*Gemini*Focus

Publication of the Gemini Observatory

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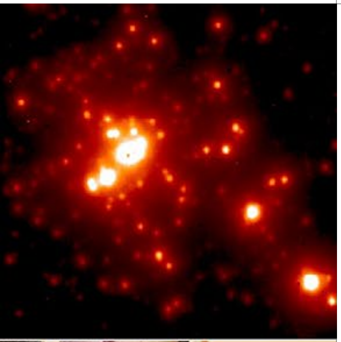

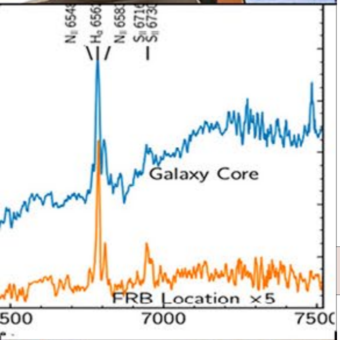

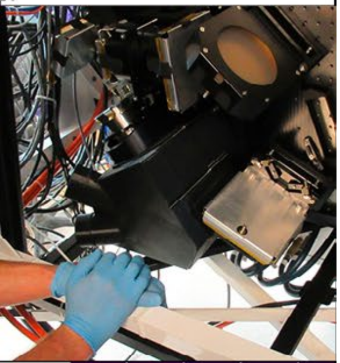

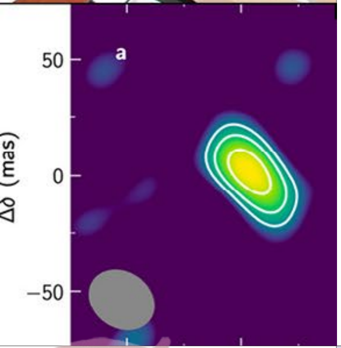

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ON THE COVER:

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 14.

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

Jennifer Lotz

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 ‘Alopeke 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, at 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***

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?

