Publication of the Gemini Observatory

GeminiFocus

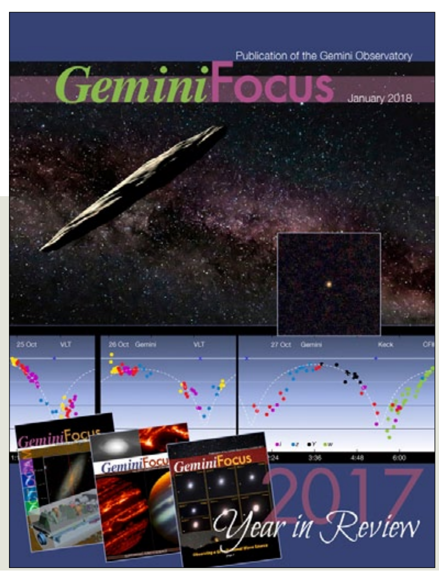
January 2018

2017 Year in Review

ON THE COVER:

Artist's concept of interstellar asteroid 1I/2017 U1 ('Oumuamua), which is unlike that of any object seen in our Solar System. The small inset at center shows a Gemini image of 'Oumuamua, while the panel below it shows the object's light curve created from VLT, Gemini (North and South), and Keck data. The article summarizing this work begins on page 3. Also shown are the covers from the April, July, and October issues of Gemini*Focus.*

Credit: Gemini Observatory/AURA/NSF (inset); University of Hawai'i Institute for Astronomy (panel); Gemini Observatory/AURA/NSF/Joy Pollard (background artwork).



*Gemini*Focus January 2018 / 2017 Year in Review

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Director's Message

2017: An Exciting Year at Gemini

Is there no end to the excitement at Gemini?

Much has happened at Gemini both before and since I took on my new role as the Observatory's Interim Director in July 2017. One major event, reported in the October issue of *Gemini*Focus, was the GW170817 gravitational wave whose signal rattled the LIGO and Virgo detectors for almost two minutes on August 17th. The Gravitational Wave was triggered by two neutron stars spiraling closer to each other and finally merging — the first ever of its kind. Gemini "pulled out all the stops" and for three weeks followed up the source and helped bring it into focus, allowing astronomers to dissect the first optical and infrared light emissions ever associated with such an event.

Two months later we witnessed yet another exceptional event: on October 19th, the Pan-STARRS survey detected a small, high-velocity asteroid, A/2017 U1, moving away from Earth. Nothing unusual… if it weren't for the fact that the visitor was from interstellar space, earning A/2017 U1 the new designation 1I/2017 U1 and the Hawaiian name of 'Oumuamua (meaning "Scout"); at Gemini, we observed 'Oumuamua for three days and helped reveal its unique nature.

And there were other research "firsts" in 2017: Gemini Multi-Object Spectrograph observations at Gemini South provided the first confirmations of strong gravitational lensing systems at galaxy- and galaxy-cluster scales (enabled by our Large and Long Program); a joint Gemini-North/Very Large Array effort localized and identified — for the first time — the host galaxy of a once mysterious fast radio burst (some 1 billion parsecs distant); Gemini North + GRACES data revealed the only likely candidate known to date of a star ingesting a planet; and data from the Gemini Near-InfraRed Spectrograph allowed astronomers to constrain the mass of the most distant known quasar to a whooping 800 million solar masses.

Technical Triumphs

Gemini also celebrated several technical triumphs in 2017. In February, after a year of preparation, we achieved a major milestone with Base Facility Operations (BFO) officially starting at Gemini South. BFO is now in full swing at both sites (Chile and Hawai'i): all observations are carried out from our headquarters in La Serena and Hilo, with no personnel present on the mountain at night, significantly improving our environmental stewardship (mostly due to fewer trips up and down the mountains). We also saw much forward progress in software development that will benefit our users, including new Gemini MOS Mask Preparation Software, and a new GMOS WaveMapper. Also, plans are now underway to upgrade the very dated Observatory Control Software, on which both Gemini and our users rely.

On the instrumentation side, in 2017, we celebrated the selection of OCTOCAM as our next facility-class instrument; this wide-band (visible/near-infrared) medium-resolution spectrograph and imager will support a wide range of science and take advantage of the Large Synoptic Survey Telescope follow-up opportunities. Beyond allowing spectral studies over a broad wavelength range (ideal, for instance, to determine photometric redshift of distant galaxies and quasars), OCTOCAM will also enable broadband timing studies, such as reverberation mapping of X-ray binaries and active galactic nuclei (AGN). While Gemini will always rely on facility instruments, we also have a long-admired, and popular, Visiting Instrument Program that continued to grow in 2017. One highlight is the visiting speckle instrument 'Alopeke on Gemini North which has just recently completed commissioning by Principal Investigator (PI) Steve Howell.

And finally, on October 26th, just as 'Oumuamua was making its way through the Solar System, staff at Gemini South propagated the Gemini Multi-conjugate adaptive optics System (GeMS) laser guide star constellation for the first time with the new TOPTICA Phototronics laser. This was the first of several important steps designed to restore GeMS to its intended performance. As this issue goes to press, the new TOPTICA laser for Gemini North has arrived on Maunakea and preparations are underway for its commissioning in 2018.

Closing on a High Note

Gemini prides itself in not only the excellent research conducted by its PIs and their teams, but also its public outreach departments in both hemispheres. One significant achievement was Gemini Observatory assistant scientist Meg Schwamb being awarded the 2017 Carl Sagan Medal for Excellence in Public Communication in Planetary Science. Her efforts were aligned with Gemini's two outstanding and public outreach programs — *Journey Through the Universe* in Hawai'i and *Viaje al Universo* in Chile — whose combined programs bring scientists and professionals from different observatories into the classroom to motivate students into pursuing future careers in science, technology, engineering, and math (STEM).

I'm proud to be a part of the Gemini community and grateful for the opportunity to help advance the Observatory's mission: "Exploring the Universe, Sharing its Wonders."

Laura Ferrarese is the Gemini Observatory Interim Director. She can be reached at: lferrarese@gemini.edu

John Blakeslee

Gemini North and South Join in Welcoming the Solar System's First Interstellar Emissary

Two months after the first electromagnetic counterpart to a gravitational wave detection caused Gemini to "pull out all the stops" in its effort to follow the event as long as possible, the Observatory reprised its performance, but this time for a few nights only, when the first known interstellar object streaked through our Solar System. Observations were carried out with both the Gemini North and South telescopes during late October 2017 and enabled astronomers to characterize the peculiar properties of this exotic visitor.

Note: Parts of the following article are adapted from the Gemini Observatory press release issued on November 20, 2017. The original release is ***available online***.

Planet formation is a messy, sometimes violent, affair. The evidence is imprinted in the countless impact craters that pockmark the face of our Moon and the other airless, rocky bodies that retain the scars of the distant past. It is believed that numerous asteroids and comets were ejected entirely during the early stages of our Solar System as a consequence of interactions with the giant planets Jupiter and Saturn. The same should be true of all other planetary systems with giant planets, which may comprise the majority of the systems around stars in the Milky Way. Doing the numbers, one finds that trillions of objects must be wandering the vast expanses between the stars. However, the likelihood that any one of these wanderers would make a close approach to another planetary system is tiny.

On October 19, 2017, a small near-Earth object discovered by the Pan-STARRS1 survey telescope on Haleakala was found to be moving away from the Earth at a speed so high that the Sun's gravity was insufficient to prevent the object from escaping. Thus, the object was

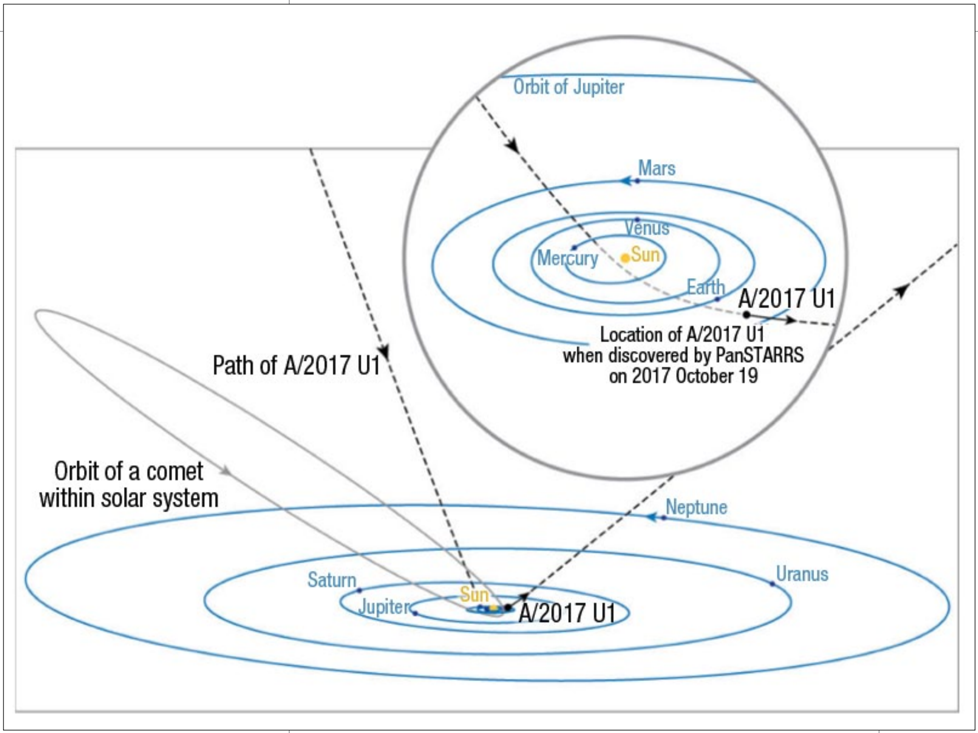

Figure 1.
The trajectory of 'Oumuamua, previously known as A/2017 U1, through our Solar System. Orbits of the eight major planets and a Halley-type comet are also shown.
Credit: Brooks Bays, SOEST Publication Services, UH Institute for Astronomy

on a hyperbolic path passing through our region of space, rather than a closed elliptical (or borderline parabolic) orbit like the Earth and all other planets, asteroids, and comets ever encountered within the Solar System. This meant that it must have originated from some other star system, the first definitively detected emissary from the stars.

The object's discovery was officially *announced by the Minor Planet Center* (MPC) on October 25th and given the provisional cometary designation C/2017 U1. Gemini received a Director's Discretionary Time (DDT) proposal from the discovery team for multi-band imaging with the Gemini Multi-Object Spectrograph (GMOS) at Gemini South and obtained the requested observations on the evenings of October 25th and 26th. Although the target was accessible from both Cerro Pachón and Maunakea, weather conditions in the North were poor on the first night, and therefore the two widely separately sites proved once again a major advantage.

Two additional teams submitted DDT proposals for GMOS and Near-InfraRed Imager and spectrometer (NIRI) imaging at Gemini North and obtained data over three nights beginning on October 26th (UT October 27th). During the course of this campaign, the object's provisional designation was *changed to A/2017 U1* because no cometary tail was detectable in very long exposures. Thus, excluding sci-fi explanations, its surface must be rocky like an asteroid, rather than icy like a comet. The change with respect to the designation specified in the DDT programs initially caused the observing software not to find the target coordinates from the online NASA database, but the issue was quickly solved by alert Gemini staff. All three DDT programs were successfully completed in October and have produced publications.

Before the interstellar visitor sailed away from our shores forever, it was renamed once more. The naming convention for minor planets (such as comets and asteroids) prescribed by the International Astronomical Union (IAU) did not allow a formal name to be assigned based on the too-brief arc of observation. However, as explained in an *MPC Circular issued on the 7th of November*, "Due to the unique nature of this object, there is pressure to assign a name." The will of the people was heard, and the IAU introduced a new designation scheme for interstellar objects. The asteroid formerly known as A/2017 U1 received the permanent designation 1I (to indicate its status as the first interstellar object) and the name 'Oumuamua. The name is of Hawaiian origin and connotes the idea of an advance scout, or a messenger "reaching out" to us.

Science Returns

The scientific developments resulting from 'Oumuamua's passage through our Solar System are even more remarkable than those related to nomenclature. The observations from Gemini and other observatories imply that the object is exceptionally elongated in shape. "What we found was a rapidly rotating object, at least the size of a football field, that changed in brightness quite dramatically," said Karen Meech of the University of Hawai'i's Institute for Astronomy, and the leader of the discovery team that first obtained Gemini DDT observations of the object. "This change in brightness hints that 'Oumuamua could be ten times longer than it is wide — something which has never been seen in our own Solar System." The best current estimates are that the object has the dimensions, roughly speaking, of five football fields laid end to end (omitting endzones).

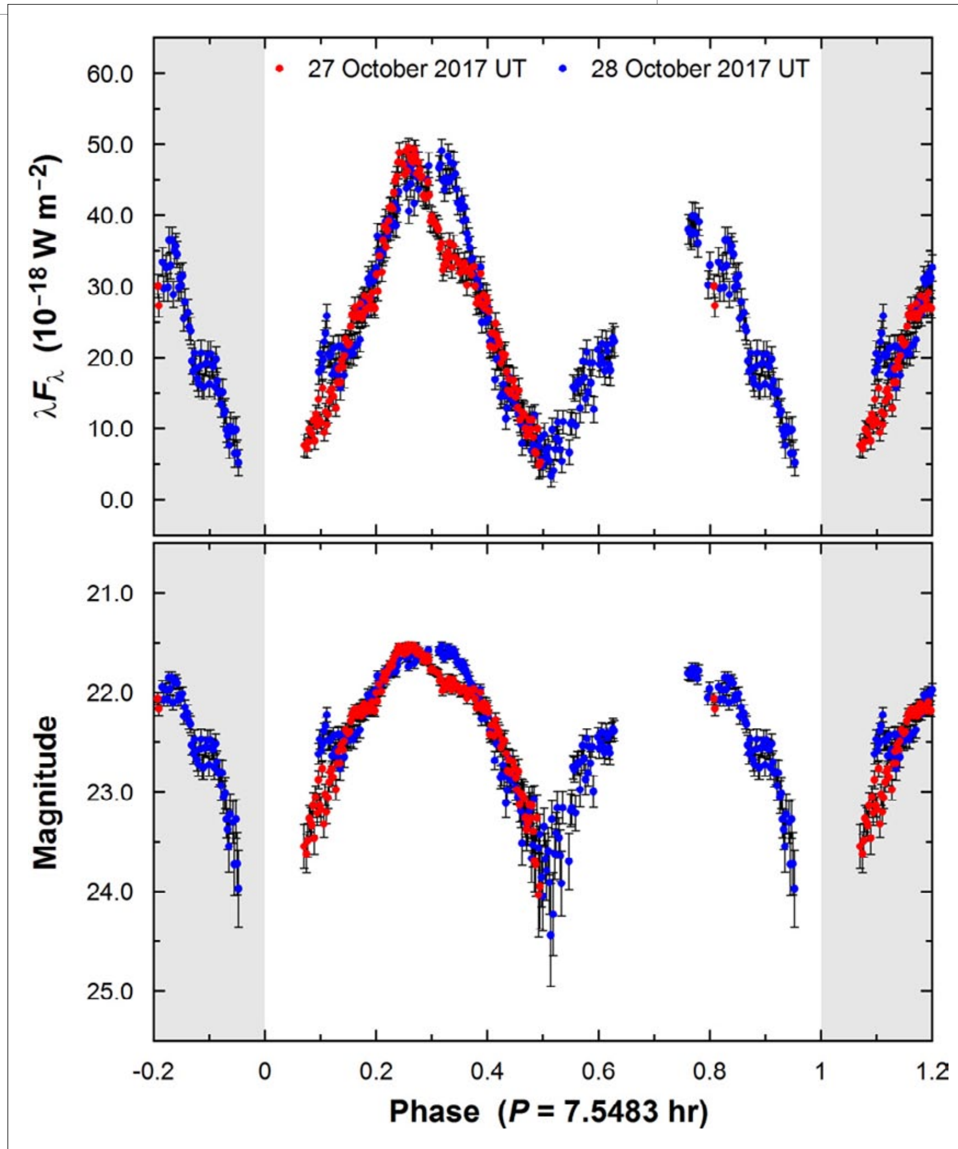

Figure 2.

Variations in the brightness (top) and magnitude (bottom) of 'Oumuamua, as measured in the r-band filter with GMOS on successive nights in late October. The rotation period is determined with high precision to be 7.5483 hours, but the light curve does not repeat exactly from one rotation to the next. This indicates the object is "tumbling." Figure reproduced from Drahus et al., https://arxiv.org/abs/1712.00437.

The research led by Meech combines observations from the Gemini South and Very Large Telescopes in Chile, as well as from Pan-STARRS, Keck 2, Canada-France-Hawai'i, and the United Kingdom Infrared Telescope in Hawai'i. The study was published in the ***November 20th online issue of* Nature**.

Although the shape of 'Oumuamua is like nothing seen in our Solar System, its color is more conventional. "Our first interstellar planetesimal is just slightly redder than reflected sunlight," said Michele Bannister, an astronomer at the Astrophysics Research Centre of Queen's University in Belfast, and the leader of another team that obtained Gemini DDT observations of 'Oumuamua. "This is fascinating, as we might have expected it would be deep red from spending a long time travelling between stars, where cosmic rays would alter organic molecules on its surface. Instead, its colour looks a lot like those of tiny minor planets in our own Solar System that orbit in Jupiter's Trojan clouds, or some that orbit beyond Neptune."

Bannister adds, "Gemini's ability to observe near-simultaneously in the optical and near-infrared with rapid instrument-switching was ideal, as 'Oumuamua turned out to be strongly variable in brightness, and we had to quantify that to properly measure its colours." A paper presenting the results from Bannister's team has been accepted by *The Astrophysical Journal Letters*. A preprint is ***available online***.

An additional surprise from 'Oumuamua was highlighted in a study by the third team that obtained Gemini observations during the event. The team, led by Piotr Guzik and Michal Drahus of the Astronomical Observatory of Jagiellonian University in Kraków, obtained 442 individual exposures all in the same red filter. "Thanks to the long, continuous observations at Gemini, we found that the light curve does not repeat itself — there are small differences from one rotation to the next," explained Siyi Xu, an astronomer at Gemini Observatory and a coauthor on the study. "The most likely explanation is that this object is 'tumbling' — its rotation axis is not aligned with its principal axis."

These results have been submitted for publication, and a preprint is ***available online***.

Catastrophic Remains

The "tumbling" motion of 'Oumuamua as it travels through space suggests that it may have experienced a catastrophic collision in the distant past, perhaps the event that sent it, and likely myriad compatriots, careening across the cosmos. However, ***another preprint*** by Bannister's team points out that tidal torquing during close encounters and outgassing events can also set a body tumbling.

It is unlikely that 'Oumuamua is unique. The Large Synoptic Survey Telescope, now under construction near the Gemini South telescope in Chile, will begin operations in a few years and is expected to find many more of these interstellar wanderers. What will be their shapes, colors, and trajectories? The Gemini telescopes will be ready to characterize these new discoveries as well. Notably, the forthcoming OCTOCAM instrument on Gemini South will enable high-cadence observations in eight wavelength bands simultaneously, a truly revolutionary innovation for such follow-up studies.

Predictably, science fiction allusions abounded in the wake of 'Oumuamua's passage through our neighborhood. Most commonly, the reference was to the Arthur C. Clarke novel in which an enormous cylindrical object, dubbed Rama, arrives in our Solar System on a hyperbolic orbit and executes a gravitational "slingshot" maneuver during a close passage to the Sun. However, at 50 kilometers across, the fictional Rama was about 100 times larger than 'Oumuamua and was spinning on its symmetry axis, rather than tumbling headlong.

Another comparison, inspired by the name 'Oumuamau, can be made to Carl Sagan's novel *Contact*, in which a message is detected from the direction of the star Vega in the constellation Lyra. Tracing back the trajectory of 'Oumuamua, one finds that it likewise points to Lyra, very near the position of Vega. It is tempting to imagine that this messenger has come to us from the debris disk known to encircle that brilliant star that stands almost directly overhead, beckoning us from amidst the stream of the Milky Way on midsummer nights in the Northern Hemisphere.

Alas, the Milky Way is dynamic, and one million years ago, roughly when 'Oumuamua would have been at the distance of Vega, the star itself was in a very different place. Neither the signal in Sagan's novel, nor our recent interstellar visitor, truly originated in the Vega system. However, both emissaries carried the same message, and it is one worth pondering in our turbulent times. The meaning is most succinctly encapsulated in the final two lines of a very different piece of literature, a poem by the great Argentine writer Jorge Luis Borges:

"Más allá de este afán y de este verso
Me aguarda inagotable el universo."

A popular, though loose, English translation of the work puts it as follows:

"Beyond these efforts and beyond this writing
The universe awaits, inexhaustible, inviting."

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Carlos Saffe

Rocky Planet Engulfment Explains Stellar Odd Couple

To date, astronomers have found more than 3,600 planets orbiting around stars in the solar neighborhood. Nevertheless, current observational techniques challenge those searching for possible planets engulfed by their host star. By using Gemini North + GRACES high-resolution spectra in the Fast Turnaround mode, we have found a notable difference in the chemical pattern between the stars of the HAT-P-4 binary system, which could be attributed to the ingestion of at least ~10 M_{Earth} of rocky material onto the primary star.

The story begins with the star HAT-P-4, which hosts a giant planet detected by the Hungarian Automated Telescope Network (HATNet) transit survey (Kovács *et al.*, 2007). This planetary companion, designated HAT-P-4b, has a mass of 0.68 M_{JUP} (between the mass of Jupiter and Saturn), and orbits the star at a distance of only 0.04 astronomical units — about ten times closer than the distance between Mercury and the Sun. The planet's estimated density of ~0.4 grams per cubic centimeter (g/cm^3) is even lower than that of Saturn (~0.7 g/cm^3), so we consider it as a low-density hot-Jupiter planet. Searches for additional planets around HAT-P-4 using both transits and radial-velocity techniques have met without success.

The Dance Between Two Stars and a Single Planet

A few years after the discovery of HAT-P-4b, Mugrauer *et al.* (2014) showed that HAT-P-4 (hereafter, star A) forms a wide binary system together with TYC 2569-744-1 (hereafter, star B). The two stars are separated by 91.8 arcseconds in the sky and appear nearly equal in brightness (Figure 1). In addition to having common proper motions and similar radial velocities, the discoverers also showed that both stellar components present very similar spectral types, being about G0V and G2V. To date, no planet has been detected around the B component, which was also included in the same HATNet transit survey field (called

G191) with an 8˚ x 8˚ field-of-view. In summary, we have three actors in the scene: a wide binary system with two very similar components, and a hot-Jupiter planet orbiting around the primary (star A).

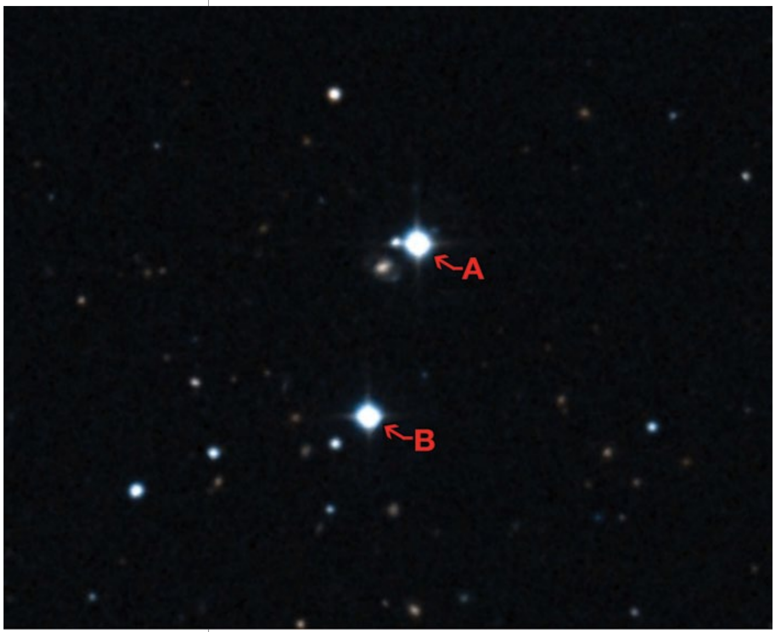

Figure 1.
Image of the HAT-P-4 binary system. The two brightest stars in the field are HAT-P-4 A and its B companion (lower left). Their Hipparcos V magnitudes are 11.12 and 11.38, respectively, and they lie 91.8 arcseconds apart.

Stars born at different times and locations in our Galaxy commonly present a different initial chemical composition due to the Galactic Chemical Evolution (GCE) effect, which leads to different chemical enrichment histories. On the other hand, it is generally assumed that individual components of wide binaries (and most multiple systems) have the same age and initial chemical composition, and formed coevally from a common molecular cloud.

This latter case is a strong advantage for comparative chemical studies, where GCE effects are greatly diminished or ruled-out; in addition, the notable physical similarity between both components of a binary system makes it possible to achieve the highest possible precision in differential chemical studies when compared to classical (*i.e.*, non-differential) methods. Such precision is a requisite in order to detect even slight differences between both stars. That HAT-P-4 is not only a binary with physical similarities between its components, but also one that harbors a planetary companion, makes it an ideal case study on the possible chemical signature of the planet formation process in a binary star system. So far, this kind of challenging analysis has been performed in only a very few systems.

A high-precision chemical abundance study requires both high signal-to-noise (S/N) and high-resolution spectra. This fact, together with the relative brightness of both stars, made the combination of Gemini North with the Gemini Remote Access to CFHT ESPaDOnS Spectrograph (GRACES) an excellent choice for the observation of this binary system. The stellar spectra were obtained under the Fast Turnaround observing mode (program ID: GN-2016A-FT-25; with the author as the Principal Investigator). We acquired the observations using the 1-fiber (object-only) observing mode, which provides a maximum resolving power of ~67,500 between 4,000 and 10,000 Ångstroms (Å). The exposure times were 2 x 16 minutes and 2 x 18 minutes for the stars A and B, respectively, obtaining a final S/N ~ 400 measured at ~6,000 Å in the combined spectra of each target.

A Surprising Chemical Difference Between Sibling Stars

We took advantage of the physical similarity between both stars and applied a line-by-line full differential technique in order to determine fundamental parameters and detailed chemical abundances. To do so, we used the FUNDPAR program (Saffe, 2011) together with ATLAS9 model atmospheres. The results showed mainly three unexpected differences in the chemical pattern of both stars. First, the exoplanet host A star is ~0.1 dex more metal-rich than its stellar companion. This difference is remarkable and much higher than most metallicity differences found in similar binary systems (see, *e.g.*, Desidera *et al.*, 2006). Second, star A shows a clear enhancement in its photo-

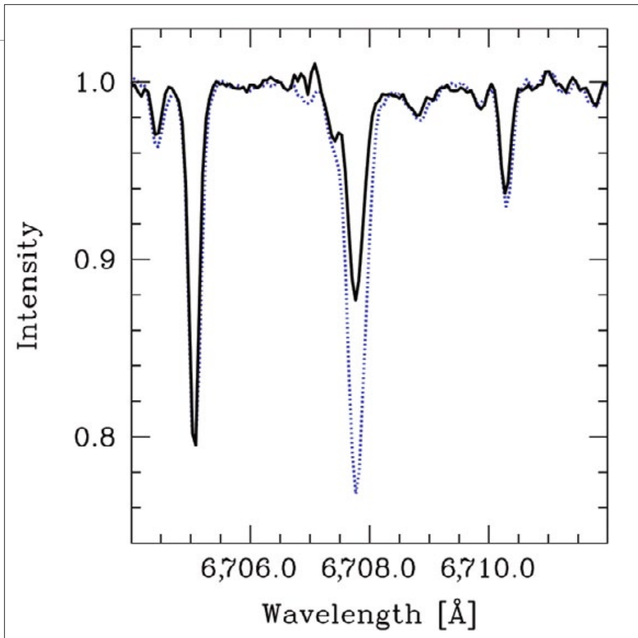

Figure 2.

GRACES spectra near the 6,707.8 Å lithium line for star A in HAT-P-4 (blue dotted line) and its B companion (black continuous line). The lithium content is notably enhanced in star A.

spheric lithium content, being about 0.3 dex more abundant than its B companion (Figure 2). As lithium is most likely destroyed when it reaches the high temperatures of the stellar interior by means of stellar convection, this great difference between two similar coeval stars is surprising and unexpected.

In addition, we also found that star A is enhanced in refractory elements when compared to its stellar companion; here we identify as "refractory" and "volatile" those species with condensation temperatures (T_C) > 900 K and < 900 K, respectively. To obtain this result, we plotted the abundance difference (B – A) between both stars versus T_C for each chemical species. Figure 3 also shows weighted linear fits (long dashed lines) to all species and only to the refractory components. A similar refractory to volatile content between both stars would correspond to null slopes in this plot. However, the negative slopes in Figure 3 point notably toward a higher content of refractory species in star A than in its stellar companion.

Chemically Peculiar Stars?

Our attempts at classifying the HAT-P-4 components to other stars with peculiar chemical patterns also brought surprises. We looked at three cases in particular: λ Bootis stars, δ Scuti stars, and blue stragglers. The so-called λ Bootis stars are a small group (only 2%) of population I stars, that show moderate to extreme surface underabundances of iron (Fe)-peak elements, but with solar abundances of carbon, nitrogen, and oxygen. In contrast, both stars A and B in the HAT-P-4 system are metal rich, and their effective temperatures are lower than those of the λ Bootis group; this allowed us to discard them as belonging to the λ Bootis class. δ Scuti stars are regularly pulsating variables with ~A6–F6 spectral types, located in the instability strip of the Hertzsprung-Russell diagram. While most of these stars present overabundances of heavy elements (between 0.5 – 1.0 dex), both the effective temperature and mass of stars A and B are not only lower than those of the δ Scuti group, but they also lie out of the instability strip boundaries. Furthermore, no stellar pulsations have been reported in either component A or B; so we also abandoned a possible δ Scuti classification. Finally, blue stragglers are stars significantly bluer than those placed on the main-sequence turnoff of the cluster (or population) to which they belong.

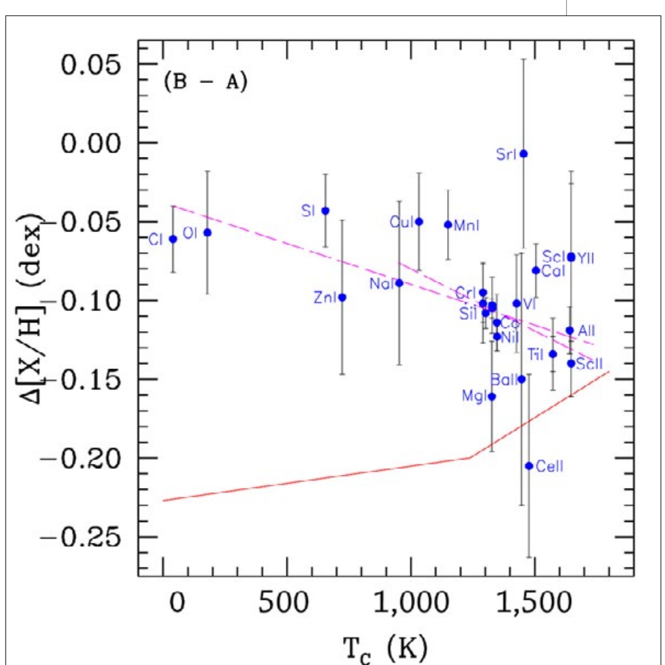

Figure 3.

Differential abundances (B - A) vs. condensation temperature T_C. Long dashed lines are weighted linear fits to all species and to refractory species. The solar-twins trend of Meléndez et al. *(2009) is shown with a continuous line for comparison.*

They also display simultaneously significant rotational velocities, activity, and very low lithium content; alas, we see none of these characteristics in the stars of the HAT-P-4 binary system.

On the Planet Engulfment Scenario

To explain the chemical abundance difference between stars A and B, we propose that at the time of planet formation, star A locked the orbiting refractory material (in the shape of planetesimals, rocky planets, or both), and formed a gas giant planet in its external disk. This was followed by the accretion of most of these refractories descending onto star A – possibly due to the migration of the detected giant planet which finally ended as a hot-Jupiter transiting planet. We estimate that some 10 M_{Earth} of rocky refractory material must have accreted onto star A in order to reproduce the observed T_C trends and metallicity. This scenario agrees with the following observational facts:

- The enhancement of ~0.1 dex in metallicity of star A compared to B. These objects do not show a peculiar chemical pattern (λ Bootis, δ Scuti, or blue straggler). In addition, the binary nature of stars A and B discards possible GCE or age effects.
- The enhancement of refractory elements in the HAT-P-4 A star compared to its B companion.
- The slightly higher mass of A compared to B, which corresponds to a lower convective mass and a lower mixing of the possible accreted material.
- The detection of a hot Jupiter and no additional planets in the A star, which do not discard a possible migration and accretion process.
- The lithium enhancement in star A compared to B.

In other words, the proposed scenario of planet engulfment fits all the observational pieces of the puzzle. Very few previous works claim a similar accretion scenario on a main-sequence star, such as the case of HD 82943 (which was then strongly disputed), or HIP 68468 (Meléndez *et al.*, 2017). That leaves HAT-P-4 as the only main candidate in a remarkable system, studied through the unique combination of Gemini North as collector with the high-resolution spectra of GRACES. We also want to stress that this work was carried out thanks to the Fast Turnaround observing mode being offered by Gemini, which is the only observatory that provides this kind of time proposal. We expect to continue this exciting study by extending the sample to other similar systems.

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Wes Fraser

July 2017

Blue Binaries Suggest a Smooth Migration for Young Neptune

A Large and Long Program using simultaneous ultraviolet and near-infrared data from Gemini North and the Canada-France-Hawai'i Telescope lead to the discovery of a peculiar population of blue-colored, tenuously bound binaries residing among the otherwise unanimously red "cold classical" Kuiper Belt objects. These widely separated binary objects could have survived perturbing forces during the early phases of Neptune's migration, helping us to better understand the planet's accretion history in the outer Solar System.

A Brief History of the Kuiper Belt

The Kuiper Belt is complicated, and weird. Consider its shape (see Figure 1). First a disclaimer: the community uses the term belt pretty loosely. Imagine instead a broad torus hundreds of astronomical units (AU) thick and tens of AU tall, with a 30 AU radius hole cut out of the middle. That's the true shape of the Kuiper Belt.

Beyond its poorly named shape, what really catches a scientist's eye is the Belt's layered dynamical structure. The first Kuiper Belt Object (KBO) discovered, 1992 QB1, belongs to the so-called cold classical population, named for what may have been expected to reside beyond Neptune: a population of planetesimals on circular, low inclination orbits, in a ring (or belt).

Unlike the asteroid belt, whose empty Kirkwood gaps can clearly be attributed to the clearing effects of mean-motion

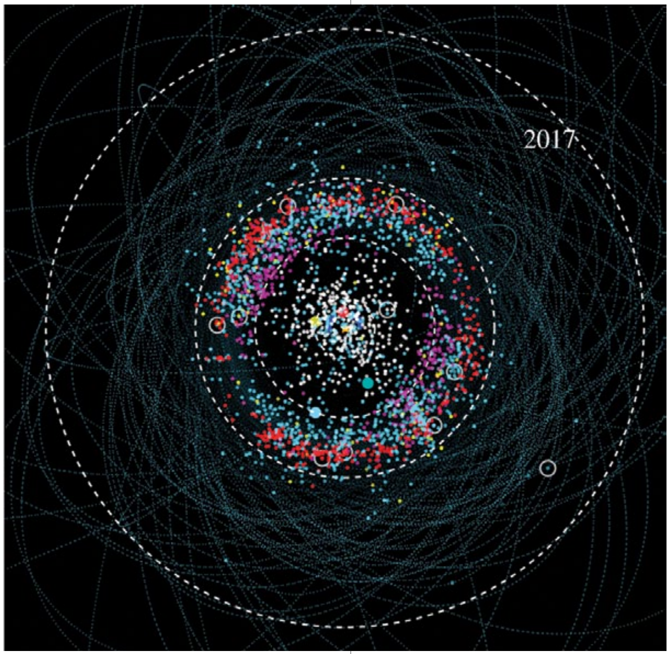


Figure 1.
Rendering of the outer Solar System. Small points correspond to the >1,700 known and tracked objects. Colors correspond to different dynamical classes — the cold classicals are in red, the resonant plutino and twotino objects are in purple and yellow, the transitory centaurs are in white, and the non-resonant excited objects are in light blue. A handful of the orbits of this class are shown by the dotted blue lines. The gas-giant planets are the larger circles, and the largest ten dwarf planets are identified with white circles. Distances at 30, 50, and 100 AU are shown by the dashed white circles.

resonances (MMRs) with Jupiter, the Kuiper Belt's external MMRs with Neptune are just teeming with objects — including the famously demoted Pluto. At first glance this is an odd state of affairs, because the action of placing an object into a MMR requires overcoming a potential barrier. Once inside one of Neptune's MMRs, resonant KBOs experience a restoring force keeping them at nearly the same semi-major axis, and are generally protected from other disturbing forces that might cause them to drift through the region. How so many objects got into resonance in the first place, however, was perplexing.

The overabundance of KBOs in resonances with Neptune is the best evidence we have that, at one point, Neptune moved outward to its current position. We have Renu Malhotra and her excellent work to thank for that (Malhotra, 1993). Malhotra recognized that if Neptune migrated outward, so too would the locations of Neptune's MMRs. Those moving MMRs would have a sweeping effect on any planetesimal populations they pass over, picking up many of those objects into resonance as the MMRs moved past. This breakthrough realization reflects the mindsets of many KBO scientists; the interest is not so much in the KBOs, but what the KBOs tell us about the Solar System's early formation and evolution.

Figure 2.
Gemini North and the Canada-France-Hawai'i Telescope (left, background). Both telescopes played a critical role in this research on blue binary Kuiper Belt objects.

