The Mirror

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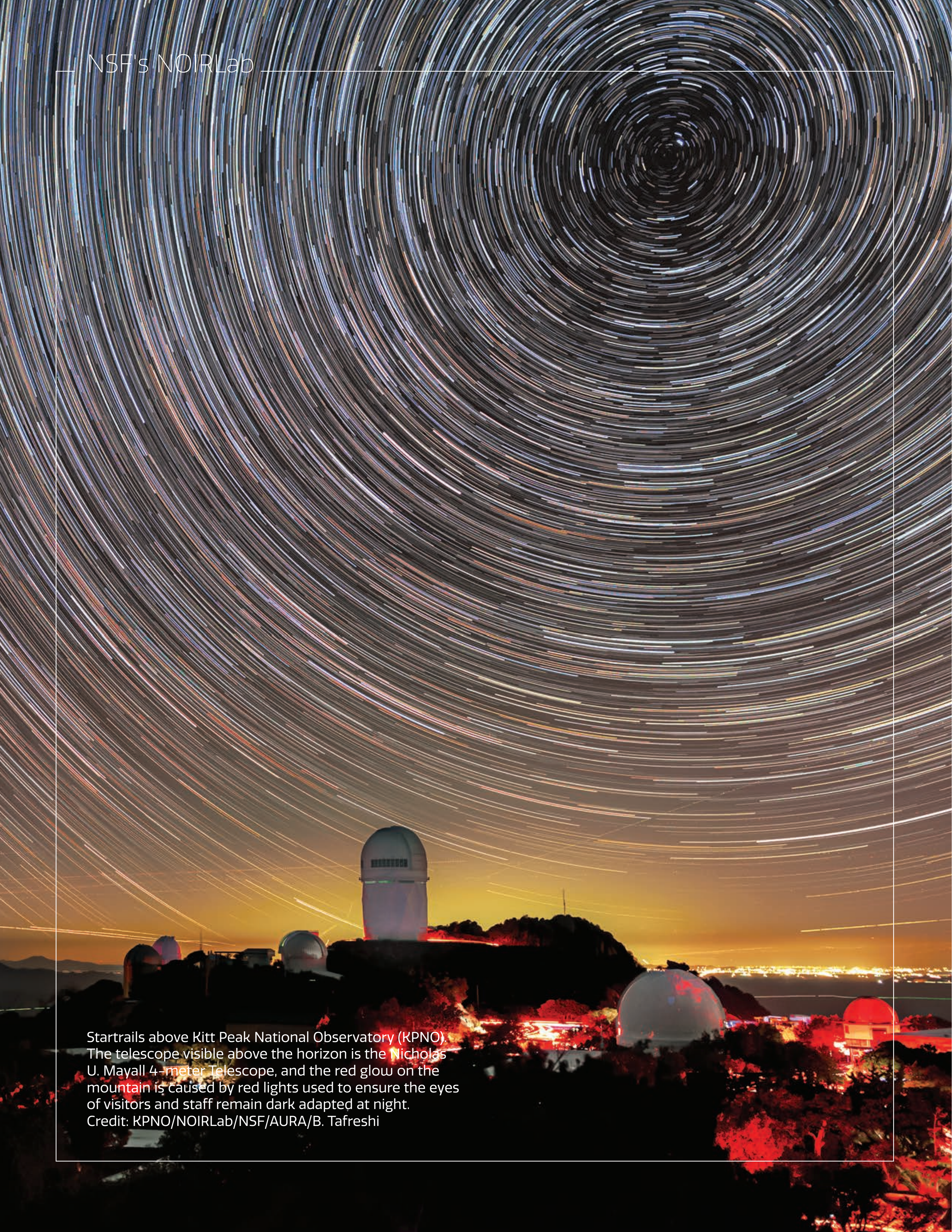

Startrails above Kitt Peak National Observatory (KPNO). The telescope visible above the horizon is the Nicholas U. Mayall 4-meter Telescope, and the red glow on the mountain is caused by red lights used to ensure the eyes of visitors and staff remain dark adapted at night.
Credit: KPNO/NOIRLab/NSF/AURA/B. Tafreshi

THE MIRROR

ISSUE 1 | JUNE 2020

On the Cover

The Milky Way arcs overhead at Kitt Peak, Cerro Pachón, Cerro Tololo, and Maunakea (top to bottom), the mountaintops that host CTIO, KPNO, the international Gemini Observatory, and the Vera C. Rubin Observatory. Data from these facilities flow into the Community Science and Data Center (CSDC), NOIRLab's "fifth mountaintop."

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NSF's NOIRLab

The Silver Sliver Galaxy—more formally known as NGC 891—is shown in this striking image from the Mosaic instrument on the Nicholas U. Mayall 4m Telescope at Kitt Peak National Observatory, a Program of NSF's NOIRLab. NGC 891 is a spiral galaxy that lies almost perfectly edge-on to us, leading to its elongated appearance and its striking resemblance to our home galaxy, the Milky Way, as seen from the Earth. Since NGC 891 is oriented edge-on, it's great for investigating the galactic fountain model. When stellar winds and supernovae from the disk of a galaxy eject gas into the surrounding medium, it can create condensation that rains back down onto the disk. The condensed gas then provides new fuel for star formation. In addition to the portrait of NGC 891, this image is littered with astronomical objects near and far—bright foreground stars from our own galaxy intrude upon the view of NGC 891, and distant galaxies lurk in the background.

Credit: KPNO/NOIRLab/NSF/AURA
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From the Office of the Director

Patrick McCarthy

Welcome to the inaugural edition of The Mirror—the newsletter for NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab for short). A new organization that unifies all of NSF's night-time ground-based observatories under a single umbrella, NOIRLab is also much more. It unifies observatories and communities to create a center that is stronger, more capable, and more diverse and inclusive than the sum of its parts. While our name reflects the central role of our primary sponsor, the US National Science Foundation, NOIRLab brings together US and international partners through Gemini, SOAR, and other initiatives, as well as inter-agency partnerships and collaborations with the US Department of Energy and NASA.

Our choice of "The Mirror" for the name of this newsletter series is more than a reflection on the central role of optics in our field. A mirror allows us to see ourselves as others do. As we launch NOIRLab and this newsletter series, it is important that we be aware of how you see us in the present, understand the aspirations of our community, and engage with you as we create a shared vision for the future. In this inaugural volume, five distinguished scientists share their thoughts on the proper role of a national observatory.

While its name is new, The Mirror builds on the missions and traditions of its predecessors, the GeminiFocus and NOAO Newsletter series. The new newsletter series will continue to provide updates for all of the programs that comprise NOIRLab, both information of interest to a broad community and communications targeted to specific user communities (e.g., Gemini's international partners). So you can rest assured that information critical to users, and their sponsors, will be provided in forms tailored to local needs.

As you will read in this volume, an enormous amount of activity is underway at NOIRLab. We are revitalizing the AO capabilities of Gemini North, working with our colleagues from Lawrence Berkeley National Laboratory to commission the Dark Energy Spectroscopic Instrument on the Mayall telescope, and collaborating with a team of scientists led by Penn State to bring a next-generation precision radial velocity instrument to the WIYN telescope with the support of NASA. The operations team for the Rubin Observatory is well along in developing operations plans that will drive both the time-domain and data revolutions that are underway in our field.

All of this activity and planning has, however, not escaped the current global pandemic. Our mountaintop facilities and offices in Chile and Arizona are closed temporarily as a result of COVID-19 to protect the health of our staff, their families, and local communities. Gemini North is now back online, and we look forward to getting back on the sky with the telescopes at Kitt Peak, Cerro Tololo, and Cerro Pachón when local conditions allow. Please check our websites for regular updates.

Lastly, while this is a newsletter for the NOIRLab community, the news is ultimately generated by our user community and sponsors. We would be delighted to hear from you regarding interesting science results, your opinions and aspirations, capabilities you would like to see, and suggestions for improvements in our communications. Stay in touch and, most importantly, stay safe.

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Gemini Science

John Blakeslee

Gemini Observatory achieved its first science observations in July 2000, when it targeted the Galactic center from Maunakea using the adaptive optics instrument Hokupa'a, then on loan from the University of Hawai'i. Thus, this year we are celebrating 20 years of science with the Gemini telescopes. Here we highlight a few of the more recent scientific results from Gemini, including a high-dispersion study of evolved exoplanet hosts, the discovery of the most energetic quasar outflow observed to date, and the first colorful glimpse of Earth's fleeting mini-moon. The objects targeted in these programs were brought to light by the Kepler mission, the Sloan Digital Sky Survey, and the Catalina Sky Survey. These stories therefore illustrate the enormous potential for synergy between wide-field sky surveys and fast, flexible, large-aperture facilities such as Gemini. They also presage some of the key science we anticipate from Gemini during its third decade of operations, as we begin a new era of synergy with the Vera C. Rubin Observatory.

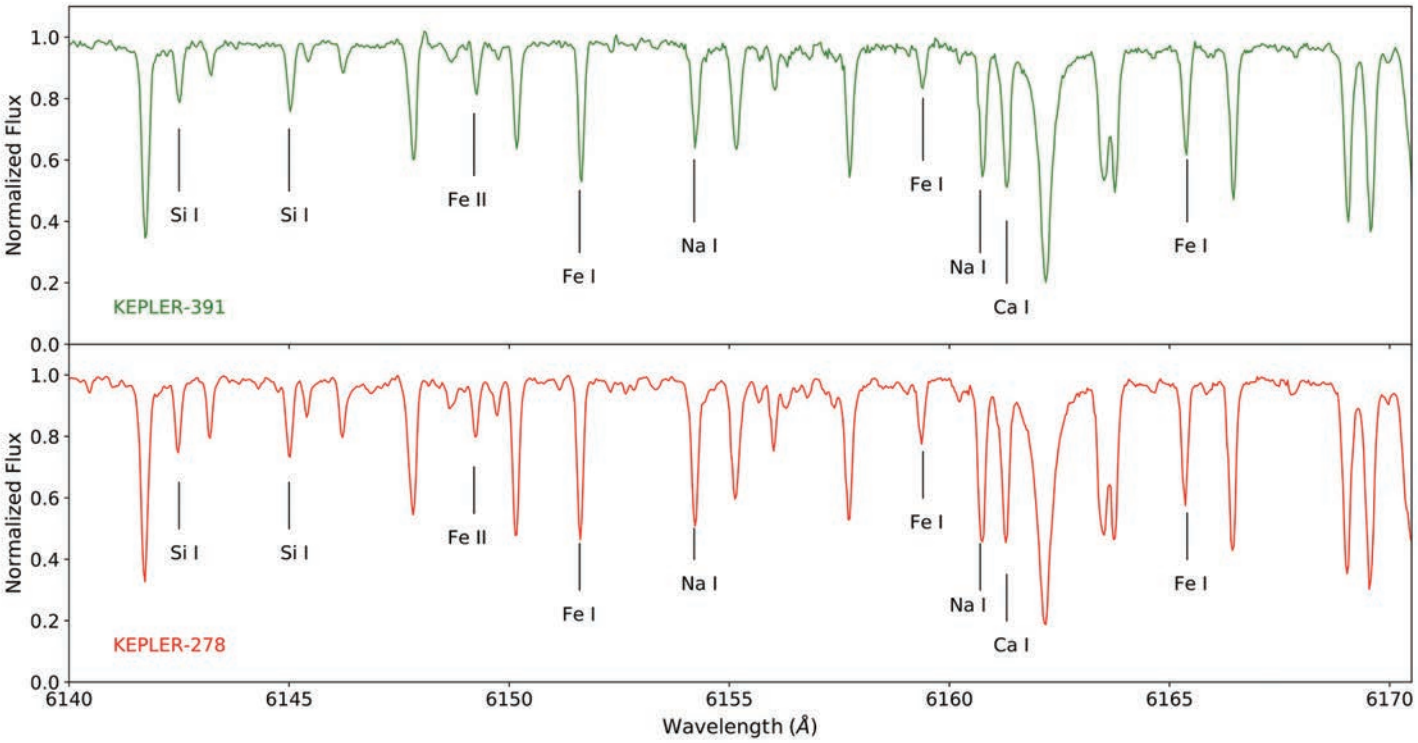

Figure 1: Small portions of the high-resolution Gemini/GRACES spectra of the early-stage red giants Kepler-391 and Kepler-278, both of which host multiple confirmed transiting exoplanets. Various lines used in deriving chemical abundances, effective temperatures, and surface gravities are labeled. (Reproduced from Jofré et al. 2020, A&A, 634, A29)

Insight into Exoplanets around Red Giants

NASA's *Kepler* mission monitored over 150,000 stars for four years and yielded over 4760 exoplanet candidates, about half of which have been confirmed, and new searches of the *Kepler* database by independent teams continue to turn up additional candidates. The vast majority of the exoplanet hosts lie on the main sequence, but *Kepler* also monitored over 16,000 stars on the red giant branch (RGB). Other things being equal, one might expect the yield of transiting exoplanets around RGB stars to be in the hundreds, and detailed studies of these could constrain models of planet-star interaction in evolved systems.

However, of course, other things are not equal for red giants. The stars' large sizes (which decrease the depths of transits) and irregular variabilities make detecting planetary transits much more difficult. As a result, only 0.1% of the observed red giants have confirmed planets found by *Kepler*, and only three of these stars are known to host multiple transiting exoplanets. A recent study, led by Emiliano Jofré of the Observatorio Astronómico de Córdoba, uses new high-quality, high-resolution Gemini GRACES data to derive stellar parameters and chemical abundances of 25 elements for two of the three known multi-planet RGB systems. Portions of the GRACES spectra for these stars, Kepler-278 and Kepler-391, are shown in Figure 1.

Both of the stars were observed for the full four years of the *Kepler* primary mission. Kepler-278 hosts two Neptune-sized planets with periods of 30 and 51 days, while Kepler-391 hosts two somewhat smaller planets with periods of 7.4 and 21 days. Analysis of the GRACES data, combined with *Gaia* parallaxes, indicates that the stars are near twins, with temperatures of 5000 K, radii three times that of the Sun and masses 25% larger than the Sun's; for Kepler-278, this is 15% lower than previous estimates of its mass. The study finds that both stars are spectral type K2 III-IV with ages close to 5 Gyr, and both are just beginning to ascend the RGB. However, Kepler-278 has a metallicity about 1.6 times the solar value, compared to 1.1 times solar for Kepler-391.

The new high-quality measurements of the stellar parameters allow for refined analyses of the *Kepler* light curves, enabling improved estimates of the exoplanet properties and better characterization of their orbits. In particular, for the Kepler-278 system, the study confirms the presence of transit timing variations (TTVs) for the outer planet Kepler-278c and detects for the first time the TTV signal for the inner planet as well. This makes possible the first measurements of the masses of these planets, 56 and 35 Earth masses for Kepler-278b and Kepler-278c, respectively. No TTVs were detected in the Kepler-391 system, so only upper limits on the planetary masses could be derived. The analysis indicates that the orbits of the Kepler-278 planets are coplanar and surprisingly eccentric, which could have resulted from a sudden mass loss event by the host star, but precise radial velocity follow-up is needed to confirm the high eccentricities.

As these two stars continue to ascend the RGB, all four of their known planets are expected to be engulfed. Studies of larger samples of planets around evolved stars, including those further along the RGB, are needed to constrain scenarios for planet-star interaction in such systems. The *TESS* mission will observe hundreds of thousands of red giants and should provide a much larger sample of transiting exoplanets for detailed high-resolution follow-up studies.

Fathoming the Outflow in an FeLoBAL

Gas heating via energetic feedback from active galactic nuclei has become the semi-analytic modelers' go-to mechanism for halting star formation in massive galaxies. One way to probe the physics of this phenomenon in the real universe is through broad absorption line (BAL) features in quasar spectra. The large blueshifting of the absorption is clear evidence of rapidly outflowing material. Broadly speaking, quasars with such features can be divided into those that show broad absorption by only highly ionized species (HiBAL) and those that also show it for

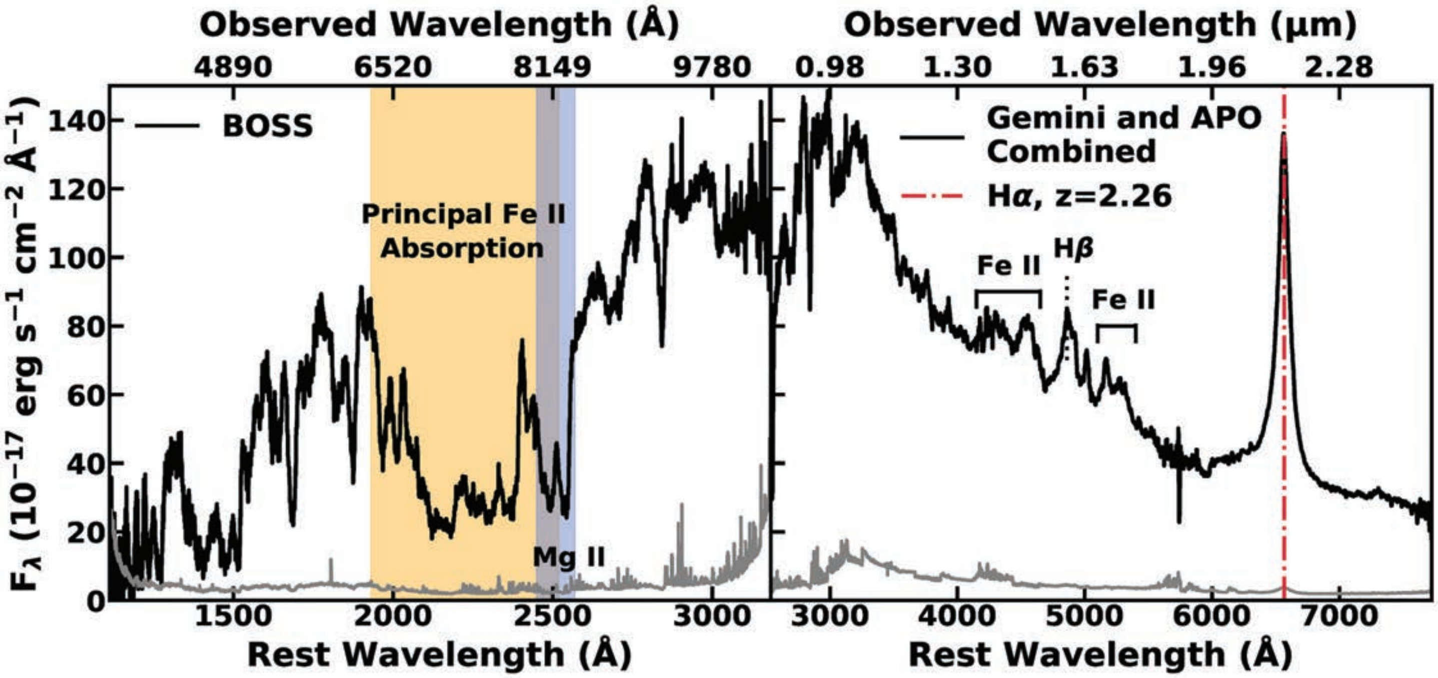

Figure 2: Spectrum of the quasar SDSS J1352+4239, showing the "overlapping trough" of low-ionization iron absorption characteristic of such FeLoBAL quasars. The spectrum is a composite of BOSS data at optical wavelengths and Gemini/GNIRS and APO/TripleSpec data in the infrared. Key features are marked. The strong Hα line observed at 2.14 µm provides the redshift, which was difficult to constrain precisely from the optical because of the broad absorption and lack of strong emission features. (Reproduced from Choi, Leighly, Terndrup 2020, ApJ, 891, 53)

low-ionization lines (LoBAL). A subclass of the latter are the FeLoBAL quasars, which show broad Fe II absorption. While the outflows in some HiBALs have velocities near 20% the speed of light, outflows in the rarer FeLoBALs have higher column densities and can be more energetic. However, blending of the numerous broad Fe II features creates a major challenge to extracting the physical properties of the outflows.

A new study led by graduate student Hyunseop Choi of the University of Oklahoma uses the novel spectral synthesis code *SimBAL* to analyze the outflow of material in the FeLoBAL quasar SDSS J1352+4239. The data, shown in Figure 2, are a combination of an optical spectrum from the Baryon Oscillation Spectroscopic Survey (BOSS) and infrared spectra obtained with the Gemini Near-Infrared Spectrograph (GNIRS) at Gemini North and the TripleSpec instrument at the Apache Point Observatory. The prominent Hα line observed in the IR data provides an unambiguous redshift of z = 2.264, which is higher by 0.23 than previously reported from optical data alone. The *SimBAL* code, developed by Karen Leighly (University of Oklahoma) and Donald Terndrup (Ohio State), performs Bayesian forward-modeling of quasar spectra to constrain the physical parameters of the outflowing gas. The code is designed especially for quasars with blended BAL features, such as the "overlapping trough" of Fe II lines evident in the rest-frame UV spectrum of SDSS J1352+4239.

Based on the detailed spectral modeling, the study derives outflow velocities reaching 38,000 km/s, with a velocity width of about 10,000 km/s. This is the highest outflow velocity ever measured for an FeLoBAL. The black hole mass estimated from the Hβ line is 8.6 billion solar masses, which means that SDSS J1352+4239 is radiating near its Eddington limit, with an inferred mass accretion rate of 176 solar masses per year. In comparison, the estimated mass outflow rate exceeds 3000 solar masses per year, and the momentum flux of the outflow exceeds that of the quasar photons by a factor of twenty. This can be explained by the presence of dust, which would scatter the photons and could serve as an accelerating mechanism for the outflowing material.

The authors conclude that the outflow in SDSS J1352+4239 is the most energetic found to date. The energy flux easily exceeds the threshold required for quasar feedback to be an efficient means of quenching star formation in the surrounding galaxy. The team is currently analyzing a larger sample of FeLoBAL quasars to determine the distribution of their outflow properties and how SDSS J1352+4239 fits within the larger population.

Welcoming a New Neighbor

Dynamical models of the Solar System predict that meter-sized asteroids are captured roughly once per year into temporary orbits by our planet; for asteroids 3m in size, it's about once per decade. Such objects, that make at least one complete revolution around the Earth, are called temporarily captured orbiters (TCOs). More colloquially, at least since the discovery of 2020 CD3 hit the press in late February this year, they are known as "mini-moons." They are extremely difficult to detect because they not only are tiny by astronomical standards but also move the fastest along their plunging geocentric orbits when they are at their closest and brightest.

On 15 February of this year, astronomers Kacper Wierzchos and Teddy Pruyne at the University of Arizona's Catalina Sky Survey detected a rapidly moving near-Earth object that observations on the following night confirmed to be on a geocentric orbit. Originally designated C26FED2, the object's motion over the next week showed no evidence of perturbation due to solar radiation pressure; thus, its area-to-mass ratio was consistent with that of an asteroid, rather than a misplaced hunk of debris from Earth's space program. In addition, integration of the orbit backwards in time revealed no associations with past space missions. These results strongly supported a natural origin for the object, which would make it only the second TCO discovered while in geocentric orbit. The previous one, 2006 RH120, also found by the Catalina Sky Survey, orbited for a bit over a year before escaping.

The international Gemini Observatory received a Director's Discretionary Time proposal from a team led by Grigori Fedorets of Queens University Belfast to observe the mini-moon candidate, still going by the moniker C26FED2 at time. The program was approved and rapidly made ready on 23 February; the resulting observations, shown in Figure 3, were obtained later that night. At the time of discovery, the object was at 0.7 lunar distances, headed outward from a closest approach of only 0.12 lunar distances two days earlier. By the time of the Gemini observations, it was already at 2.4 lunar distances and almost 3 magnitudes fainter than at discovery. On 25 February, in view of the evidence favoring a natural origin, the International Astronomical Union's Minor Planet Center bestowed the formal designation, 2020 CD3. Analysis of the multiband Gemini data will enable broad classification of the asteroid type.

