CENTER FOR ADAPTIVE OPTICS CfAO

# ADVANCING THE SCIENCES OF SKY AND EYE

**The Center for Adaptive Optics (CfAO) has brought together two very different worlds in science: one that treats the astronomically large, and another that treats the very small.**

These realms—astronomy and vision science—have found common cause in the need for technologies to obtain very clear, sharp images. Together, they are advancing a remedy.

It's called adaptive optics (AO), a method for removing the blurring of images caused by changing distortions in optical systems. Turbulence in the Earth's atmosphere, for example, causes images of stars and planets to appear fuzzy. But by using adaptive optics, ground-based telescopes can see as clearly as if they were in space. Imperfections in the eye cause blurring of images, but adaptive optics for vision science provides a way to sharpen an image of the human retina.

Headquartered at the University of California, Santa Cruz (UCSC), the center has united a team of astronomers, physicists, engineers, and vision and life scientists in the quest for next-generation adaptive optics.

When the center started in 2000, AO wasn't something that the astronomy community had entirely accepted. NSF funding of the center helped make it a mainstay of astronomy—and transformed the field of vision science in the process.

"There has been a huge amount of cross-fertilization between those disparate communities," says center director Claire Max. "When we got started, there was one AO system for vision that was tentatively trying out what they could do. Now there are more than a dozen instruments in clinical settings and laboratories."

At the heart of an AO system is a wavefront analyzer along with a deformable mirror, which can change its shape rapidly to correct for distortions in the incoming light. In order to analyze the incoming wavefronts, a bright reference source of light is needed. In astronomy, the reference may be a bright star or an artificial star created by aiming a laser beam up into a sodium layer that surrounds the Earth at a height of about 100 km. It creates a spot of light called a laser guide star that can be used as a reference for measuring distortions caused by the Earth's atmosphere. In vision research, a laser reflected off a spot in the retina provides a reference.

Based on this information, commands are sent to actuators that exert force on the surface of the deformable mirror to change its shape—for the Earth's atmosphere, that means changing several hundred times a second.

Until recently, commercially available deformable mirrors have been relatively large and expensive, but for many applications, smaller and less-expensive mirrors are needed. The enabling technology is a micro-electromechanical system, or "MEMS," deformable mirror that consists of a reflective layer on top of a membrane under which are many tiny electrodes that impart forces on the mirror. Each device may have from hundreds to thousands of such deformation points.

The center has funded several companies including Boston Micromachines and Iris AO to spur improvements in MEMS deformable mirrors. "By setting benchmarks and performance characteristics to meet, we've helped to push the capabilities forward," notes Chris Le Maistre, managing director of CfAO.

