GeminiFocus

Publication of the Gemini Observatory January 2020

2019 Year in Review

ON THE COVER:

Gemini North Multi-Object Spectrograph image of NGC 5394/5, otherwise known as the Heron Galaxy. This four-color composite captures an intimate moment in an elegant dance by two interacting galaxies some 160 million light years distant. To read more about this compelling interacting pair, turn to page 48.

Credit: Gemini Observatory/NSF's National Optical-Infrared Astronomy Research Laboratory/AURA

*Gemini*Focus January 2020 and 2019 Year in Review

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Director's Message

A New Decade for Gemini Observatory Begins

Happy New Year to everyone in the Gemini Observatory community! The past year has encompassed a number of "firsts" and milestones for me, personally, as Gemini Director: I hosted my first Gemini Observatory Open House at the 2019 winter American Astronomical Society meeting; visited Korea and Korea Astronomy and Space Science Institute (KASI) for the first time (and got some very important lessons on how to use sujeo, the super-skinny metal Korean chopsticks); met with Argentinian astronomers for the first time in their country at Reunión annual de la Asociación Argentina de Astronomía and at the Universidad Nacional de La Plata; worked on the basics of Chilean Spanish (but still have a long way to go); got a crash course on the nuances of Hawaiian politics and history; and, last but not least, kicked-off the October launch of the National Science Foundation's (NSF's) National Optical-Infrared Astronomy Research Laboratory.

The best parts of the year were my interactions with Gemini's global community, and learning about the fantastic scientific discoveries led by our users: observations from the Gemini Near-InfraRed Spectrometer (GNIRS) pinned down the mass of the supermassive black hole of a gravitationally-lensed quasar at the edge of the Universe (Fan *et al.*, 2019); ultra-sharp near-infrared images from Gemini's multi-conjugate adaptive optics (MCAO) imager GeMS/GSAOI uncovered the age of one of the oldest star clusters in our Galaxy (Kerber *et al.*, 2019); the visiting high-resolution spectrograph IGRINS discovered an extremely rare molecular composition of carbon monoxide and nitrogen in the ices of Triton, Neptune's largest moon (Tegler *et al.*, 2019); the Gemini Planet Imager Exoplanet Survey (GPIES) of over 500 stars concluded its five-year run and revealed very different pathways for the formation of Jupiter-like planets and the smallest brown-dwarf stars (Nielsen *et al.*, 2019);

ultra-high-resolution speckle imaging with visiting ʻAlopeke at Gemini North traced the orbit of a Jupiter-sized exoplanet in a close binary star system and conclusively demonstrated, for the first time, which star the planet orbits (Steve B. Howell *et al*., 2019); and over the past few months, Gemini North and South have joined the chase of our first known interstellar comet, 2I/Borisov (Guzik *et al*., 2019).

Gemini Observatory had its most scientifically productive year ever in 2019! We closed out the year with a record number of Gemini publications — over 250, a sharp increase from the previous year. Some of this rise in publications can be attributed to the increasingly popular and productive Fast-Turnaround proposal program, with over 10% of 2019 publications and an average oversubscription rate of ~ 2.2. We have also seen increasing demand for Gemini's Director's Discretionary Time, accounting for an average of 12% of the refereed papers over the past several years, compared to a nominal 5% of the allocated time.

The Large and Long Program (LLP), started in 2014 to support more ambitious and longer-term projects, also had a banner year, with the largest number of LLP publications. This year we started three new LLPs: *ZF2K: The First Exploration of the K-Band Window and a Complete Census of Massive Galaxies at $4 < z < 6$*, led by Casey Papovich at Texas A&M University, will obtain medium-band *K* imaging over 0.5 square degrees to detect $4 < z < 6$ and higher-redshift emission-line objects; *Observational Characterization of Recurrently Active Main-Belt Comets and Near-Earth Main-Belt Comet Candidates*, led by Henry Hsieh (Planetary Science Institute), will characterize the activity and nuclei of a number of known main-belt comets (MBCs) and near-Earth MBC (NEMBC) candidates; and *Monitoring Seasonal Reversal in Uranus' Upper Atmosphere*, led by Laurence Trafton (University of Texas at Austin) will use the GNIRS to search for and characterize the expected reversal of the 20-year long-term downtrend of the temperature of Uranus' thermosphere. Letters of Intent for the 2020 LLPs are due February 4th; these include new opportunities to use the multi-object spectroscopy mode on FLAMINGOS-2 and to apply for Subaru Intensive Programs as an extension of our Subaru Telescope time exchange program.

Gemini Observatory's staff and collaborators have also achieved significant milestones in development, operations, and user support over the past year that we expect to pave the way for Gemini's science in the next decade. We released the first phase of DRAGONS (*Data Reduction for Astronomy from Gemini Observatory North and South*) to support all of the Gemini facility instrument's imaging modes with a modern, Python-based software package. The Gemini South MCAO GeMS upgraded natural guide star sensor is performing well, and will enable more efficient observations over three times the previous available sky area.

A number of ongoing facility and visiting instrument development projects made significant progress: the Gemini High-resolution Optical SpecTrograph (GHOST) is undergoing final testing at National Research Council Canada's Herzberg Astronomy and Astrophysics before shipping to Gemini South; the new visiting high-resolution spectrograph MAROON-X (Principal Investigator (PI) Jacob Bean) is in commissioning at Gemini North; SCORPIO, the facility 8-channel imager/spectrograph, passed its Critical Design Review; and a state-of-the-art MCAO system at Gemini North, integral field unit upgrades for GNIRS, and the visiting Gemini InfraRed Multi-Object Spectrograph (PI Suresh Sivanandam), all held successful Conceptual Design Reviews. Finally, the GPI instrument team has secured independent funding from Heising-Simons Foundation (PI Quinn Konopacky, University of California San Diego) and the NSF (PI Jeffrey Chilcote, University of Notre Dame) to upgrade GPI and move it to Gemini North.

What the Future Holds

The next year — and the next decade — are shaping up to be transformative for Gemini Observatory and astronomy as a whole. We cannot yet know how new discoveries and facilities will disrupt the way we do and think about astronomy. Therefore, Gemini Observatory's strengths of flexibility, diversity, and agility will continue to serve us well as we prepare for the decade of discovery to come.

Over the next several years, we will enhance our ability to provide efficient and rapid observations through the development of updated user interfaces and proposal tools, automated dynamic scheduling, and the spectroscopic DRAGONS pipelines. We will deliver the first MCAO system to Maunakea by the middle of the next decade, with nightly, queue-ready operations. The pathway to full ground-layer adaptive optics described in the ***Astro2020 white paper*** will significantly increase Gemini's photon-collecting power by the end of the decade, enabling unknown discoveries to come.

In these early days of 2020, I was happy to see so many in the US community at what was my second Gemini Observatory Open House during the AAS winter meeting in Honolulu, Hawai'i. Looking ahead, one of the highlights of 2020 will undoubtedly be the next Gemini Science Meeting: "20th Anniversary and Beyond," in Seoul, Korea, from June 21-25, 2019. Registration is now open, and I can't wait to see you all there.

Although the unrest in Chile and protests at Maunakea have provided challenges for our staff and to doing science over the past year, I am grateful for the privilege to be part of our journey of discovery about the Universe and for everyone in the Gemini community that makes that journey possible. Clear skies and happy new year!

Jennifer Lotz is the Gemini Observatory Director. She can be reached at: ***jlotz@gemini.edu***

*Gemini*Focus in Transition: A New Era in User Communications

With the publication of this issue of Gemini*Focus, a new era in communications with our international user community begins. Beginning in Quarter 2 of 2020, a joint publication of all of NSF's NOIRLab facilities will launch that will encompass all of the news that users expect in* Gemini*Focus, plus similar news from Kitt Peak National Observatory, Cerro Tololo Inter-American Observatory, the Community Science & Data Center and the Vera C. Rubin Observatory. Gemini users throughout the international Gemini Partnership will continue to receive the information needed to carry out the cutting-edge science we've come to expect from our community and, with the additional content, to expand everyone's horizons.*

The Gemini e-newscast will for the time being continue to provide the latest time-critical information in email format for users, such as proposal deadlines, instrument availability and other important events. We welcome your input as we embark on this transition to better serve the entire Gemini Partnership.



Benito Marcote, Kenzie Nimmo, and Shriharsh Tendulkar

The First Repeating Fast Radio Burst in a Spiral Galaxy

Observations with the European VLBI Network and the Gemini North telescope have localized for the second time in history a Fast Radio Burst (FRB) source that repeats. Known as FRB 180916.J0158+65, it originates from a prominent star-forming region in a spiral galaxy that resembles our Milky Way. Surprisingly, this source and its host galaxy are radically different from those of the first repeating FRB. The observed diversity in hosts and local environments may point to multiple classes of FRBs with different progenitors.

Fast Radio Bursts (FRBs) are extremely bright radio flashes of millisecond duration and extragalactic origin. Astronomers have known of their existence for only about a decade. The first FRB was discovered in 2007, in archival pulsar data from the 64-meter Parkes radio telescope in New South Wales, Australia. These data revealed a single, bright signal lasting only a few milliseconds (now known as the Lorimer Burst; Lorimer *et al*., 2007). Since then less than a hundred FRBs have been discovered. Despite estimates that some 1,000 FRBs occur in the sky every day, their nature is one of the most topical questions in astrophysics today (Petroff, *et al.,* 2019; Cordes and Chatterjee, 2019).

Zeroing in on the First Repeater

Given the short intrinsic duration of the source's radio flashes, we can measure the dispersion delay that the radio waves suffer. The delay is proportional to the column density of electrons from the source to the observer, a quantity called dispersion measure (DM). Taking into account how electrons are distributed in the Milky Way and the Universe, the DM can provide a rough distance estimate to the source.

All FRBs show dispersion measures that significantly exceed the expected values from the electrons in our Milky Way. This indicates that FRBs originate at cosmological distances. Those detected lie billions of light years distant, and are around a trillion times more luminous than the brightest pulsars in our Galaxy. There is no clear solution to scale pulsar emission mechanisms to match the luminosity and recurrence rate of FRBs. A large number of possible scenarios have been proposed: from giant magnetar flares and colliding neutron stars, to exotic models invoking axions and cosmic strings (see *e.g.*, Platts *et al.*, 2018; Petroff *et al.*, 2019).

An important step forward in the field occurred in 2012 with the discovery of multiple bursts from the same source — FRB 121102 (Spitler *et al.*, 2014 and 2016; Scholz *et al.*, 2016). This discovery rules out cataclysmic models, at least for this particular source. A handful of similar repeating FRBs have been discovered since. It remains unclear if all FRBs have the capability of repeating, or if there are two distinct classes of FRBs: repeating and non-repeating. To date, only a small fraction of the observed population of FRBs repeat; perhaps more observing time for longer durations and more constant monitoring with a more sensitive instrument is required to detect bursts, we just do not know.

While single-dish radio telescopes are powerful FRB detectors, they do not have the resolution to localize their host galaxy. Since FRB 121102 exhibits repeating bursts, this allowed for follow-up observations with the Karl G. Jansky Very Large Array (VLA), the European VLBI Network (EVN), Gemini North, and the *Hubble Space Telescope*. In 2017 they uncovered the precise location of FRB 121102, confirming its extragalactic nature; the source was found within a low-metallicity star-forming region of an irregular dwarf galaxy some 3 billion light years distant (Chatterjee *et al.*, 2017; Marcote *et al.*, 2017; Tendulkar *et al.*, 2017; and Bassa *et al.*, 2017).

Interestingly, the radio bursts from FRB 121102 have an extremely high rotation measure — a rotation of the plane of polarization that occurs during the propagation of electromagnetic waves in a magnetized plasma (Michilli *et al.*, 2018). They were also found spatially coincident with a luminous persistent radio counterpart (Chatterjee *et al.*, 2017; Marcote *et al.*, 2017). This extreme environment suggests a possible connection between FRBs and other energetic transients, such as long gamma-ray bursts (Metzger *et al.*, 2017). However, the observations are also consistent with models invoking extreme objects such as neutron stars or massive black holes (Chatterjee *et al.*, 2017; Michilli *et al.*, 2018).

Within the last year, three new localizations have been reported; so far, all are non-repeaters. In all three cases, the observed host galaxies are radically different from the first repeating FRB: they are all located in massive galaxies: two reside in the outskirts of ellipticals, and one in a spiral galaxy (Bannister *et al.*, 2019; Ravi *et al.*, 2019; and Prochaska *et al.*, 2019).

The large discrepancies between the local environment and host of the first repeater, FRB 121102, when compared with those of the apparently non-repeating sources, deepened the idea of two distinct classes of FRBs: repeating and non-repeating. Cleary, we required more localizations of both repeating and non-repeating FRBs to clarify the nature of these events.

Localizing a Second Repeating FRB

The Canadian Hydrogen Intensity Mapping Experiment telescope and Fast Radio Burst detector (CHIME/FRB) at the Dominion Radio Astrophysical Observatory in British Columbia has proven to be the most prolific FRB-detecting machine. Since 2018, the telescope's large collecting area, wide band receiver, and enormous field of view has led to the discovery of many new repeating FRBs (CHIME/FRB Collaboration *et al.*, 2019a,b), including eight in August 2019.

One of the discovered repeating sources is FRB 180916.J0158 + 65. The CHIME/FRB Collaboration refined the source's position to a few arcminutes in the sky. This source exhibits a low DM, placing it somewhere between the Galactic halo and a redshift up to ~0.1.

We observed the field of FRB 180916.J0158+65 on June 19, 2019, with the EVN, combining data from a total of eight radio telescopes in real time to reach unparalleled resolution and sensitivity at 1.7 gigahertz (GHz). In parallel, we also recorded from the 100-meter Effelsberg telescope in Bad Münstereifel, Germany, high time and frequency resolution data to directly search for single, bright radio bursts coming from the source.

During this EVN run, we detected four bursts from FRB 180916.J0158 + 65, with each burst lasting for, at most, a few milliseconds. As shown in Figure 1, the resolution reached in this observation allowed astronomers to pinpoint the origin of the bursts in the sky with an accuracy of about 3 milliarcseconds (Marcote *et al.*, 2020). Our team found no persistent radio counterparts consistent with this position, unlike with FRB 121102 (the first repeater). In archival images from the Sloan Digital Sky Survey and PanSTARRs, this position placed it at the edge of a diffuse, seemingly elliptical galaxy. Was this repeating FRB, which is in the same kind of environment as the non-repeating FRBs, drastically different from that of the first repeater?

With the GMOS imager/spectrograph on the 8-meter Gemini North telescope, we observed this field between July and September 2019 with the g and r photometric

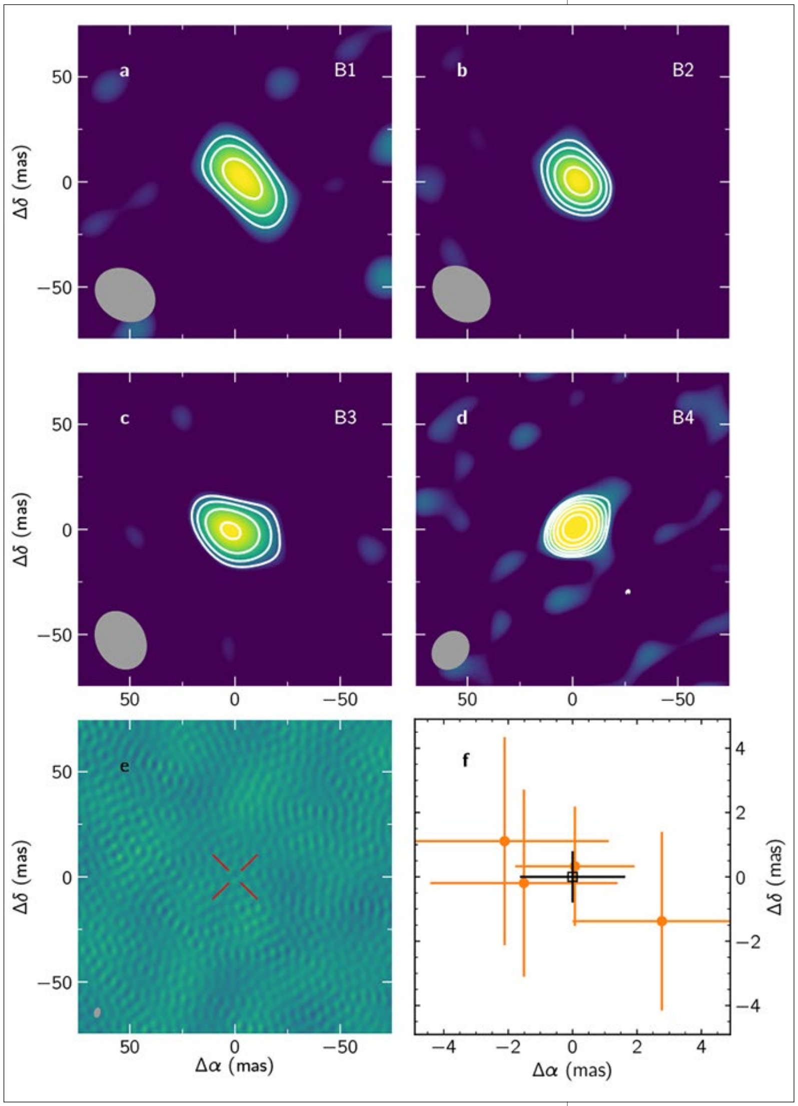

Figure 1.
The interferometric localization of FRB 180916.J0158+65 using the EVN. Panels a to d show the images of the four detected bursts. Panel e shows the continuum radio image of the field, where no significant persistent radio counterparts are reported. Panel f shows the derived positions for each of the bursts (orange circles) and the averaged final position (black square), to which all plots are referred: a (J2000) = 01h 58m 00.75017s (± 2.3 mas), δ (J2000) = 65° 43′ 00.3152″ (± 2.3 mas). Error bars represent 1-σ uncertainty.

filters, but also with long-slit optical spectroscopy. FRB 180916.J0158+65 was found to be at the apex of a prominent V-shaped star-forming region of a spiral galaxy located at a redshift of 0.0337, or about 149.0 Megaparsecs. Figure 2 shows both the optical image and the spectra at both the location of FRB 180916.J0158+65 and from the core of the galaxy.

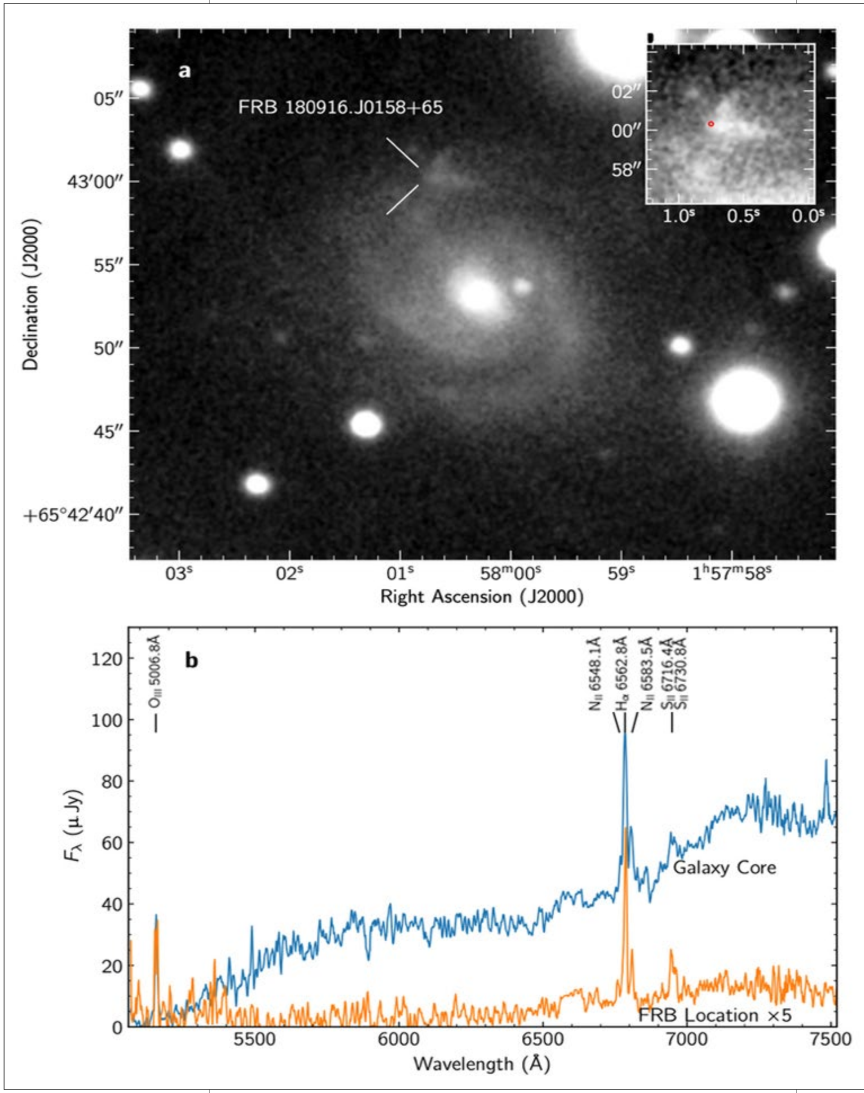

Figure 2.
Gemini North image and optical spectra of the source. Panel A shows the r image of the host galaxy and a zoom-in of the star-forming region where FRB 180916.J0158+65 is located (highlighted by the white cross and red circle, respectively). The uncertainty in the position of FRB 180916.J0158+65 is smaller than the resolution of the optical image. Panel B shows the spectrum extracted from a 2-arcsecond aperture around the position of FRB 180916.J0158+65 (orange) and a 5-arcsecond aperture around the core of the host galaxy (blue). Significant emission lines are labeled.

Towards the Understanding of FRBs

The host and local environment of FRB 180916.J0158+65 is markedly different and less extreme than that of the first repeating FRB, which was located inside a low-metallicity star-forming region of a dwarf galaxy, and associated with a very compact (< 0.7 parsecs) persistent radio counterpart of unclear origin. This new host also contrasts with the massive elliptical galaxies where two of the three localized non-repeating FRBs were located, where little or no star-formation is present. However, it may be consistent with the star-forming galaxy associated with the third localized non-repeater. The observed diversity in hosts and local environments may point to multiple classes of FRBs with different progenitors.

Many scenarios were proposed to explain FRB 121102, the first repeating FRB. Several of them proposed that the bursts originate from a young and rapidly rotating magnetar, either interacting with a superluminous supernova or a massive black hole. The former models could still explain FRB 180916.J0158+65 by invoking an older source, of approximately 300 years, whereas the latter seems to be less likely in this case given the location in the host galaxy (see Marcote *et al.*, 2020, for further details).

The origin of FRBs remains unclear, and a large number of precise localizations will be required to establish the ultimate physical conditions required to produce these kinds of bursts. The proximity of FRB 180916.J0158+65, the closest FRB so-far localized, allows dedicated observations across the full electromagnetic spectrum, from radio to very high energy gamma rays, to search for prompt or persistent multiwavelength counterparts and to constrain magnetar-based models.

Finally, not only are FRBs an intriguing new astrophysical transient, but they also provide the opportunity to investigate the history of the Universe by probing the baryonic content on large cosmological scales.

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Tom Geballe

NGC 2071-IR: A Who-dunnit Mystery

Two recently retired Gemini staff members (author Tom Geballe and Dolores Walther) have utilized Gemini North to obtain the sharpest composite infrared images ever of the chaotic core of one of the nearest star-forming clouds. These images, combined with key infrared spectral signatures of two of the embedded protostars, are helping astronomers determine the causes of the mayhem.

Star formation can be a messy process. When gravity causes a portion of a calm interstellar gas cloud to collapse, and a star is born, some of that infalling gas is violently blown back into the surrounding cloud, disrupting much of it. In the process, small portions of the cloud are briefly shock-heated to temperatures of thousands of degrees.

If only a single protostar at a time is engaged in this destructive activity, astronomers can usually identify it. But when more than one protostar in a cloud is doing this at the same time, understanding what is going on, including determining which protostars are responsible for which parts of the disruption, is a challenge.

Such is the case with one of the nearest star-forming clouds to the Sun, NGC 2071. The core of this cloud, known as NGC 2071-IR because of its bright infrared emission, has long fascinated Dolores Walther, who retired in 2017 as head of Gemini North's crew of Science Operations Specialists.

Walther had always wanted to use Gemini and its powerful infrared instruments to get a better look at NGC 2071-IR and solve some of its mysteries. I joined in the study and co-published the results with her in the ***April 20, 2019, issue of* The Astrophysical Journal.**

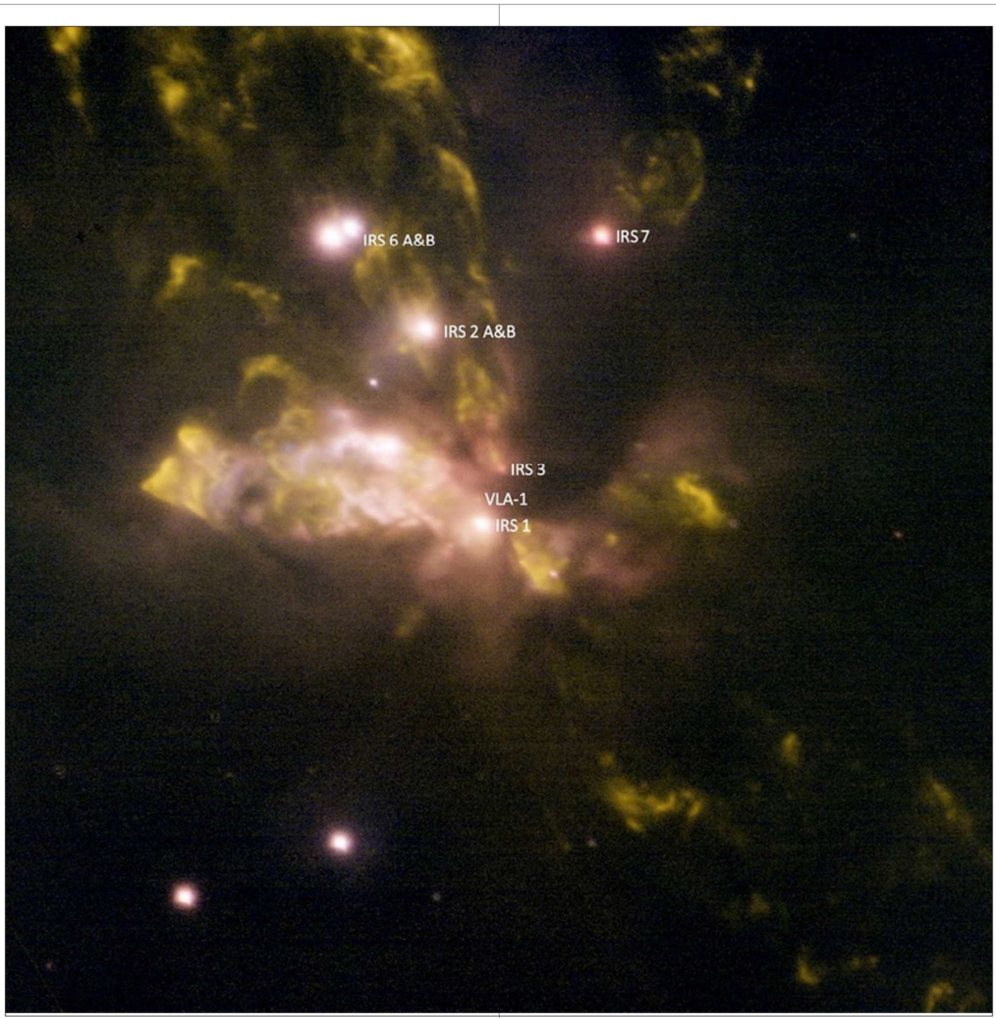

Figure 1. *Gemini North / NIRI infrared image of NGC 2071-IR in the combined light of the broad J, H, and K filters and a narrow band filter at the wavelength of a line of shock-excited molecular hydrogen (H_2). The resolution of the image is ~0.40″, at least three times higher than any previously obtained images of the region. The field of view is 2′ x 2′. North is up and East is to the left. Most of the finely structured emission is from H_2, while the more smoothly distributed emission is the combined light of H_2 and starlight scattered off of dust particles. Identified protostars have been labelled.*

Color composite image created by Gemini Science Operations Specialist Jennifer Miller.

To help identify the young culprits responsible for disrupting the core of NGC 2071, Walther and I used the Gemini North Near-InfraRed Imager and spectrometer (NIRI) in 2017 and 2018 to dig deeper into the complex region. Figure 1 shows our results — the sharpest composite infrared image ever obtained of the region. We combined images taken individually through several filters — one of which was sensitive to the emission of hot molecular hydrogen (H_2). Putting them together created a coherent picture.

Stars, light from glowing gas, and light reflected off of dust particles are readily apparent in the image. The complex V-shaped structure extending from the center of the image toward the upper left, whose left arm extends across the positions of IRS 2 A&B and IRS 6 A&B, is emitted by shock-heated molecular hydrogen, where gas ejected from a protostar is colliding with quiescent gas in the surrounding cloud. A fainter V extension can be seen at lower right. Both extend far beyond the edges of the image. Such "bipolar outflows" of gas are commonly observed from stars accreting material from their natal clouds.

While it was originally supposed that IRS 1, by far the most luminous and likely the most massive protostar in NGC 2071-IR, was generating this bipolar outflow, these new data, along with radio and infrared observations published by other scientists, strongly suggest that the less luminous IRS 3 is the culprit.

To the left of the center of the image lies the brightest region of H_2 line emission in NGC 2071-IR, which others had recently suggested might be associated with IRS 1. In our paper, Walther and I concur with this suggestion. In addition, we propose that the rather compact and amorphous appearance of this region is due to the outflow of material being directed almost exactly toward the Sun.

The Gemini image gives us a view somewhat akin to looking down the barrel of a cannon that has just been fired.

We also captured the most detailed infrared spectra ever obtained of IRS 1, the bright fuzzy object at the middle of the image, and IRS 3, the much fainter object located close to IRS 1, just to its upper right. The emission lines of atomic and molecular hydrogen, ionized iron, and hot carbon monoxide that we found in their spectra attest to both stars generating intense outflowing winds.

Other protostars within NGC 2071-IR could also be producing outflows that are disrupting the cloud. If we are correct, NGC 2071-IR may be generating more outflows simultaneously than any cloud core in the solar neighborhood. However, spectra do not exist of most of the other stars in Figure 1.

We are hoping to be granted additional time to obtain infrared spectra of all of them. A crude spectrum of IRS 7, located far from IRS 1 and IRS 3, that we obtained 30 years ago, shows strong evidence of outflow activity. One especially mysterious source, detected in the infrared for the first time by NIRI, but found earlier at radio wavelengths by the Very Large Array (in New Mexico) and dubbed VLA-1, shows signs of activity at radio wavelengths. Located between IRS 1 and IRS 3, but apparently much more deeply buried in the star-forming cloud than either of them, it may be an important key to understanding the entire region.

Identifying all of the active protostars within NGC 2071-IR will allow us to complete the picture of how these violent activities are sculpting the surrounding cloud. The active ones not only could be preventing more stars from forming, but also could be disrupting the abilities of other younger protostars to collect nearby gas, placing limits on how massive they can become. Walther and I hope that additional spectra will give a clearer understanding of the activities within this fascinating cloud.

For additional details see Walther, D. M., and Geballe, T. R., *The Astrophysical Journal*, **875:** 153, 2019, or *arXiv* 1903.03583

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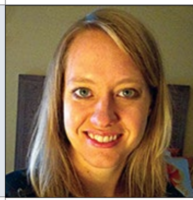


Rachel Matson and Andy Stephens

Speckle Imaging Takes Gemini to Its Diffraction Limit

For nearly a decade, speckle imaging at Gemini Observatory has produced an abundance of notable results, including a monumental breakthrough in exoplanet research in binary star systems. Now with the recent addition of an innovative pair of powerful high-resolution speckle instruments to permanently reside at Gemini North and South, the Observatory stands on the forefront of high-resolution ground-based exploration.

Recently our team at the NASA Ames Research Center authored a high-impact journal article that featured key Gemini data on the transit by a giant exoplanet of one of the components of the Kepler-13AB binary star system. system. This study, led by Steve Howell, not only classified the Jupiter-sized exoplanet (Kepler-13b) in this close binary system but, in a first for ground-based imaging, conclusively determined which star the planet orbits. The Gemini press release on our finding is reprinted starting on page 15 of this issue, and *The Astronomical Journal* paper is available ***here***.

To execute this type of diffraction-limited science and uncover the hidden secrets of close exoplanet binary star systems, in which about one half of all exoplanets reside, our team designed under Howell's leadership an innovative pair of twin instruments that perform high-resolution "speckle imaging" — collecting a thousand 60-millisecond exposures every minute; after processing this large amount of data, the final images are free of the adverse effects of atmospheric turbulence which can bloat, blur, and distort star images.

Our team aptly named the two permanently mounted instruments Zorro and 'Alopeke (Figure 1), which come from the Spanish and Hawaiian (respectively) words for Fox — because the instruments are both speedy and sly like foxes. The instruments were built to take advantage of innovation and crafty approaches to problems with only a fraction of the resources necessary for most 8-meter-class telescope instruments.

