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
We advance the frontiers of astronomy and share our discoveries to inspire the imagination of all.

Observatory Groundbreaking: 1985
First light Keck I telescope: 1992
First light Keck II telescope: 1996

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)

EIN: 95-3972799

Director: Taft E. Armandroff
Deputy Director: Hilton A. Lewis
Number of Full Time Employees: 125
Number of Observing Astronomers FY2007: 397
Number of Refereed Articles FY2007: 279
Total Number of Keck Science Articles Citation Count to December, 2006: 67,631
Fiscal Year: October 1 - September 30

Cover photo:
The twin 10-meter telescopes peer into the cosmos from the stunning summit of Mauna Kea.
It is with great pleasure that I welcome you to the 2007 annual report of the W. M. Keck Observatory. The past year has been noteworthy in both the measure of Keck’s scientific achievement and in our continued leadership in breakthrough technologies and innovation. In the following pages, we will share highlights of recent accomplishments and introduce you to some of my colleagues who helped make this an exceptional year.

One of the key metrics for evaluating the success of our Observatory, and indeed any scientific enterprise, is the number of scholarly articles published in top academic journals. Keck Observatory surpassed a major milestone in fiscal year 2007 having 279 papers published in professional astronomy journals. This is a record for Keck, and it significantly exceeds the number of papers published per telescope of any ground-based observatory worldwide. More sophisticated metrics that track not only the number of papers published, but also how impactful each paper is to change a scientific area or spawn a new field of research, confirm that Keck is the most scientifically productive observatory on Earth.

The range and depth of the scientific discoveries achieved with the Keck telescopes in 2007 is inspiring. Dan Stark, Richard Ellis and colleagues revealed the oldest, most distant galaxies in the universe using our large 10-meter telescopes, strengthened further by using the powerful cosmic phenomenon of gravitational lensing. The light from these galaxies has travelled for over 13 billion years before reaching the Keck telescopes. Closer to home but equally spectacular were discoveries made by studying new images of the rings of Uranus captured with Keck’s adaptive optics system with unprecedented clarity. Highlights of other recent discoveries are in the pages that follow.

This year witnessed the supercharging of our world-class adaptive optics systems via the installation and commissioning of the next-generation wavefront controller on both Keck I and II. The new technology built into these systems enabled Keck astronomers to easily surpass previous image clarity records for key scientific targets, such as the Galactic center, Pluto, and star forming nurseries.

Other programs to enhance our telescopes, instruments and engineering continued strongly in 2007. While the Keck Observatory is a leader in efficiently obtaining spectra of hundreds of astronomical sources simultaneously in the optical portion of the electromagnetic spectrum, until recently, the technology was not available in the infrared. However, scientific imperative, technological developments, and a public-private funding partnership have enabled the Observatory to develop a breakthrough multi-object spectroscopic instrument for the infrared: MOSFIRE. This past year, MOSFIRE transitioned from its design phase into fabrication. The integration of MOSFIRE systems will begin in January 2008, and we expect this uniquely capable instrument to be delivered to our Mauna Kea summit facilities in late 2009.

Also underway this year was the development of a new laser guide star adaptive optics system for the Keck I telescope. This new system will use technological advances to surpass the world-leading performance of the current Keck II adaptive optics system. Progress was also made this year in two other technology enhancements: 1) upgrading our popular first-generation optical spectrograph LRIS to increase its performance and efficiency and 2) making improvements to our acquisition/guide cameras to better track the science targets in the sky.

During 2007, the Keck Observatory Advancement Advisory Council was formed to provide wisdom and expertise to the Observatory in the realm of private fundraising. I am thrilled at the caliber and commitment of these Observatory supporters who have agreed to serve on our Council. With federal sources of funding not at the scale needed for modern technological advances, private philanthropy and the work of the Advancement Advisory Council are crucial for our future success.

Throughout its young history, Keck Observatory and the world’s most accomplished scientists have been at the leading edge of astronomical research and innovation. In closing, may I take this opportunity to thank our governing board, professional staff and Observatory donors for their encouragement and for their unwavering commitment to exemplary scientific achievement.
Dawn meets the summit of Mauna Kea and Hualalai.

Information technology student intern Eric Dela Rosa learning the computer intricacies that power the Keck telescopes.

Dawn meets the summit of Mauna Kea and Hualalai.
At its inception in the 1980’s, the W. M. Keck Observatory radically challenged the scientific status quo. For forty years prior, the 5-meter (200") Palomar telescope had reigned supreme. To produce the next leap in telescope design, astronomers and engineers at UC and Caltech, under the leadership of Project Scientist, Dr. Jerry Nelson, came up with an innovative and controversial design to build a mosaic mirror from segments rather than using a single giant piece of glass. Many in the astronomy community were convinced the concept would fail. The visionary design did, however, capture the attention of the W. M. Keck Foundation. The Foundation’s namesake, William Myron Keck, an entrepreneur and founder of Superior Oil Company of California, was familiar with high risk and bold moves, and his foundation recognized an extraordinary opportunity to advance science. The Keck Foundation funded both the original Keck I 10-meter telescope and six years later, its twin on the summit of Mauna Kea. The total grant of $138 million represented 25% of the Foundation’s assets, and, at the time, was also the largest charitable contribution of its kind ever made. The project was managed by the world’s leading centers for astronomical research, the University of California and Caltech, who formed an enduring partnership of pioneering science and technology. In 1996, the National Aeronautics and Space Administration (NASA) joined as a one-sixth partner in the Observatory.