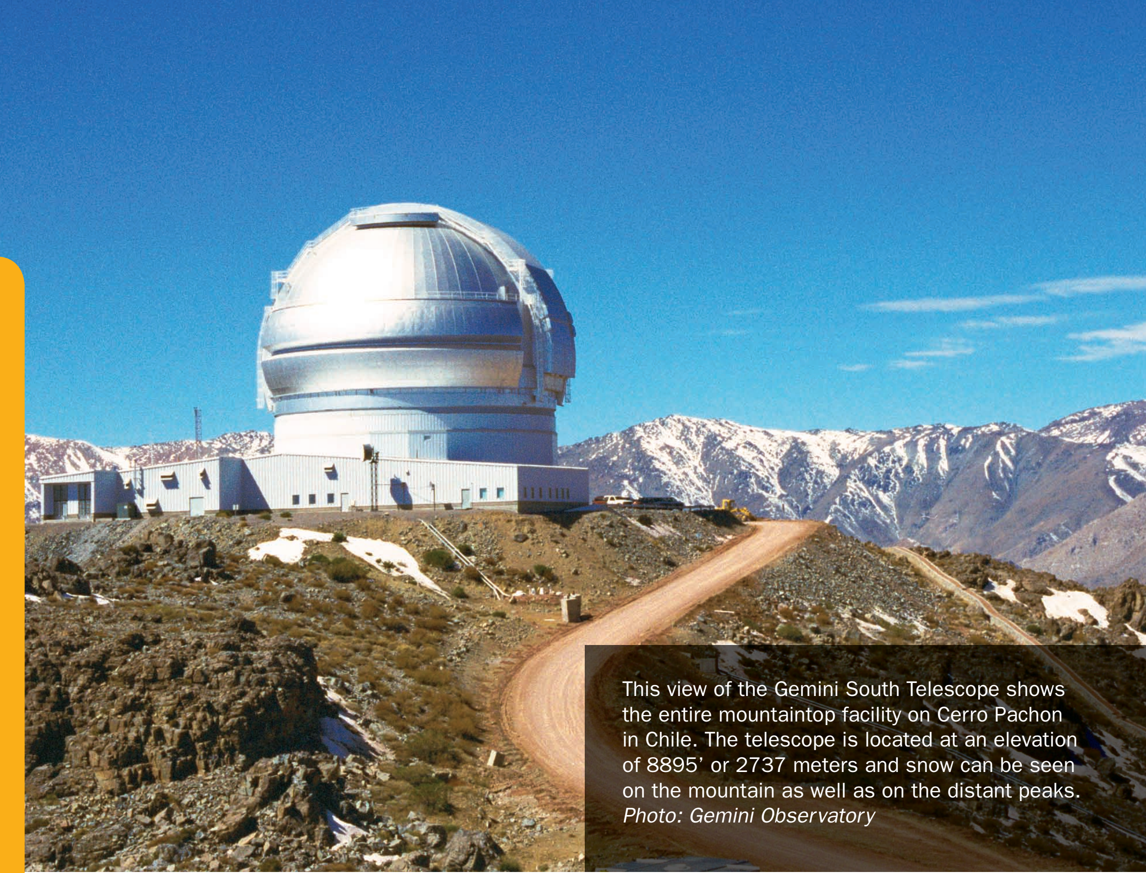
One legacy of the center is the Laboratory for Adaptive Optics (LAO) at UCSC, a facility within the UCO/Lick Observatory established with more than $9 million from the Gordon & Betty Moore Foundation. The laboratory provides a place to develop and test new AO technologies and to train postdoctoral and graduate researchers. □


*W.M. Keck Observatory*

Pictured in background: Gemini Observatory

## TIMELINE OF THE TECHNOLOGY

CfAO has rapidly catalyzed the development of a technology that had a long induction time. First envisioned in 1953 by Horace Babcock, adaptive optics languished for nearly two decades for lack of practical technologies until the U.S. Department of Defense picked it up in the 1970s. In the 1980s, military research continued as astronomers independently started working with the technology. With the development of the first facility sodium-layer laser guide star in the 1990s—work led by CfAO director Claire Max—the field was poised for rapid growth with the establishment of the center in 2000.



This view of the Gemini South Telescope shows the entire mountaintop facility on Cerro Pachon in Chile. The telescope is located at an elevation of 8895' or 2737 meters and snow can be seen on the mountain as well as on the distant peaks. *Photo: Gemini Observatory*

## A CONVERSATION WITH THE DIRECTOR

## Claire Max

Claire Max, director of the Center for Adaptive Optics

**Q: Why team science?**

**Max:** When you're building a big instrument, the classical pyramid with the dictatorial PI on top and a bunch of minions working below just doesn't work anymore—you need a wider variety of expertise and skills. And when the project is big—aiming to look at thousands of galaxies for instance, doing the observations and understanding the results takes a lot of people. Big ambitious projects require a big team. The team needs to match the size of the dream.

