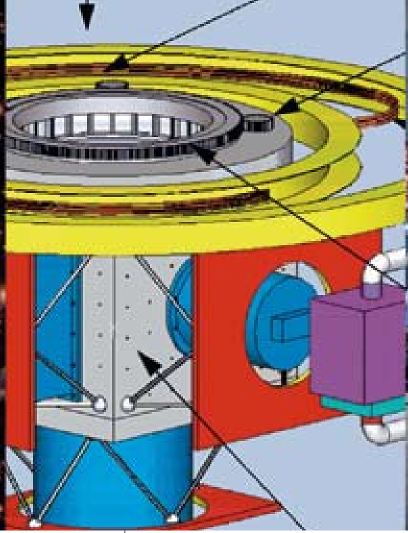
GeminiFocus

December2009 Publication of the Gemini Observatory






On the cover: Saturn and its moon Titan obtained using adaptive optics on the Gemini North telescope. For more details on this image and the related discovery of unexpected weather on Titan see the article by Henry Roe and Emily Schaller starting on page 7.

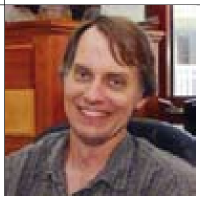
Managing Editor, Peter Michaud

Associate Editor, Carolyn Collins Petersen

Proof Reader, Stephen James O'Meara

Designer, Kirk Pu'uohau-Pummill

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.



by Doug Simons
Director, Gemini Observatory

Timing is Everything

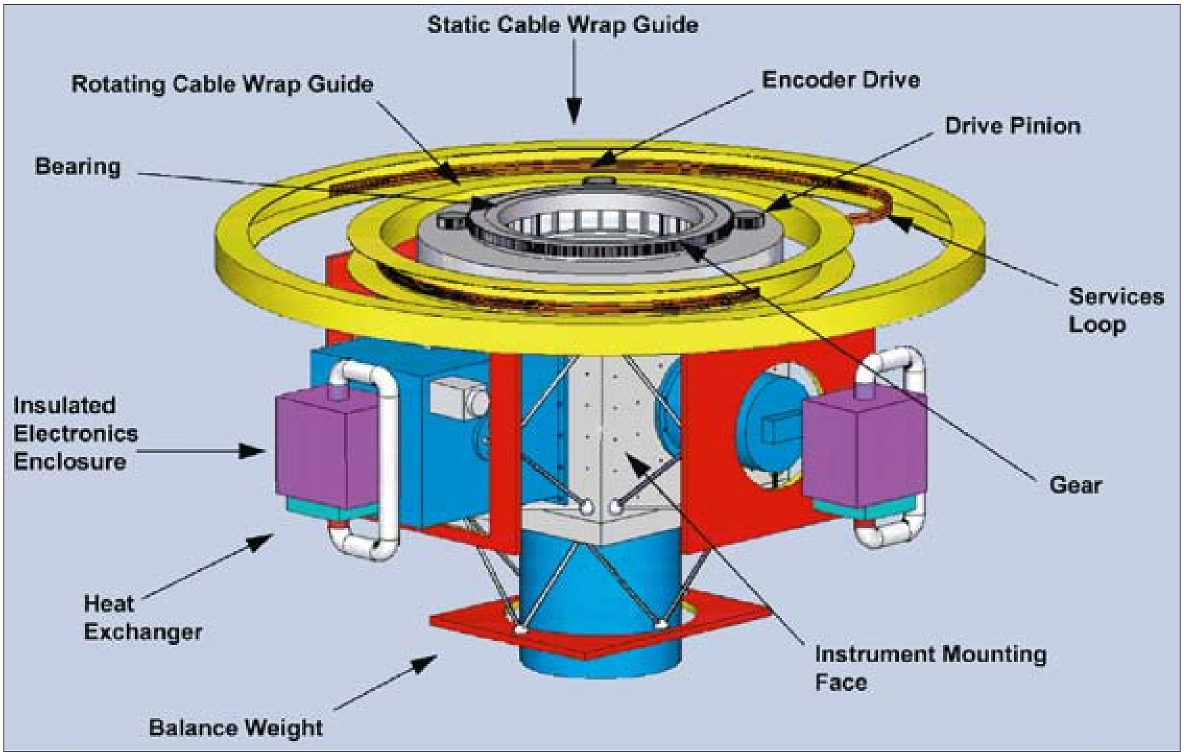


Figure 1. *This illustration (presented during the 1995 SPIE conference on astronomical instrumentation) is an early view of the planned Gemini cassegrain instrument cluster. A total of five beam feeds are provided around a rigid cube containing a highly articulated fold mirror and acquisition and guiding system. The design includes a calibration unit and an adaptive optics module that can feed any instrument. Electronics enclosures using air-liquid heat exchangers remove heat from the telescope environment. An infrared optimized up-looking port is preserved as well. This marvel of engineering serves as the "central nervous system" for each Gemini telescope and is fundamental to the success of our Target of Opportunity program.*

Perhaps the only thing predictable about nature is its unpredictability. Of course, many natural events are highly predictable, such as the ebbing of tides and changing of seasons. But, as one tunnels deeper into natural phenomena, the vast majority of the universe appears unpredictable simply because it is so poorly understood. The splendor of the universe stems from not only its beauty but its capricious violence. Understanding natural chaotic phenomena is a field in which Gemini's incredibly creative research community is growing adept, using Gemini as an observation platform. Back when Gemini was originally designed, however, we frankly never predicted these giant portals on the universe would be so effective at exploring astronomy's time domain. This edition of *Gemini*Focus highlights several recent observations that beautifully illustrate how engineering decisions made long ago can sometimes, for one reason or another, actually work together for a completely different purpose today. The result is a powerful new research tool for our community. This could be a lesson worth noting as the next generation of giant telescopes is designed, and similar tough design decisions are made to help them remain within budget and seemingly limit their capabilities. The "moral to the story" is to not underestimate the discovery potential of an inventive community, powerful telescopes, and a target-rich sky to take astronomy in unexpected directions.

Like many observatories, the Gemini Observatory we know today bears, at best, a limited resemblance to how it was first envisioned roughly two decades ago. A tremendous amount of effort went into finding an optimal system performance within the Gemini 8-meter Telescope Project's finite budget. Some of the effects of this design process are obvious, others less so. A key early decision eliminated the Nasmyth foci at Gemini, leaving the telescopes with unconventional focal stations compared to our contemporary facilities at Keck, Subaru, and the Very Large Telescope. Having instruments function exclusively in a Cassegrain environment, compared to a more benign (and spacious) Nasmyth focus, effectively transferred complexity and risk from the telescopes to Gemini's instruments—all of which must fit within a 2,000-kilogram mass limit (900 kilograms for the adaptive optics (AO) systems) and limited space envelope, and function under any gravity vector.

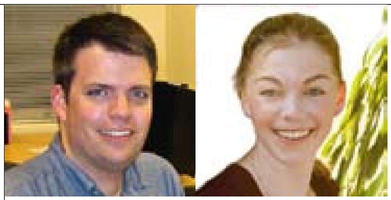
Recognizing these limitations, and out of concern for the notorious service and maintenance problems that frequent instrument changes cause, Gemini's engineers developed an innovative multi-instrument cluster capable of rapid remote reconfiguration while the instruments remain on the telescope for months at a time. It featured an AO system that could direct a corrected beam into any instrument mounted on the telescope. Merged with a clever calibration system (which replicates the telescope's beam), an acquisition and guidance (A&G) system (featuring three wavefront sensors), and on-instrument wavefront sensors (built into most instruments), the cassegrain cluster at Gemini packs an enormous range of capabilities and sophistication into a relatively small space. Figure 1 shows the early (~ 1995) Cassegrain focal station concept at Gemini. Interestingly, this design was well underway before serious consideration was being given to running a queue-based science operation model, and the term "Target of Opportunity" (ToO) was seldom, if ever, heard in the bustling Gemini Project office while this system was being designed. Ironically, being forced to consider "out of the box" solutions, due in large part to the highly cost-constrained environment in which Gemini was designed, bore the "fruit" hanging on the back of each Gemini telescope we enjoy today.

Another important design distinction at Gemini that is crucial to our ToO program's success is, of course, the use of a queue-based operations model. Even in this case, though, the rationale behind adopting a queue-based model was only weakly linked to ToO's at its genesis. With telescopes that were engineered to be site-limited in performance, and having several instruments available concurrently, the dynamic range of the facility's sensitivity and possibility of matching observing programs with changing weather conditions to maximize Gemini's scientific product is what really drove the queue concept behind the scenes. Finally, the last key ingredient in Gemini's ToO system is simply the fact that Gemini—with twin telescopes—has access to the entire sky; again, this originated in large part to provide ground-based back-up for space-based observations.

The advantages in running a ToO program with 8-meter telescopes on either side of the equator and separated by ~10,000 kilometers was not a strong driver at the time. In the end, it was a unique combination of clever engineering, global coverage, and queue-based science operations that made Gemini the "ToO machine" that is so powerful today. I wish those of us on the original project team could claim credit for having the far-reaching scientific insight about research trends in the 21st century and using that insight to deliberately design an observatory that is so effective for ToO observations. However, the truth is—we just got lucky.

The ToO system now in place makes it possible to receive a signal at either Gemini telescope via the Internet from a principal investigator (PI) anywhere in the world. That signal, when handled by the night staff, allows them to seamlessly interrupt say, a Near-Infrared Imager (NIRI) queue observation, slew the telescope to the opposite side of the sky, configure the Gemini Multi-Object Spectrograph (GMOS) for single-slit spectroscopy, and begin collecting photons from a ToO source. It often takes as little as 15 minutes for a ToO trigger to yield science photons. Another 5-10 minutes after the observation is complete, the anxious PI can retrieve the data from the Canadian Astronomy Data Centre (CADC) and evaluate it immediately, perhaps leading to another trigger using a different instrument. It is this observing system that is responsible for the remarkable ToO science results found in this issue of *Gemini*Focus. It was this system that made it possible to observe the weather on Titan using Altair and NIRI when photometry from smaller telescopes indicated that interesting meteorology was emerging on Saturn's largest satellite (see Henry Roe and Emily Schaller's article on page 7, and cover image of this issue). It was this system that captured the oldest photons ever recorded, sans those from the Cosmic Microwave Background, from a gamma-ray burst that is a staggering $z \sim 8.2$ away (see Edo Berger's article on page 10). Finally, it was this system that made it possible to record fantastic mid-infrared images of the still-hot impact site on Jupiter after an unseen comet plowed into Jupiter's stormy atmosphere (see the Science Highlight on page 39). We await with excitement the many targets of opportunity that will come within range of Gemini in the years ahead. In the longer term, we foresee a rich ToO discovery horizon at Gemini because there are few large facilities better positioned to study the fast-changing targets that will surely be revealed by the next generation of synoptic survey telescopes.

Doug Simons is Director of the Gemini Observatory. He can be reached at: dsimons@gemini.edu



by Henry Roe & Emily Schaller

Titan's Weather: Caught in the Act

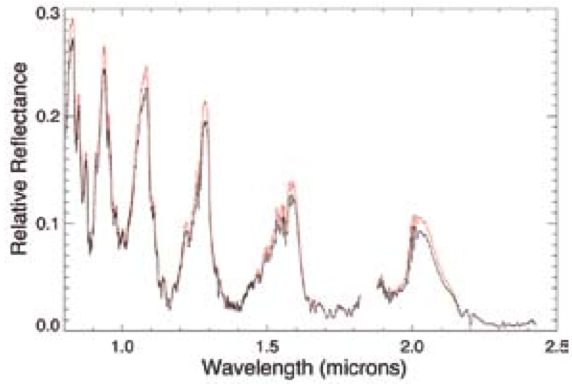
After several years of patiently waiting, in April 2008 Titan, Saturn's largest moon, fell into a trap carefully set by our team of collaborators.

On April 13, our spectral monitoring program at the NASA Infrared Telescope Facility (IRTF) indicated unusual cloud activity in Titan's atmosphere. On the next evening, April 14, we triggered our Target of Opportunity (ToO) program at Gemini North to acquire high-resolution adaptive optics imaging to see what was happening.

Our ToO sequence requires only 10-20 minutes of telescope time to image Titan using three filters that separate surface features, tropospheric methane clouds, and the global stratospheric haze. We trigger these ToO observations dozens of times per year based on cloud activity seen by one of our smaller telescope observing programs, cloud activity seen in previous Gemini data, the need for baseline data, and a variety of other reasons.

The data are retrieved from the archive and reduced automatically every night, using a set of software scripts. For the first time in more than a year, these scripts failed when they encountered the April 14 data. A quick investigation that morning revealed that the new storm greatly outshone Titan; this had befuddled the reduction pipeline, leaving it unable to precisely locate Titan in the data. In our multiple years of observing Titan with Gemini, this was by far the largest storm we had ever seen. A few quick fixes to the code, and the pipeline

Figure 1.
Near-infrared spectra of Titan from March 28, 2008, and April 13, 2008. Both spectra have approximately the same central longitude (227° W). But the spectrum from April 13 (red) shows increased flux in the transparent regions of Titan's atmosphere (0.8, 0.95, 1.2, 1.6, and 2.0 microns), while staying the same brightness in the high-opacity regions. Because the surface reflection in these two spectra was essentially the same, the increased flux is due to tropospheric clouds. (Figure from Schaller et al. 2009.)



happily reduced these new data. (See the image labeled "2008-04-14 UT" in Figure 2 on page 9.)

Why were these observations so important? Titan resembles Earth because many of the processes active on its surface, and in its atmosphere, are similar on both worlds. While the materials involved are somewhat alien to us on Earth but perfectly normal for Titan, the processes are completely familiar. For instance, Titan's clouds, rain, and surface liquids are all made of methane rather than water, but the processes of methane cloud formation, rainfall, and evaporation from lakes all have Earthly analogs. Most water-based hydrologic or meteorologic processes here on Earth have directly analogous methane-based processes on Titan. Like Earth, both Mars and Venus are terrestrial planets and are closer in size to Earth than Titan, but from the point of view of planetary processes on the surface and in the atmosphere, Titan stands out as the most similar body to Earth in our Solar System.

Titan has seasons for the same reason Earth does: its axis of rotation is tilted 26.4 degrees, just three more degrees than Earth's tilt. However, Titan's year is much longer. One Titan year lasts 30 Earth years.

We've only had the technology to observe Titan's methane weather directly for about a decade, and our campaign to study the weather in detail began only about five years ago. Titan's northern vernal equinox occurred in August 2009. Imagine trying to understand Earth's complicated weather from only having seen January, February, and part of March, and you can see why we are planning to continue to observe Titan for decades to come.

The events of April 2008 demonstrated the value of a multi-telescope observing approach for Titan. By using smaller telescopes (such as the 3-meter IRTF in this case) to monitor cloud coverage on Titan each night, we can better and more efficiently allocate our precious and limited Gemini observing time to focus on Titan when it is most active. The April 2008 events also demonstrated why ground-based observations of Titan are so crucial, even with the Cassini spacecraft in orbit around Saturn. Cassini flies by Titan every few weeks, but has limited ability to observe that world in between those flybys. In the spring of 2008, Cassini flew by Titan on March 25 and then did not visit Titan again until May 12. In Cassini images from the later flyby, a few, faint strange-looking clouds remain. However, for the most part, Cassini entirely missed the events of the previous month.

Most importantly, the events of April 2008 gave new insight into how and where clouds form on Titan. That initial storm of April 13-16, 2009, was convective and violent enough to kick off waves in the atmosphere, just as a dropped stone generates waves on the surface of a pond. These ripples, technically known as Rossby waves, then traveled throughout Titan's southern hemisphere and triggered cloud formation elsewhere, including at the south pole and in the equatorial regions. On April 28, the wave had circled Titan and caught up to the original storm, triggering new cloud formation and a brightening of the storm.

These were the first observations of wave activity in Titan's atmosphere and demonstrated convincingly that a strong-enough punch to the atmosphere in one location can trigger cloud formation anywhere in the same hemisphere on Titan. This overturned a recently developed understanding of Titan suggesting that its equatorial region is a dry desert and should never see clouds or rainfall, while the polar regions should be wet in early summer and dry the rest of the year. These observations demonstrate that clouds, and presumably rainfall, do occur at the equator and can occur out of season at the poles. Further, this helps solve the mystery of what process could have formed the dry streambeds and channels seen at Titan's equator by Cassini and its lander probe Huygens. Researchers had begun to invoke the existence of underground springs, geysers, or other even stranger geologic features, but these observations show that methane rain showers are the likely source of the liquid that cut those streambeds.

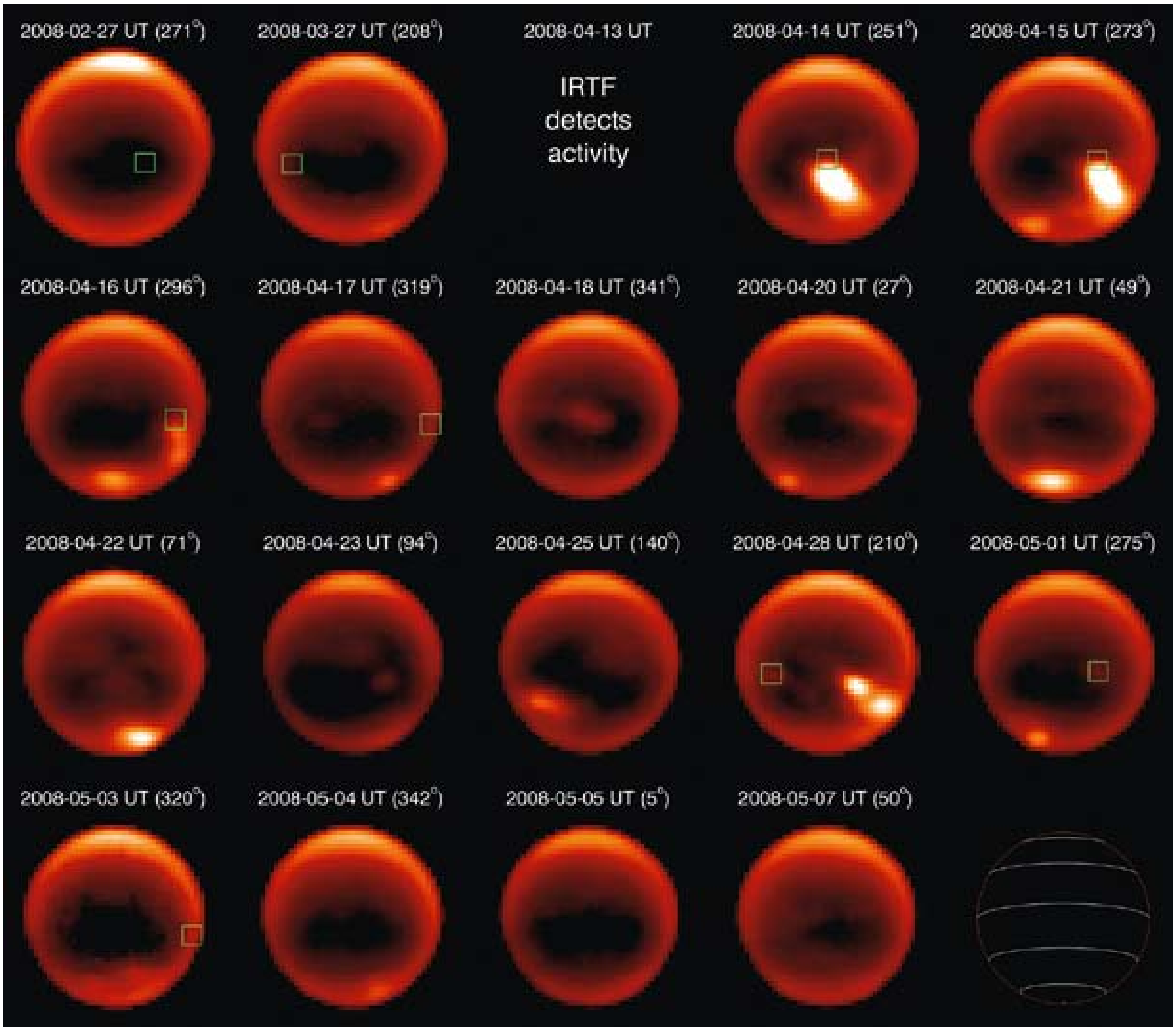


Figure 2. *These images from Gemini North were taken using a filter (H21-0, 2.12 microns) that obscures Titan's surface, but highlights the variable bright clouds and more static high stratospheric haze. On March 27, 2008, there were essentially no clouds present. The central longitude is indicated above each image. The green box indicates the initial location of the large storm. The original storm rotates to the night- side of Titan after a few days with Titan's 16-Earth-day rotational period.*

The biggest remaining mystery from April 2008 is: What was the original trigger? What could have punched the atmosphere so hard as to set off one of the biggest storms yet seen on Titan? The most likely two possibilities are seasonal atmospheric dynamics or some type of geologic activity on the surface. The atmospheric dynamics possibility requires just the right combination of winds shifting around on Titan, which could happen. From Cassini images there is strong evidence that Titan's surface is still active, with cryovolcanoes, mountain formation, and erosion, and possibly even small-scale plate tectonics. Any of these processes could release enough subsurface methane into the atmosphere to kick off a storm of the size we saw. Curiously, the surface region where the storm initiated (shown by a green box in Figure 2) remained bright for weeks. With further observations of Titan over the next few years, we'll be able to distinguish between these scenarios as our network of telescopes and observing programs capture more of Titan's methane weather.

For further information see:

Schaller, E. L., Roe, H. G., Schneider, T., & Brown, M. E., 2009, *Nature*, **460**, 873.

Henry Roe is an astronomer at the Lowell Observatory in Flagstaff, Arizona. He can be reached at: hroe@lowell.edu

Emily Schaller is an astronomer at the University of Arizona (however, much of this work was done while she was at the Institute for Astronomy at the University of Hawai'i). She can be reached at: emilyschaller@gmail.com

by Edo Berger

The Most Distant Known Object in the Universe

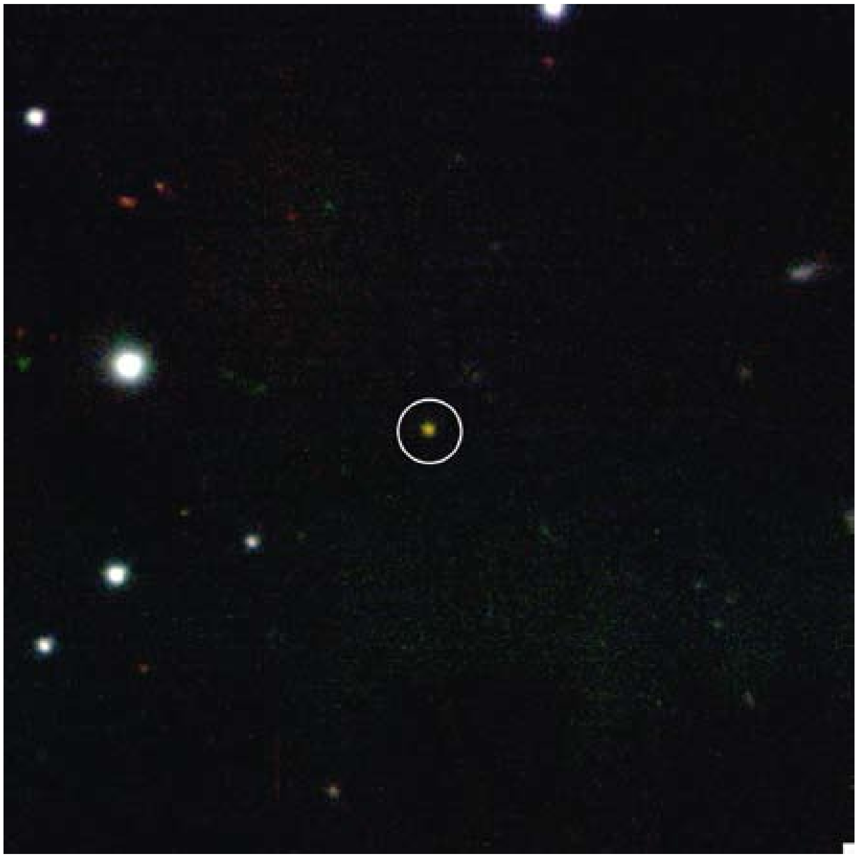


Figure 1. *The fading infrared afterglow of gamma-ray burst GRB 090423 appears in the center of this false-color image taken with the Gemini North telescope in Hawai'i. This burst is the farthest cosmic object/event yet seen.*

One of the most fundamental questions facing 21st-century astronomy is how the universe evolved from the simple and smooth remnant of the Big Bang to the magnificent and complex interplay of stars, galaxies, and clusters that we see around us today. A key piece of this puzzle is the formation of the first stars and galaxies, and their inevitable role in reshaping the universe around them. This is called the process of cosmic reionization.

On April 23, 2009, I participated in a discovery that is sure to shed light on this cosmological inquiry. We found evidence for the most distant known object in the universe—a type of explosion known as a gamma-ray burst (GRB). Our observations showed that this burst, dubbed GRB 090423, took place when the universe

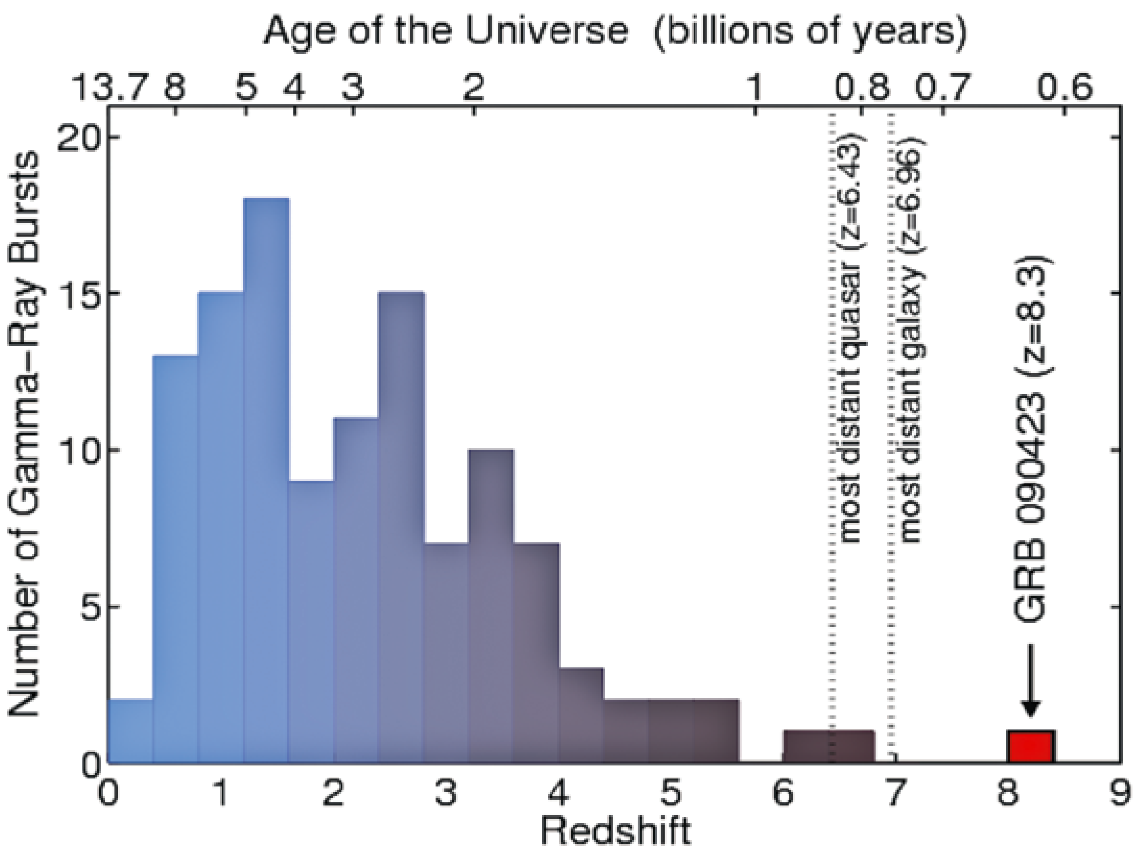


Figure 2. *The redshift distribution of gamma-ray bursts, including the record-breaking GRB 090423 at z = 8.3. Also shown are the highest redshift galaxy (z = 6.96) and quasar (z = 6.43).*

was only 630 million years old—a mere 4.6% of its current age. The discovery of this extraordinary event pushes our view of the universe earlier by 150 million years of cosmic evolution, bringing us ever closer to the very first generation of stars and galaxies.

We could detect GRB 090423 and determine its redshift at such an extreme distance for two important reasons. First, GRBs and their long-wavelength afterglows are the most luminous objects in the universe. In this particular case, the afterglow peaked at a K-band AB magnitude of about 20, at least 10 magnitudes brighter than the expected luminosity of typical galaxies at a comparable redshift!

Second, we used Gemini's rapid Target of Opportunity capability to determine a photometric redshift of z = 7.6-9.2 within two hours of the burst discovery (see Figure 2). This value was later refined spectroscopically to z = 8.3.

How does this record-breaking burst fit within the broader distribution of high-redshift objects? Over the past several decades, the quest to study the high-redshift universe and the process of reionization has been driving a race between several astronomical communities: those studying bright quasars, faint galaxies, and most recently, GRBs. Starting with their discovery in the 1960s, and up until the mid-1990s, quasars have dominated the race. These objects, powered by billion-solar-mass black holes, are extremely luminous, but also exceedingly rare. The advent of the Hubble Space Telescope and large ground-based telescopes in the 1990s propelled distant galaxies into the forefront, and they have since been competing neck-and-neck with the distant quasars. Indeed, before our April 23 discovery, the most-distant known object in the universe was a

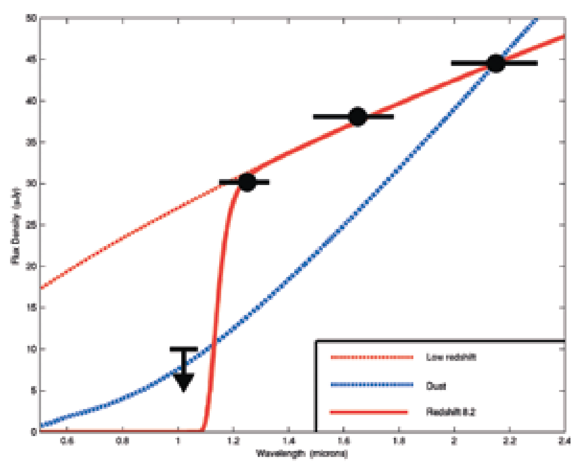


Figure 3. *Near-infrared observations of GRB 090423 in the Y-, J-, H-, and K-bands. The dashed red line indicates spectral flux density in the absence of neutral hydrogen absorption at high redshift, while the solid red line includes the effect of absorption at the redshifted wavelength of the Lyman-alpha line. The blue line indicates the effect of dust extinction, which clearly cannot explain the sharp cut-off at about 1.2 microns.*

small galaxy dubbed IOK-1, at a redshift of 6.96. Only slightly behind that was a quasar called CFHQS J2329-0301, which lies at a redshift of 6.43. GRBs entered the race much later, but have quickly taken the lead.

Starting with the first distance measurements for GRBs in 1997, they have quickly climbed the distance ladder, reaching out to a respectable redshift of 6.29 in 2005 and overtaking the quasars with a redshift of 6.7 in 2008 (Figure 2).

The quest for high-redshift galaxies and quasars has been stalled at $z \sim 7$ for physical reasons. Beyond this redshift, the optical emission is fully absorbed by neutral hydrogen in the intergalactic medium (IGM), and searches require extensive infrared observations. Wide-field infrared surveys are required to find the bright but exceedingly rare $z > 7$ quasars, while deep narrow-field observations are more conducive to finding the more numerous, but much fainter, $z > 7$ galaxies. Spectroscopic confirmation of faint candidate $z > 7$ galaxies is currently another bottleneck. It is unlikely to be resolved before the launch of NASA's James Webb Space Telescope around 2015. In all cases, the signature of a high-redshift origin is a sharp cut-off at the redshifted wavelength of the Lyman-alpha line induced by the IGM. This requires deep limits in the optical band and high signal-to-noise ratio detections in the infrared bands to avoid confusion with more mundane processes effects, such as dust extinction and intrinsic spectral features in galaxy or quasar spectra.

