Adaptive Optics

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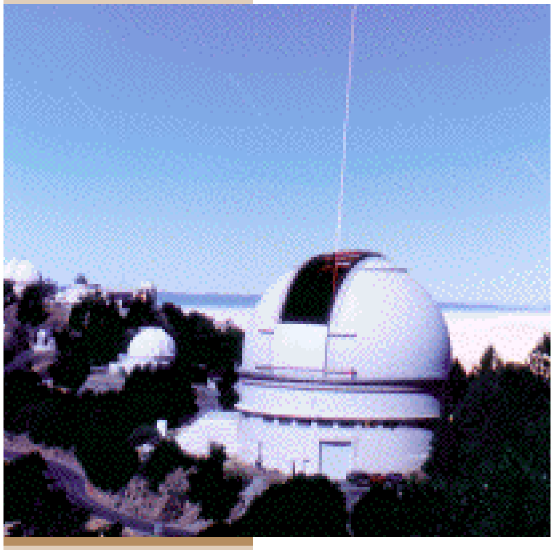

The laser beam at Lick Observatory Mt. Hamilton CA, used for creating Sodium guide stars

Introducing Adaptive Optics

Stars twinkle at night because air currents in the atmosphere cause aberrations in the transmitted light waves causing the images to vary with time (twinkle). Until recently, because of these same aberrations, astronomers have been limited to obtaining fuzzy images of distant astronomical objects viewed through land-based telescopes. Similarly, vision researchers have been unable to obtain sharp images of the living retina because of blurring caused by the medium through which the light passes. The National Science Center for Adaptive Optics is dedicated to development of the technology that will automatically compensate for the aberrations causing the loss of image quality, thus enabling a new era in astronomy and human eye research and vision correction.

Adaptive optics utilizes a high speed computer to actively compensate for the changing distortions that cause blurring of images. Additionally the system requires precision optics, special sensors and deformable mirrors, as well as a point source of light for use as a reference beacon to measure precisely the distortion created by the atmosphere (or for the eye, the internal imperfections and fluids in the eye).

NSF Science and Technology Center for Adaptive Optics

The amount of distortion is determined and an "adaptive optical element," usually a deformable mirror under computer control, is used to cancel the effect by applying an opposite distortion. In astronomy, such corrections are applied hundreds of times per second, because the adaptive optics faint objects can be imaged with long exposure over time. However this necessitates a

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Native Hawaiian Interns at LLNL

The Sky is the Limit for Adaptive Optics Interns from Hawaii

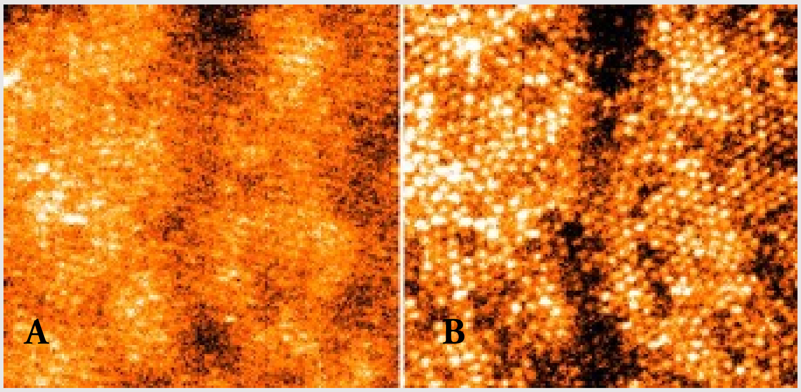
Doug Knight, ALU LIKE

In the thin air on the summit of Mauna Kea, two ALU LIKE Native Hawaiian interns from CfAO visited Keck Observatory to tour the telescope and the Adaptive Optics (AO) system. For Edward Akana II and Kehau Apana, the November 2000 visit was the conclusion to a 6-month hands-on field experience at Lawrence Livermore National Laboratory (LLNL). Their special assignments were with LLNL's Laser Guide Star Adaptive Optics group. The Keck tour gave them the opportunity to meet informally with observatory staff as prospective future technicians, to get exposure to research, and to expand their own

See Interns P. 3

Introducing Adaptive Optics

bright "reference beacon" nearby the faint object to enable the AO system to analyze and correct for atmospheric effects. This beacon can be a bright natural guide star located in close proximity to the faint system being observed, or an artificial "bright star" created by using a laser beam that causes sodium ions in an upper atmosphere layer to flouresce. The photo on page one shows the laser beam at the Lick Observatory, Mt. Hamilton, California.