Although we hardly got to know it, 2020 CD3 departed Earth orbit by May 2020 and won't drift our way again until 2044. However, more mini-moons are in the pipeline—specifically, they will be in the moving object pipeline of the Vera C. Rubin Observatory. Estimates for the number of TCO discoveries by Rubin Observatory vary between ~ 1 per month and ~ 1 per year, depending mainly on the exact cadence of the observations and the efficiency of confirmation. Most will be only tens of centimeters in size. Follow-up of these TCOs by Gemini and other large facilities can reveal their surface compositions and constrain the origin of the smallest objects in the inner Solar System. Discoveries of mini-moons with long capture durations would also provide easy targets for retrieval missions, perhaps of an entire meter-sized asteroid.

Figure 3: This crisp little dot amongst the colorful star trails is the temporarily captured object 2020 CD3, more popularly known as Earth's latest "mini-moon." It was observed with GMOS at Gemini North in the early morning hours of 24 February 2020. The color image is a composite of six 5-minute non-sidereally tracked exposures in the g,r,i filters. (Credits: The international Gemini Observatory/NOIRLab/NSF/AURA/G. Fedorets/Queen's University Belfast)

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RR Lyrae Stars in Ultra-faint and Ultra-diffuse Dwarf Milky Way Companions

Clara Martínez-Vázquez, Kathy Vivas, and Alistair Walker

Searching for RR Lyrae stars (RRLs) in ultra-faint dwarf (UFD) and ultra-diffuse dwarf (UDD) Milky Way companions is important for obtaining accurate distances to these systems, which then allows determination of their physical properties (e.g., size and luminosity) and computation of their orbits. Furthermore, given that they may be among the most ancient and primitive galaxies formed (Bose et al. 2018; Simon 2019), the pulsation properties of the RRLs can provide important clues about the contribution of these systems to the formation of the halo of the Milky Way, helping us to better understand the hierarchical formation and evolution of our Galaxy.

Over the past two decades, we have witnessed the discovery of more than 50 new UFDs and the first two UDDs (Crater II and Antlia II; Torrealba et al. 2016, 2018). These have been detected thanks to large-area, deep, multi-color imaging sky surveys; those carried out with the Dark Energy Camera (DECam) on NOIRLab's Victor M. Blanco 4m Telescope at Cerro Tololo Inter-American Observatory (e.g., DES, SMASH, MagLiteS, DELVE) have so far contributed to the discovery of more than 20 UFDs. *Gaia* proper motions, spectroscopy for radial velocities and abundances, and time-series photometry are essential ingredients to allow full interpretation.

Our team has concentrated on increasing the census of RRLs in UFDs. The low mass, the scarcity of stars, and the large contamination by field stars make the determination of morphological parameters and distances for these galaxies a challenging task. An attractive method to improve the distance determination to these ultra-faint systems—and thus to clarify their nature—is to find RRL members. As pulsating variable stars with periods ranging from 0.2 to 1.2 days, RRLs are readily identifiable with suitable time-series photometry. Since RRLs obey well-calibrated period-luminosity relations, they are an excellent distance indicator, and are observable throughout the Local Group. Moreover, since RRLs are older than 10 Gyr, they can also provide insight on the properties of the old stellar population in any systems in which they are found.

In Martínez-Vázquez et al. (2019), we have searched for RRLs in some of the DES UFD systems using *gri* time-series observations with the Goodman High Throughput Spectrograph at SOAR. We also took additional data with DECam, collecting a total of around 40 epochs per filter per galaxy. As an example of the results we have detected two RRLs in the field of Grus I (Figure 1), one in Phoenix II, and four RRLs near Grus II; however, it is clear that one of these RRLs is a Galactic halo member and two of these are more distant than the galaxy itself, and are likely associated with the Chenab/Orphan Stream. The new distances measured with the newly detected RRLs in these systems allowed us to set their location farther than previously thought, thus implying larger physical sizes for these systems.

In Vivas et al. (2020a) we extended the search to 27

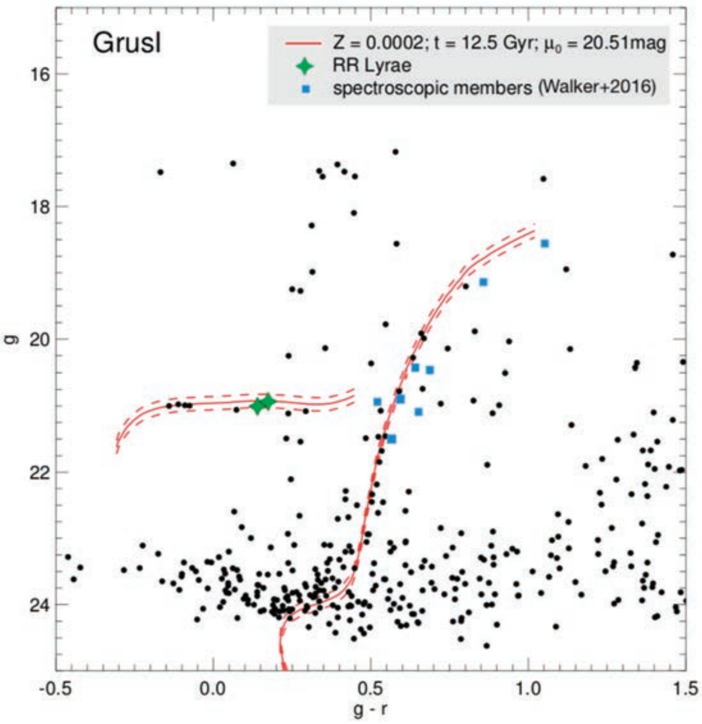

Figure 1: CMD of Grus I from our Goodman/SOAR photometry. Two RRLs were detected in this galaxy at the same distance modulus of 20.51 mag. The red line shows the best isochrone shifted to the distance obtained from the RRLs. (Figure modified from Martínez-Vázquez et al. 2019).

UFDs within 100 kpc using the *Gaia* DR2 RRL catalog (Clementini et al. 2019). From proper motions, magnitudes and location on the sky, we associate 47 *Gaia* RRLs to 14 different satellites. We have identified RRLs for the first time in Tucana II; found additional members in Ursa Major II, Coma Berenices, Hydrus I, Boötes I and Boötes III; and distinguished candidate extra-tidal RRLs in Boötes I, Boötes III, Sagittarius II, Tucana III, Eridanus III, and Reticulum III. Finding extra-tidal RRLs suggests that an undergoing tidal disruption in these galaxies may have happened; however, radial velocities are needed to confirm these extra-tidal RRLs as members. We have also measured the distances to those galaxies. Figure 2 shows a comprehensive and updated analysis of the number of RRLs in dwarf galaxies. In particular, it allows us to predict that the method of finding new UFDs by using two or more clumped RRLs will work only for systems brighter than $M_V \sim -5$ mag.

In parallel, our team has also been involved in the search for RRLs in the UDD Galactic companion Crater II. The results of this project have been presented in a pair of papers (Walker et al. 2019; Vivas et al. 2020b). Crater II is impressively large—comparable to classical dwarfs like Sculptor or Fornax. It has a population of ~ 100 RRLs (Joo et al. 2018). From the spatial distribution of the RRLs in the

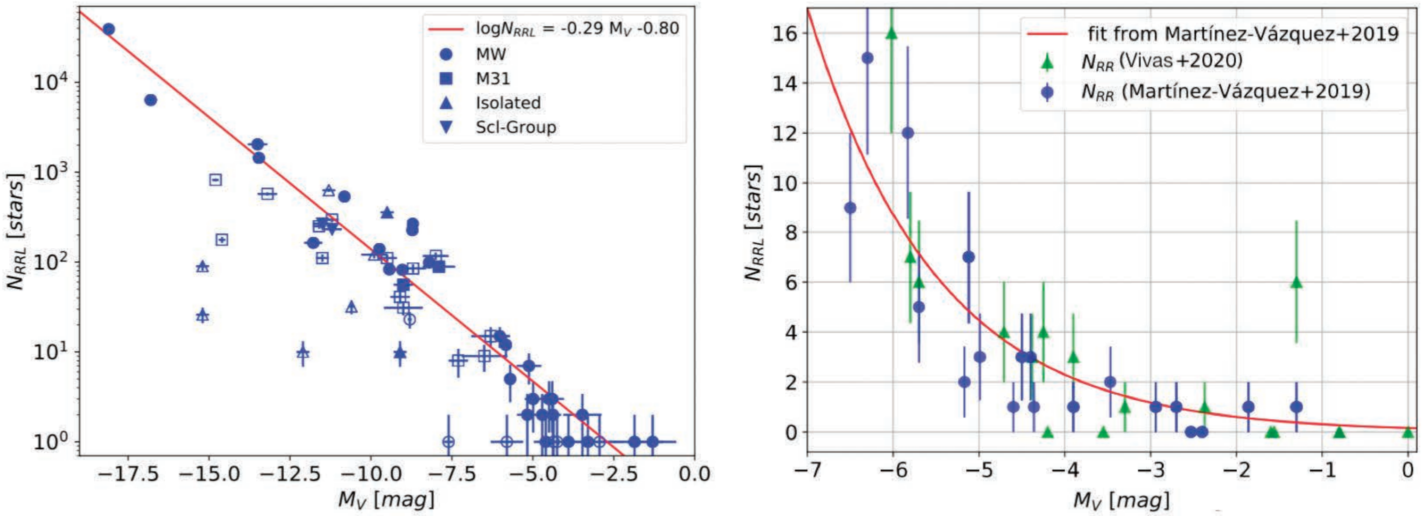

Figure 2: Left: Literature number of RRLs versus M_V for all the dwarf satellites in the Milky Way, Andromeda Galaxy, isolated dwarf galaxies, and two Sculptor group dwarfs. Filled symbols represent those dwarf galaxies for which the RRL search was carried out farther than two half-light radii and for which we expect approximatley 100% completeness in the number of RRLs. The red line shows their linear fit. (Figure from Martínez-Vázquez et al. 2019). Right: Updated number of RRLs versus M_V for the UFDs. Red curve corresponds to the same fit as in the left panel. Note that the axes are not semi-logarithmic in this plot. (Figure modified from Vivas et al. 2020a).

sky, we have found that Crater II has an elongated shape. Using our high-quality light curves, we have obtained accurate pulsation parameters for the RRLs, which we have used to measure a new distance for Crater II of 117 ± 4 kpc. Also, when simply dividing the RRLs into two groups on the basis of whether they are brighter or fainter than the fitted fiducial in the *i*-band period-luminosity diagram, we find that the two groups have significantly different spatial distributions, with the brighter group being more centrally concentrated. The mean difference in brightness, when interpreted as a metallicity difference, is consistent with the metallicity dispersion of 0.2 dex found for the RGB members stars by spectroscopy (Caldwell et al. 2017; Fu et al. 2019) and is consistent with the relatively narrow RGB.

By stacking the best images from the same data set, we have produced a deep CMD that reaches well below the Crater II main sequence turn-off and shows that Crater II is an old system with no intermediate age or young stars (Figure 3). The subgiant branch (SGB) clearly splits in two, showing two burst events of star formation in its very early epochs. The isochrones indicate a mean age of 12.5 Gyr for the main event and a mean age of 10.5 Gyr for the brighter SGB. With such multiple star formation events, Crater II shows similarity to more massive dwarfs that have intermediate age populations. However, for Crater II, there was early quenching of the star formation, and no intermediate age or younger stars are present.

We are continuing our observations on these interesting and important systems and anticipate a harvest of new galaxies to study following the commencement of the Legacy Survey of Space and Time (LSST) on the Simonyi Survey Telescope of the Vera C. Rubin Observatory.

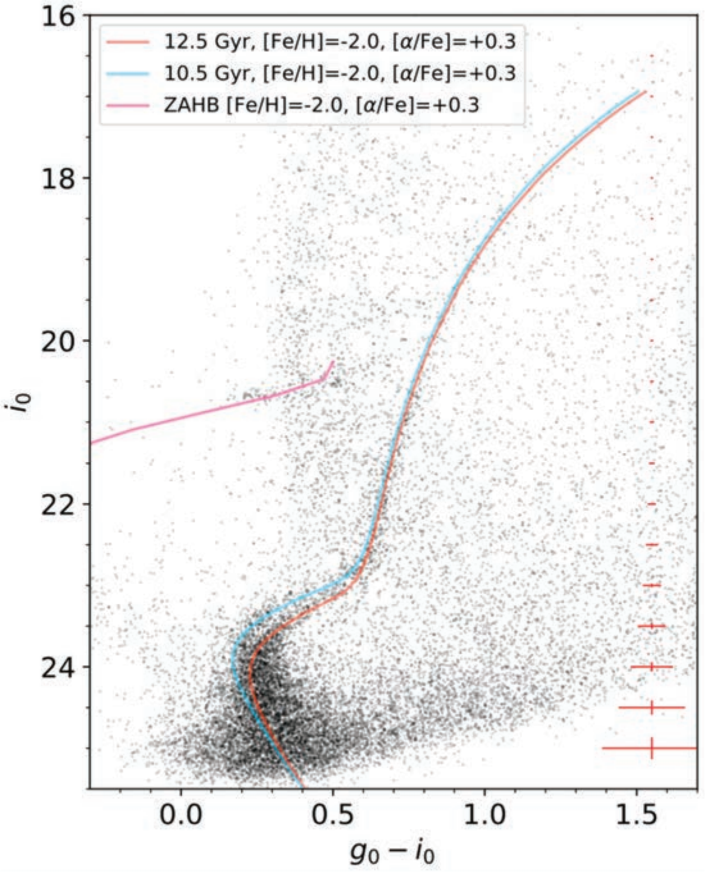

Figure 3. CMD for the central field (r < 0.78 deg) of Crater II obtained with DECam. Orange and light blue lines represent the best set of alpha-enhanced isochrones from the BaSTI library. Pink line shows the zero-age horizontal branch (ZAHB). Isochrones and ZAHB were shifted using a distance modulus for Crater II of 20.33 mag (Vivas et al. 2020b). RRLs are displayed with purple circles. (Figure modified from Walker et al. 2019).

References

Bose, S., Deason, A. J., Frenk, C. S. 2018, ApJ, 863, 123
Caldwell, N., Walker, M.G., Mateo, M. 2017, ApJ, 815, 117
Clementini G., et al. 2019, A&A, 622, A60
Fu, S. W., Simon, J. D., Alarcón Jara, A. G. 2019, ApJ, 883, 11
Joo, S. J., et al. 2018, ApJ, 861, 23
Martínez-Vázquez, C. E., et al. 2019, MNRAS, 490, 2183
Simon, J. D. 2019, ARA&A, 57, 375
Torrealba, G., Koposov, S. E., Belokurov, V., Irwin, M. 2016, MNRAS, 459, 2370
Torrealba, G., et al. 2018, MNRAS, 475, 5085
Vivas, A. K., Martínez-Vázquez, C. E., Walker, A. R. 2020a, ApJS, 247, 35
Vivas, A. K., Walker, A. R., Martínez-Vázquez, C. E., et al. 2020b, MNRAS, 492, 1061
Walker, A. R., Martínez-Vázquez, C. E., et al. 2019, MNRAS, 490, 4121

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Speckle Interferometry at NSF's NOIRLab

Andrei Tokovinin

Speckle interferometry is a vital technique for follow-up observations of exoplanet candidates identified by the *Kepler* and *TESS* space probes.[1] Many large telescopes operated by NSF's NOIRLab (Gemini,[2] SOAR,[3] WIYN, and the guest Robo-AO at the KPNO 2.1m) are equipped with speckle instruments for diffraction-limited imaging in optical light. These instruments also provide an exciting capability to survey binary-star statistics or study the orbital motion and architecture of multiple-star systems. The new generation of speckle instruments offers increased sensitivity, large productivity (at SOAR ~ 300 stars can be observed in a single night), and data-reduction pipelines.

Speckle follow-up of exoplanet host stars at first sight appears to be only a technical activity needed to detect false positives or to account for close stellar companions that can dilute the amplitude of planetary transits or mimic them if they contain an eclipsing binary. However, the results from speckle observations throw new light on planet formation. It turns out that the frequency of planets in close stellar-binaries (separation < 50 au) is much lower than that seen in single stars or wide stellar-binaries (2020AJ....159...19Z; Figure 1). Suppression of planet formation in close binaries is believed to be related to the faster dissipation of their disks. The same phenomenon (fast disk disappearance) causes differences in the stellar rotation: young stars in close binaries rotate faster than single stars. This has been recently proven by speckle imaging of pre-main sequence stars in the Upper Scorpius stellar association for which Kepler found several photometric periods, hinting at their binary nature (2018AJ....156..138T). Subsequent comparison of rotation periods of single and binary stars has highlighted the role of disks in braking stellar rotation (2019A&A...627A..97M). This example shows how links between binary stars and exoplanets become stronger as exoplanet science comes into maturity.

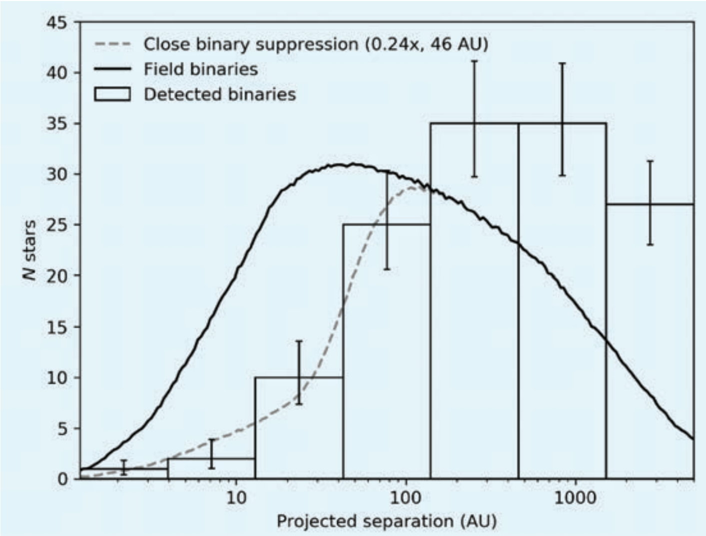

Figure 1: The separation distribution of *TESS* exoplanet hosts observed at SOAR reveals a reduced frequency of pairs closer than ~50 au, compared to the field stars. The apparent excess of wide pairs is likely explained by contamination of the *TESS* sample by close eclipsing binaries that indeed frequently have wide tertiary companions.

Stimulated by the *Kepler* study of multi-periodic stars in the Upper Scorpius association, we used speckle with SOAR to uniformly survey 614 known association members down to 0.4 solar masses for close binary companions (2020AJ....159...15T2; Figure 2). The combination of speckle coverage with *Gaia* astrometry more than doubled the number of known binaries in this association. The study revealed that the binary population of the association differs from similar binaries in the field in several ways, e.g., there is a larger frequency of close pairs among low-mass stars and a mysterious deficit of equal-mass pairs with intermediate separations of a few hundred au. This finding implies that formation of binaries (and, by extension, of stars and planets) critically depends on the environment.

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1. *https://www.nasa.gov/tess-transiting-exoplanet-survey-satellite*
2. *https://www.gemini.edu/sciops/instruments/alopeke-zorro/*
3. *http://www.ctio.noao.edu/~atokovin/speckle/*

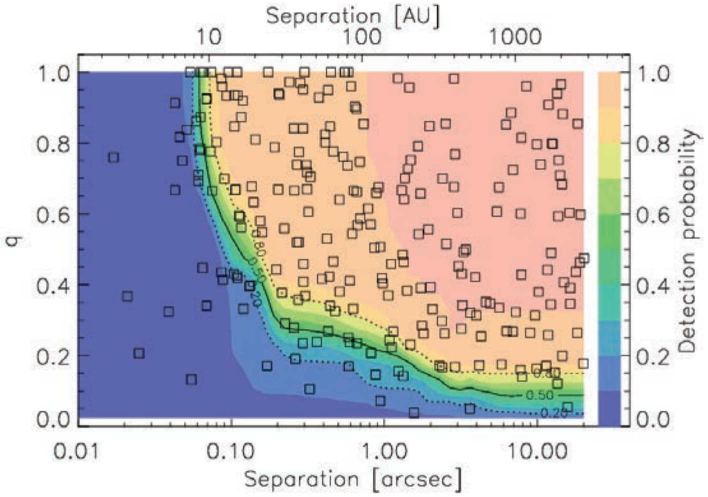


Figure 2: Projected separation and mass ratio q of 250 binaries in the Upper Scorpius stellar association. The colors indicate completeness and is dominated by the SOAR speckle survey (a few binaries closer than 8 au were discovered at Keck). Note the mysterious paucity of pairs with q ~ 1 wider than 100 au, despite the ease of their detection. This effect has been noted before, but the small size of prior surveys could not ascertain its reality.

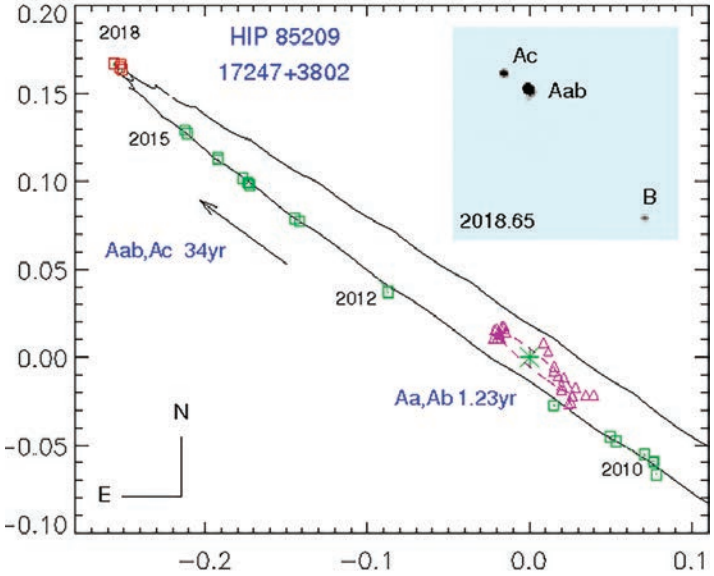


Figure 3: Orbits in the nearby (48 pc) quadruple system HIP 85209 studied at WIYN (scale in arcseconds). The insert shows the reconstructed speckle image where the closest pair Aab is not resolved. The intermediate 34-year orbit of Aab, Ac shows waves caused by the inner subsystem, while the distant star B moves very slowly (estimated period 500 yr). All orbits appear to be approximately co-planar, resembling the architecture of a planetary system.

While binary surveys and support of space exoplanet missions require only a single visit per target, repeated measurements with high accuracy are needed to determine binary orbits. The high angular resolution provided by speckle interferometry gives access to orbits of fast pairs with separations of 1–10 au, which are comparable to the size of the Solar System. Time-domain speckle data accumulated at SOAR over a decade have resulted in hundreds of new orbits (e.g., 2019AJ....158...48T). Recently, the study of orbital architecture of multiple systems has been extended to the northern sky using WIYN (2019AJ....158..167T; see Figure 3).

Millions of new close binaries will be revealed in the *Gaia* data release 5 (still several years off). Following up all of those pairs by speckle interferometry will be impractical, but also unnecessary. Nevertheless, large subsets of *Gaia* binaries will certainly require ground-based observations for various reasons; therefore, efficient speckle instruments will continue to be in high demand in the coming decade. The current fleet of speckle cameras will benefit from improved observing procedures and data reduction to further boost their productivity and assure a steady flow of high-resolution data.

