# *Gemini*Focus

January 2017

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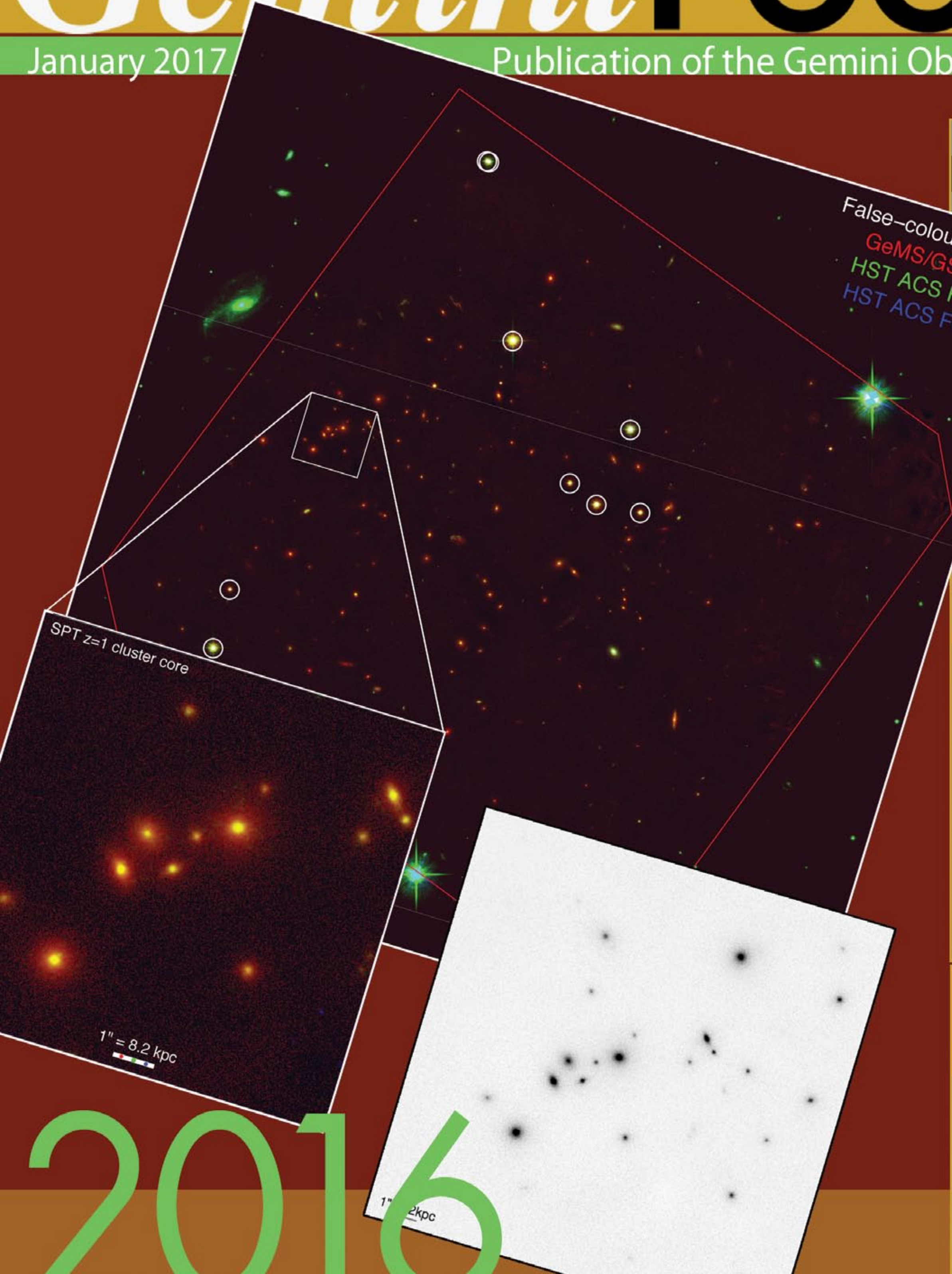


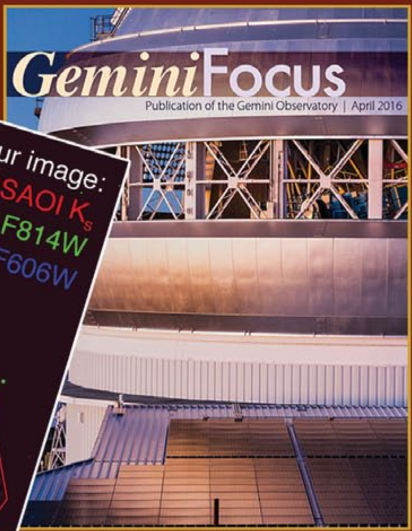



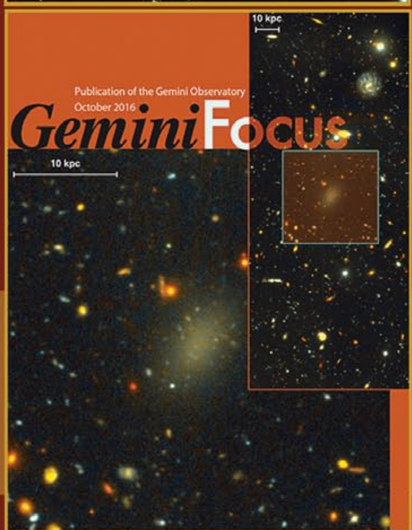


# 2016 YEAR IN REVIEW

## ON THE COVER:

*Color composite image of the galaxy cluster SPT-CL J0546-5345, comprised of Gemini GeMS/GSAOI and HST data. White inset at right bottom shows Gemini $K_s$ image of the region. The article on this work begins on page 3. Also shown are the covers from April, July, and October issues of GeminiFocus.*



Gemini*Focus*

*January 2017 / 2016 Year in Review*

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# Director's Message

## *Gemini Brings 2016 to a Successful Close*

Gemini is looking back at the rapid passing of a another successful year — the first full one after the transition to operating the Observatory on a 25% reduced budget, which translates to ~25% less staff. Of course a few things are moving forward more slowly, but, overall, the Observatory is as productive as ever and continues to operate smoothly. In fact, we have introduced several new and innovative ideas into our operations and instrumentation programs, as described in the following overview.

With December comes the end of the first full year of Base Facility Operations at Gemini North — that's a full year without nighttime staff at the telescope on Maunakea. Both our telescope operators and observers have been enjoying the increased oxygen in Hilo, and we have not seen any negative impact on our technical downtime. To the contrary, from the control room in Hilo the team operating the Differential Speckle Survey Instrument (DSSI) established a new record this past January for the number of targets (>130) observed in a single night!

The first night of Base Facility Operations at Gemini South began on November 14th, as described in this issue's *News for Users* for January 2017. We still retain the option of observing from Cerro Pachón or Maunakea — especially in instances where a visitor instrument requires it — but we anticipate that summit observers will be rare in the future.

2016 was also the first full year of Fast Turnaround programs, which offer researchers in the Gemini community 10% of the time on both telescopes every month; participants typically obtain their data as quickly as six weeks after applying for time. Additionally, the Subaru community joined this Gemini program in May in exchange for time on the Subaru telescope. We continue to improve the Fast Turnaround schemes and will gradually offer all modes and all instruments in the regular Call for Proposals.

In 2016 we saw a surge of contacts from Principal Investigators offering potential visitor instruments. Consequently, we now have over 10 instruments in the queue to exploit Gemini's state-of-the-art telescope facilities. The Observatory continues to invite inquiries from all instrument teams that would like to bring their instruments to our telescopes. Over the past 12 months we have welcomed back some old friends — including DSSI, Texas Echelon Cross Echelle Spectrograph (TEXES), Phoenix, and Gemini Remote Access to CFHT ESPaDOnS Spectrograph (GRACES) — all offered in the regular Call for Proposals, as well as some newcomers (*e.g.*, the hyper-precision polarimeter POLISH 2, which visited in November). We also had groups projecting into the future, such as the Immersion GRating INfrared Spectrograph (IGRINS) team, from the University of Texas Austin, that obtained ~ 130 hours of observations for 2018A through the latest round of Large and Long programs; we are looking forward to supporting the IGRINS team and offering this great instrument to the rest of the Gemini community in about a year.

Internally, 2016 was an equally important year, as AURA was awarded a new six-year cooperative agreement to manage the Gemini Observatory — after a long recompetition process launched by the National Science Foundation at the end of 2014. We can now work closely with the Large Synoptic Survey Telescope project and with the National Optical Astronomy Observatory to streamline and coordinate our operations in Chile (and beyond).

Gemini's public education and outreach remained vibrant throughout the year, hosting its 12th and 6th editions of our flagship programs *Journey Through the Universe* in Hawai'i and *Viaje al Universo* in Chile, respectively. These programs paralleled Gemini's many other outreach activities, including the dissemination of numerous press releases that made front page news in national and international publications. And as has become custom over the past few years, Gemini made a strong presence at the recent Society of Women Engineers meeting, joining forces with all the other AURA centers in a large booth to promote engineering positions at the observatories.

Yes, looking back, 2016 was a very successful, productive, and innovative year, and 2017 promises to be exciting as well — with both telescopes fully functional in remote operation mode, more visitor instruments in the queue, and progress being made in upgrades to our facility instruments (*e.g.*, the multi-object spectroscopy mode of FLAMINGOS-2). Also significant, we have procured a new laser for Gemini South (and are in the procurement process for Gemini North); Gemini is rapidly moving towards making laser adaptive optics a true part of our queue operations, rather than it being restricted to a block schedule. Stay tuned, because surely, in 2017, we will continue *Exploring the Universe, Sharing its Wonders!*

*Markus Kissler-Patig is the Gemini Observatory Director. He can be reached at: mkissler@gemini.edu*

Sarah Sweet, Rodrigo Carrasco, and Fernanda Urrutia

# Gemini South Explores the Growth of Massive Galaxy Clusters

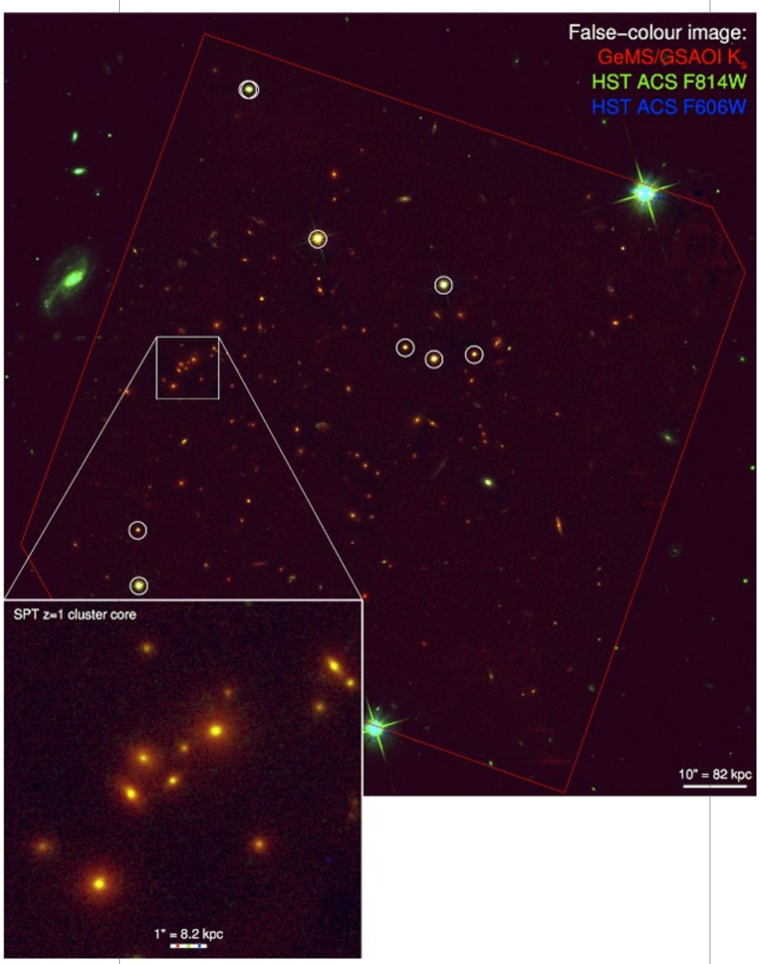
*Using high-angular-resolution images obtained at Gemini South, we have measured, for the first time, the stellar mass–size relation for 49 galaxies in a cluster environment at redshift z ~ 1. Our data suggest that the most likely relationship between stellar mass and size has a constant slope over time. This finding leads us to conclude that the probable evolutionary course for the most massive spheroid-like galaxies since z ~ 1 is either from minor mergers (i.e., when a galaxy grows via accretion of small satellite galaxies), or adiabatic processes (such as outflows from active galactic nuclei), or a combination of both.*

## *The Evolution of Massive Galaxies Over Cosmic Time*

During the past 20 years astronomers have developed a picture for the evolution of the size and structure of galaxies — from the formation of the first galaxies in the early Universe, to what we see today. One of the most important discoveries in the last decade is that the most massive spheroid-like galaxies (*i.e.*, galaxies with masses > $10^{11}$ $M_{Sun}$) in the distant Universe ($z > 1$) are much smaller in physical size than those with the same stellar mass in the local Universe; the effective radii of these massive galaxies at $z \sim 1$ - 4 are observed to be, on average, a factor of 2-6 times more compact when compared with local systems with the same stellar mass. At $z = 0$, massive compact galaxies are very rare; only a few have been found to date. Presumably, the most massive high-redshift galaxies must evolve significantly in size to become present-day passive elliptical galaxies.

**Figure 1.**

*False-color image of SPT-CL J0546–5345 at z = 1.067. Gemini GeMS/GSAOI $K_s$ (this work) = red, HST ACS F814W = green, HST ACS F606W = blue. The red polygon shows the approximate sky coverage of the GSAOI pointings. PSF stars are indicated by white circles. The star near the top of the image with two circles is a binary star. The inset at lower left is a zoom-in of the cluster core. The scale bars in the inset and full image show the angular and physical projected distances at the cluster redshift. The red, green, and blue spots on the scale bar in the inset show the PSF FWHM for each band. North is up and east is left.*




One important open question remains. It concerns how these galaxies grew in size and what main physical mechanism(s) are involved. Mergers of galaxies with similar stellar masses (major mergers), accretion of small satellite galaxies (minor mergers), and rapid mass loss caused by active galactic nuclei (AGN) or supernova winds (adiabatic expansion) could all contribute to the dramatic growth in the size of these galaxies. We can distinguish between these physical mechanisms by comparing the slope of the stellar mass–size relation of the massive high-redshift galaxies with the local sample.

Accurate determination of the stellar mass–size relation depends most strongly on the resolution of the images, the rest-frame wavelength of the observations, and the number of galaxies observed. Superb resolution is required to accurately measure the effective radius for the most compact galaxies at $z > 1$. We need rest-frame observations at wavelengths longer than the 400 nanometer spectral break to restrict the observations to galaxies dominated by the light of the underlying old stellar population. The accuracy of the stellar mass–size relation is also improved as the number of galaxies observed increases. Previous high-angular-resolution images obtained from the ground are limited by the small effective field-of-view of the instruments used for the observations. Given the large field-of-view provided by the Gemini Multi-conjugate adaptive optics System, combined with the Gemini South Adaptive Optics Imager (GeMS/GSAOI), we avoid this problem by simultaneously observing several galaxies in a single field.

## A High-angular-resolution View of Cluster Galaxies at z ~ 1

We used GeMS/GSAOI, the world's most advanced adaptive optics system, to image galaxies in the cluster SPT-CL J0546-5345 at redshift $z = 1.067$. This cluster, detected as part of the 2,500 square degree South Pole Telescope Sunyaev-Zel'dovich survey (Brodwin, Mark, *et al.*, *ApJ*, **721:** 90, 2011), is a massive cluster with a virial mass of $10^{15}$ $M_{Sun}$ and several compact massive spheroid-like galaxies at its center. We imaged the galaxies using the $K_s$ filter at 2.2 microns. The final combined image presents a variation of the Point Spread Function (PSF) Full-Width Half-Maximum (FWHM) between 80-130 milliarcseconds (mas) within the GSAOI 85" x 85" field-of-view (Figure 1) — translating to a physical size between 0.66-1.07 kiloparsecs (kpc) within a field-of-view of 697 kpc$^2$ (1" = 8.2 kpc at the cluster's rest frame). The PSF FWHM achieved with GeMS/GSAOI is, on average, a factor of 1.5 better than the angular resolution provided by the $H_{160}$ filter of the Hubble Space Telescope (HST) Wide-Field Camera 3, which has a

PSF FWHM of 180 mas, and is comparable to that of the HST Advanced Camera for Surveys' F814W (I-band) filter (Figure 2).

## *The Stellar Mass–Size Relation at z = 1*

An accurate calculation of the stellar mass–size relation requires a robust determination of the stellar mass and physical size of the galaxies. We estimated the stellar mass for 49 of the SPT-CL J0546–5345 cluster member galaxies using public codes. We then fit publicly available stellar population synthesis models (used as tools for interpreting the integrated light of galaxies) to the derived photometry assuming a certain Initial Mass Function (which describes how mass is initially distributed within a stellar population).

We selected galaxies with ages older than 10 giga-years and younger than the age of the Universe (details can be found in the article accepted for publication; see end of article). We used the publicly available code GALFIT (Peng, C. Y., *et al.*, *AJ*, **139:** 2097, 2010) to measure the circularized effective radius, defined as $r_e = ab$, where $a$ and $b$ are the effective semimajor and semiminor axis, respectively, as a measurement of the physical size of the galaxies. The $K_s$-band stellar mass–size relation for the SPT-CL J0546-05345 cluster member galaxies at $z = 1$ and SDSS galaxies at $z = 0.1$ is shown in the top left panel of Figure 3. The stellar mass–size relation at $z = 1$ is offset from the local relation by ~ 0.21 dex, with a slope consistent with the slope seen for galaxies with same stellar masses in the local Universe.

The results, obtained here for the first time for galaxies in a cluster environment, are consistent with previous findings for field galaxies, indicating that the primary mechanism for galaxy growth in size since $z \sim 1$ in clusters is either minor mergers or adiabatic expansion due to AGN mass loss winds, or both. If major mergers were a dominant source of the evolution in the stellar mass–size relation, then the most massive galaxies would experience the most rapid growth; the slope of the stellar mass–size relation would then be steeper in the local Universe than at $z = 1$ — an effect we do not see in our results.

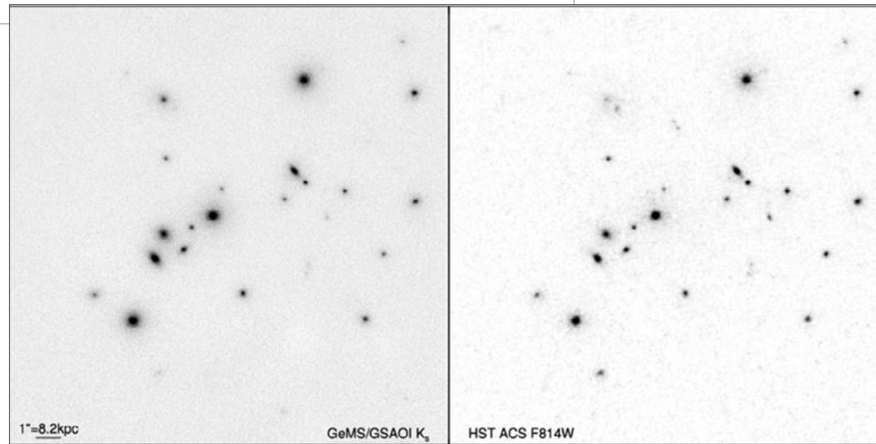



**Figure 2.**
*The core of the SPT-CL J0546-5345 galaxy cluster at z = 1.067. Left: GeMS GSAOI $K_s$ image. Right: HST ACS F814W image. The scale bar at the lower left shows the angular and physical projected distance at the cluster redshift. North is up and east is left.*

Figure 3 also shows the stellar mass-size relation for the cluster SPT-CL J0546-5345 compared with other work in the literature. Our results emphasize the importance of high-resolution observations at the rest-frame wavelength of the cluster galaxies. Observations at shorter wavelengths — *i.e.,* at the B-band and U-band rest frame (top-right plot in Figure 3) — show a shallower slope and larger scatter in radius, due to ultraviolet-bright star-forming knots. In addition, the effect of resolution (bottom right plot in Figure 3) can lead to misinterpretation of the true physical mechanism involved in the extraordinary growth in size of the massive galaxies over time.

With this research we have demonstrated that wide-field, near-infrared adaptive optics observations, such as those we obtained with GeMS/GSAOI, are critical in order to characterize the galaxy population at high redshifts. GeMS is limited by the magnitudes of the natural guide stars (NGS) used to compensate for tip-tilt and plate-scale mode variation (currently R < 15.5 magnitude). High-redshift clusters are located in regions where bright stars are absent or have magnitudes fainter than the current limit. The new NGS

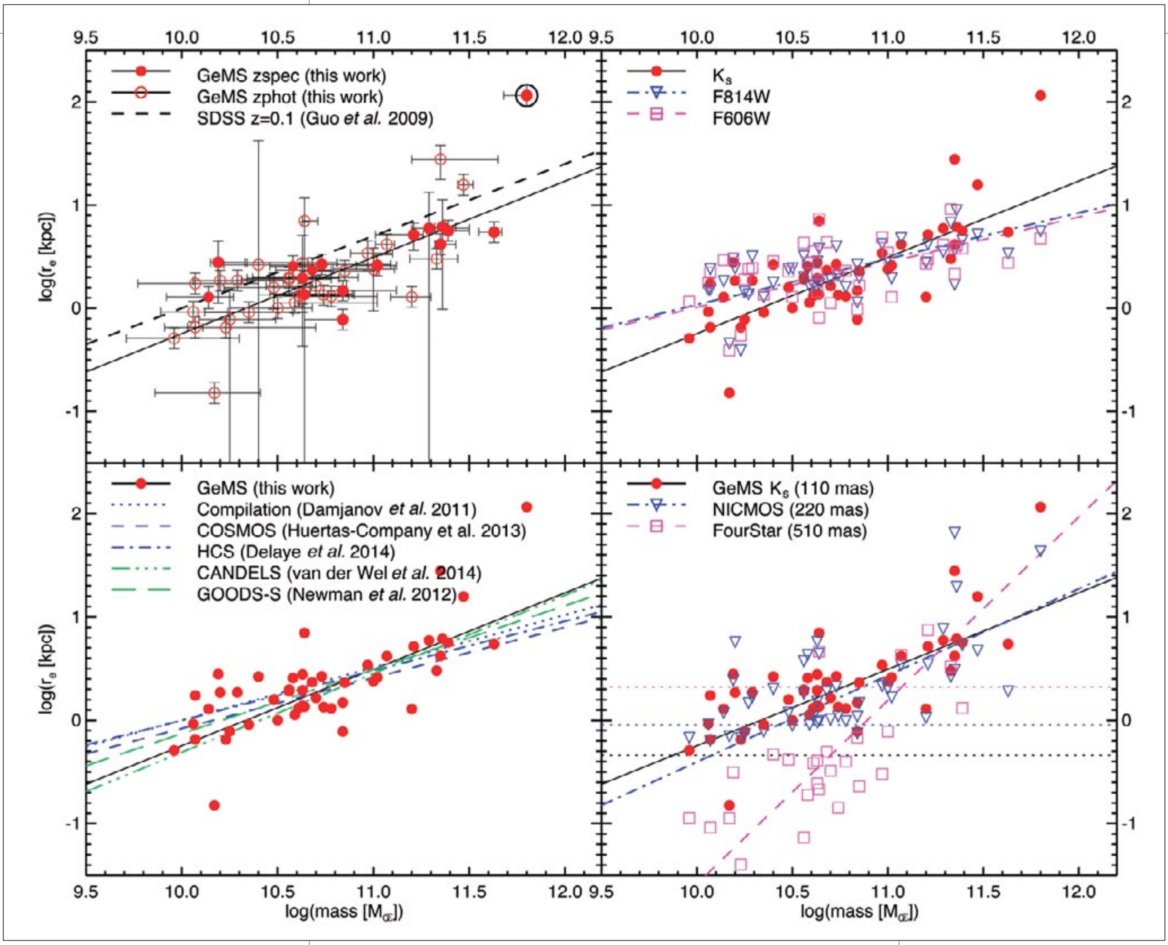



**Figure 3.**
*Stellar mass-size relation for the cluster SPT-CL J0546-5345 compared with other work in the literature. Top left: $K_s$-band stellar mass-size relation at z = 1. The relation, defined by our cluster members, has a slope of β = 0.74, consistent with, but offset by, 0.21 dex from the z = 0 relation shown as the dashed line. Both relations trace the underlying stellar population. Top right: stellar mass-size relation for the SPT cluster measured in GeMS/GSAOI $K_s$ (red filled circles and black solid line), HST ACS F814W (rest-frame B-band shown as blue down triangles and dot-dashed line), and F606W (rest-frame U-band as magenta squares and dashed line) bands. Bottom left: other z ~ 1 samples from the literature, measured in various rest-frame wavelengths. Rest-frame B-band measurements are shown in blue, and rest-frame V-band in green. Bottom right: the effect of resolution on the stellar mass-size relation. Filled red circles and solid line depict our GeMS/GSAOI $K_s$-band imaging (FWHM ~ 110 milliarcseconds). Blue down triangles and dot-dashed line show measurements from our imaging smoothed to the resolution of Gemini's Near-Infrared Camera and Multi-Object Spectrometer (220 milliarcseconds); magenta squares and dashed line are from smoothing to the resolution of the FourStar infrared camera (510 milliarcseconds) at the Magellan Baade 6.5-meter telescope at Las Campañas Observatory in Chile. The horizontal dotted lines indicate the physical size at z = 1, which corresponds to the resolution of each instrument.*

system (NGS2) at Gemini South will extend the guide stars accessible to GeMS by 2-2.5 magnitudes deeper than the current system. This new capability will allow us to extend the observations to massive galaxy clusters beyond redshift $z \sim 1$ in order to determine the main cause of galaxy growth in size since cosmic high noon.

This work is accepted for publication in *Monthly Notices of the Royal Astronomical Society* and is availabe at ***this site***.

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Andy Skemer

October 2016

# A Gemini Spectrum of a World Colder than a Night on Maunakea

*Gemini North's unique spectroscopic capabilities at 5 microns combined with queue scheduling delivered challenging deep spectra of a nearby, very cool brown dwarf. The results provide a strong analog of a Jupiter-mass planet and the coolest known compact object outside of our Solar System.*

For more than 50 years, scientists have observed our Solar System's gas giant planets in the infrared. At these wavelengths, it is possible to measure their intrinsic luminosities, chemical abundances, and thermal profiles. We now live in an age where thousands of planets have been discovered orbiting other stars. For a handful of these worlds, we are beginning to study their individual properties in a way that emulates Solar System studies from 50 years ago.

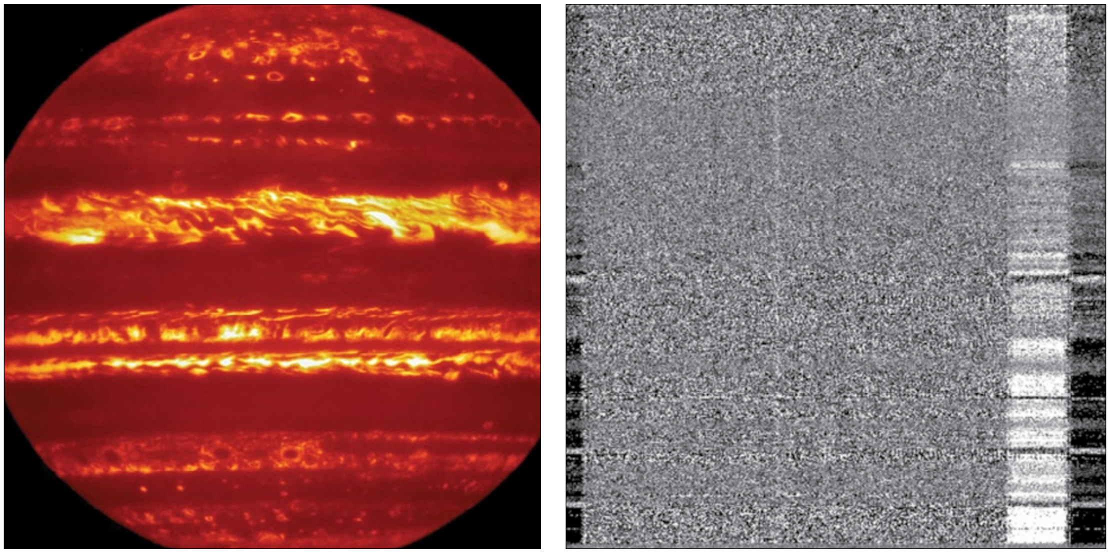


**Figure 1.**
***Left:*** *VLT image of Jupiter at 5 microns Image credit: Leigh Fletcher*
***Right:*** *Gemini spectrum of WISE 0855 at 5 microns (the faint white vertical line).*

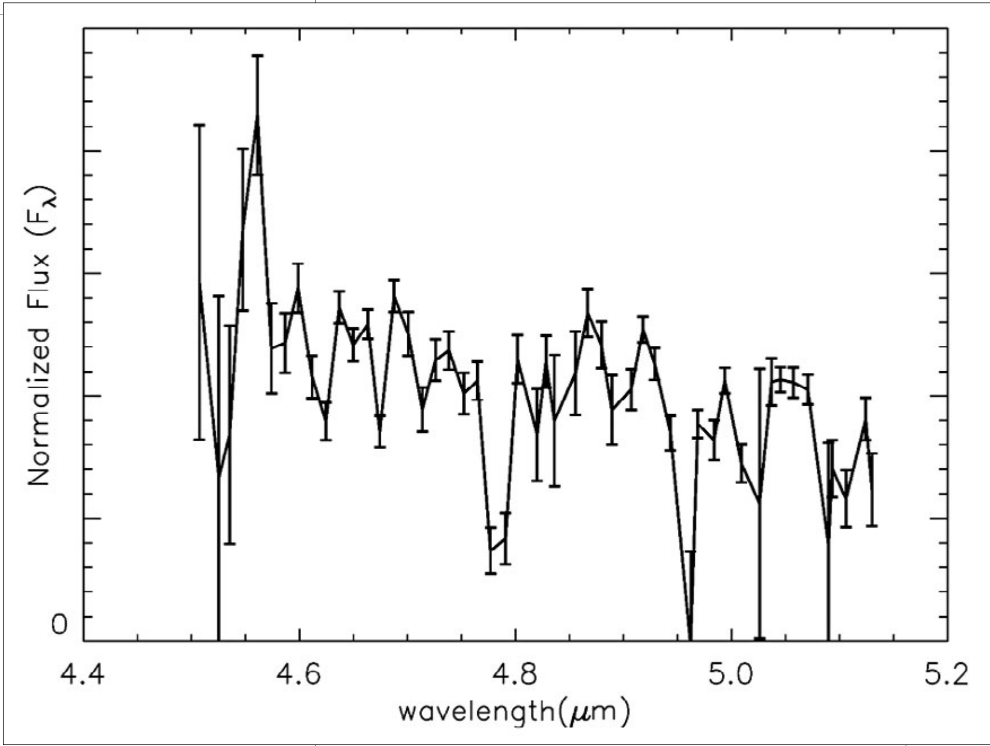



**Figure 2.**
*GNIRS spectrum of the 250 K brown dwarf, WISE 0855. WISE 0855 is our first opportunity to study an extrasolar planetary-mass object that is nearly as cold as our own gas giant planets.*

The difficulty of studying exoplanets is that they are much fainter than their host stars. Dedicated instruments, such as the Gemini Planet Imager, can detect the light of warm Jupiter-mass analogs. However, the capability does not yet exist to image a planet as cold as Jupiter around another star.

