NOAO
NEWSLETTER

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NOAO NEWSLETTER

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On the Cover

Star trails arc around Polaris located immediately above the ten-story-tall McMath-Pierce Solar Telescope at Kitt Peak National Observatory. The McMath-Pierce is being transformed into the Windows on the Universe Center for Astronomy Outreach thanks to a $4.5 million grant from the National Science Foundation. (Credit: W. Livingston/NSO/AURA/NSF)

From the Office of the Director

In July 2018, the National Science Foundation requested that formation of the new National Center for Optical-Infrared Astronomy (NCOA) be postponed until at least 1 October 2019 to allow more preparation time. Consequently, NOAO lives on. For our organization, under any name, FY19 promises to be an exciting year in the areas of wide-field surveys, time-domain science, and exoplanet characterization as well as advancing the concept for a bi-hemispheric system of extremely large telescopes (ELTs). It's also going to be another exciting year for our education and public outreach team, with the July 2019 total solar eclipse in Chile as a highlight.

The wide-field survey science theme within NOAO will make several major advances. At the KPNO Mayall telescope, the DOE-sponsored Dark Energy Spectroscopic Instrument (DESI) Stage 4 dark energy survey will commence. Piggybacking on the main redshift survey will be major sub-surveys of approximately 10 million bright galaxies within z ~ 0.2 and approximately 10 million Galactic stars. Meanwhile, at the CTIO Blanco telescope, the Dark Energy Survey (DES) will finish its 5.5-year run, as will the DECam-enabled subset of the Legacy Survey. With those major surveys completed, a new set of major community-driven imaging surveys will begin. The NOAO Data Lab will continue to support exploration and analysis of all these major surveys with additional capabilities. While enabling "science now," these surveys and tool developments are pathfinders for LSST community science support in FY22 and beyond.

Major advances will also be made in the time-domain research infrastructure arena. The Arizona-NOAO Temporal Analysis and Response to Events System (ANTARES) will process the public alert stream produced by the Zwicky Transient Facility (ZTF) and publish a variety of value-added information while allowing scientists to find transients of interest in the stream. Access will be provided to telescopes operated by NOAO, the Gemini Observatory, and the Las Cumbres Observatory (LCO) for ZTF follow-up. We also anticipate providing follow-up support to characterize the sources of gravitational wave events detected by LIGO/Virgo. In collaboration with Gemini and LCO, NOAO will continue development of the Astronomical Event Observation Network (AEON), which will integrate brokering, scheduling, and data acquisition and reduction and will enable coordination among multiple groups to optimize resource use. We look towards a key preliminary AEON test using the SOAR 4.1m Observatory in Chile. As an aside, SOAR capabilities will be enhanced with the arrival of the cross-dispersed near-IR spectrograph TripleSpec 4 as it transfers from the Blanco telescope and also with the new optical echelle spectrometer STELES built by Brazil's national observatory, LNA. With its broad instrument complement and ability for flexible adaption to circumstances, SOAR is emerging as the ideal 4m-class time-domain research machine in the Southern Hemisphere. Again, this activity not only supports time-domain research now but also lays the foundation for the LSST-driven time-domain research revolution to come.

The discovery and characterization of exoplanets and exoplanet systems will take a giant step forward as NASA's Transiting Exoplanet Survey Satellite (TESS) mission hits full stride. Several facilities affiliated with NOAO will provide critical support. The fraction of close stellar binary pairs vs. actual exoplanets will be constrained by speckle-imaging observations at the SOAR 4.1m and WIYN 3.5m Observatories in Chile and Arizona, respectively. Exoplanet masses will be measured via doppler spectroscopy obtained using the CHIRON spectrometer at the SMARTS 1.5m telescope in Chile and the NEID spectrograph at the WIYN 3.5m telescope in Arizona. Much of this activity is supported by the NASA-NSF Exoplanet Observational Research (NN-EXPLORE) program.

As discussed in more detail later in this newsletter, the US Extremely Large Telescope Program is under development jointly by NOAO, the Thirty Meter Telescope International Observatory (TIO), and the Giant Magellan Telescope Organization (GMTO). Our mutual goal is to strengthen scientific leadership by the US community-at-large through access to extremely large telescopes in the Northern and Southern Hemispheres. This two-hemisphere model will provide the US science community with greater and more diverse research opportunities than can be achieved with a single telescope, and hence more opportunities for leadership.

Later in this issue, you will read about preparations for the July 2019 total solar eclipse in Chile, where CTIO is in the zone of totality. Keep your fingers crossed for clear skies! NOAO is also deeply involved on the global level with the IAU Einstein Schools Programme and dark skies education as well as outreach to primary and secondary school students at the local levels in Arizona and Chile. These activities are all outstanding demonstrations of how focusing expertise can have high impact despite limited resources.

Before ending, two notes about NOAO senior management. First, after 10 years as NOAO Deputy Director, Robert (Bob) Blum has been appointed Acting LSST Director for Operations. Not only did Bob manage much of the day-to-day operation of NOAO, he also played critical strategic leadership roles in its ongoing evolution. NOAO's loss is LSST's great gain! Second, my term as NOAO Director has been extended through 30 September 2019. It's a privilege to serve in this role, and I look forward to working to enable scientific leadership by a broad user community for another year.

In short, during FY19, NOAO will continue to be one of the world's most productive astronomical observatories while we lay the foundation for continued leadership during the 2020s and 2030s as part of NCOA. No matter what, it's going to be an interesting and exciting year.

Looking Ahead to Looking Back in Time with DESI

Daniel Eisenstein (Harvard University)

In 2019, the Kitt Peak National Observatory (KPNO) Mayall 4m telescope will begin the next epoch in its long scientific career as host of the ambitious Dark Energy Spectroscopic Instrument (DESI). DESI will conduct a five-year survey of galaxies, quasars, and stars, designed to make the most detailed three-dimensional map of the Universe yet surveyed. Installation of the instrument is now underway at the Mayall, with spectroscopic commissioning expected next summer.

Figure 1. The old top ring and prime focus cage being lifted out of the Mayall telescope in June 2018, to be replaced by the DESI top ring and corrector. (Credit: D. Sprayberry/NOAO/AURA/NSF)

DESI has been designed to study the phenomenon of dark energy, and more generally the consistency of our cosmological model, by the study of the large-scale angular correlations of galaxies and of the neutral hydrogen density of the intergalactic medium. The correlations in these maps probe cosmology in a variety of ways. Most central to the design of DESI is the measurement of the cosmic distance scale to sub-percent accuracy using the baryon acoustic oscillation (BAO) method. Here, we use the subtle but pervasive tendency of galaxy pairs to be separated by 150 Mpc due to the propagation of sound waves in the early Universe. Famously seen in the temperature anisotropies of the cosmic microwave background (CMB), these sound waves supply a well-calibrated distance scale that we can map at a wide range of redshifts, including to $z = 1080$ in the CMB itself. DESI will map 1/3 of the sky from redshift 0 to 3.5, detecting this correlation and inferring the distance scale and expansion history of the Universe.

These same maps will provide exquisite tests of our cosmological predictions for the growth of large-scale structure. For example, the comparison of galaxy clustering for pairs separated along the line of sight to those transverse to the line of sight reveals the amplitude of "peculiar" velocities, that is, the random velocities of galaxies superimposed on their Hubble velocities. Such velocities result from the large-scale gravitational forces generated by large-scale structure. Given a measurement of the cosmic expansion history, our standard cosmological model predicts the amplitude of velocities, and a mismatch could indicate a breakdown in general relativity, perhaps related to the accelerating expansion rate.

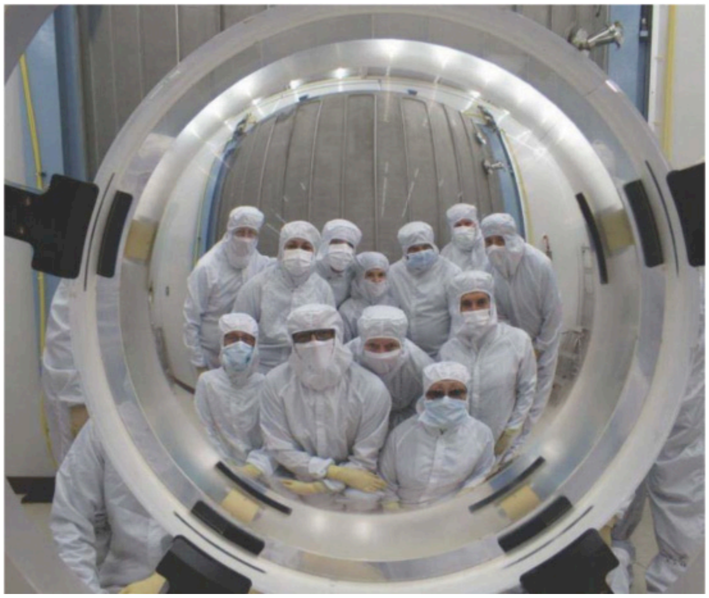

Figure 2. One of the six lenses of the new DESI corrector, which will give the Mayall telescope an 8-square-degree field of view, together with the crew who applied the anti-reflective coating. (Credit: Viavi Solutions)

By providing access to these two probes, galaxy redshift surveys remain a key part of the observational cosmology portfolio. They stand alongside studies of cosmic microwave background anisotropies, supernovae distance measures, weak gravitational lensing, galaxy cluster counting, direct Hubble constant measures, light element abundances, and other data as we seek to measure the cosmological parameters and search for disagreements that signal a need for new model ingredients. Sometimes these datasets can be combined to provide multiple measurements of the same quantity, to provide sensitivity to lurking systematic

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errors. Other times, the datasets can be combined to test a new cosmological feature. A currently exciting example is the ongoing disagreement between the Hubble constant inferred from CMB, BAO, and supernova relative distances (around 67 km/s/Mpc) with that inferred from Cepheid variables and the local distance ladder (around 73 km/s/Mpc). Could this be the sign of new physics? Or is the disagreement simply due to some undiagnosed observational problem? New data from DESI and other upcoming experiments will sharpen our view of these issues and hopefully reveal the resolution.

The new DESI spectrograph will provide a huge new capability for the Mayall telescope. It features 5000 fibers, each 1.5” in aperture, feeding a bank of 10 spectrographs. The fibers sit behind a new prime-focus corrector with an enormous 8-square-degrees field of view. The fibers are positioned by individual robotic arms, each patrolling a radius of 6 mm. The spectrographs provide full coverage from 3600 Å to 9800 Å at resolutions up to 4500 and with state-of-the-art throughput.

In dark sky conditions, the survey will focus on galaxies at $0.4 < z < 1.6$ and quasars to $z = 3.5$. In bright conditions, the survey will pursue a sample of flux-limited galaxies and stars. All told, about 35 million extragalactic redshifts and 10 million stellar spectra will be measured.

The DESI maps will have many other uses, from cross-correlations with lensing surveys and multiwavelength maps, to tests of galaxy evolution as a function of environment, to measurements of the signals of cosmic mass of the cosmic neutrino background. This is particularly notable at redshifts below 0.7, where DESI will provide a denser sampling of galaxies in groups and clusters and where its cartography can be matched to the rich array of pan-chromatic imaging.

With commissioning quickly approaching, each month brings new excitement for the DESI collaboration, which now includes over 600 people from 75 institutions. The new field-corrector has arrived at KPNO and will be tested on-sky later this fall. The robotic fiber positioners have been completed and are now being integrated into the focal plane. And the imaging surveys from which DESI will select targets are nearing completion, with the 7th data release now available at *http://legacysurvey.org*.

The DESI project is led by Lawrence Berkeley Laboratory, with the bulk of the funding coming from the US Department of Energy Office of Science. The collaboration is large and international, with additional funding provided by the US National Science Foundation, the Science and Technology Facilities Council of the United Kingdom, the Gordon and Betty Moore Foundation, the Heising-Simons Foundation, the

