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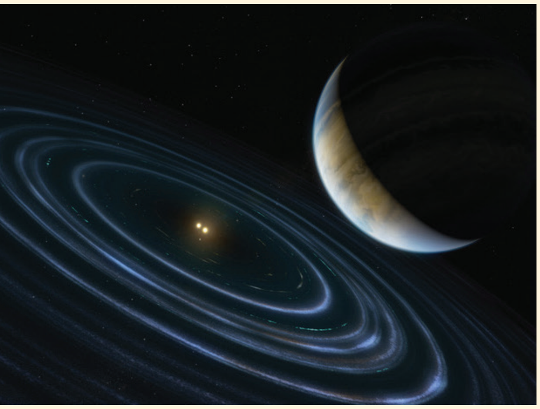
Astronomy in the News

EXOPLANET AROUND DISTANT STAR RESEMBLES OUR REPUTED 'PLANET NINE'

December 10, 2020 – By Robert Sanders | Media Relations | rlsanders@berkeley.edu

Astronomers are still searching for a hypothetical "Planet Nine" in the distant reaches of our solar system, but an exoplanet 336 light years from Earth is looking more and more like the Planet Nine of its star system.

Planet Nine, potentially 10 times the size of Earth and orbiting far beyond Neptune in a highly eccentric orbit about the sun, was proposed in 2012 to explain perturbations in the orbits of dwarf planets just beyond Neptune's orbit, so-called detached Kuiper Belt objects. It has yet to be found, if it exists.



Artist's impression of the exoplanet HD 106906 b located a great distance away from the central binary star and the disk of dusty material that surrounds it (Credit: ESA/Hubble, M. Kornmesser).

A similarly weird extrasolar planet was discovered far from the star HD 106906 in 2013, the only such wide-separation planet known. While much heavier than the predicted mass of Planet Nine — perhaps 11 times the mass of Jupiter, or 3,500 times the mass of Earth — it also had a very unexpected location, sitting far above the dust plane of the planetary system, tilted at an angle of about 21 degrees.

The big question until now has been whether the planet, called HD 106906 b, is in an orbit perpetually bound to the binary star—which is a mere 15 million years old compared to the 4.5 billion-year age of our sun—or is on its way out of the planetary system, never to return.

In a paper appearing Dec. 10 in The Astronomical Journal, astronomers finally answer that question. By precisely tracking the planet's position over 14 years, they determined that it is likely bound to the star in a 15,000-year, highly eccentric orbit, making it a distant cousin of Planet Nine.

If it is in a highly eccentric orbit around the binary, "This raises the question of how did these planets get out there to such large separations," according to Meiji Nguyen, a UC Berkeley graduate and first author of the paper. "Were they scattered from the inner solar system? Or, did they form out there?"

According to senior author Paul Kalas, UC Berkeley adjunct professor of astronomy, the resemblance to the orbit of the proposed Planet Nine shows that such distant planets can really exist and that they may form within the first tens of millions of years of a star's life. And based on the team's other recent discoveries about HD 106906, such planets seem to favor a scenario where passing stars also play a role.

"Something happens very early that starts kicking planets and comets outward, and then you have passing stars that stabilize their orbits," he said. "We are slowly accumulating the evidence needed to understand the diversity of extrasolar planets and how that relates to the puzzling aspects of our own solar system."

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150 Years of Women at Berkeley

October 3, 2020 marked the 150th anniversary of the UC Regents' unanimous approval of a resolution by Regent Samuel F. Butterworth: "That young ladies be admitted into the University on equal terms in all respects with young men." The first women were admitted in 1872, and Rosa Scrivner became the first woman graduate in 1874, earning a Bachelor's degree in Agriculture.

Since then, numerous women have graduated from UC Berkeley. Many more staff, faculty, and community members have made invaluable contributions to our campus and the world beyond. An archive documenting this important historical information on the last 150 years of the university is shared at www.150w.berkeley.edu/home.

Among the first two women to earn a PhD in astronomy at Berkeley, both awarded in 1914, was Phoebe Waterman Haas (1883–1975). She graduated from Vassar College with a BS and MS in astronomy and worked as an astronomer before being accepted to Berkeley's graduate program. Her thesis title was "The Visual Region of the Spectrum of the Brighter Class A Stars." Waterman is believed to be the first woman astronomer to conduct her own telescopic research and not rely on the observations of others. She studied at the Lick Observatory near San Jose. Despite her productivity as an independent scholar, Phoebe Waterman never attained a faculty position. (Excerpt from "Women Pioneers in STEM" essay by Sheila Humphreys)

Fast forward 69 years, now Professor Emerita and Professor of the Graduate School, Imke de Pater was the first woman appointed on the Astronomy Faculty, where she quickly advanced through the ranks from Assistant to Full Professor, and finally to "Above Scale," a rank that is reserved for only the top scientists. She served as the chair of the Astronomy Department from 2010–2015, while she oversaw the building of our present "new" Campbell Hall. We asked Professor de Pater to reflect on her time at Berkeley and her current research.

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A YOUNG, DUSTY STAR WITH A WEIRD PLANET

HD 106906 is a binary star system located in the direction of the constellation Crux. Astronomers have studied it extensively for the past 15 years because of its prominent disk of dust, which could be birthing planets. Our solar system may have looked like HD 106906 about 4.5 billion years ago as the planets formed in the swirling disk of debris left over from the formation of the sun.

Surprisingly, images of the star taken in 2013 by the Magellan Telescopes in Chile revealed a planet glowing from its own internal heat and sitting at an unusually large distance from the binary: 737 times farther from the binary than Earth is from the sun (737 astronomical units, or AU). That's 25 times farther from the star than Neptune is from the sun.