Credit: Joy Pollard

Since Malhotra's original work, a number of competing theories about Neptune's outward migration have been put forth, which generally fall into two categories: 1) smooth migration, as originally envisioned; or 2) a violent outward jump. The latter is best typified by the Nice model: the gas-giant planets, originally in a more compact configuration, through mutual gravitational interaction, hopped from their primordial locations to nearly their present-day locations in an explosive outward jump (Tsiganis *et al.*, 2005 ; Levison *et al.*, 2008). If this idea is true, Neptune moved outward quite rapidly, by as much as ~ 10 AU. It now appears that some combination of smooth migration and dynamical instability-driven migration is responsible.

Investigating the Remnant Populations

The picture of the Kuiper Belt we now have is of two remnant populations: the dynamically excited objects, and the cold classicals. The dynamically excited objects, or hot objects, which include objects in MMRs, are a remnant that survived the reorganization of the gas-giants, and were scattered into the general Kuiper Belt region. The cold classicals have long been thought to be objects that formed *in-situ*, having avoided any significant perturbations by the marauding gas-giants.

The idea of *in-situ* formation of the cold-classicals is supported by three lines of evidence: 1) their cold orbit distribution, which signifies their avoidance of any past significant dynamical perturbation; 2) their unanimously red surfaces, which contrast with the two color classes (blue and red) found in the hot KBO populations; and 3) the fact that many are found in widely separated binary pairs. In a landmark publication, Alex Parker demonstrated that the wide binaries seen in the cold classicals would not have survived outward scattering experienced by the hot population, providing the strongest evidence we have that the cold classicals have not moved significantly since formation (Parker & Kavelaars, 2010).

For some time, the Kuiper Belt science community has recognized an opportunity to trace out Neptune's dynamics using the current distribution of KBOs — not just their orbital distribution, mind you, but their color distribution as well. The simple version goes like this: if the cold classicals all formed within the current cold classical belt, then it holds that by identifying these objects outside that region by their red colors and high frequency of binarity, we can place strong constraints on the possible migration scenarios that have sculpted the region.

Currently, there are more than 1,700 KBOs catalogued in the Minor Planet Center. A big boost has come from the Outer Solar System Origins Survey (OSSOS; Bannister *et al.*, 2016) which searched and tracked nearly 1,000 KBOs over a total area of about 170 square degrees. OSSOS provided the perfect survey from which to apply the idea of color mapping to trace the early dynamics of the Kuiper Belt. From this, the Gemini Large and Long Program, Colours of the Outer Solar System Origins Survey (Col-OSSOS), was launched. Operating simultaneously on Gemini-North and the Canada-France-Hawai'i Telescope (CFHT; Figure 2), Col-OSSOS measured UV-Optical-NIR colors of 81 objects (to date and counting) to find identifying surface signatures of unique populations like the cold-classicals, and then map those populations throughout the Kuiper Belt region.

The first big success of Col-OSSOS came from the unexpected discovery of a population colloquially known as the blue binaries (Fraser *et al.*, 2017; Figure 3). As their name suggests, these objects are predominantly (if not entirely) in widely separated, binary pairs (Figure 4), and belong to the blue class of KBOs. What's strange, however, is that these blue binaries are only found among the cold classicals; to first order, their orbital distribution is indistinguishable from the red cold classicals.

The six known blue binaries contrast with most properties of the red cold classicals: they aren't the same color; they are entirely binary compared to the red cold classicals of which only ~ 30% are binary; and, critically, they are all in extremely fragile widely separated pairs. That last detail was important to recognize; recall that the fragility of these binaries has been used as the best evidence for the hypothesis of *in-situ* formation for the cold classical KBOs. It implies then that the blue binaries also formed *in-situ*.

The difficulty with this idea, however, is that no known coloring process could reproduce the observations: only binary cold classicals are blue; only some binaries are blue; and for all binaries observed to date, both components are equally colored. For example, stochastic collisions could dredge up fresh blue ice and recoat the surfaces of only a few

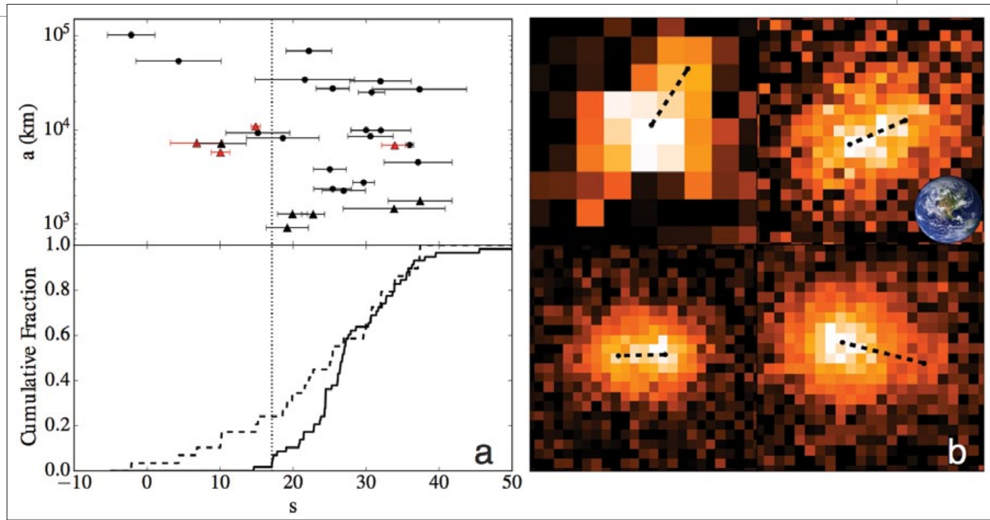


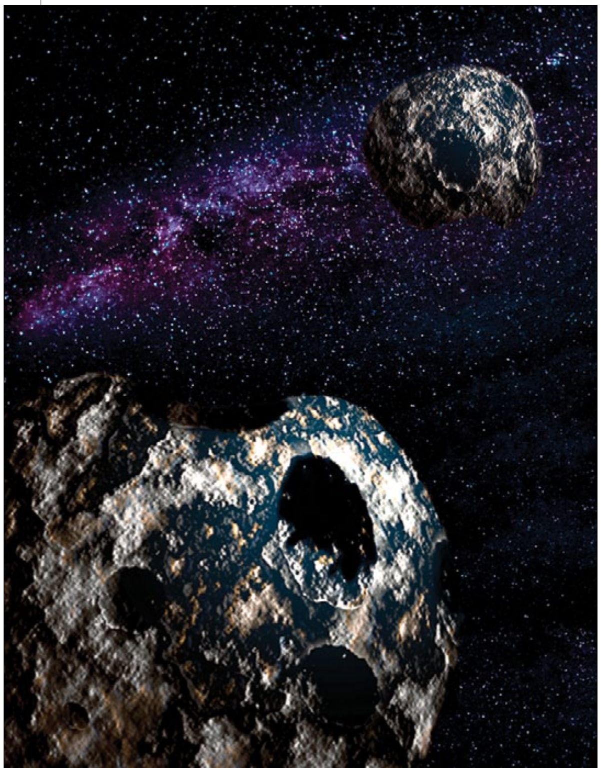
Figure 3.

Left Top: *Binary semi-major axis versus optical spectral slope, s, of known CCKBO binary objects with well determined colors. We quantify a target's color with spectral slope, defined as percent increase in reflectance per 100 nm change in wavelength normalized to 550 nm. Points in red are new binaries presented here. Round points indicate systems for which the binary semi-major axis has been determined. Triangles are lower limits on semi-major axis.*

Bottom: *Cumulative spectral slope distribution of single (58 objects, solid line) and binary cold classical objects (29 objects, dashed line). The vertical dotted line is the spectral slope that divides the blue and red classes of the dynamically excited KBOs.*

Right: *Images of the four new binaries, scaled to the same relative distance scale. Black lines show the fitted distances of the two components. The points are roughly 5x larger than the true sizes of the objects. Clockwise from top-left, 2002 VD131, 2016 BP81, 2014 UD255, and 2013 SQ99. The Earth, with mean diameter 12,742 km, is shown for scale.*

Figure 4. *Artist's concept of a tenuously bound blue binary pair. Such loosely coupled icy fragments may have joined young Neptune in its smooth outward migration from the inner to the outer Solar System. Credit: Gemini Observatory/AURA/NSF, artwork by Joy Pollard.*



systems. But this would act to favor recoloring of the impacted body more frequently than the secondary. Moreover, single KBOs would be affected in the same way as the binaries, and yet we see no blue single cold classical KBOs.

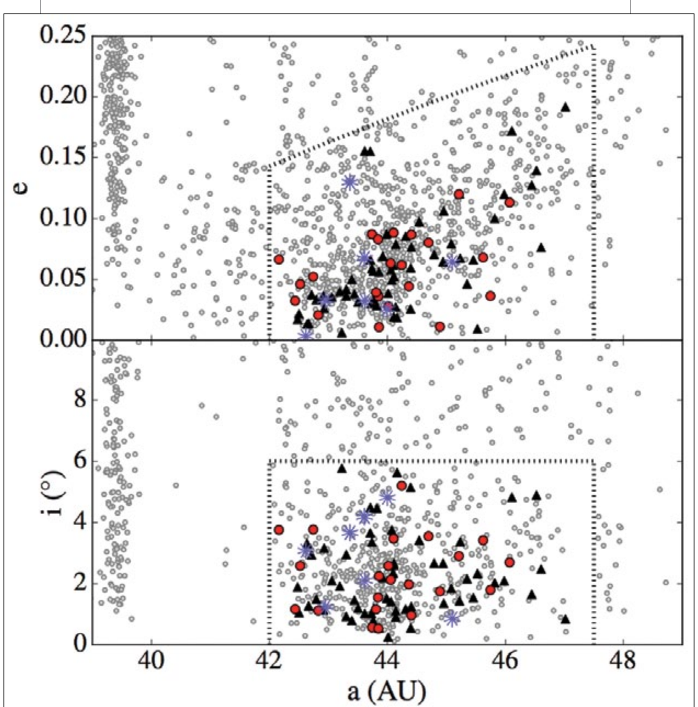


Figure 5. *Barycentric orbital elements, eccentricity (top) and inclination (bottom) vs. semi-major axis of KBOs. The dashed lines show the boundaries of the cold classical region we adopt; colored points are CCKBOs with well measured colors. Grey points are objects with no reliable color measurement. Black triangles, red circles, and blue stars represent single, red binary (s > 17%), and blue binary (s < 17%) CCKBOs.*

We concluded that the blue color of these objects was primordial. But how?

A Solution?

The idea for a solution occurred upon a review of work by Nesvorný (2015) who argued for a Neptune migration scenario that involved an early stage of smooth, gentle migration, followed by a late stage instability or jump. N-body simulations demonstrated that during Neptune's smooth migration, widely separated binaries could survive sweep-up and push-out in the 2:1 MMR, some of which were dropped into the cold classical region during the later jump. The key realization was of the gentle push-out that occurs during smooth migration, and not the violent scattering that populated all hot KBO populations. This led us to conclude that, unlike the red cold classicals, the blue binaries are interlopers or contaminants that survived this push-out process (Figures 5 and 6).

From the existence of these blue binaries, we now know that Neptune must have undergone an early phase of smooth outward migration. Our simulations suggest that the blue binaries could be accounted for if Neptune migrated ~ 7 AU over an exponential timescale of ~ 30 million years. It is still early days, however, as much of the parameter space around this migration needs to be tested. How fast could Neptune have migrated without disrupting the blue binaries? How far did the binaries likely get pushed out? These and other important questions are yet to be determined.

The astute reader will immediately see the elephant in the room. Beyond what the blue binaries have told us about Neptune's early days, we are faced with the surprising result that before push-out, the majority of planetesimals near ~ 35 AU were binary. We know this from the simple fact that no blue singles have been found in the cold classical region. Only binaries with only blue or only red components would not have formed in the current environment. This result is genuinely surprising, as it is difficult — but not impossible — to envision a planet growth scenario that, at one point, all objects were bound up in binary or higher multiplicity systems.

Various binary mechanisms have been proposed, like the so-called L2s mechanism by Peter Goldreich in which two large planetesimals (the "L2") are temporarily captured, and sufficient angular momentum to bind the pair is subsequently removed through friction with a sea of small pebbles (the "s" in L2s). This idea was deemed to be inefficient, as it requires what was considered a much too massive sea of pebbles to produce a high binary fraction. With our new findings, however, Goldreich's idea, and other binary formation mechanisms deserve another glance; clearly, whatever mechanisms could plausibly produce a near 100% binary fraction will inevitably provide reformation of our — admittedly poor — understanding of the planet accretion history in the outer Solar System.

I can't, in good conscience, conclude without a mention of the CFHT and the amazing u-band data it is providing for us. In all respects, the blue binaries result made use of only the (g'-r') color observed at Gemini. Much of the rest of the data, including the CFHT u-band, remain untapped, and still needs to be thoroughly analyzed. Col-OSSOS was designed to look for KBO color signatures that could inform us of Neptune's migratory history, and indeed the formation of the outer Solar System. Other publications by our group are in the pipeline which follow this theme; there is much to come.

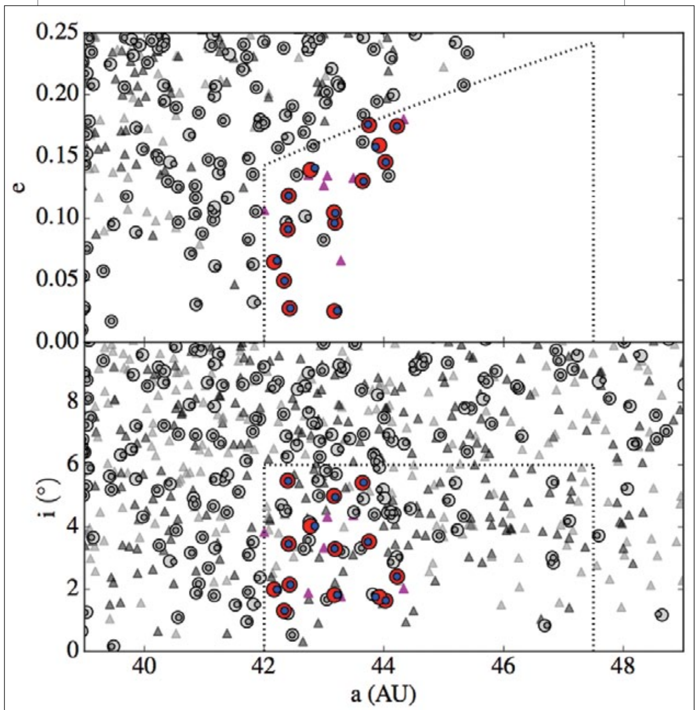


Figure 6. *Barycentric orbital elements of the surviving particles immediately after Neptune's jump, at 27.8 AU. Dotted lines demark the cold classical region. Pairs of overlapping large and small round points mark bound binary pairs, and triangles mark single objects — all of which are the result of binary unbinding. Red-blue pairs and purple triangles are those binary and single objects which were emplanted in the cold classical region. As in Levison* et al.*, some objects transported outward into the cold classical region fell out of the 2:1 MMR before the jump due to Neptune's non-smooth migration, while others dropped out of the resonance when the planet jumped.*

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April 2017

Shriharsh P. Tendulkar, on behalf of the FRB 121102 collaboration

The Host Galaxy of the Repeating Fast Radio Burst FRB 121102

Fast radio bursts (FRBs) are a recent astronomical mystery consisting of short, yet extremely bright, pulsar-like bursts of radio waves that seem to traverse cosmological distances. Although they occur at a stunning rate of 1,000 per day in the entire sky, we know little about their origins, generation mechanisms, and, until recently, even their distances. Using the combined forces of the Karl G. Jansky Very Large Array in New Mexico and the Gemini North telescope in Hawai'i, we have localized and identified — for the first time — the host galaxy of an FRB. Surprisingly, the host galaxy is a low-metallicity, star-forming, dwarf galaxy ~1 billion parsecs distant, which hints at possible similarities of this FRB host to those of superluminous supernovae and long-duration gamma-ray bursts.

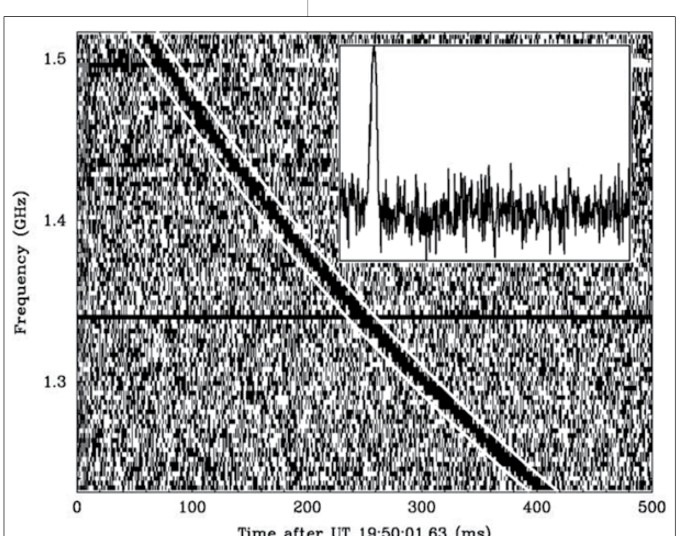


Figure 1. *The arrival of the Lorimer burst heralded a new era in radio astrophysics. The dynamic spectrum of the pulse is shown with frequency along the y-axis and arrival time along the x-axis. The grayscale depicts the 1-bit digitized intensity. Two thin white lines are drawn along the theoretical dispersion relation to guide the eye. The inset shows the total intensity profile as a function of time after correcting for dispersion. Figure adapted from Lorimer* et al., *2007.*

Almost exactly ten years ago, Duncan Lorimer and his team at West Virginia University were searching archival data from the 64-meter Parkes telescope in New South Wales, Australia, for bright single pulses from Galactic radio pulsars. They discovered a short and brilliant burst (Figure 1; now known as the "Lorimer" burst) with a flux density or radio brightness of 30 Jansky (Jy)[1], bright enough to saturate the detectors at Parkes (Lorimer *et al.*, 2007). More oddly, unlike Galactic radio pulsars, the burst had a dispersion measure (DM; see the box, next page) far greater than the contribution of the Milky Way along that line of sight — 375 pc/cm^3 compared to the Galactic contribution of 25 pc/cm^3.

[1] Jansky = 10^{-23} erg/cm^2/s/Hz.

The simplest, yet unbelievable, explanation is that the source is extragalactic and the excess DM is contributed by the electrons in the intergalactic medium (IGM) — placing the source of the Lorimer burst at a redshift of $z \sim 0.3$, a distance of ~ 1 billion parsecs. The emitted power at the source would have been 10^{42} erg/s, about a billion times more luminous than the brightest radio pulsars ever observed in the Milky Way.

Cold Plasma Dispersion

When electromagnetic waves pass through interstellar plasma, the inertia of electrons moving in response to the electric fields causes the lower frequency waves to propagate slower than the higher frequency waves. For non-relativistic, diffuse plasma, the pulse arrival time difference between two frequencies is given by

$$t_1 - t_2 = \frac{e^2}{2\pi m_e c} DM\ (\nu_1^{-2} - \nu_2^{-2}),$$

where the dispersion measure $DM = \int_s^o n_e dl$ is the integral of the electron density from the source to the observer, ν is the radio frequency and m_e, e and c are the mass and charge of an electron and the speed of light, respectively. The Milky Way interstellar medium (ISM) contribution to the DM along different lines of sight has been characterized using pulsar DM measurements, HI maps and Galactic models. Any excess in DM would have to be attributed to either excess electrons near the source or the intergalactic medium (IGM).

The Population of FRBs

Over the next decade, such radio bursts were detected at multiple radio telescopes — Parkes, Green Bank (West Virginia), Arecibo (Puerto Rico), and Molonglo (near Canberra, Australia) — and came to be known as Fast Radio Bursts (FRBs). To date, only 26 bursts have been reported in the literature, but considering the narrow fields-of-view of radio telescopes and the survey durations, the expected sky rate of FRBs is large — 10^3 per sky per day above a peak flux density of 1 Jy at an observing frequency of 1.4 GHz (Lawrence *et al.*, 2016).

Despite this prodigious rate, we have little knowledge about the sources that emit FRBs and the emission mechanisms that allow such luminous coherent bursts. Until this work, even the distance to any FRB was only estimated from the excess DM. Due to the paucity of observational constraints, there are more theoretical models of FRBs than the total number of observations (see box at right). In the future, FRBs are projected to serve as excellent cosmological probes of the electron and baryon distribution in the Universe.

The Repeater

FRB 121102 was discovered by the 300-meter Arecibo Observatory during a survey of the Galactic plane with a DM of 557 pc/cm^3 (Spitler *et al.*, 2014). In follow up Arecibo observations conducted in 2015, eleven more bursts were found at the same location with the same DM (Spitler *et al.*, 2016), earning FRB 121102 the moniker "Repeater." None of the other FRBs, even after several follow up observations of various durations, have yet been observed to repeat.

It is not clear at this time whether the Repeater belongs to a separate population from the rest of the FRBs or whether all FRBs are a homogeneous population — but the much higher sensitivity of Arecibo compared to other radio telescopes allowed Arecibo to detect fainter bursts; ones that are likely to be more frequent than bright bursts and may

Theoretical Models for FRBs

Due to the very short timescale (few milliseconds) and the bright, often polarized emission, it is almost necessary to invoke a compact magnetic field to produce an FRB, making some varieties of neutron stars an obvious choice for FRB sources. However, the observed energy scales of FRBs are far higher than those of galactic radio pulsars. A plethora of models have been proposed including magnetar giant flares, Crab-like giant pulses from young extragalactic pulsars, planets in pulsar magnetospheres, asteroids impacting neutron stars, neutron star mergers, neutron stars collapsing into blackholes, black hole-neutron star mergers, magnetar pulse-wind interactions, flares from nearby stars, quark novae, and axion stars. For a more complete review, please see Katz, 2016.

have been missed by smaller telescopes such as Parkes.

The Repeater became the focus of our effort for the interferometric localization of FRBs. Radio interferometry is a technique to combine the signals from different radio telescopes to effectively achieve the resolving power of a radio telescope that is as large as the separation between the telescopes. Using the Very Large Array (VLA) and collecting interferometric data with a sampling time of 5 milliseconds (instead of a few tens of seconds), our team was able to search for repeated bursts.

Compared to the 10-arcminute localization of the single 300-m dish at Arecibo Observatory, the ~30 kilometer baseline of the VLA was able to localize nine bright bursts from the Repeater to a 100 milliarcsecond precision (Figure 2; Chatterjee *et al.*, 2017). Using the European Very Long Baseline Interferometry Network of radio telescopes spread across Europe, our team further localized the bursts to a precision of 4 milliarcseconds (Marcote *et al.*, 2017), allowing us to further constrain the environment of the FRB.

This was a watershed moment in the emerging field of FRBs. For the first time, the localization was sufficient to search for optical and infrared counterparts and perhaps identify where FRBs originate.

Optical Counterpart

Archival R-band images from the Keck Observatory showed a very faint (R = 24.5 magnitude) object detected at about 5-σ but it was not clear whether it was an extended source or a point-like object. We were granted nine hours of Gemini Director's Discretionary Time for further imaging and spectroscopy with the Gemini Multi-Object Spectrograph to characterize the counterpart and investigate whether the FRB was Galactic or extragalactic.

Gemini Observatory's flexible queue scheduled observations were critical to the success of this project. The faint target required dark observing time with very little cloud

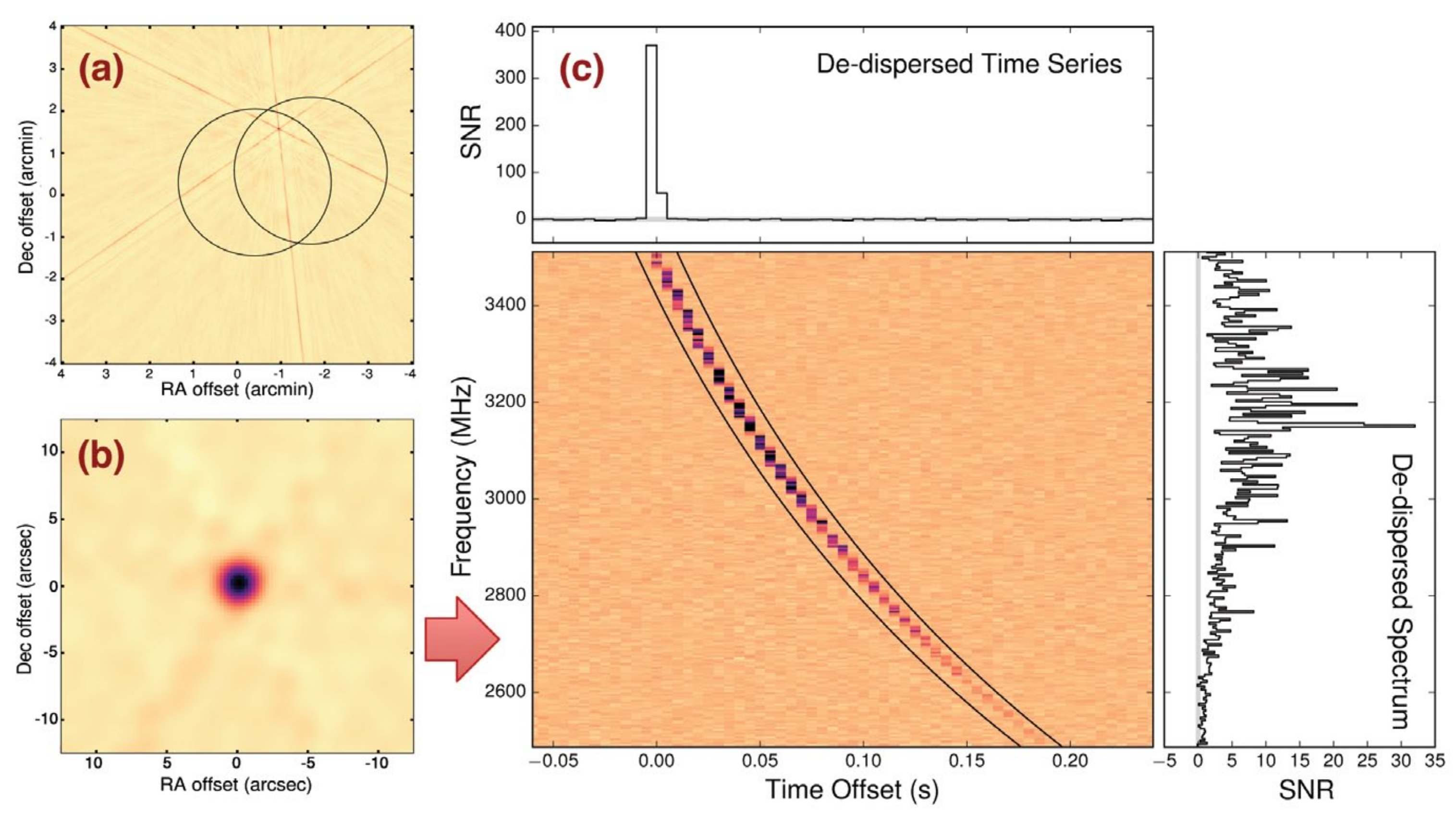
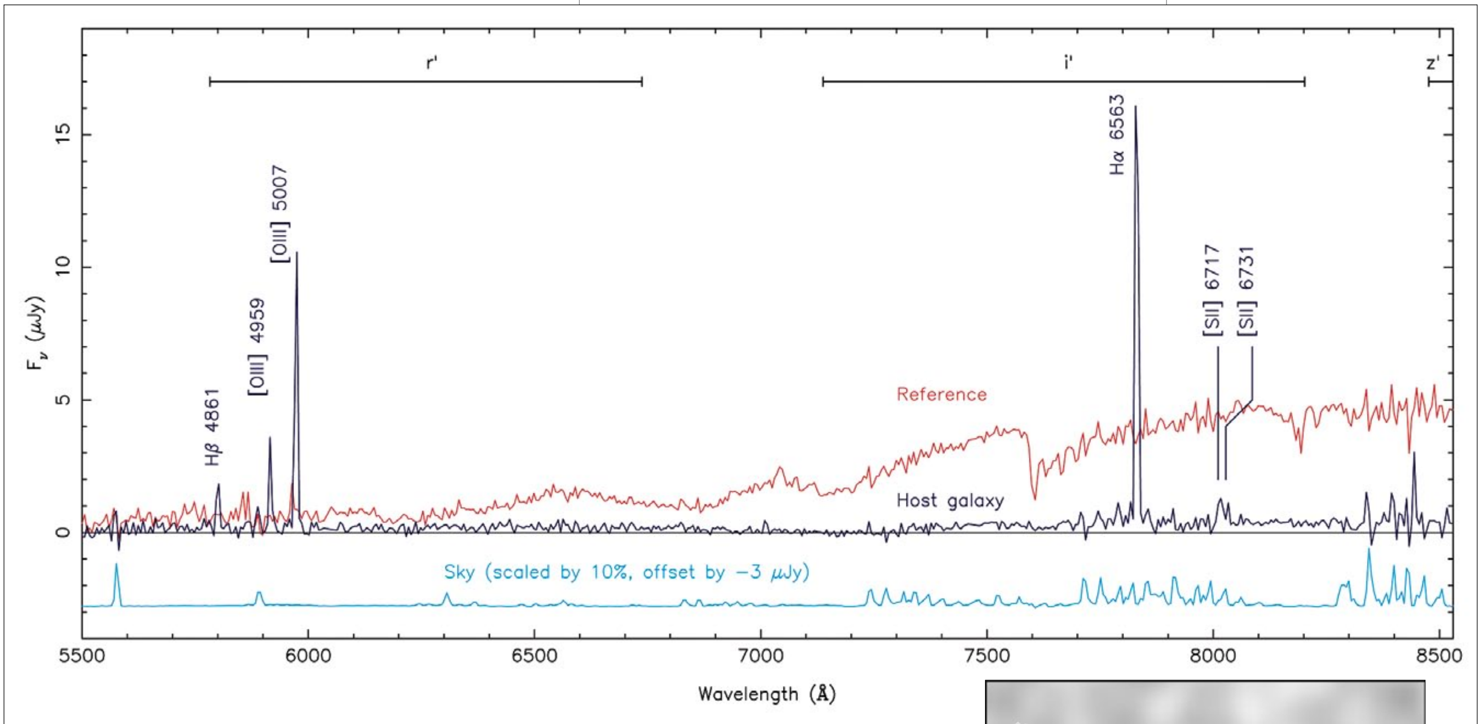
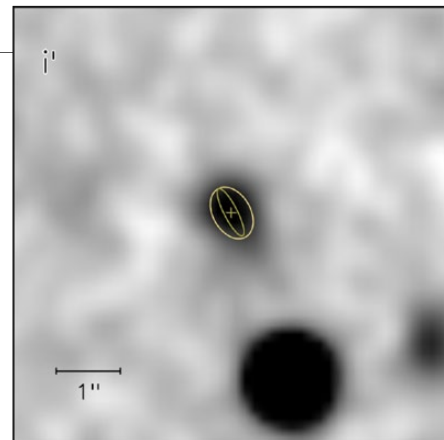


Figure 2.
The interferometric localization of the bursts from FRB 121102 using the VLA. Panel (a): radio image of the burst; the black circles are Arecibo beam sizes. Panel (b): zoom-in of the radio image; the position precision for each burst is less than one arcsecond. Panel (c): the de-dispersed time profile, spectrum, and dynamic spectrum of the burst. Figure adapted from Chatterjee et al.*, 2017.*





cover and excellent seeing (for the imaging). Unlike the nights lost to weather in classical observing, we obtained our data with the required sensitivity despite uncooperative weather over Maunakea.

Results

The Gemini North imaging and spectroscopic observations revealed that FRB 121102 was hosted in a low-metallicity star-forming dwarf galaxy at a redshift of $z = 0.19273(8)$ — the first incontrovertible proof that FRB 121102 is at a cosmological distance (Figure 3; Tendulkar *et al.*, 2017). The redshift is consistent with the $z < 0.3$ redshift that was estimated from the excess DM for this FRB. If this holds for other FRBs, it implies that we have been observing FRBs from redshifts up to $z = 3$!

The most surprising aspect of this result is the location in a dwarf galaxy. The host galaxy, with an absolute magnitude $M_R > -16$ AB mag, has an estimated stellar mass of $M_* < 4 \times 10^7\ M_\odot$, almost three orders of magnitude lower than that of a typical L_* galaxy. The total star forming rate, 0.5 $M_\odot$ per year, is very large compared to the stellar mass of the host, yet it is very small compared to the 10–100 $M_\odot$ per year star formation rates of massive starburst galaxies. If FRBs were expected to originate from generic neutron stars, or indeed any typical stellar origin, we would have expected them to emanate from galaxies with the largest number of stars.

One of the special properties of dwarf galaxies at low redshift is that they retain a lower metallicity as compared to larger galaxies. The low metallicity plays a major role in explaining why hydrogen-deficient superluminous supernovae (SLSNe Type I) and long-duration gamma-ray bursts (LGRBs) preferentially occur in low-metallicity dwarf galaxies (*e.g.,* Modjaz *et al.*, 2008; Lunnan *et al.*, 2014; and future work).

In the magnetar model unifying SLSNe and LGRBs, the low metallicity allows for the formation of extremely high mass (60–100 $M_\odot$) stars with high angular momentum that undergo supernovae and leave a very rapidly

Figure 3.
Top panel: GMOS-N spectrum of the FRB host galaxy (dark blue line) shows prominent [O III] and H-alpha emission lines. Other emission lines are also marked. The pink line shows a neighboring Galactic star.
Side panel: An i-band image of the host galaxy and the neighboring star. The galaxy is slightly extended compared to the seeing and is well fit with a Gaussian profile. Figures adapted from Tendulkar et al.*, 2017.*

spinning, hypermagnetized neutron star. It is conceivable that FRBs are emitted by some yet unknown mechanism from these magnetars (*e.g.,* Metzger *et al.*, 2017).

The Future of Fast Radio Bursts

The radio observations of FRBs give us almost no measure of distance, although, under some circumstances, we may expect to measure a lower bound on the redshift via neutral hydrogen absorption. They do, however, give us a limited view of the environment in which FRBs are born. Multi-wavelength observations are essential for identifying and characterizing hosts and the environments of FRBs.

Future arcsecond-precision FRB localizations will tell whether the dwarf galaxy hosting FRB 121102 is typical of all FRBs, but it is certain that large optical observatories such as Gemini, Keck, and VLT will be crucial for the studies of this enigmatic class of transients.

With new FRB experiments such as the Canadian Hydrogen Intensity Mapping Experiment (CHIME; Kaspi *et al.*, 2017, in prep), and Swinburne University of Technology's digital backend upgrade for the Molonglo Observatory Synthesis Telescope (UTMOST; Bailes *et al.*, 2016), and Caltech's 10-element Deep Synoptic Array prototype (DSA-10; Ravi *et al.*, 2016) coming online in the near future, the rate of FRB detection will increase significantly — and along with it the challenge of identifying and characterizing the hosts of these bursts, in many cases with imprecise localizations.

The mystery of FRBs is an interdisciplinary challenge that can only be solved with the combined forces of sensitive radio and optical observatories to support a motley group of bewildered astronomers.

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Peter Michaud

Astronomers Feast on First Light From Gravitational Wave Event

Gemini Observatory "pulled out all the stops" to bring a gravitational wave source into focus and capture early optical and infrared light from the merger of two neutron stars. The critical ground-based observations spanned almost a month during the summer of 2017 and allowed astronomers to dissect the first electromagnetic light emissions ever associated with a gravitational wave event.

Note: The following story is adapted from the Gemini Observatory press release issued on October 16, 2017. The original release (with videos and additional images) is ***available online****.*

The first-ever detection of optical and infrared light linked to a gravitational wave event initiated a time-critical sequence of observations at the Gemini South telescope in Chile. "Gemini pulled out all the stops to get these data," said Ryan Chornock of Ohio University who analyzed the resulting flood of data in his team's study of the event. The Gemini data allowed multiple research teams to form a complete picture of the aftermath from the gravitational wave event (GW170817) localized by the Laser Interferometer Gravitational-wave Observatory (LIGO), Virgo interferometer, and Fermi Gamma-ray Space Telescope on August 17, 2017. The Gemini imaging and spectroscopy spanned a period of 25 nights — while the object's light gradually faded from view.

Researchers from around the world announced their results on October 16th at press conferences in Washington D.C., Caltech, and one hosted by the European Southern Observatory in Europe. Well over a dozen papers have also been accepted for publication in the journals ***Nature***, ***Science***, and ***The Astrophysical Journal Letters***.