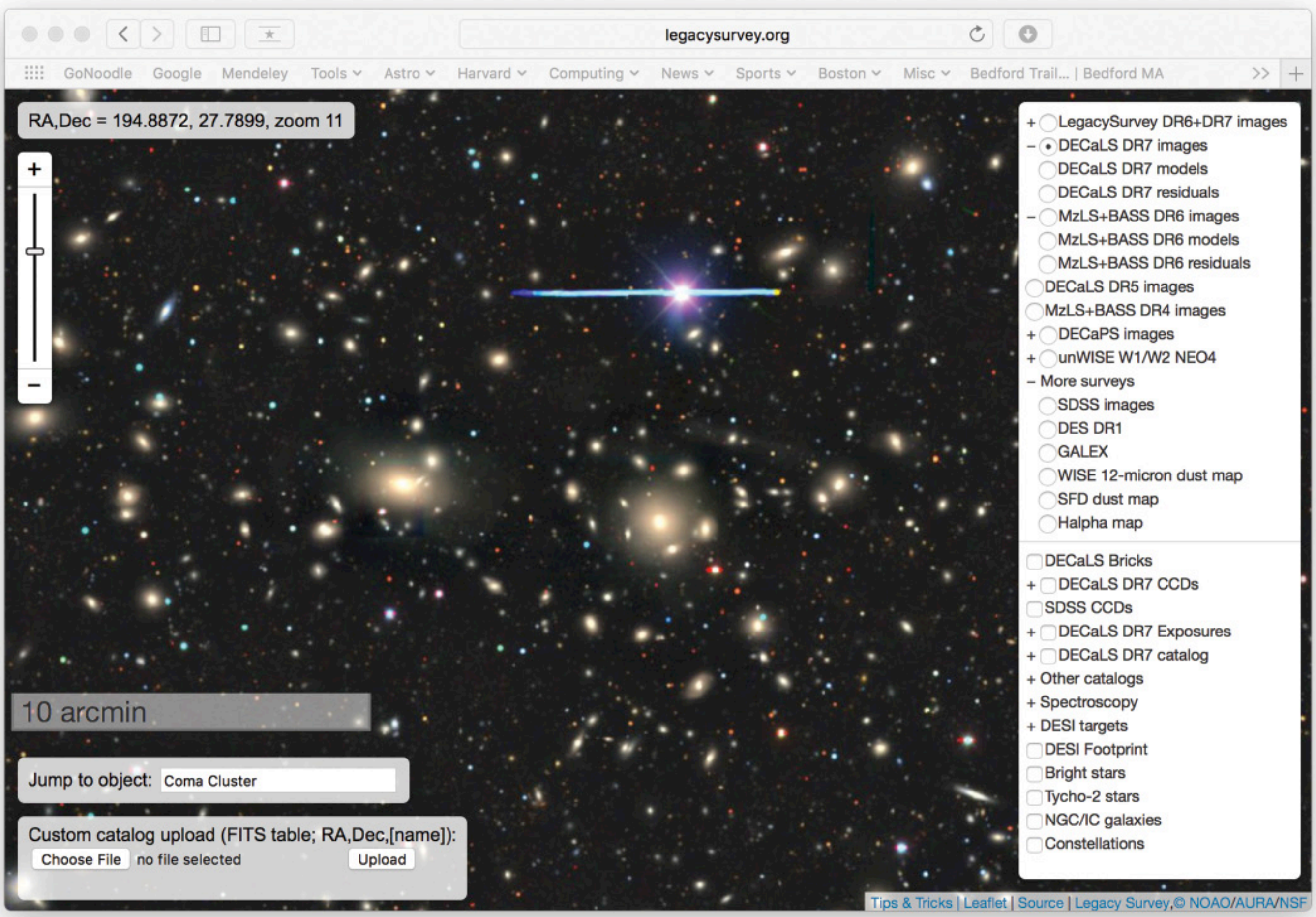

Figure 3. Image of the Coma cluster of galaxies from the Dark Energy Camera Legacy Survey (DECaLS) Data Release 7 in the g, r, and z bands. One can browse the sky and link interactively to the catalogs at http://www.legacysurvey.org and further study the data with the NOAO Data Lab. (Credit: D. Lang and Dark Energy Camera Legacy Survey)

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National Council of Science and Technology of Mexico, and the DESI Member Institutions. NOAO plays a central role in the collaboration, leading the installation of the instrument at the Mayall and of course the ongoing operations at KPNO.

DESI is one of several next-generation fiber-fed spectrographs now under construction, offering a large increase in multiplex and light collection. While these instruments differ in their science specialization, together these will mark a radical improvement in the world's capability for wide-field spectroscopy. For cosmology and extragalactic astronomy, the coming decade of spectroscopic and imaging datasets will bring a far sharper view of our Universe, all in the effort to exquisitely test, and perhaps break, our cosmological models.

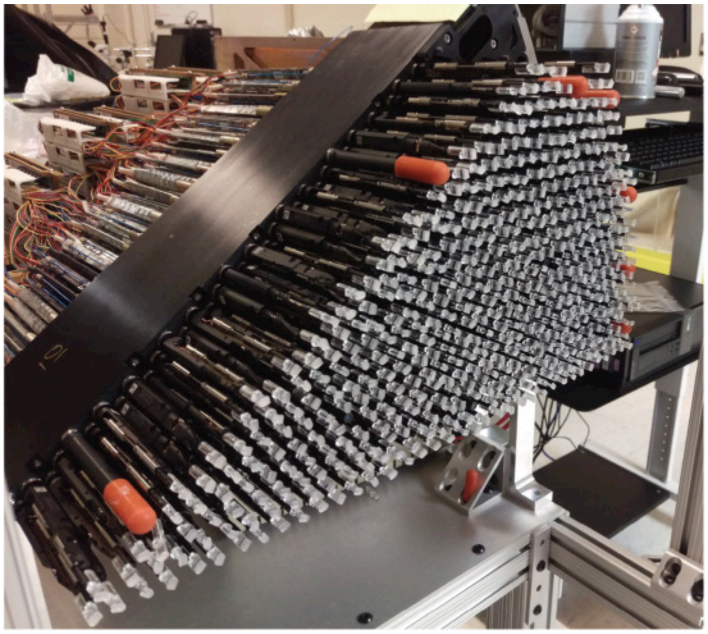

Figure 4. One of the ten petals of the DESI focal plane loaded with its 500 robotic fiber positioners, each of which positions one fiber to an accuracy better than 5 microns. (Credit: Lawrence Berkeley National Laboratory)

The Dark Energy Survey: The Journey So Far and the Path Forward

Josh Frieman, Fermilab and the University of Chicago

The Dark Energy Survey (DES), which finished five 105-night observing seasons in February 2018, is entering its home stretch. Using the 570-megapixel Dark Energy Camera (DECam) the collaboration built for the CTIO Blanco 4m telescope, DES is imaging and cataloging several hundred million galaxies over 5000 sq. deg. of southern extragalactic sky to ~24th magnitude in the grizY bands (900 sec total exposure in griz and 450 sec in Y). Over its first five seasons, DES also carried out a time-domain griz survey over 27 sq. deg. that yielded discovery of and light curves for several thousand distant supernovae. The primary goal of the survey is to probe the origin of cosmic acceleration via galaxy clusters, weak gravitational lensing, the large-scale galaxy distribution, and type Ia supernovae.

Through five seasons, DES took about 70,000 survey-quality exposures over its wide-area footprint, with a median Point Spread Function FWHM for the riz exposures a bit over 0.9 arcsec. In a partial sixth season, running from September 2018 to early January 2019, roughly 8000 more wide-area exposures will be taken to complete the survey, i.e., to reach full depth over the entire footprint.

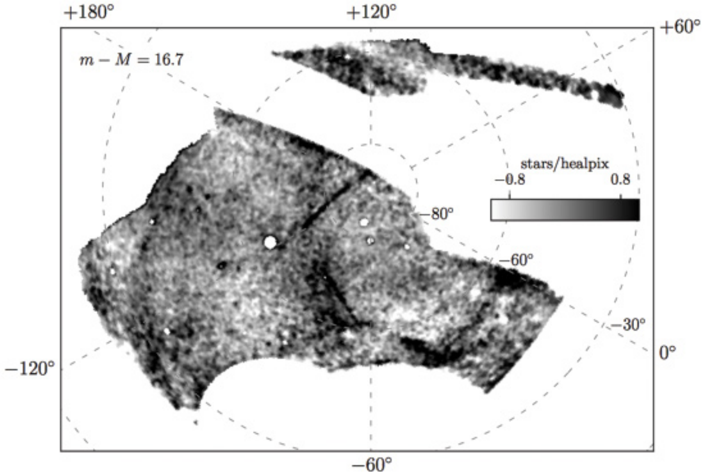

Figure 1. Map of stellar density at distance modulus m-M=16.7 showing a number of tidal streams in the first three years of DES data (Shipp et al. 2018)

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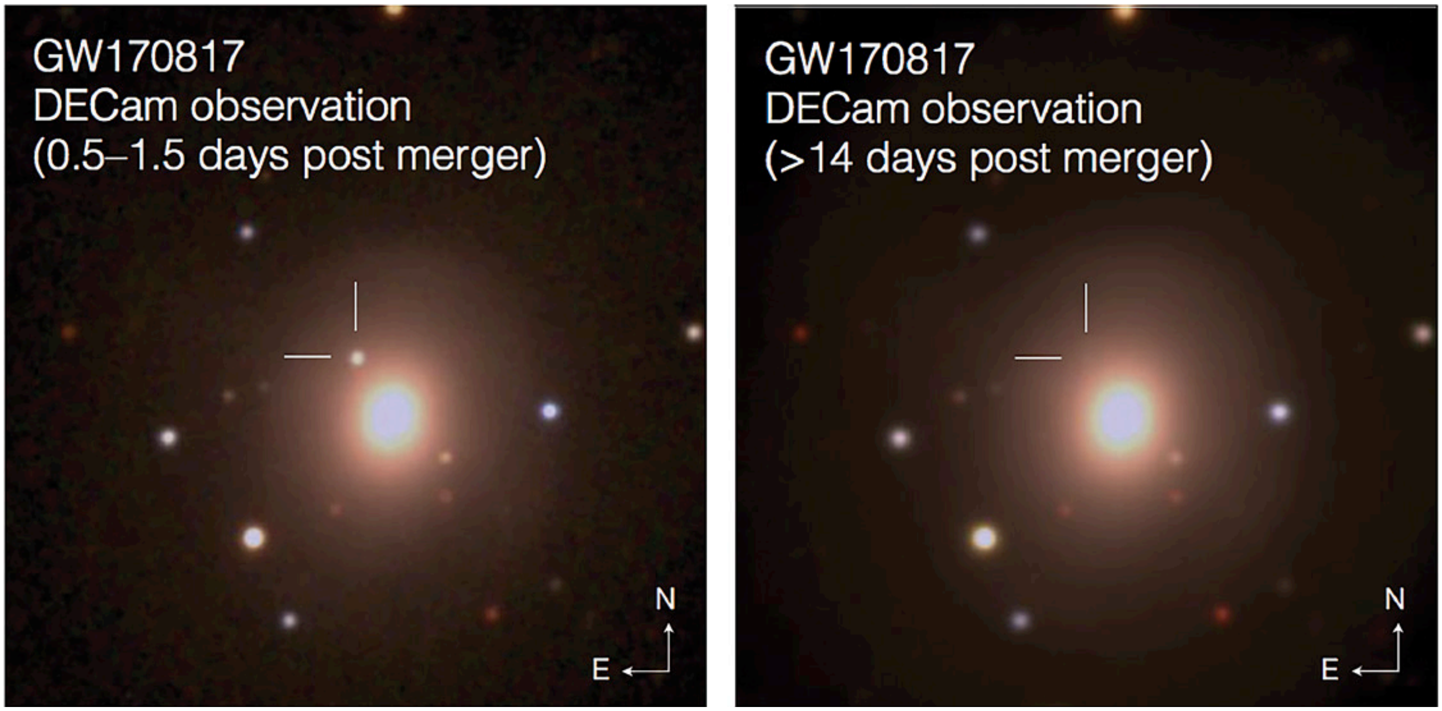

Figure 2. DECam image of NGC 4993 about one day after the GW170817 binary neutron star event (left) and two weeks later (right), showing an optical transient that faded in the interim, with light curve consistent with an r-process powered kilonova (Soares-Santos et al. 2017)

The international DES collaboration, comprising over 400 scientists from 26 institutions in 7 countries, has already harvested a wealth of astronomical discoveries from the first years of the survey data, with the best still to come. As of mid-September 2018, the collaboration has submitted over 180 papers for publication on topics ranging from new objects in the outer solar system to the discovery of distant quasars. Highlights so far include the discovery of 17 ultra-faint Milky Way dwarf galaxy satellites—and the derivation of constraints on dark matter from them, in conjunction with Fermi-LAT gamma-ray observations—and the discovery of nearly a dozen tidal stellar streams in the Galaxy (Shipp et al. 2018; Figure 1); the discovery of tens of superluminous supernovae, including the most distant spectroscopically confirmed SN at redshift z = 2 (*see the article by Mat Smith, Chris D'Andrea, and Yen-Chen Pan in the March 2017 NOAO Newsletter, and references therein*); the discovery of scores of strongly lensed galaxies and quasars, with follow-up time-delay measurements initiated for several of the latter (e.g., Treu et al. 2018); detection of thousands of galaxy clusters to redshifts of order one and calibration of the cluster mass-richness relation via statistical weak gravitational lensing measurements (McClintock et al. 2018); construction of the largest map of the large-scale mass distribution of the Universe from a galaxy survey, using weak lensing (Chang et al. 2018); and discovery of a number of Trans-Neptunian Objects, including the second most distant dwarf planet candidate (Gerdes et al. 2017).

Over the last several years, DES has collaborated with a group of community astronomers to follow up gravitational-wave event triggers issued by the LIGO-Virgo Collaboration (LVC). This program takes advantage of DECam's wide field of view to efficiently cover the relatively large localization area for these events. Since DES has been on the sky for roughly two-thirds of the nights in the B semesters, it has been possible to fold in a small number of such transient programs that may require observations over multiple nights, with minimal disruption to survey operations. On 17 August 2017, LVC issued its first binary neutron star merger gravitational wave alert, and the DES-GW collaboration independently discovered an optical kilonova counterpart in the galaxy NGC 4993 (Soares-Santos et al. 2017; Figure 2) in the course of an automated search of the GW170817 localization region. We measured its multi-band light curve over succeeding weeks, finding consistency with expectations from radioactive decay of r-process nucleosynthesis elements (Cowperthwaite et al. 2017). Among many other studies, this event provided a first measurement of the Hubble constant using the standard siren technique (Abbott et al. 2017).

In a series of papers in early August 2017, DES published cosmology results from the first season of wide-area data (Y1), based on measurements of 35 million galaxies over about 1500 sq. deg. Measurements of the galaxy angular correlation function (Elvin-Poole et al. 2018), of the galaxy shear correlation function (aka weak lensing cosmic shear; Troxel et al. 2018), and of the cross-correlation of the positions of foreground galaxies with background galaxy shears (galaxy-galaxy lensing; Prat et al. 2018) in several tomographic photometric-redshift bins were used to test the Λ-Cold-Dark-Matter (LCDM) cosmological model. Through this combination of measurements, DES was able to measure the amplitude of large-scale mass clustering and the matter density of the Universe with precision comparable to—and amplitudes in agreement with—the LCDM prediction from Planck cosmic microwave background (CMB) anisotropy measurements of the early Universe, ushering galaxy surveys into the era of precision cosmology (DES Collaboration 2018a; Figure 3).

