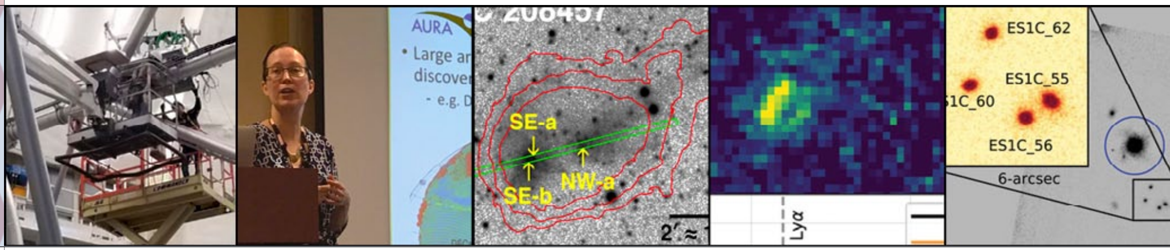
GeminiFocus

Publication of the Gemini Observatory

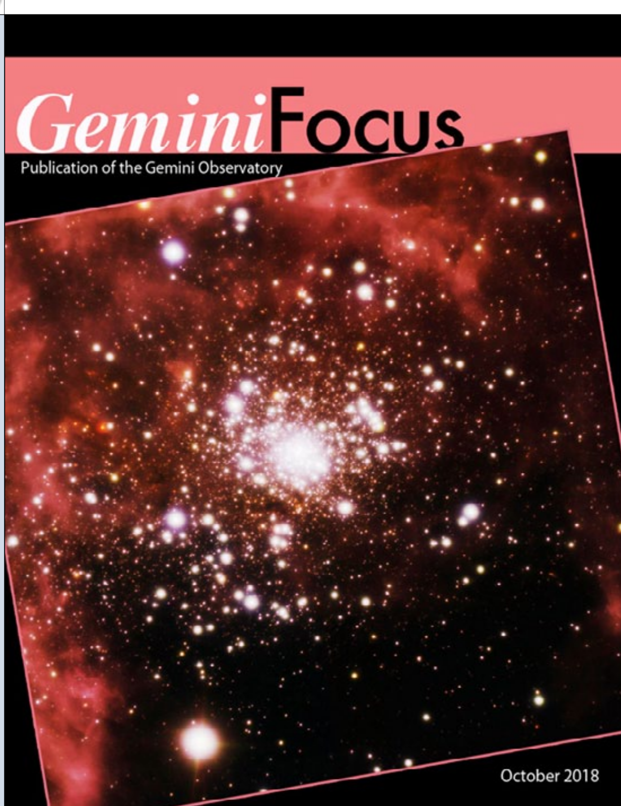
October 2018

GeminiFocus



ON THE COVER:

Image of R136, a young stellar grouping in 30 Doradus (a massive star-forming region in the Large Magellanic Cloud) obtained during commissioning of the GeMS adaptive optics system at Gemini South. See page 3 for a recent result from GeMS on distant galaxies and page 12 for an announcement on new funding which will bring an updated version of this multi-conjugate adaptive optics capability to Gemini North.



*Gemini*Focus October 2018

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Jennifer Lotz

Director's Message

New Beginnings

Aloha, Hola, Olá, 안녕하세요, Bonjour, and Hello from the Gemini Director's office! It is my great honor and pleasure to write my first Director's Message.

I look forward to engaging with Gemini's diverse community and working with our staff in Hilo and La Serena in the coming months and years. Thanks to the leadership of former Director Markus Kissler-Patig and Interim Director Laura Ferrarese, I am fortunate to arrive at Gemini during a particularly exciting time in its history. Our new partnership with the Republic of Korea and the recent award from the US National Science Foundation (NSF) for enhancements to the Gemini North adaptive optics (GNAO) system (see page 12) are just two of the promising new developments at the Observatory. I took this position because I believe that Gemini Observatory has tremendous potential for scientific discovery and leadership, and together we can push the forefront of astronomical discovery into the 2020s.

I come to Gemini Observatory from the Space Telescope Science Institute (STScI), where I worked on developing policies and tools to help future *James Webb Space Telescope* users and lead the Hubble Frontier Fields program. Prior to STScI, I was a National Optical Astronomy Observatory (NOAO) Goldberg Fellow in Tucson, Arizona, and I am looking forward to returning to Tucson. My time at the NOAO and STScI have instilled in me a strong commitment to service to the US and international astronomy communities. Every astronomer with a great idea should have the opportunity to test their idea with world-class facilities such as the Gemini Observatory. As Director, I plan to put science first. With the Gemini staff, we will prioritize the delivery of high-impact science and enable the scientific leadership of our community through the next decade.

Gemini is well-positioned to be the leading transient follow-up facility for the Large Synoptic Survey Telescope (LSST) and gravitational wave sources, but these new opportunities must be balanced against the needs of the general Gemini observer community. Our strong visiting instrument program, new partnership with the Korea Astronomy and Space Science Institute, new facility instruments — Spectrograph and Camera for Observations of Rapid Phenomena in the Infrared and Optical (SCORPIO) and Gemini High-resolution Optical SpecTrograph (GHOST) — and new funding to develop GNAO are all steps in the right direction toward a strong instrumentation suite.

The incorporation of Gemini Observatory into the new National Center for Optical-infrared Astronomy (NCOA) offers a unique opportunity to leverage the intellectual and infrastructure assets of the NCOA institutions (which include Gemini, the current NOAO, and LSST). My job will be to ensure that NCOA succeeds at meeting the needs of the entire Gemini community.

Crafting a robust strategy to achieve these goals will require many conversations with all stakeholders: the Gemini user communities, the Gemini Observatory Board, international partners, NSF, and the Association of Universities for Research in Astronomy (AURA); the cross-observatory partnerships, including LSST, NOAO, and Maunakea observatories; local communities; and most importantly, the Gemini Observatory staff.

I hope to engage with as many of our community members and staff as possible in the coming months in order to develop our collective vision for the future of Gemini. I have found that working with talented, dedicated, and diverse teams of people toward the common goal of pushing the boundaries of human knowledge to be a great thrill and privilege.