Kalas, whose main interest is searching for planets and dust disks around young stars, co-led a team that used the Gemini Planet Imager on the Gemini South Telescope to obtain the first images of the star's debris disk. In 2015, these observations provided evidence for theorists to propose that the planet formed close to the binary star and was kicked out because of gravitational interactions with the binary. The evidence: the stars' outer dust disk and inner comet belt are lopsided, suggesting that something — the planet — perturbed their symmetry.

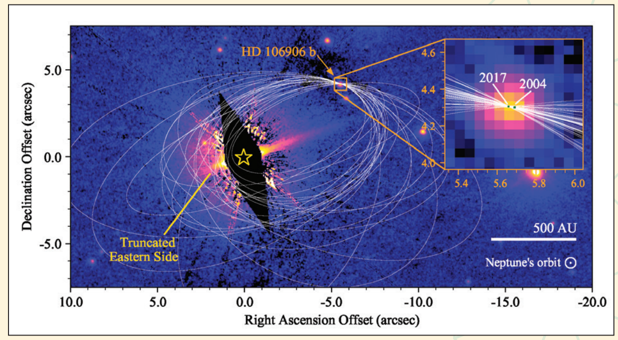
"The idea is that every time the planet comes to its closest approach to the binary star, it stirs up the material in the disk," said team member Robert De Rosa of the European Southern Observatory in Santiago, Chile, who is a former UC Berkeley postdoctoral fellow. "So every time the planet comes through, it truncates the disk and pushes it up on one side. This scenario has been tested with simulations of this system with the planet on a similar orbit — this was before we knew what the orbit of the planet was."

The problem, as pointed out by those simulating such planet interactions, is that a planet would normally be kicked out of the system entirely, becoming a rogue planet. Some other interaction, perhaps with a passing star, would be necessary to stabilize the orbit of an eccentric planet like HD 106906 b.

A similar scenario has been proposed for the formation of Planet Nine: that its interaction with our giant planets early in our solar system's history kicked it out of the inner solar system, after which passing stars in our local cluster stabilized its orbit.

Kalas went looking for such a fly-by star for HD 106906 b, and last year he and De Rosa, then at Stanford University, reported finding several nearby stars that would have zipped by the planetary system 3 million years earlier, perhaps providing the nudge needed to stabilize the planet's orbit.

Now, with precise measurements of the planet's orbit between 2004 and 2018, Nguyen, de Rosa and Kalas present evidence that the planet is most likely in a stable but very elliptical orbit around its binary star.



A Hubble Space Telescope optical image of HD 106906 taken in 2017. A black mask blocks light from the bright binary star, revealing the system's asymmetric dusty debris disk, and the gas giant exoplanet HD 106906 b located above the disk plane to the upper right. For the first time Nguyen, De Rosa and Kalas (2020) detected orbital motion for the planet, which moves counterclockwise (inset). The white ellipses represent possible orbits and for comparison the size of Neptune's 30 au orbit is shown beneath the scale bar. Like the hypothetical Planet Nine, the orbit of HD 106906 b is detached from an inner planetary system yet may be distorting the shape of the outer debris disk."

"Though it's only been 14 years of observations, we were still able to, surprisingly, get a constraint on the orbit for the first time, confirming our suspicion that it was very misaligned and also that the planet is on an approximately 15,000-year orbit," Nguyen said. "The fact that our results are consistent with predictions is, I think, a strong piece of evidence that this planet is indeed bound. In the future, a radial velocity measurement is needed to confirm our findings."

The science team's orbital measurements came from comparing astrometric data from the European Space Agency's Gaia observatory, which accurately maps the positions of billions of stars, and images from the Hubble Space Telescope. Because Hubble must obscure the binary star to see the debris disk, astronomers were unable to determine the exact position of the star relative to HD 106906 b. Gaia data allowed the team to determine the binary's position more precisely, and thus chart the movement of the planet relative to the binary between 2004 and 2018, less than one-thousandth of its orbital period.

"We can harness the extremely precise astrometry from Gaia to infer where the primary star should be in our Hubble images, and then measuring the position of the companion is rather trivial," Nguyen said.

In addition to confirming the planet's 15,000-year orbit, the team found that the orbit is actually tilted much more severely to the plane of the disk: between 36 and 44 degrees. At its closest approach to the binary, its elliptical orbit would take it no closer than about 500 AU from the stars, implying that it has no effect on inner planets also suspected to be part of the system. That is also the case with Planet Nine, which has no observed effect on any of the sun's eight planets.

"What I really think makes HD 106906 unique is that it is the only exoplanet that we know that is directly imaged, surrounded by a debris disk, misaligned relative to its system, and is widely separated,' Nguyen said. "This is what makes it the sole candidate we have found thus far whose orbit is analogous to the hypothetical Planet Nine."

The work was supported by the National Science Foundation (AST-1518332) and National Aeronautics and Space Administration (NNX15AC89G, NNX15AD95G, NAS5-26555). This work benefited from NASA's Nexus for Exoplanet System Science (NExSS) research coordination network sponsored by NASA's Science Mission Directorate.

News and Noteworthy

Reinhard Genzel, a professor emeritus of physics and of astronomy at the University of California, Berkeley, and director of the Max Planck Institute for Extraterrestrial Physics in Garching, Germany, will share half the 2020 Nobel Prize in Physics with UCLA professor Andrea Ghez "for the discovery of a supermassive compact object at the center of our galaxy."

The other half of the prize goes to United Kingdom theoretical physicist Roger Penrose "for the discovery that black hole formation is a robust prediction of the general theory of relativity."

