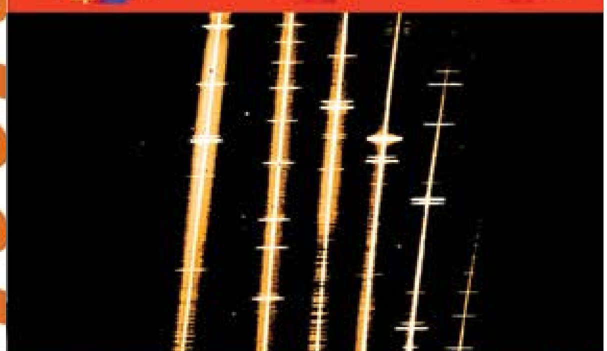
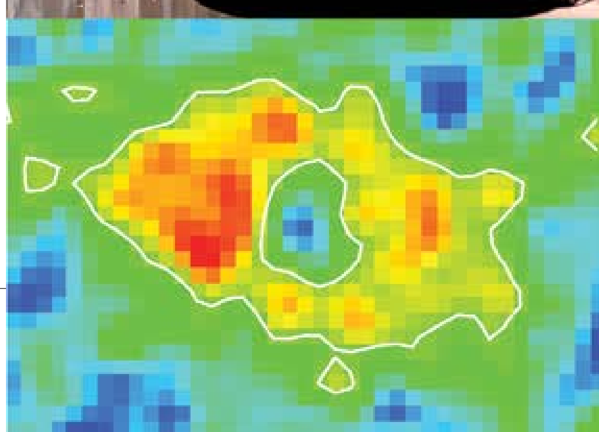
GeminiFocus

December 2010 Publication of the Gemini Observatory

Gemini Focus





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On the cover:
Time-lapse sequence of the Gemini North telescope laser guide star (LGS) sodium laser. Joy Pollard of Gemini's Public Information and Outreach office obtained this all-night sequence of images that she stacked in Photoshop® to create a record of the night sky and LGS from dusk to dawn. The glow of evening and morning twilight can be seen to the left and right side of the image respectively. The photograph was obtained using a 9-mm, circular-format, fish-eye lens from outside of the University of Hawai'i 88-inch telescope on the night of May 21, 2010. Each image was a 30-second exposure using a Canon EOS DI Mark II digital camera.
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by Doug Simons
Director, Gemini Observatory

Director's Message

In October 2008, the world watched in amazement as the New York Stock Exchange entered what appeared to be a free fall, with other markets around the globe following suit. The news was filled with terms like "too big to fail" and "government bailout," as the global economy seemed to take on a life of its own — a life that was nearly out of control as governments and investors scrambled to reign in this juggernaut. At Gemini's overseas sites, thousands of kilometers from the world's financial centers, there was a sense of tacit isolation from these catastrophic economic events. I knew that, through the many government agencies that provide our funding, Gemini would be affected, but exactly how and when was less clear.

Like the rest of the world, I was mainly looking for the stock market crash to bottom out; at least I would know the magnitude of the problem and could begin to assess its impact on Gemini Observatory and our international community. With the UK's Science and Technology Facilities Council (STFC) already planning a major review of its program in 2009 — as well as recent budget challenges within the STFC, and the anticipated 2012 renegotiation of Gemini's International Agreement — it was no secret that our UK partner was in a precarious position when the 2008 global economic crisis struck.

In a sense, the economic turmoil in late 2008 behaved like a tsunami with waves that propagated around the world repeatedly before they eventually damped out. For Gemini Observatory, the tsunami, which started in New York, was felt in the UK and ultimately washed upon Gemini's "shores" in Hawai'i and Chile with the announced withdrawal of the UK from the Gemini partnership at the end of 2012, resulting in an unprecedented budget reduction for the observatory.

While daunting, Gemini's budget challenges are certainly not unique. This newsletter article is being read by hundreds within our community who are facing similar budget shortfalls; astronomers, engineers, and administrators are now forced to absorb pay and benefit cuts, adapt to furloughs, or cope with work-force reductions. Though Gemini's budget challenges are unique in our brief history, it is important to place them in the context of similar circumstances across our international community. Despite this setback, Gemini Observatory remains committed to providing its community with advanced tools to support their research ambitions. The question is "how?"

Gemini's Transition Plan

During the November 2009 Gemini Board meeting, the UK announced its likely intention to withdraw from the Gemini partnership (a position confirmed at the March 2010 Board retreat). In response, the Gemini Board instructed the Observatory to "compile an executable operations plan that involves a reduction of 7 to 10 percent per annum in current O&M expenditures, base-lined to the 2009 revised budget …that shall be phased into place during the period 2011 through 2013."

Immediately thereafter, Gemini's senior managers began an extensive analysis of options for continued operations with a 20-25 percent budget cut effective December 31, 2012. This included an assessment of past labor and non-labor costs, forecasts of future cost growth and contraction, and the merits and risks of a range of operations models.

One option quickly dismissed was to uniformly apply budget cuts across all cost categories (labor and non-labor). Though that option ostensibly carried a sense of fairness in spreading the burden (and has been used elsewhere), it would have likely left some key capabilities of the observatory threatened. Likewise, I ruled out an approach to "rebrand" Gemini as a completely different type of observatory; attempting what amounts to an identity change while in such a vulnerable state is unwise and unnecessary — a lesson that has been demonstrated repeatedly within the for-profit and non-profit arenas when similarly challenged.

This is the time to ground the observatory in the context of its key strengths and in a vision forward to achieve stability, not seek radical change that would be divisive and lead to even greater instability across the remaining partners. At first glance, the likelihood of preserving core strengths of the Observatory under such a large budget reduction seemed implausible. But as our analysis progressed and risks retired, a strategy crystallized.

Gemini Board Priorities

During the Gemini Board's retreat in March 2010, the essential elements of the observatory's priorities were identified, namely:

- *To deliver and operate high-quality instruments that represent the priorities of our community;*
- *To provide a high fraction of queue operations with appropriate data quality control, data products, and completion fraction;*
- *To have the ability to remotely operate the telescopes; and*
- *To better interface with the partner community.*

These priorities were carefully factored into further refinements of the observatory's Transition proposal. Broadly speaking, they can be characterized by two basic pillars in Gemini's plan forward.

One pillar is represented by having an instrumentation program that meets the needs of Gemini's community. The "lifeblood" of any observatory is substantially represented by the quality and extent of its instrumentation, and Gemini is no exception. Building a modern suite of optical and infrared imagers and spectrometers, coupled with certain leading-edge technologies (*e.g.*, adaptive optics), is a balanced and robust approach — well matched to the superb focal planes provided by the twin Gemini telescopes.

The second pillar is captured by a strategy to provide a long-term, affordable, and sustainable operations model that takes advantage of the strengths already built into the Gemini facilities. This is achieved by continuing a blend of classical and queue operations, but doing so with a combination of non-research staff and additional software to support the generation and execution of Gemini's queues in Chile and Hawai'i. Both classical and queue observing are in demand by the community and have tangible benefits worth preserving. The burgeoning Target of Opportunity community (nearly 25 percent of Gemini observations are now used for them), and advantages of running laser adaptive optics (AO) systems under queued operations, all point toward preserving these aspects of our operational model. Likewise, classical observers bring new ideas, innovation, and welcome interaction between Gemini's staff and the community.

In the long-term, the infrastructure we are building as part of our Transition plan will also support other innovative modes; this will probably allow astronomers to "eavesdrop" on their observations while they are being executed and/or conduct them from distant sites. Through this combination of new capabilities, Gemini expects to interface with its broad community much more directly than has been possible in the past, to the benefit of everyone.

What Will Change During This Transition Period?

I am asked this question frequently. While we are working toward positive change under difficult financial circumstances, much of the change anticipated represents real hardship. The bulk of the cost savings needed under our Transition proposal is achieved through a significant reduction in our workforce. We project a reduction of ~ 32 full-time equivalents (FTEs) over the next few years to meet our budget goals. Given the breakdown in labor *vs.* non-labor costs at Gemini (which are typical of most observatories), there is no practical way to meet projected budget cuts without such a loss of positions.

In general, this reduction in workforce will occur across all branches of the observatory and must be carefully managed to ensure that we have the right expertise, when we need it, to support activity in our Transition plan. We will rely primarily on attrition across all branches of the observatory during this time frame to achieve this reduction. As we migrate toward the use of non-research staff to conduct most queue observations, the total research product of Gemini's science staff will be reduced. This is a significant departure from the philosophy adopted by the Gemini Board early in our operational phase.

Furthermore, the reduced staff size will mean fewer instruments can be supported and the adoption of a "4+1" model at each site (four instruments plus adaptive optics). This will lead to the consolidation and/or decommissioning of capabilities over the next few years. Exactly what will change in our currently offered instrument set will be discussed in depth with the Gemini Science Committee and Board in the months ahead.

Finally, our margin to adapt to unexpected changes in the future will be considerably reduced with a smaller resource base to tap. So, while our Transition plan preserves certain core capabilities while taking us in a new direction, inevitably we are on a path of reduced scope in the context of Gemini's overall mission.

Still a Bright Future

Despite our budget setback, I remain very optimistic about Gemini's future. Our laser AO systems, featuring the world's only laser Multi-Conjugate Adaptive Optics system at Gemini South, will remain an essential arrow in Gemini's "quiver." Our workhorse optical imager/spectrometers will receive major upgrades with fully-depleted CCDs. The Gemini Near-Infrared Spectrometer (GNIRS, see article on page 37) is already resuming science operations. FLAMINGOS-2 will be brought on-line next year. The Gemini Planet Imager (GPI, see article on page 40) is about to enter its final integration phase. And we are about to launch the development of our next instrument: a high-resolution, optical spectrometer.

These are all signs of growth and advancement. These new capabilities will be rooted in a lower-cost, operational model which, while less robust than what we have had in the past, will be sustainable over the long haul. With the next generation of Extremely Large Telescopes many years away, the next decade of ground-based research will substantially be led by the current 8- to 10- meter-class facilities, of which Gemini will remain a vital member.

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

By David Lafrenière

First Directly Imaged Exoplanet Around Sun-like Star Confirmed

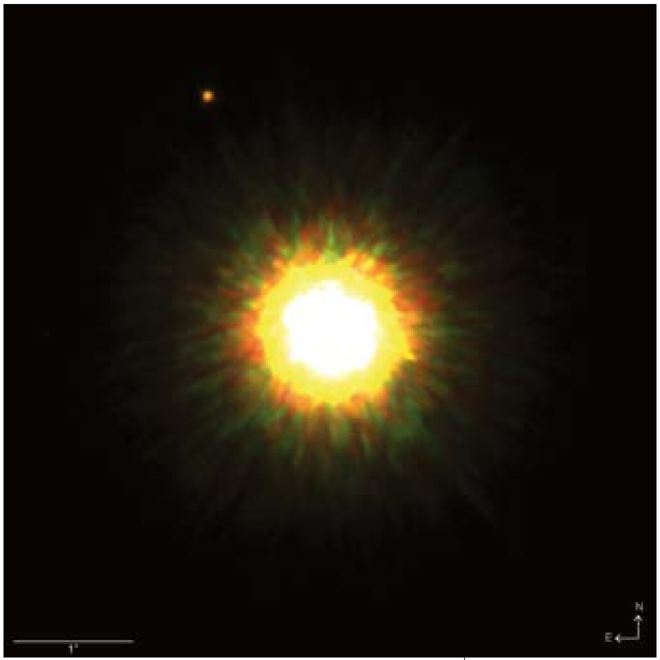

Figure 1.
Image of 1RXS J160929.1-210524 and its ~ 8 Jupiter-mass companion. This image is a composite of J-, H-, and K-band, near-infrared images obtained with the Gemini North adaptive optics system and the NIRI camera.

Discoveries of exoplanets have been occurring at an escalating pace for well over a decade now, with about 500 currently known. Still, as of only two years ago, no exoplanet had been imaged directly around a star. Fortunately, this situation suddenly changed in the fall of 2008, when four direct-imaging exoplanet discoveries were announced within only a few weeks of each other.

The first of these — made in the spring of 2008, using the Near-infrared Imager and Spectrometer (NIRI) and the Altair adaptive optics system of the Gemini North telescope — uncovered an 8 Jupiter-mass planet around the very young solar analog 1RXS J160929.1-210524 (hereafter 1RXS 1609, Lafrenière *et al.*). Although the planetary nature of the new object was clear, we were, at the time, a tad uncertain as to whether the planet was linked with the primary star; at least one or two more years of observations would be needed to fully confirm the discovery. As detailed below, this has now been achieved.

A few weeks after we announced our find, two other discoveries were reported simultaneously: a roughly Jupiter-mass planet orbiting just inside the dust belt of the star Fomalhaut (Kalas *et al.*), made with the Hubble Space Telescope; and three 7-10 Jupiter-mass planets orbiting the nearby young star HR 8799, jointly made with the Keck and Gemini North telescopes (Marois *et al.*). These announcements were quickly followed by yet another: the detection of an 8 Jupiter-mass planet in the circumstellar disk of the star β Pictoris, made using the Very Large Telescope (Lagrange *et al.*).

Our observation of 1RXS 1609 was actually part of a larger program to observe 85 stars in the Upper Scorpius association — a group of stars located about 500 light-years away. The association formed in a burst merely 5 million years ago. We targeted these stars precisely because of their young age: we wanted to study the multiplicity of stars almost immediately after they had formed, thereby gaining insight into the star-formation process; we were mostly looking for stellar, or brown dwarf, companions to our targets. Of course, detecting a planet would have been a delightful surprise, but it wasn't the primary goal of our study.

Our image of 1RXS 1609 (Figure 1) revealed a source lying only 2.2 arcseconds away (~ 330 astronomical units (AU) at the star's distance) and about 1000 times fainter. Given its faintness, a quick calculation revealed that, if this object were orbiting the star, it would most likely be a planet. To verify the nature of this source, we quickly requested Director's Discretionary Time to obtain additional imaging and spectroscopy in various near-infrared bands. Our request was granted, and the data came in promptly.

The relative brightness of the object in the different bands, and the features seen in its spectrum (Figure 2) — mainly absorption by water vapor and carbon monoxide — indicated it has a temperature of about 1800 Kelvin (1500° C) and a low surface gravity. This is exactly what we had hoped to find. The low surface gravity means that the object is larger than usual, which, in turn, means that it has not yet finished contracting under its own gravity. In other words, it is very young (which we also expected, because the star belongs to the 5 million year old Upper Scorpius association).

For an object so young, the temperature of 1800 Kelvin indicates a mass about eight times that of Jupiter, comfortably within the planetary regime (applying to objects with less than 13 times the mass of Jupiter). Thus, the new object is a young planet, seen on the sky only a "hair's width" away from a young Sun-like star.

At the time, we had no hard evidence, other than their proximity and common young age, that the two objects were linked to each other. The planet still could have been seen close to the star only by a chance alignment, meaning both objects were unrelated and traveling through space independently. Given the overall space density of objects in the Upper Scorpius association, however, the odds were largely in favor of a real connection. On that account, we decided to publish the result right away, in September 2008.

The news immediately engaged the public and media, and the picture of the star and planet quickly made it round the globe. Of course, a few skeptics asked for the proper confirmation — that both objects moved through space together, a signature of their gravitational bond.

Thus, for the past two years, we have been repeat-

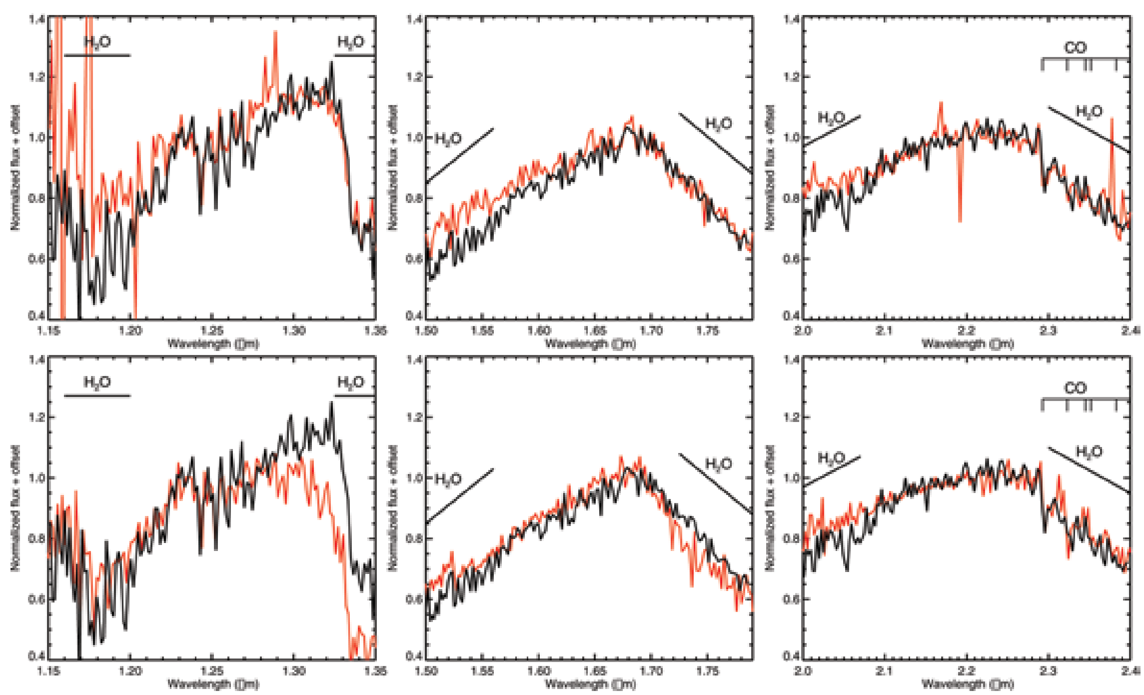

Figure 2.
The spectrum of the planet obtained with the NIRI and NIFS instruments at Gemini is shown in black. On the top row, the spectrum is compared with that of a young, slightly warmer, more massive, free-floating, brown dwarf that is also a member of the Upper Scorpius association (red, from Lodieu et al., *2008). On the bottom row, the spectrum is compared with a model spectrum of temperature 1800 K and low surface gravity (red, from DRIFT PHOENIX models, Witte* et al., *2009, Helling* et al., *2008).*

edly observing the 1RXS 1609 system with Gemini to precisely measure the relative positions of the planet and primary star as a function of time. And lo-and-behold, our monitoring confirmed that the planet is gravitationally "attached" to the star (see Figure 3). This confirmation secures the standing of exoplanet 1RXS 1609b among the first few to have been discovered around a star with direct imaging; notably, it's also the first exoplanet around a star to have its spectrum measured directly. The spectrum covers a wide range and will be extremely valuable for theorists to improve atmosphere models of young giant planets.

1RXS 1609b has the largest orbital separation currently known for an exoplanet (because other techniques tend to favor planet detection at closer distances to the primary star). Reciprocally, it is the least-massive companion known to a star at such a large orbital distance (because previous imaging observations could only detect more massive companions). It's too early to tell whether a planet with such a large orbital separation is wildly unusual, particularly at young ages and around a Sun-like star. But its very existence does pose some challenges to models of planet formation. In fact, the discovery of this planet has encouraged theorists to pursue new studies to find out how gas giants may form, or end up, in wide orbits.

The answers are already upon us, although they still face some hurdles. First, the standard mechanism for gas-giant formation — whereby they form within a circumstellar disk by first growing a solid core and then accreting large amounts of gas — cannot operate at separations of hundreds of AU: the orbital periods are too long, and the density of solid material within the disk is too low. This means that if the planet formed through this mechanism, it must have done so much closer in and somehow moved outward to a larger orbit. One possibility is that several gas giants formed at small separations, where the above mechanism works fine, but their mutual gravitational interaction eventually "kicked" one of the planets out. If this were the case, 1RXS 1609b would likely be ejected eventually from the system.

However, the planet could have formed through a different mechanism — by the rapid collapse of a part of the circumstellar disk under its own gravity, for example. There are important uncertainties associated with this model though, and it's unclear whether it can operate efficiently. But given the right conditions — namely, a massive, extended disk with low metallicity — it appears to be a viable scenario.

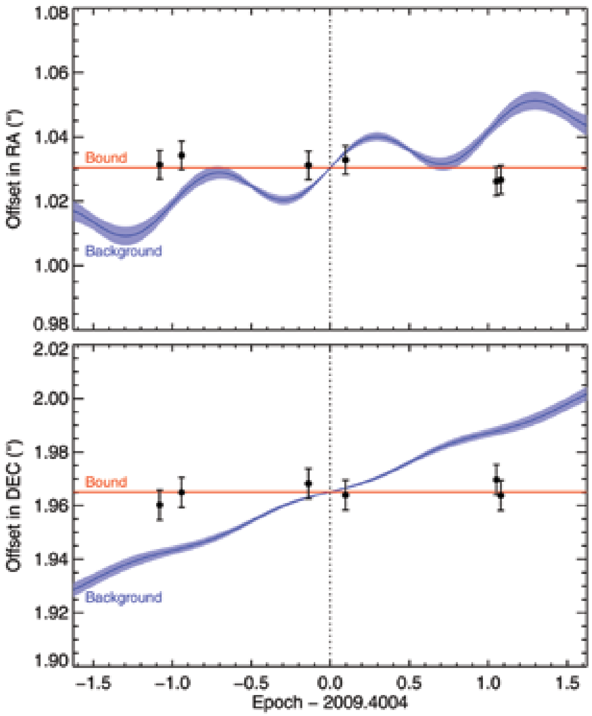

Figure 3. *Position of the planet 1RXS 1609b relative to the primary star as a function of time (black points). The relative position shows no change over time, indicating that the planet is bound to the star. Had the planet been a distant, unrelated background star, the relative position would have followed the blue curve. The RA and DEC plotted on the figure are coordinates on the celestial sphere similar to longitude and latitude, respectively, on the surface of the Earth.*

Another possibility is that the planet formed in the same manner as more massive, brown dwarf, or even stellar, companions to stars, through the fragmentation of a pre-stellar core. The difficulty here is explaining how one fragment ended up with so little mass compared with the other. Future observations of this planet will hopefully provide clues to help us elucidate its origin.

The discovery of 1RXS 1609b serves to show that planets can be found at locations relative to their host star where they were not expected, and that direct imaging is an essential tool for completely probing the diversity of exoplanets out there. With the Gemini Planet Imager (see article starting on page 40 of this issue) planned to start operation next year, as well as similar specialized instruments at other observatories, the coming years promise to be exciting. The many new planets likely to be found by direct imaging will greatly expand our views of the variety of alien worlds and help us understand how planetary systems form and evolve.

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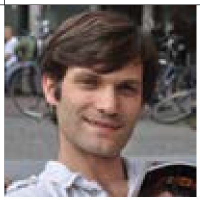
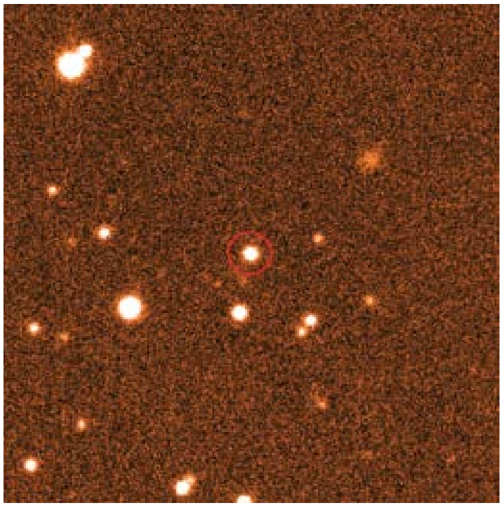
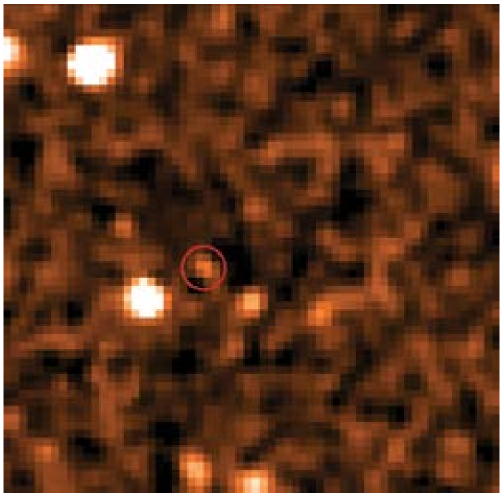


by Phil Lucas

Hunting for the Coolest & Nearest Brown Dwarfs

Figure 1. *(top) UKIDSS discovery image of the star field around UGPS 0722-05 (circled), taken in November, 2006. (bottom) The image of the same field taken with the 2MASS survey in 1998. The brown dwarf had moved 8 arcseconds in the intervening years.*





Perhaps the oldest purpose of astronomy was to establish the nature of the heavens near the Earth. In recent years, great strides have been made in discovering small dwarf planets and icy asteroids in the Kuiper Belt at the edge of the Solar System. Now the search is moving outward to the nearest stars. Astronomers have long suspected that some cool, isolated objects remain undiscovered in this realm within a few parsecs (pc) of the Solar System.

