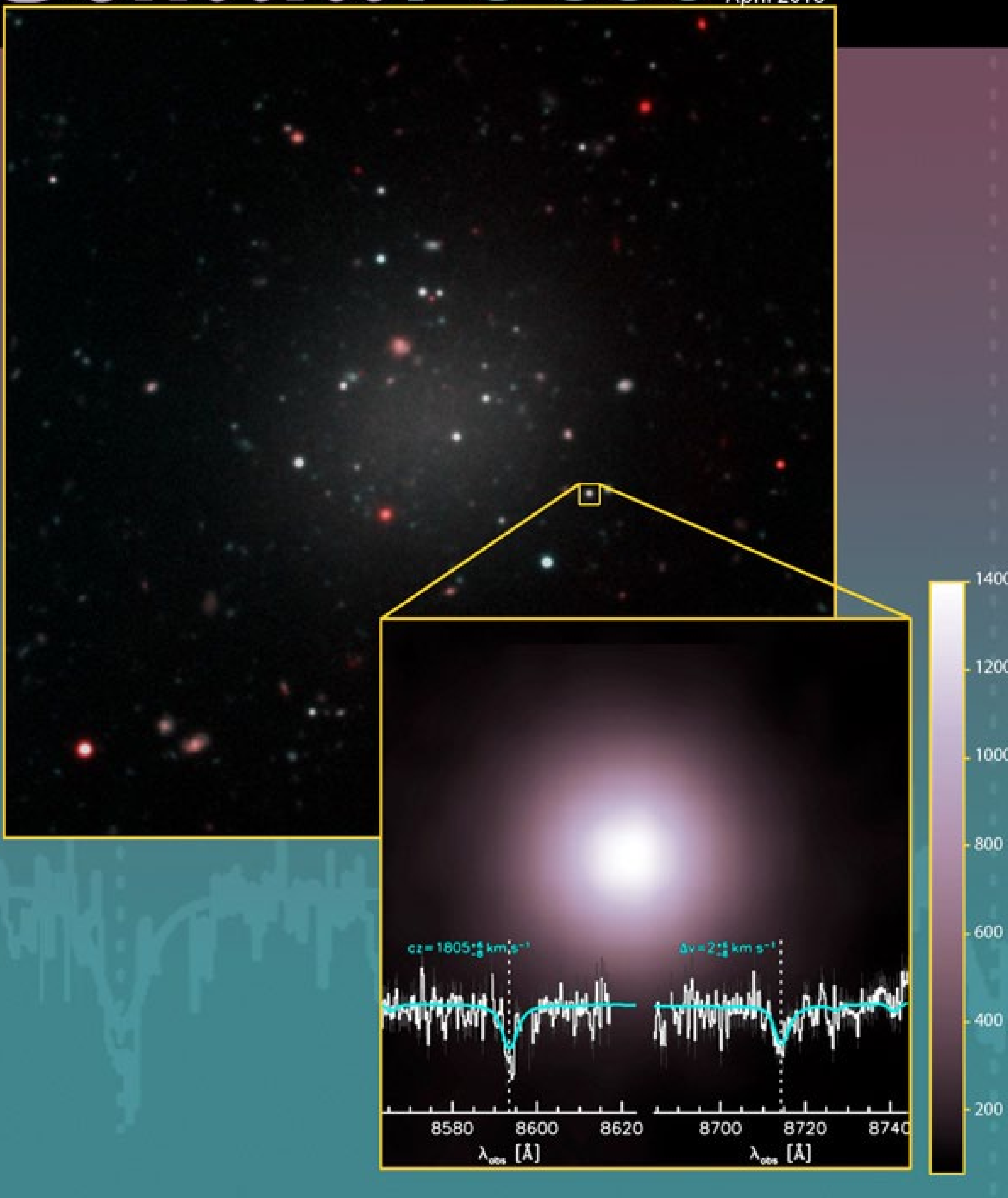
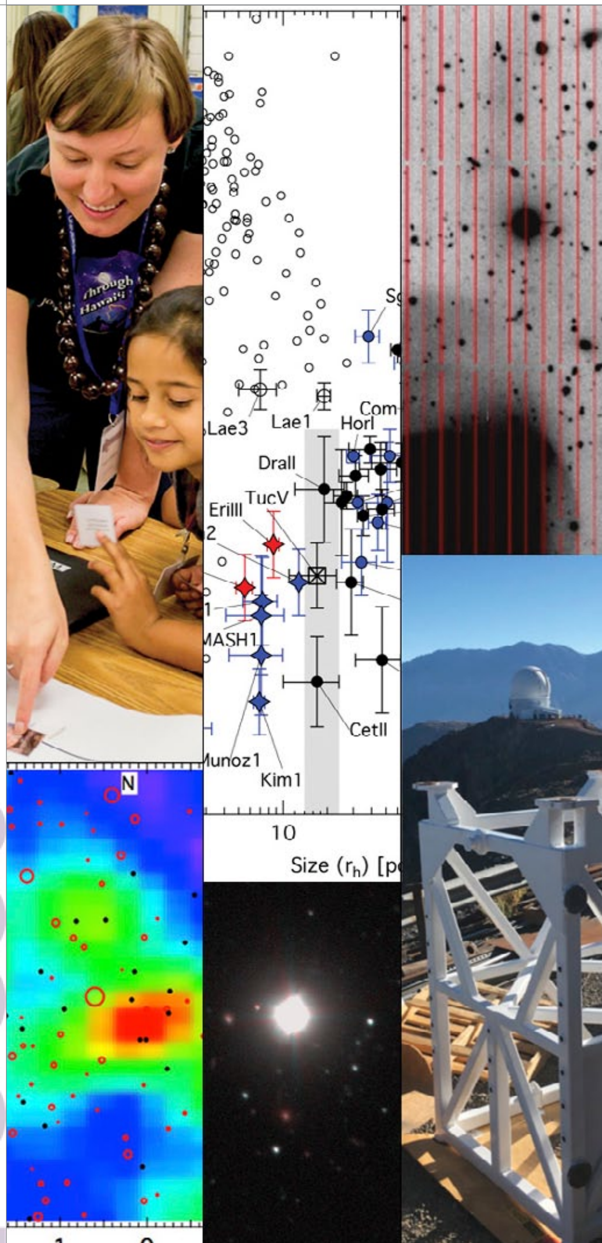
Publication of the Gemini Observatory

GeminiFocus

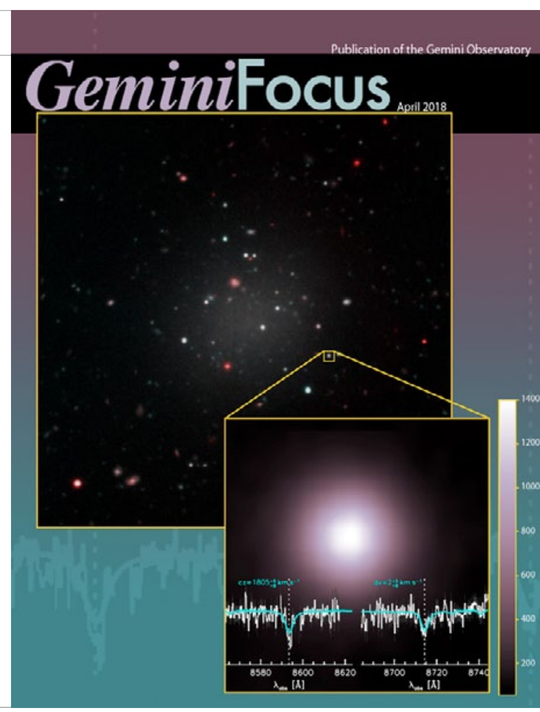
April 2018





ON THE COVER:

Composite image of the ultra-diffuse galaxy NGC1051-DF2 which was found to be devoid of dark matter. Also shown is a blow-up of one of the galaxy's globular clusters and a spectrum of it from the W.M. Keck Observatory. The work, led by Pieter van Dokkum of Yale University, is featured in this issue's Science Highlights starting on page 8.



