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THE LOWELL OBSERVER

THE QUARTERLY NEWSLETTER OF LOWELL OBSERVATORY

SPECIAL RESEARCH ISSUE

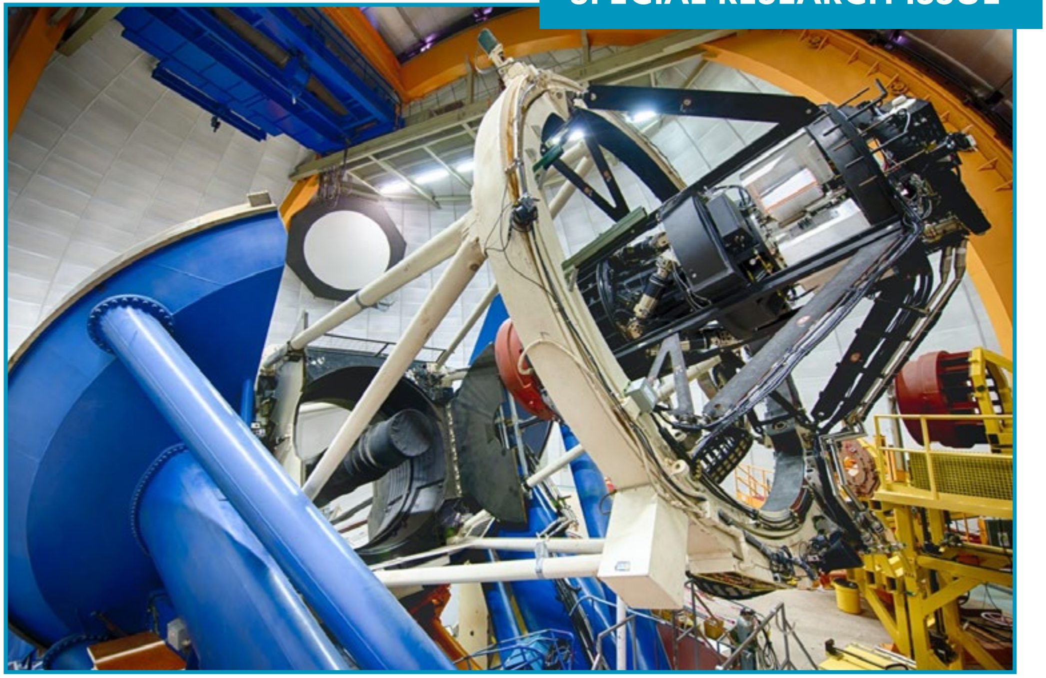
COVID-19 STATUS

As of May 2021, Lowell Observatory is in Phase 2 of reopening, offering Premium Access and Guided Tours to small groups with reservations. For updates see **lowell.edu/welcomeback** or follow us on social media.

IN THIS ISSUE

2 Director’s & Trustee's Updates
3 Searching for Star Companions
4 Research Telescopes of Lowell
5 What's a Wolf-Rayet Star?
6 Dwarf Irregular Galaxy Research

7 Lab Studies of Methane & Ethane
7 Staff Highlight: Brian Skiff
8 Comets Borisov & NEOWISE
9 New Method for Detecting the Youngest Planets
10 The Slipher Society
12 Videos and Live Streams



The Quest to Understand Dark Energy

By Dr. Kyler Kuehn, Deputy Director for Technology

The Dark Energy Survey (DES) was a large-scale astronomical survey covering 5000 square degrees—roughly 1/8 of the entire sky—focusing primarily in the southern hemisphere. I joined a team of astronomers in capturing survey data over 758 nights from 2013-2019 with the primary goal of understanding the nature of dark energy. The survey used the Dark Energy Camera, a purpose-built instrument of 62 science detectors combined into a single detector with 570 million pixels. The camera observed from its perch on the Blanco 4-meter telescope at Cerro Tololo Inter-American Observatory.

In order to determine the effect of dark energy on the universe (both now and in the distant past), Dark Energy Survey data were used in four independent but mutually reinforcing methods. First, Type Ia supernovae were used to measure the expansion rate of the universe—including how that rate changes over cosmic time. Second, the Dark Energy

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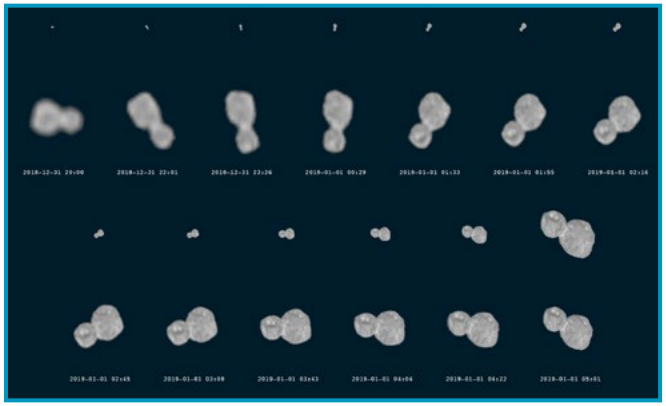


Deciphering Contact Binary TNOs

By Dr. Audrey Thirouin, Research Scientist

My expertise is the study of the diverse small body populations in our solar system using different techniques from observations to modeling. Currently, my work is focused on the small bodies beyond Neptune’s orbit called the trans-Neptunian objects (TNOs, or Kuiper belt objects). The TNOs are the leftovers from the formation of the solar system, and so by studying them we can understand how the planetesimals, or building blocks of the planets, were formed.

continued on page 11

DIRECTOR'S UPDATE

By Jeffrey Hall

A long time ago, at one of my first meetings of the Lowell Advisory Board, I gave a talk about the kinds of investigations into stellar variability one could do with a 4-meter telescope. That talk was part of a "use case" presentation to the Board about what was then called NGLT - the Next Generation Lowell Telescope. At the time, there were also a few holes in the ground, near our 1.1-meter telescope at Anderson Mesa, that were the first excavations for what would become the Navy Precision Optical Interferometer.

About 20 years after that presentation to the Board, we completed commissioning of the 4.3-meter Lowell Discovery Telescope (LDT). Ownership of our own telescopes is a fundamental strength for enabling the research of Lowell Observatory, with the LDT filling that role admirably today, just as the 24-inch Alvan Clark refractor did a century ago. I hope you enjoy reading about the wide range of programs our faculty carry out with LDT and many other facilities—programs that will continue and expand for decades to come. Many discoveries await!

TRUSTEE'S UPDATE

By W. Lowell Putnam

Welcome to this special edition of the *Lowell Observer*. There is a tremendous range of astronomical and planetary science being done at Lowell Observatory, and this is no accident. Percival Lowell felt it important to support not only his own areas of interest, but those of the scientists he hired. So while Percival was looking at Mars, V. M. Slipher was capturing the first evidence of the expanding universe and Carl Lampland was building up a tremendous body of knowledge about comets in our solar system.

