

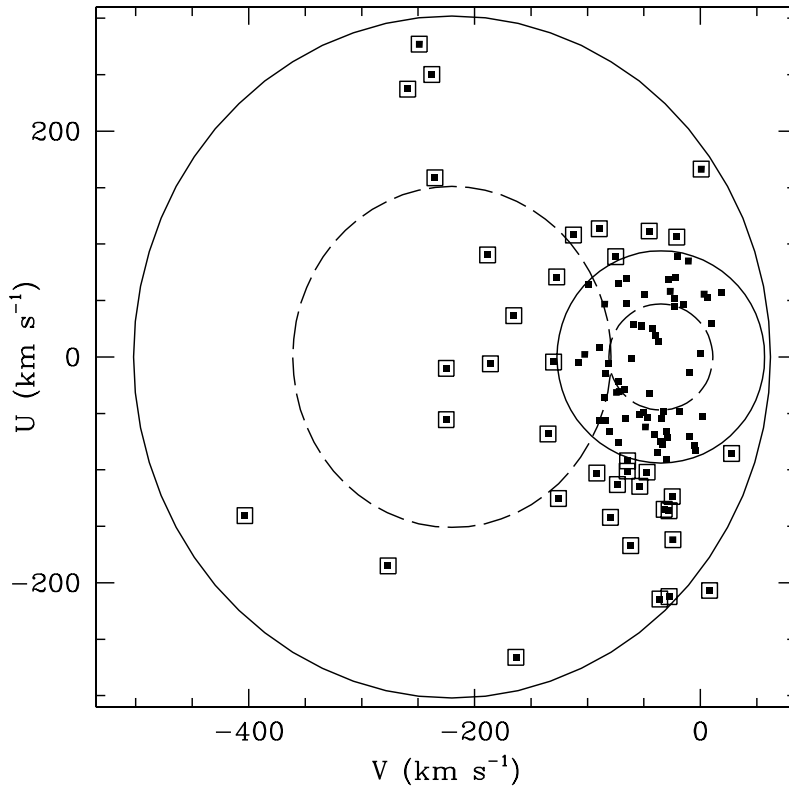
# White Dwarfs - Dark Matters

Tod R. Lauer

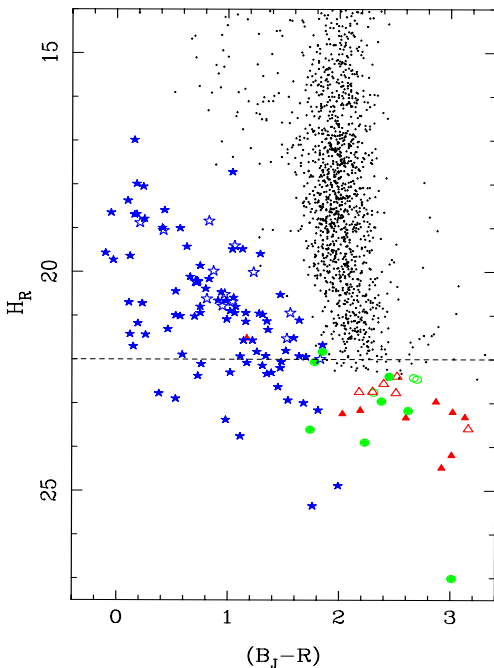
Ben Oppenheimer (Berkeley), N. C. Hambly, A. P. Digby (Edinburgh), S. T. Hodgkin (Cambridge), and D. Saumon (Vanderbilt) used the CTIO 4-m Blanco Telescope to identify a sample of white dwarfs that appear to be members of our galaxy's halo population. Detection of this new population argues that a substantial fraction of our galaxy's dark matter halo may be provided by white dwarfs.

Oppenheimer et al. used a three-epoch photographic survey of ~4,900 square degrees over the South Galactic Pole to identify faint stars with high proper motions. Proper motions were then used statistically to estimate distances, generating a color-magnitude diagram. Candidate white dwarfs are visible in the diagram below as the subluminescent sequence of objects to the left of the nearly vertical stellar main sequence.