Today, Keck Observatory is managed by the California Association for Research in Astronomy as a private 501(c)3 research and education corporation. Charged with sustaining the Observatory at the vanguard of world astronomy, the governing board membership in 2007 and their institutional affiliation were Chair Dr. Edward C. Stone, California Institute of Technology; Vice-Chair and Chancellor Dr. France A. Cordova, University of California at Riverside; Alphonso V. Diaz, University of California at Riverside; Dr. Shrinivas Kulkarni, California Institute of Technology; Dr. Michael Bolte, University of California Observatories/Lick Observatory; and Dr. Thomas Tombrello, California Institute of Technology. Liaisons to the board were Dr. Stephen Ridgway, NASA and Theodore J. Keck, the W. M. Keck Foundation.

In the photograph above, taken on campus at Caltech in November, 2007, are standing left to right: Tom Soifer, Science Steering Committee Co-Chair; Shrinivas Kulkarni, Board member; Michael Bolte, Board member; Jean Brodie, Science Steering Committee Co-Chair 2008; Taft Armandroff, Observatory Director; Edward Stone, Board Chair; George Blumenthal, Board Vice-Chair 2008; Margarita Scheffel, Keck Chief Financial Officer; Hilton Lewis, Deputy Director; Thomas Tombrello, Board member; T. J. Keck, Keck Foundation liaison; and Elaine Stamman, Board secretary.
The revolutionary twin Keck telescopes are the most powerful tools to study the cosmos. The milestones below represent the Observatory’s commitment to being first and foremost in the rapidly evolving technical field of astronomical research.

1974  Jerry Nelson presents initial design concept for 10-meter telescope
January 3, 1985  Presidential telegram sent by Ronald Reagan acknowledging $70 million donation from the W. M. Keck Foundation to construct the world’s largest telescope
September 12, 1985  Ground blessing, W. M. Keck Observatory - summit of Mauna Kea
November 24, 1990  First light – Keck I Telescope - 9 segments installed
November 7, 1991  Dedication of Keck I Telescope and Keck II ground blessing
April 14, 1992  First light – Keck I Telescope - 36 segments installed
May 21, 1993  First light – LRIS (Low Resolution Imaging Spectrometer)
May 8, 1996  Dedication of Keck II Telescope
February 5, 1999  First light – Adaptive optics instrument on Keck II telescope
March 13, 2001  Interferometer - First fringes with the Keck telescopes
December 23, 2001  First laser guide star over Mauna Kea created with the Keck II sodium laser
June 3, 2002  First light – DEIMOS instrument (DEep Imaging Multi-Object Spectrograph)
August 25, 2004  First light – Upgraded HIRES (High Resolution Echelle Spectrometer) CCD detectors
February 22, 2005  First light – OSIRIS instrument (OH-Suppressing Infra-Red Imaging Spectrograph)
January 27, 2007  First light – Cassegrain ADC (Atmospheric Dispersion Corrector)
February 27, 2007  First light – NGWFC (Next Generation Wavefront Controller)
Access to the Keck telescopes is highly prized and the 365 nights of observing time are divided each year among its partner institutions, Caltech (36.5%), UC (36.5%), NASA (14.5%), and the University of Hawai’i (UH) (12.5%). In 2007, the Observatory also provided observing time to other astronomy communities through the Telescope System Instrumentation Program (TSIP) funded by the National Science Foundation and administered by the National Optical Astronomy Observatory (NOAO), and through specific time exchanges with both the Gemini Observatory and Subaru Observatory in order to access some of their instrument capabilities that are not emphasized at Keck. Each observing community has its own Time Allocation Committee (TAC) that reviews proposals semi-annually and approves them based upon their scientific merit.

A Science Steering Committee, comprised of 11 astronomers from the partner institutions, meets regularly to develop the priorities of the Keck science community and communicate them to Observatory leadership. The co-chairs of the Science Steering Committee in 2007 were Tom Soifer, representing the California Institute of Technology, and Ian McLean, from UCLA, representing the University of California astronomy community.

The annual Keck Science Meeting was held September 19, 2007, on the campus of Caltech in Pasadena, with resounding participation by the Keck observing community. The breadth of science presented at the meeting ranged from physics of the onset of galaxy formation to measurements of solid methane on Saturn’s largest moon Titan, reflecting the diverse scientific themes pursued by Keck’s astronomers. The consensus of the assembled astronomers is that Keck’s investment in our laser guide star adaptive optics system and related infrared spectroscopy tools, particularly our new OSIRIS instrument, is clearly positioning Keck at the forefront of several scientific fields. For example, OSIRIS has become a unique tool for long-term studies of the physical conditions, chemistry, and cloud cover in the atmospheres of solar system bodies, including Titan. This type of research was once the exclusive domain of space probes.
OBSERVING A RARE OPPORTUNITY

The rings of Uranus were oriented “edge-on” to Earth in 2007 and were imaged for the first time from Earth by Keck Observatory. The solar system’s seventh planet was discovered in 1781, but its rings were not found until 1977. NASA’s Voyager 2 spacecraft sent back the first images of the rings in 1986. The “ring plane crossing” event in 2007 provided a rare opportunity (not to be repeated for another 42 years) to observe their dark (unlit) side. Observations showed that the ring system, in particular the distribution of dust, had changed dramatically since previous views, suggesting that Uranus has suffered occasional large impacts over the past 21 years. Imke de Pater of the University of California, Berkeley, led the study.