Living Human Retina
A. Conventional Optics
B. With Adaptive Optics
Courtesy Austin Roorda

A current major drawback is that adaptive optics corrects only for a small patch of atmosphere at the center of the telescope's field of view – that through which the guide beacon light travels. However, the "faint object" being studied is at a slightly different viewing angle. The pockets of atmospheric turbulence are small enough that such a slight change in viewing angle could mean a whole different pattern of distortions than those for which corrections are being made. Nevertheless, despite this limitation and while improved techniques are being considered, current AO systems have yielded high quality images rivaling those obtained by the Hubble space telescope.

> AO *promises to provide new tools for the diagnosis of eye disease, as well as improving corrections to vision*

Relative to Space Telescopes, land based AO telescopes are larger and much less expensive to build and operate. For comparison "Hubble" cost roughly twenty times more to build and launch than the land based Keck Adaptive Optics telescopes, yet Keck has 20 times the light gathering area and — potentially — 4-5 times better resolution. This is not to say that space based telescopes have been rendered obsolete. There are certain wavelengths which cannot be measured from land based AO telescopes and in fact, the two systems are complementary.

The AO used for vision systems is very similar to that in astronomy. The point light source (reference beacon) is a laser beam reflected off the retina and distortions in the wave front caused by the eye components are detected and compensated for by a deformable mirror or some other "adaptive optical element". AO promises to provide new tools for the diagnosis of eye disease - see figure, as well as improving the correction of vision via laser surgery and contact lenses.

The Center for Adaptive Optics, is headquartered at the University of California Santa Cruz (UCSC). It was established in 1999 by a $20 million, five-year grant from the National Science Foundation's Science and Technology Centers Program. The Center conducts research, educates students, develops new instruments, and disseminates knowledge about adaptive optics to the both the scientific community and public. The Center is a consortium of eleven institutions - research universities and a national laboratory. It interacts with over 20 partner institutions located throughout the U.S. The Center's administrative headquarters is currently being built on the UCSC campus and will house faculty, visiting scientists, and administrators. A state-of-the-art videoconferencing facility is planned that will enable direct communication with center affiliates located anywhere in the US.

Interns from Hawaii

educational horizons.

These field assignments are part of an internship program sponsored by the CfAO with assistance from LLNL. The program, now in its second year, is integrated with other CfAO activities through LLNL's Claire Max. Marjorie Gonzalez at LLNL is the founder and manager of the program, in coordination with this correspondent, Doug Knight of ALU LIKE, Inc.

ALU LIKE, Inc., the name means "working together", serves Native Hawaiians by providing vocational education, training, and employment. The agency assists participants to gain social and economic self-sufficiency using an approach grounded in traditional Hawaiian values and culture. The correspondent is employed by ALU LIKE. He does the recruiting and screening for future CfAO interns in Hawaii and help to find them on-the-job training opportunities upon their return to the island. In addition, he has researched the role of technology in Native Hawaiian culture and developed a presentation showing the high respect that was historically accorded to new technologies by cultural leaders in the Hawaiian community.

These field assignments were part of an internship program sponsored by the CfAO

Preparing Versatile Technicians:

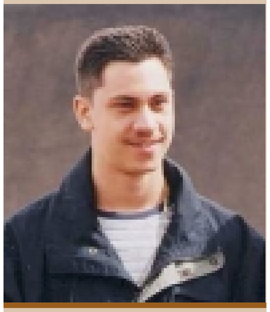
The CfAO's project with ALU LIKE aims to provide Native Hawaiians with hands-on field experience, build technical skills, and mentor interns to prepare them for technician positions in scientific research and development environments. Upon completion of the internship at LLNL, the project links them to on-the-job training positions in Hawaii and encourages them to further their college education. The overlapping mission between ALU LIKE, the CfAO, and LLNL is to promote high tech careers for Native Hawaiians, enabling their full participation in the technical workforce in Hawaii and its astronomomical observatories.