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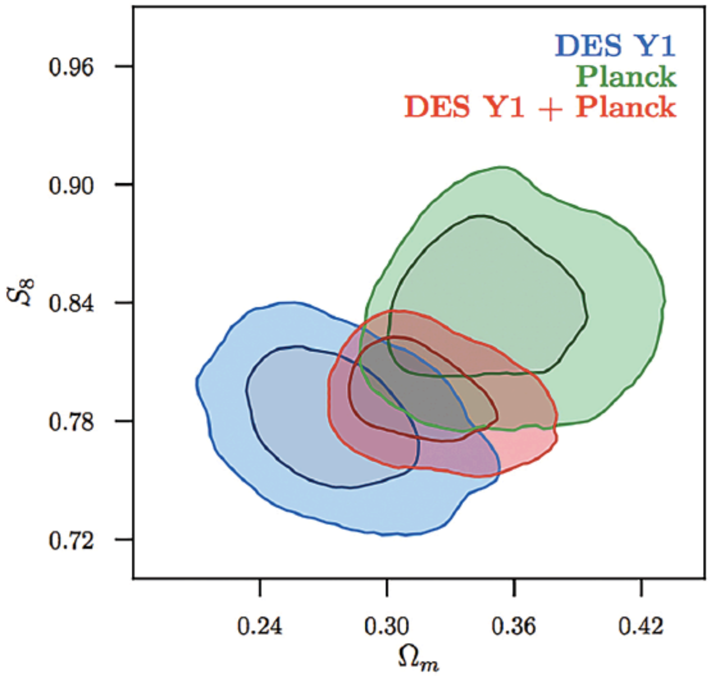

Figure 3. Constraints on the amplitude of matter clustering, $S_8 = \sigma_8\sqrt{\Omega_m/0.3}$, and the matter density parameter, Ω_m, where σ_8 is the rms amplitude of matter clustering in spheres of radius 8h^{-1} Mpc, in the context of the LCDM cosmology with non-zero neutrino mass. DES Year 1 results from galaxy clustering and weak lensing are shown in blue, Planck CMB results projected to the present epoch are shown in green, and the joint constraint is shown in red (DES Collaboration 2018a).

At the January 2018 American Astronomical Society meeting, DES unveiled its first supernova cosmology results, based on a sample of 334 spectroscopically confirmed type Ia supernovae (206 from the first three years of DES and 128 from external, low-redshift samples). These results will be submitted in fall 2018 and will be followed by analysis of a much larger sample of a few thousand photometrically classified SNe Ia. Cosmological analyses of the abundance of galaxy clusters and measurements that include cross-correlation of DES with CMB maps are also in the works. Over the coming year, DES will extend the Y1 cosmological analyses described above to data from the first three years of the survey (Y3), which cover the full 5000 sq. deg. footprint and which incorporate a number of improvements to the DES Data Management (DESDM) system compared to the Y1 data products. Beyond that, the collaboration will carry out analysis of the full, six-year survey dataset. Many of the analysis techniques being developed and refined for DES will find direct application in LSST in coming years.

DES is releasing multiple data products to serve the interests of the astronomy community. The raw DES images are made publicly available from the Science Data Archive at NOAO (SDA, *https://archive.noao.edu*) 12 months after they are taken. Reduced, calibrated images passing data-quality criteria are also released on a longer timescale, once they are vetted; reduced images from the first three years of the survey are now available at the SDA. In January 2018, DES put out its first major public data release (DR1), comprising co-added images and object catalogs based on the first three seasons of data (DES Collaboration 2018b; *https://des.ncsa.illinois.edu/releases/dr1*). The second and final release (DR2) will include corresponding data products for the entire six seasons of the survey and is planned for late 2020.

On 1 October 2018, DES released a multitude of Y1 value-added data products, including those that were used by the collaboration in its cosmological analyses of the Y1 data (*https://des.ncsa.illinois.edu/releases/y1a1*); these include value-added galaxy catalogs with weak lensing shape and photometric-redshift estimates, data vectors and likelihoods for the 3 two-point correlation function measurements in the context of the LCDM model, and a number of other products (see Drlica-Wagner et al. 2018 for a description of the Y1 photometric catalog). While the DES collaboration will continue to plumb these data for cosmological and astrophysical insights, we hope and expect the broader astronomy community will use them to make discoveries we haven't yet dreamt of.

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A Reconnaissance of RECONS

Todd Henry (RECONS Institute)

The REsearch Consortium On Nearby Stars (RECONS), directed by Todd Henry, recently summarized their steady progress in performing an accurate census of the Sun's closest stellar neighbors (Henry et al. 2018). RECONS was among the very first investigations enabled by the NOAO Survey Program and has continued over the last two decades to provide the best picture of what our immediate volume of the galaxy looks like. On this occasion we've asked Todd to summarize the highlights of his team's investigation.

Through the auspices of the NOAO Survey Program, in 1999 the RECONS group began a three-year project using the Cerro Tololo Inter-American Observatory (CTIO) 0.9m and 1.5m telescopes to measure parallaxes of "missing" members of the solar neighborhood. The original goal was to reveal 300 new southern star systems within 25 parsecs via trigonometric parallaxes. The program did not quite go as planned ...

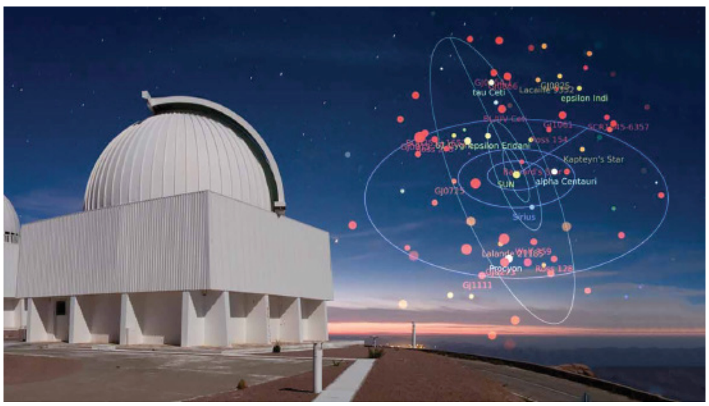

Figure 1. The CTIO/SMARTS 0.9m telescope is shown, with a frame from the RECONS Movie (see www.recons.org) created by Adric Riedel that illustrates nearby star systems. The RECONS team has carried out a long-term astrometry and photometry program at the 0.9m, revealing nearly 400 new star systems within 25 parsecs of the Sun. (T. Abbott & NOAO/AURA/NSF)

In 2003, the small telescopes at CTIO were grouped into the SMARTS Consortium, and the program continued. In August 2018, the RECONS program at the 0.9m passed the 19-year mark and is still going strong. The 0.9m has proven to be an incredibly reliable telescope, now dubbed "The Best Telescope in the World" (TBTW). Equipped with a single instrument over the past two-plus decades—the Tek 2K CCD camera—the telescope+camera combination has allowed for extensive student training and unique long-term science. From the 1530* nights of observations at the 0.9m, the RECONS team has published 27 papers (and counting), with highlights that include the following:

- An accurate census of the nearest stars, indicating that M dwarfs account for 75% of all stars and comprise half of the stellar mass in the solar neighborhood.
- 388 newly discovered stellar systems within 25 parsecs, including 48 new white dwarfs, which account for 40% of all white dwarfs this close to the Sun.
- 44 of the 317 systems known to be within 10 parsecs, including 11 of the nearest 100 systems, and at 8.4 parsecs, the nearest pre-main sequence star (AP Col).
- Determination that the smallest main sequence star has a size 9% that of the Sun.
- An understanding that 80% of red dwarfs vary by less than 2% at visible wavelengths over decade-plus timescales. While some red dwarfs flare and show signs of being covered with spots, four of five red dwarfs are photometrically quiet and likely to be suitable locations for life-bearing planets.

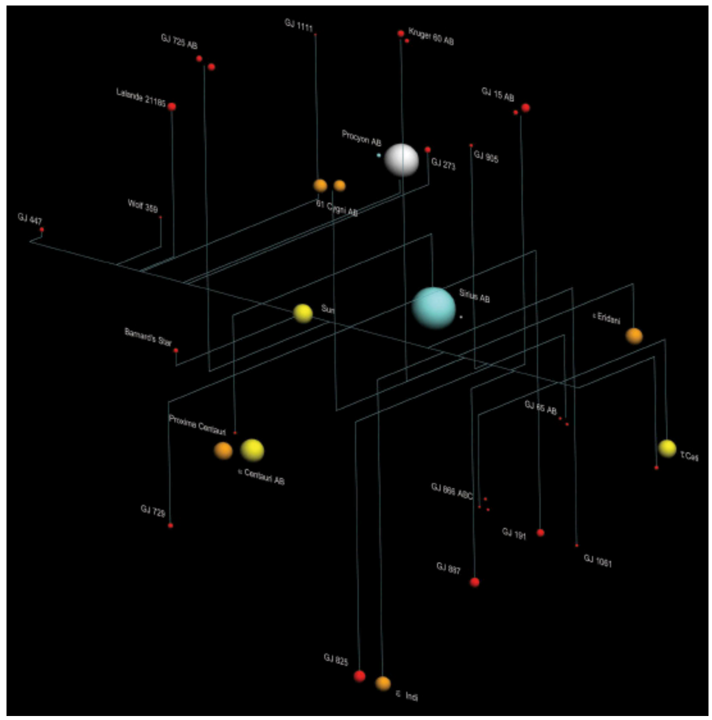

Figure 2. The nearest 25 stellar systems to the Sun are shown at their respective distances, locations, sizes, and relative colors. Note the predominance of red dwarf stars.

In all, 47 different observers have used the 0.9m for the RECONS program since 1999, including 7 undergraduate students, 21 graduate students, and 3 postdocs. To date, 8 PhD projects have depended on 0.9m data and 5 more are in progress. There is no doubt that the 0.9m has been a great asset for astronomers in RECONS and many other groups, and we certainly plan for it to remain open for many years to come.

* On a more personal note, of the 330 nights I have spent at the 0.9m, all have been enjoyable experiences, even the 27 (data were acquired on 91% of nights) when no data were taken.

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Discovering 12 New Moons Around Jupiter

Scott S. Sheppard (Carnegie Institution for Science)

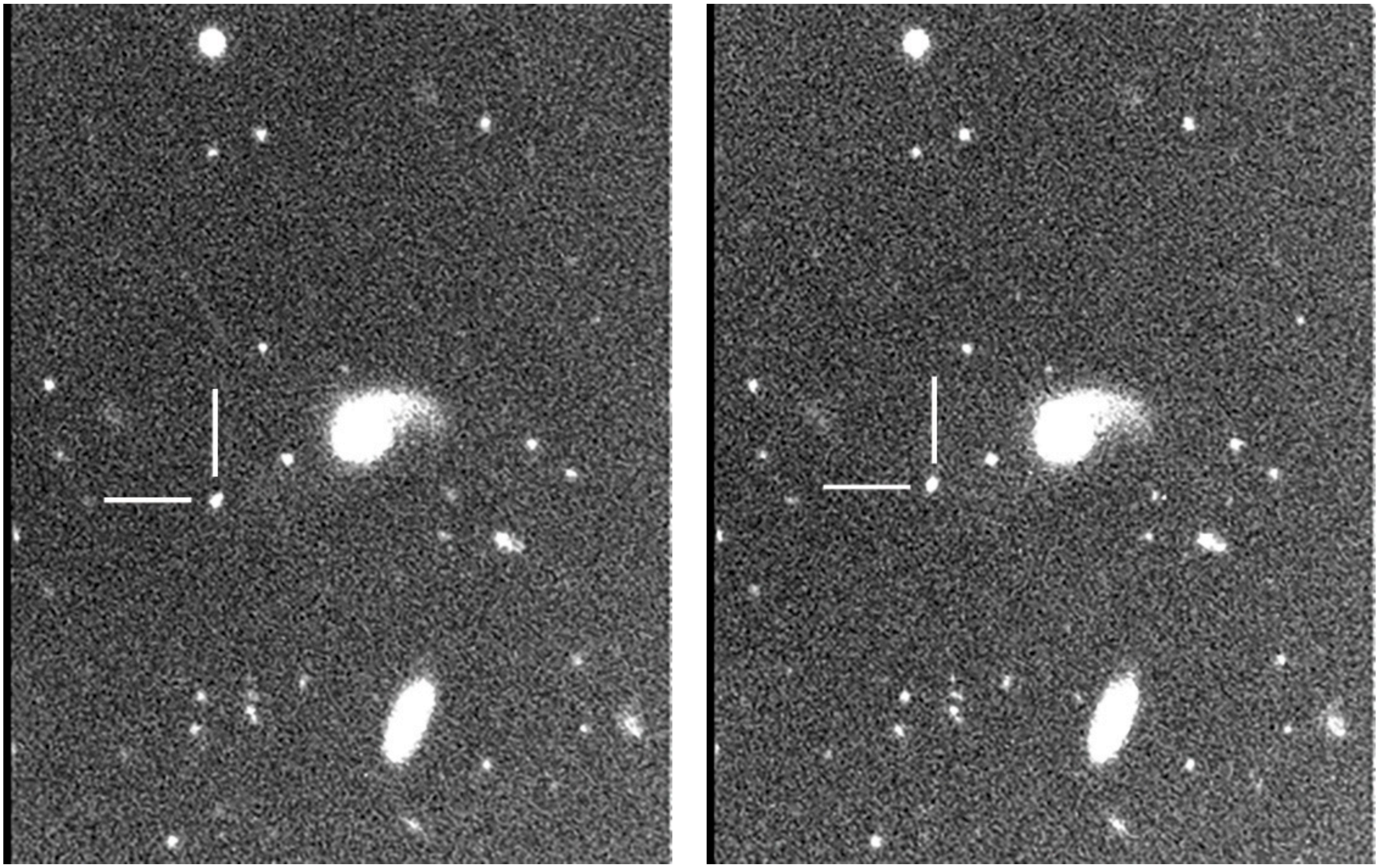

Figure 1. Gemini recovery images in June 2017 of the oddball moon S/2016 J2 (Valetudo)

The search for objects at the fringes of our solar system has led to the discovery of 12 new moons of Jupiter, using a deep and wide survey with the Dark Energy Camera (DECam) on the CTIO Blanco 4m telescope. Our main goal was to have a large uniform survey for the most distant trans-Neptunian objects (TNOs) that would limit the observational biases from observing in only a few locations. This means our survey operated at all times of the year so as to have uniform longitude coverage. We also used the HyperSuprime Camera at the Subaru telescope in Hawai'i for northern coverage. Our survey thus limited the discovery biases of extreme trans-Neptunian objects (ETNOs), allowing us to better statistically determine the clustering of ETNOs. This is to follow up on the hypothesis that these objects could be shepherded into similar orbits by an unknown distant planet, as first reported in Trujillo and Sheppard (2014) from the discovery with DECam of 2012 VP113, which has the most distant orbit in the solar system.