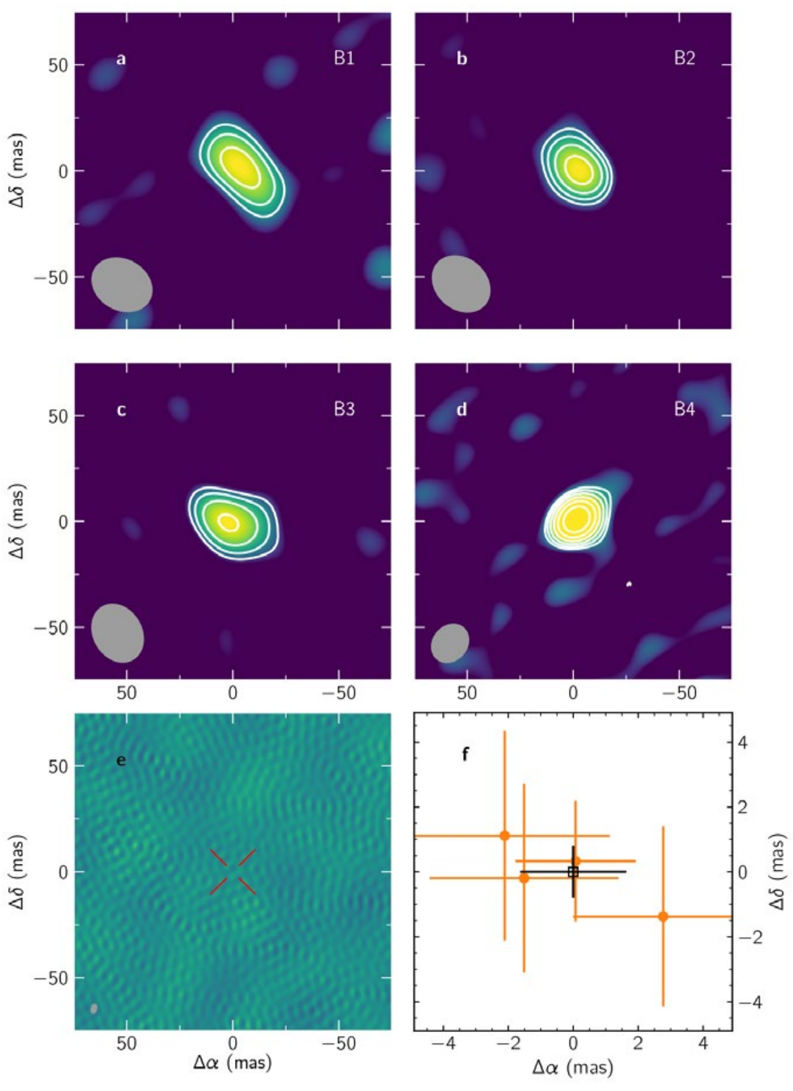

Figure 1.
The interferometric localization of FRB 180916.J0158+65 using the EVN. Panels a to d show the images of the four detected bursts. Panel e shows the continuum radio image of the field, where no significant persistent radio counterparts are reported. Panel f shows the derived positions for each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

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 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.

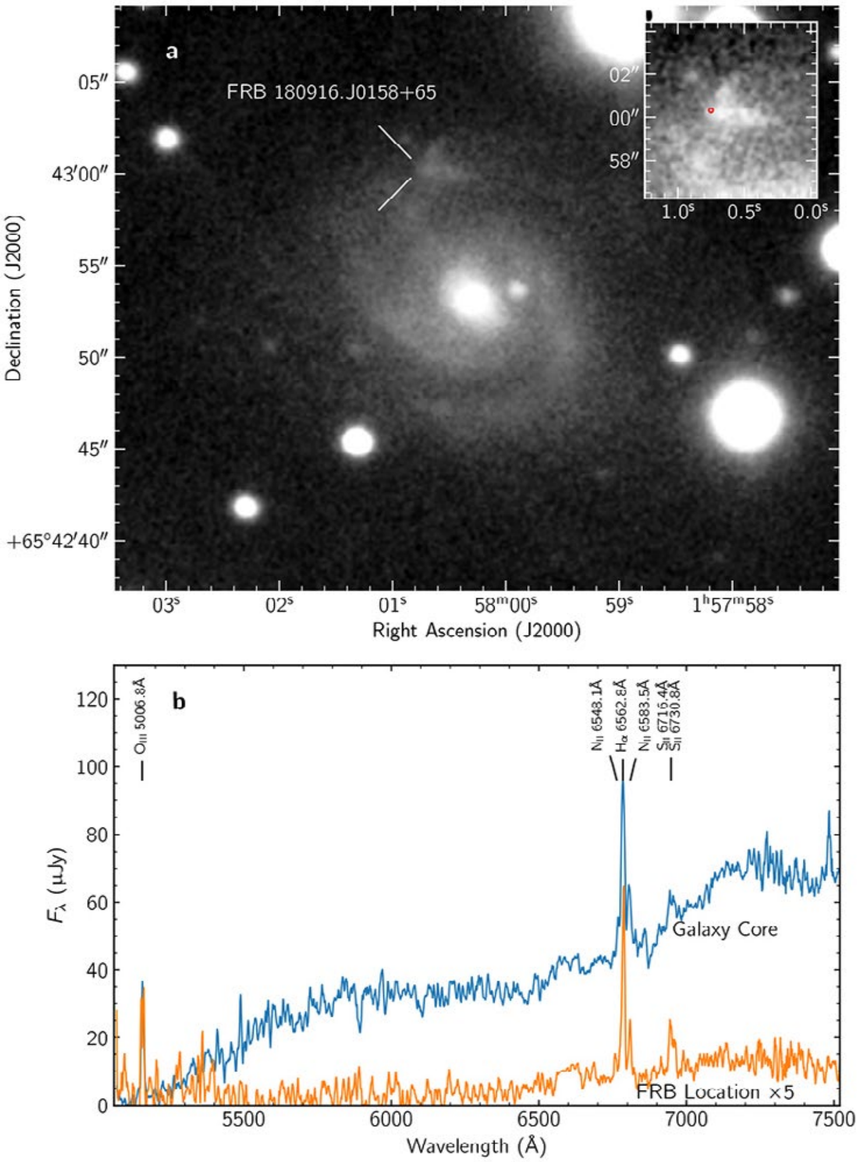

Figure 2.

