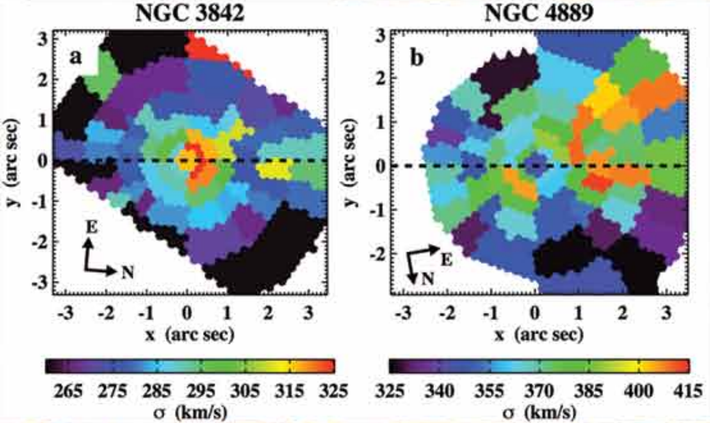
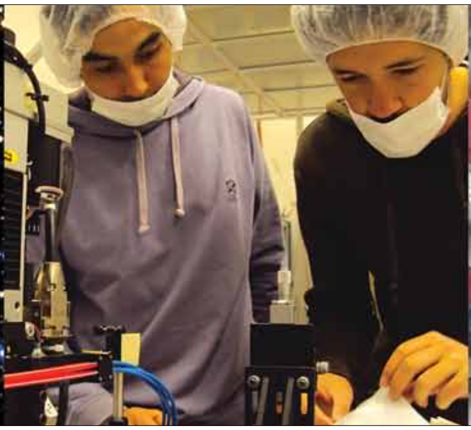
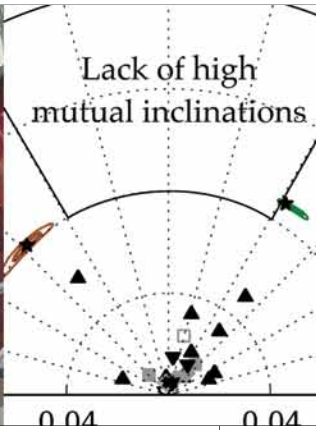
*Gemini*Focus

December 2011 Publication of the Gemini Observatory





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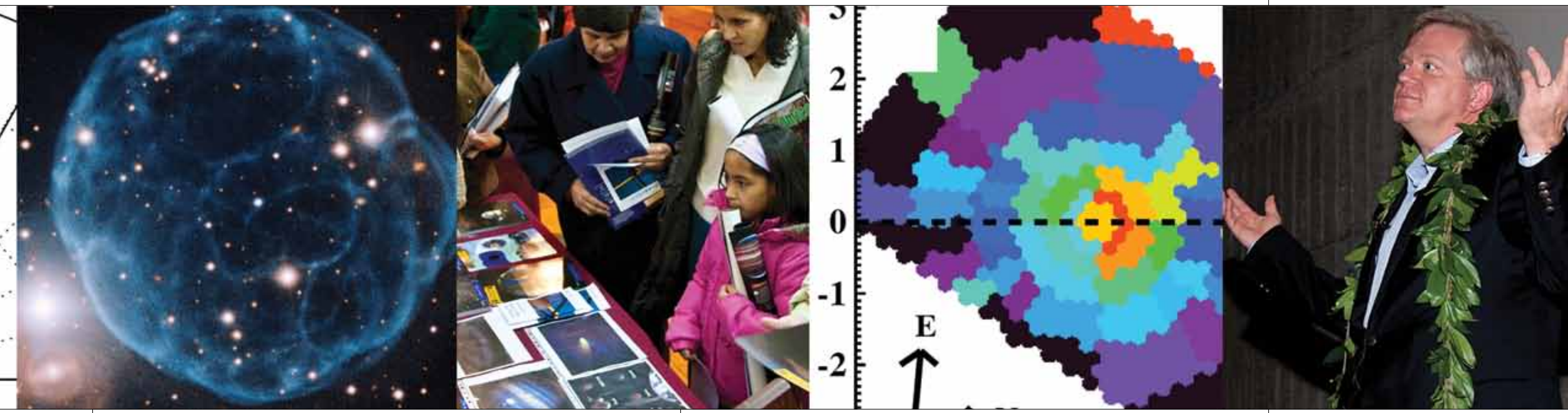

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by Fred Chaffee
Interim Director, Gemini Observatory

Director's Message

It has been an eventful six months since I arrived in Hilo, Hawai'i, to take up my responsibilities as Interim Gemini Director while a worldwide search goes on for a permanent one. As of this writing, that process is moving forward, and it looks likely that the new Director will be named early next year.

Meanwhile much has happened. We've instituted new organizational changes. Among them we've: (1) eliminated the positions of Associate Director (AD) for Administration and AD for Engineering; (2) established a Chief Financial Officer position; (3) appointed Maxime Boccas as Associate Director for Development; (4) combined the science and engineering branches into a single operations branch under Andy Adamson; and (5) appointed Steve Hardash and Richard Oram as separate heads of Gemini North and Gemini South engineering, respectively.

The goal of all these changes is to better focus our development efforts and structure operations to more effectively serve our "customers," the Gemini users in our partner countries.

In response to the many pent-up needs of our users, we also immediately established four high-level, short-term development priorities:

1. Upgrading the CCDs for the Gemini Multi-Object Spectrograph (GMOS) at Gemini North (see page 6 in this issue);
2. Completing upgrades to FLAMINGOS–2 at Gemini South (we've informally dubbed the rebuilt FLAMINGOS–2, "FLAMINGOS–2+," to identify it as a very different instrument from the one that limped into our La Serena lab in February 2010 after a failed commissioning run);
3. Completing many upgrades to the Gemini Multi-Conjugate Adaptive Optics System (GeMS) — following its enormously successful first light run at Gemini South in April (see *GeminiFocus*, June 2011, page 23, and in this issue page 45); and
4. Implementing upgrades to the Phase I and II software tools (see article in this issue, page 48).

The goal was to have new GMOS CCDs, FLAMINGOS–2, and GeMS on-sky by year's end, and to have a new version of the Phase II Observing Tool released in time for Semester 2012A planning. To ensure task completion in a timely manner, we organized each project with a manager and team, whom we "ring-fenced" as much as possible from other responsibilities. It's a tribute to the entire staff that we expect to achieve all four of those goals.

We've also made much progress on longer-term development efforts. In particular, with the Gemini High-resolution Optical Spectrograph (GHOS) and the GRACES spectrograph aimed at providing much-needed high-resolution spectroscopic capability for Gemini South and Gemini North, respectively — GHOS is in the conceptual design process, and GRACES may see first light in the near future. Also, the Gemini Planet Imager (the adaptive optics instrument designed to image planets around nearby stars) is being assembled at the University of California, Santa Cruz (see the article on page 40 in this issue). These are key capabilities for Gemini's future.

Through all of this development activity, science operations, which lies at the very heart of Gemini's mission and represents the bulk of our staff effort, continues to produce high-quality science data through use of queue observing. Gemini's ability to respond quickly to observing "Targets of Opportunity" continues to provide a unique and very popular science capability. Thanks to this capability, the most distant known gamma-ray burst (GRB) was identified at Gemini (see article on page 12 of this issue).

Also in science operations, we realized a significant step forward in assuring users of the quality of Gemini data. In October/November 2011, we released the first major product of the Data Quality Assessment team: a software tool that quickly analyses GMOS acquisition images in real-time; it provides the queue observer with instant feedback about the achieved image quality, thus allowing him/her to be certain that the requirements of each program are being met.

Meanwhile, the Gemini science output reached the 1000-paper milestone with the November publication in *Nature* of a paper by Tom Geballe and his team reporting observations of previously-unknown diffuse interstellar bands toward the Galactic Center (see the article on page 27 in this issue).

An extraordinary highlight of the last six months was the announcement of this year's Nobel Prize laureates in physics — Brian Schmidt, Saul Perlmutter, and Adam Riess. All have Gemini connections, and Brian, in particular, is not only a Gemini user but also a long-standing member of the Association of Universities for Research in Astronomy's Oversight Council for Gemini (AOCG). The AOCG's long-scheduled October meeting in Hilo came only three weeks after the Nobel Prize announcement, and Brian passed up the opportunity to meet Queen Elizabeth II in order to participate in the AOCG meeting. During his short stay in Hilo, he also graciously agreed to give two talks: one to Gemini staff and spouses and another for the general public (See the article on page 38 in this issue).

With barely 10 days' notice, Janice Harvey put the Gemini public relations machine into high gear, coordinating the efforts of Gemini, 'Imiloa Astronomy Center, and the University of Hawai'i at Hilo (UH Hilo) to find the largest venue available and get the word out about this unique opportunity. The response was overwhelming, with up to 1000 people crowding into a space designed for only half that number. Brian gave a memorable talk about his Nobel Prize-winning discovery of the accelerating universe. The post-presentation "receiving line" for autographs was impressive. One student described the evening as "a rock concert for physics," and the UH Hilo Chancellor Don Straney said it was the largest crowd for an indoor event at UH Hilo he had ever experienced.

None who were there will likely ever forget it, including our honored speaker.

Thus, as 2011 draws to a close, we near the end of another eventful year at Gemini. While much progress has been made, much remains to be accomplished to achieve the enormous potential of our remarkable observatory. We look forward to the future with much anticipation.

Fred Chaffee is Gemini's Interim Director. He can be reached at: fchaffee@gemini.edu by Fred Chaffee

Gemini's New Instruments Surge Ahead!

Key milestones reached, as major new instruments/capabilities move through commissioning and integration, including first light with FLAMINGOS–2, new red-sensitive detectors for the Gemini Multi-Object Spectrograph on Gemini North, the Gemini Multi-Conjugate Adaptive Optics System, and the Gemini Planet Imager.

Figure 1.

NGC 2442 as imaged by FLAMINGOS–2 during commissioning in early December 2011. This color composite was made with 1-2 minute integrations in Y, J, and K filters. Image processed by Gemini Science Fellow Mischa Schirmer.

As this issue of *Gemini*Focus goes to press, a number of critical new capabilities are nearing completion for availability to Gemini's user community. From first light with FLAMINGOS–2 to the installation and testing of new red-sensitive detectors on the Gemini Multi-Object Spectrograph on Gemini North (GMOS-N), the highlights that follow provide a vision of Gemini's new capabilities. In addition, see the full-length articles on the Gemini Multi-Conjugate Adaptive Optics System (GeMS; page 45) and the Gemini Planet Imager (GPI; page 40), also in this issue of *Gemini*Focus.

Get ready to take Gemini where it hasn't gone before!

FLAMINGOS–2

Figure 2 (top). *FLAMINGOS–2 in the instrument lab prior to installation on Gemini South.*

As of mid-December 2011 (as this issue goes to press), the revamped FLAMINGOS–2 is halfway through its first on-sky commissioning, and things are going very well. On its second on-sky night, a beautiful first light image was obtained of NGC 2442, a spiral galaxy some 50 million light-years away. This milestone has required overcoming significant hurdles and represented a significant investment of resources to solve the challenges presented since FLAMINGOS–2's first attempt at commissioning in late 2009.

Figure 3 (center). *An old GMOS-North CCD image on the left (60-minute exposure, seeing = 0.55 arcsecond full-width at half-maximum (fwhm)), and a new GMOS-North CCD image on the right (55-minute exposure, seeing = 0.54 arcsecond fwhm). Both images use the same z-band longpass filter and the stretch is identical. In the z-band, the gain in sensitivity is ~ 0.5 magnitude (about a factor of 3) according to preliminary analysis of data. The z-band is broad and red, so it shows the greatest improvement in sensitivity; other filters will show smaller gains.*

As the run progresses, the team is putting the instrument through its many paces – testing guiding with both probes, measuring and applying astigmatism corrections, measuring the throughput in FLAMINGOS–2's single object spectroscopic modes – all information users will need to know to produce the science that FLAMINGOS–2 is uniquely able to accomplish. Testing of Flamingos–2's most scientifically exciting mode — multi-object spectroscopy (MOS) — awaits the next commissioning run in January.

Look for opportunities to use FLAMINGOS–2 for system verification starting in early 2012.

Figure 4 (bottom). *One of three new GMOS-North CCD E2V Deep Depletion CCDs with increased red sensitivity.*

GMOS-N

The Gemini Multi-Object Spectrograph on Gemini North is back on the telescope after receiving its new E2V Deep Depletion CCDs with significantly greater red sensitivity. Early imaging (spectroscopy still pending) is shown in Figure 3.

Follow progress of GMOS-N at: http://www.gemini.edu/sciops/instruments/gmos/?q=node/11666

by Daniel Mortlock and Steve Warren

Discovery of a Redshift $z > 7$ Quasar

A rich harvest of high-redshift sources from near-infrared surveys provides significant fodder for exploring the universe back to the epoch of reionization. In this work, a discovery from UKIDSS data provides a compelling target for follow-up observations with Gemini in the optical using the Gemini Multi-Object Spectrograph on Gemini North. The results show the target is at a redshift of more than z = 7, making it the most distant quasar known.

These days, the action in the high-redshift universe is in the near-infrared (NIR), and new NIR instruments have made it possible to find sources beyond a redshift of $z = 6.5$ for the first time. This equates to a distance of about 13 billion light-years. Narrow, very deep $J_{(AB)} \sim 28$ searches with the new infrared Wide Field Camera 3 on the Hubble Space Telescope (HST) by Rychard Bouwens (Lick Observatory), Ross McLure (Royal Observatory, Edinburgh), and their teams have now produced the first substantial samples of galaxies beyond a redshift of $z = 6.5$. At the same time we have been engaged in a wide, shallow $J_{(AB)} \sim 20$ search to find bright quasars at these redshifts, using data from the United Kingdom Infra-Red Telescope (UKIRT) Infrared Deep Sky Survey (UKIDSS). Aside from the intrinsic interest of such sources, quasars are vital probes of the early universe, particularly the so-called "epoch of reionization."

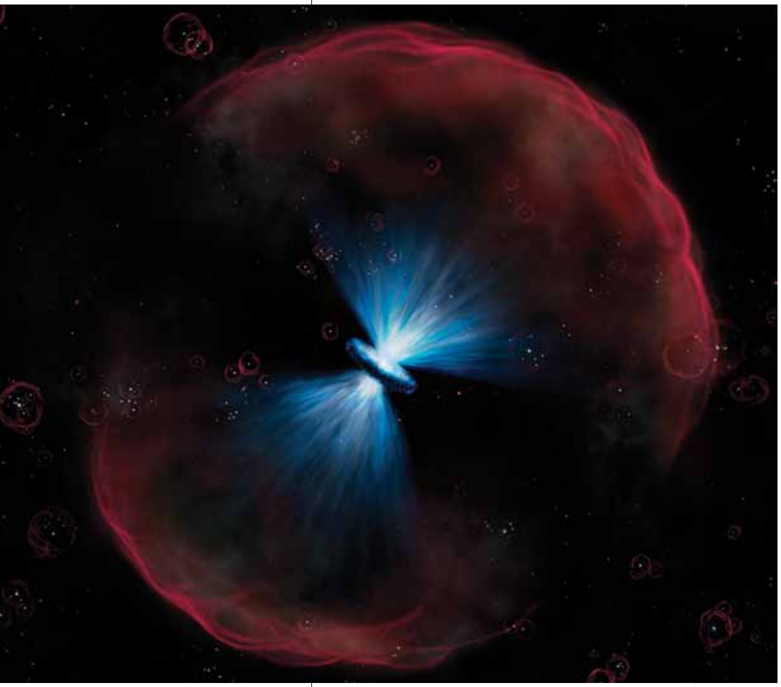


Figure 1.

Artist's concept of a quasar in the early universe during the epoch of reionization showing an expanding shell of reionized hydrogen. Gemini artwork by Lynette Cook.

Cosmic Reionization

Expanding from the hot Big Bang, the infant universe cooled, and its transition from a plasma to neutral gas (when the cosmic microwave background (CMB) radiation was emitted) occurred at redshift $z = 1100$. Then … nothing happened. The universe entered the so-called "cosmic dark ages," an epoch that lasted some hundreds of millions of years before the first stars began to light up in a period called "cosmic reionization."

Fast-forwarding one billion years to redshift $z = 5$, studies of the absorption lines seen in quasar spectra show that the material between galaxies (the intergalactic medium, IGM) was highly ionized by this time, with a volume-weighted neutral fraction of less than 10^{-5}. So when and how did the IGM become reionized? Observationally the question may be answered in two ways: (1) by detecting the sources responsible for ionization, likely galaxies rather than quasars; and (2) by finding bright sources – quasars or gamma-ray bursts (GRBs) – that can be used to measure the condition of the IGM at high redshifts.

Using data from the Sloan Digital Sky Survey (SDSS), Xiaohui Fan (Steward Observatory) and colleagues have discovered ~ 40 quasars in the interval $5.8 < z < 6.5$. They have used them to show that the epoch of reionization ended around $z = 6$. Analysis of the strength of absorption in the Lyman-alpha (Lyα) forest has revealed that the neutral fraction of the IGM increased rapidly beyond $z = 5.8$, and was 10^{-3} by $z = 6.2$.

The other big clue we have about reionization comes from observations of the CMB, which provide a measure of the integral of the free electron density along the line of sight, and so give a constraint on the history of reionization. The Wilkinson Microwave Anistropy Probe (WMAP) measurements of the CMB show that the midpoint of reionization was near $z = 10$. If $z = 6$ marks the tail-end of this process, it appears that this period lasted perhaps over the redshift range $6 < z < 15$. But, many different scenarios of how reionization progressed are compatible with these two constraints, and further progress requires the identification of bright sources with $z > 6.5$.

How to Find Quasars at $z > 6.5$

A number of factors conspire to make the discovery of quasars, galaxies, and GRBs beyond $z = 6.5$ difficult. The sources are both rarer (i.e. their space density is declining) and fainter (as they are further away), and the sky background is brighter at these longer wavelengths. However, the principal handicap has been instrumental. The quantum efficiency of the charge-coupled devices (CCDs) used in the SDSS camera (and in the HST Advanced Camera for Surveys) falls off rapidly beyond 0.9 (μm) and defines the long wavelength cutoff of the z filter. At high redshifts, most of the flux shortward of the redshifted Lyα line is absorbed by intervening neutral hydrogen that is present during the epoch of reionization. So, beyond redshift $z = 6.5$ quasars and galaxies are practically undetectable with optical CCD cameras. The development of large-format NIR arrays has made it possible to observe or detect objects at these high redshifts.

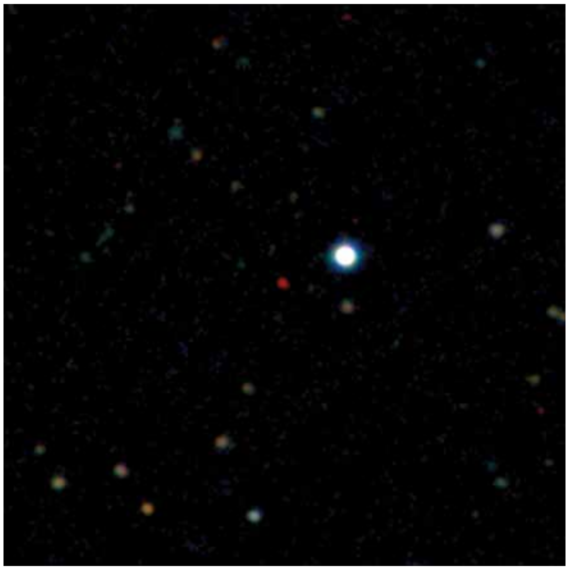


Figure 2.

Color image formed from i, z, Y, and J images of a 2' x 2' field surrounding the quasar ULAS J1120 + 0641, the very red object at center. North is up and east is to the left.

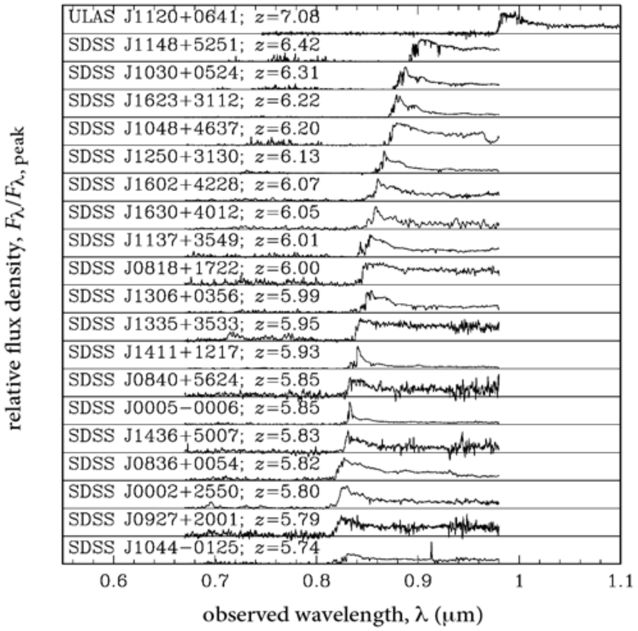
The Search with UKIDSS

UKIDSS, a seven-year project that began in 2005, uses the UKIRT Wide Field Camera (WFCAM) to map a large fraction of the northern sky in the NIR. WFCAM has four 2048 x 2048 HgCdTe arrays, and is equipped with Y, J, H, and K filters, covering the wavelength range of 1 - 2.5 μm. UKIDSS comprises five elements, including the Large Area Survey (LAS). The LAS will map 3800 square degrees at high Galactic latitude, and one of the principal goals of the LAS is the detection of quasars beyond $z = 6.5$. All of the LAS lies within the footprint of the SDSS, so matching to the SDSS catalogues provides a powerful multicolor resource. The 5-sigma depth of the LAS, $J_{(AB)} = 20.5$ gives i, z, Y, J photometry that allows a search for high-redshift quasars with $5.7 < z < 7.2$.

We selected candidate high-redshift quasars from the merged i-, z-, Y-, and J-band catalogue by a procedure that employs Bayesian model comparison. For each object the measured i-, z-, Y-, and J-

Figure 3.

Comparison of the spectrum of ULAS J1120+0641 $z = 7.085$, with the 19 quasars $5.7 < z < 6.5$ that Fan et al. (2006) studied.



band fluxes and the depths of the images are used to answer the question: Is the source more likely to be a star with normal colors scattered from the stellar locus or a rare high-redshift quasar? This allows candidates to be ranked by probability. The procedure is remarkably efficient, allowing us to reduce an initial list of millions of sources to fewer than 100 interesting candidates. The next step is to obtain deeper imaging, both to reduce the photometric errors and to obtain independent measurements not biased by the initial color selection.

At this time, we have completed analysis of 2200 square degrees of data from the eighth UKIDSS Data Release (DR8), which took place on September 3, 2010. Repeating the Bayesian calculation with the improved photometry, we were left with just 13 high-probability sources in 2200 square degrees: six previously known SDSS quasars in these fields; six new quasars with $5.7 < z < 6.4$; and one promising $z \sim 7$ candidate, ULAS J1120+0641, shown in Figure 2.

The First $z > 7$ Quasar

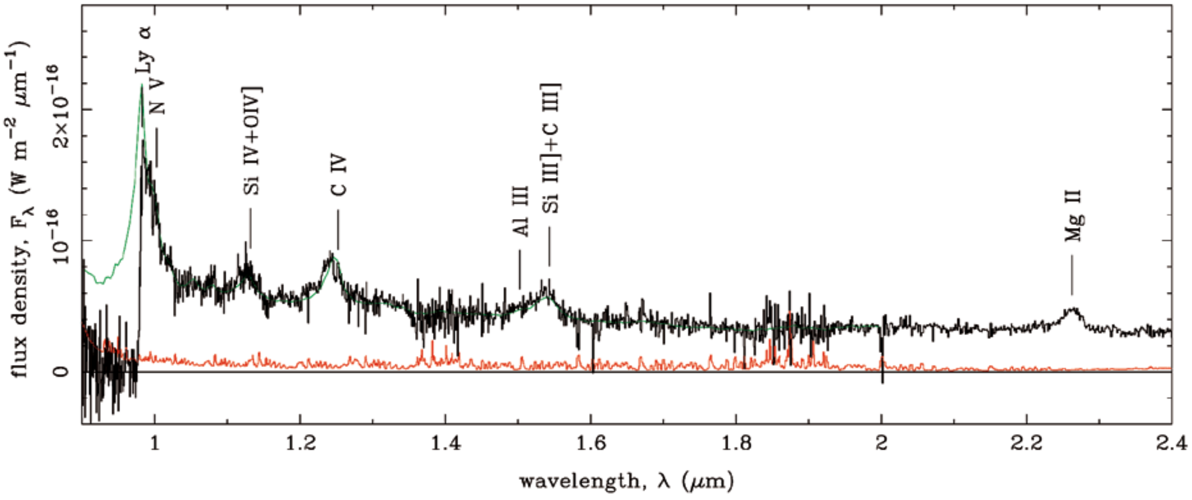
On November 28, 2010, Universal Time (UT), we obtained a spectrum of ULAS J1120+0641 with the Gemini Multi-Object Spectrograph (GMOS) on Gemini North. Thanks to the rapid availability of Gemini data in the archive, we were able to analyze the spectrum less than seven hours after its acquisition. The GMOS spectrum confirmed the source was a quasar, with the detection of a broad Lyα emission line, with negligible flux to the blue.

It also provided a preliminary redshift of $z = 7.08$. The three most distant quasars known previously have redshifts of 6.42, 6.42, and 6.44, so ULAS J1120+0641 is now the record-holder by a considerable margin, as illustrated in Figure 3. And, while there are three other sources with spectroscopic redshifts of $z > 7$ (two faint galaxies $J_{(AB)} > 26$ at $z = 7.08$ (Vanzella *et al.*, 2010) and $z = 8.55$ (Lehnert *et al.*, 2010), and a now-faded GRB at $z = 8.2$ (Tanvir *et al.*, 2010), ULAS J1120+0641 is hundreds of times brighter, and so can be followed up spectroscopically.

We were particularly fortunate that just a few days after the discovery of ULAS J1120+0641 the refurbished Gemini Near-Infrared Spectrograph (GNIRS) was returned to service on Gemini North, and we secured a spectrum in excellent (0.7 arcsecond) seeing on the night of December

Figure 4.

GNIRS spectrum (black line) of ULAS J1120+0641. The red line marks the 1-σ error spectrum. Prominent emission lines are marked. The green line is a composite spectrum formed by averaging the SDSS spectra of $z = 2.2 - 2.6$ quasars.



8, 2010. The GNIRS spectrum, shown in Figure 4, covers the wavelength range 0.9 - 2.4 μm. In most respects, the spectrum is typical of quasars of lower redshift, as shown by the excellent match to the redshifted SDSS composite quasar spectrum. The only significant difference is that the C IV line is strongly blueshifted. More importantly, the GNIRS spectrum of ULAS J1120 + 0641 includes the Mg II line, which provides an accurate redshift of $z = 7.085$.

Interpretation of the GNIRS Spectrum

An accurate redshift is required for analysis of the condition of the IGM surrounding the quasar. The absorption optical depth in the Lyα forest is substantial and there is no detectable emission over the entire redshift range $z > 6$, except very close to the quasar redshift, where ionization by the quasar results in high transmission in a region known as the "near zone." Knowing the accurate redshift of the source allows a measurement of the size of this ionized zone. The measured size of the near zone for ULAS J1120 + 0641 is 1.9 megaparsecs (~ 6 million light-years), which is a factor three smaller than the near zones around quasars of similar luminosity in the redshift range $6.0 < z < 6.4$.

This is an indication that the neutral density of the IGM at $z = 7$ is much higher than at $z = 6$ and raises the exciting possibility that we have found a bright source at a time when the IGM was substantially neutral. Further analysis appears to confirm this suggestion. As detailed in the discovery paper (Mortlock *et al.*, *Nature,* **474**: 616, 2011), we find strong evidence that the Lyα absorption extends redward of the Lyα emission line, due to the predicted damping wing of the IGM, and that the neutral fraction is greater than 0.1.

We can confirm this with new observations in two ways: (1) we can take a deeper, higher-resolution spectrum, to measure the neutral fraction more accurately, from the damping-wing profile; and (2) we may even be able to see Lyα emission from the ionization front in a deep narrow-band image. These two observations could provide the first detailed information on the process of cosmic reionization, which can then be compared against simulations of the process.