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

Mark Lacy, Kristina Nyland, and Susan Ridgway

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

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

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

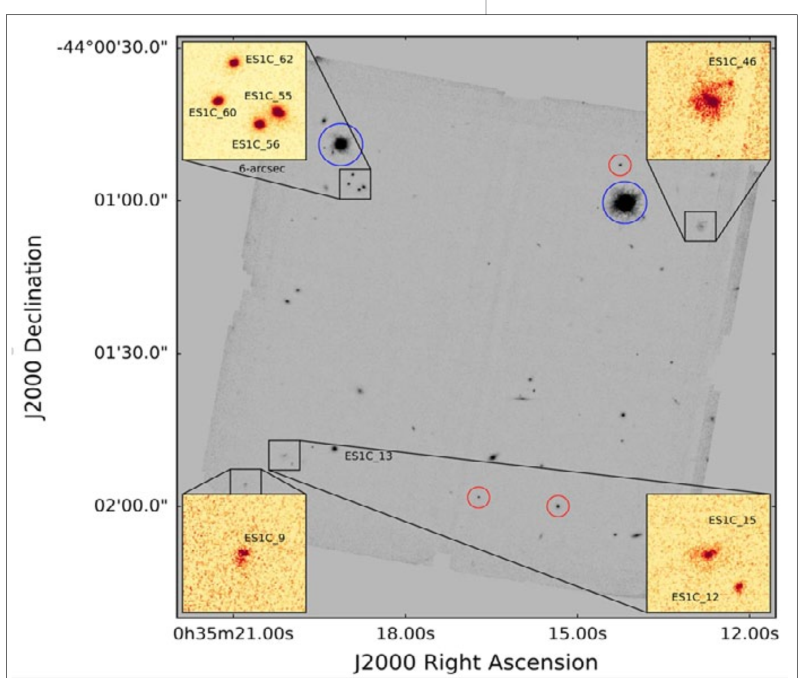
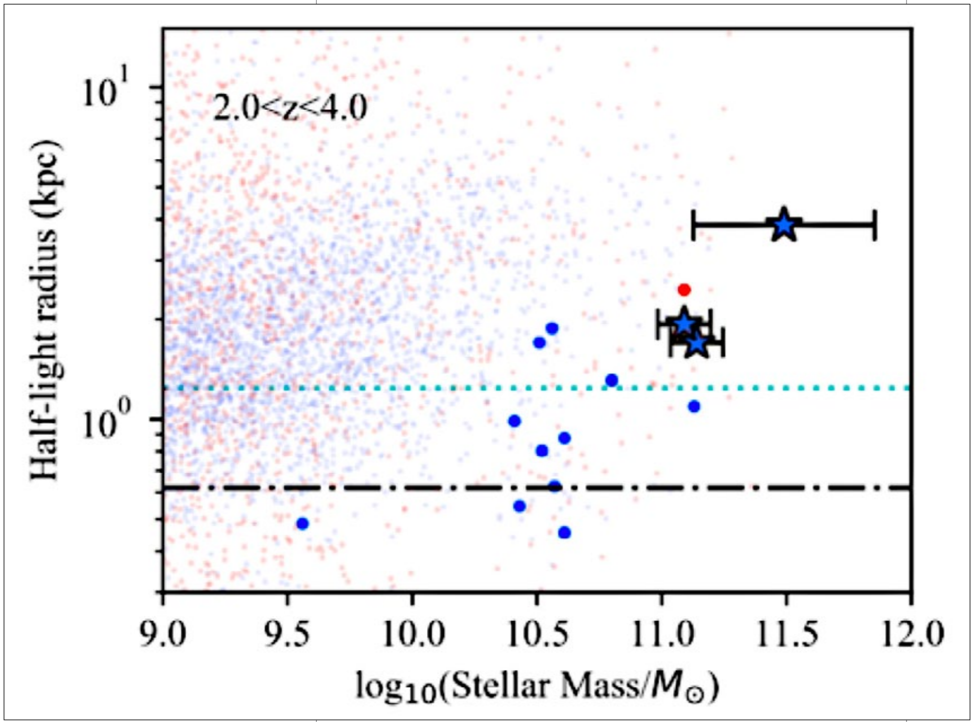


Figure 1.

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

Figure 2.

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



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

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

The GeMS/MCAO Advantage

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

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

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

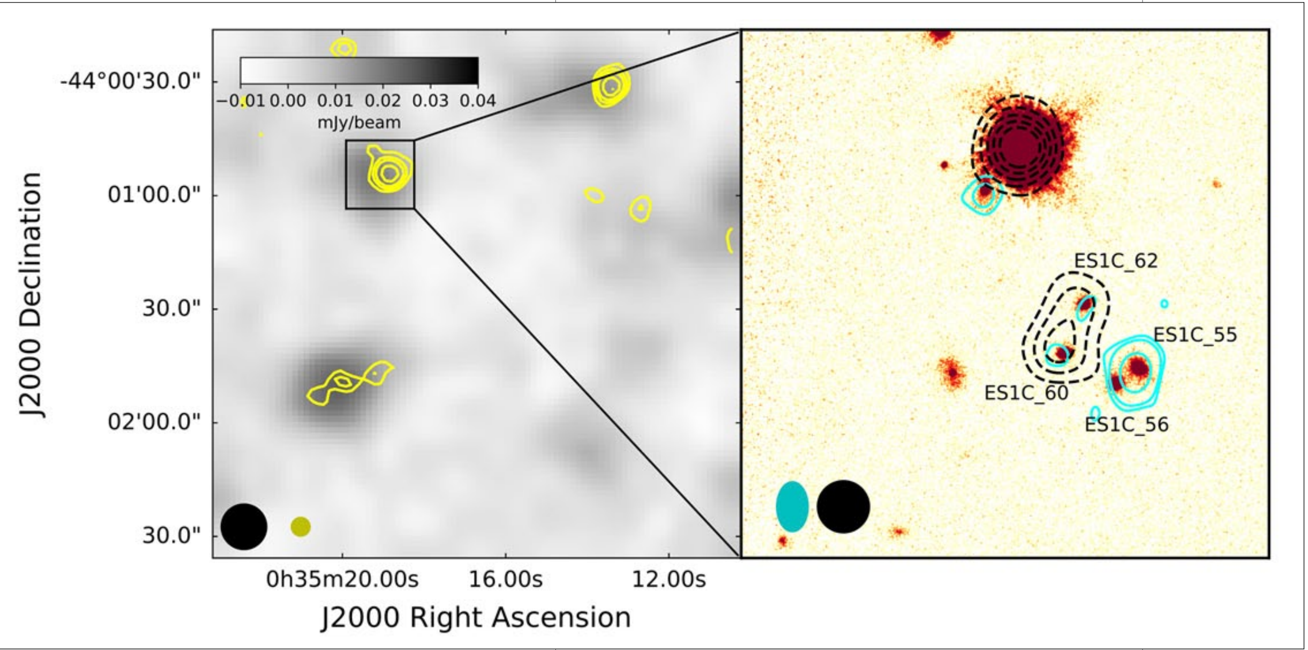
As a pilot program, we observed three of these fields (including ES1C; Figure 1) with GeMS/MCAO for between 30 and 90 minutes each (Lacy *et al.*, 2018). The resulting images have limiting magnitudes of 24-24.6 and resolutions (Full-Width at Half-Maximum of the PSF) of 0.07-0.16 arcsecond, depending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

What Can We Learn From Higher Resolution?