In March 2017, we were using DECam for our survey, and we realized that Jupiter was well placed in the sky near our survey fields. Because of this, we decided to place a few fields very near Jupiter. This allowed us to search for Jupiter moons in the foreground (moving at Jupiter's rate 15–20"/hr), while also searching for very distant objects that were beyond Pluto in the background (moving less than 2.5"/hr).

Moons are stable within about 0.6 of Jupiter's Hill radius (the region over which Jupiter's gravity dominates), which on the sky is 3 degrees in radius from Jupiter. Thus, four DECam fields cover most of the possible locations of moons bound to Jupiter. Because of Jupiter's motion, we had to limit the exposures to 150s to keep the moons from trialing, which is less than our normal 450s exposures. Thus we took three 150s consecutive images for each field near Jupiter. We added these three images to get one 450s image to still preserve the search for distant objects. To look for Jupiter moons, we shifted each image by the rate of motion of Jupiter and then added the images together, allowing us to go fainter than surveys have in the past for Jupiter moons.

We found some 30 unknown objects moving with Jupiter. We observed near Jupiter again a few days later, recovering all of the objects. Using the Magellan telescope, we recovered all the candidate moons one

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month later, giving us basic orbits for all of the objects. We noticed that one object had a very unusual orbit and thus requested Gemini director's discretionary time to recover this faint moon in June 2017 to make sure it did not get lost (Figure 1).

We had basic orbits for the unknown moons, but there were a few lost moons from 2003 that could have been in our discoveries. To know which moons were new required recovery one year later, which we obtained in 2018 with DECam in April and early May, as well as with Magellan in late May. The year-long arcs allowed Gareth Williams at the Minor Planet Center to determine which objects linked with the lost 2003 objects and which were new. We found that 12 of the moons were unknown, while several more of them were indeed linked to the lost 2003 moons (Sheppard et al. 2018). There are several more moons that were too faint to get the required year of observations for a good orbit fit. Two of these unannounced moons appear to be Himalia members, while the rest are retrograde moons, with some of them likely the few 2003 lost moons not yet linked. We also found every well-known outer moon of Jupiter. Our discoveries raise the total of known Jovian moons to 79. Our discovery rates leads to the inference that there are some 100 outer moons of Jupiter larger than 1 km.

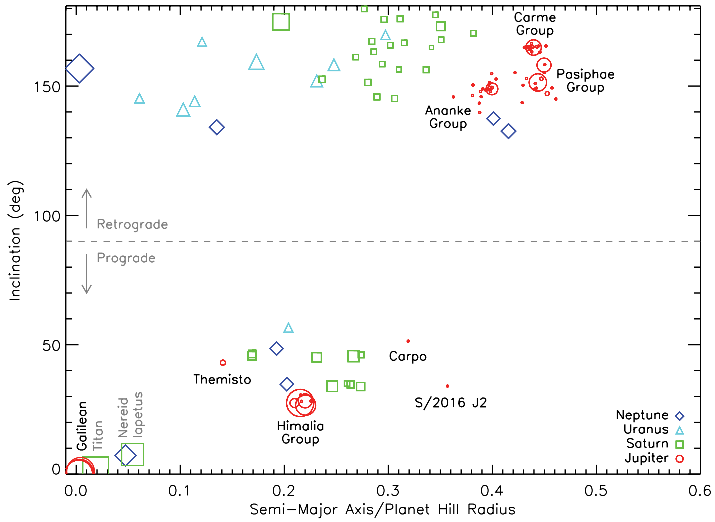

Figure 2. The semi-major axis/Hill Radius versus the inclination of the well-known outer moons of the giant planets and select larger inner moons. The size of the symbol represents the log of the diameter of the moon. From Sheppard et al. (2018).

Most of Jupiter's outer moons cluster into orbital groupings that share similar semi-major axes and inclinations around Jupiter (Figure 2). These groupings are likely the remnants of once larger parent bodies that have been broken apart from collisions with asteroids, comets, or other moons. Of the 12 new discoveries, 9 are in the distant retrograde groupings: 3 in the compact Carme group, 4 in the Ananke group, and 2 in the diffuse Pasiphae group. Two of the discoveries are in the inner prograde Himalia group. One of the new finds has an orbit unlike any other: S/2016 J2 (Valetudo) has a distant orbit near the retrogrades but yet has a *prograde* inclination of about 34 degrees. This means S/2016 J2 is orbiting around Jupiter in the opposite direction as the other moons near it.

We simulated the impact probability of S/2016 J2 with the retrogrades. Being the smallest of all the known moons at about 1 km, it only has a few percent chance of colliding with a retrograde moon over 4 Gyrs. If it did collide with a retrograde moon in the past, it would have been larger and thus more likely to collide but still not large enough to be more probable than not. If one includes all the known progrades, including Himalia group members (see Nesvorny et al. 2003) and Carpo, it is more likely than not that a prograde-retrograde moon-moon collision has happened within the Jovian system in the past.

These new discoveries also show the Jupiter moon orbital groupings continue down to the smallest sizes. If the moon orbital groupings were formed in the very distant past, during the era of planet formation, one might expect the smallest moons would spiral into the planet from remnant gas and dust from the formation of Jupiter. The survival of the smallest moons in each orbital grouping suggests the parent moons broke apart after the era of planet formation. This means comet and asteroid collisions with the moons would be less likely, as these objects may be dispersed by then, making moon-moon collisions a favored mechanism to create the moon groupings we see today.

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Nesvorny, D., et al. 2003, AJ, 126, 398
Sheppard, S., Williams, G., Tholen, D., et al. 2018, RNAAS, 2, 155
Trujillo, C. and Sheppard, S. 2014, Natur, 507, 471

"More Is Different" in Data-Driven Astronomy

Adam S. Bolton

In 1972, physicist P. W. Anderson published an article titled "More Is Different" (1972, Sci, 177, 393) in opposition to the point of view that all areas of science can ultimately be understood through reduction to their most fundamental constituents. While the phenomena studied in psychology arise from the laws of biology, and the laws of biology in turn arise from the laws of chemistry, "[p]sychology is not applied biology, nor is biology applied chemistry."

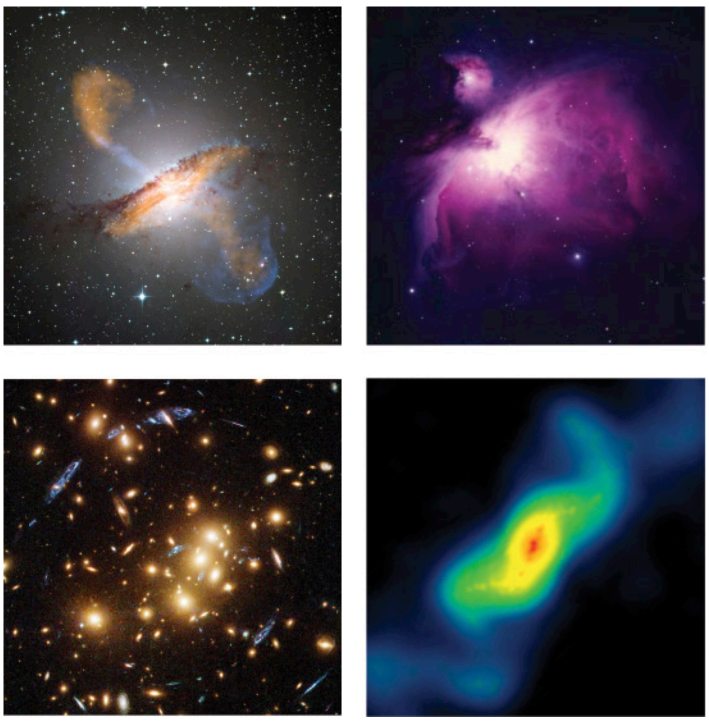


Figure 1. A selection of "favorite objects." Clockwise from top left: multiwavelength montage of nearby radio galaxy Centaurus A; KPNO–Mayall image of the Orion Nebula; VLA radio image of the Galactic "microquasar" SS 433; Hubble Space Telescope image of lensing galaxy cluster CL0024+17. (Credits: Cen A: ESO/WFI [optical]; MPIfR/ESO/APEX/A. Weiss et al. [submillimetre]; NASA/CXC/CfA/R. Kraft et al. [X-ray]; Orion Nebula: W. Schoening/NOAO/AURA/NSF; SS 433 [VLA Radio]: Blundell & Bowler, NRAO/AUI/NSF; CL0024+17: NASA, ESA, M. J. Jee and H. Ford/Johns Hopkins University)

We can see some analogy to this in the pull between astronomy on the one hand as an empirical science describing the Universe as we see it and astrophysics on the other hand as the science of understanding that phenomenology in terms of the fundamental laws of physics that we believe apply throughout the cosmos. But this article is not about the astronomy/astrophysics duality!

My goal in this article is instead to highlight the essential way in which astronomy in the era of big surveys and big data is not just *bigger* but also *different*.

Picking Favorites

Astronomy has no shortage of candidate "favorite objects." Objects such as the complex nearby radio galaxy Centaurus A, the star-forming Orion Nebula, the Galactic microquasar SS 433, and the lensing galaxy cluster CL0024 come to mind (Figure 1). Many of these classic celestial targets provide a unique opportunity to study specific object types or physical processes.

If one (as an astronomer) has a favorite astronomical object, one might (naturally) want to know everything possible about it. One might therefore want to gather up all the data that were ever collected on that object, by any astronomer, for any purpose, with any telescope or instrument anywhere. One might even design and build a system to make it possible to answer that question for oneself and for all other astronomers with regard to their own favorite objects.

But survey-scale astronomy is driven by *populations* of objects, and the above procedure does not scale. Each object will have its own unique data coverage, and the collective hodgepodge will make analysis cumbersome and intractable.

I do not have a favorite astronomical object. I do, however, have a favorite population: massive elliptical galaxies. Collectively, they are very

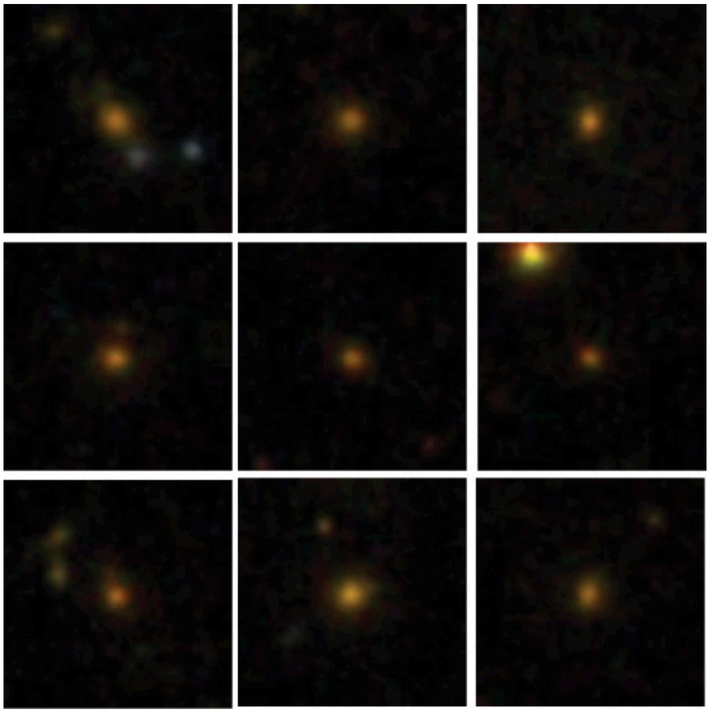


Figure 2. A selection from a "favorite population": several massive elliptical galaxies from the Sloan Digital Sky Survey (Credit: Sloan Digital Sky Survey)

continued

interesting. They mark out the densest regions of the Universe on the largest scales. Their clustering in space can be used to constrain the nature of dark energy. Their regularities encode the end state of the laws of galaxy evolution. And they are good for finding strong gravitational lenses to study dark matter. But on an individual basis, massive elliptical galaxies are pretty boring (Figure 2).

Finding Identity in Anonymity

For survey astronomy, the answers to key questions are not found in particular objects, but rather in particular surveys (or combinations of surveys) that cover a sufficient sample of an entire anonymous population with a particular sensitivity, resolution, completeness, or unique high-level data product.

