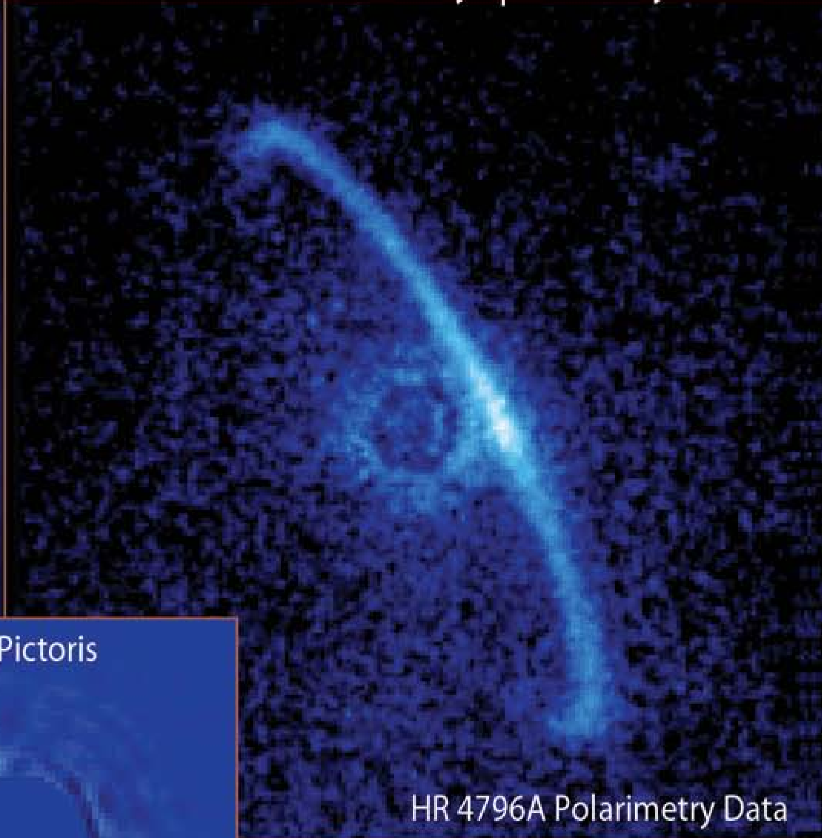
GeminiFocus

Publication of the Gemini Observatory | January 2014

HR 4796A Circumstellar Disk



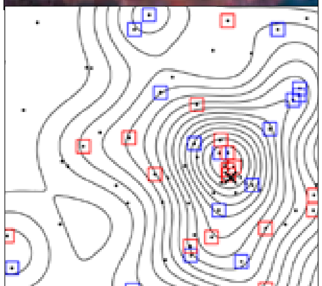
HR 4796A Polarimetry Data

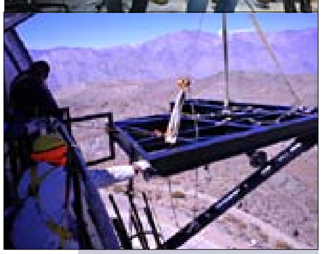
Beta Pictoris

New in this Issue:

GPI First Light!

2013 Year in Review





GeminiFocus

ON THE COVER:

The cover of this first "Annual Review" issue of *Gemini*Focus features images from the Gemini Planet Imager's first light, obtained in late 2013 (see story on page 23), and the previous covers of *Gemini*Focus from 2013. All issues of *Gemini*Focus are available at: *www.gemini.edu/geminifocus*

Gemini*Focus January 2014 and 2013 Year in Review*

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Markus Kissler-Patig

Director's Message

2013: A Successful Year for Gemini!

As 2013 comes to an end, we can look back at 12 very successful months for Gemini despite strong budget constraints. Indeed, 2013 was the first stage of our three-year transition to a reduced operations budget, and it was marked by a roughly 20 percent cut in contributions from Gemini's partner countries. Nevertheless, our staff excelled at working on the many initiatives that will allow us to operate Gemini in a sustainable way, while providing most of the services that our users appreciate.

We also managed to deliver to the Gemini community three new exciting instruments at Gemini South, as well as host two visiting instruments at Gemini North. In addition, we launched the new Large and Long Programs, complementing the standard semester-based method of administering telescope time.

Gains at Gemini South

With four facility-class instruments and an adaptive optics system, Gemini South is now configured as it will operate for the next few years. First, the Gemini Multi-conjugate adaptive optics System (GeMS) with the Gemini South Adaptive Optics Imager (GSAOI) was introduced early in the year with first science. The system moved into regular operations soon thereafter. This complex system will still require a few more semesters of operations until it runs as smoothly as some of the old workhorse instruments, but the first papers based on its data have appeared, and the instrument is heavily subscribed.

Second, FLAMINGOS-2 was commissioned in imaging- and long-slit modes during the first half of the year. It jumped immediately to the next-most demanded instrument behind the two Gemini Multi-Object Spectrographs. We anticipate that the remaining image-quality problems can be solved in 2014, after which we will add the much anticipated near-infrared Multi-Object Spectrograph mode.

Finally, the Gemini Planet Imager made a flamboyant entry with its integration of first light in November (see article on page 23 of this issue)!

Gemini North News

At Gemini North, we took routine operations to a high level — dedicating close to 95 percent of 2013 to science observations. Also, we were able and happy to host two visiting instruments: the Differential Speckle Survey Instrument (Steven Howell, Principal Investigator (PI)) and the Texas Echelon Cross Echelle Spectrograph (John Lacy, PI). Both instruments have unique capabilities that enhance Gemini's complement of facility-class instruments. Beyond being used for the PI's dedicated programs, both visiting instruments were offered to the user community while being operated by the PI's teams. In the coming years, we are looking forward to more groups bringing their instruments or experiments to our state-of-the-art telescopes!

Operations Decisions

Driven by budget cuts, we reviewed the core Observatory operations. We reflected on how our users' science could direct the way in which we operate, rather than having our operations constrain the users' science. This concept generated many ideas. In particular, it led us to consider adding two future proposal modes: 1) Large and Long programs that enable multi-year, high-impact ambitious projects; and 2) a Fast Turnaround proposal scheme, allowing users to obtain data only a few weeks after submitting their proposals.

Large and Long programs have received the go-ahead from the Gemini Board, and the first call went out in December. This scheme also led us to introduce "Priority Visiting Observing" — a way to observe classically while mitigating the risk of weather loss. Check it out at: *http://www.gemini.edu/node/11101?q=node/12096*. The Fast Turnaround scheme has been reviewed by our advisory committees and is now being prototyped. We hope to introduce it by the end of 2014.

We also recognized that more "post-observing" support would be very beneficial to the user community. While in-house efforts are being spent, we also wanted to engage our users in supporting each other. As a result, we are launching a new Data Reduction User Forum at: *http://drforum.gemini.edu*. Please add to the discussion — the best contributions will be rewarded with Director Discretionary Time!

Overall, during 2013 we saw many advances in our support of the community, with original ideas that contribute to Gemini's uniqueness. Our outlook for 2014 promises to be no less exciting. We are looking forward to many new discoveries by our community in the new year.

Markus Kissler-Patig is Gemini's Director. He can be reached at: mkissler@gemini.edu


Stephen Justham and Jifeng Liu

Weighing the Black Hole in M101 ULX-1

Astronomers have measured the mass of an ultra-luminous X-ray source, producing a puzzle over how to explain the observed X-ray properties and leaving a hole in the quest for intermediate-mass black holes.

Figure 1.
Artist's impression of M101 ULX-1. In the foreground is the black hole, surrounded by an accretion disk; matter falling into the black hole via the disk produces the X-ray luminosity of the system. That matter originates from the wind of a Wolf-Rayet star, shown in the distance. In the far background is one of the spiral arms of M101.

Gemini illustration by Lynette Cook.

M101 ULX-1 is a transient ultra-luminous X-ray source with characteristics expected of an accreting, intermediate-mass black hole (IMBH). A series of Gemini spectra have detected a Wolf-Rayet star in the system and revealed its orbital motion. This constrains the mass of the black hole in M101 ULX-1; the object is too massive to be a neutron star but very unlikely to be an intermediate-mass black hole. The data also show that the black hole accretes from the wind of the star, not the overflow of the donor star's Roche lobe, as illustrated in Figure 1.

"Ultra-luminous X-ray sources" (ULXs) sit at the intersection of two fundamental problems in astrophysics, since this class of systems contains objects which appear to be more luminous than the Eddington limit allows for stellar-mass black holes. That definition is somewhat imprecise because we don't know the definitive upper mass limit for "stellar-mass" black holes. Nonetheless, the questions raised by the existence of these systems are clear: Is the Eddington limit somehow exceeded in ULXs? Or do ULXs contain black holes with higher-than-expected masses, perhaps even intermediate-mass IMBHs?

Such IMBHs have long been the topic of speculation and searches. Two classes of black holes are observationally well-established: the stellar-mass black holes discovered in Galactic X-ray binaries, and the supermassive ones in the centers of galaxies, with a large mass gap separating the two classes. The best IMBH candidate so far is in ESO 243-49 HLX-1, for which the recently-inferred black hole mass does enter the upper end of the IMBH range (Webb *et al.*, 2012), depending on the definition adopted.

The remaining wide gap between stellar-mass and supermassive black holes is frustrating for those hunting them, since many theorists assume that today's supermassive black holes formed via "seed" IMBHs. If no IMBHs exist in the present-day universe, it would throw doubt on that scenario. Whilst not detecting IMBHs is not the same as proving they are not present — black holes are, after all, not intrinsically bright objects — a direct detection would be very welcome. There have been indirect inferences of the presence of IMBHs in globular clusters, but the arguments are not universally accepted.

Circumventing the Eddington Limit

One way around the apparent Eddington limit would be if the emitted radiation was non-spherical, *i.e.,* if the luminosity of ULXs was preferentially directed towards us. This option cannot be excluded in all cases; how would Galactic microquasars such as SS 433 or GRS 1915+105 appear if we were looking directly down their jets? However, measurements of the energy which is deposited into nebulae around ULXs suggest that the power output of typical ULXs is unlikely to be significantly smaller than the value which is derived using the assumption that the emission is spherically-symmetric (see, *e.g.*, Pakull and Mirioni, 2003).

Another easy-looking option would be to discard the Eddington limit (which assumes spherical symmetry) on the plausible-seeming grounds that accretion through a disk is not spherically-symmetric. The simple version of this argument fails, however, because, at luminosities approaching the Eddington luminosity, the inner parts of the accretion disk are expected to become radiation-pressure dominated. Without some additional unknown mechanism, the inner disk would consequently thicken and the accretion geometry would become quasi-spherical.

More complicated ways of circumventing the Eddington limit have been proposed. These have tended to invoke a mechanism for transferring energy from the inner accretion disk to a corona surrounding the black hole. The concept connects naturally with the fact that the spectra of many ULXs are dominated by a power-law component (see, *e.g.,* Gladstone, Roberts, and Done, 2009). That power law is normally identified with a "Comptonising" corona, in which photons gain energy by "inverse Compton scattering" from high-energy electrons. More energy is emitted by that component than by the component found in the spectra, which is identified with the accretion disk.

The Nature of ULXs

Since the ULX class was identified, astronomers have shown great interest in their nature. Successfully measuring the mass of the accreting object in a ULX is guaranteed to produce an interesting result for the following reasons: 1) If a particular ULX contains an IMBH, then the system affects our understanding of the cosmological population of black holes; and 2) If no IMBH is present, then we are forced to conclude that the apparent Eddington limit can be circumvented. Deducing the mechanism by which the latter is possible should teach us about the still-poor-

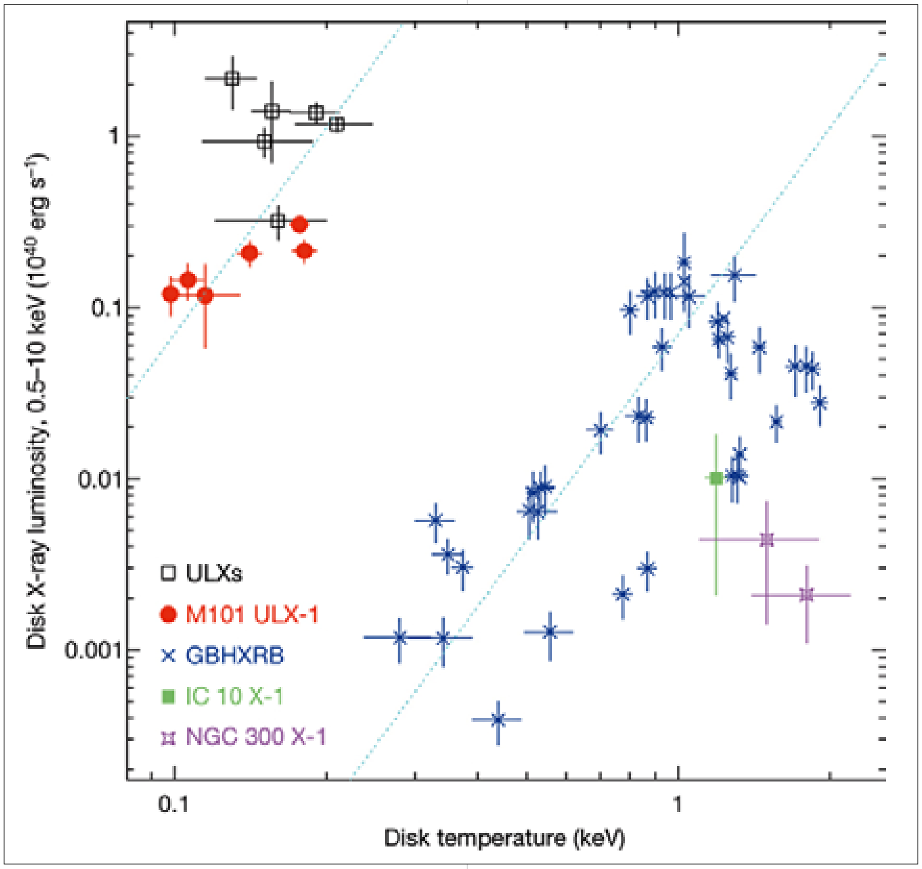


Figure 2.

Quantities derived from fits to the X-ray spectra of a variety of X-ray sources indicate that the accretion disk properties divide naturally into two groups. M101 ULX-1 (shown in red) is a member of the class which apparently maintains very cool inner disk temperatures whilst attaining a high luminosity, as would be expected for IMBHs. Galactic black-hole X-ray binaries (labelled as GBHXRB) and two other known Wolf-Rayet black-hole X-ray binaries lie in a distinctly different region of the parameter space. The dotted lines describe the expected variation in disk luminosity with a fixed inner disk radius (which, naively, would be correlated with black hole mass). For further details, please see Liu et al., *2013.*

ly-understood process of accretion, and the conditions which prevail in the strong gravity close to a black hole.

Measuring the masses of the components in ULXs is hard, partly because the great luminosity of the accretion disk overwhelms the light from the star. However, rare systems are transient, sometimes entering a state in which they are sufficiently luminous to qualify as ULXs, sometimes returning to a quiescent state in which it might be possible to directly detect the motion of the star.

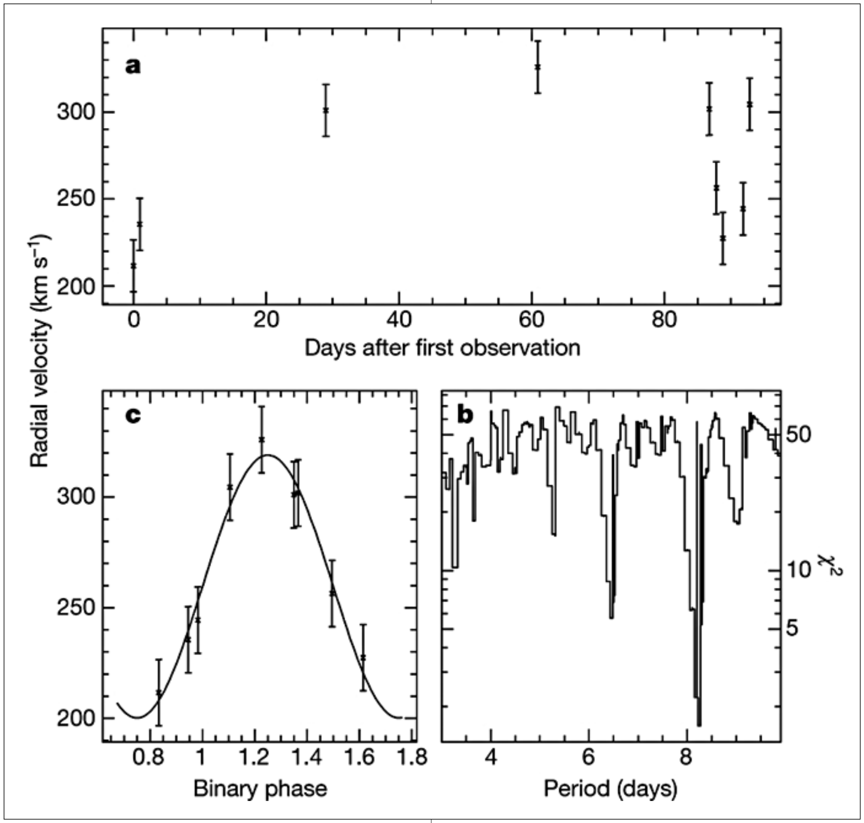
M101 ULX-1 is one such system. It was detected as the brightest X-ray source in the galaxy M101 but since then has regularly been observed in lower-luminosity states. Moreover, M101 ULX-1 is one of the ULXs from which the X-ray spectral energy distribution contains no hint of a Comptonising corona, which reduces the chance that the presently-proposed super-Eddington accretion mechanisms are helping to explain the high luminosity. Furthermore, the X-ray spectrum is easily fitted by a standard thermal accretion disk with a super-soft temperature of only 100 or 200 electron volts, which implies that the inner disk temperature is exceptionally cool (see Figure 2). This combination of spectral characteristics, combined with the high outburst luminosity, is exactly the set of properties which one would expect an IMBH to display.

Gemini Observations of a Black Hole Donor Star

Based on these arguments, a Gemini proposal was approved to try to detect the motion of the donor star in M101 ULX-1. This resulted in 10 spectra with exposures ranging between 3200 and 9600 seconds, and a combined integration time of 15.6 hours.

The first discovery from these observations was the nature of the companion star. Clear helium emission lines indicate that it is a Wolf-Rayet star (an evolved and helium rich

Figure 3. *Panel (a) presents the radial velocities measured from the 4686 Angstrom helium emission line in the Gemini spectra of M101 ULX-1. Panel (b) illustrates the chi-squared value obtained when fitting circular orbits of different periods to the data, demonstrating that the best-fitting orbital period is 8.2 days. Panel (c) again shows the measured radial velocities, now folded over the inferred orbital period. For further details, please see Liu* et al., *2013.*



massive star that burns brightly, fiercely, and erratically). More detailed analysis indicated a star with spectral type WN8, with a mass somewhere between 17.5 and 19 solar masses. For details, see the journal paper (Liu *et al.,* 2013).

The motion of those emission lines showed clear radial velocity variations, indicating that the observations had successfully detected the orbital motion of the donor star about the black hole (see Figure 3). Assuming a circular orbit, the best-fitting orbital period was 8.2 days (which achieved a chi-squared value of 1.6). Clearly substantial uncertainties remain, given moderately large error bars for each of the radial-velocity measurements and imperfect phase coverage (remember that this is in a galaxy about 20 million light-years away!)

In reality, the orbit might also have non-zero eccentricity (as often observed in the wind-accreting Galactic high-mass X-ray binaries), although the good fit to the data using a pure sine curve suggests that any eccentricity in this case would be small. The best-fit model radial velocity curve indicates a minimum mass for the compact object in M101 ULX-1 of five solar masses, which confirms that it is a black hole.

Despite those uncertainties in the precise properties of the binary, two conclusions are very hard to escape: the black hole in M101 ULX-1 is not an IMBH, and it accretes from the wind of the Wolf-Rayet star.

For any binary system whose inclination is unknown, radial velocity measurements can only ever lead to a lower limit on the component masses — since the binary could, in principle, be arbitrarily close to face-on to the line of sight. However, the chance of detecting such a system is small. For M101 ULX-1, the combination of our best-fitting orbital period and Wolf-Rayet mass would require an orbital inclination within 5 degrees of face-on to contain a black hole of 300 solar masses or greater. This means we'd have a 0.3 percent probability of discovering such a system by chance. If ULXs are systems in which the X-ray emission is strongly beamed, however, and if the beaming axis is perpendicular to the orbital plane, then that would increase the ULX's chance of being observed in such an apparently unlikely orientation.

Even so, it would be bold to invoke observationally-disfavored beaming to argue that a system has a reasonable probability of containing an IMBH, given that beaming was first applied in this context to avoid the need for IMBHs. Taken at face value, then, the system is unlikely to be sufficiently face-on to contain an IMBH. Much of the ULX community will not be surprised by that broad conclusion; the idea that most ULXs contain stellar-mass black holes has gradually become the dominant position. Nonetheless, the Gemini data are the most direct observations supporting that conclusion.

More unexpected is our finding that the black hole in M101 ULX-1 can sustain such a high luminosity from wind accretion. Capture of material from a stellar wind is typically associated with fairly low-luminosity accretion, but M101 ULX-1 demonstrates that sometimes wind capture can be extremely efficient. This unlooked-for result might be as important as the mass measurement itself.

Whatever the final scientific impact that these results produce on our understanding of black holes and their accretion, we marvel that it is possible to measure the motion of a star orbiting a black hole in M101 — some 20 million light-years away — and thereby to constrain the mass of that black hole.

Acknowledgements:

J.-F.L. and S.J. thank the other authors of the associated journal article: Joel Bregman, Yu Bai, and Paul Crowther. We also thank the Chinese Academy of Sciences and National Science Foundation of China for support during this work.

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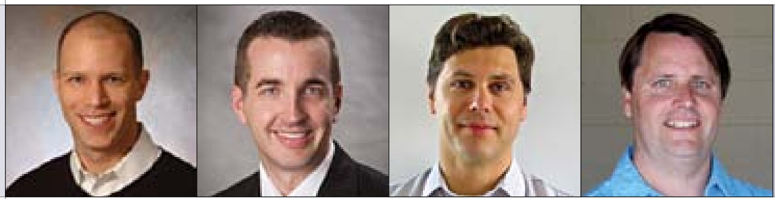


Jacob Bean, Kevin Stevenson, Jean-Michel Desert, and Marcel Bergmann

Ground-based Transit Spectroscopy of an Exoplanet Atmosphere

Using the Gemini Multi-Object Spectrograph, researchers help characterize the atmosphere of exoplanet WASP-12b. The transit spectroscopy technique used — until recently only attempted with space telescopes — opens the door for future ground-based studies that will lead to a better understanding of exoplanet systems, and even our own Solar System.

The Importance of Exoplanet Atmospheres

Recent telescopic surveys have revealed an amazing diversity of planets orbiting other stars. This wide assortment of exoplanets offers both challenges and opportunities to astronomers studying them. The challenge is to understand these objects from the perspective of a complete theory of planetary system origin and evolution, which is one of the main goals of modern astrophysics. In a broader context, the opportunity is a chance to study classes of objects that may lead to a better understanding of how our own Solar System formed and evolved.