In the case of GRBs, the signature of a high redshift is similar, but its detectability is aided by the fact that the afterglow spectrum is due to featureless synchrotron emission. Thus, the only possible source of confusion is dust extinction. In the case of GRB 090423, deep optical limits less than 20 minutes after the burst discovery and a detection in the K-band suggested either a high-redshift origin or significant dust extinction. Armed with this knowledge we immediately slewed the Gemini North 8-meter telescope to the burst's location and obtained Y-, J- and H-band observations with the Near-Infrared Imager (NIRI). The results of the observations are shown in Figure 3 and a color image is shown in Figure 1. The NIRI observations clearly demonstrated a sharp cut-off at about 1.2 microns that could only be explained by absorption in the high redshift IGM and/or by neutral hydrogen within the host galaxy. In either case, the redshift was unambiguous.

Our discovery of GRB 090423 at a record redshift of about 8.3 opens new distant horizons. It proves that stars were already dying at a time when the universe was only 630 million years old. Equally important, we now know that when the first stars died, at least some of them exploded as bright GRBs. This gives us a promising way to pinpoint their location and to find increasingly more distant objects in the future. Although new observations with the WFC3 instrument on Hubble have now uncovered potential $z \sim 8$ galaxies, it is unlikely that these will be spectroscopically confirmed until well into the next decade.

The Swift satellite, on the other hand, can certainly detect extremely distant bursts, and we are poised to determine their distances using telescopes such as Gemini.

Ultimately, our desire to find the most distant GRBs goes beyond just bragging rights and redshift records. Because they are so bright in infrared light, the bursts can be used to momentarily illuminate their otherwise extremely faint galaxies and the increasingly neutral IGM. Infrared spectroscopy will thus allow us to measure the metallicities of the highest redshift galaxies, in much the same way that we have done at $z < 6$ over the past several years. Equally important, such spectroscopic observations will allow us to precisely measure the neutral fraction of the IGM well into the process of reionization.

For more information see:

Tanvir, N., Fox, D. B., Levan, A. J., Berger, E., *et al.* 2009, *Nature* in press; arXiv:0906.1577

Bouwens, R. J., *et al.* 2009, Submitted to *ApJL;* arXiv:0909.1803

Iye, M., *et al.* 2006, *Nature*, **443**, 186

Willott, C. J., *et al.* 2003, *ApJ*, **587**, L15

Edo Berger is an assistant professor of astronomy at Harvard University. He can be reached at: eberger@cfa.harvard.edu

by Mark Swinbank

Studying a Lensed Z ~ 5 Star-forming Galaxy with NIFS/IFU

A key extragalactic science driver for the justification of the next generation of telescopes, such as the Thirty Meter and Extremely Large Telescopes, is to detail the internal properties of high-redshift galaxies on scales comparable to HII regions. This will allow us to understand how and why galaxies in the distant universe are so much more efficient at forming stars than they are today.

The study of the internal structure of typical high-redshift galaxies requires both superb sensitivity and high resolution. While present-day laser-guide-star adaptive-optics-fed (LGS AO) integral field units (IFUs) deliver resolved data for $z \sim 1.5 - 3$ galaxies on about kiloparsec scales, such observations only provide a few independent resolution elements for representative high-redshift sources typically less than 2 kiloparsecs across. Fortunately, we need not wait for the next generation of larger telescopes to obtain a much-improved spatial sampling.

One of the most striking natural phenomena seen in the universe is strong gravitational lensing by galaxy clusters, and these massive clusters act as natural telescopes. They amplify the images of distant galaxies which serendipitously lie behind them, boosting their fluxes and apparent sizes by factors of 10 to 30. By combining gravitational lensing with IFU spectroscopy we can therefore probe the dynamics and distribution of star formation and the interplay between star formation and gas dynamics in much greater detail than otherwise possible. Indeed, the spatial resolution can even reach 100 parsecs, which begins to resolve individual HII regions. This feat would otherwise be impossible without the light grasp and resolution of a 30- to 40-meter-class telescope.

One of the most spectacular gravitational arcs is the famous lensed galaxy behind MS 1358+62 at $z = 4.92$ (Figure 1, see next page). Discovered during a Hubble Space Telescope (HST) imaging campaign in 1997, this galaxy offers a nearly unique opportunity to study the internal processes that drive galaxy formation

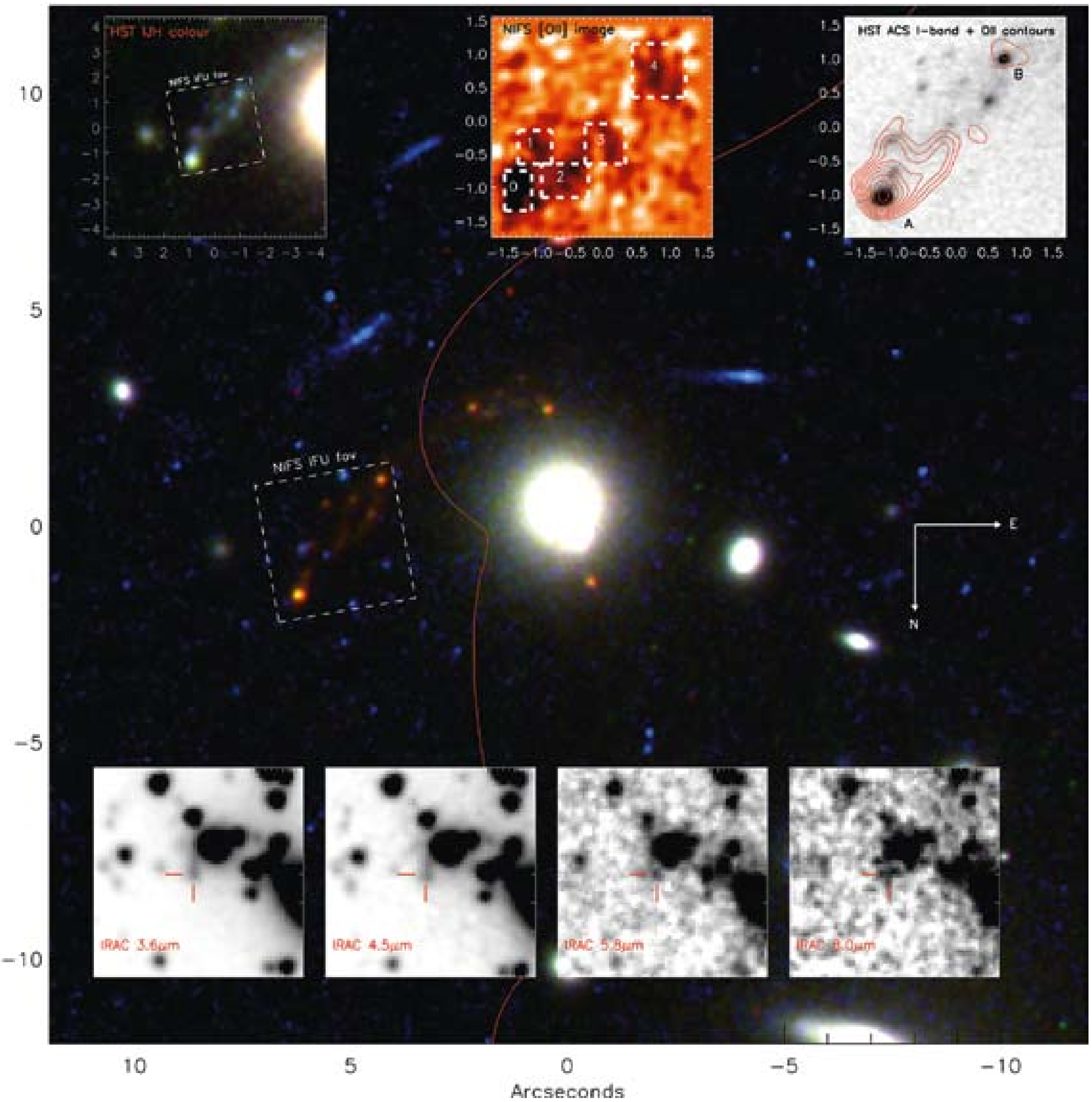


Figure 1.
A true-color HST ACS VRI-band image of the lensed z = 4.92 galaxy behind MS 1358+62 with the z = 4.92 critical curve from our best-fit lens model overlaid. The HST images clearly show the multiply imaged galaxy as two mirror images which are folded about the critical curve (red line resolved into two images of the background galaxy). The morphology of the galaxy is clearly dominated by up to six star-forming regions surrounded by a diffuse halo. The upper middle panel shows the white light (wavelength collapsed) image of the [OII] emission from the IFU; the boxes labeled 0-4, denote the regions from which spectra were extracted (see Figure 3).

in the early universe—likely at an epoch when a galaxy forms its first generation of stars. With multi-wavelength imaging from HST's Advanced Camera for Surveys (ACS) and Near-Infrared Camera and Multi-Object Spectrometer (NICMOS), as well as the Spitzer Space Telescope, this well-studied galaxy cluster has a wealth of arcs and arclets that allow for a detailed map of the mass distribution within the galaxy cluster to be constructed. In Figure 2 we show the source-plane reconstruction of the galaxy image and use this to derive a luminosity-weighted amplification factor of 12.5 and a source-plane radius of ~ 2 kiloparsecs. As Figure 2 also shows, the source-plane morphology is dominated by approximately five star-forming regions.

In order to investigate the internal properties of the galaxy in detail, we used the Near-Infrared Integral Field Spectrometer (NIFS) IFU to map the nebular [OII] 3727 emission line doublet from the galaxy. Our data allow us to spatially resolve the distribution of star formation and dynamics. As Figure 1 also reveals, the nebular emission-line map closely follows the rest-frame ultraviolet (UV) morphology, and by collapsing the data cube from the brightest regions, we derive a peak-to-peak velocity gradient of 180 kilometers per second across 4 kiloparsecs, suggesting a dynamical mass of $M_{dyn} \sim 3 \times 10^9$ M_{Sun} For comparison, the stellar mass (estimated from the rest-frame UV-to-K-band spectral energy distribution) is ~ 10^9 M_{Sun}.

This dynamical mass is an order of magnitude smaller than the median Lyman-break galaxy mass at $z \sim 3$ for which masses have been measured using similar techniques. However, it is comparable to the only other star-forming galaxy at this redshift (RCS 0224-002 arc at z = 4.88) with a dynamical mass measured in a similar way.

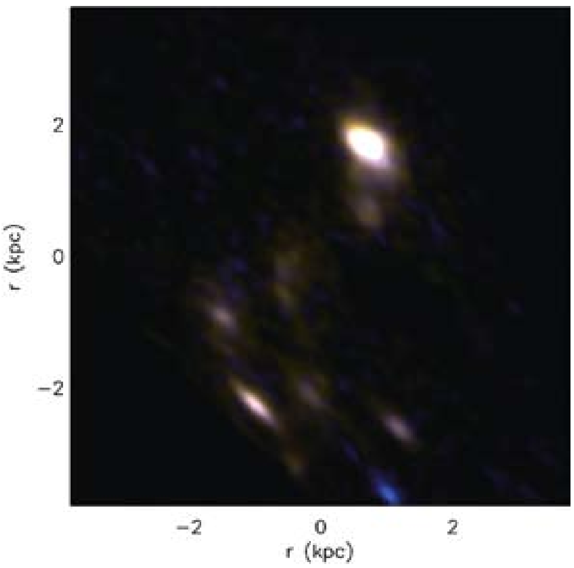


Figure 2. *A true-color HST ACS VRI-band reconstruction of the lensed galaxy. The amplification of the galaxy is a factor 12.5+/-2.0. In the source plane, the galaxy has a spatial extent of ~4 kiloparsecs and comprises at least five discrete star-forming clumps. The largest of these is only marginally resolved, with a rest-frame optical half light radii of ~ 200 parsecs.*

The spatially resolved velocity gradient seen in the galaxy disk can be compared directly to that measured from the Lyman-alpha and ultraviolet (UV)-interstellar medium (ISM) velocity structure. Franx et al. (1997) discuss the rest-frame UV spectral properties of this galaxy in detail. In particular, the UV-ISM absorption lines show velocity variations on the order of 200 kilometers per second along the arc with the [SiII] 1260 absorption line systematically blueshifted with respect to the Lyman-alpha emission, and an asymmetric Lyman-alpha emission line with a red tail.

These spectral features are naturally explained by an outflow model in which the blue side of the Lyman-alpha line has been absorbed by outflowing neutral HI. The description of the line profile is typical of the emission profiles seen in other Lyman-break galaxies. Indeed, velocity offsets between the nebular emission lines (such as Hα) and UV-ISM emission/absorption lines are now common in high-redshift star-forming galaxies, and are usually interpreted as evidence for a large-scale starburst-driven outflow.

As Figure 3 shows, within the $z = 4.92$ galaxy, the nebular emission line gradient from the [OII] emission (~ 180 kilometers per second across ~ 4 kiloparsecs) is mirrored (but systematically offset) from the Lyman-alpha and rest-frame UV-ISM lines, suggesting that this galaxy is surrounded by a galactic-scale outflow. Since the velocity gradient observed in the nebular emission is mirrored (but systematically offset) from the Lyman-alpha emission and UV-ISM absorption, this also suggests that the outflow is young (less than 10 million years) and has yet to decouple and escape from the galaxy disk.

Using a combination of the instantaneous star-formation rate, the P-Cygni Lyman-alpha emission line profile, and the UV-ISM absorption line strengths, we estimate the kinetic energy in the wind (~ 10^{54} erg) and mass loading in the wind (greater than 3×10^5 M_{Sun}). In comparison, the kinetic energy provided by the collective effects of stellar winds and supernovae explosions over 15 million years (KE ~ 5×10^{57} erg) is easily enough to drive the wind. The low inferred mass loading and kinetic energy in the wind is in stark contrast to the $z = 4.88$ galaxy behind the lensing cluster RCS 0224-002 (the only other galaxy at these early times for which similar measurements have been made). In this system, a large-scale (more than 30 kiloparsec) bipolar outflow

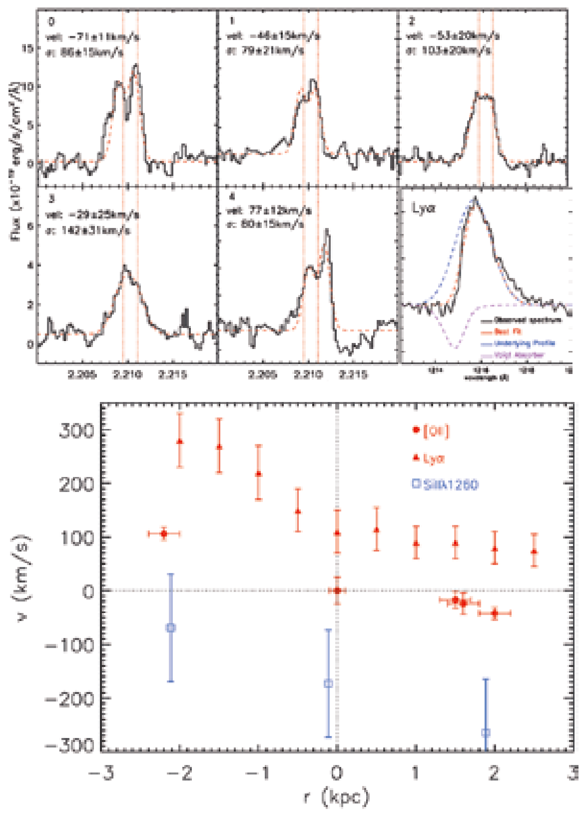
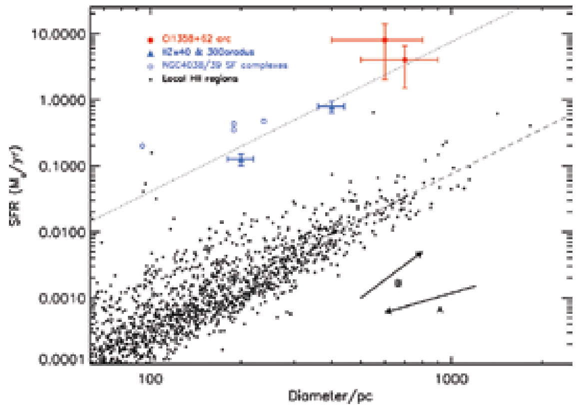


Figure 3. *(Top) A one-dimensional spectrum of the five star-forming regions within the z = 4.92 galaxy from the NIFS IFU observations. In all panels the position of the [OII] 3726.8, 3728.9 doublet is at a fixed redshift of z = 4.9296. The final panel shows the one-dimensional spectrum of the z = 4.92 galaxy around the Lyman-alpha emission. (Bottom) The extracted, one-dimensional velocity gradient along the long axis of the galaxy (source plane).*

has a high mass loading (greater than three times the star-formation rate) and is escaping at speeds of up to 500 kilometers per second. The strong contrast between the only two galaxies where such studies have been made at these early times suggests strong diversity in the outflow energies of young galaxies at high redshifts. This clearly illustrates the need for more targets and follow-ups to test the impact and ubiquity of outflows in the early universe.

Figure 4.
Correlation between size and star-formation rates from H-alpha for HII regions in local galaxies (including the largest local HII region 30 Doradus in the LMC and the nearby galaxies IIZw40 and the Antennae). The two HII regions in MS1358+62 arc are shown by the solid red points. The dashed line shows a fit to the HII regions in nearby spiral galaxies whilst the dotted line is the same but shifted in luminosity at a fixed size by a factor of 100.



Next, we estimate the sizes, masses, and star-formation rates of the two brightest star-forming HII regions in the galaxy, which are all well resolved in our data. Using the optical, near-infrared, and IFU data, we estimate that the two brightest HII regions are on the order 100 - 200 parsecs across and have line widths (from the [OII] emission) of ~ 80 - 90 kilometers per second. This suggests that the largest HII regions have masses on the order of 2 - 3 × 10^8 M_{Sun} A comparison to HII regions from galaxies in the local universe shows that these are comparable in mass and density to most local, massive star-forming HII regions. However, the star-formation rate for these HII regions (individually) is › 100 times higher than typically found at a fixed size (Figure 4). Such high star-forming rates (for a fixed size) have been observed locally in the most extreme systems, such as (eg. 30 Doradus in the LMC). Thus, the HII regions within this z = 4.92 galaxy appear to be scaled-up versions of the most extreme regions observed in the local universe, yet observed when the universe was only about one billion years old.

Could the increased luminosity within HII regions reflect real differences in the mode of star formation within massive star-forming complexes? Recent models suggest that young, massive (› 10^7 M_{Sun}), star-forming clusters are optically thick to far-infrared radiation, resulting in high gas temperatures, and, hence, higher Jeans masses. Indeed, for a 10^8 M_{Sun} star cluster (as observed in the z = 4.92 arc) the predicted Jeans mass is ~ 12 M_{Sun}. This "top-heavy" initial mass function (IMF) has the effect of increasing the fraction of *OB* stars per HII region and hence, increases the light-to-mass ratio. Although such a model could provide a fit to the data, it is dangerous to draw strong conclusions since there is little observational evidence for strong variations in the IMF (especially at high redshift). However, partially resolved spectroscopy of the nebular emission lines on scales comparable to HII regions would provide crucial diagnostics of the physics of star formation in the young universe. Indeed, the mechanical energy input from a higher fraction of *OB* stars might explain the higher turbulent speeds recently observed in primitive disks at z ~ 3 (eg. Stark et al. 2008).

Overall, these observations provide unique insights into the galaxy dynamics and the intensity and distribution of star formation, as well as the interaction between star formation and outflow energetics within a young galaxy seen less than 1 billion years after the Big Bang, on scales of just 200 parsecs. The large number of high-redshift gravitationally lensed galaxies identified by HST, combined with adaptive optics assisted integral field spectrographs on 8- to 10-meter telescopes, should finally begin to make such critical observational studies commonplace and allow us to test the route by which early systems assemble their stellar masses, their modes of star formation, and how they ultimately develop into galaxies like the Milky Way.

The international university-based research team led by the author included: Tracy Webb (McGill), Johan Richard (Durham), Richard Bower (Durham), Richard Ellis (Caltech), Garth Illingworth (UCO), Tucker Jones (Caltech) Mariska Kriek (UCO), Ian Smail (Durham), Dan Stark (Cambridge), Pieter Van Dokkum (Yale)

For more information see:
"A Spatially Resolved Map of the Kinematics, Star-Formation and Stellar Mass Assembly in a Star-Forming Galaxy at z = 4.9" in press, *MNRAS*.

Mark Swinbank is an astronomer at the University of Durham (UK). He can be reached at: a.m.swinbank@durham.ac.uk

by Mark Westmoquette &
Millicent Maier

The Integral Field Spectroscopy User's Wiki

The field of integral field spectroscopy (IFS) is now well developed, with IFS instruments installed on all the main optical telescope facilities around the world. Gemini Observatory has three of the most powerful high spatial and spectral resolution integral field units (IFUs): The Gemini Multi-Object Spectrograph (GMOS) installed at both locations and the Near-infrared Integral Field Spectrometer (NIFS) at Gemini North. However, although excellent work based on IFS data is being published by many groups, IFS continues to be avoided by large sections of the astronomical community due to perceived difficulties with data handling, reduction, and analysis. There is no doubt that dealing with IFS data is more complicated than simple imaging or long-slit spectroscopy, but many of the problems that arise could easily be avoided by benefiting from the experience and knowledge of others.

In our experience, a lack of information sharing has forced many groups to come up with their own independent solutions to data cube manipulation, visualization, and analysis (in a sense "re-inventing the wheel" each time), and because of the effort needed to do this, the tools developed are not automatically made publicly available.

Therefore, we thought it valuable to have a central repository of information: tips, codes, tools, references, etc., regarding the whole subject of IFS, which is accessible and editable by the whole community. To this end, we have set up the IFS wiki, which we hope will become this repository: http://ifs.wikidot.com

Figure 1.
A screenshot of the IFS wiki's welcome page.

After spending some time building up a solid foundation of content, the wiki was opened (made fully editable) to the community on May 18th, 2009. As of now, the wiki covers the following topics: current and future integral field spectrographs (including all those currently on the Gemini telescopes); observing techniques and observation planning; data reduction, including basic overview of the procedures for the different types of IFS instruments, and more advanced/specific tasks like mosaicking or differential atmospheric refraction (DAR) correction; and analysis techniques, from visualizing, to line fitting, to source extraction.

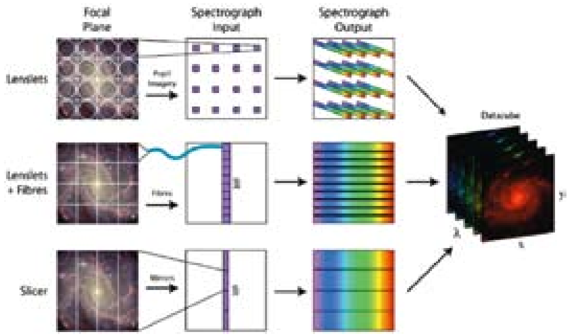


Figure 2.
The main techniques for achieving integral field spectroscopy. Adapted from Allington-Smith, Content and Haynes (1998). The Lenslets and Fibres design in the central row is most similar to the GMOS-IFU set-up. The Slicer design on the bottom row is most similar to NIFS's.

If you count yourself in the "less experienced" category, and you want to know more about IFS, then please visit the site—make it your first port of call if you have any questions or issues with IFS data. However, if you've had any experience with IFS, please think about contributing your knowledge to the wiki. Almost all of the Gemini staff who work with these instruments have already contributed their expertise to specific sections.

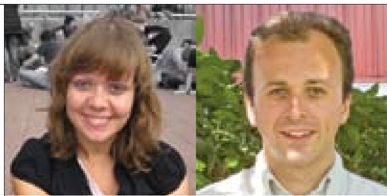
Finally, for the site to develop its full potential, we need the community to make continued contributions: if something is missing or wrong, if you have a useful hint or piece of code that has really helped you with your data, or you have experience with particular instrumental quirks, then please add this to the site. This type of information is of essential use to all the community.

The site will be regularly edited/moderated for structure and English to keep it as useable and clear as possible. So contributors who are worried about their English need not worry.

The originators and maintainers of this site are currently Dr. Katrina Exter (KULeuven, Belgium) and Dr. Mark Westmoquette (UCL, UK).

Mark Westmoquette is a postdoctoral fellow at the Physics and Astronomy Department, University College London, UK. He can be reached at: msw@star.ucl.ac.uk

Millicent Maier is a science fellow at Gemini Observatory located at Gemini South. She can be reached at: mmaier@gemini.edu



by Cristina Ramos Almeida
& Chris Packham

Modelling Nuclear Infrared Emission of Seyfert Galaxies on Parsec Scales

The unified model of active galactic nuclei (AGN) is predicated on the existence of a dusty toroidal structure surrounding the object's central engine. Accretion onto a supermassive black hole is commonly thought to produce the enormous luminosity observed in these objects. As the spatial resolution afforded by existing telescopes is typically insufficient to resolve the torus, several studies have attempted to model the infrared (IR) emission of the torus, permitting investigations of different geometries, sizes, structures, and orientations to our line of sight. However, previous modelling was tested against relatively poor spatial resolution data (angular resolution larger than ~ 1 arcsecond), which include a substantial amount of host galaxy "contamination". Hence, the optimal way to infer the torus's properties is to model the IR emission with the high angular resolution afforded by the 8-meter class of telescopes. For this purpose, we have constructed subarcsecond resolution IR spectral energy distributions (SEDs) for 18 nearby Seyfert galaxies. The data were predominantly obtained from both Gemini North and South telescopes in the mid-infrared (MIR). In addition, near-infrared (NIR) data of similar angular resolution have been compiled from the literature.

The precise torus geometry, structure, and size have been a matter of discussion for some time. Pioneering work assumed a homogeneous distribution of dust, as there was no other observational evidence and it simplified the modelling. In recent years, in order to account for new observational constraints and physical improvements over homogeneous torus models, a clumpy distribution of dust in a toroidal shape is becoming widely accepted. Figure 1 (next page) shows a graphical representation of the clumpy torus. Inhomogeneous models are making significant progress in accounting for the MIR emission of AGNs. A fundamental difference between clumpy and smooth density distributions of dust is that the former implies that both directly illuminated and shadowed cloud faces may exist at different distances from the central engine. Thus, the dust temperature is not a function of the radius only, as was the case in the homogeneous models, since illuminated and shadowed clouds contribute to the IR emission from all viewing angles. This leads to a small sized torus, where the long-wave IR emission can even originate close to the central engine.

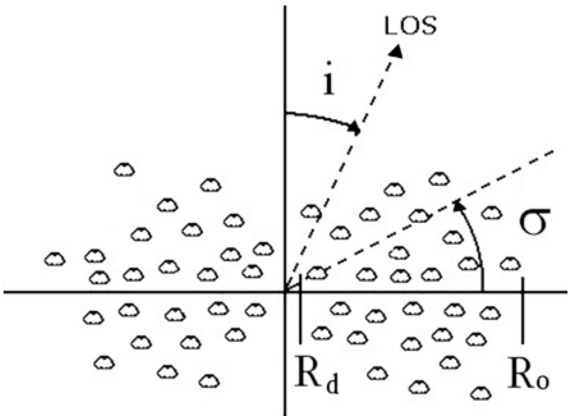


Figure 1.
A schematic of the clumpy torus. The radial extent of the torus is defined by the outer radius (R_0) and the dust sublimation radius (R_d). All of the clouds are supposed to have the same optical depth (τ_V), and σ characterizes the width of the angular distribution. The number of cloud encounters is a function of the viewing angle, i (Nenkova et al., 2008).

Observations

Ground-based MIR high-angular resolution observations of 18 nearby active galaxies were carried out over the past several years for a variety of science cases. By pooling these data sets, we make use of this archive of data here for the entirely different science case discussed above. Most of these sources are Type 2 Seyferts, but the sample also includes two Seyfert 1.9 (Sy1.9), one Seyfert 1.8 (Sy1.8), two Seyfert 1.5 (Sy1.5), and one Sy1 galaxy (see Table 1).

Table 1.
Summary of mid-infrared observations for the total sample of Seyfert galaxies.

Summary of Mid-IR Observations

Galaxy	Filters	Instrument	Telescope	Observation Epoch	On-Source Time (s)		PSF FWHM	
					N Band	Q Band	N Band	Q Band
Centaurus A	Si2, Qa	T-ReCS	Gemini S	2004 Jan	2000	1550	0.″30	0.″53
Circinus	Si2, Qa	T-ReCS	Gemini S	2004 Feb	109	109	0.″33	0.″55
IC 5063	Si2, Qa	T-ReCS	Gemini S	2005 Jul	130	304	0.″40	0.″62
Mrk 573	N, Qa	T-ReCS	Gemini S	2003 Dec	217	217	0.″36	0.″54
NGC 1386	N, Qa	T-ReCS	Gemini S	2003 Dec	217	217	0.″31	0.″54
NGC 1808	N, IHW18	OSCIR	CTIO 4m	1998 Dec	300	300	0.″94	1.″02
NGC 3081	Si2, Qa	T-ReCS	Gemini S	2006 Jan	130	304	0.″30	0.″56
NGC 3281	N, Qa	T-ReCS	Gemini S	2004 Jan	260	455	0.″34	0.″58
NGC 4388	N′, Qa	Michelle	Gemini N	2006 May	549	733	0.″34	0.″50
NGC 5728	Si2, Qa	T-ReCS	Gemini S	2005 Jul	130	304	0.″35	0.″56
NGC 7172	N	T-ReCS	Gemini S	2004 May	305	…	0.″51	…
NGC 7582	N, IHW18	OSCIR	CTIO 4m	1998 Dec	250	250	0.″76	0.″99
NGC 1365	N, IHW18	OSCIR	CTIO 4m	1998 Dec	482	482	0.″92	1.″03
NGC 2992	N′, Qa	Michelle	Gemini N	2006 May	730	1095	0.″32	0.″53
NGC 5506	N′, Qa	Michelle	Gemini N	2006 Apr	546	729	0.″36	0.″51
NGC 3227	N′	Michelle	Gemini N	2006 Apr	300	…	0.″39	…
NGC 4151	N, IHW18	OSCIR	Gemini N	2001 May	360	480	0.″53	0.″58
NGC 1566	Si2, Qa	T-ReCS	Gemini S	2005 Sep	152	304	0.″30	0.″53

Notes. Images were obtained in the 8.74 μm (Si2, $\Delta\lambda = 0.78$ μm at 50% cut-on/off), 10.36 μm (N, $\Delta\lambda = 5.27$ μm), and 18.33 μm (Qa, $\Delta\lambda = 1.5$ μm) filters with T-ReCS; in the 11.29 μm (N′, $\Delta\lambda = 2.4$ μm) and 18.11 μm (Qa, $\Delta\lambda = 1.9$ μm) filters with Michelle; and in the 10.75 μm (N, $\Delta\lambda = 5.2$ μm) and 18.17 μm (IHW18, $\Delta\lambda = 1.7$ μm) filters with OSCIR.

The first set of observations was obtained with the University of Florida MIR camera/spectrometer OSCIR, in December 1998, at the 4-meter Blanco Telescope at Cerro Tololo Inter-American Observatory (CTIO), and in May 2001, at the Gemini North telescope. Another set of observations was performed with the MIR camera/spectrograph T-ReCS at the Gemini South telescope, and the last one with MICHELLE at Gemini North. A summary of the observations, together with the afforded resolutions for each galaxy, are also presented in Table 1.

To construct well-sampled IR SEDs, we compiled NIR nuclear fluxes at similarly high spatial resolution from the literature. These fluxes correspond to the observed emission from the nuclear region of the galaxies (unresolved component), with typical spatial scales of the same order as those of our nuclear MIR fluxes.

