



W. M. KECK OBSERVATORY
ANNUAL REPORT 2008

VISION

A world in which all humankind
is inspired and united
by the pursuit of knowledge
of the infinite variety and richness of the Universe.

MISSION

To advance the frontiers of astronomy
and share our discoveries,
inspiring the imagination of all.



Director:

Taft E. Armandroff

Deputy Director:

Hilton A. Lewis

Number of Full Time Employees: 122

Number of Keck Science Investigations FY2008: 420

Number of Refereed Articles FY2008: 268

Observatory Groundbreaking: 1985

First light Keck I telescope: 1992

First light Keck II telescope: 1996

EIN: 95-3972799

Headquarters location:

Kamuela, Hawai'i, USA

Management:

California Association for Research in Astronomy

Partner Institutions:

California Institute of Technology (CIT/Caltech)

University of California (UC)

National Aeronautics and Space Administration (NASA)

Cover photo:

The view from within the Keck I dome.

Inside photo:

The twin Keck 10-meter telescopes on the summit of Mauna Kea in Hawai'i are the most powerful and productive telescopes on Earth.

Dr. Taft E. Armandroff Director

“Welcome to the 2008 annual report of W. M. Keck Observatory. 2008 was filled with exciting scientific discoveries and important progress on strategic Observatory initiatives. Included in this record of the year’s achievements are profiles of several of my colleagues and I hope you will enjoy this glimpse into some of the amazing people behind Keck’s science and technology. We are grateful to the many individuals, corporations, foundations, and government agencies whose generosity and commitment make possible our ability to fulfill Keck Observatory’s mission to advance the greatest frontiers of science.

The primary metric for evaluating an astronomical enterprise is the quantity and quality of scholarly research publications generated from a research facility’s capabilities. Keck Observatory had an impressive year both in terms of the number and impact of science results. Of historic import was the first imaging ever achieved of a planetary system orbiting another star, taken with Keck’s adaptive optics system that corrects for the blurring of astronomical images caused by turbulence in Earth’s atmosphere. The newly discovered three-planet system orbits the young star named HR8799, which is located 140 light years away and is about 1.5 times the size of our sun. Made possible by modern optical and computing technologies, this magnificent first imaging of planets outside our own solar system is a breakthrough astronomers have been striving to achieve for hundreds of years.

Adaptive optics is playing an increasingly important role in astronomy. Keck Observatory was the first large telescope to implement natural guide star adaptive optics, and also first with laser guide star adaptive optics. These adaptive optics systems enable Keck, although earthbound, to achieve angular resolutions at near-infrared wavelengths that match the capabilities of the Hubble Space Telescope in the visible.



In 2008, we reached a milestone of having published 200 refereed science papers with data obtained from Keck Observatory’s adaptive optics systems. Fifty-five of these publications include data using the more recently installed laser guide star system.

Astronomy with laser guide star adaptive optics is producing cutting-edge results impacting every area of astronomical research from small bodies in our own solar system, faint brown dwarfs, the black hole at the center of the Milky Way, to supernovae in distant galaxies. Currently underway at the Observatory are plans to develop the most technologically advanced adaptive optics system in the world, positioning Keck to continue its dominance in this spectacular field of scientific research.

Keck Observatory’s Next Generation Adaptive Optics (NGAO) will feature multiple laser beacons, tomography of the atmospheric turbulence, greatly increased sensitivity and improved resolution. In 2008 the Observatory conducted a system design review for NGAO, a major milestone in the development of this pioneering initiative. The review committee included deep expertise in the field, including individuals who lead the European Southern Observatory, Thirty Meter Telescope and (formerly) Air Force adaptive optics programs. The review panel expressed enthusiasm and confidence in the NGAO program, stating: “The panel believes that Keck Observatory has assembled an NGAO team with the necessary past experience ... needed to develop the Next Generation Adaptive Optics Facility for Keck. It is a sound, though aggressive, strategy to be among the first observatories to develop and depend on advanced laser guide star AO systems as a means to maintain Keck’s leadership in ground-based observational astronomy.”

The importance of NGAO to our science community and leadership team is well reflected in the simple statement found in the 2008 Keck Observatory Scientific Strategic plan: “NGAO will reinvent Keck.”

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The beam of Keck Observatory's world-leading laser guide star adaptive optics system reaches out into a clear Hawaiian night sky.

COMMUNITY

W. M. KECK OBSERVATORY BOARD OF DIRECTORS

Edward Stone, Chair

George Blumenthal, Vice-Chair

Michael Bolte

Alphonso Diaz

T. J. Keck, liaison

Shrinivas Kulkarni

Thomas Soifer

Zlatan Tsvetanov, liaison

KECK OBSERVATORY ADVANCEMENT ADVISORY COUNCIL

Sanford Robertson, Chair, and Jeanne Robertson

Marc and Lynne Benioff

Clive and Carol Davies

Art and Rita Levinson

Wally and Bobbie Jean Hooser

Gordon Moore

Rob and Terry Ryan

Doug and Deborah Troxel

Ex-officio: Taft Armandroff, Michael Bolte, Shrinivas Kulkarni

KECK OBSERVATORY SCIENCE STEERING COMMITTEE

Jean Brodie, Co-Chair

Thomas Soifer, Co-Chair

Rachel Akeson

Michael Bolte, *ex-officio*

Alex Filippenko

Thomas Greene

Lynne Hillenbrand

Shrinivas Kulkarni, *ex-officio*

Michael Liu

Chris Martin

Jerry Nelson, *ex-officio*

Jason Prochaska

Access to the Keck telescopes is highly prized and the 365 annual nights of observing time are divided among its partner institutions, Caltech (36.5%), University of California (36.5%), NASA (14.5%), and University of Hawai'i (12.5%). In 2008, the Observatory also provided observing time to the broad U.S. astronomy community through the Telescope System Instrumentation Program funded by the National Science Foundation and administered by the National Optical Astronomy Observatory, and through specific time exchanges with both the Gemini Observatory and Subaru Observatory allowing access to specific instrument capabilities that are not available at Keck. Each observing community has its own Time Allocation Committee that evaluates research proposals semi-annually and allocates nights based upon

scientific merit. For every proposal accepted on the schedule, five are denied.

Access to the Keck telescopes is highly prized.

Per our founding documents, the governing board consists of three representatives from the California Institute of Technology, three from the University of California. In 2008 these roles were filled by Edward Stone (Board Chair), Shrinivas Kulkarni, and Thomas Soifer for Caltech; and George Blumenthal (Board Vice-Chair), Michael Bolte, and Alphonso Diaz the University of Cali-

fornia. In 2008, Zlatan Tsvetanov was the NASA liaison to the Board, and T. J. Keck served as the Keck Foundation representative.

A Science Steering Committee (SSC), comprised of 11 astronomers from our partner institutions, meets regularly to deliberate the priorities of the Keck science community and present them to Observatory leadership. The co-chairs of the Science Steering Committee in 2008 were Thomas Soifer, representing the California Institute of Technology, and Jean Brodie, from U.C. Santa Cruz, representing the University of California astronomy community.

