BERKELEY
ASTRONOMY

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Astronomy in the News

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MILKY WAY'S CENTRAL BLACK HOLE PUTS EINSTEIN'S THEORIES TO THE TEST

June 20, 2019 - Bob Sanders, Media Relations

University of California astronomers have tested Albert Einstein's theories of relativity in the crucible of the monstrous black hole at the center of our Milky Way galaxy and found it rock solid. For now.

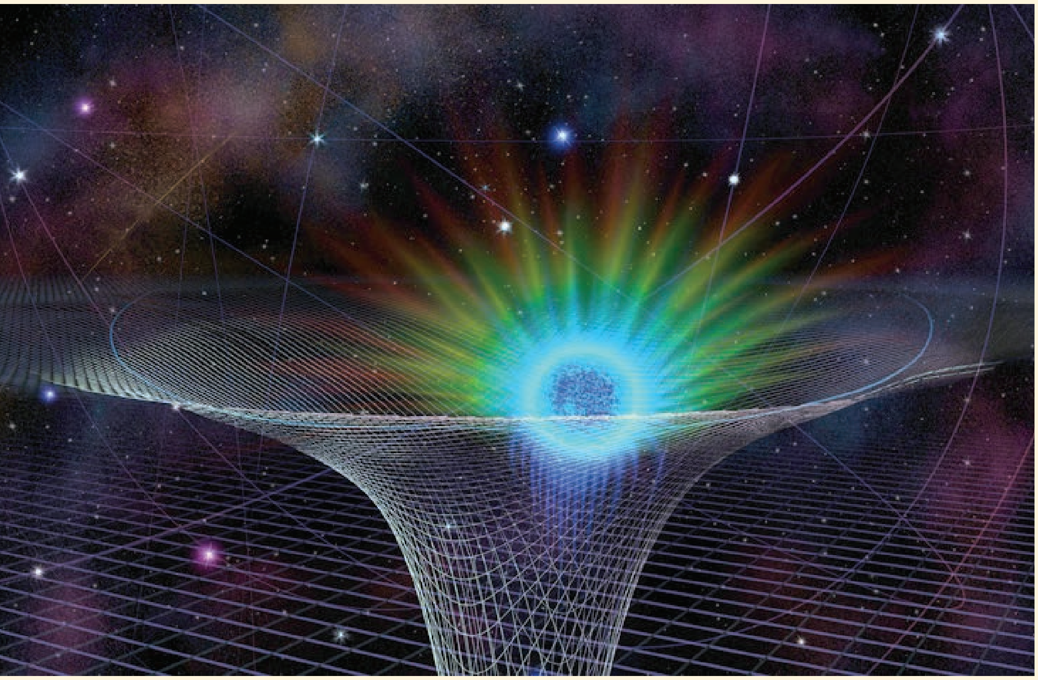
The team, led by UCLA astronomer Andrea Ghez, and with key analyses by UC Berkeley's **Jessica Lu**, an assistant professor of astronomy, followed a star orbiting so close to the black hole that the light it gives off is affected by the black hole's intense gravity. The effect, a gravitational redshift, matched exactly what Einstein's theories of special and general relativity predict.

"The measurement of gravitational redshift around a supermassive black hole is really the beginning of a new era of testing general relativity," said Lu, who began working with Ghez as a graduate student in 2003. "Our galactic center is a special place, a unique place, because we can study in detail the physics and astrophysics of a supermassive black hole. It is almost impossible to do that in any other galaxy."

General relativity, which treats gravity as a warping of space and time, has been validated within our solar system and in the interactions between pairs of dense, solar-mass neutron stars, or pulsars. But tests around extremely massive objects — the black hole at the center of the galaxy is the mass of 4 million suns — could reveal where general relativity fails to explain the universe and modifications are necessary.

"We know that, at some point, general relativity must break down, because it doesn't mesh with quantum mechanics, so it is just a constant hunt for where that breaking point is," Lu said.

"We can absolutely rule out Newton's law of gravity, (and) our observations are consistent with Einstein's theory of general relativity," said Ghez. "However, his theory is definitely showing vulnerability. It cannot fully explain gravity inside a black hole and, at some point, we will need to move beyond Einstein's theory to a more comprehensive theory of gravity that explains what a black hole is."



An artistic visualization of the star So-2 as it passes by the supermassive black hole at the galactic center, which has warped the geometry of space and time. As the star gets closer to the supermassive black hole, its light undergoes a gravitational redshift that is predicted by Einstein's general theory of relativity. (National Science Foundation graphic by Nicolle R. Fuller)

REDSHIFT, BLUESHIFT

Black holes are black because light emitted at the surface, or event horizon, cannot escape: It doesn't have enough energy. The light falls back and orbits the black hole before eventually disappearing inside, so all we see is black.

The UC team followed the star SO-2, which is far enough from the event horizon to still be visible. Nevertheless, the general theory of relativity says that the light it emits will lose energy and become redder by the time it reaches Earth, which is about 26,000 light years from the galactic center.

In addition, the special theory of relativity, which explains why people traveling at different speeds see time and space differently, says that the speed of the star will cause the light to be bluer when moving toward us and redder when moving away.

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The team, using 24 years of observations, saw both effects. When SO-2 got closest to the black hole — approximately 120 times the distance between Earth and our sun, or 120 astronomical units — the light lost about 0.03 percent of its energy while climbing out of the gravitational well of the black hole.

Also, at closest approach, when it was traveling at 16 million miles per hour — nearly 3 percent of the speed of light — the redshifts and blueshifts perfectly matched the predictions of special relativity. Because of general relativity, SO-2 was traveling 107 miles per hour faster than simple Newtonian gravity would predict, based on Isaac Newton's 17th century theory.