The IR SED and Observational Constraints

Crucial observational constraints for torus modelling arise from the shape of the IR SED of Seyfert galaxies. The bulk of the torus emission is concentrated in this wavelength range, as the torus blackbody emission peaks at the MIR wavelengths (7 – 26 μm). When large aperture data, such as those from Infrared Space Observatory (ISO), Spitzer, or the Infrared Astronomical Satellite (IRAS), are employed for constructing SEDs, the IR fluxes are a mixture of AGN plus host galaxy emission. From the comparison between our IR SEDs and large aperture data from 2MASS, ISO, and IRAS, we confirm that the high spatial resolution MIR measurements provide a spectral shape of the SEDs that is substantially different from that of large aperture data SEDs (for an example see Figure 2). Thus, our nuclear measurements allow us to better characterize the torus emission and consequently use torus models to constrain the distribution of dust in the immediate AGN vicinity.

To derive general properties of Sy2 galaxies, which constitute the majority of our sample, we constructed an average Sy2 SED, considering only the highest angular resolution data to avoid as much as possible the stellar contamination. This average Sy2 template was used to compare with the individual SEDs of the Sy2 analyzed in this work, and also with the intermediate-type Seyferts (see Figure 3).

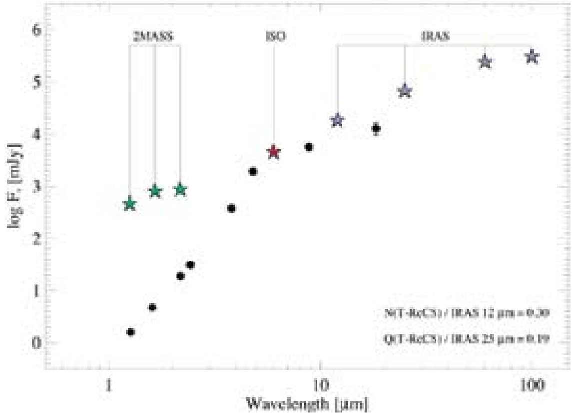


Figure 2. *A comparison between the IR high angular resolution data employed in this work (filled circles) and low resolution data from 2MASS, ISO, and IRAS (taken from the NASA/IPAC Extragalactic Database – NED; star symbols) for the Circinus galaxy. Note the difference in steepness between them and the reduced MIR T-ReCS fluxes, compared with those from IRAS at approximately the same wavelengths.*

The slope of the IR SED is, in general, correlated with the Seyfert type. Sy2 show steeper SEDs, and intermediate-type Seyferts are flatter. Seyferts 1.8 and 1.9 present intermediate values of the IR slope and the NIR to MIR flux ratio between Sy2 and Sy1.5. This ratio increases as the hot dust emission becomes important, giving an indication of the torus geometry and inclination. However, we find a range of spectral shapes among the Sy2 galaxies, and some intermediate-type SEDs have the same slopes as the Sy2. This cannot be reconciled with the predictions of smooth torus models, since large optical depth homogeneous tori strictly predict steep SEDs for Sy2 and flat SEDs for Sy1. We do not observe such a strong dichotomy, and so we pursue the clumpy torus models to reproduce the observed SEDs.

Model Results

We fit the observed SEDs with the clumpy torus models described by Nenkova and collaborators, using the BAYESCLUMPY tool. From Figure 4 (next page) it is clear that the Circinus galaxy data (eight photometric data points) provide sufficient information to the code to constrain the model parameters.

The clumpy models successfully reproduce the infrared SEDs of the Seyfert galaxies analyzed here. The models accommodate the range of IR slopes observed in the Sy2, while providing optically thick obscuration along the line of sight. The IR SED fitting does not constrain the radial extent of the torus, and this parameter remains uncorrelated with the other parameters that define the models. Because the outer torus contains the coolest material, high angular resolution measurements at wavelengths longer than 15 μm are needed to reveal significant variations in the torus size.

For the case of the Sy2 galaxies, we find a relatively low number of clouds (N_0 = [5, 15]) and large values of the torus width (σ = [50°, 75°]) from the fits. High values of the inclination angle of the torus are more probable (i = [40°, 90°]) and the optical depth per cloud is generally lower than τ_V = 100. For the intermediate-type Seyferts we find smaller number of clouds than for the Sy2 (N_0 = [1, 7]). Low values of σ are preferred from the fits of Sy1.8 and Sy1.9 (σ = [25°, 50°]) and even lower for Sy1.5 (σ < 35°). We require direct (though extinguished) emission of the AGN to reproduce the near-IR excess observed in the SEDs of Sy1.5. Views of Sy2 are more inclined than those of the Sy1.5 galaxies. More importantly, the large values of N_0 and σ resulting from the Sy2 modelling suggest that their central engines are blocked from a direct view along more lines of sight than are those of the intermediate-type Seyferts, which would have clearer views of their AGN engines. This would imply that the observed differences between Type 1 and Type 2 AGNs would not be due to orientation effects only, but to different covering factors in their tori. However, due to the limited size of the analyzed sample, these differences are not statistically significant, and a larger sample is needed to confirm whether Sy1 and Sy2 tori are intrinsically different.

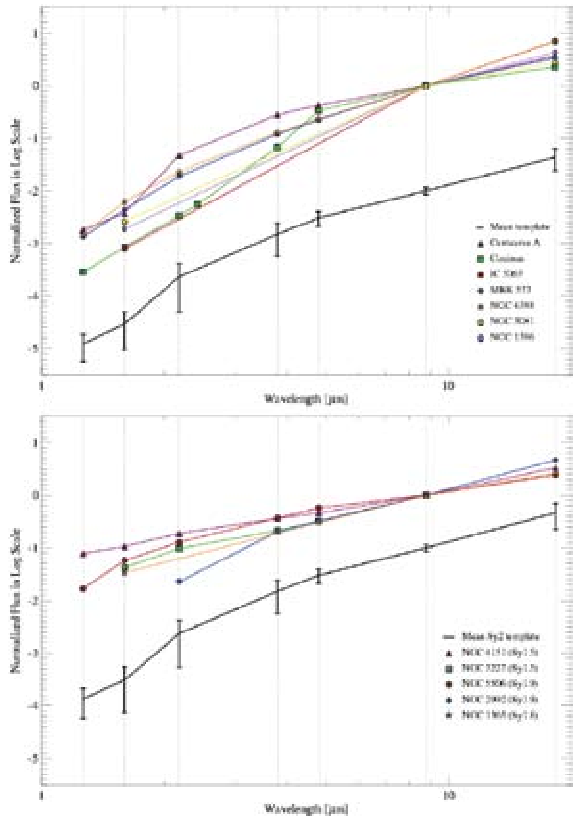
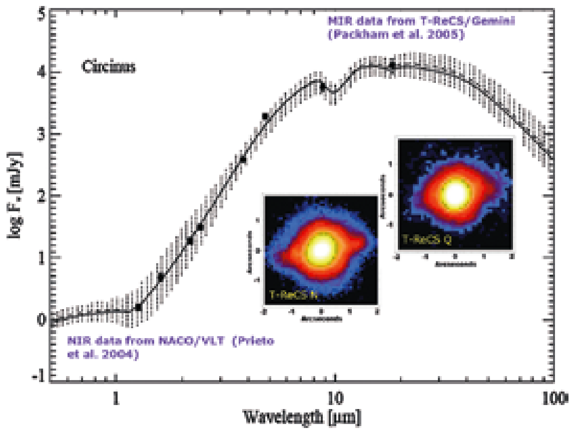


Figure 3. *Top: Observed IR SEDs for the seven Sy2 galaxies (in color and with different symbols) used for the construction of the average template (solid black). The SEDs have been normalized at 8.8 μm, and the average SED has been shifted in the Y-axis for clarity. Bottom: Comparison between the average Sy2 SED (solid black) and the intermediate-type Seyfert SEDs. Note the difference in steepness.*

Figure 4. *High spatial resolution IR SED of the Circinus galaxy fitted with the clumpy torus models. Solid and dashed lines are the best fitting model and that computed with the median of each of the six parameters that describe the models. The shaded region indicates the range of models compatible with a 68% confidence interval around the median. T-ReCS N and Q images (8.8 and 18.3 microns, respectively) are also shown.*



Only through parsec-scale observations of several AGNs, such as those presented here, can the torus geometry and properties be well constrained. Our results strongly support the clumpy torus models and provide constraints on the structure of the torus. To further these studies, we plan more similar observations (including 10-µm spectroscopy) to provide a more detailed characterization of torus properties.

Our collaborators in this study are: Nancy Levenson, (Gemini Observatory); Jose Miguel Rodríguez Espinosa, (Instituto de Astrofísica de Canarias; Tenerife, Spain); Almudena Alonso Herrero, (Instituto de Estructura de la Materia, CSIC, Madrid, Spain); Andrés Asensio Ramos, (Instituto de Astrofísica de Canarias, Tenerife, Spain); James T. Radomski, (Gemini Observatory); Scott Fisher, (Gemini Observatory); Charles M. Telesco, (University of Florida).

For more information see:

Alonso-Herrero, A., *et al.* 2006, *ApJ*, **652**, L83
Asensio Ramos, A. & Ramos Almeida, C. 2009, *ApJ*, **696**, 2095
Antonucci, R. R. J. 1993, *ARA&A*, **31**, 473
Díaz-Santos, T., *et al.* 2009, *ApJ*, submitted
Nenkova, M., Sirocky, M. M., Nikutta, R., Ivezic, Z., and Elitzur, M. 2008, *ApJ*, **685**, 160
Packham, C., *et al.* 2005, *ApJ*, **618**, L17
Ramos Almeida, C., *et al.* 2009, *ApJ*, **702**, 1127
Urry, C. M. & Padovani, P. 1995, *PASP*, **107**, 803

Cristina Ramos Almeida, recently at Instituto de Astrofísica de Canarias (Tenerife, Spain) where this work was completed, is now a postdoctoral research associate in AGN & galaxy evolution at the Physics and Astronomy Department of the University of Sheffield (UK). She can be reached at: C.Ramos@sheffield.ac.uk

Chris Packham is an associate scientist at the University of Florida. He can be reached at: packham@astro.ufl.edu

by Dougal Mackey, Annette Ferguson
& Avon Huxor

Unveiling Remote Globular Clusters in Andromeda

Figure 1.
A composite g,r, and i image of MGC1 from GMOS-North.

Globular clusters are widely recognized as extremely useful tracers of galaxy formation and evolution. Typically, they are compact and luminous objects that can be observed out to large distances. Often they are among the oldest components of any given galaxy. Globular clusters allow us to probe the star-formation history, chemical development, and mass distribution in their host galaxies. Of particular interest are globular clusters that reside in the remote haloes of their hosts, where dynamical timescales are long and these objects can offer additional insights into the history of interaction, merger, and accretion events in these systems.

Galaxies in the Local Group (i.e., out to distances of roughly 1 megaparsec (Mpc)) are sufficiently close that they may be resolved into their constituent stars with present technology. Hence, these objects are attractive targets for detailed observational study, with the aim of inferring their evolutionary histories from present-day structure and content. The "fossil record" contained in old and intermediate-aged stars in the Andromeda spiral galaxy (M31) is of special significance, as it is the closest large galaxy to our own and shares many characteristics in common with our Milky Way, suggesting a similar mode of assembly.

Over the past decade, our group has been surveying M31 and its environs to unprecedented depths using wide-field imagers attached to both medium and large telescopes. Our original survey used the Wide-field Camera on the 2.5-meter Isaac Newton Telescope to uncover a spectacular wealth of low-brightness substructure in M31's inner halo ($R < 30$ kiloparsecs (kpc)), indicative of an active history of merger and accretion events in this galaxy. Our ongoing Pan-Andromeda Archaeological Survey (PAndAS) uses the Canada-France-Hawai'i Telescope (CFHT) MegaCam to extend this work to the far outer halo ($R < 150$ kpc). This has led to the discovery of many fascinating new substructures, a gigantic stellar halo, and numerous new dwarf satellites. We have also been using these survey datasets to search for new globular clusters in the remote regions of M31. To date, we have discovered nearly 100 such objects, of which more than 60 lie at projected (on-sky) distances greater than 30 kpc from the galaxy's center. Previously, only a handful of such remote objects were known in M31, while the Milky Way appears to possess just 10.

We have been using the Gemini Multi-Object Spectrograph (GMOS) on the Gemini North telescope to obtain high-resolution deep imaging of many of our new discoveries. The extremely high optical quality and stability of the GMOS instrument, in combination with the light-collecting ability of the 8-meter Gemini North mirror and the unrivalled atmospheric conditions that sometimes occur above Mauna Kea, provide image quality (IQ) and depth in optical passbands that are unlikely to be bettered by other present-day terrestrial facilities. This combination is crucial for resolving our compact, distant cluster targets into individual stars and examining their internal contents.

The Most Isolated Globular Cluster in the Local Group

One of the most intriguing newly discovered objects in the M31 halo is a bright globular cluster named MGC1, which lies at a projected distance of 117 kpc from the galaxy's center. This already makes the cluster one of the most remote such objects known in the M31 system, and indeed in the Local Group as a whole. We obtained deep imaging of MGC1 with GMOS-N on the night of October 13, 2007, in the g, r, and i optical passbands. The data were obtained under excellent conditions, resulting in an IQ of between 0.4 - 0.5 arcsecond across the three different filters. Our GMOS image of the center of the cluster is shown in Figure 1.

We obtained photometric measurements of all stars in the image in each of the three passbands, allowing us to construct color-magnitude diagrams (CMDs) for the cluster. An example CMD, on the (g-i, i) plane, is shown in Figure 2. The red-giant branch (hydrogen shell-burning-stars) and horizontal branch (core helium-burning-stars) of MGC1 are clearly visible; our data reach at least one magnitude below the level of the latter feature.

The fact that MGC1 exhibits a well-populated horizontal branch that extends to quite blue colors is indicative of a very old (> 10 billion years (Gyr)) and rather metal-poor stellar population, typical of many halo globular clusters seen in the Milky Way. The MGC1 horizontal branch is evenly populated across the region of the CMD harboring the instability strip, meaning that the cluster likely possesses a number of RR Lyrae stars. However, our imaging does not span a sufficiently long temporal baseline to search directly for the variability expected from such members.

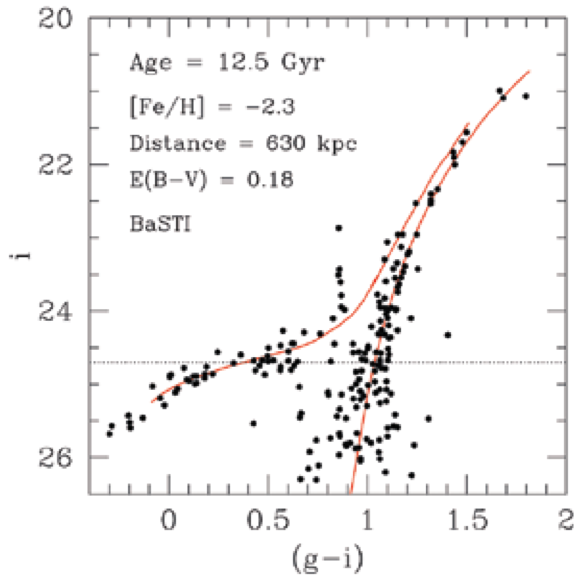


Figure 2.
A color-magnitude diagram for MGC1 on the (g-i, i) plane, along with an example ridgeline (red line) from stellar evolution models calculated by the BaSTI (Bag of Stellar Tracks and Isochrones) group. The implied properties of the cluster are indicated.

The shape and steepness of the red-giant branch allow us to obtain estimates of the cluster's metal abundance and line-of-sight distance, which we do by fitting ridgelines derived from both stellar evolution models and from observations of various Milky Way globular clusters. An example ridgeline from a set of stellar evolution models is shown over-plotted in Figure 2. Our fits demonstrate that MGC1 has a very low metal abundance, [Fe/H] = -2.3 +/- 0.2, which is comparable to the lowest-metallicity globular clusters found in the Milky Way and apparently substantially more metal-poor than the bulk of the field-halo stars observed in M31 at similarly large projected radii.

In addition, our fits show that MGC1 lies much closer to us, with a line-of-sight distance of approximately 630 kpc, than do the central regions of M31, which fall at 780 kpc. Combined with its large projected radius, this observation renders MGC1 the most isolated known globular cluster in the Local Group by some considerable margin. It has a true (three-dimensional) distance of 200 +/- 20 kpc from the center of M31. For comparison, the most remote Milky Way globular cluster is AM-1, which resides a "mere" 120 kpc from the galactic center. Our measurement shows that MGC1 lies in the extreme outer reaches of the M31 halo; its observed radial velocity (from a Keck telescope spectrum) is, nonetheless, within the probable M31 escape velocity, so there is no implication that MGC1 might be anything as exotic as an unbound or intergalactic globular cluster. Instead, our measurements suggest that the globular cluster systems of large spiral galaxies may be considerably more spatially extended than previously appreciated.

Our GMOS imaging revealed an additional remarkable feature of MGC1 – its spatial extent. We traced the cluster-centric radial distribution of stars in our images, and to our surprise found that we could identify cluster members out to the very edge of the GMOS field. Indeed, by using archival wide-field CFHT/MegaCam and Subaru/SuprimeCam images to extend the observed area around the cluster, we were able to measure MGC1 stars to a projected distance of at least 450 parsecs (pc) from the cluster center, and possibly as far as 900 pc (Figure 3). This renders MGC1 the most extended globular cluster hitherto studied (the Milky Way cluster NGC 2419 previously held this honor with a tidal radius of roughly 200 pc). Interestingly, the surface density of MGC1 falls off like a power-law with radius as opposed to following a more typical King-type profile, which would exhibit a sharp outer limit. This is broadly in line with expectations derived from numerical modelling of isolated globular clusters, in which a core-halo structure is established over several billion years, and suggests that MGC1 has been evolving in isolation in the outer halo of M31 for a very considerable period of time.

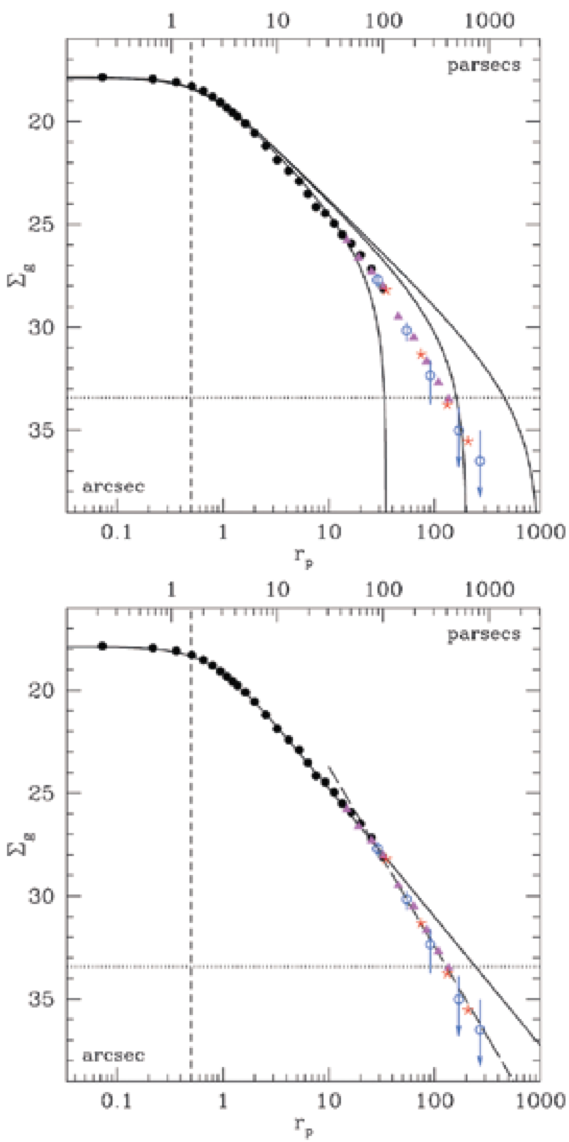


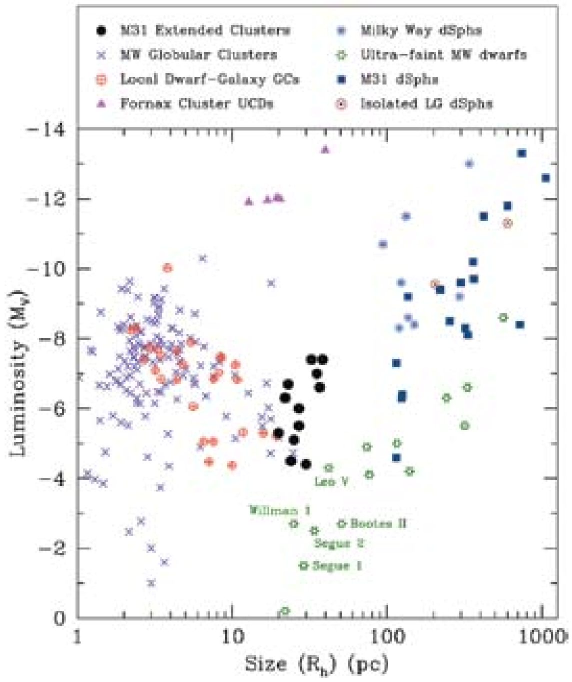
Figure 3. *Radial g-band surface brightness profile for MGC1, derived from our GMOS imaging (solid black circles and magenta triangles) and, at large radii, from archival CFHT/MegaCam and Subaru/Suprime-Cam data (red stars and open blue circles). The horizontal dotted line marks the level of background contamination, while the vertical dashed line marks the maximum reliable resolution of the images. The commonly used King family of models does not describe the data well (top panel); instead the profile breaks to a power-law fall-off in its outer regions (bottom panel).*

The Nature of Extended Clusters

Another particularly intriguing subset of the remote objects we have discovered in the M31 halo is the class of so-called "extended clusters." As shown in Figure 4 (next page), these systems occupy an unusual region of size-luminosity space, encroaching on the traditional gap between classical globular clusters (which are compact and do not appear to contain significant amounts of dark matter) and dwarf spheroidal galaxies (which are diffuse and dominated by dark matter). It is unclear whether extended clusters are more akin to classical globulars or dwarf spheroidals, or are some kind of transition population. To add to the puzzle, the Milky Way apparently does not possess similarly extended luminous clusters as those observed in M31, but does harbor a few diffuse low-luminosity globular clusters. The Milky Way also contains a number of "ultra-faint" dwarf galaxies which have roughly comparable sizes to the M31 extended clusters but exhibit tiny luminosities (note, M31 may also possess such objects; however, they would be too faint to be detected in presently available survey data).

Unveiling the nature of extended clusters is of obvious importance to help us better understand the faint end of the galaxy luminosity function. Following on from our successful observations of MGC1, we are leading an international Gemini observing program (24 hours spread across allocations from the UK, Canada, and Australia) aimed at addressing this problem. Our targets consist

Figure 4.
Various stellar systems on the size-luminosity plane. The extended clusters we have discovered in M31 apparently occupy an intriguing region, encroaching on the traditional gap between globular clusters on the left and dwarf spheroidal galaxies on the right, and of similar size to (but much brighter than) several of the new "ultra-faint" dwarf galaxies recently discovered in the Milky Way halo (labelled).



of a representative sample of 11 extended clusters in the M31 halo. They populate the full range of observed sizes, luminosities, and colors. We obtained deep GMOS-N imaging of these objects in the g and i optical passbands between July 6, and October 31, 2008. We are still in the process of analyzing these observations; however, some preliminary images and CMDs are shown in Figure 5 to highlight the exquisite quality of the data (some of our images have IQ approaching 0.3 arcsecond). Ultimately, our imaging will allow us to more accurately constrain the region of size-luminosity space occupied by the M31 extended clusters, as well as providing detailed information about the constituent stellar populations of these peculiar objects.

This work has been done in collaboration with a number of additional people, including Mike Irwin (University of Cambridge), Nicolas Martin (MPIA, Heidelberg), Nial Tanvir (University of Leicester), Alan McConnachie (HIA, Victoria), Rodrigo Ibata (Université de Strasbourg), Scott Chapman (University of Cambridge), and Geraint Lewis (University of Sydney). The work concerning MGC1 is in press at the *Monthly Notices of the Royal Astronomical Society* (2009).

For more information see:

Ferguson A., *et al.*, 2002, *AJ*, **124**, 1452

Huxor A., *et al.*, 2005, *MNRAS*, **360**, 1007

Huxor A., *et al.*, 2008, *MNRAS*, **385**, 1989

Ibata R., *et al.*, 2007, *ApJ*, **671**, 1591

Mackey A., *et al.*, 2006, *ApJ*, **653**, L105

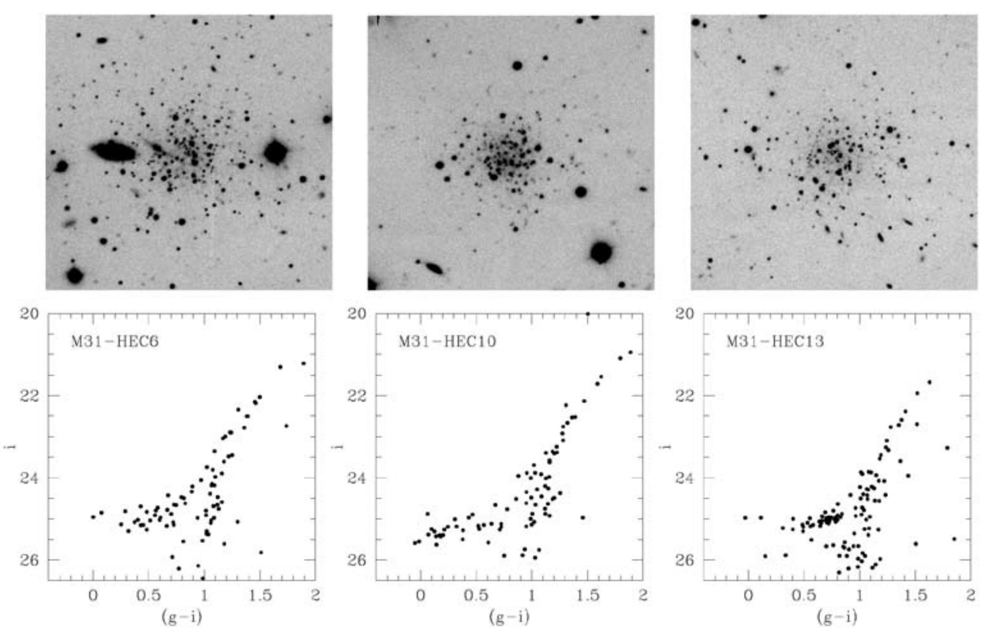
Martin N., *et al.*, 2006, *MNRAS*, **371**, 1983

Dougal Mackey is a Marie Curie Excellence postdoctoral fellow at the University of Edinburgh Institute for Astronomy (IfA). He can be contacted at: dmy@roe.ac.uk

Annette Ferguson leads a Marie Curie Excellence Team at the University of Edinburgh IfA, where she also holds a Readership in Astronomy. She can be contacted at: ferguson@roe.ac.uk

Avon Huxor is a Leverhulme Fellow in astrophysics at the University of Bristol. He can be contacted at: Avon.Huxor@bristol.ac.uk

Figure 5.
Deep GMOS-N i-band images of three of our newly discovered M31 extended clusters, along with preliminary (g-i, i) CMDs that show these objects are very likely ancient, metal-poor systems.




by Mariska Kriek
& Pieter van Dokkum

The "Wild Youth" of Massive Galaxies

Owing to the finite speed of light and state-of-the-art instrumentation on large telescopes, astronomers are able to identify and study galaxies throughout the history of the universe and witness their evolution over cosmic time. During the first several billion years after the Big Bang, the universe was essentially a large star-forming factory, with gas being converted into stars at ferocious rates. Nonetheless, as our team showed several years ago using Gemini, mature galaxies can already be found some 3 billion years after the Big Bang, when the universe was only about 20% of its current age. These galaxies resemble nearby massive elliptical galaxies in terms of their red colors, very low star-formation rates, and their large stellar masses. However, appearances are deceiving. Just a couple of years ago, we were living in ignorance of what might currently be one of the largest puzzles in galaxy evolution.

Images taken with the Hubble Space Telescope in 2008 showed that the structure of these red massive galaxies in the young universe differs considerably from the red elliptical galaxies of similar mass in the nearby universe: their sizes, parameterized by the radius that contains 50% of the light, are about a factor of five smaller. While the half-light radii of today's massive elliptical galaxies are about 5 kiloparsecs (kpc), the red galaxies typically have half-light radii of 1 kpc! Since the average stellar density of a galaxy is proportional to the cube of the inverse of the radius, these distant red galaxies were extremely dense systems. Moreover, as they were already as massive as the most massive galaxies in the nearby universe, they would have to increase in size tremendously without growing much in mass.

The difficulties associated with the mass and size determinations of such distant galaxies caused skepticism among members of the astronomical community. How well can we actually measure these fundamental

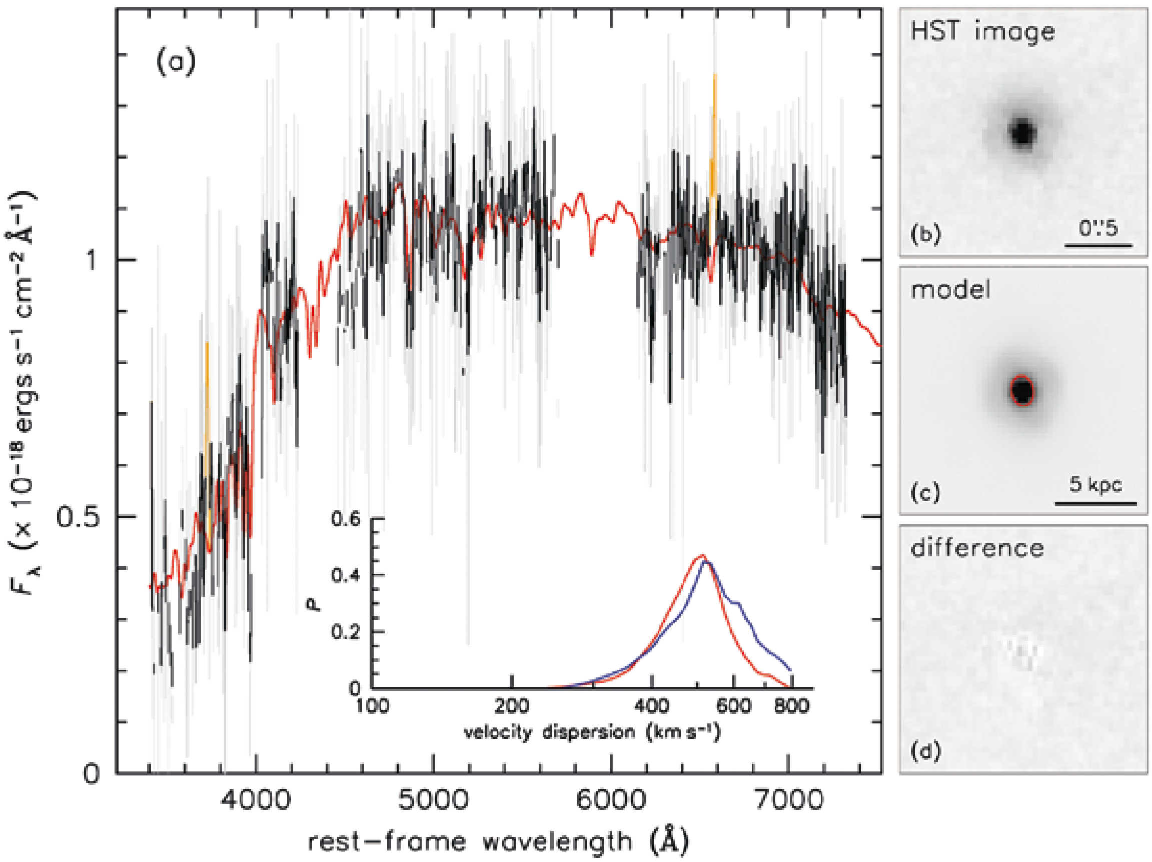


Figure 1.
(a) Spectrum of 1255-0, obtained over the course of 6 nights with GNIRS on Gemini South. (b-d) Hubble Space Telescope image of the object, along with a model of the Hubble image and the difference between the image and the model are shown at right.

properties? Were we underestimating the sizes, or perhaps overestimating the stellar masses? Due to the large cosmological distances, the observed galaxies are faint, and there were worries that fainter starlight might have been missed. Also, the technique used to determine the masses raised some eyebrows. At these distances, masses are commonly derived using an estimate of the mass-to-light ratio, which is based on the colors of the galaxies. Together with the observed luminosity of the galaxy, a "rough" distance determination, and many more assumptions, this yields a stellar mass estimate. Taken altogether, these assumptions easily lead to uncertainties of a factor of two. The ultimate test to verify the high stellar densities of the distant red galaxies is to measure the velocities of their stars. These velocities are a sensitive probe of density, as they are proportional to the square root of the mass divided by the radius. Therefore, in massive galaxies with small sizes, the stars should be whizzing around at very high speeds.