One key to understanding and exploiting the diversity of exoplanets is to study their atmospheres. Planetary atmospheres mediate the energy balance between incoming stellar irradiation and outgoing self-luminosity and re-radiation. Therefore, a planet's atmospheric properties control its size and appearance.

A planet's atmosphere also keeps a record of its origins and evolution. For example, the atmospheres of gas-giant planets make up a significant fraction of their total mass. Therefore, they must be intrinsically linked to the planet-formation process. Lower-mass planets with rocky, metallic, and/or icy compositions could also have primary atmospheres. These would have been either accreted from the primordial protoplanetary disk (as with giant planets), or appeared as secondary atmospheres created from outgassing or collisions with other bodies after the planets formed.

Over the last few years, our group has started exploring exoplanet atmospheres by making differential spectroscopic observations of exoplanets passing in front of their host suns (see details on this technique starting on page 11). These ground-based transit observations yield spectra (and thus clues to the composition of exoplanet atmospheres) with precisions that rival those taken with space telescopes.

Using GMOS to Probe WASP-12b: A Hot Exoplanet Prototype

One exoplanet that has long fascinated us is WASP-12b. This hot, Jupiter-sized planet orbits its Sun-like (G0) parent star every 26 hours. Recent work has suggested that this highly-irradiated exoplanet could have a carbon-to-oxygen ratio (C/O > 1) that is significantly higher than that of the Sun (0.54, Madhusudhan *et al.*, 2011). When a planetary atmosphere is so carbon-rich, different chemical pathways dominate and unexpected molecules, such as methane and metal hydrides, begin to emerge.

To better understand the atmospheric composition of WASP-12b (Stevenson *et al.*, 2013) we used the Gemini Multi-Object Spectrograph on the Gemini North telescope (GMOS-N) on Mauna Kea to perform the transit spectroscopy technique described starting on page 11.

Because WASP-12b's orbital period is close to one day, we were able to observe two transits on two consecutive nights in classical mode. Our observations were gathered in the red

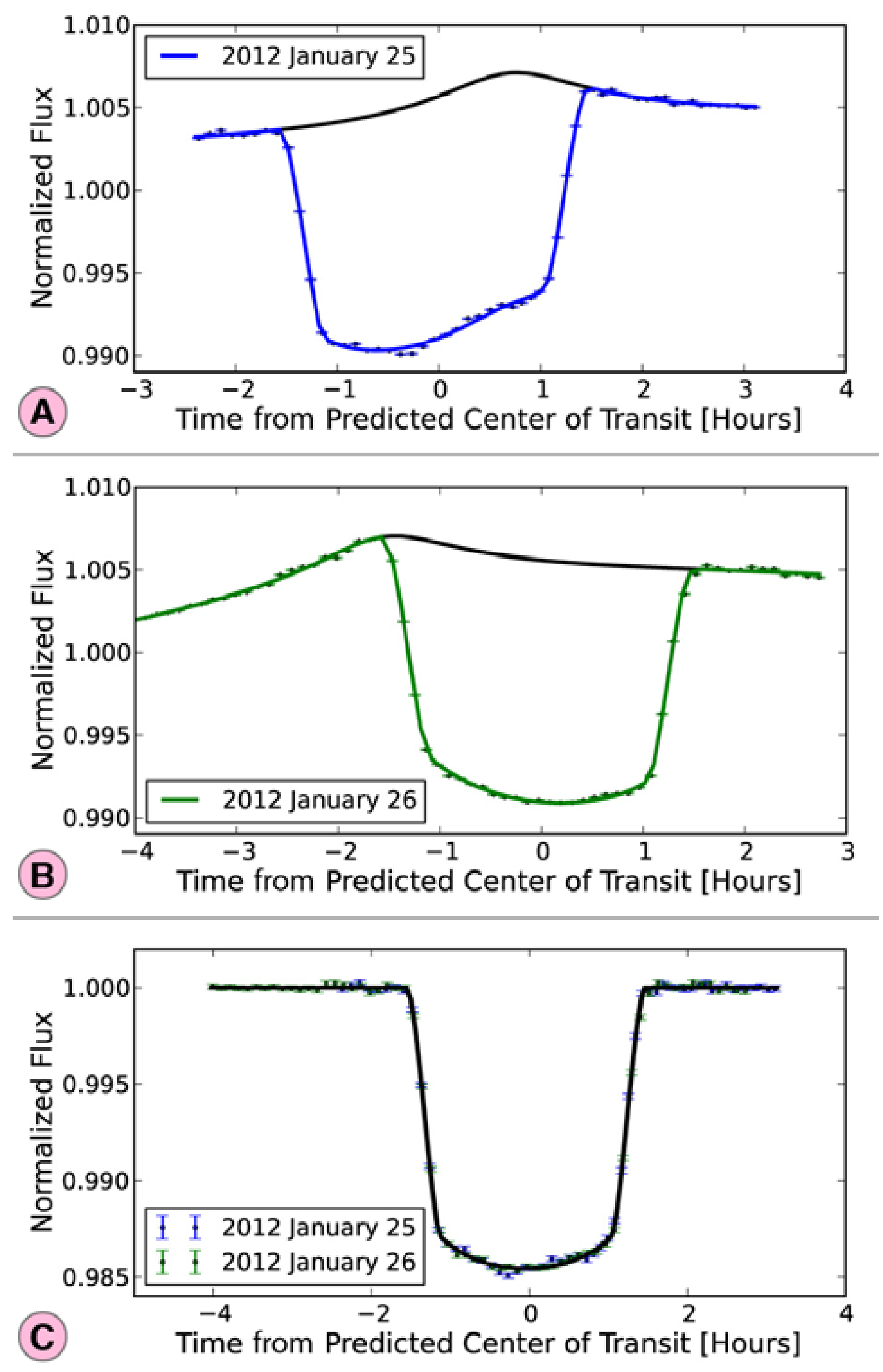


Figure 1.

"White" light curves for the hot Jupiter-type exoplanet WASP-12b Panel A: Transit time series, from January 25, 2012, after correcting for telluric effects using the simultaneously observed reference star (points). The data exhibit an unexpected instrument systematic that is modeled using an analytic function (black line). The combined transit and instrument model is shown as the blue line. Panel B: Same as panel A, but for the January 26th observation. Panel C: White light curves for both nights with the instrument systematic removed (points). The combined transit model is shown as the black line. The residuals have a root mean square of 180 parts per million.

Figure 2.
Spectroscopic light curves of WASP-12b (points) and best-fit models (lines) for the January 25th observations. The numbers on the left side give the wavelength range of the channels in units of nanometers.

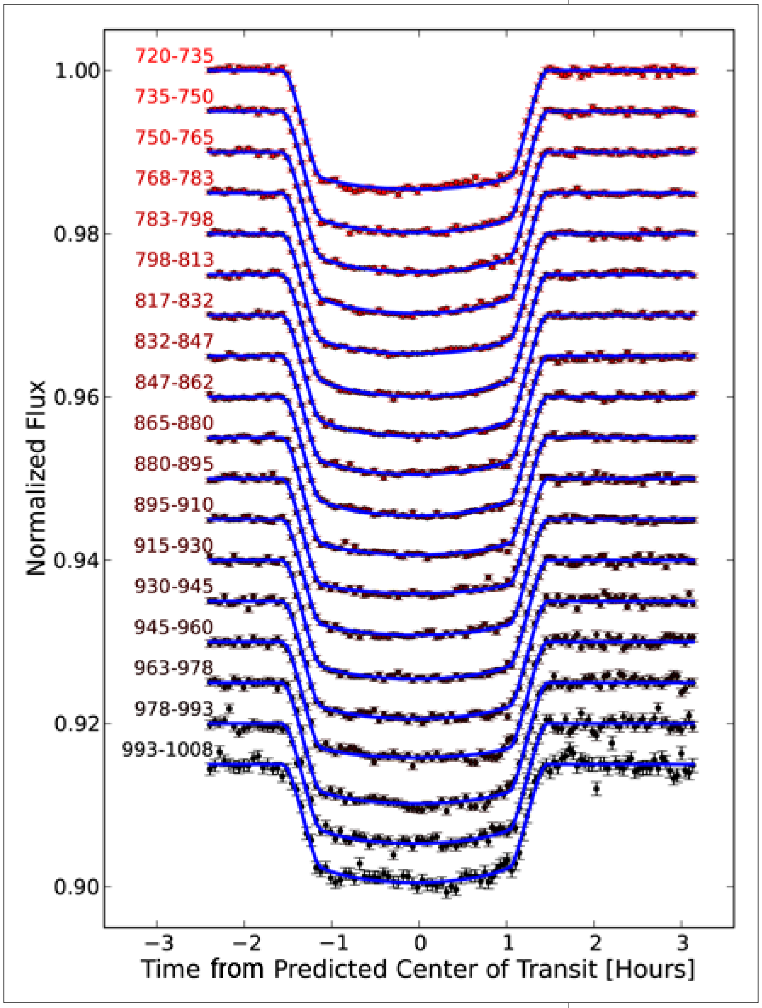
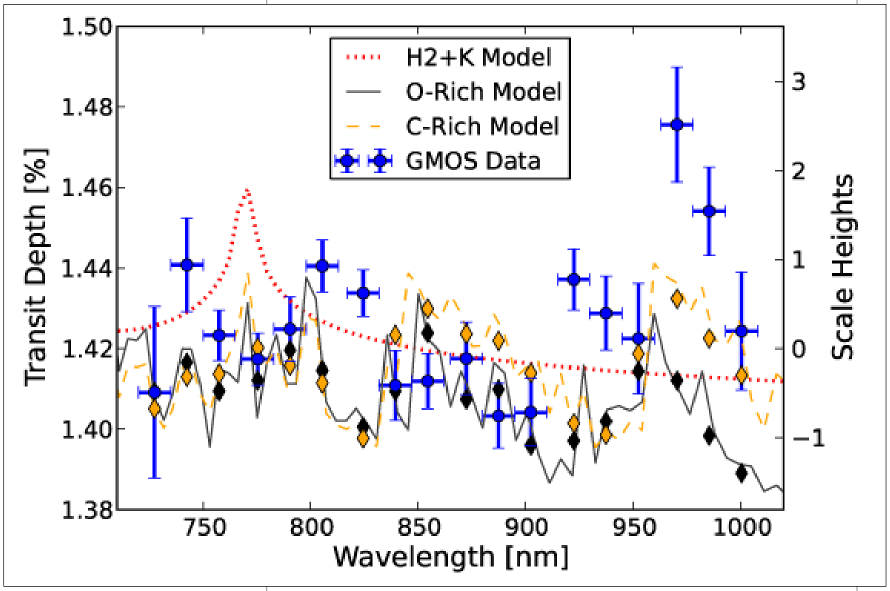


Figure 3.
Derived transmission spectrum of WASP-12b (blue circles with error bars) with the transit depth (left y-axis) and relative number of scale heights (right y-axis). The different lines represent different models for the planet's atmosphere, and the diamonds are the models binned over the data bandpasses. The red line is a model with only hydrogen and potassium. The feature in this model at 0.775 micron is due to the potassium resonance doublet. The black line is a model for an atmosphere that has solar elemental abundances (i.e., oxygen rich). The gold line is a model with a carbon-rich composition.



optical (720-1008 nanometers [nm]) and took advantage of the new e2v deep depletion CCDs that had been installed in GMOS-N just a few months beforehand. The excellent red optical quantum efficiencies and cosmetics of these detectors were a big boon to our program.

The so-called "white" light curves for WASP-12b — made from the Gemini data by summing over all of the wavelengths — is shown in Figure 1. The data exhibit an unexpected instrument systematic. The effect is correlated with the rotation angle of the Cassegrain instrument support structure. (Note that this angle changes smoothly over the course of a transit observation as the structure rotates to keep the GMOS slit mask aligned on the stars.) The origin of this effect is unknown and is currently being investigated. However, we found that it can be modeled (black lines in the top two panels of Figure 1) and removed from the data.

In Figure 2, we show the corrected high-precision spectroscopic light curves that we obtained with GMOS-N by binning the data for the first night over 15-nm-wide spectral channels. The measured transit depths vary as a function of wavelength; this gives us the planet's transmission spectrum, which in turn, tells us about its atmospheric composition.

The transmission spectrum of WASP-12b along with three atmospheric models is shown in Figure 3. The GMOS-N data rule out the possibility of an atmosphere with only hydrogen and potassium. For an oxygen-rich atmosphere, the data can be explained by the presence of metal oxides. However, the presence of metal hydrides in a carbon-rich atmosphere can also explain the data.

Looking Forward

In our study of WASP-12b, we achieved comparable precision to previous Hubble Space Telescope Wide Field Camera 3 measurements, thus proving that ground-based studies of exoplanetary atmospheres can be a complementary addition to space-based observations. We are currently conducting a National Optical Astronomy Observatory survey program (Principal Investigator (PI) Jean-Michel Desert) using GMOS to measure transmission spectra of a number of transiting planets and to investigate the nature and origins of these planets in a systematic way.

In addition, the recent commissioning of FLAMINGOS-2 opens up the possibility of applying the same differential spectroscopy technique in the near-infrared. We also have observations from late 2013 (GS-2013B-Q-71, PI Kevin Stevenson) to test the capabilities of the instrument for this science. These test observations will be used to observe secondary eclipses of a different planet, WASP-18b, allowing us to measure its thermal emission spectrum.

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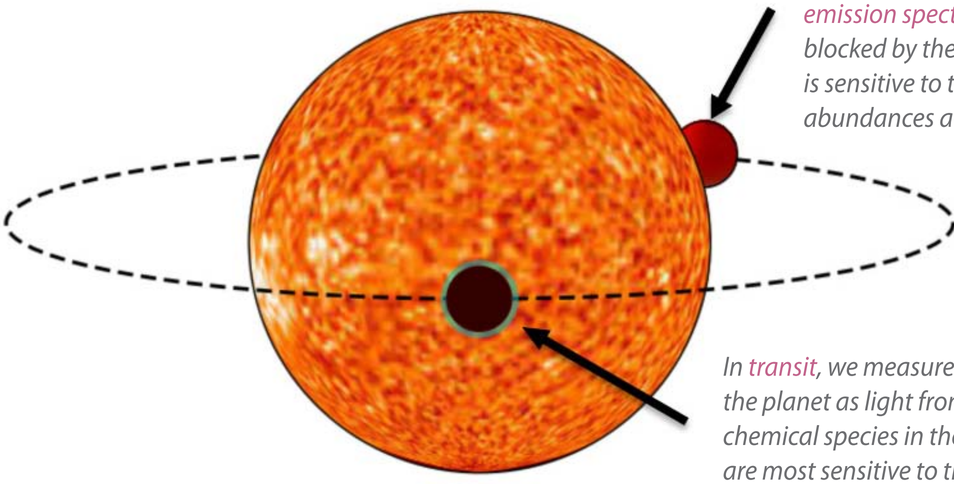
Exoplanet Transit Spectroscopy: A Primer

Conceptually, the simplest way to take a spectrum of an exoplanet is to spatially resolve the light from the planet from the light of its host star and to feed that light into a spectrograph. However, this is extremely challenging due to the large contrast and small angular separations between planets and stars.

As an alternative to the approach of direct imaging spectroscopy, transit spectroscopy involves resolving the light from exoplanets and their host stars temporally rather than spatially (*e.g.*, Charbonneau *et al.,* 2002). This is possible because a subset of known exoplanets are observed to eclipse (transit) their host stars due to a favorable geometric alignment of their orbital plane with our line-of-sight (Figure 4).

The atmospheres of transiting planets can be probed in transmission by examining the wavelength-dependency of the primary transit depth. This arises because the light from the host star is blocked at different altitudes in the planet's atmosphere

Figure 4.



In secondary eclipse, we measure the dayside emission spectrum of the planet as its light is blocked by the host star. Emission spectroscopy is sensitive to the absolute chemical abundances and the thermal structure.

In transit, we measure the transmission spectrum of the planet as light from the host star is absorbed by chemical species in the planet's atmosphere. These data are most sensitive to the relative chemical abundances and the presence of cloud or haze particles.

due to the absorption by chemical species. Also, measurements when transiting planets pass behind their host stars can reveal their thermal emission and reflection spectra. Figure 4 illustrates the geometry of transit spectroscopy observations and discusses what information can be deduced from these observations.

Transit spectroscopy measurements have been used to probe the atmospheres of planets ranging from the hottest Jupiter-size to moderate-temperature Neptune-size planets and even warm super-Earths. These measurements have been used to deduce the presence of sodium, water, methane, hazes, *etc.*, in these planets' atmospheres, and also to constrain their thermal structure, dynamics, and evaporation.

However, there are still many outstanding questions about the fundamental nature of exoplanet atmospheres despite the many recent successful applications of the transit spectroscopy technique. Progress in this area requires observations of more targets and over a wider range of wavelengths than has been obtained so far.

Observing Exoplanet Atmospheres from the Ground

Just as the blurring effect of Earth's atmosphere hinders direct imaging of exoplanets, the scintillation component of atmospheric seeing limits the precision of ground-based transit observations. That's why most transit spectroscopy observations have been done with space telescopes like Hubble and Spitzer.

However, these telescopes have limitations. Both are relatively small, and so achieving the 1 part in 10,000 or better type of precision that is needed for this work can only be done for planets orbiting very bright host stars. Spitzer also no longer has spectroscopic capabilities, and Hubble's spectrographs have limited wavelength coverage.

The large ground-based telescopes of today offer the potential for complementary wavelength coverage, especially in the optical. They also have the reach to target interesting planets around fainter host stars. However, the limitations imposed by Earth's atmosphere first need to be overcome.

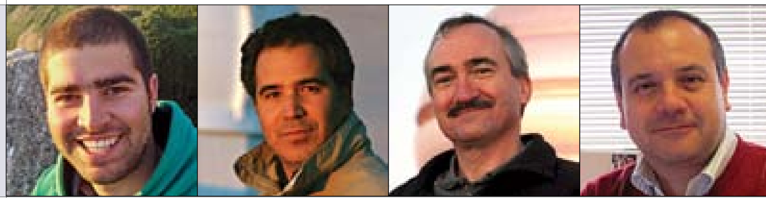
The brightness variations in ground-based time-series photometry are typically overcome by simultaneous observations of reference stars that are close to the target on the sky. On the assumption that the reference stars are not intrinsically variable, and that the effect of scintillation is a common mode across a small field-of-view, ground-based differential transit photometry can be obtained to precisions necessary to probe exoplanet atmospheres with the transit technique.

Spectroscopy is ultimately needed to resolve the lines and bands from chemical species in exoplanet atmospheres. We accomplish this by performing simultaneous time-series spectroscopy of the transiting planet host star and a few reference stars of similar brightness with multi-object slit spectrographs. A key aspect of this approach is the use of very-wide (12 arcsecond) custom slits, which are crucial for eliminating light loss at the slits due to variations in atmospheric seeing and guiding as a function of time.

The only downsides to this approach are a loss in spectral resolution over what could be obtained with slits smaller than the seeing profile, and a higher background. These factors are not major limitations. We typically have to bin the data to a significantly lower resolution than is native in the data (to boost the signal-to-noise ratio) and the stars we observe are very bright relative to the background.

History of Ground-based Transit Spectroscopy

The first application of the multi-object transit spectroscopy technique was with the Focal Reducer and Spectrograph (FORS) instrument on the European Southern Observatory's Very Large Telescope (Bean *et al.*, 2010), and we have subsequently used the technique with MMIRS on Magellan (Bean *et al.*, 2011, and 2013) and now the Gemini Multi-Object Spectrograph (GMOS) on Gemini North (Stevenson *et al.*, 2013). Recently, another group has also had success using the technique on GMOS (Gibson *et al.*, 2013).



Cristóbal Sifón, Felipe Menanteau, John P. Hughes, L. Felipe Barrientos, for the ACT collaboration

Dynamical Masses of Galaxy Clusters Discovered with the Sunyaev-Zel'dovich Effect

A large spectroscopic follow-up campaign of galaxy clusters, discovered via the Sunyaev-Zel'dovich Effect (SZE) by the Atacama Cosmology Telescope collaboration and largely carried out with the Gemini Multi-Object Spectrograph on Gemini South, has provided the first dynamical mass measurements for SZE-selected clusters.

Galaxy clusters are the most massive bound objects in the universe. Because of this, their number density is a sensitive function of the matter content of the universe. Clusters are composed of three main constituents: stars (both in galaxies and outside of them); ionized gas with typical temperatures of 10^6-10^7 Kelvin, known as the intracluster medium (ICM); and so-called "dark matter." (The presence of dark matter in clusters has been firmly established. The evidence dates back to the 1930s and the pioneering work of Fritz Zwicky at the California Institute of Technology, when he applied the Virial Theorem to galaxy velocities in the Coma cluster.) These three components have been exploited to discover and study clusters, most typically through X-ray and optical observations.

The power of galaxy clusters as cosmological probes depends largely on our ability to correctly infer their masses. However, we often estimate cluster masses from scaling relations that connect a given observable to mass itself. We usually obtain these relations through numerical simulations. Additionally, the mass function of galaxy clusters is a very steep one of both mass and redshift. Therefore, the few massive clusters at high redshift give the strongest weight to cosmological constraints.

A New Kind of Galaxy Cluster Sample

The Sunyaev-Zel'dovich Effect (SZE; Sunyaev and Zel'dovich, 1972) corresponds to the scattering of photons coming from the Cosmic Microwave Background (CMB) by the electrons in the ICM. This typically boosts the energy of individual photons, resulting in a distinct frequency dependence of the effect. Thus, the SZE is observed as a change in temperature in the direction of clusters with respect to the average CMB line-of-sight.

This effect is observed as a decrease in temperature relative to the undistorted CMB at frequencies below approximately 218 Gigahertz (GHz), peaking around 130 GHz, where it is of the order of a few hundreds of microkelvins (μK) for the most massive clusters. At approximately 218 GHz the net change in temperature is null, and the SZE is observed as a temperature increment at higher frequencies.

Importantly, since the SZE is a scattering process, the surface brightness of the SZE is strictly independent of the distance to the cluster. It is moreover, to first order, dependent only on the line-of-sight integral of the gas pressure through the ICM. Of course, more massive clusters tend to be hotter and have a denser ICM. This implies that they host ICM atmospheres with the highest pressures, making the SZE particularly sensitive to cluster mass. The bottom line is that the most massive clusters produce the strongest SZE signals.

The selection function for a sample of galaxy clusters detected with the SZE is essentially distance independent. Thus, an accurate calibration of the SZE brightness of clusters to their mass gives exciting prospects for the use of galaxy clusters as cosmological probes. This is especially true for two reasons: 1) Being almost independent of redshift, the SZE is best suited to detect the most massive galaxy clusters at high redshift (as mentioned before, it provides the strongest leverage to cosmological constraints); and 2) The SZE brightness is expected from numerical simulations to be cleanly related to the total mass of clusters, with an intrinsic scatter as low as 10 percent.

ACT Weighs In

The 6-meter Atacama Cosmology Telescope (ACT) in northern Chile was designed to scan the sky at millimeter wavelengths with a resolution approaching 1 arcminute. It is one of only two ground-based millimeter-band telescopes sensitive enough to conduct large area surveys (covering thousands of square degrees of sky) to study the CMB and other temperature fluctuations from astrophysical sources (*i.e.*, SZE clusters and distant galaxies).