*Gemini*Focus April 2018

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Laura Ferrarese

Director's Message

Gemini: So Much More Than a Place of Employment

Hello, Aloha, and Hola, everyone.

Uncharacteristically, the opening of this issue's Director's Message is not about science but about people: the people who make the science happen, and those whom they inspire.

Each year, the beginning of March marks two very special events for the Gemini facilities in Hawai'i and Chile. This year, during the week of March 5th, along the eastern side of the Big Island of Hawai'i, over 80 STEM professionals visited 300 plus classrooms, where their presentations, demonstrations, and workshops inspired over 8,000 students, from elementary to high school. The program, *Journey Through the Universe*, started 14 years ago at various locations across the US. As the original grant that funded it has run its course, *Journey* has faded everywhere else, but in Hawai'i it has been growing steadily with each passing year.

I had a small part in this year's *Journey*, participating in a "career panel" at the local Hilo High School, where my colleagues and I shared our paths that led us to our present careers, the challenges we encountered, and the opportunities that the observatories can offer. I confess that I entered my first classroom with some trepidations: how will the students (9th graders!) react? Will they be interested? Or will they just sit there wishing they were somewhere else? How misplaced my concerns were. The students were delightful — shy at first, perhaps, but attentive, interested, and curious. I left wishing I could do more, regretting how little time I can devote to outreach, and desperately searching for an excuse that would allow me to find myself on the Big Island, one year from now, at the beginning of March!

Meanwhile, in Chile, similarly inspiring activities took place during the week of March 16th. More than 3,000 people participated in *AstroDay Chile 2018*, an event that includes science workshops, lectures, career panels and, last but not least, a massive star party. And at this point I cannot help but mention, with some amount of pride, although I can take no credit whatsoever for any of it, that both *Journey Through the Universe* and *AstroDay Chile* are coordinated by the exceptional staff of the Gemini Observatory's Public Information and Outreach (PIO) Office: Alexis, Christine, Dalma, Fernanda, Janice, Jason, Joy, Manuel, Peter, and Xiaoyu, along with current Gemini North PIO interns Hannah and Jasmin. Their dedication, and the dedication of all those who participate in *Journey* and *AstroDay*, is one of the many factors that make Gemini, and all observatories, so much more than mere places of employment. See pictures from this year's *Journey* and *AstroDay* programs starting on page 21 of this issue.

Moving to instrumentation, the big news is the arrival, at Gemini South, of the Cassegrain assembly for our next facility instrument, GHOST. The assembly, built by our colleagues at the Anglo Australian Observatory, was successfully tested at the beginning of February. We are now eagerly anticipating the arrival of the actual spectrograph, built in Canada by the National Research Council-Herzberg, and scheduled for delivery in the late spring of 2019.

For OCTOCAM, the next milestone, the Preliminary Design Review, will take place on April 4-5 at Southwest Research Institute headquarters in San Antonio, Texas. Meanwhile, Massimo Robberto, from the Space Telescope Science Institute, has joined the project as Principal Investigator, and we at Gemini are very much looking forward to working with Massimo and the rest of the OCTOCAM team to bring this exciting instrument to Gemini in time for the start of the Large Synoptic Survey Telescope (LSST) operations.

And finally, some big news on the National Center for Optical-infrared Astronomy (NCOA, working name) front: on February 22nd, the U.S. National Science Board endorsed the NCOA plan and recommended its implementation. NCOA, as you might remember, calls for the integration, within a single matrixed structure, of the operations of the current Gemini and National Optical Astronomy Observatory facilities with the future operations of LSST. NCOA will facilitate collaborations and partnerships and, critically, will provide opportunities for innovation that are presently beyond the scope and capacity of the individual centers. The National Science Board's endorsement was the last of a long series of reviews for NCOA, all of which it passed successfully. NCOA is now moving full steam ahead, with a planned start date of October 2018.

All of this — the outreach activities, the instrumentation, NCOA — is done for a single purpose: the advancement of science. But for that, I will leave you to the expert and eloquent commentary of our Chief Scientist, John Blakeslee, who highlights many of the recent science highlights from Gemini starting on page 8 of this issue.

Laura Ferrarese is the Gemini Observatory Interim Director. She can be reached at: lferrarese@gemini.edu

Blair Conn and Helmut Jerjen

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

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

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

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

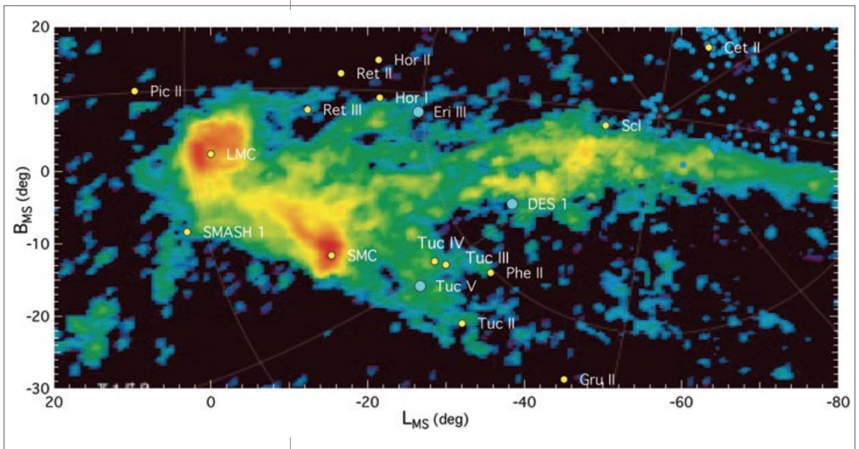

Figure 1.
The positions of three new ultra-faint dwarf galaxy candidates — DES 1, Eri III, and Tuc V (blue dots) — with respect to the Magellanic Clouds (LMC and SMC). Some additional new objects are highlighted as yellow dots. The underlying color map traces the density of neutral hydrogen gas associated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

Probing Candidates with GMOS

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

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

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

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

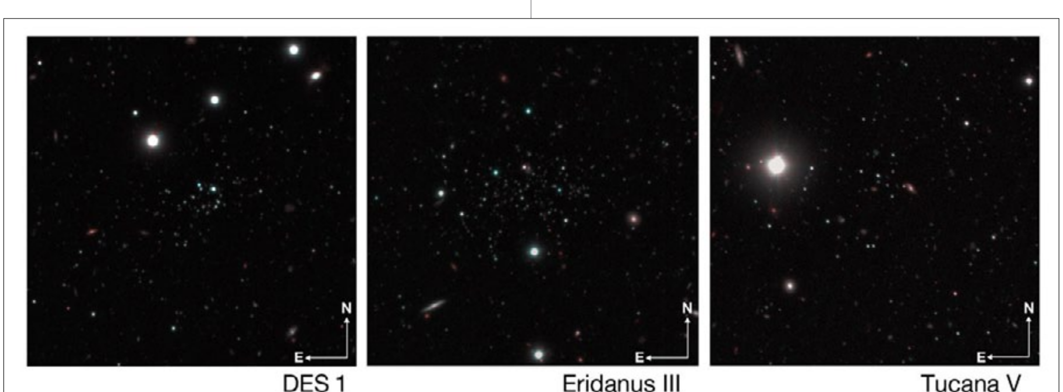

Figure 2.
Composite color images of DES 1, Eri III, and Tuc V. Both DES 1 and Eri III are noticeable as dense collections of stars in the center of the fields. Tuc V is a less-condensed collection of stars and therefore more difficult to see.
Credit: Images prepared by Jennifer Miller at Gemini North