An alternative approach is to study free-floating planets and brown dwarfs. These objects slowly cool as they radiate away the energy from their gravitational collapse, with no core fusion to create new energy. Brown dwarfs can be found over a much wider temperature range than exoplanets. And temperature, rather than mass, dominates the appearances of self-luminous planets and brown dwarfs.

By far the best extrasolar analog to Jupiter is the brown dwarf WISE 0855. Kevin Luhman of Pennsylvannia State University discovered this free-floating object in 2014 while searching Wide-field Infrared Survey Explorer (WISE) satellite data for extremely red objects with high proper motions. Using the NASA Spitzer Space Telescope, Luhman determined that WISE 0855 is just two parsecs from the Sun; together with its photometry, this implies an effective temperature of ~ 250 K (the coldest known compact object outside of our Solar System) and a mass of 3-10 $M_{Jupiter}$.

When WISE 0855 was discovered, a flurry of interest in characterizing its atmosphere ensued. Models predict that at 250 K, WISE 0855 should have a spectrum dominated by water vapor, phosphine, and perhaps a subtle influence from water clouds. But the method typically used to study brown dwarf atmospheres — near-infrared spectroscopy (1-2 microns) — is infeasible on current facilities due to WISE 0855's intrinsic faintness (J = ~ 25 magnitudes). Counterintuitively, the best way to obtain a spectrum of WISE 0855 is with ground-based M-band (5 micron) spectroscopy, which, due to the sky background brightness, is usually far less sensitive than other wavelengths. As WISE 0855 has an M-band magnitude (measured from WISE) of 13.9, it is easier to detect at M-band than J-band. There are currently no space-based 5-micron spectrographs.

## *Enter Gemini*

The previous faintest spectrum ever taken from the ground at M-band was a Gemini Near-Infrared Spectrograph (GNIRS) spectrum of Gliese 570 D which is 1.6 magnitudes brighter than WISE 0855. Scaling from previous observations, a low-resolution, low signal-to-noise GNIRS spectrum of WISE 0855 was just barely possible in a 14-hour integration (29 hours including overheads). But there are always practical considerations when working at an instrument's limits. Could we keep an invisible object moving 8 arcseconds per year in the slit for 29 hours over the course of many nights? Would we see enough of a trace in two-hours clock time to be able to co-add from night-to-night? In the end, we saw a faint trace after our first two-hour observation block, and two months later, we had a reasonable spectrum (Figures 1 and 2).

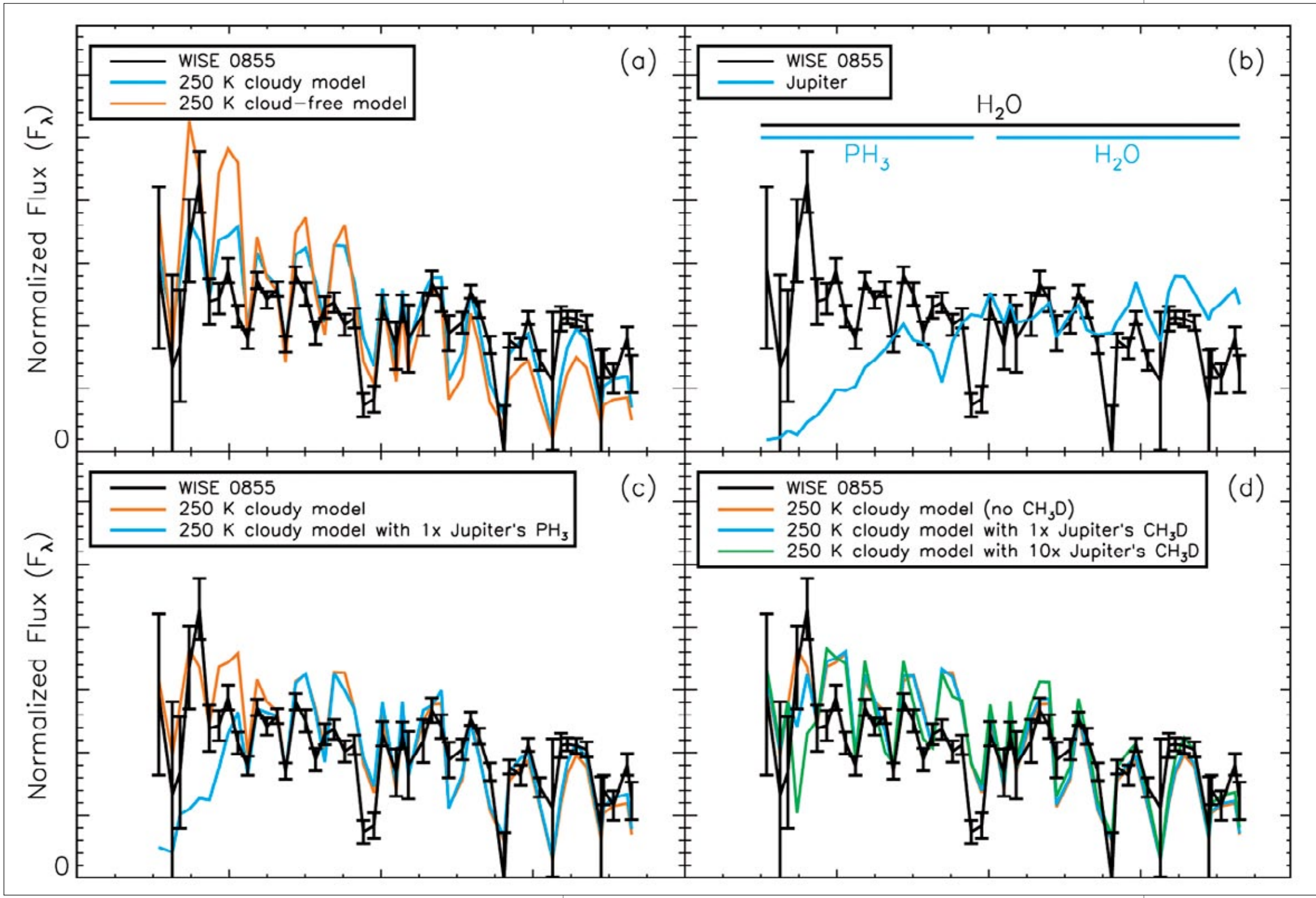
This observation could not have been done anywhere else. The combination of Gemini's low-emissivity silver primary coating, queue-mode scheduling (that provided two hours per night over 14 nights), dry Maunakea weather, and a fantastic observing staff were all necessary to obtain such a faint spectrum. Before our Gemini observation, there had never been an M-band spectrum of a brown dwarf or extrasolar planet colder than 700 K.

As theoretical work suggested, WISE 0855 should have a spectrum dominated by water vapor. When we fit the Wise 0855 data to our initial cloud-free model, all of the wiggles in the spectrum were indeed the result of water vapor but their signature appeared more muted. Borrowing a well-established technique from our friends who study Jupiter, we inserted an optically thick water cloud deep in the photosphere of our model atmosphere, to see if it would produce the muting seen in our spectrum. The cloudy model fit significantly better than the cloud-free …one (Figure 3, upper left). However, water clouds are notoriously difficult to model. WISE 0855 is just our first chance to apply these models to an extrasolar object.

## Measuring Up

By far the closest analog to WISE 0855 is Jupiter, which has a temperature of ~130 K. We compared our WISE 0855 spectrum to one of Jupiter's and noticed striking similarities from 4.8-5.15 microns (Figure 3, upper right), wherewhere water vapor absorption features dominate both objects. Shortward of 4.8 microns, the spectra diverge. Jupiter shows phosphine absorption, while WISE 0855 does not (Figure 3, lower left).

**Figure 3.**
***Upper Left:*** *Water cloud models fit better than cloud-free models.*
***Upper Right:*** *WISE 0855 looks strikingly similar to Jupiter from 4.8-5.15 microns. Shortward of 4.8 microns, the spectra diverge as Jupiter is dominated by phosphine, while WISE 0855 is dominated by water vapor.*
***Lower Left:*** *Our WISE 0855 spectrum is sensitive to a Jupiter abundance of phosphine, but none is seen.*
***Lower Right:*** *Our WISE 0855 spectrum is marginally sensitive to deuterated methane, but the feature is blended with water vapor features that are not well understood.*



Phosphine has long been held as evidence of turbulent mixing in Jupiter's atmosphere. In chemical equilibrium, phosphine is converted to phosphorus trioxide at temperatures less than ~1,000 K. In Jupiter, hot phosphine-rich gas from the interior is mixed into the photosphere at a faster rate than the phosphine is destroyed. WISE 0855 does not show the same mixing behavior, despite the fact that it is warmer than Jupiter and should not have to mix phosphine as far. This result will be studied in more detail in a future paper.

## Future Explorations

WISE 0855 will be an early target of the James Webb Space Telescope (JWST). But surprises in its spectrum suggest that we need to continue iterating our theoretical understanding of cold brown dwarfs and exoplanets before JWST launches (Figure 3, lower right). This Is Gemini done with WISE 0855? Hopefully not; having solved many of the technical problems that make faint thermal-infrared spectroscopy so difficult, we have been allocated time to pursue its 3.8-4.1 micron spectrum. At these wavelengths, we expect to see the influence of methane chemistry instead of water chemistry, and we will refine estimates of WISE 0855's luminosity, which directly impacts its temperature and mass.

We also are continuing to study the coldest brown dwarfs at M-band. Previous observations only went down to 700 K. There's a big jump from 700 K to 250 K, which we expect contains the formation of water clouds. With five more brown dwarfs spanning the 250-700 K gap, we hope to study the depths of water absorption lines, which models predict will increase with decreasing temperature until water clouds start to mute them, and/or remove a significant fraction of the available water vapor.

Gemini was designed to do thermal infrared spectroscopy, and Maunakea is the best site on Earth to do it. From the telescope, to the weather, to the instrument and observers, a lot had to work right to complete this observation. It's a testament to Gemini that when WISE 0855 was discovered, GNIRS was ready and able to obtain a spectrum for our team's work.

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Brian Nord and Elizabeth Buckley-Geer



# A Case of Warped Space: Confirming Strong Gravitational Lenses Found in the Dark Energy Survey

*Spectroscopic observations with the Gemini Multi-Object Spectrograph at Gemini South provide precise redshifts that confirm strong gravitational lensing systems discovered in early Dark Energy Survey (DES) data. These confirmations are the first at galaxy- and galaxy-cluster scales in the multi-year effort of lens follow-up enabled by a Large and Long program.*

Massive astronomical objects sufficiently warp space-time to change the path of light on its way from distant galaxies to an observer. Consequently, strong gravitational lensing systems are revealed to us by the distorted images of these galaxies.

Most of the strong lensing systems discovered during the last decade were found by searching through existing data or through new observational campaigns. These investigations across many wavebands — from the optical to the millimeter — have resulted in ~ 1,000 candidates or confirmed lensing systems of varying masses, with distorted galaxy images in arcs of varying sizes around them.

The ***Dark Energy Survey*** (DES; @TheDESurvey) — an ongoing international, collaborative effort to produce the largest and deepest contiguous map of the southern sky to date in optical wavelengths — has the potential to add to the roster twice as many strong lenses in the optical as have ever been discovered across all wavelengths.

Finding and confirming candidates are the first steps in measuring cosmic structure and dark energy with strong lenses. The results will help us to understand why the Universe is accelerating and not being slowed by the mass it contains.

## When Space Gets Warped

One maxim of Einstein's Theory of General Relativity is that space-time — the concept that space and time are one — tells energy how to move, and energy tells space-time how to curve. Gravitational lensing demonstrates both of these concepts: the path of light traveling from a distant object (like a galaxy) is deflected by a depression in the fabric of space-time caused by a massive object nearer to us. The more massive this intervening lensing object, the larger the crater, and the more distorted the observed image of the distant *source* galaxy.

Gravitational lenses act like terrestrial lenses made of plastic or glass, bending light in ways we can model well with geometric optics; the equations have multiple simultaneous solutions, which describe the different paths light can take from a single source, as well as the amount of magnification in the lensed image. A single source galaxy can appear highly magnified and have multiple images — both telltale signatures of a strong lensing system.

## What Can Strong Lenses Tell Us about the Universe?

With strong gravitational lensing we can examine in detail galaxies normally too faint to observe. The observations also provide an avenue for studying galaxy evolution at epochs earlier in the Universe than would be available otherwise. The total lensing mass and its spatial distribution dictate the morphologies of lensed images. By measuring the amount and type of distortion of the source image, we can learn more about the mass distribution (including that due to dark matter) in the lensing galaxies or clusters.

Moreover, particular configurations of lenses can help constrain dark energy models. In systems with two or more source galaxies

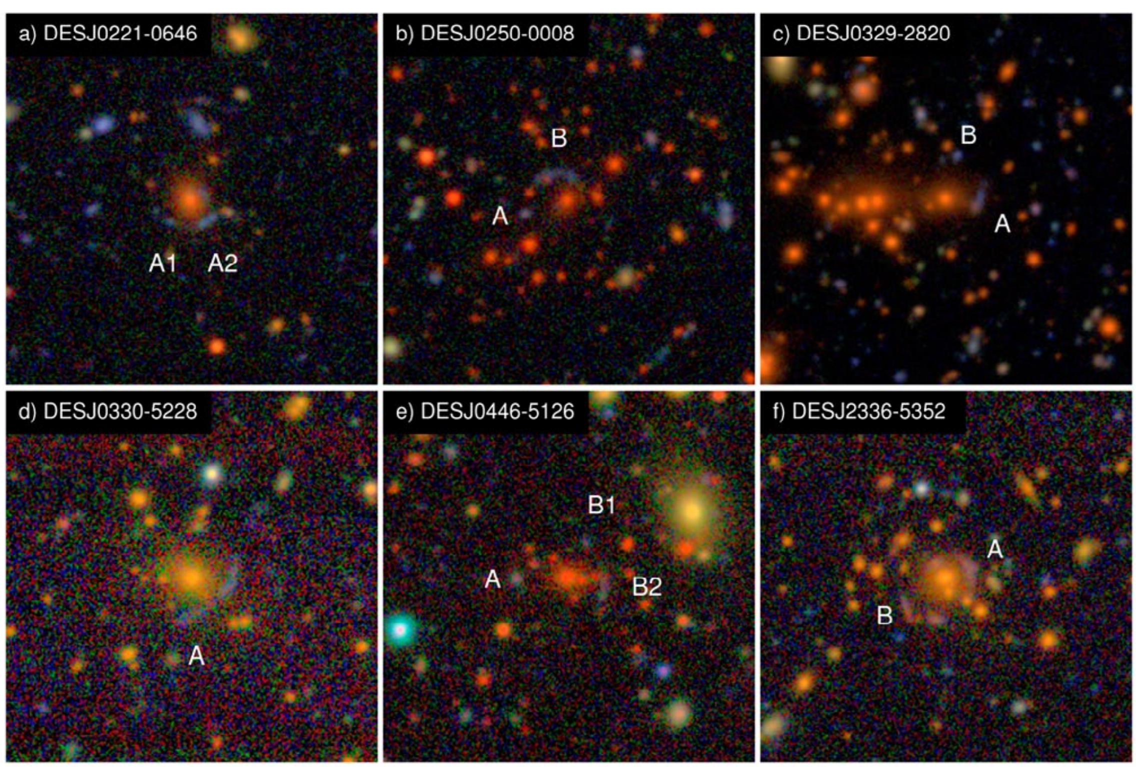



**Figure 1.**
*Color images of six strong lenses confirmed with Gemini South spectroscopic follow-up: a) DES J0221-0646, b) DES J0250-0008, c) DES J0329-2820, d) DES J0330-5228, e) DES J0446-5126, f) DES J2336-5352. Each of these systems is a galaxy group or richer cluster, but just one or a few galaxies near the center of the cluster cause most of the lensing. (All figures reproduced from Nord* et al.*, 2016.)*

along the line of sight behind the lens (*e.g.*, SDSS J0946+1006, which shows multiple concentric rings) the relationship between the distances and the lens mass contains information about the dark energy density. However, these are rare: only 10 are expected in the entire DES footprint (Gavazzi *et al.*, 2008). Also, time-delay measurements of variable-luminosity objects, like lensed quasars, can allow for measurements of the Hubble constant (Refsdal *et al.*, 1964).

We see a variety of morphologies in the first galaxy- and galaxy-cluster-scale lenses discovered in early DES data sets, shown in Figure 1; the lensed sources range in redshift, $0.80 < z < 3.2$. The STRong-lensing Insights into Dark Energy Survey (STRIDES; Treu *et al.,* 2015) program aims to discover and follow up new time-delay lenses in DES data. Under these auspices, we have also discovered and confirmed two lensed quasars at $z \sim 1.6$ and $\sim 2.4$ (Agnello *et al.*, 2015). Although these discoveries were made using Magellan/Baade, our Gemini Large and Long program is providing the capability for future confirmations.

## Detective Work

DES is a deep-sky survey that covers 5,000 square degrees (sq. deg.) of the southern Galactic Cap in five optical filter bands (g, r, i, z, and Y). The main instrument for DES is the Dark Energy Camera (DECam), a wide-field (3 sq. deg.) camera mounted on the Blanco 4-meter telescope at the Cerro Tololo Inter-American Observatory in the Chilean Andes (Flaugher *et al.*, 2015). The survey has finished three out of the planned five years. The Science Verification (SV) season took place after commissioning in late 2012 before the official science survey began. The SV data cover 250 sq. deg. (< 5% of the full area) and provide the imaging data for this work.

Searching through this area of sky is the first challenge in finding lenses. A team of ~ 20 DES scientists visually scanned the SV sky area, looking primarily for morphological features — multiple images, arcs, and full (Einstein) rings. We first performed a non-targeted search of the entire SV area, without focusing on any particular fields or objects. We then undertook a targeted search in the fields of galaxy clusters in the DES footprint. The redMaPPer cluster-finder (Rykoff *et al.,* 2014) provided optically selected clusters. Overlapping fields of South Pole Telescope (SPT) data provided clusters selected with the Sunyaev-Zel'dovich effect (Bleem *et al.*, 2015).

The resulting list of candidates was then refined by a group of three expert scanners, who reduced the total number of highly ranked candidates to 53.

We also predicted the number of lenses we could find in DES by comparing our list to a different sample of highly ranked candidates/confirmed lenses found in the Canada-France-Hawai'i Telescope Legacy Survey (CFHTLS) Strong Lensing Legacy Survey (S2LS; More *et al.*, 2012) — including source galaxies that survived a cut on the DES magnitude limit (24.5 magnitude in g-band). There may be over 2,000 similar lenses in the full DES area, and about 100 in the SV region. While we accounted for the relative sky areas and depths of the two surveys, we had no mechanism to affirm the efficiency of human visual inspection.

## Confirming Lenses with Spectroscopic Follow-up

The next puzzle piece we needed was confirmation that a source galaxy lies beyond the putative lensing galaxy. This requires a sufficiently precise spectroscopic measurement of the source galaxy's redshift. Photometric redshifts provide a measure of distance, but they are relatively imprecise and much less reliable for the more remote galaxies likely to be lensed.

To measure redshifts, we look for specific features, like emission or absorption lines, in the spectra of source galaxies: the higher the redshift, the further these features shift from their rest wavelength. We use the R150 grating in conjunction with the GG455 filter to obtain spectra with a wavelength coverage of 4500-10000 angstroms (Å). For the sources that we expect to be late-type emission line galaxies, this would allow us, in many cases, to detect [OII]3727 to $z \sim 1.7$, H-beta to $z \sim 1.0$, and Lyman-alpha in the range $2.7 < z < 7.2$. We use the B600 grating to obtain spectral coverage of 3250-6250 Å, which would allow us to detect sources with $z > 2.0$ that emit Lyman-alpha.

We acquired spectroscopic data for 21 of the 53 systems: 17 were observed at Gemini South (taken through the Gemini Large and Long program), and five were observed with the Inamori Magellan Areal Camera and Spectrograph at the Magellan/Baade telescope (with an overlap of one system). We confirmed six strong lensing candidates with Gemini South, rejected two, and the status of 13 remain inconclusive. For the rejected systems, we found that the putative source galaxies were actually foreground galaxies. The inconclusive systems may have spectral features at higher wavelengths, which would require the use of other instruments or telescopes.

Let's look in detail at some of the confirmed systems. Figure 2 shows spectra of the source galaxy images A1 and A2, along with images of the lensing system DES J0221-0646. Taking into account the absence of other spectral features, we assign the features at 4535 Å to be Lyman-alpha, which gives a redshift of ~ 2.752, placing it behind the redshift 0.672 lensing galaxy.

The middle color image of Figure 2 shows an Einstein radius estimated by manually fitting a circle that passes through the spectroscopically confirmed source images, where the center is chosen to be the arcs' center of curvature. With these radii, we estimated the mass enclosed within that circle. This system,

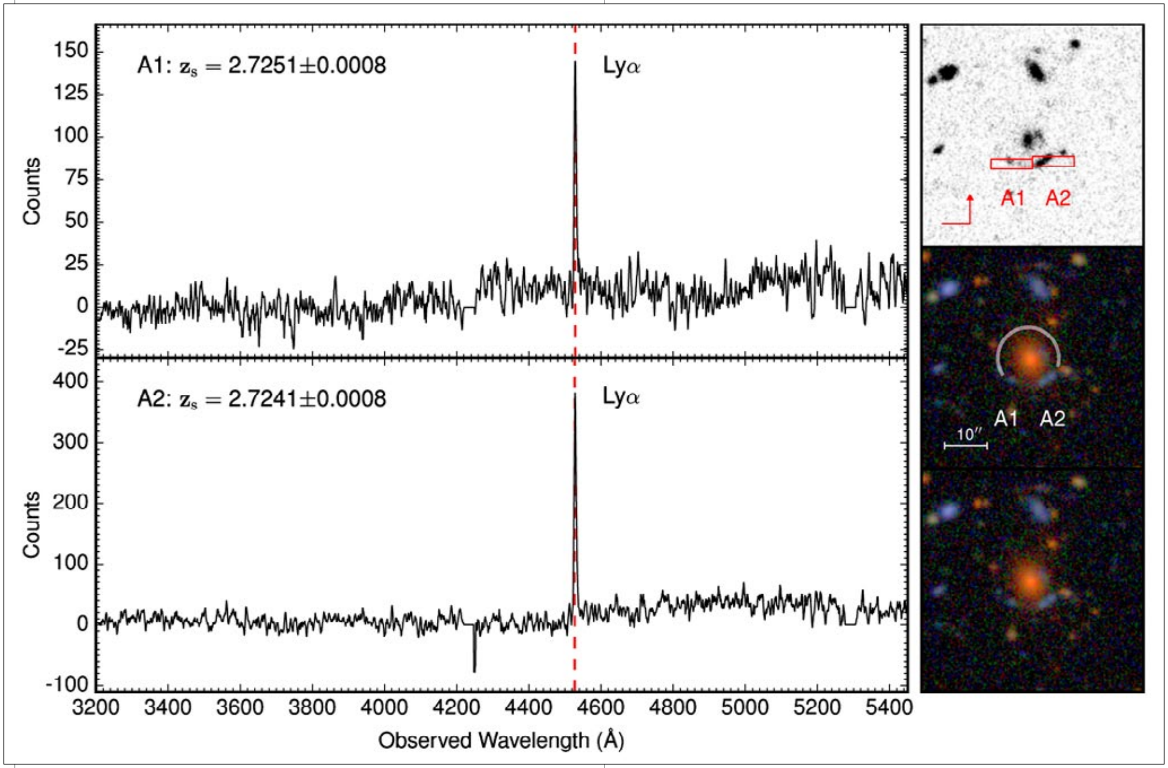



**Figure 2.** *DES J0221-0646. The spectra for source images A1 and A2 are shown on the left. The gray-scale DES g-band image in the upper right shows where we placed the GMOS slits as needed to optimize flux from the source images. In the color co-add image in the middle right panel, the Einstein radius is marked by a white arc.*

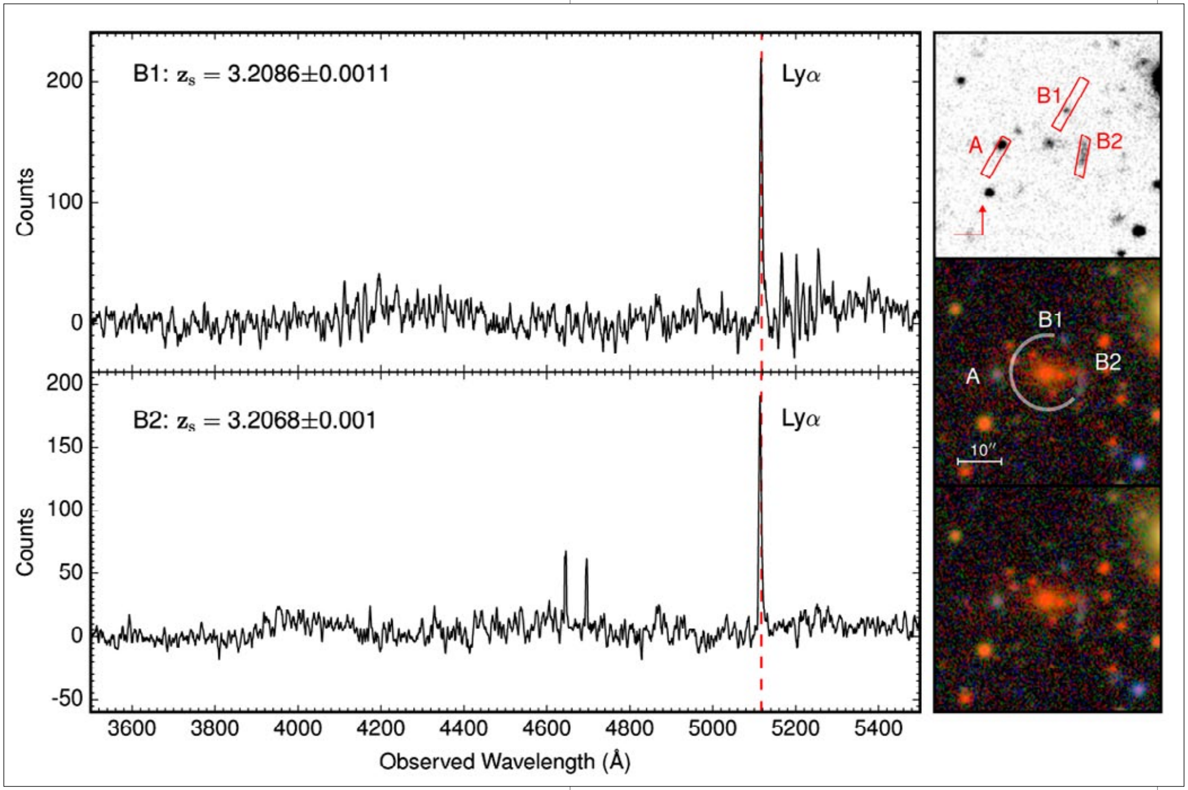



**Figure 3.**
*DES J0446-5126. The spectra for source images B1 and B2 are shown on the left. The spectrum for A is not shown, but has an emission line consistent with an interpretation as a foreground object.*

like the others from this confirmed sample, are challenging to model in detail for a precise mass measurement: while there are multiple images of the lensed galaxy, they both occur on one side of the lensing galaxy. We would need well-resolved *counter-images* for a more precise measurement. The limited resolution of DES images obscures some lensing features, especially for systems with smaller (< 3″) Einstein radii.

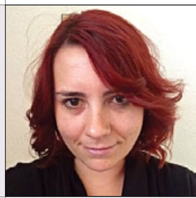
In Figure 3, we see another confirmed lensing system, DES J0446-5126. Prominent Lyman-alpha emission lines in both arcs B1 and B2 occur at the same observed wavelength of 5117 Å, originating in a single source at redshift 3.2. The object labeled A also has emission lines (not shown), which we interpret as [OII]3727 and [OIII]5007: this must then be a foreground object at redshift 0.17.

## A Warped Future

The spectroscopic observations taken through the Gemini Large and Long program made it possible to confirm six new gravitational lensing systems in DES data. We are currently reducing spectroscopic data from the 2nd season of Gemini Large and Long program observations on GMOS South. We are also developing and exploiting automated lens-finding methods, such as ring-finders, arc-finders, and machine-learning algorithms. With these tools we will continue to search for the lenses that can reveal the most about dark energy and the cosmic expansion rate. Large cosmological surveys, like DES and the Large Synoptic Survey Telescope (LSST), will have a plethora of data on strong lensing systems. Our main challenges will be not only to obtain complete and pure samples of lenses, but also to find those precious few systems that enable dark energy science.

*Brian Nord is a cosmologist and postdoctoral researcher at Fermi National Accelerator Laboratory in Batavia, Illinois. He can be reached at nord@fnal.gov or on Twitter @briandnord.*

*Elizabeth Buckley-Geer is a scientist at Fermi National Accelerator Laboratory. She can be reached at buckley@fnal.gov.*



Jennifer Andrews

# Dusting the Universe with Supernovae

*Long-term observations made with the Gemini Multi-Object Spectrograph at Gemini South, combined with Spitzer space telescope data, reveal how core collapse supernovae can make an important, yet largely unrecognized, contribution to the overall dust budget of the Universe.*

**Figure 1.**
*GMOS-S g′, r′, and i′ color composite image of SN 2011ja from April 2012 (day 112). In the original image, the supernova looks red due to a combination of bright hydrogen (Hα) emission, strong extinction around the object, and new dust formation.*

Stars more than eight times the mass of our Sun end their lives in fantastic explosions we call core collapse supernovae (CCSNe). Most common are Type II-Plateau (Type II-P) events, which show broad hydrogen emission lines in their spectra along with a near constant plateau of optical luminosity throughout the first ~100 days.

It has long been known that heavy elements and dust grains can be formed in the leftover material ejected in a CCSN explosion. However, only recently have we recognized the importance of this contribution to the overall dust budget in the Universe.

Generally we thought that asymptotic giant branch stars were the main contributors of dust in galaxies; these low- to intermediate-mass stars form dust grains in their stellar winds over millennia and deposit them into the interstellar medium (ISM). But this does not explain how high-redshift galaxies ($z > 6$) can have more dust than their young ages should allow. Thus we began to revisit the role that CCSNe play in dust production, especially their ability to quickly return gas and dust to the ISM.

## Extending the Search with GMOS

Over the past decade, our team has been using ground- and space-based optical and IR imaging and spectroscopy to look for signatures of dust formation in young CCSNe. In particular the size and sensitivity of GMOS has allowed us to follow a collection of objects for years after explosion in a search for the three telltale signs of grain condensation.

First, as dust forms, the optical luminosity will decrease while almost simultaneously the near-infrared (NIR) will increase, as the dust grains absorb the shorter wavelength light and re-emit it in the IR. Grain formation will also alter the optical spectrum, creating asymmetric and blue-shifted lines as the dust grains attenuate the red (receding) side of the ejecta preferentially.

And while we initially believed that the dust grains could only condense 300-600 days after explosion (when the ejecta had expanded and cooled) there have been more and more confirmed cases of dust forming much earlier, within 100 days of explosion.

An early onset of dust formation can occur when shocks interact with nearby circumstellar material (CSM), creating an area known as the cool dense shell (CDS) with temperatures and densities appropriate for grain growth. This not only allows a separate channel for dust formation in CCSNe, but can also reveal important properties of SN evolution and progenitor mass loss.

In February 2012, we also began using GMOS in an extensive observing campaign on SN 2011ja in NGC 4945 (Figure 1). This "normal" Type II-P SN, located ~ 11 million light years away, has an absolute I-band magnitude of ~ -18.3. Our goal was to follow SN 2011ja from near peak to well past 600 days. This allowed us to look for both channels of dust formation, and to quantify the mass and composition of any forming dust.

## The Evolution of SN 2011ja

Using the new B600 grating and 0.75 arcsecond slit, we obtained GMOS-South medium-resolution spectra of SN 2011ja — 84, 112, 159, 450, and 807 days after explosion (Figure 2). We also obtained g′, r′, and i′ imaging at the same time (Figure 1). Both datasets are supplemented by European Southern Observatory optical and NIR photometry (Figure 3), as well as optical spectra.