Using the Gemini Near-Infrared Spectrometer (GNIRS) we succeeded (for the first time) in measuring the stellar velocities in a galaxy (1255-0) seen when the universe was less than 3 billion years old. The observations were extremely challenging, as the galaxy is very faint, owing to its large distance. Furthermore, due to the expansion of the universe, the emitted optical light of the galaxy has been shifted to longer wavelengths. Thus, we had to take observations at near-infrared wavelengths, which are greatly affected by Earth's atmosphere. We observed the galaxy during six full nights under perfect weather conditions, for a total of almost 30 hours of observations. The final result is probably the deepest spectrum at near-infrared wavelengths ever taken.

This ultra-deep spectrum allowed us to estimate the typical velocities of stars by measuring the Doppler broadening of stellar absorption lines. The stars in the galaxy have different motions relative to each other, so the spectra of the individual stars are shifted slightly with regard to one another. The final effect is that the absorption line of individual stars will be smoothed out into a broader feature when combining all the light. The amount of broadening tells us the typical relative motions of the stars.

Based on our initial measurements of the stellar mass and size, and on Newtonian physics, we expected

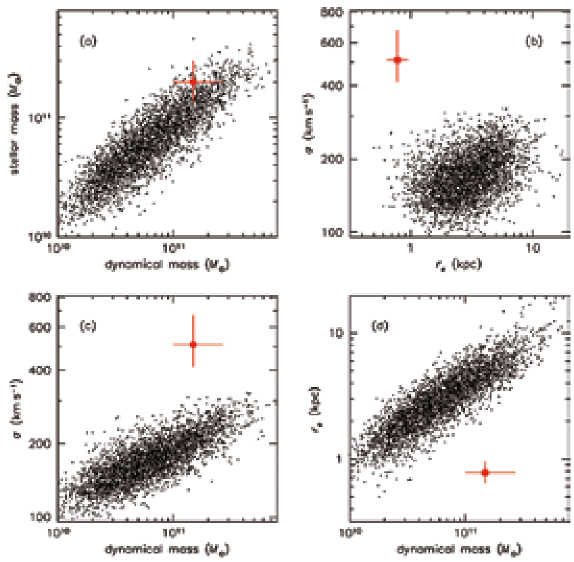


Figure 2.
The relationship between stellar mass, dynamical mass, radius r_e and velocity dispersion σ for nearby galaxies (black points) is shown. The location of 1255-0 is indicated by the red point. For its mass, the galaxy has a very small radius and a very high velocity dispersion, as compared to nearby galaxies.

to find velocities of over 500 kilometers per second (km/s) for this galaxy. The velocity dispersion that we determined from the Gemini spectrum is in excellent agreement with our expectations: 510 km/s, with an uncertainty of about 100 km/s. This confirms our initial result, namely that the stellar density in this galaxy was extremely high 11 billion years ago. Thus, the small sizes and high masses appear to be correct, and cannot easily be attributed to measurement errors.

Our new result confirms the existence of a major puzzle that still remains to be solved: how is it possible that these galaxies increase so much in size and decrease in stellar density over time, without becoming much more massive? There are several theories proposed to explain how distant compact galaxies may have been puffed up in the past 11 billion years. It is plausible that they are the centers of nearby massive elliptical galaxies, and that the outskirts were built up later by mergers with other smaller galaxies. This would change the energy distribution in the galaxy and could lower the velocities of the stars while building up low-density wings. Other processes have been proposed as well. For example, a quasar phase might be responsible for expelling gas from the galaxies, making them larger and less dense. Whereas the responsible process still remains to be identified, it is evident that the compact galaxies in the early universe do not live a quiet and undisturbed life.

Clearly, more studies are needed, and exciting times await. The Gemini Near-Infrared Spectrograph that was used for this work can only observe one galaxy at a time, although with full near-infrared wavelength coverage. With the multi-object near-infrared spectrograph FLAMINGOS-2, (currently in commissioning) these studies will be much more efficient, as more galaxies can be observed at the same time. Also, the quality of the spectrum presented here is far from what could theoretically be achieved with 8-meter-class telescopes. There is potential for considerable improvement in the capabilities of single-object near-infrared spectrographs, and a successor to GNIRS with higher resolution and much greater sensitivity would have an enormous impact on studies of distant galaxies.

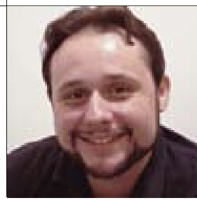
For more information see:

van Dokkum, P. G., Kriek, M., and Franx, M. 2009, *Nature*, **460**, 717

Kriek, M., van Dokkum, P. G., Labbe, I., Franx, M., Illingworth, G. D., Marchesini, D., and Quadri, R. F. 2009, *ApJ*, **700**, 221

Mariska Kriek is a post-doctoral fellow at the department of Astrophysical Sciences, Princeton University. She can be reached at: mariska@astro.princeton.edu

Pieter van Dokkum is a professor at the Astronomy Department, Yale University. He can be reached at: pieter.vandokkum@yale.edu



by Adam Muzzin
& Howard Yee

Spectroscopy of High-Z Galaxy Clusters with Band-Shuffle

Rich clusters of galaxies are some of the most spectacular objects in the universe. They are the largest gravitationally bound structures, containing hundreds of massive galaxies and thousands of smaller ones all whizzing around at thousands of kilometers per second within a relatively compact 10 to 20 cubic megaparsecs. Staring at Hubble Space Telescope images of nearby clusters is a constant reminder of just how small we are compared to the rest of the universe.

It is well known that the galaxies in clusters are different from those that aren't in clusters–which are typically referred to as "field" galaxies. Clusters contain massive galaxies that are non-star-forming, usually elliptical or type S0, whereas field galaxies are often less massive, spiral-shaped, and have star-forming regions. For decades, astronomers have been trying to understand why the cluster population is so different from the field population, but no consensus has emerged yet. We know the differences are probably related to the cluster environment, which contains hot x-ray-emitting gas, experiences high-speed encounters between galaxies, and shows extreme tidal effects from the huge dark-matter halo. Yet, we are uncertain about exactly how these factors alter the cluster galaxy population.

An obvious way to get a better handle on the problem is to observe the most distant clusters, meaning those at $z > 1$, to see how their galaxies differ from nearby clusters, as well as their counterparts in the field at $z > 1$. Galaxies are more active at higher redshifts, which should further highlight the contrast between cluster and field populations.

But, before high-redshift clusters can be observed, we have to find them. It's hard work. The intra-cluster gas in distant clusters is faint in the x-ray regime because of surface-brightness dimming that scales as $L_x \sim (1 + z)^{-4}$. Cluster galaxies are also faint, and Doppler-shifting means most of their light is not received at optical wavelengths, but in the infrared. As a result, deep x-ray or infrared surveys are needed to detect distant clusters—both of which are still hard to come by these days.

In addition to the need for deep observational data, rich clusters of galaxies are rare objects. Current lambda cold dark matter (λCDM) halo models predict about one Coma-mass cluster ($M \sim 10^{15}\ M_{Sun}$) at $z > 1$ in every 50-100 square degrees of sky. Even clusters half that massive only occur once in every 2 - 4 square degrees of sky surveyed. Putting it all together, we need to have both deep- and wide-field surveys to find distant clusters.

The SPARCS Survey

Given the observational challenges, it should come as little surprise that the number of confirmed massive clusters at $z > 1$ is still quite small: around 10-30, depending on the definitions of "confirmed" and "massive." In 2005, the public release of the Spitzer Wide-area InfraRed Extragalactic legacy survey (SWIRE) from the Spitzer Space Telescope presented a golden opportunity to look for more clusters using infrared/optical methods. At 50 square degrees, SWIRE occupies a unique parameter space. It is a wide enough field to find a significant population of massive $z > 1$ clusters, and, due to Spitzer's power in the infrared, it also reaches deep enough to reliably select $z > 1$ candidate clusters.

To take advantage of the large SWIRE area, we decided to use the well-proven Cluster Red-Sequence (CRS) method that looks for clusters as over-densities of galaxies in a combined color-position space. This method has been used extensively to look for clusters up to $z \sim 1$ in the 100-square-degree RCS-1 survey and the next generation 1000-square-degree RCS-2 survey. We conducted a deep survey of SWIRE in the *z*-band in order to use a combined *z* - 3.6-micron color to select clusters at $z > 1$. This project, the Spitzer Adaptation of the Red-sequence Clusters Survey (SpARCS), was the first to try to employ the CRS method to select $z > 1$ clusters using infrared data; it remains the largest such survey for $z > 1$ clusters to date. The survey contains several hundred candidate clusters at $z > 1$, with estimated masses between $\sim 5 \times 10^{13}\ M_{Sun}$ and $1 \times 10^{15}\ M_{Sun}$.

Spectroscopic Confirmation of SpARCS Clusters With Band-Shuffle on Gemini

To prove that SpARCS is selecting real clusters, we wanted to confirm the redshifts and masses of some of our candidate clusters with spectroscopy. However, obtaining redshifts and velocity dispersions for $z > 1$ clusters is observationally intensive work. Even at $z > 1$, where most galaxies are forming stars, cluster galaxies are still frequently devoid of emission lines, requiring long exposures to obtain high signal-to-noise on the continuum to detect absorption features. Furthermore, their extreme distances mean that even massive clusters are small in angular size, with most of their galaxies appearing in an area of sky that is only about 1-2 arcminutes across.

As an example, the left panel of Figure 1 (next page) shows a color image of a massive $z = 1.157$ cluster in a 6 × 6 arcminutes field of view (f.o.v.)—roughly the f.o.v. of the Gemini Multi-Object Spectrograph (GMOS) and other multi-object spectrographs. Canonical multi-object spectroscopy (MOS) requires long slits, ~ 10 arcseconds long, in order to facilitate the subtraction of sky lines, which means even in ideal cases a typical mask can only get 6-12 slits across the central region of distant clusters, a pretty dismal return of cluster galaxy spectra per mask.

The nod-and-shuffle (N&S) mode available on GMOS offers a major improvement in slit placement over regular MOS modes. Because targets are nodded across the slit for sky subtraction, the required length of the slit is only two to three times the angular size of the object. For distant galaxies, typically ~ 1 arcsecond across, it means only requiring slits ~ 3 arcseconds across. This provides a major gain over the typical 10 arcseconds long slits. There are two observing modes in which N&S observations can be performed: "micro-shuffle" and "band-shuffle". The majority of N&S spectroscopy with GMOS (such as the Gemini Deep Deep Survey (GDDS)) has been done in the micro-shuffle mode, where shuffled charges are stored directly above or below the location of the slit. This means a 3-arcseconds slit requires a blank space of 3 arcseconds above or below it to store shuffled charge, increasing the effective slit area to 6 arcseconds. This is still better than conventional spectroscopy, but is not ideal for clusters.

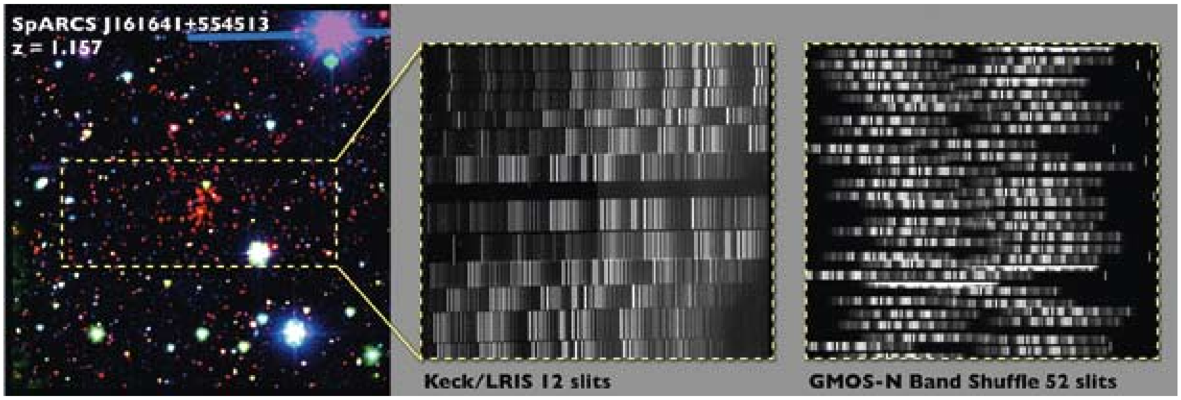


Figure 1.
Left Panel: A g,z, 3.6μm color image of the cluster SpARCS J161641+554513 at z = 1.157. The field of view (f.o.v.) of the image is 6 × 6 arcminutes, approximately the f.o.v. of GMOS. The yellow boxed area shows the region that can be used for "band-shuffle" observations. Middle Panel: Spectra within the band-shuffle region, from a spectroscopic mask observed with LRIS on Keck. Right Panel: Spectra from a band-shuffle mask on GMOS. The 3× smaller slit length from N&S, combined with a band-limiting filter, allowed 52 slits to be fit within the region, making GMOS about 4 times more efficient than LRIS for obtaining spectra of cluster galaxies at z ~ 1.

In band-shuffle mode, the entire central region of the chip is shuffled to the top or bottom of the chip, which means no space is required between slits. While it is technically less efficient in the total use of the GMOS chips (only one third of the area is used, whereas up to half can be used with micro-shuffle), it is perfect for high-z clusters. With a band-limiting filter we can now typically place 35 - 55 slits within an area of about 3.0 × 1.7 arcminutes around these clusters.

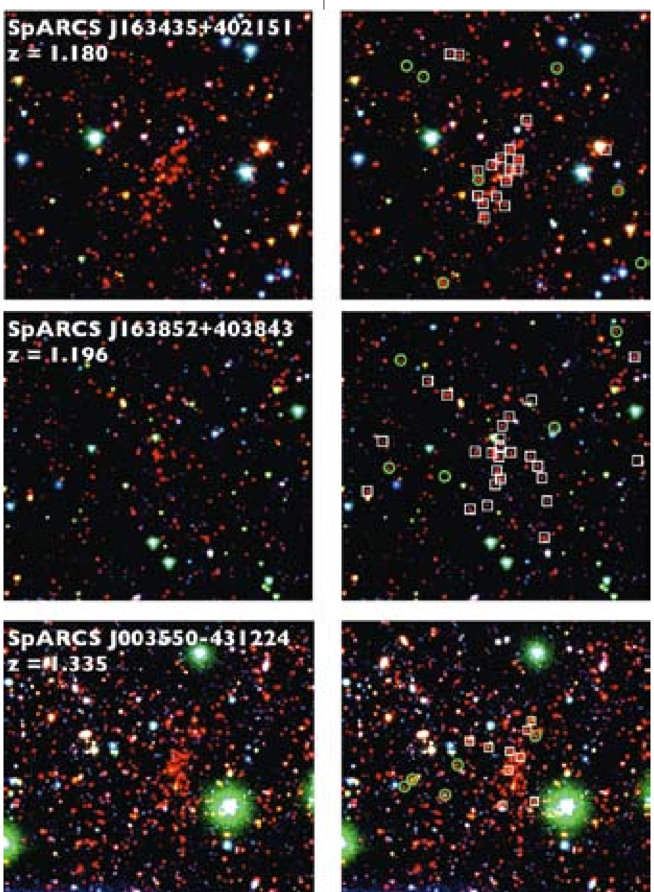


Figure 2.
Left Panels: g,z, 3.6μm color images of three z › 1 clusters from the SpARCS survey with redshifts and masses confirmed by GMOS observations. Right Panels: Same as left panels, with white squares representing confirmed cluster members, and green circles representing confirmed foreground and background galaxies. These clusters are the most distant discovered with the CRS method to date and are some of the most distant galaxy clusters known.

In the middle panel of Figure 1 we show a spectroscopic mask observed using conventional MOS with LRIS on Keck. The right panel shows one of our GMOS band-shuffle masks. Note the considerable efficiency of GMOS over LRIS in packing in the slits using band-shuffle mode.

GMOS has been a critical tool for confirming both the redshifts and masses of the first $z > 1$ cluster candidates in the SpARCS survey. In Figure 2 we show images of three SpARCS clusters, all confirmed with GMOS. SpARCS J003550-431224 at $z = 1.335$, in particular, is an important find. It is currently one of the most distant known clusters and is by far the most distant cluster detected with the CRS method, demonstrating that the highly efficient two-filter CRS method works extremely well for finding massive clusters, even out to the highest redshifts.

Next Step: Gemini Cluster Astrophysics Spectroscopic Survey (GCLASS)

After our initial observing runs with GMOS, we quickly realized how powerful the instrument would be for a detailed follow-up study of distant clusters. Individual $z > 1$ x-ray and optical/infrared selected clusters have been studied; however, no survey of a large sample of rich $z > 1$ clusters has been done. The size of the SpARCS survey meant that we had numerous rich $z > 1$ clusters that could be followed up in detail.

As of semester 2009B, we are now halfway through observations for the Gemini Cluster Astrophysics Spectroscopic Survey (GCLASS). This large, 200-hour project aims to obtain spectra of 50 galaxies in 10 rich clusters at $0.87 < z < 1.34$ selected from the SpARCS survey, making it the state-of-the-art distant cluster project. The scope of the science covered by the project is large. Here are

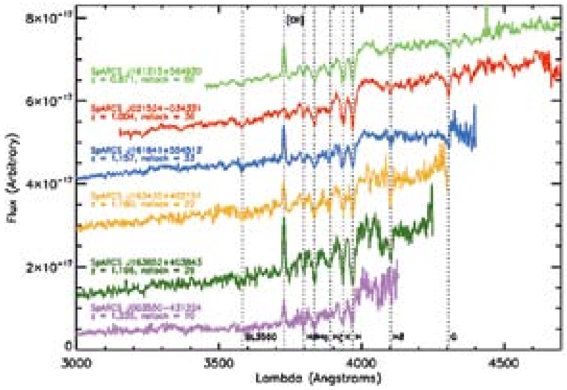


Figure 3. *Rest-frame stacked spectra of the average galaxy in six out of ten clusters in the GCLASS project. Prominent spectral features such as [OII] emission and hydrogen Balmer absorption are (Hδ, Hζ, Hη, Hθ) marked. The clusters show a diverse range in [OII] emission-line strength and Balmer absorption, which clearly shows the importance of a large sample of clusters in understanding their stellar populations.*

some highlights: the first measurement of accurate dynamical masses for a sample of $z \sim 1$ clusters, which will be a crucial factor in studying dark energy with cluster abundances; the first measurement of the average mass and light profile of a massive dark matter halo at $z \sim 1$, from "stacking" the velocity data on the clusters; and a extensive look at the stellar populations of galaxies in a sample of homogenously-selected rich clusters at $z \sim 1$.

In Figure 3 we plot stacked spectra of cluster members from the first ~40 percent of observations from the GCLASS project. With only a few of the masks on about half of the clusters, a significant diversity in both the strength of the [OII] line (typically from star formation) and the Hδ line (typically an indicator of a "post starburst" phase) can already be seen. Figure 3 not only demonstrates the exquisite quality of spectra that can be obtained for distant galaxies using N&S, but also shows the cluster-to-cluster variations in the stellar populations of their galaxies. From Figure 3, it is already clear that to get a fair sample of galaxies in distant clusters, a sample of 10 or even more clusters is crucial.

The prospects are bright for GMOS N&S spectroscopy on these clusters, and I look forward to summarizing the results from the GCLASS survey in a future article. Observations for GCLASS are expected to conclude in semester 2010B.

The work presented in this article has been done in close collaboration with Gillian Wilson (University of California, Riverside) who serves as PI of the SpARCS/GCLASS projects. The SpARCS/GCLASS team consists of 26 members from 19 institutions.

For more information see:

Muzzin, A., *et al.* 2009, *ApJ*, **698**, 1934

Wilson, G., *et al.* 2009, *ApJ*, **698**, 1943

Eisenhardt, P., *et al.* 2008, *ApJ*, **684**, 905

Stanford, S. A., *et al.* 2006, *ApJ*, **646**, L13

Muzzin, A., Wilson, G., Lacy, M., Yee, H.K.C., & Stanford, S. A. 2008, *ApJ*, **686**, 966

Gladders, M. D. & Yee, H.K.C. 2005, *ApJS*, **157**, 1

Gladders, M. D. & Yee, H.K.C. 2000, *AJ*, **120**, 2148

Adam Muzzin is a postdoctoral associate at Yale University. He can be reached at: adam.muzzin@yale.edu

Howard Yee is professor of astrophysics at the University of Toronto. He can be reached at: hyee@astro.utoronto.ca

by Richard McDermid, Davor Krajnović
& Michele Cappellari

Black Holes & Revelations Using Open-loop Adaptive Optics

Supermassive black holes are thought to reside at the heart of many, if not all, galaxies in the nearby universe. These weighty beasts can account for as much as 2% of the entire mass of a galaxy, all containing up to several billion solar masses in a compact central region smaller than our solar system. Although the actual "size" of a supermassive black hole is small, it is thought to play an integral role in the formation and evolution of its host galaxy, primarily by accreting material and generating powerful jets of energy.

Most black holes in the local universe are no longer in this accreting phase but their gravitational effects on nearby stars can be detected. Measuring the orbital velocities of stars or gas within the radius of influence—where the gravitational pull of the black hole dominates over the effect of the host galaxy—can reveal the gravitational signature of the unseen supermassive black hole. More importantly, by accurately modeling these motions, it is possible to derive the most fundamental property of the black hole: its mass.

When galaxies merge, their respective central black holes are thought to fall to the center of the remnant galaxy, forming a black hole binary system. The binary can eject stars that pass close to the galaxy center and by doing so, loose angular momentum and eventually coalesce. It is thought that this ejection of stars from the central region is a mechanism for forming the low-density galaxy cores found in massive early-type galaxies. This so-called "core-scouring" mechanism leaves a specific imprint on the orbital structure of the central region, since stars on radial orbits are preferentially ejected, leaving a higher fraction of stars on more circular (or "tangential") orbits.

To understand the orbital structure around the black hole, and hence gain an insight to the formation mechanism of the galaxy, the main issue is to spatially resolve the kinematics close to the black hole's radius of influence. For nearby galaxies, this is typically only a few tenths of an arcsecond on the sky. At these scales, the Earth's atmosphere blurs the information, mixing up light from the galaxy nucleus with light from further out in the galaxy, and greatly diluting the signature of the black hole.

Natural guide star adaptive optics (NGS-AO) on large telescopes can help overcome the limitations imposed by Earth's atmosphere. However, this technique requires bright guide stars that appear close to the nearby galaxies of interest, which are rare. Laser guide star adaptive optics (LGS-AO) allows much fainter guide sources to be used, greatly increasing the fraction of the night sky available for AO-assisted observations. LGS-AO creates an artificial star, or reference source with which to measure the atmospheric distortion by making use of a one-kilometer-thick layer of the Earth's atmosphere composed largely of sodium, located at an altitude of around 90 kilometers. A powerful laser beam that has a wavelength identical to a resonant wavelength of the sodium atom (which turns out to be the same color as most common street lighting) is fired into this layer. The laser light stimulates a narrow column of gas within this sodium layer, causing the gas to emit light.

As seen from the telescope, a bright point of light is created high in the atmosphere, allowing the atmospheric distortion to be measured and corrected by the AO system. A natural reference source is also needed to measure the bulk motion, or "tip/tilt," caused by the atmosphere, as well as to monitor relative changes in focus caused by a varying sodium layer altitude. This natural source, however, can be several magnitudes fainter than is needed for correction of higher-order modes, therefore giving a much larger sky-coverage than NGS-AO.

The advent of LGS-AO opens a new era of high spatial resolution observations from the ground. Moreover, the development of integral-field spectroscopy and infrared capabilities allow a two-dimensional region to be spectrally mapped simultaneously, while realizing spatial resolutions close the theoretical limit of the telescope. This effectively gives Gemini a spatial resolving power comparable to the Hubble Space Telescope (HST), whilst having an order of magnitude larger light-collecting area and a broader range of instrumental capabilities.

Applying all this new technology to the topic of supermassive black holes has not been entirely straightforward. The main issue is that, although LGS-AO allows fainter guide sources to be used, galaxies that may have a resolvable radius of influence tend to be nearby and spatially extended on the sky. This means that guide stars are either superimposed on the galaxy's light (requiring them to be relatively bright to be useful) or they are positioned so far from the galaxy nucleus that the spatial resolution is degraded due to anisoplanatism—incoherence of the atmosphere between two different positions on the sky.

To get around this problem, we have used a new technique at Gemini North known as the "open-loop" focus model. While the nuclei of most nearby galaxies are too faint and extended to measure the telescope focus reliably, they can still be used to determine tip/tilt. Information on the telescope focus is required to account for possible changes in the distance from the telescope to the sodium layer, which can drive the telescope out of focus.

With this technique, instead of trying to measure the focus dynamically on the galaxy nucleus, the assumed distance to the sodium layer (and therefore the telescope focus) is controlled by an open-loop model. This is a geometric model of how the distance to the sodium layer changes as the telescope tracks a target on the sky and requires no real-time focus measurements. The telescope and AO system are first "tuned," or optimized, on a nearby star, which calibrates the altitude of the sodium layer. This altitude is then kept fixed for the duration of the science observation. The galaxy is acquired, and the nucleus is used to measure tip/tilt, while the higher-order atmospheric distortions are measured from the laser beacon. The open-loop model controls the changes in focus as the distance to the sodium layer changes.

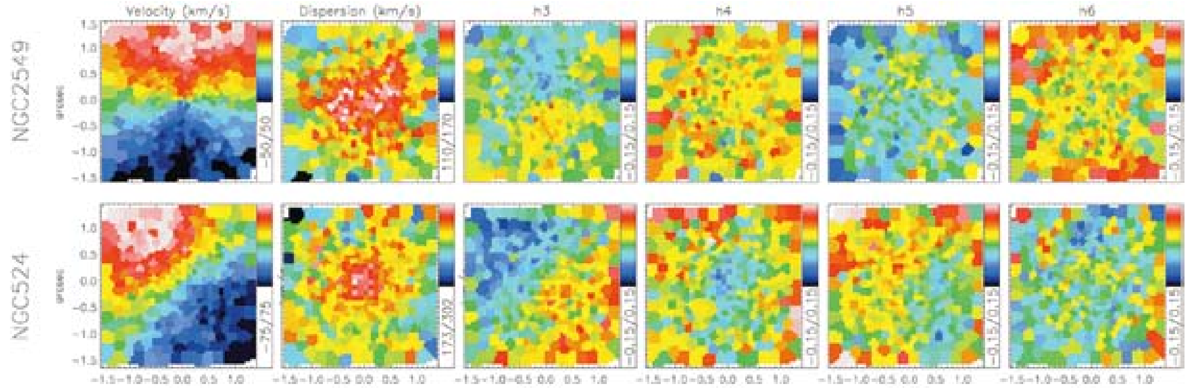


Figure 1. *NIFS stellar kinematic maps for NGC 2549 (top) and NGC 524 (bottom). The velocity profile is parameterized by the standard Gauss-Hermite series, giving the mean velocity, V, the velocity dispersion, σ, and higher-order moments h_3 to h_6. Note the observed rotation, the central increase in σ, and the anti-symmetric signatures in the higher moments. The data are spatially binned with a threshold signal-to-noise ratio of 50.*

We used this technique together with the Near-Infrared Integral-field Spectrometer (NIFS) to measure the stellar kinematics around the nucleus of two nearby early-type galaxies. Figure 1 shows the measured stellar kinematic maps for the two galaxies, NGC 524 and NGC 2549, which were observed for 3.5 and 2.5 hours, respectively, on-source (i.e. excluding blank sky fields). Neighboring spectra have been binned together in the outer regions, where the galaxy is fainter to ensure a minimum signal-to-noise ratio of around 50 in each spectrum. The central spectra have a higher signal and are unbinned, thus preserving the spatial information delivered by the LGS-AO. This excellent data quality allows the higher-order moments of the velocity distribution to be measured, using a 6th-order Gauss-Hermite series. The higher-order moments are essential to derive the detailed orbital make-up around the black hole. We combine the NIFS data with wide-field integral field kinematics of comparable quality, but lower spatial resolution, from the SAURON spectrograph at the William Herschel Telescope.

To estimate the degradation of the point-spread function (PSF) due to the use of the open-loop model, we took NIFS observations of the star used to tune the AO system both before the galaxy was observed (where all loops were optimized) and after approximately one hour of galaxy observations (with the focus loop left open, as for the galaxy). Figure 2 compares the PSFs derived from these observations, which show negligible degradation due to changes in the sodium layer or errors in the open-loop model. This is only one instance, of course, and the stability of the sodium layer altitude depends on the weather conditions for a given night. However, it seems that this mode gives a reliable performance, at least over timescales of around an hour.