The first results — based on a 450-square-degree survey of the southern sky at 148 GHz with a sensitivity of 36 μK — revealed 23 clusters in the redshift range $0.12 < z < 1.07$, of which 10 at $z > 0.28$ were newly discovered (Marriage *et al.*, 2011). The initial characterization of the sample, using optical imaging and archival X-ray data, confirmed that this was a sample of massive clusters spanning all redshifts, as expected from mass function predictions (Menanteau *et al.,* 2010).

However, a detailed analysis, including mass measurements and cosmological implications, had to wait for further observations. Figure 1 shows four sample clusters detected by ACT, showing the temperature decrements observed in 148 GHz (top) and the corresponding optical images (bottom), with the photometric redshift given in each image. Of these, the three highest redshift clusters were followed up with the Gemini Multi-Object Spectrograph (GMOS).

One of the highlights of this cluster survey was the discovery of ACT-CL J0102-4915, dubbed "El Gordo," which is at a redshift of 0.87 (Menanteau *et al.,* 2012). We character-

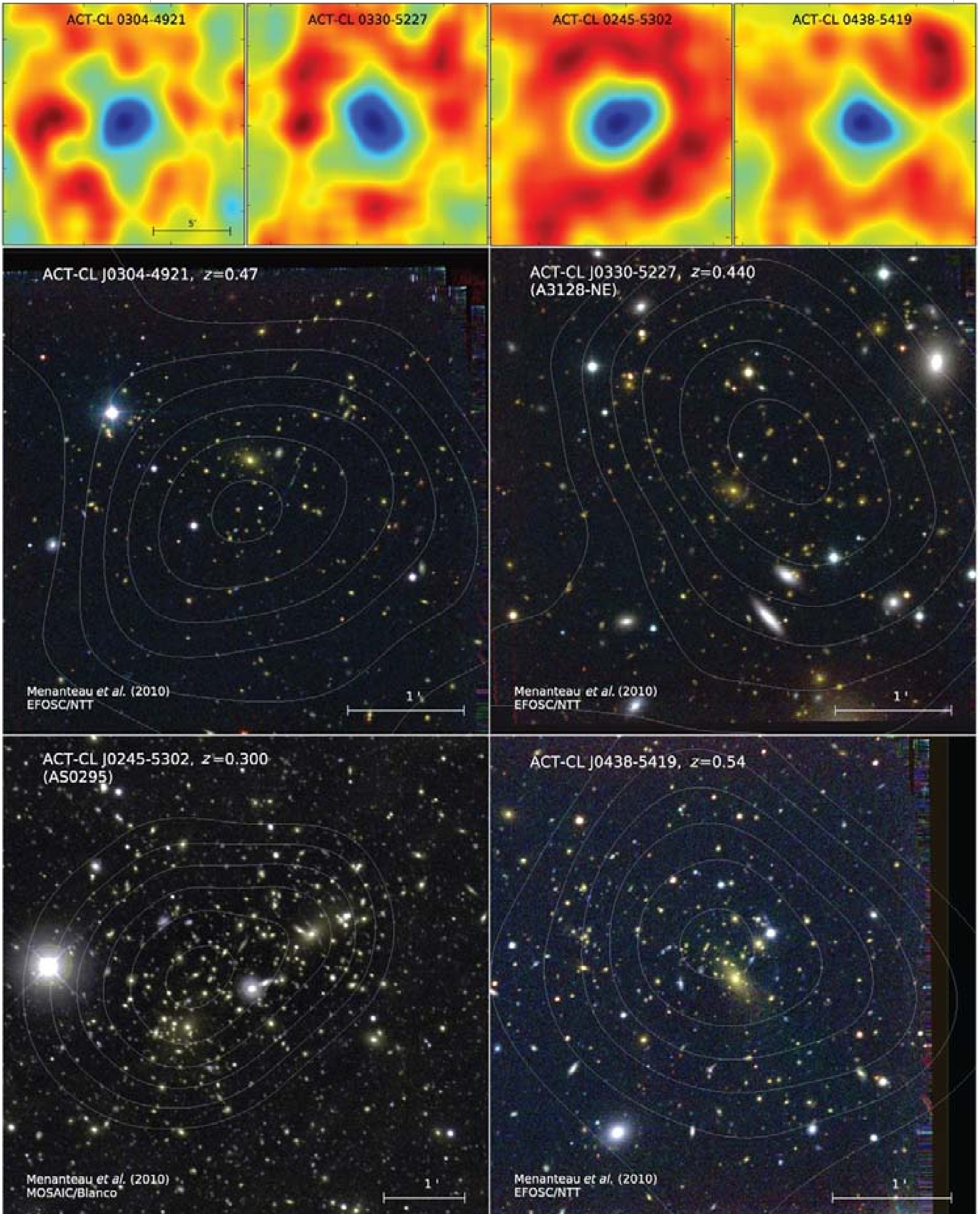


Figure 1. *Example clusters detected by ACT. The top shows the ACT clusters displaying the temperature decrements observed in 148 GHz, with blue the coldest and red the hottest. The middle and bottom panels show the optical images of the same clusters, with the ACT maps surrounding them. Three of these four clusters were followed up with Gemini.*

ized it as a system of two clusters in the process of merging roughly in the plane of the sky. It resembles the well-known Bullet Cluster. El Gordo is the hottest and most massive cluster known at redshifts above 0.6.

The Spectroscopic Follow-up

Given the potential of this cluster sample as a cosmological probe, we started a large spectroscopic follow-up campaign. We aimed to secure the redshifts of the clusters and determine their masses from velocity dispersions of member galaxies. These dynamical masses provide a proxy we can use to calibrate the SZE-mass scaling relation.

Over a total of seven nights at Gemini South in 2009-2010 (programs GS-2009B-Q-2 and GS-2010B-C-2, both joint Chile-U.S. programs), we observed some 1000 galaxies in the direction of 11 clusters in the high-redshift ACT sample. These data, obtained with GMOS in multi-object spectroscopy mode, were augmented with an additional five clusters observed with the Very Large Telescope during the same period (Sifón *et al.*, 2013).

Our selection of target galaxies, based on color cuts and further visual inspection, resulted in a high success rate. The data allowed the robust identification of cluster members. With an average of 60 members per cluster, we could determine precise redshifts for all of the clusters and velocity dispersions with typical uncertainties of ~10 percent. We used a scaling relation calibrated with numerical simulations to infer the total masses of these 16 clusters. Typical uncertainties in the total masses of each cluster are ~30 percent.

We used these dynamical masses to obtain scaling relations between the SZE and total mass. We were able to show that these two quantities can be related with low intrinsic scatter, probably less than 20 percent. Figure 2 shows the best-fit scaling relation between dynamical mass and the total SZE, integrated within a virial radius r_{200} (the radius within which the average density is 200 times the critical density of the universe at the redshift of each cluster). The figure also shows several other determinations of this scaling from different mass proxies. Our results are consistent with results from X-ray observations, weak lensing measurements, and numerical simulations.

A Second Sample: More Gemini Data, Cosmological Constraints, and Prospects

ACT also performed a second survey over the equator, taking advantage of the rich archival dataset available, largely thanks to the deep optical observations of the Sloan Digital Sky Survey Stripe 82. In this second survey we detected 68 galaxy clusters up to $z = \sim 1.4$; of them 19 are new discoveries (Hasselfield *et al.*, 2013). Menanteau *et al.* (2013) have presented cluster properties from optical imaging and X-ray archival data, including spectroscopic redshifts from GMOS for many of them. We are undertaking a large follow-up program ex-

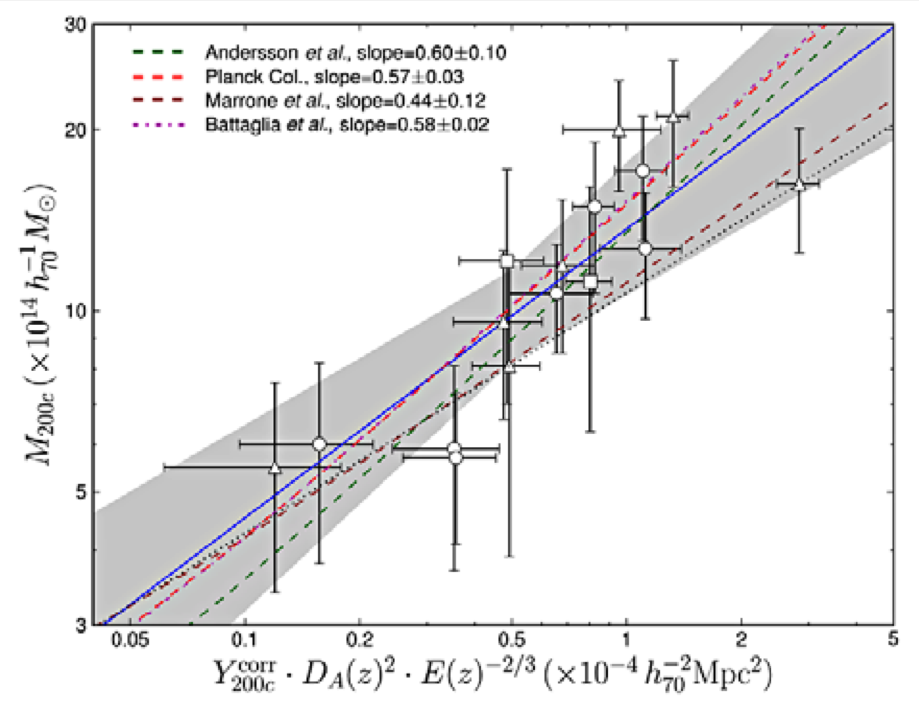


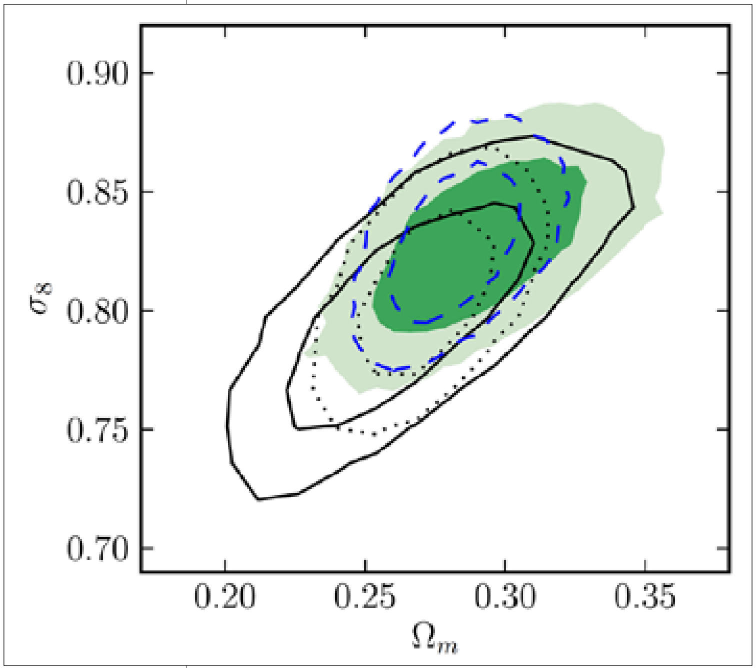
Figure 2.
Best-fit scaling relation between dynamical mass and total SZE, integrated within the virial radius (described in main text). Also shown are previous determinations of this scaling relation from different mass proxies.

clusively with GMOS observations to obtain dynamical masses for a clean sub-sample of clusters (Sifón *et al.,* in preparation).

In Hasselfield *et al.* (2013), we have used this "equatorial sample" to obtain cosmological constraints from cluster number counts. As has been shown before, we find that the calibration of the SZE-mass relation is the critical missing ingredient that will allow us to fully understand the cosmological implications of this sample.

Figure 3 shows the constraining power of the ACT sample when the dynamical masses are included in the fit (Hasselfield *et al.,* 2013), specifically for the characteristic amplitude of matter fluctuations, σ_8, and the density of matter, Ω_m. The black contours show the best-fit parameters obtained from Seven-year Wilkinson Microwave Anisotropy Probe (WMAP-7) observations, and the green contours show the results when combining WMAP-7 with ACT clusters, including the dynamical masses of the southern sample. The blue dashed and black dotted contours show the results when combining information from WMAP, baryon acoustic oscillations and the Hubble constant from measurements of the distance ladder, with and without ACT cluster information, respectively.

Figure 3.
Constraints on cosmological parameters when dynamical masses from ACT are included. The black contours show the best-fit parameters obtained from WMAP-7 observations, and the green contours show the results when combining WMAP-7 with ACT clusters, including the dynamical masses of the southern sample. The blue dashed and black dotted contours show the results when combining information from WMAP, baryon acoustic oscillations and the Hubble constant from measurements of the distance ladder, with and without ACT cluster information, respectively.



The dynamical masses provide improvements on cosmological parameter constraints because they impose strong restrictions on the scaling relations. (In statistical terminology, they are "tight priors.") Our ongoing analysis of recent GMOS observations for the equatorial sample will provide a firmer basis for using galaxy clusters as precision probes of cosmology.

This work constituted the bulk of C. Sifón's MSc thesis at Pontificia Universidad Católica de Chile, which was completed in January 2012.

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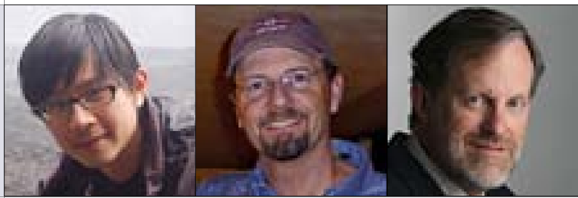


Eric Hsiao, Howie Marion, and Mark Phillips

from the April 2013 issue

The Earliest Near-infrared Spectroscopy of a Type Ia Supernova

Gemini Near-infrared Spectrograph (GNIRS) observations have led to surprising results on the nature of Type Ia supernovae (SNe Ia). Time-series, near-infrared spectra of SN 2011fe in M101 reveal that more SNe Ia harbor unprocessed carbon than previously believed, and what we thought was the main driver of the luminosity-decline rate relation may not be correct.

Figure 1.
Color image of SN 2011fe in M101. (Credit: B. J. Fulton/ LCOGT/PTF)

Type Ia supernovae (SNe Ia) provide the most direct measure of the expansion history of the universe and have led to the discovery of the accelerated expansion, which was awarded the 2011 Nobel Prize in Physics. The unknown cause of the accelerated expansion is commonly referred to as "dark energy."

SNe Ia are not perfectly homogenous, showing significant variation in the shapes and peak brightnesses of their light curves. Rather, their utility as cosmological distance indicators at optical wavelengths rests on the discovery of an empirical correlation between the SNe Ia's peak absolute magnitude and the rate at which the brightness declines (luminosity-decline rate relation; Phillips, 1993). Most astronomers agree that these explosions result from the total thermonuclear disruption of a carbon-oxygen white dwarf in a close binary system; however, the details of the explosion mechanism and the mass-donating companion star are still unclear.

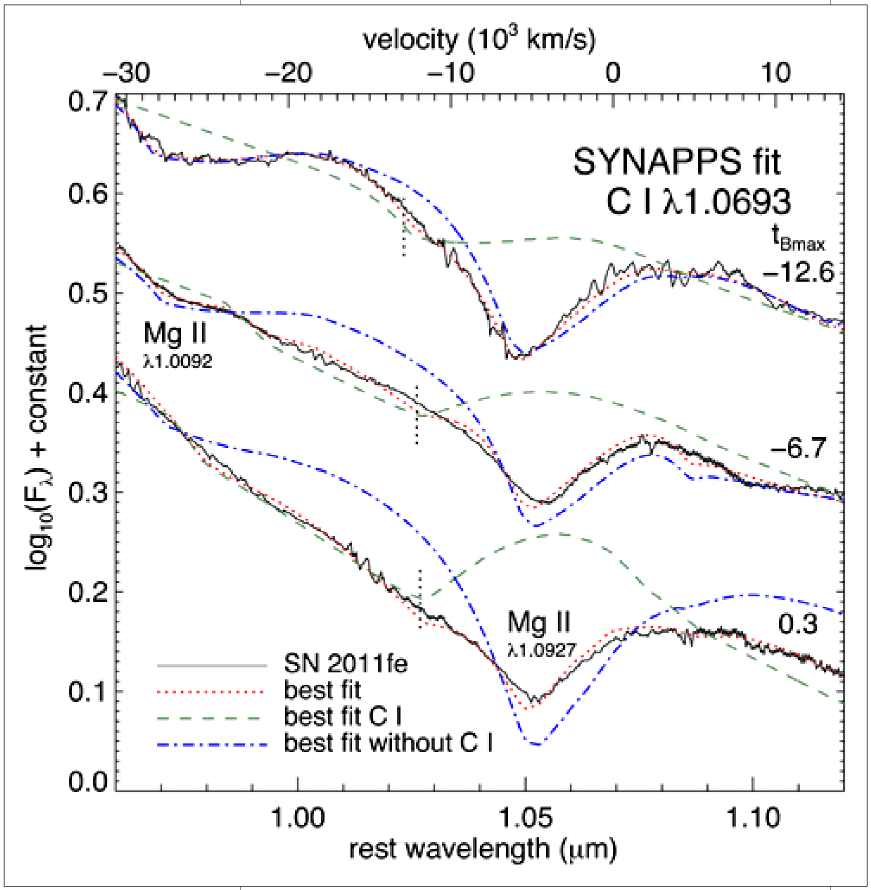


Figure 2.
SYNAPPS (Thomas et al.*, 2011) model spectrum fit to the GNIRS spectra of SN 2011fe around the near-infrared carbon line. The observed spectra are plotted as solid black curves. The best-fit model spectra are plotted as follows: with all ions, with carbon only, and with all ions except carbon. These are plotted as red dotted, green dashed, and blue dash-dotted curves, respectively. The vertical dotted lines mark the locations of the best-fit carbon velocity. The phases relative to maximum light are noted.*

A Near-infrared Shift

Although SNe Ia remain the most proven technique for studying dark energy, we do not understand the nature of these explosions, and that ultimately limits their accuracy. Fortunately, shifting the observations to the near-infrared offers a way forward. In the near-infrared, SNe Ia luminosities are less affected by dust and show much smaller intrinsic scatter than in the optical. A recent study, also using Gemini data, demonstrated an amazing distance accuracy of 6 percent using SN Ia peak luminosity in the near-infrared (Barone-Nugent *et al.,* 2012).

A key ingredient to realizing the full potential of near-infrared SN Ia cosmology is near-infrared spectroscopy, which allows us to convert the peak luminosities to the rest frame. With the limited size of the world's current sample, the time evolution and the diversity of the near-infrared spectral features are poorly understood. These uncertainties directly affect the determination of the peak luminosity.

To improve our knowledge of this relatively unexplored wavelength region, the Carnegie Supernova Project and the CfA Supernova Group have embarked on a joint program to obtain a statistically significant sample of near-infrared spectroscopic observations.

On August 24, 2011, SN 2011fe was detected within hours of its explosion in M101 (Figure 1; Nugent *et al.,* 2011). Its proximity and early detection provided a unique opportunity to make exquisitely detailed observations of a supernova. SN 2011fe appears to have been a typical SN Ia in all respects and serves as an ideal baseline to compare to other objects.

Ten near-infrared spectra of SN 2011fe were obtained in the span of a month, including one SpeX spectrum and nine GNIRS spectra. We present two of the more intriguing findings from our recently published paper on these near-infrared spectra (Hsiao *et al.,* 2013).

Primordial Carbon in Type Ia Supernovae

During a SN Ia explosion, the thermonuclear burning front rips through the carbon-oxygen white dwarf, converting carbon and oxygen into heavier elements. Since oxygen is also converted from carbon in this process, carbon provides the most direct probe of the primordial material from the progenitor carbon-oxygen white dwarf. Because conditions in the explosion models, such as the speed of the burning front, sensitively control the amount of carbon that remains, the detection of carbon in observed spectra serves as one of the most important discriminators between explosion models.

The first convincing detection of carbon in a SN Ia was presented not long ago by Thomas *et al.,* 2007. Since then, several studies using large and independent sets of optical spectra have reached the same conclusion that 20-30 percent of SNe Ia harbor unprocessed carbon. Meanwhile, there had been no detection of carbon in the near-infrared spectra of a normal SN Ia. The issue appeared settled. It was up to the theorists to find the right combination white dwarf binary systems and explosion mechanism to reproduce the observed rate of carbon detection.

The situation changed, however, in 2011. Using the high-quality GNIRS spectra and a more sophisticated spectrum modeling technique, we were able to detect carbon in SN 2011fe, a first in the near-infrared wavelengths for a normal SN Ia. In Figure 2, we show the comparison between observed and model spectra. The near-infrared carbon line we studied is relatively isolated and ideally located between two magnesium lines. Our model spectra show that the presence of carbon is required to produce the observed "flattened" profile near 1.03 microns.

Furthermore, the time-series GNIRS observations indicate that the influence of carbon increases with time (Figure 2). The carbon line in the optical, on the other hand, usually disappears very early, requiring that the supernova be discovered at a very young age. We propose that the delay in the onset of the near-infrared carbon feature can be explained simply by the change in the ionization condition.

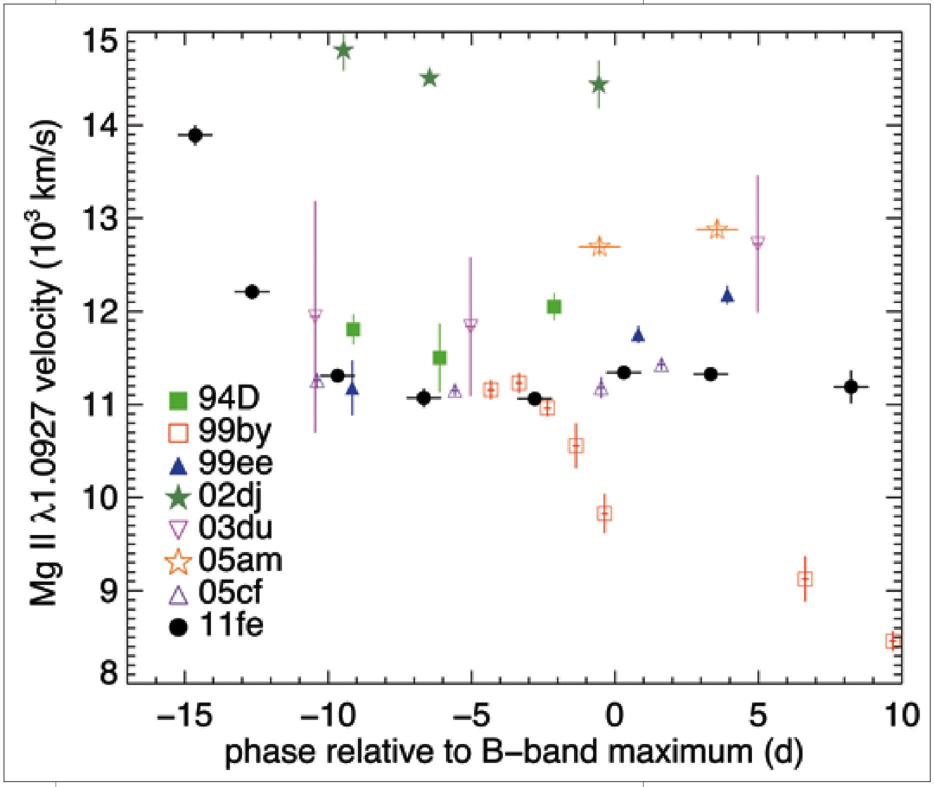
As the supernova ejecta expands, the temperature decreases. The optical carbon line in its first ionized state then gradually recombines into neutral carbon which forms the ever stronger neutral carbon feature in the near-infrared. Due to this fortuitous delay in its appearance, the near-infrared neutral carbon feature is potentially a superior probe of unprocessed material to the more commonly used optical feature.

