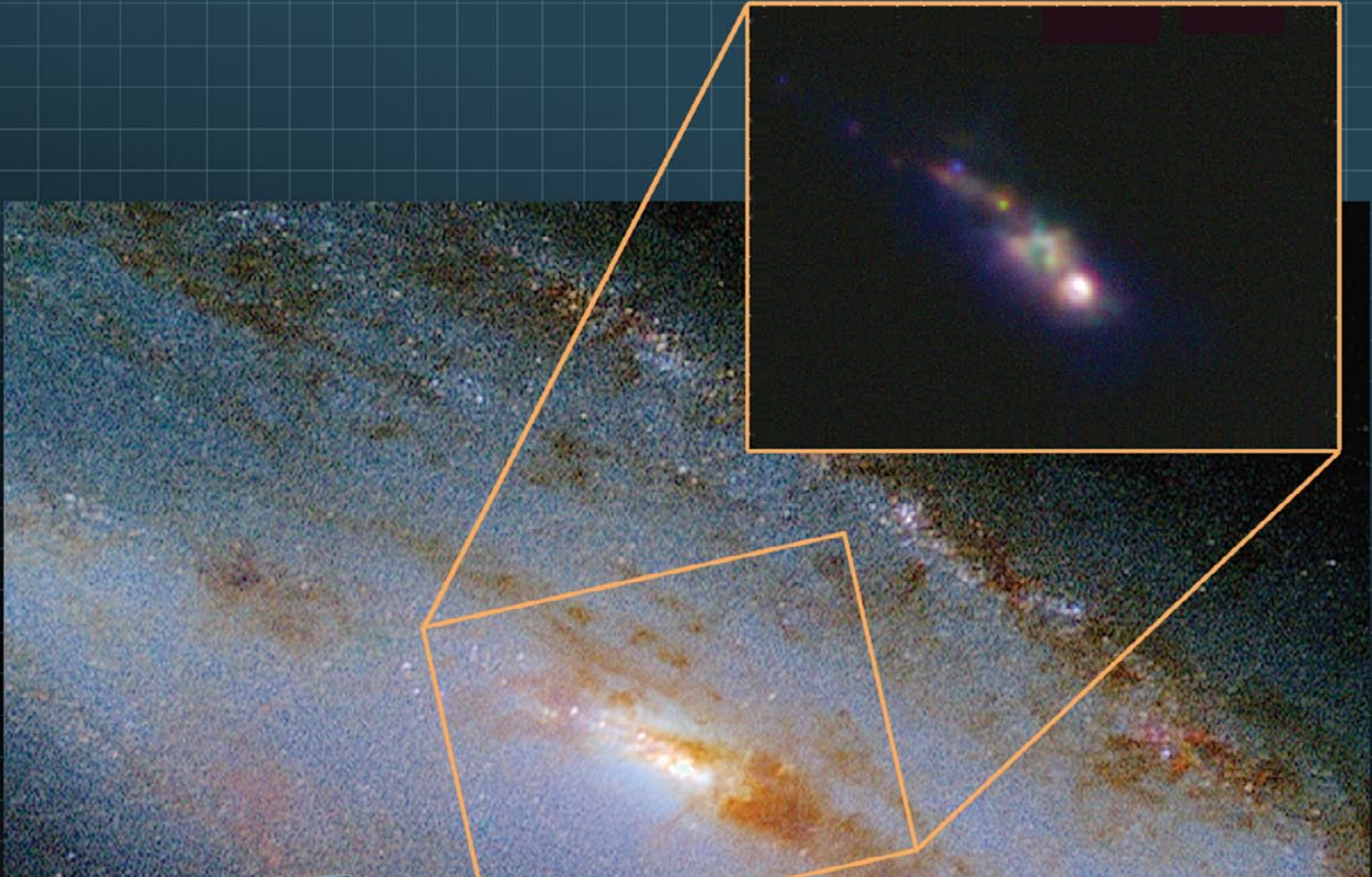
GeminiFocus

Publication of the Gemini Observatory | January 2016



YEAR IN REVIEW 2015

GeminiFocus

ON THE COVER:

A montage featuring a recent Flamingos-2 image of the galaxy NGC 253's inner region (as discussed in the Science Highlights section, page 21; with an inset showing the stellar supercluster identified as the galaxy's nucleus) and cover pages from each of issue of GeminiFocus in 2015.

Gemini*Focus January 2016*

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Markus Kissler-Patig

Director's Message

The Culmination of Another Successful Year at Gemini

After three years of effort, we proudly announce that Gemini Observatory has accomplished its transition to a leaner and more agile facility, operating now on a ~25% reduced budget compared to 2012. Achieving that goal was no easy task. It required questioning every one of our activities, redefining our core mission, and reducing our staff by almost a quarter; ultimately we relied on the ideas and joint efforts of everyone in the Observatory.

As we continue with the 2016 budget, we managed to fit all our current activities within the reduced budget, which our Finance Committee and Board of Directors have already approved. Huge kudos to all the Gemini staff for their contributions to three years of massive changes!

So Where Are We Now, and What's Next?

The Gemini Observatory's governance has provided us with ***guidelines for 2016-2021***. A key statement is that: "Gemini will strive to be the best observatory in the world for the execution of flexible, innovative, and efficient science programs." I believe that we already are, and will continue to be so well into the future! Here's at least six reasons why.

First, we are unique in offering our users multiple ways of requesting telescope time for programs (regular, Long and Large, and Fast Turnaround). Second, Gemini's twin 8-meter telescopes are now equipped with four state-of-the-art facility-class instruments, several of which utilize adaptive-optics. Third, Gemini has the only 8- to 10-meter-class telescope offering multi-conjugate adaptive optics. Fourth, we are the only 8- to 10-meter-class observatory to so openly welcome visitor instruments; so much so that our user community has built up a "waiting list" for them. Fifth, Gemini North is the first 8- to 10-meter-class telescope to fully operate remotely at night. And Sixth, Gemini is the first major observatory to archive its data in the commercial Cloud. Now for the clincher: we achieved all of this while operating with a fault downtime of less than 4%!

Gemini is magnificently set-up to enable the great science of the Gemini community in the next years. But we do not want to stop there. That is why the Gemini Board has recently kicked off a ***Strategic Vision Committee*** to explore what exciting role Gemini can play beyond 2020 — such as interacting closely with new observatories, in particular those planned on Maunakea in Hawai'i and the Cerro Tololo/Pachón complex in Chile. Stay tuned, as we ask both our stakeholders and users to contribute ideas to this vision exercise during 2016

Even More Positive News

We are also making good progress on our two next facility-class instruments. GHOST, our next high-resolution spectrograph, just passed the first part of its Critical Design Review, and is on track to be commissioned by the end of 2017/early 2018. As for the instrument after that (Gen4#3), its four feasibility studies have concluded and the reports are ***now public***. Prepare for the full Call for Proposals in 2016 Q2.

On the operations front, the biggest news is that base facility operations began at Gemini North in November and nighttime staff is no longer needed at the summit during observations. This is one step on the path to our final goal: Offering our users operations from your favorite sofa, anywhere in the world.

We also now offer monthly Fast Turnaround (FT) proposals for time on the Gemini South telescope (in addition to Gemini North), and the program is picking up fast in popularity. Also, the first peer-reviewed paper from an FT proposal earlier this year is now published (see feature science article, page 3). And, if you have not tasted our new ***archive*** yet, it is fully functioning, and we welcome feedback (see the article in this issue starting on page 62).

Finally, we had another successful year of Journey Through the Universe and *Viaje al Universo*, our flagship outreach programs at Gemini North and South (respectively). Our staff contributed to many activities and were rewarded by hundreds of smiles in the faces of the attending children.

Overall, I believe that Gemini is in great shape to face the coming years and beyond, when we hope to offer more exciting opportunities than ever. Right now, the future certainly looks exhilarating! Join us in "Exploring the Universe, Sharing its Wonders."

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

Keren Sharon

Probing Time Delays in a Gravitationally Lensed Quasar

Fast Turnaround observations with the Gemini North telescope are used to measure the difference in the arrival time of photons coming from a distant quasar, as they travel on different paths from the quasar to us due to gravitational lensing. The Gemini observations also produced deep spectroscopic data with GMOS that allowed our research team to obtain redshifts for other lensed galaxies behind the cluster.

Imaging data from the Sloan Digital Sky Survey (SDSS) has uncovered many gravitational lenses including SDSS J2222+2745 — a galaxy cluster whose projected mass density is high enough to bend space-time, causing light traveling near it from a distant quasar to change its path. This phenomenon, which is a theoretical prediction of General Relativity, is called gravitational lensing.

Describing a Strong Gravitational Lens

When we observe massive objects, such as galaxy clusters, we often find that distant background galaxies appear distorted and stretched, and their apparent position in the sky is different than their actual positions.

The equations that describe gravitational lensing dictate by how much the light is deflected due to the gravitational potential of an intervening object. The more massive an astronomical object, the stronger its lensing potential, and the larger the deflection of light. In some cases, which we call Strong Lensing (SL), there is more than one solution to the lensing equation:

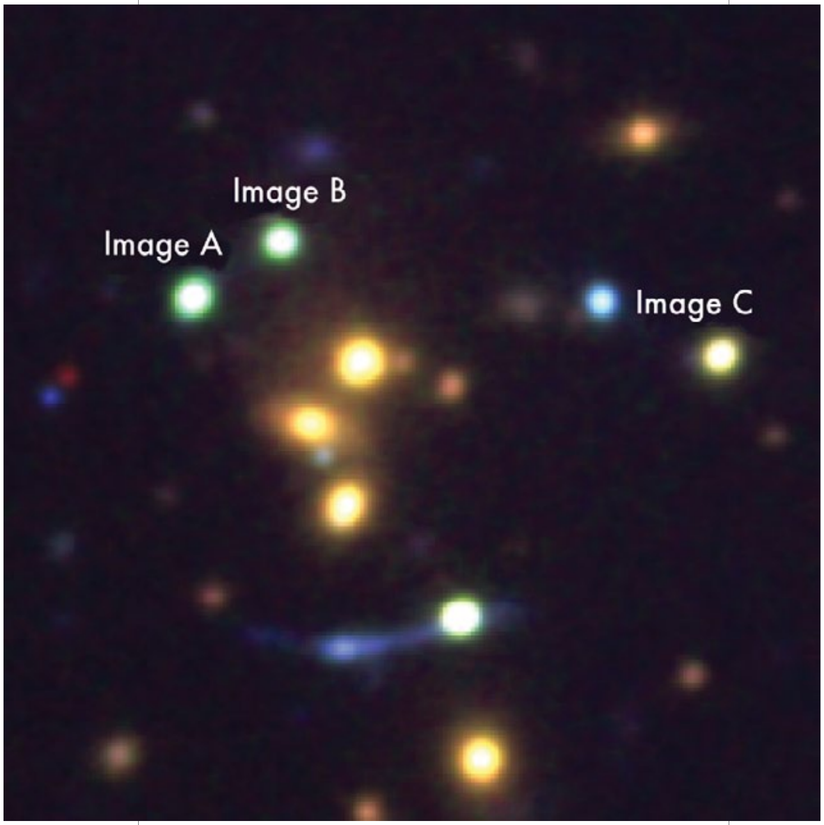


Figure 1. *A 30″ x 30″ field around the center of the galaxy cluster in the SDSS J2222+2745 lensing system. The composite color image combines Nordic Optical Telescope and Gemini North Fast Turnaround data. The slight color difference in the three images of the quasar (A, B, and C) results from the different optical filters used during the observations that were made at different times.*

light is allowed to travel from point A to point B on more than one path, resulting in multiple images of the same background source.

Such is the case of the SDSS J2222 + 2745 system — a galaxy cluster at $z = 0.5$, that strongly lenses a few background sources, including a quasar at $z = 2.82$ and a galaxy at $z = 2.3$ (Figure 1).

This lensing cluster was discovered by an international team of researchers, led by Michael Gladders from the University of Chicago, who mined data from the Sloan Digital Sky Survey to find strong lensing clusters that stretch and distort background galaxies into giant arcs. As part of this Sloan Giant Arcs Survey (SGAS), the team examined images of ~ 30,000 galaxy clusters, and systematically identified evidence of gravitational lensing in hundreds of galaxy clusters, many of which were discovered for the first time. Using follow-up imaging and spectroscopy with several telescopes, including Gemini North, Gladders' team was able to confirm these lensing clusters, and most importantly, measure the spectroscopic redshifts of the lensed background sources.

Of the hundreds of lensing clusters found in the SGAS, SDSS J2222 + 2745 is the only one that lenses a background quasar into at least six images of the same background source (Dahle *et al.*, 2013). This lensing configuration is so unique, that, in fact, this case is only the third one known of a quasar that is strongly lensed by a galaxy cluster. The other ones, SDSS J1004 + 4112 and SDSS J1029 + 2623, (Inada *et al.*, 2003; Inada *et al.*, 2006) split the light from a background quasar into five and three images, respectively.

Time-Stamping Light

Quasars are among the most luminous objects known in the Universe. They are powered by supermassive black holes accreting matter in an active galaxy's nucleus. What makes lensed quasars uniquely interesting is that their luminosity changes in time. A quasar's brightness can vary on time scales from days to months, owing to random physical changes in the accretion disk, and to the small region from which the light is emitted (the supermassive black hole). This variability allows us to put a time stamp on the arrival of light from a lensed source.

Whenever multiple lensed images of the same source are formed, each one is a snapshot of the source taken at a different cosmic time. This is because the light from each source has taken a different path from the quasar to us; and the time it takes light to arrive depends on the length of each path and the gravitational potential along this path.

In the case of SDSS J2222 + 2745, six photons leaving the quasar simultaneously at the speed of light encounter a massive galaxy cluster, whose gravity sends them on different paths to our telescope. The first may take a few billion years to arrive; the second may come a couple of years later, followed by the third a month or two later, and so on. If we can measure this time lag between the arrival of light to the different image positions, we can effectively measure the light-distance along these different paths and thus measure the geometry of the Universe.

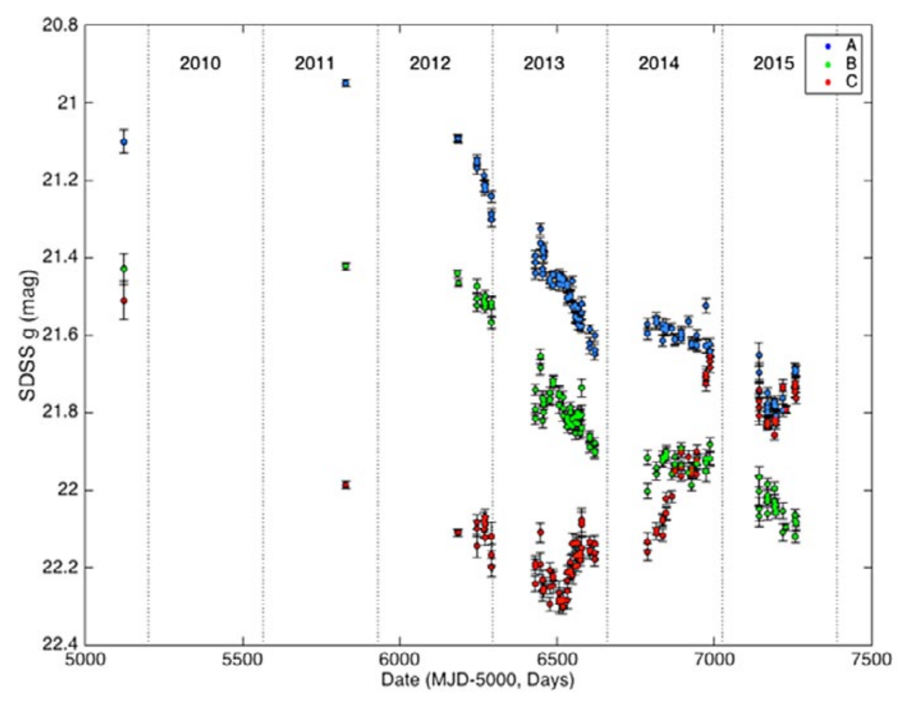


Figure 2.
Light curves of the quasar images A (blue symbols), B (green), and C (red). Figure reproduced from Dahle et al.*, 2015.*

Promptly after the discovery of SDSS J2222 + 2745 a follow-up campaign, led by Håkon Dahle from the University of Oslo, was initiated using the 2.5-meter Nordic Optical Telescope (NOT) at the Canary Islands. The team observed the field of SDSS J2222 + 2745 approximately every two weeks, resulting in over 40 observations in good conditions.

Dahle and his team used these observations to construct a light curve for the brighter three of the six images (Figure 2). They found that the quasar's brightness varies by as much as 0.8 magnitude (a factor of two increase or decrease in flux) over four years. Dahle then used computational techniques to cross-correlate the light curves of images A and B in order to identify similar patterns in the fluctuation of light. The team found that the time lag between image A and B is about 47.7 days, which means that if image A suddenly brightens, image B will do the same thing 47.7 days later.

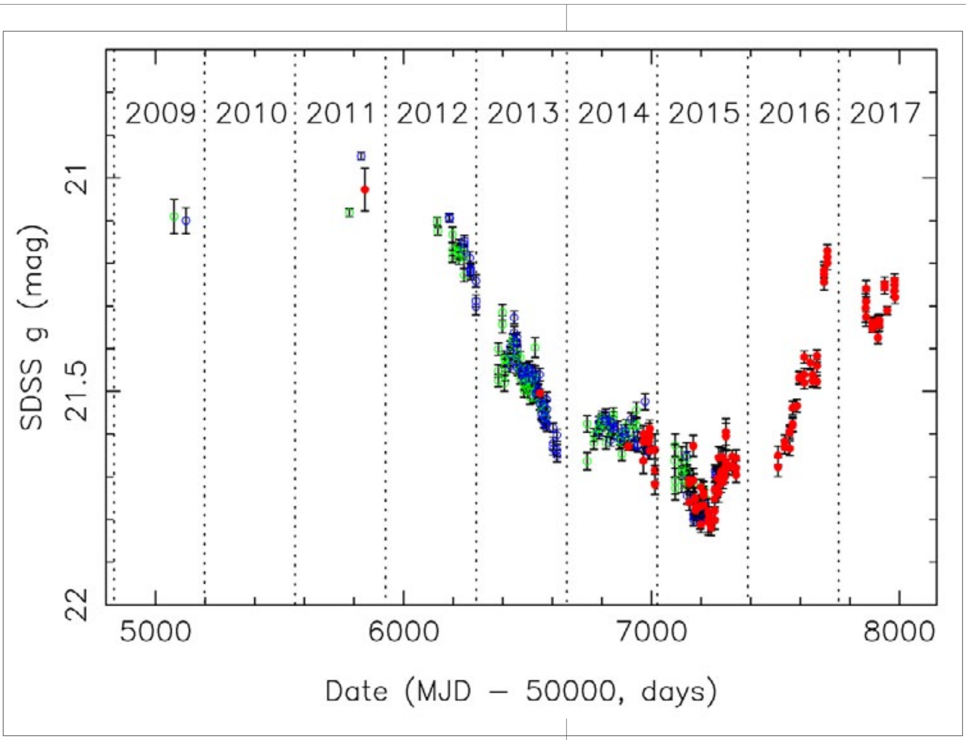
A robust measurement of the time lag of image C was harder to obtain. The team's lens model, computed by Keren Sharon (author of this article) predicted Image C to lead images A and B by a few months to years; thus to measure it required a longer monitoring period. However, recent observations, including imaging with NOT, and with the Gemini North telescope awarded through a Fast Turnaround proposal, helped pin down the elusive measurement of a time delay of image C. As predicted by the lens model, image C leads image A by about two years, at about 722 days.

What's Next?

Using spectroscopic observations with Gemini North (2015B; Principal Investigator Keren Sharon), we were able to determine the redshifts of lensed galaxies recently identified in our Hubble Space Telescope (HST) observations of this field. The new redshifts will inform a more accurate and precise lensing model of the cluster, which will improve our theoretical understanding of this system.

Having measured the lags between three of the six images of the quasar in SDSS J2222 + 2745, this lens system provides us with a rare tool: foresight. In particular, with a measurement of a negative time lag of image C, we now have a two-year warning for the behavior of images A and B (Figure 3).

Figure 3. *The combined light curve of image A (blue), B (green), and C (red), by shifting the data points of A and B by their respective time delay and magnification ratios: -47.7 days and -0.34 magnitude for B, and 722 days and 0.483 magnitude for C. The shifted light curve of C predicts the expected brightness of image A in 2016 and 2017. Figure reproduced from Dahle* et al., *2015.*



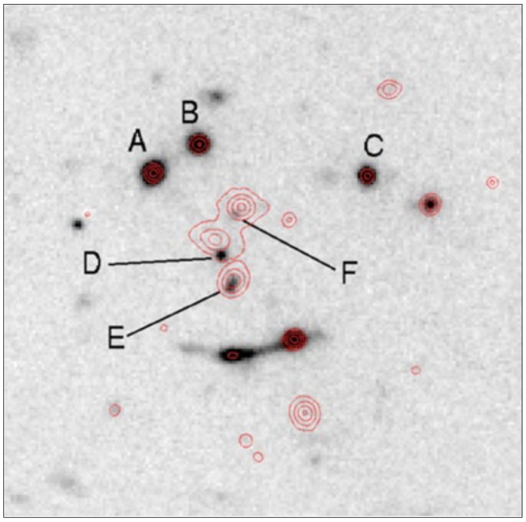
If C brightens significantly, as it did in 2014 and 2015, we know to expect the same magnitude of brightening in A and B about two years later, and plan future observations for that time.

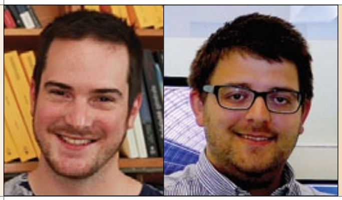
Meanwhile, our team has embarked on a multi-wavelength monitoring campaign aimed at studying the physical conditions in the quasar's host galaxy. In this program, we will use Gemini and NOT in the optical, and the Swift space telescope in UV and X-ray, in a program awarded by the University of Michigan. We'll also use observations with the HST in Cycle 22 (PI: Keren Sharon) to compute a detailed lens model of the cluster, to further constrain the mass distribution of the foreground lens.

The Gemini monitoring will uniquely enable a measurement of the time delays of the three faint images of the quasar: D, E, and F (Figure 4). These images are much dimmer than A, B, and C, and their detection is further complicated by their position near the bright galaxies at the center of the cluster. These forthcoming measurements could shed light on the details of the distribution of the luminous mass and dark matter at the very core of the galaxy cluster, at a resolution that cannot be obtained by any other method.

Keren Sharon is an astronomer and assistant professor at the University of Michigan astronomy department and can be reached at: kerens@umich.edu

Figure 4. *This figure, reproduced from Dahle* et al.*, shows the field of SDSS J2222 + 2745 after the bright cluster galaxies were modeled and their light subtracted from the image .This procedure reveals the three fainter images (D, E, and F) of the quasar that are embedded in the light of these galaxies. The red contours show the light distribution in the original image.*





Julien Rameau and Robert De Rosa

October 2015

GPI Discovers the Most Jupiter-like Exoplanet Ever Directly Detected

After 10 years of development, the Gemini Planet Imager (GPI) — the most powerful of its kind — started operating routinely in late 2013. After observing just 44 stars, GPI found its first exoplanet — a young, cool object that is the most Jupiter-like, and probably the lowest-mass exoplanet, ever directly imaged. This finding will also lead to a better understanding of how our Solar System formed.

Detecting an extrasolar planet directly from its infrared radiation is extremely challenging. This is mainly due to two factors: (1) the large contrast in brightness between the star and planet (around a million to one), and (2) the small angular separation between the star and planet (under one arcsecond). Moreover, the Earth's turbulent atmosphere strongly degrades the image quality, preventing large ground-based telescopes from reaching their theoretical diffraction limit. To overcome this detrimental effect, many world-class observatories, like Gemini, employ high-angular resolution instruments with adaptive optics (AO) systems to both sense, and correct for, wavefront distortions, producing extremely sharp images free from atmospheric distortions.

The first generation of AO-fed instruments discovered a handful of extrasolar planets with contrasts of ~10^5, or at angular separations greater than one arcsecond. To detect fainter, less-massive planets closer to their parent star (probing scales similar to our own Solar System), an international team of astronomers and engineers conceived, designed, and built the most powerful AO instrument to date: the Gemini Planet Imager (GPI) on the Gemini South telescope in Chile.

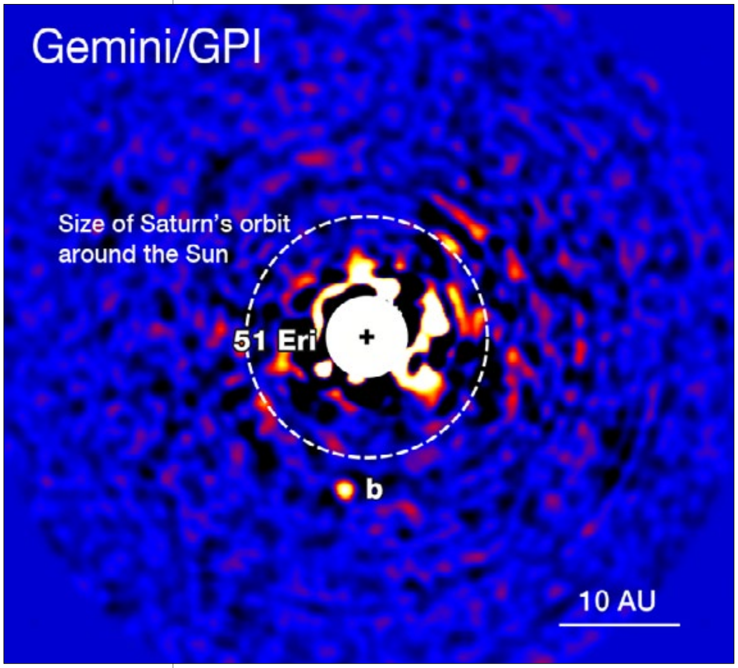


Figure 1. *Discovery image of 51 Eri b at H band (1.66 microns) with the Gemini Planet Imager in December 2014. The central star (indicated by a cross) has been subtracted as a part of the data reduction process, and the residuals are masked out to enhance the planet's contrast in the image. The projected separation between the planet and the star is approximately 13 AU, with a contrast of ~ 10^6.*

Image credit: C. Marois (NRC-Herzberg), J. Rameau (University of Montréal).

The Power of GPI

GPI uses the most advanced technologies to achieve unprecedented performance in terms of angular resolution and contrast. Image quality is restored by up to 90 percent of the theoretical diffraction limit, and most of the starlight is blocked by a coronagraph to attenuate the primary star's glare, revealing faint point sources close to the star. Instead of taking a single image, GPI obtains a low-resolution infrared spectrum for each pixel in the field-of-view, facilitating the detection of an exoplanet's atmosphere and the most prominent chemicals found there.

After a successful first light in November 2013, GPI started routine operations and became available to the wider astronomical community. Gemini Observatory also selected the GPI Exoplanet Survey (GPIES) team to conduct a 3-year, 890-hour campaign to search for, and characterize, new extrasolar systems around some 600 stars. In December 2014, after observing only 44 stars, the team identified a point source one million times fainter than one of the stars (51 Eridani; 51 Eri), at an angular separation of only 0.5 arcsecond; GPI's first planet discovery: 51 Eri b (Figure 1).

A Perfect Target

51 Eri is a nearby star 29.4 parsecs (96 light years) distant with a mass of 1.6 M_{Sun}. It belongs to the Beta Pictoris moving group, which has a well-determined age of about 20 million years (Myr). 51 Eri is also co-moving with the tight M-dwarf binary GJ 3305 at a distance of 2,000 astronomical units (AU). Studies of the star's motion through space, and spectral characteristics of the GJ 3305 binary, provide further evidence of membership within the Beta Pictoris moving group, confirming the age of the 51 Eri system.

Given 51 Eri's young age, any planetary-mass companion will still be cooling from its recent formation, and will therefore be bright enough to be detected in the near-infrared via direct imaging. Additionally, the infrared excesses measured in the spectral energy distribution (SED) of 51 Eri by infrared satellites, such as WISE and Herschel, are indicative of a circumstellar debris disk — the residuals of putative planetary formation. Determination of the precise geometry of the debris disk will require further investigation.

51 Eri proved to be the perfect target to search for an exoplanet, but despite previous attempts to search for planetary-mass companions with a number of older instruments, 51 Eri b remained elusive until the GPIES team detected it in December 2014. At a projected separation from 51 Eri of only 13.4 AU, and an estimated mass from evolutionary models of 2 M_{Jup}, 51 Eri b is the first directly-imaged exoplanet most resembling the gas giants within our own Solar System (Figures 2 and 3).

Methane, Methane, Methane

As GPI uses an integral field spectrograph, we were able to extract a low-resolution spectrum of 51 Eri b, which, like Jupiter, shows strong methane absorption. We immediately recognized the significance of the discovery, as it provides a view of what Jupiter might

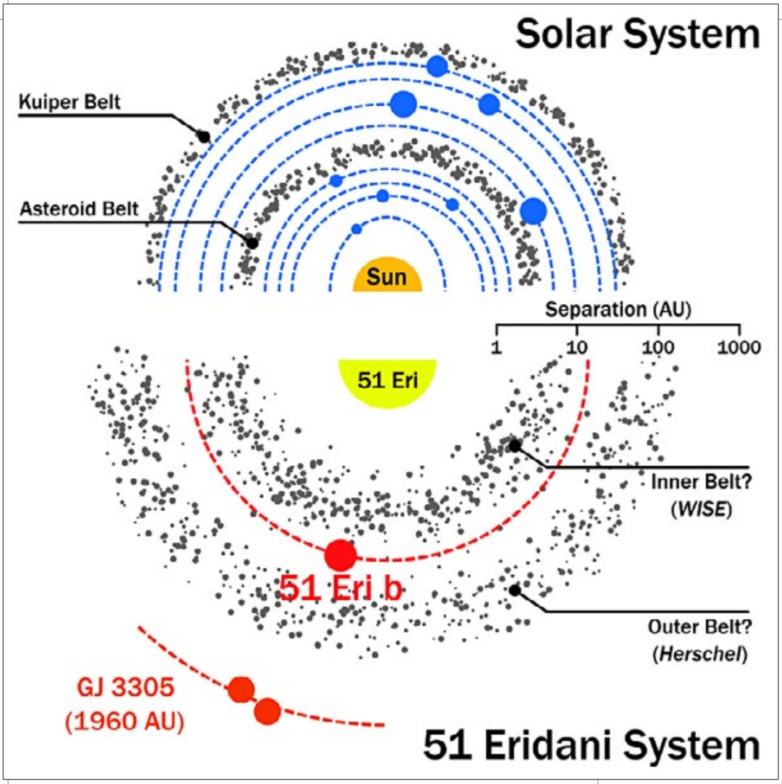


Figure 2.
Schematic diagram comparing the 51 Eri system with our own Solar System. Both systems harbor two debris belts, assuming a two-component fit to the infrared excess of 51 Eri, with gas giants in between. 51 Eri also hosts a binary M-dwarf at about 2,000 AU, a separation far too distant to gravitationally perturb the inner system. From 51 Eri b, each component of the wide binary would shine as brightly as Venus, and they would be separated by 17 arcminutes, roughly half the angular diameter of the Moon from Earth.

have looked like in its infancy, while offering us a clue as to how it formed.

In January 2015 we obtained follow-up observations with GPI at J and H bands (1.24 and 1.66 microns, respectively) as well as L′ observations (3.78 microns) with the W. M. Keck Observatory NIRC2 near-infrared imager and the facility's AO system. We then used the data to construct the planet's near-infrared SED. The most significant property of 51 Eri b was that, in addition to water vapor absorption, its spectrum exhibits the strongest methane absorption measured to date for a directly imaged exoplanet.