DOI 10.5281/zenodo.3926773

A Complete DECam Survey of Nearby Galaxy Clusters

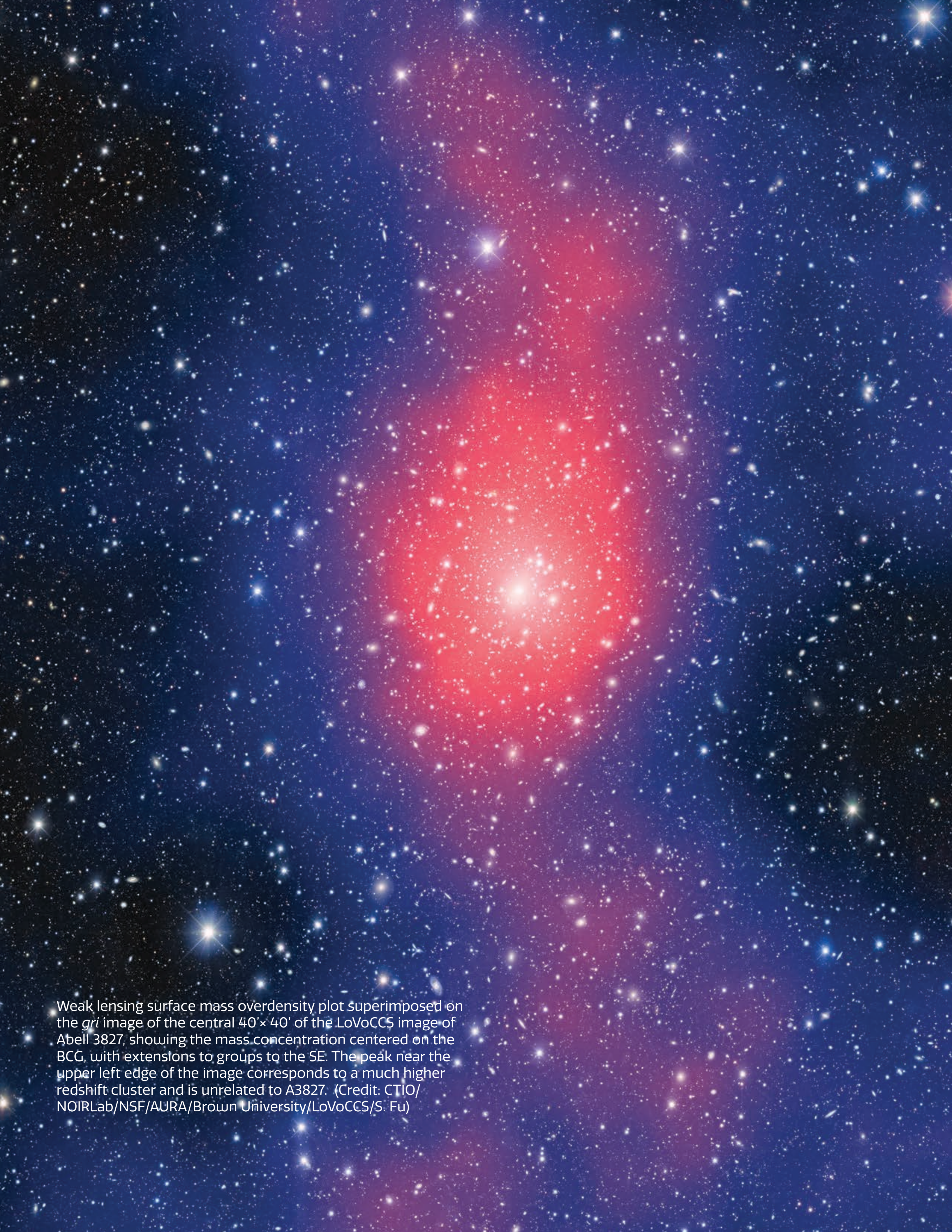
Ian Dell'Antonio (Brown University)

The Local Volume Complete Cluster Survey (LoVoCCS) is an NSF's NOIRLab Survey Program to observe all 107 nearby galaxy clusters (those within redshifts $0.03 < z < 0.12$) that are not obscured by the Milky Way and that have X-ray luminosity $L_x > 10^{44}$ erg/s. The X-ray luminosity criterion ensures that all clusters were detected in the X-ray with > 5 sigma significance. LoVoCCS takes advantage of the Victor M. Blanco 4m Telescope's Dark Energy Camera (DECam), which provides ugriz imaging with a depth equivalent to 1st- or 2nd-year LSST depth in each filter. Observations are optimized to uniformly preserve good seeing in the optimal shape measurement filter images. Ian Dell'Antonio (Brown University) is the LoVoCCS principal investigator.

The primary scientific goals of LoVoCCS are to measure the cluster masses and matter distributions at 200 kpc resolution using weak gravitational lensing. This information will be used to determine the relation between the cluster stellar populations, X-ray emitting gas, and dark matter. We will also detect faint and low-surface brightness cluster galaxies, uncover new galaxy-galaxy and galaxy-ICM interactions, and trace the evolution of galaxy properties from the cluster periphery to the center. The archival dataset will also be of great interest to the study of transients in the vicinity of the clusters. Finally, the resolution of the lensing reconstruction and the rest frame wavelength coverage match the expected measurements from WFIRST at $z \sim 0.5$. LoVoCCS will therefore serve as the low-redshift anchor to the detailed study of the evolution of clusters.

The images for LoVoCCS are being analyzed using the LSST Data Management Science Pipelines of the Vera C. Rubin Observatory. This allows us to make use of recent developments in PSF fitting and weak lensing measurements and additionally ensures that the photometric catalogs and images produced can be used as first-epoch measurements to detect transients in and behind the clusters in the Year 1 LSST data. Data-taking for LoVoCCS is about 20% complete, but the first stacked cluster images and shape and photometric catalogs have already been produced and will be available at the NOIRLab Astro Data Archive site beginning in the third quarter of 2020. Individual community-pipeline-processed exposures are already available for download.

The LoVoCCS collaboration consists of Ranga-Ram Chary (IPAC/Caltech), Doug Clowe (Ohio), Michael Cooper (UC Irvine), Ian Dell'Antonio (Brown, PI), Megan Donahue (Michigan State), Gus Evrard (Michigan), Shenming Fu (Brown), Mark Lacy (NRAO), Tod Lauer (NOIRLab), Binyang Liu (Brown), Jacqueline McCleary (NASA/JPL), Massimo Meneghetti (INAF/Bologna), Hironao Miyatake (Nagoya Univ.), Priyamvada Natarajan (Yale), Elena Pierpaoli (USC), Marc Postman (STScI), Jubee Sohn (SAO), Keiichi Umetsu (ASIAA), Yousuke Utsumi (SLAC/Stanford), and Gillian Wilson (UC Riverside).



Weak lensing surface mass overdensity plot superimposed on the *gri* image of the central 40′× 40′ of the LoVoCCS image of Abell 3827, showing the mass concentration centered on the BCG, with extensions to groups to the SE. The peak near the upper left edge of the image corresponds to a much higher redshift cluster and is unrelated to A3827. (Credit: CTIO/NOIRLab/NSF/AURA/Brown University/LoVoCCS/S. Fu)

The following essays were solicited by NOAO for the final issue of the *NOAO Newsletter* series. With the rapid transition to an integrated newsletter for all of the NOIRLab, the June 2020 issue of the *NOAO Newsletter* became the last in the series. As a result, the solicited essays are published here in the inaugural issue of *The Mirror*.

DOI 10.5281/zenodo.3926775

A National Observatory's Responsibilities Extend Beyond Telescopes

Michael Blanton, New York University

A national observatory does not just consist of telescopes.

Answering the pressing astronomical and human questions of our time—what are the origins of the Universe? how did galaxies, stars, and planets form? is there life elsewhere?—requires telescope resources beyond what individual universities or private observatories can muster, and they also require much more than the hardware. The most successful modern ground-based astronomical experiments have therefore been those that not only harnessed the resources of large consortia but also maximized their science productivity through early career training, innovative software development, and powerful and user-friendly public data-distribution tools. The Sloan Digital Sky Survey (SDSS) has operated this way for over 20 years, coordinating the resources of over 50 individual institutions, and as a result has created the largest spectroscopic maps of our Galaxy, the nearby galaxies, and the Universe as a whole.

Although mid-scale efforts such as SDSS will continue their unique contributions, ground-based astronomy now features billion-dollar-scale efforts, such as Vera C. Rubin Observatory, that require the size and stability of a national observatory. A wisely designed national observatory can simultaneously leverage its efforts to provide important supporting infrastructure for mid-scale, small-scale, and individual investigator projects. But to replicate the success of current projects on a larger scale, a national observatory needs to provide not just the telescopes but also a system of resources, including training, infrastructure development, human resource development, software products, and data archives, that can support the big efforts and the more moderate ones at the same time.

As just one important aspect of this system, the data sets emerging from Rubin Observatory will require a sophisticated and powerful data-access system. At the same time, mid-scale and small-scale ground-based projects are producing interesting data sets that also need to be archived forever. A well-shepherded effort led by a national observatory would enable an integrated system to archive and distribute the large data sets along with the smaller ones, multiplying their combined value. This national effort could ensure that these archives were maintained over timescales of decades and centuries, living up to the historical tradition set by our astronomical forebears. Similarly, the system of hardware, software, and human resources emerging from national observatory efforts can, if stewarded properly, benefit all of US astronomy.

Furthermore, a national observatory need not and should not be construed as only supporting and archiving projects that happen to be on its own telescopes. We are fortunate in the US to have found philanthropic support for a number of private telescopes, and a national observatory can leverage this support for the benefit of all US astronomers, providing critical infrastructure and encouraging and enabling greater and broader data access over truly long timescales.

A national observatory's responsibilities, therefore, extend beyond the operation of telescopes and beyond the support of projects on its own telescopes. It should lead the country and support all of our ground-based astronomy activities, providing the sort of large-scale, long-term, and community-wide support to them that only a national effort can.

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> “I'm excited to witness the reinvention of our national treasures.”

Thoughts on the National Optical Astronomy Observatory

Debra Meloy Elmegreen, Vassar College

Astronomy has entered the era of big data, big telescopes, and big surveys. When Kitt Peak National Observatory (KPNO) was established 60 years ago, the world had not yet entered the computer age, much less the internet age or the space age. Photometers and photographic plates were the prime collectors of photons, often augmented with stripchart readouts or tapes kept by the primary observer. The concept of a National Observatory, with access by anyone with good ideas as adjudicated through a peer-review process, was revolutionary. Astronomers relished the acceptance of an observing proposal for a few nights a semester. No longer would an astronomer need to be at a university with sufficient resources to build its own private observatory. Astronomy became democratized, and therefore discoveries multiplied as never before.

I was a student of the 70s and marveled at Kitt Peak National Observatory and Cerro Tololo Inter-American Observatory (CTIO) each time I went observing over the next few decades. I admired the sign proclaiming the original member institutions of AURA, the Association of Universities for Research in Astronomy, which manages the national observatories and consolidated KPNO and CTIO into the National Optical Astronomy Observatory (NOAO) in 1982. The federal share of Gemini Observatory was added to NOAO when Gemini North and South opened in 1999 and 2000. When I became a faculty member, my students were delighted to accompany me and join the ranks of mountaintop observers. I was proud this year when my small college consortium became a member institution of AURA.

As we enter a new era in which the 4-meter telescopes of Kitt Peak and Cerro Tololo are merely medium-sized telescopes, and even Gemini will soon be dwarfed by 30-meter-class telescopes, I watch with a tinge of nostalgia as the name NOAO disappears. But the grand scheme to unite the federal ground-based nighttime facilities as integrated operations under NSF's NOIRLab, facilitated by AURA and the National Science Foundation, bodes well for a future that includes a growing system of observatories. NOAO is a founding partner of the LSST, now Vera C. Rubin Observatory, project. NOIRLab, as a matrixed rather than a siloed organization, will help develop synergies that will benefit time-domain science and follow-up spectroscopy of objects discovered through Rubin Observatory surveys. More broadly, it will also facilitate observations complementary to LIGO, ALMA, VLA, HST, JWST, and WFIRST. It will be possible, finally, to develop a ground-based archive that will rival what the successful MAST has done for space data access, through the Community Science and Data Center that is part of NOIRLab. The new structure may one day make it possible to integrate cooperative private observatories into a true US Optical and Infrared System, envisioned decades ago, which ultimately will promote timesharing and foster collaborative research and instrument development for the broad community.

We’re not losing our beloved NOAO—we’re enhancing its worth through a robust new system that will help facilitate observations, coordinate efforts, and enable data access. I’m excited to witness the reinvention of our national treasures and to continue to reap the benefits from those who had the foresight to make sure the best astronomy was done by opening up the Universe to everyone through open access.

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What Is a National Observatory?

S. R. Kulkarni, California Institute of Technology

Astronomy is rooted in phenomenology. Discoveries constitute the blood; studies of well-defined samples, the shoulder; and surveys, the backbone. Astronomy is perhaps the most capital-intensive field, when normalized by the size of the professional community. Along with biology, astronomy is a leader in Big Data. "Astroinformatics" is now a major area in our field.

While large telescopes dominate our budget, the phenomenological nature of our subject requires not only a range of facilities but also a diverse and wide user base. Instrumentation enables discovery and is therefore vital. A case that addresses some of these points is the Kitt Peak 84-inch telescope, which was not a big telescope even at first light (1964) but is notable for the discovery of the first pulsating white dwarf (1969), the Lyman-alpha forest (1971), and the first gravitational lens (1979).

National organizations (e.g., NRAO) were created to build and manage facilities that lie beyond the grasp of even well-endowed radio groups. In order to articulate a future vision for a US National Observatory for optical and infrared (OIR) astronomy, we need to go back to the turn of the last century. The US was dominated by privately funded observatories that achieved spectacular successes—the determination of the size of our Galaxy, the discovery of the expansion of the Universe, the discovery of Pluto, and the cosmological origin of quasars.

However, this model has reached its limit. The Rockefeller Foundation gift of $6M to Caltech for the 200-inch telescope corresponded to a 57 ppm (parts per million) fraction of the FY1929 US GDP. The Keck Foundation gift(s) to Caltech for the two 10m telescopes was 28 ppm (circa FY1990), matched by contributions from the University of California for operations and instrumentation. It appears to me that 30 ppm is an upper limit for purely philanthropic funding of telescope facilities.

Nonetheless, a National Observatory is needed when flagship facilities cross the billion-dollar mark. However, for maximum national benefit, a National Observatory and the existing university-based observatories have to work together, complementing their strengths and minimizing their weaknesses. One should never minimize the role of universities in the training of the next generation of astronomers and instrumentalists.

Here is my vision for NSF's NOIRLab. It must, like ESO (Paranal), deliver high-performance and reliable state-of-art telescopes. NOIRLab must be able to deploy all of its assets to address ambitious projects (e.g., follow-up facilities working in tandem with Vera C. Rubin Observatory). Next, NOIRLab has to provide facilities for specialized telescopes (at Kitt Peak and Cerro Tololo) and be the steward for nurturing technological developments that are key to our field. Finally, noting the rise of trans-national projects such as ALMA, SKA, and ELT, NOIRLab must therefore be fully empowered by the US astronomical community to energetically represent the US in such projects.

University groups are well situated to lead astroinformatics and to develop new methodologies, including detectors. Universities must have stable access to federal funding to build ever more powerful instruments for all state-of-the art telescopes. The more ambitious groups can build public-private mid-scale facilities (e.g., NIR/narrow band/polarimetric synoptic surveys, massively multiplexed spectroscopic facilities) and even consider strategic partnerships with NOIRLab for mutual gains.

Failure to form and execute an ambitious Universities–NOIRLab plan will weaken the global standing of US ground-based OIR astronomy.

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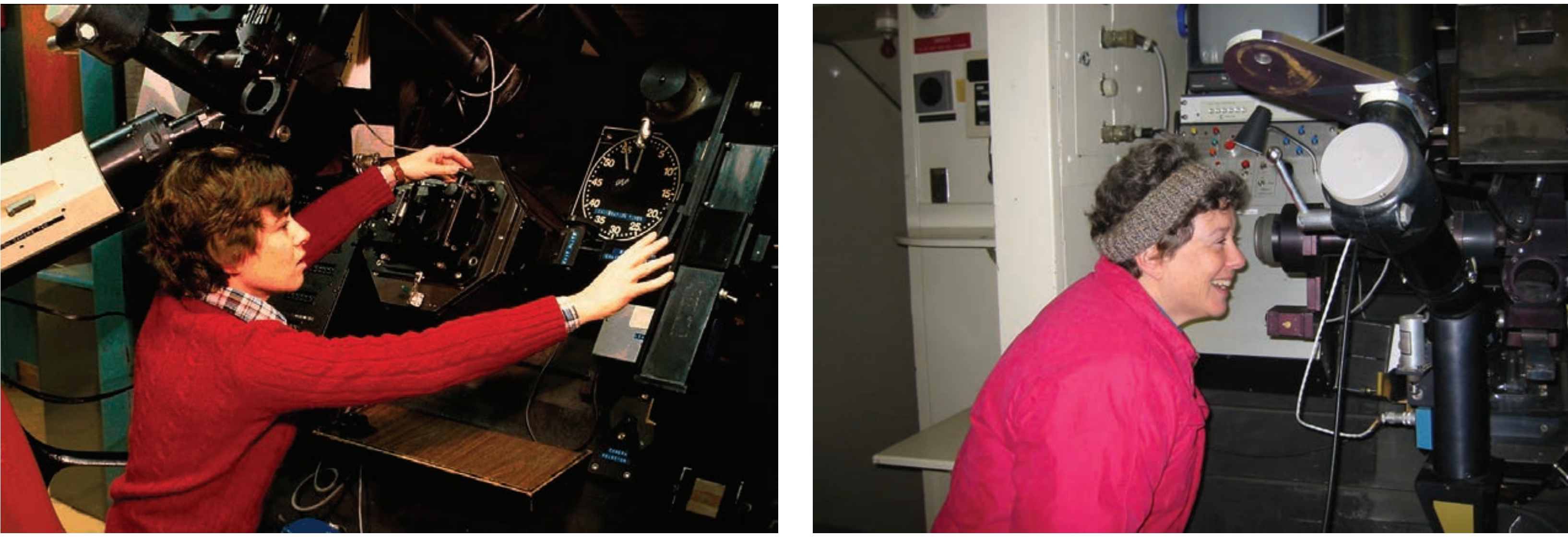
Transitions: Remembering the Past, Building the Future

Caty Pilachowski,
Indiana University Bloomington

> “Our community is strengthened as our national facilities are brought together.”

American astronomy without KPNO, CTIO, NOAO, and Gemini is hard to imagine. The contributions of our national observatories over 60 years have changed our culture, broadened our perspective, and provided opportunities for generations of astronomers. Through those 60 years, our national observatories have themselves changed and adapted to the evolving needs of our community.

My own engagement with KPNO and CTIO began in the late 1970s, while a postdoc at the University of Washington, working with the legendary George Wallerstein. Observing with the then-new echelle spectrographs on the Mayall and Blanco telescopes and at the coudé feed at Kitt Peak, collecting infrared photometry at the 50”, or PDS-ing plates at the downtown headquarters, I very much appreciated the support and help from observatory staff, most of whom became long-time friends and colleagues. Working at NOAO in the 1980s and 1990s showed me just how important the national observatories are to a thriving astronomical community, allowing any astronomer, anywhere, with a good idea to get the observations necessary to follow where that idea might lead. NOAO was a lively place, with a constant stream of visiting observers and



Dr. Catherine Pilachowski, seen working at the coudé spectrograph, part of the KPNO 2.1m Telescope facility in the 1980s (left) and in 2005 (right).

researchers. Interactions on the mountaintops and at headquarters added to the vitality of the community, enabling many new collaborations and inspiring new ideas. Many young astronomers, myself included, benefitted from those interactions with more senior colleagues, as we took advantage of opportunities to learn from the great minds of that time.

Our national observatories also fostered community leadership, in a way that may be less commonly found in a university environment. The success of these observatories relies on teamwork, where different skills are required to achieve a larger, shared goal. So many of the postdocs and observatory staff who worked at NOAO and Gemini over the decades and then moved out into universities have become community leaders, and we have all benefited from their leadership.

The first visiting observer to Kitt Peak, back in 1958, was Arlo Landolt, renowned for establishing the fundamental standard stars for photoelectric photometry. Arlo was a graduate student at Indiana University at the time, and he has been a lifelong advocate for small telescopes available to the community. A key to the flowering of American astronomy in decades since 1958 has been the broad availability of telescopes big and small, allowing astronomy to grow not just at a few institutions with their own observatories but also at so many universities around the country.

Our national facilities have changed greatly since that time, as the needs of our community and the science we aspire to do have evolved. Today's NSF's NOIRLab resides in a very different world, providing access to data and data tools, organizing the community to take advantage of new resources, hosting the engines that produce major surveys, and providing clear and reliable pathways to Gemini, to Rubin, and eventually to the extremely large telescopes of the twenty-first century. Our community is strengthened as our national facilities are brought together under the new umbrella of NOIRLab. America's leadership in ground-based OIR astronomy in the world in the twentieth century owes much to the vision of the founders of our first national observatory 60 years ago. Our leadership in the twenty-first century will depend on the combined strength of our national observatories together with our flagship independent observatories—a formidable partnership as we learn to work together.

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NOAO: Rest in Peace

Sidney Wolff, AURA

I first came to the national observatory in 1984, just a year after John Jefferies was appointed as the first director of National Optical Astronomy Observatories, which then included KPNO, CTIO, and the National Solar Observatory (NSO). After retiring several times, I am now back at the national observatory working on the US Extremely Large Telescope Program (US-ELTP) and witnessing the creation of NSF's NOIRLab. In a sense, then, I have observed nearly the entire lifetime of NOAO.

I originally decided to come to NOAO because I had experienced the thrill and the satisfaction that comes from building an observatory from the ground up. When I went to Hawaiʻi in 1967, there were no telescopes on Mauna Kea. (The name was two words in those days—now Maunakea is preferred.) When I left Hawaiʻi, the CFHT, IRTF, and UKIRT were all in operation, along with the 88-inch and two 24-inch telescopes, and Mauna Kea had been chosen as the site for the Keck Observatory. I thought that transferring to the national observatory offered me the best opportunity to continue building new telescopes and new observatories.

And build we did: WIYN, SOAR, the two Gemini telescopes, and LSST (now Vera C. Rubin Observatory) are some of the legacies of NOAO. Prior to the advent of NOAO, most of the construction at the national observatories was funded by NSF. The telescopes that we built at NOAO required unprecedented forms of partnerships. WIYN and SOAR were both projects carried out with universities, and SOAR also involved Brazil. The Gemini telescopes were carried out by an international partnership, and LSST by NSF and DOE working together. These new types of partnerships were key to expanding the capabilities offered by the national observatory.

I am proud not only of the telescopes that we built but also of the many people who gained experience at NOAO that allowed them to go on to leadership positions with other organizations. I would include in this list (in alphabetical order) Taft Armandroff, Todd Boroson, Richard Green, Buell Jannuzi, Matt Mountain, Jim Oschmann, Pat Osmer, Mark Phillips, Caty Pilachowski, Dave Silva, and Bob Williams. (I apologize to anyone that I may have left off this list.) Of course, much of our home-grown talent remains within the organization and is key to its current strength.

During my tenure as Director, I managed to build relationships between Cerro Tololo Inter-American Observatory (CTIO) and Kitt Peak National Observatory (KPNO) that allowed us to change our name to National Optical Astronomy Observatory (singular instead of plural), and NSO became independent. My biggest disappointment came when the decision was made to separate Gemini cleanly from NOAO. In my opinion, that decision was not to the long-term advantage of either organization. I am therefore very pleased to see that finally CTIO, KPNO, Gemini, and the Rubin Observatory are joining together to form a true national laboratory for ground-based astronomy. As Director of AURA's portion of the US-ELTP, I can already see the advantages. Now I can go anywhere in the organization to find the expertise needed to formulate a compelling proposal for the services that we will provide to users of GMT and TMT. TAC upgrades being carried out in Tucson, the Phase I and Phase II observing tools and the adaptive/dynamic queue scheduling system being modernized and automated by Gemini, and the plans for a unified archive by the Astro Data Lab will form the basis for services that we will provide to enable access to GMT, TMT, and to the data from both telescopes. I am also drawing on Rubin expertise in how to manage the large software project that we are planning.

From my point of view, unification of the various ground-based observatories managed by AURA has been slow in coming, but it has arrived just in time to meet the challenges of the future. We simply could not prepare the proposal for our portion of the US-ELTP without access to the expertise available in CSDC, Gemini, and Rubin.

> “The telescopes that we built at NOAO required unprecedented forms of partnerships.”

Sidney Wolff, with the telescopes on Cerro Pachón in Chile (from left to right): SOAR, Gemini South, the calibration telescope for the Legacy Survey of Space and Time, and the Vera C. Rubin Observatory.

Community Science and Community Data:

Past, Present, and Future

Adam Bolton, Sidney Wolff, Dara Norman,
and Mark Dickinson

DOI 10.5281/zenodo.3928797

> “Archives don’t just prevent data-death, they also create data-life.”