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

DES 1 and Eri III: A Comparative Review

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

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

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

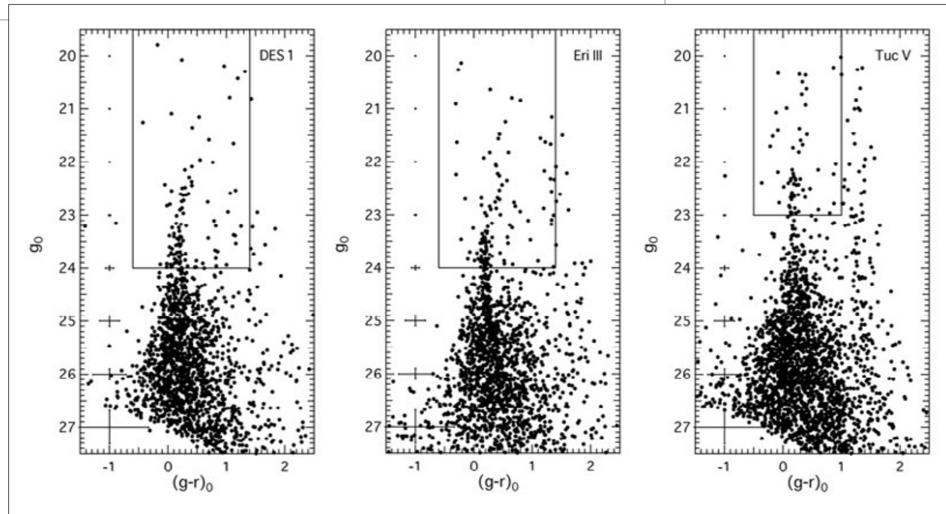

Figure 3.

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

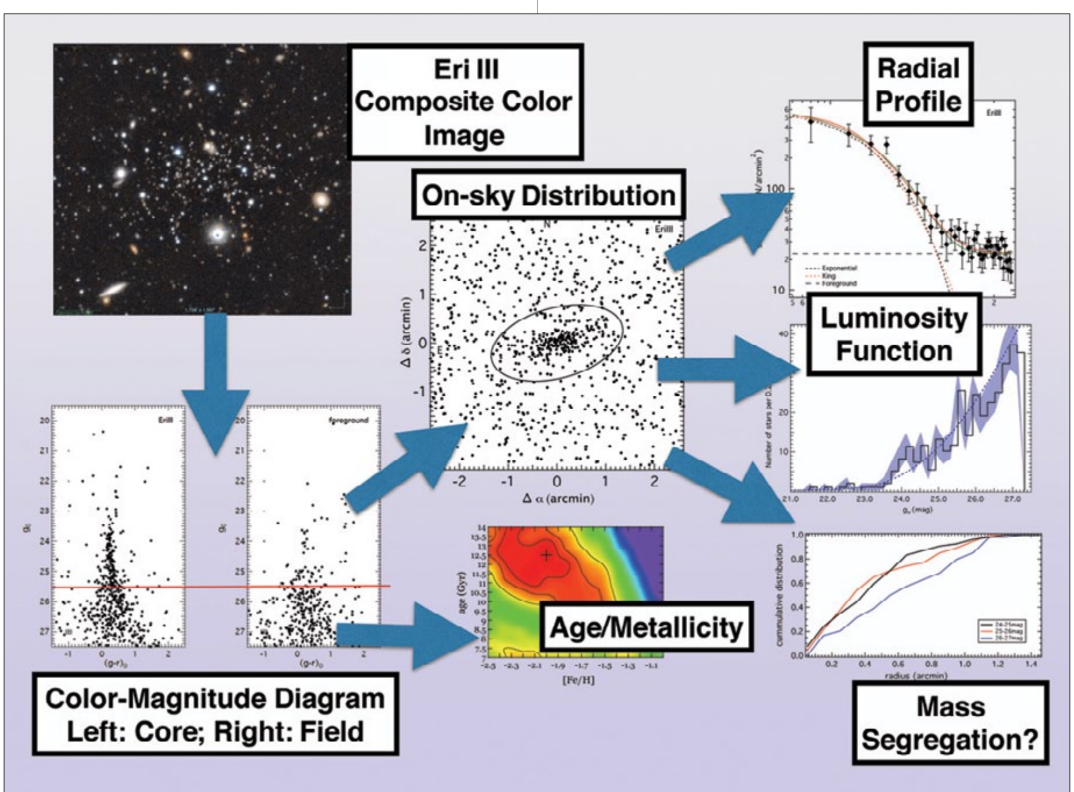

Figure 4.

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

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

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

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

What About Tuc V?

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

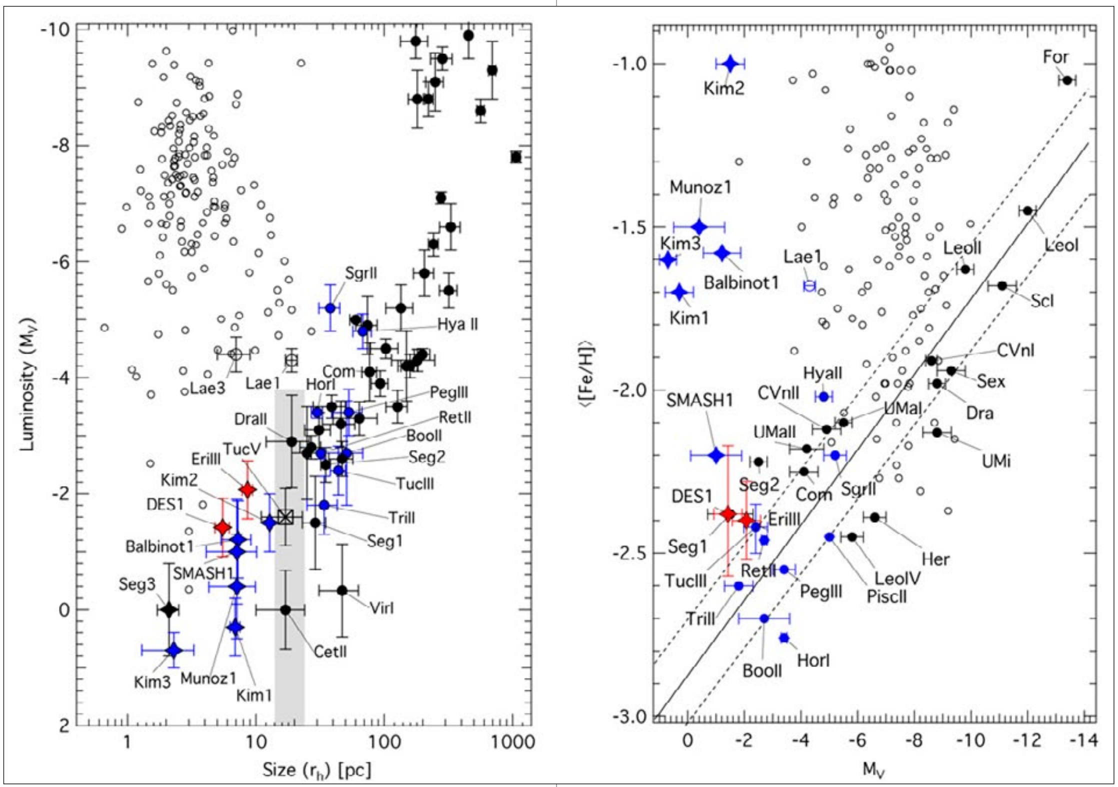

Figure 5.