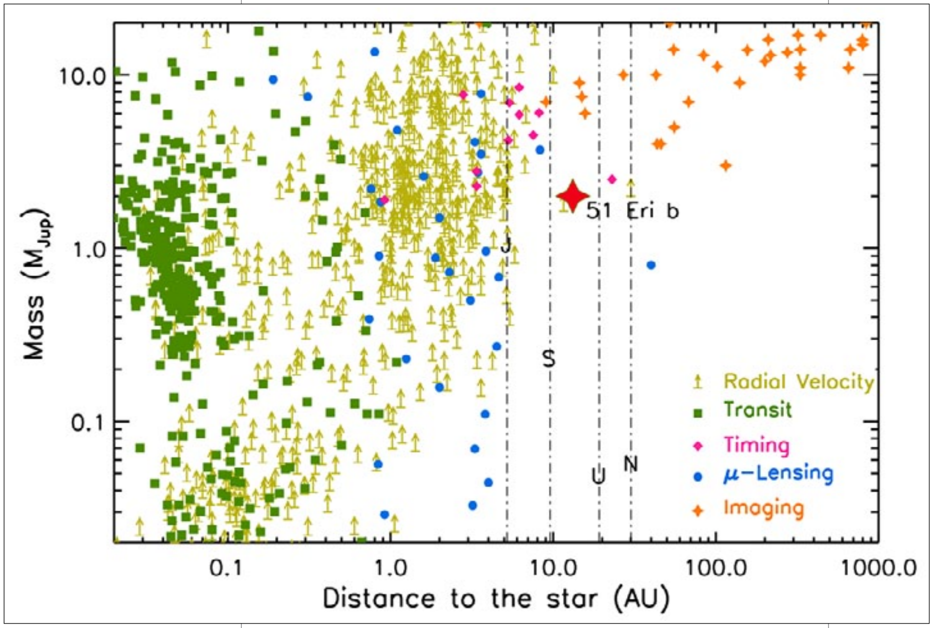


Figure 3.
The current population of known extrasolar planets classified by their detection techniques. The mass and semi-major axis of the four gas giants of our Solar System are overplotted (letters). 51 Eri b (large red star) is the least-massive directly-imaged planet, found at a separation similar to the scale of the Solar System. Source: exoplanets.eu, retrieved August 20, 2015.

While the spectrum of 51 Eri b resembles that of a typical T6 field brown dwarf several billion years old (Figure 4, top panel), its red H-L′ color suggests that the object is both younger, and less massive than, a field dwarf. A fit of the GPI JH spectrum, and the L′ photometry of 51 Eri b (with cloud-free equilibrium chemistry atmosphere models), gives it an effective temperature of 750 K, consistent with the presence of methane. But the data also suggest an unphysical radius of 0.76 R_{Jup}, and high surface gravity, as seen in the spectra of old brown dwarfs (Figure 4, bottom panel).

The results did not surprise us, since the same models had previously given similar extreme properties for other directly-imaged planets, such as HR 8799 bcde. To fit the spectrum of 51 Eri b with more realistic properties, we used a partly cloudy non-equilibrium chemistry model (Figure 4, bottom panel); models of this kind generally agree reasonably well with the observations of other imaged exoplanets. This new fit yielded a lower temperature (700 K) and a physical radius of (1 R_{Jup}) consistent with evolutionary models for substellar objects; it also favored a lower surface gravity, consistent with the planet's young age.

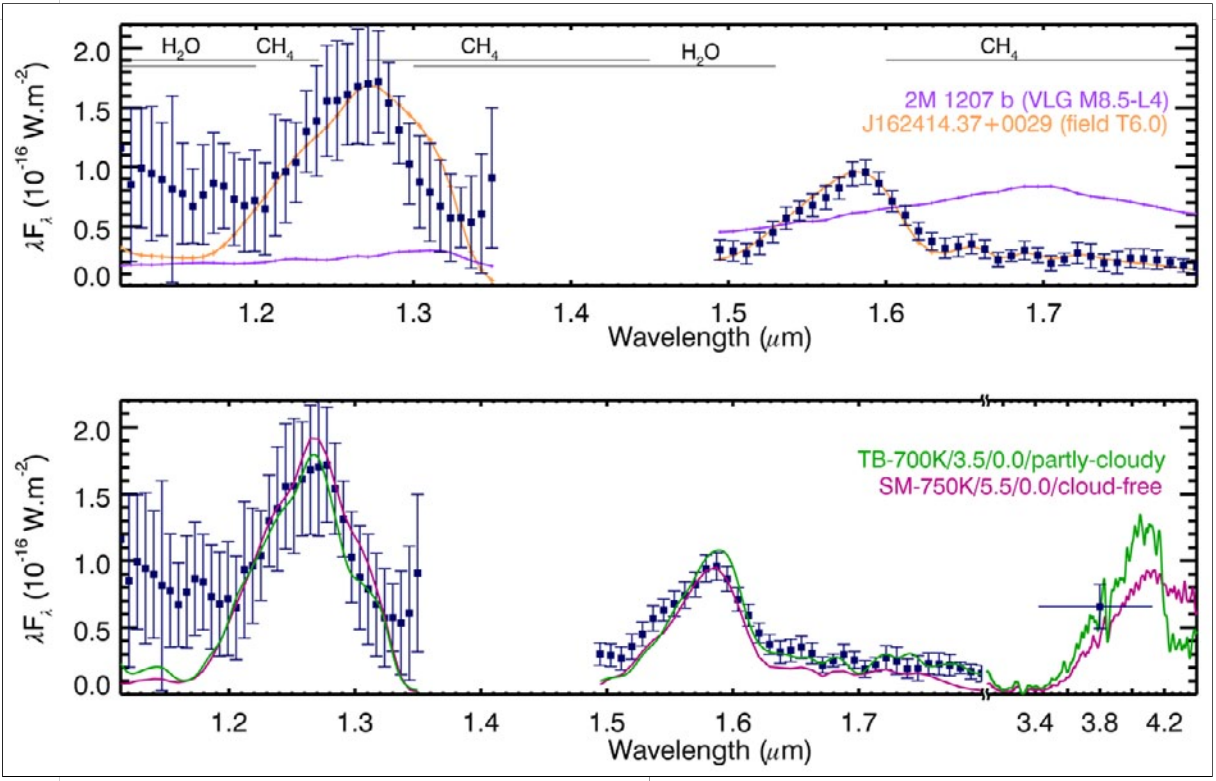


Figure 4.
Near-infrared SED of 51 Eri b measured by GPI at J and H bands, and by Keck/NIRC2 at L′ band (blue). The main molecular absorption bands are labeled on the top panel. The top panel compares the spectrum with the previously known planetary mass object 2M 1207 b (which has a very dusty atmosphere) and with a typical T6 field brown dwarf. On the bottom panel, the best fitting low-temperature, cloud-free, and partly cloudy models are able to reproduce the spectrum, but lead to distinct physical properties (see text).

Solar System-like?

51 Eri b is unique among the current population of directly imaged exoplanets in many aspects:

Location and Mass: GPI is among the first instruments sensitive enough to image planets in extrasolar systems at scales similar to our own Solar System; and the discovery of 51 Eri b demonstrates this. At 13.4 AU, the planet is located at a separation between the orbit of Saturn and Uranus, and with a model-dependent mass of 2 M_{Jup}, it would represent the least-massive exoplanet imaged to date.

The exoplanets previously resolved with direct imaging are typically found at a few tens to hundreds of AU, with masses greater than 5 M_{Jup}, making the architecture of these systems very different from that of our own Solar System. With GPI, a new low-mass population of exoplanets is now accessible by direct imaging. Further discoveries will better our understanding of the formation and architecture of planetary systems, and place the properties of our own Solar System into context.

Atmosphere: The presence of methane in the atmosphere of 51 Eri b is by far the most important aspect of this discovery. Previous directly-imaged exoplanets exhibit dusty atmospheres, where thick clouds block the light coming from the deep atmosphere and prevent an investigation of its chemical composition. 51 Eri b is different, as the clouds are more tenuous, allowing us to probe low altitude cloud layers and determine their chemical content.

51 Eri b's methane-dominated spectrum is similar to what models predict for a planet of its mass. This newly discovered world may, in fact, resemble what Jupiter looked like soon after its formation. With this discovery, astronomers now know how to differentiate between L- and T-type young planetary-mass objects, where atmospheres transition from fully dusty to cloud-free, respectively. This transition also occurs in a narrow range of effective temperatures, between the 1,000 K of HR 8799 b and the 700 K of 51 Eri b.

Formation: The formation process for gas giant planets is a long-standing debate in the community. The two scenarios currently invoked — "cold start" and "hot start" — lead to very different observable properties. For instance, in the cold start scenario, gas accretion reaches a runaway stage, producing shocks that radiate away all the incoming energy, resulting in a low temperature, low luminosity planet. In the hot start scenario, the shocks are radiatively ineffective, resulting in a planet with both high luminosity and high temperature. Of course, intermediate models are possible with initial entropy varying between these two extreme cases. The only way to determine the initial conditions is, therefore, to study young planetary systems.

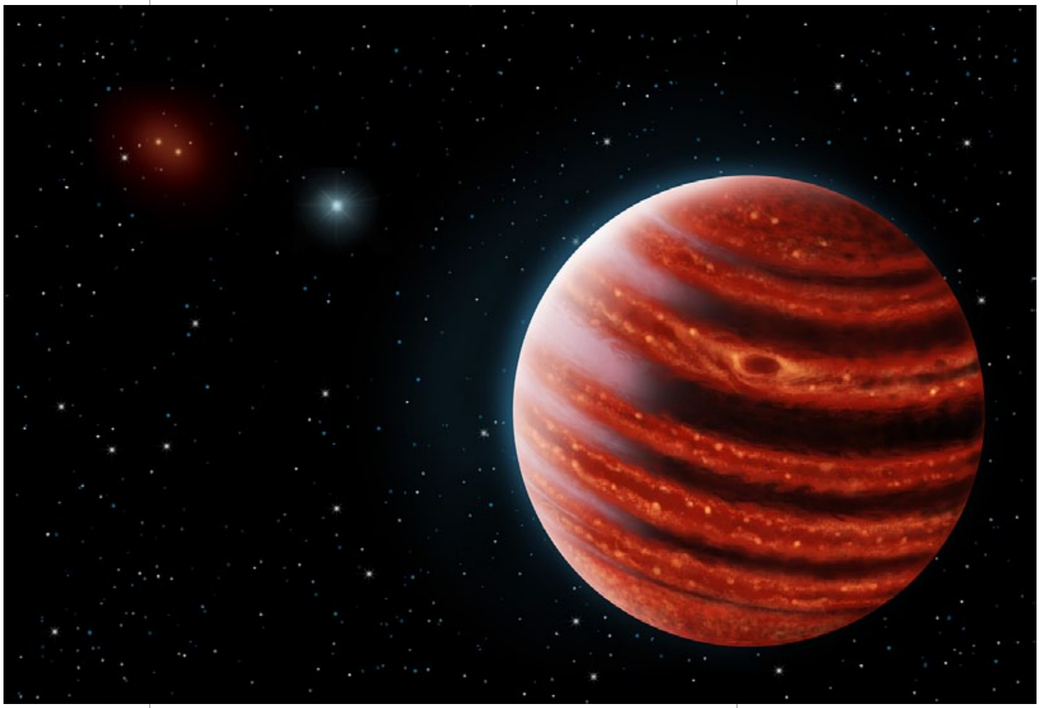


Figure 5.
An artist's visualization of the Jupiter-like exoplanet, 51 Eri b, seen in the near-infrared light that shows the hot layers deep in its atmosphere glowing through clouds. Because of its young age, this young cousin of our own Jupiter is still hot and carries information on the way it was formed ~20 million years ago.
Image credit: Danielle Futselaar & Franck Marchis (SETI Institute).

Previous directly-imaged exoplanets had luminosities only compatible with those predicted by the hot start scenario, whereas 51 Eri b is faint enough to be reproduced by both scenarios. The cold start scenario is usually associated with the core accretion formation mechanism, in which a core is built from planetesimal agglomerations followed by rapid gas capture. This mechanism is the adopted hypothesis to explain the formation of the gas giants in the Solar System. Therefore, 51 Eri b might have formed like Jupiter, with modest extensions to the classical core accretion model; like the pebble accretion which facilitates planet formation at larger distances than the typical 1-5 AU from the central star.

Tip of the Iceberg?

51 Eri b is the first exoplanet found by GPI. It belongs to a low mass, low temperature, methane dominated, close-in category to which earlier instruments were not sensitive enough to detect in previous exoplanet searches. We hope it represents the tip of the iceberg of extrasolar planets that will be directly imaged in the next few years — especially by instruments such as GPI, and its European cousin: the Spectro-Polarimetric High-contrast Exoplanet Research (SPHERE) at the Very Large Telescope.

The direct exoplanet imaging community is undertaking large-scale campaigns, which will hopefully lead to additional discoveries that will place our own Solar System in the context of other extrasolar systems. Studies such as these are the key to understanding the formation of giant planets, their evolution, and, ultimately, how they interact with potentially life-bearing terrestrial planets, which will undoubtedly be discovered with future instruments.

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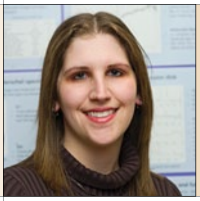


Valerie Rapson

First Likely Planets in a Nearby Circumbinary Disk

Gemini Planet Imager (GPI) observations of V4046 Sagittarii provide the first strong evidence for ongoing planet formation around a young nearby binary star with a circumbinary disk. The GPI data reveal a distinct double ring structure within the disk that roughly corresponds to the orbital positions of Uranus and Saturn in our own Solar System. The discovery provides tests of giant planet formation theories.

Stars form when a region within a giant molecular cloud, composed mostly of hydrogen gas but including more complex molecules and dust, begins to gravitationally collapse. As it does so, individual clumps start to spin up and flatten out, creating young protostars surrounded by disks of gas and dust. It's within these circumstellar disks that planets, like those in our Solar System, will form.

To better understand how planets form, we can study the nearest young stars known to host planet-forming disks. The proximity of these star-disk systems allows astronomers to more easily image the disks and search for evidence of planet formation. In the not-too-distant future, we may even begin to directly image the newborn planets themselves.

Planet Formation Around Nearby Young Stars

Planet-forming circumstellar (protoplanetary) disks have been observed to extend out to radii of a few hundred astronomical units (AU) and are composed of a vast array of molecules, including diatomic hydrogen (H_2), carbon monoxide (CO), water (H_2O), and various carbon-bearing compounds found in our Solar System — such as hydrogen cyanide (HCN), cyanide (CN), and ethynide (C_2H). Protoplanetary disks also contain carbonaceous and silicate dust grains, which coagulate over time, grow in size, and settle towards the disk midplane.

Present theories hold that giant planet formation in disks likely occurs via one of two mechanisms: core accretion or gravitational instability. In the core accretion scenario, ice-covered dust particles collide and stick together, growing into ever-larger rocky bodies; planetesimals form from this buildup of rocky material, and their collisions eventually build super-Earth-mass planetary "cores." Such massive cores can then rapidly collect gas from the disk to form giant planets.

In contrast, the gravitational instability theory holds that planets form when a perturbation in the disk causes a large amount of disk material to collapse and form a planet essentially all at once. Hence, this rapid process is similar to that by which a young central star forms from its birth cloud.

Under either scenario, once a massive planet forms, co-orbiting material either accretes onto the planet or is accelerated radially in the disk via spiral density waves, which cause material approaching them to speed up — until they reach the perturbed regions, where they slow down and linger. These mechanisms result in ring-like or spiral structures in the disk characterized by sharp radial gradients in both surface density and particle size.

The predicted spiral and ring structures have indeed been observed in disks around young stars in nearby star-forming clouds with telescopes such as the Sub-Millimeter Array (SMA) and Atacama Large Millimeter Array (ALMA), and with near-infrared cameras on 8-meter-class telescopes, such as Subaru and Gemini. However, these observations are typically probing planet formation around young stars at orbital separations many times that of the gas giants in our Solar System.

Our team is interested in studying planet formation around young nearby stars within ~ 30 AU, where we can search for evidence for gas giant planet formation on scales similar to that of our Solar System. We do so by focusing on a handful of solar mass stars within ~ 300 light years (ly) of Earth that are surrounded by, and actively accreting material from, gas-rich circumstellar disks.

Target: V4046 Sagittarii

Our team has been closely scrutinizing one such star-disk system: V4046 Sagittarii (Sgr). Lying at a distance of just ~ 240 ly, V4046 Sgr is an extraordinary binary star system surrounded by a massive disk of gas and dust roughly 0.1 solar mass. With an age of only ~ 20 million years, this system provides us with an excellent opportunity to search for evidence of recent or ongoing planet formation. The V4046 Sgr system also offers an intriguing twist: Any planets spawned in its disk would have to orbit twin stars (both only slightly less massive than our Sun) separated by just ~ 9 solar radii.

Interestingly, the V4046 Sgr disk exhibits a central clearing out to ~ 30 AU (*i.e.*, ~ 1/2 arcsecond) at submillimeter wavelengths. The presence of this inner "hole" suggests that one or more planets may be forming close to the central stars, carving out an opening within the disk (Figure 1 shows an artist's rendering of the V4046 Sgr disk based on

Figure 1.
Artist's impression of the the binary star-disk system V4046 Sgr. Image credit: NASA/JPL-Caltech/T. Pyle (SSC).

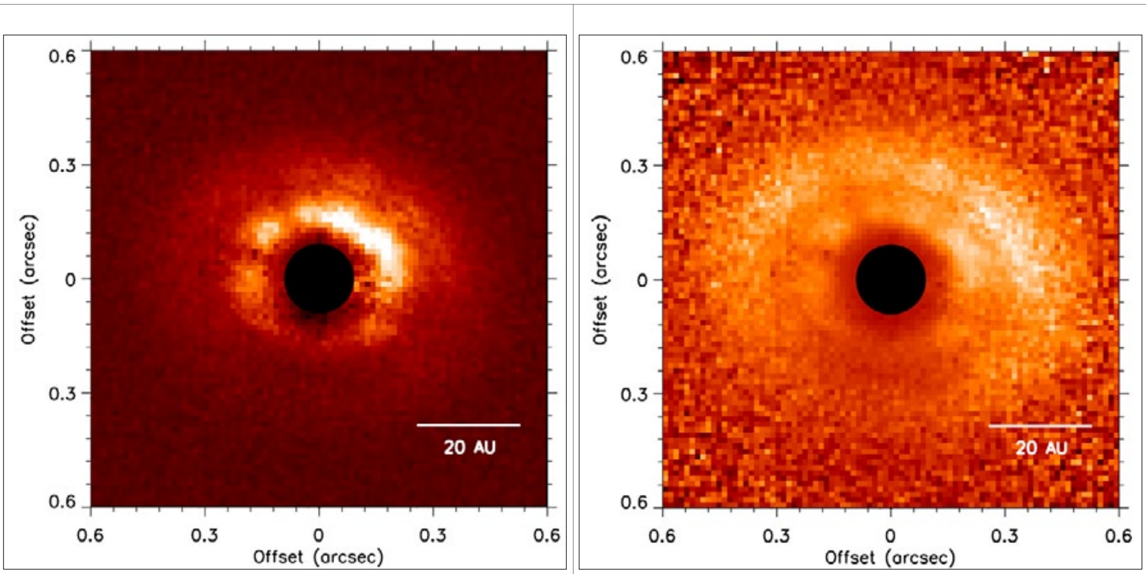


Figure 2.
Left: Total polarized intensity of the V4046 Sgr disk. Right: Total polarized intensity multiplied by r^2, to account for dilution of incident starlight.

these data).

On the other hand, our analysis of infrared observations from the Spitzer Space Telescope and Herschel Space Observatory suggests that the apparent "hole" at submillimeter wavelengths is actually partially filled with gas and dust. Since probing this inner-disk material directly requires imaging at resolutions near the diffraction limit of an 8-meter telescope, we turned to the Gemini Planet Imager (GPI) on the Gemini South Telescope to achieve this extreme resolution.

GPI Imaging of V4046 Sgr

GPI is a state-of-the-art, near-infrared instrument dedicated to directly detecting and characterizing young, self-luminous exoplanets and the dusty circumstellar disks in which they form. GPI combines high-order adaptive optics, a diffraction-suppressing coronagraph, and an integral field spectrograph to obtain near-diffraction-limited images. GPI allows us to observe these targets with unprecedentedly short integration times of just a few minutes.

We obtained Early Science observations of V4046 Sgr with GPI in April 2014, using its coronagraphic + polarimetric modes to trace light scattered off micron-sized (or smaller) dust grains in the disk. Our data consist of images through the J- and K2-band filters, at wavelengths of 1.24 and 2.25 microns, respectively.

Figure 2 shows the resulting images of the disk at J-band, which (thanks to the proximity of V4046 Sgr and the exquisite resolution and sensitivity of GPI) probe down to ~ 7 AU from the central binary at ~ 2 AU resolution. The left image is the total polarized intensity; the right image is total polarized intensity multiplied by the square of the deprojected distance from each pixel to the star (r^2) — to account for the fact that the light reaching the disk from the central star drops off as $1/r^2$.

The GPI images reveal a distinct double ring structure, with a bright inner ring centered at ~ 14 AU, and an outer halo extending out to ~ 45 AU. Two gaps appear in the disk: One between the two rings at ~ 20 AU, and one interior to the bright ring. These gaps roughly correspond to the orbital radii of Uranus and Saturn in our own Solar System. The gap/ring structure revealed by the GPI images of V4046 Sgr hence provides the first strong evidence for ongoing planet formation in a circumbinary disk within giant-planet-hosting regions similar to that of our Sun's.

Dust Segregation

Further evidence for planet-building activity in the V4046 Sgr disk comes from a comparison of the GPI and SMA data (Figure 3). GPI imaging traces light scattered off small dust grains, which appear to prevail within 10-45 AU of the central stars. Data from the SMA traces thermal emission from larger centimeter- to millimeter-sized dust grains, revealing emission concentrated in a ring whose inner edge lies at ~ 30 AU. Thus, the GPI data confirm the earlier Spitzer and Herschel spectroscopic observations, which show that the gap seen at submillimeter wavelengths is indeed partially filled with small dust particles.

Modeling of planet formation in disks suggests that we should see this phenomenon of grain size segregation. When a gas giant planet forms in a disk, it creates local density waves that trap larger (mm- to cm-sized) particles outside the planet-forming regions of the disk. Smaller (micron-sized) grains freely pass through these pressure traps, resulting in strong dust particle size gradients.

Our comparison of the GPI and submillimeter imaging of the V4046 Sgr disk provides vivid evidence in support of these so-called "dust filtration" models by describing the structure of a circumbinary disk captured in the process of actively forming planets.

In summary, our GPI images appear to provide powerful tests of two planet-forming processes in the V4046 Sgr disk: (1) That one or more young giant planets following orbits similar to those of Saturn or Uranus have simultaneously carved out a disk gap and an inner disk hole; and (2) these gas-giant planets have generated large-scale density waves, resulting in dust particle filtration and segregation by size. Together these results offer two possible ways giant planets can form in debris disks around young, Sun-like stars.

In addition, this evidence for the presence of young giant planets around V4046 Sgr helps set essential constraints on simulations aimed at understanding the conditions in which giant planets might form around binary star systems — a theoretical question that is presently of intense interest, given the Kepler Mission's detection of roughly 40 circumbinary planets to date.

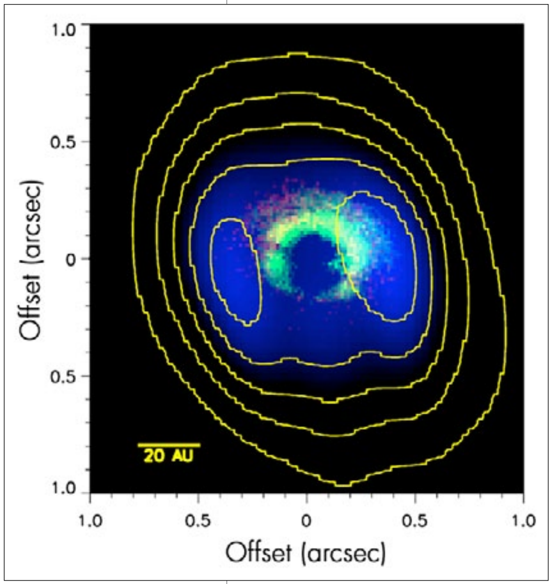


Figure 3.
Comparison of SMA data (blue shading and yellow contours) and GPI J (green) and K2 (red) data.

What's Next?

The Gemini Planet Imager has provided us with our first close look at some likely dynamic episodes in planet building activity within a circumbinary disk orbiting a young binary star system — especially in regions where gas giant planets are known to form around our Sun. Our team has subsequently obtained new time allocations with GPI to obtain deeper imaging of the V4046 Sgr disk. With these new observations, we hope to image the massive planets we suspect are forming, or have recently formed, in the disk.

We also plan to image other nearby young star-disk systems, to look for ring/gap features similar to those detected by GPI in the V4046 Sgr disk. Any additional results will further our understanding of the planet formation processes taking place in circumstellar disks orbiting young, Sun-like stars; they might also teach us something new about how gas giant planets formed in our own solar neighborhood.

Valerie Rapson recently completed her PhD at the Rochester Institute of Technology. She can be reached at: vrapson@gmail.com

April 2015

Benoit Neichel

RCW 41: Dissecting a Very Young Cluster with Adaptive Optics

High-resolution observations of a Galactic star-forming region with the Gemini Multi-conjugate adaptive optics System (GeMS), in union with the Gemini South Adaptive Optics Imager (GSAOI), have shed new light on how star-forming regions, and the young stellar objects within them, evolve.

All stars are born from an original collapsing cloud of gas and dust. When the core of one of these molecular clouds becomes unstable, it collapses and forms protostars. When the protostars are massive, they achieve temperatures hot enough to ionize the surrounding gas (mostly hydrogen) causing it to glow; we call this glowing stellar nursery an emission nebula or HII (H^+) region.

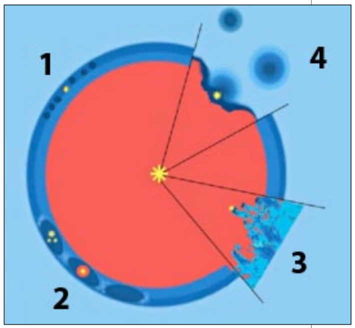


Figure 1. *The different mechanisms that may trigger the formation of a new generation of stars at the edges of an ionized (HII) region (from Deharveng* et al.*, 2010).*

Stellar Nurseries

Massive stars form HII regions that expand in the surrounding medium at supersonic speeds. Once a sphere of ionized gas is far from the newborn stars, the outer boundary (the ionization front) slows to subsonic speeds. Continued expansion of material ejected from the nebula builds pressure behind the front, before it breaks through as a shock. This second wave of expansion at the edges of the HII region can create a layer of cold neutral material, which accumulates between the ionized and the shock fronts. This layer may become unstable and form a new generation of stars through different physical mechanisms. Those mechanisms are summarized in Figure 1. These include small- and large-scale instabilities (denoted as 1 and 2, respectively; also called "collect and collapse"); interaction with a pre-existing turbulent media (3; leading to the formation of pillars); and interaction with pre-existing clumps (4).

One of the key questions in this field of research is what is the causal link between the first generation massive stars (the ones associated with the large HII regions) and the young (possibly second-generation) stars observed at the edges of HII regions? Dissecting the young clusters that formed at the edges of HII regions is therefore an important step to refine our knowledge on star-formation mechanisms.

The Sharp Gemini Eye

Studies of young star clusters are still limited. Young, recently formed stars in clusters are shy, and usually hide inside a heavily obscured and dense environment. High spatial resolution in the near infrared (NIR) is needed to resolve individual members and detect the fainter ones.

The Gemini South telescope offers one of the most advanced adaptive optics (AO) suites currently available on a large telescope. Among these capabilities, the Gemini Multi-conjugate adaptive optics System (GeMS) delivers a uniform, almost diffraction-limited image quality at near-infrared wavelengths over an extended field-of-view of 2 arcminutes across.

GeMS utilizes five artificial laser guide stars, up to three natural guide stars, and multiple deformable mirrors (DMs) that are optically conjugated with the main atmospheric turbulence layers. This results in an AO corrected field that is 10 to 20 times larger than previous generations of AO systems. GeMS works in conjunction with the Gemini South Adaptive Optics Imager (GSAOI), which covers an 85″ × 85″ field-of-view with a plate scale of about 20 milliarcseconds. This combination of new instruments is perfectly suited for young cluster studies, as it provides a uniform and unprecedented spatial resolution spanning a large portion of the young cluster's angular extent.

Figure 2.
JHK color-composite image of RCW 41 observed with GeMS at Gemini South.

Back in 2013, during the GeMS science verification period, we pointed this high-resolution machine toward RCW 41, a Galactic ionized region located in the Vela molecular ridge. We used three filters (J, H, and K_s), combined to produce the image shown in Figure 2. In this image, the resolution is ~ 0.1 arcsecond, and quite uniform over the field. At the cluster's distance, ~ 4,200 light years (1.3 kiloparsecs), the field covered by the image represents ~ 1.5 light years (0.5 pc), with a resolution corresponding to 130 astronomical units. This is 5 to 10 times better than previously available images, which were obtained in seeing-limited circumstances.

To highlight the gain in resolution brought by GeMS/GSAOI, Figure 3 compares the seeing-limited images obtained with the European Southern Observatory's large-field infrared spectrograph and imaging camera

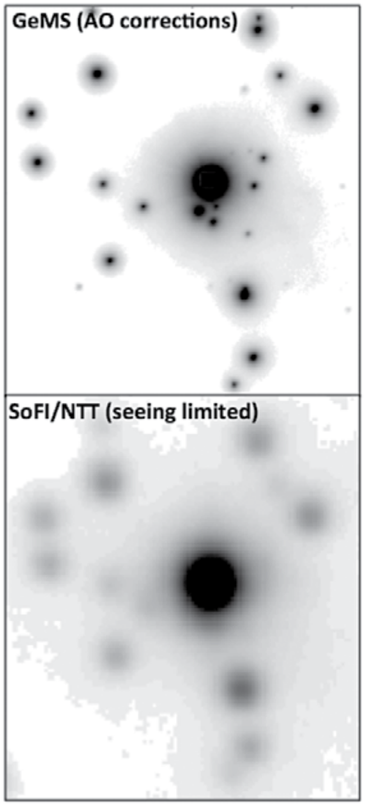
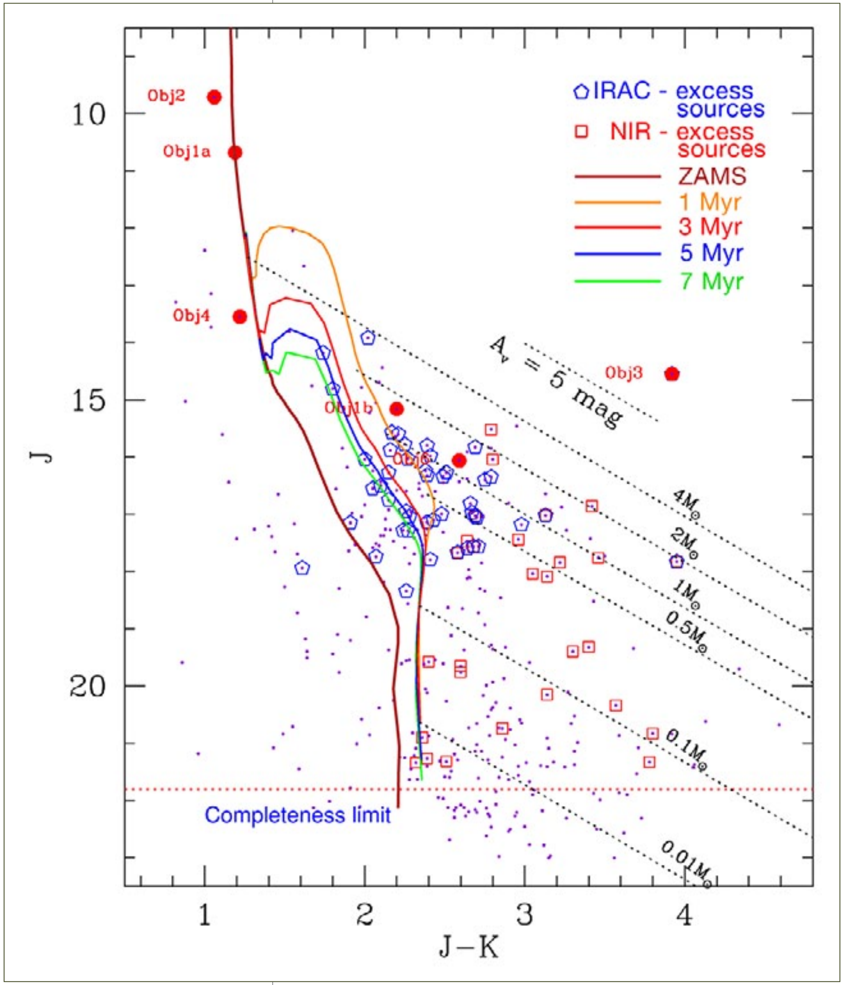


Figure 3.
GeMS/GSAOI (top) and SofI (bottom) images of the central part of the RCW 41 cluster observed in H-band.

SofI (Son of Isaac) on the New Technology Telescope, and the new GeMS/GSAOI images in H-band. The region shown here is the cluster's center, where the stellar density is the highest. GeMS/GSAOI not only resolves many more stars, but by concentrating the light over smaller areas it also enhances the sensitivity and limiting magnitude in this crowded region. Determining the stellar content of young clusters (by resolving their individual members and gaining access to their faintest ones) is a key in understanding the process of their star formation.

Figure 4.
Magnitude-color diagram for all stars detected in the RCW 41 cluster. Stars marked with a blue polygon or a red square are the YSOs. The pre-main sequence models used to estimate the cluster's age are shown with the solid color lines.