In 2008, the SSC and Keck Observatory leadership convened several activities to update the Observatory's strategic plan. The initial scientific strategic plan

was created in 2003 and last revised in November 2005. The planning activities provided the Keck community an opportunity to evaluate the state of the Observatory, review the broader astronomical environment present and future, and identify key scientific opportunities for the coming decade. This year's documents were especially timely in their ability to serve as input to the national astronomy community's 2010 Decadal Survey, a process that is used to set priorities for the federal funding agencies, including NASA and the National Science Foundation. The 2008 process included soliciting input from the community via telecons and a successful request for White Papers. In September, a two-day retreat was held in Half Moon Bay, California. The participants were members of the Steering Committee, the Observatory Directors, selected members of the Keck Observatory staff, and additional "at large" members of the science community. A scientific strategic planning document was written and circulated to the entire Keck scientific community for comment. The document reaffirmed the Observatory's commitment to leadership in scientific productivity and innovative instrumentation.

The annual Keck Science Meeting presenting the latest Keck research discoveries was held September 18, 2008

at the University of California at Santa Cruz. This year's esteemed gathering hosted 103 participants, 24 talks and



Dr. Andrea Ghez's pioneering research confirming the existence of a supermassive black hole in the center of our galaxy earned her the 2008 MacArthur Genius Fellowship.

numerous poster presentations. The meeting featured exciting new scientific results from many of the younger members of the Keck Observatory community. Breakthroughs enabled by Keck's world-leading adaptive optics system were evident in many of the presentations.

Finally, this year the Observatory was proud to join the broad astronomical community in congratulating one of its

best and brightest. Andrea Ghez, UCLA professor and prominent Keck observer, was selected as one of 25 new MacArthur Fellows for 2008. The MacArthur genius award recognizes individuals across a broad range of disciplines for their creativity, originality, and potential to make important future contributions in their fields. The award citation stated: "Ghez has advanced the use of adaptive optics in the infrared spectrum, in which an "artificial star" is created from ground-based lasers to correct for atmospheric distortions. Using both speckle imaging and adaptive optics on the 10m Keck telescope, Ghez and her colleagues mapped with extraordinarily high precision the movement of a group of stars in the Sagittarius constellation near the center of our galaxy. Through painstaking, long-term analyses, her group and another based in Germany identified a set of stars orbiting a common point at extraordinary velocities (measurable fractions of the speed of light), implying the presence of a super-massive black hole at the galactic center. Ghez has developed evidence that the stars closest to the black hole are surprisingly young. As Ghez continues to improve the spatial resolution and precision of instruments in deciphering the dust-obscured regions of the central galaxy, we will develop a much clearer picture of the role of central, massive black holes in the origin and evolution of the galaxies."



Keck Observatory's operations team is the best in the business.

RECORD EXOPLANETARY SYSTEM FOUND

A team of Keck Planet Hunters, led by Debra Fischer of San Francisco State University and Geoff Marcy of the University of California at Berkeley, announced the discovery of a record-breaking fifth planet around the nearby star 55 Cancri, making it the only star aside from the Sun known to have five planets. The discovery comes after 19 years of observations of 55 Cancri,



An artist's interpretation of the 55 Cancri system, located 41 light-years away in the direction of the constellation Cancer. The discovery of the five planet system orbiting this star was made after 19 years of observations of 55 Cancri and marked the 20th anniversary of the first measurements to identify extrasolar planets by analyzing the wobbles they cause in the orbits of their parent star.

consisting of 300 individual measurements. The Keck I telescope and its powerful High Resolution Echelle Spectrometer, or HIRES instrument, played a crucial role in this study. The unique 55 Cancri system, located 41 light-years away, is also notable because its four inner planets and one giant outer planet roughly resemble our own solar system.

BROWN DWARFS WEIGHED IN



Infrared image of the dusty brown dwarf binary HD 130948BC in orbit around a young sun-like star obtained with the adaptive optics system on the Keck II telescope. Using these ultrasharp images, astronomers for the first time were able to determine the masses of this coldest class of "failed stars."

Using ultrasharp images obtained with the Keck II Telescope and its world-leading adaptive optics system, astronomers determined, for the first time, the masses of the coldest class of "failed stars" or brown dwarfs. The images produced by Keck have an angular resolution as good as 1/20 of an arc second, about 1/40,000 the diameter of the full moon. If a person's vision were as sharp as the Keck adaptive optics system, he would be able to read a magazine that was about a mile away. In fact, the positional accuracy achieved with such sharp images is

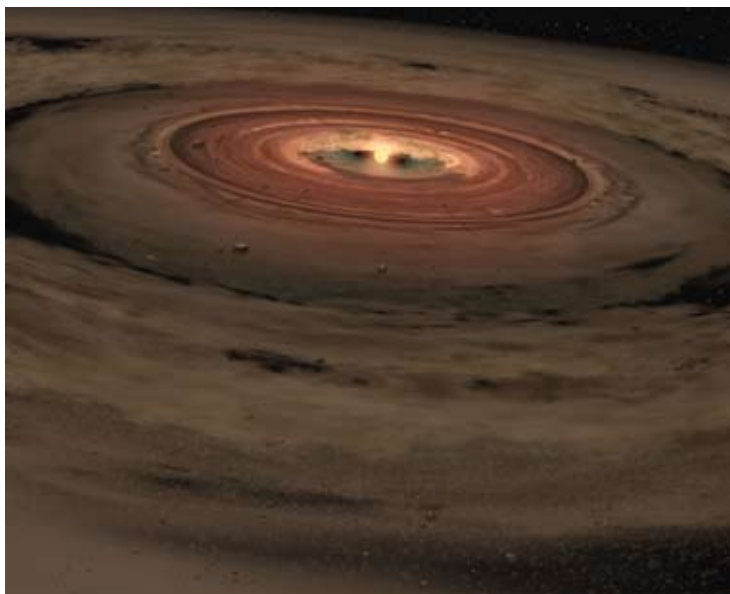
equivalent to hitting a bull's-eye on a dartboard that is 8,000 miles away. With masses as light as three percent the mass of the Sun, brown dwarfs are the lowest mass free-floating objects ever weighed outside our solar system. The observations are a major step in testing the theoretical predictions of objects that do not generate their own internal energy via the hydrogen fusion that powers the Sun. The team announcing the results was composed of Michael Liu and Trent J. Dupuy of the Institute for Astronomy at the University of Hawai'i and Dr. Michael J. Ireland of the University of Sydney.

WATER DETECTED IN PLANET FORMING ZONES

Researchers using the Keck II Telescope and the Spitzer Space Telescope discovered large amounts of simple organic gases and water vapor in a possible planet-forming region around an infant star, along with evidence that these molecules were created there. They also found water in the same zone around other young stars. Scientists believe that these regions around newborn stars called protoplanetary disks provide the building material for planets and moons and eventually, over millions of years, evolve into orbiting planetary systems like our own. Colette Salyk, a graduate student in geological and planetary sciences at Caltech and her colleagues used Spitzer Space Telescope to look at dozens of young stars with

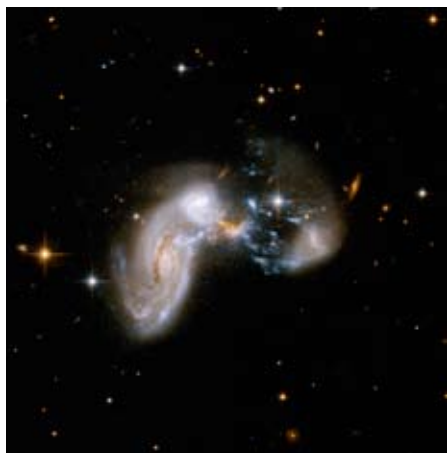
protoplanetary disks and found water in many of them. They honed in on two stars to confirm and refine the initial detection of water with high-

resolution measurements from the Keck II Telescope and its Near Infra-Red Echelle Spectrograph, or NIRSPEC instrument.



