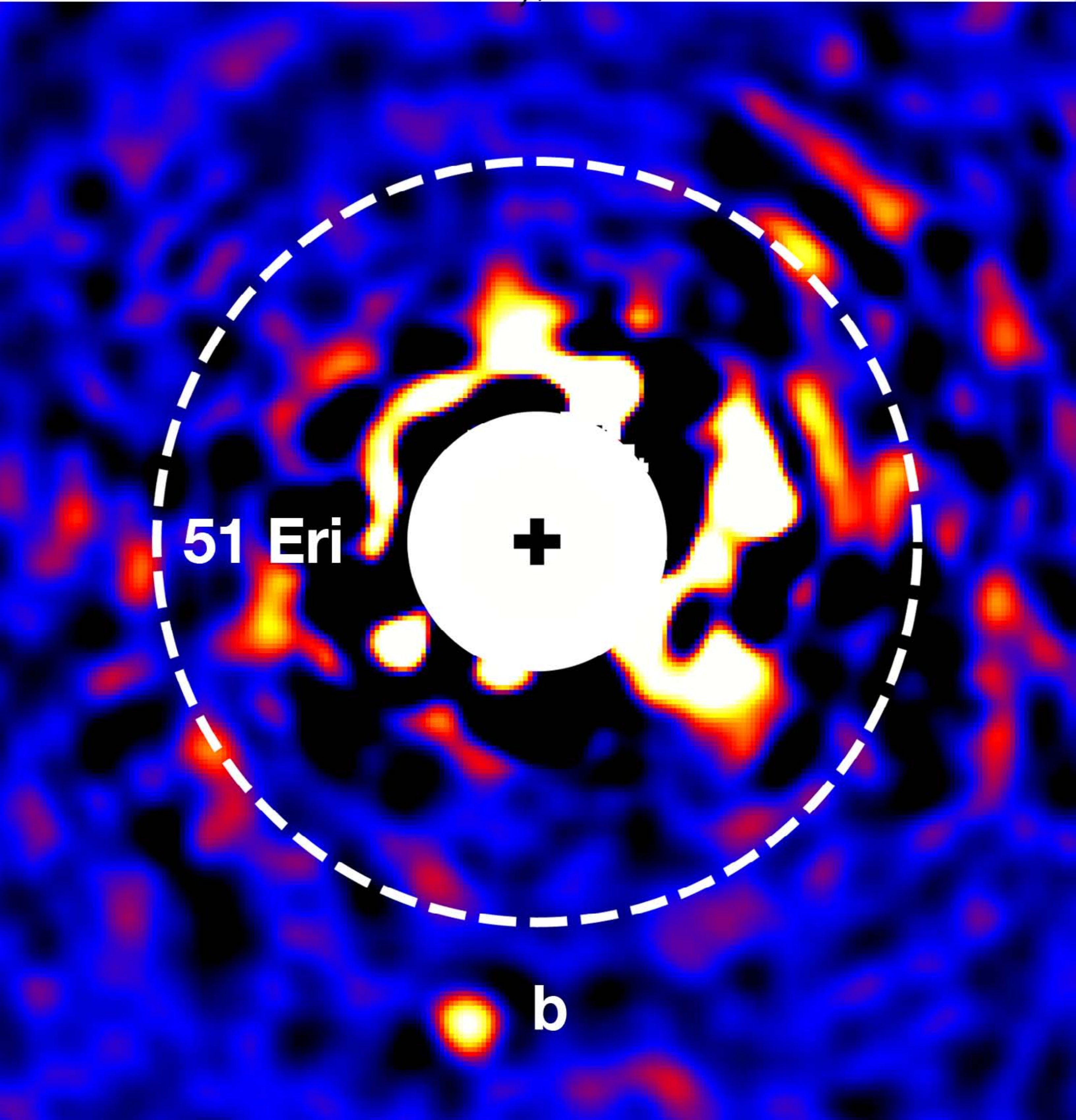
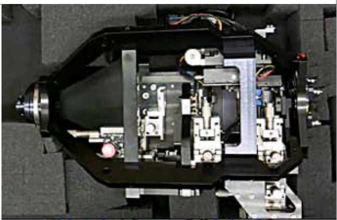
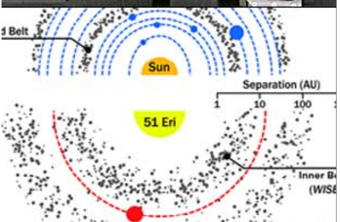
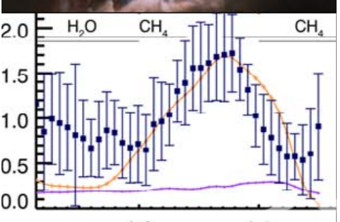
*Gemini*Focus

Publication of the Gemini Observatory / October 2015





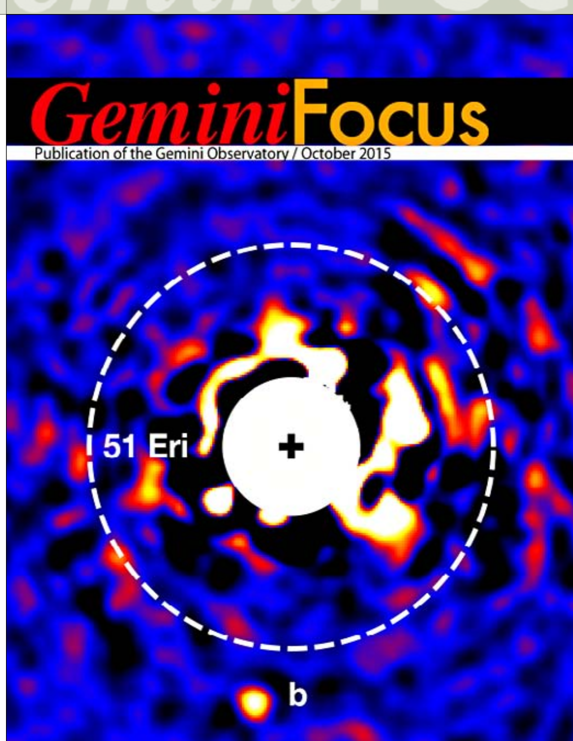




GeminiFocus

ON THE COVER:

Discovery image of 51 Eri b by the Gemini Planet Imager. See details starting on page 3.



Gemini*Focus* October 2015

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Markus Kissler-Patig

Director's Message

Ending a Strong Year in Full Stride

As we enter the last quarter of 2015, we can already predict that we will look back at another hugely successful year for the Gemini Observatory and its partners.

The scientific output of the Observatory is very high and world-leading in several areas — perhaps most prominently in the field of exoplanet research, thanks to the spectacular results made possible with the Gemini Planet Imager, whose discoveries keep making headlines in newspapers around the world. Some impressive results were also recently achieved with FLAMINGOS-2 (on Brown Dwarfs) and GeMS/GSAOI (on deep precision photometry), positioning Gemini as a premier observatory in its class. (See the lead feature article in this issue on the discovery of 51 Eridani starting on page 3, and a few selected Science Highlights beginning on page 8.)

The last quarter saw the first GRACES (Gemini Remote Access to the CFHT's Spectrograph) run in August. This collaboration between Gemini and the Canada-France-Hawai'i Telescope (CFHT) stands on solid footing and the 270-meter-long fibers that connect the Maunakea facilities continues to reliably transfer Gemini's light into CFHT's powerful high-resolution spectrograph. Although some of Gemini's time on GRACES was spent suffering through a string of near misses with Pacific hurricanes, a good number of GRACES programs were completed. We are looking forward to the first published results.

Even More Innovations

Gemini will offer two more innovations starting in October 2015. First, we will launch our new Science Data Archive, which will enable users everywhere to experience a new archive interface. Although transparent for the users, the real change is that the data are now stored on the Cloud. Indeed, Gemini has deployed the archive on the "Amazon Web

Services", as a reliable and very cost-effective solution. Watch for the launch!

The second innovation — the Fast Turnaround mode (***view here***) — is more of an expansion; the program, which we introduced in January at Gemini North, extends now to Gemini South. We used the first months of 2015 as a pilot study in order to debug the process. As the machinery now runs flawlessly, it's time to offer these monthly deadlines to our users at both telescopes. Your proposals will be collected and evaluated together for both facilities. As with Gemini North, we will grant up to 20 hours of observing time on Gemini South every month.

Base Facility Operations and More!

Just around the corner is another exciting milestone: As this issue goes to e-press, our Base Facility Operations project is undergoing nighttime testing at Gemini North; we are now on track to observe from Hilo (without anyone on the summit) before the end of the year. But no worries, we still welcome visiting astronomers and their students to visit the summit during the day — when coming to observe from the comfort of our Base Facility at night!

Speaking of infrastructure… as the Gemini Observatory ages, we need to keep our facilities up to date. In fact, we are using this opportunity not only to prevent obsolescence but also to go green as we implement a number of energy saving measures. A spectacular example is the record-breaking installation of photovoltaic panels on Gemini North on Maunakea (see story on page 28). Photovoltaic systems are already being prepared for the Hilo Base Facility and Gemini South on Cerro Pachón, as well.

