GeminiFocus

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ON THE COVER:

On-sky commissioning of the new Gemini North TOPTICA laser guide star system on October 1, 2018.

Credit: Gemini Observatory/NSF/AURA image by Jason Chu

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Jennifer Lotz

Director's Message

Happy New Year!

With the start of 2019, we are very happy to welcome Korea as a full Gemini participant. We anticipate an exciting year ahead as new projects are underway to develop Gemini's adaptive optics and time-domain astronomy capabilities, commission the new visiting instruments MAROON-X and Zorro, and begin new Large and Long Programs to study the Universe in high resolution.

The Gemini Board and Science & Technology Advisory Committee (STAC) meetings were held at the La Serena Gemini South Base Facility in mid-November. The Board welcomed the full participation of the Republic of Korea, through the Korea Astronomy & Space Science Institute (KASI), in Gemini.

I'd also like to thank departing Board Chair Rene Walterbos and STAC Chair Laura Parker for their leadership, and departing Board members Greg Fahlman, George Jacoby, Maria Victoria Alonso, and Lucianne Walkowicz for their service to the Gemini community. To fill some of these departures, I'm pleased to welcome new Board Chair Todd Boroson and new STAC Chair Elliott Horch. Gemini also welcomes new STAC members Jane Charlton, Ryan Foley, Jae-Joon Lee, Damian Mast, Henri Plana, and Lisa Poyneer, and new Board members Guillermo Bosch, Marcos Perez Diaz, Narae Hwang, and Greg Rudnick. We look forward to a productive and exciting collaboration. We are also pleased to announce that all Gemini member participants declared their intention to remain in the Partnership and participate in the renegotiation of a new international Partnership agreement starting in 2021.

Much of the discussion at the STAC meeting centered around the plan to advance the adaptive optics facilities at Gemini Observatory by the mid-2020s. With the October announcement of new NSF funding called GEMMA (Gemini in the Era of Multi-Messenger Astronomy), plans are now underway to develop a state-of-the-art multi-conjugate adaptive optics (AO) facility instrument at Gemini North (GNAO) by 2024. In combination with the exquisite observing conditions on Maunakea, GNAO will yield high-resolution imaging and spectroscopic capabilities over a 2 arcminute field of view, allowing detailed studies of galactic stars and star-forming regions, high density stellar populations, and transient events in distant galaxies.

The GEMMA award also allows us to update the real-time controllers (RTC) — which analyze data from wavefront sensors and command the deformable mirrors that correct the image for the Gemini Multi-conjugate adaptive optics System. The same RTC design will be implemented into the GNAO system (benefitting both telescopes).

Complementing the GEMMA award, the STAC and Board endorsed a plan (targeted for completion by 2026) to develop an adaptive optics secondary mirror for Gemini North which will be fully compatible with the new MCAO and RTC systems and future Gemini North instruments. These developments allow us to push Gemini North AO on a path toward an even larger corrected field of view, higher correction performance, and greater wavelength coverage; it also gives us the future potential to provide Ground-Layer AO (GLAO) and Single-Conjugate AO (SCAO) for all instruments on the telescope.

Further Expansions and Results

Time-domain and multi-messenger astronomy are also exciting areas of development and on-going science programs for Gemini. We are looking forward to the next run at the Laser Interferometer Gravitational-wave Observatory (LIGO) during the first half of 2019. Recent upgrades to LIGO will make it sensitive to gravitational wave sources at greater distances and in larger numbers than previous observations. We are also preparing for rapid follow-up of electromagnetic counterparts with Gemini's bi-hemisphere access and flexible queue scheduling.

Thanks in part to the NSF's GEMMA award, we can now begin enhancing our software infrastructure for the start of Large Synoptic Survey Telescope's (LSST's) science operations in about 2022. These improvements will benefit all users through greater observing efficiency and improved data reduction tools. In order to prepare for the strong demand for time-domain follow-up observations, while maintaining non-Target of Opportunity (ToO) science productivity, we plan to develop the software necessary for an automated, dynamic queue system. This system will also coordinate with a wider network of follow-up facilities, and include an improved spectroscopic data reduction pipeline.

We continue making excellent progress on the Gemini facility instrument SCORPIO, an eight-channel optical/infrared imager and spectrograph with simultaneous coverage from 0.38-2.5 microns. SCORPIO will serve as a workhorse instrument at Gemini South for ToO and general observers alike by about 2022. For more information, please join me at the splinter session titled Science with SCORPIO on Gemini at the Winter 2019 meeting of the American Astronomical Society (AAS).

In the near term, Gemini's science programs are going "high-resolution" by pushing the extremes of spatial and spectral resolution, including two new Large and Long Programs: one, with Ian Crossfield (University of California Santa Cruz) as Principal Investigator (PI), plans to determine if the host stars of Transiting Exoplanet Survey Satellite (TESS) exoplanet systems are binaries or multi-component; the other, with Kim Venn (University of Victoria) as PI, intends to spectrally resolve the signature of ancient metal-poor stars in our Galaxy.

High spatial resolution speckle imaging with visiting instruments 'Alopeke ("Fox" in Hawaiian) and the Differential Speckle Survey Instrument (DSSI) have studied the frequency of multiple star-systems in the exoplanet host systems found by Kepler 2 (K2) and TESS; In 2019, PI Steve Howell (NASA Ames) will replace DSSI with a new speckle imager, Zorro ("Fox" in Spanish). Additionally, recent results from Gemini Planet Imager (GPI), and plans for improving GPI's sensitivity and capabilities, will be discussed at the Gemini AAS Open House.

Meanwhile, Gemini's high-resolution spectroscopic capabilities are also expanding. The visiting instrument MAROON-X (PI Jacob Bean, University of Chicago) is on track for commissioning this year at Gemini North. MAROON-X will provide the US community with a state-of-the-art fiber-fed spectrograph with a resolving power of R = 80,000 at 0.5-0.9 microns, capable of ~ 1 meter/second exoplanet radial velocity measurements for late-type M dwarfs.

By the end of 2019, we also expect to begin commissioning at Gemini South on the new Gemini High-resolution Optical SpecTrograph (GHOST) — a facility instrument with high-throughput, high spectral resolution (R ~ 50-75,000) and continuous coverage between 0.36-0.95 microns. GHOST's world-class efficiency, resolution, wavelength coverage, and stability will enable a broad range of science by the Gemini community, including exoplanet characterization, radial velocity studies of TESS exoplanet transits, and high-resolution stellar population spectroscopic studies.

For more details on high-resolution spectroscopy at Gemini, please attend the AAS Winter 2019 meeting splinter session Resurgence of High-resolution Spectroscopy at Gemini.

We look forward to seeing many of you in Seattle, Washington, at the AAS Winter Meeting 2019 at our booth, Open House, and splinter sessions, and at the Korea Gemini User's Meeting in Daejeon in February.

May the new year bring clear skies, good seeing, and many new scientific discoveries.

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Frédérique Baron, Étienne Artigau, and David Lafrenière

A Hunt for WEIRD Planets

The WEIRD (Wide-orbit Exoplanet search with InfraRed Direct imaging) survey was designed to search for Jupiter-like companions on very wide orbits around young stars in the solar neighborhood. Using observations from Gemini-S, CFHT, and Spitzer, the survey should have enabled the discovery and direct imaging of five to eight such new planets, but none were to be seen. Our results constrain the occurrence of 1-13 M_{Jup} planetary-mass companions on orbits with a semi-major axis between 1,000 and 5,000 AU at less than 0.03, with a 95% confidence level.

In the last two decades, the nearly 4,000 exoplanets discovered to date have come in all sizes and compositions, appearing quite different from the planets in our Solar System. Most of these planets were discovered using indirect methods, meaning that astronomers measure the effect that the planet has on its host star, while the planet itself is not seen; these indirect methods are only sensitive to planets at a few astronomical units (AU) from their star or closer. Relatively little is known for planets on wider orbits.

The Interest in Giant Planets on Wide Orbits

Direct imaging of exoplanets is extremely challenging. A star is so much brighter than a planet that, at very close angular separations, the emission from a planet can be easily drowned out by the light coming from its host star. Direct imaging is possible, however, with state-of-the-art high contrast imagers (such as the Gemini Planet Imager) that suppresses the starlight and enables the detection of companions as close as 10-20 AU. In 2004, the European Southern Observatory's Very Large Telescope Array made the first direct image of a planet four times more massive than Jupiter orbiting close to the nearby brown dwarf 2MASSW J1207334-393254. As a brown dwarf's light is far less intense than that of a true star — thus making a planet orbiting it easier to detect — this discovery paved the way for astronomers to search for similar giant planets but on very wide orbits around stars.

Giant planets on wide orbits are of interest for several reasons. They are so far away from their host that the star's light does not affect them. This means they can be imaged and studied directly (as if they were isolated objects) without the need for sophisticated imaging and data analysis techniques. In some cases, high-resolution spectra can also be acquired to learn more about them. And because the planet and its host star formed together, they share the same age and distance from Earth; thus, they are generally more interesting to study than isolated objects, for which age and distance is notably more difficult to obtain.

Of the 20 or so planets detected by direct imaging, about half belong to a class of giant planets whose orbits have a very large semi-major axis (greater than 100 AU); no such planet exists in our Solar System. We, therefore, began a WEIRD (Wide-orbit Exoplanet search with InfraRed Direct imaging) survey for the most extreme planetary systems.

The WEIRD Survey

Designed to search for Jupiter-like companions on very wide orbits (1,000 to 5,000 AU), the WEIRD survey focuses on the 177 stars younger than 120 million years that are known members of moving groups in the solar neighborhood, closer than 70 parsecs. Unlike stars, planets do not have core nuclear reactions allowing them to sustain their temperature. Thus, after their formation, they cool down with time. A young planet will therefore be brighter than the same planet at an older age, and easier to detect directly.

The data collection of deep seeing-limited observations started in 2014A and ended in 2017B. We used the Gemini Multi-Object Spectrograph (GMOS) and FLAMINGOS-2 near-infrared imaging spectrograph at Gemini South to survey the southern stars in the *z* and *J* bands, respectively. We also used MegaCam (an imaging CCD camera with a 1 square degree field of view) and WIRCam (a near infrared mosaic imager) at the Canada-France-Hawai'i Telescope to survey the northern stars in the same bands, respectively. Overall, the project required about 250 hours of ground-based observing time and an additional 250 hours of *Spitzer Space Telescope* / InfraRed Array Camera (IRAC) imaging at 3.6 and 4.5 microns (μm) to complete the observations.

Results from the WEIRD Survey

As giant planets have spectra that resemble T or Y dwarfs (with different surface gravities), we employed the same strategy used by those searching for brown dwarfs with wide-field imaging. The characteristically red *z-J* and [3.6]-[4.5] colors of known planetary-mass companions and young brown dwarfs were the criteria used to identify candidates (Figure 1). The search uncovered four candidate companions with the expected colors,

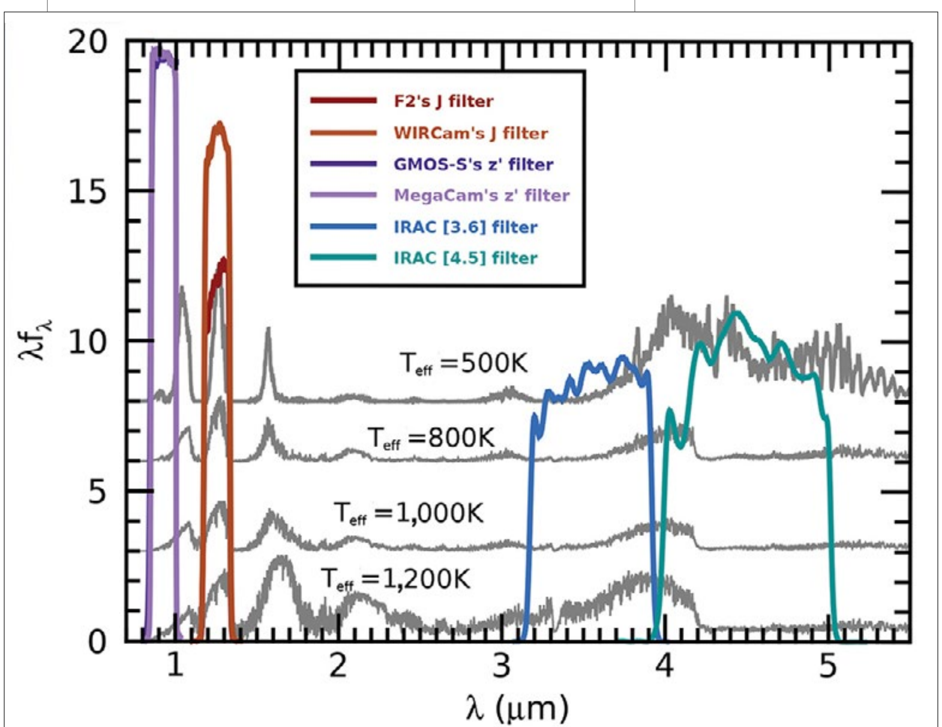

Figure 1.
Spectral energy distribution of young T to Y dwarfs. The transmission functions of the four filters used for our observations (z, J, [3.6], and [4.5]) are overlaid.

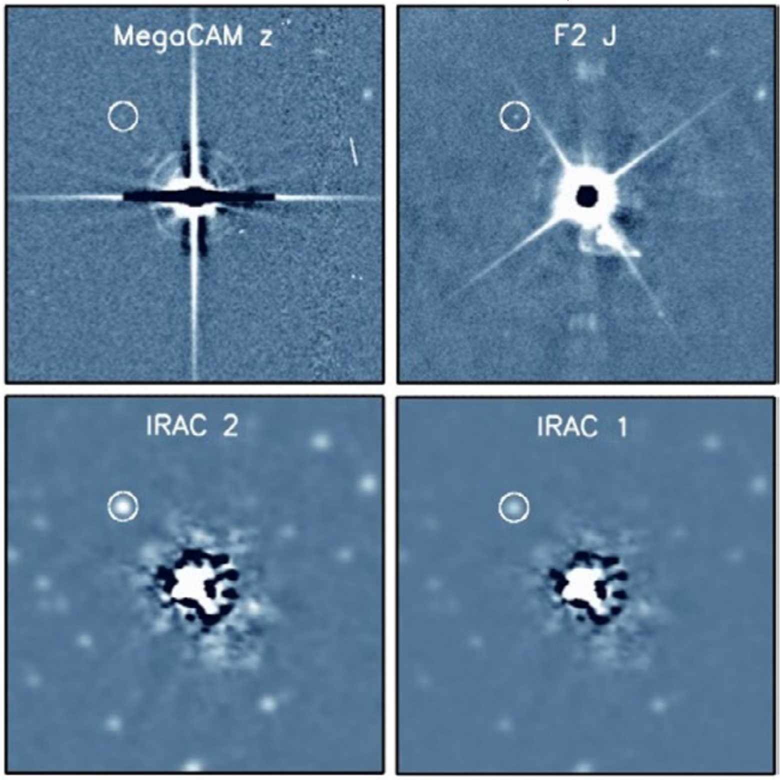

Figure 2.
Example of a planetary candidate (circled) around a young star. Clockwise starting from upper left, we see an image at 0.9 µm (CFHT, MegaCam), at 1.2 µm (Gemini-S, F2), at 3.6 µm (Spitzer), and at 4.5 µm (Spitzer). This candidate turned out to be a background object.
Credit: Frédérique Baron.

The non-detection of planetary candidates is interesting because it was unexpected. Using the occurrence rate of giant planets on wide orbits that was inferred by previous surveys — which assume that the mass function at wide separation rises for lower masses as it does for closer-in planets found by radial velocity — we expected to discover between five to eight new planets. The survey's null result is not due to a lack of sensitivity, as the expected depth was reached.

but we identified all as background objects through follow-up proper motion observations. Figure 2 shows an example of such a candidate, where you can see the very red color in *z-J*, as the candidate (circled) is barely seen in *z* (top left image) but is very well detected in *J* (top right image).

Figure 3 shows in shades of magenta the average contrast map obtained for the survey. It shows the probability of detecting a planet with a given mass between 1 and 13 M_{Jup} as a function of the planet semi-major axis. The survey reaches good completeness for companions with masses

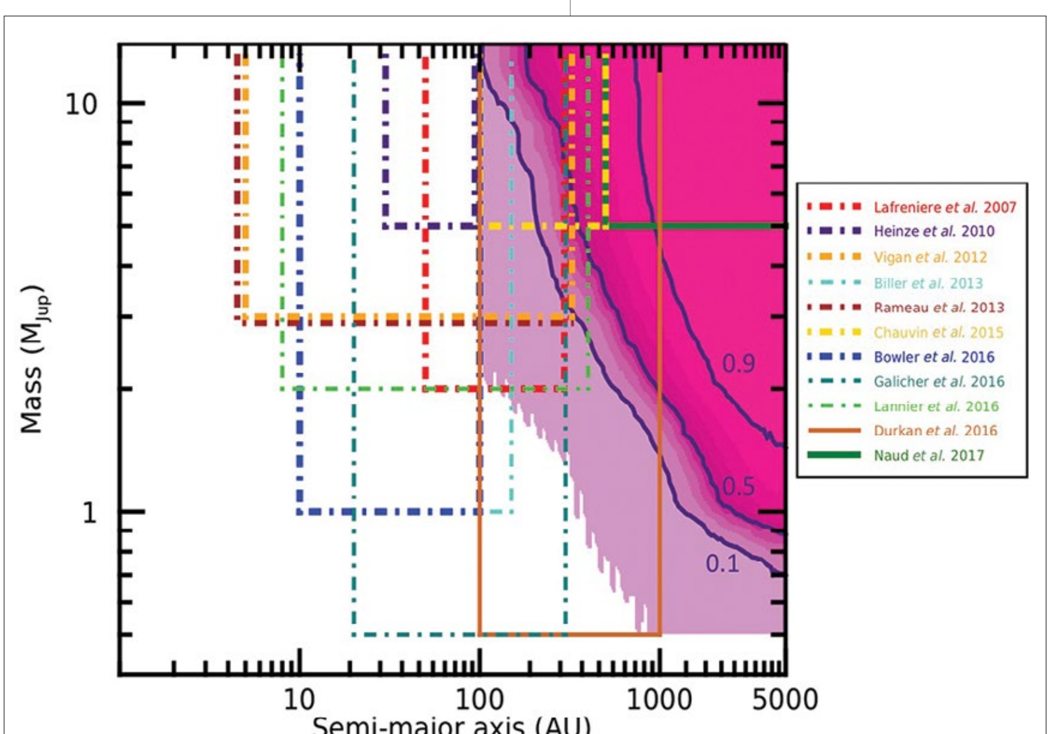

Figure 3.
Average completeness map for the WEIRD survey. Our results are shown in shades of magenta and the contours correspond to the probability of detecting a planet of a given mass and semi-major axis. The various boxes correspond to the range in masses and semi-major axes where the surveys from other teams were sensitive. All of the dotted boxes used high contrast imaging, while the solid boxes used deep seeing-limited imaging. Our observations probe larger semi-major axes than high contrast imaging surveys, but are insensitive to semi-major axes where high contrast observations are mostly sensitive.

down to 2 M_{Jup} at separation of 1,000 AU and above, meaning that if five to eight planets were living in that range of parameters, some of them should have been uncovered. Based on the null result and the sensitivity reached for each target, we inferred that less than 3% of stars host a planet with a mass between 1 to 13 M_{Jup} and a semi-major axis between 1,000 and 5,000 AU (95% confidence level).

How Weird Is It?

This work shows that giant planets around young stars on very wide orbits are quite rare. Some previous surveys have obtained similar results, but WEIRD pushed the search a little further out in orbital separation and a little further down in planetary mass, still returning a low occurrence rate. The low frequency could be a clue toward a better understanding of the formation process of Jupiter-like objects on wide orbits. Indeed, the results are probably telling us that they don't form in the same way as planets on shorter orbits.

One possibility is that the few known planetary companions at large separations represent the low-mass tail end of the distribution of brown dwarf companions that form like stars — rather than objects that form like planets. Another possibility is that these companions were once planets on short orbits that were pushed out following interactions with other planets. A lot of questions remain unanswered, and the search for exoplanets on wide orbits continues.

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Mark Lacy, Kristina Nyland, and Susan Ridgway

GeMS Delivers the Sharpest View of the Visible Light from Distant Galaxies

We recently used GeMS/GSAOI observations to make some of the first ≈ 0.1-arcsecond-resolution observations in the near-infrared of extragalactic fields exceeding 1.5 arcminutes in size. The unique capabilities of GeMS have allowed us to study the size evolution of distant galaxies in the rest-frame optical/near-infrared. In particular we have focused on z ~ 1-3 ultraluminous infrared galaxies, finding signs of recent merger activity, including a rare candidate triple active galactic nucleus. Our observations give us an indication of what the James Webb Space Telescope *will be able to deliver in a few years.*

The most massive galaxies seen today started life as some of the first structures to form in the early Universe, then grew both in mass and size through mergers and the accretion of further material. Along that evolutionary journey, most of them went through episodes of violent activity, including powerful starburst and quasar events. Today, most of them are quiescent in nature, with star formation having largely stopped, and active galactic nuclei (AGN) reduced to a very low level. Their story is therefore rich in astrophysical phenomena, offering us insights into what drives, and, ultimately, what stops the formation of galaxies.

Determining the physical mechanisms by which massive galaxies evolve into the objects we see today requires imaging high-*z* galaxies on scales less than 1 kiloparsec (kpc). Imaging in the rest-frame optical/near-infrared — longward of the Balmer break at 3646 Ångstroms, where the stellar population is dominated by the older stars that contribute most of the stellar mass in a galaxy — is particularly valuable.

Such imaging can be used to measure both the changing distribution of galaxy sizes as a function of redshift and the frequency of interactions and mergers. Furthermore, by combining near-infrared imaging of the stellar light with high-resolution radio continuum imaging (which pinpoints the regions of star formation or nuclear activity in these systems) we can build up a much more complete picture of the nature of the galaxies. This is particularly useful in dusty star-forming systems, where the peak of star formation activity may be offset from the peak of the visible stellar light.

The GeMS/MCAO Advantage

High-resolution imaging over a field of more than a few tens of arcseconds in extent has, until recently, been the exclusive domain of space-based telescopes such as the *Hubble Space Telescope* (*HST*). In the near-infrared, *HST*'s resolution is limited to between 0.1-0.15 arcsecond. Conventional adaptive optics from the ground can deliver higher resolution, but only over a patch of sky ~30 arcseconds in extent. Multi-conjugate adaptive optics (MCAO) allows larger fields to be imaged by correcting multiple layers of the atmosphere, probed by multiple guide stars. This overcomes two limitations of conventional AO: 1) the limitation of the ~30-arcsecond-radius isoplanatic patch over which correction from a single guide star is effective, and 2) the "cone effect" from laser guide stars, whereby the atmospheric turbulence probed by a single laser guide star is not the same as that from an arriving wavefront from a distant star. The Gemini Multiconjugate adaptive optics System (GeMS) on the Gemini South 8-meter telescope (Rigaut *et al.*, 2014; Neichel *et al.*, 2014) uses a five-laser guide star and a natural guide star constellation of between one and three stars to achieve a consistent point spread function (PSF) over a 1.5 arcminute field of view.

The current use of GeMS is restricted to asterisms having stars brighter than $R \approx 15$ (depending on observing conditions), ideally consisting of three stars in an approximate equilateral triangle, and within an ≈ 2 arcminute field of view. Such asterisms are rare (only about one per square degree outside of the Galactic Plane) and are even less commonly found in well-studied, small-area deep extragalactic fields, which are typically picked to avoid bright stars.

Fortunately, the new generation of deep, wide-area (> 1 square degree) extragalactic surveys — designed to study the evolution of galaxies over a wide range in environment — can complement MCAO facilities by both containing suitable asterisms and having the multi-wavelength coverage needed to obtain photometric redshifts and star formation rates for the galaxies in the field. The Spitzer Extragalactic Representative Volume Survey (SERVS; Mauduit *et al.*, 2012) and associated VISTA Deep Extragalactic Observations (VIDEO) survey (Jarvis *et al.*, 2013) provide 12 square degrees of deep near-infrared observations in seven bands from 0.9-4.5 microns (μm), enough area to find several such asterisms.

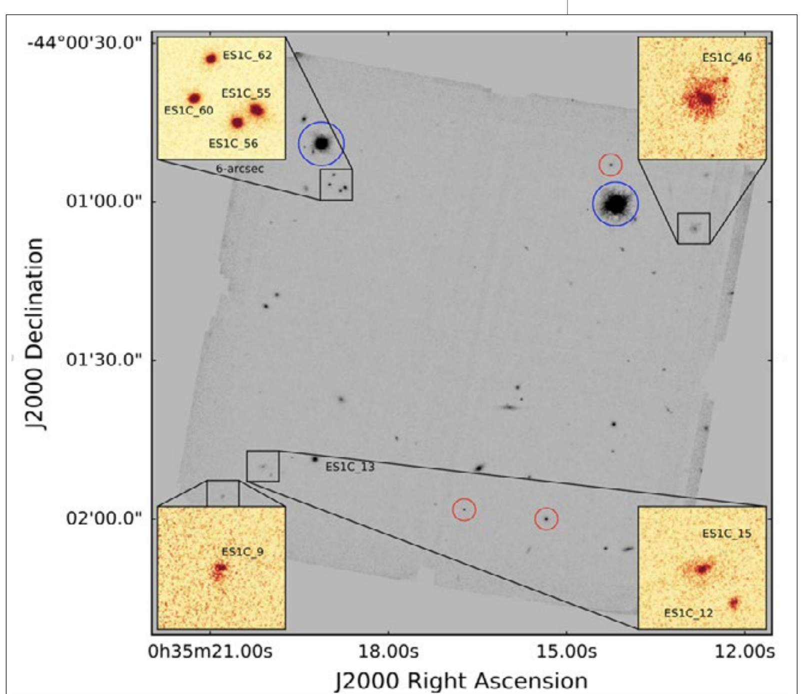


Figure 1.

The GSAOI image of the ES1C field. Objects of interest are shown as insets, each measuring 6 arcseconds on a side. The red circles indicate the stars used to determine the PSF in the field, and the blue circles show those used as natural guide stars for the adaptive optics system (one is off the image).

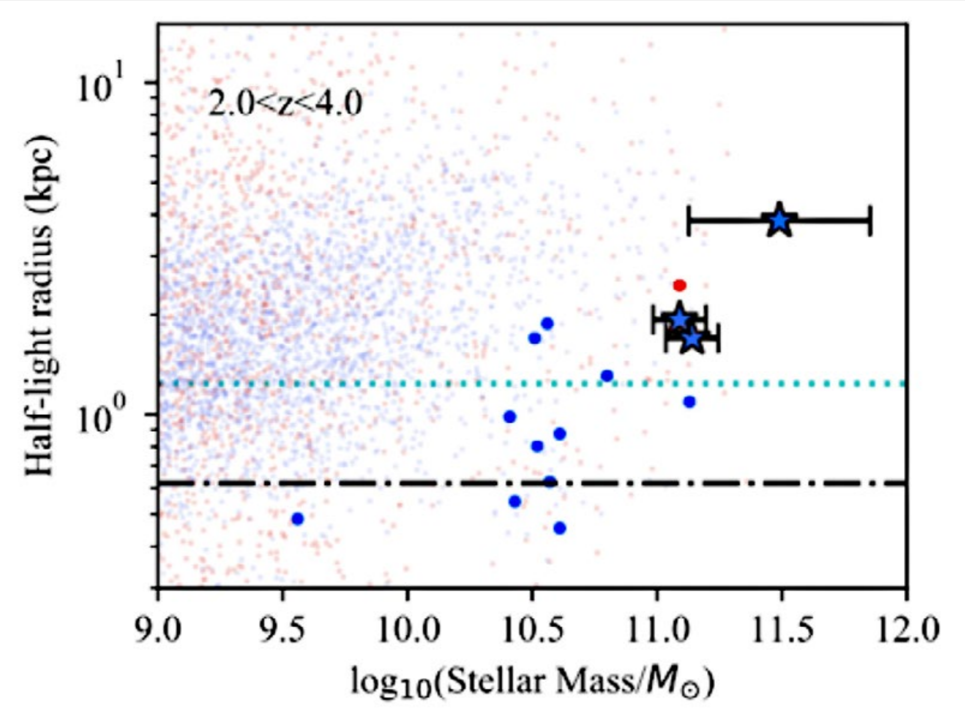
Figure 2.
Half-light radius versus stellar mass for galaxies with photometric redshifts 2 half-light radius versus stellar mass for galaxies with photometric redshifts 2 < z < 4. Red symbols indicate objects best fit with de Vaucouleurs profiles and blue symbols objects best fit by exponential disks. Objects from the CANDELS survey by HST *are shown as faint dots. Stars indicate the host galaxies of starbursts detected by* Herschel. *The dotted cyan line indicates the resolution of* HST, *and the dot-dashed black line shows that of GeMS/GSAOI. Note that the estimates from the Gemini data tend towards smaller sizes at a given stellar mass than those from* HST.

As a pilot program, we observed three of these fields (including ES1C; Figure 1, previous page) with GeMS/MCAO for between 30 and 90 minutes each (Lacy *et al.*, 2018). The resulting images have limiting magnitudes of 24-24.6 and resolutions (Full-Width at Half-Maximum of the PSF) of 0.07-0.16 arcsecond, depending on the integration time and observing conditions.

What Can We Learn From Higher Resolution?

Galaxy sizes (at a fixed stellar mass) are seen to grow rapidly with cosmic time from $z \sim 2$ to $z \sim 1$. The mechanism for this is currently the subject of debate, though mergers are likely to play an important role. The smaller Gemini PSF allows more accurate estimates of the sizes of the most compact galaxies (those with scale sizes < 1 kpc) than previously possible. At $z < 2$, we obtained results on galaxy sizes as a function of stellar mass that are similar to those from studies with the *HST* (*e.g.*, the CANDELS survey, van der Wel *et al.*, 2014). At $z < 2$, however, we see evidence of a higher fraction of compact star-forming galaxies (Figure 2). Although this needs to be confirmed by obtaining higher signal-to-noise profiles from deeper observations, this could imply an even more extreme size evolution in the galaxy population than currently assumed.

In the GeMS fields there are several sources detected in the far-infrared HerMES survey (which used the *Herschel Space Observatory*). At the redshifts we are seeing them ($z \sim$ 1-3), they correspond to ultraluminous infrared galaxies (ULIRGs). In the local Universe, the far-infrared emission from ULIRGs is typically powered by starbursts and AGN. To obtain redshift estimates, and to disentangle the contribution of these two power sources, we used multiwavelength data from surveys in the optical and infrared, as well as new radio continuum data from the Australia Telescope Compact Array and Very Large Array. The ULIRGs we identify consist of a combination of pure starburst galaxies and composite AGN/starburst objects. We find that the ULIRGS with strong AGN tend to reside in hosts with smaller scale sizes than purely star-forming galaxies of similar infrared luminosity.



Like their local counterparts, the ULIRGs in this study seem to show signs of recent merger activity, such as highly disturbed morphologies. We also find a candidate triple AGN system (Figure 3), which consists of three AGN with photometric redshifts of $z = 1.4$ (spectroscopic redshifts are required to confirm the triple AGN system): one is a radio-loud AGN, suggesting the presence of radio jets and lobes; one is a Type-2 AGN, showing both narrow and broadened optical spectral emission lines; and one is a Type-1 AGN, showing narrow emission lines only (though still wider than emission lines in normal galaxies). Both the

Type-1 and Type-2 AGN have strong mid-infrared emission that identifies them as probable AGN. This system was not identified as multiple in the standard photometry products from the VIDEO or SERVS surveys, raising the possibility that many more such systems may exist unrecognized in current surveys.

In the future, we believe that observations of extragalactic fields with MCAO will fulfill a valuable role supplementing deeper, but more resource intensive, observations with space-based platforms such as the *James Webb Space Telescope* (*JWST*) (Kalirai, 2018). For example, surveys of high-redshift ULIRGs with ground-based MCAO could be used to pick interesting individual targets for *JWST*.

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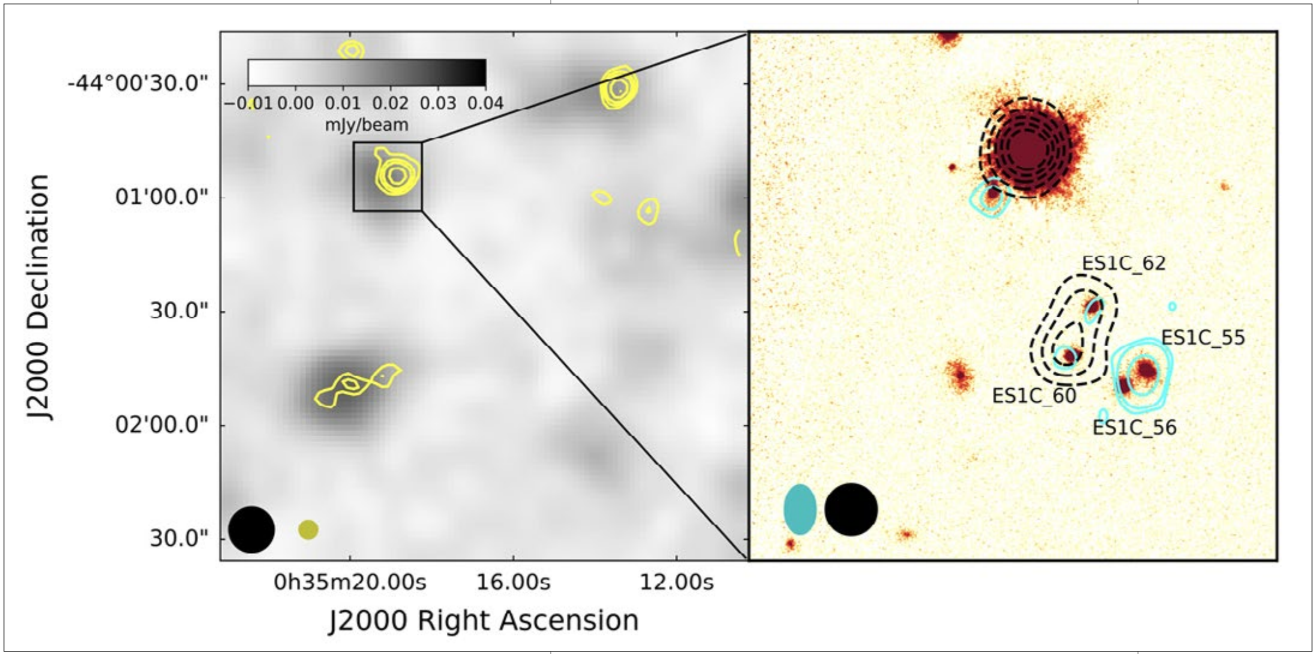
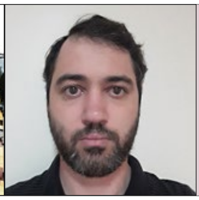


Figure 3.
Left: A greyscale of the Herschel *250 µm image with contours of 24 µm data from the Spitzer SWIRE survey (Lonsdale* et al., *2003) superposed. Right: a zoom in on the field of a candidate triple AGN (ES1C_55 [radio-loud], ES1C_60 [Type-2], and ES1C_62 [Type-1, which has a point-like nucleus]). All three, plus ES1C_56 (which appears not to be an AGN) have photometric redshifts close to 1.4. Contours of 8.4 GHz radio emission from the Australia Telescope Compact Array are shown in cyan, and dashed-black contours indicate 8 µm emission seen in SWIRE.*



Hekatelyne Carpes and Rogemar A. Riffel

Understanding the Emission of OH Megamaser Galaxies

We used multifacility observations of the OH megamaser galaxy IRAS F23199+0123 and found evidence for an active galactic nucleus still immersed in dense layers of dust and gas, as well as gas outflows associated with the maser emission. Studying this class of object is important for understanding the star forming process, black hole growth, and nature of the gas involved in this kind of galaxy environment and investigating possible factors related to OH megamaser formation.