Young Stellar Objects: Identification and Cluster Age Determination

Based on the photometry derived from GeMS/GSAOI, complemented by images taken by NASA's infrared Spitzer Space Telescope, we have identified a total of 80 Young Stellar Object (YSO) candidates based on their unusual red colors. Indeed, these recently-formed stars are still embedded in native material, and circumstellar emission from each star's disk and envelope dominate the spectral energy distribution.

The signature of their youth, however, reveals itself at longer wavelengths, where their spectrum significantly deviates from a pure photospheric emission. Constructing color-color diagrams, we find that YSOs tend to cluster in a specific region, making them easy to identify.

Once identified, these candidate YSOs can then be used to estimate the age of the cluster. Indeed, in the absence of proper motion studies, or spectroscopic information, the distinction of true low-mass members from the contaminating field stars projected along the line of sight is difficult. We therefore used these YSO sources, which are more likely associated with the cluster, to derive an approximate age of the region.

Age determination was done through the color-magnitude diagram shown in Figure 4. For each YSO, we track its position with respect to pre-main sequence models. The different models assume different colors for different YSO age. This allows us to basically assign an age for each object. Of course uncertainties are large. However, this exercise allowed us to find evidence for the cohabitation of two potentially distinct populations of YSOs.

More specifically, we found that two-thirds of the YSOs were young, with a mean age lower than 3 million years (Myr), while one-third had a mean age of about 5 Myr. This might be the sign of an evolutionary star formation sequence (progression) at work in this region.

Evolving Stars?

To test whether different evolutionary stages are present in the cluster, we looked at the spatial distribution of these two possible populations. From this it appears that the "red," highly embedded, and probably younger, YSOs are mainly distributed around the northwest region (top right), while the "blue," and probably older, population is preferentially located toward the southeast (bottom left) region. This distribution seems to indicate the presence of an age gradient diagonally across the image, and where the denser cluster region would be younger than the blue sub-cluster region.

We also found that one of the bluest massive stars, located in the southeast sub-cluster, is likely the ionizing source of the region. This star probably is the one that originally lit up RCW 41, and has already cleaned up its environment. On the other hand, moving toward the dense cluster region, the presence of a dense clump of molecular gas has been detected, a signpost of active ongoing high-mass star formation. This suggests that star formation progresses toward the clump and could have been triggered by the interaction of the ionized region with the clump.

Cluster Mass Distribution

To go one step further, we derived the mass and mass distribution of the dense cluster, formed at the edge of the RCW 41 HII region. The stars in this region have roughly the same age and metallicity. In addition, since the effects of stellar and dynamical evolution are minimal in young clusters, the observed present day mass function should be a fair representation of the underlying Initial Mass Function (IMF).

The IMF is a fundamental parameter to characterize cluster properties, and various theories of star formation predict different outcomes for its overall shape. However, as for the age, deriving a mass for each star is an indirect process, and many uncertainties may add up along the way.

We derived the IMF of the young cluster, which is presented in Figure 5. Among the first interesting features is that we can detect and study stars down to a mass limit of ~ 0.01 solar mass — only 10 times the mass of Jupiter! Only the gain in sensitivity brought by GeMS/GSAOI allows us to reach such a low mass limit in a cluster as distant as RCW 41.

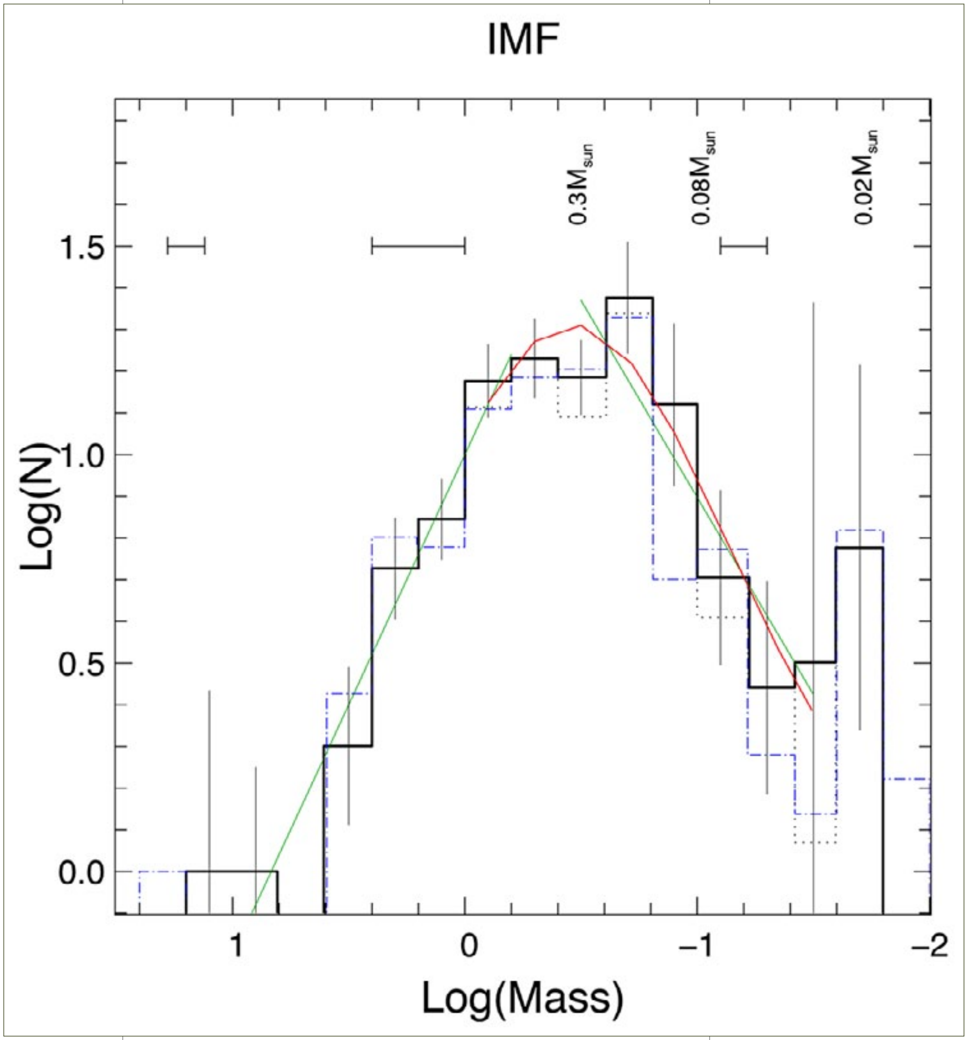


Figure 5.
Mass distribution of the young cluster forming at the edge of the RCW 41 HII region. Thanks to the gain in resolution and sensitivity brought by GeMS/GSAOI, masses down to 0.01 solar mass are probed in this cluster.

Brown Dwarfs

Objects below 0.08 solar mass, (*i.e.* below the hydrogen-burning limit) are are known as brown dwarfs. We demonstrate here that GeMS/GSAOI opens the way for studies of brown dwarfs, and brown dwarf formation processes in distant clusters.

In particular, there have been several proposed mechanisms to explain the origin of brown dwarfs — such as through turbulent fragmentation, disk fragmentation, ejection of newly formed fragments in multiple systems, and photoevaporation. All of these scenarios may predict a different brown dwarf fraction. For instance, isolated brown dwarfs may be the remains of prestellar cores, after strong ultraviolet emission from nearby massive stars photoevaporated their accretion disks. We therefore expect a higher brown dwarf ratio for clusters hosting massive stars.

RCW 41 does host many massive stars, allowing us to compare its brown dwarf fraction with other known clusters hosting massive stars, such as the Trapezium region in the Orion Nebula. From this comparison we found that the fraction of brown dwarfs in RCW 41 was actually significantly smaller than that of the Trapezium. This is also true for another distant cluster — the one in M16, the Eagle Nebula. This might indicate that different processes are at work to shape the low-mass IMF and the brown dwarf content.

Coming Next

Accurately deriving the stellar content of young clusters is a challenge for which GeMS/GSAOI is certainly a unique facility. These capabilities offer us an opportunity to pin down each of the least massive stars present in distant clusters and push the observational limits one step further. The resolution provided by GeMS/GSAOI is also an ideal complement to the radio observations delivered by the newly commissioned Atacama Large Millimeter Array (ALMA). Combining near-infrared, with radio wavelengths — at a similar spatial resolution — opens the way for strong synergies and breakthrough discoveries.

We are also exploring the need for new data reduction tools specifically designed for this new generation of AO systems. As shown in this paper, many uncertainties in the data still exist, and error bars need to be carefully treated. Finding ways to reduce these error bars will allow us to push the limits of technology, better constrain theoretical models, and improve our understanding of those rich and complex star-forming regions.

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Other members of the team are: Manash R. Samal, A. Zavagno, and A. Bernard from Laboratoire d'Astrophysique de Marseille, France; H. Plana from Universidade Estadual de Santa Cruz, Brazil; and T. Fusco from ONERA, France.

Nancy A. Levenson

Science Highlights

This 2015 Year-in-Review highlights the innovative science being done by the Gemini user community.

January 2016

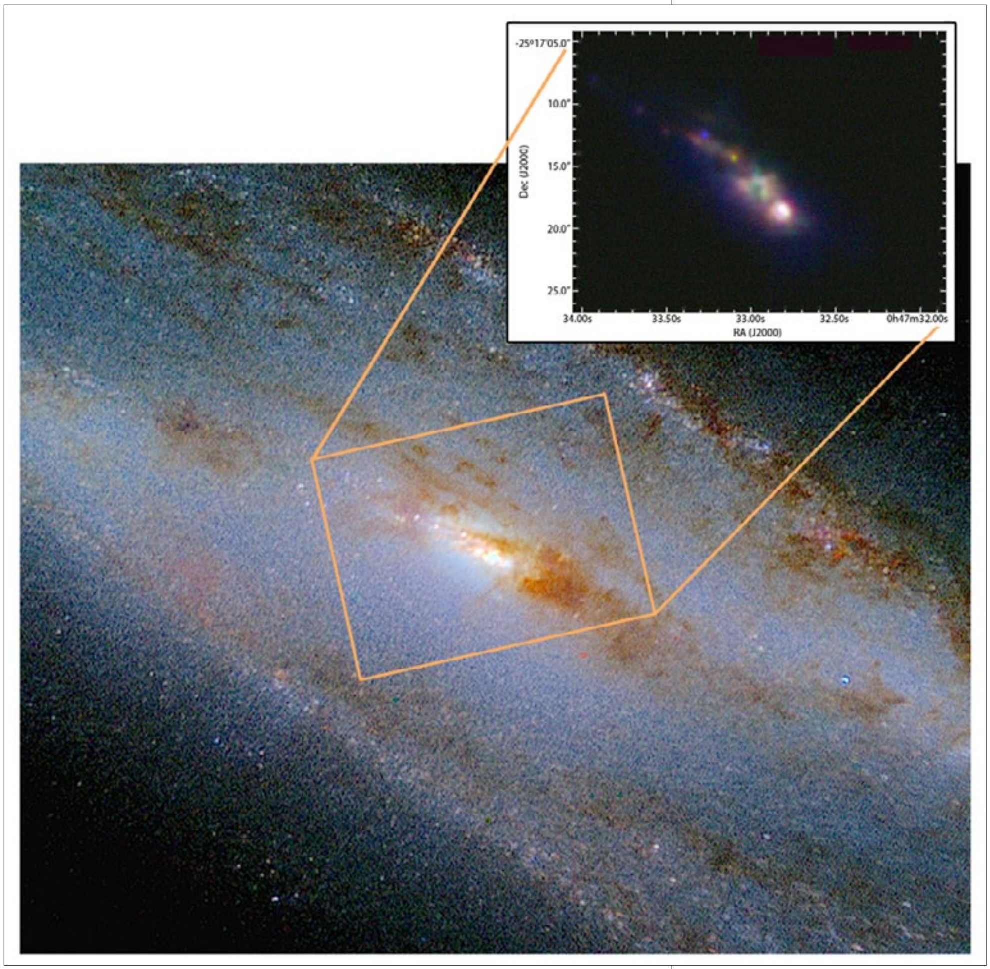
Unshrouding the Buried Nucleus of a Nearby Starburst Galaxy

NGC 253 (Figure 1, and featured on the cover of this issue) is famous among astronomers as the nearest spiral galaxy hosting a nuclear starburst. The concentrated activity and associated dust, however, obscure the center. Guillermo Günthardt (National University of Cordoba, Argentina) and collaborators have now used Gemini infrared observations to identify the galaxy's nucleus. They conclude that the brightest near- and mid-infrared source (a stellar supercluster) marks the nucleus, rather than a radio source that astronomers had previously identified.

The team used new multi-wavelength near-infrared images and spectroscopy obtained with Flamingos-2 on the Gemini South telescope, combined with archival multi-band mid-infrared images obtained using T-ReCS (Thermal-Region Camera Spectrograph) on

Figure 1.
Color composite image of the central region of NGC 253, from Flamingos-2 images using the filters J (blue), H (green), and Ks (red). Large amounts of dust completely obscure this region in optical images.

(Inset) Color composite image of the core region of NGC 253, from T-ReCS mid-infrared images using the filters Si-2 (blue), [NeII] (green), and Qa (red). The nucleus candidate IRC appears as the brightest object in the infrared.



Gemini South. The stellar supercluster, identified as the nucleus and kinematic center of molecular gas rotation, is almost coincident with the symmetry center of the galaxy's inner bar. This infrared core (IRC) is also the primary source of the starburst-driven outflow. Both the IRC and the nuclear disk are offset with respect to the galaxy's stellar bulge, which implies that the central gas reservoir and new star formation are decoupled from older Galactic structure.

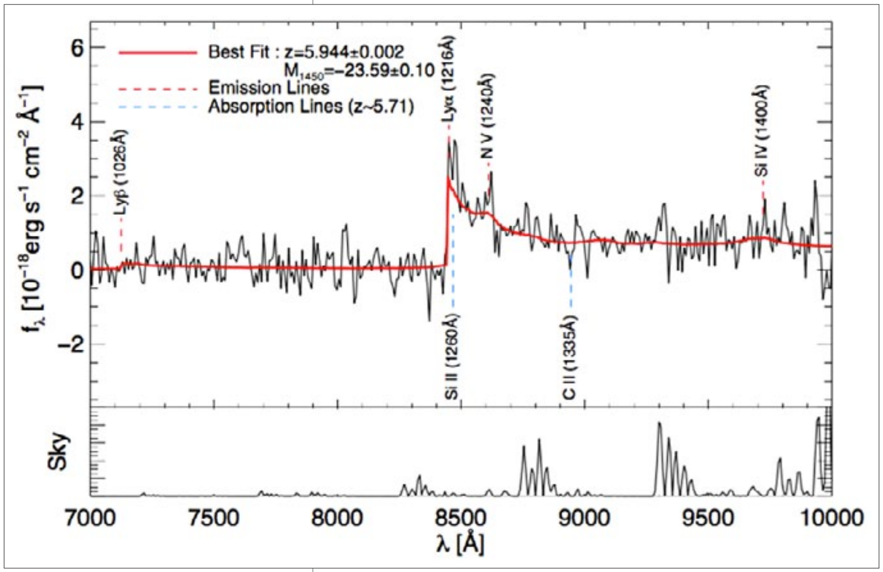
The complete results are published in ***The Astrophysical Journal***, and more information with detailed images is posted on the ***Gemini website***.

Discovery of a z ~ 6 Quasar: Rethinking Reionization Sources in the Early Universe

Korea's first result as a limited Gemini partner, the discovery of a faint quasar at a redshift of *z* ~ 6, sheds new light on the sources of reionization energy about a billion years after the Big Bang.

Ionizing the neutral atoms of the intergalactic medium requires significant sources of energy, from either galaxies' stars or their accreting central black holes (as quasars). The new discovery, however, ultimately suggests that quasars do not contribute significantly.

Figure 2.
This GMOS-S spectrum of the newly-discovered z~6 quasar confirms its identity and redshift.



In this work, the team began with the Infrared Medium-Deep Survey, based on data from Maunakea telescopes including the United Kingdom Infrared Telescope and the Canada-France-Hawai'i Telescope. Color selection revealed high-redshift quasar candidates, and observations of this newly-discovered quasar using the Gemini Multi-Object Spectrograph on Gemini South confirm its redshift and identity spectroscopically (Figure 2).

This single source and six additional candidates from the same survey are consistent with limited contributions to reionization from the faint end of the quasar luminosity function; thus, 90% or more of the ionizing flux must come from other sources.

This is the first Korean publication as part of the Gemini Partnership, and was led by Yongjung Kim (Seoul National University), Myungshin Im (Principal Investigator; Seoul National University), and colleagues. A translation of the Korean press release is posted on the Gemini ***website***, and the full publication appears in ***The Astrophysical Journal Letters***.

A Massive Black Hole in a Possible Relic Galaxy

New results based on Gemini observations of the compact, early-type galaxy NGC 1277 yield a new, lower than previously determined, mass of its central supermassive black hole. The work also has more profound implications for galaxy formation, suggesting that massive black holes were formed before stars came into place.

Jonelle Walsh (Texas A&M University) and collaborators used the Near-infrared Integral Field Spectrometer (NIFS) and laser-assisted adaptive optics on the Gemini North telescope to obtain high-resolution observations within about 1,400 light years of NGC 1277's center. These provide both sensitive data within the black hole sphere of influence and simultaneously cover extended regions where stars are

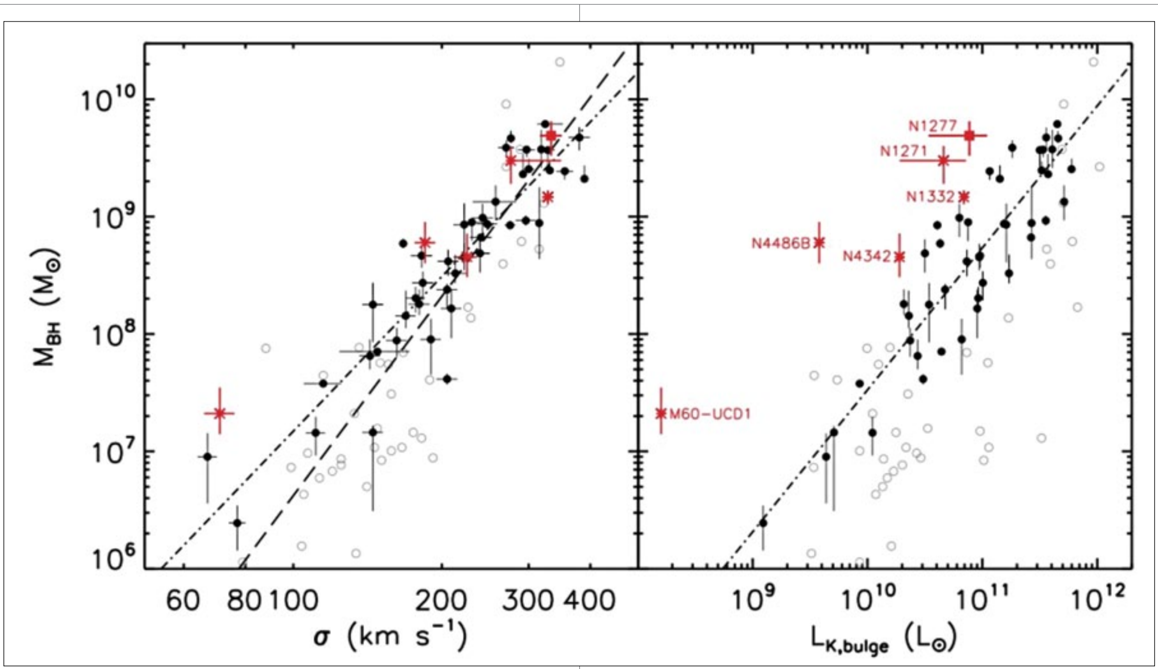


Figure 3.
NGC 1277 and other similar rotating, high-dispersion, early-type galaxies (red) are consistent with the M-sigma relation (left), but appear to be overluminous relative to their black hole mass (right).

more important. The team used these data to determine a lower black hole mass — by a factor of about three (4.9 x 10^9 M_{Sun}) — compared with earlier findings; still the black hole at the heart of this galaxy remains one of the most massive ever measured.

This result puts NGC 1277 well above the standard relationship between black hole mass and galaxy luminosity, placing it close to the relationship between black hole mass and bulge stellar velocity dispersion (the "M-sigma relation"; Figure 3). These observations and previous work identify NGC 1277 as a relic galaxy — one that has suffered only passive evolution (the aging of stars) over time, rather than the mergers and transformations that result in giant elliptical galaxies in the nearby Universe. Such relics offer windows into the early Universe and galaxy formation.

Based on these results and similar examples, the authors suggest that black holes formed first, followed by star formation, to end up with galaxies that exhibit the usual relations. The complete paper will be published in *The Astrophysical Journal*, and a ***preprint*** is now available.

October 2015

Best View of an Exoplanet Orbit

Observations using the Gemini Planet Imager (GPI) provide images and polarization measurements of the β Pictoris (β Pic) system that probe angular scales smaller than ever before, from ground or space (Figure 4). The dynamical interactions of exoplanet β Pic b and a debris disk offer tests of planet formation models. A further advantage of the new data is that they cover observations of the disk and planet together for more than a year, reducing errors in measurements of their relative positions.

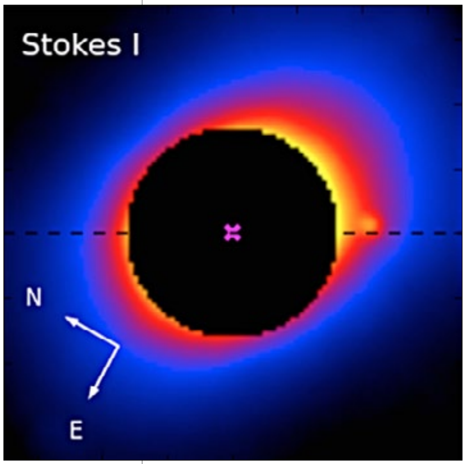


Figure 4.
Polarization component (Stokes I) of the β Pictoris system. A purple x marks the location of the star, blocked by a mask in the observation. The horizontal dashed line shows the position angle of the outer disk. The planet is separated from the star by 0.4 arcseconds, visible on the right side of the image, offset above the dashed line. This image is 1.3 arcseconds on a side.

Maxwell Millar-Blanchaer (University of Toronto) and colleagues use the polarimetric observations especially to develop a model for the disk itself. They show that the 10 - 12 M_{Jup} planet is not aligned with the large-scale disk. Ten new astrometric measurements, obtained over a 14-month period and combined with earlier data, yield the planet's orbital properties and the mass of the central star accurately: 1.61 ± 0.05 M_{Sun}.

The planet, orbiting at roughly the same distance as Saturn in our Solar System, can account for some dynamical features of the disk, such as its warp. However, it cannot fully account for several other features. In particular, β Pic b is not responsible for clearing the region to the observed inner disk edge at 23 astronomical units. Another planet could be the cause, but it would have to be very faint to avoid detection so far. Complete results are published in *The Astrophysical Journal*; part of a press release also appears on the following Gemini website, which provides a summary of the work, including additional illustrations and an animation of the data showing the planet's motion (***viewable here***).

The Deepest Ground-based Photometry in a Crowded Field

Paolo Turri (University of Victoria, Canada) and colleagues have used the Gemini Multi-conjugate adaptive optics System (GeMS) with the Gemini South Adaptive Optics Imager (GSAOI) to produce the most accurate and deepest near-infrared photometry from the ground of a crowded field. Their K_s measurements of the Galactic globular cluster NGC 1851 reach the precision and depth of optical observations obtained using the Hubble Space Telescope, and the resulting combined color-magnitude diagram reveals physical characteristics of the cluster (Figure 5).

Figure 5. (above)

This color-magnitude diagram of globular cluster NGC 1851's crowded center combines near-infrared observations obtained using GeMS/GSAOI at Gemini South and optical data from the Hubble Space Telescope. Red dots mark the main sequence turnoff and the main sequence knee, around K_s = 18 and 20.5 magnitudes, respectively.

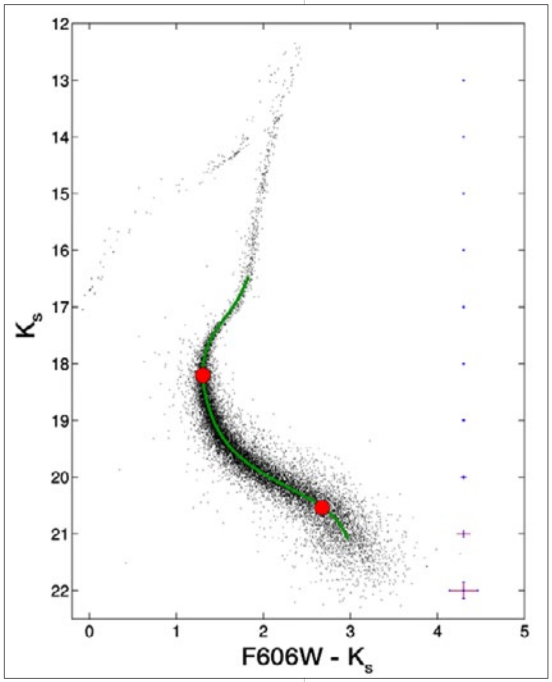
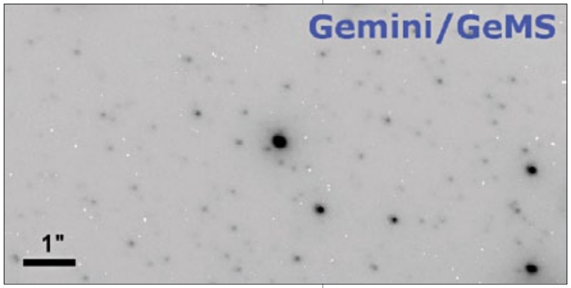


Figure 6. (below)

This small extract from the full 83-arcsecond field-of-view illustrates the quality and depth of the images from Gemini.



Specifically, the researchers detect the double subgiant branch in the cluster's center, which indicates either multiple episodes of star formation or multiple populations having distinct metal composition, rather than a single uniform population of stars. Turri *et al.* measure the main sequence well below its turnoff, for 3.5 magnitudes. A feature observed around $K_S = 20.5$ is the "main sequence knee," which may be useful to determine the cluster's age, independent of distance and reddening estimates.

The delivered image quality is near Gemini's diffraction limit, with an average measured full width at half maximum (FWHM) of 0.09". Thus, the team is able to distinguish individual stars in the very crowded field, which would overlap and contaminate each other in seeing-limited observations at lower spatial resolution (Figure 6).

Turri and his collaborators have similar GeMS/GSAOI observations of additional globular clusters, which will yield more general conclusions; these will help to guide observing and data analysis strategies for the next generation of extremely large telescopes. This work on NGC 1851 is published in *The Astrophysical Journal Letters*, and an introduction is available on the Gemini website (***view here***).

Water Vapor in a Terrestrial Planet Region

Astronomers have detected significant water vapor in the planet-forming region around the young star DoAr 44. The central star and development of its planets have not yet fully cleared the surroundings, leaving an inner ring and an outer disk around a gap that extends radially for 36 astronomical units (AU). DoAr 44 is unusual compared to similar so-called "transition disks" in showing evidence for water; yet by later stages of evolution, as young stars with disks, water vapor emission is common. The inner ring of DoAr 44 may be replenished by material from the outer disk, accounting for the large water content it maintains compared with similar objects. Alternatively, planets may affect the chemistry in this region where terrestrial planets develop.

The warm (450 K) water arises in the inner ring, appearing in emission at mid-infrared wavelengths (Figure 7). The data were obtained at a spectral resolution R ~ 80,000 using the Texas Echelon Cross Echelle Spectrograph (TEXES), a visitor instrument on the Gemini North telescope. Colette Salyk (National Optical Astronomy Observatory and Vassar College) and collaborators used the kinematic characteristics of the spectrally resolved emission to determine the location of its origin, at 0.3 AU. Avoiding destruction of water molecules in this region close to the stellar source requires material in the region — either gas or dust — as protection against the star's strong radiation. The paper appears in *The Astrophysical Journal Letters*, volume 810, page L24.

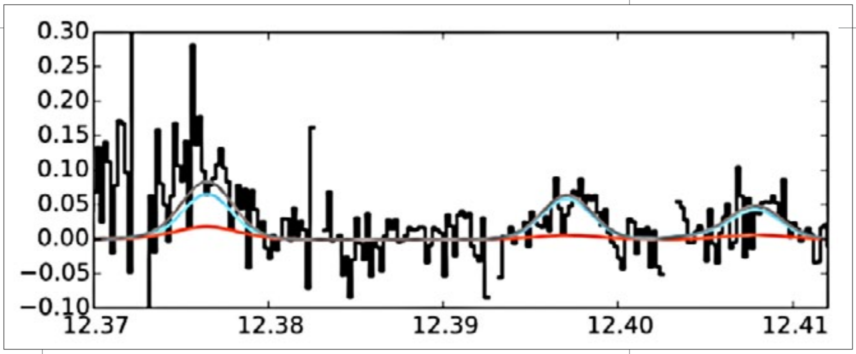


Figure 7.
Continuum-subtracted TEXES spectrum (black) and dominant "hot" model fit (blue), which yields the temperature (450 K) and location (0.3 AU) of the emitting water vapor. A "warm" component (red) is required to account for additional measurements at longer wavelengths. The sum of the models is plotted in gray.

July 2015

A Solar System Analogue, in Formation

Observations using the Gemini Planet Imager (GPI) reveal an analogue of our own Solar System at an early stage of evolution. The debris disk, which resembles the Sun's "Kuiper belt," belongs to the young star HD 115600 — a star in the right environment (a massive OB association) to represent the site of the Sun's formation, with similar mass (1.4 to 1.5 M_{Sun}). Thayne Currie (National Astronomical Observatory of Japan) and collaborators have discovered this extrasolar debris disk in direct imaging (Figure 8), and they use the images and spectral information from GPI to determine its properties and possible unseen planets.

The eccentric structure of the emitting disk is consistent with the system being shaped by planets like those in our Solar System, at similar distances from the parent star. Many previously discovered systems have required unusual planets — super-sized Jupiters far from the disk's center — to create the observed structures. GPI's excellent resolution and contrast allow probing more distant Sun-like systems than previously possible. GPI provides spectra along with the images, and the results are consistent with a significant water ice component. The complete work has been published in *The Astrophysical Journal Letters*, volume 807, page L7.

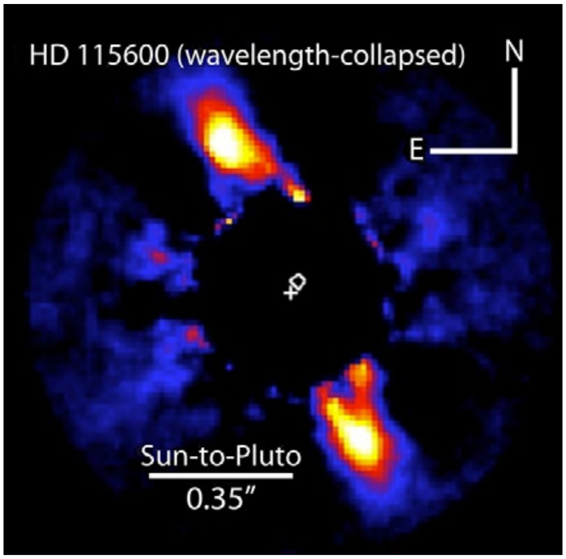


Figure 8.
This GPI image of HD 115600 in the H band (around 1.6 µm) clearly shows the disk that resembles the Kuiper belt of our own Solar System. The coronagraph blocks the light of the central star (at the position of the cross). The diamond marks the disk's center.

Finding the Outer Edge of Young Stars Near the Galactic Center

The very center of the Milky Way Galaxy contains a number of massive stars — despite either the inhospitable environment for their formation in the vicinity of a supermassive black hole or the short time available for them to relocate there after formation elsewhere. New observations, obtained using the Near-infrared Integral Field Spectrometer (NIFS) with laser and natural guide star adaptive optics, rule out at least one formation scenario (infall of a young stellar cluster) and help set the physical scale (0.5 parsecs (pc) or 1.6 light years) for the extent of *in situ* formation.

Morten Støstad (University of Toronto) and colleagues take advantage of NIFS's spatial resolution, along with the simultaneous spectroscopy it provides, to classify the observed stars (Figure 9). The distribution of early-type (young) stars exhibits a sharp decline at a radius of about 0.5 pc, which is not a limit due to the observations.

This is the first spectroscopic study to significantly support earlier photometric observations of this effect. The finding is not consistent with the relocation of the stars from elsewhere. Instead, it suggests that they were formed in place, within the very center of the Galaxy. They could either mark the outer edge of a gaseous disk's stability or define the properties of colliding clouds that formed the stars.