We immediately noticed the strange multi-peaked shape of the hydrogen lines (Figure 2, top) that appeared as the SN was transition-

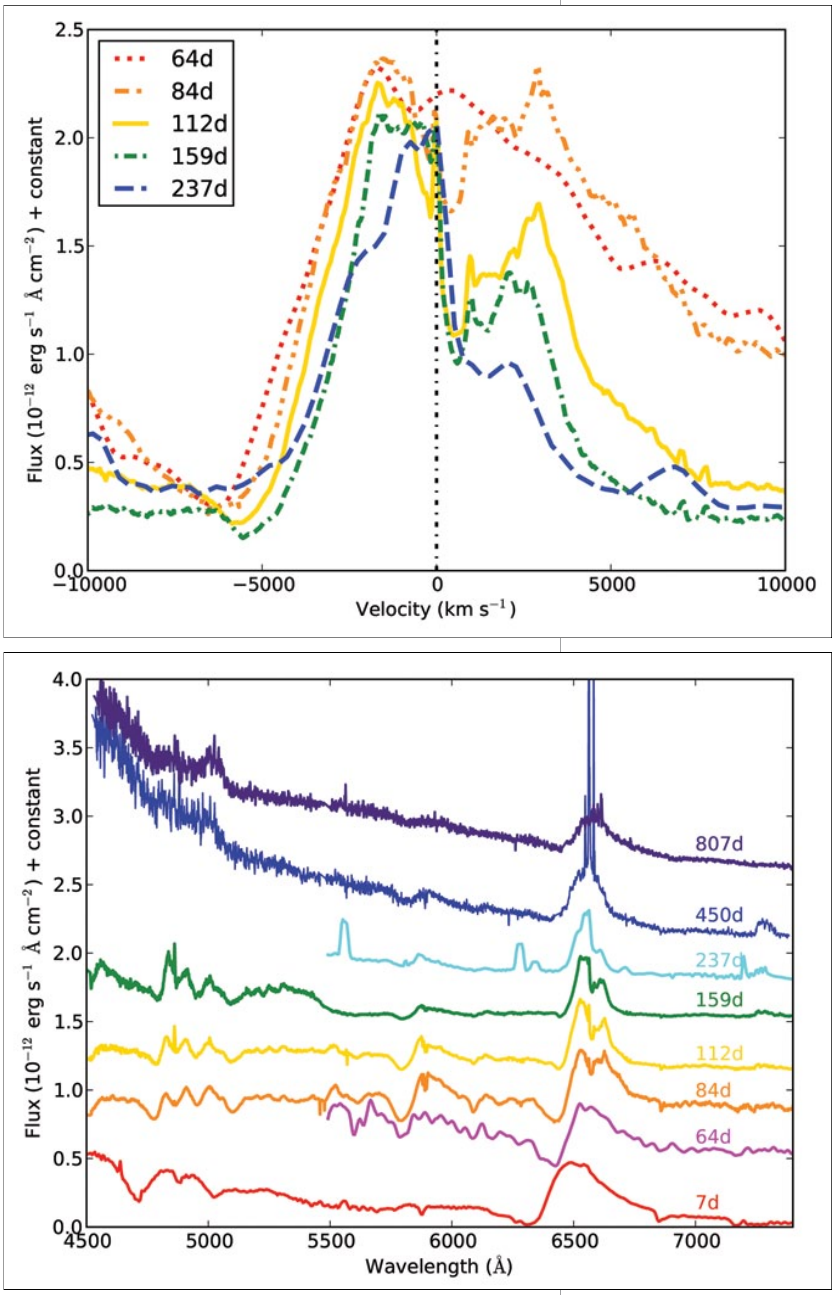



**Figure 2.**

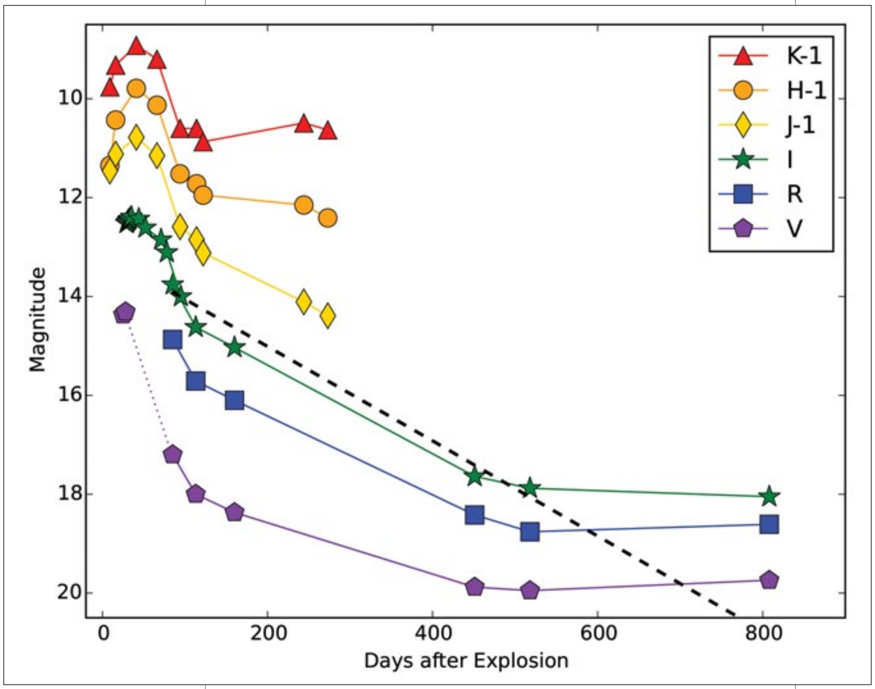
*(Top): Ha evolution of SN 2011ja during the first 8 months. The degredation of the red peak at ~2,500 km/s is a sign of dust formation. (Bottom): Full spectroscopic evolution of SN 2011ja over the first two years.*

ing out of the plateau phase. Most interestingly, the strength of the blue peak of Hα increases relative to the red, and the line peaks themselves begin to flatten over time.

Multipeaked emission lines are mostly attributed to a toroidal or disk geometry of surrounding CSM material, while the flattening is caused by the ejecta interacting with the CSM. From the optical spectra alone, we can therefore infer that the SN is running into asymmetric mass-loss from the SN progenitor. Chandra X-ray observations provide further support as the SN's early X-ray emission only increased over the first 100 days.

The degrading of the red peak with time was our first clue that dust was forming early on, as the grains were obscuring the receding side of the ejecta more than the approaching side. While this in itself may have been enough to determine dust was forming within a few months of explosion in SN 2011ja, the IR and optical light curves also added credence: there is a 0.4 magnitude brightening in the K-band between day 121 and 243, and a simultaneous drop of ~0.5 magnitude in the optical brightness as can be seen in Figure 3.

**Figure 3.**
*Optical and NIR light curves of SN 2011ja. The NIR curves have been shifted down a magnitude for clarity, and the dashed line indicates $^{56}$Co decay.*




All observational signs pointed to dust formation occurring sometime around day 100. Together with the spectral signatures of CSM interaction, this would seem to indicate that the dust is in the CDS, formed between the forward and reverse shocks created as the ejecta plows into the pre-exisitng gas and dust lost by the progenitor before the end of its life.

## Modeling the Dust

Now that we had observational evidence of dust grains forming in SN 2011ja, we could turn our attention to modeling the dust: how much, what kind, and where was it located.

Using our 3D Monte Carlo radiative transfer code MOCASSIN and our optical and IR observations, we modeled various geometries and compositions of dust, including a spherical shell of smooth and clumped dust, as well as a smooth distribution of dust in a torus of increasing inclinations around the system. We limited our dust composition to carbon grains only, since 10.8 micron Very Large Telescope observations did not detect strong silicon emission.

The modeling of four GMOS and Spitzer Infrared Array Camera epochs revealed about $1 \times 10^{-5}$ solar masses of pre-existing dust located about 3,500 AU away from the center of the SN, and up to $6 \times 10^{-4}$ solar masses of newly formed dust in a torus inclined roughly 45° from edge on and closely surrounding the SN.

This dust mass is still much less than that observed from SN 1987A and other SN remnants. By continuing to follow SN 2011ja as it expands and cools, we will likely see more and more dust being formed, albeit at a much lower temperature.

## Signs of a Massive Progenitor

While we had found evidence for early dust formation within the first 100 days, we needed to continue observing the object as long as possible to search for additional grain formation in the ejecta. After 400 days or so, we noticed little change in its optical luminosity (Figure 3). Normally we would expect to see a fading of about 1 magnitude every 100 days due to the radioactive decay of $^{56}$Co which powers the late-time lightcurves of SNe.

Light echoes scattering off dust clouds between us and the SN, or radiative shocks plowing into nearby CSM, may have caused this late-time brightness. But most likely in this case the SN continuum had faded below the brightness of the parent star cluster from which the massive progenitor star was born. This scenario would allow both the strong broad Hα emission line, and a bright blue continuum.

Comparing the day 807 spectra with Starburst99 stellar synthesis models of young massive star clusters (Figure 4) indicates that the late-time luminosity most likely has a large component of the parental stellar cluster, which is between 3-6 million years (Myr) young, corresponding to a SN progenitor mass of 20-30 Suns.

The absolute magnitude at maximum (I = ~ -18.3) in tandem with the short plateau duration and the steep drop into the radioactive decay phase of the optical light curve, all point to a CCSN with a small hydrogen envelope.

Combined with the estimated age of the parent cluster, this would suggest SN 2011ja likely went through a strong mass-loss phase not long before eruption.

## The Future

Our group is continuing to study CCSNe at late times to look for increased dust formation. Specifically we are monitoring the dust as the ejecta cools and expands, to determine how the progenitor mass of the SN correlates with dust mass. We currently have a project underway using GMOS to look at SNe with ages between 4-60 years in order to model their Hα emission.

Tests done on SN 1987A have shown that the shape and strength of the broad Hα line can be correlated to dust mass. This will be amazingly useful, especially in the era before James Webb Space Telescope, since data suggest the peak dust production may occur in the cooler dust regimes only accessible by long-wavelength instruments.

*Jennifer Andrews is a postdoctoral researcher at the University of Arizona. She can be reached at: jandrews@as.arizona.edu*

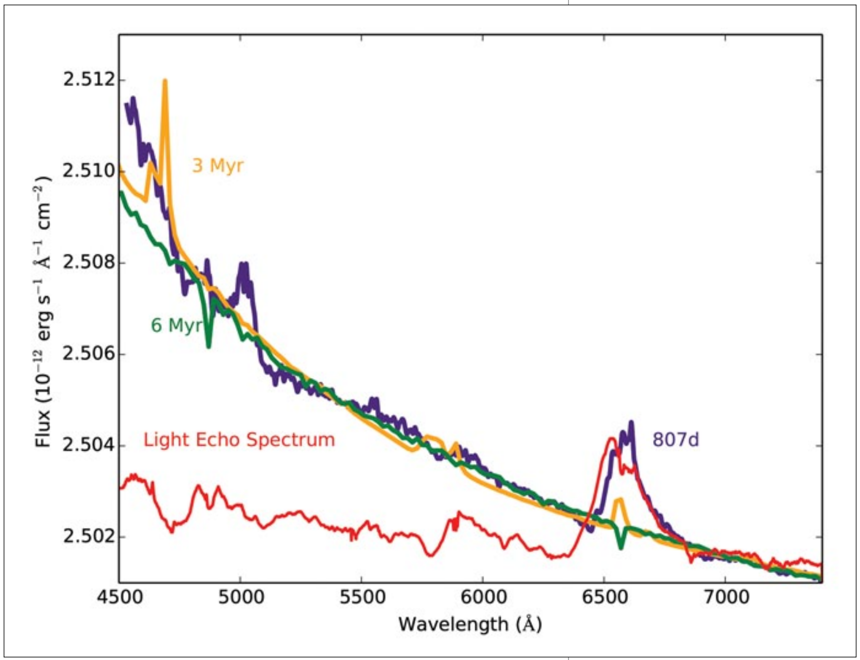



**Figure 4.**
*Day 807 spectrum (purple) of SN 2011ja showing enhanced blue emission. Comparison with the light echo spectrum created from an integrated fluency of the first 84 days (red) indicates that a light echo cannot be responsible for the flux bluewards of 6,000 Å. The orange and yellow spectra are synthesized stellar populations created with Starburst99 for 3 and 6 Myr. It is possible that the late-time luminosity has a large component of the parental stellar cluster.*

# Science Highlights

*This 2016 Year-in-Review highlights the innovative science being done by the Gemini user community.*

## January 2017

### *Unscrambling a Complex Young Stellar System*

Nicole Arulanantham of Wesleyan University (Middletown, Connecticut) and colleagues used the Gemini Near-InfraRed Spectrograph (GNIRS) on the Gemini North telescope to target the binary T Tauri system V582 Mon (KH 15D) — two K-type stars in a circumbinary ring that is inclined to the binary's orbit.

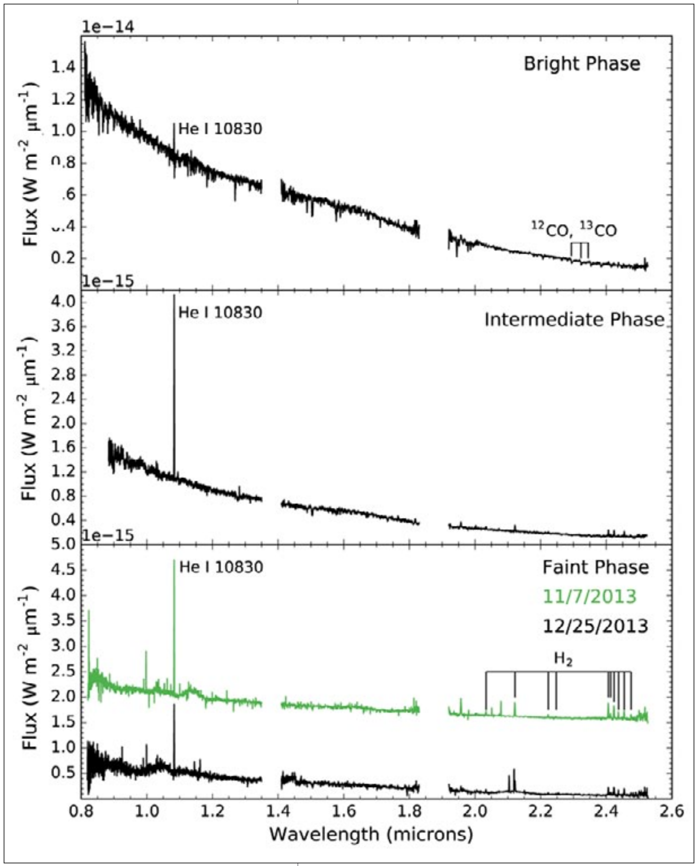



**Figure 1.** *The top panel shows the spectrum of KH 15D during its "bright" phase, when the amount of direct starlight was greatest. The middle spectrum ("intermediate" phase) was taken when star B was just below the edge of the ring. Both spectra in the bottom panel were obtained during "faint" phases from two different cycles, when both stars were near periastron and the contribution from starlight was minimized. The spectrum from November has been offset by 1.5x10$^{-15}$ W m$^{-2}$ μm$^{-1}$ for comparison to the data from December.*

The team obtained data at three different orientations of the system's two young stars (Figure 1), allowing them to study several key aspects of this complicated system — including characterizing the photosphere and magnetosphere of the companion star (B), exploring a jet of material associated with a bipolar outflow, and probing the scattering properties of its circumbinary ring. The research uncovered an excess of near-infrared radiation that is possibly the signature of a self-luminous 10-Jupiter-mass planet. While this unresolved planet displays the expected excess in infrared radiation, as well as a 2-micron spectral feature that may be due to methane or ammonia, other anticipated signs of these two compounds went undetected in the observations. The team's spectroscopic observations also indicate that a mixture of water and methane ice grains lie within the circumbinary ring — close enough to the primary stars that the frozen methane must be shielded by dust from direct radiation.

Finally, in addition to determining that star B is an early K-type subgiant, the research revealed variable helium I emission in star B's magnetosphere due to ongoing mass accretion. The team's paper is accepted for publication in *The Astrophysical Journal* *(view here)*.

## High-mass Young Stellar Objects: Are all Stars Created Equal?

A team of astronomers using the Gemini Near-infrared Integral Field Spectrograph (NIFS) on Gemini North have found the strongest evidence yet that massive stars form in much the same way as do their lower-mass brethren.

In addition to the Gemini observations, the work includes data from NASA's SOFIA airborne observatory, Calar Alto Observatory, and the European Southern Observatory. The results show that when massive stars form, they consume chunks of their surrounding accretion disks, leading to episodic explosive outbursts — much like those known to occur during the formation of average mass stars like our Sun (only more intense). This finding may have a profound impact on the way some astronomers believe massive stars grow, namely by the fusion of less massive stars.

The international team of astronomers, led by Alessio Caratti o Garatti of the Dublin Institute for Advanced Studies in Ireland, published its work in the November 14th issue of the journal *Nature Physics* *(available here)*. It was thought that an accretion disk could not survive around a higher mass star due to the star's strong radiation pressure, and thus it would not be a viable mechanism for producing the most massive stars, some of which can exceed 50-100 solar masses.

The developing star observed in this study, S255IR NIRS 3 (Figure 2), lies some 6,000 light years distant and has a mass estimated at about 20 solar masses. The Gemini observations reveal that the explosive outburst's source is a huge clump of gas, probably about twice the mass of Jupiter, accelerated to supersonic speeds and ingested by the forming star. The team estimates that the outburst began about 16 months ago and appears to still be active, albeit much weaker.

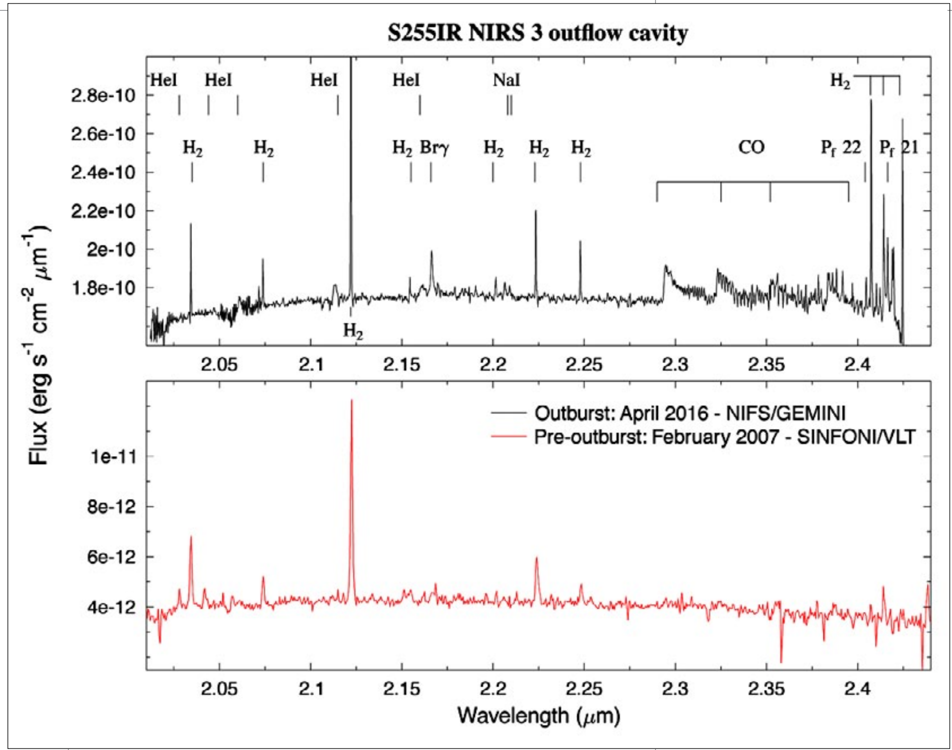
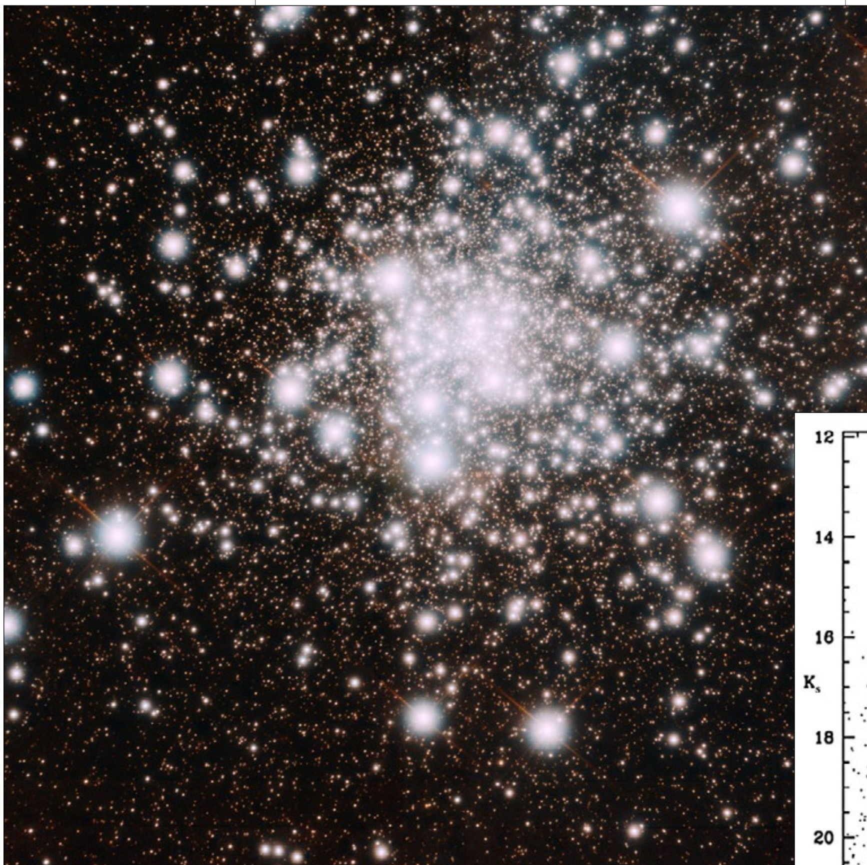



**Figure 2.**
*Gemini post outburst K-band NIFS spectrum (black at top) of the red-shifted outflow cavity of S255IR NIRS 3. The pre-outburst spectrum obtained with SINFONI/VLT is shown in red at bottom. The Gemini spectrum in the outburst phase shows a large number of emission lines typical of disk-mediated accretion outbursts.*

## Cluster's Advanced Age is in Razor-sharp Focus

Researchers using the Gemini Multi-conjugate adaptive optics System (GeMS), combined with the Gemini South Adaptive Optics Imager (GSAOI), probed the depths of the highly compact globular cluster 6624 (Figure 3). These data reveal pinpoint star images with a uniformity across the crowded field, allowing the team to perform precise photometry deep into the cluster's crowded core.

The team also detected a clear "main-sequence knee" (Figure 3, inset); this distinctive bend in the evolutionary track of low mass main-sequence stars is extremely difficult to detect without ultra-precise photometry. Indeed, this is the first time the feature has been identified in this globular cluster, and it allowed the team to determine the cluster's age with extremely high precision: about 11.5-12.5 billion years.



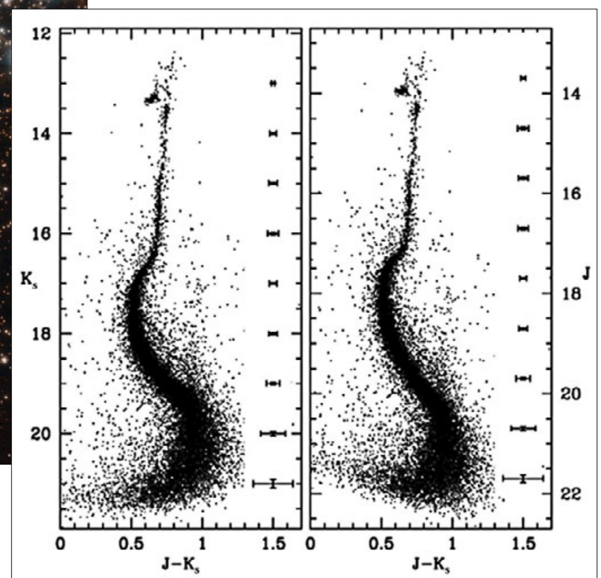



**Figure 3.** *Gemini Observatory GeMS image of globular cluster NGC 6624 revealing individual stars clear to its core. The inset shows the color-magnitude diagram with the main-sequence knee visible. The extreme sharpness of this adaptive optics image allows researchers to perform very precise photometry on individual stars — a task requiring exquisite imaging across the entire field, which would be a challenge for most adaptive optics systems. Composite color image by Travis Rector, University of Alaska Anchorage. Image credit: Gemini Observatory/AURA*

According to first author Sara Saracino of the University of Bologna, this is the most accurate, and deepest, near-infrared color-magnitude diagram ever produced of NGC 6624 and perhaps the best ever made for any bulge cluster. The results of this research are accepted for publication in *The Astrophysical Journal*, and a preprint ***can be found here***.

## Monitoring Io's Volcanoes with Adaptive Optics

The longest frequent, high-resolution imaging of Io's thermal emission is providing insights on the Jovian moon's volcanoes, thanks to a joint program between the Gemini North telescope (with the Near InfraRed Imager and spectrometer [+Altair adaptive optics instrument pairing) and the W.M. Keck Observatory. Gemini's queue scheduling provided the additional flexibility necessary to assure adequate coverage in the time domain.

The observations spanned a period of 29 months and revealed patterns in the volcanic activity over time and location on the satellite (Figure 4), but also resulted in new questions.

According to University of California Berkeley (UCB) Graduate Student Katherine de Kleer, some of the eruptions appeared to progress across the surface over time, as if one eruption somehow triggered another 500 kilometers away. "While it stretches the imagination to devise a mechanism that could operate over distances of 500 kilometers, Io's volcanism is far more extreme than anything we have on Earth and continues to amaze and baffle us." De Kleer led the analysis of the data for this study with her advisor at UCB, Imke de Pater.

The results were presented at the American Astronomical Society's Division of Planetary Sciences and the European Planetary Sciences Congress in Pasadena, California, in October. De Kleer and de Pater presented the results jointly based on a pair of papers in the journal *Icarus*, which are available ***here*** and ***here***.

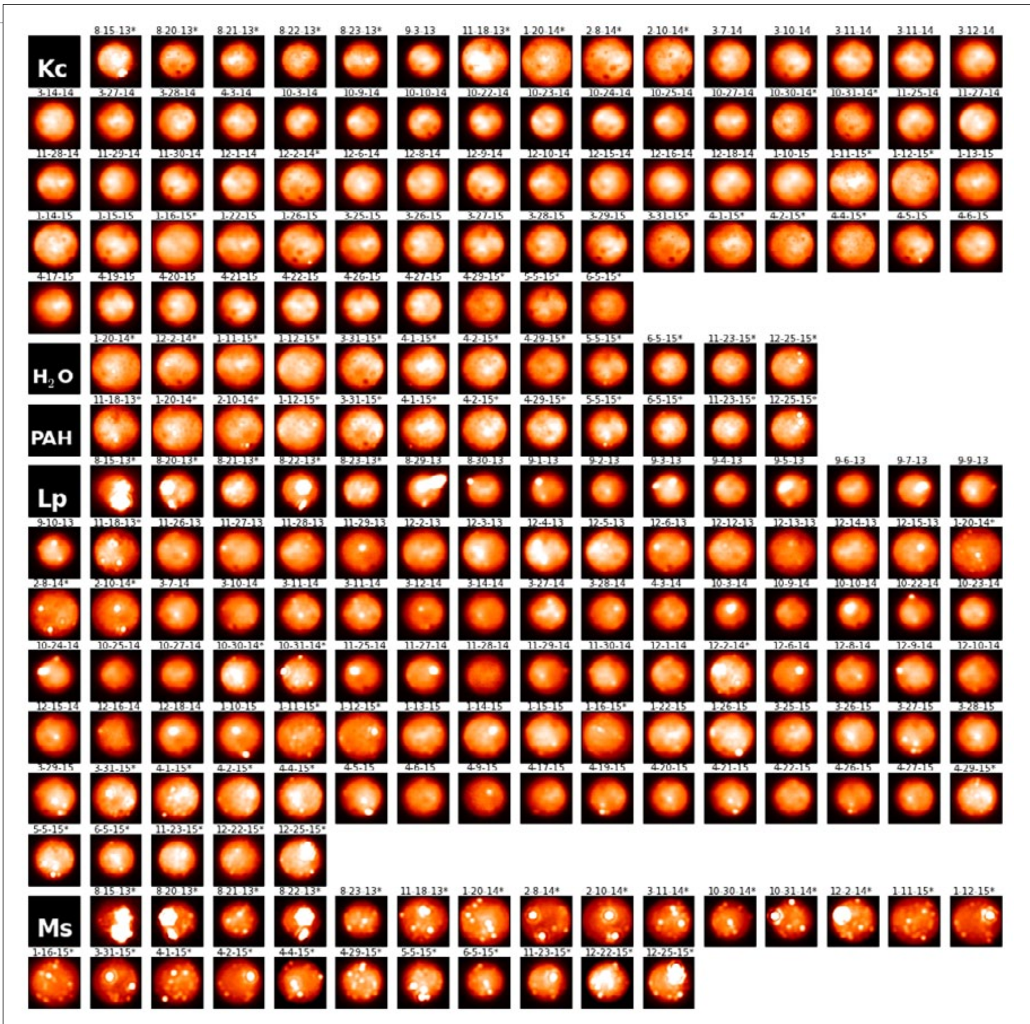



**Figure 4.**
*A sample of Io images obtained from the Gemini North telescope using NIRI with the Altair adaptive optics system for tracking volcanic activity over a 29 month period.*
*Image credit: Katherine de Kleer and Imke de Pater, UC Berkeley/ Gemini Observatory/ AURA/W.M. Keck Observatory*

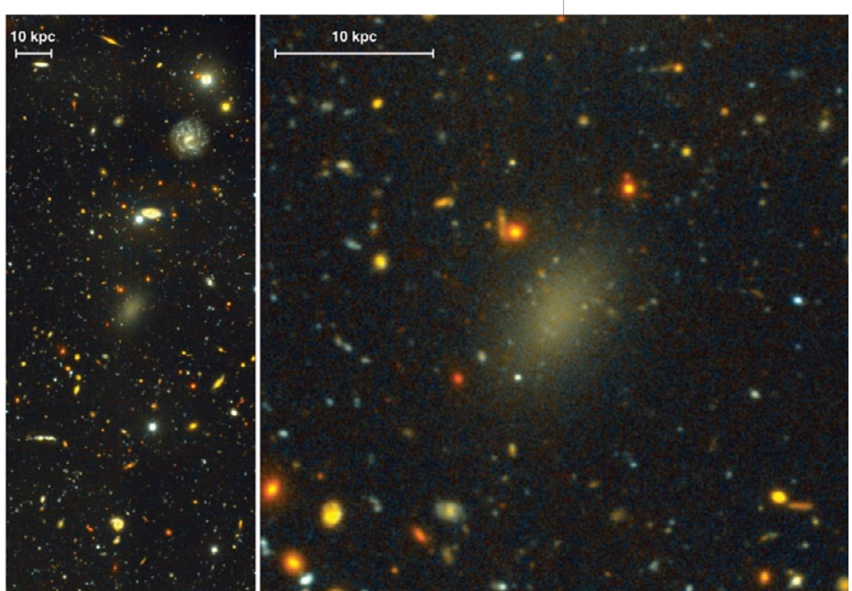
## October 2016

### A Dark Matter Milky Way

Astronomers have discovered a massive galaxy that is almost entirely dark matter. The galaxy, called Dragonfly 44, has very low surface brightness and was discovered only in 2014. New Fast Turnaround program observations using the Gemini Multi-Object Spectrograph (GMOS) on Gemini North, as well as spectroscopy from the Keck II telescope also on Maunakea, reveal the galaxy's physical properties. They show that it is like a "failed" Milky Way, in having similar total mass, size, and population of globular clusters, lacking only stars.

