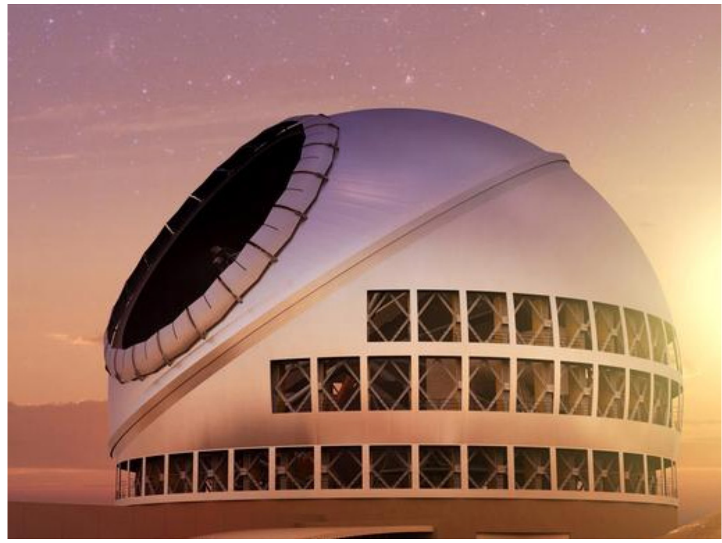
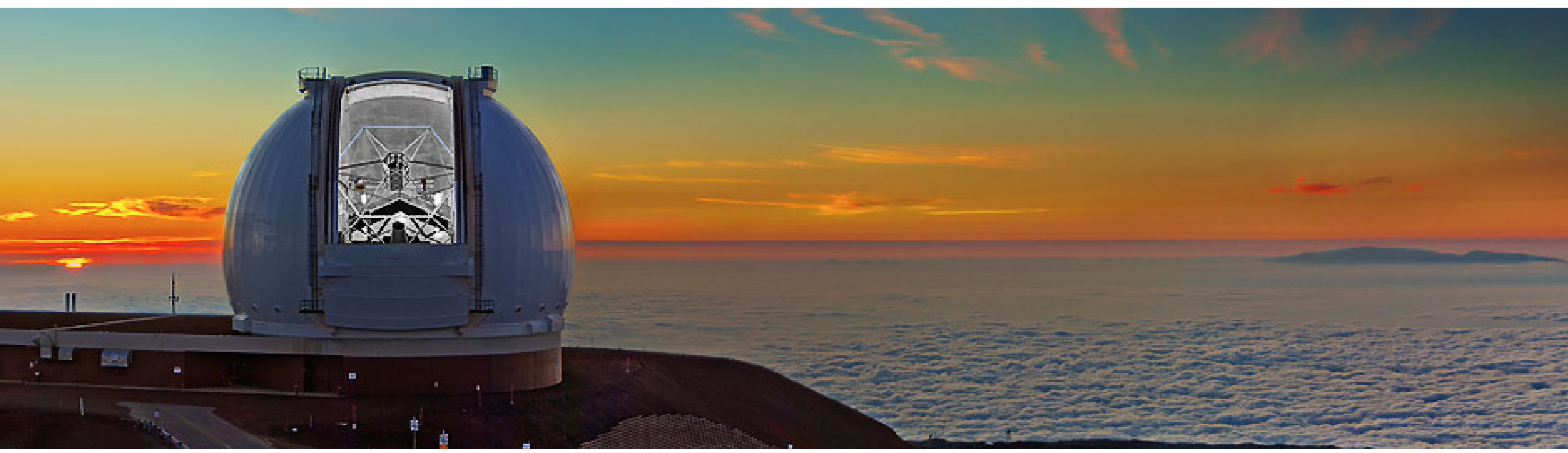
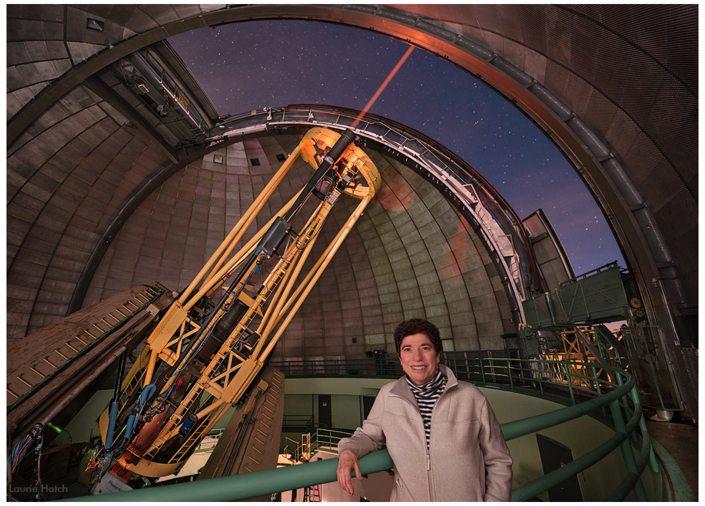
UNIVERSITY OF CALIFORNIA OBSERVATORIES





UCO FOCUS | SPRING 2015

From the Director's Desk



(ABOVE) Claire Max inside the Shane 3-meter dome while the Adaptive Optics laser is propogating. (Photos by Laurie Hatch)

Dear friends and colleagues,

Welcome to the first edition of the "UC Observatories Focus" - a periodical publication designed to highlight scientific research and accomplishments from UC astronomers at Lick Observatory, Keck Observatory, and the future Thirty Meter Telescope. You will also see updates about instrumentation from our UCO technical facilities at UCSC and from the Infrared Laboratory at UCLA.

The goal of this publication is to connect the strong network of leading astronomers and researchers across the UC system with exciting news.

We have a lot to share and celebrate:

After extensive and ongoing discussions with UCOP, things are looking up for **Lick Observatory.** Our base funding from the UC Office of the President will be steady at least through FY19. UC's Provost, Aimée Dorr, recently made additional funding available for use at Lick and Keck: about $500K of year-end funds. Google made a $1 million donation for Lick via Professor Alex Filippenko, shortly following UCOP's decision to give Lick steady funding. The Automated Planet Finder (APF) recently made worldwide headlines for the discovery of three exoplanets near the star HD 7924. The KAST spectrograph is being upgraded thanks to a generous gift from the Heising-Simons Foundation and Bill and Marina Kast. The new ShaneAO adaptive optics system is on the sky and working well; its fiber laser will be coming along shortly. Our Summer Series tickets are already sold out. Lick Observatory's following on social media is substantial – both within the scientific community and beyond.

Keck Observatory continues to be one of the most scientifically productive ground-based telescopes in the world. It gives unparalleled access to astronomers from UC, Caltech, and the University of Hawaii, as well as at other institutions through partnerships with NASA and academic organizations. Several new instruments for Keck are being built or completed right now: the Keck Cosmic Web Imager, the NIRES infrared spectrograph, and a deployable tertiary mirror for Keck 1. The Keck Observatory Archive is now fully ingesting data from all Keck instruments, and makes these data available to the whole world. Keck's new Director, Hilton Lewis, is on board and is in the midst of choosing his Chief Scientist (a new position at Keck).

A new key observatory for UCO astronomers is the **Thirty Meter telescope** (TMT). TMT has just released a revised version of its Detailed Science Case for 2015, which you can find on Astro-Ph here. It makes very interesting reading, and is full of compelling scientific areas to which TMT will make huge contributions. A TMT Science Forum is scheduled to take place in late June of 2015. However for more than a month, there have been protests in Hawaii against the construction of TMT, which have delayed the full onset of construction on Mauna Kea. Later in this UCO Focus newsletter I will describe the current status of the activities in Hawaii regarding TMT construction.

On a very sad note, the former director of UCO, Robert Kraft passed away on May 26th, just a few days shy of his 88th birthday. Bob's wonderful personality, major scientific contributions and his decade-long leadership of UCO/Lick Observatory earned him the greatest respect and admiration; he will be sorely missed. Indeed, his vision and drive were crucial in bringing the Keck telescopes into operation. On page 11 there is an obituary written by his longtime friend and colleague, John Faulkner, which details Bob's many accomplishments and reminds us that his legacy lives on. The full obituary from the Santa Cruz sentinel can be found here.

Best regards,

Claire Max

Interim Director UC Observatories

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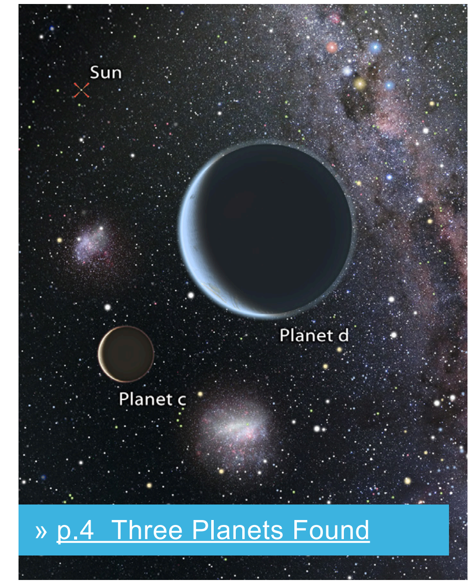
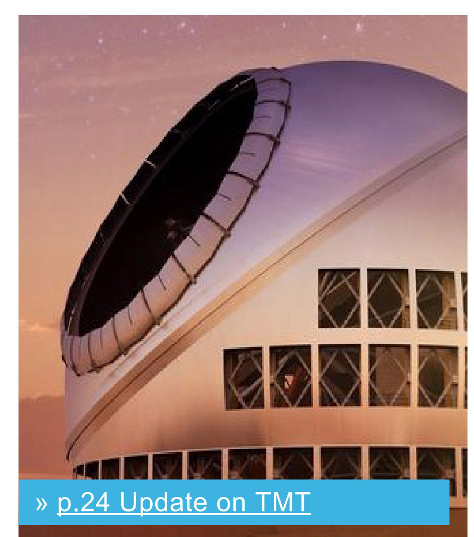




Cover Photos: (LEFT) Sunset at Lick Observatory on Mount Hamiltion (Laurie Hatch) **(RIGHT)** Artist rendering of the Thirty Meter Telescope, courtesy of TMT. **(BOTTOM)** Keck II Telescope on Mauna Kea, Hawaii (Laurie Hatch)