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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John Blakeslee

Science Highlights

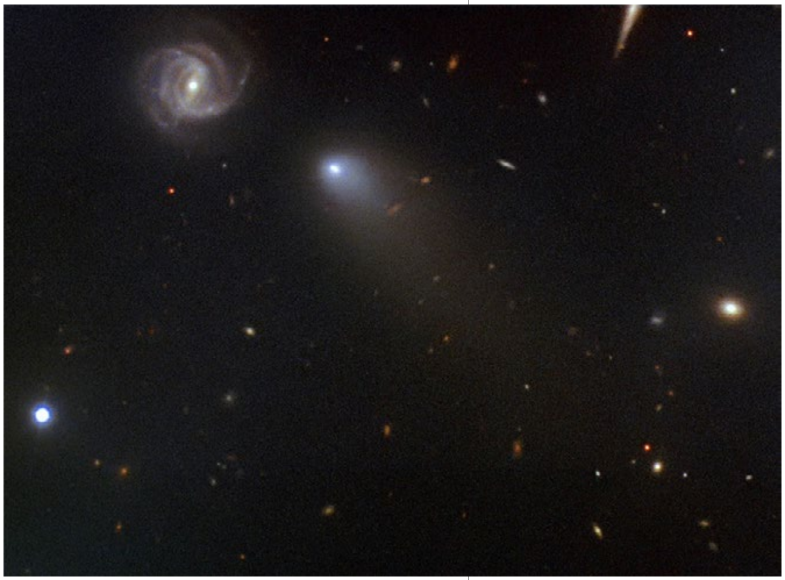
Gemini targets Comet 2I/Borisov with multiple instruments from both hemispheres; GPI bags additional debris disks in the Scorpius-Centaurus association; and Hubble *and Gemini collaborate on a close-up of a major cluster collision beyond redshift one.*

Gemini Tracks Comet 2I/Borisov from North to South

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 an existing 2019B Target of Opportunity program.

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



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***.

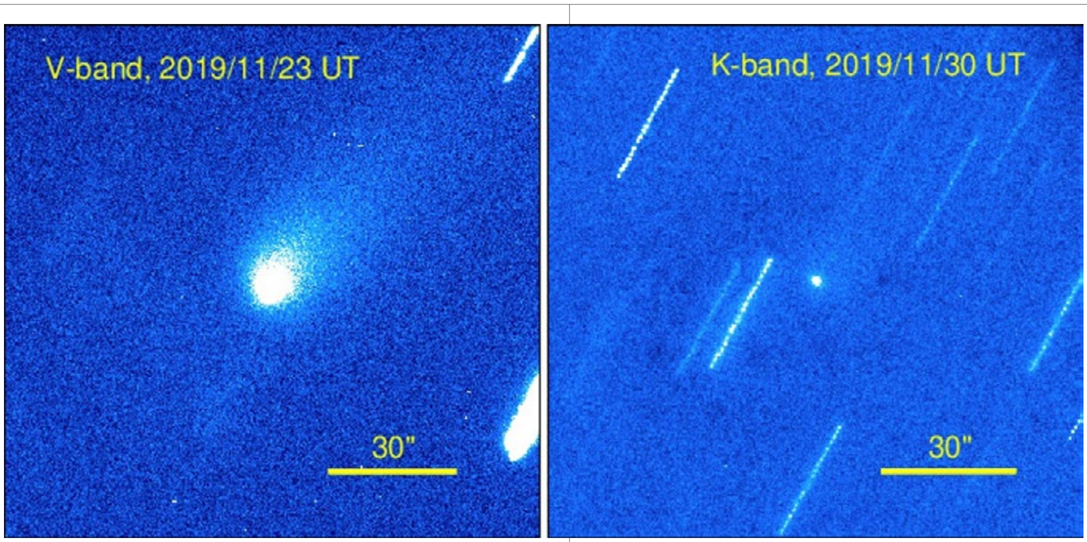


Figure 2.
Near-infrared K*-band image (right) of Comet 2I/Borisov taken on November 30, 2019, with FLAMINGOS-2 at Gemini South when the comet was 2.05 AU from the Sun, compared to an optical* V*-band image (left) taken a week earlier (when it was 2.12 AU from the Sun) at the Nordic Optical Telescope.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