The GNIRS spectrum reveals another very interesting property of this source: the existence of a supermassive black hole very early on in the history of the universe. The correlation between broad emission-line width and luminosity, calibrated by reverberation mapping at low redshift, allows a measurement of the mass of the black hole powering this quasar. The inferred mass is 2×10^9 solar masses. At $z = 7.085$, the universe is only 800 million years old. If there is sufficient surrounding matter to accrete, black holes grow in mass exponentially (since the pull gets stronger as the mass grows), on an e-folding timescale estimated to be 40 million years (this is assuming the standard efficiency of conversion of mass to luminosity of 0.1).

For a seed black hole mass of 100 solar masses there is only just enough time in the age of the universe to achieve this. It is possible that the seed black hole formed at very high redshift ($z \sim 30$), or that black holes grew in a different manner in the early universe. Either way, ULAS J1120 + 0641 is a remarkable object, and we expect to learn much more about the high-redshift universe from further observations of this source.

Our survey for the highest redshift quasars is a collaboration with Paul Hewett, Richard McMahon, Chris Simpson, and Bram Venemans. Special thanks to the GNIRS team for their hard work in recommissioning the instrument, and to Kathy Roth our Gemini support astronomer for extensive help with the observations.

For more information:

The discovery of ULAS J1120 + 0641 is described in detail in Mortlock *et al.*, *Nature*, **474**: 616, 2011. For a review on the epoch of reionization, see Fan, X., Carilli, C., and Keating, B., *Annual Review of Astronomy and Astrophysics*, **44:** 415, 2006. UKIDSS is described in Lawrence, A., *et al.*, *Monthly Notices of the Royal Astronomical Society*, **379**: 1599, 2007.

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by Antonino Cucchiara

Discovering the First Stars: Another Step Closer to the Beginning of the Universe

Using the most distant gamma-ray bursts as astronomical lighthouses, researchers can look back to the first stars and galaxies – deep into the epoch of reionization. This work explores a distant GRB that occurred as early as 600 million years after the Big Bang. The story is also a case-study in the challenges of doing cutting-edge research against the whims of nature.

Current estimates put the age of the universe at about 13.7 billion years old. It evolved from the first minutes, when only single hydrogen atoms existed, to the current epoch with its diversified ensemble of galaxies, stars, and planets, which shine into our telescopes and eyes.

We know very little about the universe's first billion years when it underwent a process known as "reionization." During that time, the first stars and galaxies produced enough energy to ionize all existing matter, allowing matter and radiation to be visible up to the current age.

Although astronomers still debate the nature of these "first stars," it is believed that long gamma-ray bursts (GRBs) may play a key role in our understanding of this very interesting period in the history of the universe. The most powerful explosions known, GRBs are likely produced by the death of very massive stars, those 30 or more times more massive than our Sun. They release energy more than 20 orders of magnitude greater than that of a supernova explosion, allowing us to detect these objects at large distances and up to what is known as the epoch of reionization.

The rarity and unpredictability of GRBs led to the creation of NASA's Swift Gamma-Ray Burst Explorer satellite. Built by an international collaboration (including the United States, the United Kingdom, and

Italy) and launched in 2004, Swift can detect these intense but fleeting events (which last only a fraction of second to a few minutes) with a large field-of-view camera, called the Burst Alert Telescope (BAT). It then quickly slews to the GRB's position, and two other instruments — an X-ray telescope (XRT) and an Optical/Ultraviolet telescope (UVOT) – immediately image it.

After the GRB progenitor explodes, the radiation emitted interacts with surrounding material, producing lower-energy photons (the "afterglow") detectable from X-ray to lower energy (such as optical and radio). Thus, within seconds of discovering a GRB, Swift also relays the object's position to ground stations, allowing both ground-based and other space-based telescopes the opportunity to observe the event's afterglow.

Such was the case on April 29, 2009, when Swift detected GRB 090429B, the most distant GRB known, and whose nature we helped establish with Gemini North. The main emission mechanism is a synchrotron process and the intrinsic spectral energy distribution (SED) is represented by a single power-law.

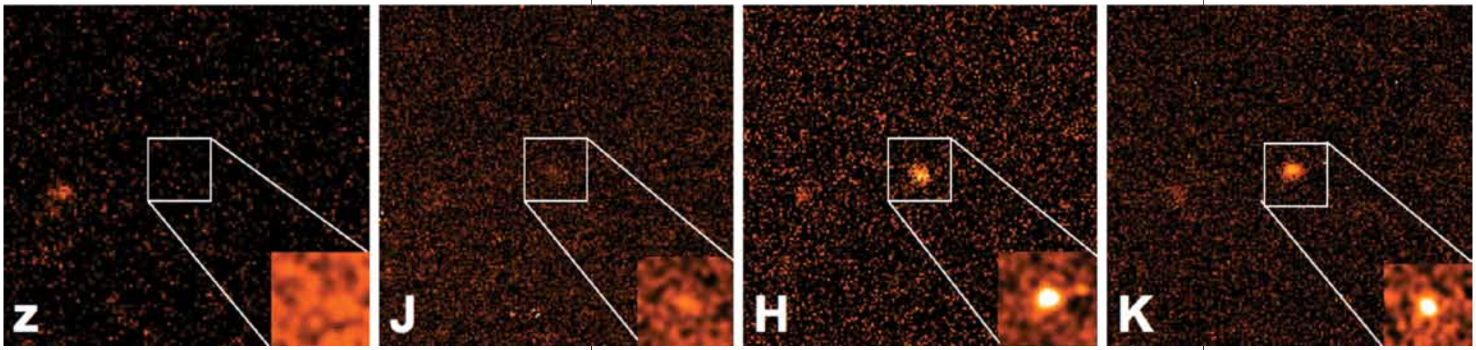

Figure 1.

GRB 090429B afterglow. The images, obtained from Gemini North, show the non-detection in the optical and near-infrared i' and z'-band, coupled with the relatively bright object seen in H and K. At z ~ 9.4, Lyman-alpha lies within the J-band, and explains the marginal detection at that wavelength.

The GRB 090429B Saga

Swift's BAT camera discovered GRB 090429B at about 5:00 Universal Time (UT) (the numbers in the object's designation indicate the date, while the letter B indicates that this was the second event discovered that day). Immediately after, the spacecraft slewed, pointing its XRT and UVOT instruments to the burst's location to image it. Simultaneously, the Swift control center's computers at the NASA-Goddard Spaceflight Center sent text messages and e-mails to several groups around the world, informing astronomers that another GRB had exploded. Thanks to this alert, we were able to immediately observe this GRB with several observatories, including Gemini North in Hawai'i and the European Southern Observatory's (ESO's) Very Large Telescope (VLT) and 2.2-meter telescope, both in Chile.

The Gamma-Ray Burst Optical and Near-infrared Detector (GROND) multichannel camera on the ESO 2.2-meter telescope, an imaging instrument designed to investigate GRB afterglows simultaneously in seven filter bands, executed the earliest observation only 900 seconds after the Swift announcement. But it did not detect any optical or infrared source at the position indicated by BAT or XRT (which found an X-ray afterglow). Also, optical observations taken one hour later with the VLT/FORS2 camera in R-band did not reveal any GRB 090429B counterpart at a very deep limit.

In light of these negative results, we decided to use our Target of Opportunity time at Gemini North to observe the afterglow using both the Gemini Multi-Object Spectrograph (GMOS) and the Near-infrared Imager and Spectrometer (NIRI) to obtain complementary observations in the optical and near-infrared. Like the VLT observations, but two hours later, our GMOS i'- and z'-band observations (centered at 763 and 905 nanometers, respectively) did not reveal any object in the GRB field. To our incredible surprise, however, we did find a new source in the Gemini NIRI J- (1.26 micron (μm)), H- (1.65 μm), and K- (2.2 μm) band images (Figure 1).

After considering all of this data, we interpreted the Gemini discovery in two ways: (1) as a local and highly dust-extinguished source; or (2) as a high-redshift event, at $z > 8$, corresponding to the first billion years after the Big Bang.

To secure the real nature of GRB 090429B, we immediately requested NIRI spectroscopic observations. This would have provided a redshift determination based on absorption-line identification and/or the presence of the Lyman-alpha (Lyα) break found in other GRBs (e.g. GRB 090423 at $z = 8.23$, so far the furthest spectroscopically confirmed object, also discovered by the Gemini Observatory).

Unfortunately, nature turned against us: The wind at Mauna Kea's summit increased and the dome had to be closed, precluding any further observations with Gemini on that night.

The fast-fading nature of GRBs usually requires securing spectroscopic observations in the first 24 hours after their discovery. Although disappointed, we did not let our bad luck stop us from pursuing our goal of determining the "secret" nature of this event. In fact, the very next night, we executed another K-band observation and verified that the discovered object was indeed a GRB and not a steady faint field source. Unfortunately, the afterglow brightness was one-third that of the previous night, making it too faint to obtain a NIRI spectrum.

Nevertheless, since a GRB's main emission mechanism is a synchrotron process, and the intrinsic SED is represented by a single power-law, our multicolor observations still allowed us to perform a reliable photometric redshift analysis.

From Color to Redshift

That we could not detect GRB 090429B optically with 8-meter-class telescopes clearly indicated that GRB 090429B must have a redshift of at least $z > 6.3$ (about 900 million years after the Big Bang). Moreover, the J-H color is very red, especially compared with the H-K color. We can interpret this as a possible Lyα break between the J and H bands, which means that it has a redshift of between 8.0 and 10.5.

Another possibility that could explain the nature of GRB 090429B and these interesting features is the presence of a large amount of extinction in the vicinity of the GRB, inside its host galaxy. To verify this we performed a photometric redshift estimate fitting the multiband data acquired on the first night. We included different host galaxy extinction laws and also considered the uncertainties in the intrinsic synchrotron spectral index derived by the afterglow observations.

In Figure 2 our results show that the GRB's spectral energy distribution can be fitted by two different curves: The dashed blue line representing a low-z solution, at $z \sim 0$, indicating both that the GRB occurred very close to the local universe, and that the galaxy must be very dusty (to produce a visual extinction of $A_V = 10.6$ magnitudes), or at least in the GRB vicinity; a second possibility, shown as the solid red line, is that the GRB occurred in a dust-free host galaxy ($A_V = 0.10$) as early as 520 million years after the Big Bang, at $z = 9.36$, making GRB 090429B the furthest object ever observed.

In Figure 3, we show the confidence contours on a parameter space of redshift and host galaxy extinction for the GRB 090429B afterglow (green contours are 90-, 99-, and 99.9-percent confidence levels). All fits at $z < 7.7$ are ruled out at >99-percent confidence, and while fits can be found at $z \sim 0$, they are worse than the high z solutions.

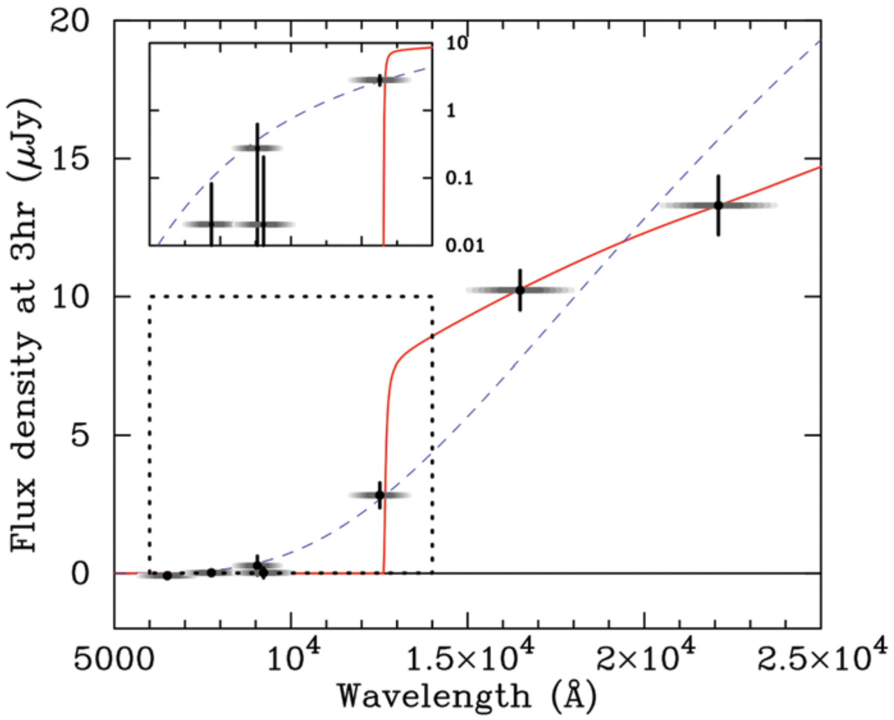

Figure 2.

Spectral energy distribution of the GRB 090429B afterglow. Error bars are 1σ and horizontal shaded bars illustrate the widths of the broad-band filters. The best fit model to the data points is $z = 9.36$. The inset shows a zoom-in (solid red line) at the short wavelength part of the figure (indicated by a dotted box) on a logarithmic flux density scale, to more clearly show the constraints from the optical measurements. The low-redshift model is also shown (dashed blue line), but is formally ruled out at high significance.

Solving the Mystery

No other ground-based observations would have helped in distinguishing between these two possibilities shown in Figure 2. GRB 090429B was already too faint to observe spectroscopically the day after the burst, and our Gemini GMOS observation conducted two weeks after the event, when we observed the field again for a total integrated time of 75 minutes in the R-band, also failed to detect it.

Our group, nonetheless, was able to obtain Hubble Space Telescope (HST) observations between January and February 2010, when we used the refurbished Advanced Camera for Surveys in the optical and the Wide Field Camera 3 in the near-infrared bands to search for the GRB's host galaxy. With the characteristics derived by our photometric redshift analysis, we determined that HST could detect such an object if, indeed, it was at low redshift.

Our analysis of the HST data, however, did not reveal any source at the position indicated by the GRB infrared counterpart, allowing us to exclude, with very good confidence, that GRB 090429B was a local event. Indeed, GRB 090429B did explode during the early stages of the universe.

The existence of such an event indicates that stars as big as the GRB 090429B progenitor had time to form and die from the first epoch of the universe, when the universe was not completely reionized (as indicated by the Wilkinson Microwave Anisotropy Probe satellite). In fact, we believe that the first generation of stars drove ionization. Finding these early stars and identifying their harboring galaxies will be a primary goal for future space missions like the James Webb Space Telescope or the Joint Astrophysics and Nascent Universe Satellite.

For more information:

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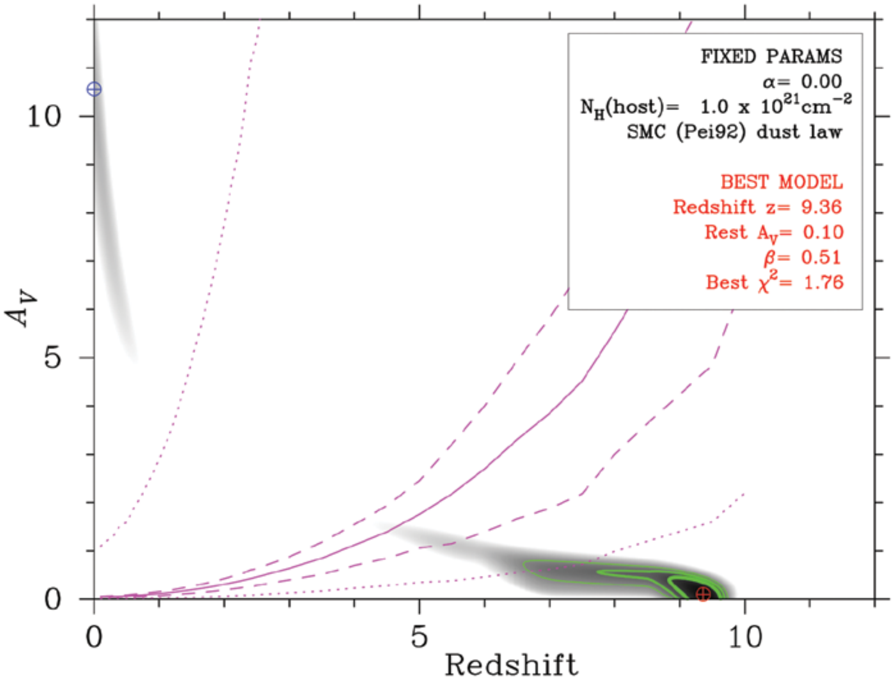

Figure 3.

Confidence contours of the redshift/A_V parameter space. Any $z < 5$ solution is disfavored by the host galaxy non-detection and also by the inconsistency of the required extinction with the hydrogen column density measured from the X-ray afterglow. To illustrate this, the best-fit N_H from the X-ray spectrum is converted into A_V and plotted as purple lines (dashed lines show the 90-percent error range, while dotted lines represent the error range derived by previous studies).

by Jessica Kay Werk and Mary E. Putman

Finding Metals in the Gaseous Outskirts of Galaxies

Deep spectra of outlying HII regions taken with the Gemini Multi-Object Spectrograph on Gemini North reveal an unexpectedly large amount of oxygen in the outermost gaseous regions of galaxies. This oxygen excess indicates that there must be a yet-unknown, but efficient, mechanism for transporting metals into gaseous galactic suburbs.

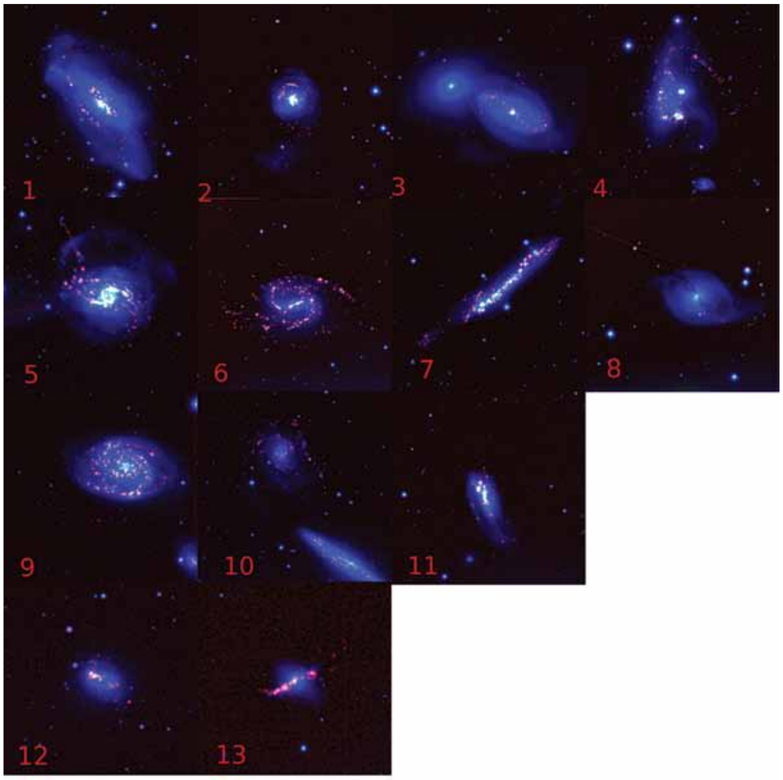

Figure 1.

The 13 galaxies in our sample, and their outlying HII regions, seen in red. In these images, blue (R-band) represents light from the underlying older stellar populations, whereas red (Hα) represents light from the most massive, youngest stars. The galaxies in our sample are: (1) NGC 2146, (2) NGC 2782, (3) NGC 3227, (4) NGC 3239, (5) NGC 3310, (6) NGC 3359, (7) NGC 3432, (8) NGC 3718, (9) NGC 3893, (10) NGC 5774/5, (11) NGC 6239, (12) UGC 5288, and (13) UGC 9562 (II Zw 71). Image Credit: J. Werk at the MDM 2.4-meter telescope.

Stars generate metals through nuclear fusion and in the final stages of their evolution. When stars die, they inject these metals (by which astronomers mean all elements heavier than hydrogen and helium) into the local interstellar medium (ISM). Since galaxies are neither static nor isolated, these metals are subsequently mixed on more global scales. Finally, metals may also flow out of a galaxy via galactic winds and galaxy interactions, and possibly even stream from one galaxy into another during the interactions. The study of how and to what extent metals disperse throughout a galaxy — called galaxy chemodynamics — is a cornerstone of galaxy evolution research.

The global processes that govern galaxy chemodynamics are largely unknown and widely debated. Furthermore, it remains uncertain as to how and to what extent galaxies lose their metal content to the intergalactic medium (IGM). While we find metals (commonly oxygen, nitrogen, magnesium, and iron) to be distributed in shallow radial gradients in some spiral galaxies, others exhibit steeply declining radial abundance gradients. What makes these metal distributions harder to probe is that few measurements of gas-phase metal abundances exist at large radii, where there are a limited number of metal-producing stars. To determine the nature and extent of metal transport in galaxies, we must observe the metal distributions in a variety of galaxy types out to large galactocentric distances.

Neutral hydrogen gas often extends far beyond the stellar components of galaxies in forms ranging from relatively quiescent extended disks to tidally stripped appendages. Occasionally, these gaseous extensions contain young stellar populations that create HII regions, and these "outlying HII regions" can shed light on the issue of large-scale metal distributions in galaxies (Figure 1).

HII regions are ionized nebulae with at least one

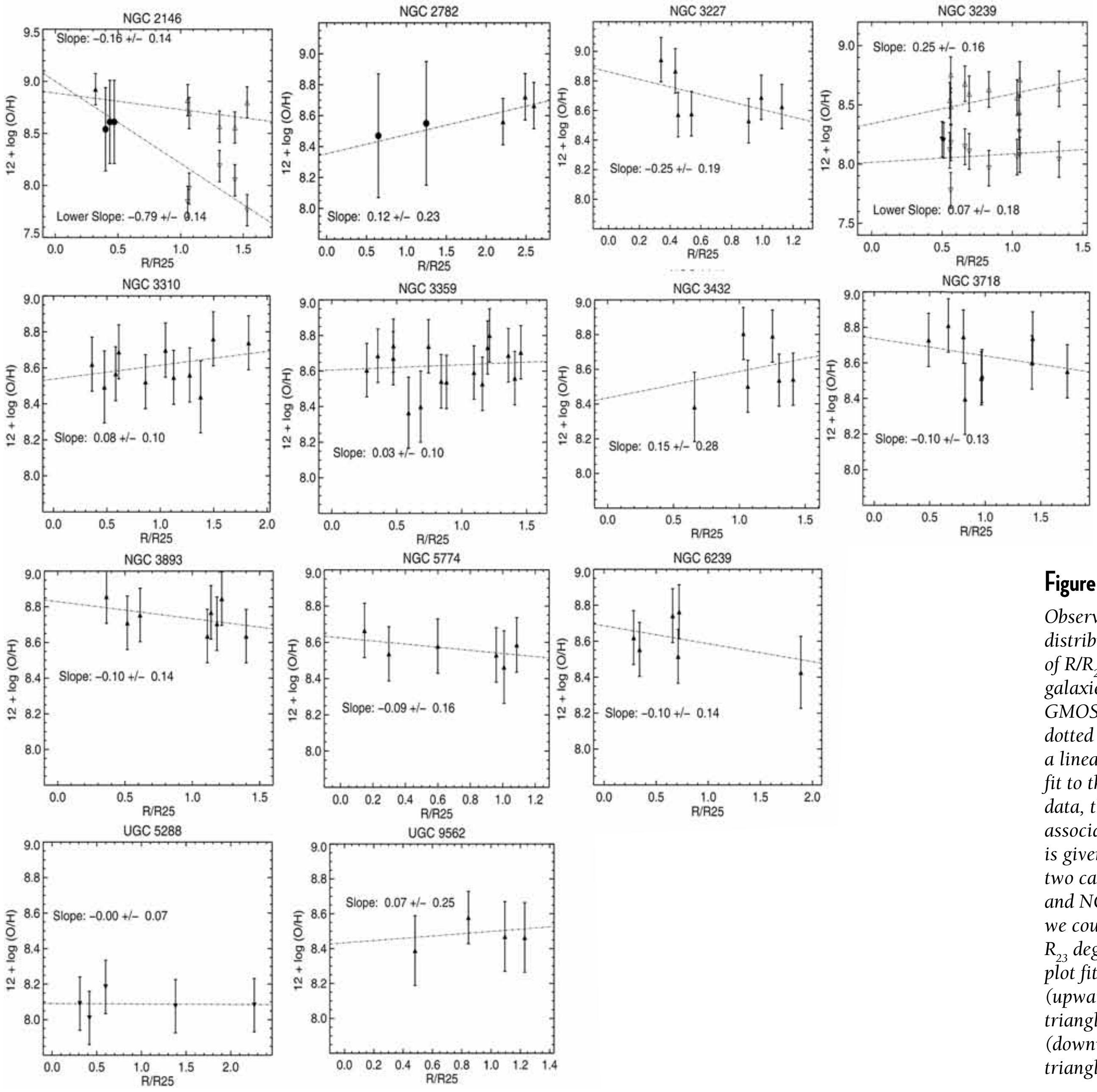

Figure 2.

Observed radial oxygen distributions (in units of R/R$_{25}$) for the 13 galaxies we studied with GMOS-N. The dashed-dotted line represents a linear-least-squares fit to the abundance data, the slope (and its associated σ) of which is given on the plot. In two cases (NGC 2146 and NGC 3239), where we could not break the R$_{23}$ degeneracy, we plot fits to both upper (upward-facing, open triangles) and lower (downward-facing, open triangles) branch values.

star massive (>15 M_{Sun}) and hot enough to ionize hydrogen. Outlying HII regions are simply HII regions located in the low-density, far-outskirts of galaxies. At first their discovery perplexed us, because we traditionally do not observe significant molecular gas reservoirs, the fuel for star formation, at large galactocentric radii. Now, 13 years after their initial discovery, we're beginning to understand their frequency, nature, and environment — first steps toward assembling a comprehensive picture of how low-density, isolated star formation is first triggered and subsequently regulated, and more broadly, how galaxies process their gas.

We can use spectroscopic studies of outlying HII regions to understand both star formation and metal transport in galaxies. At the low gas densities typical of HII regions, forbidden emission lines (such as [OIII] at 4959 and 5007 angstroms (Å) and [OII] 3727 Å) are common, along with the radiative recombination lines of the hydrogen Balmer and Paschen series (e.g. Hα). Because the strength of every emission line from every element present in the HII region depends on its chemical abundance in the nascent ISM gas, HII regions are valuable metallicity indicators. As such, they trace the star formation history of the gas (the vast majority of elements heavier than helium are fused within stars) and act as chemical tags that can aid in determining the origin of the gas.

A Sample of Outlying HII Regions

We now know that low-intensity star formation in the outskirts of galaxies isn't particularly rare. Our study of isolated HII regions in the Survey for Ionization in Neutral Gas Galaxies (SINGG — G. Meurer, Principal Investigator) finds that their overall frequency in this unbiased sample of gas-rich galaxies is 10 percent. Similarly, the incidence of extended ultraviolet emission, which traces slightly less massive stellar populations (>3 M_{Sun}), in nearby galaxies is 30 percent. In both cases, a correlation exists between the presence of extended star formation and galaxy interactions.

In Figure 1, narrow-band (Hα, red) and continuum (R-band, blue) images of 13 galaxies is shown. These galaxies are selected from the "HI Rogues Catalog," a collection of nearby galaxies with disturbed or extended neutral hydrogen distributions, many of which likely interacted with another galaxy (available online at http://www.nrao.edu/astrores/HIrogues/). The Hα emission traces the ionizing radiation from massive stars (i.e. HII regions), whereas the continuum filter shows the light that comes from older stars throughout the galaxy.

We have found a large number of outlying HII regions in the gaseous outskirts of these 13 galaxies (look toward the edges of the stamp-sized figures). The maps of the neutral gas that extends beyond the visible part of these galaxies are available on the web site referenced above. The galaxies we studied have a diverse range of properties. Ten of them have recently undergone mergers and exhibit extended gaseous features. The two dwarf galaxies NGC 3359 and UGC 5288 have very extended, but otherwise uncomplicated, HI disks. NGC 3718 exhibits a large HI warp. Each system illustrates a different stage in the interaction process.

Using Gemini to Track Metal Distributions in Galaxies

Using the Gemini Multi-Object Spectrograph on Gemini North (GMOS-N), we obtained deep spectra of the numerous isolated HII regions in the 13 HI Rogues seen in Figure 1. Our primary goal was to obtain spectral coverage of the full range of nebular emission lines typical of HII-region spectra in order to measure their oxygen abundance. We put slits on approximately 8 - 12 HII regions per galaxy, over a range of galactocentric distances. One useful marker of galactocentric distance is the radius at which the surface brightness of the galaxy's R-band light drops below 25th magnitude (R_{25}), often referred to as an optical radius. We covered HII regions that lay between 0.3 and 2.7 times R_{25}.