SOLVING THE MISSING DWARF GALAXY PUZZLE

Measurements of stars’ velocities using the Keck II telescope and its leading wide field multi-object spectrograph DEIMOS have shown that some recently discovered very low mass galaxy companions to the Milky Way are completely dark matter dominated. The study may be the first step in solving the “Missing Dwarf Galaxy Puzzle.” The puzzle is the lack of hundreds of small dwarf galaxies surrounding large galaxies like our Milky Way, and it comes from a prediction of the “Cold Dark Matter” model for the formation of galaxies and other large structures in the Universe. This result is being closely studied by astronomers interested in galaxy formation.

The “Cold Dark Matter” model postulates that dwarf galaxies form first and are the building blocks for larger galaxies. After most of these building blocks merge to form the large galaxies like our Milky Way, some should remain intact surrounding the large galaxies. The Keck result has shown that these dwarf galaxies are significantly more common around the Milky Way than previously believed. The lead author on this study is Josh Simon, Millikan Postdoctoral Scholar at Caltech.
Saul Perlmutter of the University of California at Berkeley and Lawrence Berkeley National Laboratory and Brian Schmidt of Australian National University and their teams; the Supernova Cosmology Project and the High-z Supernova Search Team, independently discovered that the expansion of the universe is accelerating. Their discovery, based on observations of distant supernovae from Keck Observatory, led to the idea of a repulsive force, known as dark energy. This implied that the fate of the universe is to just keep expanding at an ever faster rate. The physical origin of dark energy is widely believed to be one of the most important open questions in physics today. The 2007 Gruber Cosmology Prize was awarded jointly to Saul Perlmutter, Brian Schmidt, and the members of their two international teams for their discovery. This same research has been honored previously, most recently by the $1 million Shaw Prize that was shared by Perlmutter, Schmidt, and Adam Reiss in 2006.

28 MORE EXOPLANETS

Keck Observatory, with its HIRES spectrometer, is a leading facility for detecting planets around nearby stars using the Doppler wobble technique. At the summer 2007 meeting of the American Astronomical Society held in Honolulu, the California and Carnegie Planet Search team and the Anglo-Australian Planet Search team jointly announced the discovery of 28 new planets outside our solar system, increasing to 221 the total number of known exoplanets orbiting nearby stars. In addition, this group highlighted the star Gliese 436, located only 30 light years from Earth. This star features a planet, discovered using Keck data, that passes in front of the star, or transits, as viewed from Earth. From the small sample of transiting planets that also have Doppler wobble measurements, one can deduce the density of the planet. Gliese 436 was found by researchers to have a planet of 22.4 Earth masses, slightly larger than the mass of Neptune (17 Earth masses). The planet’s radius and density are also similar to Neptune’s. The Gliese 436 planet’s density is two grams per cubic centimeter, twice that of water, suggesting it is 50 percent rock and about 50 percent water. According to Geoff Marcy of the University of California at Berkeley and a leader of the California and Carnegie Planet Search team, “So this planet has the interior structure of a hybrid super-Earth/Neptune, with a rocky core surrounded by a significant amount of water compressed into solid form at high pressures and temperatures.”
The measure of success in a research facility like Keck Observatory is the advancement of knowledge, which is ultimately gauged by breakthrough discoveries that can cause paradigm shifts in the way we view the universe and our place in it. The professional metric is the number of high quality scientific publications, typically enumerated as the number of refereed journal articles, and the citation rate of these articles, produced by data derived from observations using the Keck telescopes. Over the past few years the number of papers and their scientific impact represented by Keck astronomy has far surpassed other comparable observatories, sometimes by a factor of 2 to 2.5. The continued growth of publications indicates that the full potential of the telescopes to contribute to our total knowledge of astronomy is yet to be realized. A complete Keck Observatory Science Bibliography for FY07 is presented on pages 24 to 35.
W. M. Keck Observatory Annual Report 2007

Imke de Pater: Astronomer

Imke de Pater has never forgotten the kind gentleman who first sparked her interest in astronomy, back in high school in the Netherlands. A friend’s father gave her an astronomy book and set up meetings in the neighboring town of Utrecht for Imke to learn more about this field. Imke went on to earn a Ph.D. in Astronomy from the University of Leiden, in the Netherlands, with a specialization in planetary astronomy. Imke has since emigrated to the U.S. to pursue her career and her research, and she currently works as a professor of astronomy at the University of California at Berkeley. The 2001 book Planetary Sciences, co-authored by Imke de Pater and Jack Lissauer, is regarded as the definitive textbook in the planetary sciences.

Though Imke began her career specializing in radio astronomy, the 1994 collision of comet Shoemaker-Levy 9 with Jupiter, almost simultaneously with the Keck II Telescope coming online, inspired her to expand her wavelength range to the infrared portion of the electromagnetic spectrum. Imke assembled a group to observe the impacts. “We suddenly, in real time, saw a fireball much brighter than Jupiter itself rising up. I have never since observed an event which was as dramatic as this one, with such impressive real-time changes,” says Imke.

