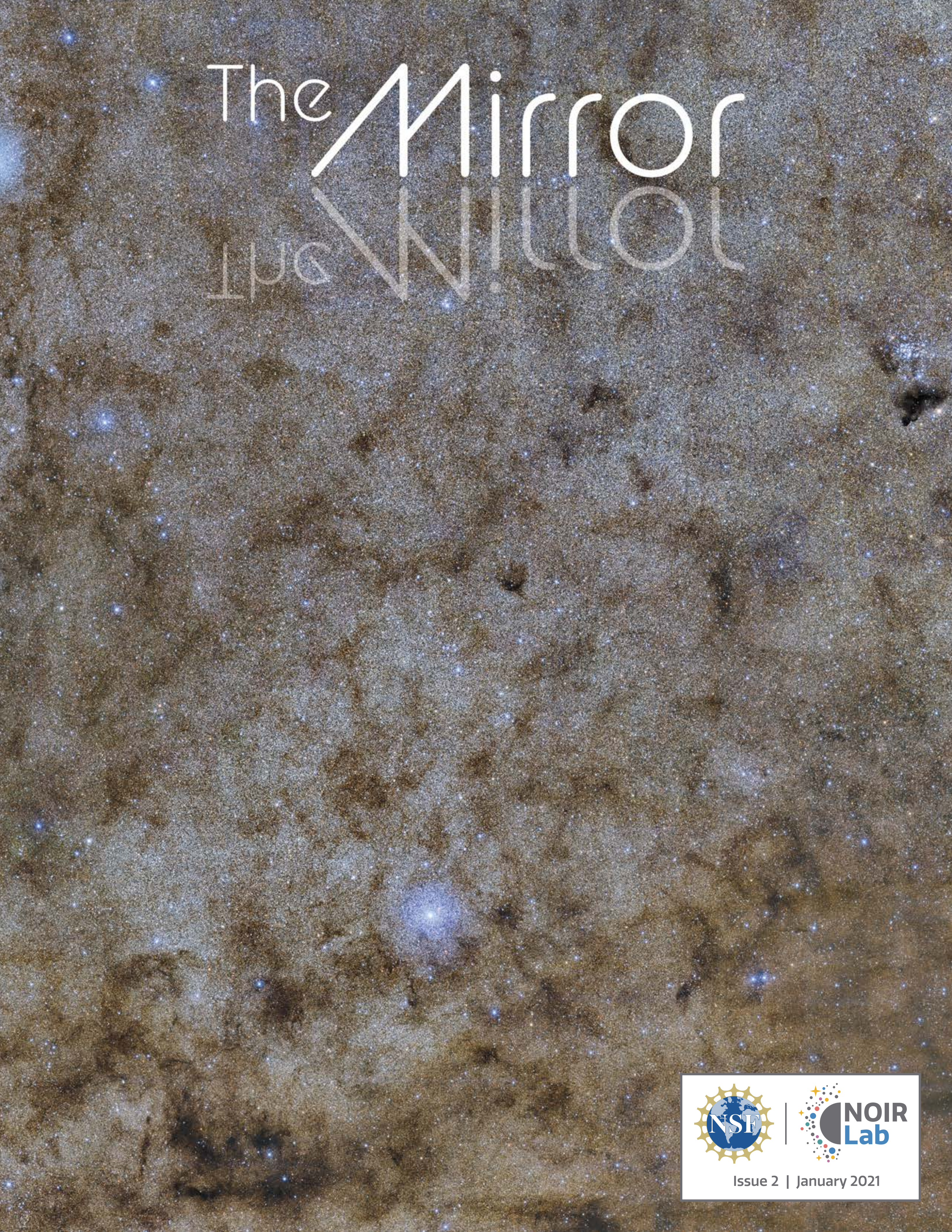
The Mirror



Issue 2 | January 2021

NSF's NOIRLab

This striking image from NOIRLab's Kitt Peak National Observatory (KPNO) presents a portrait of the irregular galaxy IC 10, a disorderly starburst galaxy close to the Milky Way. IC 10 lies around 2 million light-years from Earth in the direction of the constellation of Cassiopeia.

Credit: KPNO/NOIRLab/NSF/AURA

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Image processing: T. Rector (University of Alaska Anchorage)/M. Zamani/D. de Martin

THE MIRROR

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On the Cover

This color-composite shows a main part of the new Blanco DECam Bulge Survey of 250 million stars in our galaxy's bulge. The 4 x 2 degrees excerpt can be explored in all its whopping 50,000 x 25,000 pixels in a zoomable version that accompanies the press release. More details can also be found in the article on this work starting on page 56 of this issue. Credit: CTIO/NOIRLab/DOE/NSF/AURA

Image processing: UM-Dearborn/W. Clarkson/STScI, C. Johnson/UCLA, and M. Rich, University of Alaska Anchorage/T. Rector, M. Zamani, D. de Martin.

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A 5-light-year-long section of the western wall in the Carina Nebula, as observed with adaptive optics on the Gemini South telescope.

Credit: international Gemini Observatory/NOIRLab/NSF/AURA

Acknowledgement: PI: P. Hartigan (Rice University)

Image processing: P. Hartigan (Rice University), T. Rector (University of Alaska Anchorage), M. Zamani & D. de Martin

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Director's Corner

Patrick McCarthy

This second issue of *The Mirror* marks the end of the first year of the full NOIRLab—the unification of NSF's nighttime optical/infrared astronomy facilities in a single organization. It has not been quite the year that we planned, but we are not alone in our experience—people around the world, and all of our readers, are wrestling with the same challenges we face.

This edition of *The Mirror* reminds us that the scientific community is still going strong, people still have many clever ideas, and great science is still being done with our facilities, with new data, and with data that has had time to mature.

One of society's challenges, and a key part of our mission, is ensuring that the *best ideas* are recognized irrespective of the particulars of the person or persons who generate them. In the *Perspectives* section of this issue, two scientists share their thoughts on how we can improve our proposal review process and participation in science from people of all walks and all institutions. Their observations and recommendations are based on *data*—on methods tested at other institutions and on the power of big data to level the playing field and empower people. We are building our next generation of tools and processes with these ideas in mind, but there is more that we can, and will, do. This issue also responds to our community's interest in learning more about where their data come from: Jacelle Ramon-Sauberon shares information about the Tohono O'odham Nation, where Kitt Peak National Observatory is located.

The breadth of the science highlights in this issue is impressive. They range from uncovering the population of short gamma ray bursts at high redshifts, to observing recoiling black holes, to the discovery of low-mass dwarf stars in our own solar neighborhood, to searches for asteroids tidally captured by Venus. These ideas are backed by equally clever technology—both hardware and software—and the power of public engagement in scientific research. Adaptive optics enables dissection of dense star clusters while visible-light speckle interferometry allows our telescopes to capture images with resolution rivaling that of the *Hubble Space Telescope*. Some of the science detailed here requires deep exposures with our largest apertures; others use our smallest telescopes—and pass the light through a diffuser to allow ultra-precise measurement. Sophisticated software turns the record of photon arrival times and angles ultimately into images with brightness, color, and motion.

The hardware and software do not come from thin air—talented and dedicated people create, maintain, and operate them knowing that they too are a vital part of a larger scientific enterprise. As we work from home, it is harder to experience that sense of community between the observatories and our users, but this issue of *The Mirror* shows that it is still strong. As we return to the mountaintops and laboratories, we feel a sense of reconnecting with our world, with our peers, with the sky. During this period of remote working, our team has kept in close contact with the scientific users of our facilities, with students and educators adapting to the new and challenging circumstances, and with astronomy enthusiasts around the world. Good evidence of this are the ongoing citizen-science projects that harness the public's fascination with astronomy to drive important discoveries. The exciting science illustrated in *The Mirror* shows that while many of us are working remotely, we are still working *together* to advance our understanding of the Universe.

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The Formation Sites of Massive Young Star Clusters

Morten Andersen (NOIRLab)

Star clusters are central to our understanding of cosmic history. They are the formation sites of a large fraction, if not most, of the stars in the Universe. The surviving bound clusters allow us to trace the dynamical and chemical enrichment histories of galaxies, including the Milky Way. Moreover, because of their luminosities, they can be observed in galaxies well beyond the Local Group. Yet despite their importance, surprisingly little is known about the detailed formation of star clusters and their early evolution. This is particularly true for massive clusters (those ~ $10^4\ M_\odot$ and above).

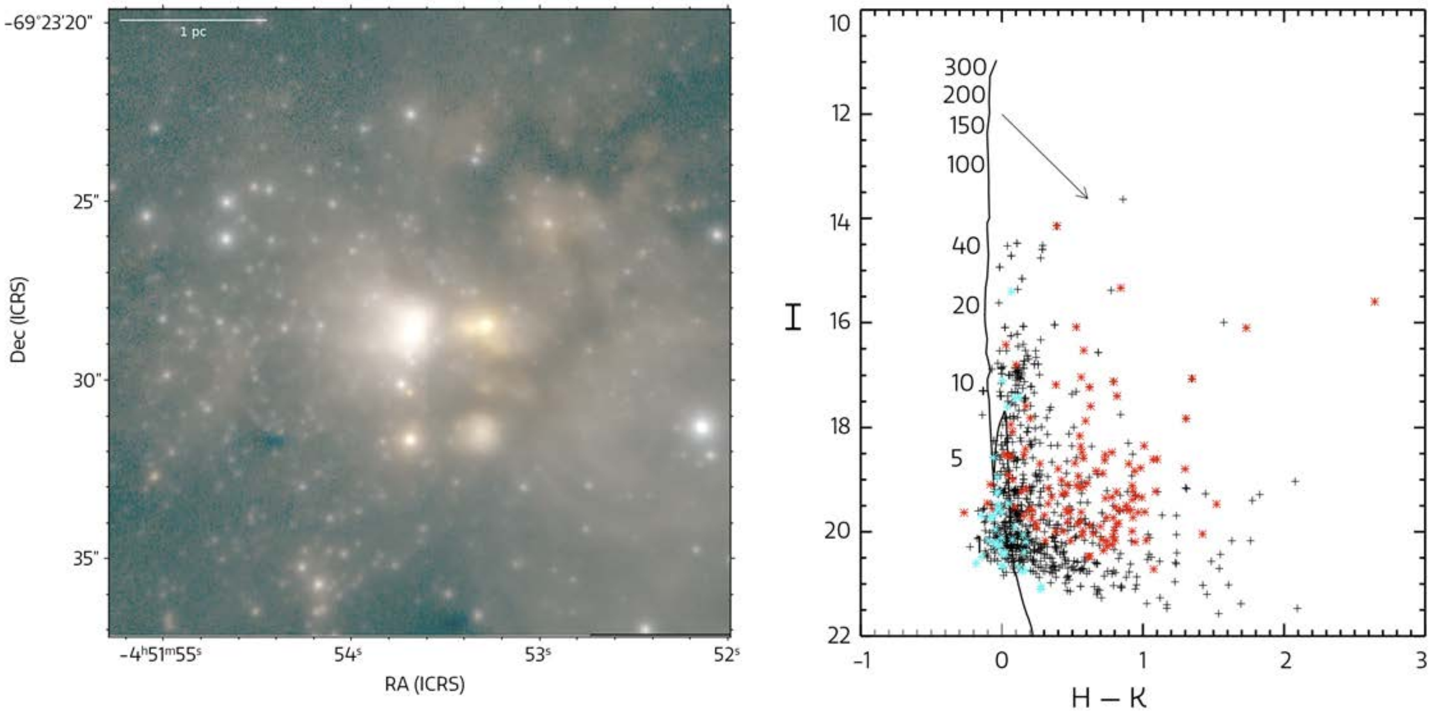
Part of the reason for our limited knowledge has been the lack of newly forming massive star cluster candidates. They are difficult to find because massive clusters are much less common than lower-mass star-forming regions; statistically, this means they are relatively more distant. They are also expected to be associated with large amounts of molecular gas and obscuring dust, making them difficult to detect optically. Near-infrared observations help, but it is hard to identify the youngest regions without broader wavelength coverage. A different approach is to search for signs of infall onto molecular clumps and/or regions where the embedded newly formed stars are heating the dust and gas still associated with the cluster.

Surveys at millimeter and far-infrared wavelengths have been successful in identifying regions that could be forming massive clusters (e.g., [1], [2]) in the Milky Way and the Magellanic Clouds. However, little is directly known about the stellar content from those wavelengths. Instead one has to turn to the near-infrared for the identified clusters. Further, owing to the distance of the massive star-forming regions, one needs both good sensitivity and high spatial resolution to reach the lowest possible stellar masses within the clusters.

One particularly exciting region discovered in the Large Magellanic Cloud (LMC) is the brightest far-infrared source in the HERITAGE survey [3] conducted with the *Herschel Space Observatory*. This bright source lies within the LMC's N79 star-forming complex, and we refer to it here as H72.97-69.39. Estimating the star formation rate in this region from other infrared-identified young stellar clusters in the N79 complex suggests that the rate has increased over the last few million years. Further, H72.97-69.39 may be an analogue, in the early stages of formation, of the well-known, extremely massive R136 cluster at the center of the 30 Doradus region [2]. However, the Herschel data do not have the spatial resolution to resolve structure below ~ 1 parsec in the LMC, and this is insufficient to resolve the dense inner regions of massive star clusters.

The multi-conjugate adaptive optics system at Gemini South, known as GeMS, coupled with the near-infrared Gemini South Adaptive Optics Imager (GSAOI), are well suited for resolving the inner structure of star clusters at the distance of the LMC. With this system, we can probe the nature of this exciting system, potentially revealing a massive star cluster in the making. The Figure shows the region around H72.97-69.39 as seen with GeMS/GSAOI in the H and K_S bandpasses.

The color-magnitude diagram shows that the cluster is deeply embedded, with extinction measures in K_S of ~ 1.5 mag or more (> 15 mag of extinction in the V band). Based on our GeMS/GSAOI photometry, the total stellar mass for the cluster is at least $10^4\ M_\odot$ after extrapolating the high-mass



Left: The central part of the GeMS/GSAOI *H* and K_s band image of the forming cluster H72.97-69.39. The stretch is logarithmic to show a large dynamic range. *Right*: The *H–K* versus *H* color-magnitude diagram for H72.97-69.39. The red dots are stars within the field shown at left, the black points are all stars detected across the full ~ 90" GeMS/GSAOI field, and cyan shows stars in a control region well away from H72.97-69.39. The line is a 1-Myr isochrone from [5]. The reddening vector shows the effect of 10 magnitudes of visual extinction. The cluster is deeply embedded in the material from which it is forming, and there are indications of additional dust lanes that could be adding more material to the cluster.
(Credit: International Gemini Observatory/NOIRLab/NSF/AURA/M. Andersen)

data over the full mass function. However, as the large amount of extinction suggests, there is a substantial amount of molecular material still present within the cluster, providing the potential for further star formation. From the measured extinction and the additional dense gas detected by the Atacama Large Millimeter/submillimeter Array (ALMA) [4], we estimate that the total amount of molecular gas remaining is more than 5000 $M_\odot$.

Although not as massive as R136, H72.97-69.39 is a compelling case of a massive cluster caught at a very early stage of its life. In the coming years we expect to learn substantially more about this cluster through deep observations from space and the ground. Studying systems like this in detail requires a coordinated multi-facility effort. This includes high spatial resolution near-infrared imaging and spectroscopy to reveal the stellar content, far-infrared observations for the initial identification and current star formation, and data at millimeter wavelengths to probe the molecular gas still within these clusters, which provides the fuel for further growth.

References

[1] Barnes, P. J., et al. 2010, MNRAS, 402, 73
[2] Ochsendorf, B. B., et al. 2017, NatAs, 1, 784
[3] Seale, J. P., et al. 2014, AJ, 148, 124
[4] Nayak, O., et al. 2019, ApJ, 877, 135
[5] Tang, J., et al. 2014, MNRAS, 445, 4287

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Merging, Recoiling, or Slingshotting of Supermassive Black Holes in a Red Active Galactic Nucleus

Dohyeong Kim (Pusan National University)
& Myungshin Im (Seoul National University)

Simulations and observational studies suggest that massive spheroidal galaxies grow by hierarchical merging. Such galaxies harbor supermassive black holes (SMBHs) in their centers, and the fate of the SMBHs during major mergers remains an intriguing question. The expectation is that the SMBHs lose their angular momenta via interactions with stars and the interstellar medium and quickly come into close proximity of each other (e.g., [1]). Eventually, the SMBHs will coalesce and emit a burst of low-frequency gravitational waves (GWs). The identification of SMBHs on the verge of merging could help constrain models of the evolution of SMBH-galaxy scaling relations (e.g., [2]). Moreover, future GW missions aim to detect GW signals from SMBH mergers; identifying the fraction of binary SMBHs with close separations can help in predicting the detection rate for such missions.

However, observational studies have difficulty finding such multiple SMBH systems. There are examples of active galactic nuclei (AGNs)—bright compact objects that are powered by accretion of matter by SMBHs in the centers of galaxies—with separations of about a kiloparsec or less, but only a

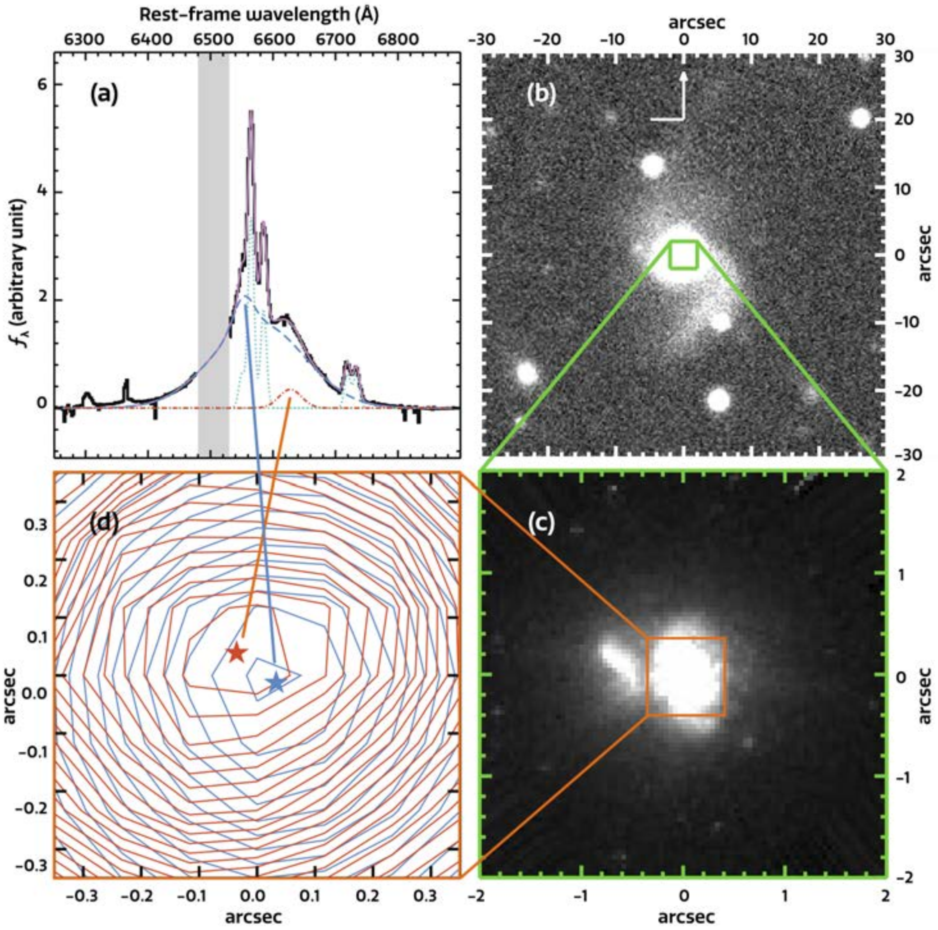

Figure 1. (a) The complex Hα line profile of 1659+1834. The black line shows the observed GMOS spectrum, and the purple line indicates the best fitting multi-component model. Blue and red curves trace the primary and secondary broad components, respectively; the cyan curve shows the narrow line component. (b) Dark Energy Camera Legacy Survey (DECaLS; [10]) r-band image of the host galaxy, showing extended features interpreted as tidal tails resulting from a galaxy merger. (c) HST/WFPC2 F814W image showing the central structure of 1659+1834. (d) Derived spatial distributions of the flux from the two broad Hα components; the spatial offset between the centers is significant. (Adapted from [8], with permission)

handful of such systems have been discovered (e.g., NGC 6240 [3]). Models predict that gas-rich galaxy mergers evolve through a highly obscured phase during which the AGN appears very red until the final SMBH merger occurs [4]. Thus, the best place to look for SMBHs in the process of merging may be within the red AGNs of morphologically irregular galaxies.

We have been studying red AGNs to test the merger-driven SMBH evolution scenario, finding supporting evidence such as red colors originating from dust extinction [5], [6] and high accretion rates associated with red AGNs [6], [7]. Among the sources we have studied [8] is the intriguing red AGN 2MASS J165939.7+183436 (hereafter 1659+1834) at $z = 0.170$. This object has double-peaked broad emission lines (BELs) separated by ~ 3000 km s^{-1}, and the host galaxy shows clear signs of merging (Figure 1b,c). If there is also a spatial separation between the two BEL components, then this would indicate separate BEL regions around two different SMBHs. Using the measured luminosities and line widths of the two Hα BELs and the relation from [9], we estimate primary and secondary black hole masses of $10^{8.9\pm0.1}$ and $10^{7.1\pm0.1}$ $M_{\odot}$.

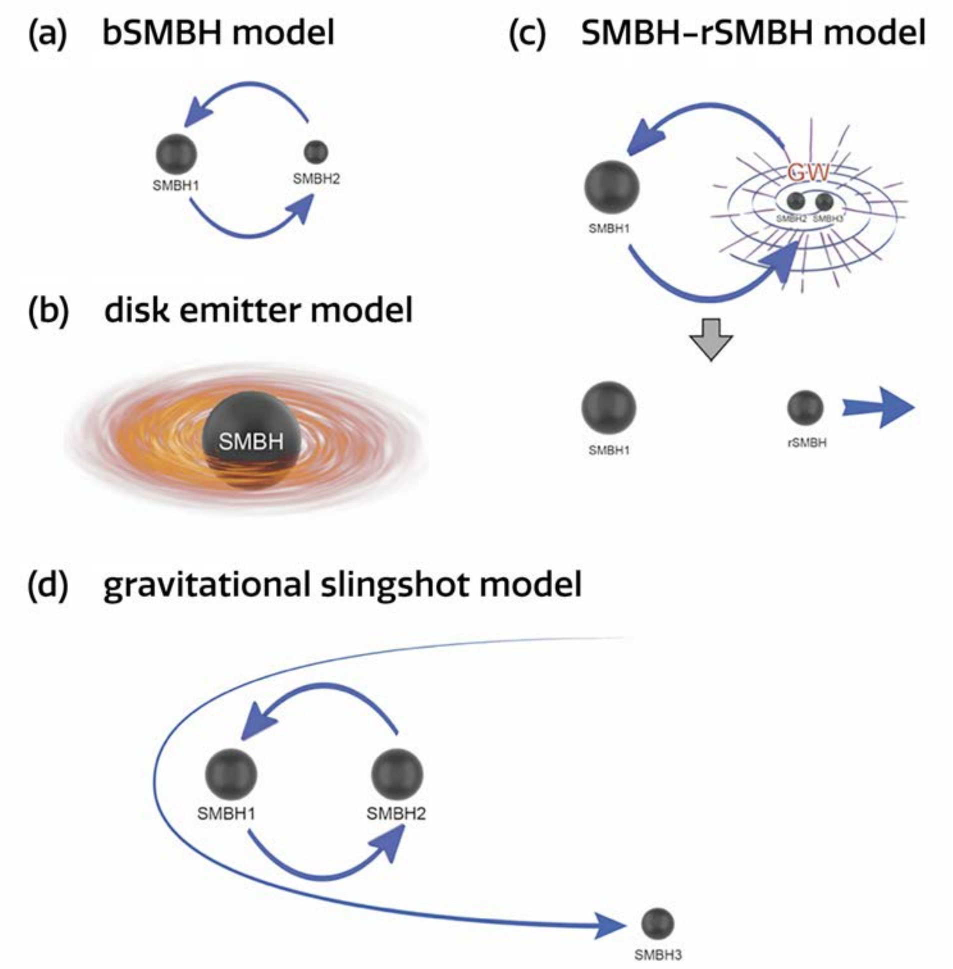

Figure 2. Models for the doubled-peaked AGN 1659+1834. (a) A stable binary SMBH system would produce lower velocities (or a much smaller separation) than observed. (b) A hot accretion disk around a central SMBH can produce double-peaked broad emission, but the size would be much smaller than the estimated spatial offset. (c) A recoiling SMBH, in which a merger of two SMBHs releases energy in GWs and causes the newly merged SMBH to recoil. (d) Gravitational slingshot: a binary SMBH gravitationally ejects the smaller intruder SMBH3 at a speed of thousands of km s^{-1}. Models (c) and (d) are consistent with the data. (From [8], with permission)

We observed 1659+1834 at Gemini North using the GMOS Integral Field Unit (IFU) and modeled the spatially resolved spectra with two broad components and one narrow-line component (Figure 1a). The narrow component was found to be spatially coincident with the dominant (or primary) broad component. However, the centroid of the flux associated with the secondary BEL component was offset by 0.085″ (Figure 1d), corresponding to a physical separation of 250 pc, with an estimated uncertainty range from 0.04″ to 0.15″. A variety of models were considered to explain the observed spatial and velocity offsets; the models are illustrated schematically in Figure 2.

Our analysis [8] found that a binary SMBH system in a stable orbit could not explain the observations, as the measured velocity offset of 3000 km s^{-1} is 10 times higher than would be expected even if the SMBHs were near the pericenter of an elliptical orbit. Likewise, double-peaked emission from a rapidly rotating disk around a single SMBH would produce a much smaller spatial separation. However, the third explanation—a recoiling SMBH—could reproduce the observed velocity and spatial offsets as long as the BEL region remains gravitationally bound to the recoiling SMBH. Finally, a 3-component gravitational slingshot scenario, involving a "small" SMBH system that approaches a binary SMBH and is ejected at high speed along with its BEL region, can also account for the observations.

Interestingly, both of the viable models for 1659+1834 involve three SMBHs. However, the interpretation depends critically on the size of the 250 pc spatial offset between the BEL components. We have pushed the limits of what can be done with the GMOS-N IFU with excellent natural seeing and by performing a careful analysis of the two observed BEL components. Further studies using adaptive optics, very-long baseline interferometry, and/or the *James Webb Space Telescope* are needed to confirm these results on this unusual system.

References

[1] Escala, A., et al. 2005, ApJ, 630, 152

[2] Kormendy, J. & Ho, L. C. 2013, ARA&A, 51, 511

[3] Komossa, S., et al. 2003, ApJL, 582, L15

[4] Blecha, L., et al. 2018, MNRAS, 478, 3056

[5] Kim, D. & Im, M. 2018, A&A, 610, A31

[6] Kim, D., et al. 2018, ApJS, 238, 37

[7] Kim, D., et al. 2015, ApJ, 812, 66

[8] Kim, D., et al. 2020, ApJ, 894, 126

[9] Greene, J. E. & Ho, L. C. 2007, ApJ, 670, 92

[10] Dey, A., et al. 2019, AJ, 157, 168

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Uncovering the Population of Short Gamma-Ray Bursts at $z > 1.5$

Kerry Paterson & Wen-fai Fong (Center for Interdisciplinary Exploration and Research in Astrophysics and Department of Physics and Astronomy, Northwestern University)

Short-duration gamma-ray bursts (SGRBs) are highly energetic, relativistic explosions with durations $T_{90} < 2$ s. Much work has been done to investigate the origin of these bursts. However, until a few years ago, there was only indirect evidence linking them to the mergers of binary neutron stars (BNS) or neutron star–black hole (NSBH) mergers (e.g., the lack of associated supernovae, host galaxy demographics, explosion environments, offsets from their host galaxies, and excess emission consistent with r-process kilonovae; see [1], [2], [3], and [4] for examples).

The 2017 discovery of the BNS merger GW170817 by LIGO/Virgo [5] and the associated short-duration GRB 170817A provided direct evidence that at least some SGRBs originate from BNS mergers. Although gravitational wave (GW) facilities continue to make ground-breaking discoveries of new BNS and NSBH mergers, the detection of these events in GWs is limited to the nearby Universe ($z < 0.05$). However, SGRBs themselves can be detected at cosmological distances, providing powerful probes of the BNS progenitor population, rates, and evolution to redshift $z \sim 2$. Thus, the combination of GWs and SGRBs allows the study of BNS mergers over the full history of the Universe.

Since 2004, the Neil Gehrels Swift Observatory [6] has discovered over 130 SGRBs [7]. Key to Swift's capabilities is its capacity to localize SGRBs to arcsecond precision, enabling multi-wavelength follow-up to catch their fading afterglow signals and identify the host galaxies. Although dedicated campaigns to characterize their host galaxies have led to secure redshift determinations for about a third of the detections, only ~ 5% of these bursts have confirmed redshifts of $z > 1$. These are particularly challenging to characterize. First, their afterglows are apparently fainter, typically $r > 24$ mag within hours of the burst, and often elude detection if not followed up with extremely sensitive facilities. Second, Swift is less sensitive to SGRBs at $z > 1$ owing to its detector characteristics. Finally, the redshift range of $1.3 < z < 2.5$ comprises the so-called redshift desert, in which it is challenging to determine redshifts for host galaxies because of their featureless optical spectra. Studies must resort to near-infrared wavelengths, but the available facilities having the required capabilities are very limited.

Using the rapid-response capabilities of Gemini North, we initiated imaging observations of the field of GRB 181123B a mere ~ 9 hrs after its detection by Swift. Combined with template observations at ~ 2.4 days, these images revealed a faint optical afterglow with $i \sim 25.1$ mag (Figure 1). This faint afterglow provided the necessary sub-arcsecond localization to identify the host galaxy of GRB 181123B. Using data from multiple large facilities including Gemini, Keck, and the MMT, we endeavored to determine the redshift of GRB181123B and study its host galaxy properties. Unlike most SGRB host galaxies discovered to date, the optical spectrum appeared featureless, suggesting a location in the redshift desert at $z > 1.3$. We therefore obtained a near-infrared spectrum with FLAMINGOS-2 mounted on Gemini South in Chile and identified a single emission line at 1.339 μm. Inferred to be Hβ, the detection gives a redshift of $z = 1.754 \pm 0.001$, in perfect agreement with the galaxy photometric redshift calculated using *grizYJHK* observations, as well as the absence of other emission lines in the observed spectra.

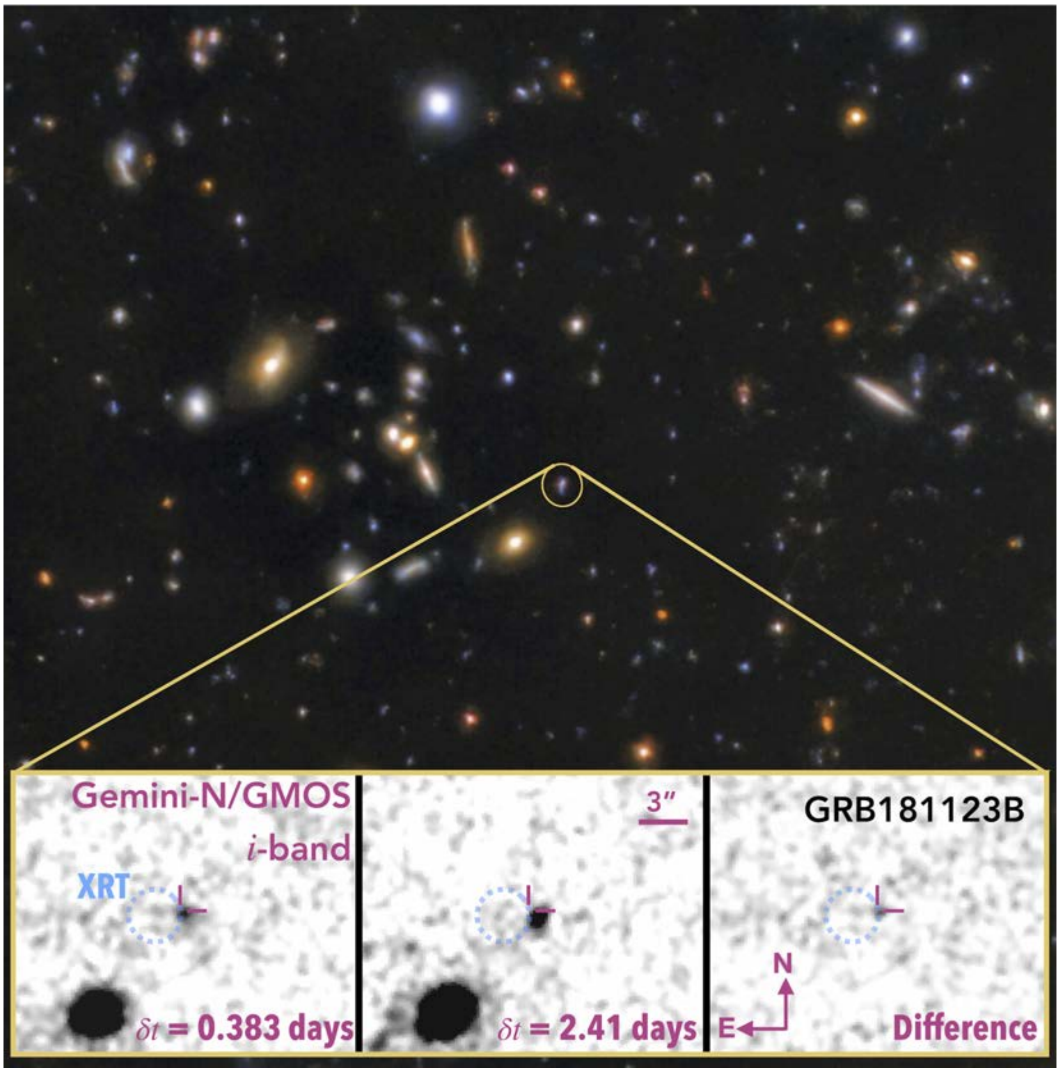

Figure 1. *Top*: Color-composite image of the field containing GRB181123B, with the host galaxy enclosed in the yellow circle. Inset: Detection of the optical afterglow using Gemini North/GMOS. In each image, the blue circle shows the X-ray position from Swift/XRT, while the pink crosshairs show the position of the afterglow. *Left*: Epoch 1 image taken ~ 9 hours after the initial burst. *Middle*: Epoch 2 image taken ~ 2 days later. *Right*: Difference image (epoch 1 minus epoch 2) showing the detection of the afterglow at the position of the cross hairs. (Adapted from [8], with permission)

The discovery of GRB 181123B at $z = 1.75$ adds to the very small, but growing, population of SGRBs with $z > 1$. GRB181123B is the second most distant SGRB with a secure redshift discovered by Swift to date and the most distant with an optical afterglow detection. Finding an SGRB at this redshift offers a unique opportunity to study these systems at a time when the Universe was only 3.8 billion years old (< 30% of its current age) and more rapidly forming stars than it is today. Modeling of the host galaxy revealed properties that are typical of other SGRB hosts, with an inferred stellar mass of $\sim 9 \times 10^9\ M_\odot$, age ~ 0.9 Gyr, and optical luminosity $\sim 0.9\ L^*$ (Figure 2). However, with a star formation rate just below the main sequence for galaxies at similar redshifts, we found that the host of GRB181123B is producing stars at a lower rate than its cosmic neighbors, perhaps transitioning to a quieter and less active phase in its life.

Motivated by the growing number of high-redshift SGRBs like our recent discovery, we explored the effects of incompleteness in the $z > 1.5$ SGRB population among the current Swift sample. We focused particularly on the effect on delay time distribution models (the delay time is the time it takes for binary stars to evolve to the BNS stage and then merge). The delay time distribution provides important clues on the formation channel of these BNS mergers (dynamical formation in globular clusters versus primordial binaries that were born and evolve as a pair), as well as their merger timescales, which are highly unconstrained by observations at present.