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

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

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

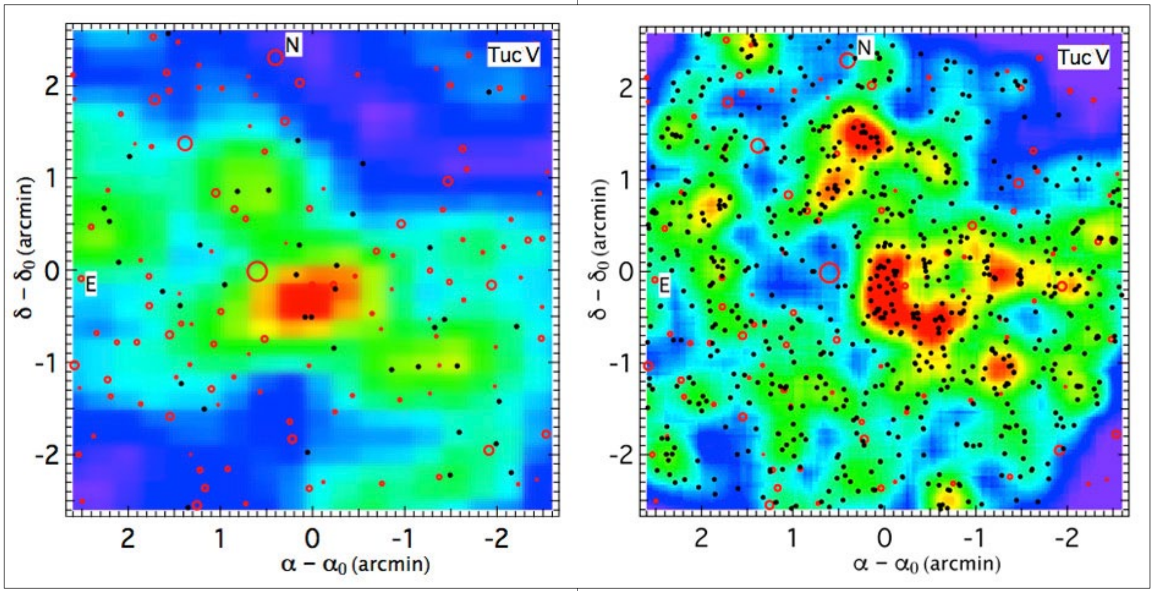

Figure 6.

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

confirm an overdensity that matched the discovery detection. In Figure 6, we can see how Tuc V looks in the discovery data (left panel) and with the deeper Gemini data (right panel). In the Gemini data, Tuc V dissolves into a series of low density knots rather than a coherent cluster as one would expect. So what is this intriguing object?

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

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

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John Blakeslee

Science Highlights

A medley of results on a diversity of galaxies: multi-slit imaging spectroscopy with the Gemini Multi-Object Spectrograph reveals star clusters being born from enriched gas around an old galaxy, stellar velocities in the most massive galaxies rise or fall depending on galaxy surroundings, and an ultra-diffuse galaxy rich in globular star clusters is startlingly poor in dark matter.

A New Generation of Star Clusters Adorning an Old Galaxy

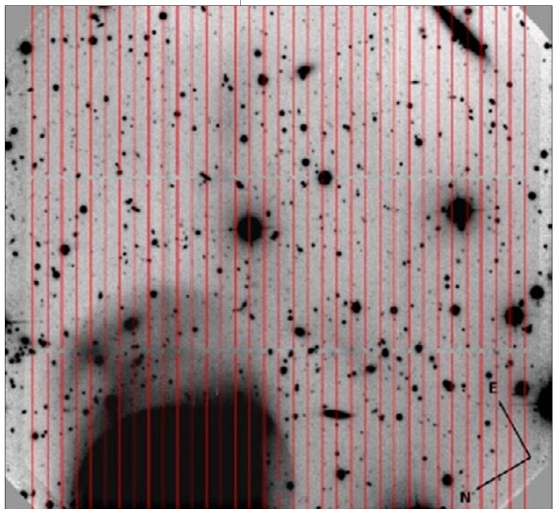
Elliptical galaxies are often described as "red and dead," meaning that the stars within them are generally many billions of years old, and they lack the material and wherewithal for any significant amount of star formation. The optical light in such old stellar populations is dominated by contribution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

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

By tuning the observed wavelength to that of the hydrogen-alpha (Hα) emission line, the MSIS technique makes it possible to find all the bright, actively star-forming regions within the GMOS field-of-view (Figure 1, right panel).

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

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



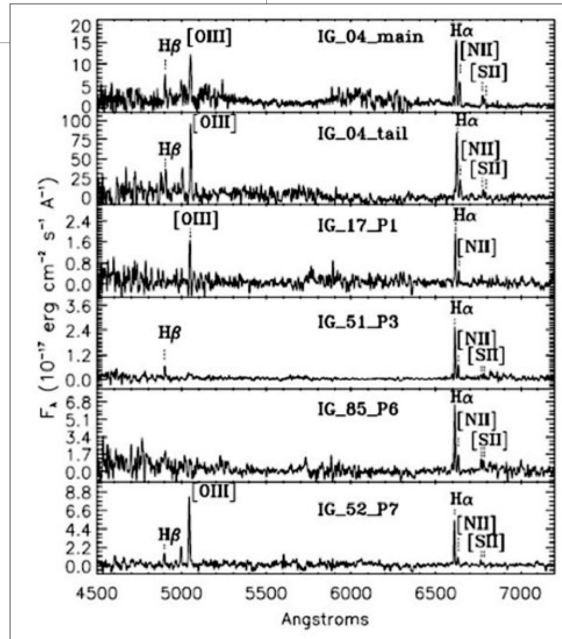


Figure 1.
Left: Design of the MSIS slit mask used to find sources of Hα emission around the galaxy NGC 2865. The red lines indicate the positions of the GMOS slits, which are one-arcsecond wide, overlaid on an r-band image of the field. A series of exposures are taken with the telescope offset by an arcsecond between exposures in order to obtain complete spectroscopic coverage of the entire field-of-view.
Right: GMOS-South follow-up spectra of six emission line regions found with the MSIS technique in the outskirts of NGC 2865. These are regions of active star formation, and the majority appear to be young star clusters being born from chemically enriched gas.