In the data-driven regime of archival research, the essential technology is then not to find all data available for any object specification, but rather to find all objects available for any data specification. This is at the heart of how “more is different”: the numbers don’t just get bigger; the entire methodology is inverted.

While the data volumes and technologies of today’s survey astronomy are new, the approach is familiar. A century ago, Annie Jump Cannon and other astronomers were systematically surveying and classifying the spectra of stars by the tens of thousands, laying the foundation for our coherent physical understanding of stars as a population, while also reducing everyone’s favorite star to just another G dwarf.

Data Lab 2.0 Is Bigger and Better

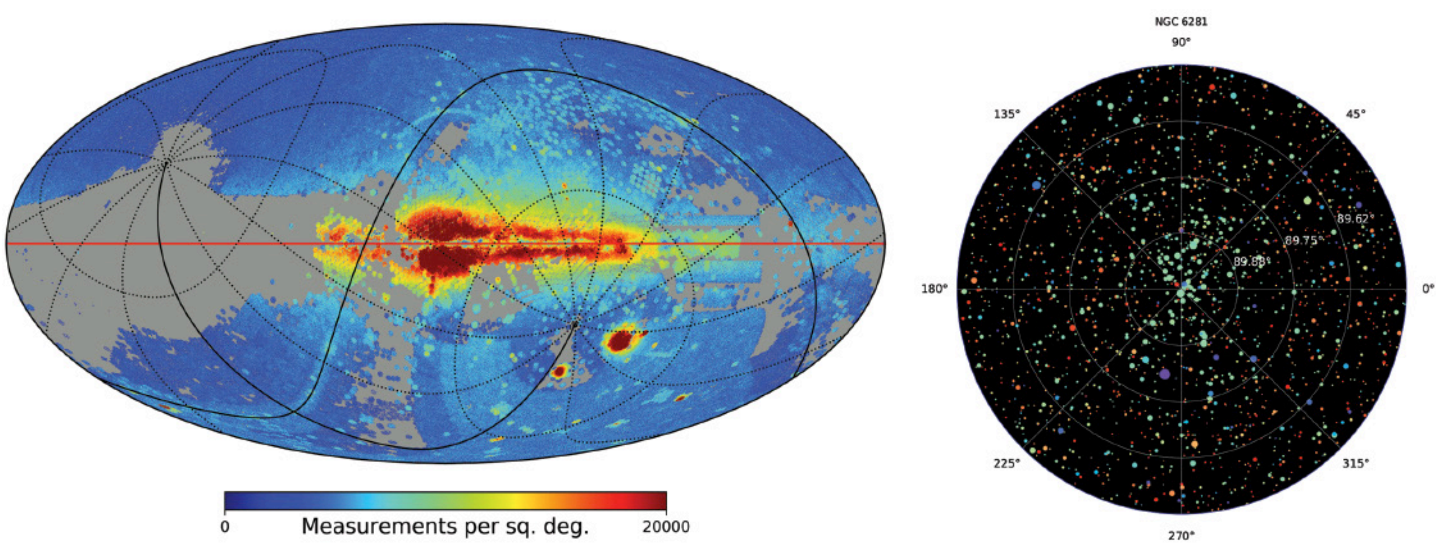
Robert Nikutta for the NOAO Data Lab Team

NOAO released Data Lab Version 2.0 and presented it at the 232nd American Astronomical Society (AAS) Meeting in Denver, Colorado, June 3–7. This expanded and improved science platform follows the initial release of Data Lab at the summer AAS meeting in 2017.

Based on feedback from the community, Version 2.0 adds many new features, such as an image cutout service and new views of storage space on the Data Lab website, shell access in the Jupyter notebook environment, and an expanded set of default notebooks to jump-start scientific analysis of an ever-expanding set of new data.

The NOAO Data Lab hosts very large and co-located datasets. The number of rows in all catalog tables recently broke the 100-billion barrier. Among the data is the new NOAO Source Catalog (NSC) of almost 3 billion unique objects with over 30 billion single-epoch measurements that enable time-domain science. The NSC comprises uniformly extracted photometric measurements from publicly available images taken by NOAO cameras on both hemispheres. The measurements are calibrated consistently across many different instruments. The NSC paper was published in September (Nidever et al. 2018, AJ, 156, 131). Other datasets newly available in Data Lab include the Legacy Survey DR6 and DR7 and a copy of the spectacular Gaia Data Release 2.

The suite of default notebooks has been expanded and updated. It includes, for example,



The left panel shows the number of measurements per square degree in the first data release of the NOAO Source Catalog. The all-sky view is in Galactic coordinates and Mollweide projection. The Galactic disk, bulge, and the Magellanic Clouds are clearly visible. The right panel shows in polar projection stars towards the open cluster NGC 6281 that were selected from the Gaia DR2 catalog. Almost 2000 stars are visualized, with the size proportional to their g-band magnitude and the color corresponding to the distance from our Solar System. Stars belonging to the cluster have approximately the same distance (light green color). Blue dots are stars closer to us, and red dots are stars more distant from us.

continued

science case notebooks on exploring the parallaxes measured by Gaia, time-series analysis of variable stars with data from several catalogs, exploration of the Panchromatic Hubble Andromeda Treasury (PHAT) survey of the Andromeda galaxy, and the detection of dwarf galaxies as overdensities in the stellar field.

A science platform, often called a "data exploration and analysis environment," comprises three key features: multimodal access and manipulation of very large datasets, an analysis and compute environment running in proximity to those datasets, and mechanisms for storing and sharing the users' own data and the results of their workflows. All three elements enable researchers to discover and process astronomical data in a multitude of ways. Exploratory data analysis should be easy, and sophisticated workflows should be possible. Data Lab enables all of this and much more with nothing required of a researcher but a web browser and curiosity.

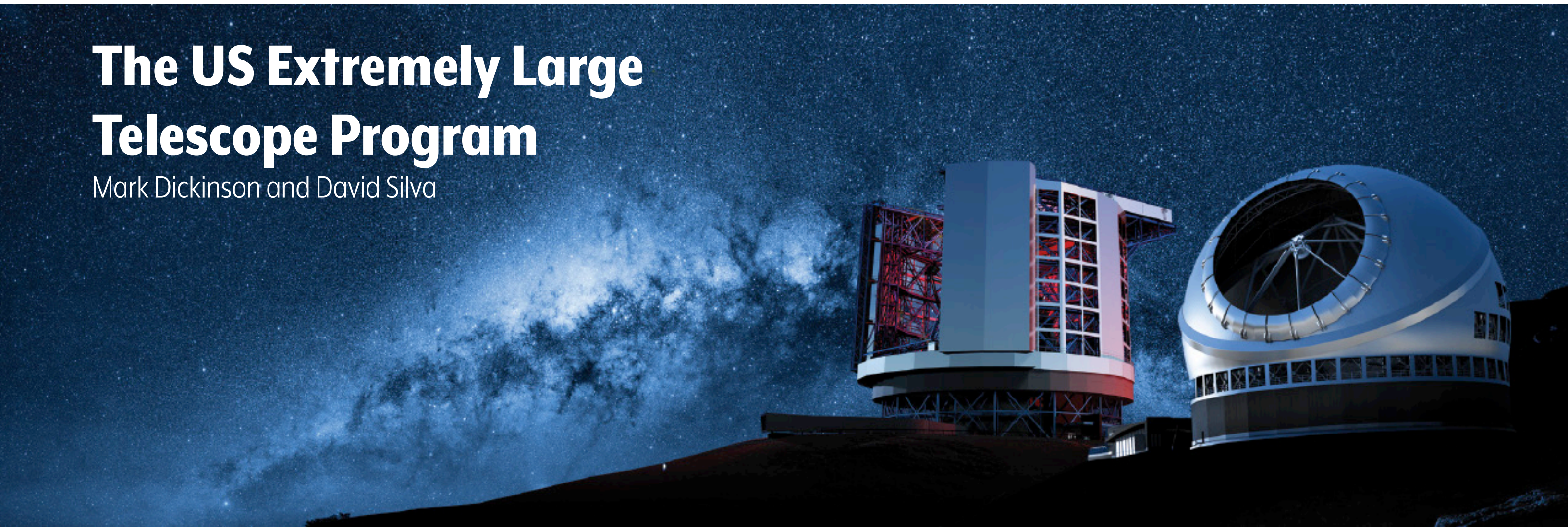
Through its integrated Jupyter notebook environment and the tools that the team develops, Data Lab offers a one-stop-shop for data discovery, catalog and image queries, analysis, and visualization. All this is made possible by the powerful yet easy-to-learn Python language. An emulated terminal shell provides a familiar interface for more advanced users. Comprehensive documentation of the Data Lab services, APIs, SQL queries, and much more provide a low barrier to entry for the novice user and a reference manual for the experienced big data astronomer.

At the AAS meeting, the Data Lab scientists gave many personal demos to booth visitors from all walks of (astronomical) life, e.g., professional colleagues, science educators, and students. NOAO's Education and Public Outreach group shared the booth with Data Lab and hosted activities for students of all ages. NL

Data Lab website: *datalab.noao.edu*
Contact the team: *datalab@noao.edu*
Find us on Twitter: *@NOAODataLab*
Data Lab code: *github.com/noao-datalab*

The US Extremely Large Telescope Program

Mark Dickinson and David Silva



A new research frontier in astronomy and astrophysics will open in the mid-2020s with the advent of ground-based extremely large optical-infrared telescopes (ELTs). With primary mirror diameters in the 20–40m range, the ELTs will peer out into the Universe with unprecedented sensitivity and angular resolution, enabling scientific investigations that are unachievable with present-day telescopes. US scientific leadership in astronomy and astrophysics will be significantly enhanced if the whole US community can take advantage of the power of these new observatories.

Toward this end, *the US ELT Program* is a joint initiative of NOAO, the *Thirty Meter Telescope (TMT) International Observatory*, and the *Giant Magellan Telescope (GMT) Organization* that aims to provide the US astronomical community with open access to significant shares of observing time with both observatories. This two-hemisphere model will provide all-sky coverage and more diverse instrumentation, enabling integrated science programs that go beyond the reach of a single telescope and providing more opportunities for US scientific leadership in the forthcoming global era of ELTs. This US ELT Program is being developed for presentation to the *2020 – 2030 Astronomy and Astrophysics Decadal Survey (Astro2020)* (an enterprise of the *National Academies*) and to the *National Science Foundation*.

While many discoveries from GMT or TMT will be achieved with relatively short observations, other problems will require substantial investments of observing time—perhaps using multiple instrument capabilities, perhaps in conjunction with other astronomical facilities—to systematically investigate and answer forefront astronomical questions. To illustrate the scientific frontiers that will be opened by this approach, the US ELT Program has engaged astronomers throughout the US community to develop concepts for Key Science Programs (KSPs). These KSPs will address questions of fundamental scientific importance that may require tens to hundreds of observing nights with TMT, GMT, or both observatories working in concert, taking advantage

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of their combined view of the full sky, or of their complementary instrumental capabilities. It is envisioned that KSPs will follow open-collaboration models that encourage broad, diverse participation by observers, data scientists, and theorists throughout the US research community. Smaller-scale, focused research projects will also be an important component of the overall science programs for these observatories, as richly illustrated by the existing detailed science cases for *GMT* and *TMT*. However, the present effort is directed towards the development of larger-scale concepts for frontier research programs, led by US community scientists, that can achieve exceptional advancements in humanity's understanding of the cosmos.

NOAO and its *US ELT Program Advisory Committee* have invited members of the US astronomical community to develop KSP concepts. More than 240 scientists are now working together on this effort, with initial discussions in eight topical groups ranging from "Our Solar System" to "Cosmology and Fundamental Physics." These groups will consider forefront problems in each subfield, formulate and prioritize KSP concepts, identify the capabilities required to address these problems with TMT and/or GMT, and then elaborate these ideas as detailed observing and analysis plans in advance of a workshop to be held November 11–14 in Tucson.

The KSP ideas developed through this process will serve as *exemplars* that illustrate the research potential of GMT and TMT for the US community and define the required scope of federal investment for a US ELT Program. Undoubtedly, astronomy will continue to evolve rapidly during construction of TMT and GMT, in part thanks to new discoveries from facilities such as TESS, JWST, LSST, and others to come. Consequently, the KSPs that will eventually be executed will be determined by peer review sometime in the future as the observatories approach their science operations phases.

If you would like to contribute to Key Science Program development, please visit the *US ELT Program website KSP web page* and *register using the online form*. More information about the US ELT Program and the community-developed KSP concepts will be presented in a session at the January 2019 American Astronomical Society Meeting in Seattle, Washington. NL

"Science and Evolution of Gemini Observatory" Conference

Letizia Stanghellini

Figure 1. Participants at the "Science and Evolution of Gemini Observatory" conference. (S. Lifson/AURA)

The "Science and Evolution of Gemini Observatory" conference, held in San Francisco in July 2018, was well attended by the Gemini community, with approximately one hundred scientists from around the globe participating. The four-day meeting was structured in a multiprong fashion to include the broad range of ideas and discussion that are essential in a science conference devoted to a specific observatory.

The conference included 11 invited science talks, with new and exciting results based on Gemini data, often in synergy with data from other observatories. The talks focused on results from roughly the last three years and covered many astronomical fields of interest, observing modes, and all Gemini instruments and displayed the uniqueness, breadth, and data impact of Gemini science.

Karen Meech reviewed the exciting discovery of the first confirmed interstellar asteroid. An ensemble of telescopes and instruments were used with Gemini observations to determine the asteroid's rotation, shape, and color. Asteroids were also discussed by Yoonyoung Kim in relation to their evolution through impacts. Rosemary Pike presented results from the COLours for the Outer Solar System Object Survey (COL-OSSOS) program, showing that Gemini photometry allows for the separation of cold classic surfaces from other targets.