Numerous calibrations between emission lines of high intensity can trace the gas metal abundance with reasonable success. One in particular, R_{23} = ([OII] 3727 Å + [OIII] 4959, 5007 Å) / Hα, seems to follow the direct oxygen abundance well, because of the stellar mass-temperature-metallicity relation which naturally produces a softening (low-excitation) of stellar spectra with increasing metallicity (McGaugh, 1991). We used the R_{23} method, with an additional correction provided by the [NII] line strength, to obtain the oxygen abundances of the HII regions with an accuracy of 0.3 dex. We parameterize the oxygen abundance as 12 + Log (O/H), essentially a number density of oxygen atoms relative to a number density of hydrogen atoms.

Figure 2 shows the radial oxygen abundance distributions for our 13 HI Rogues using GMOS-N spectral data, with oxygen abundance as a function of radius, scaled to R_{25}. In two cases, we include two separate sets of data points and resultant fitted slopes. This degeneracy mirrors the oxygen abundance calibration degeneracy that we couldn't resolve in these two cases.

Nonetheless, in the vast majority of cases, the distribution of oxygen across the spatial extent of the outer regions of these galaxies looks remarkably flat. Excluding the two ambiguous cases (NGC 2146 and NGC 3239), our derived abundance gradients range from + 0.25 dex/R_{25} to - 0.25 dex/R_{25}. Note that our data generally do not apply to nuclear oxygen abundance gradients between 0 and ~ 0.4 R/R_{25}, which may very well be declining at different rates. These galaxies have radial oxygen abundance gradients (beyond 0.4 R/R_{25}) consistent with being flat within 1σ over an average of ~ 15 kiloparsec (kpc; ~ 50,000 light-years), where typical $\sigma_{\text{slope}} = 0.15$ dex.

Understanding the Metal Enrichment Observed in Outer Galaxy Disks

Given basic assumptions, we found the amount of oxygen in the outer galaxy disks sampled to be unexpectedly large. We expected much lower metal abundances for two reasons: (1) Most star-forming galaxies exhibit declining, some very steeply, radial abundance gradients within R_{25}; while we don't well understand these declining gradients, most chemodynamical models that include disk dynamics predict that the gradients will continue to decline at large radii; and (2), the rate at which stars form is generally much lower in the outer parts of galaxies compared to that within the disks. Since all metals are created within stars, we expect to find more metals where there are more stars.

We can quantify the oxygen excess by assuming a constant yield of oxygen per solar mass of stars observed and averaging the star-formation rate in the inner and outer disks, respectively. When we do this calculation, we find the amount of oxygen atoms in the outer disk ranges between 6 and 15 times the number we expect given the current star-formation rate in the outer disks. Correspondingly, we find the inner galaxy, on average, about five times under-abundant in oxygen given the current star-formation rate in the inner disks. The bottom line: Metals in the outer disk did not originate there but were transported to that location from elsewhere.

Very generally, our results indicate that efficient metal mixing occurs out to large galactocentric radii, perhaps facilitated by galaxy interactions. Nonetheless, a few galaxies in our sample show no clear evidence of a recent merger or interaction, yet they appear still well-mixed out to large radii. The rest of our sample represents myriad interaction types. If indeed interactions primarily drive the metal mixing seen here, then the mechanism by which they act is independent of the interaction details.

We have, for the first time, observed predominantly flat radial oxygen abundance gradients in a wide variety of galaxies with varying degrees of interaction and star formation. This compelling evidence of uniform metal distribution across extended gaseous features has broad implications for galaxy chemodynamical evolution, and galaxy evolution in general. We're now working toward assembling a larger sample of galaxies with outlying star formation that have a wider range of properties and accretion histories so that we can better understand this phenomenon.

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by Nicholas McConnell and Chung-Pei Ma

Record-Breaking Black Holes Lurking in Giant Elliptical Galaxies

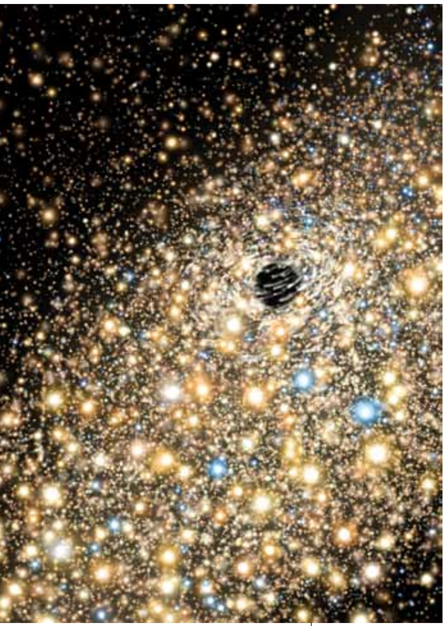

Figure 1.

Artist's conceptualization of the stellar environment around a black hole of about 10 billion solar masses. The velocity of stars in orbit (and close to) the black hole help to determine its mass. Gemini Observatory/ AURA illustration by Lynette Cook.

A new milestone in the quest to find the largest black holes in the local universe leap-frogged previous records with this discovery of two black holes approaching 10 billion solar masses. Whether these prove to be the "tip of the iceberg," as lead-author of a recent Nature *paper (December 8, 2011) Nicholas McConnell asks, or if these are unique, is still to be seen.*

Over the past several decades, the world's largest telescopes and sharpest instruments have peered deep into the hearts of nearby galaxies and revealed the presence of supermassive black holes. In fact, every galaxy with a bulge or elliptical component is now believed to host a central black hole. The cosmic collection of supermassive black holes spans an impressive mass range, from millions of solar masses in spiral bulges like that of our Milky Way, to several billion solar masses in giant elliptical galaxies. Yet even the record-holding black hole in Messier 87 (M87) — originally measured in 1978 and recently set at 6.6 billion solar masses (*Gemini*Focus, June 2011, page 18) — has not satisfied astronomers. Like cosmic bounty hunters, we have pressed on in search of something even bigger, lurking just out of reach.

Two arguments have suggested the existence of black holes with 10 billion solar masses or more. The first argument comes from observations of quasars — distant galaxies with extreme luminosities powered by enormous quantities of gas spiraling toward a central black hole. The gas is heated to glowing temperatures before it is consumed, producing an intense beacon visible from billions of light-years away. By using spectroscopic data to estimate the speed of the gas and its average distance from the black hole, astronomers can estimate a quasar's black hole mass, albeit with large uncertainties. In large surveys of quasars, the most massive black holes have been estimated at 10 to 20 billion solar masses. We observe the quasars hosting such massive black holes, however, only at high redshifts ($z \sim 2 - 5$), when the universe was less than 3 billion years old and contained more gas for consumption. Over the last 10 billion years or so, the once ravenous black holes have settled into quiet obscurity, and their present-day whereabouts are largely unknown.

The second argument for 10-billion solar-mass black holes is based upon extrapolations from a sample of approximately 60 nearby galaxies in which a central black hole mass has been obtained directly from the dynamics of gas or stars in the vicinity of the hole. The masses of the black holes across this sample range from millions to billions of solar masses and show remarkable correlations with both the stellar velocity dispersion and luminosity of the host elliptical galaxy or spiral bulge — the bigger the galaxy, the bigger the black hole (Figure 2). The most luminous galaxies in the local universe are Brightest Cluster Galaxies (BCGs), giant ellipticals lying near the centers of galaxy clusters. M87 resides in the Virgo cluster, the nearest prominent galaxy cluster to us at a distance of 17 Megaparsecs (Mpc; about 55 million light-years (ly)). To hunt for black holes bigger than M87, we would need to venture beyond the Virgo cluster.

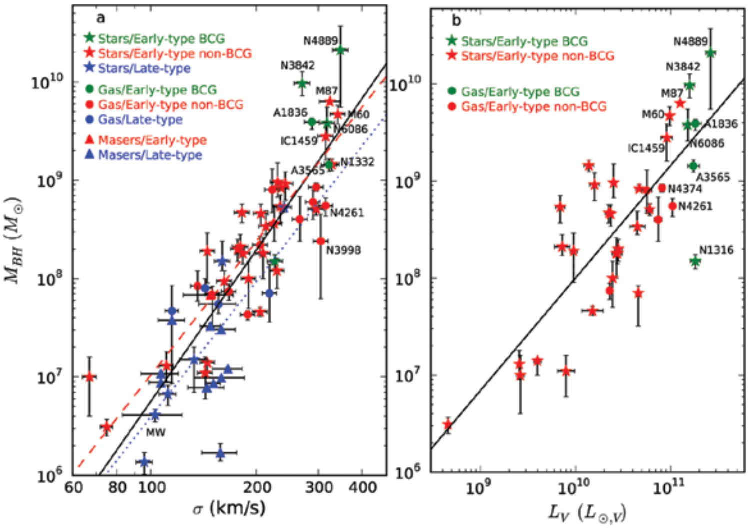

Figure 2.

In the local universe, black hole masses correlate with host galaxies' stellar velocity dispersions (left) and luminosities (right). This figure illustrates the galaxies with direct dynamical measurements of black hole masses based on masers (triangles), stars (stars), or gas (circles), from publications through August 2011. Figure courtesy of Nature.

Making direct observations of a black hole's presence in BCGs is extremely difficult because these massive galaxies are rare, and their distances are typically several times greater than M87. Like most present-day elliptical galaxies, BCGs and their black holes are "red and dead," with only small traces of gas left over from earlier periods of star formation. Without a gas reservoir feeding the black holes, they become dormant and do not give out X-ray or optical line emissions that are characteristic of active galaxies such as quasars. Yet a quiet black hole can still reveal its presence by the effect of its gravitational pull on the orbits of nearby stars.

At distances of tens to hundreds of light-years from the black hole, stars are rarely consumed but are instead accelerated to large orbital speeds. The difficult task for astronomers is to disentangle the motions of stars near the black hole from other stars orbiting beyond the black hole's region of influence. Doing so requires spectroscopic observations with superb angular resolution, in order to clearly map the galaxy's center. Only a few of the world's largest telescopes, including Gemini North and South, can resolve the center of a BCG and also collect enough starlight to permit meaningful observations.

After much effort, our team — four University of California, Berkeley, scientists (the two authors, Shelley Wright, and James Graham (also University of Toronto)), Karl Gebhardt and Jeremy Murphy (University of Texas, Austin), Tod Lauer (National Optical Astronomy Observatory), and Doug Richstone (University of Michigan) — achieved a breakthrough this year, discovering two black holes with unprecedented masses in the local universe. We've measured a 9.7-billion solar-mass black hole in the galaxy NGC 3842, the BCG of Abell cluster 1367, and another that could be as large as 21 billion solar masses in NGC 4889, the BCG of the Coma cluster (Abell 1656; Figure 3). Both galaxies are at approximately 100 Mpc (~330 million ly) from our Galaxy, six times further than the previous record holder M87.

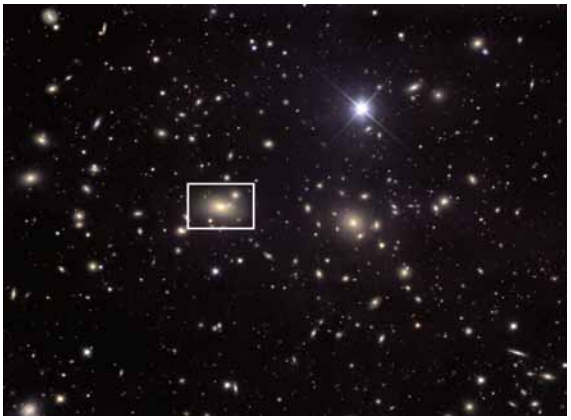

Figure 3.

NGC 4889 is the most luminous galaxy in the Coma galaxy cluster, which contains over a thousand galaxies. This galaxy cluster is one of the most massive gravitationally-bound structures in the nearby universe, and now includes at least one black hole with approximately 21 billion solar masses. This Hubble Space Telescope panorama of the Coma cluster has been marked with a box enclosing NGC 4889. Image credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA).

Our measurements are based on analysis of the stellar motions near the centers of the two galaxies, using data from GMOS on Gemini North and instruments at Keck Observatory in Hawai'i and McDonald Observatory in Texas. We obtained the most essential data for measuring the black holes in NGC 3842 and NGC 4889 with the integral-field unit (IFU) on GMOS (Figure 4). The GMOS IFU uses an array of tightly packed hexagonal lenslets to divide the focal plane, such that a single exposure records hundreds of independent spectra across a two-di-

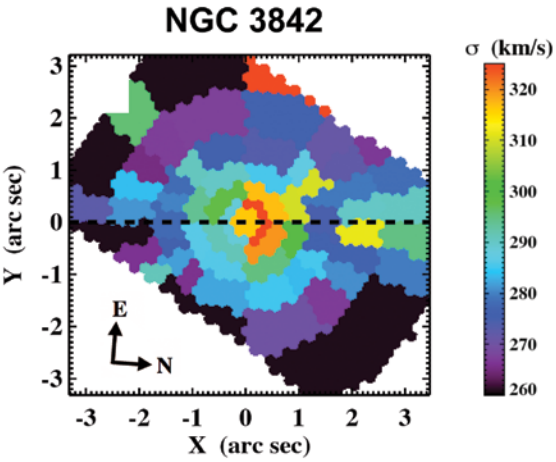

Figure 4. *Two-dimensional measurements of stellar motions from the GMOS IFU on Gemini North were crucial for determining the black hole masses in NGC 3842 and NGC 4889. This figure illustrates the Gaussian dispersion in the line-of-sight stellar velocities from millions of stars, as measured in numerous regions near the center of NGC 3842. The increase in velocity dispersion toward the galaxy's center contributes to the evidence for a 9.7-billion solar-mass black hole. Figure courtesy of* Nature.

mensional field. Flexible queue-mode observations by Gemini astronomers ensured that our data were obtained with the best seeing conditions atop Mauna Kea. We were ultimately able to resolve stellar kinematics at angular scales of 0.4 arcsecond, corresponding to approximately 200 pc (~650 ly) at the distances of NGC 3842 and NGC 4889.

Data from the OSIRIS IFU at Keck helped confirm the stellar motions at similar spatial resolutions, and the VIRUS-P IFU at McDonald Observatory recorded spectra at the outskirts of each galaxy. We determined the black hole masses by comparing our high-resolution and wide-field measurements of stellar kinematics to numeric galaxy models with stars, a black hole, and a dark matter halo. We further constrained the models with images from the Hubble Space Telescope and Kitt Peak National Observatory.

In NGC 3842 and NGC 4889, we have finally discovered nearby black holes in the same mass range as the very brightest quasars when the universe was 1 to 3 billion years old. Yet we have not proven that these specific galaxies were once quasars, or that their black holes reached such monstrous size early in the universe and have been dormant since. In fact, observational and theoretical studies of BCGs suggest that they assembled gradually over time, from the mergers of dozens or hundreds of smaller stellar systems.

Although early black hole growth and gradual stellar assembly could coexist through different evolutionary processes, this combination would likely foster a distinct trend between luminosity and black hole mass for the biggest present-day galaxies. In particular, we might expect galaxies with similar stellar luminosities to exhibit a wide range of black hole masses.

This trend can already be seen in the large scatter in black hole masses at the high ends in Figure 1. In addition, our new measurements of black hole masses lie systematically above the global power-law fits indicated by the straight lines. Observations of black holes in a larger number of BCGs will be required to understand further these important scaling relations for the most massive galaxies in the universe.

At this stage, it's too early to know whether our two black holes of at least 10-billion solar masses will be a rare find or just the tip of the iceberg. Dozens of galaxy clusters and BCGs lie at similar distances to NGC 3842 and NGC 4889, but none are guaranteed to host black holes as massive. What is certain is that with continued advances at Gemini and other observatories, astronomers' ongoing search for supermassive black holes will continue expanding to further horizons.

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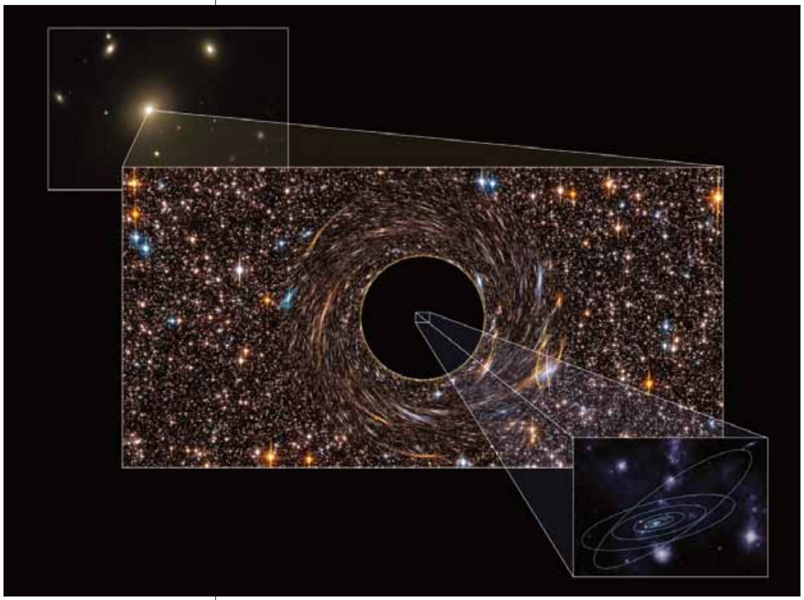


Figure 5. *This picture illustrates the immense size of the black holes discovered. The black holes reside at the centers of two galaxies, each of which is the brightest galaxy in a cluster of galaxies. The background image shows the brightest galaxy in the cluster Abell 1367, which hosts one of the black holes. The event horizons of both black holes are several times larger than Pluto's orbit. Our Solar System would be dwarfed by the holes. Figure courtesy of P. Marenfeld/NOAO/AURA/NSF.*

by Alex H. Parker

The First Mutual Orbits for Ultra-wide Kuiper Belt Binaries

Binary systems in the distant Kuiper Belt are key to understanding the environment at the extremes of our Solar System. A new study using the Gemini Multi-Object Spectrograph looking at ultra-wide systems suggests that the history of the outer Solar System is a quiet one, and that classical formation theories may need to be revised to account for the observed binary properties.

Most minor planet populations have binary systems, but we find those in the Kuiper Belt of special note. There we find many very widely-separated binary systems with primary and secondary bodies of near equal size. Since the current environment at the edge of the Solar System does not favor wide binary formation, these systems must be primordial. As such, they represent tracers of the outer Solar System's history, since their orbits not only depend on the conditions in the early protoplanetary disk, but also any intervening perturbative processes, such as impacts or planet scattering.

In 2008, a team of collaborators and I began a concerted observational campaign to determine the properties of the mutual orbits of the widest binary systems in the Kuiper Belt using the Gemini Multi-Object Spectrograph (GMOS) camera. We found that the properties of these orbits shed new light on the history of the outer Solar System.

For this study, we chose a sample of seven binaries, based on the following criteria: they had separations at discovery exceeding half an arcsecond, and had components which differed in brightness by less than 1.7 magnitudes — indicating a mass ratio less than 10, if both components have the same density and albedo. Some of these systems had been known for over a decade, but no precise orbital determination existed in the literature for any of them. Interestingly, all binaries which meet these criteria are dynamically cold, non-resonant objects that belong to only a single component of the classical Kuiper Belt, the so-called Cold Classical Kuiper Belt.

Formation Mechanisms

A number of theoretical mechanisms exist for the formation of widely-separated, near-equal mass binaries in the Kuiper Belt; they all proceed at varying rates depending on the conditions in the early outer Solar System. One possibility is that two solitary large Kuiper Belt objects (KBOs) pass each other, but dissipate energy into a sea of smaller objects surrounding them. As this energy seeps out, the two larger KBOs can become bound in a mutual orbit. Another possibility is that three relatively large KBOs encounter each other at the same time, and one is gravitationally scattered away carrying with it significant energy, leaving the other two bound together.

Astronomers have studied the preceding two mechanisms in depth. Recent work (Schlichting and Sari, 2008) found that the first mechanism (a dissipative sea of small bodies) dominates when the protoplanetary disk is dynamically cold, with low velocities during mutual encounters. It also produces an overwhelming number of retrograde mutual orbits, and low mutual inclinations are expected due to the approximately two-dimensional nature of encounters between large KBOs (eg. Noll *et al.*, 2008).

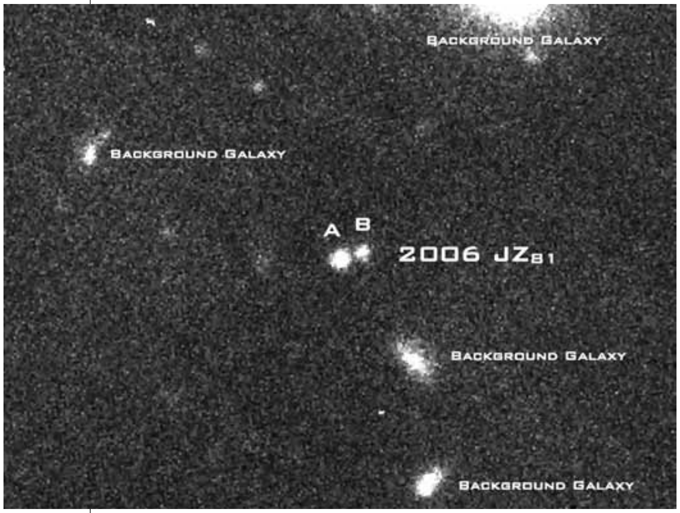


Figure 1.

Example Gemini image of an ultra-wide Kuiper Belt binary, the highly eccentric 2006 JZ$_{81}$. Primary and secondary components are marked "A" and "B," respectively. Image taken in March 2011; separation between components is approximately 1.2 arcseconds.

The second mechanism (three-body capture) dominates when the disk is more energetic, but the binary formation rate drops dramatically as the disk becomes more dynamically hot. We expect this mechanism to produce roughly equal numbers of prograde and retrograde binaries, along with a more random distribution of mutual inclinations.

A recently-proposed third mechanism may have created a large number of binaries in the Kuiper Belt, if conditions were markedly different. Nesvorny *et al.* (2010) explored the formation of binaries in the context of planetesimal formation through gravitational instability (rather than slow, ordered hierarchical accretion). They find that as planetesimals collapse out of the disk, the collapsing cloud frequently fragments and forms multiple systems.

While the simulations produce binaries with large ranges of separation and mutual eccentricity, the researchers remain cautious about the mutual inclinations and orientations of the systems as, at present, they do not know the initial conditions for the orientations of collapsing clouds. We find this third mechanism attractive because, unlike the other two, it predicts identical colors of binary components — a feature Kuiper Belt binaries exhibit. Additionally, this collapse mechanism remains efficient even at large distances from the Sun and in low-density environments, unlike classical accretion.

Mutual Orbit Determination

Over four semesters at Gemini North, we used the GMOS camera to acquire high signal-to-noise optical images of our targeted seven systems; due to the short exposure times (allowed by the light-gathering capacity of the Gemini telescope) and the flexibility of queue scheduling, we executed these observations as fast "pot shots" during short periods of extremely good seeing. This data allowed measurements of the relative positions of the binary components over time with very high precision without the use of adaptive optics or space-based imaging — a level of precision comparable to measuring the width of a human hair from over 1 kilometer (km) away.

Additionally, we used "Solar System Object Search" to search for images that might contain our targets; this service, provided by the Canadian Astronomy Data Centre, uses moving-object ephemerides to search a number of public archives that might contain targets of interest. For some of our selected binary systems, we found archival data stretching back over a decade.

By combining these precise measurements of the relative positions over time, we were able to determine the properties of the mutual orbits of these binary systems for the first time. We used a variant of the Metropolis-Hastings algorithm for finding the seven-dimensional mutual orbit fit and uncertainties. As with binary stars, a mirror degeneracy appears in the projection of the system on the sky — that is, at any given time we cannot tell if the primary is closer to us than the secondary, or vice versa. However, after sufficient time has elapsed, the motion of binary KBOs around the Sun breaks that degeneracy. We confirmed that for each of the systems in our sample, and we could rule out the mirror solution at greater than 95 percent confidence.

Several systems broke records: 2001 QW_{322} is the most widely-separated binary minor planet known, with an average separation exceeding 100,000 km. And 2006 CH_{69} has the most eccentric mutual orbit known, at $e = 0.9$; at closest approach its two components lie only about 2800 km apart, while at their most distant they have over 52,000 km between them. The smallest object in the sample, 2000 CF_{105}, has the lowest mass of any measured KBO — roughly twice that of Mauna Kea, the volcano on which Gemini North resides.

Formation Mechanisms Revisited

Unlike more tightly-bound Kuiper Belt binaries, which show a uniform distribution of mutual inclinations, the widely-separated systems prefer low mutual inclinations — having mutual orbital planes aligned with the rest of the Solar System. In fact, all the systems in our study had mutual orbits aligned (or anti-aligned) within 60° of their heliocentric orbits. If the systems had been uniformly distributed in inclination, we would expect half of them to have inclinations greater than 60°.

Crudely, finding seven systems with inclinations less than 60° is equivalent to flipping a coin seven times and finding heads-up each time — 0.5^7, or roughly 0.8 percent. This, by itself, would suggest formation in a dynamically cold disk, where very planar encounters occurred between large solitary objects; this also suggests that formation via dissipation to a sea of small bodies should have dominated.

However, we were surprised to find that, after sufficient time had elapsed that the mirror degeneracy on the orbits had been broken, about half (4) of the systems orbit each other in prograde orientation, while the others (3) orbit each other in retrograde orientation. We predicted this scenario only for more energetic, dynamically-hot disks, where binary formation proceeds through three-body interactions; but such an environment would likely not form solely low mutual inclination systems.

Could post-formation dynamics have modified the inclination distribution? One scenario we immediately checked was whether Kozai cycles (periodic oscillations of inclination and eccentricity for highly inclined systems), coupled with tidal friction, could cause the highest inclination systems to have close pericenter passages, followed by tidal evolution to tighter orbits; if so, they may have evolved out of our sample. We found that for binaries as widely separated as those we studied, even when assuming very large amounts of tidal dissipation, this process would only subtly modify an initially uniform inclination distribution, which we could still rule out at greater than 95 percent confidence.

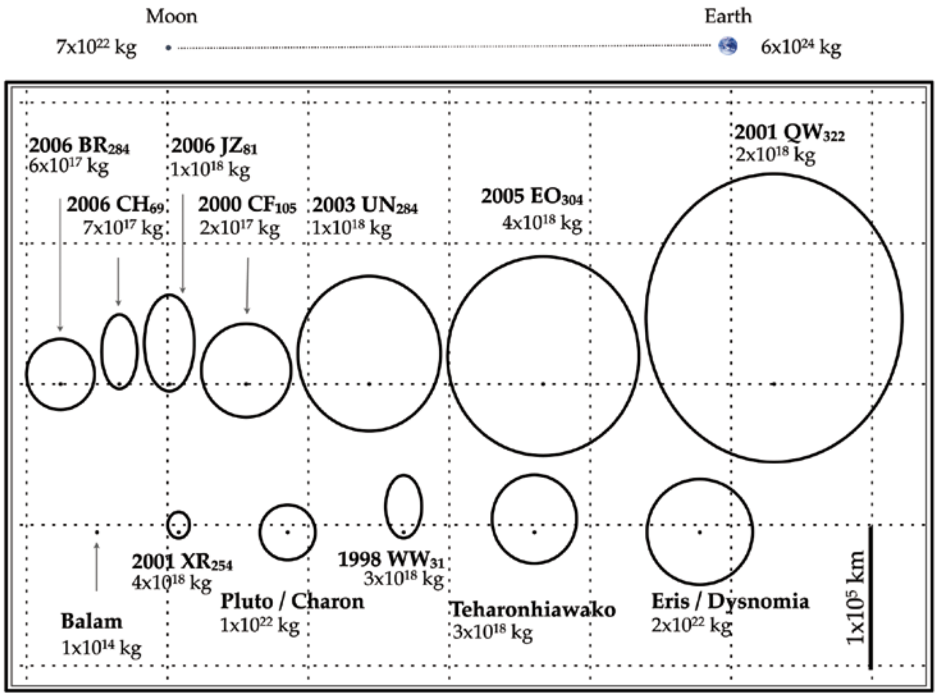
We are left seeking a binary formation mechanism that would produce equal numbers of prograde and retrograde binaries, while simultaneously producing low mutual inclinations.

Orbital Evolution and Disruption

Widely-separated systems are very delicate. The velocity change required to unbind the systems we studied is comparable to an average human walk-

Figure 2.

Top-down view of the best-fit mutual orbits of the seven ultra-wide Kuiper Belt binaries, illustrating their wide separations and large range of eccentricities. For comparison, the Earth-Moon separation is illustrated, as well as several other binary minor planets.