In the past, we understood galaxies as isolated and non-interacting systems. However, nowadays, we know that these objects are subject to the environmental effects of other galaxies immediately distributed around them. The increase in the number of galaxy catalogs has brought with it the realization that galaxies are rarely found alone, and that galaxy groups are the most common environment in which galaxies are found. The catalogs also provide numerous examples of galaxy interactions with peculiar morphologies. These systems arouse interest in understanding their properties as galaxy interactions play an important role in galaxy formation and evolution.

One example of the interaction phenomena that interests us is found among the ultraluminous infrared galaxies (ULIRGs) — a relatively new class of objects consisting typically of a mixture of galaxy pairs, galaxy interactions, and/or galaxy mergers. The now defunct *Infrared Astronomy Satellite (IRAS)* — the first ever spacecraft to survey the sky at infrared wavelengths — mapped in 1983 about 96% of the sky and detected about 350,000 infrared sources; among them were the enigmatic ULIRGs.

Luminous infrared galaxies (LIRGs) and ULIRGs have luminosities that exceed 10^{11} and 10^{12} L_{Sun}, respectively, in the infrared. The source of their very large far-infrared luminosities may reflect a quasar-like active nucleus surrounded by a torus of dense gas and dust (the latter absorbing the energetic photons from the nuclear region and re-emitting at infrared wavelengths), or a huge burst of massive-star formation in dense dusty clouds of molecular gas close to the nucleus, which heats the surrounding dust (Skinner *et al.,* 1997).

When galaxies merge, the gas clouds close to their nuclei are shocked and heated by the collision, and the emission from certain molecules especially OH is strongly amplified. These interaction environments seem to supply all the requirements to originate phenomena such as the emission of masers (microwave amplification by stimulated emission of radiation).

OH megamaser galaxies are a subclass of ultraluminous infrared galaxies, which emit predominantly at microwave frequencies, in 1665 and 1667 megahertz (MHz). In the forties, molecules were detected in the interstellar medium when absorption lines of CH, CH+, and CN were evinced in the spectra of stars. These molecules show transitions in the visible and are susceptible to detection by optical telescopes.

The hydroxyl radical (OH) was discovered in 1943 and was the only molecule detected at radio wavelengths until 1968. The first OH extragalactic megamasers were detected in the spiral galaxy NGC 253 (Whiteoak & Gardner, 1973; Gardner & Whiteoak, 1975) and in M82 (Rieu *et al.,* 1976). ARP 220 is an example of an OH megamaser emission host detected with the Arecibo radio telescope in 1982, presenting 400 L_{Sun}, about 10^8 times higher than the masers found in the W3 (OH) molecular cloud complex. This discovery led to the realization of a survey aimed at finding other OH megamasers using telescopes with big collecting areas.

Very-long-baseline interferometry also detected OH megamasers hosted in III Zwicky 35, IRAS 17208-0014 (Diamond *et al.,* 1999), IRAS 12032 + 1707 (Londsdale *et al.,* 2003a), Markarian (Mrk) 231 (Klockner *et al.,* 2003), Mrk 273 (Klockner & Baan, 2004), and IRAS 14070+0525 (Pihlstrom *et al.,* 2005). Darling & Giovanelli (2002) performed a survey with the Arecibo telescope that searched for OH megamasers in 300 IRAS galaxies at $z > 0.1$, resulting in the detection of 100 OH megamasers in LIRGs.

In a galaxy, microwave radiation can be amplified in the interstellar medium in the immediate neighborhood of young stellar objects, or circumstellar envelopes around

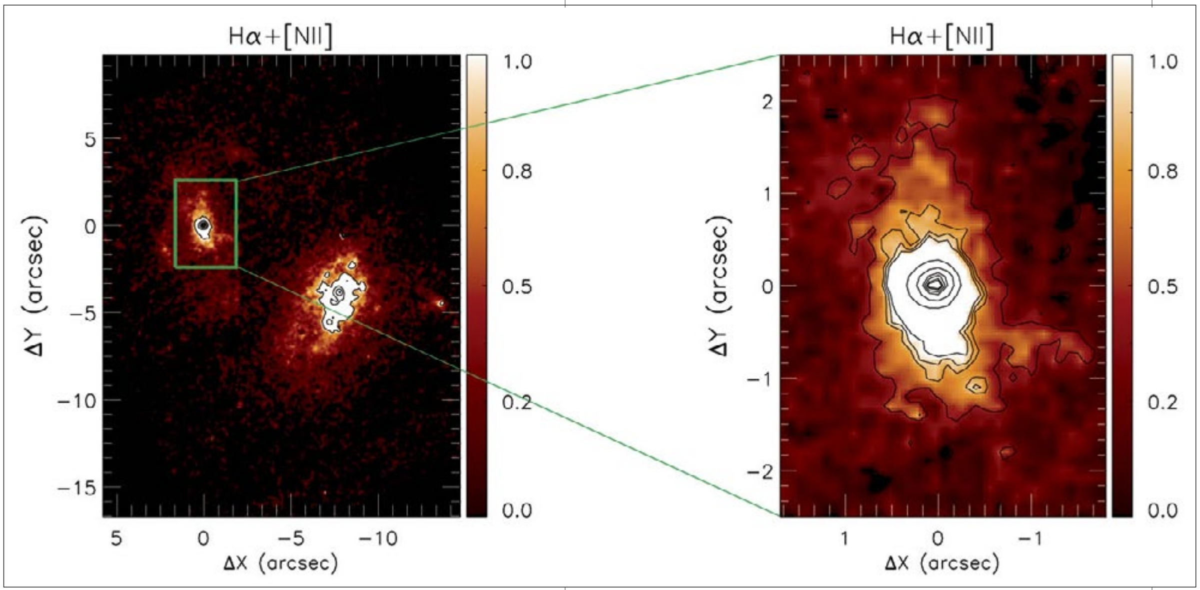


Figure 1.

Left: HST large-scale continuum-free H-alpha+[NII] image. Right: Closeup of the region observed with GMOS-IFU (green box); the field of view is 3.5 x 5.5 arcseconds, and the color bars show the fluxes in arbitrary units.

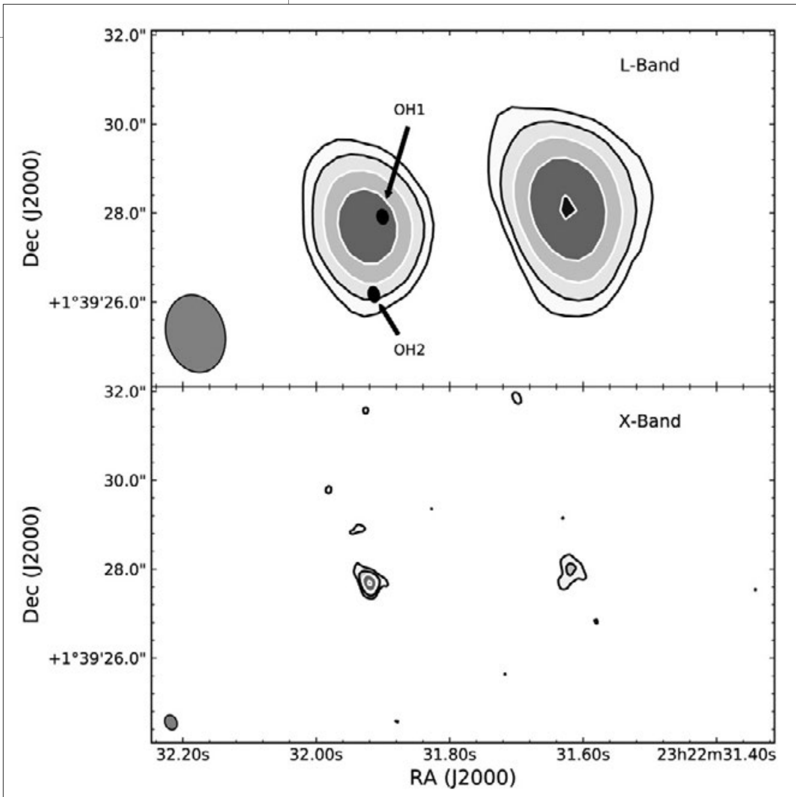


Figure 2.
Top panel: VLA L-band (1.6 GHz) continuum image of IRAS F23199+0123, shown as filled contours. The contours are (black) 0.071 (3 σ), 0.15, (white) 0.32, 0.69, and 1.5 mJy beam^{-1}. The OH1 and OH2 labels identify the locations where the OH maser sources were detected.
Bottom panel: VLA X-band (8 GHz) continuum image of IRAS F23199+0123, shown as filled contours. The contours are (black) 0.0278 (3σ), 0.0647, (white) 0.150, and 0.349 mJy beam^{-1}.

evolved stars, resulting in cosmic maser emission. Indeed, these emissions (intense laser-like spectral lines at microwave frequencies) seem to be found in star-forming regions, close to young-stellar objects such as protostars and compact HII regions. As a number of ULIRGs are also a source of OH-megamaser emissions, observations of them may hold important clues as to the main power source in these galaxies (Lo, 2005).

OH megamaser emission lines are commonly associated with ULIRGs with the warmest IR colors. Importantly, the OH luminosity is also observed to increase with the IR luminosity: the emission from these interacting galaxies is surprisingly brighter than that associated with galactic masers in non-interacting galaxies. The OH megamaser emission can be used to trace high density regions, and separation of the megamaser emission components could be linked to outflows of less dense matter, but at high speed.

A general feature of many models is that the masers are pumped radiatively by the absorption of infrared photons. Identifying the source of the maser pump may therefore indicate whether the ultimate energy source is a burst of star formation, or an active nucleus (Lo, 2005).

Dissecting an OH Megamaser Galaxy Merger

We used multiwavelength observations to investigate the origin of the gas emission and kinematics of the inner 6 kiloparsecs (kpc) of the OH megamaser galaxy IRAS F23199+0123. Located at a distance of 558 megaparsecs (Mpc), its OH megamaser was first detected by the Arecibo OH Megamaser Survey (which observed 52 objects with $0.1< z <0.26$). Previous optical spectroscopy of the galaxy suggests that it also harbors a type 2 active galaxy nucleus (AGN).

The data comprise both optical and radio imaging, as well as spectroscopy obtained with the Gemini Multi-Object Spectrograph (GMOS)/integral field unit (IFU) at the Gemini North telescope, Hubble Space Telescope (HST), and Very Large Array (VLA). We used the HST to make I-band, broad-band, and [NII]+H-alpha narrow-band images. We used the VLA to obtain 1.6- and 8-gigahertz (GHz) continuum images and spectra centered at the OH maser line. And we used Gemini's GMOS/IFU to conduct H-alpha and [N II; (6583-Ångstrom) observations that would match HST's.

The HST observations revealed that IRAS F23199+0123 is actually an interacting pair with a tidal tail connecting the two galaxies (Figure 1, previous page). The VLA observations indicate that both nuclei present extended radio emission at 3 and 20 centimeters (cm), with intensity peaks at each nucleus. The 20-cm radio emission of the eastern nucleus is elongated in the direction of the most extended emission in the HST continuum image (northeast – southwest), while in the western nucleus the 20-cm radio emission is tilted by about 45º (Figure 2).

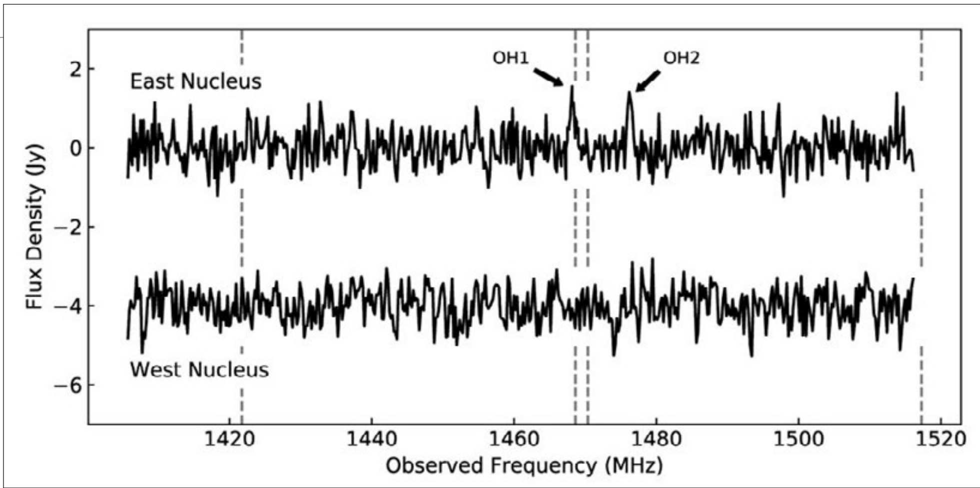


Figure 3.

VLA OH maser spectra of the eastern (top) and western (bottom, offset by -4 mJy) nuclei. The vertical, dashed gray lines mark the expected, redshifted frequencies for the 1612, 1665, 1667, and 1712 MHz maser features. Two spectral features are detected at the position of the eastern nucleus, marked OH1 and OH2.

The VLA spectra also reveal two OH maser sources associated with the eastern member of the pair (Figure 3).

The GMOS/IFU observations cover the inner ~ 6 kpc of the eastern member of IRAS F23199+0123 (IRAS F23199E) at a spatial resolution of 2.3 kpc. The data allowed us to discover that IRAS F23199E shows a Seyfert 1 active nucleus. This was only possible due to the better quality of the Gemini data as compared to previous spectra; this allowed the detection of a nuclear, spatially unresolved, broad double-peaked component in the H-alpha emission line with Full-Width at Half-Maximum of ~ 2,200 km/s (Figure 4). From these data we derive a black hole mass of $M_{\{BH\}} = 3.8^{\{+0.3\}\_\{-0.2\}} \times 10^6\ M_\odot$.

The gas velocity field of IRAS F23199E shows a disturbed rotation pattern with the line of the nodes oriented along position angle 95°. We fitted this velocity field by a thin rotating disk model. The residuals between the observed and modeled velocities combined with the velocity dispersion maps suggest the presence of non-circular motions, possibly due to outflows from the nucleus along the north-south direction (blueshifts seen in the residual map of Figure 5, next page) and inflows towards the nucleus and its vicinity (redshifts close to the nucleus observed in the residual map of Figure 5.)

The gas kinematics also show low velocity dispersions (σ) and low [N II]/H-alpha ratios for the star-forming complexes and higher

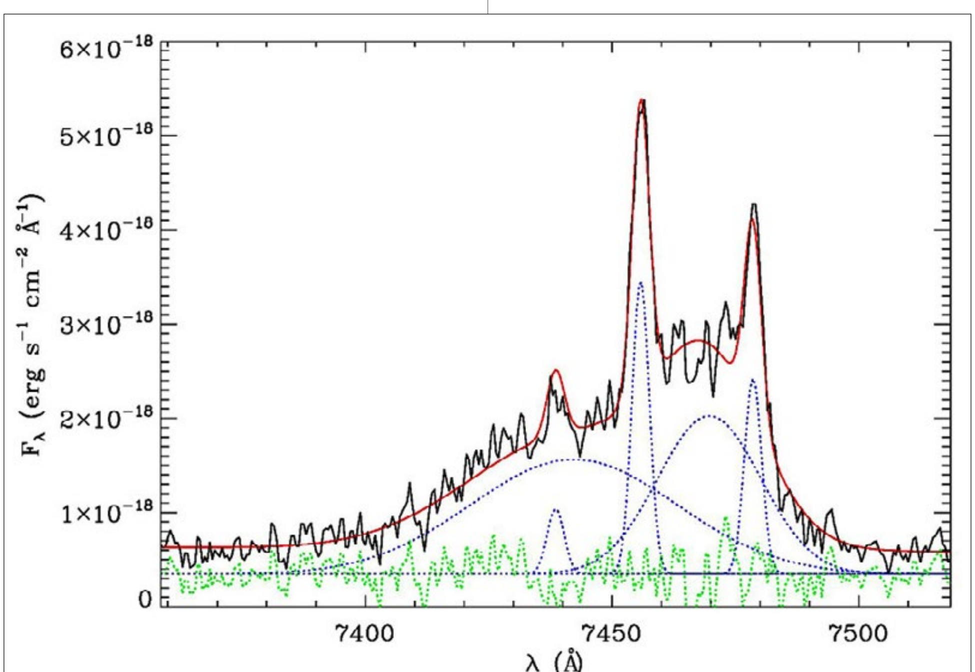


Figure 4.

Fit of the nuclear spectrum (within 0.8 arcsecond) of the IRAS F23199E nucleus, which comprises the H-alpha+[NII] complex. The observed profile is shown in black, while the blue dotted lines represent the broad and narrow components. The red line is the result of the fit, and the green dotted line shows the residual of the fit plus an arbitrary constant.

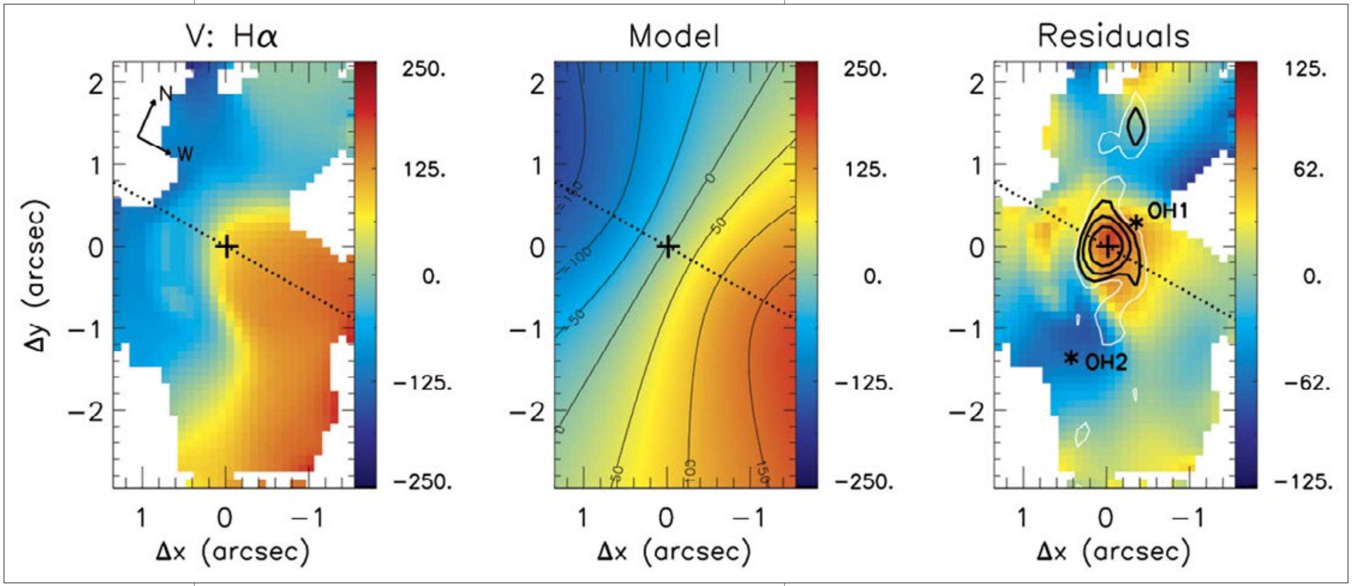


Figure 5.

Observed H-alpha velocity field (left), rotating disk model (center), and residual between the two (right). The central cross marks the position of the nucleus, the white regions are masked locations where we were not able to fit the emission-line profiles, and the dotted lines represent the orientation of the line of nodes. The black contours in the residual map are from the 3-cm radio image with the same flux levels as shown in Figure 1, and the white contours show radio contours at the 1.5 sigma level. The black asterisks labeled OH1 and OH2 mark the position of the maser sources.

σ and [N II]/H-alpha surrounding the radio emission region, supporting interaction between the radio plasma and ambient gas. The two OH masers detected in IRAS F23199E are observed in the vicinity of these enhanced σ regions, supporting their association with the active nucleus and its interaction with the surrounding gas. The gas velocity field can be partially reproduced by rotation in a disk, with residuals along the north-south direction being tentatively attributed to emission from the front walls of a bipolar outflow.

The combination of HST images, VLA line spectroscopy, and Gemini IFU spectroscopy strongly indicates that, in this system, the OH megamaser sources are associated with the AGN rather than star formation.

Analysis of the inner regions of OH megamaser galaxies can contribute to our understanding the origin of these systems and provide insights into the star formation and galaxy evolution processes. Further adaptive optics observations with Gemini's Near-infrared Integral Field Spectrograph, as well as spectroscopic observations with integral field units of next generation telescopes, will allow a better understanding of the role AGN play in the gas emission of OH megamaser galaxies.

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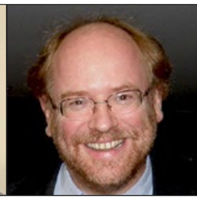

Blair Conn and Helmut Jerjen

Classifying Ultra-faint Satellite Systems in the Milky Way's Halo

By utilizing the outstanding imaging capabilities of the Gemini Multi-Object Spectrograph on Gemini South, we determine whether three newly detected ultra-faint stellar systems belong to the known population of Milky Way dwarf galaxies or its confirmed star clusters. This process, once completed for all such candidate objects (of which there are dozens), will dramatically improve our understanding of Milky Way halo objects and refine the census of known Milky Way satellites.

In recent years, around 58 new Milky Way satellite (ultra-faint dwarf galaxy and star cluster) candidates have been reported. This dramatic jump in number from the 11 classical satellite galaxies known before 1994 is entirely due to the advent of new all-sky imaging surveys: thus far, the Sloan Digital Sky Survey has revealed 16 new candidate satellites, while PanSTARRS and the Dark Energy Survey (DES) combined have added 31. Once the true nature of these objects is established, they will provide crucial empirical input for testing cosmological predictions derived from detailed observations of the nearest galaxies, and in verifying scenarios of how the Milky Way formed.

The majority of these discoveries are based on relatively shallow CCD photometry. Therefore, we know little of their stellar population, structural parameters (such as size, image concentration, asymmetry, and surface brightness), distance, and luminosity. Without accurate estimates of these criteria, we cannot properly construct a census of known Milky Way satellite galaxies and other halo objects. The only path forward then is to determine these fundamental properties with deep photometric follow-up observations.

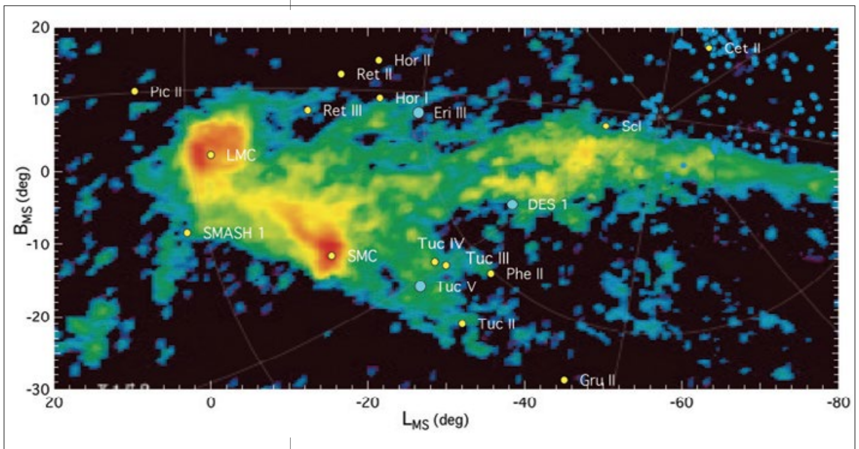

Figure 1.
The positions of three new ultra-faint dwarf galaxy candidates — DES 1, Eri III, and Tuc V (blue dots) — with respect to the Magellanic Clouds (LMC and SMC). Some additional new objects are highlighted as yellow dots. The underlying color map traces the density of neutral hydrogen gas associated with the Magellanic Clouds.

Probing Candidates with GMOS

As part of the ongoing Stromlo Milky Way Satellite Survey — the deepest, most extended search for optically elusive satellite galaxies and star clusters to date — our team took advantage of exquisite observing conditions at Gemini South to establish deep Gemini Multi-Object Spectrograph (GMOS-S) *g′, r ′* photometry for three of these ultra-faint dwarf galaxy candidates: Dark Energy Survey 1 (DES 1), Eridanus III (Eri III) (DES J0222.7-5217) and Tucana V (Tuc V) (DES J2337-6316). They have been detected in the vicinity of the Magellanic Clouds with DES 1 and Eri III located about 80 and 87 kiloparsecs (kpc) from the Sun, respectively, and Tuc V having a distance comparable to the Magellanic Clouds at 55 kpc. Figure 1 shows the positions of these three objects relative to the Large and Small Magellanic Clouds.

Interestingly, all three objects had reported half-light radii (≈10 pc [DES 1], ≈14 pc [Eri III], and ≈17 pc [Tuc V]) that moved them into the transition zone between star clusters and dwarf galaxies. However, since these objects reside at the limit of the initial detection photometry ($g_{lim} \approx 23$), this has introduced large uncertainties into all of their parameters — those generally used to discriminate between a baryon-dominated star cluster and a dark-matter dominated dwarf galaxy. Our new and deeper GMOS-S data allowed us to refine their positions in the size-luminosity plane and luminosity-metallicity parameter space where there exist well-known relations between these parameters for dwarf galaxies but not for star clusters.

Additionally, by probing several magnitudes below the main sequence turn-off, we can investigate the spatial distribution of main sequence stars with different masses and search for any evidence of mass segregation (as witnessed, for instance, in the star cluster Kim 2). Evidence of mass segregation can confirm a system as being purely baryonic and so may provide a unique opportunity to resolve their origins with photometry. Through these relations we can test the likelihood of their true nature as star clusters or dwarf galaxies.

Figure 2 shows composite color images of DES 1, Eri III, and Tuc V, while Figure 3 reveals their corresponding color-magnitude diagrams based on GMOS-S photometry. As our GMOS-S photometry allowed us to trace the stellar populations 3-4 magnitudes deeper than before (Figure 3), we could then accurately determine a whole host of properties.

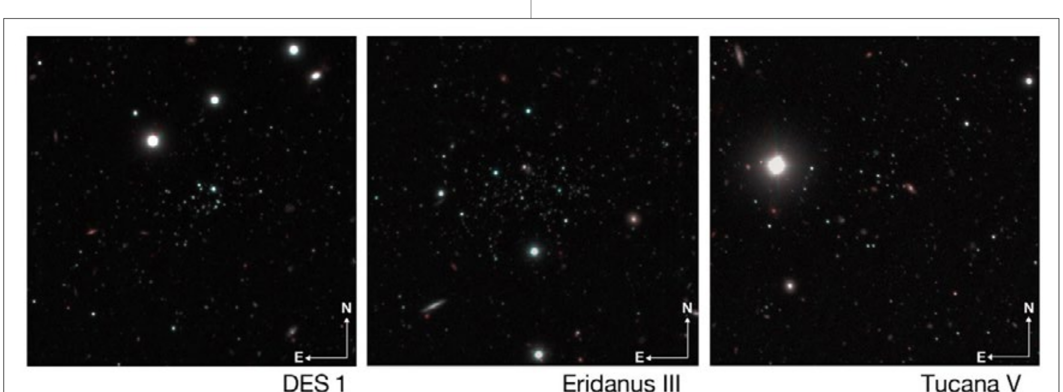

Figure 2.
Composite color images of DES 1, Eri III, and Tuc V. Both DES 1 and Eri III are noticeable as dense collections of stars in the center of the fields. Tuc V is a less-condensed collection of stars and therefore more difficult to see.
Credit: Images prepared by Jennifer Miller at Gemini North

For instance, fitting model isochrones in the color-magnitude space allowed us to establish the age and metallicity of the underlying stellar population; it also isolated those stars giving us an opportunity to perform a structural analysis of each object by obtaining half-light radius and ellipticity. From this we could fit the radial profile to understand how the stars are distributed. We further obtained a stellar luminosity function, which helped us to explore the possibilities of mass segregation.

DES 1 and Eri III: A Comparative Review

The sketch in Figure 4 shows the workflow from image to data products. For the cases of DES 1 and Eri III, this process worked exceptionally well revealing that the fundamental properties of the two stellar populations are remarkably similar. They have essentially the same metallicity ($[Fe/H]_{DES\ 1} = -2.38$ *vs.* $[Fe/H]_{Eri\ III} = -2.40$ dex) and mean alpha abundance ($[\alpha/Fe] \approx +0.2$ dex for both), along with comparable ages (11.2 billion years (Gyr) *vs.* 12.5 Gyr).

Structurally, DES 1 and Eri III also share similar properties: ellipticity ($0.41_{DES\ 1}$ *vs.* $0.44_{Eri\ III}$); position angle ($112°_{DES\ 1}$ *vs.* $109°_{Eri\ III}$); and Eri III is about 1.5 times larger than DES 1 and slightly more luminous ($M_{V,\ DES\ 1} = -2.07$ *vs.* $M_{V,\ Er\ iIII} = -1.42$).

When it comes to their location in the Milky Way halo, they are projected onto the trailing filaments of neutral hydrogen gas from the

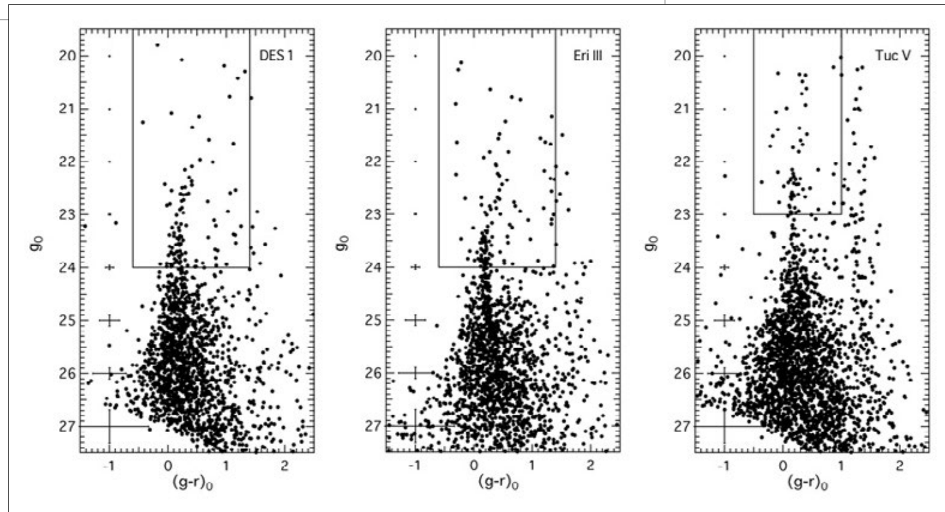

Figure 3.
Color-magnitude diagrams for DES 1, Eri III, and Tuc V (from left to right, respectively). The rectangular outline within each frame shows the window of the discovery photometry. The data are based on GMOS-S photometry, which trace the stellar populations in these ultra-faint dwarf candidates 3-4 magnitudes deeper than before.

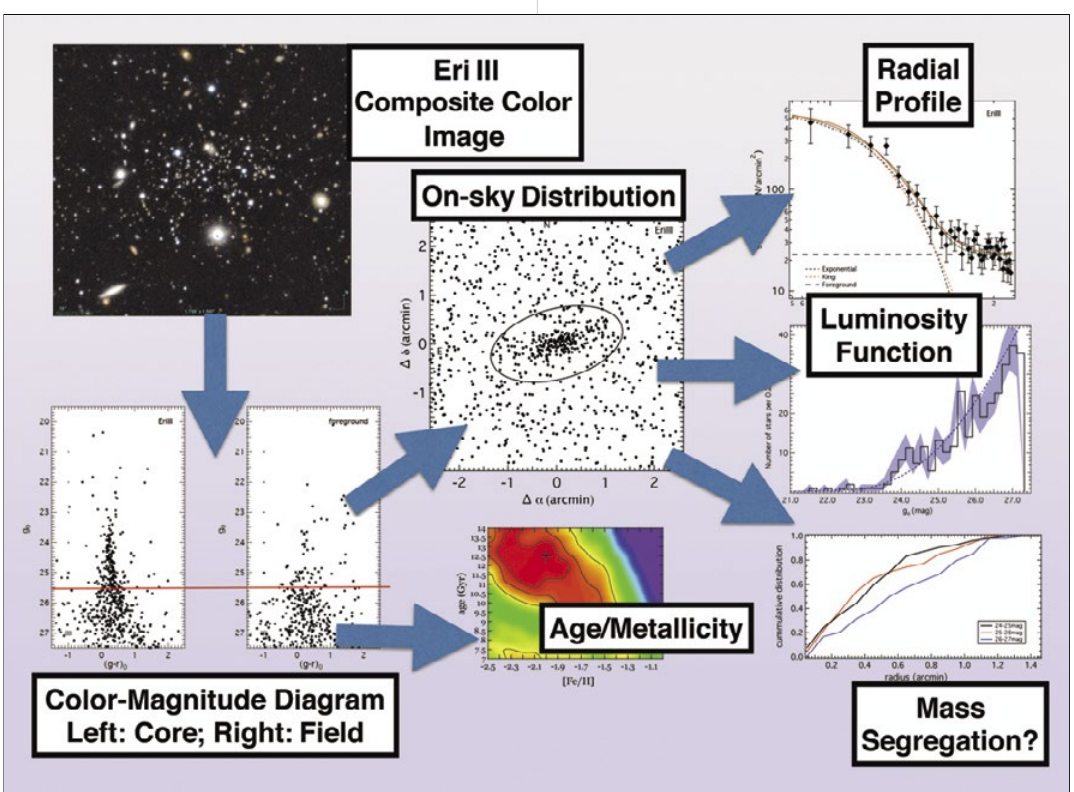

Figure 4.
Sample work flow, from image to data products, for Eri III.