To infer the mass of the black hole, and the stellar orbits around it, requires a dynamical model of the galaxy. The mass and distribution of the galaxy's stars are modeled using imaging information (from HST and ground-based telescopes), converted to mass via the mass-to-light ratio: a free parameter

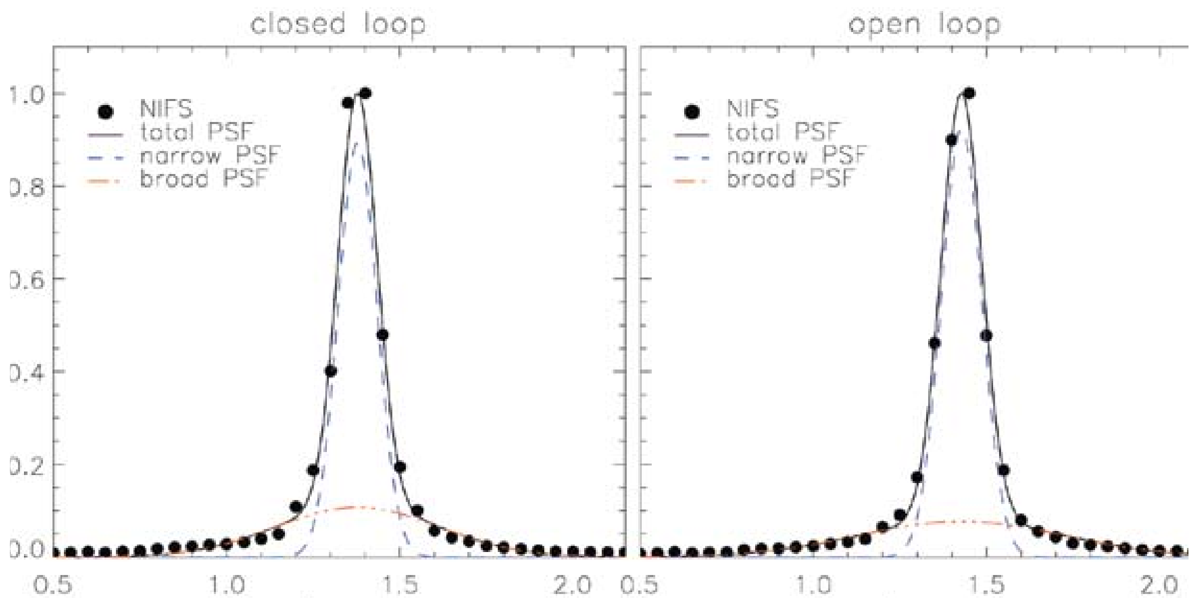


Figure 2. *Comparison of the NIFS point-spread function (PSF) derived from a star close to NGC 524 used to tune the telescope and AO system. The observations were made before (left) and after (right) observing the galaxy. The "after" images were taken without re-calibrating the sodium layer altitude. This indicates any degradation due to using the open-loop focus model. The parameters of the double-Guassian fit used to parameterise the NIFS PSF are almost identical, showing that no significant degradation occurred.*

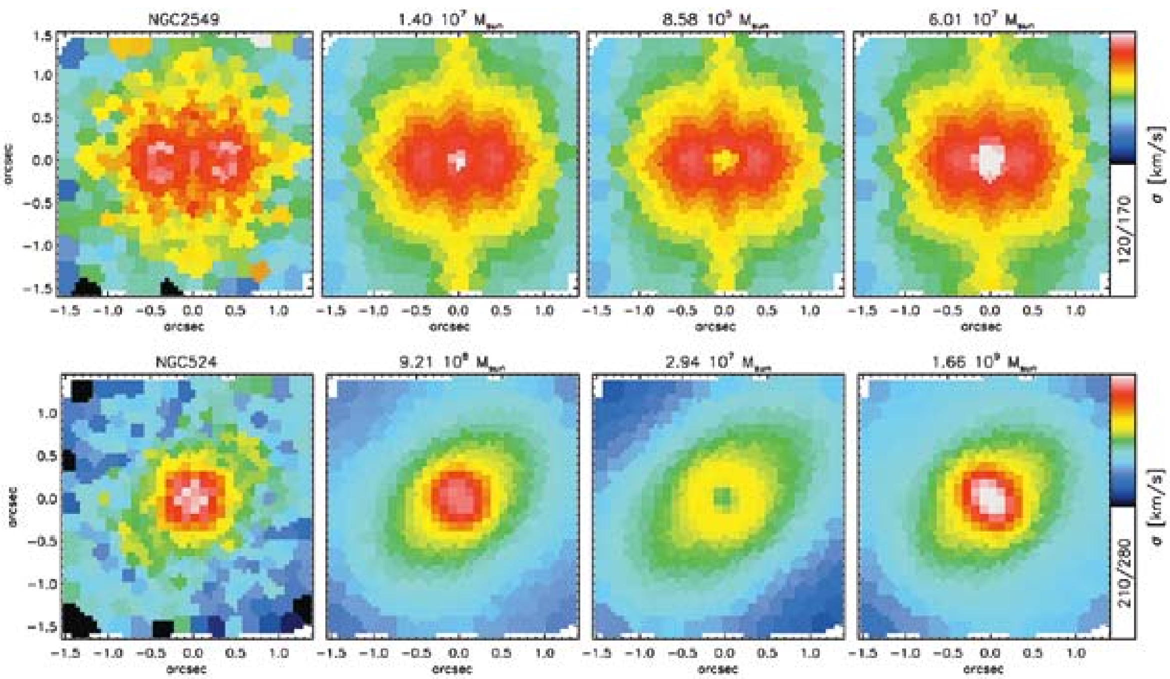


Figure 3. *Comparison of the observed NIFS velocity dispersion (left column) and the best-fitting model (second to left column) for NGC 2549 (top) and NGC 524 (bottom). Models with too small and too large a black hole (second from right and right columns respectively) are also shown for comparison. Note how only the central pixels differ significantly. The NIFS data have been symmeterized for this comparison.*

in the dynamical model. In addition to this, a central dark mass is included, which represents the black hole, and gives another free parameter. Lastly, the angle at which the galaxy is viewed must be assumed, since the shape of the galaxy we see is a two-dimensional projection on the sky of a three-dimensional body. The objects we are modeling are well described by a galaxy symmetrical about its axis of rotation, while the viewing direction is uniquely described by the inclination of the system. For both galaxies, good estimates of this inclination angle are available from the imaging data, so we assume these fixed values. Dark matter is included in the model implicitly through the mass-to-light ratio, making the assumption that the dark matter is distributed in the same way as the starlight. In practice, dark matter is not expected to dominate the stellar dynamics in the central regions of these galaxies.

Figure 3 shows a comparison of the central velocity dispersion (which is generally the most sensitive kinematic tracer of the black hole) from NIFS with that of the fit from the best-fitting model, as well as models with smaller and larger black holes. While most of the field is unchanged between the different models, the very central regions of the NIFS data show variations. It is these subtle differences that indicate the presence and mass of the central black hole.

Thanks to the high-quality NIFS integral field data ,coupled with our general dynamical modeling, we can also infer the orbital structure close to the black hole. Figure 4 shows a measure of the balance between radial and tangential orbits each galaxy. NGC 524 shows a very distinct change inside the black hole radius of influence towards tangential anisotropy, meaning a relatively higher fraction of

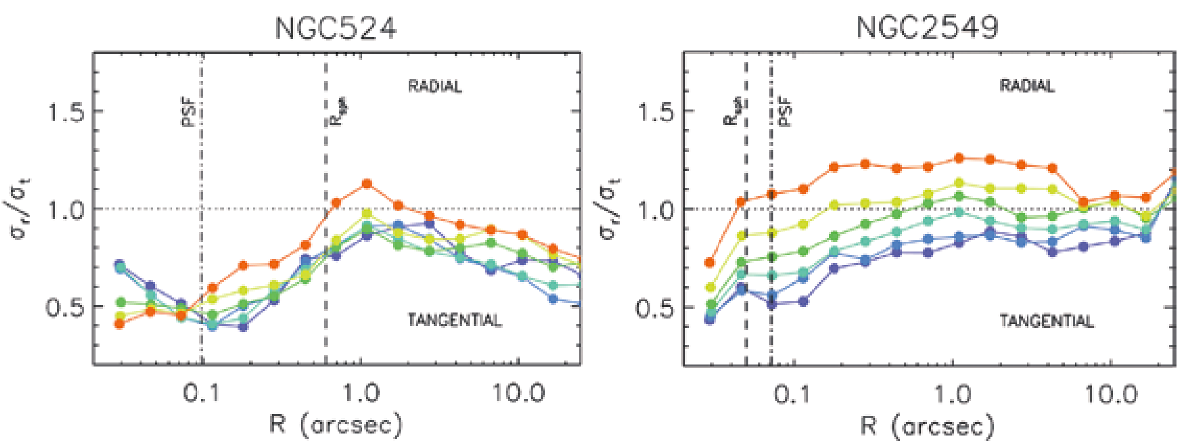


Figure 4. *Radial profiles showing the balance between radial and tangential orbits for NGC 524 (left) and NGC 2549 (right). Colored lines indicate different angles from the equatorial plane, increasing from red to blue. Dot-dash lines indicate the width of the PSF core, and the dashed lines show the radius of influence. NGC 524 shows a strong tangential anisotropy within the radius of influence. NGC 2549 shows a weaker signature, but the radius of influence is not as well resolved.*

orbits going around the galaxy center than passing through it. This is compelling evidence that the central core region of this galaxy was formed by a black hole binary following a galaxy merger that ejected the central stars on radial orbits, leaving a depleted core region biased to tangential orbits. The picture for NGC 2549, which does not have a low-density central core, is less clear. There is only weak evidence for any change in anisotropy close to the black hole, suggestive of a different formation history to NGC 524.

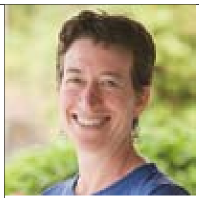
Using the open-loop focus model technique, LGS-AO at Gemini has allowed unique, high-quality spectral maps of these galaxy nuclei to be made at very high spatial resolution. These observations have revealed the presence of a supermassive black hole residing at the center of each galaxy. More importantly, they provide evidence that early-type galaxies with different central light characteristics (cusps and cores) have correspondingly different orbital structures, indicative of distinct formation scenarios. This adds new insight into the connections between supermassive black holes, galaxy nuclei, and the evolution of early-type galaxies.

This work is presented in full in Krajnović, McDermid, Cappellari, and Davies, *MNRAS*, in press. We gratefully acknowledge Chad Trujillo and the staff at Gemini North for developing the observing techniques using the open-loop focus model method for our observations. We note that this observing mode is generally offered at Gemini North as of semester 2009A.

Richard McDermid is a Gemini science fellow at Gemini North. He can be reached at: rmcdermid@gemini.edu

Davor Krajnović has recently moved from the University of Oxford to ESO as a fellow. He can be reached at: dkrajnov@eso.org

Michele Cappellari is an STFC advanced fellow at the University of Oxford. He can be reached at: cappellari@astro.ox.ac.uk



by Nancy A. Levenson

Recent Science Highlights

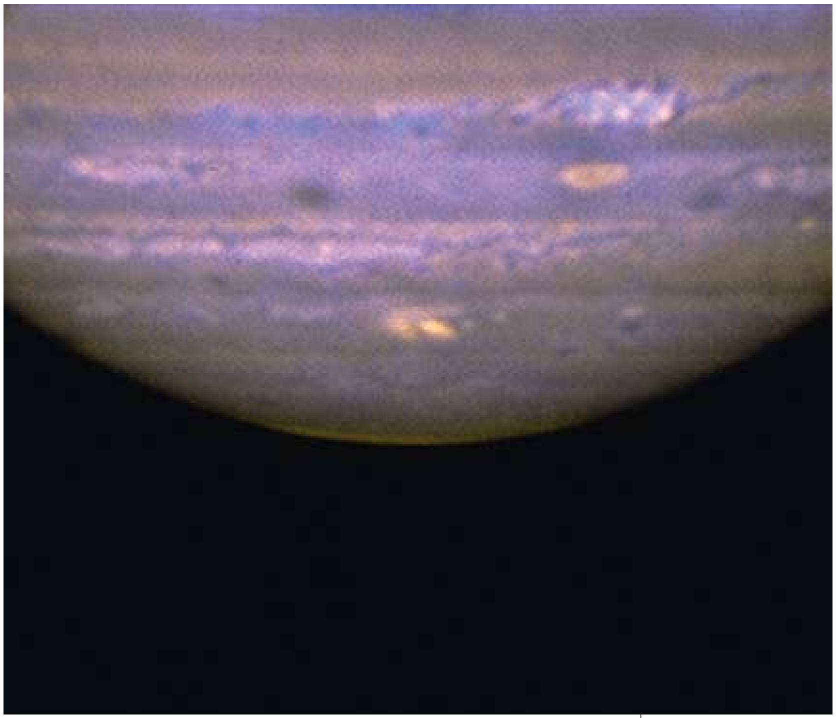


Figure 1. *A mid-infrared false color image of Jupiter, from MICHELLE observations at 8.7 (red) and 9.7 microns (blue). The new impact site appears as a bright region at the center of the bottom of Jupiter's disk. The size of this feature is consistent with an impacting object a few hundreds of meters in diameter.*

A Surprise Collision on Jupiter

Australian amateur astronomer Anthony Wesley discovered a new feature on Jupiter on July 19, 2009. This new spot, which appeared dark at optical wavelengths, was located near Jupiter's south polar region and was likely the result of a comet or asteroid impact. Scaling from observations of Comet D/1993 F2 (Shoemaker-Levy 9), which ran into Jupiter almost exactly 15 years ago, an impactor only a few hundreds of meters in diameter could have caused the new spot.

Gemini observed the consequences of the impact at mid-infrared wavelengths, using both MICHELLE on Gemini North and T-ReCS on Gemini South. Some of the measurable effects include thermal radiation following heating of the atmosphere, so the impact site was bright in the mid-infrared. Signatures of particular constituents such as methane, ammonia, and aerosols, are also evident in the data. Later observations of the impact site tracked the dispersal of the debris feature and are providing information about Jupiter's atmosphere and its winds.

Heidi Hammel (Space Science Institute), with colleagues Imke de Pater (University of California, Berkeley), and Glenn Orton and Leigh Fletcher (both of Jet Propulsion Laboratory), obtained narrow-band images with MICHELLE through seven filters, with the help of Gemini staff: Tom Geballe, Rachel Mason, Chad Trujillo, Paul Hirst, and Tony Matulonis. Two of those images (at 8.7 and 9.7 μm) provide a spectacular result (Figure 1).

The impact was truly unexpected. Gemini's multi-instrument queue enabled data collection within 24 hours from when the team proposed the observations.

High-Pressure Outflow from M82

The nearby starburst galaxy M82 is an archetype of its class. Individual regions of star formation in the galaxy can be measured accurately to account for the dynamics of intense star formation and the resulting outflowing

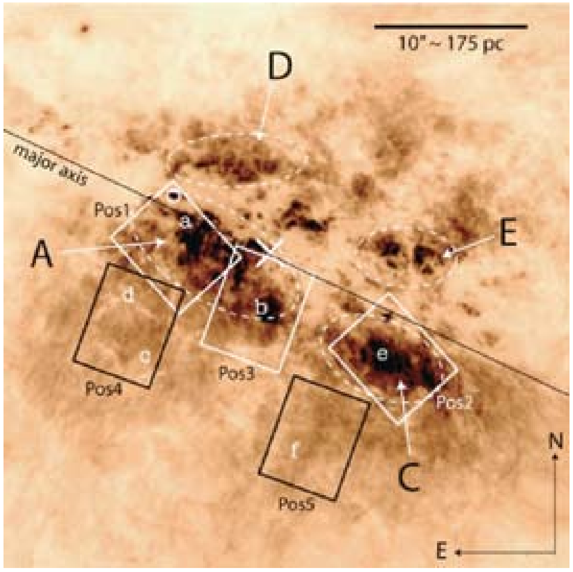


Figure 2.
The central region of M82 at optical wavelengths (HST/ACS image) showing the five 7- by 5-arcseconds fields observed with the GMOS-North IFU (white and black rectangles). Dashed lines mark some of the regions of most intense star formation.

winds driven by the collective effect of stellar winds and supernovae. An international team led by Mark Westmoquette (University College, London) used the integral field unit (IFU) of the Gemini Multi-Object Spectrograph (GMOS) to study the ionized gas and stellar dynamics at M82's core (Figure 2). This work resulted in two papers in the *Astrophysical Journal*, and the relationship between the inner and outer wind regions is the planned subject of future work.

The team's GMOS data show that the rotation axes of the gas and stars are offset, which provides supporting evidence that interaction with the nearby galaxy M81 triggered the starburst. While bright, spectrally narrow emission is common throughout the data, a diffuse broad component is also present, which the authors associate with turbulence on the surfaces of clouds in the dynamic environment.

One region in particular shows evidence for an outflow channel for hot gas, which entrains the cooler, denser material. If the material eventually escapes the galaxy's potential well, such outflows would be a mechanism for the chemical enrichment of the surrounding intergalactic medium. However, the team finds few similar coherent outflows in the observations, which may be a consequence of the irregularity of the ages, masses, and locations of the stellar clusters that drive them. In general, the electron density of the ionized interstellar medium decreases along the galaxy's minor axis (Figure 3), and the similarity of the density with spectral width and radial velocity in a second off-axis region could be a sign of another outflow channel.

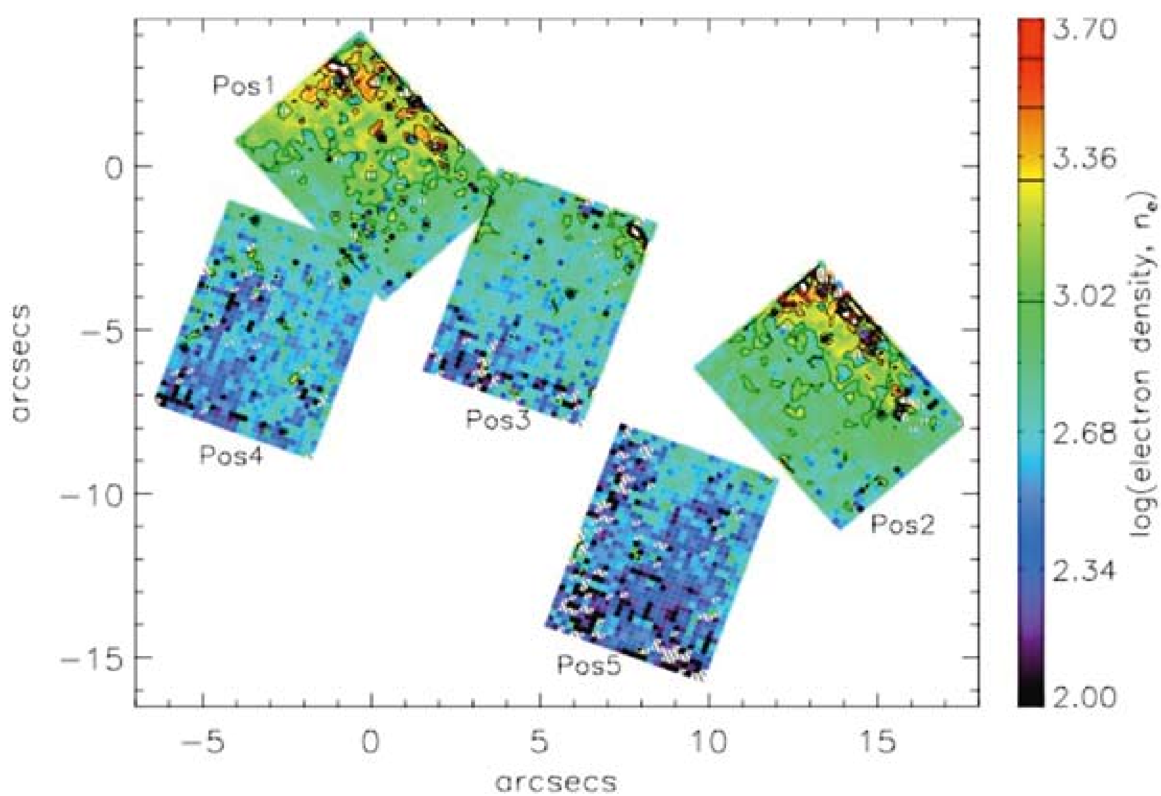


Figure 3.
Electron density measured from [SII] line ratios in the GMOS IFU data. The density generally declines along the minor axis of M82, and the highest densities arise in very compact regions, though not in the starburst complexes themselves.

Dynamics of an Ultracompact HII Region

The central massive stellar source of the ultracompact HII region K3-50A, located within the Milky Way Galaxy at an estimated distance of 7 kiloparsecs, remains hidden at near-infrared wavelengths, buried in its dusty native environment. However, new observations reveal interesting dynamics and structure within the 0.1 parsec

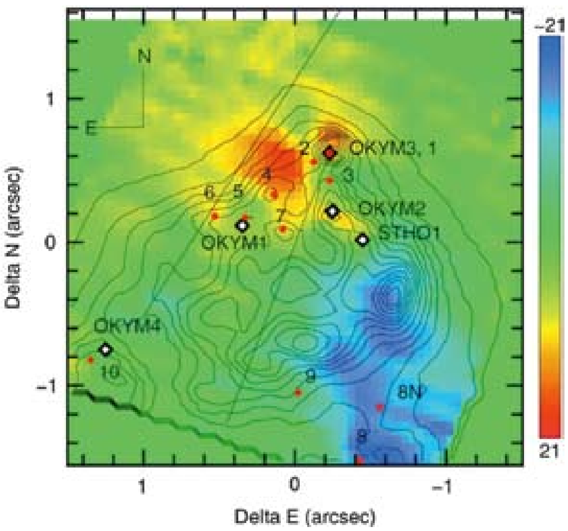


Figure 4. *Velocity for the principal component of the Brγ line, measured in kilometers per second, with the mean velocity subtracted to show spatial variations. The bipolar structure is not aligned with any known point source or large-scale ionized flow detected at radio wavelengths. Red filled circles and yellow diamonds mark previously-detected sources at near-infrared and mid-infrared wavelengths.*

scale of the ionized gas. Robert Blum (National Optical Astronomy Observatory, Gemini Science Center) and Peter McGregor (Australian National University) used the Near-Infrared Integral Field Spectrometer (NIFS) with the Altair adaptive optics system to maintain high spatial resolution over the spectral image cube.

The data reveal sharp density gradients, which are interpreted to be regions where young massive stars have cleared some of their immediate surroundings with radiation and winds. The kinematic signature of a bipolar structure is evident in the Brγ emission (Figure 4), and this double-lobed structure is not aligned with results from similar measurements at lower spatial resolution over larger physical scales. It is also not centered on any of the detected point sources in the image or on the radio continuum sources. The bipolar flow could be associated with a lower-mass protostar near the central ionizing source.

Searching for Halo Substructure

Previous studies of the gravitationally lensed quasar H1413+117 identified flux ratios among the images that a single, central galaxy acting as the gravitational lens could not produce (although a smooth central galaxy could account for the observed image positions). Structure in the lensing galaxy's halo is one possible origin for a more complex mass distribution. If dark matter forms the substructure, lens models could provide important constraints on its nature and role in galaxy formation, specifically identifying some of the low-mass satellite galaxies that cold dark matter models predict in abundance.

University of Washington graduate student Chelsea MacLeod and collaborators found a much more mundane explanation for the flux anomalies: a second galaxy. They obtained images of the system at 11 microns with MICHELLE on Gemini North. Because the quasar is extended in the mid-infrared, the images are free from the complication of microlensing by stars, and they suffer less from extinction. The combination of the main lens and the nearby galaxy reproduce both the positions and flux ratios of the quasar images (Figure 5).

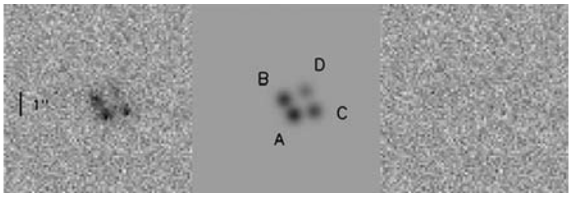


Figure 5. *The observed 11µm lensed images of the quasar H1413+117 (left), a model of the images, including two lensing galaxies (center), and the model residuals (right). The mid-infrared data offer several advantages for studies of gravitational lenses, notably reducing the effects of microlensing by stars.*

Binary Stars and Bipolar Planetary Nebulae

Planetary nebulae frequently exhibit highly axisymmetric shapes as opposed to spherical symmetry. Binary star progenitors would naturally account for the angular momentum these objects seem to require, but even with large samples of planetary nebulae, few have shown direct evidence for binary central stars.

Ph.D. student Brent Miszalski (Macquarie University and Université Strasbourg) and an international team have used GMOS on Gemini South, along with data from several other telescopes on the ground and in space, to concentrate on post-common envelope nebulae. With this restriction on the evolutionary state of the nebulae, almost 30% of the sample objects show direct evidence of bipolarity, such as the equatorial rings Figure 6 (next page) demonstrates. Moreover, after correcting for projection effects, the authors identify up to 60% of the sample as bipolar. They conclude that the common envelope phase is tied to the bipolar morphologies of

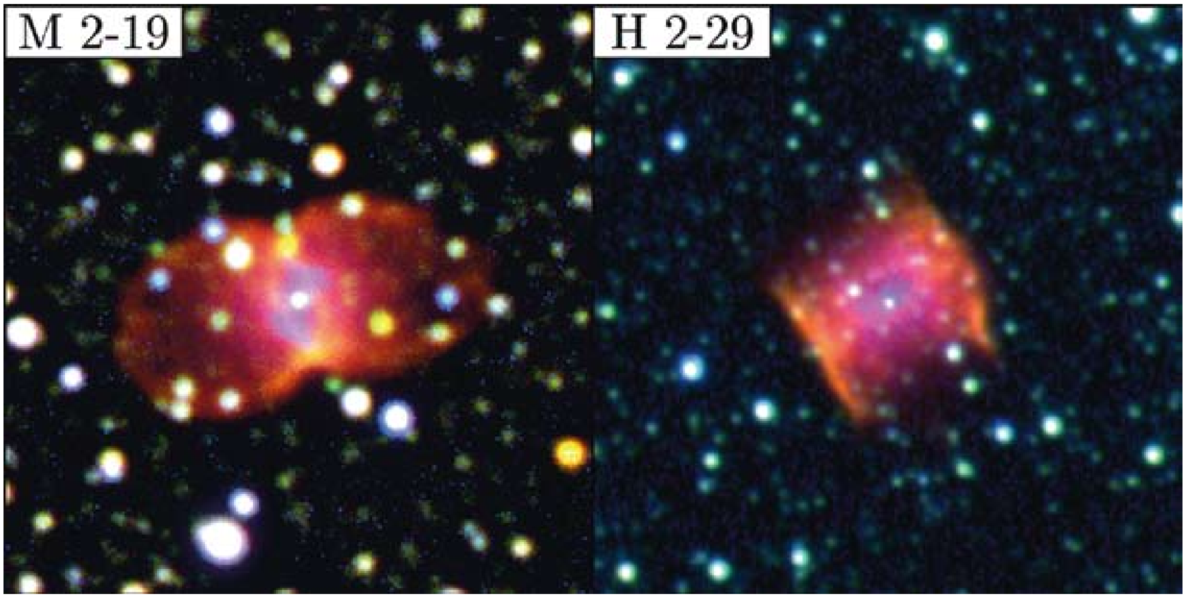


Figure 6.
The planetary nebulae M 2-19 and H 2-29 show prominent equatorial rings. The images are constructed from Hα + [NII] (red), [SII] (green), and [OIII] (blue} narrow-band GMOS images. Each image is 30 arcseconds across.

the nebulae. In addition, many of the sample members show signs of binary progenitors, exhibiting knots, filaments, and jets.

Tracing Star Formation with Planetary Nebulae and HII Regions

Stars themselves are not the only tracers of star formation. Laura Magrini (INAF - Osservatorio Astrofisico di Arcetri) and Denise Gonçalves (Universidade Federal do Rio de Janeiro) used GMOS observations of HII regions and planetary nebulae in the starburst galaxy IC 10 to reveal its star formation history. While this galaxy's current rate of star formation is high, older stellar populations are also evident. The current work takes advantage of the different phases of stellar evolution HII regions and planetary nebulae represent to quantify the star formation history from past to present.

In addition, spectroscopy of these objects provides metallicity indicators of each population when their stellar progenitors formed. The similar abundances of the HII regions and planetary nebulae indicate that little enrichment has occurred between the epochs of their formation (Figure 7). However, dispersion in each of the groups suggests inhomogeneous abundances across this dwarf galaxy, in which small-scale enrichment with limited mixing may be significant.

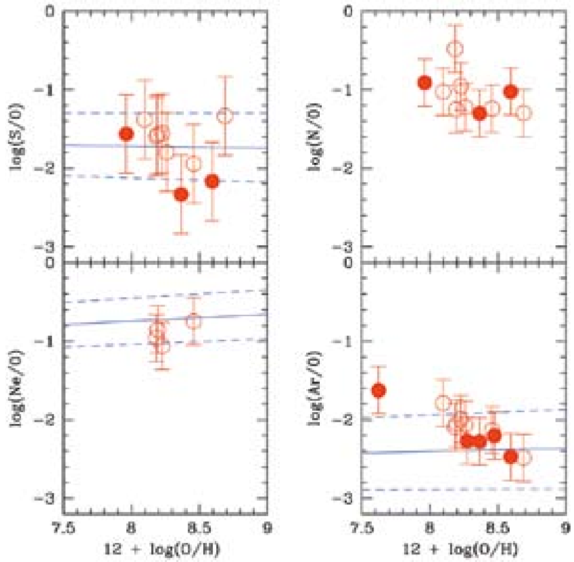


Figure 7.
Abundance ratios of HII regions (empty circles) and planetary nebulae (filled circles) in the dwarf starburst galaxy IC 10, compared with relationships derived from observations of blue compact galaxies (blue lines). There is no significant difference between the younger and older star-forming regions, which the HII regions and planetary nebulae indicate. This also implies that little enrichment has occurred over the galaxy's evolution.

Nancy Levenson is Deputy Director and Head of Science at Gemini Observatory and can be reached at:
nlevenson@gemini.edu

by Christian Marois
& Michael Liu

Exoplanet Imaging with the Gemini Telescopes

Humanity has been dreaming about other worlds for more than 2,000 years. This dream partly became reality 400 years ago when Galileo Galilei used his 1.5-inch diameter telescope to discover the first "mini-solar system": Jupiter and its four major moons. This discovery had profound philosophical implications, as it supported the Copernican model of the universe and showed that other worlds did not necessarily revolve around the Earth.

Thus, the foundations of observational astronomy are intimately connected with the drive to find and study other worlds. This drive to understand our place in the universe continues to be one of the most compelling reasons to build new telescopes and instrumentation. The past 15 years have been an especially rich time, starting from 1995 with the discovery of the first planets around Sun-like stars through precision radial velocity measurements. While radial velocities have been a boon for identifying planetary systems, measurements of them are fundamentally indirect, since the planets are detected only indirectly via their gravitational influence. Direct imaging of exoplanets is the next frontier, as detection of their photons opens the door to a wealth of physical information not otherwise available.

The Contrast Challenge

The Jupiter system is relatively easy to see with a handheld 1.5-inch telescope, due to its proximity to Earth and the modest brightness difference between Jupiter and its major moons. However, seeing planets around other stars is a far larger challenge. Planets are thousands to billions of times fainter than stars, because planets have small radii and emit very little light on their own.

On top of this fundamental problem, there are several practical complexities of observing exoplanets from Earth. To begin, stars are located millions of times farther away than Jupiter, resulting in a very small angular separation between the stars and their planets—a representative scale is about one arcsecond to a few arcseconds. Also, the turbulence of Earth's atmosphere blurs light as it travels from outer space to ground-based telescopes, causing the images of stars to be much larger and thus blend even more with the light from planetary companions. Finally, light is further blurred and scattered once it arrives into telescopes and their associated instruments, such that the central star's dazzling bright light easily overwhelms any light from associated planets.

Altogether, the combination of this small angular separation and enormous brightness difference between a star and a planet can be described as both an angular resolution and contrast problem. Large telescopes and complex instruments are required to separate the light of the star and planets in order to resolve the system, and clever techniques are needed to suppress the residual bright starlight and image faint planets in orbit around other stars.

From Galileo Galilei to Now

After 400 years of hard effort and innovation, astronomers are now overcoming these challenges and achieving the capability to see other worlds. Since Galileo's time, ever-larger telescopes have been built, placed on better observing sites, and equipped with more powerful instruments. In the 20th century, two major developments stand out as key to direct imaging discoveries of exoplanets. In the 1950s, Horace Babcock suggested a revolutionary solution to correct the blurring caused by Earth's atmosphere: rapidly change the shape of a small mirror in order to cancel the atmospheric fluctuations in real-time. This technology is now known as adaptive optics (AO).

The first generation of AO systems was installed on astronomical telescopes in the early 1990s, and AO is now nearly ubiquitous on new large telescopes. In fact, the first science instrument at Gemini Observatory was Hokupa'a-36, an AO imaging camera developed by the University of Hawai'i and deployed on Gemini North; it was used for several programs that searched nearby stars for brown dwarf companions, the high-mass analogs to exoplanets. This system was subsequently replaced in 2003 by Altair, a more permanent higher-order system built by Canada's National Research Council's Herzberg Institute of Astrophysics (NRC-HIA), which is now routinely used in conjunction with other instruments on Gemini North on many observing nights.

The other key innovation was the development, in the 1980s, of infrared (IR) array detectors, which replaced the single-channel photometers used since the 1960s. Similar to the detectors found in today's digital cameras, IR detectors are sensitive to light at infrared wavelengths and deliver digital images that can be processed by a computer. The ability to detect IR photons is very important, since exoplanets have much cooler temperatures than stars, and thus they emit most of their light in the infrared.

Opening a New Era

The hunt for exoplanets around nearby stars by direct imaging started in the 1980s. But it really grew into a serious effort in the 1990s, as large 4- to 10-meter ground-based telescopes were equipped with first-generation AO systems and infrared cameras. These developments roughly coincided with the first exoplanet detection around a Sun-like star found by radial velocity measurements (51 Peg b in 1995). Indeed these radial velocity discoveries provided new momentum to search for planets by direct imaging, now that we knew gas giant planets definitely existed and were common around other stars.

The first attempts at direct imaging with AO confirmed that it would still not be an easy task. Even with large telescopes and dedicated instruments, imperfections in telescope and instrument optics as well as the residual effects of atmospheric turbulence not corrected by AO, still inhibited the ability to probe the small angular separations around stars where planets were thought to be located. As a result of these challenges, much effort was spent on conceiving and implementing new techniques to improve the contrast. As a result, three primary strategies have been deployed to boost the power of existing telescopes: coronagraphy, spectral difference imaging (SDI), and angular differential imaging (ADI).

Coronagraphy: the coronagraph, invented by Bernard Lyot in 1939 to look at the Sun's corona, is a relatively simple and ingenious optical setup that can be adapted for high-contrast imaging of exoplanets. A small mask is placed at the instrument focal plane to physically block the on-axis light from the star. Most of the star's remaining light is then scattered to wide angles and further blocked by a complementary mask downstream. The net result is that the central star's light is greatly suppressed, making it easier to detect faint objects in close proximity. Due to its ease of implementation, the Lyot-style coronagraph is now a widespread feature of imaging instruments for current AO systems.