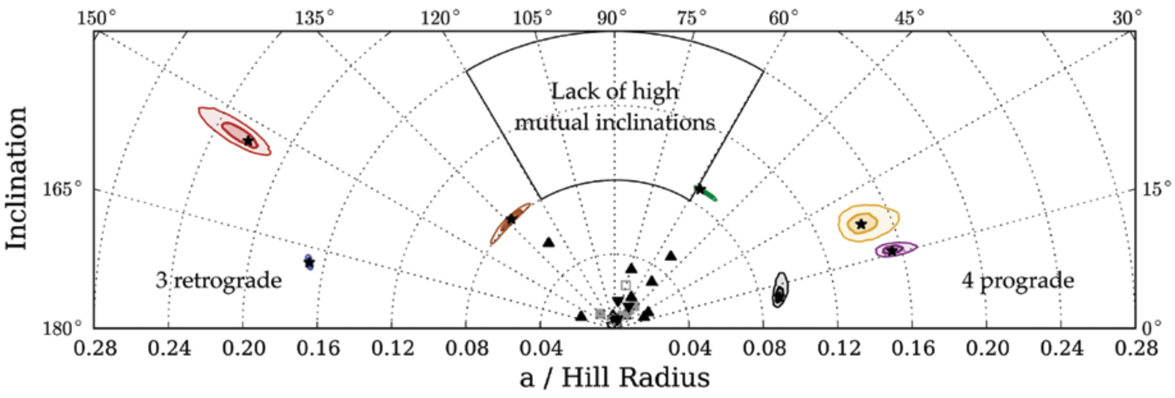


Figure 3.

Illustration of mutual inclinations and separations of Kuiper Belt binaries: filled contours indicate ultra-wide systems, other points mark literature binaries. Note lack of widely-separated, high mutual inclination systems.

ing speed, about 1 meter per second. Direct collisions with very small KBOs (radii of a few kilometers) could impart this velocity, as could even close encounters with more massive objects, like the giant planets.

In Parker and Kavelaars (2010), we considered a proposed formation mechanism for the Kuiper Belt, in which it forms closer to the Sun and then scatters outward by a migrating Neptune — but the close encounters required by this scenario would have destroyed the vast majority of the sufficiently widely-separated binaries we studied with Gemini. This suggests that such encounters never occurred in the Cold Classical Kuiper Belt; it also implies in situ formation for at least this component of the Kuiper Belt — a challenge due to the long accretion timescales at this distance from the Sun.

Implications

With these new mutual orbits in hand, we now require the following: an efficient binary formation mechanism which can produce wide-separation binaries with a range of eccentricities, low mutual inclinations, equal numbers of prograde and retrograde systems, and identically-colored components. Additionally, these binaries (and their component bodies) should be able to form in situ, to avoid being hassled by Neptune.

The model of planetesimal formation by gravitational collapse can produce widely-separated binaries and a range of eccentricities. Additionally, it remains efficient at forming objects and binaries even at large distances from the Sun, meaning that in situ formation could plausibly proceed through this mechanism. At present, its predictions for mutual inclinations and orientations remains weak, so further theoretical work is clearly required — but the evidence suggests that classical ordered hierarchical accretion may not be sufficient to explain the Kuiper Belt and its ultra-wide binaries.

This work is detailed in Parker, A., Kavelaars, J. J., Petit, J. M., Jones, L., Gladman, B., and Parker, J.-W., *The Astrophysical Journal*, 2011, in press, and

Parker, A., and Kavelaars, J. J., "Collisional Evolution of Ultra-Wide Trans-Neptunian Binaries." *The Astrophysical Journal*, 2011, in press.

Solar System Object Search:
http://www1.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/ssos/

For more information:

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by Tom Geballe

Infrared Diffuse Interstellar Bands in the Galactic Center

Infrared spectroscopy at Gemini North of hot and luminous stars in the Galactic Center has unexpectedly revealed an emission line leaking through the dusty cocoon around one of the mysterious "Quintuplet" stars. Additional observations of these stars have resulted in the surprising discovery of 13 new "diffuse interstellar bands," which could someday help solve the 90-year-old mystery as to the source of these bands.

Astronomical observations occasionally result in unexpected discoveries made while pursuing completely unrelated scientific goals. In addition to resulting in exciting new science, such occurrences can provide opportunities to enlarge our knowledge. Best of all, they are just plain fun. Together with colleagues, Paco Najarro of the Center of Astrobiology in Spain, his student Diego de la Fuente, Don Figer of the Center for Detectors at the Rochester Institute of Technology, and former Gemini Science Intern Barret Schlegelmilch, I have recently been fortunate enough to stumble upon two such discoveries. Both of them were made while pursuing one of our major research themes: infrared spectroscopic studies of stars and gas in the center of our Galaxy.

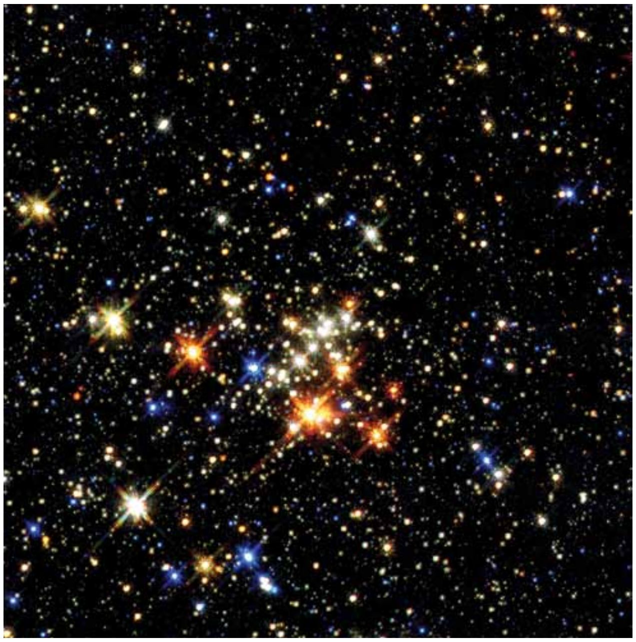

Figure 1.

Infrared multi-wavelength false-color image of the Quintuplet Cluster obtained by the NASA Hubble Space Telescope. The five brightest red stars near the center of the image are the infrared "Quintuplet" for which the cluster is named. Most of the white objects are hot stars in the cluster that, unlike the Quintuplet stars, are not encased in their own dusty cocoons. The blue objects are foreground stars.

The Galactic Center (GC) is a fascinating environment, containing a multitude of extraordinary phenomena and objects, including a four million solar mass black hole right at the center, three dense clusters of young hot stars within 30 parsecs (pc, one parsec is approximately 3.26 light-years) of the black hole, and a vast amount of gas existing in a wide range of physical conditions within 200 pc of the center. All of these are some 8 kiloparsecs from the Sun. Some of our recent research has crystallized around studying the young hot stars in one of those clusters, known as the Quintuplet Cluster (Figure 1). One of the most massive resolved young clusters in the Local Group, the Quintuplet lies only 30 pc distant (in projection) from the black hole.

The name "Quintuplet" comes from five bright infrared stars located near the cluster's center; the discovery of them 20 years ago led to the discovery of the cluster itself. The natures of these five stars have long been a mystery. Stars in the GC are obscured from view by approximately 30 visual magnitudes of extinction due to dust particles situated between the Sun and the GC. That means we can observe those stars only at infrared wavelengths.

The five bright infrared stars not only suffer that interstellar extinction, but also are obscured by dust surrounding each one of them. It is these warm dusty "cocoons," each heated by the star inside it, that makes them so bright at infrared wavelengths compared to other stars. However, the cocoons make the surfaces of those stars impossible to observe, even at infrared wavelengths, or so everyone thought until recently.

An Unexpected Discovery

Because of its smooth dust-continuum spectrum, astronomers often use the brightest of the Quintuplet stars, known as GCS3-2, to calibrate measurements of fainter stars in the GC that have more interesting infrared spectra. In 2009, while using a low-resolution spectrum of GCS3-2, obtained with Gemini's Near-infrared Imager and Spectrometer (NIRI) as a calibrator, I made the first unexpected discovery: a weak and broad emission line in its spectrum near 1.70 microns (μm). This emission, due to excited helium in very hot gas, apparently leaks through GCS3-2's dust cocoon. It provides strong evidence that the embedded star is hot and massive, and in many respects similar to the other cocoonless hot stars in the Quintuplet Cluster. It also hinted that the four other members of the Quintuplet are probably similar objects. The idea that the cocoon of each Quintuplet object contained a hot star had been put forth previously, but virtually no direct evidence existed to support it.

To test that idea, we applied for, and received, Gemini North time in Semester 2010B to obtain medium-resolution H-band (1.5 - 1.8 μm) spectra of each of the Quintuplet sources, as well as spectra of them at even shorter infrared wavelengths. Although the effects of foreground extinction are more severe at shorter wavelengths, making objects in the GC appear much dimmer there, we reasoned that the contamination by the continuum radiation from the dust cocoons would be much less. If so, then key diagnostic short-infrared wavelength emission lines from the central stars, although heavily attenuated along with the continua, would be more prominent above those continua.

No one had previously obtained such short wavelength infrared spectra of GC objects, but estimates of the performances of both the Gemini Near-Infrared Spectrometer (GNIRS) and the Near-infrared Integral-Field Spectrograph (NIFS) on Gemini showed that good quality spectra of the Quintuplet objects should be obtainable. We also obtained additional observing time in 2010B and again in 2011A to obtain more detailed spectra of many of the "naked" hot stars in the Quintuplet Cluster and nearby, including pushing measurements of them down to shorter infrared wavelengths.

Another Surprise

The first set of these spectra, obtained in 2010B with NIFS, was reduced by Gemini science intern Barret Schlegelmilch, at that time an undergraduate student at the University of California, Los Angeles. The spectra that we have obtained since 2010B use GNIRS and are being reduced by Diego and myself. To date we have found that the short wavelength infrared spectra of some of the Quintuplet's other four members indeed contain emission lines of hydrogen and helium, showing that our technique works and that the embedded stars are hot and massive like GCS3-2. The spectra of the cocoonless hot stars reveal that they cover a wide range of spectral types and evolutionary stages. Detailed analysis of them by Paco, Diego, and Don is under way. We expect to use them to derive abundances of other elements such as carbon, oxygen, and nitrogen, in order to test theories of the cluster's initial mass function and evolution.

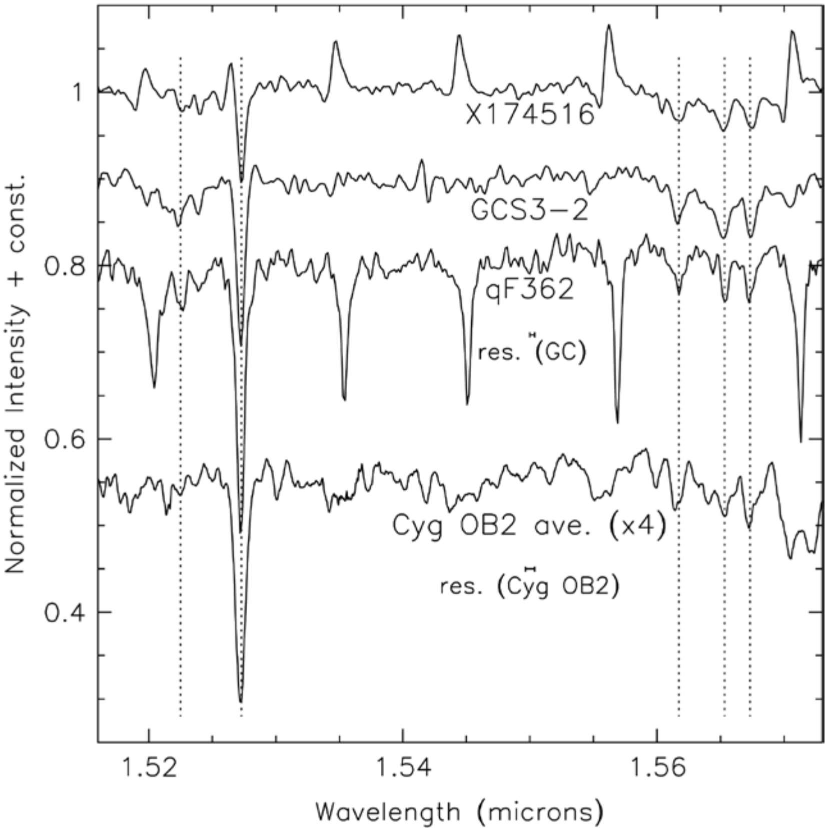

Figure 2.

Observed spectra of three hot stars in the GC, and an average spectrum (magnified by a factor of four) of seven stars in the Cygnus OB2 association. The wavelengths of five newly discovered diffuse interstellar bands (DIBs) are indicated by vertical dotted lines. The prominent emission lines in the spectrum of X174516, and absorption lines in the spectrum of qF362, are Brackett series transitions of atomic hydrogen, which are often present in hot, luminous stars. The strongest DIB, at 1.5273 µm, is blended with one of the Brackett lines in the spectra of X174516 and qF362, but is uncontaminated in the spectrum of GCS3-2.

But buried in the 1.5 - 1.8 µm spectra of each of these stars was the second unexpected discovery: a number of narrow absorption lines, which we had never seen before. Several of these are shown in Figure 2. Initially we assumed that these lines were intrinsic to the stars themselves, even though we could not identify them as we could every other spectral feature. However, we soon realized that they were invariant in wavelength and almost invariant in strength from star to star. This indicated that they were of interstellar origin, but what kind of interstellar material produced them? Nobody had previously reported these spectral features in any interstellar environment and their wavelengths did not match the absorption bands of any simple molecules.

Our initial and tentative conclusion, which was quickly supported by other evidence, was that they were new members of the family of "diffuse interstellar bands," or DIBs. Most astronomers are aware that the optical spectrum of any star viewed through a sufficient quantity of diffuse interstellar material (that is, interstellar gas that is less dense than the gas clouds out of which stars form) contains a large number of DIBs. The first DIBs were reported 90 years ago by Mary Lea Heger, while she was a graduate student at the Lick Observatory. At present well over 500 different ones are known (Figure 3).

Surprisingly, none of the DIBs have been convincingly identified with a specific element or molecule. Indeed, identifying them, individually and collectively, presents one of the greatest challenges in astronomical spectroscopy. Over the years, many scientists have proposed identifications for some of them, but none has held up under close scrutiny. The pioneering astro-chemist William Klemperer once remarked, "There is no better way to lose a scientific reputation than to speculate on the carrier for the diffuse bands." That point notwithstanding, recent studies have suggested that the DIB carriers are large carbon-containing molecules.

Almost all of the previously known DIBs occur at visible and very near-infrared wavelengths, with only two known at wavelengths beyond 1 µm (10,000 Å), The longer wavelength of those two J-band DIBs is at 1.318 µm. Thus, the new H-band DIBs, lying between 1.50 and 1.80 µm, are by far the longest wavelength DIBs detected to date. We found 13 H-band DIBs in total, with the four most prominent ones occurring between 1.52 and 1.57 µm, as shown in Figure 2.

That figure also contains a composite spectrum of several hot stars in the Cygnus OB2 star-forming region, which is located far from the GC, but which is also significantly obscured by dust in diffuse foreground gas. Paco had obtained full H-band spectra of those stars in 2002 at the Telescopio Nazionale Galileo on La Palma. Our discovery prompted him

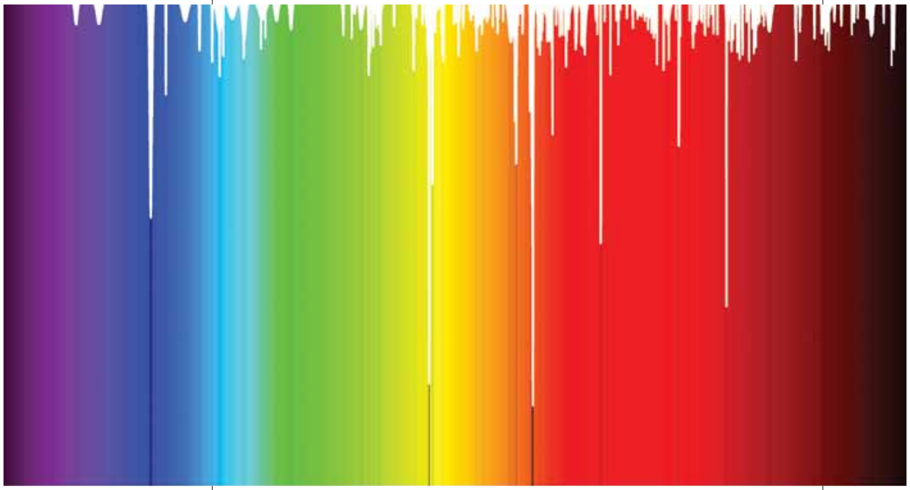

Figure 3.

Simulated 3500 - 9800Å (left to right) spectrum of diffuse interstellar bands discovered prior to 2005. Each white line segment corresponds to a DIB. Its length and the darkness of the line below it each correspond to the strength of the DIB. Figure is courtesy of B. J. McCall.

to take a closer look at those spectra. Indeed the four strong absorption features mentioned above were present, at about one-quarter the strength of their counterparts toward the GC.

As the optical spectra of the Cygnus OB2 stars are already known to contain DIBs, the presence of the H-band absorptions in both sightlines is consistent with the identification of the absorptions as DIBs. Their relative weakness toward the Cygnus OB2 association also makes sense, as the quantity of diffuse cloud material in front of the GC is known to be about four times the amount in front of Cygnus OB2.

Where along the 8-kiloparsec-long sightline to the GC are the carriers of the H-band DIBs located? We have good reason to think that most of them are found close to the very center, in a ~400-pc-diameter region known as the Central Molecular Zone (CMZ). Infrared spectroscopy of the molecular ion H_3^+ toward GC sources, including GCS3-2, obtained at Gemini, Subaru, and UKIRT by another set of scientists including me, has shown that the CMZ contains a vast quantity of diffuse gas and that compared to it, relatively little such gas is present elsewhere along our sightline to the GC.

The diffuse interstellar medium in the GC is a considerably harsher environment than the diffuse clouds where DIBs have been observed previously. The gas temperatures in the center are 200 - 300 K, compared to 30 - 100 K in Galactic diffuse clouds and the cosmic ray ionization rate is an order of magnitude higher. Thus, our finding — that the strengths of the H-band DIBs in Cyg OB2 and the Galactic Center are in rough proportion to their diffuse cloud extinctions — suggests that the carriers of these bands survive equally well in both environments.

Future Research

The discovery of the H-band DIBs should widen the study and use of these enigmatic absorptions. The new bands, together with the two J-band DIBs, can serve as infrared probes of the diffuse interstellar medium in regions that heretofore have remained inaccessible due to high optical extinction, which prevents observations of shorter wavelength DIBs on those sightlines. For example, clusters of hot, massive stars in distant regions of the Galaxy could be the background stars for such studies, as they are bright and some stars in them have relatively featureless spectra.

Astronomers might also use the infrared DIBs to constrain the nature of gas in front of heavily obscured extragalactic nuclei, such as Seyfert II nuclei and both luminous and ultra-luminous infrared galaxies. Studies of the correlation of the strengths of the strong J-band and H-band DIBs may also prove valuable in understanding whether they arise from the same molecule or families of molecules. Finally, because this portion of the infrared spectrum is less congested than the visible spectrum, accurate knowledge of the wavelengths of the infrared DIBs should improve the chances for their identification, e.g. via laboratory spectroscopy.

My colleagues and I look forward to the promise of future research and perhaps more “unexpected” discoveries as we begin to investigate these new and longest wavelength examples of a long-standing interstellar mystery.

The discovery of the H-band DIBs has recently been published by Geballe, T. R., *et al.*, *Nature*, **479**: 200, 2011. Previous observations of the diffuse gas in the GC have been published by Oka, T., *et al.*, *The Astrophysical Journal*, **632**: 882, 2005.

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by Nancy A. Levenson

Science Highlights

A Star-swallowing Galactic Nucleus

NASA's Swift satellite measured an unusual gamma-ray burst on March 28, 2011. The event has subsequently been interpreted as a tidal disruption flare due to a star being accreted by the central supermassive black hole of its host galaxy.

The source, now called Swift J164449.3 + 573451, or Swift 1644 + 57, was classified as a long-duration gamma-ray burst. Unlike most members of the class, however, this one remained bright and highly variable for an extended time. In X-rays, the object remained bright for two weeks which is unusual. Lower energy observations from Gemini and other telescopes allowed the research teams studying the transient to identify its location at the center of a galaxy at redshift $z = 0.35$.

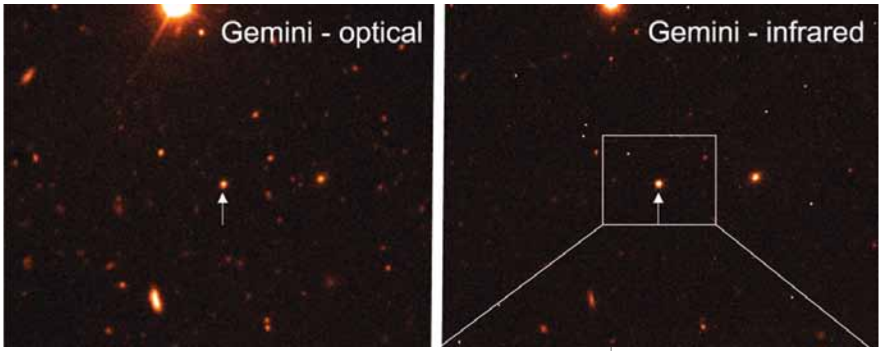

Figure 1.

Discovery images of Swift 1644 + 57 and its host galaxy from Gemini North, using GMOS (optical, at r-band; left) and NIRI (infrared, at K-band; right). These images are approximately 1 arcminute in height. Figure by A. J. Levan et al., *courtesy of* Science.

Andrew Levan (University of Warwick, United Kingdom) and collaborators triggered observations using the Gemini Multi-Object Spectrograph (GMOS) on Gemini North within about two hours of the initial gamma-ray burst (Levan, A. J., *et al.*, *Science*, **333**: 199, 2011). Unfortunately, poor weather at the time prevented deep observations, so they obtained only an upper limit on the brightness of an optical counterpart. Later spectral observations with GMOS and other facilities showed strong emission lines that characterize the host as a star-forming galaxy and yield the host galaxy's redshift.

The galaxy has a luminosity comparable to that of the Large Magellanic Cloud. Archival data and subsequent monitoring show that most optical flux does not vary much (by less than 10 percent) and is therefore due mainly to the host galaxy, not the transient. The red color further suggests that the source lies in a dusty region, such as the center of a galaxy. Observations at other wavelengths (including infrared and radio), however, did show variability due to Swift 1644 + 57.

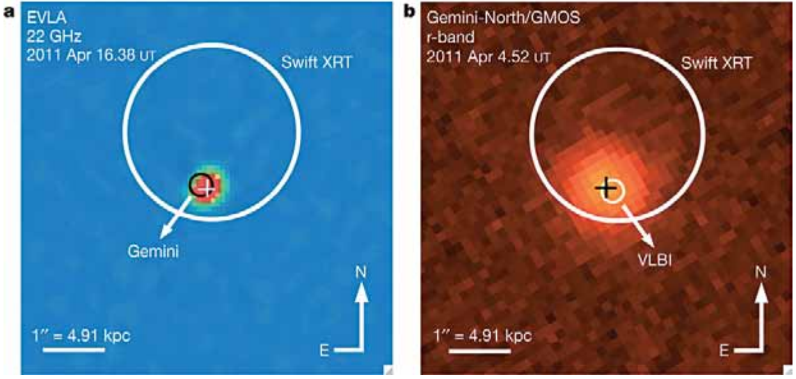

Figure 2.
Radio and optical images of Swift 1644 + 57 and its host galaxy. The radio image (left) is from the Expanded Very Large Array, at a frequency of 22 gigahertz. Figure used courtesy of Nature.

The transient event was extremely luminous, having an energy output in the first 10 days or so of about 10^{53} ergs. While the total energy is not unusual compared with other long-duration bursts, the persistence and repeated flaring is.

Joshua Bloom (University of California, Berkeley) and collaborators interpret the event as a tidal disruption flare (Bloom, J. S., *et al.*, *Science*, **333**: 203, 2011). They suggest that the central supermassive black hole has a mass of 10^6 to 10^7 solar masses, and the accreted object had a mass of about 1 M_{Sun}. They predict that Swift 1644 + 57 will fade over the next year and not repeat.

Subsequent work by Bevin Ashley Zauderer (Harvard-Smithsonian Center for Astrophysics) and colleagues explores the development of the relativistic outflow (Zauderer, B. A., *et al.*, *Nature*, **476**: 425, 2011). The very-long baseline interferometry they present provides a precise location of the transient event. Compared with the GMOS imaging of the host galaxy, these observations pinpoint Swift 1644 + 57 at the center of the host galaxy.

Cold Feedback in a Cluster

Clusters of galaxies are full of hot gas. In principle, the gas should cool over time, especially in the densest regions in the centers. Generally, however, we do not observe significant cooling of large quantities of gas in this region. This suggests instead the presence of a heating source, such as the central galaxy of a cluster, especially if it has an active galactic nucleus (AGN). R. J. Wilman (University of Melbourne, Australia) and collaborators report that in the case of cluster 2A 0335 + 096, they do find evidence for material that could sustain such AGN heating on timescales of 1 billion years (Gyr) (Wilman, R. J., *et al.*, *Monthly Notices of the Royal Astronomical Society*, **416**: 2060, 2011). The reservoir is molecular, so it would be an example of so-called "cold feedback" (as opposed to the "hot feedback" of accretion directly from the X-ray emitting gas).

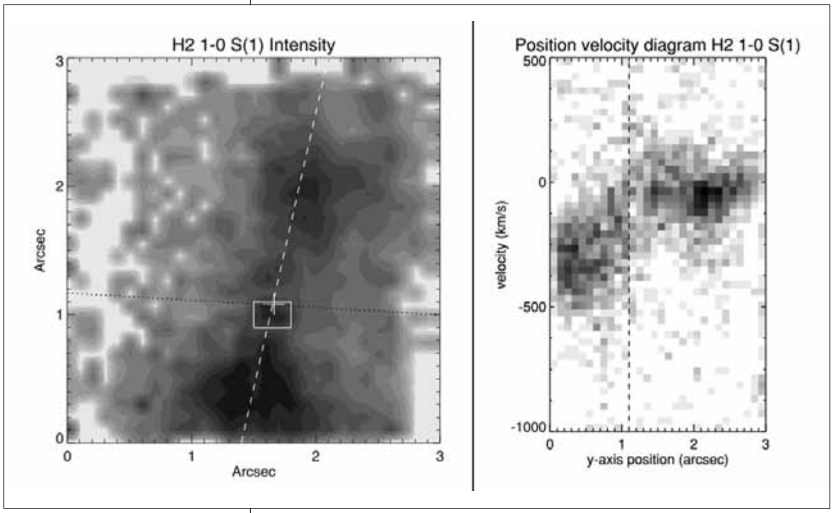

Figure 3.
(Left) The molecular emission is strongest northwest and southeast of the nucleus (marked with a cross). (Right) The corresponding position-velocity diagram (extracted along the dashed white line plotted in the intensity map at left) shows the net rotation.

The team observed the cluster's $z = 0.0349$ central galaxy using the Near-infrared Integral-Field Spectrograph (NIFS) with a laser guide star and Altair's adaptive optics on Gemini North. With this system, they probed spatial scales of 70 parsecs (pc; ~ 230 light-years (ly)) and attained velocity resolution of 60 kilometers per second. Emission in several molecular hydrogen lines is evident in the observations around 2.2 microns. The H_2 is rotating, and it is aligned with previously-observed Hα that extends toward a companion galaxy.

The star-formation rate is low in the molecular region, less than 1 M_{Sun}/year, as the upper limit on detected Brγ emission indicates. At this rate, the cold material could persist over timescales of 1 Gyr. Over such times, AGN accretion of only 5 percent of the molecular gas reservoir would be sufficient to offset cooling in the cluster core. Already 2 percent of the molecular material is located within 100 pc of the nucleus. Constant accretion would not be necessary. In fact, radio observations indicate episodic outbursts of activity have occurred in the past. Thus, 2A 0335 + 096 exhibits conditions suitable for cold feedback and AGN heating to prevent the cooling of the hot intracluster medium.