The most likely candidates to have remained hidden from view are brown dwarfs: objects with masses between those of planets and stars. Brown dwarfs probably form alongside stars in cold molecular clouds but do not accrete enough matter to allow hydrogen fusion. The best way to learn about the outcome of the formation process is to make a complete census of objects in nearby space, where it should be possible to detect even the dimmest brown dwarfs. This will tell us just how numerous brown dwarfs are in the Galaxy as a whole.

In the past decade prior to 2005, two cool dwarf stars had been discovered within 4 pc of the Sun, one of which has a brown dwarf companion, but no isolated brown dwarfs. Since then, British and European astronomers have been running a deep, wide-area survey of 10 percent of the entire sky with the United Kingdom Infrared Telescope (UKIRT) on Mauna Kea, adjacent to Gemini North. This survey (known as UKIDSS, for the United Kingdom Infrared Deep Sky Survey) has been detecting candidate cold brown dwarfs in the near-infrared, and then passing these findings on to larger telescopes (mainly Gemini, but also Subaru) for spectroscopic confirmation and analysis.

At the time of writing, UKIDSS has discovered about 100 T dwarfs within a few dozen parsecs of the Sun, as well as contributing to many other areas of astronomy. (T dwarfs, the coolest type of brown dwarfs presently known, are identified by strong absorption bands of methane that appear in their infrared spectra.) In recent years, this survey has been detecting ever-cooler T dwarfs, with surface temperatures of 600 K or less; most of the follow-up discovery spectra have come from Gemini.

Most of these new T dwarfs have been discovered by searching the sky at high Galactic latitudes — in other words, well away from the plane of our Milky Way Galaxy; T dwarfs are generally close enough to the Solar System that they can appear anywhere in the sky. This is fortunate because it's easier to search in sparsely populated star fields for rare objects than in the crowded Galactic plane.

However, UKIDSS does also survey the Galactic plane. In February 2010, the author (who is also the head of this Galactic Plane Survey) decided to search the archive of 600 million stars on the off chance that one of them would turn out to be a very cool brown dwarf. A careful search for objects with the characteristic infrared colors of the coolest T dwarfs turned up just one candidate: a fairly bright object with the catalog designation UGPS 0722-05, located in the constellation Monoceros.

UGPS 0722-05 was immediately queued for spectroscopy with the Near-infrared Imager and Spectrometer (NIRI) on Gemini North. The acquisition image showed that it had moved by 3 arcseconds in the three years since the UKIDSS image was taken; this made it possible to trace the motion back to 1998 — when the Two Micron All Sky Survey (2MASS, a less sensitive infrared survey of the whole sky) had imaged the field and weakly detected it as an uncataloged blip just above the noise level in the image (Figure 1).

The Gemini spectrum (Figure 2) also showed that it has stronger absorption features of methane and water vapor than any other previously observed brown dwarf. It was therefore provisionally classified as a T10 dwarf, to distinguish it from the warmer T dwarfs with spectral types T0 to T9. In addition, the spectrum revealed a narrow absorption feature at a wavelength similar to a feature in Jupiter's atmosphere.

This unidentified feature has only been seen very weakly in two other very cool T dwarfs. If this feature is detected in even cooler brown dwarfs after they are discovered, then it might form the basis for a new spectral type, provisionally dubbed "Y dwarfs." This would extend the existing classification sequence for stars and brown dwarfs, which, in order of decreasing temperature, uses the letters O, B, A, F, G, K, M, L, and T.

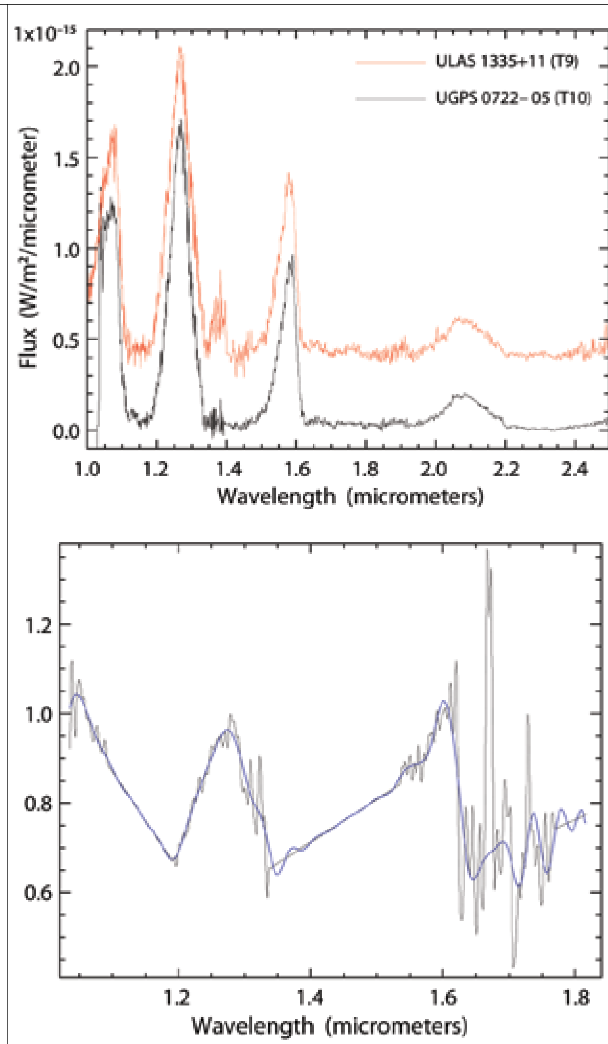


Figure 2.
(top) Gemini spectrum of the T10 dwarf UGPS 0722-05 (black line). One of the three known T9 dwarfs is shown in red for comparison. (bottom) A ratio spectrum of the T10 dwarf divided by the average of the three T9 dwarfs. It shows more clearly that the water and methane broad-absorption troughs to either side of the peaks at 1.27 and 1.59 microns are deeper in this object. The spectra are reproduced from Monthly Notices of the Royal Astronomical Society Letters.

The next step was to determine the distance to UGPS 0722-05. It seemed likely to be nearby, given that it is relatively bright despite having a spectrum of a very cool object. By measuring the trigonometric parallax over the following two months with UKIRT, aided by combining these measurements with the existing UKIDSS and 2MASS detections, the distance was found to be 4 pc (with an uncertainty of 0.5 pc that will be reduced by future measurements). This showed that UGPS 0722-05 is the nearest isolated brown dwarf, lying among the nearest 25 or so systems to ours.

Further measurements of the infrared flux at longer wavelengths were obtained with the T-ReCS spectrograph on Gemini South (via an allocation of Director's Discretionary Time) and the orbiting Spitzer Space Telescope (Figure 3). These measurements confirmed the exceptionally low temperature implied by the near-infrared spectrum and enabled a good estimate of its total luminosity over all wavelengths. The luminosity is less than

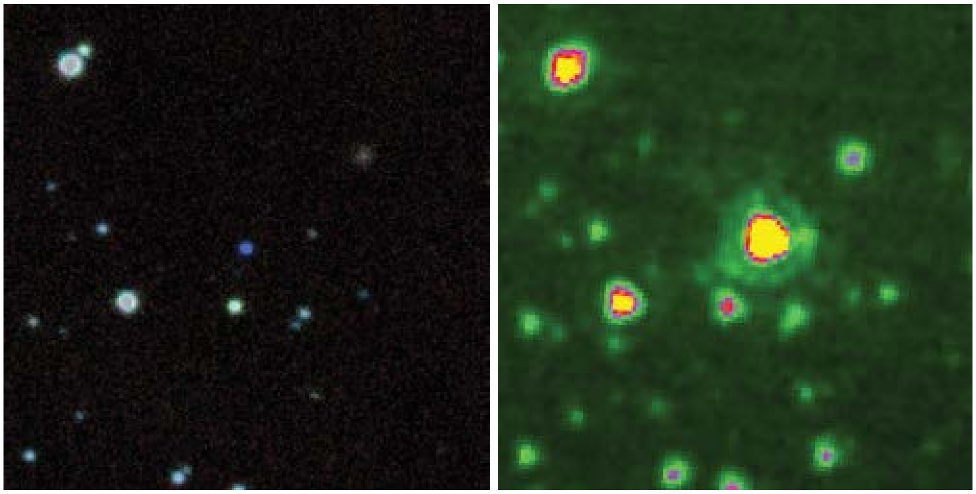


Figure 3. *(left) Near -infrared, three-color image showing UGPS 0722-05 near the center. The blue color is characteristic of T dwarfs with strong absorption by methane. (right) An image at longer wavelengths taken with the Spitzer Space Telescope. Here the object appears as the brightest source in the field, and it is seen to have moved slightly to the right of center.*

one-millionth that of the Sun, and the temperature is only about 520 K (250° C) — the lowest temperature yet recorded for a body outside the Solar System. At such low temperatures, astronomers do not yet have good calculations of what the atmospheres of hydrogen- and helium-dominated bodies like brown dwarfs should be like. These discoveries are opening up a new area for atmospheric physicists to explore.

Theoretical models of how brown dwarfs cool indicate that UGPS 0722-05 has a mass only about 5 to 15 times greater than that of Jupiter, putting it on the borderline between brown dwarfs and objects that might be thought of as free-floating "planets." Such low masses are a surprisingly common characteristic of the coolest T dwarfs previously found in the UKIDSS survey. This may be telling us something very interesting about the number of brown dwarfs that form with very low masses, or it might indicate a problem with the evolutionary models used to calculate how brown dwarfs cool down over time.

The future is now looking very bright for further discoveries of even cooler brown dwarfs in the next few months, some of which may be even closer to the Solar System. Several new facilities have begun even more sensitive searches of the whole sky, the most important of which is the NASA Wide-field Infrared Survey Explorer (WISE) satellite. Preliminary results from WISE, presented at the "Cool Stars 16" conference at the University of Washington in Seattle on September 2, 2010, suggest that discoveries of even cooler objects may be published shortly. Meanwhile the Visible and Infrared Survey Telescope for Astronomy (VISTA) and Panoramic Survey Telescope & Rapid Response System (Pan-STARRS) 1 telescopes are also conducting deep surveys from the ground to find even more candidates. The race is heating up!

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by John Tobin

Probing the Morphology of an Extremely Young Circumstellar Disk

In recent years, it has become clear that when planets form around stars, they do so out of a circumstellar disk of gas and dust. And while details of how these disks initially form and their properties have long remained elusive, new observations from the Gemini North telescope of a young protostar, named L1527, have helped shed more light on these mysteries.

The earliest stage of the star-formation process, the Class 0 phase, begins with a slowly rotating, dense clump of cold gas and dust. As the cloud contracts under its own gravity, a protostar forms at the center. Soon, the cloud's rotation naturally causes the remaining gas and dust to collapse into a disk around the protostar, rather than falling directly onto it; material from the collapsing envelope must now pass through the disk before arriving at the protostar.

In the Class 0 phase, little or no light from the protostar is detected shortward of ~ 10 microns — not because newborn protostars are faint, but because the infalling envelope of gas and dust is so opaque; this makes the youngest of these disks difficult to study. Fortunately, during the early stages of star formation, the bipolar outflow from the central protostar and disk carves cavities out of the envelope, creating scattered-light (reflection) nebulae visible in the near- to mid-infrared (1-8 microns).

One of the nearest Class 0 protostars, L1527 is located in the direction of Taurus, at a distance of about 140 parsecs. Because of its proximity, this is a popular target for studies of low-mass, star formation. In our initial study of mid-infrared, IRAC images from the Spitzer Space Telescope, we found bright, bipolar outflow cavities extending to ~ 10,000 astronomical units (AU) in radius. A large-scale (~ 1000 AU) dark lane appears to separate the cavities, giving rise to a tight "waist" in the center. Within the dark lane from 3.6 to 8 microns, we also found a point-source (as shown in Figure 1). We can explain both the "waist" and point-source emission with a model that has a narrow outflow cavity at small radii (< 100 AU) before it

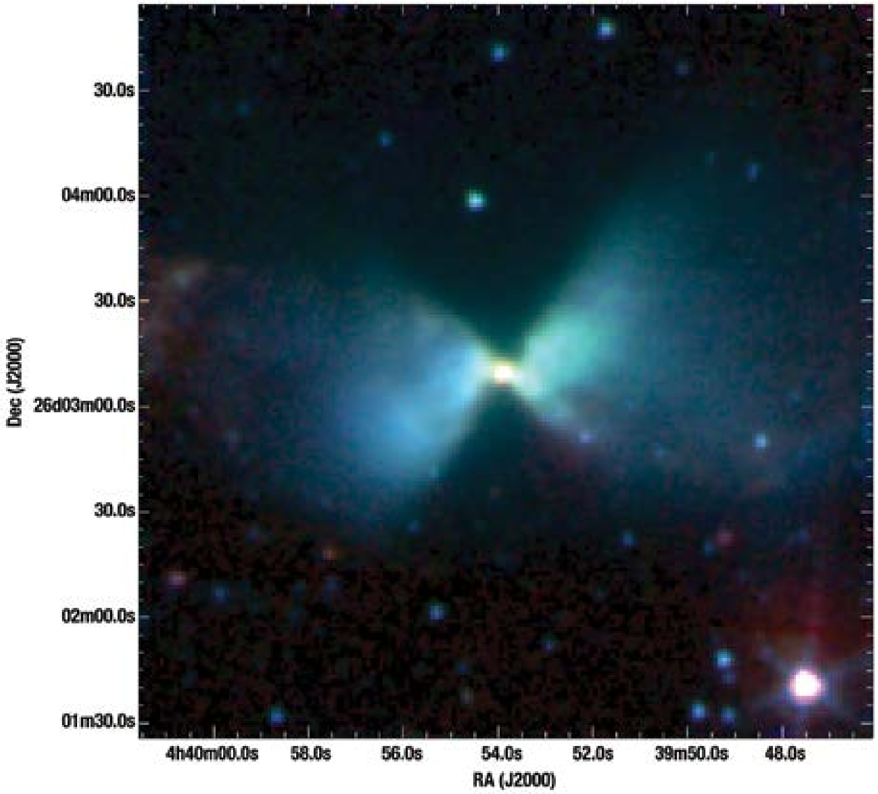

Figure 1.
False-color, IRAC image of L1527 taken with the Spitzer Space Telescope; note the unresolved point-source at the center. Blue: 3.6 microns, Green: 4.5 microns, and Red: 8.0 microns. Image box is 200 arcseconds on a side, corresponding to 28,000 AU at a distance of 140 parsecs.

fans out widely beyond 100 AU. However, at high resolution, our model appears very much like the scattered-light surface of a large disk.

Gemini NIRI Observations

To test this model and explore what was really going on inside L1527, we used the Near-infrared Imager and Spectrometer (NIRI) on Gemini North in L′-band (3.8 microns). The camera in f/14 mode has a 0.049 arcsecond per pixel scale; but we only used the central 512 × 512 pixel area of the detector for faster read-out. In this configuration, the sky background did not saturate the detector. We observed with a 5-point dither pattern and selected a nearby star for tip-tilt correction and guiding. No adaptive optics were used in these observations; however, the natural seeing conditions yielded an image with 0.3 arcsecond (42 AU, at the distance of L1527) resolution, representing 85 minutes of integration time.

The images of L1527 at L′-band and 3.6 microns are shown in Figure 2. The IRAC image clearly shows the point-like structure appearing in the center of the envelope between the large outflow cavities. The Gemini L′ image resolves that point-like structure into a compact, bipolar reflection nebula. The two lobes are separated by a narrow dark lane ~ 0.45 arcsecond (60 AU) wide, consistent with a circumstellar disk shadow. The total extent of the bipolar structure in the direction of the outflow (east-west) is ~ 2.5 arcseconds (350 AU) and ~ 1.8 arcseconds (250 AU) in width.

The L′ image reveals structure similar to that of the near-infrared images of more evolved Class I protostars; generally, these stars have a smaller, less-opaque envelope than the younger Class 0 objects, which makes their disks easier to see at shorter wavelengths. However, this is the first time such a detailed image has been captured of a Class 0 protostar. The relative brightness of the two lobes indicates that L1527 is not exactly edge-on, but rather tilted by a few degrees. In the Gemini image, we also see extended, low-surface-brightness, outflow cavity emission extending away from the inner envelope. The cavity is quite narrow until about 6 arcseconds (840 AU) from the center, at which point it expands rapidly to very wide angles.

Modeling

To interpret the observations, we used a Monte Carlo radiative-transfer code (written by Barbara Whitney) and constructed a mock-up of the protostellar system. The model has a central protostar surrounded by a disk, and an infalling envelope

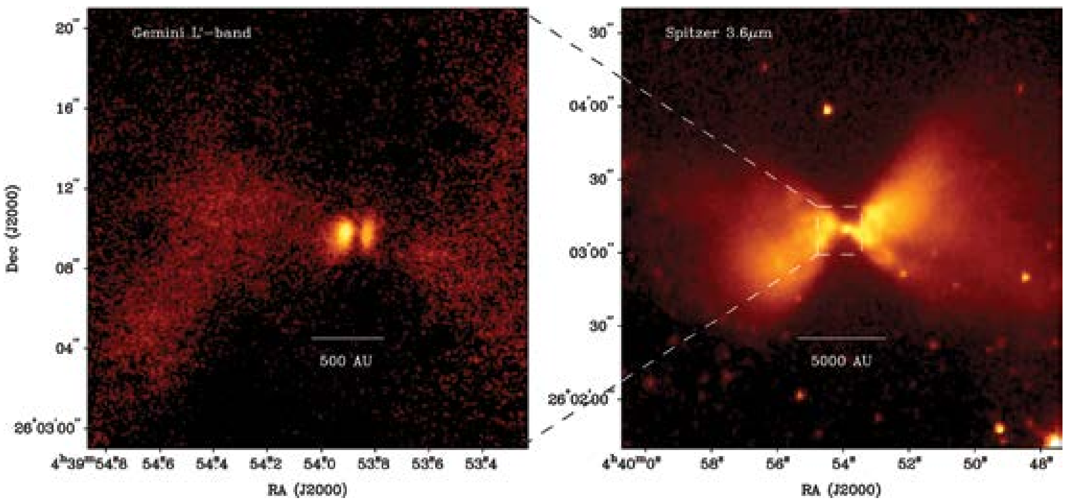

Figure 2.
The left panel shows the L' image of L1527 taken with Gemini North, which resolves the point source from the IRAC 3.6-micron image (right panel), revealing a disk.

with outflow cavities. The central protostar and disk emit photons — randomly drawn (hence Monte Carlo) from the assumed protostellar spectrum — which then interact with the surrounding envelope and disk. The photons are scattered and/or absorbed by dust grains in the envelope, which are defined by a power-law distribution with sizes up to 1 micron.

In our initial study, we inferred that the apparent point source at 3.6 microns was, in fact, a bipolar reflection nebula, with the protostar hidden by extinction. To create this structure, we modified the outflow cavities to be narrow at the base (< 100 AU) but rapidly widening outside 100 AU. Comparing the top and middle rows of Figure 3 shows that our prediction was qualitatively correct. De-

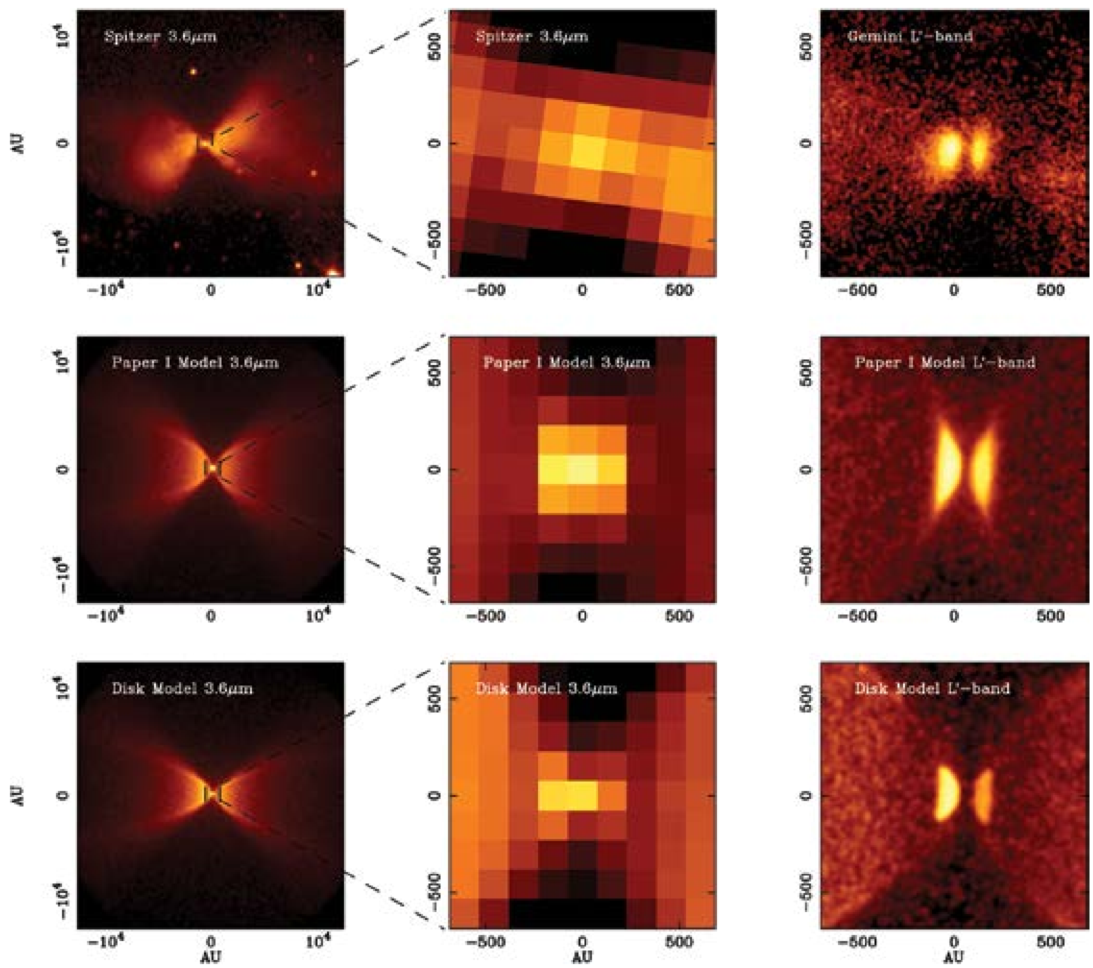

Figure 3.
Top row: Observations of L1527 from Spitzer and Gemini. Middle Row: Initial model of L1527 without any knowledge of L1527 at high resolution. Bottom Row: Model of L1527 with a 200 AU disk, better reproducing the new Gemini data.

spite our initial model not truly being a disk, the outflow cavity shape adopted appears to mimic the upper layers of a flared disk.

With the detailed Gemini image, we found disk parameters yielding scattering surfaces comparable to the observations. The model uses a parametrized disk with a power-law, radial-density profile ($\rho \propto R^{-\alpha}$) and power-law flaring ($H \propto R^{\beta}$), where H is the vertical scale height, and the disk's Gaussian vertical structure is assumed. Our best fitting model had an outer radius of 190 AU, and H, at the outer radius, was 82 AU. The disk had a very steep radial-density profile ($\rho \propto R^{-3}$), a high degree of flaring ($H \propto R^{1.27}$), and a mass of only $0.005M_{Sun}$. The bottom panels of Figure 3 show that this model agrees quite well with the observations.

The Class 0 Disk

The Gemini observations and subsequent modeling strongly indicate that we found a large circumstellar disk around L1527. This is the first time that a disk has been clearly imaged in scattered light around a Class 0 protostar. The large radii needed to model L1527 emphasizes the fact that disks with large radii are able to form quite rapidly during the Class 0 phase, with radii comparable to more evolved Class II disks in Taurus; Class II objects represent a later phase of evolution where the envelop has dissipated and there is only a disk left around the young star.