The Community Science and Data Center (CSDC) is NOIRLab’s fifth mountaintop, after Kitt Peak, Cerro Tololo, Cerro Pachón, and Maunakea. It is a virtual rather than a geological mountaintop. The word “Community” in CSDC applies to both “Science” and “Data.” The CSDC mission is to maximize community participation and science with all of NOIRLab’s telescopes and data archives, now and in the future.

This is an exciting time! We are launching a new National Lab for optical and infrared astronomy, entering a new decade (with a new Decadal Survey) when big-data and time-domain astronomy will become ubiquitous, and learning to work through a pandemic.

With respect to that third source of excitement, astronomers are now facing a new reality (who knows how long it will last?) where many of the things that we took for granted are being suspended.

As we adjust to working remotely, cancelling travel and conferences, and battening down the hatches of our observatories, we might wonder: What if we never collected another photon? How would this change our perspective on our existing archives of data? What discoveries are yet to be made there, and how would we make them?

But let’s put that worrisome view behind us and look forward to a future when our observatories open their domes again, when new data begins to flow, and when major new facilities such as the Vera C. Rubin Observatory and the Dark Energy Spectroscopic Instrument (DESI) begin to deliver major new survey data sets. Because, thankfully, the tools that would enable us to maximize science in an astronomical dark age (“dark” in the bad sense) are the very same tools that will lead us to realize the full scientific potential of the facilities and data sets of the future!

Archives are not just repositories of the past

Astronomical archives magnify scientific productivity and impact of telescopes. This has been known for a decade (White et al. 2009, Astro2010 Position Paper 64), at least. Recent work (Peek et al. 2019, BAAS, 51, 105) illuminates how archives can also make astronomy more accessible to researchers and institutions with a higher barrier to participation in PI-driven observing.

Although the importance of astronomical archives is no longer disputed, the label “archive” does not really do them justice. “Archive” has a backward-looking connotation, focusing on long-term stewardship of data obtained in the past. This is of course a critical function of archives: astronomical data is obtained at great expense, and astrophysics is dynamic on all timescales. NOIRLab's Astro Data Archive plays this stewardship role now for data from CTIO and KPNO. The creation of NSF's NOIRLab will permit further coordination of long-term data archiving services with the international Gemini Observatory and Rubin Observatory.

But data archives are also operational hubs of modern digital astronomy, of equal importance to telescopes. Data flows from mountains into archives, pipeline systems retrieve raw data from archives and deposit reduced data

> “Data archives are operational hubs of modern digital astronomy, of equal importance to telescopes.”

into them, and PIs obtain their data from archives as soon as it is available. CSDC today operates the Dark Energy Camera (DECam) Community Pipeline to provide DECam PIs with science-ready imaging data. The future will bring opportunities for increased coordination of data-reduction efforts across all NOIRLab programs.

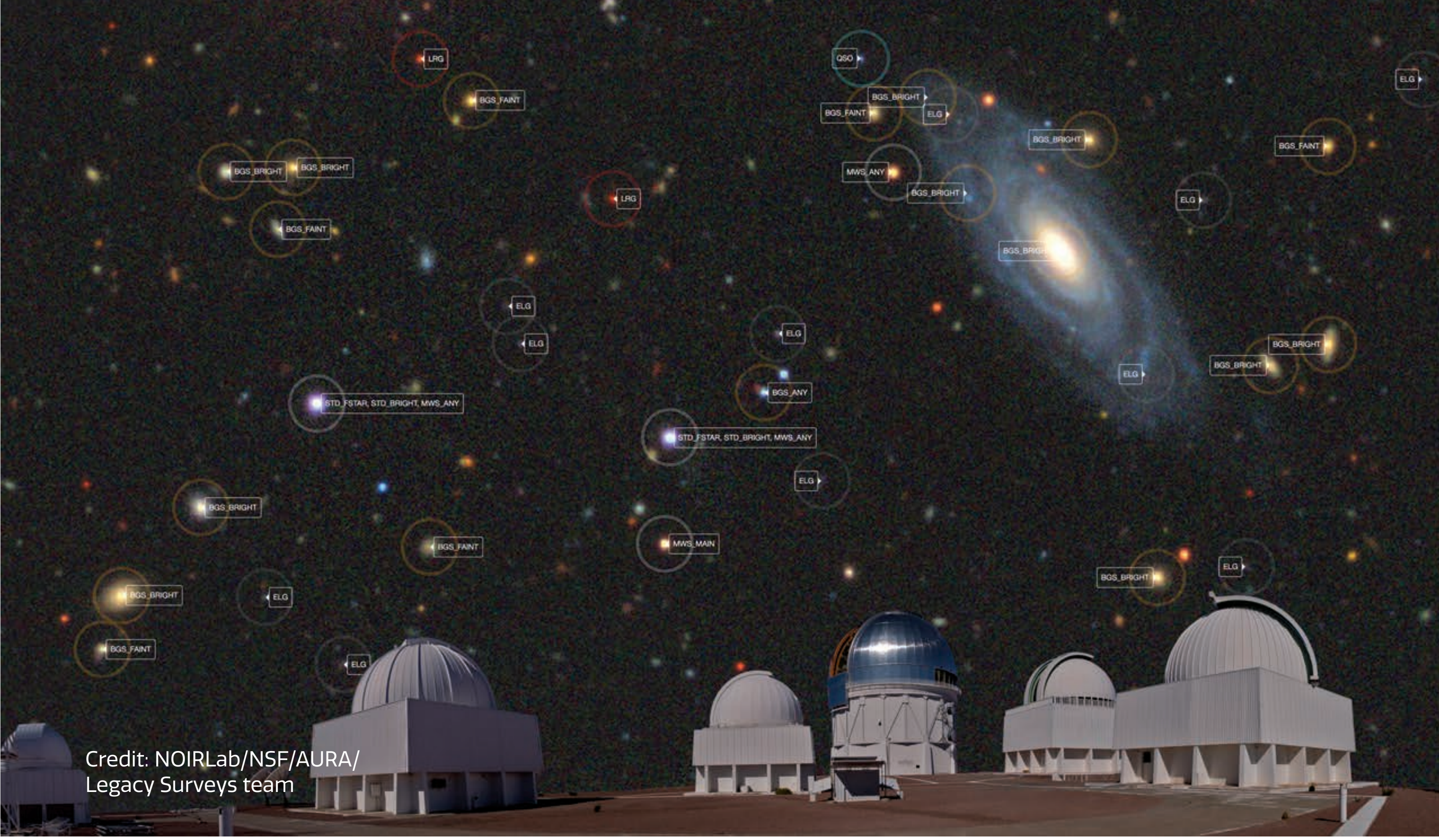
Finally, archives don’t just prevent data-death, they create data-life. Modern astronomical archives are innovative, multifaceted systems that provide astronomers with diverse tools for discovering, exploring, visualizing, analyzing, and downloading data. For data-intensive facilities such as SDSS, DESI, and Rubin Observatory, the archive is where the analysis begins, not where it ends. NOIRLab's Astro Data Lab provides these high-level science capabilities now and will be coordinated with the Rubin Observatory’s online Science Data Platform within NOIRLab in the coming years.

The proposal-driven open-access telescopes of NOIRLab have a long tradition of providing mountaintop platforms for community-driven innovation in astronomical discovery and astrophysical experiment. Going forward, this tradition will continue and expand, facilitated by CSDC’s Time Allocation Committee process. Analogously, the data sets, archives, and data services of NOIRLab will provide digital platforms for innovative research in data-driven astronomy by a broad and inclusive community of scientists at institutions across the US and the globe. The modalities are different, but the spirit is the same: *provide the platform and crowdsource the science*.

Today, a confluence of interests between astrophysics and high-energy particle physics is motivating instruments, surveys, and data sets covering huge swaths of our Galaxy and Universe and delivering catalogs of millions to billions of astronomical objects. In this era of data-intensive survey astronomy, NOIRLab can have a unique multiplier effect: whereas a night of telescope time must be allocated to *either* Project A or Project B, a survey data set can be allocated *simultaneously* to Projects A through Z. The implications for scientific productivity and inclusivity are self-evident (Norman 2018, ASP AstroBeat 162). The challenge to NOIRLab is to ensure that the interfaces, training, policies, and collaborative networks are all in place to ensure that this potential is realized for all astronomers.

Astronomy in the real-time present

The creation of NOIRLab will enable not just “horizontal integration” of data archives and data services



Credit: NOIRLab/NSF/AURA/
Legacy Surveys team

but also "vertical integration" of the end-to-end science user experience. Nowhere is this more apparent than in the area of time-domain astronomy. The Rubin Observatory will provide the world's premier time-domain astrophysics alert stream. Software systems such as the Arizona-NOIRLab Temporal Analysis and Response to Events System (ANTARES, a collaboration between CSDC, University of Arizona, and other partners) will provide a flexible platform for scientists to filter this stream down to events of interest to them. The Astronomical Event Observing Network (AEON) of NOIRLab telescopes (Gemini N+S, Blanco, and SOAR) and partners such as Las Cumbres Observatory will enable flexible real-time follow-up observing. Finally, data archives and pipeline systems will make science-ready data available to investigators in near real-time.

It is important to note that this integrated time-domain system will enhance static-sky science as well, since all observational astronomy benefits from flexible observing modes, dynamic scheduling, multi-facility coordination, and rapid data access. And in addition to coordination of observing and data systems, NOIRLab will provide an opportunity to optimize and coordinate person-to-person science user support services.

Building the future together

The National Observatory was a key founding institution for Gemini and the Rubin Observatory. Now, NOIRLab allocates US community time on Gemini and other facilities, provides support and advocacy for US Gemini users through CSDC's US National Gemini Office, and is working to maximize the community science return from Rubin Observatory. Looking further towards the future, NOIRLab aims to enable US community participation and leadership in the next generation of ground-based OIR telescopes.

NOIRLab and the Thirty Meter Telescope (TMT) and Giant Magellan Telescope (GMT) projects have joined together to create the US Extremely Large Telescope Program (US-ELTP). The goal of this program is to provide all-sky access with 30m-class telescopes for all US scientists. Because of their large apertures and diffraction-limited imaging with adaptive optics, GMT and TMT will enable researchers to address problems that are beyond the reach of today's 8–10m telescopes. Examples include the search for biological activity on Earth-like planets, determination of the properties of dark energy and dark matter, and

> NOIRLab and the Thirty Meter Telescope (TMT) and Giant Magellan Telescope (GMT) projects have joined together to create the US Extremely Large Telescope Program (US-ELTP).

observations of the earliest stages of star and galaxy formation.

The US-ELTP partners are planning to request sufficient federal funding to make at least 25% of the observing time on both telescopes available through NOIRLab to US astronomers. In addition to conducting the review of observing proposals, NOIRLab will develop Phase I and Phase II observing tools and a queue observing system for both observatories, archive all GMT and TMT data, make those data available after an agreed proprietary period, and supply tools to facilitate analysis of the data. Current user support services within NOIRLab, which already provide related capabilities, will be used as prototypes for designing software systems to meet the requirements of GMT and TMT.

At least 50% of the US open-access observing time on TMT and GMT will be devoted to large-scale Key Science Programs (KSPs) that will enable the community to undertake ambitious projects that will produce transformative scientific results. The large, coherent data sets that result will have substantial legacy value, and they will be available in the archive for subsequent reuse in other research programs.

NOIRLab will facilitate broad participation in US-ELTP science, including by researchers at under-resourced and undergraduate-only institutions. An informal survey conducted by CSDC Deputy Director Dara Norman of scientists at these institutions expressed the need for networking opportunities, data analysis tools that can be used in environments with limited computing resources, training in how to use those tools with complex data, and structural incentives to encourage their inclusion in research collaborations. The KSPs will provide a vehicle to encourage such inclusion. NOIRLab will develop training modules and documentation that will benefit all users of GMT and TMT.

Taking the long view

In all these areas, the launch of NOIRLab brings a historic opportunity. We invite the community to join us as we carry forward the scientific legacy of our predecessors, build exciting new capabilities for our own astronomical research in the present, and create an even better National Center for generations of astronomers yet to come.

The glow behind the WIYN 3.5m Telescope looks like a celestial aura, but it is really a phenomenon known as the Zodiacal Light

Credit: Kitt Peak National Observatory/NOIRLab/NSF/AURA/R. Sparks

Take a peek inside the dome of a world-class observatory in this image of the international Gemini Observatory, a Program of NSF's NOIRLab. This image of the Gemini South telescope in Chile is lit by the full moon.

Credit: International Gemini Observatory/NOIRLab/NSF/AURA/M. Paredes, P. Michaud

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DRAGONS Science Quality Verification:

A GMOS Imaging Example

Simon Conseil, James Turner, and Joanna Thomas-Osip

The first public release of the international Gemini Observatory's new Python-based data reduction platform, DRAGONS (**D**ata **R**eduction for **A**stronomy from **G**emini **O**bservatory **N**orth and **S**outh), occurred late in 2019 and supports imaging for current facility instruments. Here we present an example of Gemini Multi-Object Spectrograph (GMOS) imaging and compare it with an equivalent Gemini IRAF reduction for the purpose of demonstrating similar photometric accuracy.

The reduction is done with both DRAGONS and IRAF in a standard way as described in the *DRAGONS GMOS tutorial* and the *Gemini IRAF GMOS imaging example*, computing the master bias and flat with the default parameters. Then the science images are processed and stacked. For the purpose of this comparison, the stacking parameters are adjusted to use a similar method. IRAF's "imcoadd" uses a scaling according to the signal in the objects, so this was disabled (fl_scale-) to be consistent with DRAGONS. And to be consistent with a lack of sigma-clipping in imcoadd, the DRAGONS rejection thresholds were set conservatively (hsigma and lsigma parameters for the stackFrames primitive) to 20.

Sources are detected in both reduced images with DRAGONS's detectSources primitive, which uses SExtractor (the number of sources found is 1874 and 1925 for the DRAGONS and Gemini IRAF reduced versions, respectively). Magnitudes and a mean zero point are obtained by matching with the SDSS9 catalog. We remove sources without measured instrumental magnitudes or without reference magnitudes and sources flagged by SExtractor. The sources that are saturated or that have more than 2% of their pixels that were flagged during the reduction are plotted with a star symbol below. Of the ~1900 sources detected in both DRAGONS and IRAF stacked images, we get ~250 sources with a reference magnitude (due to lack of catalog depth) and ~150 sources after removing the flagged ones.

More information on DRAGONS and Gemini IRAF can be found at *https://www.gemini.edu//observing/phase-iii/understanding-and-processing-data/Data-Processing-Software*. DRAGONS is an open source project *available* on GitHub with *documentation and tutorials on Read the Docs*. The international Gemini Observatory is a Program of NSF's NOIRLab.

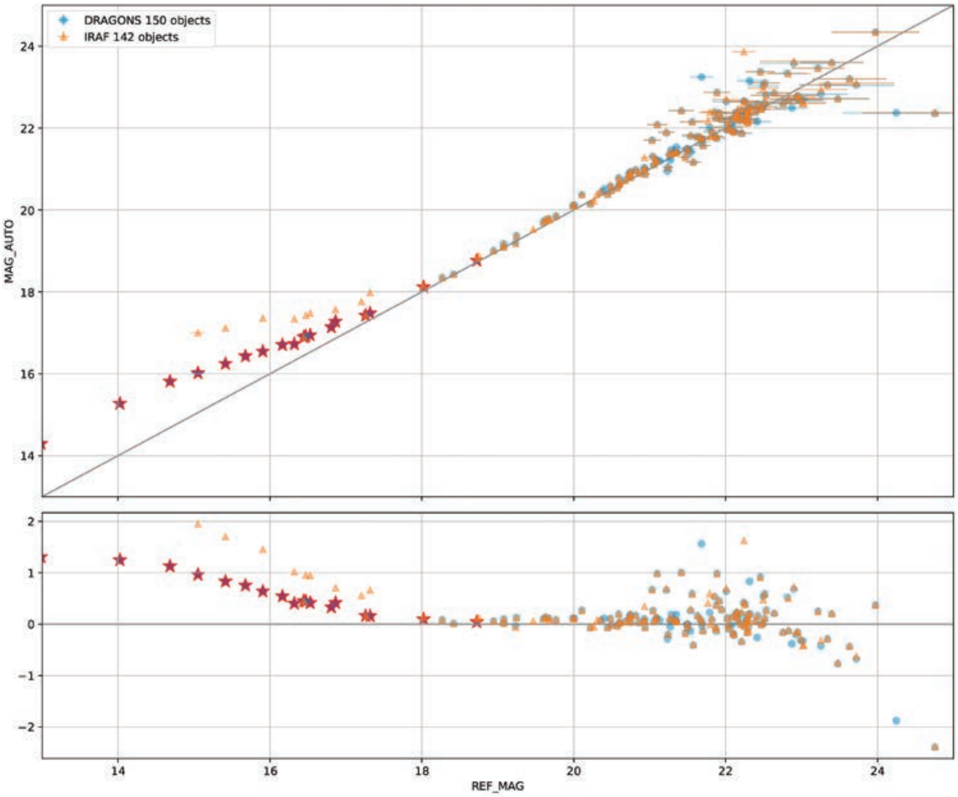

Figure 1: Top panel plots the SExtractor calculated magnitude (using the MAG_AUTO parameter that uses an adaptively scaled aperture) versus the SDSS9 catalog reference magnitude. Bottom panel shows the magnitude difference, MAG_AUTO - REF_MAG. The sources represented with star symbols are saturated. The median of the differences with the reference magnitudes is at the level of 1.5% for both DRAGONS and IRAF.

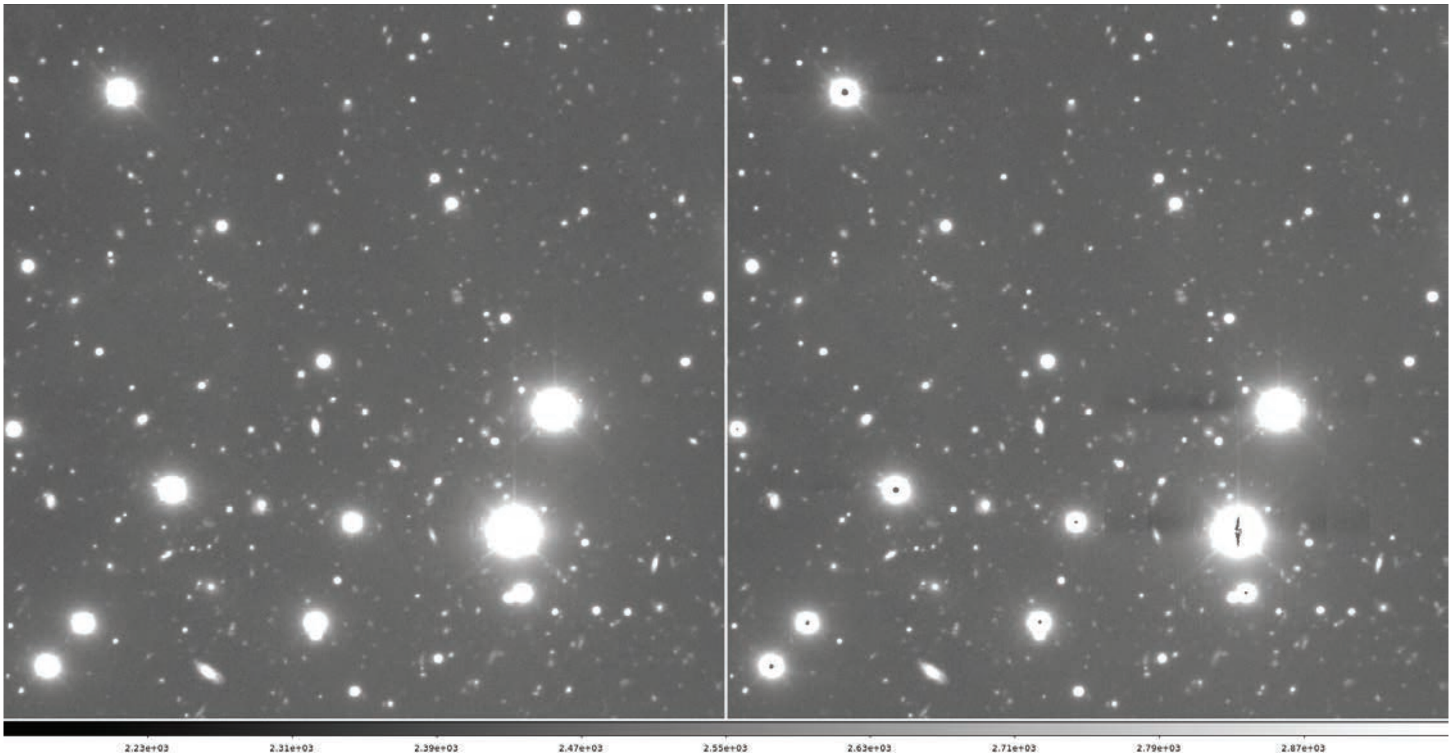

Figure 2: Comparison of the images reduced with DRAGONS (left) and IRAF (right). The data for this comparison comes from the GN-2018A-LP-15 program. It consists of 9 exposures of 180 seconds in the r band. The under-illuminated horizontal stripes in the IRAF image, near the bright and saturated stars, are due to an effect present in the raw files, where saturated pixels would depress the whole amp in that row; this is virtually eliminated in DRAGONS by an overscan subtraction method that is more appropriate for the Hamamatsu detectors. ▼

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The TOM Toolkit Development and Observing Program

Bryan Miller, Cesar Briceño, Stephen Ridgway, and Rachel Street

Astronomy has entered the era of time-domain astronomy (TDA), enabled by large, multi-epoch sky surveys. Efforts such as the SDSS series of surveys, Pan-STARRS, Skymapper, the Dark Energy Survey (DES), DECaLS, Gaia, and the Zwicky Transient Facility (ZTF) have already generated petabyte-scale datasets and alerts of transient sources. The Vera C. Rubin Observatory is under construction on Cerro Pachón in Chile, and its 10-year Legacy Survey of Space and Time (LSST) (*www.lsst.org*) will begin in just a few years. LSST will produce thousands of alerts every few minutes from variable stars, AGNs, Solar System bodies, all varieties of cosmic explosions, and transients of as yet unknown forms (Ridgway et al., 2014, ApJ, 796, 53). It will also produce extremely deep images of the entire southern sky and catalogs of billions of static and variable sources. This data set will be useful to all fields of astrophysics. Astronomers will mine the catalogs and compile very large samples of objects for further study. It will not be possible to understand the nature of many of these detections from LSST photometry alone, so additional, or follow-up, observations will be required.

The detection of an electromagnetic counterpart (kilonova explosion) to a gravitational-wave event and the association of a high-energy neutrino detection with an active galaxy shows the power of multi-messenger astronomy (MMA). Combining information from different messengers (gravitational waves, neutrinos, high-energy particles, and electromagnetic radiation) collected on short timescales allows us to understand the nature of the sources and the physical processes involved. In the era of TDA and MMA, timely follow-up, often requiring rapid response, with a multiplicity of flexibly scheduled observing facilities is essential, and the demand is growing.

MMA is one of the National Science Foundation (NSF) Ten Big Ideas. It unifies the capabilities and results from some of the NSF's major astrophysics facilities (e.g., LIGO, IceCube, Rubin Observatory, Gemini, KPNO, CTIO, and SOAR) to discover and characterize new and rare events. The NSF-sponsored report by the National Research Council, *Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System* (Elmegreen et al. 2015), recommends that NSF facilities coordinate to optimize Rubin Observatory follow-up. Similar capabilities are needed for MMA follow-up.

The sheer volume of alerts and the sizes of the survey catalogs mean that traditional methods that rely on human review for classifying and sorting cannot be applied to this scale. If the process of classifying and responding to the LSST alert stream cannot keep up with the data rate, then many interesting targets could be missed. The process of classifying sources and executing observations must be automated. The system that the community is developing to accomplish this automation is shown in Figure 1. The system is a set of tools and an envisioned workflow that operates within a time allocation process. Observing projects for following up alerts or studying selected objects from survey catalogs must still be approved by time allocation committees (TAC).