Our study found that SGRBs at $z > 1.5$ have comparatively large discriminating power between the models allowed (Figure 3). Specifically, the addition of a few bursts at

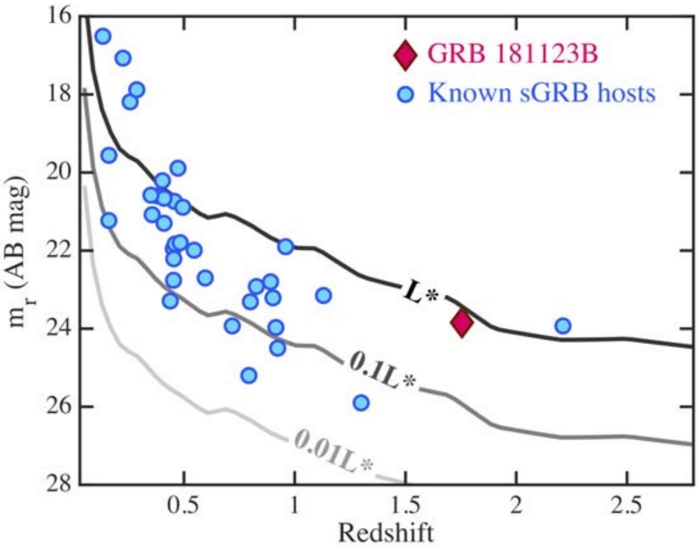

Figure 2. Apparent *r*-band magnitudes of the host galaxies of 34 SGRBs with known redshifts and optical measurements (blue circles). The high-redshift burst GRB181123B, discovered in our recent work, is indicated by the red diamond. The solid lines, corresponding to *L**, 0.1 *L**, and 0.01 *L**, show the effect of the evolving galaxy luminosity function. GRB181123B resides in a galaxy similar to others at the same redshift and in relatively uncharted territory for SGRBs. (Adapted from [8], with permission)

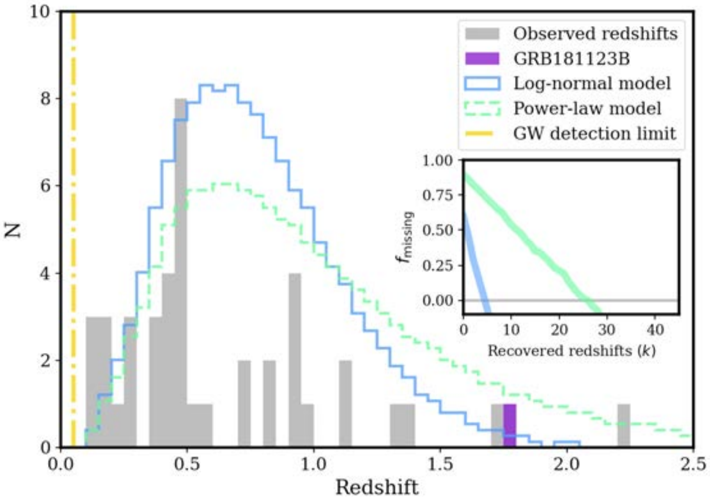

Figure 3. Observed SGRB distribution in redshift (solid histogram, with GRB181123B highlighted by the magenta bar) overlaid with predictions from two delay time distribution models from [9], one representing an example of a log-normal distribution (blue solid line) and the other an example of a power-law distribution (green dashed line). From the models we see the log-normal distribution peaks at lower redshifts, with very few SGRBs predicted at $z > 1.5$, while the power-law model predicts a larger number of SGRBs at higher redshifts. The inset shows the number of recovered (from the current Swift population) high-redshifts bursts ($z > 1.5$) it would take to rule out each model to 95% confidence (the horizontal gray line). With the current observed distribution, we see that the log-normal model is ruled out very quickly with the addition of a few recovered redshifts, while the power-law model is able to accommodate many more of the high-redshift bursts. (Adapted from [8], with permission)

$z > 1.5$ to the current Swift population could rule out log-normal delay time distribution models of BNS mergers to 95% confidence. In contrast, power-law delay time distribution models could accommodate 30 additional SGRBs at $z > 1.5$, in support of primordial formation channels. We also showed that about a third of the current Swift population could in fact originate at high redshifts ($z > 1$). Our findings are supported by complementary studies of GW170817 and observations of BNS systems in our own Galaxy. This motivates further efforts to uncover the full population of SGRBs at these high redshifts in order to properly constrain the underlying redshift distribution and probe the fundamental properties of BNS mergers. Our team will continue to use state-of-the-art facilities like Gemini to quantify the true fraction of SGRBs at these redshifts.

References

[1] Berger, E. 2014, ARA&A, 52, 43
[2] Fong, W., et al. 2013, ApJ, 769, 56
[3] Fong, W., et al. 2015, ApJ, 815, 102
[4] Lamb, G. P., et al. 2019, ApJ, 883, 48
[5] Abbott, B. P., et al. 2017, PhRvL, 119, 161101
[6] Gehrels, N., et al. 2004, ApJ, 611, 1005
[7] Lien, A., et al. 2016, ApJ, 829, 7
[8] Paterson, K., et al. 2020, ApJL, 898, L32
[9] Hao, J.-M., & Yuan, Y.-F. 2013, A&A, 558, A22

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Pinpointing the Sun's Neighbors Within Vast Data Archives

Aaron Meisner (NOIRLab)

Mapping the solar neighborhood is a time-honored quest in the field of astronomy, but surprisingly many of our closest substellar neighbors have gone overlooked. By fully scouring vast archives hosting modern survey datasets, we can uncover more of the faintest and coldest nearby brown dwarfs, thereby gaining critical insights about the substellar mass function and exoplanet atmospheres. Our Backyard Worlds citizen-science project is searching for cold and close substellar objects by combining the power of data archives with a legion of over 100,000 dedicated volunteers. The Dark Energy Spectroscopic Instrument (DESI) Legacy Imaging Surveys provide the main datasets that Backyard Worlds citizen-scientists explore: custom infrared sky maps from NASA's *WISE* satellite [1] and wide-area red-optical imaging [2], [3] from the Dark Energy Survey (DES), Dark Energy Camera Legacy Survey (DECaLS), and Mayall *z*-band Legacy Survey (MzLS). Backyard Worlds volunteers scrutinize these datasets for objects that are both unusually red and fast-moving, the telltale indicators of cold and nearby brown dwarfs (Figure 1).

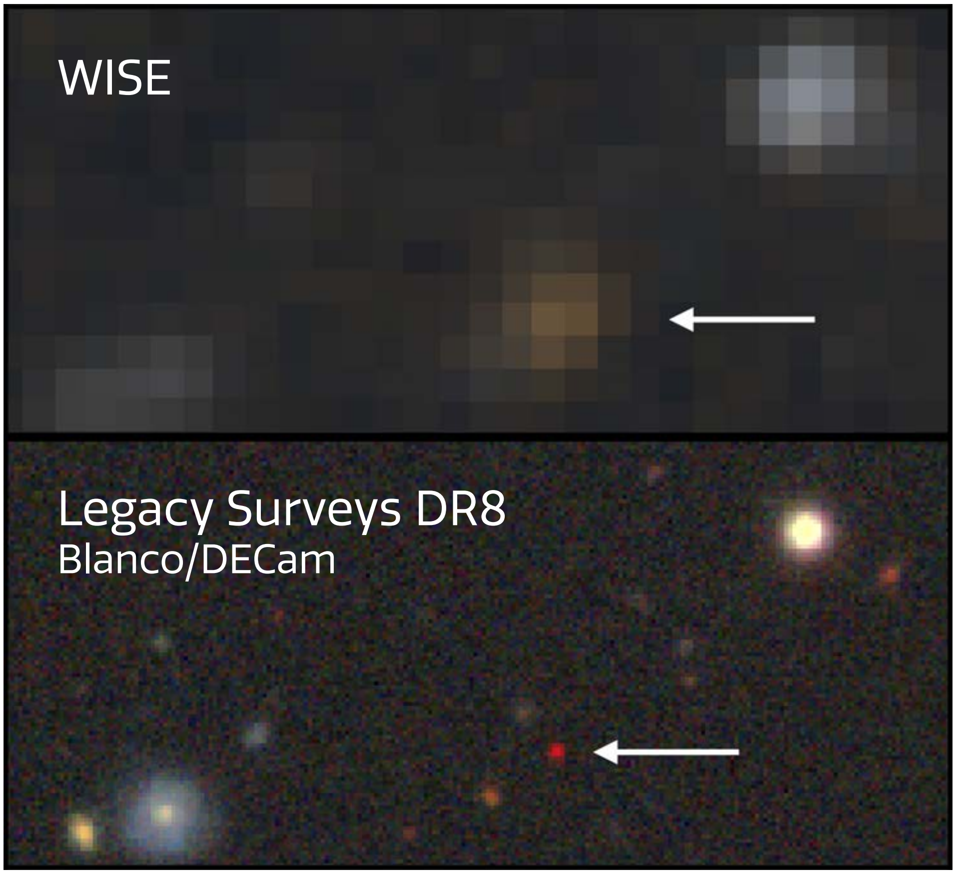


Figure 1. These screengrabs of the DESI Legacy Surveys show how its combination of data from WISE/Blanco/Mayall can aid in the process of brown dwarf discovery and vetting. The arrows point to the brown dwarf, which looks orange in WISE and deep red in DESI Legacy Surveys data from Blanco/Dark Energy Camera (DECam). (Credit: CTIO/MSO/NOIRLab/NSF/AURA/DOE)

Billion-object catalogs are far too large for each Backyard Worlds participant to simply download their own copy. Thankfully, the Community Science and Data Center's Astro Data Lab hosts these large modern datasets, enabling Backyard Worlds citizen-scientists to conveniently issue queries for new brown dwarf candidates. Discoveries made in this way by members of the general public underscore Astro Data Lab's excellent combination of accessibility, open data practices, and advanced science platform functionality.

We recently completed a *Spitzer Space Telescope* follow-up campaign targeting ~ 100 of the coolest Backyard Worlds discoveries [4]. Spitzer provides the crucial brown dwarf temperature estimates, separating out the coldest Y dwarfs ($T_{eff} < 500$ K) from more numerous and warmer T dwarfs. Several of our new Backyard Worlds discoveries are among the coldest brown dwarfs yet known. These objects begin bridging a previously wide gap between the coolest known brown dwarf and the broader substellar population (Figure 2). These results demonstrate the ability of citizen-scientists to reshape our understanding of the Sun's cosmic neighborhood.

Looking to the future, Backyard Worlds is preparing to publish follow-up observations of even more brown dwarf discoveries, obtained with telescopes including NOIRLab's Gemini North, Gemini South, SOAR, and Blanco. Thanks to initiatives such as the Rubin Observatory Legacy Survey of Space and Time (LSST), archival mining of large survey datasets—through methodologies including citizen science and machine learning—is poised to play a central role in the coming decades of astronomical research.

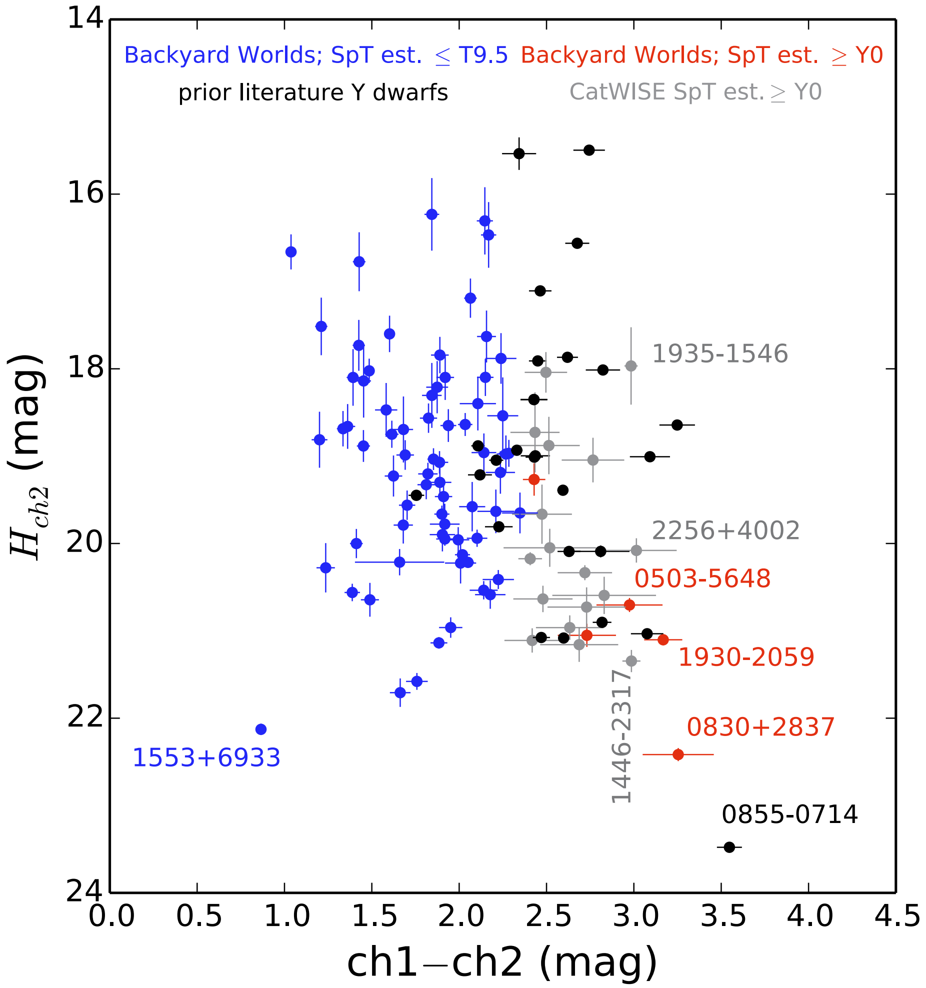


Figure 2. The red data points discovered by Backyard Worlds participants help fill in a wide gap between the bulk of the previously known Y dwarf population (gray and black data points) and WISE 0855−0714, the coldest known brown dwarf. WISE 0830+2837, discovered by citizen-scientist Dan Caselden, stands out as a potential "missing link" in the Y dwarf population. (From [4], with permission)

References

[1] Meisner, A. M., Lang, D., & Schlegel, D. J. 2018, AJ, 156, 69

[2] Abbott, T. M. C., et al. 2018, ApJS, 239, 18

[3] Dey, A., et al. 2019, AJ, 157, 168

[4] Meisner, A. M., et al. 2020, ApJ, 899, 123

10.5281/zenodo.4444079

A Deep Search for Venus Co-orbital Asteroids

Petr Pokorný (Catholic University of America)

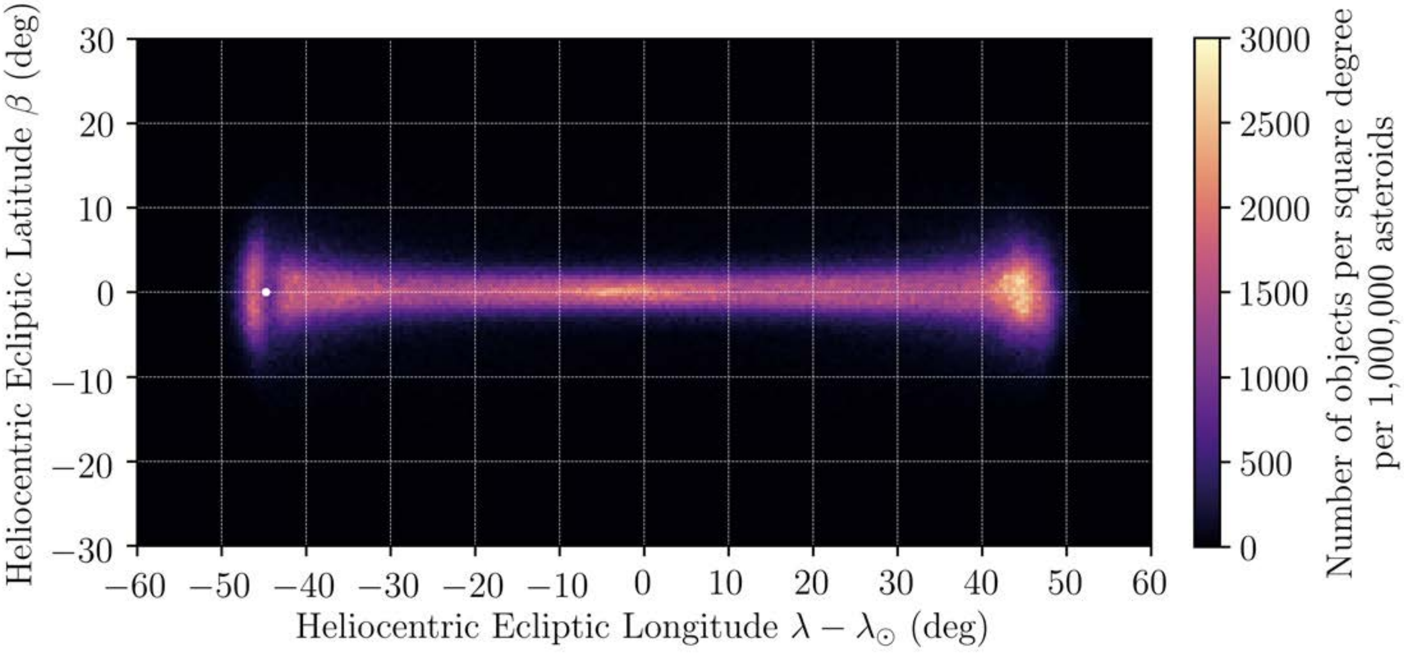


Figure 1. Density of asteroids per square degree in heliocentric ecliptic coordinates considering a population of 1,000,000 asteroids co-orbiting with Venus. In these coordinates the Sun is in the center and the ecliptic is at y = 0. The position of Venus is shown as a white dot at (−44.85,0). This image shows that there is a cavity around Venus, while the highest density of asteroids is at the other side of the Sun, i.e., at the anti-Venus point. (From [4], with permission)

Venus has recently been discovered to share its orbit with a ring of dust. This circumsolar ring of dust was imaged independently by two spacecraft: *HELIOS A/B* [1] and *STEREO A/B* [2]. *HELIOS* was able to estimate the radial and latitudinal extent of the ring by flying through it, while *STEREO* imaged its structure from 1 AU. Earlier work by Pokorný & Kuchner [3] showed that none of the currently observed small body populations in the Solar System are able to produce dust that evolves into a circumsolar structure of such a shape and magnitude. To solve this problem, Pokorný & Kuchner [3] modeled the effects of a hypothetical population of asteroids co-orbiting with Venus on low-eccentricity and low-inclination orbits. The total amount of dust in Venus's circumsolar dust ring was estimated to be equivalent to a 2-kilometer asteroid ground to dust. There are currently five known Venus co-orbitals: 2001 CK$_{32}$, 2002 VE$_{68}$, 2012 XE$_{133}$, 2013 ND$_{15}$, and 2015 WZ$_{12}$. All of these asteroids have highly eccentric orbits that cross Earth's orbit, however, and are not able to contribute to the dust ring.

We (Petr Pokorný, Mark J. Kuchner, and Scott S. Sheppard) conducted a five-day twilight search for Venus co-orbital asteroids [4] to test our ring-origin hypothesis in September

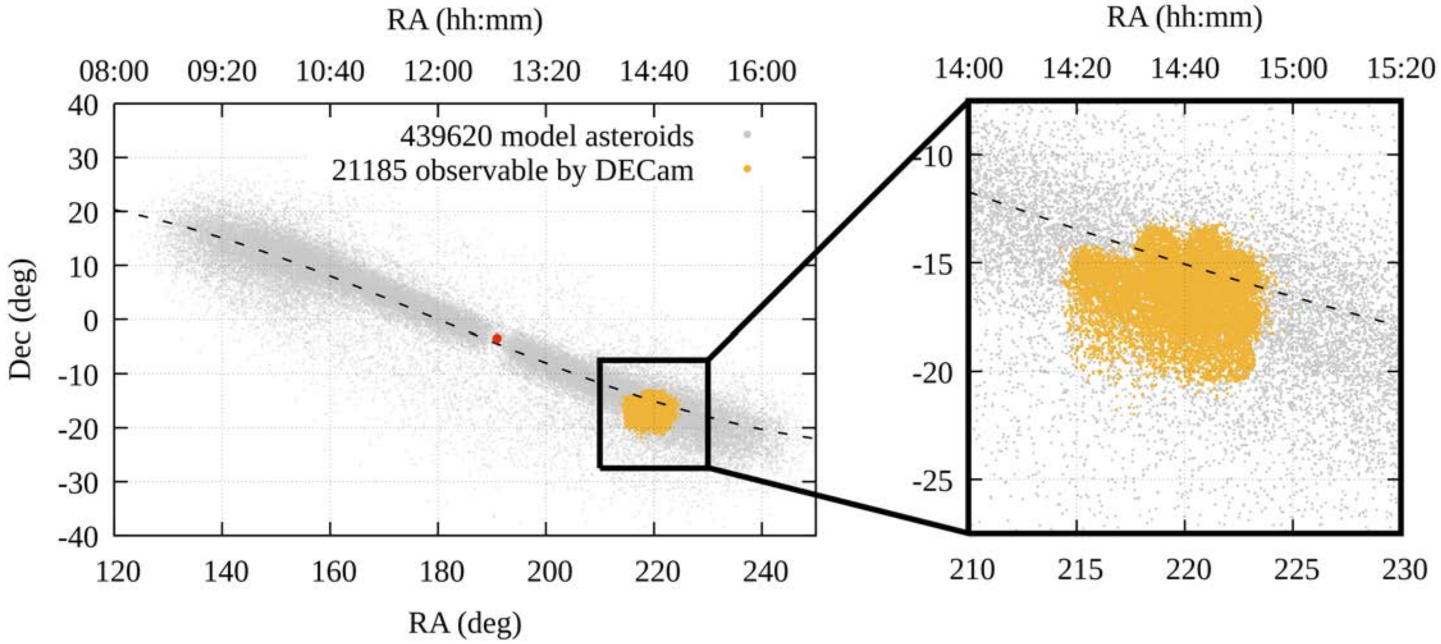


Figure 2. *Left*: Distribution of 439,620 simulated Venus co-orbital asteroids as they would appear on 23 September at 23:30 UTC (gray dots) and 21,185 asteroids that were in our field of view during our five-day survey (orange circles). The black line represents the ecliptic, the red dot is the position of Venus on 23 September at 23:30 UTC. *Right*: The same as the left panel but now zoomed in to 210 < RA < 340 and –25 < Dec. < –5. In total, our DECam survey was able to observe 4.82% of the entire population of hypothetical Venus co-orbitals. While the DECam field of view is approximately circular, the position of orange circles is not confined into circular areas. This is due to the fact that we stacked five days of data and that each asteroid has a different drift in RA and Declination (From [4], with permission)

2019, using a deep and wide survey with the Dark Energy Camera (DECam; mainly funded by the US Department of Energy) on the Víctor M. Blanco 4m Telescope at Cerro Tololo International Observatory. We detected three known near-Earth asteroids, but no Venus co-orbitals. Since Venus is inside Earth's orbit, the observing geometry provides only a short window during twilight that allows us to see kilometer-sized asteroids. Despite this, we were able to search 35 unique square degrees to 21 mag in the *r* band. By modeling hypothetical Venus co-orbital asteroids, we estimate that our survey probed 5% of the entire population that would be brighter than 21 mag. Depending on the properties of the asteroids, our survey was sensitive to bodies larger than 400–900 meters in diameter. Despite finding no Venus co-orbitals, our survey was able to narrow down the upper limit for the number of asteroids larger than 400–900 meters in diameter to $N = 18\,(+30/-14)$. This number is important for follow-up surveys and studies of the dynamical evolution of Venus co-orbitals.

Our survey was defined through extensive modeling, which allowed us to pick the most favorable observing time and geometry. Using models from [3], we simulated millions of hypothetical Venus co-orbital asteroids using six asteroid types (S, M, E, C, P, D) to determine the variation of the asteroid magnitude with respect to position in the night sky. These types represent a broad range of albedos (0.04–0.45) and have well-determined asteroid phase functions, which are necessary to estimate the asteroid brightness with respect to the Sun-asteroid-Earth phase angle [5]. Observers usually try to keep this angle close to zero (i.e., observation at opposition) to maximize the amount of light reflected from the asteroid. This is only possible for objects that orbit beyond the orbit of Earth, while asteroids like those we sought can easily have phase angles higher than 90°. Our modeling showed that the best observing strategy is to 1) look close to the ecliptic about 45° away from the Sun, 2) avoid looking in the proximity of Venus, given the cavity in the asteroid density that the planet creates in its vicinity, and 3) look for objects that are moving faster than 90 arcseconds per hour (the average drift was 130 arcseconds per hour). Findings (1) and (2) are summarized in Figure 1.

Figure 1 provides a simplified model that does not take into account the position of Earth with respect to Venus, the Sun, and hypothetical co-orbital asteroids. Once we got the results of our five-day survey with the exact time of the observation and knowledge of the position of Earth with respect to Venus and the Sun, we performed another simulation in which the observing geometry matched precisely the one of our survey. This is shown in Figure 2, which depicts the distribution of the hypothetical Venus co-orbitals in RA and Declination on 23 September 2019. Thanks to our pre-observation modeling, we were able to sample almost 5% of the entire observable population in our five-day survey.

What does the non-detection of Venus co-orbital asteroids tell us? Using Poisson statistics we were able to obtain the limits for the population that can be present in the Solar System without being detected. The 1σ interval represents 4–48 asteroids with diameters larger than 400–900 meters that are able to avoid detection by our survey. This upper limit is supported by a recent survey by the Zwicky Transient Facility [6] that was less sensitive (19.5 mag) and also found no Venus co-orbital asteroids. When we extrapolate our upper limit to asteroids with diameters larger than 2 km, our survey predicts that fewer than 6 asteroids of that size are currently co-orbiting with Venus (this is the upper limit for very low albedo asteroids, e.g., C-types). Such a number of asteroids is quite small and makes the connection between the dust ring and the Venus co-orbital challenging. This leads to the following possible implications: (1) Venus co-orbitals might be non-reflective at the observed phase angles; (2) Venus co-orbitals have a very low albedo (<1%); or (3) the Venus co-orbital dust ring has a source other than asteroids co-orbiting Venus. To shed more light on these implications a long-term survey is needed.

References

[1] Leinert, C. & Moster, B. 2007, A&A, 472, 335

[2] Jones, M. H., Bewsher, D., & Brown, D. S. 2013, Sci, 342, 960

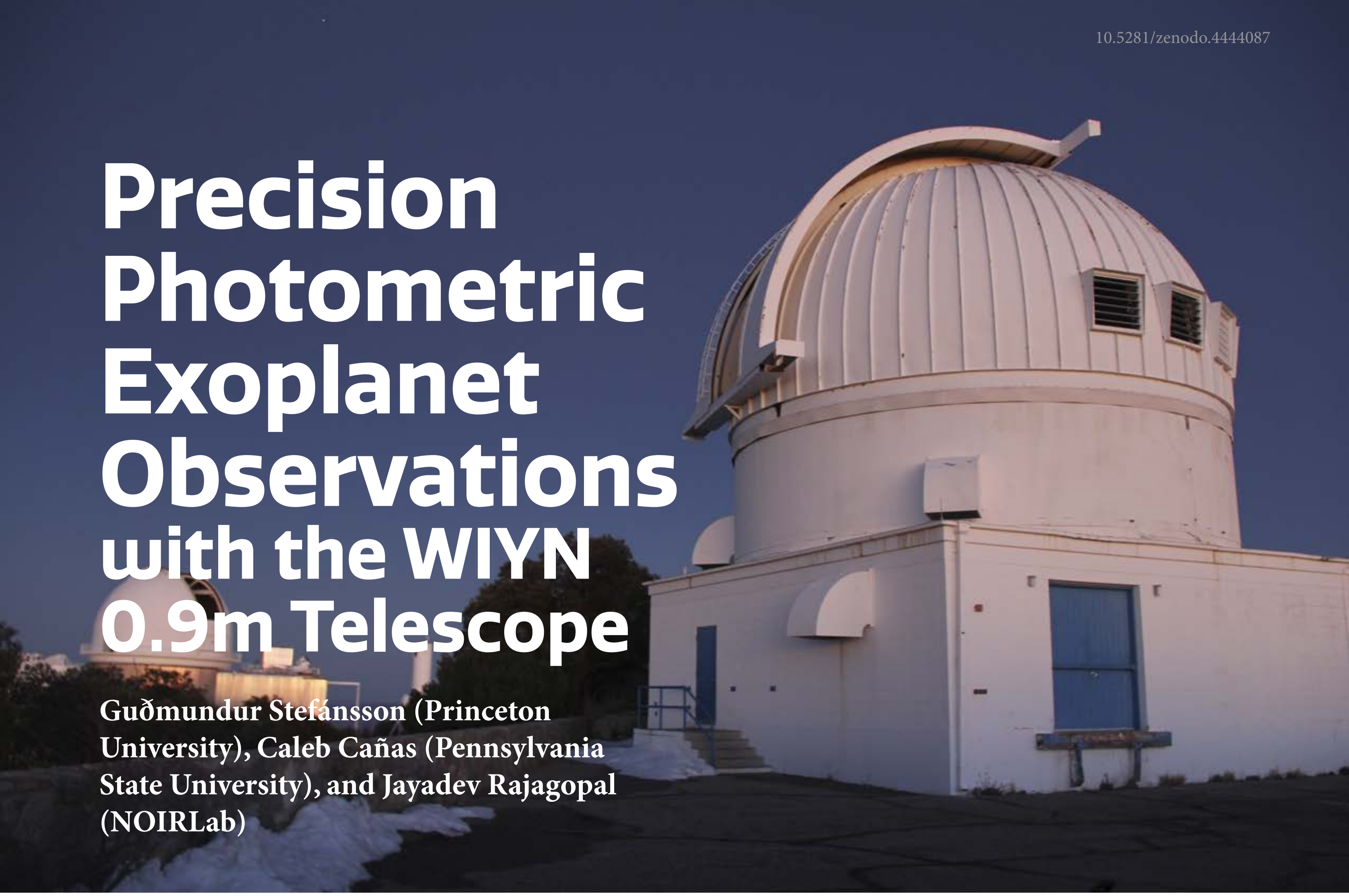
[3] Pokorný, P. & Kuchner, M. 2019, ApJL, 873, L16

[4] Pokorný, P., Kuchner, M., & Sheppard, S. 2020, PSJ, 1, 47

[5] Shevchenko, V. G., et al. 2016, P&SS, 123, 101

[6] Ye, Q., et al. 2020, AJ, 159, 70

10.5281/zenodo.4444087



Precision Photometric Exoplanet Observations with the WIYN 0.9m Telescope

Guðmundur Stefánsson (Princeton University), Caleb Cañas (Pennsylvania State University), and Jayadev Rajagopal (NOIRLab)

The WIYN 0.9m Telescope Half Degree Imager (HDI) has been used for two exciting programs that explore the properties of transiting exoplanets around nearby M-dwarf host stars. M-dwarfs form the vast majority of all stars in our galaxy, and they are therefore our most common neighbors. We now know that these stars commonly host planets. Understanding the architectures of these systems is a first step in the search for habitable planets.

One of the programs [1] found a surprisingly dense Neptune-sized planet in a short-period eccentric orbit around its host star in the Hyades cluster. The other result [2] revealed the orbital period of a newly discovered warm Jupiter from the *Transiting Exoplanet Survey Satellite* (*TESS*) mission, and the largest planet known to transit an M-dwarf star. Both programs used a new “Engineered Diffuser”—a nanofabricated optical device that is capable of molding the image of a star into a broad and stabilized top-hat shape—which has been installed and commissioned for use on the WIYN 0.9m Telescope for high-precision photometric work.

For the dense-Neptune program, Jayadev Rajagopal, Flynn Haase, and Lori Allen formed the NOIRLab team that collaborated with Principal Investigator Guðmundur Stefánsson (Princeton University) to install an Engineered Diffuser on HDI for precision photometric work on the WIYN 0.9m Telescope (Figure 1). The diffuser uses precision-engineered micro-lenselets to spread the light over many pixels in a stable manner that minimizes photometric errors due to seeing variations and averages over inter-pixel sensitivity effects. It thus enables observations of bright, nearby planet-hosting stars, including a number of recently discovered *TESS* planet candidates, with high observing efficiencies and photometric precision.

During commissioning observations for the Engineered Diffuser on the WIYN 0.9m Telescope, the team observed four transits of the young M-dwarf planet K2-25b to better constrain its orbital properties. K2-25b is a Neptune-sized planet in a 3.5-day orbit around its M4.5 dwarf host star in the ~ 600-Myr-old Hyades cluster. These observations

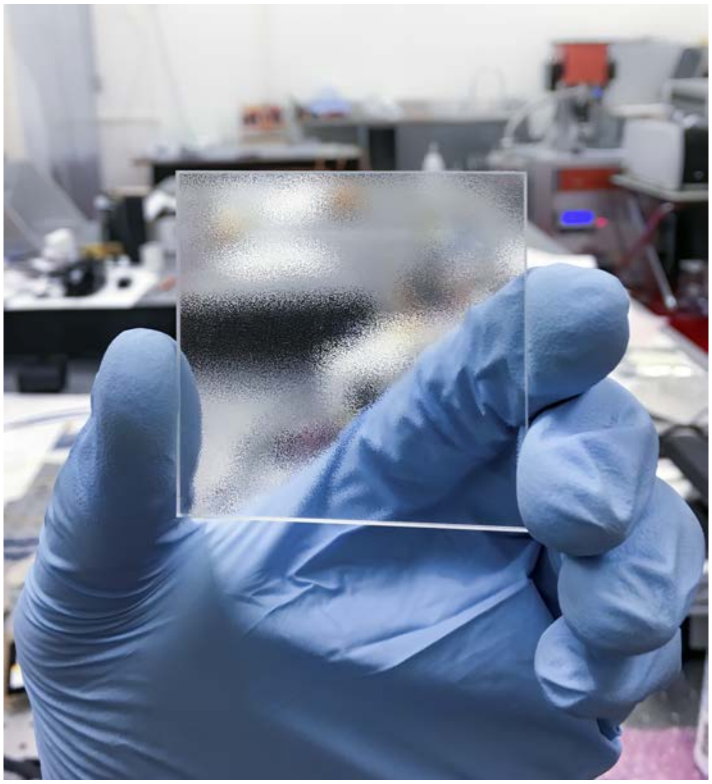


Figure 1. An example of a 5 cm x 5 cm (2 inch x 2 inch) Engineered Diffuser similar to the one installed on the WIYN 0.9m Telescope. It molds the image of a star into a broad and stabilized top-hat shape. (Credit: G. Stefánsson/RPC Photonics)

directly supplemented observations taken with other telescopes, including diffuser-assisted observations on the 3.5m Telescope at Apache Point Observatory (APO) and spectroscopic observations with the Habitable-zone Planet Finder (HPF) on the 10m Hobby-Eberly Telescope (HET) at McDonald Observatory. By combining the diffuser-assisted data and the radial velocity (RV) data, the team provided the first measurement of the mass and density of this planet, showing that K2-25b is surprisingly dense for its size and age, suggesting that K2-25b has a large core. K2-25b could either be composed of a rocky core (95% of the mass) enveloped by a 5% H/He atmosphere or even have a higher core mass fraction if it has a high fraction of water/ices in its core. More observations, such as transmission spectroscopic observations with the *James Webb Space Telescope* (*JWST*) in the future, are needed to distinguish between these composition scenarios.

To gain further insight into the formation and evolution history of the young K2-25b system, some of the diffuser-assisted observations from the WIYN 0.9m Telescope and the 3.5m Telescope at APO were conducted simultaneously with RV observations during transit with the HPF to conduct the first Rossiter-McLaughlin (RM) effect observations of the planet (Figure 2). The RM effect relies on measuring the RV anomaly that occurs as the planet transits its host star, successively blocking blue-and-red shifted light on the rotating stellar disk. The shape and amplitude of the RV anomaly are dependent on the obliquity of the system, the angle between the planet's orbit and the star's equator. The observations demonstrated that the planet's orbit is well aligned with the spin-axis of its host star, in contrast to a number of other hot Neptune-sized planets, which have been observed to orbit on highly misaligned and even polar orbits. This suggests that K2-25b likely formed and evolved via a different mechanism than the population of misaligned hot Neptunes. The result has been highlighted in a NOIRLab press release.

For the second program, the WIYN team collaborated with Principal Investigator Caleb Cañas (Pennsylvania State University) to confirm the planetary nature of and characterize a warm Jupiter-sized planet, TOI-1899 b, recently discovered by *TESS*. *TESS* observed only a single transit during a timespan of ~50 days, which led the team to observe four nights of TOI-1899 with HDI in search of an additional transit. These photometric observations directly supplemented observations (see Figure 3) taken at other telescopes, including photometry from the 0.5m ARC Small Aperture Telescope at APO, high-contrast imaging from the WIYN 3.5m Telescope and the 3m Shane Telescope at Lick Observatory, and spectroscopic observations with HPF. Though the HDI observations did not catch a transit, they further demonstrate the complementary use of these multiple techniques.

With these data, the team confirmed that TOI-1899 b is a planet ten percent larger in radius than Jupiter and orbits a cool star with a period of 29 days. While hundreds of Jupiter-sized planets have been discovered orbiting larger Sun-like stars, it is rare to see these planets orbiting low-mass stars. TOI-1899 is only the fifth known M-dwarf to host a transiting Jupiter-sized planet and the first of such systems with an orbital period longer than four days. Despite the comparatively long orbital period, this still places the giant planet much closer to its star than expected from classical formation theories. Future observations of the RM effect (similar to K2-25 b) for TOI-1899 b could help constrain if this warm Jupiter migrated to its current location or formed there.