Imke recently used the OSIRIS instrument at Keck Observatory to obtain the first-ever spectrum of a volcanic eruption on Io, one of Jupiter’s moons. Imke has also used the Keck Telescopes to observe Jupiter’s Red Oval, which formed between 1998 and 2000 when three white ovals south of the Great Red Spot merged and later turned red. Imke used the NIRC2 instrument at Keck to image Uranus’s rings during the recent ring plane crossing (when the rings were edge on). Imke’s team discovered that the dust in this ring system had changed dramatically since the rings were imaged by Voyager in 1986, suggesting that Uranus’s rings are much dustier than previously thought. Using OSIRIS, Imke’s group discovered that Titan, Saturn’s largest moon, is covered globally by a methane cloud and that on the morning side of the moon, near the highland called Xanadu, there is a persistent drizzle at lower altitudes.

“I love to find the unexpected, the superb image quality, and working at the limits of what is possible with the Keck Adaptive Optics staff. As astronomers, we know the science and what we want to observe, and together with the Keck support astronomers, we figure out how to accomplish this.”

Bob Goodrich: Senior Manager, Observing Support Group

Bob Goodrich knew he wanted to be an astronomer at a very young age. He single-mindedly pursued his passion, and in 1977 he earned an undergraduate degree in astronomy at Caltech. “I graduated at the top of my class, but also at the bottom, because I was the only astronomy major that year,” jokes Bob. The thinking at that time was that would-be astronomers should major in physics as undergraduates, then specialize in astronomy at graduate school. In Bob’s opinion, Caltech, considered one of the nation’s premier schools for astronomy, did not shirk on its physics requirements. He went on to earn his Ph.D. in astronomy at UC Santa Cruz, specializing in the study of quasars in active galaxies.

Bob is a world expert in polarimetry, a technique used to analyze light from a celestial object to determine more about its geometry. He built the polarimeter for the low resolution imaging spectrograph before being recruited to work at the Observatory as a support astronomer in 1996. Bob now manages the observing support group consisting of support astronomers (SAs), observing assistants and night attendants. He is also a member of Keck’s senior management team, the Observatory Council.

Bob proudly refers to the support astronomers as his “black belts.” They serve as the primary contact for visiting astronomers who have been awarded observing time on the Keck Telescopes. To further optimize the use of Keck’s instrumentation suite, support astronomers are also assigned roles either as instrument master or backup, responsible for the overall performance of their assigned instruments. Support astronomers are responsible for ensuring that each instrument is calibrated and working properly before each observing run. “The support astronomer’s oversight is key to keeping our astronomers happy - so that they can take maximum advantage of their precious time at the telescope,” explains Bob.

The remaining 20 percent of SAs’ time is allocated for independent research. “When they do their own research, the support astronomers become more familiar with and adept at using Keck instruments. We encourage them to utilize instruments at our neighboring telescopes, as well, so that they learn how to use new instruments and continue expanding their knowledge base. Our support astronomers are very creative and talented people, and earning research time on the best telescopes in the world helps to sustain their passion and commitment for their work.”
Sam Ragland:
Interferometer Operations Manager/Scientist

Linking the Keck I and Keck II Telescopes together as the equivalent of an 85-meter telescope has been a strategic goal for the Observatory since the second telescope was funded in 1991. Development of the interferometer, an instrument which combines the light from the twin telescopes to achieve extremely high angular resolution, began in 1996, and the first interferometer science results were published in 2004. With its recently completed nuller mode, the Keck Interferometer is now poised to produce unprecedented science.

In 2001 Sam won a prestigious Michelson Fellowship to work at the Harvard-Smithsonian Center for Astronomy and Astrophysics in Boston. The chance to utilize the IOTA interferometer in Arizona to do scientific research was enough to lure Sam Ragland away from his native India. Sam spent his fellowship years demonstrating that three telescopes at the IOTA array could be successfully linked interferometrically to reconstruct images. When Sam left Boston in 2004 to take a job at Keck Observatory, he continued this research work through an NSF grant. Last year Sam’s team found that nearly a third of the red giants they surveyed were not uniformly bright across their face, but were patchy. This data has important implications for the last stages of stellar evolution, when stars like the Sun are evolving into planetary nebulae. In 2007 Sam and his collaborators submitted their first interferometric image and the accompanying science paper for publication in the Astrophysical Journal.

Sam Ragland currently manages the science operations of the Keck Interferometer and will oversee the final performance validation run of the Keck Interferometer’s nulling mode, scheduled for late 2007. This new technique will become available for science runs in February 2008. Nulling combines the light from both telescopes and cancels, or nulls, the light from a star. Future plans for the Keck Interferometer include measuring general relativity effects around the super-massive black hole at the center of our own galaxy.

“Keck Observatory has demonstrated that new technologies like the segmented mirrors, laser guide star adaptive optics, and large aperture interferometry really work and produce outstanding science. This kind of success gives me confidence that we will continue to lead the way, using cutting-edge technology to decipher the mysteries of our universe.”

Merlita Evanoff:
Office Administrator

Merlita Evanoff was born and raised on Kaua`i, where her father worked for the sugar cane plantations. Earning $6 a day, it took her dad ten years, from 1946 to 1956, to be able to afford to bring Merlita’s mom and four older siblings to Hawai`i from the Philippines. Merlita was the fifth of six children who shared a 900 square foot plantation house.