The observed distribution of older (late-type) stars is consistent with earlier results showing a power law distribution that breaks at a similar radius, though lacking the very sharp drop-off the young stars show. Full results appear in *The Astrophysical Journal*, volume 809, number 2.

Catching Supernovae in Advance

The earliest observations of supernovae can distinguish among their formation mechanisms. For Type Ia (SN Ia) events, the progenitor white dwarf may be pushed to become a supernova by accretion from a companion or by merger with another white dwarf. Besides being useful to account more fully for the end stages of stellar evolution, understanding the SN Ia mechanism is extremely important in their application to cosmology as standard (or standardizable) light sources.

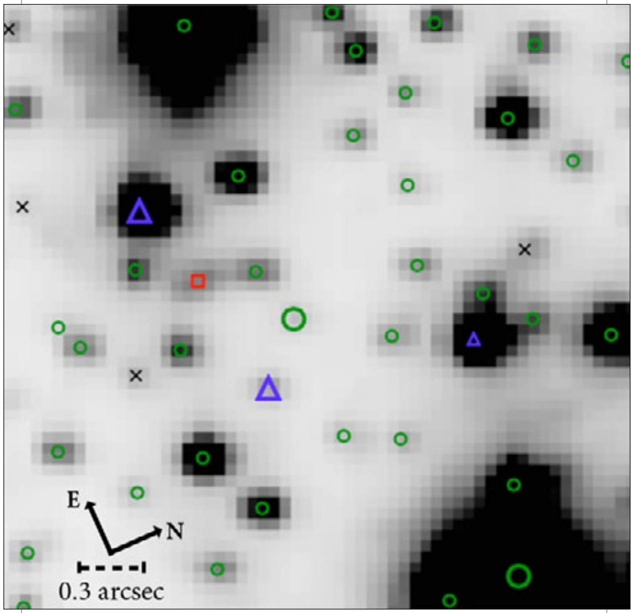


Figure 9.
The NIFS image in the K band of one of nine regions analyzed. The field measures 3 arcseconds across and is located about 0.4 pc from the Galactic center. Symbols indicate spectral types: violet triangles (early); green circles (late); black x's (ambiguous); and a foreground star (red square).

Two results find evidence for both of these SN Ia formation processes in different examples. In both papers, led by Yi Ciao (California Institute of Technology) and Rob Olling (University of Maryland), observations from Gemini and other ground-based facilities provided key pieces of evidence that helped the teams classify the supernovae as SN Ia.

NASA's Swift satellite triggered the first result. The ultraviolet emission it detected from the supernova was initially bright but decayed rapidly, which supports theoretical models of the "single degenerate" origin, where the companion star survives its collision with ejected material producing this emission. The Gemini observations were part of the Large and Long program led by Mansi Kasliwal (also California Institute of Technology), and designed to obtain rapid spectroscopy using the Gemini Multi-Object Spectrograph (GMOS).

In contrast, the second paper shows three examples with no evidence for interaction with a surviving companion. This supports a "double degenerate" origin, which leaves no material for subsequent interaction (Figure 10). NASA's Kepler satellite provided the first observations of these supernovae. The ground-based spectra, using GMOS on both Gemini North and South, showed that the hosts are passive galaxies at redshifts around 0.1. The two papers appear in the journal *Nature*, volume 521, pages ***328*** and ***332***.

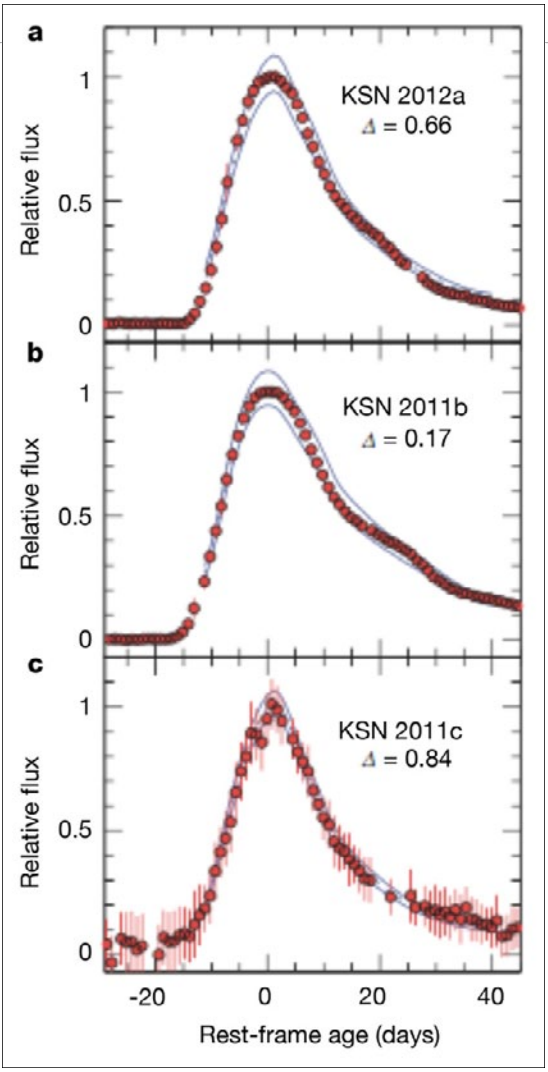


Figure 10.
Light curves of three of the doubly-degenerate SNe Ia, from the Kepler satellite (filled points and error bars), compared with models (blue lines).

April 2015

Clarity and Change in an Explosive Stellar Outflow

The outflow that emerges from the Orion Molecular Cloud 1 (OMC1) offers a rare opportunity to observe a catastrophic episode in a massive star-forming region. The outflow's large scale, and the common dynamical age of its many high-velocity knots (in the region known as the "Orion Fingers"), point to an explosive origin. Observations using the Gemini Multi-conjugate adaptive optics System (GeMS), and the Gemini South Adaptive Optics Imager (GSAOI), have provided the sharpest views ever obtained of the large region, nearly reaching the diffraction limit with a resolution of 0.08 to 0.1 arcsecond.

The narrow-band images show [Fe II] emission at the fingertips, where the material is ionized and excited at the leading shock fronts (Figure 11). Additional shocks excite molecular hydrogen in the wakes of the trailing regions. John Bally (University of Colorado) and collaborators directly measure the motion of specific fingers in the outflow and their morphological changes. They also compare the current data with earlier observations, especially those ob-

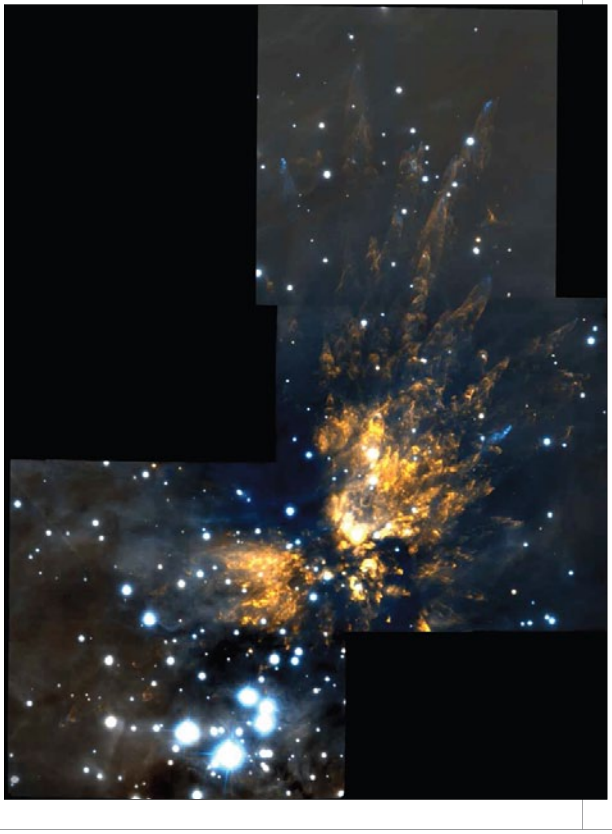


Figure 11.
The outflow of the "Orion Fingers" is evident in this high-resolution image. The leading fingertips appear in [Fe II] (cyan), and the trailing fingers are evident in molecular hydrogen emission (orange). Comparison with earlier observations shows the motion and morphological changes of the emitting knots.

tained using adaptive optics (Altair/NIRI) at Gemini North. They find proper motions up to 300 kilometers per second (km/s).

Survival of these knots requires that they have densities much larger (factors of 10^3 or greater) than the ambient medium through which they propagate. Numerical simulations reproduce the overall structure and kinematics of a moving knot. The authors suggest that stellar merger events could produce such outflows, while ejecting massive stars from their birthplaces

Additional images are posted at the ***Gemini website***. Full results appear in *Astronomy and Astrophysics*, volume 579, page 130.

A New Low-luminosity Cluster in the Outskirts of the Milky Way

New discoveries and detailed measurement of the stellar populations in the outer reaches of the Milky Way reveal the history of our Galaxy. Dongwon Kim (Australian National University) and collaborators contribute to our understanding by reporting on the discovery of a faint, low-density stellar cluster in the constellation Indus. Called Kim 2, the cluster, located in the outer Milky Way halo, is 10 times more distant than typical globular clusters and shows signs of having lost significant mass.

The lower luminosity ($M_V \sim -1.5$) and higher metallicity ([Fe/H] ~ –1.0) compared with typical Milky Way globular clusters suggest that Kim 2 was previously located in a dwarf Milky Way satellite galaxy and only recently accreted into the halo of our Galaxy. These characteristics are similar to other clusters associated with the Milky Way's dwarf satellites and tidal streams. In addition, as a low-mass cluster, the relaxation time (~1.1 billion years (Gyr)) is much shorter than its age (~11.5 Gyr), providing sufficient time for dynamical mass segregation, which is observed.

The cluster was discovered as part of the Stromlo Milky Way Satellite Survey, using the Dark Energy Camera (DECam) at the Cerro Tololo Inter-American Observatory. This work surveys large areas of the sky and uses processing algorithms to search preferentially for old and metal-poor overdensities. Director's Discretionary Time using the Gemini Multi-Object Spectrograph (GMOS) on Gemini South rapidly enabled deep follow-up observations to yield a significant color-magnitude diagram of the cluster. The main sequence is well defined to magnitude 26.5 (Figure 12), containing candidate subgiant and main sequence turnoff members, but no clear subgiant or red giant branches.

Full results are posted in a ***preprint*** and will be published in *The Astrophysical Journal*. A Gemini press release is also ***available***.

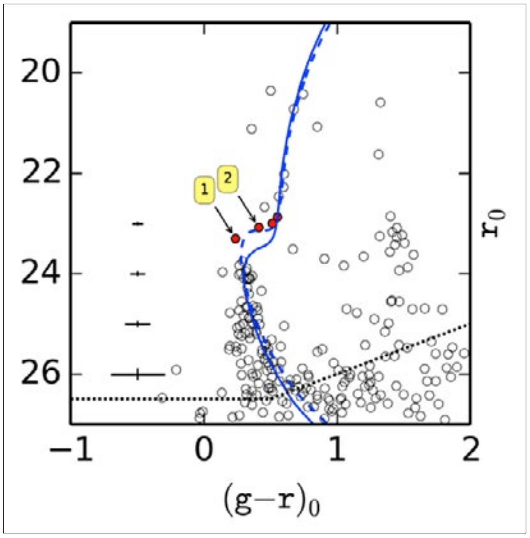


Figure 12. *Color-magnitude diagram of all stars within 1.3 arcminutes of the Kim 2 cluster center, from GMOS-S observations. The main sequence is well-defined, and the two best-fitting isochrones are overplotted (blue lines). Filled red circles mark candidate subgiant and main sequence turnoff members, and those labeled 1 and 2 are also located near the cluster center.*

An Extremely Massive Black Hole in an Extremely Distant Quasar

Infrared observations with the Gemini North telescope have confirmed a 12 billion solar mass black hole in an exceptionally bright quasar in the very early universe. The team used Gemini, as well as telescopes from around the world, to discover and characterize this extremely massive black hole at redshift $z = 6.3$, only about 875 million years after the Big Bang.

This result requires extremely rapid growth of the black hole. While black holes of comparable mass have been observed — after they have had billions of years to gradually gain mass over cosmic history — this quasar challenges astronomers to determine how such a huge object could exist so early in the history of the Universe. Mass accretion at the Eddington limit, over most of cosmic time, is required to reach the large mass at this early epoch.

Color selection in optical and infrared imaging surveys identified the target as a candidate high-redshift quasar, which the team, led by Xue-Bing Wu (Peking University, China), followed with multi-wavelength spectroscopic observations. The near-infrared observations from both the Gemini Near-Infrared Spectrograph (GNIRS) on Gemini North, and the Magellan Telescope, show the emission of ionized magnesium (Mg II), which was used to estimate the black hole mass from scaling relationships applicable to quasars (Figure 13). In addition to standing out for its extreme black hole mass, this quasar, SDSS J010013.02 + 280225.8, is exceptionally luminous, having a bolometric luminosity greater than 10^{48} ergs per second; it is in fact the most luminous one known at $z > 6$. This work is published in *Nature* (**Vol. 518, p 512**).

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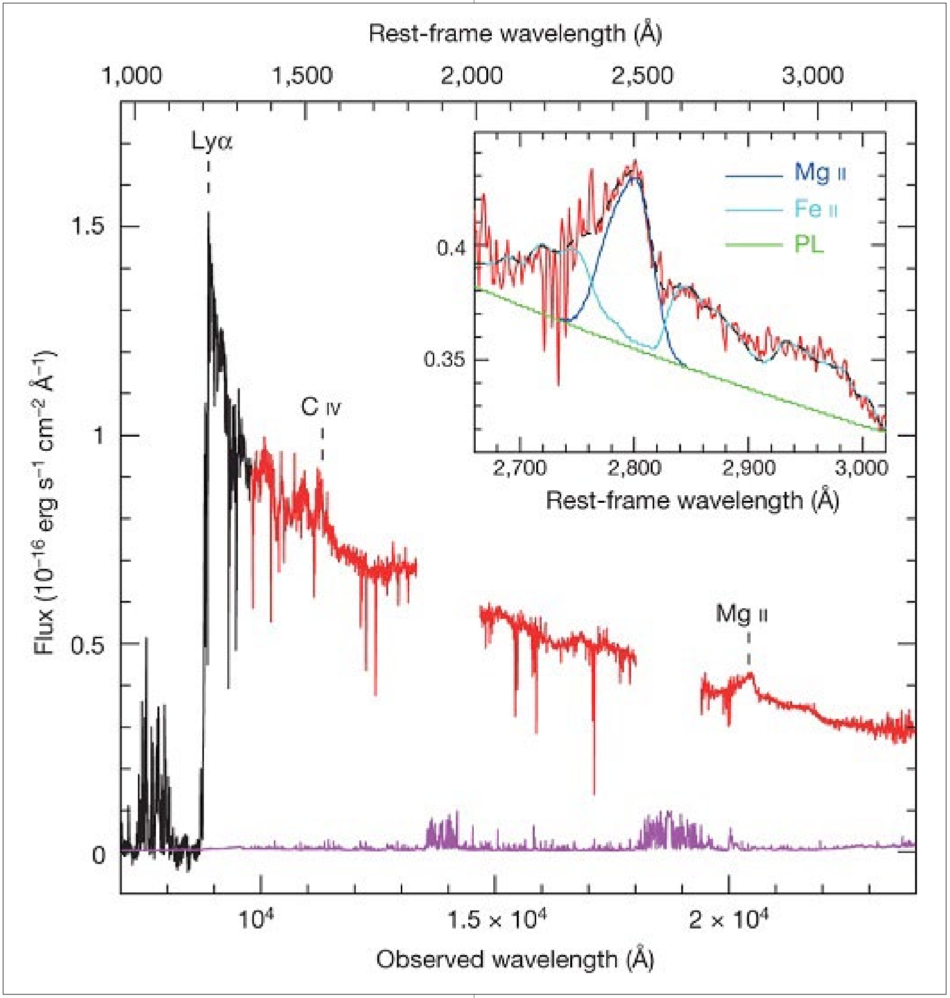

Figure 13.
The spectrum of quasar SDSS J010013.02 + 280225.8, obtained using the Gemini Near-Infrared Spectrograph combined with observations from the Magellan Telescope, appears in red; gaps are regions of low sky transparency. The optical spectrum (from the Large Binocular Telescope; black) and noise (magenta) are also plotted. The inset shows the three components of the fit to a portion of the near-infrared emission. The ionized magnesium (Mg II; blue) emission is used to estimate the extremely large black hole mass of 12 billion times the mass of the Sun.
Figure credit: Nature.

Contributions by Gemini staff

On the Horizon

A summary of instrumentation and development initiatives and progress throughout the year — with a look to Gemini's future.

January 2016

Vendor Quotes Received for New Gemini South Laser

On October 2nd, the Association of Universities for Research in Astronomy issued a request for quotes (which were due in early December) for a new laser at Gemini South. The quotes are now in, and we intend to announce vendor selection in early 2016 — after approval by the National Science Foundation. The new laser will dramatically improve the reliability of the Gemini Multi-conjugate adaptive optics System (GeMS) at Gemini South. It should also allow us to reduce staff efforts in the daytime, prior to laser runs, and at nighttime, during laser runs.

Contract Signed for Natural Guide Star Sensor Upgrade

The Australian National University and the Association of Universities for Research in Astronomy have signed a contract for the Natural Guide Star New Generation Sensor (NGS^2) and begun its design and construction; we expect delivery in 2016. The NGS^2 upgrade will allow the Gemini Multi-conjugate adaptive optics System (GeMS) at Gemini South to utilize guide stars four times (1.5 magnitudes) fainter than the current system.

Figure 1 shows the percentage of sky coverage versus Galactic latitude after the NGS^2 upgrade (blue lines) compared to the current system (red lines) for 1, 2, and 3 guide stars (dotted, dashed, and solid lines, respectively). On average, the upgrade will increase sky coverage by about 2.5 times at the Galactic poles and to about 80% in the single guide star case for targets within 50° of the Galactic plane.

GHOST News

During the first week of December, the Gemini High-resolution Optical Spectrograph (GHOST) team completed the first of a two-part project milestone: the Critical Design Review. The design team — led by the Australian Astronomical Observatory (AAO) and partnered with both Canada's National Resource Council-Herzberg (NRC-H) and the Australian National University — expect to complete the Critical Design Stage with the second part of this project milestone in early March 2016.

In order to reach this milestone, the GHOST project has continued to move forward in 2016, despite a couple of setbacks:

First, we lost NRC-H's project manager, a key player who moved on to another opportunity outside the organization. The existing NRC-H team has since absorbed his responsibilities, with some additional help from within their department.

Second, in mid-2015, the AAO experienced trouble securing an acceptable optical fiber from its vendors — until one of them finally delivered a usable fiber. With the fiber delivered, construction of the prototype fiber assembly is underway. We still believe that it is possible to manufacture a better fiber, so AAO is continuing to work with the vendor to optimize the product. While this prototype fiber assembly is not on the project's critical path, it remains a high-risk design item until completed and tested.

During the December 2015 Critical Design Review, an external committee and the Gemini GHOST internal team reviewed the spectrograph optics and system software and completed designs for the Cassegrain unit, fiber assembly, and slit-viewing assembly. Early in March 2016 a second review will cover the spectrograph's optomechanical design and electronics, as well as the thermal enclosure design and anything else that still needs addressing from the first review.

In other news, NRC-H expects the imminent arrival of GHOST's first engineering grade CCD detectors that were ordered in the first quarter of 2015. This CCD will be characterized and integrated in preparation for the arrival of the science grade detectors in third quarter 2016.

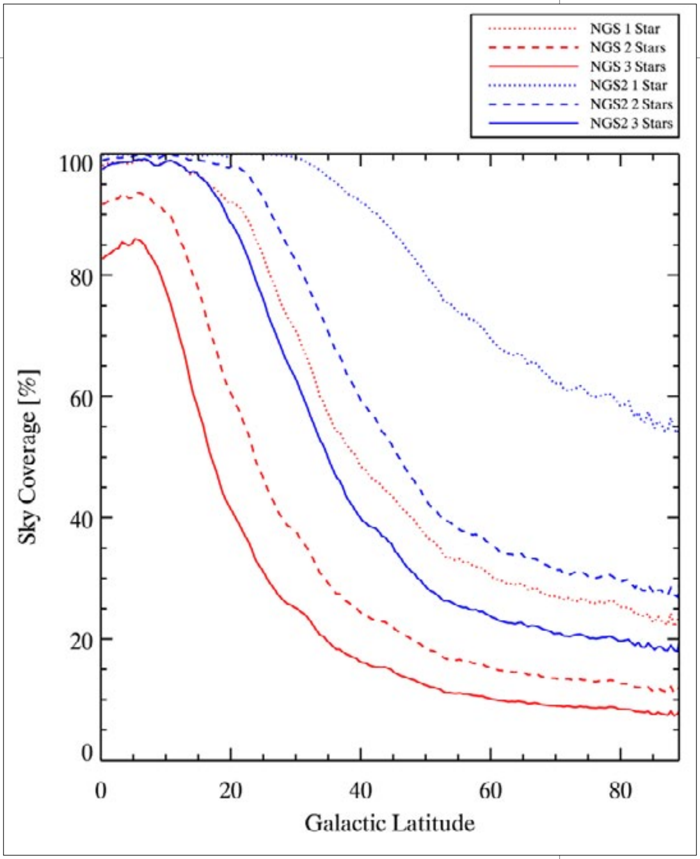

Figure 1.
Sky coverage vs. Galactic Latitude with NGS^2 on Gemini South.

Adding to this progress, the Gemini Board has recently endorsed the decision to locate GHOST at Gemini South, where preparations have begun to receive the instrument. We expect delivery near the end of 2017. After testing and commissioning, we plan to have GHOST ready for use by semester 2018B.

Gemini Instrument Feasibility Studies

In April 2015 Gemini funded a number of independent and non-competitive Gemini Instrument Feasibility Studies (GIFS). We designed these studies to help Gemini understand the science, technical requirements, and costs associated with creating the next Gemini instrument (Gen4#3) — while complying with a set of top-level Science and Technology Advisory Committee guiding principles.

GIFS resulted in four outstanding studies for Gemini: GEONIS, GMOX, MOVIES, and OCTOCAM. (A summary of these projects appear in the July 2015 news items below). Each represents a different view of what is possible for Gemini's next instruments. Howev-

Figure 2. *Presentation by Antonio de Ugarte Postigo on the OCTOCAM GIFS study during a review of all submitted Feasibility Study reports in late September 2015.*

er, the studies' outputs are not instrument design for build proposals; Gemini will use the GIFS studies to help inform the requirements that will go into the call for Gen4#3.

The community can now read the final reports and presentations from each ***team*** and provide comments and pose questions to: ***GIFSFeedback@gemini.edu***. Before completing the set of requirements for Gen4#3, Gemini will consider any comments received by December 22, 2016; we particularly welcome feedback on the science requirements, technical capability, and design aspects.

After January 22nd, Gemini will consider the community's input, along with recommendations from our advisory committees, to produce the Gen4#3 Request for Proposals (RfP). We are working towards a 2016 Q2 release of the RfP. Please visit the ***Gen4#3 home page*** for the latest information.

Instrument Upgrade — Small Projects Proposals

Gemini is committed to keeping our operational instrumentation competitive and to serving the needs of our user community. The Observatory also has a responsibility to provide major upgrades to the telescopes and their adaptive optics systems and associated instrumentation. To this end, in October we issued a request for the community to send us small-scale instrument upgrade proposals as part of our Instrument Upgrade Program.

With a total budget of $200,000, we were looking for compelling proposals requesting up to the whole budget, as well as those asking for minimal, or even no funding from Gemini. Each selected project will receive up to one night (10 hours) of observing time to be used for demonstrating the scientific potential of the upgraded instrument.

At the time of writing, we have received letters of intent and are excitedly anticipating receiving proposals by the December 17th deadline. We expect to quickly evaluate proposals and begin one or more instrument upgrade projects in 2016 Q1. For further announcements visit ***this site.***

October 2015

GMOS-South New CCDs: Performing Entirely to Specification

Soon after the commissioning of the new Hamamatsu CCDs in the Gemini Multi-Object Spectrograph at Gemini South (GMOS-S) in August 2014, we noticed that when observing in any of the binned readout modes, saturated pixels produced a decrease of counts with respect to the bias level in neighboring pixels. This effect, known as "banding," spanned the entire width of the amplifier, and while it did not destroy information, it rendered data reduction very cumbersome. Making matters worse was the saturation of a bad column on amplifier number 5 (on CCD2, the middle one in the focal plane) that affected the entire amplifier.

When a team of Gemini instrument scientists and engineers investigated the issue, they identified the root cause of the problem as the Astrophysical Research Cameras (ARC) controller video boards. Representatives from ARC suggested that we try a new revision of the video boards they now had

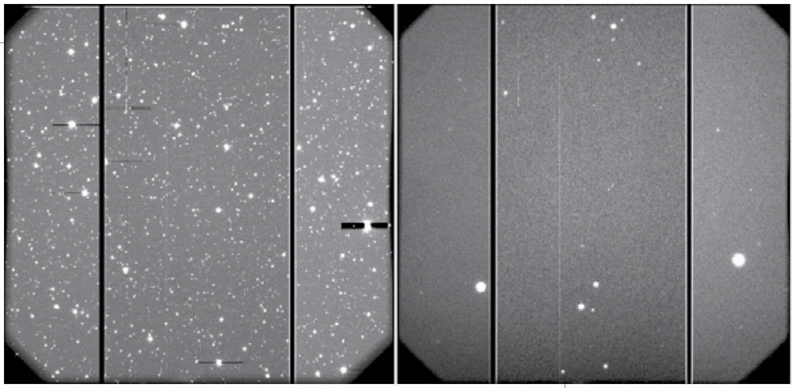

Figure 3.
Before (left) and after (right) data from GMOS-S showing the banding present before the fix (left) and a different field with bright stars after the fix (right) with no banding present.

available. After significant lab testing, we verified that these boards would solve the problem, but required that we modify our software to be compatible with them. As of August 25th, we have fully installed and integrated these new boards and eliminated the banding effect.

The screenshots shown here (Figure 3) present examples of standard star fields with bright stars using 2 x 2 binning before and after the board replacement. In the left image, the banding effect is visible as dark lanes on the saturated stars. In the right image, taken after the fix, the effect is completely eliminated and saturated stars do not produce the dark lanes.

Since the controller has changed, we are now re-characterizing the entire detector system, including re-measuring gains, read noise, and full well for all modes. Meanwhile, GMOS-S has resumed normal operation. We found the primary science mode read noise to be unchanged at ~ 4e^{-}. A nice additional benefit of this upgrade is that the full well increased by ~10% with respect to the previous value.

A second problem involving a charge transfer smearing effect, most noticeable during long nod and shuffle sequences, has gone away on its own. We have made several efforts to reproduce the problem, but the effects have remained elusive, so we continue to monitor. However, the bottom-line result is that the Hamamatsu CCDs in GMOS-S are now operating at full capacity and are ready to deliver high-quality data to our users.

Having learned from these experiences, we are building the GMOS-North Hamamatsu CCD system with the new video controller boards to avoid the banding problem entirely.

July 2015

GRACES: More Efficient than Ever

The Gemini Remote Access to CFHT's ESPaDOnS Spectrograph (GRACES) began its first scheduled observing runs in 2015B. (See page 58 for a more complete overview of the GRACES story.) The team made several improvements that make GRACES both more efficient and easier to operate. To improve efficiency, the team recoated some key optics and redesigned one element that was vignetting the optical path). As a result, GRACES's efficiency is improved by an average of roughly 20% towards the red part of the spectrum (see Figures 4 and 5).

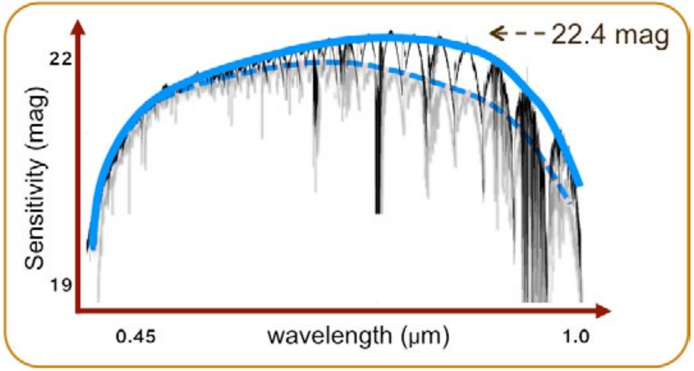

Figure 4.
Comparison of the GRACES sensitivity as measured for the 2-fiber spectroscopic mode in May 2014 (dashed line) and in June 2015 (solid line). The sensitivity is defined as the magnitude of an object that would provide a signal-to-noise ratio of 1 after an hour of integration time. This figure illustrates GRACES performances improvements in the red part of the spectrum.

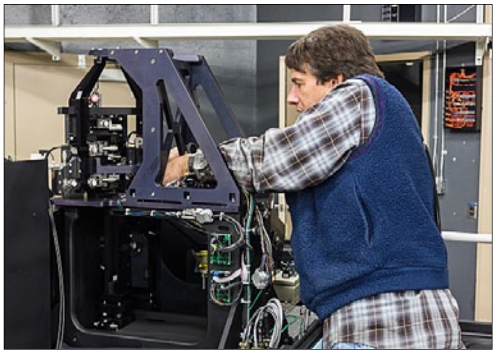

Figure 5.
Greg Barrick (Canada-France-Hawaii Telescope) installing the GRACES receiver module in the ESPaDOnS spectrograph, incorporating some of the recently improved optics.

Meet the Four Gemini Instrument Feasibility Studies

In April 2015, Gemini launched four independent instrument feasibility studies to help determine requirements for the next new Gemini instrument (also known as Generation 4#3, or Gen4#3) after GHOST. Each team's study provides Gemini with a collection of science cases, top-level science and instrument requirements, and corresponding feasible instrument designs.

The team's efforts were guided by a set of principles provided by the Science and Technology Advisory Committee (STAC) ***[viewable here]*** that describe very high-level requirements for the Gen4#3 instrument. Now completed, the four studies will aid Gemini in creating the requirements for Gen4#3. We expect to release a Request for Proposals to design and build the instrument in the first half of 2016.

Each of the four feasibility study teams presented their ideas and work in progress at the Toronto 2015 Future & Science of Gemini Observatory meeting. The meeting also allowed each team to interact with many Gemini users and included a panel discussion that reflected on the coming needs for Gemini's next new instrument.

Summaries of the four team instrument studies follow:

GEONIS

The Gemini Efficient Optical and Near-infrared Imager and Spectrograph (GEONIS) instrument concept is an efficient two-channel spectrograph and imager with wavelength coverage spanning 0.4 to 1.6 microns (μm). It is designed from the ground up as an observing system that uses new detectors, atmospheric dispersion correction, and a slit-viewing camera to maximize science collecting time and minimize overhead.

The astronomical landscape in the coming decade will be dominated by wide-field synoptic surveys, and GEONIS is driven to both classify and study transient events over a wide wavelength range in a single exposure. It also has broad reach across a variety of observational disciplines — from characterizing transiting exoplanets to pinning down the location of near-Earth asteroids, high redshift galaxies, and stars of unusual metallicity.

The study is being led by Nick Konidaris and managed by Dan Reiley, both at the California Institute of Technology. Main collaborators include astronomers at the University of Colorado Boulder, Penn State University, University of Toronto, the Jet Propulsion Laboratory, and the U.S. National Optical Astronomy Observatory.

For more information on the GEONIS study, please contact:
Nick Konidaris (PI): *npk@astro.caltech.edu*
Dan Reiley (PM): *djr@astro.caltech.edu*

MOVIES

The Montreal-Ohio-VIctoria Echelle Spectrograph (MOVIES) instrument concept is a broad bandwidth, moderate resolution (R ~3 K – 10 K) dual arm optical and near-infrared (NIR) Echelle spectrograph that simultaneously covers at least 0.40 – 2.40 μm. It is supported by a rapid acquisition camera operating simultaneously in the optical and near-infrared. Key additional features include rapid target acquisition, high stability, and a multi-band acquisition and guiding system. (See Figure 6.)

The primary science motivation for MOVIES includes spectroscopic follow up of the transient phenomena uncovered by facilities like the Large Synoptic Survey Telescope. Additional science drivers include studying the composition of stars and extrasolar planets and planetesimals.

The study is being led by Alan McConnachie and managed by Les Saddlemyer, both at the National Research Council of Canada Herzberg. Main institutional collaborators include Ohio State University and the Université de Montréal.