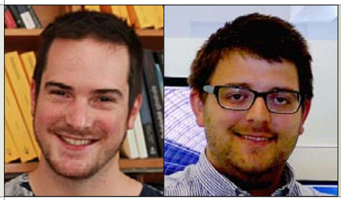
Looking forward, a new International Agreement between the Gemini partners is being signed as I write. The partners are committing funding contributions for the period 2016 to 2021. As readers of *Gemini*Focus, you probably already know that Australia could not commit funds over the entire period — hence it will not remain a full partner, but switches to a limited-term partnership in 2016.

On the other hand, the Republic of Korea, through the Korea Astronomy and Space Science Institute (KASI), is aspiring to soon become a full partner. For now, KASI has extended its limited-term partnership from 2015 to 2016.

Again, Gemini will undoubtedly look back at a highly successful year in 2015. But, stay tuned, as the year's not over yet, and even more splendid scientific results certainly await us between now and the end of the year!

Finally, as this issue goes to e-press, Gemini South has nearly recovered from the estimated magnitude 8.3 earthquake that struck Chile in mid-September. Thanks to the hard work of Gemini staff in both hemispheres, it appears that the impact on Gemini South will be minimal, and we expect to be back on track with full science operations by the time you read this.

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



Julien Rameau and Robert De Rosa

GPI Discovers the Most Jupiter-like Exoplanet Ever Directly Detected

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

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

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

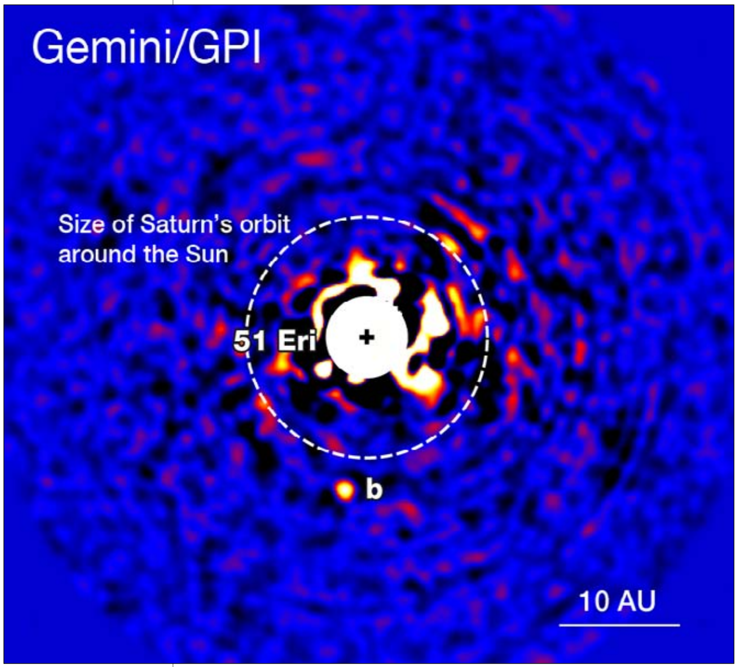


Figure 1.
Discovery image of 51 Eri b at H band (1.66 microns) with the Gemini Planet Imager in December 2014. The central star (indicated by a cross) has been subtracted as a part of the data reduction process, and the residuals are masked out to enhance the planet's contrast in the image. The projected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

The Power of GPI

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

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

A Perfect Target

51 Eri is a nearby star 29.4 parsecs (96 light-years) distant with a mass of 1.6 M_{Sun}. It belongs to the Beta Pictoris moving group, which has a well-determined age of about 20 million years (Myr). 51 Eri is also co-moving with the tight M-dwarf binary GJ 3305 at a distance of 2000 astronomical units (AU). Studies of the star's motion through space, and spectral characteristics of the GJ 3305 binary, provide further evidence of membership within the Beta Pictoris moving group, confirming the age of the 51 Eri system.

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

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

Methane, Methane, Methane

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

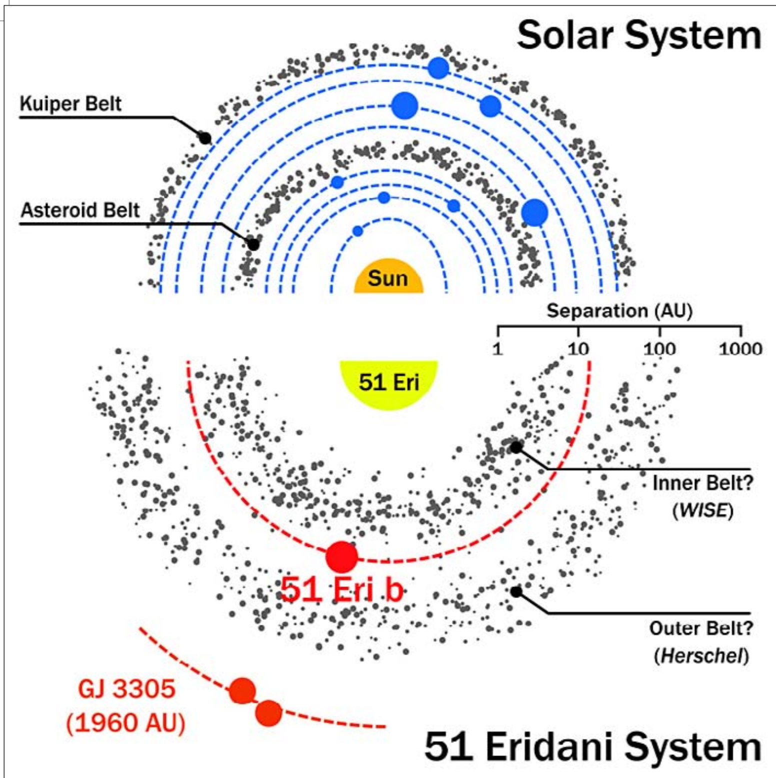


Figure 2.
Schematic diagram comparing the 51 Eri system with our own Solar System. Both systems harbor two debris belts, assuming a two-component fit to the infrared excess of 51 Eri, with gas giants in between. 51 Eri also hosts a binary M-dwarf at about 2000 AU, a separation far too distant to gravitationally perturb the inner system. From 51 Eri b, each component of the wide binary would shine as brightly as Venus, and they would be separated by 17 arcminutes, roughly half the angular diameter of the Moon from Earth.

as it provides a view of what Jupiter might have looked like in its infancy, while offering us a clue as to how it formed.

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

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

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

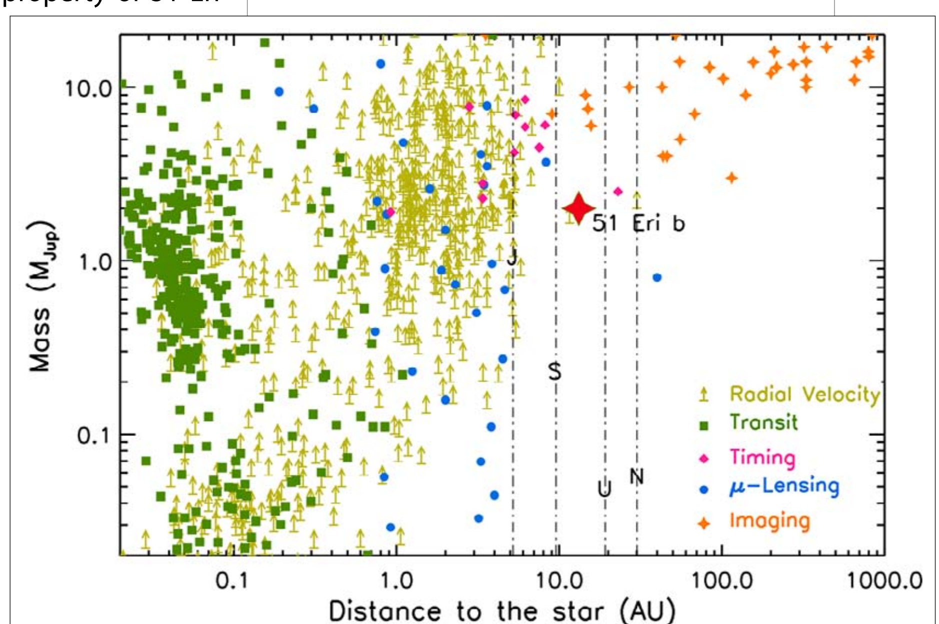


Figure 3.
The current population of known extrasolar planets classified by their detection techniques. The mass and semi-major axis of the four gas giants of our Solar System are overplotted (letters). 51 Eri b (large red star) is the least-massive directly-imaged planet, found at a separation similar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