Similar results were reported a year ago by a competing team led by **Reinhard Genzel,** an astrophysicist at UC Berkeley and director of the Max Planck Institute for Extraterrestrial Physics in Germany. Those results came before three key events in the 16-year orbit of SO-2: its closest approach to the black hole, referred to as SagA* (found in the direction of the southern constellation Sagittarius); its fastest and most blue-shifted motion relative to Earth; and its slowest, most red-shifted motion relative to Earth.

The new results include these three events in the analysis, providing a better check on general relativity and making it the most detailed study ever conducted on supermassive black holes and Einstein's theory of general relativity.

"The star SO-2 is orbiting on a very eccentric orbit: At its farthest from SagA*, it's 16.5 times farther than its closest approach," Lu said. "It really dips in, whips around the black hole and then heads back out and hangs out far away for quite a while. That period where it passes through closest approach is very short, but very important to measure."

The measurements also provided a more accurate mass for the black hole at the center of the galaxy — 3.984 million times the mass of the sun — and pinpointed its distance at 7,971 parsecs (25,916 light years).

Lu led the team's astrometry group, which precisely measured the position in the sky of SO-2 relative to SagA* using the twin 10-meter telescopes at the Keck Observatories in Hawaii. Those telescopes are equipped with adaptive optics to remove blur from the atmosphere. Ghez and Do led the group that measured the red and blue shifts of light from SO-2. Together, these data provided the three-dimensional position of the star's orbit necessary to test relativity.

The team is eager to again put relativity to the test by astrometrically measuring the precession of the orbit of SO-2 — that is, a gradual rotation of the orbital plane predicted by general relativity. A key early test of relativity was its explanation for an anomaly in the precession of the orbit of Mercury, which turned out to be due to the warping of space-time by the sun's gravity.

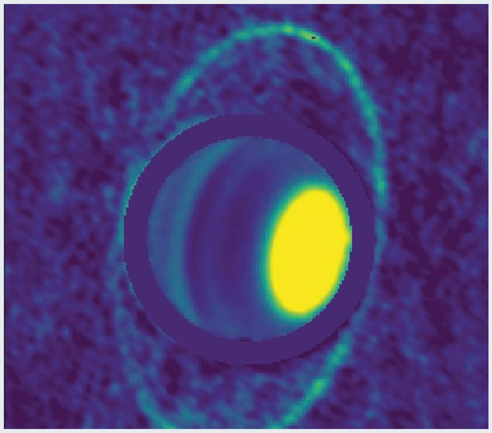
"The stars around SagA*, the supermassive black hole in our galaxy, should also show this orbital precession, just like Mercury," she said. "We have never measured that around a supermassive black hole before. It will be another probe of general relativity."

Co-authors with Lu, Ghez and Do are researchers from Japan, Germany, France, Spain and the United States. The National Science Foundation has supported the UCLA Galactic Center Group for the last 25 years, with additional funding from the W. M. Keck Foundation, Gordon and Betty Moore Foundation and Heising-Simons Foundation.

ASTRONOMERS SEE "WARM" GLOW OF URANUS'S RINGS

June 20, 2019 - Bob Sanders, Media Relations

The rings of Uranus are invisible to all but the largest telescopes — they weren't even discovered until 1977 — but they're surprisingly bright in new heat images of the planet taken by two large telescopes in the high deserts of Chile. The thermal glow gives astronomers another window onto the rings, which have been seen only because they reflect a little light in the visible, or optical, range and in the near infrared. The new images taken by the Atacama Large Millimeter/submillimeter Array (ALMA) and the Very Large Telescope (VLT) allowed the team for the first time to measure the temperature of the rings: a cool 77 Kelvin, or 77 degrees above absolute zero — the boiling temperature of liquid nitrogen and equivalent to 320 degrees below zero Fahrenheit. The observations also confirm that Uranus's brightest and densest ring, called the epsilon ring, differs from the other known ring systems within our solar system, in particular the spectacularly



Composite image of Uranus's atmosphere and rings at radio wavelengths, taken with the ALMA array in December 2017. The image shows thermal emission, or heat, from the rings of Uranus for the first time, enabling scientists to determine their temperature: a frigid 77 Kelvin (-320 F). Dark bands in Uranus's atmosphere at these wavelengths show the presence of molecules that absorb radio waves, in particular hydrogen sulfide gas. Bright regions like the north polar spot (yellow spot at right, because Uranus is tipped on its side) contain very few of these molecules. (UC Berkeley image by Edward Molter and Imke de Pater)

beautiful rings of Saturn. "Saturn's mainly icy rings are broad, bright and have a range of particle sizes, from micron-sized dust in the innermost D ring, to tens of meters in size in the main rings," said **Imke de Pater**, a UC Berkeley professor of astronomy. "The small end is missing in the main rings of Uranus; the brightest ring, epsilon, is composed of golf ball-sized and larger rocks." By comparison, Jupiter's rings contain mostly small, micron-sized particles (a micron is a thousandth of a millimeter). Neptune's rings are also mostly dust, and even Uranus has broad sheets of dust between its narrow main rings.

"We already know that the epsilon ring is a bit weird, because we don't see the smaller stuff," said graduate student **Edward Molter**. "Something has been sweeping the smaller stuff out, or it's all glomming together. We just don't know. This is a step toward understanding their composition and whether all of the rings came from the same source material, or are different for each ring." Rings could be former asteroids captured by the planet's gravity, remnants of moons that crashed into one another and shattered, the remains of moons torn apart when they got too close to Uranus, or debris remaining from the time of formation 4.5 billion years ago.

The new data were published this week in The Astronomical Journal. De Pater and Molter led the ALMA observations, while Michael Roman and Leigh Fletcher from the University of Leicester in the United Kingdom led the VLT observations. The Berkeley research was funded by the National Aeronautics and Space Administration.

TRACKING DOWN A STAR THAT DISAPPEARED 65 MILLION YEARS AGO

November 18, 2018 - Bob Sanders, Media Relations

Astronomers may finally have tracked down the type of star that explodes with a distinctive but unusual signature: They show no evidence of hydrogen and helium, by far the most abundant elements in the universe.