This continues at Lowell. As you look through this edition, watch for the range of different areas of study our current faculty are pursuing. To understand the universe and our place in it, it is important to recognize how interconnected our studies become. You cannot understand how Earth has come to be if you do not understand planetary formation in general and understand how other planetary bodies evolved, or did not. Understanding our solar system and particularly our star, the Sun, requires observing other systems and stars and their formation. As you expand the lens of what you look at, understanding other, similar but not identical, objects for context and comparison helps build a truer understanding of ourselves and how we came to be.

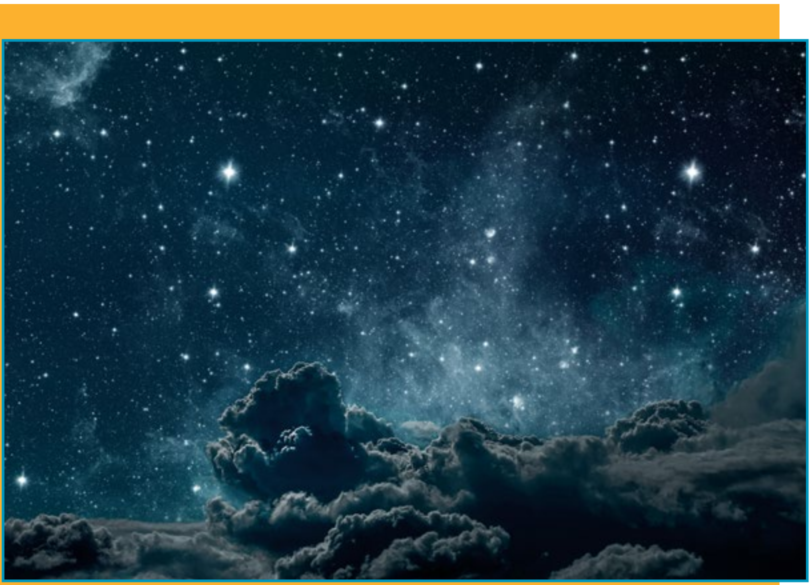
So I hope you enjoy reading the various articles in this *Observer* and thank you for your support in making all this possible.

Comets to Cosmology: Science at Lowell Observatory

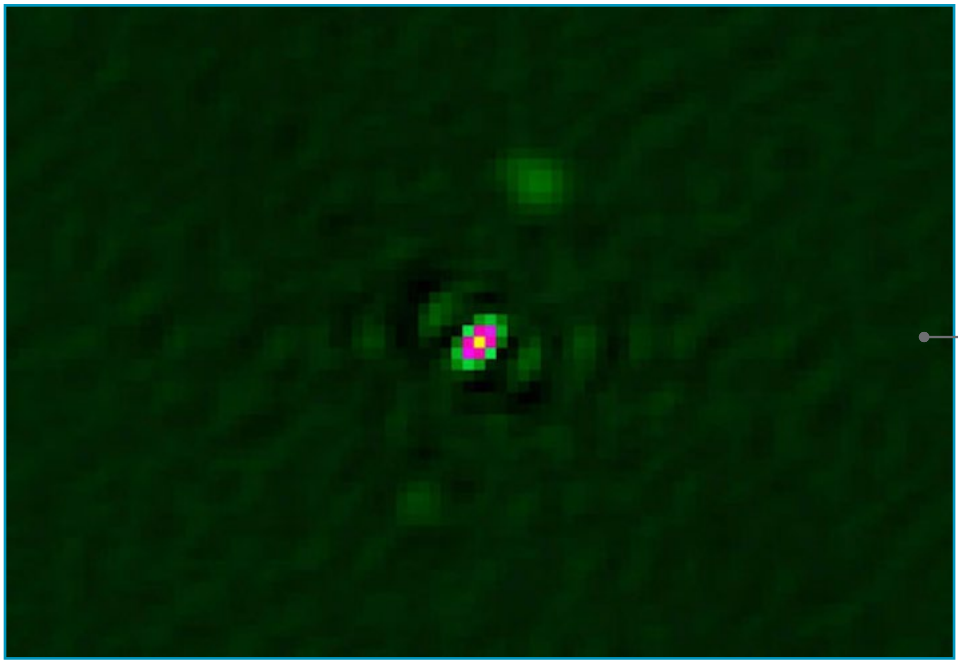
By Dr. Michael West, Deputy Director for Science

Few scientific organizations have a richer history of discovery than Lowell Observatory. It was here that Vesto Slipher made his pioneering measurements of the universe's expansion in 1912, and Clyde Tombaugh first spotted Pluto in 1930.

This tradition continues today with a vibrant research program by Lowell astronomers that explores everything from the smallest objects in our solar system to the universe's structure on the largest scales. In this issue of the *Observer*, you'll meet a few of these Lowell astronomers and learn more about their ongoing studies.



"*Step by step, astronomy wrests fresh secrets from the starry abysses.*" These words, written by the 19th century English poet and journalist Edwin Arnold, are as true today as they were then. We are truly living in a Golden Age of astronomical discovery, and Lowell Observatory is at the forefront of this exploration.



An M7 main sequence star, with an even smaller M8 companion, newly discovered by the LDT, at a separation of 290 millarcseconds.

Searching for Companions of the Nearest, Smallest Stars

By Dr. Gerard van Belle, Astronomer & Catherine Clark, Research Assistant

The extremely large 4.3-meter primary mirror of the Lowell Discovery Telescope (LDT) bestows two main benefits upon the astronomers at the observatory. First, its function as a massive light bucket allows the faintest of objects to be seen. The large size of that mirror also has the potential for extreme angular resolution, allowing for teasing apart the finest of details from an on-sky image. However, that latter capability of LDT is typically obfuscated by the turbulent, boiling atmosphere, much akin to trying to see a coin at the bottom of a disturbed swimming pool.

In theory, the limiting resolution of the LDT is roughly 35 millarcseconds—about the apparent size of an orange at 500 miles—but Earth's atmosphere usually limits the LDT to about one arcsecond, some 25 times worse than that. To overcome that obstacle, we have been using the technique of speckle interferometry to recover the full resolving power of the LDT. This technique begins with taking a large number of very rapid images of objects of interest—usually 1,000 frames or more at frame rates of roughly 25 frames per second. While this does not remove the distorting effects of the atmosphere, this has the effect of at least freezing out those distortions and preventing them from smearing on top of the neighboring frames. The second key to speckle is in the post-processing of these speckle frames: using pattern-searching mathematical techniques like Fourier analyses, we can see past those frozen distortions and recover the full resolving power of the 4.3-meter LDT primary mirror.