The "flattened" profile caused by the presence of carbon in SN 2011fe appears to be common in normal SNe Ia. This suggests that many SNe Ia harbor unprocessed carbon. Again, the low rate of detection in the optical may be caused by the difficulty of obtaining spectra within a few days of the explosion. Since the conclusion of ubiquitous unprocessed carbon would have profound implications for our understanding of SNe Ia explosions, we are currently conducting a careful survey of the near-infrared carbon feature in our growing sample of near-infrared spectra.

The Main Driver of the Luminosity-decline Rate Relation

A landmark paper by Wheeler *et al.* (1998) identified the strong and relatively isolated absorption feature near 1.05 microns as magnesium. They predicted that the velocity of this feature would decrease rapidly and then settle to a constant velocity. The prediction is finally confirmed 15 years later, as our SpeX and GNIRS spectra caught the rapid decline

Figure 3.
Time evolution of SN Ia near-infrared magnesium velocity. The magnesium velocity of the GNIRS SN 2011fe spectra underwent a rapid decline and an extended period of constant velocity. Note that SN 1999by is a spectroscopically peculiar SN Ia, much like SN 1991bg. The magnesium velocity of normal SNe Ia all show similar constant behavior as that of SN 2011fe.



for the first time and unambiguously showed the subsequent constant velocity (Figure 3).

Magnesium is a product of thermonuclear carbon burning and not oxygen burning. At the phase of constant velocity, the magnesium line therefore locates the boundary between carbon and oxygen burning. This boundary is thought to be where the transition from a subsonic to a supersonic burning front occurs, and its location is sensitively controlled by the density under which the transition occurs. If the transition density is the origin of the observed spread in the peak luminosities, it might also drive the luminosity-decline rate relation (Hoeflich *et al.* 1995).

The time-series GNIRS spectra of SN 2011fe shows an extended period of constant velocity for the magnesium feature, beginning at 10 days before maximum light and lasting until the feature disappears at 10 days past maximum light. Therefore, a single spectrum obtained at any phase within this range is sufficient to determine the transition density of a SN Ia. Armed with this insight, we surveyed the near-infrared spectra in the literature and measured their near-infrared magnesium velocity in a consistent manner (Figure 3).

Surprisingly, when we plot up the magnesium velocities, as a proxy for the transition densities, against the decline rate of the supernova light curves, there is no correlation. The transition density does not seem to have a strong influence on the peak luminosities. We need to go back to the drawing board and rethink the origin of the observed variation in the peak luminosities. It is likely that the transition density affects the luminosity on a secondary level, which offers the possibility of improving further the standardization of SN Ia luminosities. We are currently investigating the cosmological utility of these velocity measurements.

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Bruce Macintosh and Peter Michaud

World's Most Powerful Planet Finder Turns its Eye to the Sky: First Light with the Gemini Planet Imager

The following article is an adaptation of the news featured in a press conference at the January 2014 meeting of the American Astronomical Society.

After nearly a decade of development, construction, and testing, the world's most advanced instrument for directly imaging and analyzing planets around other stars is pointing skyward and collecting light from distant worlds.

The instrument, called the Gemini Planet Imager (GPI), was designed, built, and optimized for imaging faint planets next to bright stars and probing their atmospheres. It will also be a powerful tool for studying dusty, planet-forming disks around young stars. It is the most advanced such instrument to be deployed on one of the world's biggest telescopes — the 8-meter Gemini South telescope in Chile.

"Even these early first light images are almost a factor of 10 better than the previous generation of instruments. In one minute, we are seeing planets that used to take us an hour to detect," says Bruce Macintosh of the Lawrence Livermore National Laboratory who led the team that built the instrument.

GPI detects infrared (heat) radiation from young Jupiter-like planets in wide orbits around other stars, those equivalent to the giant planets in our own Solar System not long after their formation. Every planet GPI sees can be studied in detail.

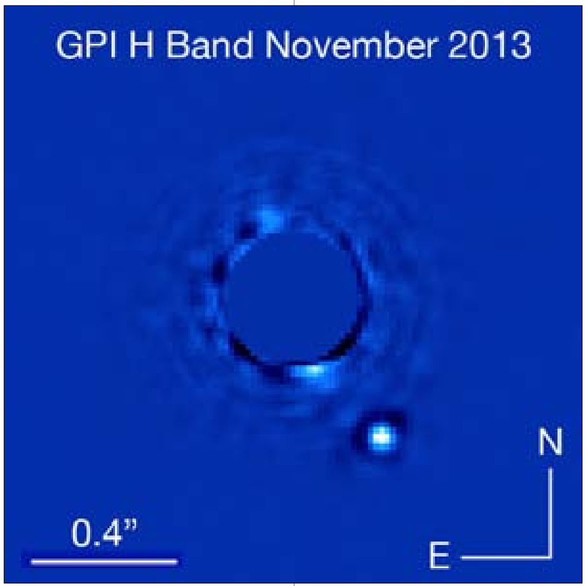


Figure 1.
Gemini Planet Imager's first light image of Beta Pictoris b, a planet orbiting the star Beta Pictoris. The star, Beta Pictoris, is blocked in this image by a mask so its light doesn't interfere with the light of the planet. In addition to the image, GPI obtains a spectrum from every pixel element in the field-of-view to allow scientists to study the planet in great detail.

Beta Pictoris b is a giant planet — several times larger than Jupiter — and is approximately 10 million years old. These near-infrared images (1.5-1.8 microns) show the planet glowing in infrared light from the heat released in its formation.

Processing by Christian Marois, NRC Canada.

"Most planets that we know about to date are only known because of indirect methods that tell us a planet is there, a bit about its orbit and mass, but not much else," says Macintosh. "With GPI we directly image planets around stars — it's a bit like being able to dissect the system and really dive into the planet's atmospheric makeup and characteristics."

GPI carried out its first observations last November — during an extremely trouble-free debut for an extraordinarily complex astronomical instrument the size of a small car. "This was one of the smoothest first light runs Gemini has ever seen," says Stephen Goodsell, who manages the project for the observatory.

For GPI's first observations, the team targeted previously known planetary systems, including the well-known Beta Pictoris system; in it GPI obtained the first-ever spectrum of the very young planet Beta Pictoris b. The first light team also used the instrument's polarization mode — which can detect starlight scattered by tiny particles — to study a faint ring of dust orbiting the very young star HR 4796A. With previous instruments, only sections of this dust ring, (which may be the debris remaining from planet formation), could be seen, but with GPI astronomers can follow the entire circumference of the ring.

Figure 2.
GPI is mounted on the Gemini South telescope prior to first light observations in late 2013.

Although GPI was designed to look at distant planets, it can also observe objects in our Solar System. The accompanying test images of Jupiter's moon Europa, for example, can allow scientists to map changes in the satellite's surface composition. The images were released at the 223rd meeting of the American Astronomical Society.

"Seeing a planet close to a star after just one minute was a thrill, and we saw this on only the first week after the instrument was put on the telescope!" says Fredrik Rantakyro, a Gemini staff scientist working on the instrument. "Imagine what it will be able to do once we tweak and completely tune its performance."

"Exoplanets are extraordinarily faint and difficult to see next to a bright star," notes GPI chief scientist Professor James R. Graham of the University of California who has worked with Macintosh on the project since its inception. GPI can see planets a million times fainter than their parent stars. Often described, 'like trying to see a firefly circling a streetlight thousands of kilometers away,' instruments used to image exoplanets must be designed and built to "excruciating tolerances," points out Leslie Saddlemyer of NRC Herzberg (part of the National Research Council of Canada), who served as GPI's systems engineer. "Each individual mirror inside GPI has to be smooth to within a few times the size of an atom," Saddlemyer adds.

"GPI represents an amazing technical achievement for the international team of scientists who conceived, designed, and constructed the instrument, as well as a hallmark of the capabilities of the Gemini telescopes. It is a highly-anticipated and well-deserved step into the limelight for the Observatory", says Gary Schmidt, program officer at the National Science Foundation (NSF), which funded the

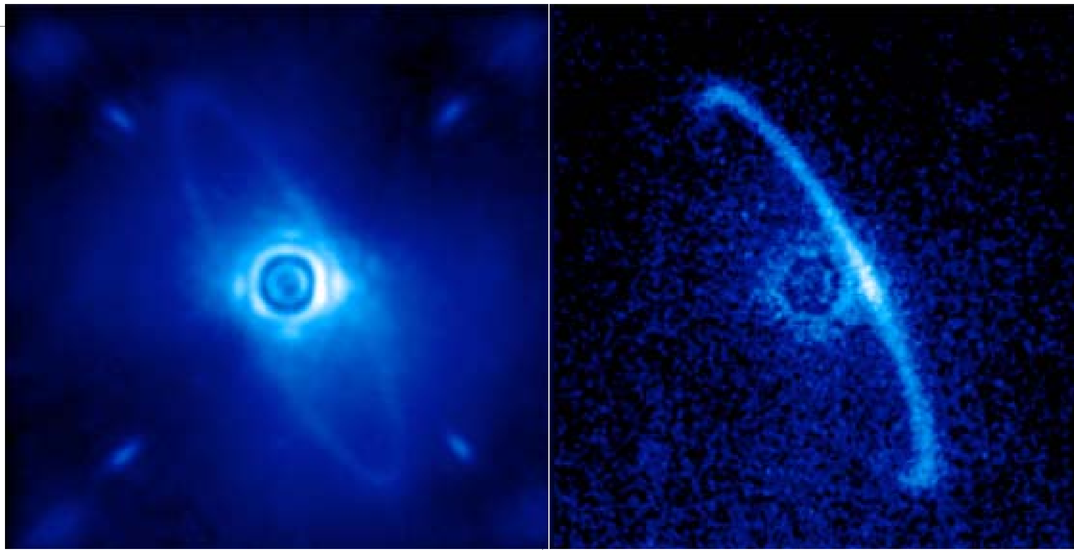


Figure 3.
Gemini Planet Imager's first light image of the light scattered by a disk of dust orbiting the young star HR 4796A. This narrow ring is thought to be dust from asteroids or comets left behind by planet formation; some scientists have theorized that the sharp edge of the ring is defined by an unseen planet. The left image (1.9-2.1 microns) shows normal light, including both the dust ring and the residual light from the central star scattered by turbulence in the Earth's atmosphere. The right image shows only polarized light. Leftover starlight is unpolarized and hence removed from this image. The light from the back edge of the disk is strongly polarized as it scatters towards us.

project along with the other countries of the Gemini Observatory partnership.

"After years of development and simulations and testing, it's incredibly exciting now to be seeing real images and spectra of exoplanets observed with GPI. It's just gorgeous data," says Marshall Perrin of the Space Telescope Science Institute.

"The entire exoplanet community is excited for GPI to usher in a whole new era of planet finding," says physicist and exoplanet expert Sara Seager of the Massachusetts Institute of Technology. Seager, who is not affiliated with the project adds, "Each exoplanet detection technique has its heyday. First it was the radial velocity technique (ground-based planet searches that started the whole field). Second it was the transit technique (namely Kepler). Now, she says, "it is the 'direct imaging' planet-finding technique's turn to make waves."

In 2014, the GPI team will begin a large-scale survey, looking at 600 young stars to see what giant planets orbit them. GPI will also be available to the whole Gemini community for other projects, ranging from studies of planet-forming disks to outflows of dust from massive, dying stars.

Looking through Earth's turbulent atmosphere, even with advanced adaptive optics, GPI will only be able to see Jupiter-sized planets. But similar technology is being proposed for future space telescopes.

"Some day, there will be an instrument that will look a lot like GPI, on a telescope in space," Macintosh projects. "And the images and spectra that will come out of that instrument will show a little blue dot that is another Earth."

GPI is an international project led by the Lawrence Livermore National Laboratory (LLNL) under Gemini's supervision, with Macintosh as Principal Investigator and LLNL engineer David Palmer as project manager. LLNL also produced the advanced adaptive optics system that measures and corrects for atmospheric turbulence a thousand times

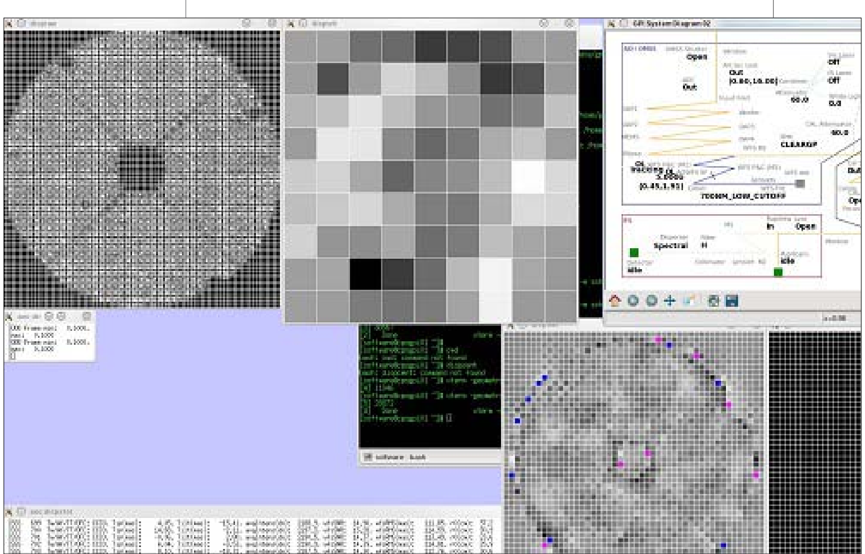


Figure 4.
Status display showing wavefront sensor (upper-left), upper-middle grid represents values being sent to lower order deformable mirror (woofer), upper-right is the GPI light-path, lower-right grid represents values sent to the higher order deformable mirror (tweeter).

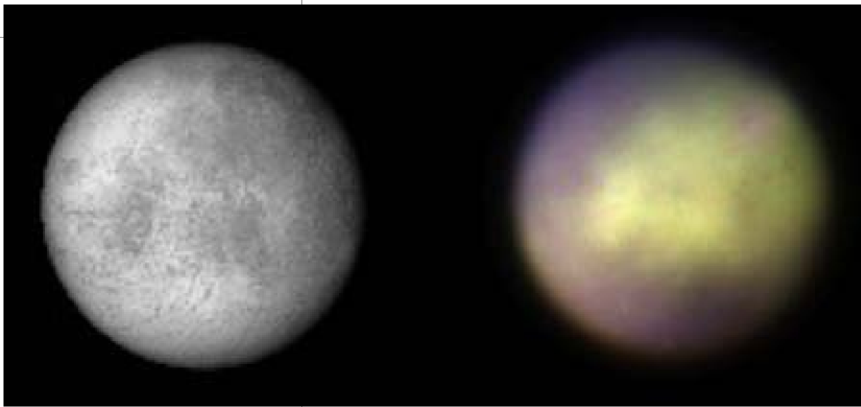


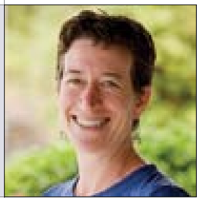
Figure 5.
Comparison of Europa observed with Gemini Planet Imager in K1 band on the right and visible albedo visualization based on a composite map made from Galileo SSI and Voyager 1 and 2 data (from USGS) on the left. While GPI is not designed for "extended" objects like this, its observations could help in following surface alterations on icy satellites of Jupiter or atmospheric phenomena (e.g., clouds, haze) on Saturn's moon Titan. The GPI near-infrared color image is a combination of three wavelength channels.
Image credit: Processing by Marshall Perrin, Space Telescope Science Institute and Franck Marchis SETI Institute

per second. Early studies for the GPI project were spearheaded by the University of California's Center for Adaptive Optics, with funding from the National Science Foundation. Donald Gavel, at Lick Observatory UC Santa Cruz, led laboratory research efforts that proved the micromirror and coronagraph technologies. Scientists at the American Museum of Natural History, led by Ben Oppenheimer (who also led a project demonstrating some of the same technologies used in GPI on the 5-meter Palomar project) designed special masks that are part of the instrument's coronagraph which blocks the bright starlight that can obscure faint planets. Engineer Kent Wallace and a team from NASA's Jet Propulsion Laboratory constructed an ultra-precise infrared wavefront sensor to measure small distortions in starlight that might mask a planet. A team at the University of California Los Angeles' Infrared Laboratory, under the supervision of Professor James Larkin, together with Rene Doyon at the University of Montreal, assembled the infrared spectrograph that dissects the light from planets. Data analysis software written at University of Montreal and the Space Telescope Science Institute assembles the raw spectrograph data into three-dimensional cubes. NRC Herzberg in British Columbia Canada, built the mechanical structure and software that knits all the pieces together. James R. Graham, as project scientist, led the definition of the instrument's capabilities. The instrument underwent extensive testing in a laboratory at the University of California Santa Cruz before shipping to Chile in August. Franck Marchis at the SETI institute in California manages GPI's data and communications.

Bruce Macintosh an astrophysicist at the Lawrence Livermore National Laboratory. He can be reached at: macintosh1@llnl.gov

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

Figure 6.
The GPI first light imaging team celebrates the success of the instrument on the sky at Gemini South.



Nancy A. Levenson

Science Highlights

A diverse collection of scientific results were published with Gemini data in 2013. These highlights provide a sample of the types of cutting-edge science our users are doing.

In this current issue, Science Highlights reports on the most powerful flare ever observed on an L dwarf, spiral patterns in a protoplanetary disk, and the properties of galaxies in intermediate-mass clusters.

January 2014

The Most Powerful Flare ever Observed on an L Dwarf

Astronomers used the Gemini Multi-Object Spectrograph on Gemini North to capture the most powerful flare ever observed on an L dwarf. At its peak, the brightness of the Jupiter-sized source increases by a factor of three, with a total flare energy output of 1.6 x 1032 ergs. The team suggests that similar flares may be common in this class of substellar objects, occurring once or twice per month. The Gemini data also provided the L1 spectral type of the brown dwarf, named WISE J190648.47+401106.8 for its discovery using NASA's WISE satellite, or W1906+40 for short.

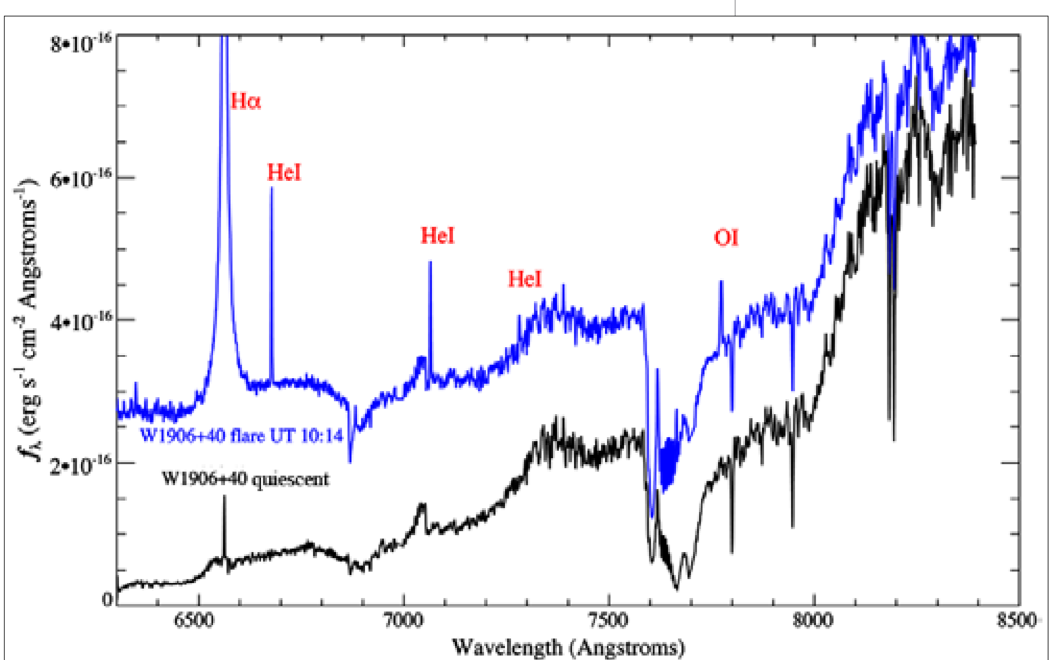


Figure 1.
Gemini spectrum of W1906+40, in its quiescent state (black) and during a strong flare (blue). In addition to the overall increase in luminosity, the Ha emission appears broad and the overall spectral shape corresponds to higher temperatures during the flare. (The spectra are not corrected for the effects of Earth's atmosphere.)

John Gizis (University of Delaware) and collaborators have been observing W1906+40 using the Kepler satellite and a variety of ground-based facilities. The long-term (15-month)

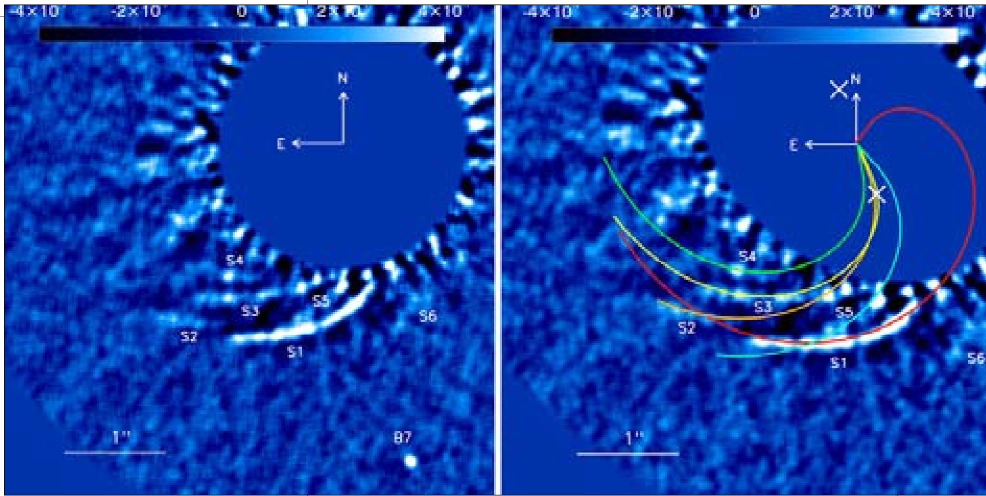


Figure 2.
NICI observation of HD 100546 in the K_s band, processed to reveal multiple southern spiral arms (left), which are modeled (colored lines overlaid, right).

monitoring with Kepler shows a regular brightness variation at the 1 percent level with a period of 8.9 hours. The team models this variability as the presence of a single "spot" of lower-than-average luminosity that moves in and out of view as the dwarf rotates. They suggest that a magnetic starspot could provide such cooler material, although they also consider the possibility of clouds in the atmosphere (similar to Jupiter's Great Red Spot), which could also produce the same effect.

