The Mirror

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On the Cover

An artistic celebration of the Dark Energy Spectroscopic Instrument (DESI) year-one data, showing a slice of the larger 3D map that DESI is constructing during its five-year survey. By mapping objects across multiple periods of cosmic history with extremely high precision, DESI is allowing astronomers to make unprecedented measurements of dark energy and its effect on the accelerating expansion of the Universe. *Credit: DESI Collaboration/KPNO/NOIRLab/NSF/AURA/ P. Horálek/R. Proctor*

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Director's Message

Patrick J. McCarthy

There have been many interesting developments at NOIRLab since the last edition of *The Mirror*. Several developments are particularly noteworthy and are featured in this letter.

On April 4, the primarily U.S. Department of Energy-funded Dark Energy Spectroscopic Instrument Survey (DESI) released their first-year science results. Like the Dark Energy Survey on the Víctor M. Blanco 4-meter Telescope, DESI is using the Nicholas U. Mayall 4-meter Telescope to conduct a world-leading study of the expansion history of the Universe to probe the properties of dark energy. DESI will collect 50 million or more redshifts for galaxies across the northern sky. Ripples in the distribution of matter arising from acoustic waves, frozen-in when radiation and matter decoupled, are imprinted on the distribution of galaxies. The separation of the peaks in the galaxy distribution provides us with a "standard ruler" to gauge the geometry of the Universe.

The first-year results from DESI use 10 million redshifts to measure these peaks and deduce a range of cosmological parameters. Combining the DESI data with measurements from supernovae and the cosmic microwave background, the DESI team has made the most precise measurements ever of the Hubble Constant and the dark energy parameter, Lambda. These agree with the now "standard" ΛCDM cosmology to exquisite precision.

More interestingly, the DESI team posed the question: do the data prefer a Universe with a constant density of dark energy (perhaps Einstein's cosmological constant) or one in which the dark energy density changes with time? Tantalizingly, the data prefer the model in which the dark energy parameter varies with time. Dennis Overbye, in his *The New York Times* article about the DESI results, called this a "hint" that our standard model of cosmology needs revision. Such a change could have profound implications for our understanding of fundamental physics, the evolution of the Universe and its ultimate fate. Analysis of the remaining 40 million redshifts should clarify the situation and lead to higher confidence levels in the final parameters (See the Science Highlight article by Hee-Jong Seo on page 11 of this issue for a full discussion of the dark energy constraints provided by the first-year DESI observations.).

Five thousand miles from the Mayall and the DESI instrument, in Chile, the Rubin team is transforming steel and silicon into a world-leading cosmological observatory. On 27 April, the Rubin team applied a 10-nanometer thin layer of silver to Rubin's combined primary and tertiary mirrors. The thin layer of reflective silver was promptly covered with a transparent protective coating of silicon nitride, following coating processes developed at Gemini years ago.

All of the Rubin optics are now coated and ready to be installed in the telescope. At the same time, the team at Stanford's SLAC National Laboratory delivered the LSST Camera to the summit of Cerro Pachón. The LSST camera is now safely situated in the clean room at Rubin ready for the next step towards full integration of the observatory. First light is now tantalizingly close. The start of the Legacy Survey of Space and Time (LSST) will soon follow (see the images of the silvered primary and the LSST Camera on page 32 of this issue).

The connection between these events is clear — DESI's "hints" at incompleteness in the standard model of cosmology only increases the excitement around the start of Rubin's LSST. While DESI will measure tens of millions of galaxies, the LSST will sample *billions* of galaxies and *millions* of supernovae to gauge the expansion history of the Universe. If there is more to dark energy than meets the eye, Rubin will help us find out.

While cosmologists ponder the overall geometry of the Universe, most of astronomy is concerned with the contents of the Universe — the dark matter, galaxies, stars, gas, and black holes that gives the Universe its rich character. Observing these phenomena requires a diverse and capable toolkit of instruments and software. In recent months Gemini has commissioned a number of new instruments (e.g., GHOST, IGRINS-2) and advanced others through the design and construction phases (SCORPIO, GNAO, GIRMOS). Other instruments have been given a new life with updates and new modes.

In February a team from Stanford led by Tirth Sutri and Roger Romani published a fascinating result concerning the most massive black holes in the Universe. They used the integral field spectrograph on Gemini North to observe a binary black hole system in the radio galaxy 4C+37.11. Weighing in at 28 billion solar masses, these two black holes are among the most massive known, and they orbit each other at a distance of only seven parsecs. These two massive black holes are locked in close embrace; they have shed angular momentum by ejecting stars from the central region of the galaxy through dynamical friction, but may have exhausted the potential for further angular momentum exchange. They may spend billions more years orbiting each other – trying to merge but unable to do so due to one of the first rules of physics – the conservation of angular momentum!

Our mission is to enable breakthrough discoveries. We are off to a great start in 2024, and excitement for the next generation of telescopes and instruments continues to build, driven by remarkable discoveries with today's tools.

Empowering Change: NOIRLab's Integrated Approach to DEI

Alysha Shugart
(NSF NOIRLab)

NOIRLab's commitment to diversity, equity, and inclusion (DEI) begins with the NOIRLab mission statement:

Enabling and sharing breakthrough discoveries in astronomy and astrophysics with state-of-the-art ground-based observatories, data products, and services for a diverse and inclusive community

Our vision is to develop and embed a robust culture of DEI throughout the Lab, with a shared understanding and responsibility among all staff. This vision requires us to embrace inclusive behaviors and procedures as integral to our work, not as separate activities. Our commitment to DEI includes both outward-facing activities and policies impacting the (future) scientific community and the public, and inward-facing activities that support our workforce. These are integrated throughout NOIRLab as an organization.

All NOIRLab employees are responsible for creating a sense of belonging in the organization and positive spaces for all people who want to share the wonders of the Universe with us. These efforts are part of all staff duties, and to encourage participation, employees are invited to spend up to 3% of their work time on DEI, outreach, or community-driven activities.

Community astronomy and creating meaningful relationships and shared leadership in STEM are outlined as strong priorities in the Astro2020 Decadal Survey.

Community-based science—a model for research in which at every step in a project at least partial control remains with the community—is an approach that has been implemented to various degrees in archaeology, forestry, arctic science, and other fields. It can serve as an example for a community astronomy approach to active, upfront, and sustained engagement with local and Indigenous communities.
[Section 3.4.1, Figure 3.14]

NOIRLab holds a key position in several sites across the world to lead this effort. The Communications, Education and Engagement (CEE) Service has expanded to include members who are dedicated to building new and strengthening existing partnerships in Hawai'i and with the Tohono O'odham Nation (TON) in Arizona. NOIRLab staff are encouraged to use their 3% DEI+Outreach time to participate in initiatives and events in this realm.

NOIRLab DEI Committee

The NOIRLab DEI Committee has members from management, science staff, engineering, and administration and from all of NOIRLab's sites. Four volunteers, three diversity advocates, two appointed members from leadership, one member of Human Resources, and the DEI Officer form the committee, which kicked off in September 2022. They quickly implemented their charter, aligning under these goals:

- Leverage the Broadening Participation program and increase manager participation among themselves and their employees.
- Take ownership in fostering a culture of diversity, equity, and inclusion within NOIRLab. The committee will assist in promoting and encouraging the DEI objectives and initiatives, driving a culture of inclusion where everyone within NOIRLab feels included, respected, and supported.
- In partnership with CEE and the NOIRLab Programs that have active DEI-based working groups (e.g., US-ELTP Research Inclusion project and the Community Science and Data Center), lead NOIRLab's approach to external community engagement on DEI-related topics and propose initiatives to share astronomy and career possibilities at NOIRLab as a diverse and inclusive field to external audiences.
- Partner with Human Resources to strengthen the impact of DEI in employee Performance Annual Reviews (PARs) and to create an annual DEI report, including DEI programming, Key Performance Indicator (KPI) reporting, and strategic goal adjustments.

The Committee has worked diligently over the past two years in partnership with CEE to provide staff newsletter articles with DEI content, including information about DEI and outreach opportunities and affinity days and celebrations, such as Pride Month, Juneteenth, and Transgender Day of Remembrance.

DEI learning opportunities are prevalent throughout the Lab and publicized approximately every two weeks in the internal staff newsletter via articles announcing DEI discussions, special colloquia, and CEE-led events inviting staff to engage with the public and be good stewards of astronomy in their communities. CEE and the DEI Committee have standardized messaging to clearly connect all of these opportunities to the Broadening Participation program and emphasize that employee participation is a part of, not in addition to, work time. In addition to these opportunities, the DEI Committee has created a number of programs to further their mission, a few of which are highlighted below.

DEI Discussion Club and Diversy-Con

The DEI Discussion Club and Diversy-Con program provide recurrent DEI learning and discussion opportunities. The monthly DEI Discussion Club is an opportunity for staff to discuss any topic related to DEI in a safe space. Staff can share research articles, moderate a discussion on a certain topic, or present a proposal for DEI improvements. Diversy-Con follows a similar structure but is offered in Spanish to include the NOIRLab-Chile employee base and place a focus on DEI topics with respect to Latin America.

Kindness Program

The Kindness Program celebrated a milestone in 2023 by celebrating Random Acts of Kindness Day across NOIRLab and the Vera C. Rubin Observatory Construction Project on 17 February. Partnering with CEE and the Rubin EPO team, staff from NOIRLab and Rubin collaborated on a month-long communications campaign and Kindness chain activity at each of the NOIRLab/Rubin offices in the U.S., Hawai'i, and Chile. Staff were encouraged to thank other staff for their acts of kindness in the workplace by adding a link to a chain or by acknowledging them in the Slack channels. The month of activity culminated in a Zoom celebration, which included all of the sites. Cookies and baked goods were arranged to be delivered to every office and summit. All participants in the Kindness chain program had their names entered into a prize raffle, and winners were selected during the Zoom celebration. Staff that have been noted for their kindness and good work in the #kudos channels are thanked again during every NOIRLab All-Hands Meeting.

Women in STEM and International Women's Day

During the month of March, NOIRLab celebrates Women in STEM and International Women's Day. The DEI and CEE teams work to produce a campaign to invite all women-identifying employees in NOIRLab to share their work and passions in videos and texts for social media. Throughout the year, expert-led sessions discussing how to manage stress in the workplace, navigate COVID-19 and new working arrangements, and create a more empathetic workforce were led by a psychologist from the National Alliance of Mental Illnesses (NAMI). SafeZone training was held, inviting participants from the Rubin Observatory Construction Project and NOIRLab, and over 40 employees received their SafeZone certifications to make NOIRLab more inclusive and welcoming to the LGBTQIA+ community.

The ongoing improvement and implementation of DEI best practices at NOIRLab is a key initiative driven by both employees and management. As a leader in the astronomical community, we continue to develop and support programs that advance our organizational commitment to diversity, broaden participation, and encourage the advancement of diversity throughout the astronomical scientific workforce.

Confirming (and Refuting) *JWST* Luminous Ultra-distant Galaxy Candidates

Pablo Arrabal Haro and Mark Dickinson
(NSF NOIRLab)

A surprising result from the first deep field images with the *JWST* was the unexpectedly large number of UV-bright ($M_{UV} < -20$ AB) galaxies identified at $z > 9$, in disagreement with pre-*JWST* galaxy evolution models and with predictions extrapolated from *HST* measurements at lower redshifts. However, these high number densities were purely based on photometric selections, whose robustness in the new regime of ultra-high redshifts was still uncertain. Spectroscopic confirmation that some of these UV-bright galaxies were representative of the first 500 Myr of cosmic time was crucial. In two recent works, we made use of deep *JWST* NIRSpec spectroscopy to study some of the most promising $z > 9$ galaxy candidates. These observations confirmed that most of our targets were truly at the inferred redshifts, thus consolidating the results derived in the photometric studies. But we also found an outstanding interloper along the way.