When Merlita finished her schooling, she felt she needed to experience life in the big city. She moved to San Francisco, then to Albuquerque, and then to Denver, where she spent several years working as a secretary for a large defense contractor. Along the way, Merlita and her husband had four sons. Every year the family came home to Hawai`i to visit relatives. In 2000, Merlita and her husband purchased a small parcel of land in North Kohala, thinking that someday they would retire there. A few years later, they decided that they had had enough of city life, and they packed up and moved to Kohala.

Merlita’s family is now enjoying fresh fruits from their orchard, the close-knit community here on the island, and the slower pace of life. Merlita landed a job at Keck in 2004, a few months after she moved here, as administrative assistant to several different departments within the Observatory. Merlita’s duties range from researching employee benefits and ordering office supplies, to scheduling use of facilities, supervising front desk staff and arranging catering for in-service trainings. “My main priority is making sure that our employees’ needs are taken care of. It is never boring working here and I am always learning something new,” says Merlita.

“Our Keck `ohana works well together to carry out our mission. We inspire interest in our young adults in science and technology, and we give back to our Island community. Our Keck employees are out in the community sharing their knowledge and passion about astronomy, and their helping hands.”
Allen Agliam:
Facilities Systems Maintenance Technician

Allen Agliam grew up in the small village of Honohina on the Hamukua Coast of Hawai’i Island. When the sugar plantation closed in 1970, the village of Honohina was torn down, and its few hundred residents were relocated to neighboring communities. Allen Agliam was 18 years old, and he had already spent three years working as a part-time laborer in the sugar cane fields. Determined to find alternative work, Allen earned a degree in Machine Shop Technology from Hawai’i Community College (HCC) in Hilo. After college Allen still worked off and on for the sugar cane industry, but as a machinist overseeing mill operations. In 1980 Allen accepted a full-time job with the Hawai’i Army National Guard, responsible for training weekend soldiers. Allen spent the next 20 years as a sergeant with the National Guard in Hilo, administering the weekend training program, including coordination of resources, maintenance of a fleet of 80 vehicles, setting training schedules, and teaching soldiers reconnaissance skills and use of various weapons systems.

When Allen retired from the National Guard in 2000, he still had a mortgage to pay. Allen landed a temporary machinist position at Keck Observatory, and three months later he was promoted into a regular position in the facilities department. Allen’s first priority is to perform scheduled preventative maintenance and to maintain a parts inventory for the summit facilities. When this work is done, Allen focuses on special projects. He recently assisted in the design of an automated cleaner to remove oil, grease, and dust from the telescopes’ drive track mechanisms. This cleaner is activated electrically every time the telescopes are rotated, and it eliminates the need for five people to do this task manually. Allen is currently working on an upgrade to install new safety features to the segment crane which is used to lift mirror segments from the Keck II Telescope, and on the installation of new air compressors for both the Keck I and Keck II Telescopes.

“I love working here. All our departments have talented and skilled personnel with the desire to do an outstanding job and provide outstanding service. The people here go the extra mile to provide service from the heart. We enjoy the work and the sense of accomplishment when we get the job done.”

The People of Keck continued on page 17.
Keck Observatory is all about cutting-edge technology and visionary science. In this, we are guided by four broad strategic goals:

- Achieving highly efficient operations
- Maintaining scientific leadership through state-of-the-art instrumentation
- Maintaining world leadership in high angular resolution astronomy
- Complementing (the next generation of) extremely large telescopes

These goals form the framework for all activities at the Observatory, both in routine operations and the development of new capabilities. Translating these broad goals to a practical operating philosophy is the role of the leadership team – the Board, Science Steering Committee, Directorate and senior management at the Observatory. One of the great strengths of the Observatory is the close connection between this leadership, the astronomer users, our staff at Keck and the instrument builders.

The Observatory continues its vigorous program to develop new scientific capabilities. The foundation for new capabilities is state-of-the-art technical advances. These include advanced laser technology, advanced computing hardware and sophisticated high performance software, cryogenic components that operate just a few degrees above absolute zero and ultra-sensitive detectors for optical and infra-red light. As challenging as the technology itself is managing the dramatically increased complexity that is a natural consequence of ambitious instrumentation. In many ways, it is system complexity that limits the ability to field instruments that are reliable enough for sophisticated observational programs. In addition to the technology and the complexity issues, all installations and upgrades have to be planned in great detail to minimize the impact on nightly observing, a very tough challenge in a fully operational facility.

In 2007, three major new capabilities were brought on line for science use. The highly successful Next Generation Wavefront Controller funded by grant from the Keck Foundation was completed on schedule and within budget. This system, which is at the heart of the adaptive optics systems, determines the correction to be made to the incoming light up to 2,400 times per second. This upgrade has exceeded our expectations for technical performance and provides a major enhancement to both natural and laser guide star adaptive optics.

After several years of work, an atmospheric dispersion compensator (ADC) was commissioned. This instrument counteracts a property of the earth’s atmosphere which spreads out light into its component colors. It is currently used in conjunction with the Low Resolution Imaging Spectrograph (LRIS), the most efficient optical spectrograph in the world and one of the most productive instruments at Keck Observatory. The ADC further improves spectrograph efficiency by up to 20%, enabling science that was formerly out of reach. The combination of LRIS’ capabilities and the ADC has made Keck Observatory the definitive leader in ground-based ultra-violet/blue spectroscopy and imaging.