Magellanic Stream (see Figure 1). However, both systems are much more distant than the Magellanic Clouds themselves. As measured from the Galactic center, DES 1 and Eri III are 74 and 91 kpc distant, which are 37% and 69% further away, respectively, than the Magellanic Clouds. However, they have similar angular separations (23.9° *vs.* 22.3°) and 3D distances (31.7 kpc *vs.* 41.0 kpc) to the Small Magellanic Cloud.

How do DES 1 and Eri III compare with known satellites of the Milky Way? Figure 5 shows data for our two candidates compared to the size-luminosity and metallicity-luminosity relations of known dwarf galaxies (large and bright), globular star clusters, and confirmed star clusters (small and faint). We can see that although non-globular cluster objects show a general trend in the diagrams, at the small and faint end of the scale (lower left corner) these objects are exclusively star clusters. It is only above sizes of around r_h = 20 pc that objects are more unequivocally dwarf galaxies. In the size-luminosity space, DES 1 and Eri III are located much closer to the star clusters.

In the metallicity-luminosity space, they once again are found just outside the 1-sigma trend line, although the errors show that they are not inconsistent with a dwarf galaxy population, though rather unlikely members. This seems to be a common trait for these new objects, as they share many properties with both star clusters and dwarf galaxies. As for DES 1 and Eri III, the majority of evidence points to them as being star clusters associated with the Magellanic Clouds. That raises even more interesting questions. Did they fall into the Milky Way halo with the Magellanic Clouds or another dwarf galaxy? Were they stripped off in the same event that is currently disrupting the Magellanic Clouds themselves? What are the other objects in the same region of sky?

What About Tuc V?

Under analysis, Tuc V presented another interesting challenge. While we found an excess of stars in the color-magnitude diagram, the object was not centrally concentrated

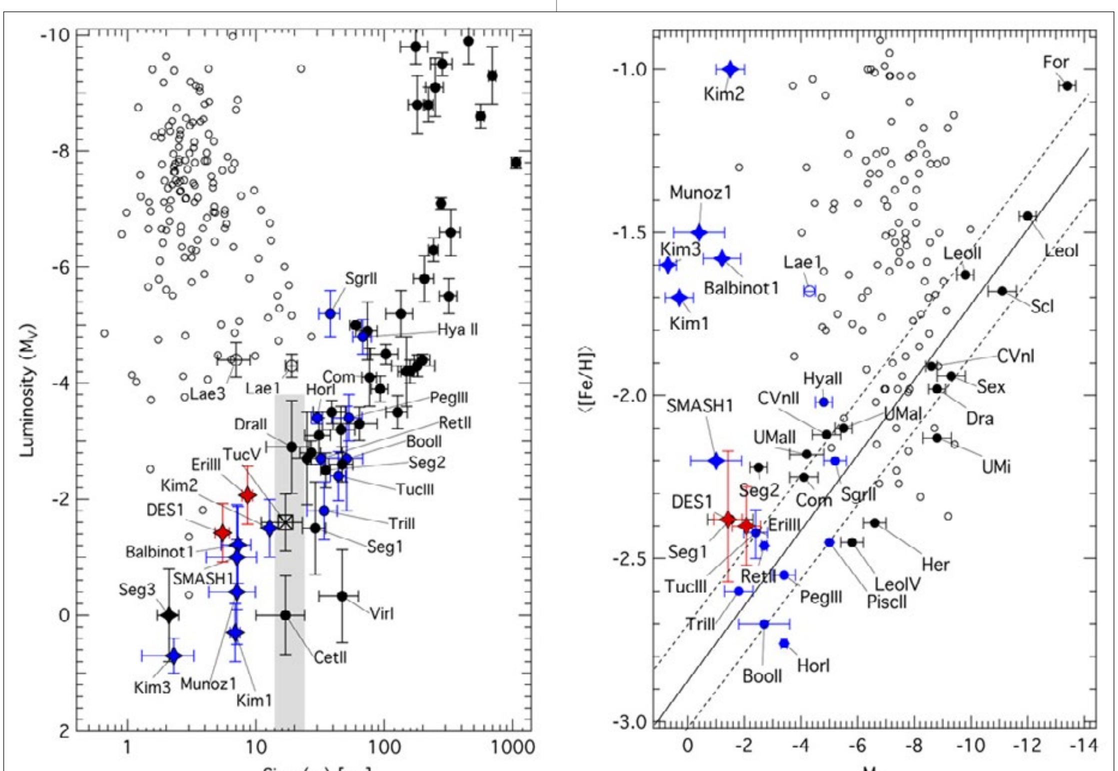

Figure 5.

Two diagrams demonstrating how candidates DES 1 and Eri III (red dots) compare to Milky Way globluar star clusters (open circles) and other satellite galaxy candidates, known dwarf galaxies (large and bright), and confirmed star clusters (small and faint) (all black dots).

Left: The size-luminosity characteristics of both DES 1 and Eri III are closer to star clusters than dwarf galaxies, which become more definite when their half-radius is roughly ≥20 pc (gray strip)

Right: Although the metallicity-luminosity characteristics of DES 1 and Eri III are more consistent with the Milky Way dwarf galaxy population, they are borderline objects, just outside the 1-sigma trend line (dotted lines), and probably not members.

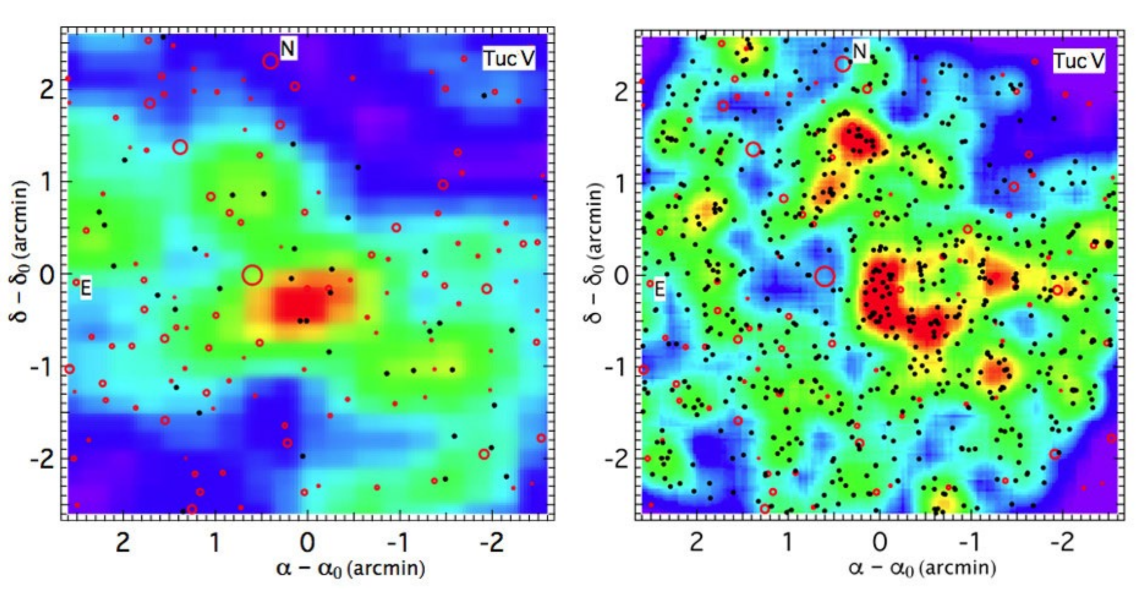

Figure 6.

Images showing how candidate Tuc V appears in the discovery data (left panel) and in the Gemini data (right panel). Open circles show the position of foreground stars. The dense core region displayed in the discovery image dissolves into a series of low-density knots in the Gemini data, indicating that Tuc V may not be a coherent cluster.

like the other two candidates. We could not confirm an overdensity that matched the discovery detection. In Figure 6, we can see how Tuc V looks in the discovery data (left panel) and with the deeper Gemini data (right panel). In the Gemini data, Tuc V dissolves into a series of low density knots rather than a coherent cluster as one would expect. So what is this intriguing object?

Tuc V has a 3D spatial distance of only 13 kpc from the Small Magellanic Cloud's (SMC) core. The SMC is also known to have an extended stellar halo with the SMC Northern Overdensity (SMCNOD) residing at 8 kpc from the SMC's center. So at 13 kpc, Tuc V is plausibly within the stellar halo of the SMC. The best fit isochrone for Tuc V suggests an 11.8 Gyr stellar population with a metallicity of [Fe/H] = -2.09 dex. However, the age-metallicity degeneracy of isochrone fitting makes an SMCNOD-type stellar population with an age of 6 Gyr and [Fe/H] = -1.3 dex consistent with the data. Our GMOS-S results advance the picture that Tuc V is not a bound stellar system, but a disrupted star cluster, merging dwarf galaxy, or a stellar feature in the SMC halo.

As the in-depth analysis of DES 1, Eri III, and Tuc V has demonstrated, by utilizing the outstanding imaging capabilities of Gemini Observatory, we are able to determine whether a newly detected ultra-faint stellar system belongs to the class of dwarf galaxies or star clusters. We will continue our study of these objects with Gemini, as each of them raises very interesting questions on how they formed and how they entered the Milky Way. Our Galaxy may harbor hundreds of satellite galaxies and clusters, most of which have yet to be discovered and explored. Finding and teasing apart their mysteries will drive this field forward into the future, helping us to better understand the substructure of our Galaxy's halo.

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John Blakeslee

Science Highlights

This 2018 year-in-review recaps some of the most significant and innovative science conducted by the Gemini user community.

JANUARY 2019

Nearby Supernova Illuminates Early Origins of Distant Dust

Interstellar dust constitutes about 1% of the mass of interstellar matter in the Milky Way. Most of this dust is thought to originate in intermediate-mass evolved stars that ejected their outer layers as red giants or thermally pulsating asymptotic giant branch stars. Once the ejecta cool to temperatures lower than about 2,000 K, dust particles inevitably start to form from carbon and other elements. However, this process cannot explain the large amounts of dust observed in some galaxies in the early Universe, since such stars would not have had time to evolve to the dust-producing stage. The only viable explanation for the dust observed in such galaxies is production in the ejecta of core-collapse supernovae (ccSNe), and this can be tested through careful observations of ccSNe in the local Universe. Until now, detailed evolution of dust production in such supernovae, which can take place over several years, has only been followed in one object, SN 1987A in the Large Magellanic Cloud.

However, the recent explosion of SN 2017eaw in the nearby galaxy NGC 6946 has provided another excellent opportunity to follow that evolution in detail over an extended period. NGC 6946 is only about 7 megaparsecs away and is popularly known as the Fireworks Galaxy because it is a prodigious producer of supernovae, all of the core-collapse variety. SN 2017eaw was discovered in May 2017, just as its host galaxy became observable in the eastern sky before dawn. This fortuitous circumstance provided an opportunity to follow SN 2017eaw continuously from May until December, before it became too low in the western sky to observe from Maunakea.

Through a combination of Director's Discretionary Time and Fast Turnaround programs at Gemini North, a team of astronomers led by Jeonghee Rho of the SETI Institute and Gemini's own Tom Geballe were able to follow the evolution of SN 2017eaw's near-infrared (0.84-2.52 micron) spectrum in Semesters 2017A, 2017B, and 2018A. The first nine of these spectra, obtained with the Gemini Near-InfraRed Spectrometer in 2017, are shown in Figure 1. They are a gold mine of information on the abundances, nucleosynthesis, changes in ionization, and velocities of the ejecta, but the main goal of the observations was to study the formation of carbon monoxide (CO) at wavelengths from 2.0-2.5 µm. CO is a powerful coolant, which aids in making dust formation possible; its presence is detected by day 124 based on the sharp increase in signal near 2.30 µm. Evidence of dust also begins at day 124, based on the flattening of the continuum slope longward of 2.1 µm.

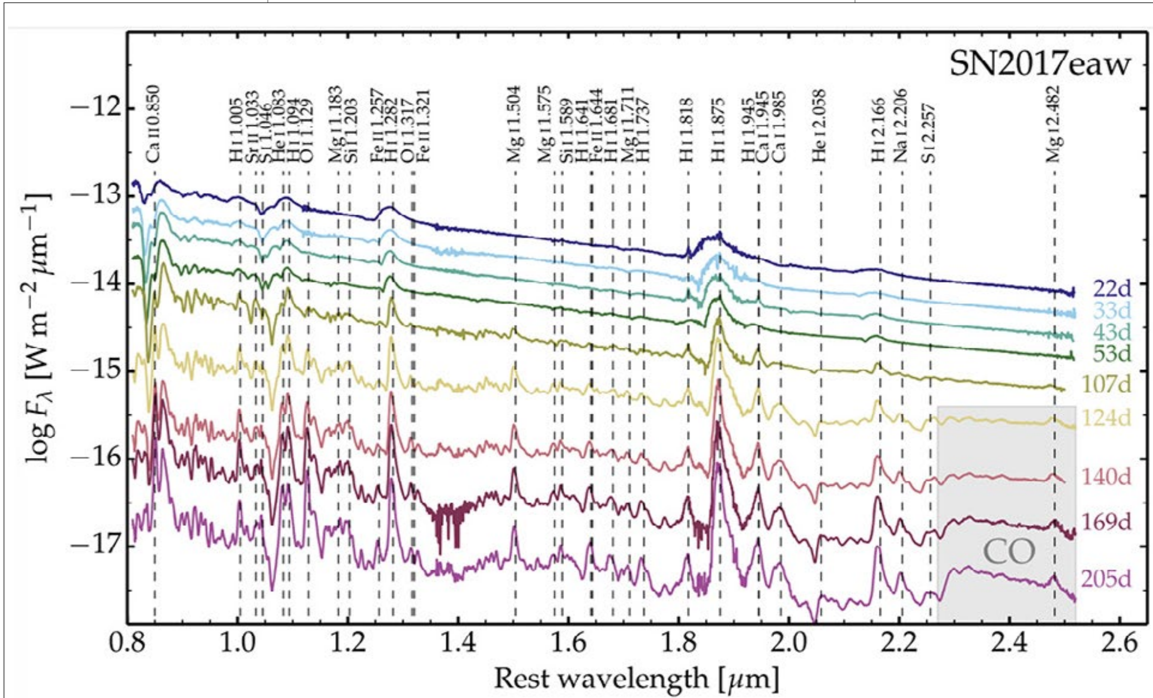


Figure 1.
Gemini/GNIRS spectra of SN 2017eaw obtained from 22 to 205 days post explosion, in time order from top to bottom. The prominent emission and absorption lines are listed. The spectra have been scaled to give a uniform vertical spacing. The gray shaded region indicates the wavelengths at which CO emission is present; the flattening of the long-wavelength continuum at 124 days and later is the signature of dust production.

[Figure reproduced from Rho et al., ApJ, ***864:*** *L20, 2018.]*

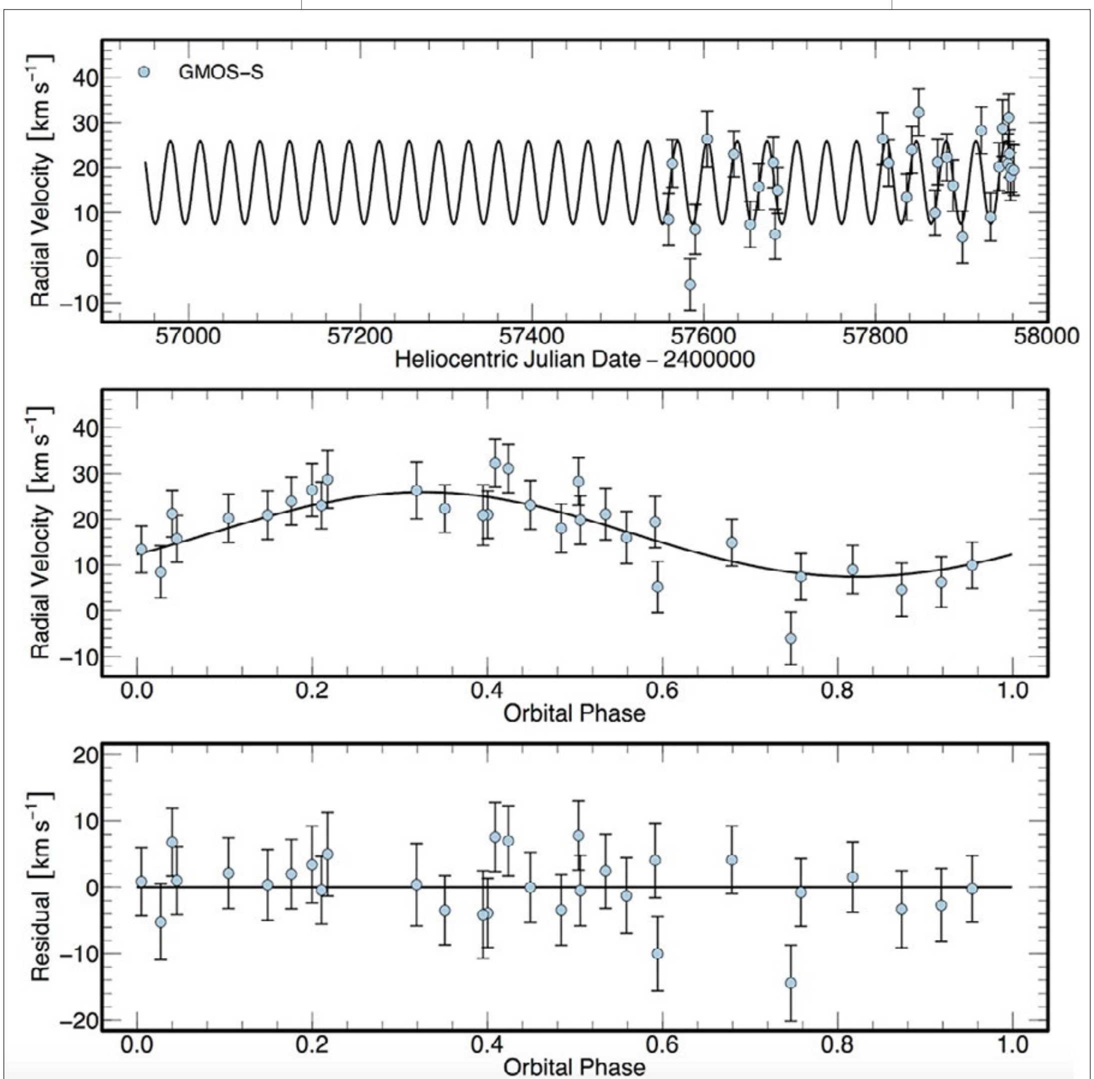
The resulting study, [***published in ApJ Letters***], used the spectra to estimate the CO mass produced by SN 2017eaw and found that the results qualitatively matched models for a progenitor star of roughly 15 solar masses. However, the dust production was observed at earlier times than predicted. Fits to the continuum indicate that the temperature of the dust emitting at 2.1-2.5 µm is roughly 1,300 K and that the dust is mainly graphitic, which can condense at higher temperatures than amorphous carbon. The team continued to monitor the evolution of SN 2017eaw throughout much of 2018, both spectroscopically with GNIRS and photometrically using the Near-InfraRed Imager and spectrometer. Thus, we have more to learn from the latest pyrotechnics displayed by this nearby galaxy.

Discovery of the Lowest Mass Ultra Metal-poor Star

The properties of extremely metal-poor (EMP; with a metal to hydrogen ratio [Fe/H] < –3.0 dex), ultra metal-poor (UMP, [Fe/H] < – 4.0 dex) and hyper metal-poor (HMP, [Fe/H] < –5.0 dex) stars provide information on the early chemical enrichment of our Galaxy and the products of the first generations of stars in the Universe. Because gas composed entirely of primordial elements cannot cool efficiently, only high-mass protostellar cores have sufficient gravity to overcome their internal pressures and collapse to form stars. Thus, the first generation (Pop III) of stars in the early Universe are believed to have had high masses and short lifetimes. The exact mass range of Pop III stars remains a subject of debate, but recent simulations suggest a lower limit of about 10 solar masses ($M_\odot$).

In a recent study [*published in The Astrophysical Journal*](), Kevin Schlaufman of Johns Hopkins University and two collaborators discovered the lowest mass UMP star known. The star is an invisible companion to 2MASS J18082002–5104378 A, a star measured by Meléndez *et al.* (*A&A*, **585:** L5, 2016) to have a metallicity [Fe/H] ≈ –4.1 dex, placing it within the UMP category. Schlaufman and collaborators report the results of an extensive spectroscopic campaign including 14 observations with the Magellan Inamori Kyocera Echelle (MIKE) high-resolution spectrograph on the Magellan Clay Telescope and 31 observations with the Gemini Multi-Object Spectrograph at Gemini South, both in Chile. "Gemini was critical to this discovery, as its flexible observing modes enabled weekly check-ins on the system over six months," said Schlaufman. The velocities derived from the Gemini data are shown in Figure 2.

Figure 2.
Measured radial velocities of 2MASS J18082002–5104378 A from Gemini/GMOS-S compared to the best-fit Keplerian orbit, derived from the high-dispersion MIKE data. The GMOS-S observations span 31 epochs over a 13-month period from June 2016 to July 2017. [Figure reproduced from Schlaufman et al., *ApJ,* ***867:*** *98, 2018.]*



The spectroscopic data show that 2MASS J18082002–5104378 is a spectroscopic binary with a circular orbit and a well-determined period of 34.76 days. The primary star (designated A) has a derived mass of 0.76 $M_\odot$, which is typical for UMP stars, while the best-fit mass for the secondary (designated B) is only 0.14 $M_\odot$, or about 0.05 $M_\odot$ above the hydrogen-burning limit for this metallicity. Assuming that 2MASS J18082002–5104378 B has the same composition as the primary, it is by far the lowest mass UMP star yet discovered. Moreover, because of its low mass and metallicity, it has the smallest quantity of metals of any known star, roughly the same amount of heavy elements as contained in the planet Mercury. Put another way, if 2MASS J18082002–5104378 B had formed entirely from primordial material (hydrogen and helium), it could achieve its current metallicity by swallowing the smallest planet in our Solar System.

Another interesting finding is that the systemic motion of 2MASS J18082002–5104378 indicates that it belongs to the thin disk component of our Galaxy. The derived orbit of the system about the center of the Milky Way has a pericenter of about 5.6 kiloparsecs (kpc), an ellipticity of 0.16, and a very low inclination so that the system never wanders more than 0.13 kpc from the Galactic plane. This makes the binary the most metal-poor star system yet discovered within the thin

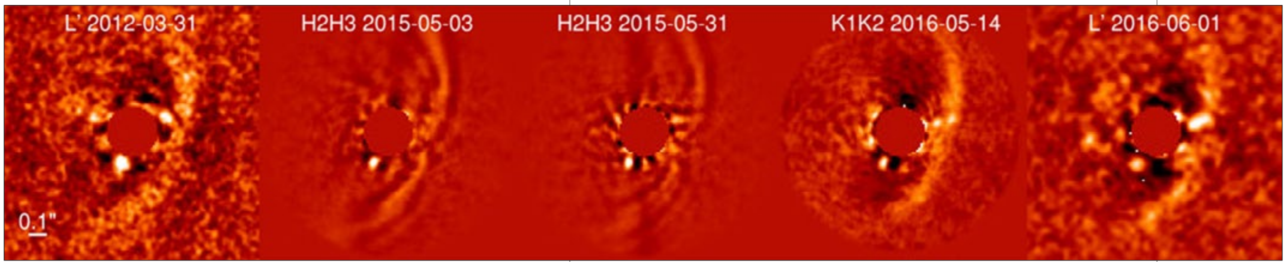


Figure 3.
Direct images of the exoplanet PDS 70b, from left to right: Gemini/NICI L′-band (2012-03-31), VLT/SPHERE H2H3-band (2015-05-03 and 2015-05-31), VLT/SPHERE K1K2-band (2016-05-14), and VLT/NACO L′-band (2016-06-01). North is up and east is to the left in all images. [Figure from Keppler et al., *A&A,* ***617:*** *A44, 2018.]*

disk. Moreover, the study estimates that the age of the system exceeds 13 billion years, which would suggest that the thin disk may be considerably older than generally believed. However, the age is based on isochrone fitting to the primary star and is subject to systematic uncertainty.

In addition to setting astronomical records, 2MASS J18082002–5104378 B is a diminutive star with big implications. The study argues that the existence of this low-mass object, as well as a known brown dwarf within an EMP system, implies that low-mass primordial-composition stars could form as members of binaries via fragmentation within the protostellar disks of the supposed high-mass Pop III stars. If this is the case, although the primary stars would have long since burnt themselves out, the liberated low-mass Pop III secondaries could still be wandering inconspicuously about our Galaxy, just waiting to be discovered.

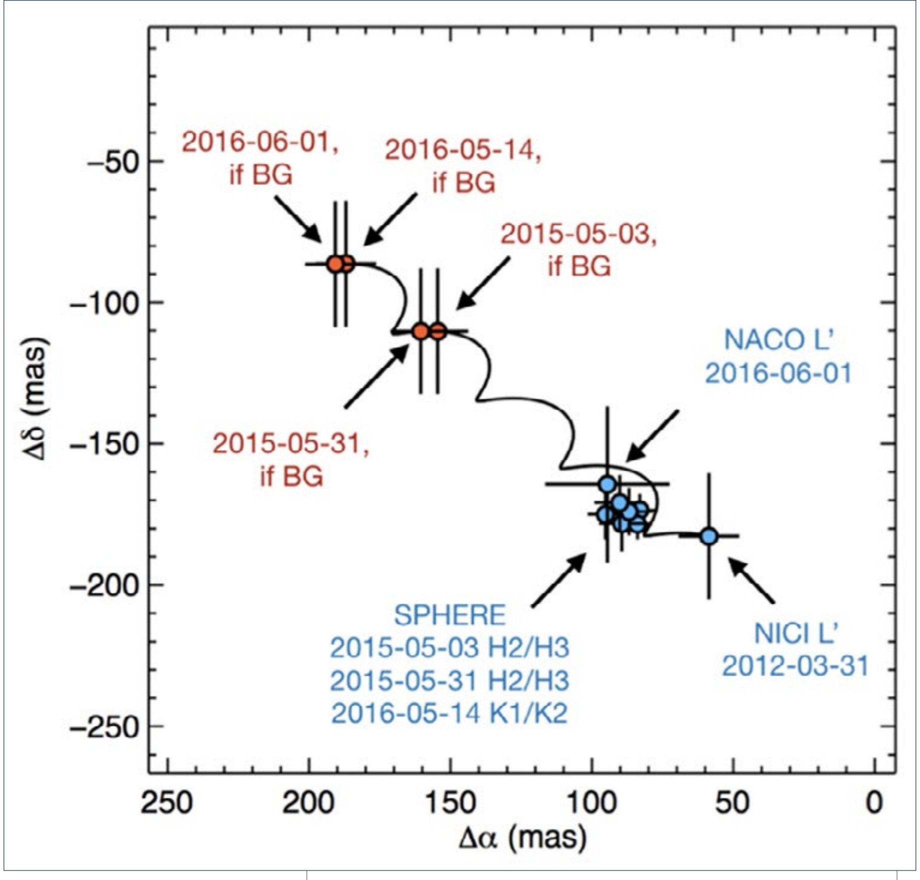
Gemini's Role in the Discovery of the Young Planet PDS 70b

This past July as Gemini Observatory was preparing for its triennial Science Meeting, our colleagues at the European Southern Observatory (ESO) ***announced the discovery*** of a planet caught in the act of formation within the transition disk (a debris disk with a central gap) surrounding the young low-mass star PDS 70. The star was targeted because it was known from ***previously published Gemini and Subaru observations*** to host a transition disk with a large central gap, suggestive of ongoing planet formation. PDS 70 belongs to the Scorpius-Centaurus association at a distance of 113 parsecs (determined from Gaia Data Release 2). It has an estimated age of 5.4 million years and a mass of about 0.8 $M_{\odot}$. The discovery, based on observations obtained at the Very Large Telescope (VLT) and Gemini South, was published in the ***September 2018 issue of Astronomy & Astrophysics***.

This is the first time that a young planet has been caught in the act of plowing out the central region of a transition disk. "Disks around young stars are the birthplaces of planets, but so far only a handful of observations have detected hints of baby planets in them," said Miriam Keppler of the Max Planck Institute for Astronomy. Keppler led the large team of over 100 astronomers who made the discovery. Using the Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (SPHERE) on the VLT, the team detected a point source about 22 astronomical units from PDS 70 within the gap of the surrounding disk. The detection was confirmed at five different epochs using three different instruments at wavelengths ranging from 1.6-3.8 μm (Figure 3). The astrometry from the multiple epochs shows that the object has a very similar motion to that of PDS 70, and thus is likely a bound planetary companion.

The crucial first epoch was provided by an archival L′-band image taken in March 2012 with the Near-Infrared Coronagraphic Imager (NICI) on Gemini South. Although the faint source follows the star, its relative position measured in the 2012 NICI data does not coincide precisely with the positions

Figure 4.
The relative position of the companion object PDS 70b. The blue points show the measured positions from the Gemini and VLT data. The red points (labeled "BG") show the positions that would have been expected in the VLT data if the object detected in the first-epoch NICI observations had been a distant background object, for which the relative position would follow the plotted curve. The offset in position between the NICI and later observations is consistent with the expected orbital motion.
[Figure from Keppler et al., A&A, ***617:*** *A44, 2018.]*



derived from the VLT observations taken in 2015 and 2016 (Figure 4). This is likely due to orbital motion over the four-year baseline spanned by the Gemini and VLT observations analyzed in the discovery paper. The inferred orbital motion is clockwise, which is in the same direction as the disk rotates. A ***second study*** adds an additional SPHERE observation from early 2018 and finds a best-fit circular orbit with a period of 118 years.

The multi-band photometric analysis combining the VLT and Gemini data indicates that PDS 70b is likely a gas giant with a mass a few times that of Jupiter and a temperature of about 1,200 K. Additional observations of PDS 70b should allow testing of theoretical predictions of the role of planet-disk interactions in the evolution of young planetary systems.

OCTOBER 2018

Fast Outflows in the Echoes of Eta Carinae's Great Eruption

Students of the history of solar astronomy and telecommunications will be familiar with the Carrington Event, named for the English astronomer Richard Carrington who witnessed a brilliant solar flare erupt from a cluster of sunspots one September morning in 1859. The flare was associated with the largest coronal mass ejection on record, which traveled at a speed of about 2,000 kilometers per second (km/s) and reached the Earth less than 18 hours later. Although the explosion on the Sun's surface lasted only about a minute and involved a negligible fraction of an Earth mass of material, the blast of charged particles impinging on the Earth's magnetosphere wreaked havoc with telegraph lines across Europe and North America and produced stunning auroral displays visible even in the tropics.

Around the same time, stellar astronomers were witnessing the final stages of a far more energetic and sustained eruption by the southern star Eta Carinae (then known as Eta Argus). Formerly a 4th-magnitude object, Eta Car brightened to 1st magnitude in the late 1820s and underwent a series of luminosity spikes during which it occasionally rivaled Canopus, a convenient comparison star located in the same constellation. The star then entered a plateau phase when it stayed above 0th magnitude from 1843 to 1858, before rapidly fading below naked-eye visibility in the 1860s. The extended period from the 1830s through the 1850s is called the Great Eruption.

Eta Car is now known to be a binary star with an orbital period of 5.5 years, a distance of 2.3 kiloparsecs (kpc), and a combined mass of at least 250 solar masses. The pre-1845 luminosity spikes appear to coincide with periastra of the binary orbit when mass transfer would be most efficient, while the plateau phase of the Great Eruption may have been the effect of a hydrodynamic explosion of uncertain origin and its consequent shock plowing through the circumstellar material. What is clear is that the eruption involved enormous mass loss: the bipolar "Homunculus Nebula" contains at least 15 solar masses of material expanding away from the star at about 600 km/s and dates from this event.

Although the Great Eruption concluded 160 years ago, it is possible to observe the light from that event reflected off cold clouds on the far side of the extended Carinae Nebula complex. A 2012 study of such "light echoes" reported observations of Eta Car's pre-1845 luminosity spikes illuminating a group of background clouds. Now, the same team has published two new papers dissecting light echoes reflected by another cloud at a lesser distance from the star. Based on the geometry, the team believes the light is associated with the enormous mass loss that occurred during the plateau phase of the Great Eruption in the 1850s. Figure 5 shows spectra of the light echoes taken with the Gemini Multi-Object Spectrograph (GMOS) at Gemini South and the Inamori-Magellan Areal Camera and Spectrograph (IMACS) at Magellan Observatory.

The H-alpha emission lines in the new spectra have wings that reach –10,000 km/s to the blue and at least +12,000 km/s to the red. The team argues that the wings span the range of mass outflow speeds during the plateau phase of the Great Eruption; such speeds on stellar scales have only been seen previously in supernova ejecta and outflows from accreting compact stellar remnants. The broad wings are absent in the previously studied echoes of the earlier phases of the eruption. The extremely fast material constitutes only a small fraction of the total ejecta, the majority of which is expanding at about 600 km/s. However, it provides strong evidence in favor of the explosive outflow explanation of the Great Eruption. The new papers have been accepted for publication in the *Monthly Notices of the Royal Astronomical Society*.