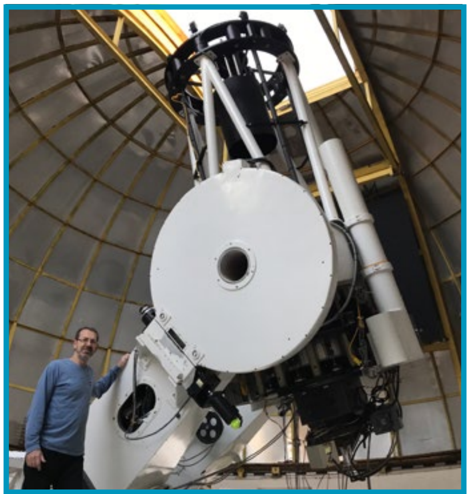
The high frame rates of speckle, and attendant short frame times, have limited the sensitivity of speckle work in the past, but the large collecting area of LDT has allowed us to extend our reach with this technique. In particular, we have been engaged in a survey of all of the low-mass stars near to our own solar system. These stars, the so-called 'M-dwarfs', range in mass from half a solar mass all the way down to 8% the mass of the Sun; below this limit, objects cease to be full-fledged, fusion-burning stars and transition into the murky realm of brown dwarf objects. Because of their small size, they tend to be quite faint. M-dwarfs are very numerous—roughly 75% of all stars are these low-mass objects—and are currently the most favorable targets for detecting exoplanets in the habitable zone. However, the propensity for these stars to themselves host fainter secondary stars—which could inhibit planetary hosting—is poorly understood, in part due to their intrinsic faintness.

In partnership with Dr. Elliott Horch of Southern Connecticut State University, we have been carrying out the Pervasive Overview of Kompanions of Every M-dwarf in Our Neighborhood (POKEMON) survey using his Differential Speckle Survey Instrument (DSSI)—and with DSSI have imaged every such M-dwarf out to 15 parsecs, roughly 1,200 in total, resulting in more than 30 new companions being detected. To extend this work even further, we recently have deployed to LDT an upgraded speckle camera, the Quad-camera Wavefront-Sensing Speckle Imager (QWSSI), which follows in DSSI's footsteps but advances speckle imaging even further with greater wavelength coverage and advanced sensing of atmospheric distortion. The new instrument will allow us to further leverage the unique capabilities of LDT at the frontiers of spatial resolution.

Research Telescopes of Lowell

LO-CAMS

Dr. Nick Moskovitz and his team operates Lowell Observatory Cameras for All-Sky Meteor Surveillance (LO-CAMS) to document meteoroids. Moskovitz is shown here with one of the systems set up on the roof of the Slipher Building at Lowell's main Mars Hill site.

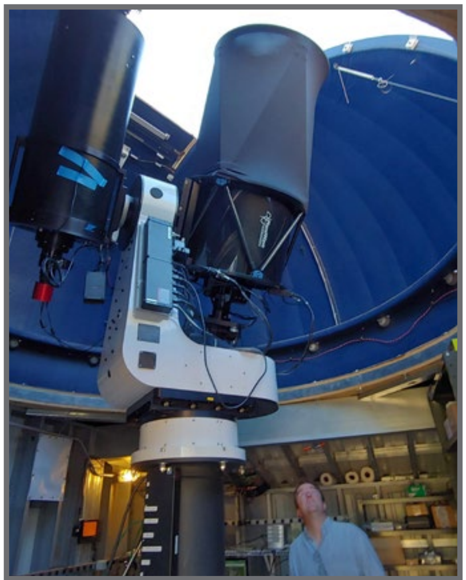


42-inch

The 42-inch Hall Telescope, shown here with Lowell Observer/Research Assistant Tom Polakis at the Anderson Mesa dark sky site, has been a workhorse for the study of comets, solar analogs, and other celestial objects for more than 50 years.

LDT

The 4.3-meter Lowell Discovery Telescope (LDT) at Happy Jack is Lowell's flagship telescope. Astronomers use it to study asteroids, Kuiper belt objects, extrasolar planets, galaxies, and more.



TiMO

The TItan MOnitor (TiMO) facility at Lowell's main Mars Hill site currently houses two dually-mounted telescopes. Lowell Adjunct Astronomer Dr. Kaspar von Braun is shown here with the 0.5-meter TiMO previously used to observe Saturn's moon Titan and a 0.32-meter telescope used for high-speed occultation observations.

NPOI

The Navy Precision Optical interferometer (NPOI) at Lowell's Anderson Mesa dark sky site is a highly specialized telescope for making high-precision measurements such as star positions.

LOST

The Lowell Observatory Solar Telescope (LOST), on the roof of the Lowell Discovery Telescope's auxiliary building at Happy Jack, is being used to search for Earth-sized exoplanets. It feeds sunlight through a 75-millimeter lens into a fiber optic cable and into the EXtreme PREcision Spectrograph (EXPRES).

Phil Massey and Kathryn Neugent searched for Wolf-Rayet stars in the Large Magellanic Cloud using the 1-meter Swope Telescope at Las Campanas in northern Chile.

Credit: Kathryn Neugent

What's a Wolf-Rayet Star?

By Dr. Phil Massey, Astronomer

As an undergraduate, I had done a senior project on the light distribution of compact galaxies, and a few months into graduate school in Colorado I found myself adrift. I walked into the office of the only observational astronomer at CU Boulder, Peter Conti. I introduced myself, and asked if there wasn't some research project I could do. After some reflection and questions, he handed me a box of photographic spectra and said, "Well, you could get started on measuring these. They're spectra of a Wolf-Rayet binary." I looked at him puzzled. "What's a Wolf-Rayet star?" The year was 1975, and I've been studying WR stars ever since.

In 1867, Charles Wolf and Georges Rayet were observing the spectra of stars using the 40-centimeter (16-inch) Foucault telescope at Paris Observatory. They were using a visual spectrometer, basically a prism with an eyepiece. They chanced upon three stars in the constellation Cygnus whose spectra showed broad, bright emission bands rather than the normal absorption lines that are found in normal stars. In the ensuing decades, dozens more were discovered. Sixty-some years later, in 1929, the Canadian astronomer Carlyle Beals identified the emission as due to helium, nitrogen, carbon, and oxygen. The spectra fell into two camps: either helium and nitrogen were seen, or helium, carbon, and oxygen. Neither type showed any hydrogen. These became known, respectively, as WN-type and WC-type Wolf-Rayets.