Figure 1.

The 'Alopeke/Zorro team at Gemini North preparing 'Alopeke for installation.

Credit: Alison Peck

The power of these instruments was demonstrated when Howell and his team used 'Alopeke to probe the Kepler-13AB system. 'Alopeke sharply resolved the two stars (Kepler A and B), and captured a clear drop in the light from Kepler A, proving that the planet orbits the brighter of the two stars. Moreover, as 'Alopeke simultaneously provides data at both red and blue wavelengths, the researchers could see that the dip in the star's blue light was about twice as deep as the dip seen in red light.

As a very extended atmosphere would more effectively block light at blue wavelengths, the researchers characterize Kepler-13b as a Jupiter-like gas-giant exoplanet with a "puffed up" atmosphere due to exposure to the tremendous radiation from its host star; Thus, these multi-color speckle observations give us a first tantalizing glimpse into the appearance of this distant world orbiting a star in a binary system — something we know very little about.

Our work with Kepler-13b stands as a model for future research on exoplanets in multiple star systems. The observations highlight the ability of high-resolution imaging with large telescopes like Gemini, not only to assess which stars with planets are in binaries, but also robustly determine which of the stars the exoplanet orbits.

The Rise and Promise of Speckle Imaging at Gemini

Speckle imaging at Gemini began in 2012 when the Differential Speckle Survey Instrument (DSSI; designed by Elliott Horch) came to the Observatory as a visiting instrument. This precursor to 'Alopeke and Zorro was granted 10 hours on Gemini North to observe high-priority planet candidates from NASA's (now-retired) Kepler mission, whose prime objective was to explore the structure and diversity of exoplanetary systems, including estimating how many planets there are in multiple-star systems.

To search for planets around other stars, the *Kepler Space Telescope* would stare at thousands of stars and look for a slight decrease in brightness, indicating that a planet had transited (crossed in front of) the star as viewed from Earth. While the transit method is very successful at finding planets, other phenomena can mimic the signature of a planet. Because of this, other methods must be used to confirm whether a planet caused the star's dimming.

High-resolution speckle imaging enables astronomers to not only resolve other objects near the star hosting the planet candidate, but detect or rule out other, non-planetary objects that can cause a star's light to dim (speckle cannot see planets). This is achieved by employing statistical techniques to assess whether the observed dimming is likely to be a true transit by an orbiting planet or a "false positive." Using this technique, the DSSI observations at Gemini North in 2012 helped confirm over a dozen planet candidates, including the five-planet system Kepler-67; DSSI would eventually provide more than 2,100 observations of Kepler planet candidate host stars.

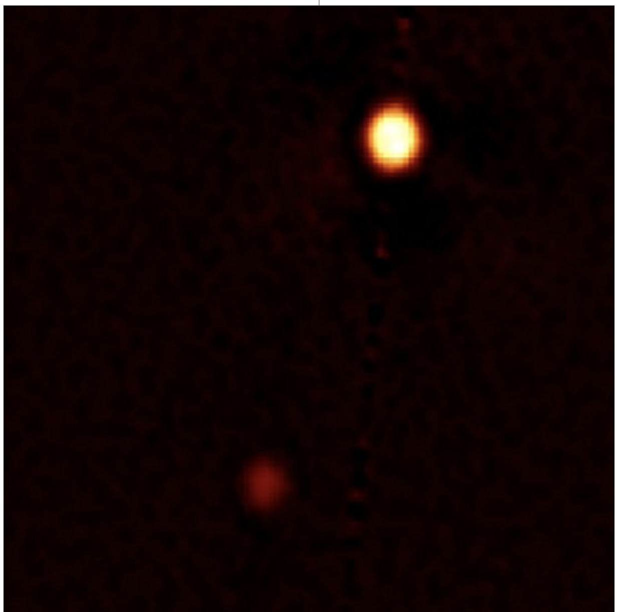

Figure 2.
Speckle image reconstruction of Pluto and Charon obtained in visible light at 692 nanometers (red) with the Gemini North 8-meter telescope using the Differential Speckle Survey Instrument (DSSI). Resolution of the image is about 20 milliarcseconds average. This is the first speckle reconstructed image for Pluto and Charon from which astronomers obtained not only the separation and position angle for Charon, but also the diameters of the two bodies. North is up, east is to the left, and the image section shown here is 1.39 arcseconds across.

Credit: Gemini Observatory/NSF/NASA/AURA

Based on the success of DSSI, and the need to validate and characterize the 4,000 exoplanet candidates discovered to date by NASA's *Kepler/K2 Space Telescope* and the *Transiting Exoplanet Survey Satellite (TESS)*, Howell initiated the design of two new speckle instruments: 'Alopeke and Zorro, which our team went on to build at NASA Ames Research Center. The twin instruments each use two electron-multiplying CCDs and combinations of narrow-band (40- to 50-namometer-wide) filters to provide simultaneous two-color diffraction-limited photometric and astrometric information at optical wavelengths.

Each instrument can also identify background objects and companion stars — to within < 0.1 to 1.2 arcseconds of, and up to 10 magnitudes fainter than, the exoplanet's host star — that can contaminate exoplanet transit detections. For any detected companion, speckle imaging provides the position and separation from the host star, as well as color and contrast information that greatly reduces the likelihood of false positives and improves the estimates of the exoplanet size.

Zorro and 'Alopeke: Specifics for Users

'Alopeke and Zorro add great new capabilities, and having identical instruments on both Gemini telescopes allows collecting homogeneous datasets over the whole sky. The speckle mode provides diffraction-limited (0.016 arcsecond Full-Width at Half-Maximum at 500 nm and 0.025" at 800 nm) resolution imaging at optical wavelengths over a narrow field of view (~6 arcseconds). The wide-field mode provides high-sensitivity natural-seeing imaging with virtually no readout delay in the standard Sloan broadband filters over a moderate field of view (~60 arcseconds).

Both instruments are considered "permanent resident" visiting instruments, meaning they are available throughout the semesters for regular queue and Fast Turnaround proposals. This makes them great for programs that need simultaneous photometry in two filters, variability studies, and rapid events like occultations, which also benefit from the flexibility of Gemini's queue scheduling.

Differential Speckle Imaging at Gemini

Some Science Highlights

Speckle imaging at Gemini Observatory is a forefront technology allowing researchers to push the limits of high-resolution imaging (Figure 2). The following science references provide a sampling of past successes while hinting at what is possible with these instruments.

- *Pluto + Charon imaging* (Howell *et al.*, 2012).
- *TRAPPIST-1* (Howell *et al.*, 2016)
- *Half of all exoplanet host stars are binary* (Matson *et al.*, 2018)
- Kepler-13AB: see press release below.

Other science being pursued:

- Ages of moving groups (and imaged planets in the moving groups) via dynamical mass determinations using Gemini speckle + GPI
- Light curves of white dwarfs
- Studying multiplicity of nearby M-dwarfs, massive stars, halo binaries, massive young stellar objects, and
- Deriving/improving mass-luminosity relationships for low-metallicity stars and M-dwarfs.

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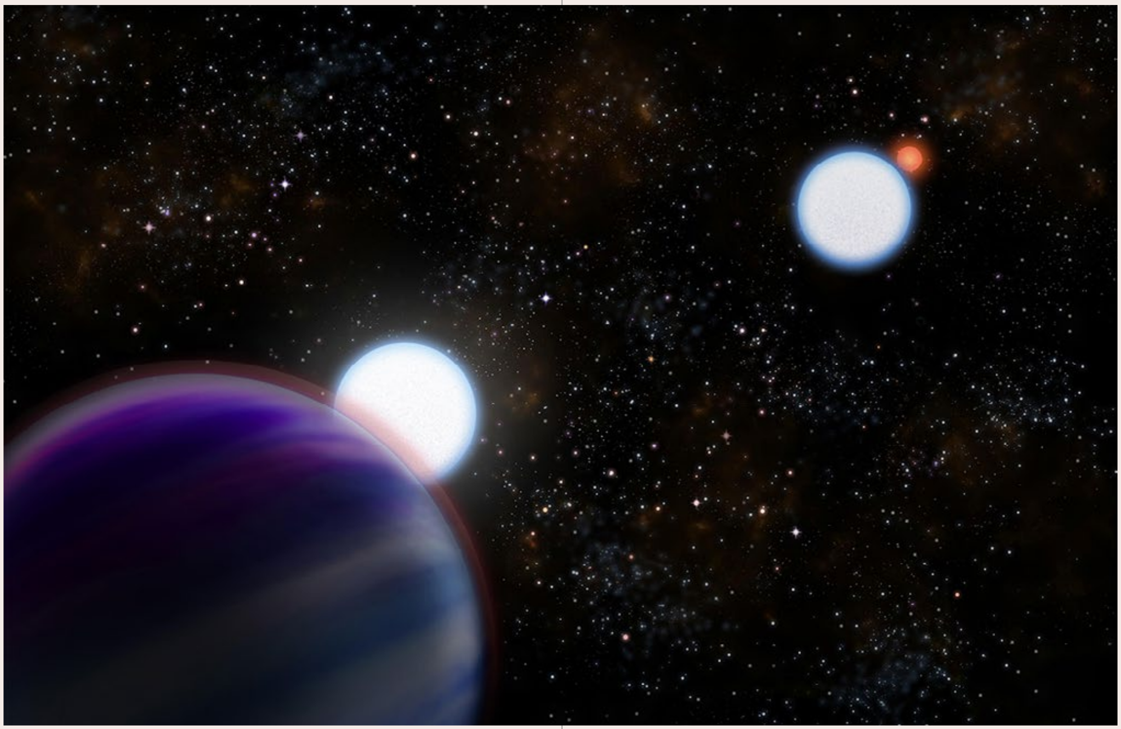
Exoplanets Can't Hide Their Secrets from Innovative New Instrument

A cunning new instrument at Gemini Observatory has achieved what was once thought impossible — namely, the characterization of an exoplanet orbiting a binary star and determining which star of the pair it orbits.

In an unprecedented feat, an American research team discovered hidden secrets of an elusive exoplanet using a powerful new instrument at the 8-meter Gemini North telescope on Maunakea in Hawai'i. The findings not only classify a Jupiter-sized exoplanet in a close binary star system, but also conclusively demonstrate, for the first time, which star the planet orbits.

The breakthrough occurred when Steve B. Howell of the NASA Ames Research Center and his team used a high-resolution imaging instrument of their design — named 'Alopeke (a contemporary Hawaiian word for Fox). The team observed exoplanet Kepler-13b as it passed in front of (transited) one of the stars in the Kepler-13AB binary star system some 2,000 light years distant. Prior to this attempt, the true nature of the exoplanet was a mystery.



Artist's conception of the Kepler-13AB binary star system as revealed by observations including the new Gemini Observatory data. The two stars (A and B) are large, massive bluish stars (center) with the transiting "hot Jupiter" (Kepler-13b) in the foreground (left corner). Star B and its low mass red dwarf companion star are seen in the background to the right.

Credit: Gemini Observatory/NSF/AURA/ Artwork by Joy Pollard

"There was confusion over Kepler-13b: was it a low-mass star or a hot Jupiter-like world? So we devised an experiment using the sly instrument 'Alopeke," Howell said. The research was recently published in *The Astronomical Journal*. "We monitored both stars, Kepler A and Kepler B, simultaneously while looking for any changes in brightness during the planet's transit," Howell explained. "To our pleasure, we not only solved the mystery, but also opened a window into a new era of exoplanet research."

"This dual win has elevated the importance of instruments like 'Alopeke in exoplanet research," said Chris Davis of the National Science Foundation, one of Gemini's sponsoring agencies. "The exquisite seeing and telescope abilities of Gemini Observatory, as well as the innovative 'Alopeke instrument made this discovery possible in merely four hours of observations."

'Alopeke performs "speckle imaging," collecting a thousand 60-millisecond exposures every minute. After processing this large amount of data, the final images are free of the adverse effects of atmospheric turbulence — which can bloat, blur, and distort star images.

"About one half of all exoplanets orbit a star residing in a binary system, yet, until now, we were at a loss to robustly determine which star hosts the planet," said Howell.

The team's analysis revealed a clear drop in the light from Kepler A, proving that the planet orbits the brighter of the two stars. Moreover, 'Alopeke simultaneously provides data at both red and blue wavelengths, an unusual capability for speckle imagers. Comparing the red and blue data, the researchers were surprised to discover that the dip in the star's blue light was about twice as deep as the dip seen in red light. This can be explained by a hot exoplanet with a very extended atmosphere, which more effectively blocks the light at blue wavelengths. Thus, these multi-color speckle observations give a tantalizing glimpse into the appearance of this distant world.

Early observations once pointed to the transiting object being either a low-mass star or a brown dwarf (an object somewhere between the heaviest planets and the lightest stars). But Howell and his team's research almost certainly shows the object to be a Jupiter-like gas-giant exoplanet with a "puffed up" atmosphere due to exposure to the tremendous radiation from its host star.

'Alopeke has an identical twin at the Gemini South telescope in Chile, named Zorro, which is the word for Fox in Spanish. Like 'Alopeke, Zorro is capable of speckle imaging in both blue and red wavelengths. The presence of these instruments in both hemispheres allows Gemini Observatory to resolve the thousands of exoplanets known to be in multiple star systems.

"Speckle imaging is experiencing a renaissance with technology like fast, low noise detectors becoming more easily available," said team member and 'Alopeke instrument scientist Andrew Stephens at the Gemini North telescope. "Combined with Gemini's large primary mirror, 'Alopeke has real potential to make even more significant exoplanet discoveries by adding another dimension to the search."

First proposed by French astronomer Antoine Labeyrie in 1970, speckle imaging is based on the idea that atmospheric turbulence can be "frozen" when obtaining very short exposures. In these short exposures, stars look like collections of little spots, or speckles, where each of these speckles has the size of the telescope's optimal limit of resolution. When taking many exposures, and using a clever mathematical approach, these speckles can be reconstructed to form the true image of the source, removing the effect of atmospheric turbulence. The result is the highest-quality image that a telescope can produce, effectively obtaining space-based resolution from the ground — making these instruments superb probes of extrasolar environments that may harbor planets.

The discovery of planets orbiting other stars has changed the view of our place in the Universe. Space missions like NASA's *Kepler/K2 Space Telescope* and the *Transiting Exoplanet Survey Satellite* (TESS) have revealed that there are twice as many planets orbiting stars in the sky than there are stars visible to the unaided eyes; to date the total discovery count hovers around 4,000. While these telescopes detect exoplanets by looking for tiny dips in the brightness of a star when a planet crosses in front of it, they have their limits.

"These missions observe large fields of view containing hundreds of thousands of stars, so they don't have the fine spatial resolution necessary to probe deeper," Howell said. "One of the major discoveries of exoplanet research is that about one-half of all exoplanets orbit stars that reside in binary systems. Making sense of these complex systems requires technologies that can conduct time sensitive observations and investigate the finer details with exceptional clarity."

"Our work with Kepler-13b stands as a model for future research of exoplanets in multiple star systems," Howell continued. "The observations highlight the ability of high-resolution imaging with powerful telescopes like Gemini to not only assess which stars with planets are in binaries, but also robustly determine which of the stars the exoplanet orbits."

Jennifer Hanley

Neptune's Moon Triton Fosters Rare Icy Union

Observations from the visiting IGRINS spectrograph at Gemini South reveal for the first time beyond the lab, an extraordinary union between carbon monoxide and nitrogen ices. The discovery offers insights into how this volatile mixture can transport material across Neptune's moon Triton via geysers, trigger seasonal atmospheric changes, and provide a context for conditions on other distant, icy worlds.

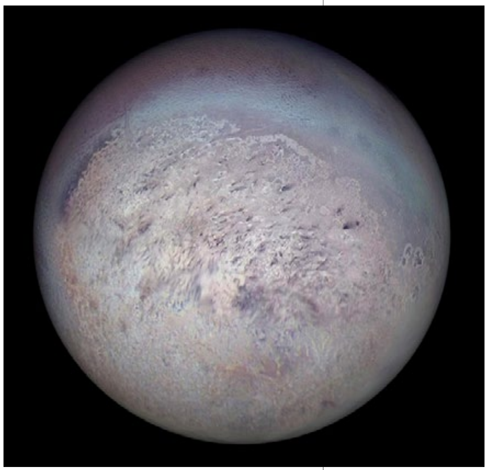


Figure 1.
Voyager 2 *image of Triton showing the south polar region with dark streaks produced by geysers visible on the icy surface. Credit: NASA/JPL*

Neptune's largest moon Triton has been mysterious ever since its discovery in 1846 as the only large retrograde-orbiting satellite: in 1989, the *Voyager 2* flyby (Figure 1) showed geologic activity despite extremely cold temperatures, and later ground-based observations showed it and Pluto sharing similar surface compositions. Triton is now thought to be a captured dwarf planet from the Kuiper Belt, but further observations are necessary to unmask the moon's many secrets.

Until we can return to the Neptunian system (and there are proposals underway), our best way to understand Triton is through telescopic observations, laboratory investigations, and chemical modeling. Our research at the Astrophysical Materials Laboratory at Northern Arizona University in Flagstaff, Arizona, has combined these techniques in order to study the composition of Triton's surface. For the telescopic observations, we utilized the visiting high-resolution near-infrared spectrometer IGRINS — built as a collaboration between the University of Texas at Austin and the Korea Astronomy and Space Science Institute (Park *et al.*, 2014; Mace *et al.*, 2018) — which allowed us to acquire a high signal-to-noise spectrum of Triton to make an unprecedented discovery beyond the lab. We recently published the synthesis of these results in *The Astronomical Journal* (Tegler *et al.*, 2019).

Laboratory Investigations

While previous studies have shown that carbon monoxide (CO) and nitrogen (N2) ices exist on Triton, we decided to investigate their spectral features — specifically, we wanted to see how the spectra changed as a function of the mixing ratio between the CO and N2.

In order to study spectroscopic telescopic data, one needs to have an appropriate library of laboratory spectra. Most laboratory experiments collect spectra of thin ice samples of only microns thick. These experiments are superb at studying intrinsically strong absorption bands. Thin film experiments are not as good for studying intrinsically weak absorption bands. Longer path lengths are needed to study these bands. In the Astrophysical Materials Laboratory, we have a unique experimental setup that enables us to study ice samples as thick as 2 centimeters. As a result, we can study very weak absorption bands.

Our thick cell is mounted on top of a cryocooler. Gas enters the cell from above via a fill tube (Figure 2a). The dotted lines in Figure 2 represent the spectrometer beam through the sample. Thermometers (T1 and T2) and heating elements (H1 and H2) control the temperature of the sample down to 30 Kelvin (K). Further details concerning the cell are described in Tegler *et al.* (2019).

We measured the absorption coefficient of varying mixtures of CO and N2, and noticed an unidentified, weak band that wasn't in either pure species. This band was strongest when the ratio of CO to N2 was at 50:50 (Figure 3). The spectra shown in Figure 3 are all taken at 60 K, where the ice mixture is in the β-phase. A maximum band strength for samples with nearly equal amounts of CO and

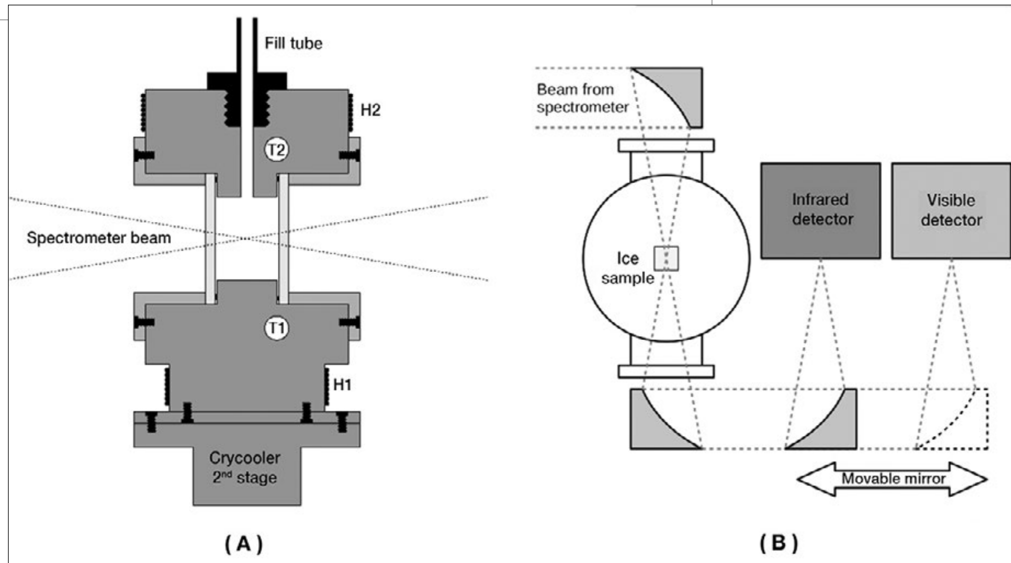


Figure 2.
(A) Schematic diagram of the Astrophysical Materials Laboratory thick cell in cross section as seen from the side. (B) The optical train in our experiment as seen from above. The spectrometer beam is represented by dashed lines. Only the infrared detector was used in the experiments described here.

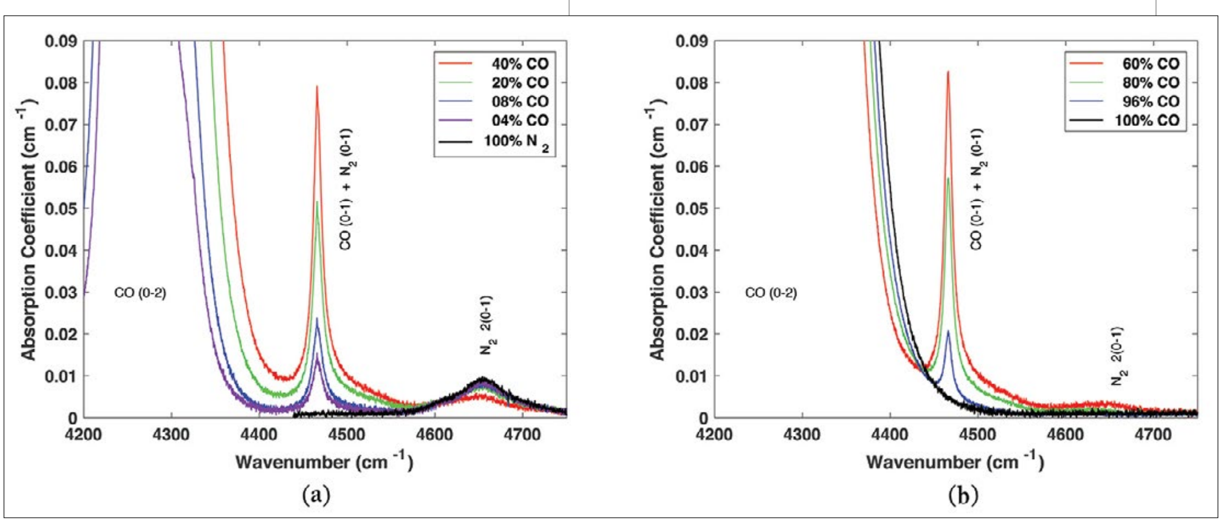


Figure 3.
Spectra of CO/N2 ice samples with the CO abundance ranging from (a) 0% to 40% and (b) 60% to 100%. In panel (a), the spectra show the new band near 4467 cm^{-1}. The new band is not present in the pure N2 sample (black line) and increases in strength with increasing CO abundance. The saturated band at 4252 cm^{-1} is a CO overtone and the weak, broad band at 4654 cm^{-1} is N2. The strength of the weak, unidentified band at a CO abundance of 60% in panel (a) is nearly the same as its strength at 40% in panel (b) and then decreases in strength with increasing CO abundance. The band is not present in the pure CO ice sample in panel (b). Figure and caption modified from Tegler et al. *(2019).*

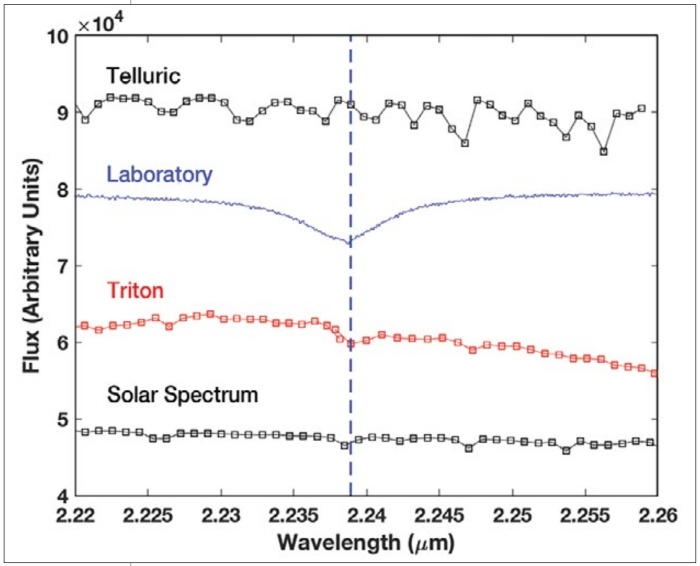


Figure 4.

A portion of an 80-minute, binned-spectrum of Triton taken with the 8.1-meter Gemini-South telescope and the IGRINS spectrometer (red squares). The broad absorption in the Triton spectrum is consistent with the broad absorption of the two-molecule combination band at 2.239μm (4466.5 cm^{-1}) in our laboratory transmission spectrum (blue line). Both broad bands are inconsistent with the telluric (black squares at top of figure) and the solar (black squares at bottom of figure) spectra.

Figure and caption modified from Tegler, et al. *(2019)*

N2, and its absence in pure N2 and pure CO, reinforces the idea that the band is caused by the CO and N2 molecules being near each other, and probably interacting.

Molecular Understanding

Individually, carbon monoxide and nitrogen ices each absorb their own distinct wavelengths of infrared light, but the tandem vibration of an ice mixture absorbs at an additional, distinct wavelength. Looking at the pure species, we are able to identify the fundamental vibrational frequencies, as well as their overtones and combinations. However, this band (first noted but not identified by Quirico and Schmitt, 1997) did not align with any known features. Since the band had maximum strength in samples with nearly equal amounts of CO and N2, and was absent in pure N2 and pure CO, we realized it must arise from both molecules simultaneously. We refer to the band as a two-molecule combination band.

We were able to quantitatively show the new band was the result of the simultaneous excitation of adjacent CO and N2 molecules. Specifically, we found the energy (wavenumber) required to excite the weak, unidentified band was equal to the sum of the energies (wavenumbers) required to excite the CO fundamental and the N2 fundamental. For this to happen, the CO and N2 molecules have to be intimately mixed together.

Triton Observations

One exciting aspect of this work is that if we detect this band on any astronomical object we know that carbon monoxide and nitrogen must be intimately mixed together at the molecular level. That excitement rose as we used the 8-meter Gemini South Telescope in Chile on the night of July 2, 2018, to explore Triton's icy surface with IGRINS. The combination of this large aperture telescope with the phenomenal throughput of IGRINS over long exposure times, coupled with the high spectral resolution gives the ability to bin to get desired signal-to-noise ratio. All this was necessary to even have a chance to detect this weak feature. We summed our individual Triton spectra to obtain a single spectrum with a total exposure time of 80 minutes.

Since our objective was to detect the spectrally broad CO-N2 combination band at 2.239 microns (μm) (4466.5 cm^{-1}), we used inverse variance weighting to bin the spectrum into blocks of 64 pixels, and thereby improve the signal-to-noise ratio of the Triton spectrum. The binned spectrum had a resolution of $\lambda/\Delta\lambda = 2{,}500$.

As can be seen in Figure 4, there is a broad feature in the Triton spectrum (red squares) located at the same position as the band in our laboratory spectrum of 8% CO and 92% N2 ice sample at 60 K (blue line). For comparison, we show absorption due to Earth's atmosphere (black squares seen at top) and reflected sunlight, *i.e.,* Fraunhofer lines (black squares at bottom of figure). The telluric and solar spectra are binned to the same resolution as the binned Triton spectrum, *i.e.,* $\lambda/\Delta\lambda = 2{,}500$. The vertical dotted line marks the wavelength of maximum absorption by the broad band in our Triton spectrum. The band in our Triton spectrum coincides with the 2.239 μm (4466.5 cm^{-1}) band in the laboratory spectrum.

The strength of absorption of Triton's N2 and CO ice bands varies with longitude, by roughly a factor of two, with the strongest absorption being on the leading part of the sub-Neptune hemisphere (longitude ~50° East; see Grundy *et al.,* (2010). We observed when Triton was at a sub-Earth longitude of 113° East, not far from the maximum in N2 and CO absorption.

Looking ahead

On distant Triton, carbon monoxide and nitrogen freeze as solid ices. They can form their own independent ices, or condense together in the icy mix detected in the Gemini data. Our discovery, for the first time beyond the lab, of an extraordinary union between carbon monoxide and nitrogen ices is important, as it could be involved in Triton's iconic geysers — first seen in *Voyager 2* spacecraft images as dark, windblown streaks on the moon's south polar region back in 1989 (Figure 1).

Since *Voyager 2's* discovery of the geysers, theories have focused on an internal ocean as one possible source of erupted material. Or, the geysers may erupt when the summertime Sun heats this thin layer of volatile ice on Triton's surface, potentially involving the mixed carbon monoxide and nitrogen ice revealed by the Gemini observation. That ice mixture could also migrate around the surface of Triton in response to seasonally varying patterns of sunlight.

Seasons progress slowly on Triton, as Neptune takes 165-Earth years to orbit the Sun. A season on Triton lasts a little over 40 years; Triton passed its southern summer solstice mark in 2000, leaving about 20 more years to conduct further research before its autumn begins.

We expect that these findings will shed light on the composition of ices and seasonal variations on other distant worlds beyond Neptune. Astronomers have suspected that the mixing of carbon monoxide and nitrogen ice exists not only on Triton, but also on Pluto, where the *New Horizons* spacecraft found the two ices coexisting in Sputnik Planitia (Protopapa *et al*., 2017) — an icy basin that has apparently caused Pluto's entire crust to shift over time. The same may be true for more recently discovered small planets like Eris and Makemake, both of which host volatile ices like those on Pluto and Triton. This Gemini finding is the first direct spectroscopic evidence of these ices mixing and absorbing this type of light on either world.

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Vinicius Placco

Making Good Use of Bad Weather: Finding Metal-poor Stars Through the Clouds

The Gemini telescopes played a key role in identifying low-metallicity stars in the Galaxy by gathering medium-resolution spectroscopic GMOS data for 666 bright (V < 14) stars under poor weather conditions. In-depth studies of these stars provide a unique opportunity to witness not only the chemical and dynamical evolution of the Milky Way but also to identify and distinguish between a number of possible scenarios for the enrichment of star-forming gas clouds in the early Universe.

Low-metallicity stars are the Rosetta Stones of stellar astrophysics. Encoded in the atmosphere of these low-mass, long-lived relics are the signatures of nucleosynthetic processes, by which the first light elements were cooked up; this could have occurred as early as a few tens of millions of years after the Big Bang. The first generation of stars to be born in the Universe were formed (mostly) out of hydrogen and helium. These are thought to be massive (tens to hundreds of solar masses), short-lived, and to end their lives in an explosive event that would seed the up-to-then chemically pristine Universe with most of the chemical species we know today. By studying the mass distribution of these so-called Population III (Pop. III) stars it is possible to constrain models for the chemical evolution of the Universe at high-redshifts and the formation and evolution of our Galaxy. However, most (if not all) of the Pop. III stars are long gone, and the only way to infer their existence is by observing the low-mass stars formed right after.

Extremely Metal-poor Stars: Windows into the Early Universe

The only way to understand and characterize the first generation of stars is to look for their direct descendants that would still be alive today: second-generation low-mass, low-metallicity stars. A subset of these, the Extremely Metal-Poor (EMP; [Fe/H] < -3.0) stars, with iron abundances of 1/1,000 of the solar value, are believed to carry in their atmospheres the chemical fingerprints of the evolution of as few as one Pop. III massive star. Apart from the very low iron abundance, the majority (more than 60%) of the observed EMP stars show a very strong molecular carbon signature in their optical spectrum. Such high carbon abundances are one of the expected yields of the final stages of evolution of zero-metallicity Pop. III stars and can help trace back the nature of the first stars in the Universe.

Finding the Needle in the Haystack

Identifying such pristine objects is a challenging endeavor. EMP stars are intrinsically rare (less than 30 stars identified to date with [Fe/H] < -4.0) and can only be properly characterized as such via spectroscopic studies. In addition, metal-poor stars are generally found in higher fractions in the halo populations of the Galaxy, making most of them faint and "expensive" in terms of telescope time. Thus, it is important to have reliable selection criteria in the search for the brightest metal-poor star candidates for high-resolution spectroscopic follow-up.

Since changes in metallicity affect the colors in optical wavelengths in predictable ways, we pre-selected a number of such candidates from broadband or narrowband photometry. Even though these methods can successfully identify metal-poor star candidates, they become more and more uncertain as metallicities decrease. As a result, medium-resolution ($R = \lambda/\Delta\lambda \approx 1{,}500$) spectroscopy becomes a valuable tool not only for pre-selection of targets to be followed-up in high-resolution ($R \approx 30{,}000$) but also for parameter determination and stellar population studies.

