GeminiFocus

December2007 Newsletter of the Gemini Observatory

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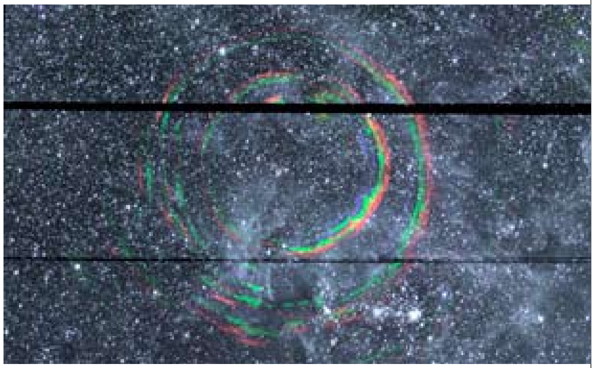
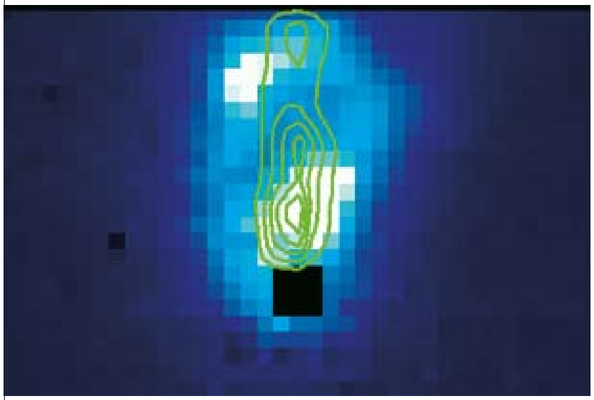


On Cover: GMOS-South image of NGC 3311/09, see article page 10



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User Profiles

GeminiFocus

by Doug Simons
Director, Gemini Observatory

Director's Viewpoint

On August 7, 2007 a milestone in sports history was reached that many thought would never occur. On that day, Barry Bonds surpassed the home run record owned by Hammerin' Hank Aaron for several decades—a record previously held by the legendary Babe Ruth. Interestingly, Bonds also has the most walks in baseball history by a wide margin, meaning his focus on the "long ball" was successful despite being intentionally walked thousands of times over his career. Given the diversity of readers (and sports fans!) across Gemini's community, I'm sure not all would agree that the lifetime home run total in professional baseball is the most revered record in all of sports but it certainly ranks among the top ones. In any event, whether you love or hate Bonds (yes, it tends to be one or the other), just one look at this guy at the plate and one thing is obvious—he knows how to swing a baseball bat.

The records Tiger Woods has accumulated in his relatively short career on the golf links are no less spectacular. He has won more than 60 titles in his career, including 13 so-called "major" golf tourneys, amassing an astounding ~$75,000,000 in winnings in the process. Woods has finished either first or second in about half of all the PGA tournaments he has entered and has been ranked #1 in the entire world for more consecutive and total weeks than any other player. All of this in a professional career that only spans about 10 years. He earned these achievements while playing, on average, about a third fewer golf tournaments than the average professional player each year. In other words, like Bonds, Tiger Woods' achievements have been constructed through highly focused effort, not by seeking every opportunity possible. And like Bonds, just one look at Tiger and it's obvious this guy knows how to handle a golf club.

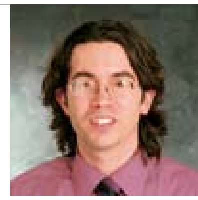
What lessons can we take from these professional athletes and why are they even relevant to Gemini? The answer has been staring at me since I became Director, but I confess I have only recently come to recognize and appreciate it. It has been camouflaged in the complex high-tech environment modern major observatories like Gemini operate in, which includes machines like magnetrons, cryogenic detectors, sodium lasers, nested servo loops, and control systems utilizing literally hundreds of processors that work concurrently every night to support every science program executed in our queue. This high-tech menagerie, which is replete with complexity, naturally tends to blind those caught in it from the simple lessons that Barry Bonds and Tiger Woods used to build their astounding careers. Yes, the philosophy of these winners is really quite simple—it's called focusing on the fundamentals. Tiger Woods does not rely on the latest in golf club technology to keep well ahead of the pack. He does it by relentlessly focusing on the fundamentals of his swing, the position of his feet, and his follow-through. While the fundamentals at Gemini are different, their importance to our success is the same.

The key for a young facility like Gemini to becoming a truly great observatory is ultimately linked to the extent to which our staff masters the fundamentals of running a complex and highly distributed network of systems. These fundamentals aren't mysterious or difficult to identify. They are essentially the same as those needed by any highly distributed business and include such challenges as communications, priorities, planning, and execution. It is tempting to seek solutions to these challenges via today's ever-advancing technologies that are touted to "make life simple." In practice though, such high-tech tactics frequently distract us from the fundamentals of running organizations that are actually grounded in human behavior, not integrated circuits. Let me elaborate on this.

At Gemini, the senior management team annually interviews a large cross-section of the staff to understand various perspectives on what the observatory is doing right and wrong, to garner ideas on how we can improve both the quality and quantity of our scientific product, to improve as a team and to come to grips in a highly open and visible manner with the "brutal facts" of our organization. It's a sobering process but an essential one if we are to build the best team possible at Gemini and fulfill our true scientific potential. Among the many comments we heard through this process is that there is "lots of e-mail at Gemini but not enough communication." Sound familiar? Again, this problem isn't deep but it is amazingly easy to overlook when we are immersed in the complexity of running a high-tech facility like Gemini. How should Gemini respond to this insightful criticism? Perhaps we should respond by putting a cell phone in the pocket of every Gemini employee or forcing even more meetings into our busy schedules to drive more face-to-face dialog. Those strategies will make an impact but they will not improve the staff's fundamental communication skills. Increasing the bandwidth between people may help increase information exchange, but that alone will not help with actual human communication which is fraught with misunderstandings, filters, false perceptions, and stories. These all conspire to render our clever tools of communications dull and only marginally helpful. Instead, as part of Gemini's program for professional development, we have begun comprehensive training of our staff in the power, meaning, and methods of communication. The response to this training by our staff has been overwhelmingly positive. These communication skills are useful not only at work, but because communication is universal and foundational to human interactions, this training helps Gemini's staff grow as a team and as individuals, with benefits felt in our offices and in the homes of Gemini's hanai (extended) families in Hawai'i and Chile.

Mechanical Engineer, Briar Schumacher and Mechanical Technician Helper, Rody Kawaihae tag-team a project at Mauna Kea.

On many occasions I have likened myself to the Gemini staff as a head coach rather than a director. Good head coaches always stress the fundamentals of the game because they understand it is impossible for a team to reach its real potential if it consists of players without solid fundamental skills. Whether it is swinging a baseball bat or operating the world's foremost infrared ground-based observatory, we cannot escape the need to build our fundamental human skills to reach our potential in whatever game of life we play. This is because humans are at the core of all our activities. At Gemini Observatory, we are determined to look beyond the confines of technology, to develop our fundamental skills as a world-class team, and to deliver a transformational scientific product to our community for the ultimate benefit of humanity.



by Jason C. Cook

Possible Evidence for Surface Renewal on Charon

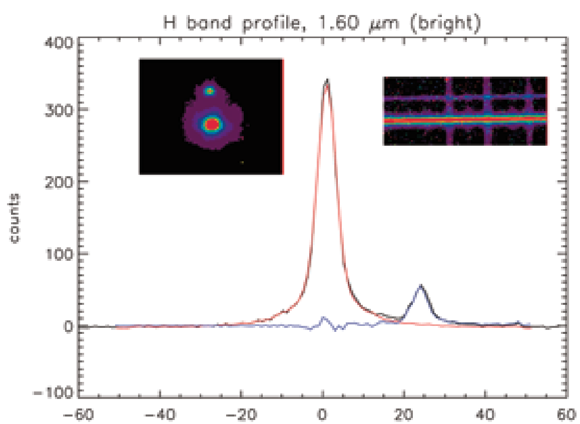


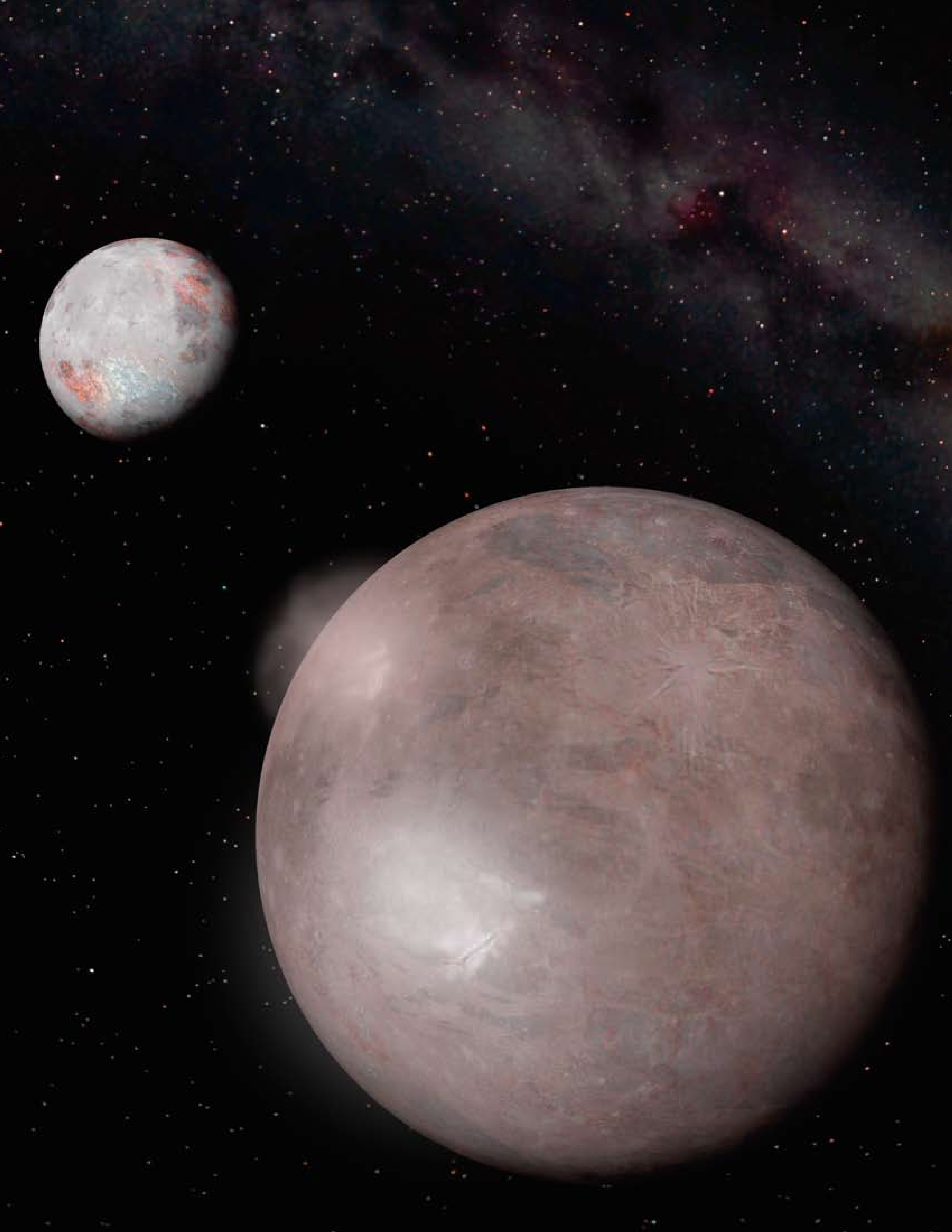
Figure 1.
An image of Pluto and Charon in H band is shown in the upper left. The upper right inset shows a section of the 2D spectra of Pluto and Charon centered at 1.60 microns. The profile of Pluto and Charon derived from the upper-right image (black line), a mirrored Pluto profile (red line) and the residual (blue line) showing Charon's profile by itself.

Figure 2.
(Facing page) an artist's conception of Pluto and Charon, showing its possible plume activity. Image created by Mark C. Petersen, Carolyn Collins Petersen (Loch Ness Productions) and Richard Wright (Software Bisque).

Charon, the largest of Pluto's three satellites, likely has a surface composition that is similar to many Kuiper Belt Objects (KBOs). Increasing our understanding of this icy world gives us a true glimpse into the realm of the Kuiper Belt. Because Pluto is about two magnitudes brighter than Charon, and the separation between these two worlds is always less than 0.9 arcseconds, observations of Charon are typically contaminated by scattered light from Pluto. However, during the late 1980s, Pluto and Charon were aligned in such a way that from our point of view on Earth they eclipsed each other every 3.2 days. These "mutual events" allowed observers to obtain the first spectrum of Charon free from the contamination of Pluto's scattered light. The data showed that Charon's spectrum lacks any of the deep methane (CH_4) absorption features seen on Pluto. Instead, its spectrum showed wide absorption features at 1.5 and 2.0 microns, characteristic of water ice, but not much else (including whether the ice was in the crystalline or amorphous state). Little else was determined about Charon's surface until early this decade.

Observations from the Hubble Space Telescope, which clearly resolved the two bodies, and observations from the W.M. Keck Observatory, which relied on moments of better-than-average seeing, showed an additional absorption feature at 1.65 microns, indicating that the water ice was in the crystalline state. This was somewhat surprising since crystalline water ice forms when amorphous water ice is warmed to over 100 K. The relationship between crystallization temperature and time increases exponentially as temperature decreases, such that at around 80 K it would take about the age of the solar system for amorphous water ice to crystallize. The temperature of Charon, as determined by the 1.65-micron feature may reach 60 K, but would never exceed 80 K. Therefore, some other mechanism must be responsible for heating the surface.

Crystalline water ice was not all that was detected in these observations. A second feature was seen around 2.21 microns. However, this feature was only a few pixels wide at best and was seen at just above the level of the noise in these data sets. Nonetheless, the observations suggested the feature could be due to ammonia (NH_3), ammonia hydrate ($NH_3 \cdot H_2O$), and hydrogen cyanide (HCN). It was clear that observations at higher spatial and spectral resolution would be needed to understand this feature.



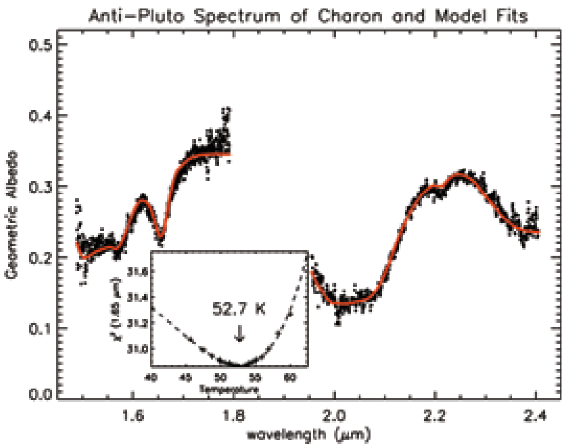


Figure 3.
Observed spectra (black dots) and model fit (colored line) to the anti-Pluto face of Charon for crystalline water ice, dark neutral absorber, and ammonia dihydrate. The inset shows χ^2 as a function of temperature for fits between 1.60 and 1.70 microns only.

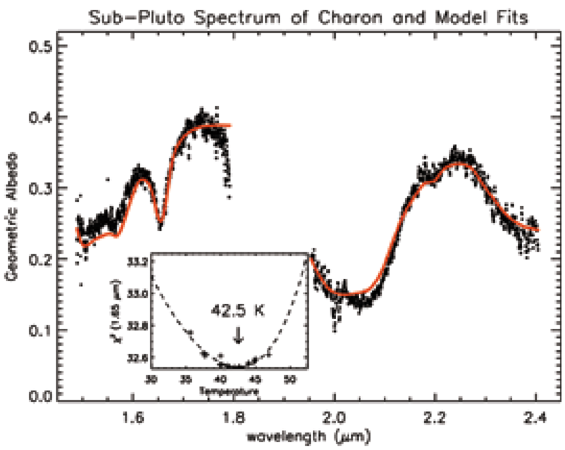


Figure 4.
Identical to figure 3, but shows the sub-Pluto hemisphere of Charon and is modeled with ammonia hemihydrate instead of ammonia dihydrate.

We obtained new observations of Charon in 2005 using NIRI and Altair, the adaptive optics (AO) instrument on Gemini North. In AO mode, Pluto and Charon were easily resolved (Figure 1 on previous page). The observations were made when Pluto and Charon were at minimum separation (0.4 arcseconds, typical for good seeing from Mauna Kea without AO), thus sampling the anti- and sub-Pluto hemispheres of Charon (Figures 3 and 4). These observations revealed the feature near 2.21 microns on both hemispheres. On the anti-Pluto hemisphere, the feature was identified as ammonia dihydrate ($NH_3 \cdot 2H_2O$). But on the sub-Pluto hemisphere, the feature had a minimum closer to 2.20 microns, suggesting this may be due to a different hydration state, possibly ammonia hemihydrate ($2NH_3 \cdot H_2O$) (Figure 5).

Both crystalline water ice and ammonia hydrate have limited lifetimes on Charon, suggesting that its surface is renewed by some mechanism. Crystalline water ice can be amorphized given a dose of radiation equivalent to 2-3 electron volts per molecule (eV/molecule). It should be noted that this dose is valid for temperatures of 50 K, but at 70 K the necessary dose may be as high as 100 eV/molecule. There are two sources that might provide this energy. First, Lyman-alpha photons (at 10.2 eV) have been shown to convert crystalline water ice to an amorphous state (that is, without a crystalline structure). However, if a photon of 2-3 eV is all that is necessary, then sunlight out to 600 nanometers may also amorphize the ice. If this is true, then the crystalline fraction is reduced by 1/e (37%) down to a depth of 1/3 millimeter (the depth probed by H- and K-band observations) in about 50,000 years. Second, at Charon's expected cosmic ray flux the crystalline fraction is reduced by the same amount at the same depth in about 1.5 million years. Thus, total amorphization must take place on time scales of a few million years or less. And, like water ice, cosmic rays will also remove NH_3 in about 20 million years.

We examined several mechanisms which could produce freshly crystallized water ice, such as impacts, solid-state greenhouse, solid-state convection, and cryovolcanism. The rate of crystallization for these mechanisms, except cryovolcanism, was too slow to explain crystallization in less then a few million years. But, how can cryovolcanism take place on a small body such as Charon? It has been shown that an object with an 800-kilometer radius that is completely differentiated into a rocky core and ice layer should have frozen out (that is, be completely frozen today). However, this is not the case for Charon. Chemically, the addition of ammonia to water suppresses the melting point of pure water from 273 K to as low as 176 K for an ammonia-water mixture of about 33%. This is known as the ammonia-water eutectic. Based on solar nebula models, the total abundance of ammonia is 15% at most. Observations of comets show the ammonia fraction is typically around 0.5%, and no greater than about 1%. This abundance may be a lower limit since even a comet with a thousand year orbital period may have circled the sun millions of times, preferentially outgassing the more volatile NH_3.

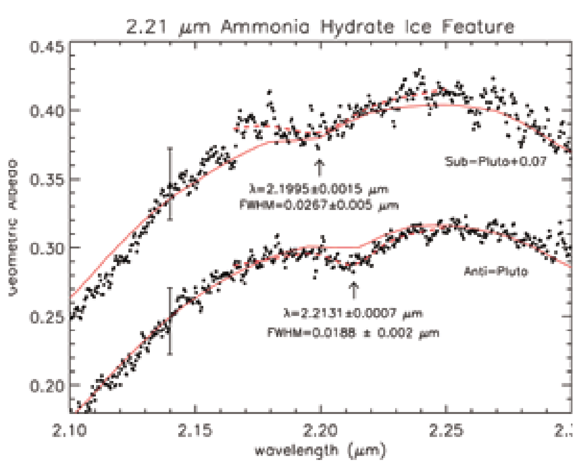


Figure 5.
The 2.21-micron feature shown up close for the anti- and sub-Pluto hemispheres of Charon. The solid red line shows the best fit model. The dashed red lines are Gaussian fits to the ammonia hydrate feature with the minima indicated in the figure. A representative error bar is shown.

Relying on steady-state models, we assumed that Charon is differentiated into a rocky core with a solar abundance of ^{40}K (potassium-40) and an icy shell with various amounts of ammonia. The decay of radiogenic material in the core produces a flux of about 10^{-3} W m^{-3} at the surface. By knowing the flux and temperature (about 50 K) at the surface, and thermal conductivity for ammonia-water ice, we were able to derive the thermal profile of the interior. At 16% ammonia, an abundance similar to the maximum allowed in solar nebula models, the models are still insufficient to reach the melting point (196 K) for this ammonia-water mixture. In the past however, the radiogenic heating should have been about nine times greater than today. So clearly, Charon can not be treated as a steady-state system.

We then investigated time-evolutionary models, starting with a homogeneous mixture of ice and rock. These models show that within the first two billion years, most of the rock migrates to the center, heating reaches a maximum, a liquid ocean forms, and a homogeneous layer of rock and ice remains. These time-dependent models are favorable for two reasons. First, the rock-ice crust has a lower thermal conductivity than pure water ice. This aids in retaining heat in the liquid layer. Second, radiogenic heat released in the first two billion years is stored as latent heat when the ice melted, and released upon refreezing. This extra energy source can account for an additional 30% of the surface flux. As the ocean cools, pure water ice preferentially freezes, concentrating the ammonia fraction and allowing the abundance to reach the ammonia-water eutectic. If the ammonia fraction increases above 33%, then ammonia monohydrate is preferentially frozen out, driving the system back to the eutectic. These time-dependent models show that Charon may still maintain a liquid layer that is about 20 kilometers thick today.

If there is a liquid layer, then how does liquid reach the surface? As the ocean freezes, the ice will occupy 7% more volume than in its liquid phase. Since the ocean is bound by the core and ice shell, the pressure will increase as the volume of liquid decreases. The increasing pressure might then lead to cracks at the base of the ice shell. Models of cracks in Jupiter's moon Europa suggest that they are initiated from the base of the ice layer, not from the surface. The models also show that once the crack reaches a critical length (on the order of a kilometer), it will then self-propagate toward the surface on timescales of a few hours. Liquid from below will be forced up through the crack to coat the surface as it freezes. The same processes may be taking place on Charon, allowing for the surface of Charon to be renewed. The detection of ammonia hemihydrate suggests a non-equilibrium process may be taking place. Perhaps freezing along the crack walls reduces the water content, increasing the ammonia abundance above the eutectic value.

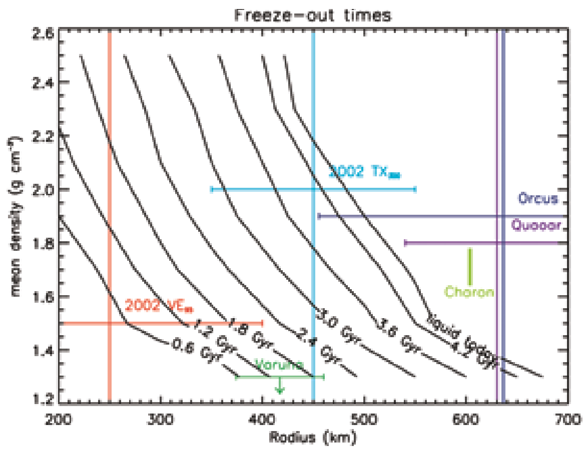


Figure 6. *Freeze-out time contour plot of density and radius. The y-axis shows for which mean density a KBO may still harbor a liquid ocean today. The assumed initial NH_3 abundance is 5%, and the assumed rock density is 3,300 kg/m³. No oceans should be present on KBOs with r < 450 km and mean density < 2500 kg/m³. Contour plot courtesy of Wendy Hawley and Steve Desch.*

If such a scenario is taking place on Charon, then the same might be said for other KBOs. Ammonia hydrate may be present on Quaoar and Orcus. By applying the same time-dependent model to other KBOs we find that many objects may currently contain a liquid ocean (Figure 6). This would mean there could be more liquid water at the outer reaches of the solar system than in all of Earth's oceans. This has immeasurable ramifications for astrobiological life in the cold depths of a KBO ocean.

Much of this work was done as part of Jason's doctoral thesis under Dr. Steven Desch while he was at Arizona State University.

For more information, please see:

Cook, J. C., Desch, S. J., Roush, T. L., 2007, *LPI Conference*, **1357**, 30.

Cook, J. C., Desch, S. J., Roush, T. L., Trujillo, C. A., Geballe, T. R., 2007, *ApJ*, **663**, 1406.