For more information on the MOVIES study, please contact:
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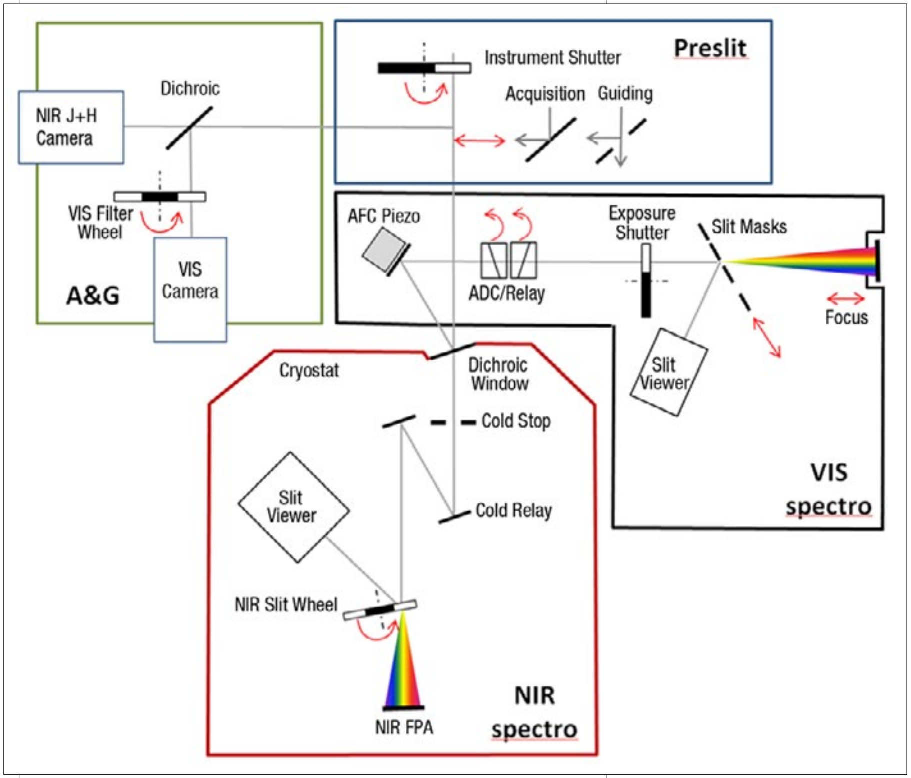


Figure 6.
Schematic of the MOVIES instrument layout.

GMOX

The Gemini Multi-Object eXtra-wide-band spectrograph (GMOX) instrument concept is a wide-band (R ~ 5,000) spectrograph covering the entire optical/near-infrared spectrum accessible from the ground — from the U-band to K-band (0.32 – 2.4 μm) via five spectroscopic arms (Figure 7). Using existing micro-electromechanical systems technology, GMOX plans to exploit the exceptional image quality of the Gemini Multi-conjugate adaptive optics System (GeMS).

Prime GMOX science drivers include probing the high redshift universe from $6 < z < 10$ through deep spectroscopy of lensed galaxies and the re-ionization epoch. With its large observable wavelength range and capability of operating in crowded fields, GMOX can also study ultraviolet/optical spectral features in a variety of regions, ranging from star formation at redshifts $1 < z < 3$ to stellar clusters in the Milky Way.

The study is being led by Massimo Robberto (Space Telescope Science Institute; STScI) and managed by Stephen Smee (Johns Hopkins University). Main institutional collaborators include the STScI and the Rochester Institute of Technology.

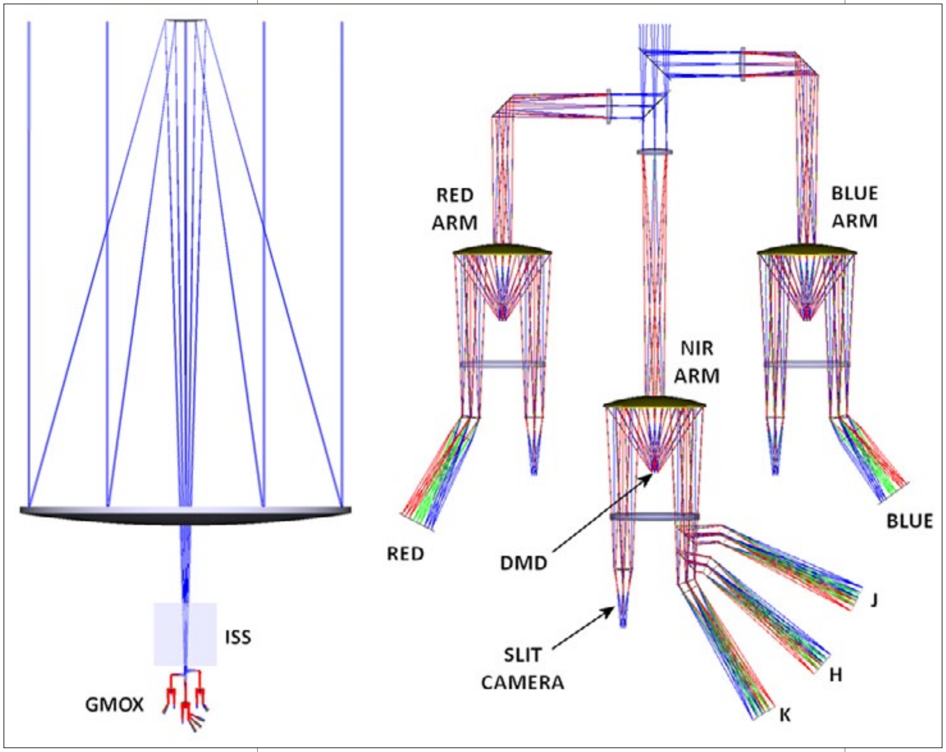


Figure 7.
Optical layouts of a preliminary concept for GMOX. (a) GMOX on Gemini, shown beneath an ISS-sized cube for scale. (b) Schematic of a 3-arm arrangement for GMOX.

For more information on the GMOX study, please contact:
Massimo Robberto (PI): *robberto@stsci.edu*
Stephen Smee (PM): *Smee@idg.jhu.edu*

OCTOCAM

The (OCTOCAM) instrument concept is an 8-arm, multi-band imager and spectrograph, covering 0.37 - 2.35 µm with R~3,000-4,000 and high time-resolution capabilities (Figure 8). The team will also study the potential science cases opened by including an additional integral field unit and a spectro-polarimetric mode in the instrument design.

OCTOCAM's key science driver is the study of astronomical transients. Subsecond time resolution observations could allow the identification and characterization of extra-solar planets and their atmospheres through transits, the study of the internal structures of stars through asteroseismology, the study of the Solar System's history through trans-Neptunian object occultations, massive stellar explosions and outbursts, supermassive black hole environments, and the physical properties of jets.

The study is being led by Antonio de Ugarte Postigo (Instituto de Astrofisica de Andalucia; IAA-CSIC) and managed by Pete Roming (Southwest Research Institute) and Christina Thöne (IAA-CSIC). The project is being coordinated from the IAA-CSIC, with main institutional collaborators at the Southwest Research Institute, Fractal SLNE, and George Washington University.

For more information on the OCTOCAM study, please contact:
Antonio de Ugarte (PI): *deugarte@iaa.es*
Pete Roming (PM): *proming@swri.edu*
Christina Thöne (PM, Spain): *cthoene@iaa.es*

See page 31 for the most recent updates on GIFS progress in 2015.

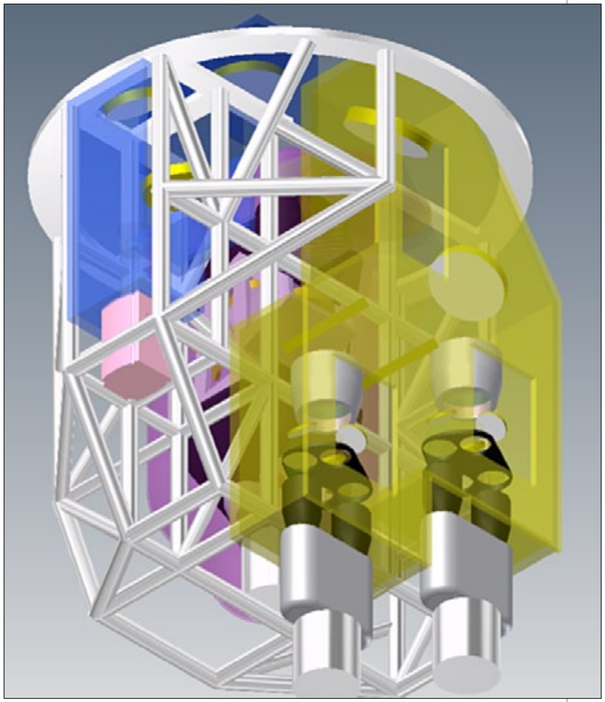


Figure 8.
A 3D view of the OCTOCAM concept.

Contributions by Gemini staff

News for Users

A summary of news of relevance to Gemini's users during 2015.

January 2016

Operating Gemini North from the Base

Gemini North is now operating every night from the base facility on North A'ohoku Place in Hilo. We've been working for more than a year to make this possible, developing and implementing new monitoring and control capabilities; gradually we confined the night staff to the summit control room, to gain confidence that we hadn't missed anything before relocating to sea level.

Once we had cameras and microphones up and running on the observing floor, and a reliability upgrade to the mirror covers, we removed the need for night staff to be in the dome; we could now open or close the dome or telescope mirror covers remotely. As evaluating weather was the most challenging task for the night staff, we installed additional weather sensors outside the building to monitor sky conditions, precipitation, and summit-level fog (Figures 1 and 2). Software enhancements ensure that the dome will close automatically should the network link from Hilo go down while the dome is open, and we then encounter precipitation. In November, we started trial operations from the base (Figure 3), with the help of members of the day crew who stayed late in case of problems at startup. After a month of trials, which resulted in a lot of useful feedback, we were ready to "fly solo."

Figure 1 (top). *Image from the west-pointing cloudcam, showing a moonlit UKIRT and a nice meteor in the background. Cloudcams are used as part of the Base Facility Operations at Gemini North.*

Figure 2 (bottom). *Not what you want to see. This image from the north-facing cloudcam, on a night in mid-November, shows the Keck and IRTF domes in the foreground, with approaching cirrus in the background.*

Figures 3.
Gemini staff operating Gemini North from Hilo.

From here on, if you come observing at Gemini North (*e.g.*, for a Classical or Priority Visitor run), you can expect more air to breathe than you would have if observing at the summit.

We're now working on the plan to repeat this operation at Gemini South. In the interests of efficiency, we'll "copy and paste" as much as possible from what we did in the north. However, as this remains one of the single biggest projects ever undertaken at Gemini South, we don't expect to relocate to its base facility in La Serena until late in 2016. See the article on Base Facility Operations starting on page 54.

GeMS Laser and the September Earthquake

The large earthquake that hit Cerro Pachón in September 2015 put the complex GeMS "sodium" laser totally out of alignment (see news item below under October 2015); the quake also caused us to lose the first of three GeMS runs scheduled in Semester 2015B.

The GeMS laser works by generating two infrared laser beams at different wavelengths, mixing and amplifying these in a nonlinear crystal, and producing a signal at the sum of the two input frequencies. The resulting beam is then directed into beam-transfer optics for launch onto the sky. There are many delicate, micron-scale adjustments in this system, and a magnitude 8.4 earthquake within 100 kilometers of the telescope site was more than sufficient to take the laser's alignment back to "square one."

To fix the laser, we essentially had to start from scratch. We adopted a systematic approach, implementing some enhancements that will make for much quicker recovery, especially should we suffer a recurrence (which we all, of course, hope we will not). By late November it became clear that we would lose the second GeMS run; now we're certain that we will not be operating GeMS in January either. We're now focusing on protecting the February run. Hopefully a final concerted push will get us back to 30 Watts of light at the sodium wavelength with the steady performance that had been achieved before the earthquake.

Mirror Coatings North and South

Both Gemini telescopes were shut down for maintenance in September and October (North and South, respectively). At both sites, a variety of maintenance tasks were scheduled, with the biggest single task being the M1 (primary mirror) recoating at Gemini South (Figure 4), followed by the M2 (secondary mirror) at Gemini North. Numerous preparations, documentation revisions, and rehearsals were performed in anticipation of the Gemini South event, and the team safely and successfully completed this delicate and complex primary mirror coating process. Particular attention was given to a collaborative cross-training program with other AURA centers in Chile.

The beneficial effect of a fresh coating on M2 is clearly seen in the GMOS-N zero points shown in Figure 5. In Chile, the coating of the Gemini South primary mirror was a team effort, with staff from both Gemini sites, Cerro-Tololo-Inter-American Observatory and the

Southern Astrophysical Research (SOAR) telescope. The results were excellent.

Also in the south, we continued to modify the cooling arrangements for the top-end control computer; the warmer ambient temperatures on Cerro Pachón have caused problems with condensation on the cooling lines in the past, causing us to lose telescope time due to high humidity. The modifications are designed to increase the flow rate to the top end, thus enabling the temperature of the cooling water to be reduced. Despite the loss of summit access for three days due to a spate of bad weather, we got back on sky on schedule — a considerable achievement reflecting the planning and effort that the whole team puts into these shutdowns.

GMOS-S CCDs update

Work is complete on two major quality issues with the GMOS Hamamatsu CCDs at Gemini South (see a detailed review of progress on this issue starting on page 32). The "saturation effect," which produced banding artifacts on images with saturated pixels, was solved by a video board upgrade. Charge smearing effects, which we had also identified as an intermittent (and hard to reproduce) problem, were not convincingly identified; we could not pinpoint a particular cause in our investigation inside the detector cryostat, but the readout cable on the affected chip was replaced just in case. The smearing effect is now at a level so low that it will not affect any conceivable science observation. We have released an *update* to Gemini's Image Reduction and Analysis Faciity (IRAF) which is capable of handling data from the new video boards and includes significant improvements to the GMOS data reduction examples.

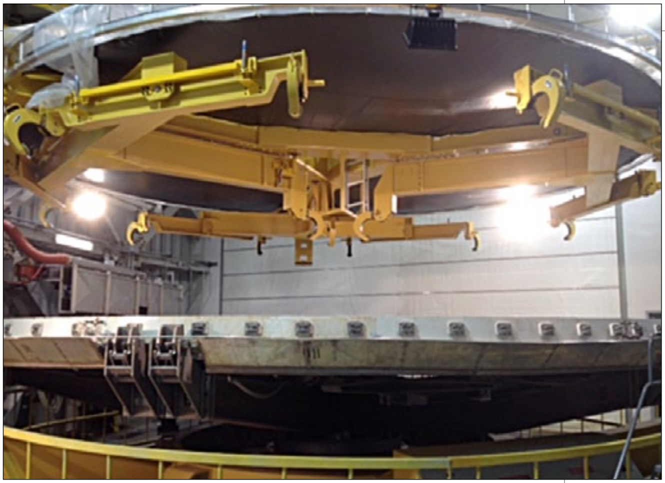


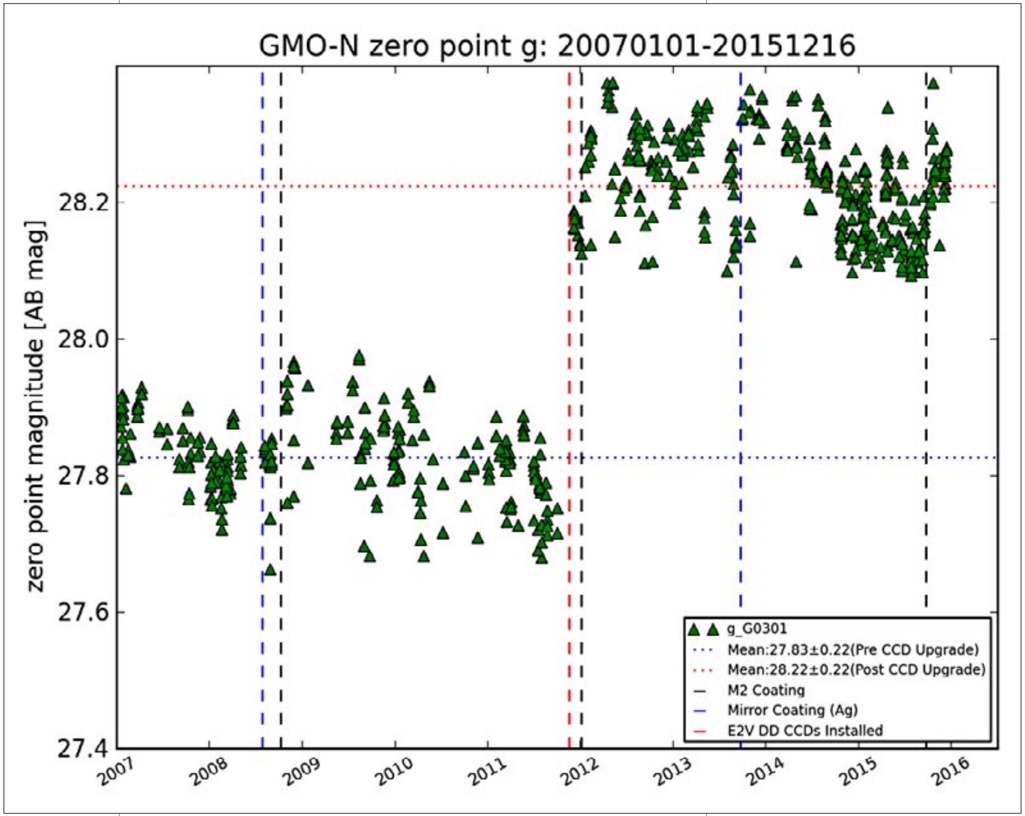
Figure 4.
Rehearsal for the Gemini South M1 recoating: Preparing to lift the dummy mirror.

Visiting Instruments

Gemini continues to welcome visiting instruments. After an absence of a few years, Phoenix (high-resolution near-infrared spectrograph) returns to Gemini South in 2016A. Also in the south, we will host a first run for the dual-band Differential Speckle Survey Instrument (DSSI). Watch the Call for Proposals pages for these and future opportunities.

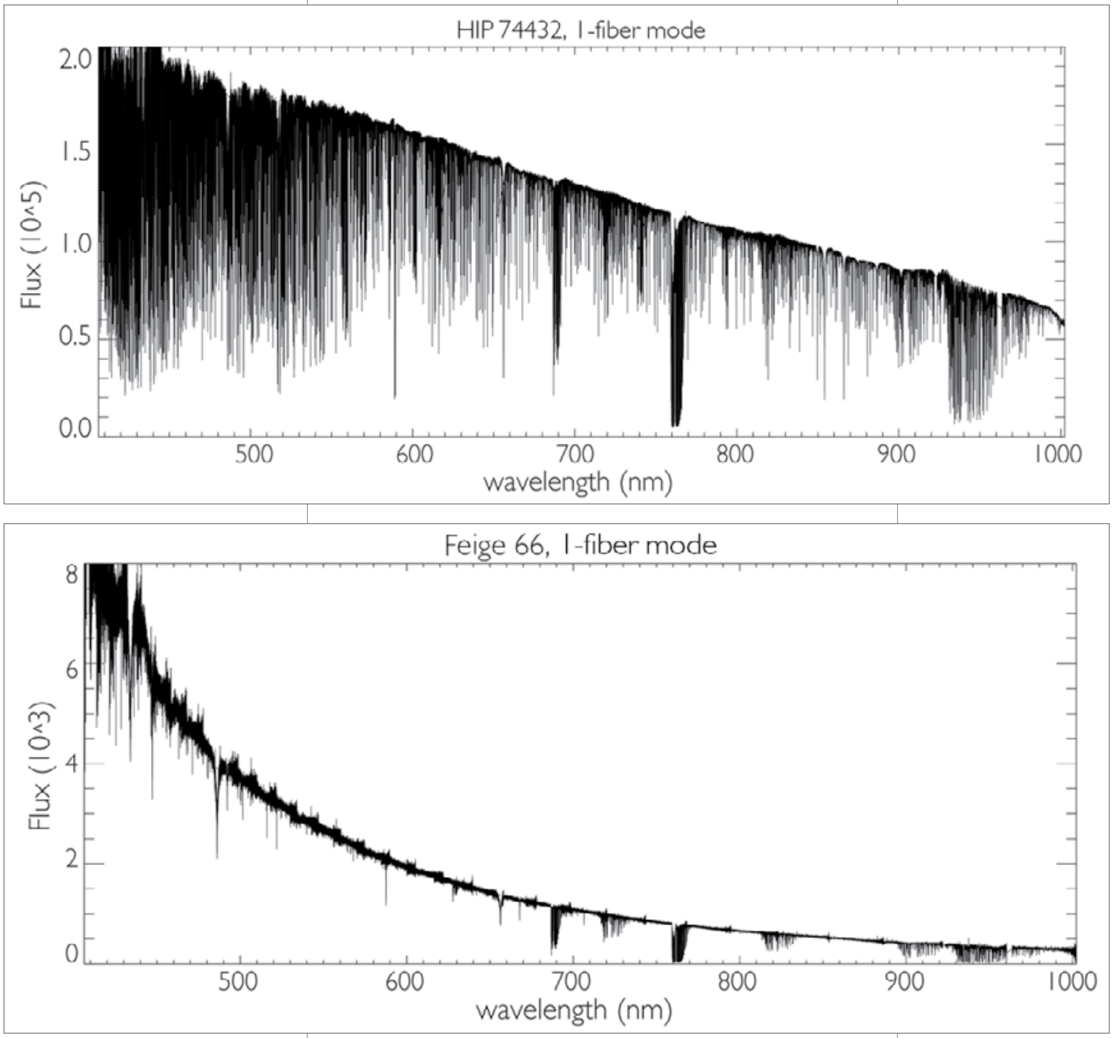
You may also have noticed that GRACES, our high-resolution spectroscopy capability realized by sharing CFHT's ESPaDOnS Spec-

Figure 5.
GMOS-N g band zero point as a function of time. The various mirror coatings and CCD installations are marked with vertical dotted lines. Far right is the recent uptick due to the recoating of M2.



trograph, is now listed with the other facility instruments on the web pages, where previously we listed it as a “visitor” instrument. In reality, GRACES is neither, but it has some of the properties of both. GRACES relies on a sharing agreement with CFHT, so we necessarily schedule it in a limited number of blocks per semester; we cannot fully integrate it into the queue as we do with facility instruments. In that respect, it is not dissimilar to instruments such as NIRI and NICI, which have relatively limited usage and are not always installed on the telescope.

The project which developed GRACES was not tasked to deliver a facility instrument, but to give us a reasonably sensitive high-resolution spectroscopy capability; we would then monitor its performance and usage for about a year before deciding whether it should become better integrated into the Observatory’s observing systems. We’re now in that latter stage wth GRACES, running the instrument for real and gauging demand and success.



Figures 6-7. *(upper): HIP 74432, a solar-analog star observed with GRACES in 1-fibre (object-only) mode. (lower) For comparison, Feige 66, an O-type spectrophotometric standard star observed in the same mode. Both spectra have resolving power in excess of 65,000.*

If you want to see how GRACES performs on a range of targets, refer to the ***sample data*** taken in the run-up to the 2015B semester. You can get preview images of the reduced spectra in Figures 6-7 and ***here***.

October 2015

Fast Turnaround Expanding to Gemini South

Active since early 2015 at Gemini North, Fast Turnaround (FT) observing has been a successful addition to the list of proposal modes supported by the Observatory (see feature article on page 50). Principal Investigators have taken their refereeing duties very seriously to date, and programs have generally achieved a good completion rate. Participants have also reported finding the process engaging and educational. We will soon extend the FT program to Gemini South. The first proposal deadline was scheduled for the end of October, for observations to begin in December 2015. All future proposals received will go into a common pool, and we don’t expect to enforce a particular split of allocations between the two telescopes; up to 20 hours of observing time will be awarded to FT programs on each telescope each month.

Yet More Weather

Both Gemini North and Gemini South were closed by midyear snow. In the north Central Pacific, Hawai'i was like the target in a shooting gallery, as hurricane season generated more than 10 named storms to date (Figure 8). Thankfully, there were no direct hits, but significant side effects included long periods of fog and precipitation at the summit, not to mention a fairly continual stream of flash flood warnings at sea level.

In August, Southern Hemisphere winter weather at Cerro Pachón deposited large amounts of snow and ice on the summit, forcing an evacuation; as a precaution, Gemini South switched to generator power that day. After several more days of bad weather, copious amounts of snow continued to accumulate on the access roads and the summit itself.

When the storms abated, hard work by AURA Shared Services cleared the roads and allowed observers and crew to get back to the telescope after a week (Figure 9). By that time, however, almost all of the observatory's fuel had been consumed; and without the possibility of getting a fuel truck to the site, there was no alternative but to completely shut-down all systems.

Excellent teamwork between the engineering groups allowed for a quick and safe switch off of all equipment. Last to be shut down was, of course, the generator, with just 10 hours of fuel remaining! In total, the observatory ran on generator power for over nine days, consuming almost 15,000 liters of diesel fuel. The following week, with assistance of the grader and motor digger, a fuel truck made it to the site, all systems were restarted, and normal operations resumed.

All in all, Gemini South was closed for more than two weeks, a rare occasion in recent times and not good for our observing statistics. However, the great amounts of snow melt water did a lot of good for the region, and despite some local damage, was gratefully received.

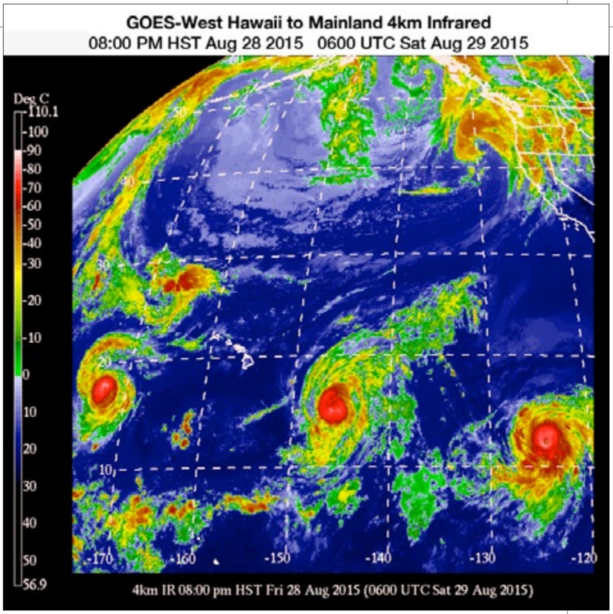


Figure 8.
Hurricanes Kilo, Ignacio and Jimena (left to right) in the Hawaiian environment, characteristic of the active Central Pacific hurricane season of 2015. Image from Maunakea Weather Center, obtained on August 29, 2015.

Figure 9.
Snow clearing after winter storm at Cerro Pachón.

Gemini South and the Chilean Earthquake

As you're probably aware, Gemini South was affected by the large (magnitude 8.4) earthquake which struck Chile on September 16th. At the time of the quake, Gemini South was closed due to sever weather (see news item above). Since systems were powered up, the secondary mirror system effectively acted as a seismometer. Figure 10 shows the secondary oscillations in response to the early arriving P waves, followed some 20 seconds later by the major shock of the main quake.

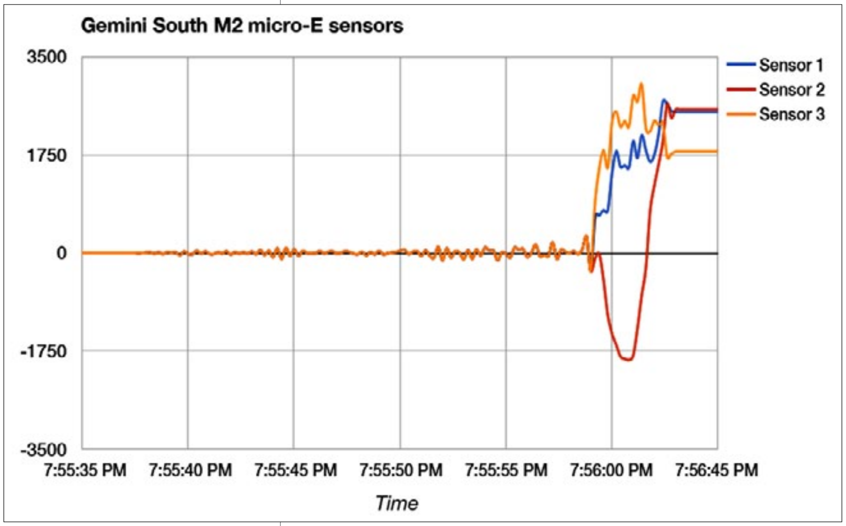


Figure 10.
Data from the Gemini South secondary mirror sensors at the time of the September 16th earthquake.

July 2015

Guarding Against Future Shutter Failures

As Gemini Observatory and its users are both painfully aware, Gemini North lost a large amount of time in 2013B and 2014A due to two dome shutter failures. Since those events, we have carried out internal engineering studies, which resulted in a redesign of parts of the shutter drive gearboxes, and have procured spares (Figure 11) to speed the recovery process from a future similar failure, should one occur.

Also, we have engaged an external contractor to carry out a completely independent study of the dome and its mechanisms, to ensure that nothing is missed. Request for Bids for this consulting work was released in the early part of 2015, and Dynamic Structures was awarded the consulting contract in March.

A Dynamic Structures team visited Maunakea in late April to review the shutter system enclosure. They also took metrology data on the arch girders and top shutter in various positions.

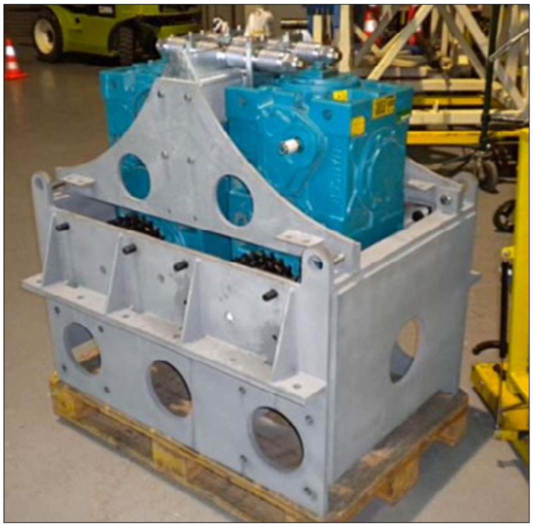


Figure 11 (above, right).
A fully assembled, spare shutter gearbox at Gemini North. Redesigned torque arms are at the top of the assembly.

Flamingos-2 Stand-down Successfully Completed

In March, Flamingos-2 was given a preventive maintenance stand-down, in which we fixed the gate valve baffle issue and installed a spectroscopic K-band filter. The gate valve baffle, stuck in place since late 2014, is now working well, returning the thermal radiation from the gate valve to nominal levels in spectroscopy mode (Figure 12).