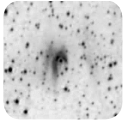
*continued*



A plot of the inferred galactic V (angular) and U (radial) velocities of the white dwarfs. The large dashed and solid circles correspond to the 1σ and 2σ velocity dispersions for the halo, while the smaller circles at the right give the same parameters for the old disk.



A color-magnitude diagram constructed from the Oppenheimer et al. photographic survey. The HR magnitude is an estimate of the absolute magnitude based on proper motions. Filled stars are spectroscopically confirmed white dwarfs (open stars are suspected white dwarfs); other symbols are either M dwarfs or other subdwarfs. The horizontal line is the completeness limit of the classic Luyten catalog.



## *White Dwarfs continued*

From this diagram, Oppenheimer et al. identified 92 stars for spectroscopic follow-up with the Blanco Telescope. Observations were obtained for 69 of the stars, of which 38 were identified as old cool white dwarfs.

Photometric distances to the white dwarfs allowed their proper motions to be converted to tangential spatial velocities. None of the stars showed spectral lines sufficient for the estimation of radial velocities; however, since the stars are all near the South Galactic Pole, their tangential velocities do provide for estimation of their galactic U (radial) and V (rotational) velocity components (see top image on previous page). The large range in U and the strongly negative V velocities argue that a substantial fraction of the white dwarfs observed are part of our galaxy's halo population.

Oppenheimer et al. estimate a local mass density of  $1.3 \times 10^{-4} M_{\odot}/\text{pc}^3$  for the halo white dwarf component visible within their completeness limit, which is about 2% of the local mass density of  $8 \times 10^{-3} M_{\odot}/\text{pc}^3$  for the halo overall. The number density of white dwarfs is still rising at this limit, however, and they do not observe any indication of the expected turnover due to the finite lifetime of the halo. Oppenheimer et al. thus argue that the true halo white dwarf component may be substantially larger, perhaps consistent with MACHO project estimates that 8% to 50% of the halo is in the form of compact objects. As it is, even a 2% white dwarf halo population is an order of magnitude larger than expected, given a standard initial mass function. The Oppenheimer et al. result may thus be a window on the early star formation in our galaxy as well as a current glimpse into the composition of its halo.

## Mass Transit

*Based on a contribution solicited from William Keel (Alabama)*

William Keel used the DensePak fiber array at the WIYN Telescope in conjuncture with HST observations to map an apparent exchange of mass taking place between the NGC 1409 and NGC 1410 galaxy pair. This appears to be the first case in which mass is observed in the entire process of transfer between interacting galaxies. Such transfer has been inferred from polar ring galaxies and H I on the outskirts of some elliptical galaxies, as well as from the Magellanic Stream in our own neighborhood, but has proven elusive to catch in the act.

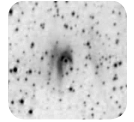
A striking dust structure suggestive of mass transfer in the NCG 1409/1410 pair was discovered by Keel in archival HST WFPC2 images, and was examined in detail using follow-up STIS images. A filament of dust appears leaving the spiral pattern of the Seyfert galaxy NGC 1410 (also known as III Zw 55), crossing the 8-kpc gap to NGC 1409, and twisting in a helical fashion around NGC 1409 to become a polar ring. This picture was amplified using a velocity field measured in H $\alpha$  and the adjacent [N II] lines, with the DensePak fiber array at the WIYN