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by Elizabeth Wehner

The Missing Link Between Dwarf Galaxies & Globular Clusters

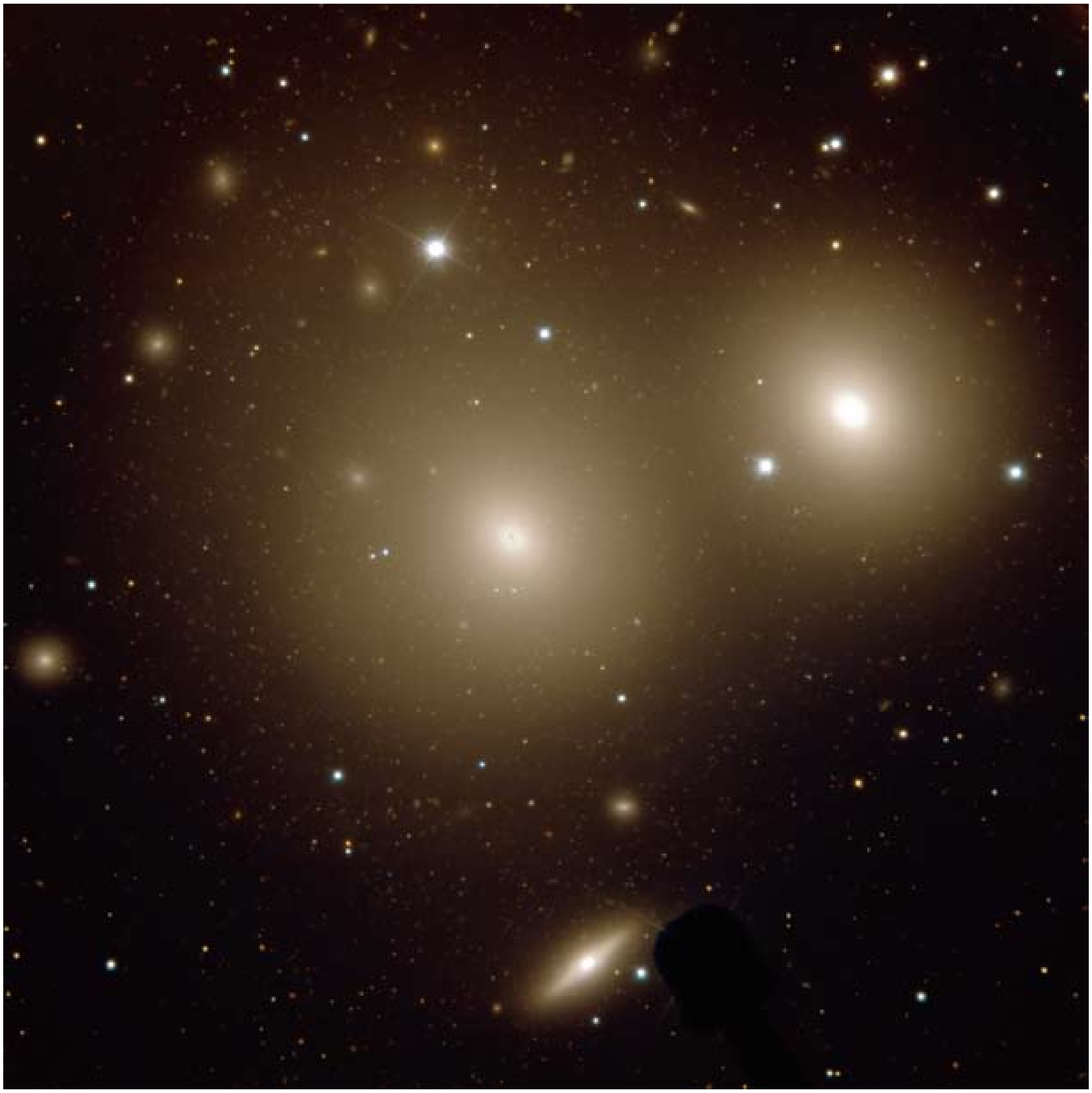

Figure 1.
NGC 3311 (center) and its nearest neighbor, NGC 3309. The thousands of globular clusters surrounding NGC 3311 comprise the richest system of this type ever observed. (This image is featured on the front cover.)

A new category of galaxy-like objects has recently been identified. These new galaxies (or stellar systems) are extremely compact, more closely resembling tightly-bound globular clusters than the more extended dwarf galaxies. But strangely, they're orders of magnitude more luminous than typical globular clusters. Because of these qualities, they're called "ultra compact dwarfs" (UCDs), and their exact nature is not yet known. In fact, they may make up a hybrid class of object that contains multiple compact stellar systems that formed by completely different mechanisms.

While UCDs are significantly smaller and denser than typical dwarf galaxies, they share many of the same structural characteristics found in the nuclei of some dwarf ellipticals. In fact, the disruption of one of these nucleated dwarf ellipticals (abbreviated dE,Ns) is one way a UCD might form. Such destruction can occur in large galaxy clusters as the dE,Ns orbit the cluster's dynamical center. Over multiple orbits, they undergo "threshing," a process by which the outer stars of a dE,N are stripped away by tidal forces. According to the threshing scenario, the dE,N loses its entire envelope of stars over time and only the nucleus (which is now a UCD) remains.

Another possibility is that UCDs form from smaller stellar systems, such as young massive clusters that collide and merge together. This is most likely to occur during a violent episode of star formation when many such clusters are formed. A third explanation for the genesis of UCDs is that they may simply be high-mass versions of ordinary globular clusters. One difficulty with this explanation is that such massive clusters are not typically observed in our local universe. However, in locations of extreme star formation, as in galaxy clusters, such extreme globular cluster formation may be theoretically possible. UCDs have so far been discovered only in the nearby galaxy clusters Fornax, Virgo, and Abell 1689. They're difficult to detect because they are so compact that they resemble foreground stars in most ground-based observations, and are often overlooked. With high-enough resolution, a UCD can be identified as a compact stellar system. Therefore, deliberate searches for UCDs require deep, high-resolution images. Given the observational difficulties, other nearby galaxies provide our best hope for future UCD discoveries.

At a distance of only 54 Mpc (176 million light-years), the Hydra cluster is the third-closest galaxy cluster. At its center sits a giant elliptical, centrally-dominated (cD) galaxy, NGC 3311, which has one of the largest globular cluster systems ever observed. In order to examine this unusually rich system, we used GMOS on Gemini South to obtain extremely deep g' and i' images of NGC 3311 and its surroundings. The resulting combined color image is shown in Figure 1 (and on the cover of this issue). NGC 3311 and its nearest neighbor, NGC 3309, are both visible in this image, and surrounding these galaxies are thousands of small star-like objects. These are globular clusters that make up a vast system surrounding NGC 3311, and are the targets of our investigation.

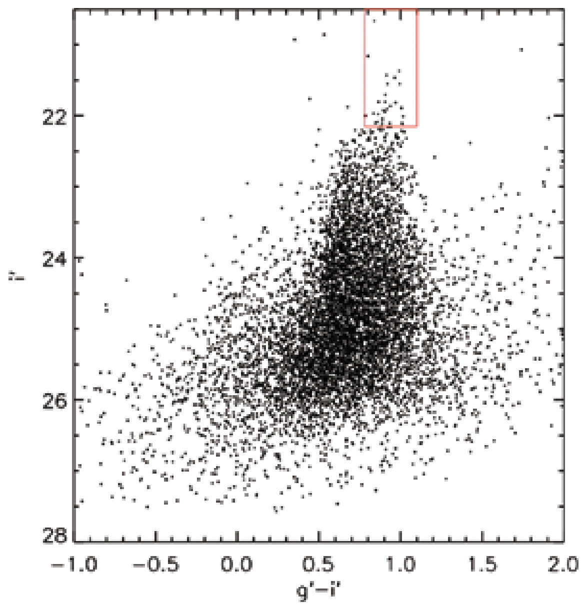

Figure 2.
Color-magnitude diagram for the globular clusters around NGC 3311. The red box shows the location of the UCD candidates.

One way to examine the properties of a globular cluster system is to construct a color-magnitude diagram, as shown in Figure 2, which plots the brightness of each object versus its color in (g'-i'). Typically, globular clusters are roughly divided into two populations: blue, and metal poor or red, and metal-rich. While there are so many globular clusters in this system that it's difficult to visually discern the distinction, statistically, the globular cluster system of NGC 3311 is well-fit by these two populations. Perhaps the most interesting feature of this diagram is the presence of an extension of objects to high luminosities on the red side of the globular cluster system. At approximately (g'-i') ~ 0.95, there are 27 objects which have i' magnitudes brighter than 22.2. At first glance, these appear to be members of the system, due to the smooth transition from the normal globular cluster population up to higher luminosities. However, when we convert their luminosities to masses, using even a conservative mass-to-light ratio, we find these objects approach the higher mass range of UCDs.

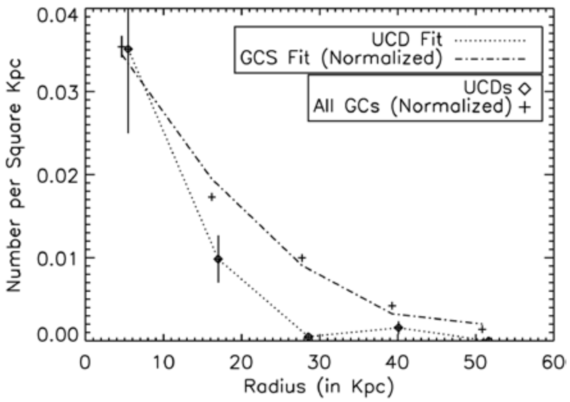

Figure 3. *Radial distribution of UCD candidates relative to NGC 3311. For comparison, the normalized radial distribution of the GCs has been overlaid. The UCD candidates appear to be strongly associated with NGC 3311.*

If these are indeed extremely luminous (and therefore extremely massive) globular clusters, and if they are a legitimate extension of the globular cluster system, then this is the first time such a direct connection between globulars and UCDs has been observed.

One of the next steps is to determine if our luminous UCD candidates are really connected to NGC 3311, and to rule out the possibility that they are merely misleading field contamination. One possible complication is that an extremely luminous object may, in fact be two globular clusters coincidentally lying along the line of sight. This can increase their observed brightness by almost a magnitude. However, we can estimate the number of such expected blends and find that this sort of coincidence would occur less than one time in our data. Also, if these objects are only foreground stars, we would expect them to have a larger spread in color and to be more randomly distributed across the color magnitude diagram, which is clearly not the case. Lastly, if the objects in question were interlopers, we would expect them to be randomly located in the image, with no central concentration around NGC 3311. Figure 3 shows the distribution of these objects as the number of objects per unit area measured in rings around NGC 3311. The number density of objects drops substantially with distance from NGC 3311, clearly indicative of a radial distribution. While spectroscopic follow-up is needed to confirm their place around NGC 3311, the locations of the UCD candidates strongly suggests they are in orbit around Hydra's cD galaxy.

If this connection is confirmed with spectroscopy, what can we learn from it? Work on globular clusters in other galaxies, such as M31 and NGC 5128, is starting to provide evidence that massive globular clusters may indeed be the beginning of the long-missing bridge between the ordinary globulars and dwarf elliptical galaxies. For example, it's long been thought that ordinary globular clusters have a constant scale size, which is independent of mass, while dEs have scale sizes that behave differently, increasing as an exponential function of mass. But recently, massive star clusters have been found with scale sizes that change with mass—meaning that ultra-massive globular clusters (and UCDs) may indeed structurally be the bridge to dwarf galaxy-like objects.

When UCDs from different clusters are combined and studied together in velocity dispersion and magnitude space, a continuous sequence from globular clusters up to UCDs, and on to dE nuclei and dEs emerges. Our data on NGC 3311 are the first to show this direct connection in a single galaxy.

While UCDs are difficult to detect, requiring long exposures under ideal observing conditions, as well as follow-up spectroscopy, they may provide the fascinating evolutionary link between globular clusters and dwarf galaxies. And ultimately, these objects may provide us with new and exciting insights into how star clusters and galaxies form, and how and why their distinct structural properties develop.

This result appears in the October 10, 2007 issue of the *Astrophysical Journal Letters* (volume 668, L35) and is based on work done in collaboration with William Harris at McMaster University in Hamilton, Ontario.

For more information, please see:

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Wehner, E. H. and Harris, W. E. 2007, *ApJ*, **667**, L.

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by Edo Berger

Unusual Magnetic Activity in the M8.5 Dwarf Star TVLM513-46546

In recent years, the stellar mass function has been extended at the bottom of the main sequence and beyond with the discovery of numerous ultra-cool dwarfs (very low-mass stars and brown dwarfs of spectral types late-M, L, and T). Significant observational and theoretical progress in our understanding of these objects has been made since their discovery but many questions regarding their structure and formation remain unanswered. Of particular interest is whether ultra-cool dwarfs, which have fully convective interiors, can generate and dissipate magnetic fields, and support chromospheres and coronae. The answer has important ramifications for our view of the internal structure of ultra-cool dwarfs, and the physical conditions in their atmospheres.

Past observations of the traditional stellar magnetic activity indicators (chromospheric H-alpha and coronal x-ray emission) revealed peak activity in the mid-M dwarfs, followed by a dramatic decline in the fraction and level of activity in the ultra-cool regime. However, in recent years it has become evident that at least some ultra-cool dwarfs are capable of producing unanticipated levels of magnetic activity, manifested primarily in their strong quiescent and flaring radio emission. This emission is produced by relativistic electrons propagating in the stellar magnetic field, and therefore it traces the strength and geometry of the field. Indeed, the radio luminosity as a function of the total bolometric luminosity appears to increase relative to early- and mid-M dwarfs.

The discrepancy between the various magnetic activity indicators is most readily seen in the context of the radio/x-ray correlation that holds for a wide range of active stars and for solar flares, but is violated by many orders of magnitude in the ultra-cool dwarfs.

In order to assess these conflicting trends, and to gain unique insight into the origin of magnetic activity in ultra-cool dwarfs, we recently initiated a comprehensive program of multi-wavelength simultaneous observations of the various activity bands in several late-M and L dwarfs. Simultaneity is essential for tracing the effects of magnetic energy release on various components of the atmosphere, particularly during flares. To this end, we obtained x-ray observations from the Chandra X-ray Observatory, radio data from the Very Large Array, optical spectroscopy from the Gemini North telescope, and ultraviolet imaging from the Swift satellite. The observations at these facilities are coordinated to occur simultaneously with an advance notice of only 1-2 weeks. With these constraints, the flexible queue scheduling at Gemini proved invaluable to achieving the goals of this program.

The first object we have targeted as part of this project is the M8.5 ultra-cool dwarf TVLM513-46546. This object has a known rotation velocity of about 60 kilometers per second (km/s), and a bolometric luminosity of $10^{-3.6}$ that of the Sun. It has been detected at radio wavelengths by our group over the past several years. The observations

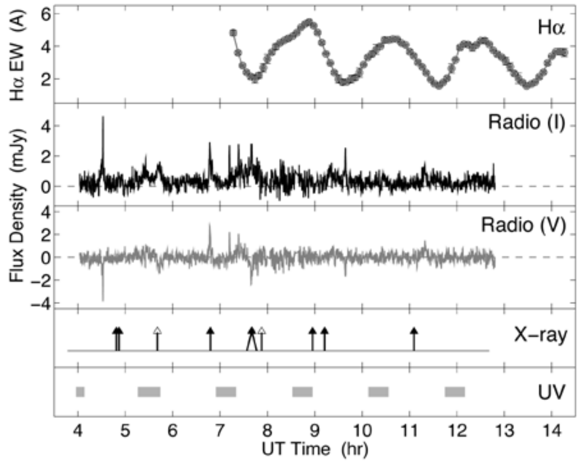

Figure 1. *Radio, H-alpha, ultraviolet (UV), and x-ray observations of TVLM513-46546. For the radio data, "I" and "V" designate the total flux and the circularly polarized fraction, respectively; negative values indicate left-handed polarization. The arrival times of the x-ray photons are shown with arrows. Empty arrows correspond to likely background events, with two expected from the background statistics. Times of UV coverage are marked by gray squares; no UV emission is detected. The H-alpha emission is clearly sinusoidal and periodic, with P=2 hours matching the rotation period of TVLM513-46546. There is no clear correspondence between the various emission bands.*

took place on April 20, 2007 and the results are summarized in a paper in press in the *Astrophysical Journal* (astro-ph/0708.1511). We detected the object in the x-ray regime, with the faintest x-ray to bolometric ratio of any ultra-cool object to date. We additionally detected the object at radio wavelengths, with a steady quiescent component superposed with multiple short duration flares (with luminosities up to 20 times higher than the persistent emission, see Figure 1). Surprisingly, there is no clear correspondence between the radio and x-ray light curves. This provides the first direct confirmation that these two indicators are decoupled in ultra-cool dwarfs despite being highly correlated in early-type stars and in solar flares. The ratio of radio to x-ray luminosity exceeds that of typical active stars by about four orders of magnitude! (See Figure 2).

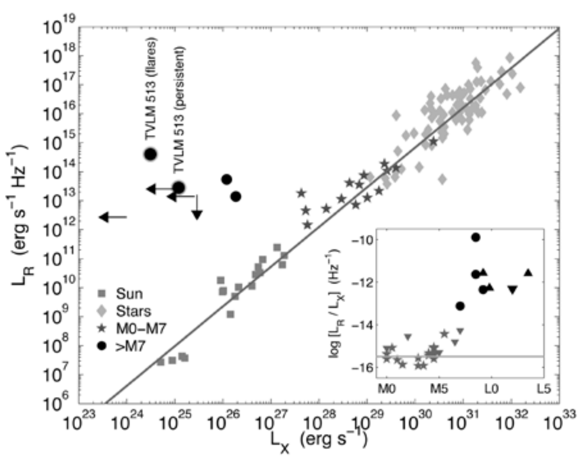

Figure 2. *Radio vs. x-ray luminosity for a large range of stars exhibiting magnetic activity, including solar flares and microflares. The data points for TVLM513-46546 persistent emission and flares are marked. The strong correlation between radio and x-ray luminosity is evident, but it severely breaks down in the ultra-cool dwarfs around spectral type M7 (inset).*

From the radio emission, we infer the presence of a steady large-scale magnetic field with a strength of about 50 Gauss (G), in good agreement with the value required to confine the x-ray emitting corona. The radio flares, on the other hand, require a field component of about 3 kG, similar to that of the most active early- and mid-M dwarfs. The random arrival time and circular polarization of the radio flares points to a tangled, multi-polar configuration for this field component.

Perhaps the most intriguing aspect of our observations emerges from the Gemini spectroscopy. As shown in Figure 1, the H-alpha equivalent width shows a sinusoidal and periodic modulation with a period of about two hours; the same effect is seen for H-beta (Figure 3). This two-hour periodicity matches exactly the rotation period of TVLM513-46546, given a rotation velocity of 60 km/s and a radius of about one tenth of a solar radius. Thus, it appears that the hydrogen Balmer line emission is produced in a region that is highly active, covers about half of the stellar surface, and co-rotates with TVLM513-46546. This region may be a chromospheric "hot spot" or alternatively, a large scale "bubble" trapped by the persistent magnetic field structure. The latter scenario gains credence by the fact that the H-alpha luminosity exceeds the x-ray luminosity, whereas in early-type stars the x-ray corona appears to be responsible for heating of the chromosphere, and thus has a higher energy output. Returning to Figure 1 we see that the H-alpha modulations do not correspond to any of the radio or x-ray emission features.

Theoretical work on magnetic dynamos in ultra-cool dwarfs is in its early days, and remains largely inconclusive. Initial studies suggest that a non-axisymmetric and multi-polar field may be generated under certain conditions. Our observations of TVLM513-46546 provide some of the first clear constraints for these models, and indicate that there is a shift in the nature of the magnetic dynamo, or the resulting field configuration of this star, compared to early-type stars. Clearly, simultaneous multi-wavelength observations are essential for providing a complete picture of the magnetic field and its interaction with the stellar atmosphere.

We are in the process of obtaining similar observations for six additional sources that cover the largely unexplored spectral type range between M7 and L3. We expect with this larger sample to find additional surprising trends that will ultimately reveal how the lowest mass stars and brown dwarfs generate magnetic fields.

The paper with the results of this work is now in press in the *Astrophysical Journal*, and a preprint is available at http://xxx.lanl.gov/abs/0708.1511.

For more information please see:
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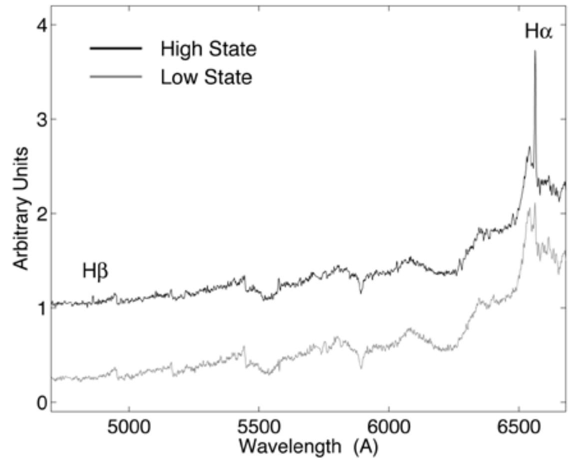

Figure 3. *Sample Gemini-North GMOS optical spectra of TVLM513-46546 in the high and low Balmer emission line states. The high state spectrum has been offset upward for clarity.*

by Linhua Jiang

Quasars & Supermassive Black Holes in the Early Universe

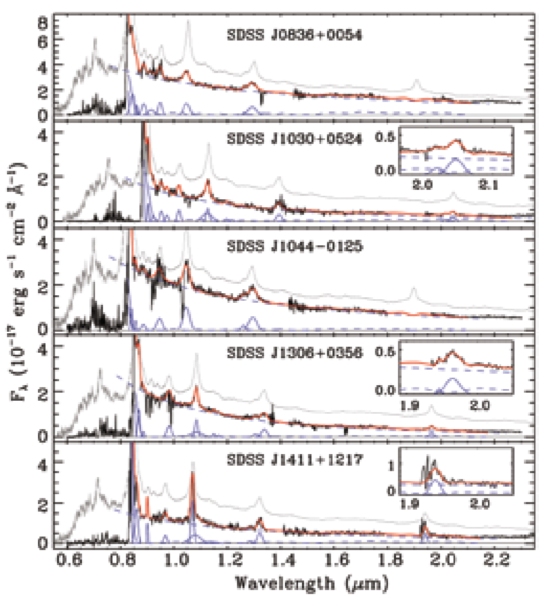

Figure 1.
Optical and NIR spectra of five $z \sim 6$ quasars. The spectra at wavelengths greater than 1 micron were obtained with GNIRS. The blue lines are the best fits to continuum and line emission. The red lines are the sums of all the components. For comparison, a low-redshift composite spectrum is shown in gray.

When quasars (or quasi-stellar objects (QSOs)) were first discovered they were believed to be star-like objects in the sky. However, they were soon determined to be extragalactic sources with extremely high luminosities that radiate across the electromagnetic spectrum. They are among the most energetic phenomena known in the universe, powered by large amounts of hot gas falling into massive black holes at the centers of their host galaxies. Because of their high luminosities, quasars can be seen at great distances from the Earth. The most distant quasars known to date are at redshift $z \sim 6.4$; at this epoch the universe was less than one billion years old, only 7% of its current age. Therefore, these distant quasars serve as cosmological probes for studying the universe in its first billion years.

Understanding quasars requires observations ranging from radio to x-ray wavelengths since each spectral region probes different aspects of quasar physics. Recently, we observed six quasars at redshifts between $z = 5.8$ to 6.3 using the Gemini Near Infrared Spectrograph (GNIRS) at Gemini South and the Near-Infrared Imager (NIRI) at Gemini North. The observed near-infrared (NIR) spectra (Figure 1) contain strong emission lines from the so-called broad-line region, which can be used to estimate the black hole mass and the metallicity of the broad-line region gas. We find that these very distant quasars are powered by black holes that contain more than a billion solar masses, and that the gas in the quasar environment close to the central black holes has supersolar metallicity.

The Rapid Growth of Central Black Holes

One fundamental question about quasars is how they produce such tremendous energy. It was proposed soon after the discovery of the first quasars that the energy output was related to massive black holes. At the center of each quasar, there lies a black hole with a typical mass of a hundred million solar masses. As the surrounding gas falls onto the central black hole by gravitational accretion, a huge amount of potential energy is converted to radiation detected over a broad spectral range.

The masses of the black holes that power quasars can be calculated using empirical mass-scaling relations based on the width of emission lines and continuum luminosities. Since the broad-line region is gravitationally bound to the central black hole, the widths of its emission lines are a measure of the virial motions of the gas in the region. Moreover, the size of the broad-line region is expected to be larger for more luminous objects. As a consequence, quasars with broader emission lines and higher luminosities have higher black hole masses. For the distant quasars in our sample, our data allow us to estimate their black hole masses to be between 1 to 10 billion solar masses. We also find that these quasars are shining close to the Eddington limit, which is the maximum energy output rate at which the inward gravitational force is balanced by the outward radiation pressure.

It is remarkable that billion-solar-mass black holes can form less than a billion years after the Big Bang. How did they grow with time? According to recent physical models, seed black holes can be produced from the collapse of the first generations of stars or gas clouds as early as z~20, when the universe was about 0.2 billion years old. They contain roughly a hundred to ten thousand solar masses. Seed black holes with a thousand solar masses at z~20 must grow by a factor of 3 million times in only 0.7 billion years to produce z~6 black holes with typical masses in our sample. This rapid growth may challenge our current understanding of black hole assembly, since the most massive black holes in our sample barely had enough time to grow, even with continuous accretion at the Eddington limit. The existence of such supermassive black holes at z~6 suggests a very fast and efficient growth mechanism for black holes in the early universe.

Rapid Enrichment of Heavy Elements

The two lightest elements, hydrogen and helium, are mostly primordial, having been made in the first 10 minutes after the Big Bang. Almost all heavier elements are synthesized inside stars at a much later time and released to space during late stages of stellar evolution. One might expect that chemical abundances in very distant galaxies are lower than those in nearby galaxies, given that the chemical enrichment time scales from star formation range from hundreds of millions to a billion years. Using emission-line strength ratios measured from the Gemini NIR spectra, we calculated the chemical abundances of gas in the broad-line region of the six quasars. Somewhat to our surprise, we found that heavy elements in z~6 quasars are already super-enriched, with a typical abundance four times that of the solar abundance. A comparison with low-redshift observations shows no strong evolution in chemical abundances of quasars from z~2 to z~6 (Figure 2).

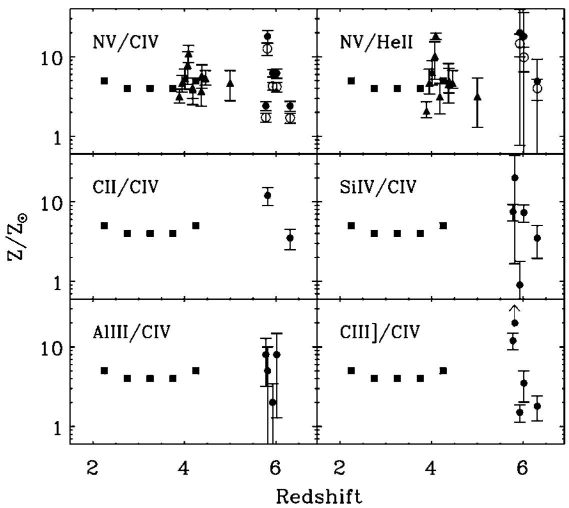

Figure 2. *Chemical abundances of quasars at z=2-~6 derived from emission-line ratios. The filled and open circles represent our results, and the low-redshift measurements are from the literature. This figure shows no strong evolution in chemical abundances of quasars up to z~6.*

The ratio of iron (Fe) to the oxygen family elements (such as oxygen, carbon and magnesium; also called the alpha elements) is of particular interest. The alpha elements are produced in massive stars and are ejected on a short timescale. On the other hand, most of the iron in the solar neighborhood is generated from long-lived intermediate-mass stars, so appreciable iron enrichment can only happen on a timescale of a billion years or longer. However, the age of the universe at z~6 was less than one billion years, so the Fe/alpha ratio is expected to be a strong function of age in the first billion years. We find that the Fe II/Mg II (Fe^+/Mg^+) ratios for the six distant quasars are quite high and are consistent

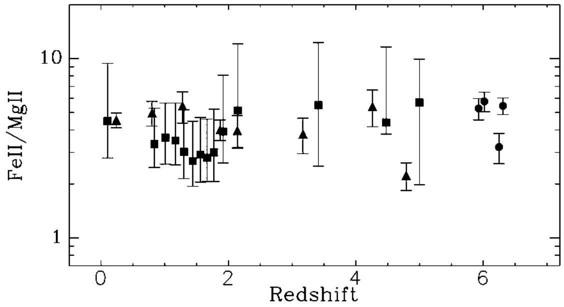

Figure 3.
The Fe II/Mg II ratio shows no strong evolution with redshift up to z › 6. The filled circles represent our results, and the low-redshift measurements are from the literature.

with low-redshift measurements (Figure 3). Therefore, the iron at z~6 has to be generated in very different and efficient ways compared to the local iron.