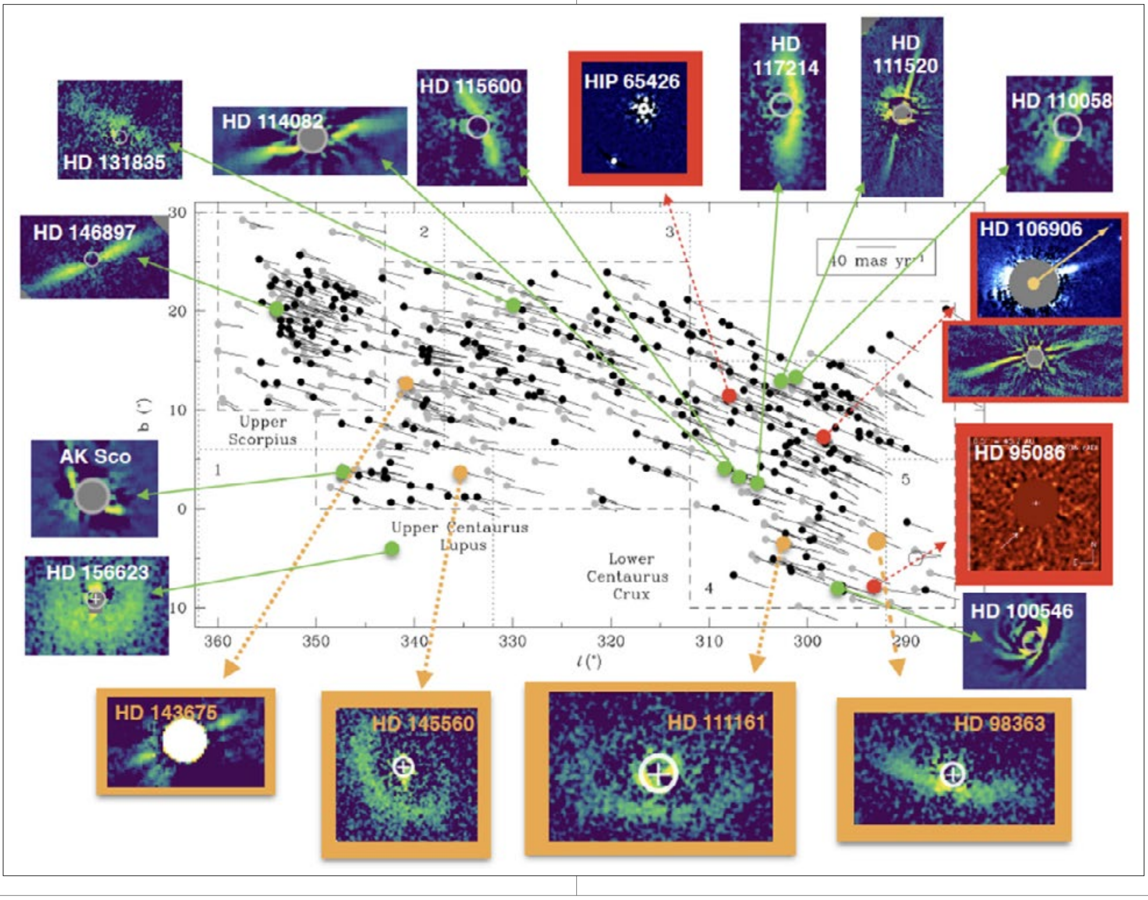


Figure 3.

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* 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.