In this artist's conception of a protoplanetary disk, gas and dust, the raw materials thought to form into rocky planets such as Earth, orbits a young star.

POPULATION EXPLOSION IN DISTANT GALAXY



The image of this galaxy, called II Zw 96, resembles the recently discovered "Baby Boom" galaxy, an extreme star making machine discovered by observations using multiple ground and space-based telescopes. The Keck II telescope was used to measure the galaxy's location to be a whopping 12.3 billion light-years from Earth, when the Universe was only 1.3 billion years old.

Astronomers have uncovered an extreme stellar machine of a galaxy in the very remote Universe, pumping out stars at a surprising rate of up to 4,000 per year. In comparison, our own Milky Way galaxy turns out an average of just ten stars per year. The discovery led by Peter Capak of NASA's Spitzer Science Center at Caltech and Nick Scoville, also of Caltech, was made possible by combining data from several telescopes on Mauna Kea with results from NASA's Hubble and Spitzer Space Telescopes. The Keck II telescope, with its Deep Imaging Multi-Object Spectrograph

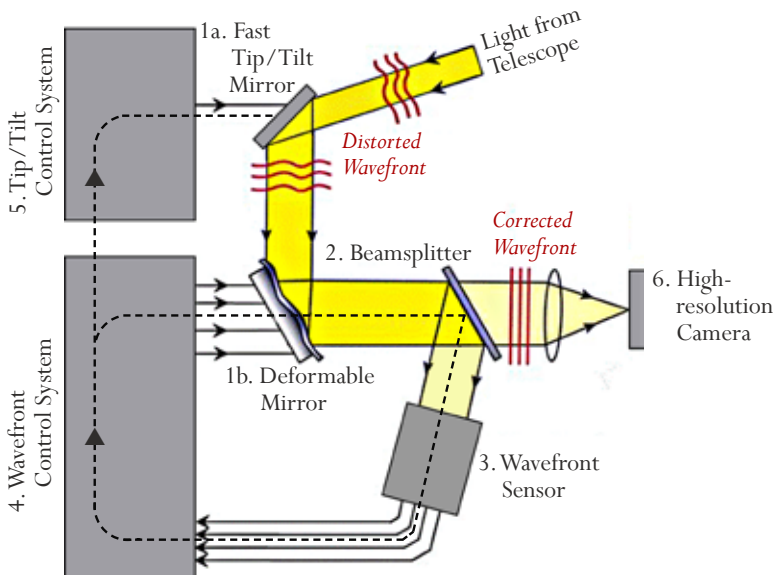
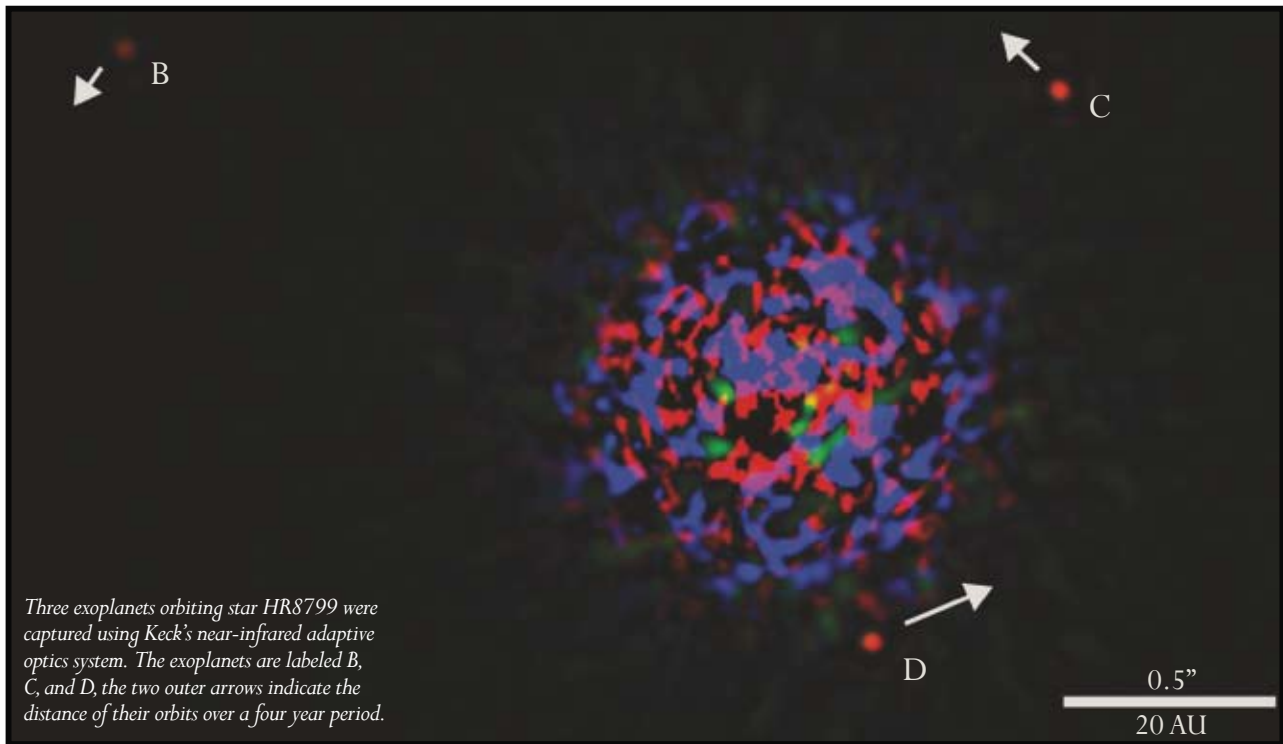
or DEIMOS instrument, was used to determine that the galaxy lies in the distant Universe. The extreme distance of 12.3 billion light years places it in the Universe's infancy. "This galaxy is undergoing a major baby boom, producing most of its stars all at once," said Peter Capak of NASA's Spitzer Science Center at Caltech. The results go against the most common theory of galaxy formation. According to the Hierarchical Model, galaxies slowly build up their stars over time by absorbing small "dwarf" galaxies -- and not in one big burst as observed in the newfound "Baby Boom" galaxy.

FIRST IMAGES OF EXO-PLANETS

Using high-contrast, near-infrared adaptive optics observations on Keck, a team of astronomers led by Christian Marois of Canada's Herzberg Institute of Astrophysics and Bruce Macintosh of Lawrence Livermore National Laboratory, for the very first time captured images of a planetary

system orbiting another star. Three planets, roughly ten, ten and seven times the mass of Jupiter, were found orbiting the young star named HR8799, which is located 140 light years away from Earth and is about 1.5 times the size of our Sun. More than 300 exo-planets have been discovered

circling nearby stars; however those discoveries have been determined by the gravitational pull of the planet on its parent star. These direct observations are a milestone in the search and characterization of planetary systems around stars. Astronomers, science journalists, and the public were captivated by this historic finding.