The nature of the host star and the long orbital period also make TOI-1899 b a candidate for future atmospheric studies. The radius of TOI-1899 b is slightly larger than planetary models predict for cool, non-irradiated Jupiter-sized planets, which cannot be inflated by heating from the host star. With the wavelength coverage and precision of the upcoming *JWST*, it will be possible to observe features in the atmosphere of TOI-1899 and begin to constrain the exact source of this apparent inflation.

References

[1] Stefansson, G., et al. 2020, AJ, 160, 192S

[2] Cañas, C., et al. 2020, AJ, 160, 147C

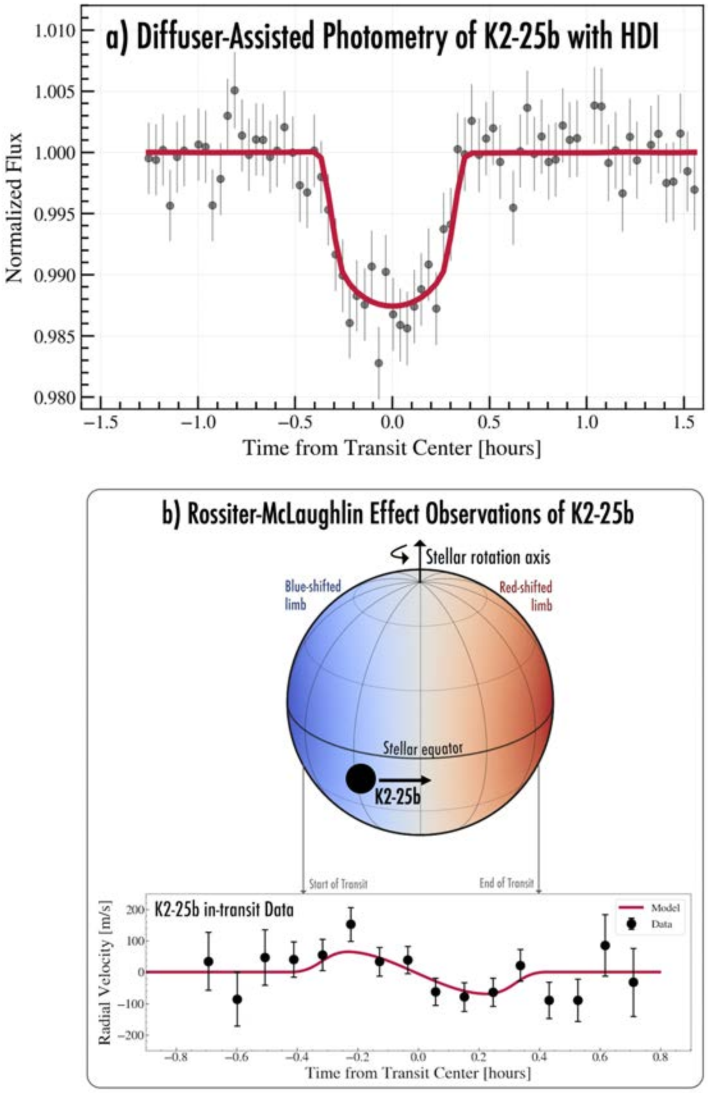


Figure 2. *Top*: Example diffuser-assisted photometric observations taken with the Engineered Diffuser on the WIYN 0.9m Telescope of the transit of K2-25b. *Bottom*: In total, four transits were obtained with the WIYN 0.9m Telescope, one of which was taken simultaneously with in-transit RV observations with the HPF Spectrograph on the 10m HET. The data show that K2-25b's orbit is well aligned with the equator of its host star. (Credit: NOIRLab/NSF/AURA)

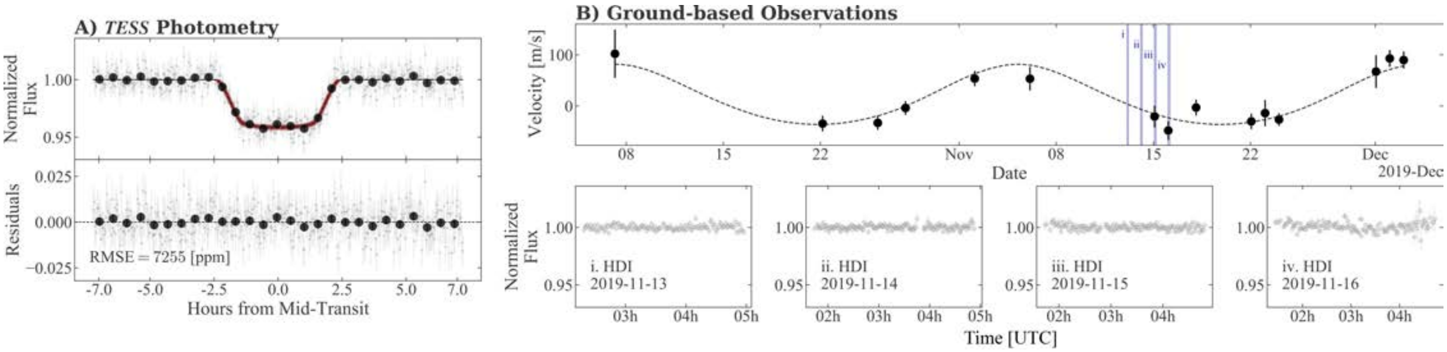


Figure 3. *Left*: The single transit of TOI-1899 b observed by *TESS*. Precise characterization of the transiting planet requires additional data to determine the orbital period. *Right*: The top part displays the HPF RVs which were necessary to determine TOI-1899 b takes ~29 days to orbit its star. The vertical lines indicate nights where HDI photometric observations were obtained. The HDI photometry is displayed on the bottom row where no transits were observed. (From [2], with permission)

Perspectives

In this issue of *The Mirror*, the Perspectives section focuses on “science and society” issues, taking a look at cultural practices within astronomy and our interaction with society beyond the professional community.

In the first article, Dara Norman shares highlights from her plenary talk at the June 2020 AAS meeting on “The Inclusion Revolution.” She describes how we must evolve our culture in astronomy to make our field more diverse and inclusive, three action items the community must embrace in order to make meaningful change, and how the Decadal Survey must play a role in creating change by returning to its own practices from the 1960s.

The second contribution, from Andrea Dupree, discusses how we can improve one of our cultural practices—proposal selection by peer review. She describes a selection method that is reminiscent of “banding,” a concept from the world of hiring practices and procedures, which reflects the idea that small differences between candidates’ scores or grades may not be meaningful (e.g., because of measurement error) or predictive in terms of outcome (e.g., job performance or scientific research outcome). Banding is also used as a method to reduce the impact of biases (e.g., against women and minorities) in the hiring process. The proposed approach can potentially mitigate a wide range of biases, not only those associated with proposer names and institutions but also those associated with language and ideas.

The third contribution responds to our community’s interest in learning more about where their data come from. As part of our ongoing effort to create informational materials in response to community interest, in this article Katy Garmany interviews Jacelle Ramon-Sauberan about the history and culture of the Tohono O'odham Nation, where Kitt Peak National Observatory is located.

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Recipe for an Inclusion Revolution

Dara Norman (NOIRLab)

Culture refers to the customs, institutions, and achievements of a particular group of people. Science has a culture, as does the field of astronomy and astrophysics. In common with other cultures, astronomers have a language (equations and how we describe phenomena), traditions (how and when we do things, like clapping after talks and having 1–3 postdoc positions before a permanent job), and norms (expectations of how we are supposed to act, like asking questions in the middle of a talk). We have values (things we judge as significant to assessing scientific merit and things we deem less so), and we have our own art (how we give talks and take our data). At the virtual AAS meeting in June, my talk entitled "The Inclusion Revolution" was about acknowledging our culture and addressing the changes needed to make the field more diverse and inclusive, that is, how we must evolve the culture to achieve an inclusion revolution.

The Decadal Surveys are important to the culture of astronomy and astrophysics. As consensus documents, they affirm what is most important (values) and the norms of how we plan to accomplish our science over the subsequent 10 years, both inwardly to our community and outwardly as advice to the federal funding agencies. If we are interested in making cultural changes, then the Decadal Survey must play a part.

Although we might not think of the Decadal Survey as having the agency for cultural change now, these surveys certainly have played that role in the past. In the first Decadal Survey, in 1964, the community was concerned about the professional workforce and the lack of large public telescopes available to support graduate student observational research. From this primary concern, exclusivity of resources to do research, came the initiative to establish the national optical and radio telescope facilities. While now we may think of the Decadal Surveys as being about building satellites or telescope facilities, in fact, this first Decadal was all about enabling and expanding the opportunities for researchers to do their science by providing them with the necessary tools. The impact of the national facilities for astronomical research changed both the culture of astronomy and the workforce by shifting the ability to do observational research to institutions that did not have their own private telescopes. Now, as we look to make the field more diverse and inclusive, similar to what happened in 1964, we need to understand the barriers to participation in research and tackle them deliberately and strategically.

Our community has recognized problems and taken steps, individually and within departments and collaborations, to implement some changes. Women are the largest underrepresented group in the field, and the Women in Astronomy conference series has long provided opportunities to address concerns about inclusion and how our traditions, norms, and values have not supported everyone in the field. However, the recognition of women's issues has not lifted all boats equally, in part because the concerns of other minority communities are different, and therefore the approaches to improvement must be different. Pipeline programs to support students are popular, but while fundamental to bringing more underrepresented minorities into the field, they do not address issues of retention.

> “The impact of the national facilities for astronomical research changed both the culture of astronomy and the workforce by shifting the ability to do observational research to institutions that did not have their own private telescopes.”

In 2015, a grassroots group interested in promoting better inclusive practices, especially around intersectional identity, organized the Inclusive Astronomy meeting at Vanderbilt University. The goal was to provide recommendations for improving inclusivity by adjusting our norms, traditions, and values, particularly with respect to multiple intersections of identity. The sessions on "Access to Policy, Power, and Leadership" were envisioned to provide, especially to early-career researchers, information on centers of power in the field and how to put themselves in the rooms where they could bring about cultural change. This work carried into the Inclusive Astronomy 2 (IA2) conference where presentations were given on adjusting norms in collaborations through improved communication and codes of conduct. Other speakers cited efforts to identify metrics that enable an understanding of how changes in traditions, norms, and values are impacting the science we do and the ways we do it. They are using our language and our art to demonstrate the value of these changes for the science we accomplish.

These examples of informal institutional change have pushed conversations of comprehensive change forward. However, if we seek real cultural change in astronomy and astrophysics, we must also embrace formal institutional changes in departments, in projects, and at agencies. Formal change requires overhauling policies and procedures, and it must include strong incentives for people to make those changes through rewards and consequences. Listed below are three actions the community needs to embrace if we are to make meaningful changes.

Enable Broader Advisory and Resource Access

The make-up of science advisory and policy-making committees—and input to those committees—often come from a narrow group of scientists with experiences in science that are too similar. These narrow groups often don't even know what they don't know and underestimate barriers to inclusion that stymie good ideas. To better understand the needs of the whole community, we must diversify the experiences and expertise of advisory groups and the input given to committees and leaders who make decisions.

Understanding the barriers around access to resources is critical. We are losing opportunities for great science and for cultivating great scientists because of limited resources and access spread unequally. Survey data and large datasets have the potential to extend research opportunities to a broader community. But archival data alone, which often require additional resources to fully access and special expertise to navigate, are not enough. The development of science platforms and software tools can help provide services to support users and enable them to make the most of archival data. The Astro Data Lab and ANTARES projects at NOIRLab are intended to democratize the ability of individuals to do cutting-edge research by providing software tools that allow researchers to keep their scientific questions foremost in their minds as they navigate complex datasets and data products.

Tie Research Funding to Progress on Inclusion

Currently, funding for research is not tied to metrics or progress on inclusion of underrepresented and disenfranchised groups. "Broadening Participation" in our field must be about workforce and research participation, not just public outreach and education. If we are to make any progress on research inclusion, we must reward those who make inclusion part of their science goals and incentivize those who currently do not in order to adjust their thinking. For advancement, better practice around diversity and inclusion must be part of how we assess the scientific merit of our research. Until we embrace inclusion of a broader range of expertise and perspective in our research, we will not be doing the best science.

Bottom Up Is There; Top Down Is Lacking

As demonstrated in the examples above, individuals and groups have been making substantial progress on pushing for changes to our culture, i.e., what and whom we value in our pursuit of science, as well as the norms of what we expect of our scientific interactions and who can participate. However, at the highest levels of policy-making and funding support, discussions around inclusion in science are often shunned. We need leaders in high-level policy-making groups and at agencies to engage in the discussion for there to be traction, e.g., recommendations that insist on funding for inclusive programs, as well as access to resources for the broader community. In short, we need our leaders to lead on these issues.

As we look to the future, we need to get out of the more recently constructed box of thinking of the Decadal Survey as being just about the hardware and think about how we enable science by enabling access to resources for the broadest community to realize their scientific goals. This means embracing new traditions, norms, and values that will improve our culture and advance scientific discovery. We need the Decadal Survey to take a page out of its own history.

Further reading

Norman, D. 2018, AstroBeat

Norman, D., et al. 2019, BAAS, 51(7)

Norman, D., et al. 2019, BAAS 51(7)

10.5281/zenodo.4444094

An Alternate Proposal for Peer Review

Andrea Dupree (Center for Astrophysics | Harvard & Smithsonian)

Procedures for peer review of grant proposals and requests for telescope time have come under scrutiny because of demonstrated gender biases [1], [2], [3], [4], [5]. Studies of proposal success rates in the United States, Europe, and Canada involving major astronomical facilities both on the ground and in space reach similar conclusions: "proposals submitted by female PIs show a significantly lower probability of being allocated time"; "deficit in acceptance by female proposers is significant"; "proposals submitted by women were rated significantly worse than those submitted by men"; "significant gender-related systematic trend"; and "an overall signal favoring men."

Recognizing this problem, the Space Telescope Science Institute (STScI) has experimented with new proposal formats. After trying two different stylistic changes,[a] they experimented with a third variation, which required that proposals list investigators alphabetically without identifying the Principal Investigator (PI). STScI also examined their review process, which consists of an initial ranking of proposals made separately and individually by each reviewer, followed by an in-person meeting of the entire committee to continue the evaluation. Analysis of the first step, the independent individual ranking, revealed no gender bias [6]. However, gender bias did arise in the second step, the group discussion. Professional observers of the committee deliberations noted that conversations focused on the PI, the team, and the laboratory about 50% of the time [7].

These results motivated STScI to devise a dual-anonymization procedure that completely eliminates the names (and institutions) of the Investigators from proposals in order to focus the review on the science [8], [9]. After proposals are selected, the names of investigators and their expertise and backgrounds can be revealed and reviewed by the committee. NASA's Science Mission Directorate has initiated a dual-anonymous peer review procedure for several programs as well.[b] These are admirable developments.

The creation of fully anonymous proposals represents a substantial change and introduces new constraints and added responsibilities for everyone involved in the peer review process. Dual-anonymization requires pre-screening of proposals by observatory staff to ensure stylistic compliance and creditable submission. Additionally, "levelers" are required in each meeting room to carefully follow reviewer discussions and interrupt when necessary to direct the topic back to the science. In addition, segments of the "old procedures" still exist as reviewers meet to discuss and evaluate proposals together.

A different, and in many ways superior, peer review procedure is suggested by a study sponsored by the National Academy of Sciences to assess the effectiveness of peer review. The study, by Cole and collaborators [10] of the National Science Foundation (NSF) peer review process, was carried out as part of a larger study by the National Academy of Sciences Committee on Science and Public Policy (COSPUP) [11].

Figure 1. The author in the Cassegrain cage of the 4m Mayall Telescope at Kitt Peak National Observatory

Cole and collaborators studied three areas of research supported by NSF: chemical dynamics, economics, and solid-state physics. “Blue ribbon” NSF panels had previously ranked the proposals in each area. These proposals were in the traditional format in which the PI and team are identified. The same proposals were then given to a second set of equally “blue ribbon” panels for evaluation. The rankings of the proposals are shown in Figure 2, with the initial NSF rankings on the vertical axis and the new COSPUP rankings on the horizontal axis.

These results are illuminating. In all 3 subject areas, both panels easily identified and agreed on the best 3–4 proposals and the worst 3–4 proposals. However, proposals in the middle show little correlation between the scores. Cole and collaborators concluded that “getting a research grant depends to a significant extent on chance.”

The conclusions of this research lead us to suggest an alternate method of peer review and selection that has numerous advantages. Here, we outline this alternate method.

Without an in-person meeting, proposals (with proposers identified alphabetically) are read and ranked independently by the members of the review committee, and the scores are tabulated. The “top-ranked” proposals are accepted. The lowest-ranked proposals are rejected, similar to the triage process that occurs in the evaluation of HST proposals. The remaining proposals in the middle are selected randomly until the available observing time is filled.

This peer review method has many advantages:

- Follows procedures demonstrated to identify the best and worst proposals.

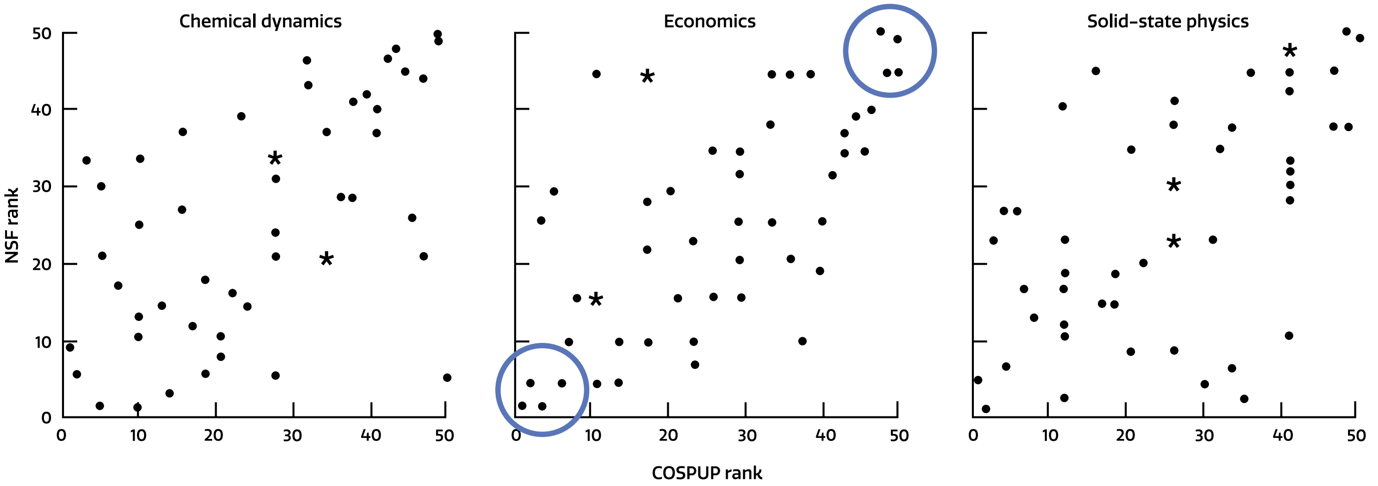


Figure 2. The NSF rank (y-axis) and the corresponding rank from the COSPUP reviewers (x-axis). The asterisks mark two proposals with identical ranks. I have inserted circles to mark extremes: the "best" and the "worst." (From [10]. Reprinted with the permission of the American Association for the Advancement of Science.)

- Eliminates the step in which gender bias occurs, as documented by STScI studies: the face-to-face meeting of the panels.
- Allows out-of-the-box ideas to be selected.
- Eliminates gender bias.
- Potentially eliminates bias for race, career stage, institution, and nationality.
- Eliminates the need for detailed review (and disqualification) by observatory staff of a non-compliant proposal.
- Eliminates the need for staff levelers to oversee discussion sessions.
- Avoids committee preferences for small proposals that distribute resources to the many rather than restrict resources to a few.
- Saves money and time.
- Eliminates the challenge of writing "masked identity" proposals.

Some have argued that good science cannot be a random choice. This new process is not random. The best proposals will be successful. The worst proposals will not advance. The process explicitly acknowledges that the final selection under most current review systems is highly dependent on the peers who happen to be around the meeting table that day. Evidence-based research demonstrates that success with the current procedures already depends to a significant extent on chance. This may be an opportune time to initiate new procedures.

References

[1] Reid, I. N. 2014, PASP, 126, 923
[2] Patat, F. 2016, The Messenger, 165, 2
[3] Lonsdale, C. J., Schwab, F. R., & Hunt, G. 2016, arXiv:1611.04795
[4] Norman, D. 2018, private communication
[5] Spekkens, K., Cofie, N., & Crabtree, D. 2018, Proc. SPIE, 10704, 107040L
[6] Strolger, L. & Natarajan, P. 2019, Physics Today Commentary and Reviews, March
[7] Reid, N. 2020, STScI Newsletter, 37(01)
[8] Johnson, S. K. & Kirk, J. F. 2020, PASP, 132, 034503
[9] Kirk, J. F. 2020, BAAS, 52 (3)
[10] Cole, S., Cole, J. R. & Simon, G. A. 1981, Science, 214, 881
[11] National Research Council. 1978. *Peer Review in the National Science Foundation: Phase I of a Study.* Washington, DC: *The National Academies Press*

Notes

[a] In one proposal cycle, the PI and team were listed on the second page rather than the first. In another cycle, only the first initials of the PI and team were allowed.

[b] https://science.nasa.gov/researchers/dual-anonymous-peer-review

10.5281/zenodo.4444099

Tohono O'odham Facts, History, and Culture

A conversation with Jacelle Ramon-Sauberan by Katy Garmany (NOIRLab)

As part of our effort to develop informational materials for the professional community and the public about the Tohono O'odham Nation, where Kitt Peak National Observatory (KPNO) is located, NOIRLab has been working with Jacelle Ramon-Sauberan. Jacelle is a PhD candidate in the University of Arizona American Indian Studies Program and a member of the Tohono O'odham Nation. The following is an informal interview with Jacelle, conducted by Katy Garmany of NOIRLab.

Katy: Let's start with a few quick facts: How many people live on the Tohono O'odham Nation? How big is it? How many traffic lights are there? Can non-O'odham live there?

Jacelle: There are about 34,000 enrolled tribal members, with half living on the reservation and half off the reservation. There are no traffic lights on my reservation, just stop signs. Traditionally, if an O'odham married a non-O'odham, they would live off the reservation. But that has changed over time, and there are non-O'odham living on the reservation.

The Tohono O'odham Reservation is 2.8 million acres and is broken up into four parcels. The four parcels are San Xavier; Main (where KPNO resides); San Lucy District near Gila Bend, Arizona; and Florence Village near Florence, Arizona. The Main part of the reservation is approximately the size of the state of Connecticut with one grocery store and one post office. For some tribal members, it can take 2–3 hours one way to check their mail, purchase food, or buy gas/fuel.

Katy: Some people remember when you were referred to as the Papagos. Can you explain the history of this name and why your Nation changed it?

Jacelle: The name Papago was given to us by the Spanish, and there are different stories on how we got the name, but the bottom line is that it was a lack of understanding / language barrier. Papago translates to "Bean Eater," because one of our traditional foods is tepary beans. In 1986, my tribe changed our name to what we call ourselves, which is Tohono O'odham. Tohono means Desert and O'odham means People. So if you ever write or talk about O'odham, do not say O'odham people because you are saying "People people."

Katy: The Nation has its own language. How has this been preserved? Do younger people speak it fluently?

Jacelle: The O'odham language is still spoken. However, it was put on the endangered language list by UNESCO. There are O'odham-language classes offered at the University of Arizona and Tohono O'odham Community College. Also, there are O'odham-language teachers within the pre-K through 12th grade schools on our reservations. Our

> "The O'odham language is still spoken. However, it was put on the endangered language list by UNESCO."

language is mostly spoken by older people, and there are not nearly enough youth who speak it fluently.

Katy: The TON borders Mexico. How do border issues affect daily life for the Nation?

Jacelle: You cannot leave my reservation without going through a Border Patrol checkpoint. More recently, the border wall has affected my tribe by the desecration of sacred areas where our ancestors are buried and where we have a spring called Quitobaquito. Also, in the construction of the wall, saguaro cacti (Ha:san/Haha:san) have been bulldozed. We view saguaros as human beings, so seeing them being hurt is not okay.

Katy: How does government work on the Nation? Is the TON a sovereign nation?

Jacelle: The Tohono O'odham Nation is comprised of three branches of government: Executive (which houses the Chairman and Vice Chairman of the Nation), Legislative (which houses the Tribal Council representatives: 2 from each of the 11 Districts), and Judicial (which houses the courts and judges). The Tohono O'odham Nation is divided into 11 Districts, and each District has its own chairman and vice chairman. The 11 Districts are Baboquivari, Chukut Kuk, Gu Achi, Gu Vo, Hickiwan, Pisinemo, San Lucy, San Xavier, Schuk Toak, Sells, and Sif Oidak.

To better understand: Look at the Tohono O'odham Nation as if it were the United States. The Districts are like states, and within the Districts, there are communities that would be like towns. And our Chairman is like a President, and the District Chairman would be like a governor, and the Legislative Representatives are like State Representatives.

Katy: Most people have very little knowledge of the history and culture of the Tohono O'odham even if they live in Tucson! What are some of the things you find yourself explaining over and over to people you meet?

Jacelle: How to pronounce Tohono O'odham. If the person can't get the pronunciation down, I tell them it is okay to just say "T.O."

Katy: Astronomers, of course, know Kitt Peak National Observatory is on your Nation. How do you think most O'odham view the observatory?

Jacelle: I cannot speak for others, but for myself I have never had any issues with the observatory being on the O'odham *jewed* (land). It was something agreed upon between O'odham and astronomers. The old photos I have seen from the lease signing and when O'odham took astronomers on horseback to the top of Ioligam Du'ag (Kitt Peak Mountain) are amazing and historical.

Katy: What sorts of things can NOIRLab, which operates Kitt Peak National Observatory, do to be a better neighbor?

Jacelle: I just ask that NOIRLab continue working on building a relationship with my Tribe, especially the Schuk Toak District where the observatory resides.

Katy: If someone wants to visit Sells, what should they know in order to be respectful?

Jacelle: O'odham have been here for time immemorial, and we view the O'odham jewed as the center of the Earth. So if you visit our reservation, understand you are visitors. Please respect our culture, traditions, and way of life. I guess it would be similar thinking to if you visited another country.

Jacelle Ramon-Sauberan is Tohono O'odham and from the San Xavier District. A PhD candidate in American Indian Studies with a minor in journalism, Jacelle's dissertation topic is on the history of land and water in San Xavier. She is also an adjunct instructor at Tohono O'odham Community College, where she teaches Tohono O'odham history and culture. A two-time graduate of the American Indian Journalism Institute, as well as the Chips Quinn Scholars Program for Diversity in Journalism and The New York Times Student Journalism Institute, Jacelle has written for news publications in Arizona, New Mexico, Washington, South Dakota, Oklahoma, Tennessee, Florida, and New York. She was also a freelance journalist for the Indian Country Today Media Network from 2009 to 2017.

To learn more, visit the Tohono O'odham Nation's website (http://www.tonation-nsn.gov) and that of their cultural museum (http://www.himdagki.org).

Archival image from the Nicholas U. Mayall 4m Telescope at Kitt Peak National Observatory, a Program of NSF's NOIRLab, captures a snapshot of some cosmic pyrotechnics—the asymmetric spiral arms of the galaxy NGC 925, which host dazzling bursts of star formation. This stunning image is only one example of the spectacular firework displays that astronomy has to offer.

Credit: KPNO/NOIRLab/NSF/AURA

Acknowledgement: New Mexico State University/
PI: M. T. Patterson

Image processing: T. Rector (University of Alaska Anchorage)/M. Zamani/D. de Martin

10.5281/zenodo.4444117

The ANTARES Time-Domain Event Broker

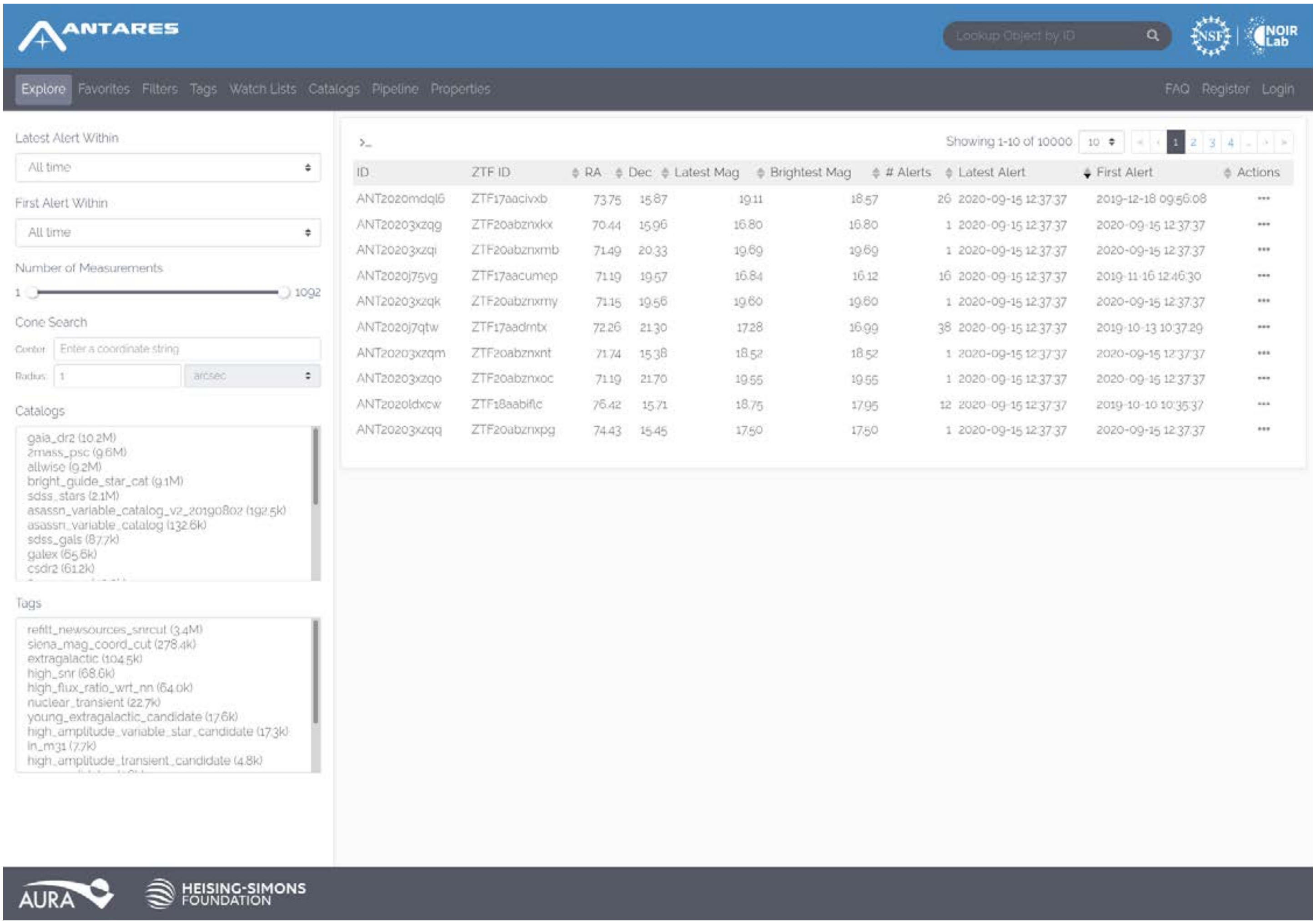
Tom Matheson & Nic Wolf (NOIRLab)

The astronomical community is in the midst of a revolution in Time-Domain Astronomy. The age of serendipitous discoveries of a few objects that were followed by a handful of astronomers is well in the past. Wide-field telescopes with large-format CCDs have enabled time-domain surveys that cover hundreds to thousands of square degrees every night. Digital image subtraction provides an automated pathway to finding all objects that have changed in brightness or position in any given image. The Zwicky Transient Facility (ZTF) produces several hundred thousand public time-domain alerts (notifications) each night through the portion of their survey funded by NSF. The Rubin Observatory Legacy Survey of Space and Time (LSST) will conduct a wide, fast, and deep survey of the southern sky that should generate several million alerts per night. This scale of alerts will require automated tools to filter the stream so that astronomers can find the specific objects of interest to them.

In addition, the advent of multi-messenger astronomy brings with it the promise of whole new areas of astrophysics where electromagnetic counterparts will be invaluable sources of information. Multi-messenger events usually have poor localizations on the sky, often tens to even thousands of square degrees, meaning that there will be hundreds or thousands of potential candidates for electromagnetic counterparts. Rapid identification of these counterparts will also require automated filtering systems.

A team of scientists and engineers at NOIRLab's Community Science and Data Center, along with researchers in the University of Arizona's Department of Computer Science, have been developing a software system to process and filter time-domain alerts. These tools are typically referred to as brokers as they sit between the producers of alerts and the consumers, while adding value. Our broker is the Arizona-NOIRLab Temporal Analysis and Response to Events System (ANTARES). We released v1.0 of ANTARES in June 2020, and it is currently processing the public portion of the ZTF alert stream. Access to the system and instructions for use can be found on the ANTARES website.

ANTARES ingests alerts from ZTF using a streaming technology that LSST intends to employ. Each alert is checked against our internal database to determine whether or not this astrophysical source has been seen before. If not, a new source is created, and we then check multiwavelength catalogs of objects to see if this alert can be associated with any of them. These associations are attached to the alert. If ANTARES has seen an alert at this location before, the



Latest Alert Within: All time

First Alert Within: All time

Number of Measurements: 1 – 1092

Cone Search

Center: Enter a coordinate string

Radius: 1 arcsec

Catalogs

gaia_dr2 (10.2M)
2mass_psc (9.6M)
allwise (9.2M)
bright_guide_star_cat (9.1M)
sdss_stars (2.1M)
asassn_variable_catalog_v2_20190802 (192.5k)
asassn_variable_catalog (132.6k)
sdss_gals (87.7k)
galex (65.6k)
csdr2 (61.2k)

Tags

refitt_newsources_snrcut (3.4M)
siena_mag_coord_cut (278.4k)
extragalactic (104.5k)
high_snr (68.6k)
high_flux_ratio_wrt_nn (64.0k)
nuclear_transient (22.7k)
young_extragalactic_candidate (17.6k)
high_amplitude_variable_star_candidate (17.3k)
in_m31 (7.7k)
high_amplitude_transient_candidate (4.8k)

>_

Showing 1-10 of 10000 | 10

ID	ZTF ID	RA	Dec	Latest Mag	Brightest Mag	# Alerts	Latest Alert	First Alert	Actions
ANT2020mdql6	ZTF17aacivxb	73.75	15.87	19.11	18.57	26	2020-09-15 12:37:37	2019-12-18 09:56:08	•••
ANT20203xzqg	ZTF20abznxkx	70.44	15.96	16.80	16.80	1	2020-09-15 12:37:37	2020-09-15 12:37:37	•••
ANT20203xzqi	ZTF20abznxmb	71.49	20.33	19.69	19.69	1	2020-09-15 12:37:37	2020-09-15 12:37:37	•••
ANT2020j75vg	ZTF17aacumep	71.19	19.57	16.84	16.12	16	2020-09-15 12:37:37	2019-11-16 12:46:30	•••
ANT20203xzqk	ZTF20abznxmy	71.15	19.56	19.60	19.60	1	2020-09-15 12:37:37	2020-09-15 12:37:37	•••
ANT2020j7qtw	ZTF17aadmtx	72.26	21.30	17.28	16.99	38	2020-09-15 12:37:37	2019-10-13 10:37:29	•••
ANT20203xzqm	ZTF20abznxnt	71.74	15.38	18.52	18.52	1	2020-09-15 12:37:37	2020-09-15 12:37:37	•••
ANT20203xzqo	ZTF20abznxoc	71.19	21.70	19.55	19.55	1	2020-09-15 12:37:37	2020-09-15 12:37:37	•••
ANT2020ldxcw	ZTF18aabiflc	76.42	15.71	18.75	17.95	12	2020-09-15 12:37:37	2019-10-10 10:35:37	•••
ANT20203xzqq	ZTF20abznxpg	74.43	15.45	17.50	17.50	1	2020-09-15 12:37:37	2020-09-15 12:37:37	•••

Figure 1. The ANTARES website. Users can browse alerts, examine the pipeline, look at filters, create watch lists, search for alerts, and mark favorite alerts. (Credit: NOIRLab/NSF/AURA)

information in the current alert is added to the history that we already have, including catalog associations.