L1527 resembles the images of disks around more evolved young stars such as HH30 and HV Tau C; however, the scattered-light surface and dark lane of L1527 is about a factor of two thicker. The difference between the disk around L1527 and older disks is that dust growth and/or depletion in upper disk layers (dust settling) relative to interstellar medium conditions is well advanced. Dust settling, in particular, causes the scattered-light disk and dark lane to be much thinner than we see in L1527. The contrast with more evolved objects suggests that the L1527 disk has had very little dust evolution, consistent with its youth.

Overall, the high-resolution, L' imaging of L1527 with Gemini demonstrates that much can be learned of inner-envelope structure and newly forming disks with high-resolution, scattered-light observations of Class 0 protostars. The observations and subsequent modeling clearly indicate that our images have captured a glimpse of a proto-planetary disk forming around this young star, showing that the ingredients for planet formation are already in place at a very early time in protostellar evolution.

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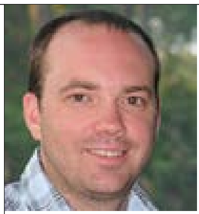

by Patrick Dufour

Probing Rocky, Extrasolar Material with White Dwarf Stars

In recent years, we have seen a spectacular increase in the number of planets discovered outside our Solar System (about 500 as this article goes to press), most of which are Jupiter-like gas giants. It's certainly only a matter of time before exoplanet researchers succeed in finding Earth-like planets. But the techniques used to find these worlds (radial velocity, transit, or direct imaging) provide practically no information about their bulk chemical composition (at best, only a mean density can be estimated).

Hence, until we find a way to travel on-site and take soil samples, there is little hope of obtaining detailed elemental composition of small rocky planets and/or planetesimals orbiting distant stars. However, we must not necessarily give up on trying to get any useful information about them. Indeed, as Gemini's contribution to discoveries described in this article will show, recent advances in the relatively small field of white dwarf research have revealed that studies of cool, metal-enriched degenerate objects may offer a unique glimpse into the bulk composition of extrasolar material. How is that possible? Let's first begin with a short introduction on white dwarf stars.

A white dwarf is the final evolutionary state reached by all stars not massive enough to explode as supernovae. After going through mass-loss episodes in the red-giant phases, these low-mass stars ultimately run out of thermonuclear fuel and end up as compact objects known as white dwarfs. Most have more than 99 percent of their mass composed of carbon and oxygen, the products of hydrogen and helium nuclear burning.

The processes of nuclear fusion and mass loss do not destroy or evaporate 100 percent of the hydrogen and helium that was initially present in the star at birth. Since the surface gravity of a white dwarf is extremely high (~ 10,000 times that of the Sun), light elements, such as hydrogen and helium, quickly float to the surface in large enough quantities to form an optically thick photosphere. Meanwhile, heavier elements sink rapidly out of sight. Hence, the majority of white dwarfs mainly show a pure hydrogen or helium surface composition.

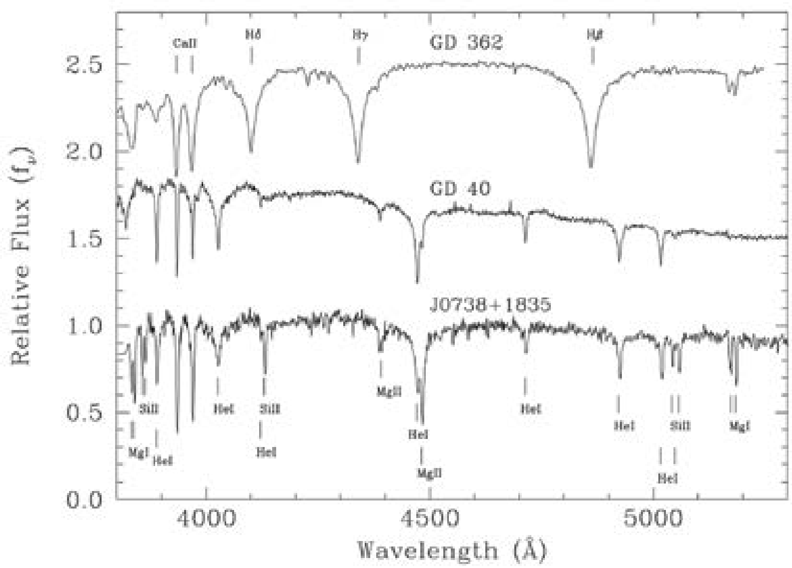

Figure 1. *Medium-resolution spectra of J073842.56+183509.6, GD 40, and GD 362. GD 362 spectrum is taken from Gianninas et al. (2004), while the other two spectra are from SDSS.*

However, there exists a family of cool white dwarfs, with a significant amount of metals (Ca, Mg, Fe, *etc.*) polluting each member's photosphere. Since these stars are relatively old (several hundred million to a few billion years), heavy elements have had more than enough time to sink below the photosphere; note that radiative levitation is completely negligible for these cool stars. Thus, each member's atmosphere must have been contaminated only recently by an external source.

For many years, the commonly accepted explanation was that these stars had accreted heavy material by passing through dense patches or clouds in the interstellar medium (ISM). But this scenario has several drawbacks — the most severe being the absence of a correlation between the position of metal-rich white dwarfs and known dense regions of the ISM.

A new scenario has recently gained strength following the serendipitous discovery of the extremely metal-rich white dwarf GD 362. In 2005, infrared observations with Gemini North showed that this star has a large infrared excess, best explained by the presence of a dust ring comparable in size to Saturn's rings. It is now believed that this dust ring is the result of the tidal destruction of a large rocky body that ventured too close to the white dwarf — most probably an object from an asteroid belt, or a small rocky planet, whose orbit was gravitationally perturbed by a larger nearby object.

High-resolution, spectroscopic observations of GD 362 have also revealed that the elemental abundance pattern observed in the star's photosphere is remarkably similar to that of the Earth-Moon system. Apparently, unique insights into the bulk chemical composition of extrasolar material may be revealed through metal-polluted white dwarfs, providing data that cannot be obtained in any other way.

In recent years, infrared observations of many of the most metal-rich white dwarfs have revealed the presence of debris disks around many other objects, and sometimes even silicate emission features. This accumulation of evidence has led to a paradigm shift in favor of a picture where most, if not all, cool white dwarfs with metal lines acquired their photospheric elements from circumstellar rocky bodies.

Unfortunately, the number of white dwarfs amenable to a full, detailed elemental analysis is relatively low, especially if one relies only on observations in the optical. Indeed, most metal-rich white dwarfs show only one or two elements in their optical spectra, hardly enough to infer anything about planet composition. Besides, such an analysis by itself is not sufficient. One cannot simply relate the observed photospheric abundances to that of the accreted material, because the diffusion timescales of the various elements are different; it's not known how long ago the accretion process stopped.

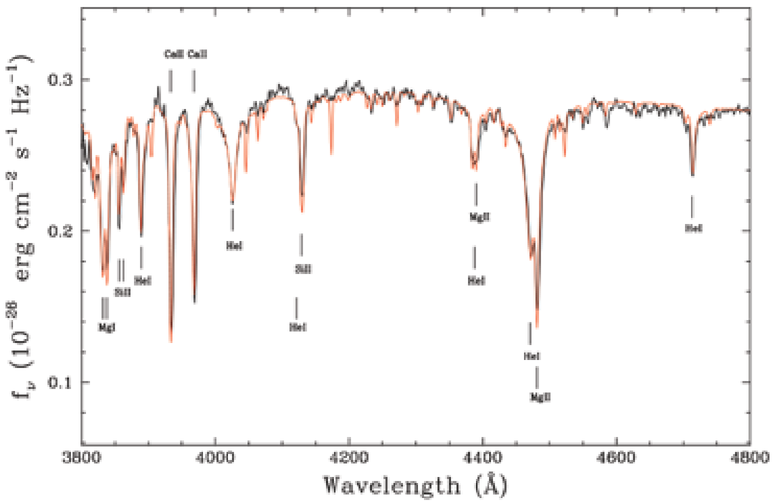

Figure 2.
MMTO spectrum (in black) and best-fit model (red line) of SDSS J073842.56+183509.6. The strongest lines are indicated by tick marks. All the other numerous, non-identified lines are from iron. The fit of the star yields an effective temperature of 13,600 K, 0.91 solar mass, 0.97 Earth radius, and a distance of 136 parsecs (or 444 light-years). The determined abundances are log H/He = -5.7, log O/He = -4.0, log Mg/He = -4.7, log Si/He = -4.9, log Ca/He = -6.8, and log Fe/He = -5.1.

Only when a so-called "steady state" is reached (where accretion and diffusion proceed at the same rate) can the observed photospheric abundance pattern be related to that of the accreting material; under these conditions, the abundance ratio of two elements observed at the photosphere is simply the abundance ratio of the accreted material multiplied by the ratio of the diffusion timescales.

That a steady state has been reached can be safely assumed only when a large infrared excess is still present, since this indicates that a debris disk is currently feeding the white dwarf's surface with heavy elements. Cool white dwarfs showing the most extreme metal pollution and a large infrared excess thus represent our best hope of learning anything useful about rocky extrasolar material. Every object showing these characteristics certainly deserves proper scrutiny.

Detailed analyses of high-resolution observations performed on two of the most metal-rich white dwarfs (GD 362 and GD 40) provided relative abundances of 16 and 9 elements, respectively. Interestingly, those analyses are remarkably consistent with the idea that the source of the material is asteroids and/or planetesimals with compositions similar to that of bulk Earth. Following these pioneering studies, it now appears to be of the utmost importance to increase the sample of similar white dwarfs in order to potentially learn more about ancient planetary systems.

After careful inspection of thousands of spectra from the Sloan Digital Sky Survey, one such object has recently caught our attention: SDSS J073842.56+183509.6. This star has a remarkable spectrum with many strong metallic lines. When we compare its spectrum to that of similar, medium-resolution observations of GD 362 and GD 40 in Figure 1, the uniqueness of this object is striking. (Note in particular that the MgII 4481 line is even stronger than the HeI 4471 line, a unique feature among metal-polluted white dwarfs.) Since the myriad elements uncovered in GD 362 and GD 40 were found only when higher-resolution observations became available, a close look at Figure 1 leaves little doubt of the extraordinary potential of future high-resolution spectral studies of SDSS J073842.56+183509.6.

As a first step in our effort to understand this remarkable object, we obtained a medium-resolution, high signal-to-noise ratio observation of the star with the 6.5-meter MMT Observatory (MMTO) atop Mount Hopkins, Arizona. Our best solution, obtained from detailed, model-atmosphere fitting, is presented in Figure 2 as a red line. Our analysis shows that SDSS J073842.56+183509.6 is a ~ 595 million year old white dwarf situated ~ 136 parsecs away, with an

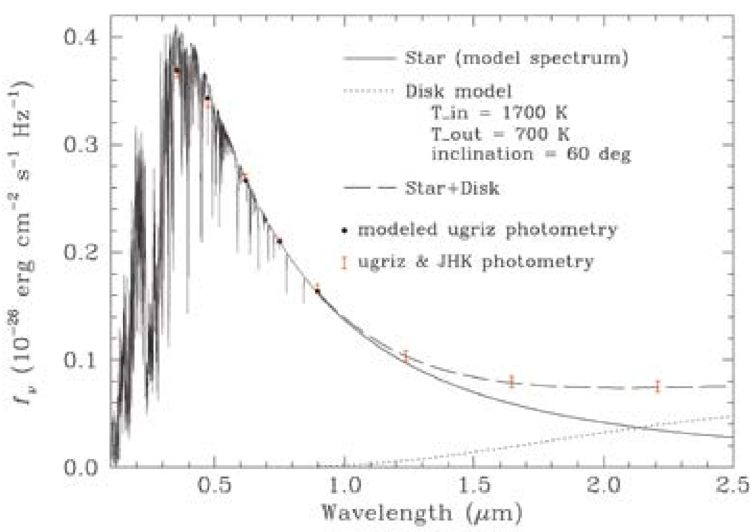

Figure 3.
Photometric measurements using NIRI in the infrared, the Sloan Digital Sky Survey in the optical, and GALEX in the ultraviolet, compared to the best models of the star and the debris disk. The disk is most apparent at the longer wavelengths (above 1 micron) that NIRI measures.

effective temperature of ~ 13,600 K and a mass of ~ 0.91 M_{Sun}. Five heavy elements (O, Mg, Si, Ca, and Fe) are clearly detected (with a few more being uncertain).

The proportion between these elements is very similar to that of GD 40. Given that early lower-resolution observations of GD 362 and GD 40 initially showed the presence of only three metals, future high-resolution observations of SDSS J073842.56+183509.6, which we hope to obtain in early 2011, are expected to reveal an extremely rich abundance of heavy elements.

Next, we verified whether this object harbored the signature of a debris disk. This task was accomplished by obtaining JHK photometry using NIRI on the Gemini North telescope. Our observations, presented in Figure 3, clearly show that the infrared photometry is in excess of that expected from the white dwarf photosphere alone. This excess is best explained by the presence of a warm inclined debris disk, which indicates a currently ongoing accretion process and that the steady state has most probably been reached. When high-resolution spectroscopy becomes available, a more detailed analysis should allow us to determine the composition of the accreting body with unprecedented accuracy.

Another interesting quantity obtained from our modeling is the total amount of heavy elements present in the outer layers of the star. Indeed, by combining the mass of the helium convection zone (where the elements are homogeneously mixed) from evolutionary models with the measured abundance of each element with respect to helium, we find at least some 4.3×10^{23} grams of material in the photosphere of this star.

Since an unknown quantity of metals has probably sunk out of sight already, and that an unknown amount of material is present in the disk, it is safe to assume that the object responsible for all the features observed in SDSS J073842.56+183509.6 was at least as large as the dwarf planet Ceres, the largest body in the Asteroid Belt. This is the largest amount of heavy material that has ever been found in a white dwarf photosphere.

Slowly but surely, the sample of interesting white dwarfs suitable to such detailed analyses is growing. While it is too soon to start drawing conclusions about circumstellar objects that have survived the later stages of stellar evolution, a few more years of metal-rich white dwarf research will undoubtedly fill some gaps in our knowledge about old planetary systems. It is now estimated that perhaps as much as 30 percent of white dwarfs are orbited by circumstellar material. All we need to do is to identify the best candidates, follow them up with infrared and ultraviolet observations, and learn as much as we can from the patterns that emerge.

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by Eleazar R. Carrasco and Percy L. Gomez

ESO 146-IG005: The Most Massive Galaxy in the Local Universe?

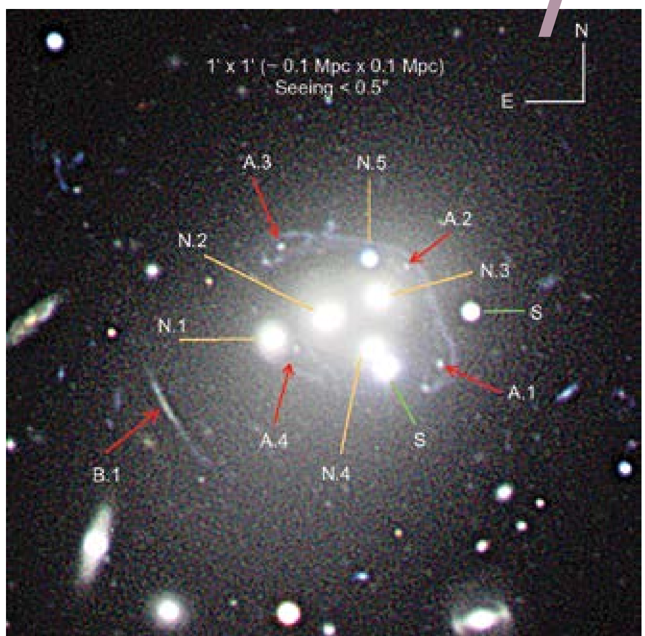

Figure 1. *Color-composite image (g', r', and i') of the multi-component BCG in Abell 3827. The five galaxies that form the BCG are labeled N.1 to N.5. The strong gravitational lensing features are also seen in the image.*

Rich, massive galaxy clusters are remarkable laboratories to study how galaxies form and evolve. Their cores are expected to host the strongest dynamical evolution, because they harbor the densest environments a galaxy can inhabit. Indeed, we find the brightest cluster galaxies (BCGs) at their centers. Among these, the D or cD types are the most massive and luminous in the universe.

William Morgan introduced the type D classification 52 years ago. It's a system showing rotational symmetry and an extended envelope, but no pronounced spiral or elliptical structure (Morgan, 1958). Six years later, Matthews, Morgan, and Schmidt (1964) introduced the cD galaxy — a sub-class of particularly luminous D galaxies. (Additional information about these classification systems can be found in van den Bergh, 1998.)

The cD galaxies have elliptical-like cores and very extended luminous halos, which are not necessarily smooth; they also contain multiple or complex nuclei. These galaxies often reside close to the peak of the diffuse X-ray emission, and their rest-frame velocities could have small offsets from those of their host clusters. This suggests that the formation of the BCGs might be distinct from galaxy evolution in general and could be linked to the formation and evolution of the clusters themselves.

Understanding how BCGs form and evolve became one of the most important topics in extragalactic astronomy during the last decade. Early theoretical work suggested that tidal stripping or dynamical friction ("galaxy cannibalism") mechanisms might be responsible for their formation. The problem with these mechanisms is the low probability (cross-section) of galaxy-galaxy encounters in a virialized galaxy cluster core, given the large galaxy velocity dispersion (~ 1000 kilometers per second (km/s)). However, dynamical friction or "cannibalism" may be responsible for forming the diffuse and large stellar envelopes observed in cD galaxies.

Recent works have shown that BCGs are likely formed by dissipationless or "dry" mergers (a process that does not involve a large amount of gas) of smaller, early-type galaxies (*e.g.* Bell *et al.*, 2006; de Lucia and Blaizot, 2007). These dry mergers are thought to be the primary mechanism through which massive galaxies grow from z ~ 1 to the present day; they continue populating the upper end of the mass function without changing the overall mass density of elliptical systems.

Some authors have pointed out that the merger rate increases with the stellar mass and age of galaxies. Therefore, if this is the case, we would expect to find a large fraction of major dry mergers in the nearby universe. Indeed, dry major mergers are not rare in the local universe; Liu *et al.* (2009) noted that ~ 4 percent of the BCGs show ongoing evidence of mergers. In addition, numerical simulations performed by Khochfar and Silk (2009) have shown that ~ 10-20 percent of these massive galaxies have undergone a dry merger in the last gigayear.

From an observational point of view, our understanding of BCG formation is limited by the small number of multiple galaxies at the initial merging stage that we have actually observed in detail. Only a small number of these systems have been identified, and only within clusters at moderate redshift (z ~ 0.2 – 0.5). In this context, the discovery of a multi-component BCG in the core of galaxy cluster Abell 3827 provides a special opportunity to study the formation of a massive elliptical in more spatial detail than it is possible for more distant examples.

Abell 3827 and Its Central Galaxy

Abell 3827 is one of the most X-ray luminous galaxy clusters in the nearby universe (L_X=4.7 × 10^{44} erg/s in the 0.1 - 2.4 keV band). And the BCG located at its core (ESO 146-IG 005) — a supergiant elliptical galaxy that appears to be in the throes of devouring at least five other galaxies — is perhaps the most extreme example of ongoing galaxy cannibalism known in the local universe. The galaxy's giant asymmetric halo extends for more than 1 arcminute (~ 100 kiloparsecs (kpc) at the distance of the cluster) and provides additional evidence of one or more recent major mergers.

One of the most impressive signatures of this supergiant galaxy is the presence of features arising from strong gravitational lensing. Most prominent is the magnified ring-shaped configuration of four, similar-shaped images around the central galaxy (labeled A.1 to A.4 in Figure 1). A thin, tangential arc (B.1) is also seen at ~ 20 arcseconds southeast from the central galaxy. These features provide a unique possibility to study the mass distribution and the evolution of BCGs in unprecedented detail.

Observations

We used the Gemini Multi-Object Spectrograph (GMOS) at Gemini South to obtain multi-band imaging (g', r', and i') and multi-object spectroscopy of the galaxies in the central region of Abell 3827 to achieve four main objectives: 1) to confirm spectroscopically that the five "nuclei" of the central galaxy constitute a bound system, rather than a chance superposition of objects; 2) to determine initial conditions for modeling the evolution of the system (to test whether it is the progenitor of a normal cD-like giant elliptical galaxy); 3) to derive the total mass profile of the cluster with multi-object spectroscopy, including the presence (or absence) of a cuspy dark matter halo profile; and 4) to search for fine structure (such as tidal streams and ripples) and localized star formation, due to interaction between the central galaxy and its victims.

The multi-band images were obtained under excel-

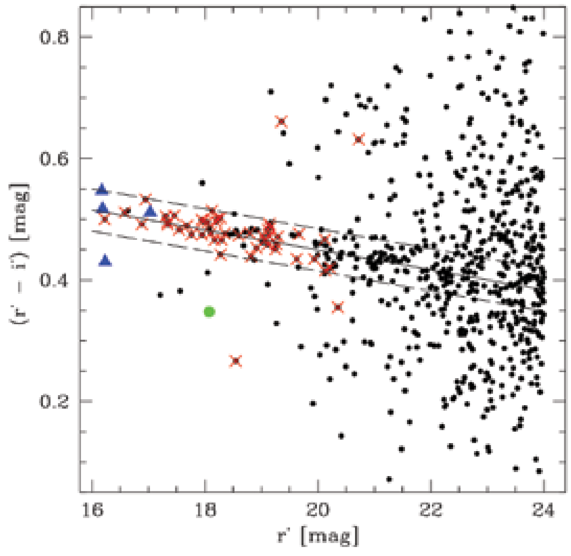

Figure 2.
Color-magnitude diagram for all galaxies with r' brighter than 24 mag. The red crosses are galaxy members of the cluster. The blue triangles are the central ellipticals that are bound (N.1 to N.4). The green circle indicates the location of the background galaxy N.5.

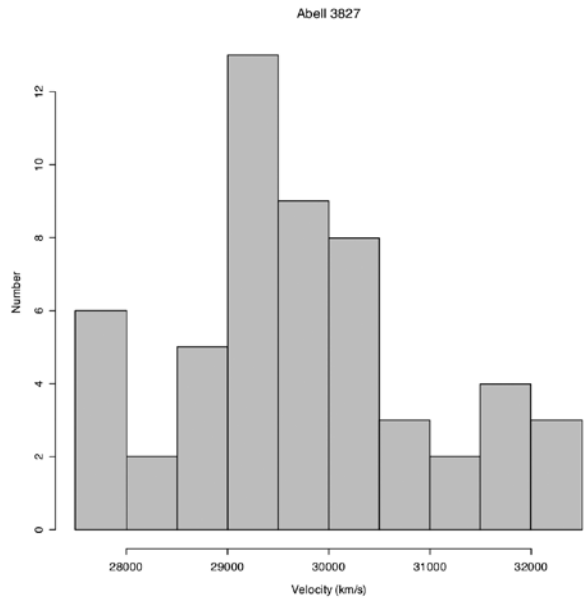

Figure 3.
Histogram of the velocity distribution of the 55 galaxy members of the cluster.

lent conditions, with a seeing between 0.4 and 0.6 arcsecond. The images were used to select the candidates for spectroscopic follow-up. Radial velocities were measured for 67 galaxies. We derived an average velocity for the cluster of 29,700 ± 160 km/s, and a line-of-sight velocity dispersion of 1100 ± 130 km/s with 55 member galaxies. At a radius of 0.3 megaparsec (Mpc), the estimated virial mass is 3.9×10^{14} solar masses. Figure 2 summarizes our results in the form of a color-magnitude diagram.

Using multi-slit spectroscopy, we confirmed membership for four of the central elliptical galaxies (blue triangles in Figure 2). Three of the galaxies have similar colors, and the velocities are consistent with the systemic velocity (within 300 km/s for N.1, N.2, and N.3). The galaxy N.4 has a radial velocity ~ 1000 km/s higher than the systemic velocity. Galaxy N.5 (green circle), with a radial velocity of 33,820 km/s may not be in the cluster, but in the background; an interesting feature of this galaxy is that it has an elliptical shape and no signs of emission lines in the spectrum (the galaxy has a very blue color).