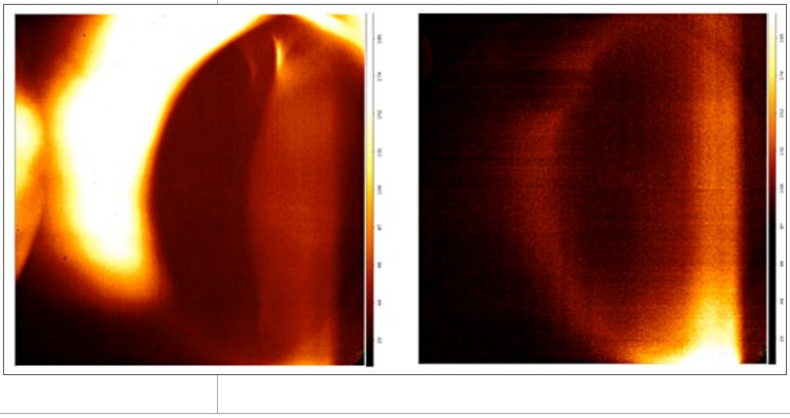
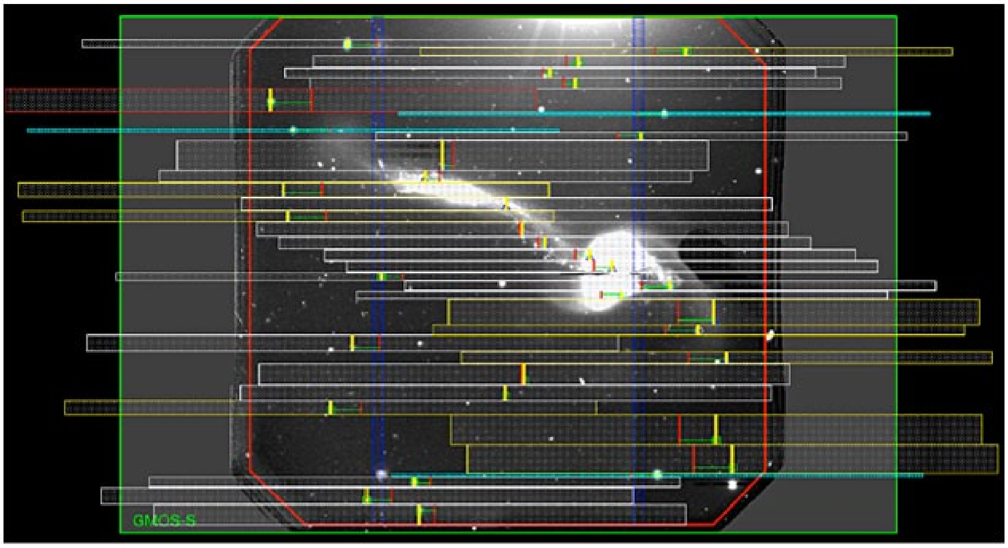
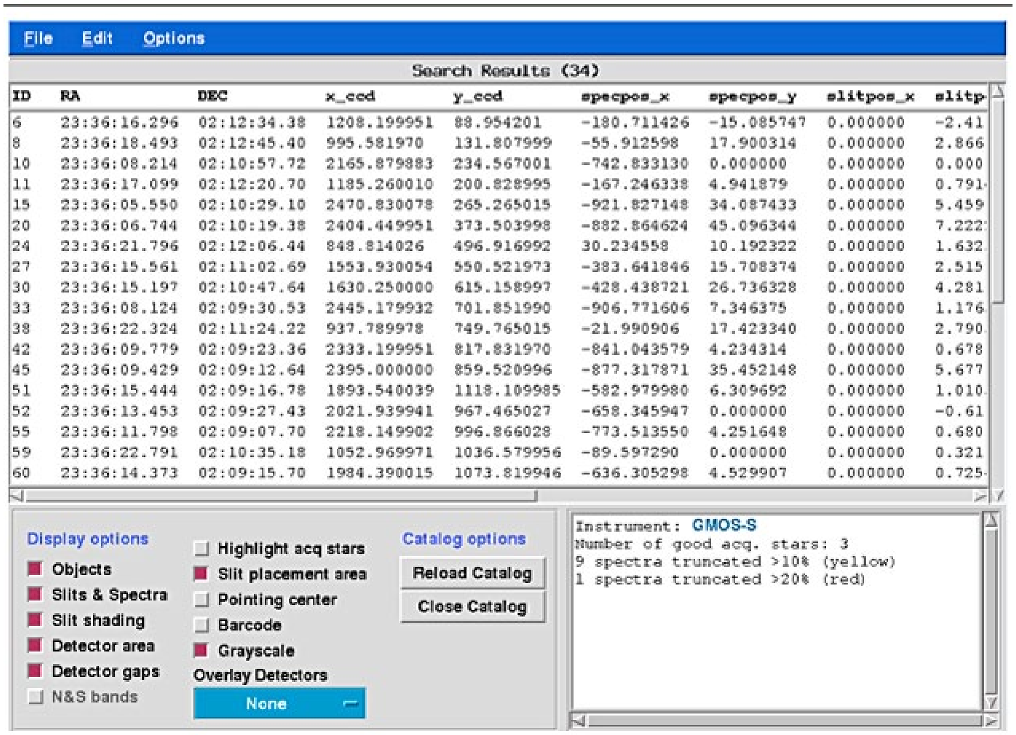


Figure 12.
"Before and After" images of Flamingos-2's thermal background in spectroscopy mode, with the baffle not correctly in place (left panel) and correctly in place (right panel).





Search Results (34)

ID	RA	DEC	x_ccd	y_ccd	specpos_x	specpos_y	slitpos_x	slitp
6	23:36:16.296	02:12:34.38	1208.199951	88.954201	-180.711426	-15.085747	0.000000	-2.41
8	23:36:18.493	02:12:45.40	995.581970	131.807999	-55.912598	17.900314	0.000000	2.866
10	23:36:08.214	02:10:57.72	2165.879883	234.567001	-742.833130	0.000000	0.000000	0.000
11	23:36:17.099	02:12:20.70	1185.260010	200.828995	-167.246338	4.941879	0.000000	0.791
15	23:36:05.550	02:10:29.10	2470.830078	265.265015	-921.827148	34.087433	0.000000	5.459
20	23:36:06.744	02:10:19.38	2404.449951	373.503998	-882.864624	45.096344	0.000000	7.222
24	23:36:21.796	02:12:06.44	848.814026	496.916992	30.234558	10.192322	0.000000	1.632
27	23:36:15.561	02:11:02.69	1553.930054	550.521973	-383.641846	15.708374	0.000000	2.515
30	23:36:15.197	02:10:47.64	1630.250000	615.158997	-428.438721	26.736328	0.000000	4.281
33	23:36:08.124	02:09:30.53	2445.179932	701.851990	-906.771606	7.346375	0.000000	1.176
38	23:36:22.324	02:11:24.22	937.789978	749.765015	-21.990906	17.423340	0.000000	2.790
42	23:36:09.779	02:09:23.36	2333.199951	817.831970	-841.043579	4.234314	0.000000	0.678
45	23:36:09.429	02:09:12.64	2395.000000	859.520996	-877.317871	35.452148	0.000000	5.677
51	23:36:15.444	02:09:16.78	1893.540039	1118.109985	-582.979980	6.309692	0.000000	1.010
52	23:36:13.453	02:09:27.43	2021.939941	967.465027	-658.345947	0.000000	0.000000	-0.61
55	23:36:11.798	02:09:07.70	2218.149902	996.866028	-773.513550	4.251648	0.000000	0.680
59	23:36:22.791	02:10:35.18	1052.969971	1036.579956	-89.597290	0.000000	0.000000	0.321
60	23:36:14.373	02:09:15.70	1984.390015	1073.819946	-636.305298	4.529907	0.000000	0.725

Display options

☑ Objects
☑ Slits & Spectra
☑ Slit shading
☑ Detector area
☑ Detector gaps
☐ N&S bands

☐ Highlight acq stars
☑ Slit placement area
☐ Pointing center
☐ Barcode
☑ Grayscale

Overlay Detectors: None

Catalog options

```
Instrument: GMOS-S
Number of good acq. stars: 3
9 spectra truncated >10% (yellow)
1 spectra truncated >20% (red)
```

Figures 13-14.

Top: A final mask design overlaid over a GMOS-S pre-image. The large green rectangle displays the detector area where spectra are recorded. The thick red polygon indicates the field-of-view within which slits (small yellow vertical bars) may be placed. The spectral footprints are shown as filled horizontal rectangles.

Bottom: The user interface that controls which elements are shown in the pre-image display. It also shows the number of valid acquisition stars and issues warnings if spectra are truncated by the finite detector geometry.

Mask-making Software Updated

Multi-Object Spectroscopy (MOS) is in high demand at both Gemini telescopes. Principal Investigators individually design the MOS masks for each science program using the Gemini Mask Making Preparation Software (GMMPS). Once checked, the physical masks are precisely cut using a laser milling machine in Chile (shared between Gemini, Cerro-Tololo International Observatory, and the Southern Observatory for Astrophysical Research).

After the installation of the new red-sensitive Hamamatsu CCDs in GMOS-S, which have different geometries and pixel scales compared to the detectors in GMOS-N, we recognized that the GMMPS source code had significant shortcomings that prevented its use for creating masks for both GMOS instruments. In a concerted effort, the code was recently made less instrument-dependent. This fix also paves the way for mask creation for the MOS mode of the near-infrared Flamingos-2 instrument, commissioning of which will begin this year. At the same time, all user interfaces were made more transparent and user friendly. A series of internal consistency checks minimizes the number of submitted faulty mask designs, and a comprehensive user manual is available. All in all, this amounts to a significant overhaul for GMMPS, making it a more effective and user-friendly tool for mask creation (Figures 13-14).

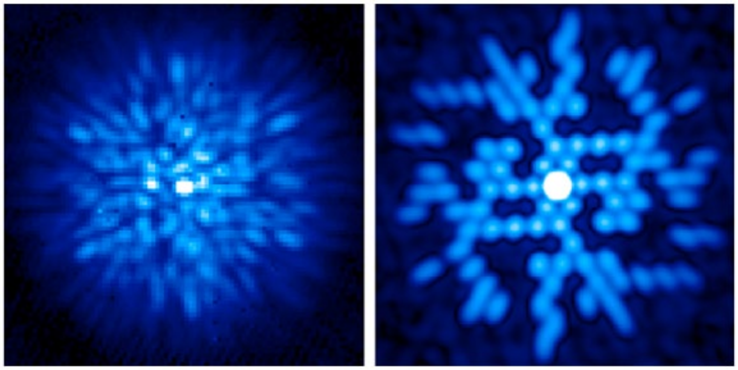


Figure 15. *GPI NRM "snowflakes" observed during the commissioning time in May 2015. Left: Raw data frame. Right: Power spectrum.*

Non-redundant Masking with GPI

Commissioning of the Gemini Planet Imager (GPI) Non-Redundant Mask (NRM) mode was scheduled for late March, and coincided with the horrendous flooding event described at right. Because of this, no data were taken. Since this mode was to produce some of the highest-contrast observations with GPI, we rescheduled a commissioning night in May. The team, led by Peter Tuthill and Alexandra Greenbaum, visited the telescope and obtained a night's worth of useful data, which they are now working to reduce.

Future users will need to become familiar with the "snowflake" patterns produced when the seeing is good and the NRM mask is in place; two samples of this effect appear in Figure 15.

For the technically inclined, the raw image taken through the mask can be thought of as an interferogram — a pattern formed from fringes containing high spatial resolution; these cross the Airy disk diffraction pattern caused by the individual circular holes. The power spectrum image shows fringe power at 45 individual baselines; these correspond to each pair of holes in the mask and reveal the surprising degree of inherent order in the image.

Data Center Re-engineering

Relatively unseen by the outside user, the summit data centers have been re-engineered over the past six months. The new data centers are split into hot and cold zones, producing significant energy savings. They also foster greater sustainability and cybersecurity.

Destructive Weather Event in Chile

Near the end of March, Chile suffered a freak storm that dumped many inches of rain on the high deserts and caused major flooding and destruction right down to the coast. Cerro Pachón was one of the affected areas. As a result, Gemini South lost power, communications, and nights of telescope time. Thanks to the quick and effective work by the engineering staff, the telescope was back on line very shortly after the storm passed.

Washing the Gemini South Primary Mirror

A few times annually, the Gemini South primary mirror is subjected to an *in situ* wash in which the mirror, left in place on the telescope, is cleansed with specialized detergents to remove dust particles. The latest wash occurred in April; we show a picture of the process here (Figure 16). An *in situ* wash requires that we very carefully seal the bottom end of the telescope so that the instruments, science fold mirror, *etc.* do not get wet.

If you're wondering whether we do this in Hawai'i also, the answer is no, and it's because of geology. The wind-blown dust on Cerro

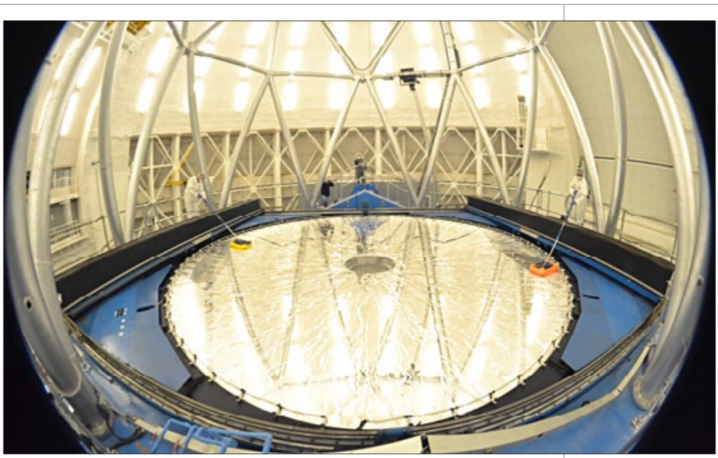


Figure 16.
Washing the Gemini South Primary Mirror in situ.

Pachón is granitic, while that on Maunakea is light basalt. Granitic dust on the Gemini South primary does not fully come off with CO_2 cleanings, whereas basaltic dust on the Gemini North primary does. Therefore, given only carbon dioxide cleaning, reflectivity of the Gemini South primary would decrease more quickly than Gemini North's.

April 2015

First Korean Time on Gemini

With Korea now Gemini's first limited-term partner, the Korea Astronomy and Space Science Institute (KASI) has taken on the job of coordinating the vetting of proposals from all over Korea and producing "miniqueues," which will be executed in pre-scheduled blocks of time on both Gemini North and Gemini South.

The Korean community showed great interest in observing at Gemini North and a total of seven Principal Investigators or Co-Investigators, plus three KASI staff, helped with implementation of the programs during an intense week carried out in Priority Visitor observing mode (see Figure 17). The science is varied — star clusters, active Galactic nuclei, galaxy clusters, high-redshift galaxies, *etc.* — but mostly of extragalactic nature. The Gemini Multi-Object Spectrographs (both North and South) dominated the proposal statistics.

Welcome, Korea, and we hope this relationship is long and fruitful. See page 22 in Science Highlights for Korea's first results as a limited Gemini partner.

Gemini IRAF Software Package Released

A new version of the Gemini Image Reduction and Analysis Facility (IRAF) software package (v1.13) for data reduction has been released (January 29, 2015) and is available. This full release supersedes the recent commissioning and patch releases.

Of special note, this latest release will support GMOS-S Hamamatsu data with quantum efficiency corrections, provide new and improved tasks in support of GMOS integral field unit data reduction, and offer better handling of variance and data quality planes throughout the GMOS package.

The new package is available for download on ***this web page***.

Figure 17.
The first Korean observing team at Gemini North, shown here while making observations in March.

April 2015

Gaetano Sivo, Vincent Garrel, Rodrigo Carrasco, Markus Hartung, Eduardo Marin,
Vanessa Montes, and Chad Trujillo

News in Adaptive Optics at Gemini South

Adaptive optics (AO) activities conducted at Gemini South have not only improved image quality but also resulted in some exciting science obtained with the Gemini Multi-conjugate adaptive optics System (GeMS) coupled with the Gemini South Adaptive Optics Imager. Future AO activities are expected to expand dramatically at Gemini South once the Natural Guide Star system for GeMS is upgraded and a more reliable laser is installed.

Adaptive optics systems rely on laser guide star wavefront sensors (LGSWFS) for high-order measurements of distortions to starlight caused by Earth's atmosphere. Of course precise alignment of the system is critical for optimal performance. During the winter (Southern Hemisphere) telescope shutdown of 2013, the AO group decided to realign the CCD and lenslets assembly of the LGSWFS; we had calculated that the system's collimator and lenslets were offset by 1.8 centimeters, which corresponds to a misconjugation of about 51 (km) on the sky.

A Puzzling Image Quality Issue with Canopus

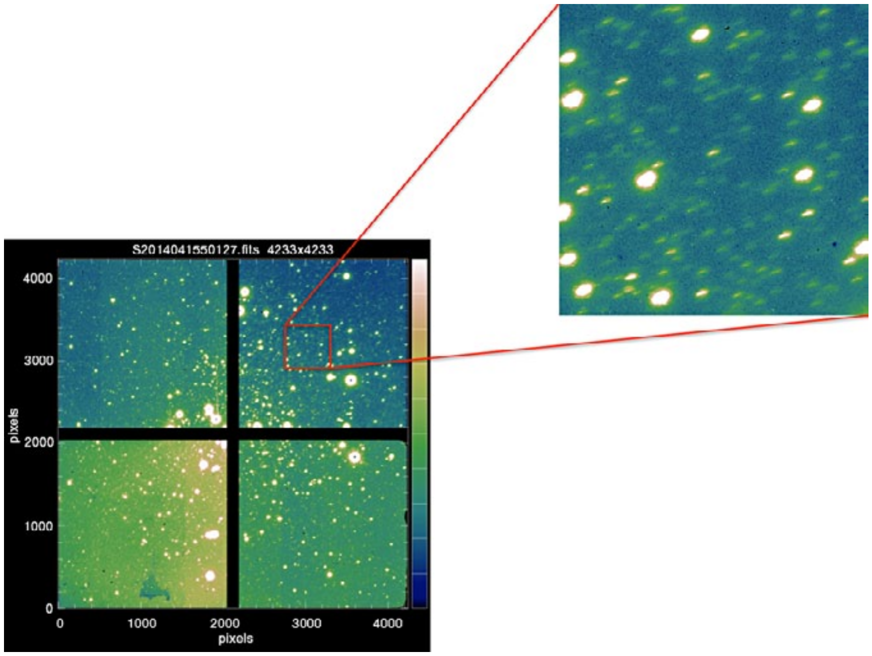
Post shutdown, the laser beacon showed a Rayleigh pattern on the LGSWFS that appeared physically impossible. This first led the AO team to believe that a pixel was swapped inside a quadcell subaperture used to center the laser beam to a certain spot. Even if this were the case, the reconfiguration of the WFS introduced unwanted side effects, so the AO team reverted very quickly to the original configuration, which required two additional days of work on the telescope.

In early 2014, during the first run of Semester 2014A, our team discovered that stars imaged with the Gemini South Adaptive Optics Imager (GSAOI) were elongated especially at the edges of the field, yielding poor performance (up to 250 milliarcseconds). One of the issues uncovered was an incorrect procedure used for saving Zernike coefficients (that control the figure of the Gemini South 8.1-meter primary mirror (M1)). Figure 1 illustrates the image elongation issue.

Once the M1 model was fixed, we still had a somewhat intermediary situation, where elongation was present, but to a lesser extent. After a few simple tests, we determined that the LGSWFS system was the problem, since running GeMS with only the Deformable Mirror (DM) conjugated to 0 km (DM0), used essentially in a ground layer adaptive optics mode, showed no signs of the elongation seen while running in a full MCAO mode with DM at an altitude of 9 km (DM9; Figure 2).

This indicated that we had something odd coming from the LGSWFS that was being offloaded to the DM when conjugated to an altitude of 9 km (DM9). During two further runs in 2014 (May and June), we acquired some science data using a software patch that removed a semi-static shape on the DM9. As several optical phenomena could cause this issue, the AO team decided to shutdown the GeMS system in concert with the general telescope shutdown and proceed with a more thorough investigation inside Canopus — the AO bench that is the heart of GeMS.

To maximize the effectiveness of this shutdown, we approached previous GeMS AO team members François Rigaut, Benoit Neichel, and Marcos van Dam, all of whom agreed to assist the current AO team in diagnosing and correcting the issue.



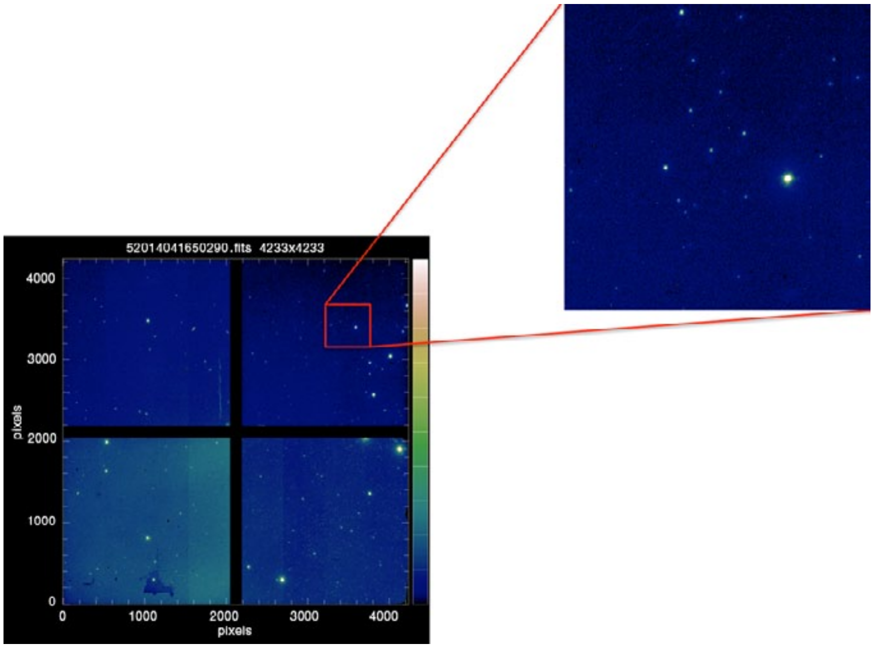


Figure 1 (Top). *Example of the elongation issue present on GeMS/GSAOI images.*

Figure 2 (Bottom). *GeMS/GSAOI image using a ground-layer adaptive optics reconstructor.*

Finding the Source, and a Solution, for the Elongation

During August 2014, we removed Canopus from the telescope and installed it in the instrument laboratory on Cerro Pachón. After several tests, we found that its five field stops were not properly aligned with the rest of the optical train, thus vignetting the beam. The vignetting pattern was different for each of the five WFS, which explained the unusual semi-static pattern on DM9.

The field stops are extremely difficult to reach, as they are enclosed in a mechanical set positioned between two lenses, a consequence of the compact design of the Canopus optical bench. Rather than adjust the field stops, the other option we identified was to realign the CCD behind each LGSWFS and the calibration source. Doing this, we realized, would restore alignment to the calibration source, the field stops, and the CCDs.

We proceeded with this option because (1) it was the least invasive, and (2) the LGSWFS CCDs were the easiest elements to move. We then remounted Canopus on the telescope and waited for the telescope shutdown to end.

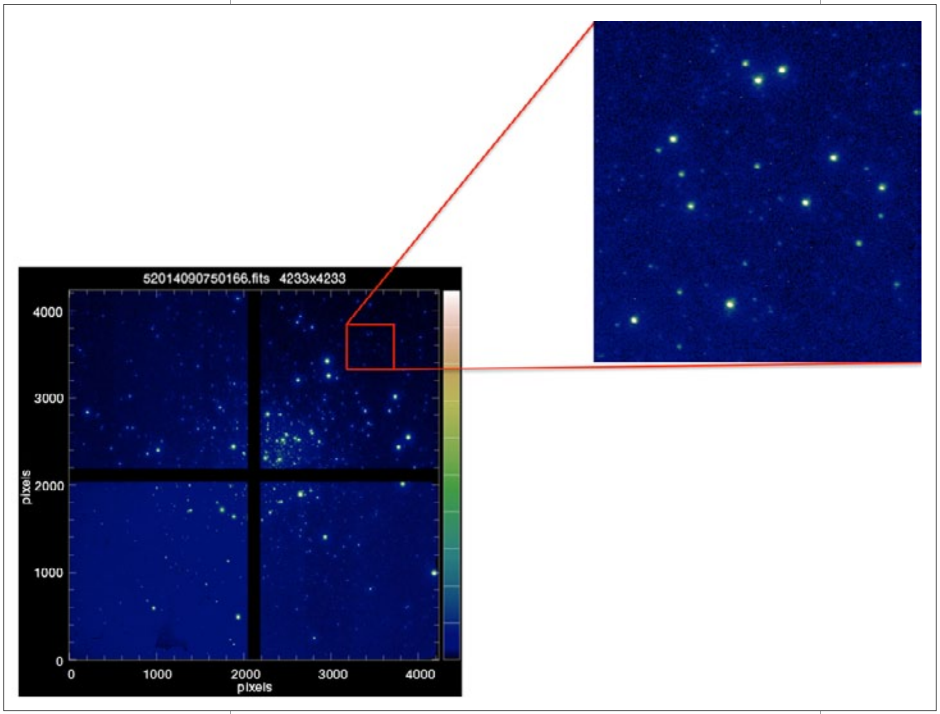


Figure 3 (Top). *Post shutdown GeMS/GSAOI image.*

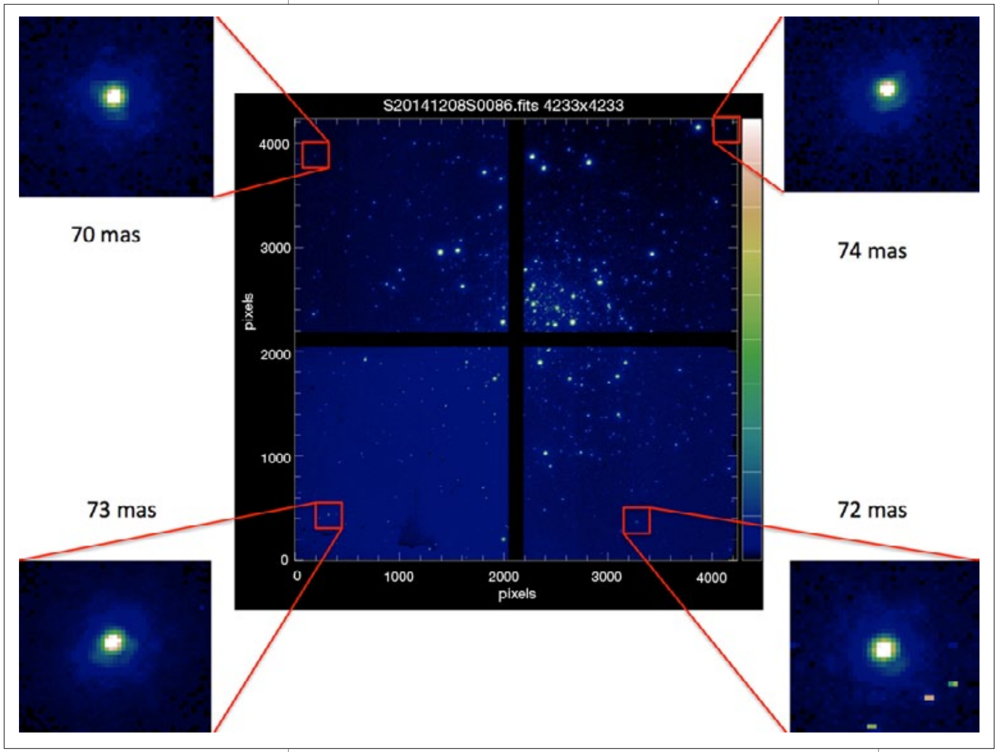


Figure 4 (Bottom). *Performance results achieved using GeMS/GSAOI. ~75 mas in the whole field-of-view.*

During the first post shutdown GeMS observing run (September 2014), we confirmed that the realignment of the CCDs had indeed removed the elongation issue (Figure 3). Since then, several successful science runs with the system have produced excellent results. Figure 4 illustrates the level of performance that the system can now provide.

Future Plans for GeMS

A New Natural Guide Star WFS System

The AO team at Gemini, with collaborators from the Australian National University, is currently working on upgrading the Natural Guide Star Wave Front Sensor (NGSWFS) system (see page 30 for an update). This upgrade will allow the system to use natural guide stars as faint as magnitude 17.5 — a gain of about two magnitudes over the current NGSWFS. This gain will increase AO sky coverage by a huge margin, while opening up many extragalactic science opportunities; up to 50 percent of the sky around the Galactic poles would be available with at least one guide star.

A More Reliable Laser

The laser currently used in Gemini South is a 50 Watt (W) sodium laser created by non-linearly combining two infrared beams inside a crystal. Since its infancy, the laser has required a well-qualified technician to perform the necessary (and precise) optical alignments. After the unfortunate passing of our colleague, and friend, Vincent Fesquet — who was the laser specialist at Gemini South and the keystone of the laser's maintenance — Gemini has committed a huge effort to maintain the laser. This commitment included four external contractors, and utilized help from Gemini North staff. This has allowed sustained operations, but at a level that is somewhat disappointing. To date we have not been able to maintain a laser output higher than 35 W, even requiring the cancellation of two runs over the past year.

The goal now is for Gemini to replace the existing laser with a more sustainable upgrade. A dedicated team is overseeing a feasibility study to consider replacing the current GeMS laser with a more reliable version using the most recent technologies (see details on page 30).

Despite the challenges presented in this article, the GeMS system has already produced some exciting science (see, for example, the feature article in this issue starting on page 16, and the Science Highlight about Galactic globular cluster NGC 1851 on page 24). This bodes well for the system's future potential, especially with the improvements described here.

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April 2015

Rachel Mason

Fast Turnaround Program Pilot Underway

The Fast Turnaround program enjoyed a successful launch and and proved popular with our user community during 2015. Work continues behind the scenes to monitor and improve the process, including the novel peer review scheme.

The Fast Turnaround (FT) program offers monthly opportunities to submit proposals for observations that will be executed starting roughly a month after each proposal deadline. To enable this rapid response, proposals are reviewed by the Principal Investigators (PIs) or designated Co-Investigators of other proposals submitted during the same cycle. The experimental scheme has been in operation at Gemini North since January of this year, accounting for 10% of the available telescope time for Argentina, Brazil, Canada, the University of Hawai'i (UH), and the rest of the US community.

The FT program moves quickly, and we are constantly gaining experience and receiving feedback. This article is therefore necessarily a snapshot of the first few weeks of the system. With that in mind, the following is an overview of the first 1.5 cycles.

Cycle Overview

The first Call for Proposals, with a January 31, 2015, deadline, elicited an enthusiastic (and encouraging) response. We received 17 valid proposals, requesting 60 hours of observing time. Since Gemini dedicates three nights per month to the program, and because the weather loss on Maunakea is typically in the range of 25-30%, the response corresponds to an oversubscription factor of about three. The science areas covered by the proposals were very diverse, as were the reasons for asking for FT time. Some of these include:

- obtaining data to complete a thesis or get the last pieces of data needed to complete a paper;
- compensating for an observing run lost to poor weather at another telescope;
- conducting pilot observations or gathering information for upcoming standard proposals;
- complementing multi-wavelength monitoring campaigns;
- and, finally, simply pursuing topics of interest to the submitting PI.

On the other hand, the proposals were generally short (all but one asking for less than about six hours). Roughly 75% requested the Gemini Multi-Object Spectrograph (GMOS), and most came from the mainland United States. This is not to say that the other partners were not represented; Canada, Brazil, and UH also participated in this first cycle.

The mix of proposals received for the second call, due at the end of February, was somewhat different, with more emphasis on infrared instrumentation. Slightly less time (54 hours) was requested overall from the 12 proposals submitted. We speculate that the oversubscription of the FT program will eventually self-regulate, with high values discouraging people from submitting proposals (too much work for too small a chance of success) and low values having the opposite effect (”free” telescope time!).

On Trial: Fast Turnaround Peer Review

The peer review process is the most novel, high-profile, and little-tested, aspect of the FT program, and we have been watching it unfold with great anticipation.

Would there be signs of bias and unfairness in the system? Would the reviewers all submit on time? Would the reviewers choose the ”right” proposals?

Reviewers are assigned eight proposals each, which they must grade from 0 (poor, do not observe) to 4 (excellent, must observe). They also must provide a brief written review and assess their own knowledge of the subject area on a scale of 0 (“I know little about this field”) to 2 (“I work or have recently worked in this field”).

It’s too early for a statistically sound analysis of the process. However, it does appear that most of the reviews — which are returned anonymously to the PIs — have been thoughtful and useful. Of the handful of PIs who have filled in their feedback surveys so far, 75% report that the reviews they received were ”mostly helpful,” with 25% considering them to be ”variable.” A small fraction of reviewers essentially restated the proposals, or gave single-sentence assessments, prompting us to update the web pages with advice about how to write a helpful review.

We have also found that reviewers tend to weigh the need for rapid response more highly than instructed. A main aim of the program is to enable good science, whether that means timely observations of an object that is swiftly fading, or simply taking data for a project that the researcher is excited about right now. Whether a program is time-critical is intended to be a secondary consideration. We are not sure why people are putting so much emphasis on this. Perhaps they feel that, to paraphrase the feedback of one early-career reviewer, “Time Allocation Committees [TACs] are better at judging proposals than we are, so only proposals that really need the FT program should go through this route.” Or perhaps there’s a psychological component, something like “my program really needs to be done soon, so why should it compete against something that can wait?” In any case, we have updated

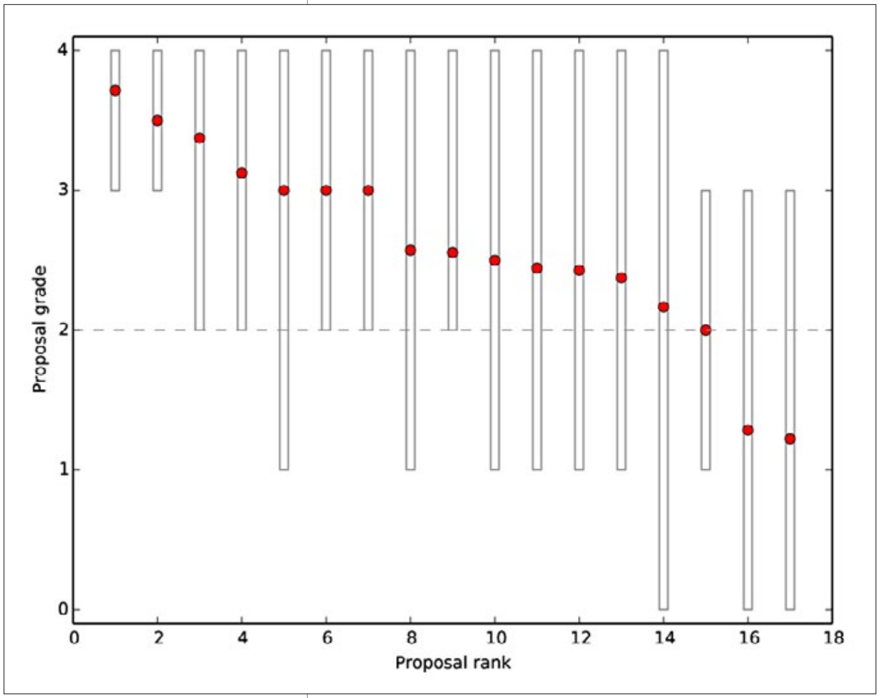

Figure 1.
Mean proposal grade vs. proposal rank for the first FT cycle. The vertical bars show the range of scores received by each proposal (on a scale of 0-4), and the dashed horizontal line indicates the cutoff score that any proposal must reach in order to be awarded telescope time.

the instructions to emphasize that the need for a quick response is not paramount. Time will tell if this works.