Given their spectral characteristics, which include broadening of emission lines and a bluer or hotter continuum, the strong flares observed with Gemini (Figure 1) also have a magnetic origin. In contrast to the quiescent characteristic temperature of 2300 K, the flare corresponds to a temperature of 8000 K. These results show a continuity of flare properties from the higher-mass M dwarfs to the L class. They also confirm W1906+40 as a magnetically active brown dwarf, despite the attribution of variability observed in some L dwarfs due to atmospheric variations, such as changing cloud distributions.

Complete results are in press in *The Astrophysical Journal*; a preprint is available at arXiv 1310.5940.

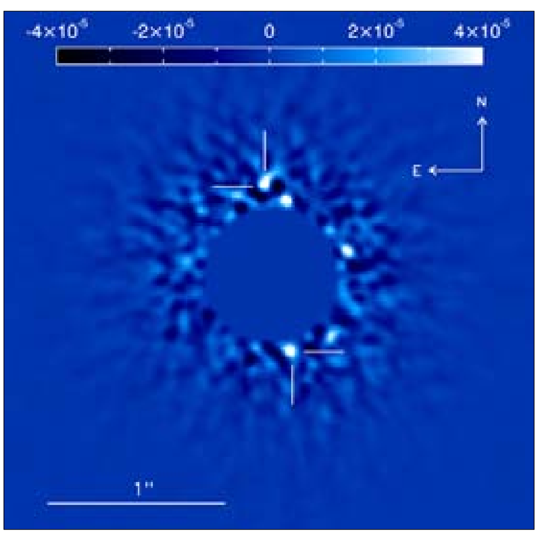


Figure 3.
Zooming in to the star's central 3 arcseconds shows a candidate planet to the south, which may be responsible for producing the spiral arms. (The spot marked to the north of the star is an artifact of processing).

Spiral Patterns in a Protoplanetary Disk

Spiral patterns measured in a protoplanetary disk offer an exemplary study aimed at accounting for the full process of planet formation. Planets are expected to form in the remains surrounding the formation of a star, called a protoplanetary disk. The star HD 100546 is an excellent candidate for such a detailed investigation, being young (age 5–10 million years), and showing excess infrared emission, which is characteristic of a dusty—potentially planet-forming—disk.

The disk, which extends from the central star to distances of 80 times that between the Earth and Sun, has previously been resolved and some of its spiral patterns identified. In new work using archival observations obtained with the Near-Infrared Coronographic Imager on the Gemini South telescope, Anthony Boccaletti (Observatoire de Paris, France) and collaborators show additional detail of the spiral patterns in HD 100546 and uncover hints of a planet that may be responsible for producing them.

Special data processing techniques of angular differential imaging reveal the subtle details of the spirals in the near-infrared, resolving the southern feature into multiple arms, and provide contrast at the level of 10-5 to 10-6 at distances of 1 and 2 arcseconds from the star, respectively (Figure 2). The team models these arms and concludes that gravitational perturbations by inner bodies most likely cause the spirals. Concentrating on the star's immediate vicinity shows a candidate source responsible (Figure 3). The source emerges just at the detection limit, so confirmation requires more contrast at closer separations from the bright star — capabilities that the Gemini Planet Imager can provide.

Full results will appear in *Astronomy and Astrophysics*; a preprint is available now (**arXiv:** 1310:7092).

Observations of Galaxies in Intermediate-mass Clusters

Do galaxies evolve in intermediate-mass clusters the same way they do in high-mass clusters? The environment is a function of cluster mass, and therefore influences evolutionary processes that reflect "nurture" as opposed to intrinsic "nature" of galaxies. José Luis Nilo Castellón (IATE-CONICET, Argentina and Universidad de La Serena, Chile) and colleagues present first results from a sample of seven galaxy clusters and find that the general trends of these intermediate-mass clusters match those observed in high-mass clusters, in agreement with previous related work.

The sample was selected based on low X-ray luminosity, and multi-band imaging observations using both Gemini Multi-Object Spectrograph instruments, allow classification of the galaxies. In color-magnitude plots, the low-redshift examples tend to show a red cluster sequence of early-type galaxies that is well-defined over several orders of magnitude with little scatter and which contains most of the cluster members. These clusters tend to be centrally concentrated, and nearly 70 percent of the red galaxies are located in the cluster cores. Similar to the case for richer clusters, the fraction of blue galaxies increases with redshift. In the higher-redshift group here, red and blue peaks are evident in the overall distribution of galaxy colors. In addition, the higher-redshift examples of the cluster density maps show multiple concentrations and a mix of red and blue galaxies in the cores (Figure 4).

This work is in press in *Monthly Notices of the Royal Astronomical Society*; a preprint is available at **arXiv:** 1311.0788.

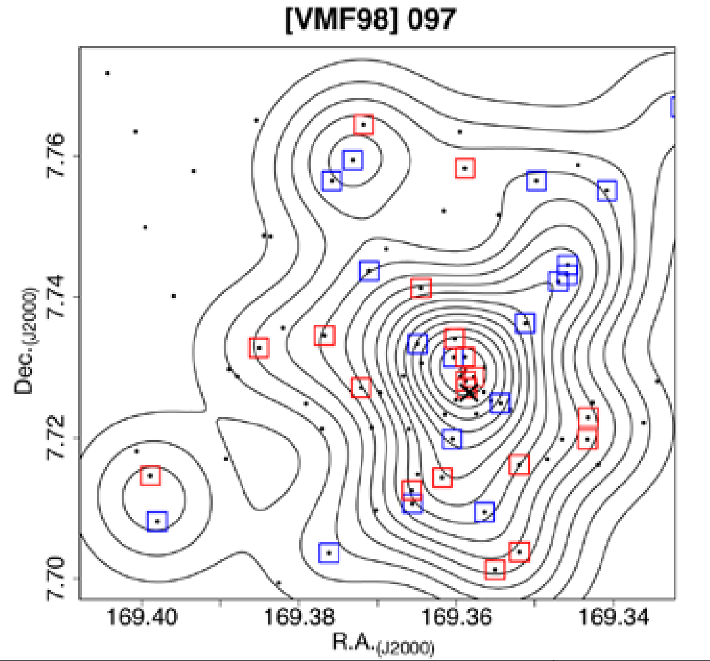


Figure 4.
Contours show the galaxy density distribution in the redshift 0.48 cluster [VMF98] 097, with red and blue galaxy cluster members plotted in color. A cross marks the location of the X-ray emission peak. This cluster is not relaxed, and shows several significant concentrations as well as a mix of red and blue galaxies in the central region.

October 2013

Intergalactic and Interstellar Medium Studies with Gamma-ray Bursts

The high-redshift gamma-ray burst denoted GRB 130606A rapidly demonstrated its utility as a probe of the intergalactic medium — both along the line-of-sight to Earth and through the interstellar medium of its host galaxy. On June 6, 2013, Ryan Chornock (Harvard University) and colleagues used the Gemini Multi-Object Spectrograph at Gemini North to obtain sensitive observations of the GRB's afterglow within 13 hours of when NASA's Swift satellite first detected the burst. They used the data to measure-

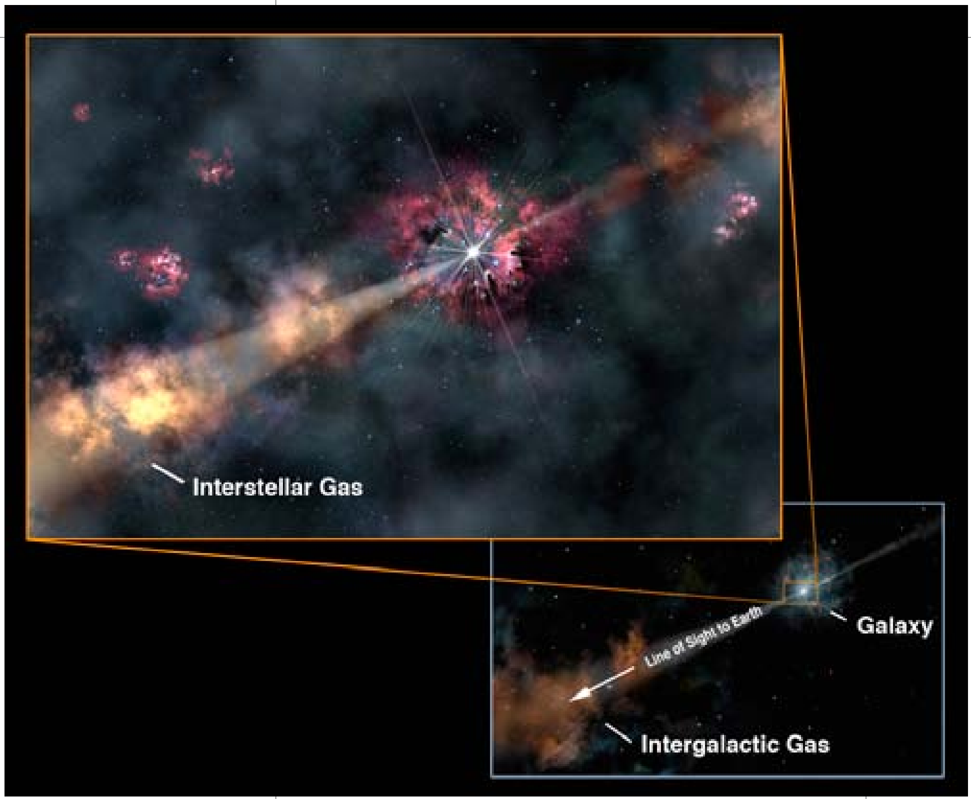


Figure 5.
This artistic rendering illustrates how the light from GRB 130606A serves as a beacon through the interstellar gas of the host galaxy of the burst source. It also reveals the ionization state of the medium between galaxies along the line-of-sight.

reionization in the early universe and properties of the host galaxy (Figure 5).

At redshift $z = 5.91$, GRB 130606A remains one of just a handful of spectroscopically confirmed GRBs at $z \gtrsim 6$. Quasars have been used to probe the intergalactic medium (IGM) at this epoch, when the universe was only one billion years old. This work is the first to provide a similarly high-quality GRB spectrum for analysis.

An advantage of pursuing this work with GRBs is that there is no expected bias toward highly ionized areas, as may be the case with quasars. The net results along this single sightline are similar to those obtained based on quasar observations, showing an increase in the Lyman-α optical depth from $z = 4.9$ toward larger redshifts.

A particular feature is that the IGM appears nearly opaque in a region around $z = 5.77$, although measurable Lyman-β and Lyman-γ flux show that the IGM is still significantly ionized over this high-redshift interval. In addition, at the redshift of the host galaxy, Chornock *et al.* establish an upper limit on the neutral fraction of the IGM of 0.11.

A number of absorption lines were used to determine the host galaxy's redshift. Some of these lines are useful tracers of the galaxy's metallicity, with the expected result of low metallicity — about one-tenth of solar values. Assuming these lines are optically thin, it sets a lower limit; *e.g.*, [Si/H] $\gtrsim$ -1.7. The non-detection of some ionized sulfur lines sets an upper limit of [S/H] $\gtrsim$ - 0.5.

The complete results are published in *The Astrophysical Journal*, **774:** 26, 2013.

First Refereed GeMS Results: Young Stars Leave the Nest

The first refereed astronomy paper based on data using the Gemini Multi-conjugate adaptive optics System (GeMS) demonstrates the effective use of young, lower-mass stars to determine the age of a star cluster. In this case, the infrared sensitivity and resolution of GeMS, together with the Gemini South Adapative Optics Imager (GSAOI), enabled measurements of stars in the low-mass cluster Haffner 16 in the Milky Way.

In particular, photometry of faint, pre-main-sequence stars is now possible. These become essential for determining the cluster's age accurately because the higher-mass stars usually used are often absent in low-mass clusters. The GeMs/GSAOI data yield an age $\gtrsim$ 10 million years (Myr). In contrast, optical measurements result in an age about 2 Myr greater for this cluster.

One of the broader interests of lead author Tim Davidge (Dominion Astrophysical Observatory, Canada) is the origin of the field-star population — stars that have "left the nest" of the clusters where they likely formed. Haffner 16 is an example of a cluster in the processes of dissolving, providing evidence of the transition of stars from a cluster to the field. In particular, the authors found that the sub-solar mass population is deficient in Haffner 16, which they suggest results from the cluster's dynamic evolution, during which it lost protostars of sub-solar masses.

Haffner 16 contains a large population of pre-main-sequence stars that are still accreting material, demonstrated by their line emission. This is unexpected given Haffner 16's age — usually the accretion phase ends after only a few Myr. This extended period of mass buildup may eventually result in somewhat overly massive stars for their position on the main sequence. To explain the observations, the authors suggest that the supernovae and strong stellar winds of massive stars that normally disrupt accretion are absent, allowing the process to continue unabated.

For astronomers interested in all subjects, these observations most importantly demonstrate the utility of the GeMS AO system even in the relatively poor seeing conditions under which these data were obtained. The delivered image quality here (Figure 6) provides full-width at half-maximum in the K_s band of < 0.16 arcsecond. This represents a significant improvement over the natural seeing, which, on the night these data were obtained, was roughly 0.8 arcsecond — a value worse than average at Gemini South on Cerro Pachón.

The paper appears in *The Publications of the Astronomical Society of the Pacific*. Davidge, T. J., *et al.*, "Haffner 16: A Young Moving Group in the Making." eprint **arXiv:**1308.5432.

Limits on Quaoar's Atmosphere

The Kuiper Belt Object Quaoar (pronounced Kwa-whar), located well beyond the orbit of Pluto, can be studied through occultations as it passes along the line of sight through the crowed plane of the Milky Way. Occultations are an effective probe because astronomers know the speeds of Solar System bodies very precisely from their orbits, so the duration when starlight is blocked provides a direct measurement of the size of the occulting object. In addition, an occultation can uncover information about the nearby body's atmosphere, if it exists. A rocky body without an atmosphere will immediately extinguish the starlight, while one with an atmosphere will create a "fuzzy" event with a slow dimming and eventual blocking of the starlight.

Recent "near-misses" of Quaoar occultations provide some constraints on a possible atmosphere, as Wesley Fraser (National Research Council Herzberg, Canada) and collaborators rule out some pure N_2 and CO models. They find that a methane atmosphere is possible, with temperature and pressure values that prevented detectability in the latest observations.

The background stars are relatively faint, and rapid photometry is required, so the acquisition camera on Gemini, normally used to adjust the telescope pointing, became

Figure 6.
This image of Haffner 16 illustrates that the GeMS AO system can successfully sharpen data even under relatively poor imaging conditions. With the correction, the point sources appeared spread by less than 0.16 arcsecond (full-width at half-maximum, in the K_s band). This represents a significant improvement over the natural quality of the sky, which, on the night these data were obtained, was roughly 0.8 arcsecond — a value worse than average at Gemini South on Cerro Pachón.

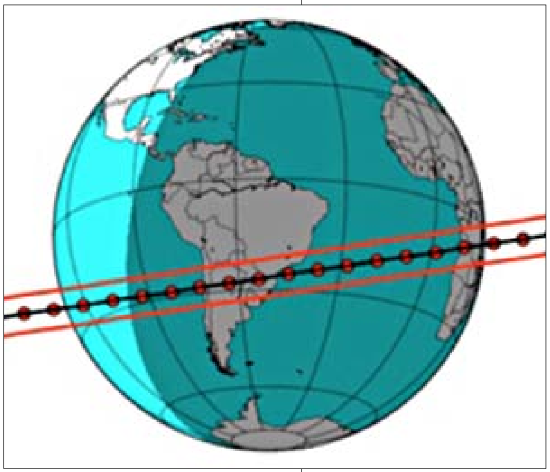


Figure 7.
Predicted track of Quaoar during an occultation attempt on August 5, 2013. This event was another "near-miss" at Gemini South.

(unusually) the science instrument. Photometric measurements were recorded several times per second.

One of the challenges of these observations is that the catalogued positions of many of the stars are not sufficiently precise to predict an occultation with certainty. The team uses observations from the Canada-France-Hawaii Telescope (CFHT) Legacy Survey to make the predictions of upcoming occultations, and then they only observe events that have the highest probability of being successful. Despite these efforts, to date no occultation event of the large (1000-kilometer-diameter) Quaoar has been observed. Nonetheless, as previously mentioned, full analysis of the observations obtained on July 13, 2013, at Gemini South set useful limits on the atmosphere.

References:

Fraser, W., *et al.*, *The Astrophysical Journal Letters*, **774:** L18, 2013

Fraser, W., *et al.*, *The Publication of the Astronomical Society of the Pacific*, **125:** 1000, 2013

July 2013

Mass, Metallicity, and History of Supernova Progenitors

What are the progenitors of various types of supernovae? Spectral signatures and light-curve shapes characterize supernovae, and their range reveals the variety of progenitor stars that may produce these events. Differences in progenitor mass, metal abundance, or multiplicity are all possible origins of supernova diversity. In recent work, Hanindyo Kuncarayakti (University of Tokyo) and collaborators determine the properties of supernova progenitors through observations of the stellar population at the host sites.

This study concentrates on the local environments of Type Ib and Ic supernovae — those that do not show hydrogen in their spectra and likely result from the core collapse of massive stars, specifically, Wolf-Rayet stars. Strong stellar winds or mass loss to a companion could strip the outer hydrogen layers of a progenitor. Indeed, the team generally found the Type Ic supernovae in more metal-rich environments than the Type Ibs. Furthermore, both types have higher metallicity than Type II supernovae, which are also due to core collapse of massive stars but have retained their hydrogen shells. The higher metallicity would promote mass loss through stellar winds.

Another difference between the Types Ib and Ic is that the latter are generally younger, implying more massive stellar progenitors. Some of the progenitors of both types are less massive than about 25 times the Sun's mass and thus not massive enough to be stripped Wolf-Rayet stars. These authors instead suggest a history of mass loss through evolution in a binary system. Thus, binary environments appear to be important for some core-collapse supernovae.

For the study, the team used the integral field unit of the Gemini Multi-Object Spectrograph (GMOS) on Gemini North as part of

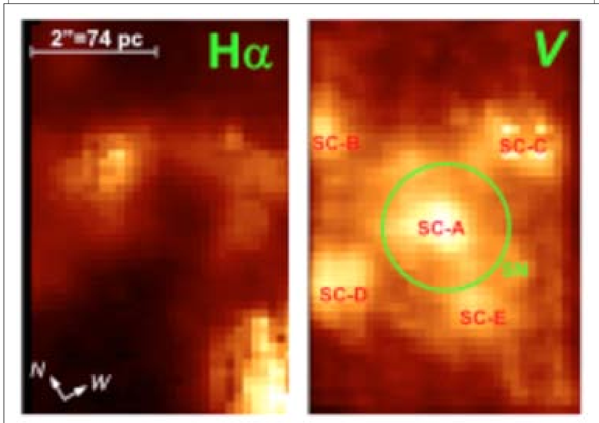


Figure 8.
Images of the SN 2007gr environment extracted from the integral field unit observations corresponding to Hα and V band. A green circle marks the supernova host star cluster, and other nearby star clusters (SC-B, etc.) are noted.

Subaru exchange time, along with the SuperNova Integral Field Spectrograph at the University of Hawai'i 88-inch telescope, also on Mauna Kea. They targeted nearby galaxies, where 1 arcsecond typically corresponds to 230 light-years (70 parsecs), to distinguish the progenitor star clusters. The data show that other nearby clusters display a somewhat different history and metallicity from the supernova site (Figure 8). These results are published in *The Astronomical Journal*, and in a separate paper. The team applies identical techniques to the host environments of Type II supernovae.

Resolving a Stellar Disk at Earth-Sun Distance Scales

Planets in the disks around young stars may carve gaps or dynamically affect their environment. These so-called transitional and pre-transitional disks are therefore interesting as important stages in the development of planets. An international team led by Stefan Kraus (Harvard-Smithsonian Center for Astrophysics) used multiple telescopes, including Gemini South, to resolve the disk around V1247 Orionis on physical scales of astronomical units (AU; the average Earth-Sun distance), finding asymmetries and unambiguous evidence for a gap in the disk.

The observations included an uncommon use of Gemini's Thermal Region Camera Spectrograph (T-ReCS) for mid-infrared (MIR) imaging, using short exposures and interferometric analysis techniques to determine the disk orientation and geometry. Considering longer-baseline MIR interferometry in addition, a compact disk is evident, extending over 0.2 AU. The inferred structure (Figure 9), based on the full set of observations, shows a hot inner disk, a cool outer disk, and optically thin carbon-rich dust in the gap between them. The emission in the gap region appears to be asymmetric, and the dependence on observed wavelength implies that this is due to density inhomogeneities, rather than the presence of a single body like a planet.

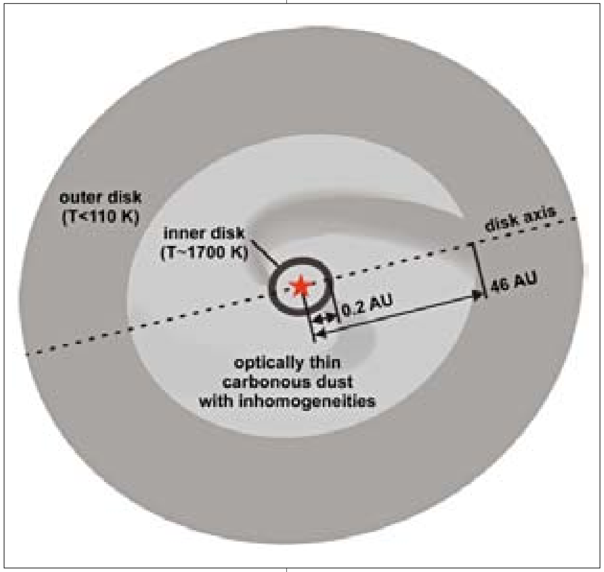


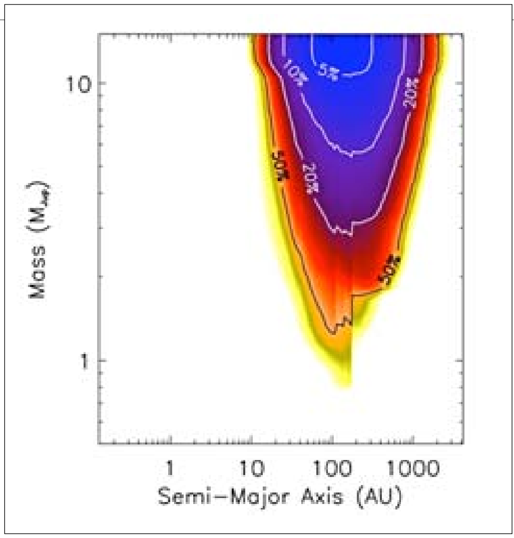
Figure 9.
Model of the environment of V1247 Orionis includes a hot optically thick inner disk, a cool optically thick outer disk, and optically thin dust in the gap between them.

The persistence of the hot inner disk, with material located at the dust sublimation radius (corresponding to the hottest temperature where it can survive), rules out some proposed methods of clearing gaps in similar planetary disks, including photoevaporation, instabilities, and grain growth. Instead, the authors conclude that dynamical clearing of the gap, due to developing planetary or other companions, is the most likely origin. Other well-studied transitional and pre-transitional disks do not show evidence for such optically thin material close to the star, which suggests that V1247 Orionis may show us an earlier stage of development. The complete results are published in *The Astrophysical Journal*.