The main components of the follow-up system are the following:

1. Alert Broker: This accepts transient event alerts from one or more surveys and tries to classify the object.
2. Target Observation Manager (TOM): This is a target and observation management tool for specific research projects.
3. Interfaces and Schedulers: Facilities must have programmatic interfaces to receive observation requests and return status. The schedulers dynamically create the observing plans for the telescopes on the network in real time. There can be a single network scheduler, or individual telescopes can have their own schedulers.
4. Telescopes: These are the individual nodes of the network. They must be able to broadcast their current observing status (closed, open, current target), receive observation plans from the scheduler, and execute the observations.
5. Data-reduction pipelines: These reduce the data immediately after they are taken. Both raw and processed data are transferred to an archive.
6. Data archives: These are databases for the raw and reduced data. Authenticated users (often TOMs) can download the data as soon as it is available.

The brokers classify transient alerts based on all available information, e.g., position, color, and light-curve information. Catalog matching and artificial intelligence algorithms are often used. Users can define search filters in order to extract objects of interest. There are several ongoing broker projects including NOIRLab's ANTARES (*https://www.noao.edu/ANTARES*), Chile's ALeRCE (*http://alerce.science*), and the United Kingdom's Lasair (*https://github.com/lsst-uk/lasair*).

The Target Observation Managers (TOMs) are a key component of the envisioned system since they are a core tool of the science teams. It is expected that different projects will have their own TOMs, which contain the "science logic" of these projects that will help prioritize the targets culled by the brokers and allow the teams to request observations on the facilities on which they have been awarded time (Street et al. 2018, SPIE, 1070711). TOMs are modern and highly capable bookkeeping tools that enable scientists to keep up with large and constant streams of targets, but they can also be used for data reduction, visualization, and access management. Various projects have created and used TOMs for studying supernovae, AGN, microlensing events, and Solar System objects, among other targets (*https://www.noao.edu/meetings/lsst-tds/*). Each of these was a bespoke system developed independently even though they share common functionality. Since they are unique and developed by astronomers, they are also time-consuming to produce and maintain.

Any telescope facility that has application programming interfaces (APIs) for communicating with the TOMs can participate in the ecosystem shown in Figure 1. However, there are advantages to networks of telescopes for sharing time and/or coordinating observations. Projects

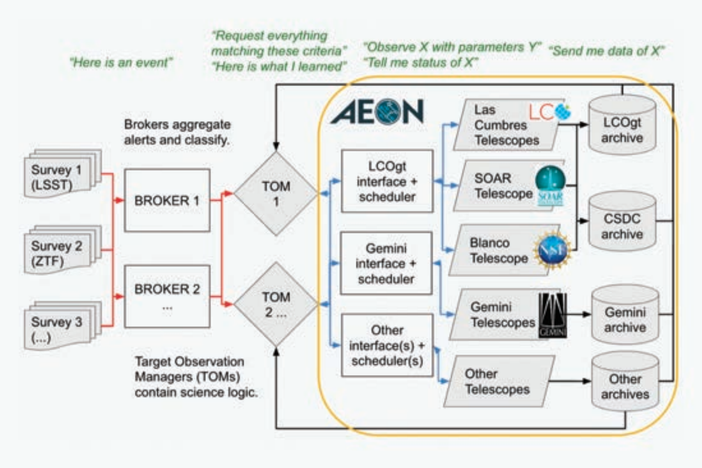

Figure 1: The developing alert and survey follow-up system. The components are described more fully in the text. NOIRLab is involved in developing an alert broker (ANTARES), and NOIRLab telescope facilities are part of the Astronomical Event Observatory Network (AEON) collaboration. The scope of AEON is outlined in yellow. The red, blue, and black arrows indicate where APIs are required for communication between the different components of the systems. Participation in AEON is not required to be part of the overall ecosystem. (Figure concept: Rachel Street, Las Cumbres Observatory)

> “MMA is one of the National Science Foundation's (NSF) Ten Big Ideas.”

that have targets with a wide range of brightnesses, e.g., SNe, can make use of telescopes of different apertures. Telescopes distributed in longitude allow follow-up at any time and can provide near-continuous coverage.

The Astronomical Event Observatory Network (AEON; *http://ast.noao.edu/data/aeon*) is a collaboration between the member observatories, currently Las Cumbres Observatory and NOIRLab, to develop observatory capabilities and procedures for supporting this follow-up network. It has been focused on dynamical scheduling capabilities, interfaces, and data reduction and archiving. Las Cumbres is already a network of 0.4m, 1m, and 2m telescopes. AEON adds telescopes of larger apertures. The progress on SOAR dynamical scheduling is described in an accompanying article. The TDA project of the Gemini in the Era of Multi-Messenger Astronomy (GEMMA) program (*www.gemini.edu/gemma/index.html*) will further develop APIs, a dynamic scheduler, and real-time data reduction to provide Gemini with equivalent capabilities. In the future, additional telescopes such as the CTIO Victor M. Blanco 4m Telescope may join the network. Other observatories have also expressed interest in joining and may be added once technical details of how the network will function have been finalized.

In order to make TOMs easier to develop and maintain, the Las Cumbres Observatory built on their staff's experience with early TOMs to create a professionally-developed TOM Toolkit (*https://tom-toolkit.readthedocs.io*). The toolkit provides common functionality such as database creation and interfaces to alert brokers, telescope facilities, and archives. It is designed to be easy to install and customize.

In 2019, Las Cumbres initiated the TOM Toolkit Development and Observing program to promote community use and development of the TOM Toolkit and the fledgling follow-up system. Las Cumbres offered 1000 hours of time on their 1m telescope network, and both SOAR and Gemini Observatory (both operated by NOIRLab) contributed 50 hours each. Las Cumbres also raised approximately $250,000 from the Heising-Simons Foundation and the Zegar Foundation to fund TOM development via a competitive proposal process. The funds are being distributed by the LSST Corporation.

In the lead-up to the proposal deadline, interested teams attended a workshop at the Carnegie Observatories

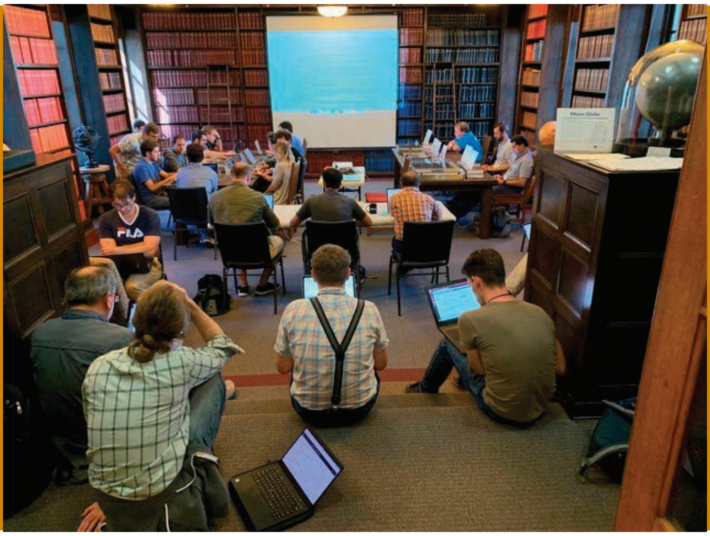

Figure 2: Attendees of the TOM Toolkit Workshop attend a tutorial on customizing the toolkit for their needs.

Table 1. Observatory and Over-subscription Factors

Observatory	Las Cumbres	SOAR	Gemini South	Gemini North
Hours Requested	3210	199	110	225
Over-subscription	3.2	4.0	6.7	

in Pasadena, California, between 30 September and 04 October 2019 (*https://tom-toolkit.readthedocs.io*). Over 40 participants learned about the capabilities of the participating facilities and how to use and modify the TOM Toolkit. Some participants in deep concentration during one of the tutorials are shown in Figure 2.

Thirty-three proposals were received, and the over-subscription factor for the NOIRLab-operated facilities was over 4 (see Table 1). The proposals covered supernovae and gravitational wave follow-up to microlensing, exoplanets, and the Solar System. Most were time-domain proposals, but this was not a requirement. A single TAC consisting of experts in both the science topics of the proposals and the facilities evaluated the proposals. The result is that four projects were awarded time on Gemini, five projects on SOAR, and fourteen on the Las Cumbres network. Seven of the projects received development funding with the largest award being $45,000. The teams are currently developing their TOMs. The programs will run through the end of the ZTF public survey in December 2020.

The TOM Toolkit proposal opportunity is not only an early end-to-end test of the system in Figure 1 but also a trial of a possible TAC process and observing procedures for AEON. The AEON participants are discussing new ways of allocating time to simplify the process for PIs and promote the use and capabilities of the network. By default, the current proposal processes will be used, but alternatives that will make it easier to apply for time on the network and reduce multiple jeopardy are being considered.

While the system described here is designed mainly for automating alert follow-up, many of the tools such as TOMs and facility APIs, schedulers, and data reduction/archiving, will be of great value to a wide variety of projects, especially those with large numbers of targets and those that would benefit from automation. Updates on the status of the system will be given in future newsletters.

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MAROON-X:
A New Earth-Finder Spectrograph for Gemini North

Alison Peck

One of the most exciting areas of exoplanet research is identifying and characterizing nearby habitable planets. The ultimate goal is to make a credible search for life on planets outside of our Solar System, and key to realizing such a comprehensive exoplanet science program is an instrument for measuring radial velocities to sufficiently high precision. To meet this need, the University of Chicago's Bean Exoplanet Group has constructed a next-generation radial velocity spectrograph called MAROON-X for use as a Visiting Instrument at the Gemini North telescope (the international Gemini Observatory is a Program of NSF's NOIRLab).

An important goal of exoplanet science is to measure masses and radii for a large enough sample of low-mass planets that robust statistics emerge. Transiting planet finder missions that are designed to exploit the synergy between radial velocity and transit techniques include the *Kepler*/ K2 mission; NASA's *Transiting Exoplanet Survey Satellite (TESS)* mission; ESA's *CHaracterising EXOPlanet Satellite (CHEOPS)* mission; and ESA's *PLAnetary Transits and Oscillations of stars (PLATO)* mission, now set for 2026. The many new small transiting planets that will be identified by these missions present an enormous opportunity to expand the study of planetary statistics into the regime of planet bulk compositions—if we can measure the masses of these objects using the radial velocity method.

Design Goals

MAROON-X was designed for high-precision radial velocity (RV) measurements (~ 1 m/s or better) of fainter stars than is possible with existing spectrographs. Existing radial velocity instruments become very inefficient around V = 12th magnitude, and objects with V > 13th magnitude are essentially out of reach for all but the most intense campaigns. The instrument was also designed to study planets in the habitable zone of the very lowest-mass M dwarfs (those with $M_{star} < 0.3\ M_\odot$). In contrast to solar-type stars, the habitable zones of M dwarfs are close-in enough so that planets in this region have a significant chance of transiting, making them feasible targets for transit spectroscopy observations to characterize their atmospheres. The lowest-mass M dwarfs are intrinsically very faint, however, and current instruments can achieve 1 m/s precision only for the handful of these stars within a few parsecs (e.g., Proxima Centauri and Barnard's Star). To take advantage of the opportunities offered by transiting low-mass planets around low-mass M dwarfs, we need high-precision radial velocity measurements for these stars out to 20 pc (Deming et al., 2009, PASP, 121, 952).

MAROON-X

The MAROON-X team has carried out detailed simulations to identify the optimum wavelength range to observe low-mass M dwarfs for radial velocity measurements. They find that the red part of the optical spectrum contains comparable radial velocity information as the near-infrared for stars down to masses of 0.10 $M_\odot$ ($T_{eff} \approx$ 2,600 K), because radial velocity measurements depend not just on the number of collected photons but also on the spectral line density. Although M dwarfs are brighter around 1 micron (μm), the very high line density at shorter wavelengths more than compensates for the difference. This means that the optimum wavelength intervals for radial velocity measurements of solar-type and low-mass stars are not very different, and they can be spanned by a single spectrograph.

Thus, MAROON-X is a red-optical (500–900 nanometers [nm]), high-resolution (R = 80,000) spectrograph capable of delivering high-precision radial velocities with an intrinsic instrument stability of < 0.5 m/s. The instrument's core spectrograph is fiber-fed (including a fiber for simultaneous calibration), enclosed in a vacuum chamber, and thermally and mechanically isolated from its environment (Seifahrt et al., 2016, SPIE, 9908, 990818). The spectrograph's design is based on an asymmetric white-pupil approach, which re-images and then re-collimates all dispersed beams after the echelle grating into a common pupil to minimize the diameter of the cross-disperser and camera. This design variation has been used successfully on other instruments, for example, on the High-Resolution Spectrograph (HRS) at the Southern African Large Telescope. The table provides a summary of MAROON-X's expected properties at Gemini North.

MAROON-X Main Characteristics

Spectral resolution	R = 80,000
Acceptance angle	FOV = 0.77″ at the 8m Gemini North telescope
Wavelength range	500 nm–900 nm (in 56 orders)
Number and reach of arms	Two (500–670 nm and 650–900 nm)
Cross-disperser	Anamorphic VPH grisms
Beam diameter	100 mm (at echelle grating), 33 mm (at cross-disperser)
Main fiber	100 µm octagonal (CeramOptec)
Number and type of slicer	3x pupil slicer
Slit forming fibers	Five 50 × 150µm rectangular (CeramOptec), including sky and calibration
Inter-order and inter-slice spacing	≥ 10 pixel
Average sampling	3.5 pixel per FWHM
Blue detector	Standard 30 µm thick 4k × 4k STA 4850 CCD (15 µm pixel size)
Red detector	Deep-depletion 100 µm thick 4k × 4k STA 4850 CCD (15 µm pixel size)
Calibration	Fabry-Perot etalon for simultaneous reference (fed by 2nd fiber)
Exposure meter	Chromatic
Environment for main optics	Vacuum operation, 1 mK temperature stability
Environment for camera optics	Pressure sealed operation, 20 mK temperature stability
Long-term instrument stability	0.7 m/s (requirement), 0.5 m/s (goal)
Total efficiency	11% (requirement) to 15% (goal) at 700 nm (at 70th percentile seeing)
Observational efficiency	S/N=100 at 750 nm for a V=16.5 late M dwarf in 30 minutes

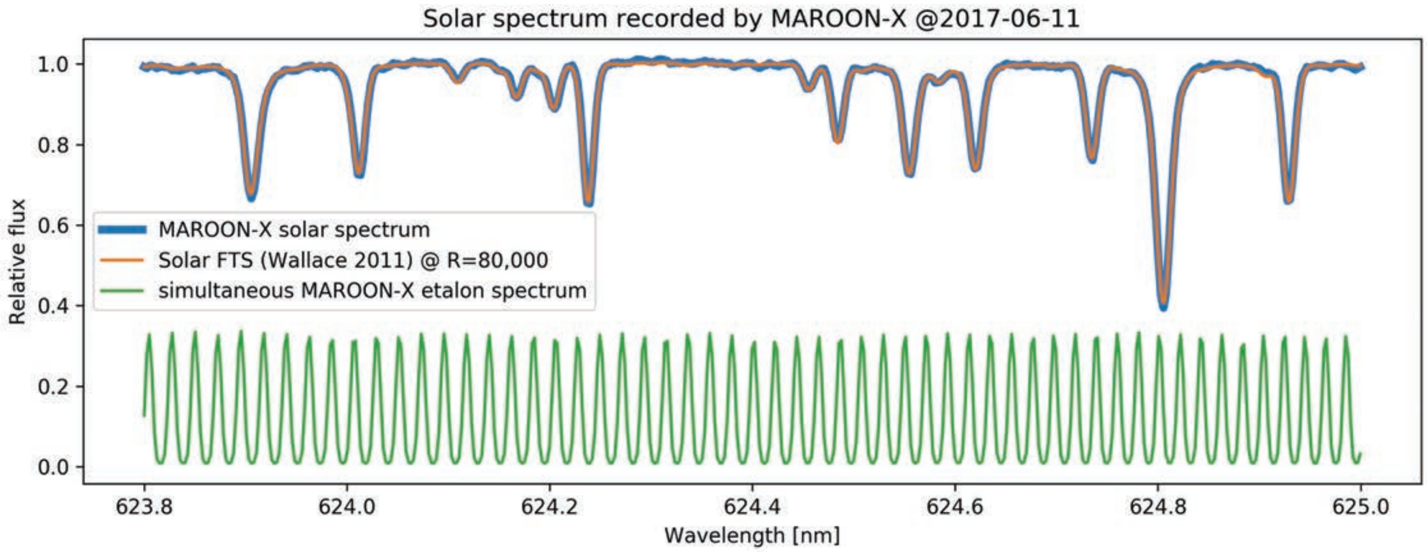

Figure 1: Small subsection of a solar spectrum recorded with MAROON-X at the University of Chicago. For comparison we overplot the same region from the solar atlas of Wallace et al. (2011, ApJS, 195, 6) obtained with the Fourier Transform Spectrometer (FTS) at the McMath-Pierce Solar Telescope, reduced to the spectral resolving power of MAROON-X (R=80,000). In the bottom of the figure we show the simultaneously recorded spectrum from the MAROON-X etalon calibrator. The spectra have been flat-fielded and are blaze corrected.

The primary wavelength calibrator for the instrument is a stabilized Fabry-Perot etalon, traced to the hyperfine transition of rubidium. This device delivers a comb-like spectrum of about 500 bright and unresolved lines per spectral order with frequencies traceable to a few cm/s (Stürmer et al., 2017, JATIS, 3, 025003). In addition, an automated solar telescope was available in the lab to deliver solar light to the spectrograph (see Figure 1), allowing the team to test and improve the data reduction and radial velocity analysis pipeline.

In January 2017, KiwiStar Optics delivered the core spectrograph and the blue wavelength arm to the University of Chicago. This was installed in a chamber with temperature control to better than 20 milliKelvin. All the expected characteristics of the spectrograph (e.g., resolution, scattered light, and efficiency) were confirmed with lab measurements. First tests with the etalon calibrator demonstrated that even over the limited spectral coverage of the smaller and less stable lab detector system, the science and calibration fibers track each other to better than 20 cm/s over timescales of minutes to days. The high line density and exquisite stability of the etalon allow for unprecedented stability vetting and calibration at a level otherwise offered only by a much more complex and expensive laser frequency comb.

Integration at Gemini North

The instrument team, with input from Gemini staff, designed a front end for MAROON-X to connect to an instrument port, while the instrument itself will reside in the Pier Lab. This front end was successfully commissioned at Gemini North in 2018, in advance of shipping the instrument from Chicago (Figure 2).

In April 2019, MAROON-X passed its pre-ship acceptance in Chicago and was disassembled to begin its voyage to Hawai‘i, to be reassembled and aligned in the thermally controlled enclosure that had been prepared for it in the Pier Lab. Uncrating and inspection began on 6 May, with assembly and positioning of large items (such as the cryo-

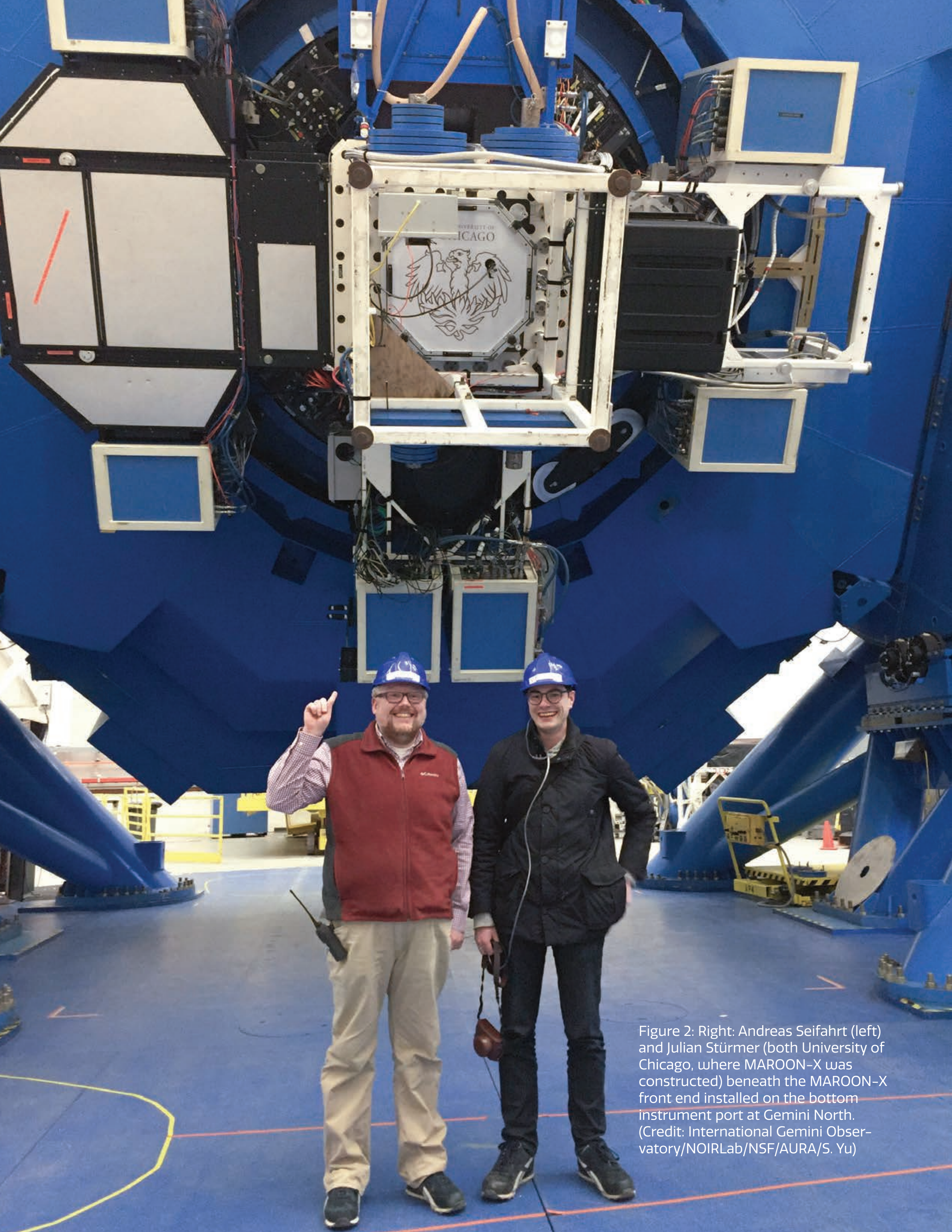

Figure 2: Right: Andreas Seifahrt (left) and Julian Stürmer (both University of Chicago, where MAROON-X was constructed) beneath the MAROON-X front end installed on the bottom instrument port at Gemini North. (Credit: International Gemini Observatory/NOIRLab/NSF/AURA/S. Yu)

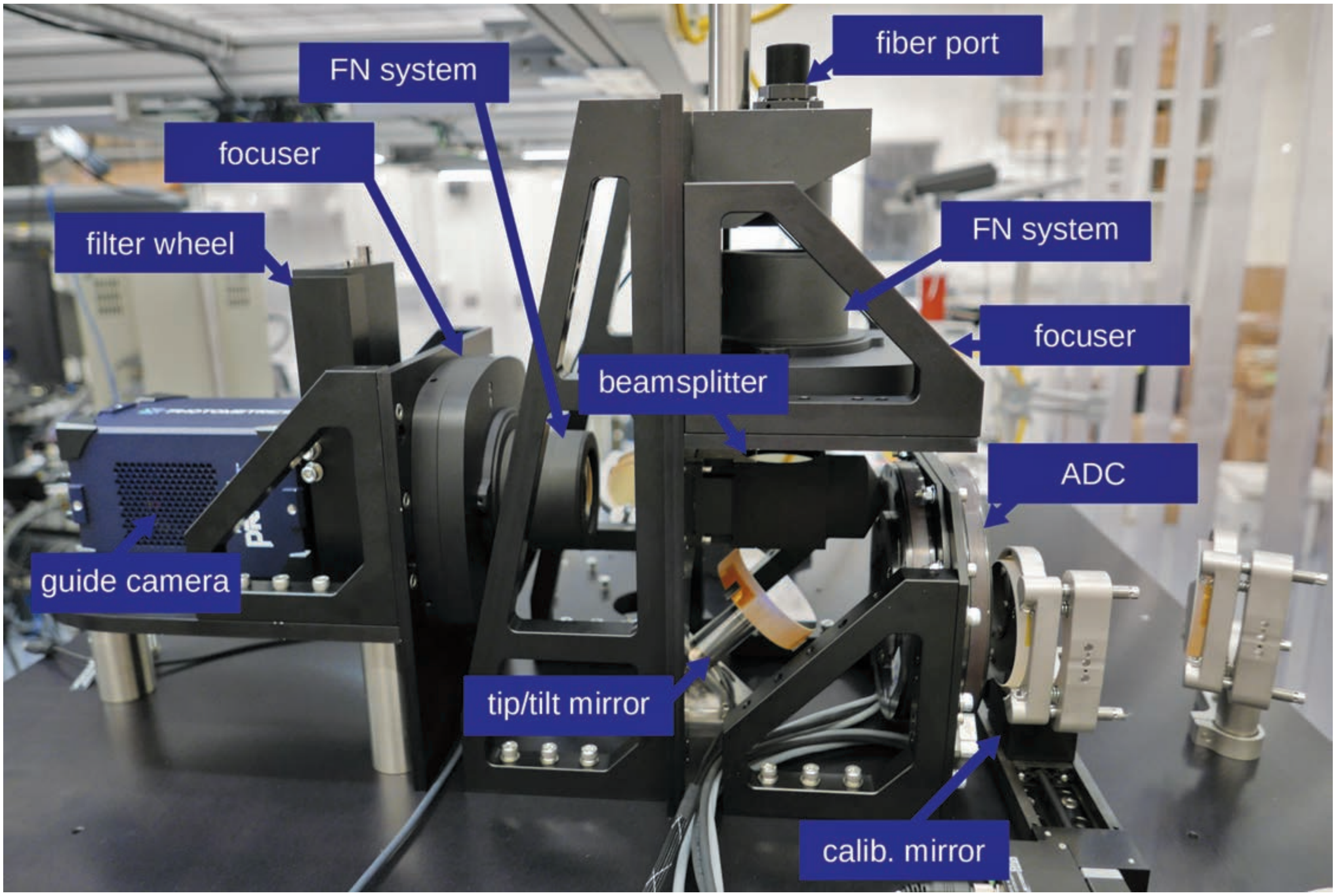

Figure 2: The internal organs of the MAROON-X front end in the lab in Chicago, preparing for the acceptance test. (Credit: University of Chicago/A. Seifahrt)

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stat) taking place over the next few days. During the week of 13 May, the optics were unpacked, integrated, and aligned. The work went extremely smoothly, thanks to the outstanding instrument team and the assistance of the skilled Gemini day crew, but commissioning was delayed a few months due to the Maunakea Access Road closure from July to December 2019. Fortunately, the team were flexible, and we were able to resume work on the instrument as soon as access was available.