Once alerts have associated history or known objects, ANTARES then evaluates them based on the features in the alert, from the associated objects, or from the full light curve of the source. Each of these evaluations is a filter, a short piece of Python code that runs on alerts in real time. Once filters have flagged an alert for some criterion, those alerts can be accessed as a separate, smaller stream. Filters can be as simple as finding alerts brighter than a certain threshold or alerts that occur within M31. They can also be complex, such as filters that use machine learning to classify objects based on the shape of their light curves. They can even be dynamic, as our LIGO filter must recognize new detections of gravitational wave sources and then identify new alerts that fall within the footprint of the LIGO detection. Most important, though, is that filters can be user created. Anyone who has an idea about how to identify transient or variable sources of interest can write a filter to implement that idea, and we can then deploy that filter on the alert stream. You can get the subset of the alert stream that you want using ANTARES.

In addition to filtering the alert stream, ANTARES allows users to monitor objects for activity through watch lists. Users can upload a file with coordinates of objects of interest, and then any time there is an alert associated with one of those objects, they will be notified. Currently, this notification goes through the ANTARES Slack channel, so the level of intrusiveness for the notification is completely configurable.

At the ANTARES website (Figure 1), users can browse through recent alerts from ZTF or search for alerts of interest. Each alert page (Figure 2) displays an interactive light curve of the object along with the filters that have flagged that alert. There are also links to external astronomical data repositories. From the website, users can also manage their watch lists, select and follow favorite alerts, and create filters (via a development kit on the NOIRLab Astro Data Lab website). In addition, one can see the overall state of the ANTARES pipeline.

The ANTARES team is already producing scientific results with the system. We have authored more than 30 Astronomer's Telegrams with classifications of transients. We've also reported on the discovery of the first R Corona Borealis star in the public ZTF stream [1] as well as observations of a tidal-disruption event [2]. Soraisam et al. [3] have presented an algorithm to detect anomalies in time-domain streams that we are testing within ANTARES.

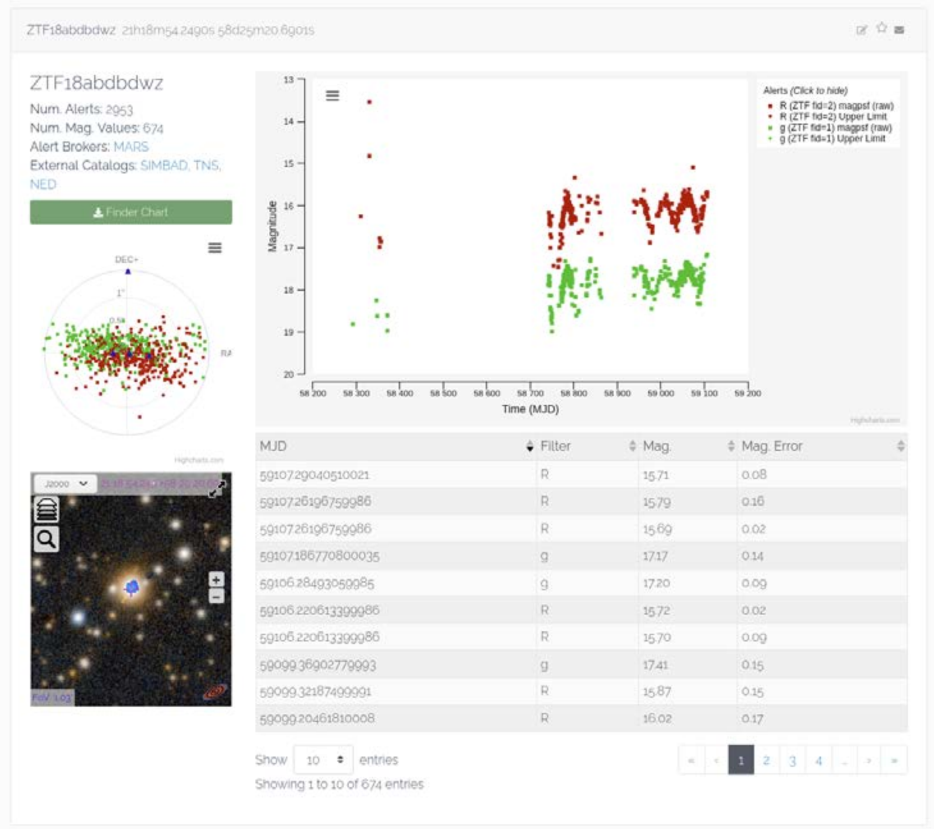
The current implementation of ANTARES can process alerts at the scale produced by ZTF. Our tests indicate that our choices of technology for ANTARES will scale to the LSST production rate with a commensurate increase in CPUs and data storage. We are currently evaluating the options for increasing our resources, including cloud-based solutions. ANTARES is a containerized system, so we can deploy to, and operate on, a wide array of data centers. We look forward to the challenges and promise that the LSST alert stream will bring.

The most valuable input we can receive right now is how you, the user, would like to see the system operate. Our goal is a world-class, community-driven broker. Let us know how we can help you do fantastic time-domain science.

Acknowledgments
The ANTARES team gratefully acknowledges financial support from the National Science Foundation (NSF) through a cooperative agreement with the Association of Universities for Research in Astronomy (AURA) for the operation of NSF's NOIRLab, through an NSF INSPIRE grant to the University of Arizona (CISE AST-1344024, PI: R. Snodgrass), and through a grant from the Heising-Simons Foundation (2018-0909, PI: T. Matheson).

References

[1] Lee, C.-H., et al. 2020, AJ, 159, 61
[2] Lee, C.-H., et al. 2020, ApJL, 892, L1
[3] Soraisam, M. D., et al. 2020, ApJ, 892, 112



ZTF18abdbdwz

Num. Alerts: 2953
Num. Mag. Values: 674
Alert Brokers: MARS
External Catalogs: SIMBAD, TNS, NED

MJD	Filter	Mag.	Mag. Error
59107.29040510021	R	15.71	0.08
59107.26196759986	R	15.79	0.16
59107.26196759986	R	15.69	0.02
59107.186770800035	g	17.17	0.14
59106.28493059985	g	17.20	0.09
59106.220613399986	R	15.72	0.02
59106.220613399986	R	15.70	0.09
59099.36902779993	g	17.41	0.15
59099.32187499991	R	15.87	0.15
59099.20461810008	R	16.02	0.17

Showing 1 to 10 of 674 entries

Figure 2. Page for an individual object, ZTF18abdbdwz. It plots the light curve and location of alerts as well as contextual imagery from other surveys. The page links to information in other catalogs about this object and provides a finder chart to support follow-up observation. (Credit: NOIRLab/NSF/AURA)

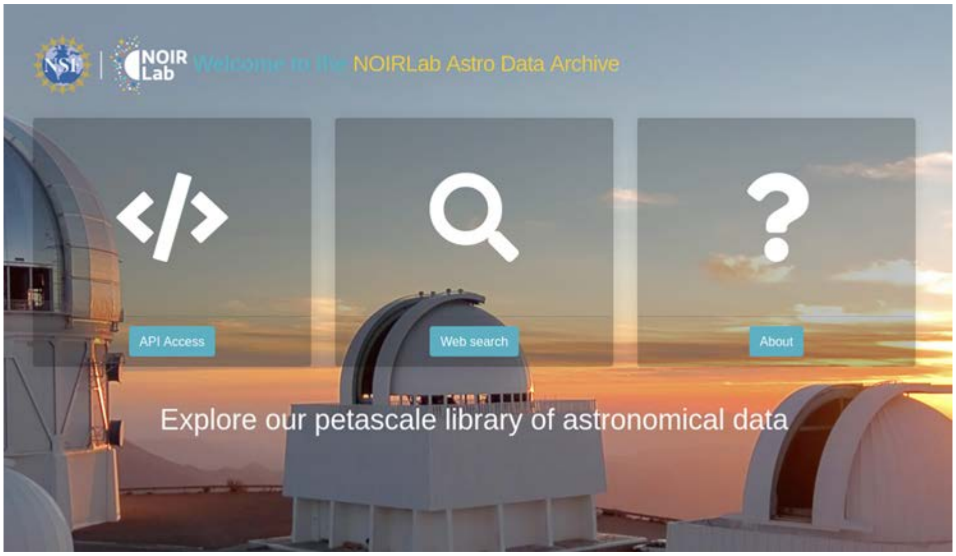
10.5281/zenodo.4444119

NOIRLab Astro Data Archive

Sean McManus & Knut Olsen (NOIRLab)

An archive of raw, reduced, and high-level data products is critical to maximizing the scientific productivity of an observatory. Archives act as multipliers of scientific impact and accessibility and prepare their communities to become frontline users of observatory facilities. The NOIRLab Community Science and Data Center (CSDC) maintains a multi-petabyte-scale library spanning 25+ years of data taken at Cerro Tololo Inter-American Observatory (CTIO) and Kitt Peak National Observatory (KPNO). This resource comprises data acquired through the National Optical Astronomy Observatory (NOAO) and partner (e.g., WIYN, SOAR, SMARTS) observing programs. As NOAO merges into the new NOIRLab organization, CSDC continues to maintain stewardship of this essential asset for the astronomical community. To that end, sustained investments are needed in computer hardware and software technologies to ensure continued access going forward.

To meet the growing technological needs of data-intensive astronomy, CSDC has rolled out a new data archive platform, the NOIRLab Astro Data Archive (Figure 1).


Welcome to the NOIRLab Astro Data Archive

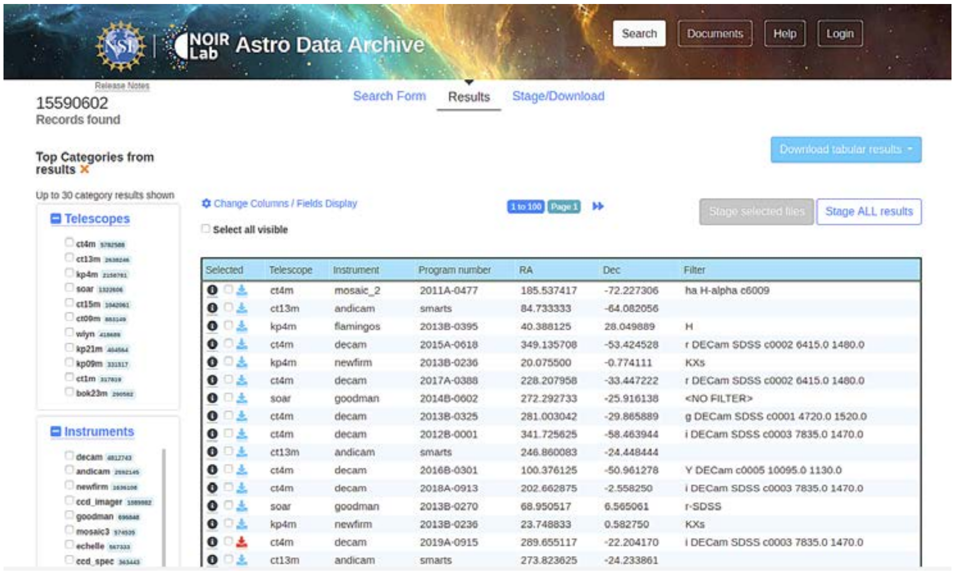
Explore our petascale library of astronomical data

Figure 1. NOIRLab Astro Data Archive home page. (Credit: NOIRLab/NSF/AURA)

The new software system is a complete replacement of the legacy NOAO Science Archive and surpasses its predecessor in capabilities and maintainability. The Astro Data Archive continues the core mission of providing long-term access to public and proprietary telescope data products derived from PI and survey-scale observing programs. In addition, new tools offer enhanced capabilities that add value to data that might have otherwise have been left “dark” or not easily discoverable.

The new Archive source code is built on open-source software, including Django, Postgres, Vue.js, and Elasticsearch. Leveraging these libraries has shrunk the codebase to 20% of that of the legacy system. With the smaller, more nimble software stack, CSDC software engineers are able to quickly deliver new services to users.

While serving a long legacy of historic astronomy data, the Astro Data Archive is also on the front line of capturing data from ongoing operations at CTIO and KPNO, including the hundreds of gigabytes produced each night with the Dark Energy Camera (DECam; mainly funded by the US Department of Energy) on the Víctor M. Blanco 4m Telescope. Images captured with DECam and other instruments are typically stored in FITS (Flexible Image Transport System). FITS images include both data (pixels) and metadata, which consists of ancillary information related to an observation, such as proposal, principal investigator (PI), epoch, filter, and target information.



15590602
Records found

Top Categories from results

Up to 30 category results shown

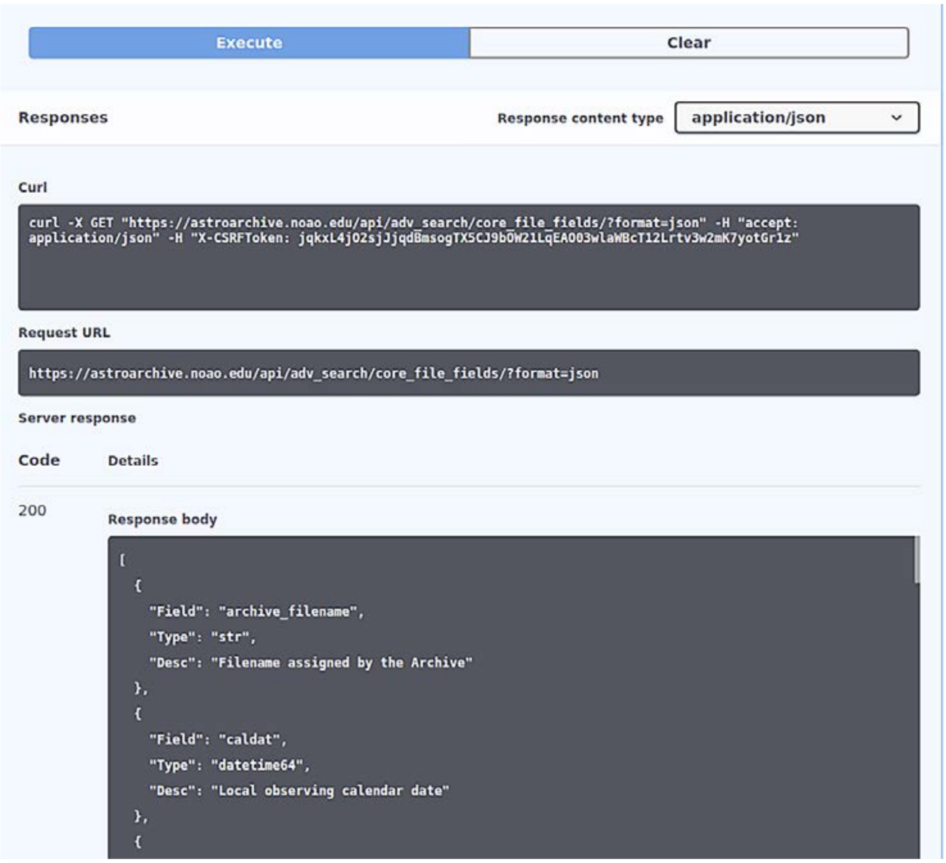
Telescopes
- ☐ ct4m
- ☐ ct13m
- ☐ kp4m
- ☐ soar
- ☐ ct15m
- ☐ ct09m
- ☐ wiyn
- ☐ kp21m
- ☐ kp09m
- ☐ ct1m
- ☐ bok23m

Instruments
- ☐ decam
- ☐ andicam
- ☐ newfirm
- ☐ ccd_imager
- ☐ goodman
- ☐ mosaic3
- ☐ echelle
- ☐ ccd_spec

☐ Select all visible

Selected	Telescope	Instrument	Program number	RA	Dec	Filter
☐	ct4m	mosaic_2	2011A-0477	185.537417	-72.227306	ha H-alpha c6009
☐	ct13m	andicam	smarts	84.733333	-64.082056	
☐	kp4m	flamingos	2013B-0395	40.388125	28.049889	H
☐	ct4m	decam	2015A-0618	349.135708	-53.424528	r DECam SDSS c0002 6415.0 1480.0
☐	kp4m	newfirm	2013B-0236	20.075500	-0.774111	KXs
☐	ct4m	decam	2017A-0388	228.207958	-33.447222	r DECam SDSS c0002 6415.0 1480.0
☐	soar	goodman	2014B-0602	272.292733	-25.916138	<NO FILTER>
☐	ct4m	decam	2013B-0325	281.003042	-29.865889	g DECam SDSS c0001 4720.0 1520.0
☐	ct4m	decam	2012B-0001	341.725625	-58.463944	i DECam SDSS c0003 7835.0 1470.0
☐	ct13m	andicam	smarts	246.860083	-24.448444	
☐	ct4m	decam	2016B-0301	100.376125	-50.961278	Y DECam c0005 10095.0 1130.0
☐	ct4m	decam	2018A-0913	202.662875	-2.558250	i DECam SDSS c0003 7835.0 1470.0
☐	soar	goodman	2013B-0270	68.950517	6.565061	r-SDSS
☐	kp4m	newfirm	2013B-0236	23.748833	0.582750	KXs
☐	ct4m	decam	2019A-0915	289.655117	-22.204170	i DECam SDSS c0003 7835.0 1470.0
☐	ct13m	andicam	smarts	273.823625	-24.233861	

Figure 2. Astro Data Archive search results page and category filters. Users can filter and sort by common fields, view image headers, and download images or tabular data. (Credit: NOIRLab/NSF/AURA)



Responses

Response content type: application/json

Curl

```
curl -X GET "https://astroarchive.noao.edu/api/adv_search/core_file_fields/?format=json" -H "accept:
application/json" -H "X-CSRFToken: jqkxL4jO2sjJjqdBmsogTX5CJ9bOW21LqEAO03wlaWBcT12Lrtv3w2mK7yotGr1z"
```

Request URL

```
https://astroarchive.noao.edu/api/adv_search/core_file_fields/?format=json
```

Server response

Code	Details
200	Response body

```
[
  {
    "Field": "archive_filename",
    "Type": "str",
    "Desc": "Filename assigned by the Archive"
  },
  {
    "Field": "caldat",
    "Type": "datetime64",
    "Desc": "Local observing calendar date"
  },
  {
```

Figure 3. Screenshot of Astro Data Archive live documentation. This page describes basic API usage and options with real working examples that users can edit and try out. In this particular example, the core file fields service provides common field descriptions available for search for all instruments. (Credit: NOIRLab/NSF/AURA)

Because the Archive stores millions of files from nearly 40 different custom telescope and instrument combinations spanning decades, it is a challenge to normalize heterogeneous data sufficiently to make them discoverable to a simple user interface. The new system abstracts this complication into so-called "personalities," which are applied when the data are ingested. Personalities define a set of instructions on how to process metadata for each instrument and provide the mapping functions needed to translate raw FITS keywords into commonly known search fields (e.g., RA, DEC, FILTER). Some instrument-specific keywords don't map to well-understood fields but are still potentially valuable to the end user (e.g., engineering data). Those extra keywords are also captured into a special data type that is searchable via the application program interface (API) Advanced Search mechanism (see below).

A main goal of the Astro Data Archive is to offer several modes of data access and to make petabytes of file holdings transparent to a variety of use cases for users with different interests and technical expertise. This is accomplished by providing complementary graphical and programmatic search interfaces.

The graphical user interface aims to provide a convenient means of data discovery and distribution to the user, whether it be a PI seeking their observing run or a general researcher looking for information on a particular target. Similar to most search engines, users are able to provide as much or as little information as desired to explore the entire petabyte-scale Archive. The graphical user interface is backed by Elasticsearch, which is an open-source distributed search engine. It works similarly to Google in the sense that search results are delivered nearly instantaneously by a scaled back end, which facilitates ad hoc data exploration and discovery. Users can add or remove filters to their search without providing a priori information (Figure 2).

To meet the demands of data-intensive science, a new API is available for researchers seeking programmatic entry to the Archive. The API offers many service endpoints for varying use cases. For example, the well-established Simple Image Access protocol is available for quick data discovery with RA/DEC position and radius. In addition, the Advanced Search service offers an interface for deep searches across the entire Archive, including instrument-specific metadata. API search results are available in many formats (CSV, JSON, VOTable) and deliver direct access to image-pixel data through a download service.

To lower the learning curve of using programmatic interfaces, the Archive API endpoints are described and illustrated through live documentation (Figure 3) that includes working examples of search specifications and results in common formats. In addition, science workflows are demonstrated through Python Jupyter notebooks, and the NOIRLab module is provided through Astroquery.

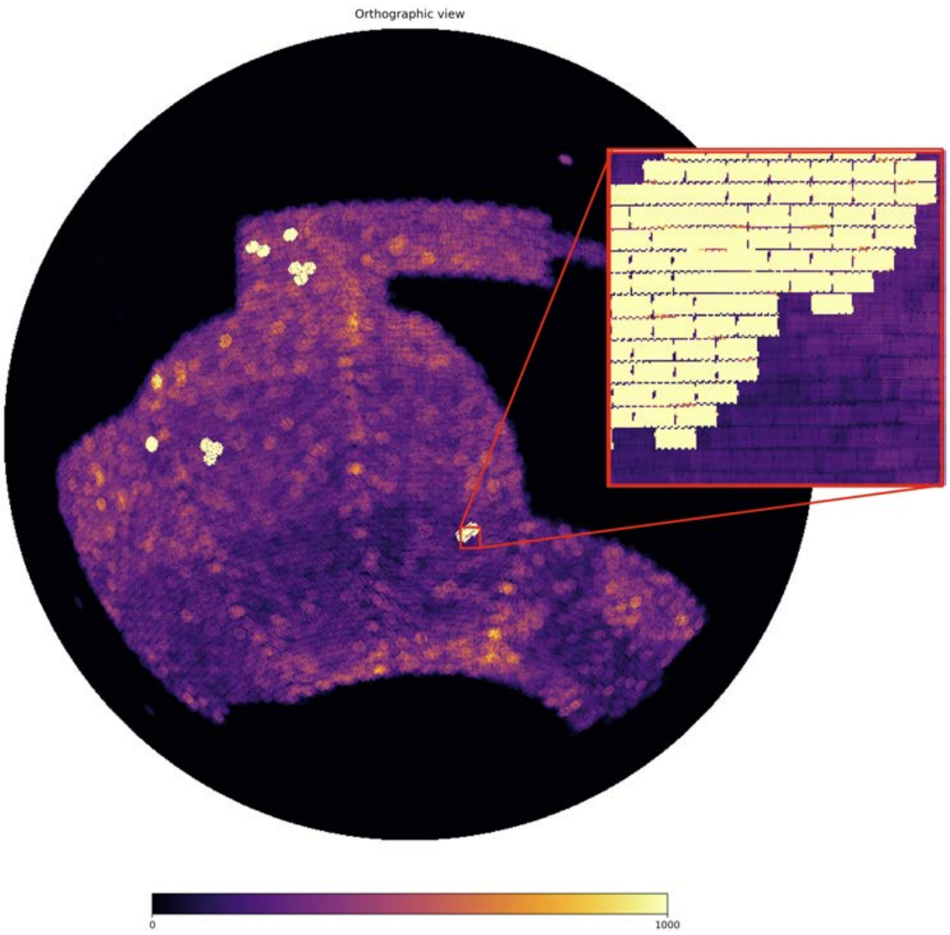


Figure 4. Effective exposure time for the Dark Energy Survey, as computed by the exposure-map.ipynb notebook found in the Archive GitHub repository. The larger map shows the effective exposure time variation across the DES footprint, which is largely uniform except for features introduced by the deep supernova fields, seams in the tiling scheme, and variations in observing conditions. The inset, which features a small region near a pair of supernova fields, shows the map's resolution, which is finer than that of the individual Dark Energy Camera CCDs.
(Credit: NOIRLab/NSF/AURA)

As an example use case of the Astro Data Archive's new capabilities, a user wanting to probe the Dark Energy Survey (DES) DR1 catalog (served through the NOIRLab Astro Data Lab) for new Milky Way structures would likely need the spatially dependent DES depth map to uniformly measure the density of detected objects. This depth depends on the exposure time of all of the images covering each location in the survey footprint and the seeing, sky brightness, and transparency when those images were taken. As demonstrated in the exposure-map.ipynb notebook linked from the Astro Data Archive, the archive is able to retrieve, within a few minutes, information on transparency and exposure time from the headers of 50,000+ full-focal-plane DECam images in seconds and information on image quality, sky brightness, and CCD corner coordinates for the more than 3 million individual DECam CCDs contained in those images. With this information in hand, the notebook shows how to create a high-resolution map of total effective exposure time, shown in Figure 4.

Visit the Astro Data Archive website to give the interface a try, and contact us if you have ideas for more example use cases that we could showcase in notebooks!

10.5281/zenodo.4444121

Crowdsourcing the Sky

David Nidever (Montana State University, NOIRLab), Katie Fasbender (Montana State University), Arjun Dey (NOIRLab), and the NOIRLab Astro Data Lab team

Astronomy is now firmly in the era of Big Data!

Starting with the Sloan Digital Sky Survey over twenty years ago and continuing with Pan-STARRS-1, the Dark Energy Survey (DES), and most recently the Zwicky Transient Facility (ZTF), large and systematic imaging surveys have established themselves as foundational to the progress of astronomy. They have opened new doors to our understanding of the Galaxy and the Universe more broadly and allowed more systematic studies with larger samples. The next big step forward will be the Rubin Observatory Legacy Survey of Space and Time (LSST), which will begin in a few years and will map the southern sky roughly every three days.

In addition to these systematic surveys, the Astro Data Archive at NOIRLab is a valuable storehouse of numerous multi-band images that now cover almost the entire sky. These data, taken by many diverse programs, offer a new opportunity to study the variability and motion of astronomical sources. The NOIRLab Source Catalog (NSC; formerly known as the NOAO Source Catalog; [1], [2]) uses this diverse "crowd-sourced" data to construct a novel new catalog of the sky. The NSC uses an automated implementation of Source Extractor to detect sources on each individual image in the archive and then attempts to gather together the multi-epoch and multi-band photometry for each unique object.

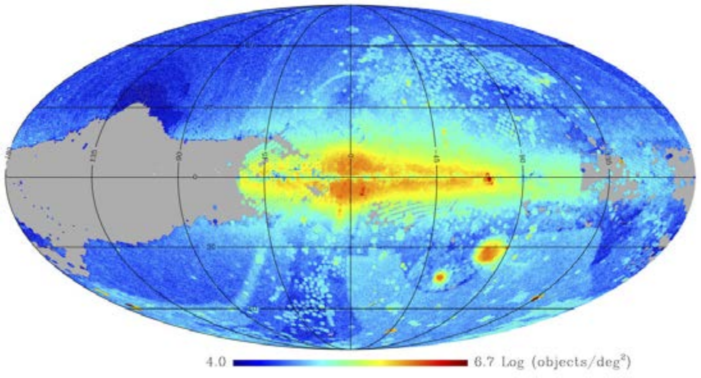


Figure 1. Density of 3.9 billion objects in NSC DR2 in an Aitoff projection and Galactic coordinates. (Credit: NOIRLab/NSF/AURA)

The second NSC data release (DR2) was made publicly available in November 2020 and is described in [2]. The data are accessible in the Astro Data Lab at NSF's NOIRLab. NSC DR2 contains 68 billion time-series photometric measurements of 3.9 billion objects over 86% of the sky spanning seven years in multiple photometric bands, as well as accurate proper motion measurements (Figure 1). It catalogs the largest number of unique astronomical objects to date. The NSC includes a lot of temporal information, with 100 million objects having at least 100 measurements. This opens up the faint "variable sky" to exploration. The NSC is novel in many respects: (a) it covers almost all of the southern sky, which has not yet been well-studied and; (b) it has tens to hundreds of epochs of time-series measurements of hundreds of millions of objects that are significantly deeper than previous surveys (~1.5 mag deeper than single epoch Pan-STARRS1, PS1; [3]).

The NSC offers new ways of addressing diverse astrophysical questions:

1. The Milky Way is orbited by faint dwarf galaxy satellites that can be challenging to detect. Many Milky Way dwarf satellites may remain undetected [4], especially in the southern sky. The NSC covers most of the Southern Hemisphere in multiple bands to depths that would allow for more satellites to be uncovered.
2. The Milky Way halo hosts a number of stellar streams from tidally stripped galaxies and globular clusters, the most famous of which, the Sagittarius stellar stream [5], [6], stretches 360° around the sky. Under the currently favored hierarchical galaxy formation model, galaxies like the Milky Way are formed through the continual merging and accretion of smaller galaxies. The streams that we currently see are relics of this process. Studying these streams can help us understand how the galaxy was formed, its accretion history, and its mass. The NSC covers regions of the sky that have not yet been explored for stellar streams.
3. Variable stars, such as RR Lyrae, are standard candles that can be used to explore coherent structures in the Milky Way halo. The NSC sensitivity to RR Lyrae stars extends

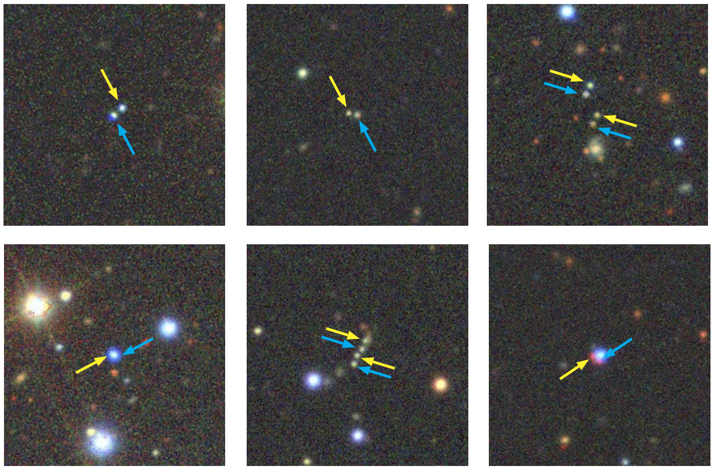


Figure 2. Six examples of high proper motion stars detected in NSC DR2. In the images in the printed version of this edition, the large motion of each star is indicated by a blue arrow and a yellow arrow which identify the star at two epochs. In the online version the images are animated to blink between two epochs to show the large motion. Images produced by A. Dey from the Legacy Survey Viewer. (Credit: NOIRLab/NSF/AURA)

throughout the Milky Way and its satellites. The NSC's precomputed variability indices make it especially easy to select variable stars for further analysis, with over 23 million objects flagged as variable at the 10σ level.

4. The temporal information can also be harnessed to explore the motion of stars in the plane of the sky. The NSC's accurate proper motions can be used to extend kinematic studies of the solar neighborhood and the Milky Way to fainter objects than are available to *Gaia* by at least two magnitudes. Nearby high proper motion objects are especially interesting, to study the population of white dwarfs and brown dwarfs. See Figure 2 for examples of some high proper motion objects detected in NSC DR2.

5. Closer to home, faint Solar System objects await discovery within the NSC. Follow-up work has already identified ~500,000 Solar System "tracklets" (see Figure 3,) and full orbital fitting is soon to follow [7]. In particular, there is interest in finding nearby objects that could potentially impact the Earth, and NSC can be used to "precover" objects that will be discovered in future surveys. Finally, evidence of Planet 9 [8], if it exists, could be lurking inside the NSC.

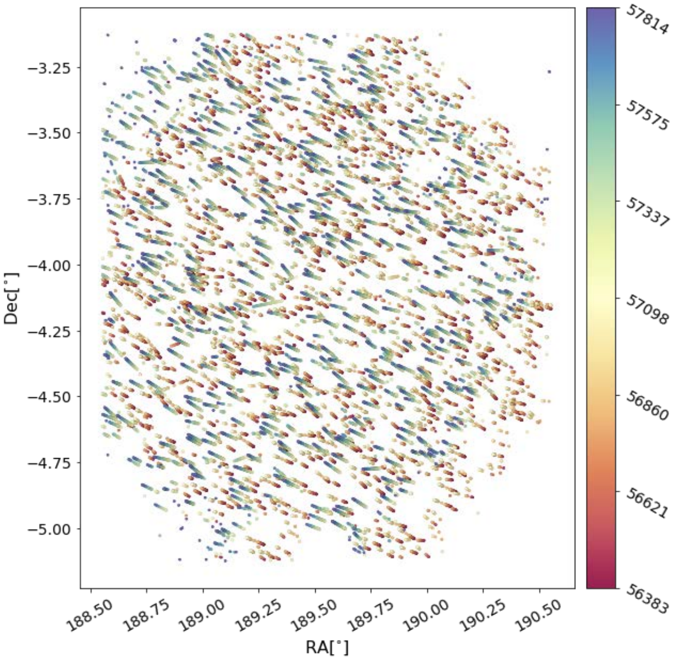


Figure 3. Tracklets of Solar System objects in NSC DR2 near the ecliptic plane, color-coded by Modified Julian Date [8].

6. Active galactic nuclei host supermassive black holes at the centers of galaxies and investigating their NSC photometric variability could be used to study the accretion history of material onto the black hole, estimate the black hole mass, and explore the structure of the broad emission-line region.

The NSC opens up many interesting science cases and allows us to hone our Big Data analysis skills and software in preparation for the LSST.

References

[1] Nidever, D. L., et al. 2018, AJ, 156, 131
[2] Nidever, D. L., et al. 2021, AJ, in press, arXiv:2011.08868
[3] Chambers, K. C., et al. 2016, arXiv:1612.05560
[4] Nadler, E. O., et al. 2019, ApJ, 873, 34
[5] Majewski, S. R., et al. 2003, ApJ, 599, 1082
[6] Koposov, S. E., et al. 2012, ApJ, 750, 80
[7] Batygin, K. & Brown, M. E. 2016, AJ, 151, 22
[8] Fasbender, K. M. & Nidever, D. L. 2021, AJ, submitted

10.5281/zenodo.4444126

TAC Modernization

Dara Norman, Nicole van der Bliek (NOIRLab), and the NOIRLab TAC Team

NOIRLab's mission is to *"promote excellence in astronomical research by providing access to information about the Universe from state-of-the-art facilities, surveys, and archives."* The Time Allocation Committee (TAC) process is an important part of that mission.

The TAC process is a core function of NOIRLab and is used to allocate time on both NOIRLab and privately operated telescopes. We issue calls for standard proposals every six months, and there are opportunities to apply for survey and long-term observing time. The TAC proposal review process operates as part of a larger user support infrastructure.

Although the NOIRLab TAC process is well respected and held up as a standard in the astronomical community, it is evident that both the software infrastructure and processes need to be modernized. We have embarked on a project to upgrade the TAC processes to better support evolving good practices for subjective evaluations, as well as to upgrade the TAC infrastructure to support these changes and improve our user support.

As with other modern subjective evaluation systems, the NOIRLab TAC will be moving to a 2-stage review process. Here we answer some common questions about plans for the new process.

Why is the NOIRLab TAC moving to a 2-stage process?
Several groups have studied proposal acceptance outcomes from their telescope allocation process and concluded that gender bias may be a factor [1], [2]. NOIRLab staff examined proposal acceptance information over 17 semesters from 2008A through 2016A. Total submissions are consistently ~400 proposals per semester. We find that with the exception of 4 semesters (08B, 09B, 11A, 13B), proposals by female principal investigators (PIs) had a consistently lower than expected acceptance rate compared to proposals by male PIs. We recognize that there are many factors that influence TAC decisions about the acceptance (or rejection) of any individual proposal; however, our goal since semester 14A has been to take incremental steps to mitigate the role of unconscious bias in our TAC process.

Why isn't the NOIRLab TAC adopting the same dual-anonymous process as STScI and NASA?
The NOIRLab TAC team is familiar with the modern good practices for proposal review including lessons learned from the STScI dual-anonymous review process. However, the procedure adopted by STScI is not entirely compatible with some of the mission objectives of our TAC process, including support for thesis datasets and provision of access to researchers at small and underserved institutions. Therefore, we plan to implement our review as a 2-stage process where the first stage includes a review of

> "The TAC process is a core function of NOIRLab and is used to allocate time on both NOIRLab and privately operated telescopes."

anonymized proposals and the second stage, after a proposal team reveal, allows for ranking adjustments that support NOIRLab mission priorities.

These adjustments include taking into consideration the mission objective mentioned above, i.e., considerations such as thesis proposals and access to researchers at small and underserved institutions. Guidance for panel members (and proposers) will be provided in advance about what makes proposals eligible to be considered for adjustments. Only those proposals with science rankings above or close to the scheduling cutoff will be considered for adjustment.

When will this change to a 2-stage process for the NOIRLab TAC happen?
We anticipate that this 2-stage process will be implemented no earlier than 2022B and at least one semester after the new infrastructure implementation.

Why isn't this change happening sooner?
Our TAC modernization project includes an upgrade of both the TAC process and the TAC infrastructure. The NOIRLab TAC infrastructure upgrade is necessary to implement a system architecture that can support the required procedural changes. Moreover, the current legacy system, which was implemented in the 2000s, is outdated and difficult to maintain, integrates poorly with the TAC database and software frameworks adopted in other parts of NOIRLab, and requires significant manual intervention. Our team plans to have comprehensive documents and instructions available for all stakeholders at the time of rollout of the new procedure.