The Obscuring Dust of a Deeply Buried Active Galactic Nucleus

Active galactic nuclei (AGN) exhibit a range of observable characteristics, and many of these can be simply explained by the presence of optically thick dust at their centers. We can detect the dust emission and absorption directly, as D. A. Sales (Universidade Federal do Rio Grande do Sul, Brazil) and collaborators have done in the case of NGC 3281 (Sales, D. A., *et al.*, *The Astrophysical Journal*, **738**: 109, 2011). While they do find evidence for thick dust obscuration, they do not observe emission from polycyclic aromatic hydrocarbons (generally associated with star formation), which is unusual for such examples.

Spatially resolved mid-infrared observations using the Thermal-Region Camera Spectrograph (T-ReCS) on Gemini South show thermal dust emission, along with broad absorption due to silicates. The nucleus itself is unresolved, on the scale of 65 pc (~ 210 ly), and the dust emission is concentrated within the central 200 pc (~ 650 ly). Subsequent modeling (as a clumpy distribution of clouds) yields a size of only about 11 pc (~ 36 ly) for the dusty obscuring region. Similar to observations of some other AGN, the deepest silicate emission does not appear at the nucleus itself.

Because the same material both emits and absorbs, determining the amount of intervening matter requires modeling. The straightforward case of a cold foreground absorber incorrectly indicates only modest absorption (optical depth in the silicate feature $\tau_{sil} = 1.3$). Instead, the team finds $\tau_{sil} \approx 5$ (from spectral decomposition) or $\tau_{sil} \approx 25$ (in the clumpy modeling). The large dust optical depth sufficiently accounts for the total X-ray absorption along the line-of-sight. In X-rays, the AGN is classified as Compton thick, with no direct nuclear emission emerging at energies less than 10 kiloelectron volts, which requires an obscuring column density greater than 10^{24} cm^{-2}. The gas to dust ratio is ordinary here, and thus eliminates the potential problem of earlier results (based on near-infrared colors, so similarly confusing the sources of emission and absorption), which had suggested an unusually high gas to dust ratio.

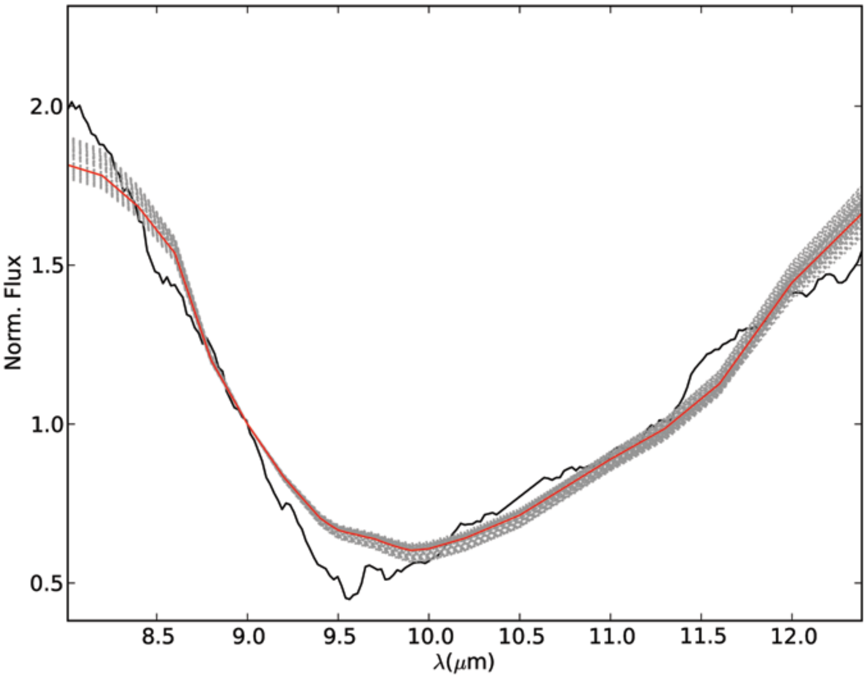

Figure 4.

The solid black line shows the observed nuclear spectrum of deeply obscured AGN NGC 3281. The best-fitting model of obscuration by a toroidal distribution of clouds is plotted in red, with other good solutions marked in gray. The models account for the significant absorption of X-rays that has been observed, at standard gas to dust ratios.

Another Dwarf Companion of the Andromeda Galaxy

In addition to the large Milky Way and Andromeda spirals, the Local Group of galaxies includes many smaller dwarfs, which tend to contain a high proportion of dark matter. Theories of galaxy formation in a dark matter dominated universe make specific predictions about the presence and quantity of such minor systems. Yet the Local Group contains many fewer dwarf galaxies than these “standard” models predict, so at least two outstanding questions remain: Have astronomers missed some

Figure 5.

Central region of the GMOS-N observations of And XXIX against the less dense field of stars. The image is 4.3 arcminutes on a side, corresponding to 900 pc (or ~ 3000 ly) at the distance of And XXIX.

of the dwarfs (while relatively close, Local Group dwarfs are intrinsically faint, making them hard to see); or, do dark matter theories need revision?

Eric Bell (University of Michigan) and collaborators announced in *The Astrophysical Journal Letters* (**742:** L15, 2011) the discovery of another dwarf spheroidal companion to the Andromeda Galaxy, called Andromeda XXIX (And XXIX). Fainter than some individual stars in the Milky Way (e.g. Eta Carinae), this dwarf system is particularly interesting owing to its great distance from the Andromeda Galaxy (over 200 kiloparsecs; over 650,000 ly), where the distribution and properties of dwarf companions to Andromeda are very poorly understood. At such large separations, dwarf irregular galaxies should become more common than dwarf spheroidals.

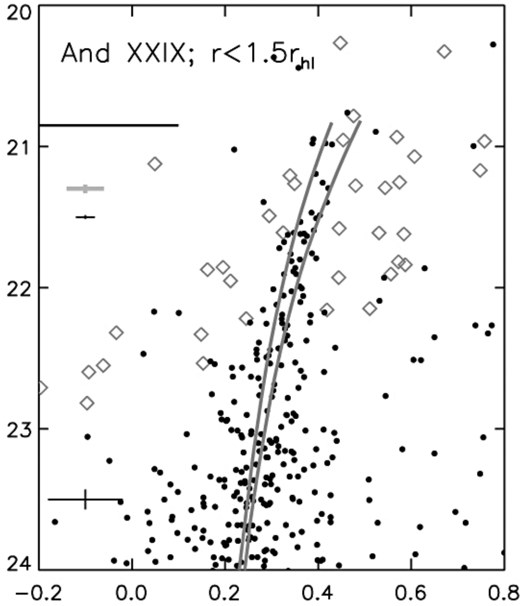

Figure 6.

The solid points show the stars of dwarf galaxy And XXIX observed with GMOS on a color-magnitude diagram; open diamonds were measured from SDSS observations. The near-vertical lines show the predicted location of the red giant branch stars, for two different assumptions about metal abundance. The horizontal line marks the magnitude of the red giant branch tip, which implies a distance to And XXIX of about 730 kiloparsecs (nearly 2.4 million ly).

The team first identified the candidate in the Sloan Digital Sky Survey, where it appeared as a slightly more populated region of the sky at the outskirts of the Andromeda Galaxy.

Bell *et al.* followed up with deeper observations using the Gemini Multi-Object Spectrograph (GMOS) on Gemini North, which allowed them to confirm the dwarf's existence and measure its properties. The deep GMOS imaging data (Figure 5) show the clear signature of red giant branch stars with no sign of other, more luminous, bluer stars (Figure 6). These data led to its confirmed identification as a dwarf spheroidal galaxy. The team also measured other physical properties of And XXIX, finding that it is typical of other dwarfs in the Local Group in terms of size (half-light radius 360 pc; ~ 1175 ly) and ellipticity (0.35), given its luminosity (M_V = -8.3).

Unveiling the Next Generation of Stars in M33

Massive stars form in giant HII regions, and other galaxies in the Local Group offer some of the best views of the largest ones. Despite these advantages, the dusty environments of star formation present an intrinsic challenge, as they block the emergence of visible light. Thus, near-infrared (NIR) observations are valuable, with the longer-wavelength light able to penetrate the dust. Recently, Cecilia Fariña (Universidad Nacional de La Plata and IALP-CONICET, Argentina) and collaborators took advantage of these benefits, using the Near-infrared Imager and Spectrometer on Gemini North to take deep, multi-band observations of NGC 604, a giant star forming region in M33 (Figure 7) (Fariña, C., *et al.*, *The Astronomical Journal*, in press). The second-most luminous giant HII region in the Local Group, after 30 Doradus, NGC 604 offers the contrast of star formation spread broadly across a large area (~ 10,000 square pc or ~ 100,000 square ly), as opposed to being centrally concentrated.

The primary objective of this work was to identify likely massive young stellar objects. The team succeeded in finding 68 candidates, from excess infrared emission. Circumstellar material emits most of the NIR excess, and most of the suggested massive young stellar objects are located against a background of (being possibly embedded in) nebular emission. Significantly, this substantial population of young objects points to a current generation of star formation, in addition to the older population of the main central cluster of NGC 604.

To identify and measure distinct knots of star formation, the crowded field required fine angular resolution. The team obtained the observations in good seeing, with the 0.35 arcsecond full-width at half-maximum corresponding to about 1.5 pc (5 ly). The team also enumerated the properties of a number of individual Wolf-Rayet and other massive stars.

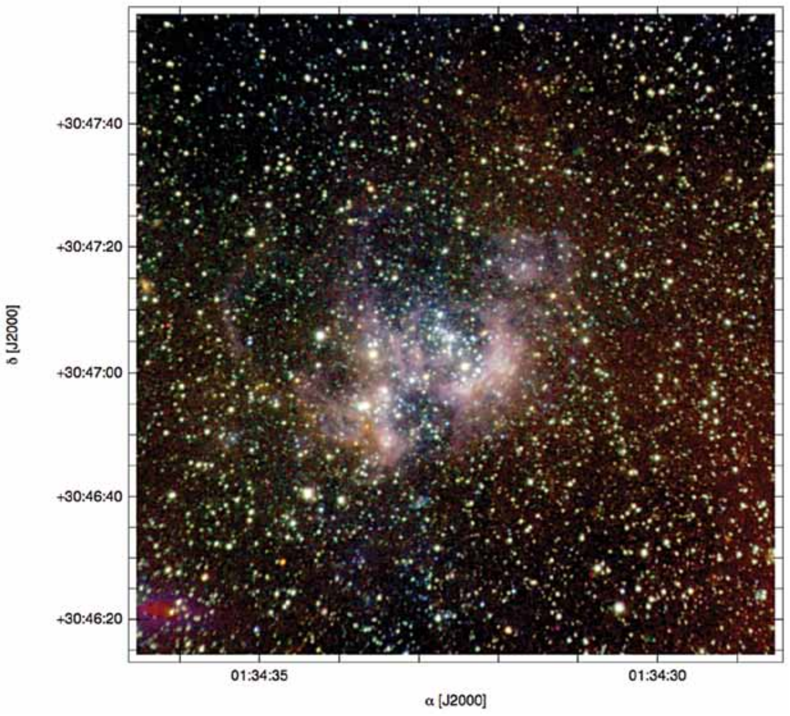

Figure 7.

NIRI observations in J, H, and K_S are combined for this color image of the giant star-forming region NGC 604 located in the Local Group galaxy M33. Infrared excesses identify massive young stellar objects, showing a new generation of star formation. The image corresponds to about 490 pc (~ 1600 ly) on a side.

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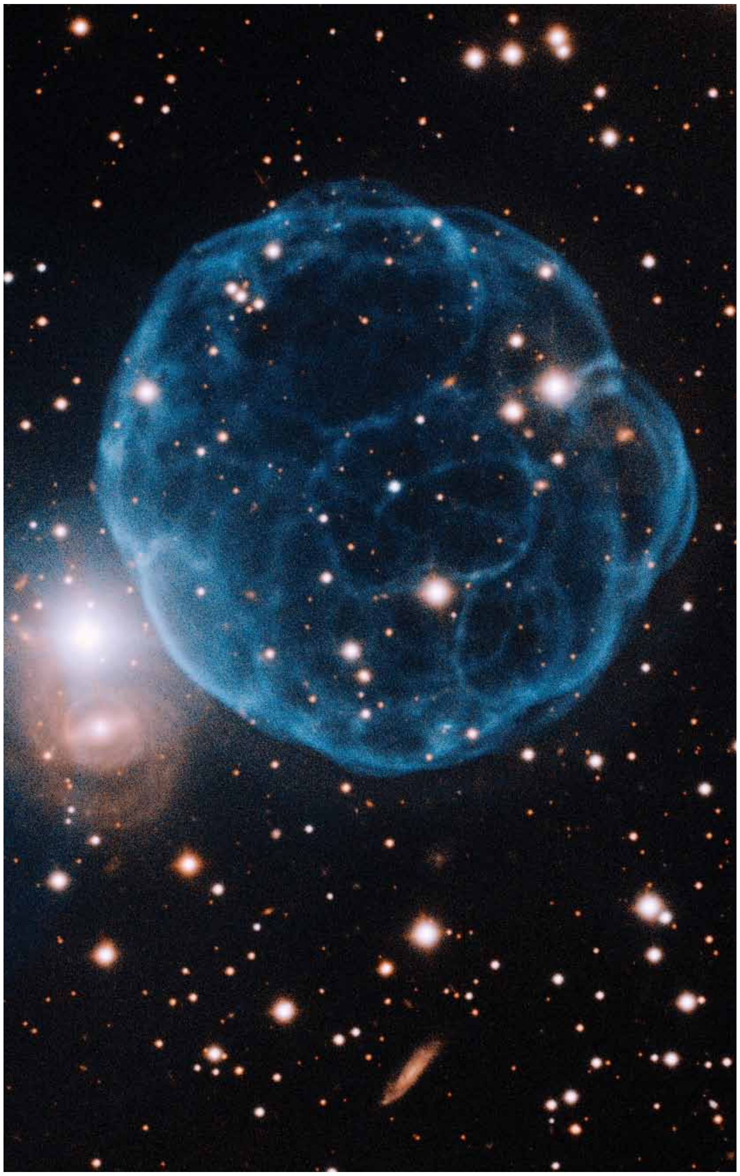
In November 2011, we reached the milestone of 1000 papers published in the professional literature based on Gemini data. The real credit goes to the scientists throughout the international partner community whose discoveries and efforts they report in these papers. The publications reflect the typical usage of Gemini, with about half based on observations with the Gemini Multi-Object Spectrograph, either North or South. We expect to complete 2011 with nearly 200 publications this calendar year. The rise in the number of papers per year (from the first handful that appeared before 2002) is typical after the commissioning of a new facility, and there is still room for continued growth.

In the 1000th paper, Tom Geballe (Gemini) and collaborators report the discovery of new diffuse interstellar bands at infrared wavelengths. The first of these absorption bands were recognized 90 years ago, but their origin is still not fully explained. The bands may be associated with large, carbon-carrying molecules, but no specific carrier has been identified. See the article on page 27 in this issue for a full report on the newly-discovered bands, which were observed along the line-of-sight toward the dense Galactic Center.

During November and December of 2011, Gemini celebrated this publication milestone by sharing through Facebook and the Observatory website highlights of some of Gemini's top science results and beautiful images. Consider becoming a friend of Gemini on Facebook to keep up with the latest news.

Gemini Images a "Soccer Ball"

As part of the Gemini Legacy imaging program, the newly discovered planetary nebula Kronberger 61 was targeted by the Gemini Multi-Object Spectrograph on Gemini North. The object is within the Kepler spacecraft's field-of-view and may shed light on how planetary nebulae derive their peculiar shapes.



Gemini Observatory image of Kronberger 61 showing the ionized shell of expelled gas resembling a soccer ball. The light of the nebula here is primarily due to emission from twice-ionized oxygen. The nebula's hot central star (T= 100,000 K) can be seen as the slightly bluer star very close to the center of the nebula. The field-of-view is 2.2 x 3.4 arcminutes with north up (rotated 22° west of north). A color composite image, it consists of two narrow-band images ([O III] and hydrogen alpha with three, 500-second integrations each) obtained with the Gemini Multi-Object Spectrograph on the Gemini North telescope on Mauna Kea in Hawai'i. Below the bright star at left is a barred spiral galaxy in the distant background. Careful inspection will reveal several additional distant galaxies in the image. More details can be found at: http://www.gemini.edu/node/11656

Do stellar companions shape the extraordinary structure of some planetary nebulae? The Gemini North Multi-Object Spectrograph (GMOS-N) image of newly discovered Kronberger 61 (Kn 61), a small and dim planetary nebula some 13,000 light-years distant, may help astronomers resolve that decades-old debate. The nebula's ornate shell of gas, previously expelled by the central star when it was a giant, is whimsically shaped like a soccer ball. The intricate structures of planetary nebulae, says Orsola De Marco (Macquarie University, Sydney), may suggest that most planetary nebulae form in close binary systems or even by the interactions of stars and their planetary systems.

To date, however, a low percentage (about 20 percent) of these central stars have been found with companions. If this low fraction is due to the fact that the companions are relatively small or distant, then current ground-based observations simply cannot detect the companions — in which case, observations by NASA's space-based Kepler telescope may fill this observational gap.

Kn 61 is, in fact, and not coincidentally, located in Kepler's field-of-view. Launched in 2009, Kepler monitors a 105-square-degree portion of the sky near the northern constellation of Cygnus the Swan — a field-of-view comparable to the area of your hand held at arm's length. The spacecraft continuously stares at more than 150,000 stars in the same patch of sky observing any changes in brightness. The presence of a companion can cause these brightness fluctuations through eclipses, heating effects, and tidal disruptions.

With Kepler now continuously monitoring Kn 61's central star with exquisite precision for tiny brightness changes, we may soon know if a companion is present. Such a discovery, coupled with Gemini's image of the suspected telltale structure in Kn 61's shell, would add additional evidence to the three-decade-old question of what shapes planetary nebulae.

A Pro-Am Collaboration

The Gemini image of Kn 61 also represents the result of a successful collaboration between professional and amateur astronomers. In an effort to help professional astronomers comb through the entire Kepler field looking for planetary nebula candidates, George Jacoby (Giant Magellan Telescope Organization and the Carnegie Observatories, Pasadena) requested the help of a group of amateur astronomers in Weiden, Austria, called the Deep Sky Hunters (DSH). It was during a visual scan of Digitized Sky Survey plates that DSH member Matthias Kronberger discovered Kn 61. When Travis Rector (University of Alaska, Anchorage) learned that Ph.D. student Dimitri Douchin at Kitt Peak National Observatory imaged Kn 61, confirming it as a likely planetary nebula, he immediately applied for, and received, Director's Discretionary Time to image this fascinating new object with Gemini North. The result may not only help astronomers unlock one of the most profound mysteries of planetary nebulae, but Kn 61's aesthetically pleasing structure makes for an exquisite Gemini Observatory Legacy image.

The discovery, as well as the new Gemini image, were both presented at the International Astronomical Union Symposium: "Planetary Nebulae: an Eye to the Future," in Puerto de la Cruz, Tenerife, Spain, from July 25-29, 2011.

Nobel Prize Laureate Accelerates Minds in Hawai‘i

In mid-October 2011, Brian Schmidt, one of three astronomers who shared the 2011 Nobel Prize in Physics, enthralled audiences of upwards of 1000 local residents, in Hilo, Hawai‘i, with his talk on the accelerating universe, dark energy, and the part that Mauna Kea observatories may have played in this important research.

The 2011 Nobel Prize in Physics honors the discovery of the accelerating expansion of the universe through observations of distant supernovae. Although Gemini was only a concept when the original studies that led to this particular prize began, Gemini's unique ability to spectroscopically target exceedingly dim and distant supernovae in optical light has since played a key role in refining the observational evidence, as the research teams of the ESSENCE survey and SuperNova Legacy Survey (SNLS) have used advantageously.

This capability is due in large-part to the implementation of a technique called nod & shuffle (N&S). When used with the Gemini Multi-Object Spectrograph (GMOS), N&S removes sky glow and allows the telescope to achieve exceptionally deep limits.

According to Isobel Hook, team member for the SNLS, "Gemini's key role was to provide spectroscopic redshifts and classification of the supervovae types for the most distant (hence faintest) supernovae candidates. The N&S mode on GMOS made this possible by greatly reducing systematic effects associated with sky subtraction." Gemini's precise values for the acceleration of expansion will help astronomers better understand how dark energy (one of the greatest mysteries of the universe) will determine the ultimate fate of the universe.

Gemini's support to this work continued in a much different vein on the evening of October 19, 2011, when Brian Schmidt (Australian National University, Weston Creek, Australia), one of the three U.S.-born scientists who shared the 2011 Nobel Prize in Physics, spoke for the first time since receiving the award to a crowd of almost 1000 in Hilo, Hawai‘i. The Nobel laureate speculated that the evening's audience was the largest he'd ever addressed. Based on the crowd's enthusiastic response, it seems unlikely that the record will stand for long — Brian's speaking schedule will likely become much more demanding. Someone even quipped that his lecture was like attending a rock concert for physics, and that he was an astrophysics "Rock Star!" Brian definitely won the Hilo audience's hearts and minds.

Gemini's Community Outreach and Education Programs Leader Janice Harvey coordinated the lecture on very short notice and used the Observatory's partnerships with the ‘Imiloa Astronomy Center and the University of Hawai‘i at Hilo to make it a true community event. Schmidt's presence in Hilo was part of his participation in the Association of Universities for Research in Astronomy Oversight Committee's Gemini meeting, held at the Gemini Base Facility. After Gemini Interim Director Fred Chaffee asked Brian if he would consider speaking before a Hilo audience, he graciously agreed to provide two lectures: one to Gemini staff and one to the public.

The staff of the Gemini Observatory wish to congratulate Brian Schmidt and his two colleagues who shared the 2011 prize: Saul Perlmutter (Lawrence Berkeley National Laboratory and University of California, Berkeley), and Adam G. Riess (Johns Hopkins University and Space Telescope Science Institute, Baltimore). Discoveries such as theirs will keep observatories like Gemini busy for future generations of astronomers. Furthermore, lectures by researchers who can convey the excitement of discovery, as Brian Schmidt did on that magical evening in Hilo, may just be the inspiration needed for today's students to someday explore with Gemini.

(Opposite page): Brian Schmidt delivers his first talk since receiving the Nobel Prize.

(Above, left): Brian Schmidt shares insight into our accelerating universe with University of Hawai‘i at Hilo Chancellor Donald Straney, ‘Imiloa Astronomy Center's Director Ka‘iu Kimura, and an audience participant (right to left, respectively).

(Below): Standing (and sitting) room only as local Hilo residents engage in the talk by Brian Schmidt at the University of Hawai‘i at Hilo.

by Stephen Goodsell, Bruce Macintosh, and Fredrik Rantakyrö

Gemini Planet Imager Project Update

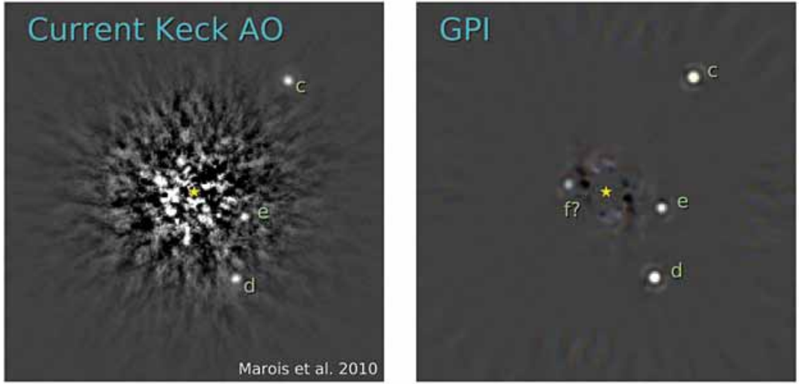
Work on the Gemini Planet Imager is progressing quickly as this issue of GeminiFocus goes to press. Lead-author Stephen Goodsell is now in Santa Cruz to engage in the final integration of all systems prior to planned shipping to Chile at the end of 2012. In anticipation of scientific availability in 2013, results from the solicitation for campaign proposals are also presented.

The Gemini Planet Imager (GPI) is a next-generation, fully optimized, exoplanet-finding instrument designed to detect and fully characterize Jovian-sized planets at both near-infrared wavelengths and high-contrast ratios (planet/star ratios of 10^{-7}). Once deployed, it will place Gemini at the forefront of this exciting emerging field. The GPI project is now a year into its Integration and Testing (I&T) stage. At the time of writing, all subsystems have been integrated at the University of California, Santa Cruz (UCSC), with the exception of the Integral-Field Spectrograph (IFS).

To recap, the GPI instrument comprises four major hardware subsystems: the IFS, opto-mechanical super-structure (OMSS), adaptive optics (AO) system, and interferometer calibration system (CAL). Distributed among these are the diffraction-controlling coronagraph masks and two additional software-only subsystems: the top-level computer (TLC) and data-reduction pipeline (DRP). (*Gemini*Focus last featured an article on the project in its December 2010 issue. You'll find further details regarding exoplanet imaging with the Gemini telescopes and the GPI instrument in the December 2010, December 2009, and December 2006 issues of *Gemini*Focus.)

Figure 1.

HR 8799 exoplanetary system. Left: Inner portion of Keck NIRC2 K' adaptive optics image from Marois et al.(2010). Right: Simulated GPI H-band exposure of the system with an additional 5 Jupiter-mass planet inserted. Photo credit: Christian Marois and Marshall Perrin.



Subsystems Status Update

OMSS and TLC: The opto-mechanical super-structure, constructed by the Herzberg Institute of Astrophysics (HIA), successfully passed its Subsystem Acceptance Review in November 2010. Before year's end, UCSC received both the OMSS and the top-level computer (also developed at HIA) for integration. On arrival, tests showed the OMSS subsystem alignment had shifted by less than 0.12 millimeter, a very small and fully acceptable amount.

We deferred a number of minor tasks, such as installing the coronagraph apodizer masks and AO wavefront sensor (AOWFS) filter slide, until the two subsystems arrived at UCSC; our teams have since completed all OMSS and TLC subsystem level tasks. Teams led by Les Saddlemyer (HIA) and Jennifer Dunn (HIA) have worked continuously during 2011 to support activities relating to the OMSS and TLC, respectively, at UCSC.

AO: By mid-January 2011, Lawrence Livermore National Laboratories (LLNL) had delivered to UCSC the adaptive optics subsystem's four major components: the 4096-actuator, science-grade Boston Micromachines Corporation deformable mirror ("Tweeter"); the 97 actuator CILAS deformable mirror ("Woofer"); the AOWFS with its Lincoln Labs 160 x 160 pixel CCID-66 detector; and the AO computer (AOC).

Integration of the components and associated electronics went smoothly, except for the AOWFS. Designed to sample the seeing-limited point spread function, AOWFS is a much faster optical system than the rest of GPI, and its finely-spaced grid of lenslets leads to strong Fresnel diffraction effects. These effects, coarsely sampled by the wavefront sensor CCD, can mask the true focus. UCSC led a multi-month effort to remedy the difficulties associated with this alignment, and, on conclusion, reinstalled and realigned AOWFS.

The project since has demonstrated impressive closed loop performance of the AO system using phase plates that simulate atmospheric turbulence — 24 nanometers root-mean-square wavefront error on a bright source (4th magnitude equivalent). Technical efforts by Dave Palmer and Lisa Poyneer (LLNL), Sandrine Thomas (UCSC, now at Gemini), and Markus Hartung (Gemini GPI AO Scientist) have ensured continual system improvements and understanding in 2011; the goal is to optimize performance on dim stars (by GPI standards – 9th magnitude equivalent) and maximize science reach. Stability of the sensitive AOWFS optics and detector head over large temperature swings remains a challenge. The collective GPI team is currently addressing these challenges.

Figure 2.

The OMSS after arrival at UCSC for I&T.

CAL: The calibration subsystem is a precision infrared interferometric wavefront sensor, integrated with the coronagraph focal plane masks to maintain a perfectly centered and unbiased wavefront at the coronagraph focus. It arrived at UCSC in November 2010 from the Jet Propulsion Laboratory. Two months later UCSC received funding to perform some additional CAL tasks, such as installing the coronagraph's final focal plane masks. These millimeter-thick wafers of silicon reflect the off-axis light (such as a planet) while the on-axis star falls down a perfectly circular hole into the CAL sensor.

Daren Dillon (UCSC), assisted by Kent Wallace (JPL), successfully performed a number of additional remediation tasks before validating that CAL had met subsystem performance specifications. The UCSC team finally integrated CAL into GPI in September 2011 and is currently finely aligning it with respect to the rest of the system.

DRP: The data-reduction pipeline subsystem's review was held at University of Montréal (UdeM) in March 2011. Under the supervising of René Doyon (UdeM), Jerome Maire (now at University of Toronto) coded most of the DRP. Kathleen Labrie (Gemini) thoroughly reviewed the code and has since worked closely with Jerome. A notable success is that UCLA has used the pipeline to reduce IFS calibration data.

