Center for Adaptive Optics

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Challenges with the MMT Adaptive Optics System

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CAAO, Steward Observatory

INTRODUCTION

The Adaptive Optics system for the 6.5m Multiple Mirror Telescope (MMT), located in Southern Arizona on Mount Hopkins, is the first in the world to use a deformable secondary mirror to provide wavefront correction. This system (which has been developed by Steward Observatory at the University of Arizona in Tucson and the Osservatorio Astrofisico di Arcetri at the University of Florence) has been in use for over three years at the MMT Observatory (MMTO).

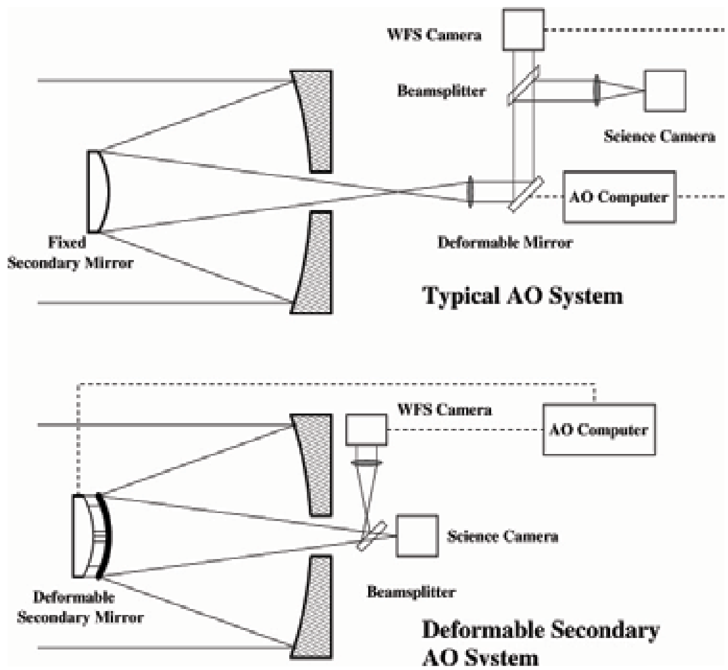

Fig 1 Comparison of the optical layout of the MMT AO system and other AO systems.

There are several advantages to making the secondary mirror be the correcting element for the system, and these can be seen in Figure 1. With a traditional AO system, the science beam path passes through reimaging optics onto a small deformable mirror, before more optics re-image the focus at the science camera. The large number of surfaces increases the thermal background whilst decreasing the optical efficiency of the system as a whole. By making the secondary mirror the deformable element, the science camera 'sees' a classical telescope made up of a primary and secondary mirror. The number of warm optics in the scientific beam path is reduced to the absolute minimum required, reducing the thermal background and allowing imaging from much longer thermal wavelengths. The emissivity of the telescope at 11 microns

Fig. 2 The Secondary Mirror installed on the 6.5m MMTO telescope.

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MMT Adaptive Optics System

The Adaptive Optics system for the 6.5m MMTO telescope, located in Southern Arizona on Mount Hopkins, is the first in the world to use a deformable secondary mirror to provide wavefront correction. This system (which has been developed by Steward Observatory at the University of Arizona in Tucson and the Osservatorio Astrofisico di Arcetri at the University of Florence) has been in use for over three years at the MMTO.

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The optical system consists of two separate components – the wavefront sensing optics which reside in a 'top box' that is bolted onto the telescope in front of the Cassegrain focus, and the secondary mirror package, which sits inside the secondary hub at the primary focus of the 6.5 meter diameter mirror (see Fig.2)

Light from the science field and nearby guide star is imaged at the f/15 Cassegrain focus of the telescope, and a tilted dichroic some 8 inches in front of the focus picks off the visible light and sends it into the top box optics. By making the tilted dichroic the entrance window for the science camera dewar, transmission losses are further minimized.

DEFORMABLE SECONDARY MIRROR

Making the secondary mirror have the required mechanical properties was a considerable challenge - the goal was to make a flexible mirror that could be adjusted to within a few nanometers accuracy with an update rate of a 1000Hz. This task was successfully accomplished by the University of Arizona's Steward Observatory Mirror Laboratory.

The deformable mirror was formed by using two pieces of glass, a blocking body and the glass block that would subsequently become the deformable mirror, and grinding matching concave and convex surfaces which are then bonded together with a thin layer of pitch. The glass to be shaped into the deformable mirror has its concave side facing the pitch glue line. The free surface is subsequently ground down to a membrane having a spherical surface. It is further polished to form the final convex hyperboloid (with 80 microns of departure from spherical) using a technique previously used for polishing the larger 8.4m primary mirrors for the Large Binocular Telescope being constructed on Mt. Graham, in Arizona.

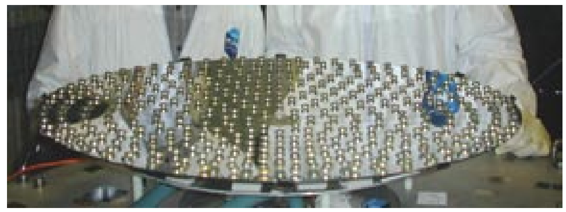


Fig 3 The Secondary Deformable Shell. The 336 magnets can be seen on the back surface of the mirror.

The resultant deformable mirror resembles a contact lens, 640mm in diameter and 2mm thick. This meniscus lens was removed by warming the glass blocking body and mirror to 120 Celsius, thus reducing the viscosity of the pitch enabling the glass to slide off the blocking body. The front surface of the glass is aluminized to form the mirror.