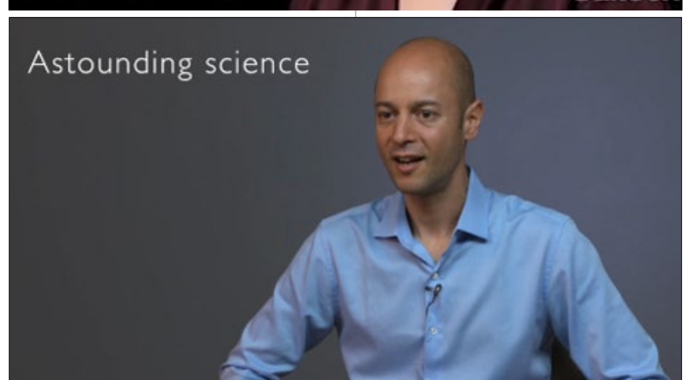


Figure 1.
Astronomers Mansi Kasliwal of Caltech (above) and Edo Berger of Harvard (below) spoke with much excitement about gravitational waves, and the role Gemini played in understanding them, in their videos describing the 2017 summer observation event and its significance. The videos can be found ***here****.*

Credits: Caltech and Harvard University

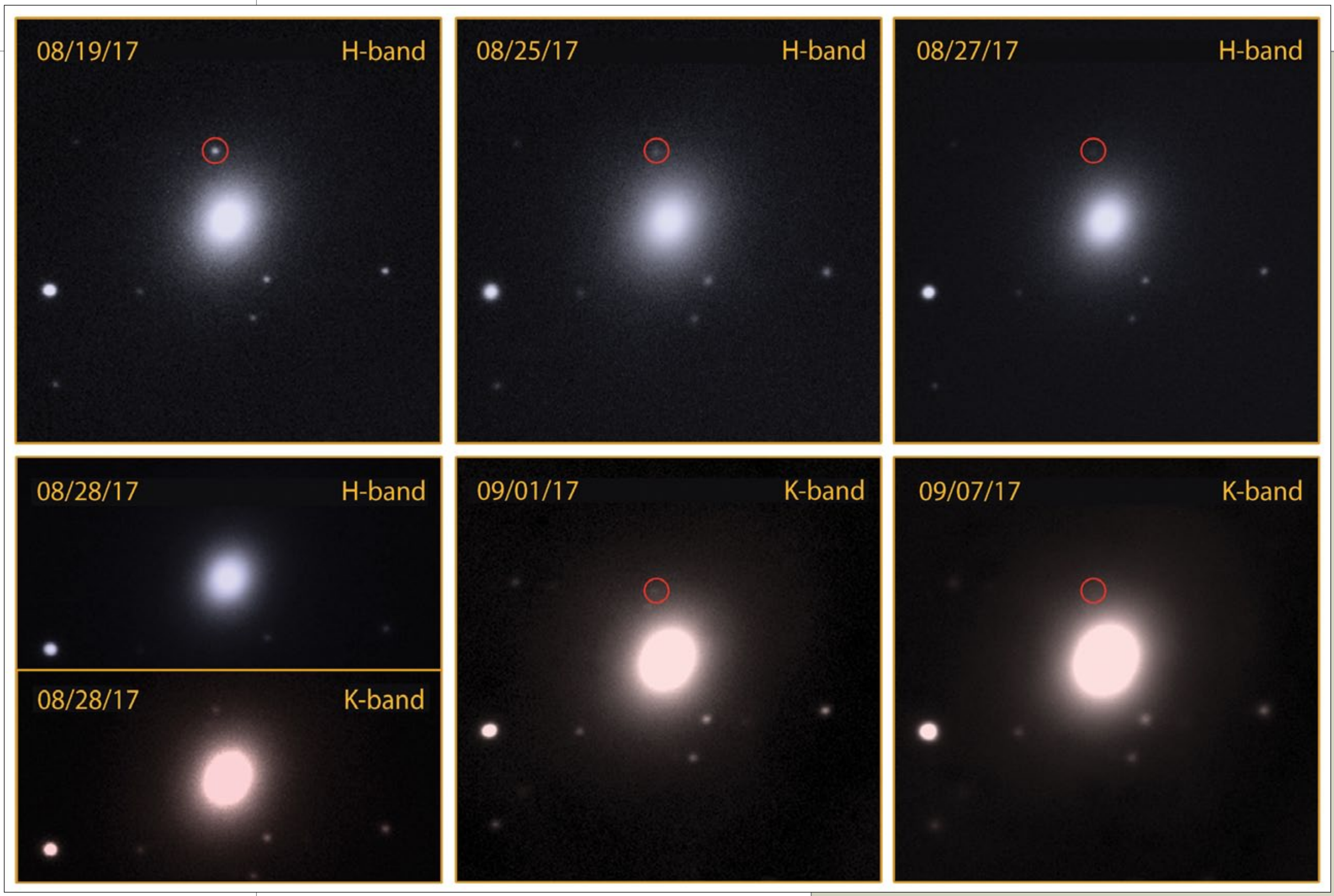


Figure 2.

The sequence above shows infrared imaging from the FLAMINGOS-2 imager and spectrograph for a period of over two weeks. The top row features images in the H-band, a shorter (bluer) wavelength of infrared light. The bottom row focuses mostly on K-band images, which are longer (redder) wavelengths of light. This sequence reveals how the object became redder as it faded from view.

Credit: Gemini Observatory/NSF/AURA/Edo Berger (Harvard), Peter Blanchard (Harvard), Ryan Chornock (Ohio University), Leo Singer (NASA), Mansi Kasliwal (Caltech), Ryan Lau (Caltech) and the GROWTH collaboration, Travis Rector (University of Alaska), Jennifer Miller (Gemini Observatory)

Mansi Kasliwal, Assistant Professor of Astronomy at Caltech, presented her team's findings at the Caltech press conference in Pasadena and recalls the excitement of the discovery: "Within 23 minutes of submitting our observing proposal to hunt for infrared photons it was approved by the Gemini Director!" Kasliwal, who was Principal Investigator of the worldwide Global Relay of Observatories Watching Transients Happen (GROWTH) team studying the event, continues, "On that first night the 8-meter Gemini South telescope successfully captured some of the first infrared photons ever seen from a neutron-neutron star merger — it was thrilling!"

Harvard astronomer Edo Berger, who presented at the D.C. press conference, describes the Gemini observations as, "collectively the longest-running, and finest, infrared imaging and spectroscopy of this object that we have available." Berger adds that the data directly demonstrate that the much-speculated mechanism of a neutron star binary merger caused this gravitational ripple in space and time. In the process the event formed and dispersed heavy elements, like gold, into space. "Here, for the first time, using Gemini, we showed the direct signature of the formation of heavy elements," says Berger. "[This] solves the decades-long mystery of the origin of the

The observations of this gravitational wave source brought out the best in Gemini's staff and their commitment to obtaining the best data under extreme circumstances. Of special note are the individuals below who played critical roles in acquiring these data:

Morten Andersen
Pablo Candia
Joy Chavez
Gonzalo Diaz
German Gimeno
Hwihyun Kim
Ariel Lopez
Lindsay Magill
Pablo Prado
Ricardo Salinas
David Sanmartim
Alysha Shugart
Karleyne Silva
Erich Wenderoth

heaviest elements in the periodic table." (See excerpts from a Harvard University interview of Berger in the online version of the release).

Leo Singer, of NASA's Goddard Space Flight Center, and a collaborator with Kasliwal in the GROWTH group adds, "Continued monitoring over many subsequent nights at Gemini allowed us to paint a stunning infrared portrait of neutron star mergers." In agreement with other researchers, the GROWTH team concluded that these neutron-neutron star mergers are primary sites for the production of elements heavier than iron. According to Kasliwal, "Each of these events is capable of forging over ten thousand times the Earth's mass in heavy elements such as gold and platinum — cosmic bling!"

Folding the Gemini data into observations from radio to X-rays, Eleonora Troja, of the University of Maryland, joined Berger in presenting her findings at the D.C. press conference. Troja's team focused on the time evolution of the event starting with the very early Gemini observations in the optical (visible) part of the spectrum.

"It surprised me very much when I saw how bright this was in the optical," says Troja. "The question we asked is if this really was a so-called kilonova when a neutron pair merge, or some kind of exotic transient or supernova making fun of us!" Troja and her team concluded from the optical spectra that this was not like anything they had seen before.

"We are just beginning our effort to model and understand these explosions and the physics behind them," says team member Brad Cenko from NASA's Goddard Space Flight Center. "We need to add to our models an outflow of slower and more transparent material to account for the bright optical light component. This outflow is likely responsible for the production of less precious metals, such as silver and tin."

"The joint detection of light and gravitational waves from cosmic sources is one of the holy grails of present-day astronomy," exclaims Marcelle Soares-Santos (Fermi National Accelerator Laboratory), the first author of the paper from Berger's team that reports their discovery of the optical counterpart. Both signals, light and gravitational waves, contribute unique information about extreme astrophysical events. As Soares-Santos explains, "Gravitational waves tell us about the motions and masses of the neutron stars, and light reveals the astrophysics of the event — what happened exactly as the stars merged, the mass of heavy elements produced."

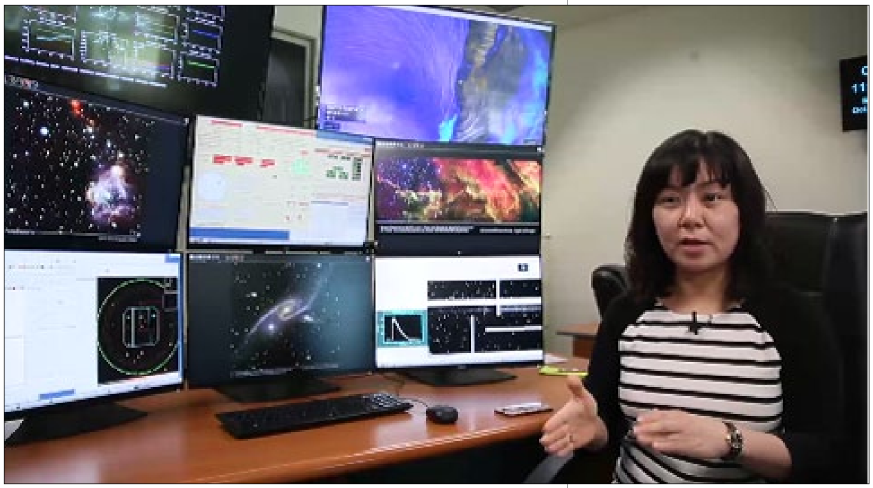
"This is a game-changer for astrophysics," says Andy Howell who also spoke at the D.C. press conference. Howell leads the supernova group at the Las Cumbres Observatory and is a coauthor on a paper in *The Astrophysical Journal Letters* based on the Gemini data. He adds, "One hundred years after Einstein theorized gravitational waves we've seen them and traced them back to their source to find an explosion with new physics of the kind we only dreamed about before."

"It is tremendously exciting to experience a rare event that transforms our understanding of the workings of the Universe," says France A. Córdova, director of the National Science Foundation (NSF), which funds LIGO and a majority of the international Gemini Observatory. "This discovery realizes a long-standing goal many of us have had, that is, to simultaneously observe rare cosmic events using both traditional as well as gravitational-wave observatories. Only through NSF's four-decade investment in gravitational-wave observatories, coupled with telescopes that observe from radio to gamma-ray wavelengths, are we able to expand our opportunities to detect new cosmic phenomena and piece together a fresh narrative of the physics of stars in their death throes."

Figure 3.

*Gemini assistant scientist Hwihyun Kim describes the sequence of events at Gemini during the gravitational wave event in a video clip viewable **here**.*

Credit: Gemini Observatory



Gemini Observatory Interim Director Laura Ferrarese recounts the challenges faced by the flood of requests for observations once the source was pinpointed. "Several teams contacted us with requests to observe the source," according to Ferrarese. "Everybody at Gemini was terribly excited: we all knew that we were witnessing a historical event!" Ferrarese adds that the greatest challenge involved scheduling the observations so that all of the teams would receive the data they needed — a task that, in her words, "required lots of coordination, and a good dose of diplomacy!"

The challenges extended to the observations themselves, according to Gemini astronomer Hwihyun Kim, who was instrumental in obtaining the Gemini data which primarily used the FLAMINGOS-2 infrared imager and spectrograph. "We were very lucky with observing this target," says Kim. "It was not always easy to see the source, but the field had a very bright star that helped our pointing even when the object was getting lost in the glow of twilight." Kim adds that everyone in the control room was nervous as the observation window got shorter and shorter each night. "Each night we pointed the telescope until we hit the absolute lowest limit that the telescope could reach." (See interview of Kim on the online version of the release.)

"Gemini's unique combination of depth and high-cadence through the hard work of staff like Kim have generated a totally unique data set for this fascinating event," says Nathaniel Butler from Arizona State University, and also part of the team with Troja and Cenko. Butler concludes, "The Gemini observations will provide a critical perspective on gravitational waves for years to come."

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Peter Michaud

July 2017

Striking Gemini Images Point Juno Spacecraft Toward Discovery

Very detailed Gemini Observatory images peel back Jupiter's atmospheric layers to support the NASA/JPL Juno spacecraft in its quest to understand the giant planet's atmosphere.

*Note: This article is based on the June 30th Gemini Observatory press release. Text includes significant contributions by Glenn Orton and Michael Wong. All images are available electronically in the **release**.*

High-resolution imaging of Jupiter by the Gemini North telescope on Maunakea is providing critical data used to direct the Juno spacecraft toward compelling events in Jupiter's atmosphere. "The Gemini observations, spanning most of the first half of this year, have already revealed a treasure-trove of fascinating events in Jupiter's atmosphere," said Glenn Orton, Principal Investigator for this Gemini adaptive optics investigation and coordinator for Earth-based observations supporting the Juno project at Caltech's Jet Propulsion Laboratory.

"Back in May, Gemini zoomed in on intriguing features in and around Jupiter's Great Red Spot: including a swirling structure on the inside of the spot, a curious hook-like cloud feature on its western side, and a lengthy fine-structured wave extending off from its eastern side," added Orton. "Events like this show that there's still much to learn about Jupiter's atmosphere — the combination of Earth-based and spacecraft observations is a powerful one-two punch in exploring Jupiter."

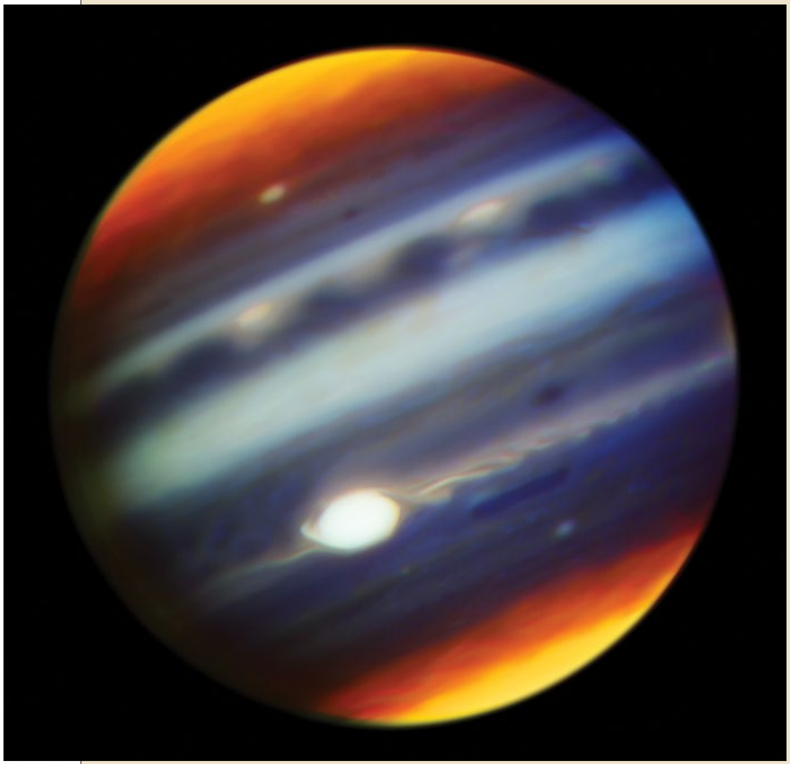
Juno has now made five close-up passes of Jupiter's atmosphere, the first of which was on August 27, 2016, and the latest (the fifth) on May 19th of this year. Each of these close passes has provided Juno's science team with surprises, and the Juno science return has benefitted from a coordinated campaign of Earth-based support — including observations

Figure 1.

A composite color infrared image of Jupiter reveals haze particles over a range of altitudes, as seen in reflected sunlight. The image was taken using the Gemini North telescope's Near-InfraRed Imager (NIRI) on May 18, 2017, one day before the Juno mission's fifth close passage ("perijove") of the planet. The color filters cover wavelengths between 1.69 to 2.275 microns and are sensitive to pressures of 10 millibars to 2 bars. The Great Red Spot (GRS) appears as the brightest (white) region at these wavelengths, which are primarily sensitive to high-altitude clouds and hazes near and above the top of Jupiter's convective region – revealing that the GRS is one of the highest-altitude features in Jupiter's atmosphere.

The features that appear yellow/orange at Jupiter's poles arise from the reflection of sunlight from high-altitude hazes that are the products of auroral-related chemistry in the planet's upper stratosphere.

Narrow spiral streaks that appear to lead into the GRS or out of it from surrounding regions probably represent atmospheric features being stretched by the intense winds within the GRS, such as the hook-like structure on its western edge (left side). Some are being swept off its eastern edge (right side) and into an extensive wave-like flow pattern; and there is even a trace of flow from its north. Other features near the GRS include the dark block and dark oval to the south and the north of the eastern flow pattern, respectively, indicating a lower density of cloud and haze particles in those locations. Both are long-lived cyclonic circulations, rotating clockwise — in the opposite direction as the counterclockwise rotation of the GRS. A prominent wave pattern is evident north of the equator, along with two bright ovals; these are anticyclones that appeared in January. Both the wave pattern and the ovals may be associated with an impressive upsurge in stormy activity that has been observed in these latitudes this year. Another bright anticyclonic oval is seen further north. Juno may pass over these ovals during its July 11th closest approach. High hazes are evident over both polar regions with much spatial structure that has never been seen quite so clearly in ground-based images, with substantial variability in their spatial structure. The central wavelengths and colors assigned to the filters are:1.69 microns (blue), 2.045 microns (cyan), 2.169 microns (green), 2.124 microns (yellow), and 2.275 microns (red).



Credit: Gemini Observatory/AURA/NSF/JPL-Caltech/NASA

from spacecraft orbiting the Earth (covering X-ray through visible wavelengths) and ground-based observatories (covering near-infrared through radio wavelengths).

Orton added that the types of light Gemini captures provides a powerful glimpse into the layers of Jupiter's atmosphere, as well as a 3-dimensional view into Jupiter's clouds. Among the questions Juno is investigating include poorly understood planetary-scale atmospheric waves south of the equator. "We aren't sure if these waves might be seen at higher latitudes," said Orton. "If so it might help us understand phenomena in Jupiter's circulation that are quite puzzling."

"Wow — more remarkable images from the adaptive optics system at Gemini!" said Chris Davis, Program Officer for Gemini at the National Science Foundation (NSF), one of five agencies that operate the observatory. "It's great to see this powerful combination of ground and space-based observations, and

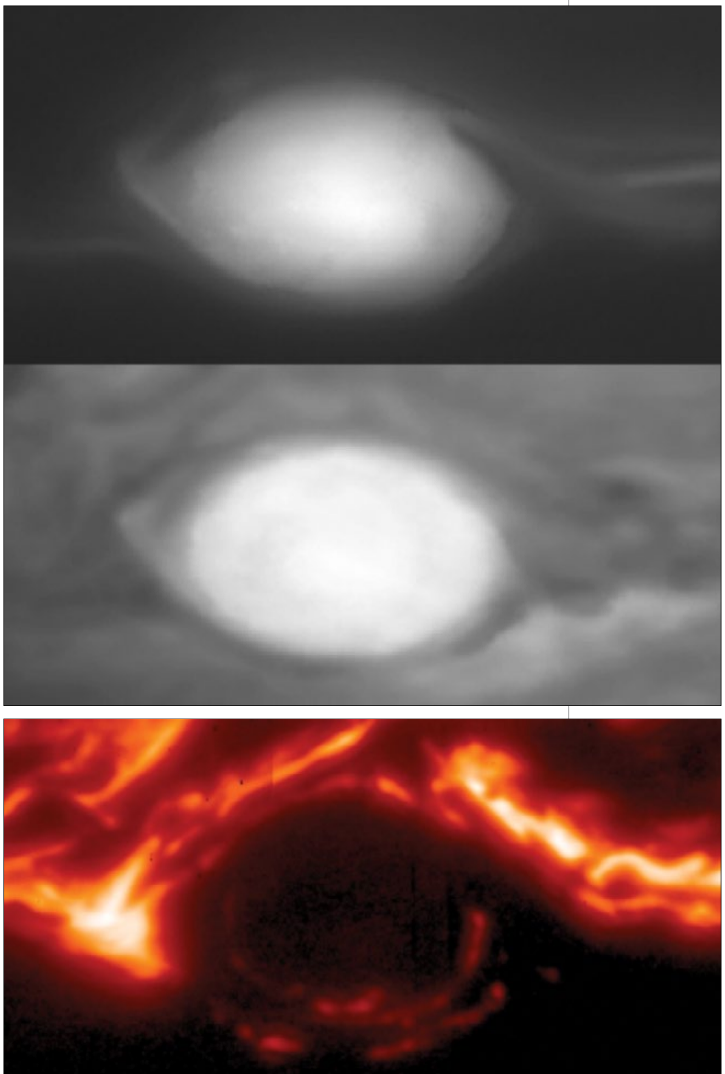


Figure 2.
Close-up images of the Great Red Spot from Gemini Near-InfraRed Imager (NIRI) images showing differences in the interior structure of this giant vortex with altitude. The top image was taken with a filter at 2.275 microns that is sensitive to particles at, and above, pressures of about 10 millibars (about 1% of the pressure at sea level on the Earth) in Jupiter's lower stratosphere. It shows that particles at this level tend to increase toward the center of this gigantic vortex. The middle image was taken with a filter at 1.58 microns, sensitive to virtually no gaseous absorption, and is sensitive to the brightness of clouds, very similar to visible red light. Subtle oval-shaped banded structure going from the outside to the interior can be spotted in the image. The difference between these two images illustrates major differences in the dynamics of this vortex with altitude. The bottom image was taken with a filter at 4.68 microns, and shows bright thermal emission from the deeper atmosphere wherever there is "clear sky" (low cloud opacity in the 0.5-3 bar range). Top two panels show data from May 18, 2017, while the bottom panel shows data from January 11, 2017.

Credit: Gemini Observatory/AURA/NSF/JPL-Caltech/NASA/UC Berkeley

the two agencies, NSF and NASA, working together on such scientifically important discoveries."

The Gemini observations use special filters that focus on specific colors of light that can penetrate the upper atmosphere and clouds of Jupiter. These images are sensitive to increasing absorption by mixtures of methane and hydrogen gas in Jupiter's atmosphere. "The Gemini images provide vertical sensitivity from Jupiter's cloud tops up to the planet's lower stratosphere," said Orton.

The observations also employ adaptive optics technology to significantly remove distortions due to the turbulence in the Earth's atmosphere and produce these extremely high-resolution images. Specifically, the detail visible in these images of Jupiter is comparable to being able to see a feature about the size of Ireland from Jupiter's current distance of about 600 million kilometers (365 million miles) from Earth.

In addition to images using adaptive optics technology, a parallel Gemini program headed by Michael Wong of the University of California, Berkeley, used a longer-wavelength filter, for which adaptive optics is not needed. To obtain these data several images were made with short exposures, and the sharpest images were combined in processing — an approach commonly called "lucky imaging." Images obtained with this filter are mainly sensitive to cloud opacity (blocks light) in the pressure range of 0.5 to 3 atmospheres. "These observations trace vertical flows that cannot be measured any other way, illuminating the weather, climate, and general circulation in Jupiter's atmosphere," noted Wong. This image is shown in Figure 3.

Subaru Telescope also supplied simultaneous mid-infrared imaging with its COMICS instrument — measuring the planet's heat output in a spectral region not covered by Juno's instrumentation, and producing data on composition and cloud structure that compliment both the Juno and Gemini observations. For example, they show a very cold interior to the Great Red Spot that is surrounded by a warm region at its periphery, implying upwelling air in the center that is surrounded by subsidence. They also show a very turbulent region to the northwest of the Great Red Spot. The Subaru image is available ***here***.

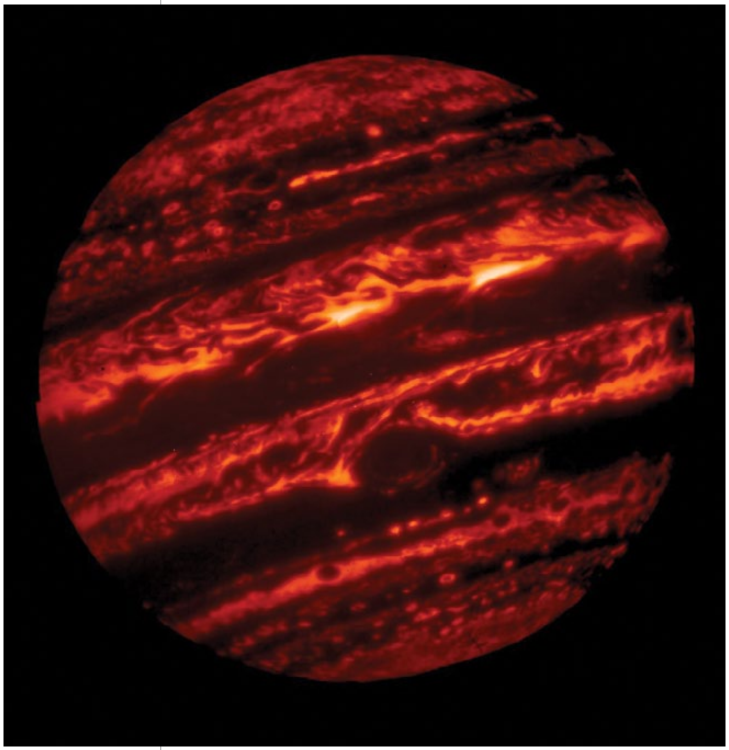


Figure 3.

At longer infrared wavelengths, Jupiter glows with thermal (heat) emission. In the dark areas of this 4.8-micron image, thick clouds block the emission from the deeper atmosphere. The Great Red Spot is visible just below center. This image, obtained with the Gemini North telescope's Near-InfraRed Imager (NIRI), was obtained on January 11, 2017, so the relative positions of discrete features have changed with respect to the near-infrared image in Figure 1.

Credit: Gemini Observatory/AURA/NSF/ UC Berkeley

The NASA Juno spacecraft was launched in August 2011 and began orbiting Jupiter in early July 2016. A primary goal of the mission is to improve our understanding of Jupiter — from its atmospheric properties, to our understanding of how Jupiter and other planets in the outer Solar System formed. Juno's payload of nine instruments can probe Jupiter's atmospheric composition, temperature, and cloud dynamics, as well as the properties of the planet's intense magnetic field and aurora.

Gemini's near-infrared images are particularly helpful to Juno's Jupiter Infrared Auroral Mapper (JIRAM). JIRAM takes images at 3.5 and 4.8 microns and moderate-resolution spectra at 2 - 5 microns. The Gemini images provide a high-resolution spatial context for JIRAM's spectroscopic observations and cover wavelengths and regions of the planet not observed by JIRAM. They also place an upper-atmospheric constraint on Jupiter's circulation in the deep atmosphere determined by Juno's Microwave Radiometer (MWR) experiment.

Orton leads the observing team for the adaptive-optics imaging and Wong heads the observing team for the thermal imaging. Additional team members include Andrew Stephens (Gemini Observatory); Thomas Momary, James Sinclair (JPL); Kevin Baines (JPL, University of Wisconsin); Michael Wong, Imke de Pater (University of California, Berkeley); Patrick Irwin (University of Oxford); Leigh Fletcher (University of Leicester); Gordon Bjoraker (NASA Goddard Space Flight Center); and John Rogers (British Astronomical Association).

In the full campaign of Earth-based support, the Gemini observations provide a key element that extends the spectral coverage of other facilities, as well as providing a strategic sampling to compare with the lower-resolution but more frequent imaging by NASA's Infrared Telescope Facility (IRTF) that tracks the evolution of atmospheric features. These Gemini data are also a useful measure of cloud properties to compare with mid-infrared thermal imaging and spectroscopy of Jupiter's atmosphere, such as that provided by Subaru's COMICS experiment. The space platforms are involved in the Juno-support campaign include the XMM, Chandra, and NuSTAR X-ray observatories, and the Hitaki ultraviolet observatory, together with the Hubble Space Telescope. The many ground-based observatories include the Very Large Telescope (VLT), the Atacama Large Millimeter Array (ALMA), Calar Alto Observatory, and a suite of visible and radio observatories. Full details of the campaign can be found ***here***.

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Tom Geballe

Persistence Pays Off in the Study of Shock-heated Gas

A breakthrough has been made in a two-decade old mystery concerning the frequently observed shock-heated gas in dense star-forming clouds, thanks to sensitive new measurements using Gemini North and its infrared spectrographs NIFS and GNIRS.

Shock waves in dense interstellar clouds occur when the powerful winds generated by stars forming within the clouds ram into quiescent portions of the clouds. As a consequence of shock heating in a previously quiescent cloud, its most abundant molecule, molecular hydrogen (H_2), emits numerous strong spectral lines, especially in the 2.0-2.5-micron wavelength range, as the shocked gas cools. Measurements of the velocities and both the absolute and relative intensities of these lines reveal much information about the nature of the shock as well as the protostars responsible for them.

As reported in two recently published papers, Rosemary Pike (Academia Sinica, Taipei, Taiwan), Michael Burton (Armagh Observatory, Northern Ireland), Antonio Chrysostomou (Square Kilometer Array Office at Jodrell Bank, UK) and I have discovered lines of H_2 from much higher energy levels than previously observed, in two shocked clouds. We have tentatively linked these lines to H_2 that has recently reformed on dust particles following its destruction by the shock waves. If our interpretation is correct, our data are giving scientists a first look at the spectrum of newly formed H_2, the most abundant molecule in the Universe.

Shocking Shock Waves

In the late 1980s and early 1990s, Burton (first a graduate student at Edinburgh University and then a research fellow at NASA Ames), Chrysostomou (also a grad student at Edinburgh) and I (then employed at the United Kingdom Infrared Telescope; UKIRT), were part of a team led by Peter Brand at Edinburgh that was attempting to understand the physics of shock waves in star-forming molecular clouds. In a pure hydrodynamic shock, H_2 is dissociated into its constituent hydrogen atoms when collisions involving it and atoms or molecules in the wind from the protostar occur at speeds exceeding 20 kilometers per second (km/s).

During 1978-1981, however, when I was a Carnegie Fellow in Pasadena working with Gary Neugebauer of Caltech and his graduate student Daniel Nadeau, we had found that the H_2 lines in the Orion Molecular Cloud have velocity widths of over 100 km/s. Similar high velocity and high temperature H_2 was later found in other clouds as well. Molecule-molecule or atom-molecule collisions occurring at even a small fraction of that speed would have destroyed the H_2, and the emission lines from H_2 thus would not be observed.

Our finding helped to stimulate the development by theorists of magneto-hydrodynamic shock models in which the quiescent gas is accelerated and heated more slowly and the H_2 survives. Because these so-called continuous shocks, or C-shocks, are naturally created if the cloud contains a magnetic field, as is always the case, they appeared to be a natural explanation for the observations.

Brand, Burton, Chrysostomou, and I, along with a few other Brand grad students tested the C-shock models by measuring the relative intensities of numerous lines of shocked H_2. To our surprise, the relative intensities did not match the predictions for C-shocks. The highest excitation lines we could detect at the time (with upper energy levels as high as 25,000 K above the ground state) were far too strong; their strengths actually much more closely matched the predictions for pure hydrodynamic shocks than for C-shocks. Yet at the observed speeds, none of the H_2 could have survived a hydrodynamic shock. Unable to find a satisfactory resolution to this puzzle, we researchers eventually went our separate ways and moved on to other unrelated projects.

On the Sky Again … at Gemini

My move from UKIRT to Gemini and its set of powerful infrared spectrographs eventually led me to return to the problem, and I reassembled part of my old Edinburgh team (Burton and Chrysostomou) to do so. We chose as our target the Herbig-Haro object HH 7, a small patch of nebulosity associated with a newly born star well known for its strong H_2 line emission and its simple geometry in the sky, that of a classic bow shock. As our spectrograph, we selected Gemini's Near-Infrared Integral Field Spectrometer (NIFS), which was capable of dicing the bow shock into tiny regions that could be analyzed separately.

Gemini System Support Associate Rosemary Pike (now a PhD astronomer) reduced the complex NIFS spectral data on HH 7. In addition to the well-known high-excitation lines of H_2 that were the intended target of the program, the reduced data (see Figure 1) revealed a large number of very faint emission lines that were eventually identified as also due to H_2, but emitting from energy levels far above the highest ones previously observed (25,000 K). Some of these levels are 50,000 K above the ground state, very close to the dissociation energy of H_2.

Surprisingly, Burton successfully modeled all the line emission as arising from H_2 at just

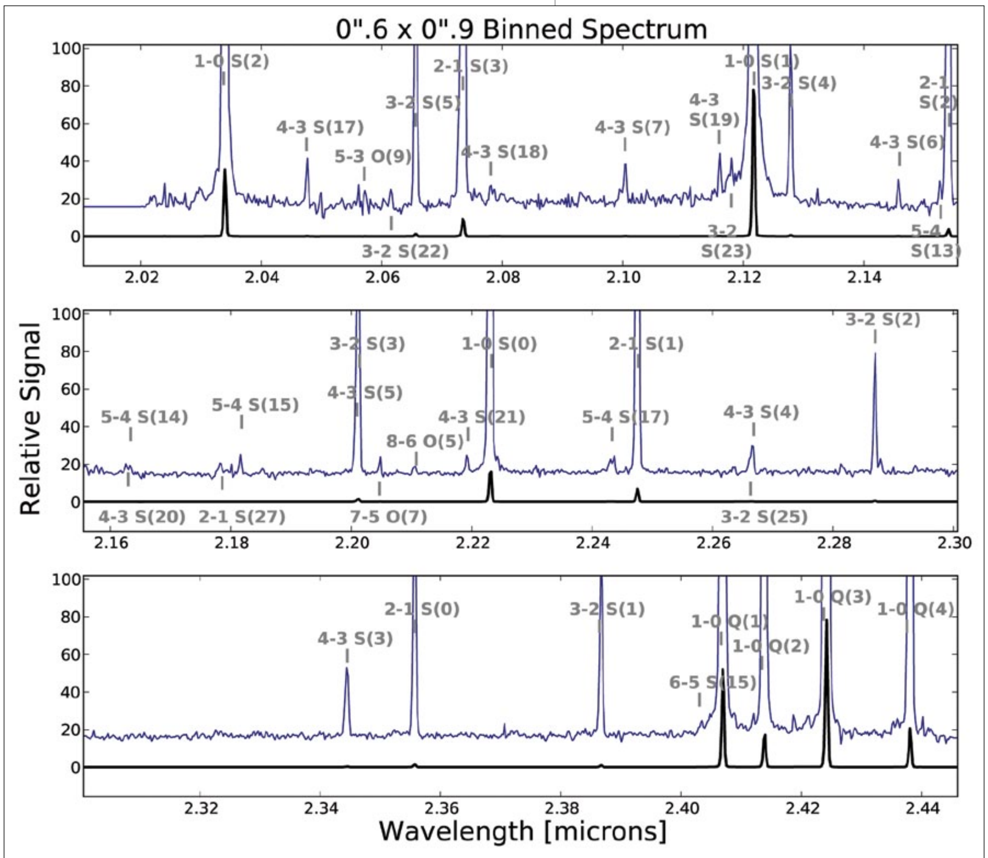


Figure 1.
Spectrum of a bright region near the apex of the HH 7 bowshock (as published in Pike et al., ApJ, ***822:*** *82, 2016). All lines are due to molecular hydrogen and are labeled according by their vibrational and rotational transitions. The blue trace is the same as the black trace, but is multiplied by a factor of 150 and offset vertically to show the weaker lines, which had not been detected previously in any astronomical object.*

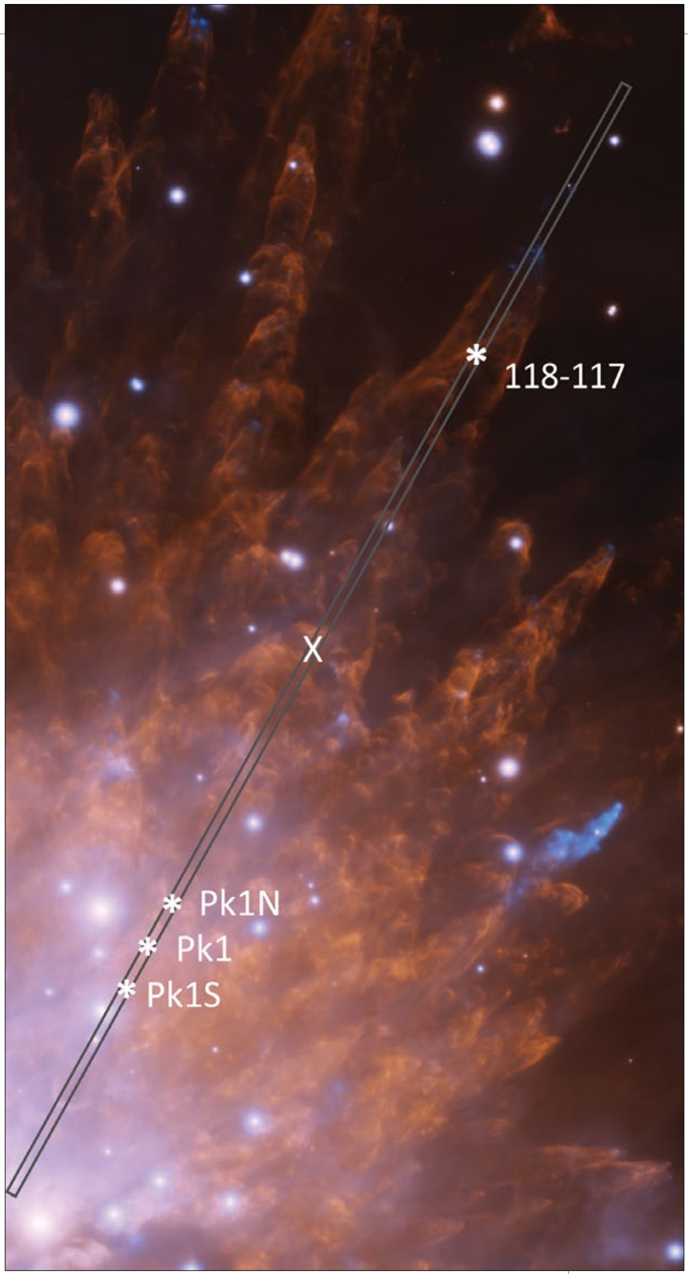
two temperatures: 1,800 K and 5,000 K. Approximately 98.5% of the H_2 is at the lower temperature, which corresponds closely to the temperature expected for a C-shock. The higher temperature component, which is only 1.5% of the hot H_2, accounts for virtually all of the emission by the most highly excited H_2. The origin of the 5,000 K component is of intense interest. It seems most likely to be due to H_2 that has reformed on dust grains following destruction by the shock wave.