How adaptive optics works: the distorted wavefront enters the telescope and is sent to the adaptive optics system where it is reflected off of two mirrors, a fast tip-tilt mirror (1a) and a deformable mirror (1b) before reaching a beamsplitter (2). The beam splitter allows the longer wavelength near-infrared light to pass on to the high resolution science camera (6) and diverts the shorter wavelength visible light to the wavefront sensor (3). The wavefront sensor measures the distortions in the wavefront over a thousand times per second, sending the information to the wavefront control system (4). The wavefront control system computes the corrections necessary to rapidly move the fast tip-tilt mirror (1a) to stabilize the image on the high-resolution camera and also to position a deformable mirror (1b) to correct for the wavefront distortions. The deformable mirror is made of a very thin sheet of glass which can be computer-controlled to have the same shape as the wavefront distortions, cancelling their blurring effects. The result is a corrected wavefront that is passed on to the high-resolution science camera allowing the images to be recorded at the full resolving power of the telescope.

Mike Bolte

Keck Observatory Board Member

“Keck is the biggest, most capable optical observatory built in the history of mankind,” says Mike Bolte, Director of University of California Observatories, or UCO. As a former co-chair of Keck’s Science Steering Committee and current member of the Observatory Board, he has deep roots in the Observatory’s history and a firm hand in determining its full potential.

Much of Keck’s future lies in its next generation instrumentation. Many instruments have been designed and fabricated at UCO’s technical facilities, including the Moore Laboratory for Adaptive Optics at UC Santa Cruz. Adaptive optics (AO) is a field of particular interest for Bolte. It corrects for turbulence in the Earth’s atmosphere by real-time monitoring of the signal from a natural or artificial guide star, the latter created using a laser.

“The next generation of AO at Keck will offer spectacular improvements to angular resolution,” he candidly shares. “Astronomy is a fiercely competitive world. People like to make discoveries first to get the satisfaction of breaking new ground.”



Bolte offers utmost respect to the people who fund this research forefront.

“The most important advancements in astronomical research and instrumentation have very often been funded by private individuals. Galileo had a patron, James Lick provided the funding for the Lick Observatory, Andrew Carnegie supported forefront telescopes in the early 1900s and of course the Keck Foundation funded the twin 10-meter telescopes. It is a wonderful reflection on mankind that the quest to understand the Universe is so highly valued.”

The evolution of stars and the nature of the earliest stars to form in the Universe command Bolte’s own research interests. He earned his B.S. in physics from the University of Central Florida, his M.S. in physics from Florida State University and a Ph.D. in astronomy from the University of Washington. He was a Hubble Postdoctoral Fellow at UC Santa Cruz before joining its faculty in 1993.

When he travels to Hawai’i, Bolte packs not only his laptop but also his fly rod. When he is not casting his sights on the stars, he enjoys fly fishing along the shorelines of the Big Island’s beautiful Kohala Coast.

Chuck Steidel

Astronomer

Every day, internationally heralded astronomer Chuck Steidel collects or analyzes information to help answer: How did galaxies form in the early Universe?

Steidel is the Lee A. DuBridge Professor of Astronomy at the California Institute of Technology. He and his colleagues have been exploring the nature of thousands of primeval galaxies and constructing the most complete “map” of the Universe as it appeared 10-12 billion years ago.

His results have shattered barriers in cosmology, the science concerned with the structure and evolution of the Universe as a whole, and W. M. Keck Observatory is paramount to this frontier research.

“My entire scientific focus came to be during my first nights on the Keck telescope in 1995. Ever since then, I think of Keck as an extension of where I work, almost like an extended family. I’ve probably observed as many nights using the Keck telescopes as anyone,” Steidel shares with pride.

“This is a most exciting time for the study of galaxy formation. It is reaching a peak. We’re studying early galaxies and everything in between,” he says. “Keck broke through the barrier to

studying the distant Universe, and continues to lead the way thanks to continued development of unparalleled state-of-the-art instruments.”

MOSFIRE, Keck’s most ambitious instrument currently under construction and due to be operational in 2010, is the observatory’s breakthrough multi-object spectroscopic instrument for the infrared. Steidel serves as Project Scientist.

“MOSFIRE will allow the telescopes to be ~50 times more efficient for spectroscopy in the near-infrared, thanks to a wide field of view and the ability to observe 46 objects (instead of one) simultaneously. This huge gain in capability allows for fundamentally new kinds of observations and means there will be 50 times higher probability of discovering something never seen before.”

Steidel received an A.B. from Princeton University and a Ph.D. in Astronomy from the California Institute of Technology. He returned to Caltech in 1995 after serving as a Hubble Fellow at UC Berkeley and as a physics faculty member at the Massachusetts Institute of Technology. In 2006, he was elected to the prestigious National Academy of Sciences.



Margarita Scheffel
Chief Financial Officer

Margarita Scheffel leads Keck Observatory’s Finance Department. For the past four years, the financial reports produced by her team have received “squeaky” clean external auditor opinions - an exemplary achievement for an organization where funding comes from multiple federal and state grants, public agency agreements and subcontracts, and private philanthropy.

“Yes, it’s true,” Scheffel confirms with bright eyes. “The Observatory has received truly outstanding audit opinions. That means no findings, no recommendations. We’re clean!”



With a strong background in information systems, Scheffel’s focus is on finding innovative ways to improve Keck’s financial systems. “Our goal is to continually perfect our reporting tools, decision making processes and reliability.” Accomplishing this with a management style that is far from rigid and unyielding, Scheffel’s consistent directive: “Let’s do this well and have fun doing it.”

Scheffel firmly believes in building strong working relationships. At Keck she has championed “partnership meetings,” encouraging her finance team to reach across department lines to collaboratively resolve challenging issues. “My goal is to bring people

together, build consensus and develop processes that offer rewarding solutions for the organization and everyone involved.”

Growing up in Chicago, Scheffel pursued a variety of scholarly interests. Initially majoring in architecture, she then switched to engineering and ultimately earned a business degree. After receiving her C.P.A. certification and then an M.B.A. in international business, she began working toward a Ph.D. in business. Professional opportunities came her way to apply her talents to non-profit organizations, and she never looked back.

For a long while Scheffel dreamed of living in Hawai’i. In 2003, she realized that dream when a financial position opened at Keck. “As part of the interview process, Keck asked me to prepare a presentation that would engage people. For over two decades I’ve passionately ridden coasters with various clubs so I chose “Coastin’ thru England” for the topic,” she recalls. “People became so interested in the topic that we ran out of time during the question-and-answer session.”

Margarita’s travel tip for her favorite rollercoaster of all time? The Megafobia at Oakwood Theme Park, in Pembrokeshire, Wales, U.K.