Spectral Differential Imaging (SDI): SDI is an observing technique based on the very different surface temperatures between a cool planet and a hot star. Since planets are not sufficiently massive to sustain nuclear fusion, planets steadily cool with time from their initial hot state at formation. After about 100 million years, gas-giant planets are cool enough that many complex molecules can form in their atmospheres—a process that does not occur for ordinary stars. These molecules include the formation of gaseous methane (CH_4), which produces very strong features. One of the strongest is at 1.6 microns, where the planet flux is bright at wavelengths bluer than 1.6 microns and then sharply drops to nearly zero at redder wavelengths. In contrast, stars have nearly blackbody spectra, smoothly continuous at these wavelengths. SDI acquires simultaneous imaging at two (or more) wavelengths adjacent to this sharp 1.6 micron drop to counteract the time-variable images produced by the Earth's turbulent atmosphere.

Subtraction of the two spectral imaging channels removes the bright (methane-free) glare of the target stars and reveals any faint, ultracool (methane-bearing) planetary companions. Since the images at different wavelengths are acquired simultaneously, the images of the bright star suffer the same atmospheric AO residual and instrument aberrations at both wavelengths, producing much better subtraction than if the images were acquired non-simultaneously. The TRIDENT near-infrared camera was the first instrument to test this approach, installed at the Canada-France Hawai'i Telescope on Mauna Kea in 2001 as part of the Ph.D. thesis work of one of us (C. Marois, under the direction of René Doyon, Daniel Nadeau, and René Racine at the University of Montreal). It has also been employed for the SDI camera at the Very Large Telescope and is one of the key features of Gemini's new NICI instrument, described in more detail below.

Angular Differential Imaging (ADI): ADI is an observing strategy that uses Earth's rotation to separate the light of a planet from the light of a bright star. It thereby allows very accurate star light subtraction by post-processing in software. Large 8- to 10-meter telescopes are usually built such that the telescope rotation axes differ from the Earth's axis, leading to rotation of images as the telescope tracks an object in the sky over time. To compensate for this field rotation, telescopes usually employ an instrument rotator. With ADI, the rotator is turned off, causing the instrument to be perfectly aligned with the telescope for an entire sequence of observations. All the noise induced by the telescope and instrument defects then stays fixed with time relative to the instrument detector, while the image of planet revolves in the field of view around the bright star. The images are then analyzed to subtract the static noise and retain the planet's flux. ADI was first successfully used for science in the early part of this decade by the two of us independently, M. Liu at the W. M. Keck Observatory and C. Marois at Gemini North (where ADI imaging was actually one of the first science observations made with the Altair AO system). Recent improvements in the post-processing reduction methods made by David Lafrenière have further increased the power of this technique (the "LOCI" algorithm). ADI was the key method used for the discovery of the HR 8799 multi-planet system, first detected in 2007 with the Gemini North telescope (Figure 1).

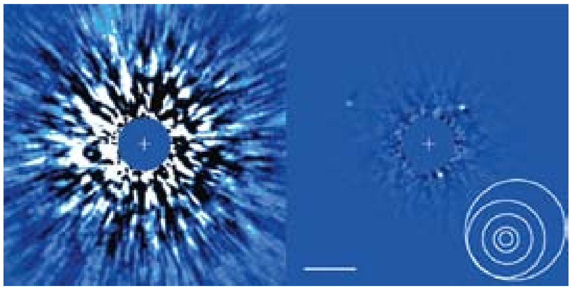


Figure 1.
Before (left) and after (right) ADI processing of Altair/NIRI HR 8799 data acquired in September 2008 at K-band. The left panel shows a 30-second exposure filtered to remove the smooth radially symmetric halo, while the image to the right is the combination of 60 ADI-processed 30-second exposures. The three 7- to 10-Jupiter mass planets are easily visible in the ADI-processed images, while they were completely hidden by scattered light from the primary in the raw image. The solid white line in the right panel represents a one arcsecond angular separation. The concentric circles are the orbits of Jupiter, Saturn, Uranus, Neptune, and Pluto, viewed face-on at the distance of HR 8799 (39 parsecs or 127 light years). The central part of the images are masked out due to detector saturation. Both images are displayed with the same linear intensity range and have a 5.6 x 5.6 arcseconds field of view. North is up and east is left.

Up to now, three large-scale direct imaging surveys for exoplanets have been completed, or are ongoing, at Gemini. The first one, the Gemini Deep Planet Survey or GDPS (led by David Lafrenière, then at the University of Montreal), was carried out between 2004 and 2007. A total of 86 of mainly GKM stars have been acquired with ADI for an hour with Altair/NIRI at Gemini North. No planet was found, but the survey placed very good constraints on the presence of Jupiter-like planets in wide (30-300 astronomical unit (AU)) orbits. GDPS concluded that less than 9% of GKM stars have a 3-12 Jupiter-mass planet between 50-250 AU.

An extension of the GDPS survey, called the International Deep Planet Survey (IDPS), led by one of us (C. Marois) began in late 2007. The survey combines the use of the Gemini Telescopes, Keck, and VLT to acquire 1-2 hour ADI sequences of 100 nearby young, high-mass (*A*- and *F*-type) stars. The main goal is to remove the late-type bias of the GDPS and study planet formation for a wide range of stellar host masses. This survey made a breakthrough discovery

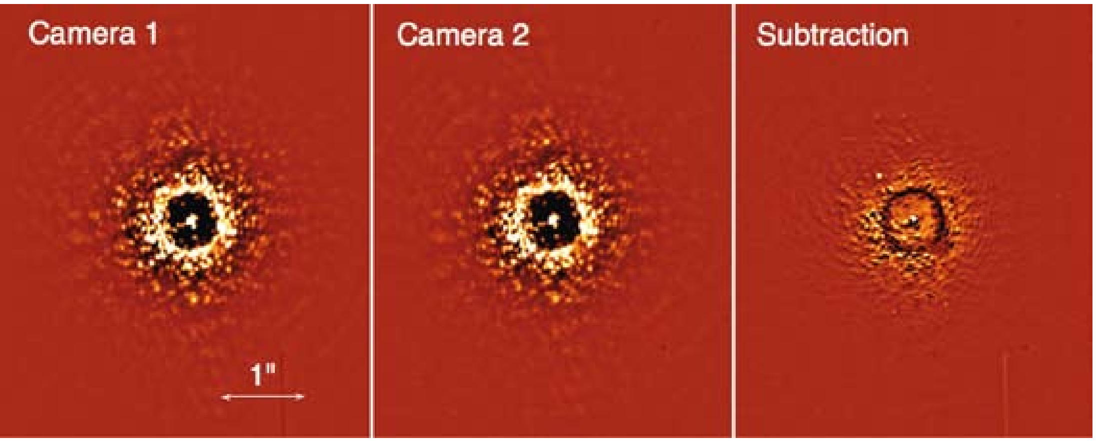


Figure 2.
Speckle subtraction using NICI's dualchannel cameras. The left and center panels are images of the same star taken at the same time at slightly different wavelengths. The difference between the two images is shown in the right-hand panel. The darker circle in the center is due to the coronagraph (which allows about 1% of the star light through so the precise location of the star can be determined). This example is only one of many exposures that were taken of this star, with the cassegrain rotator stationary, so any possible real planets would appear to rotate around the star in subsequent exposures. For more details on this technique (called ADI) see page 45 for descriptions of the ADI technique.

in 2008 when the HR 8799 planetary system was first imaged at Gemini (see Figure 1, previous page). The survey is still ongoing and follow-up observations are being done on other candidate planets. (Each candidate needs to be acquired at two epochs to confirm that the object is in orbit around the star and not an unrelated background object.)

The NICI Planet-Finding Campaign

Gemini's latest exoplanet finding campaign is the NICI Planet-Finding Campaign, being carried out at Gemini South and is led by one of the authors (M. Liu). The survey started in December 2008 and is in the process of imaging about 300 nearby young stars. The NICI Planet-Finding Campaign assembles a large-scale coherent science program with a unified set of goals, observing methods, and data analysis techniques. This is the first such large official campaign being carried out by the Gemini Observatory, and, accordingly, the NICI program is also intended to serve as a model for even larger Gemini observing projects carried out with future instruments.

The campaign is based on Gemini's latest facility instrument, the Near-Infrared Coronagraphic Imager (NICI). This is a powerful new AO instrument and, in fact, is the first instrument for any large (8- to 10-meter) telescope designed from the outset for direct detection of extrasolar planets through high contrast imaging. NICI was built by Mauna Kea Infrared (MKIR) in Hilo, Hawai'i, with Doug Toomey as the principal investigator (PI), Christ Ftaclas (IfA/Hawai'i) as the project scientist, and Mark Chun (IfA/Hawai'i) as the lead for the AO system.

NICI was designed as a complete end-to-end system for high-contrast imaging, minimizing the wavefront distortions from the atmosphere, telescope, and instrument. The heart of NICI is its dedicated, advanced AO system, based on an 85-element curvature-deformable mirror developed by the University of Hawaii's AO group. In addition, NICI employs all three of the observing methods described above—coronagraphy, SDI, and ADI—making it the first such instrument to use all these powerful techniques to perform a large exoplanet imaging campaign. As a result, NICI achieves excellent contrast and sensitivity to planetary companions around a large number of nearby stars.

Looking Ahead

Over its history, Gemini Observatory has played a leading role in the hunt for planets by direct imaging: deploying state-of-the-art AO systems, helping astronomers to develop innovative high-contrast observing strategies, and pursuing major dedicated surveys to search a large number of targets. This continuous support, and the use of powerful instruments and algorithms, led to the breakthrough discovery of the HR 8799 multi-planet system in 2007. And the major surveys being carried out now at both Gemini North and South telescopes promise to further stretch our horizons about planetary systems around other stars.

In addition to the two vigorous AO surveys currently ongoing, Gemini is also building a next-generation, fully optimized, exoplanet-finding instrument called the Gemini Planet Imager (PI Bruce Macintosh). This Aspen-derived instrument is scheduled for deployment in 2011. It is designed to detect and fully characterize Jovian planets located between 5 and 100 AU around nearby young stars. Gemini is definitely at the forefront of this exciting emerging field!

Christian Marois is a research associate at the National Research Council Canada Herzberg Institute of Astrophysics. He can be reached at: Christian.marois@nrc-cnrc.gc.ca

Michael Liu is an astronomer at the Institute for Astronomy at the University of Hawai'i. He can be reached at: mliu@ifa.hawaii.edu

by Dennis Crabtree

Time-Exchange Programs

Gemini, which provides telescope access for seven national communities, has a user base with very broad science interests. However, instruments for 8- to 10-meter telescopes are expensive. This makes it very challenging for Gemini to provide instrument capabilities that meet the full scientific needs of our diverse community.

Other 8- to 10-meter telescopes also face this challenge to various degrees, and in addition may not have access to both hemispheres. For example, Keck decommissioned their mid-infrared instrument several years ago. Also, the W. M. Keck and Subaru observatories do not provide access to the southern skies for their communities.

One obvious solution to this problem is to establish time exchange agreements between various facilities so that users can get access to a broader range of instrumentation. Gemini has been very active in providing access to an expanded instrumentation suite for our community by establishing time exchange programs with Keck and Subaru. (See the companion article by Tom Geballe on the early Gemini time exchange program with Keck (NIRSPEC) following this article.)

Time Exchange with Keck

Gemini's time exchange program with Keck provides access to the HIRES—the high-resolution echelle spectrometer (http://www2.keck.hawaii.edu/inst/hires/hires.html). This program began in semester 2005A. HIRES is a very powerful and successful instrument that provides spectral coverage between 0.3 and 1.0 micron with resolutions between 25,000 and 85,000. In exchange for access to HIRES, the Keck community can apply to use MICHELLE or the Near-Infrared Imager and Spectrometer (NIRI) on Gemini North or the Thermal-Region Camera Spectrograph (T-ReCS) on Gemini South.

While time exchanges are simple in concept, putting them into practice is a bit more complicated. Since Keck runs exclusively in classical mode, our agreement with Keck is to simply exchange classical nights. The base number of nights exchanged is five nights per semester, but can be lower if one partner's demand is lower.

Then there is also the issue of sky brightness to agree upon. Since Gemini is giving the Keck community access to infrared instruments, this is essentially bright time. However, HIRES is an optical instrument and some of the science requires, or at least would benefit from, being scheduled in dark time. Keck is very protective of their dark time, so the Gemini HIRES nights are scheduled in either bright or gray time, with the exact windows in the semester being advertised as part of the Call for Proposals.

In recent semesters, the actual number of nights exchanged with Keck has been less than five nights as a result of low demand for Gemini time from within the Keck community.

Time Exchange with Subaru

Gemini's time exchange program with Subaru has evolved since it began in semester 2006B. Initially, Gemini and Subaru exchanged 50 hours of queue time (service mode on Subaru) with the Gemini community having access to SuprimeCam (a wide-field optical imager) and MOIRCS (a near-infrared wide-field imager for which multi-object spectroscopy (MOS) capability became available in later semesters).

Subaru is classically scheduled, with specific nights set aside for service-mode observing. This is not the same as the Gemini queue, as the observing conditions cannot be guaranteed, and the observing time may be completely weathered out. Gemini observers, used to our queue model, expected that they would receive Subaru data taken in the conditions specified in the proposal, and problems arose when this didn't happen. After two (three for SuprimeCam) semesters of trying to exchange Gemini queue time for Subaru service time, both sides realized that this was impossible with the two very different operations models. Beginning with semester 2008A, the time exchange program with Subaru reverted to the Keck model of exchanging classical nights for classical nights with five nights being exchanged.

For semester 2010A the time exchange with Subaru has been expanded significantly. First, there are 5-10 nights available depending upon demand. The possibility of having access to 10 nights of Subaru time may increase the number of proposals from the Gemini community. At the Gemini Users' Meeting in Kyoto (see page 52), more than one person noted that they were discouraged from applying for the Subaru time because of the small number of nights available. Second, the instruments available on Subaru have been increased to include most of Subaru's instrument suite. This includes Subaru's High Dispersion Spectrograph (HDS) (http://www.naoj.org/Observing/Instruments/HDS/hds_umev111.pdf), a high-resolution echelle spectrograph providing a resolution of 95,000 with a 0.4 arcsecond slit. Wavelength coverage is from 0.3 – 1.0 micron.

Gemini is working to formalize the time exchange agreement with Subaru, and we hope to increase the amount of time exchanged to 25 nights. The amount of time exchanged will necessarily be limited by the demand from each side, with either partner able to establish a lower number of nights for a given semester if their community doesn't express sufficient interest. We hope to have an agreement in place with Subaru before the 2010B Call for Proposals.

Lessons Learned

Time exchanges can be a very effective approach for providing instrumental capabilities to the Gemini scientific community that are not available at Gemini. As in any barter agreement, each side must have something that the other side considers of interest. In this context, Gemini can provide:

- access to both hemispheres;
- excellent mid-infrared capabilities at both sites;
- laser guide star adaptive optics at Gemini North;
- multi-conjugate adaptive optics at Gemini South (future);
- cryogenic infrared multi-object spectrograph at Gemini South (future).

While we are working to expand the time exchange with Subaru, we are always exploring possible time exchanges with other 8-meter telescopes. These strategic time exchanges need to be kept in mind when developing future instrumentation plans. It may be more effective to exchange time to get access to an instrumental capability than it is to build a similar instrument for Gemini.

Dennis Crabtree is Gemini's Associate Director of Science Operations. He can be reached at: dcrabtree@gemini.edu

by Tom Geballe

Gemini Community Access to Keck in 2000-2001: Early Time-Sharing

In 1999, the Gemini and W. M. Keck observatories agreed to a unique exchange of assets. Gemini provided Keck with a science-grade Aladdin-I 1024 × 1024 InSb array for Keck's medium- and high-resolution near-infrared spectrograph, NIRSPEC. In return, Keck allocated three nights of observing with NIRSPEC per semester to the Gemini community for the next two years, beginning in semester 2000A. Science fellow Marianne Takamiya and I were given the task of conceiving, developing, and carrying out, on behalf of the Gemini partnership, an observing program that would utilize those twelve nights.

At that time, Gemini North was just entering its operations with a paucity of instrumentation, and Gemini South was still under construction. Gemini data were only slowly seeping out to the Gemini community. Marianne and I proposed to model the Gemini/NIRSPEC Program after the highly successful United Kingdom Infrared Telescope (UKIRT) Service Observing Program, in which investigators could easily apply for small amounts of observing time within a few weeks of the observing dates. We hoped that such an approach would give many astronomers across the community their first experience with infrared data from a large telescope.

Our suggestion was accepted by Gemini Science Committee and recommended to then Gemini Director (Matt Mountain), who gave us the go-ahead. We familiarized ourselves with NIRSPEC, created a website (still accessible at: http://www.gemini.edu/sciops/instruments/nirspec/nirspecindex.html) and an application form, assembled a small group of external scientific assessors, prepared to technically assess the proposals, advertised the program to the community, and awaited the response.

On the website we provide the following description of the program: "The primary selection criteria for the proposals are scientific quality, technical feasibility, efficiency, and observing time requirements... The primary

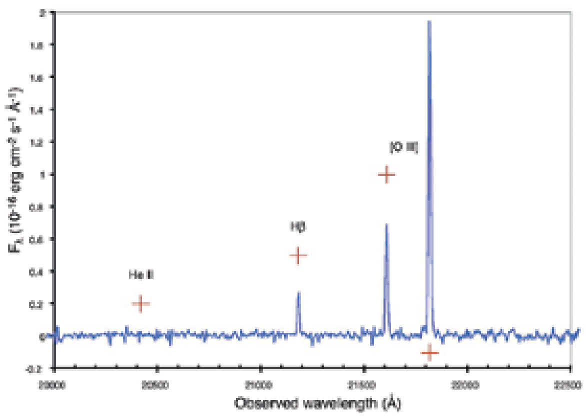


Figure 1.
The K-band NIRSPEC spectrum of the Lynx gravitational arc (z = 3.357), reported by Fosbury et al. (2003, ApJ, **596**, *797). Analysis shows that this remarkable arc is an H II galaxy containing roughly one million O stars, magnified by a factor of ~10 by a complex foreground cluster of galaxies.*

intent ...is to obtain science for the international Gemini community, which has many members and interests. It is expected that most proposals will request from one-half hour to a few hours of integration time. Unless a long program is judged to be superior to several shorter programs, it is unlikely to be done first."

The response from the community was overwhelming. A total of 179 proposals were received during the two-year period, covering a wide range of topics. The roughly 45 proposals per semester were far more than could be accommodated in three nights. Typically the 15-20 highest-rated programs were tentatively accepted, and only about half of these were attempted. The choice of which of these to observe was based on scientific priority, weather conditions, and brevity.

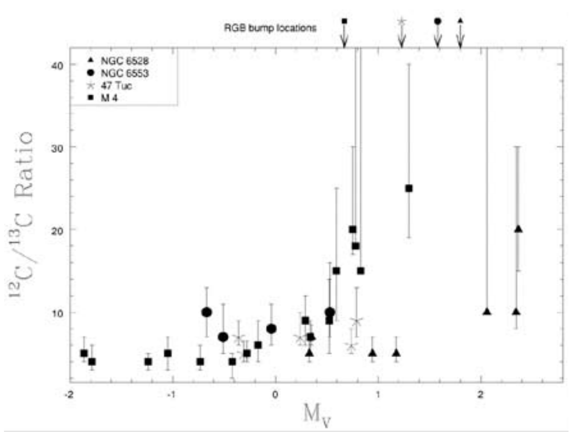


Figure 2.
A plot of $^{12}C/^{13}C$ versus absolute stellar magnitude for red giants in four globular clusters, showing different values of $^{12}C/^{13}C$ above and below the bump in the luminosity function (BLF). Gemini/NIRSPEC data are denoted by triangles. These observations, reported by Shetrone (2003, ApJ, **585**, *L45) are the first time that the predicted decline of $^{12}C/^{13}C$, due to extra mixing at the BLF, was detected in globular clusters.*

Now, eight years after the end of the program, we can perhaps at last tally the final results. Despite poor weather on four of the 12 nights, and several hours of good weather lost to technical problems, high-quality data were obtained for roughly 25 programs. At present, at least 14 refereed papers (the most recent of which appeared in early 2009) and at least as many contributed papers and posters have resulted from the Gemini/NIRSPEC Program. The first authors of the refereed papers come from four of the seven partner countries: the U. S., UK, Brazil, and Australia, from Gemini staff, and also from Korea. The list of refereed publications can be found on the Gemini website at: http://www.gemini.edu/science/publications/gemini_keck.html

These papers report observations of a wide range of objects: $z = 6$ quasars, gravitationally lensed galaxies at high redshift, globular clusters, old metal-poor stars, young stars, and solar system objects. Two examples are shown in the accompanying figures. Figure 1, from a paper by British astronomer Robert Fosbury (of the European Southern Observatory) and collaborators shows the infrared spectrum of a galaxy at a distance of 11 billion light years that is undergoing an intense episode of star formation. As viewed at that distance such an event normally would be unspectacular. However, in this case the star-forming galaxy lies behind a cluster of foreground galaxies, whose gravity amplifies the light coming toward us by an order of magnitude.

In contrast, the data in Figure 2, measurements of the ratio of the two stable isotopes of carbon, are for stars in our own backyard, that is within the Milky Way. The rarer isotope, ^{13}C, is manufactured deep in a star and is mixed to the surface of the star during the star's red giant phase, reducing the observed value of $^{12}C/^{13}C$. The mixing is believed to proceed in two stages and these data, reported by University of Texas astronomer Matthew Shetrone, are the first time that the predicted decline of $^{12}C/^{13}C$ due to the second stage of mixing, at the so-called "bump in the luminosity function" in red giants, was detected in globular clusters. The Gemini/NIRSPEC contributions to this study were the observations of NGC 6528 (denoted by triangles) and clearly were key to establishing the result, because, unlike the data from two of the other three globular clusters, the NIRSPEC data included red giants both above and below the bump.

One two-hour NIRSPEC observation of the 3-micron spectra of Saturn and its largest moon Titan in November 2001 has resulted in four papers by an international team headed by Professor Sang Joon Kim of Kyunghee University in Korea. Three of these concerned Titan. The first reported the discovery of mesospheric line emission by several species of hydrocarbon. The second refined and expanded the analysis of the Titanian spectrum and provided much additional information on chemical abundances in the upper and lower atmosphere, as well as on the altitudes of cloud decks and haze layers. The third (published in 2009) reported the detection of additional molecular bands, for which laboratory data had been unavailable earlier.

In some ways, the Gemini/NIRSPEC program, although limited to one instrument, can be considered a forerunner of queue observing and Director's Discretionary Time at Gemini. On each night of the program, sky conditions as well as scientific priorities influenced the observers' on-the-spot decisions as to which program to observe. Advances in astronomy clearly require time-consuming observing projects as well as quick looks. Nevertheless, it is interesting to note how programs such as this one, involving only short projects, can result in high publication rates compared to normal classical or queue observing.

The success of the Gemini/NIRSPEC program was due in large part to the support of the staff of the W. M. Keck Observatory. The program is also indebted to Professor Ian McLean of UCLA, who built NIRSPEC and provided helpful advice to the observers, and to the referees who volunteered many hours of their time: Beatriz Barbuy, Antonio Chrysostomou, Malcolm Coe, Fred Hamann, Tim Heckman, Robert Howell, George Mitchell, Keith Noll, Steve Rawlings, Kris Sellgren, Verne Smith, David Tholen, Chris Tinney, and Sylvain Veilleux.

Tom Geballe is a staff astronomer at Gemini North. He can be reached at: tgeballe@gemini.edu

by Jean-René Roy, Atsuko Nitta
& Nancy A. Levenson

Joint Gemini/Subaru Science Meeting & 2009 Gemini Users' Meeting

Figure 1.
Participants at the 2009 Gemini/ Subaru Science Meeting in Kyoto, Japan.

Set among the historical setting of the old capital city of Japan, Kyoto, about 200 users and staff of the Gemini and Subaru observatories and of the National Gemini Offices participated in the first joint Gemini and Subaru science conference, from May 18 to 22, 2009. The meeting was held in the Clock Tower Centennial Hall of the University of Kyoto.

The five-day meeting provided a unique opportunity for participants to share a wide range of research topics spanning studies of our solar system and exoplanets, super-metal poor stars, cosmology and the high redshift universe. Users also discussed innovative observing techniques and unique collaborations, while they looked toward the future of both observatories and at how we can work together to best serve very demanding users while remaining competitive. In particular, methods and procedures for coordinating the use, planning, and construction of future instruments were discussed, as well as expanding the exchange of observing time, which would take advantage of the complementarity of the strengths of Gemini and Subaru (see articles on time exchange programs starting on pg. 47).

The conference concluded with the 3rd Gemini Users' Meeting on Friday, May 22, when Gemini staff updated users on issues related to doing science on Gemini and provided a forum for user input. Several Japanese astronomers attended the Gemini Users Meeting as well. Members of both communities expressed a strong desire to see the observing exchange program between Subaru and Gemini expanded significantly to a larger number of nights per semester with all instruments of both facilities made available, which has begun for 2010A. (Through 2009B, the exchange was for five nights/semester, using two instruments; now up to 10 nights may be exchanged, with Gemini user access to six Subaru instruments.)

The meeting included the rather dramatic announcement that Gemini's financial participation in the Wide-Field Multi-Object Spectrograph (WFMOS) would not proceed as planned, following the cancellation of the WFMOS Project by the Gemini Board. Details on this announcement can be found in the Gemini Board WFMOS Resolution at: http://www.gemini.edu/node/11260. Gemini's Director, Doug Simons, made the announcement at the opening of the conference and emphasized the fact that future collaborations between Gemini and Subaru are still a core foundation for the two observatories. "While I'm extremely disappointed about the status of Gemini's participation in WFMOS, we are still committed to a partnership with Subaru to best serve our user communities," said Simons.

The two main goals of the conference were to promote a mutual understanding of both communities and to highlight the international nature of modern astronomy.

These goals were clearly achieved through the presentation and discussion of new ideas, the fostering of collaborations, and the building of new friendships. The sharing and interactions were helped by several activities such as a tour of

Figure 2.
Noboru Ebizuka of Nagoya University shares a poster with Gemini's Bernadette Rodgers.

Buddhist temples in the beautiful northern hills of Kyoto. The evening banquet on Wednesday, May 20, was a lively get-together, and many participants had the opportunity to get introduced to lesser-known aspects of Japanese culture. Before and after the meeting, several attendees took vacations to discover more about this fascinating country.

The scientific and logistical success of the joint conference was in large-part due to the efforts of the scientific and local organizing committees (SOC and LOC). The SOC was led by two co-chairs Masashi Chiba (Tohoku University) and Timothy C. Beers (Michigan State University). The LOC was chaired by Kouji Ohta (Kyoto University). On behalf of all the participants and users of the Gemini and Subaru Telescopes, we also wish to acknowledge the support provided by the members of the SOC and LOC:

Masashi Chiba (Tohoku University) Co-Chair
Toru Yamada (Tohoku University)
Motohide Tamura (NAOJ)
Kazuhiro Shimasaku (University of Tokyo)
Yoshiko Okamoto (Ibaraki University)
Kouji Ohta (Kyoto University)
Timothy C. Beers (Michigan State University) Co-Chair
Isobel Hook (Oxford University)
Chris Packham (University of Florida)
Scott Croom (Sydney University)
Marcin Sawicki (St Mary's University)
Local Organizing Committee (LOC)

Kouji Ohta (Kyoto University) CHAIR
Hajime Sugai (Kyoto University)
Tomonori Totani (Kyoto University)
Hideko Nomura (Kyoto University)
Atsuko Nitta (Gemini Observatory)

Figure 3.
Gemini's Jean-Rene Roy (now at the NSF) speaks at the meeting's banquet.

Figure 4.
Participants at the Gemini/Subaru Science Meeting banquet.

Finally, we wish to highlight the masterful leadership and careful management of Kouji Ohta and his team at the University of Kyoto for a very smooth meeting: in particular the cautious behind-the-scene handling of the threatening uncertainty that the H1N1 pandemic was casting on the conference. Luckily the University of Kyoto did not shut down (as was possible), and we used their excellent conference facilities to the very end of the conference and for the 2009 Gemini Users' Meeting.

The two previous Gemini Science Conferences were held in May 2005 in Vancouver, Canada, and June 2007 in Foz do Iguaçu, Brazil.

Jean-René Roy is Senior Scientist at Gemini Observatory and is currently on leave of service in the Large Facility Project Group at the National Science Foundation. He can be reached at: jrroy@gemini.edu.

Atsuko Nitta is a Gemini science fellow at Gemini North. She can be reached at: anitta@gemini.edu

Nancy Levenson is the Gemini Deputy Director and Head of Science at Gemini South. She can be reached at: nlevenson@gemini.edu

by Dennis Crabtree

On-site Observing with the Gemini Telescopes

When most observers hear of on-site observing, they automatically think of visiting the telescope as a classical observer. While Gemini supports classical observing runs, 90% of the scheduled time is in queue mode, which does not require anyone from the program team to be present. However, having a program in the queue does not preclude a visit to the telescope and participation in the execution of your program.

A visiting observer for a classical run will typically come a day or two before their observing run starts and leave almost immediately after the end of the run. They may be at Gemini long enough to give a colloquium, interact with a few staff members, and perhaps go out for lunch. Of course, nothing stops the visiting classical observers from staying longer if they wish!

Gemini welcomes visits from either the principal investigator (PI) or co-investigators (co-I) on queue programs. Ideally, the visit will be scheduled during the period of the year when the queue program is most likely to be observed. We encourage queue visitors to come to Gemini for a period of at least a week, perhaps even longer if they are students.

A typical visit by a queue observer will include the visitor talking with various Gemini staff to learn how the Gemini queue is populated, optimizing their Phase II with their contact scientist, and learning a bit more about how Gemini really works. It is very worthwhile for a visitor to spend time with the queue coordinator on duty to understand the factors that determine how the nightly plans are populated. Gemini will make every effort to ensure that the visitor's program is in the queue during the period of the visit. Of course, the program will not be executed unless the observing conditions match those required by the program.

The visitor will then spend a few nights at the summit to see night-time operations. Hopefully, he or she will get to see their program being executed (and most likely run the telescope for these observations) and have a chance to look at the data to ensure everything is working as planned. One of the benefits of visiting during queue operations is that the visitor gets an opportunity to see other instruments being used for a variety of science programs. And the night may be livened up by a "slew now" GRB Target of Opportunity observation!

In our experience, the students associated with queue programs who visit Gemini are the ones who benefit the most. The students get a chance to experience the complete range of workings of a modern observatory. They can spend time talking to their contact scientist about their program, talk with others on staff with similar science interests, participate in colloquia and science coffees, learn about our instrument development (particularly Multi-Conjugate Adaptive Optics (MCAO)) if they visit Gemini South) and participate in queue observations for their programs and others. Those who visit Gemini South also get a chance to sample local Chilean culture and activities.

Once visitors have data for their programs, they can get advice on data reduction or plans for follow-up observations with the same instrument or perhaps another of Gemini's instrumentation suite. Students are encouraged to give a science lunch talk or a colloquium during their visits.

All visiting queue observers, in particular students, have found their visits to be a rewarding experience.

For details on arranging visits to either Gemini site please see: http://www.gemini.edu/sciops/visiting-gemini/

Dennis Crabtree is the Associate Director of Science Operations and located at Gemini South. He can be reached at: dcrabtree@gemini.edu

The visit to Gemini South was a unique and valuable experience. Being a beginner in near-infrared spectroscopy and the only Phoenix user at University of Toronto Astronomy, it was difficult for me to follow all the instrument details and data acquisition requirements at the beginning. During my visit to Gemini South, I worked closely with the instrument scientist German Gimeno to learn about details of Phoenix data reduction and analysis. I also worked on the summit for six nights and participated in queue observations with various instruments, including Phoenix, GMOS, and T-ReCS. During the Phoenix observations, I learned about the data acquisition process, which was extremely helpful for me to better understand the intricacies of the observations. I also learned about the instrument capabilities of GMOS and T-ReCS which may be useful in future research.

