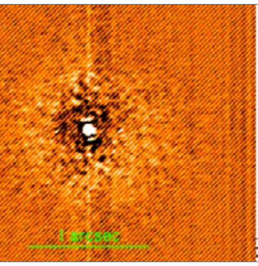
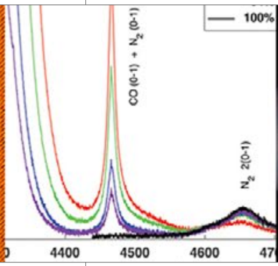
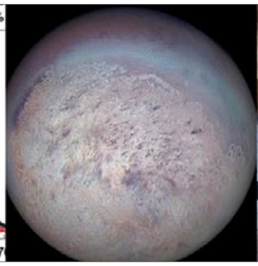
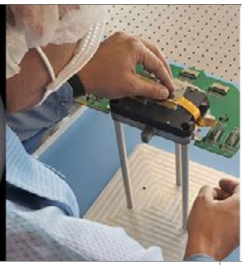
*Gemini*Focus

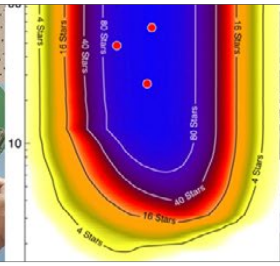
July 2019 Publication of the Gemini Observatory

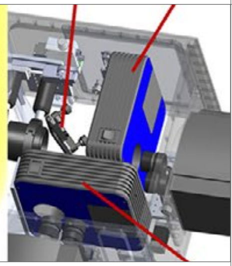








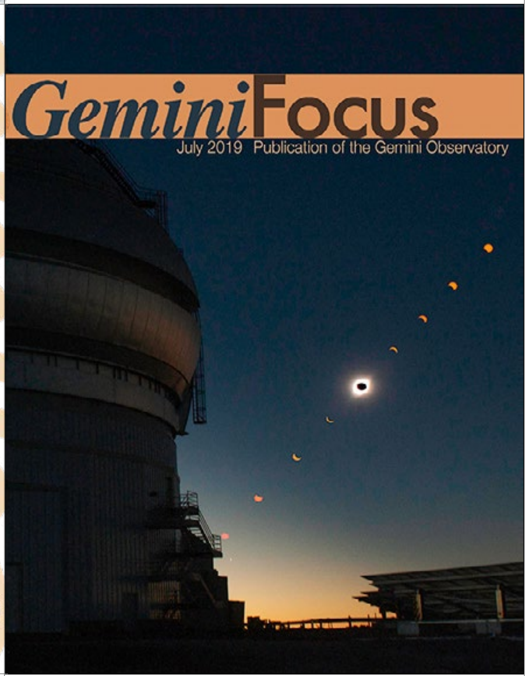




ON THE COVER:

On July 2, 2019, a total solar eclipse swept over parts of central Chile and immersed the Gemini South telescope in darkness for over two minutes. Gemini Public Information Officer Manager Peter Michaud was there to capture the eclipse sequence shown here with the Gemini South dome. Gemini South's Manuel Paredes compiled the images to make this composite for the issue's cover.

Credit: Gemini Observatory/AURA/Peter Michaud/Manuel Paredes



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Director's Message

Change is on the Horizon

Big changes are afoot for the Gemini Observatory Director, and Gemini Observatory as a whole. In preparation for the official start of the new joint venture between Gemini, the National Optical Astronomy Observatory (NOAO), and the Large Synoptic Survey Telescope (LSST) — currently known as the National Center for Optical-infrared Astronomy (NCOA) — I've recently relocated to Tucson, Arizona. In October, the first phase of NCOA will launch, and by October 2020, all of Gemini Observatory's staff will be part of the new center for National Science Foundation-funded ground-based optical/IR astronomy.

By being based in Tucson, I can work more closely with the NCOA leadership team to help develop this new organization and better advocate for the needs of Gemini's partners, users, and staff. If all goes well, Gemini's users should not notice any significant changes this October. But longer term, the new organization will improve Gemini Observatory's ability to respond to the rapidly changing astronomical landscape by pooling resources from across all of the astronomy centers, allowing better execution of "big new ideas," and better retention and recruitment of our highly-talented staff.

While unpacking my belongings in the "dry heat" of Tucson in late June, I couldn't help wishing I were in Chile enjoying the eclipse celebrations on the top of wintry Cerro Tololo and Cerro Pachón! The path of totality for the July 2nd total solar eclipse passed right over these mountaintops. Working with the Association of Universities for Research in Astronomy and NOAO staff, Gemini Observatory helped to host a number of dignitaries for the eclipse events, including the Korean Ambassador to Chile In-gyun Chung, Korea's National Research Council of Science and Technology (NST) Chairman Kwangyun Wohn, Korea Astronomy and Space Science Institute (KASI) President Hyung Mok Lee, and several members of the US Senate Appropriations Committee. While the main festivities on the day of the eclipse were held at the Cerro Tololo International Observatory site, Gemini staff led tours of the Gemini-South telescope on the days before and after the eclipse.

As obvious by the cover image of this issue of *Gemini*Focus, the weather for the eclipse was picture-perfect!

Strategic Science Plans

In May, Gemini North welcomed its own set of VIPs at the Gemini Board and Science & Technology Advisory Committee (STAC) meetings, led by new Board Chair Todd Boroson of Las Cumbres Observatory and new STAC Chair Elliot Horsch of Southern Connecticut State University. During that week, the Gemini governance endorsed the *Strategic Scientific Plan for Gemini Observatory*. This ~30 page plan (led by Gemini Chief Scientist John Blakeslee) expands upon the *Beyond 2021: A Strategic Vision for Gemini Observatory* document approved by the Gemini Board in May 2017. The plan lays out the path for Gemini's scientific development through the 2020s to ensure Gemini "best serves its international user community by remaining at the forefront of astronomical research throughout the coming decade."

With the advent of exciting new facilities — such as the LSST, *James Webb Space Telescope*, *Wide Field Infrared Survey Telescope*, and the extremely large telescopes, as well as continued observations from Laser Interferometer Gravitational-Wave Observatory and Atacama Large Millimeter/submillimeter Array — Gemini Observatory must carefully set priorities to maximize our ability to explore the new discoveries to come.