Kyle Kinoshita
Senior Manager, Mechanical Systems

Growing up on the Big Island in the 1970s, energetic and quick-witted Kyle Kinoshita had a single minded focus: surfing Honoli’i, a popular Hilo break.

Today, with a graduate degree in mechanical engineering from Stanford University topping his vita alongside a 16-year career at Keck Observatory, Kinoshita is a strong advocate of education to other Hawai’i-born children.

“I’m passionate about community outreach,” Kinoshita says in upbeat tone. “When I speak to middle school students, I talk about the joys of the surf and the island, and I also encourage them to do well in school and get an education.”



At Keck, Kinoshita supervises a staff of 14. His team’s primary responsibility is to maintain the operating performance of the mechanical systems of the two telescopes and dome enclosures, a particularly complex task given the diverse requirements of operating heavy equipment in conjunction with science instruments dependent upon micron precision accuracy.

Kinoshita’s group is creative, resourceful and adept at solving engineering quandaries. He reflects, with pride, on his team’s recent successes: The group designed and built “the equivalent of

a train switchyard” to move an instrument off the telescope and put the next one into position. For the dome’s crucial suspension system, where each wheel shaft supports about 17 tons, Kinoshita’s crew applies an ultrasound machine to locate problems. Early detection gives the crew time to make repairs and avoid catastrophic failure and dreaded down time on the telescopes.

Basic maintenance can be formidable. “Imagine hauling power tools and a 500-pound gearbox to the top of the dome eight stories high in order to repair the shutter. We installed cranes atop the dome to solve this problem,” Kinoshita recalls. “This job is a mechanical engineer’s dream.”

Currently, Kinoshita and his crew are working on the infrastructure to install MOSFIRE, the Observatory’s breakthrough multi-object, infrared spectrograph. In addition, the team made modifications to the observing platform on the Keck I telescope in preparation for installation and commissioning of its next generation laser system in 2009.

Kinoshita and his wife, Laura, have a two year-old son who is learning to surf with Dad and to appreciate the joys and responsibilities of growing up Hawaiian style.

The People of Keck continued on next page.

Steve Doyle

Laser Guide Star Adaptive Optics Development Technician

Steve Doyle just may be Keck Observatory's equivalent to Indiana Jones, for no one knows the challenges of working atop the 13,800-foot summit of Mauna Kea better than this 18-year Keck veteran. Doyle has been flattened to the ground by violent wind gusts that carry with them a harsh pummeling of rocks and cinder.

"Working on the summit is an adventure. Sometimes you can't get through due to snow, sometimes you don't think clearly due to the lack of oxygen and sometimes the weather will change dramatically in a matter of minutes," he says.

When news of severe weather conditions appears unexpectedly, he and his other summit crew members have to make "mad scrambles" to secure summit instruments and the facility before retreating to the safety of lower elevation.

Not all in Doyle's job is so gripping. His current list of projects revolves around preparing for the incoming, next-generation, energy-efficient laser for Keck I. The new laser will create an all-important beacon for the telescope's adaptive optics (AO) system.



Natural guide stars are not always available in the area that an observer wishes to study, Doyle shares. "But a laser creates an artificial guide star anywhere in the sky, opening up larger numbers of targets for study with AO."

AO substantially removes atmospheric distortion so researchers can enjoy viewing with the clarity of a telescope that is above earth's atmosphere.

These are the types of exciting technological advancements that keep Doyle keen about his particular area of expertise in electronics and ready for the challenges of working at high elevation.

"Keck is an inspiration that will always be there, regardless of wars or the economy," Doyle says. "The stars, the Universe, they give us an opportunity to look outside of ourselves. It is fascinating to contemplate and wonder, 'what is out there'? Keck is answering the big questions."

When Doyle is away from his role as Keck's Indiana Jones, he and his wife, Kauai, serve as community health advocates and are enthusiastic participants in the American Cancer Society's Relay for Life.

Liz Chock

Software Engineer

"Our main goal is to go on-sky every night and everyone at Keck works as hard as possible to get that done. We all feel pride in ownership of the telescopes," says Liz Chock, a 15-year employee of the Observatory.

Chock is noted among her colleagues for going the extra mile to help design, develop, maintain and finely tune Keck's multi-faceted software with a can-do attitude and her radiant smile.

Her job and that of her coworkers is 24/7/365, with Chock and her software department colleagues serving on-call, in rotation, during evening hours for issues that arise during precious observing time.

After the sun rises, the first item on Chock's desk is the review of nightly email reports from the summit crew, which includes a prioritized detail of any possible software considerations that arise amidst the complex interactions of the telescopes, instruments and adaptive optics systems.

"Sometimes we must act immediately to check into a possible bug. Other portions of the day are spent with individual instrument or technology software. Most of our programs are designed in-house by our team specifically for Keck."



Chock's job is to know the software from its code to configuration management and to "keep the software in a known state so that it is well documented and usable." She currently serves on the Adaptive Optics (AO) Operations Team as the Observatory looks forward to implementing the next generation of AO and sustaining its leadership in revolutionary image clarity in astronomy.

Chock is passionately involved with community education. Through Keck's 2% Community Service program, Chock annually presents a hands-on workshop for fifth-grade girls enrolled in the GEMS program (Girls Exploring Math and Science). She also mentors Honoka'a Middle and High School students in robotics and helped the team earn a spot at the

National FIRST Competition in Atlanta.

Honolulu born and raised Chock holds a degree in computer science from University of Hawai'i at Manoa. She and husband Jonathan, Keck's Computer and Network Systems Manager, have two boys, Nick and Chris, ages 14 and 8, who themselves are active participants in the next generation of innovation.

The People of Keck continued on page 16.

A composite image of two galaxies, one yellowish and one bluish, set against a dark background with scattered stars. The yellowish galaxy is in the upper left, and the bluish galaxy is in the lower right. The text "Let the Universe Inspire You" is overlaid on the right side of the image.

Let the Universe
Inspire You

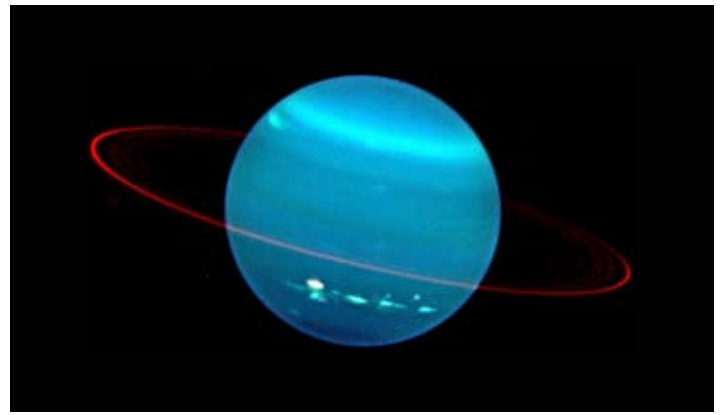
FINANCIAL RESOURCES

Throughout its young history, Keck Observatory has been at the cutting edge of astronomical research and innovation, and our discoveries into the nature and evolution of the cosmos has burgeoned. Today the Observatory is strategically developing breakthrough technologies that will sustain its leadership for decades to come in an increasingly competitive international environment. Support from the private sector is essential to funding these new capabilities of the Keck telescopes to ensure the Observatory reaches its full and enormous potential.