Although we don't yet have a lot of data to work with, in true astronomer fashion we haven't been able to resist the temptation to start analyzing the numbers we do have. Figure 1, for instance, shows the mean proposal grade vs. proposal rank for the first FT cycle. Clearly, the dispersion in grades is rather large for most of the proposals. However, a couple of things stand out. The top two proposals were uniformly recognized to be very good or excellent, and the three lowest-ranked proposals were not rated as excellent by any of the reviewers. This roughly mirrors what many people say about proposal assessment mechanisms in general: the top and bottom proposals are easy to recognize, while those in the middle elicit much less agreement.

One concern that we have heard from the community is that non-expert reviewers may be too easily swayed by a proposal and unable to recognize its flaws. Figure 2, which shows the number of times each score was awarded, separated by the reviewer's self-proclaimed expertise, allows us to look for signs that this is the case.

If anything, it seems that the opposite may be happening; the lowest scores were given almost exclusively by reviewers who consider themselves not to be particularly familiar with the subject area of a proposal. While data from more FT cycles are certainly needed to show whether this trend persists, prospective PIs may wish to ensure that their proposals are accessible to a broad, non-expert audience.

Figures 1 and 2 also show that most reviewers thought most proposals were "good" or better. Some have wondered whether people will exploit the peer review system to give competing proposals unfairly low grades. We see no evidence of this so far, although we will continue to monitor carefully.

Others have questioned how the quality of FT proposals will compare to that of "regular" Gemini proposals. Will the people with the best ideas be wary of the peer review system? To gauge this, the feedback survey asks how the FT proposals compare to other proposals the reviewers may have judged in the past. Of the reviewers who have replied so far, all reported that the FT proposals were largely similar in quality with those they have assessed elsewhere. For an independent (if subjective) measure of this, the successful proposals are also being sent to two (former) members of Gemini TACs.

Seven out of 17 proposals were accepted during the first cycle. The FT team's job was to assess the technical feasibility of the top-ranked proposals, and then figure out which ones could be accepted given all the potential conflicts between a target's right ascension, observing conditions, GMOS gratings, *etc.*, while sticking as closely as possible to the peer review rankings. We were relieved that in the end it was feasible to select the seven top-ranked proposals.

Also on Trial: Success of Accepted Programs

Once selected, we need to observe the accepted programs. As one (otherwise positive) first cycle participant commented, ”The verdict is out until we see whether the queue actually collects most of the data for the approved Fast Turnaround programs.” Indeed, we have to (sadly) report that the first scheduled FT observing block (March 9-11) is being wiped out, as this is written, by a blizzard so severe that even the road-clearing crew can’t reach the summit of Maunakea. FT observations remain valid for three months, but still it’s unfortunate to have lost the first block to winter weather.

At this point, you might be asking why we don’t simply merge the FT programs with the regular queue, instead of reserving distinct nights. There are several reasons for this.

First, unpredictable weather losses mean that observations pile up at certain right ascensions as the semester progresses. To avoid PIs writing proposals for regions of the sky that already have too many queue programs to complete, we would have to track this and make the information available for FT PIs every month. Not only do we not have appropriate tools to do that, but our data would always be out of date by the time the proposals were accepted.

Second, separating queue and FT programs means that their relative priorities are clear. A highly-ranked FT program is not competing against an already-started Band 1 queue program, and vice versa.

Third, we value the transparency the present system provides. We can very clearly state what happened to the FT programs during their observing nights, rather than having them ”disappear” into hundreds of hours of other programs. We may have to rethink this approach, as we see how things progress, but for now we’ll simply monitor and evaluate.

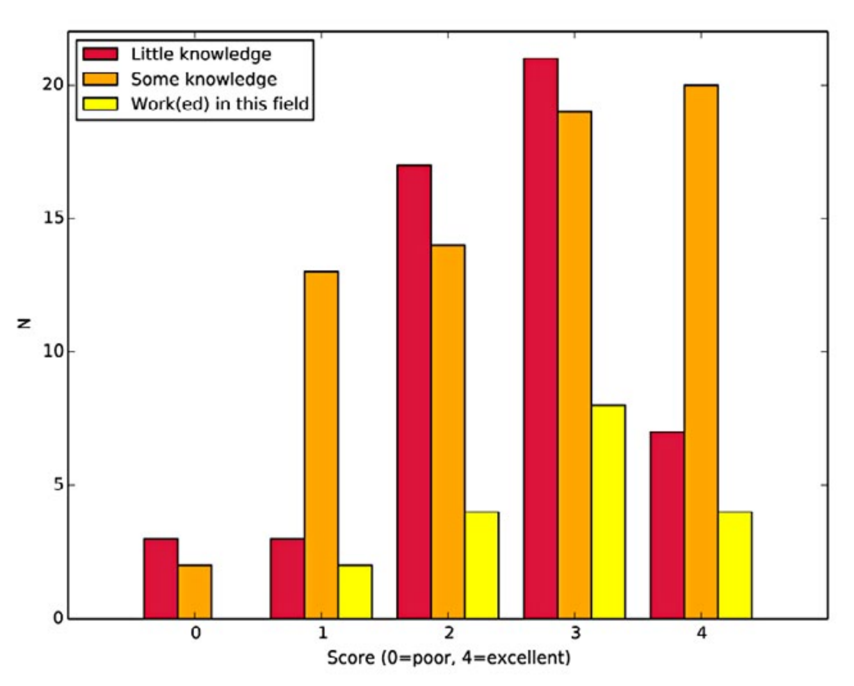

Figure 2.
Histogram of proposal scores, separated by reviewers’ self-declared level of knowledge of the subject area.

Monitoring the FT program will be an important part of our team’s work. We’ll be gathering statistics, soliciting user feedback, and also preparing reports for the oversight committee’s meetings. Once we have sufficient data for a reliable evaluation, we (in conjunction with the oversight committees) will make a decision about the program’s future — should it continue in similar or modified form? Be scaled up and expanded to Gemini South? Or be stopped entirely?

We will be sure to share our evaluation and assessment with our user communities. Meanwhile, regular updates can be found on the ***FT blog***.

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Gustavo Arriagada

Base Facility Operations: The Dawn of Fully Remote Operations is Here!

Gemini's Base Facility Operations are moving Gemini toward an exciting new era of fully remote operations.

Editor's note, this article was published prior to the successful implementation of remote operations at Gemini North in late 2015 / early 2016. Instances of future-tense statements have been addressed where appropriate (see the update on page 37 for additional information).

Figure 1.

Tom Cumming and Dolores Coulson during testing of BFO systems in the Hilo control room.

Base Facility Operations (BFO) is Gemini Observatory's large project aimed at eliminating the need for nighttime observing staff and visiting astronomers at the telescope facilities on Maunakea and Cerro Pachón. The ultimate goal is to allow the execution of observations completely from the base facilities in Hilo and La Serena. If you have visited either telescope, you will know that many remote functions were already possible. However, operating the telescopes at night, without anyone at the mountain facilities, still requires new capabilities that, once implemented, will address a long list of possible risks and safety concerns. Once done, the BFO project will assure the safety of the staff, telescope, building, and instruments, while allowing astronomers to acquire the highest quality astronomical data from base facilities without interruption.

Major Accomplishments at Gemini North

Although much of Gemini North's infrastructure was already set up to run the telescope remotely, several steps in the current operations routine still required changes/upgrades before moving the night crew to the base facility.

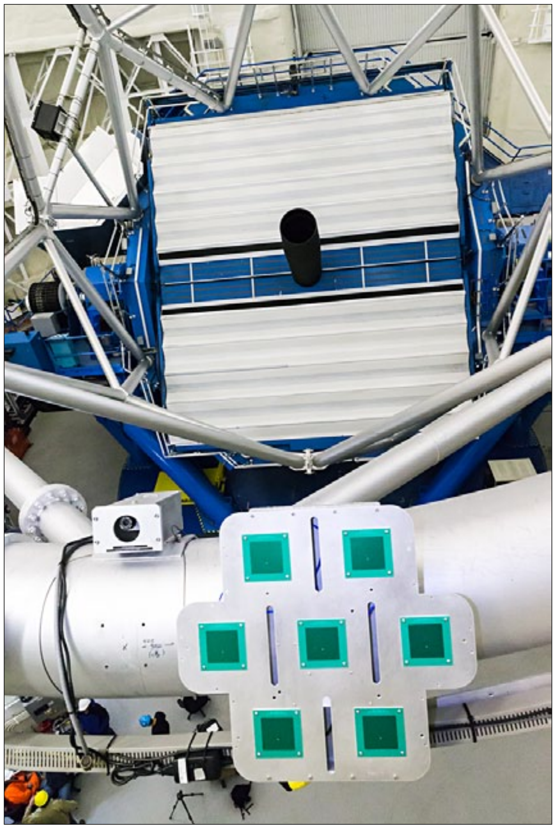

Figure 2.

TBAD receiver on the top ring of the Gemini North telescope in Hawai'i.

For instance, Gemini North can now remotely turn systems on and off that could previously only be controlled at the telescope facility. Also, Gemini has long used human spotters to detect aircraft and alarm telescope operators of possible accidental illumination from the Gemini laser. This system became unworkable under the new operational model, so we reached out to our colleagues at the W.M. Keck Observatory and joined in a very successful collaboration that resulted in an automated Transponder-Based Aircraft Detector (TBAD). Developed by Keck and Tom Murphy at the University of California, TBAD can monitor aircraft transponder signals, determine whether the craft are too close to the area of laser propagation, and, if so, send a command to close the laser shutter without any human intervention.

Our Gemini North generator power transfer system also needed attention, so we modified and improved it to remotely, and autonomously, close the dome if a power outage occurs. The system will also work even if the network connection to the summit is lost. In addition, without any staff available to press buttons when something minor needs resetting, BFO also needed the provision for remote reset capabilities.

A complex software sequence for dome closing was also developed at the lowest level (Programmable Logic Controllers). This new feature avoids relying on computers to perform one of the most critical tasks identified when we defined our telescope and instruments safety requirements — the autonomous closing of shutters and vent gates.

The electronics that control the primary mirror covers and their mechanisms were also upgraded to make their operation not only safer for the primary mirror but also more reliable. This improvement allows us to open and close the covers remotely from the base facility as well.

To make the work environment more suitable for nighttime operations at the base facility, we've modified the control room so it can accommodate additional monitors and network connection ports, provide better lighting, and support additional security. Finally, the telescope facility had to be upgraded to improve its dialup notifications infrastructure and security system, as well.

The Trial Run in Hawai'i

During BFO's trial operations phase at Gemini North, we completed internal testing of most of the critical work packages and followed that with user testing and verification.

For the first time, on the night of September 8-9, 2015, a full test of the remote observing capabilities at Gemini North was successfully completed operating in "base mode" while the night crew was still at the telescope. Over the two following weeks, the night crew (Science Operations Specialists, SOSs) refrained from going outside the control room to see

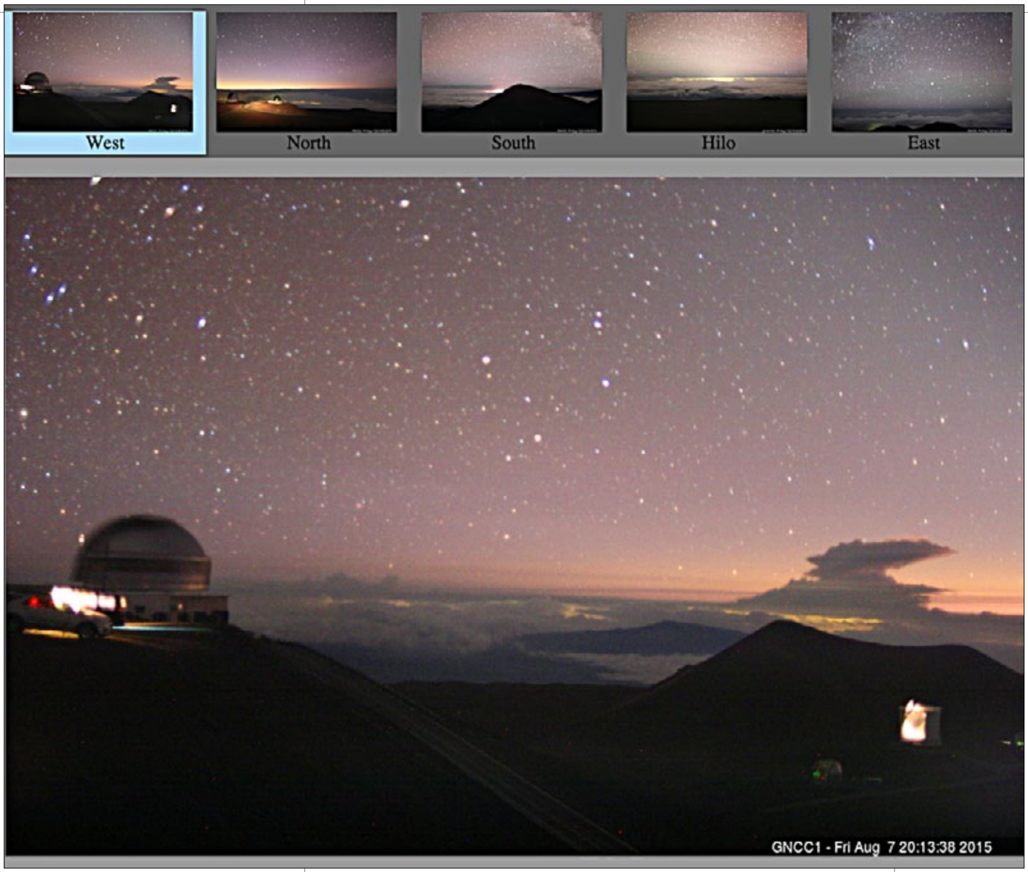

Figure 3. *Sample of data from the Gemini North CloudCam system.*

if what we have developed and tested works in the real remote observing configuration.

During base operations trial runs, several systems were tested, which included a set of five Cloud Sensing Cameras (strategically located on the roof of Gemini's support building), two external surveillance cameras, one external fog camera (equipped with a remotely operated flashlight), five internal pan tilt cameras (located in the observing floor), and two sets of environmental sensors (designed to measure humidity, temperature, and detect the presence of snow, ice, and rain).

Figure 4. *Eduardo Tapia (left) and Gustavo Arriagada (right) work on the remote sensing system which is now mounted on the roof of the Gemini North Maunakea support building adjacent to the telescope.*

In addition, we tested the software that allows SOSs to start and stop telescope systems and protect the entire facility in case of rain — or worse — if we experience loss of the network or a major earthquake. This software acts autonomously, ensuring the telescope and dome are safely parked, closed, or stopped, even with the loss of commercial power.

The first trial run was part of our "gradual descent" strategy, which broke down the work into 17 manageable pieces (work packages) that followed different schedules.

The second run started on October 12th, and we ensured that all SOSs had opportunities to use the summit configuration and learn how to operate in base facility operations mode, before attempting remote operations from Hilo.

In November, the third trial run focused on operating from the base facility, while still having personnel on the summit — at the very least at the beginning of the night. SOSs were able to open and close the upgraded primary mirror covers from the base facility control room. This was a big milestone for BFO, since, as mentioned, it was necessary to modify the covers to eliminate the risk of damaging the primary mirror while performing this function remotely. We achieved this by implementing a design upgrade that effectively captured the overall project's guiding principle of doing the minimum to obtain the maximum possible benefit.

The team undertook the fourth and final run only once all problems identified in the first three runs had been prioritized and any potential showstoppers solved. This time, observers performed all operations from the base facility control room with no personnel on the summit.

As this year in review issue goes to press, full remote operations are ongoing at Gemini North.

Implementation in Chile

As we enter 2016, we officially begin work on BFO at Gemini South, with the goal of handing over to Operations during the third quarter of 2016.

While one might think that most of the work required to establish BFO at Gemini South would be very similar to what has been done at Gemini North, there are significant differences. These will require the introduction of some level of development before we start to install, integrate, and test the work package products at Gemini South.

An Impressive Team Effort

BFO is the result of the effort and dedication of many engineers, technicians, and SOSs who incorporated this effort into their operations work in order to schedule tasks related to the project. Without their enthusiastic participation it would have been impossible to keep the 17 concurrent work packages progressing at a steady state — from gathering requirements, to conceptual design, and then to final design and implementation — over a period of many months.

Because of its nature, we believe that everyone at the Observatory was at some level involved in the success of BFO. This is truly an Observatory-wide project.

Special acknowledgments also have to go to the people at the Canada-France-Hawai'i Telescope (CFHT) who shared many of their lessons learned and important ideas on how to develop and implement BFO at Gemini. CFHT engineers and scientists were very patient and collaborative, especially considering our many visits (even at the beginning of the night) to either ask for design details or observe their facility operating remotely. Their willingness to provide information was always superb, and the information they provided was accurate and in-depth. We learned much from the CFHT staff and management, and for that we are extremely grateful.

BFO Legacy

With BFO fully implemented at Gemini North we are the first 8-10-meter-class observatory to routinely operate from a base facility at night. This will save money (important in this era of diminishing budgets for research), and reduce environmental impact on Maunakea and, ultimately, Cerro Pachón (which was pointed out as an important and welcome outcome at a recent Maunakea management meeting in Hawai'i).

Finally, Gemini's remote operations will open up new operational models. It is now possible to imagine observers in full control of the telescopes and instruments, executing their observations from anywhere on our planet, and uniting our Partnership in new ways that we cannot yet even imagine.

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André-Nicolas Chené

GRACES:

The Beginning of a Scientific Legacy

The Gemini/Canada-France-Hawai'i (CFHT) partnership to provide Gemini users with access to the CFHT's high-resolution optical spectrograph ESPaDOnS is now complete. Called GRACES, initial commissioning in 2015 was a resounding success, and regular operations have already started in Semester 2015B. This project provides users with a powerful new capability of high-resolution optical spectroscopy.

The Gemini Remote Access to CFHT's ESPaDOnS Spectrograph (GRACES) project has had a long and interesting history. Suffice it to say, however, that there has always been a healthy level of skepticism about the feasibility of the project and the likelihood of its success.

History and Background on GRACES

At the core of early doubts was the project's need for two 270-meter-long fiber cables (Figure 1) to feed light from the 8-meter primary of Gemini North into ESPaDOnS — a bench-mounted high-resolution échelle spectrograph and spectropolarimeter at CFHT designed to obtain a complete optical spectrum — from 370 to 1050 nanometers (nm) — in a single exposure (see Figure 2). Could light travel through such a fiber and make it to the other end without a lot of it being lost in the process? This was the key question and risk in the project. GRACES can now answer this question affirmatively, having achieved success earlier this year, thereby marking a major milestone for astronomy. The result allows Gemini to share the ESPaDonS instrument with CFHT and provide a short and inexpensive way to add a significant new user-desired capability in the process.

Key to the GRACES success was the challenging job completed by the National Research Council-Herzberg (Canada) to create the GRACES fiber cable (the longest astronomical fiber ever made) in collaboration with FiberTech Optica. Together they worked more than a

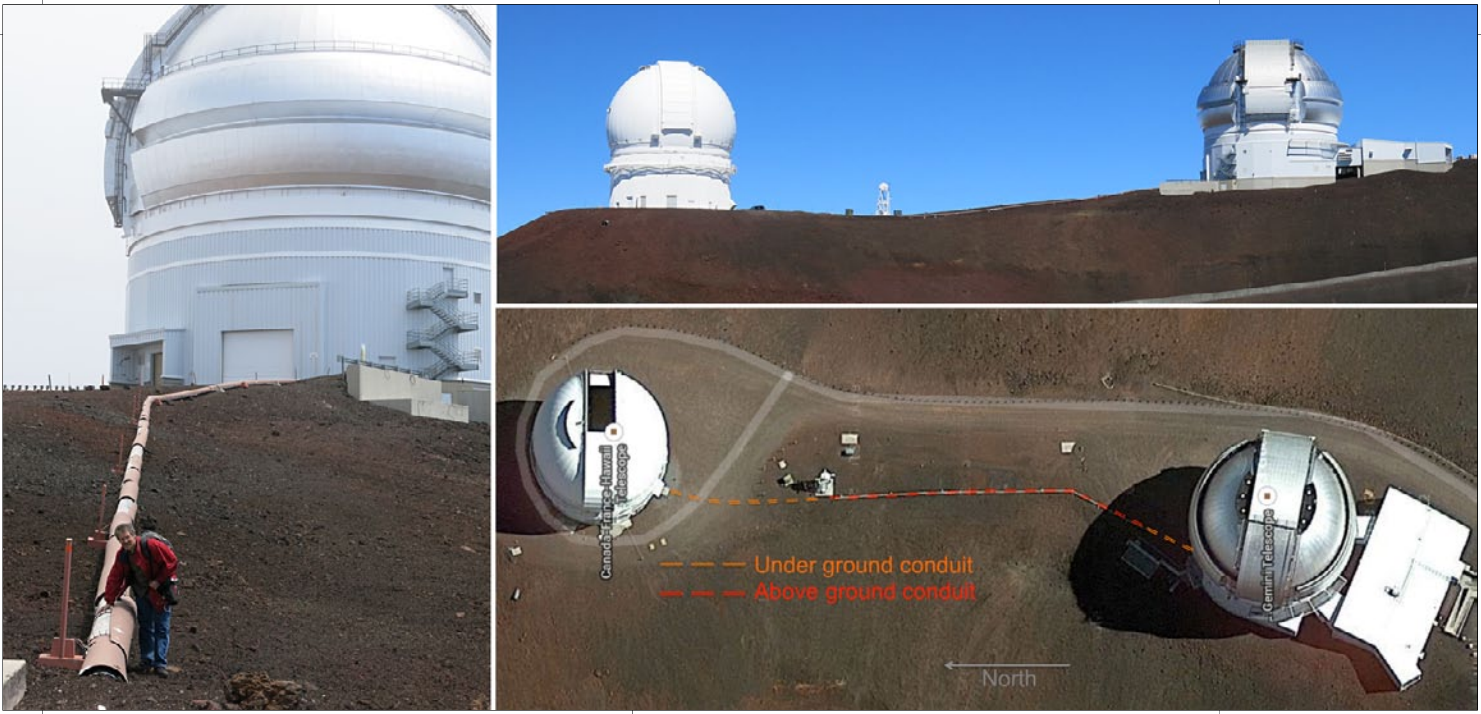


Figure 1.
Different perspectives showing the conduit between CFHT and Gemini.

year on the polishing and cabling methods that would make the fiber so efficient that one might forget it is even there.

Today, with commissioning complete, we find that even the most optimistic estimates of throughput (*i.e.* the percentage of photons that hit the mirror and subsequently fall on the detector) with the fiber were below what we would ultimately achieve. The recent commissioning observations reveal that the total throughput of GRACES in the red part of the spectrum is the same (~12%) as it is for ESPaDOnS, which is fed by a much shorter fiber at the CFHT.

In its Gemini state, GRACES' sensitivity is ~ 22 magnitude at R band (*i.e.* a target with R = 22 magnitude gives a signal to noise of 1 after a 1 hour exposure). This sensitivity compares favorably (in some cases exceeds) what is possible with other similar instruments elsewhere in the world (see comparisons, Figure 3).

Early Observations

Gemini offered GRACES for the first time this year and the demand was huge! The Canadian and Brazilian communities requested GRACES for over 30 and 40 percent of their time, respectively.

Some early users have already benefited from GRACES' high performance: for instance, Tim Davidge (Principal Research Officer at NRC-Herzberg) used GRACES to study aspects of galaxy evolution — to characterize the large-scale events that have influenced their present-day appearance.

"One thing I can say is that I am impressed by the signal-to-noise ratio of the M101 and NGC 6946 data", Davidge says.

Lison Malo, CFHT resident astronomer and scientific lead for the GRACES project, is equally enthusiastic about GRACES' performance. She comments, "The exposure was 300 seconds long and the final signal-to-noise ratio is around 50 per pixel, which is higher than expected!!! And it was not possible to observe this object using just ESPaDOnS at CFHT."

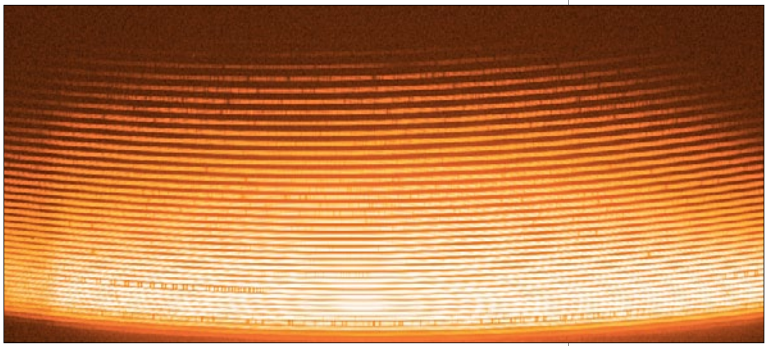
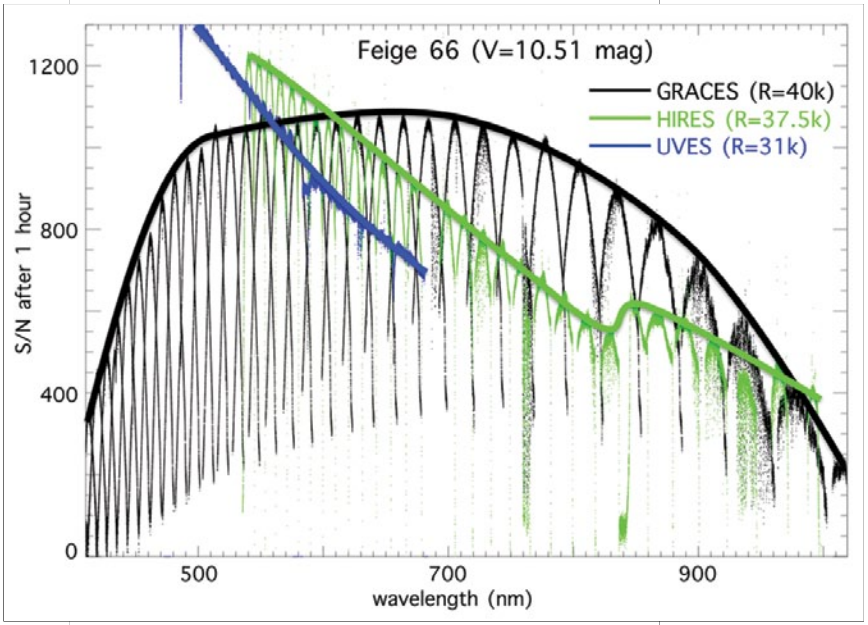


Figure 2.
Full GRACES spectrum of the Moon in the 1-fiber mode. Up to 36 orders are visible, i.e., *from order #22 (centered on 1029nm) to #58 (centered on 408nm).*

Figure 3.

Comparison of the GRACES spectrum of Feige 66 observed in the two-slice mode, and the HIRES spectrum leveled to match GRACES observations weather conditions and resolution.



Prepping and Using GRACES

GRACES consists of three components: (1) an injection module (Figure 4) that sends light from the Gemini Multi-Object Spectrograph at Gemini North (GMOS-N) into (2) the two long fiber cables (that connect Gemini North to CFHT, and (3) a receiver unit responsible for injecting the light from the fibers into the ESPaDOnS.

In preparation of a GRACES observing block, Gemini staff need to install the injection module in GMOS-N, occupying the same mask slot as the instrument's integral field unit (IFU). The injection can, like the IFU, be moved in and out the beam, so GMOS-N imaging capability can be used for the target acquisition.

On the CFHT side, the pick-off mirror in the receiver unit injecting Gemini's light in ESPaDOnS is deployed, and the control of the spectrograph is given over to the Gemini observer. This handover process requires transparent communication between Gemini and CFHT at each step and has proven to work very well.

For Gemini's users, GRACES provides high-resolution (up to R ~ 67,500) optical (400 – 1000 nm) spectroscopic capabilities with an on-sky fiber covering 1.2 arcseconds. Because of its unique configuration (*i.e.*, the GRACES injection module replaces the IFU module in GMOS-N, making it impossible to do both GMOS-N IFU and GRACES observations on the same night), it is only available for 10-night blocks, twice each semester. Proposing for GRACES is handled through the normal Gemini two-semester proposal process.

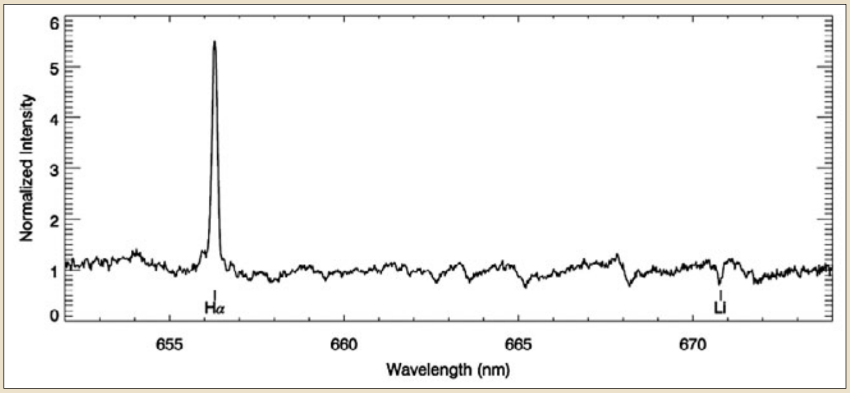
First GRACES' Science Paper

The first paper based upon GRACES data is nearing completion by Lison Malo of CFHT. Her work focuses on nearby young associations of stars in order to better understand their formation history, determine the initial mass function, and test theories of stellar evolution.

Her team's work with GRACES is to establish the membership and age of very low-mass stars and brown dwarfs in nearby kinematic groups. Observations focus on the most probable candidates visible in the sky in Semester 2015B that do not currently have high-resolution spectra.

Shown here is representative GRACES data of an M6 dwarf which is a target from Malo's research program.

It is expected that Malo's work will be published soon in a *Letter*, which will also include a description of the data reduction pipeline.



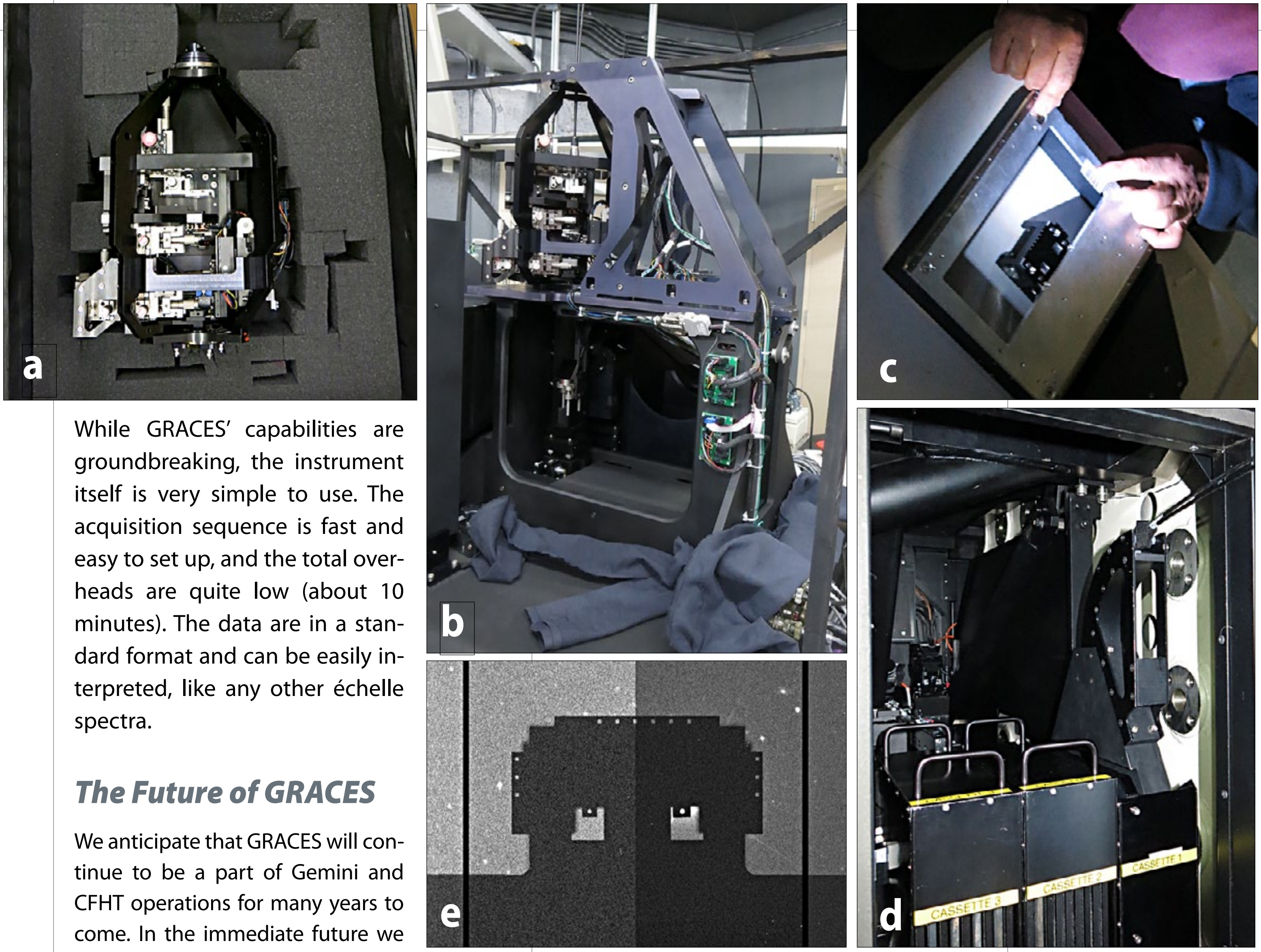


Figure 4.