Our first work (Arrabal Haro et al. 2023a) was based on deep (5h exposure time) NIRSpec micro-shutter array (MSA) multi-object spectroscopy

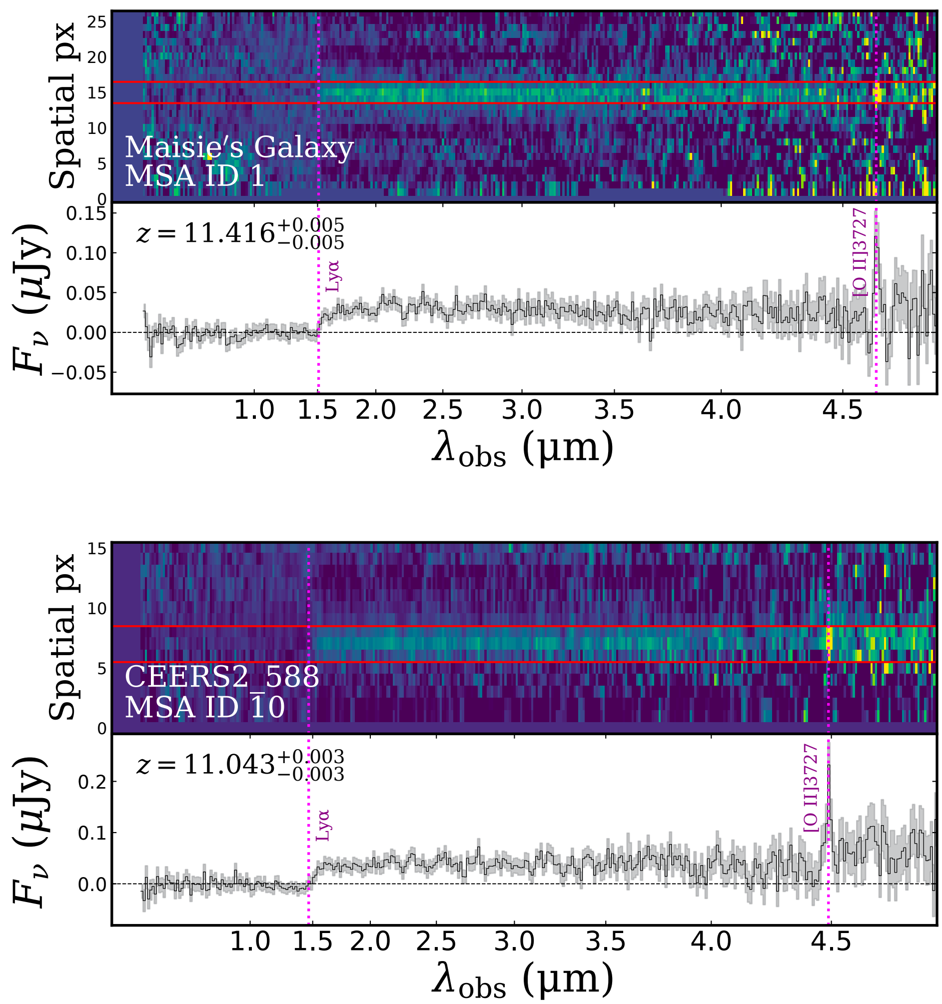

Figure 1: 2D (top panels) and 1D (bottom panels) show *JWST* NIRSpec spectra of the confirmed bright $z > 11$ galaxies. The Lyα breaks and blended [O II] doublets are labeled (Arrabal Haro et al. 2023a).

obtained through program DD-2750 (PI: P. Arrabal Haro), in which we targeted bright ultra-high-z candidates selected from the broadband NIRCam imaging of the Cosmic Evolution Early Release Science (CEERS) survey (PI: S. Finkelstein). That program imaged 100 arcmin^2 in the Extended Groth Strip (EGS) field, which had been previously surveyed with *HST*. The CEERS observations used the NIRSpec prism, covering the 0.6–5.3 μm NIR wavelength range at a low spectral resolution ($R \approx 30$–300), which was ideal to detect high-z continuum dropouts. The most remarkable sources analyzed in this work included the galaxies dubbed Maisie's Galaxy (Finkelstein et al. 2022), CEERS2_588 (Finkelstein et al. 2023), and CEERS-93316 (Donnan et al. 2023). The former two were proposed to be at $z_{phot} \sim 11$–12. Our observations confirmed them to have $z = 11.416$ and $z = 11.043$ through the identification of both the Lyman break and the [O II]3727,3730 (blended) doublet (Figure 1), making them the most distant UV-bright ($M_{UV} < -20$ AB) galaxies spectroscopically confirmed at the time.

On the other hand, CEERS-93316 had been characterized as an outstandingly luminous $z_{phot} \sim 16$ candidate by several works carried out by independent research groups. Our study, however, unequivocally determined it to be at $z = 4.912$ through the identification of the Hα and Hβ emission lines, the [O III]4960,5008 and [S II]6585,6718

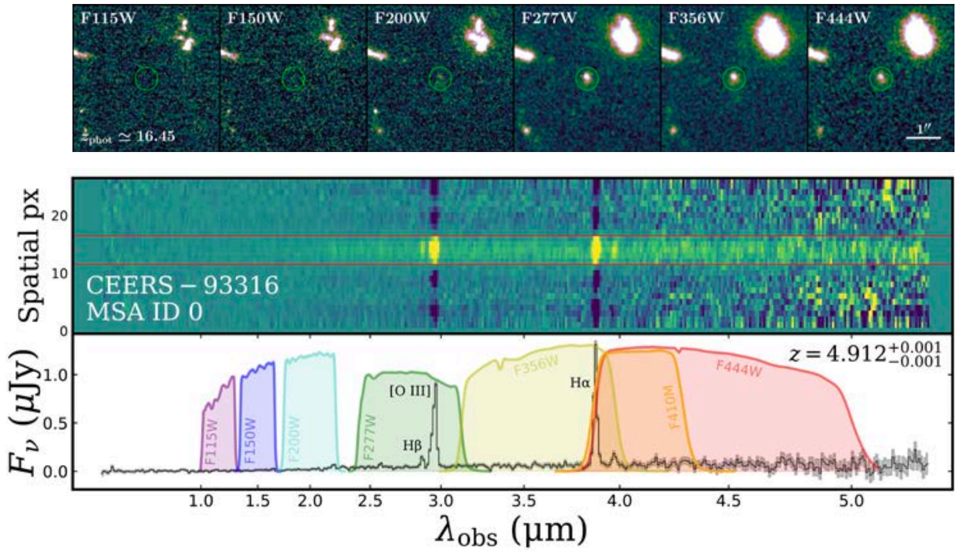

Figure 2: NIRCam imaging and NIRSpec spectrum of the $z_{phot} \sim 16$ candidate CEERS-93316. Top: Image cutouts from all the broad bands employed in CEERS, showing an abrupt dropout between filters F200W and F277W. Bottom: NIRSpec spectrum showing strong emission lines at an unambiguous z = 4.912. The transmission curves of the NIRCam filters are overlaid in different colors, highlighting how [O III] contamination in F277W (green) and Hα contamination in three filters – F356W (yellow), F410M (orange), and F444W (red) – conspired to mimic the signature of a blue continuum and Lyα break at very high redshift in the photometry (Arrabal Haro et al. 2023a).

doublets, and other emission features. This is indeed a very peculiar case in which the strong Hα line simultaneously boosts the emission measured in *three* of the consecutive broad and medium bands employed in the CEERS NIRCam photometry (F356W, F410M, and F444W) (Figure 2), with the [O III] doublet and Hβ lines affecting the next filter bluewards (F277W). These strong lines, on top of a highly reddened stellar continuum, make the broadband colors of this source resemble the characteristic blue UV continuum plus "dropout" pattern usually employed in the photometric selection of high-z galaxies, falsely suggesting a much higher redshift than the actual value.

In a subsequent work (Arrabal Haro et al. 2023b), we confirmed two more UV-bright galaxies at $z \sim 10$ using NIRSpec MSA data from the CEERS program. Those observations consisted of eight NIRSpec pointings employing different combinations of the prism and the three medium resolution (R ~ 1000) gratings (G140M, G235M, G395M), with ~50 min of exposure time at each configuration. In combination with the data from program DD-2750, 35 $z > 8$ candidates were targeted, 25 of which were robustly detected. Only 2 of these were lower z interlopers (8%), demonstrating the high reliability of the photometric samples and reinforcing the surprisingly high number densities and brightness of early galaxies reported in those previous studies.

Nonetheless, we also found that photometric redshifts do tend to be slightly overestimated for these extremely distant galaxies (with typical $\langle \Delta z \rangle = 0.45 \pm 0.11$; Figure 3). It seems likely that this is due to the presence of certain spectral features in very high-z galaxies that are absent in the stellar population models typically used to estimate photometric redshifts. For example, our NIRSpec spectra frequently show evidence for strong Lyα damping wings that "soften" the ordinarily sharp Lyα break due to the very high density of neutral hydrogen in the intergalactic and/or circumgalactic media during the first few hundred Myr of cosmic time.

Following the confirmation of the first spectroscopic samples of ultra-distant galaxies, several scenarios have been proposed to explain the observed excess of bright sources at $z > 9$, such as negligible dust attenuation, a top-heavy stellar initial mass function, unexpectedly strong and frequent contribution of emission from active galactic nuclei, or high star formation efficiency and stochasticity. Aiming to build from our spectroscopic analyses with CEERS and to test some of these proposed scenarios, we will soon carry out The CANDELS-Area Prism Epoch of Reionization Survey (CAPERS), a *JWST* Cycle 3 Treasury Program led by NOIRLab principal investigator Mark Dickinson. CAPERS will observe ~10,000 high redshift galaxies with NIRSpec MSA spectroscopy, including deep (5h) exposures for more than 100 candidates at $z > 9.5$.

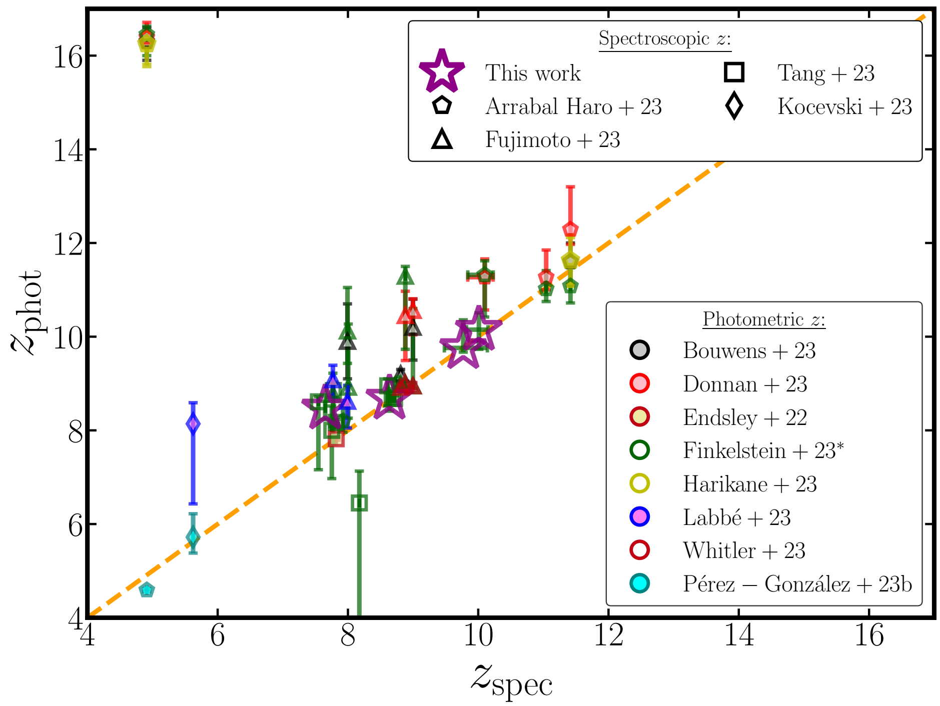

Figure 3: Redshift verification of the complete CEERS $z \geq 8$ spectroscopic sample, showing only two clear interlopers but also signs of slight photo-z overestimation (Arrabal Haro et al. 2023b).

