with typically excellent weather in April, as well as easy accessibility, makes Waco an ideal location for an eclipse event.

We have reserved several room blocks in Waco hotels for Lowell members. If you are a member, contact Sherry Shaffer at sshaffer@lowell.edu for information.

For information and to reserve your spot at this event, see eclipseovertexas2024.com.



Supporter Feedback

Compiled by Heather Craig, Marketing Operations Specialist

The visit to Lowell Observatory was the high point of our many-high-points visit to Flagstaff and the area. Our especially favorite parts were spending time with the outdoor telescopes and the younger astronomers who were full of information and passionate about their careers!

Google Review

We have been members for years. It's great for families, especially for the kids' summer camp!

Google Review

Google Review

Such an intriguing and educational experience. The exhibits and science seminars were presented well and all questions were answered. The staff were knowledgeable, engaging, and friendly.

Yelp

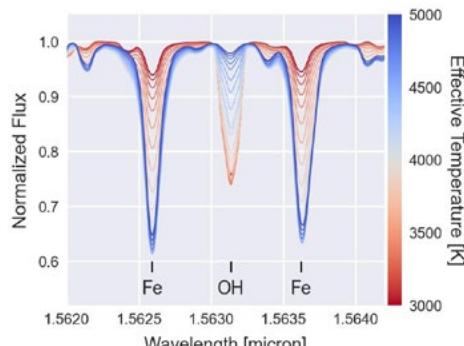
Definitely worth a visit, my son and grandson came from Australia on vacation and I am so glad we decided to do this. Out of this world.

These are similar to the dark spots observed on our Sun, but cover half or more of the young stellar surface. These starspots, about 1000 degrees Kelvin cooler than the rest of the stellar surface, interfere with the widely used radial velocity method for exoplanet detection. Such spots can mimic the signals we associate with planet-star reflex motion, making it significantly more challenging to confirm the presence of a hot Jupiter.

To circumvent the above issues, my current research aims to develop an innovative approach for identifying the starspot impact by tracing the temperature variations in young stars resulting from the spots coming in and out of view of our telescopes as the star rotates. We analyze spectroscopic absorption lines in the outer layer of the stars caused by atoms like vaporized iron (Fe) and molecules like gaseous hydroxide (OH). By studying these lines, we can glean crucial information about temperature changes on the stellar surface, as illustrated in the figure below, facilitating estimates of the temperature contrast, distribution, and size of starspots.

Our recent data analysis delved into stars younger than ten million years, unveiling intriguing findings about their fluctuating surface activity.

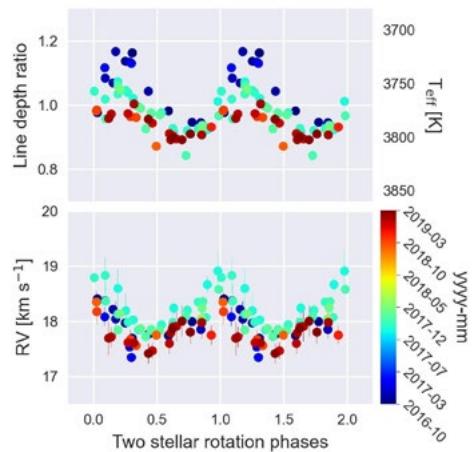
Model spectra demonstrating the changes in Fe and OH lines as a function of stellar temperature: hot stars (blue) have deep Fe lines and shallow OH. Cool stars (red) have deep OH absorption by shallow Fe lines. The ratio of the depth of the OH line to the depth of the Fe lines thus yields a sensitive stellar thermometer!



Top: Changes in the OH/Fe line depths over two stellar rotations for the five-million-year-old star V827 Tau.

The variations were greater in 2016 (blue circles), indicating greater spot coverage that slowly diminished through 2019 (red circles).

Bottom: Faux radial velocity variations resulting from distortions in the spectra induced by the spots over the same two stellar rotations. In the absence of spots, radial velocity variations like these signal the presence of a giant planet close to the star.