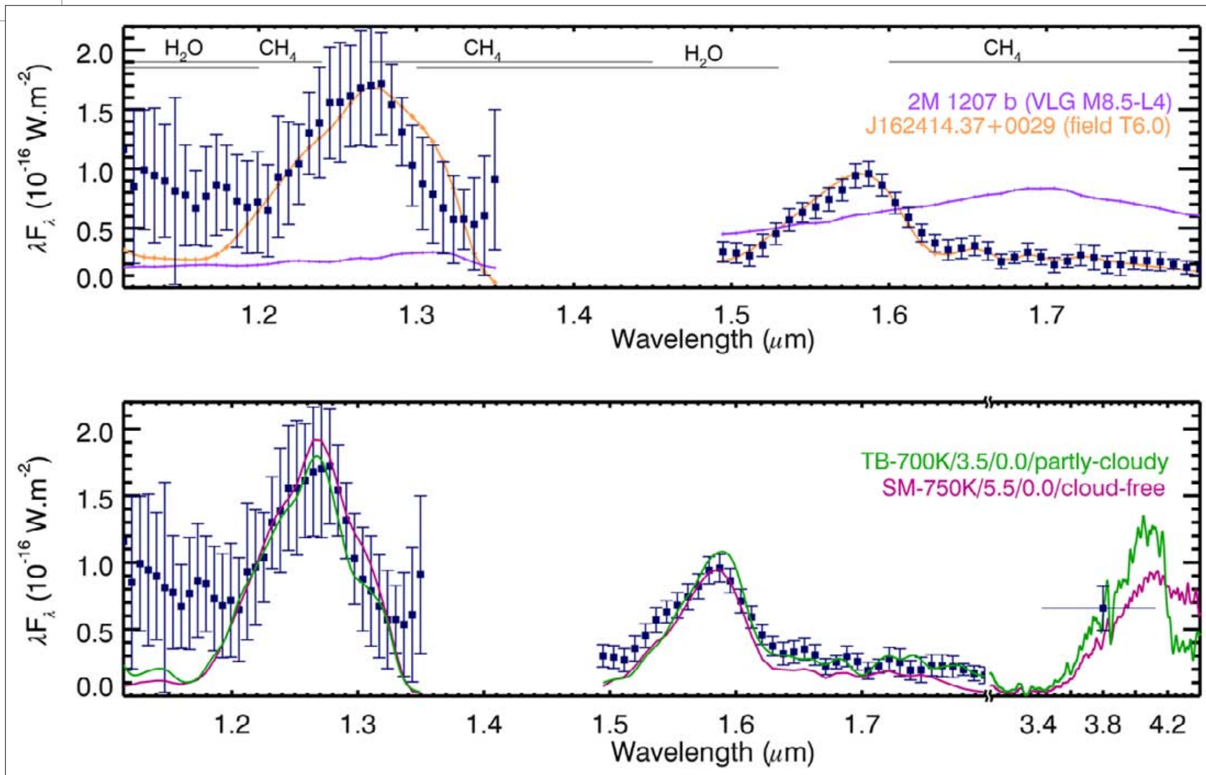


Figure 4.
Near-infrared SED of 51 Eri b measured by GPI at J and H bands, and by Keck/NIRC2 at L′ band (blue). The main molecular absorption bands are labeled on the top panel. The top panel compares the spectrum with the previously known planetary mass object 2M 1207 b (which has a very dusty atmosphere)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

Solar System-like?

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

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

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

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

51 Eri b's methane-dominated spectrum is similar to what models predict for a planet of its mass. This newly discovered world may, in fact, resemble what Jupiter looked like soon after its formation. With this discovery, astronomers now know how to differentiate between L- and T-type young planetary-mass objects, where atmospheres transition from fully dusty to cloud-free, respectively. This transition also occurs in a narrow range of effective temperatures, between the 1000 K of HR 8799 b and the 700 K of 51 Eri b.

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

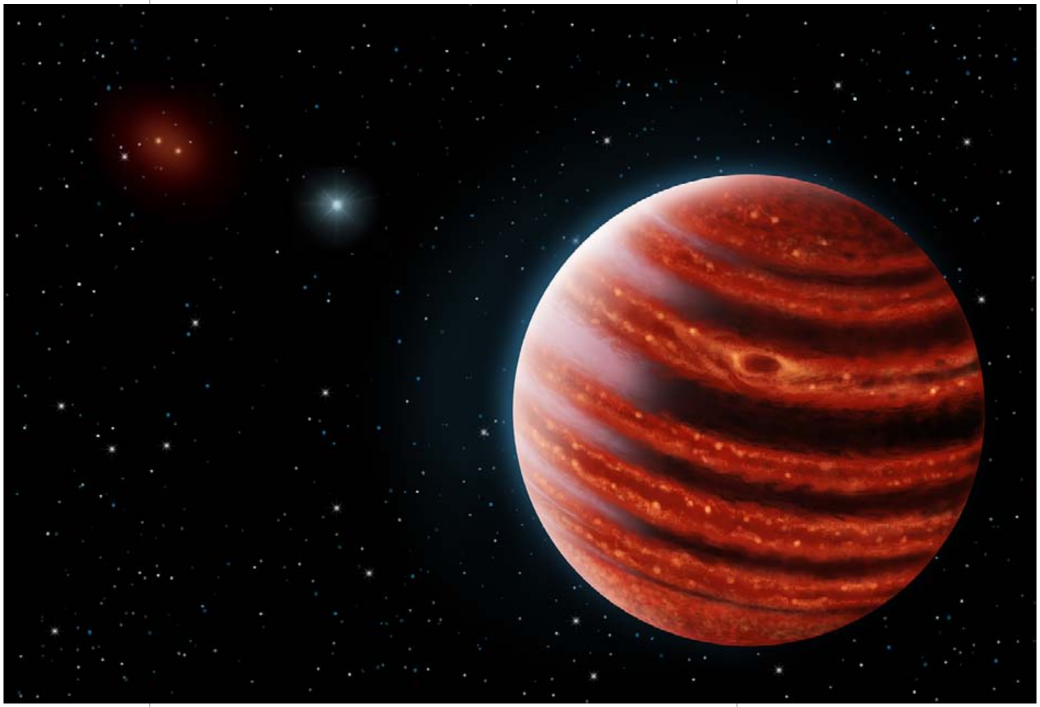


Figure 5.
An artist's visualization of the Jupiter-like exoplanet, 51 Eri b, seen in the near-infrared light that shows the hot layers deep in its atmosphere glowing through clouds. Because of its young age, this young cousin of our own Jupiter is still hot and carries information on the way it was formed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

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

Tip of the Iceberg?

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

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

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Nancy A. Levenson

Science Highlights

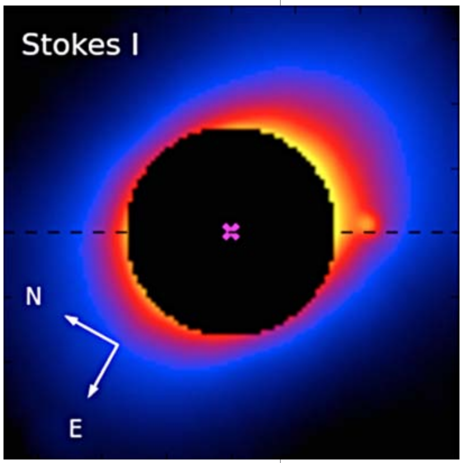
A variety of instruments deliver amazing results: The visiting TEXES spectrograph detects an uncommon amount of water vapor in a debris ring where terrestrial planets develop; The Gemini Planet Imager resolves the Beta Pictoris system to unprecedented angular scales; and GeMS/GSAOI probes the crowded heart of a globular cluster to new depths with exceptional clarity.

Best View of an Exoplanet Orbit

Observations using the Gemini Planet Imager (GPI) provide images and polarization measurements of the β Pictoris (β Pic) system that probe angular scales smaller than ever before, from ground or space (Figure 1). The dynamical interactions of exoplanet β Pic b and a debris disk offer tests of planet formation models. A further advantage of the new data is that they cover observations of the disk and planet together for more than a year, reducing errors in measurements of their relative positions.

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

Figure 1.
Polarization component (Stokes I) of the β Pictoris system. A purple x marks the location of the star, blocked by a mask in the observation. The horizontal dashed line shows the position angle of the outer disk. The planet is separated from the star by 0.4 arcseconds, visible on the right side of the image, offset above the dashed line. This image is 1.3 arcseconds on a side.



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

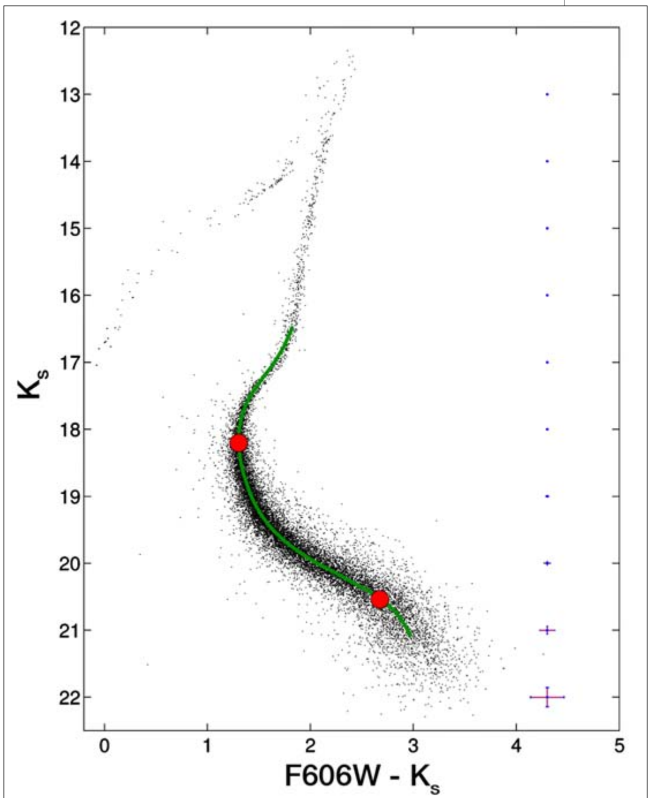


Figure 2.
This color-magnitude diagram of globular cluster NGC 1851's crowded center combines near-infrared observations obtained using GeMS/GSAOI at Gemini South and optical data from the Hubble Space Telescope. Red dots mark the main sequence turnoff and the main sequence knee, around K_s = 18 and 20.5 magnitudes, respectively.