Robert Novak (left) and Gary Anderson (right) repair the Keck II telescope control system damaged by the October 2006 earthquake.

Facilities Senior manager Dennis McBride assesses damage at headquarters. A stopped clock shows when the 6.7 magnitude quake hit.

The complex inner workings of Keck’s leading edge adaptive optics system.
Finally the Nuller, an instrument that works with the Keck Interferometer, was commissioned this year. The Nuller, which was funded and built by NASA’s Jet Propulsion Laboratory is a particularly challenging instrument and makes extraordinary demands on the Observatory infrastructure, requiring sophisticated technology to deal with vibration and turbulence. It functions by suppressing the light from a star, leaving the faint glow from the dust surrounding the star. This remaining light allows astronomers to study the formation of planets around young stars and the life cycle of dying stars as they blow off their outer layers.

New capabilities are the key to sustaining long term competitiveness and the science output of the twin telescopes rests on our ability to provide a high level of service to astronomers. Our staff and leadership are completely committed to this goal. The telescopes have to be ready for use every night, 365 nights per year. Every day our crew of technicians and engineers confront a challenging mix of preparing the telescope and instruments for the upcoming night, performing maintenance and upgrading or installing equipment. All of this has to be done at the summit of Mauna Kea at nearly 14,000 feet altitude and ready in time for the evening’s observing. Supporting this effort is a headquarters staff, responsible for all technical and logistical issues, as well as for the detailed planning essential for efficient execution.

An excellent example of the service ethic that is central to Keck’s success is given by our response to the major earthquake we experienced in the past year. On October 15th, 2006 Hawaii Island experienced a magnitude 6.7 earthquake. Both Keck telescopes suffered significant damage, though very fortunately the key optics were spared. Our headquarters in Waimea also sustained moderate damage, but we were able to continue to occupy them. Recovery efforts were focused initially on restoring our operational capability as quickly as possible. Through intense effort and extraordinary team work, we were able to return to close to full operations on both telescopes within six weeks. This remarkable achievement was accomplished safely through the dedication, skill and unwavering commitment of our entire staff, a fact of which we are very proud.
The People of Keck

Cindy Chong:
Purchasing Agent

Cindy is an Island girl, born and raised in the town of Honoka’a. Cindy worked as a bank teller in Waimea for ten years before Keck Observatory was built, when the majority of town consisted of cow pastures. When the Observatory moved its permanent headquarters to Waimea, Cindy was hired as a mail clerk. “There was not much for me to do here back then,” says Cindy, “with only a handful of employees.” Not liking to be idle, Cindy took on the task of sorting and paying bills, then took the initiative to help out with other tasks.

For the past 16 years Cindy has overseen the purchasing of most of the goods and services for the Observatory. Once a purchase has been approved by the respective department manager, Cindy takes over to work out the details. “I use good common sense to ensure that we do business in the best interest of the company,” says Cindy. Goods purchased by Keck range from paper booties for use by clean room personnel, to furniture, to one-of-a-kind components for the telescopes. Cindy also sets up consultant contracts for services such as the production of the Advancement e-magazine and the maintenance of elevators at the summit. Keck uses local vendors whenever possible, and Cindy prides herself on doing her job right from start to finish.

“Meeting the demands of my co-workers, who are driven by schedules to develop, repair, or improve the operations of the Observatory so that our astronomers are able to make good use of their observing time can be very challenging. I look forward to coming to work and doing my part to keep the Observatory at the forefront of astronomy.”

After work Cindy paddles with the Kawaihac Canoe Club, which allows her to unwind and feel the wind on her face. Cindy was part of the first women’s crew to cross the treacherous Alenuihaha Channel between Hawai’i Island and Maui, and they recently paddled in the Na Wahine O Ke Kai Race from Moloka’i to Waikiki in just under seven hours. “It’s a spiritual experience,” she says.

Allan Honey:
Software Engineer

Allan (Al) Honey joined the Keck team as one of the Observatory’s first software engineers over 20 years ago. He originally planned to stay at Keck for 5 years. The rewards and challenges of his job designing software programs for the telescope and instrument motor control systems have kept him here much longer. Though Al is far from his native British Columbia, Hawai’i is now home.

As a member of the Island ‘ohana (family), Al has given generously of himself. His service includes 14 years as a scouting leader, 8 years with the YMCA sailing program, 8 years conducting classroom presentations on science and technology, 6 years mentoring school-based engineering projects, and 2 years as a board director for the West Hawai’i Tennis Association.

During the regular work day, Al is part of Keck’s operations team. To keep the twin 300 ton telescopes and multiple sophisticated instruments operating smoothly is a daily challenge, and Al and his colleagues are busy people. Al is on call one out of every 11 nights, available to consult with observing assistants at the summit to resolve issues that arise when the telescopes are “on sky.” Most problems are fixed fairly quickly, thanks to the copious observing logs that the Observatory maintains, enabling Keck software engineers to precisely diagnose problems in normal operations.