The high metal abundances and the Fe ll /Mg II ratios at z~6 indicate that vigorous star formation and element enrichment have occurred in quasar host galaxies in the first billion years of cosmic time. This is consistent with millimeter and submillimeter observations, which have revealed that the star formation rates in luminous quasars at z~6 can be more than a thousand solar masses per year, while the star formation rate in our galaxy is only a few solar masses per year.

The paper reporting this research appears in the September 2007 issue of the *Astronomical Journal* (2007, *AJ*, **134**, 1150). The collaborators include X. Fan, M. Vestergaard, J. D. Kurk, F. Walter, B. C. Kelly, and M. A. Strauss.

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by Mark Westmoquette and Linda J. Smith

Mapping the Galactic Outflow Roots in NGC 1569

In pursuit of an understanding of galaxy evolution, it is of critical importance to study how successive generations of stars interact with their environment. This mechanism, called "feedback," controls the amount of enriched material returned by stars to the interstellar medium (ISM) and regulates the overall star formation rate. However, feedback can be very hard to observe and quantify due to the complexity of the interactions and the many forms they can take.

Although massive stars (larger than eight solar masses) are rare, they completely dominate feedback processes due to their powerful radiation fields, large mass outflow rates, and subsequent supernova explosions. In periods of enhanced star-formation activity (such as a starburst), many massive stars can be formed in large concentrations, particularly within "super" star clusters, and the results of feedback can have quite spectacular consequences.

In a young star cluster, stellar winds from the massive stars, and later supernovae explosions, will combine to form a cluster wind. The expansion of this hot wind will carve out a shell in the surrounding ISM. The resulting bubbles can become so large that they overlap and begin to coalesce with neighboring bubbles. If a coalesced bubble inflates to a size on the order of a galactic scale-height (that is, of the same height as the galaxy) it is termed a "super-bubble." When the density of the ISM that acts to contain the bubble decreases at the edge of the galaxy, the bubble can "blow out" (pop), allowing the hot gas contained within it to vent out into the galactic halo. If this flow can be sustained and collimated, then a quasi-steady-state can be reached. This is termed a "galactic wind."

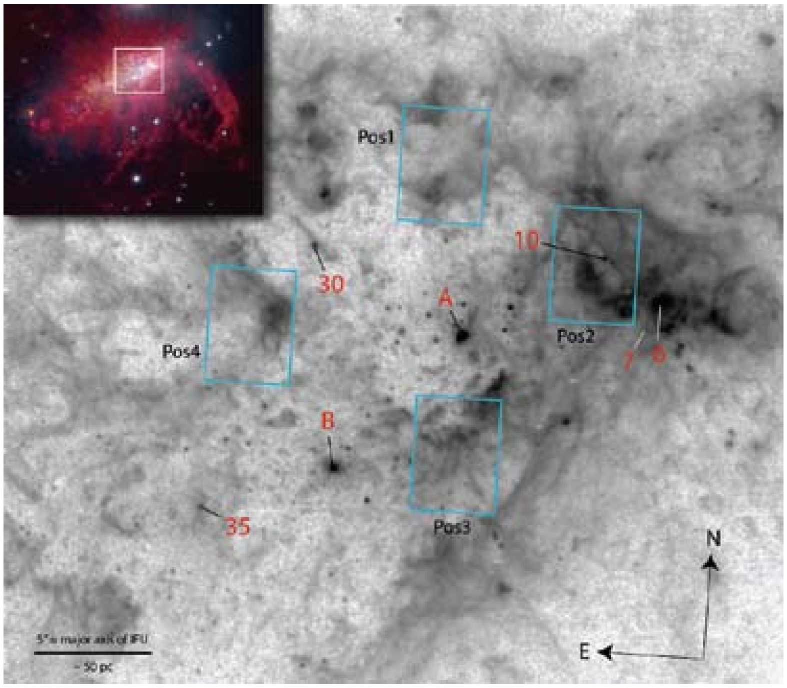

Figure 1.
An HST Hα image of the central region of NGC 1569 (corresponding to the area indicated on the deep ground-based Hα image inset in the top left). The four IFU fields are marked in blue and a number of bright star clusters are labeled in red.

True galactic winds have the potential to eject large amounts of matter from the host galaxy. The consequences of this ejection include the quenching of subsequent star formation by stripping out the gas-rich ISM and enriching the inter-galactic medium with metals. Thus, understanding exactly how galactic outflows are powered and evolve is important. Unfortunately winds

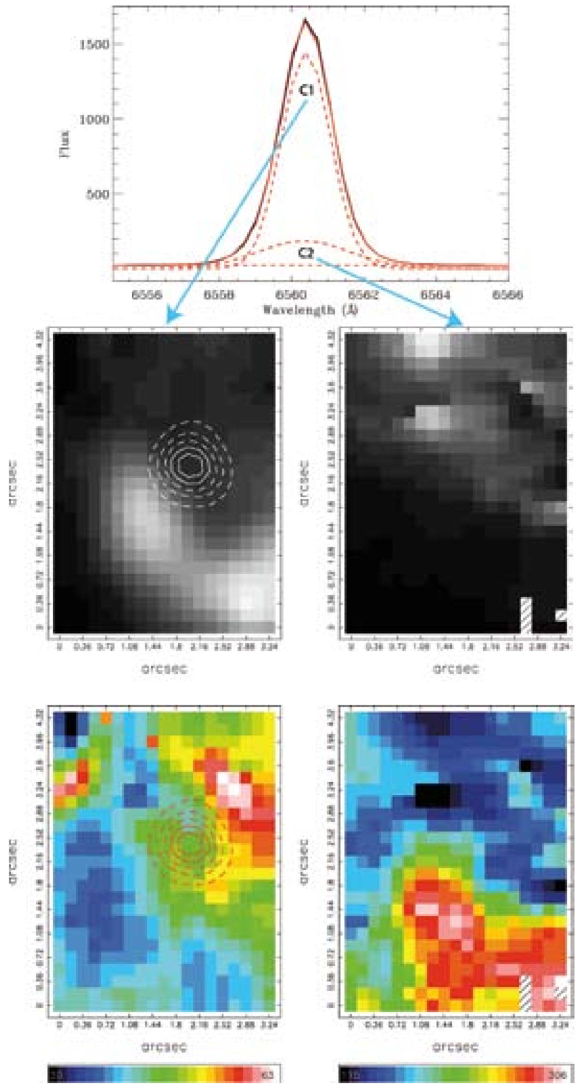

Figure 2.
(top) An example Hα line profile showing the two Gaussian components required to fit the line shape, one bright and narrow, the other faint and broad (middle and bottom). Maps of the flux and FWHM of the Hα line components (C1 left, C2 right) in IFU position 2. The contours show the position of cluster 10 as labeled Figure 1.

are inherently multi-phase and exhibit complexity over a large range of spatial scales. Therefore, observations ideally need to have good spatial resolution over a continuous area, and have good spectral resolution in order to accurately separate different line-of-sight velocity components.

Our target for investigating the star-formation feedback/outflow phenomenon was the dwarf irregular starburst galaxy NGC 1569, a system containing a number of young massive star clusters and clear signatures of large-scale outflows. We observed four "interaction regions" near the base of the outflow using the Gemini North Multi-Object Spectrograph Integral Field Unit (GMOS IFU) covering the bright nebular emission lines such as hydrogen-alpha (Hα) and doubly-ionized oxygen [OIII] (Figure 1.) The 500-fibre IFU thus gave us a total of 2,000 spectra over the four fields. The GMOS IFU is ideally suited to this type of observation due to its excellent combination of spatial and spectral resolution.

The first thing we noticed in our spectra was that the emission-line profiles were not Gaussian (that is, they do not have the shape we expected). Analysis showed that a broad low-intensity feature could be identified under each of the lines (Figure 2, top). We thus set out to fit each emission line observed in each of our spectra with a multi-component Gaussian fit—a task that had to be automated, but only after a set of statistical and physical constraints were in place to determine the appropriate number of components to employ and the quality of fit. The results of the line-fitting gave us a measurement of the radial velocity, full-width half-maximum (FWHM) and intensity of each line component, which could then be individually mapped out for each of the regions observed. Figure 2 shows maps of flux and FWHM for component 1 (C1; the main bright component, left panels) and component 2 (C2; the underlying broad component, right panels) for IFU position 2 only. Although a great deal of information is contained within these maps the three most important results are the following: the narrower component (C1) has a characteristic FWHM of 30-60 kilometers per second (km/sec) which is already supersonic for an Hα-emitting gas at 10,000 K; the width of the broad component (C2) spans a range of 120 to an incredible 300-400 km/sec; the area of broadest C2 is quite faint and does not stand out in the corresponding flux map, but is highly spatially correlated with the brightest C1-emitting gas, i.e. where C1 is brightest, C2 is broadest.

Line profiles such as we observe here have been reported in the literature, but the proposed explanations that can account for the broad widths and small radial velocity offset between the components vary significantly. Mechanisms such as champagne flows (where hot gas appears to flow in a manner similar to the way champagne flows out of an uncorked bottle) and effects such as multiple unresolved components cannot reproduce the line widths observed or the spatial coincidence between the broadest C2 and brightest C1. The only proposed mechanism that fits our data is turbulent mixing on the surfaces of cold gas clumps. We know that copious high-energy photons and fast-flowing winds are emitted from the nearby star clusters, and they exchange energy with the cooler ISM gas clumps through processes that can disrupt or destroy clumps, such as photo evaporation and thermal evaporation (where the surface of a clump is vaporized by radiation), or ablation (where the surface is eroded by the wind). Additionally however, shearing between the hot fast flow and the cloud surface can set up

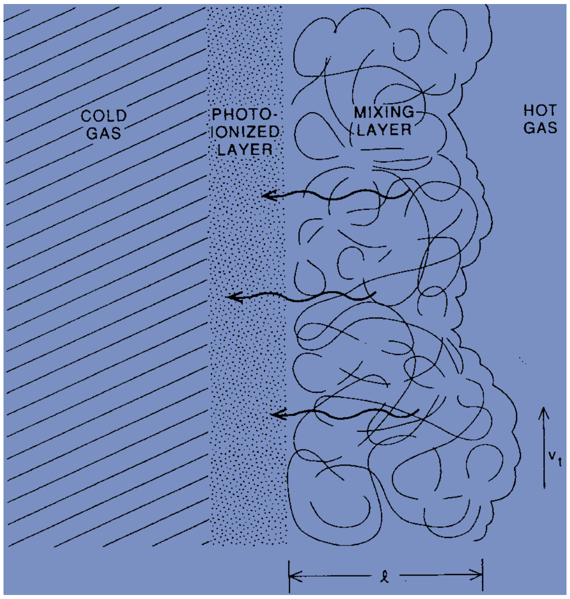

Figure 3.
A model of a turbulent mixing layer from Slavin et al., (1993). A hot wind (right) flows past a cold gas cloud (left) and the resulting turbulence on the surface of the cloud allows the different gas phases to mix together.

what is known as a turbulent mixing layer. A schematic representation of such a layer is shown in Figure 3. Models of mixing layers predict optical line-emission (produced in a similar way as within shock precursors) with characteristic widths equal to that of the turbulent velocities within the layer thus providing an explanation of our results. If this interpretation is correct, we are observing direct evidence of the interaction between the cluster winds and the ambient ISM.

Over the four IFU fields observed, the total spread in radial velocities between C1 and C2 is only about 70 km/sec. Comparing this value to the line widths we measure shows that, at these earliest stages of the outflow, turbulent velocities dominate over any bulk motions; that is, the gas has yet to develop into an organized outflow. This is consistent with the latest hydrodynamical models of galactic outflow formation, where the inner regions of the flow possess only a very small net outward velocity. This grows slowly until a point is reached at which bulk flows begin to dominate over the turbulence, corresponding to the base of large-scale outflow structures such as the super bubbles in NGC 1569.

Since broad components are also observed in other starburst systems (M82, He 2-10, NGC 1705), this may suggest that turbulent mixing layers are a ubiquitous phenomenon in environments where a fragmented ISM is subject to the effects of strong winds. The broad component may thus serve as a powerful diagnostic of the galactic wind phenomenon since it probably traces both mass loading of wind material and mass entrainment. This work represents a significant step forward in the understanding of galactic outflows, and would not have been possible without the facilities offered by Gemini Observatory.

For more information please see:

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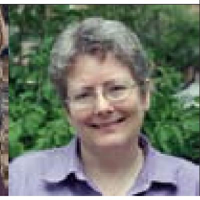

by Katia Cunha and Kris Sellgren

Chemical Evolution at the Milky Way's Center

The inner 200 parsecs (650 light-years) region of the Milky Way Galaxy is an energetic and active environment. At its heart lurks a supermassive black hole, surrounded by a swarm of stars called the Central Cluster. This region is densely populated with a mix of old (more than 1 billion years) and young (less than 10 million years) stars. In fact, two massive clusters of young stars, the Quintuplet Cluster and the Arches Cluster, lie within 30 parsecs of the galactic center, demonstrating recent and extensive star formation. These young clusters sparkle within an older stellar population spread throughout the central 200 parsecs, indicating that star formation has occurred fairly steadily over the lifetime of the galaxy.

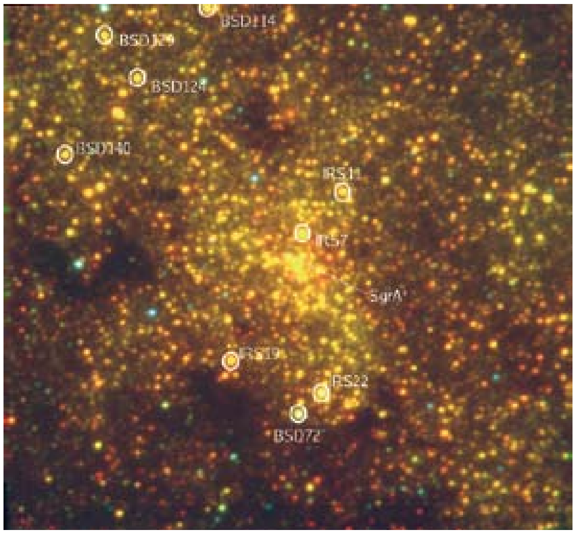

Figure 1. *JHK infrared image (25 x 25 arcminutes, corresponding to 4.1 x 4.1 parsecs) of the Central Cluster in the galactic center. Stars with high-resolution infrared spectra are labeled. The position of SgrA*, associated with the supermassive black hole, is indicated. Image obtained with OSIRIS on the CTIO Blanco 4-meter telescope by R. Blum.*

Our galaxy's center is dimmed by about 30 visual magnitudes of interstellar extinction (caused by the absorption of light by intervening dust clouds), and thus is undetectable with optical techniques. However, the extinction is only a few magnitudes in the near-infrared (at 1-2 microns). Continuing advancements in infrared astronomy, using both imaging and spectroscopy on large telescopes, makes it possible to study stars at the very center of the Milky Way in ever-increasing detail.

The sources of the gas that fuel the star formation at the galaxy's center are uncertain. How much gas has fallen in from the Milky Way's bulge or halo? Is gas driven in from the disk, and if so, how does this change if our galaxy's bar evolves with time? What fraction is simply recycled gas from previous generations of galactic center stars themselves? These are the types of questions that can be answered by studying the current and historical episodes of star formation in the center of the Milky Way. Insight into the star-formation history and chemical evolution of galaxies comes from studies of their elemental abundances. Ratios of the abundances of the alpha-elements to the abundance of iron (Fe) can be used to probe the relative amounts of material that have been cycled through short-lived massive stars, which end their evolution by exploding as a core collapse supernova (SN II), or through longer-lived intermediate-mass binary systems, which end in the nuclear detonation of a white dwarf (SN Ia).

The nuclear reactions that occur in the massive progenitor stars that give rise to SN II produce large amounts of alpha-elements, such as oxygen (O) or calcium (Ca). During the explosion of a SN Ia, large amounts of iron (Fe) are synthesized. Thus, comparing the abundance of O or Ca with that of Fe can be used to determine how much material in the star being studied was at one time ejected from SN II, compared to the amount that was cycled through SN Ia. Since massive stars (15-40 solar masses) evolve and explode as SN II much more quickly than the lower-mass binary systems that end their evolution as SN Ia, measures of the abundance ratios of O/Fe or Ca/Fe can be used to indicate whether star formation occurred on the short timescales of SN II (10 million years), or on the longer timescales of SN Ia (a billion years).

We have investigated, for the first time, the ratio of alpha-elements to Fe in a sample of ten galactic center stars, with high-resolution infrared spectra from which chemical abundances can be derived. We and collaborators Bob Blum, Verne Smith, Solange Ramirez, and Don Terndrup obtained spectra for stars in the Central and Quintuplet Clusters. We used the NOAO high-resolution infrared spectrograph PHOENIX on Gemini-South, as well as CSHELL on the NASA IRTF, to observe these cool, luminous young stars, which are supergiants or red giants with ages from eight million to one billion years. Figure 1 shows a three-color J, H, K image of the central cluster with nine of our observed stars indicated. The spectra were obtained at 1.55 microns and 2.23 microns, with R=40,000. We analyzed molecular lines from carbon monoxide (CO), hydroxyl (OH), and cyanide (CN), along with selected atomic lines from neutral iron and calcium (Fe I and Ca I). The CO, OH, and CN lines can be combined to derive individual elemental abundances of ^{12}C, ^{14}N, and ^{16}O, while the atomic lines yield the abundances of Fe and Ca. Figure 2 illustrates the high quality of our PHOENIX spectra of galactic center stars.

We found that the carbon and nitrogen abundances (but not the oxygen abundances) have been altered by convective mixing in three cool, evolved galactic center stars. This alteration is caused by material that has been exposed to nuclear hydrogen burning, via the C-N cycle, deep within the star and then dredged up to its surface. This exposure appears as a modest decrease in the ^{12}C abundance, accompanied by a larger increase in the ^{14}N abundance. We observe this signature of C-N cycle mixing in three galactic center stars, in amounts predicted by stellar evolution theory. The three cool, luminous stars we have observed in the galactic center show C-N-cycle mixing similar to that found in solar neighborhood disk stars, with no alteration of the surface ^{16}O abundance. This gives us confidence in interpreting the O abundance as a tracer of alpha-element abundance.

A combination of the oxygen, calcium, and iron abundances provides insight into the chemical pedigree of the galactic center gas that went into the formation of these stars. Looking first at Fe, we find that all ten stars have the same Fe abundance value, to within our measurement errors. This abundance of Fe is slightly larger than the solar value (which is fairly characteristic of disk stars at the solar galactocentric distance) by about 0.15 dex (a logarithmic unit).

What is perhaps more surprising is that the galactic center stars exhibit elevated ratios of O/Fe and Ca/Fe. Such high ratios of the alpha-elements O and Ca, relative to Fe indicate larger contributions to the chemical evolution of the gas from SN II, relative to SN Ia, when compared to similarly metal-rich gas in the disk, such as the gas that went into the formation of the Sun.

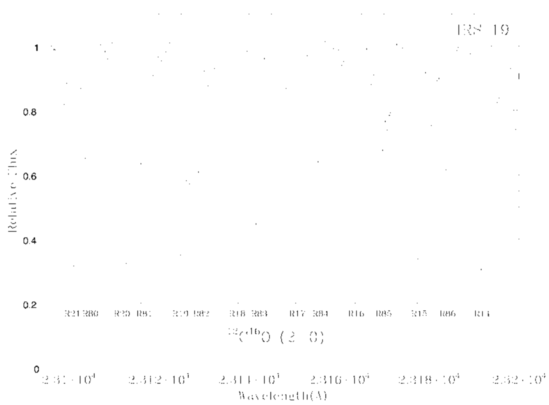

Figure 2. *PHOENIX/Gemini-S spectrum of IRS 19, an M supergiant two parsecs from the galactic center. At this spectral resolution (R≈ 40,000), individual lines of CO and OH molecules can be used to derive O and C abundances in young (~100 million-year-old), massive cool stars.*

Elevated ratios of O/Fe or Ca/Fe are more typical of the older populations of the Milky Way, such as the halo or the bulge, and point to rapid formation timescales in which SN Ia do not have time to make significant contributions to the metal enrichment relative to those from SN II. What makes our results for the galactic center unique (and surprising) is that the SN II signature is found in a young population of massive, metal-rich stars where one might naively expect SN Ia to have made significant contributions to chemical evolution over the lifetime of the Milky Way.

This puzzle is placed into the context of other galactic populations shown in Figure 3, which illustrates [O/Fe] versus [Fe/H]. Both panels display galactic disk and halo stars (open blue circles), with the halo having [Fe/H] $<$ -1.0 and disk stars being more iron-rich. There is a clear increase in [O/Fe] as the iron abundance decreases. The elevated values of O/Fe in the halo are expected in a population of stars which have formed from gas dominated by material processed through SN II. Some Fe is also created in SN II, but in amounts that are much smaller than in SN Ia, thus the increased abundances of oxygen relative to iron. After a time delay, SN Ia begin to contribute to chemical evolution, producing large amounts of Fe, which then drives the ratio of O/Fe to smaller values.

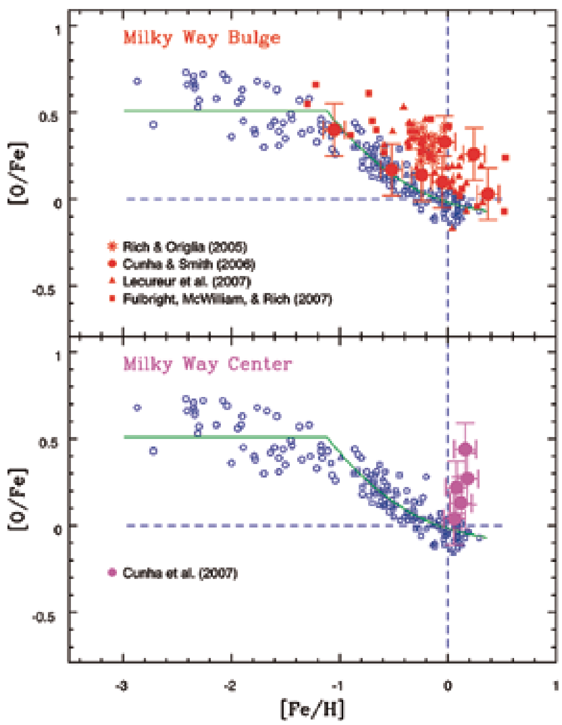

Figure 3.
[O/Fe] vs. [Fe/H] for halo and disk stars (open blue symbols), compared to old bulge red giants (red symbols, top panel) and young galactic center M giants and supergiants (magenta filled circles, bottom panel). The green curve is a simple chemical evolution model for SN II and SN Ia yields.

The top panel of Figure 3 shows [O/Fe] vs. [Fe/H] for galactic bulge stars compared to disk and halo stars. Bulge stars have high values of [O/Fe] that extend to large values of [Fe/H]. The bulge trend also falls above the trend defined by the disk and halo. The bulge behavior is interpreted as being caused by very extensive and rapid star formation in the early bulge. The gas was rapidly enriched to large values of [Fe/H] before the onset of SN Ia, which then begin to drive the O/Fe ratio down. The bulge population is an old one and exhibits chemical evolution that ended several billion years ago.

In the bottom panel of Figure 3, galactic center stars stand out distinctly. These stars all have roughly solar [Fe/H], with [O/Fe] elevated compared to the disk at solar [Fe/H]. This pattern is similar to the results exhibited by the bulge stars at this same Fe abundance. However, the bulge population is ancient, while the galactic center stars are young. If the gas from which these young stars formed has been polluted over the age of the Milky Way, it would be expected to contain material that has been cycled through both SN II and SN Ia. If this is indeed true, then the elevated values of O/Fe in these young stars need to be explained.

Two promising avenues come to mind for modeling the high alpha-to-iron ratios we observe in young galactic center stars. One idea is that the generations of stars that have formed in the galactic center have driven chemical evolution there and that the mass function in this region is weighted towards more massive stars; such a "top heavy" mass function in the galactic center has been suggested by a number of investigators. This would mean that SN II would be larger contributors to gas in the galactic center and thus would yield larger values of [O/Fe] (the amount of oxygen ejected by SN II increases dramatically with increasing progenitor mass, while the amount of Fe is predicted to be roughly constant). Another suggestion is that alpha-enhanced gas which helps fuel star formation in the galactic center arrives from outside. If this were disk gas, it would be puzzling as no metal-rich disk stars exhibit the alpha-element enhancements we observe in the galactic center. Gas could fall in from the bulge, provided through mass-loss from old red giants. The mass average of bulge abundances of O, Ca, and Fe would fit the abundance patterns we observe in the galactic center stars. Further abundance studies of a larger galactic center population, as well as the first detailed chemical evolution models of the central 200 parsecs of the galaxy, are needed to investigate these possibilities and others.

This result appears in the Nov. 10, 2007 issue of *Astrophysical Journal*.