The Deepest Ground-based Photometry in a Crowded Field

Paolo Turri (University of Victoria, Canada) and colleagues have used the Gemini Multi-conjugate adaptive optics System (GeMS) with the Gemini South Adaptive Optics Imager (GSAOI) to produce the most accurate and deepest near-infrared photometry from the ground of a crowded field. Their K_s measurements of the Galactic globular cluster NGC 1851 reach the precision and depth of optical observations obtained using the Hubble Space Telescope, and the resulting combined color-magnitude diagram reveals physical characteristics of the cluster (Figure 2).

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

The delivered image quality is near Gemini's diffraction limit, with an average measured full-width at half-maximum (FHWM) of 0.09". Thus, the team is able to distinguish individual stars in the very crowded field, which would overlap and contaminate each other in seeing-limited observations at lower spatial resolution (Figure 3).

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

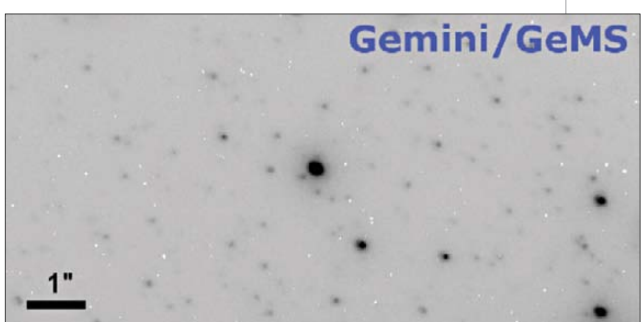


Figure 3.
This small extract from the full 83-arcsecond field-of-view illustrates the quality and depth of the images from Gemini.

Water Vapor in a Terrestrial Planet Region

Astronomers have detected significant water vapor in the planet-forming region around the young star DoAr 44. The central star and development of its planets have not yet fully cleared the surroundings, leaving an inner ring and an outer disk around a gap that extends radially for 36 astronomical units (AU). DoAr 44 is unusual compared to similar so-

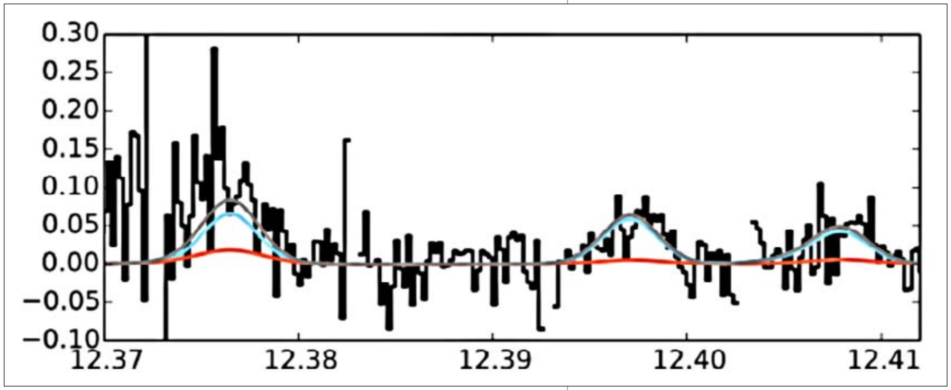


Figure 4.
Continuum-subtracted TEXES spectrum (black) and dominant "hot" model fit (blue), which yields the temperature (450 K) and location (0.3 AU) of the emitting water vapor. A "warm" component (red) is required to account for additional measurements at longer wavelengths. The sum of the models is plotted in gray.

called "transition disks" in showing evidence for water; yet by later stages of evolution, as young stars with disks, water vapor emission is common. The inner ring of DoAr 44 may be replenished by material from the outer disk, accounting for the large water content it maintains compared with similar objects. Alternatively, planets may affect the chemistry in this region where terrestrial planets develop.

The warm (450 K) water arises in the inner ring, appearing in emission at mid-infrared wavelengths (Figure 4). The data were obtained at a spectral resolution R ~ 80,000 using the Texas Echelon Cross Echelle Spectrograph (TEXES), a visitor instrument on the Gemini North telescope. Colette Salyk (National Optical Astronomy Observatory and Vassar College) and collaborators used the kinematic characteristics of the spectrally resolved emission to determine the location of its origin, at 0.3 AU. Avoiding destruction of water molecules in this region close to the stellar source requires material in the region — either gas or dust — as protection against the star's strong radiation. The paper will appear in *The Astrophysical Journal Letters* and a preprint is now ***available***.

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The HH 24 Jet Complex:

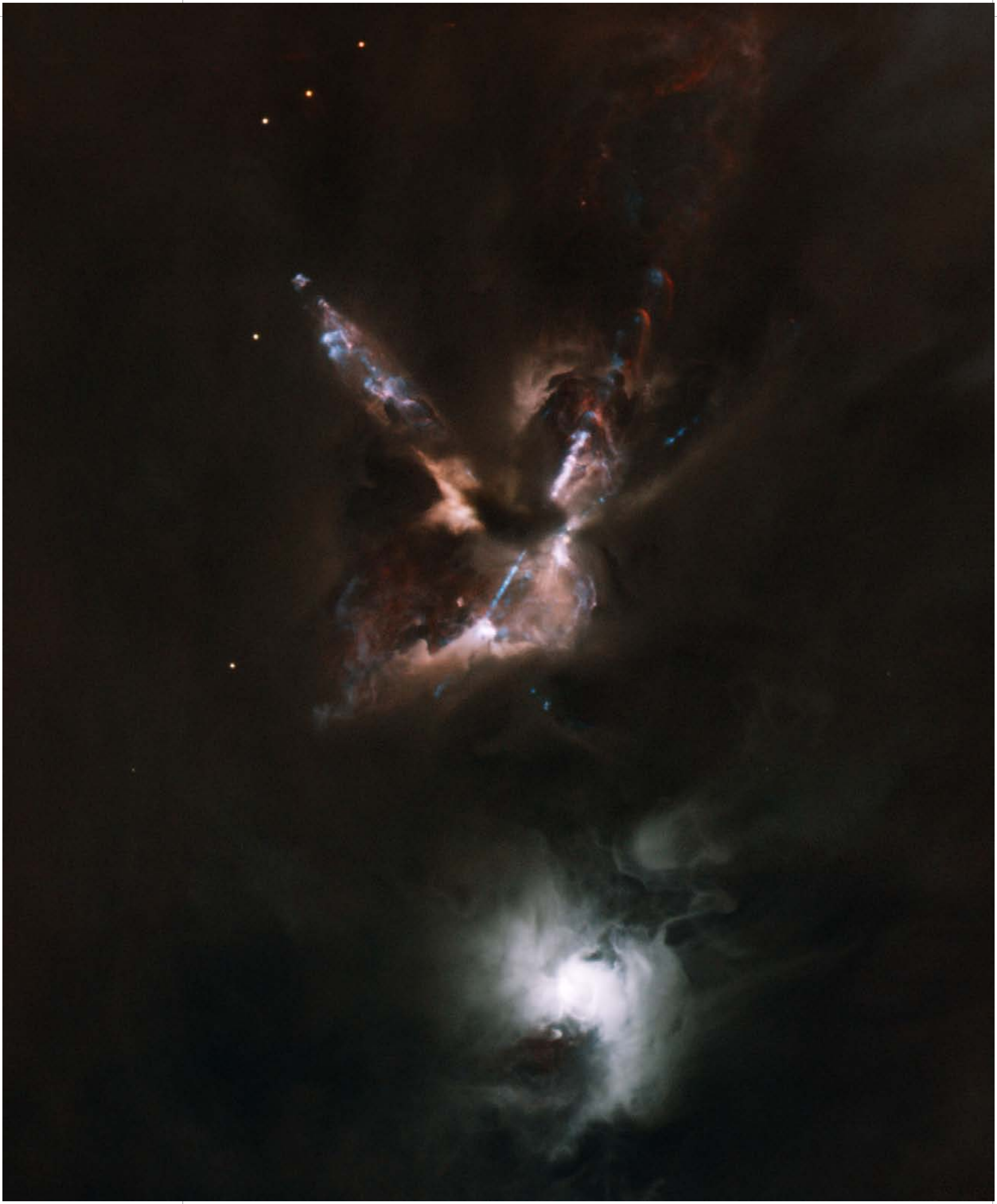
Searching for Orphan Stars Amid Starbirth Fireworks

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

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

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

Reipurth along with co-researcher, Colin Aspin, also at the IfA, are using the Gemini North data from the Gemini Multi-Object Spectrograph (GMOS), as well as the Gemini Near-Infrared Imager, to study the region which was discovered in 1963 by George Herbig and Len Kuhi. Located in the Orion B cloud, at a distance of about 400 parsecs, or about 1300 light-years from our Solar System, this region is rich in young stars and has been extensively studied in all types of light, from radio waves to X-rays.