The problem of maintaining high precision control of the membrane shape at high frequency rates was solved by our Italian col-

Fig 4 Looking into the reference body, the capacitance sensors are visible as metal coated rings surrounding the actuator fingers. Through the reference body, the cooling plate can be seen.

laborators. The 2mm glass mirror is prone to resonate at the operating frequencies, so some form of damping is needed to remove the spurious shapes from the surface. The Arcteri group discovered that the air damping that resulted when a rigid glass reference body was positioned 40 microns from the back surface of the deformable secondary mirror was sufficiently large to remove all the spurious resonances from the mirror surface.

In the fully assembled mirror, the membrane's shape is controlled by actuators consisting of 336 voice-coils coupled to 336 rare-earth magnets glued to the back of the membrane (see Figure 3). The separation between the copper coils and the magnets is 0.2 mm and actuator movement is controlled by the current through each coil exerting a force on the corresponding permanent magnet and so moving the glass membrane. Accurate determination of the stroke of each actuator is determined by capacitive sensors (see Figure 4). The capacitors are chromium rings deposited on the front surface of the reference plate around each of the 336 actuators. The capacitance between each chromium ring and an aluminum coating on the back of the deformable mirror across the 40 micron air gap is about 65 pF. Applying a square-wave voltage enables the capacitance to be read at 40 kHz. This enables the position of the membrane relative to the rigid reference plate to be determined with an accuracy of 3 nm.

The actuator coils are connected to a cold aluminum plate behind which are three electronics units containing 68 digital signal processors (DSPs). Each DSP is responsible for controlling two actuators, reading the capacitive sensors at 40 kHz, and updating the drive currents in the coils providing the desired mirror profile. This feedback "stiffens" the normally flexible mirror enabling it to withstand disturbances from vibrations in the telescope, wind buffeting, and changes in the direction of gravity relative to the mirror's surface as the telescope tracks across the sky.

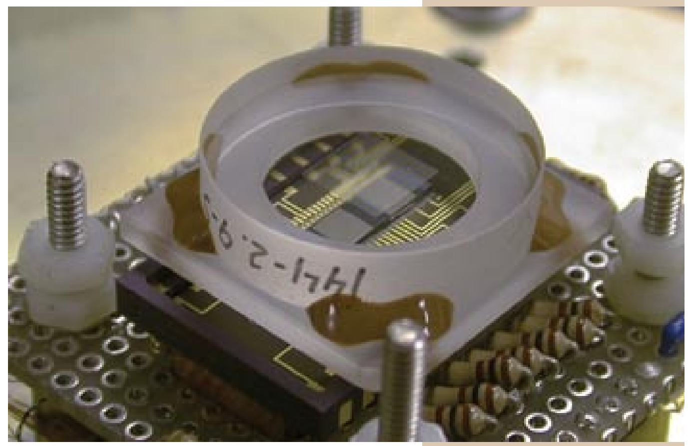


Fig 5 The Shack-Hartmann wavefront sensor. The lenslet array is just visible as a square patch within the hockey puck shaped glass substrate.

Cooling fluid circulates through grooves milled into the cooling plate, using a 50/50 mixture of distilled water and methanol and has been effective in removing heat generated by the voice coils.

THE BOX AND WAVEFRONT SENSOR

The visible light beam is reflected from the tilted dichroic and passes into an all reflecting re-imaging system. The beam collimated by an off-axis paraboloid, forms a pupil image on a field steering mirror, and a star image at an f/23 focus off another off-axis paraboloid. This image then passes into the wavefront sensor camera, which is based on the EEV39 array.

In the wavefront sensor camera, a doublet lens images the telescope pupil onto a Shack-Hartmann sensor, which consists of a microlenslet array of 12 by 12 subapertures with 144 mi-

MMT Adaptive Optics System

cron pitch fastened onto the imaging array's plastic carriage. As there are no reimaging optics used to match the lenslet array to the pixel size on the detector, the optics of the beam path are considerably simplified (see Figure 5). Initial concern with the registration of the lenslets with the imaging array proved unfounded, and a r.m.s. centroiding error of less than a micron was determined for the sensor when illuminated with a plane parallel beam. The array is binned 3 by 3 pixels to form tip-tilt sensors 144 microns to a side.

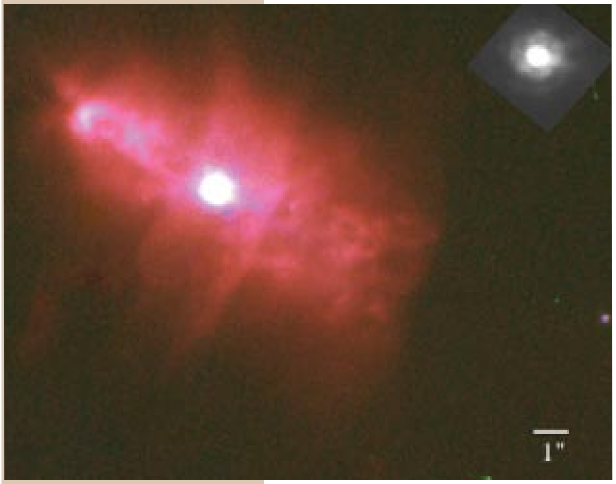


Fig. 6 The planetary nebula IC 2149, imaged by the ARIES near-infrared imager and adaptive secondary on the 6.5m MMT. The image is a false color composite of three narrow band filters at 2.088, 2.118, and 2.17 um, (blue, green, and red, respectively). The central star has been allowed to saturate in order to bring out details in the surrounding nebula, which is several thousand times fainter. The inset is a narrow band continuum image of the central bright region magnified by a factor of two.