Will there be other important changes to the proposal process?
Yes. Proposal form fields will no longer support LaTeX formatting, and proposal submissions must be made using the upgraded proposal form. In the future, text sections, such as scientific justification and experimental design, will be accepted as PDF attachments.

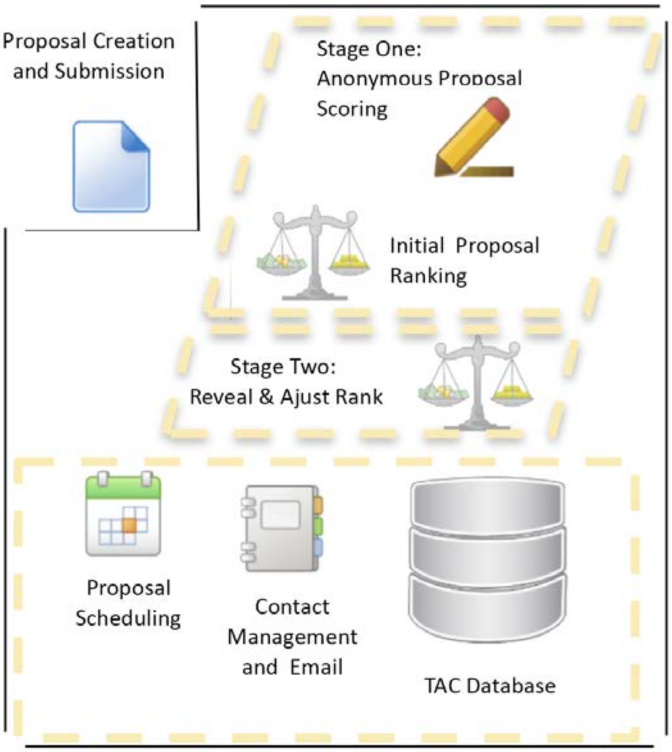


Figure 1. The time allocation process includes a number of activities. Among these are proposal acceptance, review panel assembly and ranking, receipt of proposal scheduling and management of notifications. Modernization of the time allocation process will improve the organization of the system workflow, allowing for better automation and new software features that will enable the implementation of current good practice in proposal review. This updated practice will include a dual-anonymous review of proposals in stage one.

References

[1] Reid, I. N. 2014, PASP, 126, 923
[2] Patat, F. 2016, arXiv:1610.00920

10.5281/zenodo.4444128

DRAGONS Science Quality Verification: Imaging Part 2

Simon Conseil, Rodrigo Carrasco, Kathleen Labrie, Chris Simpson, Joanna Thomas-Osip, and James Turner (NOIRLab)

This is the second of a series of articles on the verification of Data Reduction for Astronomy from Gemini Observatory North and South (DRAGONS), the first public release of which occurred in late 2019. The first article in the series was presented in the inaugural issue of The Mirror. Here we present another example with a different instrument, the Gemini South Adaptive Optics Imager (GSAOI), and compare with an equivalent Gemini Image Reduction and Analysis Facility (IRAF) reduction for the purpose of demonstrating similar photometric accuracy.

The GSAOI dataset covers three bands (*J*, *H*, *Ks*). For each band, we have 24 raw images, as well as lamp-on and lamp-off dome flat exposures (only lamp-on for the *J* band). The data are available in the Gemini Observatory Archive. The reductions were done with both DRAGONS and IRAF (using the PyRAF wrapper) in a standard way as described in the DRAGONS tutorials and the Gemini IRAF examples. DRAGONS and Gemini IRAF do not have the same default parameter options, so it is important to consider certain parameters carefully, as will be shown.

The output units for Gemini IRAF are either Analog to Digital Units (ADUs) (F2, NIRI) or electrons (GMOS, GSAOI), whereas DRAGONS' output is always in electrons. Sources are detected in the stacked images, using DRAGONS' detectSources primitive which runs SExtractor [1]. A list of reference sources with magnitudes from the Two Micron All Sky Survey[a] (2MASS) catalog is included with the stacked data. The reference catalog is matched to the sources detected in the image and it is used to determine the astrometric solution, and can then be used to measure the magnitude zeropoint. This is very similar to the procedure used by the Quality Assessment Pipeline (QAP, an internal Observatory tool used by observers to assess the data characteristics). Sources without measured instrumental magnitudes or reference magnitudes are removed.

To reduce the science images with PyRAF/IRAF, we use the **skyimg="time"** option to compute the sky image in a way similar to DRAGONS, filtering the current list for images that are within maxtime=900s of the image currently being reduced. The parameters **"fl_mult=no"** and **"fl_autosky=no"** are used to keep the values in ADUs and to avoid adding back the median sky level, respectively. The latter parameter choice makes it easier to compare the PyRAF reduced images with DRAGONS.

Finally, for both IRAF and DRAGONS, we correct the distortions and stack the images with Disco-Stu, with the

“--reference” option to use the same World Coordinate System (WCS) for the purpose of the comparison. Before running Disco-Stu, the mean background level was manually subtracted for both the DRAGONS and IRAF reductions. The **“skysub”** option in Disco-Stu did not work for this data set because at the time, it was not using the object masks and was using a less robust fitting method. This has been fixed and will be available in a future release.

To compare the photometric accuracy of the reductions, we provide two types of plots. Figure 1 compares the measured magnitudes with the reference catalog magnitudes. This plot has fewer sources, because the 2MASS reference catalog does not have many measured objects over the Gemini/GSAOI field. We compute a mean error for the magnitude difference, weighted by the individual magnitude errors. The sources that are excluded from DRAGONS for the reasons mentioned above are also excluded from the IRAF results in order to use the same sources. Figure 2 compares the magnitudes for all the sources that have been detected and matched in the two final images.

With this comparison we have shown that the magnitudes obtained from the stacked images produced using the two software packages are consistent. The mean difference with respect to the reference magnitudes is usually less than 0.05 to 0.1 mag and DRAGONS performs at least as well as IRAF.

DRAGONS has a better handling of bad, non-linear, and saturated pixels, with data-quality flags that are propagated through the reduction and to SExtractor, and then used to exclude these problematic sources. DRAGONS also provides a much faster data processing and a simpler reduction experience compared to IRAF. Further details can be found in the report DRAGONS Science Quality Verification: Imaging[b].

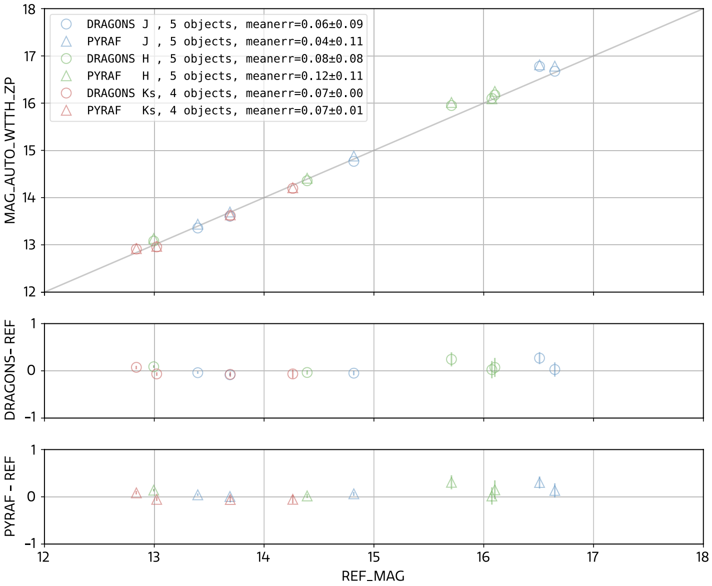


Figure 1. The top panel plots the magnitude from SExtractor (using the MAG_AUTO parameter that uses an adaptively scaled aperture) versus the 2MASS catalog reference magnitude. The bottom panels show the magnitude difference, MAG_AUTO – REF_MAG, for DRAGONS and IRAF. (Credit: NOIRLab/NSF/AURA/U. Mass/IRAC/Caltech/NASA)

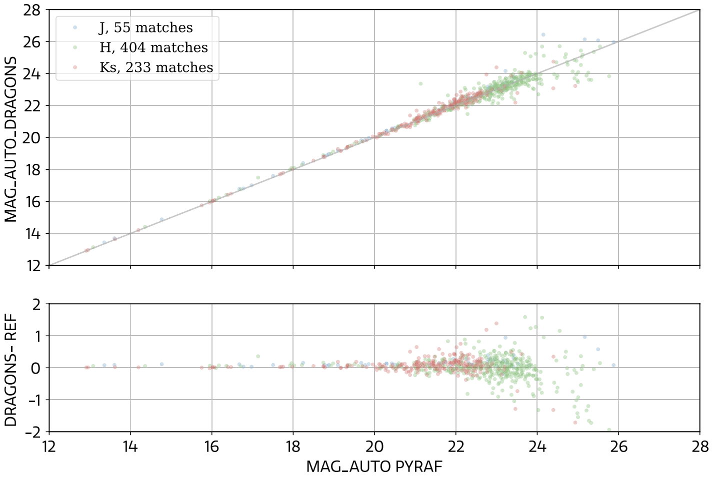


Figure 2. Comparison of DRAGONS and IRAF magnitudes (both from SExtractor MAG_AUTO) for the *J* (blue), *H* (green) and *Ks* (red) bands. (Credit: NOIRLab/NSF/AURA/U. Mass/IRAC/Caltech/NASA)

References

[1] Bertin, E. & Arnouts, S. 1996, A&AS, 117, 393

Notes

[a] This publication makes use of data products from 2MASS, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

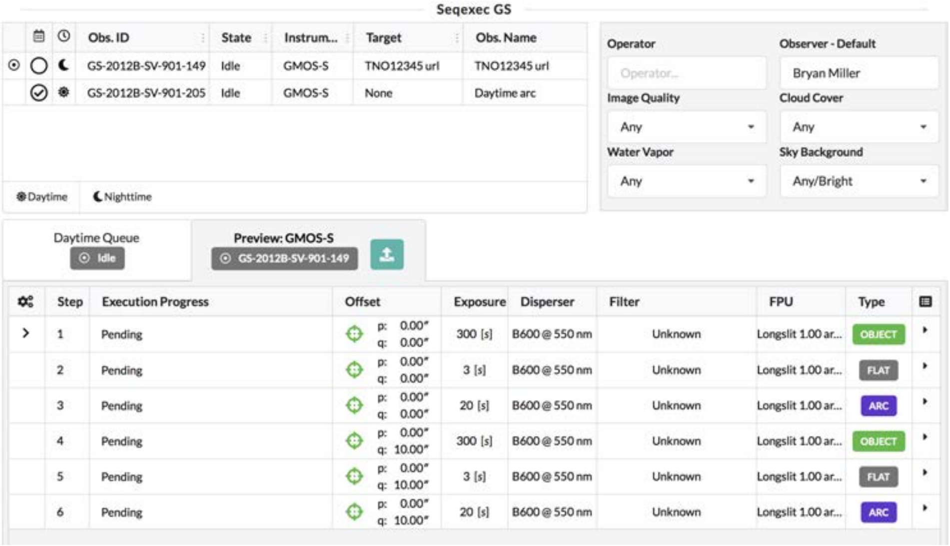
[b] http://www.gemini.edu/sciops/data/SUSD/DRAGONSimagingSVReport.pdf

10.5281/zenodo.4444130

Gemini OCS Upgrades: A Blueprint for NOIRLab Operations Software in the 2020s

Bryan Miller, Andrew Stephens, Arturo Nuñez, and Andy Adamson (NOIRLab)

Gemini's Observatory Control System (OCS) is the set of high-level software tools for proposal submission through observation execution, for example, the current Phase I Tool (PIT) and the Observing Tool (OT). While these tools have been improving since the start of science operations in 2000, limitations in their design and technology make them difficult to maintain and to update with the capabilities required for the next decades.



Seqexec GS

			Obs. ID	State	Instrum...	Target	Obs. Name
⊙	○	☾	GS-2012B-SV-901-149	Idle	GMOS-S	TNO12345 url	TNO12345 url
	✓	✹	GS-2012B-SV-901-205	Idle	GMOS-S	None	Daytime arc

Operator: Operator...
Observer - Default: Bryan Miller
Image Quality: Any
Cloud Cover: Any
Water Vapor: Any
Sky Background: Any/Bright

Daytime Queue: Idle
Preview: GMOS-S: GS-2012B-SV-901-149

Step	Execution Progress	Offset	Exposure	Disperser	Filter	FPU	Type
1	Pending	p: 0.00″ q: 0.00″	300 [s]	B600 @ 550 nm	Unknown	Longslit 1.00 ar...	OBJECT
2	Pending	p: 0.00″ q: 0.00″	3 [s]	B600 @ 550 nm	Unknown	Longslit 1.00 ar...	FLAT
3	Pending	p: 0.00″ q: 0.00″	20 [s]	B600 @ 550 nm	Unknown	Longslit 1.00 ar...	ARC
4	Pending	p: 0.00″ q: 10.00″	300 [s]	B600 @ 550 nm	Unknown	Longslit 1.00 ar...	OBJECT
5	Pending	p: 0.00″ q: 10.00″	3 [s]	B600 @ 550 nm	Unknown	Longslit 1.00 ar...	FLAT
6	Pending	p: 0.00″ q: 10.00″	20 [s]	B600 @ 550 nm	Unknown	Longslit 1.00 ar...	ARC

Figure 1. Web seqexec client view. (Credit: NOIRLab/NSF/AURA)

Therefore, Gemini/NOIRLab has embarked on an ambitious software development program to replace the entire suite of desktop applications with modern, redesigned, web-based tools. This program is composed of a set of related projects that replace different components of the system using common underlying libraries and interfaces. The goals of the program are to:

- Improve usability—e.g., make proposal and observation preparation much easier;
- Improve efficiency—e.g., improve flexibility and reduce staff workload;
- Support Time Domain Astronomy (TDA)—e.g., provide the software framework for Gemini's new adaptive scheduling tool and application program interfaces (APIs);
- Support new instruments and systems—e.g., SCORPIO and GNAO;
- Avoid obsolescence—e.g., make the code maintainable and scalable;
- Provide a framework for future telescope operations—e.g., the US ELT Program.

Tremendous progress has been made since this effort was first described in the October 2017 issue of *GeminiFocus*. This article summarizes recent advances, provides the current timelines, and describes how the community can contribute.

Web-based Sequence Executor

The sequence executor, or seqexec, is the tool that carries out the observation sequences defined in the OT. It communicates with the telescope and instrument hardware in order to manage guiding, do telescope offsets, configure instruments, and take the data. The original version was written in Tcl/Tk as a temporary application. Functional but limited, it remained in use but grew rather ungainly over the years. It is now very hard to find developers who are familiar with Tcl/Tk.

> “This project has allowed us to solve many technical issues and gain experience with the libraries that will be used for the remaining development.”

The Tcl/Tk seqexec has now been replaced with the first product of the OCS Upgrades Program. The new **web seqexec** started being used in regular nightly operations in August, 2020. It is designed with a client-server architecture that is more suited to base-facility operations. The server is written in Scala, a commonly used, modern functional programming language that is the standard of the new system. It runs at the summit and coordinates the use of the hardware. This improves instrument safety since it remains in control of the systems even if communication with the client is lost. It also improves efficiency by allowing simultaneous calibrations with multiple instruments. Multiple users can connect to the server using standard web browsers, allowing easy control and monitoring of activities. A screenshot of a client is shown in Figure 1. This project has allowed us to solve many technical issues and gain experience with the libraries that will be used for the remaining development.

Gemini Program Platform

The Gemini Program Platform (GPP) is the largest of the OCS Upgrades projects and forms the core since it will replace the PIT, OT, and the observing databases. The main concepts were developed from user input over the years, an OCS Upgrades working group that included Gemini and National Gemini Office (NGO) staff and community representatives, and internal staff discussions. The top-level concepts and changes are as follows:

- It will use scientific or physical descriptions whenever possible (for example wavelength range, spectral resolving power, signal-to-noise ratio, and on-source physical conditions constraints—e.g., IQ in arcsec, extinction in magnitudes—rather than percentile bins);
- Valid, complete observations will be created automatically with the option for user customization;
- Observations with Gemini North and South will be supported in the same science program;
- Interfaces will be available as web applications; no more downloading and installing large desktop applications every semester;
- It will be built around and use the Integration Time Calculators (ITCs) for determining exposure times and signal-to-noise ratios;
- Calibration steps will be generated automatically and the configurations will be kept in sync with the associated science observations;
- Logical observation grouping (e.g., AND/OR) and relative timing constraints between observations will be implemented for organizational flexibility and supporting complex cadences.

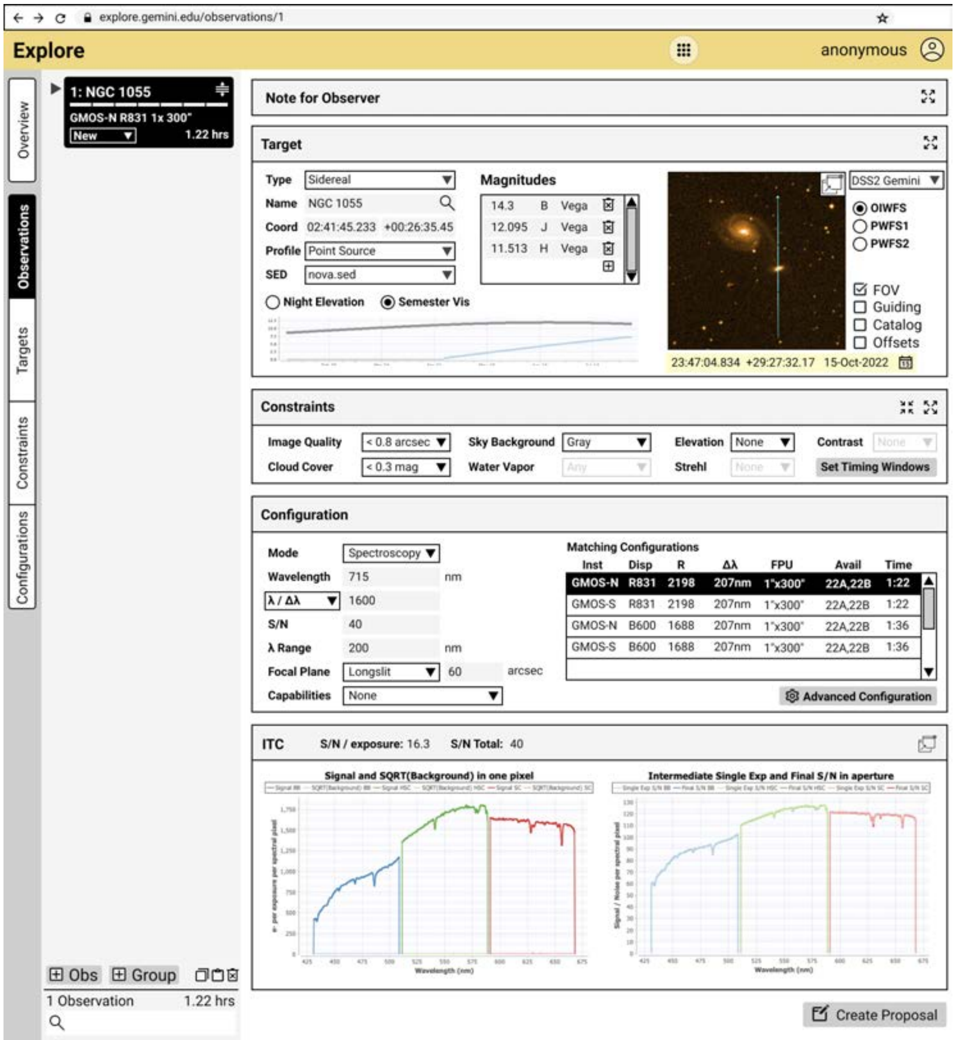
The core of the system will be a Postgres database located on a cloud service. A relational database of this sort has important performance and scalability advantages over the current system. All of the other services and applications will connect to the central database and provide task-specific views of the database. There will also be a set of APIs for enhanced programmatic access.

The community will mainly interact with an application that we call Explore. This is the functional replacement for both the PIT and OT. It is built around the ITCs and also has a “Phase 0” capability for finding and choosing the instruments and modes that meet the requirements on capability, wavelength range, spatial and spectral resolution, etc. A mockup of a possible Explore interface is shown in Figure 2.

GPP passed its Inception (Design) Review in early July 2020 and is now under construction. The documentation is available from the Operations Development web page. The current project plan has early science use starting in 2022 and operational deployment in 2023.

Adaptive Queue Scheduler

Currently, Gemini queue plans are created manually by the queue coordinators at each site. While of high quality, they can take several hours a day to produce and then can be



1: NGC 1055
GMOS-N R831 1x 300"
New 1.22 hrs

Target
Type Sidereal
Name NGC 1055
Coord 02:41:45.233 +00:26:35.45
Profile Point Source
SED nova.sed

Magnitudes

14.3	B	Vega
12.095	J	Vega
11.513	H	Vega

23:47:04.834 +29:27:32.17 15-Oct-2022

Constraints
Image Quality < 0.8 arcsec
Cloud Cover < 0.3 mag
Sky Background Gray
Water Vapor Any
Elevation None
Strehl None
Contrast None

Configuration
Mode Spectroscopy
Wavelength 715 nm
λ / Δλ 1600
S/N 40
λ Range 200 nm
Focal Plane Longslit 60 arcsec
Capabilities None

Matching Configurations

Inst	Disp	R	Δλ	FPU	Avail	Time
GMOS-N	R831	2198	207nm	1"x300"	22A,22B	1:22
GMOS-S	R831	2198	207nm	1"x300"	22A,22B	1:22
GMOS-N	B600	1688	207nm	1"x300"	22A,22B	1:36
GMOS-S	B600	1688	207nm	1"x300"	22A,22B	1:36

ITC S/N / exposure: 16.3 S/N Total: 40

1 Observation 1.22 hrs

Figure 2. A mockup of a possible GPP Explore interface showing target information, constraints, ITC results, and matching configurations (Phase 0). (Credit: NOIRLab/NSF/AURA)

difficult to modify when changes occur at night. Therefore, we have begun a project to develop an automatic scheduling capability. This will run in real time and create new plans as conditions change and new observations are triggered, for example from alerts originating from the Legacy Survey of Space and Time (LSST). Both telescopes, North and South, will be scheduled together, thereby increasing the chances of finishing high-priority programs, simplifying some target-of-opportunity programs, and enabling better coordination between the sites. Intermediate and long-term schedulers that can make recommendations about instrument component swaps and the best times for classical runs are also being investigated. We are currently running a trade study of scheduling algorithms and working towards a design review by mid 2021. This capability should save significant staff effort and make operations more flexible. We expect that the scheduler will be deployed along with GPP in 2023.

This work is being funded in part by the GEMMA supplemental funding award that will also deliver real-time GMOS long-slit data reduction using the DRAGONS pipeline.

Engage

Engage will replace the legacy Tcl/Tk Telescope Control Console (TCC) that is the telescope operator's main interface for slewing the telescope, configuring the subsystems, and starting the guiding. Engage will use a similar client-server architecture and infrastructure as the web seqexec. The project started in early 2020 and we are currently reviewing the operations concept and working on user interface designs.

Testing and the Future

Community involvement is important for the success of this effort. Suggestions can be submitted using the form provided on the Operations Development page. In 2021 we will be recruiting testers for the early versions of GPP. Stay tuned to the Operations Development web page, the Science Software blog, and future electronic newsletters.

After a couple of years of planning, the OCS Upgrades Program is now producing new tools and actively developing the system that will underpin Gemini operations for the next two decades. The resulting system will be easier to use and easier to maintain. It is also being considered as the core of operations management systems for future facilities that NOIRLab may be involved in, such as the US ELT program. GPP in particular could be readily integrated into a future NOIRLab observing program management and operations system.

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Wide-Field Speckle Imaging from Both Hemispheres

Elliott Horch (Southern Connecticut State University) and Ricardo Salinas (NOIRLab)

Although speckle imaging has been used in astronomy since the 1970s, it remains a somewhat mysterious method to many astronomers. At its essence, the reduction of speckle data is in the category of deconvolution problems in mathematics: the atmosphere acts as a linear, if complicated, operator on the image itself, and so this permits the deconvolution of the image if the point spread function (PSF) is sufficiently well known. Ideally, one would have an isolated point source very close to the object of interest and one could take speckle data simultaneously of both. However, the approximation of linearity only works over a small patch of sky, and usually there is not a bright point source close enough to the target of interest to satisfy this requirement.

The speckle technique is able to overcome the latter limitation so that, generally speaking, the PSF need not be measured at the same time as the object of interest. However, for a robust deconvolution, the point source data should be taken under the same atmospheric conditions (that is, similar statistics to the turbulent layer[s] creating the speckle effect, and therefore similar seeing). Nonetheless, a key advantage in working with speckle data is that the image improvements are obtained after the observation is complete, through mathematical manipulation of the images. This permits the reduction and analysis of the raw data in ways that can be changed later, tailoring to the image morphology itself. In a star cluster, for example, which may be viewed as a collection of point sources, a bright, reasonably isolated star in the cluster can serve as the PSF for the reconstruction. On the other hand, an extended object, like a planet or asteroid, may require a different reduction method to achieve the desired result.

The ʻAlopeke and Zorro speckle cameras, built by Nic Scott, Steve Howell, one of us (E.H.), and Emmett Quigley, are permanently mounted on the telescopes at Gemini North and Gemini South, respectively. They have been designed to take advantage of this post-processing flexibility. In particular, a wide-field mode was designed into the optics that allows speckle data to be taken over a field of view of nearly 1 x 1 arcminute. While speckle methods have traditionally been used over fields of only a few arcseconds, we are currently developing analysis tools to extend the reach of the high resolution for which speckle is famous to the wide-field optical mode.

We show here two examples of promising results. In the first case, the globular cluster NGC 6723 was imaged with Zorro on Gemini South in July 2019. In Figure 1, we show both an integrated image and a wide-field speckle image reconstruction of a portion of the cluster near its center. The exposure time is about 18 minutes in total. The reduction methodology here was remarkably similar to that of normal speckle imaging. The central star, which was relatively bright, isolated, and unsaturated, was excised from the raw speckle data frames and a new data file of just that point source was created. This was then used as the point source in the standard speckle reduction for the original speckle frames using the method of bispectral analysis [1]. While this reconstruction was made over a field of view of approximately 37 arcseconds and not the full area of the wide-field mode, reconstructions of various sub-arrays over the full chip could be made with different point source candidates and a final image “stitched” together. Judging from the faintest stars seen in the reconstruction, we are

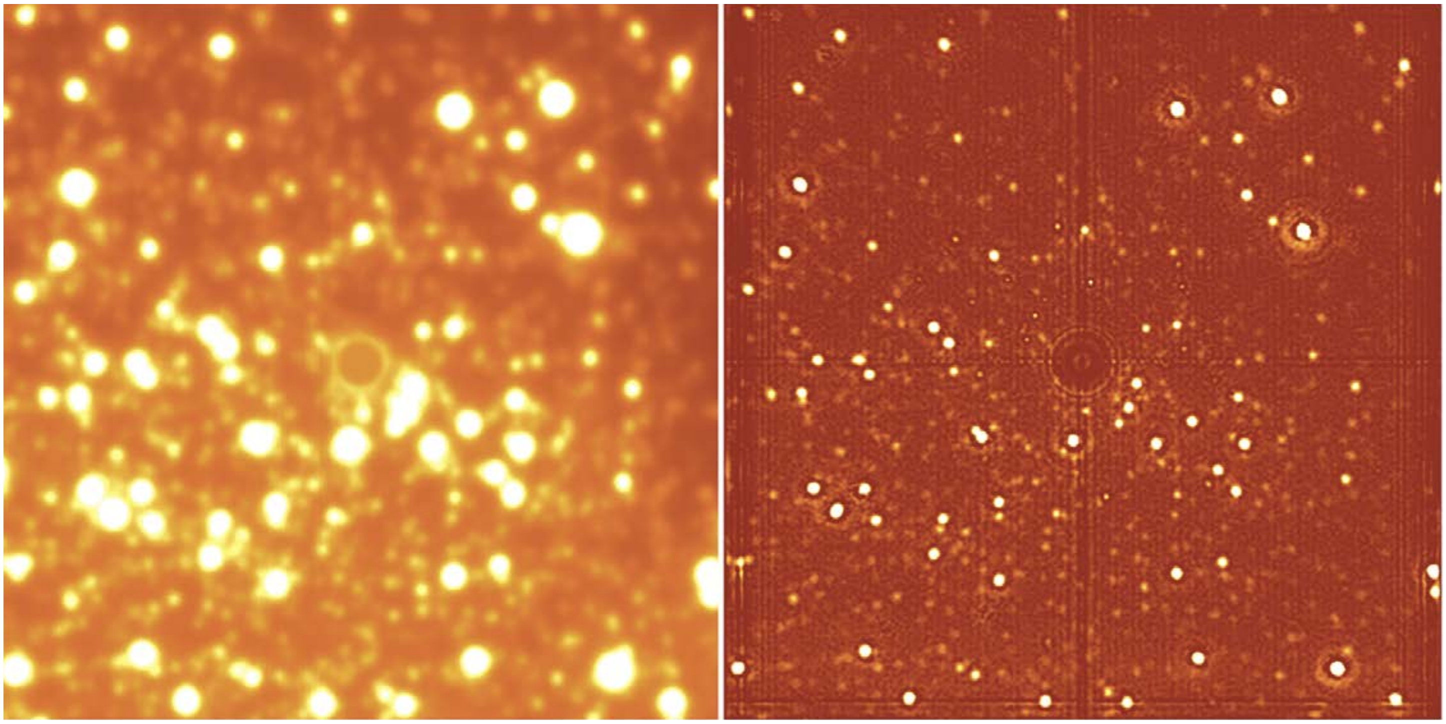

Figure 1. An integrated (left) and reconstructed (right) image of a region near the core of the globular cluster NGC 6723. Both images are on the same color scale, and the central star, used in the deconvolution, has been subtracted here so that fainter stars can more easily be seen. (Credit: International Gemini Observatory/NOIRLab/NSF/AURA)

approximately reaching the main sequence turn-off of the cluster at $V = 18$ to 19 mag; fainter magnitudes are probably achievable with longer exposure times. The resolution over the full field is improved from the seeing limit of 0.76 to 0.36 arcseconds in the reconstructed image, and there are a number of examples of stars that are severely blended in the original image but become clearly resolved in the reconstruction.

An example of a wide-field speckle reconstruction of an extended object is shown in Figure 2. These data of Jupiter were taken using the ‘Alopeke camera at Gemini North in December 2017, and first appeared in Physics Today. This is a very different situation from NGC 6723 from the point of view of image reconstruction. Here there is no point source on the field to use, so a bright point source was taken right after the speckle frames on the planet; the selected star was within a few degrees of Jupiter on the sky. The seeing conditions throughout were relatively stable. Another change to the reduction method was to use the speckle frames only to derive the modulus of Jupiter’s Fourier transform. For the phase used in the reconstruction, which is a much lower signal-to-noise calculation when using the speckle data frames, the values derived from the integrated image were used to improve the signal-to-noise. Thus, for modulus and phase, different choices were made in the reduction to maximize the signal-to-noise and resolution of the final product. We hope to encode various options for the reduction of wide-field ‘Alopeke and Zorro data within the DRAGONS framework at Gemini in the future.

The gains in resolution seen in these reconstructions are not without cost, nor is wide-field speckle imaging a technique that can be expected to reach the diffraction limit. Improvement in resolution through image reconstruction is often achieved at the expense of limiting magnitude, and

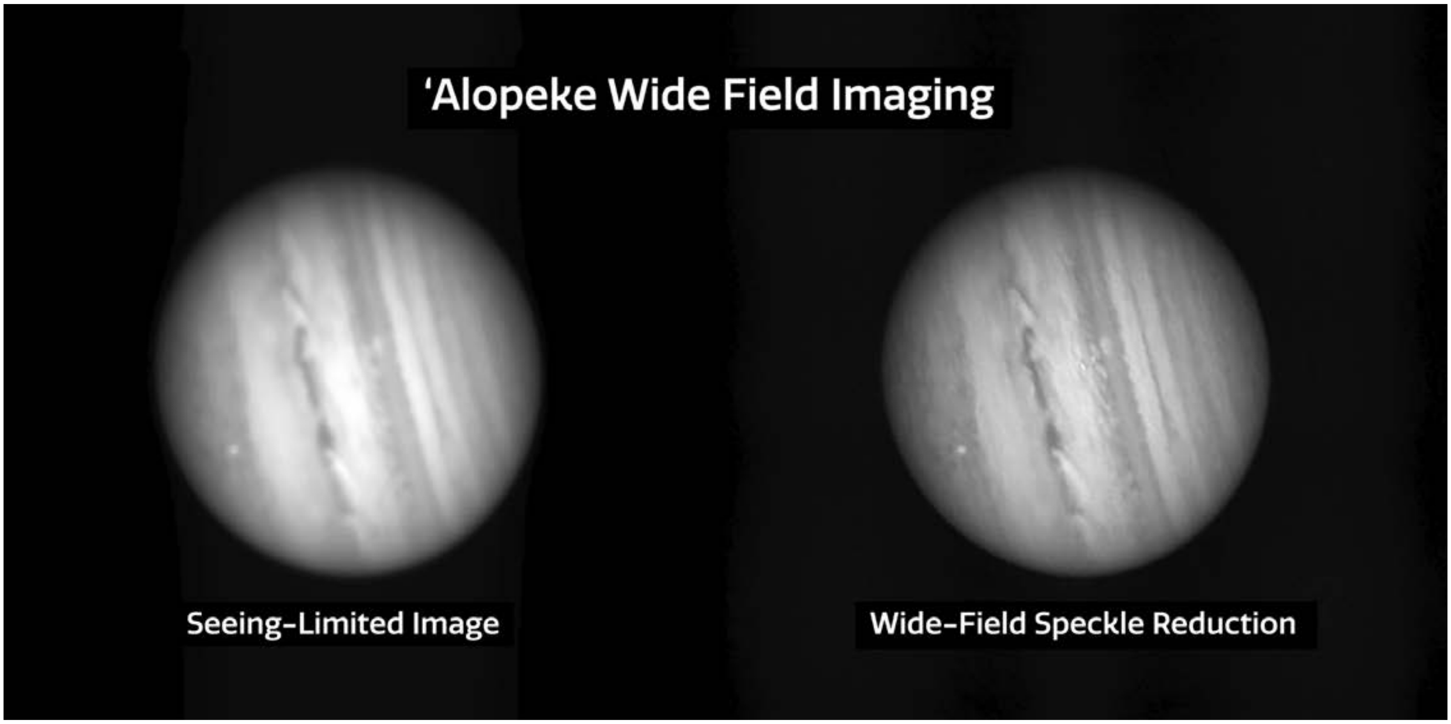

Figure 2. Integrated (left) and reconstructed (right) images of Jupiter made in December 2017 with the 'Alopeke camera at Gemini North. The diameter of Jupiter is about 43 arcsec. (Reproduced from [2], with the permission of the American Institute of Physics).

although wide-field speckle reductions are in their infancy, this is likely true here as well. More importantly, the wide-field mode for Zorro and 'Alopeke has a pixel scale of 0.0725 arcseconds pixel^{-1}, and therefore speckles, which have a typical width of about 0.02 arcseconds at Gemini, are severely undersampled.

Nonetheless, what we find in the individual short-exposure wide-field speckle frames is that the stellar images retain a high-resolution "granular" appearance (presumably caused by pairs and triples of unresolved speckles) over a wider field than the traditional size of the isoplanatic angle. This makes sense—the information retrieved is not diffraction-limited, and therefore the correspondence between all speckles in one star's speckle pattern need not be identical to those in another star in order to achieve improved resolution—that degree of linearity and PSF invariance is only needed for diffraction-limited resolution. Since the wide-field methods focus on the retrieval of lower-resolution information (though still significantly higher than the seeing limit), the field-of-view requirement typically used in speckle imaging may be relaxed.

Both Zorro and 'Alopeke are open to the community and available through regular Gemini queue, Fast Turnaround, and Director's Discretionary Time proposals. We thank Steve Howell, Nic Scott, and Dan Nusdeo for conducting these observations.