Astronomers Discover Three Super-Earths Only 54 Light-Years Away

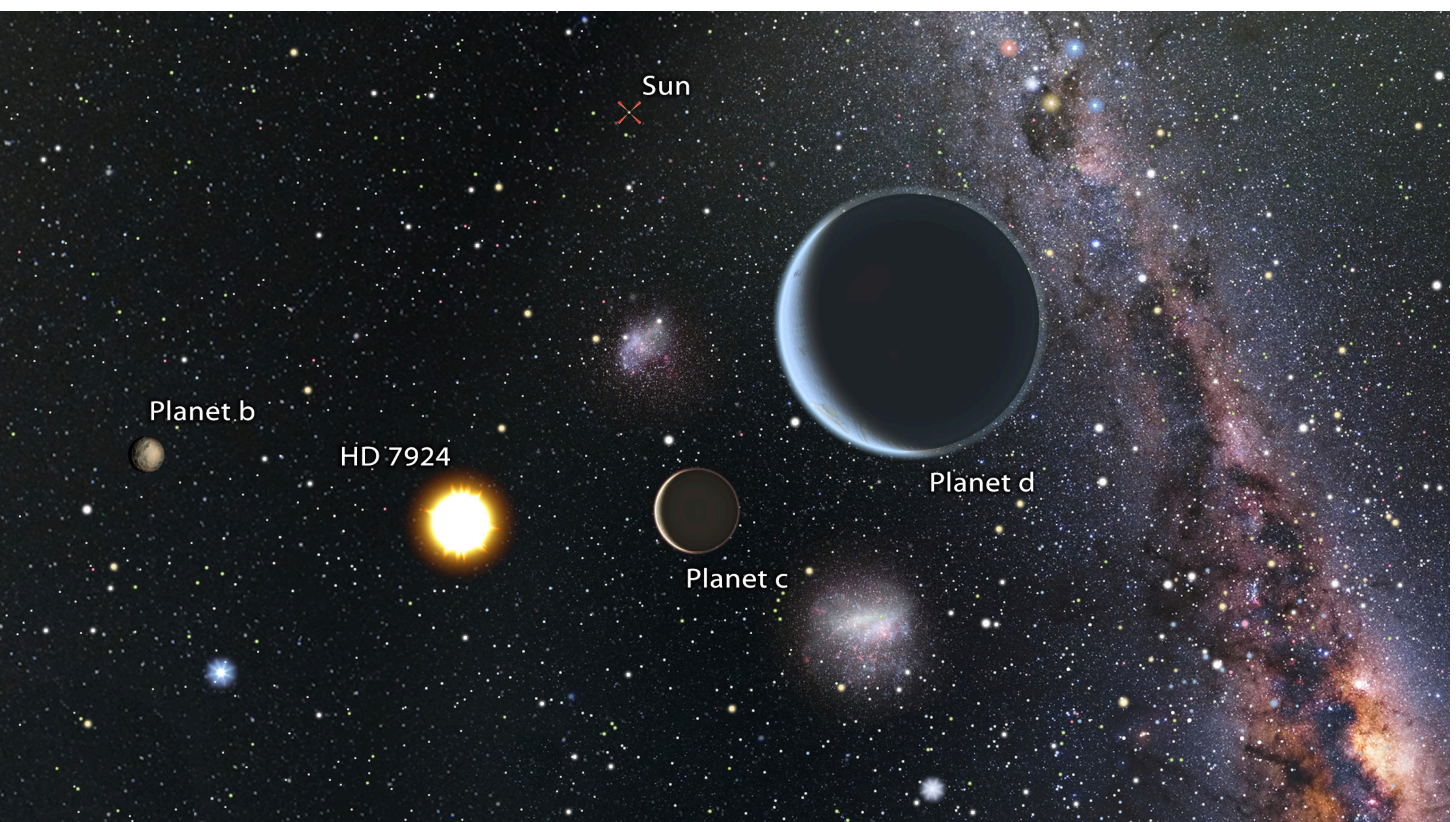
Astronomers have discovered a planetary system orbiting a star only 54 light-years away with the Automated Planet Finder (APF) at Lick Observatory and ground-based telescopes in Hawaii and Arizona.

The team discovered the planets by detecting a wobble of the star HD 7924, a result of the gravitational pull of the planets orbiting around it. All three planets orbit the star at a distance closer than Mercury orbits the sun, completing their orbits in just 5, 15, and 24 days.

The APF facility at Lick Observatory offers a way for astronomers to speed up the exoplanet search. The fully-robotic telescope searches for planets every clear night of the year, so planets and their orbits can be discovered and traced quickly.

"The APF is great for two reasons. One, it has the superb Levy spectrometer. Two, it is a modern computer controlled telescope so we can automate it. This combination means that we can observe stars night in and night out to look for the wobble," said Bradford Holden, an Associate Research Astronomer for UC Observatories (UCO) who helped to make the telescope robotic.

"The automation of the telescope means that astronomers can fully use all the time available, and make discoveries faster," said Holden.



(ABOVE) Artist's impression of a view from the HD 7924 planetary system looking back toward our sun, which would be easily visible to the naked eye. Since HD 7924 is in our northern sky, an observer looking back at the sun would see objects like the Southern Cross and the Magellanic Clouds close to our sun in their sky. (Art by Karen Teramura & BJ Fulton, UH IfA)

(BELOW LEFT) The 2.4-meter APF is framed by a darkening sky, the bright planet Venus, the Lick Observatory Main Building, and the glow of city lights from Silicon Valley. **(RIGHT)** UC Berkeley grad student Lauren Weiss observes remotely with the APF telescope from the UCB Campbell Hall control room. (Photos by Laurie Hatch)

Training computers to run the observatory all night, without human oversight, took years of effort by the UCO staff and graduate students on the discovery team.

"We initially used APF like a regular telescope, staying up all night searching star to star. But the idea of letting a computer take the graveyard shift was more appealing after months of little sleep. So we wrote software to replace ourselves with a robot," said University of Hawaii graduate student Benjamin "BJ" Fulton.

The Keck Observatory found the first evidence of planets orbiting HD 7924, discovering the innermost planet in 2009 using the HIRES instrument installed on the 10-meter Keck I telescope. This same combination was also used to find other super-Earths orbiting nearby stars in planet searches led by UH astronomer Andrew Howard and UC Berkeley Professor Geoffrey Marcy. It took five years of additional observations at Keck Observatory and the year-and-a-half campaign by the APF Telescope to find the two additional planets orbiting HD 7924. The Automatic Photometric Telescope (APT) at Fairborn Observatory in Arizona also made crucial measurements of the brightness of HD 7924 to assure the validity of the planet discoveries.

The Kepler Space Telescope has discovered thousands of extrasolar planets and demonstrated that they are common in our Milky Way galaxy. However, nearly all of these planets are far from our solar system. Most nearby stars have not been thoroughly searched for the small "super-Earth" planets (larger than Earth but smaller than Neptune) that Kepler found in great abundance.

This discovery shows the type of planetary system that astronomers expect to find around many nearby stars in the coming years. "The three planets are unlike anything in our solar system, with masses 7-8 times the mass of Earth and orbits that take them very close to their host star," explains UC Berkeley graduate student Lauren Weiss.

Observations by APF, APT, and Keck Observatory helped verify the planets and rule out other explanations. "Starspots, like sunspots on the sun, can momentarily mimic the signatures of small planets. Repeated observations over many years allowed us to separate the starspot signals from the signatures of these new planets," explains Evan Sinukoff, a UH graduate student who contributed to the discovery.

The robotic observations of HD 7924 are the start of a systematic survey for super-Earth planets orbiting nearby stars. Fulton will lead this two-year search with the APF as part of his research for his doctoral dissertation. "When the survey is complete we will have a census of small planets orbiting sun-like stars within approximately 100 light-years of Earth," says Fulton.

The paper presenting this work was published in the Astrophysical Journal on April 29, and is available online here. The authors of the paper are Benjamin J. Fulton (UH), Lauren M. Weiss (UC Berkeley), Evan Sinukoff (UH), Howard Isaacson (UC Berkeley), Andrew W. Howard (UH), Geoffrey W. Marcy (UC Berkeley), Gregory W. Henry (TSU), Bradford P. Holden (UCO), and Robert I. Kibrick (UCO).

In honor of the donations of Gloria and Ken Levy that helped facilitate the construction of the Levy spectrograph on APF and support Lauren Weiss, the team has informally named the HD 7924 system the "Levy Planetary System." The team also acknowledges the support of NASA, the U.S. Naval Observatory, and the University of California for its support of Lick Observatory. ■

UC Observatories press release published on April 28, 2015 by Hilary Lebow.

LICK OBSERVATORY

Search for Extraterrestrial Intelligence Expands at Lick

Astronomers are expanding the search for extraterrestrial intelligence into a new realm with detectors tuned to infrared light at UC's Lick Observatory. A new instrument, called NIROSETI, will soon scour the sky for messages from other worlds.

"Infrared light would be an excellent means of interstellar communication," said Shelley Wright, assistant professor of physics at UC San Diego who led the development of the new instrument while at the University of Toronto's Dunlap Institute for Astronomy & Astrophysics.

Wright worked on an earlier SETI project at Lick Observatory as a UC Santa Cruz undergraduate, when she built an optical instrument designed by UC Berkeley researchers. The infrared project takes advantage of new technology not available for that first optical search.

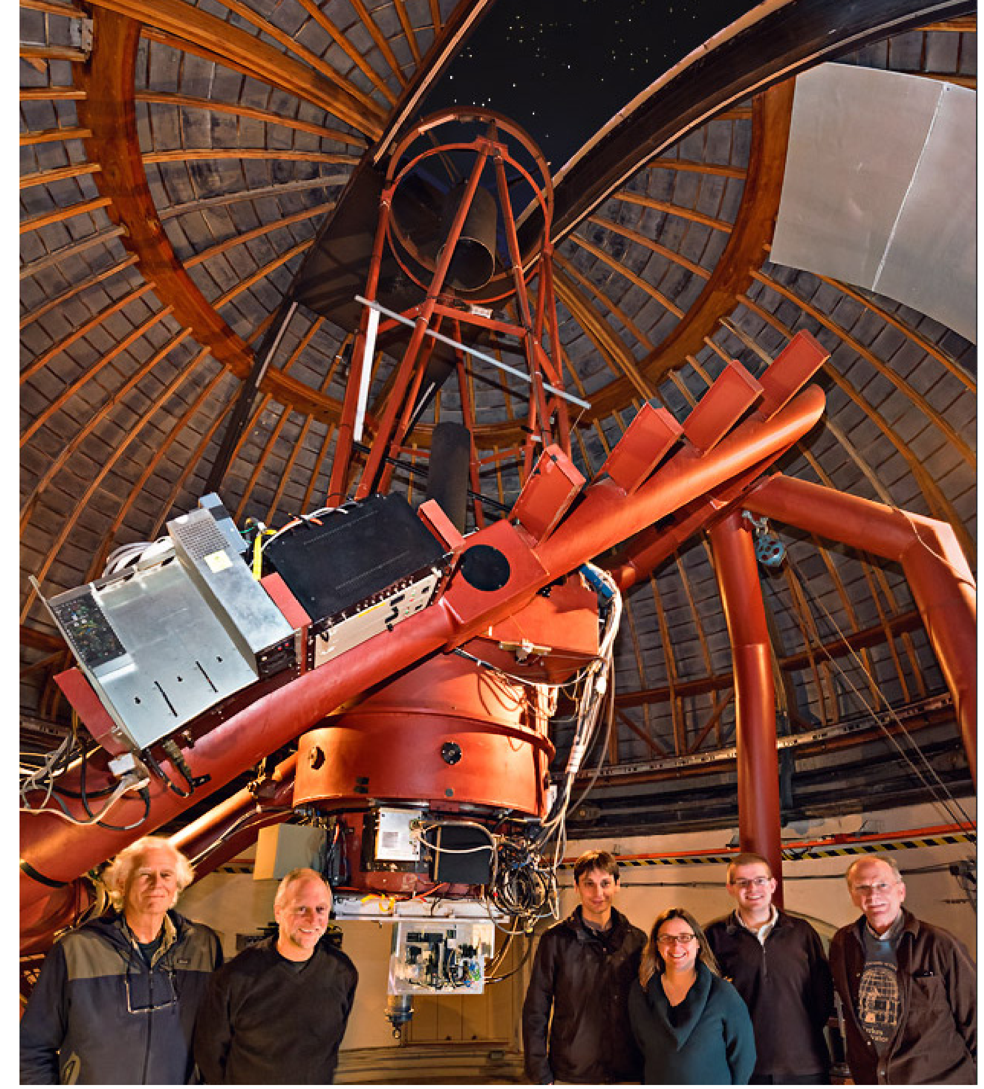
Infrared light would be a good way for extraterrestrials to get our attention here on Earth, since pulses from a powerful infrared laser could outshine a star, if only for a billionth of a second. Interstellar gas and dust is almost transparent to near infrared, so these signals can be seen from great distances. It also takes less energy to send information using infrared signals than with visible light.