Such explosions have been labeled Type Ic supernovae, and make up some 20 percent of all stars that explode when their cores collapse. Most, however, have been observed at such large distances that astronomers could not pinpoint what was there before the explosion blew it to smithereens.

But a team that included UC Berkeley astronomer **Alex Filippenko** got lucky.

Last year, after a Type Ic supernova dubbed SN 2017ein was discovered by astronomers in Arizona, the group dove into past photos of that region of the sky taken by NASA's Hubble Space Telescope in search of its progenitor. In the archive from 2007, they found an image of a hot, bright blue object in the exact spot where the supernova was observed. It was located near the center of the relatively nearby spiral galaxy NGC 3938, roughly 65 million light years from Earth, which means the star exploded 65 million years ago.

Artist concept of a blue supergiant star that astronomers believe exploded as a Type Ic supernova detected by the Hubble Space Telescope in 2017.

Based on an assessment of the star by this and another team that discovered the same 2007 image, two possibilities exist for the source's identity. The progenitor could be a single hefty star between 45 and 55 times the mass of our sun that had earlier shed its hydrogen and helium, perhaps blown off in an intense stellar wind.

Alternatively, it could have been a massive binary-star system in which one of the stars weighed between 60 and 80 solar masses and the other roughly 48 suns. In this latter scenario, pre-explosion, the stars were orbiting closely and interacted with each other. The more massive star was stripped of its hydrogen and helium layers by the close companion, and eventually exploded as a supernova.

This potential link between massive stars and Type Ic supernovae could yield insight into stellar evolution, including how the masses of stars are distributed when they are born in batches.

"We finally found a good candidate for the massive star that goes boom," Filippenko said.

"Disentangling these two scenarios for producing Type Ic supernovas impacts our understanding of stellar evolution and star formation, including how the masses of stars are distributed when they are born, and how many stars form in interacting binary systems," explained team member Ori Fox of the Space Telescope Science Institute (STScI) in Baltimore, Maryland. "And those are questions that not just astronomers studying supernovas want to know, but all astronomers are after."

Financial support for Filippenko's research group at UC Berkeley was provided by NASA through a grant from the Space Telescope Science Institute, the National Science Foundation, TABASGO Foundation, Christopher R. Redlich Fund, and the Miller Institute for Basic Research in Science. Research at Lick Observatory is partially supported by a generous gift from Google and contributions from numerous individuals. A major upgrade of the Kast spectrograph on the Shane 3-meter telescope at Lick was made possible through generous gifts from the Heising-Simons Foundation as well as William and Marina Kast.

JUPITER-LIKE EXOPLANETS FOUND IN SWEET SPOT IN MOST PLANETARY SYSTEMS

June 12, 2019 - Robert Sanders, Media Relations

As planets form in the swirling gas and dust around young stars, there seems to be a sweet spot where most of the large, Jupiter-like gas giants congregate, centered around the orbit where Jupiter sits today in our own solar system.

The location of this sweet spot is between 3 and 10 times the distance Earth sits from our sun (3-10 astronomical units, or AU). Jupiter is 5.2 AU from our sun.

That's just one of the conclusions of an unprecedented analysis of 300 stars captured by the Gemini Planet Imager, or GPI, a sensitive infrared detector mounted on the 8-meter Gemini South telescope in Chile.

The GPI Exoplanet Survey, or GPIES, is one of two large projects that search for exoplanets directly, by blocking stars' light and photographing the planets themselves, instead of looking for telltale wobbles in the star — the radial velocity method — or for planets crossing in front of the star — the transit technique. The GPI camera is sensitive to the heat given off by recently-formed planets and brown dwarfs, which are more massive than gas giant planets, but still too small to ignite fusion and become stars.

The analysis of the first 300 of more than 500 stars surveyed by GPIES, published June 12 in the *The Astronomical Journal*, "is a milestone," said **Eugene Chiang**, a UC Berkeley professor of astronomy and member of the collaboration's theory group. "We now have excellent statistics for how frequently planets occur, their mass distribution and how far they are from their stars. It is the most comprehensive analysis I have seen in this field."

ONE NEW PLANET, ONE NEW BROWN DWARF

Since the GPIES survey began five years ago, the team has imaged six planets and three brown dwarfs orbiting these 300 stars. The team estimates that about 9 percent of massive stars have gas giants between 5 and 13 Jupiter masses beyond a distance of 10 AU, and fewer than 1 percent have brown dwarfs between 10 and 100 AU.

The new data set provides important insight into how and where massive objects form within planetary systems.

"As you go out from the central star, giant planets become more frequent. Around 3 to 10 AU, the occurrence rate peaks," Chiang said. "We know it peaks because the Kepler and radial velocity surveys find a rise in the rate, going from hot Jupiters very near the star to Jupiters at a few AU from the star. GPI has filled in the other end, going from 10 to 100 AU, and finding that the occurrence rate drops; the giant planets are more frequently found at 10 than 100. If you combine everything, there is a sweet spot for giant planet occurrence around 3 to 10 AU."

"With future observatories, particularly the Thirty-Meter Telescope and ambitious space-based missions, we will start imaging the planets residing in the sweet spot for sun-like stars," said team member **Paul Kalas**, a UC Berkeley adjunct professor of astronomy.