Professor Chung-Pei Ma, the Judy Chandler Webb Professor in the Physical Sciences in the departments of astronomy and physics, has been elected to the American Academy of Arts and Sciences (AAAS). Ma is a cosmologist and astrophysicist who studies dark matter and dark energy, the cosmic microwave background, gravitational lensing, galaxy formation and evolution, supermassive black holes and the large-scale structure of the universe.

Chung-Pei Ma by Elena Zhukova

Professor of Astronomy and Department Chair for the academic year 2019-20 **Eliot Quataert** has been elected to the National Academy of Sciences (NAS). Quataert is a theoretical astrophysicist who specializes in compact objects, galaxy formation and plasma astrophysics.

Professor **Alex Filippenko's** interview with Lex Fridman had a quarter million views within the first seven days! You can watch it too; just log on to our website (astro.berkeley.edu) and look for News & Events and choose Selected Talks.

UC BERKELEY PLAYED BIG ROLE IN REINHARD GENZEL'S NOBEL PRIZE-WINNING WORK

October 2, 2020 – By Robert Sanders | Media Relations | rlsanders@berkeley.edu

Huge leaps in technology allowed Reinhard Genzel to probe stars zipping around the center of the Milky Way galaxy 25,000 light years away, eventually earning him a portion of today's 2020 Nobel Prize in Physics. But later in the day, Zoom technology proved too balky to bridge the gap between the physicist, currently in Munich, and his fans in Berkeley.

Nevertheless, Genzel's voice was patched in to a group of some 175 colleagues and students eager to hear from the newest UC Berkeley Nobel laureate and to learn about the steps along the way to his discovery and that of co-winner Andrea Ghez of UCLA: A black hole sits at the center of our galaxy.

Genzel, a Berkeley professor emeritus of physics and astronomy, as well as director of the Max Planck Institute for Extraterrestrial Physics in Germany, credited the late Berkeley Nobel laureate Charles Townes for initiating the studies that led to the discovery. Decades ago, Townes, the inventor of the maser and laser, desperately wanted to use infrared detectors to study the center of the galaxy, which some astronomers thought might host an unseen and very large black hole.

Yet, Genzel said, the technology was not up to it then.

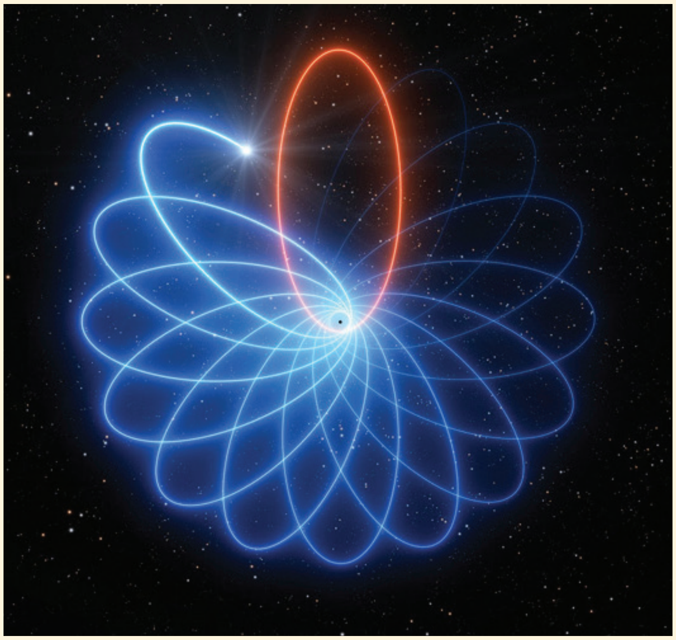
"Charlie Townes' dream was to do this experiment we have done, already in the 1970s," he said. "And he, in fact, did these fantastic, pioneering experiments. But (when he saw) the results, he knew he would never get to the galactic center, which was a real disappointment to him."

It was up to Genzel, Townes' postdoctoral fellow, to create a team to improve detectors one hundred thousandfold to be able to track stars with such precision that they could essentially measure the concentration of mass in the galactic center.

"I was very pleased that I got mails from all four of Townes' daughters," he said. "That is very important to me, because they appreciate where it all comes from. Berkeley has played a big role in this."

"You worked with our late, great Charlie Townes, also a Nobel laureate. I cannot imagine a more profound academic lineage than that, and I thank you for passing along your knowledge to generations of students and collaborators here at Berkeley," Chancellor Carol Christ said to Genzel, in her welcoming remarks.

Genzel's research group, working with an adaptive optics system to sharpen images from the Very Large Telescope array in Chile, and Ghez's group, using equivalent adaptive optics with the Keck I and II telescopes in Hawaii, ran neck and neck for decades, each spurring the other to greater precision and, eventually, to certainty that the heavy object at the galactic center could be nothing other than a supermassive black hole, some 4 million times more massive than our sun.



Observations by Genzel's team of the stars orbiting the black hole at the center of the Milky Way galaxy confirm predictions of Einstein's general theory of relativity: that the stars' orbits will precess, or follow, a rosette pattern instead of an ellipse. This artist's impression exaggerates the precession of a star's orbit for ease of illustration. (Image courtesy of ESO/L. Calçada)

"I very much appreciated the competition," Genzel said. "It was like we were both artists, ... and the scientific audience was in a perfect position to see us perform the same exercise and then judge whether the outcome was the same. And so, when the two teams would agree, the audience would believe what we have. It was initially very much of an advantage."