(a) The receiver unit in its shipping box when received at Maunakea. (b) The receiver unit during its installation in ESPaDOnS. (c) The injection module in its cassette during alignment. (d) The GRACES cassette (at right) installed into GMOS, next to the two GMOS mask holders. (e) Shadow image of the injection module taken with GMOS in imaging mode when a bright star was centered on one fiber; we can see the silhouette of the mask containing the fiducial holes that were used to calibrate the acquisition of the target during on-sky commissioning.

While GRACES' capabilities are groundbreaking, the instrument itself is very simple to use. The acquisition sequence is fast and easy to set up, and the total overheads are quite low (about 10 minutes). The data are in a standard format and can be easily interpreted, like any other échelle spectra.

The Future of GRACES

We anticipate that GRACES will continue to be a part of Gemini and CFHT operations for many years to come. In the immediate future we will continue to improve GRACES' performance for optimal operations on sky. We will also continue to collaborate with CFHT on a data-reduction pipeline based on the currently existing open source software named OPERA, used at CFHT since 2004.

Given the strong initial success of GRACES with its commissioning science, we look forward to seeing lots of exciting and cutting-edge science results from our user community. While the obvious uses for GRACES are clear, it will be those innovative observing programs our community will undoubtedly reveal that will ultimately define the legacy of this project.

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Paul Hirst

The New Cloud-based Gemini Observatory Archive

The new Cloud-based Gemini Observatory Archive is now online and available to our user community and anyone wanting to retrieve Gemini data. The new archive has many powerful tools and features that are described here — take it for a test-drive!

The new Gemini Observatory Archive (GOA) provides a simple yet powerful way for the Gemini user community (especially those who wish to write scripts) to search for and download data. A key feature of the new Cloud-based archive is its ability to automatically find and match optimal calibration data for your search results. GOA's powerful web interface also allows bookmarking search results and provides an easy-to-use Application Programmer Interface (API).

As I write these words, I have one eye monitoring several windows in the corner of my computer screen, which shows that our new archive server is running quietly and smoothly. One window shows me that afternoon calibrations are being taken on Gemini North, and I see those data files transferring into the archive. More than a hundred users have already created accounts on the system and I see them accessing proprietary data for their projects; more users are accessing the server anonymously, either to just check out the system, or search for older data. The Gemini Observatory Archive can be accessed ***here***.

Data Management Dilemma

Shortly after I started working at Gemini in late 2006, I realized we had a problem with in-house data management: data were being manually copied between different disks and backup media in a somewhat ad hoc manner. In addition, a disk failure on an aged Sun workstation left us scrabbling to locate backup copies of some Near-infrared Integral Field Spectrometer engineering data that had been lost. The final straw came as an urgent phone call from the night crew who needed to free up disk space for incoming data, but they weren't 100% sure that the data they wanted to delete was safely on another disk or even in the archive.

> *"I have used the new Gemini Observatory Archive to retrieve data for our LP-3 and I found it very easy to use and fast so I don't anticipate any problems. I am grateful to the team at Gemini that has been working on it. "*
> *— Catherine Huitson, PI of GN-2015B-LP-3*

To solve all these problems, I initiated the FITS (Flexible Image Transport System) storage project and wrote a software package that would scan through the FITS files on a file system and record details of them in a database. A simple web interface presented concise summaries of the data files. Gemini also bought some modern LTO4 (high capacity and performance) tape drives, and wrote software to record (in the database) file details as it wrote them to tape.

With these changes, we'd never lose a single file again. We'd also be able to know with a few mouse clicks which files were safely on tape, and which tapes they were on. We wrote scripts that tied into the system to clear old data off disk (after first checking it was safely on multiple tapes) to ensure that disks didn't fill up.

Fast forwarding into the Transition Plan years, we realized that the FITS Storage System had evolved to the point where it would be possible, with a reasonable amount of effort, to expand it into a fully fledged archive system. As neither the Hilo nor La Serena base facilities have adequate internet connectivity for users to simultaneously download data from all over the world, they seemed unattractive as locations to host an archive server. However, when we researched the costs of Cloud computing services — such as Amazon Web Services and Google Cloud Platform — it became pleasantly apparent that substantial cost savings could be realized by moving to an in-house developed archive system hosted on a commercial Cloud platform.

We were given the go-ahead at the end of 2013, spent 2014 developing a prototype system; then, following approval by an external group of testers, worked through 2015 transforming the prototype into the fully developed GOA. The system is now deployed on Amazon Web Services, using an EC2 (Elastic Compute Cloud) virtual server and storing data on S3 (Simple Storage Solution) with backups on Amazon Glacier.

Cloud Computing

The decision to store data "in the Cloud" has raised more than a few eyebrows, but once we started researching this option, it quickly became obvious that this approach offers many advantages. As far as we know, we're the first major observatory hosting our archive on a commercial Cloud computing platform, though I'm sure more will follow.

Cloud computing prices, especially for data storage, have plummeted over the last few years; we're actually now paying about a quarter of what we estimated two years ago. One of the real strengths of the Cloud for us is Internet connectivity. As mentioned, our Internet connections from Hilo and La Serena aren't geared up for users simultaneously downloading data from all over the world, whereas that's exactly what Cloud systems are designed to support.

For a modest cost, we are able to buy into massive global computing and network infrastructure that also supports such Internet giants as Netflix and Dropbox. The GOA software itself is very flexible, and can run both on the Cloud or on a conventional Linux server. In fact, we run instances of the same software at both our summit sites to provide internal data management facilities.

"I've tried using the new archive for some PI data and I just wanted to let you know how impressed I am with how it works. The interface is easy to use and intuitive." — Tom Matheson, US NGO

Mixing this with Cloud computing gives us a huge range of scalability options; for example, if a new (or existing) Gemini partner country or institution found that their internet connection to the current archive server isn't so great, we could deploy an extra server, either within the Amazon Cloud at a data center located closer to them, or even potentially on a server located within an astronomical institution.

Keeping It Simple

In developing the GOA archive web interface, we wanted to keep things as simple, yet as powerful, as possible. There is only one search form for the archive; it provides a single and clear starting point for any archive search — whether it's a Principal Investigator (PI) looking for data from his or her own observing program or someone interested in searching for public data on an object. Searches by a variety of parameters (such as instrument, observing date, and observing modes) are provided, along with instrument-specific details and, of course, target names and sky positions.

GOA was by definition a lean project; the driver was cost savings, and this meant limited functionality. While we deliberately decided to make it a simpler system than the previous Gemini Science Archive, we would also maintain the functionality that had proved most beneficial over the years. The only example of lost functionality that users have commented on is that the archive no longer provides details of proposal abstracts in the database, and searching by PI name is not possible. We're keeping a list of ideas and feature requests to consider for future upgrades.

Bookmarkable Searches

Another particularly useful feature of GOA is its ability to bookmark searches. When you enter a field in the search form and click "search," your browser is directed to a URL that represents that search. This allows you to bookmark the page, copy and paste the URL from your browser, save the URL in your notes, email it to a Co-Investigator, or whatever you like. And if you visit that URL in the future, that search is preserved and will find all the data from that program; if any new data has been added since you saved the URL, you'll see the new results too.

Low Latency

Some time ago, we started "remote eavesdropping," whereby PIs could connect to the Gemini control room while their observations were being made. This allows users to interact with the queue observing team and provide feedback on the data as it comes in. With Base Facility Operations already happening at Gemini North, we might look to a future that also includes Remote Observations — GOA is already prepared for this, as we designed the new archive to make data available promptly. Data typically are available to download within a minute or so of completing a readout. At the moment, Gemini North data are slightly quicker (often as fast as 20 seconds) due to the better Internet connection to Maunakea. However, as the Large Synoptic Survey Telescope begins laying fiber optics to Cerro Pachón, we anticipate Gemini South data to fall into the same regime.

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Alexis-Ann Acohido

October 2015

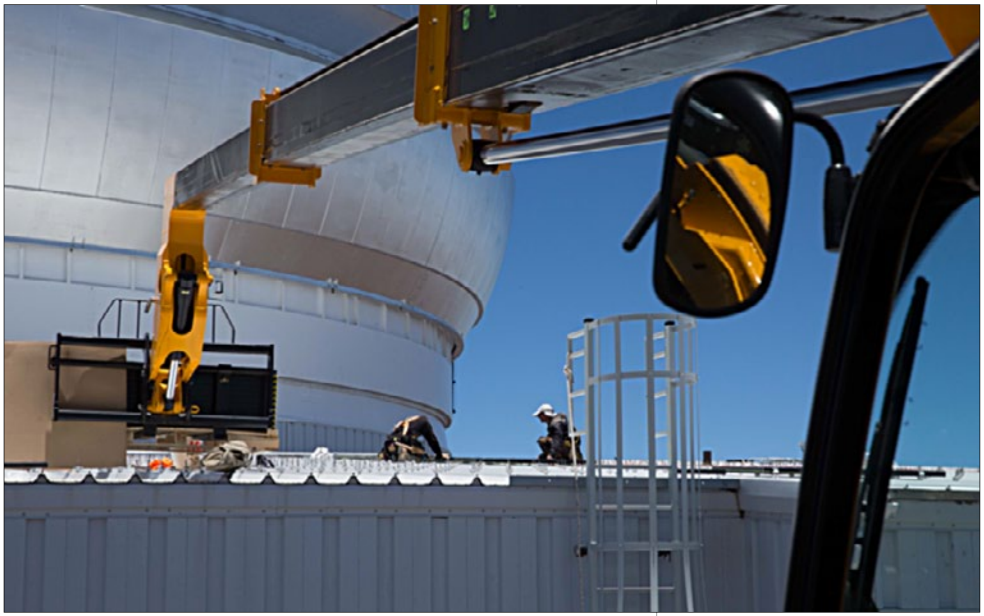
Record-breaking Rooftop Solar Panel System Installed at Gemini North

Gemini Observatory leads the way in the use of renewable energy sources on Maunakea, as evidenced by the latest installation of PV solar panels on the rooftop of Gemini North. This move toward a more eco-efficient operation shows Gemini's commitment to the positive stewardship of our planet.

The Gemini Engineering group has finished the installation of photovoltaic (PV) solar panels on the roof of the Gemini North telescope. Maui Pacific Solar installed the panels and it took about six weeks to complete.

"The PV panels [on Maunakea] are the second highest in the world (the highest are in Tibet) by about 200 feet [~61 meters]", says Maui Pacific Solar Founder and President Mike Carroll. "However, [Gemini's] is the highest rooftop mounted PV system in the world that is connected to the utility."

Figure 1.
The PV panels were transported to the roof by crane.



The solar panels will (conservatively) generate about 10% of the power required to operate the Maunakea facility, and will be roughly 70% more energy productive than the panels planned for installation on the roof of the observatory's base facility in Hilo. PV systems operating on Maunakea are more efficient than at sea level for three important reasons: first, Maunakea receives on average 6.4 peak

Figure 2.
The Gemini Roof Cam captures workers installing the PV panels on the roof of Gemini North.

Figure 3.
PV panels now cover the entire roof.

Sun hours a day as opposed to Hilo, with only 4.6 peak Sun hours a day, resulting in a 39% benefit; second, PV systems operating on Maunakea at low summit temperatures of ~45° F versus ~80° F at sea level result in another 10% improvement in performance; finally, PV systems operating almost 14,000 feet (4,200 meters) above sea level, where the Sun is more intense due to reduced atmospheric absorption, results in an additional 10% benefit. The approximate energy output of the panels on the telescope is expected to be about 100 kilowatts.

Gemini Observatory continues to explore new ways to improve operational efficiency. "While PV panels require a significant investment", says Gemini Lead Engineer for the project Chas Cavedoni, "we predict that the investment will be recovered in less than four years."

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Gemini Legacy Image Releases

October 2015

The HH 24 Jet Complex

A new Gemini Observatory image reveals a fascinating display of celestial "fireworks" accompanying the birth of stars. The image captures in unprecedented clarity the complex structures of a gas jet complex emanating from a stellar nursery at supersonic speeds. The striking new image hints at the remarkably dynamic (and messy) process of star birth. Researchers believe they have also found a collection of runaway (orphan) stars that result from all this activity.

Gemini Observatory has released one of the most detailed images ever obtained of emerging gas jets streaming from a region of newborn stars. The region, known as the Herbig-Haro 24 (HH 24) Complex, contains no less than six jets streaming from a small cluster of young stars embedded in a molecular cloud in the direction of the constellation of Orion.

"This is the highest concentration of jets known anywhere," says Principal Investigator Bo Reipurth of the University of Hawaii's Institute for Astronomy (IfA), who adds, "We also think the very dynamic environment causes some of the lowest mass stars in the area to be expelled, and our Gemini data are supporting that idea."

Reipurth along with co-researcher, Colin Aspin, also at the IfA, are using the Gemini North data from the Gemini Multi-Object Spectrograph (GMOS), as well as the Gemini Near-Infrared Imager, to study the region which was discovered in 1963 by George Herbig and Len Kuhi. Located in the Orion B cloud, at a distance of about 400 parsecs, or about 1,300 light years from our Solar System, this region is rich in young stars and has been extensively studied in all types of light, from radio waves to X-rays.

"The Gemini data are the best ever obtained from the ground of this remarkable jet complex and are showing us striking new detail," says Aspin. Reipurth and Aspin add that they are particularly interested in the fine structure and "excitation distribution" of these jets.

"One jet is highly disturbed, suggesting that the source may be a close binary whose orbit perturbs the jet body," says Reipurth.

The HH 24 jet complex emanates from a dense cloud core that hosts a small multiple protostellar system known as SSV 63. The nebulous star to the south is the visible T Tauri star SSV 59. Color image based on g, r, and i images obtained with GMOS on Gemini North in 0.5 arcsecond seeing. *Image produced by Travis Rector. Image credit: Gemini Observatory/AURA/B. Reipurth, C. Aspin, T. Rector.*

The researchers report that the jet complex emanates from SSV 63 — a Class I protostar system, which high-resolution infrared imaging reveals to have at least five components. More sources are found in this region, but only at longer, submillimeter wavelengths of light, suggesting that there are even younger, and more deeply embedded sources in the region. All of these embedded sources are located within the dense molecular cloud core.

A search for dim optical and infrared young stars has revealed several faint optical stars located well outside the star-forming core. In particular, GMOS found a halo of five faint hydrogen-alpha (H-alpha) emission stars (which emit large amounts of red light) surrounding the HH 24 Complex well outside the dense cloud core. Gemini spectroscopy of the H-alpha emission stars show that they are early or mid-M dwarfs (stars with very low mass), at least one of which being a borderline brown dwarf.

The presence of these five stars well outside the star-forming cloud core is puzzling, because the gas there is far too tenuous for star formation. Instead they are likely orphan protostars ejected shortly after birth from the nearby star-forming core. Such ejections occur when many stars form closely together within the same cloud core. The crowded stars start moving around each other in a chaotic dance. This ultimately leads to the ejection of the smallest ones.

A consequence of such ejections is that pairs of the remaining protostars bind together gravitationally. The dense gas that surrounds the newly formed pairs brakes their motion, so they gradually spiral together to form tight binary systems with highly eccentric orbits. Each time the two components are closest in their orbits they disturb each other, leading to accretion of gas, and an outflow event that we see as supersonic jets. The many knots in the jets thus represent a series of such perturbations.

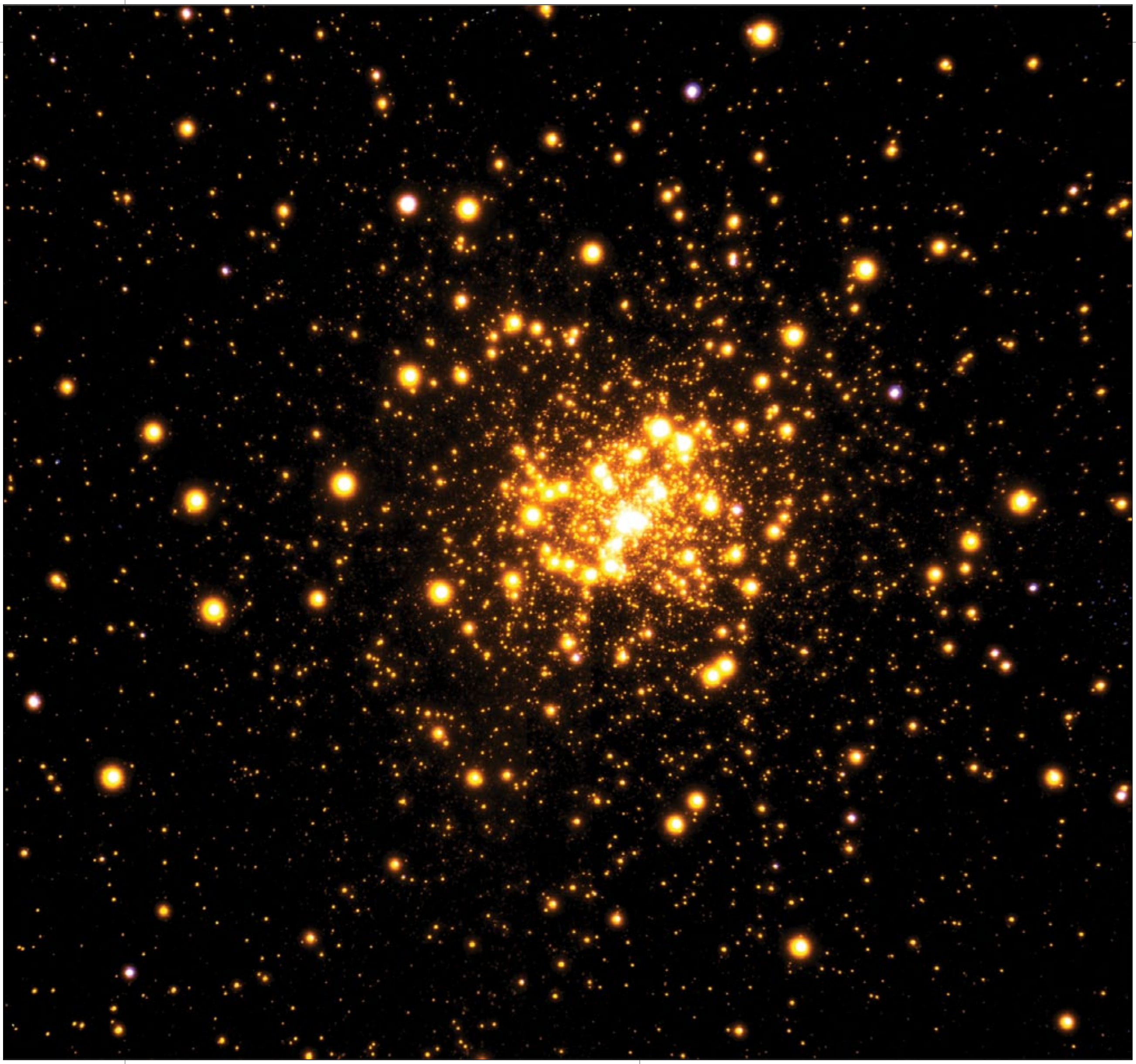
July 2015

Seeing Where Stars Collide

Using the advanced adaptive optics system GeMS, on the Gemini South telescope, astronomers have imaged a beautiful stellar jewel-box — a tightly packed cluster of stars that is one of the few places in our Galaxy where astronomers think stars can actually collide.

Scientists have imaged a cluster of stars, heavily obscured by material in our Galaxy, where stars are so densely packed that it is likely a rare environment where stars can collide. “It’s a bit like a stellar billiards table, where the probability of collisions depends on the size of the table and on the number of billiard balls on it,” says Francesco R. Ferraro of the University of Bologna (Italy), one of the team members who used the Gemini Observatory to make the observations.

Liller 1 is a tight sphere of stars known as a globular cluster. Globular clusters orbit in a large halo around the center, or nucleus, of our Galaxy; many of the closer globular clusters are spectacular showpieces, even in small telescopes or binoculars. “This isn’t one of these showpieces, it is so obscured by material in the central bulge of our Galaxy that it is almost completely invisible in visual light,” observes Sara Sarachino of the University of Bologna and lead author on the paper. Indeed, Liller 1 is located at almost 30,000 light years from Earth, and only about 3,200 light



Gemini Observatory near-infrared image of the globular cluster Liller 1 obtained with the GeMS adaptive optics system on the Gemini South telescope in Chile.

years away from the center of the Milky Way — in one of the most inaccessible regions of our Galaxy, where thick clouds of dust prevent the optical light from emerging. "Only infrared radiation can travel across these clouds and bring us direct information on its stars," comments Emanuele Dalessandro, also of the University of Bologna.

"Although our Galaxy has upwards of 200 billion stars, there is so much vacancy between stars that there are very few places where suns actually collide," says Douglas Giesler of the University of Conception in Chile and Principal Investigator of the original observing proposal. "The congested overcrowded central regions of globular clusters are one of these places. Our observations confirmed that, among globular clusters, Liller 1 is one of the best environments in our Galaxy for stellar collisions."

The unprecedented ultra-sharp view of the cluster reveals a vast city of stars estimated by the team to contain a total mass of at least 1.5 million suns, very similar to the two most massive globular clusters in our Galaxy: Omega Centauri and Terzan 5.

Geisler's team specializes in the study of globular clusters near the center of the Milky Way, while Ferraro's team is adept at the reduction of infrared data on globular clusters. Both groups worked together to obtain the beautiful and detailed observations of Liller 1 with Gemini.

The observations of the tightly packed cluster used Gemini Observatory's powerful adaptive optics system at the Gemini South telescope in Chile.

A technical jewel named GeMS (derived from "Gemini Multi-conjugate adaptive optics System"), in combination with the powerful infrared camera Gemini South Adaptive Optics Imager (GSAOI), was able to penetrate the dense fog surrounding Liller 1 and to provide astronomers with this unprecedented view of its stars.

This has been made possible thanks to the combination of two specific characteristics of GeMS: first, the capability of operating at near-infrared wavelengths (especially in the K pass-band); second, an innovative and revolutionary way to remove the distortions (blurriness) that the Earth's turbulent atmosphere inflicts on astronomical images.

To compensate for the degrading effects of the Earth's atmosphere, the GeMS system uses three natural guide stars, a constellation of five laser guide stars, and multiple deformable mirrors. The correction is so fine that astronomers are provided with images of unparalleled sharpness.

In the best K-band exposures of Liller 1, stellar images have an angular resolution of only 75 milliarcseconds, just slightly larger than the theoretical limit (known as the diffraction limit) of Gemini's 8-meter mirror. This means that GeMS almost perfectly corrected Earth's atmospheric distortions.

The international research team published the results in the June 15th issue of *The Astrophysical Journal* (volume 806, page 152). The astro-ph version of the article can be found ***here***.

The results achieved on Liller 1 have been so important that the research team is currently expanding their work to other globular clusters, which promise to deliver even more exciting science.

Background: Stellar Collisions

Stellar collisions are important because they can provide the key to understanding how certain exotic objects, which cannot be explained by the passive evolution of single stars, originate. "Blue Stragglers," for instance, are old stars that mysteriously appear younger than they should be; these exotic stars may be formed by nearly head-on collisions that cause the stars to merge, mixing their nuclear fuel and restoking the fire of nuclear fusion. But collisions can also involve binary systems, with the effect of shrinking the initial size of the system, promoting the two components to interact and producing a variety of objects like low-mass X-ray binaries, millisecond pulsars, *etc*.

In particular, millisecond pulsars are old neutron stars in a binary system whose rotation periods have been reaccelerated to milliseconds by matter accreting onto them from a companion star. Astronomers suspect that Liller 1 harbors a large population of these exotic objects. Although no millisecond pulsar has been directly observed up to now, the detection of intense gamma-ray emission (the most intense detected so far from a globular cluster) suggests a large hidden population. The Gemini observations confirm that this is possible.

"Indeed, our observations confirm Liller 1 as one of the best 'laboratories' where the impact of star cluster dynamics on stellar evolution can be studied: it opens the window to a sort of stellar sociology study, aimed at measuring the impact of the reciprocal influence of stars when they are forced to live in conditions of extreme crowding and stress," concludes Ferraro.

Additional information can be found ***here.***

April 2015

Janice Harvey

Journey Through the Universe

Gemini North's flagship local outreach program launches into its second decade with unflagging support from the community and Maunakea observatories.

Jeff Donahue, Gemini's senior optics technician, explores the properties of light with students at Hilo Union Elementary School as part of a Journey Through the Universe *classroom presentation.*

2015 ushered in the second decade of *Journey Through the Universe* on the Big Island of Hawai'i. During our 11th year of "Journey" week, over 50 astronomers, engineers and observatory staff continued to inspire and engage thousands of local Hawai'i students (over 5,000 this year).

Since its conception well over a decade ago, Journey has partnered successfully with Hawai'i Department of Education's Hilo/Waiakea School Complex, to augment its science curriculum and spark an interest in astronomy and Science, Technology, Engineering and Mathematics (STEM)-related initiatives. District Superintendent Valerie Takata elaborates, "Our schools' stellar partnership with the observatories, business organizations, and community is Journey Through the Universe's STEM initiative. As part of the educational system, our complex area is overwhelmed with appreciation for the enthusiasm and energy this initiative has generated for our schools… students, teachers and administrators, and families. This concerted effort has made this grassroots program a sustaining reality as we move into our second decade. We humbly thank the community for their continued support as we all work together toward common goals and building a better future."

As Takata so eloquently explained, this stellar outreach initiative has a broad impact on our community. Following is a sampling of the events that lit up the Hilo schools and community with our STEM-inspired outreach activities.

We welcome you to become a part of our Journey team. For more information please visit **www.gemini.edu/journey**.

Janice Harvey is the Community Outreach and Education Programs Leader at Gemini North. She can be reached at: jharvey@gemini.edu

Gemini astronomer, Chad Trujillo, demonstrates the scale of our Solar System to 3rd grade students at Ha'aheo Elementary School.

Hawai'i State Department of Education Superintendent Kathryn Matayoshi participates with a 4th grade class at Keauakaha Elementary School in Hilo as students build and explore a 3D constellation using wooden beads hanging from strings. The demonstration was led by Gemini's André Nicolas-Chené (not shown).

Gemini North's local outreach assistant Christine Copes helps an interested visitor build an origami cube featuring Gemini images at the annual Journey Family Science Day. The event, which attracted over 2,300 participants, is a partnership with the 'Imiloa Astronomy Education Center.

Honoring Janice Harvey, a Gemini "Shining Star!"

At the annual Hawai'i Island, and Japanese Chamber of Commerces' Journey celebration, attended by a record number of Journey participants and local businesses, Gemini North's Community Outreach and Education Program Leader Janice Harvey received the Department of Education's prestigious Shining Star award (inset). In the photo, Hawai'i State Department of Education Superintendent Kathryn Matayoshi (right), and District Superintendent Valerie Takata (left) present the award to Janice for her hard work and devotion to the Journey program. The award recognizes outstanding service and dedication to education in Hawai'i and, as Gemini staff know, Janice's efforts are indeed stellar. We are especially proud of her seemingly infinite ability to share our work and inspire the future of students.

— Peter Michaud

For his presentation at Hilo High School, Gemini Director Markus Kissler-Patig discusses how, when looking for life in outer space, we might first look at Earth's own extreme life forms.

Gemini North's Public Information and Outreach Manager Peter Michaud enlightens 6th graders at Hilo Union Elementary School as they design and build simple spectroscopes to explore light.

Gemini science operations specialist Michael Hoenig uses an infrared camera at a 5th grade class at Hilo's De Silva Elementary School to demonstrate how astronomers observe the universe in different types of light.

Maria-Antonieta García

Viaje al Universo 2015: Learning, Fun, and Laughter!

The Gemini South flagship outreach program, Viaje al Universo *engaged and inspired thousands of students in late 2015.*

"Sharing what I do with local students is so energizing," says Gemini astronomer Erich Wenderoth as he reflects on time spent with students in classrooms in, and around, Gemini's host community, La Serena, Chile. Since 2006 Erich has participated in Gemini's annual *Viaje al Universo* (*Viaje*) program, sharing his passion for astronomy and science. "I look forward to the day that a young astronomer approaches me and reminds me of a talk I gave to the classroom," Wenderoth says, following his visit to San Nicolás school during the latest *Viaje* program in October.

Viaje al Universo is a week long program that brings astronomers, engineers, and science educators into local Chilean classrooms in order to share the excitement of scientific discovery with students and teachers. In addition to the classroom visits, a variety of other activities bring science down to Earth, such as StarLab portable planetarium shows, hands-on activities for the entire famililiy (see Figure 3), and a popular panel discussion that shares the job opportunities available at astronomical observatories.

Three members of Spain's stand-up/interactive comedy troupe, *"The Big Van: Scientists on Wheels"* added a healthy dose of humor to this year's mix (Figure 2). "It was an excellent week, and we discovered a lot of enthusiastic and creative people," says troupe member Irene Puerto, who, along with Alberto Vivó and Javier

Figure 1.

In early December, Gemini hosted five students and one teacher from each of the participating Viaje *schools as special guests at the Gemini South telescope facility on Cerro Pachón.*

Santaolalla, entertained and inspired nearly 4,000 students and teachers during their week in Chile. “Beautiful stages were waiting for us at the schools and two astronauts accompanied our performance in a fruit market and in front of a cathedral. It was definitely an unforgettable experience!” adds Vivó.

“Gemini is thrilled that we have many new partners in our effort this year,” said Gemini Deputy Director Nancy Levenson at *Viaje’s* opening ceremony. “It is indeed a sign that we are having an impact when our community steps up to participate actively in our work.”

This year’s *Viaje al Universo* program engaged students and teachers from six regional schools: San Nicolas, Trinity, St. Mary’s, San Joaquin, Carlos Condell de la Haza, and Martin de Porres. Helping to advance their knowledge were staff from the following observatories and astronomy affiliates: the Association of Universities for Research in Astronomy, Gemini Observatory, Cerro Tololo Inter-American Observatory, Las Campanas Observatory, the Giant Magellan Telescope, the Office for the Protection of the Northern Sky of Chile, and the University of La Serena.

As a special treat, Gemini also hosted in early December five students and one teacher (from each of the schools that participated in the *Viaje* activities) as guests at the Gemini South telescope facility on Cerro Pachon (Figure 1). More surprises and special events are now being planned for Viaje 2016. We hope to see you there!

To learn more about *Viaje al Universe*, please visit: ***www.gemini.edu/viaje***

Antonieta García is Gemini South’s Outreach and Media Specialist. She can be reached at: agarcia@gemini.edu

Figure 2.
Students from Carlos Condell de La Haza Christ School (La Serena), and República de Israel (Coquimbo) join the “Big Van: Scientists on Wheels” and Gemini staff after a presentation of fun scientific monologues.

Figure 3.
Learning phases of the Moon is much more attractive when you can eat the cookies, at least according to members of this Trinity School’s family after their participation in Viaje al Universo *program.*

Figure 4.
Big Van's Javier Santalaolla (third from left), illustrates a proton collision by having San Joaquín School students interact in front of the entire high school audience.

Figure 5.
Although the Viaje program targets schools, a public event at La Serena's "Café ConCiencia" coffee shop attracted an engaged audience.

Figure 6.
Staff from the La Serena City Hall Department of Tourism participate in a special workshop lead by the Big Van members to help improve their skills at communicating science to the public.

This image shows Gemini staff (Andy Stephens, Andreea Petric, and Adam Smith, front to back) during the recently initiated remote operations at the Gemini base facility in Hilo, Hawai'i.

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.

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