The plan maps out three broad areas for Gemini future scientific activities: (1) preservation of Gemini's current facilities and strengths; (2) development of instrumentation and software systems to enable new capabilities that build on those strengths; and (3) strategic investment in visiting instrumentation.

The first Strategic Scientific Plan objective states Gemini's continued commitment to providing a diverse set of proposal opportunities, observing modes, and instrumental capabilities to our diverse international user community. In particular, we envision science programs, led by individual Principal Investigators (PIs) and awarded through the peer-review process, that continue to determine Gemini's observational program. This peer-review process will guide the time allocated to transient and non-transient science programs.

Additionally, we recognize that the Gemini Observatory telescopes will be celebrating their 20th year anniversaries in 2020. Continued efficient and productive science operations require a dedicated commitment to ongoing maintenance, upgrades, and improvements to the telescopes, instruments, and infrastructure. A critical element of this plan is already underway in the form of updates to the suite of operations software for observation preparation software and execution, known as the Observatory Control System. In particular, the updated software platform will further enable Gemini's transient follow-up programs, as well as overall improved efficiency of operations and scheduling. Another exciting opportunity is Gemini's development (in collaboration with the Giant Magellan Telescope) of a new mirror coating recipe that would greatly enhance ultraviolet reflectivity while maintaining high reflectivity at wavelengths >400 nanometers.

Over the next decade, Gemini Observatory will be building on its capabilities in agile operations and adaptive optics in order to provide our users with improved science opportunities for time-domain and high spatial resolution studies. The science cases supported by the *Gemini in the Era of Multi-Messenger Astronomy* (GEMMA) award to build a multi-conjugate adaptive optics system at Gemini North are described in our Astro2020 white paper "Probing the Time Domain with High Spatial Resolution" (***viewable here***), and span topics from stellar evolution to distant Universe cosmology.

The Strategic Scientific Plan also outlines Gemini's ambition to replace the Gemini North secondary mirror with an adaptive secondary mirror in order to enable ground-layer adaptive optics. Time-domain science will be supported not only by improved operations, but also with new Python-based data reduction packages (DRAGONS) and the availability of SCORPIO — the facility 8-channel imager/spectrograph being developed by PI Massimo Robberto (Space Telescope Science Institute), Southwest Research Institute, the Spanish private technological company FRACTAL, and Johns Hopkins University. Finally, the Strategic Scientific Plan advocates for continued support for high-demand, high-impact visiting instruments as a cost-effective way to provide new instrumentation.

Looking forward to the coming months, Gemini users can expect a number of new (and returning) capabilities at both telescopes. ZORRO was successfully commissioned on Gemini South in May/June, and will be offered as a visiting instrument during the 2020A semester (see the article on ZORRO commissioning on page 14 of this issue); this dual-channel optical speckle imager (PI Steve Howell, NASA Ames) is the twin of 'Alopeke at Gemini North. Also in May, the initial tests for MAROON-X commissioning at Gemini North went smoothly, and final commissioning is planned. MAROON-X (PI Jacob Bean, University of Chicago) is a visiting instrument for high-resolution and high-stability spectroscopy designed to detect Earth-size planets in the habitable zones of mid- to late-M dwarfs via radial velocity signatures.

Finally, Gemini users will be happy to hear that negotiations are underway with KASI and the University of Texas to bring the high-resolution near-infrared spectrograph IGRINS back to Gemini South as a visiting instrument in 2020. Look for our 2020A Call for Proposals in August for the full set of facility and visiting instrument capabilities.

By the time this article is in press, I'll have escaped the Tucson summer for an extended visit to Hilo and a chance to meet the Gemini Users' Committee. Wishing all clear skies, like we experienced during the July 2nd eclipse!

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

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.

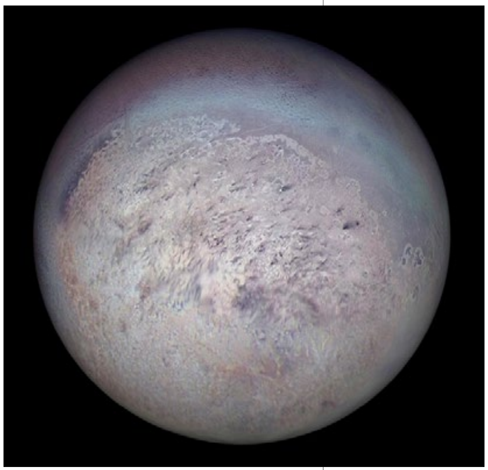

Figure 1.
Voyager 2 *image of Triton showing the south polar region with dark streaks produced by geysers visible on the icy surface. Credit: NASA/JPL*

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

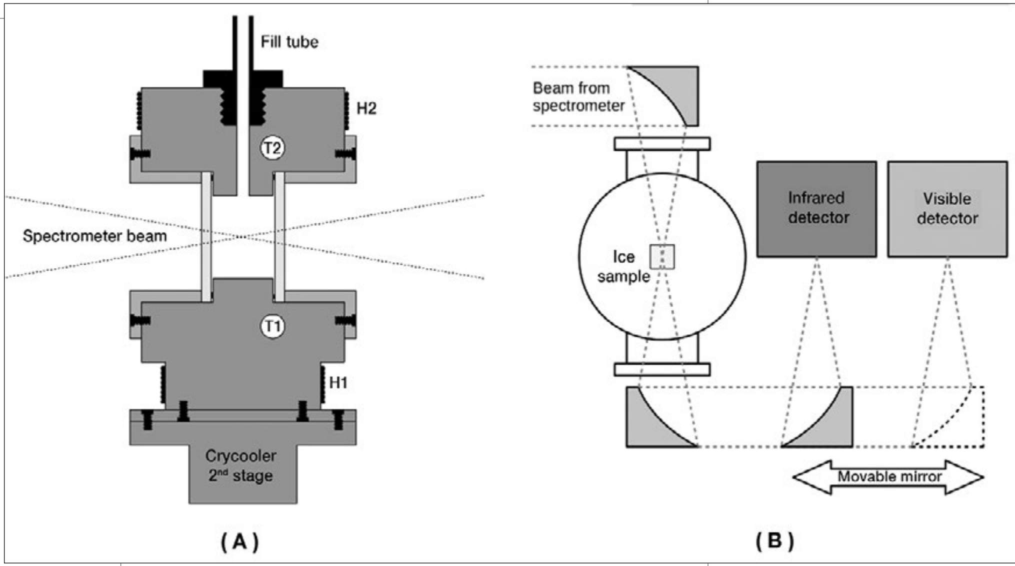

Figure 2.
(a) Schematic diagram of the Astrophysical Materials Laboratory thick cell in cross section as seen from the side. (b) The optical train in our experiment as seen from above. The spectrometer beam is represented by dashed lines. Only the infrared detector was used in the experiments described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