For more information please see:

Blum, R. D. *et al.*, 2003, *ApJ*, **597**, 323
Carr, J. S., Sellgren, K., and Balachandran, S. 2000, *ApJ*, **530**, 307
Figer, D. F. et al. 2004, *ApJ*, 601, 319
Morris, M. and Serabyn, E. 1996, *ARA&A*, **34**, 645
Ramirez, S. V. et al., 2000, *ApJ*, **537**, 205

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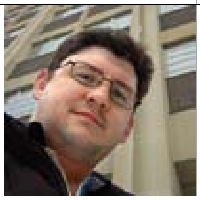
Kris Sellgren is a professor in the Astronomy Department at the Ohio State University. She can be reached at: sellgren@astronomy.ohio-state.edu.



by Roberto Abraham

The Gemini Deep Deep Survey: A Tenth Paper Redux

By the time you read this, the tenth paper in the Gemini Deep Deep Survey (GDDS) series will have been submitted for publication. This artificial milestone provides a nice opportunity to recapitulate a few highlights from the survey.

The primary science driver of the GDDS is to use a stellar-mass-selected sample to probe galaxy evolution at $1 < z < 2$. Something like half the stellar mass in galaxies forms over this redshift range, and it spans the epoch at which star-formation in the universe is at its peak. At the time the survey was proposed the main challenge was to get any redshifts at all at $1.2 < z < 2$, which had come to be known as the "redshift desert," in reference to the paucity of optical redshifts known over this interval. However, by the time the GDDS had actually begun, some progress had already been made in obtaining redshifts for ultraviolet (UV) selected samples in the redshift desert by Charles Steidel and collaborators, using the blue-sensitive LRIS-B spectrograph at the W.M. Keck Observatory. So, even from the outset, the "redshift desert" was something of a misnomer, albeit a rather catchy one. However, UV-selected surveys are biased in favor of high star-formation-rate galaxies, and it was clear that passive red galaxies with high mass-to-light ratios that are missed by UV selection could well dominate the high-z galaxy stellar mass budget. Our ambition was to probe the sorts of galaxies being missed by other surveys.

The goal of the GDDS was therefore to obtain ultra-deep spectroscopy from which we could obtain a fair census of massive galaxies at $1 < z < 2$. Integration times as long as 30 hours per field allowed us to determine continuum redshifts from rest-frame UV metallic absorption features, rather than relying on emission lines from star-forming galaxies (Figure 1). A similar goal motivated the K20 Survey on the Very Large Telescope (a European Southern Observatory Key Project), and the two surveys reported

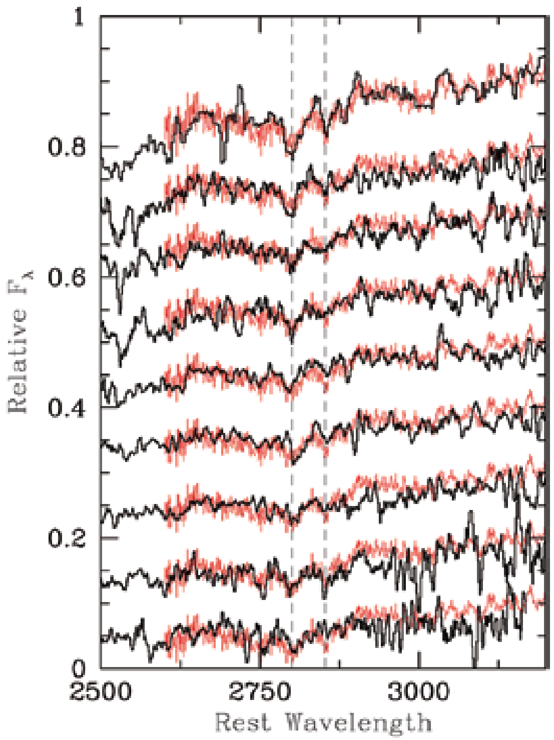


Figure 1. *Spectra of evolved/quiescent GDDS galaxies at $z > 1.3$ (black lines). The Sloan Digital Sky Survey Luminous Red Galaxy composite (red lines) has been overlaid on each spectrum and an offset has been applied to each spectrum in order to stack them vertically. The locations of the stellar MgII and MgI lines are indicated by the dashed lines. (Taken from GDDS paper IV.)*

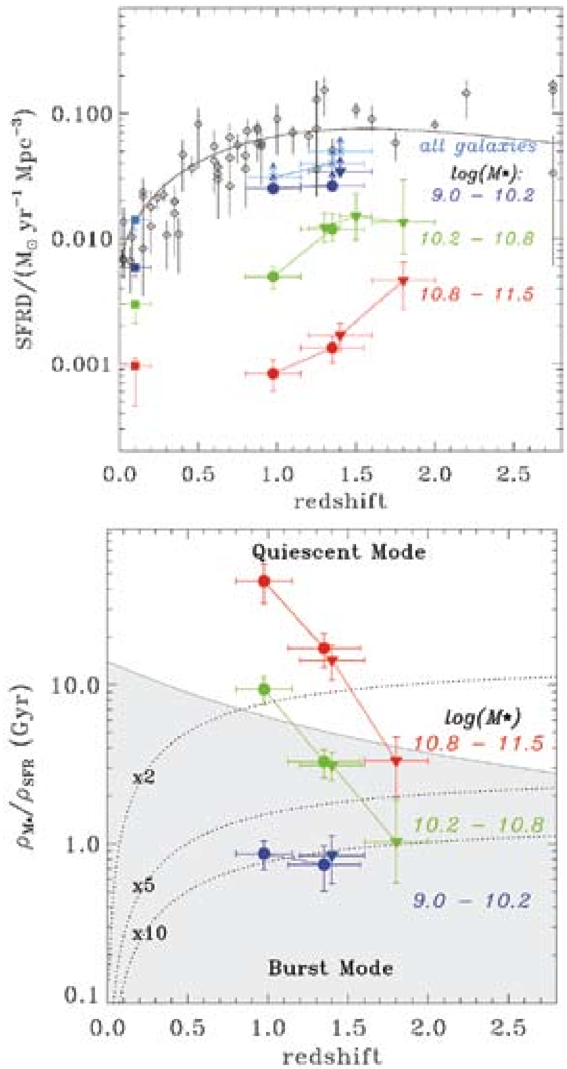


Figure 2.
(Top panel) the universal star-formation rate per unit volume for galaxies in different stellar mass ranges (from GDDS Paper V). Star-formation rate evolution is a very strong function of stellar mass. Rates were derived from L([OII]) (circles) and from rest-UV flux (triangles). The symbols are color-coded by the logarithmic mass ranges. The error bars in redshift show width of the redshift bins used. Squares: values found locally by Brinchmann et al. (2004) converted according to our assumed IMF and dust correction. Diamonds: the compilation made by Hopkins (2004), where all values are converted to a (Ω_M = 0.3, Ω_Λ = 0.7, h = 0.7) cosmology. The solid black line: the fit derived by Cole et al. (2001) assuming A_V = 0.6. (Bottom panel) The characteristic timescale of galaxy growth plotted by dividing the universe's mass density function by its star-formation rate function. Gray region: the age of the universe in our adopted cosmology. Curve crossings from gray to white indicate the transition from quiescent star-formation mode to burst star-formation mode (gray area). Along the dotted lines, look-back time to the present allows galaxy stellar mass to increase by a factor of 2, 5 or 10, if the SFR stays constant, as labeled.

similar results at similar times. (Amusingly, key papers even appeared in the same issue of *Nature*.) For example, GDDS and K20 obtained similar evolving stellar mass functions and ages for massive "red and dead" systems. The main result from both surveys is that massive galaxies are far more common than originally expected at z~1.5 (GDDS Paper III), and that many of these systems are surprisingly old (GDDS Paper IV). In retrospect, the convergence on such fundamental results from two independent surveys strengthened the credibility of the results from both teams. Taken together, these early results lent considerable impetus to the notion, originally put forward by Lennox Cowie (University of Hawai'i) in 1996, of galactic "downsizing," in which the most massive galaxies form first. Evidence for downsizing was summarized in GDDS Paper V (Figure 2). Subsequent observations from a host of other teams using a broad range of other methods have strengthened this basic picture, and it is probably fair to say that downsizing is now entrenched as the *de facto* observational paradigm for high-redshift galaxy formation.

Although the highest-impact papers to have emerged (so far) from the GDDS focus on the abundance of massive red galaxies at high redshift, it comes as no surprise that much of the most interesting science to emerge from the GDDS has nothing to do with the original science goals of the survey. A prime example of this is the work that has emerged on the metallicities of 0.4 < z < 1 galaxies. GDDS paper number VII, from a team led by Sandra Savaglio, reports the discovery of a mass-metallicity (M-Z) relation in high-redshift galaxies. This result emerges from an investigation of the bluer galaxies on our spectroscopic masks. The canonical way to determine metallicities in high-z galaxies is to use emission lines originating in HII regions. By definition, this technique is selecting young star-forming galaxies which, as noted earlier, are not high-priority targets for the GDDS. However, we did have significant numbers of these systems in our survey as second priority targets. By combining spectra for 29 blue GDDS galaxies with a similar data set from the CFHT at lower redshift (obtained as part of the the Canada-France Redshift Survey; CFRS) we obtained a total sample of 65 galaxies. The resulting mass-metallicity relation, clearly detected in the GDDS and CFRS sample, is different from the same relation defined by Christy Tremonti and collaborators in the local universe. It appears that by z~0.7 massive galaxies have achieved a mature chemical state, similar to massive galaxies at z~0.1. On the other hand, small galaxies are still in the process of forming their metals. By combining our mass-metallicity relation with the local relation, we were able to build up a simple empirical model for the evolution in the relation which reproduces the more recent mass-metallicity relation in z~3 Lyman-break galaxies reported by Dawn Erb and collaborators. This model is also consistent with downsizing since, in our model, the e-folding time for star formation is inversely proportional to the initial mass of galaxies. It provides an extra dimension to the exploration of galaxy formation: time evolution of the heavy element enrichment in galaxies with different initial conditions.

More recent papers in the GDDS series have tended to use the survey data as a starting point for analyses of data obtained from other facilities (e.g., the Hubble Space Telescope and the Spitzer Space Telescope). Data from the Hubble Space Telescope has proved particularly valuable, forming a key component of the analysis in five of the later GDDS papers. For example, in GDDS paper VIII we used the Hubble Space Telescope's Advanced Camera for Surveys to measure the mass density function of

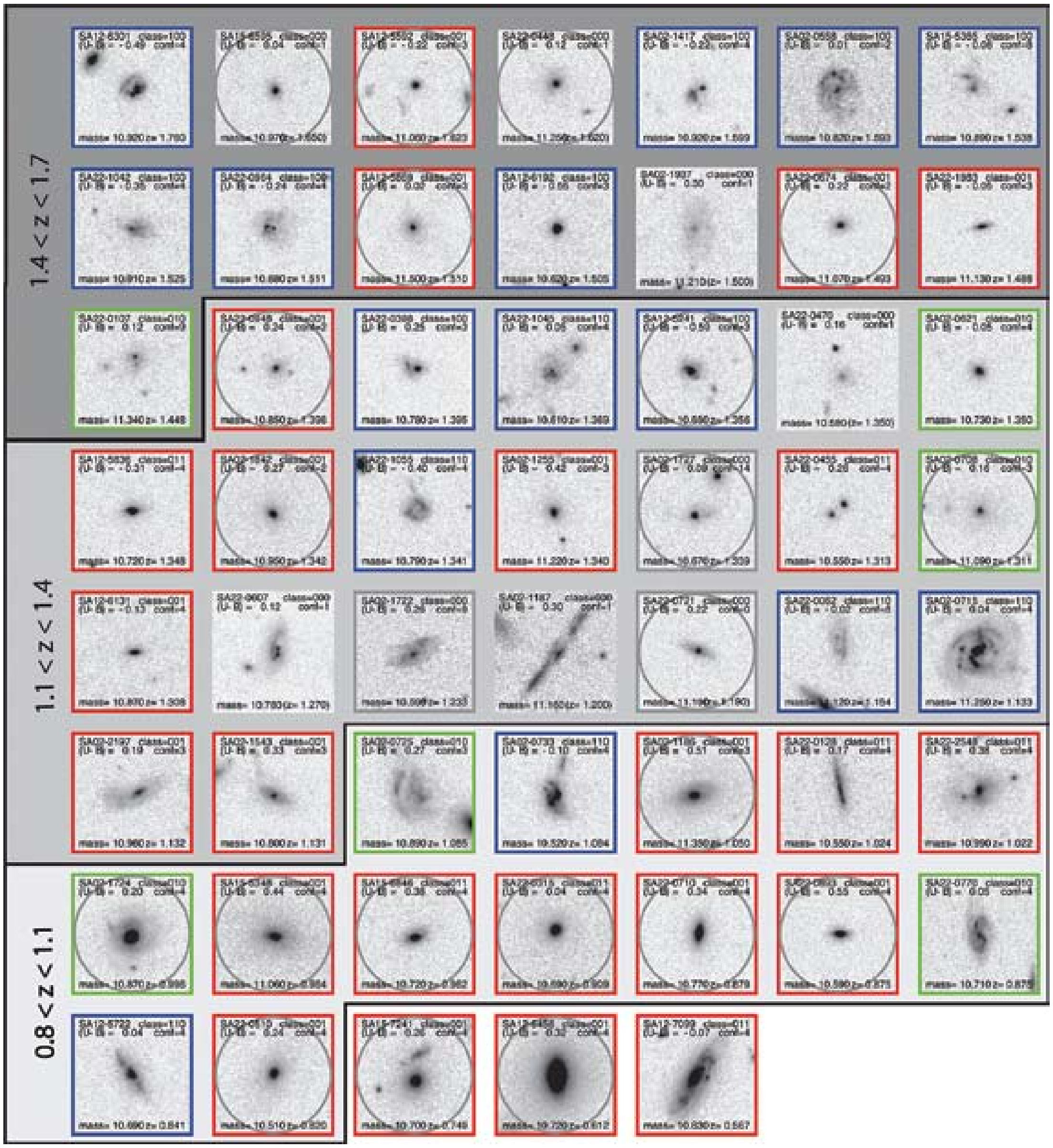


Figure 3. *Postage-stamp images (from GDDS Paper VIII) showing the morphologies of the 54 galaxies in our GDDS sample with log(stellar mass)>10.5. These galaxies are sorted in order of decreasing redshift. Early-type galaxies are circled. Each image is 5" × 5" in size, with galaxy ID number, spectroscopic classification, redshift confidence class, rest-frame (U-B) color, redshift, and stellar mass. Objects without high-confidence spectroscopic redshifts have their redshifts labeled in parentheses. The border of each galaxy image indicates the spectroscopic classification. Red borders indicate evolved spectra. The gray regions surrounding groups indicate which of three broad redshift bins the objects fall within.*

morphologically-selected early-type galaxies in the GDDS fields. We find that at z~1 approximately 70% of the stars in massive galaxies reside in early-type systems (Figure 3). This fraction is remarkably similar to that seen in the local universe. However, we also detect very rapid evolution in the abundance of massive early-type galaxies over the range 1.0 < z < 1.6, suggesting that, in this epoch, the strong color-morphology relationship seen in the nearby universe is beginning to fall into place. This work begins to place downsizing in a broader context, which encompasses the formation of the Hubble sequence.

Finally, for users of GMOS who do not work on ultra-faint galaxy evolution, perhaps the main highlight of the GDDS survey has nothing to do with our team's papers. Instead, it may lie in the GDDS team's work to make a "nod & shuffle" sky subtraction mode available on this spectrograph as a common-user mode available to you for your own research. The GDDS team proposed and implemented this mode, working (literally) shoulder-to-shoulder with scientists and engineers from Gemini and the Herzberg Institute of Astrophysics. Seven of the twelve most cited papers produced by Gemini make use of nod & shuffle, and this is a source of deep satisfaction to the GDDS team. No doubt the technical partnership developed between Gemini and the team in developing this mode played a central role in cementing the deep scientific partnership between universities, national and international observatories encapsulated by Figure 4. This team slide is updated regularly and is the only PowerPoint/Keynote slide which all members of the GDDS collaboration are asked to exhibit in every GDDS-related talk given (with 5-minute AAS job talks excepted.)

Figure 4.
The GDDS team, circa 2006, recorded for posterity on a PowerPoint/Keynote slide. The only hard-and-fast "rule" mandated by the collaboration is that the latest version of this slide be shown at least once during major talks.

Appendix: Summary of GDDS Papers (So Far)

GDDS Paper 1: Abraham *et al.* (2004). *AJ*, **127**, 2455. *"The Gemini Deep Deep Survey. I. Introduction to the Survey, Catalogs, and Composite Spectra."* All data from Gemini.

GDDS Paper 2: Savaglio *et al.* (2004). *ApJ*, **602**, 51. *"The Gemini Deep Deep Survey. II. Metals in Star-forming Galaxies at Redshift 1.3 < z < 2."* All data from Gemini.

GDDS Paper 3: Glazebrook *et al.* (2004). *Nature*, **430**, 181. *"A High Abundance of Massive Galaxies 3-6 Billion Years after the Big Bang."* All data from Gemini.

GDDS Paper 4: McCarthy *et al.* (2004). ApJ, **614L**, 9. *"Evolved Galaxies at z > 1.5 from the Gemini Deep Deep Survey: The Formation Epoch of Massive Stellar Systems."* All data from Gemini.

GDDS Paper 5: Juneau *et al.* (2005). *ApJ*, **619L**,135. *"Cosmic Star Formation History and Its Dependence on Galaxy Stellar Mass."* All data from Gemini.

GDDS Paper 6: Le Borgne *et al.* (2006). *ApJ*, **642**, 48. *"Gemini Deep Deep Survey. VI. Massive Hδ-strong Galaxies at z ~= 1."* Data from Gemini and HST (ACS).

GDDS Paper 7: Savaglio *et al.* (2005). *ApJ*, **635**, 260S. *"The Gemini Deep Deep Survey. VII. The Redshift Evolution of the Mass-Metallicity Relation."* Data from Gemini and HST (ACS).

GDDS Paper 8: Abraham *et al.* (2007). *ApJ*, in press. *"The Gemini Deep Deep Survey: VIII. When Did Early-type Galaxies Form?"* [arXiv:astro-ph/0701779]. Data from Gemini and HST (ACS).

GDDS Paper 9: McCarthy *et al.* (2007). *ApJ*, in press. *"A Compact Cluster of Massive Red Galaxies at a Redshift of 1.5."* Data from Gemini, HST (ACS and NICMOS), and Spitzer.

GDDS Paper 10: Damjanov *et al.* (2007). *ApJ*, submitted. *"The Sizes of Early-type Galaxies at High Redshifts."* Data from Gemini and HST (NICMOS).

Roberto Abraham is professor of astronomy at the University of Toronto and a specialist in galaxy evolution. He can be reached at: abraham@astro.utoronto.ca

by Doug Welch

Ancient Supernova Light Echoes

They have been out there for hundreds of years. We have probably recorded any number of them on images in the past. However, until now, no one recognized them for what they are—the reflected and delayed light from the most spectacular events in the heavens: supernovae. Now, we are using the Gemini telescopes and the Gemini Multi-Object Spectrographs (GMOS, north and south) to learn about ancient outbursts that were either missed entirely or occurred prior to the development of the spectrograph and other sensitive detectors.

The story of the discovery of ancient supernova light echoes by the SuperMACHO Project began with the allocation of a five-year survey program to detect microlensing using the Blanco 4-meter telescope at the Cerro Tololo Inter-American Observatory. Unlike the MACHO Project, which sought the presence of unluminous (or underluminous) mass by looking for the brightenings of background stars already identified in a list, SuperMACHO made use of "difference imaging." This technique allowed many images to be compared in a way that reduced the effects of crowding and could detect any brightening objects within the images, not just those originally on a star list. This technique also proved to be sensitive to motion. No interesting moving objects were anticipated—even high proper motion stars don't move much on images taken over the course of five years. Indeed, for the first two years, the sky did not move.

Quelle différence!

Beginning in the 2002-2003 observing season, this changed. Our algorithms for differencing images became more sophisticated and better able to reject image artifacts. As our analysis techniques improved, a class of not-quite-starlike features that tended to arrange themselves in lines began making their way into our alert pages for visual inspection. Curiously, as the months passed, the difference patterns became more and more distinct. We now recognize that these features were the locations where supernova outburst light was intersecting interstellar dust and scattering some of that light in our direction. The direct light from the outburst had arrived at Earth centuries ago, but because the length along the reflected path—all the way back to the supernova—is longer, we are just now seeing the outburst light scattered from these events.

At first, what we were seeing was not so obvious. The CCDs in the focal plane of the Blanco 4-meter telescope have lots of edges and there are frequently difference

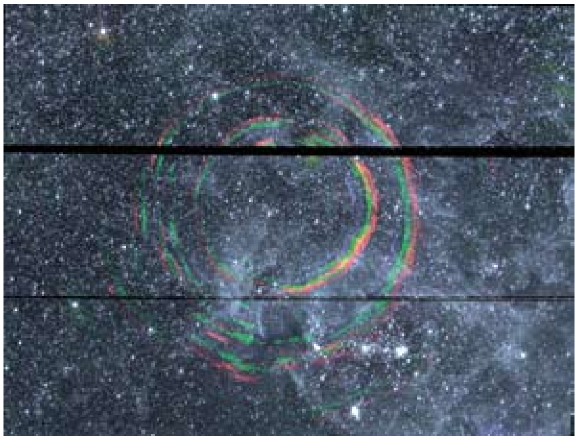


Figure 1.
A composite image of the region around SN1987A (created by Pete Challis (SuperMACHO project). Difference images at intervals of three years are superimposed on this region. Blue indicates the earliest difference image and red the most recent; the ellipsoid surface grows with time. Later difference rings are larger than earlier ones for dust at the same line-of-sight difference.

artifacts from near-edge bright stars. The monotonic progress of the features eventually caused us to rule out that proposed explanation for their existence. Then, we suspected that we had found outlying echoes of SN1987A (which had boasted previously discovered light echoes) but we weren't paying enough attention to how distant the features were from that outburst and what direction they were traveling. When Armin Rest sat down and sketched where the features were on the sky and where they were heading, two things immediately became obvious. First, the features we had discovered were not associated with SN1987A. Second, the motion vectors originated from a small number of positions. After a very short time, we identified the centers of the patterns as being coincident with three of the apparently youngest supernova remnants in the Large Magellanic Cloud (LMC).

Gemini Rising

We figured out the nature of these mystery features at the very end of the LMC observing season. The next obvious step was to try to get some spectra of the scattered outburst light. Such observations held the promise of allowing us to type the supernovae and link them to the properties of the now half-millennium-old remnants. (The remnants, of course, are the matter blown into space at velocities of roughly 10,000 kilometers per second (km/sec). They occupy a much smaller patch of "real estate" on the sky than the light echoes do.)

Our first attempt to obtain the spectrum of a light-echo made use of a few hours of Director's Discretionary (DD) time with long-slit GMOS-South spectroscopy in March 2005. Jean-René Roy informed me that he would approve the DD request at noon of the day in question and asked if I could put together a more formal observing plan… by dusk of that same day! I did, and the observations were acquired. A thorough reduction of the data by Tom Matheson, Marcel Bergmann, and Knut Olsen made it clear that the stellar spectral background of the LMC contaminated the data too much to allow us to extract the diffuse echo light.

Marcel suggested that we would likely need to nod (move the telescope pointing between the object and another sky position to improve sky sampling) a great distance off the LMC to get to a sufficiently sparse stellar background, and would need to implement and test wide-angle nods. Such large nods reduced the effectiveness of the sky spectrum removal somewhat, as well as the efficiency of on-target time, but empty sky was critical for the success of this project. After additional exposures, it became clear that the optimum strategy was to cut custom masks and utilize the wide-angle nods. We adopted this in our application for the 2006B semester.

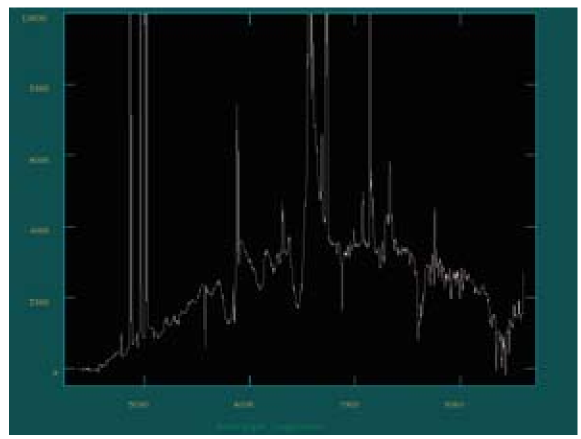


Figure 2.
A GMOS-S spectrum of the brightest portion of a SN1987A light echo obtained on December 24, 2006. (Sharp vertical lines are imperfectly subtracted LMC field emission lines and night sky lines.) The Type II outburst spectrum of SN1987A is clearly seen in light reflected from dust in the vicinity of the supernova, which occurred 20 years earlier.

The Supernova that Created SNR 0509-67.5

We can be pretty sure that someone saw the supernova that gave rise to the remnant SNR 0509-67.5, even though it took place roughly 300-500 years ago, because it would have been as bright as a first-magnitude star! However, no known chronicles of the far southern skies exist from this period. The first routine scientific records of the region appear to be from Sir John Herschel in the 1830s.

We have completed the analysis of our MOS spectra of echo light associated with SNR 0509-67.5 obtained during our program GS-2005B-Q-11 and have submitted the paper to the *Astrophysical Journal*. Our spectra are able to distinguish the classification sub-type; this event was an over-luminous Type Ia supernova, similar to SN1991T.