The supporting computer hardware sits in a control room nearby and deals with the real-time reconstructor calculations for the system.

LESSONS LEARNED

The system has been in operation for 4 years and can routinely lock onto V < 11 stars with full correction, enabling correction of 100 modes with the current wavefront sensor camera with the capability of correcting up to 300 modes in the future using the current mirror. In good (sub-arcsecond) conditions the loop can be closed and run with 56 mode correction for hours at a time, even in fairly strong winds at the telescope. The closed loop speed is 550Hz, limited by the read noise and control electronics of the EEV39 controller being used. Next year with the installation of a new SciMeasure controller, the closed loop speed will be increased to 1kHz with a reduction in the read noise, allowing fainter guide stars to be used.

Currently Strehl ratios are being measured on the order of 30%, which fall short of the expected Strehl of 50% for the system in its current state.

These lower ratios arise from various factors:

1. The interaction matrix relates the measured WFS signal to the given mirror deformation required for correction. This matrix was initially determined in laboratory tests by applying successively higher order Zernike modes to the mirror and measuring the resultant signal on the WFS. The laboratory test optical set-up differs from that on the telescope. Consequently measurements for the higher order modes must be done in-situ on the telescope with the secondary installed. A team member, Guido Brusa, has developed a novel technique for determining the interaction matrix with the AO loop locked on a bright guide star. A given Zernike mode with a time-varying sinusoidal amplitude is injected into the commanded mirror positions. By breaking the reconstructed wavefront from the WFS camera into Zernike modes, the injected signal can be recovered from the noise introduced by atmospheric turbulence. By successively applying each Zernike mode, a new interaction matrix is determined.

2. There is the presence of a 20 milliarcsecond amplitude oscillation at about 20Hz in the telescope secondary support structure. The AO loop bandwidth extends to 19Hz, so it is difficult to remove this signal completely from the corrected image. This oscillation degrades the Strehl ratio by about a third, and several different methods have been tried to dampen out this oscillation. Most recently four triaxial accelerometers have been installed in the secondary mirror unit, and it is planned to generate and inject a feed forward signal into the control loop to mitigate the undesirable oscilllation.

3. Initial concerns with the heat gener-

MMT Adaptive Optics System

ated by the actuator coils proved to be unfounded. The heat dissipation continues to be monitored as we move to higher order operation, where the higher spatial frequencies require the mirror to be deformed over smaller areas.

THE FUTURE

Currently there are two instruments that are optimized for use on the AO system - BLINC/MIRAC3, a near to mid-infrared imager and nulling interferometer, and ARIES, a 1.2 - 2.5 micron near infra-red imager and high spectral resolution long slit spectrograph. Science done with ARIES has included imaging of planetary nebulae (see Figure 6), high redshift quasars, and the use of a simultaneous differential imager to look for brown dwarf and extrasolar planets in nearby star systems.

The PSF FWHM for the 6.5m MMT is 0.32 arcsec for 10 microns, and the AO system provides an extremely stable PSF for the MIRAC3 camera, allowing accurate PSF subtraction and image deconvolution to be performed. Typically the Strehl ratio at 10 microns is 98 and a paper on imaging of post asymptotic giant branch stars and other high angular resolution investigations has been published.

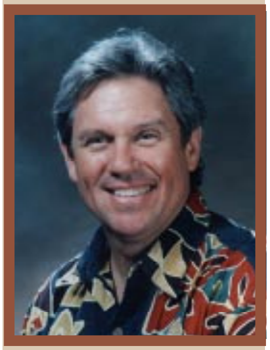
A working prototype deformable secondary system producing scientific results has resulted from the efforts of the Steward Observatory and Arcteri teams. This unique system continues to be developed and refined. Its success has led in part to the building of two further secondaries for the Large Binocular Telescope to be commissioned in the near future.

People in CfAO Education

Sarah Anderson is a senior engineering assistant at Keck. She has accepted a part time position with the Center as our Akamai Internship Coordinator for our Hawaii Island program. Sarah helped expand CfAO's 2005 internship program on the Big Island with support from the observatories. She has actively participated the Akamai Observatory Short Course and the Center's Professional Development Workshops.

Carlos Andrés Cabrera first learned of the Center when he met Professor James Larkin at SACNAS and was accepted into our summer internship program working at UCLA in the Larkin lab. On transferring to UCSC he continued his summer studies on photometric redshifts, working with Professor Faber and Dr. Drew Phillips. In addition, Carlos travelled to local high schools and community colleges to talk about his research and recruit students for CfAO education programs. At the Center, Carlos begana project with Dr. Don Gavel and Mark Reinig to build a tomography engine for the new generation of Adaptive Optics systems which lead him to forming an undergraduate research group and was the basis of his senior thesis. Carlos graduated from UCSC in June 05 with a Bachelors degree in computer engineering and is curently in UCSC's graduate program in Electrical Engineering.

Oscar Azucena was a CfAO intern in the summer of 2003. He worked with Kevin Baker and Scot Oliver at Lawrence Livermore National Laboratory on "Coherent Communication, Imaging and Targeting: Phase Plate Characterization". After graduating from The University of Houston with a BS in electrical engineering, he came to the CfAO as a research assistant and worked under contract to Keck Observatories on CCD's for AO under the direction of Sean Adkins. He is now a graduate student at UCSC in the electrical engineering dept. and has received the Cota-Robles Fellowship.