A group of invited talks in conjunction with the Gemini Planet Imager (GPI) presentations covered extrasolar planets (Laurent Pueyo), debris disks (Christine Chen), and YSO (John Monnier), showing the variety of GPI applications and their importance in modern astrophysics. There were two additional invited talks on extra-solar planets: Jacqueline Faherty spoke about brown dwarfs analogs to exoplanets, and Carlos Saffe spoke about the chemical signatures in stars from planet formation.

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On the stellar astrophysics topic, Kim Venn observed metal-poor stars in several environments with the Gemini Remote Access to CFHT ESPaDOnS Spectrograph (GRACES), with the plan of obtaining stellar parameters and abundances. Symbiotic binaries, not representing a unique evolutionary phase, need to be understood individually: Ken Hinkle showed how IR spectroscopy with Gemini can be used to study both the evolution of the stars and the binary system.

Three invited talks were presented on nearby galaxies topics: Sukanya Chakrabarti presented her work on halo stars; Sabrina Stierwalt discussed her use of Gemini and several other telescopes to determine the mass assembly history from isolated dwarf galaxies; and Jonelle Walsh talked about central black holes in galaxies and how Gemini NIFS/AO spectroscopy is essential for their orbital/mass assessment.

Speakers on cosmic explosions included Ryan Chornock, who explained the role of Gemini in defining the parameters of neutron star mergers following the gravitational wave detection in 2017, and Ryan Foley, who gave a presentation on SN Ia.

Results on galaxies in rich environments within the Gemini Observations of Galaxies in Rich Early Environments program (GOGREEN) were presented by Michael Balogh. In this program, the galaxy group structure and evolution are constrained by measurements of halo stellar contents in redshifted galaxy clusters and groups at $z > 1$. The survey is very deep and covers ample halo mass range. Mark Brodwin presented the Massive and Distant Clusters of WISE Survey (MaDCoWS) program, which studies galaxy evolution in rich environments and the dependence of galaxy formation on halo mass at $z > 0.8$. Finally, Yongjung Kim focused on high-redshift quasars for insight on cosmic reionization.

A wealth of contributed talks and posters, highlighted by the lightning poster presentations, nicely rounded out the science program.

Two other sessions completed the conference. A welcoming session gave the floor to the directors and heads of the Gemini governing bodies for their perspective on the observatory. For this session on observatory synergies, directors of other observatories and programs compared and discussed their strategies with the Gemini science community.

A special session on GPI dovetailed with the related science talks, with discussion on future development of the instrument. An invited session on the Gemini strategic plan for the 2020s allowed all participants to discuss the topic of Gemini's future with an intriguing set of expert panelists. The sessions on the future of GPI and on the Gemini strategic plan were especially lively and interesting, with participation by the broad international community.

Instrument themes were presented by invited instrument scientists and included new and developing facility and visitor instruments.

Several workshops took place in connection to the main conference: (1) a data reduction workshop, where participants learned how to reduce GMOS IFU data; (2) a speed collaboration workshop, where participants mixed and mingled with the goal of a science collaboration, which especially allowed young participants to meet their colleagues in an informal setting; and (3) the under the hood workshop, where the leaders of Gemini Long and Large programs revealed all the tricks and secrets for these programs to be successful and productive.

The international Scientific Organizing Committee (SOC), chaired by Letizia Stanghellini, selected the science speakers. SOC members were Lilia Bassino, John Blakeslee, Mark Brodwin, Narae Hwang, Sandy Leggett, Bruce Macintosh, Karen Meech, Armin Rest, Verne Smith, Thaisa Storchi-Bergmann, Joanna Thomas-Osip, Kim Venn, and Beth Willman. The Gemini directorate, and other Gemini specialists, supported the SOC in the preparation of the special sessions.

The conference was seamlessly organized by the Local Organizing Committee, chaired by Terry Lee, with members Jason Kalawe, Peter Michaud, Joanna Thomas-Osip, Ken Hinkle, and André-Nicolas Chené.

The conference web page (*www.gemini.edu/seg2018/program)* lists all organizers, speakers, and sessions, with links to the presentations. We invite you to visit the web page to have a current reference of Gemini science activities. NL

DESI Collaboration Meets in Tucson

Lori Allen and Arjun Dey

The annual DESI collaboration meeting was held May 23–25 in Tucson, Arizona. Approximately 120 scientists, engineers, postdocs, and students from more than 10 countries gathered for three full days to discuss all things DESI: progress on the instrument construction and telescope modifications; plans for installation, commissioning, data pipelines, science validation and operations; and preparations by the science working groups. Numerous meeting participants contributed to the DESI project archives, in short video interviews with a LBNL videographer. NOAO and the DESI Science Collaboration team are excited that the instrument will be on sky within the next calendar year and are working hard preparing for the arrival of science data. Other highlights from the meeting included tours of the University of Arizona Richard F. Caris Mirror Lab on Friday evening and a visit to Kitt Peak National Observatory on Saturday, where visitors got a close-up look at the Mayall 4m telescope and the current status of DESI installation.

The La Serena School for Data Science: Applied Tools for Data-Driven Sciences

Guillermo Damke (AURA-O / Universidad de La Serena) and Alfredo Zenteno (NOAO)

The AURA campus in Chile welcomed the fifth La Serena School for Data Science (LSSDS) August 20–29. The school seeks to introduce advanced undergraduate and early graduate students from diverse scientific disciplines to statistical techniques and computational tools that will be required to deal with the complexity and size of increasingly large volumes of data. Such tools will be necessary in the LSST era as well as in other disciplines that are facing data challenges akin to astronomy, such as biology and medical sciences.

This year LSSDS received almost 200 applications from students of 23 different nationalities enrolled in universities in eight separate countries, with the majority of students from Chilean and US institutions. A scientific committee selected 32 students with diverse academic backgrounds and majors, such as astronomy, physics, computer science, electrical engineering, medicine, and medical informatics. Each student was awarded a scholarship that covered school expenses, travel expenses, lodging, and a portion of their meals. The group was composed of 16 students from 16 American universities (fully funded through a grant from the National Science Foundation, NSF), 13 students from 8 Chilean universities, and 3 students from universities in Argentina, Colombia, and Germany (fully funded by institutions other than the NSF).

The school was taught by an interdisciplinary group of 11 professors from institutions in Chile and the US. The curriculum consisted of statistics, introduction to data science, supervised and unsupervised machine learning, image processing and Gaussian processes, and high-performance computing (HPC), with an emphasis on hands-on "laboratories" that included databases (SQL), HPC, deep learning, time series, science platforms (such as the NOAO Data Lab), and best programming practices.

Group projects are a key aspect of the LSSDS curriculum. These projects are short research activities where students have the opportunity to apply the techniques learned in school lectures and labs. Each professor designs and proposes a project in their field of expertise to mentor an interdisciplinary group of four students. This "learning by doing" is so important to the school that students devote over one-third of their time to it. The projects offered this year included classification of ATLAS variable stars, classification of exoplanets in the Kepler dataset, determination of important factors and characteristics for global obesity prevalence, estimation of photometric redshifts using symbolic regression, distance metrics for images, matching ZTF alerts to existing catalogs for transient follow-up, and classification of lymphoma types in images using convolutional neural networks. The school culminated with a seminar consisting of 20-minute presentations by each group of their project.

The school also provided the students with the opportunity to visit the local observatories. They enjoyed a guided visit to the Gemini South telescope on Cerro Pachón, led by the Gemini Education & Public Outreach team, and to the SMARTS Consortium 1.5m and CTIO Blanco 4m telescopes on Cerro Tololo. The visit culminated with a stargazing session under the pristine skies of northern Chile on Tololo's summit led by the Cerro Tololo Inter-American Observatory's Education & Public Outreach team.

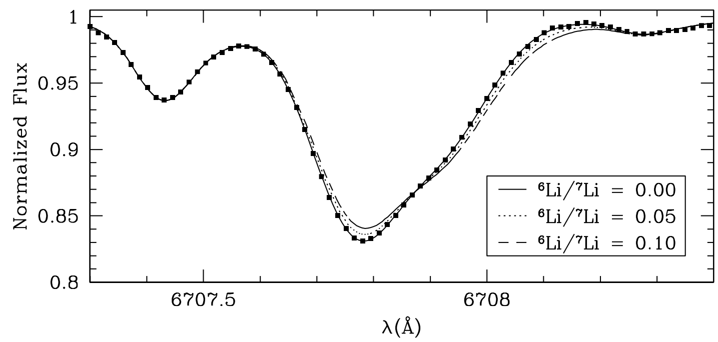
Applications for the 2019 La Serena School for Data Science will open in January 2019. For more information, visit the *school website* or contact *Guillermo Damke*.

NOAO Mini-workshop: "The Resurgence of High-Resolution Spectroscopy at Gemini"

Ken Hinkle

The US National Gemini Office (US NGO) is planning a mini-workshop for the January 2019 American Astronomical Society (AAS) Meeting in Seattle, Washington, on high-resolution spectroscopy at Gemini. This will be the fifth meeting in the NOAO mini-workshop series. These mini-workshops focus on topics of interest to the US Gemini user community. The workshops are splinter sessions that run concurrently with a 90-minute afternoon session of the winter AAS meeting. For the Seattle AAS meeting, we have requested Tuesday afternoon, January 8, with details to be provided by the AAS in late November.

The initial suite of facility instruments at Gemini included one high-resolution spectrograph (see figure). In the last few years, several visitor spectrographs have been offered with capabilities exceeding those on other 8–10m-class telescopes. Gemini will soon be offering a selection of facility and visitor high-resolution spectrographs that span a wide variety of applications in the near-IR and optical.



The line profile of Li I 6707 Å in the planet hosting F9 dwarf HD 82943. The spectrum was observed at R=143000 and S/N > 1000 using the Gemini high-resolution spectrograph bHROS. A suite of spectrographs has replaced this early instrument. (Figure from Ghezzi et al. 2009, ApJ, 698, 451.)

The session will start with an overview by Verne Smith (NOAO) of science from high-resolution spectrographs at Gemini. Jeff Carlin (LSST) will discuss science from the optical spectrograph GRACES. Hwihyun Kim (Gemini) will discuss results from the visit of the 1.5–2.5-micron near-infrared spectrograph IGRINS to Gemini South.

Two future instruments will then be discussed. Jacob Bean (Chicago) will review plans for the high-precision radial velocity spectrograph Maroon-X. Maroon-X should be available at Gemini North in 2019. Finally, Steve Margheim (Gemini) will discuss the status of the new Gemini facility optical spectrograph GHOST.

PowerPoint presentations for previous mini-workshops can be found on the US NGO website at *http://ast.noao.edu/csdc/usngo*.

DECam Community Science Workshop 2018: "Science Highlights, Coming Opportunities, LSST Synergies"

Tim Abbott and Alistair Walker

On 21–22 May 2018 in Tucson, NOAO hosted its second DECam community science workshop. As the Dark Energy Survey comes to a close and the Dark Energy Camera becomes fully at the disposal of the NOAO community throughout the year, especially in the B semesters when the southern Galactic cap is most easily observed, we are motivated to explore how the community has already used the instrument and how it might be used in the future.

Approximately 68 registrants gathered at the Tucson Marriott to hear 28 speakers on topics ranging from the Solar System, cosmology, and exploiting use of DECam and its products from mining the archive through ongoing programs to future work in the era of LSST. A splinter session covered issues of data reduction, and a final roundtable explored possible new surveys, new filters, and two science cases complementary to LSST.

We are grateful to the speakers and attendees for their participation, having ourselves accumulated many pointers for supporting this very active and productive community. Hopefully they too left the workshop inspired. Most of the talks have been posted on the meeting web page at *https://www.noao.edu/meetings/decam2018/agenda.php*.

NOAO Time Allocation Process

Verne V. Smith

Proposal Preparation Information and Submission Help
All information and help related to proposing for telescope time via the NOAO Time Allocation Process (TAC) is available through the NOAO "Proposal Information" web pages and links. The NOAO website is the definitive location for help with proposal preparation and submission as well as for the most current information available to proposers. See the table to the right for specific URLs and email addresses.

Accessibility
NOAO is committed to observing accessibility for all qualified proposers. Many of the telescopes available through NOAO support remote observing. To inquire about remote observing and other forms of access, or to request specific accommodations, please contact any of the following individuals:

Dr. Verne Smith
NOAO TAC Program Head
(*vsmith@noao.edu*)

Dr. Letizia Stanghellini
Head of US National Gemini Office
(*lstanghellini@noao.edu*)

Dr. Lori Allen
NOAO Associate Director for KPNO
(*lallen@noao.edu*)

Dr. Steve Heathcote
NOAO Associate Director for CTIO
(*sheathcote@ctio.noao.edu*)

Dr. Dara Norman
NOAO Deputy Associate Director for Community Science and Data Center
(*dnorman@noao.edu*)

Proposal Preparation and Submission

Proposal Information and Online Proposal Form
http://ast.noao.edu/observing/proposal-info

Time Allocation Committee (TAC) information, approved program lists, proposal request statistics, and telescope schedules
www.noao.edu/gateway/tac/

Online Thesis Student Information Form
www.noao.edu/noaoprop/thesis/

Questions or Need Assistance?

Proposal preparation
noaoprop-help@noao.edu

Gemini-related questions about operations or instruments
Letizia Stanghellini (*lstanghellini @noao.edu*)

CTIO-specific questions related to an observing run
ctio@noao.edu

KPNO-specific questions related to an observing run
kpno@noao.edu

A Newly Coated Primary Mirror for Blanco

Tim Abbott and Roberto Tighe for the Blanco realuminizing team

On 28 June 2018, a new coating of aluminum was applied to the Blanco 4m primary mirror, replacing the old coat dating from November 2011 (Figures 1 and 2). Ideally, we would prefer to realuminize more frequently than we did, but weekly CO_2 snow cleaning and wet washes every three to four months maintained the mirror quality at an acceptable level throughout this time period. There are several reasons for the unusually long interval between coatings.