Figure 3.

The calibration unit being installed for I&T at UCSC.

IFS: The Integral-Field Spectrograph will remain at the University of California, Los Angeles (UCLA), until it ships to UCSC by the end of 2011. To cool the IFS, and reduce vibration transmitted to the rest of GPI, the project selected two *Sunpower GT7* Stirling-cycle, closed-cycle refrigerators over the more traditional Gifford-McMahon coolers. But three separate failures, including those in March and then in May 2011, added considerable delay to the completion of the subsystem.

The subsystem finally underwent acceptance review in August 2011, which identified three remaining issues; Gemini has requested further remediation work before declaring the subsystem fit for I&T. The main issue was the amount of vibrational energy being transmitted from the closed-cycle refrigerators to the Hawaii 2RG detector, resulting in microphonic noise in the output images.

At the time of writing, a new fabricated antivibration mount was designed and tested and found to reduce the amount of transmitted vibration energy by more than 90 percent. The subsystem is due to be transported to UCSC on December 15, 2011. James Larkin and Jeff Chilcote (UCLA) look forward to finally integrating the remaining subsystem into GPI. Although we've confidently resolved the issues with the closed-cycle refrigerators, we've executed a risk mitigation plan to prepare an alternative solution.

We've currently scheduled an end-to-end instrument system alignment for Q1 2012, with Acceptance Testing in Q2 and Q3 2012, and expect to transport the instrument to Chile in Q3 2012.

Other Contributions

Gemini has made substantial progress in its internal work packages in 2011, especially in the area of software. The Gemini GPI software team — including Arturo Nuñez, Carlos Quiroz, and Nicolas Barriga — has worked through a list of Gemini Instrument Application Programming Interface (GIAPI) /Observatory Control System (OCS) related interface tasks; very recently, they created a first complete release of the GIAPI to include the new Data Service. Based on the Software Requirements document written by Fredrik Rantakyrö (GPI Instrument Scientist), they've also modified the Observing Tool (OT) and OCS to operate and monitor GPI. A new release of the OT, set for December 2011, will have a large amount of required changes.

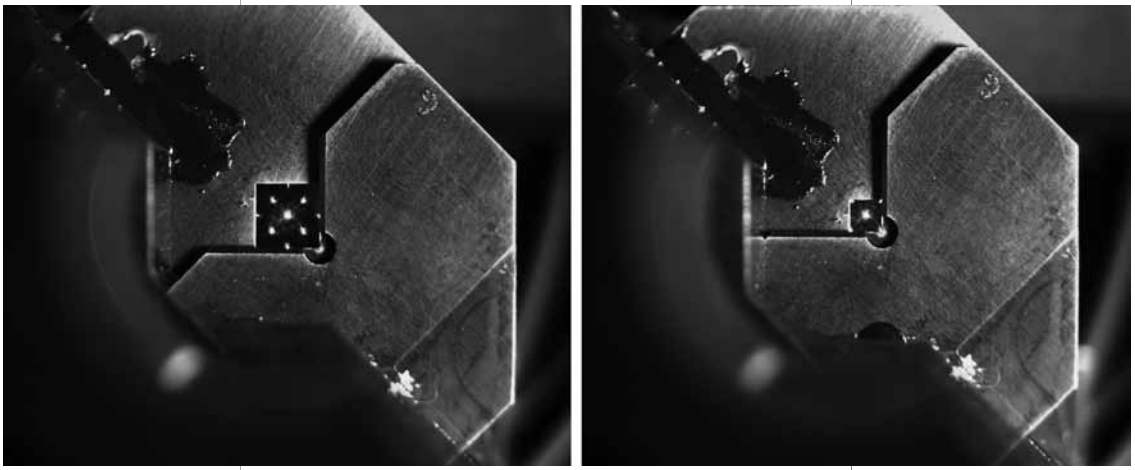


Figure 4.

The variable size spatial filter for AOWFS. Shown in two configurations. The deformable mirror has been commanded with a "waffle" pattern for alignment (left); with the spatial filter adjusted to the correct size (right) the waffle-mode bumps are just barely blocked.

Other members of the Gemini team — including Fredrik Rantakyrö, Manuel Lazo, Eric Christensen, Julian Christou, Eric Tollestrup, and Robert Wyman — have also all made significant contributions in helping to review designs, test subsystems, and conduct oversight visits.

Finally, after a couple of years of flying across the Pacific between Hawai'i and the West Coast, Stephen Goodsell relocated to Santa Cruz in September 2011 to directly oversee the I&T stage. He is assisting Bruce Macintosh (GPI Principal Investigator (PI)), Les Saddlemyer (GPI System Engineer), and Don Gavel (GPI UCSC Co-PI) with managing this stage to completion. This change allowed Dave Palmer (GPI Project Manager and AO Real-time control software engineering) to stand down from his project management position and dedicate his remaining project time to progressing the AOC and solving technical issues. Gemini is thankful for all the time, energy, and wisdom Dave invested into managing the project since the beginning.

In 2012, Ramon Galves (Electrical Engineer), Gaston Gausachs (Mechanical Engineer), and Vincent Fesquet (Optical Engineer) will have active roles in the project as the I&T efforts gear towards the instrument pre-ship review.

GPI Campaign

Gemini received a positive response to the Call for Proposals for the GPI science campaign. Eighteen proposals with a wide range of science were submitted, requesting over 6500 hours of observing time. Since the Call for Proposals specifies a ceiling of 1400 hours, the Time Allocation Committee (TAC) provided a ranked evaluation of the proposals based on their scientific content and feasibility, before passing them on to the Board via the Gemini Observatory. The Board then further discussed additional criteria provided in the Call for Proposals, which the TAC had not specifically evaluated.

After due consideration, the Board awarded 890 hours of GPI campaign time to the top-ranked science proposal: the Gemini Planet Imager Exoplanet Survey (GPIES). This initiative, led by Bruce Macintosh and James Graham, not only involves an international team of 51 astronomers from the United States, Canada, United Kingdom, Argentina, Brazil, and Australia, but also makes best use of the advertised GPI capabilities. The next several proposals in the TAC ranking either had narrow Gemini partnership representation or required capabilities beyond those initially available on GPI, but may use the instrument effectively as regular principal investigator programs.

The GPIES team designed the project foremost for statistical depth; over the course of three years, the collaboration will survey 600 nearby young (< 100 million years (Myr), < 245 light-years (ly)) and adolescent (< 300 Myr, < 114 ly) stars. Combined with GPI's ability to see planets as close as 3 - 5 astronomical units (AU) from their stars, models tied to known exoplanet populations predict the discovery of 50 exoplanets — enough to allow statistical investigation of planet properties. Together

Figure 5.

Members of the GPI team integrating the CAL system at UC Santa Cruz. From left to right: Darren Dillo, Les Saddlemyer (HIA; seated), Kent Wallace (JPL), Markus Hartung, and Jim Ward (UCSC; closest).

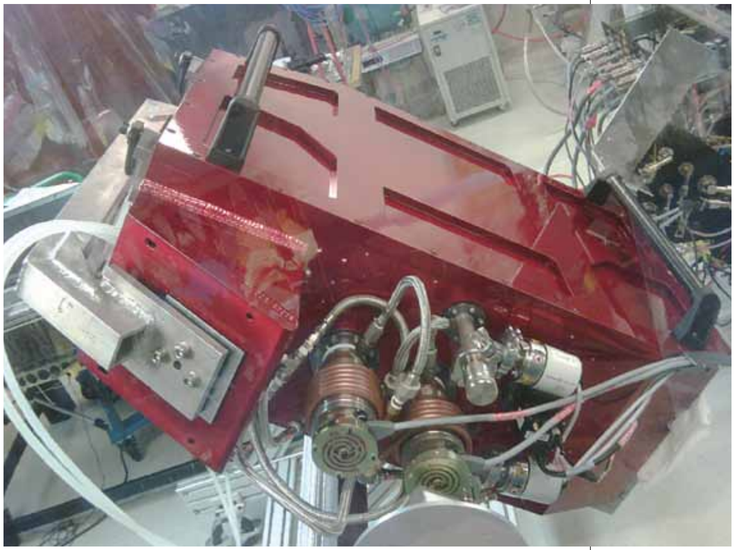


Figure 6.

The IFS undergoing tests at UCLA.

with the current Near-Infrared Coronagraphic Imager campaign, Gemini instruments will produce a comprehensive study of exoplanet occurrence from 5 to 200 AU — completing the exoplanet inventory begun with Doppler and transit techniques.

The GPIES will deliver a publically-released catalogue of exoplanets with estimated effective temperatures and luminosities, and estimated orbital parameters, leading to empirical measurements of the number of young planets as a function of mass, semi-major axis, and stellar properties. It will also image polarimetrically a subset of stars to study debris disks that trace the properties of planetary systems. An automated speckle-rejection pipeline will process all data, which we'll make available to other GPI users. We'll also publically release the final catalogue of reduced spectral cubes for all stars.

The large sample will for the first time match the statistical power of extant studies of older planets using indirect techniques. GPI spectroscopy will reveal atmospheric conditions and thermal history, thereby calibrating atmosphere and accretion models. The statistical properties of the distributions will arbitrate between various formation and migration scenarios.

In October 2011, the science team held a kickoff meeting at the SETI institute in Mountain View, California, and is ramping up in preparation for campaign observations in 2013.

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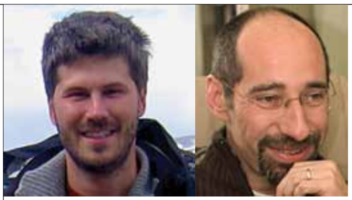
Fredrik Rantakyrö is an associate scientist at Gemini South. He can be reached at: frantaky@gemini.edu

Figure 7.

GPI science meeting attendees at SETI, October 2011.



by Benoit Neichel and François Rigaut

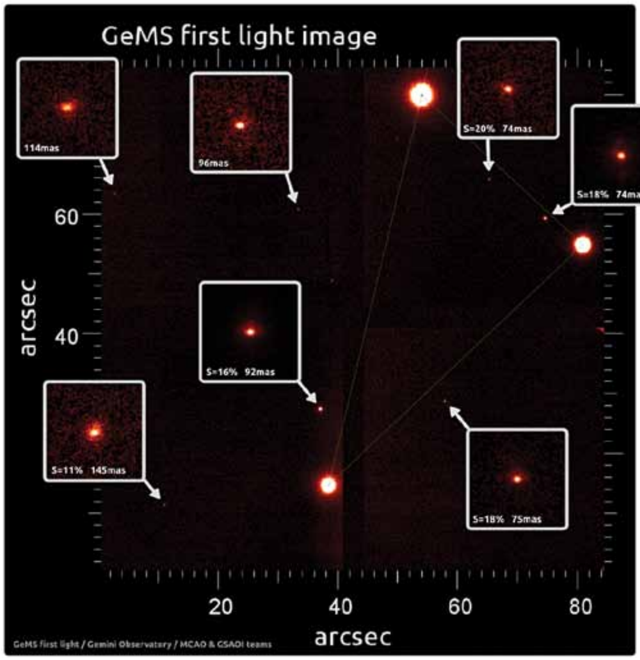
GeMS Commissioning Progress

The next-generation GeMS adaptive optics (AO) system at Gemini South is scheduled to become available for science in 2012. GeMS commissioning is on a fast-track and, as described on the following pages, is well on its way to becoming the next standard for AO imaging.

During the first half of 2011, the Gemini Multi-Conjugate Adaptive Optics System (GeMS) went through an intensive on-sky commissioning period. From January to May, one week per month around the full Moon, we shined the five-point laser guide star (LGS) constellation above the Gemini South telescope. The first two and half commissioning periods were dedicated to the laser and its associated subsystems (for a summary of the laser's performance, see *Gemini*Focus, June 2011, page 23). Since then, we've improved the laser's spot size; typical performance obtained on-sky gives a full-width at half-maximum (FWHM) value of 1.3 arcseconds, as seen by the telescope's acquisition camera.

The best sodium photon return obtained so far (and measured on the LGS wavefront sensors (LGS WFSs)) was on the order of 15 photons/s/cm^2 and per watt (W) of laser propagated to the sky. We achieved this during the last commissioning runs (April and May 2011) when the sodium season was more favorable. In Southern Hemisphere summer, and due to the sodium season effect, we expect a return lower by a factor of two to three. This would not be enough to run the adaptive optics (AO) loop at full speed, but we could (and will) improve this by increasing the throughput of the Beam Transfer Optics (BTO). Laser stability has shown to be good, with 45 to 65 W regularly achieved during the runs. Only one major failure occurred during this highly-laser-intensive period: one of the diodes that amplifies the laser light died during the last commissioning run in May, temporarily reducing the output power to 14 W.

The commissioning of Canopus (the Gemini South AO system) started in March 2011, with two subsequent runs in April and May, for a total of nine clear nights. To date, we've concentrated on its functionality, since this very complex instrument includes multiple subsystems linked together by closed loops, as well as offloads that the Multi-Conjugate Adaptive Optics (MCAO) team had to characterize, debug, and optimize. The system has as many as 20 loops that must work together in harmony — communicating and interacting with one another. It's also worth noting that GeMS contains as many loops as those in the



GeMS first light / Gemini Observatory / MCAO & GSAOI teams

Figure 1.

GeMS engineering first light image obtained with GSAOI on April 19, 2011. The field-of-view is 85 x 85 arcseconds, and the wavelength is 2.12 microns. Strehl ratio and full-width at half-maximum values for all stars appear in the insets. NOTE: As this issue of GeminiFocus goes to press, new images are being released that demonstrate the power of GeMS on Gemini South. See these at: www.gemini.edu/node/11715

entire telescope and other instruments combined! Currently, almost all these loops and offloads are working and stable, and we've found no show-stoppers along the way.

As previously mentioned, the objective of this first commissioning period was to work out all the functionalities of the system. Thus, we've performed very few optimizations so far. As a result, we've acquired only a few astronomical images. Figure 1 shows our best target to date: the technical first light image, obtained on April 19, 2011, with the Gemini South Adaptive Optics Imager (GSAOI).

This is truly an engineering image, as we chose the field for its bright "constellation," and not for any astronomical interest. We obtained it after very crude focusing, and the loop controlling the plate scales was not even closed at that time, so it by no means represents the system's expected performance. We expected the poor quality of the image's left edge, as this part of the field lies outside the constellation, defined by the three bright stars in the image that we used to control Tip-Tilt.

Nevertheless, the image is very encouraging and illustrates the main advantage of MCAO, namely a relatively uniform compensation across a large field-of-view. As a comparison, the GSAOI image would cover ~16 times the Altair+NIRI field-of-view! After this successful April run, we planned to concentrate our next efforts in areas such as performance optimization and characterization. However, bad weather and various technical issues prevented us from acquiring additional astronomical images that would demonstrate the system's capabilities more dramatically.

One surprise of this first commissioning period was the so-called "Fratricide effect," due to the Rayleigh diffusion of the laser photons in the first ~30 kilometers (km) of the propagation. The effect creates the nice beams we see in Figure 2, visible with the naked eye. But the LGS WFS also detects this scattered light, which increases the background noise in some sub-apertures; this is a known effect for multiple LGS systems but, as GeMS is one of a kind, it was very interesting to look at this effect for the first time with it.

Despite the fact that this background increases the noise in some sub-apertures, we found it very useful to center and acquire the LGS constellation. Using the specific geometrical properties of this background, we can center the five-point LGS constellation in front of the WFSs in less than a minute, dramatically speeding up the acquisition time with respect to the Altair AO system at Gemini North. The natural guide star (NGS) acquisition has also proved very efficient, so even if GeMS is more complex than a regular AO system, we expect to keep the overhead time for acquisition at a very low level.

This first GeMS commissioning period also provided an opportunity for us to share our first lessons learned on-sky with other AO teams around the world. During three consecutive runs, we were pleased to receive the support from three AO specialist visitors: Damien Gratadour (Observatoire de Paris), Jean-Pierre Veran (Herzberg Institute of Astrophysics), and Brent Ellerbroek (Thirty Meter Telescope project).

We also diffused the first GeMS results during two important AO conferences: The Optical Society of America (Toronto, Ontario, July 2011), and the AO4ELT2 conference (Victoria, British Columbia, September 2011). All of the presentations are available on the AO4ELT2 website: http://ao4elt2.lesia.obspm.fr/. In both events, our GeMS results were very well received, especially from the Extremely

Large Telescopes (ELTs) community, as most of them have similar systems planned for their first light AO observations.

In early June 2011, GeMS entered a planned five-month rework period. Since wintertime in Chile is the least favorable for AO observations, we took advantage of this perfect opportunity to fix, repair, and upgrade many systems based on our on-sky experiences. As early as June 10th, we removed Canopus from the telescope and installed it in the instrument lab of Cerro Pachón. We also planned this shutdown to perform upgrades of sub-packages that were deliberately put aside when we decided to go on the telescope at the end of last year.

Another one of the main drivers for this shutdown was our desire to fix the throughput of the NGS WFS. During integration at Gemini's Southern Base Facility, we uncovered an issue that reduces the sensor's sensibility by approximately two magnitudes. This would significantly reduce the number of targets that GeMS could observe, or what is called its sky coverage. Thus, we designed and implemented a new NGS WFS module (Figure 3). Our first measurements in the lab indicate that we will recover the missing photons, and the new NGS WFS will be commissioned at the end of this year (2011).

Another big, and unexpected, complication of this shutdown was related to one of the three deformable mirrors (DMs) in Canopus: the one conjugated to the ground was progressively losing actuators, impacting the system's performance. We've ordered a replacement DM, and it should arrive at the beginning of 2013. Meanwhile, we've also decided to remove the faulty DM from the bench and replace it with one of the DMs conjugated in altitude. Thus, GeMS will have only two functioning DMs until we receive the replacement, but we estimate that the impact on the performance will be acceptable.

We also performed intensive work on the laser and BTO. Specifically, the laser had a failing diode; after the laser team replaced it, the laser went through a thorough cleaning, realignment, and optimization. As for the BTO, improving its reliability has been at the heart of a major engineering effort, requiring mechanical, electronic, and software upgrades. To summarize, it has been a very intense five-month period, during which time we orchestrated many activities in parallel, ones that will eventually result in a more reliable and better performing system.

As of this writing, we expect commissioning to resume in November 2011, at the same frequency as before, of approximately one week per month around the full Moon. Although we'll need to recommission all of the functionalities that were working, as well as all of the new upgrades, the focus will quickly turn to performance and integration with the observatory's high-level software. We'll then dedicate two more runs, in January and February 2012, when we expect to finish the commissioning of new capabilities, the integration into operations, and GSAOI science commissioning. Science verification should then begin as soon as March and April of 2012. After more than a decade of effort, this final sprint should eventually conclude with GeMS being offered to the community during the second half of 2012.

Figure 2.

Laser constellation and Rayleigh diffusion. Photo credit: M. Boccas.

Figure 3.

Crisitan Moreno and Gaston Gausach working on the new NGS WFS module.

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by Bryan Miller and Arturo Nuñez

Improving Gemini's Phase I and II Software Tools

Gemini users have expressed many concerns regarding the Observatory's software tools for proposal submission (Phase I) and observation definition (Phase II). This article describes major improvements in the tools that will be released starting in late 2011.

Gemini Observatory has begun an initiative to significantly improve its Phase I and II tools for user proposal submission. Our primary goal is to make the transition between Phase I and II more helpful and, in particular, the preparation of Phase II easier and faster.

Gemini's Phase II tool (also known as the Observing Tool (OT)) has a significant learning curve. Based on user experiences, it does not provide sufficient built-in guidance. Designed to be both powerful and general, the OT allows for a wide range of organizational schema for observations. Therefore, some users find it difficult to initiate or optimize observation sequences. Also, the software has interface limitations that make it challenging to edit large numbers of observations.

However, 10 years of experience working with users preparing queue programs has taught us some valuable lessons. Thanks to suggestions from our community, we know where to make the major improvements. Fixing the Phase II software requires automating the configurations' setting and building on features such as the current observation checks and OT libraries, which help guide users in producing valid observations and programs. We aim to accomplish this with a series of software updates beginning in late 2011.

The project's first priority is to improve the "skeleton" observations of the original Phase II program. Currently these observations contain little more than the target names and coordinates, observing conditions, and the instrument requested. All information regarding necessary instrument components (e.g. filters and gratings) is discarded. Furthermore, the initial observing sequences cannot be filled in, since the organization of the information in the current proposal document makes it impossible to reliably determine how the principal investigator (PI) needs the components used. The OT example libraries developed by the instrument scientists over the years have proven useful for helping the PIs fill in the sequence, but they must sort through the examples to determine the proper one to use. In the last two semesters, staff at some of the National Gemini Offices (NGOs) have started manually including relevant library examples in the skeleton for some programs. This approach seems beneficial, but we need to automate it.

Therefore, we plan to restructure the Phase I Tool (PIT) and OT such that proposers can use all of the information in the Phase I document to select and fill in OT library examples. Instead of users picking all instrument resources needed from a single list, the new tools will guide them through a decision tree of instruments and observing modes, allowing them to select only the resources that apply to a particular mode. For example, they can select dispersers and slits only for spectroscopy modes (Figure 1). Proposers for the Hubble Space Telescope select instrument components in a similar way.

The observing modes give the information needed for the software to pick the required OT libraries, or "blueprints," that will be copied into the Phase II skeleton and filled in with the selected components. Successful PIs will then add the sequence details — such as individual exposure times, offset patterns, etc. — and iterate with their NGO contacts until they complete the blueprints; these will then be applied to all targets that need that mode to create the final observations. After some final target-dependent tweaking, the observations will be ready for execution.

A second major initiative is to automate guide star selection. We're carefully reviewing the guide star catalogue options, since the choice is critical for selecting valid guide stars and not extended sources or artifacts. We're also updating the parameters for guide star searches and adjusting magnitude limits for the observing conditions. Algorithms for automatically selecting guide stars are also being prototyped. We plan to implement these improvements in the 2012A OT in December 2011, for at least the Gemini Multi-Conjugate Adaptive Optics System, Gemini South Adaptive Optics Imager, and the Gemini Multi-Object Spectrographs at both Gemini North and South.

In future releases, we'll include automatic selection for additional instruments and wavefront sensors. Proposers can still override the default settings or manually pick a guide star. However, in most cases we expect that the automatic selection features will make the choice of guide stars easier and give the chosen stars a very high probability of being usable.

In the PIT, we would like to provide better feedback about the availability of guide stars, while removing the need for most proposers to explicitly include them in the proposal. Rather, the tool will automatically check the availability of guide stars for the selected targets, using algorithms similar to those being developed for the OT. PIT will also provide feedback about the likelihood of a guide star's availability. For a low-likelihood, or if the project requires specific guide stars, then the proposer will have an option to specify the stars. Guide stars selected at Phase I will be copied automatically to the Phase II skeleton, so they don't have to be defined again.

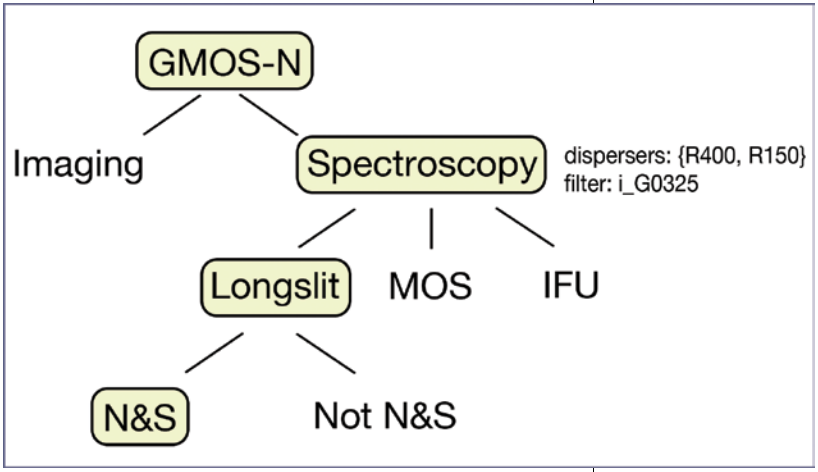


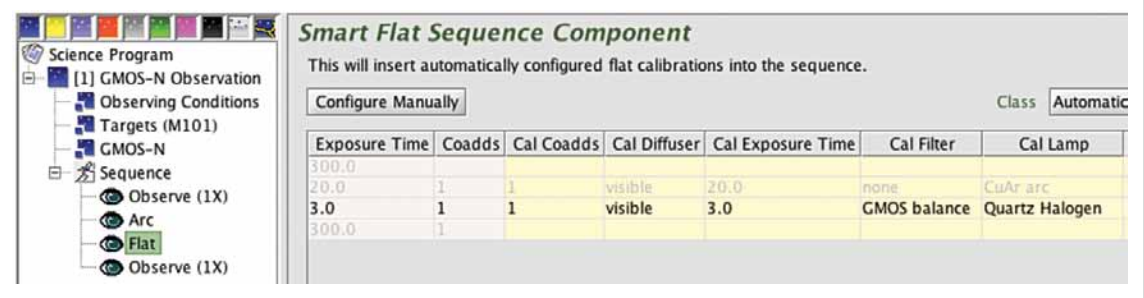
Figure 1.

An example of Phase I instrument configuration decision tree.

Progress

Work on the new Phase I Tool has begun. The changes needed for the decision trees and guide star selection are substantial enough. But the work provides an opportunity for us to improve PIT's usability, while adding smaller features that proposers have desired for some time. We also plan to remove the text entry boxes for some sections, like the science and technical justifications from the tool, providing Word and LaTeX templates instead. Proposers can then use their preferred text-preparation system to create a single PDF of the formatted text with figures attached to the proposal.

Also, we'll relabel the conditions bins (to make them easier to interpret), update the keywords list, and, finally, reorganize the interface for faster navigation and to help guide the user through the process. The PIT will still be an installable application, but we'll work to make installation and updating as



Smart Flat Sequence Component

This will insert automatically configured flat calibrations into the sequence.

Class: Automatic

Exposure Time	Coadds	Cal Coadds	Cal Diffuser	Cal Exposure Time	Cal Filter	Cal Lamp
300.0						
20.0	1	1	visible	20.0	none	CuAr arc
3.0	1	1	visible	3.0	GMOS balance	Quartz Halogen
300.0	1					

Figure 2.

Automatically configured GCAL calibration exposures for GMOS-N.

easy as possible. We expect to release the new PIT with the majority of these features for the 2012B call for proposals in March 2012. We've scheduled the related OT changes for the improved skeletons and blueprints for the 2012B OT, with a release slated for June 2012.

The last major part of the project's first stage is to automate the setting of calibration observations. First, we'll need to incorporate the Gemini Calibration Unit (GCAL) setting into the OT. We intend a variety of options for automatic, or "smart," arc and flat calibration observation nodes. These will configure GCAL and set the proper exposure time, number of co-adds, etc., depending on the instrument configuration at the location of the node in the sequence (Figure 2). We expect to have these features included in the 2012A OT, for release in December 2011.

In later project stages, we'll work on the automatic creation of different types of standard star observations, as well as keeping them in sync with the related science observations as the configurations in the science observations change. We expect additional stages of this project will likely continue throughout 2012 and into 2013.

The next set of priorities will be to improve the interface and usability of the Observing Tool. This will require some fundamental changes in the observing database infrastructure, and we're conducting on-going studies of what needs to be done. If we implement these changes in 2012, then we'll be in a position to complete the work more easily on calibration observations — to allow the simultaneous editing of multiple observations, to calculate overheads more consistently, to add better history recording and undo/redo features, to change the structure and behavior of instrument iterators, and, finally, to make significant interface improvements.

The nature of this project requires close interaction among the Gemini software development team, the Gemini science staff, and the user community. This collaboration is needed to ensure that the software will both improve the user experience and meet the deadlines outlined above.

To encourage and direct this interaction, a modern software development methodology has been adopted for the execution of this project. This methodology is based on short (three-week) development "sprints." In each sprint, a subset of the requirements are implemented, tested, and validated. Working software is always delivered at the end of each sprint, providing the opportunity to make adjustments based on early feedback given by the users. This methodology has been very successful and we anticipate using a similar approach for future software development projects.

Gemini would like to thank the members of the community who have sent in suggestions and comments on the software over the years, and we encourage additional feedback on these plans. We want to ensure that the new tools will simplify proposing and preparing observations for Gemini.

Please contact the authors (below) with any questions or comments on this project or if you would like to be involved with beta-testing the software.

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by Ricardo Schiavon and Rodrigo Carrasco

Data Reduction Workshop for South American Gemini Users

This third and highly successful partner country workshop focused on providing Gemini users training on data reduction with four key Gemini instruments.