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

Diversity in Dispersion Profiles of the Most Massive Galaxies

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

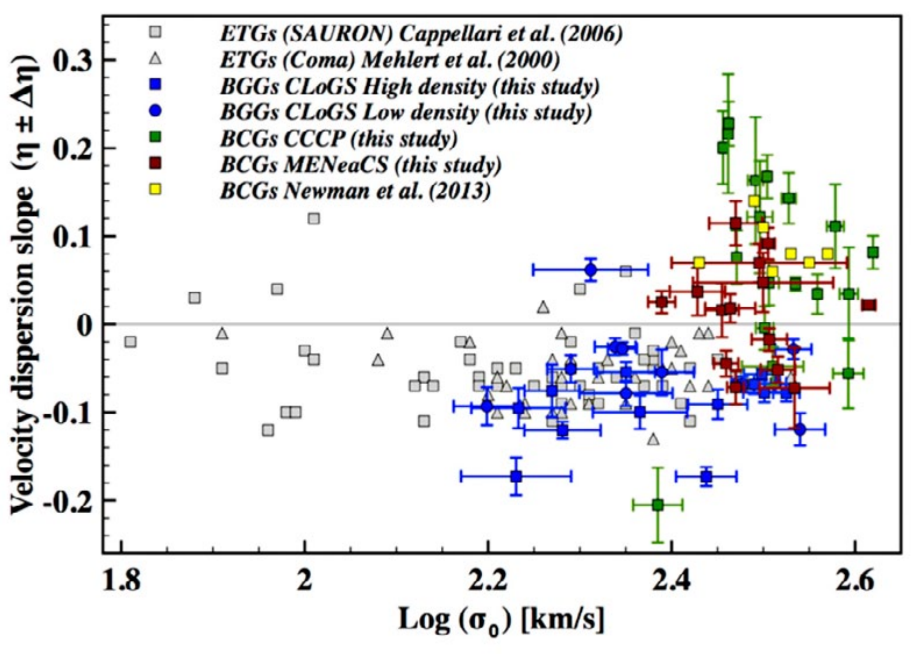


Figure 2. *The slope η of the velocity dispersion profile is plotted against the central velocity dispersion σ_0 for individual galaxies in multiple different samples of galaxies (indicated in the legend). The blue points represent brightest galaxies in groups (BGGs) of high (square) and low (circles) density, while the green, red, and yellow points represent brightest cluster galaxies (BCGs) in various samples of galaxy clusters. The grey points indicate generic "early-type galaxies" (ETGs). The central dispersion σ_0 is larger for massive galaxies because their stars move more rapidly in the stronger gravitational fields of such galaxies. The dispersion profile η is negative if the stars farther from the galaxy center move more slowly, and it is positive if the stars move rapidly at larger distances. Thus, massive BCGs tend to have rising profiles, with the stars increasing their velocities at larger distances from the galaxy center.*

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

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

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

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

The study also found that the slopes of the velocity dispersion profiles correlate with the galaxy luminosity (Figure 2), in the sense that the increase in the speed of the stars was greater in brighter BCGs, as well as in brightest group galaxies. Whether the full diversity in the observed velocity dispersion profiles is consistent with standard models for the growth of massive galaxies is not yet clear. The researchers present their results as a challenge for detailed cosmological simulations.

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

An Ultra-diffuse Galaxy Devoid of Dark Matter

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

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

Because the UDGs themselves are so faint, in many cases the easiest way of estimating their total masses is from the motions of the globular star clusters associated with the galaxies, as long as the galaxies are near enough to allow spectroscopic observations of the globulars in a reasonable amount of time. These compact star clusters move in response to the total gravity field, regardless of whether it is produced by luminous or dark matter. Values of the total mass derived from the speed of orbiting stars or star clusters are referred to as "dynamical mass" estimates. When the Dragonfly team noticed that one of their UDGs, dubbed NGC1052-DF2 because of its association with the NGC 1052 galaxy group, contained multiple bright compact points of light likely to be globular clusters, they knew it was a promising candidate for further study with larger telescopes.

"We used several of the world's premier observatories, and the flexibility and fast response time of Gemini were a key factor in the analysis," said Pieter van Dokkum of Yale University, lead author of the new study of NGC1052–DF2. "We requested Director's Discretionary Time to observe NGC1052–DF2, and it was observed nine days later. The Gemini image showed us that we had found a truly unusual galaxy." According to researchers, the Gemini data, taken with GMOS-North, provided "the best available information on the regularity of the galaxy at low surface brightness levels." Visual inspection of the Gemini images (see Figure 3) prompted the team to request a change in the scheduling of their Hubble program targeting UDGs found with Dragonfly; as a result, NGC1052–DF2 was given higher priority and observed sooner. The GMOS images were also used to select the globular clusters for spectroscopy with the Keck I telescope (see this issue's cover image montage).

The spectroscopic observations revealed remarkably little spread in the velocities of the ten globular clusters observed in NGC1052–DF2, and this narrow range of velocities has major implications for the mass of the galaxy. The researchers concluded that the total dynamically determined mass was very close to the observed mass of the stars in the galaxy. This is unusual because UDGs of this size typically have hundreds of times more mass in dark matter than in stars. "If there is any dark matter at all, it's very little," van Dokkum explained. "The stars in the galaxy can account for all the mass, and there doesn't seem to be any room for dark matter."

Because their result was so surprising, the researchers considered several possible sources of error in the analysis. One possibility was that NGC1052–DF2 is not actually in the NGC1052 group at a distance of 20 megaparsecs (65 million light years), but much closer to us. If so, the estimated mass in stars would be much lower, meaning that a substantial amount of dark matter would then be needed. Such a nearby distance would be unlikely based on the velocity of the galaxy, but perhaps not more unlikely than a galaxy devoid of dark matter; moreover, the brightness of the globular clusters suggested that the distance might be only half as large as assumed. Fortunately, the high-resolution Hubble images enabled an independent measure of the distance via analysis of the galaxy's surface brightness fluctuations, the same statistical method that recently provided the most precise distance to the host galaxy of GW170817, the first gravitational wave event with an observed electromagnetic counterpart. Using this technique, the researchers found evidence that the UDG was within the NGC 1052 group, reducing this source of uncertainty.

Somewhat counterintuitively, the conclusion that NGC1052–DF2 lacks detectable dark matter constitutes a strong argument against theories that dispute dark matter's existence. Such alternative theories posit that gravity simply works in a different way than described by Einstein's highly successful General Relativity theory, and there is no need for dark matter to provide additional gravitational force to hold galaxies together. But if this were the case, gravity should always act in the same alternative way for a given amount of visible matter, such as the stars observed in NGC1052–DF2. Clearly this is not the case, since other galaxies with the same quantity of stars show very different internal motions indicative of a much stronger gravitational field, easily explained by dark matter.

So far only a few UDGs have dynamically measured masses, and most of these are abundant in dark matter. However, the team is continuing to follow up on others discovered by the Dragonfly array. If more galaxies like NGC1052–DF2 come to light, it will provide much needed demographic information to aid in understanding how such galaxies form in the absence of dark matter.