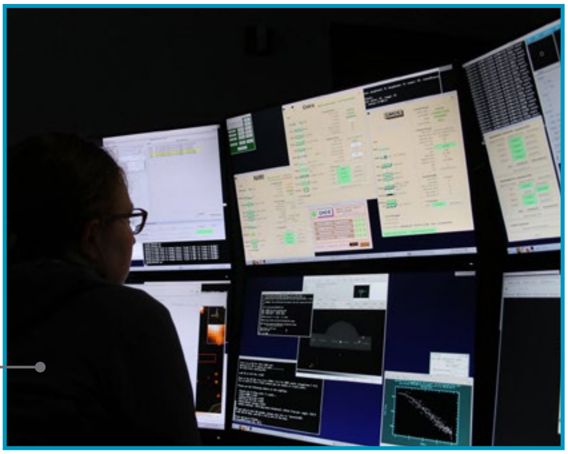
This was only a few years after Arthur Eddington had suggested that the Sun and other stars were powered by nuclear fusion. In a star like the Sun, hydrogen is converted into helium via the proton-proton chain; in the process a wee bit of mass is converted into energy. In Einstein's famous equation, the mass is multiplied by the square of the speed of light; this is a very big number, and the little bit of mass that is lost provides enough energy to power the stars. In stars hotter and more massive than the Sun, an alternative reaction chain, known as the CNO cycle, converts hydrogen into helium. As a byproduct, it produces nitrogen in addition to helium. An older star, once it has exhausted its hydrogen, will convert helium into carbon. Once there's enough carbon built up in the core, it will react with the helium to produce oxygen. Note that the carbon and oxygen we're talking about here is where the atoms in your body came from, produced in the cores of these stars. As Carl Sagan famously put it, "We are made of star stuff."

It was left to the physicist George Gamow to connect the dots: in 1943, he wrote a paper saying that WN and WC stars had these peculiar abundances because (somehow) they were showing the products of these nuclear burning processes at their surface. But how did this matter get to the surface, and what removed the surface hydrogen? [Side note: you may have come across Gamow's popular science books, "One, Two Three, Infinity," or his Mr. Tompkins series. And my graduate student office was in the Gamow Tower at CU Boulder.]

Our research group at Lowell includes Erin Aadland, a PhD student at Northern Arizona University, and Kathryn Neugent, a long-time Lowell Research Associate who just earned her PhD at the University of Washington and will be taking up the prestigious Dunlap Fellowship at the University of Toronto in the Fall.

Our work on Wolf-Rayet stars involves identifying them in nearby galaxies and measuring their physical properties, all with the aim of better understanding how they form and what they will become. Binary Wolf-Rayet stars will someday become binary black holes, spiraling closer and closer until they merge, emitting the gravitational waves that physicists have identified a few years ago. Our work frequently takes us to Chile, to study WRs in the southern sky; we travel to international conferences around the world to present our results to other researchers. We are constantly finding new and exciting things. For instance, Kathryn discovered a new type of WR a few years ago and wrote her Masters Thesis on them.

I have no regrets about taking that box of plates from Peter that day. It's a good gig: I get paid for doing what I would do for free. As I've been known to remark, Lowell is a great place to do research: we are free to go where the science leads us.



Kathryn Neugent observing Wolf-Rayet stars with the Gemini 8-meter telescope on the Big Island of Hawaii.

WLM, a little dwarf irregular galaxy in our Local Group of galaxies. Red is the atomic hydrogen gas, green is an image that emphasizes older stars, and blue is an ultraviolet image that is dominated by young stars with ages of less than 100 million years.

Dwarf Irregular Galaxy Research

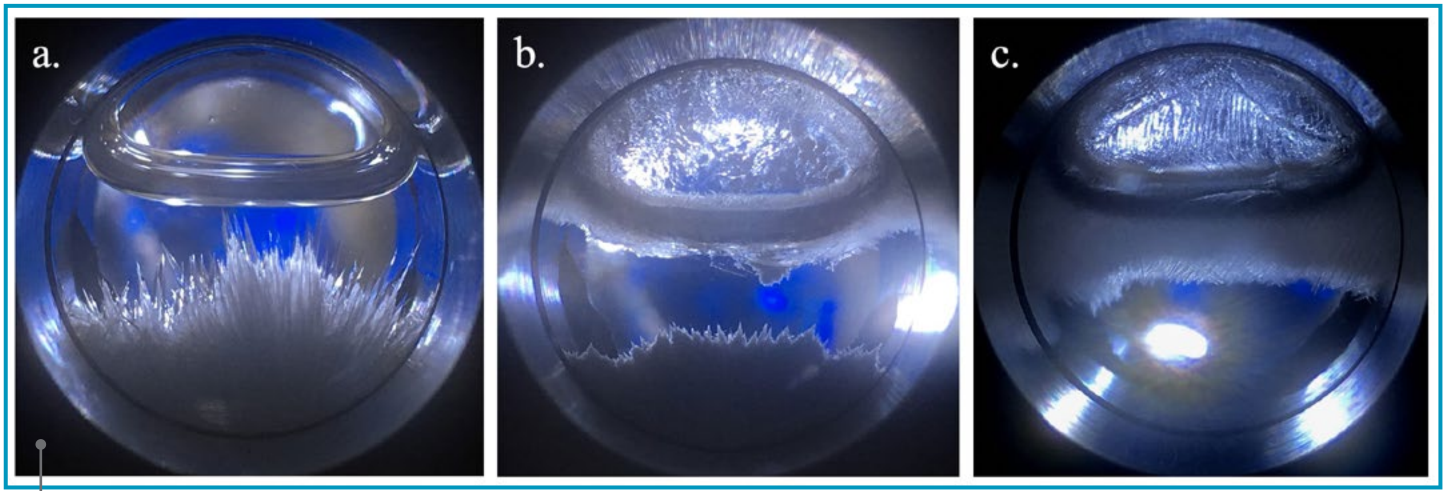
By Dr. Deidre Hunter, Astronomer

Dwarf irregular galaxies, the smallest galaxies in the universe, regularly form new stars. This is in spite of the fact that their interstellar gas densities are so low that theoretical models say they shouldn't be able to form stars at all. Furthermore, stars in galaxies like the Milky Way form in cold, dense molecular clouds that have formed out of the interstellar atomic hydrogen gas, but the low dust and heavy element content of dwarf galaxies means that the structure of molecular clouds is different in dwarfs than in spirals. The surrounding ultraviolet light from older stars destroys the molecules that try to form in a cloud, leaving a thick skin of destroyed molecules around a tiny molecular core. My collaborators and I used the new millimeter radio interferometer ALMA in the Atacoma Desert in Chile to map CO in molecular clouds in WLM, a nearby dwarf galaxy that has only 13% as much heavy elements as our Sun. Combining these data with images from the far-infrared space telescope Herschel, we showed for the first time this structure of a relatively pristine molecular cloud.