Trainees are required to complete a "versatech" core training course before commencing field work. The "versatech" core training provides basic knowledge skills in a range of technologies and certifications, including fiber optics and category 5 cable fabrication and installation, AUTOCAD 2000

Claire Max, Associate Director for Technology CfAO and Lisa Hunter Associate Director for Education and Community Partnerships visit Keck Observatory with the Interns.

Author Doug Knight, ALU-LIKE and XXXX reflecting at the Keck Observatory

Interns from Hawaii



Kahau Apana

computer design, machine shop, and use of various electro-mechanical, opto-mechanical, and electro-optical equipment. It also gives them practice in using database, spreadsheet, and graphic applications. They are required to keep a journal and provide regular reports to Marjorie Gonzalez on their progress and impressions. The later field experience provides the AO interns with hands-on skill electronic component building experiences, using one-on-one mentoring by the scientists and technolo-gists within LLNL.

Kahau and Ed ay work

Interns' Assignments: After completing this core versatech training, each intern worked at special assignments under mentors on projects related to adaptive optics for the Shane Telescope at Lick Observatory. Ed Akana, from Papakolea Hawaiian Homestead in urban Honolulu, came to LLNL as a student attending Honolulu Community College's Computer Electronics Networking Technology Program. His special project involved assisting the LLNL AO team by researching, evaluating, selecting, and programming a hardware platform for an intelligent camera system that operates laser correction instrumentation. He defined an embedded system that would interface with the metrology system and presented his evaluation to the AO team, which approved and adopted his recommendation. Ed then assisted with developing the application for this system that corrects the image of the laser created guide star used to correct upper atmosphere distortions for telescopes using AO systems.

I have gained confidence in the pursuit of my goals.

Ed Arkana

Kahau Apana, from Nanakuli, Oahu, came to his CfAO internship with four years of high school electronics, and a year of experience as a classroom Education Assistant to his former high school electronics teacher. Kehau's assignment involved improving the adaptive optics bench mounted to the Shane telescope at Lick Observatory. He assisted in integrating three Galil motor controllers with serial cable connections, allowing fewer commands to initialize movement of the Filter Wheel Controllers. This project involved disassembly and reassembly of the very compact AO bench, that necessitated approximately a month's effort. Kehau also designed and manufactured two power supplies for four actuator motor controllers. Working with the AO team, he honed his machine tech and electronics skills as he learned to cope with evolving design specifications and delays in arrival of parts. Both Ed and Kehau assisted with astronomy observation runs using the AO system at Lick Observatory, Mt. Hamilton CA.

Ed Akana

During the 6 month internship at LLNL, Ed remained enrolled at Honolulu Community College and earned cooperative education credits for the field experience. Upon his return to Hawaii, Ed resumed his final semester at HCC, CENT program and will subsequently commence a six month on-the-Job training position. Ed says that he gained a wide range of technical skills, exposure to the latest technology developments, and a clear perspective on the field of study that he intends to pursue for his bachelor and graduate degrees in Information & Computer Science and Electrical Engineering. One of

Interns from Hawaii

the goals of the internship project is to clarify career choices.

Ed Akana says:
"My experience was something that I could not have fathomed before. I have gained confidence in the pursuit of my goals, and now have the ambition to attain a BA in Computer Science and a MS in Electrical Engineering after completing my AS degree. Perhaps the greatest assets to the field of Adaptive Optics are the people engaged in the success of this technology. My future successes through out my life will be attributed to these same people." ■

People and Profiles

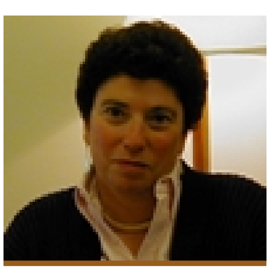

Jerry Nelson

The Director
Dr. Jerry Nelson has been the Director of the Center since its inception in November 1999. He is actively involved in the design of future giant telescopes. He is the Keck Observatory Scientist, having been involved with the design of the two Keck telescopes. He is also involved in the adaptive optics system being used and developed at Keck.