**Q: What qualities are needed to be a center director?**

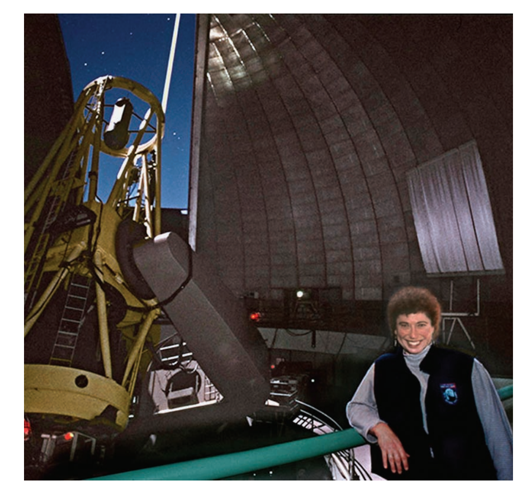
**Max:** You have to be the kind of scientist who takes pleasure in the work of others as well as in your own work. If you work very hard on your own research but it doesn't make you happy to see other people doing good stuff as well, then you're not going to be a good center director. Prior to the center, I was director of university relations at Lawrence Livermore National Laboratory. I ran a program encouraging people at national labs to do research with people from university campuses, so I had some practice before I came to the center.

**Q: How do you promote effective interactions?**

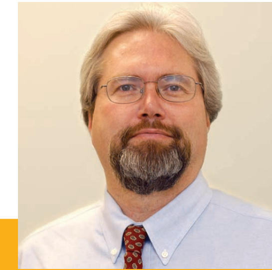
**Max:** We encouraged individuals with expertise in astronomy to spend time hanging out with vision scientists, watching how they worked, interacting with them. We realized that interpersonal interactions were going to be important, so we designed our center to have a lot of workshops and retreats and joint activities where people would get to know each other. Once people build up trust and working relationships at organized events, it becomes much more natural to say, 'Can I come to see your lab?'

**Q: Are you starting to think about life after NSF funding?**

**Max:** We are involved in exit planning now. Individual research projects will get their own grants, and we're pursuing three avenues for future education funding. But it's harder to get support to maintain the core of the center—we're trying to identify funding for core activities like retreats and workshops to keep the community going.



"We've been able to leverage off of a lot of the work that's being done in adaptive optics in astronomy to do much better things for vision science than we otherwise would have." — DAVID WILLIAMS



CfAO associate director David Williams of the University of Rochester

## AO IN THE SERVICE OF VISION SCIENCE

"The Center for Adaptive Optics gives us contact with a branch of science that we would have no commerce with at all otherwise," says center associate director David Williams of the University of Rochester. "Just listening and learning about astronomy has been a real eye-opening experience for us," he laughs at the unintended pun. "That's been exhilarating, but at a more practical level, we've been able to leverage off of a lot of the work that's being done in adaptive optics in astronomy to do much better things for vision science than we otherwise would have."

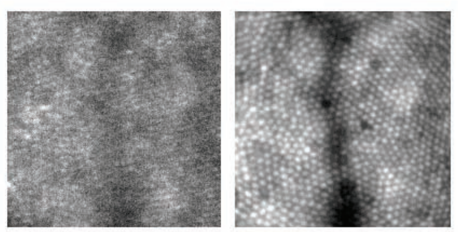
There are two main applications of AO in vision science. One has to do with correcting vision, namely, enhancements to the phoropter. If you've ever had an eye test, you know the phoropter—it's "that binocular thing you look through and the doctor asks you which is better, A or B, one or two," laughs Williams. Next-generation phoropters incorporating AO will determine your eye correction automatically in a fraction of a second. The technology is currently being developed for commercial instruments, he says.

The second application is to enhance retinal imaging for the diagnosis and treatment of eye diseases. For example, center researchers are using AO to image ganglion cells in the retina, important in treating glaucoma, one of the three major eye diseases. Using AO with fluorescence imaging, scientists are studying the layer of cells called the retinal pigment epithelial (RPE) cells, which are involved in macular degeneration. "Nobody had been able to see RPE cells in living eyes before," says Williams.

Austin Roorda at UC Berkeley and colleagues are working to track cells one at a time in a living retina. "This ability will be especially important in the treatment of diabetic retinopathy where they 'zap' portions of the retina with a laser beam to try to stop proliferation of blood vessels," explains Williams. "It may be possible to deliver this light much more precisely in a way that does much less damage to the eye."