Figure 1.

Lectures on science with Gemini instruments, data reduction and archiving, and the status of future Gemini instruments were delivered by Gemini staff and NGOs, both in person and remotely.

For years, data reduction has been among the main obstacles faced by astronomers in the process leading to the final publication of results based on Gemini observations. This conclusion has motivated observatory staff, National Gemini Offices (NGOs), and users to come together in organized workshops that aim to provide users crucial training in the reduction of data obtained with Gemini's diverse suite of instruments.

The National Optical Astronomy Observatory (NOAO) and the Australian NGO organized the first two workshops — held in Tucson, Arizona, and Sydney, Australia, respectively. The NGOs of Brazil, Argentina, and Chile hosted the third and latest event: the South American Gemini Data Reduction

Workshop, held in São José dos Campos, Brazil, between October 27 and 30, 2011. São José dos Campos is currently the fourth largest city in the state of São Paulo and the largest and most important in the Paraíba Valley. One of the largest industrial and technological centers of the country, the city is home to several well-known research centers, including the Instituto Nacional de Pesquisas Espaciais (INPE) and the Comando-Geral de Tecnologia Aeroespacial (DCTA).

The South American Gemini Data Reduction Workshop

Like the other events, this third and most recent workshop consisted of a combination of lectures and practical sessions that focused on providing Gemini users training on the reduction of data obtained with four of Gemini's key instruments: the Gemini Multi-Object Spectrograph (GMOS), Gemini Near-Infrared Spectrometer (GNIRS), Near-infrared Integral-Field Spectrograph (NIFS), and Near-infrared Imager and Spectrometer (NIRI).

Ricardo Schiavon (Gemini North) delivered the opening lecture, which presented an overview of Gemini instruments on both hemispheres, as well as recent science highlights based on Gemini data. Live by videocon, Claudia Winge (Gemini South) followed by explaining the initial phases of Gemini data acquisition, including Phase I proposal submission, Phase II preparations, data collection, and, finally, storage and archival data access.

Gemini staff and NGOs then delivered talks on the process of data reduction with Gemini instruments: Rodrigo Carrasco (Gemini South) and Ricardo Schiavon covered GMOS, Cecilia Fariña (FCAG-IALP, Argentina) focused on NIRI, and, remotely by videocon, Rachel Mason and Richard McDermid (Gemini North) concentrated on GNIRS and NIFS, respectively. Later during the workshop, lectures focused on upcoming Gemini instruments, with Rodrigo Carrasco providing an overview and status of the Gemini Multi-Conjugate Adaptive Optics System (GeMS) and the Gemini South Adaptive Optics Imager (GSAOI), while Pascale Hibon (Gemini South) talked about FLAMINGOS–2.

During practical sessions, participants worked on real-time data reductions, assisted by Gemini staff and NGOs. Some participants brought their own data, whereas others downloaded tutorial data provided by Gemini staff. The first, five-hour long, tutorial session covered the reduction of GMOS

Figure 2.

Participants in Gemini's South American Data Reduction Workshop, São José dos Campos, Brazil, October 2011.

Figure 3.

Workshop participants reduced their own data, or data provided by Gemini staff, during the practical sessions.

data in their various modes. The next day, another five-hour long tutorial session addressed the reduction of GNIRS data. On the last day, participants spent three hours on a tutorial session on the reduction of NIFS data.

An Outstanding Success

The South American Gemini Data Reduction Workshop was an outstanding success. Roughly 100 astronomers from Brazil, Argentina, and Chile attended, with the majority of the audience composed of young graduate students from these emergent astronomical communities. The latter fact is quite remarkable and particularly significant. It attests to not only the impact that Gemini has on the scientific output of these countries, but also the contribution by Gemini to the breeding of a new generation of South American astronomers.

The workshop also served to bring together Gemini staff, NGOs, and users, which is vitally important given the vast geographic separation between the observatories and its user community. The success of this and the previous workshops suggests that Gemini management and NGOs should join forces to make data reduction workshops periodic. This will prove particularly critical as a new generation of Gemini instruments is commissioned this year, which will call for the development of new data reduction techniques and software. The training of the Gemini user community on the use of Gemini data reduction software is necessary to maximize the science output and impact of the new generation of state-of-the-art Gemini instruments.

Many thanks go to the NGO astronomers — namely Alberto Ardila (GNIRS), Cassio Barbosa (NIFS), Rogemar Riffel (NIFS), and to the Ph.D. student Tiago Vecchi Ricci (GMOS IFU) — whose help made the tutorial sessions a resounding success. Finally, great credit is due to the NGOs of Argentina, Brazil, and Chile, who initiated this workshop, and the scientific and local organizing committee, who made it happen.

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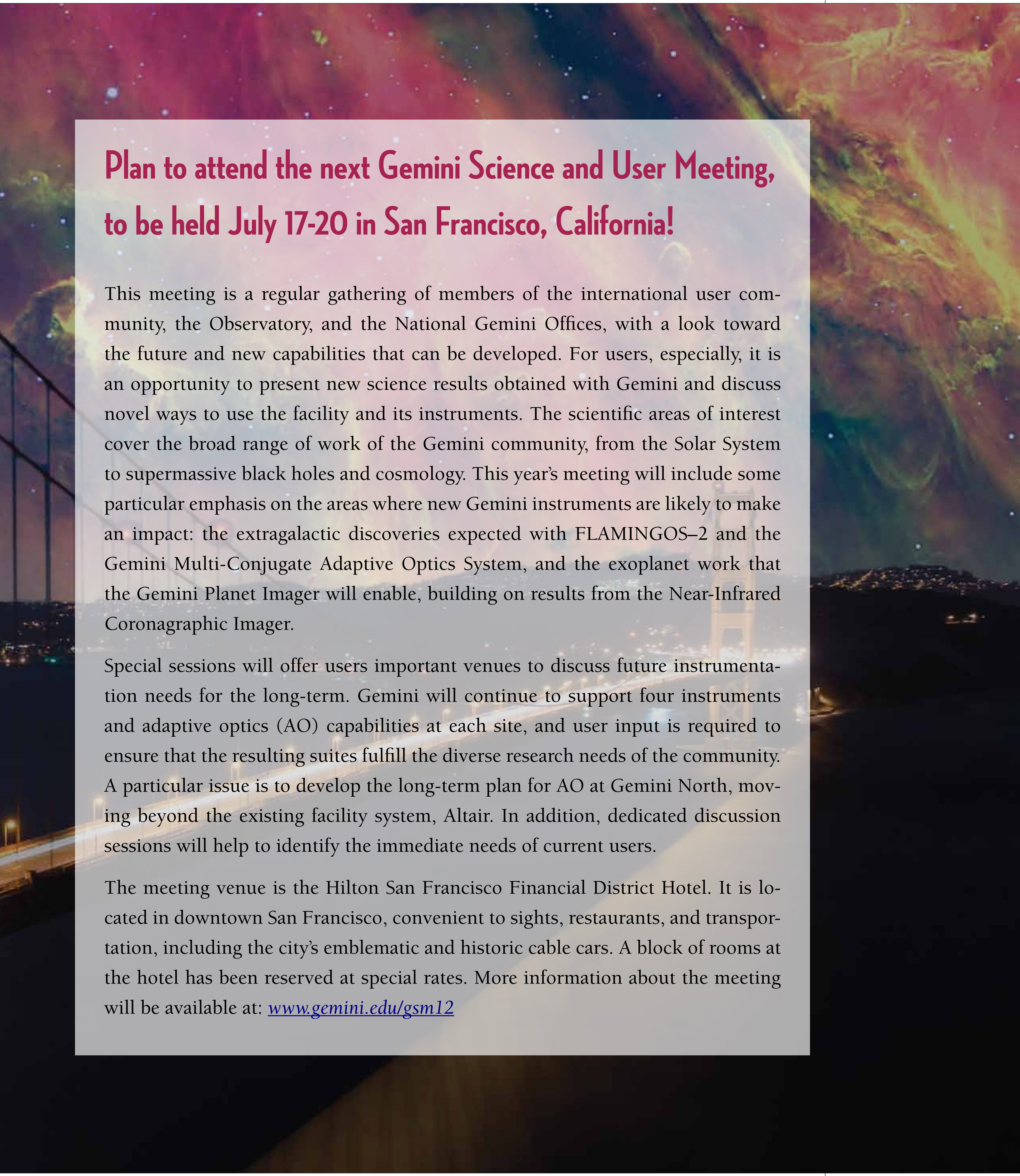
2012 Gemini Science and User Meeting



Plan to attend the next Gemini Science and User Meeting, to be held July 17-20 in San Francisco, California!

This meeting is a regular gathering of members of the international user community, the Observatory, and the National Gemini Offices, with a look toward the future and new capabilities that can be developed. For users, especially, it is an opportunity to present new science results obtained with Gemini and discuss novel ways to use the facility and its instruments. The scientific areas of interest cover the broad range of work of the Gemini community, from the Solar System to supermassive black holes and cosmology. This year's meeting will include some particular emphasis on the areas where new Gemini instruments are likely to make an impact: the extragalactic discoveries expected with FLAMINGOS–2 and the Gemini Multi-Conjugate Adaptive Optics System, and the exoplanet work that the Gemini Planet Imager will enable, building on results from the Near-Infrared Coronagraphic Imager.

Special sessions will offer users important venues to discuss future instrumentation needs for the long-term. Gemini will continue to support four instruments and adaptive optics (AO) capabilities at each site, and user input is required to ensure that the resulting suites fulfill the diverse research needs of the community. A particular issue is to develop the long-term plan for AO at Gemini North, moving beyond the existing facility system, Altair. In addition, dedicated discussion sessions will help to identify the immediate needs of current users.

The meeting venue is the Hilton San Francisco Financial District Hotel. It is located in downtown San Francisco, convenient to sights, restaurants, and transportation, including the city's emblematic and historic cable cars. A block of rooms at the hotel has been reserved at special rates. More information about the meeting will be available at: www.gemini.edu/gsm12

by Nancy A. Levenson and Henry G. Roe

New Science and Technology Advisory and Users' Committees

Gemini's advisory committees have been revised, with new terms of reference, a new name for the scientific body, and the introduction of a distinct users' committee.

Gemini has restructured some of the committees we look to for advice and guidance. We have replaced the Gemini Science Committee (GSC) with the new Science and Technology Advisory Committee (STAC). The STAC retains its strategic role in advising on scientific needs, as well as its composition that reflects all members of the international partnership. The STAC will broadly advise the Gemini Board and the Observatory on the scientific priorities for instrumentation and major facility developments. A significant change is that the committee will be appointed by and report to the Gemini Board, not the Gemini Director, although the Observatory will continue to work closely with the STAC.

The STAC has an important role to communicate with, and on behalf of, their home communities. Specifically, members have a responsibility to identify the long-range plans and priorities of their communities. They also need to inform their partner scientists of Gemini's plans and the motivation behind them. If you are a potential Gemini user, make sure the members from your community, and the STAC as a whole, understand your scientific needs for the Observatory and the capabilities it provides!

Instrument Science Teams

Another new aspect is the introduction of Instrument Science Teams (ISTs). These groups, including STAC members and additional experts in the field, will be involved over the life cycle of major instrument projects. The teams will define and confirm the scientific requirements at the outset. They will also follow instrument development to ensure that the scientific needs of the ultimate users are met effectively. For projects that do not require full ISTs, STAC members will serve as points of contact.

The STAC held its first meeting at the Southern Base Facility November 7 and 8, 2011, with additional members participating by phone and video. The committee reviewed a number of instrument and facility initiatives already in progress. Nathan Smith will lead the IST for the two new high-resolution optical spectrograph projects, the Gemini High-resolution Optical Spectrograph (GHOS) for Gemini South (the design studies of which are underway), and GRACES — an endeavor that will use the large aperture of the Gemini North telescope to provide access to the ESPaDOnS spectrograph at the Canada-France-Hawai'i Telescope. Other points of contact or IST leads are listed in the sidebar.

One major issue of discussion was the STAC's recommendation for the next instrument development project: a medium-resolution spectrometer that will simultaneously cover from optical to near-infrared (NIR) wavelengths while achieving sky-limited performance between OH lines. Such an optical-NIR instrument would serve scientific needs for rapid follow-up of transient sources and match Gemini's strength to observe targets of opportunity (ToO). This capability would also be excellent for non-ToO work, such as studies of faint galaxies at $z > 1.0$. To better understand the international community's precise needs for such an instrument, the STAC will develop a rough description of expected capabilities and solicit scientific white papers in the first quarter of 2012, with the goal of obtaining Board approval in May 2012.

Gemini North's Adaptive Optics Facility

A second major topic was the long-term plan for the adaptive optics (AO) facility on Gemini North. One option is to pursue a ground-layer AO system, which could deliver improved image quality over the entire Gemini field-of-view at red and NIR wavelengths. Other options include replacing Altair with another high-Strehl, narrow field-of-view system, or to replicate the current multi-conjugate AO system (GeMS) now being commissioned at Gemini South. Over the next six months, we'll develop science cases that make use of AO, and discuss these issues extensively at the 2012 Science and User Meeting in July (see page 54 of this issue).

The STAC's consideration of these future instrumentation and facility developments is firmly based in the current fiscal realities. These include the Transition Plan http://www.aura-astronomy.org/news/news.asp?newsID=220 that allows for only four instruments plus AO on each telescope after the end of 2012 and provides, at best, an annual instrumentation budget of ~ $5 million per/year.

In the near future, the STAC will address other significant topics, such as mechanisms to enable large programs or the development of a common time-allocation process for the entire partnership, and the medium-term plans for mid-infrared capability at Gemini. The STAC will also importantly provide scientific oversight of the system verification programs planned for FLAMINGOS–2 and GeMS/GSAOI (Gemini South Adaptive Optics Imager) in the first quarter of 2012.

Following the semiannual meetings, likely to occur in April and October each year, we'll regularly post a report from the STAC, and Observatory comments on it, at the Gemini website (www.gemini.edu/science/#stac). Contact information for members and complete terms of reference are also available at the site.

Previously, the GSC had also given input from the perspective of Gemini users. We're in the process of establishing a separate Users' Committee (UC), which will provide feedback to the Observatory on all areas of its operations that affect them as current users of the facility. Gemini and the National Gemini Offices will use this information to improve the service they together provide for users. The UC will meet annually, with the first formal meeting expected to occur during the July Science meeting.

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Henry G. Roe is an astronomer at Lowell Observatory and chair of the STAC. He can be reached at: *hroe@lowell.edu*

Points of Contact

GMOS CCD upgrades: *Tom Matheson*
FLAMINGOS–2: *Karl Glazebrook*
GeMS: *Tim Davidge*
Altair and NIRI: *Henry Roe*

by James R. Kennedy

Astronomy Observatories and Workforce Development

Remote astronomical observatories find that local workforces provide myriad challenges and opportunities. Efforts to expand local participation can take many forms, from K-12 STEM programs inside and outside the classroom to university and community college training to internships. In the end, these initiatives benefit everyone — as described in this review of Gemini's workforce development efforts on the Big Island of Hawai'i.

Figure 1.

Students experience what really happens in an observatory under the guidance of Gemini staff mentors. Here Gemini software engineer Matthew Rippa works with student intern Tyler Yoshiyama.

In the search for dark skies, smooth air, persistently clear weather, and minimal atmospheric absorption, we generally look to and select astronomical observing sites in remote, mountainous locations, usually far from large communities. Such out-of-the-way locations often have weak local economies and shallow workforce pools, especially in the technical and administrative areas generally needed by the observatories.

As many as 80 percent of an observatory's on-site employees are in technical and administrative fields. This can present not only an opportunity for both the observatories and their local host communities but also a problem. In the case of the Island of Hawai'i (the Big Island), observatories have had to import a significant fraction of these employees from overseas locations, because they couldn't find enough qualified candidates on-island. Not only has this been costly for Gemini North and the other observatories on Mauna Kea, but it has led to high turnover. Furthermore, the local community has not derived the full economic benefit from, or the sense of fealty with, the observatories that would have naturally resulted if island residents occupied more of these comparatively well-paying jobs. While by no means unique, the Big Island's situation provides a clear example of this dual dilemma.

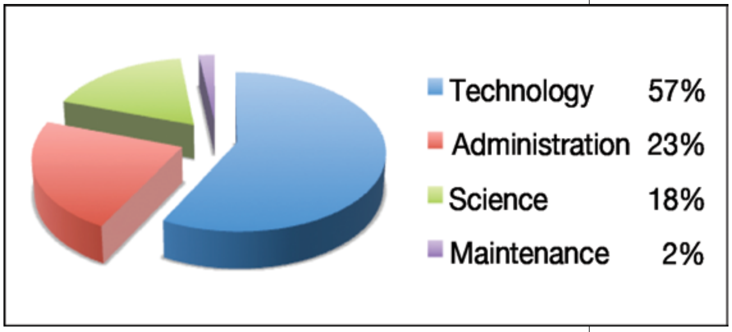

Figure 2.

Most of Gemini's jobs are in technology and then administration. Scientists make up a small fraction of the staff.

The isolation of the Hawaiian islands — lying in the middle of the Pacific Ocean, thousands of miles from other industrialized communities — also poses many problems in accessing a wide variety of otherwise basic common resources, including food, energy, education, and jobs. This occurs at a further level between the islands themselves. While barges move most goods between the individual islands, moving people between them requires expensive plane flights.

Some 25 percent of the families living on the Big Island have incomes below the Federal poverty level. Thus, a surprising number of residents, who were born and raised there, have never been off the island. For an even larger number, going off island to school or to commute to a job is financially out of the question. For these reasons, the hometown educational and vocational resources are very important to the island residents. Fortunately, these include the various public and private K-12 schools, Hawai'i Community College, and University of Hawai'i at Hilo (UH Hilo).

Historically, the educational resources were developed during a time when the Big Island's economy and its workforce were strongly dependent on large local sugar plantations. Thus, the need to service this dominant industry influenced the island's educational system. However, the total collapse of the sugar industry in the mid-1990s has had significant negative community impacts that still persist today. Ironically, while the Big Island's unemployment remains high, there are good positions locally available in the observatories. But, as mentioned, workers from overseas have already filled well over half of them.

Workforce Development Plan

In an effort to address this complex situation, the County of Hawai'i Workforce Development Board, Gemini, and the other Mauna Kea observatories (including the planned Thirty Meter Telescope) formed a partnership in 2009. Labeled the Astronomy Workforce Task Force, the group already took its first step by performing a staffing-needs assessment of all the Mauna Kea observatories. The survey helped establish the observatories' expected annual requirements in several categories of technological and administrative support from 2010 through 2023 — including each position's educational entrance requirements.

The results showed that some 473 such observatory job openings are expected on the Big Island through 2023: 333 in technology, and 140 in administration. Significantly, the vast majority of these jobs would have a minimum educational requirement of only a two-year or four-year college degree in a relevant field.

The jobs assessment also revealed that, at the entrance level, the needed skill sets would also apply to a wide range of other technology enterprises, not just observatories. Thus, success for the observatories would also create a broader technical workforce pool for other technology-based businesses. This is significant because, currently, the agriculture and tourism industries dominate the Big Island's economy. These two business sectors are especially sensitive to world economic condi-

Figure 3.

The vast majority of the technology jobs at Gemini and other Mauna Kea observatories require only a relevant two-year (red) or four-year (green) degree.

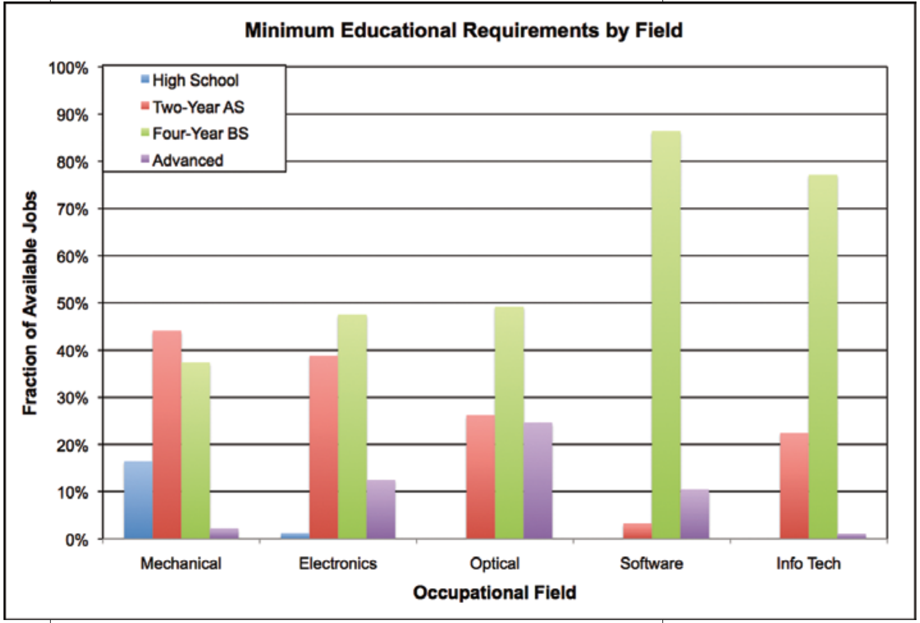

Figure 4.
Structured internships, such as the Akamai program, provide students with real-world experience doing actual projects with staff mentors, concluding with formal reports of their results.

tions, and they generally pay relatively low wages to a large fraction of their employees.

The fact that the astronomy community has to rely on imported workers, especially in the technology area, makes it clear that any other high-tech enterprises – that might consider establishing a presence on the island – face the same set of issues. Consequently, it has been very difficult to further diversify the local economy into these 21st-century areas. Hawai'i County Mayor William Kenoi noted that, "Our island must develop additional economic bases, and this project is well suited to our long-range goals."

The jobs survey findings provided the foundation for us to engage with a larger segment of the community, to determine what we needed to do to provide properly qualified local candidates for these positions. In early 2011, we sent invitations to a number of island candidates: educators at all levels, providers of informal education programs (including the observatory outreach programs) and internship programs, observatory human resources personnel, administrators, technical leaders, leaders in local business and government agencies, and other community leaders. We asked them to meet with us, to look at the survey results and explore ways of attacking this common problem.

The going-in position for this meeting was that the group should consider where the most significant issues lay. We would then start the process of looking for solutions that would adjust and optimize the existing resources and improve their interrelationships. The notion was to leverage the available working components into an even more effective system, to better meet the common needs.

There was broad agreement with the suggested approach, and we identified four broad program areas: the K-12 and undergraduate college programs, the local informal education programs (after school and outside the classroom hands-on experiences), and actual workplace-experience programs (internships, co-op programs, etc.). We then formed working groups to address each of these four areas.

The ongoing meetings have helped us to identify a number of needed actions and efforts directed at making further progress. The size of the largest group of participants has now grown to over 100 people.

Progress

The jobs survey enabled us to compare the educational requirements for these future job positions against the programs actually available on the island. We found several areas at the local community college and university levels where refinements in existing programs, or the development of new degree programs, especially in technology, might make a material difference in the ability for local graduates to find jobs in the observatories. It will also create a broader technical workforce pool for other technology-based businesses.

The Chancellors of Hawai'i Community College (HCC) and the UH Hilo have provided strong support to the efforts to find ways to facilitate successful solutions. In the words of UH Hilo Chancellor Donald Straney, "UH Hilo is committed to expanding programs and developing new programs that have a positive impact on our island economy, build workforce for the island and the state, stimulate careers on-island, and develop synergies between sectors."

Meetings also continue between senior faculty in the concerned subject areas and observatory engineering and technical representatives. The first steps were to provide the relevant HCC and UH Hilo faculty with tours of the Gemini Hilo base and Mauna Kea summit facilities. This has helped them get a sense of what people really do in an observatory on a daily basis; the faculty also met with island residents who have succeeded in getting observatory jobs and discussed with them their personal experiences.

Currently, our efforts are on comparing the subject matters currently taught in the two institutions to the knowledge, skills, and abilities requirements of actual observatory job descriptions. In fact, the Board now has the opportunity to help shape some of the new degree programs currently on the drawing boards at the HCC and UH Hilo; if all goes well, we expect these improved programs will be ready for implementation within the next two years or so. Discussions are also continuing about ways to include other relevant material in existing course offerings and develop in-service training courses.

Win-Win Activities

On another front, the observatories routinely provide student internship opportunities, typically during the summer. The HCC and UH Hilo are very eager to place as many of their students in such programs as possible. These are win-win activities for both the students and the observatories; the students get to experience the real-world workplace while doing productive work, and the observatories

Akamai Interns: A Local Workforce Success Story

For many years, the Akamai Workforce Initiative has partnered with the observatories on Mauna Kea to offer local college students a unique and extremely successful internship program. The Akamai Internship Program offers them an opportunity for a real-world experience to work at an observatory under the mentorship of a scientist or engineer. The program begins with a preparatory short course taught by a team of trained instructors, who focus on teaching the interns problem-solving, research, teamwork, and communication skills. The interns then spend the next seven weeks at an observatory, while simultaneously completing a technical communication course. They meet weekly with an instructor and have a range of assignments that help them communicate about their observatory project in many different ways.

To date, 188 Akamai students have completed internships at local observatories and high-tech companies. The program has been very successful: 84 percent of the interns have continued on a science/technology career pathway (enrolled or working). Consider James Linden. He grew up on the island of Hawai‘i, graduated from Waiakea High School there, and moved to Oahu to study mechanical engineering at the University of Hawai‘i at Manoa. In 2007, James entered the Akamai program, which placed him at Gemini North under the mentorship of Gemini engineer Chas Cavedoni. During his stay, James created a computer model of a cooling system for telescope instrumentation. Recently, the Advanced Technology Solar Telescope (ATST) has hired James as a thermal technician, and he is thrilled: “I will do design work and testing in Arizona for several years before moving home to Hawai‘i to assist in building the ATST. It’s exactly what I want to do.” And that’s exactly the kind of outcome the Akamai program strives for.

Developing a local technical workforce in Hawai‘i is *akamai* – smart, clever, insightful. Linden, and nearly 100 other college students and recent graduates, now have jobs in STEM, with many of them in Hawai‘i.

Led by the Institute for Astronomy, Akamai Workforce Initiative is supported by the National Science Foundation (#AST- 0836053), Air Force Office of Scientific Research (FA9550-10-1-0044), University of Hawai‘i, National Solar Observatory, and the Thirty Meter Telescope.

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Figure 5.

Interns have the opportunity to get supervised experience in nightly telescope and instrument operations "on the sky."

get to preview the potential talent that might move into the workforce pool in the near future.

In addition to ad hoc observatory internships, some independently organized programs at both the high school and college levels combine observatory internships with other related employee skills training. Efforts are now underway to explore enlarging the number of available internships, and to establish clear communications links with the schools' placement offices. In partnership with the University's 'Imiloa Astronomy Center, the observatories have also begun exploring a pilot program for high school job shadowing in the observatories.

In the process of these discussions, we learned that some students (or job seekers) have difficulty finding available internship (and job) opportunities, since about a dozen different astronomy entities offer them, all on different websites. We plan to overcome this problem by developing a single website that all of the observatories will use to post their job and internship openings by discipline (in addition to their own individual websites). By the end of 2011, this one-stop-shopping site will be up and operational.

K-12 educators have also pointed out that they struggle with a common problem in delivering effective Science, Technology, Engineering, and Mathematics (STEM) education: namely, poor math-skill retention. This shows up again when the students attempt to start their post-secondary studies. Although convened independently by State Representative Mark Nakashima, the astronomy group is collaborating with Nakashima's working group to address this critical area.

In collaboration with the University's Department of Education, this group is planning to convene a series of Math Summit workshops. These will first bring together highly successful Big Island math teachers ("champion" teachers) in order to harvest their experience and approaches, and then, in later workshops, share the lessons learned with other local K-12 math teachers, and also the UH Hilo's education students.

A number of informal education programs also occur in the local area. These include astronomy club outreach programs, science fairs, a variety of freestanding grant-funded programs, and, of course, K-12, HCC, and UH Hilo based programs. A special working group is currently in the process of doing an inventory of the available informal programs to help establish communications between them and the formal observatory and education programs.

In summary, although much work needs to be done, we've made quite tangible progress in all the areas discussed. The effort is providing ongoing forums for dedicated people in different branches of the education arena to discuss common problems and issues, across traditional "silo" boundaries, with positive results. As Michael Gleason, Chair of the Workforce Investment Board, observed: "This is a fine example of a community of people coming together to solve common problems, and we are looking forward to a continuing stream on ongoing results."