Managing Director - Dr. Chris Le Maistre joined the Center in July 2000. He was previously with the Science and Technology Center for Superconductivity in Illinois. His background is in Materials Science


Chris Le Maistre

Associate Director-
Dr. Claire Max led Lawrence Livermore'sLaser Guide Star Project, whose goal is to demonstrate the feasibility of laser guide stars and adaptive optics for improving the resolution of ground-based astronomical telescopes. Dr. Max is the Theme Leader for Theme 2- Adaptive Optics for Extra Large Telescopes.


Claire Max

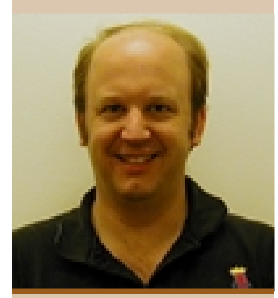
Associate Director, Education and Human Resources - Lisa Hunter joined the Center in September 2000. Lisa has a Master of Science Degree in Chemistry. She has been at UC Santa Cruz since 1988 and worked for a number of years in science and education outreach , particularly with under-represented students in Community Colleges and High Schools.


Lisa Hunter

Research Specialist - Dr. Julian Christou is a senior researcher at the Center. He is an expert in processing techniques for image enhancement - specifically deconvolution routines. Prior to joining the Center in August 2000, Julian was a scientist working at the Airforce Research Laboratory Starfire Optical Range (SOR), Kirtland Airforce base, Albuqueque, New Mexico


Julian Christou

Financial Analyst - Chris Hardy joined the Center in October 2000. He was previously with the Capital Guardian Trust Company, Brea, CA. as a Staff Accountant.He has a B.A. degree form UC Irvine.


Chris Hardy

Jerry Nelson

From the Director

On November 1st 2000, the Center for Adaptive Optics had its first anniversary. As with most new Centers, the past year had its moments of success and frustration. Putting together a strong management team and infrastructure proved to be difficult and time consuming but was successfully accomplished and I'm very pleased with the outcome. The Center for Adaptive Optics is now well into its second year and researchers are being encouraged to develop collaborative projects with other scientists or groups of scientists within the Center. We believe that our recent reorganization of research projects fromgoal to theme mode will assist this transition.

Our research results both in astronomy and vision science continue to be outstanding. A unique aspect is the bridge the Center creates between scientists in the two disciplines and our challenge lies in making this an exciting and productive union or, as our friends at the National Science Foundation express it, "Making the sparks fly". The latter is happening in the MEMs research area, where the results to date have exceeded expectations both in the deliverly dates of compact MEMs devices for Adaptive Optics and the level of interaction between vision scientists and astronomers. Center astronomers who are familiar with post processing techniques to enhance image contrast are collaborating with vision scientists in applying these to images of the human retina obtained by adaptive optics.

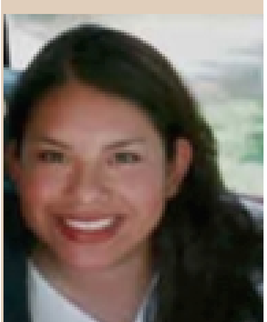
Center astronomers continue to gain recognition within the community for the quality of their research and the technology associated with Adaptive Optics. The development of lasers for use with laser guide stars continues as does that of coronagraphs. Early studies of the requirements for Extra Large Telescopes are also on the research agenda. The research and Adaptive Optics enhanced images obtained by many of our astronomers in their observations were featured in the November 14th issue of Time magazine in an article "Beyond Hubble".

In summary, the Center's purpose as described in its mission statement is "To advance and disseminate the technology of adaptive optics in service to science, health care, industry, and education." We have had a good start in our first year and will continue to work towards this objective in coming years. ■

People and Profiles (cont.)