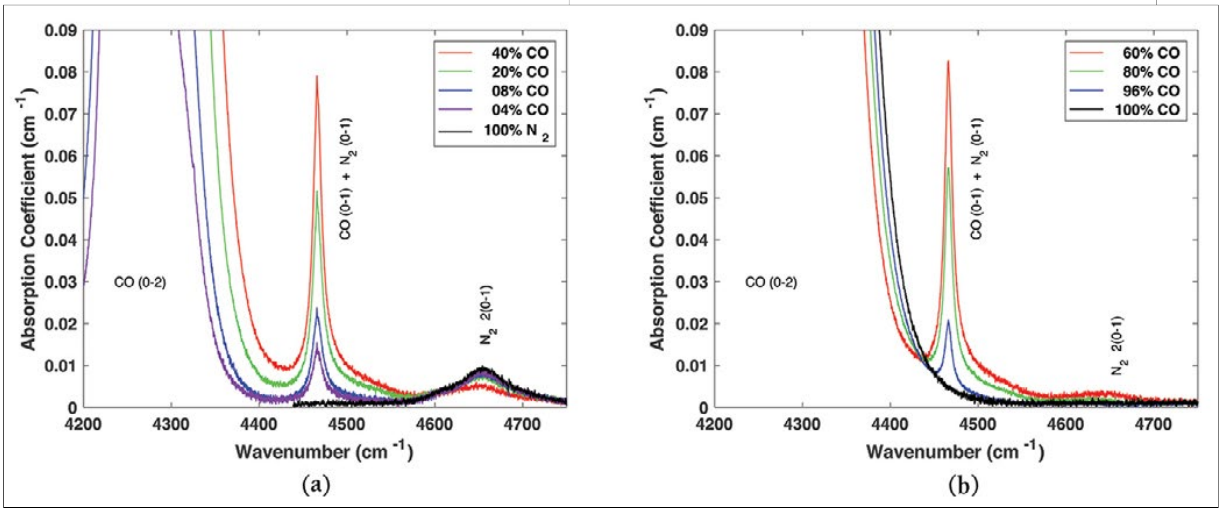

Figure 3.
Spectra of CO/N2 ice samples with the CO abundance ranging from (a) 0% to 40% and (b) 60% to 100%. In panel (a), the spectra show the new band near 4467 cm^{-1}. The new band is not present in the pure N2 sample (black line) and increases in strength with increasing CO abundance. The saturated 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).*

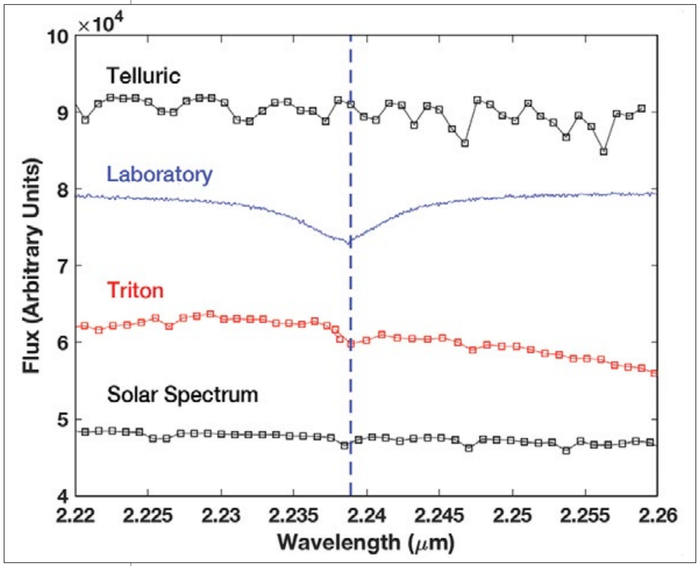

Figure 4.
A portion of an 80-minute, binned-spectrum of Triton taken with the 8.1-meter Gemini-South telescope and the IGRINS spectrometer (red squares). The broad absorption in the Triton spectrum is consistent with the broad absorption of the two-molecule combination band at 2.239μm (4466.5 cm^{-1}) 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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John Blakeslee

Science Highlights

GMOS clocks the speed of gas reverberating in the vicinity of an intermediate-mass black hole in a bulgeless dwarf galaxy; the GPI Exoplanet Survey issues its interim report on the divergent demographics of giant planets and brown dwarfs around young nearby stars; and integral field spectroscopy from the MASSIVE Survey reveals startling diversity in the kinematical profiles of 20 heavyweight galaxies.

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.