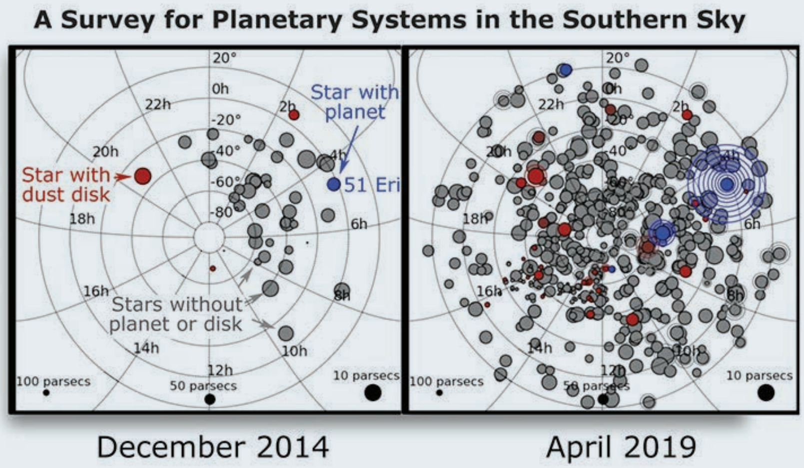
The exoplanet survey discovered only one previously unknown planet — 51 Eridani b, nearly three times the mass of Jupiter — and one previously unknown brown dwarf — HR 2562 B, weighing in at about 26 Jupiter masses. None of the giant planets imaged were around sun-like stars. Instead, giant gas planets were discovered only around more massive stars, at least 50 percent larger than our sun, or 1.5 solar masses.

"Given what we and other surveys have seen so far, our solar system doesn't look like other solar systems," said Bruce Macintosh, the principal investigator for GPI and a professor of physics at Stanford. "We don't have as many planets packed in as close to the sun as they do to their stars and we now have tentative evidence that another way in which we might be rare is having these kind of Jupiter-and-up planets."

"The fact that giant planets are more common around stars more massive than sun-like stars is an interesting puzzle," Chiang said.

Because many stars visible in the night sky are massive young stars called A stars, this means that "the stars you can see in the night sky with your eye are more likely to have Jupiter-mass planets around them than the fainter stars that you need a telescope to see," Kalas said. "That is kinda cool."

The analysis also shows that gas giant planets and brown dwarfs, while seemingly on a continuum of



Results of the survey of 531 stars and their exoplanets in the southern sky are plotted to indicate their distance from Earth (a parsec is 3.26 light years). Gray dots are stars without exoplanets or a dust disk; red dots are stars that have a dust disk but no planets; blue dots are stars that have planets. Dots with rings indicate stars imaged multiple times. (Image by Paul Kalas, UC Berkeley; Dmitry Savransky, Cornell; Robert De Rosa, Stanford.)

increasing mass, may be two distinct populations that formed in different ways. The gas giants, up to about 13 times the mass of Jupiter, appear to have formed by accretion of gas and dust onto smaller objects — from the bottom up. Brown dwarfs, between 13 and 80 Jupiter masses, formed like stars, by gravitational collapse — from the top down — within the same cloud of gas and dust that gave rise to the stars.

"I think this is the clearest evidence we have that these two groups of objects, planets and brown dwarfs, form differently," Chiang said. "They really are apples and oranges."

DIRECT IMAGING IS THE FUTURE

The Gemini Planet Imager can sharply image planets around distant stars, thanks to extreme adaptive optics, which rapidly detects turbulence in the atmosphere and reduces blurring by adjusting the shape of a flexible mirror. The instrument detects the heat of bodies still glowing from their own internal energy, such as exoplanets that are large, between 2 and 13 times the mass of Jupiter, and young, less than 100 million years old, compared to our sun's age of 4.6 billion years. Even though it blocks most of the light from the central star, the glare still limits GPI to seeing only planets and brown dwarfs far from the stars they orbit, between about 10 and 100 AU.

The team plans to analyze data on the remaining stars in the survey, hoping for greater insight into the most common types and sizes of planets and brown dwarfs.

Chiang noted that the success of GPIES shows that direct imaging will become increasingly important in the study of exoplanets, especially for understanding their formation.

"Direct imaging is the best way at getting at young planets," he said. "When young planets are forming, their young stars are too active, too jittery, for radial velocity or transit methods to work easily. But with direct imaging, seeing is believing."

Other UC Berkeley team members are postdoctoral fellows **Ian Czekala**, **Gaspard Duchêne**, **Thomas Esposito**, **Megan Ansdell** and **Rebecca Jensen-Clem**, professor of astronomy **James Graham** and undergraduates **Jonathan Lin**, **Meiji Nguyen** and **Yilun Ma**. Other team members include **Nielsen**, a former Berkeley undergraduate, **Franck Marchis**, a former assistant researcher, and **Marshall Perrin**, **Mike Fitzgerald**, **Jason Wang, Eve Lee** and **Lea Hirsch**, former graduate students.

The research was supported by the National Science Foundation (AST-1518332), National Aeronautics and Space Administration (NNX15AC89G) and the Nexus for Exoplanet System Science (NExSS), a research coordination network sponsored by NASA's Science Mission Directorate (NNX15AD95G).

URANUS AND NEPTUNE ARE MORE INTERESTING THAN WE THOUGHT, NEW IMAGES SHOW

February 7, 2019 - Robert Sanders, Media Relations

NASA's Hubble Space Telescope has snapped the latest weather pictures of our solar system's frigid outer planets, and UC Berkeley astronomers have jumped in to interpret them.

The new images, taken as part of a yearly monitoring program, show that a dark storm has appeared in Neptune's northern hemisphere, the fourth seen on the planet since 1993, all of which appear and fade within a few years. UC Berkeley undergraduate student **Andrew Hsu**, who led a study of the latest images with associate research astronomer **Michael Wong**, estimates that the dark spots appear every four to six years at different latitudes and disappear after about two years.