Now Haylee Archer, a graduate student at ASU, is doing her PhD dissertation with me on WLM. She is currently examining the galactic environments throughout WLM where molecular cloud cores were found to try to understand what conditions were necessary for their formation. She will also be using other ALMA data to look at the distribution of dust as a way to infer the presence of "dark" molecular gas, gas that is not traced by CO, in order to fully understand the molecular gas clouds of WLM. Finally, Archer will use deep near-infrared images from the Spitzer Space Telescope to trace stars, and hence star formation, far out into the disk of WLM.

Dr. Michael West Joins Review Panel

Lowell Observatory scientists are very active in the at-large astronomy community, serving on a variety of panels, boards, and committees. Dr. Michael West, for instance, just began serving on the Office of Astronomy for Development's (OAD) proposal review panel. The OAD's mission is "to use astronomy to make the world a better place" through socio-economic development. With support from the International Astronomical Union, the OAD has funded more than 200 projects on five continents since 2013 (including an award to Lowell's Native American Astronomy Outreach Program in 2020). A total of about 100,000 euro will be awarded to projects in 2021.



Characteristic ices formed in the methane-ethane binary. The coloration is a side effect of the cell and the samples themselves are not blue. Panel (a) is a typical formation of ethane ice in an ethane-rich mixture. Panel (b) shows the eutectic ice at a temperature of 72 K with a composition of 0.64 methane – 0.36 ethane. Panel (c) is an example of methane ice in a methane-rich mixture. Figure and caption modified from Engle et al., 2021, *Planetary Science Journal*.

Laboratory Studies of Methane & Ethane

By Dr. Jennifer Hanley, Astronomer

Titan, the largest moon of Saturn, is the only other body in the solar system to have liquid on its surface. Compared to Earth, the temperatures are much colder (~95 K), meaning that water ice is the bedrock, and the lakes and seas are composed primarily of methane and ethane. We have been studying the stability of these liquids in the Astrophysical Materials Laboratory through a combination of laboratory experiments and theoretical modeling. To start, we looked at the freezing point of different mixtures of methane and ethane. This pair of molecules form a eutectic system, where the lowest freezing point of the mixture is below either of the pure species individually. We see that depending on the ratio of methane-to-ethane, different ices form, as seen in the adjoining image. Ethane ice (panel a) tends to form in ethane-rich liquids, and since it is more dense than the remaining liquid, it forms at the bottom of the cell. Methane ice (panel c) tends to form in methane-rich liquids, and float. In the middle panel, at the eutectic point, the methane and ethane ice form simultaneously at the top and bottom of the sample. These results have implications for the stability of the lakes and seas on Titan's surface.

STAFF HIGHLIGHT

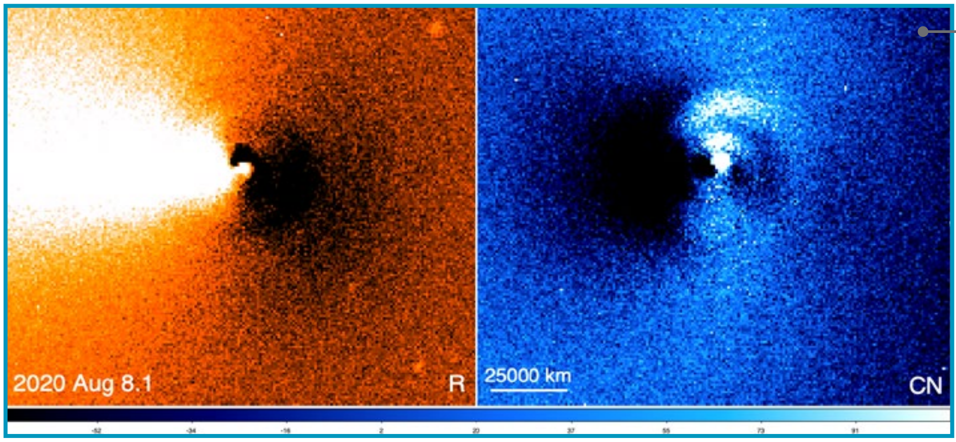
Brian Skiff, Research Assistant

By Madison Mooney, Content Marketing Specialist

Research Scientist Brian Skiff has been at Lowell Observatory for nearly 40 years, working as a research assistant. He earned a Bachelor of Science degree from Northern Arizona University in 1977. Among his impressive accomplishments at Lowell is the vital role he played in the decade-long Lowell Observatory Near-Earth-Object Search (LONEOS) survey for near-Earth asteroids. He has also measured thousands of plates, films, and CCD images to improve observations of the orbits of asteroids during a period of low activity in the skies over the Flagstaff area.

In support of the observatory's long-running solar analogs project, Brian has spent 1,200 nights over 15 years doing single-channel photoelectric photometry on Sun-like stars to explore long-term variations in the 11-year sunspot cycle. He continues this work today, conducting spectroscopic observations of stellar chromospheric activity. In recent years, Brian's work has encompassed recording the rotational light curves of more than 200 asteroids, both near-Earth and beyond, via CCD and using several telescopes. Brian maintains a comprehensive catalog of stellar spectral classifications, which is one of the most frequently used items in the VizieR catalog-query service.

Brian took the final photographic plates with the Pluto Discovery Telescope before its retirement and is a valuable resource in recounting how this and other Lowell instruments were used. His knowledge of the night sky is legendary in both professional and amateur circles, and he has also greatly impacted Lowell's visitor program, for decades volunteering during public nights to share his love for astronomy and the night sky.



A dust (left) and cyanogen gas (right) pair of images obtained in August with Lowell Observatory's 42-inch (1.1-meter) John S. Hall Telescope located at Lowell's Anderson Mesa dark sky site. Each image has been processed to remove the bulk brightness radial fall-off from the center, and then had false colors applied, revealing structure in the inner coma. By this date the comet had moved such that the Sun was towards the west (in the direction of the arrow on the dust image) and the tail dominates the frame towards the left. The processed cyanogen image exhibits several arc or shell-like structures, created by two or more source regions on the surface of the nucleus releasing gas. These jets form spirals due to the rotation of the nucleus.

Credit: Images obtained by Brian Skiff and processed by Dr. Matthew Knight of the U. S. Naval Academy.