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 be-

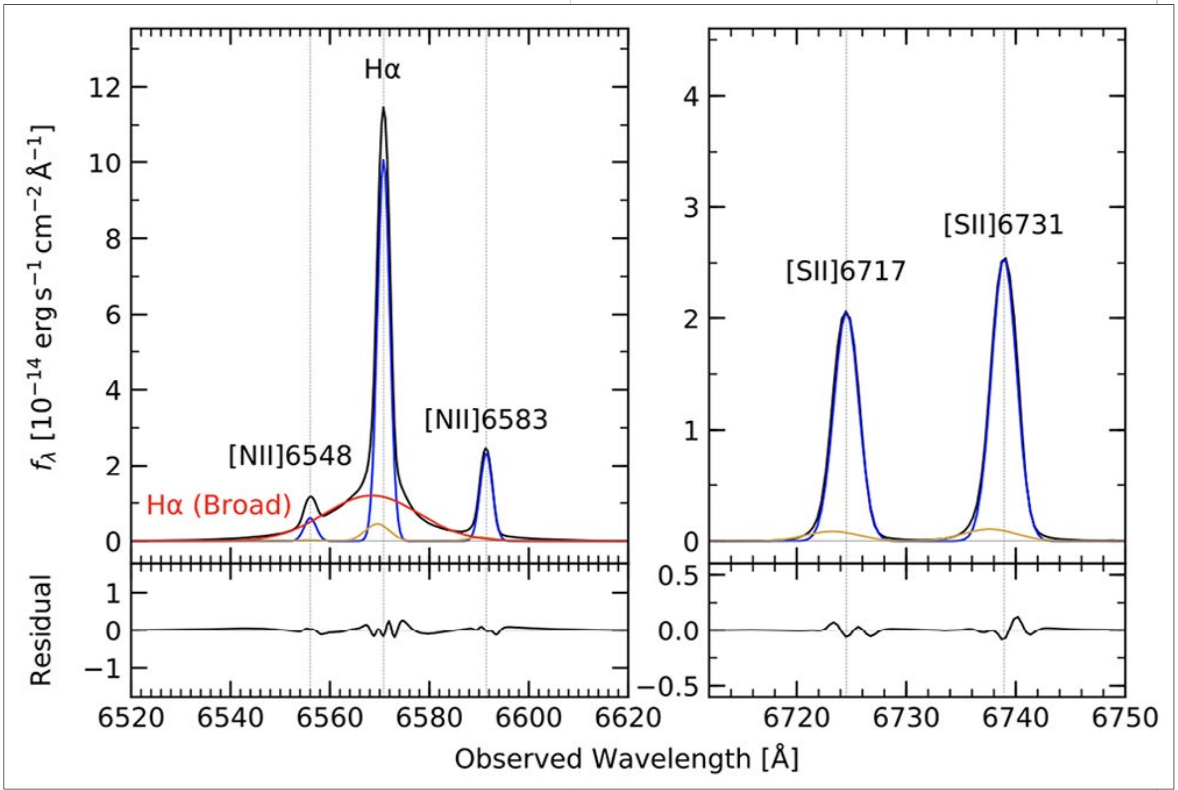

Figure 1.
GMOS spectrum of the AGN in the low-mass spiral NGC 4395, showing the narrow [NII] and Ha lines superposed on the broad Ha emission used for the reverberation measurement (left). The narrow [SII] lines at longer wavelength were used as proxies for the central stellar dispersion (right). [Figure reproduced from Woo et al.*,* Nature Astronomy*, 2019, in press (arXiv 1905.00145).]*

tween 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 luminosity 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 1). 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 disper-

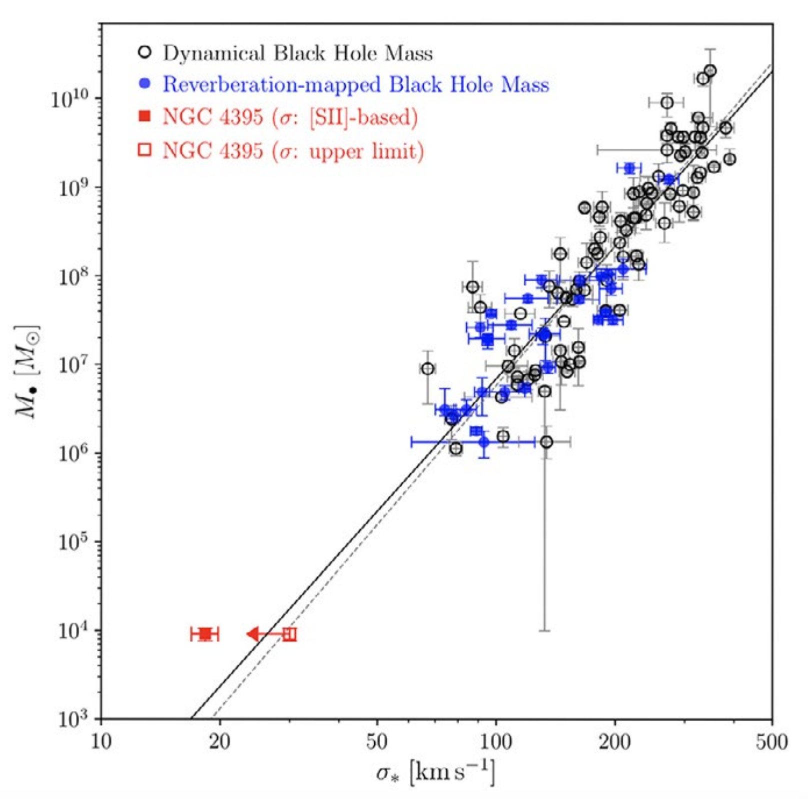

Figure 2. *The new NGC 4395 black hole measurement is plotted in the context of the relation between central black hole mass and stellar velocity dispersion for more massive systems. The stellar velocity dispersion for NGC 4395 is shown as a previously published upper limit (open red square) and the 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).]*

sion for high-mass galaxies (Figure 2), concluding it is broadly consistent with a simple extrapolation to lower masses. This suggests that the observed relations between M_{BH} 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 astronomical units (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 3. The study concludes that only about one in ten stars hosts a brown dwarf 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.

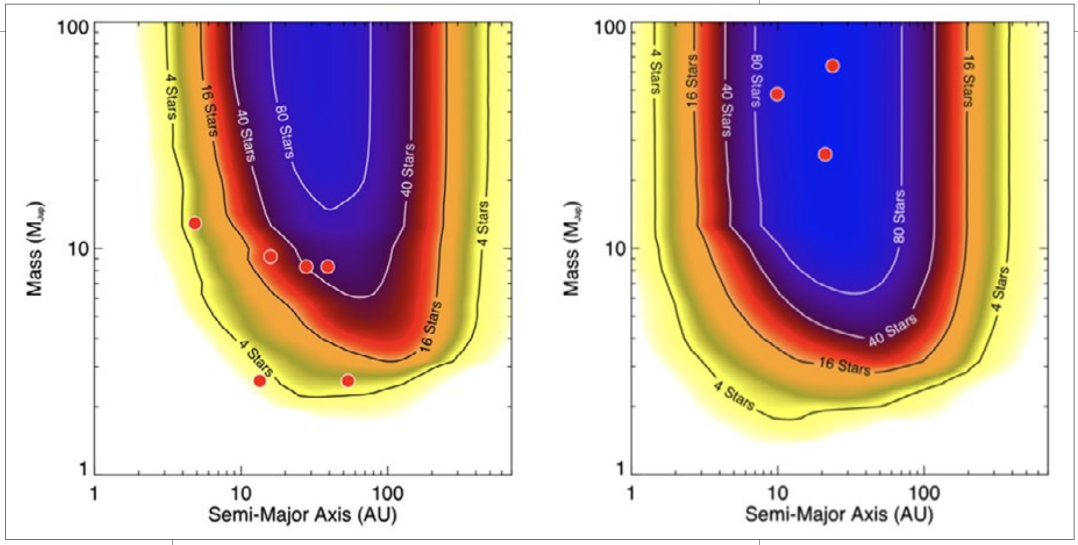

Figure 3.