Recently, our team published two studies in *The Astronomical Journal* (Placco *et al.*, 2018; Placco *et al.*, 2019), aiming to increase the inventory of EMP star candidates observed with medium-resolution spectroscopy. We observed these stars over the course of seven semesters (from 2014A to 2017A) with a variety of telescopes, including the Gemini North and South telescopes, the Southern Astrophysical Research telescope, Kitt Peak National Observatory's Mayall telescope, and the European Southern Observatory's New Technology Telescope. In total, 2,551 stars were observed.

We selected the (bright) candidates from two sources — the RAdial Velocity Experiment (RAVE) and the Best & Brightest Survey (B&B) — and used the Gemini North and South telescopes to observe 666 stars out of the 2,551. Figure 1 shows the distribution of

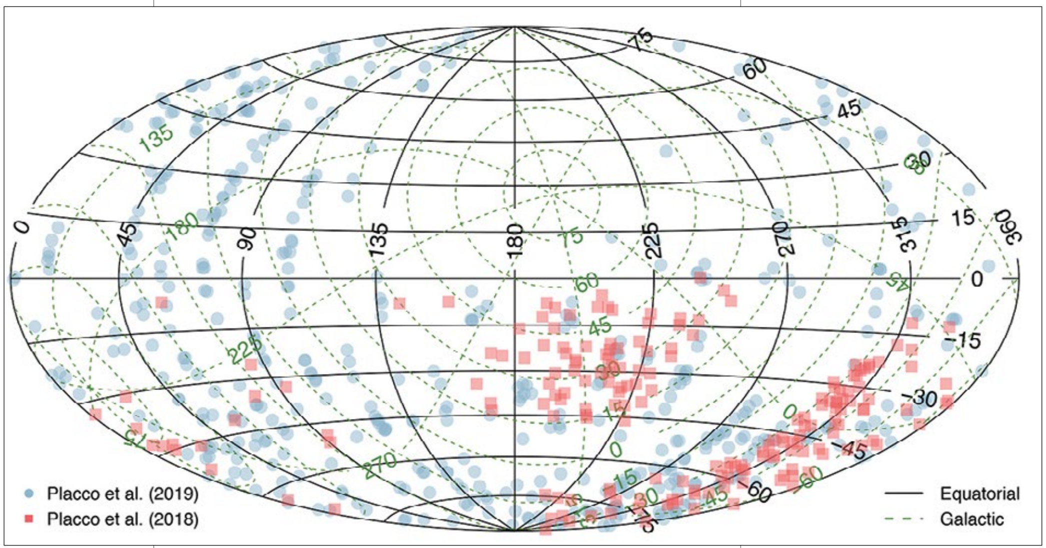

Figure 1.
Equatorial and Galactic coordinate distribution of the stars observed with Gemini North and Gemini South in poor weather conditions.

equatorial and Galactic coordinates for the Gemini targets, color-coded by catalog. All of these spectra, interestingly, were gathered exclusively as part of the Poor Weather proposal cycle offered by the Gemini Observatory.

Big Eyes and Cloudy Nights

The targets selected from the RAVE and B&B catalogs were bright enough to be observed under poor, but usable, conditions, as part of the Poor Weather programs at Gemini. Such programs are executed only when nothing in the regular queue is observable and hence considered "weather loss" for time accounting purposes. The targets followed-up as part of this effort had no observing condition constraints (CC = Any, IQ=Any, SB=Any/Bright, and WV = Any), and spectra were taken using the Gemini Multi-Object Spectrograph (GMOS; North and South) B600 gratings and 1-arcsecond slits.

Figure 2 shows the total counts at 4000 Ångstroms in the observed spectra as a function of the visual magnitude of the stars. The size of the symbols is proportional to the exposure time for each object, in seconds. It is interesting to note the large spread in counts for stars with similar exposure times in a narrow range of magnitudes (*e.g.,* blue filled circles at V ~13.5). Similarly, there are cases where it took up to four times longer to gather the same counts for stars with similar magnitudes (*e.g.*, red filled squares at V ~12.5 and Counts ~1,000). These are telltale signs of the highly variable weather conditions (mostly image quality and cloud cover) in which these stars were observed.

In total, seven GMOS Poor Weather programs were executed (three in the North and four in the South) spanning four semesters (from 2015A to 2016B). Those programs had 310 hours of allocated time. By adding all the exposure times, there were about 89 hours of on-target observations for the 666 stars, averaging about 8 minutes per exposure. Adding ~12 minutes for acquisition and calibrations, these were 20-minute observing blocks, giving an average of three stars per hour. As a result, assuming 666 targets took 222 hours of observing time, the efficiency

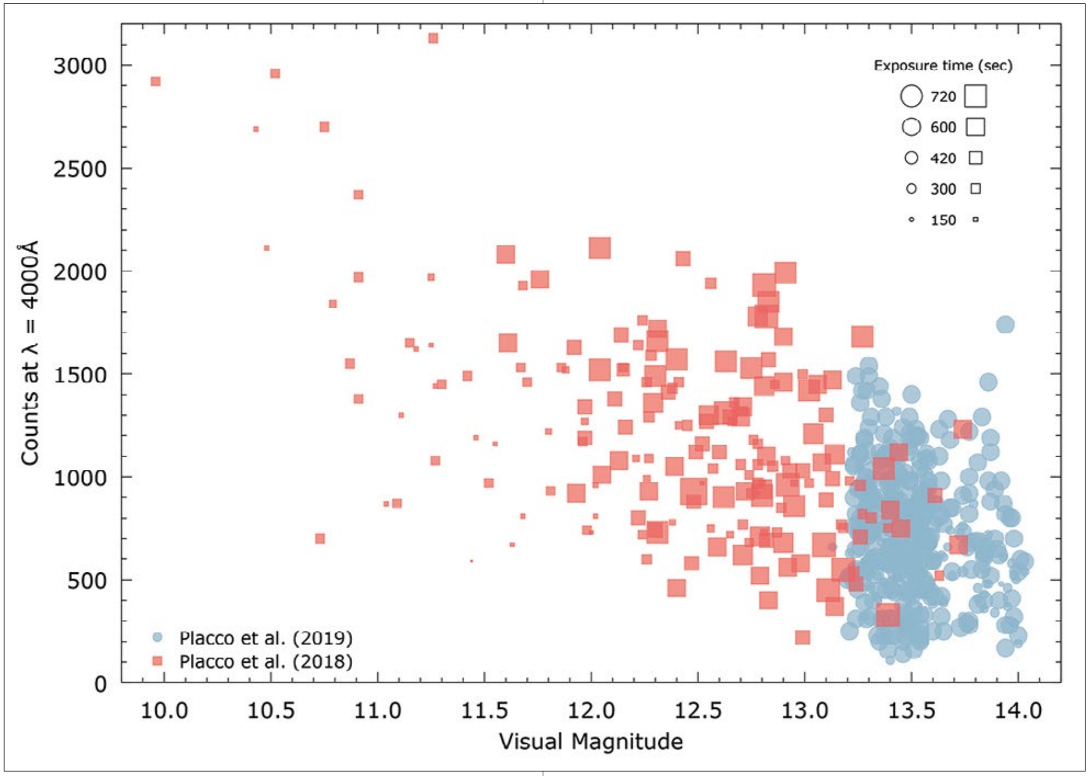

Figure 2.
Total counts at 4000 Å as a function of visual magnitude. The size of the symbols is proportional to the exposure time for each object, in seconds.

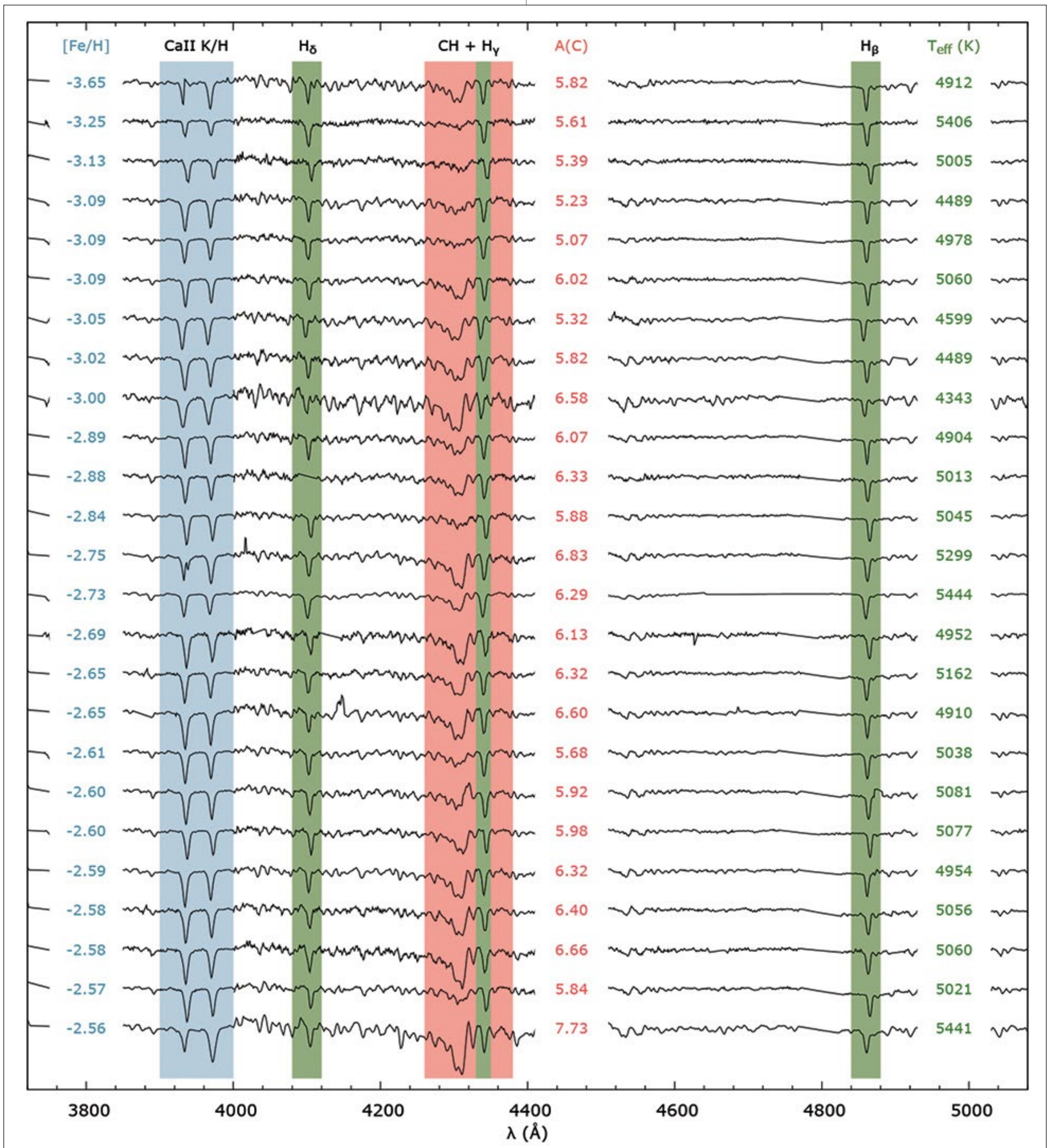

Figure 3.

Example spectra for 25 stars with [Fe/H] < -2.5 observed with Gemini/GMOS (North and South). The shaded areas highlight regions of interest for the determination of metallicity (blue - [Fe/H], Ca II K absorption feature), carbon abundance (red - A(C), CH G-band), and temperature (green - $T_{eff}^{(K)}$ hydrogen Balmer lines). The spectra are ordered by increasing values of [Fe/H].

was around 72%, meaning that only 28% of the already poor weather was lost, which is a great accomplishment for the program and the Observatory.

Scientific Gain from Weather Loss

The spectra gathered at Gemini/GMOS are of sufficient quality (signal-to-noise ratios and spectral resolution) to allow for the determination of stellar atmospheric parameters: effective temperature (T_{eff}), surface gravity, metallicity ([Fe/H]), and carbon abundances (A(C)). Figure 3 shows the GMOS spectra of 25 stars with [Fe/H] < -2.5 observed under poor weather conditions. The shaded areas highlight absorption spectral features used to determine [Fe/H] (Ca II K absorption feature), A(C) (CH G-band), and T_{eff} (hydrogen Balmer lines). The values for each parameter are also listed. From the 666 stars, metallicities could be determined for 656 (98%), including 477 stars with [Fe/H] < -1.0 (73%), 285 stars with [Fe/H] < -2.0 (43%), and 9 stars with [Fe/H] < -3.0 (including one at [Fe/H] = -3.65). Carbon abundances were determined for 653 stars.

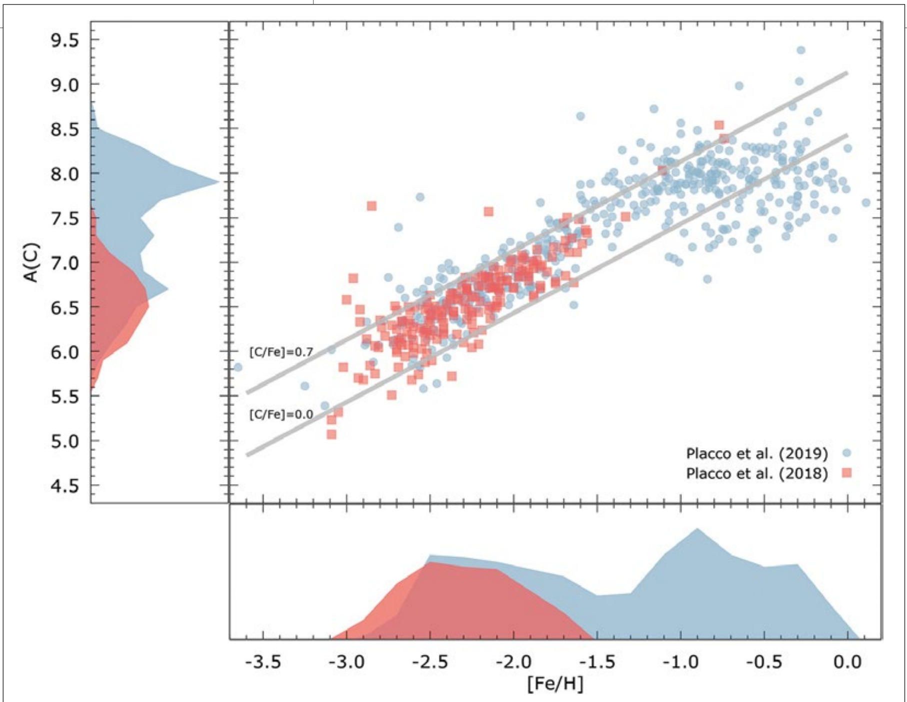

Figure 4. *Carbon abundances, A(C), as a function of the metallicity, [Fe/H], for the program stars observed with Gemini. The side and lower panels show the marginal distributions for each quantity.*

The distribution of the carbon abundances as a function of the metallicity for these stars is shown in Figure 4. The lower and side panels show marginal distributions for each quantity. The behavior is similar to that expected from high-resolution spectroscopic samples, which makes this subset important for two reasons: 1) as a tool for target selection, and 2) to have an independent estimate of quantities, such as the fraction of carbon-enhanced metal-poor stars as a function of [Fe/H], which is a crucial observational constraint to Galactic chemical evolution models.

What Have We Learned and What's Next?

The objectives of such follow-up studies, which can include Gemini Poor Weather observations, are two-fold: 1) build statistics of metallicities and carbon abundances determined from medium-resolution spectroscopy, which are crucial for studies of stellar populations and formation of the Milky Way, and 2) select interesting stars for further, more targeted, high-resolution spectroscopy efforts. One effort that is feeding directly from the Gemini data is called the "R-Process Alliance" (RPA) — a multi-stage, multi-year effort to provide observational, theoretical, and experimental constraints on the nature and origin of the astrophysical r-process (rapid neutron-capture).

The parameters determined using the Gemini spectra are extremely useful to tailor target lists for the type of (high-resolution) follow-up conducted by the RPA, and there is already a study published based on an extremely metal-poor star first identified at Gemini (Cain *et al.*, 2018). This star, J2005-3057, shows enhancements in elements formed by the r-process, such as europium, iridium and thorium, among others. Another effort currently underway is gathering high-resolution data for the most carbon-enhanced stars identified by Gemini and the results are also promising. Collectively, these discoveries help us paint a more cohesive picture of how the Universe evolved chemically and how we can reshape our current understanding of stellar evolution and galaxy formation. In the near future, such bright stars will be perfect targets for high-resolution spectroscopic follow-up with GHOST, which will be a great asset in pushing these efforts forward.

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John Blakeslee

Science Highlights

Recapping some of the most recent and significant research results achieved by the Gemini user community.

JANUARY 2020

Gemini Tracks Comet 2I/Borisov from North to South

Figure 1.
Gemini North GMOS color composite image of Comet 2I/Borisov, produced from data obtained in the g, r, and i filters on the night of November 11-12, 2019.

Credit: Gemini Observatory/ NSF's National Optical-Infrared Astronomy Research Laboratory/AURA

Last quarter's *Gemini*Focus reported on Director's Discretionary Time (DDT) observations of interstellar Comet 2I/Borisov taken with the Gemini Multi-Object Spectrograph (GMOS) at Gemini North in early September 2019, not long after it was discovered. In the ensuing months, the comet has traced a southward arc across the sky, and Gemini has been following its journey from both hemispheres. While diverse DDT programs were activated to study 2I/Borisov through October, more recent observations have been obtained via Fast Turnaround (FT) proposals and a 2019B Target of Opportunity program.

In one Gemini North FT program, Rosemary Pike (Academia Sinica Institute of Astronomy and Astrophysics, Taiwan) and colleagues used GMOS and the Near-InfraRed Imager and spectrometer (NIRI) to measure the optical and near-infrared (NIR) colors of the dust coma and tail for comparison with Solar System comets. Team member Meg Schwamb (Queen's University, Belfast) participated in the November observations via the "eavesdropping" option. Although most of the observations were taken with non-sidereal tracking, the observers also obtained a sequence of sidereally tracked exposures for photometry of reference stars. These exposures were then used to make a color composite image, shown in Figure 1, that found its way into the pages of ***The New York Times***.

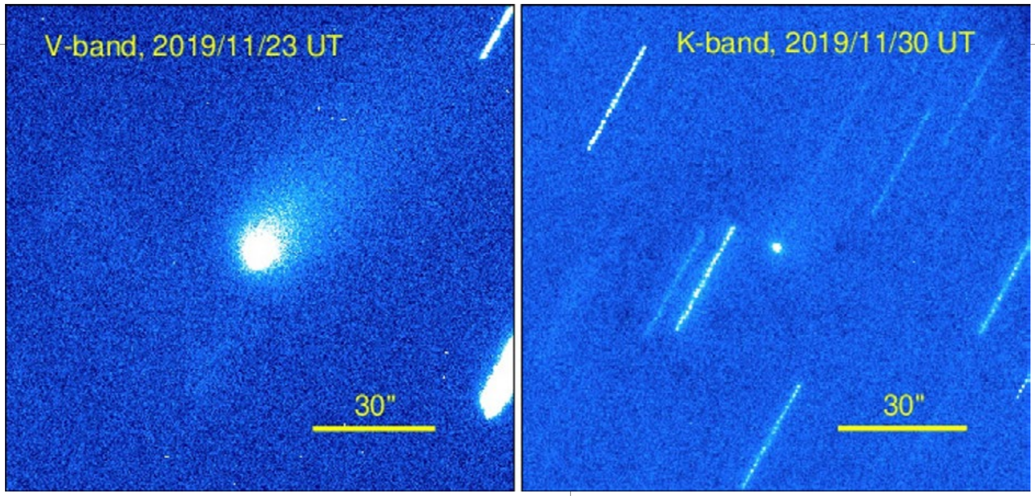


Figure 2.
Near-infrared K-band *image (right) of Comet 2I/Borisov taken on November 30, 2019, with FLAMINGOS-2 at Gemini South when the comet was 2.05 AU from the Sun, compared to an optical* V-band *image (left) taken a week earlier (when it was 2.12 AU from the Sun) at the Nordic Optical Telescope. Unlike in the optical image, the comet appears pointlike in* K.

Image reproduced from Lee et al., Research Notes of the American Astronomical Society, ***3:****184, 2019*

On November 13th, 2I/Borisov crossed into the Southern Hemisphere, and the most recent Gemini observations of it have been made from Cerro Pachón. In a study published in the Research Notes of the American Astronomical Society, Chien-Hsiu Lee (NSF's National Optical-Infrared Astronomy Research Laboratory) and collaborators analyze 2.2-micron (µm) *K*-band images of the comet obtained at Gemini South with FLAMINGOS-2 in late November. As shown in Figure 2, the comet appears point-like at 2.2 µm, unlike at optical wavelengths where the appearance is dominated by the extended coma. Assuming that the *K*-band light is reflected directly by the nucleus, and adopting an albedo of 7% at this wavelength, the study derives an equivalent radius of 1.5 kilometers (km), similar to previous estimates. A higher albedo would translate into a more diminutive nucleus.

Gemini has also observed 2I/Borisov spectroscopically, in both the optical and NIR. A study led by Bin Yang (European Southern Observatory) used NIR spectra from the Gemini Near-InfraRed Spectrometer (GNIRS) at Gemini North, as well as from NASA's Infrared Telescope Facility, to search for diagnostic absorption features of water ice. The data show a moderately red, featureless spectrum in the NIR similar to D-type asteroids, 1I/'Oumuamua, and many Solar System comets. No water ice absorption features were detected, and spectral modeling indicated that large ice grains must comprise no more than 10% of the coma cross-section. Thus, the ice grains are likely confined to the region of the nucleus. The study has been accepted for publication in *Astronomy & Astrophysics Letters*, and a ***preprint is available online***.

The GNIRS observations were taken on September 24th when 2I/Borisov was still 2.6 Astronomical Units (AU) from the Sun. It will be interesting to see how the spectrum has evolved as the comet reached its perihelion distance of 2.0 AU in December and began its long journey back to interstellar space. The observations continue, and we are sure to see more highlights from this first interstellar comet before it's gone for good.

GPI Imaging of Debris Disks in Scorpius-Centaurus

The Gemini Planet Imager (GPI) has been cranking out the results from Gemini South for the past six years, including a demographical analysis, ***published last year in*** The Astronomical Journal, of large exoplanets and brown dwarf companions from the first 300 stars observed in the GPI Exoplanet Survey (GPIES). The GPIES program also included a disk campaign, with the goal of discovering debris disks around young stars and characterizing the structure present in spatially resolved scattered-light images. In a study recently accepted for publication in *The Astronomical Journal*, the GPIES team presents the first resolved images of debris disks around four members of the Scorpius-Centaurus (Sco-Cen) association.

Sco-Cen is the nearest OB association to the Sun, with member distances ranging from about 110 to 140 parsecs and ages of 10-16 million years. It is a particularly useful laboratory for studying debris disks, as the infrared excess observed in young massive stars tends to be greatest around this age. Three of the disks newly imaged with GPI appear symmetric in morphology and brightness distributions, but vary in inclination and radial extent.

The disk around the fourth star, HD 98363, shows significant asymmetry that could indicate the presence of a sizable planet. However, HD 98363 also has a wide co-moving stellar companion, separated by 7,000 AU, that has its own debris disk at a different inclination and with differing morphological peculiarities. This makes HD 98363 A/B the first binary system with two spatially resolved debris disks; the disks are misaligned by about 60 degrees. Depending on the orbital eccentricity, it is possible that the morphological irregularities seen in both debris disks could result from external dynamical perturbations of the other star in the system. The large separation prevents an estimation of either the inclination or eccentricity of the binary orbit.

The new results contribute to the census of disks and the panoply of disk structures observed around hot young stars at this critical stage in the development of planetary systems. A total of 15 stars in the Sco-Cen association now have debris disks that have been resolved in scattered light, and at least seven of these show evidence for asymmetry. Figure 3 displays a gallery of images of scattered light disks and giant planets in the association. The rich diversity of debris disks seen around stars within a single young environment is remarkable, and we can expect even more results to emerge from GPIES and its follow-up programs in the near future.

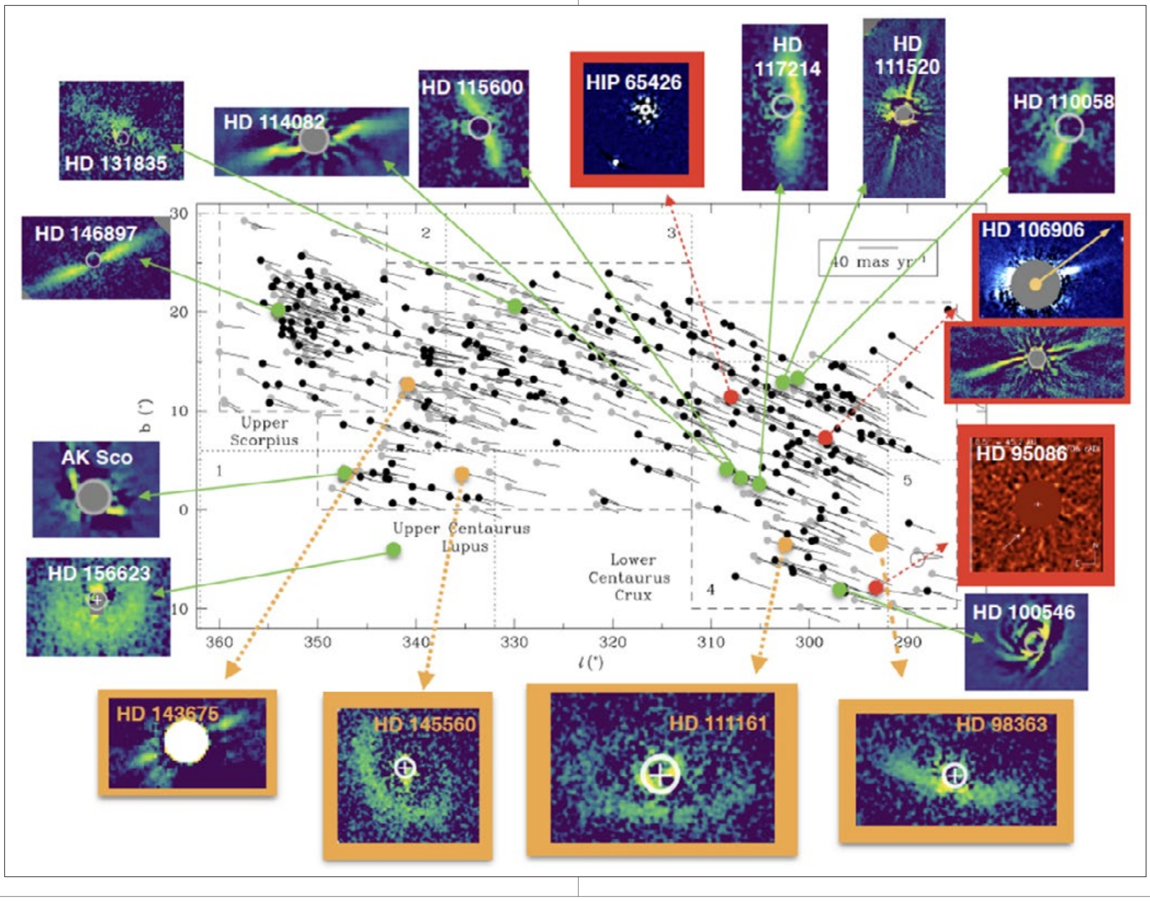


Figure 3.

Map of the Scorpius-Centaurus association in Galactic coordinates with stars having resolved scattered-light disks and imaged giant planets indicated. Proper motions are represented by the vectors. Green points represent previously resolved debris disks, while gold points are the four new systems. Red points indicate stars with imaged giant planets; HD 106906 has both a resolved debris disk and an imaged planet. The majority of the images are from GPI.

Credit: *Hom* et al., The Astronomical Journal, *in press*

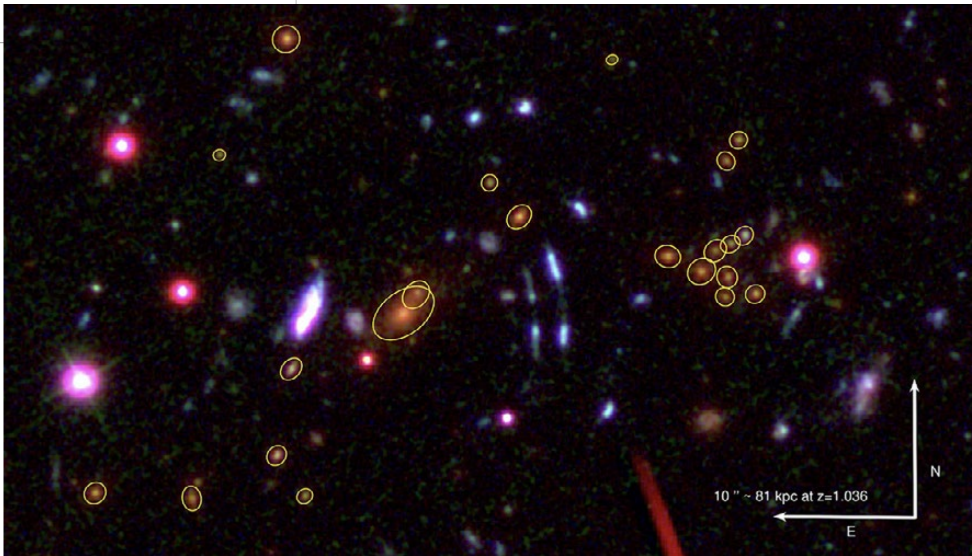


Figure 4. *Color composite image of the merging cluster SPT-CL J0356–5337 at z = 1.036, made by combining Gemini/GMOS-South g and i images with* Hubble*/ACS F606W. The yellow ellipses mark cluster members; several strongly lensed arcs are visible near the center of the field.*

Credit: Mahler et al., arXiv:*1910.14006*

The study is led by Justin Hom of Arizona State University, and a [***preprint is available online***]().

Strong Lensing by Colliding Clusters at High Redshift

Clusters of galaxies, the largest self-gravitating structures in the Universe, form via hierarchical assembly, increasing their masses through the accretion of individual galaxies and small groups, often funneled inward along cosmic filaments. Occasionally, two massive clusters coalesce, providing an opportunity to study high-speed galaxy interactions and shock physics within the colliding intercluster media, the dominant baryonic component in such clusters. If the timing and geometry are favorable, and if each cluster is massive enough to produce detectable gravitational lensing of background sources, then the event also affords a rare opportunity to constrain the physical properties of the nonbaryonic cluster dark matter. Examples of such collisions include the "Bullet Cluster" at redshift $z = 0.30$ and "El Gordo" at $z = 0.87$.

Large numbers of distant clusters have now been found via the Sunyaev-Zel'dovich (SZ) effect, the apparent decrement in brightness of the cosmic microwave background (CMB) radiation resulting from the scattering of CMB photons by high-energy electrons in the intracluster medium. In particular, hundreds of cluster candidates have been identified in this way by the South Pole Telescope (SPT), a 10-meter radio dish located at the South Pole, designed for large-area surveys at millimeter and submillimeter wavelengths. Because the SZ signal does not provide the redshift, additional observations of the member galaxies are required.

The [***SPT-GMOS Survey***](), led by Matthew Bayliss at Harvard (now at MIT), used the GMOS instrument at Gemini South to measure the redshifts of SZ-selected cluster candidates identified by SPT. The survey measured redshifts for nearly 1,600 member galaxies in 62 SPT clusters, including several with strong lensing features. The cluster SPT-CL J0356–5337 (or SPT-0356) at $z = 1.036$, for which Bayliss and collaborators spectroscopically confirmed eight members, was among the highest-redshift strong lensing clusters in the sample.

In a new study, Guillaume Mahler of the University of Michigan and collaborators present a strong lensing analysis of SPT-0356 and expand the sample of likely cluster members using single-band F606W *Hubble* Advanced Camera for Surveys (ACS) imaging combined with Gemini/GMOS-South g- and i-band imaging. Figure 4 shows a color composite made from the Gemini and *Hubble* data, with yellow ellipses enclosing galaxies lying on the cluster red sequence; the largest ellipse marks the brightest cluster galaxy (BCG). The red sequence selection is based on the color-magnitude diagram shown in Figure 5, made from a combination of Gemini and *Hubble* photometry. To enable the lensing analysis, the team used Magellan Observatory to obtain redshifts of three multiply-imaged background galaxies, lensed into the arcs visible near the center of Figure 4, about 9 to 15 arcseconds west of the BCG.

The team's strong lens modeling indicates that SPT-0356 has a two-component mass distribution, with one component centered on the BCG and the other centered on a tight clump of eight galaxies located about 22 arcseconds (170 kiloparsecs) west of the BCG. The two components have similar masses, with a 3:2 mass ratio being within the range implied by the analysis, although the galaxy distributions appear very different. Moreover, the difference in their mean line-of-sight velocities is only about 300 km/s, suggesting that most of the relative motion is in the plane of the sky. Thus, SPT-0356 appears to be a face-on major merger at $z > 1$, reminiscent of the Bullet Cluster at much lower redshift. However, additional data, including deep X-ray observations and more galaxy redshifts to supplement those supplied by GMOS, are needed to fully characterize this complex system.