Ghez's team welcomed the competition, as well, said Jessica Lu, a UC Berkeley associate professor of astronomy who has been part of Ghez's team studying the galactic center since her days as a UCLA graduate student in 2003.

"That spirit of competition really led us all to be better," she said.

"When I joined Andrea's group, the suspicion that there was a supermassive black hole (at the center of the galaxy) was very strong, and there was some observational evidence," she added. "But many still speculated that it was a swarm of dark stars or quark stars or something else exotic. We fought to prove every alternative scenario wrong, and showed that the stars had to be orbiting a supermassive black hole.

"To have a role model like Andrea to pave the way, and a friendly competitor like Reinhard to really inspire us to have great conversations and great ideas and innovations around the technology and methods and the science itself, was a real pleasure."

Said Genzel, "It was quite a trip. A long one, but a good one. And I think we are not done yet."

Lu agreed.

"The discovery of the Milky Way's supermassive black hole was the first, but not the last, at the galactic center." she said. "It opened the window to new and interesting insights about our own galactic center and galactic centers across the universe. We found that stars can be born in their immediate vicinity, right around the black hole, even though it is an extreme environment and there are strong tidal forces."

The improved observational techniques developed by the competing teams now allow them to test Einstein's 1915 general theory of relativity to extreme precision, studying, in particular, one star Ghez found — S2, also called S02 — that orbits the central black hole every 16 years at extreme velocities.

While continuing their studies, Genzel and Ghez are also passing the torch to younger scientists, like Lu, who in the future will have even larger telescopes — three 30-meter-class telescopes are currently being built — to observe the galactic center.

"I think this Nobel Prize is a special one, in that is awarded both to astrophysics, for gravity and black hole studies, and to the first female astronomer that has ever been awarded a Nobel Prize," Lu said.

For the moment, Nobel laureate George Smoot advised, Genzel should "relax. Hopefully soon, you will go home to rest, because I know how hard it is for the first few weeks. You should tell people it is not exactly trivial, what you end up going through." A third Berkeley physics Nobel laureate on the call, Saul Perlmutter, who moderated the meeting and interviewed Genzel, urged the new winner to enjoy the many emails from well wishers—if he can find the time.

Genzel regretted that he could not fly out to meet and reminisce with Berkeley colleagues. But when he can return to California, he will receive something that makes Nobelists the envy of everyone on the Berkeley campus: a free parking space.

"It is at this point in the ceremony that I would present you the most prized of Berkeley perks, a Nobel laureate parking spot," Christ quipped, in her remarks. "I hope that, when things are back to normal, you will visit, and you'll park your car. And thank you for showing the world that Berkeley is one of the best places to study in the universe."

BERKELEY STUDENT THROWS COLD WATER ON 'MONSTER' BLACK HOLE DISCOVERY

December 16, 2019 – By Robert Sanders | Media Relations | rlsanders@berkeley.edu

Sometimes, a blockbuster discovery is just too good to be true. UC Berkeley graduate student astronomer Kareem El-Badry knows that all too well — he just shot one down.

El-Badry studies unusual binary star systems in which one of the two stars orbiting each other explodes as a supernova and turns into a black hole. But he was surprised when, on Nov. 27, the day before Thanksgiving, Chinese astronomers reported such a system with a black hole that was astoundingly large: 70 times the mass of our sun.

He knew black holes that size are so rare that there may be just one in the entire Milky Way Galaxy. Theoretically, black holes formed by stellar collapse in the Milky Way should weigh less than about 30 solar masses; hence the Washington Post headline reporting a "'monster' black hole so big they didn't think it was possible."

"I was suspicious from the beginning," El-Badry says. "We know of 20 to 30 black holes in binaries, and they are all half as massive, or less than 70 solar masses. It just made me want to read the paper carefully and try to understand what (the researchers) did."

The suspicion came from his four years of work with Eliot Quataert, a Berkeley professor and chair of the astronomy department, to discover and understand the 10 million to 100 million star-sized black holes suspected of lurking unseen in the Milky Way. These black holes are distinct from the supermassive black hole at the center of the galaxy that weighs about 4 million times more than our sun.

"We only know of a few dozen star-sized black holes in the galaxy," Quataert says. "We need to discover more in order to understand which stars explode to become neutron stars, which ones collapse into black holes — basically, to understand the full life cycle of stars, from birth to death."

El-Badry didn't have time to read the new paper thoroughly until five days later, on a train back to the Bay Area after visiting his parents in Oregon. Within 15 minutes, however, he knew something about the analysis was wrong. He quickly obtained the Chinese team's original data and, within 20 minutes, confirmed the error. On Dec. 9, a week after delving into the data, he uploaded to the internet a paper — with the admonition "not so fast" in the title — in which he described where the astronomers went wrong.

Kareem El-Badry and Eliot Quataert discuss the evolution of black holes in our galaxy, which may number in the 10s of millions if not 100s of millions. (UC Berkeley photo by Hulda Nelson)

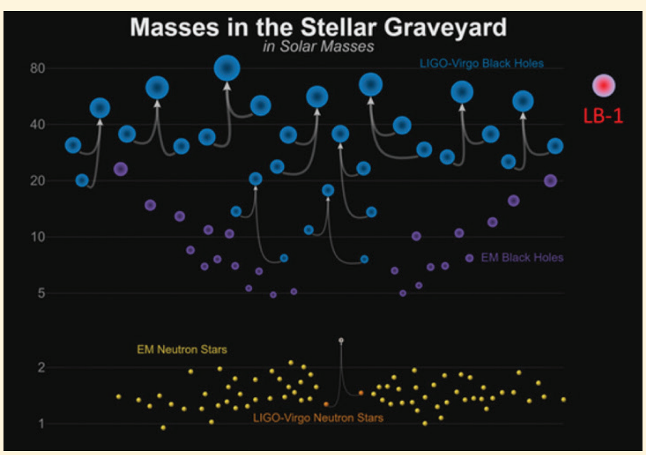
In a tweet, he wrote, "In today's dose of cold water, we argue that the data was misinterpreted, and there is no evidence of an unusually massive BH."