Furthermore, I interacted with many Gemini staff and visitors, gaining alternate perspectives on my project. The visit allowed for an opportunity to absorb much more information than would be possible during a short visit associated with a classical observing run.

Sherry Yee
Ph.D. student – University of Toronto

by Eric Tollestrup

Planning for Gemini's Future Instruments

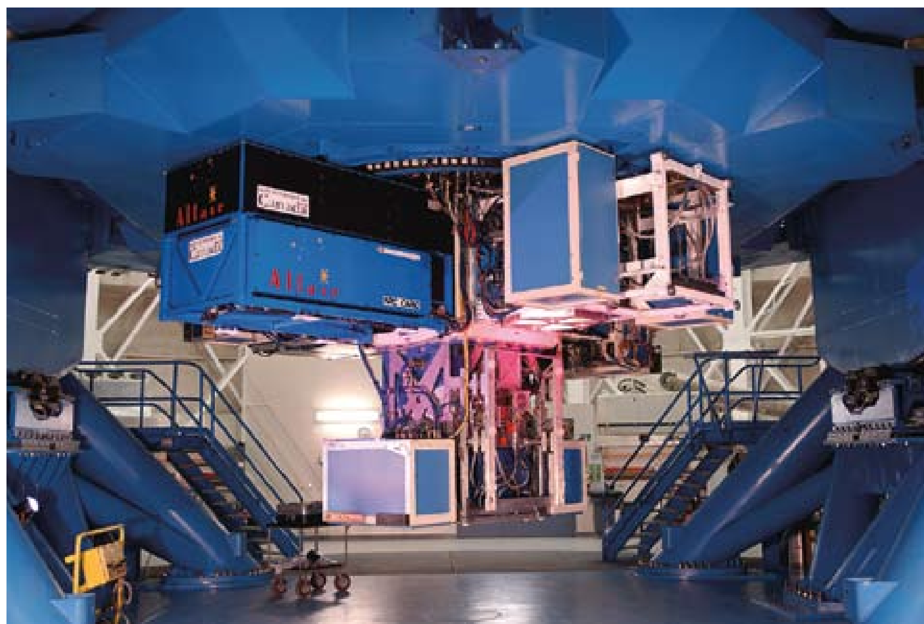


Figure 1. *Gemini North's instrument cluster, showing the current generation of instruments (without NIFS).*

As Gemini approaches its 10th anniversary, we are reminded that many of the instruments that shared first light with the telescopes—the first-generation instruments—have reached obsolescence and need to be replaced. Moreover, as we all know from our everyday experiences, technology evolves at an ever-increasing pace. This is also true for astronomy-related technology too, and these new technological advances beckon us to enrich our scientific capabilities through newer, better instrumentation. Therefore, at Gemini we have embarked on a new round of selecting the next generation of instruments (the fourth) to replace our older, more cantankerous, though inanimate friends.

So, how is this instrumentation selection done? Who is involved? The short answer to the latter is, "all of us in the Gemini community." How the selection process happens is an interesting story that everyone in the community should know about so they can participate in the decision-making. After all, without great instruments, a telescope is not much more than a wonderful expression of modern engineering prowess.

For an insightful perspective, a review of the past is instructive. In May 1994, the Gemini Board approved the first generation, or Phase I, instruments:

Mauna Kea:

- Optical Acquisition Camera;
- 1- to 5-micron Imager;
- 1- to 5-micron Spectrograph;
- Multi-object Optical Spectrograph;
- 8-to 30-micron Imager (shared);
- Canada-France-Hawai'i Telescope (CFHT) Fiber Feed;

Cerro Pachón:

- Optical Acquisition Camera;
- Multi-object Optical Spectrometer;
- High Resolution Optical Spectrograph (HROS);
- Shared Instrument with CTIO;
- 8- to 30-micron Imager (shared).

The resulting instruments included the Near-infrared Imager and Spectrometer (NIRI), Gemini Near-Infrared Spectrometer and Imager (GNIRS), Gemini Multi-Object Spectrometer (GMOS (N and S)), High-Resolution Optical Spectrometer (HROS (later to be bHROS)), Thermal-Region Camera Spectrometer (T-ReCS), acquisition and guiding cameras (not intended for science but GMOS-N/S fulfills the need for optical science cameras) and, due to limited budgets, the shared mid-infrared instrument MICHELLE (from the United Kingdom Infrared Telescope (UKIRT)) and 1- to 5-micron spectrometer Phoenix (from the National Optical Astronomy Observatory (NOAO)). Except for bHROS, all of these instruments are still actively used, though bearing the burdens of old age. These first instruments were envisioned as "workhorses." Adaptive optics systems were also part of the facility development, from which Altair resulted.

In the June 1996 issue of the Gemini Newsletter, then-director Matt Mountain first presented to the Gemini community the initial thinking on the Phase II instruments, where the emphasis was on upgrades to the Phase I instruments and on instruments that "targeted unique capabilities that the Gemini telescopes offered for instrumentation." This thinking was later refined into a set of recommendations by the first International Gemini Instrumentation Workshop, held in Abingdon, England, in January 1997. The "Abingdon" instruments that became reality were the Laser Guide Star mode for AO, the integral field unit (IFU) for GNIRS, NICI, NIFS, FLAMINGOS-2, and eventually Multi-Conjugate Adaptive Optics (MCAO)/ Gemini South Adaptive Optics Imager (GSAOI).

In November 2003, the Gemini Board approved key aspects of the Gemini Aspen Instrumentation Workshop, which led to Gemini's third-generation, or "Aspen," instruments. This generation of instruments was the most ambitious and technologically challenging suite of observing technologies seen thus far. By 2011 we should see the fruits of this endeavor with the commissioning of the Gemini Planet Imager (GPI).

Along the way there were additional visitor instruments, such as OSCIR, Hokupa'a-36/85, FLAMINGOS-1, CIRPASS, and TEXES, all of which helped fill in missing or niche capabilities. The bottom line is that Gemini and its community have always striven to provide the best instruments in an effort to capitalize on the outstanding capabilities of our two 8-meter telescopes.

As you may have noted, most of the instruments were initiated in (and therefore based on technology from) the 1990s. As we approach the second decade of the 21st century, it is time to retire or upgrade these senior citizens from the past millennium. The first step is already underway. The Gemini Science Committee (GSC), which reports to the director and advises the Gemini Board, has been developing a straw man list of possible instruments or capabilities as part of the long range planning for Gemini. This list is not definitive or exclusive, but is intended as a starting point to initiate discussions at the grassroots level—i.e., they are developing "talking points." Though the GSC has informally polled members of the community, and in this way has established a reasonable list of possible instruments. It is up to the community to build a consensus for the final recommendations for future capabilities or instruments for Gemini.

Next, over the course of 2010, each of the partner countries, lead by each National Gemini Office (NGO), will sponsor Town Hall-type meetings at their respective national astronomy conferences. These are intended to foster grassroots discussion from the community, and help determine each partner country's priorities and needs. The first of these Town Hall meetings for the U. S. community will be held as a special session at the American Astronomical Society winter meeting held in early 2010 in Washington, D. C. Similar meetings are intended for the Royal Astronomical Society National Astronomy Meeting in April, the CASCA meeting in May, the Astronomical Society of Australia Meeting in July, and the Brazilian Astronomical Society Meeting in September. These meetings are your opportunity to let your NGO know what is important for you as an observer on Gemini's telescopes. It is important to emphasize that Gemini Observatory representatives will be attending each of these Town Hall meetings to answer your questions and better understand the various subtle nuances that might arise. Since Gemini will have to successfully execute any final recommendation, it is very important to us to truly understand our community's desires.

Other meetings or avenues for input are possible, and interested Gemini community members should contact their NGOs to offer suggested input venues that would help this grassroots process. Already, some communities are conducting web-based surveys to gather information. One-on-one discussions with your NGO are encouraged too. As with a wedding, this is your chance to "speak now or forever hold your peace!"

The culmination of these grassroots efforts will be the third International Gemini Instrumentation Workshop (aka, the "A" meeting in reference to the previously mentioned Abingdon and Aspen workshops), during the middle of 2010. The intent of this third workshop is to merge together the interests of all the partner countries into a single set of recommendations to the GSC, which in turn can fine tune this into a recommendation to the director and Gemini Board for approval at the November 2010 board meeting.

The timing of this process is intimately connected to the next five-year budget and Gemini Cooperative Agreement (2011 to 2015) with the National Science Foundation (NSF), the executive agency that oversees Gemini Observatory. By having a proposed set of next-generation instruments ready for approval by the November 2010 Gemini Board meeting, the observatory can implement these instruments within the context of the next 2011-2015 budget and associated Cooperative Agreement.

So like an electioneer who cries, "If you care about the future of your country, vote!", we implore to you, as a Gemini user, "If you care about the future of Gemini, participate in Gemini Instrumentation, the Next Generation!"

Eric Tollestrup is Associate Director of Development at Gemini, located in Hilo. He can be reached at: etollest@gemini.edu

by François Rigaut
& Céline D'orgeville

MCAO Progress

Figure 1.
The laser service enclosure on the Gemini South telescope (silver box on altitude platform).

Two significant milestones were achieved over the past couple of months on the Gemini Multi-Conjugate Adaptive Optics System (GeMS) laser infrastructure.

The laser service enclosure (LSE) is the laser clean room designed and fabricated by Gemini to house the Gemini South laser for the GeMS project. The LSE was installed on the Gemini South telescope on August 13, 2009, changing the appearance of the facility from that of its twin in the north (see Figure 1). The large (8.5 × 2.5 × 2.5 meters) structure was mounted onto the new support structure that had been added to the side of the telescope about a month earlier. The LSE and its support structure add another five tons to the existing 340-ton weight of the telescope. A careful survey of the telescope, and laboratory testing of the LSE, ensured that the laser clean room could be installed in a single day without disrupting night-time operations. Performance of the 8-meter Gemini South telescope is unaffected.

Another significant milestone was reached on September 4, 2009, when Lockheed Martin Coherent Technologies (LMCT) delivered their sodium laser system to the W. M. Keck Observatory headquarters in Waimea. The Keck laser is the first of two such laser systems to be procured by Association of Universities for Research in Astronomy (AURA) on behalf of both the Keck and Gemini Observatories. Factory acceptance testing of the Keck laser in Colorado took place in July 2009, followed by about a month of retooling to address a few shortcomings. These were mainly software-related. Performance testing of the Keck laser demonstrated unexpectedly high output power at nearly twice the required 20 watts for this system, and near diffractionlimited beam qualities with M2 in the 1.1- to 1.2-micron range. Short-term and long-term laser performance stability, which is of critical importance to GeMS operations, is within specifications. This augurs well for future Gemini South laser performance. Factory acceptance of the 50-watt Gemini South laser system is expected to occur in Colorado before the end of the year, and delivery is scheduled in early 2010.

Things are also progressing well on the CANOPUS front (GeMS optical bench). After a full re-implementation of the static tomography high-level software, we were able to solve the tomographic compensation of the static non-common path aberrations, and reach Strehl ratios of 96% +/- 1% at 1.65 microns simultaneously over the entire output field of view. The specification was 94% +/- 3, so we are clearly better. This shows that we understand the system, its calibration and non-linearities fairly well. It also proves that there is very little aberration (50 nanometers or less) outside of the altitude range (0 to 9 kilometers) correctable by the three deformable mirrors.

As announced in the last *Gemini*Focus GeMS update, we went through a maintenance and upgrade of the CANOPUS real-time computer last June, working with an engineer from the Optical Science Company (tOSC). We were able to fix a number of bugs and implement long-needed features. The contract with tOSC is now essentially closed. The real-time computer is performing well, and has been extensively tested while it has been used almost daily for the past year and a half.

Concerning high-level operational software, our high-level engineering interface, MYST (MCAO Yorick Smart Tools) has also reached stable status. In the coming months, we will implement operation features in MYST, such as high-level loop control and sequencing, high-level status checks, and adaptive optics performance optimizations. The Observing Tool modifications to accommodate GeMS and Gemini South Adaptive Optics Imager (GSAOI) are also essentially complete (at least for a basic set of functionalities, more features will come with the mid 2010 release), and feature user-friendly multi guide star selectors, and other features.

On July 27, in a ceremony at the offices of the Dirección General de Aeronáutica Civil (DGAC, the Chilean equivalent of the US Federal Aviation Administration), and after several months of negotiation, AURA signed the umbrella agreement that covers the collaboration between AURA and the DGAC in support of the safe operation of laser guide star systems at the AURA observatories in Chile. This agreement achieves an important milestone in our progress toward operating the variety of laser systems that are coming to Cerro Pachón in the near future, including (in probable order of initial use) Andes LIDAR, the Gemini Multi-Conjugate Adaptive Optics (MCAO) system, and the SOAR ground layer adaptive optics system.

In parallel, we are progressing in our negotiations with VIA56, a company DGAC has been working with to implement similar applications. Using data from Chilean radar coverage, the software provided by VIA56 gives the location of any aircraft in our area. A side benefit is that it allows us to have some advance notice of a possible laser shutter, which gives us some amount of flexibility to finish an exposure and/or to switch to an alternate program before we have to shutter. Our All-Sky Camera (ASCam, see earlier *Gemini*Focus issues) still provides a backup plan.

Finally, we have had some help for the last few months from German Fernandez, an electronics engineer from El Observatorio el Leoncito, Argentina, who has been working half time (two weeks per month) on the electronics for the new cooling system on the MCAO bench.

François Rigaut is the Adaptive Optics Senior Scientist and located at Gemini South. He can be reached at: frigaut@gemini.edu

Céline D'orgeville is the Gemini South Senior Laser Engineer. She can be reached at: celine@gemini.edu

by Sarah Blanchard

The Greening of Gemini

Figure 1.
Cyclists like astronomer Rachel Mason appreciate the bike racks at both Gemini North and Gemini South Base Facilities.

Question: *How much energy does Gemini consume?*

Simple Answer: *A lot.*

First, consider electricity. In an average month, Gemini North consumes 232,600 kilowatt-hours (kWh) and Gemini South uses 246,000 kWh of electricity. Based on an average cost of U. S. $0.56 per kWh at Gemini North and an average cost of 82.29 Chilean pesos (about U. S. $0.14) per kWh at Gemini South, that translates to a total annual cost of nearly two million dollars and a contribution of more than 3,500 metric tons of CO_2 to the Earth's atmosphere.

Chile enjoys relatively low electricity costs, but energy costs in Hawai'i are among the highest in the United States. When energy prices soared in February 2008, the cost of a kWh in Hawai'i hit $1.07, pushing Gemini North's electricity bill above $240,000 for that month alone.

Then there's travel. During 2008, Gemini staff completed 616 trips by air, totaling nearly five million miles—the equivalent of almost 11 round trips to the Moon. That amount of air travel produced a carbon footprint of 2,426 metric tons of CO_2 in 2008. (A carbon footprint is the amount of greenhouse gases produced as the direct and indirect results of a human activity, usually expressed in equivalent tons of carbon dioxide. Generating electricity, using jet fuel, producing products or food—the carbon footprints for all these activities can be measured and tracked. See http://www.carbonfund.org for more information.)

Given those sobering statistics and our strong desire to be good stewards of our planet, we had to ask: How can Gemini reduce energy usage and manage our organization in a more sustainable way?

Planning for Sustainability

In mid-2008, faced with soaring energy prices and a growing awareness of our need to reduce energy use, Gemini Director Doug Simons asked Facilities Manager Peter McEvoy to begin an observatory-wide energy-reduction project by launching the "Gemini Green Blog," an internal forum that asked Gemini employees to submit their concerns, suggestions, and solutions for reducing our energy consumption and conserving resources.

The staff responded enthusiastically. Green Blog suggestions ranged from the large and complex ("install photovoltaic solar roof panels") to the simple and obvious ("set printer defaults to print on both sides of the paper," and "remind everyone to turn off lights when they leave their offices").

The Green Blog suggestions were grouped into categories: technology investments, transportation initiatives, behavioral changes, recycling, and materials reduction. These staff recommendations became the foundation for developing the plan for an observatory-wide 2009 Energy Initiatives project, aimed at reducing energy consumption through specific actions.

Figure 2.
Facilities Specialist David Moe sorts the recyclables at the Hilo Base Facility.

A second director's-level Band One project—Energy Planning Oversight and Control—was also launched to address the ongoing requirements for long-term energy monitoring and conservation. Together, these two initiatives reflect the need for immediate solutions as well as overall changes to the way Gemini Observatory monitors, consumes and conserves energy.

Setting the Stage for Success

Adopting "green" standards and behaviors requires commitment, a willingness to look critically at the way our facilities are presently operating, and an eagerness to find opportunities for improvement. Gemini's answer to these challenges has been an enthusiastic "Yes!"

The Energy Planning Oversight and Control Committee (EPOCC) first convened in January 2009 to lead both projects. Members of the EPOCC include observatory director Doug Simons and several employees from the departments with direct responsibility for managing energy purchase and consumption: engineering, facilities, information systems, administration, and finance.

The committee's initial goals were to:

- develop an energy plan and mission statement to reflect Gemini's commitment to energy efficiency;
- implement obvious and immediate energy-saving actions;
- create strategies for continuous improvement;
- make changes that are acknowledged to be the "right thing to do," even if they don't result in immediate cost savings to Gemini (e.g., recycling, proper disposal of hazardous materials, sourcing products produced from renewable energy sources, requiring vendors to follow green practices).

Immediate Improvements

After we analyzed the recommendations in the Green Blog, we found several areas for immediate and simple improvements. Over the past six months, here's what we've accomplished.

Reducing off-hours energy use in both base facilities. Although Gemini runs 24/7/365, not all of our office equipment needs to do so. We conducted energy audits to review what's plugged in and when, and what pieces of equipment can be unplugged or turned off when not in use. We found more than 400 pieces of electrical equipment plugged in at each site, and more than a hundred turned on although they were not being used. These initial findings suggest we might save about U. S. $10,000 a year by turning off all unneeded electrical office equipment. Simply identifying and communicating this issue to our staff has helped us reduce the number of items left plugged in when they're not required.

We've tested and installed motion sensors to automatically turn off lights in some areas at the South Base Facility (SBF) and on Cerro Pachón, and we're in the process of installing motion sensors in other areas, both at Gemini North and Gemini South.

Our Information Services Group (ISG) is also helping us create energy-saving efficiencies by introducing new technologies and a new computer-monitoring system that provides system-wide information such as uptime and usage statistics. These data will help us track redundant machine use, highlighting where further off-hours savings can be made. (This system also saves time and effort, making it easier for ISG to deploy computer configurations, software installations and patch management.)

Maximizing printer and computer efficiency. By installing transparent printer services for UNIX and Windows users, ISG has reduced the need to install multiple printer drivers, and duplex printers can be automatically configured to print two-sided as the default option. This service also helps monitor printer usage. Gemini South Network System Administrator Chris Morrison notes that in 2008, 68,412 pages were produced by the printers connected to the universal printer server. (Approximately eight trees were required to create those 68,000 pages of paper.)

Another major energy-saving step is to consolidate Gemini's network resources through virtualization, which uses a distributed power management system to monitor resource needs and power down unneeded servers without negative impacts to applications or users. With virtualization, work demands are balanced and consolidated among networked servers and work stations to provide greater efficiency, saving kWhs and CO_2 in required cooling. Virtualization also provides significant additional savings in physical hardware and maintenance costs. Our progress in this direction will include further user consultation and careful implementation.

Improving the efficiency of the air conditioning and heating systems at the base facilities. We installed programmable thermostats in office areas at the Hawai'i base facility (HBF) and programmed the air conditioning units to run only as needed. (Estimated savings: 200 kWh per day.) To help our Hawai'i staff members stay comfortable during hours when the AC is off, HBF has also purchased several portable fans for office use. At Gemini South, the same practice has produced similar savings, and we've also purchased several portable heaters for anyone working outside normal office hours during the winter months in La Serena.

Two older air conditioning units at HBF have been replaced with newer, more efficient models. (And we've received more than a thousand dollars in rebates from Hawai'i Electric Light Company as an added bonus.) Bids are being developed for similar chiller upgrades at SBF.

Improving the efficiency of the air conditioning systems at the telescopes. One of the biggest challenges has been to identify opportunities for energy savings at the two telescopes, which consume 70 to 80 percent of Gemini's total electricity needs. Air currents caused by warm air inside the dome and cooler air outside can play havoc with local seeing conditions, and can damage instruments through thermal changes and condensation. So the temperature of the telescope itself, the equipment and instruments, and the inside of each observatory must match the expected night-time temperature. Humans and equipment working inside the observatory create heat, so air conditioning is vital. And, anything with a large thermal mass—including the primary mirror—must also be temperature controlled. Therefore, observatories demand a great deal of energy for air conditioning.

At Gemini South, we've implemented a new program for the device that controls the way the observing floor is cooled at the beginning of the observing night. This is expected to produce a double benefit of significant annual energy savings as well as contributing to improved local seeing conditions at the beginning of the night. Its impact is being studied for consideration at the Gemini North telescope too.

Ironically, the harsh winter of 2008-2009 at Gemini North caused our energy use (and costs) to drop dramatically when compared to the previous winter, because the snow and ice prevented the dome from being opened on many nights—thus reducing the amount of energy needed to provide air conditioning.

Increasing our employees' awareness of the energy costs in travel. Effective astronomy research requires international collaboration, and travel between our two telescope sites by key personnel is especially important to Gemini's continued success. However, we're now encouraging staff to limit travel whenever possible, increase their use of interactive technologies for collaborative communication, and try to reduce Gemini's overall travel carbon footprint. We maintain a "Gemini carbon footprint database" which is updated every month to inform travelers about the carbon impact for each trip.

Promoting efforts to reduce, re-use, and recycle. Gemini has installed recycling bins wherever practical at both summit and base facilities for paper, cardboard, returnable beverage containers, batteries, plastic, and metal. We encourage staff members to bring cups, mugs, plates and utensils for use in the office, to eliminate, whenever possible, the use of disposable kitchenware.

As Gemini director Doug Simons has stated, "Energy is simply too precious a resource to use without a careful, deliberate approach to managing it." Besides, this is simply the right thing to do.

We've also standardized disposal procedures for electronic and hazardous waste, such as computer equipment and non-rechargeable batteries. We've purchased rechargeable batteries and set up battery-charging stations at HBF, SBF and the two telescope facilities to provide AAA, AA, C, and D batteries for portable tools, flashlights, and wireless equipment, such as computer mice and keyboards.

Reducing energy used in transportation. Gemini South has limited its number of vehicle trips between the base and the mountain by developing a collective transport solution that involves the use of a 37-seat passenger bus (one round-trip per day, mainly for day crew), and a combination of a 9-seater Mercedes passenger van and a double-cab Ford F-150 (for use with light cargo and in bad weather or heavy terrain conditions), used by all staff.

Gemini North is working with Mauna Kea Support Services and other Mauna Kea observatories to determine the feasibility of a similar shuttle service that would provide transportation from base facilities to the Hale Pokahu lodge. Additional solutions are also being considered to reduce transportation costs and the impact of vehicles on the mountain, while still maintaining high standards of safety for our staff.

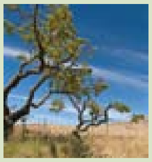
Bicycle racks are in regular use outside the offices at both Gemini North and Gemini South base facilities as well (see page 62).

LEEDing the Future

These recent initiatives represent definite process improvements, but we recognize them as piecemeal at this stage—just a good start, according to our initial plan. We know we have a long way to go on a steep learning curve, as we integrate this forward-looking philosophy into the organization. So, we are reviewing and fine-tuning the advances already made, as we consider opportunities for additional improvements. Ultimately, we want to see "green" practices become simply "business as usual," regardless of whether energy prices rise, fall, or remain the same.

So, to help us formalize our long-term energy strategy, Gemini has become a corporate member of the U. S. Green Building Council, the organization that administers the Leadership in Energy and Environmental Design (LEED) Green Building Rating scheme. We plan to use the LEED program for Operations and Maintenance in Existing Buildings as a roadmap for our energy conservation and sustainability efforts in the future, using their very detailed guide to help us plan Gemini's further initiatives.

Sarah Blanchard is the Administration and Facilities Team Leader at Gemini North. She can be contacted at: sblanchard@gemini.edu



THE GEMINI GREEN MISSION STATEMENT:
"Exploring the universe, caring for Earth"
"Explorando el Universo, cuidando la Tierra"

GEMINI'S GREEN PRINCIPLES:

- *Gemini aims to be one of the most energy-efficient major astronomical facilities, with the highest standards of environmental protection.*
- *As part of Gemini's purpose to "explore the universe and share its wonders," we are responsible and accountable for our actions. We will carefully consider and protect Earth's valuable environmental resources, while fulfilling our commitment to science and applying solid financial principles to our operations.*
- *Gemini is committed to operating responsibly in the interests of our communities, local and global, now and always. Our corporate citizenship promotes sustainability through effective, efficient operations and positive environmental stewardship.*

GEMINI WILL:

- *ENGAGE our employees' inventiveness and enthusiasm for a green working environment.*
- *INCLUDE energy efficiency and environmental considerations as an integral part of our business planning and decision-making processes.*
- *MEASURE our energy efficiency and environmental achievements.*
- *COMPLY with all relevant legislation and, wherever appropriate, seek to adopt more stringent standards of energy efficiency and environmental excellence.*
- *REDUCE consumption whenever possible, as we constantly assess our use of goods and services, travel and communications.*
- *USE recycled products wherever practical.*
- *RECYCLE, whenever possible, acquired goods and consumables at the end of their useful life.*
- *PROMOTE the highest possible standards of energy efficiency and environmental protection among our suppliers and partners.*
- *COMMUNICATE regularly with our employees and stakeholders to increase everyone's understanding and support for energy efficiency and environmental protection.*

by Neil Barker

Broadening Participation at Gemini

Gemini has always taken seriously its important role in the global astronomical community, as well as the need, through education and outreach, to inspire current and future generations in the wonders of the universe.

Figure 1. *Vincent Fesquet works with intern Lucia Poláková as part of the Akamai internship program in Hawai'i.*

Thanks to our international partnership, our two remote locations in Hawai'i and Chile, and our hiring practices, today's diverse Gemini staff originates from 20 countries around the world. Against a background of changing demographics, however, our future success depends upon inspiring the next generation from the broadest and most diverse audience possible. This will allow us to continue achieving excellence in our organization and the scientific community as a whole.

During 2009, Gemini embarked on an initiative sponsored by the Association of Universities for Research in Astronomy (AURA) to broaden participation in our future workforce. Historically, women and individuals from minority groups, and those with disabilities, have been underrepresented in astronomy. Gemini has been very successful at attracting female astronomers who make up about 30% of our Ph.D. science staff. Furthermore, the Gemini senior leadership team originates from three continents and has 50% female representation.

Figure 2.
Gemini South Science and Engineering staff planning for nighttime operations.

The objective of this initiative is to strenghten participation of women and underserved communities within our future workforce, as well as the smaller, or geographically-dispersed institutions, that use our facilities. This is not a straightforward exercise, with diversity issues being woven deeply into the political, social and economic fabric of society. However, this initiative, which Gemini has embraced, is integral to the success and future of astronomy, especially in a world that is competing for increasingly scarce resources.

How are We Going to Achieve This?

1. AURA has published an extensive action plan to highlight the principles, goals, and strategies for broadening participation at AURA facilities see: http://www.aura-astronomy.org/diversity/actionplan.asp A workforce and diversity committee, made up of experts in diversity and education, has been established to advise and support AURA. Within Gemini and the other AURA centers, a diversity advocate has been appointed to be the focal point for coordination of local Gemini and AURA initiatives.

Figure 3.
Gemini team at the Tucson Broadening Participation conference.

As Gemini's Recruiter, I have enthusiastically accepted this role on behalf of Gemini. The Diversity Advocate's role is envisioned as taking an overview of the human resource and outreach elements that affect under-represented minorities, women, and persons with disabilities.

2. The Gemini staff has also participated in an AURA Employee Climate Survey. This survey was generated across all AURA centers to improve our understanding of the employee climate. The survey has provided valuable feedback on perceptions of the climate within each institution. The results of the survey have been communicated to Gemini staff and action plans have been developed.

In April of this year, a Broadening Participation in Astronomy Workshop in Tucson, Arizona, brought together management, human resources, and outreach representatives from all of the AURA centers. The workshop featured presentations from leading scientific organizations, including NASA and the NSF. Each presentation provided insight into meeting the challenges of developing a future with a diverse workforce. The workshop culminated in a presentation to AURA member representatives which shared thinking from the workshop and some initial goals and asked for input from the member representatives present. Participants left the workshop inspired with many great ideas and the feeling that there was a real opportunity for change. There appeared to be overwhelming support for a call to action.

Following this inspiring and motivating conference, detailed planning has begun in order to develop, understand, and crystallize our goals and plans related to diversity over the next five years.

We have been asking some important questions in this process:

- How do we address the broadening participation initiative leveraging Gemini's unique international partnership and the location of our twin telescopes within Hawai'i and Chile?

- What will the future international workforce look like?

- What will attract people to work in astronomy and specifically to work at Gemini?

- How do we work with educators and professional bodies to inspire more people to pursue careers in astronomy and related fields?

- How do we better target under-represented groups within the United States and more broadly through our international reach?

- What role can Gemini and other centers play in this through outreach and work experience opportunities?

- How can our recruitment networks be expanded?

- How can we provide an environment that will balance employee and observatory needs in the future?

These are just some of the questions we are considering as we embark on this journey.

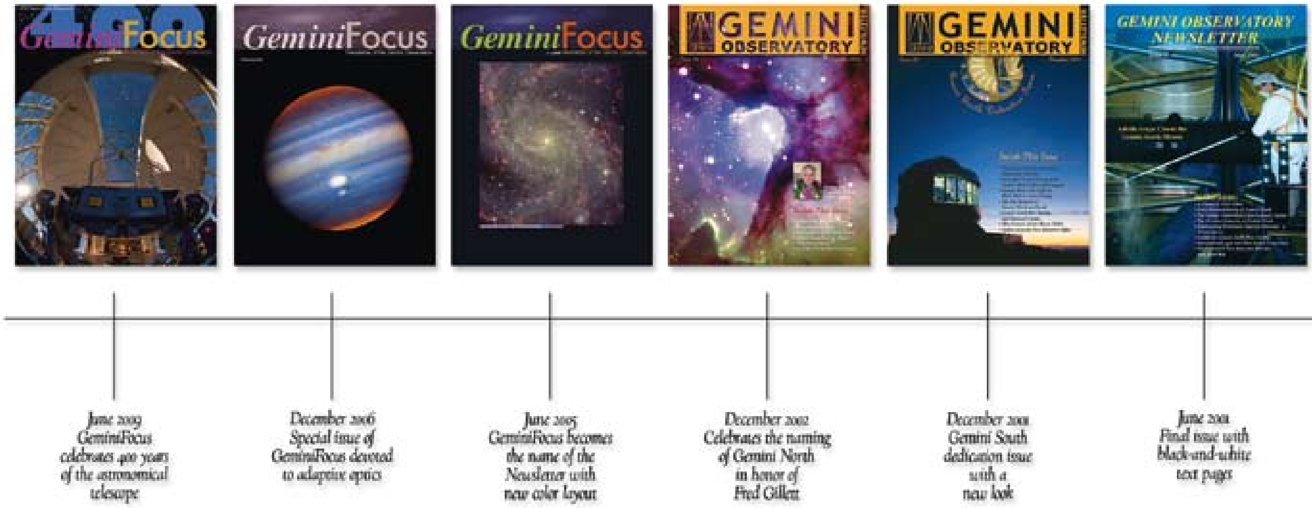
A closing remark from one of the member representatives at the Tucson conference resonates in my mind: "We can all talk about the need to change, but only through actually changing what we do will we achieve our goals."