Frank Drake, professor emeritus of astronomy and astrophysics at UC Santa Cruz and director emeritus of the SETI Institute, said there are several additional advantages to a search in the infrared realm.

"The signals are so strong that we only need a small telescope to receive them. Smaller telescopes can offer more observational time, and that is good because we need to search many stars for a chance of success," said Drake.

The only downside is that extraterrestrials would need to be transmitting their signals in our direction, Drake said, though he sees this as a positive side to that limitation. "If we get a signal from someone who's aiming for us, it could mean there's altruism in the universe. I like that idea. If they want to be friendly, that's who we will find."

Scientists have searched the skies for radio signals for more than 50 years and expanded their search



"This is the first time Earthlings have looked at the universe at infrared wavelengths with nanosecond time scales." - Dan Werthimer, UC Berkeley SETI Project Director

(LEFT) The NIROSETI instrument saw first light on the Nickel 1-meter on March 15, 2015. **(ABOVE)** The NIROSETI instrument with collaborators. Left to right: Remington Stone, Dan Werthimer, Jérome Maire, Shelley Wright (Principal Investigator), Patrick Dorval, and Richard Treffers. Also on the team but not shown here are Frank Drake, Geoffrey Marcy, and Andrew Siemion. (Photos by Laurie Hatch)

into the optical realm more than a decade ago. The idea of searching in the infrared is not a new one, but instruments capable of capturing pulses of infrared light only recently became available."We had to wait," Wright said. "I spent eight years waiting and watching as new technology emerged."

Now that technology has caught up, the search will extend to stars thousands of light years away, rather than just hundreds. NIROSETI, or Near-Infrared Optical Search for Extraterrestrial Intelligence, could also uncover new information about the physical universe.

"This is the first time Earthlings have looked at the universe at infrared wavelengths with nanosecond time scales," said Dan Werthimer, UC Berkeley SETI Project Director. "The instrument could discover new astrophysical phenomena, or perhaps answer the question of whether we are alone."

NIROSETI will also gather more information than previous optical detectors by recording levels of light over time so that patterns can be analyzed for potential signs of other civilizations.

"Searching for intelligent life in the universe is both thrilling and somewhat unorthodox," said Claire Max, director of UC Observatories and professor of astronomy and astrophysics at UC Santa Cruz. "Lick Observatory has already been the site of several previous SETI searches, so this is a very exciting addition to the current research taking place."

NIROSETI will be fully operational by early summer and will scan the skies several times a week on the Nickel 1-meter telescope at Lick Observatory, located on Mt. Hamilton east of San Jose.

The NIROSETI team also includes Geoffrey Marcy and Andrew Siemion from UC Berkeley; Patrick Dorval, a Dunlap undergraduate, and Elliot Meyer, a Dunlap graduate student; Richard Treffers of Starman Systems, and Remington Stone, former director of operations at Lick Observatory. Funding for the project comes from the generous support of Bill and Susan Bloomfield. ■

UCSC press release published on March 23, 2015 by Hilary Lebow.

Science Internship Program Expands

(LEFT) UCSC Professor of Astronomy and Astrophysics Puragra GuhaThakurta takes students to Lick Observatory. **(RIGHT)** Support astronomer Elinor Gates teaches high school students about astronomy research at Lick Observatory. (Photos courtesy of SIP)

UCSC Professor of Astronomy and Astrophysics Puragra (Raja) GuhaThakurta, started the Science Internship Program (SIP) for high school students after mentoring three students in 2009, giving them computation-based research projects to work on during the summer.

The program has grown rapidly at UC Santa Cruz and now involves faculty across campus in a wide range of STEM (science, technology, engineering, and math) fields, who have worked with students from 46 different high schools.

Now, GuhaThakurta wants to expand the program beyond UC Santa Cruz and engage a more diverse group of high school students. He will be spending the next eight months on sabbatical at Google in Mountain View, CA, working with University Relations and Engineering Education teams to expand and diversify the Science Internship Program (SIP) to serve high school students throughout the country.

"The hallmark of SIP is it embeds high-school students in real computation-based STEM research projects. Strong mentoring by university researchers--graduate students, postdocs, research staff, and faculty--has been a key reason for the program's success," GuhaThakurta said.

To date, about 60 percent of the participants in the program have been female students, he said. Of the nearly 100 SIP alumni who have decided on college majors, more than half have opted for computer science.

By working with the University Relations team at Google, which has ties to many research universities, GuhaThakurta hopes to replicate the UC Santa Cruz framework at other sites. At the same time, he is looking to diversify the program through a greater emphasis on students from groups that are underrepresented in the STEM fields.

For more on the program, see the SIP website.

UCSC press release published on March 10, 2015 by Tim Stephens.

The 35th Annual Summer Series Kicks Off This June

For 35 years the Summer Series program at Lick Observatory has drawn concert fans and astronomy devotees to the summit of Mt. Hamilton for live music, evening astronomy lectures from world-renowned scientists, and the opportunity to view celestial objects through two historic telescopes.

The **"Music of the Spheres"** concert series and **"Evenings with the Stars"** programs gives the public a rare glimpse of the observatory at night, and all proceeds from the event benefit Lick Observatory. Due to the popularity of the summer program, tickets are already sold out this year!

Visit the new Summer Series website at **ucolick.org/summer.**

(ABOVE) Main building of Lick Observatory at night. (Photo by Laurie Hatch)

Lick Observatory Panel Featured on KQED

(ABOVE, FROM LEFT) Aaron Romanowksy (SJSU), Alex Filippenko (UCB), Bob Rucker (SJSU), Brenda Norrie (SJSU), Beth Johnson (SJSU), Richard Vo (SFSU).

Renowned astrophysicists Dr. Alex Filippenko, UC Berkeley, and Professor Aaron Romanowsky, SJSU, discussed Lick Observatory in a recent panel discussion on KQED.

Topics include Lick's rich history, the current research being conducted at Mount Hamilton by students and UC astronomers, and how the public can get involved with the observatory.

See the YouTube video here. The video starts at 1 minute, 30 seconds, and the panel discussion begins at ten minutes, 40 seconds.

Robert P. Kraft Remembered

Robert P. Kraft, an eminent astronomer and former director of the University of California Observatories and Lick Observatory, died on Tuesday, May 26, at Dominican Hospital in Santa Cruz. Kraft, a professor emeritus of astronomy and astrophysics at UC Santa Cruz, was 87.

A widely recognized researcher, Kraft was also a gifted administrator who helped guide astronomy into the modern era. He joined the astronomy faculty at UC Santa Cruz and Lick Observatory in 1967. After two appointments as acting director, he was named director of Lick Observatory in 1981 and became director of the newly created UC Observatories in 1988. In that position, he oversaw both Lick Observatory and UC's role in building the state-of-the-art W. M. Keck Observatory in Hawaii.

A memorial service will take place on July 18, 2015, at 2 p.m. at the Unitarian Fellowship in Aptos, CA.

See the full press release by Tim Stephens here.

(ABOVE) Robert Kraft with David Hilyard in the Lick Observatory optical facilities at UC Santa Cruz. (Michael Bolte)

(LEFT) Robert Kraft with George Preston and George Wallerstein. **(RIGHT)** Robert Kraft with students (left) Matt Shetrone, (middle) Eileen Friel, and (right) Nick Suntzeff. (Photos by Michael Bolte)

Tribute by John Faulkner

I regret to inform you that Robert Paul Kraft, "Bob" to us all, passed away on Tuesday, 26th May, 2015. He was just 3 weeks short of his 88th birthday. His ending was peaceful, and possibly what he would have chosen for himself. His son Kevin, present with low level light in his room at Dominican Hospital in Santa Cruz, was softly playing him a recording of Bob's much loved symphony, Beethoven's 9th, when he ceased to breathe.

Bob Kraft did pioneering work on Cepheid variables and on stellar rotation. Who that heard it can ever forget his most memorably titled colloquium at Caltech "The angular momentum vector syndrome --- a new result in stellar pathology"?

Between 1962 and 1965, Bob Kraft published a remarkable series of now classic papers, "Binary Stars among Cataclysmic Variables" (I through VII). He convincingly demonstrated that both the bright classical novae, known from antiquity, and the much fainter dwarf novae, whose studies essentially began in the 19th century, all had one thing in common --- they were binary star systems! These papers clinched a novel suggestion he'd originally made during the preceding five or six years for a structural connection between the "flaring" 17hr binary AE Aqr and the nova DQ Her. For this brilliantly conceived and superbly executed earlier research, Bob was awarded the Helen B. Warner Prize by the American Astronomical Society. Subsequently, he turned his attention to the chemical evolution of the Milky Way.

(ABOVE) Robert P. Kraft

Soon after Bob Kraft joined Lick Observatory in 1967, he was persuaded to become its acting director. It was not a position he had sought; he only did it reluctantly, as a public duty. He finally agreed to become its official director from 1981-1991, a period during which the Keck Telescope projects were conceived and executed. He was the President of the AAS from 1974 to 1976, and President of the International Astronomical Union from 1997 to 2000.

Bob had a remarkable breadth of interests and loved to share his enthusiasm for them. Early on he taught a Wine Appreciation course in Stevenson College, following that up with several Music Appreciation courses, particularly his beloved Beethoven course. In recent years he gave many Lifelong Learner courses on topics such as Opera or The Enlightenment. But there was also The Beatles. After Bob had first played the vinyl LP "Abbey Road," he went round to his next door neighbor's home, declaring that "Abbey Road is the Beethoven 9th of the Rock World!" He insisted that his neighbor should immediately drop everything and go next door to listen to it with him, as he played it completely through again.

Bob's wife Rosalie Ann Kraft died on May 5, 2009, after a marriage lasting nearly 60 years. Bob is survived by his elder son Kenneth Kraft, Kenneth's wife Ginger Charron Kraft, their son and and Bob's grandson Cary Kraft, his younger son Kevin Kraft and Kevin's partner Herman Brown.

John Faulkner,

UCSC Professor Emeritus
and Bob's next door neighbor 1969-70

From Earth to Neptunes

Geoffrey Marcy, UC Berkeley

Small planets—those 1–4 times the size of Earth—are extremely common among sun-like stars. And surprisingly so, given that our own solar system has no planets at all in that size range, which would lie between Earth and Neptune. That result—and insight into the division between sub-Neptunes and super-Earths—comes from our five-year study of small planets, using NASA's space-borne Kepler telescope in tandem with the Keck Observatory.

Based on Kepler results, we estimate that 51% of sun-like stars harbor a planet 1–4 times Earth's size within half an AU. These planets seem to be sprinkled uniformly with logarithmic distance out to that limit. Keck I and its HIRES spectrometer played a key role in the discovery, by ruling out false planets and pinning down the sizes of the planets.

The Keck I observations also allowed us to measure planets' masses, by observing the wobble induced by each planet's gravity. We nailed down the masses of 33 planets.

Combined with diameter measurements from Kepler and Keck, the masses give us the planets' densities. We have found that planets smaller than 1.5 Earth radii are purely rock—akin to Earth, Venus, and Mars. The 1.5-Earth-radius mark represents something of a local maximum: These planets have the highest densities of all—nearly 10 g/cc—thanks to their self-gravitational compression. They are the super-Earths.