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

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

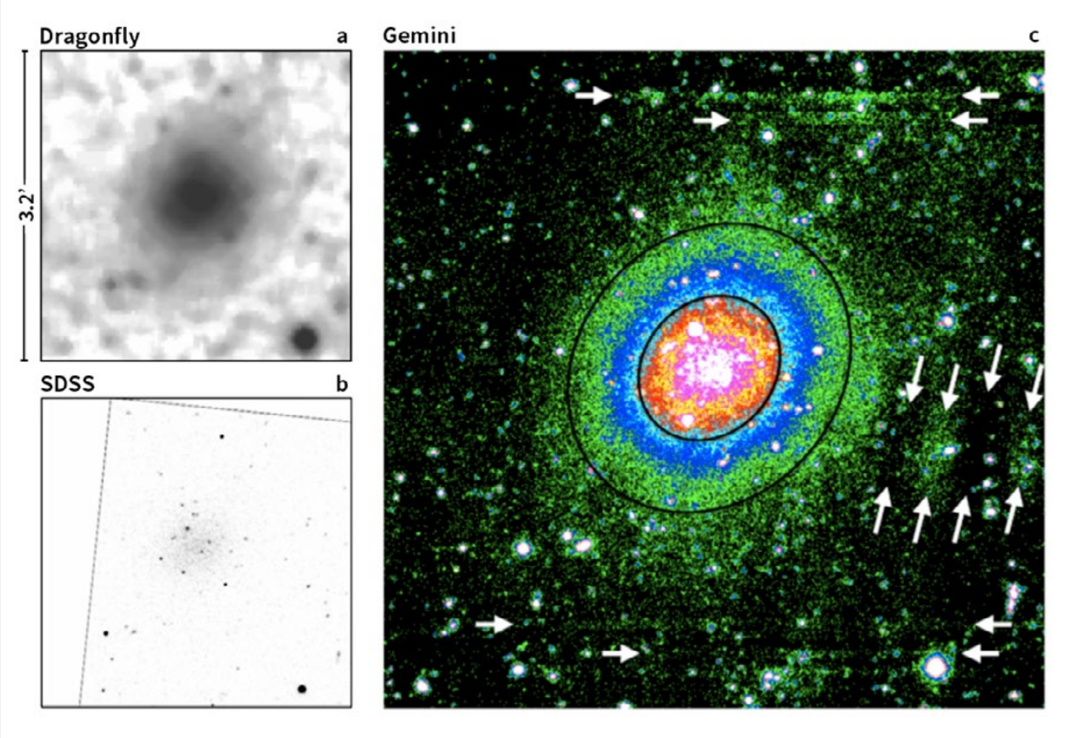
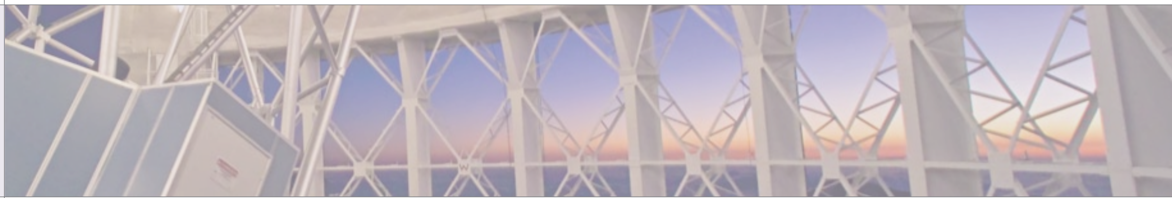


Figure 3.
Three views of the unusual dark-matter deficient galaxy NGC1052–DF2. The upper left panel shows the sum of the g and r images taken with the Dragonfly Telephoto Array, in which the galaxy appears as an extended, low-surface-brightness "blob." The lower left panel shows a sum of g, r, and i images from the Sloan Digital Sky Survey (SDSS), revealing a concentration of compact objects overlaid on a faint fuzz. The panel at right shows the Gemini North i-band image of NGC1052–DF2, which provided the best information on the morphology of the galaxy. Black ellipses indicate the effective radius (containing half the total light) and twice the effective radius; white arrows mark artifacts of the reduction that become visible at faint levels. The galaxy has a regular elliptical shape without any significant variations with radius.



On the Horizon

GHOST's Cassegrain unit captures first light. The OCTOCAM project receives both a new Principal Investigator and Instrument Scientist as it nears its Preliminary Design Review. And demand is high for the new visiting instrument IGRINS, a broad-band, high-spectral-resolution spectrometer at Gemini South.

First Light for GHOST's Cassegrain Unit

In January 2018, the Cassegrain unit for the Gemini High-resolution Optical SpecTrograph (GHOST) arrived safely at Gemini South (Figure 1). It is the first of three primary assemblies to arrive and will be mounted on the telescope's Instrument Support Structure (ISS); the other two are the spectrograph bench (to be located in the pier lab), and a 30-meter-long fiber cable connecting the two. The Cassegrain unit contains the positioning arm system, the object and sky fiber integral field units (that capture all the light), and their corresponding atmospheric dispersion correctors.

Figure 1.
Second of two trucks delivering the Cassegrain unit to Cerro Pachón.

Credit: David Henderson

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

The combined teams prepared and installed the Cassegrain unit on the telescope's ISS to make the first checks on sky in early February (Figure 2).

The team had a successful night of testing, with the instrument performing very well. A few of the evening's accomplishments included confirming that GHOSTS' coordinate systems and field center were aligned within our measurements, and ensuring that the probe map of the positioners was well behaved. The team also mapped the unit's coordinate systems to the sky, acquired targets repeatedly over the entire seven arc-

Figure 2.

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

Credit: David Henderson

minute field-of-view, and verified that target acquisition (both direct and via spiral search) worked as expected in both the single target and two target modes. The team is enthusiastic about the performance of the GHOST Cassegrain unit and look forward to the arrival of the spectrograph from Canada's National Research Council-Herzberg.

— David Henderson and Catherine Blough

OCTOCAM Making Great Strides

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

Figure 3.

Massimo Robberto, the new OCTOCAM Principal Investigator.

In March, Gemini Observatory announced Massimo Robberto of Space Telescope Science Institute and Johns Hopkins University as the new OCTOCAM Principal Investigator (Figure 3). OCTOCAM also welcomed Todd Veach of Southwest Research Institute (SwRI) in San Antonio, Texas, as the OCTOCAM Instrument Scientist.

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

— Andrea Blank

TOPTICA Laser at Gemini South

After over two years of feasibility studies, specifications, design studies, tests, integrations, and validations, Gemini South's new TOPTICA Phototronics AG laser had its first night of commissioning on October 26, 2017. It took only ten minutes for the upgrade project's team of scientists, observers, and engineers to see our lovely five laser guide star constellation back on sky using the acquisition camera; and it took them only three nights out of five to validate the laser's performance; during the tests, the laser did not suffer any faults, and its output power was very stable at 22 watts.

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

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

— *Gaetano Sivo*

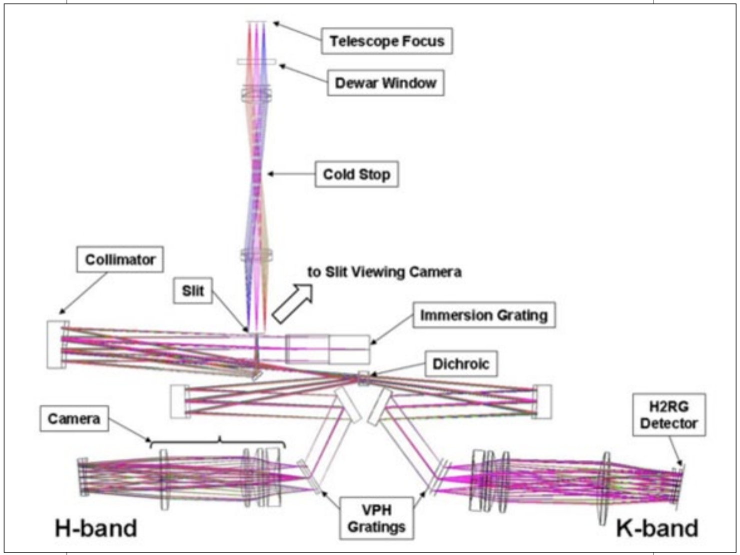


Figure 4.
Optical layout for IGRINS. All parts shown are within the cryogenic part of the instrument. For Gemini, the five optical elements between the dewar window and the slit were exchanged.