The study has been submitted to *The Astrophysical Journal*, and a [***preprint is available online***].

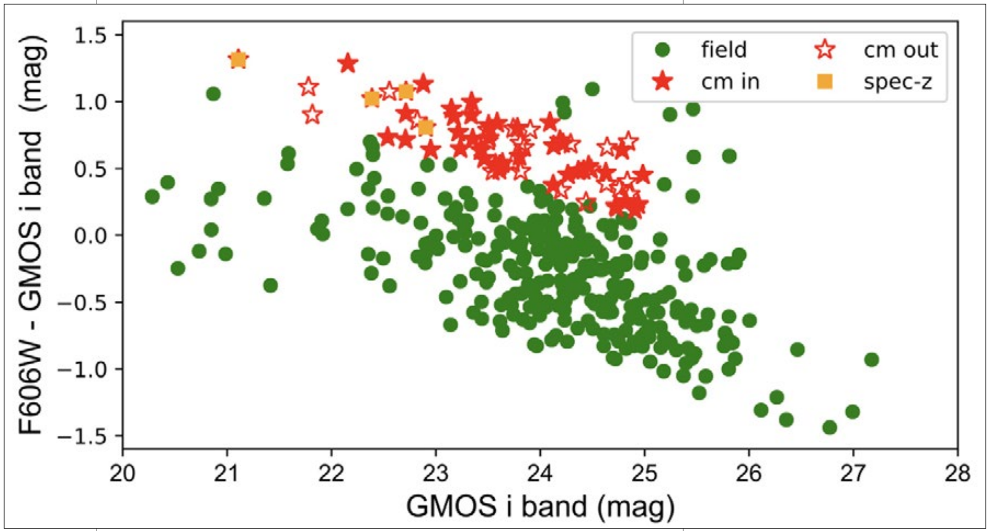


Figure 5.

Color-magnitude diagram of galaxies in the field of SPT-CL J0356–5337 made from Gemini GMOS-South and Hubble*/ACS data. Galaxies selected as being on the red sequence are marked with red stars; filled symbols indicate galaxies within 76 arcseconds (about 600 kiloparsecs) of the brightest cluster galaxy. Spectroscopically confirmed members are indicated by gold squares.*

Credit: Mahler et al., arXiv:*1910.14006*

OCTOBER 2019

Comet 2I/Borisov Breezes Through Solar System, Tail Streaming Behind

It was in October 2017, just days after this writer joined Gemini, that the first interstellar object, later designated 1I/'Oumuamua, was spotted making its expeditious escape from our Solar System. Observations by Gemini and many other observatories demonstrated that 'Oumuamua was surprisingly asteroidal in nature, with no apparent coma or tail. Moreover, judging from the dramatic variations in its light curve, this first interstellar visitor had an unusually large axis ratio, perhaps 10:1, suggesting that it may be a scattered shard from a violent collision that ejected the object long ago from its home planetary system.

Now, less than two years later, a second interstellar emissary has arrived from the direction of Cassiopeia, and it bears strikingly little resemblance to the first. If the stars are trying to tell us something, their message is inconsistent. The new object was discovered by the Crimean amateur astronomer Gennady Borisov on August 30, 2019, using a 65-centimeter telescope that he built himself. Subsequent observations have shown that its orbital eccentricity with respect to the Sun exceeds 3.3 (eccentricities above 1.0 correspond to unbound hyperbolic orbits; 'Oumuamua had an eccentricity of 1.20). Popularly known as "Comet Borisov" (even though the amateur has discovered seven other, more conventional, comets), the object received the official interstellar designation ***2I/Borisov*** from the International Astronomical Union on September 24, 2019.

Gemini Observatory was first alerted to 2I/Borisov by a Director's Discretionary Time (DDT) proposal received on the evening of September 9th, when the object was in the northern sky at a distance of 3.4 AU from from the Earth and within 43 degrees of the Sun. Following careful review, the proposal was found to be compelling, with Gemini's large aperture being well suited for investigating possible cometary activity during

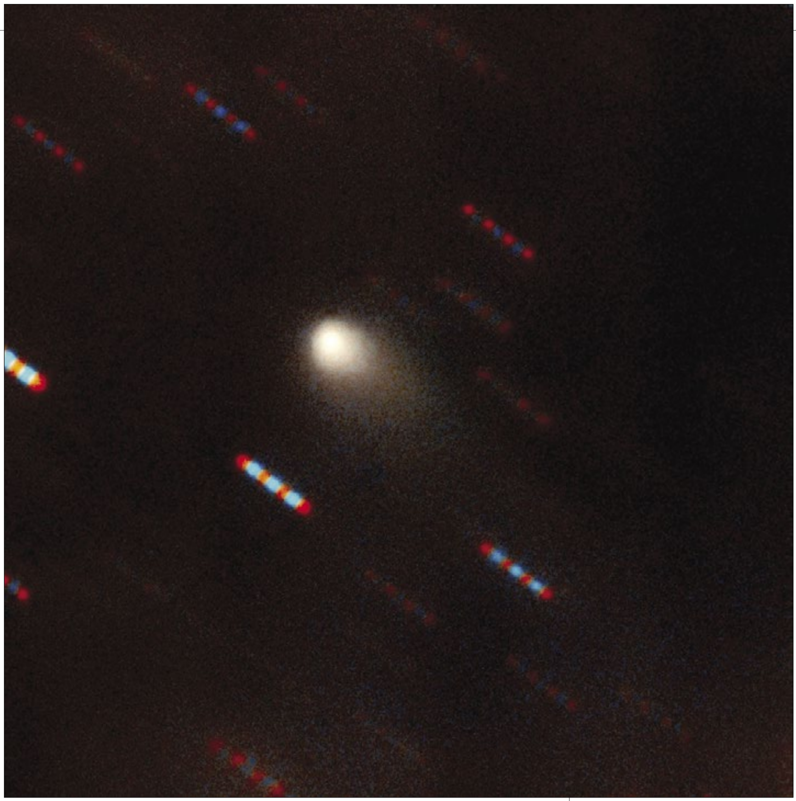


Figure 6.
GMOS-North g,r composite color image of the interstellar comet 2I/Borisov, obtained in morning twilight on September 10, 2019, at a mean elevation of less than 30° from the eastern horizon. The alternating red-blue streaks are background stars that appear trailed because the telescope was tracking the comet, which was moving non-sidereally at a rate of 75 arcseconds per hour. The comet was 3.4 AU from the Earth at the time of these observations.

the brief visibility window at the end of the night. Consequently, multi-band imaging observations with the Gemini Multi-Object Spectrograph (GMOS) on Gemini North were obtained during morning twilight, less than 12 hours after the proposal was submitted. Figure 6 displays the resulting composite color image; an extended coma and cometary tail are clearly visible. This makes 2I/Borisov the first known interstellar comet.

A study based on these Gemini North observations, with supplementary data from the William Herschel Telescope on La Palma, finds that 2I/Borisov appears quite similar to typical Solar System comets in terms of photometric color and its derived dust particle properties. Graduate student Piotr Guzik of Jagiellonian University in Poland led the study, which is currently in press at *Nature Astronomy* (a **preprint** is available online). The object's g-r color is only slightly redder than average for comets, and the estimated diameter of 2 km for the comet's nucelus, while highly uncertain, is well within the normal cometary range. In light of 'Oumuamua's anomalies, the apparent banality of 2I/Borisov is in itself remarkable.

The observational study of this second interstellar interloper has only just begun. Additional Gemini observations have already been obtained, and more are currently scheduled in the queue. 2I/Borisov is entering the Solar System from "above," and its visibility will gradually improve as it crosses the celestial equator in mid-November and moves towards a perihelion distance of 2.0 AU, near the inner edge of the Asteroid Belt, on December 8th. It reaches a minimum distance of 1.9 AU from the Earth in late December, and will continue to be visible from the Southern Hemisphere for much of next year. Thus, Gemini's access to the entire sky will enable detailed study of 2I/Borisov throughout the entire course of its visit — we are sure to have more highlights on this first interstellar comet before it leaves our corner of the Galaxy forever.

Probing for Patterns in Io's Volcanoes Using Adaptive Optics

Ever since the *Voyager* spacecrafts revealed the rampant volcanism on Jupiter's innermost large moon Io, planetary scientists have been puzzling over the variations in the timing and intensities of the splotchy satellite's many eruptions. Intense tidal heating, the stretching and squeezing of Io's crust as it follows its 1.8-day elliptical orbit around the giant planet, supplies the energy to melt interior silicates and produce magma, which eventually erupts to the surface. However, the variations in the volcanic activ-

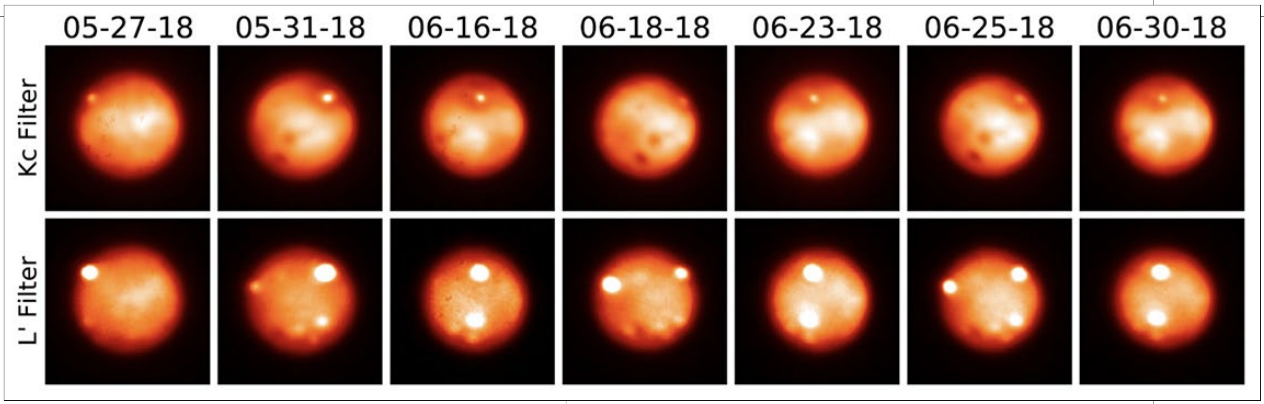


Figure 7.

AO-assisted near-infrared images taken with NIRI on Gemini North of Jupiter's moon Io, showing the eruption of Isum Patera in May-June 2018. Isum Patera is the only bright spot visible in these Kc (2.27 μm) images; it is seen at the corresponding locations in the L′ (3.78 μm) images. The bright spot south of Isum Patera in the L′ images is Marduk Fluctus.

Figure reproduced from de Kleer et al., The Astronomical Journal, **158:** *29, 2019.*

ity generally occur on longer timescales, uncorrelated with the orbital period. This contrasts with the case for other tidally heated moons such as Saturn's Enceladus, for which the degree of activity varies predictably with its distance from the planet. Although Io and Enceladus have very similar orbital eccentricities and periods, a key difference is the viscosity of the erupting fluid, which is water on Enceladus and magma for Io.

To understand what drives the variations in the volcanism on Io, a team of astronomers led by Katherine de Kleer of the California Institute of Technology has analyzed the most detailed data set on the moon's volcanic activity to date. The observations were collected on 271 nights between August 2013 and July 2018 using the Near InfraRed Imager and spectrometer (NIRI) on Gemini North with the ALTAIR adaptive optics system in natural guide star (NGS) mode and the Near InfraRed Camera 2 (NIRC2) on the Keck II telescope, also using NGS adaptive optics. The Gemini/NIRI data comprise 80% of the total visits; example NIRI images are shown in Figure 7. The study has been published in **The Astronomical Journal** and featured in **The New York Times**.

In total, the team has detected at least 75 unique hot spots of volcanic activity. The most active volcano, known as Loki Patera, was detected 113 times during the five-year campaign, essentially every time it was visible. Three other hot spots were each detected at least 80 times. Loki Patera appears to be erupting continuously, but its brightness in the near-infrared varies by more than an order of magnitude. This large data set enabled the team to uncover surprising patterns in Io's volcanic activity. For instance, of the 18 sites with the brightest eruptions, 16 are on the trailing hemisphere with respect to Io's orbital motion. This tendency remains unexplained; the likelihood of it occurring from a random spatial distribution is much less than 1%.

In a companion paper published in **Geophysical Research Letters**, de Kleer and colleagues show that the roughly 500-day variations in the intensity of Loki Patera's activity may be related to periodic changes in the shape of the moon's orbit. Regular gravitational perturbations from Europa and Ganymede, which respectively have 2:1 and 4:1 orbital resonances with Io, prevent the inner moon's orbit from circularizing. Instead, Io's eccentricity and semimajor axis vary cyclically with periods of 480 and 460 days, respectively. This evolution in Io's orbit is consistent with the timescale of the quasi-periodic behavior of Loki Patera.

At first, this link between orbital evolution and volcanic activity may seem surprising, since the range in the tidal stresses over a single orbit is larger than the variation in the mean tides resulting from the change in orbital shape. However, the researchers note that while magma is likely too viscous to change its flow significantly on the timescale of one orbit, it can adjust its flow over the longer period associated with the change in Io's orbital shape. If there is a connection,

Figure 8.
Panel A: Astrometric measurements the star S0-2 over its 16-year orbit of the supermassive black hole at the center of the Milky Way, compared with the best-fitting projected General Relativistic orbit model. The black hole is located at the origin of the coordinate system, and the dashed line shows the intersection of the orbital plane with the plane of the sky. The black points represent new observations from 2017-2018, while the gray points are earlier measurements. Panel B: radial velocity measurements over the period 2000-2018 and the best-fitting model (colored curve). Open, gray, and black circles represent previous, rederived, and new measurements, respectively. Panel C: residuals from the best-fitting velocity model. Figure adapted from Do et al., Science, ***365:*** *664, 2019.*

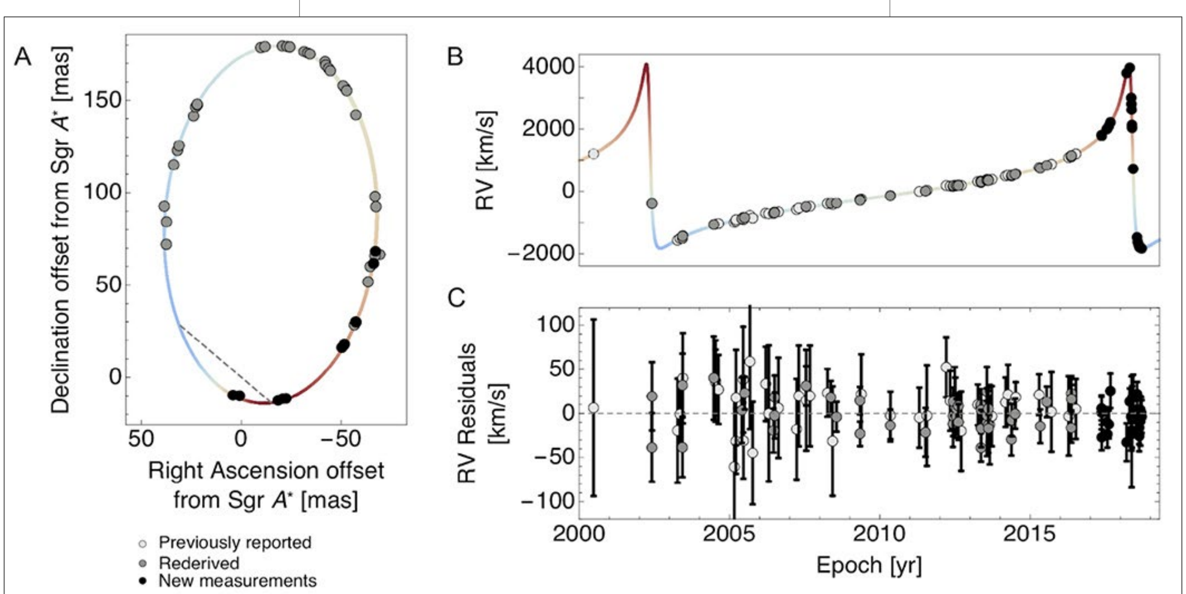
the peak in activity should coincide with the time of maximum orbital eccentricity, and the data confirm that this is indeed the case. Higher cadence observations are needed to test this hypothesis and rule out shorter period drivers of Loki Patera's variability.

Three Maunakea Observatories Track Relativistic Star around a Black Hole

If Einstein were alive today, he might be one of the few people tired of actually winning. Setting aside his long quarrel with quantum mechanics and all that business about a unified field theory, his formulation of General Relativity (GR) has proven to be one of the most successful descriptions of nature ever proposed. From the deflection of starlight in 1919 to the detection of gravitational waves in 2015, Einstein's General Relativity has triumphed over every observational test to date. Now a team of researchers led by Andrea Ghez at the University of California Los Angeles has tested GR in a new regime, the strong gravitational field near a supermassive black hole. The result: chalk up another one for the iconic physicist.

Although simple conceptually, the test was incredibly exacting from a technical perspective. GR predicts that luminous objects in strong gravitational fields should exhibit relativistic redshifts. This means that a star moving towards us in the vicinity of a black hole should appear to have a smaller blueshift, and one moving away from us should have a larger redshift, than would be the case if the law of Newtonian gravity prevailed. In the most stringent test of this prediction to date, the team analyzed over two decades of astrometric and spectroscopic data, obtained using adaptive optics, on a star known as S0-2 as it followed its eccentric 16-year orbit around Sagittarius A* (Sag A*), the supermassive black hole at the center of our Galaxy. Figure 8 shows the full set of positional and velocity data.

The star reached its closest approach to Sag A* in May 2018, when it was at a distance of only 120 AU and moving at 2.7% of the speed of light. During the critical months surrounding pericenter passage, the team used three different spectroscopic instruments at three different observatories, including the Near-infrared Integral Field Spectrometer (NIFS) on Gemini North, the OH-Suppressing Infra-Red Imaging Spectrograph (OSIRIS) on the Keck II telescope, and the Infrared Camera and Spectrograph (IRCS) on the Subaru telescope. "The velocity of the star was changing quickly every night! So having all three observatories participate was essential," said Tuan Do (also of UCLA), the lead author of the study. Combining data from multiple instruments also allowed the team to carefully check for instrumental biases.



As shown in Figure 9, GR provides an accurate description of the star's positional and velocity data throughout its very large swing in velocity near its closest approach to Sag A*. In contrast, the observations rule out Newton's law of gravity with a high statistical significance. "The GR model is 43,000 times more likely than the Newtonian model in explaining the observations," the study concludes. The measurements also provide strong constraints on the black hole's distance and mass, 8.0 kiloparsecs and 4.0 million solar masses, respectively.

Of course, no one wins forever, and at some point, namely the event horizon of a black hole, GR must also fail. However, although S0-2 plunged precipitously near Sag A*, the minimum distance was roughly 1,000 times larger than the radius of the event horizon. Thus, it may be some time before observational limits encroach on the limits of GR's validity. Meanwhile, such observations continue to enlighten our understanding of the dynamics and evolution of the center of our Galaxy. The study appears in the journal Science.

JULY 2019

Reverberations from an Intermediate-mass Black Hole in a Bulgeless Dwarf

For some, the term "reverberation mapping" might suggest the idea of pinpointing the locations of the various garage bands in the neighborhood (all with their amplifiers turned way up) based on the distribution and intensity of the vibrations emanating from one's walls and window panes. But in actuality, it denotes a powerful technique for determining the masses of the black holes embedded within the active galactic nuclei (AGNs) at the centers of many galaxies. Interestingly, the two phenomena are not entirely dissimilar. Like the perfect guitar riff, reverberation mapping requires precise timing and can be quite challenging to execute in practice. In addition, the virtue of both lies in their conceptual simplicity.

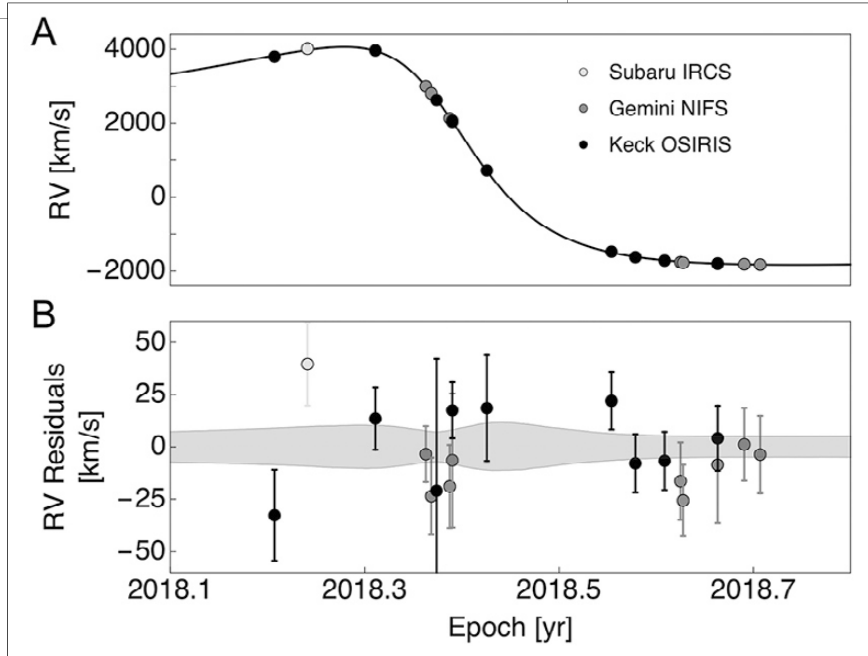


Figure 9.

Top: Zoom in on the radial velocity data from 2018, encompassing the maximum and minimum of the observed radial velocity. Measurements from the three different observatories are indicated; Gemini/NIFS and Keck/OSIRIS each provided nine measurements during this critical period, over which the observed velocity changed by 6,000 km/s. Bottom: radial velocity residuals with respect to the best-fitting General Relativistic model.

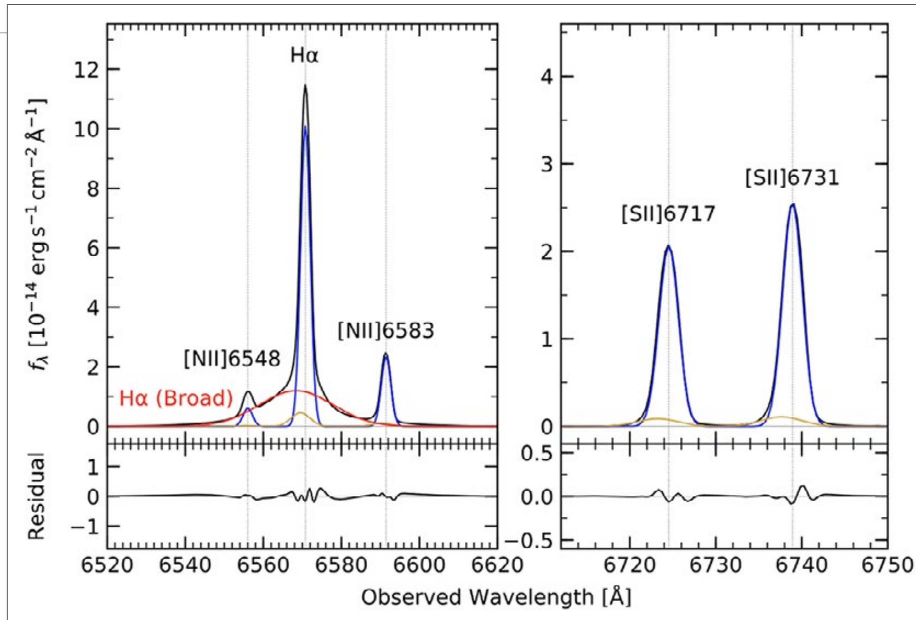
Figure from Do et al., Science*,* **365:** *664, 2019.*

Reverberation mapping works by applying the familiar virial theorem to the broad line region (BLR) of an AGN. Assuming that the motion of the gas in the BLR is primarily influenced by the central black hole, the mass of the black hole M_{BH} will be proportional to $\sigma^2 R$, where σ is the velocity dispersion determined from the Doppler width of a broad emission line and R is the characteristic radius of the BLR. The radius is determined from the delay time τ between variations in the intensity of the continuum light from the AGN, which excites the gas within the BLR, and the line emission itself: $R = c\tau$, where c is the speed of light. Because lines of different ionization show different delays, the same line should be used for determining both σ and τ. Typical AGNs powered by supermassive black holes of millions of solar masses ($M_\odot$) have delay times measured from Balmer lines ranging from a few days to many months.

A new study *published in* Nature Astronomy has measured the mass of the black hole associated with one of the lowest lu-

Figure 10.
GMOS spectrum of the AGN in the low-mass spiral NGC 4395, showing the narrow [NII] and Hα lines superposed on the broad Hα emission used for the reverberation measurement (left). The narrow [SII] lines at longer wavelength were used as proxies for the central stellar dispersion (right).

Figure reproduced from Woo et al., Nature Astronomy, *2019, in press (arXiv 1905.00145).*

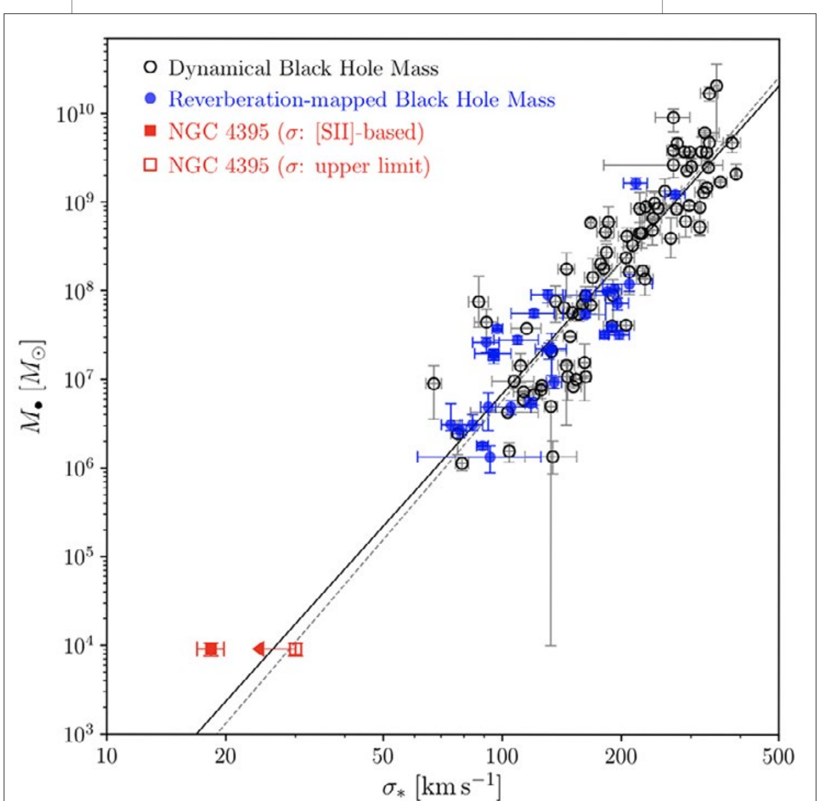


minosity AGNs known. The AGN resides within a nuclear star cluster at the center of the nearby dwarf spiral NGC 4395, and the study was led by Jong-Hak Woo of Seoul National University. Using spectroscopic data from the Gemini Multi-Object Spectrograph (GMOS) at Gemini North, Woo's team measured a line-of-sight velocity dispersion of 426 kilometers per second (km/s) from the width of the broad Hα line (Figure 10). Combined with a reverberation time delay of 83 minutes based on a combination of broad- and narrow-band imaging collected at several small telescopes, the implied black hole mass is about 9,100 $M_\odot$. Previous estimates ranged from 5 to 40 times higher, but were much more poorly constrained. The new result is securely within the realm of the elusive "intermediate-mass" black holes, which may be the seeds from which supermassive black holes grow.

There are well established relations for massive galaxies between central black hole mass and the properties of the stellar bulge; it is interesting to ask how NGC 4395, a pure disk galaxy without any bulge, fits into these. The new study estimated the central stellar velocity dispersion $\sigma_\star$ from the width of the narrow [SII] emission line, finding $\sigma_\star \approx 18$ km/s, consistent with a previous upper limit. Using this value, they place NGC 4395 on the diagram of M_{BH} versus velocity dispersion for high-mass galaxies (Figure 11), concluding it is broadly consistent with a simple extrapolation to lower masses. This suggests that the observed relations between M_{BH}

Figure 11.
The new NGC 4395 black hole measurement is plotted in the context of the relation between central black hole mass and stellar velocity dispersion for more massive systems. The stellar velocity dispersion for NGC 4395 is shown as a previously published upper limit (open red square) and the proxy value adopted from the width of the [SII] emission line (solid red square). Plotted values for the higher mass galaxies are stellar dynamical measurements in inactive galaxies (open black circles) and reverberation mapping in active galaxies (filled blue circles). The solid and dashed lines are, respectively, fits to the combined high-mass sample and to the dynamical measurements only.

Figure reproduced from Woo et al., Nature Astronomy, *2019, in press (arXiv 1905.00145).*



and central dispersion does not originate from the process of hierarchical growth, but that the galaxy mergers that produce central bulges preserve a relation that may already be present for the seed intermediate-mass black holes.

Testing this scenario will require more studies of the incidence and masses of black holes in the centers of low-mass galaxies. In addition, such studies can determine whether the familiar supermassive black holes likely originated from "light" seeds of order 100 to 1,000 $M_\odot$ (possible remnants of massive Population III stars) or "heavy" seeds of order 10^4 $M_\odot$ or more (formed via the direct collapse of giant gas clouds). As demonstrated by the impressive results on NGC 4395, reverberation mapping remains the most promising method for building up the required data samples to address these questions.

Divergent Demographics of Planets and Brown Dwarfs in the GPI Exoplanet Survey

Soon after the Gemini Planet Imager (GPI) was commissioned at Gemini South, the international team behind the instrument embarked on a major systematic survey for substellar companions and protoplanetary disks around the youngest, closest stars in the southern sky. Earlier this year, the GPI Exoplanet Survey (GPIES) observed its 531st target star, bringing the main survey to a close after more than four years, although follow-up observations of promising candidates have continued. Now, the team has published preliminary results from a statistical analysis of the first 300 stars surveyed. ***The study***, published in the July issue of *The Astronomical Journal*, was led by Eric Nielsen of Stanford University and represents the largest direct imaging survey for giant planets published to date.

GPIES is sensitive to young, self-luminous planets with masses above about 2 Jupiter masses and orbital semi-major axes from 3 to 100 AU. The detections thus far include six giant planets and three brown dwarfs. Although only about 40% of the stars included in the analysis have masses greater than 1.5 $M_\odot$, all of the detected planets orbit stars above this mass. This is even more striking because it would be easier to see such planets orbiting fainter, lower mass stars. While there have been previous indications of a correlation with stellar mass, the GPIES results confirm to better than 99.9% confidence that high-mass stars are more likely to host planets within the explored range of planetary masses and orbital separations.

Accounting for the detection sensitivity curves and combining their results with those from radial velocity studies (sensitive to companions at smaller radii), the team concluded that the most likely location for giant planets to occur is between 1 and 10 AU from their host stars. The occurrence rate drops steeply at larger separations. The number of giant planets also declines significantly with increasing planetary mass.

Although brown dwarfs are often considered transitional objects between planets and stars, they appear to have quite different demographics than giant planets, as shown in Figure 12. The study concludes that only about one in ten stars hosts a brown dwarf

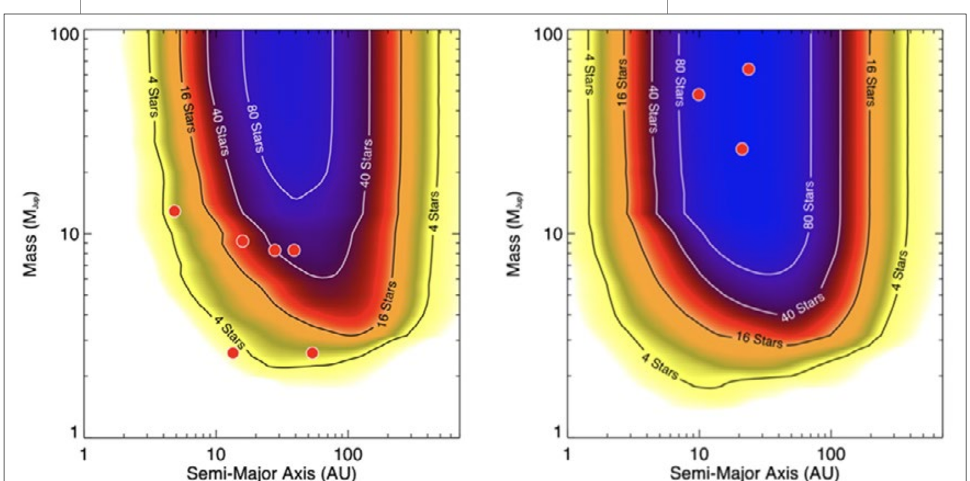


Figure 12.
GPIES sensitivity contours for companion mass (in units of Jupiter masses) and orbital semi-major axis (Astronomical Units) for planetary (left) and brown dwarf (right) companions. The six giant planets and three brown dwarfs detected in the survey are overlaid on the contours. Although the majority of these companions were not discovered by GPIES, their host stars were part of the unbiased sample and were not selected because of the presence of the companions; thus, the detections are included in the statistical analysis. The curves indicate the numbers of stars in the sample for which the sensitivity allowed detection of companions with the plotted combinations of parameters; very few stars had sensitivity sufficient to detect planets of masses < 3 M_{Jup}, but two were detected.