Figure 3 shows a histogram of the velocity distribution for the 55 members of the galaxy cluster located within 0.3 Mpc. The distribution of the velocities in the histogram suggests the presence of one or more structures along the line-of-sight. In order to investigate the structures, we used the KMM test, which is appropriate to detect the presence of two or more components in an observational data set. The results yield strong evidence that the velocity distribution of galaxies in the velocity interval given in Figure 3 is at least bimodal, rejecting a single Gaussian model at a confidence level of 99.7 percent.

Moreover, the KMM algorithm splits the galaxy ensemble into two structures: one located at 29,560 km/s (40 galaxies), and another located at 31,810 km/s (9 galaxies). This bi-modality in the velocity distribution suggests that the cluster Abell 3827 is presently merging. In comparison, recent X-ray analysis based on XMM-Newton observations by Gomez *et al.* (2010) shows that the cluster has a dynamically relaxed appearance. This is not surprising since X-ray observations are not sensitive enough to detect more than one structure along the line-of-sight. This result could help us to explain the excess of mass in the BCG. We discuss this point in more detail below.

Mass Determination Using Strong Lensing Modeling

The superb image quality delivered by GMOS allowed us to detect several strongly lensed features around the cD galaxy. Spectroscopic follow-up of the thin tangential arc (B.1 in Figure 1) and highly magnified, ring-shaped configuration of four images (A system) around the cD galaxy allowed us to determine the redshift of the lensed sources. We derived a redshift of 0.244 for the ring-shaped configuration and a redshift of 0.408 for the tangential arc.

To produce the strong lensing features seen in Figure 1, the cluster core must be very massive. We reconstructed the mass distribution in the region enclosed by the A system (*i.e.* inside 17 kpc radius) using a parametric model and the program LENSTOOL (Jullo *et al.*, 2007). We modeled the core as two components of different scales: One was a large-scale halo representing the dark mater and the cD galaxy, the other component was made of four smaller clumps representing the small-scale perturbations associated with the merging galaxies. All components were modeled with dual Pseudo-Isothermal Elliptical Mass Distributions (dPIEMD; see Eliasdottir *et al.*, 2007).

Our best model (shown in Figure 4) reproduces well the positions of the observed lens features. It

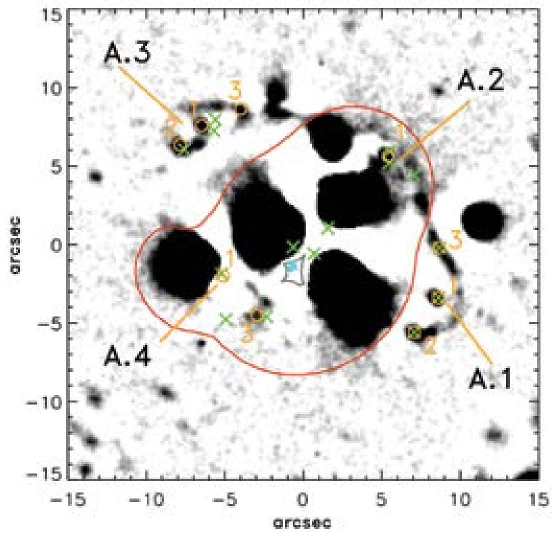

Figure 4. *g'-band image of the cD galaxy in Abell 3827 with the local median average subtracted. North is up, and east is left. The external critical line (red) and the associated caustic line (gray) for a source at z = 0.2 are depicted. Orange circles are the measured image positions. Green crosses represent the predicted image positions, using as input the three substructures that constitute arc A.1. We also show with small asterisks the positions in the source plane associated with these three points (cyan symbols in the center of the image). For clarity, we do not depict the demagnified images produced by strong galaxy-galaxy lensing events.*

is important to point out that this model is oversimplified, but it will help us to estimate a realistic mass for the core. Our models estimate that the total mass inside a radius of 20 arcseconds (or 37 kpc at the distance of the cluster) is ~ 2.7×10^{13} solar masses. Most of the mass within the core is dominated by the baryonic galaxy component. If we assume that the baryonic fraction is a conservative 30 percent of the total mass, then this implies that the cD contributes up to 8.1×10^{12} solar masses. This estimate makes this cD galaxy perhaps the most massive galaxy in the local universe.

We also compared the total cluster mass derived from the lensing data and the X-ray data. Gomez *et al.*, (2010) have performed a 3-dimensional fit for the X-ray emitting gas in Abell 3827. Based on their gas-distribution model, assuming hydrostatic equilibrium and a T = 7.2 keV, we have estimated the mass within 20 arcseconds and derived a value of 8×10^{11} solar masses. This is a factor of ~ 30 times smaller than the lensing model.

It is unlikely that the discrepancy could be explained by the dynamical state of the cluster. We believe that, at most — assuming that the cluster is relaxed when it is not — we can underestimate the mass by a factor of two (based on the X-ray data) and overestimate the mass by another factor of two (based on the lensing analysis). The overall factor of four is not enough to account for the discrepancy.

Future Work

We are continuing our studies of this intriguing cluster in order to further understand its nature — especially that of its cD galaxy. We have been granted time with the GMOS to measure the redshift of more galaxy members and more lens features, so that we can fine-tune the mass model and minimize its errors. Moreover, we have also obtained time using the Visible Multi-Object Spectrograph's integral-field unit on the European Southern Observatory's Very Large Telescope to make observations of the cluster core, to study the kinematics and star formation history of its very central part. Finally, we are planning to study the star-formation history of the galaxies within the halo by obtaining relatively higher spectral resolution observations of the cluster members.

For more details, see our paper "Strong Gravitational Lensing by the Super-Massive cD Galaxy in Abell 3827," by Carrasco, E.R., Gomez, P.L., Verdugo, T., Lee, H., Diaz, R., Bergmann, M., Turner, J.E.H. Miller, B.W., and West, M., *The Astrophysical Journal*, **715**: L160, 2010.

This work was done with the help of our collaborators (alphabetically): M. Bergmann, R. Diaz, H. Lee, B. W. Miller, J. E. H. Turner, T. Verdugo, and M. West.

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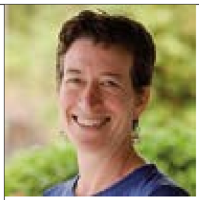

by Nancy A. Levenson

Recent Science Highlights

An Older Dusty Disk Around a Young Star

Direct images at 18 microns with the Thermal-Region Camera Spectrograph (T-ReCS) on Gemini South show a dusty disk around the young star HD 191089, including a gap at the center, which may be associated with planet formation (Figure 1). The presence of dusty disks is a normal part of star formation, but they tend to arise and persist in the early stages of the process. Within dense regions of molecular clouds, a central rotating core condenses to become a star. A surrounding disk develops, which conserves the system's angular momentum. The dust particles are very small, so the radiation pressure of even low-mass stars can drive the dust away over time.

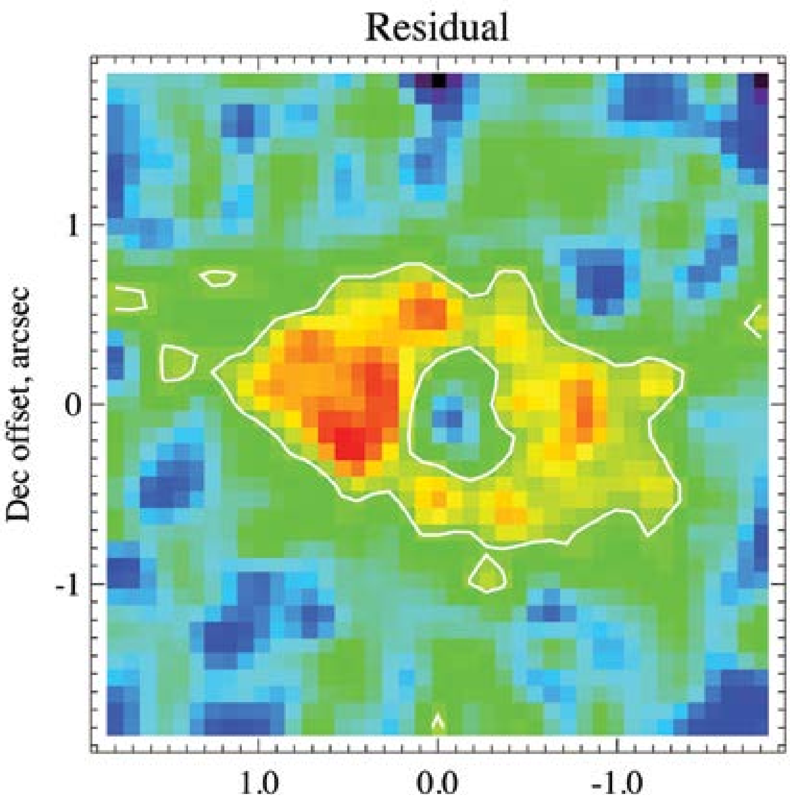

Figure 1. *This Gemini South T-ReCS observation of HD 191089 at 18 microns shows emission from the surrounding dust. Here the light from the central young star has been subtracted, to show the inner gap (extending to 28 AU) and the asymmetry of the dusty disk.*

While HD 191089 is young, it is relatively old (around 12 million years) for a star to exhibit the initial disk of its formation. The distinct disk that Laura Churcher of the Institute of Astronomy at the University of Cambridge and colleagues observed with T-ReCS therefore requires some explanation for its continued existence. Specifically, additional dust must be created — most likely by the destruction of larger bodies, such as colliding planetesimals, or through sublimation.

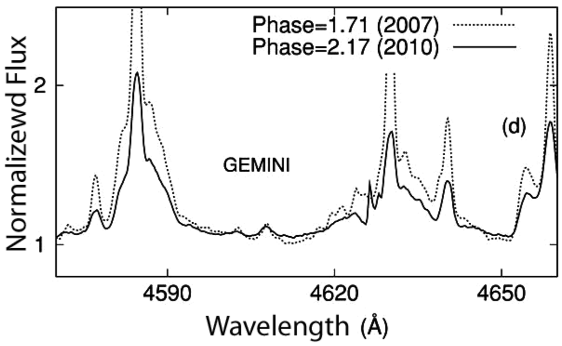

Figure 2. *The most recent GMOS-S spectra of Eta Carinae (from 2010) show stellar-wind emission lines that are about two times weaker than those that had been observed in 2007. These spectral extractions show the effect on blends of permitted and forbidden ionized iron and chromium.*

Subtracting the central star's unresolved emission shows details of the disk itself. It appears to be asymmetric, with areas of stronger emission on the eastern side. Significantly, the disk extends only from 28-90 astronomical units (AU) from the central star, leaving a gap in the center. The most likely explanation for these disk characteristics is the presence of a planet within the central cavity. A planet could sweep up the remaining dust within this region, producing the sharp boundary that is detected and dynamically resulting in the asymmetric structure of the remaining outer disk.

In their paper in the *Monthly Notices of the Royal Astronomical Society*, Churcher *et al.* also consider two other possibilities to account for the observations. The formation of Pluto-sized bodies could produce the detected emission — a process that is sensitive to the local conditions, so resulting in radial variations. Alternatively, the current disk could simply be the remains of an original protoplanetary disk, with interactions between the dust and gas helping to retain the dust.

A Sea Change in Eta Carinae

The variable star Eta Carinae has been an inconstant companion, showing magnitudes of brightness variations over timescales of centuries. Recently, most of these episodes have not been associated with corresponding spectral changes. Instead, as Andrea Mehner (University of Minnesota) and colleagues report in *The Astrophysical Journal Letters*, the brief observed periodic spectral changes can be attributed to the effects of the star's eccentrically-orbiting companion.

The "sea change," the authors say, appears as a significant variation in the spectrum observed in 2009 and 2010 compared with previous observations. Specifically, the stellar wind emission lines are now weak compared with the continuum.

The team used both recent and older observations of η Car made with the Gemini Multi-Object Spectrograph (GMOS) on Gemini South and Hubble Space Telescope's Imaging Spectrograph (STIS) in this work, so the comparisons of similar data sets minimize instrumental effects. Two high-quality GMOS spectra (from 2007 and 2010, Figure 2) show the spectral differences clearly. Those at intermediate times have lower signal-to-noise, but they suggest that the spectral change proceeded gradually rather than abruptly.

Mehner *et al.* interpret these recent changes as a consequence of decreasing wind density. If the wind density remains low, it may eventually become transparent, revealing the central source directly, which would afford direct measurements of the star's temperature and size. Moreover, because the extent of the wind is small and its velocity is large, measurable changes may continue on short (week-long) timescales.

Abundance Gradients in the Sagittarius Dwarf Galaxy

High-resolution, near-infrared spectra provide useful diagnostics of the metal abundance of stars. To make such measurements of the Sagittarius Dwarf Galaxy, Stefan Keller and colleagues at Mount Stromlo Observatory recently used Phoenix on Gemini South (Figure 3). In their observations,

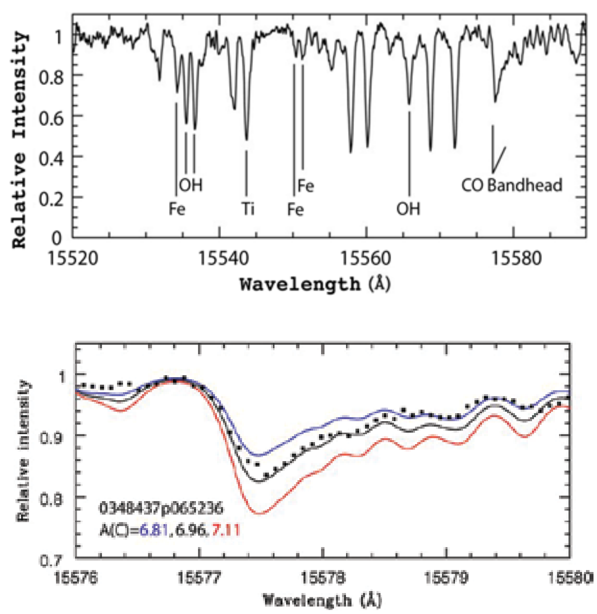

Figure 3. *The Phoenix spectrum of one of the M giants in the study of Keller* et al. *contains many absorption lines that are useful diagnostics of abundance (top). Zooming in to the spectral region from 15576 to 15580 Å (bottom) shows the data (black squares) and several synthetic spectra (lines), where the abundance of the black line provides the best fitting model.*

which they report in *The Astrophysical Journal*, they find evidence for a stellar abundance gradient in the original galaxy, which is now being destroyed as the Milky Way absorbs it. While accretion of smaller companions is an essential part of galaxy development in hierarchical formation scenarios, these authors conclude that the smaller companion does not represent a fundamental "building block" of the Milky Way's formation.

The Sagittarius Dwarf Galaxy (Sgr dSph) has repeatedly orbited the Milky Way, losing material in tidal streams that wrap entirely around our Galaxy. The current work concentrates on debris from the trailing arm, because the deposits at different epochs (from distinct regions of Sgr dSph) remain spatially separated. Metallicity differences measured in the sample stars correspond to a metallicity gradient in the original galaxy. The greater abundances toward the galactic center may be a consequence of a higher star-formation rate or more efficient retention of enriched products compared with the more distant regions.

The low average abundances in some parts of Sgr dSph are similar to the Milky Way's halo. However, the relative abundances in the debris of elements that are preferentially produced in different types of supernovae are different compared to the halo of the Milky Way. Thus, accretion of galaxies like Sgr dSph remain an incomplete explanation for the origin of the stars in the Milky Way's halo.

Asymmetric Explosions and Diversity in Type Ia Supernovae

Intense interest in Type Ia supernovae over the last dozen years is due to their utility as standard candles. Each event can be easily calibrated to determine its intrinsic luminosity, and thus allow measurement of cosmological acceleration. Fundamentally, the luminosity depends on the rate of brightness decline after maximum light. However, despite this simple description, Type Ia supernovae do show variety within their spectra, even those with similar lightcurves.

Keiichi Maeda (University of Tokyo, Japan) and collaborators use a mix of 20 new and archival supernova observations to conclude that the spectral diversity is a consequence of asymmetric explosions of the progenitor stars, which they report in the journal *Nature*. Previous theoretical work had suggested that inherent asymmetry is critical to the successful Type Ia explosion, and the new result is among the first observational pieces of evidence of the asymmetry.

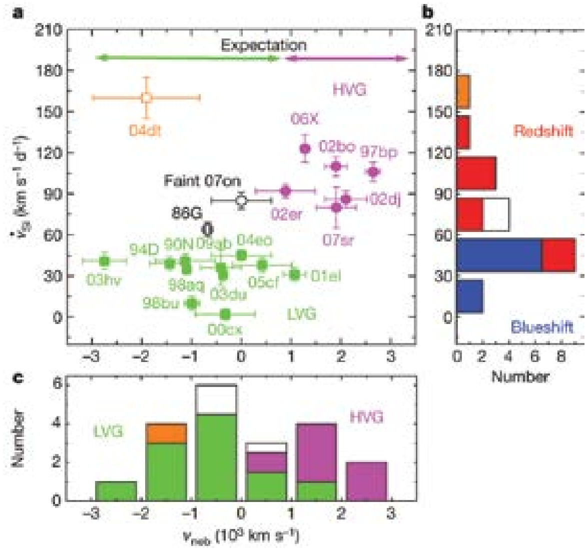

Figure 4. *The viewing angle of the nebular emission (v_{neb}) is correlated with the velocity gradient of the ejecta ($\dot{v}_{Si}$), which Maeda and colleagues explain as a consequence of asymmetric explosions of the Type Ia supernovae.*

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Maeda and colleagues specifically consider the rate of change of the ejecta expansion velocity, $\dot{v}_{Si}$, which the ionized silicon absorption feature around 6355Å shows. The temporal gradient of this spectral feature is not correlated with the decay timescale. The authors compare this expansion-velocity gradient with the observed wavelength of nebular lines, v_{neb} (Figure 4). These nebular-emission lines appear well after the explosion (about six months later, when the ejecta are transparent), so a wavelength shift to the blue or red indicates material that originates on the near or far side, respectively.

All the "high-velocity-gradient" examples are viewed from the far side of the original ignition. The "low-velocity-gradient" examples show a range of v_{neb}, but are concentrated toward blueshifted measurements (having the ignition site on the near side). The off-center-explosion origin accounts for these associations in terms of viewing orientation. Thus, the spectral variety of Type Ia supernovae does not imply intrinsic variation, so these supernovae remain good standard candles.

Observations of the supernovae used in this study were taken over time and obtained using a variety of instruments and telescopes, including GMOS on Gemini South.

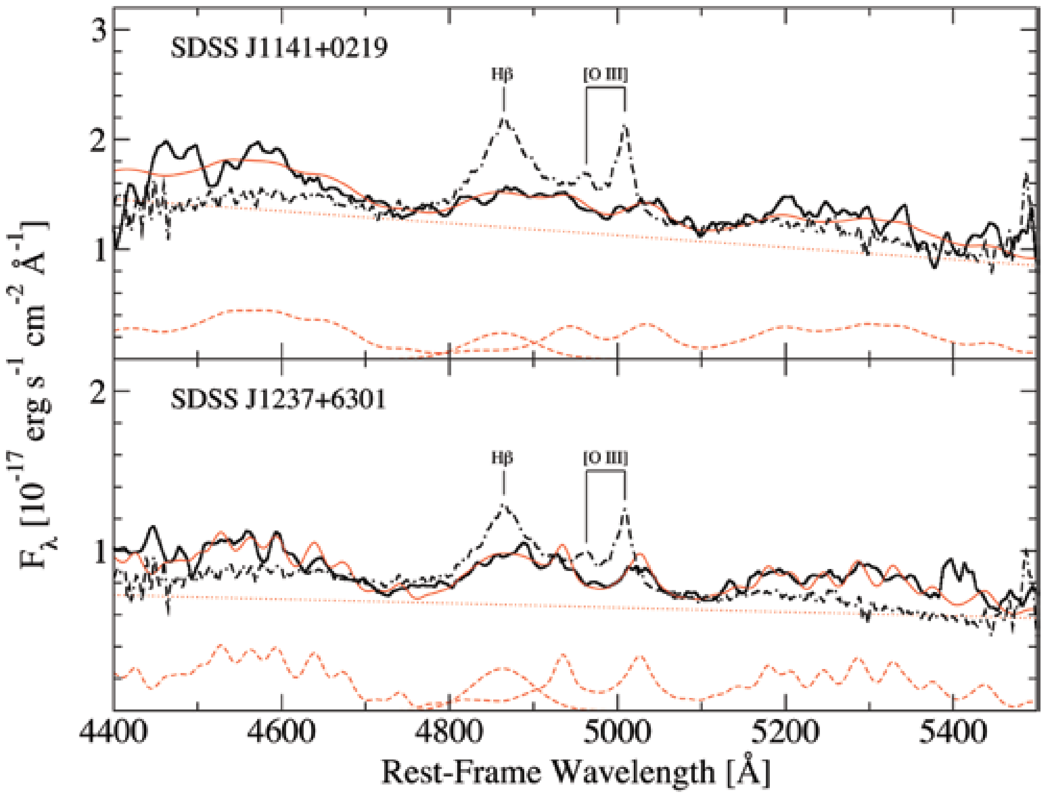

Figure 5. *Observed near-infrared spectra of two high-redshift, weak emission line quasars (solid black lines) correspond to the restframe optical emission. These sources show very different spectra than typical quasars (dot-dashed lines), especially around the emission lines (noted as* Hβ *and* [O III]*).*

Weak Emission Lines in High-Redshift Quasars

Normal quasars show strong emission lines, especially at ultraviolet and optical wavelengths, but another population of luminous galaxies in which the characteristic emission lines are weak yet detectable has emerged from the Sloan Digital Sky Survey.

Ohad Shemmer (University of North Texas) and colleagues used the Near-infrared Imager and Spectrometer on Gemini North to obtain spectra (Figure 5) covering the restframe optical emission of two of these high-redshift sources (z ~ 3.5). After measuring the lines and continuum, they determined the properties of the sources' central black holes and their accretion. They conclude that these multi-billion solar mass black holes accrete at normal rates, which argues against an unusual ionizing spectrum (especially one related to an exceptionally high accretion rate) as the origin of the weak line emission.

Instead, Shemmer *et al.* suggest, in *The Astrophysical Journal Letters*, that the region where the lines are produced is atypical. To produce the characteristic strong emission lines, gas must reside close to the accreting supermassive black hole — the energy source of a quasar. A deficit of material in the central region could account for the unusual features of these two quasars and other members of their class.

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by Chris Onken

NIFS: Celebrating Five Years of Slicing and Dicing the Universe

It's not unusual for the construction of new astronomical instruments to suffer from setbacks and delays; equipping telescopes to work at the frontiers of science is no mean feat. But few setbacks are quite as catastrophic as the one that befell Gemini's Near-infrared Integral-Field Spectrograph (NIFS). On Saturday, January 18, 2003, a massive bushfire came roaring into the outer suburbs of Australia's capital, Canberra. Hundreds of homes were destroyed. Four people tragically perished. Mount Stromlo Observatory, which overlooks Canberra from the southwest, also fell prey to the flames. Among the observatory's smoky rubble were the charred components of the nearly completed NIFS (Figure 1). Just a few months shy of being shipped to Gemini North in Hawai'i, the instrument was a total loss.

Figure 1. *The first incarnation of NIFS, sitting amid the ruins of the detector lab at Mount Stromlo Observatory following the January 2003 bushfire. Photo courtesy of Peter McGregor.*

Difficult Beginnings

The destruction of NIFS at such a late stage was particularly painful because the instrument was originally designed to quickly plug a critical capability-gap in the early days of Gemini's operation. Further complicating the process of rebuilding the instrument, just one month prior to this tragedy, the Australian National University's Research School of Astronomy and Astrophysics (RSAA), which runs the observatory at Mount Stromlo, had been awarded the construction contract for another Gemini instrument: the

Gemini South Adaptive Optics Imager (GSAOI). Now RSAA had two instruments to deliver, and no laboratories left standing to complete them.

While trying to overcome these challenges, RSAA benefited from what is normally a bureaucratic nightmare for international technology projects: customs regulations. NIFS's US $350,000 HAWAII-2 infrared detector, manufactured by the Rockwell Science Center (now Teledyne Scientific & Imaging) in the United States, was still in the hands of the Australian Customs and Border Protection Service when the fire hit Canberra. Fortunately, the detector wasn't delivered from Sydney until four days later. In another bit of good luck, the instrument design plans, which earned the New Technology & Innovation Award from the government of the Australian Capital Territory, were stored on computers in one of the few Mount Stromlo buildings that survived the fire (as well as being backed up off-site).