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The Mass and Galaxy Distributions in Nearby Galaxy Clusters

Shenming Fu (NSF NOIRLab)

Using the Dark Energy Camera (DECam), researchers from the Local Volume Complete Cluster Survey (LoVoCCS) collaboration (a NOIRLab survey program) mapped the 2D mass distribution of 58 nearby galaxy clusters via weak gravitational lensing (WL). Those clusters span a variety of dynamical states, and about half of the sample had not been subjected to detailed WL analysis before. Additionally, the researchers observed the 2D red-sequence (RS) galaxy distribution in those cluster fields and compared the orientations of those 2D distributions with that of their associated Brightest Cluster Galaxy (BCG). The results show that the galaxy distribution strongly aligns with the BCG, and that the *mass* distribution also aligns with the galaxy distribution. This work complements previous studies on the alignment of cluster components at higher redshifts.

Compared to high-redshift (high-z) galaxy clusters, low-redshift (low-z, $z < 0.1$) clusters are easier to observe since their member galaxies are apparently brighter and larger. However, galaxies only contribute to about 1% of the total mass of a cluster; most of the cluster mass (~90%) comes from dark matter. Gravitational lensing provides a direct approach to measuring the mass distribution inside clusters, revealing the properties of dark matter and the cluster evolution history. However, reconstructing the 2D mass distribution in low-z clusters via lensing has been challenging. Their low redshifts mean that lensing effects are greatly reduced compared to clusters at higher redshifts. To compensate for this, deep observations are required to obtain accurate photometry and shape measurements of sufficient background galaxies over a large sky area to reduce the noise in WL analysis. Nowadays, large-aperture and large field-of-view (FoV) telescopes with sensitive CCDs, such as the Víctor M. Blanco 4-meter Telescope / DECam, make it possible to efficiently study the lensing signals of nearby clusters.

Using the 2D mass and galaxy distributions of nearby massive clusters, one can carry out detailed studies of cluster substructure and associated structures such as individual filaments and voids because of their proximity. Moreover, by connecting the cluster mass with other observables (e.g., galaxy richness, X-ray emission, Sunyaev–Zeldovich [SZ] effect), one can build a low-redshift anchor for their scaling relations, which is useful for deriving the halo mass function and constraining the dark energy properties.

Beginning in 2019, the LoVoCCS (PI: Ian Dell'Antonio, Brown University) aimed to study the matter distributions in a complete sample of 107 nearby clusters ($0.03 < z < 0.12$) using deep DECam observations in u,g,r,i,z bands obtained through the NOIRLab survey program as well as archival data from the Astro Data Archive. Those clusters have high X-ray luminosity ($L_X > 10^{14}$ erg/s and are thus massive) and are not obscured by the Milky Way (MW). The survey has completed the observation of 83 clusters and obtained 87% of the data. Each cluster field reaches the Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST) Y1–2 depth ($r \sim 26$), but more than two years earlier than the anticipated LSST Year 1 data release. Further, several northern clusters will not be fully covered by LSST. All LoVoCCS exposures are now available for archival research – they can be used for different types of static science analyses, and they can serve as templates for future transient studies. LoVoCCS makes use of the LSST Science Pipelines to process the raw DECam data, as the software has cutting-edge algorithms designed for the upcoming LSST. The first survey paper (Fu et al. 2022) presents the data processing pipeline and early results. The second survey paper was recently submitted (Fu et al. 2024) and shows the distributions of mass and galaxies in 58 clusters and their alignment with the Brightest Cluster Galaxy (BCG). Undergraduate/graduate students at Brown University greatly contributed to the data processing (~100 exposures per cluster).

In the second survey paper, the authors mapped the aperture mass in each cluster field, including several merging systems (Figure). In some clusters only gas (via X-ray/SZ) or galaxy distributions (optical bands) had been previously studied. The WL mass maps enable detailed analysis of the substructures and filaments in those cluster fields. In addition, once the 2D mass distribution and red-sequence (RS) galaxy distribution are obtained, they can be compared with the BCG to check the consistency of the orientations and center positions. The result shows that in those clusters the orientation of the BCG and RS distribution strongly align (by ~19 deg within 2 Mpc), and the mass and RS distributions generally align (~32 deg within 1 Mpc). The centers are also aligned (~0.1 Mpc). Those results are comparable to studies of higher-redshift samples. This alignment shows the long-term effect of gravity in the cluster fields.

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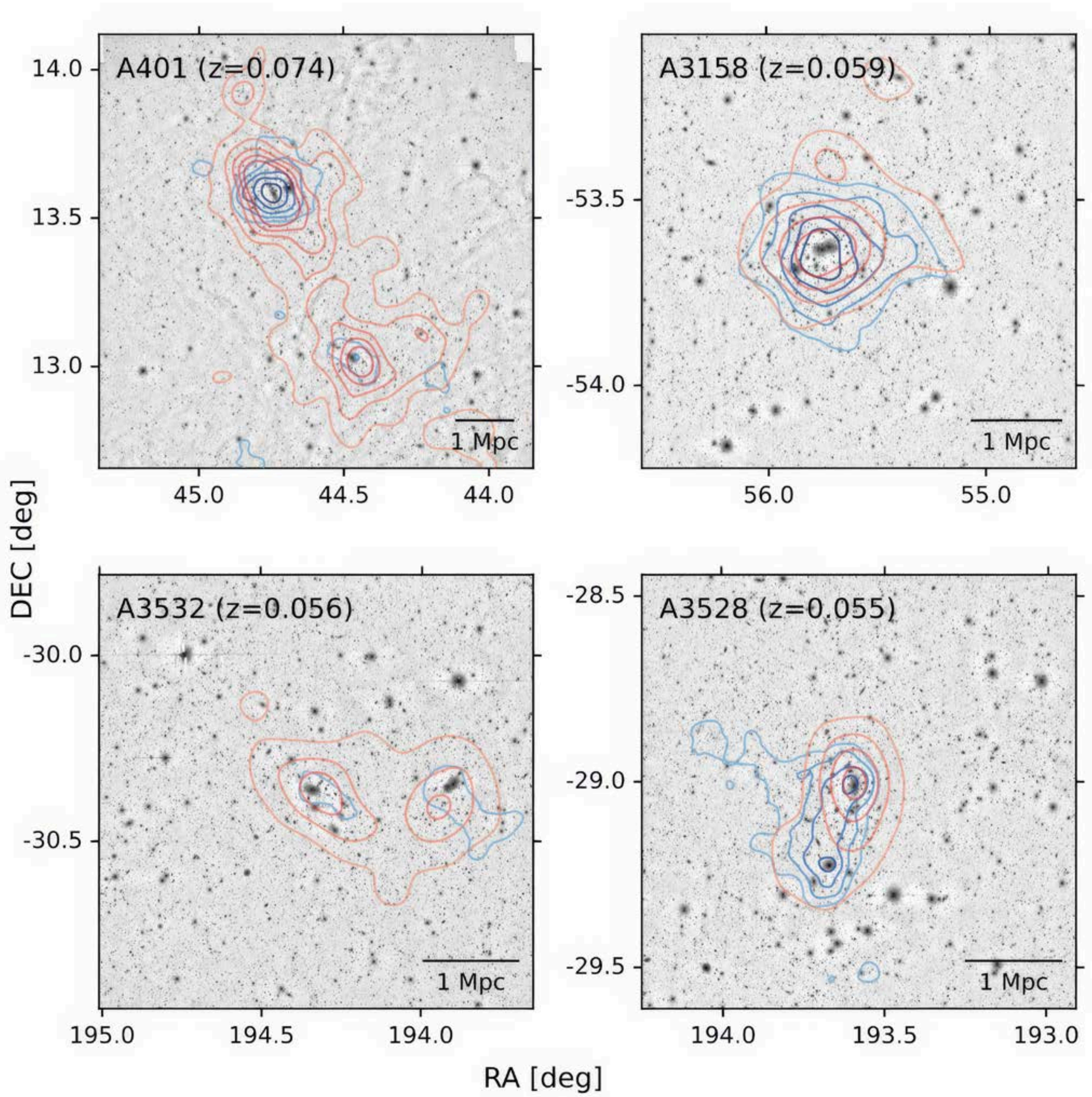
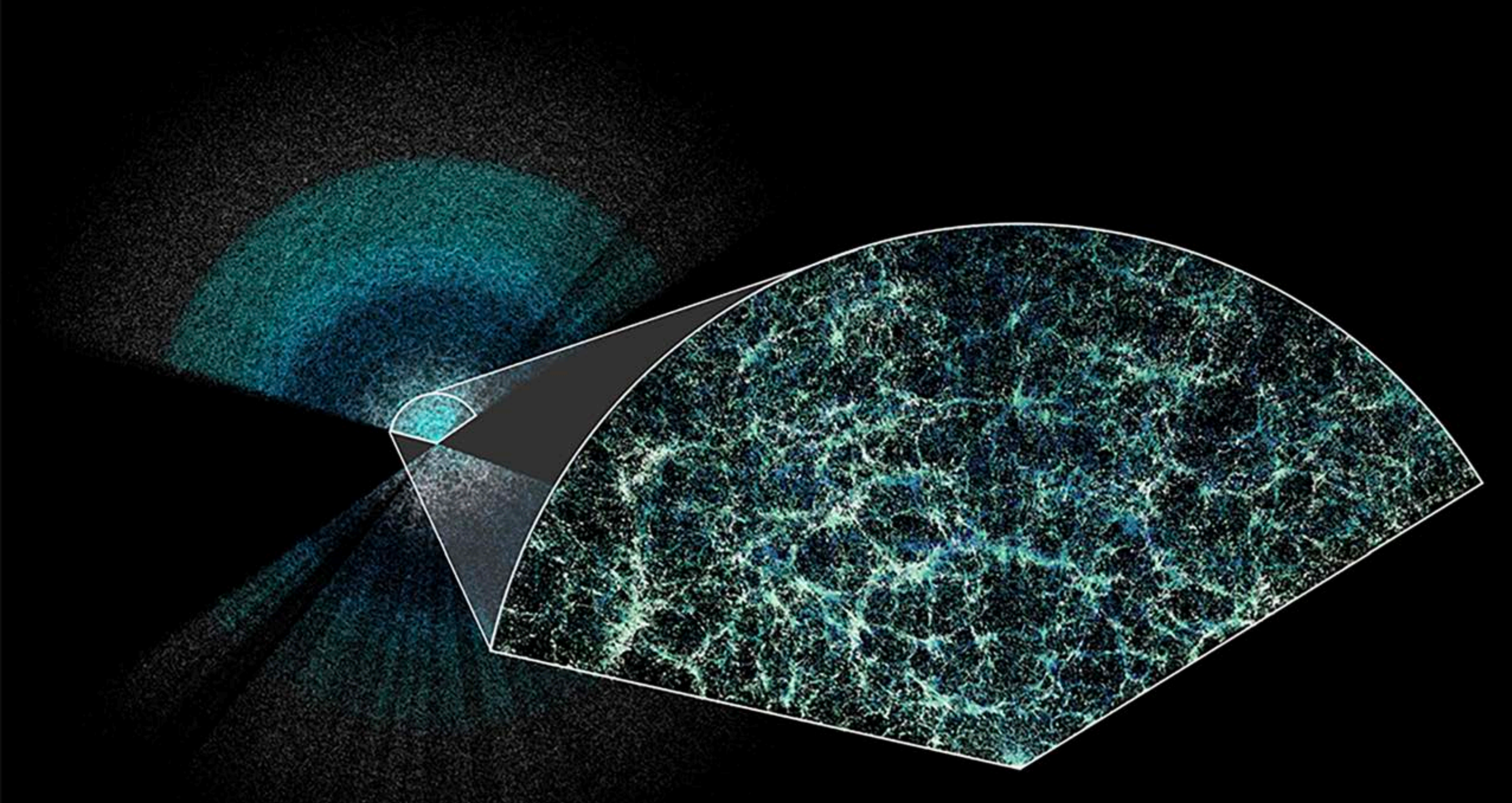


Subset of clusters presented in the article. The background is the inverted r-band co-added image; the blue contours stand for the aperture mass signal-to-noise ratio, while the red contours represent the red-sequence galaxy distribution (Fu et al. 2024).