The Keck spectroscopy enabled Pieter van Dokkum (Yale University) and collaborators to measure the mass of Dragonfly 44. The deep images from Gemini (Figure 5) then yielded the galaxy's mass-to-light ratio (48 within the half-light radius), and the Gemini imaging shows the large population of globular clusters in the halo. Considering theoretical models that include the halo, the researchers con-

**Figure 5.**
*The dark galaxy Dragonfly 44, observed using GMOS-North, in wide-field (left) and close-up (right). Dragonfly 44 is very faint for its mass, and consists almost entirely of dark matter.*
*Image credit: P. van Dokkum* et al.*, Gemini Observatory/AURA*



clude that the galaxy's mass is approximately $10^{12}$ $M_{Sun}$, and that the total galaxy is 99.99% dark matter. One specific problem this example presents is that the formation of stars is predicted to have maximum efficiency at this mass regime. Dragonfly 44, a confirmed member of the Coma cluster exhibiting a regular morphology, has formed 100 times fewer stars than expected. A *Gemini press release* provides some more information and links to high-resolution images; full results are published in *The Astrophysical Journal Letters*.

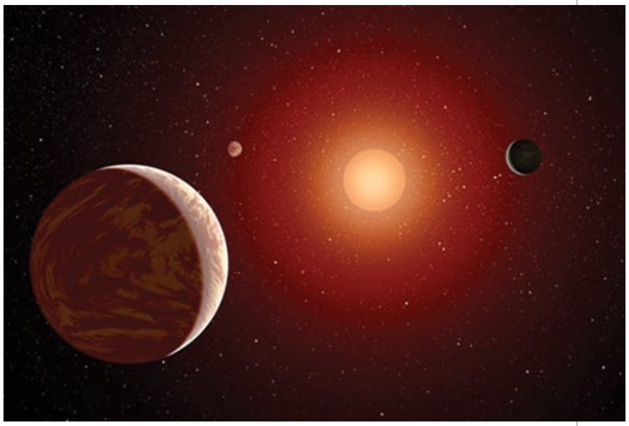


**Figure 6.** *Artist's concept of what the view might be like from inside the TRAPPIST-1 exoplanetary system, showing three Earth-sized planets in orbit around the low-mass star. This alien planetary system is located only 12 parsecs away. Gemini South telescope imaging, the highest resolution images ever taken of the star, revealed no additional stellar companions, providing strong evidence that three small (probably rocky) planets orbit this star.* *Image credit: Robert Hurt/JPL/Caltech*

## Confirming Nearby Exo-Earths

The Differential Speckle Survey Instrument (DSSI) visited Gemini South for the first time in June 2016 and is already delivering exciting results, including the validation of nearby Earth-like exoplanets. Previous observations using the TRAnsiting Planets and PlanetesImals Small Telescope (TRAPPIST) had shown variations in the light curve of the star TRAPPIST-1, implying the presence of several Earth-sized planets (Figures 6 and 7). Steve Howell (NASA Ames Research Center) and colleagues used high-resolution images from Gemini to confirm the small size and mass of these suggested planets by ruling out the presence of a very nearby companion. DSSI on Gemini provides the highest resolution images available to astronomers anywhere and here achieved a resolution of 27 milliarcseconds, or 0.32 astronomical units at the 12-parsec distance of TRAPPIST-1.

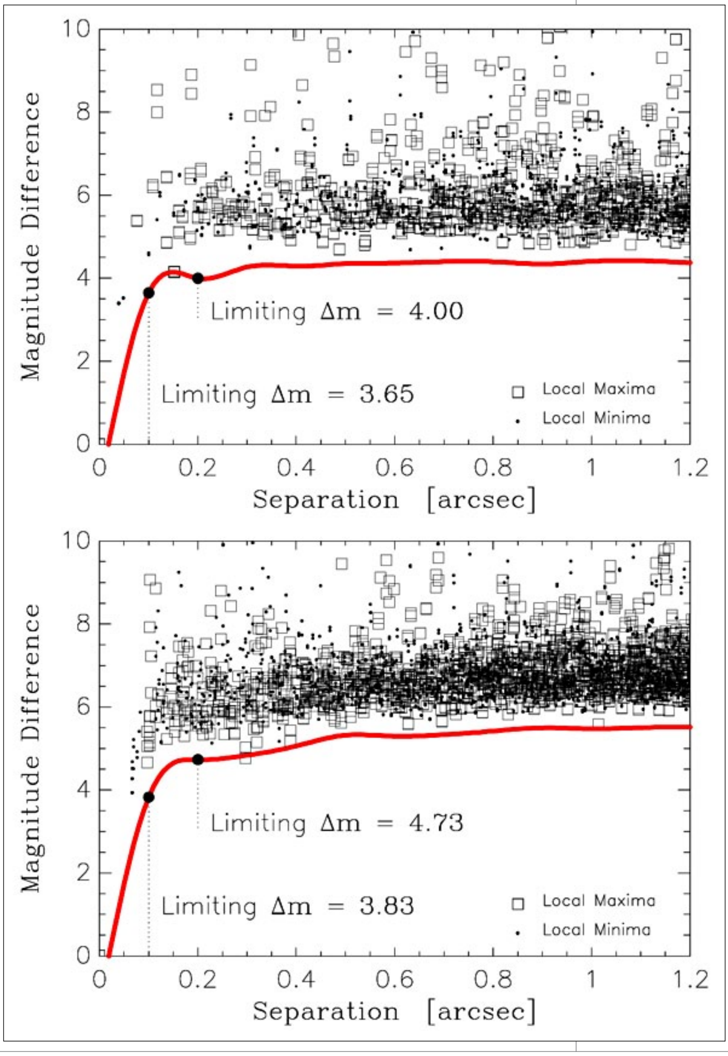



**Figure 7.** *Detection limit analysis for the June 22, 2016, Gemini-South observation of TRAPPIST-1. Detection limits observed at 692 nm (top) and at 883 nm (bottom). The red line represents the relative 5σ limiting magnitude as a function of separation from 0.027 to 1.2 arcseconds. At the distance of TRAPPIST-1, these limits correspond to 0.32–14.5 AU. The two listed limiting magnitudes given for reference are for angular separations of 0.1 and 0.2 arcsecond.*

The host star, TRAPPIST-1, is a late M dwarf. Such cool stars are interesting targets because any terrestrial planets around them would have short periods (of days) and be detectable with current technology. At least two of the three known planets in this case are very close to the star, so too hot even to be in the habitable zone. The orbit of the third planet is somewhat uncertain now. See the *Gemini press release* and *The Astrophysical Journal Letters* for full results.

## Powerful Ionizing Sources in the Nearby Universe

An international team of astronomers using GMOS on each of the Gemini telescopes has obtained the first ever close-up images of Lyman-alpha blobs (LABs) at low redshifts of $z = 0.3$ (Figure 8). LABs may extend up to 100 kiloparsecs, and emit copious amounts of Lyman-alpha radiation. They are landmarks of massive galaxy formation and have, so far, only been found at high redshifts of about 1.5 or higher. Gemini astronomer Mischa Schirmer and collaborators have shown that LABs may still exist in the low redshift Universe, 4 - 7 billion years later than previously known, based on far-ultraviolet measurements with the GALEX satellite.

One of the biggest mysteries of LABs is their ionizing power source. Various mechanisms have been suggested, such as cold accretion streams, hidden active galactic nuclei (AGN), star bursts, and supernovae; however, many LABs show no ionizing continuum source at all. The researchers found weak AGN at the cores of the discovered low-redshift LABs. Their low redshifts allowed the astronomers to study these objects in much more detail than their high-redshift cousins.

The very luminous and extended nebulae observed require that the AGN must have been in a very powerful state until a few 1,000-10,000 years ago. Such episodic duty cycles are typical for AGN, but are difficult to recognize otherwise because they last much longer than a human lifetime. One of the team's main results is that even a short burst of high AGN activity is sufficient to power the LAB's Lyman-alpha emission for a very long time.

This work is featured on the ***Gemini website*** and is published in ***Monthly Notices of the Royal Astronomical Society***.

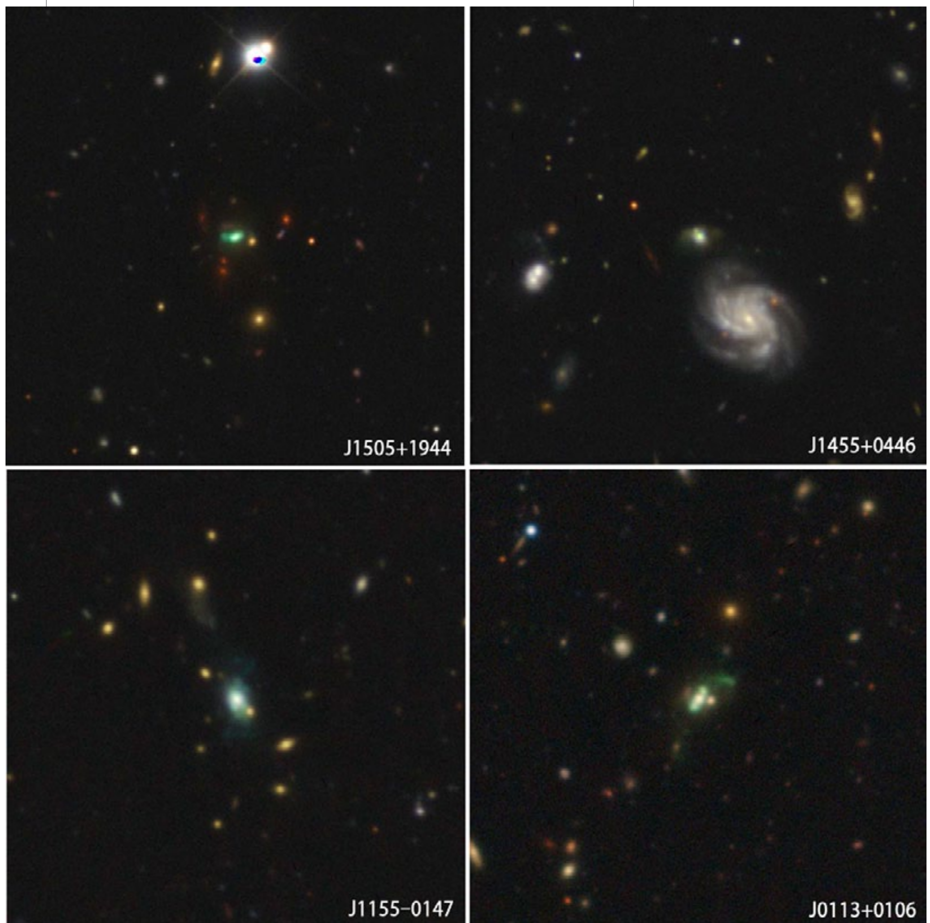



**Figure 8.**
*Gemini/GMOS images of four of the new low-redshift Lyman-alpha blobs, using g, r, and i filters. From upper left to lower right: J1505+1944, J1455+0446, J1155–0147 and J0113+0106. These objects are among the most powerful [OIII]5007 emitters known in the Universe, causing the green color in these optical images. Note that the far-UV Lyman-alpha radiation is not visible in these optical images.*

# July 2016

## A 17-Billion-Solar-Mass Black Hole Surprise

Astronomers using the Gemini Multi-Object Spectrograph (GMOS) integral field unit on the Gemini North telescope have measured a 17-billion-solar-mass black hole dominating the core of NGC 1600, a large galaxy in the low-density environment of a galaxy group. This is a surprise, given that we expect to find monster black holes in very massive galaxies at the centers of large galaxy clusters. Astronomers have also observed luminous quasars hosting very massive black holes in the distant Universe, and this result sheds light on large black holes in the more local Universe, suggesting they are likely relics, the descendants of luminous quasars at higher redshift.

In the high-mass regime, Jens Thomas (Max Planck Institute for Extraterrestrial Physics,

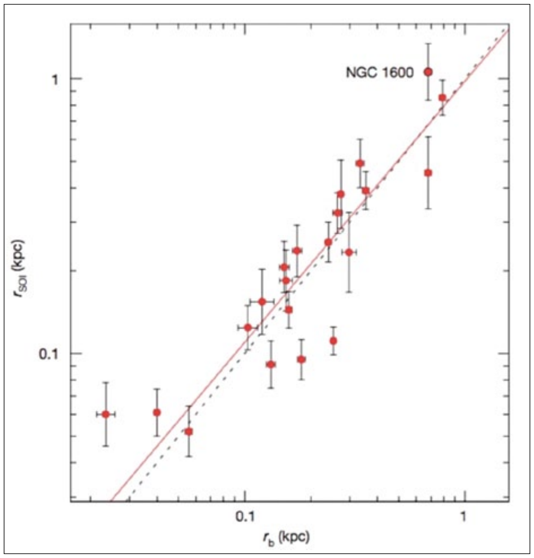



**Figure 9.** *The relationship between core radius ($r_b$) and the black hole sphere of influence ($r_{SOI}$) is tighter than other relationships with the black hole mass, such as stellar velocity dispersion.*

Germany) and collaborators find that a host galaxy's core radius is a robust proxy for the mass of the central supermassive black hole; it correlates more tightly than stellar velocity dispersion, $\sigma$. NGC 1600 is, in fact, something of an outlier on the more common "$M$-$\sigma$" plot. Figure 9 shows the relationship between this core radius ($r_b$) and the black hole sphere of influence ($r_{SOI}$). A Gemini [press release](#) features the work, and complete results are published in [*Nature*](#).

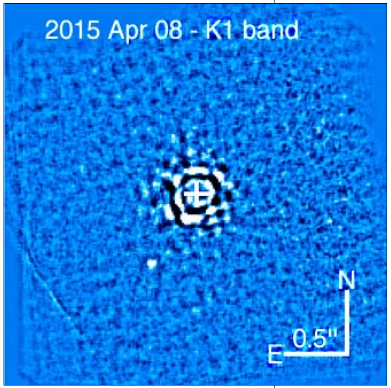
## Constraining the Architecture of the HD 95086 Planetary System

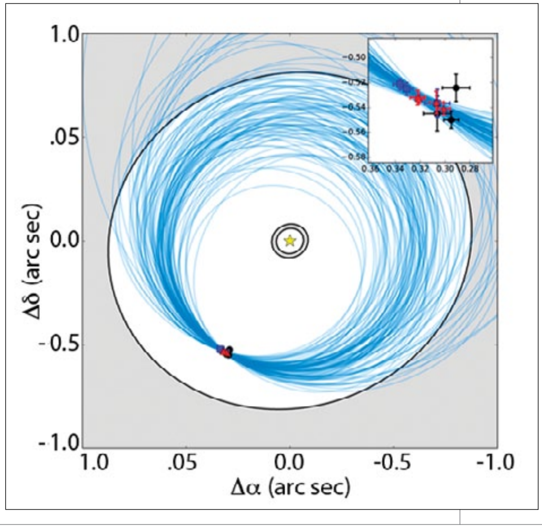
New observations obtained using the Gemini Planet Imager (GPI) on the Gemini South telescope, combined with earlier data, provide more quantitative information about the confirmed exoplanet that the star HD 95086 hosts and suggest the presence of multiple planets. Julien Rameau (Université de Montréal, Canada) and colleagues directly observed the planet, called HD 95086 b, and determined its orbital parameters. They find the orbital semimajor axis around 62 astronomical units and low eccentricity ($\varepsilon < 0.21$). (Figures 10-11).

The star's debris disk, where such young planets form, produces additional infrared emission. Considering multiple pieces of evidence, the architecture of this system — including the disk, its gaps, and the confirmed exoplanet — likely requires another planet or more in addition to HD 95086 b to explain the observations. See more about this work at the [*Gemini webpage*](#). The work has been published in [*The Astrophysical Journal Letters*](#).

**Figure 10 (below left).** *A deep K1-band image of HD 95086 from GPI clearly shows a planet, located at about the 7-o'clock position and within 0.5" of the central star.*

**Figure 11 (below right).** *This schematic diagram shows observed locations of the planet HD 95086 b (black and red points, with error bars) and numerical simulations of possible orbits (blue lines). Gray shaded regions mark the locations of inner and outer dust rings.*




## N159W: Dissecting Triggered Star Formation with MCAO

Massive stars (greater than eight solar masses) shape their surroundings by ionizing the local interstellar medium to create expanding HII regions, which may compress nearby gas and enhance local star formation. Observing this starbirth *in situ* presents a challenge because dust hides the strong ultraviolet and optical emission of the newborn stars, and all the activity occurs on very small spatial scales. PhD student Anaïs Bernard (Laboratoire d'Astrophysique de Marseille, France) and collaborators have used the Gemini Multi-conjugate adaptive optics System (GeMS) with the Gemini South Adaptive Optics Imager (GSAOI) to overcome these difficulties.

Figure 12 shows the result. The image reveals fine details (on scales of ~ 0.09 arcsecond) in the near-infrared light that penetrates the obscuring

**Figure 12.**
*Gemini South GeMS/GSAOI near-infrared image of the N159W field in the Large Magellanic Cloud. The image spans 1.5 arcminutes across, resolves stars to about 0.09 arcsecond, and is a composite of three filters (J, H, and $K_s$ in blue, green, and red, respectively). Integration time for each filter was 25 minutes. Color composite image by Travis Rector, University of Alaska Anchorage.*

dust of N159W, a young star-forming region located ~150,000 light years distant in the Large Magellanic Cloud. The 100 young stellar object (YSO) candidates associated with N159W lie mostly at the border of the ionized (HII) bubble — where cold, neutral material accumulates in clumps and subclusters — and displays signs of recent active star formation. In contrast, the estimated age of the two (blue) massive stars and the associated cluster at the bubble's center is about two million years. Thus, the authors suggest that the first generation of massive stars at the bubble's core triggered the recent birth of the YSOs around the periphery. A ***Gemini image release*** features this work, and full results will be published in *Astronomy and Astrophysics*. A ***preprint*** is now available.

## Innovative Gemini/CFHT Partnership Explores a "Hot Jupiter"

The exploration of other worlds has shown that gas-giant planets lie very close to their host stars. As they could not have formed in their present locations (radiation would have dissolved them) questions remain: do these giants move close-in when the system is young, after interacting with the protoplanetary disk, or do they only move later, following interaction with multiple planets?

The discovery of a 0.77 $M_{Jupiter}$ exoplanet located within 0.06 astronomical units of V830 Tauri — a young (< 2 million years) T-Tauri star — confirms both rapid planet formation and early migration. Such early forming "hot Jupiters" likely play a key role in shaping planetary systems overall.

High-resolution spectroscopy over a 1.5-month campaign revealed the presence of the exoplanet in a telltale spectral "wobble," leading the discovery team to isolate the signal of the planet, find its orbit, and determine its mass (Figure 13). Jean-François Donati (Observatoire Midi-Pyrénées, France) led the work, which took advantage of the novel collaboration between the Gemini Observatory and the Canada-France-Hawai'i Telescope (CFHT) in GRACES (Gemini Remote Access to CFHT ESPaDOnS Spectrograph). GRACES uses an innovative 270-meter fiber cable to transport light from Gemini North's 8-meter mirror to the ESPaDOnS Spectrograph at CFHT. For this work, the researchers also used ESPaDOnS on CFHT and the spectropolarimeter NARVAL on the 2-meter Telescope Bernard Lyot. Full results appear in ***Nature*** and are featured on the ***Gemini web page***.

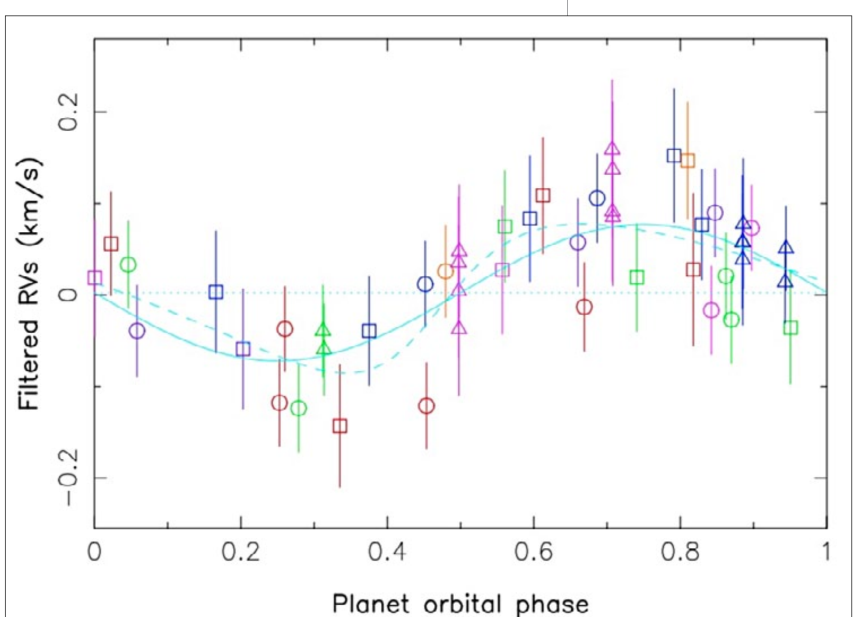



**Figure 13.**
*Radial velocity (RV) measurements of V830 Tauri, after filtering out stellar activity, reveal the presence of a "hot Jupiter." Data from ESPaDOnS/Gemini, ESPaDOnS/CFHT, and NARVAL/TBL are plotted as triangles, circles, and squares, respectively, with colors that code rotation cycles. Lines show fits to circular (solid) and eccentric (dashed) orbits.*

## Traces of Planet Formation in a Stellar Disk

Planets form in the disks around young stars, and the relatively nearby TW Hydrae is an excellent candidate in which to observe this process. In polarimetric observations with the Gemini Planet Imager (GPI) on the Gemini South telescope, Valerie Rapson (Rochester Institute of Technology, New York) and collaborators probe the disk of TW Hya — from about 80 astronomical units (AU) to within 10 AU of the central star — at a resolution of about 1.5 AU and detect structure. The observations show a gap located around 23 AU that is about 5 AU wide, suggesting the presence of a forming planet (Figure 14).

The researchers deduce the properties of the possible (proto)planet comparing with simulations. They find good agreement with a planet of mass 0.16 $M_{Jupiter}$ located at 21 AU from the star, about the distance of Uranus from the Sun. Details of the differences between the model and observations suggest that more complex distributions of dust in the disk (radially and vertically) may be relevant. The authors acknowledge other processes that can create gaps and rings, such as grain fragmentation and ice condensation fronts. A definitive test would be to observe the planet directly. It would need to be actively accreting material to be bright enough to detect easily in future GPI observations. The Gemini website has some more information, and complete results are published in *The Astrophysical Journal Letters*.

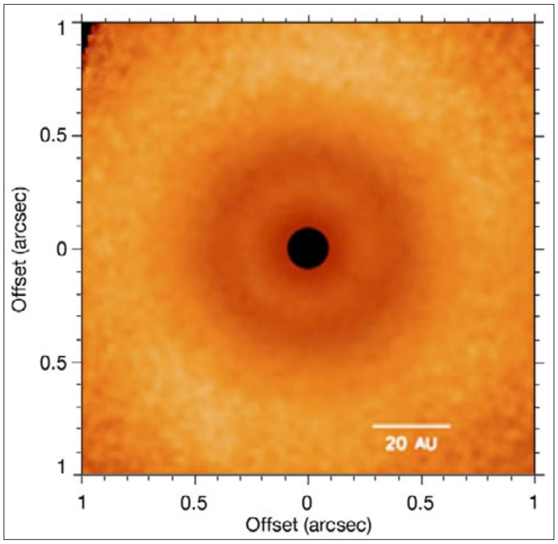



**Figure 14.** *Radially scaled polarized intensity in the J-band shows the variation of dust density distribution in the disk of TW Hydrae. The coronagraph blocks light in the central region. Comparison with simulations suggests that the gap around 23 AU could be cleared by a planet of mass about 0.2 $M_{Jupiter}$.*

## Seeking Companions of the Coolest Brown Dwarfs

Examples of the coolest and least massive brown dwarfs, Y dwarfs, were first identified in 2011. Having temperatures just above those of the gas giant planets (around 250 K), they help bridge the gap from stellar objects to planets. The binary nature of any of these objects is linked to their formation process. Previous observations indicate that the frequency of multiplicity declines from around 65% (for solar-type stars) to 10–30% (for the slightly warmer and more massive L and T dwarfs). Does this trend continue to the Y dwarfs, or does it indicate only our observational limits? Also, some Y dwarfs show a spread of luminosity or otherwise seem over-luminous. Are undetected companions the explanation?

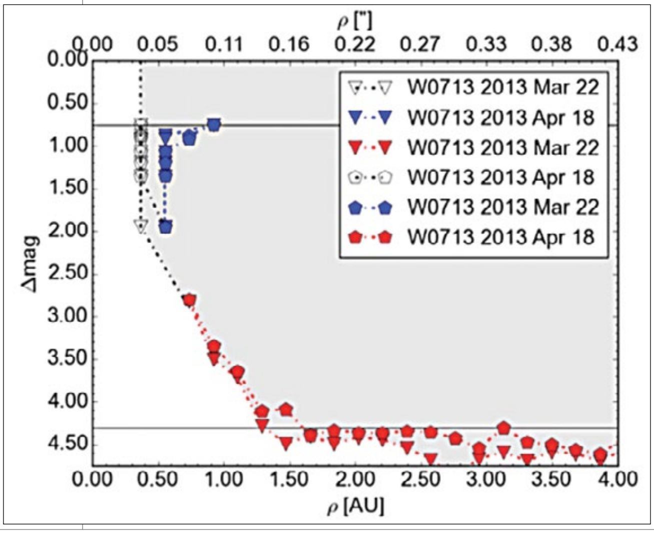
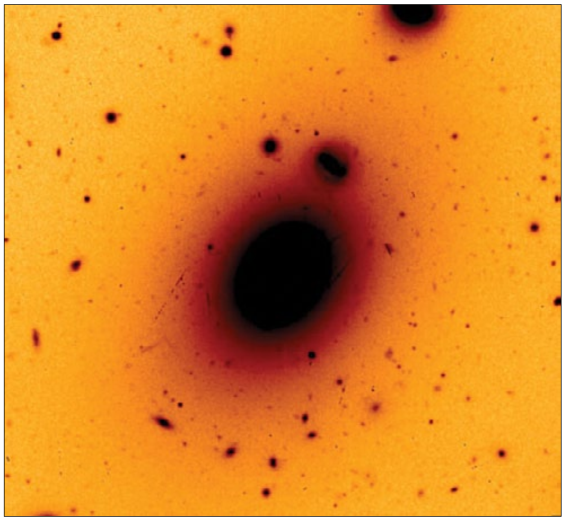



**Figure 15.** *Limits on separation and magnitude for a binary companion to one of the Y dwarfs Opitz and colleagues observed using GeMS/GSAOI. An equal-brightness companion is ruled out to within about 0.5 AU (0.04 arcsecond), and fainter companions are ruled out at somewhat larger radii.*



Daniela Opitz (University of New South Wales, Australia) and colleagues used the fine spatial resolution of the Gemini Multi-conjugate adaptive optics System (GeMS) and the Gemini South Adaptive Optics Imager (GSAOI) to begin to answer these questions, examining a small sample of five Y dwarfs. The delivered Full-Width at Half-Maximum was ~0.1arcsecond and the limiting angular separation was around 0.04 arcsecond. Although the observations were sufficiently sensitive to detect companions of roughly equal mass at separations of 0.5–1.9 astronomical units (AU), they did not find any evidence for binaries. Figure 15 shows the limits on separation and brightness for a binary companion to one of the Y dwarfs studied.

At least one of the sources had previously been identified as "overluminous." The presence of clouds in the atmosphere, rather than a companion, may account for the excess luminosity. The few cases observed here are a good start, not a definitive determination of the general trends. They do point to the extreme scenarios (separations less than 1 AU and extremely faint sources) that may arise in cases of Y dwarf binaries. This work is featured on the Gemini ***website***, and complete results appear in *The Astrophysical Journal*.

## *A Supermassive Black Hole That Wasn't So Massive*

One sign of an extreme supermassive black hole at a galaxy's core is a light deficit — the consequence of stars ejected from the central region. The brightest cluster galaxy of Abell 85 had been identified as such an example, claimed to host one of the most massive black holes ever detected in the Universe at around $10^{11}$ $M_{Sun}$.

Juan Madrid, then a Science Fellow at Gemini South, along with Carlos Donzelli (Observatorio Astronómico de Córdoba, Argentina), used images obtained with the Gemini Multi-Object Spectrograph (GMOS) on Gemini South (Figure 16) to probe the galaxy's center and demonstrate that the black hole's mass is not so extreme. Rather than a deficit, data from their Director's Discretionary Time program show the strong nuclear emission in the central kiloparsec as a light excess that may be due to a nuclear stellar disk. The observations were very short, only seven minutes. The key to the measurement was the spatial resolution to probe the innermost arcsecond. More information about this work is posted at the Gemini ***website***, and full results are published in *The Astrophysical Journal*.

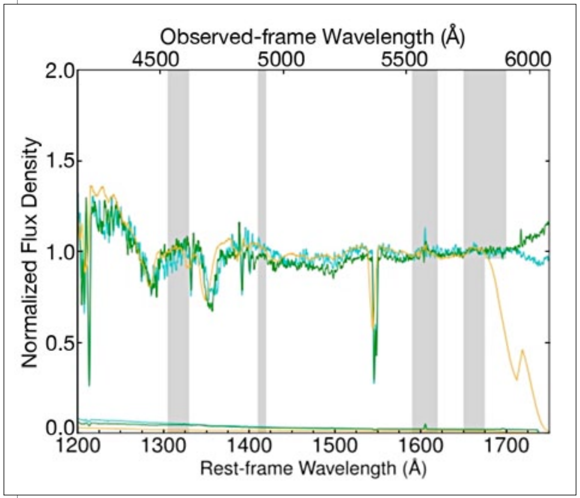
## *The Fastest Quasar Ultraviolet Wind*

Quasar winds may be fundamental to the growth of black holes and the evolution of galaxies, being an intimate part of the feedback mechanism that regulates black holes and stellar growth over cosmic time. Jesse Rogerson (York University, Canada) and collaborators have discovered an extreme example, the fastest ultraviolet wind, whose velocity approaches 20% of the speed of light.

The researchers originally used the Sloan Digital Sky Survey to find quasars that show new broad absorption line troughs. Further obser-

**Figure 16.**
*GMOS-South image of the center of the Abell 85 galaxy cluster, which shows that the brightest cluster galaxy at the center does not contain the most massive known black hole in the Universe, contrary to previous estimates.*

**Figure 17.**
*Three GMOS (North and South) spectra obtained at different times of the z = 2.47 quasar J0230 show the variability of the absorption features, especially the CIV near rest-frame wavelength 1550 Å. The spectra have been normalized based on measurements in the shaded regions.*




vations using the Gemini Multi-Object Spectrograph (GMOS) at both Gemini North and Gemini South show spectral changes over time in this case. At a redshift of $z = 2.47$, the galaxy's rest-frame ultraviolet emission appears at optical wavelengths, and broad CIV absorption is the key feature the team traced.

This exceptional example, called SDSS J023011.28 + 005913.6 or J0230 for short, is also interesting in showing a second strong component, with an outflow velocity around 40,000 kilometers per second. The multiple observations of the quasar at various times show variability (on timescales as short as 10 days in the quasar rest frame; Figure 17) and enable the team to rule out some simple models of bulk motion. Instead, they show that some more complex geometric configurations are consistent with the observations — namely a "crossing disk" model (of a circular cloud that crosses a circular emitting region) and "flow tube" (where a spatially extended absorbing region passes in front of the emitting region) for the faster and slower outflows, respectively.