Gemini NICI Planet-finding Campaign

Astronomers have evidence for hundreds of planets around stars beyond the Sun, but only a handful are observed in direct imaging. The planets are intrinsically faint, and detecting them near their bright host stars adds to the challenges. The Near-Infrared Coronagraphic Imager (NICI) at Gemini South is capable of imaging faint extrasolar planets, reaching greater sensitivity than previous ground- or space-based instruments. (NICI can detect an object one million times fainter than its bright host at a projected separation of 1 arcsecond; about one two thousandth of the Moon's apparent diameter.)

Figure 10.
Contours show the probability that a star of given mass has a giant planet at the given semi-major axis location.



Michael Liu (University of Hawai'i) and a large international team from across the Gemini partnership and beyond used NICI for the Gemini NICI Planet-Finding Campaign, the largest, deepest systematic search for planets through direct imaging. The result is that fewer stars than previously expected show evidence for planets, which will require some updates to theories of planet formation and survival. While some low-mass (substellar) companion objects have been detected, the Campaign did not image any unknown planets.

The first comprehensive result from the Campaign considers young B and A stars, of about twice the mass of the Sun. Based on observations of 70 of them, Eric Nielsen, who led this effort, concluded that fewer than 10 percent of these stars have giant planets (with masses greater than 10 times that of Jupiter) at distances of about 40–650 astronomical units (AU; the average Earth-Sun distance) from their hosts, and fewer than 20 percent have planets with masses less than four times that of Jupiter. While the Campaign did image known extrasolar planets, the systematic analysis of the total program reveals that these systems are uncommon.

The search for planets is painstaking work. One source of confusion is the chance superposition of a distant star, which can mimic the appearance of a faint companion to the nearby host star of interest. Multiple observations of the candidate objects can distinguish these scenarios, and unfortunately, most of the time the less-interesting chance alignment is the conclusion. Another important detail of the work is to determine the ages of the stars. Because age has a strong effect on the appearance of planets and other low-mass companions — they are brighter and hotter when recently formed, and fade and cool over time — the inferred planet properties are sensitive to stellar age.

This is the first of three papers presenting the systematic results from the NICI Campaign. Separate papers, led by Beth Biller (Max Planck Institute for Astronomy) and Zahed Wahhaj (University of Hawai'i at Manoa), will analyze planet frequency around stars in young moving groups and systems with debris disks. Even more sensitive observations will come with the Gemini Planet Imager (see page 23).

April 2013

Closest Solar Neighbor Discovered in Past Century

Large proper motion suggested that an object recently detected with NASA's Wide-field Infrared Survey Explorer satellite (WISE), WISE J104915.57-531906, is nearby, with parallax measurements confirming a distance of only 6.5 light-years (2 parsecs). This makes the new object the closest found in a century, and the third closest overall.

The combination of WISE and other near-infrared surveys has provided multi-epoch data for such proper-motion searches, enabling detection of nearby cool (and optically faint) objects. WISE alone, having exceeded its original planned lifetime, provides the multiple observations required.

Kevin Luhman (Penn State University) discovered the large proper motion of WISE

J104915.57 - 531906 in the WISE data. He then recovered the object in other earlier surveys to obtain a more accurate distance measurement.

The outstanding question remained: "What is this object?" Director's Discretionary Time enabled spectroscopy with the Gemini Multi-Object Spectrograph (GMOS) on Gemini South to provide an answer, and more. Luhman classified the object as an L8 dwarf, showing good agreement with a template spectrum. For ages less than 10 billion years, the temperature is well below that of the hydrogen burning limit. Also, considering the strong lithium absorption, Luhman concludes that the object is a brown dwarf.

As an unexpected bonus, the acquisition image resolved the source into two components (Figure 11). The pair, separated by 1.5 arcseconds, corresponds to 3 astronomical units at the object's determined distance. Examination of earlier, archival images does not show either source at their present location, arguing that they form a common binary system.

The secondary is only about half a magnitude fainter than the primary, which suggests that it is also a brown dwarf and near the L/T spectral class transition. Brown dwarf models are sensitive to age, so a binary system offers robust tests of models and potentially strong constraints on mass, assuming the objects formed at the same time.

The GMOS observations were obtained on February 23, 2013, and the full paper is published in *The Astrophysical Journal*, available at: http://arxiv.org/abs/1303.2401, as is more information from http://www.gemini.edu/node/11966.

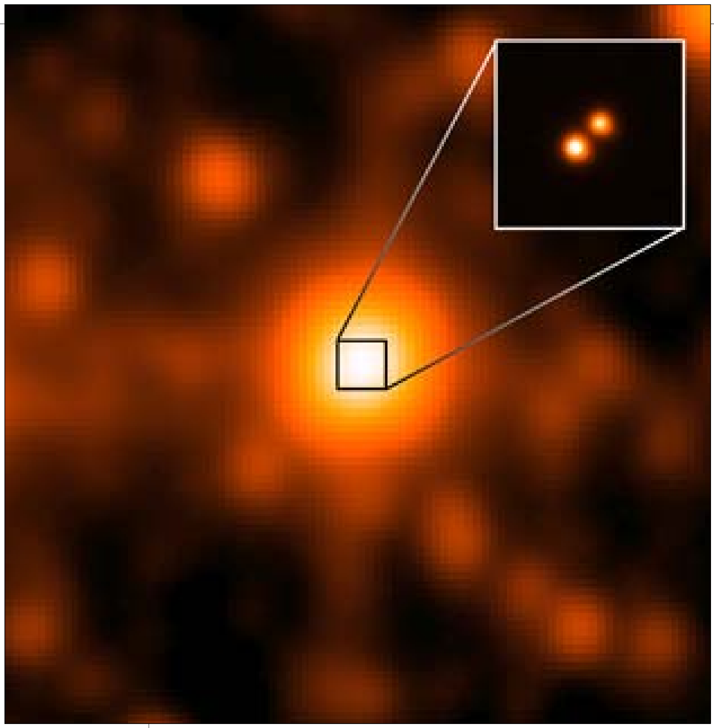


Figure 11.
WISE J104915.57 - 531906 appears as a single object at the center of the larger image from WISE. The inset shows higher-resolution observations using GMOS-South, which revealed its binary nature (inset) and enabled classification of the brown dwarf pair.

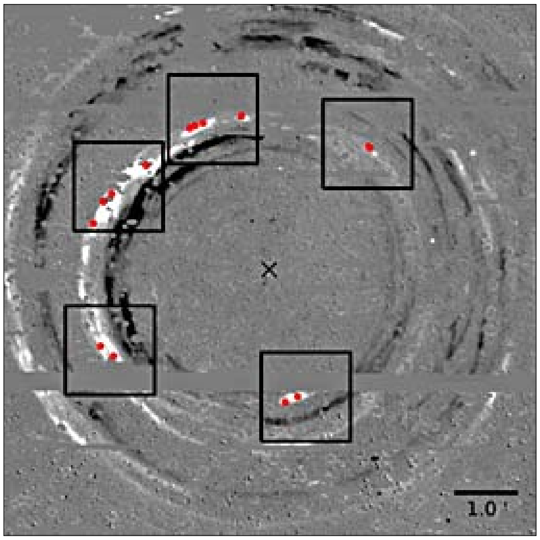
Light Echoes Show the Asymmetric Explosion of SN1987A

Observations of light echoes — reflections of a transient event in the surrounding material — allow astronomers to change perspective. Rather than being effectively fixed to a viewpoint on Earth, light echoes reveal the source object from a variety of viewing angles. Brendan Sinnott (McMaster University) and colleagues used light echoes from supernova 1987A (SN1987A) to conclude that this Type II event was asymmetric, with an elongated ^{56}Ni structure. The strongest asymmetry they measure is in the Hα line, and this asymmetry aligns well with the observed axis of ejecta.

The five fields the team observed with GMOS on Gemini South probe the supernova emission over its first 300 days. Figure 12 shows the prominent light echos, which appear as nearly circular rings, along with the slit positions on the GMOS fields.

Variations in spectra obtained at different locations alone do not imply asymmetry in the supernova emission. The source spectrum itself changes, so the reflected light depends not only on the dust properties and its dis-

Figure 12.
Difference image shows SN1987A light echoes as positive and negative (bright and dark) circular rings. They appear uniformly circular because the echo is reflected off sheet-like dust structures. Black boxes mark the GMOS fields, and red points show the spectral locations.



tribution but also on the exact region observed. The echo spectra must be compared to an appropriate isotropic source model, which is based on the original SN1987A outburst observations. The well-known source spectrum (SN1987A) is advantageous, then, because it provides an excellent reference for isotropic emission scenarios.

The Hα line shows some of the strongest deviations from the isotropic assumption (Figure 13). Two particularly interesting examples come from opposite sides of the echo circle, identified as LE016 and LE186. LE016 shows excess redshifted emission and a "knee" at around -2000 kilometers per second (km/s). LE186 shows excess blueshifted emission and a knee around 2200 km/s.

The research team argues for a one-sided asymmetry in the original supernova based on the bulk asymmetry of these line profiles. Specifically, they suggest overabundance of ^{56}Ni in the southern hemisphere as the cause. The decay of ^{56}Ni produces much of the supernova's light and determines the shape of the light curve.

In addition, the small-scale features (the knees) require some asymmetric emission, which may be related to the "Bochum event" — a transient spectral feature that lasted for only a few weeks, some three months after the supernova event. This would suggest the presence of high-velocity ^{56}Ni in the northern region of the supernova.

Most theoretical models of supernovae require some asymmetry to explode successfully, and observations such as these obtained with Gemini South of SN1987A can better constrain the simulations. The complete results will be published in *The Astrophysical Journal*, Volume 767. A link is also now available:
http://iopscience.iop.org/0004-637X/767/1/45

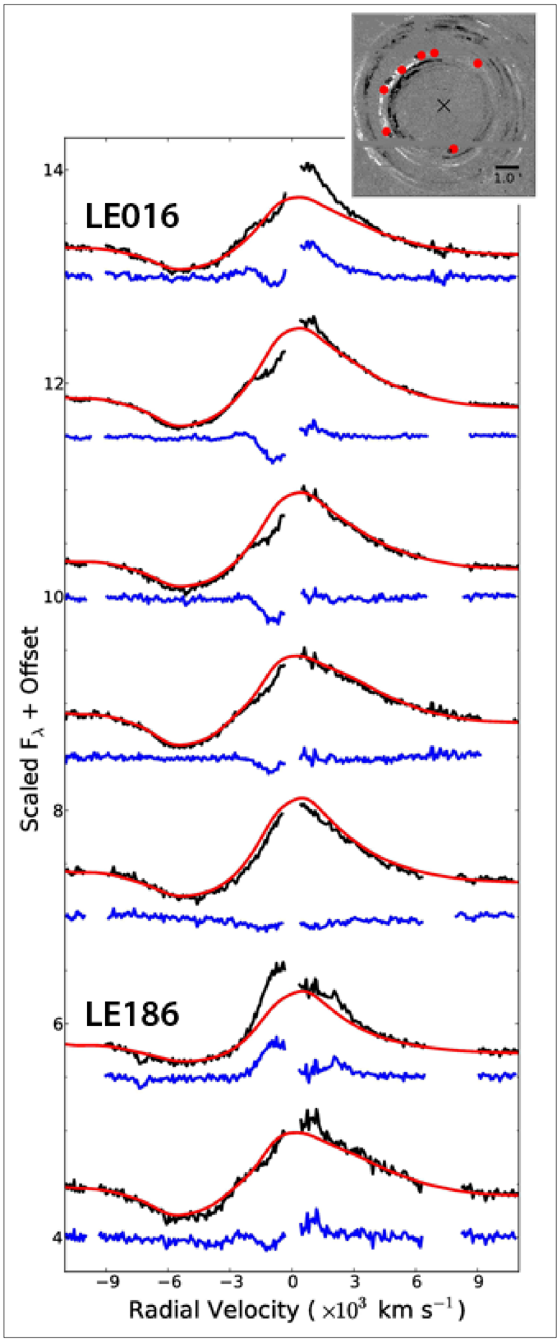


Figure 13.
Hα profiles observed (black) and modeled (red; assuming an isotropic source). Residual error is plotted in blue, and spectra are offset for clarity. Regions of poor sky subtraction are not plotted.

Black Hole Masses from Near-infrared Observations of AGN

Black holes are intimately tied to the growth and evolution of galaxies, and active galaxies offer some of the best examples in which to measure the mass of the central black hole, the quantitatively significant property. In a new work, Hermine Landt (Durham University and University of Melbourne) and collaborators expanded the sample of well-measured galaxies to allow determination of black hole masses from single near-infrared (NIR) spectra of active galaxies.

The underlying physical relationship is between the velocity of emitting material and its distance from the central black hole. The observational proxies for these properties are the spectral width of the broad emission lines and the active galactic nucleus (AGN) continuum luminosity, where the distance is expected to go as the square root of luminosity (assuming the line is produced at a location of fixed ionizing flux).

Reverberation mapping at optical wavelengths establishes this relationship, where the continuum variability is observed after a delay in the broad line emission. This technique has the disadvantage of being observationally time-consuming, and fewer than 50 AGN have been measured. Once the radius-luminosity relationship is established, however, further measurements are observationally easier.

This new work provides the observational correlations in the NIR, using observations with the Gemini Near-infrared Spectrograph (GNIRS). This wavelength regime offers advantages over the optical and ultraviolet, including being less contaminated by host galaxy stellar emission, having lines that are less confused by blending, and being less affected by dust obscuration. The sample is restricted to galaxies that have reverberation mapping results, and the new data especially help to fill out the high-luminosity range.

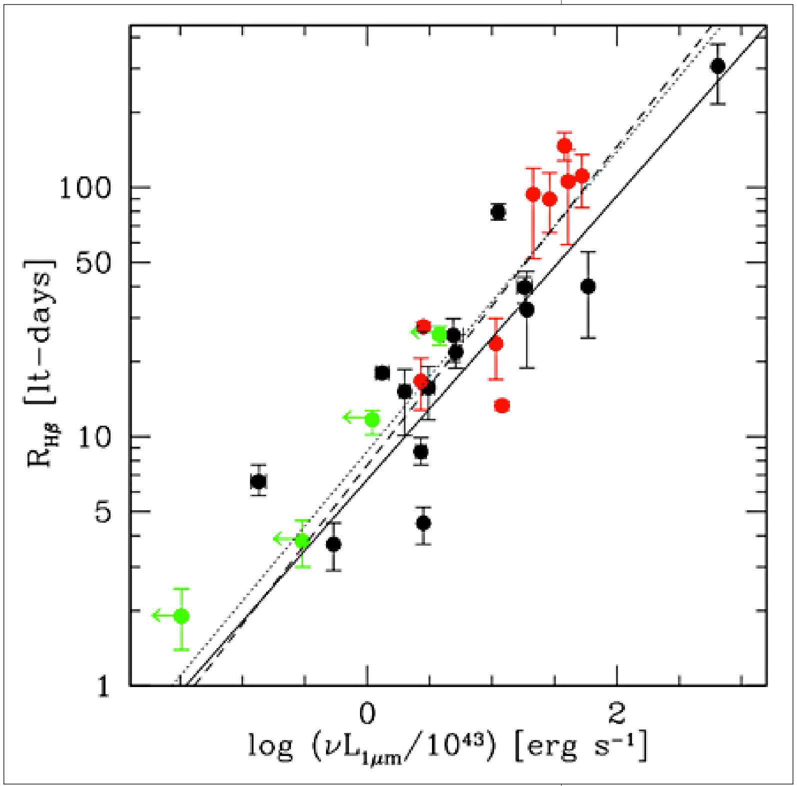


Figure 14.
The location of broad Hβ emission (measured in light-days, from reverberation mapping) versus 1-micron continuum luminosity. Previous observations are plotted in black, new results are shown in red, and upper limits result when the host galaxy dominates the emission (green). The different lines show fits obtained using various techniques, all of which are consistent with a slope of 0.6±0.1.

Figure 14 shows the resulting radius-luminosity relationship, where the radius, *R*, is based on previous measurements, and the NIR provides the luminosity, *L*. The observed scatter and lack of change with the enlarged sample here suggest that some of the scatter is intrinsic to the relationship, not measurement uncertainty. With a direct measurement of the velocity spread from the width of Paschen α or β lines, the black hole mass can be calculated.

Alternatively, the combination of NIR luminosity and line width together can be related to the previously measured black hole mass. The complete paper, to be published in *Monthly Notices of the Royal Astronomical Society*, provides the resulting quantitative relationships, including consideration of different techniques for determining the velocity spread. A preprint is available at: http://arxiv.org/abs/1303.1923

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Benoit Neichel and Rodrigo Carrasco

Gemini South's Revolutionary New Adaptive Optics System Embarks on the Universe

The first half of 2013 has been a busy one for the GeMS team, culminating with the success of the GeMS System Verification (SV). This article features many of the stunning images obtained during the SV period by our users.

Figure 1.
The Gemini South GeMS laser propagates into the night sky during GeMS/GSAOI System Verification observations.

This last semester marked the beginning of science operations with the Gemini Multi-conjugate adaptive optics System (GeMS) and the Gemini South Adaptive Optics Imager (GSAOI). GeMS/GSAOI officially started its System Verification (SV) period in December 2012 after 1 1/2 years of commissioning. Since then, the system has delivered new and exciting science to Gemini's user community.

GeMS is based on a new adaptive optics (AO) concept, called Multi-Conjugate Adaptive Optics (MCAO). The technology behind MCAO involves the use of multiple laser guide stars (five in the GeMS system) and several deformable mirrors (three in all) to sample atmospheric distortions and cancel them out in real-time as imaging data are collected.

Using algorithms similar to those developed for medical tomographic imaging, the GeMS/MCAO system creates a three-dimensional snapshot of atmospheric turbulence between

~ 500 to 1000 times per second. The result is about a 20-fold increase in the area of the observed patch of sky compared to previous AO systems, while providing uniform corrections over the entire field from edge-to-edge.

GeMS is a facility instrument, and as such it can direct its light output to different science instruments installed at the Cassegrain focus of the Gemini South telescope. The main instrument used to date is GSAOI, a wide-field camera designed to work at the diffraction limit of the 8-meter telescope in the near-infrared (NIR).

Science Verification: A Long-awaited Milestone

In August 2012, the GeMS/GSAOI team released a call for System Verification (SV) targets, offering a total observing time of 60 hours for a wide range of science topics. The SV programs provide an end-to-end test of a new instrument or capability, from the proposal process to data delivery, prior to offering it to the community for general use. With GeMS/GSAOI, one main objective was to demonstrate the gain brought by MCAO on a large variety of science topics, including extended sources, crowded fields, and faint targets. We received great feedback, with 23 programs submitted for a total of 138 hours, from which 13 were selected for execution between November 2012 and January 2013.

The SV period did not start as expected: In early November, the power produced by the sodium laser fell to a level one-half of what it was a few weeks before, preventing the team from completing the remaining commissioning tasks. With the assistance of Zach Prezkuta (a laser engineer from Lockheed Martin Coherent Technologies), Gemini laser specialist Vincent Fesquet, worked non-stop for three weeks to recover the laser light to a nominal 50 watts (W) — in time for a run in December (Figure 1). Atmospheric seeing and laser conditions were excellent during this period. The team overcame most of the delays accumulated during commissioning, and SV observations started before month's end.

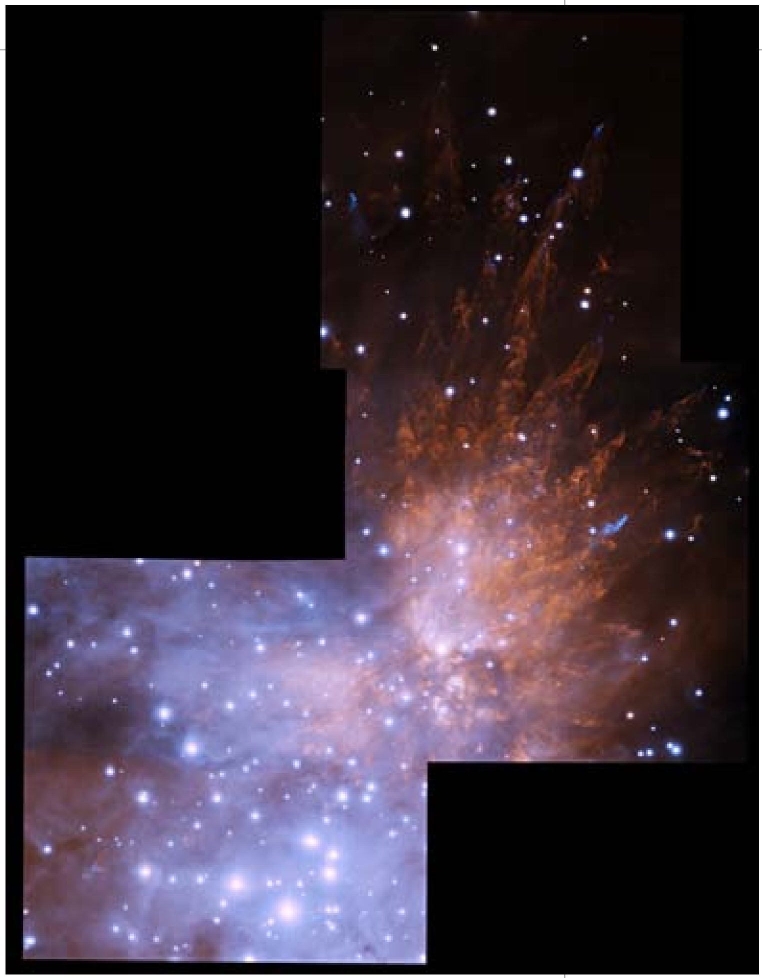

Figure 2.
A three-pointing GeMS/GSAOI image of the Orion Nebula's Bullets field.

Orion Bullets: A Dramatic Demonstration

The team selected the Orion Bullets as their first SV target (Figure 2). These wake-like features in the Orion Nebula are clumps of gas violently ejected from an unknown event associated with the recent formation of a cluster of massive stars. The strong winds produced by this "explosion" expelled these bullets of gas at supersonic speeds, leaving behind the distinctive tubular and cone-shaped wakes we now see; the wakes shine like tracers due to the bullets piercing and

Figure 3.
The globular star cluster NGC 1851 as imaged with GeMS/GSAOI during System Verification

heating the molecular hydrogen gas in the Orion Nebula.

By comparing high-angular-resolution images of this region over several years (including observations at Gemini North with the Altair AO system obtained in 2006), the team, headed by John Bally and Adam Ginsburg (both of the University of Colorado), can actually measure a bullet's motion. By mapping the proper motions of each, they can build a complete 3D dynamical model of the region. A single-pointing version of this new image also made headlines at the January 2013 meeting of the *American Astronomical Society* (held in Long Beach, California) and was featured in a press conference at the meeting.

This remarkable image also illustrates the revolution brought by MCAO. The final mosaic, made by three GeMS/GSAOI pointings, covers a field-of-view measuring almost 4 x 3 arcminutes, resulting in one of the biggest AO-corrected images ever obtained. This is the main advantage of MCAO when compared to other AO systems: in one shot, the area of sky covered is 10- to 20-times larger than any previous AO system. This makes Gemini's 8-meter telescope 10- to 20-times more efficient, giving astronomers the option to expose deeper, or explore more effectively with a wider range of filters.