It turns out that two other research groups posted papers the same day, disputing the findings, but only El-Badry's used the Chinese team's original data to swat down its conclusion.

"I had reservations, too, because the long-rumored findings are not consistent with what we understand about how stars evolve," Quataert says. "But Kareem figured out the error."

NOT SO SUBTLE ERROR

The Chinese astronomers neglected an important complication in analyzing their data, El-Badry notes. Basically, the authors — 55 in all — ignored an aspect of the spectrum of the companion star that, if taken into account, negates their main evidence that the black hole companion was much larger than thought possible. In their paper, El-Badry and Quataert estimated that the black hole is actually between five and 20 times the mass of our sun: within the range of known stellar-mass black holes.



A chart showing the many ways a star can die. At bottom (yellow) are known neutron stars, left behind after a stellar explosion (supernova). In purple are known X-ray binary star systems, each harboring a black hole left behind by the collapse of a star. In blue are black holes that merged to produce intense gravitational waves detected on Earth. The now-disproved 70-solar-mass black hole, LB-1, is shown at upper right. (Data courtesy of LIGO-Virgo, Frank Elavsky and Northwestern)

El-Badry admits he was excited to discover the error, yet, the discovery of a binary star system with a black hole, even if it isn't a monster, is significant. To date, of the stellar-mass black holes discovered in our galaxy, nearly all were found because they glow brightly with X-ray emissions: The black hole is stripping matter from its stellar companion and sucking in the hot, swirling gas.

But the newly discovered binary is X-ray dark, probably because the black hole is far from its companion. Only a handful of such detached black hole binaries are known, though they may make up a significant fraction of the millions of star-sized black holes in the galaxy.

"It has been fun to work on it," he says. "We think this is still a black hole companion, in which case it is still an interesting system — there aren't that many of these discovered. It fits in nicely with what I am working on."

The original paper, which the Chinese authors have not retracted, was published in one of the world's most prestigious journals, Nature, which is known for seeking out research that makes "audacious" claims, El-Badry says.

The Chinese team discovered the binary system when it noticed that the visible member of the binary, a bright blue star, had a periodic wobble that indicated a companion was tugging on it — a rather large companion. The astronomers analyzed the star system's wavelengths of light — the stellar spectrum — and concluded that one of its very bright features was shifting a bit, presumably because it was being red-shifted or blue-shifted as the hot gas emitted by the light swirled around the black hole at high speed. The velocity they deduced from the shifting wavelength allowed them to calculate the mass of the black hole, which they dubbed LB-1.

El-Badry found that the atmosphere of the star was absorbing that same wavelength of light — the hydrogen-alpha line — which made the emission line appear to shift when, in fact, it wasn't. He suspects the bright emission comes mostly from material surrounding the entire binary system, not from the accretion disk of the black hole.

Nevertheless, he notes, this is the way science is done: Scientists pick apart the conclusions of other scientists to arrive at the truth. Generally, though, the fall from grace is not so rapid.

Research Fellows and Postdocs

Miller Fellows

Anna Ho: Astronomy welcomes new Miller Fellow Dr. Anna Ho. On a typical day, Anna reviews a dozen cosmic explosions detected by optical time-domain surveys. Most resemble ordinary supernovae or stellar flares, but once in a while an event merits an extensive observational campaign. Anna makes particularly heavy use of the Neil Gehrels Swift Observatory, of spectrographs at Palomar and Keck, of the Very Large Array, and of millimeter observatories such as ALMA, the SMA, and NOEMA. Ultimately, her goal is to understand the mapping between a massive star, its explosion type, and the compact object it leaves behind.

Anna received her PhD from Caltech in 2020, where she worked with the Zwicky Transient Facility (ZTF). Among optical transient surveys, ZTF is particularly well suited to finding fast-evolving and rare explosions: its wide field-of-view and fast survey speed enables it to scan large areas of the sky multiple times per night. For her thesis, Anna used ZTF to investigate the extremes of massive-star death by searching for explosions that were ten to a thousand times more fleeting than ordinary supernovae, appearing and disappearing in hours, and ten to a thousand times brighter. She explored a rich landscape of phenomena, including a new type of stellar explosion with a "central engine" (a neutron star or black hole that becomes active after the star's demise and launches a powerful outflow), a stripped massive star that shed material in the final days to years of its life, and transients resembling afterglows to gamma-ray bursts (GRB) yet lacking any detected high-energy emission.

Here at Berkeley, Anna is looking forward to collaborating with theorists to better understand the origins of these mysterious explosions—why it is that some stars end their lives with these spectacular displays when most explode as ordinary supernovae. She is also an Affiliate at Berkeley Lab, where she is helping to prepare for the next decade of time-domain astronomy, in the era of massively multiplexed spectroscopy (e.g., DESI) and large-scale millimeter time-domain surveys (e.g., CMB-S4).