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.]*

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 4 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 arc-

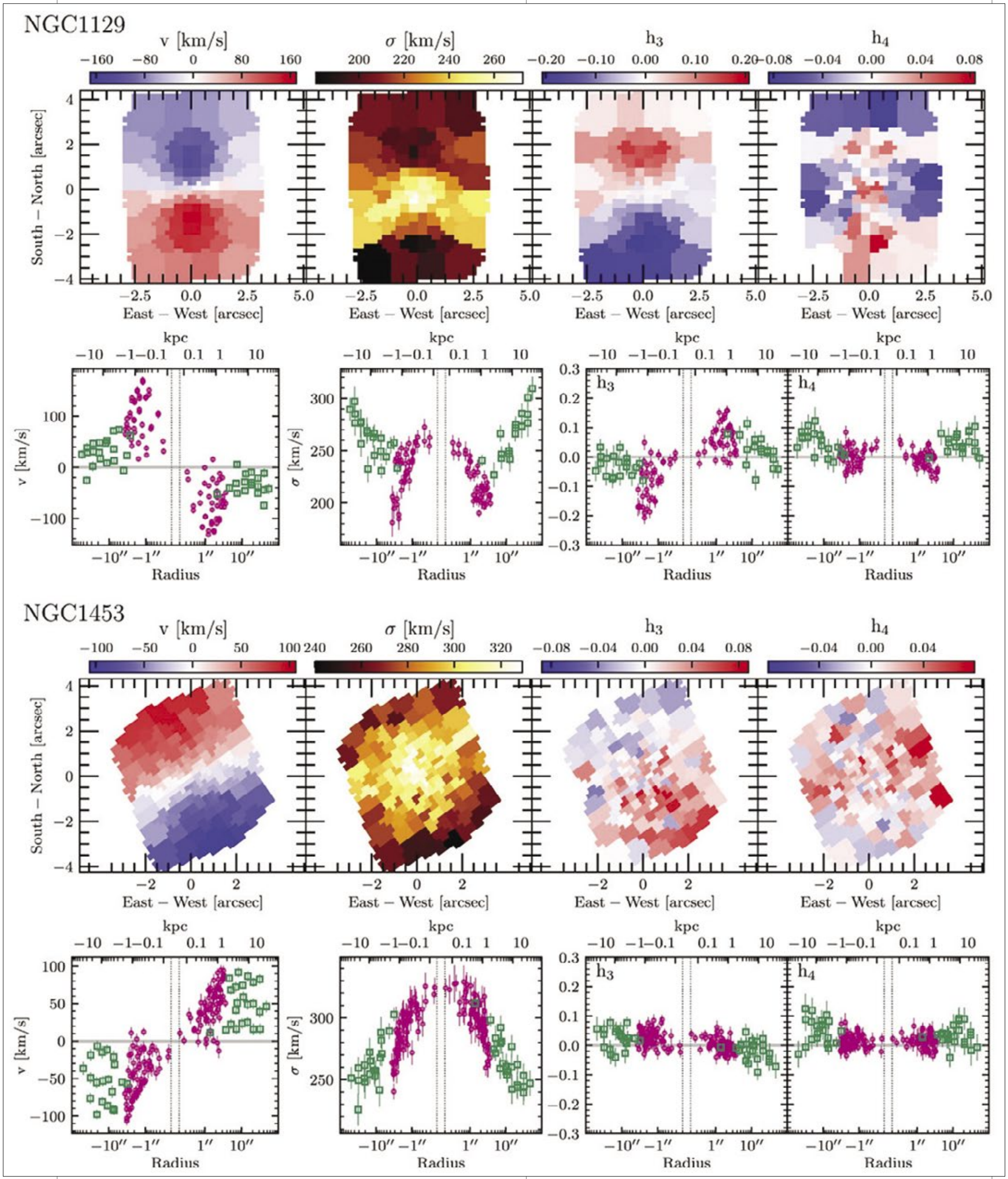

Figure 4.
Example distributions of the first four kinematical moments (v, σ, h_3 and h_4) measured from the GMOS-N IFS data for two of the MASSIVE survey galaxies. For each galaxy, the top row shows two-dimensional maps, while the bottom row shows two-sided radial profiles from GMOS (magenta circles) 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.]*

seconds. 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.