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

In the GeMS fields there are several sources detected in the far-infrared HerMES survey (which used the *Herschel Space Observatory*). At the redshifts we are seeing them ($z \sim$ 1-3),

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



they correspond to ultraluminous infrared galaxies (ULIRGs). In the local Universe, the far-infrared emission from ULIRGs is typically powered by starbursts and AGN. To obtain redshift estimates, and to disentangle the contribution of these two power sources, we used multiwavelength data from surveys in the optical and infrared, as well as new radio continuum data from the Australia Telescope Compact Array and Very Large Array. The ULIRGs we identify consist of a combination of pure starburst galaxies and composite AGN/starburst objects. We find that the ULIRGS with strong AGN tend to reside in hosts with smaller scale sizes than purely star-forming galaxies of similar infrared luminosity.

Like their local counterparts, the ULIRGs in this study seem to show signs of recent merger activity, such as highly disturbed morphologies. We also find a candidate triple AGN system (Figure 3), which consists of three AGN with photometric redshifts of $z = 1.4$ (spectroscopic redshifts are required to confirm the triple AGN system): one is a radio-loud AGN, suggesting the presence of radio jets and lobes; one is a Type-2 AGN, showing both narrow and broadened optical spectral emission lines; and one is a Type-1 AGN, showing narrow emission lines only (though still wider than emission lines in normal galaxies). Both the Type-1 and Type-2 AGN have strong mid-infrared emission that identifies them as probable AGN. This system was not identified as multiple in the standard photometry products from the VIDEO or SERVS surveys, raising the possibility that many more such systems may exist unrecognized in current surveys.

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

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John Blakeslee

Science Highlights

Fading reflections glimpsed by GMOS-South of Eta Carinae's Great Eruption evoke supernova-like outflows; GMOS-North takes the measure of dwarfs found forming in the tidal tails of interacting galaxies; and Gemini plays a key role in setting a new record for the most distant known radio galaxy.

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

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

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

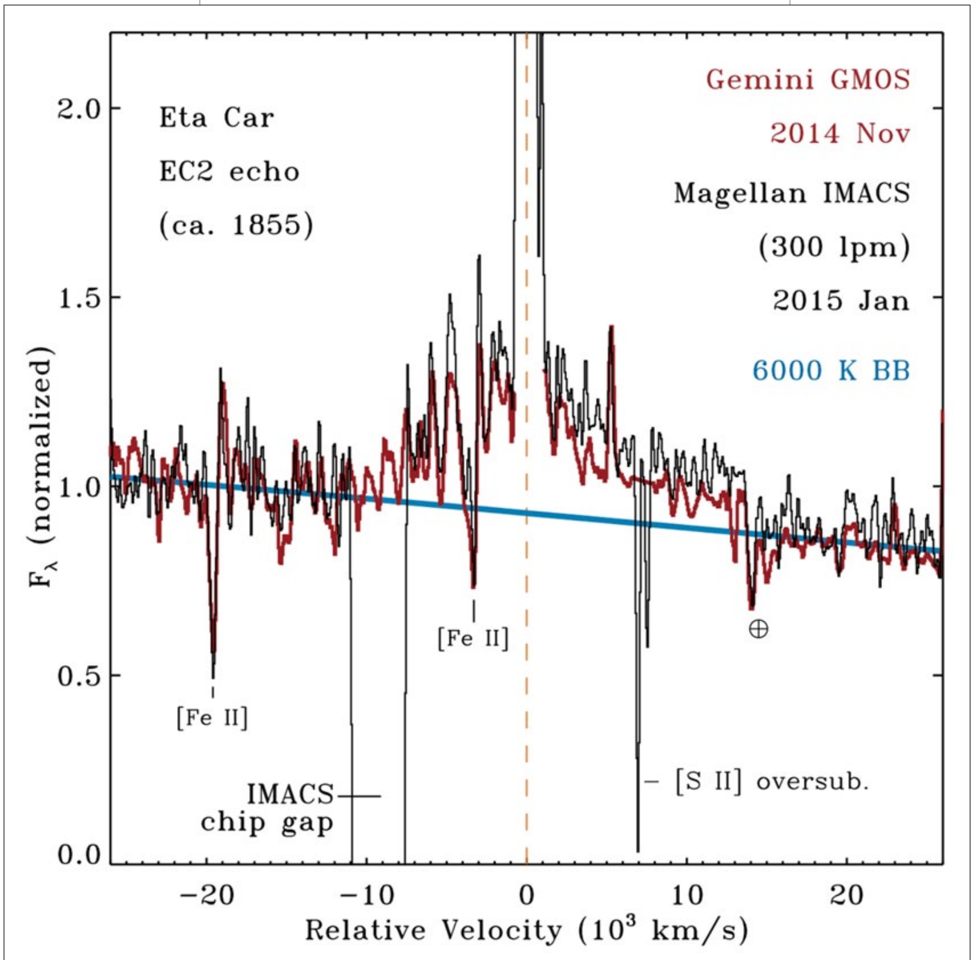


Figure 1. *Gemini/GMOS and Magellan/IMACS spectra centered on the Hα line of the light echo believed to correspond to the latter part (circa 1855) of Eta Carinae's Great Eruption. The spectra show very broad Hα line wings extending to at least ±10,000 km/s, indicating outflow velocities typically seen in supernovae. The blue curve represents a blackbody of temperature 6,000 K. (Figure reproduced from Smith, Rest, Andrews,* et al.*, 2018.)*

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

Although the Great Eruption concluded 160 years ago, it is possible to observe the light from that event reflected off cold clouds on the far side of the extended Carinae Nebula complex. A 2012 study of such "light echoes" reported observations of Eta Car's pre-1845 luminosity spikes illuminating a group of background clouds. Now, the same team has published two new papers dissecting light echoes reflected by another cloud at a lesser distance from the star. Based on the geometry, the team believes the light is associated with the enormous mass loss that occurred during the plateau phase of the Great Eruption in the 1850s. Figure 1 shows spectra of the light echoes taken with the Gemini Multi-Object Spectrograph (GMOS) at Gemini South and the Inamori-Magellan Areal Camera and Spectrograph (IMACS) at Magellan Observatory.