Unveiling Dark Energy with DESI 2024 Baryon Acoustic Oscillations

Hee-Jong Seo (Ohio University)

The Dark Energy Spectroscopic Instrument (DESI) survey unveiled its first cosmological results in April 2024, leveraging a 3D map of the Universe crafted from the initial year of data (DESI Collaboration 2024a, DESI Collaboration 2024b, DESI Collaboration 2024c). This milestone rests on distance measurements spanning seven different redshift epochs, ranging from 0.1 to 4.2 and draws on data obtained from approximately six million galaxies, quasars, and Lyman-α redshifts over a ~7500-square-degree footprint (Figure 1).

The DESI survey, a five-year Stage IV dark energy mission (DESI Collaboration 2016) is a collaborative effort supported by the U.S. Department of Energy Office of Science and 72 institutions worldwide. Its multi-object spectrograph, equipped with 5000 robotic fibers, is mounted on the Nicholas U. Mayall 4-meter telescope at Kitt Peak National Observatory (a Program of NSF NOIRLab). Designed to construct a comprehensive map of the Universe across a vast cosmic volume, DESI commenced its main survey operations on 14 May 2021, with the first-year dataset spanning observations obtained by 14 June 2022.

Distances derived from the measured redshifts transform the 3D map in the observed space of RA, DEC, and redshift to the physical, comoving space. DESI measured these distances using the standard ruler test, utilizing Baryon Acoustic Oscillations (BAO), a very large-scale, spherical shell-like feature of the primordial sound waves that are now imprinted in the distribution of matter in the Universe. The correct distance-to-redshift relation was inferred by imposing the known size and the expected isotropy of the BAO feature in the physical space. Its very large size, approximately 150 Mpc, corresponding to the sound-horizon scale right after the epoch of recombination, allows

Figure 1: The largest 3D map of our Universe to date, constructed by DESI. Earth is at the center of this thin slice of the full map. The magnified section shows the underlying structure of matter in our Universe. *Credit: DESI Collaboration/C. Lamman; custom colormap package by cmastro*

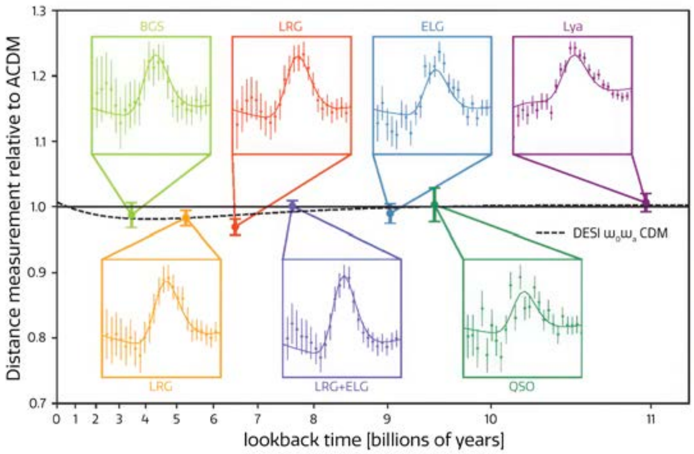


Figure 2: The differential Hubble diagram from the DESI first-year galaxy/quasar and Lyman-α BAO measurements with the spherically averaged BAO feature singled out in the insets. The solid line shows the prediction of the Planck best-fit ΛCDM model, and the dashed line shows the prediction from an evolving dark energy model fit to the DESI data. *Credit: DESI Collaboration/A. de Mattia*

us to observe this feature from vast distances in a way that does not strongly depend on small-scale physics and observational effects.

These measurements probe the background expansion of the Universe over time, with DESI's primary goal being to unravel the mysteries of dark energy. Additionally, they offer constraints on matter content, curvature, neutrino physics, and the Hubble constant that also impact the late-time background expansion.

This first data release includes three key papers authored alphabetically. One focuses on BAO in galaxy/quasar distribution for redshift less than 2 (DESI Collaboration 2024a), the second focuses on BAO from Lyman-α forests for redshift greater than 2 (DESI Collaboration 2024b), and the third presents comprehensive cosmological interpretation (DESI Collaboration 2024c). These are complemented by over a dozen supporting papers.[1]

The first-year DESI results immediately prompted a response from the science community. Particularly intriguing among these results was a hint of a departure from the long-standing and perplexing cosmological constant model. There emerged tantalizing hints towards an evolving dark energy model, sparking considerable interest and discussion among researchers.

Spectroscopic BAO measurements have progressed over two decades through various surveys, providing invaluable constraints complementary to the Supernova (SN) and the Cosmic Microwave Background (CMB) data. DESI is a clear advance over these previous BAO surveys in terms of the data as well as analysis.

The first year of DESI data provides 3× the redshifts available from the entire SDSS/eBOSS dataset (Alam et al. 2021) for galaxies and doubles the number of Ly-α redshifts obtained by the SDSS, resulting in unprecedented distance measurement precision (an aggregate distance precision of 0.52% for redshift less than 2 and 1.1% for redshift greater than 2). DESI's ability to confidently detect the O[II] emission line doublet in the observed spectra allowed a high-precision distance constraint between redshifts of 1 and 2 for the first time, using 1.4 million emission line galaxies.

One key methodological advancement by DESI is the adoption of blinded analysis, where catalogs for galaxy BAO analysis and clustering statistics for Lyman-α BAO were intentionally concealed from human examination to mitigate confirmation bias. The blinding remained in place until the analysis successfully passed a series of predetermined unblinding tests.

Traditionally, different groups within collaborations analyzed various galaxy BAO tracers using ostensibly equivalent methods. DESI galaxy-BAO has successfully adopted a unified approach, conducting systematic tests and analyses using a coordinated analysis pipeline for all galaxy BAO tracers, ensuring coherence and robustness.

The DESI BAO result was unblinded in real-time during the DESI winter collaboration meeting in Hawai'i on 12 December 2023. Members of the DESI Collaboration quickly discerned that the observed sizes of the BAOs at redshifts less than 0.8 are slightly larger than the anticipated values from extrapolating the Planck ΛCDM

[1] *https://data.desi.lbl.gov/doc/papers/*

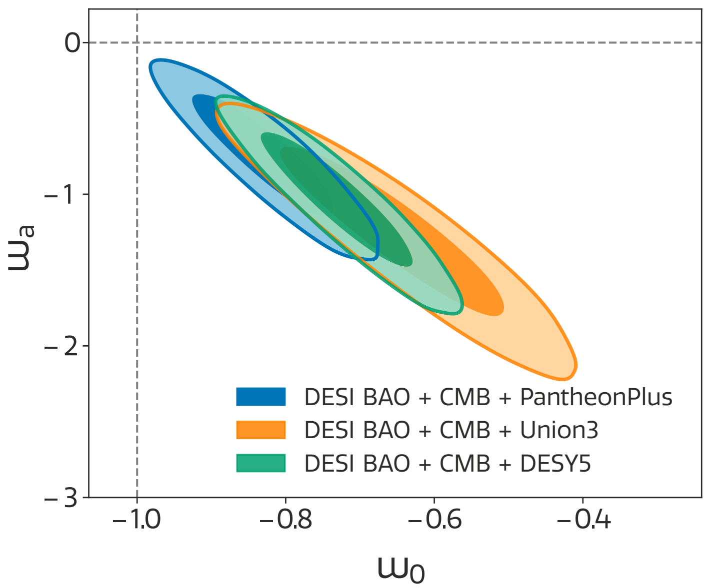


Figure 3: Figure 6 from DESI Collaboration 2024c. The 68% and 95% marginalized posterior constraints from the DESI first-year BAO combined with CMB and each of the three different SN datasets for the flat ω0ωa CDM model. The significance of the tension with ΛCDM (ω_0= −1, ω_a = 0) estimated is 2.5σ, 3.5σ and 3.9σ for these three cases respectively.

best-fit model to later epochs. This means that the inferred distances to the probed redshifts are shorter than those predicted by the Planck ΛCDM model (Figure 2). Despite this, the findings remain consistent with the cosmological constant model under the assumption of a constant dark energy equation of state.

However, when considering a time-varying equation of state in the form of $w(z) = w_0 + w_a \times z/(1 + z)$ as a function of redshift z, a preference emerges for values of $w_0 > -1$ and $w_a < 0$ compared to ΛCDM with $w_0 = -1$ and $w_a = 0$. This implies that the dark energy density has been evolving over cosmological time rather than remaining constant. This preference becomes stronger when combined with CMB and/or SN data (DESI Collaboration 2024c; Figure 3). Notably, similar indications were observed in previous studies with the SDSS BAO measurements (Alam et al. 2021) although the DESI observations provide a more pronounced evidence, reaching significance levels of 2.5–3.9 σ, contingent upon the inclusion of SN data.

The forthcoming DESI data release 2, which will comprise the first three years of observations we already possess, could either confirm this finding and elevate it to a discovery or demonstrate that the initial result from this April was a statistical anomaly, leading us back into the enigma of the cosmological constant model. Noting that the DESI survey is a five-year endeavor aimed at cosmology tests beyond BAO, the first result serves as the signal of this groundbreaking paradigm shift that the complete compilation of DESI data promises to deliver.

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Acknowledgement

The author wishes to acknowledge that this article provides a summary of the comprehensive collaboration-wide endeavor undertaken by the DESI Collaboration, where the author and Nikhil Padmanabhan coordinated the galaxy/quasar BAO measurement task.

The author thanks Andreu Font-Ribera (a co-convener of the Ly-α BAO measurement task), Ashley Ross (a co-convener of the clustering catalog task), and Sesh Nadathur (a key contributor to the cosmology inference task) for the input to the article.

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NOIRLab IRAF — Modernizing Legacy Software to Support Gemini Data Reduction and Beyond

Mike Fitzpatrick and Vinicius Placco (NSF NOIRLab)

The US National Gemini Office (US NGO), a group within the Community Science and Data Center (CSDC) at NSF NOIRLab, has recently completed a project to modernize IRAF and make it compatible with modern platforms and operating systems. The goal is to provide Gemini users with a stable, reliable, and easy-to-install data reduction option while the DRAGONS software development for all facility instruments and modes is completed. The updates to the GEMINI package required porting its code (and dependency tasks from STSDAS) to a 64-bit architecture. Additionally, the core IRAF system and all external packages were updated to fix all OS, platform, and licensing issues in the existing code. As a consequence, this project benefits the entire astronomy community. The results of this effort, which include the description of the main changes to the code and benchmark testing against different installations and platforms, were presented at the Astronomical Data Analysis Software & Systems XXXIII conference in October 2023 and are published as a preprint on arXiv and ADS.

The new NOIRLab IRAF 2.18 contains 25 of the most popular external packages and has simple and intuitive installers for Mac and Linux platforms. This eliminates the use of virtual machines to run IRAF on modern machines, in particular with the Apple M1/M2 processors. The software was launched during the 243rd AAS Meeting in New Orleans in January 2024, and the response from the community has been extremely positive. We invite the astronomy community to access the new website and install the latest version of the software. Since its launch, the software has been downloaded over 1,000 times, and the web pages have been accessed more than 4,000 times by over 1,900 unique users from 59 countries. The entire codebase for NOIRLab IRAF is open source and available on GitLab. Feedback is welcomed and can be sent to iraf@noirlab.edu.