“Some of the biggest questions that we’ve discovered and might be discovering the answers to are coming through astronomy. The dark matter and dark energy kinds of things are fascinating. The fact that we see only a few percent of the Universe is absolutely amazing. I think that a very likely path to finding out the origin of these things is going to be through astronomical observation.”

Gordon Moore
From an interview in
Physics Today, March 2008



Top: Observatory Director Dr. Taft Armandroff described to friends of Keck news from the frontiers of discovery and the breakthroughs the powerful 10-meter telescopes are poised to make with their continued philanthropic support.

Above: Amazing detail of Uranus brought to light with the Keck telescopes and their adaptive optics systems.

An agreement between the California Institute of Technology and the University of California ensures annual base operating support for the W. M. Keck Observatory through 2018. In fiscal year 2008, this amount was \$11.6 million. As a one-sixth partner in the Observatory, the National Aeronautics and Space Administration (NASA)

provided \$2.3 million in operating support in 2008. A significant milestone for the Observatory was reached in FY08 with the signing of a new five-year cooperative agreement with NASA. The agreement awards \$16.7 million over the next five years for operations, infrastructure renewal and data archiving. In addition, new awards in 2008 from

other public grants and contracts surpassed \$8.5 million to facilitate leading edge science and observing capabilities. A total of \$342,120 in new gifts from the private sector provided additional support. The total budget for Keck Observatory in fiscal year 2009 is \$26.1 million. Audited financials are available upon request.

The W. M. Keck Observatory gratefully acknowledges the following benefactors for their generous contributions to advancing our understanding of the Universe.

Individuals

Eleanor and Barry Allswang	Thomas N. Hansen	Sharon and Joe Levy	Janet Gimbel Rogers and Stephen Rogers
Liz and Taft Armandroff	Joanne and Jon Harlemin	Sue and Dick Levy	Trudy and Terry Rose
Nancy and John Ball	Sylvia and Karl Hess	Carolyn and Jack Lewis	Terry and Rob Ryan
Thomas Blackburn	Barbara and Jack Hodgson	Carol and Richard Little	Michael Sack and John Saul
Diana and Andrew Bonnici	Becky and Bob Holman	Dolly Loo	Margarita and Thomas Scheffel
Rosalind and Stephen Butterfield	Bobbie Jean and Wally Hooser	Katherine H. Loo	Joan Morgan and Richard Schleicher
Peggy and William Cameron	Carol and Winter Horton	Marlene and Sandy Louchheim	Mary and Jas Singh
Linda and James Clifford	Pam and Gary Jaffe	Veronica and Michael Miller	Liz and David Sonne
Ginny and Hal Cogger	Christine and Richard Karger	Laura and David Monahan	Alice and Edward Stone
Linda Copman and Mark Boucher	T. J. Keck	Betty and Gordon Moore	Priscilla Studholme
Carol and Clive Davies	Val Kim and Gerald Weldon	Milly and Mac Morris	Ellen and Jack Toigo
Sue and Richard Dekany	Ann and Paul Koehler	Nancy and Riley Pleas	Douglas Troxel
Marilyn and John Dougery	Gregory A. Koesting	Dave Radovich	Judi and Joe Wagner
Marilyn and Thomas Elias	Hiromi and Shrinivas Kulkarni	Candace and Robert Reuss	Leslie and Richard Wallis
Carl Feinberg	Darla and Earl Laing	Tony Rich	Marcia and Stanley Wishnick
Amy and Morton Friedkin	Linda and Doug Lanterman	R. Michael Rich	Angela and Mark Wolfenberger
Peggy and Peter Georgas	Barbara Fischlowitz-Leong and Michael Leong	Jeanne and Sanford Robertson	David Woods
Laurie and Jack Goldstein		Stephanie Robinson	
Deborah Goodwin and James Fritz	Rita and Arthur Levinson		

Corporations, Foundations and Agencies

AKCP Co., Ltd.	KTA Super Stores
Change Happens Foundation	Kaunakakai School
Chester Woodruff Foundation	W. M. Keck Foundation
County of Hawai'i	Microsoft Corporation
The Fairmont Orchid	Pleas Family Foundation
First Hawaiian Bank	Rob and Terry Ryan Foundation
M. R. and Evelyn Hudson Foundation	Tropical Dreams Ice Cream



Members of the Keck Observatory Advancement Advisory Council engaged in charting a successful course to fulfill the objectives of the Observatory's 20-year strategic plan.



Council members Rob and Terry Ryan are enthusiastic champions of the need to generate additional financial resources as core to the growth and sustainability of the Observatory.

Grant Hill

Astronomer, Observing Support Group

As an undergraduate student at the University of British Columbia pursuing a degree in engineering physics, Keck Support Astronomer Grant Hill recalls that he “blundered into astronomy by accident. I took astronomy as a pure lark, as an elective, and I was really surprised to do so poorly on that first exam.”

A simple dose of humility became a strong motivator for Hill, who later, upon receipt of his Ph.D. from the University of Western Ontario in 1994, was honored with the Plaskett Medal. The award is presented annually to the Ph.D. graduate from a Canadian university who is judged to have the most outstanding doctoral thesis in astronomy or astrophysics.

Today, Hill’s roles at Keck Observatory are multi-faceted. While a significant portion of his time is dedicated to assisting visiting astronomers with his encyclopedic knowledge of Keck’s instrumentation, the largest part of his day is reserved for establishing systems to monitor and manage the day to day demands of the world’s most sophisticated telescopes.

“I’m a scientist by training, yet I retain an interest in engineering. I enjoy being an interpreter on occasion, helping our



engineers and technicians better understand the science behind what they are doing,” Hill says.

About 20 percent of Hill’s time is spent on his own research on massive stars.

“Like the sun, massive stars have winds too, but many millions of times stronger. When two of them orbit each other, these winds collide and produce phenomena that are extremely interesting for their own sake but also allow us to learn more about massive stars in general.”

In 2008, Hill’s research focused on WR 104 a massive star binary that includes a Wolf-Rayet star. Wolf-Rayet stars are thought to be the descendents of massive stars in the last stages before undergoing a violent death as supernovae. This WR 104 system received considerable media attention due to the possibility that it could be aligned with Earth so that if it produced a gamma ray burst, our planet would be in the line of fire. Hill’s work confirmed the system is a colliding wind binary; and thankfully it is inclined away from posing a threat to our world.

Carolyn Parker

Observing Assistant

The summit of Mauna Kea is second home to Carolyn Parker. She works at the Keck telescopes during the night shift, her schedule dependent on the length of darkness of the night sky. On Keck’s swing shift schedule, Parker sleeps during the day at Hale Pohaku, the dorm-style facilities at the 9,000 foot elevation on Mauna Kea Access Road.

Parker serves as a key liaison between the observatory and visiting astronomers while science is taking place. She operates the telescope and instruments and trouble shoots with the observers.

Part of her job is also keeping watch on the weather via information provided to all the observatories on the summit.

“These are the world’s top telescopes. The mirrors and electronic components cannot be exposed to snow, water or excessive humidity,” Parker shares. “Sometimes I have to make a call to close the shutter if fog or poor weather threatens. The observers aren’t always happy with that decision, because it means their research stops.”