Globular Cluster NGC 1851: Going Fainter

Another critical SV target was NGC 1851, a globular cluster located about 40,000 light-years from our Sun (see Figure 3). Such a tightly packed city of starlight is a workhorse science case for MCAO; the AO corrections "deblend" multiple systems in crowded fields, allowing astronomers to access the cluster's fainter stars, which are crucial in studies of star formation in these different environments.

Moreover, by delivering a uniform performance over fields that encompass most globular star cluster sizes, MCAO greatly improves the photometric precision on these crowded fields. By studying the MCAO observations of NGC 1851, Alan McConnachie from the National Research Council's Herzberg Institute of Astrophysics and colleagues intend to precisely derive the different star populations that make up this cluster. By observing NGC 1851 over time, the team also expects to retrieve the cluster's orbit within our Galaxy. In that case, GeMS/GSAOI is also a perfect complement to the Hubble Space Telescope (HST): the image quality provided by the GeMS system in the NIR is very similar to that delivered by HST in visible light, which opens the possibility of combining these complementary data sets.

Galaxy Cluster Abell 780: Better Sky Coverage to Go Deep

The third SV target was Abell 780, a cluster of galaxies located at $z = \sim 0.05$ (see Figure 4). In extragalactic studies, only a few natural guide stars are available to provide AO corrections, which limits the areas of the sky available to study. With its five laser guide stars, GeMS increases the portion of the sky that can benefit from AO correction, and surpasses the previous generation of laser guide star AO systems. Put another way, only GeMS can provide this kind of uniform, sharp image quality in regions with few natural guide stars.

In this field, the team led by Rodrigo Carrasco from Gemini wants to explore not only the structure of potential massive compact galaxies in galaxy clusters but also the detailed properties of the massive galaxies with average sizes. Looking for "signatures" that could be related to ongoing merger activity (such as tidal tails, clumps of star formation, *etc.*), they would be able to decide between different competing evolutionary scenarios.

2013 and Beyond

The team continued their SV runs on 8 nights in January and 11 nights in February 2013. A total of 12 targets out of the 13 selected were observed, under different conditions, providing very useful information to the team on how to run and optimize this complex system. Also included in the SV observations, the researchers targeted planetary nebula NGC 2346, several star clusters (*e.g.,* RCW 41 and R 136), NGC 4038 in the Antennae Galaxies (see Figure 5), a candidate supernova in a nearby Luminous Infrared Galaxy, a pulsar, a quasar, and gravitational lenses induced by a galaxy cluster. All these data are also now publicly available on the Gemini archive website at: *http://www.cadcccda.hia-iha.nrc-cnrc.gc.ca/en/gsa/sv/dataSVGSAOI_v1.html*

The team also used the 2013 SV period to stabilize and characterize the performance delivered by the system. They determined that 50 percent of the time, GeMS delivers an image quality of 95 milliarcseconds (mas) or better in K band and 75 mas or better in the H band. This is not yet at the original specification level but two primary, well-understood reasons explain this.

Figure 4.
Galaxy cluster Abell 780 in a single-band image obtained with GeMS/GSAOI during System Verification.

First, one of the three deformable mirrors in GeMS failed. These mirrors are optically conjugated at 0, 4.5, and 9 kilometers. However, since the system is currently running with only two deformable mirrors, at 0 and 9 km, corrections are not optimal. Second, while the laser itself is performing very reliably, the overall transmission of its projection system is under specification. Consequently, the AO corrections are applied at a lower-than-normal rate, so the performance suffers from the variations of the sodium layer concentration.

The SV team will address both items in the following semesters, first by recovering a three-deformable-mirror configuration, and then by optimizing the laser photon return. For this latter work, the Beam Transfer Optics, which is the set of mirrors that allows shaping the laser constellation and propa-

Figure 5. *NGC 4038, one of the Antennae Galaxies, imaged by GeMS/GSAOI during System Verification.*

gating the beams on the sky, will be optimized with better coatings and a control of the light's polarization.

A third performance upgrade is also in the works for the next semester, and it concerns the Natural Guide Star wave-front sensor. Due to minor design and alignment issues, the current limiting magnitude achievable is around 15.5 in the visible. This dramatically reduces the number of targets obtainable outside of the Galactic plane. A completely new design, based on a recently developed low noise focal plane array, has been approved, and should be implemented in GeMS before the end of 2014. This fix is expected to boost the sensitivity of the system, allowing researchers to acquire stars as faint as 18.5 in visible light, hence increasing the portion of the sky accessible to GeMS.

On another front, there is also a large on-going effort to smooth the "operation ability" of the GeMS system, and perform the transition into regular operations. The objective is to progressively reduce the amount of staff required to operate the system at night. This will be achieved by deploying more high-level software and diagnostic tools. The first semester of regular science operations was also intensively used for cross-training within the various teams supporting GeMS/GSAOI.

GeMS/GSAOI is now available through the regular Call for Proposals process. The 2013A semester, offered as "shared-risk," received 11 programs, for 80 hours allocated. Semester 13B has been open for 150 available hours, which were recently allocated with 16 programs, and plans currently allow for this level of GeMS availability for the foreseeable semesters ahead. In the near-future, the goal will also be to diversify the science capabilities, by offering GeMS for FLAMINGOS-2 and possibly even the Gemini Multi-Object Spectrograph (observing at the red-end of the visible spectrum).

Impacting the Future of Astronomy…

After about 10 years of development, and almost 100 nights of commissioning, GeMS/GSAOI is now producing unique science! This accomplishment paves the way for future AO developments, and especially for the next generation of Extremely Large Telescopes, for which running multi-laser AO systems will be the baseline.

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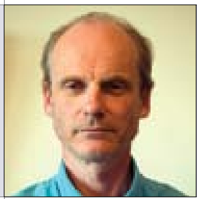


Andy Adamson

with contributions by Sandy Leggett, Chris Yamasaki, Inger Jørgensen, Bernadette Rodgers, Rodrigo Carrasco, and Benoit Neichel

Operations Corner

From visiting instruments, to changes in data checking and software development, 2013 ushered in the reshaping of Gemini's operations. With powerful new instruments like the GeMS multi-conjugate adaptive optics System, FLAMINGOS-2, and the Gemini Planet Imager — all either progressing through integration, or approaching operational status — our users can look forward to even more of the most powerful discovery tools in astronomy today.

An Exceptionally Busy Year at Gemini South

2013 was one of the most event-filled years for operations at Gemini South in recent memory. Most of the activity followed a planned maintenance shutdown early in Semester 2013B (see details in section below). During that time the Gemini Planet Imager (GPI) was not only delivered, integrated, and comissioned, but saw first light (see cover article in this issue). GeMS/GSAOI (the multi-conjugate adaptive optics system and infrared imager) was also accepted into scientific operations, and FLAMINGOS-2 began doing regular science; the latter attracted many 2013B proposals (see update in the 2013 instrument development article in this issue).

The flurry of new instrumentation at Gemini South meant that something had to give, and with T-ReCS already removed from the complement, that something was the Near-infrared Camera and Imager (NICI). Despite some hardware and computer problems in its last few weeks of operation, 70 percent of the 2013A NICI programs received more than 75 percent of their requested data.

Gemini South Shutdown

The Gemini South winter shutdown was completed successfully, with a wide variety of assignments carried out. One of the biggest jobs was a complete reworking of the summit data center, which included replacing old obsolete racks with new ones. To achieve this, we had to install the computer systems themselves in temporary racks while the old ones were swapped out. We also did maintenance and improvement work on the telescope infrastructure, including the Acquisition & Guiding (A&G) unit and the Cassegrain Rotator. Significant work was also done on GMOS-South to improve reliability of the mask exchange unit.

Finally, we replaced the large chiller, which is used for the toughest cooling tasks in the building (including the air handling units in the dome itself). This was a major undertaking. It required a choreographed exchange between the existing chillers and the new unit, which enabled the new one to run in a test mode so that stability could be achieved before we permanently switched the units. The new unit appears to work very well, and, because it is much more efficient, we expect to realize significant savings on electricity — a critical (and our largest) single expense.

Gemini North Operations in 2013

In 2013, the most significant change in operations that users noticed at Gemini North was the change in Semester 2013A in the amount of data checking performed. This was driven by the reduction of Gemini's budget and the need for staff astronomers and Science Operation Specialists to use their efforts where it has the most impact. Most significantly, at night, the observer takes responsibility for setting quality assurance flags to the best of his or her ability, using a variety of tools, including data checking programs and the environmental sensors.

Figure 1.
The Gemini North 8-meter primary mirror is inspected inside of the coating chamber.

During the day all band 1 data are checked as usual, as well as any programs where a check is deemed to be necessary by the Queue Coordinator (up to a limit of 30 percent of the night's data in total). Other programs, including band 4 and classical programs, are not checked, and may be left with their quality assessment state set to "UNDEFINED", if the nighttime observer was unable to review them in real-time

This change represented a considerable cultural shift for Gemini staff; our dedication to our product is strong. However, the change is unquestionably necessary and has already produced effort savings in the north and will soon be applied to Gemini South operations as well.

Gemini North Shutdown

An extensive planned shutdown at Gemini North in Semester 2013B, primarily to recoat the 8-meter primary mirror, started on September12th. The operation was completed successfully (see Figure 1). The mirror now has unprecedented reflectivity (blue: 470 nanometers = 93.0%; green: 530 nm = 95.0%; red: 650 nm = 95.2%; near-infrared 880 nm = 96.4%; thermal infrared 3300 nm = 99.0%). Also 100% adhesion was achieved. Senior Optical Technician Clayton Ah Hee says Gemini should get at least as long a life out of this coating as the last one, which lasted almost six years!

During this shutdown, the team also accomplished many other tasks, including repairing the mirror cover and A&G unit, and performing upgrades and repairs to the instruments.

Gemini North and South Safety Platforms

In 2013, major safety milestones were achieved at Gemini North and South with the installation of new, exterior Shutter Service Platforms (see Figures 2-7). These structures are designed to provide a safe means to perform critical periodic maintenance on the enclosure shutter drive motors, encoders, gear-boxes, and chains.

Figure 3 shows the 150-foot telescoping crane used later in the year at Gemini North, which was required to pick up and place the platforms into position. For the crane to safely perform the lift, Gemini had to excavate and grade a level foundation pad and limit the operation to wind speeds less than 20 miles per hour; both items impacted the time and cost of the installation work.

Visiting Instruments

Gemini's new visiting-instrument policy, developed jointly by the Observatory and the Science and Technology Advisory Committee (STAC), allows a quick process for bringing a visiting instrument to the telescope on a "once-off" basis. It also allows for the possibility of attracting a wider base of users within the Gemini partnership, who may be interested in the performance potential of these instruments (without going the whole way to facility class, which is a much larger, and likely prohibitive, undertaking).

The policy (see http://www.gemini.edu/sciops/instruments/visiting-instrument-policy), was put into action with the Differential Spectral Survey Instrument (DSSI); a speckle camera, which Gemini offered in the 2013B Call for Proposals. The instrument was used for eight nights on the telescope in July. Five science programs were observed, including the DSSI team's own.

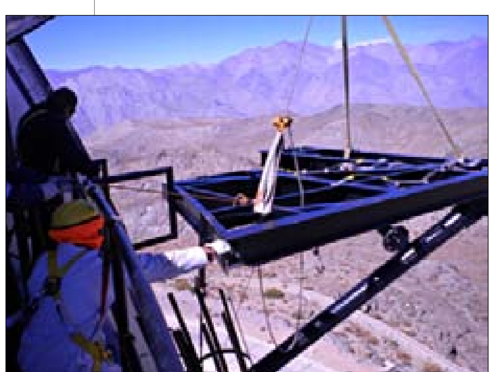
This plan worked out quite well, with three of the five programs either completed or nearly completed, and two programs more than half completed; the shortfall was due to target position and filter availability, as well as observing conditions, includ-

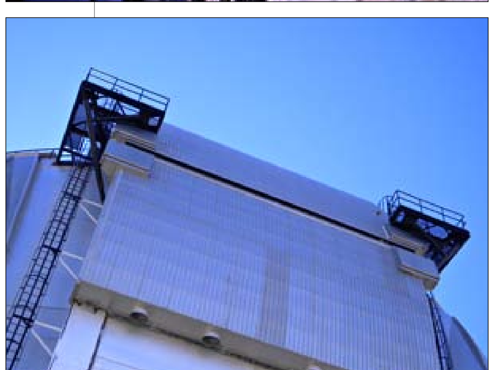
Figure 2.
View from the newly installed Shutter Service Platform at Gemini North, installed to facilitate safety and accessibility during shutter motor servicing.

Figure 3.
A 150-foot telescoping crane was needed to install the Shutter Service Platform.

Figures 4-7 (below):
Clockwise, from top left (all at Gemini South):

- *Installing the base plate of the first platform.*
- *Fleshing out the first platform.*
- *Working on the completed platform.*
- *The installed platforms, looking like they belong there even ahead of painting.*





ing the loss of a complete night to the passage of Tropical Storm Flossie.

The science included measuring the diameters of nearby stars, Kepler exoplanet confirmations, and observations of Pluto and Charon — a wide range of exciting science observations for a niche capability. It is expected that the instrument will be offered again for 2014B; its capabilities and performance are summarized here: *http://www.gemini.edu/sciops/instruments/dssi-speckle-camera-north*

In November, DSSI was succeeded onto Gemini North by TEXES, a mid-IR high-resolution spectrometer making its third visit to the telescope (the last having been before 2010). The winter weather was not very helpful, but the TEXES team still obtained useful observations on a mini-queue of programs granted by the Time Allocation Committee, with a total of 90 hours.

DSSI and TEXES were oversubscribed by factors of two and three, respectively.

User Software Improvements

The UREKA Unified Release

In june, we released a new a new mechanism for installing and running the Gemini reduction package and all of its supporting software. The idea of Ureka (also known as the "unified release") is to bundle all the required pieces and release them together in one easily-installed package. Ureka has the added bonus of not interfering with any existing installations.

A quote from the Ureka page sums up what it's about: "Ureka is a collection of useful astronomy software that is generally centered around Python and IRAF. The software provides everything you need to run the data reduction packages provided by the Space Telescope Science Institute and Gemini." Since its Beta release to the community, Ureka has been downloaded by hundreds of users, and feedback is being used to bring it to production release status.

Observatory Control Software Improvements

Work has been going on "under the hood" of the other operations software to enable significant future improvements, and to make the software more maintainable. Overall, the OCS (Observatory Control Software) has been reduced in size by about 1/3, due to the removal of internal communications layer. Users will not see much change, though the changes also required the implementation of "Sync" to replace the old "Fetch/Store" mechanism, which should be simpler for PIs to use, and prevent data loss. This change was included in the December 2013 software release.

Users' Data Reduction Forum Added

We are pleased to announce the release of the Gemini Data Reduction User Forum, located at: *http://drforum.gemini.edu/*. This is intended as a user-supported site for the trading of ideas, scripts, and best practices, and for taking part in user-driven public discussions on data reduction processes and strategies. If you have written a script, procedure, tip, or description of your own process that you think other Gemini users may find helpful in reducing their data sets, please consider posting it here.

The Forum's "start here" page (*http://drforum.gemini.edu/start-here/*) gives a brief introduction and some points to note when posting or taking part in discussions. Both the Observatory and the Users' Committee for Gemini are keen to see this Forum well utilized and become helpful to a broad segment of our user community. To encourage your involvement, Gemini Director Markus Kissler-Patig has agreed to award Director's Discretionary observing time to two individuals who will be selected based on the usefulness of their posts.

New: Large and Long Programs at Gemini

Gemini offered a new proposal mode, for Large and Long Programs (LPs), with first observations in Semester 2014B.

The participating partners — United States, Canada, Australia, and Argentina — contributed up to 20 percent of their time to a common pool for these programs. As a guideline, LPs either require significantly more time than a partner typically approves for a single program, or are extend over two to six semesters, or both.

Large programs are expected to promote collaborations across the partnership's communities, have significant scientific impact, and, normally, provide a homogeneous data set potentially for more general use. PIs must be based in an institution of one of the participating partner countries, though there is no restriction on Co-investigator affiliation.

With the LPs, Gemini will also introduce a new observing mode, "priority visiting observing." In this mode, the PI or team member comes to Gemini prepared to observe either their own program, if the conditions are sufficiently good, or execute approved queue programs, if the conditions are too poor for the LP.

The LP will be charged only for time devoted to the program, and additional observations may be made by Gemini staff during the semester. With this mode and that of traditional "classical" observing, we encourage the benefits of being directly involved with the program team in observing, and their interaction with Gemini staff who also support the program.

LPs will be reviewed through a dedicated LP Time Allocation Committee, and the process will bring additional application and reporting requirements. Specifically, Letters of Intent will be required in advance, the proposal will include a management plan component in addition to the usual scientific justification, and approved programs will be reviewed annually.

There may be additional partner-specific procedures or requirements, as well. Complete details will be available with the Announcement of Opportunity, which Gemini expects to release in early December 2013. Proposals will be due around the usual 2014B deadline at the end of March 2014. Instruments and observing modes that are fully commissioned at the time of the announcement of opportunity will be open for LPs; a specific list will be provided at that time.

Development of the Fast Turnaround Mode

The foundation for a new mode of proposing at Gemini is being laid with an initiative called Fast Turnaround Program. This new concept underwent considerable development in 2013 and is poised for implementation later in 2014. This mode of proposing is intended to provide a means for submitting proposals that have time constraints due to their dynamic or time-dependent nature. As 2013 closes, both the STAC and Gemini Board have approved the concept, and work is well-along to develop internal procedures to assure a successful launch.

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Scot Kleinman

with contributions by Bernadette Rodgers, Benoit Neichel, Rodrigo Carrasco, Andre-Nicolas Chene, Chad Trujillo, Percy Gomez, Stephen Goodsell, Fredrik Rantakyro, Eric Tollestrup, Maxime Boccas, and Peter Michaud

Instrument Development: 2013 Review

2013 was an exceptional year for instrumentation at Gemini, with a suite of new instruments and events at Gemini South, including the highly successful Gemini South Multi-conjugate adaptive optics System (GeMS) combined with the Gemini South Adaptive Optics Imager (GSAOI), and the arrival, integration, first light, and start of commissioning of the Gemini Planet Imager (GPI). In parallel, we continue to look to the future in order to develop the capabilities of both Gemini telescopes and support the diverse needs of our user community.

Rapid progress in a host of new instrumentation initiatives at Gemini occurred throughout 2013. Most of these reached fruition at Gemini South, with the most tangible being queue science with GeMS/GSAOI, FLAMINGOS-2, and first light for GPI.

At Gemini North, the fiber-fed, shared use of CFHT's ESPaDOnS instrument through the GRACES project points to a good collaborative effort that is trailblazing the astronomical use of long fibers and furthering Gemini's North's exciting future on Mauna Kea.

The following brief summaries provide a taste of what the present and future holds for Gemini instrumentation. Watch for further details in future issues of *Gemini*Focus and on the Gemini website at: http://www.gemini.edu/sciops/future-instrumentation

FLAMINGOS-2: On Sky, Doing Science

"Gemini Observatory's latest tool for astronomers, a second-generation infrared instrument called FLAMINGOS-2 (F2), has 'traveled a long road' to begin science observations for the Gemini scientific community." So begins the August 2013 press release (www.gemini. edu/ node/12047), showcasing several spectacular F2 on-sky commissioning images and presenting an update on progress (FIgure 1). Since then, science observations have begun!

After finishing optical rework in April 2013 (Figure 2), F2 stepped closer to its final round of commissioning observations when it was moved from the Gemini South summit instrument lab onto port 5 of the Instrument Support Structure on June 11, 2013. The first preliminary science queue data were obtained July 19th, and regular queue observations began in late September.

F2 began obtaining data in "shared-risk" mode in August 2013 and between then and mid-December has executed 15 queue programs. Despite this exciting milestone, challenges remained. One problem involved the instrument's On-Instrument Wavefront Sensor (OIWFS) used to optimize the delivered image quality to the camera. During on-sky checks on the night of August 24th, an alignment problem with the OIWFS became apparent. An inspection quickly followed, and the mechanism was realigned as precisely as possible with minimum intrusion (*i.e.*, without moving other optical components).

PIs with programs in the 2013B queue were informed of the possibility of reverting to the use of PWFS2, and observations were prepared for either option, allowing queue observations to continue. An additional problem was discovered with repeatability of the Lyot wheel mechanism, but a solution was identified and the problem resolved in December. However, delivered image quality is a significant remaining issue, and is still under active investigation.

These 2013B programs requested a total of 180 hours or 17 percent of the total available time on Gemini South, despite the fact that only imaging and the long-slit spectroscopy modes were offered in this first semester. Work is ongoing to offer the multi-object spectroscopy (MOS) mode later, after we gain more experience and time with the instrument.

In parallel to the start of "shared-risk" science operations, and before the end of the 2013B semester, Gemini held an internal Operations Handover Review for F2. The review took a close look at the performance and operability of F2 in its present state with respect to the ultimate goal of successfully operating, maintaining, and supporting F2 as a facility-class Gemini instrument, and delivering the expected scientific return to the Gemini community. The committee also assessed the remaining work going forward, including improving the

Figure 1.
FLAMINGOS-2 near-infrared commissioning image details part of the magnificent Swan Nebula (M17), where ultraviolet radiation streaming from young hot stars sculpts a dense region of dust and gas into myriad fanciful forms. M17 lies some 5,200 light-years distant in the constellation Sagittarius and is one of the most massive and luminous star-forming regions in our Galaxy. Field-of-view: 5.5 x 4.0 arcminutes.

Credit: Gemini Observatory/AURA.

Figure 2.
Optical Engineer Constanza Araujo works on FLAMINGOS-2's optical alignment and image quality testing prior to cool-down.

delivered image quality and commissioning the powerful multi-object spectroscopy (MOS) mode.

GeMS/GSAOI Moving Toward More Robust Operations

The Gemini Multi-conjugate adpative optics System (GeMS), along with its dedicated imager, the Gemini South Adaptive Optics Imager (GSAOI), has, in 2013, completed the transition from a development project into System Verification (SV) observations. In Semester 2013B, the instrument neared normal science queue operations.

During these transitions, GeMS/GSAOI produced a variety of very impressive results, including a stunning new first light image of the Orion Nebula "Bullets" region among several other targets (see: http://www.gemini.edu/node/11925, and Figure 3). Data obtained during the SV period also resulted in the first refereed journal article based on GeMS data ("Haffner 16: A Young Moving Group in the Making," Davidge *et al.*). This paper appeared in *The Publications of the Astronomical Society of the Pacific* and is now part of a rapidly growing collection of cutting-edge science papers made possible with GeMS.