*continued*



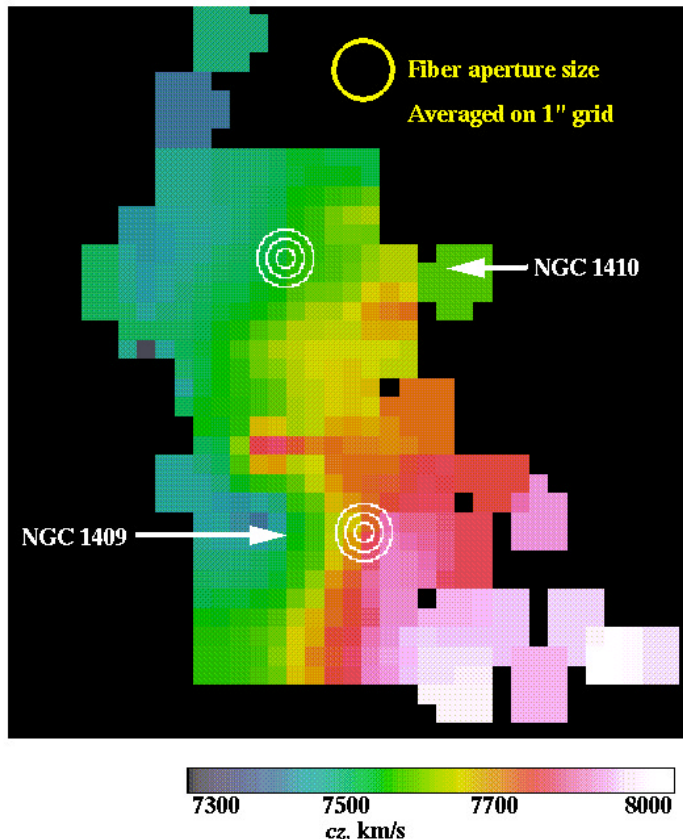
**Interacting Galaxies NGC 1409 and NGC 1410** HST • WFPC2  
NASA and W. Keel (University of Alabama) • STScI-PRC01-02

*HST images of the NGC 1409/1410 pair. The left-hand (northern) galaxy is NGC 1410, cataloged as a Seyfert Galaxy (also known as III Zw 55). NGC 1409 is a lenticular galaxy lacking clear spiral arms or star formation. The dust lane leaves NGC 1410, crosses the gap, and disappears where it would go behind the starlight of NGC 1409 if it connects to the polar dust seen in front of the nucleus.*



*Mass Transit continued*

## NGC 1409/10 H $\alpha$ +[N II] Velocity Field WIYN+DensePak



*A gas velocity map made from WIYN DENSEPAK spectral observations*

Telescope. In a half night of data taking last December, this device gave fully sampled coverage of the whole pair. Fortuitously, ionized gas was visible throughout the space between the galaxies. While it's hard to say just how much of the gas is associated with the 0.25" sized dust feature, the velocity field confirms the directions of relative motion inferred from the images and N-body simulations. NGC 1410

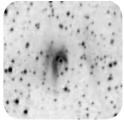
is undergoing a prograde (direct) encounter, which both analytical and numerical work shows to be most favorable for mass loss, while NGC 1409 sees a near-polar passage, in line with the polar orientation of the captured material. Further work, including specific simulations of this system, should help to answer immediate questions such as why is only a single filament of dust and gas crossing all the way over at one

time? The filament must be more of an "isochrone" than a pipeline.

Mass transfer has been a proposed mechanism to trigger AGN, but in this case the Seyfert Galaxy is the donor, and nuclear activity in the recipient (though weakly present, as shown clearly in the WIYN spectra) is about 20 $\times$  weaker. Is this because of geometry? Has incoming material not reached the core yet, or are there other factors?

There is no evidence of ongoing star formation in NGC 1409. Why isn't the infalling material forming stars?

The rate of mass transfer is very modest — a few hundredths of a solar mass per year, based on the dust absorption and typical gas/dust ratios. This is far too little to drive a powerful starburst, and similar mass dumping at a hundred times this rate would be obvious in many pairs. This may imply that the mass transfer producing powerful starbursts either happens mostly in H I where surveys are less complete than optical imaging, or that it builds up slowly until a critical mass or density is reached.



## Molecular Clouds Over Sunspot Umbrae

*T. Alan Clark (University of Calgary)*

Alan Clark, Marcel Bergman (University of Calgary), and Douglas Rabin (NASA/GSFC) have been using the Near Infrared Magnetograph (NIM) imager on the main spectrograph of the McMath-Pierce Solar Facility to image layers of molecules that appear over sunspots. Of particular interest in this work are the molecules H<sub>2</sub>O and HCl, which form over the coolest central regions of the sunspot umbrae. SiO, while forming a more extensive layer than H<sub>2</sub>O and HCl, also does not fill the area of the umbra. The molecule OH is detected in a layer over the full extent of the umbra and is detected weakly over penumbral regions. There is clear evidence that this molecule participates in the radial Evershed flow within the penumbral region. Other features of interest in these molecular layers are the apparent correlation of the equivalent widths of OH, SiO, HCl and H<sub>2</sub>O lines with the intensity of the underlying continuum and the abrupt “turn-on” of H<sub>2</sub>O and SiO absorption at specific (and different) continuum intensities (and hence, presumably, temperatures) as one approaches the coldest parts of the sunspot umbrae.