Comets Borisov & NEOWISE

By Dr. David Schleicher, Astronomer & Allison Bair, Research Associate

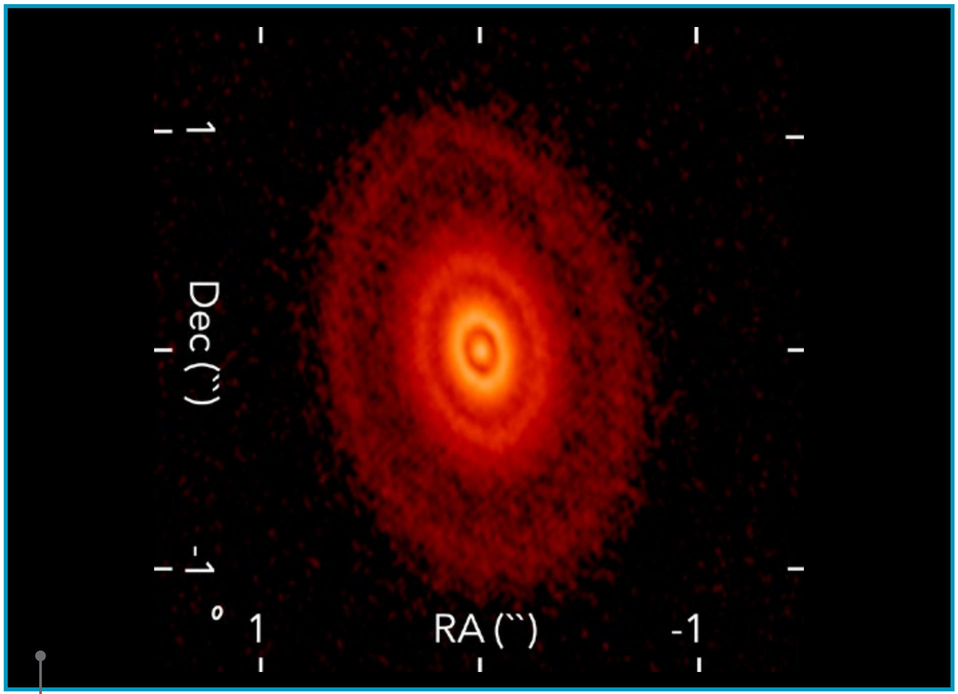
Our studies of comets take a variety of forms, depending upon an individual comet's orbit and its intrinsic properties. We sometimes observe how the brightness of the bare nucleus varies with rotation; occasionally take images to look for gas and dust jets and see how they move with time, and then attempt to model this behavior; and almost always measure the composition of the coma using specialized filters. In the past year and a half, two objects have especially caught our, and the public's, attention.

2I/Borisov, the first definitive interstellar comet detected as it passed through our solar system, gave astronomers the first opportunity to characterize how a comet formed elsewhere compares to comets we routinely observe (see the Winter 2019 Lowell Observer for details on its discovery and orbit). Initial observations of Borisov's chemical composition, beginning in September 2019, proved most interesting, with clear detections of cyanogen gas (CN), but extremely low abundances of diatomic carbon (C2) and low triatomic carbon (C3). Compared to the 200+ comets in our database (measured with Lowell telescopes over four decades), this placed Borisov among about a dozen others with similar carbon composition. Unlike comets originating in our solar system, however, the carbon chemistry of Borisov changed as it approached the Sun, and it exhibited only a mild depletion of C2 by its closest approach near the end of 2019. This change was unexpected, as heating by the Sun does not alter the abundances of these chemicals in comets from our solar system; it may be that our Sun burned off a crust that formed on Borisov during its interstellar journey. By late 2019, we additionally measured NH, a byproduct of ammonia, and OH, a direct byproduct of water, and we found the ratio of NH to OH to be higher in Borisov than in the comets originating here. Thus, while the expected chemical components were detected, the relative abundances were different than any other comet in our database, implying Borisov formed, not surprisingly, under quite different conditions.

Discovered in March of last year by NASA's NEOWISE spacecraft observatory, it was quickly determined that Comet NEOWISE (C/2020 F3) might become quite bright by mid-summer. Its orbit is very elongated, going from 10 times the distance of Pluto to inside the orbit of Mercury, with its last appearance 4800 years ago. Indeed, as it escaped the Sun's glare in July, it became the brightest comet visible from the northern hemisphere in over a decade, and conveniently for everyone it was an evening object—dominated by its extensive dust tail, though close to the horizon. Only by late July was it sufficiently high in the sky that larger telescopes could acquire it. Similar to the Borisov study above, we measured the gas composition of NEOWISE, and learned that it was "normal" in all respects, though the ratio of dust-to-gas was significantly lower than average. Having confirmed that its composition was not unusual, our next goal was to study the detailed structure of the inner coma. The left-hand panel of the image above shows an enhanced dust image, where the inner-most portion of the dust tail is obvious.

In the right-hand panel, several arc or shell-like features are visible in the enhanced cyanogen gas image. In the limited time that NEOWISE was available each night, these features moved outward from the center, and somewhat changed shape from night-to-night. Based on these motions, we estimate that the nucleus is rotating every seven-to-eight hours. Analyses of both comets are continuing.

Comet NEOWISE against the backdrop of the northern lights, as seen from Alberta, Canada in mid-July of 2020. As always, the comet's tail points away from the Sun, and is tens of millions of kilometers in length. The head or coma of NEOWISE is larger than the planet Jupiter, while all of the gas and dust forming the head and tail was released from the nucleus that is less than 5 km in size. | Credit: Bill Peters



A snapshot of CI Tau's protoplanetary disk, captured with the ALMA (Atacama Large Millimeter Array). | Credit: Clarke et al. (2018)

New Method Discovered for Detecting the Youngest Exoplanets

By Lauren Biddle, Research Assistant

The past decade of exoplanet science has inundated the astronomical community with thousands of new exoplanet discoveries and provided a wealth of information on what planetary systems look like once they've matured at least a billion years after forming. In terms of understanding planet formation, these discoveries have helped tremendously by informing possible theoretical formation pathways. This is where my research comes in. As part of my PhD work at Lowell Observatory and Northern Arizona University, I am observing young planets still in the process of forming; this is important because only a handful of these planets have ever been detected. Only a few young planets are known primarily because their host stars are incredibly magnetically active, resulting in large, sustained, star spots and plages, and frequent powerful flares that manifest in spectroscopic and photometric data, effectively drowning out a planet's signal, if present.

Along with the other members of DEFT (Disks and Exoplanets Flagstaff Team) at Lowell Observatory, and in collaboration with astronomers at Rice University, I have found a new way to detect exoplanets around the youngest stars, which perhaps unexpectedly, embraces magnetic activity rather than avoiding it. Many of the youngest stars are surrounded by a protoplanetary disk made of leftover material from their formation (the "youngest" stars in this context are less than 10 million years old. This timeframe is comparable to the first four weeks in the average human lifespan!), and it is the interaction between the young planet and this material that makes this detection method possible. The disk itself can contribute to magnetic activity signatures via the process of accretion, where material from the disk travels along the star's magnetic field lines and eventually hits the stellar surface, resulting in drastic changes in the entire system brightness. For the first time, we identified a planet, CI Tau b, that interacts with the disk in such a way that it perturbs the rate of accretion, effectively causing the brightness of the whole system to pulsate on the timescale of its orbital period. My work contributed to the confirmation of CI Tau b, the youngest planet known to date.