The HH 24 jet complex emanates from a dense cloud core that hosts a small multiple protostellar system known as SSV63. The nebulous star to the south is the visible T Tauri star SSV59. Color image based on g, r, and i images obtained with GMOS on Gemini North in 0.5 arcsecond seeing.
Image produced by Travis Rector. Image credit: Gemini Observatory/AURA/B. Reipurth, C. Aspin, T. Rector.

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

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

The researchers report that the jet complex emanates from SSV63 — a Class I protostar system, which high-resolution infrared imaging reveals to have at least five components. More sources are found in this region, but only at longer, submillimeter wavelengths of light, suggesting that there are even younger, and more deeply embedded sources in the region. All of these embedded sources are located within the dense molecular cloud core.

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

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

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

André-Nicolas Chené

GRACES:
The Beginning of a Scientific Legacy

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

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

History and Background on GRACES

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

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

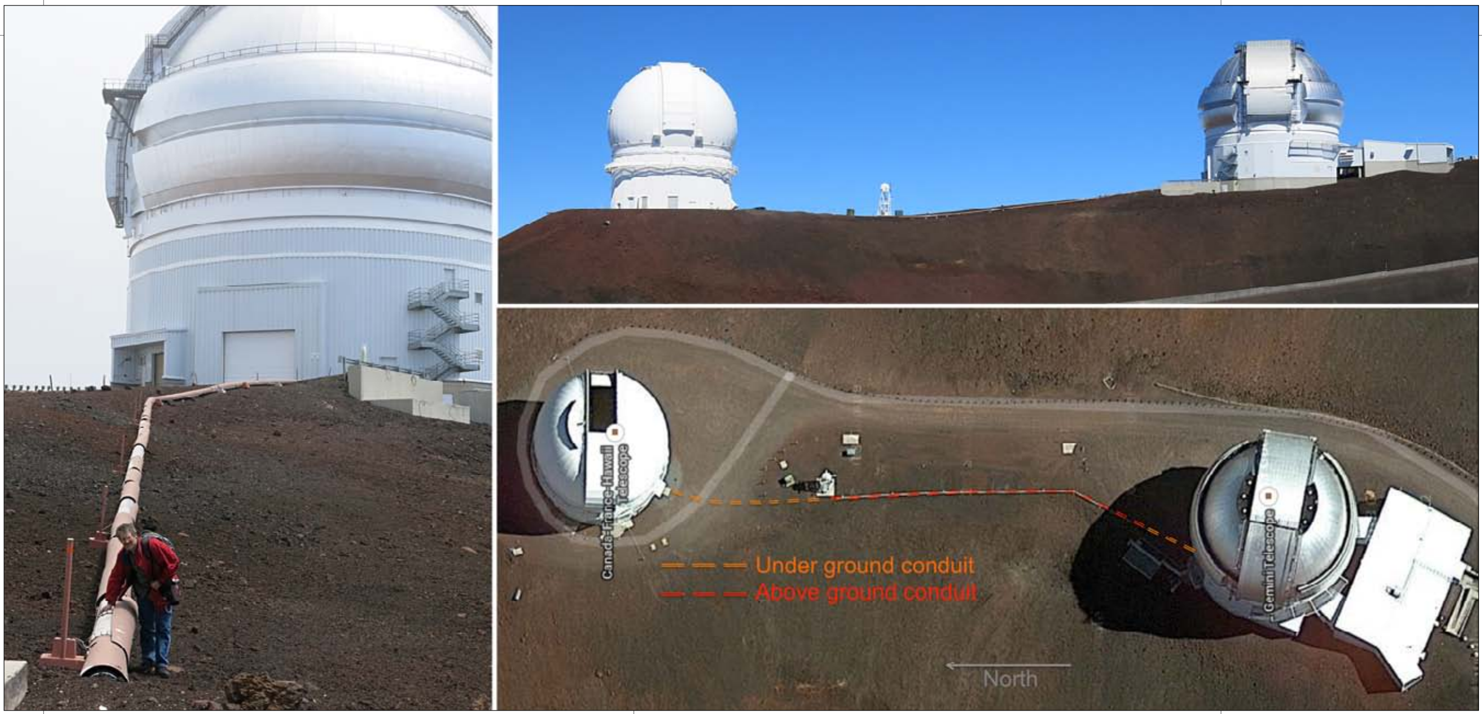


Figure 1.
Different perspectives showing the conduit between CFHT and Gemini.

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

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

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

Early Observations

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

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

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

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

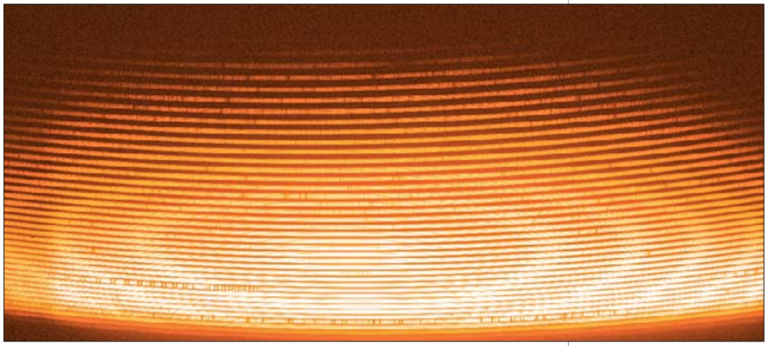
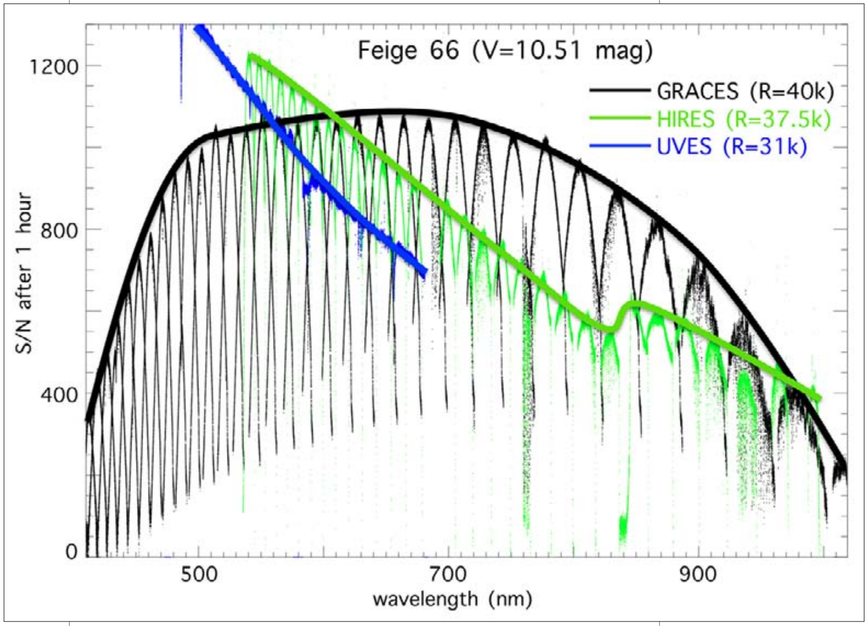


Figure 2.
Full GRACES spectrum of the Moon in the 1-fiber mode. Up to 36 orders are visible, i.e. *from order #22 (centered on 1029nm) to #58 (centered on 408nm).*

Figure 3.

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



Prepping and Using GRACES

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

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

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

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

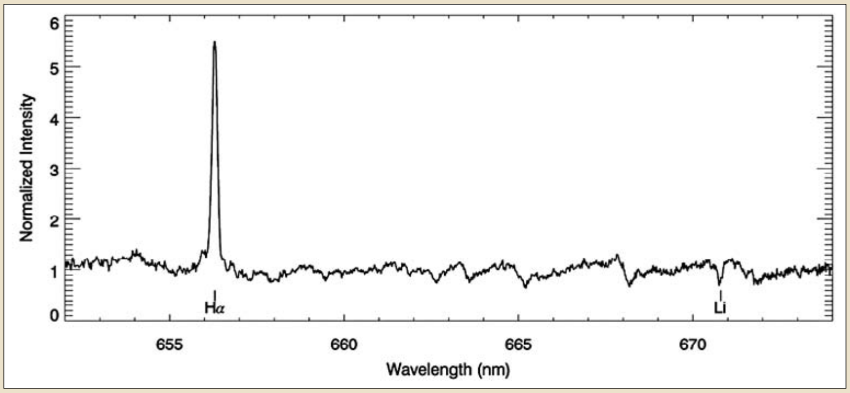
First GRACES' Science Paper

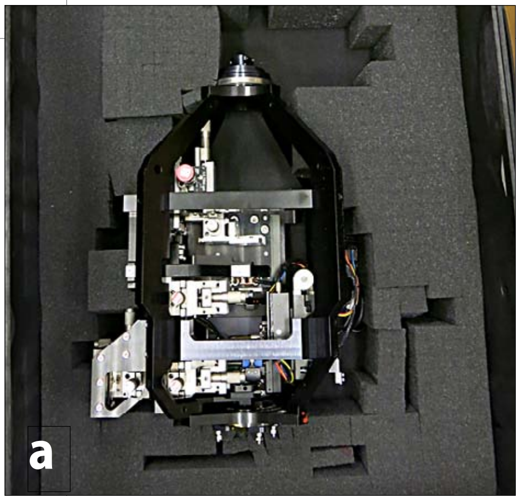
The first paper based upon GRACES data is nearing completion by Lison Malo of CFHT. Her work focuses on nearby young associations of stars in order to better understand their formation history, determine the initial mass function, and test theories of stellar evolution.