Yong Zheng: "I'm a third-year Miller Postdoctoral Fellow. My research examines the detailed astrophysical processes that govern the thermodynamic state and baryonic content in a galaxy's circumgalactic medium (CGM). The CGM is a vast plasma reservoir where baryons, momentum, and energy are circulated via gas inflows and outflows, the so-called 'cosmic baryon cycle.' My research focuses on constructing a coherent picture of how baryons are cycled and recycled between the CGM and host galaxies. In particular, I'm interested in characterizing sub-kpc physical processes that can only be gleaned from observations of nearby galaxies using multi-wavelength spectroscopy (UV Spectroscopy, HI 21cm, IFU, etc.)."

51 Pegasi b Fellows

Marta Bryan: Dr. Marta Bryan is a Heising-Simons Foundation 51 Pegasi b Postdoctoral Fellow. Since coming to UC Berkeley in 2018, Marta has led a NIR high-resolution spectroscopy survey to directly detect thermal emission of gas giant planets in their infancy. With these spectra she measures how fast these planets spin, providing the first look at their angular momentum evolution. Marta has also led a collaboration to measure the first exoplanetary obliquity, a new observable that is a unique window into planetary formation histories.

Sivan Ginzburg: "I have been theoretically modeling the internal structure and energy transport inside both planets and black widow companion stars, calculating their evolution over time. Specifically, I have been comparing these models to recent direct optical imaging of planets and black widows."

Postdocs

Joshua Tollefson: "I am holding a part time postdoctoral position at UC Berkeley where I am researching the atmospheric properties of solar system planets. Neptune is my main focus and I synthesize multi-wavelength observations from Keck, HST, the VLA, and ALMA to constrain the planet's cloud-forming species and monitor its ephemeral features. By studying the atmospheres of outer planets, we gain insight into the solar system's early thermal and chemical environment, and can extend those findings to worlds beyond."

Matthew Freeman: "I have recently moved to Berkeley to join KAPA—the Keck All-sky Precision Adaptive optics project, where we are upgrading the adaptive optics on the 10m Keck telescope. KAPA features three key upgrades. The first is a new multiple laser guide star asterism, which will increase the precision of observations by sampling a larger volume of the turbulent atmosphere. Second, KAPA will switch to doing natural guide star tip-tilt correction in the infrared, where most stars are brighter, giving Keck AO much greater sky coverage. Finally, we are developing a suite of new science tools for observers, including an exposure time calculator, an instrument simulator, point spread function reconstruction, and a new data reduction pipeline.

Scientifically, I am interested in using Keck and KAPA to search for black holes using gravitational microlensing. Lensing is an excellent technique to find these dark objects, but it provides limited information on the object's mass. The improved resolution available with KAPA will allow precise astrometric measurements to be made for microlensing events, which gives enough extra information to calculate the mass of the lens, determining that the object is indeed a black hole."

150 Years of Women at Berkeley
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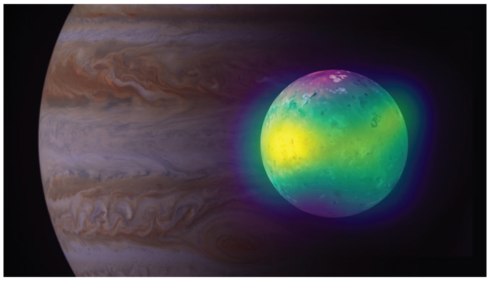
From de Pater: "I was appointed to the faculty in July 1983. At the time some faculty members wondered what I would do when "I would run out of planets," a notion that is unthinkable in this era when thousands upon thousands of exoplanets are being discovered. Although I was the only woman on the faculty for 19 years, I never gave this much thought; I always felt very welcome and supported, in particular in the then Radio Astronomy Lab. My time as Chair of the Department, however, was a most challenging period, probably not too surprising in a male-dominated environment.

My research is focused on bodies in our Solar System, using observations at radio, infrared and visible wavelengths. Some highlights include:

- The impact of comet Shoemaker-Levy 9 with Jupiter in 1994, where I led a worldwide campaign using radio telescopes from all over the world. Simultaneously we also observed at infrared wavelengths with the first 10-m Keck telescope, which had just come on-line the year before. Here we saw in real time a fireball rising up above Jupiter's limb, triggered by the impact.
- We mapped the entire atmosphere of Jupiter at short radio wavelengths, "peering" through the clouds after the Very Large Array had been upgraded. These maps took us all by surprise, as they were as detailed as images of Jupiter from the Hubble Space Telescope, i.e., we saw for the first time Jupiter's Great Red Spot also at short radio wavelengths, providing unique information about its physical conditions, and of numerous smaller storm systems. (see, e.g., https://news.berkeley.edu/2016/06/02/new-radio-map-of-jupiter-reveals-whats-beneath-colorful-clouds/)
- One of my dreams, imaging an active volcano on Io at even shorter radio wavelengths, was finally possible with the Atacama Large (sub)Millimeter Array in Chile. We observed Io essentially moving through Jupiter's shadow. These images revealed a complex system of volcanoes that were spewing out sulfur dioxide gas at high velocities, and that interacted with Io's cold atmosphere when it came back out of Jupiter's shadow. (e.g., https://news.berkeley.edu/2020/10/21/active-volcanoes-feed-ios-sulfurous-atmosphere/)"

You can read more about Professor de Pater's recent research on the Astronomy website news page (https://astro.berkeley.edu/news/).



A composite image of Io in front of a Cassini photo of Jupiter. The observations for the first time show plumes of sulfur dioxide (yellow) rising up from Io's volcanoes. [Image courtesy of ALMA (ESO/NAOJ/NRAO), I. de Pater et al.; NRAO/AUI NSF, S. Dagnello; NASA/ESA]

Message from the Chair

"We are all in the gutter, but some of us are looking at the stars."