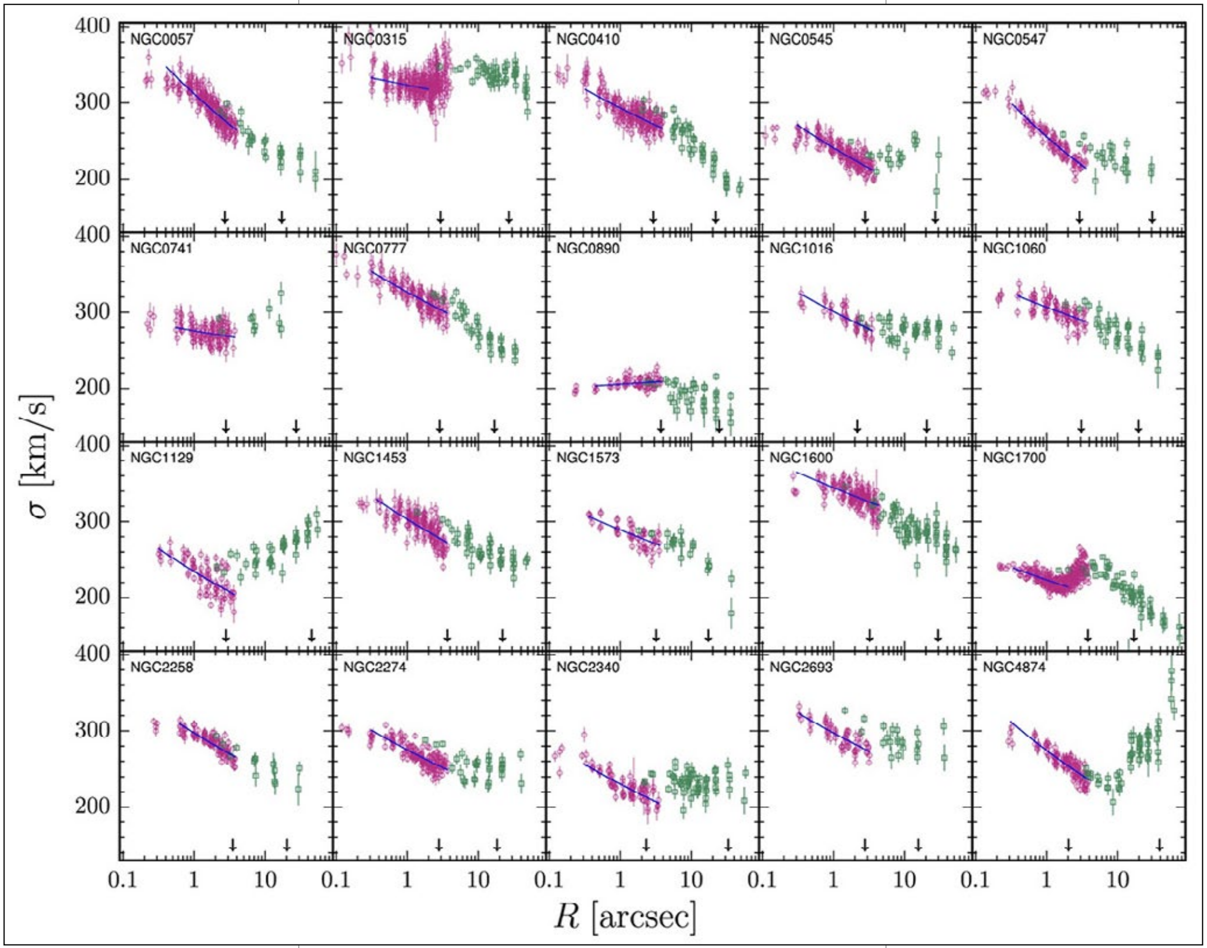

Figure 5.

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.]*

The kinematic diversity across the full sample is illustrated in Figure 5, 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 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.

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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.

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.

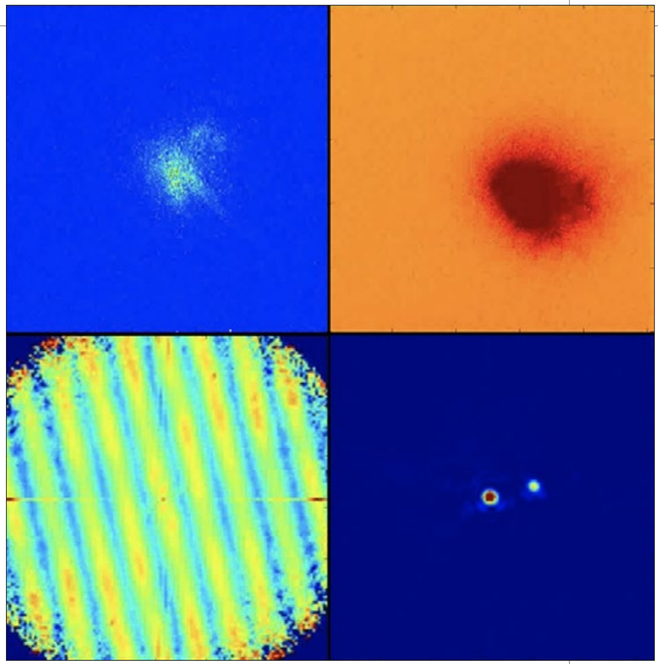


Figure 1.
An individual speckle frame (top left), the integrated image of 1,000 speckle frames (top right), the Fourier power spectrum (bottom left), and the resulting reconstructed diffraction-limited image (bottom right). Adapted from Scott and Howell (2018).

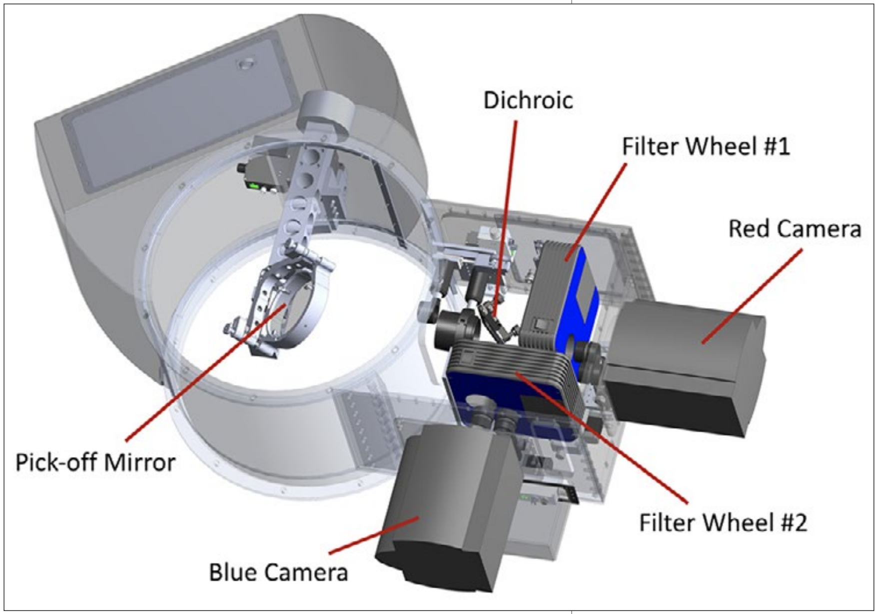
One instrument capable of doing speckle interferometry is the Differential Speckle Survey Instrument (DSSI, Horch *et al*., 2009), which visited Gemini North and South on multiple occasions since 2012. Visiting instruments expand the capabilities of what the facility instruments can offer, but come with 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."

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.



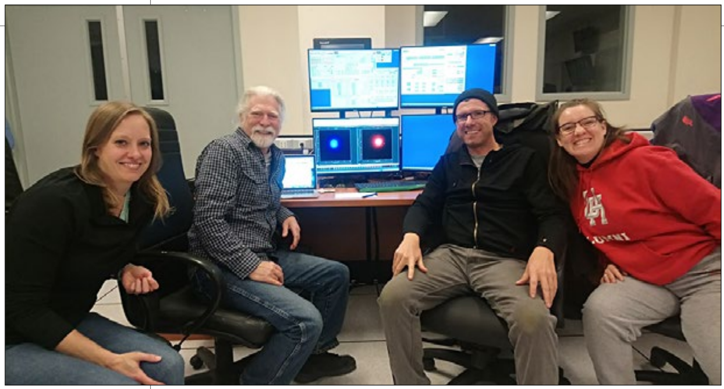


Figure 3.