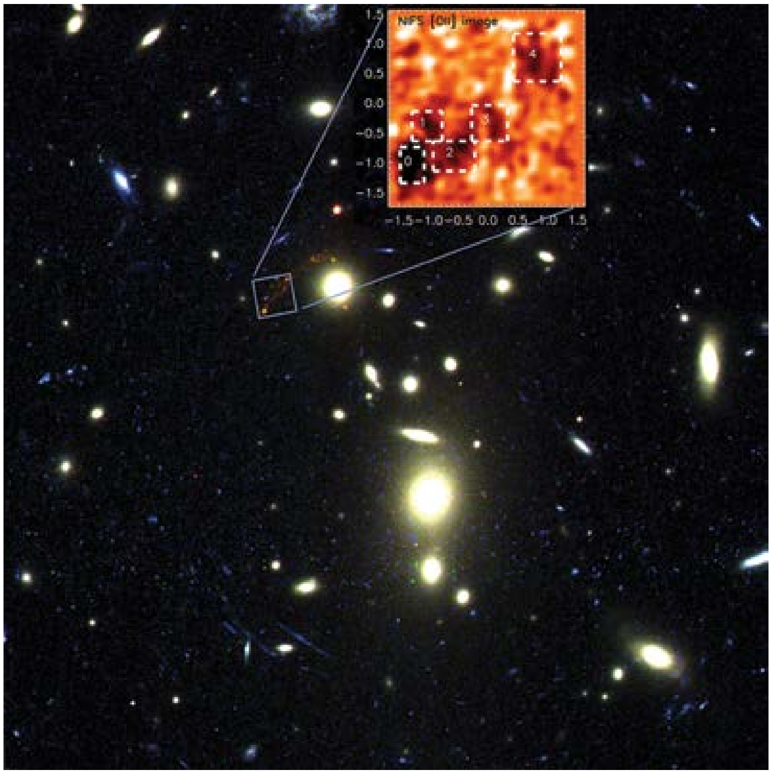

Figure 2. *A cluster of galaxies, called MS 1358+62, magnified the image of a faint, distant galaxy by a mechanism called gravitational lensing. This allowed NIFS to see the galaxy's components (inset) and study the star-formation process in the early universe. Figure courtesy of Mark Swinbank*

Immediate support for a rebuilding effort arrived from both Gemini and the Australian National University. It was decided that the primary NIFS reconstruction would be done by Auspace, an Australian aerospace engineering firm that was already involved in the NIFS project. This allowed Peter McGregor (Project Scientist for both NIFS and GSAOI), Jan van Harmelen (Project Manager, also for both instruments), and the rest of the team at RSAA, to proceed rapidly with GSAOI development. While GSAOI construction went forward in a makeshift lab built at Mount Stromlo, the NIFS team performed the final instrument tests at Auspace's facility in Canberra. The finished instrument was shipped to Hawai'i in August 2005.

NIFS Opens Its Eyes

On the night of October 18, 2005, NIFS achieved first-light, collecting its initial set of data on Gemini North. Every NIFS exposure slices up a 3-arcseconds-square region of the sky into 29 strips. Each strip is then divided into its component infrared wavelengths, or spectrum, and mapped onto the detector. Spreading the light into its spectrum allows astronomers to separate the different atomic and molecular constituents that make up the object being studied, as well as measure motion toward or away from us.

This general approach of taking two dimensions on the sky and adding the third, spectral, dimension goes by the name of "integral-field spectroscopy." The infrared version of the technique was pioneered in the mid-1990s by Germany's Max Planck Institute for Extraterrestrial Physics, with its "3D" instrument. The instrument traveled to telescopes in Chile, Spain (both the mainland and the Canary Islands) and, in the late 1990s, Australia.

During 3D's time on the Anglo-Australian Telescope, McGregor became highly impressed with the kind of data the instrument produced. When the opportunity arose to propose an instrument concept for Gemini in 1999, McGregor seized upon the utility and simplicity of 3D's design, while also incorporating improvements that had been suggested in the astronomical literature. The result was NIFS.

By no means was NIFS the only idea put forward for new Gemini instrumentation at the time. From across the Gemini partnership, astronomers suggested ways of rapidly expanding the telescopes' capabilities — modifying existing Gemini instruments, bringing in visitor instruments from other institutions, cloning successful spectrographs elsewhere, or building new equipment. In April 1999, following discussions by the Ad Hoc Infrared Science Working Group and the Gemini Instrument Forum, the Gemini Science Committee recommended that development proceed with NIFS. Within a month, the Gemini Board gave approval for a Conceptual Design Study to be conducted, and work on NIFS began in earnest.

In addition to building upon the reassuring pedigree of the 3D instrument, the team at RSAA enhanced NIFS' deliverability by duplicating parts from Gemini's Near-infrared Imager and Spectrometer (NIRI). Being able to reuse both the design and electronics control software from NIRI reduced the risk that comes with any unproven components in a new instrument. While the catastrophic events of 2003 delayed NIFS' arrival by a couple of years, the instrument's tremendous potential was undiminished.

The Universe in Three Dimensions

When partnered with a telescope as large as Gemini, NIFS can investigate objects much fainter than those accessible to 3D on 2- and 4-meter telescopes. For example, in observations from early 2006, NIFS measured how fast stars formed in a galaxy so distant that the light we see has been traveling for more than 90 percent of the age of the universe. That study, by Mark Swinbank (from the UK's Durham University) and collaborators, found that the rapid formation of stars in that young galaxy looked much like what we see happening in extreme environments locally, only with the process of star formation kicked into overdrive (Figure 2).

The placement of NIFS at Gemini North allowed it to take advantage of the Altair adaptive optics system. By watching (and sampling) how the atmosphere distorts the appearance of a relatively bright star, Altair adapts the shape of a flexible mirror in order to remove the air's blurring effects, before passing the light to the scientific instruments. By making corrections to the flexible mirror's shape up to 1000 times per second, the system can produce infrared images even sharper than those of the Hubble Space Telescope.

Altair was deployed on Gemini North in 2003, and by the time NIFS arrived, the system had a proven track record of delivering incredibly crisp images to NIRI. Consequently, there was a great deal of anticipation to see what NIFS and Altair could produce together.

Among the first adaptive optics observations with NIFS was a survey of six stars still collapsing out of their progenitor gas clouds. One of these six protostars has long lent its name to this entire class of young objects: T Tauri.

Growing a T Tauri star from a gas cloud is a messy process, with some gas being ejected while the rest falls into the condensing star at the center. The gas that gets thrown out comes in two flavors: 1) fast jets of material launched from the object's poles, and 2) slow winds that come gently wafting out in all directions. NIFS can detect the light emitted by molecular hydrogen gas from around these forming stars, and with the excellent image quality afforded by Altair, detailed maps can be made of where the molecular hydrogen is located (Figure 3).

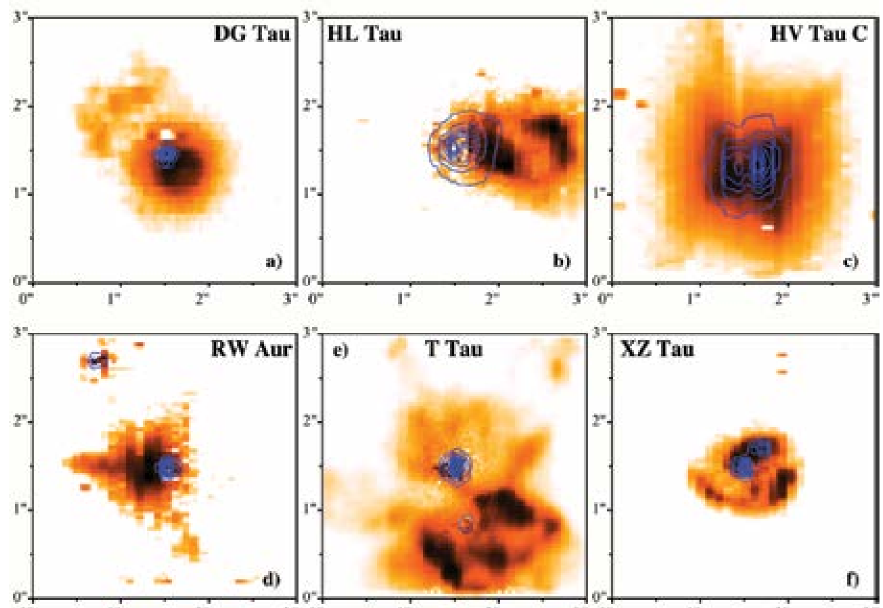

Figure 3. *Adaptive optics observations with NIFS revealed the detailed structure of molecular hydrogen gas surrounding six protostars. The gas velocities measured by NIFS traced multiple components within the gas cloud, showing signs of jets, winds, and disks of accreting matter.*
Figure courtesy of Tracy Beck

The spectral information provided by NIFS also allowed Tracy Beck (previously at Gemini, now at the Space Telescope Science Institute) and her colleagues to figure out that the molecular hydrogen is so energized that the radiation from the T

Tauri stars alone can't account for it. Instead, high speed collisions between different gas components must be occurring; the resulting shocks then release their energy through the molecular hydrogen emission. Thus, NIFS was able to address some unresolved questions about the chaotic mechanics of how stars are born.

Space Telescope, allowed the team to disentangle three distinct components of stars at the heart of the galaxy: a large galaxy bulge, which extends beyond NIFS' field-of-view; a nuclear star cluster (a dense ball of 1 billion year old stars with as much mass as 10 million Suns); and a smaller central group of younger stars.

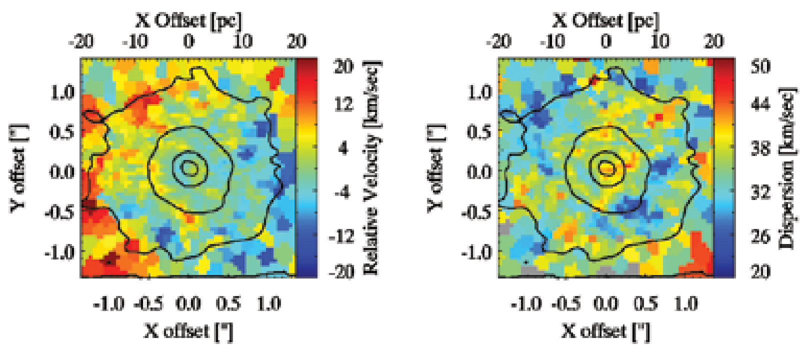

Figure 4. *The sudden change in velocity near the center of NGC 404 indicated contrasting rotation directions for the galaxy's different stellar groups. The Altair LGS system provided the spatial resolution to disentangle those components, giving clues about the evolution of NGC 404. Figure courtesy of Anil Seth.*

However, some objects in the sky don't have a bright star nearby for Altair to use as a reference. In order to correct for the atmospheric distortions in such cases, Gemini has to make its own star. In 2007, an upgraded Altair began operations—now equipped with a powerful laser. The yellow-orange laser light, about 2000 times more intense than a handheld laser pointer, is propagated skyward in a very tight beam, where it interacts with a layer of sodium atoms some 90 kilometers above the Earth's surface. The sodium absorbs the laser light and re-emits it in all directions; the light that comes back down to the telescope looks like a fairly bright star (about magnitude 8) which can be used to measure and correct the atmosphere's blurring. Although this mode of laser guide star (LGS) observations can't correct for changes in focus, that limitation can be overcome by monitoring a real star near the target — but one much fainter than is needed for Altair's full correction. Since there are many more faint stars than bright stars, this means that Altair and NIFS gain access to many more targets across the sky.

Thanks to the LGS system, one target that Altair can now reach is NGC 404, the nearest galaxy of the "S0" type. In the range of galaxy types from spirals to ellipticals, S0s sit right at the transition point: their stars are primarily old like in elliptical galaxies, but they still have clear disk components like spiral galaxies. Anil Seth (Harvard-Smithsonian Center for Astrophysics) and his collaborators used NIFS with Altair's LGS mode to study the motions of stars and gas in the central region of NGC 404.

The integral-field-spectroscopy data from NIFS, along with optical and infrared observations from the MMT Observatory in Arizona and the Hubble

Seth's NIFS observations of NGC 404 show that the stars in the small central group are rotating around the galaxy in the opposite direction to the nuclear star cluster (Figure 4). Each set of stars may have formed from gas stripped out of little neighboring galaxies, so the different directions of rotation suggest that the gas for the two components may have flowed to the center on different paths. Since the creation of S0 galaxies is still a mystery, being able to pull apart the building blocks at the center of a galaxy like NGC 404 can give us clues as to how S0s are made.

In addition to the separation of the three stellar components in NGC 404, the NIFS measurements of the stellar and gas motions show evidence for the presence of a black hole, with a mass less than 1 million times that of the Sun. Hot dust seen by NIFS at the center of the galaxy may indicate that the black hole is currently growing. If this black hole is confirmed through future observations, NGC 404 will be one of the least massive galaxies known to host a black hole.

Of course, these examples only hint at what can and has been done by NIFS; for a more complete sample, see the list of science results at: *http://www.gemini.edu/node/11531*

NIFS: The Next Five Years

Looking to the future, scientists and engineers are pushing Gemini's abilities even further. To expand on the number of targets NIFS can reach with Altair's amazing image quality, a new mode of LGS observations has been developed. When running in "open-loop" mode, Altair is focused while pointed at a bright star, and then the telescope is moved onto the science target. For science targets that are too faint to actively keep the telescope in focus, the open-loop mode uses the LGS system to remove the rapid atmospheric blurring, and tries to estimate how the focus should change based on a simple model of the sodium layer.

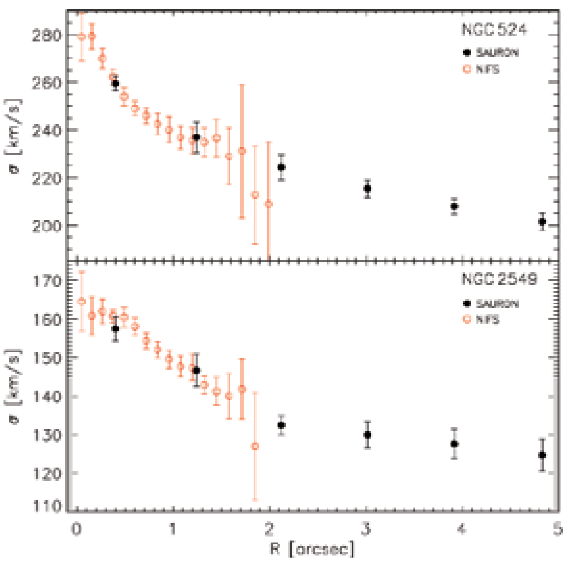

Figure 5. *The flexibility afforded by Altair's open-loop mode allowed NIFS to map the stellar motions in two galaxies with much greater detail than was possible using ground-based optical instruments (like SAURON). The way the velocity dispersion (σ) increased at very small radii revealed the presence of black holes in both NGC 524 and NGC 2549. Figure courtesy of Davor Krajnović.*

A test of this mode, led by Oxford University's Davor Krajnović (now with the European Southern Observatory), demonstrated that the open-loop image quality delivered to NIFS over the course of an hour was almost indistinguishable from normal LGS operations. Because of NIFS' ability to map objects in two dimensions with the sharp resolution afforded by the open-loop mode, Krajnović and his collaborators could measure the masses of black holes in two galaxies, for which it otherwise would not have been possible (Figure 5). Thanks to the diligent work of Gemini's staff, the open-loop observing mode is now available to any users of NIFS.

As Gemini marks the first five years of NIFS operations, teams are working to enhance the instrument's capabilities to still greater heights. Tests are currently underway that should give NIFS more freedom to use guide stars further from the science target. By using Gemini's built-in guiding system, which tracks stars anywhere within a large ring beyond the NIFS' field-of-view, significant numbers of new targets should open up for LGS observations. A few small hardware changes will make the system even more powerful, creating exciting opportunities for studying smaller galaxies, dimmer stars, and more distant planets and moons.

The tools of astronomy, like the scientific discoveries of astronomy, are built upon "the shoulders of giants." With each new idea, innovation, and lesson learned, we make the giants a bit taller, their shoulders a bit broader. The concept for NIFS can trace its lineage backwards, through the 3D instrument to Fabry-Perot interferometers, infrared grating spectrographs, and beyond. In turn, the success of NIFS has influenced the design of new instruments: the Wide-Field Spectrograph (WiFeS) at Siding Spring Observatory, and the planned Giant Magellan Telescope Integral-Field Spectrograph (GMTIFS).

Thus, a celebration of NIFS is not just an acknowledgement of those who have labored to design, build, rebuild, fine-tune, and continually push the instrument toward the boundaries of what it could do, but also a celebration of all that has come before, and all that comes hence. Happy fifth anniversary, NIFS!

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by Andy Adamson

First Science from NICI

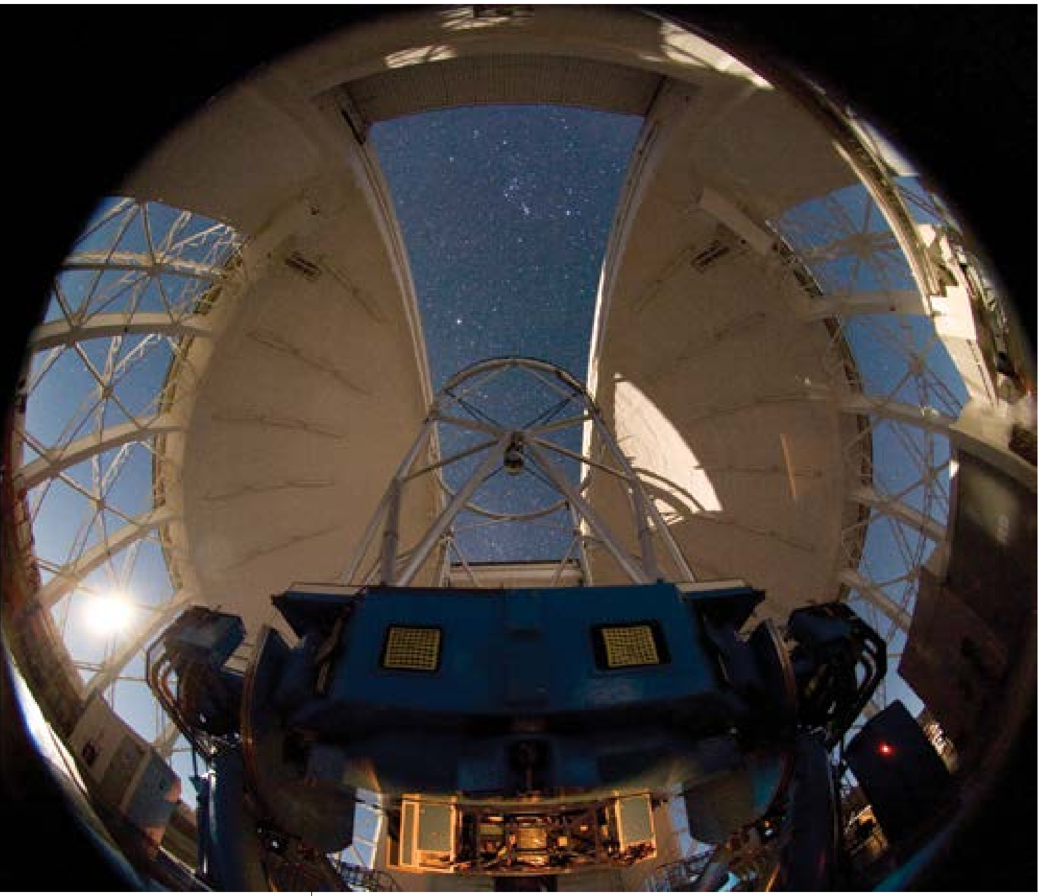

Figure 1. *Nighttime image of NICI installed on the Gemini South telescope.*

Funded by NASA and built by Mauna Kea Infrared (MKIR), the Gemini Near-Infrared Coronagraphic Imager (NICI) is a true thoroughbred, packing an 85-element adaptive optics (AO) system, Lyot coronagraph, and specialized camera into a single instrument, one whose non-common path aberrations are limited only by residual atmospheric distortion and scattering.

Without question, NICI is optimized to detect Jovian planets around nearby stars; its sensitivity in that respect is enhanced by spectrally differencing images taken simultaneously inside and outside the strong, near-infrared, methane absorption features found in cool substellar objects. Indeed, NICI, now in its second year of operation on Cerro Pachón, is being used mainly for a major campaign of direct imaging of nearby solar systems. (See the article on the NICI Planet-finding Campaign starting on page 61 of the June 2009 issue of *Gemini*Focus.)

However, some of the first science results to appear in the literature concern broader uses of the instrument. For instance, in addition to the methane filters, a variety of broad- and narrow-band filters are available, enabling science well beyond the confines of the hunt for exoplanets. This article looks at two of these early studies; they exemplify how NICI's exquisite spatial resolution, coupled with the light-gathering power of the 8-meter Gemini South telescope, can be used to unravel quite different problems.

EXTRAGALACTIC SCIENCE WITH NICI: AGB STARS IN M83

Early in the 20th century, astronomers realized that galaxies are enormous systems of stars similar to our own Milky Way. Ever since, we've pursued a better understanding of them by improving our observational instruments and techniques. Ultimately, the goal is to understand how and when the galaxies formed. Although the brightest stars in some very nearby systems (the Andromeda Galaxy, M31, for example) were detected many years ago, stars in more distant galaxies have been an insuperable challenge due to the crowding together of many stellar images, and their faintness due to distance. To overcome this problem, most studies sum up and analyze the "integrated light" from stars across wide patches of the galaxy's surface. Analysis of such information is complicated, however, and it would be better to study individual stars.

One of the first NICI papers (Davidge, 2010) reveals how astronomers have pushed current techniques to their limits, using NICI on Gemini South to detect individual "asymptotic giant branch" (AGB) stars in M83, a galaxy rather similar in appearance to our own Milky Way. More than six times as far off as M31 (the nearest large galaxy outside the Milky Way), even giant stars in M83 are extraordinarily faint; carrying out stellar studies at this distance requires detection of some of the dimmest stars ever studied in astronomy.

Given sufficiently accurate measurements of the brightness and colors of stars, it is possible to compare these data with stellar evolution models and arrive at estimates of their ages. Davidge derived NICI photometry down to K magnitudes fainter than 23rd, using images with a total of two hours exposure over each of five fields distributed across the disk of M83. These data were the first taken with NICI in queue mode, most with its beam-

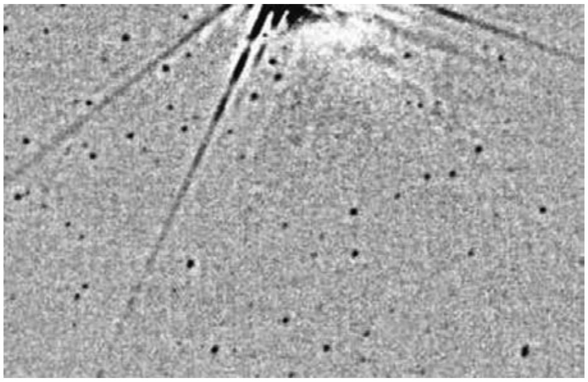

Figure 2.
Individual AGB stars in the galaxy M83. The bright object just out of the picture at the top is a much more local star, part of the Milky Way, which was used to correct atmospheric distortion and deliver ultra-sharp images.

splitting capability to observe in two infrared filters (H and K_S) simultaneously.

Figure 2 shows an example field, approximately 15 arcseconds across. Figure 3 shows the location of a bright foreground star apparent in the image from NICI. Even in this small area of sky, the correction for atmospheric distortion varies somewhat, complicating the measurement of individual stellar brightness. But with these complexities surmounted, and the colors and brightnesses of the stars analyzed, Davidge found that the stars in the outer regions of M83 are systematically younger than those in the central parts. Metaphorically, the suburbs of this metropolis of stars are younger than the town center. This lends support to models of galaxy formation which predict that large galaxies should grow, albeit slowly, with time. It also warns us to be careful in making comparisons between much more distant galaxies and those in the local universe: due to the light travel time, more distant galaxies are being seen at a younger age.