Oscar Wilde

It is safe to say that our department has been challenged this year in ways unprecedented and existential, with societal-level hardships manifesting locally in the Cal Astronomy community. The pandemic has uprooted our established means of interaction as scientists, as teachers, and students. The economic pain felt by so many has rendered decisions made with already lean budgets that much more difficult and heart wrenching. And the social upheaval that we witnessed nationally following the murder of George Floyd has brought home the need to fight systematic racism in academia.

Yet despite the overwhelming challenges, our people persist and endure. We have found new and creative ways to do science remotely with our colleagues and to teach our students. We are learning to make do with less. And many in our department have focused their energy to help us understand, come to terms with, and change the endemic biases and inequities in our community.

It is indeed in times of great struggle that we see the strength and resiliency in ourselves and those around us. Since becoming chair this summer, I have been very fortunate to bear witness to this every day. The astonishing scientific results kept pouring in: we've highlighted some of those here, like the work of Profs. **Imke de Pater** and **Paul Kalas** and graduate student **Kareem El-Badry**. On the teaching and mentorship side, Prof. **Mariska Kriek** received resounding plaudits from our undergraduates in her revamped introductory to astronomy course for majors; not only has she, through exemplary leadership, helped grow the major to all-time record numbers, she is also the driving force behind a phenomenal level of undergraduate research now conducted by our students. Prof. **Courtney Dressing** was invited to serve on the prestigious Decadal Survey on Astronomy and Astrophysics (Astro2020).

It is also one of the greatest pleasures in my role as Chair, to brag and sing the praises of Cal Astronomy members in their accolades. Emeritus astronomy Professor **Reinhard Genzel** won the 2020 Nobel Prize in Physics, a crowning achievement whose work started while Genzel was a postdoc at Berkeley working with Nobel Laureate Charles Townes. Prof. **Jessica Lu** was a key member of co-winner Prof. Andrea Ghez's team while she was a graduate student. Prof. **Chung-Pei Ma** was elected to the American Academy of Arts and Sciences in April 2020. Graduate student **Ellianna S. Abrahams**, who serves as one of the graduate student representatives, was awarded the highly competitive Two Sigma Graduate Fellowship. Prof. **Eliot Quataert** was elected to the National Academy of Sciences in April 2020, before his amicable departure from the department in the summer.

There are many who have served as the backbone for the functioning of our Department. I want to thank and congratulate **Nina Ruymaker**, who will retire in early 2021, for her years of service and dedication. Department manager **Maria Kies,** and student services and academic affairs staff **Amber Banayat**, and **Yasasha Ridel** have done a remarkable job this most difficult year.

The central importance of science and the conduct of it has been made starkly clear this year. I hope everyone reading this newsletter affirms and internalizes that statement. Despite our vantage point from what feels like the bottom of the gutter, we look up to the stars and look forward. The future of astronomy is extraordinarily bright and Berkeley will, I am convinced, illuminate the world.

– Prof. Joshua Bloom

2019-2020 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 2020

Siyao Jia
Advisor: Jessica Lu
"The Young Nuclear Star Cluster in our Galactic Center"

Chirag Modi
Advisor: Uros Seljak
"Reconstruction of Cosmological Fields in Forward Modeling Frameworks"

Abigail Polin
Advisors: Peter Nugent and Dan Kasen
"Pushing the Helium Envelope: Signatures of Normal and Unusual Supernovae from Sub-Chandrasekhar Mass White Dwarf Explosions"

Tom Zick
Advisor: Dan Weisz
"Star Formation in Low Mass Galaxies: Connecting the Near and Far Fields"

PHD DEGREES – SUMMER 2020

Nicholas Kern
Advisor: Aaron Parsons
"Mapping the Cosmic Evolution of Hydrogen: Analysis and Inference Techniques for Next-Generation 21 cm Cosmology"

Alexander Krolewski
Advisor: Martin White
"Cosmology and galaxy evolution from large-scale structure"

2019-20 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.
Nicholas Kern

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.
Kareem El-Badry

OUTSTANDING GRADUATE STUDENT INSTRUCTOR AWARD

Shaunak Modak, Kishore Patra, Arjun Savel

2019-20 UNDERGRADUATE AWARDS

Commencement Speaker
Arjun Savel

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

Dorothea Klumpke Roberts Prize For outstanding scholarly achievement.
Zoie Telkamp

Daniel Wark Award For astrophysics majors in excellent academic standing.
Nicholas Pickett

STUDENT SERVICES SPOTLIGHT

The department's Astrophysics Scholars Program is in its second year of supporting underrepresented students in their academic and future career endeavors. Initiated by our Associate Director of Student Services, Amber Banayat, the Scholars Program aims to connect undergraduates interested in Astronomy with faculty, graduate, and postdoc researchers and mentors who can help them develop their interests and pursue opportunities in STEM. Scholars from the 2019 and 2020 cohorts have been involved in the undergraduate research through the Undergraduate Lab at Berkeley (ULAB), collaborative learning sessions at The Astronomy Learning Center (TALC), and the Python DeCal for scientists and astronomers. The advising team is currently working on an online hub for resources and information about the program—please look out for it in Spring 2021!

Undergraduate Spotlight: AAS 236 Chambliss Award

The 236th meeting of the American Astronomical Society (AAS) took place virtually from June 1st to 3rd, moving its talks and presentations to an online exhibition hall. Among no fewer than 50 graduate students and 30 undergraduate students attending were UC Berkeley undergraduates Yukei Murakami and Andrew Hoffman, who presented their observations of RR Lyrae variable star light curves and their success in developing an improved method to determine the periods of these stars. Their project began in December 2018 as a development of the analysis of RR Lyrae stars in M15 put forth by UC Berkeley Astrophysics professor Alex Filippenko in 1981.