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.

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.

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.

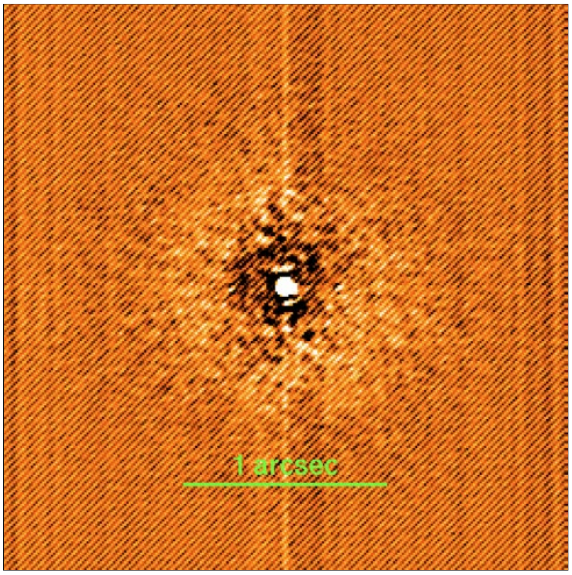


Figure 4.

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).

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!

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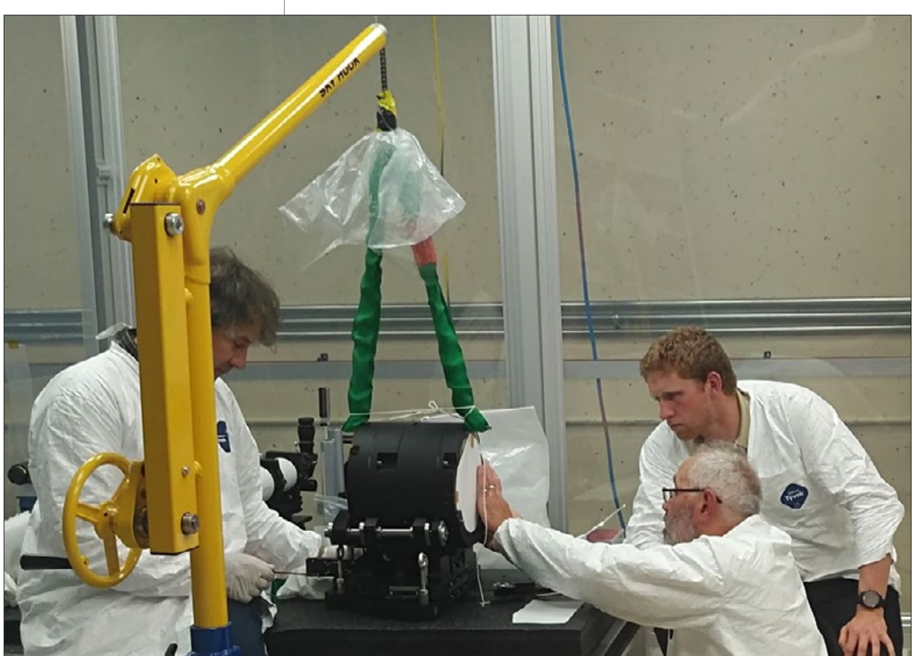
On the Horizon

The GHOST team brings together, for the first time, the instrument's fiber system, Slit Viewer Assembly, and spectrograph. Highlights from the SCORPIO project as it closes out its Design Phase and moves toward its Build Phase.

Figure 1.
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

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 1). 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 2. 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 spectrograph 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.

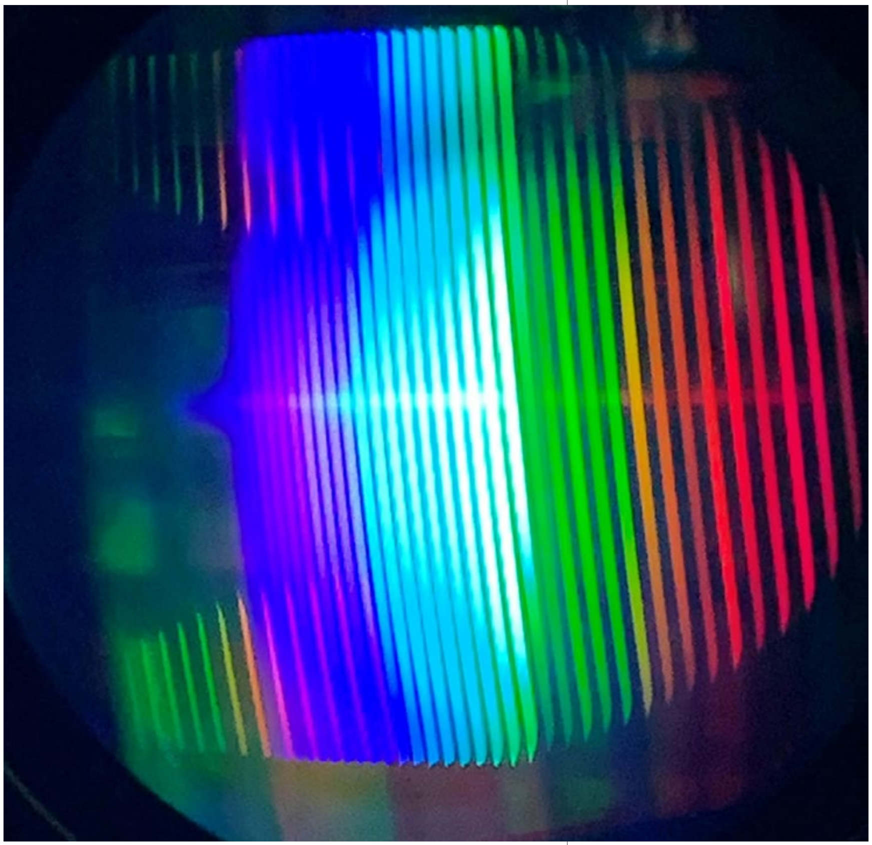


Figure 2.

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

Credit Tony Farrell

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. Look for further details in the next issue of *Gemini*Focus.