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

Dwarfs Emerge from the Tidal Debris of Interacting Galaxies

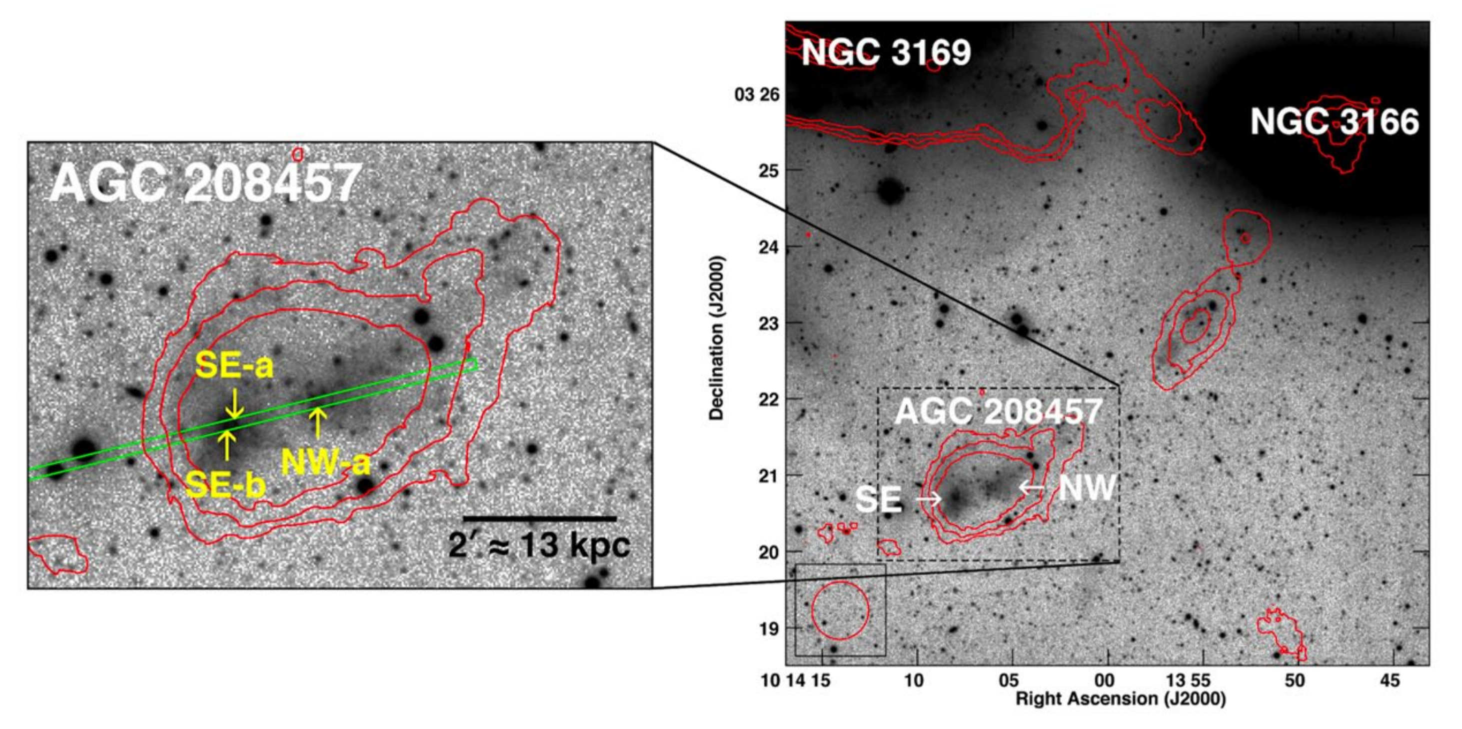
Large galaxies are produced through the merging or accretion of smaller galaxies. If the merging galaxies contain enough gaseous material, a burst of star formation may cause the stellar mass of the final galaxy to be substantially larger than the combined mass of the stars of the two original galaxies.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

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

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

The resulting study, [***published in Monthly Notices of the Royal Astronomical Society***](), confirms that the optically identified dwarf

Figure 2.
Anatomy of the tidal dwarf galaxy AGC 208457. The HI emission contours from the GMRT are superimposed on a CFHT MegaCam image of the region between the interacting galaxies NGC 3166 and NGC 3169. The northwest and southeast stellar clumps of AGC 208457, lying within the HI tail, are indicated. The green outline in the zoomed view on the left shows the orientation of the GMOS-North long slit (illustrated with twice the actual width). The yellow arrows indicate the approximate locations of the extracted spectra analyzed in the study. (Figure reproduced from Lee-Waddell, et al., MNRAS, ***480:*** *2719, 2018.)*



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

Targeting a second system, the study confirms the physical association of gaseous knots and star clusters with the extended tidal tail of NGC 4747, a disturbed galaxy that likely experienced a recent interaction with its larger neighbor NGC 4725. Like AGC 208457, these stellar aggregates likewise have relatively high metallicities, but they are in an earlier stage of evolution. Thus, they may represent a tidal dwarf galaxy in the process of formation. By using a combination of radio data, wide-field imaging, and GMOS spectroscopy to confirm the nature of these objects, this work significantly expands the limited sample of well documented tidal dwarf galaxies.