Continued study of the larger sample of about 100 candidates may reveal more systematic characteristics of the broad absorption features and their origin. This work is featured on the Gemini ***website***, and full results are published in *Monthly Notices of the Royal Astronomical Society* (***viewable here***).

Gemini staff contributions

# News for Users

*During 2016 much happened at Gemini of relevance to our user community. What follows is a compilation of news, updates, and information of interest to Gemini's users from the past 12 months.*

## January 2017

### Base Facility Operations Begin at Gemini South

Since late 2015, the Observatory has operated Gemini North at night from its Hilo Base Facility with no staff at the telescope facility on Maunakea. Gemini South has now followed suit; as of November the Base Facility Operations (BFO) project began full remote operations in La Serena, Chile. As promised in the January 2016 issue of *Gemini*Focus, in the interest of efficiency we copied much of the Gemini North project and pasted it into place at Gemini South, making this task as straightforward as possible. Along the way we made one or two locally-specific amendments and some minor improvements.

**Figure 1.**
*Javier Fuentes (left) and Joy Chavez (right) operating Gemini South from the La Serena Base Facility on November 14, 2016.*

Prior to November, we had already operated in "Base" mode with night staff at the summit of Cerro Pachón for more than two months — progressively confining them to the control room as we added more and more monitoring capabilities and remote control options to the summit systems. On November 14th we were ready as planned, and the nighttime staff carried out the first night of observing entirely from the La Serena Base Facility (Figure 1).

There are two instrument exceptions to BFO from La Serena: 1) the Gemini Multi-conjugate adaptive optics System/Gemini South Adaptive Optics Imager, for which we anticipate a new laser delivery in 2017 (and therefore we deferred the BFO safety interlock work until that new system is in place); and 2) the visiting instrument Phoenix, for which at least one subsystem required manual intervention (and therefore was run from the summit in December 2016).


**Figure 2.**
*The Phoenix near-infrared spectrometer during its run as a visitor instrument at Gemini South.*

## Visiting Instruments

The increase in visiting instruments at Gemini continues. Both Phoenix (Figure 2) and the Differential Speckle Survey Instrument (DSSI) spent time on Gemini South in 2016A, and Phoenix returned to Chile in December. Phoenix suffered very badly from the dreadful weather in Chile in 2016A, but as this issue goes to press, the weather at Gemini South has improved. In 2017A both DSSI and Phoenix return to Gemini South, while the Texas Echelon Cross Echelle Spectrograph (TEXES) mid-infrared instrument visits Gemini North.

We look forward to even more visiting instruments at Gemini in the near future. To learn more about our visitor instrument program, view Gemini's Visitor Instrument page ***here***.

## Gemini Prepares for the Large Synoptic Survey Era

Gemini is and will likely be a key facility for following up interesting targets discovered in large, time-domain surveys. We are currently working hard to prepare Gemini for the era of massive synoptic surveys such as the Zwicky Transient Facility (ZTF) and the Large Synoptic Survey Telescope (LSST). New instrument development at Gemini, such as the Gemini High-resolution Optical SpecTrograph (and especially Gen 4#3), will provide the needed spectroscopic capabilities. We are also planning to improve the software and systems for handling a larger volume of Target-of-Opportunity triggers. In an effort to better align ourselves and coordinate with the rest of the community, we have been participating in planning exercises (such as the ***Maximizing Science in the Era of LSST*** workshop) and discussing the development of prototype Target and Observation Manager systems with the National Optical Astronomy Observatory and the Las Cumbres Observatory. The community should also begin to think about other observing modes and strategies for using Gemini in the coming decade. Please contact Bryan Miller (*bmiller@gemini.edu*) for more information, especially if you are interested in participating in these efforts.

## Making the Most of Poor Weather Nights

Clouds and poor seeing can frustrate any astronomer on a classical observing night. One of the main strengths of Gemini's queue observing is that your program is observed in the conditions it requires. While users of Gemini North and South may not need to worry much about bad weather nights, less-than-ideal conditions can occur when simply no targets exist in the regular queue programs to observe. Even if that happens, Gemini rises to the occasion and makes the


**Figure 3 (left).**
*This image is a screenshot taken from the UH88 camera pointed at the Gemini North telescope, dated Monday, December 19, 2016.*

**Figure 4 (right).**
*An image taken from Hilo on December 19, 2016, of a snowy Maunakea. Image credit: Joy Pollard*

most of the night by observing Band 4 or Poor Weather proposals (if available).

Band 4 programs can be submitted at any time during the semester and are most welcome during periods of bad weather (see the following News for Users item). If you have a science case with bright targets that can handle Cloud Cover = 70% and above (or any), any Image Quality, and any Water Vapor (with no restriction on Sky Background — or any Cloud Cover and Water Vapor (with no restriction on Image Quality and Sky Background) — then consider submitting a Band 4/Poor Weather program today. More details on the proposal submission process can be found at ***this link***.

## Winter Blasts Maunakea

The tilt of our planet's axis has once again delivered an extended period of weather not conducive to astronomical observing on Maunakea. Starting in late November a series of fronts, troughs, and low-pressure systems have produced overcast skies, wind, and significant snow, (with drifting) at the Gemini North site (Figures 3 and 4). In the one month period from mid-November until mid-December,16 nights were entirely lost to weather, and an additional four were more than half lost. Overall, during this period we have only managed to obtain science for about one-third of the available time. As this issue goes to press the weather is improving!

# October 2016

## The "Super Seeing" (LGS+P1) Mode

In 2012, Gemini commissioned a new observing mode for ALTAIR's Laser Guide Star system (known as LGS + P1), which added the option of using a peripheral wavefront sensor (PWFS1 or P1) for the Natural Guide Star tip-tilt focus measurement. This mode does not provide diffraction-limited resolution, but instead gives "Super Seeing" by reducing the natural seeing point spread function Full-Width at Half-Maximum (PSF FWHM) by a factor of 2-3. The major benefit of this seeing-improver mode is that it increases the LGS sky coverage to almost 100%. While the limiting magnitude of P1 is R = ~ 14 (less than the R = < 17 magnitude for the conventional LGS mode), this is more

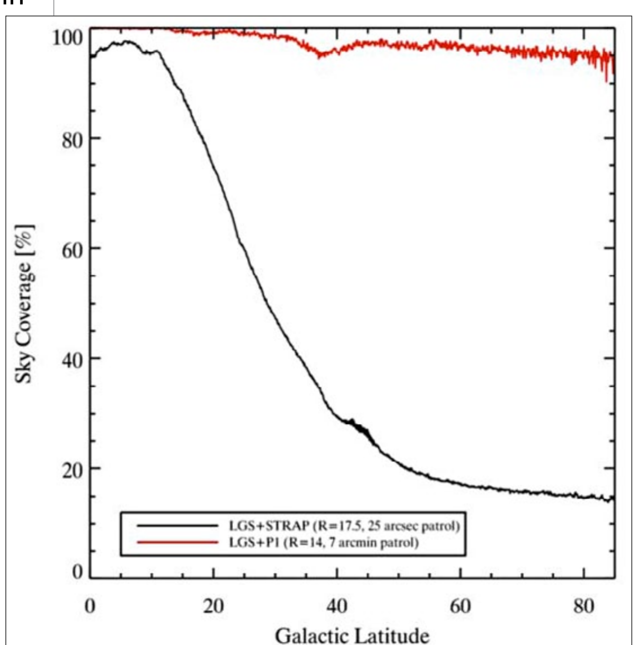



**Figure 5.**
*Comparison of estimated sky coverage for LGS+P1 (red) compared with conventional LGS (black). Note that sky coverage refers to the percentage of sky with guide stars above elevation 40˚ at Gemini North.*

than offset by P1's much larger patrol field. Figure 5 shows the predicted sky coverage as a function of galactic latitude for the LGS + P1 configuration (red) compared with the conventional LGS mode (black).

Currently, LGS + P1 has been commissioned with the Near-InfraRed Imager and spectrometer (NIRI) and Near-infrared Integral Field Spectrometer (NIFS); it is also being offered in shared-risk mode with the Gemini Near-InfraRed Spectrometer (GNIRS). It is important to understand that significant flexure issues remain, which limit the use of LGS + P1 on targets that are not visible during acquisition; this mode also significantly limits the amount of time that a target can remain in a spectroscopic slit. In fact, for spectroscopy, the Super Seeing mode requires that a continuum source be visible (signal-to-noise ratio > 1 per spectral element) somewhere in the science frame for typical exposure times (~ 15 minutes). In addition, we cannot support blind offsetting at this time. Since this is a work-in-progress, part of the mode's shared risk nature includes the possibility that we may not be able to implement the flexure model, or that the magnitude of flexure may be larger or more difficult to correct than expected.

Nevertheless the Super Seeing mode has proven to be very useful for conventional LGS mode programs for which the availability of guide stars was an issue; in about 99% of the cases, the Super Seeing mode was there to help by reducing the natural seeing PSF FWHM by at least a factor of two.

*— Marie Lemoine-Busserolle*

**Figure 6.**
*Hoisting a 150-pound drive motor, using one of the largest cranes available on the island of Hawai'i.*

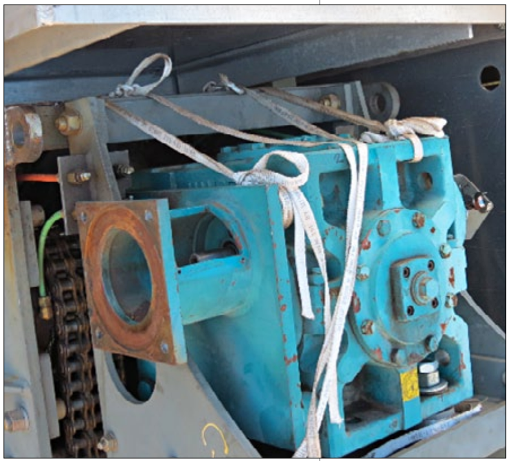


**Figure 7.**
*The Gemini North bottom shutter's broken drive box, with a segment of the drive chain showing at left.*

## Gemini North Shutdown

Gemini North had an unscheduled shutdown from August 10-31 to remedy a broken bearing in one of the drive boxes on the lower shutter (which is also responsible for deploying the wind blind during high wind conditions; Figures 6-7). This drive box failed in late July, resulting in the lower shutter being pinned in an inconveniently high position until a shutdown was possible. Favorable observing conditions near the end of 2016A allowed us to do a significant amount of 2016B observing before the semester started. This then allowed us to take advantage of a relatively light queue at this early stage in the semester and initiate an unplanned shutdown to work on the lower shutter, as well as perform work that was originally scheduled for a planned shutdown in October. That work included troubleshooting on the Acquisition and Guiding system, maintenance on the Gemini Multi-Object Spectrograph (GMOS), and a filter exchange on the Near-InfraRed Imager (NIRI). Thanks to this solution we plan to be observing on a normal schedule throughout October. A GRACES run had been scheduled during the unplanned August shutdown, but an agreement with the Canada-France-Hawai'i Telescope allowed us to continue with these programs following the shutdown.

*— Andy Adamson and Steve Hardash*

## Gemini South Shutdown

Gemini South was shut down for two working weeks from August 16-25, to carry out annual maintenance on the Acquisition and Guidance (A&G) unit (Figure 8) and, specifically, to address issues with the Gemini Multi-Object Spectrograph (GMOS) on-instrument wavefront sensor, which had become very noisy and affected our ability to guide on faint stars (Figure 9).

*— Andy Adamson and Michiel van der Hoeven*

## GMOS-S Photometric Standard Utilities

Have you ever received images of standard star fields from the Gemini Multi-Object Spectrograph at Gemini South (GMOS-S) and struggled to work out which stars are the actual flux standards? Now, help is at hand, thanks to the Australian National Gemini Office and students from Macquarie University in Sydney.

For each photometric night on which GMOS-S imaging data are taken, the Gemini South queue observer also observes at least one standard star field. These standard star fields are taken from a list of 45 fields (covering the range of right ascension and declination) drawn from the (unpublished) catalog of J. Allyn Smith *et al.*'s *Southern Hemisphere u′g′r′i′z′ Standard Stars*. However, the task of identifying which stars from this catalog are within the GMOS field-of-view has, until now, been tedious.

Fortunately, Macquarie University operates a unique program known as PACE (Professional And Community Engagement), which offers opportunities for their undergraduate students to make long-lasting contributions to the community, while integrating practical experience into their degree. In 2014 PACE students Corine Brown and Dylan Harrison — under the supervision of the International Telescopes Support Office (ITSO) staff Stuart Ryder and Richard McDermid — conducted a project to construct finding charts for all 45 fields using the Gemini Observing Tool (OT), complete with magnitudes for each standard star present in the GMOS field-of-view.

The finders are available ([view here]()), which give for each field an OT view of the field (clickable for higher resolution) and tables of magnitudes for each standard star (Figure 10).

While this utility has been available via the GMOS [photometric standards page]() for some time, it probably hasn't received the attention it deserves. In due course, efforts such as the SkyMapper Southern Sky Survey and its shallow photometric survey should make deriving photometric zero-points

**Figure 8.**
*Alejandro Gutierrez and Hector Swett (Senior Electronics Technician and Electronics Engineer, respectively) work on one layer of the A&G unit's "cake" during the Gemini South shutdown.*

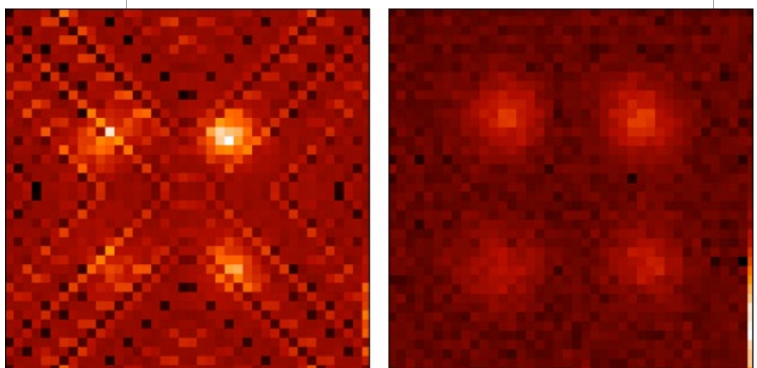


**Figure 9.**
*GMOS-S on-instrument wavefront sensor images from before (left) and after (right) the Gemini South shutdown. Each frame shows the image of a star from the four wavefront-sensor subapertures. The image at right was taken in very poor seeing, but the difference in quality of readout is clear. The "noise" in the worst parts of the "before" image is 150 analog-to-digital units (ADU) or more, although it was the systematic pattern which really caused problems with guiding. Now we consistently see only 10 - 12 ADU of truly random noise.*

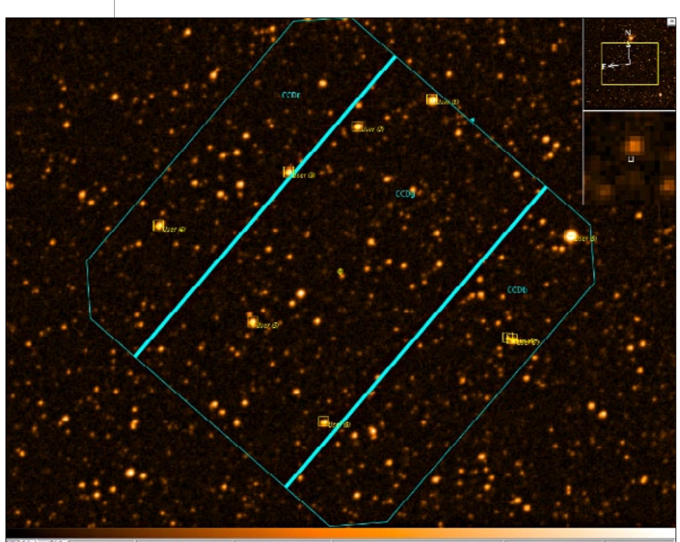


**Figure 10.**
*Finding chart for the GMOS-S standard star field NGC 458-AB, a star cluster in the Small Magellanic Cloud, based on the OT Position Editor display.*

from separate standard star observations redundant (as every GMOS field will contain multiple sources with catalogued u′, g′, r′, i′ and z′ magnitudes), but in the interim we trust that the community will find this a useful resource.

## Disco-Stu — GSAOI Image Reduction Simplified

Gemini has announced the release of a new standalone software package. Called Disco-Stu (DIStortion COrrection and STacking Utility), it is designed to help with the analysis of images taken with the Gemini South Adaptive Optics Imager (GSAOI). Disco-Stu takes images that have been reduced with the Gemini Image Reduction and Analysis Facility package for GSAOI and aligns them by matching sources with the aid of a lookup table that maps the instrument's static distortion. Stacking is then performed with bad pixel rejection and, if desired, inverse-variance weighting. The astrometry can be tied to an external source catalog, and the output image can be made to share the world coordinate system of another image. Performing both these steps results in an image that is perfectly aligned with an existing image, either taken with a different instrument, or with GSAOI at a different epoch (Figure 11).

**Figure 11.**
*A color mosaic of a region of the Pyxis globular cluster, produced from HST F606W and F814W images and a stack of GSAOI H-band frames. Disco-Stu was provided with one of the HST images and a source catalog constructed from that image (culled of faint sources and objects outside the GSAOI field-of-view) but no further guidance was required.*

Disco-Stu is written in Python and requires the NumPy and AstroPy packages (which are part of the Ureka release). SExtractor is also required for normal operation, although source catalogs can be prepared separately.

*— Chris Simpson*

# July 2016

## A Month to Forget

May 2016 may have been the worst month ever for weather at Gemini South on Cerro Pachón in Chile. In an average year, May is the first of five "bad" months, with weather loss usually on the order of 30% (see chart on page 41). By contrast, in May 2016, we had 16 nights during which we observed nothing at all, and a further seven during which we observed for less than three hours; in fact, weather interrupted observations every night to some degree during this period.

An extended and unusually poor weather period started in April and lasted well into June, with mainly high clouds as seen in Figure 12 (but resulting in surprisingly little precipitation). This could be an effect of the strong *El Niño* event that is gradually ending. Given that, on average, weather losses on Cerro Pachón peak in June and July, we can only hope that 2016 isn't "average," and that we will have better observing conditions in the following months. Obviously, the impact on observations has been significant. Bad weather wiped out most of the Phoenix visiting instrument run and greatly hindered

**Figure 12.**
*Gemini South's shutters remained closed for most of May 2016, due to persistent poor weather. Image credit: Sandra Romero, Gemini*

our progress on the many programs scheduled for this semester.

The good news is that, as reported in the April 2016 issue of *Gemini*Focus, we have begun adjusting the queue filling to account for the typical pattern of bad weather at Gemini South. So, fortunately, the queue was not overloaded in May as it had been in the past.

## FLAMINGOS-2 Stand-down Completed

In May, we removed FLAMINGOS-2 from the Gemini South telescope for a preventative maintenance stand-down. Moving to dedicated instrument stand-downs ensures that key resources and the laboratory environment are available without competing against other important tasks. This has been an issue during other single annual telescope shutdowns.

A large team of engineers, technicians, and science staff completed a variety of tasks. First they replaced the instrument's three coldheads (one is shown in Figure 13), which were approaching the end of their lifetime; indeed, the coldheads should keep the detector at a selectable temperature, but we have seen the temperatures gradually increasing. Replacing coldheads might sound easy, but accessing and replacing them requires dismantling the instrument.

Another outstanding issue was addressed by fixing the On-Instrument WaveFront Sensor used to measure distortions at the instrument imaging plane. Careful testing and analysis revealed an electronics problem, which we resolved. We also thoroughly tested all mechanisms, which raised some additional suspicions during the movement of the Multi-Object Spectroscopy (MOS) wheel (Figure 14). Further inspection indicated significant wear in some of the ball bearings, so all were replaced. The team then reassembled and successfully tested the entire mechanism.

Finally, the instrument was cooled down, first with liquid nitrogen in the lab, before we connected it to the helium compressors on the telescope. We returned FLAMINGOS-2 to the telescope, tested it during the night, and cleared it for scientific operation. With this success, a large period of intensive work came to an end. The instrument should benefit from reliable operations for the coming semesters, and we can now begin working on the commissioning of the MOS observing mode.

## Repairing the Gemini North Wind Blind

Both Gemini domes are equipped with a three-segment wind blind, which is deployed by moving the lower shutter to shield the telescope structure from wind coming from the direction of the open slit (Figure 15). Gemini North's wind blind has caused concern since early 2015, when we found excess wear on the track and roller system during regular maintenance. Considered a serious problem, we disconnected it in the

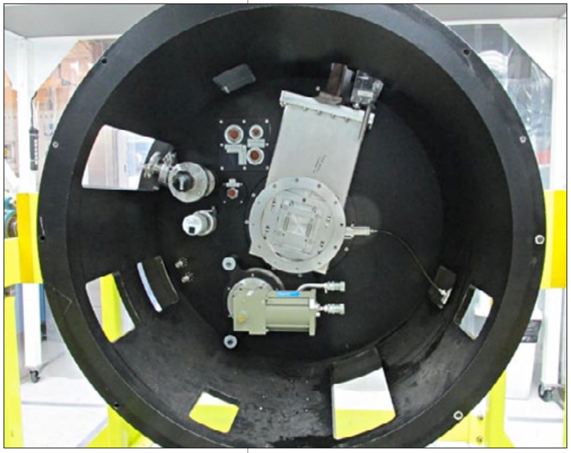


**Figure 13 (left).**
*The new camera cold head (green mechanism, at bottom). Above it is the gate valve baffle, which is employed during MOS mask swaps due to previous thermal background issues. Image credit: Gabriel Perez/Gemini/AURA*

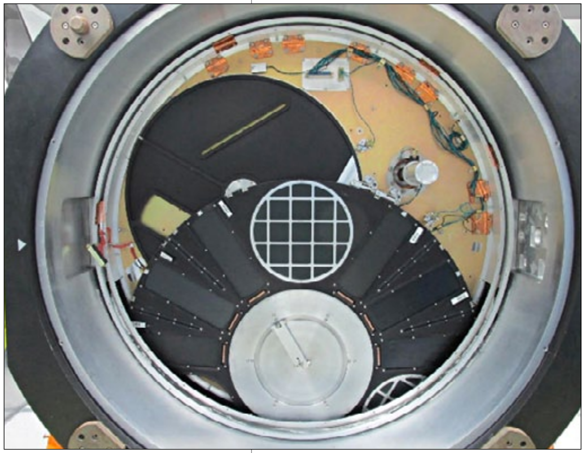


**Figure 14 (right).**
*The MOS wheel (larger segmented black wheel, in front, showing slots for MOS masks) and Dekker wheel (smaller black wheel, behind). Image credit: Gabriel Perez/Gemini/AURA*

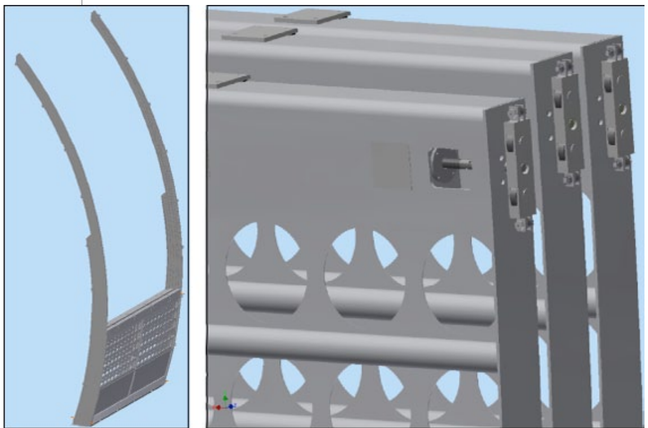


**Figure 15.**
*The Gemini wind blind design drawings. Left: blind segments all stowed, with the guide tracks above them following the shape of the dome arch. Right: detail of the segments; the largest is 5.5 meters (18 feet) high.*

second half of 2015 (when historically winds are lowest) to decrease run time and wear.

We reconnected the wind blind in November, to provide shielding during this more windy period, but decreased its maximum travel from 60 to 55 degrees. With Base Facility Operations in the North now implemented, we are able to focus on this problem and plans are now in place to work on it over the Northern Hemisphere summer. The project involves replacing all tracks guiding the wind blind and all guide roller assemblies, and performing repairs on any other damage found.

This is a major job, requiring three different pieces of heavy equipment, including a 120-ton mobile crane. We have requested and received approval to hire and use that equipment on Maunakea. Work will start immediately after the July 4th holiday, and will continue for two weeks. Observers cannot use the wind blind at night throughout this period. We'll report on the outcome in a future edition of *Gemini*Focus. The equivalent system at Gemini South has been inspected and shows no signs of similar problems, however, the process is being documented by staff to assist on future possible work.

## DR User Forum

The ***Gemini Data Reduction (DR) User Forum*** is a platform created for trading ideas, scripts, and best practices. Anyone is invited to ask questions or trigger discussions about data reduction, processes, and strategies. The DR Forum permits immediate diffusion to a broad audience. It allows users to have the attention of many experts that would otherwise be difficult to contact. The Forum also offers a different, more direct, channel to contact Gemini staff, instrument builders, and experienced researchers.

Please visit, search, read, and contribute to the Gemini DR Forum. If you would like a new topic to be covered, simply ***register*** (if you have not already) and add it to the discussions. Each new post will receive attention promptly.

For additional questions or comments, please contact us at: *sus_inquiries@gemini.edu*

***Is the DR Forum for you? The answer is probably yes, but especially if:***

- *You are performing optical or infrared data reduction for the first time:*
  - *Because you are working on your thesis*
  - *Because you are expanding your work to include wavelength bands or instruments with which you are not particularly familiar.*
- *You are adept with optical and infrared reduction but would like to share best practices with your colleagues so they can utilize good habits, which will lead to clearer and more accurate descriptions of their data reduction methods.*
- *You are simply facing a specific issue with your current data reduction, and you want to share your questions or solutions with a broad community of astronomers.*

## 2016B Observing Tool

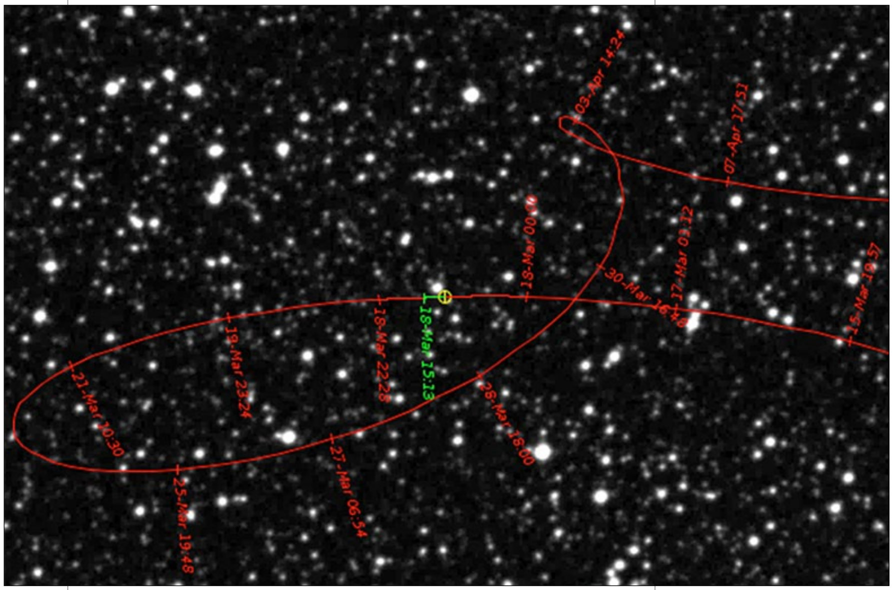



**Figure 16.**
*Position Editor showing the position of Saturn's moon Titan (green line) with the start of the observation indicated by the yellow circle.*

The 2016B Gemini Observing Tool (OT) was released on June 3, 2016. Installers for Mac, Linux, and Windows may be downloaded from the [***OT webpage***]. This version of the OT has several significant improvements to make preparing Gemini observations easier.

The first big change is the removal of the button to trigger the Automatic Guide Star (AGS) search. Guide star queries are now performed automatically in the background whenever users create or modify observations. This new feature works with all instruments and will update the guide star whenever an observation, or observing conditions, are updated. It will also automatically select the best guide star when the nighttime observer updates the time of non-sidereal or parallactic angle observations. If you don't like the automatically chosen guide star you may use the Catalog Query Tool (new in 2016A) to manually select your preferred one. Manually selected guide stars (and guide stars from previous semesters) are displayed in a "Manual" target group, and the auto-guide star system will not modify them.

The second big change is an overhaul of non-sidereal target support, which is fundamentally different in the 2016B OT. The 2016A OT handled non-sidereal targets using a mix of data — Minor Planet Center and Jet Propulsion Laboratory (JPL) minor planet orbital elements, a selectable list of the eight major planets, and manually generated ephemerides — which can be confusing and cause errors when preparing observations.

The 2016B OT supports all non-sidereal targets using automatically generated and updated ephemerides from JPL HORIZONS. When a user creates an observation the OT will download a low (~6-hour sampling) resolution ephemeris covering the entire semester for planning purposes. For accurate visualization in the Position Editor and optimal guide star selection, this is augmented by ~5-minute resolution data for the scheduled night observation. The Observing Database independently keeps track of active non-sidereal observations and downloads high (1-minute sampling) resolution ephemerides the day before an observation might be scheduled.

New plotting capabilities in the Position Editor accompany these infrastructure changes, displaying the path of non-sidereal targets throughout the semester. The red line in Figure 16 shows the orbit of Titan as seen from Maunakea in March-April 2016. The yellow circle in the center marks the start of an observation, and the green line segment shows the position of Titan during the scheduled observation.

There were many smaller improvements and bug-fixes too numerous to mention. Please see the ***OT Release Notes*** for more details, and for more news on upcoming software changes please follow the ***Gemini Science Software Blog***.

## *How the Queue Responds to Adversity*

All observatories attempt to complete science programs against a variety of competing factors: weather, equipment failures, earthquakes, *etc.* Queue scheduling attempts to preferentially complete programs blessed with the highest science ranking by the Time Allocation Committees (TACs), whatever the competing factors put in the way.

Weather losses, commissionings, earthquakes, and other events in recent years have given us quite a roller-coaster ride, and it's interesting to see how queue scheduling (recently the largest part of the Gemini science program) has responded to these challenges. Here we look at an exceptional semester (one with good conditions and more science time than originally planned) and a bad semester (affected by weather and technical problems) and summarize the results.

### *Recent Challenges*

Figure 17 shows the average program completion rate of Bands 1-3 over the past five years. Many factors are at play in these plots, but we can single out examples of exceptionally good and exceptionally bad semesters.