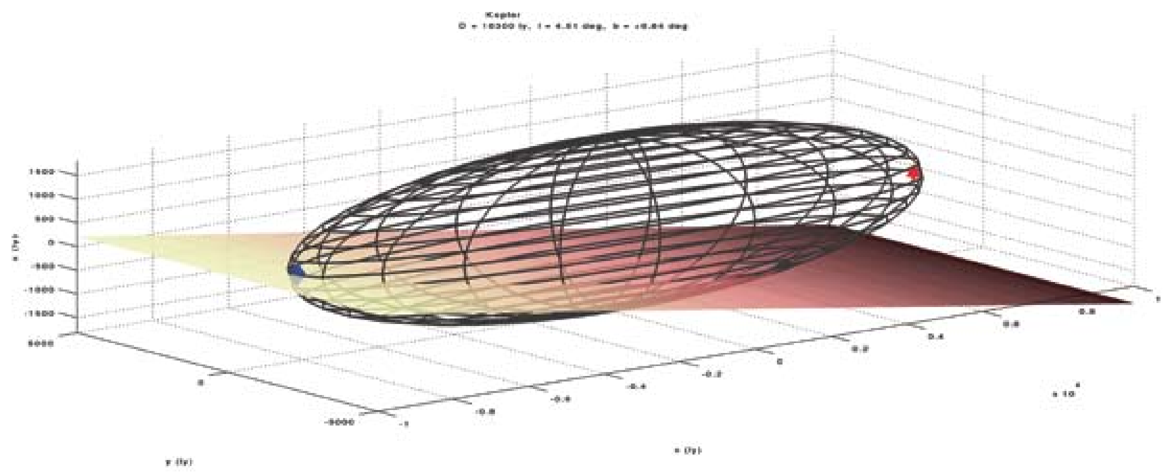


Figure 3. *This ellipsoidal three-dimensional surface diagram accurately depicts the dust-scattering situation for SN 1604 ("Kepler"). Earth (blue diamond) lies at one focus and the supernova (red star) at the other. The plane of the Milky Way (tan sheet) contains dense obscuring dust. Places where the plane and ellipsoid intersect, and where the light is forward-scattered, should be the most fruitful for echo-hunting. (Image courtesy Lindsay Oaster, McMaster University.)*

Looking at Supernovae from Both Sides Now

Dante Minniti, a SuperMACHO Project collaborator, pointed out one of the most interesting and potentially useful aspects of light echoes: the dust being illuminated has a different perspective on the event than we would have had along the line of sight. Furthermore, dust at different azimuths on the sky gives different perspectives on the outburst. In the case of SN1987A, the view differs by about 20 degrees. For the echoes associated with SNR 0519-69.0, the viewpoint varies by as much as 99 degrees. Thus, the asymmetry of the supernova can be examined observationally. We obtained observations specifically for this purpose in 2006B. They include the "control" of spectra from SN1987A where we did see the light directly.

Not Too Long Ago, In Our Own Galaxy

We have been successful in finding and studying supernova light echoes in the LMC. What about closer to home in our own Milky Way Galaxy? Wouldn't they already have been found if they were there? The answer is no. The two primary reasons for this are: 1) wide-field, linear image-differencing is a modern creation; and 2) the echo features themselves will be found at large angular distances from the remnants. Even if a decades-old image had recorded a bright echo, it wouldn't have been naturally associated with the remnant and no motion would have been evident. A surprising feature of light echoes from Milky Way supernovae in the nearest several kiloparsecs is that the proper motions are huge—roughly 30 arcseconds/year.

We have six historical supernovae which are likely to have generated observable light echoes: 1006 (in Lupus), 1054 (Crab), 1181 (in Cassiopeia), 1572 (Cassiopeia, "Tycho"), 1604 ("Kepler," in Ophiuchus), and Cassiopeia A. The last of these is very intriguing because no optical counterpart was ever noticed. Yet, it seems to have "happened" (from our perspective on Earth) in the late 1600s. We have begun a search for ancient supernova light echoes associated with the historical supernovae and I am pleased to report that our very first survey run on the KPNO 4-meter telescope produced several echo features apparently associated with Tycho or Cassiopeia A. We also expect Gemini GMOS observations to allow us to sub-type these outbursts and provide modern spectra of supernova light that, just a few years ago, seemed lost to the ages.

The research described in this paper can be found in the paper "Light echoes from ancient supernovae in the Large Magellanic Cloud" by Armin Rest et al., which appeared in *Nature*, volume **438**, issue 7071, pp. 1132-1134 (2005). For a full list of the collaborators who have contributed to this discovery, please see the author list of the above paper. A website developed to provide a greater understanding of supernovae light echoes can be found at the URL: http://www.ctio.noao.edu/supermacho/lightechos/

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by Jean-René Roy
and Scott Fisher

Gemini Science Highlights

Figure 1.
An artist's conception of M33 X-7, a binary system in the nearby galaxy M33. Artwork courtesy of Chandra X-ray Observatory.

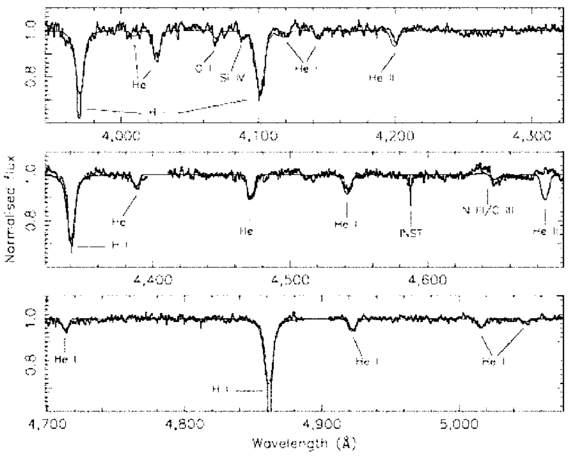
Gemini and Chandra Find the Most Massive Known Stellar Black Hole

Observations that combine data from Gemini North and the Chandra X-ray observatory have led to the discovery of the most massive known stellar black hole. Intriguingly, the black hole is associated with an exceptionally large companion star which, by a fortunate coincidence, orbits the black hole from our perspective on Earth. The edge-on nature of the orbit also allows for a high-precision determination of the masses and other fundamental parameters of the system (Table 1). The ramifications of this pairing could have a profound effect on our understanding of how the largest stars evolve.

The black hole/star pair is located about 3 million light years from Earth in the galaxy M33, in the constellation Triangulum. The combination of x-ray data with Gemini North's optical images and spectroscopy (see Figure 2) let the international team conclude that the black hole has a mass of 15.7 solar masses, which makes it the most massive stellar black hole known.

Known as M33 X-7, the black hole orbits its 70-solar-mass companion in an orientation that creates an eclipse every 3.5 days. To have such a large black hole partnered with such a portly "normal" star is an exceptional situation that will eventually result in a pair of black holes orbiting each other when the massive star eventually goes supernova. However, there is a challenge to understanding how a system like this could have formed. Since higher-mass stars evolve more rapidly than less-massive ones, the star that created the existing black hole in the pair must have already gone supernova. This implies that it was even heavier than the 70 solar-mass behemoth that remains in the system. This is puzzling since at that size, the progenitor star of the black hole would have been large enough that it would have shared its atmosphere with its companion. Current theories of mass exchange between binary pairs lead to scenarios very different from what is seen in this system. How such an unusual binary formed will, for now, remain an enigma.

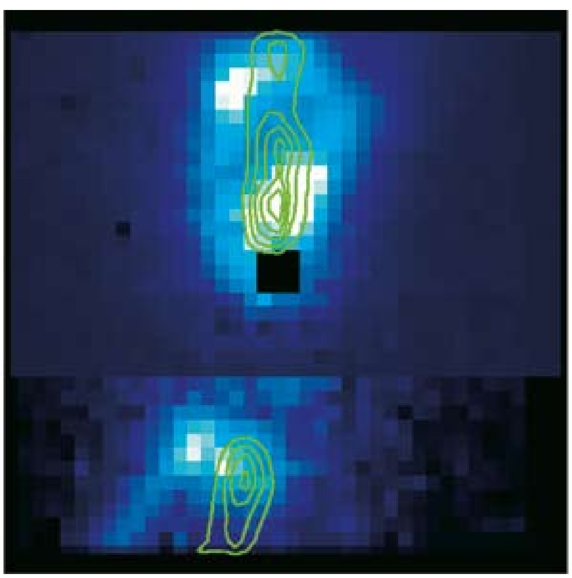
parameter	value	parameter	value
Θ (deg)	$46 = 1$	M_2 ($M_\odot$)	70.0 ± 6.9
T_{eff} (K)	$34000 - 36000$	r_d	0.45 ± 0.03
$V_{rot} \sin i$ (km s^{-1})	$250 = 7$	e	0.0185 ± 0.0077
R_2 ($R_\odot$)	$19.6 = 0.9$	ω (deg)	140 ± 27
$\log L_2$ ($L_\odot$)	5.72 ± 0.07	Ω	$0.903 = 0.037$
$\Delta\phi$	$0.0045 = 0.0014$	f_2	$0.777 = 0.017$
i (deg)	74.6 ± 1.0	a ($R_\odot$)	42.4 ± 1.5
K_2 (km s^{-1})	108.9 ± 5.7	M ($M_\odot$)	15.65 ± 1.45



The result was announced in the October 18th, 2007 issue of the British journal *Nature* (Orosz, J. A., *et al.* 2007, **449**, 872).

NIFS Views a Micro Bipolar Outflow from HL Tauri

During the earliest stages of star formation and evolution young stellar objects generate spectacular jets and outflows of molecular and atomic gases that stream away from them with high velocities. Unfortunately, the launching mechanism for these jets is not yet completely understood.



This happens in part because most of the action takes place in the inner areas of the dense accretion disk of gas and dust surrounding the forming stars, making the creation of the jet and/or outflow difficult to view. To study these inaccessible regions scientists need the best spatial and spectroscopic resolution available. To this end, a team led by Michihiro Takami (Subaru Telescope) and Tracy Beck (Gemini Observatory) used the adaptive optics-fed integral-field spectrograph NIFS on Gemini North to explore the inner structure of the jet in the young star HL Tau, located about 160 parsecs (521 light-years) away in the constellation Taurus.

The morphology and kinematics of the molecular hydrogen (H_2) and CO (carbon monoxide) outflows in the vicinity of HL Tau are quite similar. This is not surprising as the H_2 emission is partially associated with the cavity walls of the evacuated region that was created by the outflow of CO from the young star. However, the H_2 flow of HL Tau is significantly smaller than a typical young-star CO outflow. While a "normal" outflow often extends across 1,000 to 10,000 astronomical units (AU), the H_2 flow in HL Tau has a spatial scale of only about 150 AU, only twice the size our solar system.

Also, the H_2 emission has remarkably different geometry and kinematics from the [Fe II] emission of the jet, and there is no sign of interaction between the two. As seen in Figure 3, the [Fe II] jet appears to be surrounded by an as yet undetected wind from the young star. A simple description of the system is that the wind from the star interacts with ambient gas in the accretion disk. This excavates a bipolar cavity and creates shocks which induce the detected H_2 emission.

The authors of the study predict that some of the arc-like features detected with NIFS will change significantly over a scale of several years. Periodic monitoring of the source will allow the researchers to observe changes in the morphology of the emission, thus improving the determination of the dynamical age of the jet/outflow. This will lead to a better estimate of how long this critical phase of young star evolution lasts.

Search for Thermal Emission from Exoplanet TrES-1

Heather A. Knutson (Harvard-Smithsonian Center for Astrophysics) led a team using NIRI on Gemini North to make the first ground-based attempt to detect the secondary

Table 1. *(Top left) selected parameters for M33 X-7. The uncertainties correspond to one standard deviation. Table from Nature paper.*

Figure 2. *(Left, below table) mean optical spectrum of M33 X-7. The spectrum shown here is the sum of the 22 individual spectra that have been velocity-shifted to the rest frame of the secondary star. The solid line is the model spectrum described in the paper. The data were obtained using Gemini Multi-Object Spectrograph (GMOS) on the Gemini North in good seeing of always < 0.8 arcseconds.*

Figure 3. *(Bottom left) reconstructed image from the NIFS integral field spectroscopy showing the H_2 image at 2.122 microns with the narrow contour of the [Fe II] emission of HL Tau. The black spot corresponds to the star position. The field shown corresponds to about 3 x 3 arcsec².*

eclipse of the extrasolar planet TrES-1 in the near-infrared. This is done by measuring the tiny decrease in flux that occurs when the planet moves behind its parent star, as seen from Earth. The team observed the planet/star system and a nearby reference star simultaneously by positioning both objects in the same slit.

Recent observations by astronomers using the Spitzer Space Telescope have detected thermal emission from several transiting planets, including TrES-1. Although the NIRI observations led to zero eclipse depth (-0.0010 +/- 0.0015), they represent a detection sensitivity of 0.15% in the eclipse depth relative to the stellar flux. This accuracy approaches the sensitivity required to detect the planetary emission. Computer models predict that such emission should lie between 0.05 and 0.1% of the stellar flux in the 2.9- to 4.3-micron bandpass. TrES-1 was predicted in 2005 to show an eclipse depth between −0.0015 and −0.0009 for this wavelength range.

A current weak point in the experimental design lies in the limited slit widths available on NIRI. Even though the widest slit was used during the observations, pointing jitter and variations in the focus and seeing introduced large changes in the apparent flux of the targets as some photons fell outside the slit. Wider slits may be incorporated into the instrument in the future. The ability to conduct such a search from the ground will become increasingly important in the next few years as Spitzer is expected to run out of cryogens in early 2009 and will lose some of its sensitivity in these wavelength bands.

Resolving the Debris Disk around HD32297

In an unlikely occurrence of serendipity, two teams (one on each of the Gemini telescopes) independently resolved the debris disk around the star HD 32297 in the mid-infrared for the first time. Mike Fitzgerald (University of California, Berkeley) led the team that used MICHELLE on Gemini North to image the disk with the N' (11.2 microns) filter. Similarly, Margaret Moerchen (University of Florida) and her colleagues used the Thermal-Region Camera Spectrograph (T-ReCS) to obtain images of the disk at both 12 and 18 microns (Figure 4). Both teams detected extended emission from the disk out to a radius of about 150 AU (about 1.0 arcsecond at 112 parsecs, the estimated distance of this object). This detection admits HD 32297 to the exclusive group of 12 debris disks that have been resolved thus far in the mid-infrared.

The Moerchen team used its multi-filter imaging (Figure 4) to investigate both the color and color temperature of the mid-infrared-emitting dust in the system. To place the new disk into a broader context, the team compared HD 32297 to two other disk archetypes—HR 4796A and Beta Pictoris. The position of HD 32297 in a color/color diagram implies that the central region of the disk is relatively devoid of dust (although not completely empty) much like the HR 4796 system. Since the source was resolved at both 12 and 18 microns, the team could also derive a series of color temperature estimates for the disk. They found that the color temperature of the dust stays constant from the center of the disk out to a radius of about 80 AU. This reinforces the idea that there is a solar-system-sized hole in the center of the HD 32297 disk. The team goes on to suggest that the outer boundary of the cleared region may lie at the "snow line" (the region where the temperatures are cold enough to freeze water).

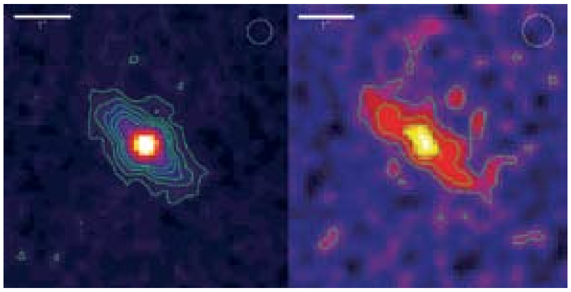


Figure 4.
T-ReCS 12-micron (left) and 18-micron (right) images of the debris disk around HD 32297. This is only the 12th disk that has been resolved in the mid-IR.

The Fitzgerald team derived a remarkable amount of information from their single-filter image. By removing the emission associated with the central star in the system, they showed that the disk exhibits a bi-lobed structure with peaks at 0.5-0.6 arcseconds from the central star. This provides strong evidence that the dust in the disk is confined to a relatively narrow ring with a radius of about 65 AU. The team's modeling of the dust particles implies that the mid-infrared-emitting grains are sub-micron sized, suggesting that the same grains are responsible for both the mid-infrared emission and the near-infrared scattering associated with the

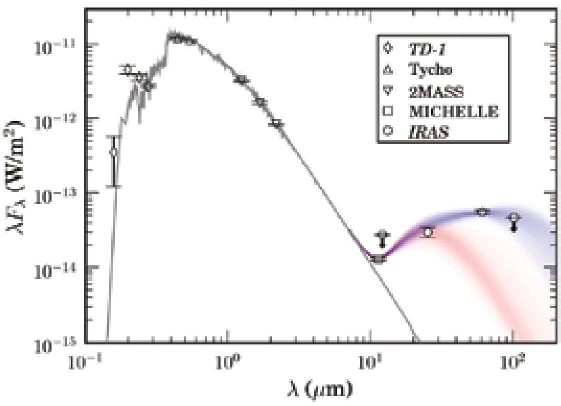


Figure 5.
Spectral energy distribution of two different grain-size models for HD32297.

system. The results of two different grain models are shown in the spectral energy distribution in Figure 5.

The Lowest-mass Brown Dwarf Found

The coolest-known star-like object beyond the solar system is giving astronomers a new look at the differences between the most massive planets and the smallest brown dwarfs. This newly discovered object, called ULAS J0034-00 and located in the constellation Cetus, has a record-setting low surface temperature of 600-700 K. This is cooler than any known solitary brown dwarf. In addition, it's a relative lightweight with an estimated mass of only 15-30 times that of Jupiter (although they both have about the same diameter). The discovery suggests that even lower-mass objects could be found. If so, they would continue to shrink the boundary between high-mass planets and the smallest brown dwarfs.

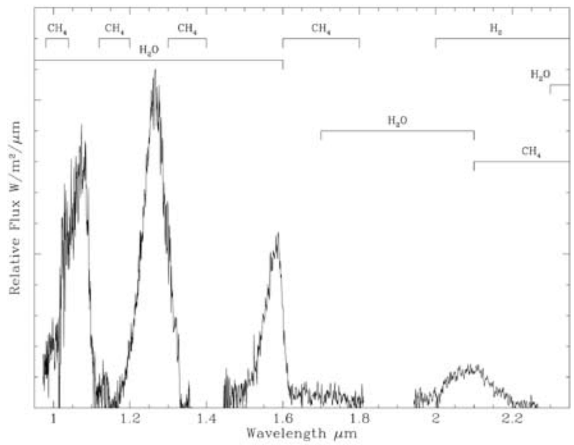


Figure 6. *(Left column) Gemini South GNIRS spectrum of J0034 (column at left).*

J0034 was discovered by S. J. Warren (Imperial College London) and a large international team during the very early stages of the United Kingdom Infrared Telescope (UKIRT) Infrared Deep Sky Survey (UKIDSS)—the world's deepest-ever near-infrared sky survey—using the Wide Field Camera (WFCAM).

Follow-up spectroscopic observations, critical for determining the brown dwarf's temperature and likely mass, were obtained with GNIRS on the Gemini South telescope in Chile. The near-infrared spectrum of J0034 confirmed that this object is indeed a very cool brown dwarf, and shows the well-known and very strong features of both water vapor and methane features (Figure 6). Only planets are cooler, and they are, by definition, bound to a parent star.

Most Distant Quasar Found at z = 6.43

Chris Willott (University of Ottawa) and a large team of astronomers participating in the Canada-France-High-z Quasar Survey, identified four new quasars at redshifts greater than z=6 (about 13 billion light-years away) in MegaCam imaging at the Canada-France-Hawaii Telescope (CFHT). Follow-up spectroscopy with GMOS at the Gemini South telescope (and the Marcario low-resolution spectrograph (LRS) at the Hobby-Ebberly Telescope) allowed the team to determine accurate redshifts. The most distant of the four objects is also the most distant known quasar, CFHGS J2329-0301 which lies at z=6.43 (Figure 7). The team also used the spectra to investigate constraints that can be put on the ionization state of the intergalactic medium at that age of the universe. From the analysis of these four distant quasar spectra, the authors suggest that reionization was well underway before z=6.4, but was still not complete by z=5.7.

The first quasars are thought to have been the first generation of light-emitting objects in the universe. This is because quasars are powerful emitters of ultraviolet radiation—so strong that they are believed to have lit up the universe in a process called "reionization".

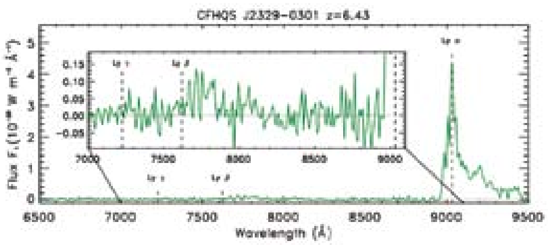


Figure 7. *GMOS South spectrum of highest redshift quasar known at z=6.43 .*

Between the period of recombination (when protons and electrons combined into neutral hydrogen), and reionization (caused by the first quasars), the universe stayed in a state that is referred to as the "Dark Ages" because of the absence of light sources. The search for end of the cosmic Dark Ages is one of the most active facets of modern cosmology.

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by Carolyn Collins Petersen

A Tale of the Starry Dandelion & the Cosmic Gecko

About 190 million years ago, a dust cloud some 5,200 light-years from the Sun coalesced to begin the process of star birth. Today, NGC 6520 (shown on the center pages) is ablaze with hot, massive young stars arrayed in a dandelion seed-shaped cluster. Not far away lies the gecko-shaped remains of what may be their birth cloud, Barnard 86. Both are set against a glittering gold-toned backdrop of stars that are far more distant and populate parts of the inner regions and bulge of our galaxy. This image, taken using the Gemini Multi-Object Spectrograph on Gemini South, shows details in a 9.7- × 5.4-arcminute section of a larger, highly populated region in the Sagittarius star cloud. It provides the striking optical view of the cluster and its nearby dark-cloud companion.

The total mass of the stars in NGC 6520 is roughly equivalent to 300-400 times the mass of the Sun, while the nearby cloud contains enough material to make about 3,000 more stars like the Sun. The close proximity between the star cluster and its nearby dark-cloud companion suggests that two are related. A robotic wide-angle survey of the southern sky (conducted by a team of astronomers led by John Gaustad of Swarthmore College and described in a 2001 paper) that singled out hydrogen-alpha emissions from warm, ionized interstellar gas shows a nebula extending from the dark globule to embrace the star cluster.

The tale of the birth of NGC 6520 begins with Barnard 86, which is likely a remnant of a once-larger cloud of gas and dust. This mysterious dark spot is a Bok globule, a cold and dense cloud of dust and molecular gas from which stars form. Such clouds are often often associated with larger complexes of glowing gas and dust called H II regions (so-named because they glow in the light of ionized hydrogen). The globules are often backlit by the glow of the H II emission, but these dense clouds themselves appear dark because they absorb most visible light. Whatever lies inside stays hidden from our view. Bok globules are named after astronomer Bart Bok, who first observed these opaque objects in the 1940s. They're known to be some of the coldest objects in the universe, often as chilly as three Kelvin. Bok and fellow astronomer E.F. Reilly were the first to suggest that these mysterious clouds of gas and dust could also be harboring stellar cocoons, hiding the hatching places of newborn stars.

The two scientists theorized that the interiors of the clouds could collapse in on themselves, eventually forming new stars. Since the action of star birth was hidden from view by the surrounding gas and dust, it was impossible to observe using optical telescopes. It wasn't until the 1990s, when the first near-infrared observations of Bok globules revealed stellar newborns hidden deep within their nests, that Bok and Reilly's ideas about hidden star formation in Bok globules was confirmed. Today, astronomers peer inside these inky, dark places with Gemini and other infrared-sensitive telescopes. They are finding sources of warmth that could be newly forming stellar objects, as well as newborn stars so far along in their formation process that they're shooting superhot jets across several light-years. If NGC 6520 and Barnard 86 lie at the same distance from us, then it's likely that they are closely related and that the dark, gecko-shaped cloud comprises the leftovers from the long-ago birth of the cluster NGC 6520.

For more information please see:

Carrarro, *et al*, 2005, *AJ* **130**, 630-642.
Gaustad, *et al*., 2001; *PASP*, **113**, 1326-1348

The color composite image on the next two pages was made using the following four filters: u-band = blue; g-band = cyan; r-band = yellow; and i-band = red. Exposures for g,r and i filters were 180 seconds each and the u filter was 720 seconds. Gemini Astronomer Rodrigo Carrasco oversaw the acquisition of these data and Travis Rector of the University of Alaska Anchorage produced the color composite image.

Amateur Note: NGC 6520 and Barnard 86 are popular observation targets for moderate-to-large telescopes (8-14 inch apertures). Look for the cluster and its neighboring Bok globule set against the starry background the Sagittarius star cloud by centering your telescope on R.A. 18h 03.3 minutes, Dec. -27° 53 minutes for the cluster. Barnard 86 lies a few arcminutes to the west.

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Open Cluster NGC 6520 and the Nearby Dark Molecular Cloud Barnard 86

Gemini Science Meeting Takes Astronomers to Brazil

Most of the more than 130 astronomers who attended the 2007 Gemini Science Meeting in Brazil.

More than 130 astronomers and staff members met for the 2007 Gemini science meeting, held at the Foz do Iguaçu Park in Brazil. The conference, held June 11-14, 2007, featured current science results, instrument and telescope capabilities presentations, and discussions about future research and collaborations.

The meeting was organized by the Laboratório Nacional de Astrofísica (LNA), which chose Foz de Iguaçu because it combines a beautiful tourist attraction with excellent infrastructure for international conventions. Albert Bruch, who chaired the local organizing committee, was pleased with the Gemini board's selection of Brazil for a meeting in what he hoped would be agreeable surroundings. "Our expectations were entirely fulfilled according to responses expressed by many participants," he said.

The Scientific Organizing Committee worked under the lead of Verne Smith, Director of the NOAO Gemini Science Center. All major themes of current forefront astrophysical research were covered by the 60 oral talks and 45 posters presented.

By François Rigaut

MCAO System Status

The Gemini South Multi-Conjugate Adaptive Optics (MCAO) system passed several important milestones during the last six months. First and foremost, we received the remaining subsystems of the AO module, CANOPUS, in July 2007. The natural guide star wavefront sensor (NGS WFS, from EOS Technologies), the laser guide star (LGS) WFS (from the Optical Sciences Company (tOSC)) and the real-time computer (also from tOSC) went through a three-week integration process in July/August which culminated with the first successful laboratory closed-loop tests of the entire system. This is a world's record–with three operating deformable mirrors and signals from five LGSs and three tip-tilt guide NGSs.

Second, an important progress review occurred in early September. This review, mandated by the Gemini Board of Directors, coordinated by the National Science Foundation (NSF), and chaired by Norbert Hubin (European Southern Observatory) was meant to assess the project management and technical risks, and the impact of the GNIRS recovery effort on the MCAO schedule. Excerpts from the executive summary of the committee report include the following: "The review committee believes that the Gemini MCAO team has the necessary past experience to develop this challenging and unique MCAO facility. The committee acknowledges the motivation and dedication of the MCAO team to complete the development of this facility [...] The committee is concerned by the lack of dedicated systems engineering for this project and the lack of global error budget monitoring, which might lead to the MCAO facility not meeting the top level requirements [...] There

Figure 1. *Damien Gratadour inspects the MCAO optical bench during its integration in late October, 2007 at the Gemini South Base Facility instrument lab.*

Figure 2.
Initial tests and alignment of the ASCAM all-sky camera are performed at Cerro Pachón.