CfAO allowed vision science groups to build and maintain engineering expertise in AO, something that would not ordinarily be affordable for vision labs, says Williams. "The budgets would be prohibitively large—outside the scope of a typical NIH grant. Having the center helped us to jump-start this area of research," and it subsequently led to funding for two major research initiatives.

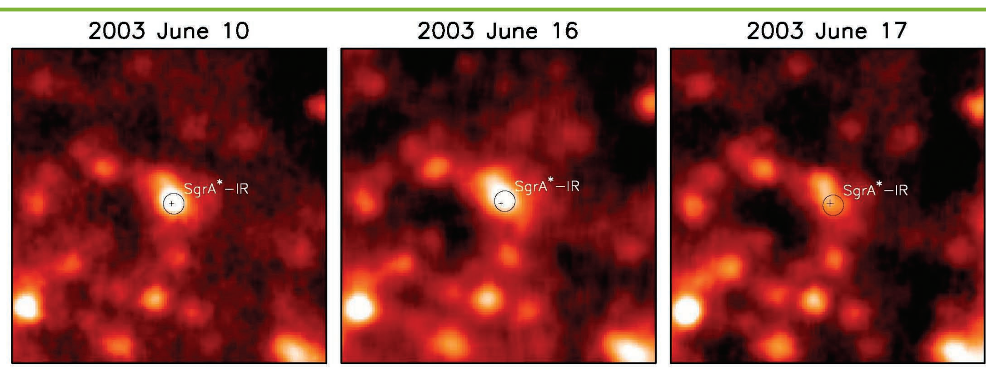
But the center mode of operation is not for every scientific project. What Williams worries about is over-hyping the team science. "What you need is a mix—and I don't know what the right balance is. It's very important to maintain both modes," he stresses. "It has to be grass roots, not top down. When you start to mandate something, that's when you lose the magic."



Living human retina. The main factor limiting high resolution imaging of the living human retina is blurr caused by aberrations in the eye's optics. Adaptive optical techniques work well to correct the aberrations. This pair of images shows the improvement offered by adaptive optics (right). *Image: Austin Roorda*

## AO HELPS DETERMINE MASS OF THE BLACK HOLE AT THE CENTER OF THE MILKY WAY

Adaptive Optics and the Keck Observatory were used to take very high resolution images of stars near the center of our own galaxy and to track their movements, a feat that enabled UCLA astronomer Andrea Ghez to estimate the mass of the black hole around which they orbit (a whopping 3,700,000 times the mass of our Sun). These results have provided the best evidence yet for a supermassive black hole at the center of the galaxy, says Ghez.




This sequence represents the first detection of infrared light from plasma falling onto the supermassive black hole at the center of the Milky Way galaxy. The location of the black hole is marked with a cross and the newly detected infrared source is encircled and labeled as SgrA*-IR. The brightness variations reveal that the plasma is much more energetic than previously believed, showing that violent events occur almost continually. *Image: A. Ghez et. al, UCLA/W.M.Keck Observatory*



## EDUCATION PROJECT YIELDS RESEARCH DIVIDENDS: EXPERIMENT IN INQUIRY-BASED TEACHING

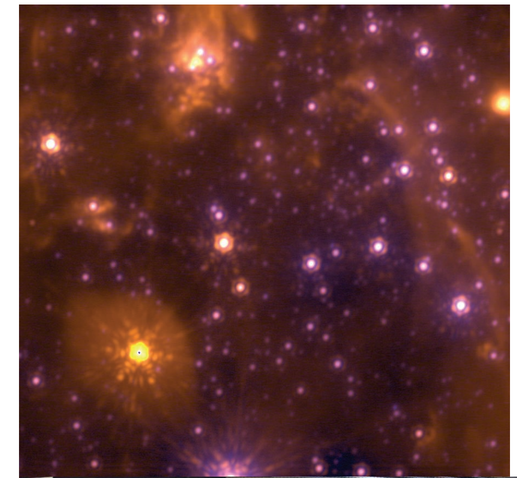
What started as a workshop opportunity for graduate students has led to unexpected dividends for researchers at the Center for Adaptive Optics and even for the university as a whole.