Bigger than 1.5 Earth radii, and planets seem to harbor low-density material, as well—likely some combination of hydrogen, helium, and ices. These seem to have an envelope of low-density material surrounding a core of rock—befitting the appellation "sub-Neptunes." ■

(LEFT, TOP) Nate Tellis, Geoff Marcy, Erik Petigura, Howard Isaacson **(BOTTOM ROW)** Matt Heising, Lauren Weiss, Lea Hirsch, Bekki Dawson **(BELOW)** Rea Kolbl

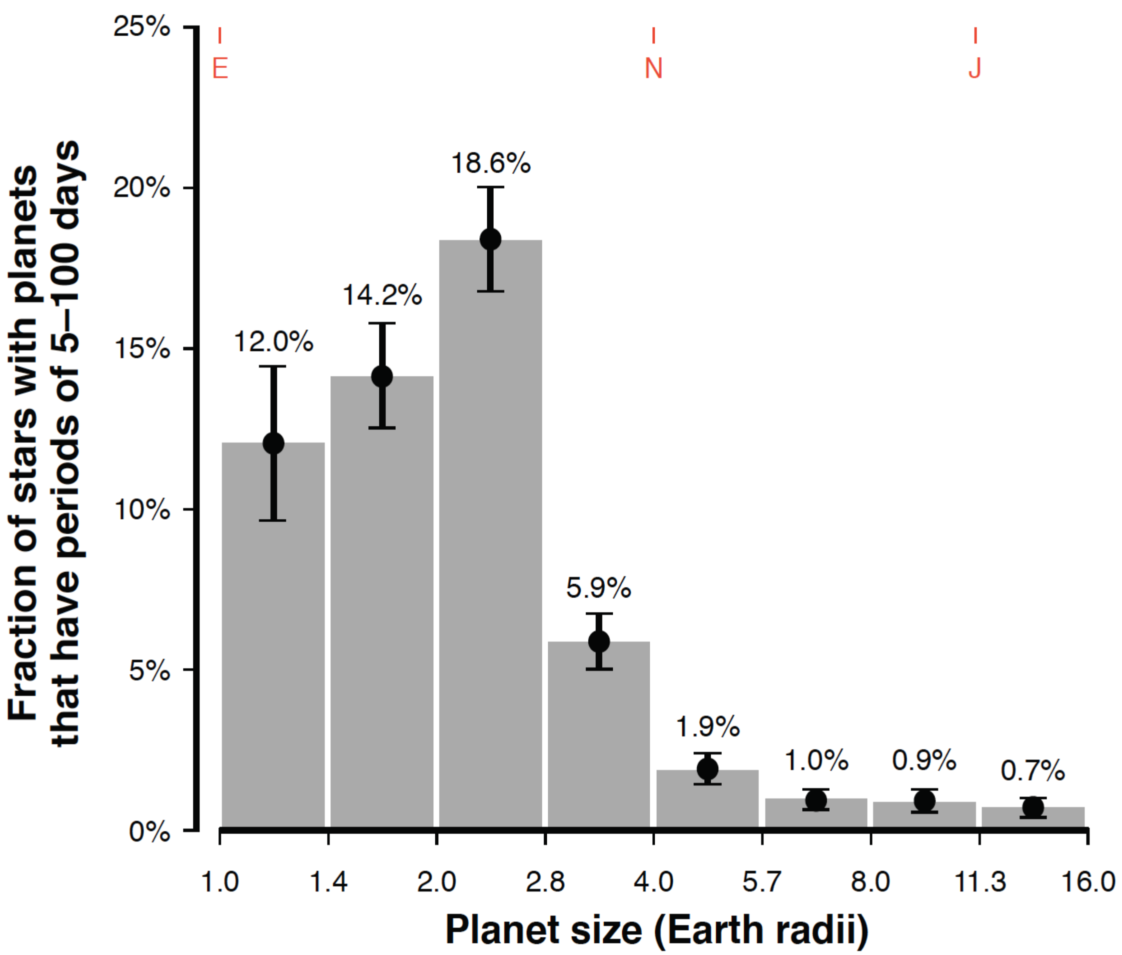


Figure 1. Planets smaller than Neptune (red "N") are more common around sun-like stars than planets larger than Neptune, at least when considering those with orbital periods shorter than 100 days. This figure is from the Ph.D. thesis of Erik Petigura (UC Berkeley).

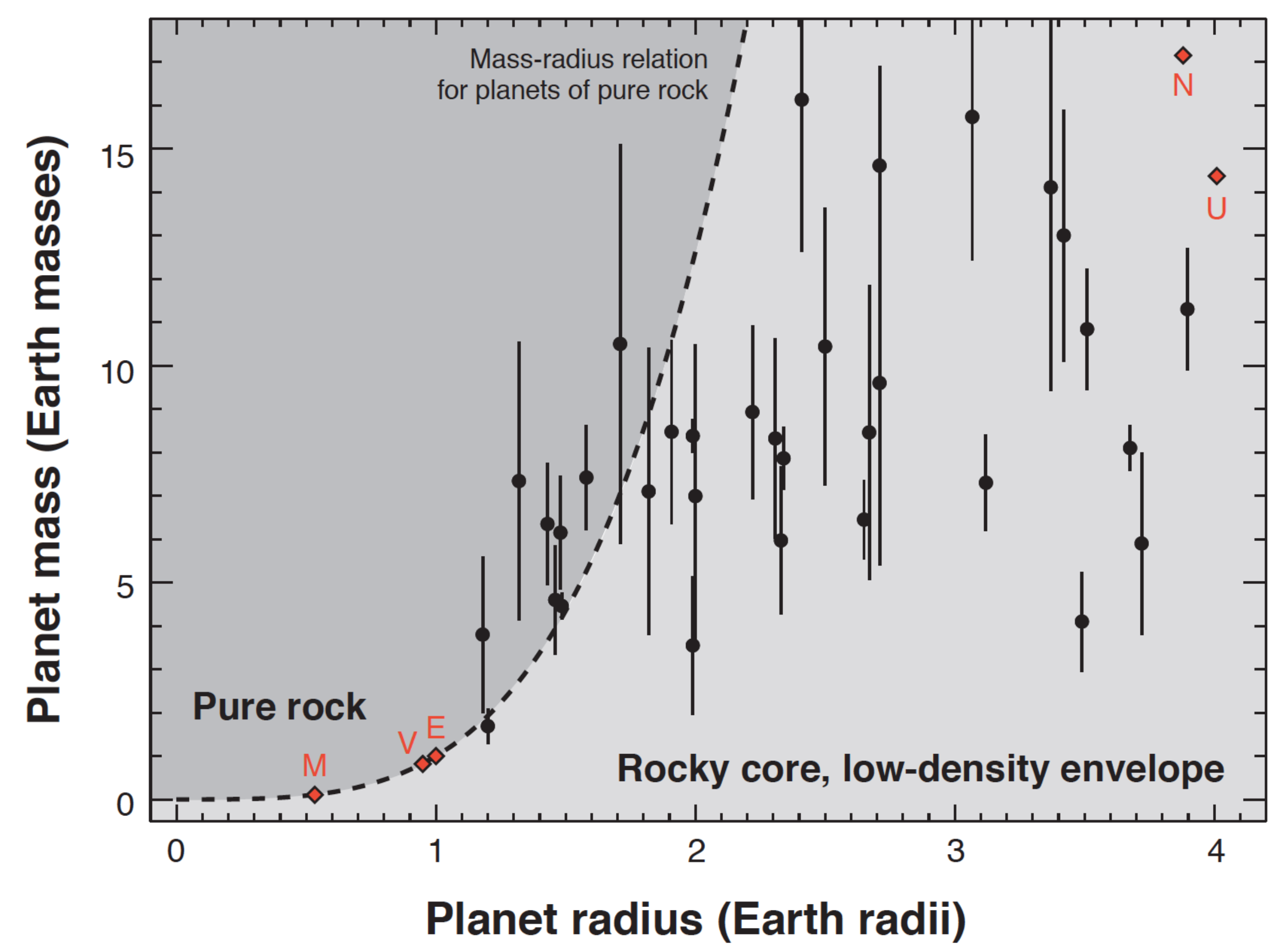
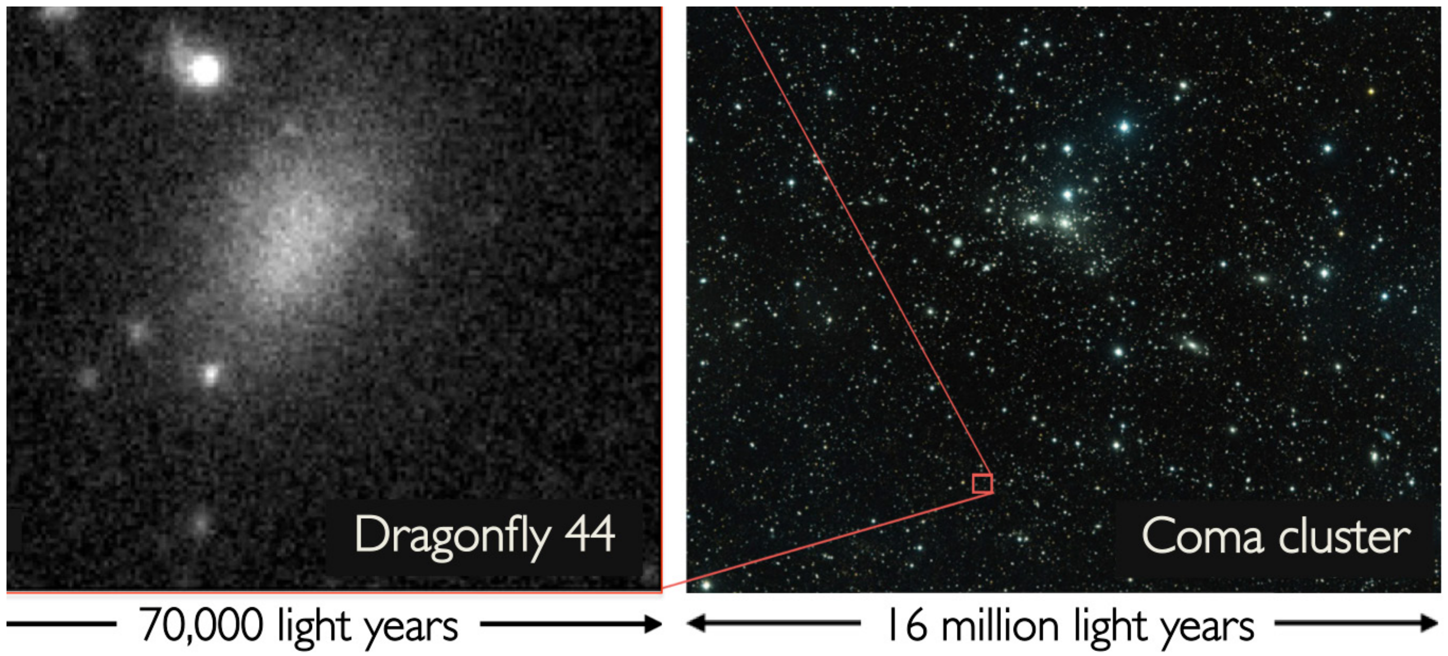


Figure 2. Planets smaller than 1.5 Earth radii tend to be fully rocky (darker gray area). Those larger than 1.5 Earth radii (lighter gray area) probably have a rocky core and an envelope of low-density material, because they're larger than planets of pure rock, yet have about the same mass. This figure is from the work of student Lauren Weiss (UC Berkeley). The core-envelope structure is exactly that predicted by theoretical work of graduate students Eric Lopez and Angie Wolfgang (UC Santa Cruz).

Astronomers Discover the Fluffiest Galaxies



(ABOVE) A collection of unidentified blobs was discovered toward the Coma cluster of galaxies, using the Dragonfly Telephoto Array. One of these puzzling objects, Dragonfly 44, was studied in detail using the Keck Observatory and confirmed as an ultra-diffuse galaxy. Even though it is 60,000 light years across, It is so far away that it appears as only a faint smudge. Credit: P. Van Dokkum, R. Abraham, J. Brodie

An international team of researchers have used the W. M. Keck Observatory to confirm the existence of the most diffuse class of galaxies known in the universe. These "fluffiest galaxies" are nearly as wide as our own Milky Way galaxy – about 60,000 light years – yet harbor only one percent as many stars. The findings were recently published in the Astrophysical Journal Letters.