Figure reproduced from Nielsen et al., The Astronomical Journal, ***158:*** *13, 2019.*

companion at separations of 10 to 100 AU. This is a factor of ten below the inferred occurrence rate of giant planets around high-mass stars. Moreover, although the numbers are low, the distributions in both mass and semi-major axis are consistent with being flat for brown dwarfs, in contrast with the falling distributions for giant planets. In addition, the detected brown dwarfs all orbit stars with masses below 1.5 $M_\odot$, again unlike the giant planets.

Based on these results, earlier suggestions that wide-separation giant planets and brown dwarfs may comprise a single underlying population is unlikely to be correct. The divergent trends strongly indicate disparate formation mechanisms. Specifically, the study concludes that giant planets likely form "bottom up" through the process of core accretion while brown dwarfs form "top down" like stars via gravitational instability. More data are needed to confirm these trends; fortunately, there are another 231 stars from the rest of the GPIES survey awaiting final analysis and publication.

Spatially Resolved Kinematics of 20 MASSIVE Ellipticals

Every galaxy has its own story, and every galaxy has been many others in the past (unlike in the human parallel, this is not purely metaphorical, as galaxies grow via hierarchical assembly). Generally speaking, the most massive galaxies have led the most interesting lives. These often reside in dense environs that have exposed them to frequent interactions with assorted neighbors, influencing in complex ways the coevolution of their component stars, gas, dark matter, and supermassive black holes.

Although the detailed formation histories of most galaxies will remain forever uncertain, the key thematic elements may be surmised through a variety of methods. A particularly powerful probe of a galaxy's dynamical structure is integral field spectroscopy (IFS). Wide-field IFS studies provide insight into global dynamics and past interactions, while IFS data on the innermost regions can constrain the central supermassive black hole (SMBH) mass and the shapes of the stellar orbits in the vicinity of its sphere of influence.

The MASSIVE Galaxy Survey is systematically targeting all early-type galaxies in the northern hemisphere with stellar masses greater than 3×10^{11} $M_\odot$ within a distance of about 100 megaparsecs for detailed kinematic and photometric analysis. The latest work in the MASSIVE series presents the first results from the high angular resolution portion of the survey, based on deep GMOS-North IFS observations of 20 galaxies. These are combined with wide-field IFS data from the Mitchell spectrograph at McDonald Observatory to obtain detailed kinematic maps spanning more than two orders of magnitude in galactocentric radius. ***The new study*** appears in the June issue of *The Astrophysical Journal* and is led by graduate student Irina Ene of the University of California, Berkeley.

Figure 13 (next page) shows example maps of the first four moments (v, σ, h_3, and h_4) of the stellar velocity distributions from the high-quality GMOS IFS data for two galaxies in the survey. The maps cover the central 5×7 arcseconds. The figure also shows the one-dimensional distributions of these parameters combined with the wider field IFS measurements. Although both galaxies exhibit strong central rotation, they have strikingly different kinematic profiles. In fact, most of the galaxies in the MASSIVE sample show only slow rotation (unlike most previous IFS studies of early-type galaxies, which were weighted towards lower luminosity). Interestingly, in galaxies that do rotate, the central rotation is often unaligned with the large-scale kinematics, indicating diverse merger histories.

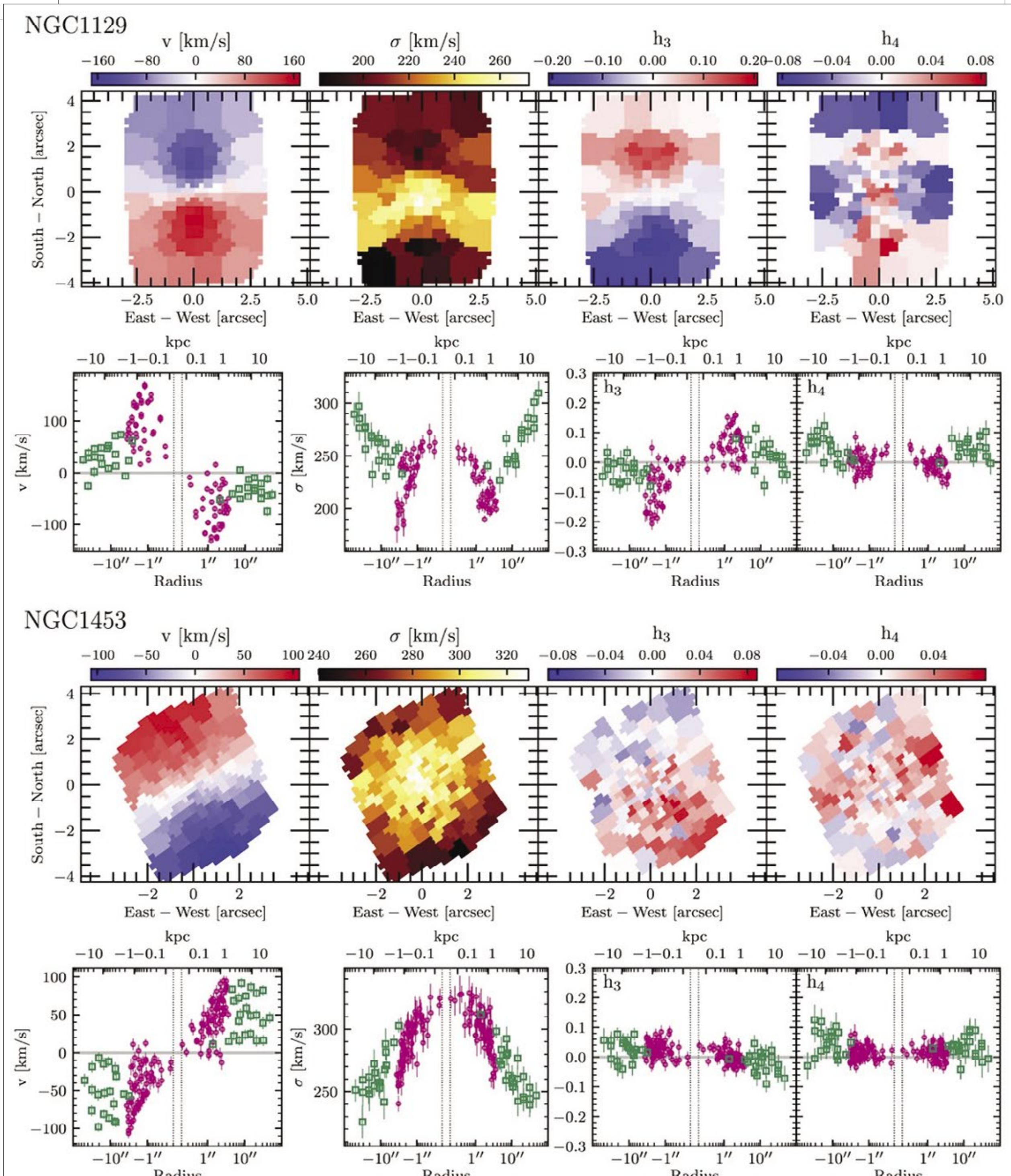


Figure 13.

Example distributions of the first four kinematical moments (v, σ, h_3 and h_4) measured from the GMOS-N IFS data for two of the MASSIVE survey galaxies. For each galaxy, the top row shows two-dimensional maps, while the bottom row shows two-sided radial profiles from GMOS (magenta circles) and Mitchell (green squares) data. The vertical dotted lines mark radii of ± 0.2 arcsecond.

Figure reproduced from Ene et al., The Astrophysical Journal, ***878:*** *57, 2019.*

The kinematic diversity across the full sample is illustrated in Figure 14 (next page), which shows the velocity dispersion profiles for all 20 galaxies. Although most of the galaxies have centrally rising dispersions, the slopes vary greatly, and in some cases change sign with radius. A sharply rising central dispersion may indicate the presence of a SMBH but can also reflect increasing radial anisotropy in the stellar velocities. Information from the higher order moments, particularly the kurtosis h_4, can determine the relative importance of these two effects. For this purpose, high spatial resolution for resolving stellar kinematics within the sphere of influence of the SMBH is essential.

As a proof of concept, the new study performs detailed dynamical modeling of the combined GMOS and Mitchell IFS data sets for NGC 1453, the most regular fast-rotating

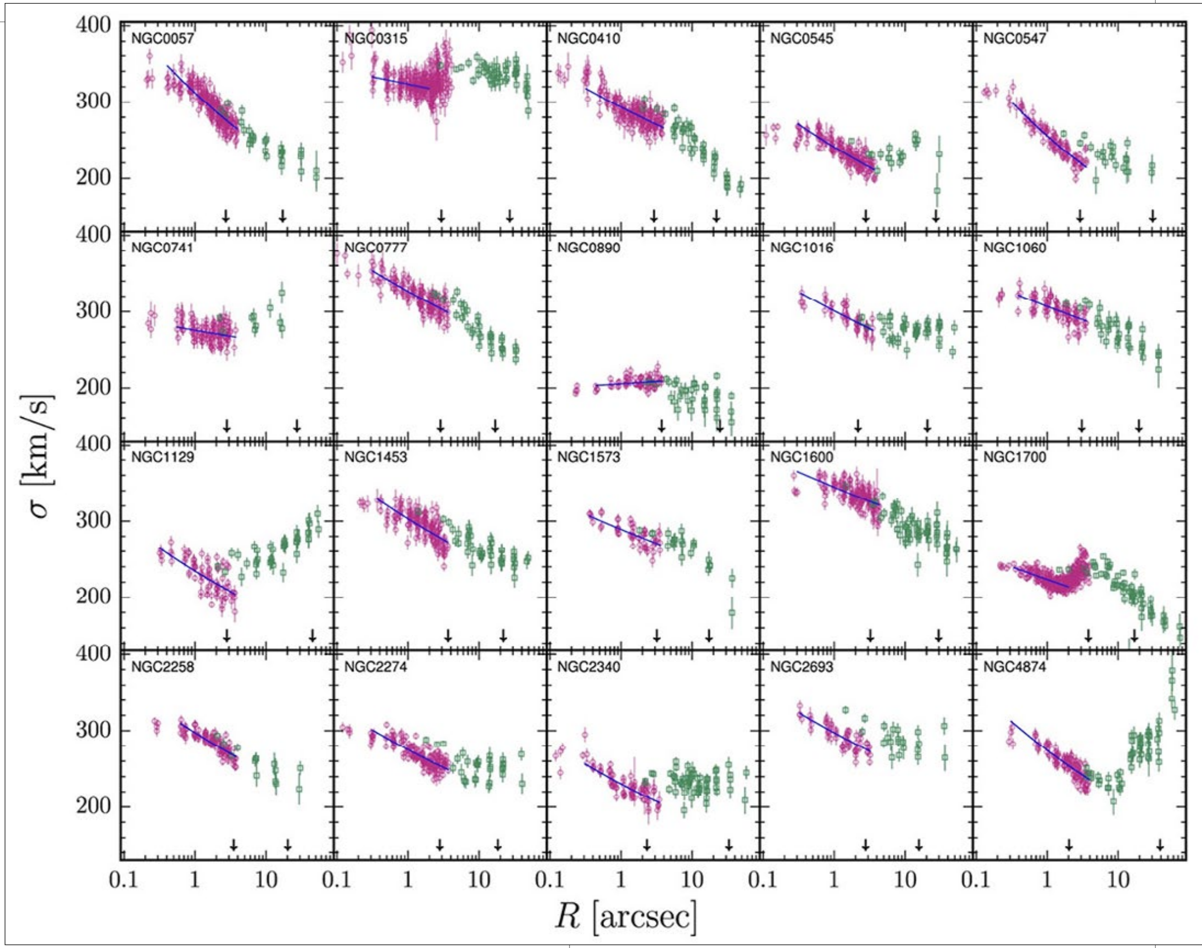


Figure 14.
Velocity dispersion profiles for 20 galaxies in the MASSIVE survey observed at Gemini North with the GMOS-N integral field unit (magenta) combined with wide-field measurements from the Mitchell spectrograph at McDonald Observatory (green). The diversity in the dispersion profiles among these high-mass early-type galaxies is evident. The blue lines show the best-fit power laws to the GMOS data.
Figure reproduced from Ene et al., The Astrophysical Journal, ***878:*** *57, 2019.*

galaxy in the sample. In addition to constraining the stellar mass-to-light ratio and circular velocity of the dark matter halo, the analysis finds both a spatially varying velocity anisotropy and a central SMBH with an impressively large mass in excess of 3×10^9 $M_\odot$. The MASSIVE Survey team, led by Berkeley professor Chung-Pei Ma, is currently running the detailed models for the full galaxy sample. The results will provide further insight into the assembly histories of the largest galaxies in the local Universe and refine our understanding of the coevolution of galaxies and their central black holes up to the most extreme masses.

APRIL 2019

Vanth Surprises with Double Dip During Occultation

The sizes and surface compositions of trans-Neptunian objects (TNOs) are notoriously difficult to study. As seen from Earth, the largest TNO has a maximum angular size of about 0.1 arcsecond; more typical ones are unresolved at 0.01 arcsecond or smaller. Except for the two TNOs that have been visited by spacecraft, the most direct measurements of TNO sizes come from stellar occultations. Consequently, planetary scientists exercise great vigilance in taking advantage of these rare opportunities.

One such opportunity occurred on March 7, 2017. Based on ground-based astrometry, it was thought that an occultation of a magnitude V = 14.6 star by the large TNO Orcus would be viewable from parts of the Pacific and the Americas on that date. With an estimated diameter in excess of 900 kilometers (km), Orcus likely meets the shape criteria for a dwarf planet. Like Pluto, it is in a 3:2 orbital resonance with Neptune, has a semi-major axis of 39 AU, and a high eccentricity. It has one large satellite named Vanth, which orbits with a period of 9.5 days. With the availability of astrometry from the Gaia space mission, it became clear that Vanth, rather than Orcus, would be the one tracing a path of occultation across the Earth's surface on the predicted date.

In anticipation of this event, an international team of occultation-chasers led by Amanda Sickafoose of the South African Astronomical Observatory organized a monitoring campaign with five telescopes located in Hawai'i, California, Texas, and Chile. To their surprise, the coordinated observations detected two non-simultaneous dips in the stellar brightness at two widely separated telescopes. The detections were made by the NASA Infrared Telescope Facility on Maunakea, and the Las Cumbres 1-meter telescope at the McDonald Observatory in Texas. The observations could not be explained by a single object occulting a single star; moreover, previous *Hubble Space Telescope* (*HST*) data ruled out the possibility of another satellite of sufficient size to explain the second dip in stellar brightness.

To test the occultation star for possible multiplicity, the team applied for Fast Turnaround time with the visiting Differential Speckle Survey Instrument (DSSI) at Gemini South. The proposal, led by Amanda Bosh of the Massachusetts Institute of Technology, was successful, and the observations were quickly processed by the DSSI instrument team. The resulting image, shown in Figure 15, reveals that the occultation star is indeed a double, with a separation of 250 milli-arcseconds and a brightness differential of about 0.9 magnitude in the red DSSI bandpass. Figure 16 compares the original prediction for the single path of occultation by Vanth with the paths of the two occultations as reconstructed from the binary star positions in the DSSI data. The reconstructions fit perfectly with the observations.

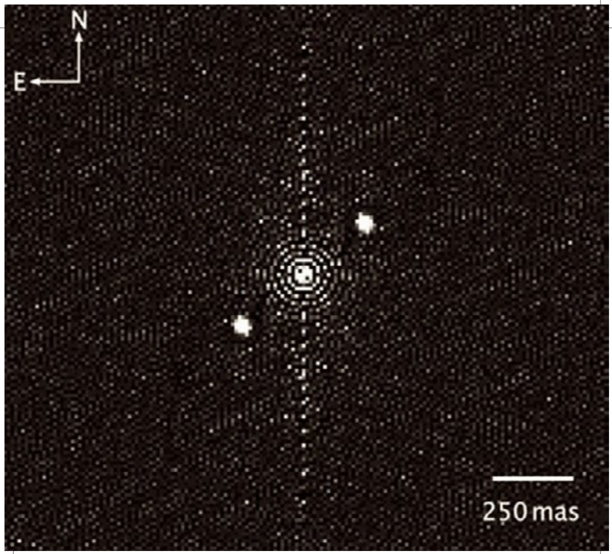


Figure 15. *Gemini South DSSI image of the star pair occulted by Vanth, a satellite of the large trans-Neptunian object Orcus. This image consists of 1,000 seconds of speckle data combined to reveal the binary pair responsible for the observed double occultation. The bright primary is at center, and the newly detected companion is at upper right (approximately 2:00 position; the other "star" at the 8:00 position is an artifact of the autocorrelation analysis used in speckle processing).*

Figure reproduced from Sickafoose et al., Icarus, ***319:*** *657, 2019.*

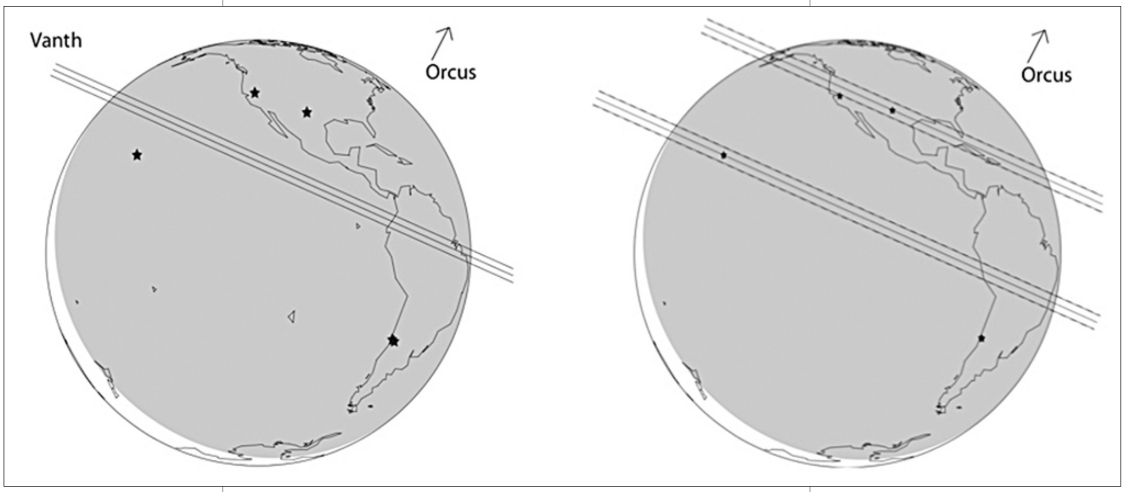


Figure 16. *The dual paths of Vanth.* ***Left:*** *the predicted path of Vanth's shadow during the occultation of March 7, 2017, based on Gaia DR1 astrometry. The locations of the telescopes participating in the occultation campaign are indicated by stars. The extent of the shadow is indicated for a physical diameter of 280 km; the shadow of Orcus is off the globe.* ***Right:*** *the actual shadow paths of Vanth as reconstructed using the positions of the two components of the double star determined from Gemini/DSSI imaging. The brighter star was occulted along the upper path, which passed over the observing location in Texas, but was not detected at the location in California. The occultation of the fainter star occurred along a path that passed over the observing location in Hawai'i; no occultations were detected at the locations in Chile. The paths are drawn for a Vanth diameter of 442.5 km, the size determined from these observations.*

Figure reproduced from Sickafoose et al., Icarus, ***319:*** *657, 2019.*

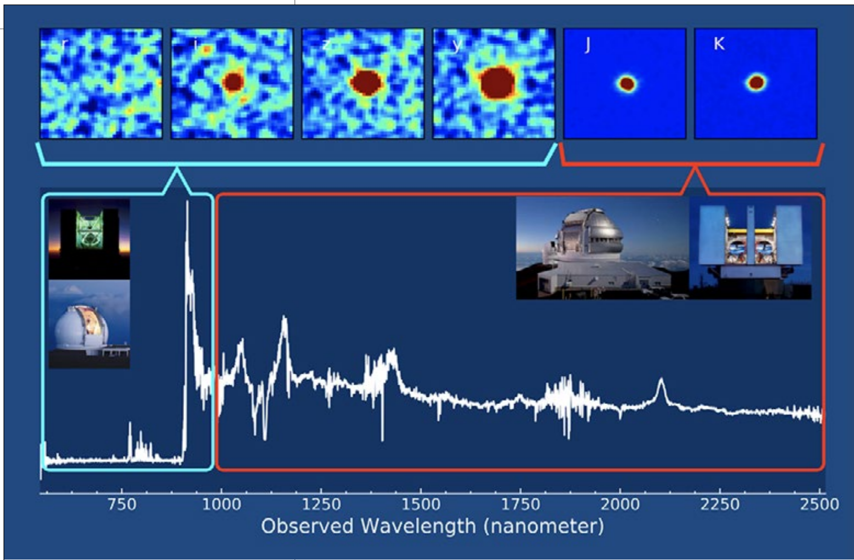


Figure 17.
Gemini was one of several large telescopes that contributed to the study of the lensed quasar J0439+1634, selected as a candidate high-redshift object because it is an r-band "dropout" with little i flux (top). The 6.5-m MMT and 10-m Keck-I telescope obtained optical spectra (outlined in cyan), while the 8.1-m Gemini North telescope obtained an infrared spectrum (outlined in red). The width of the Mg II line near 2100 nm constrains the mass of the black hole powering the quasar. The 2 x 8.4-m Large Binocular Telescope captured an adaptive optics corrected image that suggests the quasar is lensed, later confirmed by HST.
Credit: Feige Wang (UCSB), Xiaohui Fan (University of Arizona)

Once the binary nature of the occultation star was revealed by Gemini/DSSI, the two observed occultations, combined with non-detections at the other sites, allowed the team to place a tight constraint of 443 ± 10 km on the diameter of Vanth. Remarkably, this is 60% larger than previous estimates, and roughly half as large as the estimated size of Orcus. The results also placed a limit of a few microbars on any possible atmosphere around Vanth. The study has been published in the journal *Icarus*, and a [pre-print is available online](#).

The Mass of the Most Distant Lensed Quasar

Observations from the Gemini Near-Infra-Red Spectrograph (GNIRS) have confirmed the redshift and constrained the mass of the brightest quasar yet discovered at redshift $z > 5$. However, the discovery paper led by Xiaohui Fan of the University of Arizona concludes that the object, known as J0439+1634, is not the intrinsically most luminous quasar at this redshift. Rather, its apparent brightness has been boosted by a factor of about 50 by the gravitational magnification of an intervening galaxy. This makes J0439 + 1634 the most distant known strongly lensed quasar, and perhaps the first of many waiting to be revealed through high-resolution imaging.

Several decades ago it was proposed that a substantial fraction of the most distant quasars found in flux-limited surveys would be brightened above the survey limit by gravitational lensing. If this is the case, the resulting "magnification bias" would cause a systematic overestimation of the masses of the supermassive black hole population powering high-redshift quasars. However, no multiply-imaged lensed systems had ever been found above redshift $z = 4.8$ (a lookback time of about 12.5 billion years), despite intensive high-resolution follow-up of hundreds of quasars known beyond this redshift. It may be that the extended appearance of multiply-lensed quasars, and/or color contamination by the lensing galaxy, causes a strong selection bias against these systems.

Fan's team selected J0439 + 1634 as a high-redshift quasar candidate based on a combination of imaging data from the Pan-STARRS1 survey in the optical, the UKIRT Hemisphere Survey in the near-infrared, and archival *Wide-field Infrared Survey Explorer* data in the mid-infrared. Follow-up optical spectroscopy with the 6.5-meter (m) Multiple Mirror Telescope and 10-m Keck I telescope showed a prominent spectral break consistent with a redshift near 6.5 (lookback time of 12.9 billion years). A near-infrared spectrum obtained with GNIRS at Gemini North detected strong Mg II emission, yielding a firm redshift measurement of $z = 6.51$. Figure 17 shows the combined spectrum. From the width of the Mg II line in the GNIRS spectrum, the team derived a mass of almost 5 billion solar masses for the black hole powering the quasar, and the photometric measurements implied an astounding total luminosity of 5.8×10^{14} solar luminosities.

However, imaging obtained with adaptive optics on the 2 × 8.4-m Large Binocular Telescope indicated that J0439 + 1634 was broader than a point source, suggesting the presence of either a host galaxy or multiple images. Higher resolution imaging with *HST* clearly resolved the system into multiple lensed components with a maximum separation of about 0.2 arcsecond, plus an extended source about 0.5 arcsecond away, interpreted as the lensing galaxy. Photometric analysis implied a redshift of about 0.7 and a mass of 6.3 billion solar masses for the lensing galaxy. Based on these measurements, the team derived a best-fit lensing model with three quasar images and a total magnification factor of 51.3. After correcting for the magnification, the inferred luminosity of J0439 + 1634 drops to "only" 1.1×10^{13} solar luminosities, and its black hole's mass becomes a pedestrian 430 million solar masses. Together these estimates imply an extremely high mass accretion rate, as required to grow such a large black hole at early times.

The results of this study indicate that many strongly lensed, high-redshift quasars could have been missed by past surveys because standard color selection criteria will fail when the quasar light is contaminated by a lensing galaxy. Thus, changing the techniques for selecting quasars could significantly increase the number of lensed quasar discoveries. "This discovery demonstrates that strongly gravitationally lensed quasars do exist at redshift above five, despite the fact that we've been looking for over 20 years and have not found any others this far back in time," said Fan. "However, we don't expect to find many quasars brighter than this one in the whole observable Universe."

The study has been published in [The Astrophysical Journal Letters]().

Excavation of an Ancient Star Cluster Deep in Milky Way Bulge

Of the roughly 160 globular clusters known in the Milky Way, roughly a quarter appear to be associated with the Galactic bulge. Although these are generally more metal rich than those of the halo, a subclass of moderately metal-poor ([Fe/H] < –1.0), α-enhanced ([α/Fe] > + 0.3), bulge globular clusters with blue horizontal branches are thought to be among the oldest stellar systems in the Galaxy. In this scenario, the moderate metallicities of these ancient star clusters result from the early, rapid chemical enrichment of the Milky Way's innermost regions.

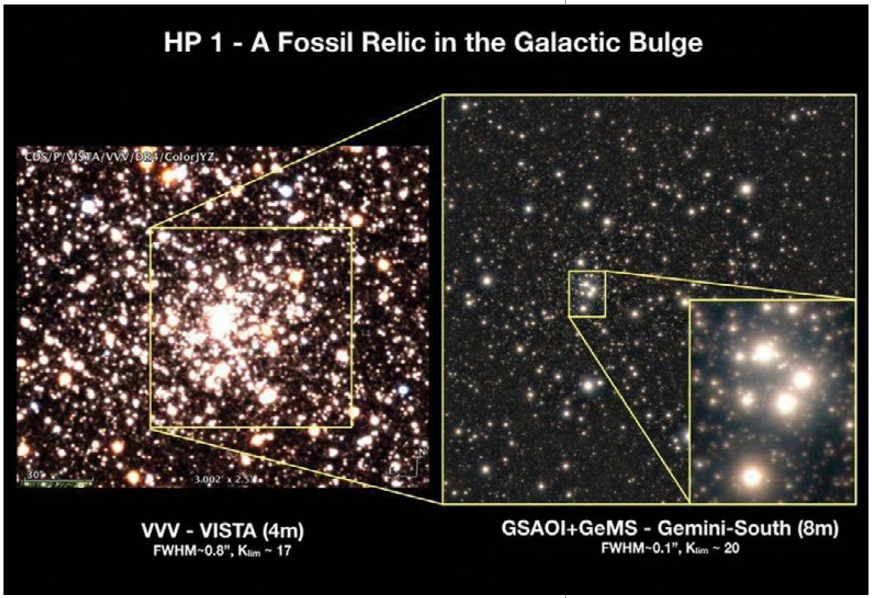


Figure 18.
The Gemini GeMS+GSAOI J, K color composite image of HP 1 (right) is shown within the context of a larger field imaged under natural seeing conditions by the Visible and Infrared Survey Telescope for Astronomy (VISTA, left).

One such candidate "fossil relic" of the bulge's early formation is HP 1, a globular cluster just 3° away from the Galactic Center with 3.7 magnitudes of visual extinction. High-dispersion spectroscopy of member red giants indicates that HP 1 has metallicity [Fe/H] ≈ – 1.1 dex and is α-enhanced by about a factor of two. However, the age had been uncertain because past photometric studies were unable to reach beyond the main sequence turn-off (MSTO).

A new study by an international team of astronomers presents a detailed analysis of deep near-infrared observations of HP 1 obtained with the Gemini South Adaptive Optics Imager (GSAOI) using the Gemini Multi-conjugate adaptive optics System (GeMS). The GeMS/GSAOI J and K_s images, shown in Figure 18, have spatial resolution of about 0.1 arcsecond and probe two magnitudes below the MSTO. The study was led by Leandro

Kerber of the Universidade de São Paulo and Universidade Estadual de Santa Cruz in Brazil.

The team combined their GSAOI data with archival F606W (wide V) images from the *HST*'s Advanced Camera for Surveys to determine relative proper motions and select bona fide cluster members. They then fitted two different sets of model isochrones to the color-magnitude diagrams (CMDs) to determine the stellar population parameters, distance, and reddening. Figure 19 shows the results for one set of isochrones using only the GeMS/GSAOI data; the team also performed fits to CMDs made with a combination of *HST* and GeMS data. The analysis indicates an age near 13 billion years, confirming that HP 1 is one of the oldest globular clusters in the Milky Way and likely formed less than a billion years after the Big Bang.

The heliocentric distance of 6.6 kiloparsecs (kpc) estimated from the isochrone fitting agrees well with the distance implied by the extinction-corrected brightnesses of 11 RR Lyrae stars identified within the cluster. The team combined this distance with the measured radial velocity and the absolute proper motion given by Gaia (Data Release 2) in order to constrain the cluster's orbit. They find that HP 1 passes just 0.12 kpc from the Galactic Center at closest approach and reaches a maximum distance of about 3 kpc. It is likely that many of the cluster's stars have been stripped away as it has repeatedly plunged through the bulge during the course of its long history.

"HP 1 is one of the surviving members of the fundamental building blocks that assembled our Galaxy's inner bulge," said Kerber. Added coauthor Mattia Libralato of the Space Telescope Science Institute, "The combination of high angular resolution and near-infrared sensitivity makes GeMS/GSAOI an extremely powerful tool for studying these compact, dust-enshrouded stellar clusters." The study appears in [Monthly Notices of the Royal Astronomical Society](#).

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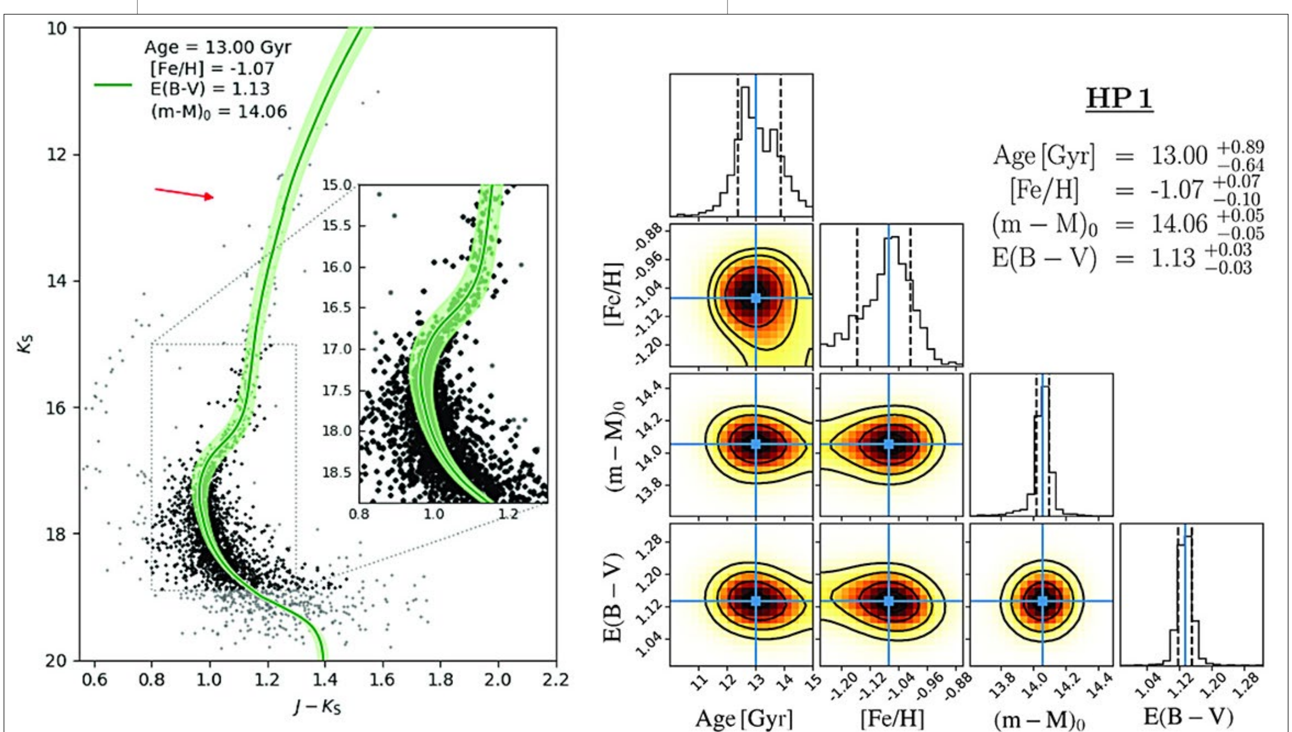
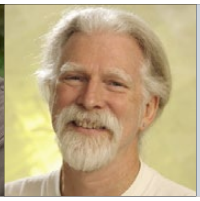


Figure 19.
Results of fitting the GeMS near-infrared CMD of HP 1 using the Dartmouth Stellar Evolutionary Database (DSED) models. ***Left panel****: CMD showing all likely member stars (grey) and those used in the fit (black). The best-fit isochrone is indicated by a thick green line; the green shading shows the uncertainty range. The red arrow indicates a change in reddening of ΔE(B – V) = 0.10 mag.* ***Right panels****: the resulting one- and two-dimensional constraints for all model parameters. The contours correspond to confidence levels of 0.5σ, 1.0σ, 1.5σ, and 2.0σ.*
Figure reproduced from Kerber et al., Monthly Notices of the Royal Astronomical Society, ***484:*** *5530, 2019.*



Ricardo Salinas and Steve B. Howell

The Legend of Zorro Begins

In May, Gemini successfully commissioned Zorro, the Observatory's new dual-channel, dual-plate speckle interferometer. Now permanently installed at Gemini South, the instrument allows diffraction-limited speckle imagery of binary stars, multiple stellar systems, Solar System objects, and your own favorite target!