It was the brainstorm of education director Lisa Hunter to engage graduate students at the center in a workshop on how to teach inquiry-based learning of science for advanced high school students and undergraduates, in a process involving staff from the nearby San Francisco Exploratorium. Inquiry-based learning refers to learning science in the way that scientists actually think and work: by posing questions, designing and conducting experiments, and analyzing results.

Teaching science in this way has captured the imagination of graduate students and cultivated ideas that they have applied in their own research. It has generated a sense of community and has become "a platform that unites the whole center," notes CfAO director Claire Max. It also led to a bit of serendipity.

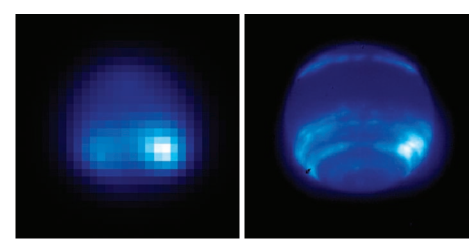
Through the workshop, a postdoc from astronomy met a graduate student in vision science and ended up helping to solve a problem with an optical system in the vision science lab.

The inquiry-based teaching experience has been made possible by long-term funding from the center grant. It led to the creation of a graduate course in the education department specifically for science and engineering graduate students.



Left: Narrow-field image of the Galactic Center. Exposures were obtained at 3.8 and 2.1 micron wavelengths, assigned a color, and combined to make a false-color image. Image is 10 arcseconds in size. *Photo: W. M. Keck Observatory*

Below: Star Trails Over Gemini North in Mauna Kea, Hawaii. Approximately 2 hours of stacked exposures of the summer sky over Gemini North. The setting moon provided light on right of dome and twilight provides a glow to the left side of dome, a small red light provides highlight on center of dome. A star field has been offset by about 30 minutes to show individual stars separated from trails revealing Scorpius and Sagittarius over the Gemini dome. *Photo: Gemini Observatory*



Neptune observed in the near-infrared (1.65 microns) with and without adaptive optics. Neptune is the outermost of the giant planets in our solar system, but also has the most dynamic and rapidly-changing weather patterns. This near-infrared image is primarily sensitive to such high-altitude clouds, which appear bright against the darker disk. Adaptive optics allows ground-based telescopes to monitor Neptune's evolving weather systems and to use spectroscopy to probe different altitudes in its poorly-understood atmosphere. *Image: CfAO*

## ADAPTIVE OPTICS IN THE SEARCH FOR PLANETS IN OTHER SOLAR SYSTEMS

Almost 200 planets have been discovered around nearby stars—not by seeing any light from the planets themselves, but rather, by watching the effect of the gravitational pull of the planet on the star.

Starlight is so bright that it swamps the light reflected from an orbiting planet. As a result, none of the planets in other solar systems has yet been seen directly, so scientists have been largely unable to analyze the composition, atmosphere, temperature, and other characteristics to see if these worlds might support life.

CfAO researchers are part of a team developing an AO system to cancel out that bright starlight and hunt for planets in other solar systems for an international telescope facility called the Gemini Observatory, which operates two 8-m telescopes, one in the Chilean Andes at Cerro Pachon, the other on Hawaii's Mauna Kea.

When the Gemini Planet Imager is built, it will be "probably the most advanced adaptive optics system in the world," says center investigator Bruce Macintosh, a physicist at LLNL, the lab leading this effort.

Parts of the system are under development at different partner institutions—the infrared spectrograph at UCLA and the precision interferometer at the Jet Propulsion Laboratory, for example. The LAO at UCSC will assemble and test the instrument before taking it to its final destination, likely the southern Gemini telescope, in about 2012.

"There is no one institution, even LLNL, that could build a system like this," says Macintosh. "We really need this collaborative, multi-institution team. It was through the framework of the center that all of us started collaborating on the project."