In the accompanying figures, a single spectral-spatial frame shows the spectrum across the center of a sunspot umbra, which appears as a dark horizontal band across the frame. Strong and weak absorption lines from N<sub>2</sub>O and other molecules in the Earth’s atmosphere cross the whole frame, while absorptions from

*continued*

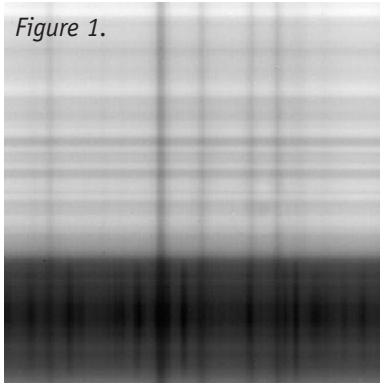


Figure 1.

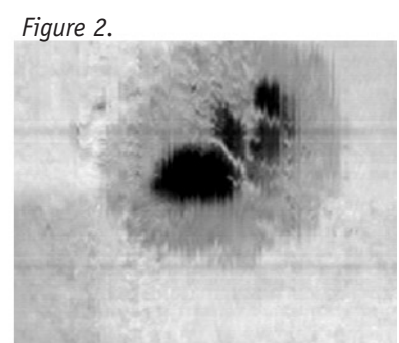


Figure 2.

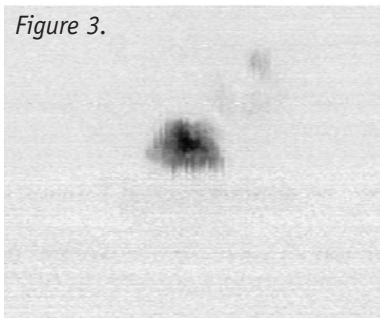


Figure 3.

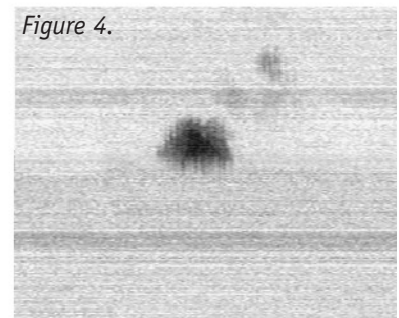


Figure 4.

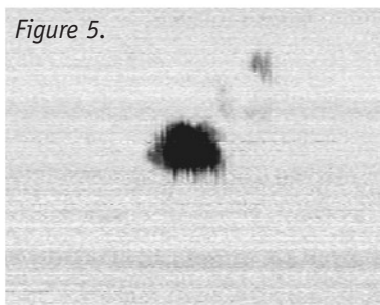


Figure 5.

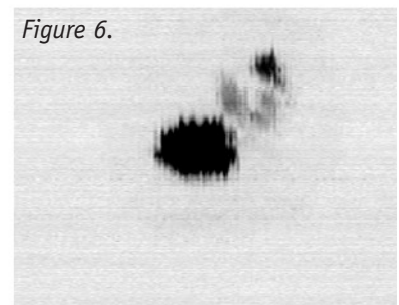


Figure 6.

Figure 1. This single spectral frame shows the region around 2428 cm<sup>-1</sup> over the active region AR8971 on 27 April 2000.

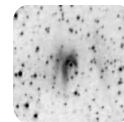
Figure 2. The IR continuum near the wavelength of Brackett  $\alpha$ .

Figure 3. Excess absorption from H<sub>2</sub>O over inner umbral regions.

Figure 4. Excess absorption from HCl over the umbral regions.

Figure 5. Excess absorption from SiO over the umbral regions.

Figure 6. Absorption from OH over penumbral and umbral regions.



*Sunspot Umbrae continued*

the above molecules appear only over the limited sunspot region. Spectroheliograms have been constructed by scanning the 52" slit across the sunspot in 0.8" steps. The image of the sunspot has been produced at a wavelength in the near-infrared continuum, while molecular images have been produced by

subtracting this spectroheliogram from those at the centers of absorption lines caused by each specific molecule. The penumbral component of the OH image is clearly visible. The more limited extent of the H<sub>2</sub>O, HCl and SiO layers is also obvious on these images.