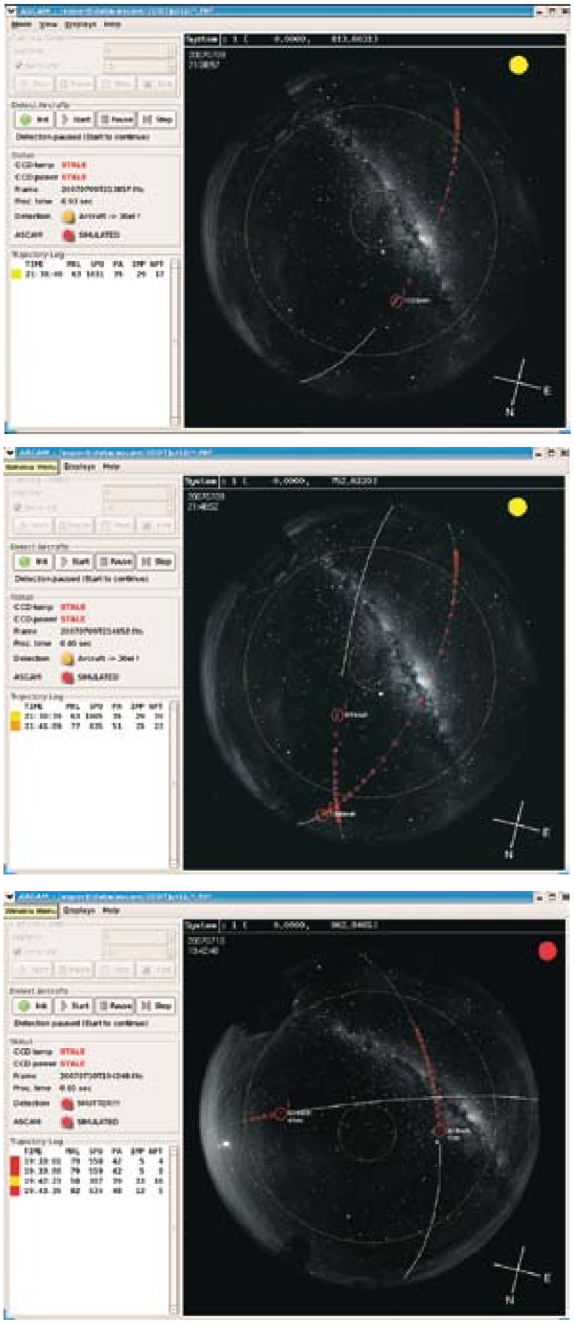

Figure 3.
The ASCAM aircraft detection user interface, with aircraft trajectory fitting.

are a number of technical risk areas which have been highlighted by the project team, and acknowledged by the review committee, but no single major technical show stopper [...]"

The other subsystems have also seen significant progress. The 50-watt laser, designed and built by Lockheed Martin Coherent Technologies (LMCT), is scheduled to be delivered to Gemini South in April 2008. A laser power of 35 watts has already been demonstrated in the laboratory at LMCT. The laser service enclosure design is complete, and fabrication has begun. The laser support structure (an extension of the telescope elevation platform) design is ongoing. The beam transfer optics opto-mechanical installation has started. The laser launch telescope is scheduled to be installed on the telescope M2 structure (secondary mirror) and aligned at the end of October 2007. Significant software and fabrication efforts have resulted in successful field tests of the aircraft traffic-monitoring camera, ASCAM, in July 2007. ASCAM is currently being upgraded with an Apogee CCD, and final integration is ongoing. After another round of field tests at Cerro Pachón in October, it will be tested next to the Palomar aircraft detection system in California and then installed on Mauna Kea in January 2008. A second unit will be built for Cerro Pachón.

Finally, a word on the MCAO schedule: we are working hard to keep an up-to-date overall integration and testing schedule. CANOPUS and the laser will be transported to Cerro Pachón in April of 2008 with first light for MCAO scheduled for August 2008. Commissioning will run from August 2008 to March 2009.

For more details, see "MCAO at Gemini," by Damien Gratadour and François Rigaut, *GeminiFocus*, December 2006, pp. 48-53

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by Joe Jensen
and Gustavo Arriagada

GNIRS Recovery Update

Figure 1.
GNIRS optical bench assembly is moved into the clean-room at the Gemini North Base Facility in October, 2007.

At the end of April, just as the June 2007 issue of *GeminiFocus* was being published, the Gemini Near-Infrared Spectrograph (GNIRS) suffered a temperature controller failure that caused it to overheat. Many details and photographs of GNIRS can be found on the Gemini web pages at: http://www.gemini.edu/index.php?option=content&task=view&id=231, where the problem was first reported to the Gemini community. Although some significant parts were damaged, most of the GNIRS instrument is undamaged. Gemini has started the process of restoring GNIRS to full functionality by bringing it to Hilo, where it will be repaired and returned to service on Gemini North, following the recommendation of the Gemini Science Committee. In this article I provide an up-to-date status report on GNIRS and plans for its future.

What Happened?

GNIRS was warmed up in April for routine cold head service. The fast warm-up system and vacuum pumps were used following normal operating procedures that had been successfully followed a dozen times before. The fast warm-up system has a completely independent hardware controller that shuts off power to the heater resistors when the temperature set point is reached. For some unknown reason, the controller failed and GNIRS was continuously heated until it reached temperatures of nearly 200° C.

When Gemini staff members recognized the problem, they shut the heaters off and allowed GNIRS to cool passively with the pumps running for several days. After the instrument had cooled, the dewar was opened and the main components inspected by a team of Gemini engineers and scientists. With the support of the experts at the National Optical Astronomy Observatory (NOAO) who built GNIRS, Jay Elias (GNIRS PI, NOAO) helped assess the damage and develop the recovery plan.

The multi-instrument queue allowed Gemini to quickly adapt to the loss of GNIRS, and no observing time was lost (although the lost opportunity to use GNIRS clearly affected many highly ranked programs). NOAO and the Southern Astrophysical Research (SOAR) consortium agreed to leave the high-resolution infrared spectrometer Phoenix at Gemini for the rest of 2007 and into 2008. A special call was issued, inviting proposals for additional bright-time programs using GMOS, T-ReCS and Phoenix. Commissioning for the Near Infrared Coronagraphic Imager (NICI) is under way now, and the NICI campaign is scheduled to begin as soon as this commissioning is complete. These steps help insure that the full scientific potential of the telescope is met and the needs of the community are addressed while GNIRS is being repaired.

Initial Inspection

The initial inspection of GNIRS showed that some components with low melting points were damaged, but most components were clearly fine. The plastic Delrin parts, which are mostly used as lens or filter spacers, had melted and the load-bearing fiberglass components were weakened to the point that some had cracked or failed. The most significant loss was the Aladdin 3 science detector, which contains a layer of the low-melting point metal indium. Unfortunately, the detector and mount will have to be replaced.

Many of the damaged parts, including the detector mount and the filters, will be replaced with spares already on hand at Gemini. We have a spare to replace the dewar window, which was coated with plastic and resin. Many of the fiberglass and plastic replacement parts have been ordered.

The dewar and optical bench, most mechanisms, wiring, motors and electronics appear to be undamaged. Until GNIRS is disassembled in the Hilo Base Facility (HBF) lab, we will be uncertain as to the status of the lens optical coatings, diffraction gratings, and diamond-turned mirror surfaces. The optics will be inspected and

Figure 2.
John White disassembling GNIRS during the initial inspection.

cleaned, repolished, or recoated as required. Many of the optics were relatively well protected, and we are hopeful that they will be clean. The mechanisms, slits, and cold head displacers will also be examined.

Current Status and Recovery Plan

In August 2007, GNIRS was prepared for shipment from Cerro Pachón to Hilo, where it will be refurbished. Before GNIRS could be safely shipped, the fiberglass supports had to be replaced. The fiberglass struts support the full weight of the optical bench in the dewar, and some cracks were visible in the fiberglass. By early September, GNIRS was packed and then flown to Honolulu, where it was loaded onto a barge for the final leg of the journey to Hilo. GNIRS arrived in Hilo on September 19, and was unpacked at the HBF shortly thereafter. In preparation for the arrival of GNIRS, Hilo staff prepared and cleaned the instrument lab, and relocated a clean room and some work benches into a newly built room at the HBF.

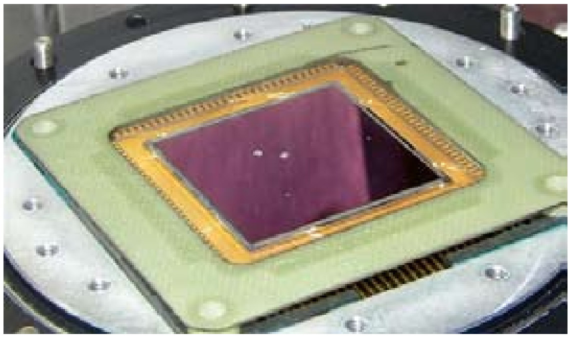

Figure 3.
The Aladdin 3 science array in GNIRS failed when the Indium bump layer melted, and pieces of the indium antimonide (InSb) detector layer fell out. Small holes in the detector are visible in the photograph at right.

By late September, Gemini staff members were just beginning the second phase of damage assessment and repair at the HBF, which involves a much more thorough disassembly and inspection than was conducted on Cerro Pachón. The next phase of assessment will include testing all the motors and wiring. Gemini engineers and technicians will also start cleaning the optics and other

Figure 4. *The GNIRS vacuum jacket was opened, revealing the radiation shields, the fiberglass supports, and the optical bench (center). Most components are undamaged.*

surfaces that have been contaminated with plastic residue. Some optics may be recoated or repolished, if necessary, after the cleaning process is complete. We will also look for ways to make improvements to GNIRS while it is being overhauled, taking advantage of this unique opportunity to examine every part of the instrument without impacting the observing schedule.

The Aladdin 3 replacement detector has been ordered. Raytheon will deliver two devices that meet our specifications to NOAO, and we will choose the best detector for GNIRS based on thorough testing at NOAO. NOAO tested the Aladdin arrays in GNIRS, NIRI, and NICI, and is in the best position to help us choose the replacement array for GNIRS. In addition to the science detector, we are also procuring a HAWAII-1 HgCdTe array for the on-instrument wavefront sensor in GNIRS. At present the science detector procurement is the pacing item in the GNIRS recovery effort, so the order was placed as soon as we could confirm that a replacement Aladdin 3 detector was available and appropriate for the refurbished GNIRS.

Once the cleaning and assessment is complete, GNIRS will require a complete optical alignment with new Delrin plastic spacers in the lens assemblies. All of the mechanisms will be reinstalled and tested. The detector mount and electronics will be tested using a bare multiplexer. Depending on the details of the schedule and delivery of the science detector, we may continue optical alignment and testing with an engineering grade indium antimonide (InSb) device. When the Aladdin 3 science detector is installed, the existing array controller will need to be tested and the new detector characterized in GNIRS.

After carefully considering how to maximize the science output of the observatory given the deployment of instruments across the two sites, the Gemini Science Committee recommended that GNIRS remain in Hawai'i after being repaired. Following optical alignment and testing, GNIRS will be transported and installed on the Gemini North telescope. A range of commissioning tests will be performed to bring GNIRS up to full operability within the Gemini queue observing system and characterized on the sky at night. One exciting aspect of the GNIRS recommissioning will be using GNIRS behind Altair, the facility adaptive optics system, for the first time. The lower level of sky background and excellent image quality on Mauna Kea promise to make the resurrected GNIRS even more productive and exciting than before.

It is worth emphasizing that GNIRS is not lost. The vast majority of its parts are fine. The work to fix GNIRS will be significant and will take several months. However, the result will be an instrument even better than the original. GNIRS is one of our most important facility instruments, and we are optimistic about getting it back on-line and working as soon as practical. To ensure that GNIRS performs as well or better than it did before the accident, we are exploring ways to improve GNIRS while we have it open for repairs. A group of astronomers and engineers at NOAO and Gemini have been looking into various improvements, including lengthening the slits and repolishing the cross-dispersion prisms to achieve better image quality behind Altair.

The recovery work will take until mid-2008 to complete. The science array procurement alone requires six months, and some time will be needed to characterize and select the best array for GNIRS. If all goes according to schedule, GNIRS should be ready for re-commissioning on Mauna Kea around the start of semester 2008B. With some patience and careful work, GNIRS will soon rejoin the ranks of the most productive and sought-after facility instruments at Gemini and once again be among the best near-IR spectrographs in the world.

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Astronomy's New Renaissance Scholar

Nathan Smith

Renaissance scholars are a thing of the past. Double majors are rare, and doctoral thesis programs take society's brightest minds and teach them to focus on narrow fields of knowledge. Outside of the academic world, there's little motivation to ever leave the house —forget about striving to become something more than a one-trick pony. For someone to have any hope of bucking these trends, they need to be a rebel.

Thus, it's no surprise that University of California, Berkeley postdoctoral fellow Nathan Smith spent his youth as one of those skateboarding punks who terrorize suburban cul-de-sacs. He was raised in the Milwaukee suburb of Waukesha, Wisconsin. He grew up loving the outdoors and was even a Boy Scout for a while, until he bought a skateboard. Nathan is also a self-professed pyro (pyromaniac). "I really like fires" he said. "I love grabbing flaming logs and putting them in the right places. I used to blow stuff up as a kid, too."

When he wasn't busy playing with fireworks or breaking his wrist on his skateboard, Nathan also painted. "I spent most of my solitary time painting," he said. "That was my main focus as far as things academic went."

In his paintings — then and now — he uses oils to create scenes inspired by abandoned industry. In college, inspiration also came from abandoned mills, steam tunnels, burned-out buildings, or the undersides of bridges. "When I was a kid, my friends and I would break into old decaying factories and foundries and climb around inside them," he said.

Nathan's first major at the University of Minnesota was music. He studied jazz and his main instrument was guitar. Music was his life. "I was playing like 20 hours a day," he recalled. "I didn't get a whole lot of sleep. I played guitar all day, I would stay up all night practicing until I noticed it was light out."

Nathan adopted astronomy as his second major. Yet, there wasn't much overlap between his music requirements and his math and physics classes. "I think I slept maybe two or three hours a night on average," he said. "I basically got two degrees, and it took me five years to finish."

However, Nathan did make time for fun. As an undergraduate he took a semester off to travel to India, where he studied Indian classical music in New Delhi, learning to play the sarod (similar to a lute). Summers were spent on the road traveling with his various rock bands. The most memorable one was named Behemoth. "The music we played tended to be really loud and heavy and kind of weird, experimental stuff," Nathan

Photo by Kim Steele

One of Nathan Smith's paintings with influences from scenes of abandoned industry.

explained. "We usually played in punk shows, but we weren't a punk band. We were pretty inaccessible for people who wanted to dance, because all of our music had odd time signatures."

Nathan and his band mates spent their summer months traveling the country with all their gear crammed into an old Volkswagen bus that had issues. For example, one of its special "features" was a back seat that always smelled of gasoline. Moreover, life on the road often meant sleeping in less than ideal conditions. At times, sidewalks or beer-soaked stages would be where he laid his head.

Somehow the unconventional musician still found time for cutting-edge science. His first undergraduate project focused on Eta Carinae, the famous supergiant double star visible from the southern hemisphere. The object might be on the verge of exploding in a massive supernova, and 160 years ago it underwent an incredible mass-loss event. Nathan's research involved analyzing the expanding nebula ejected in that event. It was perfect—the data analysis required a multi-disciplinary approach, combining newly acquired mid-infrared images from Chile with archived observations from 1945 and 1975. Plus it appealed to the pyro in him.

Nathan next headed to Boston University, where he earned his Master's degree and developed a lasting interest in star-forming regions. But music still dominated his thoughts. "Wise or not, my plan was to move to the East Coast to do music, thinking that I would do astronomy as a day job," he said. "It's funny, I thought science would be how I earned a living, and then I would then play music for real."

That was before the research bug bit. While working on Eta Carinae, he learned that he enjoyed astronomy research—enough to change his life's focus. Plus, Boston's jazz scene seemed too conventional for his tastes. "It was traditional jazz, which I had played as an undergraduate, and I was kind of sick of it."

While at BU, Nathan first started working on mid-infrared observations of the Orion Nebula and other star-forming regions. The transition from evolved massive stars molded Nathan's future research. As he was finishing his degree, his old Minnesota colleagues had just begun a large program using the Hubble Space Telescope's new Space Telescope Imaging Spectrograph to analyze his old favorite object, Eta Carinae. "I saw some of the data and it was unbelievable, and it was really complicated, and there was a lot of potential there," he recalled. "Combined with infrared spectra from the Cerro Tololo Inter-American Observatory, I thought that it would make for a good thesis project."

Nathan went to Minnesota and joined astronomer Kris Davidson's team and earned his Ph.D. After graduation, he moved to Colorado and was awarded a Hubble Fellowship to work alongside astronomer John Bally studying star formation. Just as Hubble data had lured Nathan back to Minnesota, working with Bally brought him back to star-forming regions; plus it meant studying Orion using the Hubble Space Telescope's new Advanced Camera for Surveys. "I had always kept my interest in star formation on the back burner," he said. "I wanted to work on Orion, but I was too busy with my thesis when I was in Minnesota."

It wasn't just science that drove Nathan to the Rocky Mountains. His love of nature and the outdoors weighed large in his decision. "I always wanted to live in the mountains," he recalled. "I was really frustrated in Minnesota because there was nothing big to climb. I always had mountain envy."

While breathing Colorado's mountain air, the renaissance student became the renaissance scientist. As he worked with HST observations, Nathan made it a point to weave in as many ground-based supporting observations as he could. The skateboarder who was never happy doing only music, or only art, or only science certainly wasn't going to be happy studying an object in only one wavelength. He had to expand outwards. "I tend to gravitate toward nearby bright objects for which I can get high-quality data," he noted. "Generally I'll pick one thing at a time and I try to do a multi-wavelength study of that one thing as intensively as I can. I'll combine images and spectra from Hubble with ground-based near infrared spectra and images, and mid-infrared data, and whatever else I can get my hands on to create a more complete picture of what's going on."

Thus, the twin 8-meter Gemini telescopes make for Nathan's ideal playground. He has used Gemini North's mid-infrared MICHELLE instrument in concert with Gemini South's Thermal-Region Camera Spectrograph and Hubble Space Telescope observations to better understand the Orion Nebula and Eta Carinae. He has also peered into the heart of the Eta Carinae region using Gemini South's high-resolution near-infrared spectrometer, Phoenix from NOAO.

"When you have 8-meter aperture and good seeing like you do at Gemini South, you can get mid-infrared and near-infrared data that are actually useful to compare to observations from the Hubble Space Telescope," he said. "It allows me to do the type of detailed multi-wavelength comparison that I like."

Focusing on his Eta Carinae work, and thanks to his multi-disciplinary approach, Nathan put together a picture of the three-dimensional structure of the nebula in a way that would be impossible to do with HST alone. "It allowed us to do something really unique and finally settle questions about what the structure of the nebula really looks like," he added.

In addition to his research, Nathan enjoys teaching. "I like seeing when they finally get it." However, he feels that astronomy education goes far beyond the classroom. Informing the public is another critical aspect. "Astronomy is something that is exciting and accessible, and it captures people's imagination. But at the same time it forces you to think objectively and to consider evidence. Basically it is a good way to exercise people's critical thinking skills by challenging them with abstract ideas," he said. "People who tend to think critically tend to vote a certain way. I'd love to have a population of people who are less easily swindled."

So what's next for this jack-of-all-trades? He's back to playing with fireworks, currently working on supernovae as a postdoctoral fellow at the University of California, Berkeley, alongside astronomer Alexei Filippenko. Nathan has decided — no regrets — that his career will indeed be astronomy. Still he's finding time to paint a little, play a little music, and even sleep a little.

"That was a hard thing for me, trying to decide whether to go into astronomy. I always felt like I was torn. There are moments when I miss music more than others, especially when I'm hanging out with my music friends and I go see them play. I do feel envious that I don't get to do that anymore," he said. "But I'm pretty sure that I would miss astronomy more."

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Into the Deep

Isobel Hook

There are a few scientists in the world for whom the concept of "exploration" literally includes everywhere from the mountaintops to the bottom of the sea. Oxford University astronomer and scuba diver, Isobel Hook is one of those few. She has regularly explored the outer universe from the dizzying heights of Mauna Kea and gone to the depths of the blue ocean waters around Hawai'i, enjoying the most fascinating sights humans can experience.

Yet, if it wasn't for an astronomer and baby-sitter named Mary Lou West, Isobel Hook might never have made her way to the top of Mauna Kea to work with the Gemini Observatory or found herself exploring the underwater universe.

Mary Lou (now at Mont Clair State University, NJ) nurtured young Isobel's innate curiosity by showing Isobel an astronomy book. "She got me interested in it," Isobel recalls, recalling the dramatic images, amazing distances and the "speed that things go" as the most fascinating part.

That early influence led Isobel to seek out more science educational opportunities. She attended St. Swithun's school in the cathedral city of Winchester, followed by 6th form college (similar to advanced high school in the United States). Excelling in science, she was awarded a place at the prestigious Cambridge University to study physics. The inimitable Sir Patrick Moore presented a school lecture that further inspired Isobel's interest in astronomy. She also happily recalls winning a placement on a British-Australian vocational exchange program as an undergraduate. Funded by both governments (plus airfare paid for by her parents), the program encourages students to spend two months working abroad and one month traveling. "I got a place on that and went to the Anglo-Australian Telescope, in Epping, New South Wales, and saw real astronomers working," she said. "I went to the telescope, the AAT, for a few nights, and that's what did it."

Isobel got an exciting start to her formal astronomy career in 1994. She had just finished her graduate work at Cambridge University when an opportunity to travel to the United States opened up. In a fortuitous turn of events, instead of working on radio galaxies as originally planned, her Cambridge thesis advisor introduced her to Saul Perlmutter and Carl Pennypacker (both at the Lawrence Berkeley National Laboratory), and she soon became involved in their Supernova Cosmology Project measuring distances to Type 1a supernovae. This study led to the well-known discovery of the accelerating universe.

(Opposite page) Isobel Hook dives in the waters off Hawaii's Big Island in this image by colleague and Gemini staff member Paul Hirst.


Photo by Paul Hirst

(Right) Isobel Hook in more-familiar academic surroundings at Oxford University (UK).

When asked about her achievements in her young career, Isobel is modest. "Well, I think I've been rather lucky to be involved in lots of big projects that have gone well, and one of them is this supernova search business."

Indeed, it was a perfect fit. Isobel had experience in taking lots of spectra of high-redshift quasars for her thesis work. On arrival in Berkeley, she began measuring the spectra of distant supernovae. "I started doing spectroscopy pretty much regularly. I would go to the Keck Observatory, which was great for me at the time because it was the first time I'd been to Hawai'i, and it was just amazing," she said enthusiastically. Among many other things in her current busy schedule, Isobel continues measuring redshifts and determining supernovae types as part of the Supernova Legacy Survey, a five-year project through 2008 in which the Gemini Observatory plays a crucial role.

Isobel, who has worked at Gemini during the commissioning of the Gemini Multi-Object Spectrograph, is also a member of the Gemini Board. Currently, she spends much of her time helping to define the scientific case for the European Southern Observatory (ESO) project to build the European Extremely Large Telescope (E-ELT). It involves commuting from her current home base at the University of Oxford to ESO headquarters in Garching, (near Munich), Germany. The E-ELT project is facing the usual challenges of building a science case for a telescope still in the process of being designed and built. Once built, big facilities like the Hubble Space Telescope, the Gemini Observatory, and the W.M. Keck Observatory, typically work on projects that no one could foresee when they were first envisioned. The Type Ia supernova project is a prime example of one of those cases.

Gazing into a crystal ball to see what is coming down the road is difficult. "I think that's the hardest bit," Isobel said, adding, "we're collecting all the science cases that we can imagine doing now, but the main thing is that we try and make a facility that is flexible." Flexibility was built into the first major instrument Isobel worked with—the Gemini Multi-Object Spectrograph (GMOS).

In 1998, following her Berkeley experience and two years with ESO, Isobel moved to Edinburgh, Scotland, home of the Royal Observatory. There, she began working on testing and commissioning GMOS, which was a joint project between the United Kingdom (UK) and Canada.

The UK principle investigator for GMOS, Roger Davies at Oxford University, remembers "Isobel was the first person recruited into the UK Gemini Support Group." Isobel worked hard at becoming an expert on GMOS, followed by a detailed effort that included a year working on the Big Island of Hawai'i. "She was a real reservoir of information and calmness in the frenetic activity of commissioning an instrument," said Davies.

During the six-week commissioning period in 2001 when the whole science team was on the island, Isobel worked closely with Gemini astronomer, Inger Jørgenson who had prepared a detailed plan for commissioning GMOS on the telescope. As Inger described the experience, "We both knew each other's strengths and we complemented each other." At first light in early August 2001, the entire science team was at the summit with "everyone cheering."

Inger recalls the month-long process as "very compact and very intense," and adds about Isobel, "we could not have commissioned (GMOS) on schedule without her. Her knowledge was fantastic."

GMOS is the optical workhorse of Gemini North and South, enabling high throughput imaging and spectroscopy combined in the same device. It was also one of the first to perform integral field unit spectroscopy on a large telescope. Currently GMOS is the most popular instrument used on the Gemini telescopes.

Once GMOS was up and running, Isobel returned home. "When I came back to Oxford, I started the usual more normal sort of national office type work, which is supporting users in your own country, and answering helpdesk requests, and helping people reduce their data," she recounted.

It wasn't long before Isobel was leading the UK Gemini Users Group, which included representing the UK on various committees and meeting equivalent staff from all the other national offices, collaborations that prepared her well for the later job with E-ELT. The work also meant Isobel kept returning to the "really impressive" and "really inspiring" Gemini North telescope. She also got to work at Gemini South with Brian Miller. She calls Gemini South "fantastic site, very dramatic."