The formation of H_2 by the collision of two H atoms in the gas phase is an extremely unlikely process. However, hydrogen atoms will stick to a dust particle and can easily hop around on it, find each other, and make H_2. Their association produces a lot of energy, some of which ejects the newly formed H_2 molecule from the dust particle and some of which leaves the molecule in a highly excited state, from which it can emit spectral lines as it cools. Qualitatively this explains the observations, but many questions remain, especially regarding how well the relative line strengths match predictions of the "formation spectrum."

A Fundamental Question … and the Answer

A basic question about this discovery was whether the high temperature H_2 is unique to HH 7 or is found in other clouds that have been subjected to high velocity shocks. To begin to answer this question, Burton, Pike, and I observed the shocked H_2 in the location where it was initially discovered in 1976, and where it is brighter than anywhere else: the Orion Molecular Cloud (OMC-1). Using as a guide the exquisite images obtained by John Bally (University of Colorado) and collaborators with the multi-conjugate adaptive optics System at Gemini South, we positioned the long slit of the Gemini Near-Infrared Spectrograph (GNIRS) on Gemini North to traverse several regions of intense

Figure 2.
Image of emisson from the 1-0 S(1) line of molecular hydrogen in a portion of the OMC-1 outflow in the H_2 1–0 S(1) line (from Bally et al., *A&A, **579:** A130, 2015) with the GNIRS slit superimposed. The 1.9-2.5-micron spectra (published in Geballe, Burton, & Pike,* ApJ, ***837:** 83, 2017) at the four positions denoted by asterisks show some of the same weak, high-excitation lines previously seen in HH 7.*



H_2 line emission in OMC-1, including one of the famous "bullets" or "fingers," as shown in Figure 2.

The results are unequivocal — the high temperature (5,000 K) component is present at all analyzed locations along the slit. It thus appears to be a common characteristic of shock-excited molecular gas. In OMC-1 the largest percentage of hot H_2 (still relatively small at only about 3.3%) is in the "bullet" (a dense and compact clump of gas piercing the ambient molecular cloud at about 120 km/sec). This is consistent with the hypothesis that the amount of dissociation increases with shock speed, and thus it lends support to the idea that the high temperature line emission is from recently reformed H_2.

Future detailed modeling and laboratory observations of the formation spectrum are badly needed to compare with the observations. Burton, Pike, and I have plans to obtain further observations of the high temperature H_2 at higher sensitivity and in both more extreme and less extreme environments.

Tom Geballe is an astronomer at the Gemini North Observatory. He can be reached at: tgeballe@gemini.edu.

Stephen Goodsell, on behalf of the OCTOCAM team

The Chosen One: OCTOCAM (Gen4#3)

With great pleasure we proudly announce our next facility-class instrument: OCTOCAM, a wide-band (visible/near-infrared) medium-resolution spectrograph and imager. This powerful facility will support a wide range of science and take advantage of the Large Synoptic Survey Telescope follow-up opportunities.

In May 2016 Gemini released a Request for Proposals for the next facility-class Gemini instrument (then known as Gen4#3). The Observatory received a total of four proposals by our August deadline. After a thorough selection process involving internal and external experts, we selected OCTOCAM, signing a contract to design, build, and commission the instrument with the Southwest Research Institute (SwRI) in San Antonio, Texas, in March 2017.

The OCTOCAM team began immediately thereafter to work on the Conceptual Design Stage, with Antonio de Ugarte Postigo (Instituto de Astrofísica de Andalucía, of the Consejo Superior de Investigaciones Científicas (IAA-CSIC)) as the Principal Investigator, Pete Roming (SwRI) as the Project Manager, Alexander van der Horst (The George Washington University) as the Project Scientist and Christina Thöne (IAA-CSIC) as the Deputy Project Manager. A major member of the collaboration includes FRACTAL S.L.N.E. (a private technological company specialized in astronomical instrumentation). Together, we intend to commission OCTOCAM at Gemini South for general use before the 2023 planned start of Large Synoptic Survey Telescope (LSST) operations.

What is OCTOCAM?

OCTOCAM is an eight-channel imager and spectrograph that will simultaneously observe the *g*, *r*, *i*, *z*, *Y*, *J*, *H*, and K_s bands in a 3′ x 3′ field-of-view. It will obtain long slit (3′ long) spectroscopy with a resolution of R ~ 4,000, simultaneously covering the range between 0.37–2.35 microns.

The eight independent channels in OCTOCAM allow the user to adjust exposure times in each bandpass for increased efficiency and the best match to observing conditions. By using state-of-the-art detectors — frame transfer in the optical and CMOS (complementary metal-oxide semiconductor) in the near-infrared (NIR) — OCTOCAM will have negligible readout times enabling high time-resolution observations. Table 1 provides a subset of the top-level requirements for OCTOCAM:

OCTOCAM Requirements	
Parameter	**Value**
Spectrographic	
Wavelength Range	0.37 to 2.3 µm
Simultaneous Coverage	Yes
Continuous Coverage	Yes, excluding atmospheric bands
Resolving Power (λ/Δλ)	≥3500 (@455 nm) and ≥4000 (@610, 745, 875, 1035, 1250, 1630, 2175 nm) assuming a slit width of 0.54”
Spatial Sampling	0.18 ±0.02” in all bands
Imaging	
Natural Seeing FOV	≥ 170” x 170”
Spatial Sampling	0.18 ± 0.02” in all bands
Performance	
Instrument Throughput (ADC through detector)	Average > 20% (@400) and >35% (@455, 610, 745, 875, 1035, 1250, 1630, 2175 nm) in imaging Average > 20% (@400) and >30% (@455, 610, 745, 875, 1035, 1250, 1630, 2175 nm) in spectroscopy
Photometric Time Resolution	≤ 50ms (for a 30 x 30 pixel window @50 kHz) in the *g*-, *r*-, i-, and z-band ≤ 50ms (@10 MHz) in the *Y*-, *J*-, *H*-, and K_s -band
Target Acquisition Time	Integration time + 10s (for automatic target acquisition and grism/slit setup)

OCTOCAM Science Cases

A capable instrument for extremely broadband observations (both in imaging and long-slit spectroscopy), OCTOCAM will deliver groundbreaking scientific output over a very broad range of topics that cover fields as diverse as trans-Neptunian objects and centaurs in the Solar System (Figure 2), exoplanets, neutron stars, X-ray binaries, active galactic nuclei, supernovae, tidal disruption events, and gamma-ray bursts.

OCTOCAM's multi-wavelength spectroscopy (and the possibility for simultaneous multiband imaging) makes it the optimal machine for the efficient characterization of astronomical transients — similar to those expected to be discovered in the 2020s by LSST, which promises to play a leading role in advancing our understanding of these objects identified through their explosive variability. The availability of high time-resolution, coupled with Gemini's rapid response capability, will also allow researchers to use OCTOCAM to catch transient objects in their earliest phases and monitor their rapid evolution.

Spectral coverage from the optical to NIR, both in imaging and spectroscopy, is crucial for high-redshift sources in general, and high-redshift transients in particular. With

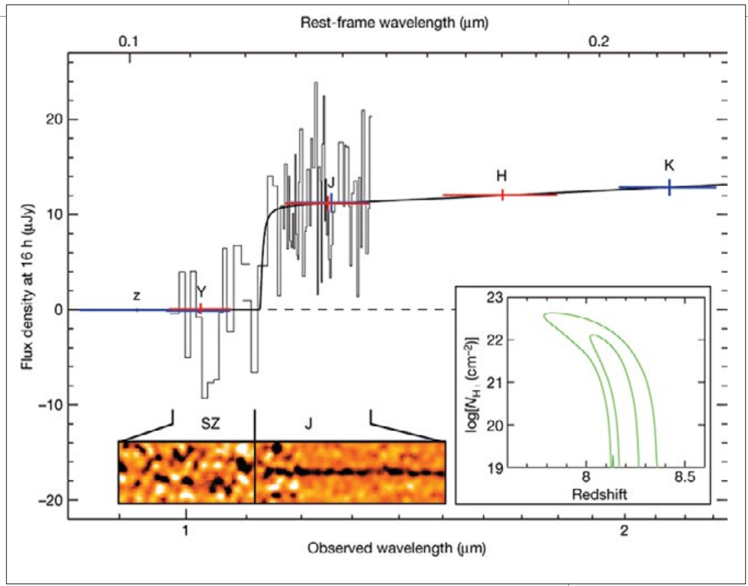


Figure 1.

Photometry and spectroscopy of the most distant spectroscopically confirmed GRB to date (Tanvir et al., Nature, ***461:*** *1254, 2009). The spectrum shows there is little dust in the host galaxy, consistent with a low metallicity. OCTOCAM will be an ideal tool for obtaining similar data sets very efficiently.*

OCTOCAM researchers will be able to use gamma-ray bursts to explore the earliest star formation events in the Universe (Figure 1). It will also be ideal for following up and characterizing kilonova signatures of neutron star mergers, and likely counterparts of gravitational wave sources

OCTOCAM will allow effective broadband timing studies or reverberation mapping of X-ray binaries and active galactic nuclei (AGN) to constrain the physical size of the emission regions around their black holes, measure the mass of their black holes, and give new insights into accretion physics near the event horizon. For AGN, the wide wavelength coverage will allow observers to study these systems over a broad redshift range. OCTOCAM will also be able to make a significant impact in the studies of tidal disruption events (TDEs) — material being blown away from a black hole after it rips a star apart. Rapid broadband follow-up observations will also provide unparalleled probes of the regions close to the black hole, and ultimately allow measuring their mass and possibly their spin.

Simultaneous spectral coverage is also crucial for characterizing variable, but non-transient, objects. Such objects include asteroids where the rotation affects the colors derived if the observations are not obtained at the same time, and pre-main sequence stellar objects where star spots and accretion disks can heavily affect the derived colors. OCTOCAM's field-of-view will ensure suitable reference objects for any region observed. Having simultaneous imaging in all of OCTOCAM's eight bands enables users to determine the photometric redshift of high *z* objects, making the instrument efficient in rapidly identifying drop-out objects across the full field-of-view.

OCTOCAM has a strong and diverse science team led by Project Scientist Alexander van der Horst from The George Washington University. Many other science cases were identified for OCTOCAM; for further details see our website ***here***.

OCTOCAM Instrument Design

Each of OCTOCAM's eight arms is an imaging spectrograph, based on the use of high-efficiency dichroics to split the light. The

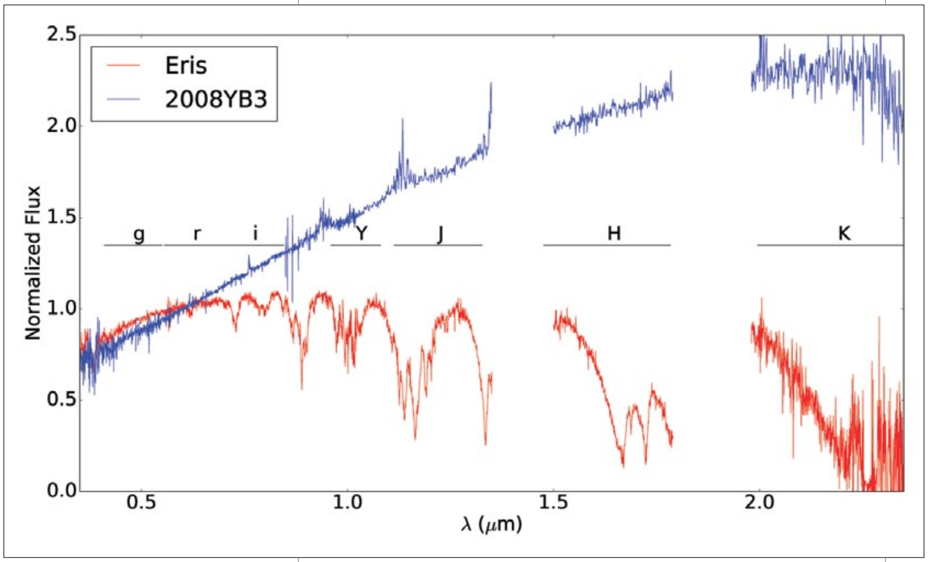


Figure 2.

Spectra of the trans-Neptunian dwarf planet Eris with deep absorption features due to CH_4 ice (Alvarez-Candal et al., A&A, ***532:*** *A130, 2011), and the centaur 2008 YB3 with no apparent absorption features (Pinilla-Alonso* et al., A&A, ***550:*** *A13, 2013). Also shown are the approximate positions and width of some photometric filters of OCTOCAM.*

light arriving from the telescope first goes through an atmospheric dispersion corrector (ADC) that compensates for atmospheric chromatic aberrations. The light then enters the NIR cryogenic chamber, where it reaches the focal plane unit. After the focal plane, the light is divided by the first dichroic into NIR and Visible (VIS) light. The VIS light then leaves the cryogenic chamber through a second window to the VIS bench which is at approximately the same temperature as the telescope. From there, the light of both beams follow similar paths, where the light is collimated and subsequently split by additional dichroics. The collimated beam of each arm passes through either a filter or grism, depending on the observing mode, and is refocused by a camera onto the detector.

As the OCTOCAM block layout diagram shows (Figure 3), the design is highly symmetrical, with the VIS and NIR arms each sharing their own common optics among themselves. Symmetry helps to constrain the effect of the mechanical flexures occurring during motion at the Cassegrain mount. All wavelengths share a common optical path to the focal plane, where the focal plane carriage positions the slit. The single slit design will ensure that all the spectrographs are fed by light from the same sky aperture and provides better data calibration. The simultaneity of OCTOCAM's eight arms make it very fast to calibrate and extremely easy to operate.

The Gemini OCTOCAM project team consists of Stephen Goodsell (Program Manager), Morten Andersen (Project Scientist), Jeff Radwick (Project Systems Engineer), Cathy Blough (Project Specialist), and Rubén Díaz (Instrument Program Scientist). Both the external team and Gemini staff will work collaboratively to complete the Conceptual Design later this year. We look forward to sharing this instrument's adventures in the years to come.

Stay tuned, and see ***this webpage*** for the latest information.

Stephen Goodsell is the Gemini Instrument Program Manager and located at Durham University. He can be reached at: sgoodsell@gemini.edu

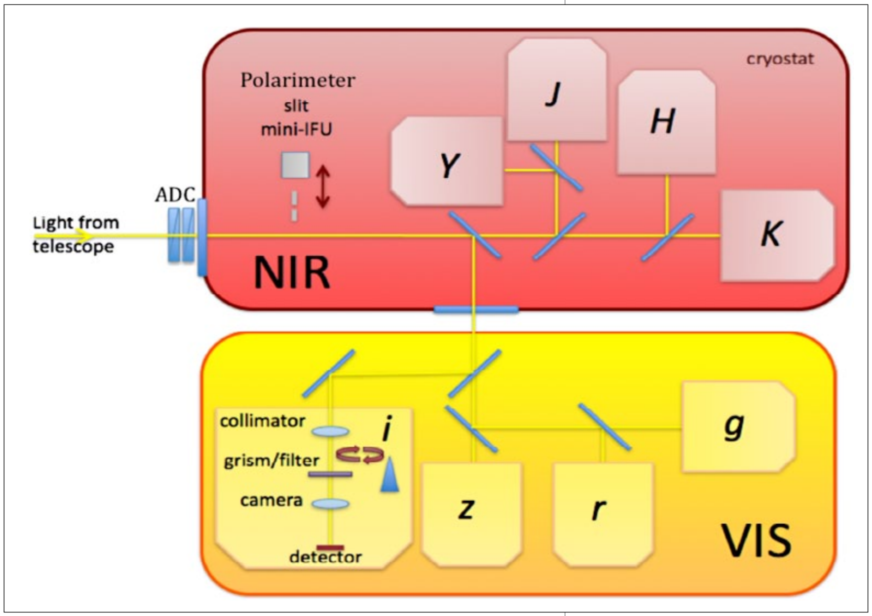


Figure 3.
Block layout diagram of OCTOCAM, showing its highly symmetrical design.



John Blakeslee and Peter Michaud

Science Highlights

Another year of ground-breaking science at Gemini demonstrates how the Observatory's diverse capabilities, flexibility, innovation, and efficiencies lead to many wide-ranging, and high-impact science results and discoveries.

JANUARY 2018

The Most Distant Kinematically Confirmed Spiral Galaxy

A team of astronomers using the Near-infrared Integral Field Spectrometer (NIFS) on Gemini North have confirmed the most distant kinematically confirmed spiral known to date. Spiral galaxies like the Milky Way have multiple structural components that formed at distinct times in the galaxy's evolutionary history. These components include the stellar halo, bulge, gas-poor thick disk, and gas-rich thin disk. Based on the maximum ages of their constituent stars, the disk components, which are emblematic of spirals and participate in ordered rotation about the Galactic center, are the least ancient parts of the Milky Way. The thick disk appears to date from about 10 billion years ago, while the thin disk began forming 2 or 3 billion years after that. If the Milky Way is typical, then we should not expect to be able to identify many spiral galaxies at distances beyond about 10 billion light years, or a redshift z beyond about 2.

A decade ago, Hubble images of the massive cluster of galaxies Abell 1689, a powerful gravitational lens, showed a highly magnified background galaxy, designated A1689B11, displaying spiral structure. Soon afterwards, its redshift was measured to be $z = 2.5$, implying a distance of 11 billion light years. This made it the most distant galaxy that appeared to be spiral in nature and indicated that spirals existed less than 3 billion years after the

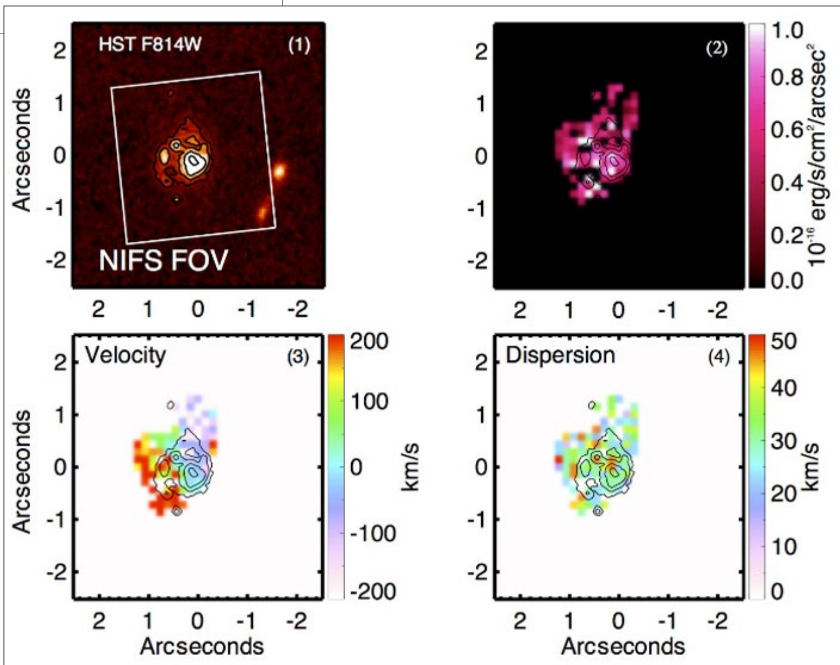


Figure 1.
Upper left: *Hubble Space Telescope (HST) image and intensity map of the lensed spiral galaxy A1689B11. The Gemini NIFS field-of-view is outlined.* ***Upper right:*** *Intensity map of redshifted Ha emission (from an atomic transition in hydrogen) as measured by NIFS.* ***Lower left:*** *The NIFS velocity map for hydrogen gas in A1689B11, showing the rotation speed of 200 km/s.* ***Lower right:*** *NIFS velocity dispersion map, showing the dispersion (velocity deviations) from the smooth rotation. The velocity deviations are generally less than 10% of the rotation velocity, indicative of a very orderly rotation pattern.*

Big Bang. Most galaxies at such distances are irregular in appearance, and even the more regular ones generally lack evidence of ordered rotation when their kinematics are studied through integral-field spectroscopy. Thus, kinematic confirmation of the spiral nature of A1689B11 was essential.

Taking advantage of the gravitational magnification by a factor of 7, the team of astronomers from Australia, France, and the United States (led by Tiantian Yuan of Swinburne University) used NIFS on Gemini North to map the internal gas distribution and velocity structure of A1689B11 (Figure 1). Although the galaxy is furiously forming stars at a rate nearly 20 times that of the Milky Way (similar to other galaxies of these early cosmic times), the gas kinematics trace out a "tranquil velocity field" with an ordered rotation of 200 km/s, very close to the rotation speed of the Milky Way. They also show a very small dispersion about this mean value. This makes A1689B11 the most distant kinematically confirmed spiral, and only the second one at a distance beyond 10 billion light years. These primitive spirals mark the formation epoch of galaxies like our own Milky Way.

The team's findings appear in a paper published in *The Astrophysical Journal*.

A Binary Supermassive Black Hole System Far Beyond Andromeda

Researchers from the University of Washington were searching Local Group galaxies for a "still-theoretical class of exotic stellar binary" composed of two red supergiant stars when they stumbled on what may be an even more exotic type of binary — one composed of a pair of supermassive black holes. The search, led by Trevor Dorn-Wallenstein, a doctoral student at the University of Washington, involved matching possible red supergiants with Chandra X-ray sources and turned up one object of interest, apparently residing in the outer disk of the spiral galaxy M31, also known as the Andromeda Galaxy.

This chimera-like object, referred to as J0045+41, had previously been classified in one study as an eclipsing stellar binary because of its optical variability. Other studies had classified it as a globular star cluster in M31 because of its brightness and noticeably extended appearance. Its X-ray properties were consistent with being either an X-ray emitting binary star in M31 or an active galactic nucleus (AGN) in the far background. In order to determine the true nature of J0045+41, the team submitted a Fast Turnaround proposal to use the Gemini Multi-Object Spectrograph (GMOS) on Gemini North.

As reported in *The Astrophysical Journal*, the GMOS spectrum conclusively showed that J0045+41 is an AGN in a galaxy at a distance of 2.6 billion light years, more than a thousand times farther away than the Milky Way's majestic neighbor (Figure 2). And careful modeling of the broad hydrogen emission lines seen in the object's spectrum turned up something even more surprising: evidence for two distinct massive objects orbiting each other with an extraordinary velocity of at least 4,800 km/s. In addition,

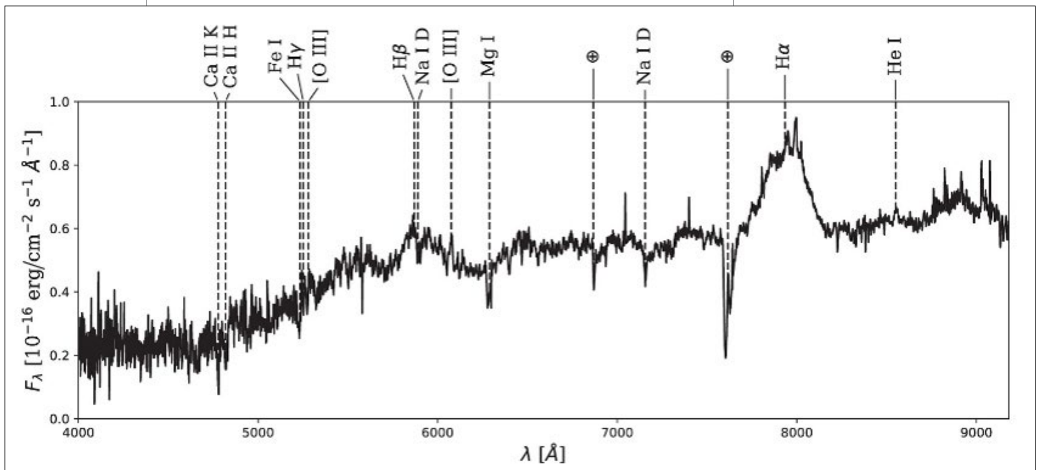


Figure 2.
GMOS optical spectrum of J0045+41, a distant AGN previously thought to be a binary star system in the disk of the Andromeda Galaxy. Emission lines from various elements are identified, including the very strong Hα emission due to atomic hydrogen. The broad range of wavelengths spanned by this emission "line" indicates an enormous spread in velocity that may be caused by a pair of supermassive black holes orbiting each other in a binary system.

photometry from the Palomar Transient Factory — a fully-automated, wide-field survey of the optical transient sky — indicated multiple periodic variations on time scales with ratios consistent with theoretical models of binary supermassive black hole (SMBH) systems. Although other possibilities exist, if this is the correct explanation, each black hole would have a mass of about 100 million times that of the Sun.

If the extreme velocities revealed by the Gemini spectra and the observed photometric variability arise from the orbital motions of two SMBHs with their associated accretion disks, then J0045+41 must be radiating gravitational waves. The researchers estimate the time for the two SMBHs to lose orbital energy as a result of gravitational radiation and collide could be anywhere from about 350 years to more than 350,000 years, depending on the exact masses involved.

Gravitational waves from merging supermassive black holes have frequencies too low for detection by facilities such as LIGO and Virgo. However, they should be detectable by a different technique that involves monitoring pulsars for correlated signals in their pulse arrival times. Objects such as J0045 + 41 provide confidence that such pulsar timing experiments will eventually succeed.

A Quasar in the Epoch of Reionization

Quasars are among the most energetic phenomena observed in the Universe. They are believed to be powered by the accretion of material by supermassive black holes during the active phase of their growth. The epoch of peak quasar activity, and therefore the time of the most rapid supermassive black hole growth, occurred about 10 billion years ago. However, quasars have been observed at earlier cosmic times, and a new record holder has now been established using data from Gemini and several other observatories.

A team of astronomers led by Eduardo Bañados at the Carnegie Institution for Science discovered the record-breaking quasar, known as J1342+0928, in observations from the Dark Energy Camera on the Blanco 4-m telescope at Cerro Tololo, NASA's Wide-field Infrared Survey Explorer (AllWISE), and the United Kingdom Infrared Telescope on Maunakea. The quasar is more than 13 billion light years from the Milky Way and is powered by a supermassive black hole with an estimated mass 800 million times greater than that of our Sun. At this distance, the Universe was only about 5% of its current age, or about 690 million years old. "That's not a lot of time for stuff to happen," commented Gemini's Peter Michaud. "That's why it's such a mystery."

According to Bañados, spectroscopic data from the Gemini Near-InfraRed Spectrometer (GNIRS) on Gemini North were key in determining the mass for the supermassive black hole. "We dove deep into the infrared light spectrum at Gemini and probed the magnesium lines," said Bañados. These magnesium lines are emitted at ultraviolet wavelengths, but at such large distances, they

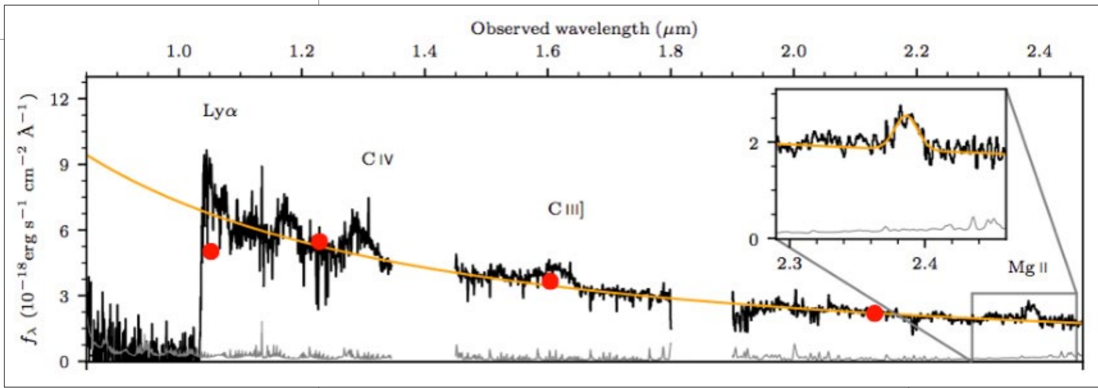


Figure 3.
Combined Magellan/FIRE and Gemini/GNIRS near-infrared spectrum of the quasar J1342+0928. The inset shows the Mg II line, which played a crucial role in determining the mass of the black hole and was obtained using GNIRS.

are "redshifted" into the infrared (Figure 3). Among the instruments used in this study, only GNIRS was able to probe these lines, and they proved critical for accurately constraining the mass. These results, including the discovery, are presented in ***Nature***.

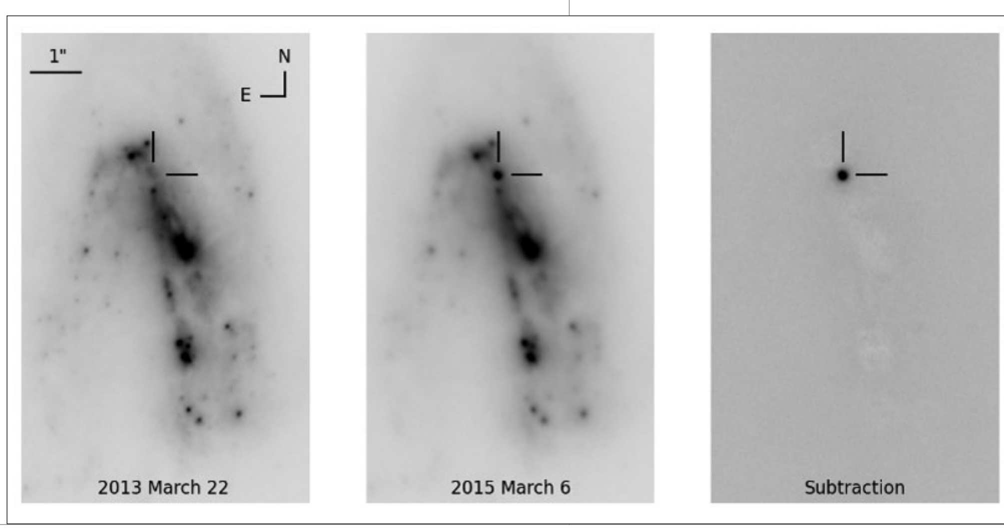
The study also concludes that J1342+0928 existed at a time when the Universe was still emerging from the cosmic "dark ages" and entering the epoch of reionization, when neutral gas in intergalactic space became ionized by luminous young stars and the onset of quasar activity. It is unknown precisely how many quasars as distant as this one exist over the whole sky. Bañados and his team plan to continue searching for similar quasars using Gemini and other large telescopes around the world.

Sifting Supernovae from the Dust in LIRGs

A star larger than about eight times the mass of our Sun is expected to end its life as a "core collapse supernova" (CCSN). However, fewer of these explosions are observed than are expected based on our understanding of the rates of stellar birth and evolution. A possible explanation for the perceived deficit of CCSNs is that, because the lifetimes of such high-mass stars are so short, these events occur within regions of intense star formation, where dust obscures the optical light. The disparity between observations and expectations is particularly apparent in luminous infrared galaxies (LIRGs), which form stars at very high rates in regions with large amounts of obscuring dust, which could lead to a significant fraction of CCSNs remaining undiscovered.

To find the "missing" supernovae, an international team of astronomers embarked on Project SUNBIRD, which stands for "Supernovae UNmasked By InfraRed Detection." The project, led by E. C. Kool of Macquarie University in Australia, monitors LIRGS with the Gemini South Adaptive Optics Imager (GSAOI) used with the Gemini Multi-conjugate adaptive optics System (GeMS) on Gemini South. By observing with GeMS/GSAOI in the near-infrared at a wavelength of 2.15 microns, where the emitted light is much less affected by dust extinction compared to

Figure 4.
The core collapse supernova SN2015cb discovered by Project SUNBIRD in the luminous infrared galaxy IRAS 17138-1017 using near-infrared imaging from GeMS/GSAOI. This is one of three supernovae studied in a paper presenting the first results from this project. From left to right, the panels show: the initial 2013 reference image; the 2015 discovery image; and the difference of the two images, highlighting SN2015cb about 2 arcseconds from the center of this dusty, star-forming galaxy.



the optical, SUNBIRD aims to uncover CCSNs that otherwise would remain hidden in the dusty, crowded star-forming regions within LIRGs. So far, in a relatively modest amount of telescope time, the project has discovered three CCSNs, and one other candidate, all of which are near the centers of intense star formation in LIRGs (Figure 4). This represents a very high discovery rate compared to previous searches. The results indicate that the majority of CCSNs that explode in such galaxies have been missed as a result of dust obscuration and inadequate image quality.

The work has been accepted for publication in *Monthly Notices of the Royal Astronomical Society*, and a preprint is ***available online***.

OCTOBER 2017

A Super-distant, Superluminous Supernova

Observations conducted with the Gemini Multi-Object Spectrograph on the 8-meter Gemini South telescope have confirmed that a brilliant explosion more than three times as bright as our Milky Way Galaxy is one of the most distant supernovae ever studied. The event, known as DES15E2mlf, occurred about 3.5 billion years after the Big Bang, at a period known as "cosmic high noon," when the rate of star formation in the Universe had reached its peak.

DES15E2mlf was initially detected in November 2015 by the Dark Energy Survey (DES). Follow-up observations at Gemini South not only confirmed the object's distance of 10 billion light years, but also revealed its unusual nature. Previous observations of superluminous supernovae show that they typically reside in low-mass or dwarf galaxies, which tend to be less enriched in metals than more massive galaxies. However, University of California Santa Cruz astronomers Yen-Chen Pan and Ryan Foley, who led the Gemini investigation as part of an international team of DES collaborators, found that the host galaxy of DES15E2mlf, is a fairly massive normal-looking galaxy, which goes counter to current thinking.

While knowing that very massive stars were exploding at that time is important, the team would now like to know the relative rate of superluminous supernovae to normal supernovae — to see if this atypical supernova is telling us something special about that time 10 billion years ago. It may be that at these earlier times in the Universe's history, even high-mass galaxies, like our Milky Way, may have had a low enough metal content to create these extraordinary stellar explosions.

Their findings appear in a paper published June 13th in the ***Monthly Notices of the Royal Astronomical Society***.

New Class of Variable Stars Confirmed

Astronomers using the Gemini Multi-Object Spectrograph (GMOS) on the Gemini South telescope have confirmed a new class of variable stars. Called Blue Large-Amplitude Pulsators (BLAPs), they are significantly bluer than main sequence stars of the same luminosity, demonstrating that they are relatively hot. Pawel Pietrukowicz (Warsaw University Observatory, Poland) led the Gemini study, following the team's discovery of 14 candidate stars as part of the Optical Gravitational Lensing Experiment (OGLE) — a variability sky survey conducted on the 1.3-meter Warsaw Telescope at Las Campanas Observatory, Chile.

The team's GMOS spectra on three of the candidate BLAPs confirmed that these stars are "low-mass giants" with helium-rich atmospheres and high surface temperatures of about 30,000 K, comparable with

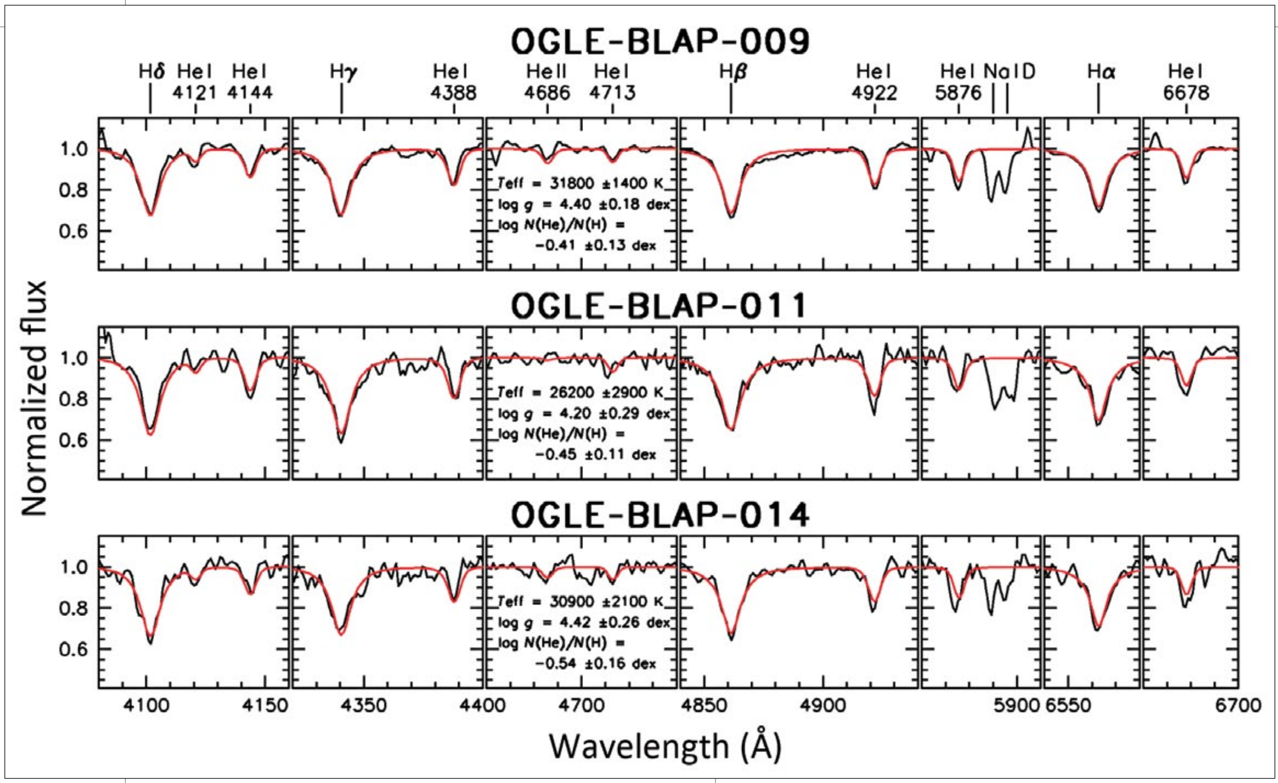


Figure 5.
Gemini South spectra for three BLAPs. Best fits of stellar atmosphere models are shown with red lines. Effective temperatures, surface gravities, and helium abundances derived for these stars are similar to the values obtained from spectra for the prototype object previously studied. This shows that all the newly discovered variables form a homogeneous class of objects.
Credit: Gemini Observatory/AURA/NSF

hot subdwarfs (Figure 5). The new pulsating stars vary with amplitudes of 0.2 – 0.4 magnitude, which is exceptionally high, given their short periods of only 20 to 40 minutes. This excludes the possibility that they are hot oscillating subdwarfs, leading to the conclusion that BLAPs form a new class of variable stars. These characteristics have not been observed in any known hot pulsators.