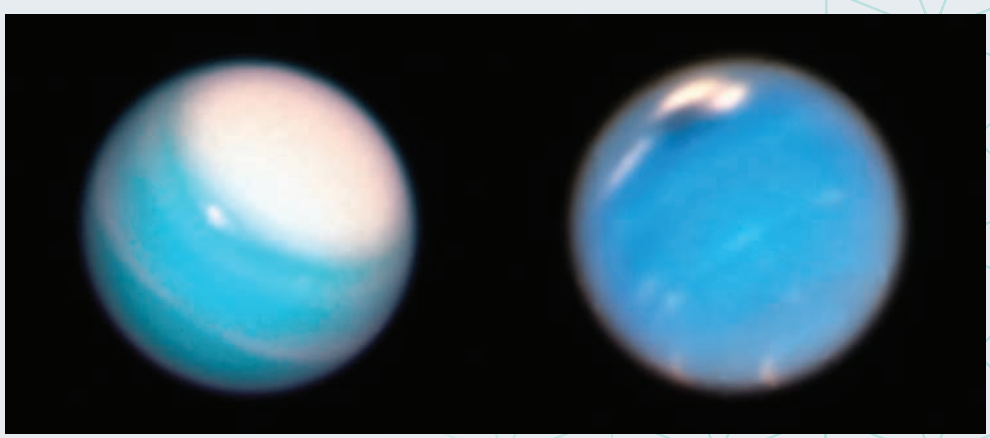
It's unclear how the storms form, Hsu said, but like Jupiter's Great Red Spot, the dark vortices swirl in an anti-cyclonic direction and seem to dredge up material from deeper levels in the ice giant's atmosphere. The latest storm was captured by Hubble in September 2018 and is roughly 6,800 miles across.

The Hubble observations show that increased cloud activity in the region as early as 2016 preceded the vortex's appearance. The images indicate that the vortices probably develop deeper in Neptune's atmosphere, becoming visible only when the top of the storm reaches higher altitudes.

The new snapshot of Uranus gives a fresh look at a long-lived storm circling around the north-pole region of Uranus, a planet that is usually thought of as featureless and boring.

Scientists believe that the polar cap is a result of Uranus' unique rotation. Unlike every other planet in the solar system, Uranus is tipped onto its side. Because of this extreme tilt, during the planet's summer the sun shines almost directly onto the north pole and never sets. Uranus is now approaching the middle of its summer season, and the polar-cap region is becoming more prominent. This polar hood may have formed by seasonal changes in atmospheric flow.

Both Neptune, the outermost planet, and Uranus are classified as ice giants. They have no solid surface. Rather, deep mantles of hydrogen and helium surround a water-rich interior, itself perhaps wrapped around a rocky core. Atmospheric methane absorbs red light but allows blue-green light to be scattered back into space, giving each planet a cyan hue.

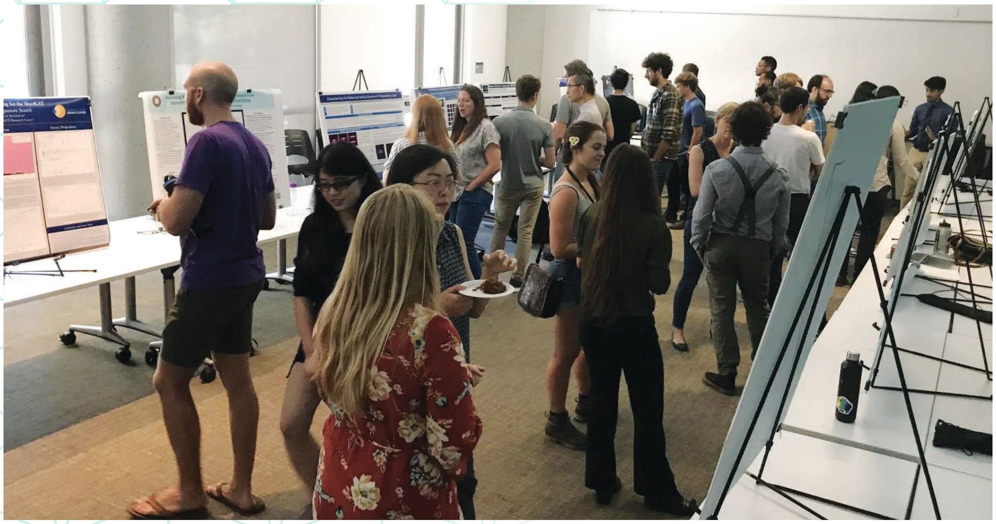


Uranus (left) sports a prominent ice cap in recent Hubble Space Telescope photos, while Neptune (right) hosts a dark storm. (Uranus image by NASA, ESA and A. Simon/NASA Goddard Space Flight Center; Neptune photo by Mike Wong and Andrew Hsu, UC Berkeley)

Undergraduate Spotlight: Fourth Annual APSIS!

The fourth annual APSIS (Astronomy Poster Summer Intern Symposium) took place on August 16 at the end of the 10-week summer session. Thirteen students participated - both UC Berkeley undergraduates, and students from other universities across the US, working on research programs with members of the department during the summer. A wide range of research was presented and many lively and interesting conversations took place during the event.

Three judges from the department scored the posters and presenters on clarity of presentation and quality of research. Three prizes (sponsored by Breakthrough Listen) were ultimately awarded. First prize went to Arjun Savel (UCB), working with Professor Courtney Dressing on high resolution imaging of stars to try to find companions. Second prize went to Cameron Nuñez (Columbia), working with Howard Isaacson to model absorption features in spectra



First prize winner Arjun Savel and Researcher Steve Croft

from the Automated Planet Finder. Third prize went to Karen Perez (Cornell), working with Dr. Vishal Gajjar to search for pulsars and potential SETI candidates in the Galactic Center. We're excited to see such fantastic research taking place and to work with enthusiastic and capable young people who are just starting their careers in astronomy!

News and Noteworthy

Dan Weisz honored for research on smallest galaxies in the universe

Professor Dan Weisz was awarded the 2019 Lacy Pierce Prize by the American Astronomical Society for his early-career research on relatively nearby "dwarf" galaxies using the Hubble Space Telescope. Dr. Weisz came to UC Berkeley in the summer of 2016 and focuses on stars, dark matter and galaxies near Earth – particularly the Local Group of galaxies that includes some 100 mostly small galaxies surrounding the two heavies, our own Milky Way and Andromeda. Weisz is looking forward to taking the first observations of the local universe with the James Webb Space Telescope, the successor to Hubble that is scheduled for launch in 2021.