After multiple rounds of interviews with AAS judges, Yukei and Andrew were awarded the Undergraduate Student Honorable Mention for the Chambliss Astronomy Achievement Student Award. The opportunity to discuss their findings with experienced researchers was

one of the major highlights of the competition for the two, whose first paper is currently under review by the Monthly Notices of the Royal Astronomical Society, with a preprint available at the open-access archive arXiv. Yukei and Andrew are currently working on a second paper that will further discuss the current and potential applications of the new Python package, Period-determination and Identification Pipeline Suite (PIPS), that they developed for their M15 project.

Welcome to our Newest Class of Graduate Students!

Jacqueline Blaum (**Physics + Computer Science, Iowa State University**)
previously studied the gamma-ray emission of supernova remnants, working on a method for finding transients in LSST data, and classifying infrared sources using machine learning. She also co-founded the Society of Women in Physics and Astronomy at ISU. Jacqueline is now interested in computational cosmology.

Tyler Cox (**Physics + Astrophysics, Arizona State University**)
worked on combining radio and infrared measurements to better understand galaxy formation and evolution during the Epoch of Reionization. He was also involved at the planetarium on campus, where he engaged in outreach and presented shows to K-12 school groups. Tyler is interested in continuing research work in radio astronomy and cosmology.

Kiran Eiden (**Physics + Astronomy, Stony Brook University**)
worked on simulations of Type I X-ray bursts, the massive thermonuclear explosions on the surfaces of neutron stars. He is now working with Dr. Dan Kasen on numerical simulations of neutron star powered transients. Kiran is a DOE CSGF fellow.

Jacob Pilawa (**Colgate University**)
is interested in supermassive black holes and their host galaxies. As an undergraduate, Jacob studied the gravitational capture of dark matter by the first stars and the chemical history of galaxies in the nearby Universe.

Caleb Harada (**Physics + Astronomy, University of Maryland, College Park**)
conducts research in exoplanetary science with Prof. Courtney Dressing. He is passionate about public outreach and strives to make astronomy a more inclusive and equitable field. Caleb is an NSF Graduate Research Fellow.

Hannah Gulick (**Physics, Astronomy, English & Creative Writing, University of Iowa**)
worked on the assembly, launch, and analysis of data from the HaloSat CubeSat, the HERCI instrument, and a sounding rocket in Norway as an undergraduate. She was also an editor for a literary arts magazine and a mentor and STEM advocate to students from rural towns.

Erika Strasburger (**Astrophysics, UC Santa Cruz**)
is interested in observational astronomy and "transients," or fast-evolving astronomical phenomena. She is a former community college student who is passionate about increasing the retention and success of transfer students in the physical sciences. Erika is a Berkeley Chancellor's Fellow and an NSF Graduate Research Fellow.

Kenneth Lin (**Physics + Astrophysics, University of Massachusetts Amherst**)
is interested in black holes and their link to host galaxies, projects involving new instruments, and statistical analysis of large datasets. As an undergraduate, he developed imaging simulations for TolTEC, a powerful new camera on the Large Millimeter Telescope, and worked on probing the carrier dynamics of atomically thin semiconductors using terahertz microscopy.

Getting To Know Astro!

A Q&A with Graduate Student, Sarafina Nance

What is your research focus? What drew you to this area of study?

I primarily work to understand supernovae from both an observational and theoretical perspective. I simulate their stellar evolution, model their explosion physics, and collect spectra of their explosions. My goals are to try to determine which types of stars explode and how their explosions progress, and to use supernovae for cosmological applications, like measuring the expansion rate of the Universe.

In a Universe that evolves on long timescales, I'm especially drawn to things that change right before our eyes—the domain of transient astronomy. Supernovae are not only incredible physics phenomena (they are explosions in space!) but their explosions occur in short enough timescales that we can actually see them change in real time from Earth. They are exotic laboratories in space that offer the ability to study the four fundamental forces of physics in one place, and their explosions can be used to measure fundamental aspects of the Universe in new and creative ways!

How has the remote semester impacted your work? What has surprised you or kept you going this year?

2020 has been an extremely challenging year. Learning to navigate a pandemic alongside the cultural revolution initiated and led by Black Lives Matter has pushed all of us to show up in new ways and use various axes of our privilege to aid those most affected by the pandemic, systemic racism, and violence. Personally, I have been working on showing up in my personal and work lives as much as I can, while also checking in with myself to ensure that I'm giving myself what I need to keep going. This is a constantly evolving relationship with myself, but one that I'm trying to pay more attention to.

Any message for the Cal Astro community?

I hope that as we collectively move forward, we can find new and meaningful ways to support each other, especially those in our community who are suffering the most under the full force of systemic racism and violence against marginalized peoples. I hope that we can continually expand our nexus of support, while maintaining the love and empathy that sustains Cal Astro from within.

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Lisa Krieshok

Supporting Astronomy

Friends of Astronomy Fund directly supports all facets of the department's operations from research to instruction, recruitment of top faculty and staff, to the day to day technology and supply needs in the classrooms and teaching labs.

Graduate Student Support Fund Funding 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.

Student Observatory Fund assists with the 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.

Gifts to any of these funds can be directed to: https://astro.berkeley.edu/astronomy-fans/make-a-gift/

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 Ryan Guasco, Associate Development Director (rguasco@berkeley.edu, or via phone at 510-599-8698)

GO BEARS!

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.

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 provide the best resources for our students. You can help us strengthen the critical financial support that enables young scientists to select Berkeley for their studies. 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.