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

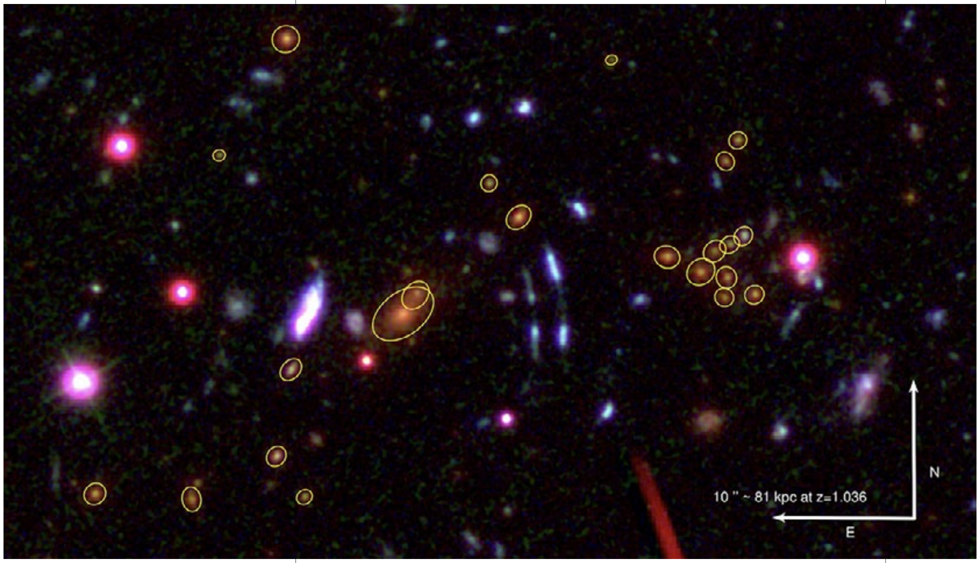


Figure 4. *Color composite image of the merging cluster SPT-CL J0356–5337 at z = 1.036, made by combining Gemini/GMOS-South g and i images with* Hubble*/ACS F606W. The yellow ellipses mark cluster members; several strongly lensed arcs are visible near the center of the field.*

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

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

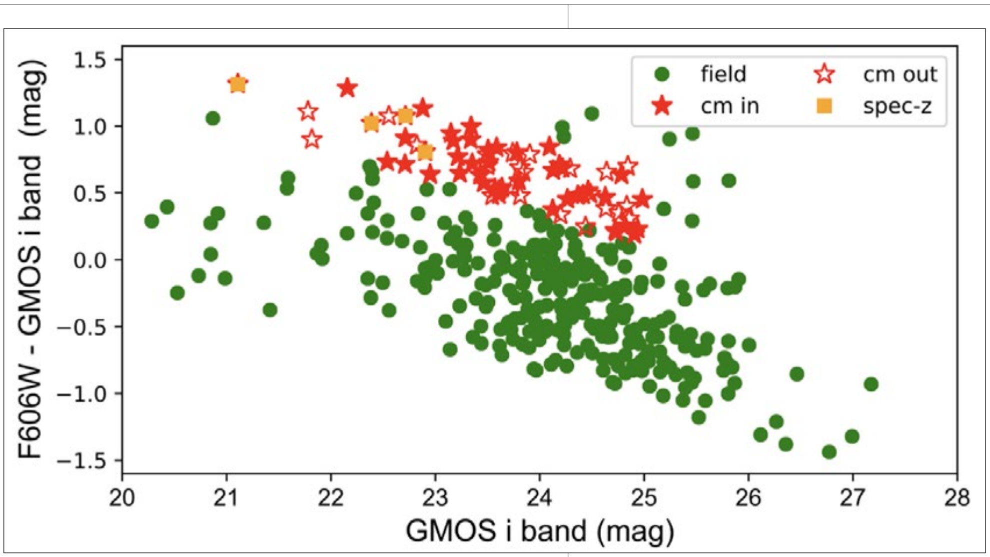


Figure 5.

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*

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***.

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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***.

On the Horizon

GHOST Acceptance Testing is extremely successful; Gemini South's Natural Guide Star Next Generation Sensor is incorporated into the Canopus optical bench and achieves official first light; and SCORPIO continues to make steady progress after five Manufacturing Readiness Reviews.

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.

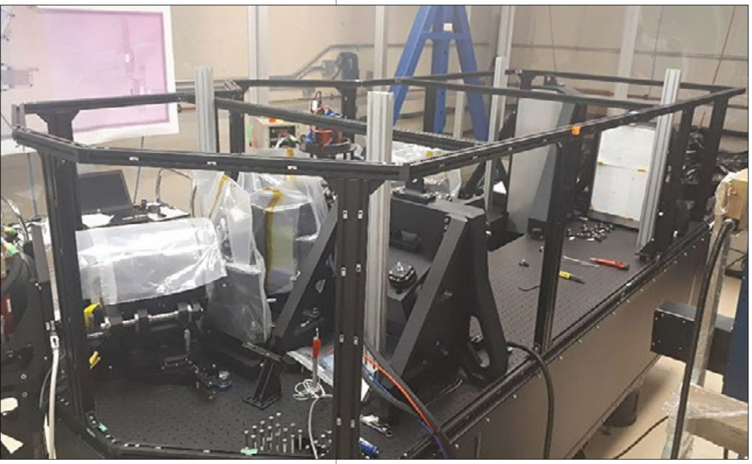


Figure 1 (top). *The GHOST spectrograph in the lab prior to the installation of the inner enclosure.*