The very small number of BLAPs known so far points to a rare, unexplored episode in stellar evolution. This work is published in the journal *Nature Astronomy*, and is available ***online*** (subscription required). The article is also on ***astro-ph***.

The Little Star That Could … Survive a Supernova Explosion

Astronomers have identified a white dwarf star in our solar neighborhood moving faster than the escape velocity of the Milky Way. The international team, led by Stephane Vennes (Astronomical Institute in the Czech Republic), used telescopes in Arizona and the Canary Islands, as well as the GRACES (Gemini Remote Access to CFHT ESPaDOnS) spectrograph atop Maunakea to study this celestial speedster, which is thought to have been expelled like shrapnel from a peculiar Type Ia supernova explosion some 50 million years ago.

The speedy white dwarf, known as LP40-365, was first identified with the National Science Foundation's (NSF) Mayall 4-meter telescope at Kitt Peak National Observatory in Arizona. Over the next two years, the discovery team received critical follow-up observations from the Canary Islands and Maunakea, which they analyzed using state-of-the-art computer codes. The analysis proved the star's compact nature and exotic chemical composition, as well as its extraordinary Galactic trajectory, which puts it on a path out of the Milky Way with no return.

Astronomers once thought that nothing survives a Type Ia supernova, which occurs in a binary system that includes a white dwarf. However, a new class of models called "Subluminous type Ia Supernova" (also known as type Iax) can leave a partially burned remnant that is instantly ejected at high velocity. LP40-365 is the first observational evidence that such high-velocity remnants of failed

Type Ia supernovae actually exist in our Galaxy, and therefore it is an invaluable object to improve our understanding of these cosmological standard candles.

Many more of these objects may be lurking in the Milky Way and awaiting discovery. The recent European Space Agency's *Gaia* mission may well help us discover many more of these objects and help us understand how a little white dwarf star can survive a supernova explosion.

This research is published in the August 18, 2017, issue of ***Science***.

Gemini North Unmasks the Infrared Quintuplet

The "Infrared Quintuplet" has long been a mystery to astronomers. These five infrared-luminous stars lie at the center of hundreds of hot and massive stars (collectively known as the Quintuplet Cluster) only 30 parsecs from the central supermassive black hole at the core of our Galaxy. Most objects in the center of the Milky Way are highly obscured from our view by intervening dust at visible wavelengths. The stars in the Infrared Quintuplet, however, are further obscured by their own dust shells. These warm, cocoon-like shells emit bright infrared continuum radiation, diluting any infrared light from the stars themselves. The combination of these effects has made it very challenging, if not impossible, at any infrared wavelength to detect light from the interiors of the shells … or so it was thought.

As reported in the August 18, 2017, edition of ***The Astrophysical Journal***, Gemini astronomer Tom Geballe and his team used the Gemini Near-InfraRed Spectrometer (GNIRS) and Near-infrared Integral Field Spectrometer (NIFS) on the Gemini North telescope to penetrate the dusty cocoons of the Infrared Quintuplet and gather data on its members (Figure 6).

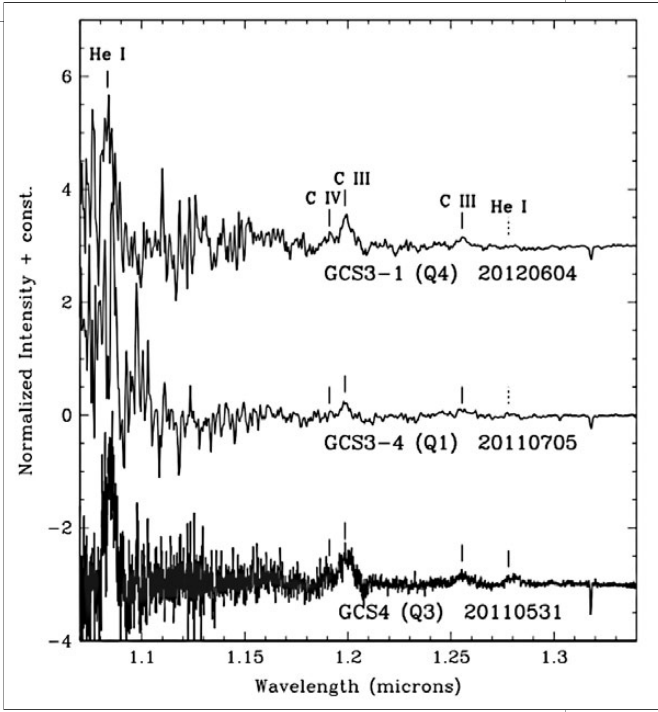


Figure 6.
J-band spectra of three of the five members of the Infrared Quintuplet showing emission lines of neutral helium and ionized carbon. The continuum radiation from the stars and their dust shells actually decrease rapidly from longer to shorter wavelengths and is barely detectable at the short wavelength edge of these spectra. In the figure the spectra have been "flattened" to more easily reveal the line emission. The increasing "noisiness" of the spectra toward their short wavelength edges demonstrates the increasing difficulty of detecting any light at all from these objects at those wavelengths.

The inspiration for the research began several years ago, when Geballe used NIFS at Gemini North for an unrelated research program and serendipitously discovered a very faint and broad emission line due to hot helium gas near 1.7 microns in the infrared spectrum of one of the Quintuplet stars. Prompted by this, he and his team obtained sensitive spectra of all five members of the Infrared Quintuplet, not only near 1.7 microns, but also down to wavelengths as short as 1.0 micron.

The team's spectra reveal the presence of emission lines from four of the five members of the Quintuplet, and have allowed the researchers to definitively identify the four as containing late-type, carbon-rich Wolf-Rayet stars, as was suspected based on the earlier imaging. These massive stars are only a few million years old, but have completely lost their outer hydrogen-rich layers and may be in the final stages of life before exploding violently as supernovae.

The existence of this Infrared Quintuplet is yet another illustration of the effects of high densities of massive stars in some clusters and of the extreme conditions at the very heart of our Galaxy.

JULY 2017

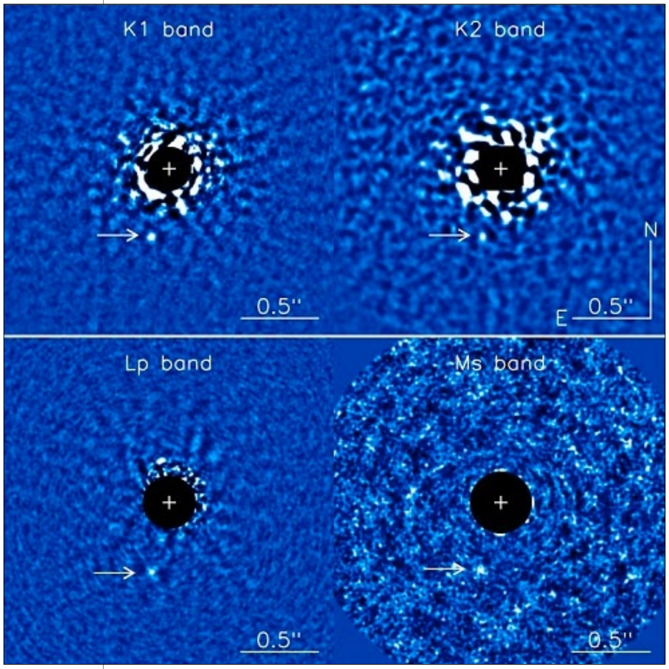
GPI Data Hint at Cold-Start Giant Planet Formation

New research on the first exoplanet discovered using the Gemini Planet Imager (GPI) — 51 Eridani b — hints that it may have formed by the the collapse of icy disk materials followed by the accretion of a thick gas atmosphere, much like that described in the cold-start model.

Two main scenarios of giant planet formation exist: hot start and cold start. In the hot-start model, gas giants form directly via the rapid collapse of a gaseous protoplanetary disk. In the cold-start scenario, a gas-giant begins as a core that forms very early on from planetesimal agglomerations before collecting the plentiful gas around it.

Abhijith Rajan (School of Earth and Space Exploration, Arizona State University), led the international team that observed 51 Eri b using GPI spectroscopy (Figure 7) as part of the Gemini Planet Imager Exoplanet Survey (GPIES), combined with mid-infrared photometry at the W.M. Keck Observatory.

Figure 7.
GPI images in the K1, K2, LP, and MS bands; the emission of the host star was blocked. The exoplanet 51 Eri b is indicated by an arrow. Located about 100 light years from Earth, Exoplanet 51 Eri b is between 2–10 times the mass of Jupiter.



These data were used to determine that the planet — a young, cool object between 2-10 Jupiter masses — is redder than brown dwarfs seen elsewhere. The enhanced reddening may be the result of clouds forming as the planet transitions from at partially- to partly-cloudy atmosphere, with lower mean surface temperatures. If true, 51 Eri b appears to be one of the only directly imaged planets that is consistent with the cold-start scenario, resulting in a low temperature, low luminosity planet.

The full results have been accepted for publication in *The Astronomical Journal*. A preprint is ***available here***.

Gemini South Joins HST in Joint Proper Motion Study

Tobias Fritz (University of Virginia) and colleagues used the wide-field Gemini Multi-conjugate adaptive optics System (GeMS) at Gemini South, combined with the Gemini South Adaptive Optics Imager (GSAOI), to study the proper motion of stars in the Galactic halo globular cluster known as Pyxis. These data, together with those from the Hubble Space Telescope, allowed the team to set a lower limit for the Milky Way's mass of 950 million Suns. This value is consistent with most, but not all, previous determinations.

GeMS/GSAOI was crucial to the study, because traditional ground-based telescopes are seeing limited and need a time baseline of more than 15 years for the types of measurements required in this survey. On the other hand, GeMS/GSAOI has better spatial resolution and can complete the project in five years — about the same time required for HST. Using GeMS/GSAOI, the team measured absolute proper motions of Pyxis to a resolution of 0.08 arcsecond (Figure 8), and combined these data with those from archival HST images, with a resolution of ~ 0.1 arcsecond.

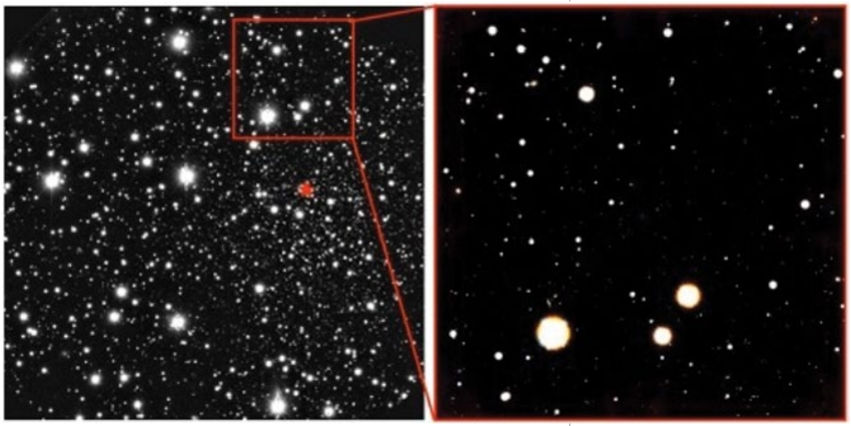


Figure 8.
Left: GMOS-South image of the Pyxis field, with the center of the cluster marked with a red star. Right: A zoom of the Pyxis area with GeMS-GSAOI. The field-of-view of GMOS is 5 x 5 arcminutes; GeMS is 85 x 85 arcseconds.

Lying at a distance of some 130,000 light years, Pyxis is one of the most distant examples of a globular cluster. It is also about 2 billion years younger than other globular clusters with the same metallicity. Together, these characteristics imply that Pyxis was likely formed in a massive dwarf galaxy that the Milky Way then cannibalized. Thus, Pyxis may have an extragalactic origin. One mystery, however, is that the orbits of other known massive dwarf galaxies are inconsistent with the orbit of Pyxis, which is derived from the new proper motion measurements.

The research is part of a much larger effort now underway to study the proper motion of several substructures across the Milky Way's halo. It is also part of a Large and Long Program at Gemini that is targeting other clusters, dwarf galaxies, and individual stars in stellar streams. ***The paper is published*** in *The Astrophysical Journal*.

Korean Astronomers Dissect a Fragmented Asteroid

In January 2017, the active and fragmented main belt asteroid P/2010 A2 made its closest approach to the Earth after its 2010 discovery, when it exhibited a mysterious comet-like dust trail. Prior to this year's passage, the fragments had not yet been characterized, due to the extremely small size (~ 120 meters in diameter) and faintness of this object.

A Korean team, led by Yoonyoung Kim of Seoul National University, received time on Gemini North to observe the object's 2017 close passage when the fragments and associated debris swarm were just over one astronomical unit away.

According to Kim, a variety of hypotheses could explain the history of this body, including rotational break-up, impact cratering, or shattering. The team determined a rotation period ~ 11.36 hours for the largest fragment, which, if the fragment's spin period has been constant after the mass ejection, would, according to Kim, fail to meet the critical spin rate for rotational break up.

The observations also reveal that the largest fragment has a highly-elongated shape with about a 2:1 ratio. Looking at the size distributions of the ejecta and other fragments, the team concludes that the body likely underwent impact shattering in order to produce the observed morphology.

The study's light curve is shown in Figure 9 and presents the largest fragment's double-

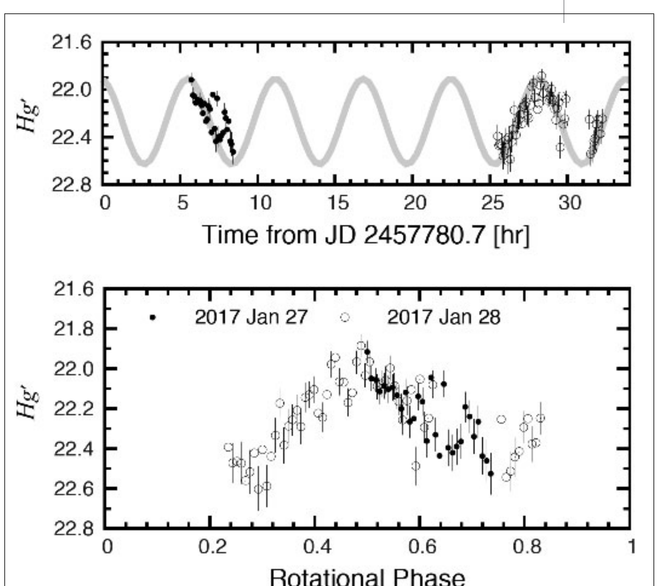
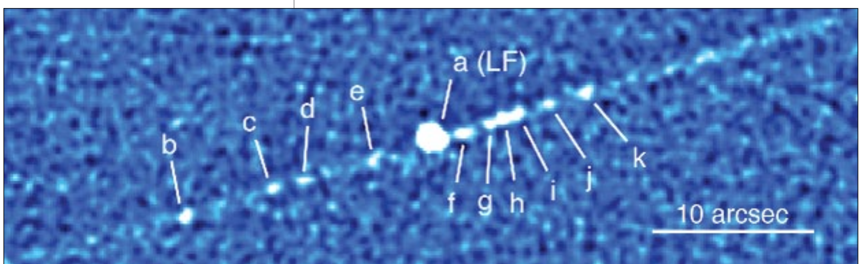


Figure 9.
Rotational light curve of the largest fragment of P/2010 A2. Time-series g0-band photometry over two nights (upper panel) and phase based on the best-t double-peaked period of 11.36 hr (lower panel). A sine curve with a period of 11.36 hr was plotted in the upper panel (gray line).

Figure 10.
Composite image of asteroid P/2010 A2 constructed from data from the Gemini Multi-Object Spectrograph on Gemini North. The team used this data to compare against models of the object's structure and dynamics.



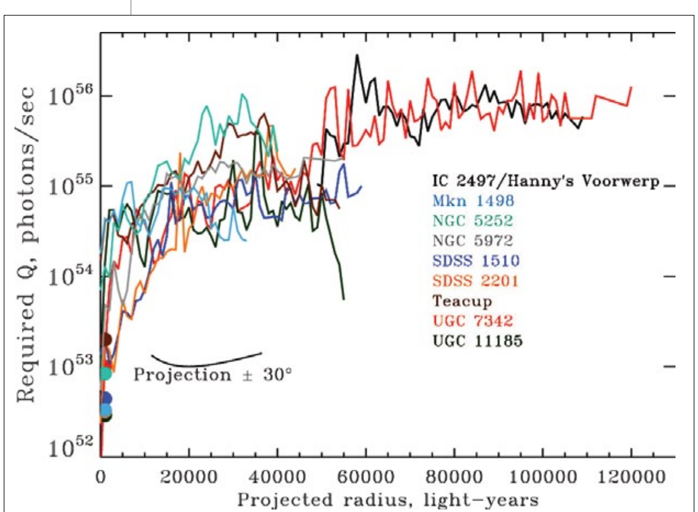
peaked period of 11.36 +/- 0.02 hours. Figure 10 presents a composite from the imaging data revealing the array of fragments and debris used to determine the mass of the largest fragment, which is about 80% of the system's mass; the other fragments and ejecta make up the remaining 20%. All figures are from the *accepted paper* scheduled for publication in *The Astrophysical Journal Letters*.

APRIL 2017

New Insights on Fading Active Galactic Nuclei in Collaboration with Galaxy Zoo

William C. Keel (University of Alabama) and collaborators use Hα narrowband filters on the Hubble Space Telescope (HST), in conjunction with the Gemini Multi-Object Spectrograph integral field unit (GMOS IFU) on the Gemini North telescope on Maunakea, to observe a set of fading active galactic nuclei (AGN). These AGN were first identified/classified as part of the Galaxy Zoo project — an online citizen science project in which the public help researchers deal with floods of incoming data aimed at classifying galaxies.

Figure 11.
Minimum ionizing luminosity of extended AGN-ionized clouds along the projected radius. These Hubble Space Telescope data show a luminosity drop in the last 20,000 years before our direct view of the nucleus, characteristic for all AGN of this study.



This work focuses on nine AGN with ionized gas clouds extending more than 10 kiloparsecs from them. Because these clouds span galaxy scales (or even larger) they can implicitly tell us about the luminosity history of the AGN. Based on this research, the nine observed AGN appear to have experienced a significant reduction in luminosity within 20,000 years or less (Figure 11).

The research team also uses GMOS IFU spectra to measure line ratios in these regions — to probe their ionization mechanisms and look for kinematic evidence of outflows marked by large (often bipolar) velocity ranges or other phenomena.

The team's results confirm what was hinted at by earlier, and less complete data (by the same team), that these fading AGN are structurally different from radio-loud AGN, which are dominated by outflows. Instead, these fading AGN are dominated by rotation and consist largely of externally illuminated tidal debris (Figure 12); the Gemini data show a shifting of the [O III] emission line due to the gas cloud's rotation.

This work appears in *The Astrophysical Journal*, and the paper can be found *here*.

Also read this *Galaxy Zoo blog* posting describing this work.

Rocky Planets Assembling in a Dwarf Binary System

To date, almost all of the known planetary systems that include a white dwarf are single stars. Now, a team studying SDSS 1557 (a white dwarf and brown dwarf binary system) using the Gemini South telescope and the European Southern Observatory's Very Large Telescope, have made a surprising

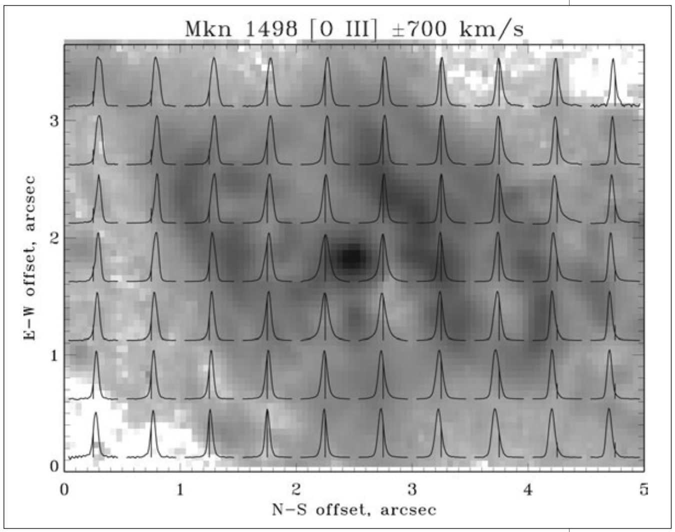


Figure 12.
[O III] emission-line profiles from the GMOS IFU spectra overlaid on the HST [O III] images for Mkn 1498, one of the galaxies studied in this work. This galaxy displays a ringlike emission feature dominated by rotation with a velocity range of ±175 km/sec, (the 700 km/sec referenced in the legend refers to the entire velocity range shown in each miniature line profile plot).

discovery that changes this old perception and opens a new window onto exoplanet formation.

Using GMOS spectra, Jay Farihi (University College London) and colleagues identified critical metal features in the system's spectrum as well as the higher Balmer lines. In contrast to the carbon-rich icy material commonly found in double star systems, the planetary material identified in the SDSS 1557 system has a high metal content, including silicon and magnesium. These elements were identified as the debris flowed from its orbit onto the surface of the white dwarf, polluting it temporarily with at least 10^{17} grams (or 1.1 trillion US tons) of matter, equating it to an asteroid at least 4 kilometers in size.

Farihi says: "Building rocky planets around two suns is a challenge because the gravity of both stars can push and pull tremendously, preventing bits of rock and dust from sticking together and growing into full-fledged planets. With the discovery of asteroid debris in the SDSS 1557 system, we see clear signatures of rocky planet assembly via large asteroids that formed, helping us understand how rocky exoplanets are made in double star systems."

The discovery came as a complete surprise, as the team assumed the dusty white dwarf was a single star, but co-investigator Steven Parsons (University of Valparaíso and University of Sheffield), an expert in binary systems, noticed the tell-tale signs of something unusual. "We know of thousands of binaries similar to SDSS 1557, but this is the first time we've seen asteroid debris and pollution," he says. "The brown dwarf was effectively hidden by the dust until we looked with the right instrument. But when we observed SDSS 1557 in detail, we recognized the brown dwarf's subtle gravitational pull on the white dwarf."

From the Gemini data the team estimated that the white dwarf has a surface temperature of 21,800 Kelvin (about 3.5 times hotter than the Sun) and a mass of ~0.4 solar masses; the brown dwarf companion has a mass of ~0.063 solar masses.

The research is published in the February 27th online issue of *Nature Astronomy*.

See the University College London ***press release here***.

β Pictoris b: an Exoplanet with the Atmosphere of a Brown Dwarf

A team of astronomers led by Jeffrey Chilcote (University of Toronto) uses the Gemini Planet Imager (GPI) at the Gemini South telescope in Chile to refine our understanding of the β Pictoris system. The system contains the ~ 13 Jupiter mass companion β Pictoris b, which is at the mass boundary sometimes used to distinguish between an exoplanet and a brown dwarf. Brown dwarfs are objects that are not massive enough for sustained nuclear reactions; and brown dwarfs less massive than 13 Jupiters cannot even start a nuclear reaction.

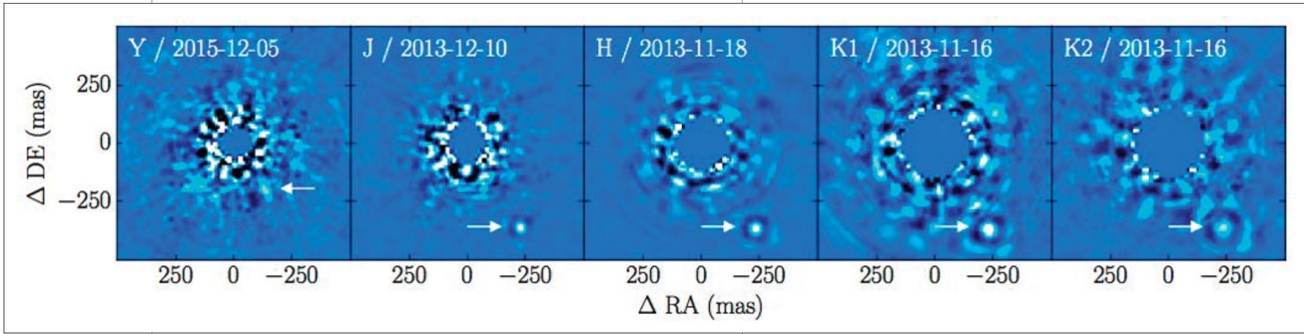


Figure 13.
Using advanced imaging techniques and the special capabilities of the Gemini Planet Imager (GPI), the light from β Pictoris has been suppressed in these images using GPI's Y, J, H, K1, and K2 filters. The arrow indicates the location of the exoplanet β Pictoris b in in all but the left image.

Based on the GPI data, combined with planetary evolution and atmospheric models, Chilcote suggests a "hot-start" planet formation scenario for β Pictoris b, which has a surface temperature of about 1,724 K. He adds, "This is consistent with the disk instability formation mechanism for wide-orbit giant exoplanets." However, the characteristics for the atmosphere of β Pictoris b found in this work best matches that of a low-surface-gravity (L2±1) brown dwarf, not a planet.

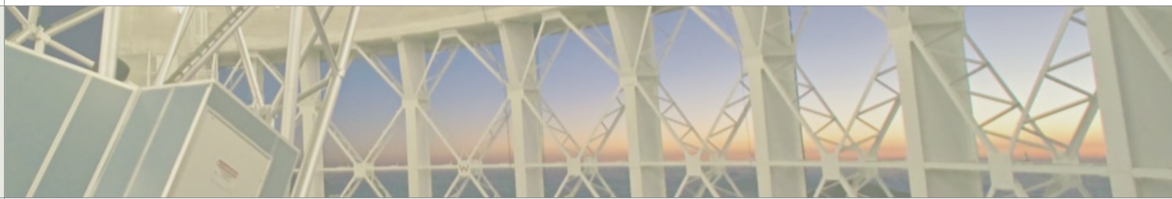
The team studied β Pictoris b during the verification and commissioning of the Gemini Planet Imager, and as part of an astrometric (position) monitoring program designed to constrain the orbit of the exoplanet (Figure 13). This work is also part of a Gemini Large and Long Program.

"With GPI, the Gemini Observatory is at the forefront of exoplanet exploration," says Chilcote. He adds, "Direct imaging allows for the discovery of planets on solar-systems-scale orbits, provides new insight into the formation and characteristics of extrasolar systems, and enables direct spectroscopic observations of their atmospheres."

The full results are accepted for publication in *The Astrophysical Journal Letters*. A preprint is available ***here***.

John Blakeslee is the Chief Scientist at Gemini Observatory and located at Gemini South in Chile. He can be reached at: jblakeslee@gemini.edu

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



Gemini staff contributions

On the Horizon

A collection of 2017 highlights from Gemini's instrumentation development efforts which will expand our future capabilities to do cutting-edge science.

JANUARY 2018

GHOST Cassegrain Unit Fully Assembled

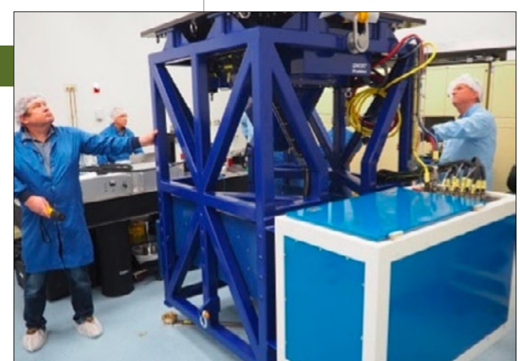


Figure 1.
AAO staff Vlad Churilov (left) and Lew Waller (right) steady the fully assembled GHOST Cassegrain unit as it is lowered onto load cells for mass and center of gravity measurements. Gemini's Gabriel Perez is in the background inputting the load cell data to calculate the center of gravity.

Credit: David Henderson

The build of the GHOST Cassegrain unit is nearly complete. In November, Gemini staff participated in weighing and inspecting the fully assembled unit at the Australian Observatory (AAO) lab in North Ryde, New South Wales. The unit is currently on its way to Chile.

In December, Gemini representatives spent a week at the AAO testing the Integral Field Unit (IFU) positioner and verifying the assembly and operation of the electronics and software of the Cassegrain unit. Following over four days of inspections, tests, and demonstrations, the positioner, electronics, and software were accepted for shipment to Gemini South. The electronics unit is expected to be shipped to Chile by year's end where the team will begin preliminary testing and debugging on the telescope in late January.

— *Cathy Blough*

OCTOCAM Starts Its Preliminary Design Stage

OCTOCAM, a wide-band medium-resolution spectrograph and imager, and the Observatory's next-facility-class instrument for Gemini South, has entered its Preliminary Design Stage (Figures 2 and 3, on the next page). Project members met for the Preliminary Design Kickoff meeting on October 17, 2017, at the lead contractor's location: the Southwest Research Institute (SwRI) in San Antonio, Texas. They used this opportunity to hold technical interchange meetings (optical, mechanical, electrical, and operations) to review the progress made against the Critical Design Review recommendations.

On December 11th, SwRI and the Gemini Observatory appointed Project Scientist Alexander van der Horst of The George Washington University as the Interim Principal Investiga-

Figure 2 (left).
Manuel Maldonado (FRACTAL Mechanical Engineer) points to a design that shows where light will enter the OCTOCAM spectrograph.

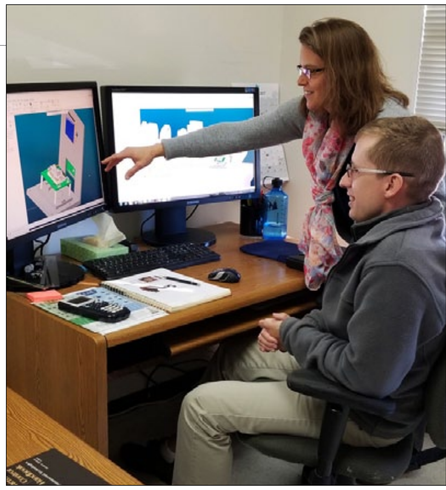


Figure 3 (right).
Susan Pope (OCTOCAM Systems Engineer, SwRI) shows the preliminary designs of the OCTOCAM IR detector and mount (left screen) to Carl Schwendehman (Mechanical Engineer, SwRI).

Credit: Andrea Blank

tor (PI) for the instrument. This appointment follows the departure of the Institute de Astrofísica de Andalucía (IAA) from the project. IAA had originally provided the PI and Deputy Project Manager roles through their subcontract with SwRI. We regret the departure and are grateful to IAA for bringing this project to Gemini.

In mid-December, Morten Andersen (Gemini Instrument Scientist) and van der Horst met to progress the Concept of Operations document, which describes the instrument's operating modes and requirements. In January, 2018, the team will come together at a Quarterly Review Meeting that will take place at both FRACTAL — a private technological company in Madrid, Spain, responsible for the instrument's opto-mechanical design and construction — and The George Washington University in January, 2018.

The team expects to hold its Preliminary Design Review in Q2 2018.

— Andrea Blank

Gemini South's New Laser Turns Skyward

For four days and nights beginning on October 26th, a team of scientists, observers, and engineers of the Gemni South Laser Upgrade project successfully commissioned the new SodiumStar TOPTICA Phototronics laser guide star facility (Figures 4 and 5). During the run, the team validated the new laser's performance, comparing it, back to back, with the old Lockheed Martin Coherent Technologies laser. The new TOPTICA laser shows very stable and reliable operation, and gives excellent sodium return despite being lower power than the LMCT laser, demonstrating the effectiveness of the sideband repumping feature of the TOPTICA laser. Direct comparison of sodium return from the two lasers allows a unique experiment comparing sodium excitation efficiency between pulsed (LMCT) and continuous (TOPTICA) lasers, with results to be presented at the SPIE conference in June.

The new laser was also used during a science laser run for six nights starting on December 6th; good seeing and a stable laser gave excellent Gemini Multi-conjugate adaptive optics System (GeMS) performance and stable adaptive optics (AO) loops.

GeMS instrument Associate Scientist Gaetano Sivo comments in the observing log: "The performance was unique. The first program we got diffraction limited in K on several exposures, we can see airy rings just on raw data [59 milliarcseconds (mas)]. All K images got sub-75 mas resolution; we got sub-80 mas in J-band."

— Manuel Lazo and Paul Hirst

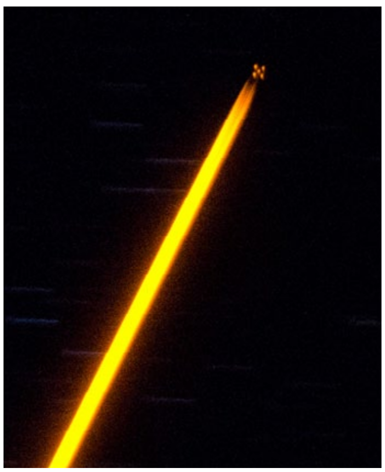


Figure 4 (left).
Gemini South TOPTICA laser constellation during the Commissioning Run on October 26-30, 2017.

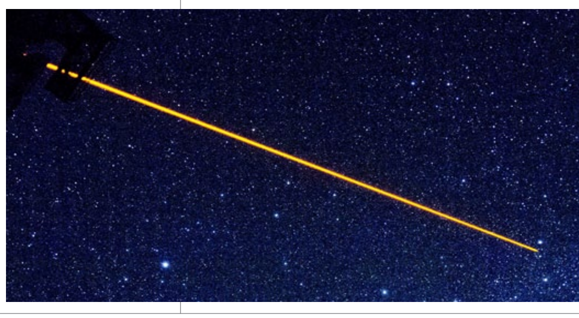


Figure 5 (right).
Gemini South TOPTICA Laser First Propagation during the October 2017 Commissioning Run.

Credit (Figures 4 & 5): Ariel Lopez, GS Science Operations Specialist Group Manager

Opportunities for Visiting Instruments

The instrumentation community should note that the National Science Foundation's (NSF) Mid-Scale Innovations Program (MSIP) Call for Proposals has been announced with a deadline of November 20, 2017. These grants can be used toward a variety of astronomical activities, including the development of instrumentation and providing the community with access to telescope capabilities.

The Gemini Visiting Instrument Program is the perfect complement to the National Science Foundation's (NSF) Mid-Scale Innovations Program (MSIP), as it provides astronomers with the opportunity to try out their own unique and innovative instrumentation on a world class telescope, while allowing all interested parties to propose for time. See the NSF Call for Proposals for more information about the MSIP. Other programs that may be of interest include the Astronomy and Astrophysics Research Grants and the Major Research Instrumentation Program. Unfortunately, Gemini facility instrument and instrument upgrade proposals are not eligible for these grants.

If you are interested in finding out more about how you might bring your instrument to Gemini, or how Gemini might support your instrumentation plans, please email us, and we will include you in the mailing list for this discussion.

— Alison Peck

OCTOCAM Meetings Lead to Forward Progress

After a successful kickoff meeting in April, the OCTOCAM team worked with Gemini staff to establish a better understanding of Gemini operations and how the new instrument (an eight-channel imager and spectrograph) would be successfully integrated. The teams came together again in early August for the Conceptual Design Review in Hilo, Hawai'i (Figure 6).

Pete Roaming (Project Manager for Southwest Research Institute) and Christina Thöne (Deputy Project Manager from the Institute of Astrophysics of Andalusia in Spain) led the presentations on work accomplished during the project's first four months. An external review panel chaired by John Troeltzsch from Ball Aerospace reviewed the required documents and led a discussion of progress thus far.

The OCTOCAM team benefited from a summit tour to familiarize themselves with the telescope's physical structure, Acquisition and Guidance unit, and space envelope. A panel report was submitted to Scot Kleinman (Gemini's Associate Director of Development) to be incorporated into recommendations to the team as they advance to the preliminary design stage.

— Catherine Blough

Figure 6.
In August, the OCTOCAM team met at Gemini North in Hilo, Hawai'i, for the instrument's Conceptual Design Review.

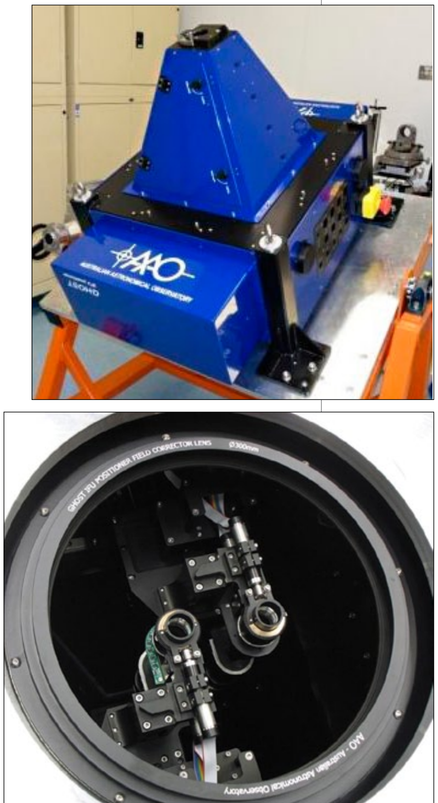


Figure 7.
AAO is completing the build phase of its work on the GHOST Cassegrain unit, including its integral field unit (IFU). ***Top:*** *The IFU subassembly enclosure (blue) and mounting frame (black) attached to the Instrument Support Structure (ISS) mounting plate (silver).* ***Bottom:*** *A detailed image of the IFUs and positioning arms.*

GHOST Takes Shape

The Gemini High-resolution Optical SpecTrograph (GHOST) — the joint project between Gemini, Australian Astronomical Observatory (AAO), National Research Council Canada-Herzberg (NRC-H), and the Australian National University (ANU) — has made good progress over the past few months. In May we held a team meeting in Sydney, Australia, with members from all four institutions to plan the project's test phase and work through other outstanding project issues.