References and links

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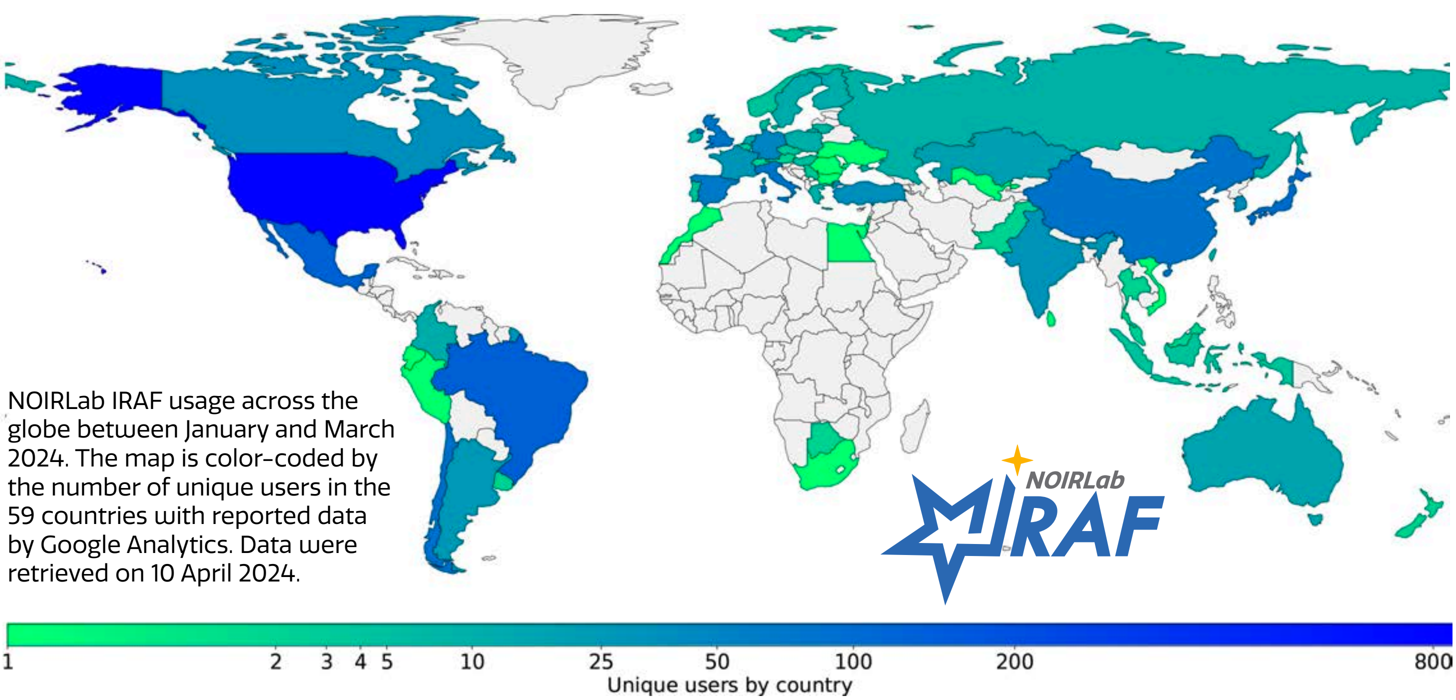
DRAGONS Data Reduction Software on International Gemini Observatory website
IRAF GitLab on NOIRLab website
IRAF web page on NOIRLab website
US National Gemini Office on X
US National Gemini Office on NOIRLab website



NOIRLab IRAF usage across the globe between January and March 2024. The map is color-coded by the number of unique users in the 59 countries with reported data by Google Analytics. Data were retrieved on 10 April 2024.

A History of the NOIRLab Time Allocation Committee Process

Compiled and edited by Dara Norman (NSF NOIRLab)

Peer review is the standard by which we live and die in science. The process can be fraught, given concerns about bias, conflicts of interest, insufficient expertise, and simply old-fashioned subjectivity. However, it is the best process we have for determining the optimal allocation of scarce resources, whether it is funding or time on telescopes. The NSF NOIRLab Time Allocation process, and its predecessors, have been a gold standard of peer review for telescope time since 1960, and the logistics of the process have evolved significantly during those years.

Over the last few years, we have been embarking on a "Modernization of the TAC" project to upgrade its infrastructure, policies, and procedures. This has been an opportunity to ask why and how various procedures were implemented, as well as capture a few stories and reminiscences about the past operation of the Time Allocation Committee (TAC) process. A few of these are collected below. Thanks to current NOIRLab and past NOAO staff (sometimes both) who contributed information and stories about the history of the TAC process: Mia Hartman, Buell Jannuzi, Tod Lauer, Caty Pilachowski, Steve Ridgway, and Verne Smith.

The Evolution of the TAC Process

"When I did my first stint on the TAC, there were separate KPNO and CTIO TACs and I was first on the CTIO TAC … which had only one panel, covering both dark and bright time. And we would receive something like 200 proposals (no kidding). I think that this was the ~1990 timeframe, with Olin Eggen as chair. Eventually Nick Suntzeff ascended to the CTIO TAC Chair to replace Olin."

"When I was chair, there were bright and dark [panels] — period. I chaired both. To be clear, that was the Kitt Peak TAC. CTIO was a separate organization. Each [panel] allocated half of the time. The bright nights of dark time were allocated mainly for their dark hours, though of course the TAC was not stupid and paid attention to the value of the moon-up time. There was some splitting of nights for different programs, only on the 4 meter I believe, especially for the deepest imaging needs."

"Initially one applied to KPNO and CTIO separately, even after they were both joined into NOAO in the 80s. My first contact with the process was applying for time at CTIO as a graduate student in 1983 (I didn't get time) … In the 80s this was pre-[World Wide] Web, and until the end of the 80s really pretty much pre-email (email was common inside departments, but external email didn't really get going until the mid-80s). The proposal required filling out a form and mailing it in. I cannot recall how I did that. I wasn't using a typewriter and was using TeX in grad school, but it must have been some form of cut and paste. If I recall correctly, information on how to observe was provided by a big notebook-style binder that was distributed to institutional/departmental libraries and could be updated by the librarians. A copy of the proposal forms was in it. This was also backed up with the newsletter, which came out quarterly then, and may have also had copies of the forms."

"Back in those days, a large part of the observing time was reserved for the KPNO staff. That time was allocated separately — I chaired a single staff TAC for that. The staff was largely made up of observers, and observing with single channel photometers and photographic plates was really not very efficient, and the staff time was heavily over-subscribed. I was about the youngest astronomer on the staff and felt rather exposed chairing the committee that told senior colleagues that their proposals were not approved or were for less time or were for brighter time than requested. I told director Leo Goldberg I was not comfortable with that, and he told me to hide behind my mustache (I had one then). I guess it was not held against me because those same folks eventually voted to support my case for tenure. I was chairing when the staff reserve was abolished and the staff had to compete in the same arena as the community. There was some consternation of how the staff would do in open competition — but in fact the relative allocations did not change much. Within a few cycles it was understood that abolishing the staff reserve was healthy all the way round. Looking at it objectively the staff had an advantage of more intimate knowledge of the instruments and telescopes, not to mention extensive contact with visitors constantly streaming through Tucson, and so could write strong proposals."

"By 1990 email was in common use by scientists, but the [World Wide] Web didn't really start until 1993 and was just moving out of the novelty phase by 1996. Somewhere along the line, NOAO provided a TeX and then LaTeX template ... Email submission became possible somewhere along with this. As I recall, this was optional at first, with the institution accepting both mailed and emailed proposals for a while. What was cool was that NOAO was the first to do this. STScI took a while to get to electronic submission after us."

"Originally the semesters started on January 1 and July 1. This led to complications and hard feelings as a result of the transition between semesters occurring during the holiday period. For example, a January 1 transition guaranteed new observer starts on all telescopes on New Year's Day, instrument changes on almost all telescopes the same day, all observers departing and arriving traveling on New Year's Day — there were complaints from observers and from support. I recommended to Leo Goldberg the change and he accepted it without debate. As I recall, the shift was promptly adopted by another observatory (CTIO?), encouraging me that it was the right thing to do."

Changes to the Panel Structure and New Panels

"The structural changes to the panels got started in the 90s. First to go, as I recall, was bright/dark in favor of galactic/extragalactic. This was driven by the increasing importance of IR instrumen-tation which had less of a bright/dark issue (the IR skies are always bright). Previously, dark/bright was pretty much naturally extragalactic/galactic, but IR work fuzzed that out. But this was all simply relabeling and an easy fix. In retrospect I truly don't know why they didn't do this from the start."

"Dark time and bright time generally had very different instruments in the 1980s and 1990s — so wanted different expertise on the panels, it was technique driven rather than subject driven — and happened to also break up roughly by subject area — that changed over time (people studying galaxies wanted dark time AND bright time), for example, optical and near-IR imaging for galaxy evolution and the near-IR imaging could be done in bright time, optical in dark, they needed both."

"The big step was unifying the CTIO and KPNO TACs. This happened in the 90s … At that point we had four panels, but it was two extragalactic and two galactic. There was no solar system panel, with the planetary stuff just shoved into the galactic panels. This was a major point of difficulty with the planetary community. In any case, this was a big change for CTIO, since all the TAC work was now being done physically in Tucson, although we did bring up CTIO staff to serve on the panels."

"When NOAO was formed, the TACs were merged ... [Solar System] was added later because the SS folks didn't feel they got a fair shake."

"The first survey proposals were done in 2000, and a new panel was set up then. Again adding this was a simple augmentation, but gave us the experience to help kick off the Gemini Large & Long program."

"After I was running the TAC lead review assignments for a few semesters/years AND having served at NSF on some grant review panels, I noticed that often at the NSF grant review panels proposals from people that could say, 'Non-federal Observatory promises to give me the observing time if this is funded' would win over those that said, 'And I'll go ask NOAO for time if I'm funded.' And at the NOAO TAC a large request for time was met with, 'How are they going to deliver on the promised science and data products without more resources?' … so [a group of us suggested] that if once a year we did a call for large programs (surveys ... where the ENTIRE data set really was needed, not something that could be incremental) and the proposers knew that they had been selected before the NSF proposal deadline, then they could propose to NSF stating that they had the observing time awarded etc. ... so that was in the late 1990s."

TAC Comments, Anecdotes, and Other Lore

"On my dark panel, for a number of years the cosmology éminence grise was Alan Sandage, an expert in what was then considered the distant Universe. Seating was not assigned, and he always arrived early and sat at my immediate left. When Alan rotated off the TAC, Halton Arp came in. Arp had distinctly different views from Alan (note to young folks — 'different' is an under-statement; reportedly they did not get along, and Alan opposed giving any telescope time to Arp). Anyway, the first morning of the first day Arp came in early, walked directly to the seat to my left (Alan's seat) as if it were reserved for him and sat there every meeting for two years. BTW I got along great with both of them; both were gentlemen from the era when there was such a thing."

"One of the periods when I was making the assignments of lead reviewers was when the two SN Cosmology groups were competing for time (Perlmutter et al. and the group that included Suntzeff, Schmidt, Kirshner, Riess, Phillips, et al.) — and I intentionally rotated who the lead reviewers were because essentially the same proposals were coming in over several years, and I was trying to help avoid reviewer fatigue. I think, just my opinion, that if either of the groups had been the ONLY group, they might not have gotten as much time — but both groups wrote different, but strong, proposals, each helping to convince the TAC that [these were possible programs to execute and would yield] important science — they had different strengths, but collectively convinced the TAC."

"One of my favorite stories … has to do with a TAC member who thought, like the space panels, they were being asked to do only one semester … when we said at the end of the meeting, see you next semester, their face was priceless … they had put a huge amount of effort into the review (noticeably more than most reviewers) so I understood why doing that repeatedly for another year and half (I think we had two-year terms at the time?) was not something they were enthusiastic about!"

"Another story was the time a proposer said in the update on past time, 'we were clouded out' — and one of the reviewers did not believe this and dug up the telescope logs to prove the nights had been clear … that was not common!"

"In all my years serving on the TACs one way or another, I ran into only one [unpleasant person] (who did not surprise me as such). I've really enjoyed working with everyone. I think the repeat attendance of the panelists is crucial to this. Everyone gets to know each other and this makes things an awful lot easier."

"Chairing the TAC was really a growing-up exercise for me. I came from a physics department and never took an astronomy course. As TAC chair I learned that most TAC members were specialized and did not know much more about any specific proposal topic than I did. It encouraged me to take on tasks that I was not 'qualified' for, in the spirit that I was as well qualified as anybody else that was available."

If you have other information or stories you would like to share about the ground-based NOIRLab TAC process or its predecessors, please reach out to us at library@noirlab.edu.