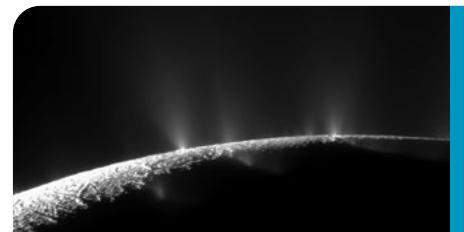


Notably, we observed variations in spot sizes and numbers, leading to shifts in average surface temperatures. In the upper panel of the figure above, we witness the dynamic changes in the line depth ratios (OH/Fe) of the five-million-year-old star V827 Tau as the star rotates. The lower panel reveals faux radial velocity variations resulting from the distortion of spectral lines by the spots. Adding a touch of color to the data provides a mesmerizing insight: bluer data points, corresponding to the winter of 2016, show cooler surface temperatures for V827 Tau, whereas redder points, observed in 2019, indicate warmer conditions and thus fewer spots.

The next critical step in our research agenda is developing a robust simulation model with the aim of replicating the observational results and isolating the misleading signals star spots produce. By accomplishing this, we hope to significantly improve the reliability of hot Jupiter detections in young stellar systems. Ultimately, this work will contribute to our broader understanding of planetary formation mechanisms and the conditions required to foster habitable zones around other stars. •

While it is impossible to accurately forecast the future, we can make some educated guesses and use our imagination to come up with dreams and wishes for the future of science at Lowell Observatory. We started with a list of potential discoveries between now and 2050 in four different areas: planetary science, stellar astrophysics, exoplanets, and extragalactic astronomy. We limited ourselves to those areas because we expect those to remain the main focus of scientific endeavors at Lowell Observatory. For instance, for the next decade, we expect that interstellar objects like Oumuamua will be discovered frequently, that we will understand how the interior and surface of Europa play together, comprehend the abundance of elements in the Sun, detect the first moon around an exoplanet, and discover clumps of dark matter in our own galaxy. By 2050, we will have detected clear signs of life on an exoplanet, carried out the first in-situ analysis of the geysers on Enceladus, determined the nature of dark matter, and for the first time correctly predicted a star to go supernova. While all of this is highly speculative, the collection of more than 100 potential discoveries provided a good overview of where astronomy and planetary science are going over the coming decades.

We then looked at each potential discovery and estimated what ambition Lowell Observatory had to contribute to actually making these discoveries. For instance, we want to be the ones to make the first movie of an exoplanet crossing in front of its host star, but we will not directly contribute to the analysis of Mars samples. Once we had analyzed Lowell's potential contributions, we wrote short sections for each case that we wanted to be involved in. These sections provide a background, list the key science questions and the driving reasons for Lowell to be involved, define the overarching goal for Lowell's involvement, and



Plumes near the south pole of Enceladus spray water ice and vapor. Credit: NASA/JPL/Space Science Institute.

CONTINUED ON PAGE 12

Front cover: The Lowell Discovery Telescope will be supplemented by other telescopes and instruments as Lowell Observatory scientists pursue research projects in the coming decades.

identify outreach opportunities as well as funding possibilities. The last part for each discovery was an analysis of what it would take Lowell Observatory to do all this work: people, facilities and necessary technology developments along with dates by when they would be required.

Of course, it is not realistic that Lowell Observatory can achieve all its ambitions dreamed up by its scientists. What helps is that many discoveries have similar needs in terms of facilities, and we started making a list of telescopes and instruments that could address more than a single ambition for a discovery. This list showed that there were a few upgrades and new facilities that could cover a large range of ambitions. Others covered only a single ambition or would not have been competitive by the time they would have been built. This led to a final, realistic list of projects that we are looking forward to presenting to the public soon. •

Recent Publications

Richey-Yowell, T., Shkolnik, E., Schneider, A., Peacock, S., Huseby, L., Jackman, J., Barman, T., Osby, E., Meadows, V., 2023, ApJ, 951, 44, HAZMAT. IX. An Analysis of the UV and X-Ray Evolution of Low-mass Stars in the Era of Gaia

Prato, L., Simon, M., 2023, RNAAS, 7, 150, Evolution of Circumstellar Disks around T Tauri Stars as a Function of Stellar Age

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: www2.lowell.edu/users/tac/bio/dct_ref_pubs_etal.html

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

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The Lowell Observer is published quarterly by Lowell Observatory
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