Jerry Nelson

From the Retired Director

The Center held its 2004 Fall Science Retreat at the UCLA Conference Center at Lake Arrowhead California in November. In 2003 this retreat was held at Yosemite, California. Approximately 130 people attended both Retreats, which were notable for the discussion groups and active participant interaction.

In earlier newsletters, I have commented that the scale, expense and complexity of the AO instrumentation required for Astronomy was beyond the scope of the CfAO, requiring us to focus our effort on the fundamental studies needed to build a 30 meter telescope AO system or design a high contrast AO system for extra solar planetary detection. The funding required for building these instruments would have to come from other sources.

The soundness of this strategy is evident, as Center researchers are now actively participating in the first stages of the 30 meter telescope design. Initial funding of $35 million having been provided by the Moore Foundation jointly to the University of California and the California Institute of Technology. In addition, Center researchers were awarded the contract for the building of a high contrast coronagraph for extra solar planetary detection. The funding to be provided by Gemini Observatories

Our support for developing lasers for laser guide star applications continues. The sum frequency laser developed at the University of Chicago has been deployed at Mt. Palomar Observatory and is being fine-tunined to optimise its performance. Additionally, the fiber laser being developed at Lawrence Livermore National Laboratory in conjunction with the European Southern Observatory, continues to meet its design milestones and shows considerable promise for the future.

The CfAO's Vision Science group is internationally recognized as the leader in the application of AO techniques to the field of vision science. The AO phoropter developed at Lawrence Livermore is under review for commercial development and progress continues to be made on the Scanning laser opthalmoscope and the AO Coherence gated Retinal camera at the universities of California at Berkeley and Indiana respectively.

The development of MEMS deformable mirrors for Astronomy and Vision Science applications is another strategic goal of the Center. While CfAO-supported companies have made considerable progress, MEMS deformable mirrors, with the desired characteristics, are not yet generally available.

The Center completed its first five years on October 31 2004 and was granted funding by the National Science Foundation for the next five years. We are currently developing strategic plans for this period and the future when NSF funding has ended.

Finally, I was appointed the Project Scientist for the Thirty Meter Telescope. This and my duties as Center Director proved to be very demanding. Consequently, I reluctantly decided to step down as Center Director. Claire Max, who has been with the Center since its onset and was the Assistant Director and the Associate Director for Theme 2 – Extremely Large Telescopes, agreed to be the new Director.

I wish to thank each of you for your past support, as the success of the Center has been a team effort. Under Claire Max's leadership the Center is destined for further success and I look forward to working with all of you in the coming years.

Claire Max

Meet the New Director

Claire Max has been affiliated with the Center for Adaptive Optics since its inception. She has had a distinguished career both as a scientist and administrator at the Lawrence Livermore National Laboratory and was the Associate Director for Theme 2 – Extremely Large Telescopes within the CfAO. Last year she agreed to act as the CfAO Deputy Director and acting Director when the Jerry Nelson was not be available. Claire's research interests include Adaptive optics and atmospheric turbulence, high-resolution astrophysics and planetary science, active galactic nuclei, and astrophysical plasmas. Her AO committee activities include the Thirty Meter Telescope, Adaptive Optics Working Group, and the Giant Segmented Mirror Telescope, Science Working Group.

On September 22, 2004, the Secretary of Energy named Claire Max as a recipient of the 2004 E.O. Lawrence Award in Physics, for her contributions to the theory of laser guide stars adaptive optics and for its application in ground-based astronomy.

CfAO Researchers in the News

Claire Max (University of California Santa Cruz). On September 22 2004, the Secretary of Energy named Professor Claire Max as one of the seven winners of the 2004 E.O. Lawrence Award. Each winner receives a gold medal, a citation, and $50,000. Professor Max received the award in the physics category for her contributions to the theory of laser guide star adaptive optics and its application for ground-based astronomy to correct telescopic images for the blurring caused by light passing through the atmosphere.

Andrea Ghez (University of California, Los Angeles). In 2004 Professor Andrea Ghez was elected to the National Academy of Sciences and to the American Academy of Arts and Sciences. She is also the recipient of:

• The 2004 Sackler Prize. The prize is administered by Tel Aviv University and is awarded each year in the disciplines of physics and chemistry to a researcher under the age of 40. This year the prize of $40,000 was awarded for outstanding research in the field of observational or theoretical astronomy and astrophysics.

• The 2004 Gold Shield Faculty Prize, an award presented to a UCLA faculty member every second year, recognizing "extraordinary accomplishment" in research, outstanding teaching and distinguished university service. The faculty prize includes an award of $30,000 for unrestricted research funding.

Austin Roorda (University of California Berkeley). Professor Roorda, formerly with the University of Houston, has joined the faculty of the University of California Berkeley, as an Associate Professor of Optometry and Vision Science. Professor Roorda's continue his reseach and development on the Confocal Scanning Laser Opthalmoscope supported by the CfAO.

Don Miller (Indiana University), was promoted from Assistant to Associate Professor, School of Optometry and Graduate Program in Vision Science. Professor Miller's research includes the development of an AO equipped Optical Coherent Tomography camera.