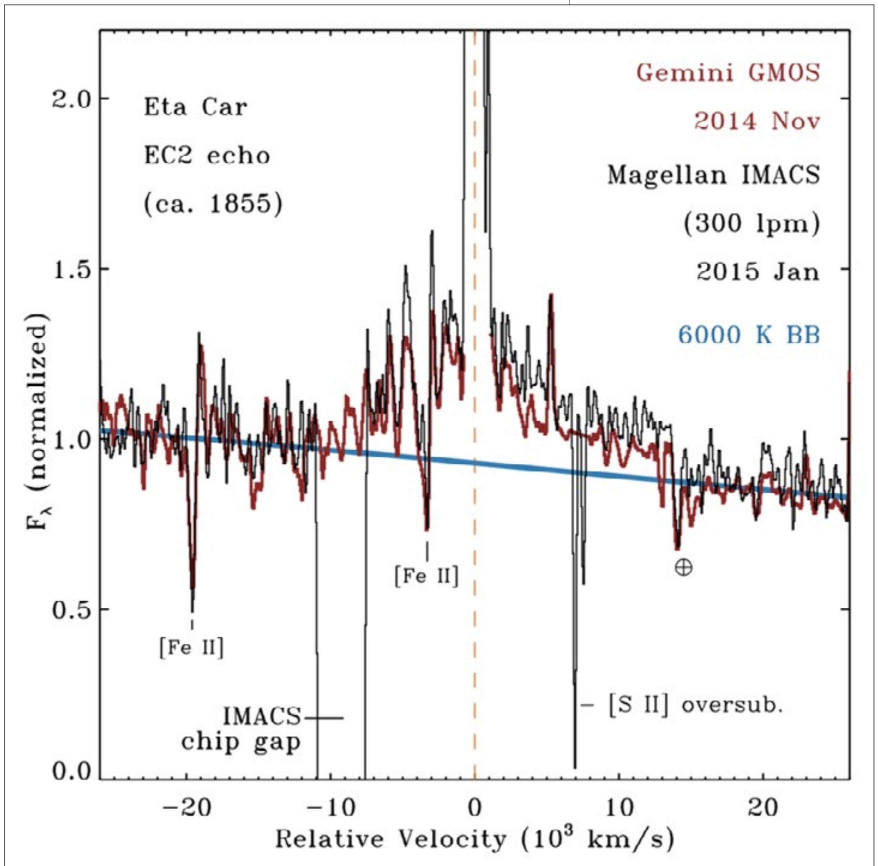


Figure 5.
Gemini/GMOS and Magellan/IMACS spectra centered on the Ha line of the light echo believed to correspond to the latter part (circa 1855) of Eta Carinae's Great Eruption. The spectra show very broad Ha line wings extending to at least ±10,000 km/s, indicating outflow velocities typically seen in supernovae. The blue curve represents a blackbody of temperature 6,000 K. [Figure reproduced from Smith, Rest, Andrews, et al.*, 2018.]*

Dwarfs Emerge from the Tidal Debris of Interacting Galaxies

Large galaxies are produced through the merging or accretion of smaller galaxies. If the merging galaxies contain enough gaseous material, a burst of star formation may cause the stellar mass of the final galaxy to be substantially larger than the combined mass of the stars of the two original galaxies. This is the basis of hierarchical structure formation, the standard paradigm in the field of galaxy evolution for many decades.

If two gas-rich galaxies exchange a glancing blow, rather than a head-on collision, the encounter may give birth to one or more smaller galaxies known as tidal dwarfs, rather than a large merger remnant. Dwarf galaxies of this type are predicted to form when gaseous material that is tidally stripped from one of the larger galaxies condenses to form a gravitationally bound stellar system. The stripped gas may be highly enriched, in which case the resulting dwarf will have an unusually high metal content for its stellar mass. Galaxies formed in this way are also expected to have very little dark matter. However, it is difficult to ascertain the past history of any particular dwarf, and identifying tidal dwarfs in the process of formation has been quite tricky in practice.

A team of astronomers from Australia, Canada, Argentina, Italy, and the United States have used GMOS at Gemini North to obtain long-slit spectroscopy of candidate tidal dwarfs found near two pairs of large interacting galaxies (Figure 6). The objects were first identified as candidate tidal dwarfs based on their neutral hydrogen emission observed with the Giant Metrewave Radio Telescope (GMRT) in India and their locations on the outskirts of larger gas-rich galaxies. Subsequent optical imaging with the Canada-France-Hawai'i Telescope identified low-surface brightness stellar counterparts of the HI tidal features and enabled stellar mass estimates. The team proposed for GMOS spectroscopy to determine if the observed stellar components are physically associated with the HI tails.

The resulting study, ***published in Monthly Notices of the Royal Astronomical Society***, confirms that the optically identified dwarf galaxy known as AGC 208457 has a velocity consistent with the HI velocity at its location within the extended tidal feature associated with the interacting galaxy pair NGC 3166/3169. The galaxy's metal abundance and star formation rate inferred from the optical emission lines indicate that it formed recently from enriched material processed within the larger galaxies. In addition, the study finds that there is no evidence for a significant amount of dark matter. Thus, AGC 208457 has all the characteristics of a genuine tidal dwarf galaxy.

Targeting a second system, the study confirms the physical association of gaseous knots and star clusters with the extended tidal tail of NGC 4747, a disturbed galaxy that likely experienced a recent interaction

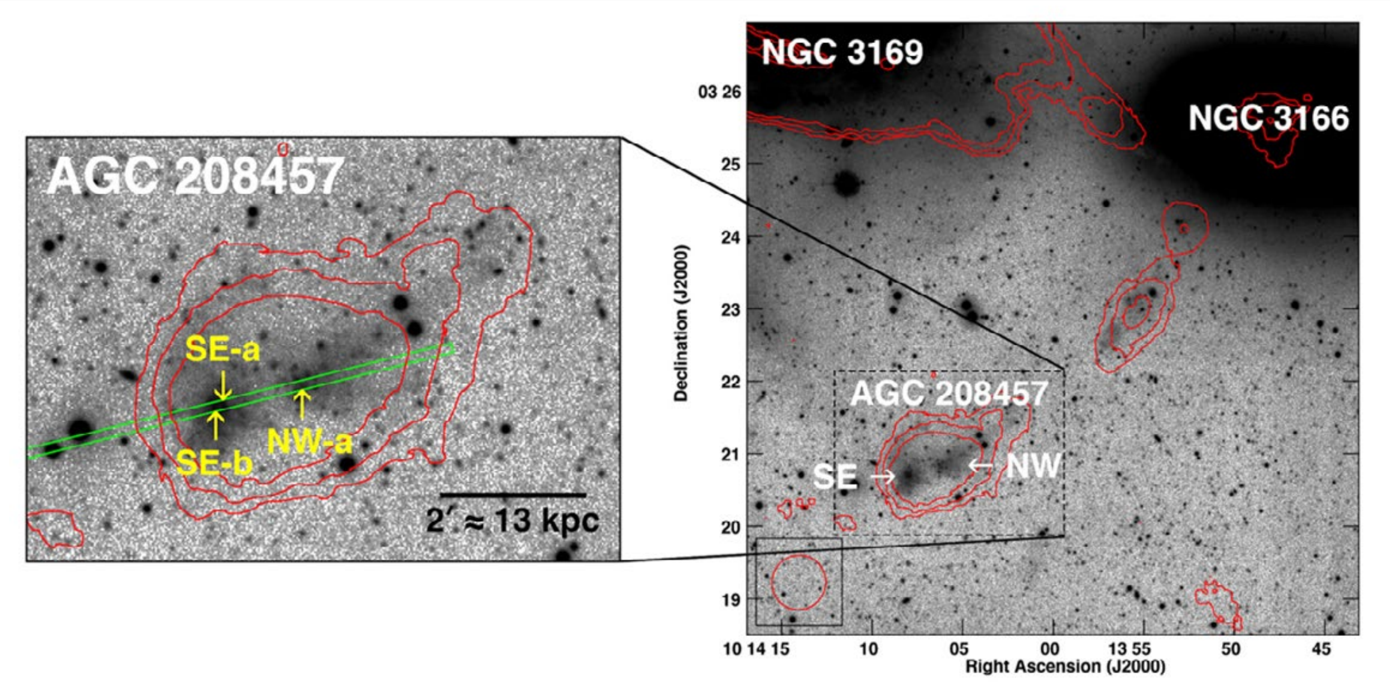


Figure 6.
Anatomy of the tidal dwarf galaxy AGC 208457. The HI emission contours from the GMRT are superimposed on a CFHT MegaCam image of the region between the interacting galaxies NGC 3166 and NGC 3169. The northwest and southeast stellar clumps of AGC 208457, lying within the HI tail, are indicated. The green outline in the zoomed view on the left shows the orientation of the GMOS-North long slit (illustrated with twice the actual width). The yellow arrows indicate the approximate locations of the extracted spectra analyzed in the study. [Figure reproduced from Lee-Waddell, et al., MNRAS, ***480:*** *2719, 2018.]*

with its larger neighbor NGC 4725. Like AGC 208457, these stellar aggregates likewise have relatively high metallicities, but they are in an earlier stage of evolution. Thus, they may represent a tidal dwarf galaxy in the process of formation. By using a combination of radio data, wide-field imaging, and GMOS spectroscopy to confirm the nature of these objects, this work significantly expands the limited sample of well documented tidal dwarf galaxies.

Confirmation of the Most Distant Known Radio Galaxy

More than a dozen galaxies have been reported at redshifts beyond 7. These tend to be highly magnified star-forming objects found at infrared wavelengths, seen when the Universe was less than 5% of its current age. However, radio emission from such objects has not yet been detected. This is mainly because the vast distances and extreme redshifting will make any radio signal difficult to detect. Moreover, powerful radio jets, and the black holes that power them, have not had sufficient time to grow to large sizes at such early times. Now, an international team of astronomers from Brazil, Italy, the Netherlands, and the United Kingdom has discovered the most distant radio galaxy to date, observed just one billion light years after the Big Bang, when the Universe was roughly 7% of its current age.

The team used spectroscopic data from GMOS-North to measure a redshift of $z = 5.72$, based on the Lyman-α line, for the radio galaxy identified as TGSS J1530+1049 (Figure 7). This is the largest redshift of any known radio galaxy. The object was selected as a high-redshift radio galaxy candidate based on its very steep spectral index at a frequency of 150 megahertz and its compact morphology in radio imaging by the Very Large Array at

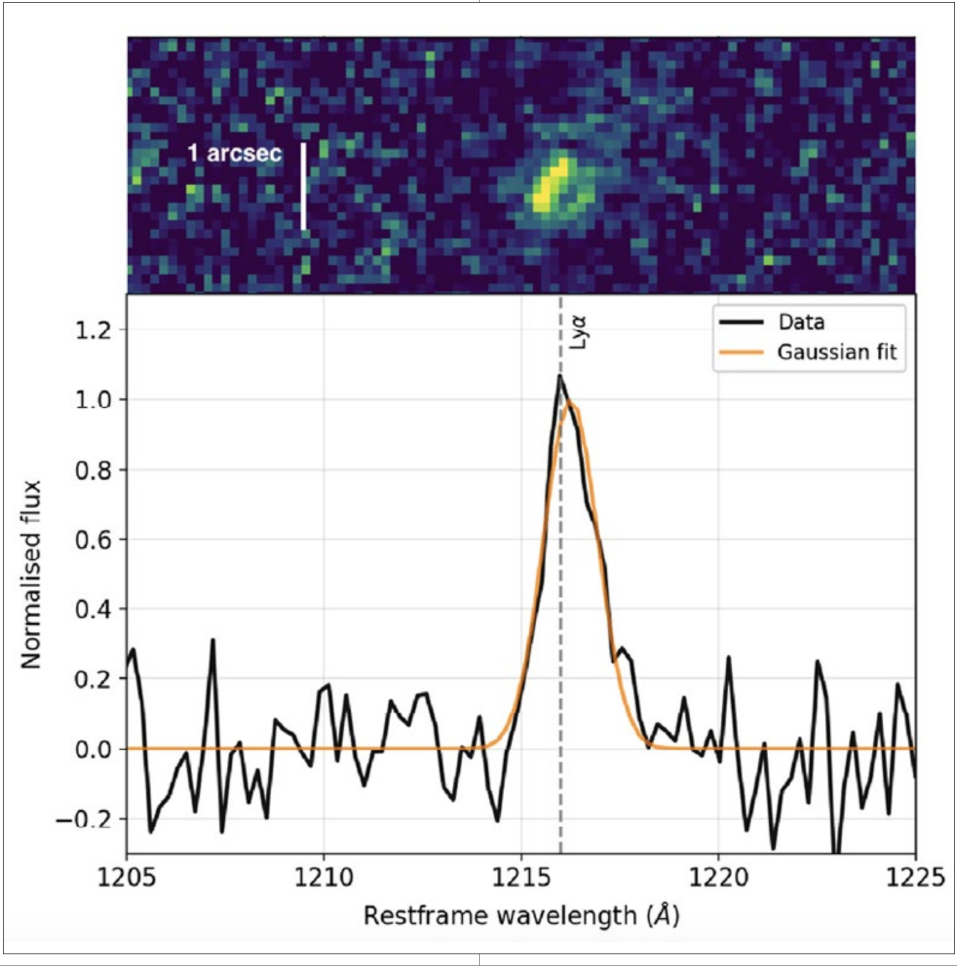


Figure 7.
Top panel: The two-dimensional GMOS spectrum showing the strong emission feature detected in the radio galaxy TGSS J1530 + 1049. The size of the emission region is a bit less than 1 arcsecond. Lower panel: One-dimensional plot of the spectrum of TGSS J1530 + 1049 (black line) is compared to a simple, symmetric Gaussian fit (orange line) to the emission feature. The asymmetry of the data with respect to the Gaussian fit indicates that the emission is Lyman-a at redshift of z = 5.72, making TGSS J1530 + 1049 the most distant radio galaxy known to date.

[Figure reproduced from Saxena, et al., MNRAS, ***480:*** *2733, 2018.]*

1.4 gigahertz. Searches for a counterpart at the location of the radio source in publicly available optical and infrared sky surveys revealed nothing. Consequently, the source was targeted, blindly, for deep spectroscopy at Gemini.

The study was led by graduate students Aayush Saxena (Leiden Observatory, the Netherlands) and Murilo Marinello (Observatório Nacional, Brazil), and the observations were obtained through Brazil's participation in Gemini. The relatively small size of the radio emission region in TGSS J1530 + 1049 indicates that it is quite young, as expected at such early times. Thus, the galaxy is still in the process of assembling. Because the radio emission is believed to be powered by a supermassive black hole, this discovery indicates that black holes can grow to enormous masses very quickly in the early Universe, since the black hole must have been in place long enough for the jet to grow to its observed size.

The measured redshift of TGSS J1530 + 1049 places this galaxy near the end of the Epoch of Reionization, when the majority of the neutral hydrogen in the Universe was ionized by high-energy photons from young stars and perhaps other sources of radiation. The question of whether or not active galactic nuclei, including quasars and radio galaxies, may have contributed to the reionization remains controversial. "The Epoch of Reionization is very important in cosmology, but it is still not well understood," said Roderik Overzier, also of Brazil's Observatório Nacional, and the Principal Investigator of the Gemini program. "Distant radio galaxies can be used as tools to find out more about this period."

The research has been ***published in Monthly Notices of the Royal Astronomical Society***.

JULY 2018

Hydrogen Sulfide in the Cloud Tops of Uranus

Despite decades of observations, including the landmark visit by *Voyager 2* in 1986, the question of whether ammonia (NH_3) or hydrogen sulfide (H_2S) dominates the visible cloud deck on Uranus has remained unresolved. However, recent observations obtained with the Near-infrared Integral Field Spectrometer (NIFS) on Gemini North confirm that hydrogen sulfide, a colorless gas with the distinctive odor of rotten eggs, is a key component of those clouds. The study reporting the long-sought evidence is led by Patrick Irwin of Oxford University and appears in the ***April 23rd issue of Nature Astronomy.***

The visible cloud deck, which forms by condensation of the gases within the atmosphere of a planet, provides information on the composition of the overall atmospheric reservoir. The NIFS observations, illustrated in Figure 8, sample reflected sunlight from the region immediately above the main visible cloud layer in Uranus's atmosphere. "The lines we were trying to detect were just barely there, but thanks to the sensitivity of NIFS on Gemini, we have the fingerprint which caught the culprit," said Irwin.

The detection of hydrogen sulfide in the clouds of Uranus contrasts with the inner gas giants, Jupiter and Saturn, where the bulk of the upper clouds are comprised of ammonia ice, and no hydrogen sulfide is detectable. These differences were likely imprinted within the proto-solar nebula, where the balance between the amounts of nitrogen and sulphur was determined by the temperature, and therefore the location, of a given planet's formation.

As reported widely in the media, in establishing a lower limit to the amount of H_2S in the

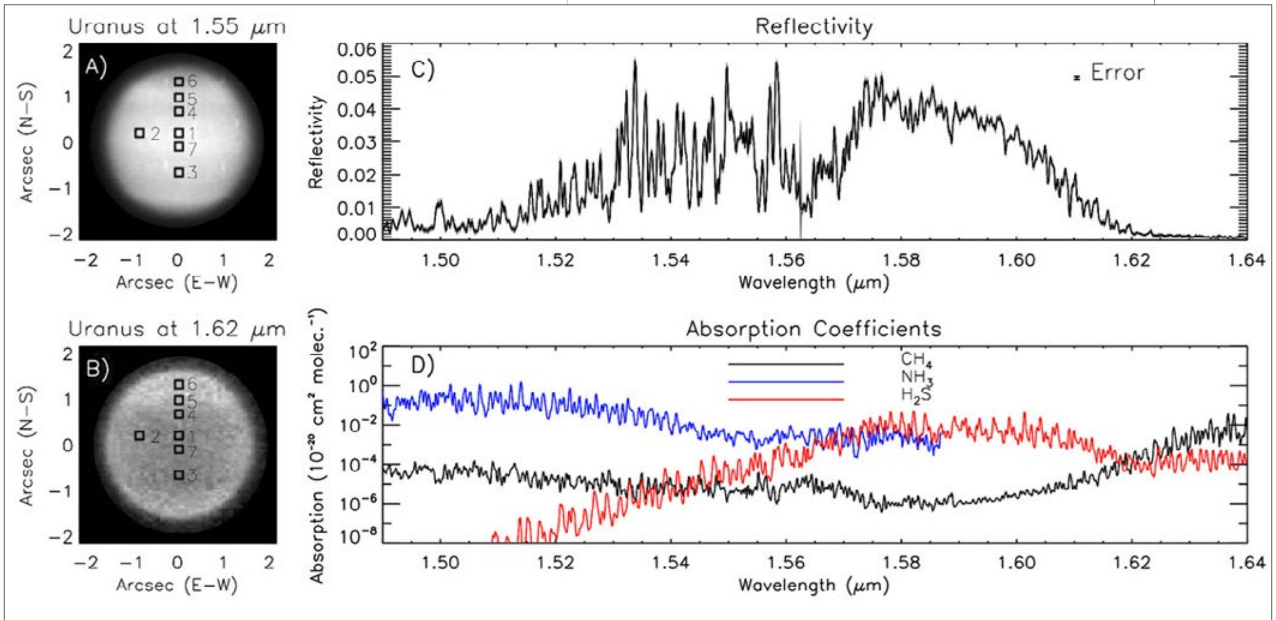


Figure 8.

Gemini/NIFS observations of Uranus. Panel A: the appearance of Uranus at 1.55 μm (low methane absorption, showing reflection for cloud/haze at all vertical levels), showing the position of the seven test areas used for analysis. Panel B: the appearance of Uranus at 1.62 μm (high methane absorption, showing reflection from upper atmospheric haze only). Panel C: reference spectrum of Uranus averaged over area "1" (in Panel A) near the center of the planet's disk, just north of the equator. Panel D: strength of the model absorption coefficients derived over the Gemini/NIFS spectral range for conditions found at the tops of Uranus's main visible clouds.

[Figure reproduced from Irwin et al., Nature Astronomy, *2018.]*

upper atmosphere of Uranus, these results not only confirm that the planet is a poisonous, frozen environment utterly hostile to life as we know it, but that its prevailing aroma is also downright offensive. More upliftingly, the study also highlights the importance of our far-flung seventh planet for understanding the early history of our Solar System, as well as the likely conditions on similarly large, icy worlds beyond the Solar System.

Gemini Speckle Imaging of Binaries among K2 Planet Hosts

The vast majority of the known exoplanets have been discovered by the *Kepler* mission via the transit method. The 4-arcsecond pixel size of *Kepler* means that light from any nearby companion or background object will be blended with that of the planetary host. The blending reduces the observed depths of planetary transits, making it harder to detect the planets and potentially biasing their inferred sizes. Thus, knowing the fraction of exoplanet hosts that are in binary systems is important for determining the distribution of planetary sizes as well as establishing any possible relationship between stellar multiplicity and planet formation. While there are theoretical reasons for expecting that a stellar companion may inhibit planet formation, apart from limiting the range of stable orbits, the influence of stellar multiplicity on the frequency and properties of planets is not yet fully understood.

Follow-up imaging studies of the host stars of transiting planets detected by the *Kepler* mission have found little or no difference in the frequency of stellar multiplicity of exoplanet hosts compared to nearby field stars, although there is some evidence that exoplanet hosts are less likely to have stellar companions within about 100 astronomical units (AU). Now, a team of astronomers have used high-resolution speckle imaging data from the visiting Differential Speckle Survey Instrument (DSSI) at both the Gemini North and South telescopes, as well as at the WIYN telescope at Kitt Peak National Observatory in Arizona, to target a sample of planetary hosts found in *Kepler's* K2 mission. The K2 mission has observed a series of fields along the ecliptic plane, each one for 80 days, and has detected more than 500 exoplanet candidates. The different observing strategy results in differences in the distributions of mass and orbital properties as compared to the original *Kepler* sample.

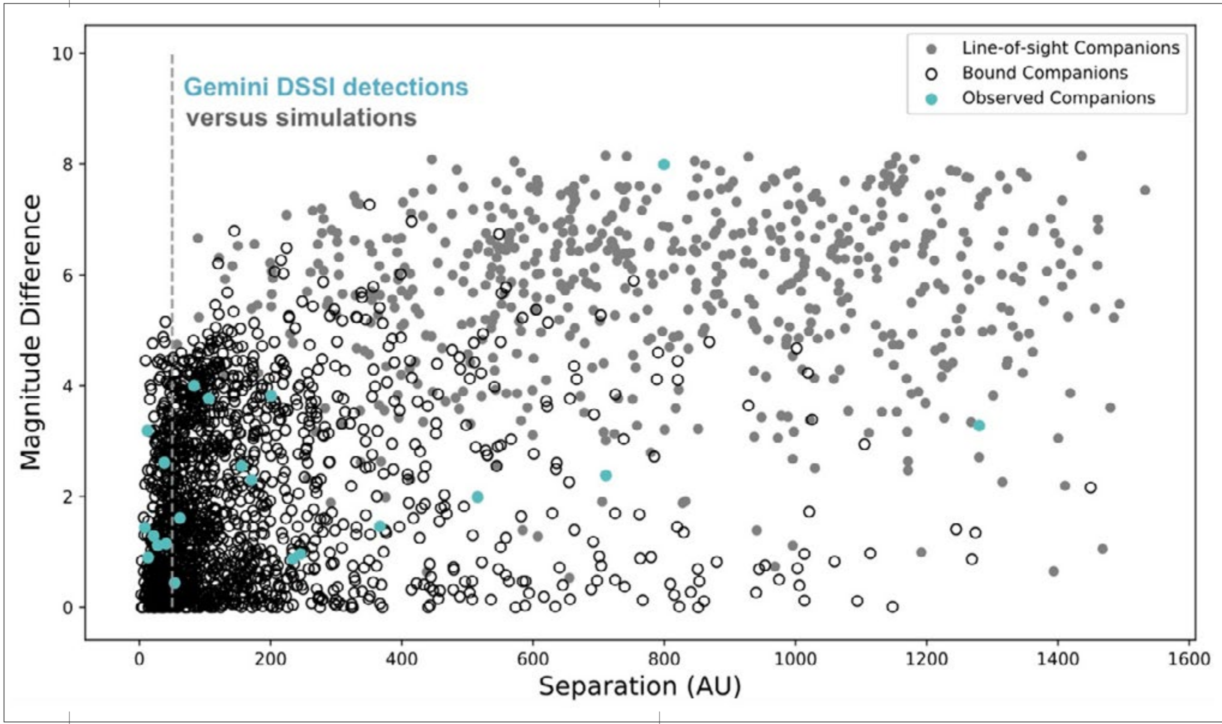


Figure 9.
Magnitude differences for real and simulated detections of stellar companions plotted as a function of separation in AU. The cyan points are the 21 K2 exoplanet hosts at known distances that have stellar companions discovered by DSSI on Gemini. Open black circles represent a random sampling of simulated stellar systems with bound components that would be detectable by Gemini/DSSI, while filled gray circles represent detectable line-of-sight companions from the same simulations. The dashed gray line at 50 AU marks the semi-major axis within which a previous study had concluded that stellar companions are suppressed among Kepler *exoplanet hosts.*
[Figure adapted from Matsen et al.*, 2018.]*

The team observed 206 unique K2 planet hosts with DSSI and detected a total of 29 stellar companions, including 23 companions to the 102 stars observed at Gemini. In order to assess the intrinsic binarity, the team compared their detections to expectations from simulations of both the Gemini and WIYN DSSI samples. Figure 9 compares the distributions in magnitude difference and separation of the simulated and actual Gemini observations. Assuming the field binarity fraction of 40-50%, the simulations predict 26 ± 6% of the exoplanet hosts should have companions detectable by DSSI on Gemini, consistent with the observations. Thus, the fraction of binary stars among K2 exoplanet hosts is consistent with that found among the general population of nearby stars of similar mass.

"While we have known that about 50% of all stars are binary, to confirm a similar ratio in exoplanet host stars helps set some important constraints on the formation of potential exoplanets seen by *Kepler*," said Rachel Matson of NASA's Ames Research Center, the study's lead author. "In our sample we did not find evidence that the proximity of a companion star suppresses the formation of exoplanets, even at distances as small as 50 astronomical units." The paper is accepted for publication in *The Astrophysical Journal*, and a preprint is ***available online***.

AO Constraints on Psyche's Shape, Density, and Polar Axis

The Main Belt asteroid 16 Psyche is one of the defining members of the metallic M-class asteroids. The classification is based on its high radar albedo, which suggests that Psyche's surface is about 90% nickel-iron metal. This could indicate that Psyche is the remnant core of a larger differentiated body. Although its mean diameter of about 225 km places it 35th among Main Belt asteroids, it ranks 11th in terms of mass. NASA's planned *Psyche Discovery Mission*, scheduled for launch in 2022 and orbital insertion four years later, will be the first to visit an M-class asteroid.

A team of astronomers led by Jack Drummond of the Starfire Optical Range at Kirtland Air Force Base in New Mexico has carried out a new analysis, published earlier this

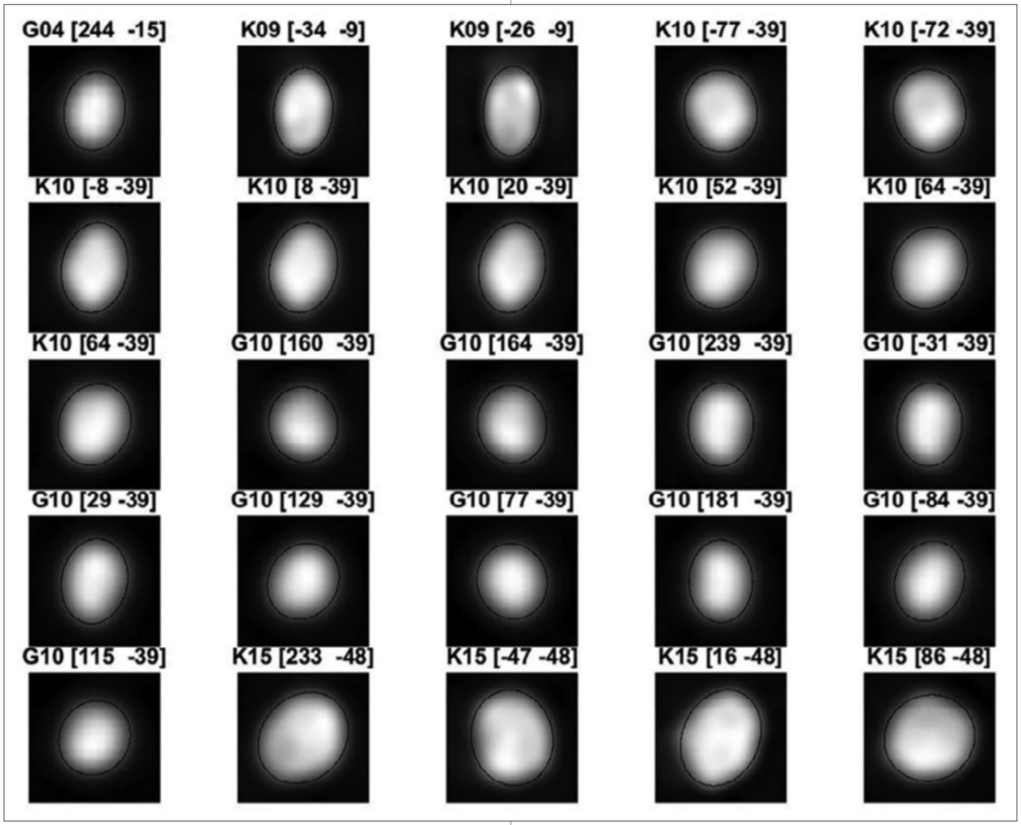


Figure 10.

Deconvolved Gemini/NIRI and Keck/NIRC2 images of asteroid 16 Psyche. Each image is labeled with the initial of the observatory and the two-digit year in which it was taken; the rotational phase and sub-Earth latitude during each observation are shown in brackets. Note that the sub-Earth latitudes are negative in all cases. The black outlines show the best-fit ellipse for each image.

[Figure reproduced from Drummond, et al. Icarus*, **305:** 174, 2018.]*

year in *Icarus* (***viewable here***), of a comprehensive set of 25 images taken with adaptive optics (AO) on six different nights spanning four oppositions of Psyche from June 2004 through December 2015. (Because the rotational period of Psyche is 4.2 hours, observations from the same night can sample significantly different orientations.) The data were acquired using the Near-InfraRed Imager and spectrometer (NIRI) with the Altair AO system at Gemini North and the NIRC2 camera with the AO system on the Keck II telescope; all images were processed using parametric blind deconvolution. The deconvolved images were then fitted simultaneously using a triaxial ellipsoidal model incorporating the known orbit and rotation of Psyche.

Figures 10 and 11 (on next page) show the 25 deconvolved AO images and the best-fit model as it would have appeared at the time of each observation. Psyche has an obliquity of 95°, meaning that it rotates "on its side," and its shape is distinctly non-spherical. The analysis yields triaxial ellipsoid dimensions of (a, b, c) = (274 ± 9, 231 ± 7, 176 ± 7) km and leads to an estimated density of 4.2 ± 0.6 grams per cubic centimeter, where the large part of the uncertainty comes from the mass. This density is considerably less than that of pure nickel-iron and would require a porosity of 47% if the bulk composition is the same as its surface. That is to say, Psyche appears to be full of holes. Instead of a solid iron core, it may be a disrupted and re-assembled heap of scrap metal. Porosities of some "rubble pile" asteroids are known to be this large, but none have such high metal contents. Alternatively, Psyche could be a stony-iron asteroid with low porosity and an interior much more silicate-rich than its surface, but such an inverted structure would be difficult to understand.

The study also derives an improved determination for the asteroid's rotational pole, with an uncertainty radius of 3 degrees. This is useful in operations planning for the *Psyche Mission*, but the precision is currently limited by the restricted range of orientations available for the modeling. Remarkably, Psyche has an orbital period of 5.00 years, which

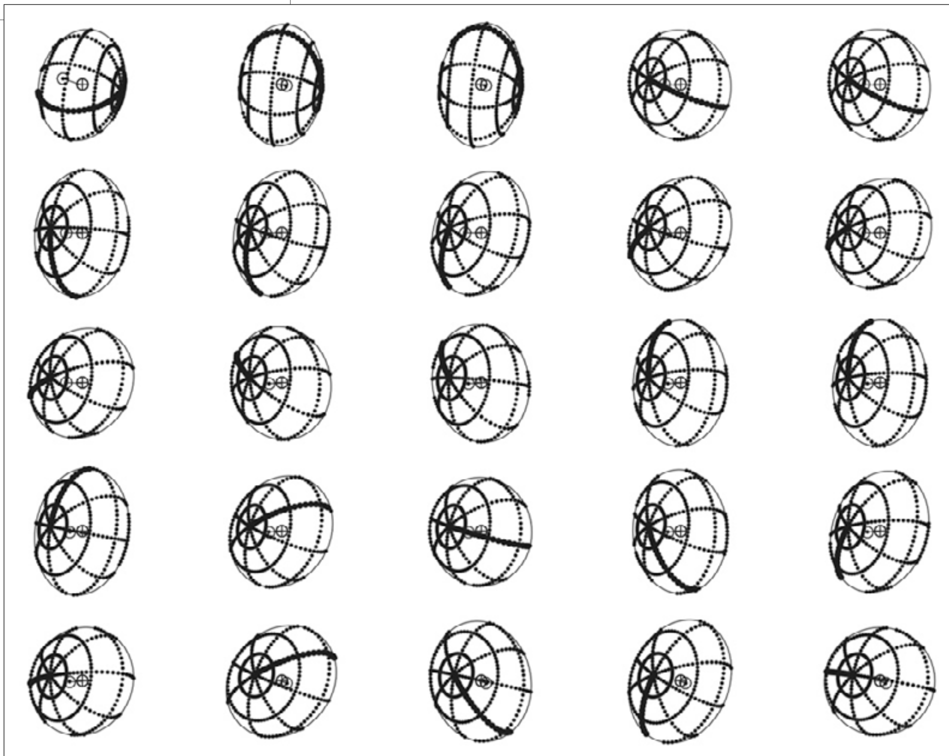


Figure 11. *Orientation during each observation shown in Figure 10 of the best-fitting triaxial model derived from the full set of deconvolved AO images. The south pole and equator are visible in all cases. The sub-Earth and sub-Sun points are labeled as ⊕ and ⊙, respectively.*

[Figure reproduced from Drummond, et al. Icarus, ***305:*** *174, 2018.]*

means that only four distinct geometries are possible at opposition. Improving the shape and orientation measurements for this unique asteroid will require further AO observations at oppositions with geometries not represented in Figure 11, as well as at times when it is challengingly away from opposition. The upcoming robotic rendezvous will provide an exciting opportunity to test the analysis methods used for the AO data and will measure the object's moment of inertia, finally revealing the secret structure beneath Psyche's shiny surface.