The atmosphere forgives no one. It does not matter whether you have a futuristic 30-meter telescope or a more modest 1-meter telescope, your image quality will be dominated and limited by the same factor: atmospheric turbulence. How can we overcome the tyranny of the atmosphere to unleash the real potential (the diffraction limit) of a telescope?

One solution is to circumvent the atmosphere altogether and put the telescope in orbit — as evidenced by the breathtaking beauty of *Hubble Space Telescope* and other orbiting astronomical observatory images, which testifies to the enormous appeal of this solution. But as much as we would like to put Gemini in orbit, we simply can't; this would not only be very expensive, but above all, our technicians and engineers would really hate their daily commute!

Reaching the Diffraction Limit from Earth

A different solution involving shorter commutes is the one given by adaptive optics. In adaptive optics, the incoming wavefront, distorted by the atmosphere, is measured and then corrected using deformable mirrors. One excellent example is the Gemini Multi-conjugate adaptive optics System combined with the Gemini South Adaptive Optics Imager, reaching near the diffraction limit in the K-band.

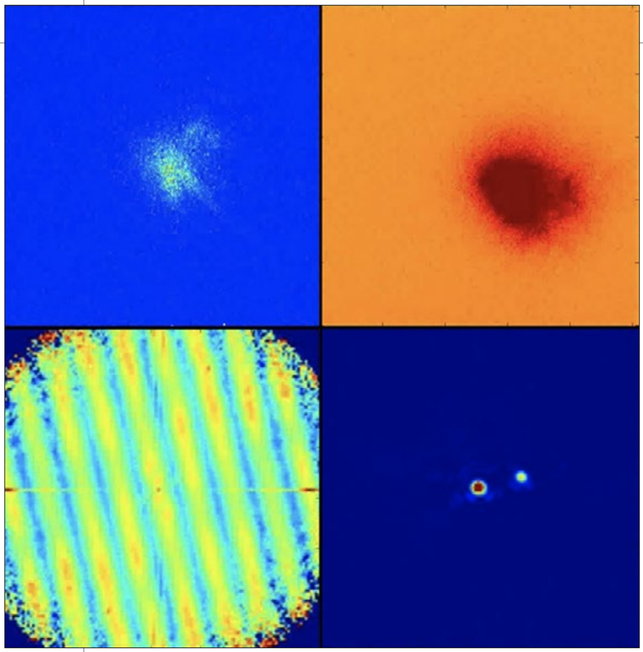


Figure 1. *An individual speckle frame (top left), the integrated image of 1,000 speckle frames (top right), the Fourier power spectrum (bottom left), and the resulting reconstructed diffraction-limited image (bottom right). Adapted from Scott and Howell (2018).*

Yet another solution, far less expensive than the latter and easily implemented at optical wavelengths, is speckle interferometry. First proposed by French astronomer Antoine Labeyrie in 1970, speckle interferometry is based on the idea that atmospheric turbulence can be "frozen" when obtaining very short exposures. In these short exposures, stars look like a collection of little spots, or speckles (Figure 1), where each of these speckles has the size of the telescope's diffraction limit. When taking many exposures, and using a clever mathematical approach, these speckles can be reconstructed to form the true image of the source, removing the effect of atmospheric turbulence.

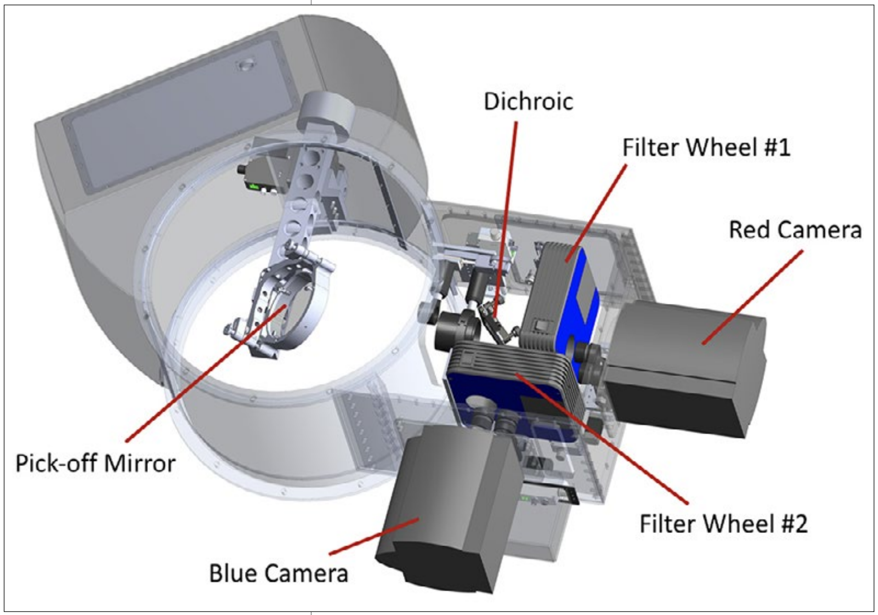


Figure 2. *The design of Zorro. A pickoff mirror deflects the light coming from the tertiary mirror, redirecting it into Zorro. Inside Zorro, the light is split by a dichroic into red and blue channels to their respective cameras equipped with electron-multiplying CCDs.*

One instrument capable of doing speckle interferometry is the Differential Speckle Survey Instrument (DSSI, Horch *et al*., 2009), which visited Gemini North and South on multiple occasions since 2012. Visiting instruments expand the capabilities of what the facility instruments can offer, but come with a significant burden in logistics: permissions must be obtained, agreements signed, the equipment shipped, a dedicated crew of people must travel, some facility instrument must be removed, and finally the visiting instrument must go through testing and commissioning. Is there another viable solution? In other words, is it possible to make the visitor feel truly at home?

Enter Zorro!

Zorro (and its sibling 'Alopeke at Gemini North) is a new dual-channel, dual-plate-scale (field of view) speckle interferometer permanently mounted on Gemini South. In simpler words, Zorro can obtain two diffraction-limited images with different filters simultaneously. Besides the speckle mode (which gives a field of view of only a few arcseconds), Zorro also has a wide-field mode with a field of around 1 arcminute. The speckle mode reaches the diffraction limit of Gemini (15 miliarcseconds at 500 nanometers), while the wide-field delivers an image quality between the diffraction limit and the natural seeing. Limited testing has shown images with an image quality of around 0.15 arcsecond.

Zorro (the Spanish word for Fox) is indeed small and clever, like its furry namesake. Mounted between the instrument support structure and the calibration unit at Gemini South, it solves the perennial problem of which facility instrument must be displaced by not displacing any. Since it doesn't require a port of its own, Zorro is free to take up residence as a "permanent visitor."

The commissioning of Zorro occurred May 20-23, 2019, when the team from NASA Ames who designed and built the instrument (Steve Howell, Nic Scott, Rachel Matson, and Emmett Quigley) came to Gemini South to assemble, install, and calibrate the instrument. Despite some battles with the weather, the first science run started immediately after commissioning.

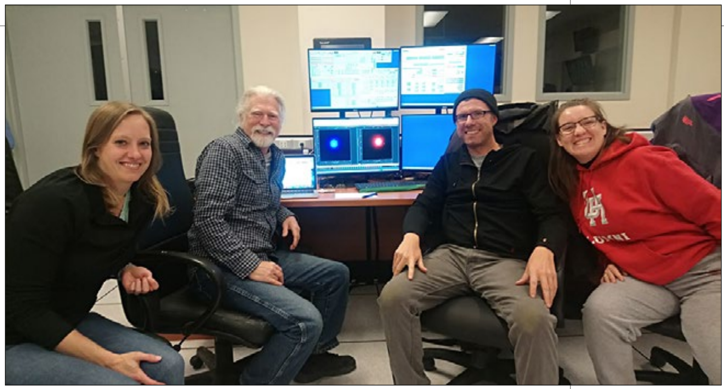


Figure 3.

The Zorro commissioning team — from left to right: Rachel Matson, Steve Howell, and Nic Scott (NASA Ames) — together with Gemini South Science Operation Specialist, Joy Chavez, look happy after achieving first light. The selected target was the star N Velorum.

Science with Zorro

What kind of science can benefit from the diffraction limited images delivered by Zorro? The main science driver of the renaissance of speckle interferometry has been the study of stars hosting exoplanets. The study of exoplanets has been revolutionized with dedicated space missions like NASA's *Kepler* (now retired), *K2*, and *Transiting Exoplanet Survey Satellite (TESS)*, which have discovered thousands of new exoplanets via the transit method — that is, the little dips in the light curve of a star when a planet passes in front of (transits) it. As impressive as these missions are, they have one problem: because they observe large fields of view containing hundreds of thousands of stars, their pixel scales are necessarily coarse, several arcseconds or more.

But what if the transited star is actually a binary star? The properties of the planet derived from the light curve can change radically whether the planet is transiting one or the other star. This is where the power of Zorro is manifest. Following up stars with transits observed by *Kepler/K2* and *TESS* and looking for close stellar companions, it can confirm and clarify the nature and properties of detected exoplanets.

One example is the newly discovered giant planet KELT-25b with a 4.4 day orbit around its parent star. This discovery was possible with a combined analysis of the Kilodegree Extremely Little Telescope (KELT) and *TESS* data. Zorro observed this system during its first science run and ruled out the presence of any other unresolved stellar companion, confirming the inferred size of the planet.

But the research done with Zorro does not stop there. Its exquisite image quality can also be used to study the whole zoology of binary stars, multiple stellar systems, Solar System objects, and maybe even to do some extragalactic science.

Zorro is now commissioned and ready to do science. What can you do with images having a spatial resolution of ~15 miliarcseconds? We wait for your observing proposals by the end of September!

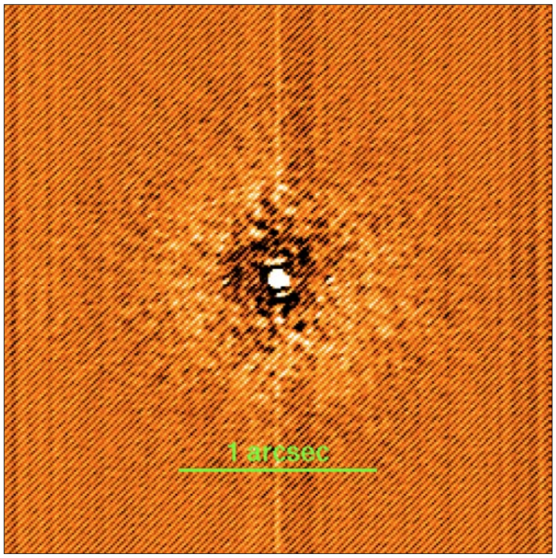


Figure 4.

Kelt-25 as seen by Zorro. The Zorro observations show Kelt-25 has no stellar companions, thereby confirming the nature of the newly discovered transiting giant planet KELT-25b.

Credit: Joey Rodriguez, Sam Quinn, and Josh Pepper (KELT-TESS); Steve Howell, Nic Scott, and Rachel Matson (NASA Ames)

Ricardo Salinas is an Assistant Scientist at Gemini South. He can be reached at: ***rsalinas@gemini.edu***

Steve Howell is the Space Science & Astrobiology Division Chief at NASA Ames. He can be reached at: ***steve.b.howell@nasa.gov***

A Galactic Dance

"Everything is determined… by forces over which we have no control. … Human beings, vegetables, or cosmic dust, we all dance to a mysterious tune, intoned in the distance by an invisible piper."

— Albert Einstein

Figure 1. *Image of the interacting galaxy pair NGC 5394/5 (also known as the Heron Galaxy) obtained with NSF's National Optical-Infrared Astronomy Research Laboratory's Gemini North 8-meter telescope on Hawaii's Maunakea using the Gemini Multi-Object Spectrograph in imaging mode. This four-color composite image has a total exposure time of 42 minutes. North is up.*

Credit: Gemini Observatory/NSF's National Optical-Infrared Astronomy Research Laboratory/AURA

Galaxies lead a graceful existence on cosmic timescales. Over millions of years, they can engage in elaborate dances that produce some of nature's most exquisite and striking grand designs. Few are as captivating as the galactic duo known as NGC 5394/5, sometimes nicknamed the Heron Galaxy. The image in Figure 1, obtained by the Gemini Observatory of NSF's National Optical-Infrared Astronomy Research Laboratory, captures a snapshot of this compelling interacting pair.

The existence of our Universe is dependent upon interactions — from the tiniest subatomic particles to the largest clusters of galaxies. At galactic scales, interactions can take millions of years to unfold. This new image released in December captures a moment in the slow and intimate dance of a pair of galaxies some 160 million light years distant and reveals the sparkle of subsequent star formation fueled by the pair's interactions.

As in all galactic collisions, these galaxies are engaged in a ghostly dance. Astronomers have concluded that the two partners have already "collided" at least once, though the distances between the stars in each galaxy preclude actual stellar collisions. Nevertheless, galactic collisions can be a lengthy process of successive gravitational encounters, with each galaxy's gravity deforming the other's overall shape. Over time the galaxies can morph into exotic forms that bear no resemblance as to how we see them today.

One by-product of the pair's turbulent interactions is that hydrogen gas coalesces into regions of star formation. In this image, these stellar nurseries appear as reddish clumps scattered in a ring-like fashion in the larger galaxy (and a few in the smaller galaxy). Also visible is a dusty ring seen in silhouette against the backdrop of the larger galaxy. A similar ring structure appears in ***this previous image*** from the Gemini Observatory, likely the result of another interacting galaxy pair.

A well-known target for amateur astronomers, the light from NGC 5394/5 first piqued humanity's interest in 1787, when William Herschel used his giant 20-foot-long telescope to discover the two galaxies in the same year that he discovered two moons of Uranus. Many stargazers today imagine the two galaxies as a heron. In this interpretation, the larger galaxy is the bird's body and the smaller one is its head — with its beak preying upon a fish-like background galaxy!

NGC 5394 and NGC 5395, also known collectively as Arp 84 or the Heron Galaxy, are interacting spiral galaxies 160 million light years from Earth in the constellation of Canes Venatici. The larger galaxy, NGC 5395, is 140,000 light years across, and the smaller one, NGC 5394, is 90,000 light years across.

See the ***full image release here***.

Gemini staff contributions

On the Horizon

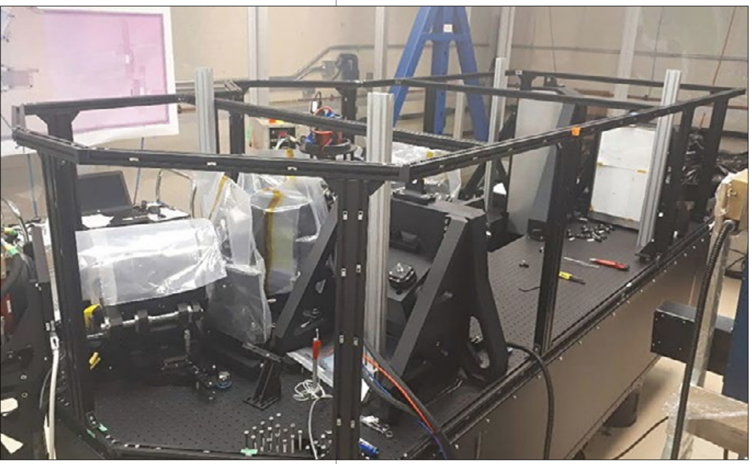
This review highlights instrumentation development efforts made in 2019 to advance the Observatory's capabilities to do leading science, especially in the era of multi-messenger and time-domain astronomy.

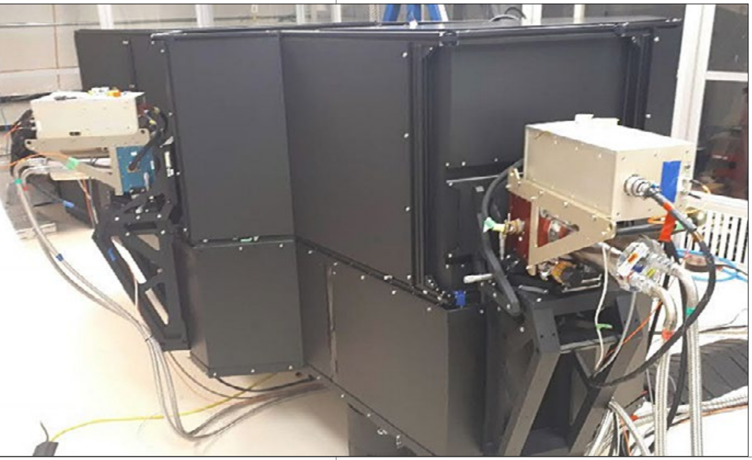
Figure 1 (top). *The GHOST spectrograph in the lab prior to the installation of the inner enclosure.*

Credit: NRC-HAA

Figure 2 (bottom). *The GHOST spectrograph with inner enclosure and assemblies for blue and red detectors.*

Credit: NRC-HAA





JANUARY 2020

GHOST on the Move

For the past six months, the assembly, alignment, and test of Gemini's High-resolution Optical SpecTrograph (GHOST) in Victoria, British Columbia, has gone very close to plan; we expect to ship the instrument to Gemini South in February 2020.

The newest instrument chosen for the Gemini South telescope, GHOST was designed, and is being built and tested, by a partnership of organizations: Australian Astronomical Optics (AAO)-Macquarie University, the National Research Council Canada (NRC)-Herzberg, the Australian National University (ANU), and Software Design Ideas. During the latter half of 2019, the AAO, which designed and built GHOST's Slit Viewer Assembly and Optical Fiber Cable, made multiple visits to NRC-Herzberg, where they participated in each sub-assembly's integration and testing with the spectrograph.

The spectrograph (Figures 1 and 2) has performed excellently during the Acceptance Testing of the past few months. Test results for resolution, throughput, and stability all look great in the lab. We will repeat the verification of these and other performance requirements after all is re-assembled at Gemini South. Having developed the data reduction and instrument control software, the ANU and Software Design Ideas were also key participants in the recent testing success. Figure 3 hints at some of GHOST's capabilities.

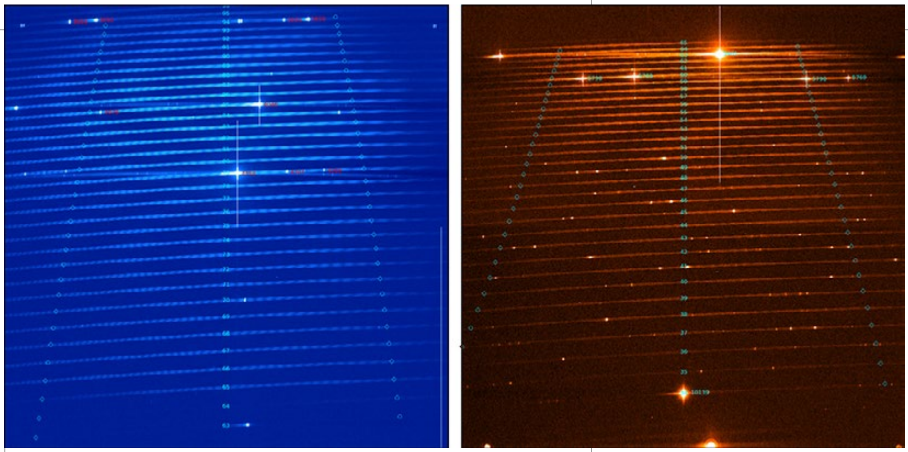


Figure 3.
Blue and red GHOST images of a mercury lamp, with the spectral orders labeled and 1.1 x free spectral range in each order highlighted. Continuous wavelength coverage from 359 nm to well beyond 1 micron (Requirement: 363 - 950 nm). Significant wavelength overlap between orders (with overlapping orders between arms).

Credit: Greg Burley

The Cassegrain Acquisition Unit, also designed and built by the AAO, was previously shipped to Chile from Australia and tested in advance of the upcoming arrival of the spectrograph. After the spectrograph, slit viewer, and optical cable arrive in Chile, we expect to have all sub-assemblies of the GHOST instrument fully integrated and functioning in the second quarter of 2020 in preparation for commissioning.

First Light with NGS2

The Canopus adaptive optics (AO) bench of the Gemini Multi-conjugate adaptive optics System at Gemini South recently received a significant upgrade: its new Natural Guide Star Wavefront Sensor, also known as the Natural Guide Star Next Generation Sensor (NGS2). The original system consisted of three moving probes to pick up guide stars in the field, channel the light into fibers, and project it onto a quad-cell for tip-tilt detection. This system worked but in practice was cumbersome to use, mainly due to each probe's tiny field of view and the large light losses in the system. This implied large acquisition times and a brightness limit for the stars that significantly restricted sky coverage.

For the above reasons, a team from the Australian National University spearheaded an alternative approach, making use of novel electron-multiplying CCD technology that allows imaging the whole field of view. Up to three guide stars can be selected on that image. For tip-tilt wavefront sensing on each of the stars, small windows centered on each star are then read out at high speed, making use of the extreme low noise characteristics of the electron-multiplying CCD.

The new NGS2 was incorporated into the Canopus optical bench last September (Figure 4). This was no trivial exercise, because it required removing the AO's three large optical components and dismantling the original NGS system. But it all worked out, thanks to the careful preparations made by the NGS2 team.

Commissioning took place last October. Apart from Gemini personnel, the team had the great pleasure to work with François Rigaut (Australian National University) and Benoit Neichel (Laboratory of Astrophysics of Marseille) during the commissioning nights (Figure 5, next page). Collaboration from the weather was a weak point, seriously hampering progress. However, the team tested the full system, and put it through its paces.

The first results have been very positive. AO performance under reasonable weather conditions achieved an image quality of 83 milliarcseconds, indicating that the fully integrated system worked well (Figure 6). Acquisition of the three natural guide stars was

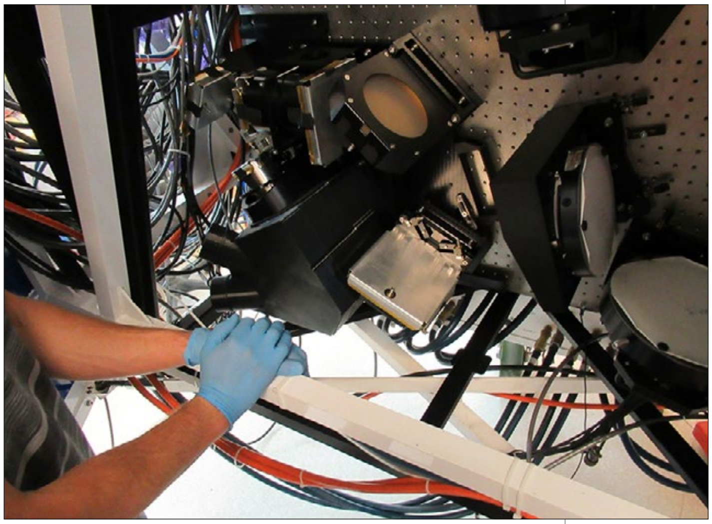


Figure 4.
The new NGS2 unit after installation into the Canopus optical bench.

Figure 5. *A tense moment in the control room when all the AO loops were closed with NGS2 for the first time. Official first light on NGS2!*

Credit: René Rutten

very quick, achieving a gain of several minutes over the original NGS system for every acquisition (Figure 7).

A key driver for the NGS2 project was to work with fainter guide stars. Whereas the original NGS system could guide down to about R = 15.5 magnitude under good conditions, the new system has been proven to work even beyond R = 18 magnitude; a remarkable improvement that significantly increases sky coverage, bringing many more objects into reach of the GeMS/GSAOI instrument.

During the upcoming observing runs with GeMS/GSAOI, we will gain more experience on NGS2's performance. We will update the web pages with the latest information for users. Meanwhile, we invite interested users to exploit the system with new and previously inaccessible targets.

The NGS2 project has been made possible thanks to the tight collaboration between many people. The initiative, a large part of the funding, and the design and build of NGS2 was primarily done by a team at the Australian National University in collaboration with Gemini engineers and astronomers. Without such a strong collaboration the project would not have prospered.

SCORPIO Making Steady Progress

With the exciting build phase of the Spectrograph and Camera for Observations of Rapid Phenomena in the Infrared and Optical (SCORPIO) — a powerful next generation instrument for Gemini South — underway, the SCORPIO team has been busy in the last quarter of 2019. On November 22nd, Gemini staff and subcontractor FRACTAL attended the project's Quarterly Review at the Southwest Research Institute (SwRI) facilities in San Antonio, Texas. Gemini staff noted that significant progress has been made on several fronts, including the Slit Viewing Camera (SVC), thermal design, Failure Mode and Effects Analysis, and Center of Gravity issue. Discussions included assembly-of-instrument and focal-plane-mechanisms failure modes.

A total of five Manufacturing Readiness Reviews (MRRs) have also taken place: an Elec-

Figure 6 (below, left). *During the brief moments of good weather on the commissioning nights, the full MCAO system with NGS2 could be tested on the central condensation of stars in the Tarantula Nebula (RMC 136).*

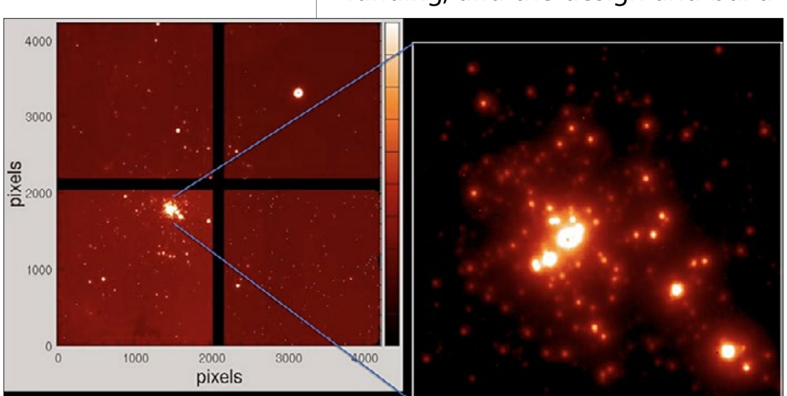
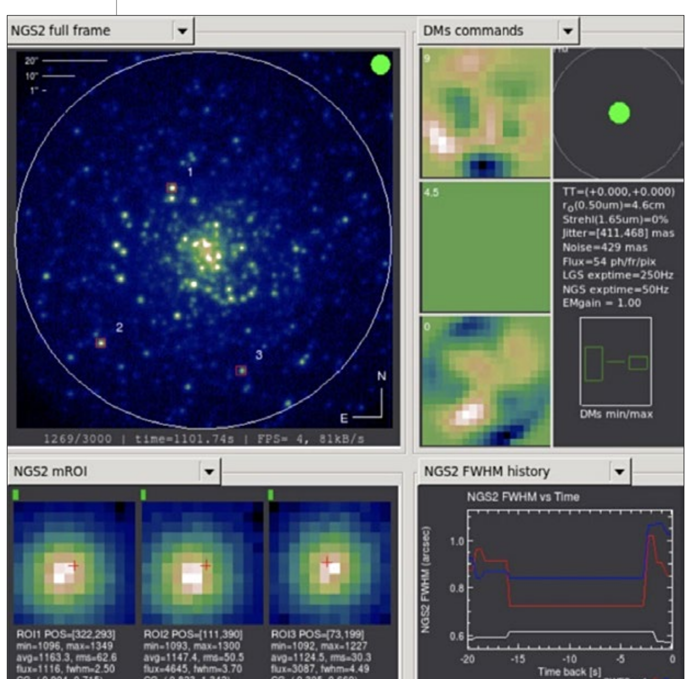


Figure 7 (below, right). *NGS2 control panel, showing the field of view on the NGS2 EMCCD camera, and the identified three natural guide stars. Individual guide star window images are shown in real time on the bottom left. This system has proven to be much easier, faster, and better to operate.*



tronics MRR on November 6th at SwRI attended remotely by Gemini; NIR Collimators and NIR Cameras Opto-mechanics MRR on November 20th, with SwRI contractor Officina Stellare in Madrid; Mounts and Mechanics MRR on November 21st in Madrid; VIS Collimators and VIS Cameras Opto-mechanics MRR on December 18th with SwRI contractor Winlight Systems; and Cooled Electronics Box and SVC MRRs on December 18th in Madrid (Figure 8).

Coming up in 2020, the SCORPIO Science Team will gather in March for a SCORPIO Science Meeting in Washington, D.C., closely followed by a project Quarterly Review taking place at Gemini South facilities in La Serena, Chile; there the SCORPIO team will get the opportunity to visit Cerro Pachón and participate in nighttime observations. Gemini is working closely with the SCORPIO team to ensure continued steady progress.

OCTOBER 2019

GHOST: Project Build Phase Nearing Completion

The National Research Council Canada's Herzberg Astronomy and Astrophysics (HAA) Research Centre is in the final few weeks of the build phase for the Gemini High-resolution Optical SpecTrograph (GHOST). HAA staff fine-aligned the spectrograph optics and are now able to take test spectra (Figure 9). The Australian Astronomical Optics (AAO) group at Macquarie University delivered the science fiber cable, slit view assembly, and associated electronics to the HAA in early July. Both groups, along with the Australian National University and Software Design Ideas, have been working together the past several months to integrate the various hardware, optics, electronics, and software into a functioning spectrograph (Figure 10, next page).

Now that this major milestone is nearly complete, the combined teams expect to enter into the test phase in October. If all testing goes to plan, the team expects to ship shortly after the start of 2020 to Chile, where the AAO-built acquisition unit is ready to connect.

GNAOI Request for Proposals

Gemini Observatory announces an opportunity for the Gemini North Adaptive Optics Imager (GNAOI) — a planned instrument to be used with both the Gemini North multi-conjugate adaptive optics system (GNAO; which is now under development) and with a planned future ground-layer adaptive optics system. We expect that this imager will

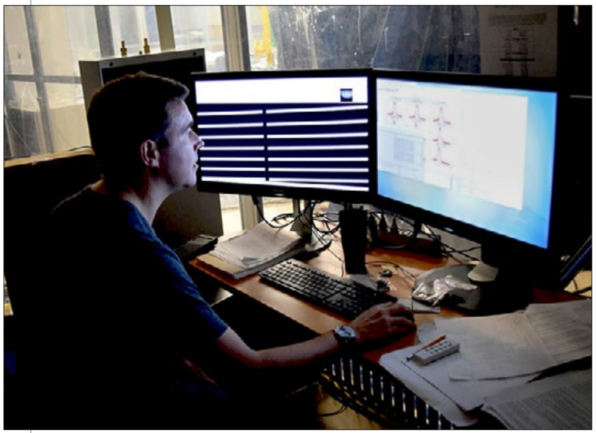


Figure 8.
On December 18, 2019, staff from Gemini, FRACTAL, SwRI, Johns Hopkins Univeristy (JHU), and SwRI contractor Winlight Systems met in Madrid for SCORPIO's VIS Cameras Opto-mechanics MRR. Standing in the back (from left to right): Kelly Smith (SwRI), Gerardo Veredas (FRACTAL), Thomas Hayward (Gemini), Manuel Maldonado (FRACTAL), Robert Barkhouser (JHU), Vincent Lapere (Winlight Systems), Jean-François Gabriel (Winlight Systems), Ernesto Sánchez (FRACTAL), Pete Roming (SwRI), and Stephen Smee (JHU). And standing in front (from left to right): Marisa García-Vargas (FRACTAL), Todd Veach (SwRI), Massimo Roberto (JHU/Space Telescope Science Institute), Ana Pérez (FRACTAL), and Stephen Goodsell (Gemini).