STARS IN PAIRS, THREES AND FOURS

Approximately one-third of the stars in the Milky Way are not loners like our own Sun, but are binary or multiple star systems. A detailed knowledge

Figure 3.
Visual image showing the galaxy M83 and the bright star (arrowed) which is seen in Figure 2. Astrophotography Credit: Robert Gendler and Stéphane Guisard.

of the number of multiple stars and their hierarchy helps astronomers to test theories of star formation. By concentrating efforts on exoplanets and ignoring multiples, we risk leaving aside a relevant aspect of our origins, ultimately how likely we are to find an accommodating environment for hosting planetary systems.

Many recent searches for nearby multiple stars have failed to provide adequate statistics: either because the sample is too small or insensitive to widely spaced binaries (in which the velocity shifts caused by the orbital motions are too small to detect with current radial-velocity techniques); or because they explicitly avoid looking for multiplicity in known binary systems.

Some 5,000 Sun-like (of spectral type F5-K0), unevolved dwarf stars lie within 70 parsecs of the Sun. Within this number, theory predicts the presence of just a few hundred triple systems, and about 100 quadruples. Another recent NICI paper (Tokovinin *et al.*) considers the statistics of multiplicity in a sample of 33 known binary stars extracted from this sample: All lie within a couple of hundred light-years of Earth, have a primary Sun-like star (the brighter of the pair), and a separation such that both known components can be accommodated within the NICI field-of-view. The researchers undertook nearly all of the observations on a single night, mostly with two narrow-band filters in the H and K bands. For the brightest stars, they used NICI's Coronagraphic mode to block the bright primary star from the image.

From this small initial sample, Tokovinin and colleagues found six new close stellar companions. Just over 10 percent of the stars studied have close companions (separated from their primary stars by less than half an arcsecond). Separating such companions would be next to impossible with traditional seeing-limited imaging, but is easy with NICI's AO resolution. Figure 4 shows two examples of the companions uncovered in the study, one of which is very similar in brightness to the primary, and one of which is very much fainter and harder to detect.

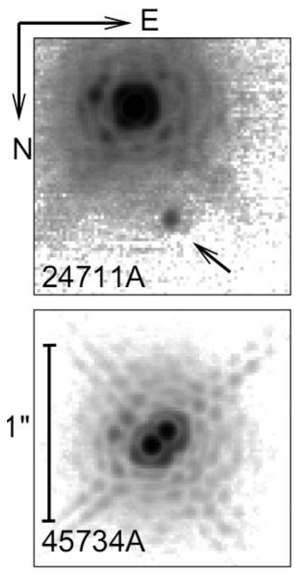

Figure 4. *Pairs of stars revealed in the Tokovinin* et al. *sample. These two images are very small (see the 1 arcsecond bar in the lower pane), emphasizing the need for NICI plus AO to resolve systems such as this into their constituent stars.*

In an exceptional case, the team found that the wide binary HIP 43947 comprises two close binary stars. The advance on traditional imaging is shown in Figure 5, which compares the Digital Sky Survey 2 image, 2MASS infrared sky survey image, and the NICI results.

This work lies at the tip of a large iceberg: The authors have focused on a sample comprising about one-sixth of the known solar-type binary stars with separations between 5 and 20 arcseconds, within a reasonable distance of the Sun. But even within this small sample, the discovery of six new close companions tells us that our current knowledge of multiplicity in nearby solar-type systems is incomplete at best.

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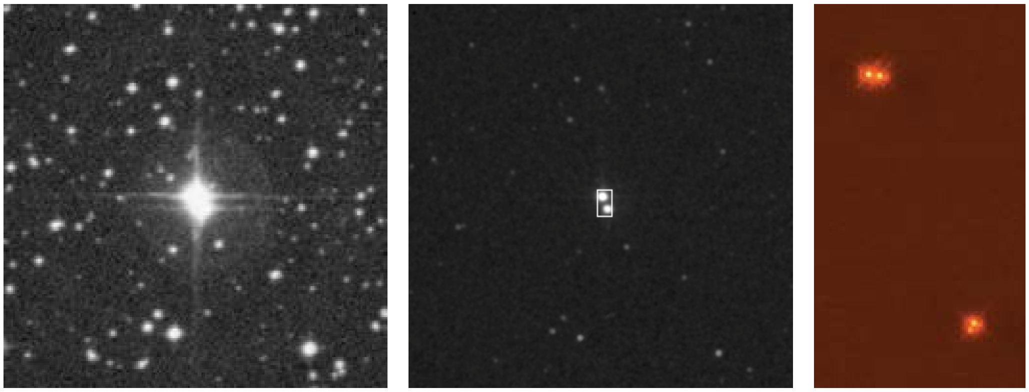

Figure 5. *(left) Digital Sky Survey 2 (DSS 2) image of HIP 43947, showing the binary nature of this quite bright star. (center) 2MASS infrared (K band) image at the same scale as the DSS 2 image with a box indicating the approximate area covered by the Gemini NICI observations. (right) NICI infrared (K band) image, revealing the binaries that make up the quadruple star system.*

by Tom Geballe

The Return of GNIRS

After a lengthy and still ongoing recovery, the Gemini Near-Infrared Spectrograph (GNIRS) is returning to scientific life. Once again, this core instrument is poised to provide the Gemini user community with a high-sensitivity, multiple-use spectrograph for the 1-5 micron wavelength region. Unlike GNIRS' previous scientific existence, when it was situated at Cerro Pachón, the instrument is now at Gemini North.

Many readers know that GNIRS was badly damaged in May 2007, when the control electronics for its internal heaters, which were being used to warm the instrument after an extended cold period, failed to shut off the heaters. The instrument was essentially baked on the inside. The accident resulted in the destruction of the detector and damage or destruction to most of the internal optics.

Progress on the repair was reported on page 39 of the June 2008 issue of *Gemini*Focus. Since then, recovery work has been continuous, although various setbacks have led to lengthy delays. (A time sequence of brief reports on this

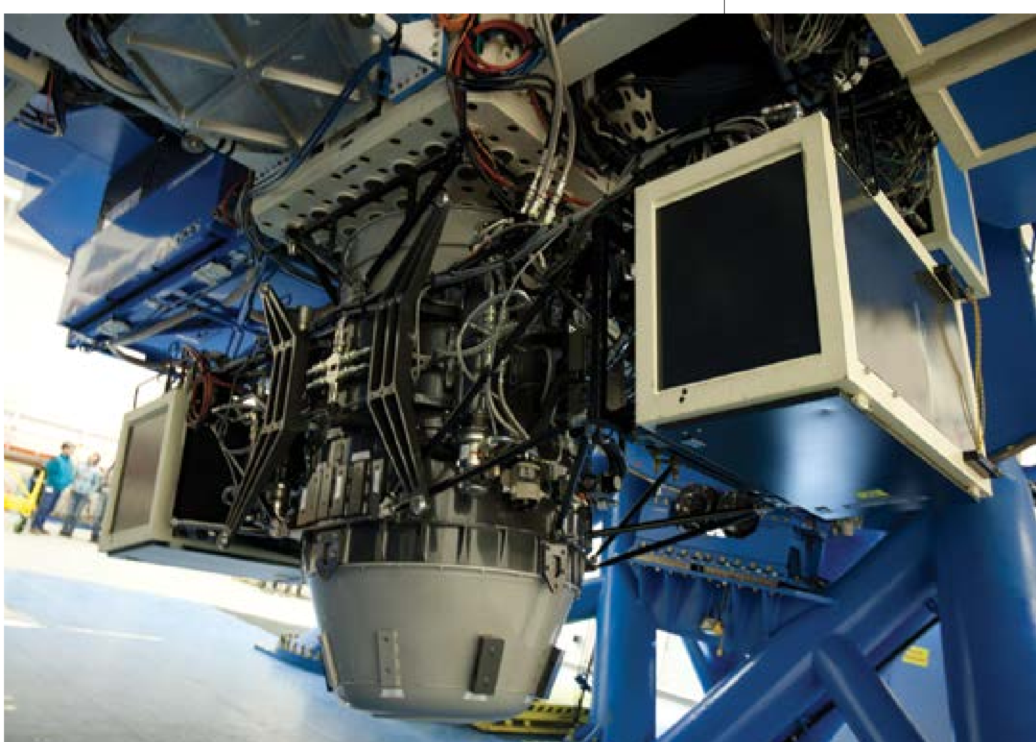

Figure 1. *GNIRS mounted on the bottom (uplooking) port of the Gemini North telescope in August 2010.*

Figure 2. *Cross-dispersed and sky-subtracted 0.9-2.5 micron spectral image of the planetary nebula NGC 6572. The orders range from 3 (1.9-2.5 microns) at left to 8 (0.8-0.9 microns) at right. In each order wavelength increases toward the bottom. A large number of emission lines from the nebula, as well as continuum from the central star and nearby regions, are evident. The exposure time was 30 seconds on the nebula and 30 seconds on the sky.*

saga is available on the GNIRS Status and Availability public web page, see: *www.gemini.edu/sciops/instruments/status-and-availability)*. However, the instrument is now mostly returned to its optimum configuration, with some improvements from its original form.

Starting in December 2009, GNIRS underwent three periods of cold-testing in Hilo. The instrument passed its acceptance tests in June 2010 and was transported to Mauna Kea at the end of that month. Since then, it has been mounted on Gemini North for about two weeks in July and one week in August. Figure 1 shows GNIRS on the telescope's bottom port. A minor but temporarily show-stopping mechanical failure interrupted the second of these recommissioning periods. At the time of writing in mid-September, a third test period has been completed.

Figure 2 demonstrates the good health of GNIRS. It shows a cross-dispersed, sky-subtracted 0.9-2.5 micron spectral image of the compact planetary nebula NGC 6572. The data were obtained early in the July run and the image represents a subtracted pair of 30-second exposures (one with the slit of the spectrograph passing through the center of the nebula, one with it on the nearby blank sky). Although this nebula is an easy target, the figure clearly shows the power of the revived instrument.

Although recommissioning is not yet complete, we are sufficiently confident of GNIRS' performance to be offering it for use in most of its observing modes in Semester 2011A. The most noticeable configuration not being offered then is GNIRS with laser guide star adaptive optics (LGSAO), which was yet to be tested at the time of the call for proposals.

Due to an unfortunate problem that has limited the Gemini Near-Infrared Imager (NIRI) to only its imaging modes since late summer 2010, system verification (SV) for GNIRS is being carried out in a novel manner. Highly ranked NIRI spectroscopy programs in Semester 2010B have been converted to GNIRS programs and some are being observed and are serving as SV tests. The remaining configurations, including LGSAO, will be tested via a normal Gemini SV process, late in Semester 2010B and in 2011A.

The laboratory tests in Hilo, and the initial on-telescope tests, have demonstrated that GNIRS' internal image quality and spectral resolution are excellent in almost all imaging and spectroscopic modes; in fact, they are similar to, or better than those when the instrument was at Gemini South. This is because several of the replacement optics are of better quality than the originals.

The on-telescope tests have demonstrated that GNIRS has achieved, or is close to reaching, the predicted sensitivity at most wavelengths — both with and without adaptive optics. At present, the image quality with adaptive optics seems to be limited to roughly 2-3 times the diffraction limit. Some degradation may not be surprising in view of the optical design of the instrument. Attempts to understand and improve the image quality when using adaptive optics are ongoing.

Due to the intense community interest in having GNIRS back in service as soon as possible, we've deferred work on the small remaining number of the problems. The most serious of the problems is that the new anti-reflection coatings on some of the camera lenses have "spontaneously" flaked off while in storage — this has happened more than once for some lenses. In response to this, the old spare set of lenses, with durable (but radioactive) coatings have been installed; unfortunately, the radioactivity results in numerous spikes on the detector array, which degrade the data if they occur in the wrong locations. *Note:* the amount of radiation from these coatings is extremely small and not a health or safety issue.

While we believe we have now acquired a set of lenses with durable, non-radioactive coatings, these optics likely will not be installed until later. Other less-significant problems include the mechanical instability of the flip-in acquisition mirror, the tilt of spectra on the detector array, and water-ice on some of the cold optics, which has probably only temporarily made the short wavelength portion of the 3-4 micron "L" band unobservable.

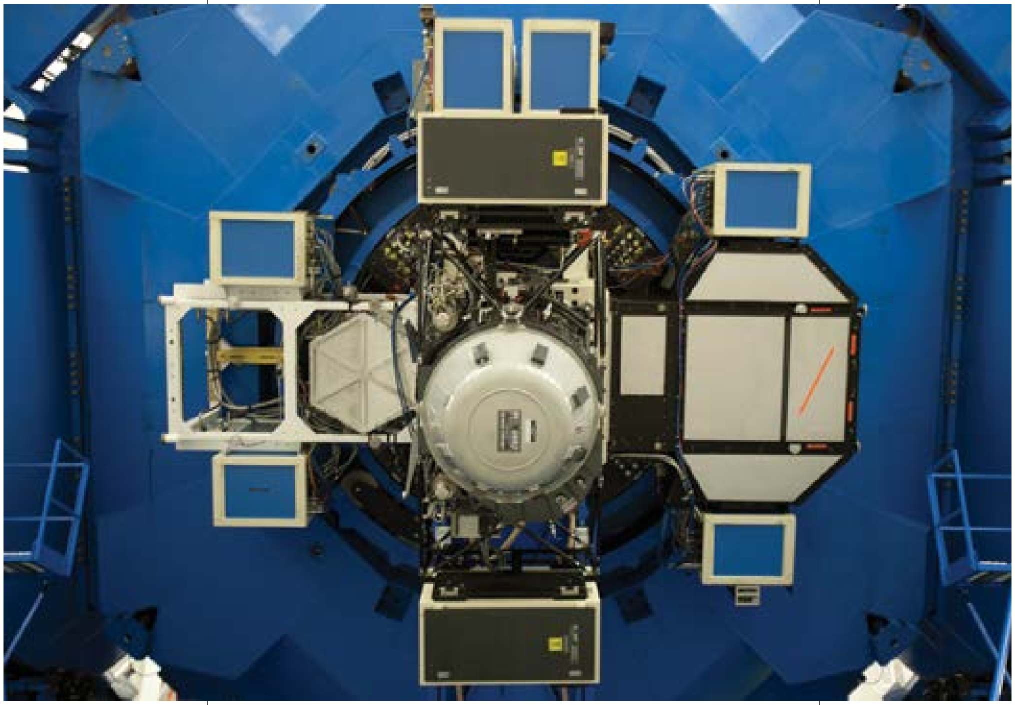

Figure 3.
GNIRS on the uplooking port at Gemini North, seen from below.

Characterization of the infrared, on-instrument wavefront sensor is incomplete; although it appears that its detector is sufficiently sensitive and can be read out rapidly enough to be effective as an internal flexure compensator and guider. Finally, the array controller for GNIRS' science detector is prone to producing an electronic pattern in the same manner as NIRI's controller. Replacement of the controller is part of the engineering plan.

The scientific recommissioning of GNIRS has been carried out by five staff scientists: Tom Geballe (the author of this article), Rachel Mason (who will become the GNIRS instrument scientist in 2011), Marie Lemoine-Busserolle, Claudia Winge (who was on the original GNIRS commissioning team at Gemini South), and Silas Laycock. Other involved science staff includes Michael Hoenig and Jesse Ball. Jay Elias at NOAO in Tucson has regularly provided guidance throughout the lengthy repair and test period. Ron George (also at NOAO) tested and evaluated the performance of several array detectors, one of which is now the GNIRS science detector. The science team in Hawai'i also has been assisted by students and interns, including Alison Faulkner and Anna Delahaye from the University of Victoria, and Svea Hernandez, a recent graduate of the University of Texas.

The main heroes of the long process of recovery, however, are Gemini staff engineers John White and Eduardo Tapia. They have put countless hours of effort and thought into disassembling, cleaning, repairing, replacing, reassembling, and testing GNIRS. Also, Gemini's Matt Rippa adapted and improved the GNIRS software for use at Gemini North. Richard Oram (also Gemini staff) has led the lengthy effort to obtain camera lenses with non-radioactive and durable anti-reflection coatings.

Many other Gemini engineers and technicians, too numerous to mention, have also contributed in significant ways. We expect that astronomers in the Gemini partnership will be the beneficiaries of all these efforts for many years to come.

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

by Stephen Goodsell

Gemini Planet Imager Update

The status of the Gemini Planet Imager (GPI) project was last reported 18 months ago in the June 2009 issue of *Gemini*Focus. At that time, the GPI team had recently completed the instrument design phase and embarked on the fabrication/procurement stage. Since then, every member of the collaboration has expended a tremendous amount of effort. Now, Gemini is pleased to announce that each GPI subsystem is fully assembled, and acceptance testing is underway. Furthermore, we're highly confident that by the time of this publication, each subsystem will have passed its Acceptance Review and been transported to the instrument Integration and Test (I&T) stage site at the University of California, Santa Cruz (UCSC).

Figure 1. *Left to right, Les Saddlemyer (HIA) and Gemini's Manuel Lazo, Gustavo Arriagada, and Scot Kleinman inspect the GPI OMSS at HIA prior to acceptance testing.*

To recap, the science case leading to Gemini's procurement of the instrument was identified during the Aspen instrument planning process in 2003. GPI's primary science mission is to detect and characterize self-luminous, extrasolar planets at both near-infrared wavelengths and high-contrast ratios (planet/star ratios of 10^{-7}). (Further details regarding exoplanet imaging with the Gemini telescopes and the GPI instrument can be found in the December 2009 and December 2006 issues of *Gemini*Focus, respectively.)

GPI's $25 million price tag reflects its complexity. The instrument is comprised of the following subsystems: an extreme adaptive optics (AO) system; an apodized-pupil Lyot coronagraph (COR); a high-accuracy, interferometer calibration system (CAL); a near-infrared, integral-field spectrograph (IFS); and

Figure 2.
The Calibration subsystem with the top cover removed.

an opto-mechnical super-structure (OMSS). Additional subsystems include the Top-Level Computer (TLC) and the Data-Reduction Pipeline (DRP). The status of each key subsystem is outlined below.

Subsystems Status

COR: A team led by Ben Oppenheimer, at the American Museum of Natural History (AMNH), took responsibility for providing the instrument's Coronagraph subsystem. The apodized-pupil Lyot coronagraph consists of three sets of components. The input pupil is apodized by a greyscale mask. The focal-plane occultor is a superpolished silicon mirror with a central hole down which the starlight falls. And, finally, a cryogenic Lyot stop inside the spectrograph blocks the remaining starlight. These sets of components were characterized at AMNH, and subsystem performance was demonstrated on their testbed. The COR subsystem was the first to be completed.

CAL: The Jet Propulsion Laboratory (JPL) provided the Calibration subsystem under the technical leadership of Kent Wallace. CAL exploits the optical properties of the coronagraph to allow precise and accurate measurement of the pre-coronagraph wavefront. This, in turn, provides feedback to the AO subsystem, which removes the residual pseudo-static wavefront errors and ensures that the time-averaged phase at the coronagraphic occultor is flat. The CAL subsystem successfully passed its Acceptance Review back in July 2010 (Figure 2).

AO: Lawrence Livermore National Laboratories (LLNL) was responsible for delivering the instrument's Adaptive Optics subsystem, in addition to providing technical leadership (from Principal Investigator Bruce Macintosh) and Project Management (from Dave Palmer). The AO subsystem consists of four main components: a Boston Micromachines Corporation (BMC) 4k MEMS Deformable Mirror (DM, referred to as the Tweeter), a CILAS 97 actuator DM (referred to as the Woofer), a CCID66 Lincoln Labs Wavefront Sensor (controlled by a SciMeasure controller), and a 16-core Dell Workstation Adaptive Optics Controller.

In August 2009, a team from Gemini visited LLNL to witness AO subsystem acceptance testing. LLNL successfully demonstrated closing the loop on their

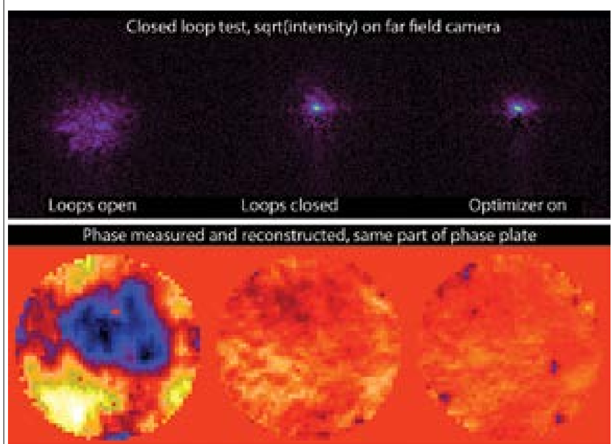

Figure 3.
Focal plane images from the AO testbed at LLNL showing the image quality improvement with the AO loop closed and the real-time optimizer operating.

testbed (running at 1.5 kHz) with a modal gain optimizer — similar to Altair — to automatically adapt to changing conditions and minimize residual wavefront error (Figure 3).

Over the past year, the successful fabrication of the BMC 4k DM proved the biggest technical risk to the project (Figure 4). After a number of fabrication runs, BMC delivered two usable, science-grade de-

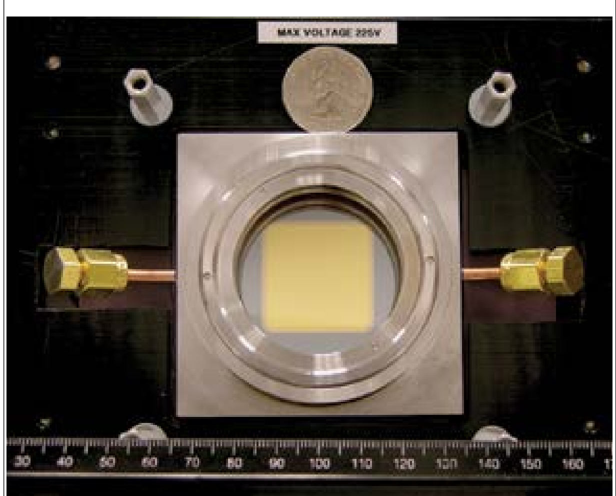

Figure 4.
An engineering-grade sample of the BMC 4k actuator MEMS deformable mirror.

vices. They have been accepted by the project and are being further characterized at UCSC.

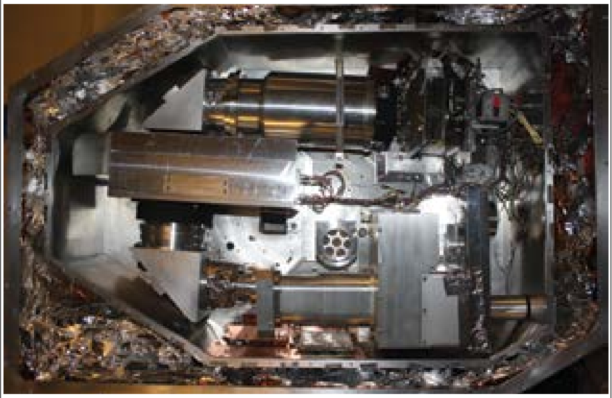

Figure 5. *View of the "internals" of the IFS with the dewar lid removed.*

IFS: James Larkin at the University of California, Los Angeles (UCLA), provided the instrument's Integral-Field Spectrograph (IFS). GPI's IFS uses a grid of lenslets in the focal plane to dissect the image into a sparse grid of dots — with enough space between them that the spectra can be dispersed. Individual spectra are 16-pixels long and separated by 4.5 pixels from their neighbors; this reduces crosstalk to acceptable levels. The spatial sampling of 0.014 arcsecond per pixel gives a field of view of 2.8 × 2.8 arcseconds on a HAWAII 2RG detector. In polarimetric mode, the spectral prism is replaced with a Wollaston prism, which separates the two orthogonal polarizations from each lenslet on the detector. The IFS subsystem began acceptance testing in September 2010 (Figure 5).

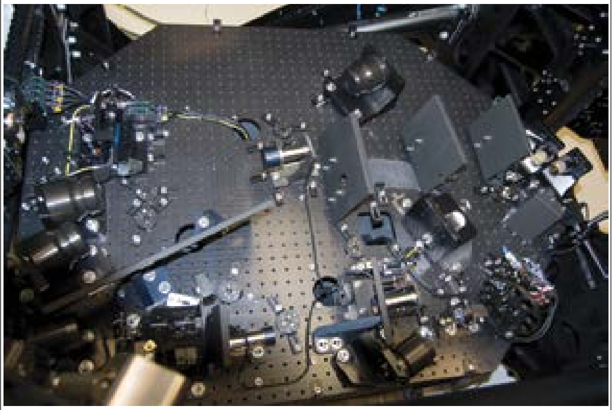

Figure 6. *View of the OMSS AO relay bench, with aligned science and wavefront sensor paths.*

OMSS and **TLC:** Gemini contracted the Hertzberg Institute for Astrophysics (HIA) to provide the instrument's TLC (led by Jennifer Dunn) and the OMSS (led by Les Saddlemyer — the project's System Engineer). The OMSS includes the instrument's Flexure Sensitive Structure, External Frame Structure, and Electronics Enclosures.