Parker came to Keck from Flagstaff, Arizona, in March 2006,



after graduating with a degree in physics and astronomy from Northern Arizona University and working with a company that makes the finest optics for both amateur and professional telescopes.

Upon arriving at Keck, she recalls having to adjust to gain an insider’s knowledge of the telescopes.

“At the summit, we have six computer screens, each with some type of software that is unique to Keck,” Parkers says. “There was a six-month learning curve for Keck I and then another one for Keck II.”

“I often get the first-hand scoop about what our observers are seeing. It’s exciting, especially when I know they will be the first to break a discovery,” she shares. “Sometimes I’ll have a long, intense night, and then I’ll walk out in the morning and see the full moon setting in the shadow of Mauna Kea. It’s amazing!”

When this Baltimore native’s time off brings her closer to sea level, she explores other amazing parts of the island, hiking and camping or paddling canoe with her local canoe club.

Charles Beichman

Executive Director, NASA Exoplanet Science Institute

As a partner in Keck Observatory since 1996, NASA has access to one-sixth of the observing nights each year. Charles Beichman, executive director of the NASA Exoplanet Science Institute at the California Institute of Technology, is a key liaison between NASA and Keck and helps determine which scientist, and which research project, will best benefit from precious time on the twin 10-meter telescopes.

“We receive more than 50 proposals each year for our limited number of nights. It’s a very competitive process,” Beichman says. “Keck represents the most valuable resource in ground-based astronomy, due to its location, great viewing and low amounts of water vapor.”

Once proposals are submitted to and prioritized by a time allocation committee, Beichman, ultimately, approves the schedule.

“It’s particularly exciting to see the research ideas as they are presented for they are cutting edge; the very latest in the subfields of astronomy,” he says.

A New York City native, Beichman originally enrolled as a philosophy major at Harvard but chose to switch majors to



astronomy in the middle of his junior year. He never looked back, earning a doctoral degree in astronomy from University of Hawai’i at Manoa, completing postdoctoral research at Caltech and chalking up an impressive list of published research articles. Beichman has also authored four books and earned several awards, including the NASA Leadership Award, the NASA Scientific Achievement Award and a NASA Exceptional Service Medal.

His research looking for planets and the evidence for planets such as debris disks around nearby young stars led him to spearhead the development of several instruments, including the Keck Interferometer. The Interferometer connects the light from the two telescopes so that the waves of photons are “uninterrupted to a small fraction of a micron,” Beichman says.

He also explains that NASA has a commitment to ground-based astronomy and to Keck. “But we can’t rest on our laurels,” he adds. “People are always going to do what they can from the ground because any time there’s a really interesting, exciting science question, people will push to get the answer by whatever technique they can as soon as they can. It’s always more expensive and slower to do almost anything from space.”

Kevin Tsubota

Senior Software Engineer

Oahu-born Kevin Tsubota has a soft-spoken and low-key style of making things happen behind the scenes at the ever-changing and demanding edge of discovery at Keck Observatory.

His job as Senior Software Engineer requires him to execute multiple projects simultaneously, including improving the capabilities and performance of the telescopes and enabling observers to collect as much data as possible once the dome shutters open to the night sky on Mauna Kea.

“At Keck, every researcher hopes to be the first to make a discovery. That means we are going to do everything we can to help them,” Tsubota says. “Software is so pliable. We are constantly implementing changes and new releases. My job is never the same and that’s what I love the most.”

Tsubota and his team of three manage the software for the Interferometer project, which combines light from the two telescopes to create an 85-meter observational baseline and unprecedented resolution. Part of his job is to ensure that the software positions an intricate system of mirrors and delay lines



to match up so that the photons collected by both telescopes reach the detectors at the same time.

The software team generally works daytime hours, yet they also provide on-call software support throughout the night on a rotating basis.

“If a telescope is down, that’s lost time,” he shares. “We are there for the midnight call to make sure the observer is back on sky a-s-a-p. In most cases, it is not the software itself but something affecting the system. A disc may be full or they need to reboot.”

Tsubota, who will soon notch 14 years of employment with Keck, sees the observatory’s greatest strength in its professional staff. “The people of Keck are relentless in their commitment to get the job done. We know that every day we are pushing the edge of discovery,” he says.

Tsubota and his wife, Myrna, also a member of Keck’s software team, have three children. They are all involved in school and club sports, keeping their parents actively cheering on the sidelines of Waimea’s sports fields.



TECHNOLOGY

Hilton A. Lewis
Deputy Director

The success of an astronomical observatory has always depended on having the latest, most effective technology to ensure its capability to do the hardest, best science, be it Galileo's simple telescope or the most complex observing machines of the Twenty-First Century. However, state-of-the-art technology by itself is not enough. Delivering the promise inherent in technology is fundamentally a complex creative enterprise requiring ingenuity, skill and passion and well-integrated technology teams. As measured by our science

output, overall efficiency and high degree of respect within the international astronomy community, Keck's performance continues to set the standard for a leading-edge modern observatory.

Our approach for delivering to astronomers the most powerful tools for doing ground breaking science is based on three key strategies: 1) build innovative, powerful and reliable systems; 2) deliver them rapidly for scientific use; and 3) provide superior service to our astronomers.

In 2008, Keck introduced the first of the new MAGIQ systems. MAGIQ is designed to maintain pin-point accuracy when tracking celestial objects and automatically measures and adjusts the quality of the image delivered to the science instrument. MAGIQ has been so popular with telescope users that we have adapted the software to run our earlier generation systems even though the full functionality of the new hardware is not yet available. MAGIQ systems are slated to be installed on all Keck instruments, with the next system planned for early 2009.

In 2006, Keck Observatory received funding from the National Science Foundation's Major Research Instru-



mentation program for ASTRA, or the ASTrometric and phase-Referenced Astronomy upgrade of the Keck Interferometry project. ASTRA leverages our already substantial investment in interferometry - the means by which the light of the two telescopes is combined to yield unprecedented detail of faint objects studied. ASTRA's first phase was completed in 2008, successfully increasing the scientific utility of the interferometer. The next phases of ASTRA, to enable even higher precision measurements on ever fainter targets, will be completed in 2010.

Two new instruments for Keck are in final construction and testing phases. An upgrade to LRIS-R, the low

resolution imaging spectrograph, red (spectrum) camera will deliver much greater sensitivity and stability in the red part of the optical spectrum. This system is being built by our partner institution, the University of California Observatories, Santa Cruz and will be commissioned in mid-2009. Significant progress was also made on MOSFIRE, a multi-object spectrograph designed to work in the near infrared portion of the spectrum. MOSFIRE is a joint venture between UCLA, Caltech and UCO Santa Cruz. The majority of the assembly is complete, and the system is now undergoing testing at temperatures close to absolute zero, its internal operating temperature, to ensure that all components will work as designed.

MOSFIRE is scheduled for delivery in early 2010 and will provide a revolutionary new capability to our astronomers, who eagerly await its arrival and commissioning.