Another of Al’s tasks is to brainstorm how best to upgrade infrastructure at the Observatory, as certain components of the system age and spare parts become increasingly difficult to come by. Al enjoys working with staff members in many departments to upgrade existing systems and to think through new ways to improve the capabilities of the Keck Telescopes and instruments. “We have not yet tapped the full potential of the Keck Telescopes,” explains Al. Figuring out how to fully exploit the vast power of the telescopes will keep Al and his colleagues busy for years to come.

“The large number of disciplines needed to construct and maintain a modern observatory requires a well educated community and, therefore, provides a career path and a place of employment for the members of this community. Astronomy is essentially a ‘clean industry,’ pushing on the leading edges of science and technology.”

The People of Keck continued on page 21.
The discoveries made by Keck astronomers have given humanity new scientific insights into the origin, structure, and evolution of the universe. Sharing these discoveries through news releases, special publications, educational programs, an annual open house and other events is an important part of the Observatory’s mission. In FY2007, 23 news releases were distributed by Keck Observatory to a growing worldwide audience with keen interest in exploration of the cosmos. The Observatory’s E-magazine, Cosmic Matters produced four issues of multimedia feature articles showcasing Keck’s research and achievements to a subscriber list of 1,133 astronomy professionals, enthusiasts and admirers. Observatory headquarters’ Hualalai Learning Theatre hosted nine astronomer presentations in 2007 to local audiences through the popular public lecture series. The lectures are also available by podcast on the Observatory’s web site www.keckobservatory.org.

Each year, Keck supports an active public outreach team made up of both astronomers and engineers who, in 2007, offered their enthusiasm and expertise to spark Hawai’i students in science, mathematics and engineering. In addition to classroom visits, students took part in special tours of the Observatory, mentorship programs, stargazing events, and family science nights designed to further their skills and passion for astronomy.

Through the initiative of Keck support astronomer Marc Kassis, the Observatory received a grant in 2007 from the Astronomical Society of the Pacific’s new SEED (Simple Ef-
In addition to education and outreach, Keck Observatory also has a commitment to building career pathways for the next generation of scientists and engineers. The Observatory’s High School Student Employment Program employs North Hawai‘i students in most departments within the Observatory. Many of these students continue their higher education in science and engineering. In 2007 the Observatory employed the following high school students: Amber Alvarez, Tiare Devenot, Alohilani Fero, Zen Kuriyama, Korina Leong, Whitney Parker, Leilani Rapaport, and Rene Scofield.

The “Akamai Observatory Internship,” funded by the National Science Foundation’s Center for Adaptive Optics and coordinated locally by Keck Observatory’s Sarah Anderson, continued to make its impact on Hawai‘i undergraduate students and on Keck Observatory. The program prepares participants for careers in the field of astronomy through an intensive academic short course, inquiry-based activities and authentic workplace internships with the Mauna Kea Observatories. The 2007 cohort participants were Isaac Crosson, Jaqueline Mena, and Joseph Hernandez for Keck Observatory and Dustyn Iwamoto, Travis Prose, Jessica Solano, Dex Alpiche, James Linden, Sarah Stoebner, Eric Dela Rosa, and Jamie Cookson for the other observatories.
The Keck II laser creates an artificial star and measures atmospheric distortions, providing unprecedented image clarity of cosmic phenomena being studied at the frontiers of astronomy.
The People of Keck

W. M. Keck Observatory Annual Report 2007  |  21

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Jon is applying his systems approach knowledge and experience to the task of collecting and analyz ing telescope performance data. Tomas creates graphical representations of this data, in order to identify areas that are not working properly and to strategize how to make day-to-day operations more efficient. The ultimate goal is to streamline operations with existing instruments, so as to free up time and resources to work on new projects, like Next Generation Adaptive Optics.

Tomas likes the openness and camaraderie of the staff at Keck. He appreciates the fact that he can freely exchange ideas with the Directorate of the Observatory in a focused environment which fosters results.

“The Observatory’s greatest challenge is to continue to push the envelope of what is possible. There are always more questions, which require more advanced capabilities. To move forward requires the continued perseverance and ingenuity of everyone at Keck.”

Tomas Krasuski:
Electronics Engineer

Before coming to Hawai’i in 2005, Tomas was on another island in the Pacific, Kwajalein, where he honed his skills designing and installing radar and sonar systems for the U.S. test missile range there. Employed by the defense industry for 20 years, Tomas pioneered use of parametric sonar, a technique to mix different frequencies to obtain a pencil-thin beam which can travel long distances underwater. He has a deep affinity for the ocean, and for the past 16 years he has pursued a secondary career as an underwater educational filmmaker. Tomas’s cinematography has won several awards, including an Emmy Award for “Underwater New England.”

While filming, Tomas spent many evenings onboard a boat gazing up at the stars. “I have always had an interest in the objects out there in the universe,” he recalls. When a job opened up for an electronics engineer at Keck Observatory in 2006, Tomas applied and joined the professional staff. As part of the Keck operations team, he is charged with maintaining the electronics equipment on both telescopes. Tomas is applying his systems approach knowledge and experience to the task of collecting and analyzing telescope performance data. Tomas creates graphical representations of this data, in order to identify areas that are not working properly and to strategize how to make day-to-day operations more efficient. The ultimate goal is to streamline operations with existing instruments, so as to free up time and resources to work on new projects, like Next Generation Adaptive Optics.