IGRINS Completes its Mission at Gemini South

Gregory Mace (University of Texas at Austin, McDonald Observatory), Hwihyun Kim (International Gemini Observatory/NSF NOIRLab)

IGRINS, the **I**mmersion **GR**ating **IN**frared **S**pectrometer, was designed to use silicon immersion gratings to deliver high-throughput spectroscopy with a compact instrument. IGRINS was developed in a collaboration between the University of Texas at Austin (UT Austin) and the Korea Astronomy and Space Science Institute (KASI). The compactness of IGRINS has allowed it to travel between telescopes at McDonald Observatory, Lowell Observatory, and Gemini South. After an initial three-month visit in 2018, IGRINS has been at Gemini South since February 2020. With nearly 500 nights of science, IGRINS had its last night at Gemini South on 21 April 2024.

IGRINS observes in the infrared H- and K-bands (1.45–2.45μm) simultaneously and peers through dust to study faraway giant stars and nearby stars in the first few million years of their formation. With a resolving power R~45,000, IGRINS separates the spectral features of the Earth's atmosphere from those of exoplanets and their host stars. IGRINS has transmissive cross dispersers and optimized optical coatings to get the highest throughput possible. The instrument has a fixed spectral format and no moving parts, to ensure repeatability. All these attributes of IGRINS, combined with the collecting area and queue observing of Gemini South, have provided the astronomical community with a powerful tool for a variety of research topics.

Figure 3: The path to science requires the hard work of many people. The IGRINS Team thanks the many people at Gemini South who have made science possible — telescope operators, queue observers, queue coordinators, technicians, and engineers working at the summit; software and IT support; janitors and cooks at Cerro Pachón; directors and deputy directors; and shipping and travel coordinators in Tucson and La Serena. The photo above from 23 April 2024 includes many of the Cerro Pachón crew at Gemini South who helped IGRINS achieve science over the years. Chao y Muchas Gracias Gemini! *Credit: International Gemini Observatory/NOIRLab/NSF/AURA/B. Medel*

Figure 1: IGRINS, which measures 0.9×0.9×0.6m, is shown here packed up in the Gemini South Instrumentation Lab as it is prepared for shipment back to UT Austin. Credit: UT Austin/E. Sawczynec

Demand for IGRINS remained strong over its time as a visiting instrument at Gemini South. In the 2018A semester, 35% of requested time on Gemini South was for IGRINS. The 10-semester average has been 435 hours each semester, or ~24% of the time requested. In total, there have been 385 IGRINS programs: 5 Large and Long, 6 Director's Discretionary, 27 Fast Turnaround, and 41 Poor Weather. All of this demand has resulted in many IGRINS spectra and some impressive science results so far.

Science publications using IGRINS at Gemini cover the topics of exoplanet atmospheres, stellar characterization, substellar atmospheres, young stellar objects, and Solar System objects. Line et al. (2021) used IGRINS to simultaneously detect CO and H_2O in the exoplanet WASP-77Ab and showed that the planet is metal depleted relative to Solar System planets. Smith et al. (2024) combined *JWST* NIRSpec observations with the Line et al. (2021) results to confirm that WASP-77Ab is metal poor and provide additional constraints on the system parameters. Brogi et al. (2023) determined the composition of the Ultra Hot Jupiter WASP-18 b by detecting H_2O, OH, and CO. Additionally, these three molecular species show velocity offsets of ~6 km/s and might be tracing atmospheric dynamics in WASP-18 b. Tannock et al. (2022) presented the spectral atlas of a 1060 K T6 brown dwarf and made the first detections of H_2S and H_2 in an atmosphere while verifying H_2O, CH_4, and NH_3 line lists used in exoplanet models. The IGRINS YSO Survey was published by López-Valdivia et al. (2023). They measured rotational velocity, temperature, surface gravity, and magnetic field strength of pre-main-sequence stars in Ophiuchus and Upper Scorpius. Tegler et al. (2019) combined IGRINS observations of Neptune's moon Triton with lab measurements of CO/N_2 ice to show that the ices on Triton are mixed rather than pure CO or pure N_2 deposits.

Science with IGRINS takes time because there are more than 20,000 resolution elements per spectrum. The IGRINS community has just begun to publish their results. With tools now developed and programs completed, publications from IGRINS at Gemini South will continue for years to come. Following a 12-month proprietary period, all IGRINS spectral products are available online in the Raw and Reduced IGRINS Spectral Archive (RRISA) curated by UT Austin graduate student Erica Sawczynec. A new version of the IGRINS data reduction pipeline (PLP v3) is available with improvements to flexure, telluric, and cosmic ray correction. In April 2024, IGRINS was packed up at Gemini South to return to UT Austin for refurbishment and upgrades before recommissioning at McDonald Observatory in late 2024.

As a newer Gemini Participant, KASI has contributed IGRINS-2 as a facility instrument, and it is currently being commissioned on Gemini North. IGRINS-2 has many similar attributes to IGRINS and is updated with newer electronics and a slit-viewing camera with a larger field of view. IGRINS-2 early science and community availability will be the subject of a future *The Mirror* article.

Details on the preparation of IGRINS for Gemini South can be found in Mace et al. (2018). Financial support for IGRINS to visit Gemini South has come from McDonald Observatory, the Korean GMT Project of KASI, Gemini Observatory, the Mt. Cuba Astronomical Foundation, and the U.S. National Science Foundation under grants AST-1229522, AST-1702267, and AST-1908892.

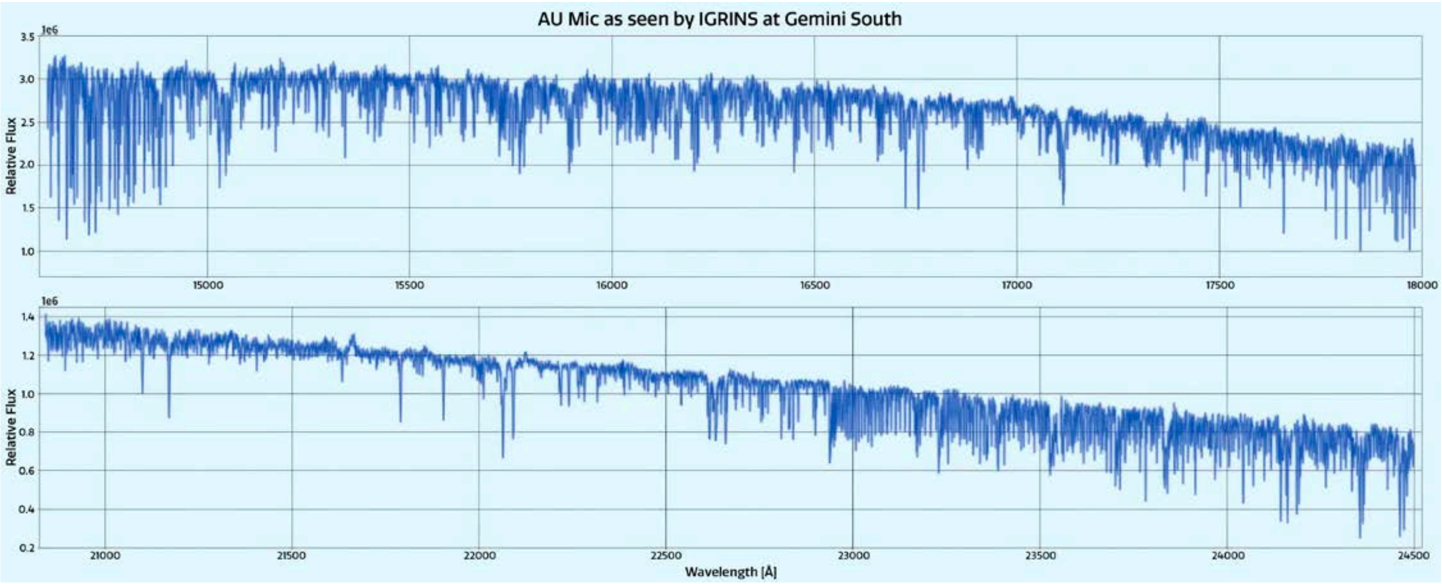


Figure 2: This IGRINS spectrum of AU Mic has a signal-to-noise ratio of nearly 1000. AU Mic is a young M1 star with a debris disk and multiple exoplanet detections. There are thousands of absorption lines from molecular and atomic species in this IGRINS spectrum. *Credit: RRISA/UT Austin/E. Sawczynec*

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4m Telescopes and Future Dark Energy Surveys

Figure 1: The Blanco Telescope on Cerro Tololo with the dome shutter open and ready to start observations

What can we learn from existing facilities for planning for stage 5 spectroscopic investigations?

Claire Poppett (UC, Berkeley)

The Dark Energy Camera (DECam) and the Dark Energy Spectroscopic Instrument (DESI)[1] are arguably the most powerful cosmological survey instruments of the last decade, and they have precipitated impressive stage 4 constraints on the nature of dark energy and dark matter. The success of surveys with these instruments has proven the power of 4m platforms and their ability to compete with larger telescopes, when dedicated wide-area sky surveys are required to obtain the needed scientific constraints.

As stage 4 experiments are now well underway, it is time to contemplate instruments capable of *stage 5* constraints on dark energy and dark matter. A likely path forward is a spectroscopic survey with a wide field of view, a large mirror, and the ability to target and acquire a high density of sources. This could be in the form of highly multiplexed fiber-fed spectrographs, similar to the DESI instrument, that would be installed on both the Nicholas U. Mayall 4-meter Telescope and the Víctor M. Blanco 4-meter Telescope — paving the way to further scientific achievements at these facilities.

When a new instrument for a stage 5 experiment is designed and developed, the success of its associated surveys will rely on the lessons learned from other world-class facilities. With that in mind I embarked on a tour of some of the major observatories in the La Serena, Chile, region to understand the variety of solutions used by groups at different sites to improve instrumental and survey-optimizing properties, such as seeing and throughput. From dome venting, to mirror coating, to data management — I learned about it all!

[1] DECam was constructed by the Dark Energy Survey (DES) collaboration, with funding from the U.S. Department of Energy and is mounted on the U.S. National Science Foundation Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory (CTIO), a Program of NSF NOIRLab. DESI is managed by the U.S. Department of Energy's Lawrence Berkeley National Laboratory (LBNL) with primary funding from the Department's Office of Science and is mounted on the U.S. National Science Foundation Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory, a Program of NSF NOIRLab.

I first visited the Blanco telescope on Cerro Tololo (Figure 1). The Blanco has the same optical configuration as the Mayall 4m on Kitt Peak where DESI is installed. The Mayall could be devoted entirely to DESI in part, I think, because installing DECam on the Blanco transformed the way the community considers adapting an existing facility to undertake a dedicated experiment. I was escorted by Telescope Operator Javier Rojas around every part of the Blanco facility (including what felt like the tunnel to the underworld!) and learned the minutiae of dome cooling required to reach the excellent seeing of ~0.65 arcsec that DECam regularly achieves.

Escorted by Steve Heathcote and Priscila Pires from NSF NOIRLab, I visited Las Campanas Observatory (LCO) and toured one of the Magellan domes with Povilas Palunas and Francesco di Mille, who are experts in mirror coating. The Magellan group coats their mirrors every other year and has the process down to a fine art (Figure 2). They highlighted how recoating takes a specialist team, which made it seem essential to retain, and regularly use, institutional knowledge. I also visited the site of the Giant Magellan Telescope and learned firsthand from Francisco Figueroa and Oscar Contreras about the staunch commitment and extensive resources required to develop an observatory from scratch. When completed, this telescope will be revolutionary; however, the difficult journey towards building a new facility was evident. Additionally, while at LCO, I visited the Local Volume Mapper (LVM) — an optical, integral-field spectroscopic survey that will target the Milky Way, Small and Large Magellanic Clouds, and other Local Volume galaxies. LVM is an example of an instrument that was able to reduce risk by taking advantage of a pre-existing design — in this case, by utilizing the DESI spectrographs in a new instrument.