New view of distant colliding galaxies captured by Keck laser system by Tim Stephens, Jan. 17 2005

For the first time, astronomers have been able to combine the deepest optical images of the universe, obtained by the Hubble Space Telescope, with equally sharp images in the near-infrared part of the spectrum using a sophisticated new laser guide star system for adaptive optics at the W. M. Keck Observatory in Hawaii. The new observations, presented at the American Astronomical Society (AAS) meeting in San Diego (January 9 - 13 2005), reveal unprecedented details of colliding galaxies with massive black holes at their cores, seen at a distance of around 5 billion light-years. Observing distant galaxies in the infrared range reveals older populations of stars than can be seen at optical wavelengths, and infrared light also penetrates clouds of interstellar dust more readily than optical light. The new infrared images of distant galaxies were obtained by a team of researchers from UC Santa Cruz, UC Los Angeles, and the Keck Observatory. Jason Melbourne, a graduate student at UC Santa Cruz and lead author of the study, said the initial findings include some surprises and that researchers will continue to analyze the data in the weeks to come.

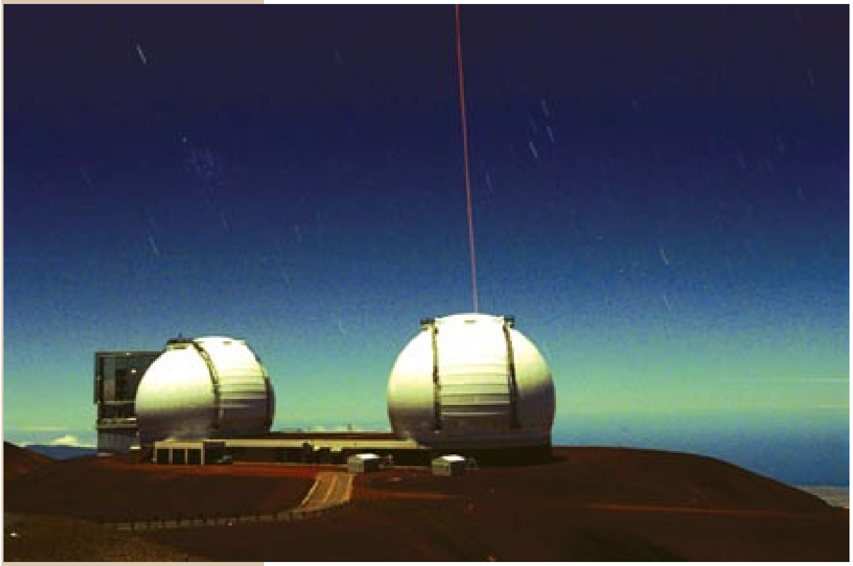


Fig. 1 The Keck laser creates a high altitude artificial star, allowing the adaptive optics system to measure and correct for turbulence in the Earth's atmosphere. Images taken with adaptive optics have a resolution at near infrared wavelengths that is comparable to optical images taken with the Hubble Space Telescope.
Credit: Sarah Anderson

"This is very exciting, because we have never been able to achieve this level of spatial resolution in the infrared before," Melbourne said. In addition to Melbourne, the research team, led by David Koo of UCSC and James Larkin of UCLA, includes Jennifer Lotz, Claire Max, and Jerry Nelson at UCSC; Shelley Wright and Matthew Barczys at UCLA; and Antonin H. Bouchez, Jason Chin, Scott Hartman, Erik Johansson, Robert Lafon, David Le Mignant, Paul J. Stomski, DouglasSummers, Marcos A. van Dam, and Peter L. Wizinowich at Keck Observatory.

Fig. 2 This galaxy contains two nuclei, indicating a recent galaxy-galaxy collision. The right-hand nucleus is slightly bluer than its partner. The galaxy is an x-ray source and is 4.6 billion light years away. This three color image combines optical light from the Hubble space telescope with infrared light from the Keck laser guide star system.
Credit: UCSC, UCLA, Keck

"For the first time now in these deepest images of the universe we can cover all wavelengths of light from the optical to the infrared with the same level of spatial resolution, which allows us to observe detailed substructures in distant galaxies and study their constituent stars with a precision we couldn't possibly obtain otherwise," said Koo, a professor of astronomy and astrophysics at UCSC.

The images were obtained by Wright and the Keck AO team during testing of the laser guide star adaptive optics system on the 10-meter Keck II Telescope. They are the first science-quality images of distant galaxies obtained with the new system. This marks a major step for the Center for Adaptive Optics Treasury Survey (CATS), which will use adaptive optics to observe a large sample of faint, distant galaxies in the early universe, said UCLA's Larkin.

"We've worked very hard for several years taking data around bright stars. But we have been very restricted in terms of the number and types of objects that we can observe. Only with the laser can we now reach the richest and most exciting targets, especially those with beautiful optical images from the Hubble Space Telescope," Larkin said.

Adaptive optics (AO) corrects for the blurring effect of the atmosphere, which seriously degrades images seen by ground-based telescopes. An AO system precisely measures this blurring and corrects the image using a deformable mirror, applying corrections hundreds of times per second. To measure the blurring, AO requires a bright point-source of light in the telescope's field of view, which can be created artificially by using a laser to excite sodium atoms in the upper atmosphere, causing them to glow. Without such a laser guide star, astronomers have had to rely on bright stars ("natural guide stars"), which drastically limit where AO can be used in the sky. Furthermore, natural guide stars are too bright to allow observations of very faint, distant galaxies in the same part of the sky.