James R. Kennedy retired as a Gemini Associate Director in 2007, after 11 years with Gemini and more than 21 years with AURA. He is currently Vice Chair of the County of Hawai'i's Workforce Investment Board, and can be reached at: jimkennedy@hawaii.rr.com


by Maria Antonieta García and Peter Michaud

Viaje al Universo Chile

When family participants filed into the public library at the La Serena Mall Plaza in La Serena, Chile, on a Tuesday afternoon in mid-July 2011, few suspected that they would become part of a living, breathing, Hertzsprung-Russell diagram (Figure 3).

But that's exactly what happened as visiting scientist Cristián Góez of Olimpiadas Libre in Colombia, handed out colored balloons to children and parents and set them out on an exploration of the temperatures, masses, and brightnesses of stars as they evolve.

Góez led this highly interactive program as part of a significant expansion of the Gemini South local outreach programming. For the past five years, the big annual local outreach program at Gemini South has been AstroDay Chile. In 2011, however, the length of AstroDay Chile (Figure 2) was expanded to include an adaptation of the very successful Journey Through the Universe, which is going on its 8th year in Hawai'i at Gemini North. As the photos in this pictorial reveal, the local community enthusiastically embraced the new combined event, now called *Viaje al Universo*.

Figure 1.

Children from ages 8-15 participate in rocket launches in a rocket building workshop held at the local army Regiment "Coquimbo" overlooking the city of La Serena.

During the 7-days of intensive programming, over 3000 people ranging from students to the general public participated in the wide variety of activities prepared by the Gemini Public Information Office staff. A total of six *juntas de vecinos* (community associations), previously selected by the local city hall,

Figure 2.

Gemini South science staff Bernadette Rodgers and Pablo Candia interact with the local community at AstroDay Chile's ask the astronomer kiosk.

participated during this week-long program: Children launched rockets (Figure 1), families shared in astronomy-related activities, and almost a dozen Gemini science staff presented public talks to enthusiastic audiences to name just a few of the events taking place.

The program's success was in part due to the extraordinary help of local scientists and educators, but also those who who traveled to Chile from Colombia, the United States, and Argentina to participate in the event. "Seeing childrens' faces as they try to figure out how to solve problems while they build their rockets, and then witnessing their mouths open when these rockets fly into the sky is what science is all about," says astronomer David Yenerall, a professor at Georgia Perimeter College in the United States and certified NASA Endeavor Project science teacher. Like others who participated from afar, David took time out of his busy schedule to travel to Chile and support this year's program.

Figure 3.

Roderick Bowen from Joan Rasé Public Observatory in Santiago, Chile, assists a child in the placement of her balloon on the Hertzsprung-Russell diagram. The activity, led by visiting Educator Cristián Góez from Colombia, explored the mass-luminosity relationship in stars and explained stellar evolution in terms that audiences could understand and touch!

Gemini looks forward to many more years of celebrating AstroDay Chile and Viaje al Universo as a joint venture, as we engage our local Chilean community in the work we do and inspire the next generation of scientists, engineers and support staff. We expect these youths to propel us into the future like the rockets launched during this exciting week of interactive science.

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Peter Michaud is the public information and outreach manager and is located at Gemini North. He can be reached at pmichaud@gemini.edu

by Christopher Onken

Australia's Gemini School Astronomy Contest: Year Three

Benjamin Reynolds dreams of taking a closer look at the stars, preferably from beyond the confines of the Earth, as he aspires to become an astronaut. For now, the 10th grader is just excited about the prize he received on October 18th for winning the 2011 Gemini School Astronomy Contest: a framed Gemini South image of the barred spiral galaxy NGC 7552 – the target he chose for his contest entry (Figure 1).

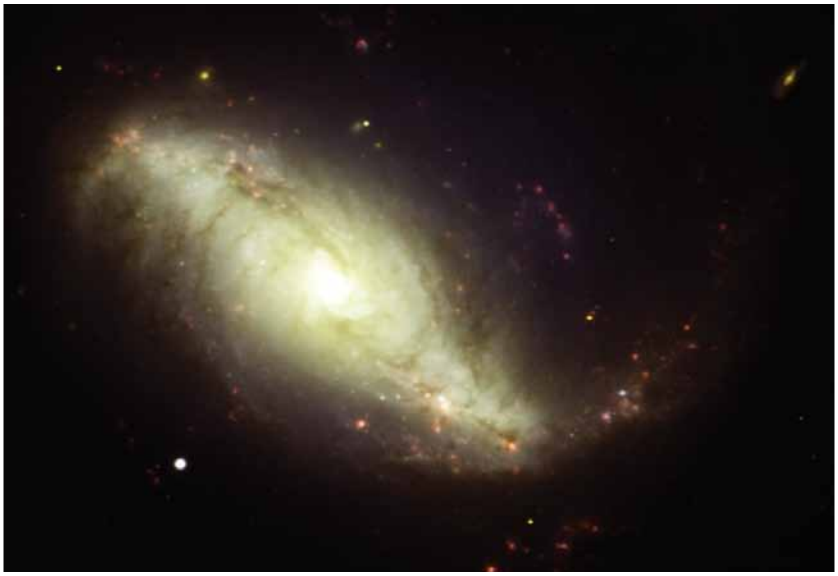

Figure 1.

Gemini GMOS image of the barred spiral galaxy NGC 7552. Benjamin Reynolds, a 10th grade student at Sutherland Shire Christian School, suggested this target for Australia's 2011 Gemini School Astronomy Contest and won. The picture consists of separate images taken with different filters: H-alpha (red), g (blue), r (green), and i (yellow). Image credit: Benjamin Reynolds (Sutherland Shire Christian School), Travis Rector (University of Alaska, Anchorage), and the Australian Gemini Office.

To win the competition, Ben had to select an astronomical target worthy of exploring with Gemini South, and then explain why it would make for a great picture. We received entries from all over Australia, but our panel of volunteer judges deemed Ben's the best. "We were impressed with the research that Ben had done and the scientific arguments that he made," said panel chairman Terry Bridges (Queen's University).

As Ben noted in his entry, the long stellar bar in NGC 7552 (running from the upper left to the lower right in the Gemini Multi-Object Spectrograph (GMOS) image) is one of the most prominent features of the galaxy; such bars, he explained, help to feed gas towards the galaxy's core, which can fuel a sudden burst of new star formation or even funnel matter onto the galaxy's supermassive black hole.

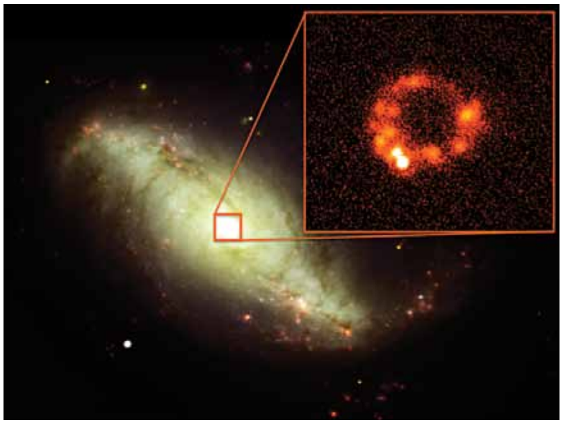

Figure 2. *The contest image, with an inset of a mid-infrared image of the center of NGC 7552 taken by T-ReCS with the Qa filter at 18.3 microns. The mid-infrared image shows a ring of dust clouds, heated by the stars that formed within the clouds some 50 million years ago.*

Previous evidence has indicated a "recent" spike in star formation, thought to have happened less than 50 million years ago. Indeed, using wavelengths of light some 20 times longer than the human eye can see, Gemini's Thermal-Region Camera Spectrograph (T-ReCS) has pierced the cold dust clouds that obscure NGC 7552's heart in the visible-light GMOS image, revealing a ring of dust clouds glowing from the heat of those young stars. (Figure 2).

The GMOS picture, composed by Travis Rector (University of Alaska, Anchorage), enhances the contrast in the dark lanes of dust by combining separate images taken across the visible spectrum, from blue to red light; since dust more strongly absorbs blue wavelengths of light, putting the different colors together makes the dust stand out in the image.

On October 18, 2011, I had the pleasure of revealing the new GMOS image and explaining some of its remarkable features to Ben and his 10th grade classmates at Sutherland Shire Christian School, just south of Sydney, New South Wales (Figure 3). The group erupted into a round of applause when the new picture finally appeared on the big screen. They were delighted with the image that Ben's hard work had yielded. We capped off this memorable event with an inspired question and answer session. This was my second visit to the school. I had gone there a couple of months earlier for the first part of Ben's prize, a "Live From Gemini" event for his class; each of the top three contest entries earned themselves one of these sessions, in which the students learn about the Observatory through a real-time video link to Gemini's Public Information and Outreach staff. One of Ben's teachers, Susan Kusch, said the link "was really interesting and the photos were spectacular!" The other two entries that earned "Live From Gemini" events came from Ryan Soares of Trinity College (East Perth, Western Australia) and a team submission by six students — Eugenie Puskarz-Thomas, Rachel Augustyn, Phoebe Duncombe, Brooke Henzel, Matilda Williams, and Louise Graham — from St. Margaret's Anglican Girls School (Ascot, Queensland).

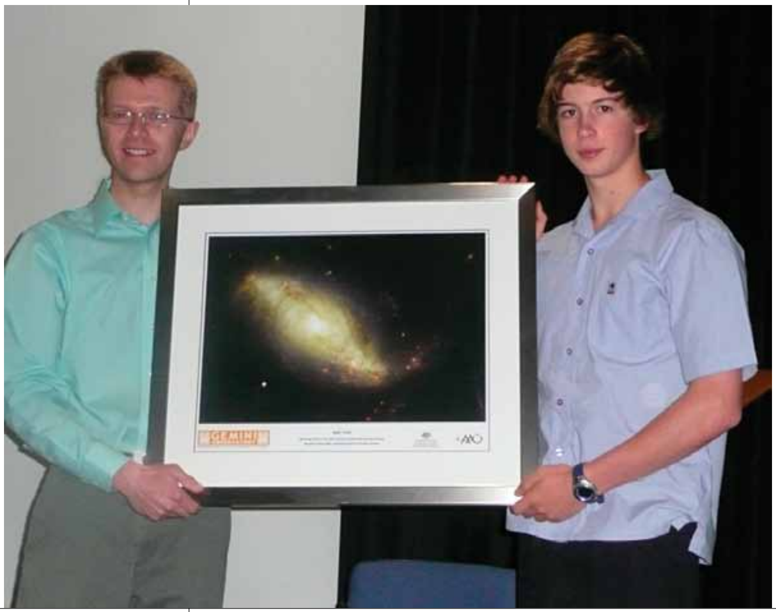

Figure 3. *Benjamin Reynolds (right) receives a framed copy of his contest-winning image from Christopher Onken (Australian Gemini Office / Australian National University) during the grand unveiling event at Sutherland Shire Christian School. Photo credit: Amanda Reynolds.*

The contest entries written by all the winning students were the jewels in a crown of universally exceptional submissions. This bodes well for our ultimate goal of trying to foster an interest in science among young people. As such, we continue to work on building the contest's scale and have applied for the telescope time to run another round in 2012.

One day, Ben Reynolds hopes to make it into space, and perhaps this 50 million light-year journey of the mind to NGC 7552 will serve as a mere stepping-stone on his voyage into the cosmos.

Learn more about the Australian contests at:
http://ausgo.aao.gov.au/contest/

Christopher Onken is the Deputy Australian Gemini Scientist and is a postdoctoral researcher at the Australian National University. He can be reached at:
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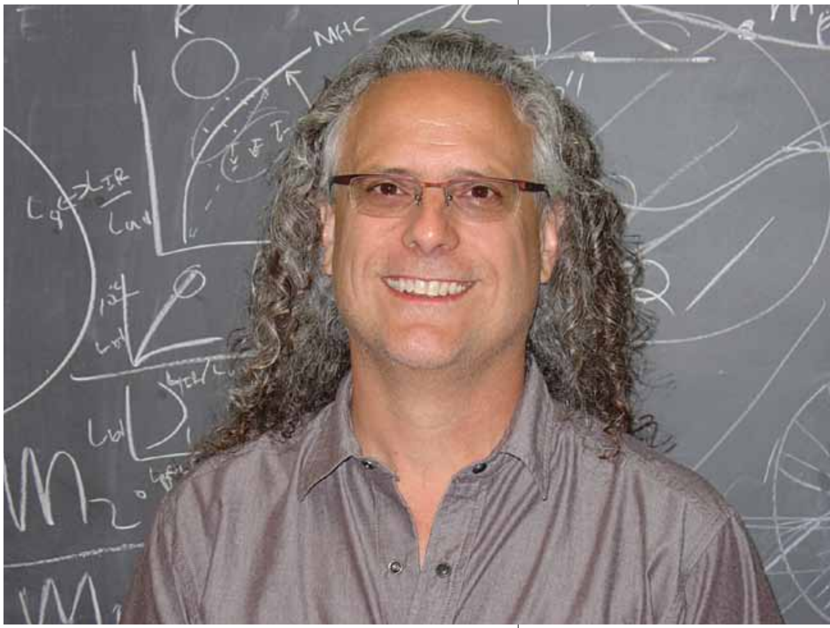
by Carolyn Collins Petersen

Karl Gebhardt:

Inspiring students with extragalactic black holes, dark energy, and his passion for understanding.



Ask any astronomer to name a scientifically significant galaxy and M87 just might come up in the conversation. That's because this massive elliptical behemoth — one of the largest nearby galaxies — has intrigued astronomers since 1918, when Heber Curtis (Lick Observatory) first noticed a ray of light streaming from its nucleus. Today, astronomers have identified that ray as a jet of plasma blasting out from a supermassive black hole. M87's central supermassive black hole has certainly fascinated Karl Gebhardt, who delves into these cosmic monsters in both massive and intermediate-mass galaxies from his office at the University of Texas at Austin (UT Austin). In fact, his research career has always been on a trajectory toward these objects that appear to exist in the hearts of many galaxies.

Karl's fascination with black holes began in graduate school in the early 1990s, where he focused his work on globular clusters. "At the time I started, there was a big controversy as to whether they contained black holes or not," he said. "I love controversy. I have to say that it is still there [whether globulars have black holes], but I have switched from those that say the evidence is not there to saying it is there."

Working with the "Nuker" collaboration (a team led by Sandra Faber and Douglas Richstone to use the Hubble Space Telescope to investigate the central structure and dynamics of normal galaxies), Karl, in particular, studied their mass distributions and the supermassive black hole at the heart of each. Modeling central supermassive black holes, particularly in intermediate-mass and larger galaxies like M87 is a very complicated process, requiring supercomputers to handle all the parameters. "I developed a powerful computer program that can model the complications that exist in galaxies," Karl said. "I first applied it to measure black hole masses. Hubble Space Telescope was in its full-glory at that time with an exciting new data set, and then I just used the same tool to measure the dark halo."

The dark halo of a galaxy is thought to contain dark matter. The gravitational influence of the dark matter shapes and constrains a galaxy and its motions. According to Karl, measuring the influence of the dark matter as well as the black hole mass at a galaxy's heart was a challenging task until relatively recently. "I finally combined measuring the black hole mass and the dark halo profile once the computers became powerful enough to tackle that problem," he said. "Combining these two studies turned out to be very important since there are some degeneracies between them. It is computer-intensive since one needs to explore both the central and outer regions of the galaxy."

The result produced by Karl and his colleagues has gone a long way toward an understanding of both the mass of a black hole in a galaxy like M87, and its dark halo profile. "This knowledge feeds back directly into understanding the formation and evolution mechanisms for galaxies," he said.

Indeed, when Gebhardt and Jens Thomas of the Max Planck Institute for Extraterrestrial Physics used the Lonestar supercomputer (one of the world's most powerful) to model M87's central black hole (using all three parameters), they found it to be 6.6 billion times more massive than the Sun, or 2 to 3 times more massive than previously thought.

After his and Thomas' ground-breaking work on M87, Karl has used Gemini Observatory to further his studies and refine the central black hole mass in M87 and other galaxies. He notes that observing with Gemini has always been excellent. "Gemini is one of the best observatories I have ever used," he said. "The adaptive optics system is unparalleled, and I have used them on all of the big telescopes."

Some of the most recent work exploring supermassive black holes at the center of galaxies — done on the Gemini North telescope in conjunction with astronomers at the W. M. Keck Observatory and the McDonald Observatory — has uncovered two of the largest supermassive black holes found so far. They lie in the galaxies NGC 3842 and NGC 4898 (see article on page 20 of this issue). Karl, who was a member of the discovery team led by University of California at Berkeley graduate student Nicholas McConnell, was amazed at the find. "They just keep getting bigger!" he exclaimed. "My record holder in M87 is now dwarfed by about a factor of two by both of these. It's all very exciting, since it tells us something fundamental about how galaxies form."

Karl is also continuing to explore dark matter. He is a leader in the forthcoming Hobby-Eberly Telescope Dark Energy Experiment (HETDEX), which will use an instrument called the Visible Integral-field Replicable Unit Spectrograph (VIRUS) to separate light from distant objects into its component wavelengths. The spectral signatures acquired with VIRUS will reveal each object's distance, speed, motion, temperature, and more. All data will contribute to a large map of the universe that should tell us how fast the universe was expanding at different times in its history; it may also help characterize the role that dark energy has played throughout the history of the universe. "I have been working on this since 2003," Karl said. "We are close to starting. That will take all of my time for the next many years. It is a change of focus for my research, but it is very exciting."

Research into the dark side of the universe isn't all that Karl Gebhardt does. He also teaches astronomy at UT Austin, and he is enthused about communicating the excitement of astronomy's modern discoveries. He has won recognition for his teaching, including a National Science Foundation CAREER award, and teaching excellence awards from the UT Austin and McDonald Observatory Board of Visitors. He uses astronomy to generate a sense of enthusiasm for science among his students.

"The excitement that one can generate in students about astronomy is very motivating," he said. "My goal is to take the most complicated questions out there — What comes before our universe? What is inside a black hole? What is the multiverse? What is gravity? What is spacetime? — and get non-science majors to grasp our basic understanding of these topics. I stress that they are learning material that could all be wrong. They have to appreciate the difference between facts and observation and then interpretation. I get so much satisfaction when a student can answer those questions in a simple way that anyone can understand."

Karl often challenges his non-science major students to be able explain the complex concepts he teaches them. "I tell the class that my goal is to get them to answer three basic questions: What comes before the universe? What do we think is inside a black hole? Where does all the matter and energy come from in our universe? I tell them that they have to be able to explain these three answers to their friends at 1:00 a.m. after they have been partying a bit too much. I just haven't found a way to test them on that yet."

Karl's zeal for teaching reaches beyond the university, particularly when he does public outreach in the schools. "Karl's a great teacher," said Mary Kay Hemenway, director of the UT Austin astronomy department's educational services office. "I heard from a teacher whose school he visited that he did such a great job. This was at a tough school — the first one to be closed by the state for poor performance and reopened with new staff."

Karl does a great deal of public outreach in astronomy, and he builds on his teaching experience to generate excitement in his talks. He speaks about once a month at public events, at everything ranging from large audiences down to small focus groups.

Karl had a passion for astronomy as a youngster and he recalls going to the Strasenburgh Planetarium in Rochester, New York, where he grew up. "I still remember the excitement I would feel, when the star machine rose from the center and then illuminated the night sky," he said. "Interestingly, the star machine there is called Carl. Anyway, that excitement clearly developed within me, and my interest in astronomy may have started then."

Karl adds that he also always wanted to do physics — mainly because he always had a hard time with it. "I am attracted to things I cannot understand, and physics definitely was that," he explained. "I did well, and started in grad school working on a large collider experiment (Dzero). I got dismayed when I saw the grad students working in a team of 100s. Astronomy is a field where individual contribution is still the dominant mode."

When he's not teaching astronomy or plumbing the depths of black holes or planning the HETDEX exploration of the universe, Karl relaxes by doing Tai Chi and exploring the spiritual experience it provides. He also does a lot of hiking and biking. "The one thing that used to really relax me is home improvement projects," he said. "In grad school, I worked almost full-time for a construction company, and that gave me some invaluable skills."

Using those skills, Karl says he has redone essentially every room in his house and claims that it's time to move to a new one. "There is nothing more enjoyable than taking a sledge hammer to your old kitchen counter. What a feeling!" he said, pointing out that he's not the only one who is into home improvement. "The great thing is that I am getting my seven-year-old daughter involved. She has become an impressive mudder. I give her a big drywall blade and a bucket of mud, and tell her what section of the wall to work on. She loves doing it, and gets it quite smooth. I haven't started her on the nail gun yet!"

With the HETDEX experiment taking more of his time, and data-gathering operations set to begin in 2012, Karl looks to stay at the forefront of dark-energy and dark-matter research. And, as the discoveries start to roll in, no doubt Karl will be there to share that information with students and the public. It's in his DNA.

Mary Kay Hemenway predicts that he'll do great things. "I suspect that someday he'll get nominated for one of those big awards in astronomy, especially if he solves that dark-energy problem!"

All that lies in Karl's future. For now, he is focused on the projects at hand, but with a sense of appreciation for what astronomers like him have accomplished in understanding the cosmos. "The great thing about astronomy is that it is 'out of this world,'" Karl extolled. "There is no other field where you can say that. We can use that to grab anyone's attention and then explain our position in it. Even though that may be intimidating, it is remarkable how far we have come as a society to understanding our place in the universe."

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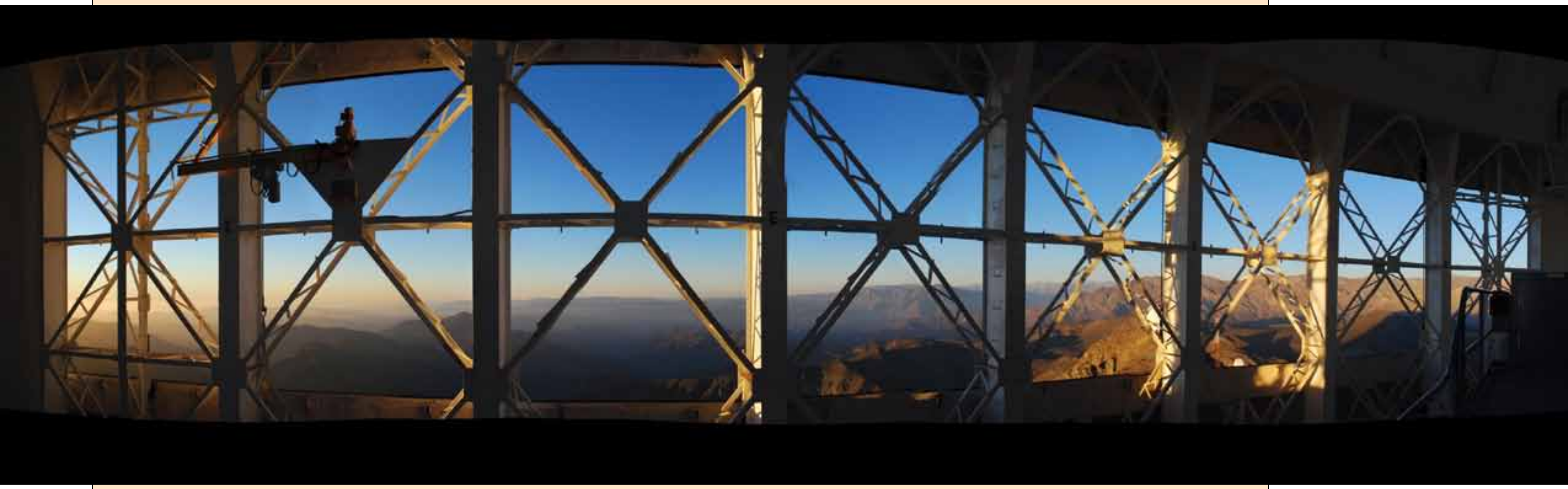
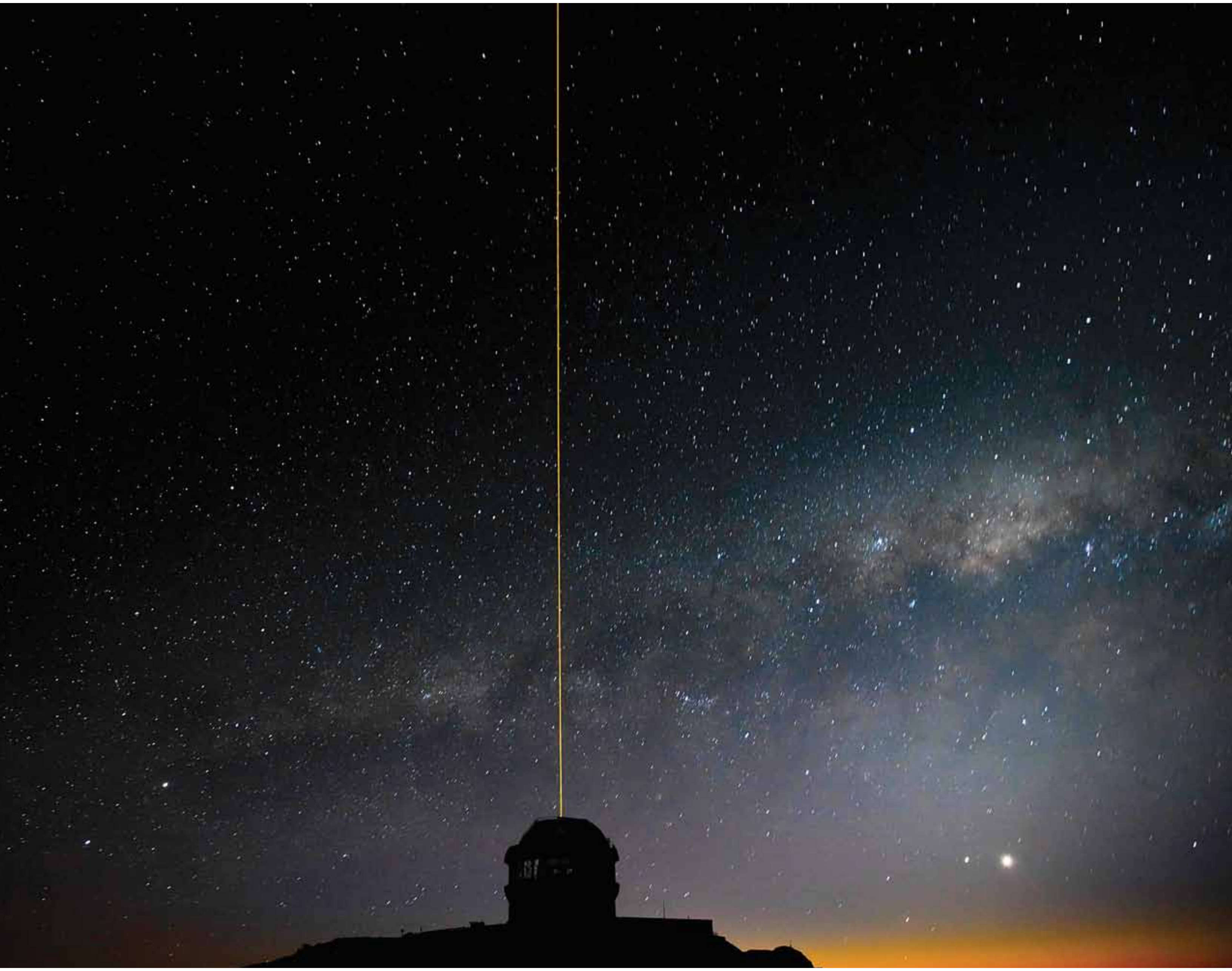
Images by Staff and Users

(Opposite page, top left): Titled "Light and Dark at Winter's Sunset," this image was made by Gemini Science Fellow Henry Lee from Cerro Pachón on August 28, 2011, 6:04 p.m. Henry used a Canon EOS 450D camera and an 18- to 55-millimeter kit-lens. Only minor alterations in brightness and contrast were made to produce the shadow effect in this image. He can be reached at: hlee@gemini.edu

(Below and bottom spread): Gemini classical user Felipe Menanteau of Rutgers University obtained these panoramic images during a GMOS run on October 24-28, 2011. He used a Nikon D40 SLR digital camera to make the interior image of Gemini South (below, "A View from inside the Dome of Gemini South") on October 25 with eight images stitched together. The sunset panorama at bottom ("A 180° View of Cerro Pachón"), showing the Gemini and SOAR telescopes, used 25 shots obtained on October 28. He can be reached at: felipe@physics.rutgers.edu

(Outer back cover): Gemini Outreach and Audio Visual Production Specialist Manuel Paredes obtained this image of the GeMS laser during commissioning on November 13, 2011, using a Canon EOS-1Ds Mark II and a 55-second exposure to capture the moonset and Milky Way along with the Gemini South laser. He can be reached at: mparedes@gemini.edu





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