2018A Brings Outstanding Near-IR Spectroscopy to Gemini South

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

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

As a visiting instrument, IGRINS is ideal because it has a single observing mode and contains no moving parts (Figure 4). By exchanging the input optics to accommodate Gemini, the IGRINS H and K echellograms will be unchanged between facilities. In March, the instrument team (Figures 5-7) will accompany IGRINS to Gemini South, where

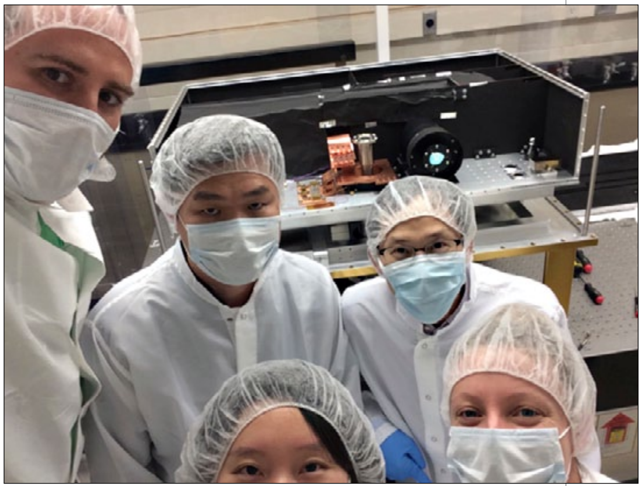


Figure 5.
The IGRINS team (left to right respectively, back row: Gregory Mace, Jae Sok Oh, Chan Park; front row: Heeyoung Oh and Kimberley (Sokal). Mace shot this "selfie" in the IGRINS lab at UT Austin in February 2018. The new input optics for IGRINS at Gemini are shown in the background after installation.

Credit: Gregory Mace (UT Austin)

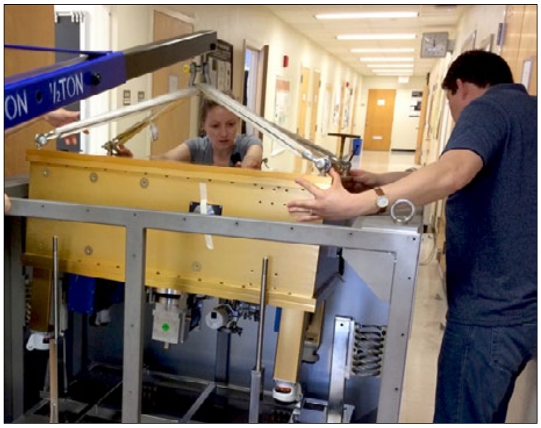
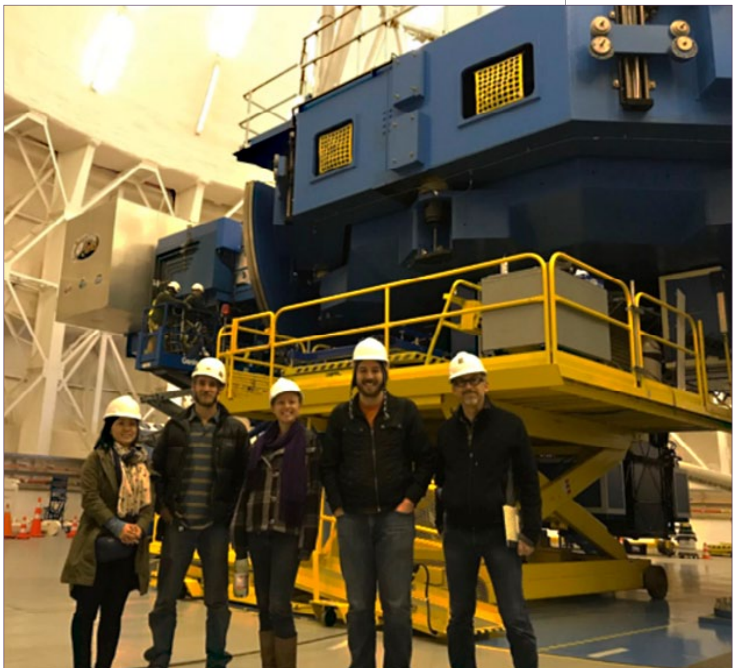


Figure 6.
IGRINS team members Kimberley Sokal (left) and Ricardo Lopez at UT Austin packing the instrument for shipping.

Credit: Gregory Mace (UT Austin)

Figure 7.
IGRINS and Gemini team collaboration during a site visit to Gemini South (Hwihyun Kim, Brian Chinn, Kimberly Sokal, Greg Mace, and John Good, from left to right respectively).
Credit: Kimberly Sokal (UT Austin).



they will install and test it before supporting observations with the help of Gemini staff for a total of 50 nights (figures 8 and 9). The team also will provide a simple data reduction pipeline to assist novice users.

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

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

— Alison Peck, Kimberly Sokal, and Hwihyun Kim

Figure 8.
Left: The IGRINS spectrograph slit (white bar) and a graduated scale used to measure optical performance. Lines resolved well below the slit width show that IGRINS optics for Gemini will perform as designed and sensitivity will be optimized.

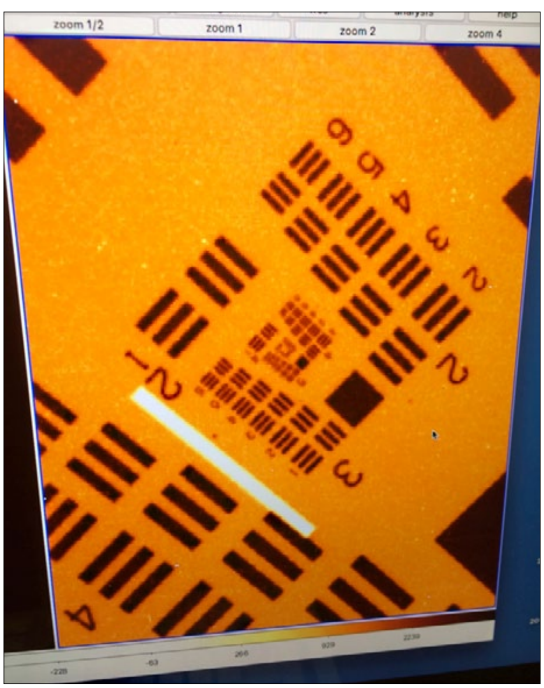


Figure 9.
Right: The modified ballast weight assembly waiting in Chile to attach IGRINS to the telescope.
Credit: Brian Chinn (Gemini)

Gemini staff contributions

News for Users

Gemini's 2018 Science Users conference promises to be the best yet. Large and Long Programs have new requirements for Principal Investigators. A recap of Semester 2017B highlights the mixed fortunes and exciting events at Gemini North and South. ANTARES feeds should become available to the community once LSST is up and running. And images from Gemini's cloudcams "went viral."

SEG 2018

The 2018 *Science and Evolution of Gemini Observatory* is shaping up to be the best Gemini Science Users conference yet. New to this year's program is a "Speed Collaboration" activity and "Under the Hood" talks; we invite you to go to our *Workshops page* to see what these programs are about and suggest a topic for the Data Reduction Workshop. Conference attendees will receive a glimpse into Gemini's place in the Large Synoptic Survey Telescope era and our plans to create synergy with the National Center for Optical and Infrared Astronomy. You won't want to miss this event! Regular *registration is open* through May 15th.