"The advent of the laser guide star at Keck has opened up the sky for adaptive optics observations, and we can now use Keck to focus on those fields where we already have wonderful, deep optical images from the Hubble Space Telescope," Koo said.

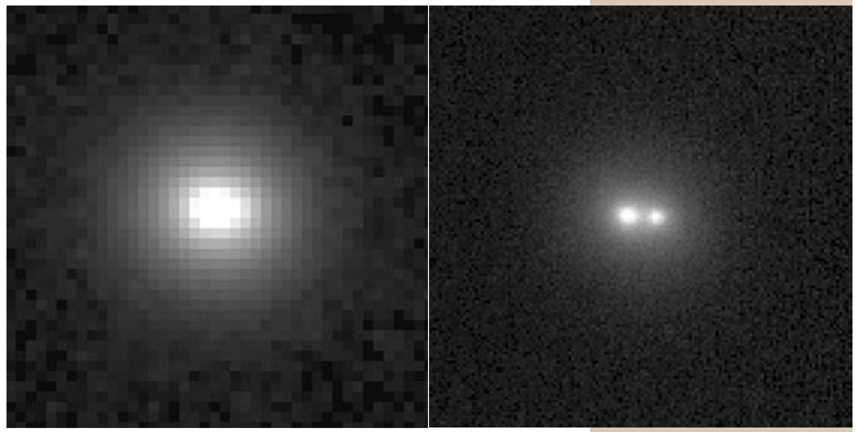


Fig. 3 Ground based near infrared images of the galaxy in Fig. 2, seen without (left) and with (right) laser guide star adaptive optics. In the right hand image, the two nuclei are separated by roughly 0.3 seconds of arc, which is the angular size of a person seen 1000 miles away.
Credit: UCSC, UCLA, Keck

Because the diameter of the Keck Telescope's mirror is four times larger than Hubble's, it can obtain images four times sharper than Hubble in the near infrared now that the laser guide star adaptive optics system is available to overcome the blurring effects of the atmosphere.

The images presented at the AAS meeting were obtained in an area of the sky known as the GOODS-South field, where deep observations have already been made by Hubble, the Chandra X-ray Observatory, and other telescopes. There are six faint galaxies in the images, including two x-ray sources identified by Chandra. The x-ray emissions, combined with the disordered morphology of these objects, suggested recent merger activity, Melbourne said. Mergers can funnel large

Colliding Galaxies

amounts of matter into the center of a galaxy, and x-ray emissions from the galactic center indicate the presence of a massive black hole that is actively consuming matter.

“We are now fairly certain that we are seeing galaxies that have undergone recent mergers,” Melbourne said. “One of these systems has a double nucleus, so you can actually see the two nuclei of the merging galaxies. The other is highly disordered – it looks like a train wreck – and is a much stronger x-ray source.”

Fig. 4 The galaxy at left is a 30-times stronger x-ray source than the one ain Fig. 2 and 3. It appears to be undergoing an even more violent merger event, which funnels gas onto a massive black hole in its core, producing x-rays. Black holes of this sort have masses up to a billion times that of our Sun. The object is 5.7 billion light years away, and is seen when the universe was just over half its present age.
Credit: UCSC, UCLA, Keck

In addition to lighting up the galactic nucleus with x-ray emissions, mergers also tend to trigger the formation of new stars by shocking and compressing clouds of gas. So the researchers were surprised to find that the system with a double nucleus is dominated by relatively old stars and does not appear to be producing many young stars.

“If we are right about the merger scenario, then this merger is occuring between two galaxies that had already formed most of their stars billions of years before and did not have a lot of gas left over to make new stars,” Melbourne said.

If additional study shows that such objects are common further back in time, these observations could help explain one of the puzzles of galaxy formation. According to the prevailing theory of hierarchical galaxy formation, large galaxies are built up over billions of years through mergers between smaller galaxies. Since mergers trigger star formation, it has been difficult to explain the existence of very large galaxies that lack significant populations of young stars.

“One idea is that you can have a so-called dry merger, where two galaxies full of old stars but little gas merge without forming many new stars. What we are seeing in this object is consistent with a dry merger,” Melbourne said. “Even in a dry merger, there may still be enough gas to feed the black hole, producing x-ray emissions, but not enough to yield a strong burst of star formation.”

Further observations at mid- to far-infrared wavelengths, expected later this year from the Spitzer Space Telescope, may help confirm this. “The Spitzer data will provide a better indication of the dust content of the galaxy, a crucial variable in interpreting these observations”, Melbourne said.

The laser guide star adaptive optics system was funded by the W. M. Keck Foundation. The artificial laser guide star system was developed and integrated in a partnership between the Lawrence Livermore National Laboratory and the W. M. Keck Observatory. The laser was integrated at Keck with the help of Dee Pennington, Curtis Brown, and Pam Danforth. The NIRC2 near-infrared camera was developed by the California Institute of Technology, UC Los Angelas, and the Keck observatory. The Keck Observatory is operated as a scientific partnership among the California Institute of Technology, the University of California, and the National Aeronautics and Space Administration.