Confirmation of the Most Distant Known Radio Galaxy

More than a dozen galaxies have been reported at redshifts beyond 7. These tend to be highly magnified star-forming objects found at infrared wavelengths, seen when the Universe was less than 5% of its current age. However, radio emission from such objects has not yet been detected. This is mainly because the vast distances and extreme redshifting will make any radio signal difficult to

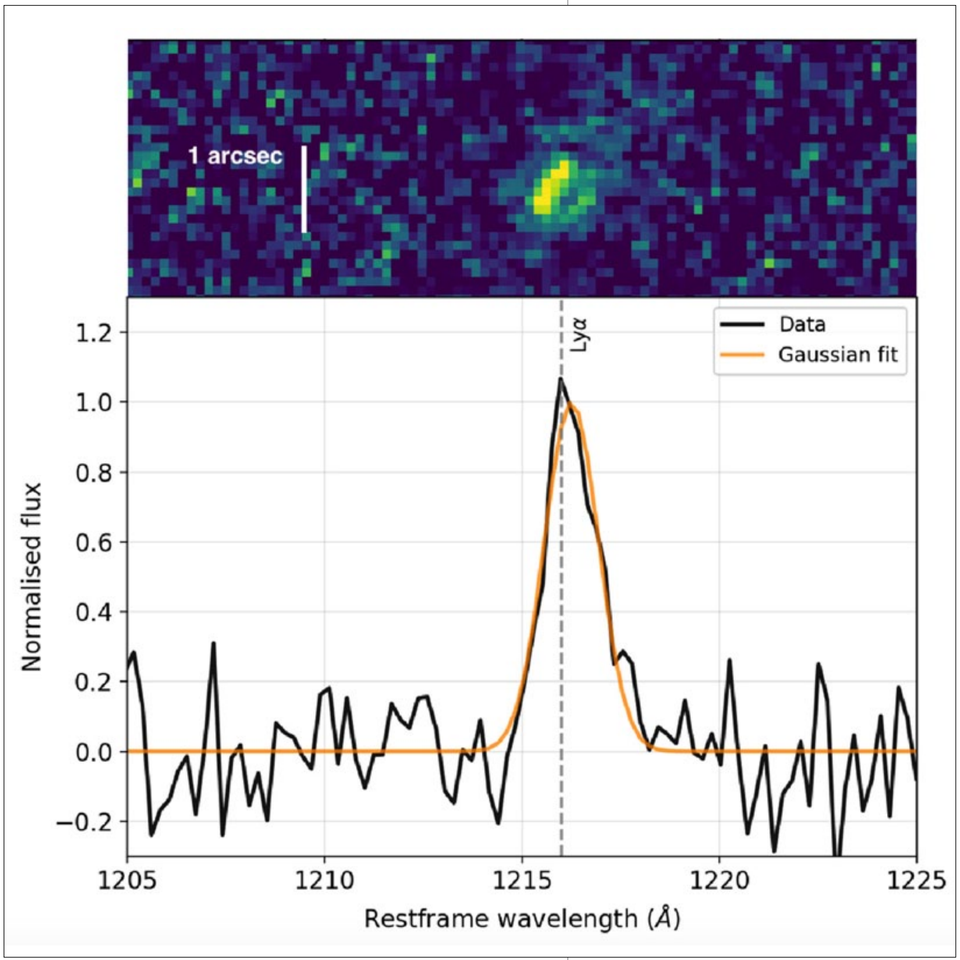


Figure 3. *Top panel: The two-dimensional GMOS spectrum showing the strong emission feature detected in the radio galaxy TGSS J1530 + 1049. The size of the emission region is a bit less than 1 arcsecond. Lower panel: One-dimensional plot of the spectrum of TGSS J1530 + 1049 (black line) is compared to a simple, symmetric Gaussian fit (orange line) to the emission feature. The asymmetry of the data with respect to the Gaussian fit indicates that the emission is Lyman-α at redshift of z = 5.72, making TGSS J1530 + 1049 the most distant radio galaxy known to date. (Figure reproduced from Saxena, et al.,* MNRAS, ***480:*** *2733, 2018.)*

detect. Moreover, powerful radio jets, and the black holes that power them, have not had sufficient time to grow to large sizes at such early times. Now, an international team of astronomers from Brazil, Italy, the Netherlands, and the United Kingdom has discovered the most distant radio galaxy to date, observed just one billion light years after the Big Bang, when the Universe was roughly 7% of its current age.

The team used spectroscopic data from GMOS-North to measure a redshift of $z = 5.72$, based on the Lyman-α line, for the radio galaxy identified as TGSS J1530 + 1049. This is the largest redshift of any known radio galaxy. The object was selected as a high-redshift radio galaxy candidate based on its very steep spectral index at a frequency of 150 megahertz and its compact morphology in radio imaging by the Very Large Array at 1.4 gigahertz. Searches for a counterpart at the location of the radio source in publicly available optical and infrared sky surveys revealed nothing. Consequently, the source was targeted, blindly, for deep spectroscopy at Gemini.

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

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

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

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Gemini staff contributions

On the Horizon

Funding from the National Science Foundation will allow Gemini to develop a multi-conjugate adaptive optics system at Gemini North and advance rapid follow-up capabilities for transient sources. SCORPIO, Gemini's next-generation instrument, remains on schedule for its Optical Critical Design Review by the end of November. The call for the Instrument Upgrade Program has been postponed until mid-2019. And the future GIRMOS instrument should ideally position Gemini to take the lead in the era of multi-messenger astronomy.

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

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

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

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

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

SCORPIO

Under the leadership of Massimo Robberto (Space Telescope Science Institute) and the management of Pete Roming (Southwest Research Institute), Gemini's next-generation instrument — the Spectrograph and Camera for Observations of Rapid Phenomena in the Infrared and Optical (SCORPIO; formerly OCTOCAM) — continues to make solid progress toward the Critical Design Review. Following a recent Quarterly Progress Meeting (see Figure 1) held at George Washington University in August, the team are on track to hold the Optical Critical Design Review by the end of November. On completion, the team will seek permission to purchase long-lead optical components for the instrument, including the collimator and camera optics for each of the eight channels.

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

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

Looking Forward to the Gemini Infrared Multi-Object Spectrograph

The Gemini InfraRed Multi-Object Spectrograph (GIRMOS) is a powerful new instrument being built for Gemini by a Canadian consortium of universities, led by the Uni-

Figure 1.
The SCORPIO team — from the Space Telescope Science Institute, Southwest Research Institute, George Washington University (GWU), FRACTAL, and Gemini Observatory — at the SCORPIO Quarterly Progress Meeting at GWU.

Credit: Alexander van der Horst

versity of Toronto and the National Research Council-Herzberg (NRC-Herzberg) Institute of Astronomy and Astrophysics. This instrument will address a key limitation in existing adaptive optics (AO) facilities where integral field spectrographs are only able to observe single objects with adequate atmospheric correction, significantly limiting many scientific programs that could be efficiently observed with multiple integral field units.