MAROON-X has now completed one commissioning run, using 20 hours of telescope time over eight nights in December 2019. Two critical measurements, the simultaneous etalon calibration and the stability tracing of the etalon, were unfortunately not ready at the time of the December run. Although the RV performance tests will thus not yet reflect the final performance of MAROON-X, the data were very promising (Figure 3). Because the instrument performed well, we are able to offer MAROON-X for general high-resolution spectroscopy to the Gemini User Community in the 2020B semester, and we look forward to offering it for high-precision RV measurements in the very near future.

Acknowledgement: The MAROON-X team acknowledges funding for this project from the David & Lucile Packard Foundation, the Heising-Simons Foundation, and the University of Chicago.

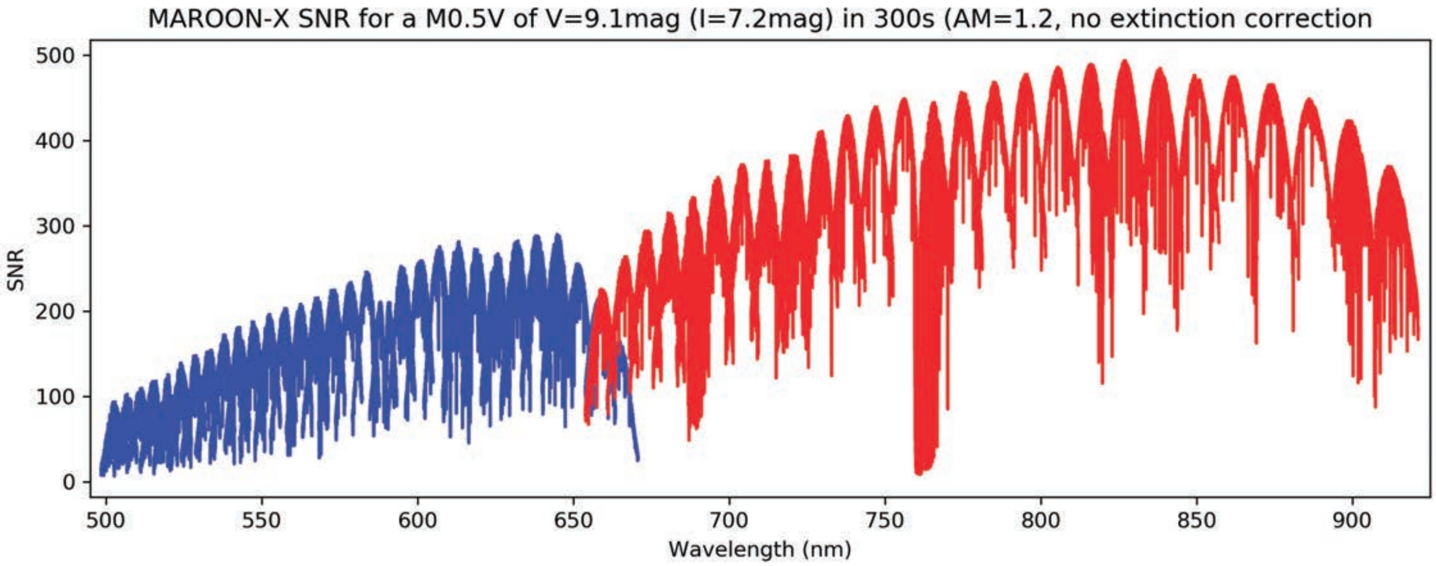

Figure 3: Plots of the signal to noise ratio (SNR) measured for two stars observed during the MAROON-X commissioning run in December 2019. For each order, the measured SNR is shown for the combined flux of all three object fibers. These data are not fully calibrated, but they provide a sense of what we may expect from a typical observation.

> “MAROON-X was designed for high-precision radial velocity (RV) measurements of fainter stars.”

DOI 10.5281/zenodo.3932178

IGRINS Brings High-Resolution Near-IR Spectroscopy Back to Gemini South

Alison Peck

Through the Visiting Instrument Program, international Gemini Observatory users now have access to a powerful capability at the Gemini South telescope (Gemini Observatory is a Program of NSF's NOIRLab). The Immersion GRating INfrared Spectrometer (IGRINS) is a cross-dispersed near-infrared spectrograph with a resolving power of R = 45,000 covering the H and K windows (1.45–2.5 microns), yielding both broad spectral coverage and high spectral resolution in a single exposure.

IGRINS has a strong track record of diverse and innovative science results, having spent over 350 nights at the McDonald Observatory in Texas and 200 nights at the Discovery Channel Telescope (now the Lowell Discovery Telescope) at Lowell Observatory in Arizona. Recent results span a range of topics from cold molecular clouds and diffuse interstellar bands to T Tauri stars, systems containing multiple stars and/or planets, and even microquasars. The response to IGRINS at Gemini has been extremely strong, resulting in a large number of successful proposals for its inaugural visit in the 2018A semester and again on its return in 2020.

As a Visiting Instrument, IGRINS is ideal because it has a single observing mode and contains no moving parts. By exchanging the input optics to accommodate Gemini, the IGRINS H and K echellograms are unchanged between facilities. For the first visit, the instrument team accompanied IGRINS to Gemini South in March 2018, installed and tested it, and then provided support for Gemini User Community observations with the help of Gemini staff for a total of 50 nights, resulting in excellent science that is starting to appear in journals now. The team also provided a data reduction pipeline to assist users.

Following the tremendous success of that visit, a much longer return visit was negotiated, and we are now excited to have IGRINS at Gemini South for six semesters, beginning with 2020A. This is perfect timing for Gemini, as we are expecting to get our very own IGRINS-2 Facility Instrument in a few years, and so for this reason, we have moved IGRINS from the status of normal Visiting Instrument to that of "Transitional Instrument." We are using IGRINS to train Gemini staff in the use of IGRINS-2, which helps them contribute to discussions of the minor upgrades that may be possible to implement in the IGRINS-2 design over the next year. Gemini staff are also able to make use of this time to begin integrating IGRINS into the Gemini software and operations planning strategies so that we can hit the ground running when IGRINS-2 arrives.

> "IGRINS is ideal because it has a single observing mode and contains no moving parts."

To learn more about the design of IGRINS, and to find out what you need to know to propose for this unique instrument on Gemini South, see *https://sites.google.com/site/igrinsatgemini/proposing-and-observing* and see the following SPIE papers: Yuk et al. (7735M, 2010), Park et al. (91471D, 2014), and Mace et al. (99080C, 2016).

The modified ballast weight assembly waiting in Chile to attach IGRINS to the Gemini South telescope, with SOAR gracing the scenery in the background. (Credit: international Gemini Observatory/NOIRLab/NSF/AURA/B. Chinn)

Figure 3: The IGRINS Team (Heeyoung Oh, Kimberly Sokal, and Ricardo Lopez) at UT Austin packing the instrument for shipping. (Credit: UT Austin/G. Mace)

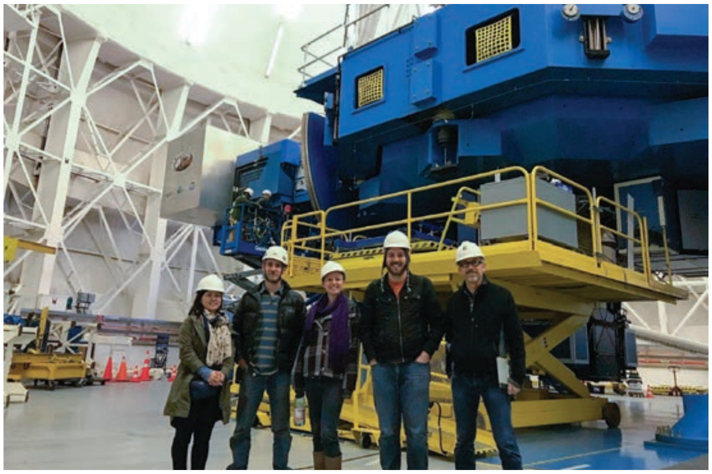

Figure 4: IGRINS and Gemini team collaboration during a site visit to Gemini South (Hwihyun Kim, Brian Chinn, Kimberly Sokal, Greg Mace, and John Good). (Credit: UT Austin/K. Sokal)

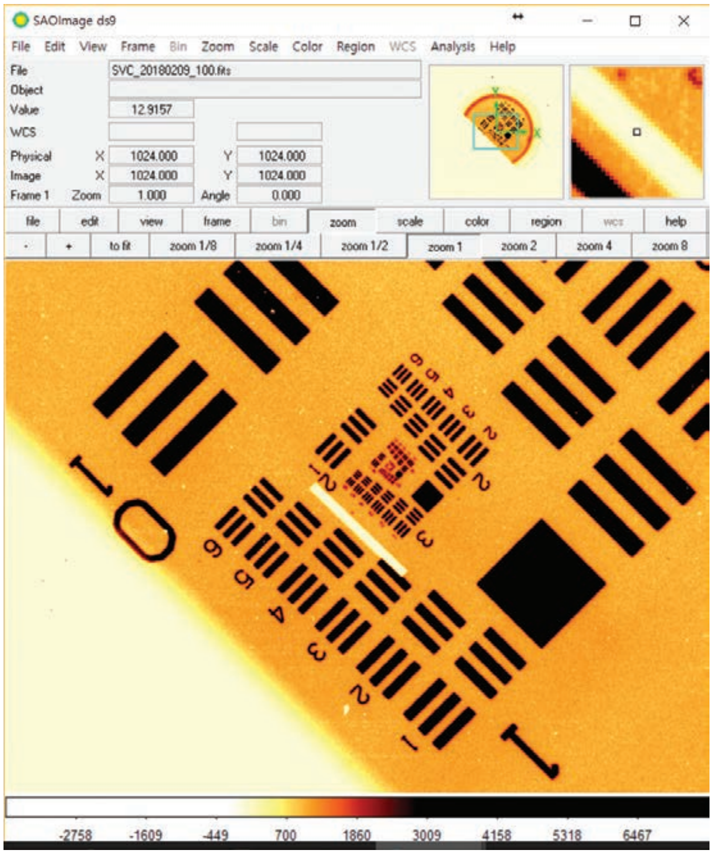

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Image X 1024.000 Y 1024.000
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Figure 5: The IGRINS spectrograph slit (white bar) and a graduated scale used to measure optical performance. Lines resolved well below the slit width show that IGRINS optics for Gemini will perform as designed and sensitivity will be optimized.

For more exciting science produced by IGRINS at Gemini South, please see the following publications:

- Hinkle, K. H., Fekel, F. C., Joyce, R. R., et al., "Infrared Spectroscopy of Symbiotic Stars. XII. The Neutron Star SyXB System 4U 1700+24 = V934 Herculis," 2019, ApJ, 872, 43
- Kidder, B., Mace, G., Sokal, K., et al., "Radial Velocities of Low-mass Candidate TWA Members," 2019, ApJ, 879, 63
- López-Valdivia, R., Mace, G. N., Sokal, K. R., et al., "Effective Temperatures of Low-Mass Stars from High-Resolution H-band Spectroscopy," 2019, ApJ, 879, 105
- Tegler, S. C., Stufflebeam, T. D., Grundy, W. M., et al., "A New Two-Molecule Combination Band as a Diagnostic of Carbon Monoxide Diluted in Nitrogen Ice on Triton," 2019, AJ, 158, 17

IGRINS is a collaboration of the University of Texas and the Korea Astronomy and Space Science Institute (KASI). Daniel Jaffe of UT Austin is the Principal Investigator, and Chan Park of KASI is deputy PI and KASI instrument PI. Jae-Joon Lee at KASI supervises the IGRINS operational program on the Korean side. The first IGRINS visit to Gemini was supported by the US National Science Foundation under grant AST-1702267 (PI Gregory Mace, University of Texas at Austin) and by the Korean GMT Project of KASI.

NSF's NOIRLab

A sunset and layers of blue mountaintops form a colorful backdrop to the Cerro Tololo Inter-American Observatory (CTIO), a Program of NSF's NOIRLab. (Credit: NOIRLab/NSF/AURA/B. Tafreshi)

DOI 10.5281/zenodo.3932184

The Mid–Scale Observatories Program

Lori Allen

Under the new NOIRLab organization, the Mid-Scale Observatories (MSO), a Program of NSF's NOIRLab, encompasses both Kitt Peak National Observatory and Cerro Tololo Inter-American Observatory. The core of the MSO Program is carried out on the four 4m-class telescopes: Victor M. Blanco and Southern Astrophysical Research (SOAR) in the south and Nicholas U. Mayall and WIYN in the north. Recent upgrades to instrumentation and operations, driven by scientific demands, have brought each of these no-longer-young telescopes exciting new capabilities.

The Dark Energy Camera (DECam) is a leading wide-field imager. Its >3-square-degree field is enabling breakthrough science from the Blanco on subjects ranging from Solar System rocks to the most distant quasars. With the deployment of AEON, the dynamic scheduling and observing program on SOAR, observers are following up transient alerts in the practice of Time Domain and Multi-Messenger Astronomy. DESI, the Dark Energy Spectroscopic Instrument, with its 5,000 fiber positioners, is poised to begin its five-year mission at the Mayall telescope to make the most detailed map of the Universe to date. NEID, the precision RV spectrometer on WIYN, is aiming to achieve state-of-the-art precision in exoplanet radial velocities, hopefully leading to the characterization of Earth-like planets in other solar systems.

MSO's mission includes providing a platform for scientific research and education carried out by the many tenants on both Kitt Peak and Cerro Tololo. These tenants contribute not only to the day-to-day operation of the mountain facilities through use fees but also to the scientific environment at the observatories, through their research and educational activities. Tenants often bring added value when they take on operation of telescopes, as in the recent roboticizing of the KPNO 2.1m Telescope on Kitt Peak by a group at Caltech.

The MSO Program is funded both publicly and privately. Blanco operations are still funded by the NSF's NOIRLab core agreement with NSF, as is the NOIRLab's share of SOAR operations. Mayall operations will be funded by the DOE Office of Science for the duration of the DESI survey. The NOIRLab share of WIYN is funded through a separate agreement with NSF, and NEID is operated under the NN-EXPLORE program, a joint NASA–NSF research initiative on exoplanets that is also funding exoplanet RV work with CHIRON at SMARTS in the south.

Taken as a group, the 4m telescopes making up the core of the MSO Program are helping drive some of the most exciting areas of astrophysics, and they demonstrate that well-built telescopes, if instrumented with new technology, can have very long and productive lives.

NEID Exoplanet Instrument Sees First Light
nationalastro.org/news/neid-exoplanet-instrument-sees-first-light/

DESI's 5000 Eyes Open as Kitt Peak Telescope Prepares to Map Space and Time
nationalastro.org/news/desis-5000-eyes-open-as-kitt-peak-telescope-prepares-to-map-space-and-time/

Automated Observing Network Inaugurated at SOAR Telescope
nationalastro.org/news/noao-automated-observing-network-inaugurated-at-soar-telescope/

DOI 10.5281/zenodo.3932228

The NEID Port Adapter being assembled for testing before installation onto the WIYN bent Cassegrain port. (Credit: NOIRLab/NSF/AURA/D. Li)

NEID at WIYN

Jayadev Rajagopal and Dan Li

NEID is a highly stabilized fiber-fed spectrometer for the WIYN 3.5m Telescope at Kitt Peak National Observatory (KPNO), a Program of NSF's NOIRLab. The name is derived from the word "to see" in the language of the Tohono O'odham Nation, who graciously allow the scientific use of Kitt Peak under an agreement with the US federal government. NEID is designed to enable unprecedented radial velocity (RV) precision (better than 50 cm/s in a single epoch), which is needed to detect Earth-like planets. NEID is funded through NN-EXPLORE, a joint NSF–NASA program to enable groundbreaking exoplanet research.

Commissioning of NEID began in mid-October 2019 with the installation of the NEID Port Adapter (developed at the University of Wisconsin–Madison), a compact fiber feed that would be permanently attached to the bent Cassegrain port on WIYN and provide crucial functions such as target acquisition, guiding with fast tip-tilt control, and atmospheric dispersion correction for NEID. About two weeks later, the NEID spectrometer arrived at Kitt Peak from Penn State University, where it was built and extensively tested.

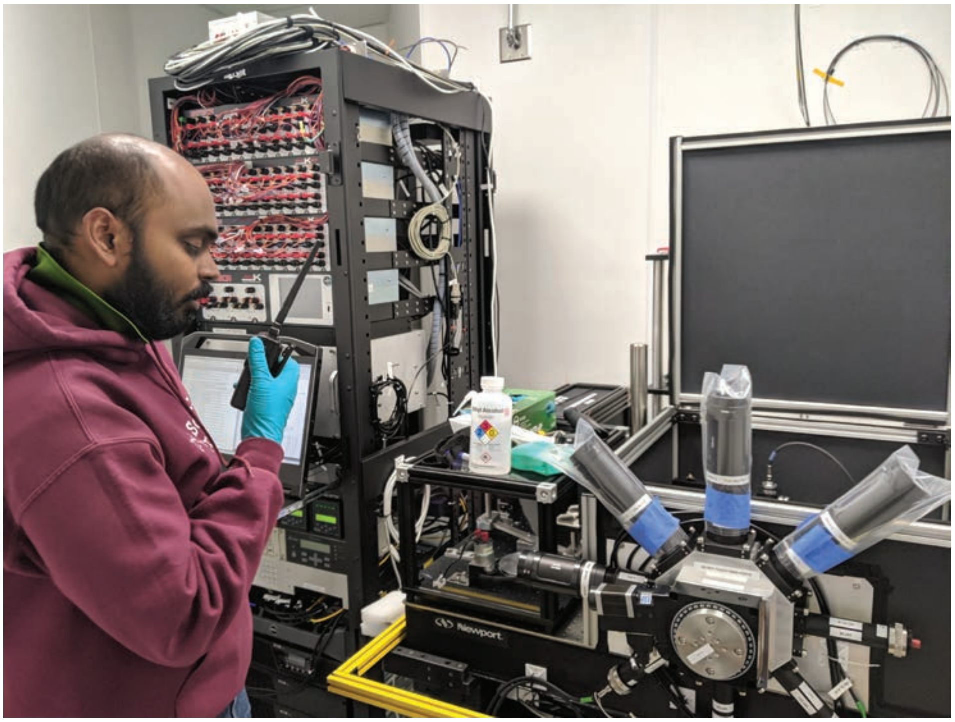
After two months of hard work by the entire team, NEID saw first light in late December, shortly before the 235th AAS meeting. The target of the first-light observation was 51 Pegasi, the first Sun-like star known to host an exoplanet (*https://nationalastro.org/news/neid-exoplanet-instrument-sees-first-light/*).

The very compressed schedule to make NEID ready for regular science operations continues at full speed. An issue with the Port Adapter's precision guiding system (consisting of a high-speed EMCCD camera and a fast tip-tilt mirror) where the guiding loop, under some circumstances, had trouble holding the target to the required stability has been resolved, and on-sky tests are in progress to

The cover being lowered carefully to close the two-ton vacuum chamber of the NEID spectrometer after the post-shipping inspection conducted inside the cleanroom where NEID is located at WIYN. (Credit: NOIRLab/NSF/AURA/E. Hunting)

further confirm this. Other ongoing commissioning tasks for the Port Adapter include incorporating an automated target acquisition algorithm (crucial to reduce observation overheads) and the capability to detect (and correct for) telescope-focus errors on the fly.

Initial data taken at WIYN showed some contamination of the surface of NEID's CCD detector from water-ice. The issue persisted after a few attempts to remove the contamination (by purging the cryostat with nitrogen and thermal cycling of the CCD). A solution involving an additional getter (cold absorption surface) and further minimizing the circulation of molecules near the CCD surface was devised by the NEID team and reviewed and approved by an external committee. At the moment, these modifications have been completed, and the chamber is being brought back to high vacuum. Regular commissioning and shared-risk science will be scheduled at the earliest possible date.



NEID's state-of-the-art equipment for calibration being tested in the cleanroom. (Credit: NOIRLab/NSF/AURA/D. Li)

NEID articles in NOAO Newsletter issues:

June 2020: *https://www.noao.edu/noao/noaonews/jun19/119news.pdf*

April 2018: *https://www.noao.edu/noao/noaonews/apr18/117news.pdf*

October 2017: *https://www.noao.edu/noao/noaonews/oct17/116news.pdf*

DOI 10.5281/zenodo.3932238

DESI and Mayall: Ready for Adventure

Arjun Dey

Now equipped with the ground-breaking Dark Energy Spectroscopic Instrument (DESI; *https://www.desi.lbl.gov*), the Nicholas U. Mayall 4m Telescope is about to embark on a new voyage of discovery. DESI can now deliver simultaneous spectra of nearly 5000 targets spread over a 3-degree-diameter field of view in a single exposure and can reacquire new fields within minutes. The DESI project, funded by the U.S. Department of Energy Office of Science and led by the Lawrence Berkeley National Laboratory, and involving an international team from 75 institutions spread over 13 nations, will revolutionize our understanding of the cosmos and shed light on its darkest and most mysterious component—the dark energy that pervades the Universe and is responsible for its accelerating expansion.