APRIL 2018

A New Generation of Star Clusters Adorning an Old Galaxy

Elliptical galaxies are often described as "red and dead," meaning that the stars within them are generally many billions of years old, and they lack the material and wherewithal for any significant amount of star formation. The optical light in such old stellar populations is dominated by contribution from red giant stars, which have exhausted their core supply of hydrogen. For this reason, some galaxy enthusiasts might consider ellipticals bland and boring compared with the more showy grand design spirals such as the Whirlpool, or even star-forming dwarf irregulars, like the Magellanic Clouds. However, sometimes when an elliptical encounters a gas-rich neighbor, sparks fly, and a new generation of stars comes into being. This appears to be the case with the galaxy NGC 2865, a post-encounter elliptical with tell-tale shells, streams, and other tidal features.

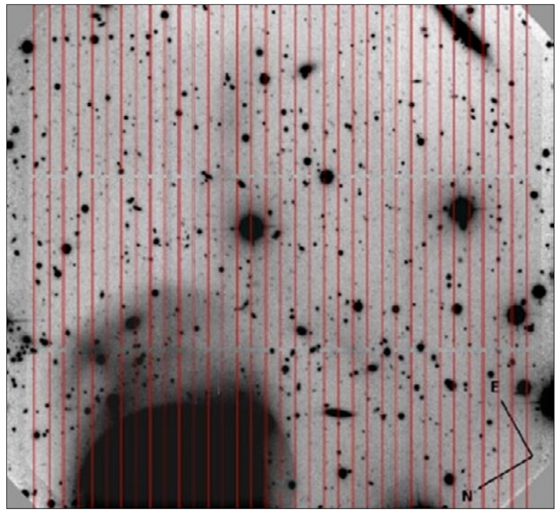
A team of astronomers led by Fernanda Urrutia (Universidad de La Serena and now at Gemini Observatory) used an observational technique called Multi-Slit Imaging Spectroscopy (MSIS), applied with the Gemini Multi-Object Spectrograph (GMOS), to pinpoint the locations of newly formed star clusters scattered amidst the tidal debris surrounding NGC 2865. The MSIS technique uses a specially designed spectroscopic mask with multiple parallel long slits and a narrow-band filter to ensure that the spectra produced by the slits do not overlap. For this study, Urrutia's team constructed a mask with 108 parallel long slits, split into three groups that each spanned a third of the length of the field. The individual slits were an arcsecond in width, and the slits within each group were spaced by 8 arcseconds (Figure 12, top panel). For the observations, the researchers moved the telescope in a series of 1-arcsecond steps — in the direction perpendicular to the slits in order to cover the full field of view — and took a spectroscopic exposure at each position.

By tuning the observed wavelength to that of the hydrogen-alpha (Hα) emission line, the MSIS technique makes it possible to find all the bright, actively star-forming regions within the GMOS field of view (Figure 12, bottom panel).

Hα light is emitted when the ambient gas is excited by high-energy radiation from nearby young massive stars. Targeting six regions of Hα emission found in the MSIS study, the team then used standard GMOS multi-slit spectroscopy that affords much broader wavelength coverage. The data reveal that these regions are actively forming massive star clusters from gas rich in heavier elements, or high metallicity. The gas was likely enriched with metals produced by generations of stars that lived out their lives in another galaxy that has since been accreted by NGC 2865. "These high metallicities could be explained if the clusters were formed by the enriched gas coming from a merger event with a spiral galaxy," said Urrutia.

"The fate of these clusters is unclear, however. We cannot discard the possibility that these objects become globular clusters in the future," adds team member Sergio Torres-Flores from Universidad de La Serena. Globular clusters are massive, compact, generally old star clusters that are common in the halo regions of galaxies, especially ellipticals. This work may therefore provide a rare glimpse into their early evolution.

A ***paper presenting the discovery*** of the young massive clusters appears in a recent issue of *Astronomy & Astrophysics*; an earlier paper on the ***MSIS observations*** was published in the same journal.



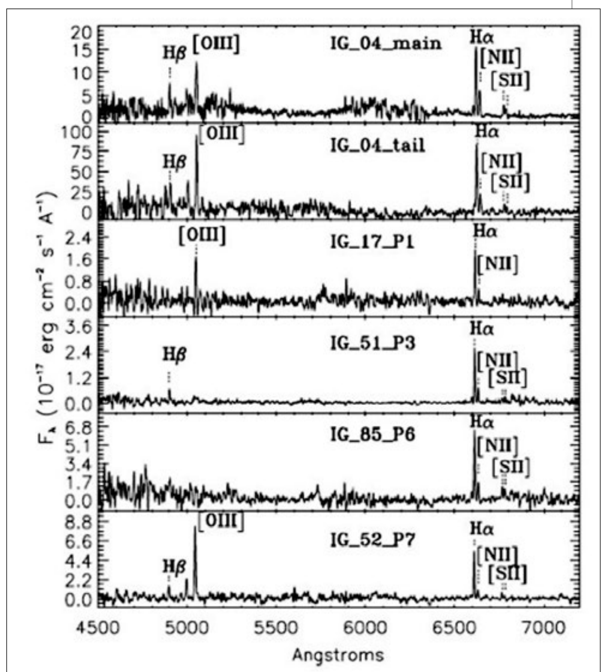


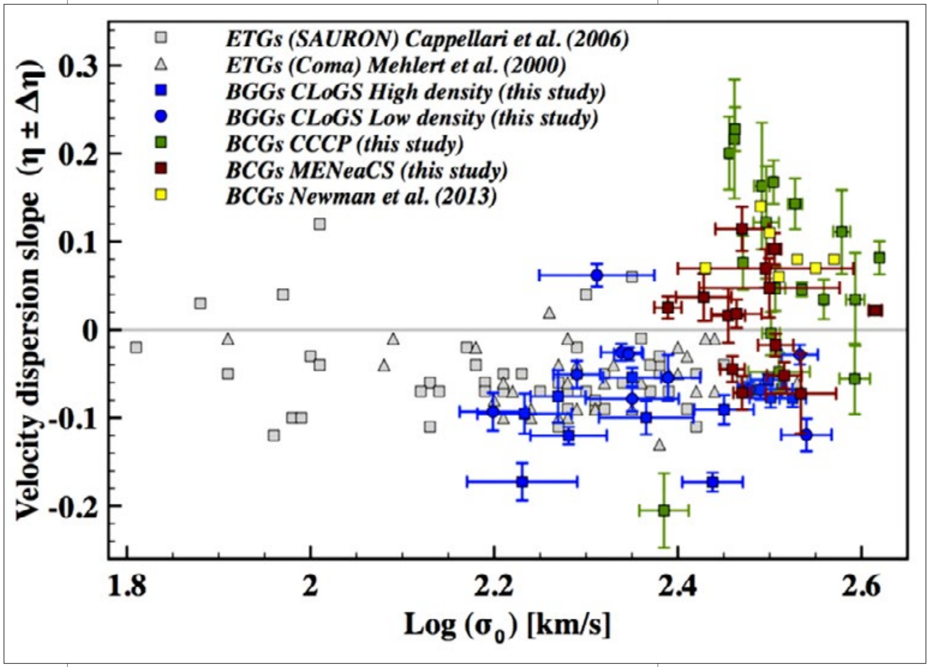
Figure 12.
Top: Design of the MSIS slit mask used to find sources of Ha emission around the galaxy NGC 2865. The red lines indicate the positions of the GMOS slits, which are 1-arcsecond wide, overlaid on an r-band image of the field. A series of exposures are taken with the telescope offset by an arcsecond between exposures in order to obtain complete spectroscopic coverage of the entire field of view.

Bottom: GMOS-South follow-up spectra of six emission line regions found with the MSIS technique in the outskirts of NGC 2865. These are regions of active star formation, and the majority appear to be young star clusters being born from chemically enriched gas.

Diversity in Dispersion Profiles of the Most Massive Galaxies

Gravity is the glue that holds galaxies together. In more massive galaxies with stronger gravitational fields, the stars must move faster in order to avoid being sucked toward the center. The gravitational tug felt by the stars, and thus their speed, also depends on the location of the stars within the galaxy and the spatial distribution of the galaxy's mass. For instance, in a small galaxy with a very massive black hole in its center, the stars must orbit at high velocity near the black hole in order to resist its strong gravitational pull, but their orbital velocities would decrease at larger galactocentric radii (distance from the galaxy's center). On the other hand, stars within spiral galaxies like our Milky Way, embedded within extensive dark matter halos, have pretty much the same orbital velocity regardless of location within the galactic disk. Thus, the velocities of the stars within a galaxy, and the way those velocities change with radius, reveal important infor-

Figure 13.
The slope η of the velocity dispersion profile is plotted against the central velocity dispersion σ_0 for individual galaxies in multiple different samples of galaxies (indicated in the legend). The blue points represent brightest galaxies in groups (BGGs) of high (square) and low (circles) density, while the green, red, and yellow points represent brightest cluster galaxies (BCGs) in various samples of galaxy clusters. The grey points indicate generic "early-type galaxies" (ETGs). The central dispersion σ_0 is larger for massive galaxies because their stars move more rapidly in the stronger gravitational fields of such galaxies. The dispersion profile η is negative if the stars farther from the galaxy center move more slowly, and it is positive if the stars move rapidly at larger distances. Thus, massive BCGs tend to have rising profiles, with the stars increasing their velocities at larger distances from the galaxy center.



mation about the mass of a galaxy and how that mass is distributed.

In a recent study, astronomers used the GMOS instruments at both Gemini North and South to measure the stellar velocity dispersions (a measure of the mean random stellar speed) and velocity dispersion profiles (its variation with galactocentric radius) in a sample of 32 massive elliptical galaxies, each of which is the brightest member within a large cluster of galaxies. Such brightest cluster galaxies (BCGs) tend to reside near the centers of their respective clusters, and therefore they are generally embedded within very extended distributions of both light and dark matter. The sample of BCGs in this study included some of the most massive galaxies in the Universe out to a distance of five billion light years.

The researchers found a surprising variety in the shapes of the velocity dispersion profiles for the BCGs, with a large fraction of them showing rising dispersion profiles. This means that the stars within these galaxies are moving faster at larger galactocentric distances in response to an increasing gravitational force. In comparison, rising velocity profiles are much rarer in other massive ellipticals that are not BCGs, including many brightest galaxies in smaller groups.

"You would naively think that massive elliptical galaxies are a homogeneous, well-behaved class of objects, but the most massive beasts, those in the centers of groups and clusters, continue to surprise us," said Ilani Loubser, an astronomer at North-West University in South Africa and the lead author of the study. She also noted, "The quality, and the wealth of information we can measure from the GMOS spectra (even in poor weather!), is remarkable."

The study also found that the slopes of the velocity dispersion profiles correlate with the galaxy luminosity (Figure 13), in the sense that the increase in the speed of the stars was greater in brighter BCGs, as well as in brightest group galaxies. Whether the full diversity in the observed velocity dispersion profiles is consistent with standard models for the growth of massive galaxies is not yet clear. The researchers present their results as a challenge for detailed cosmological simulations.

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

An Ultra-diffuse Galaxy Devoid of Dark Matter

In most galaxies, the stars are like a luminous frosting on the predominant mass of dark matter whose gravity holds the whole confection together. Both the most luminous giants and the faintest dwarfs have especially large fractions of dark matter, outweighing the stars by factors of a hundred or more. Middling galaxies like our Milky Way generally have the highest proportion of stars by mass, but still about a factor of 30 less than the mass in dark matter.

Ultra-diffuse galaxies (UDGs) are a recently identified class of extended low-surface-brightness objects with sizes that may be as large as the disk of the Milky Way but total luminosities typical of low-mass dwarfs. These galaxies have turned up in large numbers in recent imaging surveys by the Dragonfly Telephoto Array, a custom-built array of telephoto lenses with anti-reflection nano-structured coatings coupled with commercial CCD cameras. The array is located in New Mexico and operated robotically. Follow-up studies with large-aperture telescopes of several UDGs spotted by Dragonfly have found that the ghostly galaxies generally have large reservoirs of dark matter.

Because the UDGs themselves are so faint, in many cases the easiest way of estimating their total masses is from the motions of the globular star clusters associated with the galaxies, as long as the galaxies are near enough to allow spectroscopic observations of the globulars in a reasonable amount of time. These compact star clusters move in response to the total gravity field, regardless of whether it is produced by luminous or dark matter. Values of the total mass derived from the speed of orbiting stars or star clusters are referred to as "dynamical mass" estimates. When the Dragonfly team noticed that one of their UDGs, dubbed NGC 1052-DF2 because of its association with the NGC 1052 galaxy group, contained multiple bright compact points of light likely to be globular clusters, they knew it was a promising candidate for further study with larger telescopes.

"We used several of the world's premier observatories, and the flexibility and fast response time of Gemini were a key factor in the analysis," said Pieter van Dokkum of Yale University, lead author of the new study of NGC 1052–DF2. "We requested Director's Discretionary Time to observe NGC 1052–DF2, and it was observed nine days later. The Gemini image showed us that we had found a truly unusual galaxy." According to researchers, the Gemini data, taken with GMOS-North, provided "the best available information on the regularity of the galaxy at low surface brightness levels." Visual inspection of the Gemini images (see Figure 14, next page) prompted the team to request a change in the scheduling of their Hubble program targeting UDGs found with Dragonfly; as a result, NGC 1052–DF2 was given higher priority and observed sooner. The GMOS images were also used to select the globular clusters for spectroscopy with the Keck I telescope.

The spectroscopic observations revealed remarkably little spread in the velocities of the ten globular clusters observed in NGC 1052–DF2, and this narrow range of velocities has major implications for the mass of the galaxy. The researchers concluded that the total dynamically determined mass was very close to the observed mass of the stars in the galaxy. This is unusual because UDGs of this size typically have hundreds of times more mass in dark matter than in stars. "If there is any dark matter at all, it's very little," van Dokkum explained. "The stars in the galaxy can account for all the mass, and there doesn't seem to be any room for dark matter."

Because their result was so surprising, the researchers considered several possible sources of error in the analysis. One possibility was that NGC 1052–DF2 is not actually in the NGC 1052 group at a distance of 20 megaparsecs (65 million light years), but much closer to us. If so, the estimated mass in stars would be much lower, meaning that a substantial amount of dark matter would then be needed. Such a nearby distance would be unlikely based on the velocity of the galaxy, but perhaps not more unlikely than a galaxy devoid of dark matter; moreover, the brightness of the globular clusters suggested that the distance might be only half as large as assumed. Fortunately, the high-resolution Hubble images enabled an independent measure of the distance via analysis of the galaxy's surface brightness fluctuations, the same statistical method that recently provided the most precise distance to the host galaxy of GW170817, the first gravitational wave event with an observed electromagnetic counterpart. Using this technique, the researchers found evidence that the UDG was within the NGC 1052 group, reducing this source of uncertainty.

Somewhat counterintuitively, the conclusion that NGC 1052–DF2 lacks detectable dark matter constitutes a strong argument against theories that dispute dark matter's existence. Such alternative theories posit that gravity simply works in a different way than described by Einstein's highly successful General Relativity theory, and there is no need for dark matter to provide additional gravitational force to hold galaxies together. But if this were the case, gravity should always act in the same alternative way for a given amount of visible matter, such as the stars observed in NGC 1052–DF2. Clearly this is not the case, since other galaxies with the same quantity of stars show very different internal motions indicative of a much stronger gravitational field, easily explained by dark matter.

So far only a few UDGs have dynamically measured masses, and most of these are abundant in dark matter. However, the team is continuing to follow up on others discovered by the Dragonfly array. If more galaxies like NGC 1052–DF2 come to light, it will provide much needed demographic information to aid in understanding how such galaxies form in the absence of dark matter.

The study appears in the March 28th issue of the journal ***Nature***.

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

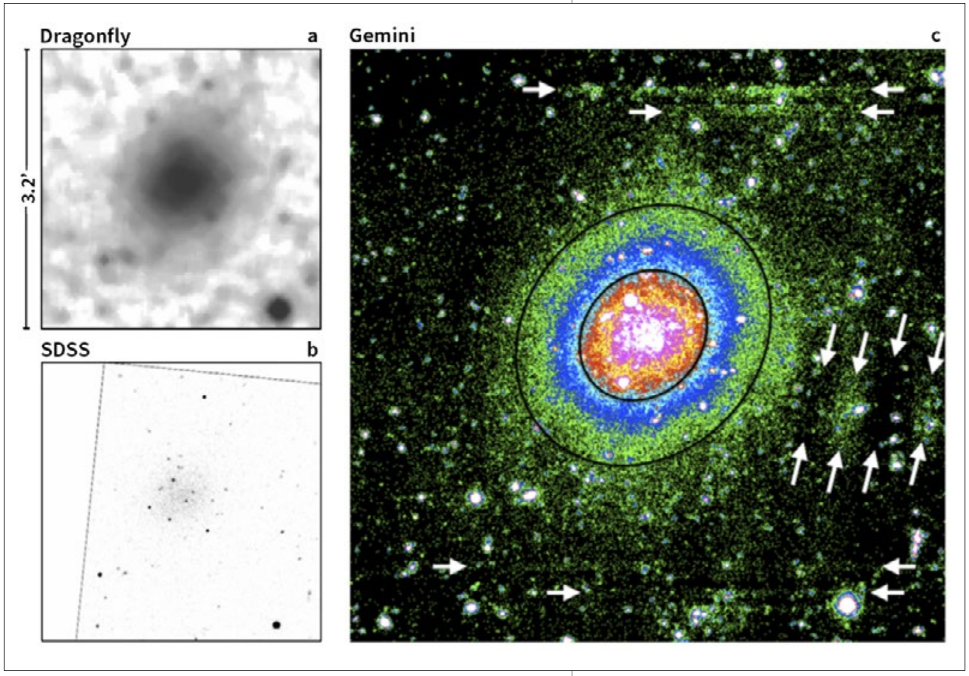


Figure 14.
Three views of the unusual dark-matter deficient galaxy NGC 1052–DF2. The upper left panel shows the sum of the g and r images taken with the Dragonfly Telephoto Array, in which the galaxy appears as an extended, low-surface-brightness "blob." The lower left panel shows a sum of g, r, and i images from the Sloan Digital Sky Survey (SDSS), revealing a concentration of compact objects overlaid on a faint fuzz. The panel at right shows the Gemini North i-band image of NGC 1052–DF2, which provided the best information on the morphology of the galaxy. Black ellipses indicate the effective radius (containing half the total light) and twice the effective radius; white arrows mark artifacts of the reduction that become visible at faint levels. The galaxy has a regular elliptical shape without any significant variations with radius.

Korea Becomes a Full Participant in Gemini

On Tuesday, July 24, 2018, the Republic of Korea became a full participant in the Gemini Observatory. The press release follows.

(More images from the signing event are viewable here.)

San Francisco, Tuesday, July 24, 2018 - An agreement between the Korea Astronomy and Space Science Institute (KASI) and the agencies that own and operate the international Gemini Observatory was signed today that established the Republic of Korea as a full participant in the Gemini Observatory.

"After being a part of Gemini for the past four years as a Limited-term Collaborator, the Korean astronomical community is thrilled to become a full participant in the twin Gemini telescopes in Hawai'i and Chile," said Narae Hwang, Head of K-GMT Science Group, Center for Large Telescopes of KASI. "We look forward to years of fruitful exploration of the cosmos with the powerful 8-meter Gemini telescopes!"

The Republic of Korea flag is raised at Gemini Base Facility in Hilo, Hawai`i.
Credit: Joy Pollard

The signing ceremony closed the second day of The Science and Evolution of Gemini Observatory meeting being held this week in San Francisco, California. Over 100 scientists — many from the partner communities in the US, Canada, Chile, Brazil, Argentina, and now Korea — are participating in the meeting, and most attended the signing ceremony. The ceremony ended with cheers, toasts, and much anticipation of the partnership's future potential.

"I am confident that the KASI's partnership with the Gemini Observatory will help Korean researchers to lead the exciting adventures to solve the mysteries of the Universe," said Hyung

Gemini Board Chair Rene Walterbos (left) and KASI President Hyung Mok Lee sign the agreement making Korea a full participant in Gemini. Credit: Shari Lifson

Mok Lee, KASI President. "We are more than happy to share this opportunity with the entire Gemini community."

Matt Mountain, President of the Association of Universities for Research in Astronomy (AURA) that manages Gemini through a cooperative agreement with the National Science Foundation (NSF) commented, "We welcome KASI as a full participant in Gemini Observatory. KASI's collaboration with Gemini has already yielded new scientific discoveries, and we anticipate exciting new projects to come from Korea's full participation."

"We know that this will be the start of a wonderful friendship, as well as a fruitful and long-lasting scientific collaboration," added Anne Kinney, Head of the NSF's Mathematical and Physical Sciences Division. The NSF funds approximately 70% of the the Gemini Observatory along with participants Canada, Chile, Brazil, and Argentina. "With Korea joining Gemini we will see a fresh new perspective which I'm certain will result in a flood of great ideas and insights," said Kinney.

"In the four years since Korea entered into a Limited-term partnership with Gemini, we have developed a very strong bond with our Korean colleagues," said Gemini Interim Director Laura Ferrarese. "I could not be more pleased to see that bond cemented today." Ferrarese continued, "Gemini is only as strong as its user-base, and we are deeply grateful for Korea's willingness to join our long-standing partners and help us define the vision and future of the Observatory."

Rene Walterbos, Chair of the Gemini Board commented, "It is a testimony to the remarkable staff at Gemini that Korea decided to become a full participant in the twin telescopes." Walterbos adds that Korea is a rising star in astronomy and rapidly establishing a leadership position in many areas of astronomical research. "I'm looking forward to watching as Korea's scientists find new and exciting ways to use Gemini, contribute to its capabilities, and further advance Korea to the forefront of modern astronomy."

"Another exciting aspect of Korea joining Gemini is the instrumentation experience they will bring to our community," said Scot Kleinman, Gemini's Associate Director for Development. "IGRINS, developed in part by a team in Korea, has proven to be one of Gemini's most popular visitor instruments and we look forward to them bringing a similar instrument specifically for Gemini as part of their initial contribution to the Observatory."

KASI started its Limited-term Collaboration with the Gemini Observatory in October 2014, which has enabled Korean researchers to access the twin Gemini telescopes in Hawai'i and Chile starting in 2015. Since then, and up to 2018, the Korean community has carried out about 100 science programs and published over 10 papers based on Gemini data, two of which were featured on the Gemini website. As mentioned, KASI is also a major partner in the team that operates the state-of-the-art near-infrared spectrometer IGRINS jointly developed by the University of Texas Austin and KASI. IGRINS was deployed at Gemini South from March to July 2018 as a visitor instrument, and established an historically high scientific demand from the community, rendering it the most popular science instrument at Gemini South for that semester.

On the Horizon

This review highlights instrumentation development efforts made in 2018 to advance the Observatory's capabilities to do leading science, especially in the era of multi-messenger and time-domain astronomy.

JANUARY 2019

GEMMA: Leading in the Era of Multi-Messenger and Time-Domain Astronomy

With the recent announcement of the National Science Foundation (NSF) award, Gemini in the Era of Multi-Messenger Astronomy (GEMMA), work is ramping up to produce the exciting deliverables promised over the next five years. GEMMA updates will be a regular feature in this column for the duration of the program.

The goals of GEMMA are broad and encompass diverse capabilities for Gemini – from instrumentation, real time software and data reduction pipelines, to public communications. The primary instrumentation capability envisioned with GEMMA is a new state-of-the-art multi-conjugate adaptive optics system for Gemini North called GNAO. Additional details on the GEMMA program can be found in this issue's Director's Message starting on page 1 of this issue.

Among the first exciting activities in 2019 is a Communications Summit in Multi-Messenger and Time-Domain Astronomy (MMA/TDA). Planning is now underway to identify and invite science communication specialists and scientists working in MMA/TDA to the summit

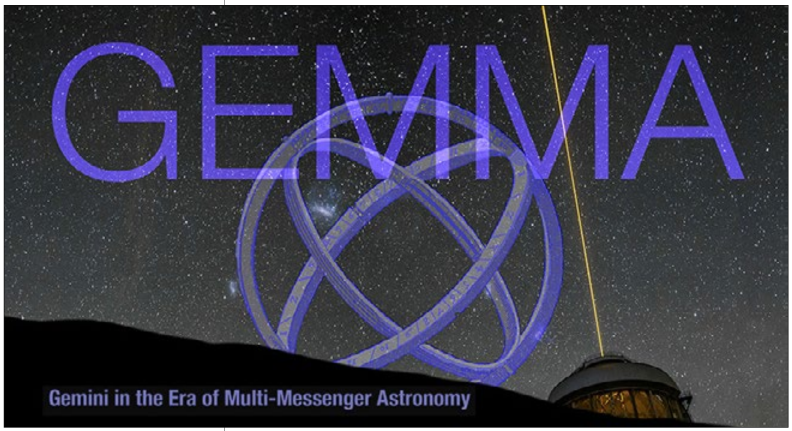


Figure 1. *The GEMMA logo incorporates an ancient astronomical instrument known as Gemma's rings.*

which will focus on the unique challenges and opportunities in sharing the complexities and new scientific horizons presented by MMA/TDA.

In January 2019 the GEMMA Program Execution Plan (PEP) is slated for submission to the NSF and work will ramp up significantly following its approval. In the meantime the Gemini user community is encouraged to provide input into the GEMMA program. The Time Domain Astronomy Working Group is being formed in order to advise the Observatory on the development of the time-domain network which will facilitate the execution of time-domain observations. Secondly, Gemini is re-establishing an Adaptive Optics Working Group (AOWG) made up of staff and engaged members of the Gemini user community. For more details on getting involved in GEMMA please ***go to this link***.

Figure 2. *SCORPIO team member Amanda Bayless with an engineering grade E2V device in the clean room.* *Credit: Stephen Goodsell*

The GEMMA logo (Figure 1) is taken from Gemma's rings, an early astronomical instrument consisting of three rings representing the celestial equator, declination, and the meridian. The rings were created by Gemma Frisius, a 16th century Dutch physician, mathematician, cartographer, philosopher, and instrument maker.

SCORPIO Completes Two Key Reviews

The Spectrograph and Camera for Observations of Rapid Phenomena in the Infrared and Optical (SCORPIO) completed two key reviews in November 2018. We held an Optical Design Review from November 14-15 at the University of Madrid, Spain, to assess the design readiness of the instrument's six Collimator Units and eight Camera Units. An assessment panel consisting of external experts reviewed whether the long-lead optical components were ready for acquisition; after the two day detailed review, they concluded the team provided sufficient analysis to justify the early purchase of the long-lead opto-mechanical units, believing the risk of proceeding was small. We expect the SCORPIO team to place contracts for all of these items in Q1-2019.

We also held a project quarterly progress review at the Southwest Research Institute (SwRI) in San Antonio, Texas, from November 26-28. The team presented a large amount of new work and demonstrated solid progress made since the last project review in August. The schedule to a Q1-2019 Critical Design Review (CDR) remains tight as there are a number of key analyses on the final design that only occur late in the schedule; the team plans to move these items earlier so we can proceed on schedule. We will re-assess readiness for the planned March 2019 CDR in January.

During the progress review, the team presented a design for a slit viewing camera to reduce target acquisition time, and we now intend to make this subsystem part of the instrument's baseline. A slit viewing camera reduces operational overhead and generally increases overall efficiency. The project's E2V engineering grade devices arrived earlier this year (Figure 2). SwRI reported that the four science grade E2V detectors and the four HAWAII-2RG arrays have updated earlier delivery dates in Q1 2019, before CDR.

New Integral Field Units for GNIRS

Gemini has a long-term commitment to produce user-motivated upgrades to the operating instruments at both sites. The Instrument Upgrade Program (IUP) provides funding to upgrade existing operational instrumentation through community-created science-driven proposals, creating a new instrument capability at the Observatory. After the public request for proposals issued in 2017, the highest ranked proposal was to return integral field unit (IFU) capabilities to the Gemini Near-InfraRed Spectrometer (GNIRS), a project lead by Ray Sharples from the University of Durham.

Ray and his team will build and commission two new IFUs for GNIRS, to replace the one that was destroyed in a 2007 accident. The first IFU will have similar specifications to the original GNIRS IFU, with a field of view of approximately 3 x 5 arcseconds and a spatial sampling of 0.15 arcseconds. It will be optimized for observations over the full GNIRS wavelength range from 1.0 to 5.4 microns.

The second IFU will be AO-optimized over the 1.0- to 2.5-micron wavelength range, with a field of view of approximately 1.0 x 1.5 arcseconds and a spatial sampling of 0.05 arcseconds. The GNIRS IFUs will complement those of Gemini's Near-infrared Integral Field Spectrometer with extensions in wavelength out to the thermal infrared L & M bands, and spectral resolutions up to R ~ 18,000.

In December we finalized the contract with the team for the work. We will hold a project kickoff in January 2019, and commissioning and science verification of both IFUs is planned for November 2020. We plan to offer the IFUs under a shared risk mode in 2021A. Re-commissioning of the IFU mode for GNIRS will open up a unique window for spatially resolved spectroscopy on Gemini, including study of the kinematics of stellar outflows around high-mass young stellar objects, probing the active galactic nucleus-starburst connection, estimating black hole masses from infrared line diagnostics, resolved spectroscopy of gravitationally lensed galaxies, and resolving jet dynamics in Herbig-Haro objects.

The project will be entirely based at the Centre for Advanced Instrumentation (CfAI) at Durham University, where the original GNIRS IFU was designed and built. The project will exploit the in-house diamond machining facilities that have since been used to deliver successful image slicing IFU instruments for the *James Webb Space Telescope* (NIRSpec IFU) and European Southern Observatory's Very Large Telescope (KMOS). This facility was not available at the time of manufacture of the original GNIRS IFU and will enable substantial improvements in performance.

GIRMOS Project Ready to Roll

The Gemini InfraRed Multi-Object Spectrograph (GIRMOS) is a welcome addition to the Gemini Visiting Instrument Program. This powerful new instrument is being de-

Figure 3. *GIRMOS Prinicipal Investigator Suresh Sivanandam (right) with Kick-off Meeting participants.*

Credit: University of Toronto

signed to have the ability to observe multiple sources simultaneously at high angular resolution while obtaining spectra at the same time (Sivanandam *et al.*, Proc. SPIE, 2018). It accomplishes this by exploiting the adaptive optics (AO) correction from both a telescope-based AO system (either the Gemini Multi-conjugate adaptive optics System (GeMS) or the prospective Gemini North AO system) and its own additional Multiple-Object Adaptive Optics system that feeds four 1- to 2.4-micron integral field spectrographs (R ~ 3,000 and 8,000) that can each observe an object independently within a 2 arcminute field of view.

GIRMOS is being designed and built by a Canadian consortium of universities led by the University of Toronto and the National Research Council-Herzberg Institute of Astronomy and Astrophysics. The GIRMOS project is just getting underway, and Gemini staff were invited to participate in the Kick-off Meeting on December 4-5 at the Dunlap Institute in Toronto, Canada (Figure 3). The meeting was extremely productive, with discussions on science cases, capabilities, schedules, and responsibilities as we move into the conceptual design phase.

In January, members of the GIRMOS team will come to Chile to participate in GeMS observing to learn more about the AO system and current telescope operations. We are very excited about working with the team on this cutting-edge new capability for Gemini, and we look forward to a fruitful collaboration over the next few years!

Figure 4. *Celebrating first light with the MAROON-X Front End. From left to right: Gemini senior instrumentation engineer John White, Gemini Instrument and user support scientist Alison Peck, and University of Chicago representatives Julian Stuermer and Andreas Seifahrt.*

Credit: Siyi Xu, Gemini Observatory

MAROON-X Front End Commissioning

MAROON-X is a radial velocity spectrograph being built at the University of Chicago, which is expected to have the capability to detect Earth-size planets in the habitable zones of mid- to late-M dwarf stars using the radial velocity method. The instrument is a high-resolution, bench-mounted spectrograph designed to deliver 1 meter/second radial velocity precision for M dwarfs down to and beyond V = 16. In order for MAROON-X to come to Gemini as a visiting instrument, the team had to construct a Front End that would fit on the bottom instrument port at Gemini North, while holding the fiber that runs down to the spectrograph located in the Pier Lab below.

This Front End unit recently arrived in Hawai'i, and was installed on the telescope for testing in December. The commissioning has gone very well, thanks to the diligence and care that the instrument team have put into the design and construction, and the excellent support we have received from the Gemini engineering staff.

We achieved first light on the same day as installation (Figure 4), and spent a few hours over the ensuing evenings verifying that the software behaved as expected, and that the atmospheric dispersion correction and guiding met specifications. Based on the success of the Front End (Figure 5), we are looking forward to the arrival of the spectrograph itself in early 2019. Watch this space for more news in the next few months!