By taking advantage of the latest developments in multi-object AO (MOAO) and integral field spectroscopy, GIRMOS is designed to have the ability to observe multiple sources simultaneously at high angular resolution while obtaining spectra at the same time (Sivanandam *et al.*, 2018). It accomplishes this by exploiting the AO correction from both a telescope-based AO system (either GeMS or the prospective Gemini North MCAO system — see page 12) and its own additional MOAO system that feeds four 1-2.4 μm integral field spectrographs (R ~ 3,000 and 8,000) that can each observe an object independently within a 2 arcminute field of view.

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

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

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

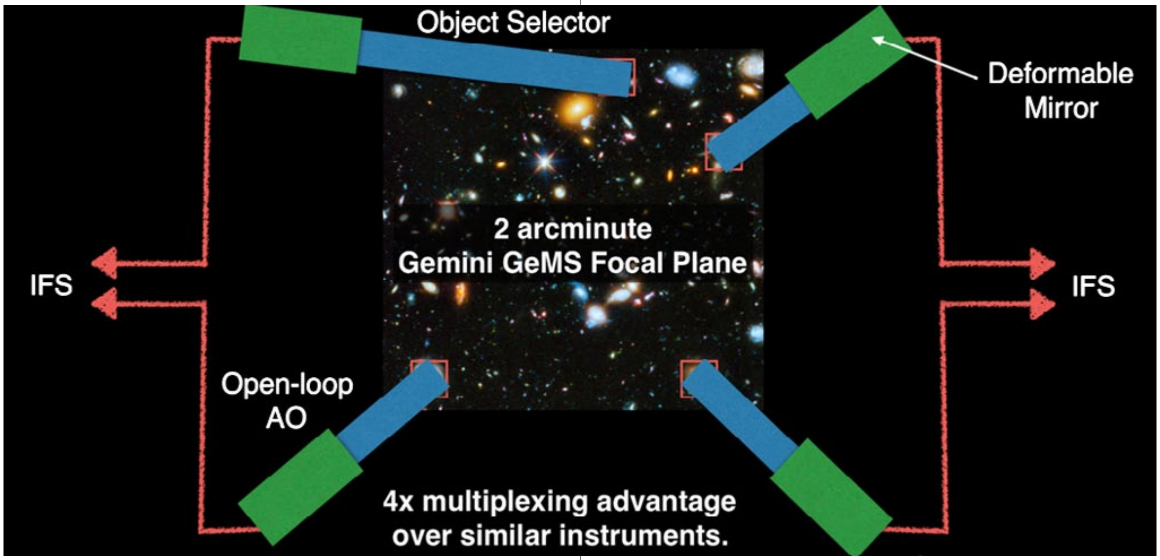


Figure 2.
Schematic of the GIRMOS instrument. Light from individual objects within the AO field is picked off by GIRMOS and corrected by an additional AO system before being fed into the IFS units. The IFS units offer larger fields of view for a given sampling scale when compared to existing IFSs. This offers up to ten times the multiplexing gain over existing AO spectrographs.

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

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

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

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

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

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

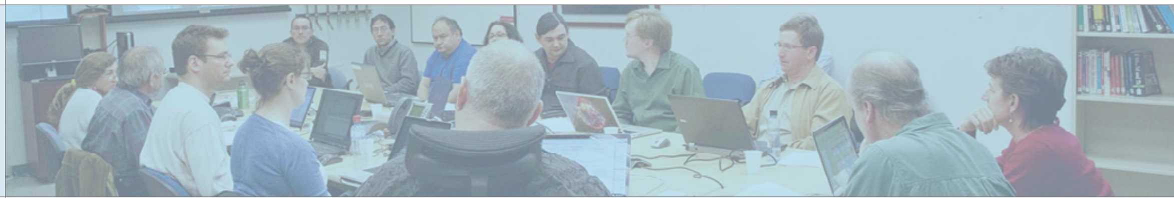
With its multiplexing ability, and particularly with the benefit of the newly announced Gemini North AO system which should provide an even better corrected field, GIRMOS at Gemini is ideally positioned to lead the era of multi-messenger astronomy, undertaking surveys of large samples of sources discovered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

No Instrument Upgrade Program Call this Year

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

References:

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



Gemini staff contributions

News for Users

Excitement mounts after Gemini hosts two new visiting instruments that promise to push polarization boundary observations at Gemini North. Work progresses on the cutting-edge radial velocity spectrograph MAROON-X and its Front End components. The new TOPTICA fiber laser for Gemini North nears commissioning. After a complete disassembly, lens bubbles have been eliminated in the collimator assembly of GMOS-S. Gemini South's annual shutdown is a rousing success as efficiency improves. Now a shutdown at Gemini North is underway.

Polarimetry Abounds at Gemini North

In July and August 2018, we had the pleasure of two visiting instruments pushing the boundaries of polarization observations at Gemini North. First Jeremy Bailey and Daniel Cotton (both University of New South Wales) arrived to test their "new-to-us" instrument HIPPI-2 (Figures 1 and 2). Designed to capture the direct polarization signatures of exoplanets, this instrument has been in use at the 3.9-meter Anglo-Australian Telescope with spectacular results (Bott *et al.*, *Monthly Notices of the Royal Astronomical Society*, **459:** L109, 2016). The Gemini visit also went well, and though the instrument has not been made available for science observations yet, these initial tests will be very helpful in characterizing the polarization characteristics of the Gemini North telescope. We hope to include HIPPI-2 in a future Call for Proposals, so please remember to check the list of visiting instruments whenever a new call comes out!

Figure 1 (bottom left). *Jeremy Bailey (left) and Daniel Cotton (right) attach their tiny HIPPI-2 instrument to the bottom port of Gemini North, with help from Harlan Uehara (Maunakea Site Manager, center).*

Credit: Alison Peck

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

Credit: Alison Peck

Figure 3.