If molecular equilibrium calculations can be used to determine the temperature threshold for the formation of these molecules, observations such as these should lead to a method for defining the temperatures of sunspot umbrae more precisely.

## Zeeman Splitting in OH at 12 Microns

*Don Jennings (NASA/GSFC) and Claude Plymate (NSO)*

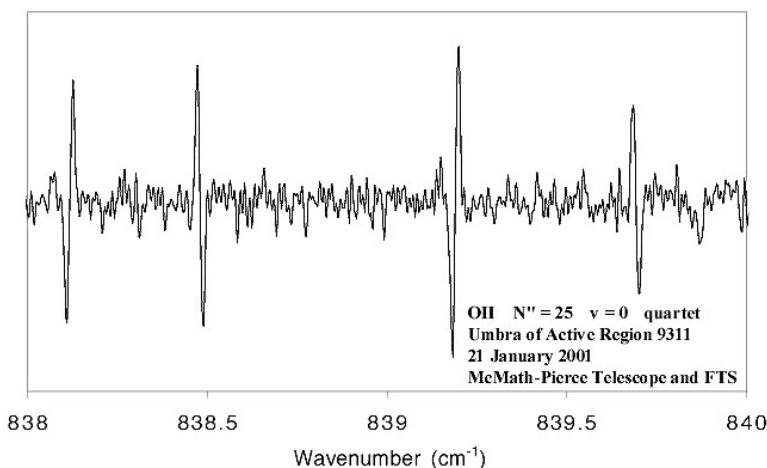
**Z**eeman splitting in the spectrum of the hydroxyl radical (OH) was recently detected in a sunspot. In January 2001, the Fourier Transform Spectrometer (FTS) at the McMath-Pierce Solar Facility was used to measure Stokes *V* profiles in OH lines near 12 microns. Splittings in these lines are of interest not only as a probe of magnetic fields, but also because the Zeeman effect is rarely seen in molecules. All four absorption components in each of the observed pure-rotational transitions exhibited small splittings, on the order of 0.01 cm<sup>-1</sup>, in both the umbra and penumbra. The figure shows a spectrum of the N" = 25 quartet formed in the v = 0 ground vibrational state. Several quartets like this one, corresponding to N" = 23 to 28 in the v = 0 and 1 states, were seen in the 11–13 micron range. The simple *V* signature suggests that the splitting is close to a "normal" Zeeman pattern. Note the alternating direction of the splitting among the four lines.

To make the measurements, scans were recorded in *I* + *V* and *I* – *V* using a quarter-wave plate and a linear polarizer. Differences between these yielded the *V* spectra. The appearance of Mg I emission

of magnetic fields into umbrae where the Mg I lines disappear.

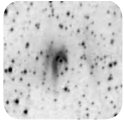
These observations were part of a continuing program to explore the solar spectrum in the mid-infrared.

OH Zeeman Splitting at 12 Microns



lines in this same spectral region help determine the OH magnetic sensitivity. In turn, the OH lines will extend the 12-micron measurements

The McMath-Pierce Solar Facility and FTS are unique in providing the capability to perform this research.