Gemini staff contributions

News for Users

A technical intervention with GMOS-South leads to promising results. The Gemini Planet Imager is in the lab to fix a problem with its Micro-Electrical Mechanical System deformable mirror. Gemini's participation in the 2019 CASCA meeting in Montréal, Canada, helped many users. Finally, Gemini North's primary mirror is ready to receive a fresh coating during a planned shutdown starting in late July.

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. 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.

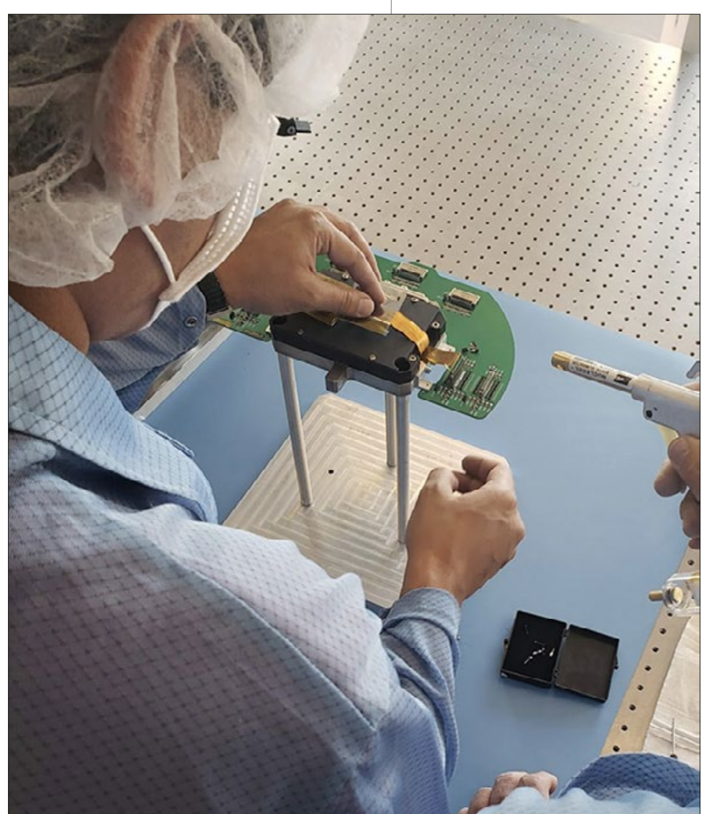


Figure 1.

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

Credit: Luc Boucher

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 2.

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

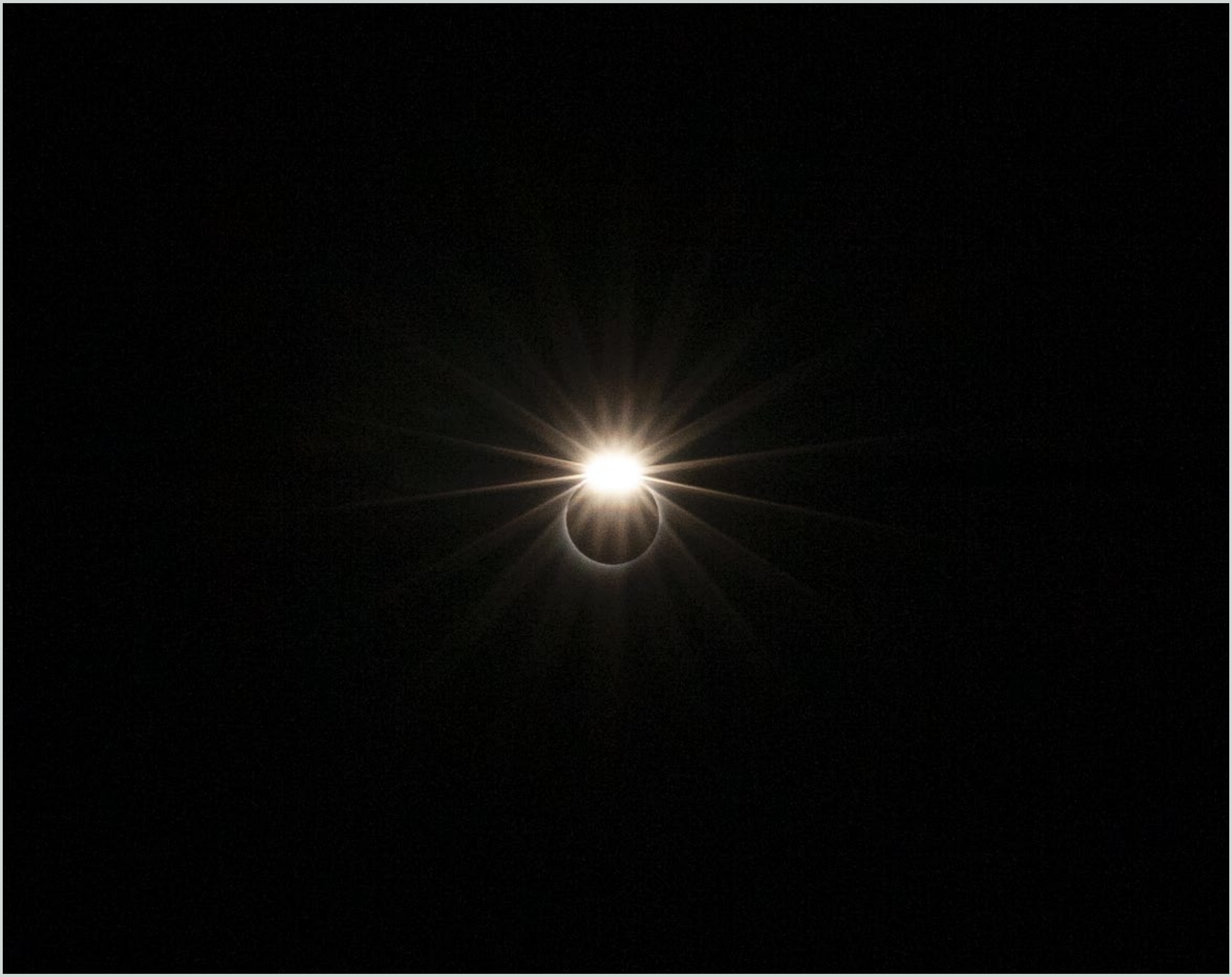
CASCA 2019 meeting in Montréal

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. 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.



A stunning diamond-ring effect signaled the onset of totality during the July 2, 2019, total solar eclipse over Cerro Pachón in Chile.
Credit: Gemini Observatory/Peter Michaud

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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