New LLP Program Policy

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

2017B Retrospective

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

Hawai'i

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

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

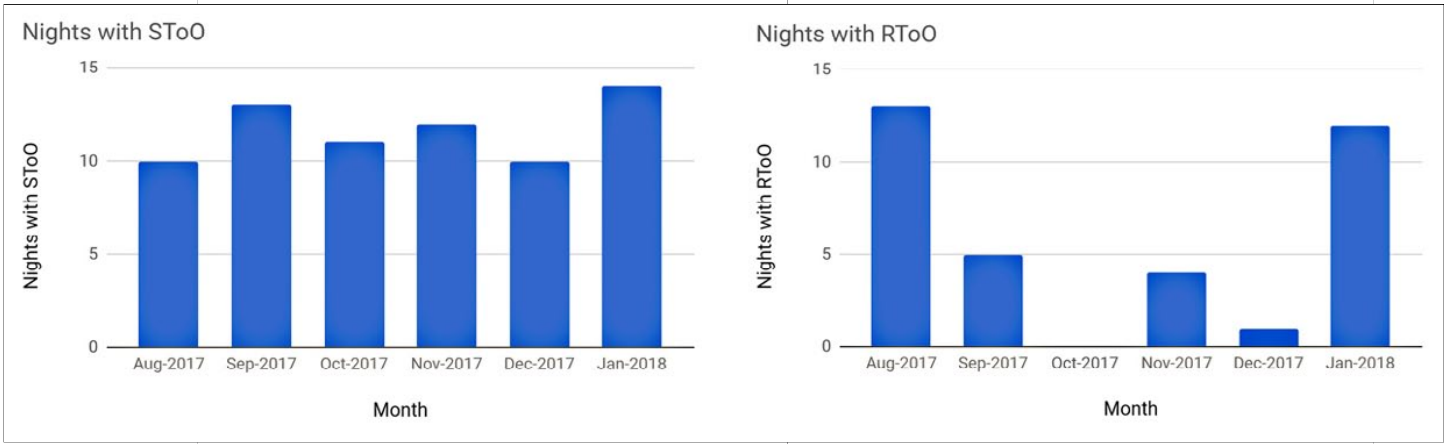
Following up on the interstellar asteroid 'Oumuamua (see the *January 2018 issue of GeminiFocus*, page 4) kept us busy and excited. 'Oumuamua was discovered during an 'Alopeke commissioning run, and we're grateful to the 'Alopeke team for bearing with us while we overrode their time to catch this extraordinary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

Chile

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

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

Figure 1. *The number of nights on which Gemini South responded to a Standard ToO request (left) and a Rapid ToO request (right).*



was due to Rapid, rather than Standard, ToO triggers (the peak in August was due to the LIGO gravitational wave event).

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

FLAMINGOS-2's on-instrument wavefront sensor (OIWFS) continued to generate mechanical problems, and we had planned an intervention early in the semester. As mentioned above, the LIGO gravitational wave event caused us to delay repairs, which we completed late in 2017. Multi-Object Spectroscopy (MOS) commissioning of FLAMINGOS-2 was delayed (as the MOS relies on the OIWFS) but is now underway. Finally, the Gemini Multi-conjugate adaptive optics System/Gemini South Adaptive Optics Imager operation profited greatly from the new TOPTICA laser (see page 14).

Possible Ways to Access ANTARES

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

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

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

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

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

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

Gemini's Cloudcams

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

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

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

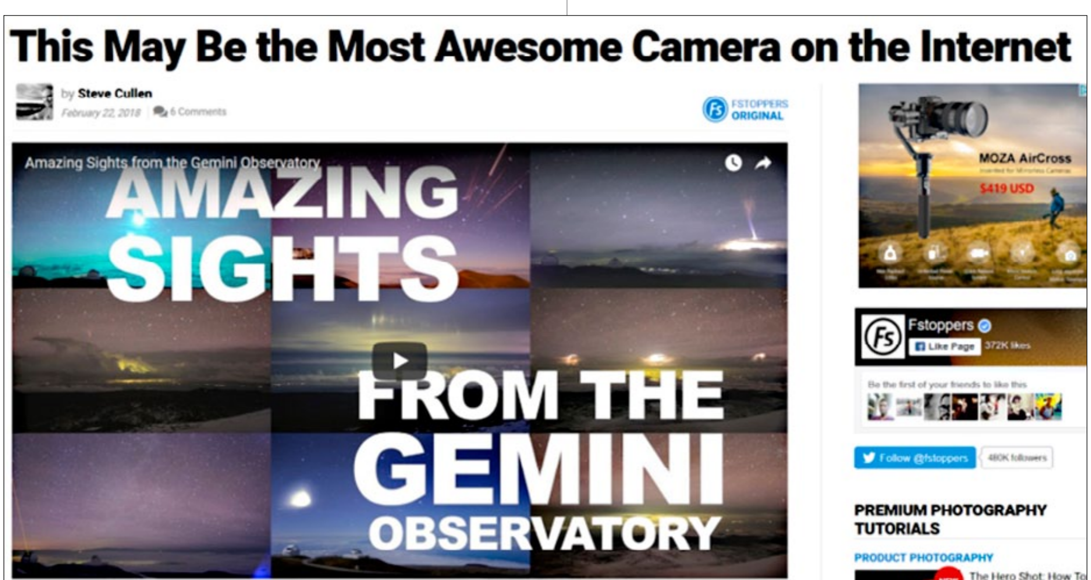
These cameras are in use every night when we are open for observing, and provide observers with the information they need. In addition, they also catch many interesting phenomena — natural and otherwise — and we fairly frequently receive requests for images when there has been, for example, extreme weather.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

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

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

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

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




Janice Harvey and Manuel Paredes

Public Outreach Efforts Soar in Hawai'i and Chile

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

Journey Through the Universe: *14 Years and Counting!*

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

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

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

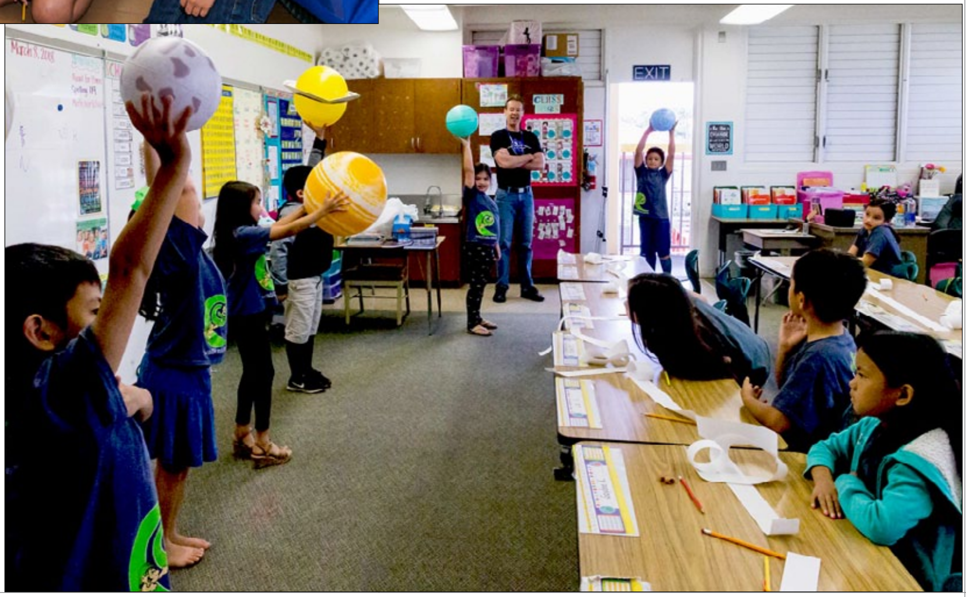
Credit: All images, Gemini Observatory

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

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

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

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



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

AstroDay Chile 2018

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

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

Janice Harvey is the Outreach Specialist at Gemini North. She can be reached at: jharvey@gemini.edu

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

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

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

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

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

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

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

A view of Gemini North by moonlight obtained by Gemini science fellow Jason Chu. Note that the skew of the Gemini dome is caused by the wide-angle lens used, not the pull of the supermassive black hole at the Galactic Center overhead!

AURA

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

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