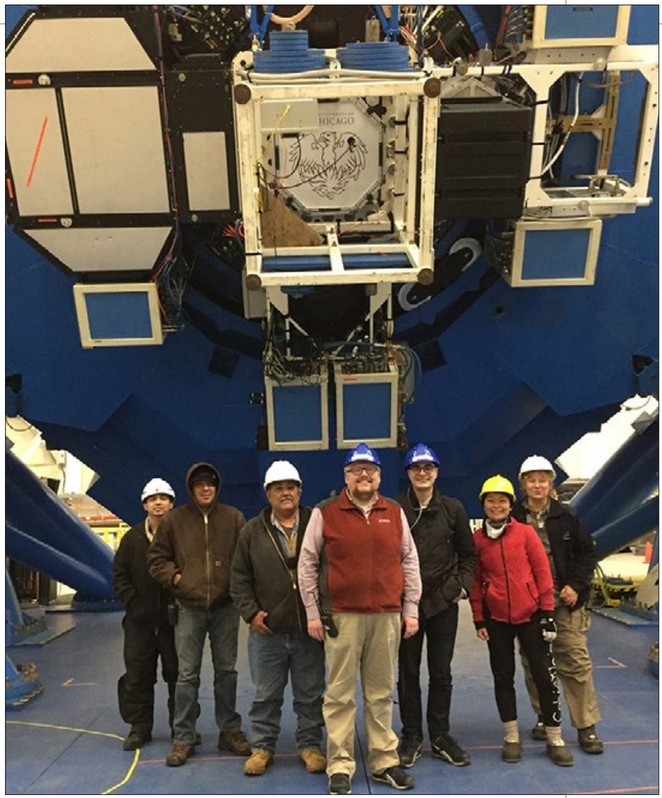


Figure 5. *Posing with the MAROON-X Front End, now installed on Gemini North. Left to right: Gemini mechanical technician Cy Bagano, electronic and instrumentation technician Eduardo Tapia, day crew member Harlan Uehara, Andreas, Julian, Gemini assistant astronomer Siyi Xu, and Alison.*

Credit: John White, Gemini Observatory

OCTOBER 2018

Gemini Observatory to Advance Adaptive Optics and Multi-messenger Astronomy with NSF Award

Gemini recently received a multi-million dollar award from the National Science Foundation (NSF) to enhance its role in the era of "multi-messenger astronomy" and improve its adaptive optics (AO) capabilities. The award funds major software and operational upgrades at both of the Gemini 8-meter telescopes for rapid follow-up studies of transient sources, as well as a state-of-the-art multi-conjugate adaptive optics (MCAO) system for wide-field, high-resolution imaging at the Gemini North telescope on Maunakea in Hawai'i.

The new funding will be used in part to develop automated systems to trigger follow-up observations and quickly deliver science-ready data to astronomers through automated data processing pipelines. "With this funding Gemini will significantly advance multi-messenger and time-domain, or transient-source, astronomy," said Anne Kinney, Head of the Mathematical and Physical Sciences Division at NSF. "We've witnessed a surge of astronomical discoveries in areas such as gravitational waves, exotic varieties of stellar explosions, and collisions within our own Solar System where a full understanding depends critically upon rapid characterization of the discoveries using ground-based facilities like Gemini," Kinney added.

The award will also fund the development of an advanced MCAO system for high-resolution studies at Gemini North, building on the experience developed from the world-leading Gemini Multi-conjugate adaptive optics System (GeMS) facility at Gemini South. Gemini will work with visiting instrument teams, including the team developing the Gemini InfraRed Multi-Object Spectrograph (GIRMOS) and the broader community, to develop additional instruments for the new AO system.

"Deep all-sky surveys such as the Large Synoptic Survey Telescope will not only revolutionize the study of transient sources, but also revolutionize our view of what we think of as the 'static Universe,' including galaxies, quasars, and other distant objects that appear unchanging on human timescales," added Gemini's Chief Scientist John Blakeslee. "With the new MCAO system in the North, and GeMS in the South, Gemini will be the only ground-based observatory capable of obtaining near-infrared imaging across the entire sky with a spatial resolution and field of view comparable to the *James Webb Space Telescope*."

Figure 6.

The SCORPIO team — from the Space Telescope Science Institute, Southwest Research Institute, George Washington University (GWU), FRACTAL, and Gemini Observatory — at the SCORPIO Quarterly Progress Meeting at GWU.

Credit: Alexander van der Horst

SCORPIO

Under the leadership of Massimo Robberto (Space Telescope Science Institute) and the management of Pete Roming (Southwest Research Institute), Gemini's next-generation instrument — the Spectrograph and Camera for Observations of Rapid Phenomena in the Infrared and Optical (SCORPIO; formerly OCTOCAM) — continues to make solid progress toward the Critical Design Review. Following a recent Quarterly Progress Meeting (Figure 6) held at George Washington University in August, the team are on track to hold the Optical Critical Design Review by the end of November. On completion, the team will seek permission to purchase long-lead optical components for the instrument, including the collimator and camera optics for each of the eight channels.

Other areas of the instrument's design are progressing well. Recent additional functionality include a mechanized cover, air purge system, and pupil imager.

The project remains on schedule to complete the design phase in 2019, delivery in 2021, and commissioning before the end of 2022.

Looking Forward to the Gemini Infrared Multi-Object Spectrograph

The Gemini InfraRed Multi-Object Spectrograph (GIRMOS) is a powerful new instrument being built for Gemini by a Canadian consortium of universities, led by the University of Toronto and the National Research Council-Herzberg (NRC-Herzberg) Institute of Astronomy and Astrophysics. This instrument will address a key limitation in existing adaptive optics (AO) facilities where integral field spectrographs are only able to observe single objects with adequate atmospheric correction, significantly limiting many scientific programs that could be efficiently observed with multiple integral field units.

By taking advantage of the latest developments in multi-object AO (MOAO) and integral field spectroscopy, GIRMOS is designed to have the ability to observe multiple sources simultaneously at high angular resolution while obtaining spectra at the same time (Sivanandam *et al.*, 2018). It accomplishes this by exploiting the AO correction from both a telescope-based AO system (either GeMS or the prospective Gemini North MCAO system) and its own additional MOAO system that feeds four 1-2.4 μm integral field spectrographs (R ~ 3,000 and 8,000) that can each observe an object independently within a 2 arcminute field of view.

While GeMS is a multi-conjugate AO (MCAO) system, which applies a global AO correction over the entire field, the GIRMOS MOAO strives to optimally correct the observable field of each individual spectrograph. In general, MOAO applies a better correction to multiple specific spots over a field of view, while MCAO provides somewhat less correction uniformly over the entire field of view. For the multiple-IFUs of GIRMOS, an MOAO system provides optimal performance with improved imaging performance along each integral field spectrograph's line of sight. This powerful capability will be unique to GIRMOS as no other 8- to 10-meter-class observatory has a workhorse MOAO instrument.

The current design parameters of the instrument concept are given in the table below. The instrument will also offer simultaneous imaging capability that is at a slightly lower resolution compared to the Gemini South Adaptive Optics Imager (GSAOI). The chosen design significantly increases the speed of integral field spectrograph surveys for science projects that target areas with high source densities, such as detailed observations of distant galaxies.

Additionally, GIRMOS will be the first multi-object infrared integral field spectrograph to offer a high spectral resolution mode that enables key science not possible on existing AO-fed spectrographs, particularly those relating to the chemodynamics of astronomical objects. This unique combination of multiplexing integral field spectrographs with high spatial and spectral resolution will make GIRMOS the forefront survey instrument for a broad range of topics in astronomical research.

The primary scientific questions that will benefit greatly from the multiplexing capabilities of GIRMOS are:

- Low- and high-mass star formation within the Milky Way
- The search for intermediate-mass black hole formation in central regions of globular clusters
- The formation process of the Milky Way's supermassive black hole and its environment
- The nature of optical, infrared, radio, and gravitational-wave transients
- Relative roles of internal processes and environment at the peak of galaxy formation
- Galaxies, black holes, and globular cluster formation processes at "Cosmic Dawn"
- Ultra-high angular resolution studies of distant galaxies aided by gravitational lensing
- Relationship between cold gas, star formation, and dynamics in galaxies at high redshift

GIRMOS will also be a powerful scientific and technical pathfinder for the Thirty Meter Telescope's (TMT) Infrared Multi-Object

Telescope Feed	Gemini 8.1-meter MCAO f/33 beam	**Individual IFS field of view (arcseconds)**	1.06 × 1.06 2.1 × 2.1 4.2 × 4.2 8.4 × 8.4 (all IFS combined)
MOAO Performance	> 50% encircled energy within 0.1″ (H and K bands)	**IFS Spatial Pixel Size (milliarcseconds)**	25 × 25 50 × 50 100 × 100 100 × 100 (all IFS combined)
Field of Regard	2′ diameter patrol field	**Spectral Resolution (R)**	3,000 or 8,000
Wavelength Range	1.1–2.4 µm (J, H, or K bands)	**Spectrograph Throughput**	> 40%
Number of IFSs	4 (with a goal of 8)	**Detector**	4,096 × 4,096 HAWAI'I-4RG for 4 spectral channels
Imager Field of View	100 × 100″	**Imager Plate Scale (milliarcseconds)**	25
Imager Wavelength Range	1.1–2.4 µm (J, H, or K bands)	**Imager Detector**	4,096 × 4,096 HAWAI'I-4RG

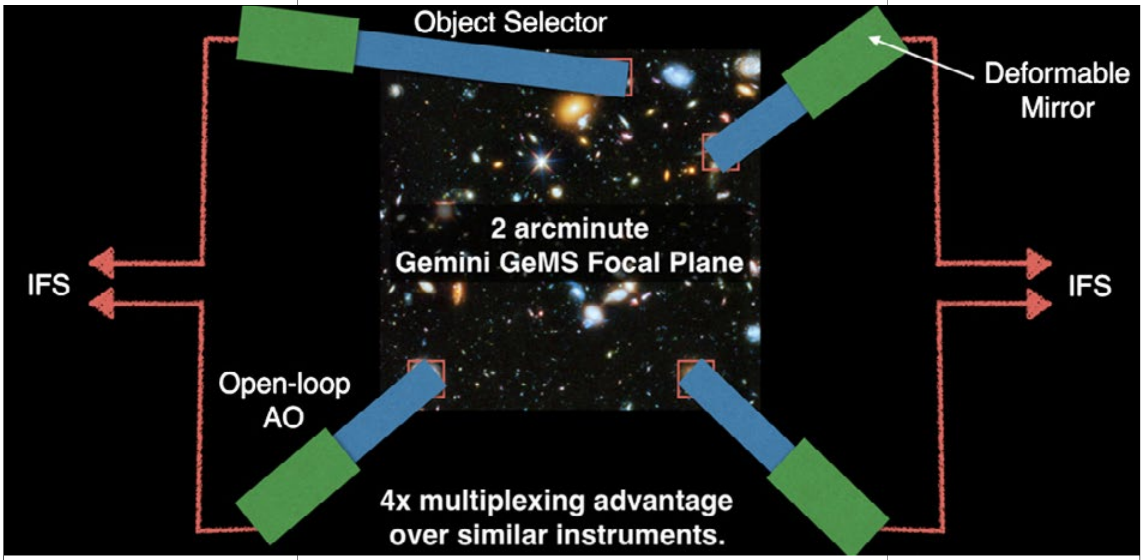


Figure 7.
Schematic of the GIRMOS instrument. Light from individual objects within the AO field is picked off by GIRMOS and corrected by an additional AO system before being fed into the IFS units. The IFS units offer larger fields of view for a given sampling scale when compared to existing IFSs. This offers up to ten times the multiplexing gain over existing AO spectrographs.

Spectrograph (IRMOS), which will be a future second-generation instrument. While highly ranked scientifically, a number of potential hurdles were identified in the original IRMOS concepts for the TMT. MOAO, which critically relies on open-loop control, had not been demonstrated on-sky, and the overall cost of the AO system and the multiple spectrographs was prohibitive. These concerns led to IRMOS not being chosen as a first-light instrument for the TMT.

However, the landscape has now changed with MOAO successfully demonstrated on-sky through technical pathfinders such as RAVEN on Subaru, led by our team members, and infrared integral field spectrographs being well-established technology (*e.g.*, Gemini's Near-Infrared Integral Field Spectrometer). Our efforts in developing GIRMOS will build the necessary scientific and technical expertise to provide similar capabilities for the next generation 30-meter-class telescopes.

We plan to commission GIRMOS in 2024 and expect to be well positioned to offer GIRMOS as a workhorse survey instrument for the Gemini community. By 2024, several exciting projects should be underway, including both the *James Webb Space Telescope* and the European Space Agency's *Euclid* space telescope, which promise to provide exciting new bright, infrared targets for spectroscopic follow-up. Gravitational wave detectors such as the Laser Interferometer Gravitational-Wave Observatory in combination with imaging follow-up will provide well-localized gravitational wave sources. Likewise, the Large Synoptic Survey Telescope (now under construction in Chile) and the Square Kilometre Array (to be built in Australia and South Africa) pathfinders will be detecting exotic transient sources; and the current Atacama Large Millimeter Array will be in an era of providing large, well-characterized surveys.

With its multiplexing ability, and particularly with the benefit of the newly announced Gemini North AO system which should provide an even better corrected field, GIRMOS at Gemini is ideally positioned to lead the era of multi-messenger astronomy, undertaking surveys of large samples of sources discovered by these diverse state-of-the-art telescopes.

References:

Sivanandam, S., *et al.*, 2018, Proc. SPIE, 10702, 107021J (*arXiv:1807.03797*)

No Instrument Upgrade Program Call this Year

As several projects from previous years are still underway, we decided not to have a Call for Proposals in our Instrument Upgrade Program this year. We expect to release our next call in mid-2019. *Visit the IUP web pages* for more information.

JULY 2018

Gemini North TOPTICA Upgrade Moves Forward

On October 26, 2017, the TOPTICA Photonics AG laser had its first night of commissioning (and successful science runs) at Gemini South. Since then, laser preparations and testing for the Gemini North laser upgrade have been completed at the Level 1 Pier Lab. Following this accomplishment, considerable work was performed to add the optical bench, or beam injection module, to the Gemini North Electronic System TOPTICA (GNEST) — home to both the laser head and optical bench; support electronics have also been added and tested (Figures 8 and 9 on this page; Figure 10 on next).

On June 1st, the laser assembly was moved from the Level 1 Pier Lab to Level 5; and there it will remain as we continue to prepare the telescope for this addition, as additional components are required before we can mount the laser on the telescope. To date, we have removed the old LMCT laser, restored the telescope to pre-laser condition, and added our in-house designed heat exchanger and laser interlock system. The software group is also working hard to develop the software interfaces that will be used to run the new laser. We expect continued preparation on the telescope this month and next.

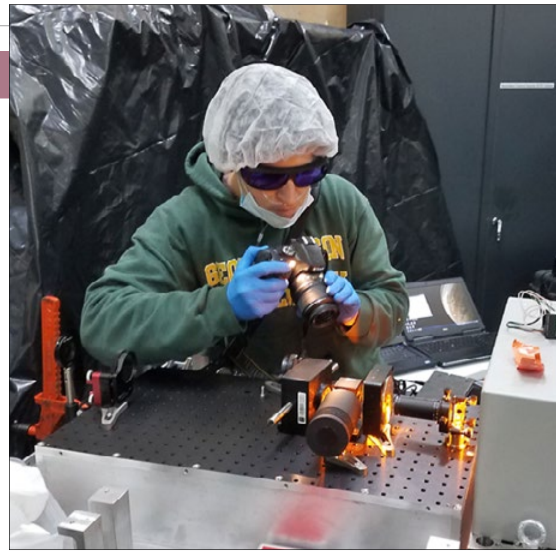


Figure 8.

Laser testing by Gemini optical engineer Tom Schneider conducted in the Pier Lab "Laser Safe Zone."

Figure 9.

Gemini science operations specialist Christy Cunningham assisting with GNEST Assembly in the Pier Lab.

Credit: Photos on this page and next by Jeff Donahue

SCORPIO: OCTOCAM's New Name

OCTOCAM, Gemini's new workhorse imager and spectrograph that will fulfill the needs of a large number of research areas in the 2020s, has a new name: SCORPIO, which stands for Spectrograph and Camera for Observations of Rapid Phenomena in the Infrared and Optical. In the words of project Principal Investigator Massimo Robberto, "This new name captures the capabilities of the innovative and powerful future Instrument, operating over a very broad wavelength range from the visible to near-infrared light." The instrument also features both imaging and spectroscopic capabilities, as well as fast readout modes.

Scorpio is Latin for "scorpion," a primarily nocturnal invertebrate, which, like the number of channels (wavelength windows) available on the instrument, has eight legs. Scorpio is also the eighth sign of the zodiac, represented in the night sky by Scorpius the

Figure 10.

Clockwise from top left:

Gemini day crew member Chris Yamasaki performs electronic assembly on GNEST in the Pier Lab.

Gemini information systems (IS) engineer Simon Chan connecting IS services to GNEST.

Gemini senior optical technician Clayton Ah Hee (left) and Maunakea administrative assistant Joe D'Amato preparing the GNEST cable support.

Gemini mechanical technician Cooper Nakayama (right) controls the crane operation, while Clayton (kneeling at left) and Gemini mechanical technicians Rody Kawaihae (kneeling at right, background) and Cy Bagano prep the EC to lift for a fit test on the telescope.

Rody, Joe, Christy Cunningham and Clayton (from left to right) after moving the TOPTICA laser from the Level 1 Pier Lab to Level 5.

Gemini summit crew member John Randrup (left) and Cooper Nakayama testing LHX, our laser heat exchanger, on the center section of the telescope.






Scorpion — a constellation that, in the winter, passes overhead at the Gemini South telescope facility where it will be used.

This name change coincides with the instrument's development moving into its Critical Design stage in May of this year. The project remains both on budget and on schedule; it is slated for commissioning in 2022.

What's New with Visiting Instruments?

IGRINS, a visiting cross-dispersed immersion grating near-infrared spectrometer provided by the Korea Astronomy and Space Science Institute (KASI) and University of Texas Austin (UT Austin) has proven extremely popular. This powerful and unique instrument, which can obtain both broad spectral coverage (from 1.45 to 2.5 microns in a single exposure) and high spectral resolution (R = 45,000), has been on Gemini South for 50 nights in 2018A. A stalwart team of postdocs, students, and faculty from Korea and the United States are supporting the instrument, and the observations are going very well. We are discussing possibilities for a longer visit in the future.

'Alopeke (a contemporary Hawaiian word for "fox") is an agile dual-purpose speckle imager that provides diffraction-limited performance on an 8-meter telescope. This upgraded version of its older sibling, the Differential Speckle Survey Instrument (DSSI) now has its own special location on Gemini North: mounted between the Gemini Calibration Unit and the Instrument Support Structure, so that we don't need to remove it between observing runs. 'Alopeke will continue to be offered regularly to provide outstanding imaging capabilities. (See Figure 11 for images related to IGRINS, 'Alopeke, and DSSI.)

DSSI is still performing well, having spent a few nights on Gemini South this year for a terrific observing run, capturing upwards of 100 targets per night. Next year, keep an eye out for another upgraded and permanently mounted version of DSSI, called Zorro, to ap-

Figure 11.
Visiting instrument team members at Gemini. Clockwise from top left.

Brian Chinn (Gemini), Lindsey Magill (Gemini; in background), and Mark Everett (NOAO) observe with DSSI at Gemini South.

Rachel Matson (NASA) installs 'Alopeke at Gemini North.

From left to right: Jae-Joon Lee (KASI), Heeyoung Oh (UT Austin), Pablo Prado (Gemini), Hwihyun Kim (Gemini), Pablo Candia (Gemini), and Kimberly Sokal (UT Austin), get first light with IGRINS at the Gemini South Base Facility.

Heeyoung Oh (UT Austin; at left) and Greg Mace (UT Austin), perform connectivity tests with IGRINS at Gemini South.

pear at Gemini South.

High-precision polarimeters now abound at Gemini with the promise of two new and exciting visiting instruments: POLISH-2 (aimed at exoplanet reflection polarimetry) and HIPPI-2 (designed to capture the direct polarization signatures of exoplanets). POLISH-2 will have its first observing run in 2018B; we look forward to hosting this instrument for a few nights in August on Gemini North and seeing the great science it can do. HIPPI-2, visiting from the University of New South Wales, is scheduled for commissioning soon; it may be ready to join the party in the next few semesters.

Planning Ahead

We are also very excited to be preparing for MAROON-X — a new visiting exo-Earth finder from the University of Chicago. This fiber-fed, red-optical, high-precision, radial-velocity spectrograph is expected to not only identify and characterize nearby habitable exoplanets, but ultimately make a credible search for life on planets outside the Solar System. Currently, it is scheduled to be deployed at Gemini North next year, and we are in the process of installing an enclosure in the Pier Lab that will help regulate the temperature and vibration environment for this advanced instrument. The instrument itself is expected to be commissioned on Maunakea in early 2019. Look for more reports on the results of testing next year, with a full description of the exciting capabilities that MAROON-X will bring to Gemini.

Looking even further ahead, we are working with a great team of folks from several institutions in Canada to bring the Gemini Infrared Multi-Object Spectrograph (GIRMOS) to Gemini around 2024. GIRMOS is an ambitious project designed to provide Gemini with high performance multi-object adaptive optics, and the ability to carry out simultaneous high-angular-resolution spatially resolved infrared spectroscopy of four objects within a 2 arcminute field when used with the Gemini Multi-conjugate adaptive optics System.

These are only a few of the visiting instruments planned for deployment on the Gemini telescopes in the next several years. You can find more information on these and others ***at this link***. Watch for announcements later this year to see what will be available for the 2019A Call for Proposals!

APRIL 2018

First Light for GHOST's Cassegrain Unit

In January 2018, the Cassegrain unit for the Gemini High-resolution Optical SpecTrograph (GHOST) arrived safely at Gemini South (Figure 12). It is the first of three primary assemblies to arrive and will be mounted on the telescope's Instrument Support Structure (ISS); the other two are the spectrograph bench (to be located in the Pier Lab), and a 30-meter-long fiber cable connecting the two. The Cassegrain unit contains the positioning arm system, the object and sky

Figure 12.
Second of two trucks delivering the Cassegrain unit to Cerro Pachón.
Credit: David Henderson

fiber integral field units (that capture all the light), and their corresponding atmospheric dispersion correctors.

The Australian Astronomical Observatory designed and built the Cassegrain unit, with the Australian National University providing the needed software. Members of each organization traveled from Australia to Cerro Pachón in Chile to unpack, assemble, and test the unit; they also had critical support from the Gemini South day crew, and from other Gemini GHOST team members.

The combined teams prepared and installed the Cassegrain unit on the telescope's ISS to make the first checks on sky in early February (Figure 13).

The team had a successful night of testing, with the instrument performing very well. A few of the evening's accomplishments included confirming that GHOSTS' coordinate systems and field center were aligned within our measurements, and ensuring that the probe map of the positioners was well behaved. The team also mapped the unit's coordinate systems to the sky, acquired targets repeatedly over the entire seven arcminute field of view, and verified that target acquisition (both direct and via spiral search) worked as expected in both the single target and two target modes. The team is enthusiastic about the performance of the GHOST Cassegrain unit and look forward to the arrival of the spectrograph from Canada's National Research Council-Herzberg.

OCTOCAM Making Great Strides

OCTOCAM — Gemini's next generation imager and spectrograph — has had a busy start to 2018. In January, a Quarterly Progress Review took place at George Washington University in the United States and at FRACTAL S.L.N.E. (a private technological company that specializes in astronomical instrumentation and scientific software working on the instrument's optomechanicals) in Madrid, Spain.

Figure 13.
GHOST team members (left to right) Tony Farrell, John Bassett, Gabriella Baker, Ross Zhelem, Peter Young, Lew Waller, Richard McDermid, Steve Margheim, and Manuel Gomez observe some of the first light captured by the GHOST Cassegrain unit at Cerro Pachón.
Credit: David Henderson

In March, Gemini Observatory announced Massimo Robberto of Space Telescope Science Institute and Johns Hopkins University as the new OCTOCAM Principal Investigator (Figure 14). OCTOCAM also welcomed Todd Veach of Southwest Research Institute (SwRI) in San Antonio, Texas, as the OCTOCAM Instrument Scientist.

Coming up, the Preliminary Design Review will take place at SwRI on April 4-5, 2018. John Troeltzsch of Ball Aerospace will chair the external review panel, which has deep expertise and a world of experience in instrumentation development and project management. OCTOCAM remains on schedule (and on budget) to be commissioned by the start of 2023.

Figure 14.
Massimo Robberto, the new OCTOCAM Principal Investigator.

TOPTICA Laser at Gemini South

After over two years of feasibility studies, specifications, design studies, tests, integrations, and validations, Gemini South's new TOPTICA Phototronics AG laser had its first night of commissioning on October 26, 2017. It took only ten minutes for the upgrade project's team of scientists, observers, and engineers to see our lovely five laser guide star constellation back on sky using the acqui-

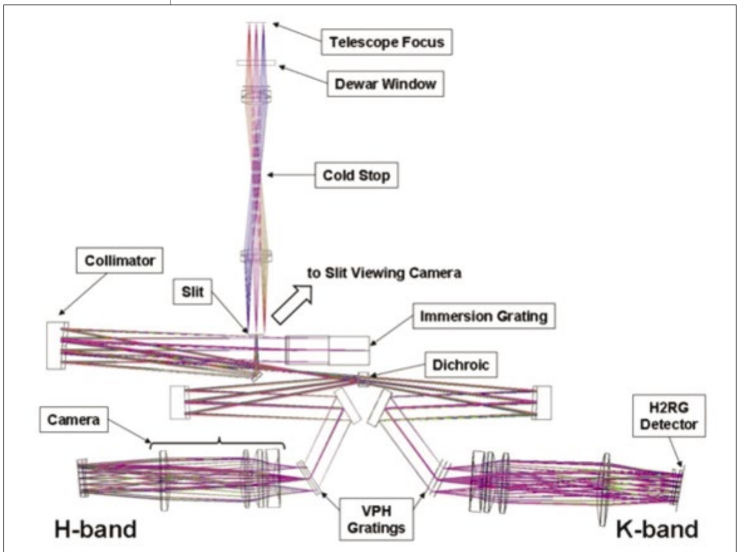


Figure 15.
Optical layout for IGRINS. All parts shown are within the cryogenic part of the instrument. For Gemini, the five optical elements between the dewar window and the slit were exchanged.

Figure 16.
The IGRINS team (left to right respectively, back row: Gregory Mace, Jae Sok Oh, Chan Park; front row: Heeyoung Oh and Kimberley (Sokal). Mace shot this "selfie" in the IGRINS lab at UT Austin in February 2018. The new input optics for IGRINS at Gemini are shown in the background after installation.

Credit: Gregory Mace, UT Austin

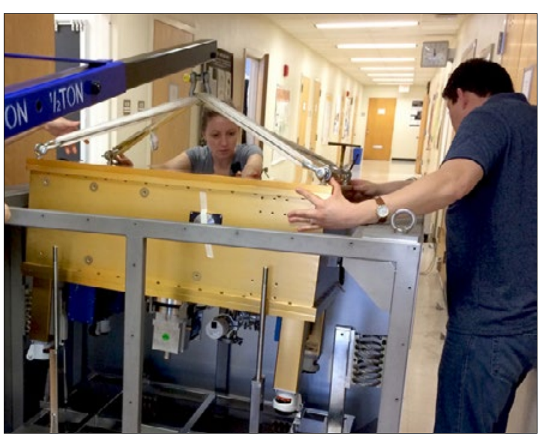


Figure 17.
IGRINS team members Kimberley Sokal (left) and Ricardo Lopez at UT Austin packing the instrument for shipping.

Credit: Gregory Mace, UT Austin

sition camera; and it took them only three nights out of five to validate the laser's performance; during the tests, the laser did not suffer any faults, and its output power was very stable at 22 watts.

Since the commissioning, we have had two very successful science runs, during which the laser remained very stable with no faults occurring. Even with its power being much lower than that of its Lockheed Martin Coherent Technologies predecessor, the return flux has been very sufficient to keep stable closed loop operation (even during low sodium season). We also achieved unprecedented performance during our first science run at sub-80-milliarcsecond-level performance in the J-band.

The TOPTICA laser has considerably lessened our daytime work to prepare for a laser night, requiring only that we turn the key on a few hours before the night, and the Gemini Multi-conjugate adaptive optics System (GeMS) is ready to operate. The GeMS team looks forward to more regular laser windows now to operate GeMS at its best.

2018A Brings Outstanding Near-IR Spectroscopy to Gemini South

Through the Visiting Instrument Program, Gemini users have access to a powerful new capability for the 2018A semester: the broadband, high-spectral-resolution Immersion GRating INfrared Spectrometer (IGRINS; Figures 15-20). IGRINS is a collaboration of the University of Texas and the Korea Astronomy and Space Science Institute (KASI). This cross-dispersed near-IR spectrometer has a resolving power of R = 45,000 covering the H and K windows (from 1.45 to 2.5 microns, respectively) in a single exposure.

IGRINS has a strong track record of diverse and innovative science results, having spent over 350 nights at the 2.7-meter Harlan J. Smith Telescope at McDonald Observatory in Texas, and 200 nights at Lowell Observatory's 3.5-meter Discovery Channel Telescope in Arizona. Recent results span a range of topics including cold molecular clouds, diffuse interstellar bands, T Tauri stars, systems containing multiple stars and/or planets, and even microquasars. The response to IGRINS at Gemini has been extremely strong, resulting in many successful proposals for 2018A.

As a visiting instrument, IGRINS is ideal because it has a single observing mode and contains no moving parts (Figure 15). By exchanging the input optics to accommodate Gemini, the IGRINS H and K echellograms will be unchanged between facilities. In March, the instrument team (Figures 16-18) will accompany IGRINS to Gemini South, where they will install and test it before supporting observations with the help of Gemini staff for a total of 50 nights (Figures 19 and 20). The team also will provide a simple data reduction pipeline to assist novice users.

At the moment, much work needs to be done to carry out the large number of planned 2018A observations and provide the data to the community — so there are no immediate plans to make IGRINS available next semester. We do hope, however, to host IGRINS at Gemini again in the future, as well as other unique and compelling capabilities. Remember to keep an eye on future Gemini Calls for Proposals!

Daniel Jaffe of UT Austin is the IGRINS Principal Investigator (PI). Chan Park of KASI is both deputy PI and KASI instrument PI. Jae-Joon Lee at KASI supervises the IGRINS operational program on the Korean side. The IGRINS visit to Gemini is supported by the US National Science Foundation under grant AST-1702267 (PI — Gregory Mace, UT Austin), and by the Korean GMT Project of KASI. Further technical details are available in Yuk *et al.* (2010), Park *et al.* (2014), and Mace *et al.* (2016).

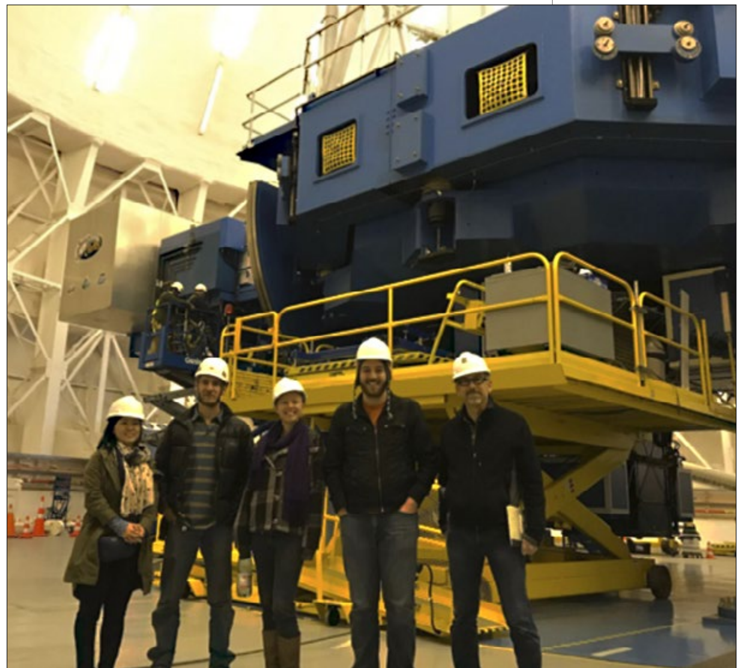
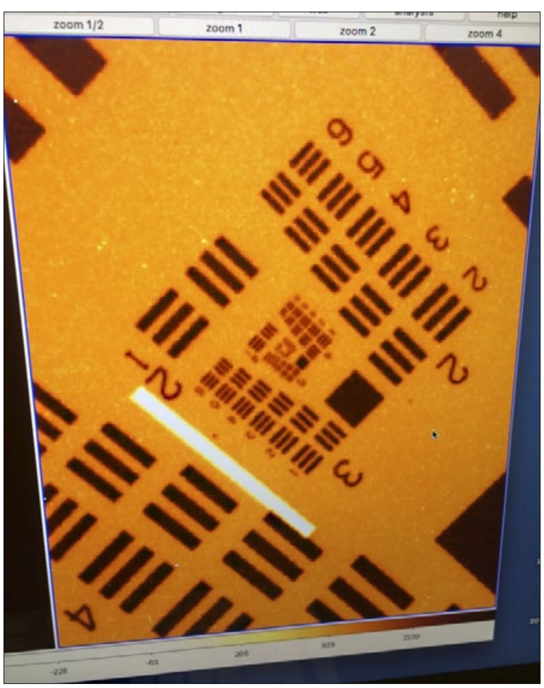


Figure 18.
IGRINS and Gemini team collaboration during a site visit to Gemini South (Hwihyun Kim, Brian Chinn, Kimberly Sokal, Greg Mace, and John Good, from left to right respectively).

Credit: Kimberly Sokal (UT Austin).



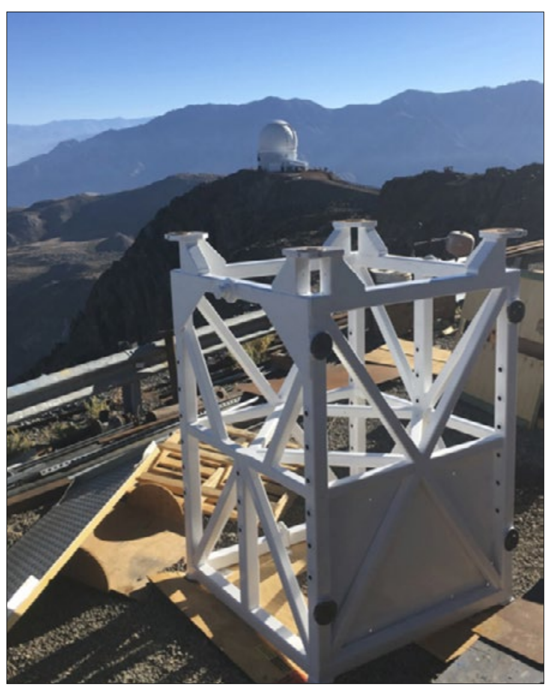
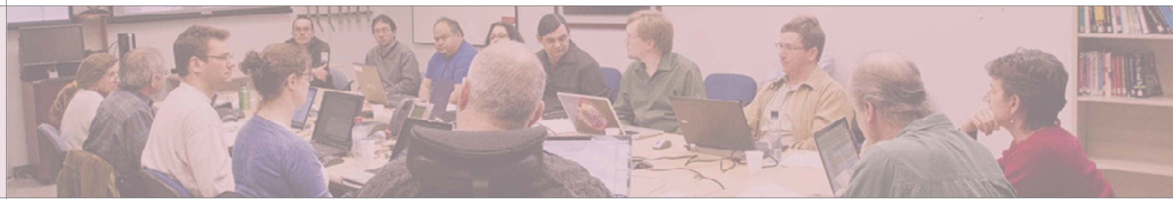


Figure 19.
Left: The IGRINS spectrograph slit (white bar) and a graduated scale used to measure optical performance. Lines resolved well below the slit width show that IGRINS optics for Gemini will perform as designed and sensitivity will be optimized.