Press Reports in Brief

Colour blindness cell loss clue (Friday, 4 June, 2004, BBC News, London)

Loss of cones in the retina may cause some types of colour blindness. Scientists have found that some colour blind people are missing as many as one third of the normal number of specialized light-detecting cells. However, apart from colour blindness, the general quality of their sight appears unaffected. The researchers hope their work will enable earlier detection of eyesight disorders. The study, by the University of Rochester, is published in Proceedings of the National Academy of Sciences. The Rochester team used a technique called adaptive optics to study the retina of the eye in much closer detail than has previously been possible. It was originally developed to help astronomers see more clearly through the Earth's atmosphere. Lead researcher Dr Joseph Carroll said: "Not only are we excited to show how this method can reveal to us living cells in a way never before possible, but it's revealed a mystery with profound implications. "If a third of the light-receiving cells in your eye are absent and you don't even notice it, it means that when a patient complains to a doctor about waning light sensitivity, then the damage must already be very serious."

Laser guide star teams with adaptive optics to shed light on massive star formation

For the first time, scientists from UC Berkeley and Lawrence Livermore National Laboratory (LLNL), in conjunction with astrophysicists from the California Institute of Technology, UC Santa Cruz, the National Science Foundation's Center for Adaptive Optics and UC's Lick Observatory, have observed that distant larger stars formed in flattened accretion disks just like the sun.

Using the laser guide star adaptive optics system created by LLNL scientists, the team was able to determine that some of the relatively young yet massive Herbig Ae/Be stars contain biconical nebulae, polarized jets and circumstellar disks. Less massive stars including the sun are believed to be formed in a swirling spherical cloud that collapses into a disk.

Adaptive optics enables astronomers to minimize the blurring effects of the Earth's atmosphere, producing images with unprecedented detail and resolution. The adaptive optics system uses light from a relatively bright star to measure the atmospheric distortions and to correct for them, but only about 1 percent of the sky contains stars sufficiently bright to be of use. The laser guide star enables astronomers to study nearly the entire sky with the high resolution of adaptive optics.

Herbig Ae/Be stars are young stars with masses between 1.5 and 10 times that of the sun and are less than 10 million years old, which is young by astronomical standards. While they are fundamentally very luminous, many are so distant that one can't see details of their immediate environments without the use of a laser guide star adaptive optics system. These stars are thought to be the young stage of the massive stars that later experience supernova explosions and trigger star formation in nearby clouds.

The only laser guide star systems in the world currently being used regularly for astronomy are at the Lick and W.M. Keck Observatories, and were built by LLNL. The sodium dye laser, built under the direction of LLNL laser scientists Deanna Pennington and Herbert Friedman, completes the adaptive optics system mounted to Lick's Shane telescope. It is operated by Lick staff.

Sum frequency laser implemented at the Palomar laser guide star test bed

The pulsed Sum Frequency Laser (CSFL) has been shown to provide a reliable source of sodium laser beacons. It consists of two pulsed, diode-pumped, mode-locked Nd:YAG lasers working at 1.064 micron and 1.32 micron

Reports in Brief

wavelengths. Light from the two laser beams is mixed in a non-linear crystal to produce radiation centered at 589 nm, with a spectral width of 1.0 GHz (FWHM) to match that of the Sodium-D2 line in the mesosphere. The laser runs at 500 Hz rep. rate with 10% duty cycle. This pulse format allows range gating of unwanted Rayleigh scatter down to an angle of 60 degrees to zenith angle. It should be possible to modify it to generate the short pulses that may be required for 30-meter class telescopes in the fuure.

The prototype laser achieved a power output of 4.3 watts of sodium light. The laser uses no active loops and is inherently stable due to a new cavity design.

The laser has been installed along the Coudé axis of the 200-inch telescope. The 200 inch telescope has a high slenderness ratio and

First Light at Mount Palomar

hence it deflects while tracking. To take out this effect and keep the laser boresited to its intended path, the Palomar team has implemented a low bandwidth (about 1 Hz speed) beam control system using motorized mirrors and quad-cells. The team constructed an aircraft detection safety system for the laser, as well as a laser launch telescope located behind the secondary mirror. On Oct. 24 2004, the system achieved first light.

Hawaii's Fading Star: Where will American astronomers go if they lose their biggest asset on earth? *Chronicle of Higher Education October 29, 2004*

"After three decades of operating largely as they wished on top of Mauna Kea, researchers have run into opposition from native Hawaiians who charge astronomers with defiling a sacred mountain. Environmentalists, too, have argued that scientists have harmed the fragile ecosystem at the summit."

Custom contact lenses for the visually impaired to be tested

Feb. 8 2005 - Rochester, N.Y., USA:

"A scientist at the University of Rochester Eye Institute is developing customized contact lenses in a four-year effort to improve the vision of people whose eyesight remains poor even with the best conventional surgical techniques, contact lenses, and glasses available.

The research study will include 30 adults who have had a corneal transplant or a condition known as keratoconus, an abnormal cone-shaped cornea. Most of whose visual problems arise from optical imperfections that weren't discovered until a University of Rochester team developed a sophisticated system that has adaptive optics as its basis.

Geunyoung Yoon, Ph.D., assistant professor of ophthalmology at the University of Rochester Medical Center, is setting out to develop more sophisticated equipment to measure the imperfections in the human eye. Scientists know that imperfections that are usually subtle in most patients can be substantial in patients who have keratoconus or have had corneal transplants. Yoon will try to specify exactly how the problem might be diagnosed and corrected." *Source - Madeforone.com*

Education Activities

New Internship Program On Hawaii Island: In collaboration with Hawaii Island observatories and educational institutions, the Center for Adaptive Optics has initiated its Akamai Observatory Internship program. Four year and community college students studying science, technology, engineering and math, are placed in paid internships at observatories over the two months of the summer.