For instance, Semester 2012A at Gemini South was particularly good, because more science time became available when the Observatory cancelled planned commissioning work. The most recent semesters at Gemini

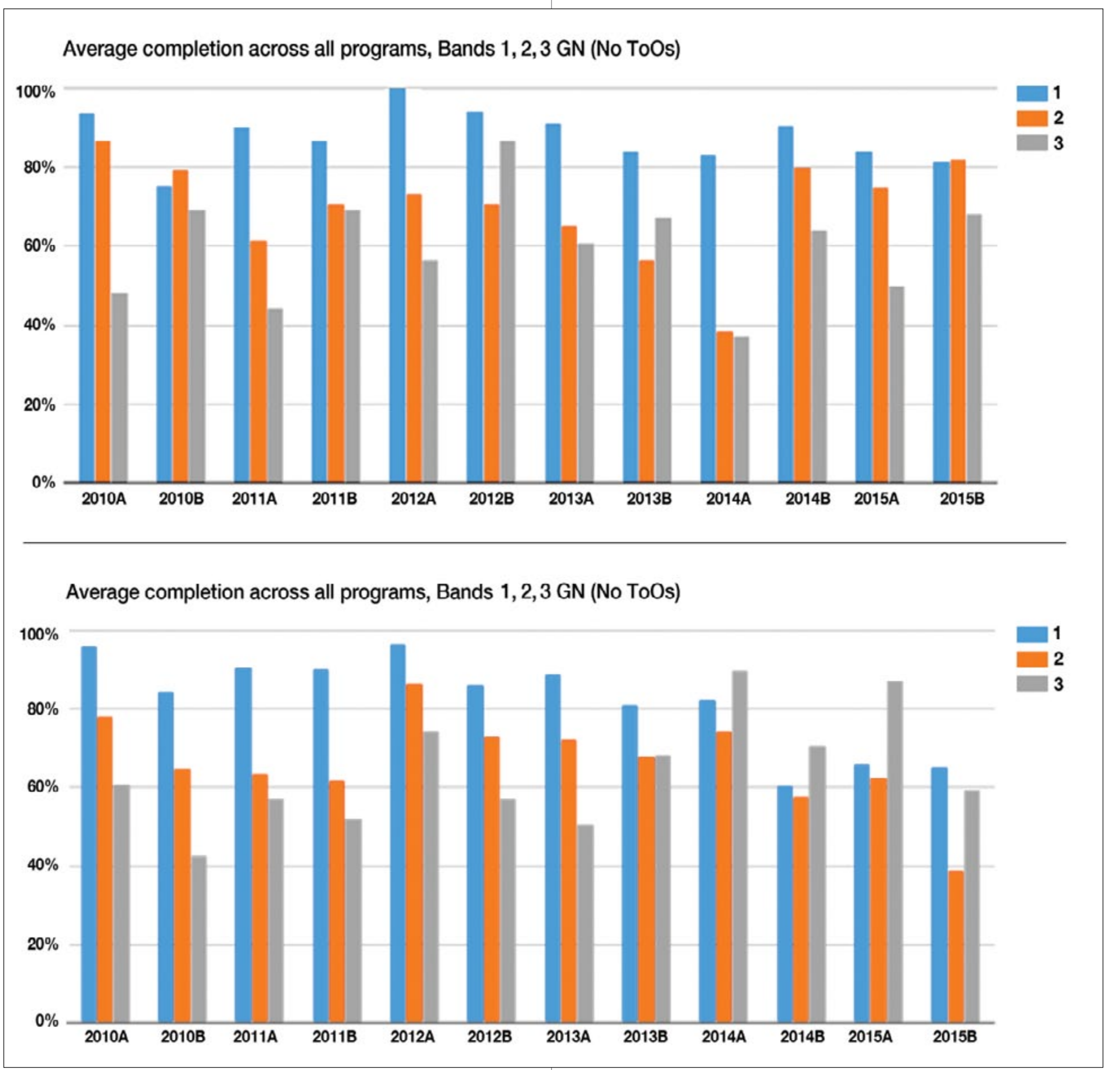



**Figure 17.** *Average program completion across Bands 1, 2, and 3 (blue, orange, and grey, respectively), for all semesters since 2010A. Top: Gemini North. Bottom: Gemini South.*

South have been challenging, especially 2015B, which we discuss later). Semester 2014A at Gemini North was unusually poor, as bad weather and dome shutter failures hit us hard; but we recovered and are now back at roughly average performance compared to the last five years.

The two charts in Figure 18 show histograms of queue program completion at Gemini South 2012A and Gemini North 2014A.

The very sparse tail of programs below the 100%-complete bin in the "exceptional" semester compares with large numbers of programs ending at 90% and below in the "bad" semester. Numerous programs were not started at all in 2014A at Gemini North.

Note that the queue preferentially protects Band 1 observations in a "bad" semester, as it should. In the "exceptional" semester at Gemini South the Band 1 completion exceeded that of Band 2, which in turn exceeded that of Band 3. In a "normal" semester (neither exceptional nor terrible) results lie somewhere between these extremes, with Band 1 completion higher than that in the other two bands.

While Band 2 completion usually exceeds that in Band 3 during a "normal" semester, it is a signature of bad weather that in some semesters Band 3, in which programs can typically take poorer conditions, does better. As you can see in Figure 18, in recent semesters, Band 3 has done well relative to the others at Gemini South; again, this is a symptom of weather adversity.

## *Addressing Weather Loss at Gemini South*

Weather conditions at Gemini South repeat themselves fairly regularly across each semester. In the past we didn't make any allow-

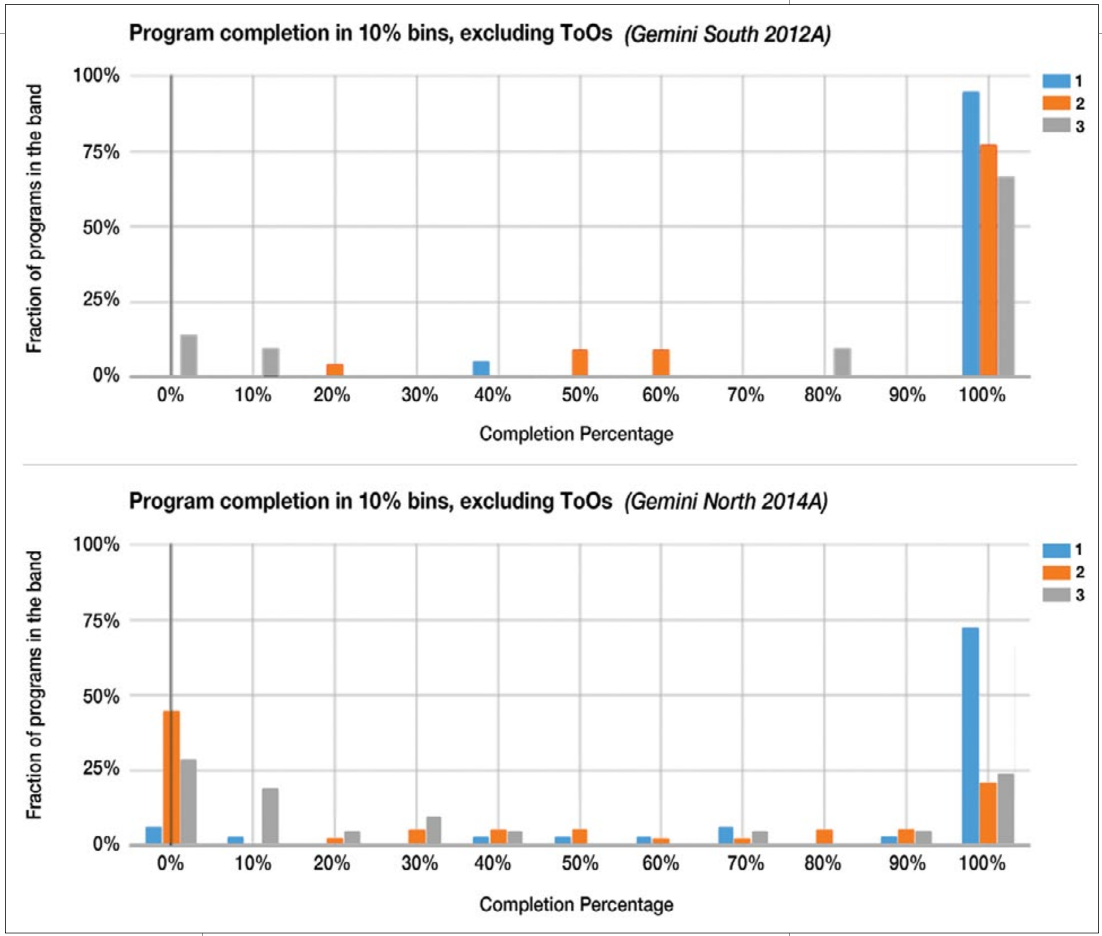



**Figure 18.**
*In 10% bins, the fraction of programs ending the semester at a given completeness level. Top: an unusually good semester (Gemini South 2012A). Bottom: an unusually bad semester (Gemini North 2014A).*

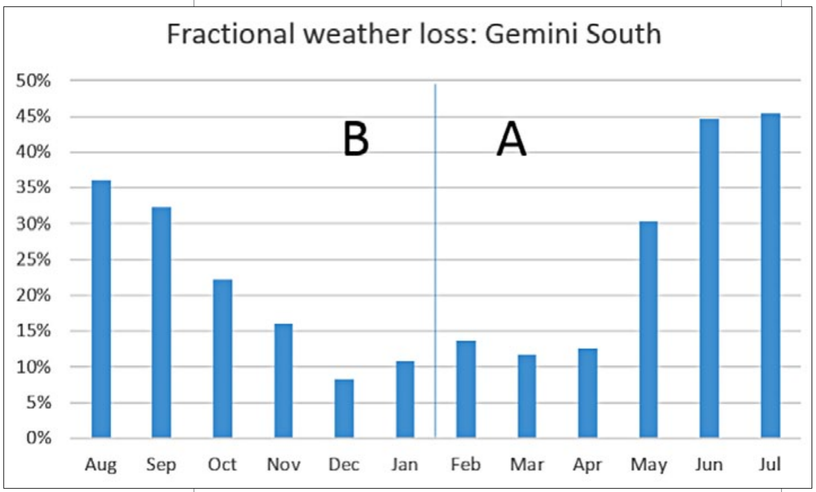



**Figure 19.**
*Percentage of time lost to weather at Gemini South. This pattern is quite reproducible from year to year. We now take better account of it in the time allocation process; we no longer overload the mid-year months (May-September), and allow more programs into the southern summer time.*

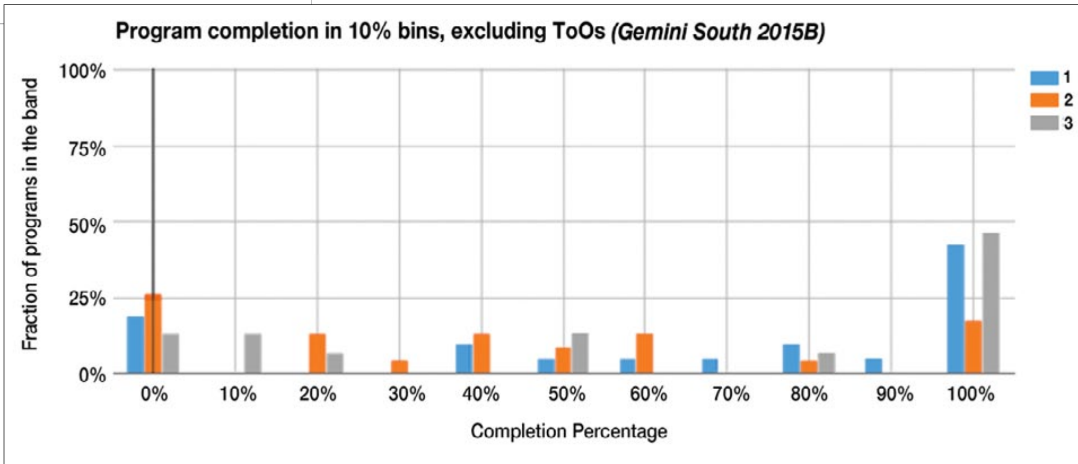



**Figure 20.** *Program completion in 2015B at Gemini South. Note the significant numbers of unstarted programs (driven by instrument unavailability), and the excess of Band 3 programs in the 100%-complete bin (a signature of bad weather).*

ance for that. Recently, we've made a change to the way we fill the queue for Gemini South. Figure 19 shows a repetitive five-year pattern of weather losses at Gemini South; because we filled the queue each month as if the weather loss was uniform (and it wasn't), we forced ourselves to battle the elements at the worst times of the year. In the 2016A TAC process, we adjusted the way we fill the queue: we no longer overload May-September, and allow more programs into the southern summer months. We'll see how it goes now that we're into the semester itself.

## 2015B: Major Challenges at Gemini South

As mentioned, Gemini South has had some challenging semesters of late. Semester 2015B, for instance, had plenty of adversity to go around: the Gemini Multi-conjugate adaptive optics System (GeMS) out of action due to a major earthquake that struck in September 2015; the Gemini Planet Imager (GPI) still ramping up; and many programs either lost completely to weather, or executed under marginal conditions. Based on the discussion above, we would therefore expect a significant hit on programs in all Bands, with Band 3 (able to take the worst conditions, and therefore not containing any GPI or GeMS programs) performing reasonably well. That's borne out by the results shown in Figure 20: a significant number of GPI programs were not attempted at all, hardly any GeMS programs started, and many programs ended up in the "tail" of completions below 100%.

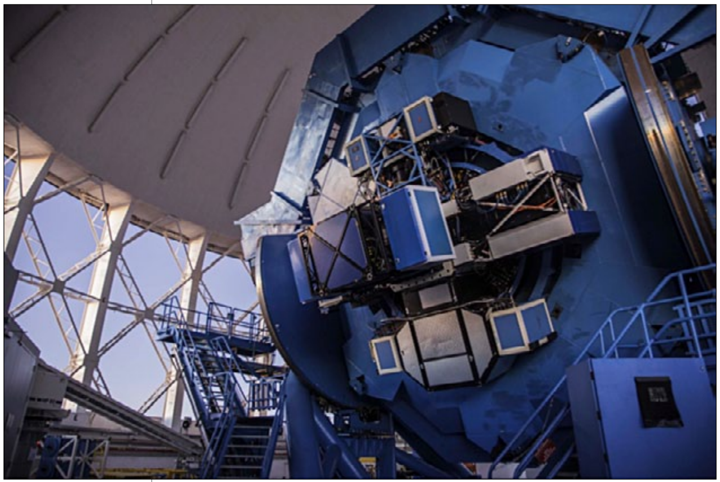


**Figure 21.** *GPI (center) installed on the up-looking port of Gemini South. FLAMINGOS-2 is at top, and GMOS-S is at bottom.*

## GPI and Telescope Vibration

In late 2013, early commissioning tests of the Gemini Planet Imager (GPI) on the Gemini South telescope (Figure 21) revealed a strong oscillation in the corrected wavefront, similar to defocus. The 60 Hz oscillation frequency pointed to the GPI Stirling cycle cryocoolers (which run at 60 Hz) as the cause. But we did not understand the mechanism that disturbed the optical wavefront. After fitting the telescope optics with accelerometers, a team of Gemini scientists and engineers detected the oscillations in the primary mirror (M1). The center of M1 was vibrating relative to the outer edge with a peak-to-peak amplitude of 840 nanometers (nm) — sufficient to cause a focus-like shift of about 1 millimeter at the GPI focus. The vibration completely disappeared when we turned off the GPI cryocoolers.

To improve the delivered wavefront, the GPI team first developed a software filter to measure the 60 Hz focus oscillations. They then applied a correction signal to GPI's adaptive optics. The filter improved GPI's performance to a satisfactory level, but the 60 Hz vibrations remained in M1, potentially affecting other science instruments. Therefore, in mid-2015, Gemini upgraded the GPI cryocooler controller to a new model — one with an active damping system that measures the cryocooler's acceleration and applies a counteracting one to dampen the vibrations at their source (Figure 22). Measurements with GPI indicate that the new system reduces the 60 Hz defocus residual wavefront errors from about 50 nm root-mean-square (rms) to as low as 1 nm rms — a factor of 50 reduction!

Work on vibrations in GPI is part of a long-term program to characterize and reduce vibration effects on both Gemini telescopes. Over the next two years, we plan to install a common accelerometer system on both telescopes to permit continuous monitoring of vibration levels.

## Early Use of the Gemini Observatory Archive

Early use of the new Cloud-based Gemini Observatory Archive has been healthy. Here are some initial statistics as of April 2, 2016.

- We have 303 registered users, and the number is increasing all the time.
- Since we went live, users have made a total of 45,000 archive searches and downloaded 550 GB in 117,000 files. We're currently seeing about 1,750 archive searches and about 30 GB (compressed) downloads per week.
- Currently, we have 3.3 million files in the archive, a total of 8.6 TB (compressed), and 29 TB ( uncompressed) FITS data.

Finally, don't forget that in order to access proprietary data from your program you will need to register your program ID with your archive user account. See ***this paragraph on the help page*** for further instructions.

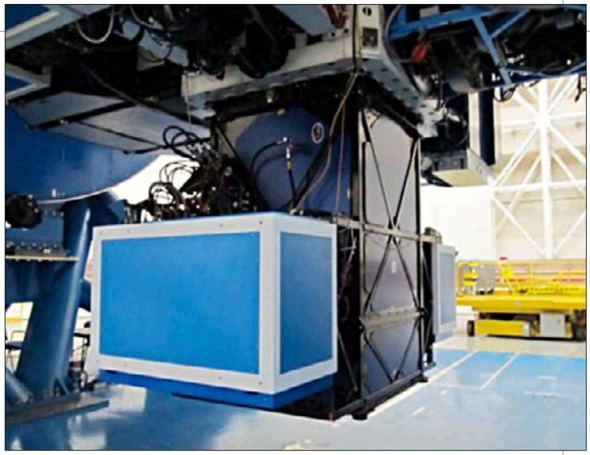


**Figure 22.**
*Close-up of GPI attached to the instrument support cube (white, at top). Vibrations from the instrument's cold heads coupled very efficiently into the cube and then into the mirror cell.*

## Australia's Partnership in Gemini: A Retrospective

*December 31, 2015, marked the end of Australia's time as a full member in the international Gemini Partnership. Stuart Ryder, Head of the Australian Gemini Office (AusGO), reflects on Australia's participation as a Partner over almost two decades.*

Australia joined Gemini in 1998, with the first time allocations made in Semester 2001A. Over the next 30 semesters, the Australian Time Allocation Committee received a total of 739 Gemini proposals. Of these, 440 were allocated queue time, and a further 25 were allocated classical nights on Gemini (or Subaru via the time exchange program). The average oversubscription factor was 2.0. Thanks to the flexibility offered by Gemini's queue mode, almost two-thirds of these programs got 80% or more of the data they requested under the required conditions.

### *Following are some notable Australian contributions to Gemini:*

- Development of the Near-infrared Integral Field Spectrograph (NIFS) and the Gemini South Adaptive Optics Imager (GSAOI), two of the more productive and reliable instruments on the Gemini telescopes.
- The Australian Gemini Undergraduate Summer Studentship (AGUSS) program. Since 2006, the program has sponsored 23

**Figure 23.** *Gemini South image of NGC 3310 obtained as a result of the Australian Gemini Cosmic Poll in 2015. NGC 3310 is a grand design galaxy about 50 million light years distant that likely collided with a smaller galaxy about 100 million years ago — warping its disk and inciting bursts of star formation (the pink regions in the galaxy's arms).*

Australian undergraduate students, who spent a summer at Gemini South carrying out research projects with Gemini staff and becoming excellent ambassadors for Gemini within the Australian community.

- The Australian Gemini School and Amateur Astronomy Contests. Since 2009, these contests have inspired school students (and more recently amateur astronomers) to suggest targets to image with GMOS-S, resulting in some awe-inspiring color pictures of galaxies and nebulae.
- A Joint Proposals Database. Established and operated by the Australian Gemini Office (AusGO, now hosted by Gemini), this database enables the sharing of one technical assessment for joint proposals, thereby improving collaboration and efficiency across the Partnership.
- With the participation of Gemini staff, the AusGO ran two very successful Observational Techniques workshops (in 2011 and 2014), with a legacy of online talks and tutorials.

Of the almost 1,800 Gemini papers in refereed journals, about 15% have at least one Australian-affiliated author, reflecting the collaborative nature of many of the programs' allocated time. This works out at one Gemini paper with Australian involvement for every eight hours of Gemini time used. Gemini data from Australia has contributed to the PhD theses of 45 students at Australian institutions.

## *Australian Gemini Cosmic Poll*

*Throughout Australia's membership in the Gemini Partnership, AusGO ran an annual competition in which school students and amateur astronomers competed to define an observation to be done in queue time.*

New AusGO staff member Elaina Hyde took the 2015 Australian Gemini Image Contest in a new direction by transforming it into the "Australian Gemini Cosmic Poll." Rather than requiring high school students or amateur astronomers to propose suitable targets as in earlier contests, the entire Australian public were invited to vote on one of four categories of objects to be observed: an individual galaxy, a galaxy pair, a planetary nebula, or another type of nebula.

In a spirit of friendly competition, each AusGO staff member pitched their favorite class of object in a short video. The science and media ***technology platform*** hosted the poll, and it received more than 100 votes in the space of two weeks; in the end, the "individual galaxy" category came out on top, and the selected target was NGC 3310. While the observations were made active in the Gemini queue, Elaina coordinated a "Live from Gemini" video event with Peter Michaud and André-Nicolas Chené, and posted regular updates to the AAO's ***Facebook page*** and ***Twitter accounts***. AusGO released the final stunning image of NGC 3310 (Figure 23) just before Christmas — a fitting way to mark the end of Australian usage of Gemini's queue mode.

Gemini staff contributions

# On the Horizon

*Myriad advances in Gemini's instrumentation and capabilities occurred in 2016. This review looks at these developments and what the future holds for Gemini's instrumentation program.*

## January 2017

### *GeMS' Next Generation Natural Guide Star Sensor: Making Progress*

GeMS, the Multi-conjugate adaptive optics System deployed at Gemini-South, has been in use for several years now, producing spectacular results with its capability to deliver diffraction-limited image quality over a field more than 1 arcminute wide. To achieve this performance GeMS uses five laser guide stars for high-order wavefront sensing, and up to three natural guide stars (NGS) for tip-tilt and plate scale modes sensing. However, operation of GeMS is rather complex, principally due to technical issues. Recent technological developments have opened the possibility to improve the operational efficiency drastically (for instance, see page 47 of this issue to read about the new laser system being procured). Here we report on developments to enhance the selection and performance of natural guide star tip-tilt sensing.

A key problem encountered in GeMS operation revolves around the acquisition of natural guide stars. The existing Natural Guide Star Wavefront Sensor (NGS WFS) used for tip-tilt sensing suffers from low throughput, which severely reduces the number of stars that can be acquired, thereby diminishing the amount of sky coverage attainable by GeMS. Furthermore, the existing NGS WFS system uses three mechanical pickup probes, each of which can patrol the whole field. But these probes have only a very small field-of-view which, due to flexure and variable field distortions, sometimes makes it time consuming to acquire the stars.

Thanks to current state-of-the-art detector technology that has become available, these limitations can now be tackled. A key change is that rather than having three mechani-

**Figure 1.**
*Design drawing of the Natural Guide Star Next Generation Sensor (NGS2) unit (shown in green) occupying one corner of the Canopus AO optical bench.*

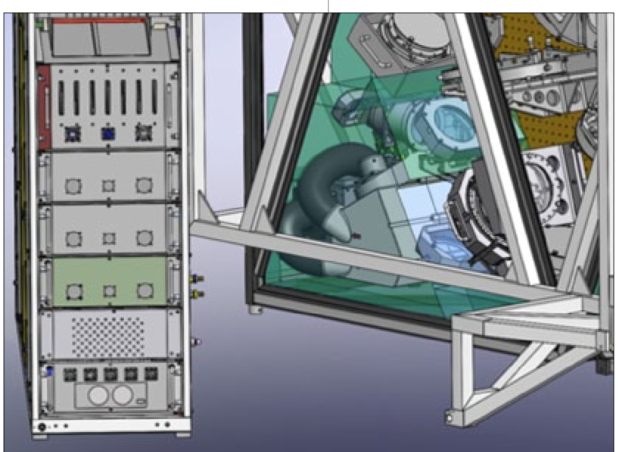
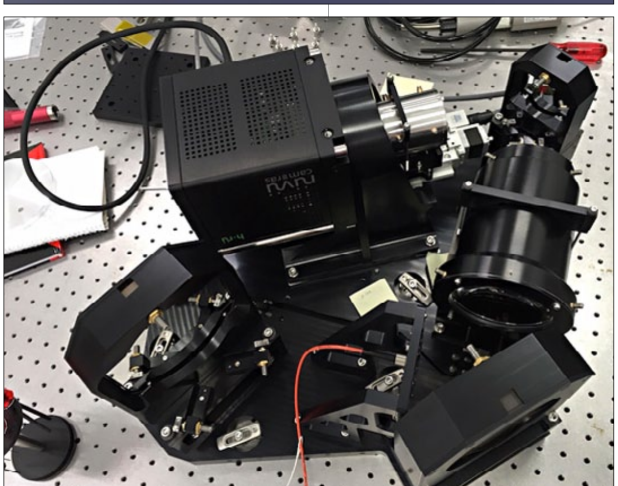


**Figure 2.**
*The NGS2 unit, nearly fully integrated in the ANU laboratory. At the bottom of the image one can see two large fold mirrors that channel the light into the re-imaging optics. The large unit at the top left houses the electron multiplying CCD detector. Image credit: courtesy of the Australian National University*



cal pickup probes patrolling the field to find and track the guide stars, the future system will use an electron multiplying charge-coupled device (CCD) detector that can image the whole field, allowing straightforward identification of guide stars.

Multiple regions of interest centered on the guide stars can also be configured and read out at very high speed — up to 800 hertz with very low read noise. This new sensor converts the existing delicate opto-mechanical arrangements of the guide probes to a system that will essentially be software configurable and more robust. Its higher efficiency is expected to improve the detection limit for natural guide stars by some 2.5 magnitudes, which will result in a dramatic improvement in sky coverage.

In 2014, we secured funding from the Australian Research Council for a proposal led by the Australian National University (ANU). This — together with additional funding from Gemini, the Australian Astronomical Observatory, and the Swinburne University of Technology — opened the possibility to design and build this Natural Guide Star Next Generation Sensor, or NGS2, in short (see Figures 1 and 2).

We expect the new NGS2 subsystem will become an integral part of the Canopus adaptive optics system, replacing the existing NGS unit with the minimum necessary modifications. In a nutshell, NGS2 is composed of an optical system that re-images the focal plane onto a high-speed electron multiplying CCD detector. In full-frame readout, the guide stars can be easily identified. For tip-tilt sensing only, small areas around the stars are read out at high speed. A dedicated central processing unit will determine the centroids and pass the necessary information to the adaptive optics (AO) real-time control system.

The space constraint for the new NGS2 system, which needs to fit onto the existing AO optical bench, is very demanding; the alignment tolerances and system integration are challenging features, as well. Figure 1 shows the design drawing of how NGS2 will just fit into a corner of the AO optical bench. Furthermore, the detector generates heat that has to be actively removed, so as not to affect the rest of the AO system. And finally, one functionality of the existing system — the focus sensing of the natural guide stars — cannot be incorporated in the NGS2 design. Therefore, one of the existing peripheral wavefront sensors will take over that function.

Very good progress has been made to date in the detector upgrade. Essentially the opto-mechanical system and the detector system have been completed and are going through the final stages of integration and alignment at the ANU laboratories. Figure 2 shows a recent picture of the NGS2 system on the bench.

The system is in a very advanced stage of development and currently undergoing the final stages of alignment. Figure 2 also shows a recent picture of the built NGS2 module on the bench, ready for testing. Formal Acceptance Testing was successfully carried out in early December.

Still, much work remains to be done. In particular, a significant amount of software development is pending while resources are very tight. Also the integration of NGS2 into Canopus will be a delicate activity and require extensive testing, during which time it cannot be used for science. Hence planning of this activity must be done with care. We have great expectations for this new natural guide star system and expect that NGS2 can be delivered to the Observatory during the course of 2017. We intend to report on further progress in future issues of *Gemini*Focus.

*— Rene Rutten*

## Gemini South Laser Guide Star Facility News

On October 5-6, the Gemini South Laser Guide Star Facility completed its Factory Acceptance Test (FAT) readiness review at Toptica AG Photonics in Munich, Germany (Figures 4 and 5). The actual FAT occurred between November 28–December 2 and was successful; all the requirements met the specifications established in the contract. Also, the Toptica team provided initial training to Gemini South scientists and engineers attending the FAT. The Toptica laser was shipped on December 2nd and arrived safely at Cerro Pachón on December 13th (Figure 3). We plan post-shipping Acceptance Testing (AT) in January 2017. During the post-shipping AT, we will verify the laser survived the shipping, maintaining all functionality at the specified performance. We plan to start installing the laser's subsystems at the telescope in May 2017, with commissioning on-sky in August 2017.

*— Manuel Lazo*

## Gemini Multi-Object Spectrograph CCDs

Through an exhaustive amount of troubleshooting, the Gemini Multi-Object Spectrograph (GMOS) upgrade team resolved the anomalies found in the as-delivered hardware for the GMOS-N CCD installation. We also called on Tim Hardy (detector engineer), who worked on the original set of GMOS-S Hamamatsu CCDs at the National Research Council of Canada-Herzberg, for additional support. As a result, we found and corrected some issues with the controller Digital Signal Processing code. We also developed a more efficient ground scheme for the Astronomical Research Camera controller to provide a more stable bias level and lower readout noise of about 4e-.

As we provide this report, the GMOS team continues to maintain schedule, having now completed the controller pre-installation Acceptance Testing in November (Figures 6 and 7). We also measured good read noise and all functioning amplifiers, and found no significant cosmetic concerns. The installation of the new CCDs into GMOS-N is scheduled to start by the first week of February 2017, with commissioning on-sky in mid March 2017.

*— Luc Boucher*

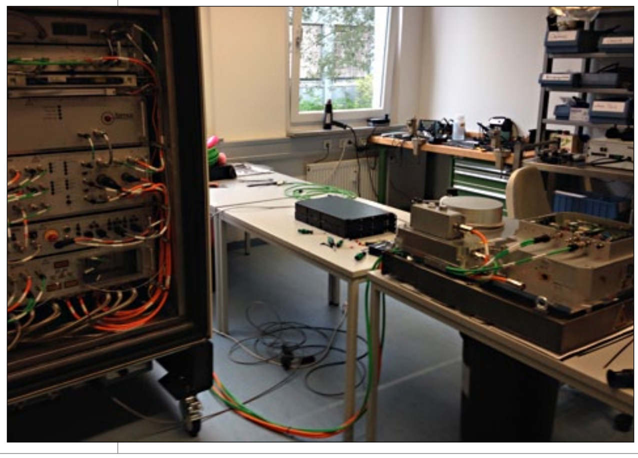


**Figure 3 (top left).** *Emmanuel Chirre (left) and Cristian Moreno stand guard over the new Toptica laser.*

**Figure 4 (bottom left).** *The Gemini South laser system being integrated at Toptica. The Electronics Cabinet (at left) is connected to the laser head without the protective covers (at right) through the black fiber splice boxes (at center).*

**Figure 5 (below).** *The Gemini South laser cabinet just before connecting to the laser head during the FAT readiness review on October 5-6. Image credt: All three images by Manuel Lazo*

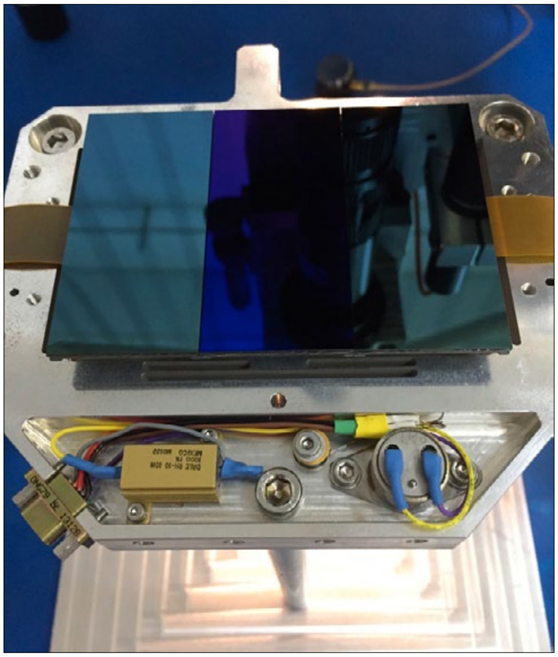


**Figure 6.**
*The new Hamamatsu CCDs mounted and aligned in the Focal Plane Array and ready to be installed into the Test Cryostat to start pre-installation Acceptance Testing. Image credit: John White*

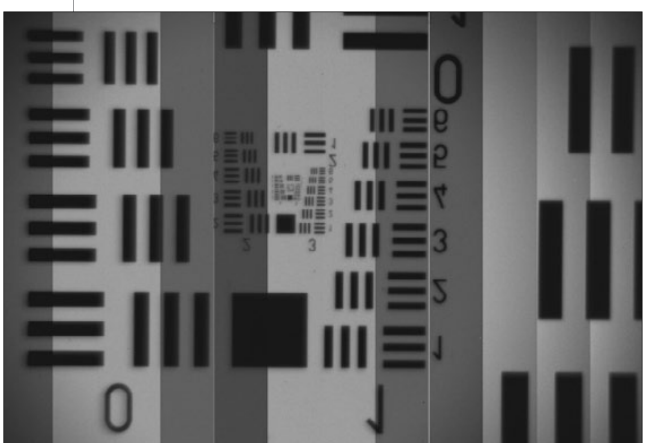


**Figure 7.**
*The first light (raw) image of the new Hamamatsu CCDs; the 12 amplifiers see light, and show no evidence of cosmetic defects. Image credit: Luc Boucher*

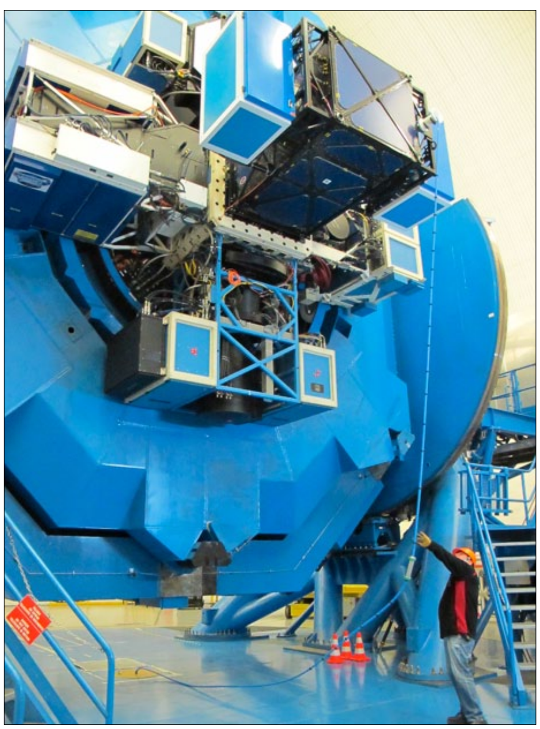


**Figure 8.**
*AAO Engineer Vlad Churilov and the GHOST mock optical cable during testing in Chile. Image credit: David Henderson*

## Gemini High-resolution Optical SpecTrograph (GHOST)

As we near the midpoint of the GHOST project build phase, the build team continues to receive parts from its suppliers, and the assembly of the instrument and the development of the software progresses on schedule. The team recently completed some verifications on the telescope at Gemini South.