The final day of my tour took me to the Vera C. Rubin Observatory, the Gemini South Telescope, and the

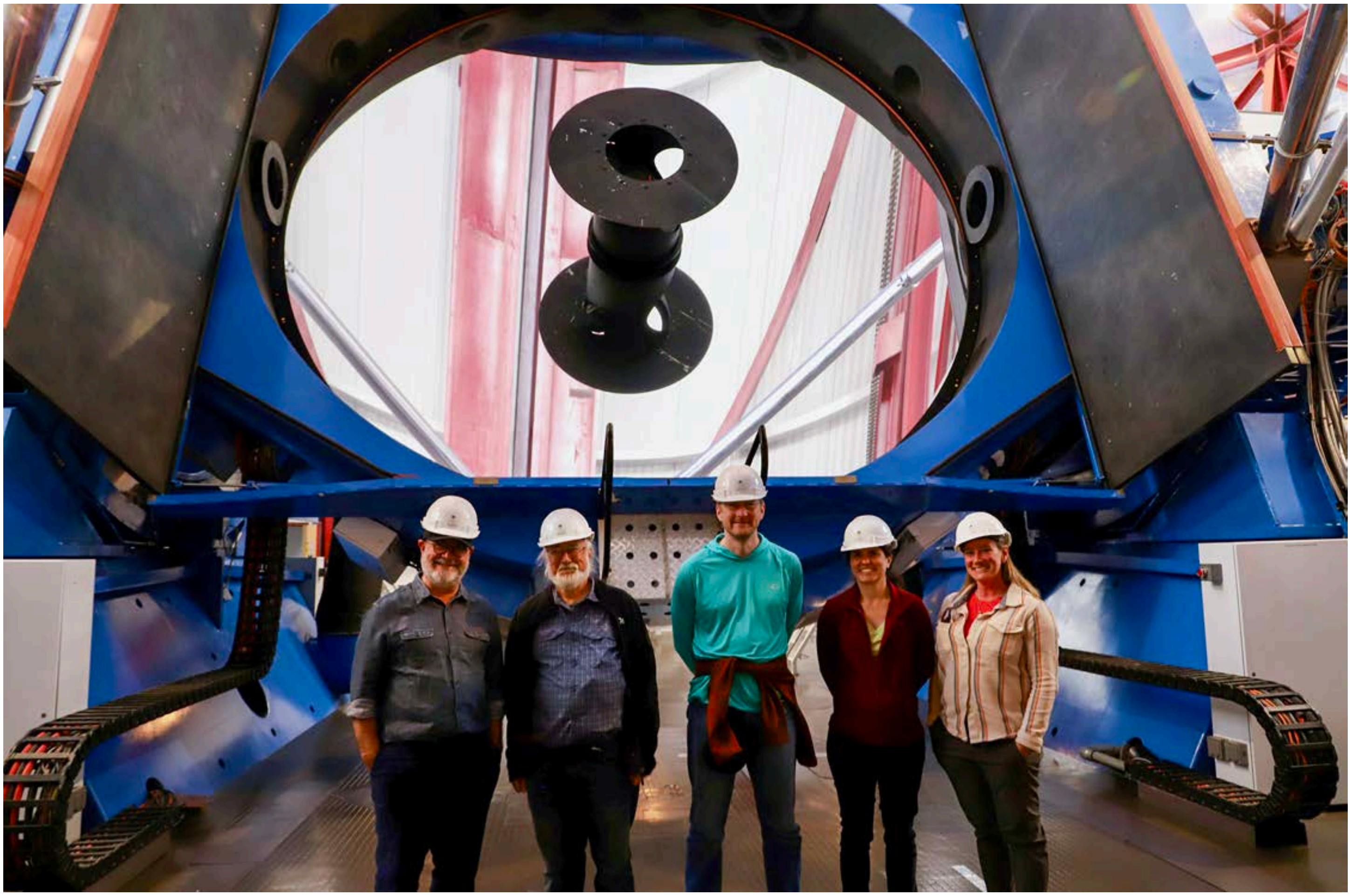

Figure 2: Standing in front of one of the recently recoated Magellan mirrors at Las Campanas Observatory. From left to right: Pablo Infante, Steve Heathcote, Adam Myers, Priscilla Pires, Claire Poppett

Figure 3: The Vera C. Rubin Observatory on Cerro Tololo

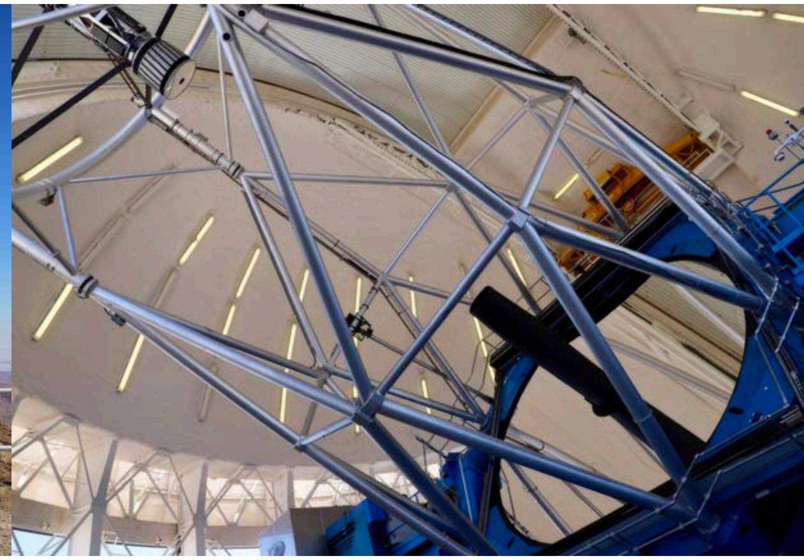

Figure 4: The recently recoated Gemini South mirror

SOAR Telescope. The visit to Rubin reminded me of the concerted devotion and wherewithal required to build a new facility. DESI was the first stage 4 spectroscopic instrument on sky, and if the DESI Collaboration wants to claim the same feat for stage 5, the new instrument will need to aim to be on sky in the early 2030s. This goal of rapid deployment may be in tension with building a new facility. I was particularly impressed with the scale and organization of the Rubin project (Figure 3). During my visit, experts were being trained to lead public tours, which demonstrated the commitment of the Rubin team to community engagement. It seems, to me, that any project that adapts NOIRLab resources should take similar care with outreach. I also learned about the tools that Rubin employs for dome cooling. In contrast to the Mayall's manually operated louvers, or the doors on the Blanco, Rubin will attempt to predictively determine the optimal louver positions and dynamically update this configuration over the course of the night. The baffles on the Rubin louvers will also reduce the sky brightness without sacrificing dome cooling.

After lunch I had a chance to see the newly coated mirror of the Gemini South telescope (Figure 4). The Gemini team pioneered a multilayer coating process where layers of aluminum and protected silver reach a thickness of ~1000Å to deliver higher throughput at redder wavelengths. The magnetic deposition process requires the chamber to be stable over ~10 hours, which is challenging. This is in contrast to the aluminum evaporation coating process at Magellan which takes only ~10 seconds when pressure in the coating chamber is reached. Upgrades to the coating chambers at new facilities should take account of these lessons to balance performance with the practicality of the process. These considerations may even drive a future stage 5 experiment towards a segmented mirror solution. Since smaller segments are easier to coat, the downtime for recoating would be vastly reduced, and an expert team could be more easily retained.

The final facility I toured was SOAR; another example of a 4m platform that remains competitive with larger telescopes by deploying appropriate instrumentation. SOAR also exemplifies how a new facility can be built and adapted on a short timescale with a relatively small budget.

Before my visit I was unaware of the plethora of approaches taken by different groups. Witnessing these varied options in person highlighted the strengths of emerging or unique approaches such as predictive telescope cooling and multilayer mirror coating. Any new project should adopt the most innovative technological solutions while emphasizing the importance of retaining institutional knowledge and reducing telescope downtime. I am extremely grateful to the experts who shared their thoughts with me at every site I visited and patiently answered my many questions. I am returning to Berkeley with lots of new ideas to be included in the planning for a stage 5 spectroscopic instrument, and I am excited to be able to contribute to the continued legacy of 4m telescopes!

SOAR Adaptive Optics Upgrades

Jay Elias (NSF NOIRLab)

Introduction

The adaptive optics (AO) system on the SOAR Telescope is a unique capability within the observing options offered by NSF NOIRLab, and within U.S. astronomy in general. The SOAR Adaptive Module (SAM) is a Ground-Layer Adaptive Optics (GLAO) system capable of providing good seeing correction at *visible* wavelengths, unlike the typical systems used on larger telescopes, which are optimized for the near-infrared.

The imaging system used with SAM is a fairly standard CCD imager and filter wheel, SAMI. It can be used with both broadband filters (typically SDSS) and narrowband filters. SAM was developed by NOAO (CTIO) staff in Chile, with Andrei Tokovinin as project scientist. A description of the instrument and its performance can be found in Tokovinin et al. (2016).

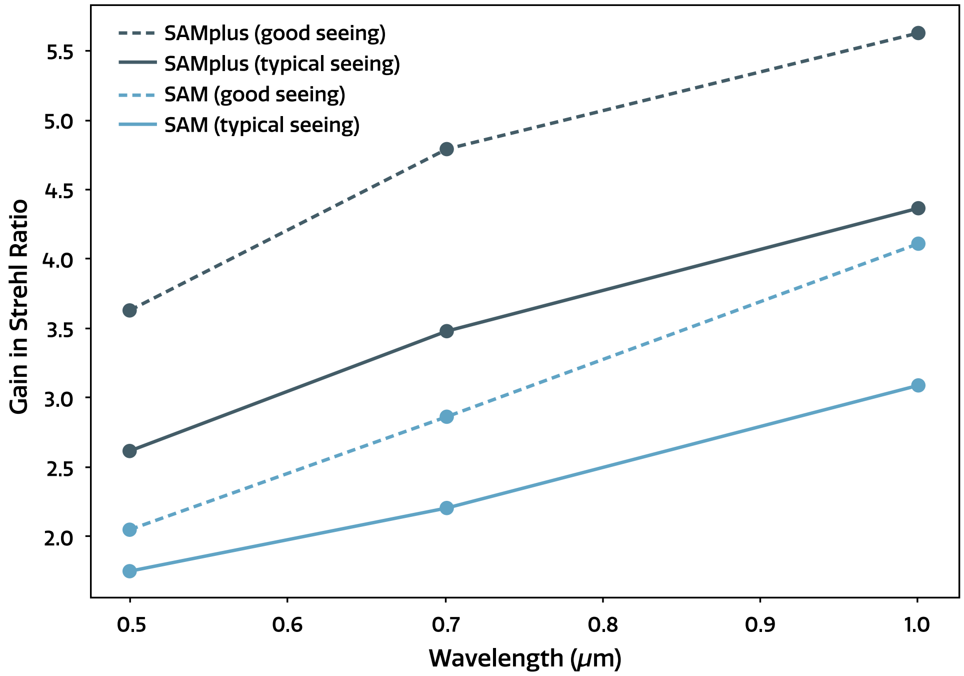

Figure 1: Expected improvements with SAM-Plus. The "Strehl ratio" is a comparison of an observed image with a perfect, diffraction-limited image. A higher Strehl image is one that is more concentrated and provides better contrast with background sources and the sky.

SAM + SAMI have been offered for science use since Semester 2013B. The system sees fairly regular use for projects that benefit from improvements in the point-spread-function (PSF) in crowded fields. The SAMI field of view of 3 × 3 arcmin is particularly attractive for projects requiring good image quality and coverage of moderate-sized areas. In this article, we describe two projects to upgrade SAM that will both extend its useful lifetime and improve its scientific output.

SAM-Plus

Like many older instruments, SAM has critical subsystems for which replacements are no longer available and for which spare components were not provided – typically due to expense. We recognized that something needed to be done, and "SAM-Plus" is the result.

SAM-Plus was intended to replace the vulnerable components with newer hardware and was expected to result in modest gains in performance, primarily due to a deformable mirror with more actuators and a wavefront sensor with greater sensitivity. A description of the upgrade concept can be found in Faes et al. (2018). Figure 1 shows the expected gain in performance.

SAM-Plus was originally proposed as a joint project between the University of São Paulo (Brazil) and SOAR by the late Joao Steiner, who also played a critical role in SOAR's early days.