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

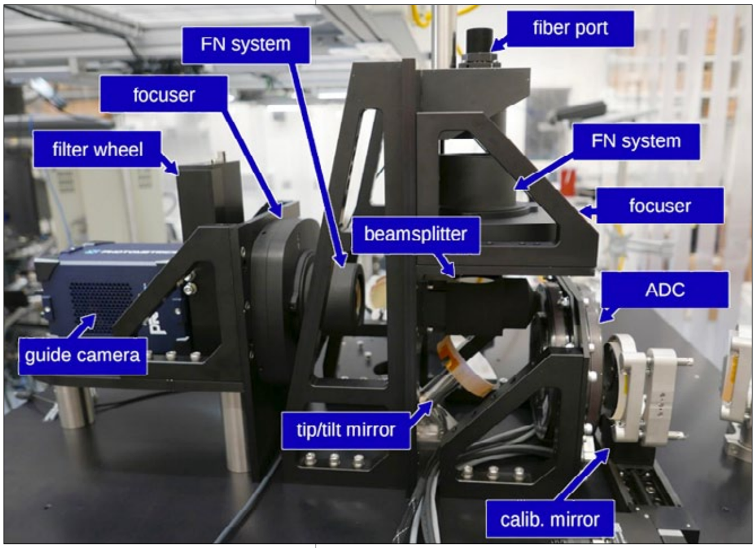
Credit: Alison Peck

In early August, we hosted a science visit by Principal Investigator Sloane Wiktorowicz (The Aerospace Corporation, El Segundo, California) with his instrument POLISH-2 (Figure 3). Aimed at exoplanet reflection polarimetry, POLISH-2 is available to the community, and we encourage everyone to have a look at the Call for Proposals and contact Sloane (using the details provided there) if they wish to take advantage of this cutting-edge polarimeter on Gemini North. The amount of time our visiting instruments are available on the telescope is driven by the number of successful proposals, so we encourage everyone to go for it! The exciting results of this recent observing run are being prepared for publication now.

MAROON-X: Coming Soon!

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

As this instrument will be located in the pier lab, under the telescope, in its own thermally controlled enclosure, Gemini has commissioned a Front End to interface to the Instrument Support Structure. This unit will hold the optical fiber that runs to the instrument and will also include some optics and electronics, as shown in Figure 4. The Front End



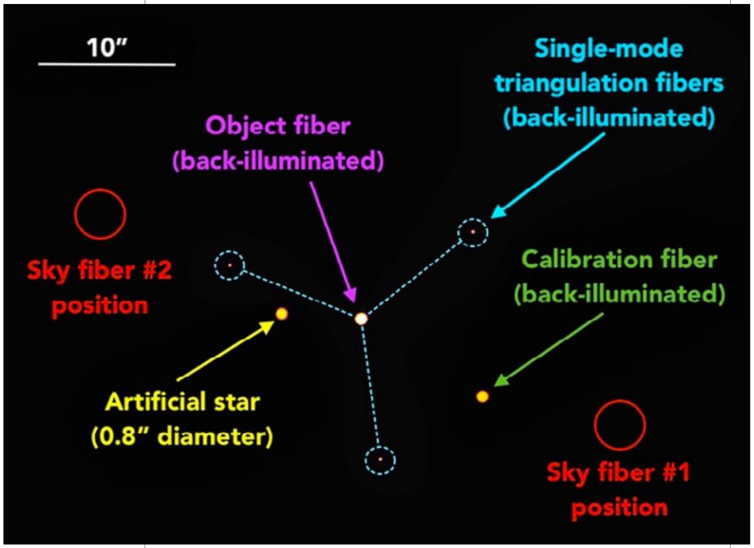


Figure 4 (above left). *The MAROON-X Front End nearing completion at the lab in Chicago.*

Credit: Andreas Seifahrt

Figure 5 (above right). *MAROON-X guide camera diagram showing the object fiber in the center (back-illuminated), surrounded by three single-mode fibers. These three fibers allow us to triangulate the position of the object fiber in real time during the observations. A tip-tilt mirror is used to center the stellar image on the object fiber. For lab testing, an "artificial star" was created by placing a pinhole at the nominal telescope focus and illuminating it with an f/16 beam. Two sky fibers, placed 20" from the object fiber in opposite positions, are used to capture the sky background for a high-dispersion spectrum in MAROON-X and for a time-resolved, low-dispersion spectrum with an external spectrograph. A calibration fiber transports light from the spectrograph room to the telescope's front end and is used to illuminate the object and one of the sky fibers for flatfield and wavelength calibration frames. Credit: Andreas Seifahrt*

components are integrated and undergoing testing in Chicago at this time; the pre-ship acceptance test is scheduled for late October. The plan is to commission the Front End on the telescope first, using a simple detector, so that we are ready to commission the MAROON-X spectrograph when it arrives next year.

TOPTICA Laser Update

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

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

The addition of new equipment high on the telescope required additional counterbalance weights for the telescope. These weights were designed and added in sequence; doing so allowed us to install the laser components (GNEST and EC) while maintaining telescope balance through the day (July 19th). We then installed the utilities and services for the laser. Testing began with power on August 16th, followed by first open-beam verification on the 22nd. Laser alignment through the optical path to the Beam Transfer Optics Optical Bench on the secondary was verified, allowing us to conduct our first on-sky propagation at zenith on August 31st.

Figure 6 (above left).
Gemini Optical Engineer Tom Schneider prepares insulation for GNEST (laser housing designed for our TOPTICA laser head and optical bench).

Figure 7 (above center).
Gemini senior optical technician Clayton Ah Hee (left, in foreground) and Gemini summit crew member John Randrup prepare GNEST for installation onto telescope.

Figure 8 (above right).
Verifying laser alignment through the optical path to the Beam Transfer Optics Optical Bench on the secondary.

Figure 9 (bottom right).
Installing GNEST onto telescope truss below top ring.

Credit: All photos this page by Jeff Donahue

This was conducted remotely from the Hilo Base Facility. We continue to prepare for commissioning.

GMOS-S Bubbles Eliminated!

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

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

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

The results as measured with the detector all fell well within specifications (the goal was to be within a 10 pixel difference, and there was a 4-pixel difference with respect to the starting position). After the telescope shutdown, we fully checked and released the instrument for operation again.

Gemini South Shutdown Completed

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

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

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

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

Gemini North Shutdown Underway

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

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

Figure 10. *Performing maintenance on the Science Fold mechanisms in one slice of the A&G unit.*
Credit: Joe D'Amato

Joanna Thomas-Osip

Science and Evolution of Gemini Observatory 2018 Conference a Success!