In the intervening years, a number of our staff have moved on, some to well-deserved retirement and some to other projects and observatories, all taking valuable experience with them. They have left a worthy legacy and are doing us proud at their new positions, but we have been faced with the challenge of finding and training their successors (as far as we are aware, no university offers a degree in observatory operations engineering).

The past decade has seen significant and healthy changes in the safety culture at CTIO, much having been learned during the installation of the Dark Energy Camera (DECam) on the Blanco in 2012. Disseminating these practices through all levels of telescope operations has taken time and practice. Realuminization is the next most complex activity after replacing the entire prime focus assembly, and therefore, it is not to be embarked upon until success is assured.

Raising our safety standards also demanded certain improvements to infrastructure. A key component in any shutdown is the mirror lift—the mechanism used to lower the primary mirror on its cell (combined weight ~30 tons) down from the telescope and to raise it back into position after realuminizing. Despite some 40 years of flawless operation, it was determined that the existing drive mechanism was inadequate by

modern standards given its safety factor of 1.15. Following an in-house design, with an upgraded static safety factor of 2.5, we replaced the drive controller, motor, transmission, and three large ball screws and fully load tested them in April 2018. This upgrade follows a similar development at Blanco's northern twin, the Mayall 4m telescope at Kitt Peak National Observatory, which was completed in 2014.

The aluminizing chamber was significantly refurbished, to improve the vacuum quality and control of aluminum deposition. As a result, pumping and using the chamber are faster and cleaner in every respect. The team also honed their skills before working on the Blanco by refurbishing and using the SMARTS 1.5m aluminizing chamber.

Finally, in recent years, CTIO has seen a significant influx of young and energetic engineers who bring modern practices to our team but who also had to master the many quirks of working at a major telescope. They have, without exception, risen to the challenge and undoubtedly refreshed our approach.

In particular, Jaime Cruz—who joined us in 2017 from Spain where he worked on LSST and E-ELT structures—completely revised the procedures for disassembly and reassembly of the telescope. Nicole David, who joined us in 2014 as an optical engineer, is now a key member of the team who stripped and recoated the mirror. One of the unseen and woefully underappreciated products of a major work package is excellent documentation, which allows the work to be done again, even by a different team—these two, with others' help, have ensured that. Worth noting, too, is that the team drew on staff kindly seconded by SOAR and Gemini.

continued

Figure 1. Cleaning the stripped surface of the primary mirror immediately before installation in the aluminizing chamber. (Credit: NOAO/AURA/NSF)

Figure 2. Inspecting the newly coated primary mirror as it is removed from the coating chamber. (Credit: NOAO/AURA/NSF)

The shutdown began on June 19 and was completed without serious incident by July 11, when the first images of the night sky were taken. The biggest setback encountered was the discovery that the Cass cage, fully loaded with DECam counterweights, caused its cart to deform excessively, despite reinforcement, preventing its use as a lifting rig to move the cage out of the way. The solution was straightforward, if time-consuming: lead weights were removed until the deflections were deemed acceptable.

The final coating, on removal from the chamber, was excellent. Reflectometry measurements show the coating has properties very close to that of nominal bare aluminum and the scattering was reduced by as much as 95% (Figures 3 and 4). The only black mark is that a few nights after the telescope was returned to use a number of "smears" appeared in the coating to the east and the west of the central obstruction. It is not entirely clear why this happened. The marks were not visible when the mirror was removed from the chamber, or we would likely have repeated the stripping and aluminizing. The marks probably indicate inadequate final cleaning of the glass surface before insertion in the chamber. We are closely monitoring them to track any possible further degradation. As it is, the affected areas have a ~10% degraded reflectivity, and the impact on the mirror as a whole is at the 1% level, at most.

On-sky results show a even greater improvement than that determined by direct reflectometry of the mirror surface, with 25%, 15%, and 10% improvement in *g*, *r*, and *i* respectively (the differences may be accounted for by the limitations of the reflectometers used), as reported by the DECam Legacy Survey (DECaLS) program and its reduction pipeline.

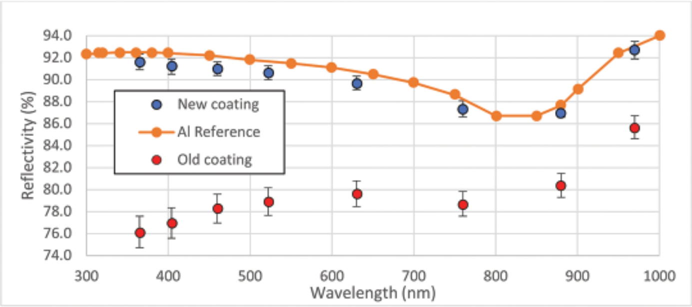


Figure 3. Reflectometry of the primary mirror before and immediately after re-aluminization on 28 June 2018. The error bars on the new coating values reflect the amplitude of variation of reflectivity across some minor imperfections in the new coat.

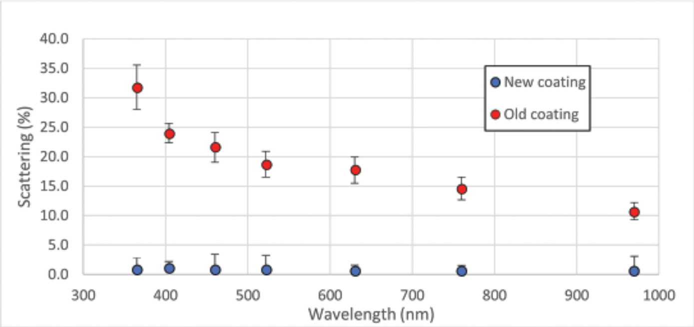


Figure 4. Improvement in scattering, before and after coating.

DES Year 5.5 Is Underway

Alistair Walker

DES, Dark Energy Survey - NGC-1976; M42; (Great Nebula in Orion) (Credit: DES Collaboration)

On the second half of the night of 8 September 2018, the Dark Energy Survey (DES) Collaboration began their final observing season with DECam on the Blanco 4m telescope. This extra "Year 5.5," equivalent to approximately 50 nights of telescope time and ending on 9 January 2019, is covered by an addendum to the existing Memorandum of Understanding between DES, Fermilab, NCSA, and NOAO. The DES Collaboration wrote a detailed proposal for the extra time, which was externally reviewed and subsequently approved by the Department of Energy and the National Science Foundation. The main motivation for the survey extension is to provide a uniform photometric depth by completing the originally planned 10 passes of the 5000 sq. deg. survey, which had fallen behind schedule principally due to the poor weather in the Year 3 season. This was a consequence of the strongest El Niño conditions in the past 50 years.

Both DES and the Community are publishing many science papers on diverse topics, which are listed on the *DECam Science papers* web page. On October 1, DES will be publicly releasing "value-added catalogs" to supplement the already released Data Release One (DR1), accessible from both NOAO and NCSA. This release consists of a subset of the data products used for DES Y1 cosmology and non-cosmology related science. The products include object catalogs, survey characterization maps, and cosmological likelihoods associated with DES Y1 papers. This additional release will provide new opportunities for community science.

SOAR Project Updates

Jay Elias and César Briceño

(Credit: Bruno C. Quint 2018)

The 2018 annual SOAR Director's report to the SOAR Board summarizes the status of a number of projects. This report is posted on the SOAR website at *www.ctio.noao.edu/soar/news*, under the "Project Status" paragraph. Those projects of particular interest to our community include

- STELES installation and commissioning (SOAR Telescope Echelle Spectrograph; dual channels, R=50,000)
- TSpec 4.1 modification and installation (previously named ARCoIRIS; transferred from the Blanco telescope; cross-dispersed, R~3500, 0.7-2.47 microns)
- Aluminizing of the SOAR mirrors
- Various telescope upgrades, including
  - Calibration wavefront sensor
  - Wavefront-sensing guider
  - Primary mirror active optics
  - Mount control upgrade
- SOAR automation and preparation for networked observing
- SAM improvements (SOAR Adaptive Optics Module)

Details on our Goodman Spectroscopic Data Reduction Pipeline (the Goodman Pipeline), a highly automated, Python-based, spectroscopic data reduction pipeline for the Goodman spectrograph, can be found at *https://goodman.readthedocs.io/en/latest/overview.html*.

Visit the *SOAR News web page* for updates on our projects. Questions can be directed to staff members identified in the SOAR Director's report or listed on the *SOAR staff web page*.

Einstein Schools Programme Launched at the IAU Meeting

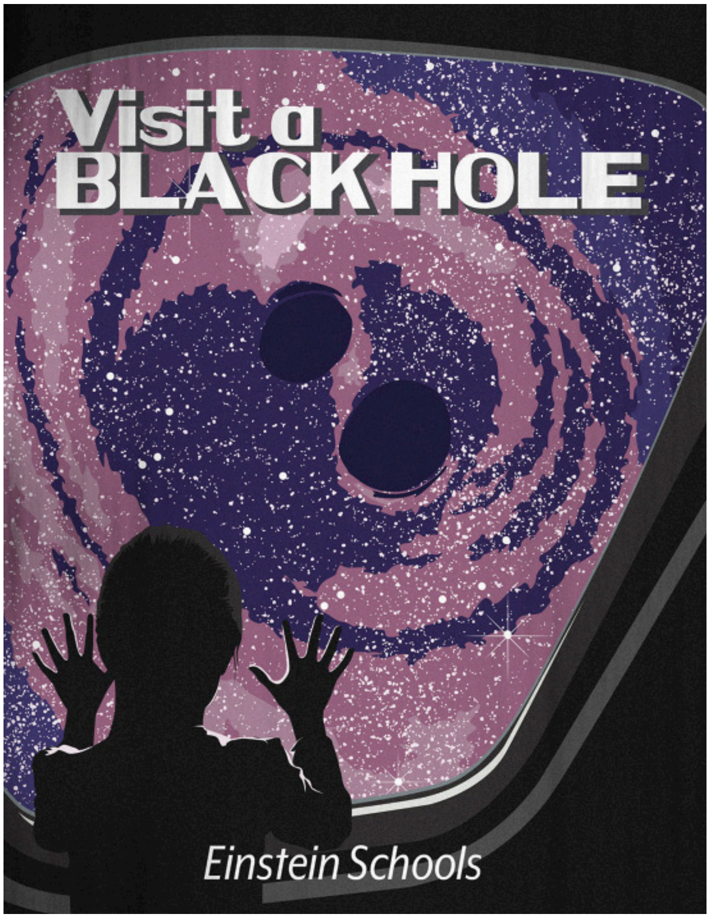
Stephen M. Pompea

The International Astronomical Union, at its 30th General Assembly in Vienna in August, held a kickoff meeting for its IAU 100 global education projects, celebrating 100 years of the IAU promoting international collaboration in astronomical research. The projects will highlight to the world the amazing science, technology, and inspiration that astronomy has brought us.

NOAO is involved in two global projects: one promoting dark skies education and the other celebrating the 100-year anniversary of the Eddington expedition that confirmed Einstein's general relativity predictions, "100 Years of General Relativity: Eclipses." The latter project also includes the Einstein Schools Programme, which encourages an understanding of the important role gravity plays in astronomy, including the study of black holes and other compact objects and the detection of gravity waves. Einstein Schools will encourage students in school clubs and classes to creatively learn and communicate about the latest advances in gravitational wave astronomy and how it has led to a deeper understanding of compact objects such as black holes and binary neutron stars.

The Einstein Schools project has a goal of reaching schools in the 100 countries that are participating in the *International Astronomical Union centennial celebrations*. Participating schools will form teams that not only explore the basics of gravitational wave astronomy but also collaborate with other Einstein Schools worldwide, in keeping with the spirit of the IAU's role in encouraging international collaboration. Einstein Schools can pursue astronomy communication and research projects together, with the support of IAU and mentors.

Astronomers can play a role in encouraging and mentoring Einstein Schools worldwide, and IAU will broker relationships between mentors and schools. An astronomer can work with a local school, a school in the astronomer's hometown, or with a school in another country. For more information on the program and how to participate, please go to *einsteinschools.org*.



Einstein Schools Programme poster (P. Marenfeld/NOAO/AURA/NSF)

Colors of Nature Summer Academy

Rob Sparks

The Education and Public Outreach group led a pair of summer academies as part of the long-term institutionalization of the NSF-funded "Colors of Nature" program. The first academy took place June 11–15 on Kitt Peak and was attended by 12 students from the Tohono O'odham Nation. The second academy was held July 9–13 at the Arizona-Sonora Desert Museum and was attended by 19 students, including 8 students from the San Xavier District of the Tohono O'odham Nation.

The Colors of Nature Summer Academy was originally funded by the National Science Foundation (NSF) through an Advancing Informal STEM Learning grant. The NSF grant ended in 2017, but NOAO is committed to continuing the program through partnerships with the Tohono O'odham Nation and the Arizona-Sonora Desert Museum.