GHOST begins verification and testing over the next several months. AAO is completing the build phase of its work on the instrument's Cassegrain unit (Figure 7) and science optical cable. The ANU has completed 70% of the instrument control software and is finishing the last lines of code needed for the upcoming testing. The GHOST data reduction software, also being developed at ANU, is also progressing well.

The team will test over the next two to three months to verify that requirements are met prior to shipping the slit viewer and science optical cable to Canada for integration with the spectrograph, which the NRC-H is building. The Cassegrain unit will also be tested prior to shipping with the prototype optical cable to Chile for preliminary testing on the telescope. All of this work is to ensure that everything is working in preparation for the arrival of the spectrograph later in 2018.

To date, the build team has submitted 74 design requirements verification reports to Gemini, all of which were accepted.

— Catherine Blough

JULY 2017

OCTOCAM Project Formally Begins

The OCTOCAM team continue to work toward the project's first major assessment point, the Conceptual Design Review (CoDR).

The team, including members from the Southwest Research Institute (SwRI), the Instituto de Astrofísica de Andalucía (IAA), Fractal, George Washington University (GWU), and Gemini, met in Granada, Spain, on April 19th to formally kick off the project to bring the next new facility instrument to Gemini.

A month later, SwRI successfully led a virtual informal Systems Requirements Review. Its main aim was to review the top-level requirements, the status of each needed trade study, and how the current design complied with the top-level requirements. Since the review, the OCTOCAM team has been progressing the design, evolving the science team, and writing project plans in preparation for the CoDR to be held in Hilo, Hawai'i, on August 2-3.

— Stephen Goodsell

GHOST's Upcoming Test Phase Planned

The Gemini High-resolution Optical SpecTrograph (GHOST) project continues to move forward during the project build phase. In mid-May, representatives from all four organizations involved with GHOST met at the Australian Astronomical Observatory (AAO) in North Ryde, Australia, to plan the upcoming test phase of the project (Figure 8). This was the first large-scale meeting of the project members since the Critical Design Review in early 2016, and was considered a very productive week.

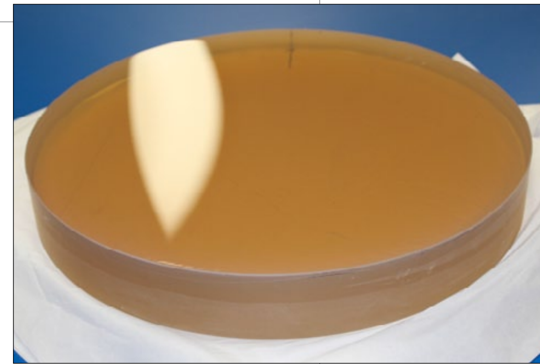


Figure 8.

GHOST team in North Ryde, Australia. Clockwise around the table: Jon Nielsen, Tony Farrell, Peter Young, Jennifer Dunn, Steve Margheim, Vlad Churilov, Ross Zhelem, Mick Edgar, Lew Waller, Richard McDermid, John Bassett, Greg Burley, Mike Ireland, and John Pazder.

Photo credit: David Henderson

Figure 9.

GHOST collimator mirror after aspheric polishing.

Photo credit: Precision Asphere, Inc.

At the end of the year we intend to move parts of GHOST to Gemini South for testing, including the AAO-built Cassegrain unit (part of which is seen in Figure 7, previous page), and prototype optical cable assembly. AAO plans to send the slit viewing assembly and science-grade optical cable shortly thereafter. The controlling computer, loaded with software from the Australian National University, will go to the National Research Council Canada-Herzberg in Victoria, Canada, for integration with the spectrograph and thermal enclosure built there. Meanwhile, multiple suppliers are processing the many spectrograph optics, such as the GHOST collimator mirror (Figure 9). A little over a year from now, these assemblies are slated to ship from Canada to Chile, where they will be coupled with the Cassegrain unit. Once completed, GHOST begins testing and commissioning on the Gemini South telescope.

— David Henderson

Gemini South Laser Nears Installation

Progress continues for the new TOPTICA laser for the Gemini Multi-conjugate adaptive optics System (GeMS). TOPTICA staff in Munich, Germany, recently found the source of the bug that was causing an intermittent Interlock error. On June 20th, the laser passed the post-shipping acceptance testing. The

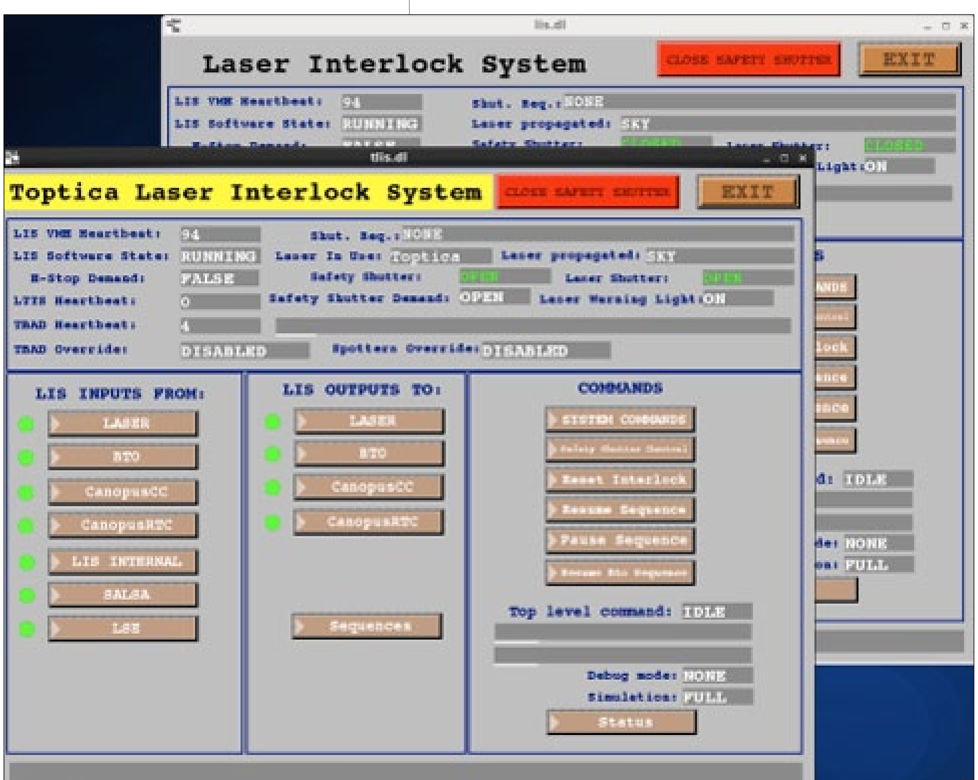


Figure 10.

The TOPTICA Laser Interlock System Data Manager screen. Angelic Ebbers developed it as part of the Experimental Physics and Industrial Control System (EPICS) code to interact with existing parts of Gemini South telescope's safety subsystems. It also interacts with the safety aspects and feedbacks of the TOPTICA Systems; Paul Collins developed the latter in a Programmable Logic Controller environment.

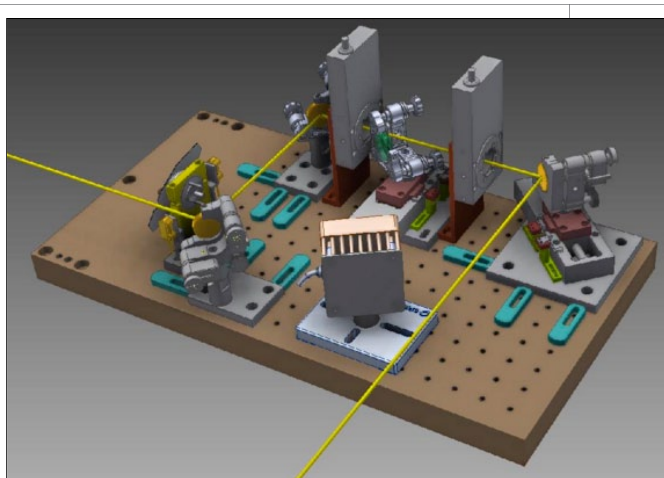


Figure 11.
The design of the TOPTICA Laser Beam Injector Interface to the telescope Beam Transfer Optics by Gabriel Pérez.

laser is expected to be installed in early August, with on-sky commissioning to follow in the last week of October.

In early May, an initial version of the Experimental Physics and Industrial Control System (EPICS) code of the TOPTICA Laser Interlock System (TLIS) completed successful lab testing testing (Figure 10; previous page). The TLIS is an important safety system required to operate the TOPTICA laser at Gemini South.

Lastly, Gemini Senior Mechanical Group Leader Gabriel Pérez completed the design of the interface between the TOPTICA Laser Head and the Beam Transfer Optics (BTO; Figure 11), and it is now ready for fabrication.

— Manuel Lazo

‘Alopeke Settles in at Gemini North

In October, Steve Howell and his team (Figure 12) will plan to commission a new speckle instrument named ‘Alopeke. The instrument is to be mounted on the Gemini North telescope as a Gemini visiting instrument. Speckle imaging is an interferometric technique by which telescopes can achieve diffraction-limited imaging performance using Fourier image reconstruction techniques techniques (Figure 13) with with cameras that are capable of reading out frames at a very fast rate. The images, reduced using specialized software, allow scientists to effectively “freeze out” the effects of atmospheric seeing and perform the equivalent of space-based imaging with ground-based telescopes.

The design of ‘Alopeke is based on the Differential Speckle Survey Instrument (DSSI). The original DSSI has been a popular visiting instrument at Gemini since 2012. Making observations at both Gemini North and South, DSSI has provided simultaneous diffraction-limited optical imaging — Full-Width at Half-Maximum (FWHM) ~0.02″ at 650 nanometers (nm) — of targets as faint as V ~16–17, in two channels over a ~2.8″ field-of-view. The diffraction-limited resolution possible at Gemini (0.016″ FWHM at 500 nm or 0.025″ at 800 nm), with no need for an adaptive optics guide star or laser, offers unique scientific capabilities.

The most recent DSSI visit to Gemini South was marred slightly by unstable weather, but in the end, the team obtained data on a large range of projects from follow-up validation of exoplanet candidates to a search for close binary companions of exoplanet host stars, as well as a study of the rate of binarity in low mass star forming regions.

‘Alopeke is the contemporary Hawaiian word for Fox, and this name was chosen

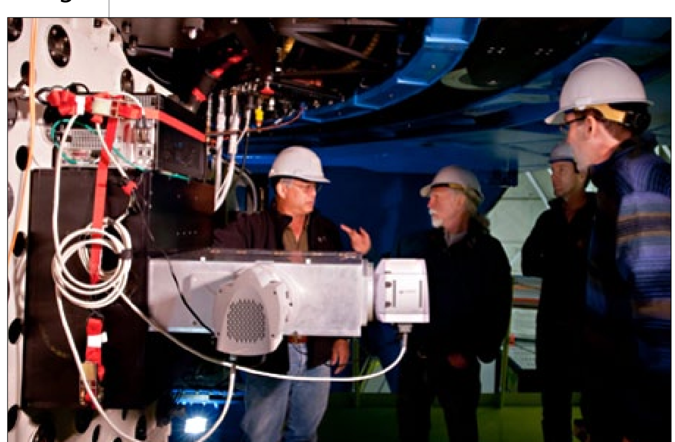


Figure 12.
Members of the ‘Alopeke team work with Gemini engineers on Maunakea. Credit: Joy Pollard

for the newest member of the DSSI family because it is very agile and quick. The new dual-channel instrument will have a larger format than the previous version, modern Electron Multiplying CCD cameras, and both speckle and wide-field imaging capabilities with standard Sloan Digital Sky Survey filters. One of the unique features of DSSI is its robust and compact design, and 'Alopeke will take full advantage of this.

'Alopeke will be permanently mounted on Gemini North in a location that does not interfere with the standard instrument ports — so users can operate it in visitor mode (when time is allocated through the Time Allocation Committee) without the additional overhead of mounting and then removing the instrument. This innovative placement will permit us to offer 'Alopeke at each Call for Proposals. It will be remotely operable from the Hilo Base Facility. The instrument team will make the observations and provide their standard pipeline-reduced data products to Principal Investigators. We will make the data available (after the standard proprietary period) via the Gemini Science Archive (in a reduced-effort mode).

In addition to other types of science, speckle observations are viewed as a critical part of the exoplanet validation process, providing essentially the only method to validate small, rocky planets. 'Alopeke will be ideal for characterizing a system of low mass planets, such as that orbiting the late M-type star, TRAPPIST-1 (Figure 14). Previous observations of that star, which is only about 8% the mass of our Sun, showed variations in the flux which suggested the presence of several Earth-sized planets. The situation could be much more complicated than that, however, if TRAPPIST-1 were part of a binary or multiple star system. The resolution afforded by DSSI on Gemini South allowed astronomers to see closer to TRAPPIST-1 than the orbit of Mercury to the Sun, and effectively ruled out the existence of any stellar or sub-stellar companion.

We expect 'Alopeke to have even better performance than DSSI. It will be mounted on the Gemini North telescope permanently and will be available for continued observations of this sort in the future.

— Alison Peck and Steve B. Howell

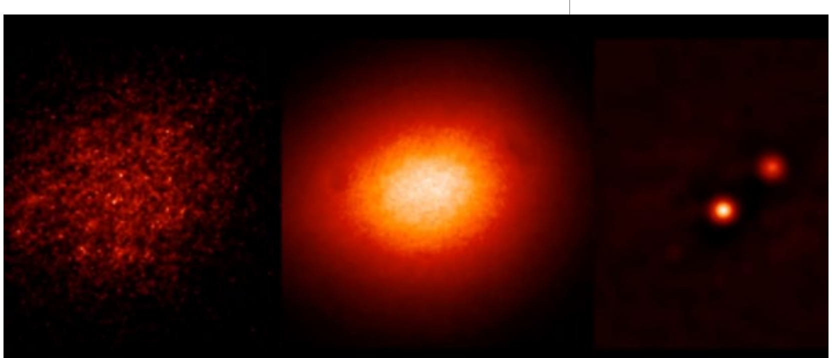


Figure 13.

This image shows some steps in the process of Speckle Image reconstruction using Fourier transform techniques. Left: A single 50 millisecond speckle image of a star. Middle: a conventional image typical of a ground-based telescope. Right: A reconstructed image revealing the star is really a close binary pair. The boxes are ~ 1 arcsecond on a side.

Credit: Elliott Horch

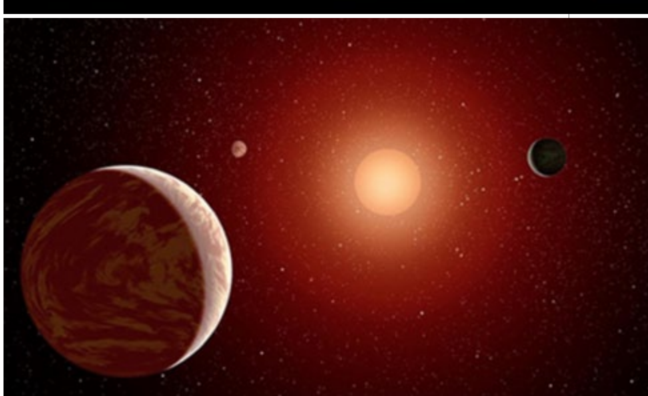


Figure 14.

Artist's impression of the TRAPPIST-1 exoplanetary system showing three Earth-sized planets in orbit around the low-mass star. Observations characterizing this system were made using DSSI on Gemini South last year.

Credit: Robert Hurt/ JPL/Caltech

For more information on the __Gemini Visiting Instrument Program__, what capabilities to expect in coming semesters, or how you can bring your instrument to Gemini, email: __gemini-vip@gemini.edu__

GHOST Taking Shape

Development of Gemini's high-resolution optical spectrograph GHOST — a joint effort by the Australian Astronomical Observatory, the National Research Council Canada-Herzberg, and the Australian National University — continues to progress. As of the end of 2016, most of the Cassegrain unit's mechanical parts have been manufactured, received, test fitted (as shown in Figures 15-17), and partially disassembled for anodizing. The Cassegrain unit's mechanical assembly is close to being completed. Most of its optics have also been received, and they have passed Acceptance Testing; optics integration will start at the end of March, followed by electronics integration.

Figure 15.
GHOST integral field unit positioner frame.

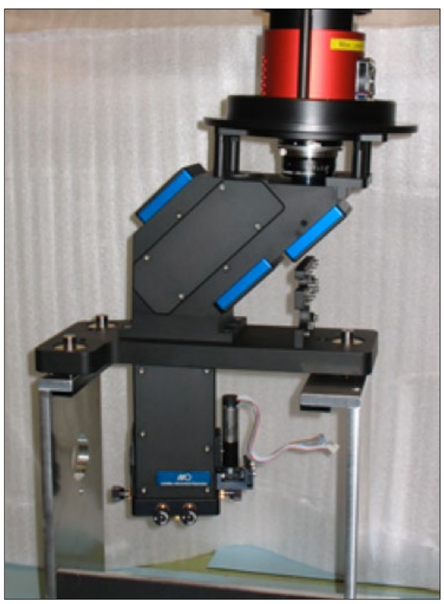


Figure 16).
GHOST Slit Viewer mechanical assembly.

Figure 17.
GHOST IFU positioner mounted in its frame on the tilt table.

Credits: All AAO

The final mechanical elements for the Guide Camera assembly, Slit Viewer assembly, and Calibration unit, have also been completed, and we are now ready to integrate their optical elements and electronics. The Guide Camera assembly and Calibration unit are on target for Instrument Control Software integration in mid-May.

— David Henderson

FLAMINGOS-2 Capabilities

Multi-Object Spectroscopy Progress

The FLAMINGOS-2 (F-2) near-infrared (NIR) imager and spectrograph was designed with multi-object spectroscopy (MOS) in mind, but we could not commission this important feature until now. F-2 MOS is achieved by cutting aluminum plates ("masks") with the desired slitlets' width, length, and target positions in the 6 x 2 arcminutes field-of-view on the sky. The masks are located on the "MOS wheel," which locates each mask on the telescope's focal plane and has slots for nine different masks.

One critical capability for MOS observations is the ability to change masks while the instrument is installed on the telescope. By addressing this important function (as we did with this work) we minimize the impact on the instrument-telescope alignment and keep the camera cryogenic dewar cold, with the detector stabilized at its working temperature of 80 Kelvin (K). Because F-2 is sensitive to part of the thermal region of the NIR (up to 2.5 microns), the masks and the instrument's front section are inside a frontal cryogenic dewar. In order to exchange the MOS masks, the frontal dewar has to be thermally cycled between the ambient temperature and atmospheric pressure, and then back down to 100 K and high vacuum. The next step is to test the engineering procedures and install a batch of masks for science commissioning, planned for the week of March 27th. The next step is to test the engineering procedures and install a batch of masks for science commissioning, planned for the last week of April.

Update on K-band Filters for F-2 (K2F2)

In Semester 2017B, Gemini will offer in shared risk mode two medium-band filters for splitting the K-band (1.9–2.5 microns): a K-red filter (2.19–2.44 microns) and a K-blue filter (1.94–2.17 microns). We have received the filters from Texas A&M University as part of the K2F2 project — a Small Project for Instrument Upgrades awarded funds in 2016 (Figures 18 and 19). The filters will be installed during a scheduled instrument shutdown spanning April 6–18. On-sky acceptance tests will follow, with science commissioning slated for May.

— Rubén Díaz

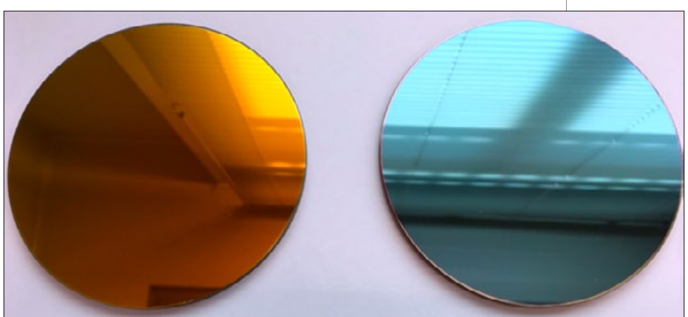


Figure 18 (left). *The K-red filter on the left and the K-blue filter on the right. Images were obtained during the filters' physical inspection.*

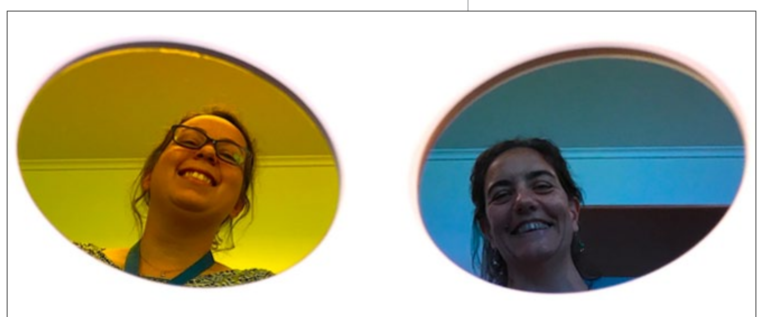
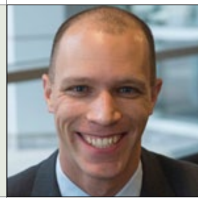


Figure 19 (right). *Reflections of Gemini South Science Fellows Karleyne Silva and Veronica Firpo, left and right, respectively.*



Jacob Bean, Andreas Seifahrt, Alison Peck

MAROON-X: A New ExoEarth-finder Spectrograph for Gemini North

Astronomers at the University of Chicago are finalizing a new visiting instrument for Gemini North. Called MAROON-X, this radial velocity spectrograph is expected to meet the challenges and opportunities facing researchers seeking not only to identify and characterize nearby habitable exoplanets, but ultimately to make a credible search for life on planets outside the Solar System.

One of the most exciting areas of exoplanet research is identifying and characterizing nearby habitable planets. Indeed, the latest National Research Council Astronomy and Astrophysics Decadal Survey report ("New Worlds, New Horizons in Astronomy and Astrophysics") listed this specific objective as one of the top three science frontier discovery areas in all of astronomy for the coming years. The ultimate goal is to make a credible search for life on planets outside the Solar System. This dream is within the grasp of the current generation of astronomers.

One of the key technology components vital to realizing a comprehensive exoplanet science program is an instrument for measuring radial velocities to sufficiently high precision. That is why the University of Chicago's Bean Exoplanet Group is currently building a next generation radial velocity spectrograph called MAROON-X — to meet the challenges and opportunities described above.

The radial velocity method has been one of the most important observational techniques in the field of exoplanet science, and it will continue to be critical for making many significant exoplanet discoveries anticipated over the next two decades.

An important goal of exoplanet science is to precisely measure masses and radii for a large enough sample of low-mass planets so that robust statistics emerge. Data from the original Kepler mission have been used to identify thousands of planet candidates, but the masses of most of these planets cannot be measured with existing spectrographs because the expected radial velocity signals are too small or the host stars are too faint, or a combination of both.

Many new transiting planet finder missions (designed specifically to exploit the synergy between radial velocity and transit techniques) have recently been approved: the Kepler spacecraft has been repurposed for the K2 mission; NASA's Transiting Exoplanet Survey Satellite (TESS) mission is scheduled for launch in March 2018; ESA's CHaracterising EXOPlanet Satellite (CHEOPS) mission is planned for the end of 2018; and ESA's PLAnetary Transits and Oscillations of stars (PLATO) mission is now set for 2026. Therefore, many new small transiting planets will be identified over the next decade. This presents an enormous opportunity to expand the study of planetary statistics into the regime of planet bulk compositions — if we can measure the masses of these objects using the radial velocity method.

The Radial Velocity Method

The techniques for Doppler spectroscopy have currently progressed to the point that precisions of 1-2 meters/second (m/s) are routinely obtained on bright stars (*e.g.*, Howard *et al.*, 2011; Lovis *et al.*, 2011), and precisions of 60-80 centimeters/second (cm/s) have been obtained in a few select cases (*e.g.*, Pepe *et al.*, 2011). However, existing radial velocity instruments become very inefficient around V = 12th magnitude and objects with V > 13th magnitude are unattainable for all but the most intense campaigns. Therefore, 85% of the nearly 5,000 planet candidates from the Kepler mission that have Kepler magnitudes greater than 13 are essentially out of reach of existing instruments.

In addition to having substantially improved precision and reach, the next generation of radial velocity spectrographs should also cover longer wavelengths for efficient observations of very low-mass M dwarfs. One pathway for studying habitable planets is focused on the opportunity offered by M dwarfs; in particular the very lowest-mass M dwarfs (those with $M_{star} < 0.3\ M_{\odot}$). In contrast to solar-type stars, the habitable zones of M dwarfs are close-in enough so that planets in this region have a significant chance of transiting, making them feasible targets for transit spectroscopy observations to characterize their atmospheres. The James Webb Space Telescope (JWST) will be able to make measurements of the transmission spectra for such planets (Deming *et al.*, 2009), but we first have to identify good targets.

Improved reach to fainter stars is important for the M dwarf science case. The lowest-mass M dwarfs are intrinsically very faint, and current instruments can achieve 1 m/s precision only for the handful of these stars within a few parsecs (*e.g.*, Proxima Centauri and Barnard's Star). To take advantage of the opportunities offered by transiting low-mass planets around low-mass M dwarfs, we need high-precision radial velocity measurements for these stars out to 20 parsecs (Deming *et al.,* 2009). Only a few percent of planets in the habitable zones of low-mass M dwarfs will have the right orbital geometry to transit. So a large volume of space has to be probed to be assured of finding some that would be ideal targets for atmospheric studies with JWST. With these conditions in mind, MAROON-X was conceived and born.

MAROON-X

To meet the opportunities and challenges described above and push towards eventually identifying other Earth-like planets, the MAROON-X team has carried out detailed simulations to identify the optimum wavelength range to observe low-mass M dwarfs for radial velocity measurements. We find that the red part of the optical spectrum contains as much radial velocity information as the near-infrared for stars down to masses of 0.10 $M_{\odot}$ ($T_{eff} \approx 2{,}600$ K), if not more, because radial velocity measurements depend not just on the number of collected photons, but also on the spectral line density. Although M dwarfs are brighter around 1 micron (μm), the very high line density at shorter wavelengths more than compensates for the difference. This means that the optimum wavelength intervals for radial velocity measurements of solar-type and low-mass stars are not very different, and they could be spanned by a single spectrograph.

We have therefore designed MAROON-X as a red-optical (500-900 nanometers (nm)), high-resolution (R = 80,000) spectrograph capable of delivering high-precision radial velocities with an intrinsic instrument stability of < 0.5 m/s. The instrument's core spectrograph is fiber-fed (including a fiber for simultaneous calibration), enclosed in a vacuum chamber, and thermally and mechanically isolated from its environment (see also Seifahrt *et al.*, 2016). We based the spectrograph's design on an asymmetric white-pupil approach, which re-images and then re-collimates all dispersed beams after the echelle grating into a common pupil to minimize the diameter of the cross-disperser and camera. The asymmetry arises from compressing the beam before entering the cross-disperser without sacrificing the aberration compensation of the classical symmetric white-pupil design. This design variation has been used successfully on other instruments, for example, on the High-Res-

Table 1.
MAROON-X main characteristics.

Spectral resolution	R = 80,000
Acceptance angle	FOV = 0.77" at the 8 m Gemini Telescope
Wavelength range	500 nm – 900 nm (in 56 orders)
Number and reach of arms	Two (500-670 nm and 650-900 nm)
Cross-disperser	Anamorphic VPH grisms
Beam diameter	100 mm (at echelle grating), 33 mm (at cross-disperser)
Main fiber	100 μm octagonal (CeramOptec)
Number and type of slicer	3x pupil slicer
Slit forming fibers	Five 50 x 150 μm rectangular (CeramOptec), incl. sky and calibration
Inter-order and inter-slice spacing	≥ 10 pixel
Average sampling	3.5 pixel per FWHM
Blue detector	Standard 30 μm thick 4k × 4k STA 4850 CCD (15 μm pixel size)
Red detector	Deep-depletion 100 μm thick 4k × 4k STA 4850 CCD (15 μm pixel size)
Calibration	Fabry-Perot etalon for simultaneous reference (fed by 2nd fiber)
Exposure meter	Chromatic
Environment for main optics	Vacuum operation, 1 mK temperature stability
Environment for camera optics	Pressure sealed operation, 20 mK temperature stability
Long-term instrument stability	0.7 m/s (requirement), 0.5 m/s (goal)
Total efficiency	11% (requirement) to 15% (goal) at 700 nm (at 70th percentile seeing)
Observational efficiency	S/N = 100 at 750 nm for a V = 16.5 late M dwarf in 30 minutes

olution Spectrograph (HRS) at the Southern African Large Telescope. Table 1 provides a summary of MAROON-X's properties. We intend to bring MAROON-X to Gemini North as a visiting instrument beginning in 2019.

Current Status

In January 2017, KiwiStar Optics delivered the core spectrograph and the blue wavelength arm to the University of Chicago. This has been installed in a chamber with temperature control to better than 20 milliKelvin (Figure 1). The spectrograph is currently undergoing an intensive test and calibration campaign. All the expected characteristics of the spectrograph (*e.g.*, resolution, scattered light, and efficiency) have been confirmed with lab measurements.

The spectrograph's efficiency in the blue arm is particularly impressive, with peak throughputs from the exit of the fiber feed to the focal plane of over 60% (Figure 2). Initial testing is being done with only the blue wavelength arm implemented and a smaller, off-the-shelf 2k x 2k e2v detector in place of the final 4k x 4k custom STA science detector systems that will be used on the telescope. Orders for the red arm and the final detector systems have been placed and delivery is expected for mid-2018. One of the detectors is a thick, deep-depletion CCD that offers quantum efficiencies of over 90% out to 900 nm to fully exploit the high throughput of the instrument and to suppress fringing which would otherwise limit the achievable radial velocity precision.

The primary wavelength calibrator for the instrument is a stabilized Fabry-Perot etalon, traced to the hyperfine transition of rubidium. This device delivers a comb-like spectrum of about 500 bright and unresolved lines per spectral order with frequencies traceable to a few cm/s (Stürmer *et al.*, 2017). In addition, an automated solar telescope delivers solar light to the spectrograph, to test and improve the data reduction and radial velocity analysis pipeline delivered with the instrument (Figure 3, on the next page).

First tests with the etalon calibrator demonstrated that even over the limited spectral coverage of the smaller and less stable lab detector system, the science and calibration fibers track each other to better than 20 cm/s over timescales of minutes to days (Figure 4, on the next page). The high line density and exquisite stability of the etalon allows for unprecedented stability vetting and calibration at a level otherwise offered only by a much more complex and expensive laser frequency comb.

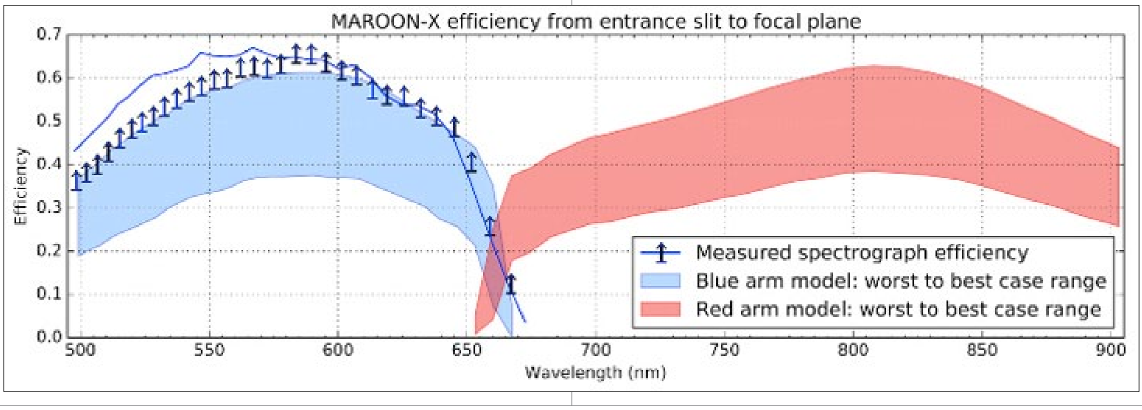


Figure 1.
MAROON-X spectrograph installed in its environmental chamber in the lab at the University of Chicago. Credit: Andreas Seifahrt for the MAROON-X team.

Figure 2.
Efficiency curves for the MAROON-X spectrograph from the fiber exit to the focal plane. The measured efficiency for the as-built spectrograph (arrows) are lower limits only due to limitations in resolving the blaze peak of each echelle order in a spectrophotometric setup. A model based on the measured throughput of all individual components is shown as the blue line. For comparison we show the theoretical predictions from an optical model with minimum and best-effort specs for the throughput and efficiency of all optical components. The delivered optics exceed the best case expectations over most of the bandpass of the blue arm and lend confidence in achieving similar efficiencies in the red arm, currently under construction at KiwiStar Optics.

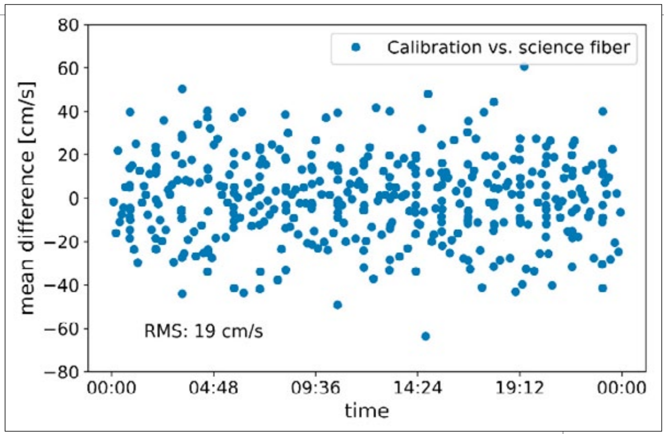


Figure 3.
Difference in radial velocity between one of the three science fibers and the calibration fiber for approximately 4,000 etalon lines from 16 orders of the blue arm. The timespan is 24 hours. Data were taken with 10 second to 5 minute cadence. No drift between the two fibers is apparent at the cm/s level with an RMS of 19 cm/s for the individual exposures.

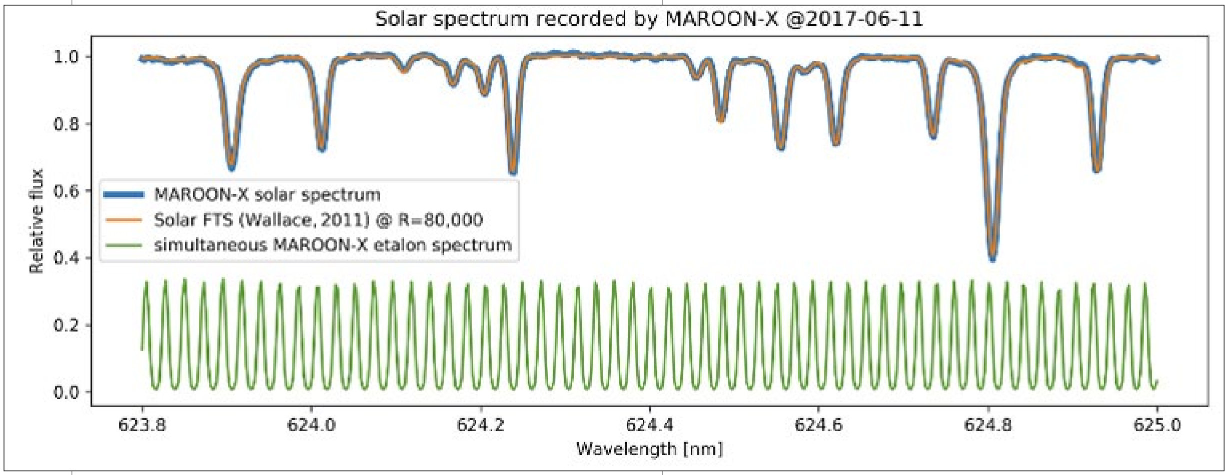


Figure 4.
Small subsection of a solar spectrum recorded with MAROON-X at the University of Chicago. For comparison we overplot the same region from the solar atlas of Wallace et al. *(2011) obtained with the Fourier Transform Spectrometer (FTS) at the McMath-Pierce Telescope, reduced to the spectral resolving power of MAROON-X (R = 80,000). In the bottom of the figure we show the simultaneously recorded spectrum from the MAROON-X etalon calibrator. The spectra have been flat-fielded and are blaze corrected.*

At present, the instrument team, with input from Gemini staff, is designing a front end for MAROON-X to connect to an instrument port, while the instrument itself will reside in the pier lab. We anticipate beginning commissioning at the end of 2018 or beginning of 2019 in order to offer this exciting new set of capabilities to the Gemini user community.

The MAROON-X team acknowledges funding for this project from the David & Lucile Packard Foundation, the Heising-Simons Foundation, and the University of Chicago.

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Gemini staff contributions

News for Users

A compilation of brief news items from throughout 2017 of relevance to the users of Gemini.

JANUARY 2018

Update on Governance Meetings

Beginning on November 9th, the Science and Technology Advisory Committee (STAC), AURA Oversight Council for Gemini (AOC-G), and Gemini Board of Directors (Board) met in La Serena, Chile, for nine action-packed days of very productive governance meetings. All three committees praised the progress the Observatory continues to make, and the dedication of the Gemini staff. Although the STAC and Board reports (which you can find posted on the ***Gemini external website***) tend to be a bit terse and down to business, the STAC did use bullet points to congratulate the Observatory staff on several fronts, including the successful installation and commissioning run of the new laser at Gemini South, the dome shutter repair at Gemini North, and successfully managing the complicated follow-up observations of GW170817.