Courtney Dressing is a 2019 Hellman Fellow
Assistant Professor Courtney Dressing has been awarded a 2019 Hellman Fellowship for her proposed research, Characterizing Planetary Systems Orbiting Nearby Stars.

She is an observational astronomer focused on detecting and characterizing planetary systems orbiting nearby stars. Her Hellman-funded research will set the foundations for future detections of life as well as advance understanding of how planetary systems form and evolve over time by investigating the properties of nearby planets.

Established by the late F. Warren and Chris Hellman in 1995, the Hellman Fellows Fund supports the research of promising assistant professors who show capacity for great distinction in their research.

Courtney Dressing was also among this year's winners of **Packard Fellowships for Science and Engineering,** announced on October 15th. The Dressing Group, using ground and space-based telescopes, is working to advance the search for life on planets orbiting nearby stars and researching their characteristics and suitability for life.

2019 Noyce Prize for Excellence in Undergraduate Teaching in the Physics Sciences awarded to Professor Eugene Chiang. The prize is awarded annually to a faculty member in the physical sciences who has demonstrated excellence in undergraduate teaching, including curriculum development.

Eugene Chiang was also elected in 2019 to the American Academy of Arts and Science. The AAAS is a prestigious research center that brings together leaders across several sectors to address complex challenges.

In June 2019, through a highly competitive peer-review process, an international team lead by Berkeley Assistant Professor **Dan Weisz** was awarded 244 orbits with the Hubble Space Telescope to measure the star formation and orbital histories of all satellite galaxies that orbit our nearest massive neighboring galaxy, Andromeda. This program, called "Tracing the 6-D Orbital and Formation History of the Complete M31 Satellite System," is the largest Hubble program aimed at low-mass satellite galaxies in the local Universe. Because of the large size of the program, observations will be taken over a 2 year period starting in late 2019 through mid-2021.

Faculty Retirements: Professor Imke de Pater joined Berkeley Astronomy in 1993 and retired in June 2019. As Professor Emerita and Professor of the Graduate School, de Pater will continue conducting research on adaptive optics, radio observations of the giant planets and their rings and satellites. Professor James Graham joined Berkeley Astronomy in 1992 and retired in June 2019. Professor Graham continues to conduct research on adaptive optics and infrared instrumentation as Professor Emeritus and Professor of the Graduate School.

Message from the Chair

After a fantastic sabbatical, split between Princeton and Caltech, I am energized and honored to assume the role of department chair. This year continues a period of transition in the department, with former chairs, Imke de Pater and James Graham, both retiring. At the same time, our newest faculty members, Courtney Dressing, Jessica Lu, and Dan Weisz, are playing ever-larger roles in the department, shaping both its climate and its intellectual direction. And our new department manager, Maria Kies, and Associate Director of Student Services Amber Banayat, are helping steer the department and mentor our ever-growing student population—90 undergraduates at last count!

Scientifically, this has been another banner year. Jessica Lu and colleagues, and separately Reinhard Genzel and colleagues, measured the mass of the black hole at the center of our galaxy to ever greater precision, and tested Einstein's theory of relativity in this environment for the first time. Spoiler: Einstein was right! Josh Bloom combined astronomy and machine learning in novel ways to find and study variable stars and stellar explosions. He also keeps reminding University officials that astronomy basically invented big data. The Event Horizon Telescope (EHT) image of a black hole released this spring is one of the most downloaded images in history. Our former chair Don Backer played a critical role in initiating this work and research staff members Dick Plambeck and Mel Wright were important members of the EHT team.

I would like to use this opportunity to recognize some of my colleagues for their honors in the past year. Dan Weisz received the Pierce Prize from the American Astronomical Society for his studies of the smallest galaxies, Courtney Dressing was awarded the Sloan and Packard Fellowships for her work on planets around other stars, and former chair Eugene Chiang (remember him?) was elected to the American Academy of Arts and Sciences.

We continue to thrive in New Campbell Hall and relish the opportunity to share Astronomy with undergraduates, graduate students, and the public alike. We hope that you will be able to join us at one of our many public events, from Astro Night to CalDay.

-Eliot Quataert, Chair
Department of Astronomy

2018-2019 Commencement Information

The future of Astronomy at Berkeley is held by the next generation of students who will come from around the world in pursuit of academic excellence. Their capacity to explore, innovate, and discover will continue to be limitless!

PHD DEGREES – SPRING 2019

Carina Cheng
Advisor – Aaron Parsons
"Methods for the Detection of the Epoch of Reionization"

Joshua Tollefson (**Earth and Planetary Sciences**)
Advisor - Imke de Pater
"Unraveling Neptune's Atmospheric Structure from Multi-Wavelength Observations"

Sean Ressler (**Physics**)
Advisor - Eliot Quataert
"Towards More Predictive Numerical Models of Galactic Center Accretion"

Yunfan Gerry Zhang
Advisor – Imke de Pater
"Modern Methods of Radio Astronomy Signal Detection with Case Studies in Epoch of Reionization, Fast Radio Bursts and Search for Extraterrestrial Intelligence"

2018-19 GRADUATE AWARDS

Mary Elizabeth Uhl Prize For outstanding scholarly achievement by a graduate student close to finishing his/her dissertation in Astronomy or in Physics with preference to Astronomy.
Sean Ressler

Robert J. Trumpler Award In recognition of academic excellence and outstanding record of involvement in the department or wider astronomical community. Anyone post-qual is eligible.
Wren Suess and **Tom Zick**