Credit: Marisa García-Vargas, FRACTAL

Figure 9.
Alan McConnachie of HAA taking some test spectra with GHOST in the HAA integration lab.

Credit: Scot Kleinman

Figure 10.
Scott Roberts of HAA showing Telescope Scientist Tom Hayward of Gemini the impressive outer enclosure for GHOST.

Credit: Scot Kleinman

be a low-cost low-risk design using a single HAWAII-4RG detector, and intend for GNAO to provide a 2-arcminute field of view with a Strehl ratio of no less than 30% over the entire field of view under median seeing conditions in *K* band. A Request for Proposals to design this imager has been released and is available on the ***Gemini website here***.

MAROON-X Deployed at Gemini North

MAROON-X, a new visiting high-resolution spectrograph at Gemini North (Figure 11), will be available to users in 2020. Constructed at the University of Chicago, MAROON-X is expected to be able to detect Earth-size planets in the habitable zones of mid- to late-M dwarfs using the radial velocity detection method.

The important wavelength range for the instrument is 700-900 nanometers and the resolving power approximately 80,000. To achieve this precision the instrument must be intrinsically stable and the optical setup fixed, so the entire instrument has been placed in a vacuum tank in a thermally stable enclosure, which the instrument team assembled in the Gemini North Pier Lab, four levels below the telescope. After a year of monitoring the temperature stability in the enclosure, commissioning the Front End (which mounts on the Instrument Support Structure and holds the optical fiber positioner), and integrating the spectrograph itself in the Gemini North Pier Lab, the team has begun commissioning. See a ***press release about MAROON-X*** available from the University of Chicago.

Figure 11.
The MAROON-X instrument team and Gemini staff pose with the instrument, installed on Gemini North on September 23rd, and ready for first light. Although the Front End was successfully commissioned in December, now if you look closely, you can see the optical fiber that runs down to the spectrograph in the Gemini North Pier Lab below. Left to right: Paul McBride, John Randrup, Rody Kawaihae, Harlan Uehara, Eduardo Tapia (all Gemini staff), Andreas Seifahrt, David Kaspar, Julian Stuermer (all University of Chicago), and Alison Peck and John White (both Gemini staff).

Credit: Julian Stuermer

GIRMOS Conceptual Design Review a Success

The Gemini InfraRed Multi-Object Spectrograph (GIRMOS) is a powerful new visiting instrument being designed and built for the Gemini telescope by a Canadian consortium of universities led by the University of Toronto and HAA. This instrument will overcome a key limitation in existing adaptive optics (AO) facilities; where exisitng integral field spectrographs are designed to observe only single objects with adequate atmospheric correction, GIRMOS is being designed to have the ability to observe multiple sources simultaneously with high spatial resolution while obtaining spectra at the same time (Sivanandam *et al.*, 2018).

GIRMOS accomplishes this by taking advantage of the latest developments in multi-object AO (MOAO) and integral field spectroscopy. It exploits the AO correction from both a telescope-based AO system (either GeMS or the prospective Gemini North AO system) and its own additional MOAO system that feeds multiple 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 in the very early stages of development, and the team, led by Suresh Sivanandam (Principal Investigator; University of Toronto, Dunlap Institute) and Darren Erickson (Project Engineer; HAA), have been working extremely hard to complete a conceptual design for the instrument and to identify the resources needed to make the project a success. We are very happy to report that they passed their Conceptual Design Review on September 18, 2019, following a very exciting few days of presentations and discussions at the Dominion Astrophysical Observatory, in Victoria, British Columbia (Figure 12). We look forward to continuing to work with this great team as they move forward to the next stage of the project. Congratulations to the team!

Multiple Opportunities to Use IGRINS

You probably remember when the visiting Immersion GRating INfrared Spectrometer (IGRINS) came to Gemini South in 2018. This cross-dispersed near-IR spectrograph — with a resolving power of R = 45,000, covering the H and K windows (from 1.45 to 2.5 microns), in a single exposure, providing both broad spectral coverage and high spectral resolution — had a very high oversubscription rate. A large number of very impressive programs were observed, but even with the exceptional instrument team supporting 50 nights of observing, we were not able to fit in all of the great science that was proposed.

If you missed your chance to use IGRINS in 2018, never fear! We are delighted to announce that IGRINS will join us once again at Gemini South for several semesters, starting with 2020A. If you were not able to get your proposal in for the 20A deadline, don't despair, keep your eye out for IGRINS in the next several Calls for Proposals.

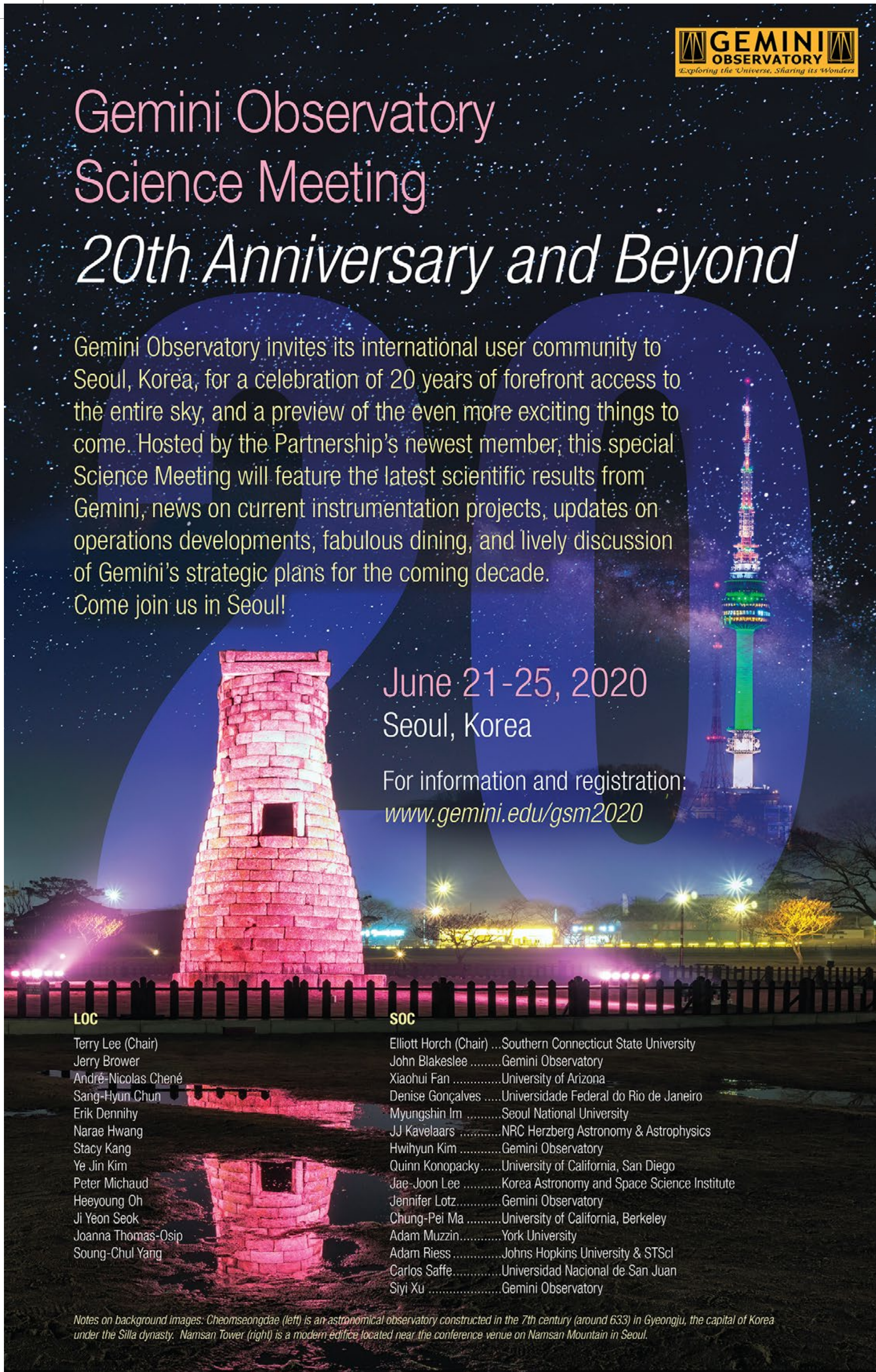
20th Anniversary Gemini Science Meeting

Gemini Observatory invites its international user community to Seoul, Korea, for a special 20th anniversary Gemini Science Meeting (GSM) celebrating 20 years of science operations and a look forward to even more exciting things to come. Hosted by the Partnership's newest member, the topics will include the latest scientific results from Gemini, news on current instrumentation projects, updates on operations developments, and lively discussion of Gemini's strategic plans for the coming decade. The GSM will take place June 21-25, 2020, followed by the K-GMT Users' Meeting on June 26th. (See poster, next page.) For information and updates, see the ***Gemini Science Meeting 2020 website***.

Figure 12.

GIRMOS PI Suresh Sivanandam (University of Toronto, Dunlap Institute; in shadow at the front of the room) presents the agenda to the Review Panel, project members, and participating Gemini staff at a GIRMOS Conceptual Design Review held at HAA in Victoria, British Columbia.

Credit: Marcin Sawicki (Saint Mary's University)


GEMINI OBSERVATORY
Exploring the Universe, Sharing its Wonders
Gemini Observatory Science Meeting
20th Anniversary and Beyond
Gemini Observatory invites its international user community to Seoul, Korea, for a celebration of 20 years of forefront access to the entire sky, and a preview of the even more exciting things to come. Hosted by the Partnership's newest member, this special Science Meeting will feature the latest scientific results from Gemini, news on current instrumentation projects, updates on operations developments, fabulous dining, and lively discussion of Gemini's strategic plans for the coming decade.
Come join us in Seoul!
June 21-25, 2020
Seoul, Korea
For information and registration:
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Erik Dennihy
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Stacy Kang
Ye Jin Kim
Peter Michaud
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Ji Yeon Seok
Joanna Thomas-Osip
Soung-Chul Yang
SOC
Elliott Horch (Chair) ...Southern Connecticut State University
John Blakeslee ....Gemini Observatory
Xiaohui Fan ....University of Arizona
Denise Gonçalves .....Universidade Federal do Rio de Janeiro
Myungshin Im ....Seoul National University
JJ Kavelaars ....NRC Herzberg Astronomy & Astrophysics
Hwihyun Kim ....Gemini Observatory
Quinn Konopacky......University of California, San Diego
Jae-Joon Lee ....Korea Astronomy and Space Science Institute
Jennifer Lotz............Gemini Observatory
Chung-Pei Ma ....University of California, Berkeley
Adam Muzzin............York University
Adam Riess ....Johns Hopkins University & STScI
Carlos Saffe.............Universidad Nacional de San Juan
Siyi Xu ....Gemini Observatory
Notes on background images: Cheomseongdae (left) is an astronomical observatory constructed in the 7th century (around 633) in Gyeongju, the capital of Korea under the Silla dynasty. Namsan Tower (right) is a modern edifice located near the conference venue on Namsan Mountain in Seoul.

JULY 2019

GHOST Project Achieves Major Milestone

During the first two weeks of July, the combined Australian and Canadian GHOST teams worked together to reach a major milestone in Victoria, British Columbia: the integration of subassemblies created by each organization for Gemini's High-resolution Optical SpecTrograph (Figure 13). The Australian Astronomical Optics Macquarie University team brought with them the Slit Viewer Assembly with electronics, as well as the Optical Fiber Cable to be connected to and tested with the Spectrograph, which the National Research Council Canada team had recently assembled. A spectrum captured with this instrument is shown in Figure 14. Software Design Ideas, and staff from the Australian National University, provided software support during this effort.

This work bought the fiber system, Slit Viewer Assembly, and spectrograph together for the first time.

The fiber system, which sits between the Cassegrain Unit and the Slit Viewer Assembly, includes the following components:

- 62 individual fibers that connect the Cassegrain Unit to the Slit Viewer Assembly.
- The microlens IFU units that consist of two low-resolution arrays and one high-resolution array, each with a separate array for sky.
- A flexible conduit for the optical cable that minimizes stress on the fibers, thereby reducing Focal-Ratio Degradation.
- Spectrograph slit optics that form a slit from each object. The slits are 1 microlens wide and either 7 or 19 microlenses long in the standard- or high-resolution modes, respectively.
- An acquisition and guiding slit.
- A simultaneous wavelength calibration light injection port.

The fiber system also includes two associated devices: (1) a mode-scrambling, noise-reducing agitator that creates variable conditions for propagation of light in all of the optical fibers; and (2) a calibrator that is the reference source for simultaneous wavelength calibration via a Thorium-Xenon lamp.

The Slit Viewer Assembly uses a beam splitter to direct 99% of the slit output to the spec-

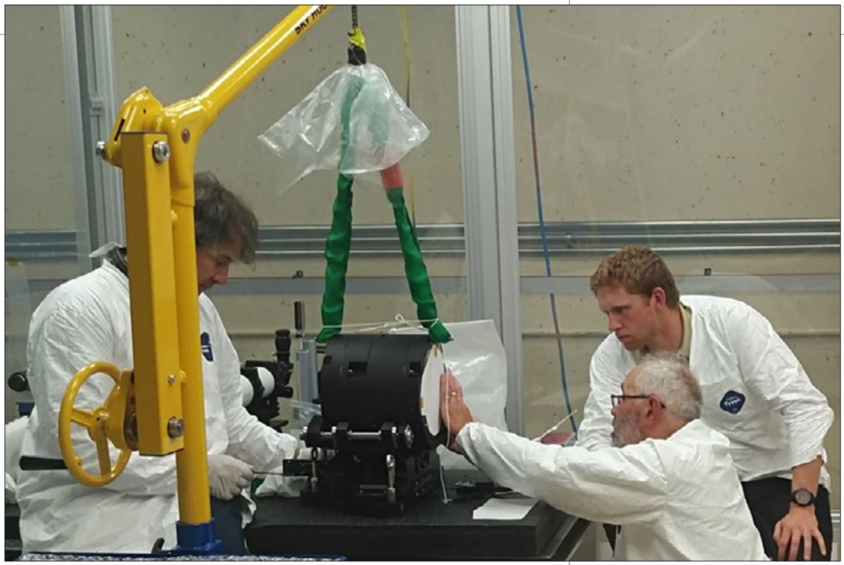


Figure 13.
National Research Council Canada team members John Pazder, Andre Anthony, and Scott Macdonald (from left to right) fit check GHOST's red camera optics onto the focus stage.

Credit: David Henderson

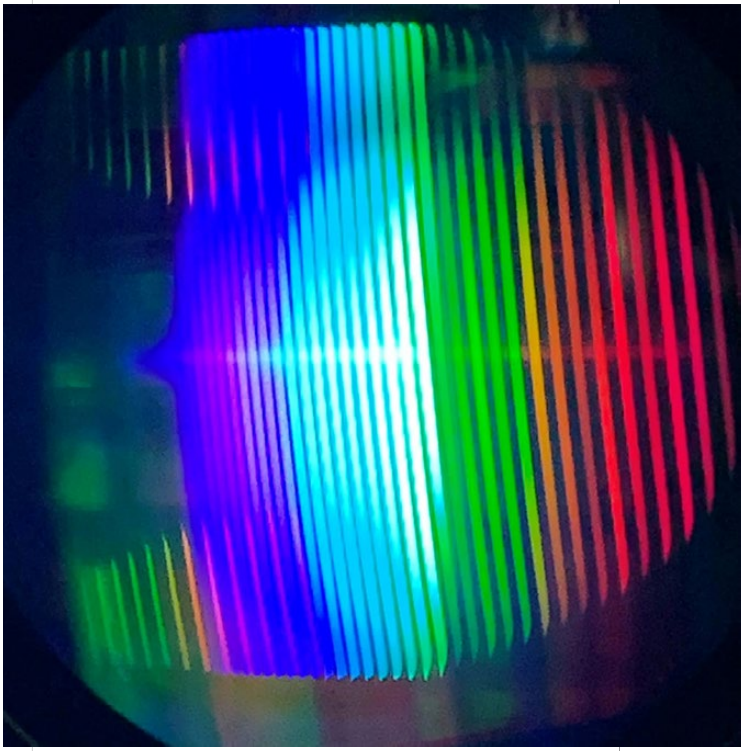


Figure 14.
Image of spectrum captured from the location where the GHOST blue detector will be positioned.

Credit Tony Farrell

trograph and 1% to the slit imaging system. It also removes the need for an on-instrument wavefront sensor for flexure compensation, with the telescope's peripheral wavefront sensor being used for fast tip/tilt and focus corrections.

The spectrograph subsystem is a gravity-stable asymmetric white-pupil échelle spectrograph, with two arms and volume-phase holographic grating cross-dispersers. It comprises the following key elements:

- An optical table that maintains spectrograph stability and provides thermal mass for the environmental enclosure sub-system.
- A Slit Viewer Assembly unit, discussed above, that directs 99% of the light from the slit to the collimator.
- A collimator mirror that collimates the beam from the Slit Viewer Assembly and directs it to the échelle grating.
- An échelle grating that disperses the light into the échelle orders.
- Two transfer mirrors: one convex fold mirror and the white pupil relay mirror. The transfer mirrors and the collimator mirror together form the white pupil relay that reimages the pupil of the dispersed light at the échelle onto the Volume Phase Holographic gratings.
- A beam splitter that separates the light into blue and red channels.
- Blue and red gratings that act as both the cross-dispersers, to separate the échelle orders, and to introduce an anamorphic factor for more efficient use of the effective area of the detector in the cross-dispersion direction.
- Blue and red multi-element camera lenses.
- Blue and red detectors that collect the full wavelength ranges of each camera, mounted in separate cryostats.
- Focus controls for each camera.

The team will work the remainder of the year to complete the final integration and testing before shipping to Chile near the end of the year.

SCORPIO: Moving Toward Its Build Phase

On June 5-7, the SCORPIO project held its Critical Design Review (CDR) at the Southwest Research Institute (SwRI) headquarters in San Antonio, Texas. Team members from SwRI, FRACTAL (an instrument design firm in Madrid, Spain), Space Telescope Science Institute, Johns Hopkins University, George Washington University, and Gemini Observatory, participated in the review, presenting material to an eight-member external review committee. John Troeltzsch from Ball Aerospace and the National Center for Optical-infrared Astronomy Management Oversight Council chaired the very experienced external review panel.

The reviewers recognized and congratulated the team for the tremendous amount of work and effort spent in progressing the project since the Preliminary Design Review. In the following weeks, Project Executive Scot Kleinman took the identified concerns, issues, and risks from both the external review committee and the internal Gemini staff reviewers and crafted a comprehensive CDR Executive Report that contained recommended actions to close out the Design Phase of the project and reduce risk going forward into the Build Phase.

We remain confident that the SCORPIO team will build a successful instrument for Gemini. SCORPIO is a complex and challenging instrument to create, and the finished product promises to become a major capability at the Observatory, aiding scientific discovery in the coming decades.

GEMMA's Out of the Gate

In the new year, the Gemini in the Era of Multi-Messenger Astronomy (GEMMA) program is off to a good start. Gemini North Adaptive Optics (GNAO) Principal Investigator Gaetano Sivo formed an external Gemini AO working group to provide community experience and expertise regarding the Observatory's AO program, including developing science cases, technical recommendations, and best practices. The Real Time Computer project is performing some technology trade studies and considering whether some components can be designed and built in-house.

The time-domain astronomy (TDA) project is also moving along, convening a working group to review user stories related to the concept of operations. In addition, Public Information and Outreach plans to hold a Time-Domain Astronomy Summit later this year; the goal is to bring together scientists and communications and education professionals to create a roadmap on how to communicate the concepts of MMA and TDA to non-scientists. The program continues to define short- and long-term benefits of the individual projects to the future of Observatory operations and the astronomy community. Dave Palmer has joined the team to work as Project Manager for both the GNAO and RTC GEMMA efforts. He will be working with Acting GNAO Project Manger Stephen Goodsell during the Conceptual Design Stage, allowing Stephen to step back from the role after the Conceptual Design Review.

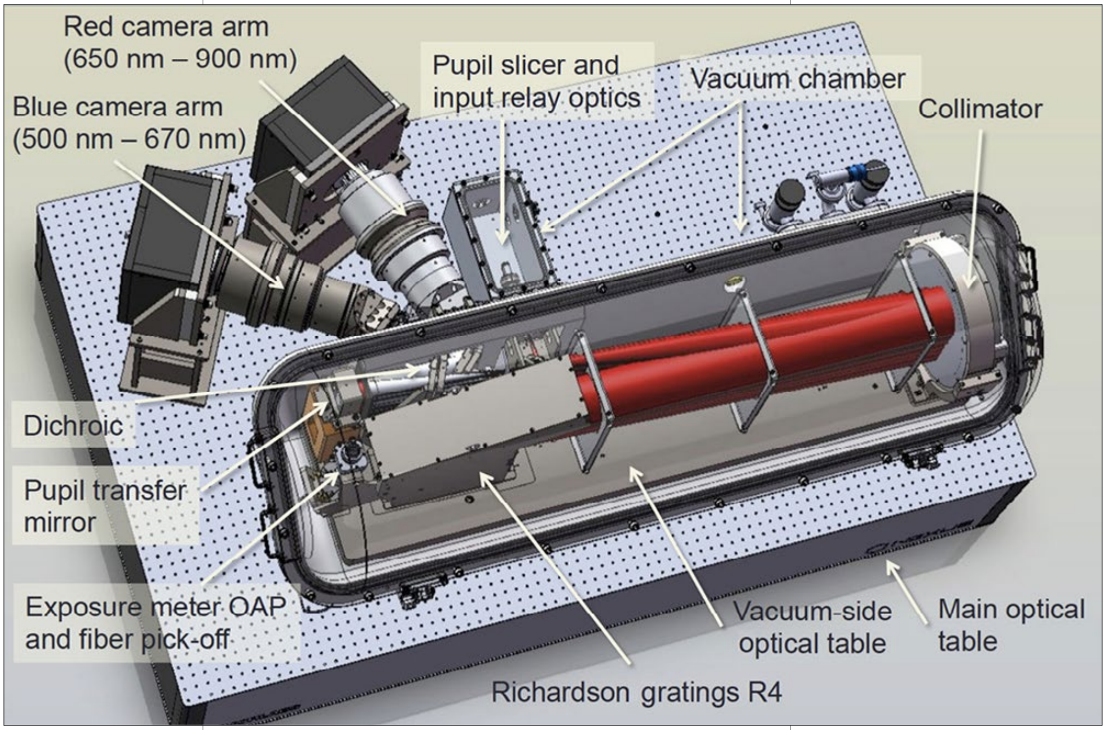


Figure 15.
Computer-aided design rendering of the vacuum chamber and cameras on the MAROON-X bench. The actual spectrograph is expected to arrive at Gemini North in May.

Preparations for MAROON-X

MAROON-X is the new radial velocity spectrograph being built at the University of Chicago and expected to be deployed at Gemini North within the next year (Figure 15). This high-resolution, bench-mounted spectrograph has been designed to deliver 1 meter/second radial velocity precision for M dwarfs down to and beyond V = 16, and is expected to have the capability to detect Earth-size planets in the habitable zones using the radial velocity method.

Following the success of the Front End commissioning, we are planning to install and align the spectrograph in the dedicated enclosure in the Pier Lab in May 2019. If all goes well, we hope to complete commissioning in time to include this exciting new visiting instrument in the 2020A Call for Proposals. Watch this space for more information as integration and commissioning progresses on Maunakea.

Second On-sky Testing of GHOST

The Gemini High-resolution Optical SpecTrograph (GHOST) team completed the second round of on-sky testing at Gemini South in November, 2018. The team successfully demonstrated proper operation of the atmospheric dispersion correctors (ADCs), the instrument on the side-port of the instrument support structure, and the interactions between GHOST and the Observatory Control System (OCS) software.

GHOST uses ADCs to correct for the dispersion of light by the atmosphere. Rather than a full-field ADC, GHOST features mini-ADCs for each fiber positioner, which offers improved efficiency. The build team tested each of the mini-ADCs to ensure that the hardware and software were working correctly to provide the optimal dispersion correction as expected. Each ADC was tested over a range of target zenith distance and position angles. These tests demonstrated that the ADCs are working as expected and produce the required correction.

These tests also marked the first on-sky testing of GHOST interoperability with the Gemini OCS. GHOST target configurations, in both high- and standard-resolution modes, were created in the Gemini Observing Tool. The telescope systems then used these target configurations to determine the telescope pointing. GHOST also used them to place the fiber positioners on the requested targets. While these successful tests were a major milestone in our internal software development process, they also improved the efficiency of the on-sky tests by greatly reducing the time for target acquisitions at the telescope.

The team operated GHOST on both the up-looking and side-looking ports. While GHOST is expected to operate primarily on the up-looking port during normal operations, we wanted to ensure proper operation on the side-looking port, as well. This mainly consisted of checking that the GHOST operations software was properly accounting for the additional reflection produced by the tertiary (science-fold) mirror and producing the correct coordinate transformations and ADC corrections, among other things. With some minor tweaks, GHOST worked successfully on the side-port.

The team used the prototype optical fiber cable for this round of Cassegrain unit testing. The science optical fiber cable is nearing build and test completion. Upon completion, the cable and Cassegrain unit build team (the Australian Astronomical Optics Group at Macquarie University) will ship these components to the spectrograph build team at the National Research Council Herzberg in Victoria, Canada, where they will be paired with the spectrograph for testing in the second half of 2019. The Australian National University team, along with a contractor, Software Design Ideas, is providing the instrument control and data reduction software for GHOST; they were also instrumental in the November Cassegrain unit testing, as were Gemini project team members from both North and South sites.

SCORPIO Update

At the end of February, Southwest Research Institute (SwRI) hosted a progress meeting in San Antonio, Texas, to assess the maturity of the SCORPIO project's Critical Design Review (CDR) documentation set. SwRI has provided Gemini with drafts of the Critical Design documents and the team continues to work on providing additional structural and thermal analysis required for the review. A readiness assessment will take place at the beginning of April. The project has now received the instrument's four science grade visible detectors.

Gemini staff contributions

News for Users

A summary of news events throughout 2019 of relevance to the Gemini user community.

JANUARY 2020

DRAGONS First Public Release

After many years in the making, it is with great excitement that we announce the first public release of Gemini's new Python-based data reduction platform, ***DRAGONS*** (Data Reduction for Astronomy from Gemini Observatory North and South). DRAGONS' capabilities were vital in enabling scientists to quickly reduce data critical to observations of the interstellar Comet C/2019 Q4 (Borisov). ***Click this link*** to access a related article for more details; also see Science Highlights in this issue starting on page 27.

2020 Large and Long Programs Call for Proposals

Gemini Observatory announces opportunities for new Large and Long Programs. Eligible Principal Investigators (PIs) from Canada and the US are invited to propose scientific investigations to begin observations in Semester 2020B. Large and Long Programs either require significantly more time than a partner typically approves for a single program or extend over two to six semesters, or both. Eligible PIs are also invited to submit Large and Long Program proposals for Subaru Intensive Programs, via the Gemini-Subaru time exchange. Letters of Intent are required to be submitted no later than February 4, 2020, with complete proposals due April 1, 2020. Details on Large and Long Programs, the proposal process, and specifics on the 2020 proposal cycle are available on the ***Large and Long Program webpages***.

Gemini Short Surveys

Gemini staff would like to thank all of our user communities for the 694 replies to the Phase I, Phase II, End of Semester, and Phase III surveys over the year 2019. Such a massive response rate is invaluable to ensure we give useful support and deliver good quality data.

Every response is compiled and all comments read and reported, in an anonymous form, to all the Gemini staff. The most recurrent problems are identified and escalated to make sure they are addressed as soon as possible. For example:

1. Many people report that they are strongly irritated by the "Observations" and "Band 3" sections in PIT (more precisely, the way targets are entered, and requested time is defined). We took note of those comments, and used them to define the requirements for the new software tool that will handle Gemini proposals. Known as the new ***OCS Upgrades Program***, this tool is expected to be completed in 2023. On the other hand, a certain number of problems met by the proposers can be avoided by following ***this tutorial***.
2. A significant fraction of PIs who need further work on Phase IIs report that defining the observing sequences is too complex and often confusing. The biggest issues happen when an important modification needs to be made, like changing the choice of grating or the observing mode. Once again we will use these comments to determine how the future Phase II software will work. Meanwhile, we strongly recommend PIs contact their contact scientist (you can find their email in the Observing Tool) or to send a ***helpdesk ticket***.
3. We look for systematic complaints from PIs of programs using a given instrument or in a certain Band. This information helps greatly to determine the semester's schedule efficiently, make decisions on the number of future allocated programs, and manage blocks of scheduled instruments (such as GPI, GRACES, or GSAOI).

We are very pleased by the high satisfaction rate we are getting from the majority of our users, and by the warm comments of appreciation on the quality of our support work. This motivates us to continue to find creative ways to improve our work, and collaborate with the researchers that depend on Gemini for their science. We hope to continue to satisfy the scientific needs of the researchers of the Gemini community, and to fix the issues that are an obstacle to our common success.

Registration Open for 2020 Gemini Science Meeting in Seoul

Registration is now open for the Gemini Observatory 20th Anniversary Science Meeting, to be held in Seoul, Korea, June 21-25, 2020. Early registration at a discounted rate is available until February 28th. See the ***meeting website*** to register and submit your abstract!

OCTOBER 2019

Maunakea Access and Gemini North Shutdown

On July 15th, protesters blocked the Maunakea Access Road in an effort to prevent Thirty Meter Telescope construction equipment from moving to the Maunakea Astronomy Precinct. This action quickly precipitated a protracted stoppage of all observing atop Maunakea, as observatories assessed the safety and reliability of access to the summit. By August 12th, we had received assurances of support from Law Enforcement and statements from the protestors of their intent to allow access for staff of the existing observatories. Combined with some improvements made to the "spur road" (a short segment of the old Saddle Road and a portion of a lava field) via which we now have to access the mountain, we returned to work on the planned maintenance shutdown (excluding coating of the primary mirror which has been deferred until next year). The maintenance was completed on August 30th, allowing a resumption of night-time observing and enabling the TEXES instrument to visit as scheduled. Access to the mountain remains intermittently compromised by conditions on the spur road in particular, but for now we are proceeding with operations.

Figure 1.

Assistant Engineer Mariah Birchard (left) and Senior Electronic Technician Alejandro Gutiérrez (right), work on the maintenance of one of the modules of the Acquisition and Guiding Unit.

Credit: Manuel Paredes

Gemini South Annual Shutdown a Success

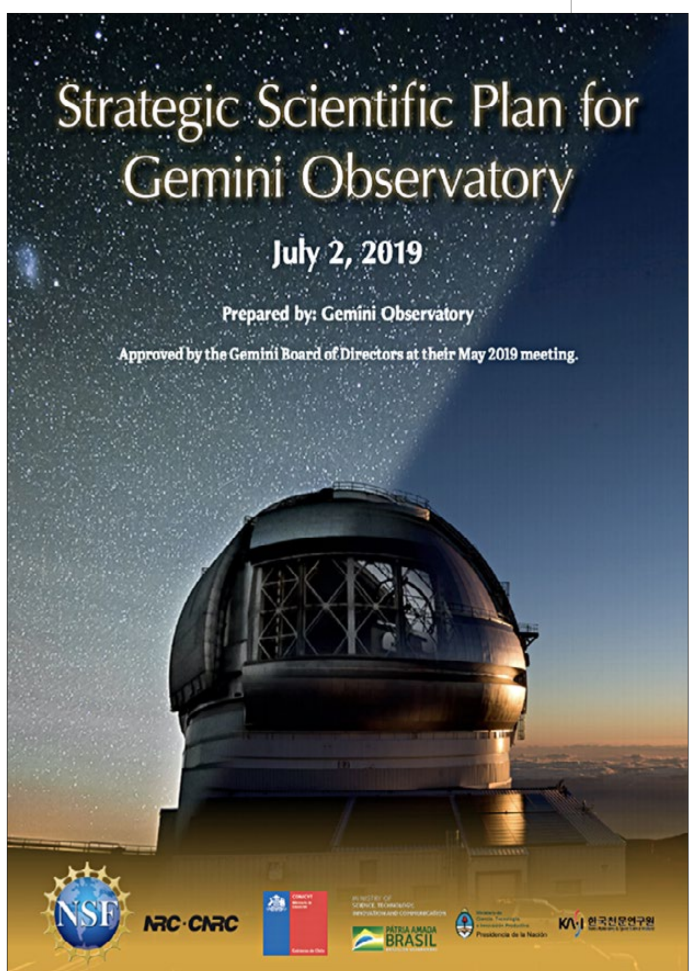
A successful annual shutdown at Gemini South ran from August 12th to August 27th. Accomplishments during this shutdown included replacement of the Cassegrain rotator encoder, repairs to the helium lines, and maintenance of the Acquisition and Guidance Unit (Figure 1). In the spirit of sharing resources ramping up to the National Science Foundation's Center for Optical-infrared Astronomy (NCOA), we had some excellent support from a few Cerro Tololo Inter-American Observatory technicians, doing cross-training and knowledge sharing and tightening relationships.