Equipped with a new tool for planet detection, I am excited to find more and more young exoplanets with the aim to increase their numbers in the exoplanet census and contribute to a more complete understanding of the formation process of planetary systems.

New Postdoc Arrives in Fall

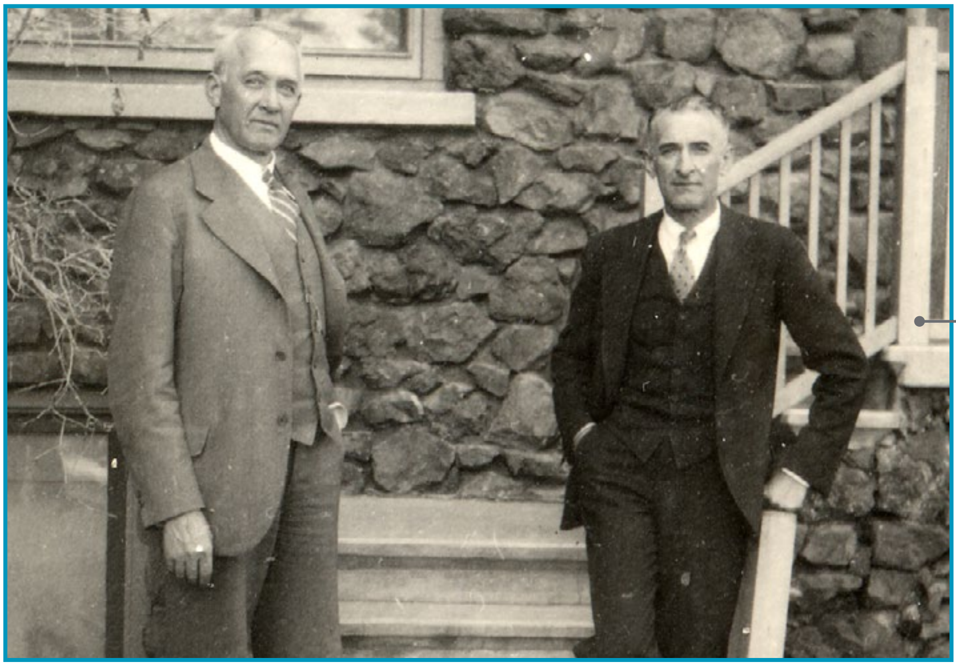
Theodore (Teddy) Kareta has accepted a postdoctoral position working with Dr. Nick Moskovitz on the MANOS project. Teddy is currently a doctoral student at the University of Arizona's Lunar and Planetary Laboratory, where he works on observations and models of centaurs, Main Belt asteroids, and near-Earth asteroids. A unifying theme of his work is understanding how mechanisms of activity and mass loss differ across the solar system. Teddy will defend his thesis this fall and start at Lowell around October 1st.

Recent Publication

Oszkiewicz, Dagmara; Troianskyi, Volodymyr; Föhring, Dóra; Galád, Adrián; Kwiatkowski, Tomasz; Marciniak, Anna; **Skiff, Brian A.**; Geier, Stefan; Borczyk, Wojciech; **Moskovitz, Nicholas A.**; Kankiewicz, Paweł; Gajdoš, Štefan; Világi, Jozef; Polčic, L. 'udovít; Kluwak, Tomasz; Wilawer, Emil; Kashuba, Volodymyr; Udovichenko, Sergei; Keir, Leonid; Kamiński, Krzysztof; **Devogele, Maxime**; Gustafsson, Annika. Spin rates of V-type asteroids. *Astronomy & Astrophysics*, Volume 643, id.A117, 26 pp.

Rector, T. A.; **Prato, L.**; Strom, A. L. Herbig-Haro Outflows in Circinus W. *The Astronomical Journal*, Volume 160, Issue 4, id.189, 8 pp.

See our website lowell.edu/research/recent-publications for more publications



V.M. and E.C. Slipher both graduated from Indiana University, both spent their entire professional careers at Lowell Observatory, both served as director of the observatory, and were both recognized leaders in their specific fields of research. They stand here in front of the building later named in their honor.

For more information, contact Sherry Shaffer at sshaffer@lowell.edu or (928) 714-7777

The Slipher Society Supports New Research

By Sherry Shaffer, Philanthropy Manager

Named after former Lowell directors and brothers, Vesto M. and Earl C. Slipher, the Slipher Society was established in 2020 to give those who are deeply interested in Lowell's research the chance to invest in new ideas and bridge funding gaps for ongoing projects. For a giving club not even a year old, the Slipher Society has sparked a lot of interest for and help with Lowell research. Already, the Society has been able to award more than $34,000 to eight projects with Lowell scientists.

Charter members met with several awardees in mid-February for a "virtual fireside chat." The awardees gave brief overviews of their projects and Society members were able to ask questions and discuss the research more in-depth. Projects ranged from: new software to robotize some of Lowell's telescopes; equipment to accelerate and streamline ongoing research; publishing fees for a completed paper; and preparatory research for a new instrument that could benefit ground-based infrared observing.

The Slipher Society is proving to be a great way for members to get more involved with Lowell scientists' research, becoming, as Percival Lowell put it, "co-discoverers" in a fun, new way. The observatory's scientists have also said they enjoy the freedom to explore new ideas and embrace opportunities they may otherwise have had to miss with "normal" grant funding.

Supporter Feedback

Compiled by Heather Craig, Marketing Specialist

"The entire staff is kind, courteous, and so obviously passionate about the Observatory and the important educational programming and research conducted there."

Google Review

YouTube Comment

"This was a fascinating installment of Cosmic Coffee! I really enjoyed hearing about the history of these stars and the differences among cultures! Thank you so much Dr. Adams, Dr. West, and Dr. Kuehn! "

Google Review

"Super loving staff, Miss Nina knew so much and had all the patience and care of the world. Do not hesitate to take a tour, especially if you enjoy stargazing! It was a truly unforgettable experience to visit Pluto's home!"

THE QUEST TO UNDERSTAND DARK ENERGY

continued from page 1

Survey cataloged millions of galaxies, each of which had arisen from minute density fluctuations in the early universe. This led to new insights into the state of the universe when it was only a fraction of its current age. These galaxies were also used to measure "weak gravitational lensing"—quantifying how massive galaxies distort the light from other galaxies located along the same line of sight from our vantage point, but much farther away in physical distance. Finally, relationships observed among galaxies clustered on the sky were also used to tell astronomers how the space between those galaxies had expanded and how that expansion had changed during the lifetime of the universe—a telltale signature of dark energy.