So much for the high mountain part of Isobel's life. Isobel's other passion is water, either on it or in it. As a member of a small rowing club, she and her friends spend time after work rowing on the River Thames, called the River Isis in Oxford city itself. Her other water passion is diving. While working in Hawai'i on GMOS, Isobel spent countless hours at over 4,200 meters (nearly 14,000 feet) working with the instrument. During time off, she went the other way, diving into the ocean depths, exploring the undersea world that is as fascinating and as varied as the universe above her head.

Isobel is the kind of diving partner anyone would want to dive with. Aside from the adventurous spirit that leads many to take up diving, she has a very wise head for safety. On one of her visits with fellow British astronomer, Paul Hirst, they came upon some hefty waves at Pohoiki Bay on the Big Island that appeared both exciting, and to Isobel, potentially dangerous. Isobel said she was not comfortable diving there, so they went somewhere else. Adventurous, but never reckless, these characteristics define Isobel's work as an astronomer, too. Paul recalled the incident clearly, saying "I consider her a better dive buddy knowing that she was happy to decide she wasn't going to dive in those conditions and say so rather than going anyway and maybe getting us both into difficulty."

Isobel first learned to dive in the warm waters of the Red Sea and continued while in Edinburgh. Once she realized she would be going to Hawai'i to work on GMOS she would face a different type of diving, Isobel recalled. "That's quite an experience, diving in Edinburgh, because you need a dry suit and the whole works," she said. "The visibility is terrible and it's cold, but fantastic though, well worth it." Yet, Isobel kept diving because she wanted to be ready for Hawai'i.

On the 25 dives that Isobel and Paul Hirst have taken, one event that resonates with both astronomers is hearing whale-song. "It sounds a bit like cows mooing actually," Paul said, adding that "if you're a bit deeper down, and the whales are close, it can be very powerful."

Isobel Hook's many contributions and experiences are emblematic of a person whose career has reached great heights and involved many interesting places. So remember, if you're an astronomer and you happen to baby-sit, don't forget to take an astronomy book with lots of cool pictures, and tell the stories of the dramatic images and amazing places to a new generation. Who knows whose career you might start—perhaps another Isobel Hook. And, to Mary Lou West, astronomy owes you a debt of gratitude.

Martin Ratcliffe is a science writer and trains planetarium staff in the use of digital planetarium systems for Sky-Skan, Inc. He studied astronomy at University College London in 1985. Martin can be reached at: martin.ratcliffe@sbcglobal.net.

by Carolyn Collins Petersen

On the Path to First Light:

Roberto Abraham

(Opposite page) Roberto Abraham shares his love of astronomy with his oldest son Christopher.

Ask astronomers what first put them on the path to studying planets, stars and galaxies and they often point to such defining moments as planetarium visits, childhood telescope adventures, and watching space missions on TV. University of Toronto astronomer Roberto (Bob) Abraham counts all three experiences as guideposts on his lifelong path to the stars.

"A trip to Vancouver's H.R.Macmillan Planetarium was what got me interested in astronomy in the first place," he said. "There was some tour of Soviet space memorabilia and then simultaneous with that there was a Viking landing on Mars. When I was 11 all this space stuff hit the headlines and that got me kind of curious."

Then, there is his lifelong love of telescopes that began when he was a child. "We had a summer place in Washington State where we'd go," Roberto recalled. "My dad had this telescope for spying on the neighbors. One night we turned it on the Moon and that was pretty much it. Just one look at the moon through that little telescope and that set me on the course for the rest of my life."

Somewhere along the line, Roberto vividly recalls watching Apollo astronauts walking on the moon on a black-and-white TV while on holiday with his parents in Spain. Connecting that to the Moon he'd seen through the telescope was a powerful call to study the stars.

By his own account Roberto's life has always been on a vector to the deeps of space. "I actually decided at age 12 that I wanted to be an astronomer," he said. "I even decided at age 18 that I wanted to be an astronomer at the University of Toronto. I have zero imagination. At no point in my life have I deviated from the plan that I devised at age 12 and refined at age 18. Things couldn't be better."

Bob's life plan first led him to study BL Lac host galaxies, a type of active galactic nuclei. This took him to galaxy morphology studies and what he described as a certain amount of notoriety for theorizing how galaxies got to be the shapes we see. The next step on the path was to organize the Gemini Deep Deep Survey (GDDS), along with Australian astronomer Karl Glazebrook (who was at Johns Hopkins University at the time) and Pat

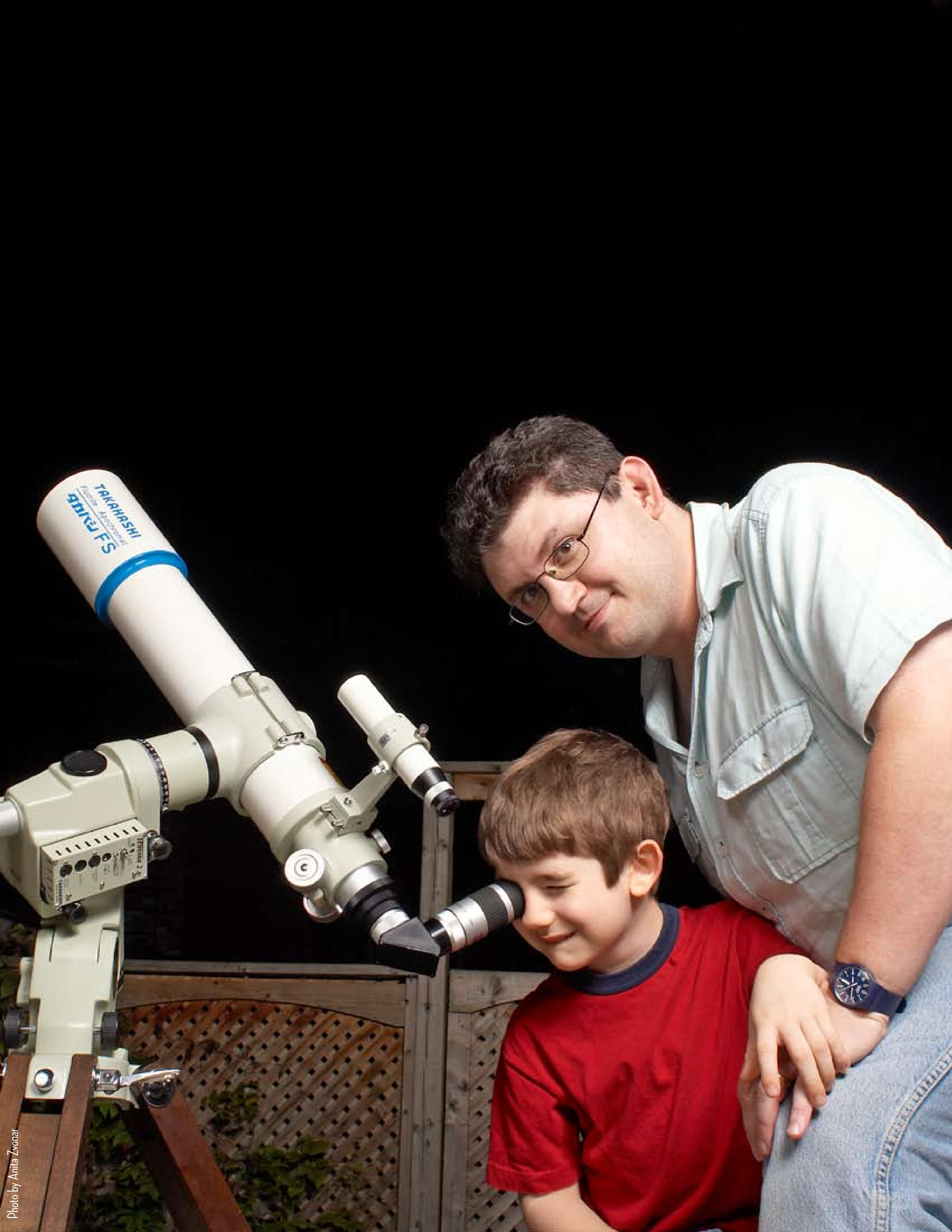

Photo by Anita Zvonar

McCarthy of the Observatories of the Carnegie Institution of Washington. It characterized about 200 galaxies at a redshift of 1-2 (placing them in cosmic history a few billion years after the Big Bang).

The data from the GDDS changed the way cosmologists define the evolution of galaxies through the so-called "hierarchical model." "Prior to the GDDS and other surveys, like K20 on the VLT," Roberto said, "the expectation was that early-type galaxies, such as the ellipticals, would have formed relatively recently because they're made of mergers of littler galaxies. GDDS and K20 showed that massive galaxies formed soon after the Big Bang. And that was a huge surprise."

For Roberto, some element of that surprise lies in how well the GDDS data has worked with galaxy formation models. Rather than upsetting the hierarchical galaxy applecart as he originally expected, he says it seems to fit right in. "Bottom line is the models were probably missing some fairly important star-formation regulating physics which our observations helped point to. So I don't think the fundamental galaxy formation model is being at all overturned by this," he said. "Really what we've shown is how poorly we understand how stars form in galaxies."

According to CalTech astronomer Richard Ellis, who works on some of the same galaxy evolution problems, Roberto was a force of nature in getting GDDS going. "With Karl Glazebrook and others, he really sold this significant program and its impressive accomplishments," said Richard who, like others who know Roberto, couldn't resist mentioning his extroverted personality and keen sense of humor. "He always adds humor to his talks on this program, as the enthusiastic and energetic Canadian observer tackling the mighty Cold Dark Matter theorists. For example, he has a slide that is often borrowed that has become an icon in the field. It shows a tombstone that says Hierarchical Formation of Elliptical Galaxies 1985-2003. RIP - Gone But Not Forgotten."

After the success of the GDDS survey, it would be understandable if Roberto had decided to pursue more galaxies. Instead, he went to the beach.

"Once every five years or so I sort of have a walk on the beach and think to myself, where do I want to vector my career," he mused. "Where do I go to learn the most stuff? One of those walks convinced me that studying first stars was the way to go. One of the really big open questions in cosmology is what were the first stars like? What caused the change in the nature of the universe? It's one of the big mysteries in cosmology or even in astronomy."

At the end of his latest walk, Roberto took off on a slightly different vector, away from early galaxies, but not away from the early universe. "I don't really like to do the same thing forever. I figure if you do that, you're not really riding the crest of change. If there's a constant in cosmology, it's change, he said with a laugh. "You can bank on it. I always want to be agile enough to try new things."

According to Karl Glazebrook, one of the collaborators on GDDS, that openness to new things is one of the hallmarks of Roberto's personality. Karl is a long-time friend. The two met during an observing run at La Palma and were postdocs together at Cambridge University. Ultimately Roberto served as best man at Karl's wedding.

"Bob's like a big kid," said Karl. "He also likes to do things differently. He's always looking at new pieces of software to use, or new programming languages to do things. He's an extroverted person, not always the norm in astronomy."

Now Roberto is turning what Karl Glazebrook calls his relentless attention to how the first stars formed. Both men are developing some new hardware to assist first light searches and looking at new ways to boost existing instrumentation to look for those first stars. "He's quite keen on first light," said Karl. "It's our main focus right now."

Luckily, Roberto's earlier work on GDDS is playing a role in this new research direction. The GDDS results earned him a prize in the form of the Steacie Fellowship, a mid-career research award given by the Natural Sciences and Engineering Research Council of Canada. Along with academic recognition, the fellowship came with a cash reward. "I'm using the money from my fellowship to build onto an instrument for Gemini," said Roberto. "It's really a mode for the FLAMINGOS-2 spectrograph. Canada is building a tunable filter for the James Webb Space Telescope, and I'm cloning it and we're putting it on Gemini. We're calling it F2T2, the FLAMINGOS-2 Tandem Tunable Filter."

The filter, which Roberto and co-PIs Steve Eikenberry and Joss Bland-Hawthorne (see profile starting on the next page of this issue) are working on together, will give the team a chance to do some JWST-like science a few years early. "The formation of the first stars is arguably one of the top three coolest things you could be doing right now in extragalactic astronomy," he said. "We don't know how to form the first stars without having the products of star formation beforehand. It's this mystery. And it's fascinating, too, because it's probably connected with reionization, that phase change in the universe that occurred that ended the Dark Ages. It really made the universe from this kind of boring hydrogen and helium-dominated thing into this site of complexity."

When he's not exploring ancient galaxies and first stars, Roberto is an extremely devoted family man. He and his wife Julie (who also has her Ph.D. in astronomy) are raising two boys, Christopher and Alfonso. "They're the joy of my life," he said. "The brightest light I have is those boys."

The oldest, Christopher is showing some interest in stargazing, so Roberto does a little backyard type observing with him as time and weather permit. "I have never sold my old telescopes from when I was a kid," he said. "Now that I can afford to, I buy new ones. I do occasionally pop out into the backyard. There's a little bit of the twelve-year-old that's still in me. With the queue systems and using HST pretty heavily, it's nice to kind of feel the old photons hitting the back of the eyeballs. Even if it's for a half an hour a couple of times a year out on the deck to look at something like Jupiter or Mars."

Roberto occasionally tries out other outside interests, especially now that he claims he's getting older. "Alas, I'm 42. I'm mad about that, too. I'm getting old," he said, adding with a laugh that he's thought of some really off-the-wall hobbies. "I was thinking of motorcycles but my wife axed that idea as too unsafe. But there's this Harley called a Fat Bob, and I'm like, my name is Bob and I'm fat. Hey, it's destiny, there's a motorcycle for me! She's okay with it when the kids are grown up and then she can ride with me. But, I have to wait another 15 or so years for that."

Today, with several successful projects under his belt, a new survey about to begin, designing a filter mode for a telescope, and a busy teaching and research schedule, Roberto Abraham has made his leap to space, all the while making his mark as an outgoing guy with a great sense of humor and the chance to chart his own path to the intergalactic depths.

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by Helen Sim

Looking for the Next Page-turning Surprise

Joss Hawthorn

Nestled inside the small brass box is a paper-thin device: the first prototype of an integrated photonic spectrograph for astronomy, the product of three years' work. "Careful," says Joss Hawthorn to the photographer. "Don't drop it."

Joss is the head of instrument science at the Anglo-Australian Observatory in Sydney, Australia, and the photonic spectrograph is his brainchild. An object you can slip into your shirt pocket, it could potentially replace the room-size spectrographs of today's large telescopes. Light is fed into the 7-centimeter-long device by an optical fiber, dispersed by a phased array (at R~4000), and emerges as a continuous spectrum. This and related devices could rein in the spiralling costs of instrument construction for large telescopes, Joss says. "Instruments based on integrated circuits will be more easily scaled to larger sizes, cheaper to mass produce, and easier to control."

(Opposite page) Joss Hawthorn holds his first prototype of an integrated photonic spectrograph for astronomy.

Although significant investment will be required to produce devices specifically for astronomy, photonics and telecommunications research groups have already laid the groundwork. The "spectrograph on a chip" could realize the long-term vision of a million-element integral field unit (IFU): a million fibers feeding a thousand circuit boards, each with a thousand photonic spectrographs, the whole shebang packed into a cabinet the size of a refrigerator.

Yet, Joss is not interested in ground-breaking instrumentation for its own sake. Rather, he is intrigued by the research that it makes possible. And the link is physics: of the instrument, and of the cosmos. "My real pleasure is in understanding the physics of the instruments I'm using—how far can I push them—and when I obtain my observations, what can I really learn in terms of new physical models," he said. "If a new technology comes along, one should be asking new questions, solving new problems that you couldn't before."

He even takes this view of mathematics: interesting for its own sake, but says "truly, mathematical physics is far more interesting, applying the laws of mathematics to understand physical problems." A large part of studying physical phenomena, he points out, is recognizing patterns, then reducing complexity to a few simple rules. His interest in patterns—of words, of numbers—was there from an early age, but he started to focus on ways to reduce complexity only in the last year of his Ph.D., when confronted by masses of data.

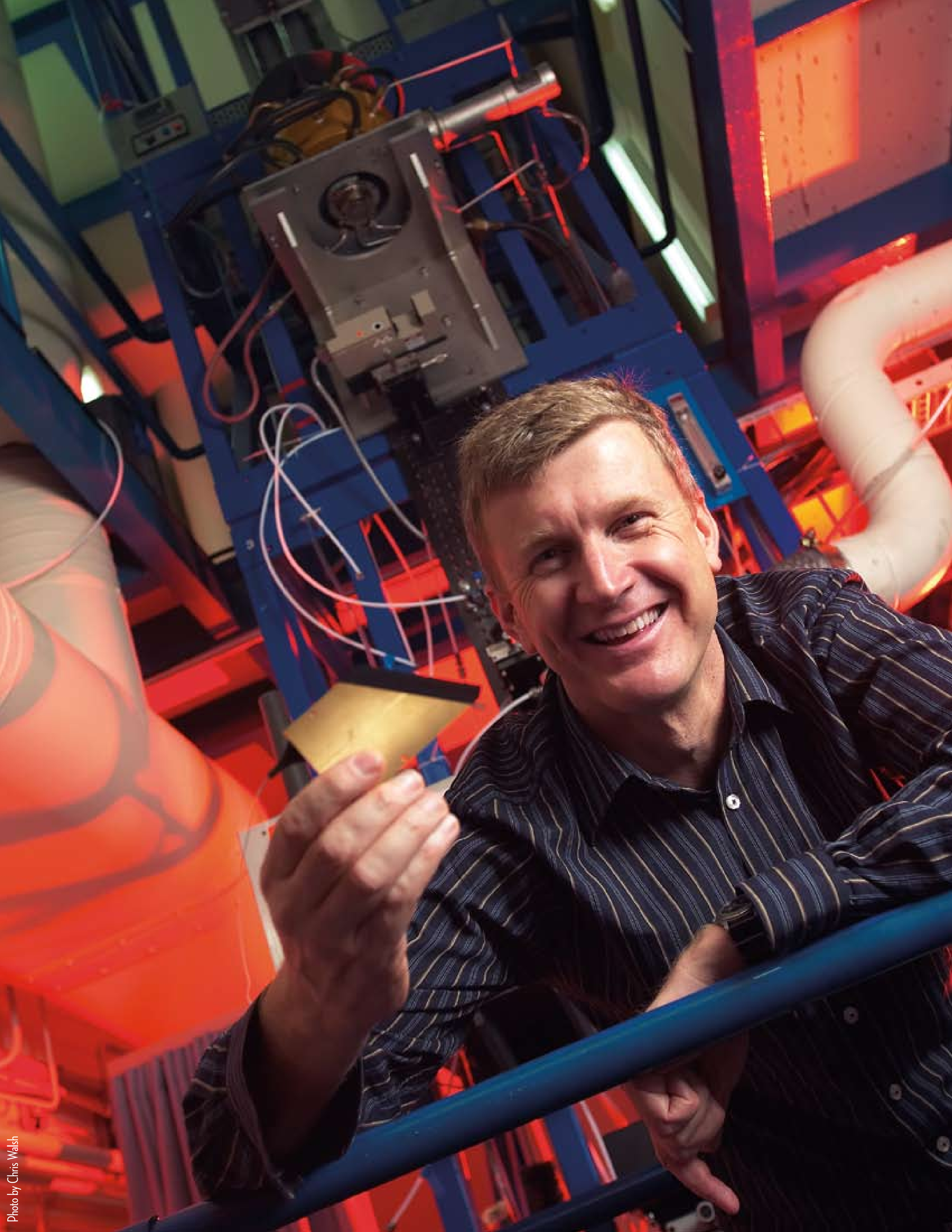

Photo by Chris Walsh

That Ph.D., the first to exploit the Taurus imaging spectrograph, was done at the Royal Greenwich Observatory in the mid 1980s, and eventually led to him developing the Taurus Tunable Filter for the Anglo-Australian Telescope. Following his Ph.D., Joss took a postdoctoral position at the Institute for Astronomy, University of Hawai'i, for three years. After that, he had a number of short stints at Lawrence Livermore National Labs, the Naval Research Labs, Princeton and Space Telescope Science Institute (STScI), "discovering how the U.S. system works." He then settled at Rice University in Houston for five years. This was a formative period, he recalled. "It was a wonderful time, my first chance to teach advanced graduate courses, to have graduate students."

He was one of a few astronomers in a large, strong, physics department. "I think that really brought home my love of the physics side of things," he said. His time in the U.S. also added a slight twang to his southern English vowels. Further vowel modification followed from 1993, when he moved to Australia to join the Anglo-Australian Observatory. He sets off again this November, moving to the University of Sydney to take up a Federation Fellowship. This prestigious Australian Government award will fund him to set up a group to explore some of his ideas for astronomy technology, including Bragg gratings embedded in optical fibres for suppressing OH emission lines from the atmosphere, and new research programs motivated by these advances.

"Joss is, without a doubt, one of the most creative individuals that I know," says Sylvain Veilleux of the University of Maryland, one of Joss's long-time collaborators. "He is passionately interested in getting to the truth. He has an abundance of energy that drives him to understand how things work." Veilleux recalls an episode in March 1994 when "Joss kept me awake for a few hours in the middle of the night discussing his burgeoning ideas on the best possible way to use CCDs to remove the bright sky from an exposure of a faint astronomical object."

Joss's thoughts became the starting point of the "nod-and-shuffle" technique, first used at Gemini and now used widely by observatories around the world to remove the sky's glow from astronomical exposures. "It is one of those rare cases where simple changes in old methodology had a deep impact on the field," says Veilleux, "and Joss figured it all out during one sleepless night."

Another colleague, Ken Freeman at the Australian National University, shares Veilleux's view. "He is lots of fun, full of ideas. Always interesting. A very original individual. You can see him doing this both in his technical work and on the astrophysical side."

For his part, Joss talks about how important colleagues have been to him, and how his best work is often done with one key collaborator. "It takes [just] one person to find what you do interesting, to make it all worthwhile," he said. "One person, someone you respect."

Joss has worked together with Ken on the ideas of the "chemical tagging" of stars (determining key abundances in millions of stars) and "near-field cosmology" (reconstructing the history of galaxy formation by observing galaxies within 20 megaparsecs (65 million light-years) rather than at high redshifts). "They're both new ideas," said Ken. "Their full potential hasn't been realised yet." In 2005, Joss and Ken, along with Bruce Draine of Princeton, collaborated on observations using Gemini South to study the galaxy NGC 300 to determine the extent of its stellar disk. The disk turned out to be much larger than previously thought—a factor of two or more greater in diameter. Some disks do truncate, it seems, while others appear to go on forever," Joss said. "Even more excitingly, there is a third class of disks that decrease steadily and then flatten out. It's weird—I don't know what that means yet."

Joss's current research with Gemini builds on his role in the DAZLE experiment (done in collaboration with the University of Cambridge) to find the highest-redshift galaxies—an endeavour, he says, that will be boosted by the FLAMINGOS-2 spectrograph. He hopes that follow-up observations will be able to take advantage of the OH-suppression fibers he is now working on. (OH is the hydroxyl molecule.) However, his fundamental research interest is disk formation, with its many unknowns. "A lot of what I'm going to be looking at now is how gas gets into galaxies, because we just don't know. We have limited physical understanding of how disks build. It's a real puzzle."

Like a galaxy building up, his own childhood interest in astronomy developed over time from when he was seven or eight years old, prompted by things that he read, or that people told him. "Little facts amazed me," he said. "So, for example, when I was twelve or thirteen years old, someone explained to me that the Milky Way was a consequence of living in a flat galaxy. I didn't get it at first: I wasn't sure what they meant by a flat galaxy. But they left the thought with me. And then, it clicked. What they meant was that we were looking through a disk of stars. Had we lived in a sphere of stars, we would not have had a Milky Way. And that blew my mind. I just couldn't believe that there was something about the nature of the galaxy, which is hundreds of thousands of light-years across, that we could learn from Earth."

The universe has never lost its fascination for him. "Once or twice a week I learn something new about physics; once or twice a month I learn something new about astronomy. Those new insights are what makes it all worthwhile," he said.

Despite this fascination with the physical side of the cosmos, he was an Arts student until age fifteen, when he switched to the sciences almost overnight. This happened largely, he said, because of inspiring teachers and success in the Math Olympiad. But he didn't leave the humanities behind entirely: his interests overflow into "areas that have nothing to do with my field at all," such as languages and history. His home in Mosman, one of Sydney's harborside suburbs, bulges with books. Reading is a lifelong obsession: even at boarding school, aged seventeen, he owned more than a thousand books. He reads two books a week, "about anything", but claims to be out-read by his wife, Susan, a medical writer, and elder son, Christian, who are similarly voracious readers.

When he isn't reading or working on his research and teaching, Joss spends time each week playing on a Mosman soccer team, and also swims, kayaks, does a little scuba diving, and a form of mountain hiking called "fell walking". In addition, he travels with his family overseas every year. "Typically we head for historic cities in Europe," he said. "Places like Lyon, for example, which has extraordinary Roman passageways and architecture."

Joss is a self-proclaimed "people person"—at least partly, he thinks, as a result of being packed off to an Oxford boarding school at an early age, and becoming "a creature of institutions," encountering and being influenced by a wide range of people. He enjoys working with students and they with him. Mary Putman, one of his former students now at the University of Michigan, recalls, "Whenever the thesis was weighing heavily, a visit to Joss's office would brighten up the scientific day."

Joss also does a lot of outreach activities with schools. "Kids are wonderful. I just love their enthusiasm," he says.

When it comes to running a research group, he has a clear philosophy, stressing how important it is to give each person a sense of empowerment and ownership of a project, and to give them projects that are well-matched to their skills, "Even if they don't know it," he said.

The new group he's establishing at the University of Sydney will be focused mainly on astrophysics but also committed to technology development. Despite the allure of the widgets, "my main driver now is [astronomical] research," he said. "I am haunted by ideas that have been with me for twenty years—a couple of which I will get to act upon in the next five years, because the technology now exists."

It's a somewhat scary prospect, putting long-held ideas to the test. "After twenty years I could well be disappointed by the result," he said. But there is no likelihood he'll hold off. "I will always leap at something [a research problem] if I feel the technology is there—that it can be done."

Note: Joss's new photonic spectrograph is described in the Anglo-Australian Observatory Newsletter 112 (August 2007), http://www.aao.gov.au/local/www/lib/newsletters/aug07/aug07.pdf

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Solving Mysteries at the Heart of a Galaxy

Thaisa Storchi-Bergmann

Active galactic nuclei are some of the hottest research topics in astronomy today. These bright, shiny galactic cores radiate across the electromagnetic spectrum, their emissions belying the existence of something very interesting inside. Those brilliant signposts immediately attracted the attention of Thaisa Storchi-Bergmann, a professor of physics and astronomy at the Physics Institute of the Federal University do Rio Grande do Sul in Porto Alegre, Brazil. For her, these objects (usually referred to as AGNs), remain as mysterious as the day she first began to study them.