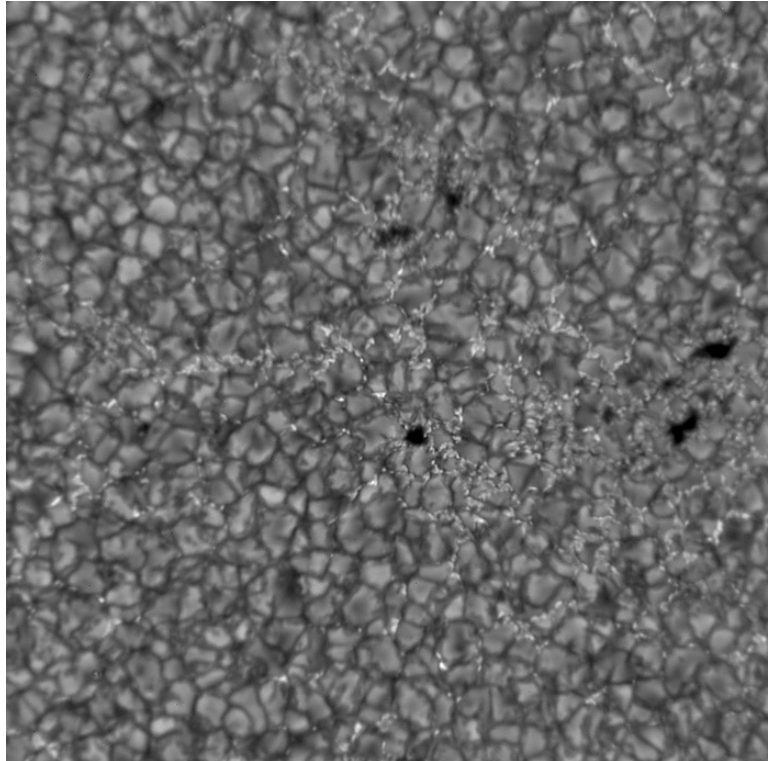


## Solar Adaptive Optics Program Update

*Thomas Rimmele and the NSO Adaptive Optics Team*

**N**SO, in partnership with the New Jersey Institute of Technology (NJIT), the Air Force Research Laboratory (AFRL), and the Kiepenheuer-Institute (KIS) in Germany, recently started a three-year project to build three high-order adaptive optics systems for use on the 65-cm telescope at Big Bear Solar Observatory (BBSO), the 76-cm Dunn Solar Telescope (DST) at Sacramento Peak, and the planned 1.5-m German Gregory Telescope (GREGOR) on Tenerife. The high-order Adaptive Optics (AO) system will upgrade each of these leading high-resolution solar telescopes, greatly improving scientific output of each facility. These efforts will serve the diverse needs of a broad solar community, from individual researchers to teams conducting campaigns. The resulting systems will also serve as proof of concept for a scalable AO design for the much larger Advanced Technology Solar Telescope. The solar AO program is funded by the NSF Major Research Instrumentation Program and through substantial contributions by the partner institutions.

With the design phase nearing completion, development of the high-order solar AO system is progressing on schedule. A Digital Signal Processor board for the correlating Shack-Hartmann wavefront sensor processor unit has been selected. Two deformable mirror systems, one for BBSO and one for the DST, have been



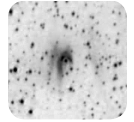
ordered, and a fast, flexible format wavefront sensor camera is under development. BBSO is developing a fast tip/tilt control system that will be an integral part of the high-order AO system. The servo loop has already been closed on this system. Three students have started their thesis work within the project, and additional students are expected to begin their thesis work this fall.

Software improvements and modifications to the optical setup on the low-order AO system at Sacramento Peak have resulted in better performance and a more user-friendly

system. Low-order AO is frequently used as a test bed for high-order AO development but also is in high demand for observing runs at the DST. A number of spectacular diffraction-limited observations of small-scale solar magnetic fields were recently achieved in the visible and at near-infrared wavelengths.

The figure above shows bright points observed in a plage region using a G-Band filter centered at 430.5 nm and with a FWHM of 1 nm. The field of view is 58 arcsec  $\times$  58 arcsec. The image was taken at the DST

*continued*



### *Program Update continued*

using solar adaptive optics. A CCD camera with a pixel resolution of 0.05 arcsec was used; the exposure time was six seconds.

G-Band is a band of spectral lines formed by the CH molecule. Small-scale magnetic flux elements appear bright when observed in G-Band. The actual size of the bright points is at or most likely below the diffraction limit of today's solar telescopes, and bright points can usually be observed only in images taken

during the very best seeing conditions and with very short (<20 ms) exposures in order to "freeze" the seeing. Spectroscopic and polarimetric analysis of these bright points, however, requires exposures typically lasting several seconds.

Adaptive optics can largely correct the adverse effects of seeing within an isoplanatic patch and thus enable diffraction-limited, long-exposure spectroscopy. The central part of the image where the AO system was

locked is visibly sharper, and the image contrast and resolution gradually deteriorate as one moves away from the isoplanatic patch.