The Mayall telescope was taken out of service in February 2018 in order to perform various upgrades and install the DESI instrument. The process involved installing on the Mayall telescope structure a new top end ring capable of supporting the barrel containing the new prime focus optics, the DESI focal plane holding the 5000 robotic fiber positioners, and roughly 1 million feet of fiber-optic cable. In addition, a thermal enclosure was installed in the old coudé room and equipped with ten 3-arm spectrographs covering the optical wavelength range 360–980nm with a (blue-to-red) resolution of 2800–5000. The Mayall's Cassegrain cage now holds an upward-looking fiber-view camera, capable of imaging the 5000 fibers (when back illuminated) and precisely measuring their relative positions. A new control room was constructed and equipped on the U-floor of the Mayall building. The installation was completed in fall 2019, and the instrument saw first light on 22 October 2019.

DESI was fully commissioned over the following five months. The instrument can now efficiently position fibers with ~0.1 arcsec accuracy with high reliability and repeat-

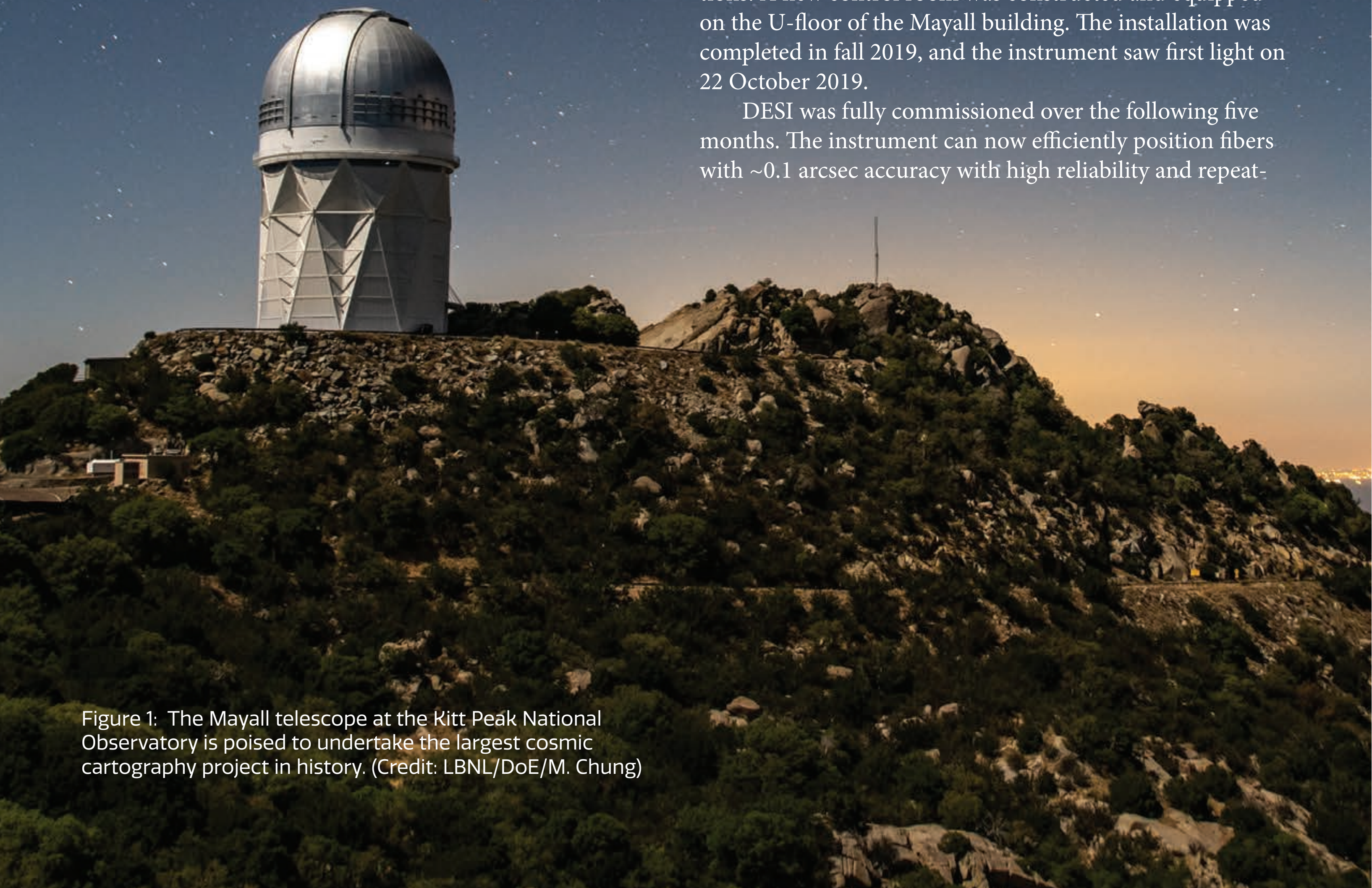


Figure 1: The Mayall telescope at the Kitt Peak National Observatory is poised to undertake the largest cosmic cartography project in history. (Credit: LBNL/DoE/M. Chung)

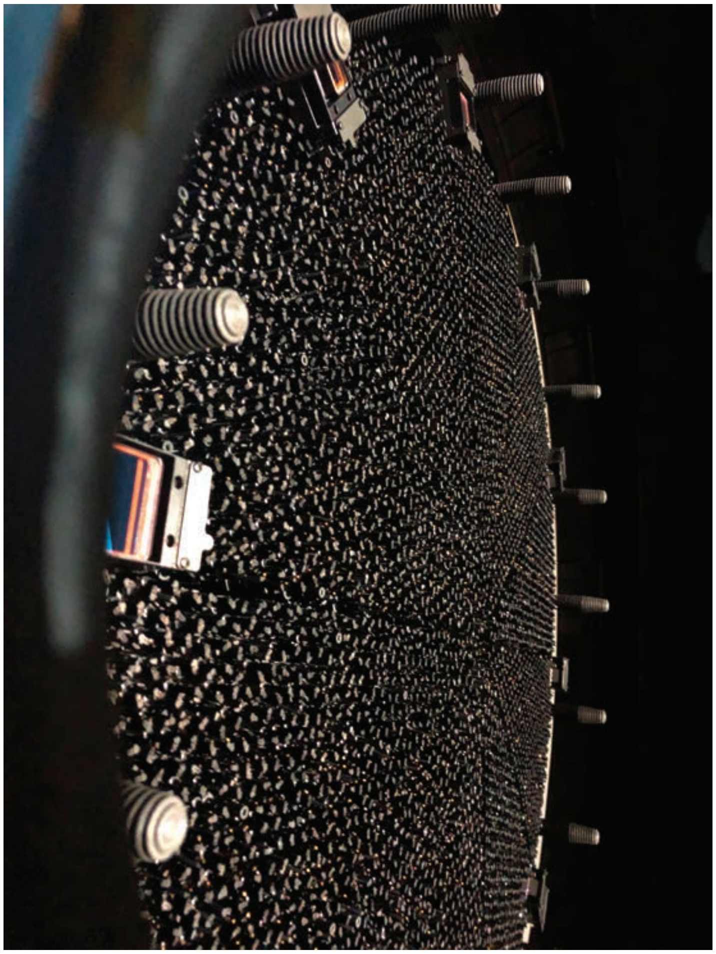


Figure 2: The DESI focal plane, with 5000 robotic fiber positioners, has the largest grasp of any multi-object spectroscopic instrument ever built. (Credit: LBNL/DoE/R. Besuner)

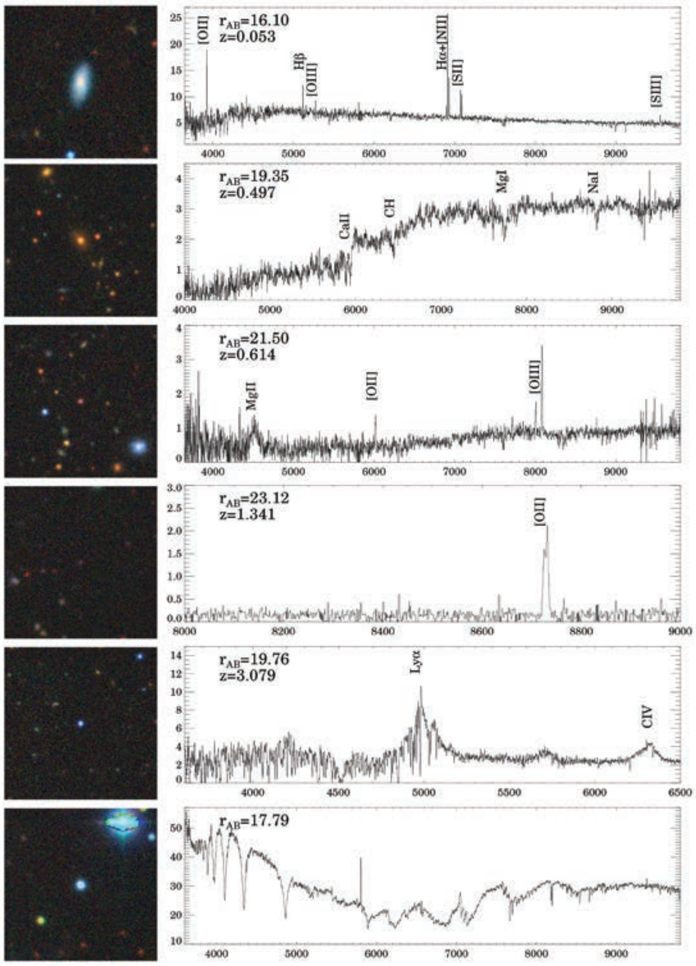


Figure 3: Images from the Legacy Surveys and sample spectra obtained with DESI in March 2020. The image panels, 66 arcseconds on a side, show false-color grz images with the target in the center. The spectra show examples of a bright galaxy, a luminous red galaxy, two emission line galaxies, a quasar, and an unusual white dwarf – M-star binary. The wavelength scale is in Angstroms, and the flux density scale is in nanomaggies. (Credit: DESI Collaboration)

ability. The team successfully obtained some science data in early March before shutting down operations (and placing the instrument in a safe state) in response to the COVID-19 pandemic.

The DESI collaboration is busy actively analyzing science data and working to improve the project's operational and data processing capabilities. Over the course of the commissioning campaign, DESI collected spectra of around 0.7 million unique targets! Despite the untimely cessation of operations, the DESI project successfully passed the Department of Energy's construction completion review with flying colors. The instrument is now ready for its new mission—which will resume when the Observatory restarts operations sometime in fall 2020.

Over its five-year mission, DESI will measure the redshifts of 35 million galaxies and quasars, with the goal of producing the most precise measurement of the expansion history of the Universe and the best constraints on the equation of state of dark energy to date. DESI will also measure the velocities of many millions of Milky Way stars and explore the dynamical and chemical formation history of our Galaxy's halo and disk. DESI's targets will be chosen from the large public imaging dataset produced by the Legacy Surveys (*http://legacysurvey.org*). The combination of the imaging and spectroscopic data will provide an invaluable resource for answering a wide range of astrophysical questions.

We look forward to restarting operations and reopening the DESI data floodgates soon. The Universe awaits ...

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AEON
Astronomical Event Observatory Network

The Astronomical Event Observatory Network on SOAR:

Implementation and First Results

César Briceño on behalf of the AEON collaboration

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Developers: D. Gomez, O. Estay, R. Cantarruti (CTIO/NSF's NOIRLab); S. Torres (SOAR/NSF's NOIRLab); J. Nation, E. Heinrich, M. Bowman, N. Volgenau (Las Cumbres); S. Fanale (formerly at University of North Carolina at Chapel Hill)

Observatory Representatives: L. Storrie-Lombardi (Las Cumbres), J. Elias (SOAR/NSF's NOIRLab), A. Adamson (Gemini/NSF's NOIRLab), S. Heathcote (CTIO/NSF's NOIRLab), A. Bolton (CSDC/NSF's NOIRLab)

Figure 1: Nightscape of the SOAR and Gemini South telescopes on Cerro Pachón. These are the first 4–8m-class facilities that will be integrated into the AEON system. (Credit: NOIRLab/NSF/AURA/B. Quint)

Introduction

The Astronomical Event Observatory Network (AEON) is a collaboration among NSF's NOIRLab, Las Cumbres Observatory, the Southern Astrophysical Research (SOAR) 4.1m Telescope, and the international Gemini Observatory 8.4m telescopes. The goal is to develop an ecosystem of facilities to provide rapid and efficient follow-up observations of alerts created from modern astronomical surveys, with particular emphasis on the new windows into time-domain and multi-messenger astronomy brought about by the Legacy Survey of Space and Time (LSST) on the Vera C. Rubin Observatory 8.4m Simonyi Survey Telescope on Cerro Pachón, Chile.

AEON is envisioned as a collection of world-class telescopes (Figure 1) that can be accessed on demand through highly automated tools, operating in the wider context of astronomical surveys, alert brokers such as ANTARES (Saha et al. 2016, SPIE, 9910, 99100F), Target and Observation Manager systems (TOMs; Street et al. 2018, SPIE, 10707, 1070711), observing facilities, and data archives. To deliver on the goal of responding within minutes to hour timescales to survey alerts with appropriate follow-up observations, all of these elements need to interact programmatically with each other in a sequence of steps following a survey discovery.

AEON builds on the extensive experience of Las Cumbres Observatory in running a worldwide network of 1m and smaller telescopes. Early on it was decided that the SOAR 4.1m Telescope on Cerro Pachón would be an ideal pathfinder facility to develop the required software tools, capabilities, and operational experience for bringing 4m-class and larger telescopes into the Las Cumbres system. SOAR and Gemini South, with their flexible instrument suites, and the Victor M. Blanco 4m Telescope, with its DECam wide-field imager, are the natural "first-line responders"
for alerts from the LSST.

Here we describe the implementation of AEON-mode observing at the SOAR telescope and the results after 2019B, our first semester of operations in shared-risk mode.

Implementing AEON at SOAR

The Goodman spectrograph, the facility workhorse, was the first instrument to be offered (*http://www.ctio.noao.edu/soar/content/goodman-high-throughput-spectrograph*). SOAR would be operated in "AEON mode" on selected nights during a given semester, the actual number dictated by the total time approved for all programs requesting this new mode by the NOIRLab Time Allocation Committee and other SOAR partners.

A base requirement was that the AEON queue be highly automated, with no intervention or target decision-making required from the Telescope Operators (TOs) who would be carrying out the observations, supervised by existing support scientists. The SOAR AEON queue would be externally generated, in an automated and unsupervised way, by the Las Cumbres scheduling software. Because the Goodman instrument control software was not designed to be run programmatically, remote operation capability had to be added.

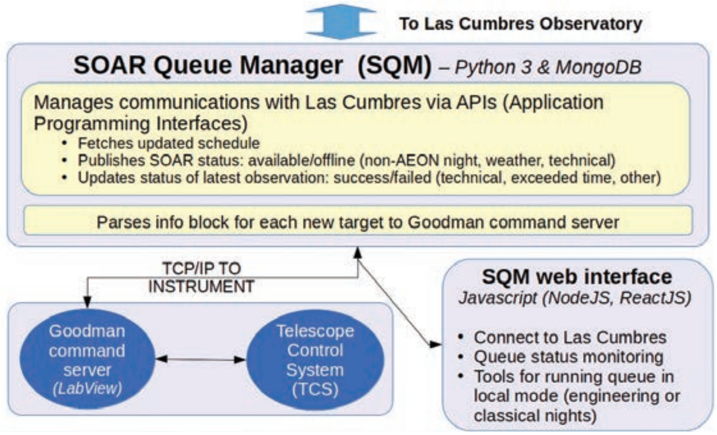


Figure 2: Architecture of the SOAR Queue Manager (SQM) software. The SQM handles communications with the Las Cumbres scheduler via a common API. Communication with the instrument and telescope is handled via sockets through a TCP/IP protocol.

The required software development was carried out by staff at Las Cumbres, the Cerro Tololo Inter-American Observatory (CTIO) Information Technology group, SOAR, and the University of North Carolina at Chapel Hill (UNC–Chapel Hill), with the following charges:

- Define a common Application Programming Interface (API) to allow an observation request from the scheduler to be received, interpreted, and parsed as commands to the telescope and instrument at SOAR and for the resulting data files to be transmitted to both the Las Cumbres archive and the Astro Data Archive at NSF's NOIRLab.
- Modify the Las Cumbres automated scheduler software to handle SOAR/Goodman.
- Develop scripting capabilities for the Goodman spectrograph.
- Develop the SOAR Queue Manager (SQM) software (Figure 2), with a web-based interface for the SOAR TOs, to handle all communications with Las Cumbres and with the SOAR telescope and the Goodman instrument.

This effort spanned three major phases, starting in late 2017 with the first visit of Las Cumbres staff to La Serena and culminating with the demonstration of AEON on SOAR in semester 2019B.

The work was carried out on schedule, and we had our first on-sky nights of testing AEON on 20 March and 15 April 2019. Classifications for several SN were published (Cartier et al. 2019, ATel, 12671, 1).

2019B Semester: Testing AEON on SOAR

We enrolled as beta testers eight approved science programs for 2019B that were a good match to AEON, totaling a maximum of 200 hours distributed over 20 nights. The science spanned a wide range of use cases, ranging from imaging of Near-Earth Objects (NEOs; Principal Investigator [PI]: N. Moskovitz, Lowell Observatory) and a study of asteroids with small perihelion distances (PI: M. Knight, University of Maryland) to time-domain spectroscopy of solar-like pre-main sequence stars in Orion (PI: T. Thanathibodee, University of Michigan), spectroscopic characterization of microlensing sources (PI: R. Street, Las Cumbres Observatory), spectroscopic classification of Young Supernovae (PI: R. Foley, University of California,

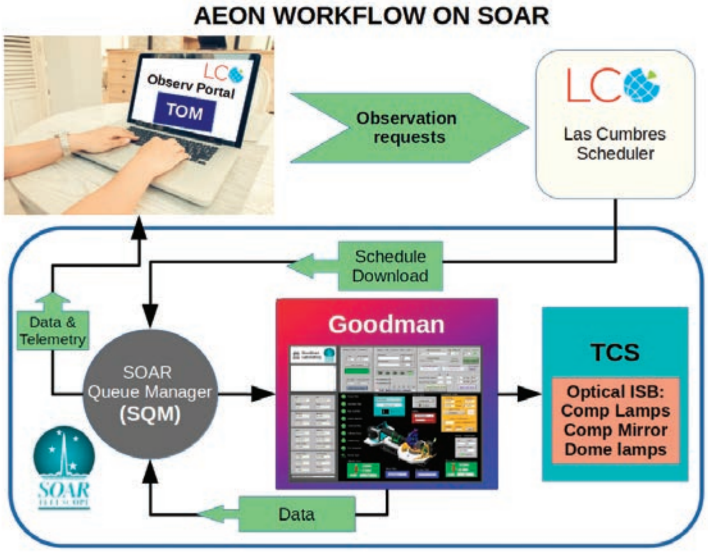


Figure 3: AEON workflow on SOAR. The user submits targets via the web-based Las Cumbres Observatory Observations Portal or via a TOM or custom Python script with the appropriate API. Observation requests are received at SOAR by the SQM and parsed as commands to the Goodman instrument and the Telescope Control System (TCS). The TCS in turn controls systems inside the optical Instrument Support Box (ISB), which carries auxiliary systems including the comparison lamps and mirrors. Data are sent to both the Las Cumbres and the NSF's NOIRLab Astro Data Archive as soon as the files are written on disk. At present, the users mostly retrieve their data through the Las Cumbres portal. SOAR TOs run the SQM software. Currently, the only interactive parts are acquiring the guide star and putting the science target on-slit. These two steps are done by the TO.

Santa Cruz), a multi-band, variability imaging search for RR Lyrae stars in ultra-faint dwarf galaxies (PI: C. Martínez, Cerro Tololo Inter-American Observatory), spectroscopy of gamma-ray blazar candidates (PI: F. Massaro, Observatorio Astrofisico di Torino), and determination of spectroscopic galaxy redshifts at low galactic latitudes (PI: L. Macri, Texas A&M).

These programs used the Goodman spectrograph in one or more of the following configurations: a low-resolution spectroscopic mode, using the 400 l/mm grating in M1 (300–700nm) and M2 (500–900nm) setups, with the 1 arcsec wide long slit, and 2×2 binning, at a resolution R ~ 900. A high-resolution mode used the 2100 l/mm grating centered at 650nm and the 0.45 arcsec wide long slit, providing a resolution R ~ 12000 and 63nm coverage. Imaging was done in 2×2 binning (plate scale = 0.3 arcsec/pixel) with the Sloan set of g, r, and i filters, and a wide VR filter.

Users were able to submit targets at any time for any of the scheduled nights and could do so either manually using the Las Cumbres Observation Portal or programmatically via a TOM or custom Python scripts using APIs. Most users accessed their data through the Las Cumbres portal. In Figure 3, we show the schematic workflow of AEON on SOAR.

During semester 2019B, we had a total of 185 hours available for scheduling. We lost 53.2 hours to weather (28.7%) and 10.3 hours to technical problems (5.6%; including the loss of internet connectivity, issues with the scheduler software, and problems with the telescope or instrument). We therefore had 121.7 effective hours to observe. We were on-sky 113.7 hours (~93%) and observed on average 8 targets/night, or ~1h/target. This includes overheads to slew the telescope, on-slit target acquisition (for spectra), changes in configuration (many targets were observed in both 400 l/mm grating configurations), and readout time.

Some imaging programs, such as the ones studying moving Solar System objects, obtained hour-long sequences of short exposures on a given object. The setup of the required non-sidereal rates was automated specifically for AEON operations and is handled by the SQM software, which connects with the JPL HORIZONS database and downloads the ephemeris for the start of the observation. No intervention from the TO is required.

Figure 4: Screenshot of the web-based interface to the Python live Goodman spectroscopic pipeline, showing a fully reduced spectrum of a standard star. It features basic interactive visualization tools that allow zooming into particular regions, coordinates of the mouse position, and saving a view to a png file. Analysis capabilities such as equivalent width and signal-to-noise measurements will be added in future versions.

The raw data files were transferred in real time to both Las Cumbres and the NSF's Astro Data Archive. Users could access their data a few minutes after the observations had been made.

The Future: 2020A and Beyond

For the start of semester 2020A, we implemented the observation of a spectrophotometric standard star every AEON night. This is configured in the SQM by the TO and is executed in an automatic way, the software selecting the star closest to the current position of the telescope, setting up the spectrograph, and selecting the appropriate exposure time. These observations are done ideally in twilight, before the start of the science queue, and they are publicly available to all users.

During semester 2019B, we only provided raw data files. For semester 2020A, we are offering, in beta-testing mode, the web-based live data pipeline for Goodman (Torres-Robledo and Briceño 2019, ASPC, 523, 203), which allows SOAR-AEON users to obtain extracted, wavelength-calibrated one-dimensional spectra seconds after the data have been written to disk and visualize them in their browser without the need to download any software (Figure 4). This product was not originally within the scope of the AEON-SOAR implementation plan, but because we made significant advances, we decided to offer it for testing by our semester 2020A users. The live version is based on our Goodman offline pipeline available at GitHub (*https://github.com/soar-telescope/goodman_pipeline*) and fully documented (*https://goodman.readthedocs.io/en/latest/index.html*).

In the future, we expect requests for the Goodman Blue camera and some additional configurations and the addition of other instruments such as the TSpec near-IR spectrograph (*http://www.ctio.noao.edu/soar/content/triplespec41*). Further engaging users from the SOAR partners—Brazil, Chile, Michigan State, and the University of North Carolina at Chapel Hill—would add more AEON time, offering better cadence for time-domain programs and better chances of observing transients. For semester 2020A, we are already supporting one Chilean program. We are also working to automate the guide star and target slit acquisition.

AEON on SOAR brings a new window of opportunity not only for time domain and multi-messenger astronomy but also for programs with large numbers of targets over the sky and standard setups that would be able to observe during many nights through a semester.

The 21st–Century Visitor Center Renaissance

Bill Buckingham

The new mural on the concrete 4m "donut" in the Visitor Center parking lot.

DOI 10.5281/zenodo.3932275

The Visitor Center is the public's window to the people, facilities, science, and accomplishments of Kitt Peak National Observatory (KPNO) and has been since 1964. It is the public face of the observatory and a dynamic public portal, showcasing the history, unique research facilities, and new capabilities of KPNO, a Program of NSF's NOIRLab.