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

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

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





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

The Future of GRACES

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

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

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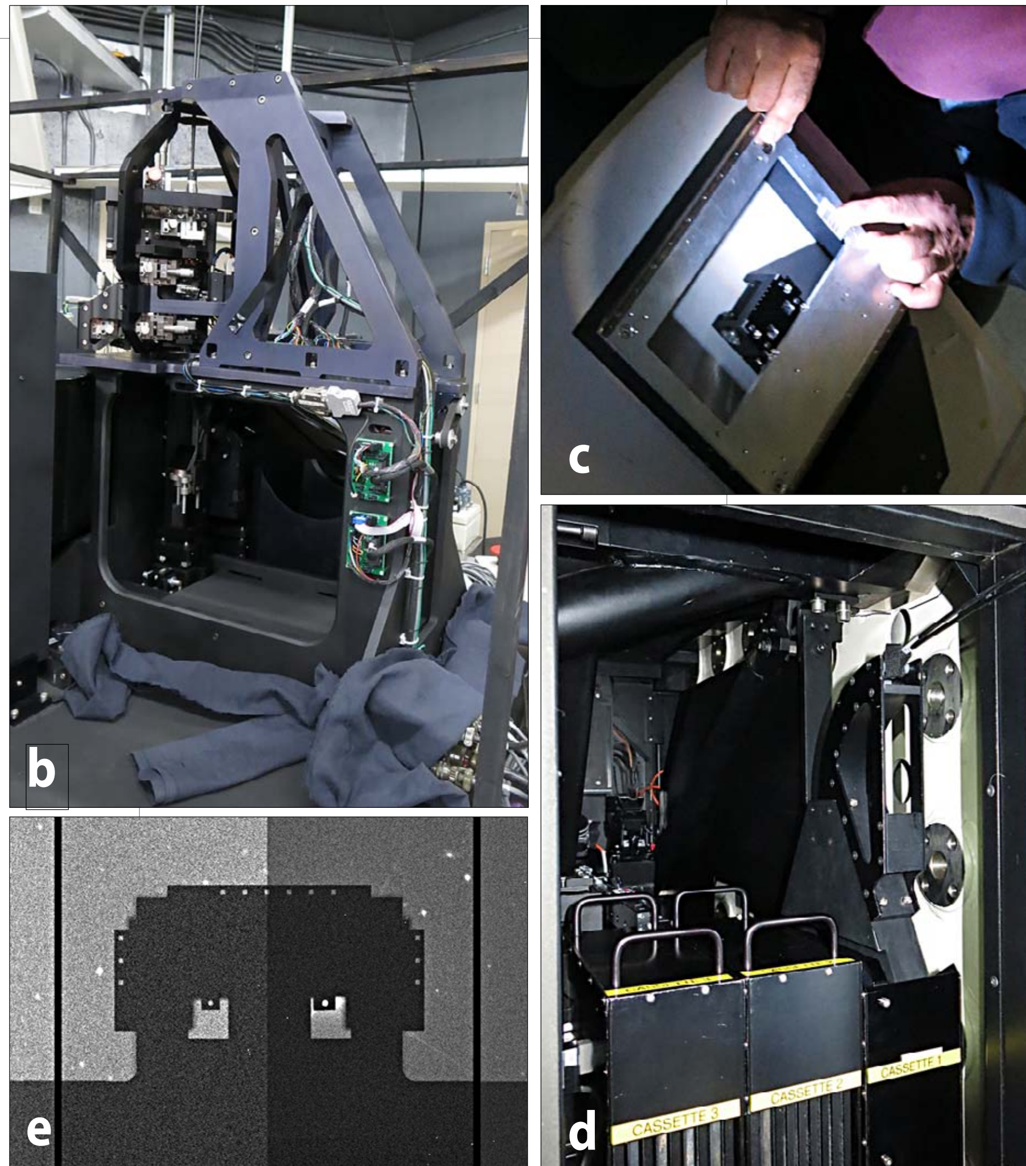


Figure 4.

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

Gustavo Arriagada

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

As Gemini's Base Facility Operations enters its trial phase in Hawai'i and integration at Gemini South approaches, the Observatory is rapidly advancing toward an exciting new era of fully remote observing.

Figure 1.
Tom Cumming and Dolores Coulson during testing of BFO systems in the Hilo control room.

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

Major Accomplishments at Gemini North

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

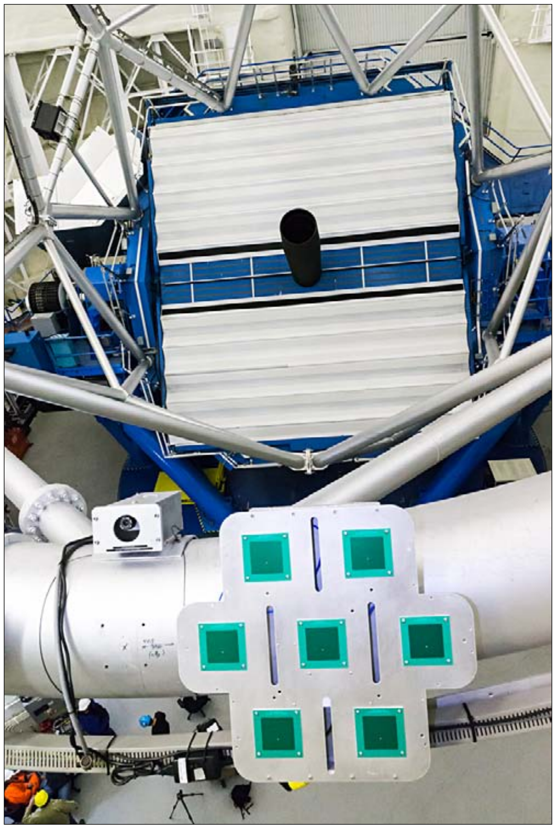


Figure 2.

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

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

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

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

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

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

Trial Run Begins in Hawai'i

BFO has already entered its trial operations phase at Gemini North. We have completed internal testing of most of the critical work packages and followed that with user testing and verification. As this issue goes to e-press the products and work of the BFO team are being tested as an orchestrated collection of subsystems.

For the first time, on the night of September 8-9, 2015, a full test of the remote observing capabilities at Gemini North was successfully completed operating in "base mode" while the night crew was still at the telescope. Over

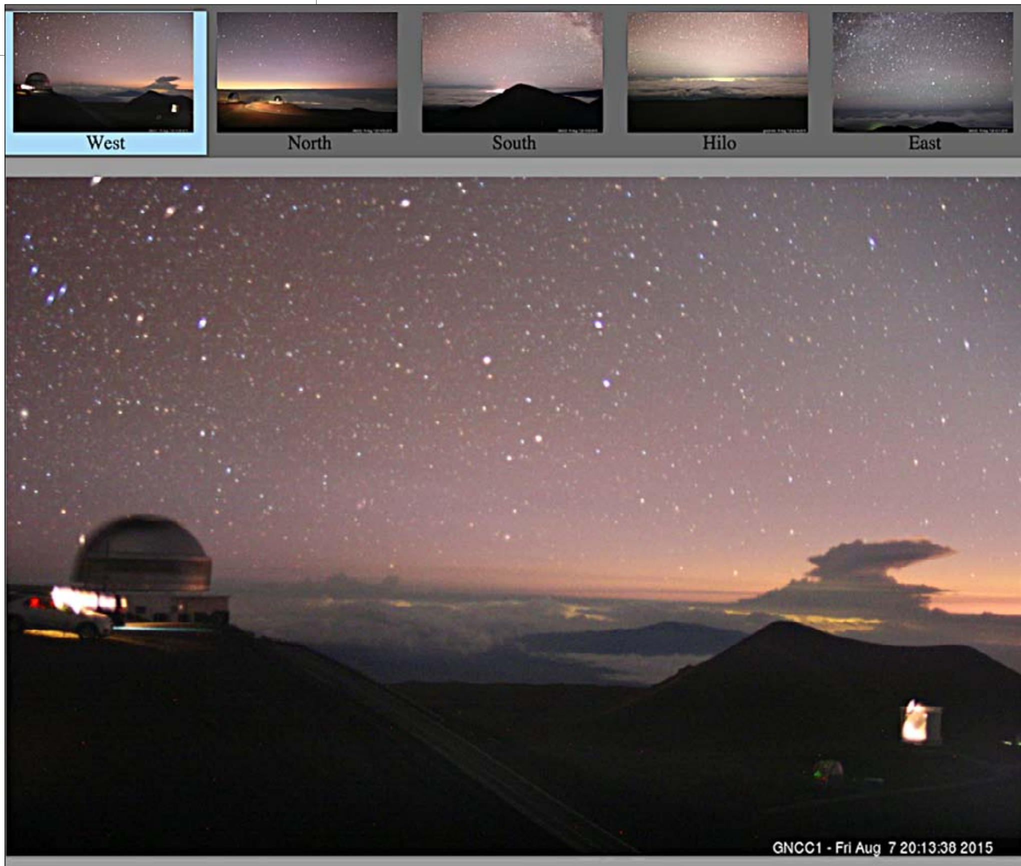


Figure 3. *Sample of data from the Gemini North CloudCam system.*

the two following weeks, the night crew (Science Operations Specialists, SOSs) refrained from going outside the control room to see if what we have developed and tested works in the real remote observing configuration.