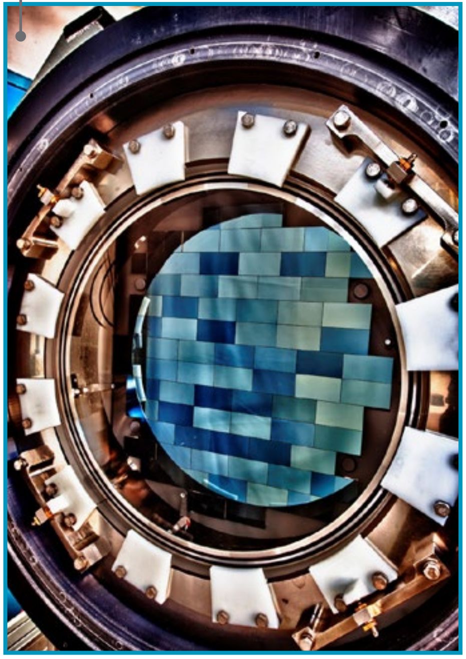
Though we don't yet know what dark energy is, astronomers and cosmologists model its behavior using two parameters: w_0 and w_a. The parameter w_0 describes the baseline, unvarying strength of dark energy, while w_a describes how the strength of dark energy varies over cosmic time. In the standard model of cosmology, w_0 equals -1, while w_a is 0 (i.e., dark energy is just Einstein's cosmological constant). Thus far, the Dark Energy Survey has measured values for w_0 and w_a consistent with -1 and 0, respectively—but the final analysis of the full six years of data is not yet complete, and could still yield surprises for our understanding of dark energy.

In addition to the improved understanding of dark energy achieved from the preliminary DES data, hundreds of other scientific results have also been published by the DES collaboration—from searches in the outer solar system for Planet X, to studies of the stellar streams that continue to orbit around our galaxy, to tests of Einstein's theory of general relativity and confirmation of the optical counterparts of gravitational wave sources. Nearly 400 scientists and engineers from 25 institutions worldwide continue to work on the full six-year dataset to render the most complete analysis of dark energy to date. And the Dark Energy Camera remains on the Blanco Telescope to this day, with astronomers from around the world able to use this unique instrument in support of their own scientific efforts.

FRONT COVER IMAGE: The Dark Energy Camera on the Blanco Telescope.

Credit: Fermilab/Reidar Hahn

The focal plane of the Dark Energy Camera, with 62 digital detectors comprising 570 megapixels. | Credit: Fermilab/Reidar Hahn



For more information, see darkenergysurvey.org

DECIPHERING CONTACT BINARY TNOs

continued from page 1

Some of the most interesting TNOs are the binary systems because they have a large diversity of characteristics; some binaries have a large primary and a tiny satellite, others have a primary and a satellite with a similar size, some are ultra-wide binaries with the two components barely bound together and others called contact binaries have the primary touching its satellite or the primary is very close to the satellite.

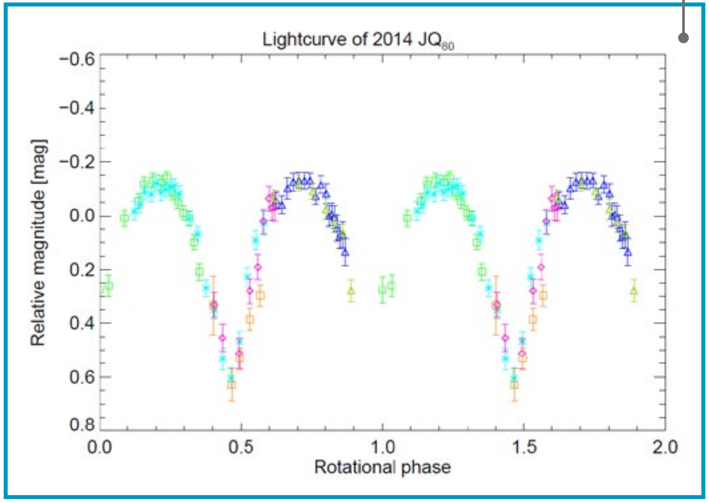
In January 2019, the New Horizons spacecraft flew by the small TNO Arrokoth, which is a contact binary located in the dynamically cold classical population (front cover image). Unfortunately, the Arrokoth flyby left us with a large number of unanswered questions regarding contact binaries. So, one of my research projects is to discover and characterize contact binaries to constrain where, how many, and how the contact binaries have formed.

Finding contact binaries at the edge of our solar system is difficult. The most efficient technique to find a contact binary is through its rotational light curve (periodic variation of an object's brightness as a function of time due to its rotation). The light curve of a contact binary is easily identifiable with large variability, a V-shape at the minimum, and an inverted U-shape at the maximum of brightness (see figure below).

Using the Lowell Discovery Telescope (LDT) and the Magellan Telescope in Chile, our team has found 16 of the 17 contact binaries in the trans-Neptunian belt discovered with the light curve technique. All systems have been characterized, which means that we have obtained their rotational light curve and their surface colors. We estimate that the dynamically cold classical population (where Arrokoth is) has a deficit of contact binaries, but some mean motion resonances with Neptune have an excess of contact binaries. However, most of the contact binaries have a very red to ultra-red surface which is the typical color of the dynamically cold classical population. Therefore, it is possible that the contact binaries found so far originated in the dynamically cold classical population but managed to escape and are now trapped in different populations. Our next step will be to study how these systems can form and extend our survey to other populations in the trans-Neptunian belt.

FRONT COVER IMAGE: New Horizons images of its encounter with Arrokoth.

After several nights of observations with the LDT, we obtained the rotational light curve of the contact binary 2014 JQ80 (each night of observations has a different color).



THE LOWELL OBSERVER

As part of Lowell Observatory's efforts to stay connected and continue our mission of science education, we are providing video resources that include live streams, kids activities, observing tips, educational series, and much more. Visit **lowell.edu/youtube** for our latest videos.

Interactive Stargazing

Join Lowell Observatory educators at the Giovale Open Deck Observatory for a guided, interactive observing session. Weather-dependent.

Cosmic Coffee

Explores a different topic in astronomy or planetary science each week.

Sagas in the Sky

Explores some of the stories behind the stars in the night sky.

Mars Hill Almanac

Tune in to see what is happening in the night sky over the next month.

Meet an Astronomer

Meet some of Lowell's astronomers, and the occasional guest astronomer, and hear about their research.

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Keep kids engaged with STEM with these at-home science challenges. Find them on the LOCKs facebook page: facebook.com/orbitsscience

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125 YEARS | 1894 - 2019

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