The most significant advance in observing technologies in the past decade has been the implementation of adaptive optics (AO) systems, and in particular, laser-guide-star adaptive optics systems. These systems are designed to compensate for turbulence in the earth's atmosphere, allowing telescopes to generate images with extraordinary clarity. Keck Observatory has led the field in the development, operation and scientific exploitation of AO systems, with exponential growth in the number

and quality of scientific papers associated with Keck's AO capability. In 2008, progress was made towards equipping the Keck I telescope with an advanced laser-guided AO system. And looking ahead to the more distant future, Keck has been hard at work designing the Next Generation Adaptive Optics system in collaboration with our partners at Caltech and UCO Santa Cruz. NGAO will provide the ability to study fainter targets with even greater detail and at a wider range of wavelengths, spanning the near infrared to the red end of the visible spectrum of light, sustaining Keck's leadership in this breakthrough capability for astronomical research.

While new high-tech systems are important, the ability of our technology teams to function well and effectively integrate their efforts is a crucial element in commanding great science year after year. This past year the observatory leadership reorganized the vital daily operations activities under a single department, led by gifted senior manager, Rich Matsuda. The skills of our staff are now more fully utilized, with specialized knowledge and experience from all sectors being brought to bear on the tough issues inherent in operating a technically sophisticated enterprise. We move forward as a stronger organization with a highly cohesive approach and a heightened sense of purpose.

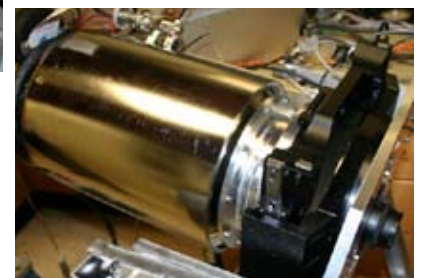
Keck Observatory continues to generate world leading astronomical research to answer a vast array of scientific questions. Astronomers and the Observatory are mutually dependent and synergistic partners in this success. As Deputy Director with responsibility for engineering developments and operations, I am proud of our talented and dedicated professional staff, which I regard as Keck's finest asset.



Rich Matsuda (left) and Hilton Lewis oversee management of telescope operations to sustain science productivity, overall efficiency and the high degree of respect the Observatory has earned within the global astronomy community.



Above: Individual mirror segments are cleaned and re-coated to optimize telescope performance. Top right: MOSFIRE undergoes final testing at temperatures close to absolute zero. Bottom right: Upgrades will deliver greater sensitivity and stability to Keck's most in demand spectrograph, LRIS.





Rapt visitors pause to capture their moment of being up close and personal with the Keck II telescope.

EDUCATION AND OUTREACH

Keck Observatory produces more scientific results than any other observatory in existence, pushing the frontiers of astronomy to find new worlds beyond our solar system, probe the mysteries of the Milky Way, measure distant galaxies, in turn generating a plethora of new cosmic questions to investigate. The process of discovery, however, is not complete until it is shared. Whether communicating to influence policy makers to support science and mathematics education or presenting Keck research through public lectures and the media to engage enthusiasts, connecting our work to a growing local and international audience is integral to our continued success.

As a leading research facility, Keck Ob-

servatory remains of significant interest to documentary film crews around the world. 2008 premiered outstanding projects including National Geographic's "Engineering Connections" and "Naked Science: Pluto Rediscovered" and the BBC Horizon Series: "Are we alone in the Universe?" The Observatory and veteran astronomer Alex Filippenko were featured in the BBC production of "Stephen Frey in America" and its popular companion book.

In 2008, the Observatory's complementary E-magazine, Cosmic Matters was published quarterly and featured multimedia articles highlighting Keck discoveries and achievements to a growing Keck Nation subscriber list. Our headquarters Hualalai Learning

Theater hosted six public evening talks by Keck astronomers as well as a new program called "Sharing Astronomy with Kupuna," a series to celebrate common ground between culture and science. "Evenings with Astronomers," a winter lecture series sponsored by the Rob and Terry Ryan Foundation, presented talks by Jerry Nelson, Richard Ellis, Mike Bolte, Greg Laughlin, and Taft Armandroff.

Keck Observatory annually supports an educational outreach team led by Support Astronomer Greg Wirth. Thousands of Hawai'i students from Hilo to Kuanakakai, Molokai, were introduced to Keck's innovation and inspiration through special tours of the Observatory, hands on astronomy and engi-

neering lessons, stargazing events, and mentorship programs. Keck employees served as judges in local science fairs and again participated in a program for young women called Girls Exploring Math and Science.

Each year Keck also helps sponsor numerous technology education programs including a statewide electric car contest. Of special merit in 2008, the Honoka'a Robotics Club, mentored in part by Keck representatives Liz Chock, Allan Honey, Kyle Kinoshita and Branning Sung, was selected "Rookie All Star" team at the Hawai'i Regional First Tournament, (For Inspiration and Recognition in Science and Technology). The award secured them an invitation to the National Competition in Atlanta, Georgia. Liz Chock summed the experience with: "I have always been impressed with their commitment, respect, tenacity and overall

spirit of 'ohana' and would like to see these kids from rural Honoka'a excel at this varsity sport for the mind."

All staff members at Keck are encouraged to contribute up to 2% of their work time to community service projects of their choice and a wide variety of local organizations benefit from their time and talent, from the American Cancer Society Relay for Life to the annual Waimea Christmas Parade.

In addition to supporting education and our community, Keck Observatory continued its commitment to building career pathways for next generation scientists and engineers. The High School Student Employment program employed the following North Hawai'i students in 2008: Amber Alvarez, Honoka'a High School, Wayne Straus, Kanu O Ka Aina; Joyce Vitales, Honoka'a High School; Anna Micco,

Parker School. Whitney Parker from Hawai'i Community College and Kate Kharitonova from the University of Hawai'i-Hilo expanded classroom walls to include the Observatory as a part of their higher education.

The "Akamai Observatory Internship" summer science and engineering program completed its fifth year in preparing college students for future careers in science and technology and Keck Observatory again coordinated the Hawai'i Island program. The 2008 participants were Michelle Simon, Jeff Fines, Vahid Ajimine, and Scott Hamilton for Keck and Amber Imai, Tamarah Binek, Kim Bott, Shem Livai, Kyle Loo, Brandon Bonilla, Joshua Loving, Jianwei Zhou, Jahrain Jackson, Katherine Hall, and Kim Brenton for the other observatories on Mauna Kea.



The twin 10-meter optical/infrared telescopes are dedicated to advancing human knowledge, a scientific pursuit where often unexpected dividends are born.



These images reflect the commitment of Keck's professional staff to inspire students of all ages to excel at science, a varsity sport for the mind.

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AdSpR	Advances in Space Research
AJ	Astronomical Journal
ApJ	Astrophysical Journal
ApJL	Astrophysical Journal Letters
ApJS	Astrophysical Journal Supplement Series
Ap&SS	Astrophysics and Space Science
Icarus	
JPhCS	Journal of Physics Conference Series
JQSRT	Journal of Quantitative Spectroscopy and Radiative Transfer
MNRAS	Monthly Notices of the Royal Astronomical Society
Nature	
NewAR	New Astronomy Review
PASP	Publications of the Astronomical Society of the Pacific
PhST	Physica Scripta Volume T
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Aerial view of the summit of Mauna Kea.