In November 2016, engineers from the Australian Astronomical Observatory (AAO) and Gemini successfully verified the alignment of the Instrument Support Structure (ISS) mounting surface relative to the telescope optical axis. This was important to check because any misalignment needed to be within tolerance to ensure that the GHOST system throughput is maintained. The GHOST Cassegrain unit is designed to be mounted directly on the ISS and both of its integral field units are designed to project the telescope pupil, which is coincident with the secondary mirror, onto the fiber core of the fibers which connect with the spectrograph in the pier lab. The fibers are protected by an outer conduit, constituting the optical cable assembly, running the length between the telescope and pier lab.

In October, other engineers from AAO and Gemini ran some tests using a mock optical cable assembly to demonstrate how this cable would move, and to identify any potential problem areas, such as snagging, as the telescope changes positions (Figure 8). These tests resulted in some minor design tweaks, and an overall confidence in the cable design. We expect the first delivery of GHOST subassemblies, Cassegrain unit, and cable assembly at Gemini South to occur in the fourth quarter of this year.

*— David Henderson*

## Gen 4#3 Instrument Development

Gemini Observatory received four very good Gen 4#3 proposals before the Request for Proposals (RfP) deadline at the end of August. We then sent the proposals to an expert evaluation committee for assessment. Within two weeks, we received excellent feedback against the predetermined evaluation criteria. We held an evaluation committee meeting at AURA's Center for Administration in Tucson, Arizona, on September 23rd, and the committee created a number of highly-valued recommendations in their report.

In addition, upon receiving the proposals, Gemini extracted information and sent a short report for review by a subcommittee of the Gemini Board of Directors. As stated in the RfP, final selection is based on a number of components, some outside the remit of the evaluation committee, and these are the areas that the Board subcommittee is assessing. The Board subcommittee responded promptly, helping us to maintain our schedule in the early stages of the project.

In October, Gemini will make a number of physical and virtual site visits to seek clarification from proposers before making a final recommendation to the Gemini Board by the end of the month. We expect a selection decision to be made at the Board meeting in November. We hope to be able to start the Gen 4#3 first design stage in the first quarter of 2017, although there is some risk in this date, pending the nature of the contract negotiations and approval processes.

## GHOST Progressing Through Build Phase

The Gemini High-resolution Optical SpecTrograph (GHOST) project continues to progress through the build phase. When completed, this instrument will bring long-desired capabilities at a high level of performance to Gemini South. At the June 2016 conference of the international society for optics and photonics (SPIE), held in Edinburgh, Scotland, several GHOST project team members reported on the project's status.

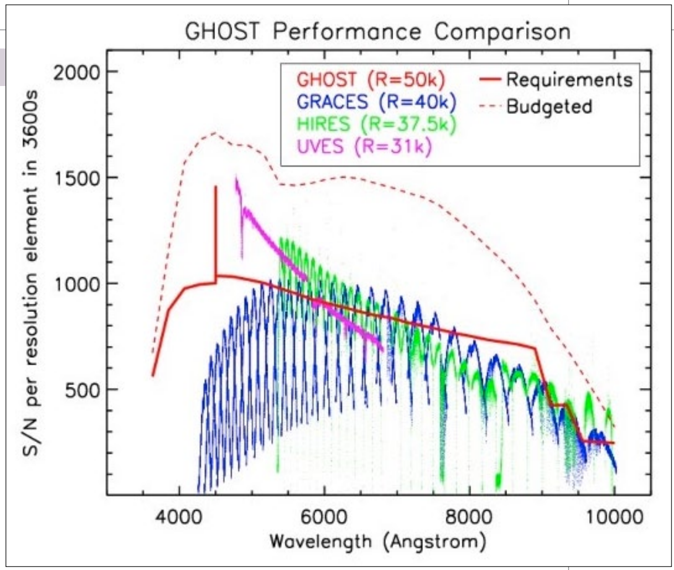



**Figure 9.**
*GHOST expected performance comparison against other current instruments in the field today.*

Andy Sheinis, Head of Instrumentation at the Australian Astronomical Observatory (AAO), which leads the multi-institution team building GHOST, described the technical advances incorporated into the instrument. GHOST is designed to deliver R = 50,000 and R= 75,000 spectroscopy for up to two objects simultaneously. GHOST uses a fiber-based image slicer to allow for a much smaller spectrograph than that described by the resolution-slit–width product; it will also have a sensitivity in the wavelength range between 363-950 nanometers (nm) that equals or exceeds that of similar instruments on other world-class facilities. Figure 9 shows the chart that Andy presented at the SPIE conference, which compares the GHOST predicted performance (dashed red line) against other current instruments in the field today. Andy also described the unique scientific role GHOST will have in an international context, from exoplanets to the distant Universe.

Also presenting at SPIE from the GHOST project team were Software Project Man-

ager Peter Young, Software Engineer Jon Nielson, and Project Scientist Mike Ireland — all from the Australian National University. Peter and Jon presented a paper and poster on how GHOST will be controlled with software using the Gemini Instrument Application Programmer Interface (GIAPI), the newest Gemini software framework. Mike's paper and poster showed the precision radial velocity error budget for the instrument, obtained from end-to-end simulations. Although GHOST was not designed for radial velocity precision, the 10 meters per second requirement is feasible; GHOST may also achieve a significantly higher performance than this.

**Figures 10-11.**
*John Pazder and the first three optics for the GHOST spectrograph. Credit: Greg Burley, NRC-H*

John Pazder, Project/Optical Engineer at Canada's National Research Council-Herzberg (NRC-H), presented a paper and poster covering the optical design of the bench-mounted spectrograph and the predicted resolution and efficiency for the spectrograph. The following GHOST project team members were also in attendance: Project Manager/Detector Engineer Greg Burley, from NRC-H; Optics Engineer Ross Zhelem, from AAO; and Instrument Scientist Steve Margheim, Systems Engineer Andrew Serio, and Project Manager David Henderson, from Gemini.

The NRC-H team building the bench-mounted spectrograph subsystem recently received the first major optical components from vendors. The first three optical blanks (Figures 10 and 11) came from Schott in Germany and were inspected at NRC-H prior to being shipped out for further processing: grinding, polishing, and coating at another vendor. These optics make up the spectrograph's white pupil relay section. We expect the build phase, the project's longest phase, to conclude at the end of 2017, with commissioning at the telescope in 2018.

## New Laser Guide Stars Coming to Both Gemini Telescopes

Gemini offers Laser Guide Star (LGS) adaptive optics (AO) at both Gemini telescopes – with Altair in the North, and as an integral part of the Gemini Multi-conjugate adaptive optics System (GeMS) at Gemini South. The lasers are projected into the sky where they excite a small patch of sodium ions in the ionosphere. The re-radiated light from the sodium layer then forms an artificial "guide star" (or stars for GeMS) that the AO system uses for wavefront reference.

Our existing diode-pumped, solid-state lasers were state-of-the-art when developed, but that was well over a decade ago; they are now very difficult and expensive to maintain and operate and require significant effort — from both in-house specialists and external contractors — to keep them calibrated and operational at useful power levels.

Recently, a new technology has emerged that presents us with an opportunity to upgrade our lasers. Called Raman fiber laser amplification, it is in widespread use in fiber optics communication systems. A partnership between Toptica Photonics in Germany and MPB Communications in Canada, has applied this technology — licensed from the European Southern Observatory (ESO) — in LGS systems that use their *SodiumStar* laser system; Gemini selected this option after an open competition to provide new lasers for Gemini. The *SodiumStar* system provides a "turn-key" laser, with very low maintenance requirements, and is very simple to operate.

We are planning to put *SodiumStar* lasers on both Gemini telescopes, starting at Gemini South. The project is well under way with the laser in production at Toptica and Factory Acceptance Testing scheduled for late

2016. We expect to install the laser on the Gemini South telescope in mid-2017 and start on-sky commissioning. Meanwhile, we're preparing the telescope for the new laser's mounting and cooling systems and negotiating the contract to purchase a similar laser for Gemini North. The timeline is less certain, but we would expect to have the laser on-sky sometime in 2018.

## Coming Soon: Gemini Instrument Upgrade Projects — Request for Proposals

Gemini Observatory is planning to invite the community to participate in the 2016 Request for Proposals (RfP) for Instrument Upgrades. This initiative aims to establish annual proposal calls for science-driven upgrades to Gemini's facility instruments, including projects that may rely upon in-kind contributions or telescope time as compensation. This year, Gemini will provide a total budget of 600,000 USD to fund one or more projects. The available budget was developed to fund one small (~100,000 USD) and one medium (~500,000 USD) upgrades, but we are open to the distribution of funds from 0 to the 600,000 USD total available budget.

To encourage a wide variety of participant organizations in this opportunity, Gemini will provide up to one night (10 hours) of observing time per project to be used on demonstrating the scientific potential of the upgraded instrument. The RfP will be released by or in October 2016 and will remain open through the end of the year. Further information and updates can be *found here*.

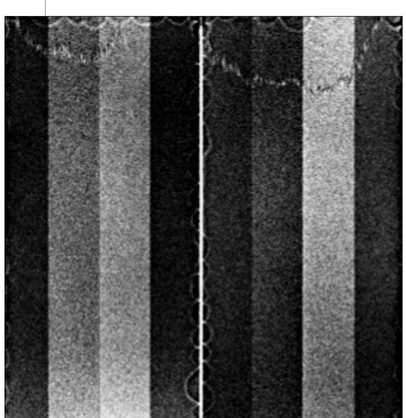
In the 2015 RfP, the total budget was 100,000 USD and the award went to Casey Papovich and his team from Texas A&M University and astronomers from the University of Toronto, Swinburne University of Technology, Leiden University, and Macquaire University. The project will upgrade the near-infrared wide-field imager and multi-object spectrometer FLAMINGOS-2 (F-2) with two medium-band filters designed to split the 1.9-2.5 micron spectral range for sensitive imaging surveys of very red objects.

After the start of the project, the team completed the design of the filters and finished the specifications in collaboration with Gemini's F-2 team. A TAMU subcontract is now making filters and planning the quality check tests the team will execute in both the laboratory and the Gemini telescope. The aim is to make this new capability available to the community in the second quarter of 2017, enabling a wide range of potential science from detecting young stellar object candidates in deeply obscured star-forming regions, to deep K-band imaging to study the demography of high-redshift massive galaxies.

# July 2016

## GMOS CCD Update

The GMOS-N CCD upgrade project encountered some technical delays and is now back on track for installation later this year. The reason is because the latest Astronomical Research Camera (ARC) controllers (which are different from those in GMOS-S) created unexpected technical issues, such as high read-out noise (RON).



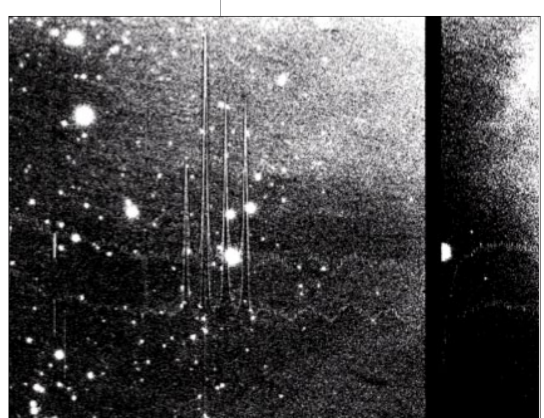


**Figure 12 (left).**
*Bias image with the new GMOS-N focal plane array while adjusting the vertical clock voltages to optimize the full well.*

**Figure 13 (right).**
*Sum of 10 acquisitions from GMOS-S to reveal the very low level pattern.*

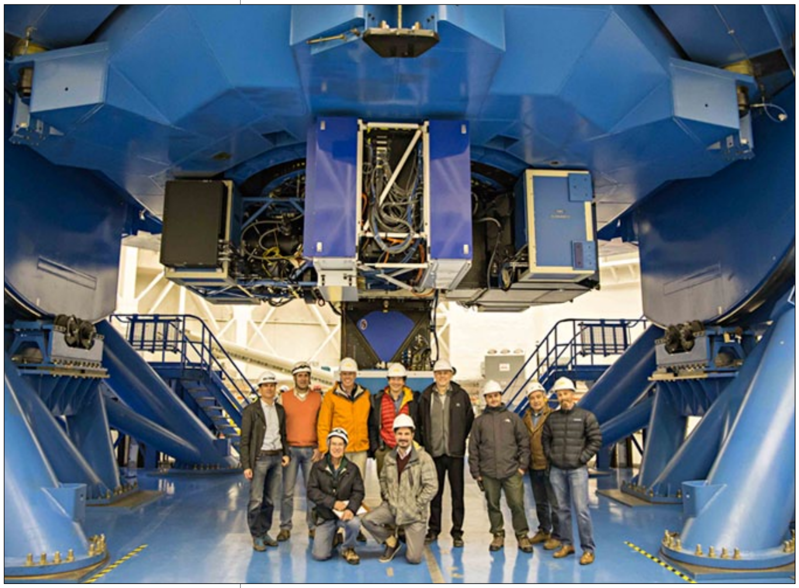


**Figure 14.**
*Participants of the LGSF kick-off meeting visit the Gemini South telescope facility in Chile.*

Tim Hardy from Canada's National Research Council-Herzberg (NRC-H) helped debug the GMOS-N detector system, getting its performance closer to that of the already-installed GMOS-S system. We have been able to lower the RON from 5.6 electrons-root mean square ($e_{rms}$) down to 3.9$e_{rms}$ (current GMOS-S performances). We also replaced the two original cable sets that were found to be erratic, and repaired two new boards designed to mitigate electrostatic damage to the charge-coupled devices (CCD). By reproducing one of the "unwanted features" of the current GMOS-S focal plane array (very low level pattern removable by dithering) we have learned how to work around this issue in the future (Figures 12-13).

We conducted some of these tests using a custom printed circuit board that simulated the CCD's electrical interface, allowing direct and safe measurement of the signals at the CCD pins. This also provided faster testing as we could avoid the thermal cycle overheads. This "dummy CCD board" will become a new diagnostic tool for operation at both Gemini North and South.

## LGSF Update

Gemini South is procuring a new laser from the German corporation Toptica Photonics AG for the Gemini South Multi-conjugate adaptive optics System. On April 28th three representatives of Toptica's Laser Guide Star Facility (LGSF) upgrade project, and stakeholders from science and engineering operations, attended the kick-off meeting for Toptica's SodiumStar 20/2, the company's new laser guide star system.

Participants visited Cerro Pachón where they clarified several technical issues to ensure smooth installation of the new laser at the Gemini South telescope (Figure 14). Meeting participants also discussed the delivery schedule and required infrastructure to receive the new laser.

For efficient operations we will install the Toptica Laser Control Electronics Cabinet (EC) and the Laser Head (LH) on the elevation platform of the telescope, near the Lockheed Martin Coherent Technologies laser enclosure. This will allow easier injection of the Toptica laser beam into the telescope Beam Transfer Optics. Figures 15 and 16 show the EC and LH as well as their planned location on the telescope structure.

**Figure 15 (left).**
*Illustration showing the area on the altitude platform where the EC and LH will be located on the Gemini South telescope.*

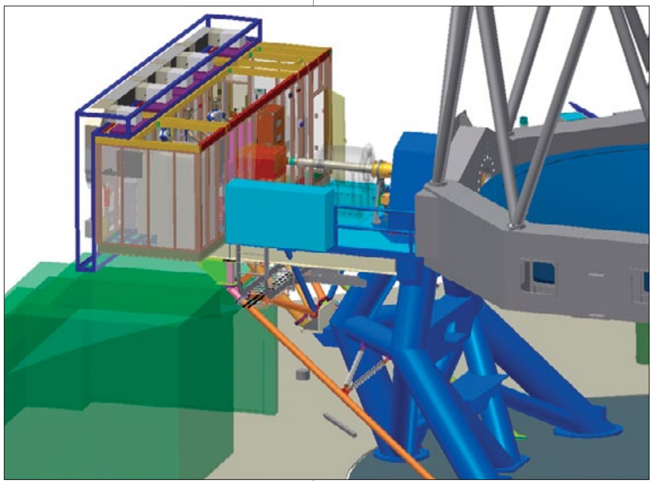


**Figure 16 (right).**
*Laser Head (left) and Electronics Cabinet (right).*



## GHOST on the Move

The Gemini High-resolution Optical Spec-Trograph (GHOST) team has started the project's build phase. This means that the two organizations building the hardware — the Australian Astronomical Observatory (AAO) and Canada's National Research Council-Herzberg — are busy procuring and fabricating components; meanwhile, the Australian National University (ANU) software team continues to move forward on their work. As components arrive, assemblies will be built and tested. Several of these assemblies are highlighted here.

The NRC-H has built a prototype cryostat for the charge-coupled device (CCD) detector system, shown in Figure 17. The tall cylinder contains the cryocooler, with the vacuum valve and vacuum sensor in front of the cooler. NRC-H has used this prototype for various tests to check the system design and is now fabricating the final cryostats for the instrument. The team will run them through a series of tests before they are ready for installation of the CCD detectors, the most costly components in the instrument.

The AAO continues to make progress on the optical cable assembly (see Figure 18). The work to test the performance of the optical fibers after the ends were fixed and polished is complete, yielding excellent results. The next step is to attach the microlens arrays to the fiber ends. The team will do this after these arrays receive their optical coating.

The ANU keeps steadily working on both the instrument control system software and the data reduction pipeline.

**Figure 17.**
*Prototype cryostat for GHOST at the NRC-H.*

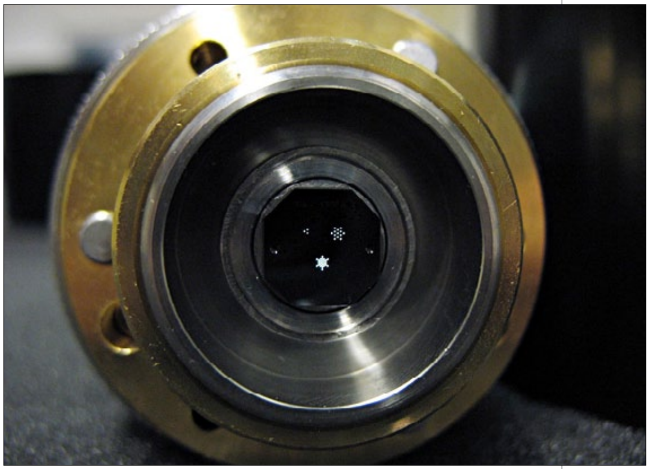


**Figure 18.**
*The assembled GHOST optical fiber array now assembled in the input pattern. Seen here are the illuminated fiber arrays for the low-resolution object and sky Integral Field Units (IFUs) on top, and the high-resolution object IFU on bottom.*

# April 2016

## GHOST Update

We continue to make good progress on the Gemini High-resolution Optical SpecTrograph (GHOST) project. In early March 2016, we held the second half of a two-part project milestone: the Critical Design Review at Canada's National Research Council-Herzberg in Victoria, British Columbia. The review committee was generally quite pleased with the progress made, impressed with the quality of the GHOST team's design, and satisfied with the improvements made in team coordination and integration, expressing confidence in the team's ability to successfully complete the instrument.

This review primarily focused on the spectrograph's opto-mechanical and thermal enclosure designs. It also provided several recommendations for design and process improvements that we are currently implementing.

Another bit of positive news is the arrival of the red and blue CCD detectors, both engineering and science grade. For both science grade CCDs, the vendor test results show excellent quantum efficiency performance and a higher grade quality than expected.

## GeMS Laser Progress

Users of the Gemini Multi-conjugate adaptive optics System (GeMS) will know that the GeMS laser has caused significant issues over the past year, particularly since the earthquake of September 2015. Major efforts finally got us back to a working system (delivering 30 of its 50 watts, which is sufficient in good conditions) by the time of the February 2016 GeMS run. However, as the current laser (Figure 19) is not robust enough for regular operations, the process of finding a replacement system is now well under way.

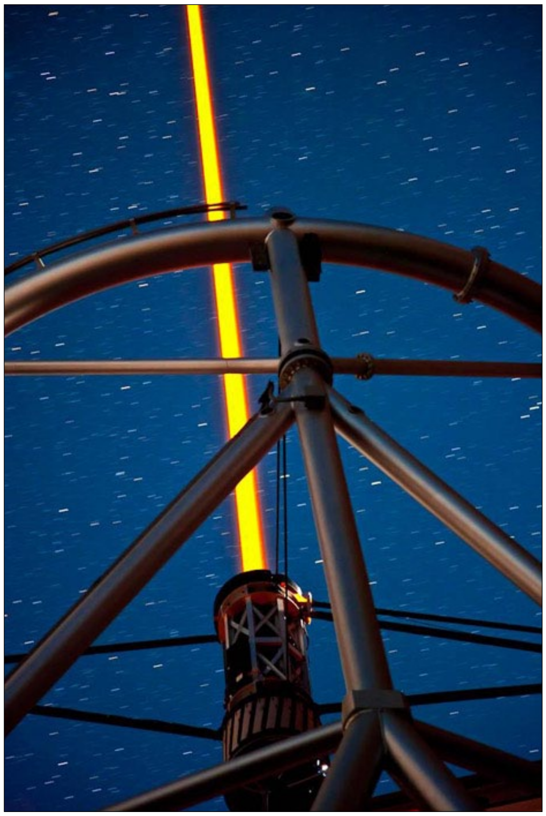


**Figure 19.**
*The Gemini South laser propagating prior to the September 2015 earthquake.*

The National Science Foundation, in partnership with AURA/Gemini, has selected Toptica Photonics AG to produce a new laser for GeMS. The new laser will still produce the constellation of five artificial guide stars on which GeMS relies to provide excellent and stable image quality over the Gemini South Adaptive Optics Imager's full field-of-view. We expect the new laser will be significantly more robust and reliable than the old one, removing what has been an achilles heel of GeMS in operation.

## Gen 4#3

The Gen 4#3 team has made steady progress in the past three months on crafting the Request for Proposals (RfP) for this next facility instrument. In their November 2015 meeting, the Gemini Board requested the Science and Technology Advisory Committee (STAC) review the outcomes of the Gemini Instrument Feasibility Studies and work with Gemini to identify core capabilities. The Board also placed a high priority on schedule and cost control. The STAC met in December and identified some expanded core capabilities for the Gen 4#3 instrument. They also highlighted the importance of instrument throughput and operational efficiency. They agreed that schedule is a primary driver for Gen 4#3, and emphasized that Gemini should be fully prepared to use Gen 4#3 to take advantage of early Large Synoptic Survey Telescope (LSST) science. We are therefore driving the Gen 4#3 schedule to help ensure the instrument is commissioned by the planned start of LSST science operations.

Inger Jørgensen

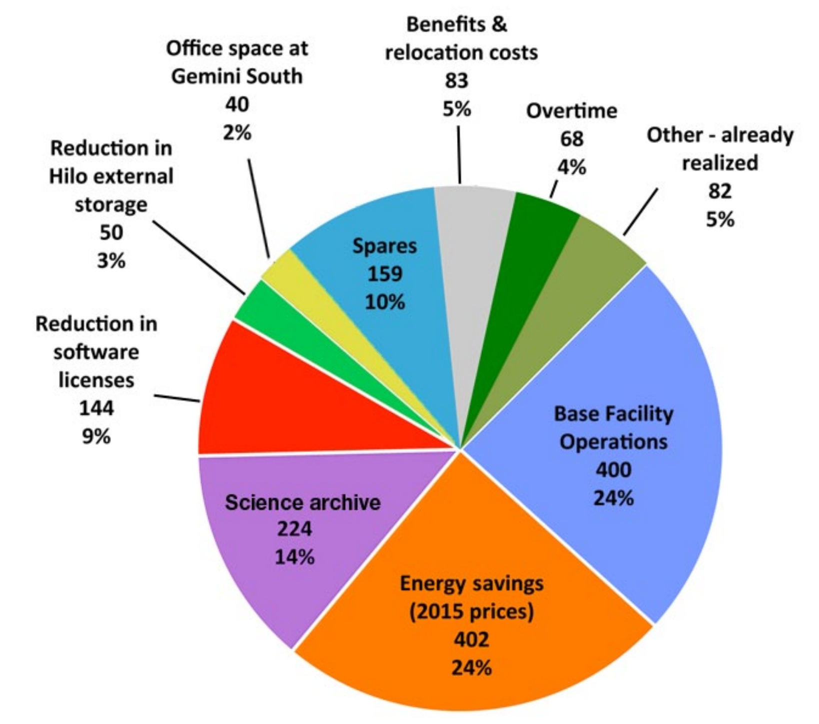
# A Transition Comes to an End

## *Gemini's Transition Program 2011-2015*

In 2010 the United Kingdom announced its intention to leave the Gemini Partnership. This prompted the Observatory to plan for a roughly 25% reduction in its annual operations budget, which translates to about \$6.5 million in 2012 dollars. To handle this situation, we developed a plan that touched all areas of the Observatory, including nighttime science operations, energy consumption, maintenance schedules for printers, and just about everything in between. Thanks to the Observatory's available cash reserves, we could stretch the implementation through 2015.

The plan, called the Transition Program, consisted of three general areas of focus: staff reductions, general reductions, and the implementation of specific projects. Staff reductions contributed about \$3.5 million to the required savings. General reductions in non-labor expenses — enabled by tight tracking of budgets, reduction in travel expenses, lower computer prices, *etc.* — saved about \$1.5 million. And the implementation of about 25 projects (aimed at reducing non-labor costs or enabling operations with a smaller staff) also secured about \$1.5 million, of which about \$400,000 are still to be realized in 2016. Figure 1 gives an overview of these savings.

**Figure 1.**
*Savings from the Transition Program projects. Amounts are in thousands of dollars.*




Some of the changes resulting from the Transition Program are visible to our users while many are only visible internally. As of this writing, the

Observatory has implemented the majority of the Transition Program. Ongoing developments continue in 2016 on projects that enable additional energy savings, reduce expenses (such as restructuring lab space at Gemini South for use as office space), and support for the transition to Base Facility Operations at Gemini South.

## Changes that Affect Our Users

Users are most directly affected by changes within Science Operations. Table 1 summarizes these changes as well as those within Engineering Operations, which indirectly impact our users.

**Table 1.** *Changes affecting our users.*

| Change | Description |
|---|---|
| ***Reduced (and changed) data quality assessment*** | *In early 2013 we changed the quality assessment on queue data to be done primarily at night by the observer. Only Band 1 data receive additional checks during the day. In addition, we have implemented an automatic data quality assessment pipeline, which covers all imaging and acquisition observations. Users are encouraged to review their data promptly and contact us in case of issues. The fraction of observations that have to be repeated has not increased due to these changes.* |
| ***Non-research queue observers*** | *We have gradually phased in non-research staff members as queue observers. The goal is for non-research staff to perform 75% of the queue observing. This has been the case at Gemini North for several semesters and we expect that Gemini South will reach a similar level within 1-2 semesters, as training is completed.* |
| ***Base Facility Operations*** | *We have moved nighttime operations to the Gemini North Base Facility. The same will take place at Gemini South in 2016. Visiting observers are (positively) affected by this change, which also saves a total of about $400,000 annually in lodging, meals, and transportation costs.* |
| ***Archive*** | *We have implemented an archive that serves all science (and engineering) data from the Amazon Web Services. The archive went through extensive reviews by the Users Committee, staff from the National Gemini Offices, and repeat users of Gemini. Full implementation was in place by December 2015, and the move saves us more than $200,000 annually. The archive is available here: https://archive.gemini.edu* |
| ***Priority Visitors*** | *Principal Investigators of Large and Long programs and selected Band 1 programs can now visit Gemini as Priority Visitors. They can take their own data (if conditions allow) or execute queue observations. This arrangement improves our contact with users, while saving a small amount of staff effort.* |
| ***Four facility instruments + adaptive optics at each site*** | *The two Gemini telescopes will each operate with a maximum of four facility instruments and a facility adaptive optics system. This ensures that we (with the reduced staff) have sufficient effort to support these instruments.* |
| ***Reductions in engineering staff*** | *A reduction in engineering staff, coupled with the above-mentioned limitation on facility instruments, means that we will not be able to support future major instrument rework or instrument building (such as on FLAMINGOS-2 and Canopus). Thus, any instruments procured in the future will have to meet requirements prior to arriving at Gemini. The reduced engineering staff may also mean that major technical faults have a longer response time.* |

## Behind the Scenes

Our users will not see many of the essential Transition Program changes required for realizing savings on the non-labor budget, as well as those enabling us to operate with a reduced staff. Table 2 presents a brief overview of the most important of these changes. Figure 1 shows the non-labor savings from some of them.