Credit: NRC-HAA

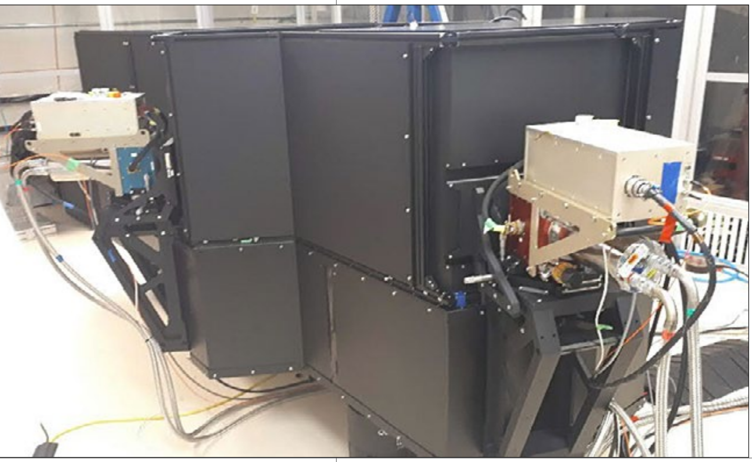


Figure 2 (bottom). *The GHOST spectrograph with inner enclosure and assemblies for blue and red detectors.*

Credit: NRC-HAA

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.

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.

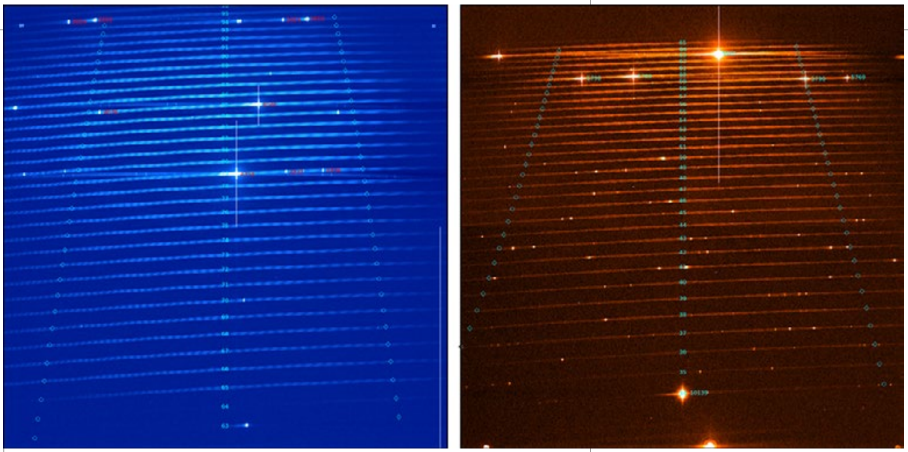


Figure 3.
Blue and red GHOST images of a mercury lamp, with the spectral orders labeled and 1.1 x free spectral range in each order highlighted. Continuous wavelength coverage from 359 nm to well beyond 1 micron (Requirement: 363 - 950 nm). Significant wavelength overlap between orders (with overlapping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

Credit: Greg Burley

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

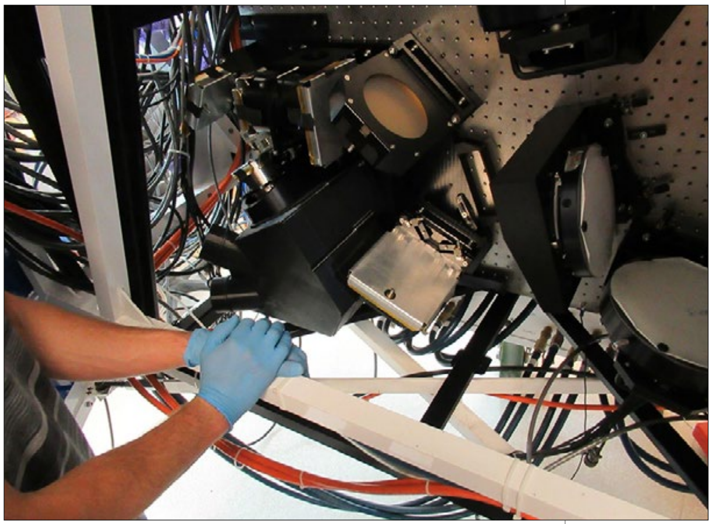


Figure 4.
The new NGS2 unit after installation into the Canopus optical bench.