"If the Milky Way is a sea of stars, then these newly discovered galaxies are like wisps of clouds", said Pieter van Dokkum of Yale University, who lead the team of researchers. "We are beginning to form some ideas about how they were born and it's remarkable they have survived at all. They are found in a dense, violent region of space filled with dark matter and galaxies whizzing around, so we think they must be cloaked in their own invisible dark matter 'shields' that are protecting them from this intergalactic assault."

The team made the latest discovery by combining results from one of the world's smallest telescopes as well as the largest telescope on Earth. The Dragonfly Telephoto Array used 14-centimeter state of the art telephoto lens cameras to produce digital images of the very faint, diffuse objects. Keck Observatory's 10-meter Keck I telescope, with its Low Resolution Imaging Spectrograph, then separated the light of one of the objects into colors that diagnose its composition and distance.

Finding the distance was the clinching evidence. The data from Keck Observatory showed the diffuse "blobs" are very large and very far away, about 300 million light years, rather than small and close by. The blobs can now safely be called Ultra Diffuse Galaxies (UDGs).

"If there are any aliens living on a planet in an ultra-diffuse galaxy, they would have no band of light across the sky, like our own Milky Way, to tell them they were living in a galaxy. The night sky would be much emptier of stars," said team member Aaron Romanowsky, of San Jose State University.

The UDGs were found in an area of the sky called the Coma cluster, where thousands of galaxies have been drawn together in a mutual gravitational dance. "Our fluffy objects add to the great diversity of galaxies that were previously known, from giant ellipticals that outshine the Milky Way, to ultra compact dwarfs," said Jean Brodie, UC Observatories astronomer and professor at UC Santa Cruz.

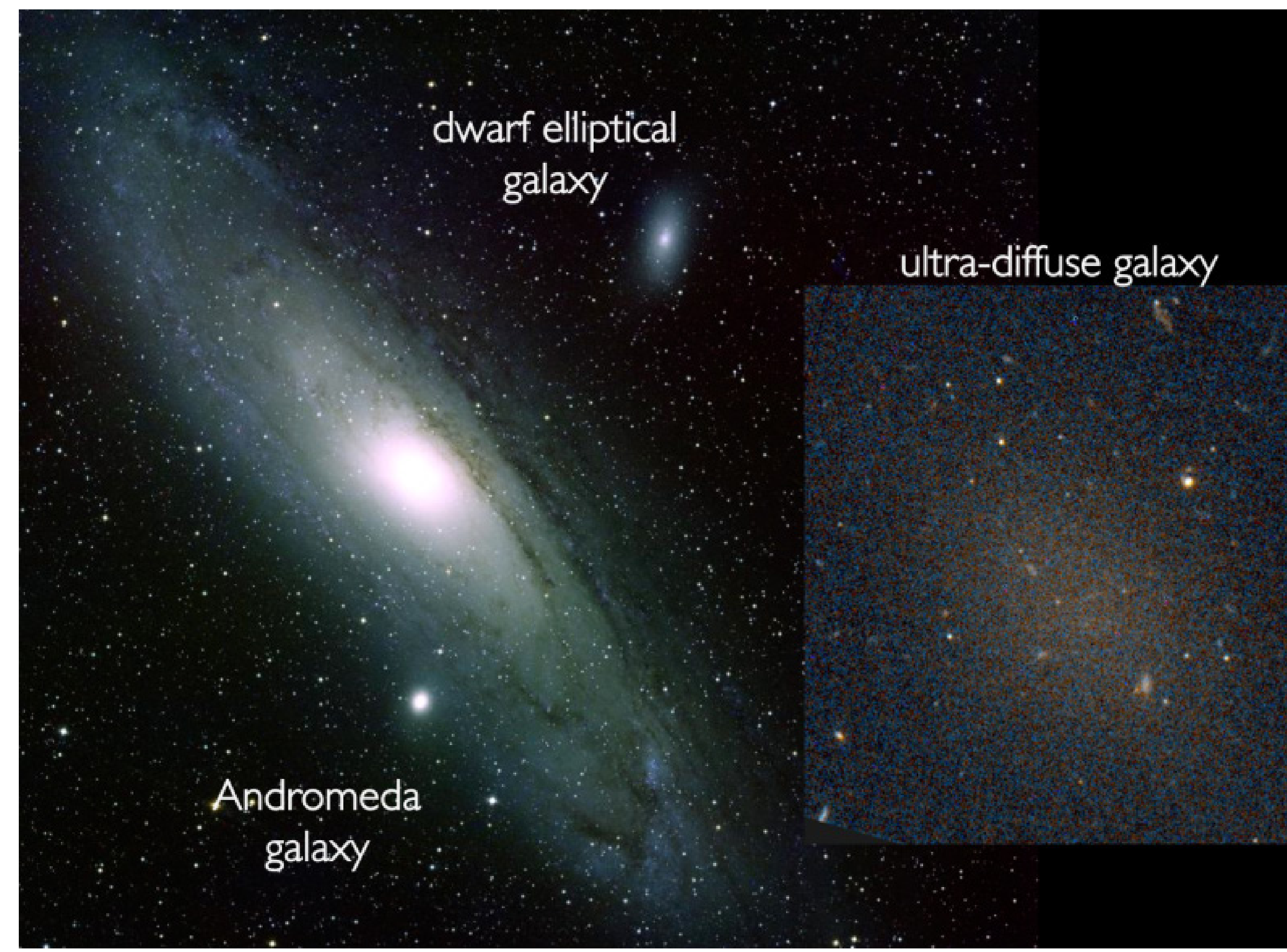
"The big challenge now is to figure out where these mysterious objects came from," said Roberto Abraham, of the University of Toronto. "Are they 'failed galaxies' that started off well and then ran out of gas? Were they once normal galaxies that got knocked around so much inside the Coma cluster that they puffed up? Or are they bits of galaxies that were pulled off and then got lost in space?"

The key next step in understanding UDGs is to to pin down exactly how much dark matter they have. Making this measurement will be even more challenging than the latest work.

The W. M. Keck Observatory operates the largest, most scientifically productive telescopes on Earth. The two, 10-meter optical/infrared telescopes near the summit of Mauna Kea on the Island of Hawaii feature a suite of advanced instruments including imagers, multi-object spectrographs, high-resolution spectrographs, integral-field spectrographs and world-leading laser guide star adaptive optics systems.

Keck Observatory is a private 501(c) 3 non-profit organization and a scientific partnership of the California Institute of Technology, the University of California Observatories (UCO) and NASA. ■

UCO press release published on May 14, 2015.



(ABOVE) Reconstructed spectrum of light spread out from the ultra-diffuse galaxy, DragonFly44, as seen by the Keck/LRIS instrument. Dark bands occur where atoms and molecules absorb the galaxy's starlight. These bands reveal the compositions and ages of the stars, and also the distance of the galaxy. Credit: P. Van Dokkum, A. Romanowsky, J. Brodie

Galaxy Formation with the MOSDEF Survey

Alice Shapley, UCLA, on behalf of the MOSDEF team

Key questions in the study of galaxy formation include: What are the physical processes driving star formation in individual galaxies over cosmic time? How do galaxies exchange gas and heavy elements with the intergalactic medium?

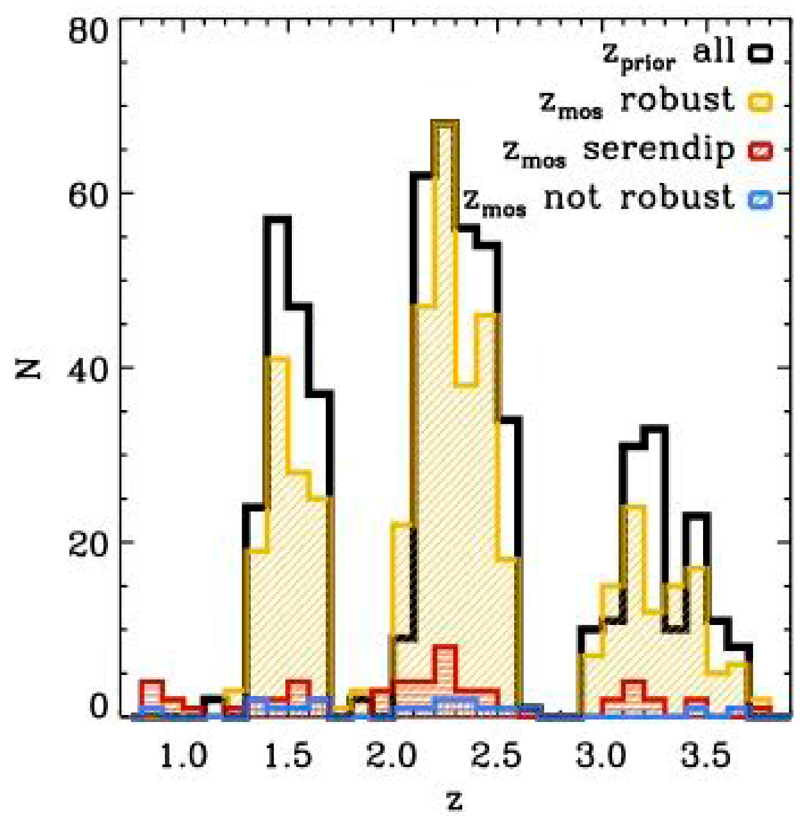
How are stellar mass and structure assembled in galaxies (in situ star formation vs. mergers)? What is the nature of the co-evolution of supermassive black holes and galaxies?

The MOSFIRE Deep Evolution Field (MOSDEF) survey, a Keck LMAP program allocated 44 nights from 2013 - 2016, is designed to address these questions.

The co-PIs of the MOSDEF survey are at UC Riverside (Naveen Reddy, Brian Siana, and Bahram Mobasher), UC Berkeley (Mariska Kriek), UC San Diego (Alison Coil), and UCLA (Alice Shapley).