Figure 20.
Right: The modified ballast weight assembly waiting in Chile to attach IGRINS to the telescope.

Credit: Brian Chinn (Gemini)



Gemini staff contributions

News for Users

A summary of news events throughout 2018 of relevance to the Gemini user community.

JANUARY 2019

Gemini North TOPTICA Laser Availability

The TOPTICA laser has been successfully commissioned for nighttime operation at Gemini North. The Laser Guide Star (LGS) mode will be available for Fast Turnaround and Director's Discretionary programs using the Phase 1 Tool released on December 11, 2018. The new laser allows us to move away from block scheduling and offer LGS mode on a greater number of nights. We are in the process of activating one Large program that was put on hold when our old LGS system failed.

During on-sky commissioning, we confirmed the stability of delivered power by the TOPTICA laser (Figure 1). We estimated the on-sky return to be the equivalent of an ~8 magnitude star (V mag), when propagating at zenith. This of course will vary as the sodium layer density fluctuates. In terms of image quality delivered by the adaptive optics system in LGS mode, a brief summary of the commissioning results is given in the table on the next page.

Figure 1.

Jesse Ball (foreground) operates the Gemini North telescope during on-sky commissioning of the new TOPTICA laser. Joining him are (from left to right) adaptive optics science fellow Laure Catala (in hat), optical engineer Tom Schneider, and Gemini scientist Paul Hirst.

Credit: Joy Pollard

LLP Call for Proposals

Gemini Observatory is again accepting Large and Long Program (LLP) proposals in 2019. LLPs are Principal Investigator-defined and -driven programs that, as a guideline, either require significantly more time than a partner typically approves for a single program

AO mode	NGS or TTGS V mag / separation	Seeing (@ zenith)	Elevation [deg] (seeing @ El)	NIRI imaging in K' FWHM (Moffat fit)
NGS vs LGS comparison (on-axis)				
NGS	8.75 / on-axis	0.39"	78 (0.40")	**91 mas**
LGS	12.6 / on-axis	0.40"	57 (0.44")	**102 mas**
Faint TTGS and Elevation dependance (on-axis)				
LGS	17.1 / on-axis	0.42"	67 (0.44")	**130 mas**
LGS	17.1 / on-axis	0.45"	40 (0.59")	**180 mas**
Performance Comparison off-axis				
LGS	16.4 / on-axis	0.48"	47 (0.58")	**125 mas**
LGS	16.4 / 22" off-axis	0.51"	47 (0.62")	**136 mas**

or extend over two to six semesters, or both. Large programs are expected to promote collaborations across the partnership's communities, have significant scientific impact, and provide a homogeneous data set, potentially for more general use.

The announcement of opportunity was released on December 15, 2018, and information on proposal submission can be found within the *Large and Long Program webpages*. All interested teams are required to submit a Letter of Intent no later than February 4, 2019, with full proposals due on April 1, 2019. In addition to the Gemini suite of instrumentation, Principal Investigators from LLP participating partners are invited to submit proposals for Subaru Intensive Programs via the Gemini-Subaru time exchange program.

New Data Reduction Resources for 2019

The FLAMINGOS-2 data reduction *cookbook* provides Python scripts that wrap tasks in the *Gemini IRAF package* and serve as a guide to the reduction and calibration of imaging and long-slit spectroscopy data. Visit the *FLAMINGOS-2 data reduction* webpage for more details. Comments, questions, or notifications of errors are encouraged and can be *submitted via email* or *helpdesk* request using the Gemini IRAF category.

A new, hands-on four-hour tutorial on reducing Gemini Multi-Object Spectrograph (GMOS) Integral Field Unit-1 data was presented live at the Science and Evolution of Gemini Observatory 2018 meeting in July. The participants were shown how to obtain the data and calibrations and go from raw data to a stacked cube, all the while addressing various possible data issues. An online version of the step-by-step tutorial is now available to everyone *at this link*. Software installation instructions are included.

A *document is now available* describing data reduction solutions to some of the more serious issues that arose due to problems with the GMOS instrument or detectors. The document is based mostly on issues with the GMOS-South Hamamatsu data and for now only discusses imaging data. It will be expanded to cover spectroscopy in the future. Feedback is welcome (*email here*).

A new version of the *DRAGRACES pipeline* fixes a previously problematic wavelength calibration. Please use version 1.2, or later, from now on. If you have ever used a previous DRAGRACES version, please have a second look! Note that it is always recommended to compare your GRACES extracted spectra using DRAGRACES and OPERA (extracted spectra are distributed by the *Gemini Observatory Archive*) before performing a detailed analysis. (Disclaimer: DRAGRACES is not a pipeline supported by the Gemini Observatory, and is therefore not required to follow the maintenance and testing standards. Visit the [*GRACES Data Reduction webpage*] for details.)

Join Gemini Staff at the January AAS Meeting in Seattle

Gemini Observatory and its partners will have many events at the 233rd American Astronomical Society (AAS) meeting in Seattle, Washington, January 6-10, 2019 (*www.gemini.edu/AAS*).

If you are at the AAS, please join us for the annual Gemini Observatory Open House on Tuesday, January 8th, from 5:30-6:30 p.m., in Room 305 of the Washington State Convention Center. We'll provide an overview of current activities and let you know how you can become involved in the ongoing developments at Gemini.

It has become a new tradition to offer personalized help at the Gemini booth at AAS winter meetings. If you have Gemini data, an active program, or even a vague project idea, come visit the Gemini booth any time during Exhibit Hall hours. You can also book an appointment in advance by emailing *SUS_inquiries@gemini.edu*.

Also at the AAS meeting don't miss the National Optical Astronomy Observatory US National Gemini Office mini-workshop on high-resolution spectroscopy at Gemini (Tuesday, January 8th, 2:00-3:30 p.m., Room 305), the Gemini Open House (Tuesday, January 8th, 5:30-6:30 p.m., Room 305), and the Gemini Workshop on science with SCORPIO (Wednesday, January 9th, 2:00-3:30 p.m., Room 310).

Finally, we will be distributing the base decks of the new Gemini Card Game at the Gemini booth (see next story).

Get Ready for the Gemini Card Game!

Gemini is creating an original card game with unique designs and challenging gameplay (release planned for January 2019).

The Gemini Card Game is a cooperative game for two to four players who work together to complete the required number of Band-1 programs, and as many additional programs as possible, in 12 rounds (*i.e.*, a semester) — all while avoiding loss of all their Reputation Points resulting in loss of funding and losing the game.

We will distribute the 90-card basic deck at the following annual, national, or Gemini user meetings: AAS 233, 233, K-GMT 2019, CASCA 2019, and LARIM 2019. Make sure to find our booth to get yours!

Complete rules can be found *here*.

Do you have something to contribute to the Gemini Card Game? Share your ideas, suggestions, comments, questions, experiences, *etc*. on the *GCG Forum*.

OCTOBER 2018

Polarimetry Abounds at Gemini North

In July and August 2018, we had the pleasure of two visiting instruments pushing the boundaries of polarization observations at Gemini North. First Jeremy Bailey and Daniel Cotton (both University of New South Wales) arrived to test their "new-to-us" instrument HIPPI-2 (Figures 2 and 3). Designed to capture the direct polarization signatures of exoplanets, this instrument has been in use at the 3.9-meter Anglo-Australian Telescope with spectacular results (Bott *et al.*, *Monthly Notices of the Royal Astronomical Society*, **459:** L109, 2016). The Gemini visit also went well, and though the instrument has not been made available for science observations yet, these initial tests will be very helpful in characterizing the polarization characteristics of the Gemini North telescope. We hope to include HIPPI-2 in a future Call for Proposals, so please remember to check the list of visiting instruments whenever a new call comes out!

In early August, we hosted a science visit by Principal Investigator Sloane Wiktorowicz (The Aerospace Corporation, El Segundo, California) with his instrument POLISH-2 (Figure 4). Aimed at exoplanet reflection polarimetry, POLISH-2 is available to the community, and we encourage everyone to have a look at the Call for Proposals and contact Sloane (using the details provided there) if they wish to take advantage of this cutting-edge polarimeter on Gemini North. The amount of time our visiting instruments are available on the telescope is driven by the number of successful proposals, so we encourage everyone to go for it! The exciting results of this recent observing run are being prepared for publication now.

Figure 2.
Jeremy Bailey (left) and Daniel Cotton (right) attach their tiny HIPPI-2 instrument to the bottom port of Gemini North, with help from Harlan Uehara (Maunakea Site Manager, center).

Credit: All photos on this page by Alison Peck

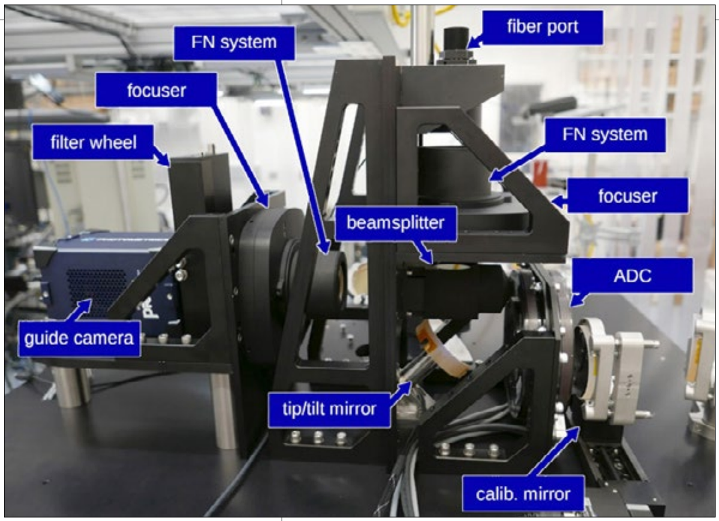
Figure 3 (left).
Harlan Uehara (left) and Gemini North's Senior Instrumentation Engineer John White (right) position the ballast weight assembly so that it attaches to the instrument port around HIPPI-2. The ballast weight is necessary to balance the telescope because HIPPI-2 weighs much, much less than the facility instruments!

Figure 4 (right).
Gemini day crew members Clayton Ah Hee (left) and Rody Kawaihae (right, kneeling) assist Sloane Wiktorowicz (center) in installing POLISH-2.

MAROON-X: Coming Soon!

MAROON-X is the hotly anticipated new spectrograph in construction at the University of Chicago that will be coming to Gemini North as a visiting instrument next year (Figures 4 and 5). MAROON-X is expected to have the capability to detect Earth-size planets in the habitable zones of mid- to late-M dwarfs using the radial velocity method. The instrument will be a high-resolution, bench-mounted spectrograph designed to deliver 1 meter per second radial velocity precision for M dwarfs down to and beyond V = 16. More information about MAROON-X can be found in the *January 2018 issue of GeminiFocus*.

As this instrument will be located in the Pier Lab, under the telescope, in its own thermally controlled enclosure, Gemini has commissioned a Front End to interface to the Instrument Support Structure. This unit will hold



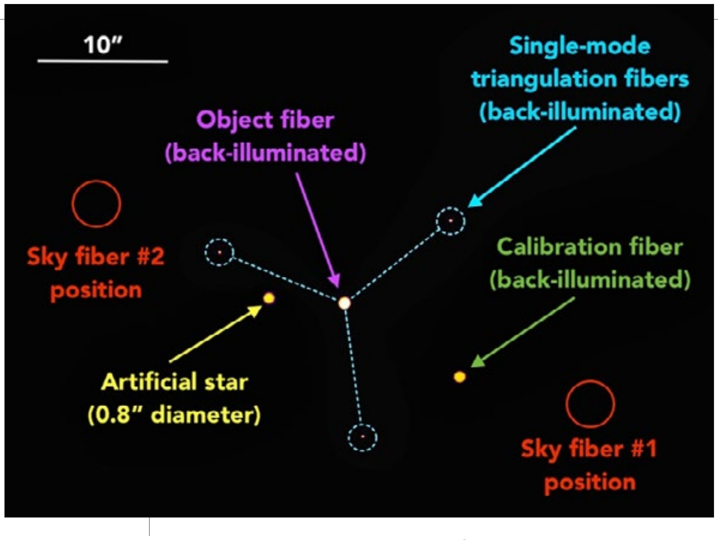


Figure 5 (above left). *The MAROON-X Front End nearing completion at the lab in Chicago.*

Credit: Andreas Seifahrt

Figure 6 (above right). *MAROON-X guide camera diagram showing the object fiber in the center (back-illuminated), surrounded by three single-mode fibers. These three fibers allow us to triangulate the position of the object fiber in real time during the observations. A tip-tilt mirror is used to center the stellar image on the object fiber. For lab testing, an "artificial star" was created by placing a pinhole at the nominal telescope focus and illuminating it with an f/16 beam. Two sky fibers, placed 20" from the object fiber in opposite positions, are used to capture the sky background for a high-dispersion spectrum in MAROON-X and for a time-resolved, low-dispersion spectrum with an external spectrograph. A calibration fiber transports light from the spectrograph room to the telescope's front end and is used to illuminate the object and one of the sky fibers for flatfield and wavelength calibration frames. Credit: Andreas Seifahrt*

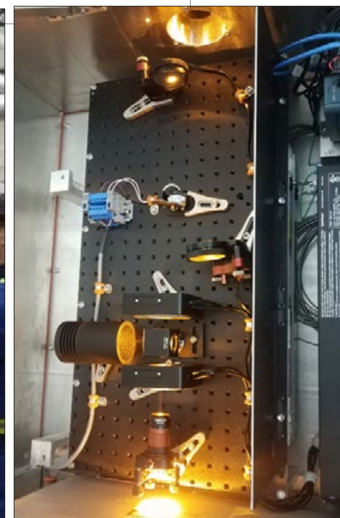
the optical fiber that runs to the instrument and will also include some optics and electronics, as shown in Figure 5. The Front End components are integrated and undergoing testing in Chicago at this time; the pre-ship acceptance test is scheduled for late October. The plan is to commission the Front End on the telescope first, using a simple detector, so that we are ready to commission the MAROON-X spectrograph when it arrives next year.

TOPTICA Laser Update

As a proven, stable laser platform, the new TOPTICA fiber laser is expected to bring more power and stability to Gemini North (GN) laser operations. We continue to make progress with the installation of the system (Figures 7-10). With the old Lockheed Martin Coherent Technologies laser removed and telescope restored, we were able to begin modifying the telescope to accept the new laser and, in June, we began preparations to install it.

The GN laser design allowed the creation of a single housing for both the laser head and Beam Injection Module Optical Bench. We refer to the housing as GNEST (Gemini North Enclosure System for TOPTICA). The laser head within the GNEST is coupled to the TOPTICA Electronics Cabinet (EC) by optical fibers and communication cabling. We maintained the fiber coupling during installation, which was quite demanding logistically and required careful planning.

The addition of new equipment high on the telescope required additional counterbalance weights for the telescope. These weights were designed and added in sequence; doing so allowed us to install the laser components (GNEST and EC) while maintaining telescope balance through the day (July 19th). We then installed the utilities and services for the laser. Testing began with power on August 16th, followed by first open-beam verification on the 22nd. Laser alignment through the optical path to the Beam Transfer Optics Optical Bench on the secondary was verified, allowing us



to conduct our first on-sky propagation at zenith on August 31st. This was conducted remotely from the Hilo Base Facility. We continue to prepare for commissioning.

GMOS-S Bubbles Eliminated!

A long-standing problem affecting the Gemini Multi-Object Spectrograph (GMOS) performance has been resolved recently. In GMOS a special optical oil is used between the different lenses to minimize interface surface effects, particularly loss of throughput by partial reflection, and degradation of image quality. Over time, minuscule leaks cause bubbles to appear in the interfaces between the lenses. Many of these bubbles can be filled again with small amounts of optical oil, as has been done on both GMOS North and South on several occasions. However, the lenses in the collimator assembly are embedded within the instrument, not allowing access to the filling ports — unless the instrument is disassembled, something which had never been done before. Yet this was the task before us.

To access the filling ports, a complete disassembly was required. We first designed and built an opto-mechanical alignment set-up, with a combination of lasers and detector read-out and alignment telescopes used to reference the collimator in its original position. After several months and a thorough study and characterization of the problem, the team spent a lot of time rehearsing the alignment techniques, until they felt confident enough to dismantle GMOS.

The mask mechanism, on-axis wavefront sensor probe, and the collimator were then taken out of the instrument. With the collimator now on the bench, the first step was to modify the system to allow for future filling without taking the instrument apart again. After that, we used a special set-up (combining a small vacuum pump to extract the air, and a filling system to inject new optical oil) to fill the bubbles. We then reassembled the instrument, confirming at every step the alignment and mechanical repeatability.

The results as measured with the detector all fell well within specifications (the goal was to be within a 10 pixel difference, and there was a 4-pixel difference with respect

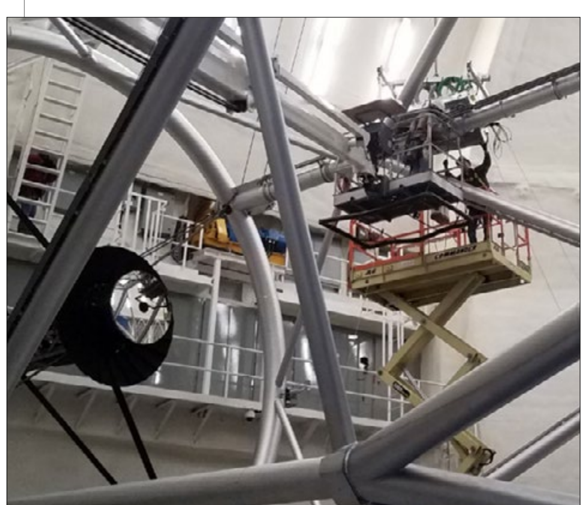


Figure 7 (above left). *Gemini Optical Engineer Tom Schneider prepares insulation for GNEST (laser housing designed for our TOPTICA laser head and optical bench).*

Figure 8 (above center). *Gemini senior optical technician Clayton Ah Hee (left, in foreground) and Gemini summit crew member John Randrup prepare GNEST for installation onto telescope.*

Figure 9 (above right). *Verifying laser alignment through the optical path to the Beam Transfer Optics Optical Bench on the secondary.*

Figure 10. *Installing GNEST onto telescope truss below top ring.*

Credit: All photos this page by Jeff Donahue to the starting position). After the telescope shutdown, we fully checked and released the instrument for operation again.

Gemini South Shutdown Completed

Gemini South completed its annual telescope shutdown on August 31st. Some additional mechanical support staff from the National Optical Astronomy Observatory joined in — an example of sharing resources, which we expect to continue. The shutdown's main objective was to carry out preventive maintenance on the acquisition and guidance unit (A&G; Figure 11). Excellent teamwork and cross-training ensured this system is ready for another year's observations. Apart from the regular maintenance, an encoder on the science fold linear stage mechanism was replaced, restoring redundancy and skew detection functionality. After working in the lab to prepare the spare cable wrap motors, we replaced both motors for the elevation wrap, since one of them was drawing high currents. This marks the conclusion of an important task within our reliability program.

On Saturday August 18th, a full facility shutdown was required in order to install new cabling to the uninterruptible power supplies. Some time ago these units (feeding the data center among other things) were replaced with higher capacity ones, but the cabling prevented their use at full capacity. A small portable generator provided emergency power for some lighting at the work locations. The data center was switched off and all instruments powered down and started to warm up. We completed all the work in one day; the data center was brought back up, and the instruments recovered. Net result: we reduced both the number of potential points of failure and the overall cost of maintenance.

Figure 11. *Performing maintenance on the Science Fold mechanisms in one slice of the A&G unit. Credit: Joe D'Amato*

Other issues addressed in this shutdown were the installation of improved encoder mounts on the elevation axis, checks on valves within the hydrostatic bearing system, and leak checking on the Cassegrain wrap Helium lines (one leak was found, and we swapped that line to a backup).

On Friday August 31st, all systems were handed back for observing; although bad weather wiped out the first night while the team was having a shutdown party. All systems were found in perfect working order, and all the instruments checked out (including GMOS after the bubble fix); the telescope is now ready for another year of operation. Every year, these shutdowns become more efficient and streamlined. Careful planning and attention to procedures and risk assessments are paying off in making this more and more a routine operation. A big thanks to all involved in making this a success!

Gemini North Shutdown Underway

Gemini North commenced its annual shutdown on Monday, September 17th. Work is progressing on several systems, including A&G issue follow-up and maintenance, Gemini Near-InfraRed Spectrometer coldhead refurbishment and other maintenance, GMOS VME hardware work, Near-InfraRed Imager and spectrometer Detector Controller troubleshooting, and Primary Mirror Control System maintenance. Additional work planned includes enclosure bogie work and enclosure bottom shutter work, which will commence later in the shutdown.

Big Island Mechanical, the contractor installing the Gemini North energy savings hardware, worked together with Gemini day crew to move the new Chiller 2 modules into the Exhaust Tunnel and onto the vibration isolation frame. Gemini is also temporarily shutting down the Chiller 1 cooling water circuit during the shutdown so that Big Island Mechanical can cut into the existing piping to install new hardware.

JULY 2018

IGRINS Achieves First Light at Gemini South

IGRINS, the visiting high-resolution near-infrared spectrometer — a collaboration of the University of Texas Austin (UT Austin) and the Korea Astronomy and Space Science Institute (KASI) — achieved first light on the night of April 2nd at Gemini South, with a remarkable spectrum of the T-Tauri star TW Hydrae (Figure 12).

What's unique about IGRINS is its revolutionary combination of spectral coverage (the entire H and K bands in a single exposure), high spectral resolution (R = 45,000) and high throughput (achieved through the use of a silicon immersion grating). It is also extremely compact and mechanically simple — having a single observing mode and no cryogenic moving parts. IGRINS adapts easily to different telescopes, requiring only a change of either fore-optics or input optics; in the case of Gemini, the input optics required replacement. IGRINS and Gemini South offer the most powerful combination yet.

Since installation, IGRINS has been performing exactly as expected; at its spectral resolution (45,000), IGRINS' sensitivity is about seven times better than any other high-resolution IR spectrometer on an 8- to 10-meter-class telescope, and it has many times the spectral coverage of other instruments at that resolution. Not surprisingly, demand for it at Gemini has been extremely high, with a list of 21 approved programs from the Gemini Participants, as well as a Large and Long Program of the instrument team.

This is IGRINS' first visit to the Southern Hemisphere, and the results from our first light target, TW Hydrae, is a good example of how much latitude matters. When IGRINS was running at McDonald Observatory in the Northern Hemisphere, observers worked hard for several years to obtain a spectrum of TW Hydrae, which was always very low in the Texas sky. With IGRINS at Gemini South, however, TW Hya was right overhead, and the first-light spectrum was not only quickly and easily observed,

Figure 12.

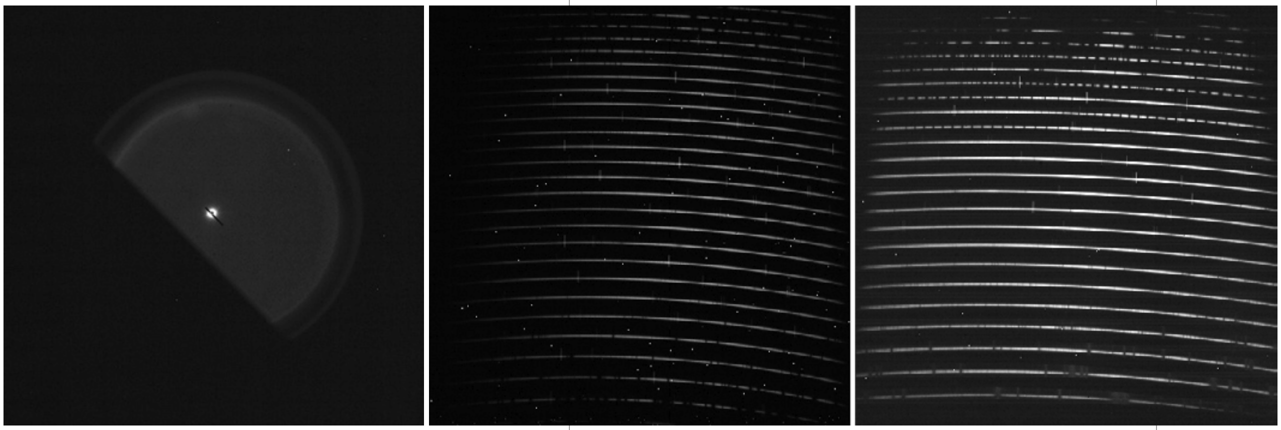
IGRINS+Gemini South first light.

Left:TW Hydrae in the slit-viewing camera.

Center: the H-band spectrum.

Right: the K-band spectrum.

Credit: K. Sokal and the IGRINS team



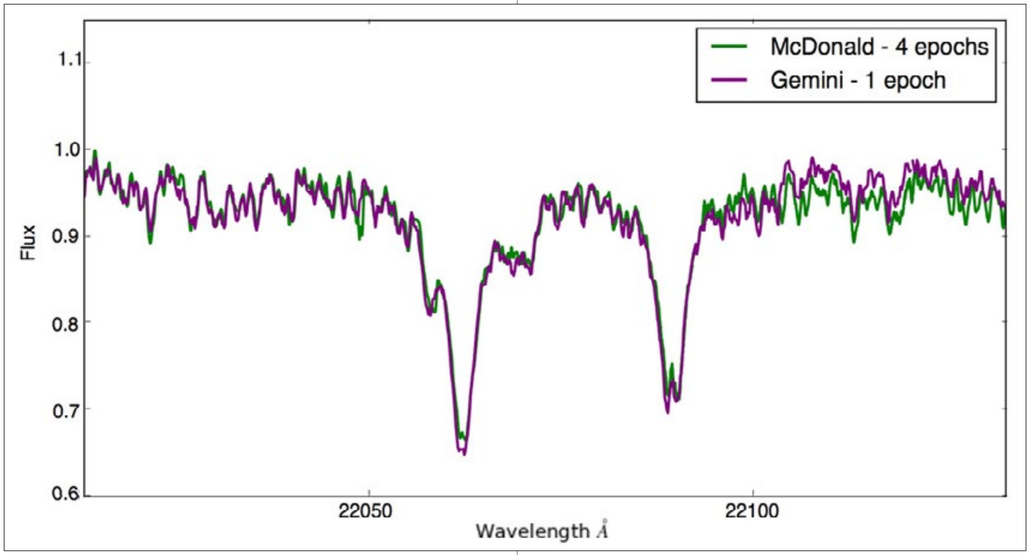
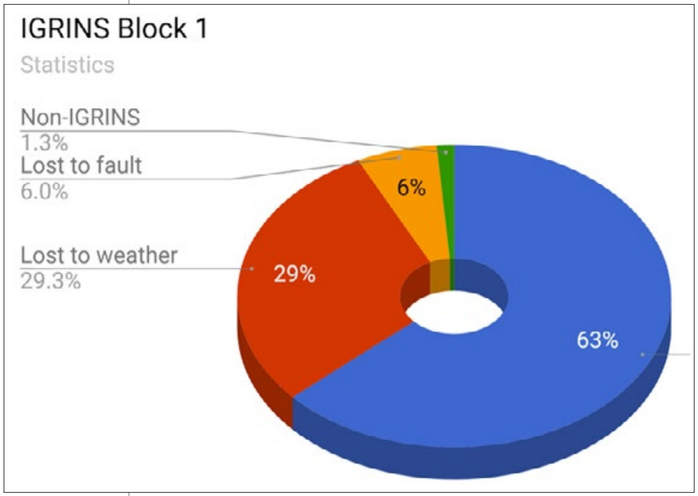


Figure 13.
A small section of the IGRINS first-light spectrum. Purple - IGRINS spectrum of TW Hya from Gemini South. A small part of the K band in both cases. Green - combination of multiple epochs of spectra on the same object from McDonald Observatory
[Figure from Sokal et al.*, 2018]*

but it produced a spectrum that rivals the hard-earned published one from McDonald Observatory (Figure 13). With such remarkable first impressions, the IGRINS team is extremely excited to be sharing the IGRINS+Gemini combination with Gemini's broad astronomical community, and as its 2018 observing blocks at Gemini South draw to a close, we all look forward to the exciting results to come.

IGRINS was scheduled for three separate observing blocks in Semester 2018A. As this issued goes to e-press IGRINS' time at Gemini South is complete for now. In the first block, apart from worse than usual weather and one significant fault due to a compressor failure (Figure 14), we've spent almost the entire time observing IGRINS programs with one or two observations done in the regular queue. Hopefully the weather will hold up through the second and third blocks, but it's already apparent that IGRINS is a very powerful (as well as popular) visitor instrument to Gemini.

Figure 14.
IGRINS first-block (April) observing statistics.



Daniel Jaffe of UT Austin is the IGRINS Principal Investigator (PI). Chan Park of KASI is deputy PI and KASI instrument PI. Jae-Joon Lee at KASI supervises the IGRINS operational program on the Korean side. The IGRINS visit to Gemini is supported by the U.S. National Science Foundation under grant AST-1702267 (PI - Gregory Mace, University of Texas at Austin), and by the Korean GMT Project of KASI. Further technical details are available in Yuk, *et al.* (2010) ***(view here)***, and Mace, *et al.* (2016) ***(view here)***. IGRINS science support at Gemini is provided by Hwihyun Kim.

Volcano Watch Activity at Gemini North

Hawai'i Island has suffered a long series of major earthquakes and lava eruptions in the "East Rift" zone of the Kilauea volcano, and a large number of smaller quakes and ash emissions from the summit crater, Halema'uma'u. While all of this action is a 60-mile drive or more from Maunakea, it

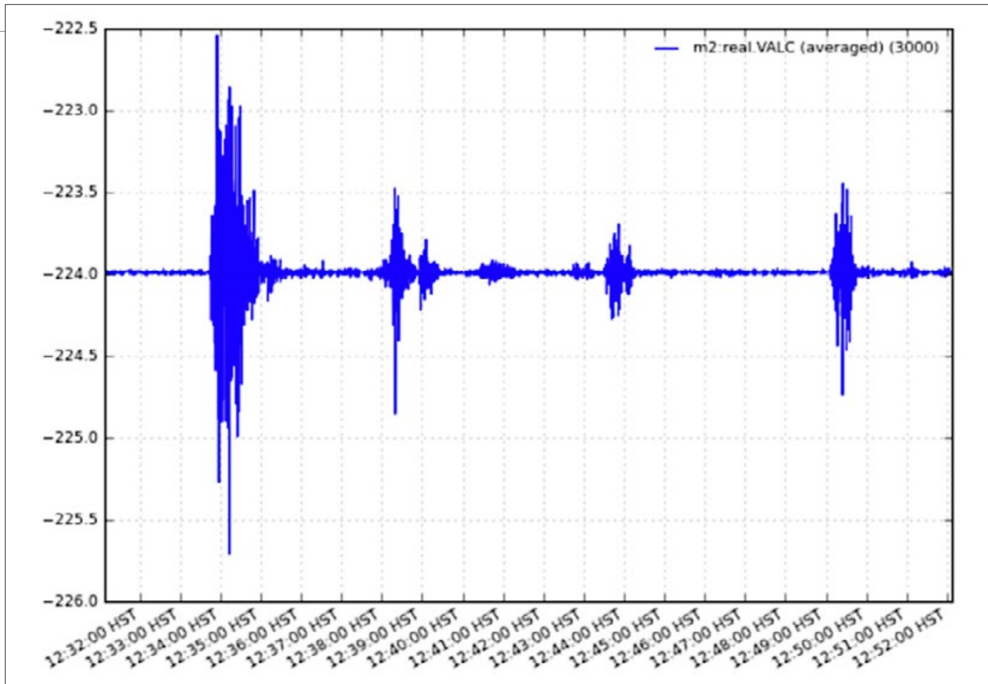


Figure 15.

The May 4, 2018, Big Island earthquake, associated with intense volcanic activity at Kilauea volcano, as recorded by the secondary-mirror sensors on Gemini North.