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Jonathan Chock:
Computer and Network Systems Manager

When Jon Chock was growing up on O’ahu, a friend’s cousin suggested that since Jon was good at math, he should consider a career in the computer field. This seemed like a reasonable option to Jon, so he enrolled in his first BASIC programming class at McKinley High School. Jon went on to earn a B.S. from UH Manoa in Information Computer Science, a popular major in the early 1980s when the first PCs were being released on the market. After college, Jon worked for the U.S. Army Corps of Engineers and for Hughes Aircraft Company in Los Angeles, doing primarily systems administration work. Jon missed Hawai’i, especially the rural lifestyle on the outer islands, so when a position doing systems administration opened up at Keck Observatory in 1992, Jon moved home.

Jon and his staff of three manage roughly 250 PCs, 150 Sun computers, and 200 network devices. Jon and another team member specialize in the Unix operating system, which the Observatory uses to run the telescopes and scientific applications, and the other two team members specialize in the Windows operating system, which is used for business operations. Jon and his group work on about 20 major projects in the course of a year, such as reconfiguring the networks to accommodate new instruments at the Observatory. In the course of a day, team members may also be called upon to troubleshoot user or network problems, something which can happen frequently in a system with 400+ computers.

Jon is currently working on upgrading the speed of the network connecting Keck Headquarters to the summit to 1 gigabit per second. This upgrade should be completed by year end 2007, and “it will make a huge difference,” says Jon, in the speed at which information can be transferred from the telescopes to astronomers in Waimea or elsewhere in the world.

“When something is not working here, we do not leave until it is fixed. We do what it takes to get the job done. This is true across the board. The dedication of our staff makes possible the wonderful discoveries at Keck that people all over the world have benefited from.”
Throughout history, private philanthropy has been instrumental in driving advances in the study of astronomy. Four hundred years ago, Galileo Galilei and the world’s first telescope received critical funding and endorsement from Christina and Ferdinard Medici, a wealthy family in Florence, Italy. Keck Observatory’s predecessor in U.S. ground-based astronomy, Mount Palomar’s Hale telescope, was financed through the generosity of The Rockefeller Foundation. And the revolutionary twin Keck telescopes were funded almost entirely by the W. M. Keck Foundation.

It is the leadership of visionary philanthropists that will encourage the continued increase of charitable giving to causes that matter most to humanity. In 2007 the Keck Observatory was fortunate to gain the expertise and alliance of a new Advancement Advisory Council. Under the leadership of San Francisco businessman Sanford (Sandy) Robertson, the Council will champion the Observatory’s need to generate philanthropic revenue as core to the long term success of Keck. In addition to Robertson, the other foundational Council members are Jeanne Robertson, Marc and Lynne Benioff, Clive and Carol Davies, Art and Rita Levinson, Wally and Bobbie Jean Hooser, Gordon and Betty Moore, Rob and Terry Ryan, and Doug Troxel. The job of linking these incredible luminaries in their respective fields to the greater Keck community is entrusted to Observatory Director Taft Armandroff and governing board members Mike Bolte and Shri Kulkarni.

The role of the Observatory’s Advancement advocates is to connect the Observatory’s accomplishments, assets, and spirit to individuals who are inspired and will contribute to its continued success. A key initiative to accomplish this in 2007 was the signature Evenings with Astronomers winter lecture series sponsored by the Rob and Terry Ryan Foundation and held at The Fairmont Orchid at Mauna Lani Resort. In an elegant setting surrounded by distinguished friends of the Observatory, five prominent Keck astronomers presented research on the frontiers of astronomy: Dr. Taft Armandroff, Dr. Mike Brown, Dr. Claire Max, Dr. Charles Beichman, and Dr. Ed Stone.

In April, a new giving program was initiated that invites individuals to contribute to planetary ($1,500), stellar ($3,000), and galactic ($10,000) annual giving levels. These donations go toward the highest priorities of the Observatory, including enhancements to Keck’s research tools and systems.

In FY07, the Observatory received 49 gifts and pledges which totaled $940,226 in support of the observatory’s major funding priorities. This brings the total amount raised to $6.1 million by the Advancement program just completing its second year.

The capital cost for the Observatory was funded through a generous donation of $138 million made by the W. M. Keck Foundation. The project was managed by the world’s premier centers for astronomical research, the University of California and Caltech. An agreement between Caltech and the University of California ensures operating support at the level of approximately $11.3 million annually (CPI adjusted annually) for the Observatory through 2018. As a one-sixth partner in the Observatory, NASA provided $2.2 million in operating support in 2007. In addition, new awards in 2007 from public grants and contracts totaled over $7.4 million. Almost $1 million in charitable donations from the private sector provided additional support. Audited financials are available upon request.
The W. M. Keck Observatory gratefully acknowledges the following benefactors of the 2007 fiscal year for their generous contributions to advance humanity’s understanding of the universe.

**Individuals**

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Rob and Terry Ryan Foundation  
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The Society of Forensic Engineers and Scientists
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| AJ | Astronomical Journal |
| ChJAS | Chinese Journal of Astronomy and Astrophysics Supplement |
| GeoRL | Geophysical Research Letters |
| JGRE | Journal of Geophysical Research (Planets) |
| JPhCS | Journal of Physics Conference Series |
| MNRAS | Monthly Notices of the Royal Astronomical Society |
| PASP | Publications of the Astronomical Society of the Pacific |

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