Strategic Scientific Plan

The ***Strategic Scientific Plan*** (SSP; Figure 2), approved by the Gemini Board of Directors during their most recent meeting, outlines the scientific direction and activities of the Gemini Observatory in the 2020s. It also provides a timeline for the Observatory's major instrumentation and operations development efforts. The motivation for the SSP is to ensure that Gemini remains at the forefront of ground-based optical/IR astronomy and best serves the needs of our international user community throughout the coming decade. We encourage all of our users to have a look and see where Gemini is headed!

Figure 2.

Cover of Gemini's Strategic Scientific Plan, approved by the Gemini Board of Directors.



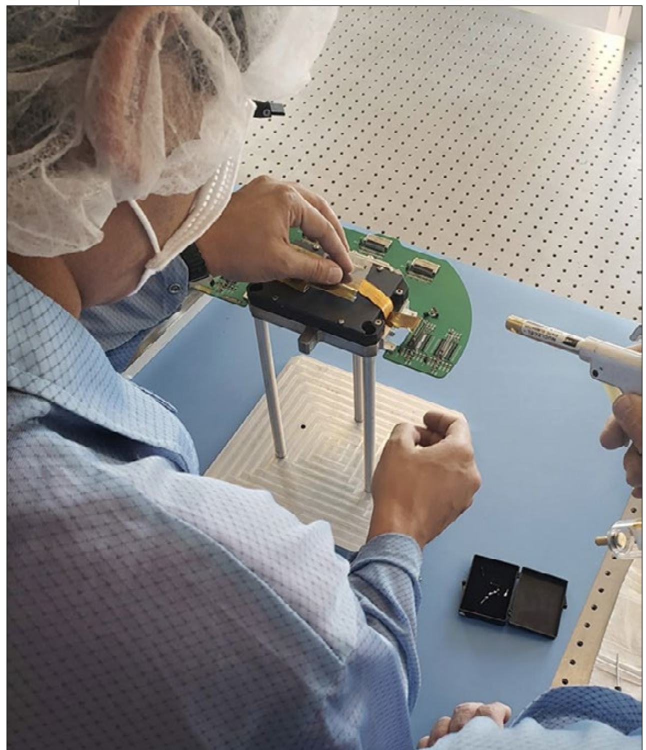


Figure 3.

Gemini North engineer John White working on the CCD focal plane array just prior to replacing the electronics board.

Credit: Luc Boucher

GMOS-South CCD Intervention

The Gemini Multi-Object Spectrograph (GMOS) at Gemini South has, for some time, suffered from instabilities in the charge-coupled device (CCD) readout. Since the installation of the Hamamatsu CCDs, they have been performing sub-optimally. In particular, we have seen instances where the charge transfer efficiency became too large, causing smearing on the images, which affects the popular Nod & Shuffle mode of the instrument. We have been planning to tackle this issue by changing the existing electronics board inside the cryostat with one of a better design. This design has been proven to work for the GMOS instrument at Gemini North, which does not experience the same smearing effect. The critical and very sensitive intervention was carried out in June (Figure 3). The technical intervention went very well, and the lab tests quickly showed very promising results. GMOS-S was put back in normal operation and the effect of charge smearing has not been seen again. The CCD array performs to specification.

Gemini Planet Imager Temporarily in Lab for Testing

Recently the Gemini Planet Imager developed a problem with its Micro-Electrical Mechanical System deformable mirror. Investigations in the lab have indicated that a critical electronics board related to the power supply has failed. Repairs are underway, and in the meantime, the instrument will remain in the lab and unavailable for science.

Figure 4.

Gemini staff share information with CASCA participants in the June meeting in Montréal.

CASCA 2019 meeting in Montréal

Gemini staff participated in the 2019 CASCA (Canadian Astronomical Society/Société Canadienne d'Astronomy) meeting in Montreal, which was held at McGill University from June 17-21 (Figure 4). Besides hosting a booth in collaboration with the Canadian Gemini Office (Stéphanie Côté, Joel Roediger, and Tim Davidge), we were available to directly work with many users who had Phase I, Phase II, and data reduction questions. Scot Kleinman also presented a talk about the future role of Gemini in the Time-Domain Astronomy era. We thank McGill University for organizing a successful meeting, and we look forward to meeting with everyone again at York University, in Toronto, next year.

Gemini North Primary Coating During Shutdown

The Gemini North primary mirror will get a new coat in the course of an extended mid-year shutdown, which is scheduled to start on July 23rd. The same coating recipe will be used as is currently on the mirror, which comprises four distinct layers deposited by sputtering different magnetron targets. Closest to the glass substrate, a 65-Ångstrom (Å)-thick layer of nickel chromium (NiCr) acts as an adhesive layer between the glass and the overlying reflective silver layer. The silver is sputtered onto the NiCr, at a much greater thickness of 1100 Å. Next a wafer-thin layer of NiCr is sputtered on top of the silver; with a thickness of only 6 Å. Finally, an overcoat of silicon nitride is applied by sputtering a boron doped silicon target with nitrogen process gas. The thin NiCr appears to facilitate the growth of a dense and protective silicon nitride layer, and slows any corrosion. The current coating has lasted well, but at six years since the last coating, it's time to replace it.

Other jobs in the shutdown include replacing and upgrading the helium supply hoses in the Cassegrain wrap, replacing the glycol coolant hoses, and some instrumentation work, including dealing with a bubble in the oil interfaces in the Gemini Multi-Object Spectrograph lens system.

APRIL 2019

GEMMA-TDA Advisory Group Assembled

Guided by a Gemini Science and Technology Advisory Committee action regarding time-domain astronomy (TDA) and multi-messenger follow-up, we have assembled a representative team of astronomers from across the Partnership to advise us on our developing plan for TDA. This advisory group, chaired by Abhijit Saha of the National Optical Astronomy Observatory (NOAO), has had two meetings as of early March.

The members are: Abhijit Saha (US; NOAO) - Chair; Andres Jordan (CL); David Sand (US); Basilio Santiago (BR); Meg Schwamb (Gemini); Federica Bianco (US); Myungshin Im (KR); Maria Drout (CA); Craig Heinke (CA); Victoria Alonso (AR); Alexander Vanderhorst (US); and Andy Adamson, Bryan Miller, and John Blakeslee (all Gemini, in attendance).

Not all of the members of this time-domain advisory group work on time-domain science; the mission of the group includes protecting the completion of non-TDA programs in the coming Large Synoptic Survey Telescope era when we expect to have an increased number of Target of Opportunity proposals. We are grateful to Abi and the group for helpful commentary to date.

TOPTICA Laser: Available Every Night!

With a fully commissioned TOPTICA laser, we are back in operation for Laser Guide Star (LGS) mode at Gemini North. The 19A semester will be a "transition" period from scheduled laser blocks to a fully-integrated LGS queue operations model. This will allow for LGS programs to be observed on any night when conditions allow, giving Gemini Principal Investigators access to LGS adap-

Figure 5.

Gemini Science Operations Specialist Michael Hoenig (back) and Gemini Senior Laser Technician Jeff Donahue discussing LGS operations for the TOPTICA laser in the Gemini Base Facility Control Room in Hilo.

Credit: Jeff Donahue

Figure 6.

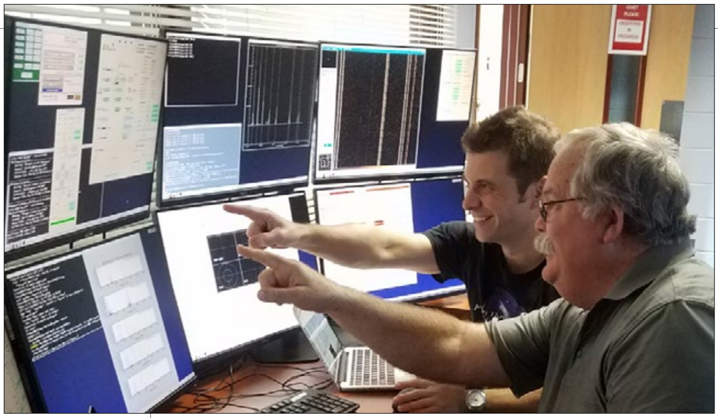
The NGS2 unit on the test bench in La Serena. The high-speed EM CCD camera is on the left-hand side. The orange lines are fibers to mimic multiple guide stars that are imaged onto the detector.

Figure 7.

The NGS2 test team, from left to right: Cristian Moreno, Mariah Birchard, Gaetano Sivo, Brian Chinn, François Rigaut, Ian Price, Ignacio Arriagada, Pedro Gigoux, Natalie Provost, Gianluca Lombardi, and Eduardo Marin. René Rutten is on the business end of the camera.

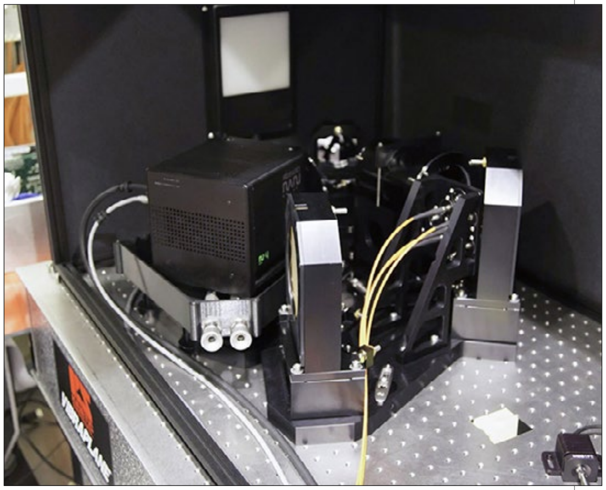
Credit: René Rutten

tive optics observing throughout the semester (Figure 5).



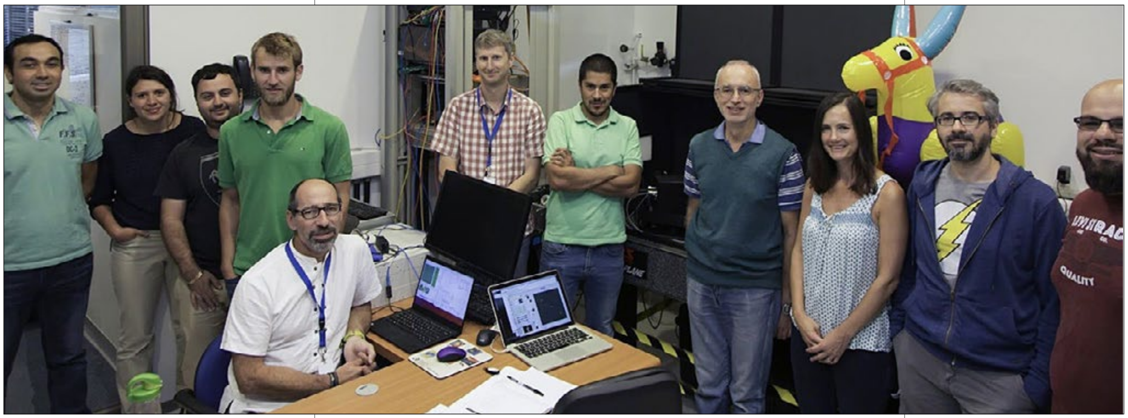
The Next Generation Natural Guide Star Sensor for GeMS

Gemini South's multi-conjugate adaptive optics system provides for an adaptive optics (AO) corrected field of about one arcminute. To achieve this important capability, the system relies on a constellation of five laser guide stars and up to three natural guide stars in order to sense and correct for atmospheric turbulence. The original design of the natural guide star sensor has been in operation now for several years. It is based around three mechanical probes picking up stars in the field. Each probe channels the light onto optical fibers leading to avalanche photodiodes for fast centroiding. Unfortunately, the sensitivity of this system leaves much to be desired, and the mechanical arrangement is complex in operation.



Therefore, some years ago, Gemini entered into a collaboration with the Australian National University (ANU) to develop a better system designed around the now available high-speed Electron Multiplying (EM) CCD cameras. Using an EM CCD imager will result in much improved sensitivity. The moving probes will no longer be necessary, as the full patrol field will be imaged onto the CCD, while regions of interest around the selected stars will be read out at high speed to provide centroiding information to the AO real-time control system. This results in much simpler acquisition procedures, and achieves much better sky coverage, since fainter stars will become accessible.

In February a major milestone was achieved on this project. The system developed by ANU arrived in La Serena, Chile, where it was installed on a test bench and integrated with the AO real-time control system (Figures 6 and 7). The results have been excellent, proving that the system will work as designed. Much work remains to be done. Integration of the new system, named "NGS2," in the existing multi-conjugate AO system will not be a trivial task. If all goes well, we expect to do this early in Semester 2019B.



Semester 2018B Outcomes

We're now in the thick of Semester 2019A and taking stock of the outcome of 18B. Preliminary completion results for programs in the regular queue (in other words, excluding Targets of Opportunity and block-scheduled instrument modes) are shown in Figure 8. Band 1 programs at both sites fared rather well, three quarters of them reaching 100% completion. In the North, Band 3, which typically takes the more relaxed observing conditions, fared relatively worse — another reflection of the fact that 18B was better than either of the preceding B semesters in Hawai'i.

In the South, the completion rate was better than it has been for many semesters, thanks to a healthy percentage of stable, good conditions despite the loss of five nights to a major earthquake in January 2019. Note that in 18B we took data on the last of the traditional "rollover" programs; from now on, regular queue Band 1 programs (except Target of Opportunities, Fast Turnaround, Director's Discretionary, and Large and Long Programs) have one semester of "persistence," and so some of those will continue to accumulate data as we continue into 2019A.

Gemini North Survives Wild Weather

As we reported in our recent e-newscast, on February 10, 2019, a low-pressure system (Figure 9, next page) subjected Maunakea to some of the highest wind speeds ever recorded. While there's reason to be skepti-

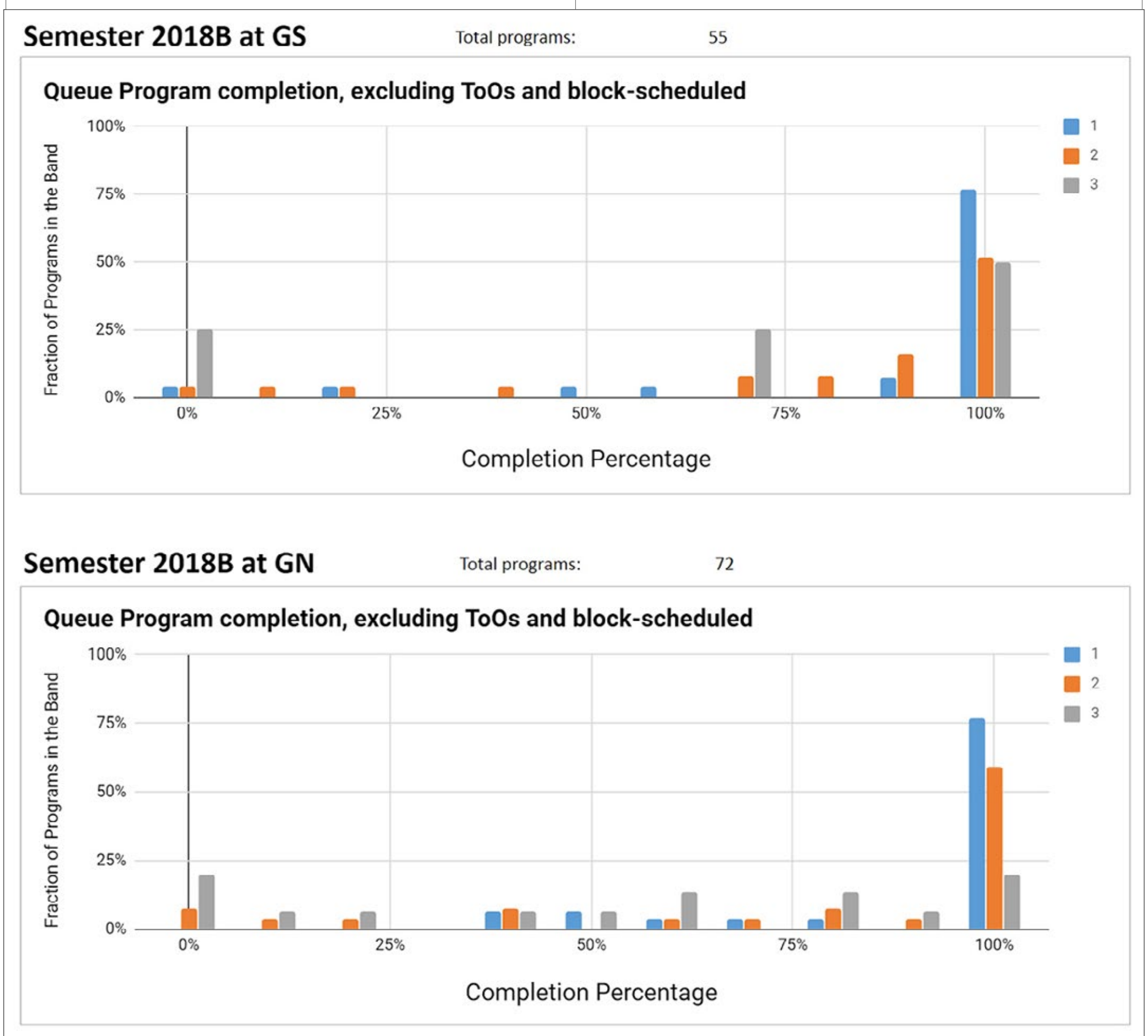


Figure 8.

For Gemini South (upper) and Gemini North (lower) the completion histogram for Semester 2018B. Horizontal axis shows the program completion in 10% bins, and vertically the colored bars show the fraction of programs in Bands 1, 2, and 3, which reached that completion percentage. Main features are described in the text.

Credit: Andy Adamson

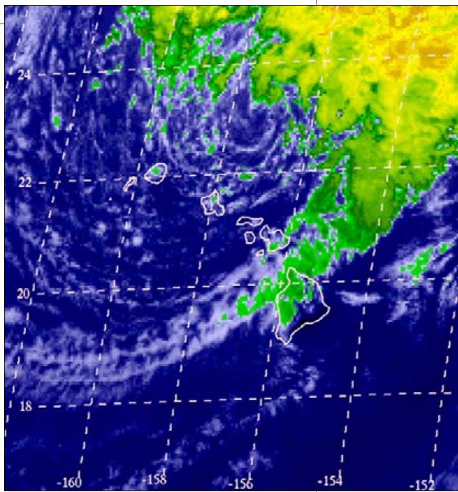


Figure 9.

The low-pressure system to the north of the Hawaiian Islands, on February 10, 2019, Hawaiian Standard Time. The circulation center is clearly visible in the lower-level cloud pattern (in grey). Image taken from the [MKWC satellite archive](); go there and select 11-Feb UTC to see animations.

cal of the widely-reported peak gust speed of 191 miles per hour (mph), winds in excess of 150 mph (just below Category 5 Hurricane force) were reliably recorded on the summit on that day (Figure 10).

Winds of that speed at this elevation, pushing on a structure of the scale of the Gemini dome, is sufficient to produce a force of around 280 tons sideways. The Gemini telescope facility is rated to survive such winds with no distress to materials or structure. Even somewhat stronger winds of order 160 mph would not threaten the structure, as deformations would remain below the elastic limit. However, at 200 mph, significant failures would be expected. The recent additions to the support building, namely the many solar panels and base-facility operation environmental sensors, were designed to the same wind speed standard as the rest of the building, and all survived the wind event intact and remained functional.

This wasn't a particularly unusual storm system; it was a "Kona low," a low-pressure system which usually settles to the west of the islands (hence the name) but which this time was to the north. To put the wind speeds in perspective, an extreme winter storm on Mount Washington in New Hampshire, USA, in 1934, produced a wind gust of 231 mph, and in 1996 Cyclone Olivia produced a wind gust of 253 mph, setting a new world record.

Observations

STN	DATE HST	TIME HST	TEMP °C	DPNT °C	RH %	WSPD mph	PK WSPD mph	WDIR dir	PRES mb	RAIN mm	PW mm	Seeing arcsec	Road Condition	Trends
UH88	--	--	--	--	--	--	--	--	--	--	--	--		--
CFHT/GEM	02/10/19	16:43	-7.4	-8.1	96	124	161	SW	596	T				Meteogram
UKIRT	02/10/19	16:38	-7.0	-7.8	95	46		WSW	596				Dry	Meteogram
IRTF	02/10/19	16:43	-7.9	-8.8	94	0	0	N						Meteogram
SUBARU	02/10/19	16:39	-7.3	-8.1	95	0	0	SSW	603	0				Meteogram
KECK	02/10/19	16:42	-6.7	-6.9	98				601					
JCMT	02/10/19	16:38	-7.0	-9.2	86	145		S	606					Meteogram
SMA	--	--	--	--	--	--	--	--	--	--	--	--		--
VLBA	02/10/19	16:03	-2.9	-3.0	99	4	8	WSW	637	0				Meteogram
HP	--	--	--	--	--	--	--	--	--	--	--	--		--
UNITS	UTC | HST		°C | K | F		%	mph | Kts | mps		dir	mb	mm	Tau | mm	arcsec		

Wind Field

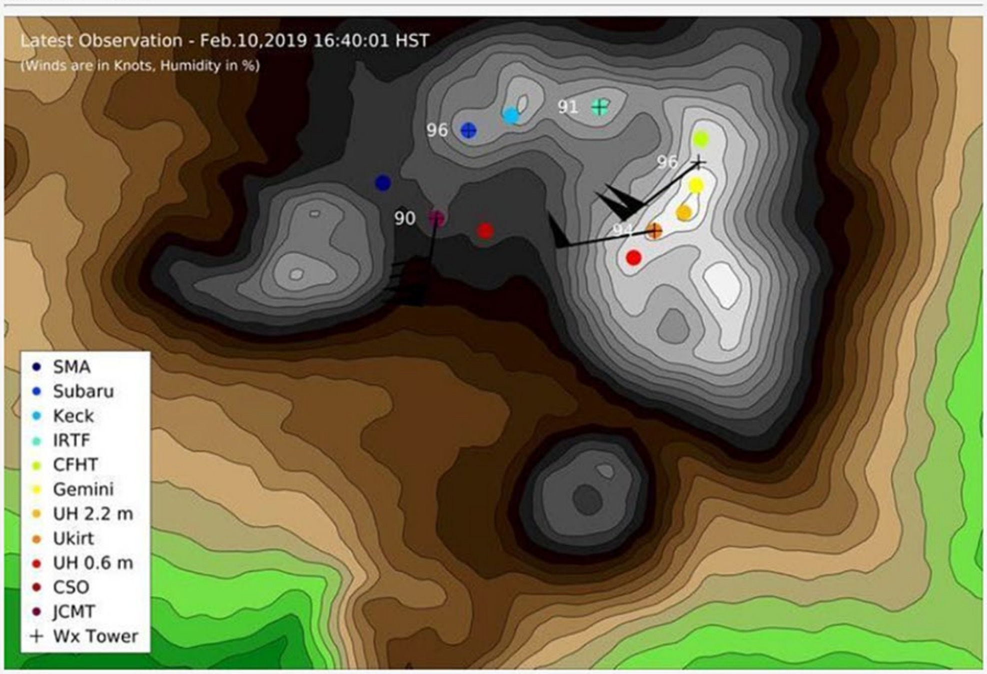


Figure 10.

Top panel: The CFHT/ Gemini observed weather data from the [Maunakea Weather Center site](), at the time (16:43 HST) of the highest gust experienced there — 161 mph (top row, middle, red). Bottom panel: This screenshot from the Maunakea Weather Center shows a wind speed of 96 knots (110 mph) recorded by the CFHT/Gemini weather tower on February 10th at 16:40 HST (bottom frame).

Manuel Paredes and Alyssa Grace

Gemini Outreach Programs Sparkle in Both Hemispheres

Gemini's two leading public outreach endeavors — AstroDay Chile *and* Journey Through the Universe *continue to uphold one of Gemini's primary missions: to share the wonders of the Universe with the public.*

Astroday Chile *2019: Preparing our host communities for the July 2nd Total Solar Eclipse*

With excitement mounting over the upcoming July 2nd total solar eclipse over La Serena, Chile, *AstroDay Chile* on March 23rd was primed to educate its ~3,000 visitors about this special event. Held at the Seminario Conciliar School of La Serena, the program provided educational material and talks about the eclipse, and taught participants how to view the partial phases safely (Figure 1). Numerous other activities and exhibitions were also featured. To help make *AstroDay Chile* 2019 a success, 23 organizations joined in on the excitement of bringing astronomy to the people.

Coordinated by Gemini South's Public Information Office, the event offered to students, families, and the public, a wide variety of activities, such as science workshops, lectures, 3D cinema, water-rocket launches, solar viewing, and portable planetarium presentations.

Two key partners helped organize this year's event: the Association of Universities for Research in Astronomy (AURA), and the Municipality of La Serena. All of the major observatories in Chile — including the European Southern Observatory (ESO), ALMA, and Las Campanas — and most of the astro-tourist facilities in the surrounding Coquimbo Region also united to participate in this year's program.

The images shown on page 70 illustrate some of the the activities of the day.

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Figure 1. *Families took advantage of* AstrodayChile’s *special solar-viewing event to learn how to safely observe the total solar eclipse on July 2nd in the Region of Coquimbo.*

Figure 2. *A mother helps her kids inject air into a water rocket for an amazing lift off! This workshop was the one most preferred by children and adults during* AstroDay Chile.

Figure 3 (left). *After sunset, many participants formed lines to see the Moon and stars through telescopes supplied by local amateur astronomers and the Cerro Tololo Inter-American Observatory. Through their kindness and help, AstroDay fulfilled its promise to share the wonders of the Universe.*

Figure 4 (right). AstroDay Chile *was a good venue for the AURA staff to work together in outreach activities. Seen here, from left to right, Gemini Electronics Engineer Vanessa Montes, and Kathy Vivas and Cesar Briceño (both astronomers from Cerro Tololo Inte-American Observatory, interact with the public to explain the science and technologies that AURA centers currently apply in Chile.*

Figure 5. *The Gemini/AURA booth was one of the most visited, thanks to the help of the kids from the Gemini Robotics Club. They in turn explained to children how robotics can be used to control remote systems, such as the one that controls the Base Facility Operations at Gemini South.*

Credit: All photos on this page by Manuel Paredes

Journey Through the Universe: *Hawai'i 2019*

The 15th year of *Journey Through the Universe*, Gemini Observatory's flagship education and outreach program, brought astronomy professionals from Maunakea and across the nation into Hawai'i island classrooms, visiting thousands of students — one classroom at a time (Figures 6-11). The diverse group of astronomers, scientists, engineers, and informal educators provided an authentic and personal window into the process of scientific discovery and the splendors of our Universe.

During *Journey* "week," which began on March 2nd, 80 astronomy educators shared their passion for science with approximately 8,000 students. *Journey* as a year-round program also includes StarLab Portable Planetarium shows for grades K-1, career panel presentations for high schoolers, astronomy educator workshops, Lunar and Meteorite Sample Certification workshops hosted by NASA's Solar System Exploration Research Virtual Institute team, Family Science Night, and a public presentation on recent discoveries from the telescopes on Maunakea.

Updates on what *Journey* is accomplishing in the community can be ***viewed here***.

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Figure 6. *Hilo-Waiākea and Ka'ū-Kea'au-Pāhoa Complex Area Superintendent Chad Farias speaks about the success of* Journey *in the community and its future.*
Credit (all Journey *photos): Joy Pollard*

Figure 7. *Two students learn about robotics provided by the Hawai'i Science and Technology Museum at* Journey's *Family Science Night.*

Figure 8. *Science Operations Specialist, Jocelyn Ferrara (far left) uses an 8-meter tarp in the classroom to model the size of the primary mirror in the twin Gemini telescopes.*

Figure 9.
Digital Architect, Jason Kalawe (standing) discusses careers and career diversity at the Maunakea observatories with local high schoolers.

Figure 10.
Science Fellow, Matt Taylor (fourth from the right), uses a large scale interactive model to show students the relationship between actual distances to stars and perspective.

Figure 11.
Assistant Astronomer, Trent Dupuy (left), helps students understand the scale of star sizes by making paper models.

Alison Peck

Papa ʻŌlelo Hawaiʻi Kilohōkū*

Astronomers in Hawaiʻi have long embraced Hawaiian culture and traditions, including finding ways to include them in the naming of astronomical discoveries. Now, through a new exciting program, hosted in part at Gemini Observatory, Observatory staff are on their way to better understanding the history and culture that shape the communities in which they live.

Figure 1.

Kaʻiu Kimura, Executive Director of ʻImiloa, speaking to 2,000 astronomers and students at the January 2019 American Astronomical Society meeting in Seattle, Washington.

Credit: ʻImiloa Astronomy Center

One of the many wonderful aspects of living in Hawaiʻi is the strong sense of history and culture that makes these islands unique. Learning more about this culture and how it has shaped the communities we live in is an important goal for most observatory staff, whether they grew up here, have become long-term residents, or are making the most of a short-term position, like an internship or postdoctoral fellowship. In addition to everyday life in the community, we can see the ʻano nui (importance) of Hawaiian culture through novel astronomy programs such as A Hua He Inoa, a Hawaiian phrase that refers to the practice of calling forth a name. This collaborative naming project, led by the ʻImiloa Astronomy Center in Hilo, Hawaiʻi, includes experts in Hawaiian culture, language, and astronomy and aims to weave traditional culture and practices into the process of officially naming astronomical discoveries. In January 2019, Kaʻiu Kimura, Executive Director of ʻImiloa, was invited to give a lecture about the program at the January 2019 meeting of the American Astronomical Society in Seattle,

* *Hawaiian language lessons for astronomers*

Washington, which attracted an audience of more than 2,000 astronomers and students.

But not only astronomers work at the observatories, of course. There are engineers, technicians, librarians, accountants, educators and more, many of whom were born here in the islands. Many observatory staff have the opportunity to hear ʻōlelo Hawaiʻi (Hawaiian language) and oli (chants) through their children, who learn about important traditions and moʻolelo (stories) in school, but gaining a more in-depth knowledge and understanding requires a more concerted effort. That's why the ʻImiloa Astronomy Center recently joined forces with the University of Hawaiʻi at Hilo's (UHH) Ka Haka ʻUla O Keʻelikōlani College of Hawaiian Language to provide a weekly class on Hawaiian language and culture to staff from all observatories on Maunakea. The observatories paid the tuition for the 12 week course, and the participants purchased their own textbooks, which they kept after the classes finished.

and the UH Institute for Astronomy (both in Hilo and Mānoa on Oʻahu) registering, and attendance and enthusiasm remaining just as high throughout the semester.

In Hilo, the class met in the Lecture Hall at the Gemini North Base Facility, which is optimized for sound quality and ease of class participation. The class was streamed in realtime to sites in Waimea on the Big Island, Mānoa, and even one participant in Iowa, using videoconferencing technology that the observatories have in place to enable scientific collaboration. Although this undertaking was technically challenging at first, after a few learning experiences on the part of the organizers, the class was transmitted smoothly to all sites.

The organizers also recorded each class and made them available to all participants, so that they would not miss anything if they could not attend. This was all made possible by the outstanding skill of kumu (teacher)

Figure 2.

Maunakea observatory staff preparing for the Merrie Monarch parade in April. The Merrie Monarch is a week-long festival that honors the legacy of King David Kalākaua, who inspired the perpetuation of Hawaiian traditions, native language and arts.

Credit: East Asian Observatory

The first class was a bit experimental, as it was difficult to gauge how many people would be able to attend the class every Friday lunchtime, and how many would be able to make time to watch the recordings and practice the lessons on their own if they were traveling or on a night shift. Nevertheless, participation was outstanding with over 100 staff from Maunakea Observatories

Kamalani Johnson (UHH), and his willingness to embrace not only the challenges of distance learning, but also an unusual set of haumāna (students) from all over the globe and all types of jobs, from scientific research and education, to engineering, computer support, and administration. With participants from diverse backgrounds, all levels of proficiency in ʻōlelo Hawaiʻi, and

Figure 3.

Haumāna Alyssa Grace (left) and Jocelyn Ferrara (middle) present kumu Kamalani Johnson with a photo of the Maunakea observatories signed by several class participants.

Credit: Alison Peck (Gemini)

extremely varied personal and professional interests, one would expect that holding the attention of everyone in the class for 12 weeks would be a challenge. But Kamalani handled it with ease, dividing the class time between stories (legends, place names, traditions, hula) and grammar, vocabulary, and sentence structure.

Participants in the class said they looked forward to Friday lunchtime every week, and were quite sad when the course ended. We at Gemini Observatory are extremely grateful for kumu Kamalani Johnson and to Kaʻiu Kimura for their eagerness to lead this initiative, and especially for their willingness to work with the observatories on plans to continue providing these courses for observatory staff who are so grateful to have the opportunity to pursue their careers while also becoming more knowledgeable about the history and culture that shape the communities in which they are privileged to live and work.

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Gemini staff engage local Honolulu students in an infrared imaging activity at the January meeting of the American Astronomical Society at the Hawai'i Convention Center.

Credit: Joy Pollard/Gemini Observatory

NSF's National Optical-Infrared Astronomy Research Laboratory

AURA

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