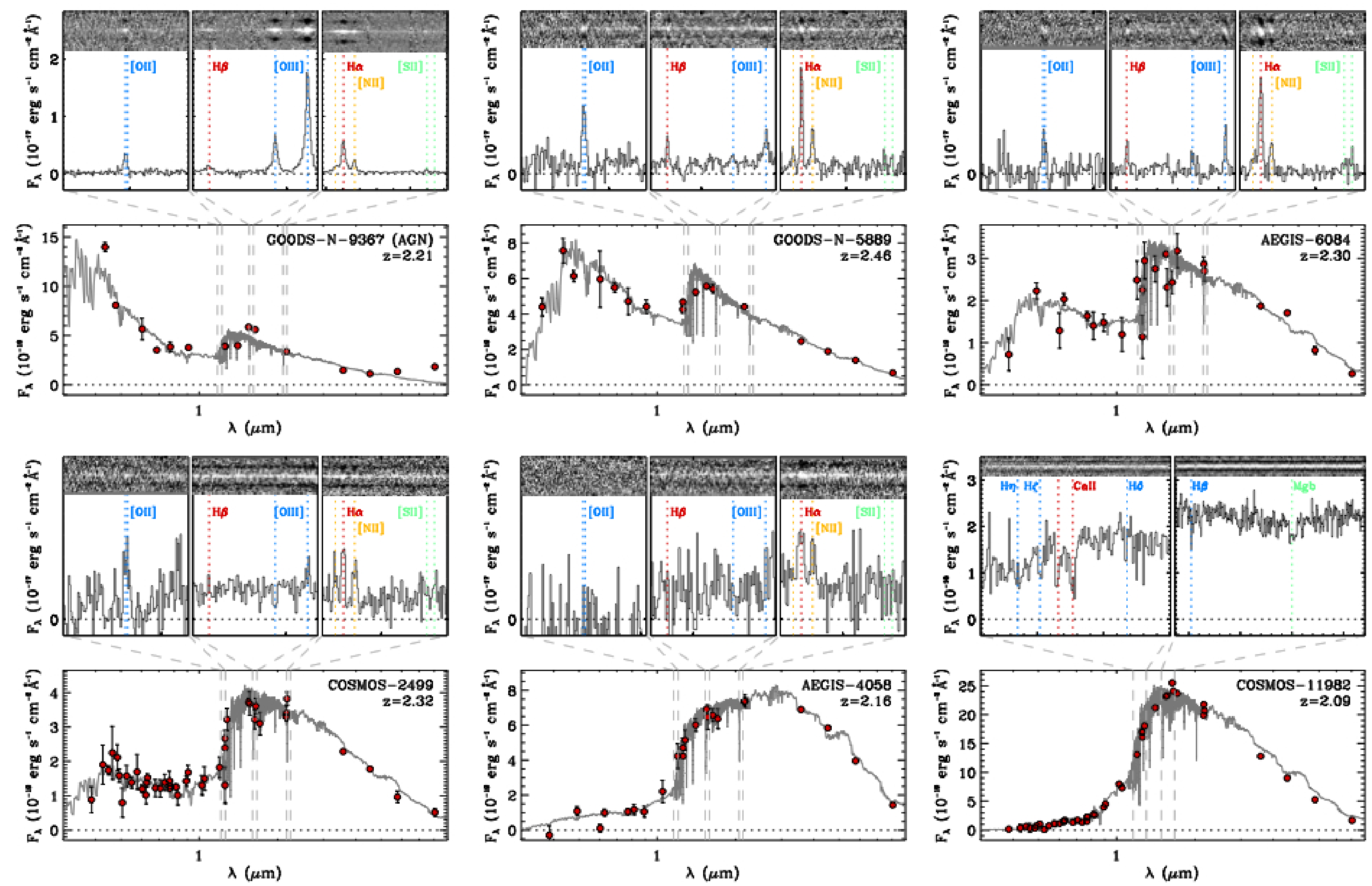
The MOSDEF team is collecting rest-frame optical spectra and observing the stellar, gaseous, chemical and black hole content of ~1500 galaxies in the COSMOS, AEGIS, and GOODS-N legacy fields when the Universe was only 1.5 to 4.5 billion years old. So far, MOSEF has obtained spectra for more than 700 galaxies, covering both nebular emission lines such has [OII], H-beta, [OIII], H-alpha, [NII], and [SII], and stellar absorption features such as Ca II H+K.

Early published science results include an investigation of the relations among stellar mass, gas-phase oxygen abundance, and star formation at z~2, the physical properties of z~2 star-forming regions, the multi-wavelength selection of AGNs, the dust attenuation curve at z~2, and a full description of the survey. MOSDEF data products will be made public at the completion of the survey, and redshifts from the first season of observing are available here.



(ABOVE) The MOSDEF redshift distribution compared to the prior redshift distribution used for target selection (black histogram). The MOSDEF redshift distribution is divided into robust redshifts (yellow histogram), inconclusive redshifts (blue histogram), and robust redshifts derived for serendipitous detections (red histogram).

"So far, we have obtained spectra for more than 700 galaxies."



This figure features examples of spectra collected as part of the MOSDEF survey, along with spectral energy distributions (SEDs) showing the multi-wavelength electromagnetic output of each galaxy.

The overall spectral shape highlights the relative importance of young, massive stars, relative to older stellar populations, as well as the effects of dust attenuation. Both the presence of dust and old stars tend to redden the SEDs. The MOSDEF survey covers galaxies with a wide range of stellar populations, spanning from young, blue galaxies to old, red galaxies. Accordingly, the MOSDEF team is obtaining a representative sampling of galaxies in the early universe. The MOSFIRE spectra typically show emission lines from ionized hydrogen, oxygen, nitrogen, and sulfur gas. In one case (lower right), stellar absorption lines from hydrogen and calcium are observed.

Astronomers Discover Rare Quasar Quartet

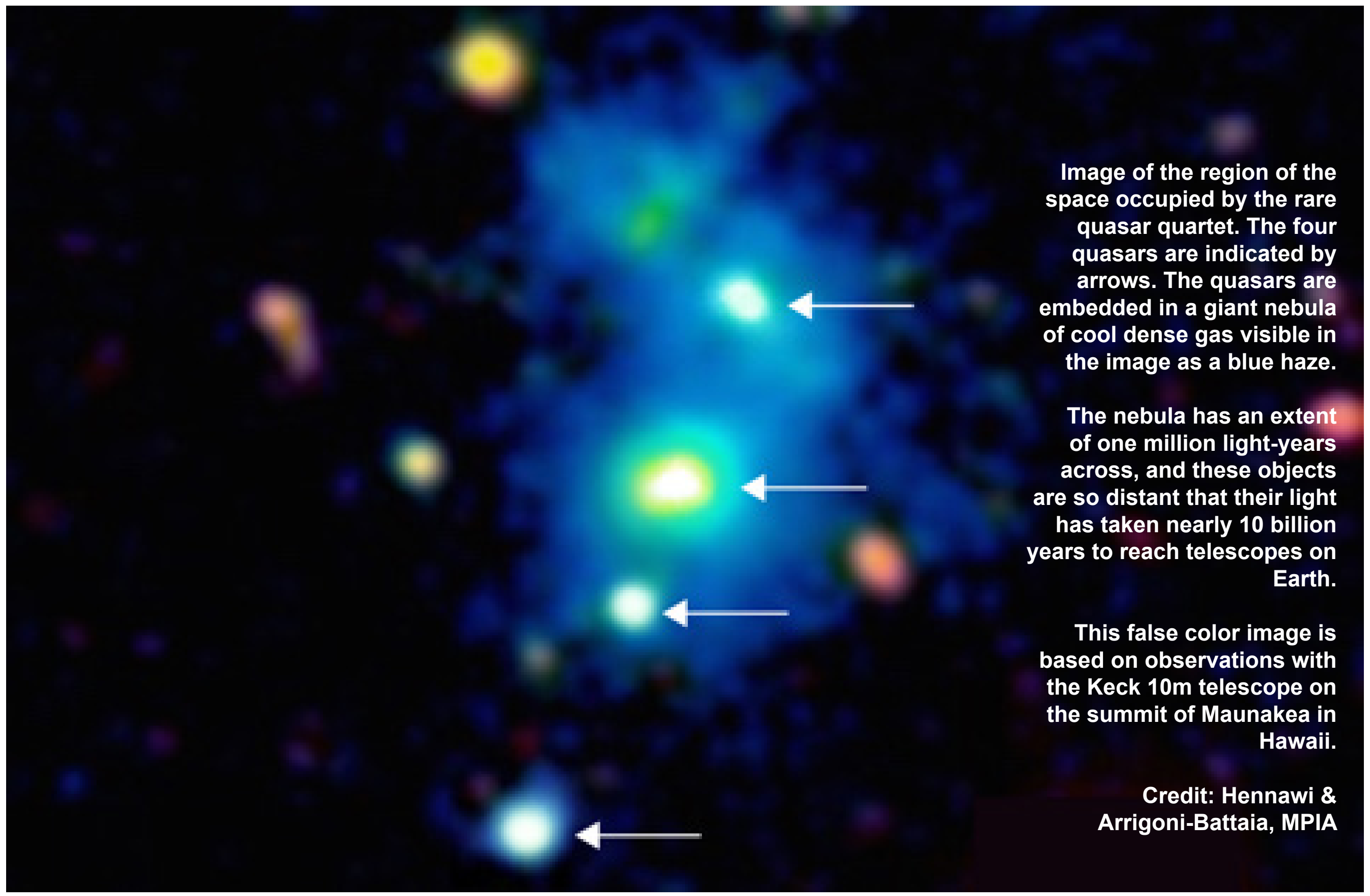


Image of the region of the space occupied by the rare quasar quartet. The four quasars are indicated by arrows. The quasars are embedded in a giant nebula of cool dense gas visible in the image as a blue haze.

The nebula has an extent of one million light-years across, and these objects are so distant that their light has taken nearly 10 billion years to reach telescopes on Earth.

This false color image is based on observations with the Keck 10m telescope on the summit of Maunakea in Hawaii.

Credit: Hennawi & Arrigoni-Battaia, MPIA

Using the W. M. Keck Observatory in Hawaii, a group of astronomers led by Joseph Hennawi of the Max Planck Institute for Astronomy have discovered the first quadruple quasar: four rare active black holes situated in close proximity to one another. The quartet resides in one of the most massive structures ever discovered in the distant universe, and is surrounded by a giant nebula of cool dense gas. Because the discovery comes with one-in-ten-million odds, perhaps cosmologists need to rethink their models of quasar evolution and the formation of the most massive cosmic structures. The results are published in the May 15, 2015 edition of the journal Science.

Hitting the jackpot is one thing, but if you hit the jackpot four times in a row you might wonder if the odds were somehow stacked in your favor.

Quasars constitute a brief phase of galaxy evolution, powered by the in-fall of matter onto a supermassive black hole at the center of a galaxy. During this phase, they are the most luminous objects in the Universe, shining hundreds of times brighter than their host galaxies, which themselves contain hundreds of billions of stars. But these hyper-luminous episodes last only a tiny fraction of a galaxy's lifetime, which is why astronomers need to be very lucky to catch any given galaxy in the act. As a result, quasars are exceedingly rare on the sky, and are typically separated by hundreds of millions of light years from one another. The researchers estimate that the odds of discovering a quadruple quasar by chance is one in ten million. How on Earth did they get so lucky?

Clues come from peculiar properties of the quartet's environment. The four quasars are surrounded by a giant nebula of cool dense hydrogen gas, which emits light because it is irradiated by the intense glare of the quasars. In addition, both the quartet and the surrounding nebula reside in a rare corner of the universe with a surprisingly large amount of matter. "There are several hundred times more galaxies in this region than you would expect to see at these distances," said J. Xavier Prochaska, professor at the UC Santa Cruz and the principal investigator of the Keck Observatory observations.

Given the exceptionally large number of galaxies, this system resembles the massive agglomerations of galaxies, known as galaxy clusters, that astronomers observe in the present-day universe. But because the light from this cosmic metropolis has been travelling for 10 billion years before reaching Earth, the images show the region as it was 10 billion years ago, less than 4 billion years after the big bang. It is thus an example of a progenitor or ancestor of a present-day galaxy cluster, or proto-cluster for short.

Piecing all of these anomalies together, the researchers tried to understand what appears to be their incredible stroke of luck. "If you discover something which, according to current scientific wisdom should be extremely improbable, you can come to one of two conclusions: either you just got very lucky, or you need to modify your theory," Hennawi said.

The researchers speculate that some physical process might make quasar activity much more likely in specific environments. One possibility is that quasar episodes are triggered when galaxies collide or merge, because these violent interactions efficiently funnel gas onto the central black hole. Such encounters are much more likely to occur in a dense proto-cluster filled with galaxies, just as one is more likely to encounter traffic when driving through a big city.

"The giant emission nebula is an important piece of the puzzle since it signifies a tremendous amount of dense cool gas," said Fabrizio Arrigoni-Battaia, a PhD student at the Max Planck Institute for Astronomy who was involved in the discovery.

Supermassive black holes can only shine as quasars if there is gas for them to swallow, and an environment that is gas rich could provide favorable conditions for fueling quasars.