For more information please contact Neil Barker (address below) and view the Broadening Participation Website at: *http://www.aura-astronomy.org/diversity/*

Neil Barker is the Recruiter at Gemini North. He can be reached at: nbarker@gemini.edu

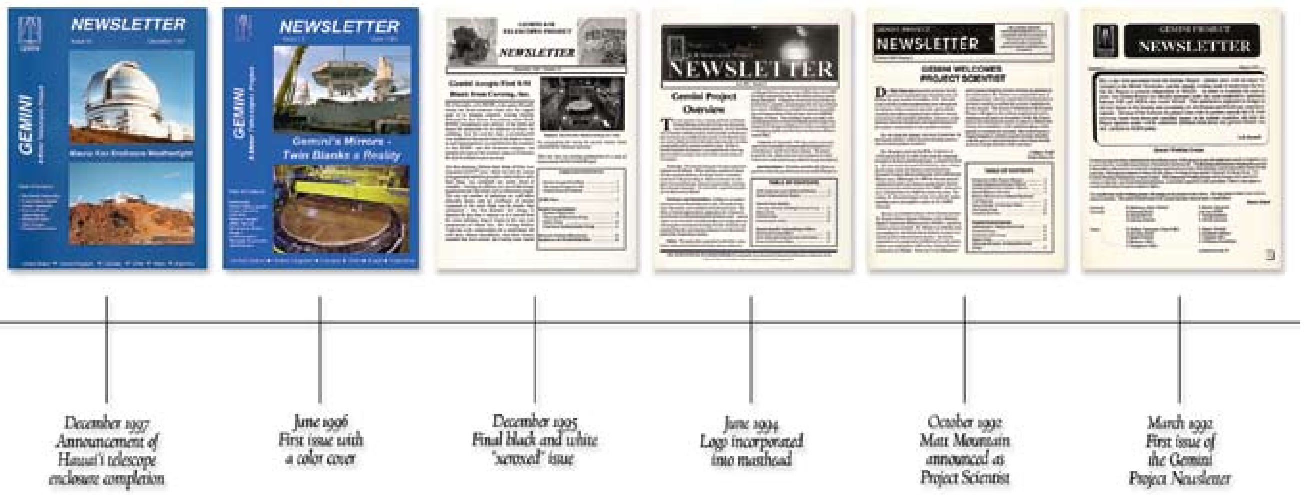
by Peter Michaud

Looking Ahead With Your Help



In March of 1992, the Gemini Project Newsletter was born with the rather matter-of-fact opening sentence: "This is the first newsletter from the Gemini Project." As we approach the 20th year of publication, it is time to re-evaluate the future of Gemini's key communication tool to our various communities.

As the montage above reveals, the Gemini Newsletter has evolved dramatically during its lifetime. From a very utilitarian collection of photocopied black-and-white pages, to the full-color publication you are looking at now, the Gemini Newsletter has matured in lockstep with the observatory. Today, *Gemini*Focus, the name adopted for the newsletter in 2005, is a publication produced by our staff and supported by our users; it is the observatory's flagship publication.



Of course, every publication has to plan for the future, and the future of any print publication looks very dynamic. As Gemini explores ways to communicate more effectively, efficiently, and with a greener global impact, we need you, our reader's input to determine the best way forward.

To that end, we have created a web-based survey to collect opinions on the evolution of this publication (see: *http://www.gemini.edu/gfsurvey*). If the web survey isn't able to capture your opinion, please send a note to the *Gemini*Focus Managing Editor, Peter Michaud at: *pmichaud@gemini.edu*

The staff working on *Gemini*Focus appreciate your input and time to help us plot this future. We hope this publication will continue to serve your needs as a user, associate, or interested layperson.

by María Antonieta García

Gemini's Rapa Nui Connection

Figure 1. *Students, teachers, tourist guides, hotel staff, and local firefighters prepare to enter the StarLab® portable planetarium after participating in a FamilyAstro workshop.*

The connection between Gemini Observatory and Easter Island (or Rapa Nui) began last year with the creation of an astronomy booklet (*Cuadernillo Astronómico*, Volume 1) that included information on the profound relationship between the Chilean Indians and the cosmos. A few months later, when the International Year of Astronomy began, Gemini Observatory—together with the University of Concepción and the Anthropological Museum of Father Sebastián Englert—coordinated the first astronomical cultural exchange with Easter Island. The events, occurring from August 1 to 9, included staff lectures, presentations in the Gemini StarLab® portable planetarium, solar observing, and nighttime stargazing. In addition, the *FamilyAstro* program provided engaging activity/inquiry-based learning opportunities for island families and teachers.

"It's good that the students listen to what is actually going to happen [in the sky] and thus value what we have the chance to witness," said Kava Calderón Tuki, a local elementary school teacher, who attended a presentation in Gemini's StarLab planetarium.
Other events included a guided tour of the millenary lava caverns (hosted by staff of the Anthropological Museum), a chance to witness the sunrise at the Ahu Tonga Riki, and a lecture given by local archeaologists on the most recent discoveries made in Rapa Nui.

More than 700 people, about a third of the Rapa Nui population, participated in the program's activities. In the same week, an important soccer match was played on the island, and there was also an ardent political debate in the background, which without a doubt also appealed to the interests of the islanders. Having so many people show up for our festivities was an accomplishment given the competition.

The director of the museum, Francisco Torres, referred to the Polynesian origins of the island as he

Figure 3.
Rapa Nui students study the sun with a Sunspotter® solar viewer while a University of Concepción student explains total solar eclipses, like the one that will be visible in July 2010 over the island.

discussed the importance of the astronomy event. "The first sailors who arrived down here were guided by the stars as an only tool," he pointed out, "which is a very important detail that also unites us with Hawai'i."
Nearly 200 kilograms of educational materials were transported for the event as a donation by Lan Cargo. This allowed us to offer the people of Easter Island an opportunity to learn more about astronomy before the total eclipse of the Sun they will be able to see in July of 2010.

Easter Island is located 3,700 kilometers from continental Chile, and is a special territory of

Figure 2.
Students from 3rd to 12th grade from four Rapa Nui schools receive educational materials after enjoying a StarLab® planetarium program.

Chile, annexed in 1888. (It is currently governed as a province of Chile's Valparaiso Region.) The island culture is of Polynesian origin, and residents call their home *Rapa Nui*, or *Te Pito Te Henua*, which means "The World's Belly Button." The island was originally colonized around the 4th or 5th century AD by the Ariki (King) Hotu Matu'a and a group of followers, who came from the island of Hiva, in the Marquesas Islands. The island was discovered by Europeans when the Dutchman Jacob Roggeveen reported seeing it on Easter Sunday in 1722. That discovery date led to the island's current (common) name.

María Antonieta García is the Outreach and Media Specialist at Gemini South. She can be reached at: agarcia@gemini.edu

by Peter Michaud

An Outreach Conjunction

Figure 1. *Participants in the annual Kona Teacher Workshop, a Journey Through the Universe west-side event for science educators.*

A conjunction of a unique astronomical sort occurred on October 3, 2009, at the Natural Energy Lab in Kona, Hawai'i. This wasn't a conjunction of astronomical bodies *per se*, but an alignment that was a long time in the making, and it shone brightly for those who participated.

This conjunction brought together several dozen very motivated Hawai'i Island teachers, an impressive stack of GalileoScopes (an International Year of Astronomy product, see: https://www.galileoscope.org), a team of astronomy educators, and sponsors that included other Mauna Kea observatories and local businesses. The day-long workshop was organized by Gemini Observatory as an extension of the *Journey Through the Universe* program that traditionally focuses on the east side of the Big Island. Janice Harvey, coordinator of the event, provides some background on the program, "For some very complex reasons, the *Journey Through the Universe* program (http://www.gemini.edu/journey) is limited to East Hawai'i (Hilo area)," she said. "So West Hawai'i (Kona region) gets the short end of the stick. We do this workshop to help address this imbalance."

At the end of the workshop, teachers provided comments as part of an evaluation, and excerpts throughout this article capture the enthusiastic reaction of the participants. Based on the evaluations, it appears that the east/west scales were well on their way to achieving a better balance.

Figure 2. *Nancy Tashima (Onizuka Space Center) and Tom Chun (Kamehameha Schools) building their GalileoScopes.*

The 2009 workshop is the second annual Kona teacher event organized by Gemini and, based on its success, will not be the last. "This year was special because we were able to introduce the GalileoScope to the teachers, and they loved it. We really got to teach some wonderful optics and astronomy," said Tim Slater of the University of Wyoming, Wyoming Excellence in Higher Education, Endowed Chair in Science Education, who led the teacher activities.

"I really appreciate Gemini's outreach to teachers. We're fortunate to live near the planet's prime astronomical location, and I thank you for sharing knowledge and materials with the students of the Big Island. Our students are a great investment."
Joanna Yin,
Na'alehu Elementary

According to Janice Harvey, "This was the first GalileoScope teacher workshop to include a 128-page teacher's resource and activity book produced by Tim and his group at the University of Wyoming." Each teacher received a copy of the book and a completed GalileoScope (sponsored by Gemini) as part of the workshop.

Figure 3. *Rhanda Vickery from Waikaloa Elementary prepares to build her GalileoScope.*

"Lately, professional development has been limited and could be costly. I appreciated the expertise of the presenters, the hospitality, including lunch, and the materials."
Kristin Tarnas, Hawai'i Preparatory Academy

"And I saw the craters on the moon from my house!!!! Thanks!!!!!!!"
Debbie Low,
Kealakehe Elementary

Gemini wishes to thank the other Mauna Kea observatories who participated (especially the Thirty Meter Telescope), and Big Island Toyota for providing lunch and refreshments.

"Thank you for organizing such a fantastic workshop and for giving us that wonderful Galileo Telescope...I can hardly wait to introduce my students to it."
Phyllis Cabral, Connections Public Charter School

The Gemini North outreach staff has a similar workshop in East Hawai'i planned as part of the "flagship" *Journey Through the Universe* program in February 2010.

Peter Michaud is the Public Information and Outreach Manager at Gemini Observatory. He can be reached at: pmichaud@gemini.edu

by Peter Michaud

Australian Student's Image Revealed

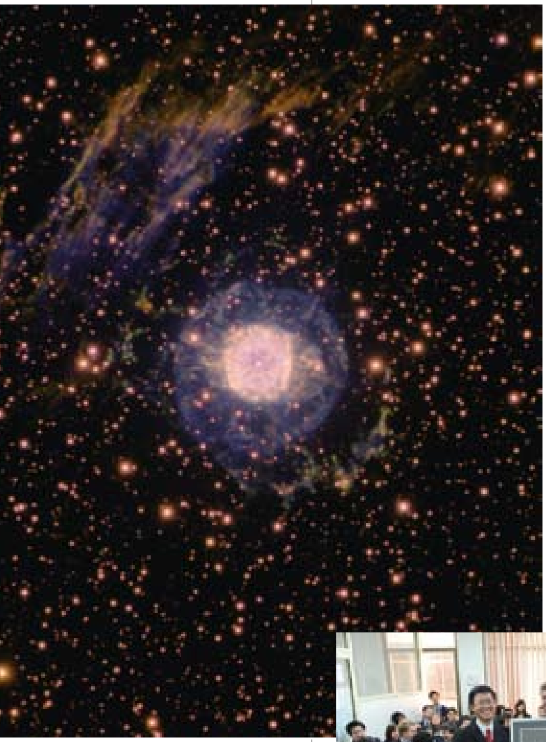


Figure 1.
Image of NGC 6751 obtained for the Australian Student Imaging Program. Inset image shows the presentation on September 23, 2009. Holding the photo are (left to right), PAL College (high school equivalent) teacher David Lee; Christopher Onken from the Australian Gemini Office; and PAL College student Daniel Tran, who was responsible for the winning entry. Photo: David Marshall.

"I thought they were pulling my leg," said Australian high school student Daniel Tran when he first found out that his entry into the Australian Gemini Partner Office imaging contest was selected as the winner.

His target, known as the Glowing Eye Nebula (NGC 6751), entered the Gemini South queue for 2009A, where it received one hour of telescope time for multi-band imaging with the Gemini Multi-Object Spectrograph. The image is shown here as a color composite produced by Travis Rector from Daniel's data.

The contest, sponsored by the Australian Gemini Office solicited high school students from across Australia to submit a target and explain why it would make a good image. According to Daniel, when he saw the object online at the WorldWide Telescope (WWT, a project of Microsoft), he found that "its unique color and structure made me want to know more about it, and the name itself caught my attention and started to reel me in." Note: see the Gemini image gallery on the WWT at: http://www.gemini.edu/wwt

The image was revealed at an event on September 23, 2009, hosted by Christopher Onken (Mount Stromlo Observatory) and Dr. David Frew (Macquarie University), who explained to the students the context of the image and how this planetary nebula glows due to its central star at the end of its life.

The image will appear on the cover of the January 2010 issue of the Australian version of *Sky and Telescope*.

The Australian Gemini Office (AusGO) also announced that the second iteration of this program is now being planned for 2010.

by Joy Pollard

Introducing Nancy Levenson

Bringing her contagious smile and warm laughter to the Gemini offices, Nancy Levenson is a welcome addition to the Gemini *familia* (or *'ohana* in Hawaiian). As the new Deputy Director and Head of Science, Nancy assumed her role at Gemini South only a few months ago and already her influence is propelling Gemini forward.

Nancy's first introduction to Gemini established her as a mid-infrared user partnering with Gemini North astronomer Rachel Mason to probe the core of the active galaxy NGC 1068. Nancy's research interests focus on active galactic nuclei (AGN). She is anxious for more opportunities to utilize Gemini's mid-infrared capabilities, combined with space-based shorter wavelength observations, to help unravel the mysteries shrouded within AGNs.

A Rhodes Scholar, Nancy graduated with bachelor's degrees from both Harvard and Oxford Universities, completing both her Master's, and Ph.D. in astronomy at the University of California at Berkeley in 1997. She conducted her postdoctoral research at Johns Hopkins University.

In 2002, she joined the faculty of the University of Kentucky in the department of Physics and Astronomy, where she gained first-hand experience with Gemini's optical/infrared capabilities and queue-based observing model. Nancy's experience with Gemini equips her with a strong user perspective and sensitivity to the needs of our science communities.

In addition, she has served on the Gemini Science Committee (from 2007) helping the directorate understand the user's perspective from representatives of the Gemini partner countries. She also served on the ALTAIR committee (2008-2009) that surveyed and assessed the user needs of large telescopes in the U. S.

Nancy says she is excited about addressing one of the key findings of the ALTAIR committee, namely, providing

Gemini users with access to new and improved instrumentation. She also wants to better understand the perspectives of partner countries and their needs in selecting and funding new instruments.

When asked about future scientific research at Gemini, she says she prefers to defer to the many "brilliant" minds that have already been making these decisions; supporting a vision where Gemini plays to its well-established strengths in infrared observations, and developing adaptive optics capabilities.

Since her move to Chile, Nancy feels she is finding her stride, and, as is obvious at the staff birthday parties, is enjoying flexing her Spanish language skills! To relax from her frequently demanding workload she plans to spend some time adapting to the clay tennis courts in Chile.

by María Antonieta García

Gemini's Adaptive Optics Chef

François Rigaut

(Opposite page) François Rigaut enjoys the tranquility of cooking in his kitchen.

Not 10 minutes after lighting the fire under his well-used wok and beginning to cook, the aromas from François Rigaut's kitchen begin to flow. He's totally concentrated on his work—adding tomato, zucchini, onions, and eggplant to sauté—all to create ratatouille which, in addition to being the name of a popular animated movie, is a delicious vegetarian dish that François likes to prepare for his family.

"I'm the chef of the house," he asserts proudly. François, when he's not cooking at home, is the Adaptive Optics Senior Scientist at Gemini South, and he makes it clear that he works without any recipe whatsoever (when cooking!) His repertoire includes an array of more than 20 favorites, with curry and au gratin dishes being his specialty. "I enjoy good cuisine," he points out while savoring a sip of red wine, which evokes memories of flavors from his homeland in France. Eventually, he shares the name of his favorite restaurant in Paris, which, until now has been a well-kept secret; it is the Brasserie Bofinger, located in the Bastille district.

It has been 17 years since François last lived in France, and during this time he has been fortunate enough to travel millions of kilometers around the world. His unique work locations have allowed him many special experiences. "Being able to watch lava flowing in Hawai'i is something really incredible," he recalls. Once while scuba diving near Hilo, he recalls encountering a single dolphin that suddenly expanded into a pod of them. "That was a wonderful sensation which," he says regretfully, "I only photographed in my memory."

François also savors and appreciates the more mundane

Photo by M. Paredes

or subtle experiences in life, such as the time on Paranal when he became totally absorbed in the tranquility of his surroundings. "For the first and only time, I experienced total silence," he says. "The sensation was so incredible that I could hear my blood beating in my veins. I have been very fortunate to experience all these feelings."

François' training is in astronomy, but he feels that he has a wider scientific viewpoint these days. "I don't consider myself as an astronomer anymore; I am a physicist," he says, noting that he does not write astronomical research papers anymore and he has devoted himself professionally to the development of the field and theory of adaptive optics. It is in this area where François feels he can build more concrete, tangible things than with pure astronomical research.

A French community called Limours, just south of Paris, is where François grew up. He is the only child of a medical laboratory administrative assistant and an engineer. His dad (the engineer) worked in the Atomic Energy Commission, and François believes he inherited his inclination for science from him. Youthful experiences at an international school, where he mingled with a diverse, multinational group of friends, made him comfortable with many different kinds of people. "Since then, I have coexisted in multicultural and multi-ethnic environments all of my life," he points out.

François spent many years of his adolescence learning to play classical guitar. "I practiced between eight and ten hours a week, but I never considered it as a profession," he recalls, while confessing that these days he barely takes the guitar out of its case more than a couple times a year.

Although he doesn't make his own music these days, François does appreciate the classical music of Johann Sebastian Bach, particularly the pieces from the Well-tempered Clavier—a collection that Bach wrote to show that the unification of the musical scale works. "In the past, musical instruments were not tuned with the current keys," he explains.

Bach is not the only musician François favors. He has an eclectic appetite for many modern genres, including pop and rock music of the '70s and '80s. At yet another extreme, he enjoys the Pakistani musician Nusrat Fateh Ali Khan who François first heard during an observing run several years ago. Ali Khan's qawwali music is based in repetitive chants that are supposed to eventually take listeners into a trance.

François' first experiences in what would become a long affiliation with Chile began in 1987 as part of France's compulsory military service. It also offered the option of civil service abroad. This allowed François to spend 16 months working with the site testing group at Observatorio La Silla. "This led me to install testing equipment in Cerro Vizcachas," adding that "I went to Paranal while it was still [in] a very natural environment."

After fulfilling his French military commitment, François returned to France to embark on his Ph.D. in Instrumentation and Astronomy at the Université Paris VII under the supervision of Pierre Léna. There, he had the good fortune to work on the final development stages of the first adaptive optics system for astronomy called "COME-ON".

With his Ph.D. and experience in the rapidly emerging field of adaptive optics, François was quickly hired by the Science Research National Center in France. He relocated to the Canada-France-Hawai'i Telescope (CFHT) in Hawai'i, where he led the development and commissioning of PUEO (named after the Hawaiian owl with exceptional eyesight). François describes it as the first user-friendly adaptive optics system, allowing astronomers to use it with the push of a button. "It has tremendously aided the work of astronomers who, before its development, had to rely on three or four persons to do the work, which is now automated," he explains.

Gemini Director Doug Simons (also at CFHT during the same period as François in the early '90s) recalls, "[PUEO] was a radical concept at the time and sparked great debates within CFHT. Was this technology really mature enough to catapult [AO] into the realm of "reliable" facility-class instruments?"

In the end, Simons concludes that the project was a great success and contributed profoundly to astronomy. "PUEO proved that it's possible to package/control an adaptive optics system that works with just a few clicks on a computer screen that the general astronomy community can use. This was a big confidence builder for others around the globe pondering the merits and risks of building similar systems amid a myriad of skeptics." Simons continues, "I feel lucky to have just witnessed the beginning of this revolution on the summit of Mauna Kea nearly 20 years ago."

François's early work on PUEO would eventually have a profound impact on Gemini as well. However, before coming to work at Gemini, he was hired by the European Southern Observatory (ESO) as the AO Group Head. There, he discovered some of his strengths and also determined some his life's priorities. "I was not made for management," he confesses. "I figured management could come later in life, and I still wanted to do some research."

After two years at ESO he decided it was time for a life change, and he gave up what was a lifetime position in France to accept his position at Gemini so he could help lead the observatory's nascent adaptive optics program to maturity. That began eight years of living in Hilo and working at Gemini North. During this period, François was responsible for what he describes as his most challenging projects; the completion and commissioning of the Altair AO system and integrating it with the laser guide star system on Mauna Kea.

It was also in Kona, Hawai'i, on Bastille Day, 2002 that he married Gemini's senior laser engineer Céline D'orgeville. Today, the family lives in Chile, with two children (daughter Anaïs, 3, and Lucas, 1). François also remains close to his two teenage daughters (Natacha, 17, and Camille, 15) from a previous marriage. While his older daughters live in France, they have both visited Hawai'i and Chile, making his family almost as global as himself.

François' "professional family" also includes students he has mentored. "I am proud to have trained several students who have now succeeded well in the adaptive optics community," he said. Meanwhile, his professional life is still extremely demanding, with the development of the Multi-Conjugate Adaptive Optics (MCAO) system for Gemini South, which he calls "our baby." (See the MCAO update on page 60 of this issue.)

Among François' other professional accomplishments, he is particularly proud of having written the first paper proposing ground layer adaptive optics (GLAO), a new approach to wide-field AO.

"I feel a sense of responsibility to Gemini and the user community," François says. "I love what I do. I am one of those few persons that when Friday comes, I say, 'Darn, it's already Friday!'"

María Antonieta Garcia is the Outreach and Media Specialist at Gemini South. She can be reached at: agarcia@gemini.edu

by Peter Michaud

In Love with the Stars

Dolores Coulson

"I love stars, that's what it's all about." With these words, Gemini North's lead System Support Associate, Dolores Coulson, only hints at her passion and enthusiasm for her life's work.

(Small Image) Dolores stands outside the Palomar Mountain Observatory as a youth. (Opposite) Dolores today outside of Gemini.

As a teenager, Dolores recalls being profoundly impacted by early visits to the Palomar Mountain Observatory. "I would sit on the stairs and say to myself, 'How can I get in there, this is what I want to do!'" After getting an immediate response to an inquiry (with pictures) from Palomar astronomer Jesse Greenstein, her fate was sealed. "I was beyond the Moon," she said. "That was it; I had to do it! [What Jesse did] was wonderful. It was such a nice thing to do to encourage someone."

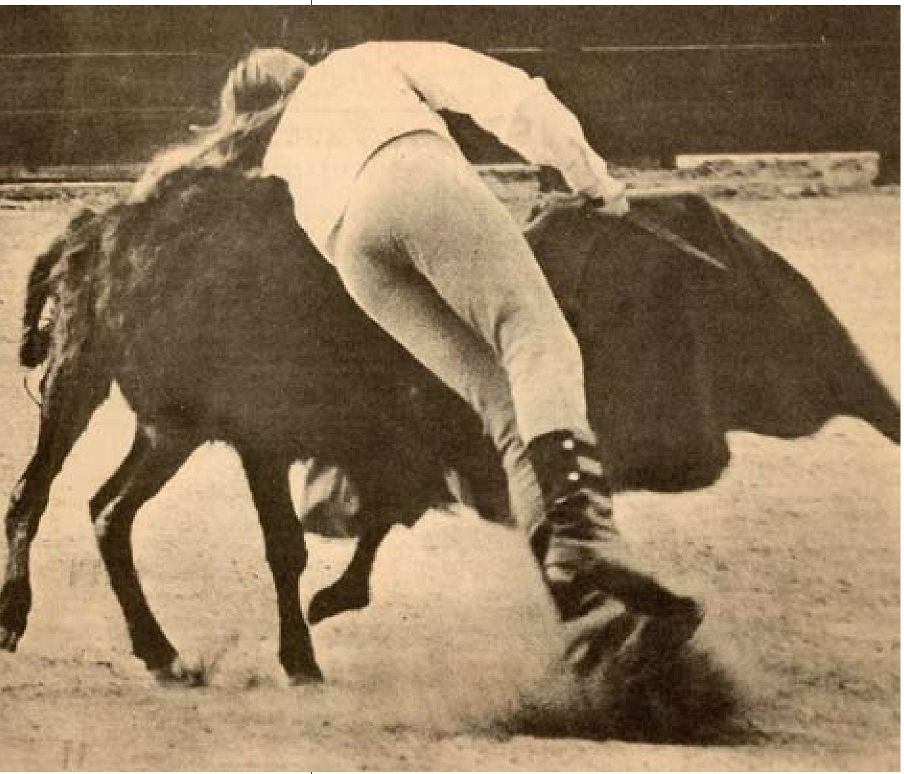
But, Dolores had a very different encounter a few years later that could have literally bumped her off this path to the stars. It all started when she was working in her hometown of Encinitas, California, as a typesetter at a local newspaper and she (characteristically) tried to help out a friend.

That friend, a reporter, was writing a story on a new bullring in Tijuana. He asked Dolores if she was willing to have her picture taken in the bullring, but that it


Photo by K. Pu'uohau-Pummill

would require some training first, since the photos would involve a close encounter with a bull. As it turns out, the encounter was a lot closer than Dolores ever envisioned!

"For six weeks, every weekend I'd go down there to practice," she recalls. At that point, she got tired of losing her weekends to the bullring and said, "I'm not doing this anymore. Let's do it now. I'm not going to get any better!" On the day that she was to be photographed in the ring, Dolores had to select her bull from the corral. "I picked the nicest, kindest, sweetest little bull with the shortest little horns and very kind eyes," she said.



Dolores has a much closer encounter with a bull than she ever anticipated...

However, while walking down a narrow corridor to join her "kind-eyed" bull in the ring, she heard a commotion from behind. There was shouting (in Spanish), and when she looked back she saw bulls stampeding toward her in what looked like an impromptu running of the bulls! According to Dolores, "I made myself as thin as possible. I sucked in my stomach, I think it went through the other side of the building! The last thing I remember seeing was this huge bull's horn coming right at me. I closed my eyes and that was it. I don't even remember hearing anything, then I opened my eyes and they were all gone—and I was still alive; I had already said goodbye!"

She shook off the trauma of the bull stampede and entered the ring for the rest of her commitment. But the adventure wasn't over. Her bull (which she suspects was switched, or grew longer horns) threw her to the ground. She recalls from her shaken memory, "All I remember is all of these people running around and trying to keep the bull away. I even remember seeing a clown!"

In her usual fashion, Dolores tells this story with humor, humility, and a lot of humanity, ("... there was no way I was gonna hurt that bull... .") But most of all, her story shows her determination to succeed. She finished the photo shoot, and since then, her determination has been reflected in her professional achievements.

Dolores came to Gemini in 1997, at a very critical time both for herself and the observatory. She transitioned to Gemini from her work at the Joint Astronomy Centre, which supported her pursuit of a graduate degree from the University of Central Lancashire (in the United Kingdom). Her thesis, titled "A Detailed Infrared Study of the Star-forming Region NGC 2071 IRS," allowed her to consummate her love affair with stars and the starbirth process; all while she envisioned a creative new structure for staffing nightly telescope operations. This became the foundation for Gemini's System Support Associate (SSA) model. Dolores says that today she is most proud of how that vision has been implemented at Gemini and the fact that SSAs are able to advance and broadly participate in observatory operations. "No other observatory has that," she said. "I'm proud of that."

Being the first person hired by Gemini to establish the observatory's nightly operational functions, and the telescope's user interface, Dolores is able to share a history that few current staff members can fully appreciate. Nowhere is this more obvious than when she describes the first nights when the telescope was pointed skyward.

Reflecting on the early commissioning of the Gemini North telescope system, Dolores says, "We used to observe from the observing floor, and things used to get so cold. Those were the days of old, the days of cold!"

She recalls the uncoated mirror reflecting the Moon's light and using a hand-panel to point the telescope. "It was cold," she said, "until we built a 'homeless shelter' on the observing floor. It was made out of plastic and everyone tried to get near the one heater in the shelter!"

One night, while aligning the telescope (before the shelter was built), Dolores was so engaged that when advised to go down and warm up she protested. "No, no, I'm okay. I'm fine. I don't need to go down," she recalls saying. "When I finally did get up, my legs almost gave out. I was completely numb!"

Today, Dolores spends a lot less time on the mountain, and while her devotion is physically less straining, her commitment to the successful operation of Gemini is as strong as ever. "Comparing then to now is like comparing a covered wagon to a Mercedes. I never thought a telescope with so many peripherals could end up working so smoothly," she added. Of course, as Gemini astronomer Tom Geballe points out, Dolores is a key reason that this is true. "I've known Dolores since our days together at the United Kingdom Infrared Telescope," he said. "She was the first telescope operator hired there and had the same deep involvement as she has at Gemini. Her curiosity about all aspects of telescope operations, not to mention astronomy, naturally led her to advocate broader responsibilities for telescope operators than was the norm. This was key to developing the SSA model at Gemini."

When Dolores looks back at her past 26 years on the mountain, she has myriad memories and unique experiences—from the nighttime visitor who started a fire under the United Kingdom Infrared Telescope slit (which corrupted her data), to natural phenomena like the plasma ball from a lightning storm that seemed to follow her on the Saddle Road; Mauna Kea is a part of Dolores and she, likewise, is a part of the mountain. Her words capture the deep relationship she has established with the mountain. "I feel privileged to be there. I don't think everyone has a chance to experience that," she said. "I'll walk that mountain in pitch darkness. I feel safe on it. It is very unusual. I don't normally walk in the dark, but I feel that way about the mountain."

So how does a person with Dolores' overflowing mental and physical energy ever relax? First, she has to be caught up on her e-mail. "I log on… I have to do that before I can actually go and relax!" she admits. "From that point on I'm happy. I love gardening. I love pulling weeds; it's very relaxing."

Her close personal friend and colleague Colin Aspin recalls how passionate she is about the Dallas Cowboys football team, partly because of the big star on their helmets! Colin tells of a Superbowl party at his house where Dolores had thrown so many colored paper stars into the air that three years later, "… I was still finding them when we moved out of the house!" Oh, and her star-studded team won.

Dolores is also passionate about the humane treatment of animals, loves to snorkel, camp, and has numerous cats and (paradoxically) feeds wild birds, which she says, she can watch forever (as can her cats). Of course, all her loves—from the stars to her husband (an astronomer whom she has been with for more than 20 years), her daughter and two grandchildren, as well as the plants and animals she protects—have converged on the island of Hawai'i, making her life quite complete.

As for the future, Dolores confesses that she doesn't need to work anymore, but continues, "The only reason I'm working is because I enjoy it," she said. "I'm glad I am where I am."

Peter Michaud is the Public Information and Outreach Manager at Gemini Observatory. He can be reached at: pmichaud@gemini.edu

Shadows stretching over Mauna Kea Pu'u.

Mauna Kea's cinder cones, caught at sunset, with clouds riding the inversion layer beyond.

Joy Pollard obtained this image on July 16, 2009, at about 6:30 pm, on the slopes of Mauna Kea outside of the Gemini North telescope. The image was taken during a tour with University of Hawai'i REU (Research Experiences for Undergraduates) students.

Joy used a Nikon D90 with an 18.0 - 105.0 millimeter f/3.5-5.6 lens.

Sunrise at Ahu Tonga Riki, on the west side of Rapa Nui.

Manuel Paredes took this photo to create a view of the Moai highlighting the colors of the sunrise as a backdrop. His idea was to show them as part of nature by revealing only their silhouettes so they would not dominate the natural scene.

Manuel used a Nikon D1X digital camera with a Nikkor 17 - 35 millimeter f/2.8 lens.

GeminiFocus

University of Hawai'i REU students watch a sunset from the altitude platform of Gemini North. Photo by Joy Pollard

Gemini Observatory
Northern Operations Center
670 N. A'ohoku Place, Hilo, Hawai'i 96720 USA
Phone: (808) 974-2500 Fax: (808) 974-2589

Gemini Observatory
Southern Operations Center
c/o AURA, Casilla 603 La Serena, Chile
Phone 56-51-205-600 Fax: 56-51-205-650

Gemini Partner Agencies:

United States

United Kingdom

Canada

Australia

Brazil

Argentina

Chile

The Gemini Observatory is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation on behalf of the Gemini Partnership.

To receive GeminiFocus, please send a request (with your mailing address) to: xzhang@gemini.edu