The AOC-G, which tends to be a bit more effusive in their reports, noted that "Once again, the management and staff of Gemini are performing at an outstanding level and the entire Gemini team is clearly operating very efficiently with excellent science return, on modest resources."

Speaking of modest resources, all three committees recognized the critical importance of not only maintaining the current level of funding, but of stepping up efforts to expand the Partnership and increasing both our operating and development budgets. Looking for new partners has always been a Board prerogative, but at this meeting the Board directed the Observatory to take the lead. We fully intend to do so, as our recent efforts with Israel and Korea demonstrate.

Another common theme brought up by all three committees was the strategic importance of adaptive optics and the recognition that this is a real strength for Gemini. In the months ahead, we will step up our efforts to restore the Gemini Multi-conjugate adaptive optics System (GeMS) to its intended performance, and improve Altair, Gemini North's adaptive optics system. The STAC further recommended, and the Board approved, to explore options to move GeMS to the North, once the Gemini High-resolution Optical SpecTrograph (GHOST) and OCTOCAM become fully operational in the South. This is a bold suggestion, but one that does make a great deal of sense for many reasons, including ensuring that GeMS is guaranteed the time it needs at the telescope, and giving a unique capability and a new purpose to Gemini North.

Changes to Large and Long Programs

Since 2014, Gemini has enabled Large and Long Programs (LLPs), via a pool of time contributed by participating partners. The aim of LLPs is to produce "flagship" science by granting major allocations of time to programs that are either large (in the sense that they exceed what one would normally expect the national Time Allocation Committees (TACs) to allocate), or long (spanning multiple semesters), or both. However, while we have achieved completion rates comparable to those in the regular queue for most of these programs, a formal target completion rate has been missing. This leaves Principal Investigators uncertain regarding what to expect, and is inconsistent with the "flagship" designation.

At the recent STAC meeting, we asked the committee to help us resolve this problem. They agreed that for LLPs in Band 1 a target completion rate of at least 80% should be guaranteed. As discussed in the current LLP Announcement of Opportunity, if a Band-1 LLP reaches the end of its term (the set of semesters over which it was granted time) and is less than 80% complete, we will extend it automatically semester by semester until it reaches that mark. LLPs at term with more than 80% completion, and Band-2 LLPs, still have the option of formally requesting an extension via the LLP TAC. This new policy won't apply to Target of Opportunity programs, and it won't be backdated to existing LLPs.

An End to Rollover

The process of "rolling over" designated queue programs until they are complete has been a feature of Gemini's operations for many years. However, it added a significant degree of complication and guesswork in semester planning, was not well understood by Principal Investigators or even by Time Allocation Committee (TAC) members, and was not applied by all participants.

Recognizing the benefit that rollover brought for programs in Band 1, we have been discussing, over the course of a number of Operations Working Group meetings, the possibility of replacing it with something simpler (or removing it altogether). By August 2017, we agreed on a proposal: to replace the current rollover system, in which selected Band-1 programs are extended for two full semesters after the conclusion of their first, with a new rollover system, in which we allow all Band-1 programs to begin execution before their designated semester and continue executing throughout the entire semester after that.

This proposal was discussed with the STAC, the data that led to it were described, and the STAC approved the proposal; their recommendations can be seen on the ***Gemini website***. It appears that the amount of time required to support this will be small enough that, at least initially, we will not topslice anything from the TAC process in a given semester. We will reassess after a year of operating this way. As with the formal rollover before it, this policy won't apply to Target of Opportunity programs, for which completion rate is not in our control, or for Large and Long Programs, limited-term partner programs, or programs using visiting instruments.

'Alopeke Update

'Alopeke (Hawaiian for "Fox") arrived at Gemini North in October. It is a more sophisticated variant of DSSI, the speckle camera which has been visiting Gemini since 2012. This new instrument occupies essentially the only spot on the telescope where it is possible to get light to it without disturbing other instrumentation — that is, in the small gap between the calibration unit (GCAL) and the Instrument Support Structure (ISS). There's not much room in there, but 'Alopeke is small enough to fit. Therefore, although it's a visiting instrument maintained and operated by a non-Gemini team, it is able to remain on the telescope at all times and thus offers much greater scheduling flexibility.

'Alopeke has the usual speckle capabilities — two-color simultaneous speckle imaging over a 5 arcsecond field, significantly larger than was possible with DSSI, allowing diffraction-limited imaging in the visible — but now with a wide-field mode covering 60 arcseconds with rapid (26 Hertz full-frame) readout. This, of course, enables fast, two-color photometry over the larger field-of-view and should be excellent for occultation or high-speed photometry work.

Interestingly, the early commissioning data show that the wider field may also be amenable to image reconstruction. The left image in Figure 1 shows a shows a field in the globular cluster M15, taken in poor conditions (1 arcsecond seeing and very windy). Individual exposures were just 60 milliseconds with two sets of 500 images in each filter. Integrating all of the readouts produces, as expected, a blurry image consistent with the seeing, and with significant elongation due to windshake. From that rather uninspiring input, the team's image reconstruction produces a remarkably sharp image, with 0.15 arcsecond point spread function (Figure 1, right). Strictly speaking, these data are windowed, covering only the central 256 x 256 pixels (18.5") of the 1-k square array; however, the technique should also work over the full field.

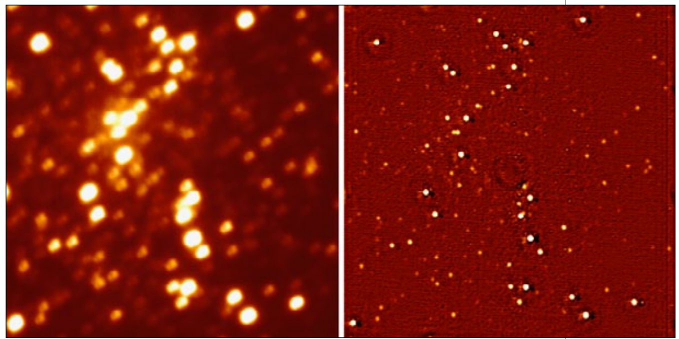


Figure 1.
A 19-arcsecond-wide field in globular cluster M15, imaged in half a minute with 'Alopeke at 832 nm. The stacked raw frame (left) has seeing of approximately 1 arcsecond and significant elongation due to windshake. Point sources in the reconstructed image (right) have FWHM approximately 0.15 arcsecond. These commissioning data cover the central quarter of the `Alopeke field, but the technique should also be extensible to the full field.

'Alopeke commissioning is not quite complete at this point due to a manufacturing problem in one of the cameras. However, we expect it to figure into Gemini's offerings over the coming semesters. We will post updates on its performance as this becomes clear. Interested Principal Investigators should consult the ***'Alopeke web pages*** and ***contact Steve Howell***, Principal Investigator for the Gemini Speckle program, for more details on its capabilities.

Update on Science and Evolution of Gemini Meeting

As this issue goes to press, early registration opens (on January 4th) for the Science and Evolution of Gemini Observatory 2018 conference. This meeting is scheduled for July 22-26 and features San Francisco's historic Fisherman's Wharf as a backdrop. Learn more about this exciting opportunity to be a part of Gemini's future by visiting the ***conference website***.

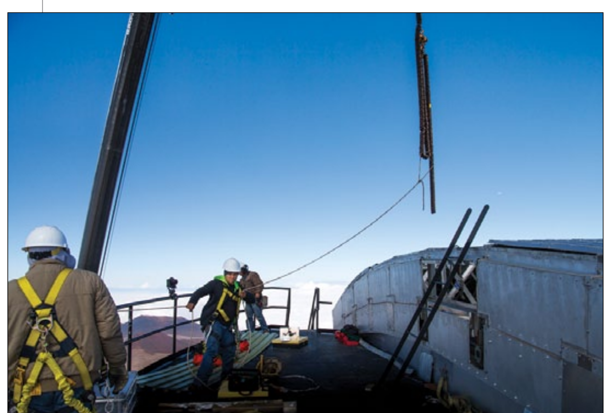
Gemini North Shutdown Ends

On August 25th, Gemini North returned to regular night-time operations after an extensive seven-week shutdown. As quoted, the project's definition was to "place the shutter mechanism in an as-new state or better, and ensure that no major failure occurs in the coming 15 years or longer."

You may recall the failure of shutter drive boxes, which cost significant observing time in late 2013/early 2014, and again in in mid-2014. Although we fixed those failures by installing spares, a deep analysis of root causes revealed two fundamental issues: (1) the drive chains suffered differential stretching over time, and (2) the drive assemblies were not mechanically free enough within their drive boxes. These issues contributed to the further failure of a lower-shutter drive box in August 2016. At that time, we responded by locking the lower shutter in place until the work required to fix it could be planned and budgeted. As we said in the October 2016 issue of *Gemini*Focus, only complete replacement of the chains and refurbishment of the drive boxes would fully mitigate the chance of future failures.

The drive chains are essentially stationary relative to the dome arch girders; the drive boxes are attached to the dome shutters, and crawl along these chains carrying the shutters with them. Extracting and replacing the drive boxes require pinning the dome shutters at various locations; the chains can only be replaced by extracting them from the very top of the dome and inserting new chains in the same way. The top of the Gemini dome is the highest point in the Pacific, thus we needed the largest crane on the island of Hawai'i to do the chain replacement.

The summit team (led by Gemini North Mechanical Engineering Group, and supple-



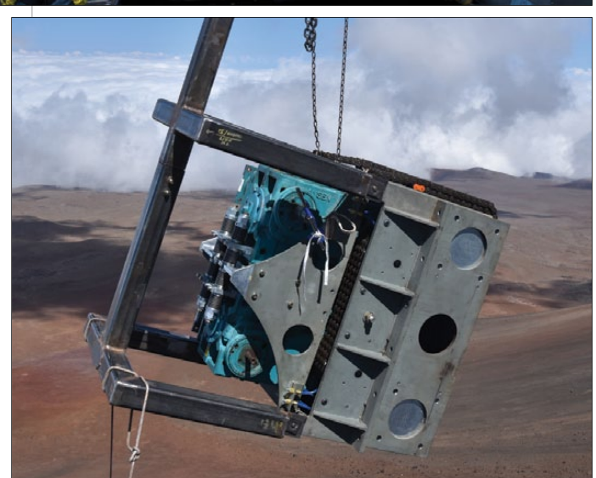
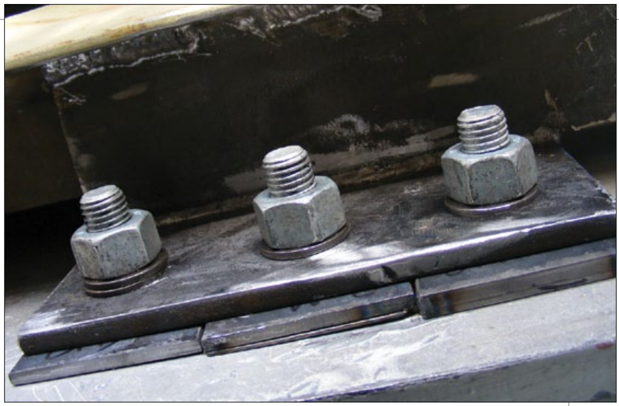


Figure 2 (top left). *A drive chain being extracted from the top of the arch girders. At this point, the tip of the crane is about 200 feet above ground level.*

Figure 3 (top right). *Handling drive chains at the very top of the dome.*

Figure 4 (below left). *Extracting a drive box from the dome. At this point the shutter structure, to the left in this photo, has been immobilized so that it will not move once disconnected from the drive chain.*

Figure 5 (right). *The extracted drive being lowered to ground level for refurbishment.*



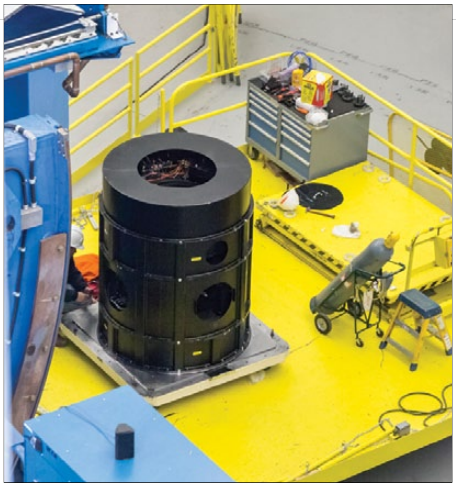


Figure 6 (left). *How the shutter was immobilized. Simple, but effective.*

Figure 7 (right). *The Acquisition and Guidance unit, extracted from the heart of the telescope for maintenance.*

mented with occasional help from the Science Operations Specialists group) worked through their well-choreographed plan almost exactly to schedule (Figures 2-5). The weather largely cooperated, and after starting on July 10th, we were back on sky as planned on August 25th.

We expect work of this scale to produce some surprises, and one that came up late in the project was a 10- to 12-millimeter misalignment of the lower shutter. We're still working to understand this. Until we're certain, the lower shutter will be kept out of normal operations at night (Figure 6). Meanwhile, the upper shutter is working more smoothly than anyone can recall, and night-time operations are going well.

In parallel, we took advantage of the closed time to carry out essential maintenance on a wide variety of instruments and telescope systems (Figure 7). The work involved essentially all disciplines, from mechanical to instrumentation, and from electronics to software. We worked on all the following needs: maintenance of instrument optics, replacement of part of the mechanism for the Gemini Multi-Object Spectrograph on-instrument wavefront sensor, refurbishment of the Gemini Near-InfraRed Spectrometer cold heads and work on its filter wheel and focus mechanisms, and inspection of the helium hoses within the Cassegrain Rotator. We also carried out upgrades of various processors in the Enclosure Control System and made a lot of progress on our project to counter obsolescence in our real-time control systems.

Upgrading the Observatory Control Software

When it comes to observing (and preparing for observing), virtually everything Gemini and its users do relies on the Observatory Control Software (OCS) — most of which has been around for more than a decade and a half. The user software (Observing Tool and Phase I Tool, referred to as OT and PIT, respectively) are large Java packages that require users to download hundreds of megabytes per semester. New users find the organically-grown OT over-complex and opaque. Even more youthful items, such as the PIT (which was completely rewritten in 2012), have significant scope for improvement and better integration with other user tools, such as the integration time calculators.

At the business end, we store observation definitions in a very non-standard database, which does not scale well; it also feeds a "Sequence Executor" (which runs the telescope and instruments) written in TCL/TK — now essentially a dead and unsupportable language.

For all these reasons, and with the approach of Large Synoptic Survey Telescope (LSST) operations (and the likely sea of change in time-domain and transient astronomy that it will bring), the time has come to step back and rethink/redesign the OCS, and we've started a project to do that.

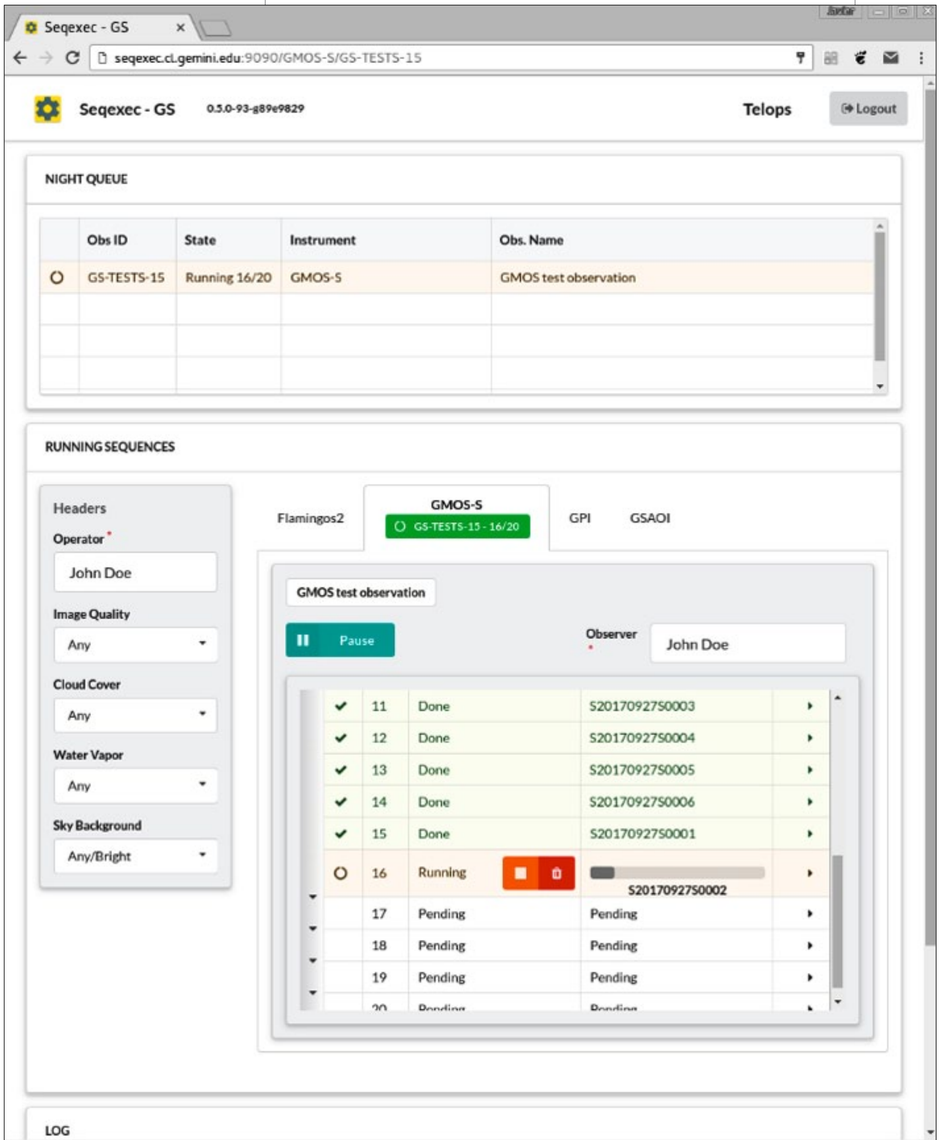


Figure 8.
The new seqexec, currently under development, running in a web browser.

As the Observing Database (ODB) lies at the heart of it all, we made it an early candidate for replacement; we are now progressing on a modern Postgres SQL database design to replace the current bespoke database, and a new web-based Sequence Executor (seqexec) to go with it (Figure 8). Along with these changes, we're developing a new "sequence model" (which represents the detailed observing sequence within the OT), as the current model is overcomplicated and the source of many maintenance headaches.

We plan to deploy the new database with the new seqexec in early 2018; this will be usable with FLAMINGOS-2 and the Gemini Multi-Object Spectrograph, and may also enable some tests of on-the-fly scheduling typical of what the LSST will need once it becomes operational.

For proposal submission, observation preparation, and program monitoring, we anticipate a set of interconnected web-based tools to replace the current large downloadable packages. We will absolutely not simply take the existing tools and re-implement them on the web; we intend to take a full step back and have a clear view of requirements and usability before we even think about a line of code.

Therefore, we will be starting a working group to develop the high-level user requirements. The membership of this group will include Gemini staff, NGO representatives, and members of the user community. The working group will review all feedback we have had on the existing tools, discuss possible fundamental changes in approach, and make recommendations for top-level needs and requirements, with examples written as user stories.

Note that the fundamental change in the underlying infrastructure may also make possible some other changes, such as enabling Principal Investigators to request physical observing conditions (seeing, *etc.*) "on target" rather than by conditions percentiles.

What's the timescale for all this? A little hard to say given the scale of the work, but we hope to switch off the old OCS by the end of 2019. Meanwhile, there will be incremental releases of the various tools and facilities as they develop.

Announcing Gemini's New Chief Scientist John Blakeslee

As of the publication of this issue, John Blakeslee begins his duties as Gemini's new Chief Scientist. John comes to Gemini from the National Research Council's Herzberg Institute of Astrophysics, in Victoria, British Columbia, where he has served as an Astronomer and Senior Research Officer. Prior to that, he was a faculty member at Washington State University and a Research Scientist at Johns Hopkins University. He also held postdoctoral positions at the California Institute of Technology and Durham University in the UK. John earned his PhD from MIT in 1997, and has worked on a variety of research topics, including galaxy structure and evolution, supermassive black holes, the extragalactic distance scale, globular cluster populations, and data analysis pipelines.

John is very familiar with Gemini, and for the past several years has worked in Canada's National Gemini Office. In his capacity as Chief Scientist, John will be instrumental in setting and implementing Gemini's scientific goals and directions while working closely with our international user community from the Gemini South Base Facility in La Serena, Chile. Gemini's Interim Director Laura Ferrarese notes, "The remarkable breadth of John's scientific interests makes him ideally suited to lead Gemini's vision into the next decade. We are all looking forward to welcoming him at Gemini and working together to further enhance the role our Observatory will play in the years to come."

JULY 2017

F-2 Stand-down Completed

FLAMINGOS-2 was removed from the telescope on April 4th for its annual maintenance stand-down. One imminent problem affecting operations: a filter wheel failure forced us to move the stand-down forward from its original schedule. With the instrument in the lab, we took the opportunity to resolve other instrument issues (Figure 9), including the outstanding problem with the On-Instrument Wavefront Sensor. During previous interventions, we inspected and improved the base mechanism; this time we inspected the pick-off drive mechanism and replaced its motor. While the instrument was still open, we also installed several new K-band filters. As a preventive measure, and according to the maintenance scheme, several cryogenic motors were replaced as well. After nearly three weeks of hard work, we successfully pumped, cooled down, and installed the instrument back on the telescope.

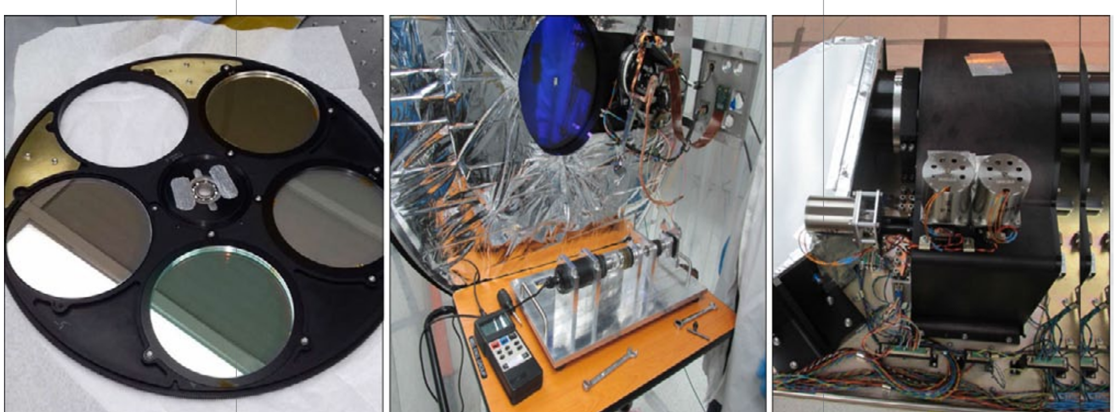


Figure 9.
Several instrument fixes were made during the annual FLAMINGOS-2 maintenance stand-down, including those shown here.
Left: K-band filters installation.
Center: New pick-off motor under torque testing.
Right: Cryogenic motors replacement.
Credits: Left and Right, Brian Chinn; Middle, Gabriel Perez

2016 Weather Losses at Gemini South

The 2016 winter season started off very wet, with precipitation levels at the beginning of the year reaching the annual average total within just a couple of days, bringing with it corresponding problems, including a washed out road to Cerro Pachón, and a snowed-in dome that the day crew did a fantastic clear-

Figure 10. *Gemini South telescope winter landscape.*

Figure 11. *Gemini South day-crew member Claudio Araya, who helped clear snow and ice from the dome.*

ing (once the summit road became accessible (Figures 10 and 11).

Since we now operate in Base Facility Operations mode, we have learned to use our cameras to assess the situation with the dome and shutter. In doing so, we have detected some limitations; for instance, we have recognized that an *in-situ* inspection is mandatory after any severe weather event.

Also, despite several power cuts during this period, our systems responded very well. To further optimize our operations and reduce fuel consumption, we have now enabled remote switching back to commercial power, once normal power is restored. This avoids running the generator for unnecessary periods once commercial power is available but access to the summit is not an option.

Figure 12 shows the weather losses at Gemini South over the period 2008-2016. The relatively reproducible year-to-year variation in weather loss (at least until 2014) is why we started, a year or two ago at an international Time Allocation Committee meeting, to reduce the amount of schedulable time in the winter and increase the available time in the summer.

Astroconda Now Recommended for Gemini Users

Following some significant Image Reduction and Analysis Facility (IRAF) integration and testing work on Gemini's data processing software, we now recommend that all new installations be performed using Astroconda, in place of Ureka; see instructions and further information *here*.

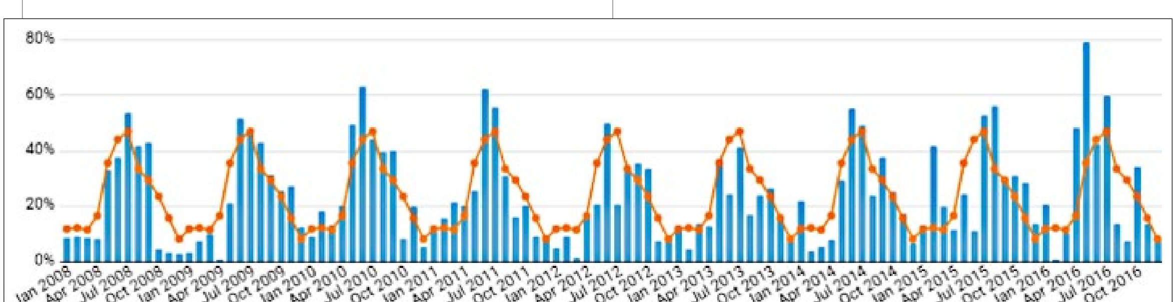
New Version of GMMPS Released

The recent release of the Gemini MOS Mask Preparation Software (GMMPS) version 1.4.5, offers full support for the new Gemini Multi-Object Spectrograph Hamamatsu detector array at Gemini North (GMOS-N), as well as support for FLAMINGOS-2 (F-2) at Gemini South. Commissioning for the MOS mode of F-2 is scheduled to commence in July 2017, boosting Gemini's strength in the area of near-infrared spectroscopy.

The new version of GMMPS is a major improvement over its predecessor. Driven by the need to accommodate the new GMOS-N detectors, and in particular F-2, the source code was overhauled in many ways to make it more instrument-independent and modular. These changes come with greater stability, internal consistency checks, many bug fixes, and new features including the following:

- Safe placement and proper motion check of acquisition stars;
- No more external band-shuffling files;

Figure 12. *Blue bars show the percentage of time rendered unobservable by weather, for Gemini South over the period 2008-2016. The orange trace shows the average per month over that same period.*



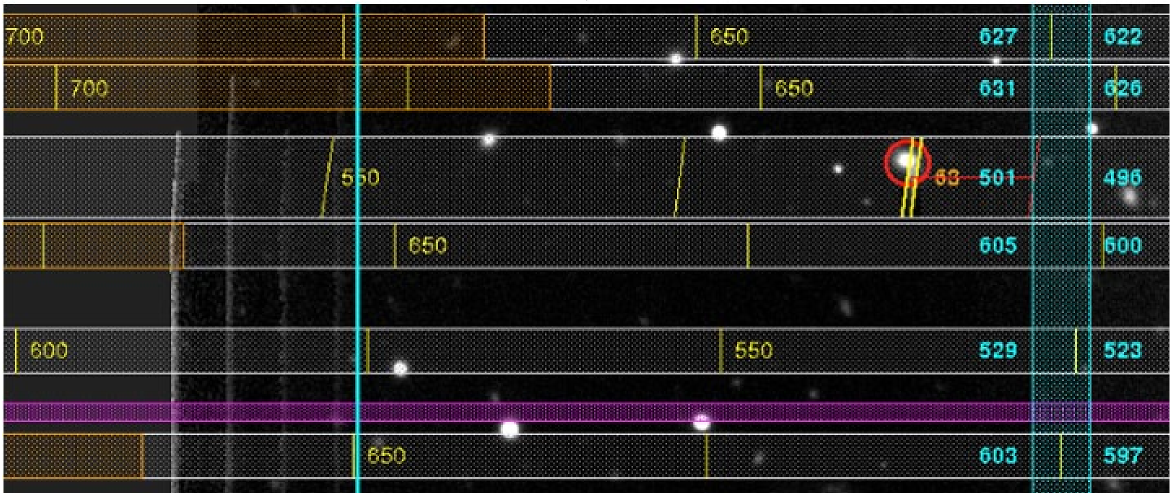


Figure 13.
GMMPS optionally displays a wavelength grid (yellow numbers) for each spectrum, including the wavelength interval (bright blue) cut out by the detector gaps. Second order contamination can also be shown (orange shaded area).

- Slit placement area accurately measured (no more lost slits);
- Consistent visualization of band- and micro-shuffling mask designs;
- Spectral packing in micro-shuffling mode, allowing for much greater slit density;
- Allowing tilted slits in micro-shuffling mode (*e.g.*, for faint strong lensing arcs);
- Display of required Phase II parameters for the Observing Tool;
- Extensive integrated help web pages, also available online ***here***;
- Simpler and more robust source code installation.

In addition, accurate mathematical models of both GMOS spectrographs have been integrated (see the GMOS WaveMapper item on next page). They predict accurately (within a few pixels) where a certain wavelength will fall onto the detectors — as a function of slit position, central wavelength, and grating. Using these models and full optical throughput curves, the length of the spectra and their location are accurately known in advance, allowing users to perform the following tasks (among others):

- Overlay wavelength grids and display 2nd order contamination (Figure 13);
- Display individual wavelengths and atomic line series (optionally redshifted);
- Display the wavelength intervals cut out by the detector gaps;
- Interactively adjust the central wavelength to preserve spectral features of interest (Figure 14).

The new version of GMMPS allows users to design the masks in a more transparent and robust manner, and provides a quantitative and accurate preview of any data obtained.

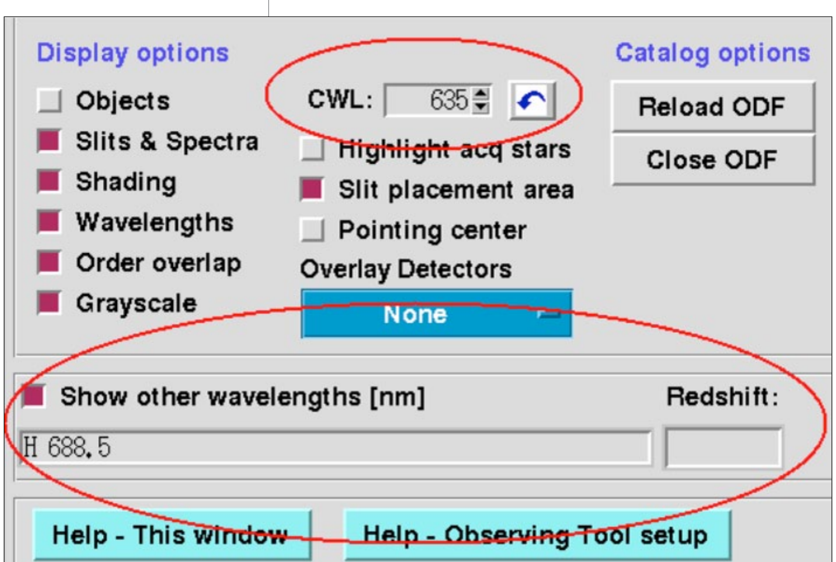


Figure 14.
The central wavelength (CWL) of GMOS can now be adjusted interactively, guided by the wavelength displays (see Figure 13). Optionally, individual wavelengths and atomic line series can also be shown.

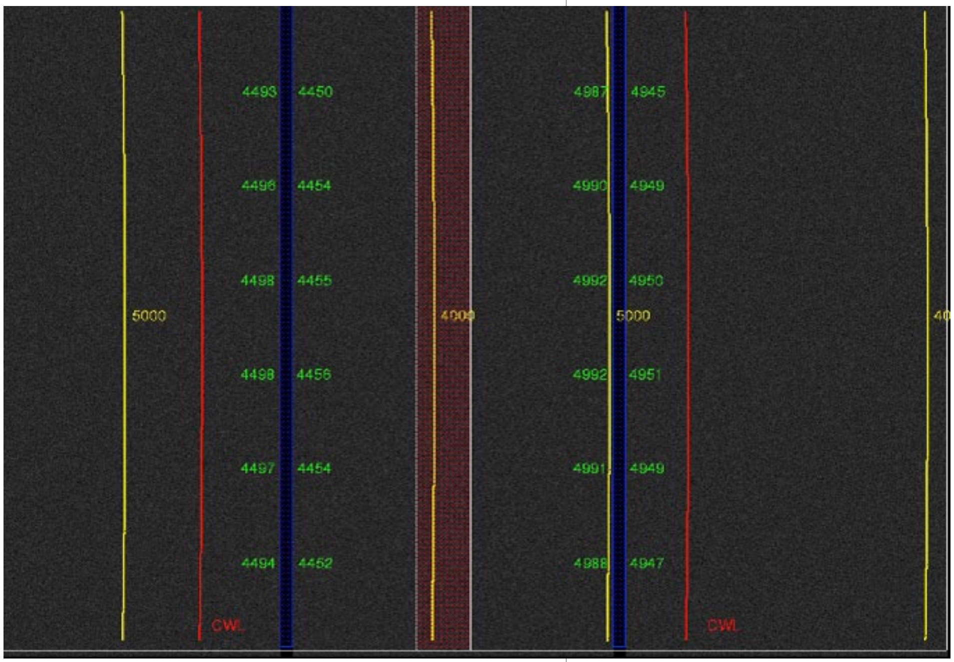


Figure 15.
Wavemapper display for the GMOS IFU-2 mode, the B600 grating, and G-band filter, for a central wavelength of 475 nm. The two spectral banks overlap near the center of the display (red shaded area).

New: WaveMapper — Modeling the GMOS Spectrographs

The GMOS WaveMapper is a new and highly useful tool that predicts accurately where a certain wavelength will fall onto the Gemini Multi-Object Spectrograph (GMOS) detectors, depending on the chosen grating and central wavelength (CWL). It works for all GMOS modes including long-slit, Integral Field Unit-R (IFU-R), IFU-2, and MOS. Principal Investigators can now accurately plan their observational setup, avoiding important spectral features being lost due to detector gaps and boundaries.

The tool's creator, Gemini astronomer Mischa Schirmer, used dedicated arc line observations to build the various mathematical models for each mode and grating. In the case of the MOS mode, he designed a special slit mask containing 135 slits on a tilted grid, covering the entire slit placement area. Mischa then observed arc lamp spectra with each grating, tightly stepping the CWL through the 380–950 nanometer range. More than 17,000 arc spectra were automatically calibrated for the MOS mode using a third-order polynomial. The coefficients of the polynomials are in turn functions of the slit position and CWL with their own polynomial dependencies, resulting in a 60 parameter model for each grating.

The models predict the wavelength positions with an accuracy of a few pixels — much smaller than the diameter of the GMOS detector gaps. It is also smaller than the long-term stability of the grating mechanism when establishing a certain CWL setting. The interactive tool allows the user to adjust the CWL and visualizes the wavelength grid of the spectra on the GMOS detector arrays. Individual wavelengths, atomic line series (optionally redshifted), and 2nd order overlap can be displayed as well.

The IFU-2 mode in particular benefits from the new tool, making the selection of a suitable grating/filter/CWL combination much easier. A substantial challenge inherent to the IFU-2 mode is that two spectral banks are mapped simultaneously on the detector array (Figure 15). The spectra are cut asymmetrically by the detector gaps, such that a certain spectral feature might be lost in one of the two spectra. This can be avoided by fine-tuning the CWL, but only within a certain limit before one of the spectra gets pushed off the detector array. Previously, finding the optimal balance has been a tedious, if not impossible, task; also because the two spectra have different dispersion factors. With the GMOS WaveMapper, this task has been much simplified, making IFU-2 a significantly more powerful, attractive, and less scary mode.

The GMOS WaveMapper is a plugin for the European Southern Observatory's (ESO) Skycat tool. It is distributed together with the Gemini mask making software, GMMPS, which uses the WaveMapper models for its internal calculations, but the mask design process is entirely independent of it otherwise.

APRIL 2017

Gemini Now Operates Remotely in Both Hemispheres!

On February 17, 2017, Gemini celebrated a final milestone with the official handover of Base Facility Operations (BFO) at Gemini South. It took a year to complete this important step and involved all departments from Gemini South. About a year prior, Gemini North reached the same milestone, so now both Gemini telescopes operate routinely from the base facilities in La Serena, Chile, and Hilo, Hawai'i.

The move has had a profound impact on our nighttime operations, but so far with no losses in data acquisition or on-sky observing efficiencies. The move to BFO also significantly improves our environmental stewardship (Figure 16), mostly due to fewer trips up and down the mountains in both Chile and Hawai'i. For Gemini users, this change makes visiting Gemini easier, and we hope that more users will consider visiting Gemini North or South via our ***Priority Visitor*** mode, as well as for ***Classical*** observing programs. Principal Investigators should also remember that our ***Bring-One, Get-One*** program for early-career astronomers is ideally suited to BFO.