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

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

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

This first (current) trial run is part of our "gradual descent" strategy, which breaks down the work into 17 manageable pieces (work packages) that follow different schedules. As such, these products can be added progressively until we complete the full BFO system. We envision having four BFO trial runs, with each having unique objectives.

In the second run, to start on October 12th, we will ensure that all SOSs have opportunities to use the summit configuration and learn how to operate in base facility operations mode, before attempting remote operations from Hilo.

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

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

If everything proceeds according to plan, we expect to handover BFO to Operations at Gemini North by the end of December 2015.

Implementation in Chile

During the fourth quarter of this year, we will officially begin working on BFO at Gemini South, with the goal of handing over to Operations during the third quarter of 2016.

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

An Impressive Team Effort

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

Because of its nature, we believe that by the time BFO is completed, everyone at the Observatory will have been involved at some level. This is truly an Observatory-wide project.

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

BFO Legacy

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

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

Gustavo Arriagada is Senior Project Manager in the Engineering Group at Gemini South and leads the BFO project for Gemini. He can be reached at: garrigada@gemini.edu

Contributions by Gemini staff

News for Users

The Fast Turnaround observing mode, so successful at Gemini North, is now expanding to Gemini South. Both Gemini telescopes weather severe storms prior to planned maintenance shutdowns and Gemini South suffers a powerful earthquake with a rapid recovery. Finally, watch for the launch of Gemini's new data archive.

Fast Turnaround Expanding to Gemini South

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

Yet More Weather

We continue to have an interesting time with the weather. Both Gemini North and Gemini South were closed by midyear snow. In the north Central Pacific, Hawai'i was like the target in a shooting gallery this summer, as hurri-

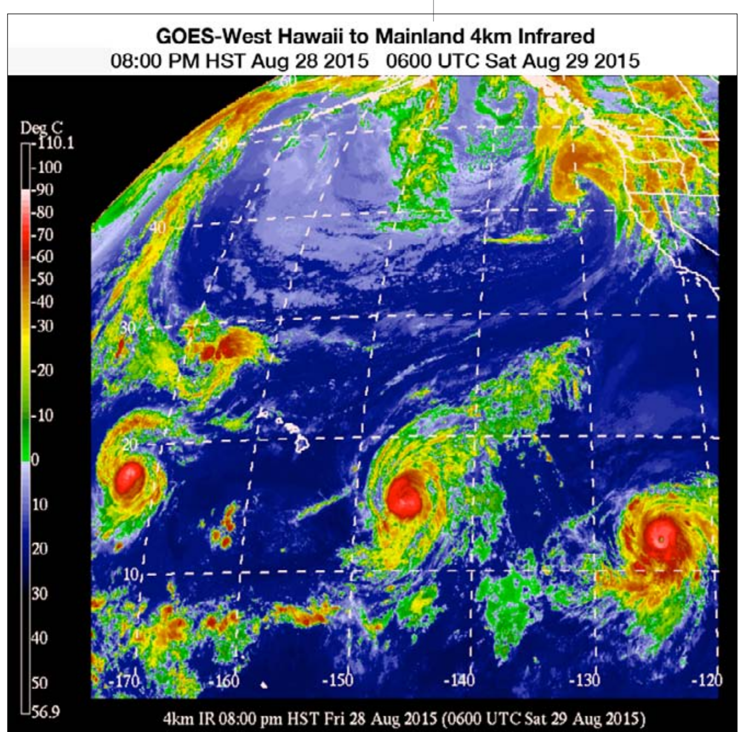


Figure 1.
Hurricanes Kilo, Ignacio and Jimena (left to right) in the Hawaiian environment, characteristic of the active Central Pacific hurricane season of 2015. Image from Maunakea Weather Center, obtained on August 29, 2015.

cane season generated more than 10 named storms to date. Thankfully there have been no direct hits, but significant side effects have included long periods of fog and precipitation at the summit, not to mention a fairly continual stream of flash flood warnings at sea level. Hawaii's hurricane season generally lasts until the end of November, and we can only hope it quiets down significantly before then.

Figure 2.
Snow clearing after winter storm at Cerro Pachón.

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

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

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

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

Telescope Shutdowns

Both Gemini North and South telescopes will be offline for maintenance shutdowns during late September/mid-late October, as this issue goes to e-press. At both sites, a variety of maintenance tasks are scheduled, with the biggest single task being the M1 (primary mirror) recoating at Gemini South; in the north, the M2 (secondary mirror) will be recoated. Numerous preparations, documentation revisions, and rehearsals have occurred in anticipation of the Gemini South event, and the team is ready to safely and successfully complete this delicate and complex primary mirror coating process. Particular attention has been given to a collabora-

Figure 3.
Rehearsal for the Gemini South M1 recoating: Preparing to lift the dummy mirror.

tive cross-training program with other AURA centers in Chile.

New Archive Imminent!

The new Gemini Observatory Archive will be launched in October. Developed in-house as a project led by Observatory Scientist Paul Hirst, the user interface is quite different from the archive at the Canadian Astronomy Data Centre (CADC) which it replaces. However, one of the most significant changes is "under the hood". The archive is now being hosted by Amazon Web Services and stored on the Cloud. This cost-effective solution is well suited to our globally distributed user community. The change is imminent, so keep watching!

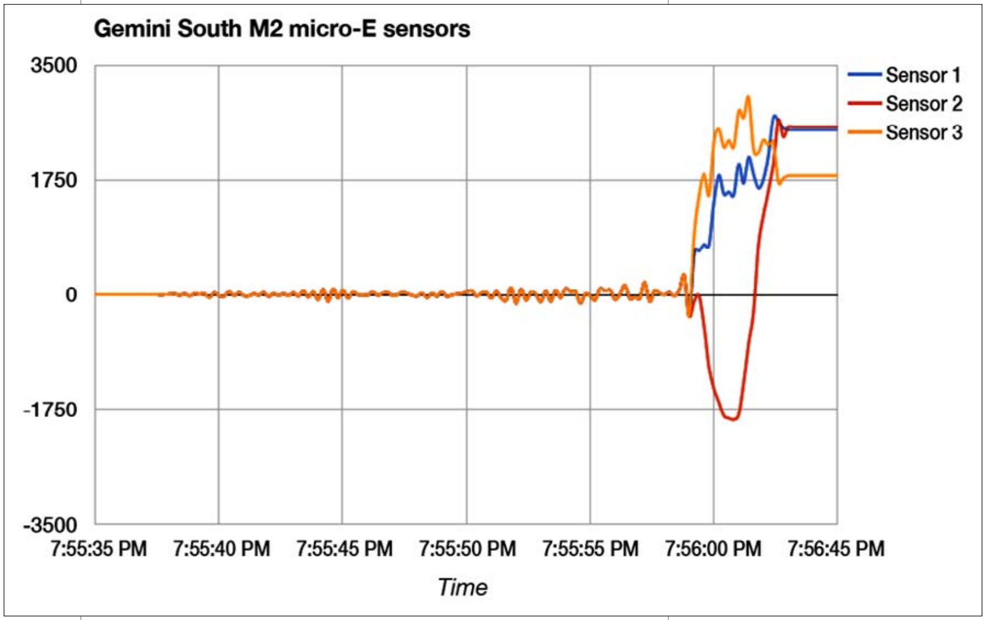
GRACES First Science

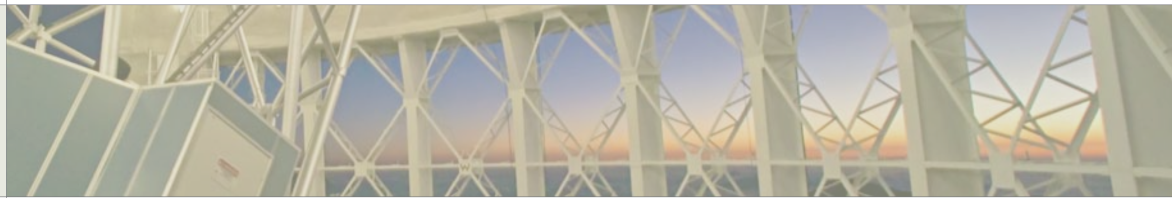
GRACES has moved from development into operations; see the article by André-Nicolas Chené on the commissioning and first science data, starting on page 14 of this issue.