Thaisa's is a career that has combined searching out the deepest secrets at the hearts of galaxies with the challenges of raising a family that she started at a very young age. This "double career" found her, at least once, racing up and down a mountain to nurse her child while doing an important observing run at Cerro Tololo. Having a research career while raising children was not always easy for Thaisa and her family, but the draw of studying AGNs made it all worthwhile.

"When I began to look at AGNs, I was drawn by the mysteries surrounding these objects, including the fact that they were harboring supermassive black holes in their nuclei," she said. "Nowadays we know that most galaxies have a supermassive black hole at the nucleus, but I continued to be interested in the study of AGNs because some mysteries, some questions remain, such as how does material get to the center of the galaxy to feed the supermassive black hole?"

Lately, Thaisa has been using the integral field unit (IFU) on the Gemini Multi-Object Spectrograph (GMOS) to study the gas kinematics (the motions of gas) in nearby galaxies with active nuclei. Her work has allowed her to measure for the first time the motions of gas as it streams toward the nucleus. In the current paradigm for active galactic nuclei, the central supermassive black hole (present in all galaxies which have a stellar bulge) is being fed by mass accretion. Previous observations of the gas around active nuclei have only shown outflows, which are also a characteristic of active nuclei: the more active

Photo by Peter Michaud

and luminous they are the stronger are the observed outflows.

These strong outflows make it difficult to observe inflows. Nonetheless, Thaisa envisioned an approach to solve the problem. "What I did, in collaboration with my team, was to look for inflows in galaxies with low activity, such that the outflows would also be weak," she said. "So far we have found two cases—NGC1097 and NGC 6951—in which we have observed inflows towards the nucleus. We are now observing more active galaxies to look for more inflows and confirm the scenario in which the mechanism to send gas inwards to feed the supermassive black hole within the inner few hundred parsecs of the galaxies is a stream moving along nuclear spiral arms."

Thaisa and her colleagues are about to submit a paper describing the outflows in six Seyfert galaxies (a subclass of AGNs). "In most cases, the outflows follow the radio emission of these galaxies, suggesting that the gas emission originates in circumnuclear gas which has been pushed by a nuclear radio jet," she said. "We have reached a similar conclusion in the case of the galaxy ESO428-G14, observed with the Gemini Near-Infrared Spectrometer IFU. We are now concluding research based on observations using NIFS and adaptive optics of the galaxy NGC 4151, where we find mostly outflows, except in the molecular gas, which may be flowing inwards. Finally, we are also using NIFS to try to constrain the black hole mass in nearby Seyfert galaxies."

In talking with Thaisa it is obvious that she is a person in love with her research subject and her family. She has been a scientist much of her life. "I realized that I wanted to be a scientist when I passed the exams for architecture and enjoyed the physics classes more than the ones more related to architecture," she recalled. "I have been interested in science since I was 12 or so, but did not think at first of pursuing a career in science."

That changed when she went to college and continued through her graduate work and her subsequent research in AGNs using Gemini and other telescopes. Yet, there's time in her life for much more than science, including travel, enjoying good company, and raising a family of three sons, Bruno (24), Frederico (23), and Arthur (10) with her husband, Renan Bergmann. "My sons rule most of my free time. There is always something to do related to their needs," she said. "Also, my husband and I have a group of friends with whom we meet once a month or so, usually for barbecues or good dinners. I play tennis with my youngest son. I like to travel, but I travel a lot for work already, so lately I have also enjoyed simply staying at home."

Thaisa has traveled in Europe, which she says she loves for its cultural life. One recent trip she enjoyed was to Istanbul, noting that Turkey was so beautiful, with all of its historical sites ranging from Roman times through the Ottoman Empire. "I also like the United States because everything seems to work there," she said, pointing out that hers is the point of view of a person who lives in a country where this is not always the case. "I enjoy going observing, but this is less frequent now, as I am mostly using Gemini in queue mode."

Raising three boys while pursuing a career in astrophysics made Thaisa's life interesting in many ways. Her advisor and colleague at the Federal University do Sul, Miriani Pastorza, said that Thaisa's attention has always been focused squarely on both her work and her family. "She was a very dedicated student, very intelligent. These are personal qualities that have been fundamental to the success of her career."

According to Miriani, Thaisa's greatest contribution to the field of AGN studies has been the discovery of variability of the double-peaked Balmer lines in the spectra of the nucleus of the spiral galaxy NGC 1097. "She has done several studies with collaborators showing that such variability is the result of tidal disruption of stars by a central black hole of a million solar masses," said Miriani. "I am very proud of her work as I feel that it is a continuation and improvement of the line of research that she started with me. I am impressed but not surprised by her success. Thaisa has always been single-minded."

Both Thaisa and Miriani are mothers who have raised children while pursuing research careers, a fact that helped them understand each other. "We have the same attitude regarding women working in science, in the sense that children are not an excuse to impede a woman reaching the top in science," said Miriani. "I remember telling Thaisa of my experience working at the Cordoba Observatory where I used to take my new born daughter Ana to sleep in the dome while I was observing. It turns out Thaisa did the same thing with her baby son Arthur. She took him to the Cerro Tololo observatory because she did not want to miss her turn with the telescope."

That observing run occurred when Arthur was just a few months old. Thaisa remembered wondering how she could reconcile the observing run with keeping up a feeding schedule for her baby. Her solution was to hire a babysitter (at her own expense), and get a special permit from the director to bring them both along. "The director was concerned that the baby would disturb the other astronomers," Thaisa recalled. "He reluctantly agreed that I bring the baby along and gave me a house far away from the other dorms and I could then observe. The babysitter would call me at the times the baby needed to nurse (usually two times per night) and I would come down the mountain to feed him. This did not take more than half an hour per feeding, thus I could observe during most of the time of the run!"

During another observing run, her children brought Thaisa some interesting attention from abroad. "For my Ph.D. research, I had a run at Cerro Tololo together with my advisor, Dr. Pastoriza. This was in February, 1987," she said. "We arrived there the day that the discovery of supernova 1987a was announced. During that night and on the following nights of my run, I had to use part of my time to observe the supernova at the beginning of the night, which was, in principle, not so good for my thesis observations, but was a lot of fun. There were reporters coming to our dome for two nights and one of them published a column at the New York Times, with our picture. He was impressed by the fact that I had two small boys at the time, and had left them with their father to be able to come for my observations."

The reporter wrote a story that inspired a number of U.S. women to write to Thaisa saying how much they admired and envied her because she hadn't given up her career to stay home and take care of the family. "I didn't recall exactly what I said to him," she said, "but he attributed to me the following: There must be a place for supernovas as well as families in one's life. One must be allowed to contemplate the big picture as well as the small."

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by María Antonieta García

Reaching for the Stars

Simon Casassus

Simon Casassus is a man with stars in his eyes and in his family. At work, he specializes in the study of planetary nebulae, sun-like stars that are in the last throes of their lives. "My field is astrophysics, I study the nature of celestial objects, but at the same time I am an office astronomer," he said, referring to his position as an associate professor at Universidad de Chile in Santiago. He has been teaching physics since 2001 at the engineering faculty. "I teach because it allows me to be in touch with society," he emphasized.

At home, this vegetarian who roller-skates around Santiago and has devised "safe paths" to ride his bicycle to work, lives with his wife Maisa and two bright young stars: their daughters aged four years and eight months. "My daughters are absolutely charming," he explains with fatherly tenderness. "Maia starts the day so early, even on weekends, and Adara is not much of a sleeper. Maia is named after 20 Tauri in the Pleiades, and bright Adara is epsilon Canis Majoris. Both are hot, blue stars."

By contrast to his contented family life these days, Simon's early life in Chile was disrupted by a military coup. His parents were forced to leave the country in 1975, and they arrived in France when he was only four years old. The Casassus-Montero family stayed in Paris until 1988, returning to Santiago when Simon was already 18 years old and brought up in a largely French lifestyle. "These were difficult days," Simon remembered, adding that he returned to France very quickly. "All of my friends were back in France, and for an 18-year-old Parisian it was just impossible to adapt to dictatorial Chile."

Science fiction movies seem to have fostered Simon's interest in astronomy as early as age six. "I found that nature in general was fascinating, either life or rock," he says. "Eventually however, my imagination was provoked by the celestial sphere. Perhaps it was because I felt that knowing the sky is Earth-bound humanity's means of transcending, as a substitute to actually flying to the stars."

Photo by Cristóbal Sanchez

Simon recalls not having excelled much at school as a youth, nor to have been the recipient of medals and prizes. "I was just a standard good student," he recalled. "My academic performance improved at a later stage in my studies, when I started doing what I liked: research. In hindsight, I believe that research-like activities should replace standard passive courses, in which students bursting with vitality are forced to sit in a classroom all day long."

When he went back to France in 1988, Simon understood that if he was to become an astronomer, he would have to complete his studies in Chile. "I perceived a reigning Parisian depression among young people" he said. "At the time France didn't seem to have too many professional options, particularly in the field of astronomy."

So, he returned to Chile and enrolled himself in the Universidad de Chile where he received a Bachelor's in Physics, and then a Master's degree in Physics, with a thesis in astronomy. His interest in research finally blossomed at Oxford University in England, where he obtained his doctorate in astrophysics thanks to a scholarship awarded by Gemini Observatory, the former Particle Physics and Astronomy Research Council (PPARC, now Science and Technology Facilities Council) and Fundacíon Andes, a foundation supplying post-graduate funding for Chilean citizens to study abroad.

Simon's relationship with Gemini Observatory started with the Gemini-PPARC scholarship. He made an immediate impression, according to his Oxford thesis advisor, Patrick Roche. "Simon came to Oxford to study for his doctorate, researching properties of planetary nebulae and demonstrated a very good knowledge of atomic physics," Patrick said. "He has always had a unique approach and he sought out some unusual aspects of life in Oxford. For example he spent some time living on a houseboat rather than in a more conventional apartment."

After receiving his Ph.D., Simon used Gemini South for observations in 2005 and 2006. He enjoyed the human aspects of his experience at Cerro Pachón, where personal relations are not replaced by institutional procedure, as is the case in some other observatories. "The Gemini staff members are very efficient at their tasks; everyone is committed to the success of observations." Even though he is an expert astronomy researcher, Simon admits that he depends on other experts to be able to handle a telescope during his observations. "Whether it is a backyard telescope or a big one like Gemini, I wouldn't know how to use them properly on my own," he admits.

One of Simon's research projects is the planetary nebula NGC 6302, also known as the Bug Nebula. He sees planetary nebulae as test laboratories for nebular astrophysics because they represent a simple environment, especially compared to star-forming regions. In 2003, Simon and colleagues from the United Kingdom used the TReCS mid-infrared imager and spectrograph and the PHOENIX instrument on Gemini South to look more closely at the central regions of this object. Their data provided a new technique to measure nebular isotopic ratios. "The T-ReCS data revealed an intriguing central point source which probably corresponds to circumnuclear material," he said. "At 250,000 Kelvin, the central star of this planetary nebula is thought to be one of the brightest and hottest known. Radiation pressure should have blown out the stellar envelope, and formed a central cavity. Yet our PHOENIX program on NGC 6302 has revealed that the expansion velocity of NGC 6302 is probably the lowest of any planetary nebula. We've found a filled-in structure, not a cavity. We do not know what to make of this."

Another aspect of planetary nebulae that motivates Simon's interest is the part they play in the galactic cycle. "My research has been drifting from the circumstellar to the interstellar medium," he said. "The nebular material will merge with other stellar outflows to form interstellar clouds, which subsequently collapse into new stars—the stellar material is thus recycled and enriched."

Simon is currently pondering on the efficiency of elemental mixing in the interstellar medium. "What is the fate of the dust produced in planetary nebulae?" he asks. "The meteoritic evidence shows that part of the stardust does indeed survive the harsh galactic environment to build up protoplanetary disks. That survival of stardust leads to the picture of a clumpy and elementally heterogenous interstellar medium."

Simon's work has led to greater involvement with Gemini Observatory. Early in 2007, he attended the Gemini Science Meeting held in Foz de Iguaçu, (see page 40 of this issue), and just recently he was invited to join the Gemini Science Committee. "This is a very interesting opportunity to give Gemini feedback from the user community and also to advise on strategic planning" he said. "Gemini has very unique instrumentation in the southern hemisphere."

Like other users, Simon continues to propose for time on Gemini, and some proposals are successful while others are not. "I think that some weren't accepted because they were too technical in the infrared area," he said.

He has subsequently served on the Chile Gemini time allocation committee and understands some of the issues involved in general and multi-disciplinary committees. As a consequence, he has taken some of his research into radio astronomy. "It turned out to be very fruitful," he said. "Nowadays my proposals combine both the infrared and the radio regimes."

His original approach to solving problems and his research interests have earned Simon a great deal of respect among his colleagues. María Teresa Ruiz, former head of the astronomy department at the University of Chile at Santiago says of his work, "Simon is one of the few people that I know who are genuinely original. In every viewpoint, every step that he makes, he has a very unique sense of what to do, which is not too common, but is extremely valuable when one tries to do science. He always brings a fresh viewpoint to the science problems he is interested in solving."

As an educator, Simon helps his students along as a valued mentor. "Here at the Universidad de Chile my academic performance is measured partly by the quality of professionals whom I am educating," he said. He has guided three of his students to study at Oxford and University College London, much as he did under the aegis of PPARC.

For others who are thinking of studying astronomy, Simon points out how important it is to be aware from the beginning that science is a gamble. "As an astronomer you bet for particular projects which you guess may lead to scientific results, but sometimes turn out to be unconducive," he said. "It could be a large computer program written on a bad idea, for example, or an unsuccessful application."

Simon knows how difficult it is to deal with having a proposal or an application rejected. "As an astronomer you compete for a project," he said. "If your work is not good enough, you have to be able to swallow your own pride and start all over again. The key for any scientific endeavor is perseverance. It is an attitude that one should have in mind if one wishes to continue on the science research path."

If he could evaluate the different experiences that he has gone through in his life, Simon does not hesitate to say that he has lived many wonderful moments. "If I could average it all out and point out the happiest year of my life, it would be 1998, when I was living on a boat," he said. "My life then was very free, without any material possessions or many responsibilities, quite "hippie" in other words. I was dedicated exclusively to my thesis, and enjoyed living in Oxford town, which has a pleasant bucolic atmosphere and is very tolerant of its own cultural diversity. That was a wonderful time."

Nowadays, Simon has his research and family responsibilities. He spends his mornings at the university, teaching and doing research, and his afternoons in the company of his daughters. He still finds time for work at home, and in his scarce free time he practices yoga, and more recently kung fu. His health-oriented vegetarian lifestyle leads him to avoid driving his car whenever possible. All in all, Simon Casassus is a man who lives his life intensively, whether studying his stars, spinning through Santiago on his skates or bicycle, or spending time with his family.

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Exploring at the Limit

Michael Liu

A telescope is only as good as its users, and for Gemini Observatory, that means having people who know the telescopes intimately and can coax the best images and data from them. Michael Liu, currently an Associate Astronomer at the University of Hawaii's Institute for Astronomy (IfA), has been a highly effective Gemini user, pushing the performance of the 8-meter Gemini North telescope to its limits while pushing himself to excel in new areas of astronomy research.

In 2001, Michael used the IfA's Quick Infrared Camera (QUIRC) along with the Hokupa'a adaptive optics (AO) system to make a direct image of the closest known substellar object orbiting a Sun-like star. This brown dwarf (or "failed star") has a mass 55 to 78 times that of Jupiter and is separated from its parent star by less than the distance that separates Uranus from the Sun. Until Michael's discovery, no one knew that brown dwarfs could exist in a region of giant planet formation. How did this renegade object form? And what does this discovery say about the ways in which solar systems form around Sun-like stars? These are questions Michael would someday like to be able to answer.

A decade ago Earth's turbulent atmosphere would have made direct imaging of substellar objects impossible. But as Michael points out, the advent of adaptive optics technology eliminates most of the atmosphere's deleterious effects. "Today, we routinely make images in infrared light that are many times sharper than what is possible with Hubble Space Telescope," he said. "And this may only be a glimpse of what's to come."

A native of Washington, D.C., Michael enjoyed astronomy as a child. However, his professional interest didn't blossom until he attended Cornell University in New York. At the time, he thought he might become a chemist or a historian, until he took an introductory astronomy course taught by Steve Squyres (now Principal Investigator for NASA's Mars Science Exploration Rover team). "He was a marvelous teacher and really inspiring," Michael said. "Suddenly chemistry as a subject didn't excite me any more, not the way astronomy did."

Michael left behind the cold New York winters to attend the University of California, Berkeley as a graduate student in astronomy and physics. He was especially

Photo by Kirk Pu‘uohau-Pummill

passionate about adaptive optics, infrared astronomy, and star and planet formation. Although he did not realize it at the time, the seeds for his future success in all three fields were being sown. "Things are often clearer in hindsight than they are in the present," he said.

His research interests brought Michael to the Institute for Astronomy in 2000, where he worked as a Beatrice Watson Parrent Fellow. This endowment recognizes and supports newly graduated Ph.D. recipients in astronomy, allowing them to follow promising areas of research. "It's always a great opportunity to have the freedom to pursue the research you've longed to follow," he said about the fellowship. "It allowed me to wander off in new directions, to see if I would succeed or fail. It was also a great opportunity because it allowed me to come to Hawai'i. Not only is Hawai'i a beautiful place to live, but, as an observational astronomer, there's no better place to be, especially when you can use a world-class telescope like Gemini."

Michael pointed out that the Parrent fellowship allowed him to pursue his passion for understanding how stars and planets form. "In particular, I was trying to understand how brown dwarfs formed, these strange beasts in between stars and planets," he recalled.

Along with several colleagues, Michael set off to discover whether young brown dwarfs have circumstellar disks, as young stars do. The journey resulted in the first systematic survey for circumstellar disks around young brown dwarfs and very low-mass stars. According to Michael, it's now fairly common to see brown dwarfs with estimated ages of 1 to 3 million years that have circumstellar disks. "That's evidence that brown dwarfs form in the same way that stars do," he said. "It also suggests that brown dwarfs might have their own planetary systems, because circumstellar disks are the necessary first step toward forming planets."

The survey and follow-up work has earned Michael respect in the community. "Mike is quick to recognize important questions in science and is ambitious and motivated in pursuing their answers," said Joseph Jensen, Head of Instrumentation at Gemini. Jensen, who has been a friendly competitor and collaborator of Michael's for about 12 years, noted Michael's quick-thinking and tenacity as a researcher. "He is a quick thinker and skilled at digging deep enough to find the gaps in our general knowledge of a topic or the holes in our assumptions," he said. "Mike has extensive experience observing with AO systems on a variety of the largest telescopes in the world, including Gemini. He's a leader in the field of substellar companions."

Indeed, employing the various telescopes on Mauna Kea, Michael has gone on to discover the nearest example of a young planet-forming star that sports a spectacular circumstellar dust disk and indirect evidence for newly formed planets. Recently, he has also been working with Sandy Leggett (now Associate Astronomer at Gemini) to survey nearby brown dwarfs using the new laser guide star adaptive optics systems on the Keck and Gemini North telescopes on Mauna Kea. Thus far the search has led them to discover a strange new pair of brown dwarf twins—ones with the same age and composition but having vastly different appearances. This discovery has helped to explain what is happening in the atmospheres of these planet-like objects.

"Mike is dedicated, focused and intense," Sandy said about her colleague. "He is a terrific collaborator as he is highly skilled with both obtaining and analyzing observational data. He is an extremely hard worker, and I often get emails from him at 1 a.m.! More than once during our collaboration we have obtained data at a telescope, and he has produced an excellent, detailed and thorough paper within days of the observation."

Michael stresses that the discovery could not have been made without the new capabilities provided by laser guide star AO. "It's amazing how interesting AO technology seemed when it was young," he said. "And now it's all the more exciting. It's such a big part of what I do, and it's still growing and flourishing. I'm keenly interested in what the next AO systems will be like, and where they will take the science."

Michael is already on a new path to understanding what technology can do to advance astronomical understanding. Beginning in late 2007 he will lead an international team of astronomers in a major Gemini campaign to directly image gas-giant planets around nearby stars. The crown jewel in this effort is the Near-Infrared Coronagraphic Imager (NICI). This new, high-contrast, adaptive optics imager for Gemini South is tailored specifically for the detection of extrasolar planets by direct imaging. The NICI Campaign will be carried out over the next two to three years using 50 nights of observing time. It is expected to be the largest and most sensitive imaging survey to date for searching out massive, Jupiter-size planets around other stars.

"The campaign is exciting and challenging," Michael says, "because it's the first of its kind. No one has ever done a dedicated, multi-year campaign to find these new worlds. It's going to set us on the path to imaging planets that are closer to their parent stars and smaller in mass."

Sandy Leggett thinks that under Michael's leadership, great discoveries could be made perhaps as early as this year. Joseph Jensen agrees, "Mike plays a dynamic and active leadership role in the NICI planet-search campaign," he said, "and he has assembled an impressive international team of scientists and engineers to help Gemini find the next extrasolar planets."

Michael points out that the project will likely have some surprises. "When doing research, you never quite know where the road is going to take you. I have expectations for this planet-finding campaign, but who knows what we'll discover along the way? Our research might lead us down a new path of discovery—one that uncovers some unanticipated gems," he said. "An important part of being an effective researcher is about seeing new opportunities, about knowing how to use a telescope in ways that people weren't thinking about when they first built the machine."

Michael feels fortunate to be an astronomer. "It's an amazing, wonderful opportunity to have jobs that allow us to think and learn about where we came from," he said. "There's no immediate practical value to our research. There's no commercial product that we're creating. But, we are contributing to science and to society by learning about where we've come from and where we're going. It's a privilege to be one of the people doing this."

When he's not contemplating "origins," Michael likes to play volleyball, cook for his wife and try exotic foods. He loves to travel. His work takes him around the U.S. and to Chile. He finds constant insight from the people around him and the places he sees. "You have to be inspired," he said. "And, one needs a certain level of passion and commitment to pursue research as a lifelong occupation."

Stephen James O'Meara is a well-known astronomy popularizer located on the Big Island of Hawai'i who also specializes in studying and photographing volcanoes. He can be reached at: someara@interpac.net

Photograph by R. Scott Fisher

Gemini North in the Pale Moonlight

R. Scott Fisher took this image of Gemini North on Mauna Kea under the brilliant light of a full moon and clear skies. The enclosure is fully open to let air currents cool the inside of the dome.

R. Scott Fisher is the Gemini Outreach Scientist. He took this photograph with a Nikon D70, 70mm lens, 30 sec., f/3.5.

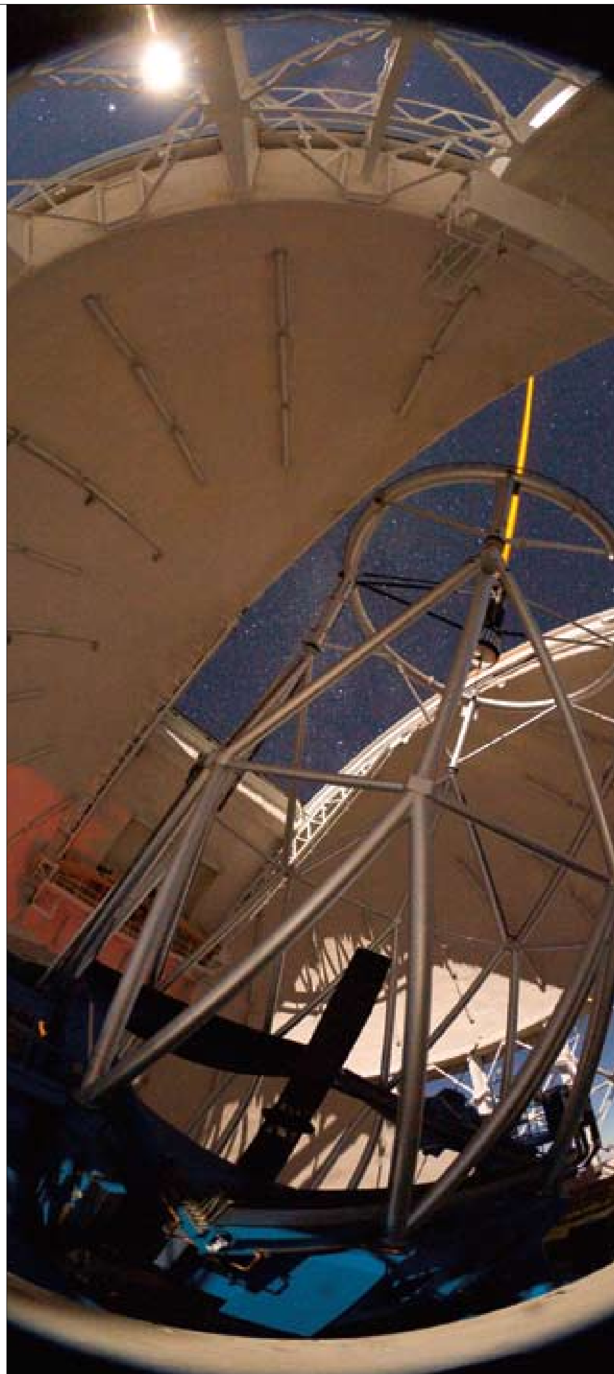
Photograph by Gustavo Arriagada

A Gemini South Nature Scene

Vizcachas are shy animals in the same family as chinchillas. They are often seen in the mountain terrain near Gemini South, generally hiding in shady areas around sunset or sunrise. Gustavo Arriagada, who took this image near Cerro Pachón, noted that it was a difficult one to get. “This particular vizcacha was standing at the edge of the cliff on a rock, surrounded by many more,” he said. “It made it almost impossible to use a tripod and and hard to walk around without scaring the animal.”

Gustavo is Director for Engineering/Chief Engineer at Gemini South. He used a 75- to 300-mm zoom left over from his old film camera days, mated to a Canon EOS 20D 8-megapixel camera.

GeminiFocus



Gemini North LGS photo by K. Pu'uohau-Pummill

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