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

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

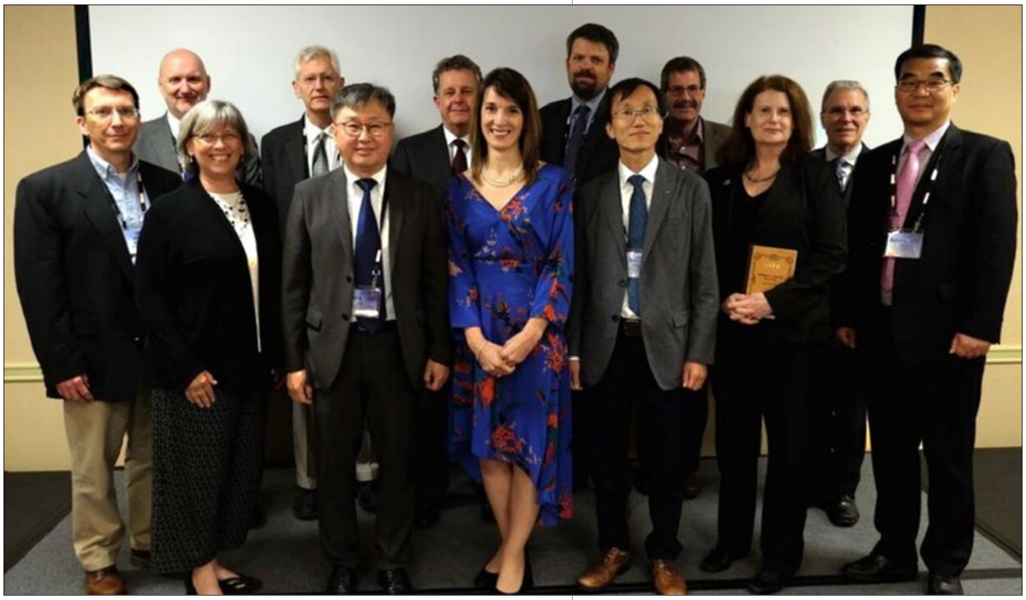
Extra-curricular activities included a ***tutorial on GMOS IFU data reduction***, "Under the Hood" talks on the practical aspects related to running a Large and Long Program, and a Speed Collaboration workshop. The Gemini User's Committee also held its annual meeting in conjunction with this conference.

Joanna Thomas-Osip is the Head of the Science User Support Department at: jthomas@gemini.edu

Science and Evolution of the Gemini Observatory 2018 conference participants.

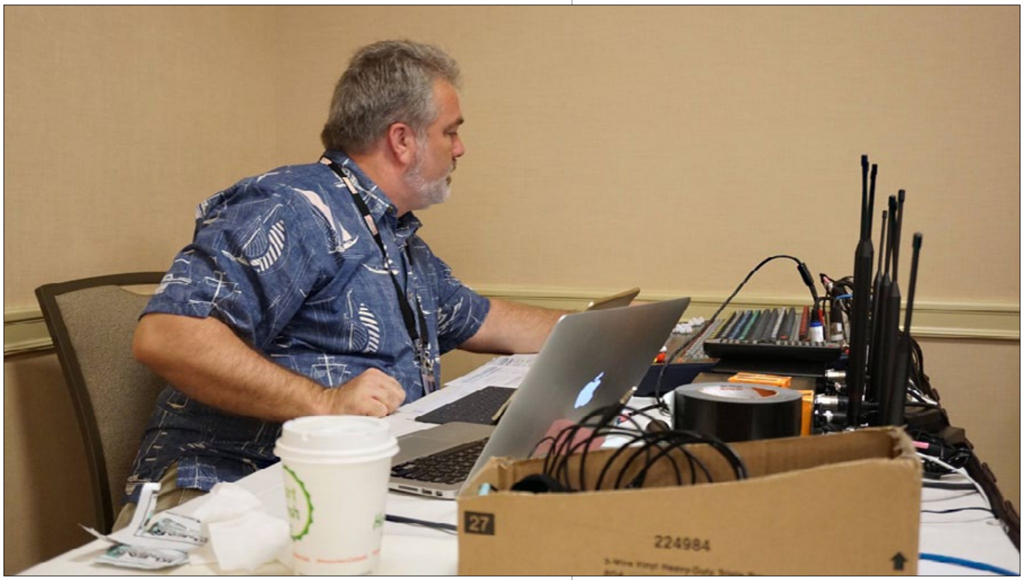
Credit: All photos in this article by Shari Lifson

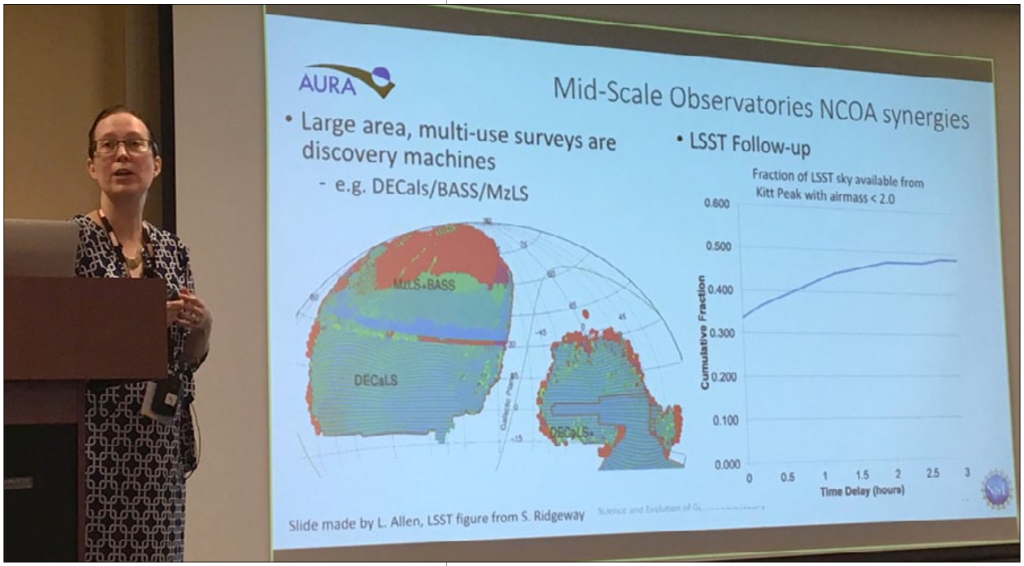
KASI, NSF, AURA, and Gemini leadership at Korea signing event. Left to right: John Blakeslee, Chris Davis, Heidi Hammel, Rene Walterbos, Hyung Mok Lee, Matt Mountain, Laura Ferrarese, Henry Roe, Narae Hwang, Ralph Gaume, Anne Kinney, Richard Green, Byeong-Gon Park.



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

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





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

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

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

"On the Horizon" Sunset on Maunakea captured by Joy Pollard during commissioning of the Gemini North TOPTICA laser. Watch for more images of the new laser in future issues of Gemini*Focus!*

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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