References

[1] Lohmann, A. W., Weigelt, G., & Wirnitzer, B. 1983, Applied Optics, 22, 4028
[2] Howell, S. B. & Horch, E. P. 2018, Physics Today, 71, 11, 78

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The GOGREEN Survey

Michael L. Balogh (University of Waterloo/ Waterloo Centre for Astrophysics) and the GOGREEN collaboration

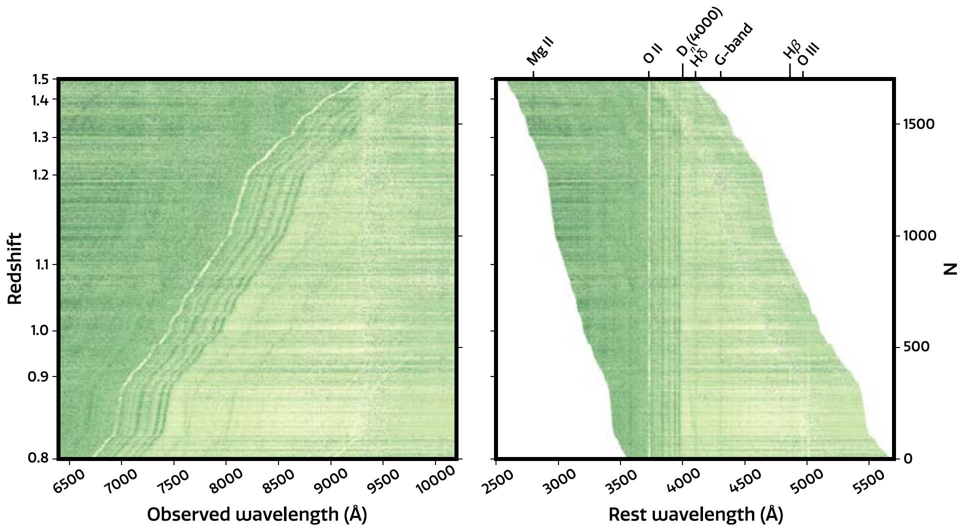

Figure 1. These figures show all GOGREEN and GCLASS spectra with robust redshifts in the interval $0.8 < z < 1.5$. The spectra are arranged in order of increasing redshift, from bottom to top as shown on the y-axis. The left panel shows the spectra in observed wavelength, while on the right they are in rest-frame coordinates. The [OII] emission line, 4000 Å break and several absorption lines (indicated at the top of the right panel) are clearly visible. (From [4], with permission)

This August saw the first public release of advanced data products from the Gemini Observations of Galaxies in Rich Early ENvironments (GOGREEN) survey [1]. The data release was announced during a five-day workshop, sponsored by the Waterloo Centre for Astrophysics. The first days of this workshop were open to the public, and nearly 100 people from around the world attended to hear a description of the survey, the released data products, and the recent and upcoming science results.

GOGREEN is a spectroscopic and imaging survey of 21 overdense galaxy systems in the redshift range $1 < z < 1.5$. The overdensities span a wide range of mass, from groups of only a few galaxies up to the most massive clusters at those early epochs. The spectroscopic program was approved in the first round of Gemini Large and Long Programs in 2014, with an unprecedented allocation of 438 hours on Gemini North and South. Originally planned as a three-year survey, the observations ultimately ran over ten semesters and were completed in mid-2019. Thanks to strong support from Gemini, including program extensions and Director's Discretionary time, the project executed nearly 100 percent of the originally allocated time. In addition to the spectroscopy, deep multiwavelength imaging over the full optical/near-infrared spectrum was obtained from over 100 hours of integration on 4m- and 8m-class facilities around the world. The imaging approaches the depth of the UltraVISTA survey [2] and covers a field of view generally much larger than our GMOS spectroscopy. HST/WFC3 imaging in F160W was also obtained on all clusters; this enables the measurement of structural parameters for most of the spectroscopic sample.

GOGREEN complements the earlier GCLASS cluster survey [3], extending it to higher redshift. The data products from these two surveys were homogenized and combined for the release. The final spectroscopic catalogue consists of 2771 unique objects, of which 2257 have good redshifts. An overview of the spectroscopic sample in the redshift range $0.8 < z < 1.5$ is shown in Figure 1.

Science goals and survey design

Because of the high spatial density of galaxies at essentially all the same distance from the observer, galaxy clusters provide an efficient way to observe large samples of galaxies, and to uncover fundamental relationships between them. Such observations become very challenging from the ground for clusters at $z > 0.8$, where many of the spectral features we require are shifted to wavelengths where atmospheric absorption and emission, and declining detector sensitivity, become limiting factors.

The upgraded GMOS instrument on Gemini has several unique capabilities that make it ideally suited to observations of distant clusters. The nod-and-shuffle mode enables

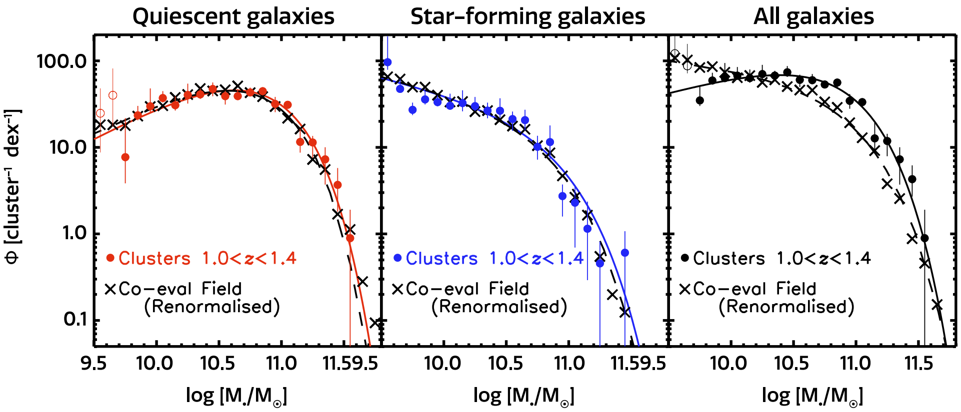

Figure 2. *Left*: The SMF of quiescent galaxies in the cluster environment ($R < 1$ Mpc), compared to the field. The field is normalized so that it integrates to the same number of quiescent galaxies. *Middle*: Same but for star-forming galaxies. The best-fitting Schechter functions are over-plotted. The resemblance in the shapes of the separate (quiescent versus star-forming galaxies) SMFs is evident. *Right*: Same comparison but for all galaxies, where there clearly is a difference between the cluster and field SMFs. (From [10], with permission)

excellent sky subtraction at red wavelengths and a high surface density of slits. With a field of view that contains the full virialized cluster volume, it is possible to obtain an unbiased census of the cluster population, including redshifts for hundreds of faint, quiescent galaxies.

In addition to its legacy value, GOGREEN was optimized to address three main topics:

1. *Environmental quenching and growth of the stellar mass function.* Despite a solid theoretical foundation for the gravitational growth of dark matter structure, galaxy formation models struggle to explain: a) the rate of decline in the global star formation rate; b) the mass dependence of this decline; and c) the star formation histories (SFHs) of satellite galaxies. These problems may be related, as they are all sensitive to assumptions about how gas accretion, ejection and heating processes depend on epoch, environment and halo mass [5].
2. *The hierarchical assembly of baryons.* Measurement of the stellar fraction, gas fraction, and star formation rate in haloes of a given mass provides a close link between galaxies and the fundamental prediction of hierarchical assembly from ΛCDM [6]. Precision measurements of this type are critical for calibrating and constraining models, and are an essential complement to abundance-matching and halo occupation model approaches (e.g., [7]).
3. *Cluster Dynamics and Masses.* The distribution and kinematics of cluster galaxies provide crucial information on the total halo mass, independently of X-ray emission and gravitational lensing, especially at high redshift where these other measurements are particularly difficult to make.

First Science Results

The first results from GOGREEN have already proved surprising. At low redshift, it is well known that clusters host an excess of quiescent (non-star-forming) galaxies relative to the surrounding field. This manifests itself in the stellar mass function (SMF) of quiescent galaxies, which rises steeply toward lower masses in clusters, but drops in the field—a strong indication that normally star-forming galaxies are undergoing a quenching process as they are accreted (e.g., [8]). What we observe at $z > 1$ is strikingly different. The same overall excess of quenched galaxies is observed—the excess is about 40% at both low redshift and $z > 1$. However, unlike at low redshift, the shape of the SMF for these quiescent galaxies is identical to that of the surrounding field, as shown in Figure 2. The first signs of this were seen in the *H*-band luminosity function [9], and firmly established with the analysis of the stellar mass functions in [10]. This seems to rule out an accretion-based quenching mechanism that is analogous to what we see locally.

We have also used the spectroscopic features to look in more detail at the star-forming and quiescent galaxy populations. Using the [OII] emission line, we measure the star formation rate (SFR) and its correlation with stellar mass. We find the distribution of these SFRs shows little or no environmental dependence [11]. For the quiescent galaxies, we use the *Prospector* code [12] to simultaneously fit the photometry and spectroscopy and measure the mass-weighted ages of these galaxies. The results, shown in Figure 3, were unexpected and show that these ages are only slightly older

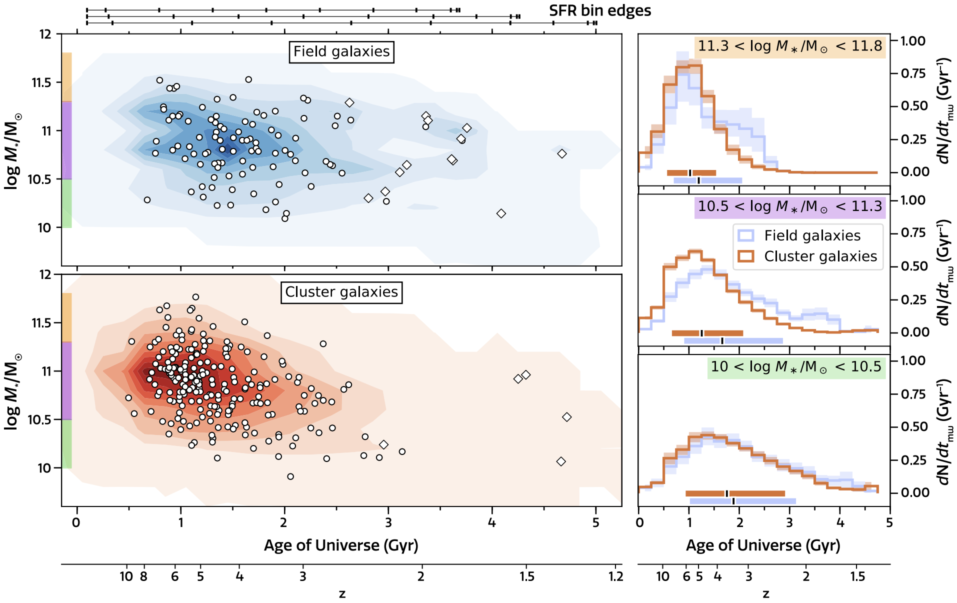

Figure 3. *Left*: Combined posteriors of stellar masses and mass-weighted age (in units of cosmic time), shown as contours. The medians of the individual posteriors are marked with white circles/diamonds (diamonds indicate galaxies that have formed more than 10% of their stars in the last Gyr). *Right*: Combined mass-weighted age posteriors for field and cluster galaxies, shown in three mass bins. The medians (black mark) and 68 percent credible regions (colored bar) of each distribution are marked at the bottom of each subplot. Although there are field galaxies that formed as early as the oldest cluster galaxies, and cluster galaxies that formed as late as the youngest field galaxies, on average field galaxies have more extended SFHs to reach the same final stellar mass. (From [13], with permission)

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among the cluster population than in the field [13].

In these papers we consider simple models, whereby the cluster is either a) evolved in a similar way to the field, but with a “head start”, or b) built through the accretion of field galaxies which prematurely end their star formation on some timescale. Neither simple model is able to explain all our observations. It appears that the majority of the cluster population must have ceased forming stars long ago ($z > 4$) and were already quenched when they reached the cluster's virialized region. Ongoing work includes measuring the halo mass dependence of this effect [14], the abundance of recently quenched and post-starburst galaxies [15], the morphological differences between cluster and field galaxies [16], the abundance of active galactic nuclei [17] and the cluster dynamical mass profiles [18].

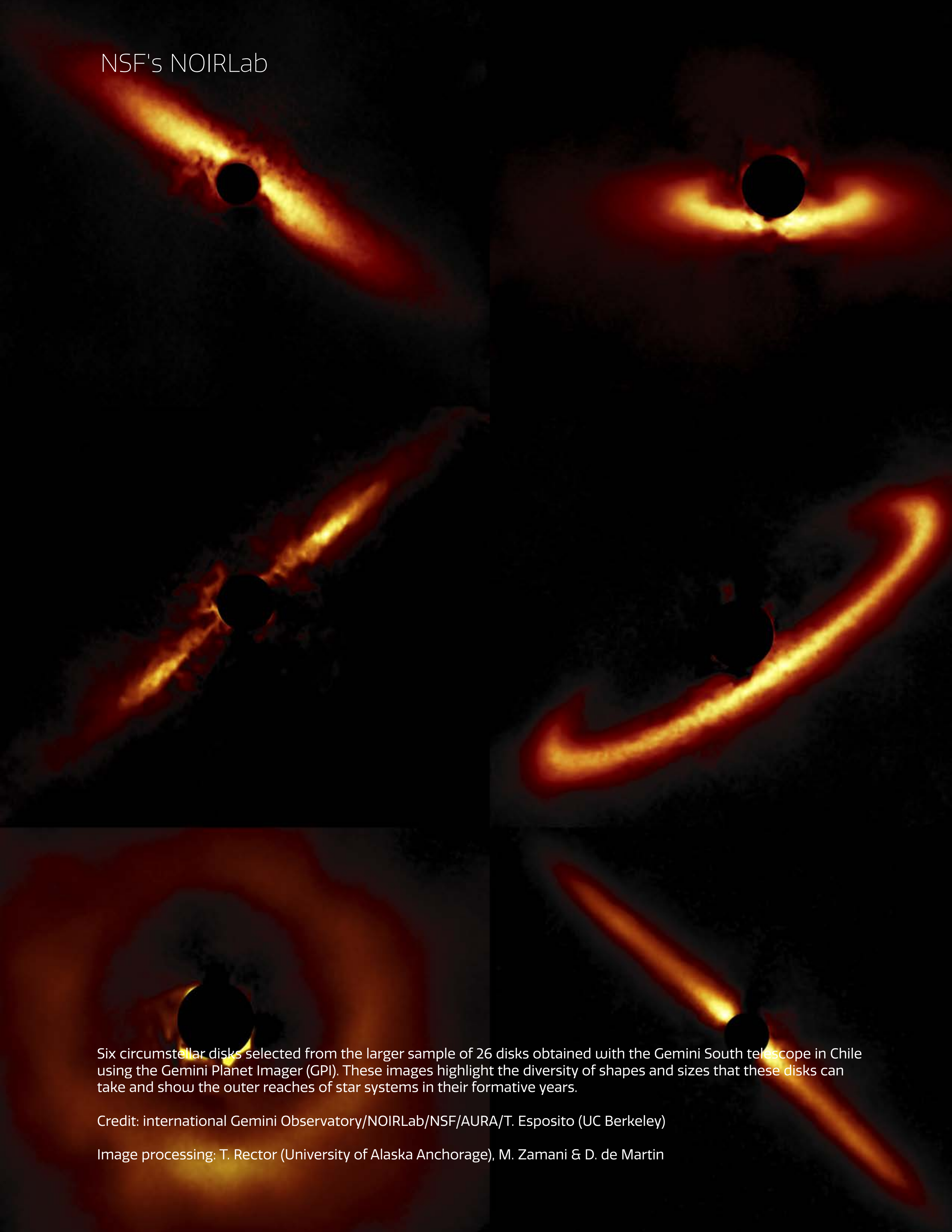
Data Release

The joint GOGREEN and GCLASS data release, described in [4], is distributed via the CADC, and NSF's NOIRLab. In addition to the reduced images and spectroscopy we provide catalogs of measured and derived quantities (stellar masses, star formation rates, line indices, etc.) and Jupyter notebooks for working with the data.

References

[1] Balogh, M. L., et al. 2017, MNRAS, 470, 4168
[2] Muzzin, A., et al. 2013, ApJS, 206, 8
[3] Muzzin, A., et al. 2012, ApJ, 746, 188
[4] Balogh, M. L., et al. 2021, MNRAS, 500, 358
[5] McGee, S. L., Bower, R. G., & Balogh, M. L. 2014, MNRAS, 442, L105
[6] Balogh, M. L., et al. 2008, MNRAS, 385, 1003
[7] Behroozi, P. S., Wechsler, R. H., & Conroy, C. 2013, ApJ, 770, 57
[8] Peng, Y.-jie, et al. 2010, ApJ, 721, 193
[9] Chan, J. C. C., et al. 2019, ApJ, 880, 119
[10] van der Burg, R. F. J., et al. 2020, A&A, 638, A112
[11] Old, L. J., et al. 2020, MNRAS, 493, 5987
[12] Leja, J., et al. 2017, ApJ, 837, 170
[13] Webb, K., et al. 2020, MNRAS, 498, 5317
[14] Reeves, A. M. M., et al., in preparation
[15] McNab, K. L., et al., in preparation
[16] Chan, J. C. C., et al., in preparation
[17] Pintos-Castro, I., et al., in preparation
[18] Biviano, A., et al., in preparation

NSF's NOIRLab



Six circumstellar disks selected from the larger sample of 26 disks obtained with the Gemini South telescope in Chile using the Gemini Planet Imager (GPI). These images highlight the diversity of shapes and sizes that these disks can take and show the outer reaches of star systems in their formative years.

Credit: international Gemini Observatory/NOIRLab/NSF/AURA/T. Esposito (UC Berkeley)

Image processing: T. Rector (University of Alaska Anchorage), M. Zamani & D. de Martin

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The SOAR Telescope in the Time–Domain and Multi–Messenger Astronomy Era

César Briceño & Regis Cartier (NOIRLab)

Introduction

Astronomy is living through exciting and groundbreaking times. The advent of facilities that search for transients and measure time-variable objects across all the sky, such as the Zwicky Transient Facility (ZTF), *Gaia*, and the upcoming Vera C. Rubin Observatory with its Legacy Survey of Space and Time (LSST), together with the gravitational wave instruments LIGO, VIRGO, and now KAGRA, is positioning Time-Domain Astronomy (TDA) and Multi-Messenger Astrophysics (MMA) among the forefront areas of astrophysics for the next decade. Studies of the content and nature—including the identification of possible potential collision threats—of small bodies in our Solar System, exoplanet discoveries, studies of stellar variability in all its forms, explosive and violent phenomena such as supernovae (SNe), gamma ray bursts, and mergers of dense stellar remnants such as black holes and neutron stars, using variable stars and SNe in other galaxies to gauge the cosmic ladder, and observing active galactic nuclei all illustrate that the range of science spanned by TDA and MMA is both broad and exciting.

TDA also brings a scale of data management and mining not seen before. ZTF is producing thousands of alerts per night, covering ~3760 square degrees/hour of the sky visible from Mt. Palomar, to median 5σ depths of $g \sim 20.8$ and $r \sim 20.6$ mag (AB magnitudes; [1]). The LSST will map the entire sky accessible from Cerro Pachón, Chile, in the *ugrizy* filters to a 5σ single-visit depth of $r \sim 24$ mag (AB), producing about 10^6 alerts per night. Although the LSST will make many visits—typically hundreds—and the resulting data can be co-added, for most transient phenomena, whether time-variable or moving objects, the relevant sensitivity is set by a single visit. The LSST has well-defined science goals that will be achieved with the survey data alone: an inventory of the Solar System, Mapping the Milky Way, Exploring the Transient Optical Sky, and Probing Dark Energy and Dark Matter.

However, full exploitation of the LSST data products will depend on the ability to carry out complementary and follow-up observations that will provide confirmation, characterization, and further study of transients and variable objects [2]. The need for LSST follow-up was also recognized by the National Research Council (NRC), commissioned by the National Science Foundation (NSF). In *Optimizing the U.S. Ground-Based Optical and Infrared System* [3], the NRC presented a series of recommendations for the national ground-based optical-infrared (OIR) system, advising that NSF support the development of the ground-based facilities needed to optimize LSST follow-up science. The report targeted the synergy between the Gemini telescopes, the Southern Astrophysical Research (SOAR) Telescope, the Víctor M. Blanco 4m Telescope, and the Rubin Observatory Legacy Survey of Space and Time (LSST), and discussed how existing or new instruments and operation modes can be implemented and managed in ways that maximize the scientific return. A subsequent review of the NSF-funded Gemini, Blanco, and SOAR telescopes [4] reinforced this conclusion.

Time-Domain and Multi-Messenger Astronomy at SOAR

SOAR is particularly well-suited for LSST follow-up. First, it is co-located with Vera C. Rubin Observatory (Figure 1) and therefore has access to the same targets and experiences the

Figure 1. *Upper panel*: Panoramic view of Cerro Pachón with (from left to right) the SOAR, Gemini South, and Vera C. Rubin observatories. (Credit: Rubin Observatory/NSF/AURA)
Lower left panel: SOAR building under the Milky Way. (Credit: C. Briceño/CTIO/NOIRLab)
Lower right panel: SOAR 4.1m telescope. (Credit: SOAR/NOIRLab/NSF/AURA)


SOAR
Gemini South
Vera C. Rubin Observatory

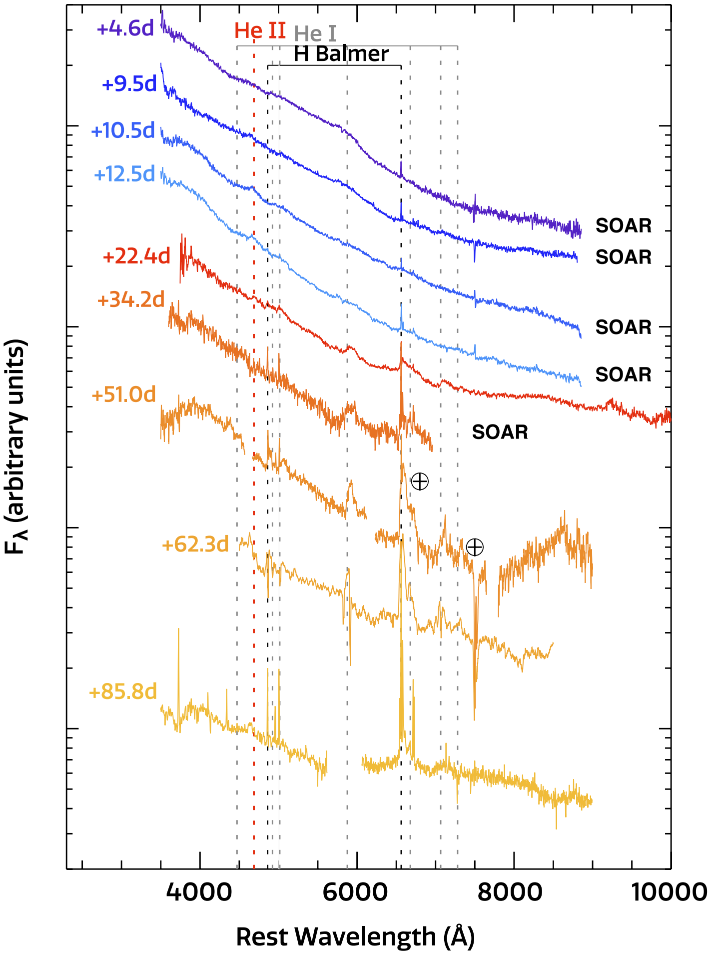

Figure 2. Spectral sequence of AT2018cow. The phase is measured relative to the epoch of discovery, MJD=58285.44 [20]. (Adapted from [10], with permission)

same observing conditions. Second, SOAR has a suite of permanently installed optical and infrared instruments, both imagers and spectrographs, available to be used within minutes. Built for excellent image quality across a relatively small field (less than 10 arcminutes in diameter for all instruments), SOAR can reach the LSST single-visit limit (5σ) of $r \sim 24$ (AB), in ~90s in imaging mode in the *g*, *r* filters and can obtain SNR~5 optical spectra at $R \sim 1000$ down to $r \sim 22$ in 1 h. There will be a significant number of LSST targets accessible to 4m-class telescopes such as SOAR; in particular, the brighter ones will be within reach of a broad range of astronomical facilities, as noted, for example, in the 2015 NRC report to the National Academies [3].

But even before Rubin Observatory comes online, SOAR has been playing an important role in TDA and improving its instruments and operations to enhance its capabilities in the LSST era. The high level of experience and quality of the staff operating the SOAR telescope at the mountain, forming a cohesive team with the support scientists at La Serena, has allowed us to become one of the premier facilities for transient science, including characterization of Small Solar System bodies and Near Earth Objects [5], [6], [7] and gravitational wave (GW) follow-up (e.g., [8], [9]). The SOAR Target of Opportunity (ToO) policy allows quick handling of requests for a variety of fast-evolving or young transients, including GW alerts, that require rapid response, while taking into account the science needs of the astronomer scheduled for the night of the ToO interrupt.

SOAR has recently further shown its effectiveness as a TDA and MMA tool by providing optical and near-IR data of excellent quality in breakthrough discoveries, such as the follow-up campaign of the rare, bright, and fast-evolving transient AT 2018cow [10], powered by a non-standard central engine. The observations obtained with the Goodman spectrograph at SOAR were key for securing a set of early, well time-sampled spectra (Figure 2). Other recent examples are the near-IR spectrum of the rapidly evolving calcium-rich transient SN 2019ehk [11], obtained during the commissioning of the TSpec near-IR spectrograph at SOAR, or the early optical and near-IR spectra (Figure 3) of the Type Ic SN 2020oi [12], which enabled the study of the outermost layers of this SN explosion in exquisite detail [13]. Both objects exploded in the nearby galaxy Messier 100 within the course of a year. The high-throughput Goodman spectrograph, reaching down to ~21–22 mag objects in ~1 h, and SOAR's rapid response to ToO alerts have been key for the follow-up of possible electromagnetic counterparts of GW alerts during the O3 LIGO/VIRGO run in 2019. Various research groups have published their latest results, including lessons learned from this campaign, highlighting the role of SOAR [14], [15], [16].

Preparing for the LSST Era

Looking ahead, we are carrying out a number of upgrades and improvements to both SOAR instruments and operations. Starting in late 2017, we embarked on an ambitious automation plan, which has positioned SOAR as one of the founding partners of the Astronomical Event Observatory Network (AEON; [17]) and the pathfinder

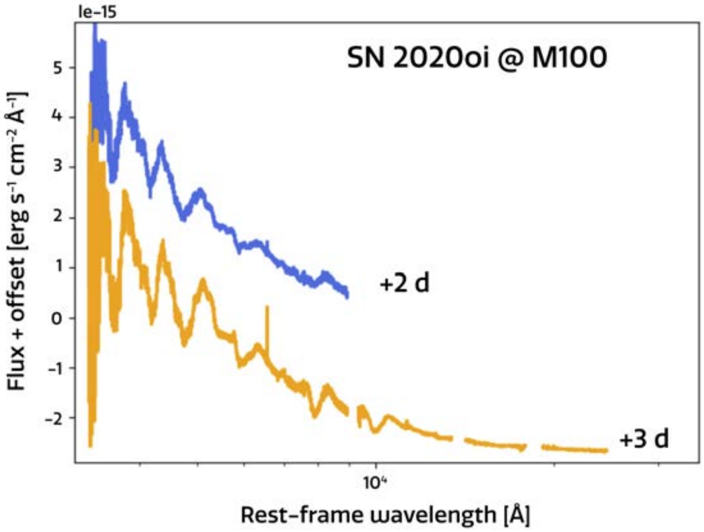

Figure 3. Early spectra of SN 2020oi obtained with the Goodman and TSpec spectrographs on SOAR. The phase is the time relative from the estimated epoch of the SN explosion. (Adapted from [13])

facility for incorporating 4m-class and larger facilities in a future LSST follow-up system. With AEON we have started running a highly automated queue using the Goodman spectrograph, on select nights. This degree of automation also benefits all users, beyond AEON, by providing observers of classically scheduled nights web-based tools for queueing their targets and automating many steps of the spectrograph operation, with the resulting gain in efficiency and reliability of data acquisition. We are also actively developing data-reduction tools. We have implemented a Python-based spectroscopic pipeline for the Goodman spectrograph [18], which makes extensive use of Astropy modules and libraries, with extensive documentation written following best practices and standards. We are currently developing a real-time version of the Goodman spectroscopic pipeline, accessible via a web browser (no software to download and install), that produces fully reduced 1D, wavelength-calibrated spectra seconds after the raw data are written to disk [19]. This new tool provides users with real-time visualization of their reduced spectra, allowing them to make rapid decisions on whether to obtain more data on the same target or change to another object. We expect these and other ongoing efforts will position SOAR among the forefront 4m-class facilities for TDA, MMA, and a wide range of science cases in the next decade.

References

[1] Masci, F. J., et al. 2019, PASP, 131, 018003
[2] Najita, J., et al. 2016, arXiv:1610.01661
[3] National Research Council. 2015. *Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System.* Washington, DC: The National Academies Press
[4] Honscheid, K., et al. 2019, https://www.nsf.gov/mps/ast/aaac/gbs/GBS_CommitteeReport.pdf
[5] Bauer, J. M., et al. 2011, ApJ, 738, 171
[6] Thirouin A., et al. 2016, AJ, 152, 163
[7] Devogèle, M., et al. 2020, PSJ, 1, 15
[8] Abbott, B. P., et al. 2017, ApJL, 848, L12
[9] Nicholl, M., et al. 2017, ApJL, 848, L18
[10] Margutti, R., et al. 2019, ApJ, 872, 18
[11] Jacobson-Galán, W. V., et al. 2020, ApJ, 898, 166
[12] Siebert, M. R., et al. 2020, ATel, No. 13393
[13] Rho, J., et al. 2020, ApJ, submitted
[14] Hosseinzadeh, G., et al. 2019, ApJL, 880, L4
[15] Morgan, R., et al. 2020, ApJ, 901, 83
[16] Wiesner, M., et al. 2020 (DESGW collaboration), ApJ, in preparation
[17] Briceño, C. 2020, The NOIRLab Mirror, 1, 52
[18] Torres-Robledo, S., et al. 2020, ASPC, 522, 533
[19] Torres-Robledo, S. & Briceño, C. 2019, ASPC, 523, 203
[20] Smartt, S. J., et al. 2018, ATel, No. 11727

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DECam Opens a New Window on the Galactic Bulge

Christian I. Johnson (STScI), R. Michael Rich (UCLA), Mike Young, Scott Michael, Caty Pilachowski (Indiana University), Will Clarkson (University of Michigan, Dearborn), Željko Ivezić (University of Washington), Andrea Kunder (Saint Martin's University), & Kathy Vivas (NOIRLab)

Project Motivation and Overview

The last decade has seen an era of intensive research on the Galactic bulge spearheaded by large spectroscopic surveys, such as the Bulge Radial Velocity Assay (BRAVA; [1], [2], [3]) and ARGOS [4], along with deep near-IR imaging campaigns such as VVV [5]. However, optical imaging remains an important tool for examining the formation history of the bulge since optical colors are more sensitive to stellar metallicity than the near-IR, and such observations are not as expensive as high-resolution spectroscopy. The modern era has lacked a uniform, deep, multi-band optical survey of the bulge, but the potential scientific return on such an analysis is too great to ignore. Motivated by these considerations, we undertook the Blanco DECam Bulge Survey (BDBS; [6], [7]), named in honor of the scientific contributions of Víctor and Betty Blanco, which is a survey of ~200 square degrees of the Southern bulge (Figure 1) using the mainly US Department of Energy (DOE)-funded Dark Energy Camera (DECam) on the Víctor M. Blanco 4m telescope and imaging in its *ugrizY* passbands.

The need for an optical imaging survey is driven by several factors. First, the detection of two red clumps (see, e.g., bottom-left panel of Figure 2) along various sightlines points toward an X-shaped bulge, which is a feature of bars. Further, there is a strong debate regarding whether the bulge's metallicity distribution, traced primarily through iron abundances, is bimodal or is composed of as many as five different populations. Another point of contention is the bulge's age. Most stars appear to be uniformly old (~10 Gyr; e.g., [8], [9]), but spectroscopy of lensed bulge dwarfs argues for a substantial population of young and intermediate-age stars (e.g., [10]). Saha et al. [11] even found evidence for a younger population of massive He-burning stars. A third challenge is the spatial distribution of stars, with Zoccali et al. [12] arguing that metal-poor stars follow a spheroidal distribution while those with higher metallicities than the Sun are concentrated near the Galactic plane. Contributions to the bulge from dissolved globular clusters also remain as an open question (e.g., [13], [14]). BDBS was tailored to address many of these questions, particularly spatial and chemical composition variations traced by *u*-band observations, but accomplishing this task requires processing, calibrating, and dereddening a large data volume.

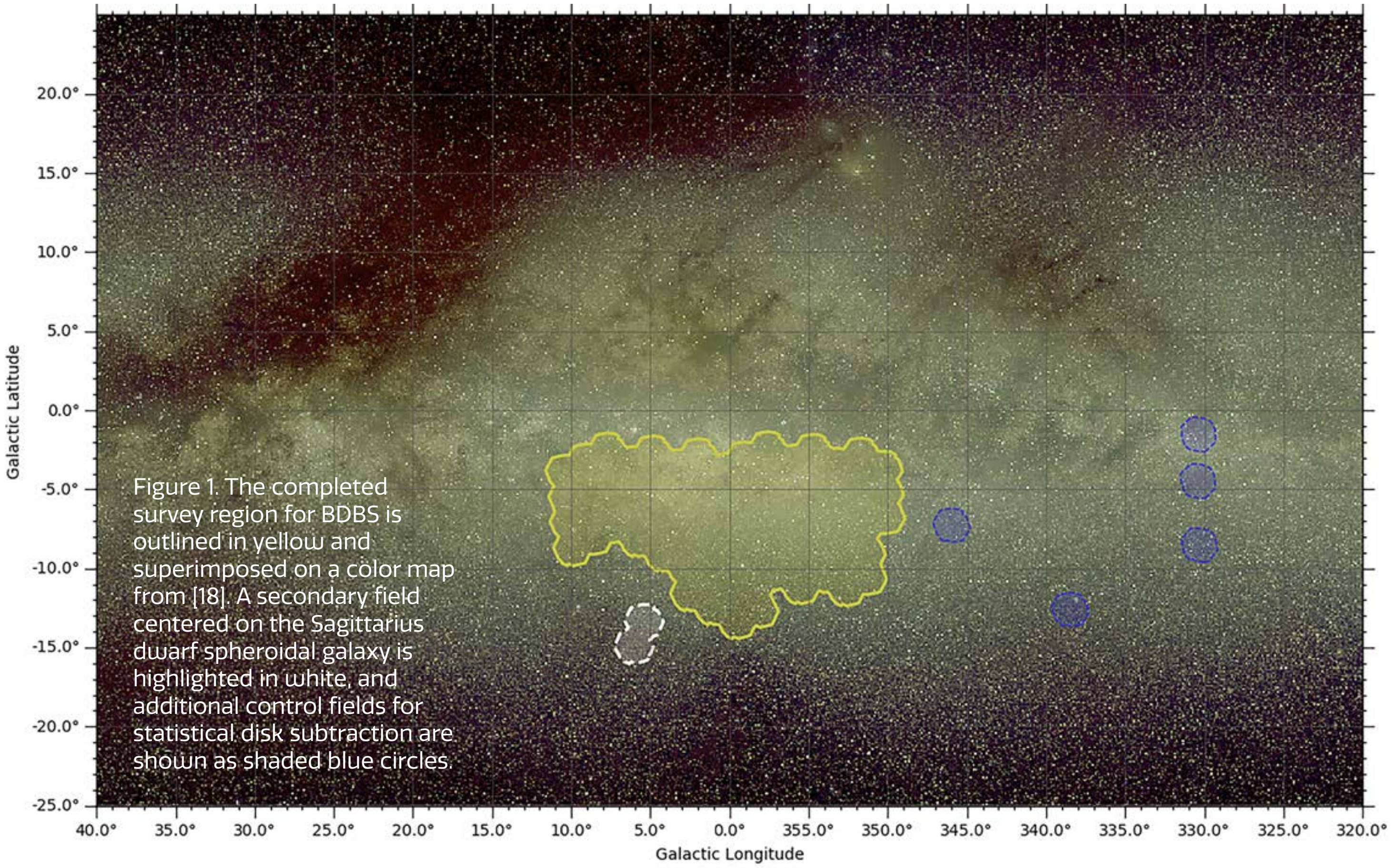


Figure 1. The completed survey region for BDBS is outlined in yellow and superimposed on a color map from [18]. A secondary field centered on the Sagittarius dwarf spheroidal galaxy is highlighted in white, and additional control fields for statistical disk subtraction are shown as shaded blue circles.

Data Management Challenges

Comprising 62 science CCDs that span more than 2 degrees on the sky, DECam's large field of view allowed us to cover the > 200-square-degree survey area with 6 filters in only 14 nights of observation. One of the most challenging aspects of the project was the data management and processing needed for the 7000+ DECam exposures, equivalent to > 450,000 individual CCD images and > 3.5 trillion pixels. Our small group was able to solve the data storage and processing problems using the petabyte-scale Data Capacitor II (DC2) high-speed shared storage system, in combination with Carbonate, Indiana University's (IU) large-memory computer cluster, both of which are managed by the Pervasive Technology Institute at IU. The combined computational and storage capabilities of DC2 and Carbonate enabled us to process individual CCD exposures with DAOPHOT [15] in parallel and execute > 2 years of CPU time in just a few weeks. The DC2 system also provided a central location for our geographically dispersed collaborators to interact with the raw and final data products.