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.

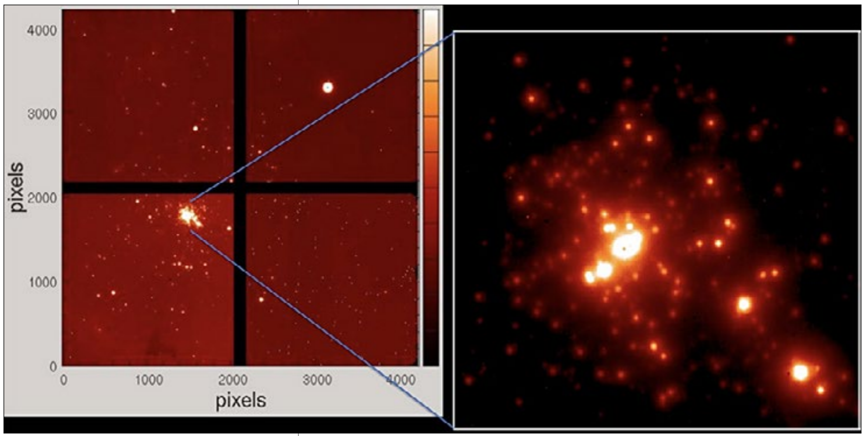
The NGS2 project has been made possible thanks to the tight collaboration between many people. The initiative, a large part of the funding, and the design and build of NGS2 was primarily done by a team at the Australian National University in collaboration with Gemini engineers and astronomers. Without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

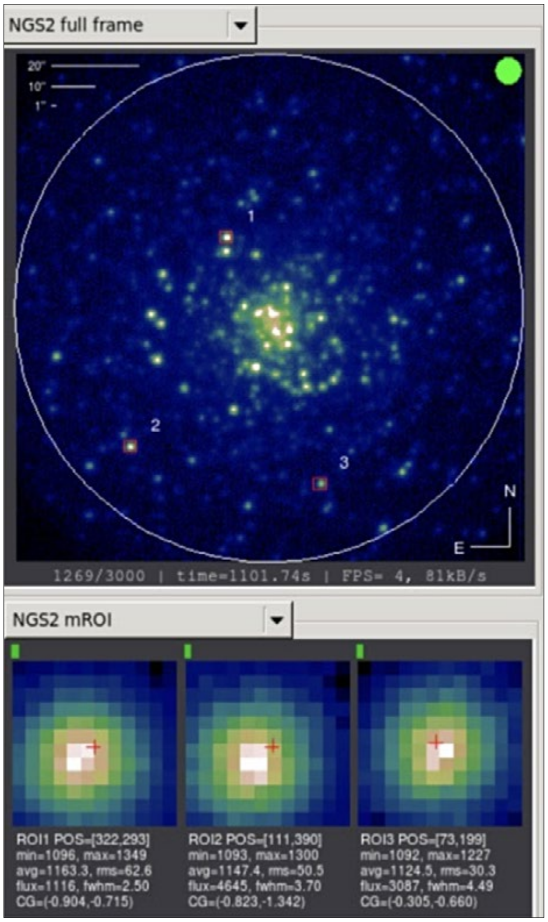
SCORPIO Making Steady Progress

With the exciting build phase of the Spectrograph and Camera for Observations of Rapid Phenomena in the Optical and Infrared (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 sev-

Figure 6 (bottom 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 (bottom 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.





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avg=1124.5, rms=30.3
flux=3087, fwhm=4.49
CG=(-0.305,-0.660)
```

eral 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 Electronics 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.

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

Gemini staff contributions

News for Users

The public release of Gemini's brand-new rapid data reduction pipeline DRAGONS is pressed into immediate action on a critical observation; Gemini announces the Call for Proposals for Large and Long Programs to start in 2020; and helpful responses to Gemini's Short Surveys point to a high satisfaction rate, while addressing the need to fix some remaining obstacles.

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 9.

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!

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

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

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