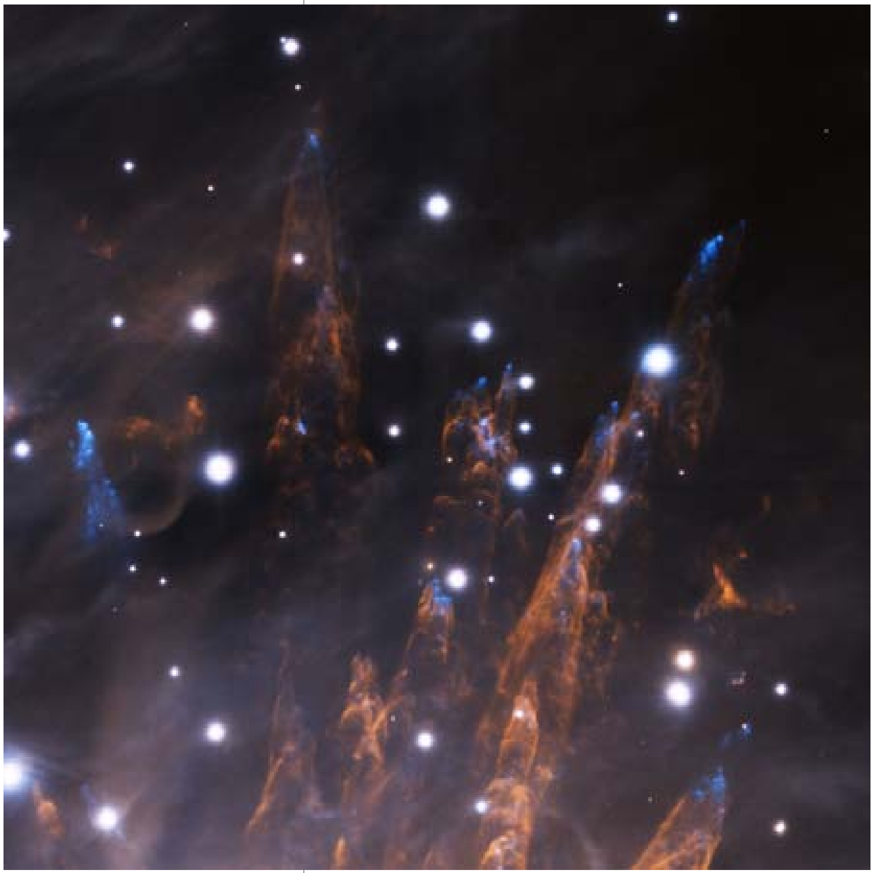

Figure 3.
Image of the Orion Bullets obtained during the late commissioning phase of the GeMS adaptive optics system, with the Gemini South AO Imager (GSAOI). The large adaptive optics field-of-view (85 arcseconds across) demonstrates the system's extreme resolution and uniform correction across the entire field.

Image Credit: Gemini Observatory/AURA.

During a telescope shutdown in June and July, many improvements were made to GeMS. These included: 1) Routine cold head maintenance of the Gemini South Adaptive Optics Imager (GSAOI, the science camera behind GeMS); 2) Repair of filter wheel #2 and the utility wheel, along with cleaning of optical elements; 3) Maintenance (including diode replacement) to improve the power output of the laser used to produce the artificial guide stars and provide better adaptive optics corrections; 4) Installation of new higher reflectivity mirrors in the transfer optics that launch the Laser, and 5) Movement of the laser wavefront sensor in Canopus (the adaptive optics instrument itself) to improve performance and investigation of some minor optical alignment issues related to the natural guide star (NGS) part of the system, and make improvements in the operational software. Overall, these improvements were designed to increase the operability and performance of the system as it entered normal queue operations mode.

From September 12-16, the system was scheduled to be on-sky in order to return GeMS to a state of readiness for queue operations after the shutdown work. This was only partially accomplished, in part due to poor weather during the run (cirrus clouds prevented use of the laser, and poor seeing prevailed), and because a number of technical issues were uncovered. Despite these problems, some useful progress was made, including: 1) successful testing of a number of operational software improvements; 2) calibration of beam transfer optics for the laser; 3) calibration of Canopus probes that acquire the natural guide stars; and 4) on-sky use of the GeMS laser. The October and December runs culminated in the return of GeMS to queue readiness, including the first Classical time observations made with GeMS in late December.

The GeMS team also completed the instrument's first operational Acceptance Review (AR) in November, with the final review scheduled for January 2014. The AR clearly defined the extra support personnel and tasks needed prior to each GeMS run to ensure that the instrument is ready for science. This effort includes members of many groups across Gemini — Science Operations, Optical Systems, Electronics and Instrumentation, Systems Engineering, Software, Information Systems, and, of course, the Adaptive Optics group — and demands that they work together in a coordinated manner.

In addition, the AR stressed that every successful night of GeMS operation requires careful communication between the telescope operator, observer, laser technician, adaptive optics group support, and laser spotters. The key to a successful transition to routine queue operations of GeMS is communication between all of these highly technical and savvy individuals.

Finally, the GeMS AR also documented key performance metrics and identified areas where improvements can be made in 2014 and beyond. During queue operations the roles and communications defined in the AR will allow Gemini to navigate a clear path to our goal of state-of-the-art adaptive optics success.

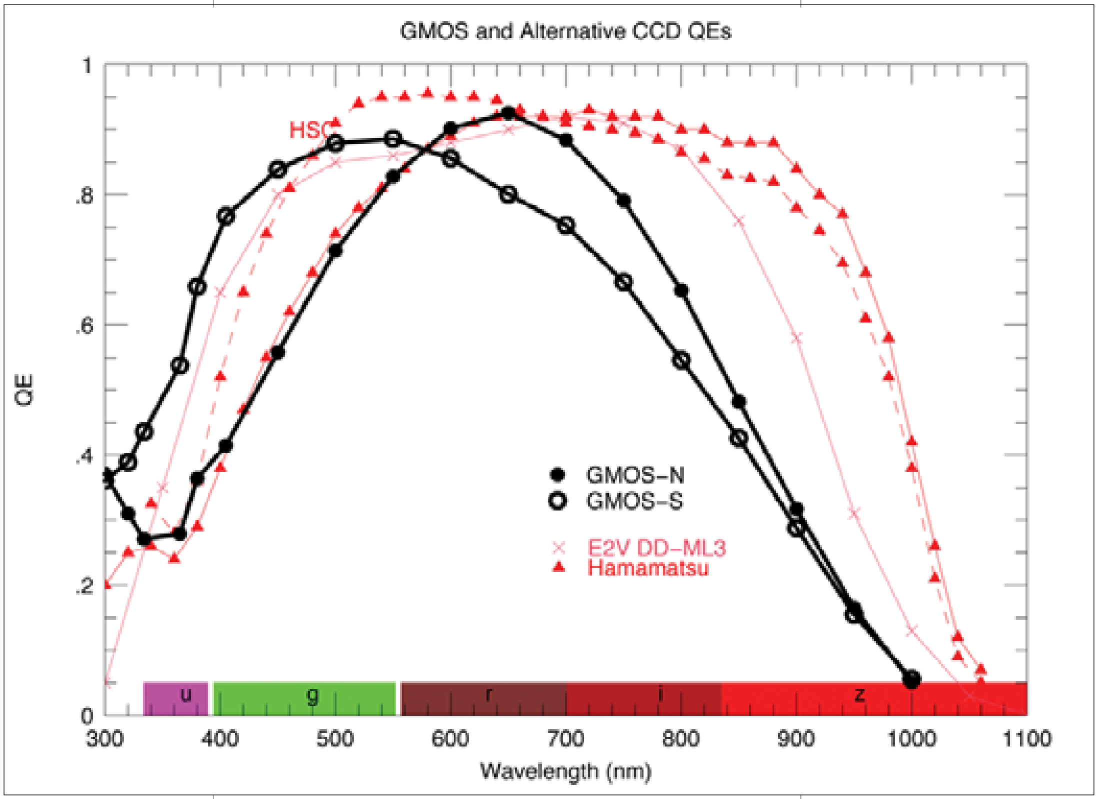

Figure 4.
Quantum Efficiency (QE) comparison for the legacy GMOS-N CCDs, the current GMOS-N e2v-DD devices, the current GMOS-S, and the Hamamatsu detectors planned for the pending upgrade. This plot considers only the detector, not the instrument camera, telescope, or atmospheric transmission.

GHOS

Since the loss of one of the proposed subcontractors for the Gemini High-resolution Optical Spectrograph (GHOS), we have been working closely with the instrument team and our governing and advisory committees to develop the best path forward. As these plans finalize, we will make announcements on the Gemini website.

GMOS

New Hamamatsu CCDs for the Gemini Multi-object Spectrograph (GMOS) are now successfully integrated in the Hilo lab with an in-dewar electrostatic discharge protection board. The system has been fully characterized at Gemini North and will be shipped to Gemini South in early 2014, pending required approvals from the U.S. government for some of the International Traffic in Arms Regulations (ITAR) controlled components. We expect to install the CCDs into GMOS at Gemini South in May 2014, with the revitalized instrument returning to science use in July.

We are currently ordering additional detectors for GMOS-N and expect installation into the instrument during 2015. Compared to the relatively recently installed e2v Deep Depletion CCDs in GMOS-N, we expect to get improved sensitivity in the red, specifically ~30 percent improvement at 900 nm and ~2x greater sensitivity longward of 950 nm (according to the reported QE values). (See Figure 4.)

The Gemini Planet Imager

The Gemini Planet Imager (GPI) project — a revolutionary instrument in the field of exoplanet research — saw final testing, shipment to Gemini South, integration, the start of commissioning, and official first light all in 2013 (see the story starting on page 8 featuring the GPI first light press release).

Early in 2013, GPI was turned almost upside down and frozen down below 0° Centigrade.

Figure 5.
The Gemini Planet Imager being tested on the flexure rig at the University of California Santa Cruz.

First, GPI was mounted on the flexure rig, then tilted and hung vertically, to simulate the effects of gravity on the instrument, which changes when the telescope points to different parts of the sky (figure 5). Next, GPI went into a cold room and was exposed to the large range of temperatures that will occur at Gemini South.

While being tilted at varying angles and subjected to freezing temperatures, the team took GPI through a large set of tests and demonstrated to micrometer precision that it was able to maintain its extremely high contrast performance. As expected, GPI passed these rigorous exams, resulting in successful pre-ship acceptance tests and the OK to ship to Gemini South.

GPI was transported to Chile in August, and unpacked on August 26th at Cerro Pachón. It then went through another subset of these rigorous tests to assure that shipping the instrument several thousand kilometers didn't cause any ill effects. Next, GPI was mounted onto the telescope at the beginning of the fourth quarter of 2013. The instrument's much awaited first light for engineering and testing followed on the night of November 11-12, which revealed the instrument's amazing capabilities (see article on GPI first light also in this issue). On-sky observations are currently ongoing for technical integration with the Gemini South telescope. Commissioning and System Verification activities occupied GPI for the rest of the year.

GRACES

Work on the Gemini Remote Access to the Canada-France-Hawaii ESPaDOnS Spectrograph (GRACES) project is proceeding substantially on course. GRACES is tentatively scheduled for commissioning in 2014. A call for SV proposals will be made once commissioning on Gemini is completed.

The primary accomplishment of 2013 was the successful production of a complete 200-meter-long test fiber that met all the project requirements. The fiber is GRACES's most critical component. As the article goes to press, the vendor (FiberTech) has completed one of the two needed full-length science fibers with initial testing that appears promising. The final 270-meter-long optical fiber cable, with its two individual shielded fibers, is expected to be completed and sent to NRC-Herzberg (formerly the Herzberg Institute for Astrophysics) in January, 2014. In order to compete with other similar 8- to 10-meter class instruments, the fiber must achieve its specified high performance in term of its focal-ratio degradation (FRD), internal transmission, and spectral range coverage.

The successful 200-meter test fiber was a milestone event toward achieving the required FRD within the 270-meter-long science cable of ~10 percent (required) to ~20 percent (goal); the test cable was fabricated, polished, shielded, and had connectors attached before it was tested and delivered in July. All of the optics (*e.g.*, lenses and slicer) and commercial hardware (*e.g.*, translation stages, adjusters, and mounts) have been received, and the custom hardware parts have been fabricated, many of them in the machine shop at NRC-Herzberg.

The injector unit uses a Gemini North Multi-Object Spectrograph (GMOS-N) filter cassette, which allows GMOS-N to act as an acquisition camera for GRACES. Permanently installed in ESPaDOnS, the slicer (see Figure 6) includes a deployable fold mirror that allows ESPaDOnS to be used with the CFHT or GRACES by simply moving the fold mirror in and out of the optical path of ESPaDOnS. Critically, this swap can be done without affecting the alignment or performance of either instrument.

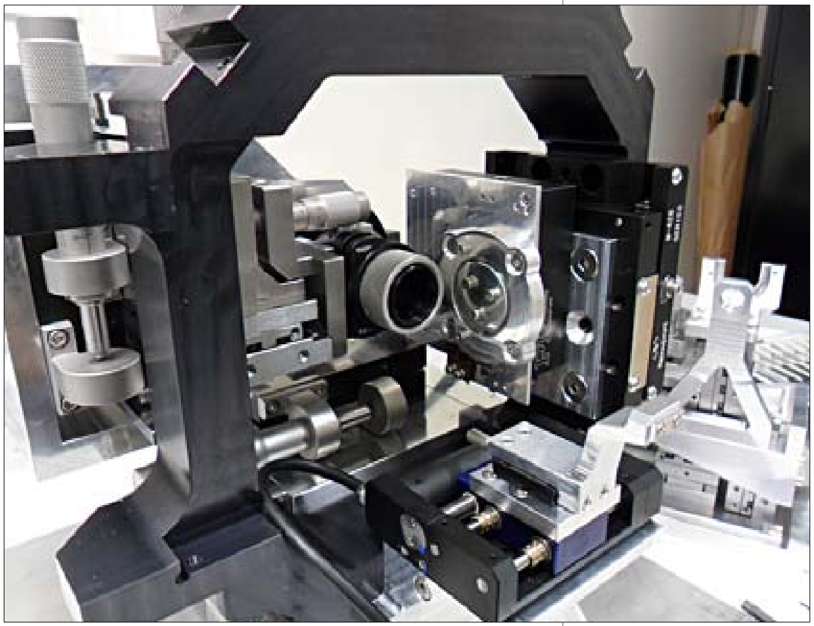

Figure 6.
The slicer bench, which will be installed inside ESPaDOnS, will receive light from the fiber and send it to the image slicer (not yet installed on the bench). The sliced image is then directed to the ESPaDOnS spectrograph.

Looking Ahead to 2014

Our plans for 2014 are to see a completely revitalized instrument suite at Gemini South with GeMS/GSAOI, GPI, and FLAMINGOS-2 in regular operations and new state-of-the-art detectors in GMOS-S. We expect to complete the preliminary design stage of GHOS and launch a request for proposals for the next-generation, new Gemini instrument in 2014.

We plan to be testing GRACES during the second quarter of 2014 and, if successful, will work to offer high-resolution optical spectroscopy to our community with this instrument. In the lab, we will start assembly of a new focal plane array for GMOS-N, to be installed in early 2015.

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Peter Michaud

Gemini Interns: A Glimpse to the Future

Gemini's intern program has never been more active — especially this year at Gemini North, where, already in 2013, 14 students have participated in diverse projects in science, engineering, and operations.

Figure 1. *Interns Emily Berkson, Mikeala Leners, and Andrew McNichols (left to right) are part of this year's "Intern Explosion" at Gemini North!*

A critical role for an observatory like Gemini is to inspire and help prepare the next generation of scientists, engineers, and others who want to play a part in our exploration of the universe. We achieve this in many ways — from reaching out to K-12 students to providing in-depth experiences at the observatory, which help prepare university students for successful careers in science.

It is the latter approach that brings a diverse collection of students to both the Gemini South and North offices, every year. Intern programs like Research Experiences for Undergraduates, INSPIRE, and the Akamai Observatory, as well as programs like the one at the University of Victoria in British Columbia, are representative of the opportunities available. Gemini Senior Scientist (and frequent intern mentor) Tom Geballe knows how important it is to have these "future scientists" involved in the "nitty-gritty" of our work. He notes that, "Their freshness and eagerness cannot help but inject excitement into our work and renew enthusiasm."

Indeed, 2013 was a banner year for interns at Gemini. Specifically, at Gemini North, no fewer than 14 budding scientists filled the rather "communal" intern's office in Hilo (see Figure 2). Here, interns shared ideas, life in Hawai'i, and even bicycles as they were challenged with projects and problems that are only found in a working observatory.

While both sites frequently host multiple interns, Gemini Human Resources Assistant Carolyn Medeiros commented on the 2013 "explosion" at Gemini North. "It's great to have so many interns here. 2013 was exceptional. Each intern brings so much energy and when it is multiplied by so many at once, it's been an intern explosion!"

Intern Emily Berkson (Inger Jørgensen, mentor), who recently completed her undergraduate studies in astronomy at the University of Arizona, shares her experiences at Gemini North in her blog, which she fills with compelling stories and images. Anyone visiting her page, titled "Day Trip VII: Mauna Kea Observing Run," can get a feel for the beauty, exhilaration, and exhaustion of an observing run at Gemini North — from a perspective that only a student on the mountain for the first time can capture.

Human Resources Assistant Carolyn Medeiros witnessed the "explosion" this year at Gemini North. "It's great to have so many interns here. 2013 was exceptional. Each intern brings so much energy, and when it is multiplied by so many at once, it's been an intern explosion!"

Emily touts that her time on Mauna Kea was the "peak" of her Hawai'i internship. "Standing atop Mauna Kea at night for the first time is definitely a surreal experience," she says. "The entire four-night stay is something most budding astronomers only dream of doing. I know I'll never forget it!" Readers can find Emily's collection of stories and images at: http://emilyberkson.com.

Jeremy Bullis, working with Mathew Rippa and Chas Cavedoni in the engineering department, was the first Gemini intern from the University of Oregon's program. He arrived through a grant from former Gemini scientist Scott Fisher. According to Cavedoni, "Jeremy quickly got up to speed on a new 24-channel acceleration monitoring kit, providing critical support and expertise in capturing, logging, and analyzing data." Cavedoni adds that Jeremy's support was so critical that they talked him into staying during the recent Gemini North shutdown so he could make more measurements.

Figure 2.
Interns Hulali Kaapana, Emily Berkson (talking to Data Processing Developer, Kristina Fedorenko), Erini Lambrides, and Erin O'Leary (left to right, back to front) exemplify intern camaraderie at Gemini North.

While on the mountain, Jeremy recalls that he constantly had a smile on his face, "like a kid in a candy store! "Like many interns, Jeremy said his time at Gemini was the "experience of a lifetime," adding that he cannot wait to return, "hopefully as an employee instead of an intern!"

The nature of internships is to provide opportunities for students that offer valuable work experience. It can also challenge them to complete projects that are beyond the scope of what staff can ordinarily do. Gemini has gained much thanks to the efforts of interns over the years, and if this year's trend continues, lots of exciting times lie ahead for future interns at both Gemini sites.

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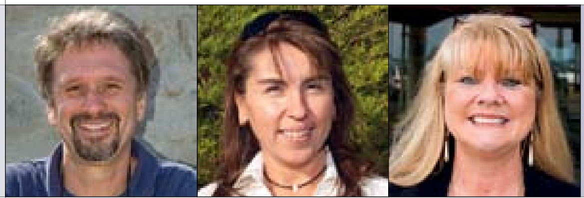

Peter Michaud, Maria Antonieta García, and Janice Harvey

Giving Back

Gemini's guiding principle, "Exploring the Universe, Sharing its Wonders," has rarely been more apparent than in the first few months of 2013.

During this period, two of Gemini's flagship annual outreach programs — AstroDay Chile (held in January), and Hawai'i's Journey through the Universe (held in March) — inspired thousands of students and residents in our host communities of La Serena and Hilo, respectively. For staff and others who participated, these programs offered excellent opportunities for them to share their passion for the stars with the public who support us. They also got to inspire local students who may become our next generation of scientific explorers.

The images that follow strive to capture the essence of exploration that drives both of these programs.

AstroDay Chile

An estimated 2700 visitors descended upon the Outreach Center at the University of La Serena on Saturday, January 12, 2013, for Gemini's annual celebration of AstroDay Chile. Because Gemini South hosted it this year during the peak summer season, both visitors and local residents experienced the thrill of exploring the universe from a Chilean point of view.

Dignitaries cut a ceremonial ribbon to officially open AstroDay Chile 2013. This year 17 institutions participated in the program, including Association of Universities for Research in Astronomy (AURA) facilities, Cerro Tololo Inter-American Observatory, and the Southern Astrophysical Research Telescope. Other participants came from as far away as Santiago, as well as a number of public observatories in the La Serena/Coquimbo area (Region 4).

The head of the university, Nibaldo Avilés, stated the importance of astronomy to the university. "Responding to a community request and obvious need, the University of La Serena is offering the Bachelor in Astronomy degree for the first time. We hope to continue creating stronger ties in the area of scientific research but also contributing to tourism."

Gemini scientist Rodrigo Carrasco explains distances in the universe. Gemini and AURA Observatories' staff played an integral role in making the program a success, while all of the participating organizations made this year's activities especially dynamic and engaging.

La Serena's Mayor Roberto Jacob (left) visits the Gemini display at the University of La Serena's Outreach Center; he is joined by Gemini's Deputy Director, Nancy Levenson, astronomer Peter Pessev, and engineer Pedro Gigoux (left to right). Jacob remarked that La Serena and Hilo, Hawai'i, have been sister cities united under the stars since 2000. "It is an honor to host such great research centers in our city," he said, "and we look forward to find out what projects each one of you are developing these days."

Ariel López explains the positions of celestial objects, while Viviana Bianchi, a volunteer from Argentina, shares educational booklets with possible future scientists.

For the almost 3000 people who joined in AstroDay Chile 2013, a wide assortment of displays and activities captured both the attention and imagination of participants.

Journey through the Universe Hawai'i

Journey through the Universe (JttU) 2013 was the ninth and biggest year yet for the program. Over 50 scientists and engineers went out to local Hawai'i Island schools and reached almost 8000 students. "This program is alive and well in Hawai'i," said Jeff Goldstein, who started the U.S. national JttU program. "Thanks to Gemini, the Big Island community, and all of the Mauna Kea observatories, the spirit of TttU continues to grow in many new and exciting ways — ways that even I couldn't have even imagined when we started the program back in 1991."

Gemini's Janice Harvey, who directs the program, sees this year's success as only a glimmer of what to expect next year, noting specifically that 2014 will be our 10th anniversary. "We are going to pull out all the stops to make it even better and more inspiring than it was this year," she said.

JttU 2013, though, will be a tough act to follow, as illustrated by the images shown here.

Students at Waiakea Intermediate School experiment with light using a "Light House," which demonstrates reflection, refraction, and how telescopes collect light to study the universe.

Gemini PIO Manager Peter Michaud explains condensation, clouds, and sublimation with a block of dry ice later used to make a comet for second grade students at Hilo's E.B. DeSilva School.

Subaru Observatory's Olivier Guyon shows students at Ha'aheo Elementary School the surface of the Sun using a safe solar filter.

Gemini Astronomer Richard McDermid uses an exercise ball to engage students in understanding the scale of our Solar System at E.B. DeSilva Elementary School.

Robotic insect critters are used to challenge Waiakea Intermediate School students as they solve problems and understand the mechanics of mobile mechanical devices.

This image showing the propagation of the Gemini South laser guide star system is dedicated to the memory of Vincent Fesquet. Vincent worked tirelessly to make the Gemini South laser guide star system work efficiently and reliably. This image shows the laser propagating for the first time since Vincent's passing. Leave your memories of Vincent at: www.gemini.edu/staff/vfesquet

Special thanks to the W.M. Keck Observatory and Pete Tucker for the extra assistance necessary to make this laser propagation possible in early December 2013.

Image by Manuel Paredes. Gemini Observatory/AURA.

AURA

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