The second major technical challenge involved collating the enormous data volume into useful catalogs. The PSF photometry runs produced > 10 billion detections across six passbands of approximately 250 million unique objects on nights with a wide variety of zero points and observing conditions, including a handful of partial and non-photometric nights. For a large fraction of the survey area, we were able to adapt previous high-resolution (1 × 1 arcminute) near-IR reddening maps from [16] to obtain our final catalog of dereddened *ugrizY* photometry for > 175 million Southern bulge point sources.

Early Science Results and Future Work

One of the most interesting results to come out of BDBS so far is the strong correlation between red clump stellar metallicity and $(u-i)_o$ color (Figure 2). This mapping increases the sample size of red clump stars with accurate metallicity measurements by at least two orders of magnitude when compared with even the largest current spectroscopic surveys. In contrast with many previous results, we find that a large

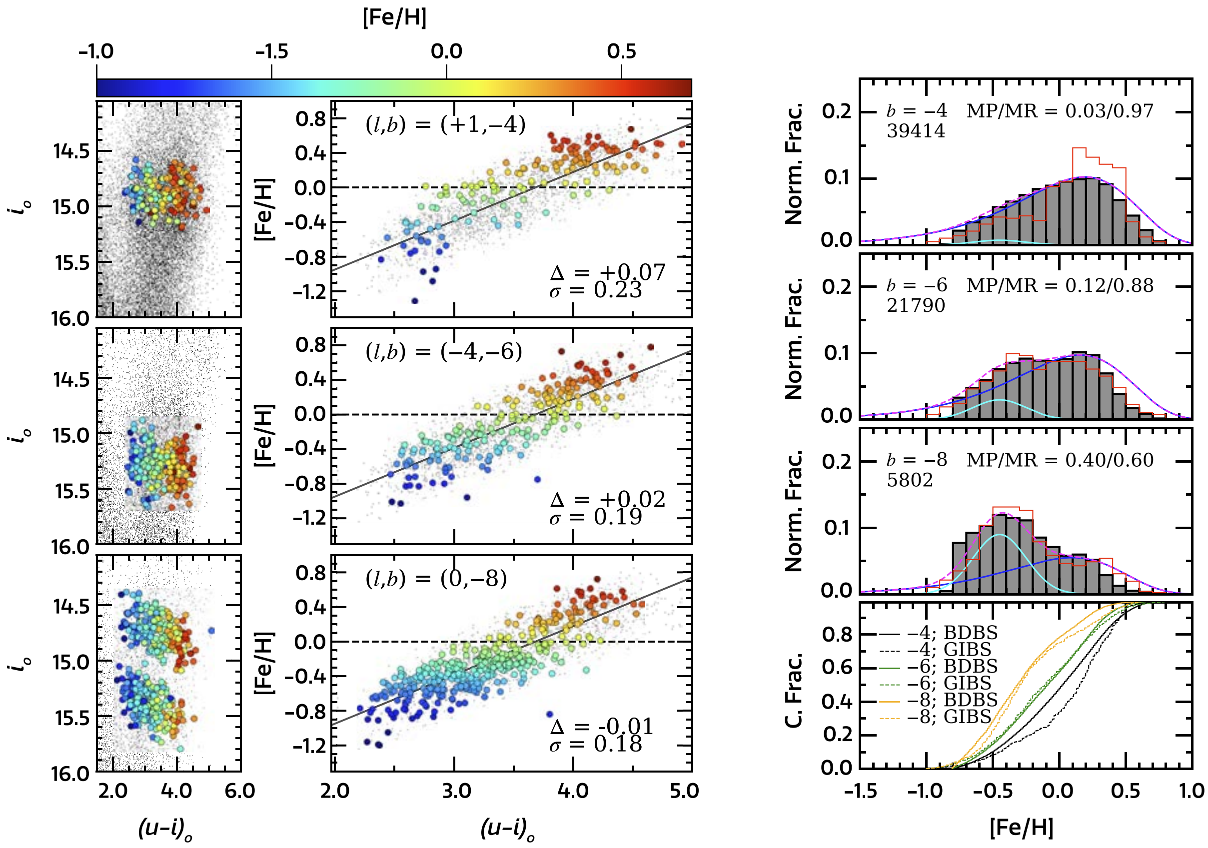


Figure 2. The correlation between $(u–i)_o$ and red clump metallicity as measured via spectroscopy (*left*) along with the derived metallicity distribution functions summed across lines of constant Galactic latitude (*right*). The gray histograms are the BDBS results, while the red histograms are for the smaller-sample spectroscopic results from [12]. Note that the *b* = −4 degree field does not show any evidence of bimodality, but a secondary metal-poor component (cyan lines) seems required to explain the outer bulge distributions. (From [6], with permission)

fraction of the bulge mass, particularly at lower latitudes, follows a unimodal metallicity distribution with a long tail that is reminiscent of one-zone closed-box enrichment models (e.g., [17]), rather than a bimodal distribution. The result suggests that a large fraction of the bulge's mass formed during a single high-intensity star formation event < 1 Gyr, and not through multiple short bursts.

Interestingly, Figure 2 does show that fields exterior to *b* ~ −6 degrees appear bimodal. However, if the underlying metal-rich peak represents the same distribution as the unimodal population observed for interior fields, the contribution of the metal-poor component is significantly reduced compared to previous estimates (e.g., [12]), in some cases by more than 50%. The origin of the metal-poor component is not understood, but future work will investigate this problem by leveraging photometric BDBS metallicities with *Gaia* proper motions to produce 3D chemodynamical maps for millions of red clump stars.

Our survey footprint spans an area large enough to include the complete tidal radii of 26 globular clusters, all with ~ 1” image quality, and our catalogs frequently reach near or below the main sequence turnoff. The mysterious object FSR1758 was advanced as a possible new dwarf galaxy, but BDBS reveals it to be an interesting metal-poor globular cluster in the bulge without any obvious tidal structure (Figure 3).

A full data release of the BDBS data to the community is contemplated for late 2021. As Rubin Observatory sees first light, it will become possible to use the BDBS survey as a first-epoch astrometric dataset, potentially with Rubin/LSST imaging pushing precise astrometry (and bulge/disk separation) to g = 22 or fainter (3 mag past *Gaia*) and perhaps providing a definitive answer to the question of whether a significant number of intermediate age stars lurk in the bulge. The BDBS survey also provides a glimpse of what is to come when Rubin Observatory images the Milky Way.

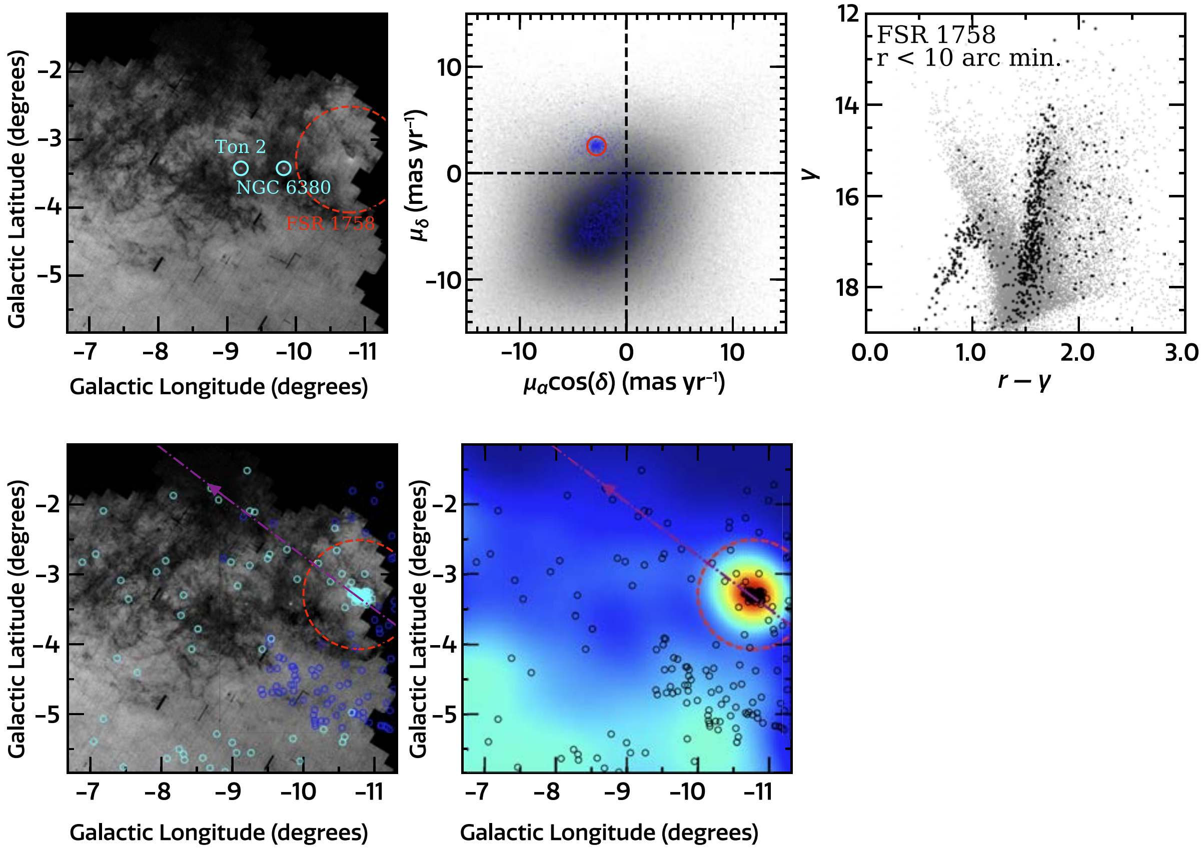


Figure 3. The top left panel shows the BDBS density map within several degrees of FSR 1758 with two nearby, but unrelated, globular clusters highlighted in cyan. The top middle panel shows a *Gaia* vector point diagram with the cluster members indicated by the large red circle. A BDBS CMD is shown in the top right panel for an area within 10′ of the cluster center (gray points are all data; black points are proper motion members). The bottom left map shows the integrated orbit (purple) and potential member stars identified by BDBS (cyan) and Barbá et al. [19] (blue). Note that previous claims of tidal structure, such as the clump of blue stars near (*l*,*b*) ~ (−10.5, −4.5), appear to be related to an over-density of background stars that happen to have a comparable proper motion to the cluster. (From [6], with permission)

The authors acknowledge support from grant NSF AST-1413755.

References

[1] Rich, R. M., et al. 2007, ApJL, 658, L29
[2] Kunder, A., et al. AJ, 143, 57
[3] Rich, R. M. 2013, in Planets, Stars and Stellar Systems, Vol. 5: Galactic Structure and Stellar Populations. ed. T. D. Oswalt & G. Gilmore (Dordrecht: Springer), 271
[4] Ness, M., et al. 2013, MNRAS, 432, 2092
[5] Minniti, D., et al. 2010, New Astronomy, 15, 433
[6] Johnson, C. I., et al. 2020, MNRAS, 499, 2357
[7] Rich, R. M., et al. 2020, MNRAS, 499, 2340
[8] Clarkson, W., et al. 2008, ApJ, 684, 1110
[9] Renzini, A., et al. 2018, ApJ, 863, 16
[10] Bensby, T., et al. 2017, A&A, 605, A89
[11] Saha, A., et al. 2019, ApJ, 874, 30
[12] Zoccali, M., et al. 2017, A&A, 599, A12
[13] Ferraro, F. R., et al. 2009, Nature, 462, 483
[14] Schiavon, R. P., et al. 2017, MNRAS, 465, 501
[15] Stetson, P. B. 1987, PASP, 99, 191
[16] Simion, I. T., et al. 2017, MNRAS, 471, 4323
[17] Rich, R. M. 1990, ApJ, 362, 604
[18] Mellinger, A. 2009, PASP, 121, 1180
[19] Barbá, R. H., et al. 2019, ApJL, 870, L24

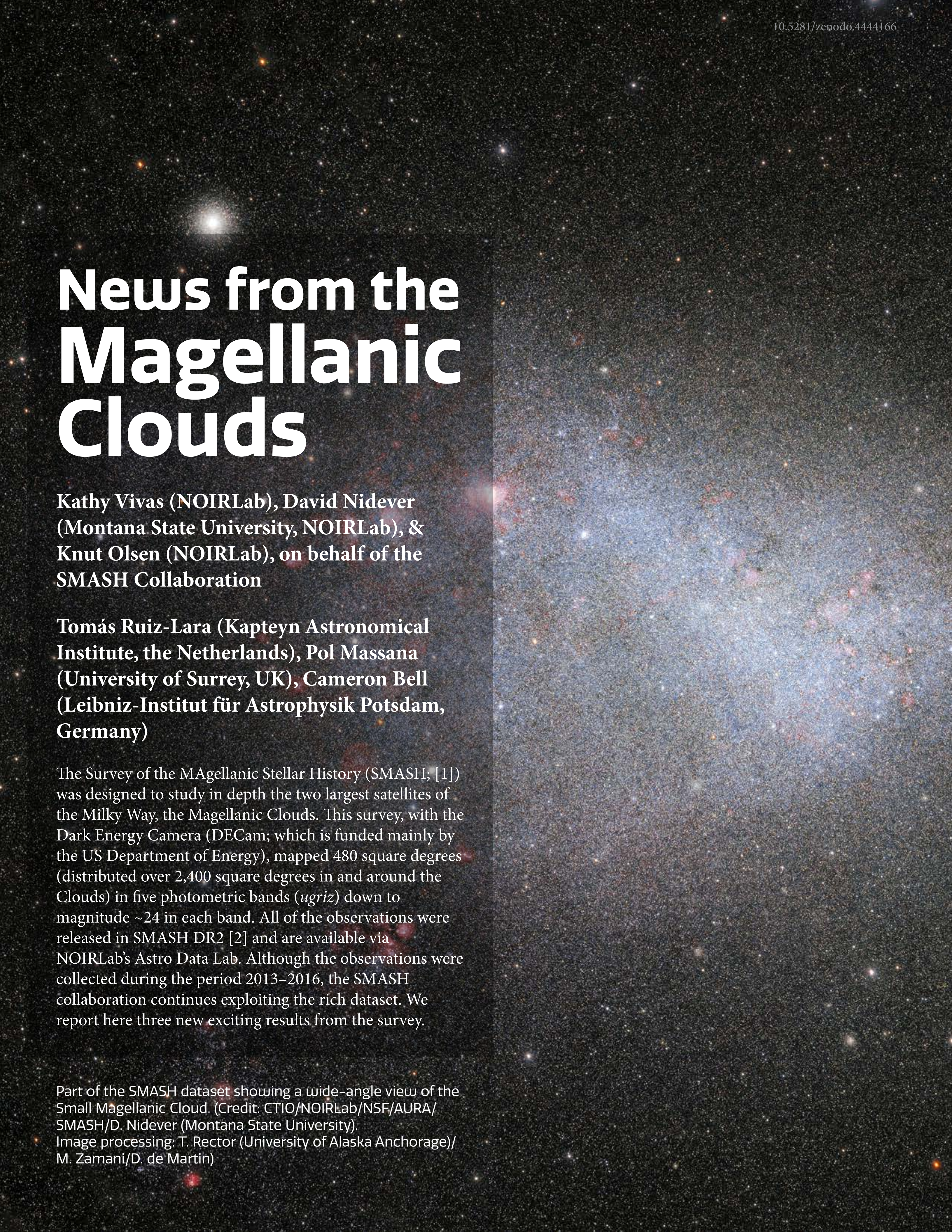
10.5281/zenodo.4444166

News from the Magellanic Clouds

Kathy Vivas (NOIRLab), David Nidever (Montana State University, NOIRLab), & Knut Olsen (NOIRLab), on behalf of the SMASH Collaboration

Tomás Ruiz-Lara (Kapteyn Astronomical Institute, the Netherlands), Pol Massana (University of Surrey, UK), Cameron Bell (Leibniz-Institut für Astrophysik Potsdam, Germany)

The Survey of the MAgellanic Stellar History (SMASH; [1]) was designed to study in depth the two largest satellites of the Milky Way, the Magellanic Clouds. This survey, with the Dark Energy Camera (DECam; which is funded mainly by the US Department of Energy), mapped 480 square degrees (distributed over 2,400 square degrees in and around the Clouds) in five photometric bands (*ugriz*) down to magnitude ~24 in each band. All of the observations were released in SMASH DR2 [2] and are available via NOIRLab's Astro Data Lab. Although the observations were collected during the period 2013–2016, the SMASH collaboration continues exploiting the rich dataset. We report here three new exciting results from the survey.



Part of the SMASH dataset showing a wide-angle view of the Small Magellanic Cloud. (Credit: CTIO/NOIRLab/NSF/AURA/SMASH/D. Nidever (Montana State University).
Image processing: T. Rector (University of Alaska Anchorage)/M. Zamani/D. de Martin)

The Stability of the Spiral Arms in the LMC

Tomás Ruiz-Lara

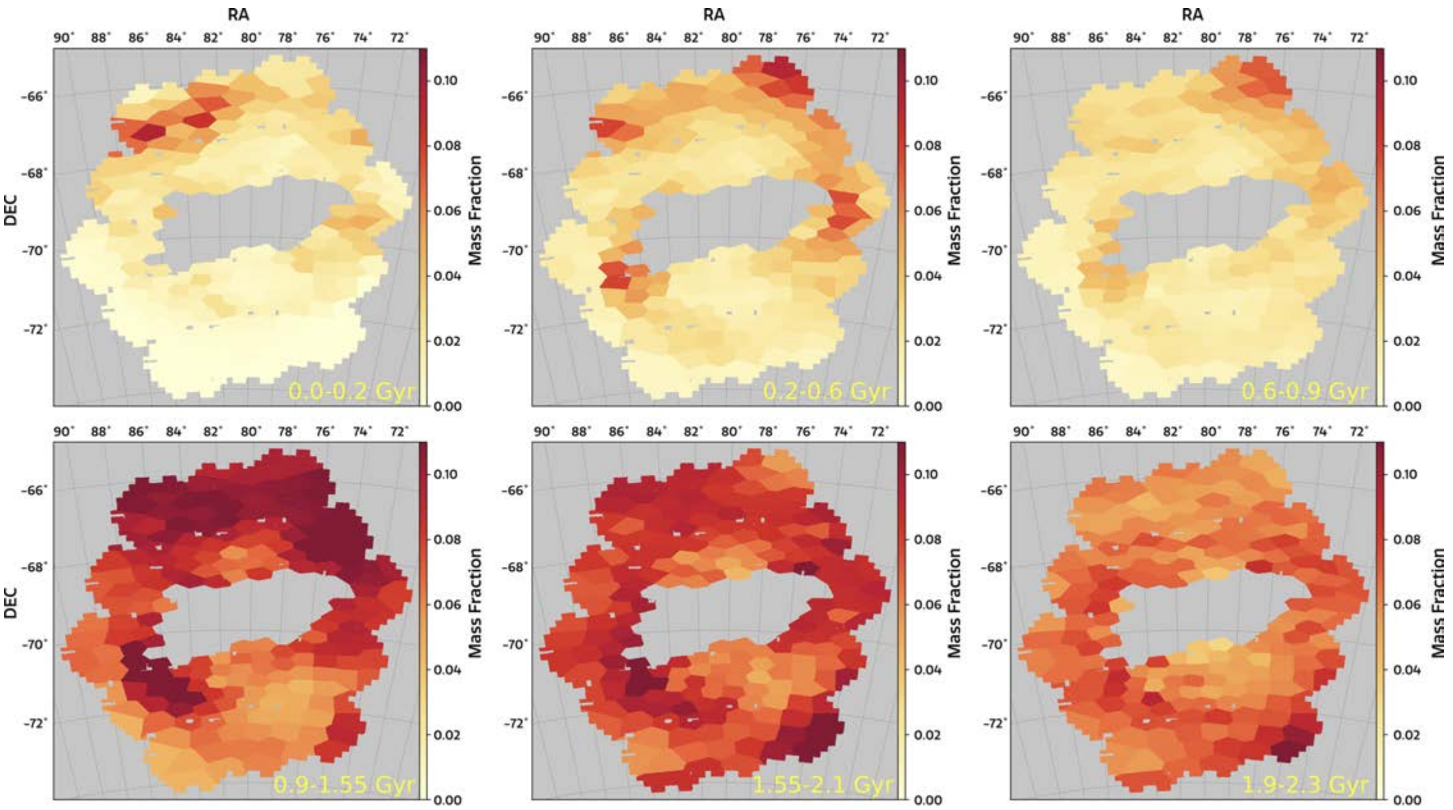


Figure 1. Spatial distribution of the stellar mass fractions of stars of different ages in the LMC disk (youngest to oldest from the top-left to the bottom-right panels). Note how the spiral arm is easily seen at most ages, especially those younger than 2 billion years. (From [3], with permission)

Some galaxies in the Universe display beautiful and appealing features known as spiral arms. In fact, these spiral arms are the most peculiar characteristic of the spiral galaxies, among which we find our own galaxy, the Milky Way. However, although we might be familiar with images of galaxies displaying gorgeous symmetrical arms emerging from their centers, spiral arms can manifest themselves in other ways. In fact, the Large Magellanic Cloud (LMC) is the prototype of one entire family of galaxies, the Magellanic Spirals. These galaxies are characterized by the presence of barred stellar structure near their centers (the galactic bar) and one single spiral arm.

We know that galactic collisions can result in the formation of spiral patterns and that these patterns are linked to overdense regions where the formation of new stars is triggered. Nevertheless, we are still far from knowing all about these peculiar structures. How are they ultimately formed? Are they long-lasting or destroyed and reformed every now and then?

Taking advantage of the high quality of the SMASH data, Ruiz-Lara et al. [3] studied the star formation history of the entire LMC. To do so, they compared color-magnitude diagrams (CMDs) with sophisticated stellar population models to determine the locations of stars of different ages within the LMC. The result is shown in Figure 1. Stars younger than 2 billion years accumulate in the northern part of the system, coinciding with the position of the spiral arm. If star formation tends to proceed in the spiral arms, it is normal that young stars are located in the arm. However, we need to consider an important aspect here: the LMC is a dynamical system and its stars are in constant movement. Roughly speaking, it takes around 200 million years for a star to orbit around the center of the LMC, and in a couple of such orbits, everything should be well mixed.

The reported spatial coherence for stars younger than 2 billion years provides clear evidence that this structure has been in place for at least the last ~2 billion years. In other words, the LMC spiral arm is a stable, long-lived structure.

What happened to the LMC around 2 billion years ago? Mutual interactions between the LMC and the Small Magellanic Cloud (SMC) have long been invoked to explain large-scale structures in the Magellanic system. In particular, recent numerical studies claim that recurrent interactions between the Clouds started happening ~2.7 billion years ago.

If we put all the pieces of this puzzle together, a coherent scenario emerges. Around 2–3 billion years ago, there was a close approach or encounter between the LMC and the SMC that triggered the formation of a stable dynamical structure, the LMC spiral arm. This structure has been in place and forming stars for the last couple of billion years.

Exploring the Outermost Parts of the SMC

Pol Massana

The outskirts of galaxies can hold important clues to their past interactions, in particular in the form of tidal debris. The identification and characterization of such debris are crucial to our understanding of galaxy assembly, and the SMC holds an important key in trying to solve this puzzle. Being the smaller galaxy in the Magellanic Cloud pair, it is expected to lose more of its stellar content as a result of tidal stripping under the presence of the LMC, as evidenced by its elongated shape and the existence of the Magellanic Stream.

In Massana et al. [4], we use the excellent depth of the SMASH data to analyze the structure in "island" fields in the outskirts of the SMC. We use stars in the oldest main sequence turn-off (MSTO) area of the color-magnitude diagram to trace faint structures. For the SMC, we

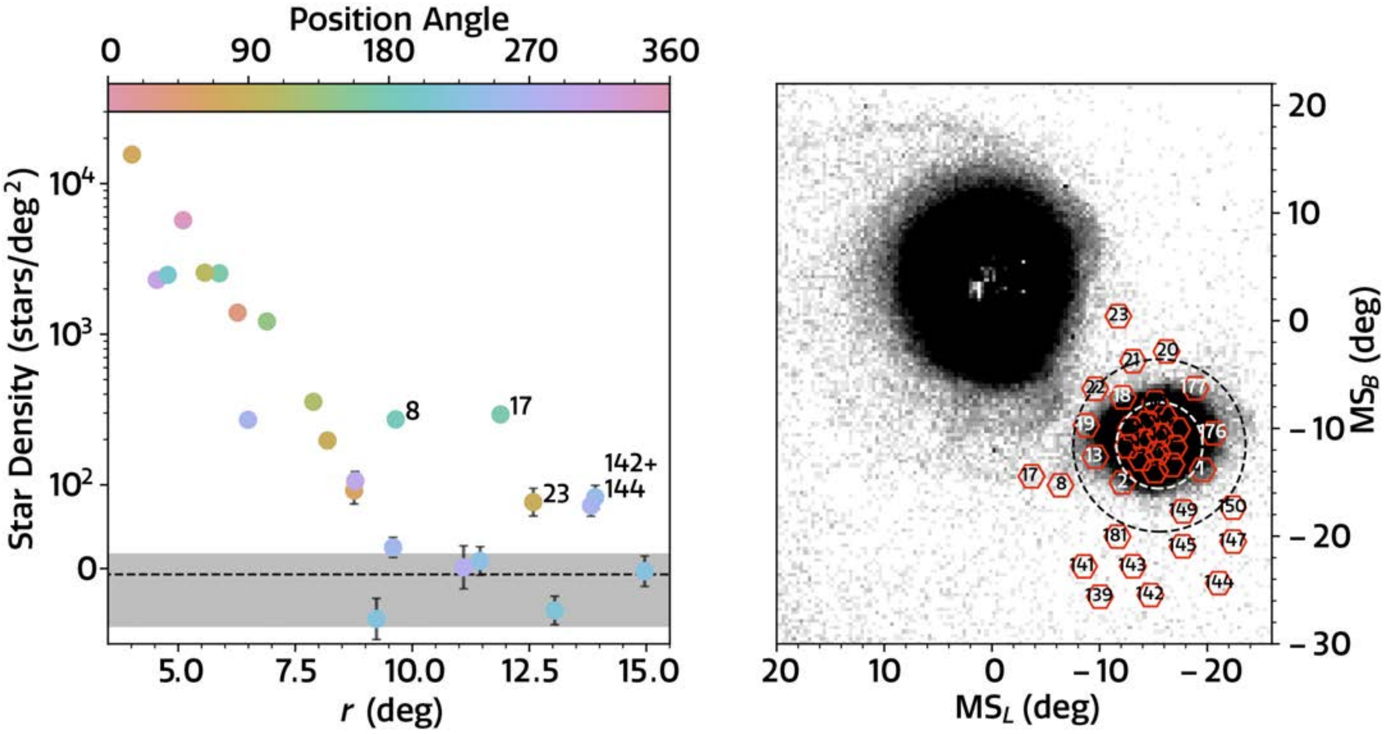


Figure 2. *Left:* Star count density profile of SMC MSTO stars. The points are color-coded according to the position angle of each field. The gray band shows our uncertainty in the foreground counts of the Milky Way, and the error bars for each field represent the statistical Poisson uncertainty. We highlight the position of fields 8 and 17 that show a significantly higher density than the foreground level at radii larger than the expected for the SMC. *Right:* Density map of RGB stars, with saturation at 140 counts, from [5], with the SMASH fields overlaid as red polygons. The two dashed circles represent the 4 (white) and 8 (black) degree circles around the center of the SMC. Fields 8 and 17 sit on an overdense region of Magellanic Cloud debris. (From [4], with permission)

constructed a stellar density profile that reveals its very disrupted nature. We find evidence for Magellanic Cloud debris out to a radius of ~12 degrees from the center of the SMC (Figure 2, left panel). This profile shows the density of Magellanic Cloud stars above the Milky Way foreground level (gray). This provides further evidence of the picture given by *Gaia* DR2 [5], which also found a Magellanic feature in the same area (Figure 2, right panel). This is an exciting result that helps bring to the forefront the analysis of tidal structures around the Magellanic Clouds to explore their past interactions.

A New Method for Obtaining the Reddening of the SMC

Cameron Bell

The Magellanic Clouds are benchmark laboratories for studies of, among other things, star formation at lower metallicities and constraining the extragalactic distance scale (and by extension the Hubble constant). Such studies are dependent upon an understanding of the amount and spatial distribution of dust across the Magellanic Clouds. However, the issue is that the use of differently aged stellar populations to quantify the reddening in the Magellanic Clouds results in statistically significant differences.

Bell et al. [6] introduced a technique to map the intrinsic reddening of a foreground extinguishing medium using the spectral energy distributions (SEDs) of background galaxies. This technique not only removes the aforementioned stellar population dependency but also probes the total reddening by sampling the full column depth of the extinguishing medium.

Recently, Bell et al. [7] extended this technique to map the intrinsic reddening across ~34 deg^2 of the SMC. The reddening map was derived using optical (*ugriz*) and near-infrared (*YJKs*) SEDs of background galaxies that were created from the SMASH survey and the VISTA survey of the Magellanic Clouds system (VMC) data, respectively. Figure 3 shows a 20 × 20 arcmin^2 resolution reddening map of the combined SMASH-VMC footprint created from a sample of ~30,000 background galaxies with low levels of intrinsic reddening. The map reveals statistically significant enhanced levels of reddening associated with the main body of the SMC compared with regions in the outskirts [$\delta E(B-V) \sim 0.3$ mag].

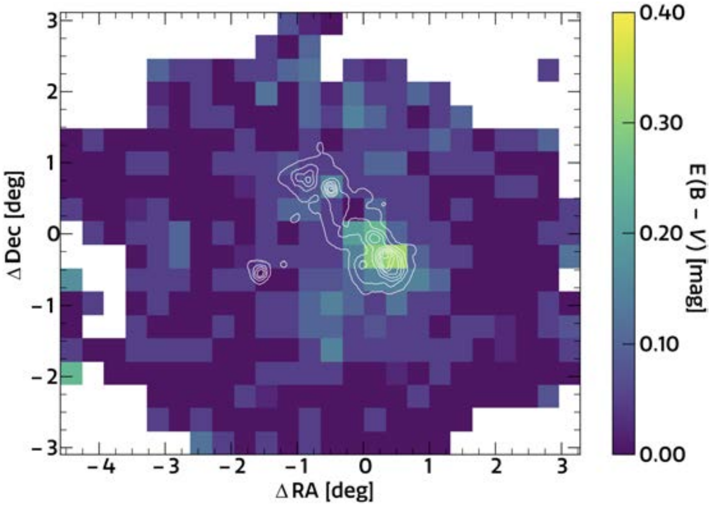


Figure 3. 20 × 20 arcmin^2 resolution reddening map of the combined SMASH-VMC footprint covering ~34 deg^2 of the SMC. This map was created using only galaxies with low levels of intrinsic reddening according to the LePhare SED-fitting routine. (From [7], with permission)

A comparison with reddening maps of the SMC in the literature shows that, after correcting for differences in the volume sampled, there is good agreement between maps created using background galaxies and young stars. In contrast, significant discrepancies are found with respect to maps created using old stars or based on longer-wavelength far-infrared dust emission that could stem from biased samples in the former and/or uncertainties in the far-infrared emissivity and optical properties of the dust grains in the latter.

References

[1] Nidever, D. L., et al. 2017, AJ, 154, 199
[2] Nidever, D. L., et al. 2020, arXiv.org:20111.3943
[3] Ruiz-Lara, T., et al. 2020, A&A, 639, L3
[4] Massana, P., et al. 2020, MNRAS, 498, 1034
[5] Belokurov, V. A. & Erkal, D. 2019, MNRAS, 482, L9
[6] Bell, C. P. M., et al. 2019, MNRAS, 489, 3200
[7] Bell, C. P. M., et al. 2020, MNRAS, 499, 993

Gemini South, sitting on the summit of Cerro Pachón in Chile framed by the Milky Way's Galactic Center, which—thanks to the photographic technique used—appears as a celestial arch, curving across the sky.

Credit: international Gemini Observatory/ NOIRLab/NSF/AURA/K. O. Chul

On the night of Thursday 17 September 2020 10:52 pm, a very bright meteor was reported by more than 25 eyewitnesses in and around Tucson and Phoenix, Arizona. The meteor was also spotted by one of the robotic cameras at Kitt Peak National Observatory (KPNO), a Program of NSF's NOIRLab: an all-sky camera operated by the University of Arizona's Spacewatch that operates the Spacewatch 0.9m Telescope and the Spacewatch 1.8m Telescope (seen in the image as the white dome near the top of the image respectively on the left).

Credit: Spacewatch/Arizona Board of Regents/KPNO/NOIRLab/NSF/AURA

10.5281/zenodo.4444171

Coming in 2021: The First Rubin Observatory Data Preview

Kristen Metzger (Rubin Observatory)

Vera C. Rubin Observatory will soon begin the Legacy Survey of Space and Time (LSST), providing the scientific community with an unprecedented amount of astronomical data. Progress on Rubin's data infrastructure and pre-operations planning has continued on schedule, despite the COVID-19 pandemic, and the Rubin Observatory Operations team is pleased to announce a series of three "data previews" in advance of the start of the LSST. Work on the first Data Preview (DP0) will continue throughout FY21.

The three data previews will provide opportunities for the Rubin Operations team to rehearse and refine the data release process—which will occur annually during the LSST—before the survey begins. Just as importantly, the data previews will help members of the science community familiarize themselves with the tools and the analysis techniques they will need to do science with LSST data. Lessons learned from each data preview will ensure that everyone is as ready as possible when operations begin. *"This will definitely be a work in progress,"* notes Amanda Bauer, Deputy Director of Operations for Rubin Observatory, *"with plenty of opportunity for input along the way."*

Although the Operations team's goal is to make the three data previews resemble, as much as possible, the data releases that will occur during Rubin Operations, it's important to note that the preview data will be very different from the survey data. DP0 will use a simulated dataset intended to look very much like Rubin data, in the sense that the images will resemble full-frame LSST Camera images, and the catalog products will feature the kinds of measurements that will be made using the science pipelines during the survey. The second and third data previews (DP1 and DP2) will feature commissioning data. The primary objective when gathering data during the commissioning phase is to test every aspect of the Rubin Observatory system, so although the observations will be on-sky, commissioning data won't really start to resemble LSST data until the very end of the commissioning phase—and even then it will mostly have different (in many cases higher) temporal sampling from the survey data.

The simulated dataset that will be used in DP0 was built by the Rubin Observatory LSST Dark Energy Science Collaboration (DESC) and is referred to as DC2. The Rubin Operations team has partnered with DESC to provide this dataset for DP0 because it will allow the science community to experience the true scale of LSST data. "*DP0 is designed to get people thinking about how to handle the LSST data,*" points out Phil Marshall, Deputy Director for Rubin Observatory Operations at SLAC National Accelerator Laboratory (SLAC), *"so even if the data aren't exactly what they want for their science, they will get them started working with the kinds of tools that will help them make the best use of subsequent data previews—and eventually, the survey data."*

In the fall of 2020, the Rubin Operations team established a cloud-based Interim Data Facility (IDF) to host Rubin preview data and support pre-operations activities while a permanent US Data Facility is selected. Now, multiple efforts are proceeding simultaneously in preparation for DP0. The DC2 dataset is being ingested by the IDF, and the Rubin Data Management construction team is preparing the science pipelines to process the data and refining the tools the science community will use to access it (all deployed by the Operations team at the IDF). Meanwhile, the newly formed Rubin Observatory Community Engagement Team (CET) is working with scientists and building an online collaborative community and coordinating the development of scientific documentation and tutorials. The CET is part of the Rubin Operations System Performance department; these efforts start during the pre-operations data previews and will continue into Rubin Operations. The CET is committed to facilitating equitable access to LSST data and services, in order to enable scientific excellence from our broad and diverse user community. *"The groundbreaking scientific potential of the LSST dataset requires a proportionally innovative and progressive community engagement model,"* says Melissa Graham, the Lead Community Scientist for Rubin Observatory. *"DP0 is the first in a series of steps towards operations, and the CET is looking forward to working with the community to build an effective model for scientific engagement."*

```
def _lookupNames(self) -> Tuple[LookupKey, ...]:
    """Keys to use when looking up this DatasetRef in a configuration.

    The names are returned in order of priority.

    Returns
    -------
    names : `tuple` of `LookupKey`
        Tuple of a `LookupKey` using the `StorageClass` name.
    """
    return (LookupKey(name=self.name), )

def knownParameters(self) -> Set[str]:
    """Return set of all parameters known to this `StorageClass`

    The set includes parameters understood by components of a composite.

    Returns
    -------
    known : `set`
        All parameter keys of this `StorageClass` and the component
        storage classes.
    """
    known = set(self._parameters)
    for sc in self.components.values():
        known.update(sc.knownParameters())
    return known

def validateParameters(self, parameters: Collection = None) -> None:
    """Check that the parameters are known to this `StorageClass`

    Does not check the values.

    Parameters
    ----------
    parameters : `~collections.abc.Collection`, optional
        Collection containing the parameters. Can be `dict`-like or
        `set`-like.  The parameter values are not checked.
        If no parameters are supplied, always returns without error.

    Raises
    ------
    KeyError
        Some parameters are not understood by this `StorageClass`.
    """
    # No parameters is always okay
    if not parameters:
        return

    # Extract the important information into a set. Works for dict and
    # list.
    external = set(parameters)

    diff = external - self.knownParameters()
    if diff:
        s = "s" if len(diff) > 1 else ""
        unknown = '\', \''.join(diff)
        raise KeyError(f"Parameter{s} '{unknown}' not understood by Stora
```

A visual representation of the Rubin Science Platform in use with a background image of the spiral galaxy IC342. (Credit: Rubin Obs/KPNO/NOIRLab/NSF/AURA/H. Schweiker (WIYN/NOIRLab)/T. A. Rector (University of Alaska Anchorage))

During the LSST, Rubin Observatory data will be available to all scientists with data rights, but DP0 must be deployed with a subset of the science community to prevent overloading the IDF and other data infrastructure still in development. The community members selected for DP0 will broadly represent the Rubin community, including those identified as experienced users, inexperienced users, members of the Science Collaborations, Chilean colleagues, and scientists and educators from small and underserved institutions. As the data previews progress, support for community participation will increase until (at least by the start of operations) all data rights holders are able to engage with the commissioning data. The process for selecting science community members to participate in DP0 will be announced in early 2021. As there will be two stages of DP0—as first the original DESC simulated dataset is made available to users (2021), and then later after this dataset is reprocessed by the Rubin science pipelines in order to more closely mimic an LSST data release (2022)—there will be multiple opportunities for participation. The CET is currently preparing resources to support DP0 community participants and help them learn about the simulated data products and how to access them in the IDF.