In addition to G-Band images, narrowband UBF filtergrams are recorded and are currently analyzed with the goal of studying velocity patterns in and around magnetic flux tubes and the evolution of small-scale magnetic fields. Results are posted on the Web at: [www.sunspot.noao.edu/AOWEB](http://www.sunspot.noao.edu/AOWEB).

## The NOAO Hokupa'a Image Analysis Workshop

*Tod R. Lauer*

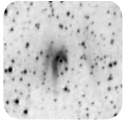
NOAO hosted a two-day workshop on February 26-27 concerning the analysis of images obtained with the Gemini North Hokupa'a adaptive optics camera. The primary goal of the meeting was to share understanding of the diverse issues, algorithms, problems, and tactics required to produce research-quality results from Hokupa'a images. Approximately 40 people attended, with heavy representation from the NOAO staff, the Gemini Observatory, and the NSF's Center for Adaptive Optics (CfAO). A portion of the attendees included those who had worked with other adaptive optics systems besides Hokupa'a. Most of the problems faced by observers using Hokupa'a are generic to natural guide-star adaptive optics systems. All but a few of the talks have been converted to Web documents at: [www.noao.edu/usgp/ao\\_workshop.html](http://www.noao.edu/usgp/ao_workshop.html).

Briefly, Hokupa'a is producing cutting-edge results in a diverse set of research areas. The ease of extracting quantitative results varies widely from problem to problem, and successful observing with Hokupa'a requires

a sophisticated understanding of its limitations. Robert Blum (NOAO), for example, is conducting crowded-field stellar photometry on the Gemini Galactic Center data set and obtains significantly smaller scatter in an H-K CMD than that shown by HST NICMOS observations of areas in common. Tim Davidge (HIA) and collaborators at Gemini have recovered the AGB tip in highly crowded Hokupa'a images of M32. Joe Jensen (Gemini), in some sense observing "ultra" crowded fields, has obtained reliable SBF observations of nearby galaxies with Hokupa'a. The most difficult observations with Hokupa'a are those that require accurate knowledge of the Point Spread Function (PSF). Francois Rigaut (Gemini) presented a sobering assessment of the form of the Hokupa'a PSF and its variability with time and detector position. In short:

*1. The PSF resolution and Strehl ratio decrease steadily with angular distance from the AO guide star.*

*continued*



### *NOAO Hokupa'a continued*

*2. The PSF is highly time variable -- 10% variations in FWHM are likely to occur on time scales longer than a few minutes.*

*3. PSF Strehl is a function of the AO guide star apparent magnitude.*

*4. The PSF has a broad halo.*

*5. At high-contrast ratios, the PSF halo is highly non-uniform. Quasi-stationary "speckles" or hot spots occur in the halo that change only over time scales of several minutes or with selection of different stars.*

Observations that are particularly challenging are detection of faint companions to the AO guide star and the detection of faint host galaxies associated with QSOs. For observations of these sorts there is no simple path to success. A key minimal requirement does appear to be repeated observations over a span of time and different conditions to discriminate between artifacts and real source structure. In addition, it is necessary to obtain PSF calibrations over a span of time with attention to characterizing the range of PSF variability and care to matching PSF observations to the properties of the source AO guide star.

Many of the talks presented at the workshop focused on characterization of the PSF, given its central role in the analysis of Hokupa'a observations. Mark Chun (Gemini) and Eric Steinbring (CfAO) emphasized programs to characterize the field variability of the PSF, while Joe Jensen (Gemini) explored recovery of the PSF from the SBF power spectrum itself. In short, it appears possible to characterize PSF spatial variations in crowded fields from a relatively sparse sampling of the PSFs over the field. The most challenging observations are those where only the AO guide star PSF is available or where the guide star itself is the target.

Clever image analysis algorithms are also central to success with AO observations. Keith Hege (Steward) and Julian Christou (CfAO) discussed the method of "blind deconvolution," which is particularly useful in an AO context because it is explicitly designed to leverage multiple observations obtained under varying conditions to separate the PSF and source structure. In conclusion, the workshop proved to be a successful sharing of AO experience, observing, analysis, calibration, and reduction issues. A quick skimming of the Web pages of the presentations should serve as an excellent point of departure for anyone interested in the problems of analyzing AO imagery.