The students are expected to complete projects that are in their field of interest, appropriate to their level of knowledge, and useful to the observatory. Mentors appointed by the observatories, design the projects to ensure a successful work experience for the student, and a useful outcome for the observatory. Prior to starting the internship, students attend a week long course taught by CfAO graduate students, postdocs and observatory staff.

Interns on Mauna Kea with Keck Observatory in the *background*

The Akamai Observatory Short Course uses a hands-on participatory approach to provide students with an overall idea of how observatories function, workplace expectations, as well as relevant science and engineering concepts.

Eleven students participated in the 2005 summer program, at the conclusion of which they presented technical talks based on their experience at the Akamai Observatory Intern symposium held July 2 at Subaru telescope headquarters.

Akamai Internship Program on Maui. With the support of Maui Community College (MCC), the Maui Development Council, the Air Force Maui Optical and Supercomputing Site (AMOS) and local high-tech industry, ten students participated this summer and three made technical presentations at the AMOS conference. A measure of the success of the program is that seven of the eighteen interns in the first two summers have been hired full time in technology occupations and four hold part-time positions, primarily on Maui.

For summer 2005, two of the ten students have already been tapped for jobs while others continue their studies with high hopes of connecting with companies after graduation.

Dr Andy Sheinis sets up an optics experiment at the Maui short course for interns

An additional benefit from the internship has been the development of a new astronomy lab course at MCC and the fine-tuning of other courses that better prepare students to work in the technology field after graduation.

MCC instructor Mark Hoffman said the curriculum and approach to teaching have changed over the last five years to accommodate the greater number of students interested in technology. In the case of the electronics and computer engineering fields the current freshman class of 25 students is the largest class he's had in the last five years.

Mainland Internship program – Started in 2002, this program continues to cater to 10-15 students per year. Students complete a one week introductory course in optics before entering research programs at the research institutions affiliated with the Center for Adaptive Optics.

Education Activities (continued)

CfAO at National Conferences:

The Center's booth manned by CfAO undergraduate interns, faculty and education staff was seen at two national student conferences this school year.

2005 SACNAS Conference:

Five Mainland and six Hawaii Island Interns attended the SACNAS conference in Denver, Colorado. Congratulations to Emily De La Garza, a 2005 intern at UC Santa Cruz who worked with David Koo and Jason Melbourne, for winning a Poster Presentation Award and to Pearl Yamaguchi, a 2005 intern at Subaru Telescope who worked with Steve Colley, for receiving Honorable Mention for her poster presentation.

The National Society of Black Physicists and The National Society for Hispanic Physicists.

Congratulations to Elizabeth Hernandez, a 2004 CfAO intern, for winning an undergraduate poster award at this conference for her poster, which described her research at Lawrence Berkeley National Laboratory. Nella Barrera, from UC Irvine gave an oral presentation at this conference describing her work as a CfAO intern over the summer of 2004 while at the Laboratory for Adaptive Optics.

Saturday Open Lab. at The University of Rochester.

Professor David Williams

For the second year in a row, the Williams laboratory at the Center for Vision Science at the University of Rochester has opened its doors for undergraduate students to come share a Saturday with them. The Saturday Open Lab is a recent program for CfAO's education program. Focusing on recruitment for graduate school as well as the undergraduate internship, CfAO education staff worked with the Rochester group to create an exciting day with various activities including two inquiries, a tour of the Williams' laboratory and an exciting scientific talk from Dr. David Williams. One inquiry was on color vision and the other on the optics of the eye. This year seven students attended the event: six from the University of Maryland, Baltimore and one from the University of Rochester.

Open Lab. instructors Lana Nagy, Jessica Wolfing, Joe Carroll, Julianna Lin, Dan Gray and Jason Porter

Lana Nagy, a graduate student at the University of Rochester is working on an optics inquiry with Cendrine Robinson, a University of Rochester undergraduate, and Conswela White and Kyla McMullen of the University of Maryland at Baltimore.

Adaptive Optics Summer School

The CfAO annual Adaptive Optics summer school was held from August 6th to 12th 2005 at UC Santa Cruz. There were 80 US and 20 international attendees. This year's summer school was on advaned AO topics and included a visit to inspect the AO system at Lick Observatory on Mt. Hamilton and presentations from CfAO summer interns.

Two views of the Center for Adaptive Building

CfAO Annual Fall Retreat (2005)

The CfAO held its annual Fall Retreat at the UCLA Conference Center, Lake Arrowhead CA on November 10th to 13th 2005. The Retreat was attended by 100 CfAO researchers and approximately 20 collaborators from industry. In addition to the research papers, invited review papers were presented by Professor Steven Kahn from Stanford University who spoke on "The Large Synoptic Survey Telescope", Professor Ray Applegate, University of Houston, speaking on "Aberrations predict Visual Performance in Good Eyes (20/17 and better)" and Professor Julie Schnapf, University of California, San Francisco presented "How Photoreceptors work".

Lake Arrowhead Conference Center

Center for Adaptive Optics

Laser Guide Star, First Light at Keck Observatory

A very faint beam from the Keck sodium laser appears in this 20-minute exposure. The laser creates a "virtual" star high above the Earth's surface, which is not visible to the human eye, but is bright enough to guide high resolution adaptive optics at Keck. This photo was taken from 600 meters away. Hazard lights from an automobile mark the steep descent path of the summit, and the motion of the Earth has created star trails in the sky. Photo by John McDonald from Canada France Hawaii Telescope (CFHT)

Extract from CfAO's 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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