On the other hand, given the current understanding of how massive structures in the universe form, the presence of the giant nebula in the proto-cluster is totally unexpected. "Our current models of cosmic structure formation based on supercomputer simulations predict that massive objects in the early universe should be filled with rarefied gas that is about ten million degrees, whereas this giant nebula requires gas thousands of times denser and colder," said Sebastiano Cantalupo, currently at ETH Zurich, that led the imaging observations a the Keck Observatory during his previous research appointment at UCSC. "It is really amazing that this discovery was made the same night of the Slug Nebula while we were hunting for giant Lyman alpha nebulae illuminated by quasars – my first night at Keck Observatory and definitely the most exciting observing night I have ever had!"

"Extremely rare events have the power to overturn long-standing theories" Hennawi said.

As such, the discovery of the first quadruple quasar may force cosmologists to rethink their models of quasar evolution and the formation of the most massive structures in the universe.

The authors wish to recognize and acknowledge the very significant cultural role and reverence that the summit of Mauna Kea has always had within the indigenous Hawaiian community. We are most fortunate to have the opportunity to conduct observations from this mountain.

The W. M. Keck Observatory operates the largest, most scientifically productive telescopes on Earth. The two, 10-meter optical/infrared telescopes near the summit of Mauna Kea on the Island of Hawaii feature a suite of advanced instruments including imagers, multi-object spectrographs, high-resolution spectrographs, integral-field spectrographs and world-leading laser guide star adaptive optics systems.

The Low Resolution Imaging Spectrometer (LRIS) is a very versatile visible-wavelength imaging and spectroscopy instrument commissioned in 1993 and operating at the Cassegrain focus of Keck I. Since it has been commissioned it has seen two major upgrades to further enhance its capabilities: addition of a second, blue arm optimized for shorter wavelengths of light; and the installation of detectors that are much more sensitive at the longest (red) wavelengths. Each arm is optimized for the wavelengths it covers. This large range of wavelength coverage, combined with the instrument's high sensitivity, allows the study of everything from comets (which have interesting features in the ultraviolet part of the spectrum), to the blue light from star formation, to the red light of very distant objects. LRIS also records the spectra of up to 50 objects simultaneously, especially useful for studies of clusters of galaxies in the most distant reaches, and earliest times, of the universe.

Keck Observatory is a private 501(c) 3 non-profit organization and a scientific partnership of the California Institute of Technology, the University of California Observatories and NASA.

Keck press release published on May 14, 2015.

UCLA to lead NSF-Funded Map of Milky Way's Central Bulge

Michael Rich, UCLA

The National Science Foundation has funded an international team led by UCLA astronomer R. Michael Rich, Caty Pilachowski (Indiana University), and Will Clarkson (U. Michigan Dearborn) to use the world's largest camera to map the central bulge of the Milky Way from Chile.

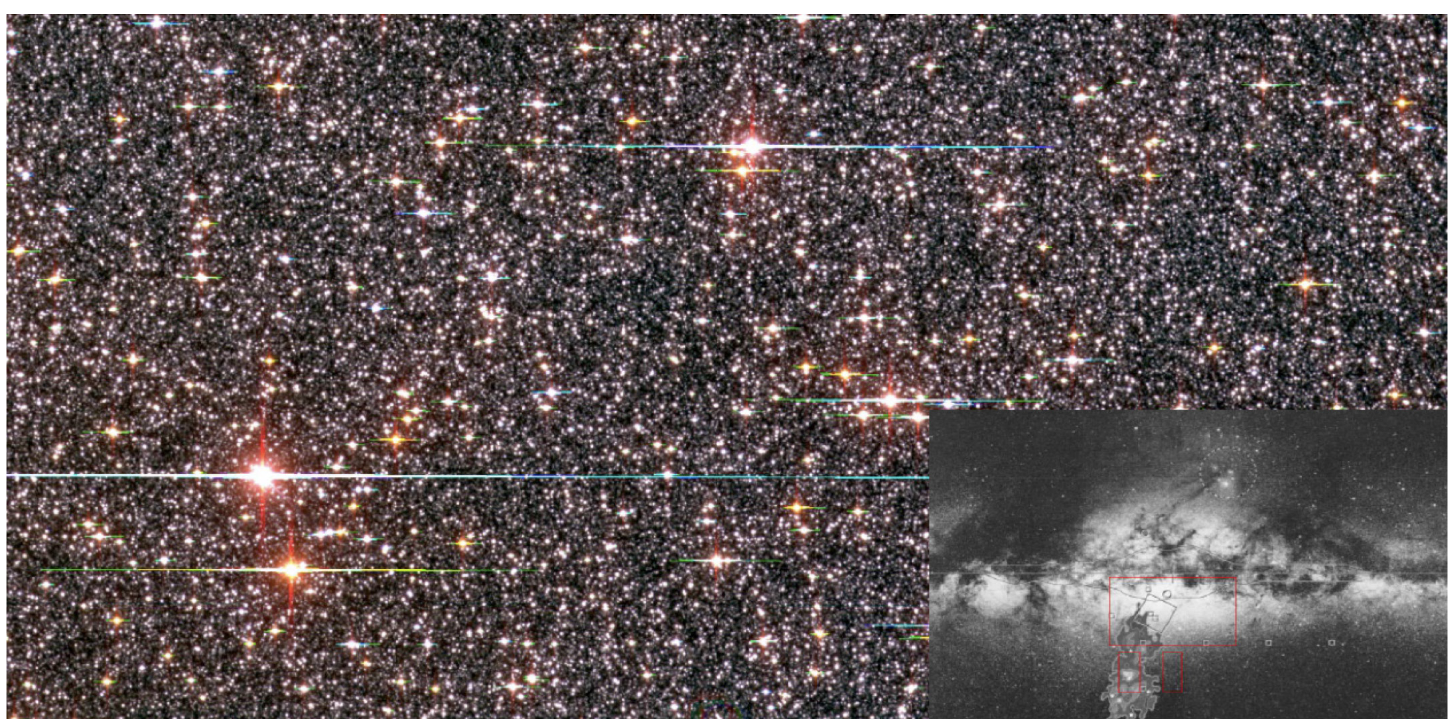
The Blanco DECam Bulge Survey image will span from ultraviolet to near-infrared light in Sloan ugrizY passbands and has produced data very similar to that of the future Large Synoptic Survey Telescope (LSST).

The team will map the three dimensional structure, orbital motions, stellar age, and metal content of stars in the inner 3000 light years of the Milky Way, gaining new insight into its formation history.

The Milky Way's central regions are like a huge metropolitan area, with an enormous black hole at the center that is the equivalent in mass of 4 million Suns, surrounded by a host of stellar suburbs. These are habitats for stars ranging in age from about 12 billion years old to only a few million years old; the survey may give us a picture of how this region of our Galaxy has formed and changed over time. The Dark Energy Camera, funded by the DOE and NSF, is at the prime focus of the Blanco 4m telescope at Cerro Tololo Observatory in Chile and is able to take an image of 3 square degrees of sky with a single 520 megapixel picture.

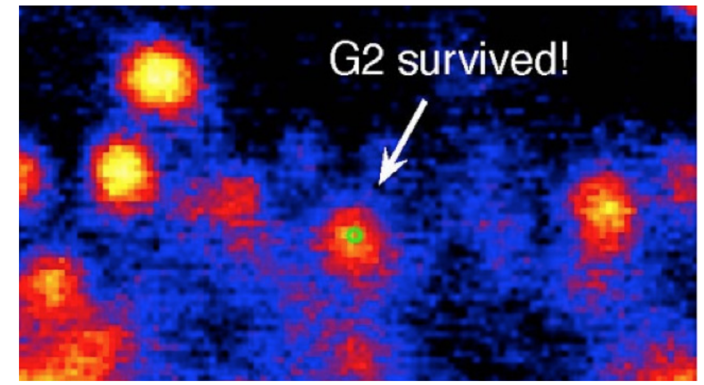
The final map will be over 100 times as large, covering all of the bright parts of the Milky Way seen toward Sagittarius; the data trove will be exploited with detailed spectroscopic observations at optical and infrared wavelengths, from the Keck Observatory. So far, the catalog has one billion stars and is still growing in size; the entire catalog will be made available to the public and world astronomical community, upon completion.

The survey and telescope are named after Victor M. Blanco, who was the first Director of Cerro Tololo Observatory. ■



Astronomers Solve G2 Puzzle in the Center of the Milky Way

Andrea Ghez, UCLA



For years, astronomers have been puzzled by G2, a bizarre object in the center of the Milky Way that was believed to be a hydrogen gas cloud headed toward our galaxy's enormous black hole with a prediction of tidal disruption this past summer.

The UCLA/Keck Galactic Center Group reported in Astrophysical Letters that G2 survived its closest approach and determined that G2 is most likely a pair of binary stars that had been orbiting the black hole in tandem and merged together into an extremely large star, embedded in gas and dust - its movements choreographed by the black hole's powerful gravitational field. See the UCLA story here.

Background: The UCLA/Keck Galactic Center Group, founded 20 years ago by Professors Andrea Ghez, Mark Morris & Eric Becklin, is dedicated to researching the innermost regions of the Milky Way at the highest angular resolution possible in order to understand the formation and evolution of galaxies and their central supermassive black holes. Over the past two decades, dramatic advances in imaging technology have led to order-of-magnitude improvements in spatial detail, and the UCLA Galactic Center Group has been consistently at the forefront of these advances with the Keck telescopes.

One of the most important early outcomes of this work was the co-discovery of the presence of a supermassive black hole at the center of our Galaxy. This was done by tracking the motions of stars. The rapidity with which these stars move on small-scale orbits indicates a source of tremendous gravity and provides the best evidence that supermassive black holes, which confront and challenge our knowledge of fundamental physics, do exist in the Universe. In other studies of the Galactic center, they have shown that what happens near a supermassive back hole is quite different than what theoretical models have predicted, which changes many of our notions about how galaxies form and evolve over time.

Learn more about the UCLA/Keck Galactic Center.

Keck Imager in Development

UCSB Associate Professor Ben Mazin and collaborators are developing a new instrument concept for KECK called KRAKENS.

KRAKENS is a one square arcminute imager using superconducting MKIDs, which can count single photons and determine their energy.

Those interested in helping to develop the science case for KRAKENS should contact Professor Mazin at **bmazin@physics.ucsb.edu**. ■

Projects at UCSC Shops

Dave Cowley, Technical Facilities Manager

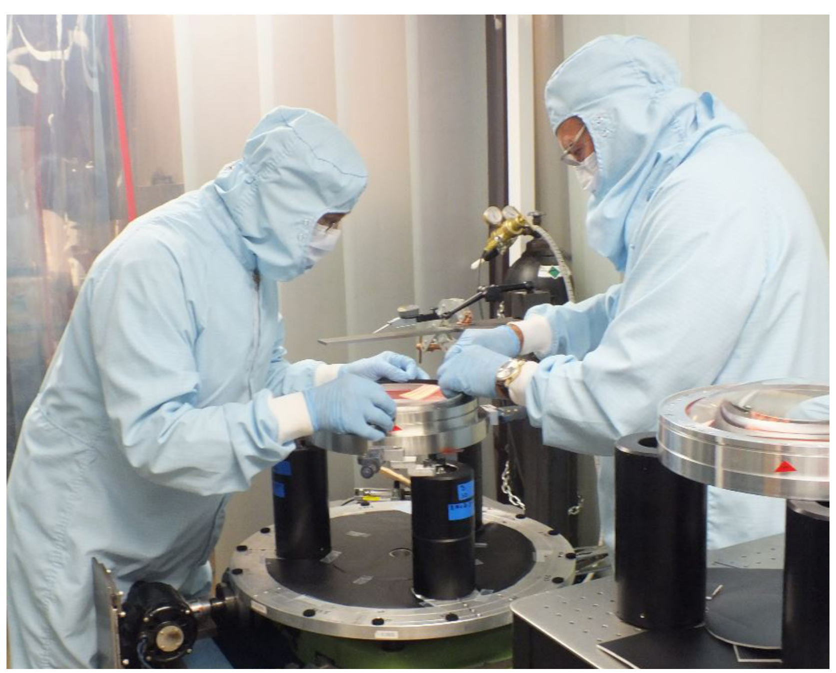
There are three major projects currently on going in the labs along with research into optics coatings.