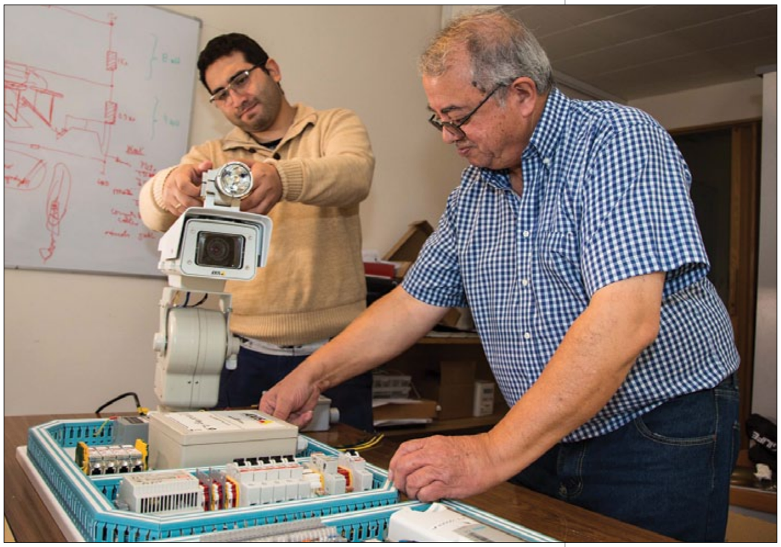


Figure 16.
Francisco Meza and Herman Díaz work on the Gemini South all-sky cloud cameras which are instrumental in BFO implementation.

Credit: Manuel Paredes

First 20 Months of Hamamatsu CCDs in GMOS-S

In June 2014 we installed new red-sensitive Hamamatsu CCDs in GMOS-S. The main scientific driver behind this important upgrade was the improved quantum efficiency at the longest accessible wavelengths, combined with reduced fringing. We achieved both of these improvements, and initially everything looked positive. Since then, however, a number of problems have developed, some of which still defy explanation. A brief summary of the problems' history, and an update on the current status of the detectors, follows.

An Unfortunate Turn

After successful commissioning of the new CCDs, a couple of unexpected technical problems appeared that negatively affected the CCDs' expected performance: severe smearing of charge ("bleeding") on CCD1; and a "banding" effect when binning, under which saturated pixels caused a depression with respect to the zero level across all the pixels from the same row within the affected amplifier. The bleeding problem was intermittent and made data on CCD1 essentially useless for all purposes; the banding issue was manageable, although it made data reduction very complicated.

As science operations were already underway, we had to make the best of the situation while trying to find a technical solution for the problems. Eventually we found the charge bleeding problem in the controller backplane, which we replaced during the telescope shutdown in August 2014. The fix brought the charge transfer efficiency (CTE) measurement back to ~ 0.999999 and therefore within specifications.

With the bleeding fixed, the "banding" issue remained, and by February 2015, we saw more serious complications when it coupled to a column of hot pixels that accumulated spurious charge on amplifier #5 (on CCD2). With longer exposure times and binning, the saturation of this column became worse, causing the background level in the section of the CCD on the same amplifier to deviate from the normal level by up to 25%. The best strategy was to avoid using the region of amplifier #5 as much as possible. An investigation of the historic trend of this effect showed that the problem had become progressively worse, particularly for long exposures and full frame binned readout.

After lengthy investigations we identified a solution for the banding problem by implementing new ARC47 Rev.E video boards — which still had to be modified in order to offer the same good readout noise performance as the previous boards. Satisfactory results were finally reached in May of 2015.

Mysterious Events

In May 2015, another problem cropped up, namely a CTE issue affecting CCD1 in Nod & Shuffle (N&S) data. CCD2 and CCD3 were not affected at all. Again we formed an *ad-hoc* tiger team to work on a remediation plan. Complicating matters, GMOS-S, our most highly-demanded instrument, was in near-continuous use. Then what no one expected happened: by the end of July 2015, the CCD1 CTE problem spontaneously disappeared, without any intervention, and N&S spectroscopy programs were resumed.

Although the detectors behaved well from September 2015 until June 2016, we were not out of the woods yet. Following a thermal cycling event of the cryostat in June 2016, a new vertical structure appeared in the bias of CCDs 2 and 3, as well as repetitive sharp horizontal lines. A few months later these structures became even stronger, now seriously affecting the science quality of the data; in particular, due to the increased noise over significant parts of the CCD array. Once again we looked for measures to minimize the effect and carried out many tests following advice from the chip manufacturer… but nothing seemed to improve the situation; it seemed desperate.

Then one day in February 2017 a fault on a compressor used for the cooling of GMOS-S caused the cryostat to warm up. We all feared the worst and were anxious to see the first bias frame come out of the instrument. To everyone's surprise, the bias looked normal, without any of the vertical banding or horizontal stripes!

A Happy Ending?

Well… yes and no. At this moment the detectors are performing well, and we are monitoring their behavior; but clearly something's not right as more than once serious problems have come and gone without any clear indication why. We need to take stock of the situation and determine the best way forward.

LSST: Gemini South´s Neighbor Comes Closer to Reality

New large telescope facilities always attract attention, and the Large Synoptic Survey Telescope (LSST), currently under construction on Cerro Pachón, is no exception. In December 2016, for instance, two eminent astronomers — Ewine van Dishoeck (Professor of Molecular Astrophysics at Leiden Observatory and President-elect of the International Astronomical Union), and European Southern Observatory Director Tim de Zeeuw — visited both LSST and Gemini South. The images in Figures 17, 18, and 19, taken during their visit, give an impression of the rapid progress being made with the LSST construction; but if you want an up-to-date view of the site, please visit ***this link***.

Planning Continues for LSST Follow-up Observations

The flood of Large Synoptic Survey Telescope (LSST) transient follow-up observations is not expected to begin until 2021 or 2022. In preparation, the National Optical Astronomy Observatory (NOAO) is leading an effort to establish a network of follow-up facilities, and we are working with them to ensure that Gemini is not only well-integrated into this network but can perform the necessary observations. Continuing the momentum from last year's workshop, titled ***Maximizing Science in the Era of LSST***, several facilities — including Gemini, NOAO, Southern Astrophysical Research (SOAR) Telescope, and Las Cumbres Observatory — are defining a system for efficient follow-ups of LSST discoveries.

One major contribution from Gemini will be our new Gen4#3 instrument now in development. Called OCTOCAM, this multichannel imager and spectrograph will perform the subsecond time-resolution observations critical to LSST follow-ups. Gemini will also participate in the development of Target and Observation Management software systems for rapid follow-up of LSST events.

We're also considering helping with the proposal processes, observing modes, and data reduction and analysis. The Gemini community is encouraged to provide input on how we should use Gemini to complement the LSST survey. Please send your ideas to Bryan Miller (*bmiller@gemini.edu*).

Figure 17.
View of the LSST telescope enclosure from where the LSST coating plant will be located.

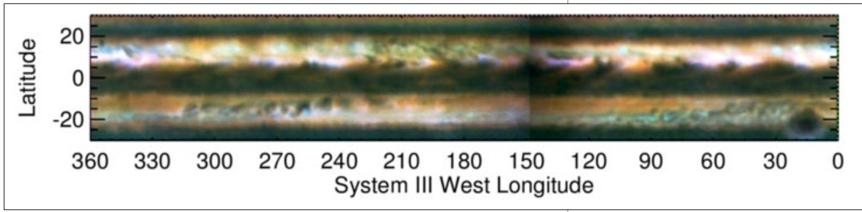
Figure 18.
LSST´s neighbor, Gemini-South, shines in the distance.

Figure 19.
Staff and visitors inspect the LSST pier and enclosure.

Credit: All LSST photos by René Rutten

Figure 20.
Combination of three TEXES spectral scans, with red through blue, corresponding to increasing altitude above Jupiter's cloud tops. Note the cool wake to the left of the Great Red Spot seen at lower right (about 15˚ west longitude and -20˚ Latitude).

Credit: L. Fletcher, University of Leicester, UK



TEXES Returns to Gemini North

TEXES, the visiting high-resolution mid-infrared spectrograph, returned to Gemini North in March 2017. This run supported a wide-ranging set of community science programs, including the following: summer-solstice observations of Saturn's polar vortex; three programs studying Jupiter's atmosphere and aurora; studies of the chemistry of the gaps in protoplanetary disks around other stars; organics in hot star-forming cores; and the motions of gas in embedded super star clusters.

One of the science programs, carried out in collaboration with the TEXES team and Leigh Fletcher of the University of Leicester in the UK, involved mid-infrared (8-micron) observations to explore the meteorology and chemistry of Jupiter's dynamic weather layer. According to Fletcher, to truly understand the atmospheric phenomena at work in Jupiter, we must investigate three different domains: spatial, temporal, and spectral. Past investigations have allowed them to target one of these domains, but today they are able to explore all three by combining the Gemini Observatory, the TEXES spectrograph, and the worldwide campaign of Earth-based support for NASA's Juno mission.

The three-color map shown in Figure 20 reveals Jupiter's weather layer near 8.6 microns, where temperature, cloud opacity, and gaseous species (like deuterated methane and phosphine) govern Jupiter's spectrum. The researchers constructed the map from spectral scans over two nights (March 12–13, 2017), and it represents close to the highest spatial resolution ever achieved by the TEXES instrument. At mid-infrared wavelengths most of the seeing is due to image motion, which Gemini's rapid tip-tilt secondary mirror removes. The result is diffraction-limited images with 0.3 arcsecond resolution without the use of adaptive optics. This easily surpasses the spatial resolution afforded by past spacecraft flybys of Jupiter (Voyager and Cassini) in the mid-infrared wavelength range.

A high-resolution spectrum was measured for every pixel in this map. The essential information from the spectra is shown in the false color image: deep, warm temperatures at the cloud tops (red); cooler temperatures at higher altitudes near the tropopause (blue); and an intermediate altitude (green). The Equatorial Zone and the Great Red Spot at the bottom right are cold and dark at all three wavelengths. The turbulent wake seen to the west (left) of the Great Red Spot is darker (cooler) and distinct from the rest of Jupiter's South Equatorial Belt (SEB). An outbreak of dark, cold, and cloudy plumes can be seen in the SEB near 15˚ south, 270˚ west. Finally, the pattern of cold, cloudy plumes (dark) and warm, bright hotspots (white) can be seen encircling the planet near latitude 7˚ north, on the edge of Jupiter's North Equatorial Belt. These data will be used to determine the 3D temperature, aerosol, and gaseous structure to support Juno's close-in observations of the giant planet.

GMOS-N CCD Upgrade Update

The Gemini-North Multi-Object Spectrograph (GMOS-N) is currently being upgraded with a new detector array (Figure 21), consisting of three CCDs manufactured by Hamamatsu Photonics. During February, the commissioning team successfully installed and aligned the new array in the Gemini North lab. In early March, following the CCD installation, GMOS-N was mounted back on the telescope, where it passed the first light milestone during on-sky nighttime commissioning observations.

We expect the new Hamamatsu CCDs to show improved red sensitivity compared to the previous GMOS-N e2v deep depletion detectors. The new detectors are similar to those previously installed in GMOS-S. Further information and updates are available on the Gemini North ***night log summary pages***; watch for updates in our monthly ***e-newscast*** and on the ***instrument availability webpage***.

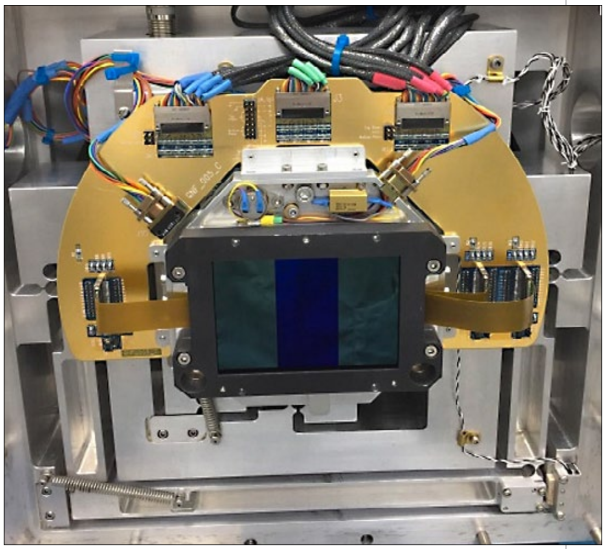


Figure 21.
The new GMOS-N detector array showing the three new CCDs, which consists of two different types of detectors: the two outer detectors (left and right) have an improved red and blue response compared to the middle detector.

André-Nicolas Chené

Gemini's Users Provide Valuable Feedback for the Future

Initial results from Gemini's Short Surveys are helping staff to address issues shared by our user community, especially regarding the performance of Gemini's software tools (PIT and OT). Among other items, users provided staff with valuable insight into the quality of data received by Principal Investigators. Most respondents shared their appreciation for the support they received from Gemini staff, and their current efforts to improve actionable items.

The Gemini Science User Support Department[1] has begun direct dialog between the Observatory and its users by sending out routine Short Surveys (2–3 questions) at every critical phase of Gemini's user programs (Table 1). The effort has several key objectives: 1) monitor the usefulness and usability of our software tools and documentation; 2) determine how well the observations went; and 3) assess how satisfied the Principal Investigator (PI) is with the data. Another objective is to identify actionable items that can improve the whole observing process at Gemini. In brief, the Short Surveys provide a direct way to listen to what is most important to our user community.

As the name Short Surveys indicates, the surveys are designed to be short; they should take only a few minutes to complete. Still, for users who want to have more lengthy communications with Gemini staff about the topics covered, the surveys always include one question offering a text box that has no length limit. All of these comments are read by Gemini staff.

[1] The Gemini User Support Department was formed in 2015 to create a collaborative community of users and staff. In addition to the Short Surveys, the department is working on a next generation helpdesk system, Gemini website, and data reduction suite.

Phase I		Phase II		Observing		Data Quality	
Sem. A	Sem. B	Sem. A	Sem. B	Sem. A	Sem. B	Sem. A	Sem. B
April	October	March	September	August	February	July	January

Table 1.
The four Short Surveys and the time of year in which they are launched. There were small delays with some of the surveys in 2017 due to technical issues that have since been resolved.

Users in semesters 2017A and 2017B were already invited to fill out one or two of the Short Surveys for that observing semester, or Phase I/Phase II processes. We were very pleased to receive relatively high response rates (between 30% and 50%; many thanks!). This provides us with a clear snapshot of the current status of our observing tools, data quality, and support satisfaction.

Current Results and Their Impact

2017B Phase I. As shown in the upper left pie chart in Figure 1, ~65% of respondents either liked or really liked the system; of these, ~20% had suggestions for improvement. Yet, ~11% were strongly unsatisfied, and shared very useful comments about what they believe should be improved. The rest of the respondents commented on specific issues they encountered that deserve our attention. Additionally, six respondents sent us compliments about the service and the help they received… You are welcome.

Most of the comments were about the Phase I Tool (PIT). For another few semesters you'll find the PIT unchanged, but that's because we are currently focusing our resources on creating a new one. Of course, we are using the Short Survey comments to help determine the requirements for the new PIT. Meanwhile, we have made ***better PIT training documentation available***.

2017B Phase II. The Phase II process is generally less appreciated than that of Phase I; only ~42% of respondents either liked or really liked working on their Phase II, and ~25% of them were significantly unsatisfied. Most comments we received are fairly uniform:

1. The Observing Tool (OT) is tedious (*e.g.*, setting up acquisition sequences, entering and changing parameters).
2. The documentation is deficient (sometimes inaccurate).
3. The support is excellent.

While we take pride in the quality of our support (thanks to those who mentioned it), we strive to reduce the number of comments focused on problems users experience with our tools. The following are current efforts to improve the Phase II preparation process:

1. We are currently producing a new OT, and survey results will be used to determine requirements (like that done for the PIT).
2. We have improved some of the OT ***training documentation***.
3. We are preparing better-focused Phase II instructions and tutorials for all facility instruments for 2018.

2017A Observing Semester. Of the PIs whose programs received observations, about 73% of the respondents evaluate that their data meet, or exceed in some ways, their expectations. While this is a good sign, it does not reflect the opinion of all respondents — most of whom were PIs of observing programs with the Gemini Planet Imager and Gemini South Adaptive Optics Imager, which require complex observations that are often strongly dependent on good weather conditions. When compiling all the responses, we found ~21% came from PIs who did not get data from their program — mainly due to bad weather, combined with program priorities.

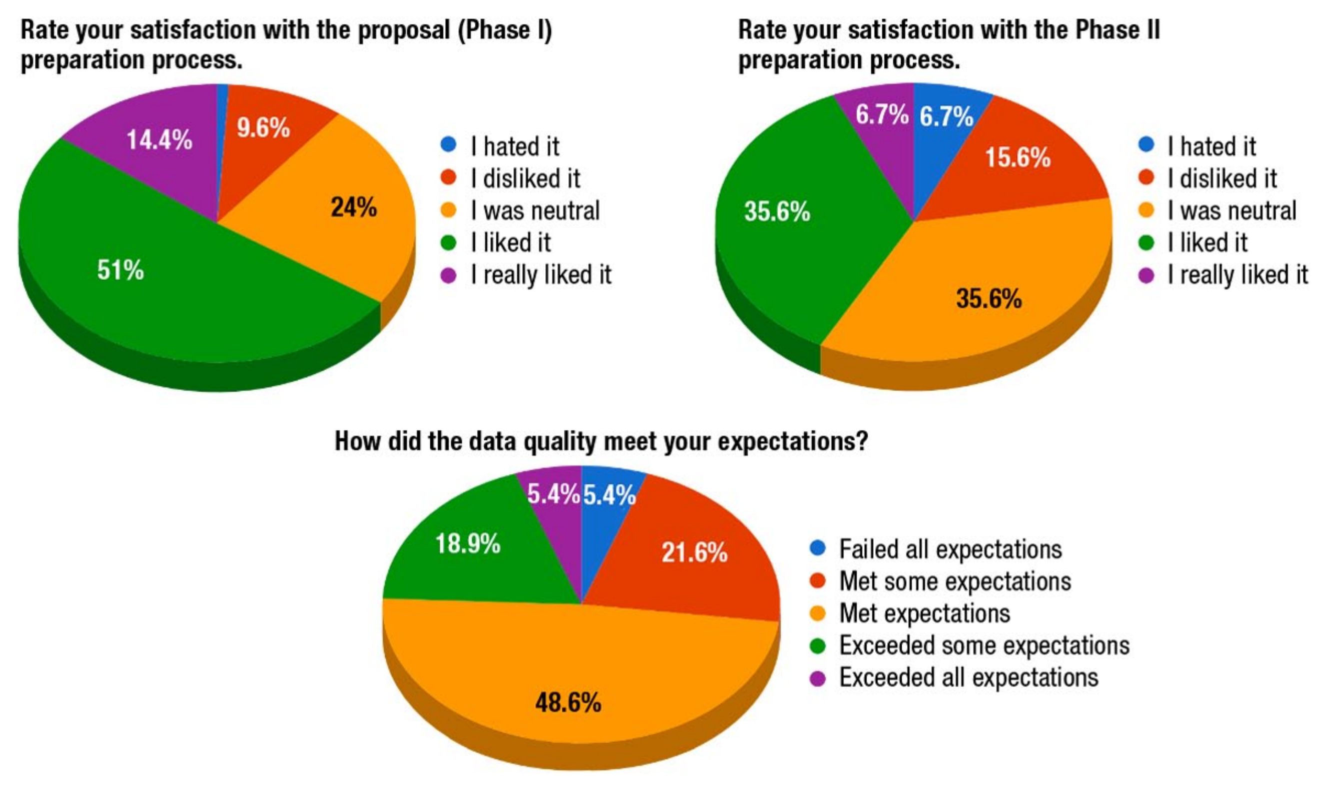


Figure 1.
Pie charts showing the ratings for the 2017B Phase I process (top left), 2017B Phase II process (top right), and 2017A observing semester (bottom).

Overall, the outcomes of this survey are diverse; they also reveal three additional points:

1. We lack clear descriptions of what PIs should expect from the Observatory, and vice versa, especially in the context of Queue observing. We are arranging new web pages that should help with these communication issues.
2. PIs pointed out that some GMOS-S data observed in 2017A were difficult to reduce due to bias and cosmetic problems. The hardware issues that caused these problems are now resolved, and we continue to work with PIs on the complications introduced by these features in their data reduction process. Affected PIs, if they have not already done so, are encouraged to contact us.
3. Many who took the survey thanked staff for their helpful support. We recommend that PIs continue to start with early communications with the Contact Scientist of their program, and inform them of what is important for their project's success.

Some PIs used the survey to send us specific complaints. This was very useful, since these few situations would have been missed otherwise. We, of course, recommend that PIs address their concerns to us as early as possible, but we appreciate any opportunity to discuss what happened and find more productive future strategies.

We look forward to hearing more from you through our future surveys, so we can better align our work with your research needs. Also, stay tuned, because the Science User Support Department will continue to address responses in future issues of *Gemini*Focus.

André-Nicolas Chené is an assistant astronomer in the Science User Support Group. He is located at Gemini North and can be contacted at: achene@gemini.edu

Alison Peck

Internships

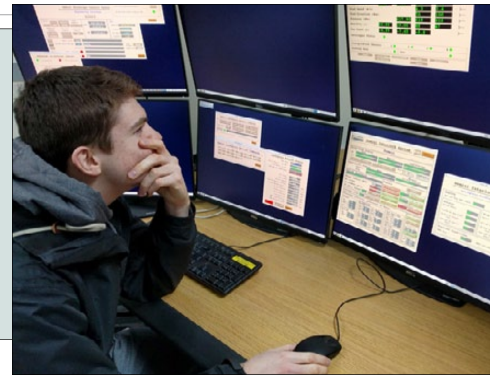
Preparing the Next Generation at Gemini

Gemini offers opportunities for upper-level undergraduates, recent grads, and early graduate students at both its Hilo, Hawai'i, and La Serena, Chile, locations. These positions can involve multifaceted projects in science, engineering, education and outreach, or software. Our internships not only offer participants first-hand experience in a real-world working environment, but allow them to perform in a professional capacity while establishing valuable relationships with workers in their fields of interest. The internships can vary in length depending on the project and funding source, but all range from ten weeks to six months. The positions can take place at any time during the year, making these programs good "gap year" opportunities.

In the last several months, Gemini has hosted three interns at Gemini North and four at Gemini South. We asked the interns to tell us a bit about themselves and their exciting projects.

Tomás Ahumada recently graduated in astronomy from Pontificia Universidad Católica de Chile in Santiago. He has been working at Gemini South with Bryan Miller on a project using the high-performance, wide-field CCD Dark Energy Camera on the Blanco 4-meter telescope at Cerro Tololo Inter-American Observatory. He is doing photometry on images of the elliptical shell galaxy NGC 3923, a unique elliptical galaxy, whose halo stars are arranged in concentric layers. His goal is to search for unseen shells hidden within the structure of this intriguing system. He will also analyze the globular clusters found in the images, hoping to identify potential dwarf galaxy satellite candidates. Tomás' project is part of a six-month internship.

A recent graduate of New York's Stony Brook University, ***Tyler Cohen*** has spent four months at Gemini North analyzing Hubble Space Telescope images of the distant galaxy cluster XMM2215. He performed basic photometry on these images to derive colors for each galaxy in the field. These results were then used to select a sample of galaxies for further study as part of a larger program led by mentors Inger Jorgensen and Kristin Chiboucas. Tyler gave a presentation to Gemini staff on his results in February.



Sylvia Kowalski graduated from the University of Washington in 2016 and recently completed her six-month program as a Public Information and Outreach Intern in Hilo. Her work focused on creating events and curricula that bring the wonders of the Universe to groups not as frequently exposed to science topics. A few of the great events Sylvia organized during her internship include the *Astronomy on Tap* night at the Hilo Town Tavern (see item on page 92), free science nights at public libraries and schools across the island, and multimedia outreach through the Gemini blog.

Grace Lawrence came to us from Swinburne University of Technology in Melbourne, Australia, during the 2016 Southern Hemisphere summer break and interned with Morten Andersen at Gemini South. She used Gemini Multi-conjugate adaptive optics System near-infrared observations, in conjunction with Hubble Space Telescope data, to investigate the massive, young, and local Galactic cluster Westerlund 1. During her ten-week stay, Grace applied crowded field photometry techniques to resolve the low mass stellar population to the brown-dwarf limit; she also performed preliminary disk fraction measurements.

Daniel Muthukrishna received his Bachelor of Science in Physics and Engineering from the University of Queensland, Brisbane, Australia. He just completed a ten-week project at Gemini South, working with Veronica Firpo, to analyze the internal kinematics of giant H II region candidates in interacting galaxies. This program involved developing an open-source Python software package to model emission lines using multiple Gaussian components. The software automates the process so that all emission lines (in any number of spectral regions) can be modeled, and the corresponding luminosities, star-formation rates, and other region properties can be extracted.

Prabhani Rajakaruna earned her Master of Science in Physics at Central Michigan University, following her BS at the University of Peradeniya in Sri Lanka. She completed a four-month project at Gemini North, testing the data reduction pipeline and improving the data quality for the Observatory's new high-resolution optical spectrograph GRACES. This involved verifying the stability of the spectrograph focus with temperature and pressure, and identifying the optimal parameters for the calibration process. Prabhani has also written a script to gather the ideal calibrations for each GRACES observation in order to send the best data to the archive. In addition, she has thoroughly enjoyed the opportunity to observe with Gemini and see GRACES in action.

Piera A. Soto King earned her BS and MS at the Universidad de La Serena in Chile. She is working with Rodolfo Angeloni at Gemini South on spectroscopic confirmations of candidate symbiotic stars. Symbiotic stars are long-period interacting binaries composed of a hot compact star and an evolved giant star. For her six-month project, Piera will reduce and analyze long-slit spectroscopic data of a carefully selected sample of symbiotic star candidates to fully characterize their nature. She is also working on a proposal to observe more candidates for this project with the Gemini Multi-Object Spectrograph at Gemini South.

Keep an eye out for more great work from these students as they move forward in their careers, and please do check the Gemini ***job opportunities link*** for internship opportunities at both Gemini North and South.

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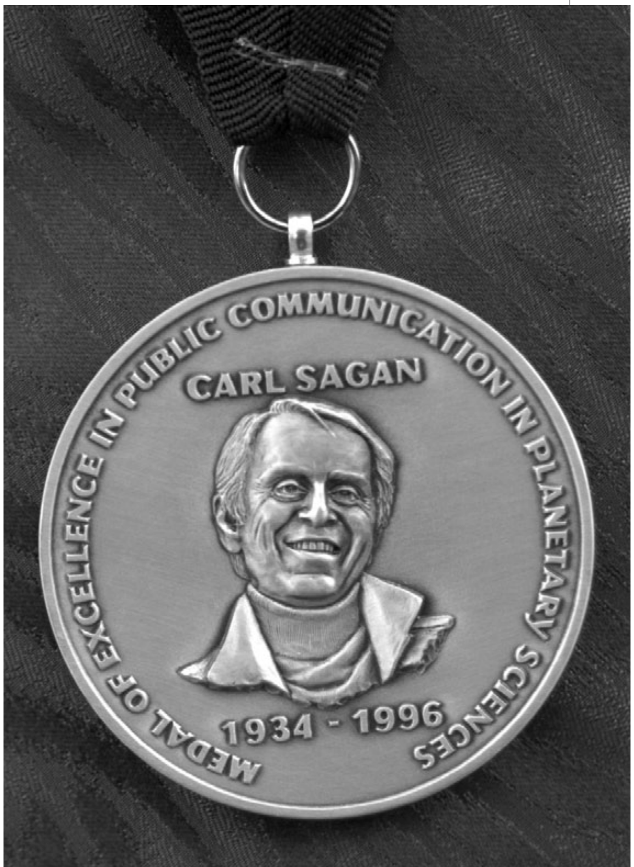
Gemini staff contribution

Gemini Assistant Scientist Awarded the 2017 Carl Sagan Medal

Gemini Observatory assistant scientist Meg Schwamb is this year's recipient of the Carl Sagan Medal for Excellence in Public Communication in Planetary Science.

Each year, the Division for Planetary Sciences (DPS) of the American Astronomical Society (AAS) awards the Carl Sagan Medal to recognize and honor outstanding communication by an active planetary scientist whose efforts have significantly contributed to a public understanding of, and enthusiasm for, planetary science. This year's recipient is Gemini Observatory astronomer Meg Schwamb. Meg will receive the medal in October at the Division of Planetary Sciences' annual meeting hosted in Provo, Utah.

Schwamb is being honored for her involvement in the creation and development of new tools used to facilitate planetary science communication, including online citizen science projects via the *Zooniverse* platform — such as identifying planet transits in data from NASA's Kepler mission (*Planet Hunters*), as well as mapping the locations and sizes of surface features on the Martian South Pole produced by carbon dioxide jets in images taken by NASA's Mars Reconnaissance Orbiter (*Planet Four* and *Planet Four: Terrains*). Schwamb



has also been instrumental in conveying the science goals and results generated by these projects.

In addition, Schwamb is being honored in part for her efforts with Astronomy on Tap and the recurring Twitter account Astrotweeps: Astronomy on Tap — a series of popular talks given by astronomers in bars and pubs — brings the latest planetary science and astronomy news and results directly to the public in a fun and relaxing environment; Astrotweeps hosts a different astronomer or planetary scientist each week, highlighting their research and life as a scientist. Schwamb helped create and organize the original Astronomy on Tap events in New York City and is the co-creator of Astrotweeps. (See page 92 for information on an Astronomy on Tap program Meg initiated in Hilo, Hawai'i.)

Heidi Hammel, Vice President of the Association of Universities for Research in Astronomy (AURA), and herself a winner of the Sagan Medal in 2002, notes, "it is an exceptional honor for Meg to be recognized so early in her career for her work in astronomy outreach." The sentiment is shared by Henry Roe, Deputy Director of Gemini Observatory, who adds that this award is only the beginning for Meg.

Schwamb earned her PhD in Planetary Science from the California Institute of Technology in 2011. She was a National Science Foundation postdoctoral fellow at Yale University and an Academia Sinica postdoctoral fellow at the Academia Sinica Institute of Astronomy and Astrophysics. Currently Schwamb is an assistant scientist at the Gemini Observatory at the Gemini North telescope in Hawai'i, where her research focuses on the small body populations residing in our Solar System and mining large datasets for Solar System science.

Manuel Paredes

Viaje al Universo 2017 Encourages Diversity in Astronomy and More

Gemini South's 2017 Viaje al Universo *focused heavily on promoting gender equity in astronomy and encouraging STEM careers.*

In October 2017, *Viaje al Universo* (*Viaje*) — one of Gemini South's most popular public outreach programs — celebrated its seventh year of bringing the wonders of science and astronomy to classrooms in La Serena and Coquimbo, Chile. During the week-long event over 5,000 people participated in *Viaje's* many exciting and educational programs and activities.

Over 30 professionals from the University of La Serena, Gemini South, Cerro Tololo Inter-American Observatory (CTIO), and the Giant Magellan Telescope (GMT), visited 32 classrooms and over 1,500 students. These scientists, engineers, and astronomers shared the wonders of the Universe using fun, interactive presentations.

Viaje 2017 introduced two new events designed to foster diversity in Science, Technology, Engineering, and Mathematics (STEM) careers: (1) Gemini presented a public talk sponsored by the Chilean Government's Ministry of Women that emphasized the importance of women in astronomy; and (2) a *Mateada Astronómica* — an event similar to an English "Tea Time"; typically participants converse in a relaxed environment while sipping on *mate*, a traditional South American caffeine-rich drink. The events engaged over 200 local women and encouraged them to pursue astronomy-related careers.

Viaje activities also extended beyond the week-long classroom visits in October. One such event was a Career Panel for over 200 students at the Centro Cultural Palace in Coquimbo; The panelists represented a broad spectrum of inspired scientists, engineers, and technicians, who endeavored to motivate the students into science and astronomy careers. The photos on the following pages show the fun and privilege we had in sharing our knowledge.

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Veronica Firpo (in black at center) joined a group of female students for a photo at the end of Firpo's public talk about women in astronomy, as part of Viaje al Universo's *activities.*

Gemini Deputy Director Henry Roe (bearded, in background), joins others in a photo with the three winners of the 2017 Astronomical Costume Contest, at the Gemini South Base Facility in La Serena.

Gemini South Public Information Office Staff member Fernanda Urrutia (kneeling at center) posing with the participants of the Mateada Astronómica *— an initiative boost by Gemini South during* Viaje al Universo *to promote women into STEM careers.*

CTIO Education and Public Outreach officer Juan Seguel (top) offered a spectroscopy workshop for high school students at the Liceo Fernando Bingvinat, in Coquimbo. The students learned several aspects of spectroscopy, including light's properties using a diffraction grating (center), while one student used his mobile phone to image a display of the visible spectrum (bottom).

Gemini South Starlab Operator Dalma Valenzuela leads a classroom workshop about how to identify the most popular constellations in the night sky at the Carlos Condell school in La Serena.

Fernanda Urrutia explains the importance of women in science and astronomy, during the Mateada Astronómica *"tea-time" at the Christ School in La Serena.*

Science Operations Specialist Manuel Gomez explains features of the Gemini South telescope to a capacity crowd at the colegio Maria Educa in La Serena.


Alexis Ann Acohido and Manuel Paredes

Exploring, Learning, and Fun: Gemini Outreach Events Span Both Hemispheres!

Gemini staff have been busy in both hemispheres leading local outreach events that foster public awareness in astronomy, support STEM content in classrooms, and inspire the next generation of explorers.

Journey Through the Universe *2017*

From March 13-17, over 70 observatory professionals and informal STEM educators extended their reach to dozens of schools across the Big Island of Hawai'i, visiting over 8,000 students in the 13th year of the *Journey Through the Universe (Journey)* program. The *Journey* program extended beyond the main week of events with several outstanding outreach programs, including classroom visits for students in grades 2-12 (Hilo-Waiākea, Honoka'a, Pa'auilo, and Waimea) and StarLab Portable Planetarium shows for students in K–1 (Hilo-Waiākea).

Journey also featured workshops for teachers, including one for 40 teachers from the Ka'ū-Kea'au-Pāhoa Complex area. This important event — to support the integration of Next

Figure 1.
Devin Chu shares his career story at the Journey Through the Universe/Chamber of Commerce Educators' Reception at the Naniloa Hotel in Hilo.

Generation Science Standards (NGSS) — sponsored a NASA Lunar and Meteorite Sample Certification Workshop led by NASA Solar System Exploration Research Virtual Institute's (SSERVI) Brian Day and Joseph Minafra. In addition, NASA's Brian Mitchell — the Education and Public Outreach manager for NASA's Discovery/New Frontiers/ Lunar Quest Program Office at the Marshall Space Flight Center in Huntsville, Alabama, — delivered an inspiring public talk titled, "Discovery, New Frontiers, and Solar System Exploration."

A highlight of this year's *Journey* program was the return of Hilo-raised student and astrophysics PhD candidate Devin Chu from University of California Los Angeles (Figure 1). An alumnus of the Journey program (and Hilo High School), Chu shared with students, teachers, and the community how the Journey program influenced and helped guide his dream of becoming an astronomer. During the week he also returned to his *alma mater* of Hilo Intermediate to model the effects of gravity on massive bodies using a "gravity well."

Figure 2 (below).
Gemini Public Information and Outreach intern Sylvia Kowalski (left) takes directions from Gemini Associate Director of Development Scot Kleinman (right) and Keaukaha Elementary students as she pretends to be the Mars Curiosity Rover.

Figure 3 (above).
NASA SSERVI's Jennifer Baer engages Kapiolani Elementary students in an activity on manipulating graphics using a tablet.

Figure 4 (right).
Tomonori Usuda, Director of the Thirty Meter Telescope-Japan, has fun with Hilo Intermediate School students, showing them the ins and outs of the Subaru Telescope.

Figure 5.
Audience members ask Gemini astronomer Alison Peck about black holes.

Astronomy on Tap

Gemini Public Information and Outreach intern Sylvia Kowalski along with Gemini astronomer Meg Schwamb put their heads together to organize the Big Island's inaugural *Astronomy on Tap* at the Hilo Town Tavern. *Astronomy on Tap* is a worldwide program that "combines the powers of space and spirits," according to Sylvia. Meg and her colleague Emily Rice started the *Astronomy on Tap* program in 2012, in New York City, and it has since expanded to more than 15 cities, including sites in the US, Canada, and Taiwan.

It was standing room only at the Hilo Town Tavern on February 23rd as four Gemini astronomers presented mini-talks interspersed with astronomy-themed drinks, trivia contests, and bar games! Talks from the program included:

- *Tales from the Outer Solar System* – Meg Schwamb
- *Asteroseismology: A Celestial Shake 'n Bake* – Atsuko Nitta
- *Star-Eating Monsters: Fact or Fiction?* – Alison Peck
- *Vanishing into the Darkness…* – André-Nicolas Chené

Figure 6 (top).
Gemini astronomer André-Nicolas Chené shares his passion for astronomy with a standing-room-only crowd at the Hilo Town Tavern.

Figure 7 (bottom).
Gemini astronomer Meg Schwamb defends Pluto's dwarf planet status to a packed Tavern.

AstroDay Chile 2017

Gemini South's annual AstroDay Chile is one of the biggest outreach events at Gemini South, gathering representatives from both the most influential scientific observatories in the country and the largest amateur observatories of the Región de Coquimbo. More than 1,200 people participated in this year's AstroDay Chile, which was held (for the first time) at the Christ School in Las Compañías, La Serena, on Friday March 24th.

During the 2017 event, dozens of exhibitors shared the latest news about the science and technology related to astronomy in Chile. Thousands of people of all ages flooded the workshops and presentations prepared for the event, which included portable planetarium shows, scientific lectures, FamilyAstro workshops, 3D movies, video games, and more. The images here show some highlights of the diverse events.

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Figure 8 (top).
Gemini Administrative Specialist, Adriana Gutierrez, talking with the public about the technology used by the Gemini South telescope.

Figure 9 (middle).
Students get some hands-on experience in the spectroscopy workshop guided by Juan Seguel, EPO NOAO-S Coordinator from the Cerro Tololo Inter-American Observatory (not shown).

Figure 10 (bottom).
AstroDay Chile attendees waiting to observe Jupiter and its moons through a CTIO public outreach telescope.

A view from the top of the Gemini North dome as seen during the shutdown to perform repairs on the dome.
Credit: Gemini Observatory/AURA/NSF/Joy Pollard

AURA
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