## The End Result

With the Gemini Transition Program changes largely executed, the Observatory is now in a healthy state to move forward in a more streamlined, efficient, cost-effective, and energy-conscious way. The Observatory is thankful for the universal cooperation it received during this difficult period. Gemini is now better positioned to focus on the

**Table 2.** *Changes "behind the scenes."*

| Change | Description |
|---|---|
| ***Software supporting queue operations*** | *We have developed software that decreases the effort needed to operate the queue. The software covers queue filling during the Time Allocation Committee process, queue planning through visualization tools, and handling of the military's requirement for clearances during laser operations.* |
| ***Software leading to lower maintenance effort*** | *The Observatory Control System software has been upgraded and improved, primarily to lower the maintenance effort. However, improvements in both the Phase I Tool and the Observing Tool have greatly benefited our users.* |
| ***Energy*** | *Energy saving projects are a core component of the Transition Program. We have installed photovoltaic panels at the telescope on Maunakea (Figure 2); in 2016 we plan to do the same at the Base Facility in Hilo and on Cerro Pachón. We are also applying the recommendations from an energy audit of the Gemini North facilities, which include replacing the chillers at the summit, refurbishing the air conditioners at the base, and replacing all lighting with LEDs. All computer rooms have been separated into hot/cold zones. The total annual savings on our electricity costs are $400,000, while we reduce by about 30% our reliance on utility-provided power (most of which is produced using fossil fuels).* |
| ***Base Facility space usage*** | *We have reduced the need for external storage at Gemini North, while at Gemini South lab space will be converted to office space; these changes will remove the need for renting additional buildings for offices.* |
| ***Spares*** | *After reviewing our spares inventory and purchases and making better risk assessments, we have significantly reduced the funds used annually to restock spares.* |
| ***Overtime*** | *We reduced overtime payments to hourly paid staff, primarily by eliminating weekend checks at Gemini South and limiting overtime usage during telescope shutdowns.* |
| ***Software licenses*** | *Sizable savings were realized by switching either to software with lower license costs or to free software.* |
| ***Administrative services*** | *Purchasing, contracts, and human resources administration are centrally handled by AURA, either in Tucson or by personnel in La Serena.* |
| ***Transportation*** | *We have eliminated several vehicles at both sites, and restructured the use of common transportation at Gemini South.* |

needs of its global Partnership, the future of its scientific programming, and the suite of leading-edge instruments that will take us to the forefront of research while remaining fiscally responsible.

*Inger Jørgensen is Gemini's Deputy Associate Director of Operations. She can be reached at: inger@gemini.edu*

**Figure 2.**
*Recently installed photovoltaic panels on the Gemini North telescope facility on Maunakea are some of the energy saving initiatives that are part of the Transition Program. Since installation, the panels have provided approximately 10% of the energy needed at the Gemini North telescope.*
*Image credit: Joy Pollard*

Alexis-Ann Acohido

# Gemini Harnesses the Sun from Both Hemispheres

**Figures 1-2.** *Photovoltaic panel installations at the Gemini South Cerro Pachón facility in Chile (top and bottom).*

In 2015 the Observatory installed photovoltaic (PV) panels on the Gemini North Maunakea facility. Now we have done the same on the Gemini South Cerro Pachón facility and the Gemini North Hilo Base Facility. The effort is part of our commitment to positive stewardship of our planet and eco-efficient operations.

Installation of an impressive 680 panels at the Gemini South Cerro Pachón facility was completed in late June, 2016, and the cabling phase to connect them to Gemini's electrical system should be completed by the release of this issue of *Gemini*Focus. The panels are on the rooftop adjacent to the telescope dome, as well as mounted on the ground (Figures 1 and 2), and are estimated to provide ~20% of the annual power consumption at the telescope.

Almost simultaneously, panel installation on the roof of HBF (Figures 3 and 4) started in late May 2016 and ended in mid-June 2016. Cabling of the system was completed on June 15, 2016, and the panels are now online.

*Alexis Ann Acohido is a Media Relations and Local Outreach Assistant at Gemini North. She can be reached at: aacohido@gemini.edu*

**Figures 3-4**
*Installation of photovoltaic panels on rooftop of Gemini's Hilo Base Facility in Hawai'i (top and bottom).*

Peter Michaud

# Gemini Connections

*Authors of three recent books on astronomy share direct ties with Gemini. The books cover topics spanning the history of modern astronomy on Maunakea, how astronomers create stunning astronomical images, and the story of George Herbig's pioneering work in early stellar evolution. Brief reviews of these works follow.*

## *A Sky Wonderful with Stars: 50 Years of Modern Astronomy on Maunakea*

This absolutely stunning book by Michael J. West is clearly a labor of love fueled by a passion for astronomy. Some will recall that Michael served as Gemini's Head of Science Operations at Gemini South from 2006-2007, as well as a professor of astronomy and physics at the University of Hawai'i Hilo, and his influence remains strong especially on Maunakea. Michael is currently the Deputy Director of Science at the Lowell Observatory in Arizona.

Michael's love for astronomy and Maunakea is evident on every page of this book. Thanks to the vision of the University of Hawai'i Press this book was made possible in 2015 to coincide with the 50th anniversary of the first telescopic observations of the Universe from Hawaii's highest peak.

**Figure 1.**
*Image from the Michael West book "A Sky Wonderful with Stars: 50 Years of Modern Astronomy on Maunakea."*

With each page readers experience a profound view, and written perspective, of the mountain and the Universe (Figure 1). Michael tells the story of modern astronomy on Maunakea with an elegance that borders on poetry; his words transcend the printed page and succeed in conveying the poetry of the mountain and modern astronomy. This large-format book belongs on the coffee table of everyone who loves the unparalleled beauty of both Maunakea and astronomy.

**Figure 2.**
*Excerpt from the book "Coloring the Universe" that features dozens of Gemini images.*

## Coloring the Universe: An Insider's Look at Making Spectacular Images of Space

Anyone familiar with Gemini's Legacy Images will recognize Travis Rector's name as the creative genius who massages selected Gemini data into aesthetically pleasing pictures. While his work isn't limited to Gemini data (he has worked for years with Cerro Tololo Inter-American Observatory, Kitt Peak National Observatory, and other observatories) his experience makes him uniquely qualified to serve as an "insider" as the book's subtitle states. Joining Travis in this ambitious work are NASA's Kimberly Arcand and Megan Watzke, who collectively have produced and promoted astronomical imaging to a level of artistry that is evident with even a quick flip-through of this 250-page large-format book.

The authors use accessible language and striking astronomical images to describe and show the telescopes and instruments used to take these colorful images (Figure 2), the techniques of astronomical data processing, and what astronomy we can learn from the results. The chapters are merged seamlessly into a cohesive story in this book published by the University of Alaska Press, Fairbanks (where Rector teaches astronomy and physics).

## George Herbig and Early Stellar Evolution

A new Gemini Board member, Bo Reipurth, from the University of Hawaii's Institute for Astronomy, is author of a recently published book that chronicles the life and work of astronomer George Herbig (Figure 3). All astronomers (and most Astronomy 101 students) know something about George and his work on the early evolution of stars. However, did you know that although his mother encouraged him to become a chemist (it paid well), his passion for astronomy and amateur telescope making kept him firmly entrenched on his ultimate career path (which is fortunate for astronomy).

Bo is in a unique position to write this biography, since George — prior to his death at age 93 and while still in his mid-70's — entrusted to Bo volumes of his detailed notes, comments, and autobiographical sketches. In the book's foreword, Bo includes this quote from George, as he documented his life as a scientist:

*"For reasons not entirely clear, I have thought it worthwhile to try to put down a kind of inventory or outline of the various astronomical activities that I have pursued, and how my involvement in each of them came about — to the extent that I can remember or reconstruct reasons and motives at this late date (January 1993). The scornful phrase 'jack of all trades, master of none' has more than once come to my mind, for I recall old-timers speaking with contempt of colleagues who frittered away their energies on a host of activities rather than spending their lives bearing down on a single area... ."*

Astronomy owes a huge debt to George's "frittering," as does Bo for telling the engaging story of this remarkable man. Bo has generously made this self-published e-book freely available for download ***here***.

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

**Figure 3.**
*Extracted pages from Bo Reipurth's book on George Herbig.*

*1. The Budding Astronomer*

Figure 5: *Griffith Observatory above Los Angeles.*

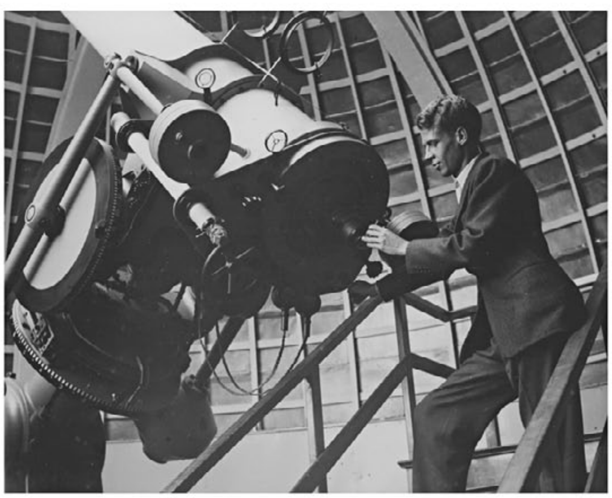


Figure 6: *During his undergraduate studies in the early 1940s, Herbig worked as an assistant at Griffith Observatory showing the sky and the exhibits to the public.*

6

*6. Clustered Star Formation*

...g and Dahm noted the presence of several other luminous young stars as-...ed with L988, and in particular commented on the chemical peculiarities ...ted in one of those (see discussion in Section 4.3). More recently, L988 ...een found to have numerous Herbig-Haro objects distributed across the ...surface (Walawender et al. 2013), indicating the presence of a distributed ...ation of embedded young stars.

...e 90: *The IC 1274 star forming region forms a cavity about 5 arcmin in diameter ...appears to have been carved out of the L227 molecular cloud by several B-type stars. ...from the CFHT by J.-C. Cuillandre. From Dahm, Herbig, Bowler (2012).*

**IC 1274**

...s 188 is a complex of several weakly ionized HII regions within a few ...es of M8 and M20. One of these HII regions is IC1274, whose morphology ...the impression that the ionized gas has carved out a near-spherical cavity ...adjacent L227 molecular cloud (Figure 90). Near the center of IC 1274 ...B0 V star HD 166033, which appears to be the dominant ionizing source. ...early study of the region, Herbig (1957b) identified six faint H$\alpha$ emission ...in and around IC 1274. In a detailed study, Dahm, Herbig, & Bowler ...) acquired deep BVRI CCD photometry of IC 1274 together with slitless ...H$\alpha$ spectroscopy to reveal the faint T Tauri population in the region. ...80 H$\alpha$ emission stars were identified, more than half of which lie within

140

# A New Look for Gemini's Legacy Images


A beautiful new set of 16 Gemini Legacy images, in English and Spanish, are now available in redesigned 8.5 x 11-inch prints (or as electronic files). Shown here are several examples of the new sheets (including background information which is provided on the flip-side of each sheet).

All of these, plus prior Legacy images not included in this update, are available as full-resolution downloads on the ***Gemini Image Gallery***. Gemini's participating country offices (and the public) may request printed copies via ***email***.

We hope you enjoy these images, and watch for spectacular new ones as Gemini continues to explore the Universe!


Light from Dark
Image Credit: Gemini Observatory/AURA
Gemini Observatory Legacy Image
GEMINI OBSERVATORY
Exploring the Universe, Sharing its Wonders
Gemini Observatory Facts
PRIMARY MIRRORS:
Diameter: 8.1 meters; 26.57 feet; 319 inches
Mass: 22.22 metric tonnes; 24.5 U.S. tons
Composition: Corning Ultra-Low Expansion (ULE) Glass
Surface Accuracy: 15.6 nm RMS (between 1/1000 - 1/10,000 thickness of human hair)
TELESCOPE STRUCTURES:
Height: 21.7 meters; 71.2 feet; 7 stories (from "Observing Floor")
Weight: 380 metric tonnes; 419 U.S. tons
Optomechanical Design: Cassegrain ; Alt-azimuth
DOMES:
Height: 46 meters; 151 feet; 15 stories (from ground)
Weight: 780 metric tonnes; 860 U.S. tons (moving mass)
Rotation: 360 degrees in 2 minutes
Thermal Vents: 10 meters; 32.8 feet (width – fully open)
GEOGRAPHICAL DATA:
Elevation: Gemini North: 4,214 meters; 13,824 feet
Gemini South: 2,737 meters; 8,980 feet
Location: Gemini North: 19°49.4'N; 155°28.1'W
Gemini South: 30°14.5'S; 70°44.8'W
To see this, and many other images, please visit:
http://www.gemini.edu/legacyph
of the Sun, while the dark cloud contains enough material
to make about 3,000 more stars like the Sun.


GEMINI OBSERVATORY
Exploring the Universe, Sharing its Wonders
AURA
The Gemini Observatory is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation on behalf of the Gemini Partnership.
United States
NRC·CNRC
Canada
BRASIL
Brazil
Argentina
Chile
Laser Vision
This exterior shot of the Gemini South telescope shows the result of the Gemini Multi-conjugate adaptive optics System (GeMS) with the Gemini South Adaptive Optics Imager (GSAOI) propagating a laser guide star skyward. The laser's light is split into five separate beams that are necessary for the Gemini South adaptive optics system.
The GeMS/GSAOI system is a revolutionary approach to adaptive optics in astronomy. The technique samples the turbulence structure in the atmosphere at several levels and then uses a technique similar to medical tomography to reconstruct a 3D snapshot of how the atmosphere is distorting starlight. This is then used to shape a series of deformable mirrors to cancel out this distortion. All of this happens about 1,000 times a second.
In the sky to the upper left of the dome, floating like detached fragments of the Milky Way, lie the Large and Small Magellanic Clouds. These glowing orbs are actually irregular dwarf galaxy companions to the Milky Way some 200,000 light years distant.
Gemini dedicates this image to the memory of Vincent Fesquet, who worked tirelessly to make the Gemini South Laser Guide Star System work efficiently and reliably.
Gemini Observatory Facts
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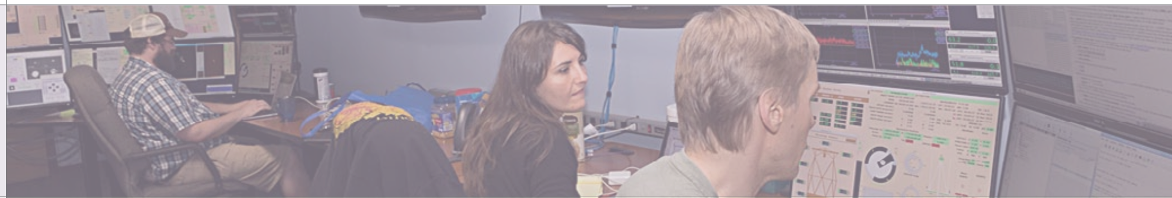
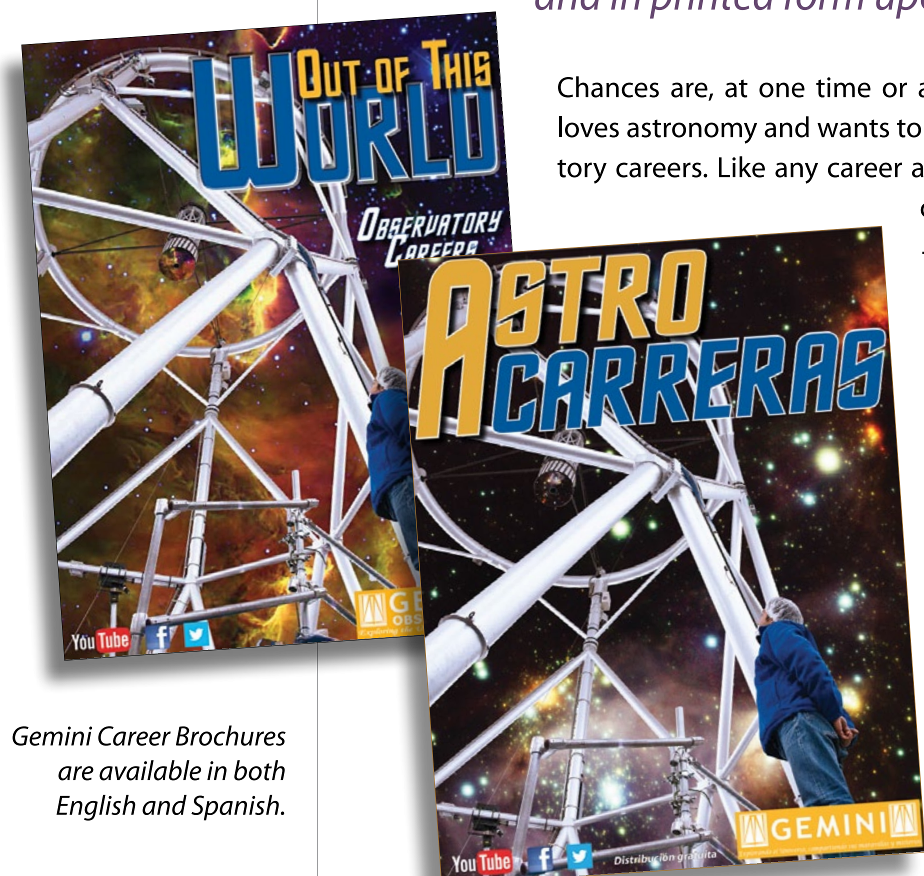
To see this, and many other images, please visit: http://www.gemini.edu/legacyph
Laser Vision
Gemini Observatory Legacy Image
Image Credit: Gemini Observatory/AURA/Manuel Paredes



# Observatory Careers: New Resources for Students, Teachers, and Parents

*Gemini first developed resources for promoting observatory career opportunities primarily for use in our local host community outreach. We've now made updated (and expanded) versions which are available to anyone online — and in printed form upon request.*

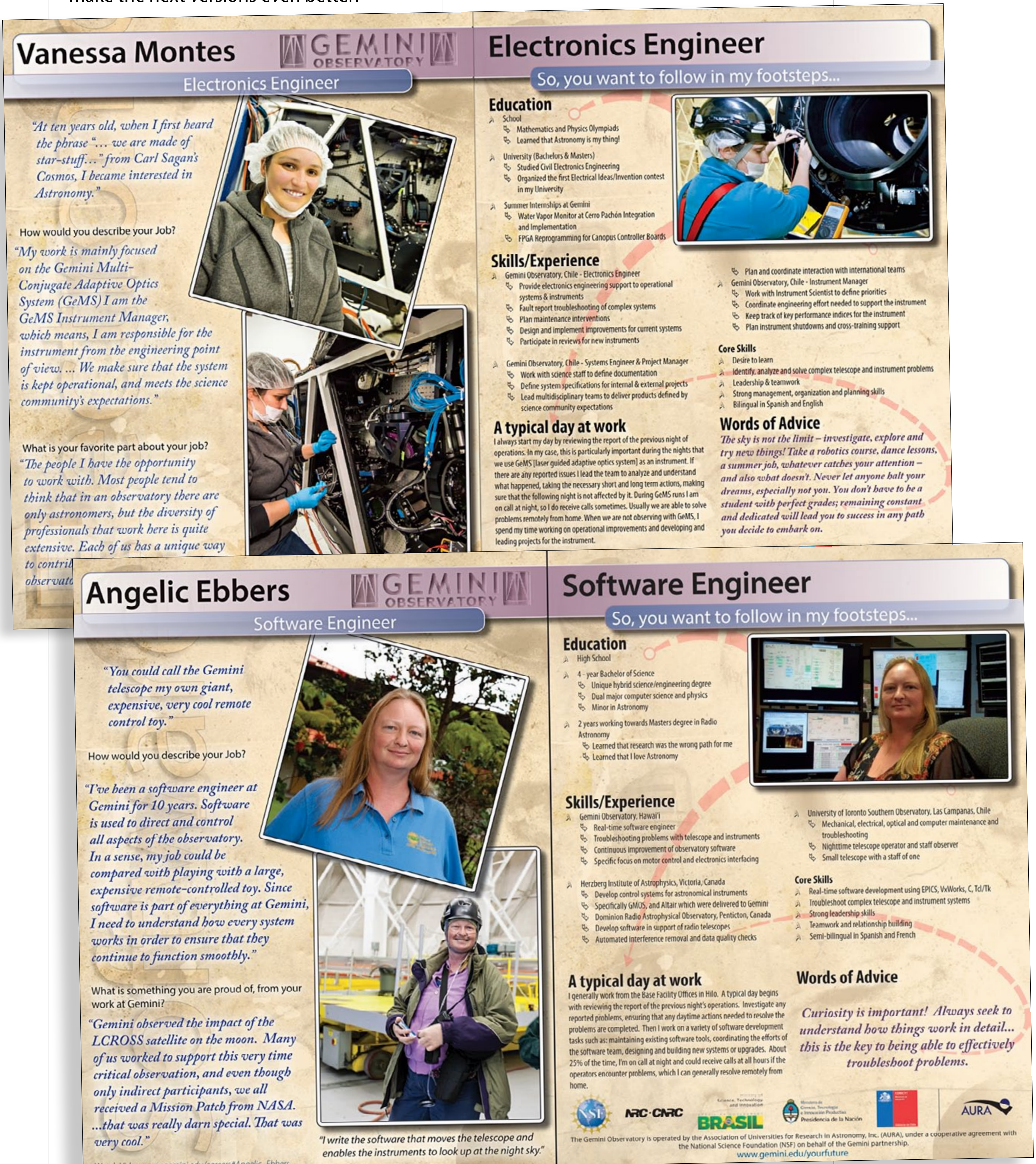



*Gemini Career Brochures are available in both English and Spanish.*

Chances are, at one time or another, you've met a young student who loves astronomy and wants to know more about astronomy and observatory careers. Like any career advice, there is no simple answer for everyone, so Gemini is here to help!

The latest update (Version 2.0) of Gemini's Career Brochure and companion website is now available. Here you will find a selection of highlighted observatory careers, from research astronomers to administrative support. To augment the brochure, we now offer in-depth profiles of selected staff, with more on the way. The website also offers online video interviews of staff from a wide variety of occupations. Online materials are available in both English and Spanish ***at this site***; and printed versions are available by sending a request via email to: ***English***, and ***Spanish***.

We hope you find these resources helpful, and we look forward to your input so we can make the next versions even better!



Alexis-Ann Acohido

**Figure 1.** *Hilo High students observe various light sources through gratings that create a spectrum and separate the light into a rainbow of colors.*

**Figure 2.** *Gemini Safety Manager John Vierra engages students with safety equipment that observatory technicians must wear to work on large telescopes.*

# *Journey Through the Universe:* Twelve Years, and Counting!

*Each year, for the past 12 years,* Journey Through the Universe, *Gemini North's premiere local educational outreach program, has impacted thousands of Hawai'i Island students. The program is designed to increase their interest in Science, Technology, Engineering, and Math, while inspiring them to participate in the exploration of the Universe.*

Early in March 2016, over 80 observatory staff professionals — ranging from astronomers to information technology specialists — shared their passion for exploration with over 7,000 local Hawai'i students. The excitement and energy can be seen here in the selection of images from the 12th annual *Journey Through the Universe* program on the Big Island of Hawai'i, a week-long event that began on March 4th.

The program is a collaboration with the Department of Education Hilo-Waiākea Complex, Hawai'i Island business community, Maunakea observatories, and NASA. More images and details can be found on the ***program's webpage***.

**Figure 3 (top, left).**

*Evan Sinukoff (University of Hawai'i Institute for Astronomy) and Virginia Aragon-Barnes (Thirty Meter Telescope; both at left) direct students on how to "pace" the Universe, using their steps as measurements.*

**Figure 4 (top, right).**

*Subaru Astronomer Julien Lozi (left) and Gemini Public Information and Outreach staff person Alyssa Grace (second from left), make scaled-down comets for students at Waiākeawaena Elementary School using dry ice, gravel, colored sand, and corn syrup.*

**Figure 5 (center, left).**

*NASA Solar System Exploration Research Virtual Institute director Yvonne Pendleton uses coin faces to help students visualize how the Moon rotates as it orbits the Earth and keeps the same side facing the Earth.*

**Figure 6 (center, right).**

*Gemini Science Fellow Jenny Shih (standing) helps students at Waiākea Intermediate School classify galaxies.*

**Figure 7 (bottom, left).**

*Gemini Software Engineer Angelic Ebbers inspires students at Waiākea Elementary to show off their engineering skills in a "Zip Line Challenge."*

STATE OF HAWAII · 1959 · UA MAU KE EA O KA AINA I KA PONO

*Proclamation*

*Presented to*

**Mauna Kea Observatories**

**WHEREAS,** Journey Through the Universe promotes sustained education in the critical areas of science, technology, engineering and mathematics (STEM), and is a celebration of exploration and the joys of learning science and astronomy; and

**WHEREAS,** Journey Through the Universe brings together scientists, educators, community leaders and Hawai'i Island students for an unparalleled exploration of astronomy in the classroom; and

**WHEREAS,** Journey Through the Universe demonstrates the power of cross-sector support for astronomy throughout the community and the limitless possibilities for Hawai'i; and

**WHEREAS,** meeting and learning from a diverse array of Mauna Kea Observatory scientists and NASA specialist showcase the inspiring types of career opportunities our youth can aspire to, sparked by a love of STEM and the presence of the Mauna Kea Observatories here in Hawai'i; and

**NOW, THEREFORE, I, DAVID Y. IGE, Governor,** and **I, SHAN S. TSUTSUI, Lieutenant Governor** of the **State of Hawai'i,** do hereby proclaim March 4 – 11, 2016 as

**"JOURNEY THROUGH THE UNIVERSE WEEK"**

**DONE** at the State Capitol, in the Executive Chambers, Honolulu, State of Hawai'i, on this first day of March 2016.

**DAVID Y. IGE**
**Governor, State of Hawai'i**

**SHAN S. TSUTSUI**
**Lt. Governor, State of Hawai'i**

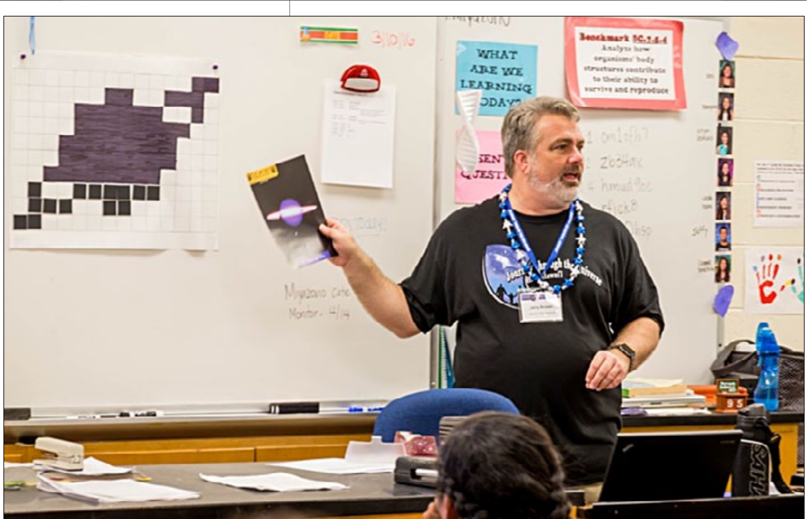


**Figure 8 (top left).**
*Hawai'i Governor David Ige and Hawai'i Lieutenant Governor Shan S. Tsutsui proclaimed March 4-11, 2016, as* Journey Through the Universe *Week.*

**Figure 9 (top right).**
*Robert Sparks of the National Optical Astronomy Observatory has students at Waiākea High School use filters to observe how light is polarized.*

**Figure 10 (bottom right).**
*Gemini Astronomer Rachel Mason works with students from Hilo's Connections school to model the relative distances to the planets with toilet paper.*

**Figure 11 (bottom left).**
*Information Systems Engineer Jerry Brower features a simple representation of the Saturn Gemini Legacy Image, where the pixels are enlarged to illustrate how pictures are stored in computers for students at Waiākea Intermediate.*

Manuel Paredes

# *Viaje al Universo* 2016: Empowering Students with Science

*Gemini South's premiere annual public outreach event extends its programming to expand its impact on our local host community in Chile.*

In late October 2016, Gemini South began its sixth annual *Viaje al Universo* in La Serena, Chile. As in previous years the annual event — which is one of the Observatory's core public outreach efforts — brought more than 20 scientists and professionals from different observatories into the classroom to motivate students into pursuing future careers in science, technology, engineering, and math (STEM).

Unlike any other *Viaje*, which generally lasts one week, Gemini South extended the 2016 event to offer more public talks, Starlab presentations, school lectures, family astro-events,

**Figure 1.**
*People of all ages attend* Viaje's *opening talk by Gemini's Science Operations Specialist Erich Wenderoth. Image credit: All images by Manuel Paredes*

**Figure 2.**
*Gemini South Senior Electronic Technician Pedro Ojeda explains the function and features of astronomical telescopes to students at the Colegio San Nicolás, in La Serena.*


**Figure 3.**
*Gemini South Public Information Office team member Dalma Valenzuela leads one of the Family Astro activities at the San Martin de Porres school, in Las Compañías, La Serena.*


and tours to the Gemini South telescope and its La Serena Base Facility. The idea was to give students, teachers, and parents more time than ever to attend these special activities, which are designed to help develop a long-term interest in astronomy.

Gemini's Science Operations Specialist Erich Wenderoth kicked off *Viaje al Universo* 2016 with a public talk titled, "A Walk through the Universe," which took the audience from the Solar System and beyond — from nebulae and clusters in our own Galaxy to other galaxies that reached the edge of the observable Universe. A near-capacity audience of more than 120 people of all ages attended this event, held at the Intendencia, the government house of the Region de Coquimbo in La Serena. At the end of the lecture, Wenderoth voiced his opinion on the importance of a prolonged *Viaje* event: "Extending *Viaje al Universo* beyond the classic week of activities is a huge opportunity to reach a more diverse public interested in the development of science in Chile."

During the week of October 24-28, over 1,300 students were directly impacted with a variety of activities in different schools throughout La Serena. Over 30 classrooms


**Figure 4.**
*Gemini Observatory, Cerro Tololo Inter-American Observatory, and Las Campañas Observatory professionals made up the Career Panel speakers. The feature continues as one of the most popular activities in the annual* Viaje al Universo *programming.*

were visited by 21 professionals from many Chilean observatories, including 14 Gemini Staff.

These presentations covered a wide-range of topics from technical work (such as engineering and instrument design) to scientific research — including breakthroughs based on observations from Chile.

Fernanda Urrutia, an outreach astronomer at Gemini South who offered a presentation during *Viaje*, said, "I was delighted with the talk I offered about the Solar System at the public school San Martin de Porres, as I got very positive feedback from the 10-year-old students. I realized that they came away with an understanding of basic concepts that they didn't know before my presentation. That is something encouraging!"

The *Viaje* program ended with its popular Career Panel, featuring helpful insights on how students can pursue a career in astronomy or a related STEM field. Norma Isla, a professor at Christ School in La Serena, commented, "...the opportunity to share with top-level scientists is a huge boost for my students. In addition, the little ones had a lot of fun drawing constellations with stars sprinkled on cookies that they happily ate later!" For more information about *Viaje al Universo* activities please visit ***this site***.

**Figure 5.**
*Information Systems Engineer Eduardo Toro chatting with students after the panel event about careers in astronomy.*

*Manuel Paredes is the Communications Coordinator at Gemini South. He can be reached at: mparedes@gemini.edu*

## *Reflection Nebula GGD 27 Revealing the Chaotic and Messy Environment of a Stellar Nursery*

*This near-infrared image was obtained using FLAMINGOS-2, the infrared imager and spectrograph on the Gemini South telescope in Chile. It is a color composite made using four filters: Y (blue), J (cyan), H (green), and $K_s$ (red). The total integration (exposure time) for all filters is just over one hour. The image is 4.6 x 3.5 arcminutes in size and is rotated 35 degrees clockwise from north up and east left. More information can be found* ***here***.

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

NSF United States | NRC·CNRC Canada | Ministry of Science, Technology and Innovation, Brazilian Government, BRASIL Brazil | Ministerio de Ciencia, Tecnología e Innovación Productiva, Presidencia de la Nación Argentina | CONICYT Ministerio de Educación, Gobierno de Chile Chile

Gemini Observatory
670 N. A'ohoku Place
Hilo, HI 96720, USA