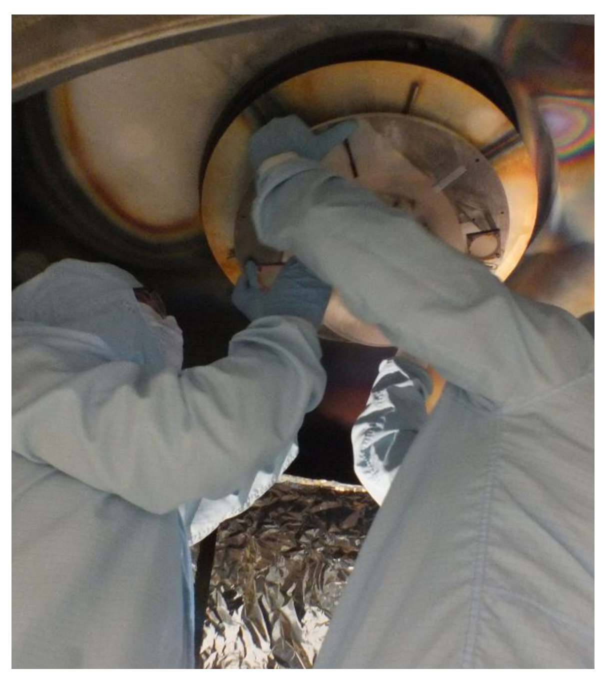
We are in the final stages of assembling a camera lens for the Keck Cosmic Web Imager, Blue side, which has 9 optical elements. The surfaces of the optical elements, some of which are very particular optical glasses from Ohara in Japan, and 4 of which are Crystal Calcium Fluoride, were fabricated to optical precision by David Hilyard in our Optics Lab. The metal cells were designed to very accurately hold the optics when being installed and maintain that accuracy when the camera is cooled to 0 degress Celcius, which is the operating temperature at the Keck Observatory in Hawaii. The cells were made both in our Instrument Lab and at UCLA's physics department. We expect to complete and deliver this camera in June this year. The NSF grant through Keck is managed by Sean Adkins, with PI Chris Martin.

We are working on the detailed design of a new deployable Tertiary Mirror for the Keck I telescope. This mirror will replace the existing one,which generally limits observing to a single instrument on any given night. The new mirror will allow any instrument mounted on the Keck I telescope to be used by changing the position of the mirror with computer commands. This will allow observers to take data from "targets of opportunity" with instruments other than the currently scheduled one when particular events occur, such as a Gamma Ray Burst. We started this project in October 2013 and expect to see first light from it at Keck in Nov 2016. Plans are being considered to design and fabricate a second one for Keck 2. The NSF grant is managed through UCSC, with PI J. Xavier Prochaska.

We have just started a project to upgrade the red detector in the Kast Spectrograph at Lick to a Hamamatsu device This device will greatly improve efficiency of the Red side of the Kast Spectrograph on the Shane Telescope. Funding for this project was provided by the Heising-Simons Foundation and from Bill and Marina Kast.

Drew Philips and Brian Dupraw continue to research new optical coatings for both reflective and refractive optics. Recently they have been developing silver coatings for large mirrors that are both more efficient in the blue wave lengths than standard silver coatings, and more durable. In March this coating was put on the M2 and M3 mirrors of the APF telescope on Mt Hamilton. Coatings research physical upgrades are funded by NSF grants and on going research funded by UCO, with PI Drew Phillips. ■





(LEFT) David Hilyard and Terry Pfister measuring the position of a KCWI lens in its cell. **(RIGHT)** David Hilyard and Drew Phillips mounting the APF M2 mirror in the coating tank.

Infrared Lab Milestones

Ian McLean, Director of UCLA Infrared Laboratory

In the past year, the UCO/UCLA Infrared Laboratory (IR Lab) achieved several new milestones in its long run of successes since the lab was founded in 1989 by Professors McLean and Becklin.

In the fall of 2013, a powerful new instrument called the Gemini Planet Imager (GPI) obtained "first light" on the 8-m Gemini South telescope in Chile. GPI, a high-contrast, adaptive optics camera, was led by Dr. Bruce Macintosh (the first graduate of the IR Lab in 1994, now at Stanford). The UCLA group designed and built GPI's integral field spectrometer (PI James Larkin), which allows astronomers to capture images and spectra of planets orbiting nearby stars. First-light results were spectacular. Some of the early measurements contributed to the PhD of UCLA student Jeff Chilcote (Bachman awardee 2013), who graduated UCLA in June 2014 and is now a postdoctoral researcher at the Dunlap Institute, University of Toronto. James Larkin, Mike Fitzgerald, and other members of the GPI team, are now actively engaged in science programs with the GPI instrument.

In February 2014, UCLA's infrared camera for NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) was successfully commissioned in flight (PI Ian McLean). UCLA graduate student Sarah Logsdon made 8 flights with SOFIA to collect data with the camera, appropriately known as FLITECAM.

Later, in April 2014, the IR Lab celebrated two anniversaries, the second anniversary of first-light with MOSFIRE (April 2012), and the 15th anniversary of first-light with NIRSPEC back in April 1999. Ian McLean was the PI for both projects. MOSFIRE, the first multi-object spectrograph for the infrared to use a cryogenic reconfigurable slit mask unit, is working well and producing excellent science. By today's standards, NIRSPEC's detectors are old, and so the IR Lab is currently working on a proposal to upgrade NIRSPEC (PI Mike Fitzgerald). Grants from the NSF and the Moore Foundation are already in hand to upgrade OSIRIS, which the IR Lab delivered to Keck in 2005 (PI James Larkin). OSIRIS is a powerful instrument for high-angular resolution imaging and spectroscopy using the adaptive optics systems at Keck. Originally commissioned on Keck II, OSIRIS is now operational on Keck I. Including our contribution to the detector system for NIRC2 (PI Keith Matthews, Caltech), the UCLA IR Lab has therefore played an important role in all four of the currently operational infrared instruments at the Keck Observatory (see figure opposite).

Finally, yet another major milestone was reached in 2014 with the announcement of the formation of an international observatory consortium to move forward on the construction of the proposed Thirty Meter Telescope (TMT) in Hawaii. This news was significant for us because the UCO/UCLA IR Lab is the lead organization for IRIS, the Infra-Red Integral-field Spectrograph, which will be the first infrared instrument on the new telescope (PI James Larkin). ■

(ABOVE) Keck infrared instruments. (TOP ROW) OSIRIS and MOSFIRE. (BOTTOM ROW) NIRSPEC and NIRC2.

Canada Funding for TMT Announced by Prime Minister

Prime Minister Stephen Harper announced the Government of Canada's intention to provide significant support for the Thirty Meter Telescope (TMT), an international project that will build one of the world's largest and most advanced astronomical observatories in Hawaii.

Canada will provide $243.5 million toward completion of the project construction. They join California Institute of Technology, the University of California, and the science institutions of China, India, and Japan as partners in the project to build one of the world's largest and most advanced astronomical observatories in Hawaii.

Harper stated, "It was a pleasure today to announce the Government's support for the Thirty Meter Telescope project. This revolutionary facility has the potential to transform astronomers' understanding of the universe. Our Government is proud to be an official partner in this important project and to be contributing to science that will advance Canadian and international scientific discovery."

"The TMT is the top priority in Canada's Long Range Plan for Astronomy and Astrophysics, our roadmap to continued international leadership in this field. Canada's astronomers will point to today's announcement for decades to come as a critical moment in furthering our excellence in the field," said Christine Wilson, President of CASCA and Co-Chair of the Coalition for Canadian Astronomy.

Press release published on March 8, 2015 by the Thirty Meter Telescope Project.

(BELOW) Artist's rendering of the completed Thirty Meter Telescope. (Photo courtesy of TMT)

Update on TMT Protests from Director Claire Max

Dear Colleagues,

For more than a month there have been protests against construction of the Thirty Meter Telescope on Mauna Kea, following the attempted initiation of site construction there. Protests on social media have circulated worldwide, largely focused on the sacred role of Mauna Kea in Hawaiian culture.

There is a lot of information swirling around about TMT's construction on Mauna Kea.

As always, UCO remains respectful of the opinions of all parties, no matter what side of the debate you are on. In the spirit of science, all angles should be considered, and every person has a right to express their ideas and concerns in a respectful way.

UCO supports TMT in their profound regard for Hawaii's culture and environment, as well as for its people and their ancestors. The project team has launched a microsite to address and, where needed, to correct many of the grievances that are making their way around the internet. The website www.maunakeaandtmt.org provides background information, facts, answers to frequently asked questions, and a collection of balanced news coverage.

Going forward, I invite you to join the conversation. Read, widely share TMT information, and get involved with other members of the UC astronomy community. Respectful participation is the best way for us to move forward and build the greatest telescope in the world.

On May 26th, Hawaii's Governor Ige gave an important speech in which he said "My review found that the TMT project took the appropriate steps and received the approvals needed to move forward. The project has the right to proceed with construction, and the state will support and enforce its right to do so. We also acknowledge the right to protest this activity. We will protect the right to peaceful protest and will act to ensure the public safety and the right to use our roads for lawful purposes." The governor noted that there is a court challenge to the project and he will abide by the decision of the court on this matter.

The governor asked the University of Hawaii to take 10 significant actions related to enhanced stewardship in general and to the Thirty-Meter Telescope (TMT), specifically, and asked the TMT team to increase its support for Native Hawaiian students interested in science and technology. You can read the full text of this important speech here.

Claire Max

Interim Director, UC Observatories

(BELOW) The telescopes on Mauna Kea, Hawaii. (Photos by Laurie Hatch)

Total lunar eclipse over Mt. Isabel looking southeast from the Main Building rear parking area at Lick Observatory, 4 hour continuous time exposure. (Photo by Laurie Hatch)

UC Astronomy Latest Updates

Jean Brodie, professor of astronomy and astrophysics at UCSC, presented a talk on galaxy formation as part of Keck Observatory's 'Evenings with Astronomers' lecture series.

Ruth Murray-Clay, an exoplanet theorist, recently joined the faculty at UCSB. She also received the 2015 AAS Warner Prize for Astronomy.

Alex Filippenko (UCB) was elected to the American Academy of Arts and Sciences.

Piero Madau, professor of astronomy and astrophysics at UCSC, has been inducted into the Johns Hopkins Society of Scholars for achieving marked distinction in the physical sciences.

Claire Max, professor of astronomy and astrophysics at UCSC and Interim Director of UC Observatories, received the 2015 AAS Weber Award for Astronomical Instrumentation.

Imke de Pater (UCB) and **Mark Morris (UCLA)** presented their research in Keck Observatory's public talk series.

The UCO Focus is a periodic publication showcasing the scientific accomplishments, research, discoveries, instruments, technical facilities, and programs at Lick and Keck Observatories, and for the future Thirty Meter Telescope.

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If you have ideas for the next edition of the UCO Focus or Lick Observer, please e-mail your suggestions to jbrodie@ucsc.edu and lebow@ucolick.org.