Gemini South and the Chilean Earthquake

As you're probably aware, Gemini South was affected by the large (magnitude ~8.3) earthquake which struck Chile on September 16th. At the time of the quake, Gemini South was closed due to sever weather (see news item above). Since systems were powered up, the secondary mirror system effectively acted as a seismometer. The picture here shows the secondary oscillations in response to the early arriving P waves, followed some 20 seconds later by the major shock of the main quake. As this issue goes to e-press Gemini South is almost completely recovered from the earthquake, and is back on the sky doing normal science operations.

Figures 4.
Data from the Gemini South secondary mirror sensors at the time of the September 16th earthquake.





Contributions by Gemini staff

On the Horizon

Gemini continues its efforts to provide new and improved instrumentation at both sites. The problems with the GMOS-South CCDs have been solved, showing the way now for similar successful implementation at Gemini North. Feedback from the Gemini Instrument Feasibility draft study reports are being reviewed, and resources for existing instrument upgrades are now committed, and will be available soon to users with compelling ideas.

GMOS-South New CCDs: Performing Entirely to Specification

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

When a team of Gemini instrument scientists and engineers investigated the issue, they identified the root cause of the problem as the Astrophysical Research Cameras (ARC) controller video boards. Representatives from ARC suggested that we try a new revision of the video boards they now had available. After significant lab testing, we verified that these boards would solve the problem, but required that we modify our software to be compatible with them. As of August 25th, we have fully installed and integrated these new boards and eliminated the banding effect.

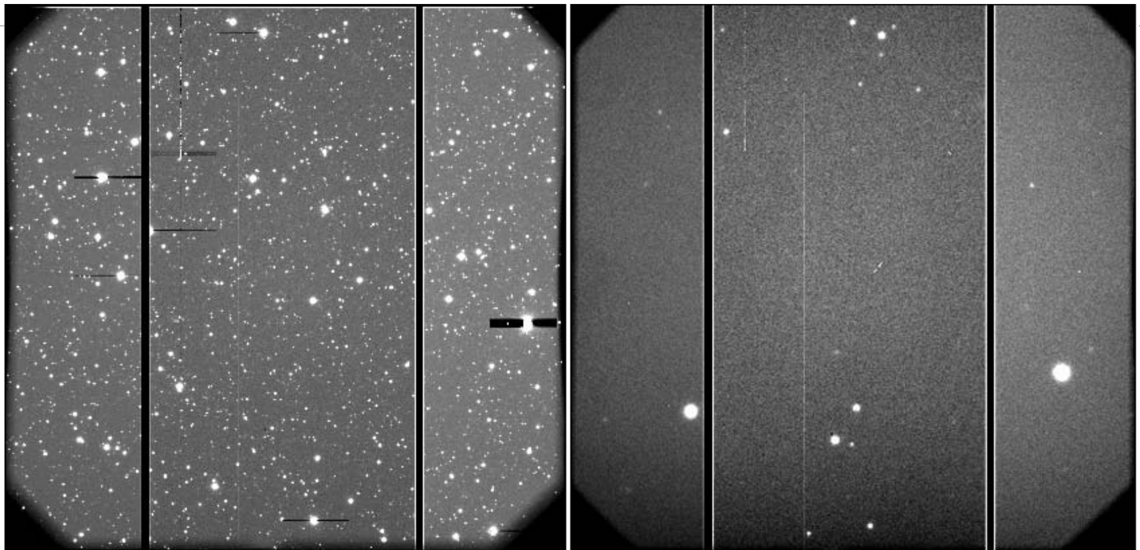


Figure 1.
Before (left) and after (right) data from GMOS-S showing the banding present before the fix (left) and a different field with bright stars after the fix (right) with no banding present.

The screenshots shown here (Figure 1) present examples of standard star fields with bright stars using 2 x 2 binning before and after the board replacement. In the left image, the banding effect is visible as dark lanes on the saturated stars. In the right image, taken after the fix, the effect is completely eliminated and saturated stars do not produce the dark lanes.

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

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

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

Gemini Instrument Feasibility Studies (GIFS) Review

Each of the four GIFS proposal teams presented their draft study reports during meetings held at the Gemini North Base Facility in late September. The teams will take the feedback gathered from these meetings and incorporate them into their final reports, due in October. Figure 2 shows some of the excitement during the OCTOCAM report.

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

Small Projects Fund: Accepting Proposals Soon

Have you ever used a Gemini instrument and dreamed about the additional science you could do if it only had this one little additional capability? Well, now is your chance to make it a reality. As part of continuing efforts to maintain the competitiveness of our Gemini North and South instruments, we recently released a Request for Proposals (RFP) for community-led upgrades to our existing instrument suite. The goal of this program is to provide opportunities for Gemini users and instrument teams to provide new science-driven capabilities to our operating instruments.

This year, we have a total budget of $200,000 for these projects. We intend to fund two or more projects. However, we will also consider compelling proposals requesting up to the whole budget as well as those requesting minimal or no funding from Gemini. Proposers can also request up to 10 hours of telescope time for immediate science with their upgrade after it is installed and commissioned.

Sample projects could include adding and commissioning a new filter or grating, commissioning a new detector mode for more optimal rapid time-series performance, or bringing an integral field unit back to GNIRS. If it adds scientific capability to existing instruments, and you can do the work within the program's constraints (see the detailed request for proposals at the link below), we're interested.

The RFP is open to all institutions or companies from nation partners that fund the Gemini Observatory and to non-partner country Principal Investigators who have significant and relevant experience in using, designing, and/or building a Gemini instrument. More information including the relevant timescales and selection process is available ***here***.

Alexis-Ann Acohido

Record-breaking Rooftop Solar Panel System Installed at Gemini North

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

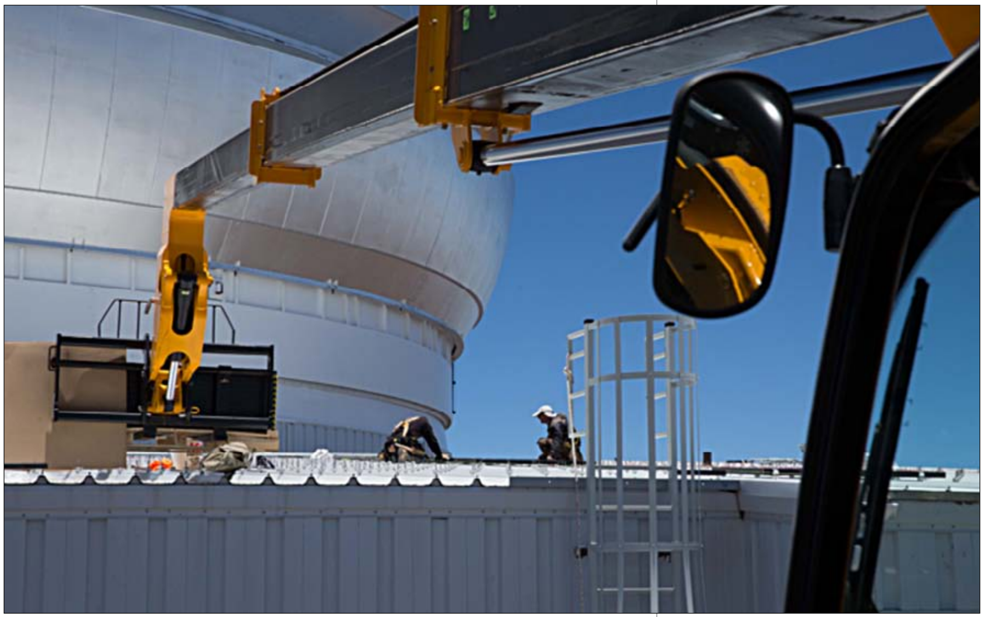


Figure 1.
The PV panels were transported to the roof by crane.
Photo Credit: Peter Michaud

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

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

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

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

Figure 3.
PV panels now cover the entire roof.
Photo Credit: UH88 Camera.

6.4 peak Sun hours a day as opposed to Hilo, with only 4.6 peak Sun hours a day, resulting in a 39 percent benefit; second, PV systems operating on Maunakea at low summit temperatures of ~45° F versus ~80° F at sea level result in another 10 percent improvement in performance; finally, PV systems operating almost 14,000 feet (4200 meters) above sea level, where the Sun is more intense due to reduced atmospheric absorption, results in an additional 10 percent benefit. The approximate energy output of the panels on the telescope is expected to be about 100 kilowatts.

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

The panels are scheduled for connection to the electrical grid by late October.

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The Gemini North secondary mirror (M2) undergoing recoating during a maintenance shutdown in September 2015. Here, the nickel-chromium layer is sputtered onto the mirror's surface by the magnetron. The pink illumination is provided by glowing plasma excited by the magnetron. Photo by Thomas Schneider.

AURA

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