The OMSS also contains an optical bench hosting a number of optical elements, including an Atmospheric Dispersion Corrector (ADC), an Artificial Star Unit (ASU) to produce artificial sources for calibration, the AO components, and a mechanism containing the coronagraph's pupil-plane masks (Figure 6). During September 2010, Gemini staff engineers and scientists inspected the OMSS for quality and workmanship (Figure 1). The Subsystem Acceptance Review for HIAs subsystem was scheduled for November 2010.

The TLC is responsible for issuing commands to the CAL, AO, and IFS subsystems, as well as sending information up to the Observatory Control System (OCS); it is the instrument's software interface to Gemini (Figure 7).

DRP: The Data Reduction Pipeline subsystem is the responsibility of René Doyon at the University of Montréal. The first version of the DRP was released internally to the GPI team this year and has been used to analyze acceptance test data coming from the IFS subsystem. The software has been written in Interactive Data Language (IDL) and will be made available to the community when completed.

Looking Ahead

Gemini now looks forward to the system's I&T stage, and Don Gavel at UCSC is fully prepared to technically lead the acceptance testing. Aided by a team including Daren Dillon and Sandrine Thomas, UCSC has constructed the required clean room facilities in their high Bay Area and has assembled and tested their telescope simulator. We expect that all of the subsystems will be integrated at UCSC in early 2011, to form the final GPI instrument.

The GPI instrument science team, (led by James Graham — project scientist, Figure 8) has high anticipation for the instrument's completion and continues to evolve the instrument's science case, which will help define the details of the post-delivery science-verification and commissioning stage.

In addition to the super-human efforts at each of the institutions developing GPI, Gemini has been preparing quietly in the background for the arrival of the instrument at Gemini South. A number of subtle internal changes have occurred in the last 18 months in this regard.

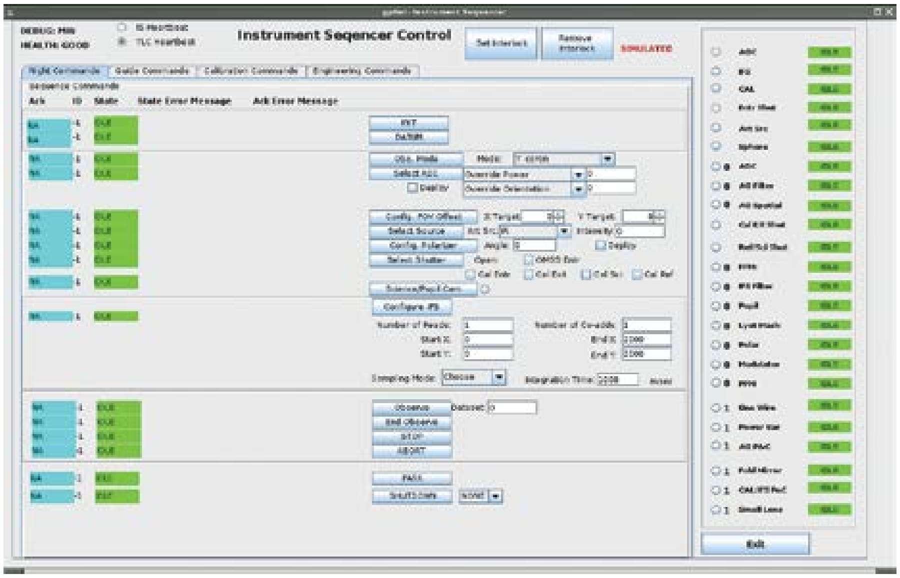

Figure 7. *One of the engineering graphical user interfaces being utilized for testing and verifying GPI.*

To ensure that we're prepared for GPI's delivery, Gemini has assembled its own core team: Stephen Goodsell (author of this article and Project Manager), Fredrik Rantakyro (Project Scientist), and Manuel Lazo (System Engineer). In addition, Gemini has scheduled a number of internal GPI work packages to be conducted in 2011.

To assist in demonstrating that the instrument meets its requirements prior to delivery, Gemini will also increase technical oversight during the I&T stage. The author became Gemini's Instrumentation Program Manager in August 2009 and has worked closely with the instrument team over the previous year; he will continue to do so during the I&T stage by becoming part of its management team. This interaction is also designed to start the knowledge transfer process. As can be imagined, a $25 million one-of-a-kind instrument will almost certainly have some "teething" problems when delivered. Knowledge transfer of complex instruments is challenging. Thus, ramping up early in the I&T stage is essential.

Arturo Nuñez (Software Engineer), Markus Hartung (AO Scientist), and Julian Christou (AO Scientist) also play critical roles with the team at UCSC by assisting with system integration and characterization. Nuñez has already successfully completed one internal GPI work package in 2010: the Gemini Instrument Application Programming Interface (GIAPI) software allowing the TLC to talk to the OCS. The interface between the GIAPI and the OCS is next on the list of initiatives.

Eric Christenson (GPI System Support Associate), Gaston Gausachs (Mechanical Engineer), Tomislav Vucina (Optical Engineer), Ramon Galvez (Instrument Engineer), Rolando Rogers (Electronics Engineer), Kathleen Labrie (Data Reduction Specialist), and Gelys Trancho (System Engineer) will all have vital roles to play over the coming year as well. The entire activity is being overseen be Eric Tollestrup (Associate Director for Development) with assistance from Scot Kleinman (Development) and Andy Flach (Contracts).

Delivery of GPI to Gemini South is expected in late 2011. This will be followed by a post-delivery acceptance test stage, and then a Science Verification and Commission stage, before being offered to the community in mid-2012. Expect to see a number of GPI detected and characterized exoplanets in a future issue of *Gemini*Focus!

Stephen Goodsell is the instrument program manager based at Gemini North. He can be reached at: sgoodsell@gemini.edu

Figure 8. *GPI science team gathering at a recent science meeting hosted by AMNH.*

by Peter Michaud

Gemini South's New Silver Lining

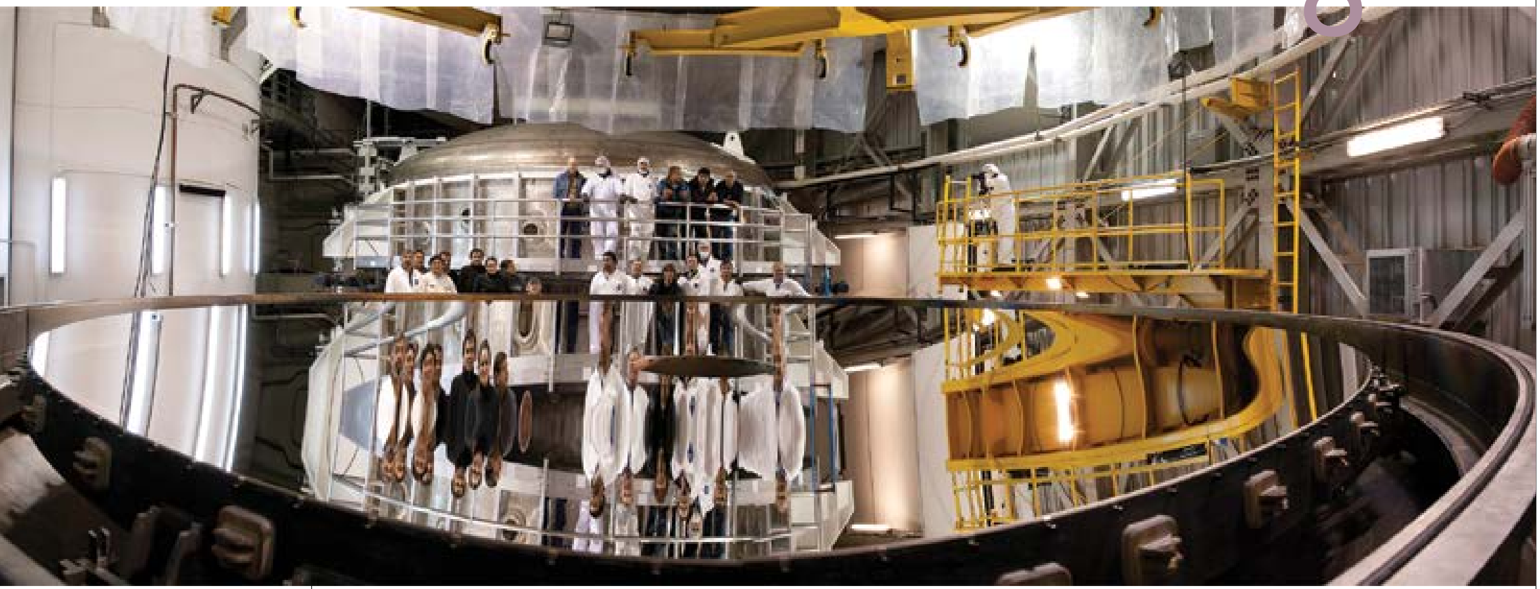

Figure 1.
The mirror coating and support team reflected in the fresh coating on the Gemini South mirror shortly after it emerged from the coating chamber seen in the background.

As this issue of *Gemini*Focus goes to press (mid-October 2010), a pristine new coating of protected silver is reflecting starlight on the Gemini South telescope (Figure 1). The coating, applied to the 8-meter primary mirror on October 8, 2010, is believed to be among the best coatings ever achieved at Gemini. In addition, the process implemented many new safety procedures and refinements that are documented at: *www.gemini.edu/node/11533*

The coating procedure, which tapped the expertise of approximately 30 Gemini engineering staff from both sites, began on September 27th with the beginning of a planned 28-day (including engineering checks on the sky) routine maintenance shutdown. The shutdown, which started with a late-spring Andean snow, also addressed significant issues with the Cassegrain wrap, the acquisition and guiding unit, adaptive optics fold mirror, and various instruments.

As most readers of *Gemini*Focus are probably aware, Gemini uses a unique four-layer protected silver coating process that provides significantly better infrared performance than is possible with more tradi-

tional aluminum coatings. In addition, the process utilized at Gemini results in coatings that last significantly longer than aluminum. The previous coating at Gemini South was applied in 2004.

As the photos in this pictorial show, the coatings reflect well on the Gemini coating process and each of the individuals involved in the process. Look for an exciting time-lapse movie of the coating process soon.

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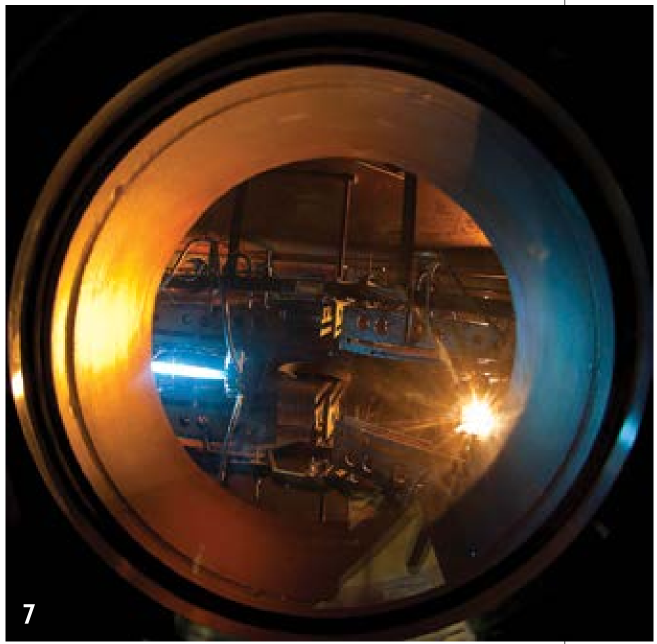
Photography by Manuel Paredes and Joy Pollard

Figures 2 - 7.
Counterclockwise from top right:
2) primary mirror shortly after removal of mirror cell,
3) application of paper towels to absorb acid used to strip off the old coating,
4) cleaning of mirror after removal of the old coating,
5) final cleaning of mirror with carbon dioxide snow prior to coating,
6) concurrent work on Cassegrain rotator,
7) view of mirror during coating with magnetron (left) applying a coating layer.



by Sergio A. Cellone
Favio R. Faifer and Mercedes Gómez

Argentina: Observing with Gemini

Figure 1.
Gemini's François Rigaut explains the details of multi-conjugate adaptive optics.

June 2, 2010. A bright and cold autumn morning at La Plata, Argentina. A few people jog or ride their bicycles under the centenary trees lining the broad streets of *El Bosque* ("The Wood") — a park that houses the Natural Sciences Museum, the Astronomical Observatory, and two football (soccer) stadiums. Since no football match is scheduled, the stadiums are empty; their surroundings look quiet and lonely. Instead, the action seems to have moved to the observatory, where the usual flow of students is notably outnumbered by a gathering crowd of young men and women armed with books and laptops. Shortly before 8:30, they all file into the observatory's conference room, where they wait for "Observing with Gemini," a three-day-long workshop, to start.

Planning for the Future

The 2010 "Observing with Gemini" program was the first dedicated Gemini user's workshop to be held in Argentina since 1999.

After National Gemini Office (NGO) head Mercedes Gómez welcomed the attendees, three short speeches completed the opening act. These were given by Hernán Muriel (President of the Argentine Astronomical Association, one of the organizing institutions), Adrián Brunini (Dean of the Faculty of Astronomical and Geophysical Sciences, the host institution), and Alejandro Cecatto (representing the Ministry of Science and Technology, the other organizing institution).

Figure 2.
Astronomy Ph.D. student José Luis Nilo Castellón from Córdoba National University investigates a multi-object spectrograph mask from Flamingos-2.

Brunini underscored the fact that the nearly 80 Ph.D. students, postdocs, and young astronomical researchers from various Argentine institutions, who had come to learn about Gemini and its instruments and operation, were setting very auspicious prospects for the future of observational astronomy in Argentina.

This was recognized to be particularly true, given some well-known institutional challenges previously encountered by the Argentine participation in Gemini. That situation, in Muriel's words, changed thanks to the "astronomical community, with people who struggled to convince us about the importance of continuing within Gemini."

Muriel also thanked the Ministry of Science and Technology, whose representatives listened to the astronomical community's concerns and undertook the appropriate actions to adequately address them. In turn, Cecatto stressed the Ministry's commitment to continue supporting the Argentine participation in Gemini, as was evident by its active role in the workshop's organization.

Through invited talks — by the Argentine representative to the Gemini Board of Directors, Aníbal Gattone, and Diego García Lambas (of the Gemini Science Committee) — the participants learned about the observatory's operations and instrumentation plans. Mercedes Gómez, in turn, explained the duties and functioning of the NGO. And Juan Carlos Forte gave an enlightening historical review on the Argentine participation in Gemini.

Science and Technology

Following the opening, Gemini Observatory scientists Rubén Díaz, Percy Gómez, and François Rigaut exposed the participants to the scientific and technical aspects of observing with Gemini, the backbone of the workshop. Skillfully and enthusiastically the speakers captured and sustained the audience's attention.

Díaz gave two one-hour talks on near-infrared astronomy with Gemini. These encompassed the assortment of instruments operating, and soon to operate, in that spectral range (GNIRS, NIRI, GS-AOI, Flamingos-2, and NIFS). Percy Gómez also gave two talks: one that focused on optical astronomy with Gemini, another on GMOS instruments and their various modes.

In their talks, both Díaz and Gómez presented the main technical aspects of each instrument, illustrating the science being done with them. The participants were also given the opportunity to see (and touch) real multi-object spectrograph (MOS) masks — an interesting experience, not only for rookies, but also for queue observers who don't ever see the physical result of their work with the mask-making software (Figure 2).

Rigaut, in turn, introduced the participants to adaptive optics with Gemini. The simulations he presented drew widespread surprise and admiration from the audience; the attendees became fully convinced that adaptive optics certainly is a very powerful technique.

Figure 3.
"How can I do that?" — "You just have to click here!" Gemini's Rubén Díaz assists one of the students with her Phase II preparation.

The outstanding capabilities of current and future Gemini instrumentation, clearly explained by the lecturers, soon triggered new ideas among the audience. Coffee breaks and lunchtime provided the opportunity for those ideas to grow; some even began to take shape as future observing proposals. Several principal investigators of recent successful proposals also gave short talks addressing new results with Gemini observations.

Lab Work

The last two afternoons were devoted to the "classroom-mode" of the workshop, using the computer-room facilities. The idea was that a subset of the participants would be trained on how to prepare proposals for observation, both at the Phase I and Phase II levels.

When the workshop's registration opened, the organizers expected no more than 40 or 50 participants, about half of whom would be interested in the laboratory classes. Thus, the computer room of the Astronomical Observatory, with its 25 desktop computers, was thought to be sufficient. However, when the number of registered participants crept up to near 80, with most of them desiring to take the PI and PII classes, it became evident that some sort of imaginative solution would be necessary.

This solution was to bring in small, portable desks and strategically spread them about the room, filling every available free space (except for the very minimum space needed to walk around). A dozen additional students sat at those desks with their laptops. The observatory's technical departments, connected all the computers to the Internet and loaded them with the required software (*i.e.*, the Phase I Tool [PIT], Observing Tool [OT], and Sky Catalog [SkyCat], *etc.*).

For those who have been with Gemini long enough to recall the winding track of the Argentine participation in Gemini, the sight of the computer room, literally flooded by young astronomers working at their proposals, was a particularly impressive and touching experience. It was also striking (and humorous!) to see Rubén Díaz struggling to maneuver between the desks, while explaining how to select the appropriate guide star or fetch the correct library example.

After the workshop ended, one Local Organizing Committee (LOC) member said he was impressed by the participants' interest to learn. "This was great!," he said, recognizing that "our invited lecturers deserve most of the credit, because they gave us very enjoyable, didactic, and interesting talks."

In this respect, Bernadette Rodgers' support was crucial; she was the link between the organizers and the three members of Gemini staff who generously dedicated their time and expertise to guarantee a successful workshop.

The general feeling was that "Observing with Gemini" had met its goal to serve as a first step in training young Argentine astronomers willing to take full profit of Gemini's instrumental capabilities. One idea for the near-future that emerged from the La Plata workshop is to organize a data-reduction workshop, possibly as a joint collaboration between the Argentine, Brazilian, and Chilean NGOs.

In the end, this workshop spurned myriad ideas and interpersonal relationships, and points toward a bright future for Argentine participation in Gemini. The momentum that this workshop initiated will undoubtedly result in many more meetings and workshops and propel the Argentine community in its use of Gemini for exciting future science.

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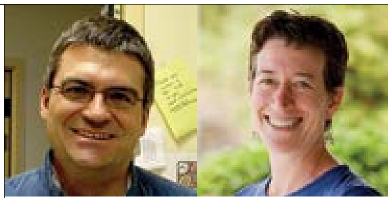
Figure 4.
Participants of the "Observing with Gemini" workshop, in front of the north gallery of La Plata's Astronomical Observatory.

Note: The three authors are members of the Argentine National Gemini Office, department of the Ministerio de Ciencia, Tecnología e Innovación Productiva (MinCyT). They were also members of the workshop's LOC, along with Roberto Gamen and Mónica Oddone.

Photos: Guillermo Sierra



by Thomas Matheson
and Nancy A. Levenson

NOAO-Gemini Data Workshop

During the third week of July 2010, the National Optical Astronomy Observatory (NOAO) and Gemini offered a four-day workshop on Gemini data reduction. The goal was to provide users of the Gemini telescopes with an opportunity to interact with staff from Gemini and the U.S. National Gemini Office (NGO). The users could learn data reduction directly from instrument scientists and get personalized help with their own data.

More than 60 people attended, mainly from U.S. institutions. Several participants came from other Gemini partner countries, including Brazil, Canada, and Chile. Most of them were graduate students. But postdocs, some faculty members, and even a highly motivated high-school science teacher partook in the experience. NOAO provided some travel support, chiefly for graduate students from U.S. institutions. Eight members of the Gemini staff were also present, along with five people from the U.S. NGO, two from the Canadian NGO, one from the Chilean NGO, and five others from the NOAO staff. The total also included three members of the Gemini Data Reduction Working Group.

The workshop began with a general overview of astronomical data reduction. Steve Howell (NOAO) described how CCDs work and the basics of calibration. He also furnished some actual CCDs for inspection. Dick Joyce (NOAO) further explained infrared detectors, highlighting the differences between optical CCDs.

The subject matter then segued to software, with an overview of the Image Reduction and Analysis Facility (IRAF) software from Frank Valdes (NOAO) and a description of Gemini IRAF from Kathleen Labrie (Gemini). Tod Lauer (NOAO) followed with a high-level view of how astronomical images are formed and processed, including the importance of considering the Fourier domain. Abi Saha (NOAO) then discussed photometry and showed many of the pitfalls that users need to avoid.

A talk on adaptive optics from Julian Christou (Gemini), a presentation on low-resolution optical spectroscopy by NOAO's (and co-author of this article) Tom Matheson, focusing on the need for, and use of, good calibrations, and tutorials on the Gemini HelpDesk and the Gemini Science Archive by Gemini's Emma

Figure 1. *Participants at the NOAO-Gemini Data Workshop in July 2010.*

Hogan and Marie Lemoine-Busserole (respectively), rounded off the day.

The workshop devoted the next two days to the specifics of data reduction for Gemini instruments. Rodrigo Carrasco (Gemini) described how to work with Gemini Multi-Object Spectrograph (GMOS) imaging and long-slit and multi-slit data. He went through the specific Gemini IRAF commands and showed how to proceed at each step. Reduction of the nod-and-shuffle mode with GMOS came next, with presentations by Kathy Roth (Gemini). We finished the day with Richard McDermid (Gemini) explaining the reduction of GMOS integral-field unit (IFU) data.

Knut Olsen (NOAO and the U.S. NGO; see Olsen's profile starting on page 53 of this issue) kicked off the third day by showing how to reduce imaging and spectroscopic data from Gemini's Near-infrared Imager. Knut took the bold move of actually reducing the data in front of the crowd, so that they got to see each step as it happened, including the inevitable glitches of data reduction. McDermid then continued his IFU discussion, but this time describing reduction of Near-infrared Integral-Field Spectrograph (NIFS) data.

On the final day, Lemoine-Busserole ended the formal workshop sessions with a brief overview of reduction for mid-infrared instruments. The rest of the day was devoted to providing users one-on-one help to reduce their own data. Individual users were able to get specific answers from Gemini instrument scientists. In addition, Labrie and Hogan provided help with many Gemini IRAF issues. Despite the long hours and full schedule of the previous days, most people stayed until the end of the last day working on their own data.

All of these tutorials and presentations, as well as the sample data used, are available at the workshop web site (*http://www.noao.edu/meetings/gdw/*). In addition, Labrie prepared packages (available at the web site) that will enable a complete install of IRAF and Gemini IRAF for the more popular operating systems. This software represents a "snapshot" of a current installation. It is not a full, supported package and is not guaranteed to work on every system, but the overwhelming majority of workshop attendees who used them were able to get IRAF installed.

Both NOAO and Gemini plan to continue to hold such workshops in the future, and the content will be available for those who cannot attend the workshops. Given the enthusiasm shown by the attendees, clearly there's a strong interest in learning how to work with Gemini data. We hope to build on the success of this workshop to develop a new generation of observers who will fully utilize the capabilities Gemini has to offer.