Paula Towle

Office Manager - Paula Towle has been with the Center since its inception. She manages the office and is the first point of contact for researchers from the other sites. She is central to the organizing of "Center" workshops and conferences both on and off the Santa Cruz campus.



Naeyli Cruz

Assistant to the Office Manager - Nayhieli Cruz was confirmed in this position in October 2000. She is completing a second Associate Degree at Cabrillo Community College, majoring in Business and intends to continue her studies at San Jose State University. ■

Themes (Continued)

Theme 4: Compact Vision Science Instrumentation for Clinical and Scientific Use

Ophthalmic AO systems have been demonstrated in the laboratory for scientific research. The next horizon is to engineer compact, robust AO systems for use in clinics as well as scientific laboratories. These systems will be developed in cooperation with the MEMs efforts at the Lawrence Livermore laboratory, in particular and other associated CfAO institutions. The long-term goal is to commercialize a compact

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The Center's Education and Research Themes

Theme 1: Education & Human Resources

Education and Human Resources (EHR) spans all Center activities and includes formal education, informal education, professional training (workshops, summer schools, short courses, etc.) and activities focused on increasing the diversity of the Center. EHR focuses its efforts on two areas (1) funding EHR programs and projects, and (2) developing and supporting opportunities for all Center scientists to contribute to EHR goals. These two mechanisms often overlap and merge, taking advantage of the extensive resources of the Center and the specific skills and talents of individual members.

Theme 2 - AO for Extra Large Telescopes (ELTs):

Motivation: The highest recommendation of the NAS Astronomy and Astrophysics Survey Committee (2001) was the design and construction of a ground based 30-m telescope, equipped with adaptive optics (giant segmented mirror telescope, or GSMT). Developing an adequate adaptive optics system for this will be extremely challenging and require developments in most technical areas of adaptive optics. Making a major contribution towards achieving this national priority is a natural and suitable objective for the CfAO. The benefits of multi-conjugate adaptive optics include widening the diffraction-limited field of view and achieving near-complete sky coverage with laser beacons (by overcoming the cone effect). While the ultimate implementation of a multi-conjugate adaptive optics (MCAO) system for a 30-m telescope will require both time and resources beyond the scope of the CfAO, we believe that we can implement the crucial steps needed for its successful implementation.

Theme 3: Extreme Adaptive Optics (eXAO) enabling ultra-high-contrast astronomical observations

Motivation: The eXAO theme is scientifically driven by the need to achieve high-contrast imaging and spectroscopic capabilities to enhance the detection and characterization of extra-solar planetary systems and their precursor disk material. By improving image quality, eXAO systems enable faint objects to be detected close to bright sources that would otherwise overwhelm them. This is accomplished both by increasing the peak intensity of point-source images and by removing light scattered by the atmosphere and the telescope optics into the “seeing disk”. This combination of effects can dramatically improve the achievable contrast ratio for astronomical observations. The primary goal of this theme is to catalyze the development of the next generation of high-order adaptive optics systems in order to achieve unprecedented capabilities for high-contrast astronomy. This will require activities in eXAO system design along with the design of instruments, such as coronagraphs, optimized for high-contrast observations. Additional crucial activities include the development of new simulation capabilities for eXAO systems and instruments, along with better characterization of the performance existing high-order AO systems, and the development of new technologies in high-order wavefront correction devices, such as MEMS deformable mirrors, and in wavefront control system algorithms and architectures. Ongoing scientific utilization of high-contrast observational capabilities and development of data processing techniques optimized for high-contrast observations are also critical activities for this theme.
There are likely to be many cross cutting issues with Theme 2.

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Adaptive Optics Mirror

AO system for ophthalmic applications. Along the way, these new and existing AO systems will be used to advance our understanding of human vision, and to explore medical applications of adaptive optics. This is a crucial way to provide feedback for the utility of the advanced AO designs.

Extract from Mission statement

"Our purpose is to advance and disseminate the technology of adaptive optics to serve science, health care, industry, and education."

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