OUTSTANDING GRADUATE STUDENT INSTRUCTOR AWARD

Philip Kempski, Casey Lam, and **Nathan Sandford**

Special Recognition for Outstanding Teaching of Astronomy
Deepthi Gorthi

2018-19 UNDERGRADUATE AWARDS

Commencement Speaker
Nick Choksi

Department Citation For outstanding scholarship. The recipient of this award needs to have maintained a grade point average of 3.5 in the department.
Jose Nijaid Arredondo

Dorothea Klumpke Roberts Prize For outstanding scholarly achievement.
Melissa S. Carlson and Costas Q. Soler

Daniel Wark Award For astrophysics majors in excellent academic standing.
Oscar A. Chavez Ortiz

STUDENT SERVICES SPOTLIGHT

In summer of 2018, the department welcomed new Associate Director of Student Services, **Amber Banayat,** who spent her first year augmenting services to both the undergraduate and graduate degree programs. Highlights over the past year include: building out a network of resources and support for incoming transfer students, coordinating with high school counselors and community college instructors to introduce Berkeley astronomy to budding scientists, and ramping up alumni activities to create opportunities for students pursuing a degree in astrophyiscs. It's an exciting time of growth for our student support unit and we are excited to offer new ways for students to network and pursue research in their fields of study!

NEW RESEARCH FELLOWS

51 Pegasi B Fellow
The astronomy department is pleased to welcome **Cheng Li**, a 2019 recipient of the Heising-Simons Foundation's 51 Pegasi b Postdoctoral Fellowship. Cheng joined UC Berkeley this fall, after completing a NASA postdoctoral fellowship at the Jet Propulsion Laboratory, and will use information recently collected from the Juno mission to challenge and refine theories about the atmospheres of giant planets. His work will include profiling exotic cloud-forming materials on distant worlds to better understand their formation, distribution, and dissipation. He joins three other Heising-Simons fellows currently in the department, **Peter Gao, Marta Bryan,** and **Sivan Ginzburg.**

Recipients of the fellowship are recognized for their outstanding research achievements, their creativity, and their great promise in tackling risky and novel ideas.

Miller Fellow
Astronomy welcomes new Miller Fellow **Ekta Patel**. Prior to joining UC Berkeley, Ekta received her PhD at the University of Arizona in 2019, where she focused on modeling the dynamics of satellite galaxies around the Milky Way. Ekta will be extending her theoretical studies to include new information from Gaia and is also working to reconstruct the orbital histories of dozens of satellite galaxies around Andromeda, the sibling galaxy of our Milky Way.

Hubble Fellow
New Hubble Fellow, **Anna McLeod,** has joined Berkeley Astronomy. Anna previously held a joint postdoctoral position at UC Berkeley and Texas Tech University in which she studied how energy output from the most massive stars influences their immediate surroundings. As a Hubble Fellow, Anna is leading several surveys of nearby galaxies using integral field spectrographs to link together how star formation on small scales can affect galaxy formation on larger scales.

The Distinguished Lecture in Astronomy at UC Berkeley: From Spinning Black Holes to Exploding Stars— New Views on the Energetic Universe

The 2019 Distinguished Lecture in Astronomy was given by Dr. Fiona Harrison, Benjamin M. Rosen Professor of Physics and Kent and Joyce Kresa Leadership Chair, Division of Physics, Mathematics, and Astronomy at Caltech.

In her talk, Dr. Harrison discussed using space-based telescopes that image the cosmos in high energy radiation to explore the densest, hottest, and most energetic regions in the Universe. Dr. Harrison covered in great detail how these observatories are aiding in understanding how black holes grow, how the elements that make up life are forged in extreme environments, and how matter behaves in conditions beyond any we can create on Earth. During the lecture, she spoke on how exploring the universe in X-rays, and how these new observations are shedding light on the way energetic processes shape objects - both familiar and exotic.

Dr. Harrison's research is divided between developing new optics and detectors for high energy astrophysics, and using current NASA missions (Chandra, Swift, XMM and Fermi) combined with Caltech's optical telescopes (Palomar and Keck) to study energetic phenomena ranging from gamma-ray bursts, black holes on all mass scales, to neutron stars and supernovae. Currently most of her effort is concentrated on the Nuclear Spectroscopic Telescope Array (NuSTAR), which will be the first focusing telescope to view the Universe in the high energy X-ray band. As Principal Investigator, she is working with the Jet Propulsion Laboratory and an international team to build the telescope, launch it into orbit, and plan, execute, understand and publish the scientific results from the mission.

Welcome to our Newest Class of Graduate Students!

Sergiy Vasylyev (**Physics, UC Santa Barbara**) AS an undergraduate, Mr. Vasylyev contributed to one of the discoveries of the optical counterpart of the binary neutron-star merger GW 170817. He is interested in observational time-domain astronomy involving supernovae, kilonovae, gamma ray bursts, gravitational waves, and tidal disruption events.

Brian Lorenz (**Pomona College**) During his undergraduate studies, Mr. Lorenz was very involved in outreach, leading a program called Science Bus, which brought astronomy education to low-income K-12 schools in the LA area. He was awarded an NSF graduate fellowship in 2019 and is interested in galaxy evolution.

Aliza Beverage (**Physics + Astronomy, University of Minnesota**) As a student, Ms. Beverage undertook a variety of research experiences including looking at the effects of galaxy mergers on quenching, using the WFC3 grism to study massive galaxies, and making predictions for EUCLID in the local Universe.

Nick Choksi (**Physics + Astrophysics, UC Berkeley**) While an undergraduate, Mr. Choksi was the department student rep and an organizer of the AstroJustice group. He is interested in galaxy formation and dynamics from a theoretical point of view, globular clusters, dynamics, and connections to host galaxies, and supermassive black holes.

Emily Ramey (**Washington University, St. Louis**) As a student, Ms. Ramey participated in undergraduate research in physics and astronomy with an emphasis on computational and radio astronomy. She was awarded an NSF graduate fellowship in 2018.