The Operations team anticipates that the data previews will improve with each iteration, as the Rubin Observatory Data Management team continues to develop the data infrastructure, and as community feedback is incorporated. *"We're as eager to provide Rubin Observatory data to the science community as they are to receive them,"* says Bob Blum, Rubin Observatory Acting Operations Director. *"We expect the data previews to be exciting—and a learning process—for everyone involved."*

10.5281/zenodo.4444175

Education and Engagement in the Era of Social Distancing

Peter Michaud (NOIRLab)

The birth of NOIRLab and the uniting of diverse programs and activities from sites in Tucson, Chile, and Hawai‘i offer exciting challenges with myriad opportunities. Specifically, the transition of the Communications, Education and Engagement (CEE) group is now well underway—resulting in dozens of press and image releases over the past year, multiple internal and external publications (including this newsletter), professional conference coordination (e.g., AAS), and many more activities too numerous to list.

Among these successes are many challenges. Arguably, one of the greatest challenges has been to unite all of NOIRLab's Education and Engagement (E&E) programming in the era of COVID-19 social distancing. Just a year ago, visiting local classrooms and interacting directly with students was trivial—now it's impossible. Where once accommodating visitors at our telescopes was routine, we now focus on virtual experiences to share our facilities. Programs like Globe at Night, Journey Through the Universe, Viaje al Universo, Colors of Nature, Teen Astronomy Café, and AstroDay all rely on high levels of direct, in-person interaction, but with social distancing the current norm, new models utilizing virtual programming are necessary.

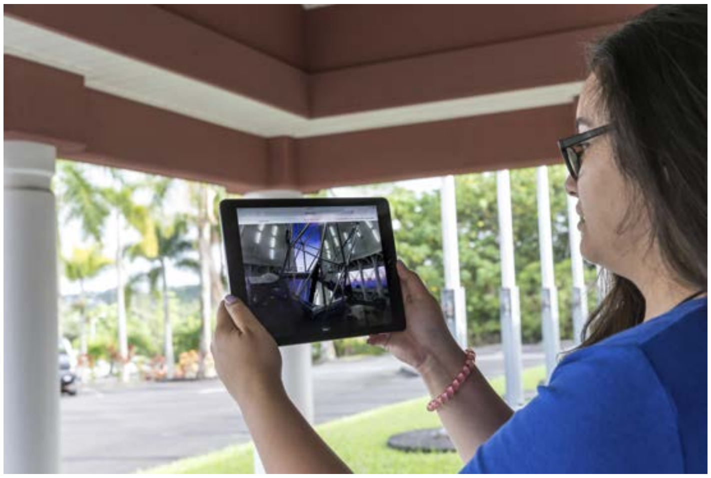


Figure 1. Alexis-Ann Acohido explores Gemini North with interactive iPad version of the Gemini Virtual Tour. (Credit: NOIRLab/NSF/AURA)

In addition to adapting previously "in-person" programming to virtual delivery, the expansion and adaptation of virtual experiences, like the long-running Live from Gemini program, and virtual tours, have found new relevance in core NOIRLab E&E programming.

It is reasonable to expect that the development of new and expanded virtual programming will extend well into the post-COVID-19 era. Meanwhile, virtual programming expands participation globally and far beyond the local host community audiences traditionally targeted by many of our educational programs.

> “With social distancing the current norm, new models utilizing virtual programming are necessary.”

The Teen Astronomy Café program, a long-running staple of local outreach in Tucson, is an example of an effective adaptation of previously in-person programming. *“When social distancing became commonplace, we wondered how we could still do Teen Astronomy Café,”* said Connie Walker, who has led the program since 2017. *“Then we started looking at the tools available and prototyped a virtual version of the program,”* Walker adds. *“In the end it worked amazingly well and we continue to move the program forward and experiment with new ways to engage students.”* Expanding the program to all NOIRLab sites and beyond is also on the horizon.

This program was adapted as an early virtual program and continues to be offered with pandemic protocols. It is expected that a virtual version of this program will continue beyond COVID-19 and attract new audiences across the NOIRLab sites.

Another example, one that required less adaptation, is the expansion of the Live from Gemini program. For over a decade, this virtual (hosted) program provided classrooms and public audiences an opportunity to visit the Gemini control rooms, meet staff, and participate in a behind-the-scenes exploration of observatory operations and recent science highlights.

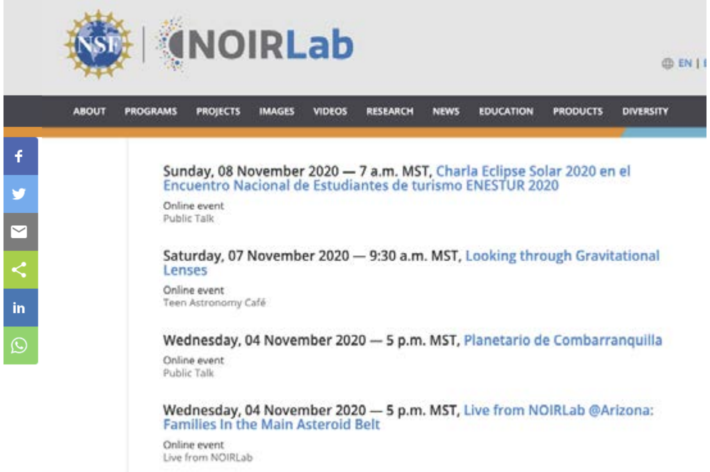
Expansion of this program in the COVID-19 era has resulted in a new name, Live from NOIRLab. Each site (Hawai‘i, Tucson, and Chile) presents the program every third week (with the Chile version in Spanish), and features a staff or guest astronomer to share NOIRLab-relevant technology, science, and operations. A YouTube archive of these programs is available at NOIRLabAstro on YouTube.

Figure 2. Banner from a recent Live from NOIRLab event. These banners are used to promote the weekly programs on social media and on the events webpage. (Credit: NOIRLab/NSF/AURA)

Figure 3: The Viaje al Universo program went virtual in October 2020 with virtual events, including this virtual star party led by CEE staff person Juan Seguel. During these star parties NOIRLab staff share objects currently visible in the night sky in the context of research at our facilities. (Credit: NOIRLab/NSF/AURA)

The annual Viaje al Universo program in Chile was adapted to virtual delivery in October of 2020. The program, based on the Journey Through the Universe program in Hawai'i, is based on in-person events in local classrooms and public talks and skygazing.

Adapting this program to virtual delivery presented many challenges. *"At first we thought the program wasn't adaptable to virtual delivery,"* said program manager Manuel Paredes. *"However, as we started looking at the situation we found ways to adapt the program, such as hosting virtual talks, workshops, and a star party, that will become regular elements in upcoming years even after social distancing is no longer necessary."*



Sunday, 08 November 2020 — 7 a.m. MST, Charla Eclipse Solar 2020 en el Encuentro Nacional de Estudiantes de turismo ENESTUR 2020
Online event
Public Talk

Saturday, 07 November 2020 — 9:30 a.m. MST, Looking through Gravitational Lenses
Online event
Teen Astronomy Café

Wednesday, 04 November 2020 — 5 p.m. MST, Planetario de Combarranquilla
Online event
Public Talk

Wednesday, 04 November 2020 — 5 p.m. MST, Live from NOIRLab @Arizona: Families In the Main Asteroid Belt
Online event
Live from NOIRLab

Figure 4: Examples of virtual programing on the NOIRLab Events Webpage. (Credit: NOIRLab/NSF/AURA)

Looking ahead, the Journey Through the Universe program in Hawai'i is being adapted for virtual delivery in March 2021 and is expected to include elements similar to those used in the Viaje al Universo program.

As NOIRLab moves forward and adapts existing programs across sites in Chile, Tucson and Hawai'i, lessons learned in adapting to social distancing have provided excellent opportunities for CEE staff to work together under difficult circumstances and find innovative solutions. In the process, the challenges of COVID-19 have helped CEE staff to bond, broken down barriers, and prepared us for a confident future of mutual, coordinated E&E programming.

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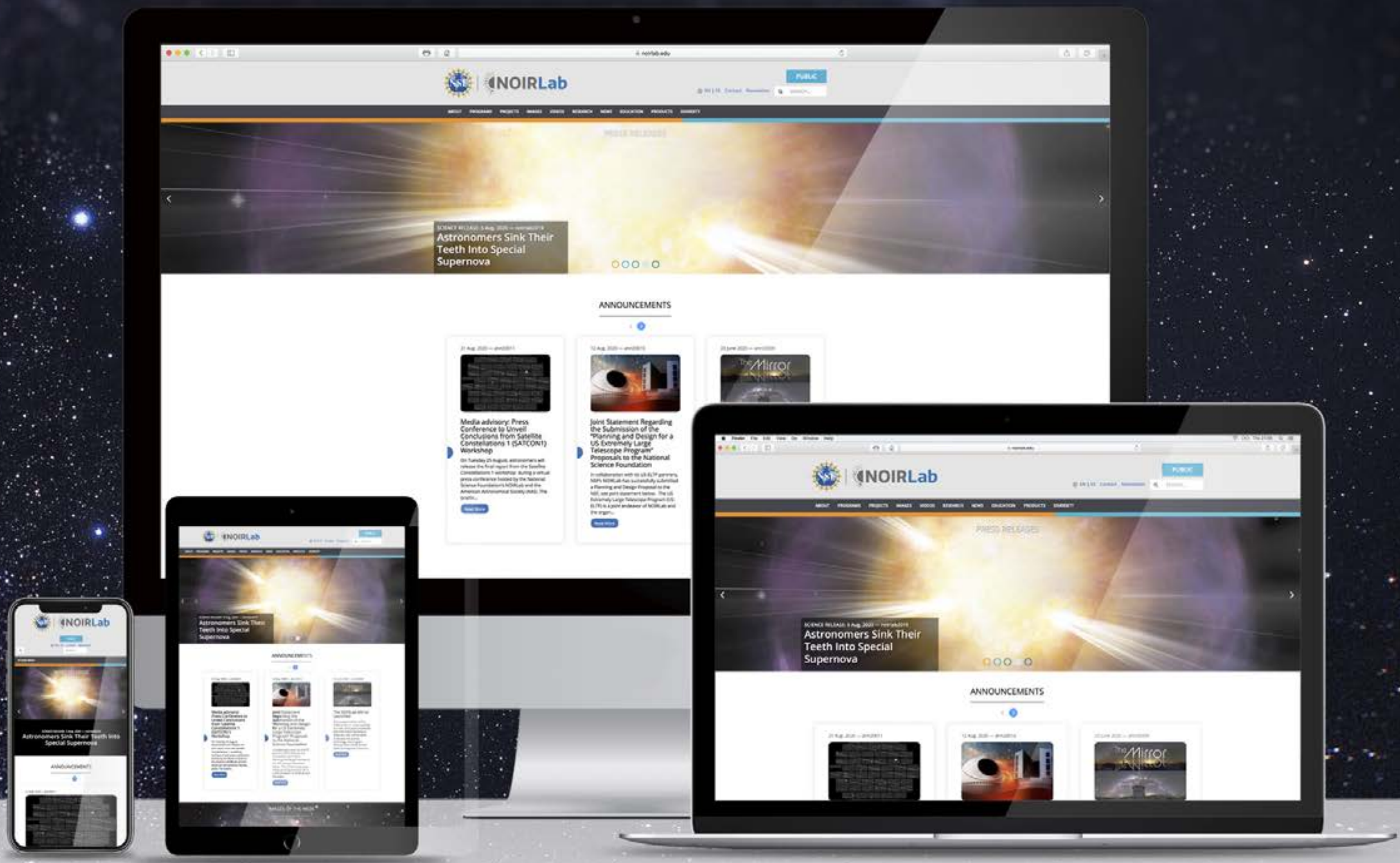

Figure 1. Sample screens of the new NOIRLab website illustrating functionality on mobile to desktop platforms. (Credit: NOIRLab/NSF/AURA)

New Website for NSF's NOIRLab

Mark Newhouse (NOIRLab)

When NSF announced the formation of the National Optical-Infrared Astronomy Research Laboratory on 1 October 2019, it was clear that the full name was quite a mouthful! A shorter name would be needed to make it easier to refer to, at the same time providing an option for a relatively short domain name for a website. At the time we used the interim name "OIR Lab" and set up an interim website at noirlab.edu to serve as our public website. When we received our official short name in the Northern Hemisphere spring of 2020, a targeted effort began to move NOIRlab's public internet presence to its new domain at noirlab.edu. This public site has since been launched as the main web portal for the public and media to receive information about NSF-funded ground-based nighttime astronomy and the valuable data generated by NOIRLab facilities.

Each of NOIRLab's five Programs—the Cerro Tololo Inter-American Observatory, the Community Science and Data Center, the international Gemini Observatory, Kitt Peak National Observatory, and Rubin Operations—brings a long and rich history of scientific breakthroughs spanning more than five decades. The new website shines a spotlight on NOIRLab's role as a focal point for community development of innovative scientific programs, the exchange of ideas, and creative development. NOIRLab's infrastructure enables the astronomy community to advance humanity's understanding of the Universe by exploring significant areas of astrophysics, including dark energy and dark matter, galaxies and quasars, the Milky Way, exoplanets, and small bodies in our own Solar System.

Features

The new website offers a complete archive of all NOIRLab information for the public and media—nearly 6,000 images with rich contextual metadata, hundreds of videos, news, print products, fulldome sequences for planetariums to download and show in their domes, and more.

Dive into the full 3.2 gigapixels of the first image from the Rubin Observatory LSST Camera. Subscribe to the latest images and videos. Download the whopping 124 GB sequence of 8k planetarium frames that together show a 3-minute state-of-the-art timelapse sequence of a night at Gemini South. Read about each of the more than 60 telescopes operated or hosted by NOIRLab. Follow the progression of each of NOIRLab's programs through press releases back to 1994. All NOIRLab images and videos are directly available in the domes of more than 500 planetariums with a dynamic feed using a metadata standard called Data2Dome.

The site is regularly updated with press releases and announcements from all of our Programs, as well as a new image every week featuring interesting and beautiful photographs of NOIRLab's facilities, as well as inspiring images taken by NOIRLab's many telescopes. Our diverse education and engagement activities are also highlighted on the site.

The assets are freely available to download and use under a Creative Commons Attribution license. The site also offers a historical perspective, and archives of newsletters and announcements from the National Optical Astronomy Observatory (NOAO) and Gemini are available. The website can be accessed in both English and Spanish.

The system behind the site, Djangoplicity, is a tried and tested recipe used by ESA/Hubble, ESO, UNAWE, the IAU, the International Year of Astronomy 2009, and others. It is an open-source platform that integrates a standard Content Management System for the web pages with Digital Asset Management of all the assets, as well as an automated system for delivery of content to different audiences. The system uses Django, which is a high-level Python web framework that encourages rapid development and clean, pragmatic design, and was designed to handle the pressing deadlines of a newsroom.

The Team Behind the Website

An effort like this does not happen overnight, or with just one or two people. The construction and delivery of the site was a heroic effort by several of NOIRLab's communication, education and IT staff, working with the company Enciso Systems. It is through their coordinated efforts that the new site has come to fruition.

- NOIRLab web project coordination: Mark Newhouse (NOIRLab)
- Development of noirlab.edu: Javier Enciso, Edison Arango, Edwin Moreno, Francisco Rodriguez and Andrés Linares (Enciso Systems)
- Content migration: Paula Velásquez, Ingry Romero, Samuel Medina, Diego Palacios, Alejandro Vivas, Javier Riveros and Jonathan Garzón (Enciso Systems)
- Design: Jason Kalawe (NOIRLab), Peter Marenfeld (NOIRLab), Joy Pollard (NOIRLab), Emily Acosta (Vera C. Rubin Observatory)
- Infrastructure: Jason Kalawe (NOIRLab), Jared Eckersley (NOIRLab) & Enciso Systems
- Archive consolidation & post-processing: Mahdi Zamani & Maral Kosari
- Djangoplicity legacy development: Lars Holm Nielsen (ESO, ESA/Hubble & IAU), Mathias André (ESO, ESA/Hubble & IAU), Gurvan Bazin (ESO), and Bruno Rino (UNAWE)
- Djangoplicity project management: Lars Lindberg Christensen (NOIRLab)

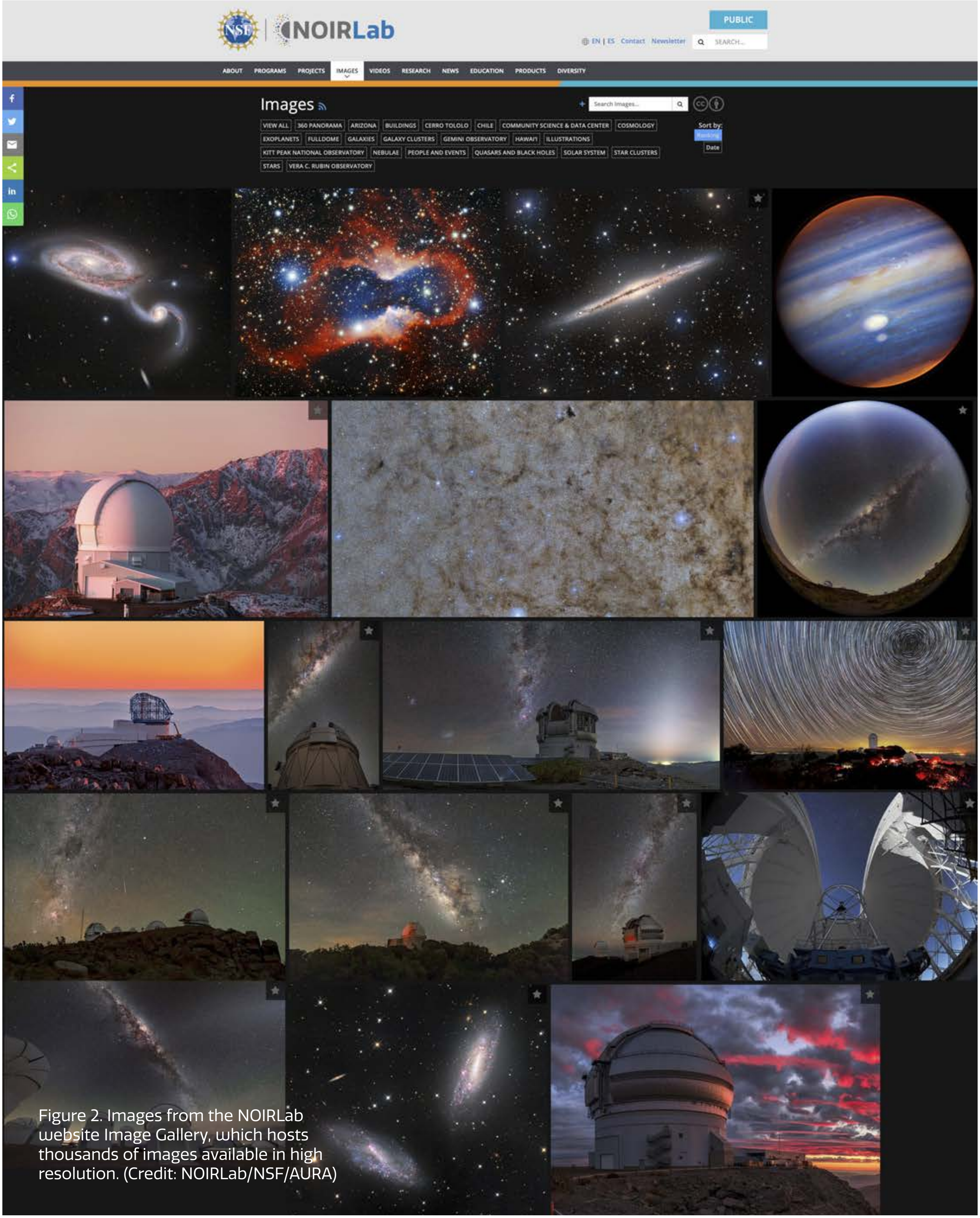

Figure 2. Images from the NOIRLab website Image Gallery, which hosts thousands of images available in high resolution. (Credit: NOIRLab/NSF/AURA)

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Outcome of the SATCON1 Online Workshop

Connie Walker (NOIRLab)

In May 2019, the astronomical community was somewhat stunned at the brightness of the streaks of 60 SpaceX Starlink satellites seen in images. This underscored how we are experiencing a major intersection of technologies between deep, wide-field sky surveys and potentially large numbers of low-Earth-orbiting satellites (LEOsats), also known as constellation satellites. For instance, with potentially tens of thousands of Starlink satellites, SpaceX's capability to provide internet service to billions of people worldwide has definite merits. At the same time, there is a tremendous amount of new technology coming online within the field of astronomy in the next decade that will substantially increase humanity's understanding of the Universe. However, observatories require a dark night sky to uncover the secrets behind some of the most fundamental questions about the nature of our Universe. Prime examples of these new technologies are Vera C. Rubin Observatory and the 30-meter telescopes, coming online in the next decade. For reasons of expense, maintenance, and instrumentation, such facilities cannot be launched into space. Ground-based astronomy is, and will remain, vital and relevant.

The collective response from the astronomy community to the emergence of the constellation satellites commenced this Northern Hemisphere spring, as 46 experts from around the world came together under an NSF grant to NOIRLab. As part of four working groups, they were tasked with studying the impacts of satellite constellations on astronomy, and determining possible mitigation steps that could feasibly be implemented by observatories, satellite operators, and funding agencies. Connie Walker (NSF's NOIRLab) and Jeff Hall (Lowell Observatory) co-chaired the Scientific Organizing Committee (SOC). The four working groups (WGs) focused on the following areas: observations, simulations, mitigations and metrics. They were led by Lori Allen (NOIRLab), Pat Seitzer (U. Michigan), Tony Tyson (UC Davis/Rubin Observatory) and Richard Green (Steward Observatory/U. Arizona), respectively. In about a month each group had completed its report.

NOIR Lab AURA AAS

Impact
of Satellite
Constellations
on Optical Astronomy and
Recommendations Toward
Mitigations

Figure 1. Cover of the report “Impact of Satellite Constellations on Optical Astronomy and Recommendations Toward Mitigations” from the SATCON1 workshop. (Credit: NOIRLab/NSF/AURA/AAS)

A workshop called SATCON1 was organized jointly by NSF’s NOIRLab and the American Astronomical Society (AAS), and held online from 29 June to 2 July 2020. It focused on technical aspects of the impact of existing and planned large satellite constellations on optical and infrared astronomy. At the workshop, members of the working groups presented in a zoom webinar and discussions followed. There were 250 attendees from industry and astronomy.

The goals of SATCON1 were to better quantify the scientific impacts of huge ensembles of LEOsats contaminating astronomical observations and to explore possible ways to minimize those impacts. The remarks from the discussions were included in revisions and a few weeks later a final main summary report and an appendix with the working group reports were released at the start of a press briefing. The two parts of the final report can be found here (main document) and here (appendices).

The report concludes that the effects of large satellite constellations on astronomical research and on the human experience of the night sky range from “negligible” to “extreme.” At the press briefing organized by NOIRLab and AAS on 25 August 2020, the chairs of the SOC and WGs presented the highlights of the findings and the recommendations of the studies by the four working groups. These are summarized below.

Findings

Finding 1

The projected surface density of bright satellites in constellations is greatest near the horizon and during twilight. For this reason, LEO constellations disproportionately impact science programs that require twilight observations, such as searches for near-Earth objects (NEOs), distant Solar System objects, and optical counterparts of fleeting gravitational wave sources. Depending on constellation design, LEOsats can also be visible deep into the night, broadening the impact to encompass all astronomical programs. We find that the worst-case constellation designs prove extremely impactful to the most severely affected science programs. For the less affected programs, the impact ranges from negligible to significant, requiring novel software and hardware efforts in an attempt to avoid satellites and remove trails from images.

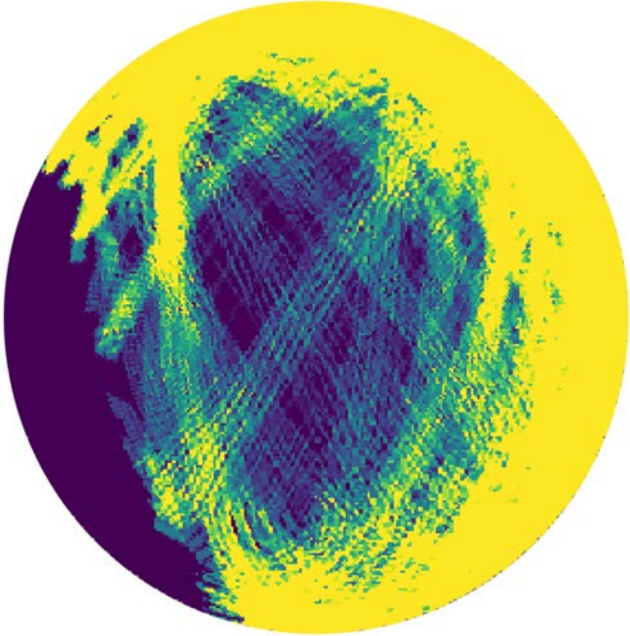


Figure 2. A simulated all-sky plot of trails of 47,708 illuminated LEOsats over a 10-minute time period as seen from Rubin Observatory in Chile with the altitude of the Sun at −18.4 degrees. Zenith is at the center, north is up and east is left. The trails are bunched due to populating the orbital planes. The trail-free region is caused by the Earth's shadow. (Credit: P. Yoachim, U. Washington/Rubin Observatory)

We find two step-functions in impact based on the brightness of the satellites: naked-eye visibility and instrument sensor calibration range. If satellites are visible to the naked eye, the scope of impact expands to include non-professional, unaided-eye observers including amateur astronomers and astrophotographers, and possibly indigenous peoples and members of religions that observe the sky for calendar-keeping. Satellites whose apparent brightnesses are below unaided-eye visibility can have a much more severe impact on astronomical science if they are bright enough to cause non-correctable artifacts in the camera sensors. For fainter satellites, of course, the trail itself remains and must be dealt with. In the cases where it might be impossible to fully mask or remove trails, a bright enough satellite could induce systematic errors impacting some science investigations.

Satellites below 600 km (373 miles)
LEOsat constellations below 600 km are visible for a few hours per night around astronomical twilight from observatories at middle latitudes, but they are in Earth's shadow and invisible for several hours per night around local solar midnight, with some satellites visible during the transitions. This visibility pattern causes these constellations to most heavily impact twilight observers (see the examples mentioned above). Since these orbits are closer to Earth, satellites at these altitudes will be brighter than the same satellites would be at higher orbital altitudes. The reduced range makes them more likely to exceed the unaided-eye brightness threshold if operators fail to design with this criterion in mind.

Satellites above 600 km
Satellites above 600 km are an even greater concern to astronomers because they include all the impacts mentioned above, but can also be illuminated all night long. Full-night illumination causes these high-altitude constellations to impact a larger set of astronomical programs.

Finding 2
Approaches to mitigate LEOsat impacts on optical-NIR astronomy fall into six main categories.

1. Launch fewer or no LEOsat constellations. This is the only option identified that can achieve zero impact.
2. Deploy satellites at orbital altitudes no higher than ~ 600 km
3. Darken satellites by lowering their albedo, shading reflected sunlight, or some combination thereof.
4. Control each satellite's attitude in orbit so that it reflects less sunlight to Earth.
5. Remove or mask satellite trails and their effects in images.
6. Avoid satellite trails with the use of accurate ephemerides.

Recommendations

1. For Observatories

Recommendation 1
Support development of a software application available to the general astronomy community to identify, model,

subtract, and mask satellite trails in images on the basis of user-supplied parameters.

Recommendation 2
Support development of a software application for observation planning available to the general astronomy community that predicts the time and projection of satellite transits through an image, given celestial position, time of night, exposure length, and field of view, based on the public database of ephemerides. Current simulation work provides a strong basis for the development of such an application.

Recommendation 3
Support selected detailed simulations of the effects on data analysis systematics and data reduction signal-to- noise impacts of masked trails on scientific programs affected by satellite constellations. Aggregation of results should identify any lower thresholds for the brightness or rate of occurrence of satellite trails that would significantly reduce their negative impact on the observations.

2. For Constellation Operators

Recommendation 4
LEOsat operators should perform adequate laboratory Bi-directional Reflectance Distribution Function (BRDF) measurements as part of their satellite design and development phase. This would be particularly effective when paired with a reflectance simulation analysis.

Recommendation 5
Reflected sunlight ideally should be slowly varying with orbital phase as recorded by high etendue (effective area × field of view), large-aperture ground-based telescopes to be fainter than $7.0\ V_{mag} + 2.5 \times \log(r_{orbit} / 550\ \text{km})$, equivalent to $44 \times (550\ \text{km} / r_{orbit})$ watts/steradian.

Recommendation 6
Operators must make their best effort to avoid specular reflection (flares) in the direction of observatories. If such flares do occur, accurate timing information from ground-based observing will be required for avoidance.

Recommendation 7
Pointing avoidance by observatories is achieved most readily if the immediate post-launch satellite configuration is clumped as tightly as possible consistent with safety, affording rapid passage of the train through a given pointing area. Also, satellite attitudes should be adjusted to minimize reflected light on the ground track.

3. For Observatories and Operators in Collaboration

Recommendation 8
Support an immediate coordinated effort for optical observations of LEOsat constellation members, to characterize both slowly and rapidly varying reflectivity and the effectiveness of experimental mitigations. Such observations require facilities spread over latitude and longitude to capture Sun-angle-dependent effects. In the longer term, support a comprehensive satellite constellation observing network with uniform observing and data reduction protocols for feedback to operators and astronomical programs. Mature constellations will have the added complexity of deorbiting of the units and on-orbit aging, requiring ongoing monitoring.

Recommendation 9
Determine the cadence and quality of updated positional information or processed telemetry, distribution, and predictive modeling required to achieve substantial improvement (by a factor of about 10) in publicly available cross-track positional determination.

Recommendation 10
Adopt a new standard format for publicly available ephemerides beyond two-line-elements (TLEs) in order to include covariances and other useful information. The application noted in Recommendation 2 should be compatible with this format and include the appropriate errors.

The next workshop, SATCON2, which will tackle the significant issues of policy and regulation, is tentatively planned for early to mid-2021.

NSF's NOIRLab

Jupiter and Saturn in Conjunction over Maunakea

In December 2020 Jupiter and Saturn appeared closer in the sky than they have for 800 years. This image was obtained on 20 December 2020 with the Gemini North cloud monitoring camera on Hawaii's Maunakea. In this image the two planets appear as one object, but they are about one-tenth of a degree apart. The faint glow of the zodiacal light can also be seen stretching to the horizon.

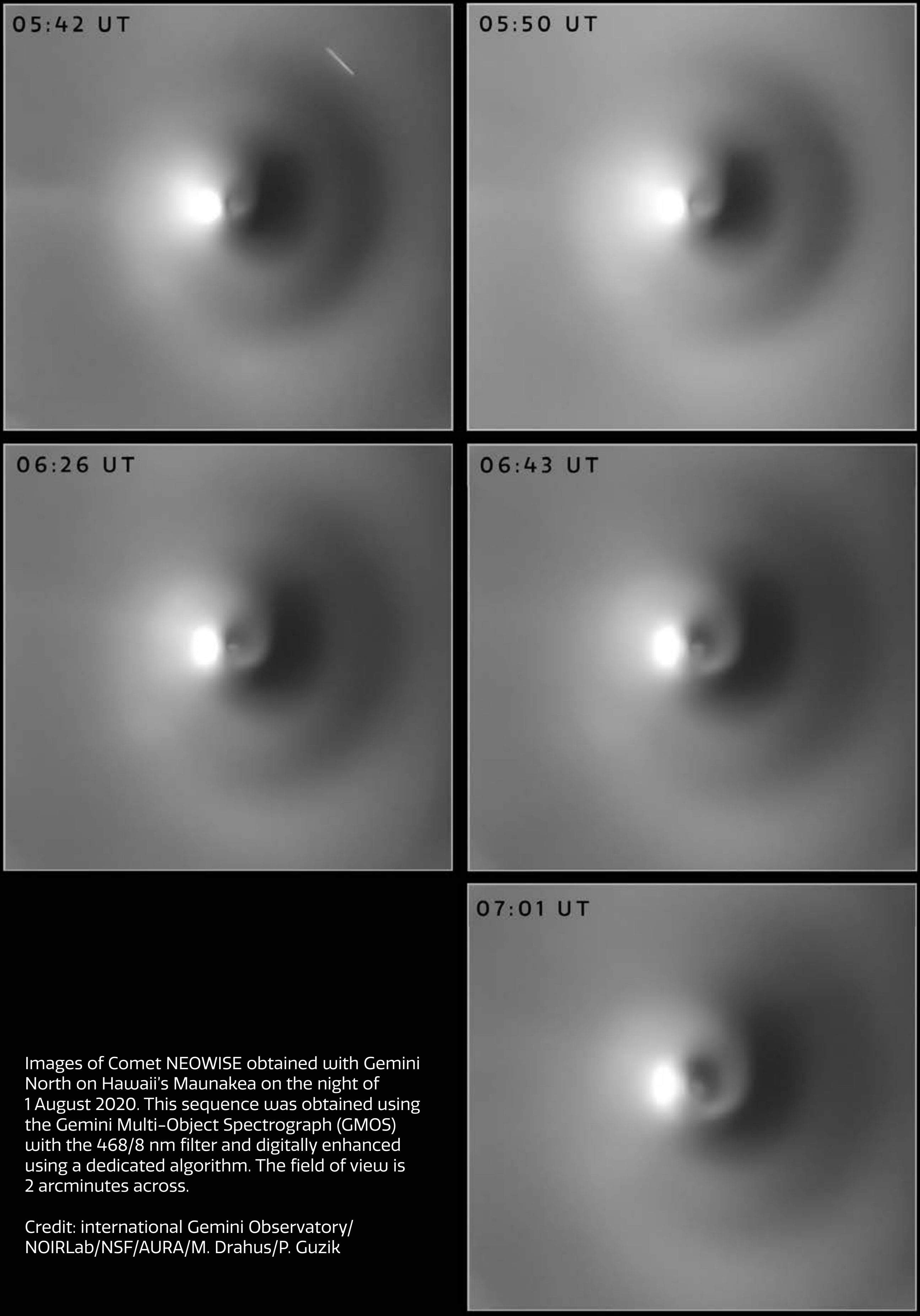
Credit: international Gemini Observatory/ NOIRLab/NSF/AURA

NSF's NOIRLab

This view of the December 2020 conjunction of Jupiter and Saturn was obtained by Rob Sparks of NSF's NOIRLab.

Credit: R. Sparks/NOIRLab/NSF/AURA

NSF's NOIRLab



Images of Comet NEOWISE obtained with Gemini North on Hawaii's Maunakea on the night of 1 August 2020. This sequence was obtained using the Gemini Multi-Object Spectrograph (GMOS) with the 468/8 nm filter and digitally enhanced using a dedicated algorithm. The field of view is 2 arcminutes across.

Credit: international Gemini Observatory/ NOIRLab/NSF/AURA/M. Drahus/P. Guzik

Discovering Our Universe Together

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