The Kitt Peak Visitor Center has completed a four-year-long, much-needed renaissance that we hope will lead to an even more dramatic transformation in the near future. The timing of the improvements coincided nicely with recent multimillion dollar investments at three scientific workhorse facilities on Kitt Peak: the KPNO 2.1-meter Telescope, the WIYN 3.5-meter Telescope, and the Nicholas U. Mayall 4-meter Telescope.

The visitor program is not funded by any federal agency or observatory, so the Visitor Center relies entirely upon outside assistance for any improvements or new exhibits and from program and gift shop income to operate on a daily basis. We were able to undertake transformations to the Visitor Center interior and several exterior areas and bring online a new dual-purpose observatory, all at a very low cost. We have utilized donations to our Visitor Center Telescope Fund, a one-time allocation of funds from the National Optical Astronomy Observatory, funding from the SARA observatory consortium, and donations made as memorial gifts by two families. The recently completed improvements demonstrate the impact that modest-scale donations can make at the Visitor Center.

We chose to put these investments into selected areas that would make the most impact for our visitors and audience members. We wanted first impressions to be positive impressions, so we partnered with Tohono O'odham artist Michael Chiago to repaint the mural on the 4-meter-diameter concrete "donut" in the visitor parking

The new Visitor Center entry wall, floor, front desk, and signage (Credit: NOIRLab/NSF/AURA/D. Salman)

lot. A new exterior sign was designed and placed near the Visitor Center entrance, and the wall immediately inside the entrance was replaced with a very large mural comprised of nighttime views of Kitt Peak. We completely rebuilt the admissions and gift shop area, doubled the number of cash registers to speed up check-in lines, replaced all the slat walls throughout the gift shop, and redesigned the check-in desk. We installed a PA and microphone system to make it easier for audience members to clearly hear our daytime and evening presentations.

A large new exhibit was designed and installed, introducing guests to the importance of maintaining dark skies everywhere. Several exhibits were installed describing Kitt Peak's role in training NASA astronauts during the Apollo program. The classroom in our Roll Off Roof observatory, which is heavily used by our nighttime programs and astrophotography workshop participants, received modern IT, power, monitors, computers, and Blu-ray players enabling far more dynamic presentations by staff than previously possible.

A popular activity for Kitt Peak visitors has been the safe viewing of the Sun through specially designed telescopes during daytime hours. Visitors were previously required to walk a quarter of a mile in each direction to reach the small dome on the mountaintop housing these three special telescopes. For mobility-challenged and elderly guests, this represented a barrier. With some ingenious engineering work by one of our docents, we redeveloped a storage shed located only 80 feet from the Visitor Center entrance into a unique split-function observatory. The south room within this building now houses the three solar telescopes, and the north room houses a donated 12.5-inch imaging telescope to support our popular Overnight Telescope Observing Programs. We call this repurposed building SOLARIO, for SOLAR & Imaging Observatory.

Five new outdoor exhibits were designed and installed.

New outdoor exhibits located at the western overlook where the sunset viewing portion of our nighttime programs occurs (Credit: NOIRLab/NSF/AURA/W. Buckingham)

Relatively near to the Visitor Center, the first exhibit introduces our audiences to the WIYN 3.5m Telescope. Located farther up a small hill, the second exhibit describes the SARA-North Telescope. The other three exhibits provide an introduction to radio astronomy, identify all the observatories on the southwest ridge, and discuss why the daytime sky is blue and sunsets are red. The pathway that all five exhibits are located along is the most heavily utilized pedestrian pathway at the observatory.

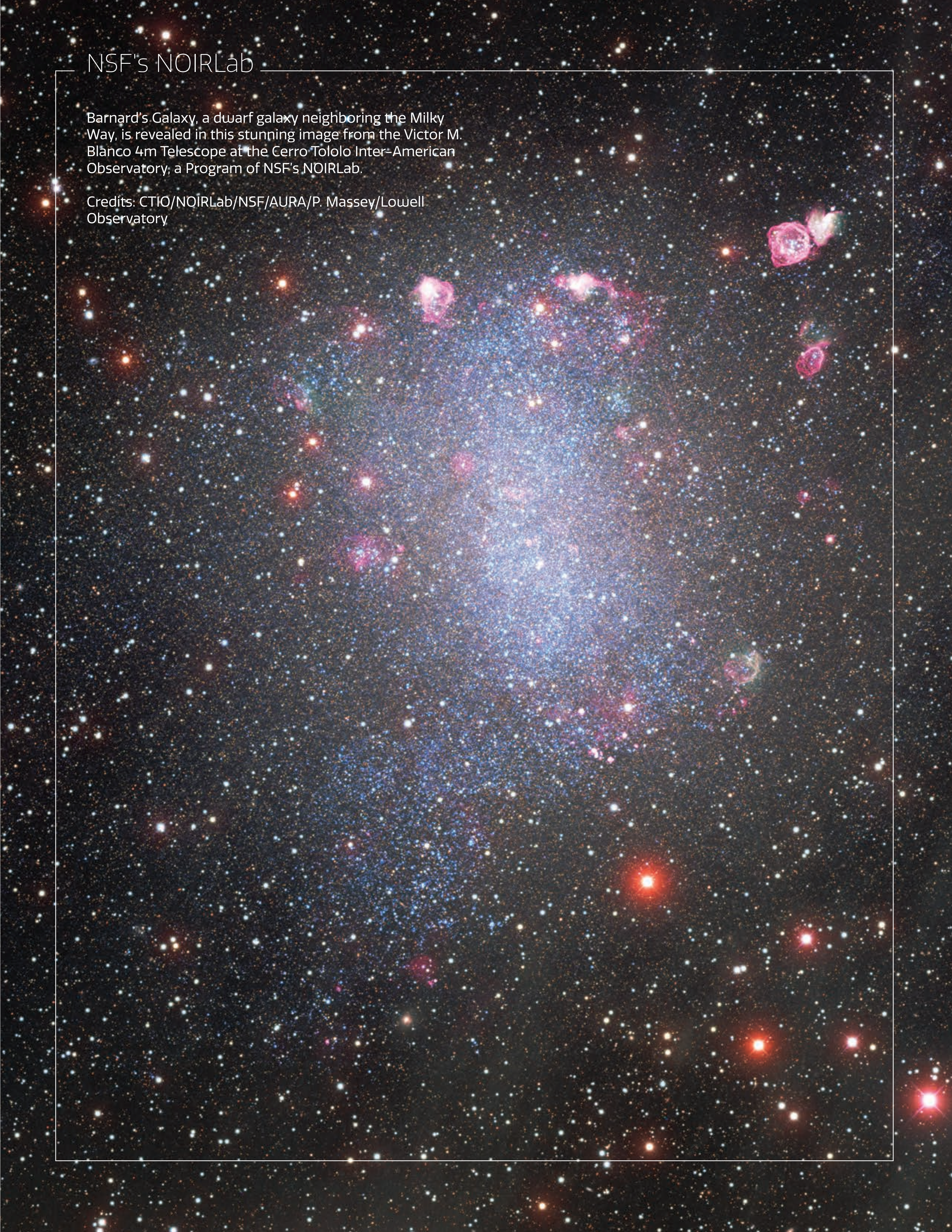
While all these improvements were being designed, constructed, and installed, we developed the plan to preserve the McMath-Pierce Solar Telescope after its retirement by the National Solar Observatory at the end of December 2017. Originally built in 1962 as the world's largest solar observatory, the McMath-Pierce remains in solid shape and has a number of rooms and areas that ceased to be actively used well before its formal retirement. Most of these areas lie underground and include former photographic dark rooms, a large machine shop, electronics and optical shops, photographic plate storage, and offices. It was the realization that nearly all of these spaces were no longer being used by the few researchers still observing with the McMath-Pierce that was the driver behind the Visitor Center–developed concept to convert the facility into a world-class astronomy outreach center. The National Science Foundation is the major funder of this initiative.

Although most of the rooms are too small to function in this new role, when common interior walls are removed during major reconstruction starting later this year, we will gain areas large enough for a planetarium, several immersive exhibits areas, and a Science On a Sphere theater. We plan to continue operating the three large solar telescopes, or heliostats, located atop the facility to provide both daytime and evening celestial viewing for visitors.

Once completed, the new facility within the McMath-Pierce will be known as Windows on the Universe Center for Astronomy Outreach. This represents the next big leap for the Kitt Peak Visitor Center in its capacity to welcome, engage, and provide enjoyable learning experiences for visitors. It will enable us to broaden our story to include the work and discoveries from ground-based telescopes around the world now operated or being developed by the National Science Foundation. Visitors will learn a more comprehensive story of modern astronomy than we can presently provide. We will also have the capability to create and share dynamic astronomy images and visualizations with hundreds of museums, bringing the excitement of modern astronomy to entirely new audiences.

Visitor Center docents and staff familiarize themselves with the new SOLARIO facility (Credit: NOIRLab/NSF/AURA/D. Salman)

The August Milky Way arches over the McMath-Pierce solar observatory (Credit: NOIRLab/NSF/AURA/D. Salman)



Barnard's Galaxy, a dwarf galaxy neighboring the Milky Way, is revealed in this stunning image from the Victor M. Blanco 4m Telescope at the Cerro Tololo Inter-American Observatory, a Program of NSF's NOIRLab.

Credits: CTIO/NOIRLab/NSF/AURA/P. Massey/Lowell Observatory

Rubin Observatory

The LSST Operations team is now the Vera C. Rubin Observatory Operations team following the announcement of the new name in January at the winter AAS meeting in Hawaiʻi. Rubin Observatory, partially operated by NSF's NOIRLab, will execute the Legacy Survey of Space and Time (LSST) over a 10-year period beginning in late 2022. The Operations team delivered a comprehensive preliminary Operations Plan to NSF and DOE for review by a joint agency external panel of experts. The review was successful and the Rubin team received helpful input for improvements. A detailed Operations Plan will be submitted for review within a year from now and will be closely followed by the Operations funding proposal for the full survey.

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Impact of Satellite Constellations

Tony Tyson

The Vera C. Rubin Observatory science community is concerned about the increasing deployment of communications satellite constellations which, if unchecked, could jeopardize the discoveries anticipated from Rubin Observatory when science operations begin in 2022. Because Rubin Observatory is uniquely impacted by these satellite constellations, its science team is taking an active role in pursuing mitigation strategies to reduce the impact of the satellites on Rubin Observatory science.

The Rubin Observatory is nearing completion, and its Legacy Survey of Space and Time (LSST) will soon offer an unprecedented, detailed view of the changing sky. Starting in late 2022, Rubin Observatory will employ the 8.4-meter Simonyi Survey Telescope and the 3200 megapixel LSST Camera to capture about 1,000 images of the sky, every night, for ten years. Each image will cover a 9.6-square-degree field of view, or about 40 times the area of the full Moon. Because of the telescope's large light-collecting area, each nominal 30-second exposure will reveal distant objects that are about 20 million times fainter than those visible with the unaided eye. This combination of large light-collecting area and field of view on the sky is unprecedented in the history of optical astronomy.

LSST survey images will contain data for about 20 billion galaxies and a similar number of stars and will be used for investigations ranging from cosmological studies of the Universe to searches for potentially dangerous Earth-impacting asteroids. However, the revolutionary discoveries anticipated from the Rubin Observatory LSST could be significantly degraded by the fast deployment of Low Earth Orbiting (LEO) communications satellite constellations.

In late May 2019, SpaceX launched the first 60 of its planned Starlink constellation of 42,000 communications satellites to LEO orbits at altitudes of about 550 km. Since then, SpaceX has launched several more groups of 60 satellites and plans to launch a similar group every 2–3 weeks in the near future. Other companies, including Amazon and Samsung, have also entered the race, and the number of satellites launched may exceed 50,000 over the next decade. The negative impact of these satellites on optical astronomy depends on the number and brightness of satellites. According to Patrick Seitzer, an astronomer at the University of Michigan who studies orbital debris, "Satellites launched by SpaceX and others will be brighter than 99 percent of the population of objects of all types currently in Earth orbit."

Rubin Observatory is an extreme case for the sensitivity of astronomical observations to satellite constellations because of its unprecedented ability to repeatedly monitor the sky widely and deeply. During the nominal 30-second visit to a sky patch, SpaceX satellites in LEO orbits typically

> “The number of satellites launched may exceed 50,000 over the next decade.”

move about 15 degrees across the sky (about four times the diameter of Rubin Observatory’s field of view), and they are visible a few hours after sunset and before sunrise. With 42,000 satellites orbiting Earth, well over a thousand satellites would be visible above horizon, and it would be difficult to find a circle of 9.6 square degrees anywhere on the sky that does not contain satellite streaks. Simulations of the LSST observing cadence and the full SpaceX satellite constellation show that as many as 30% of all LSST images would contain at least one satellite trail. Measurements of the brightness of the current LEO satellites in their final orbits indicate that these trails would cause residual artifacts in the reduced data. If these LEO satellites can be darkened to 7th magnitude, then a new instrument signature removal algorithm can remove the residual artifacts. The bright main satellite trail would still be present, potentially creating systematics at low surface brightness. This is a challenge for science data analysis, adding potentially significant effort. LEO satellites at 550 km are slightly out of focus—given the large 8.4m mirror, this effect makes the trail significantly wider and lessens the peak surface brightness.

Strategies to lessen the impact of satellite constellations are currently being studied. Below are two mitigation plans currently in discussion:

Taking multiple exposures: When the nominal LSST visit time of 30 seconds is split into two back-to-back exposures of 15 seconds, one of the exposures with a satellite trail in it can be rejected if the other exposure didn’t contain any satellite trails. This mitigation scenario would cost 8% of LSST observing time to accommodate the additional read-out time and shutter motion and assumes a negligible cost due to rejected pixels. This only mitigates in certain science cases.

Decreasing satellite brightness: If satellites were darkened to 7th magnitude, they would be far below saturation in LSST images. In this case, it is likely that only small fractions of pixels in the affected images—probably in the 1% to 10% range—would be rendered scientifically useless. If this estimate proves correct, the net fraction of lost LSST pixels would be in the range of 0.3% –3%, which corresponds to several months of observing time.

Nevertheless, of additional concern are various systematic effects that do not simply scale with the number of lost pixels—in other words, the effect these mitigation strategies would have on the science cases for which LSST was designed. For example, the LSST ability to detect asteroids approaching from directions interior to the Earth’s orbit would be severely impacted because those directions are visible only during twilight when LEO satellites are brightest—nearly every LSST image taken at this time would be affected by at least one satellite trail. Precision cosmological studies are another example; they are very sensitive to small systematic effects and might suffer from artifacts due to the removal or masking of elongated rectangular regions around the satellite tracks. At the low surface brightness of many LSST science programs, the trail is several hundred pixels wide.

The Rubin Observatory team is working closely with SpaceX engineers to jointly find ways to lessen the impact of the satellite trails. Efforts such as designing fainter satellites, improving image processing algorithms so they are capable of dealing with satellite streaks at the exquisite fidelity required for LSST science, and improving scheduling algorithms based on knowledge of the satellites’ orbital motions may provide additional mitigation strategies. Current efforts are centered on satellite darkening; one satellite currently in orbit, “DarkSat,” has been partially darkened as an initial experiment and appears 6.1 g magnitude. Further experiments, such as “VisorSat,” are planned, and results will be assessed via ground-based calibrated imaging in the months ahead. Once sufficient data are collected and analyzed, the Rubin Observatory team will share the results with the rest of the astronomical community and the public.

For more details, please see Document-33805 (*https://docushare.lsstcorp.org/docushare/dsweb/Get/Document-33805*).

The interacting galaxy pair NGC 5394/5 obtained with NOIRLab's Gemini North 8-meter telescope on Maunakea in Hawai'i using the Gemini Multi-Object Spectrograph in imaging mode. This four-color composite image has a total exposure time of 42 minutes. Read the full image release (*https://nationalastro.org/news/a-galactic-dance/*). (Credit: International Gemini Observatory/NOIRLab/NSF/AURA)

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MathMovesU Event

Credit: NOIRLab/NSF/AURA/R. Sparks

Robert T. Sparks

NSF's NOIRLab partnered with Raytheon and the University of Arizona Office of Early Academic Outreach for MathMovesU day on 10 February 2020. Over 200 middle school students from schools around Tucson built their own Galileoscope and learned about careers in STEM fields.

Since the partnership began in 2010, NOAO (and now NOIRLab) has partnered with Raytheon to build Galileoscopes every year (except 2019 when Galileoscopes were temporarily unavailable and MathMovesU built Snap Circuits® as a temporary replacement). Over 3,200 students have built Galileoscopes over the course of this partnership. Raytheon recently hired its first engineer who built a Galileoscope at a previous MathMovesU event.

The Galileoscope was created for the International Year of Astronomy in 2009 to commemorate 400 years since Galileo embarked on his historic observations. Over 250,000 Galileoscopes have been distributed worldwide. It is a small, low-cost telescope designed to have a similar size and magnification to telescopes used by Galileo but with a modern optical design. The telescope was designed by a team of engineers, astronomers, and educators, with NOAO staff playing a key role in the design and in the production of educational materials to accompany the Galileoscope. The Galileoscope kit comes with two eyepieces: a modern Plössl eyepiece (yielding a magnification of 25x) and a Galilean-style eyepiece. The eyepieces can be combined to create a Barlow lens doubling the magnification of the telescope to 50x.

At MathMovesU day, NOIRLab staff led the Galileoscope build while members of Raytheon's Leadership Development program (called LDPs) assisted students with building telescopes and talked with them about careers in STEM fields. The LDPs are early-career engineers at

Credit: NOIRLab/NSF/AURA/R. Sparks

Raytheon learning the skills needed to succeed in their careers. The LDPs learn how to build Galileoscopes at a workshop conducted by NOIRLab staff before the MathMovesU event.

During the build, students learn about the Six Sigma process for quality control. This process is used by companies worldwide to detect and remove defects before the final product. Students have several checkpoints where they must inspect the Galileoscope before continuing the build. Students must sign off that they did the procedure correctly, and the LDP must also perform an inspection and verify that the student's work is correct.

The Galileoscope can be used to recreate Galileo's observations of the Moon, Venus, Jupiter, Saturn, and many other objects in the night sky. Each student takes home their Galileoscope and a tripod to continue their exploration of the night sky.

> “Over 200 middle school students from schools around Tucson built their own Galileoscope.”

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Figure 1: Gemini Director Jennifer Lotz describes constellations and shares their stories with Haa'heo elementary students. (Credit: NOIRLab/NSF/AURA/J. Pollard)

Journey Through the Universe Celebrates 16 Years (and Counting!)

Janice Harvey

The Journey Through the Universe (Journey) program celebrated 16 continuous years of astronomy education in Hawaiʻi in March of this year! With the support of community businesses and over 60 local and national astronomy professionals, NOIRLab's flagship outreach program, led by the Communications, Education & Engagement (CEE)-Hawaiʻi team, continues to inspire students to reach for the stars. This year, Journey educators visited 250 classrooms and held StarLab sessions in 10 Journey kindergarten classrooms. In addition, ten career panels at Hawaiʻi Island high schools and a presentation for the public on the future decade of astronomical discoveries were held at the University of Hawaiʻi at Hilo. A two-day teacher workshop with a focus on the Next Generation Science Standards (NGSS) is planned for the fall of 2020 (pending COVID-19 restrictions).

Journey Through the Universe has flourished on Hawaiʻi Island for the last 16 years thanks to the commitment of the Hawaiʻi Department of Education, the support of the local business community, and the contributions of our many volunteer astronomy educators and ambassadors. The program has expanded over time from one week of classroom visits to a year-long program. Although the majority of the classroom visits are still consolidated into one week, astronomy educators continue to visit classrooms throughout the year.

During Journey week, 2–6 March 2020, over 60 astronomy educators shared their passion for astronomy with over 6,000 local students of all ages. Thirteen schools in the Hilo-Waiākea complex area, four schools in North

Figure 2: Gemini astronomer Siyi Xu leads an activity on the relative distance of our planets with a class from Walakeawaena Elementary School. (Credit: NOIRLab/NSF/AURA/J. Pollard)

> “
>
> encourage our students to reach for the stars.
>
> ”

Hawai‘i Island, and, for the first time, classrooms in Maui (part of a partnership with the National Solar Observatory) were part of the Journey through the Universe program in 2020. To prepare for these visits, astronomy educators attended an educational workshop with tested activities and lessons and a special guest appearance by the school district superintendent Esther Kanehailua.

The superintendent stated: “Because Journey has been around for 16 years we can speak of its success, and because of the astronomy educators continuing to partner with us, we can grow these STEM opportunities for students. Journey Through the Universe has become the inspiration and template for growing many of our STEM/NGSS programs. The NGSS framework is to act as the foundation for science education standards while describing a vision of what it means to be proficient in science. It emphasizes the importance of the practices of science where the content becomes a vehicle for teaching the process of science.”

NSF’s NOIRLab takes very seriously our role as a member of local Hawai‘i communities, specifically their education and outreach needs. For more information on the Journey Through the Universe program, visit *www.gemini.edu/journey*.

Note: Participation numbers referenced in this article reflect several cancellations by astronomy educators due to COVID-19. Originally over 300 classroom visits were scheduled, but over 50 were cancelled due to the early stages of the COVID-19 pandemic.

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Stay-at-Home Education and Engagement
with NOIRLab

Constance E. Walker, Carolina Vargas, Peter Michaud

Screen shot from the first episode of Science@Home where students made Pocket Solar Systems in an activity led by Rob Sparks in Tucson.

Owing to ongoing concerns about COVID-19, all public, in-person NOIRLab engagement activities have been canceled or postponed until social distancing restrictions are no longer required. In response to the pandemic and the resulting challenges for parents, teachers, and students, NOIRLab's Communications, Education and Engagement (CEE) group has initiated a Virtual Programming initiative with a range of resources aimed at stay-at-home learners and the interested public. Planned programming ranges from live video events to pre-recorded video and social media content highlighting NOIRLab's people, science, and technology. It is anticipated that virtual learning will have

an expanded and permanent place in our education and engagement programming long after the COVID-19 pandemic.

Recently, families of NOIRLab staff participated in a pilot project called Science@Home. Participants in the first session held in early April enjoyed an activity called Solar System in Your Pocket followed by a session on becoming a citizen scientist by taking night sky brightness measurements with the Globe at Night (*www.globeatnight.org*) application. Additional Science@Home topics covered Moon phases and making a home-made gravity well. Currently, with schools out for the Tucson summer, Science@Home is on hiatus and expected to evolve into a program based on virtual Project ASTRO programming.

Another live NOIRLab program stems from the long-running Live from Gemini (*www.gemini.edu/node/132*) video "field trips." Versions are offered in English (Live from NOIRLab @ Gemini) and Spanish (En Vivo desde NOIRLab). During these programs, students (K-12 through Astro 101) and public participants are introduced to the operation of a modern astronomical observatory, the technology that makes our research possible, and highlights from exciting recent discoveries. Each program includes a guest scientist or other staff who share their work in research or technology. Programs are archived on the NOIRLab YouTube channel at *www.youtube.com/channel/UC6doHJLYMtAbJIEIQDB4Bdw*

Of course, NOIRLab social media (*www.facebook.com/NOIRLabAstro/photos*) is an important component of virtual learning and engagement, and the CEE team is developing a minimum of two posts per week in Spanish and English that engage audiences in NOIRLab science, technology, people, and history. Also, check out recent "What's Up in the Sky" Facebook video posts (*www.facebook.com/pg/NOIRLabAstro/videos*). Additionally, in Hawai'i, the MKO@Home (*www.hawaii.edu/news/2020/04/06/maunakea-observatories-at-home/*) project is a joint effort by Gemini and all of the Maunakea Observatories. MKO@Home delivers a wide variety of weekly videos featuring astronomy-related activities, demonstrations, and interviews designed to encourage K-12 students and families to explore the Universe from home.

Watch NOIRLab social media pages (*www.facebook.com/NOIRLabAstro*) for details on upcoming programs for your families and friends!

The international Gemini Observatory composite color image of the planetary nebula CVMP 1 imaged by the Gemini Multi-Object Spectrograph on the Gemini South telescope on Cerro Pachón in Chile.

Credit: The international Gemini Observatory/
NOIRLab/NSF/AURA

Discovering Our Universe Together

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