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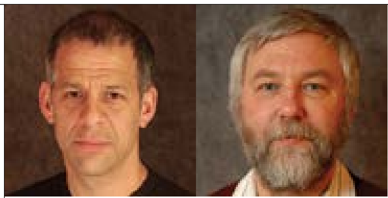
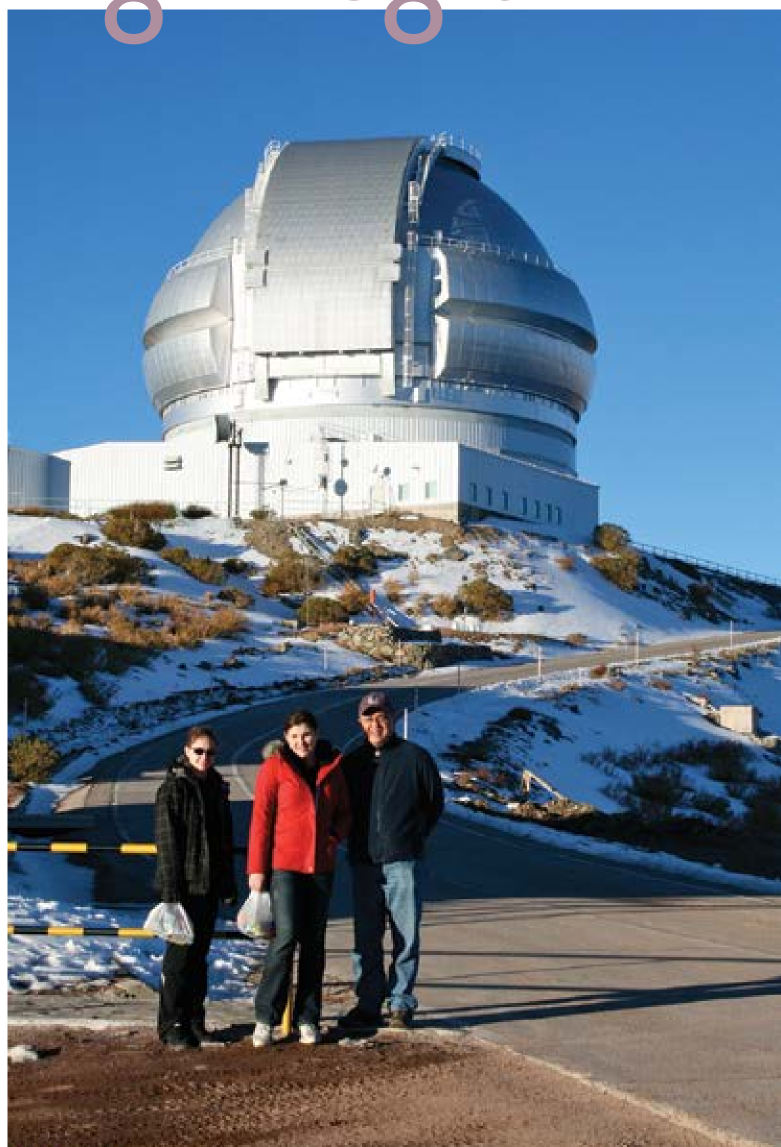


by Stéphane Courteau and David Hanes

Canada Engages in Gemini's Student-Training Program



With queue-scheduled telescope operations increasingly supplanting classical observing modes, students of observational astronomy are no longer required to train at a telescope. Consequently, many important skills are becoming unfamiliar to our young astronomers. Indeed, now that queue-acquired or archived data can be delivered directly to any computer in the comfort of an office or home, students are losing the ability to develop a comprehensive strategy for an observing run. Not only do they miss out on learning how to make real-time decisions at the telescope in the face of changing night-time conditions, but also on developing the ability to assess and maintain data quality, thereby expediting program execution; the list goes on.

Last February, graduate students Melanie Hall, Joel Roediger, and Jonathan Sick (Figure 2, next page) joined supervisor and author Stéphane Courteau at Gemini North's special student training to nurture these important observational skills. The experience — a wonderfully instructive three-week visit on the Big Island, shared between the Canada-France-Hawai'i Telescope (CFHT) and Gemini North — was a tremendous opportunity for

Figure 1. *(previous page) Queen's University students Amanda Schembri (left) and Ainsley Campbell (center) with Gemini's Henry Lee at the Gemini South telescope.*

the students to learn about the challenges of setting up observing programs, improve their ability to write effective proposals, and develop a deeper appreciation of instrumental (Phase II) intricacies. Exposure to the suite of on-site instruments served to expand their scientific horizons, and may have even inspired subsequent science projects. Moreover, their personal interactions with members of the observatory staff resulted in lasting ties with the very people whose knowledge and skills are important ingredients in the eventual success of an ambitious observing campaign.

During the part of the trip specific to Gemini, Melanie, Joel, and Jonathan first spent five days on the summit of Mauna Kea, where they witnessed queue operations in practice at Gemini North. (Other student trainees at Gemini North have, on occasion, stayed on the summit for more than two weeks.) Once back down at the Gemini Headquarters in Hilo, they enjoyed coordinated meetings with astronomers, instrument engineers, data-processing and archival specialists, and many others. These sessions gave the students invaluable exposure to every facet of an observatory's operation.

Following his experience, Joel commented that the training at Gemini North "really helped cement concepts and techniques that one is introduced to in a traditional instrumentation course. We were especially fortunate that nearly every instrument in Gemini North's arsenal saw some dark sky during our training."

More recently, Ainsley Campbell and Amanda Schembri, both students of author David Hanes, visited the Gemini South telescope for a similar learning experience (Figure 1, previous page). This group spent a total of 10 days in Chile, with the time divided between La Serena and Cerro Pachón. The students were treated to a full tour of the facilities, in-depth discussions with the staff astronomers about the suite of facility instruments and protocols for their operation, and real-time experience with the efficient and effective use of instruments on the telescope. They were particularly interested in witnessing the use of the Gemini Multi-Object Spectrograph (GMOS) on Gemini South, since the theses of both students benefited enormously from the excellent data acquired with that versatile instrument.

"Watching the system support associate and senior astronomer communicate throughout the night revealed a delicate balance between optimizing the scientific data and protecting the instruments collecting it," says Ainsley, who also noted that variable weather conditions posed a constant challenge for the Gemini staff, but "reinforced the importance of agile problem-solving skills for every scientist."

The authors hope that the experiences of these students will remind the entire Gemini user community about the availability of these training opportunities at Gemini (and also at CFHT, for our Canadian readers). Although Gemini cannot defray travel expenses or local accommodations, Mauna Kea or Cerro Pachón residency can be arranged. As for the additional expenses, one can think of such opportunities as akin to those provided by dedicated winter or summer astronomy schools. The Gemini student-training program can provide benefits to students that are quite literally priceless. Please consider participating in this opportunity!

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Figure 2. *Queen's University students Joel Roediger (left), Jonathan Sick (second from right), and Melanie Hall (right), join Gemini system support associate Anthony Matulonis (second from left) and astronomer Chad Trujillo (center) in the Mauna Kea control room at Gemini North. Training that night focused on the science operations of the adaptive optics system (Altair).*

by Bernie Walp

Knut Olsen: a Jack-of-all-Trades

Tyra and Knut Olsen visiting CTIO in Chile in November 2009. Tyra was born in Chile, while Knut worked at CTIO for eight years.

Astronomers once did everything for themselves. Alone on summits, they made finder charts, cooled their instruments with nitrogen (or dry ice and alcohol), made tea, cranked telescopes into position, guided their instruments by hand from a chair at the prime focus, and exposed and developed their own film plates. That was before large 8- to 10-meter-class telescopes came into use, long before remote observing and queue coordination became commonplace, and before astronomers morphed into highly specialized researchers. Back then many observational astronomy job descriptions called for people who were, in essence, "jacks-of-all-trades." The days when one person did all those things as part of their work are long gone. But, there are still jobs in astronomy that do require a jack-of-all-trades, and Knut Olsen has one of them.

"In general," Olsen says, "my job is to ensure that U.S. users get the support they need to make the best use of the U.S. public observing system, which includes Gemini." Now that he has taken over leadership of the U.S. National Gemini Office (NGO), the Tucson-based Olsen finds himself drawing on his own broad range of experiences, observing modes, and many areas of specialized knowledge.

Yet, even though his job is to help astronomers get the best science they can from the complex instruments available to them, Olsen maintains that users do have an important role to play in the process. Olsen believes that in spite of (or maybe, because of) the community's extensive reliance on remote operations and service observing, many telescope users can benefit from more regular contact with a telescope and its instruments. "Closer contact brings about better science and a more successful discovery process," he says.

Olsen's career underscores this outlook. Though occupying a senior position in the world of astronomy, he continues to live very close to the instrumentation and data collection processes. In 2007, after eight years as a National Optical Astronomy Observatory (NOAO) staff astronomer at the Cerro Tololo Inter-American Observatory (CTIO), Olsen was appointed to the U.S. headquarters at NOAO. Today, one of his many charges is to manage user support for NOAO's Systems Science Center. This unit supports instrument users and promotes cooperation among the many NOAO facilities and user communities.

The recent addition to Knut's responsibilities as "U.S. NGO Head" for Gemini Observatory seems to fit him well in several ways. Gemini NGOs serve as advocates for the needs of their users, making sure that astronomers understand, and can effectively put, Gemini telescopes and instruments to their best use. With the United States now receiving the greatest share of all Gemini time, Knut serves and represents the needs of a complex and growing group of scientists.

The U.S. NGO is the focal point for assembling the observing programs for U.S. astronomers. Olsen answers user queries about the proposal and scheduling process (at an increasing rate as deadlines approach), and clarifies information available from instrument scientists. NGOs are also charged with "Phase II Checking," the critical and detailed technical examination of each scheduled observation. NGOs must ensure that each target can be observed under current sky and weather conditions in the modes a Principal Investigator (PI) requests, that it can be reached on the astronomical calendar, and that it meets a variety of other criteria aimed at assuring usable data.

Great observatories make great science possible, Olsen believes, by helping PIs as fellow researchers. In keeping with that view, while back at CTIO supporting several spectrographs and cameras for observers, he made use of the same instruments and telescopes for his own research. "It is really important for observers to see and know a telescope," Knut says. "Good science requires a good understanding of instrument processes, capabilities, reduction methods, and calibrations."

Olsen traces his interest in astronomy to the time when he was five years old and his parents, both Norwegian academics, brought him to a large U.S. toy store. A 4-inch telescope both thrilled and disappointed him. "Even with this telescope, the stars are still just little points of light," he remembers thinking. "But also I found the Milky Way overwhelming. And today, the study of stellar populations in nearby galaxies is one of my strongest research interests."

Eventually Knut's wonder and curiosity lead to his undergraduate work at Swarthmore College in Pennsylvania where he was awarded a special major in physics and astronomy. From there, Olsen earned a doctorate in astronomy at the University of Washington in Seattle and launched his long run at CTIO. He moved from his work on a post-doctorate fellowship to working as an instrument scientist and taking on staff astronomer responsibilities. At CTIO, he performed and published a large body of research into the stellar populations in the Large Magellanic Cloud, and the globular cluster systems of galaxies beyond the Milky Way. His work included new estimates of the ages and stellar concentrations of galaxies themselves.

Somewhere in his busy post-graduate life, Knut found time to marry fellow astronomer Dara Norman. They met in graduate school and have been married since 2003. While in Chile, she worked on the CTIO staff with research interests in gravitational lensing and large-scale structure. Currently, Dara and Knut have offices in the same building in Tucson, and lead the hectic, but happy, life of married astronomers. They have a daughter, Tyra (shown in the photo on page 53), and are expecting a son later this year.

Tyra, who has just entered kindergarten, has shown some interest in following in her parents' footsteps, and has traveled with Knut on several trips to Norway. He notes that she once attained platinum elite status on American Airlines. "I have a picture from one of our trips to Norway — a picture of us when we got bumped up to business class on the way back. In the picture she looks like she's just luxuriating in this business-class seat and eating ice cream," he says. "She's got a pretty distorted view of what flying on airplanes is like."

Olsen sees his daughter as something of a miracle and ponders what her future profession might be. "I think it would please me if she wanted to be a scientist. If she said she wanted to be an astronomer, I'd have to ask her if she knew what she was getting herself into," he laughs. "I'll be proud of whatever she wants to do. Right now it's whatever role models that she has — she says that her profession will be a teacher during the daytime, she'll be an astronomer at night, and then a hairdresser on the weekends!"

Though his career may have carried him into the rooms of science management, and his personal life into the realm of proud fatherhood, Knut is no stranger to the nighttime excitement of observation and discovery. In 2006, he led a study of the stellar population of the Andromeda galaxy using Altair, Gemini's near-infrared adaptive optics system. This work has led to a new understanding of that galaxy's star-formation history and age. In September 2009, responding to an urgent e-mail request from asteroid scientist and Gemini PI Franck Marchis, Olsen and a collaborator interrupted a Keck II observing run to take images which provided the first independent confirmation of two moonlets around the asteroid 93 Minerva.

How does Gemini's future look to an experienced astronomer such as Knut Olsen, a man so well-positioned among users at so many observatories? It's all part of the larger challenge of the changing, and increasingly complex field of big-telescope astronomy. "One night of the Gemini queue is a night of multiple wavelengths, using several instruments, in both spectroscopy and imaging, with and without AO, laser or natural guide stars. It's a lot to ask of any observer, even one with a Ph.D., to work continuously and competently, switching among so many observing modes," he says.

As Gemini continues to evolve, Olsen sees that user representatives must involve themselves more deeply to advocate the improvements PIs need in software, instrument development and telescope operations.

Olsen sees it as the NGO's responsibility to help get clear information to users so they know what capabilities they can propose to use, clarify logistics for PIs once time is allocated, and ensure, once observations are made and data recorded, that the experience is understood clearly. "NGOs will likely have a major role in defining better data reduction tools for Gemini, better web pages and cleaner documentation," he points out.

"Knut Olsen does take a very well-rounded view of observational astronomy," says Alexander Fritz of Italy's National Institute for Astrophysics in Milan. As a former Gemini astronomer, Fritz pointed out Knut's exceptional qualifications. "Knut covers many aspects of a modern support astronomer, such as telescope operations and instrumentation support, research, software development and management," he says.

As the observatory continues to change, Olsen will probably feel more and more like a modern-era, "jack-of-all-trades" astronomer as he makes use of his many perspectives and interests on behalf of Gemini's users.

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By Lauren Gravitz

Marilia Sartori: Brazil's Gemini Connection

Marilia with her husband Bruno Castilho and their son Bernardo at the lake of the Federal University of Itajubá.

The year was 2004, and Marilia Sartori was finally making a living as an astronomer. She was working at the Laboratório Nacional de Astrofísica (National Astrophysics Laboratory) alongside her husband, Bruno Castilho, in Itajubá, Brazil. She had completed her post-doctoral work on stellar nurseries and the births of young stars, and she was on track for a productive career in astronomy studying star formation. But, a different kind of birth — that of her son Bernardo — changed everything.

Bernardo was born 12 weeks early and weighed less than two pounds. He was so small and fragile that he was hospitalized for 80 days. Sartori put her astronomy career on hold and dropped everything to stay home and care for him. “When he left the hospital, he was okay,” she says. “He was healthy, but we didn’t know if he would grow normally, or what special needs he might have”. To ensure he developed normally and successfully hit his developmental milestones — things like sitting, standing, walking, and talking — he needed some professional support early in life.

For three years, until Sartori was convinced that Bernardo was developing as he should, she was there for every uncertain step, providing the attention he needed to thrive. It was, in many ways, ideal training for her next job. When Sartori went back to work full time in 2007, it was as the head of the Brazilian National Gemini Office (NGO) in Itajubá, where she now spends a good portion of her time nurturing the relationship between Gemini and its Brazilian users.

“Before my son, I was not so… patient,” she explains, choosing her words carefully. “You have to listen with care to others and try to understand what they are feeling and what they are thinking. Before, I think I was more reasoned — I would think, ‘This is right, this is wrong, and there is nothing in between.’ But now I’m more flexible.”

As liaison between the observatory and its observers, that flexibility has served her well. Sartori cultivates the relationship between the two groups, helping address the users’ concerns while ensuring they get the training and support they need. “Just as Marilia is a careful and dedicated mother, she is also dedicated to the people who need her help during the telescope proposal submissions,” says Jane Gregorio-Hetem, a professor of astronomy at the University of São Paulo, who was Satori’s postdoc supervisor. “While it may not be good for her to spend more time working for others than for herself, it is great for the people counting on her.”

Sartori was just a young girl when she first learned about the Solar System in an elementary school class. It captured her attention and her imagination like nothing else, and by the age of 14 she had wheedled a telescope from her parents for Christmas — a lovely 4-inch Newtonian she still uses today. But it never occurred to her that astronomy could be a way to make a living, since professional astronomy was not a common career choice in Brazil at the time, Sartori recalls. Rather, she thought she was probably going to be a chemical engineer like her father, who had a strong influence on her and was a daily example of someone dedicated to his work. Engineering seemed an obvious career choice for someone with a flair for physics and math.

While pursuing her engineering degree at the Universidade Federal de Rio de Janeiro, Sartori peppered her coursework with astronomy classes, but didn’t commit to switching majors — at least, not at first. “It was tempting to choose astronomy at the time,” she says, “but I didn’t know what the work of a professional astronomer would be like.”

Ultimately, the lure of the sky proved too strong, and mystery won out over practicality. Sartori changed course, and it was during her undergraduate studies that she discovered the very young stars that are still the focus of her research today.

These so-called “pre-main-sequence” stars are still babies, stars that have yet to reach the ripe old “middle age” of 5 billion years or more. Researchers think that these young stars emerge from their nurseries in clusters and share similar characteristics with the molecular cloud that birthed them. “But, sometimes, when we find young stars, they’re not related to any cloud or groups of stars,” Sartori says, “so the formation of these stars is not clear.”

For her graduate research, Sartori and her Ph.D. advisor, Jacques Lépine, a professor of astronomy at the Universidade de São Paulo, examined a group of star-forming regions that were in close proximity, but that astronomers thought to be separate. By showing that these regions shared not only similar ages but also the same kinematics, Sartori was able to prove that the groups were related and may actually be part of the same galactic spiral arm.

She also took a hard look at individual, isolated stars to see if she could determine whether they are related to a nearby star-forming region — a difficult prospect, since the same region of sky can have groups of stars that formed during different epochs. At the time, she concluded that the single stars she was looking at could potentially be related to the known star-forming region. "But now I can see it's not that simple," she says, and the next big question she plans to address is whether isolated star formation is really feasible. "Some people say that very small clouds can form only one star, but I'm not sure whether this is the case, whether these nearby young stars are really isolated." One day, she says, she hopes to look further into the formation history of these so-called isolated stars to see whether they developed independently of the other young stars in that region.

Studying young, pre-main-sequence stars requires an ability to see not just how things are, but to think about how they were and what they will be — to have an understanding of how they evolve. "To understand our Sun, and to understand the formation of our Solar System, we have to study all the things that are in situations we have been through or are going to go through," Sartori says. "That's the importance of it — to understand where we came from and where we're going."

In many ways, that's precisely what she's doing at Gemini — seeing the Brazilian NGO not just for what it is, but how it could be, and constantly thinking up ways for it to evolve and work ever harder for its members. "Marilia does not like to have shallow solutions for the issues that she faces — she always goes deep inside the problems and never gives up until they are satisfactorily solved," says Gregorio-Hetem. "She is very persistent and always creative in looking for different solutions."

And, her friends say that Sartori has the organization and the determination to see it through. "She knows what she wants, and she is able to argue to defend what she thinks are the correct positions," Lépine points out. "This is a good trait for being a Brazilian ambassador at Gemini. We are a minor partner, and it would be easy to let the others make decisions. But, we must be able to defend our interests."

Since her arrival three years ago, Sartori has increased the flow of astronomers to and from the Gemini sites at Mauna Kea and Cerro Pachón, providing both on-site and remote training for the users with whom she works. She has introduced classes on preparing observational proposals, regularly gathers Gemini astronomers to talk about the future of Brazilian participation in the consortium, and continues to encourage open discussion about current and future directions of the telescope.

Looking back, Sartori sees beyond her accomplishments and envisions ways that the NGO can be even better. Now, she says, the challenge is to create a better organized NGO, an NGO with improved relations between the users and Gemini — and to really represent the users' interests. "My biggest concern, always, is how we can do better than we are doing now."

In Gemini, just as in her studies of the sky, Sartori will always be searching for a better answer. "I think there are no simple questions and no simple answers for anything in astronomy," she says. "But this is how science is made. We try to — with some small parts — we try to build the whole picture."

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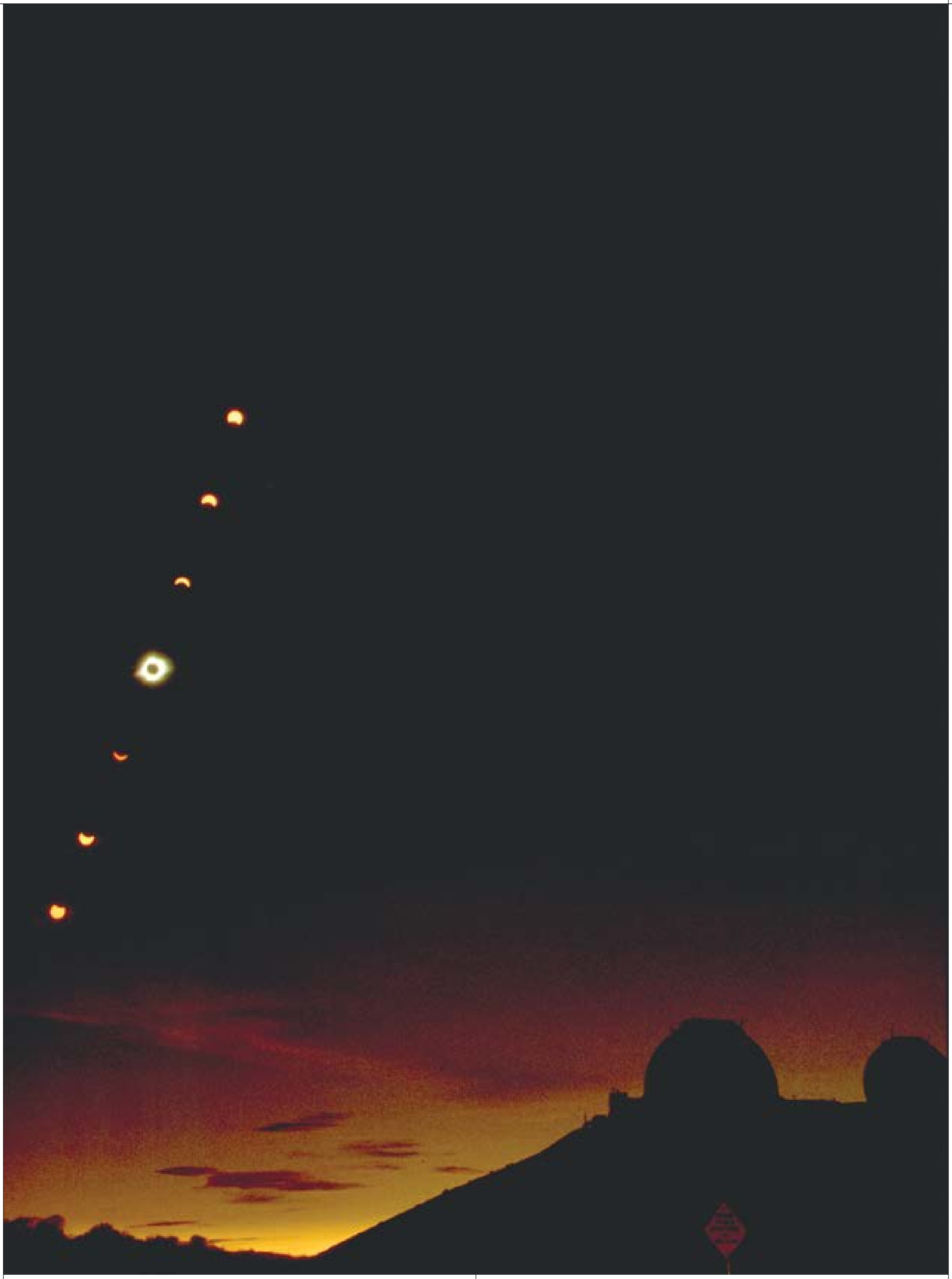

This archival image of the 1991 total solar eclipse over Mauna Kea shows the Canada-France-Hawai'i Telescope at the far right and the NASA Infrared Telescope Facility to its left. The future location of Gemini North would be to the right, and out of this frame. Gemini's Public Information and Outreach Manager Peter Michaud obtained this image during the famous eclipse that passed directly over the summit of Mauna Kea on July 11, 1991, a few minutes after 7:00 am. The sequence used traditional 35-mm slide film (all on one frame) with a 50-mm lens and a neutral density filter for the partial phases (every 15 minutes). Totality was captured with no filter and shows the surrounding landscape and the edge of the Moon's shadow just above the horizon. The camera's location is where the Keck II telescope is now located. Peter Michaud can be reached at: pmichaud@gemini.edu

Gemini Focus

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