NOAO staff working on the academy include Rob Sparks (Tucson Program Coordinator), Jessica Rose (Logistics), and former project Co-PI Stephen Pompea. Instructors included Perrin Teal Sullivan (University of Alaska Fairbanks), Ekta Patel (Steward Observatory), Amy Orchard (Arizona-Sonora Desert Museum), and Lois Liston and Delphine Saraficio (Ha:sañ Preparatory & Leadership School). Junior docents from the Desert Museum also supported the program. The Tohono O'odham Recreation Division provided round-trip transportation from Sells to Kitt Peak every day for the summer academy. The San Xavier District Education Department provided round-trip transportation from the San Xavier District south of Tucson to the Arizona-Sonora Desert Museum.

continued

Figure 1. The Colors of Nature students use "light painting" to draw different shapes and outline Tohono O'odham elder and academy instructor Lois Liston. (Credit: R. Sparks/ NOAO/AURA/NSF)

The Colors of Nature program explores the science of how color is produced and the role color plays in nature. It also gives students the opportunity to apply their knowledge of color to create original artwork. Exploring the natural environment played a large role in both academies. Students spent time exploring the sky island of Kitt Peak, observing its plant and animal life, and discussing how it differed from life on the desert floor. A trip to the lake on Kitt Peak allowed students to see much of the wildlife on the mountain. Students also went on tours of the 2.1-meter telescope, the WIYN 3.5-meter telescope, and the McMath-Pierce Solar Telescope. On the last day of the academy, students displayed their work at the Sells Recreation Center, giving their families and friends a chance to see the work students had created during the week.

The Arizona-Sonora Desert Museum provided another great environment to observe colors in the natural environment as students observed plants and animals. Each day students explored a different part of the museum including the caves, grasslands, aquarium, underground cave exhibit, and art galleries. Daily visits by animal ambassadors from the Desert Museum gave students opportunities to see animals up-close and learn about their behaviors. The last afternoon of the academy, parents were invited to see the work the students created during the week. Through their explorations, students learned about the various roles color plays in nature, including camouflage and signaling. Each student kept an extensive notebook of the observations and sketches they made during the academy.

This summer, the Colors of Nature program included Tohono O'odham culture and traditions. Two members of the Tohono O'odham Nation, Lois Liston and Delphine Saraficio, who are culture and language instructors at Ha:sañ Preparatory & Leadership School, brought O'odham culture and language into the academies. Students learned O'odham words for colors, animals, and other topics covered in the academy. O'odham stories and traditions were shared with the students, providing a culturally rich experience in both academies to complement their scientific explorations.

continued

The Colors of Nature program team has been awarded a dissemination grant from the NSF to provide professional development to youth program leaders in libraries and science centers in the states of Alaska, Washington, and Arizona. This grant is a partnership between NOAO, the Geophysical Institute of the University of Alaska Fairbanks, and the University of Washington Bothell who are working with the Pima County Library in Arizona to provide professional development that will form the basis of a long-term program in Arizona.

Figure 2. The Colors of Nature participants pose at Kitt Peak National Observatory with lead instructor Perrin Teal Sullivan from University of Alaska Fairbanks, Tohono O'odham elder and cultural instructor Lois Liston, instructor Ekta Patel from Steward Observatory, and instructor Amy Orchard from the Arizona-Sonora Desert Museum. (Credit: R. Sparks/NOAO/AURA/NSF) NL

Planning by AURA Observatories in Chile for the 2019 Total Solar Eclipse

Leonor Opazo

A total solar eclipse will occur on 2 July 2019. Totality will be visible from the southern Pacific Ocean east of New Zealand to the Coquimbo Region in Chile and Argentina before sunset. Some regions in the Pacific and in South America, including locations in Peru, Ecuador, Brazil, Uruguay, and Paraguay, will see a partial solar eclipse, if the weather permits. Of particular importance is that the eclipse will be total on Cerro Tololo and Cerro Pachón.

In the Coquimbo Region the path of totality will be about 200 kilometers wide from the community of Domeyko in the North (Atacama Region) to Guanaqueros in the South. At the centerline of the region of totality, totality will last for approximately 2m 40s; in Cerro Tololo it will be approximately 2m 06s. In the last 500 years in the Coquimbo Region, the phenomenon of a total solar eclipse has occurred only on three occasions: 9 June 1592, 15 March 1839, and 16 April 1893.

Given the importance of the total solar eclipse to astronomy education efforts in the Region of Coquimbo, the EPO teams of AURA Chile, Cerro Tololo, and Gemini have created a plan to get the most from this event through education and outreach with the available resources. AURA and its programs in Chile (CTIO, Gemini, SOAR, and LSST) are an important source of high-quality eclipse information, including safety advice and basic education about the Sun.

The goals of our program are to

- provide accurate and timely eye safety education;
- provide accurate and timely information to local authorities for logistical planning and coordination;
- take advantage of the excitement of the solar eclipse to strengthen our profile in the local community through our STEM education efforts, incorporating solar eclipse education in outreach to public, teachers, students, and media; and
- provide comprehensive assistance to AURA facilities in the areas of planning, safety, and emergency management.

The key elements in the plan include both pre- and post-eclipse activities (2018–2020) and day-of-the-eclipse activities. The pre- and post-eclipse activities include awareness and training events that were developed starting at the end of 2017 and that have reached more than 20,000 people so far. These activities include

- training events for professors and students;
- the use of eclipse-themed programs in major public events, such as AstroDay and Viaje al Universo;
- training events for astro-tourism and other tourist guides;
- collaboration with local public institutions, SERNATUR (Chilean National Tourism Service), the Chilean Ministry of the Environment, and the tourism offices of various municipalities;
- informative seminars for media and local authorities;
- support for implementation of large-scale events by the municipalities of the Region of Coquimbo. Already in place are plans for a large event in the La Serena soccer stadium with a talk by Chilean astronomer José Maza and the webcast of the eclipse from Cerro Tololo, and for a second webcast from Las Campanas Observatory; and
- a Spanish-language web page, *www.eclipsesolar2019.cl*

Day-of-eclipse activities include

- observing support for five science programs at CTIO during the eclipse;
- support for extensive media coverage from the Region of Coquimbo, with worldwide broadcasts of the event; and
- support for VIP visitors at CTIO.

An enormous amount of planning has gone into this very short but important astronomical event. Most of our education programs are centered on the schools and communities in the path of totality. There will be enhanced access to CTIO one week before and one week after the eclipse, in order to better serve public and educational groups. The eclipse planning team has studied the programs and lessons learned from the recent US eclipse to maximize the return on our planning investment.

Summit on Chilean Astronomy Education

Stephen Pompea and Leonor Opazo

Figure 1. EPO staff member Jessica Rose and students from Escuela Maule dive into an activity about how light pollution affects animals during Daniel Munizaga's light pollution summit workshop at the Interactive Center for Science, Arts, and Technologies, CICAT, in Coronel, Chile. (Credit: K. Flores, NOAO/AURA/NSF)

Several NOAO Education and Public Outreach staff had an opportunity to participate 5–7 September 2018 in the "Fourth Summit of the Chilean Network of Education and Dissemination of Astronomy." NOAO's EPO-South Coordinator Leonor Opazo played a role in the planning of each of the summits and was on the organizing committee for this summit, which was held at the University of Concepción.

The summit focused on the upcoming eclipses in Chile as well as on discussion of many aspects of astronomy education, astronomical tourism, the teaching of critical thinking skills, and the latest research on science communication. Participants included professional astronomers, schoolteachers and principals, and education and public outreach experts from NOAO, Gemini, LSST, ESO, and AUI. Also participating were science communication specialists, museum and planetarium educators, amateur astronomers who do outreach, and astronomical tourism operators and advisors.

There was a focus on the two eclipses that will occur in Chile during the next two years. The challenges of educating the public on the safe viewing of the eclipses were discussed in detail. There was a concentration on program planning for the regions inside and outside of the region of totality. Other topics such as dark skies education, girls in science, teaching astronomy with everyday materials, visitor experiences at observatories, program metrics and evaluation, the teaching of robotics, social media strategies, and Einstein Schools were also discussed. The topics were addressed using talks, panel discussions, expositions, and hands-on workshops. One day of the program was held at the hands-on science center CICAT (Centro Interactivo de Ciencias, Artes y Tecnologías) in nearby Coronel, while an evening session was held with the theme "Night of the Stars."

The summit was an outstanding opportunity for dialog among the many diverse components of the Chilean astronomical education, tourism, and communication ecosystem.

Figure 2. Group photo of "Fourth Summit of the Chilean Network of Education and Dissemination of Astronomy" participants at the University of Concepción. (Credit: NOAO/AURA/NSF)

NOAO Staff Changes at NOAO North and South

(16 February 2018 – 30 September 2018)

New Hires / Rehires

North

Davis Jr., Troyd E.	Cook
Doyen, Guillaume C.	Student Assistant
Dunlop II, John H.	Consultant (Seasonal)
Hay, Stephen M.	Driver
Kadowaki, Jennifer Y.	Data Reduction Specialist
Lee, Chien-Hsiu	Assistant Scientist
Li, Dan	Assistant Scientist
Meisner, Aaron M.	Post Doc Research Assoc
Merrill, Catherine D.	Project Manager
Petris, Miguel	Program Manager
Smith, Ralph	Head of Facilities Oper
Stephenson, Devin A.	Technical Assoc I
Stubens, Carl A.	Software Systems Engineer

South

Gomez, Diego	Scientific Programmer
Reyes, Juan C.	Maintenance Man 4
Rojas, Luis M.	Driver 3
Sanhueza, Andres E.	Head of Facilities Operations
Soto, Mauricio J.	Electrical Supervisor / Associate Engineer

Promotions

North

Allen, Lori	Senior Scientist
Dickinson, Mark E.	Astronomer/Tenure
Hunting, Emily	Engineer
Matheson, Thomas D.	Astronomer/Tenure
Norman, Dara J.	Scientist
St. Paul-Butler, Karen D.	Sr Observing Associate
Stanghellini, Letizia	Astronomer/Tenure
Summers, David L.	Sr Observing Associate
Thompson, Sara	Public Program Specialist 2

South

Abbott, Timothy	Observatory Scientist
Aguirre, Victor R.	Electronic Technician 2
Araya, Mauricio	Technician 2
Correa, Carlos	Electrical Technician 3
Diaz, Cristian	Electronic Technician 2
Godoy, Luis	Senior Technician/Foreman
Ordenes, Ian E.	Electronic Technician 2
Torres, Manuel P.	Electronic Technician 2
Vivas, Caterine	Associate Astronomer

Terminations

North

Brittain, Sean	Scientist
Christensen, Robert D.	Senior Engineer
Davis Jr., Troyd E.	Cook
Doyen, Guillaume C.	Student Assistant
Fulmer, Leah M.	Data Reduction Specialist
Hendricks, Mikelyn	Visitors Guide/Cashier
Kadowaki, Jennifer Y.	Data Reduction Specialist
Lutz, Jennifer L.	Program Manager
Rankins, Judith	Volunteer & Membership Coord
Robinson, Brian	Public Program Specialist 1
Salmon Delgado, Felix F.	Craftsperson I
Saucedo, Miranda	Safety Documentation Specialist
Sellers, Jhoedi	Public Program Specialist 1
Siquieros, Johnathan M.	Public Program Specialist 1
Watson, David	Public Program Specialist 1

Windows on the Universe Center for Astronomy Outreach at Kitt Peak National Observatory

The National Science Foundation (NSF) has awarded the Association of Universities for Research in Astronomy (AURA) a $4.5 million grant for the development of the Windows on the Universe Center for Astronomy Outreach at NSF's Kitt Peak National Observatory. Located in the McMath-Pierce Solar Telescope facility, an iconic structure that was once the world's largest solar observatory, the center will provide the public with a new way to experience the cutting-edge research being carried out at Kitt Peak and other NSF-funded astronomy facilities around the globe, including ground-based optical, radio, solar, and gravitational wave facilities.

Recently retired as a scientific research facility, the McMath-Pierce will be repurposed for astronomy outreach. Dedicated in November 1962, the McMath-Pierce made important scientific discoveries about the Sun, planets, and the Moon over its 55-year research career. It was once the only solar telescope capable of observing the Sun at infrared wavelengths, and it has a long history of contributing to instrumentation development for both solar and nighttime astronomy.

The telescope now turns to a new mission focused on astronomy outreach and education, in an ambitious transformation of a research facility into a state-of-the-art outreach center. The center is expected to open to the public in about two years.

The grant will fund the renovation and transformation of the McMath-Pierce into an astronomy visualization and presentation center with potentially global reach. The center will feature data visualization systems, interactive exhibits, and a simulated telescope control room, which will give visitors the virtual experience of being at a telescope and participating in research carried out at NSF facilities around the world, including those in Hawai'i, Chile, and the South Pole.

Visitors to the center will explore the wide variety of research carried out at NSF's astronomy facilities, including Kitt Peak, Cerro Tololo Inter-American Observatory, Gemini Observatory, the Large Synoptic Survey Telescope, and the Daniel K. Inouye Solar Telescope—all managed by AURA—as well as the Very Large Array, Atacama Large Millimeter Array, South Pole Telescope, and Laser Interferometer Gravitational-Wave Observatory. The visualizations created for Windows on the Universe will feature imagery from these NSF facilities and will be designed for export to compatible visualization centers around the world, expanding the center's reach.

To highlight its location in the McMath-Pierce facility, the Center will feature special exhibits on the history of solar astronomy. The grant will also fund public programs, including educational programs to be developed in collaboration with the Tohono O'odham Nation. Kitt Peak National Observatory, which is located in the Schuk Toak district on Tohono O'odham Nation land, 56 miles west of Tucson, Arizona, is part of the National Optical Astronomy Observatory (NOAO), which is operated by the AURA under an agreement with NSF.

The development and operation of the new center will be led by the Kitt Peak Visitor Center and its manager, Bill Buckingham. NOAO's Education and Public Outreach group will partner in developing new educational programming for students and teachers. Staff from NOAO and other NSF astronomy facilities will be invited to help develop exhibits that showcase results from their respective facilities.

The National Optical Astronomy Observatory is operated by the Association of Universities for Research in Astronomy (AURA), Inc. under a cooperative agreement with the National Science Foundation

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