Wanying Fu (**Physics, Cal Poly - Pomona**) is interested in APOGEE data of MW stars and stellar spectroscopy in Local Group dwarf galaxies. As an undergraduate, Ms. Fu was a mentor to younger URM undergraduates in physics at Pomona. She also was involved with the Femineers program, designed for high-achieving female high school students.

Maude Gull (**Mathematics + Physics, MIT**) is interested in span metal-poor stars, cosmic inflation, and planet detection via radial velocity. Ms. Gull is committed to mentoring junior scientists and improving representation of minorities in STEM. As an undergraduate, she assisted with the annual pre-orientation program for the MIT Physics Department and served as a mentor through the Undergraduate Women in Physics and the McCormick Big Sister programs.

Massimo Pascale (**University of Arizona**) While an undergraduate, Mr. Pascale identified new lensing arclet families for a cluster that has now been approved for JWST observations to search for high-z lensed galaxies. He also founded a peer mentoring program after he saw retention in the astrophysics major at UA was low. He is interested in computational astrophysics, gravitational lens modeling of cluster galaxies, and computational projects in cosmology.

Emma Turtelboom (**Physics, MIT**) As an undergraduate, Ms. Turtelboom worked to probe the spectral properties of near-Earth asteroids. She was a member of the Undergraduate Women in Physics group and helped members of her fraternity who were not native English speakers to improve their essays and job applications.

Getting To Know Astro!

A Q&A with Graduate Student, Kareem El-Badry

As a graduate student, what is your research focus? Can you describe what this means for a wider audience? What drew you to this area of study?

When I started graduate school, I worked mostly on simulations of galaxy formation. These are theoretical calculations that take an initial condition just after the Big Bang and solve the equations of gravity and gas dynamics to predict how galaxies should form and evolve. The whole Universe in a computer!

During grad school, I've started working more on problems in stellar physics, especially related to binary stars. There has been an explosion of data from industrial-scale astronomical surveys in recent years that made this field irresistible: it's like we've taken off a blindfold and our Galaxy is coming into view for the first time. This ends up connecting back to my galaxy formation work, because binary stars evolve differently from single stars and can change how galaxies evolve.

If you weren't a graduate student in Astrophysics, what would you choose to be?

I've occasionally thought I should be working on climate science. A lot of the gas physics we use to model stars and galaxies carries over to the Earth's atmosphere, and obviously the impact of this kind of work is a bit closer to home. A bit farther afield from my current work, I spent the first couple years of college studying philosophy. Maybe if I switched from astronomy to climate science, I could use this philosophy background to make peace with policymakers ignoring my recommendations.

What are some of your favorite past times/hobbies outside of Astronomy?

I really like food: cooking new (vegetarian) dishes, trying interesting restaurants in the Bay Area, and exploring different cuisines when traveling. I spend a fair amount of time reading terms and conditions to credit card and frequent flyer rewards programs to travel the world for free. I also enjoy many kinds of outdoor activities, such as hiking, running, cycling, and playing tennis.

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UPCOMING EVENTS

Evening with the Stars
Spring 2020

Cal Day
April 18, 2020

Astro Night Public Lecture and Star Viewing
April 2020
(first Thursday of each month)

Commencement
May 17, 2020

Newsletter Credits:
Robert Sanders, Lochland Trotter, Eliot Quataert, Steve Croft

Supporting Astronomy

Student Observatory Fund The Student Observatory Fund assists with the purchase and maintenance of the latest instrumentation and teaching observatories managed by the Astronomy Department. The fund also provides support for the department's upper-division undergraduate laboratory course - the capstone experience for all astronomy majors.

Friends of Astronomy Fund A discretionary fund that directly supports all facets of the department operating budget. From research travel for students, to recruitment of top faculty, to the day to day supply needs of the classrooms and teaching labs.

Graduate Student Support Fund Funding for fellowships is a top priority in the department, as a full year fellowship can cost more than $40,000 and will only continue to increase. Offering student support is one of our best tools for attracting the brightest and most promising students.

Gifts to any of these funds can be directed to: https://give.berkeley.edu/#astronomy

Thank you for your supporting the future of Berkeley Astronomy!
Many employers will match your gifts to UC Berkeley. To discuss matching or other opportunities to support Astronomy at Berkeley, contact Maria Hjelm, Assistant Dean of Development and College Relations, mhjelm@berkeley.edu.

GO BEARS!

NEW GIVING OPPORTUNITY – SUPPORTING OUR GRADUATE STUDENTS

On behalf of the faculty, students, and staff we extend our greatest thanks to our friends and donors for helping to preserve and enhance the teaching, scholarship, and research excellence of the Berkeley Astronomy Department.

Berkeley Astronomy is home to world-renowned scientists and researchers and is universally regarded as one of the top astronomy departments in the world. Our award winning faculty and outstanding students are engaged in some of the most fascinating research today – from studying the relationship between planets and moons in our solar system, to discovering new planets, galaxies, and black holes, to creating a road map for exploring the structure of the Universe.

One of the top priorities for the Astronomy Department, and the Division of Mathematical and Physical Sciences, is advancing our recruitment efforts to attract the best and most promising graduate students.

As a friend of the department, you already know the important role private funding plays in supporting our endeavors toward excellence. Increasingly, the Astronomy Department relies on the generosity of our alumni and friends to maintain our mission of award-winning teaching and research. Without the support of our extended family, we would be unable to maintain our standard of providing the best resources for our students. To help us strengthen the critical financial support that enables young scientists to select Berkeley for their studies, there is a new and much needed opportunity to aid in recruiting the brightest students and allow them to thrive as they embark on their futures at Berkeley -– the Graduate Giving Society.

We invite you to connect with Maria Hjelm, Assistant Dean of Development and College Relations, 510-642-5979, to learn more about how you can make a gift to the Department of Astronomy and the Graduate Giving Society.