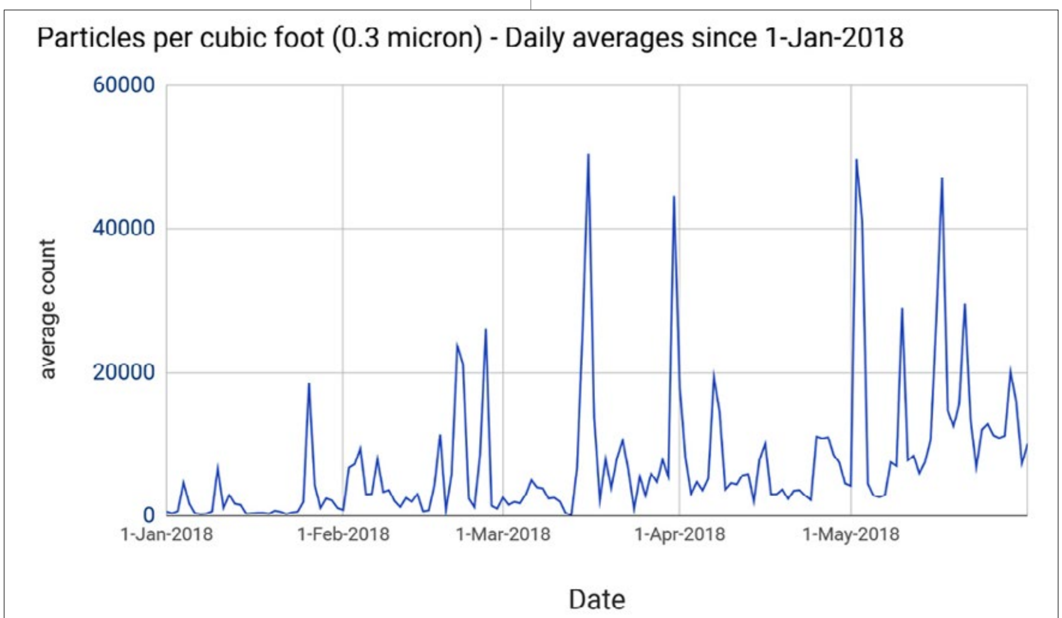


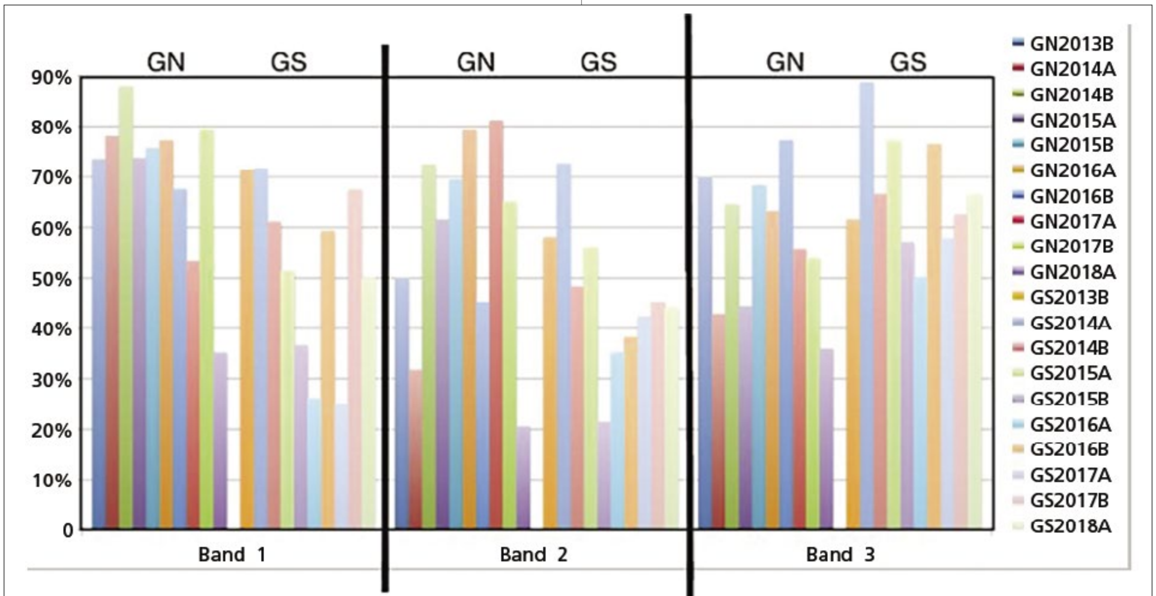
Figure 16.

Daily average numbers of sub-micron-sized particles at the Nasmyth platform of Gemini North.

nonetheless has been a concern, as some of the earthquakes have been major (*e.g.*, the 6.9-magnitude quake on May 4th, the largest since 1975), and volcanic ash reaching the summit could pose a threat to our optical systems (chiefly the primary mirror).

So far, Gemini has survived this period quite well; the large earthquake referred to above was felt strongly at the summit (and seen by the secondary-mirror sensors, Figure 15), but produced no damage to the telescope or enclosure. As for ash, we have a particle sensor (installed as part of the Base Facility Operations project), which gives us information on the flux of particles of various sizes at the telescope's elevation (Figure 16). To date, the only major ash event which produced a significant spike happened while the telescope was closed due to high humidity; but we're definitely living in strange times when we have to watch for this sort of event at night. To complete our monitoring equipment, we are in the process of procuring a sulphur dioxide (SO_2) detector; there have been times when observatory staff on the summit have reported the distinct smell of sulphur in the air.

Figure 17.
The percentage of 13B to 18A (partial semester, up to July 3rd) programs that obtained 80% or more of their science time in each semester. Regular queue and Large and Long Programs are included, but not Fast Turnaround or Director's Discretionary programs. Low completion rates correspond to poor-weather semesters (e.g., North 16B and 18A; South 15A-16A and 17A) or dome problems (North 13B and 14A).



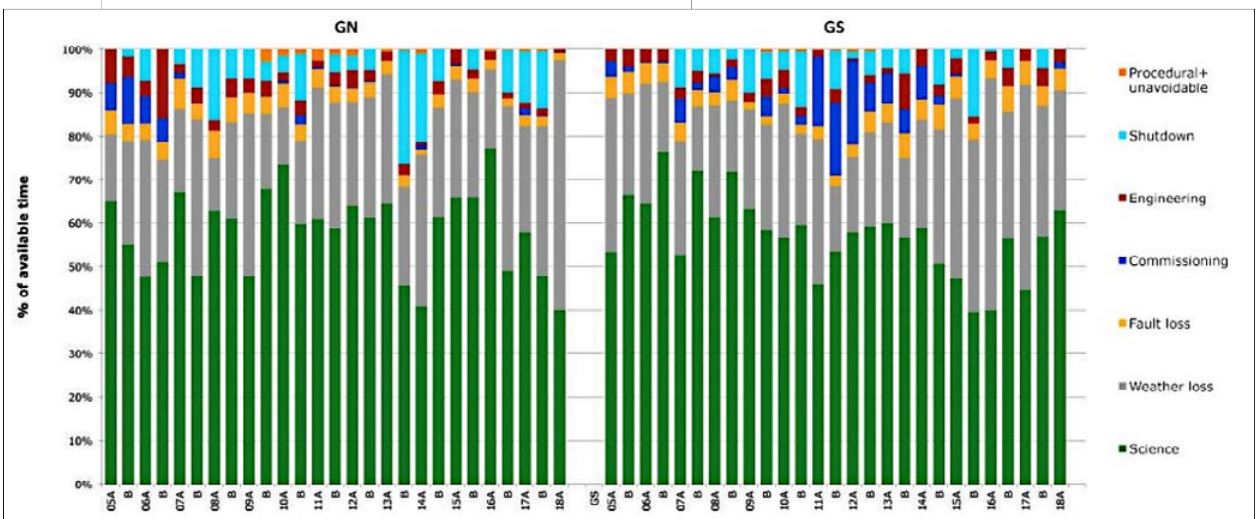


Figure 18.
Telescope time use for semesters 5A to 18A (partial semester, up to July 3rd). The distribution of time used for science and engineering, and lost to faults and weather, is shown.

2018A Weather

The weather loss at Gemini North was a record high (in 18A as of early July). The weather loss of more than 55% is similar to what Gemini South suffered in 16A (see the April 2016 issue of *Gemini*Focus, page 17). In both cases the science program completion suffered greatly (Figures 17 and 18). Due to the newly implemented "persistent band 1" philosophy, many of the 18A Band 1 programs in the North will be extended into 18B and will have future opportunities to get data.

New Data Reduction Cookbook for FLAMINGOS-2

A new data reduction cookbook for FLAMINGOS-2 is ***now available***. It offers instructions and PyRAF scripts for the reduction and calibration of imaging, as well as long-slit spectroscopy data in an easy-to-follow format with a focus on the complete process. A PDF version is also available by clicking on the version tab (see the "v: latest" icon in the lower right corner of Figure 8). A Multi-Object Spectrograph (MOS) mode section will be added with the completion of the MOS commissioning. Also, remember that the ***Getting Started page*** has information on data reduction for all Gemini facility instruments.

Maunakea Science Support Group Assembles at Gemini North

On April 27th, about 30 members of the Maunakea Science Support Group (open to staff at all Big Island observatories) gathered at Gemini North headquarters in Hilo to share their science, exchange information and ideas, and work together to solve problems that could affect all observatories, regardless of size or wavelength (Figure 19). Attendees enjoyed talks that ranged from science results to software projects, to instrument upgrades. They also participated in discussion sessions that included how to engage more with students in Hilo, and how to help staff new to the islands find everything they need to settle in and enjoy the beautiful and unique community on the Big Island.

Figure 19.
Maunakea Science Support Group members preparing for the next talk after a cookie break.

ITAC Outcomes for 2018B

After weeks of iterations between the National Time Allocation Committee (NTAC) Chairs and Gemini International Time Allocation Committee (ITAC) staff — Rodrigo Carrasco (Chair), Marie Lemoine-Busserolle (incoming Chair), Lindsay Magill (Technical Secretary) and Jen Miller (incoming Technical Secretary) — the ITAC met on June 4th to generate a workable semester queue.

It seems there is always something which complicates to the process of taking the results from all the participant's TACs and assembling a semester queue that is plausibly executable (weather permitting). This time the complication was provided by the Gemini North laser (which is not yet ready and could not be scheduled) and by a lack of Band-3 programs; the latter problem proved surmountable, and the iterations in the meeting were reasonably quick.

The National TACs forwarded a total of seven programs aimed at following up LIGO/VIRGO gravity wave events. At present, it appears that LIGO will be back in operation in January 2019, which could make that an interesting month if the expected sensitivity improvement is realized. All of the follow-up programs were considered and top-ranked by their respective national TACS. If a gravity wave event indeed happens in January, we will doubtless need to break out the "Competitive ToO" policy announced last year (***view here***) and work with PIs to attempt to maximize science outcomes. In the event that agreements cannot be reached we will fall back to the set of clearly-defined criteria on the policy.

It was a good round for visiting instruments. More than a hundred hours of GRACES programs were approved; the speckle camera DSSI and its new variant `Alopeke have been scheduled for ~115 and ~80 hours in South and North, respectively; and POLISH-2 will be returning to Gemini North for an approximately six night run.

With respect to the division of time between instruments, the two sites look quite different: the South is dominated by GMOS-S, with FLAMINGOS-2 a distant second (Figure 20). In the North, GMOS-N and GNIRS take approximately the same amount of time; the other facility and visiting instruments will take the remaining time in more or less equal shares.

APRIL 2018

New LLP Program Policy

Beginning with the 2018 Large and Long Program proposal cycle, all principal investigators (PIs) of new Large programs will be required to submit processed data to the Gemini Observatory Archive (GOA) within one year after the program's original planned end date, as stated in the proposal. The data must be in the FITS format, and contain header metadata such that it is searchable within the GOA. PIs will also be required to submit documentation detailing the data reduction procedure and describe the data provided. A ***document*** containing the detailed requirements on delivering processed data products to the Observatory is now available. We encourage potential PIs with questions about this requirement to email ***largeprograms@gemini.edu*** .

2017B Retrospective

Now that we're in 2018A, the time has come for a brief recap of events in 2017B at the two Gemini sites. Mixed fortunes with the weather, plenty of visiting observing, and some exciting astronomical events characterized the semester.

Hawai'i

At Gemini North, the semester started later than usual while we finished repairing the shutter in late August. That, combined with weather loss later in the semester, meant that we had less science time on-sky than usual. This adversely hit completion rates in Band 1, but Band 2 programs held up reasonably well compared to previous B semesters. When we were on the sky, conditions were reasonably good and so Band 3 completion rates ended up relatively low.

Visiting observers came through Gemini North fairly regularly, conducting four short classical runs and three more extended Priority Visitor runs.

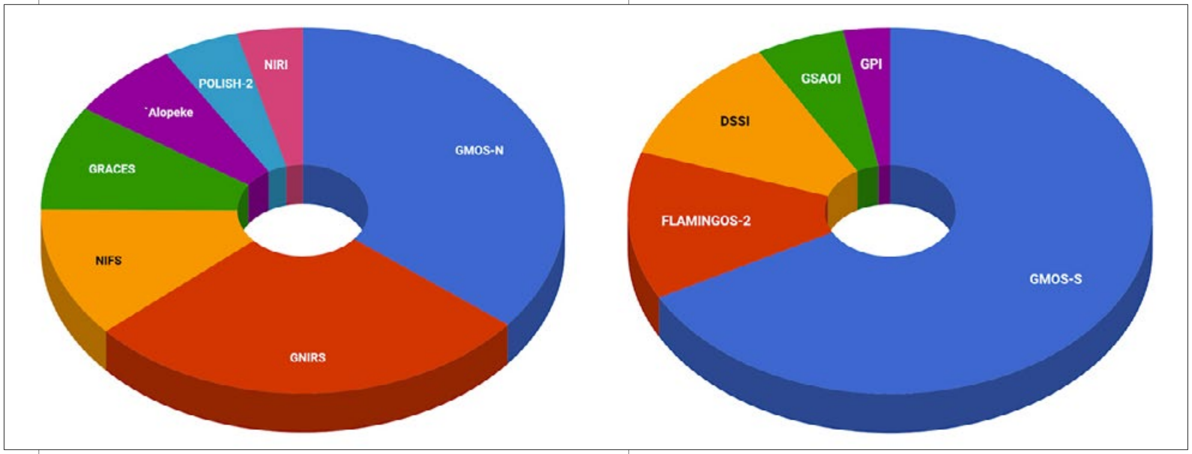


Figure 20. *The breakdown of time requests for Gemini North (left) and South (right). GMOS-S continues to dominate in the South, while the North sees significant allocations to visiting instruments and GRACES.*

Following up on the interstellar asteroid 'Oumuamua (see the *January 2018 issue of GeminiFocus*, page 4) kept us busy and excited. 'Oumuamua was discovered during an 'Alopeke commissioning run, and we're grateful to the 'Alopeke team for bearing with us while we overrode their time to catch this extraordinary and unprecedented event; this sacrifice enabled Gemini to help characterize the peculiar properties of this exotic visitor. 'Alopeke commissioning was, incidentally, completed, despite this interruption.

Chile

Early 2017B brought with it the LIGO gravitational wave event whose source Gemini South brought into focus, capturing early optical and infrared light from this merger of two neutron stars (see the *October 2017 issue of GeminiFocus*, page 7). This exciting first-time event kept staff busy for a couple of weeks and required delaying some remedial work on FLAMINGOS-2; this was scientifically well worth it, as we used the instrument to produce some compelling infrared spectroscopy that confirmed the nature of the event's afterglow. See more on FLAMINGOS-2, below.

While the first part of the semester presented some weather issues, the second brought much better weather, so we were able to catch up on the Band-1 programs and bring the completion rate back to reasonable levels. Late in the semester we received a remarkable number of Target of Opportunity (ToO) triggers: in January alone, there were 31 triggers, peaking at four on a single day. Figure 21 shows the number of nights on which Gemini South responded to a ToO request per month (left: Standard ToOs; right: Rapid ToOs). Most of the variation, and in particular the end of the semester bump, was due to Rapid, rather than Standard, ToO triggers (the peak in August was due to the LIGO gravitational wave event).

We had frequent visiting observers in the South as well: among them four conducted Priority Visitor runs, and visiting Korean astronomers occupied two time blocks. We also received Phoenix at the telescope as a visiting instrument late in 2017.

FLAMINGOS-2's on-instrument wavefront sensor (OIWFS) continued to generate mechanical problems, and we had planned an intervention early in the semester. As mentioned above, the LIGO gravitational wave event caused us to delay repairs, which we completed late in 2017. Multi-Object Spectroscopy (MOS) commissioning of FLAMINGOS-2 was delayed (as the MOS relies on the OIWFS) but is now underway. Finally, the Gemini Multi-conjugate adaptive optics System/Gemini South Adaptive Optics Imager operation profited greatly from the new TOPTICA laser.

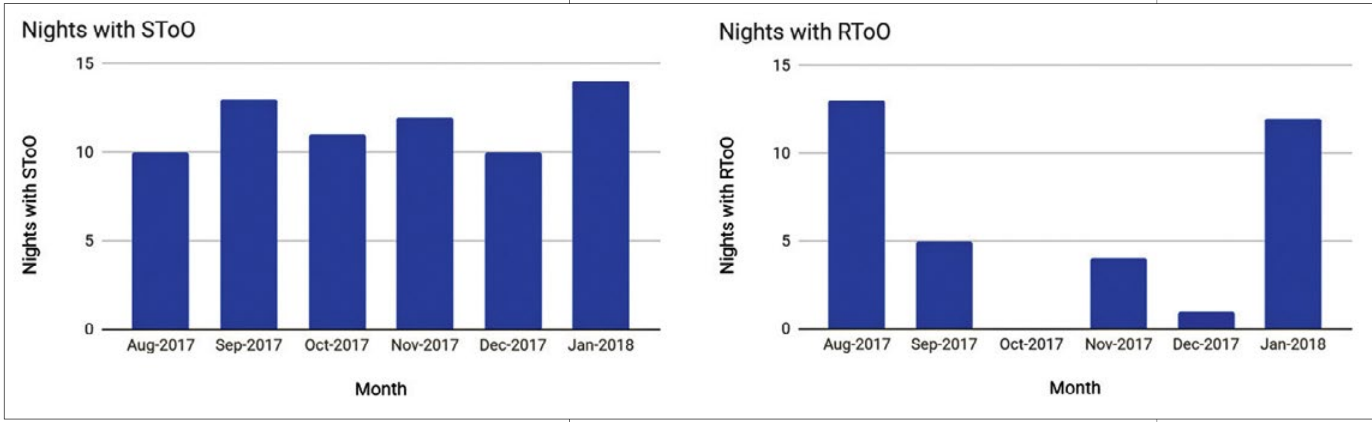


Figure 21.
The number of nights on which Gemini South responded to a Standard ToO request (left) and a Rapid ToO request (right).

Possible Ways to Access ANTARES

The future Large Synoptic Survey Telescope (LSST) alert stream of detected transient objects is anticipated to amount to ten million raw alerts per night, and we expect to have a significant number of Principal Investigator programs following up on these events with Gemini (both South and North). A key to handling such a massive influx of transient events is to filter the stream down to a quantity and science focus appropriate for an individual program.

The first step in that process will be done by "event brokers." These automated software systems will sift through, characterize, annotate, and prioritize events for follow up. The LSST project is planning to provide only a very simple filtering system, or mini-broker, however, so any work on catalog matching or classification must be done by the community.

One example of a community broker is the Arizona-NOAO Temporal Analysis and Response to Events System (ANTARES) — a joint project of the National Optical Astronomy Observatory and the Department of Computer Science at the University of Arizona. The follow-up System that is currently taking shape will begin with ANTARES, which will attempt to classify events by cross-matching them with existing catalogs and by identifying light-curve shapes. Users will be able to define filters to select objects of interest.

The resulting more bespoke, but still large, streams will be evaluated by program-specific software, which will provide another level of filtering and generate actual requests for observations on the system telescopes. ANTARES itself is being prepared for testing with the Zwicky Transient Facility (ZTF) public survey alerts, and NOAO has advertised limited, shared-risk, capabilities via the NOAO call for 2018B. The intention is to see how it goes, then reassess for a wider call in 2019A.

In the future, and in particular when LSST is operating, how will the Gemini community access ANTARES? There are two possible routes: first, once ANTARES reaches steady-state, NOAO expects to make it available as a standalone facility to all astronomers (perhaps limited by resource and/or performance considerations); second, because Gemini will be a member of the wider follow-up system (including at least ANTARES, Las Cumbres Observatory, Southern Astrophysical Research Telescope, and Gemini), it should be possible for the communities of all these facilities to prepare proposals which require multiple facilities in the network.

We are in the early stages of developing concepts to realize this. Check back here for more information as plans develop over the coming two years, but the takeaway message is that ANTARES feeds should be available to the Gemini community once LSST is operating.

Gemini's Cloudcams

One of the benefits of observing at a telescope site is that, in the case of iffy weather, one can "pop outside the dome" and quickly (dark adaptation allowing) see what the sky is doing. So when Gemini relocated astronomers from the summit to base facility operations (at the end of 2015 at Gemini North; end of 2016 at Gemini South) we were keen to ensure that our observers would be able to gauge the sky.

For some years, the Canada-France-Hawai'i telescope has been operating "cloudcams" — small and sensitive commercial cameras capable of long exposures — to provide current time-lapse photography of parts of the sky over Maunakea.

The timelapse videos from these cameras quickly became popular among staff on the mountain and the public alike. After a comparative study of as many alternatives as we could manage, we decided to adopt the same technology for Gemini's Base Facility Operations project. With a view to maximize coverage, we set up five cameras: one points up, three face a cardinal direction (covering north, west, and south) and one points towards Hilo (rather than due east, to better pick up approaching fog which often comes upon us from that direction).

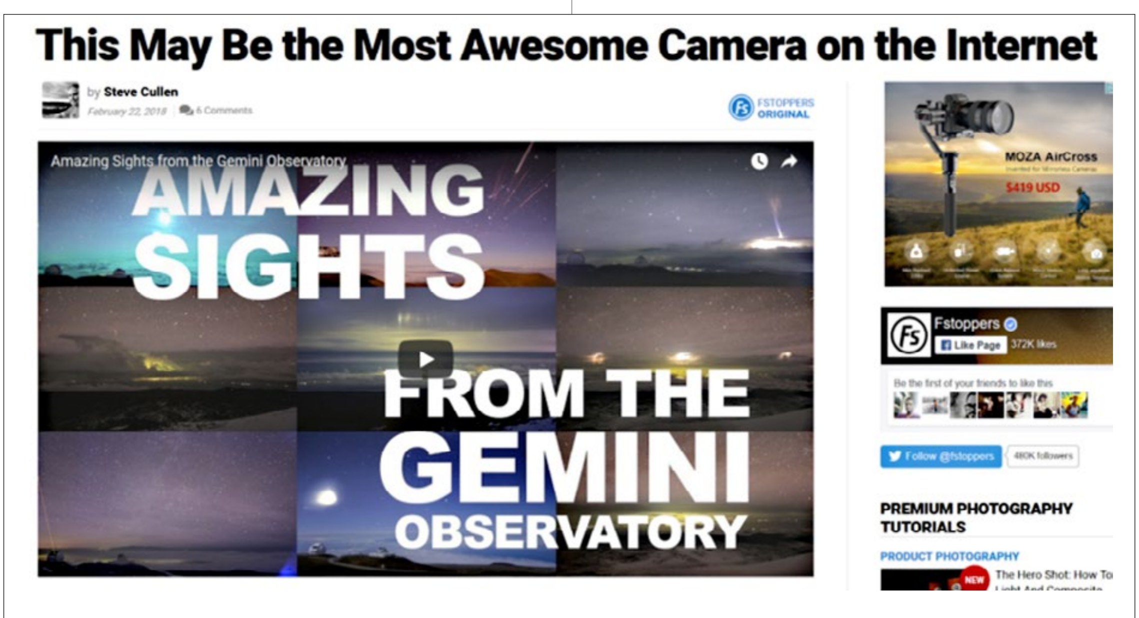
These cameras are in use every night when we are open for observing, and provide observers with the information they need. In addition, they also catch many interesting phenomena — natural and otherwise — and we fairly frequently receive requests for images when there has been, for example, extreme weather. Recently, fstoppers.com — a news site for photographers — ran an article with the byline "This May Be the Most Awesome Camera on the Internet"!

You can access the most ***recent 30 minutes of the cloud cams here***.

And the ***f/stoppers article is linked here*** (at the time of writing).

All-night videos from the ***different cloud-cams are posted here***.

Finally, for a view of the southern sky from Gemini South, check ***the all-night archive here***.



Joanna Thomas-Osip

Science and Evolution of Gemini Observatory 2018 Conference a Success!

The July 2018 Science and Evolution of Gemini Observatory meeting on San Francisco's Fisherman's Wharf celebrated many milestones, shared exciting science, and looked at future strategies for the Observatory.

In July over 100 participants gathered in San Francisco, California, to share their recent successes with Gemini. There was a lot to celebrate, including our new partnership with the Republic of Korea (see article on page 39). With the Gemini Planet Imager Exoplanet Survey (GPIES) coming to a close, we also enjoyed a full session on results from the survey and a discussion of the future evolution of the instrument. Other exciting scientific results reported (the **conference proceedings are available online**) included details about 'Oumuamua —the first known interstellar asteroid — and the first electromagnetic counterpart to a gravitational wave detection from a neutron star merger. In addition to sessions on new instrumentation (both facility and visiting), we discussed synergies with other observatories, such as the Large Synoptic Survey Telescope and the *James Webb Space Telescope*, as well as a strategic plan for Gemini as we move forward into the era of multi-messenger astronomy and transient follow-ups.

Extracurricular activities included a **tutorial on GMOS IFU data reduction**, "Under the Hood" talks on the practical aspects related to running a Large and Long Program, and a Speed Collaboration workshop. The Gemini User's Committee also held its annual meeting in conjunction with this conference.

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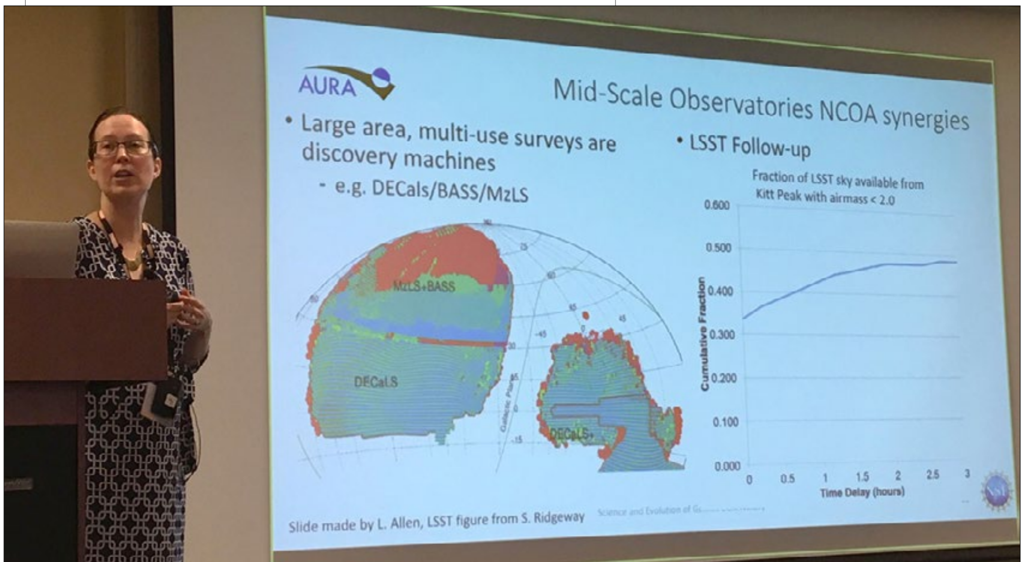
Science and Evolution of Gemini Observatory 2018 conference participants.

Credit: All photos in this article by Shari Lifson

KASI, NSF, AURA, and Gemini leadership at Korea signing event. Left to right: John Blakeslee, Chris Davis, Heidi Hammel, Rene Walterbos, Hyung Mok Lee, Matt Mountain, Laura Ferrarese, Henry Roe, Narae Hwang, Ralph Gaume, Anne Kinney, Richard Green, Byeong-Gon Park.

Bruce Macintosh giving a review of the GPI instrument and the GPIES exoplanet survey.

Jerry Brower, aka IT Guy to the stars, who kept the presentations organized and all things AV functioning.



Beth Willman presents a review of plans for the National Center for Optical-infrared Astronomy (NCOA).

Facilitators for a discussion on the strategic plan for Gemini in the 2020's (from left to right): Laura Parker, Todd Boroson, Henry Roe, Dara Norman, Thaisa Storchi Bergmann, and John Blakeslee.

Bryan Miller talking about Gemini's participation in a transient follow-up network (AEON).

Janice Harvey

AstroDay Hawai'i 2018

Staff from all of the Maunakea observatories, including over a dozen from Gemini, joined in the fun at Hilo's Prince Kuhio Mall on Saturday, May 5th, for AstroDay Hawai'i on the Big Island.

Celebrated since 2002, Hawai'i's AstroDay is an annual event organized by the Hilo office of the University of Hawai'i Institute for Astronomy. It coincides with an international grass-roots movement of the same name that has shared the excitement of astronomy with local communities every spring since 1973. While the parent event generally focuses on nighttime stargazing, AstroDay Hawai'i is offered for six hours during the day, allowing it to incorporate more than stargazing alone to capture the public's attention and help promote astronomy to our local community.

Despite a large earthquake the day before, this year's AstroDay Hawai'i was well attended. AstroDay presenters included volunteers from facilities on Maunakea, Maunaloa, Haleakalā, and O'ahu, as well as educators, students, community groups, and educational vendors. Over 30 science, education, and community organizations also participated in the festivities, creating a well-rounded and exciting day for celebrating knowledge.

Attending families and individuals were able to look at the Sun through telescopes with safe solar filters in the mall's parking lot and learn about our nearest star. Inside the mall, booths were set up where guests could participate

As these AstroDay Hawai'i participants learned, you can explore Gemini North on a smart phone by scanning the QR code for Gemini's virtual tour.

Credit: all photos by Joy Pollard

Gemini Outreach Assistant Alyssa Grace (right) prepares families before they enter our StarLab portable planetarium for a show on the current night sky.

Gemini North astronomers Julia Scharwaechter (center) and Kristin Chiboucas (right, in black) watch children make marks (representing galaxies) on a balloon, which they used to understand how the Universe expands.

in hands-on astronomy-related activities, or be entertained by demonstrations offered by the staff at all of the Maunakea observatories.

At the Gemini booth, we received hundreds of guests, many of whom (especially children) took in a star show inside of our StarLab portable planetarium, modeled the expanding Universe with balloons and markers, sorted galaxies by morphology, and colored images of Kea and Pachón — the twin mascots of our twin telescopes.

"My first AstroDay experience did not disappoint," said Gemini North outreach intern Hannah Blomgren. "It was rewarding to see the passion and enthusiasm of the astronomy community out in full force, and to watch that excitement being transferred to others. I was reminded of how vital these connec-

Outreach intern Hannah Blomgren (right) shows guests how to model the expanding Universe.

Telescope Operator Jocelyn Ferrara (left) and astronomer Siyi Xu (sitting to her left) help participants explore and sort galaxies by morphology.

tions are and the importance of creative science engagement. AstroDay showcases the multitude of ways in which we can forge these connections and have fun doing it!"

We invite all of our staff to get involved next year and share Gemini's amazing science with local families.

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


Janice Harvey and Manuel Paredes

Public Outreach Efforts Soar in Hawai'i and Chile

Gemini Observatory's two key outreach events — one in each Hemisphere — continue to expand the public's knowledge of astronomy and inspire youngsters into STEM careers.

Journey Through the Universe: 14 Years and Counting!

While Gemini's flagship outreach endeavor — the multi-faceted *Journey Through the Universe* program — has evolved from a week-long event to a year-round program, this year's "*Journey* Week" on Hawai'i's Big Island was an outstanding success. From March 5-9, 2018, over 80 STEM professionals from Gemini North and beyond visited over 300 island classrooms. Participating in this year's program were staff from the Maunakea observatories, NASA, and several local universities and research facilities. In total, over 8,000 Big Island students were inspired by *Journey's* activities this year.

In addition to classroom visits, *Journey* featured a host of educational events and workshops which went far beyond the *Journey* Week activities, including Observatory staff "career panels" that focused on the diversity of observatory careers, personal stories, and the excitement of exploration!

Gemini Interim Director Laura Ferraese (standing, in red pants) talks about her career to students at Hilo High School during Journey *Week. Fellow panelists include (left to right): Gemini Safety Manager John Vierra, UCLA Astronomy PhD student (and Hilo High alumnus!) Devin Chu, Astrobiology PhD student Niki Thomas, W. M. Keck Observatory Software Engineer Liz Chock, and W. M. Keck Observatory Chief of Operations Rich Matsuda.*

Credit: All images, Gemini Observatory

Below: UCLA Astronomy PhD student (and Hilo High alumnus!) Devin Chu shares his thoughts on the positive impact of the Journey *program on his career choices.*

Left: Gemini Observatory Journey *Team Leader Janice Harvey and Keone Farias, Superintendent of the Hilo/Waiākea & Ka'ū-Kea'au-Pāhoa Complex Areas.*

Above: Gemini Public Information and Outreach intern Hannah Blomgren (right, standing) takes students on a journey back in time with a timeline of the Universe.

Above: Gemini Science Operations Specialist Jocelyn Ferrera (far left, edge) and Gemini Science Fellow Matt Taylor (left, pointing) instruct students on where to stand to construct constellations. The exercise demonstrates how perspective affects the way see star patterns from Earth.

Gemini Safety Manager John Vierra (center, back) has eager students line up to demonstrate the order of planets in our Solar System.

AstroDay Chile 2018

More than 3,000 participants enjoyed the activities and exhibitions featured during *AstroDay Chile 2018* in mid-March. Coordinated by Gemini South's Public Information Office, the event includes the Association of Universities for Research in Astronomy (AURA) and the Municipality of La Serena as key partners. This year, staff from all of the major professional observatories and tourist facilities from the Coquimbo Region converged at the Seminario Conciliar School of La Serena, Chile, for a day of astronomical fun.

Students, families, and other members of the public joined in a wide-variety of activities — ranging from science workshops, lectures, and 3D cinema, to the launching of water rockets and public stargazing, among other events. Public participation in this celebration of astronomy far exceeded our expectations. The images here illustrate some of the activities… and the fun we had. Thanks to everyone who shared their time and passion for astronomy, especially with the kids and their families.

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

Top: Gemini Information Systems Engineer Eduardo Toro explains the features of Gemini's Base Facility Operations, using a small robotics kit at the Gemini booth during AstroDay Chile 2018.

Middle: Rodrigo Zelada, North Optics company owner, paying attention to his telescope's solar filter, while a group of students enjoy observing the Sun.

Children participating in a spectroscopy workshop (offered by Cerro Tololo Inter-American Observatory's Outreach Coordinator Juan Seguel) use handheld spectroscopes to learn about the properties of light.

Gemini South Electronics Engineer Vanessa Montes uses an optics kit to demonstrate how Gemini's telescope mirrors reflect light to an instrument so that scientists can image distant objects in the Universe.

After sunset, many families joined in AstroDay's *public starparty. Visitors enjoyed their closeup views of the nighttime sky which were provided by local amateur astronomers and their telescopes. Despite the late hour, participants didn't want to leave!*

Gemini's senior software engineer Pedro Gigoux shares with students how astronomers measure the temperatures of objects in the Universe as part of an astronomy career panel.

Jason Chu (left) and Joy Pollard (right) in silhouette during on-sky laser commissioning of the Gemini North TOPTICA laser.
Credit: Joy Pollard/Gemini Observatory/NSF/AURA

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

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