Funding was obtained from the São Paulo Research Foundation, Brazil (FAPESP), and conceptual work began in late 2017 at the University of São Paulo. Conceptual design reviews were held in 2018 and 2019 for hardware and software, respectively. Subsequent work was slowed significantly by personnel turnover and, especially, university closures during the COVID-19 pandemic. The project continued to advance, and a final

Figure 2: Tarcio Vieira and Andrei Tokovinin at the SOAR Telescope optics lab, installing cables inside SAM for the new deformable mirror

acceptance test was held in December 2023 in São Paulo; all components were shipped to Chile in January 2024.

A team from São Paulo (Tárcio de Almeida Vieira, Tommy Lazaneo Zirnberger, and Hugo da Silva Bernardes Gonçalves) traveled to SOAR in early February to work with Andrei Tokovinin and NOIRLab Engineering Services staff on replacing the older subsystems. SAM was removed from the telescope and moved to the SOAR optics lab in preparation for this work. The team took advantage of access to the instrument's interior to perform maintenance on mechanisms that were not being replaced, such as the guide probes. During two weeks of intensive effort (Figure 2), the team completed all planned objectives and was able to demonstrate laboratory operation of the upgraded instrument in simulation mode.

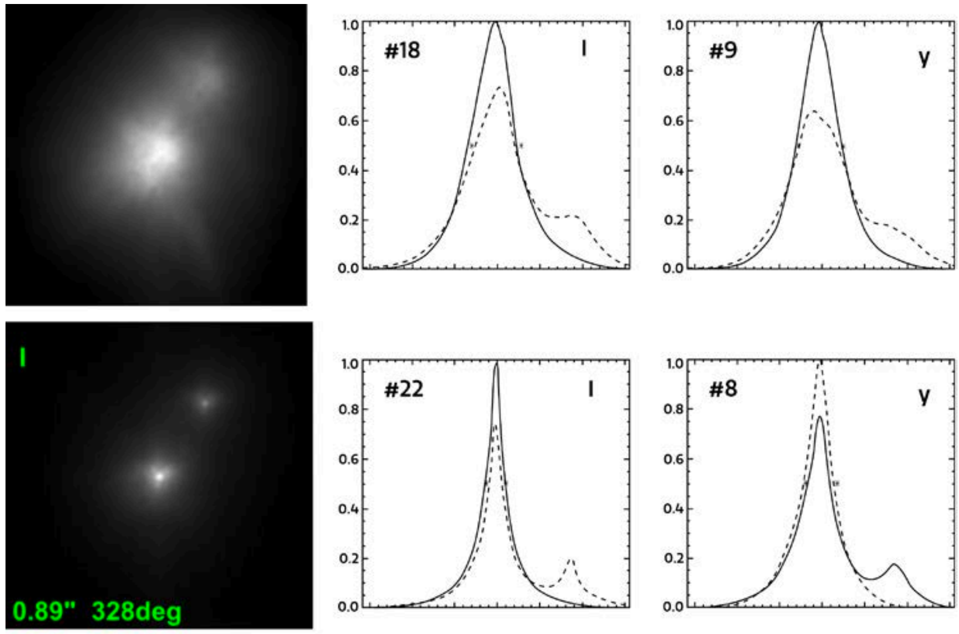

Figure 3: Average images and their profiles recorded on 25 March under excellent seeing with HRCam. The full and dashed lines show profiles perpendicular (horizontal) and along the binary (vertical) directions, respectively; the axis scale is in arcseconds. The image number and FWHM resolution (see asterisks on the horizontal profiles) are indicated. The top row shows open-loop data; the bottom row shows corresponding closed-loop data. Images are shown for the I band. The double star STF 1146 has a separation of 0.89″ and a magnitude difference of 1.6 mag in the I band. Data are shown for I and y [similar to V] bands. At the time of the observations, the free atmospheric seeing was ~0.25 arcsec.

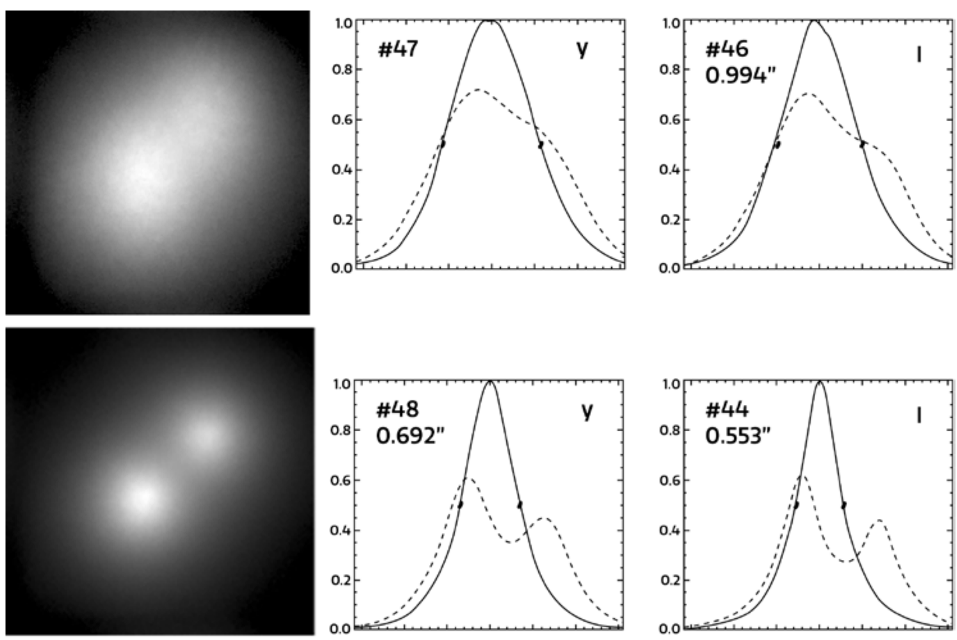

Figure 4: Similar to Figure 3 for the data of 27 March, with worse seeing. Here, the y-band images are shown on the left. The double star STF 1426 has a separation of 0.913″. At this time, the free atmospheric seeing was significantly worse than on 25 March, nearly 0.5 arcsec.

Work then continued preparing to re-install SAM on the telescope, which was done mid-March, with further engineering tests leading up to nighttime work 25–27 March. Imaging was done with HRCam rather than SAMI, as the latter needed some minor repairs (completed subsequently). Results in excellent seeing and more average seeing conditions (25 and 27 March) are shown in Figures 3 and 4. The improvement in different filters for the night of 27 March is shown in Figure 5. From these data, it appears that SAM is capable of producing images limited only by upper atmospheric turbulence (free atmospheric seeing) under good conditions.

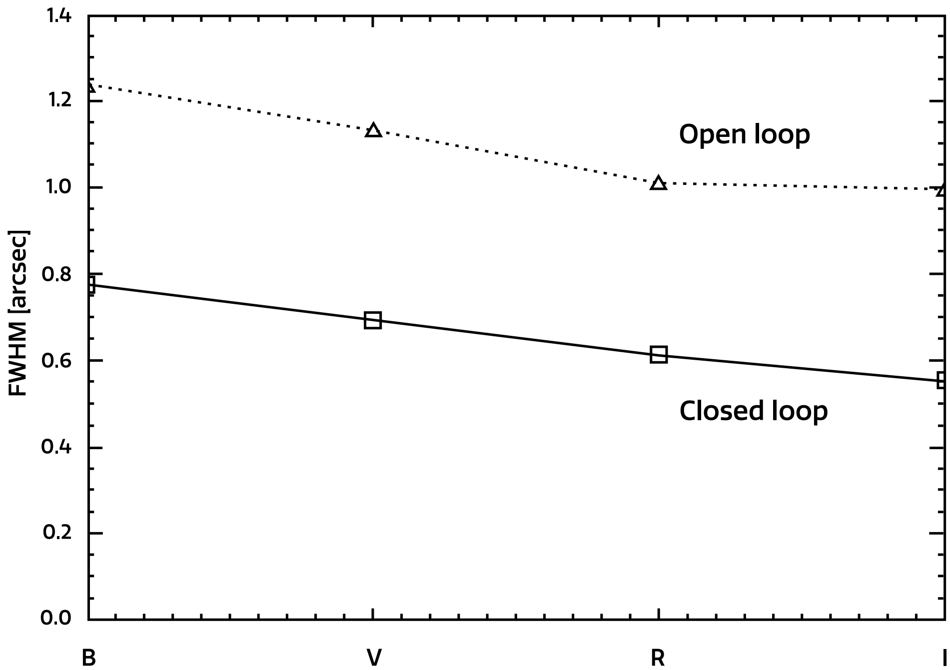

Figure 5: FWHM improvement by wavelength; data from 27 March

Additional work is required to complete documentation and provide software tools for the SAM operators and for general optimization of the AO system to ensure that it operates robustly in average conditions. This work is continuing.

Proposers requesting SAM time in Semester 2024B were advised to propose using current SAM performance specifications; assuming all goes well they will see improved performance. Data from commissioning and early 2024B observing runs will be used to update information for proposals for Semester 2025A and beyond.

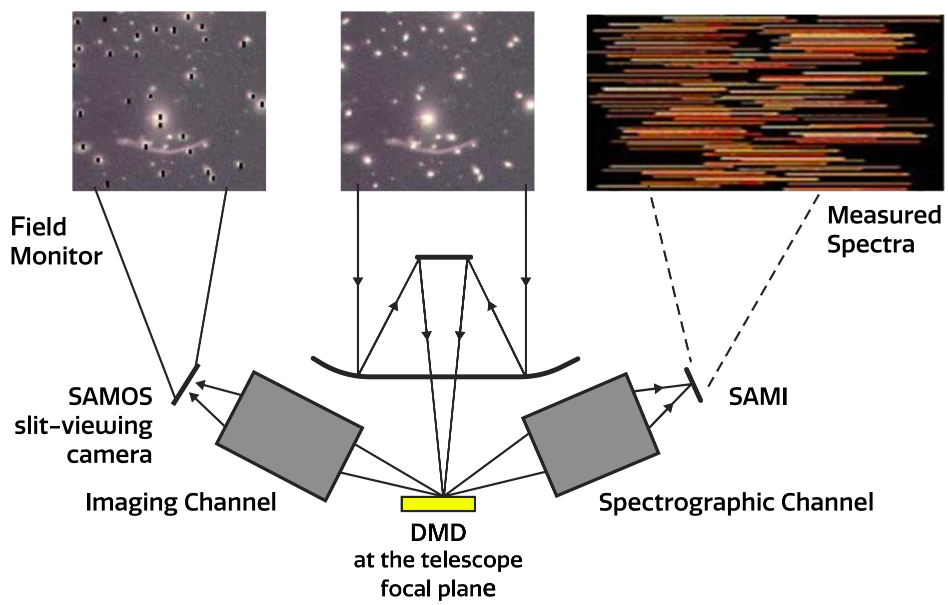

Figure 6: SAMOS concept. The SAM focal plane is imaged on the DMD, which directs light from the "slits" through the spectrograph arm, while light from the rest of the field is sent to the slit-viewing camera.

SAMOS

SAMOS is a novel concept: a configurable multi-object spectrometer that is inserted between SAM and SAMI, where the latter is no longer doing direct imaging, but rather recording multi-object spectra. The SAMOS input focal plane is a configurable digital micromirror device (DMD), which allows the "slits" to be configured in real time, rather than making use of pre-imaging and mask cutting. (In this regard, it's worth noting that the higher spatial resolution that SAM provides requires pre-imaging with SAM in complex fields.) Figure 6 shows the basic concept, while Figure 7 shows a more detailed instrument layout.

SAMOS is another joint project, a collaboration between John Hopkins University (JHU), the Space Telescope Science Institute, Michigan State University, and SOAR. Primary funding is from an NSF ATI grant to JHU. A description can be found in Robberto et al. (2016); more details are provided in associated references.

SAMOS has also passed pre-ship acceptance and was recently shipped to SOAR. The plan for commissioning SAMOS is to wait until SAM-Plus commissioning completes – nominally in late April – and then install SAMOS and commission it. Initial installation took place in May, but final on-sky testing will take place later in the semester.

SAMOS is initially being commissioned as a visitor instrument, but if the performance meets expectations, and there is demand from the general user community, the SOAR partnership would consider taking it on as a facility instrument. In either case, SAMOS would be block scheduled, probably for a month at a time, and SAMI would be available for the remainder of the semester.

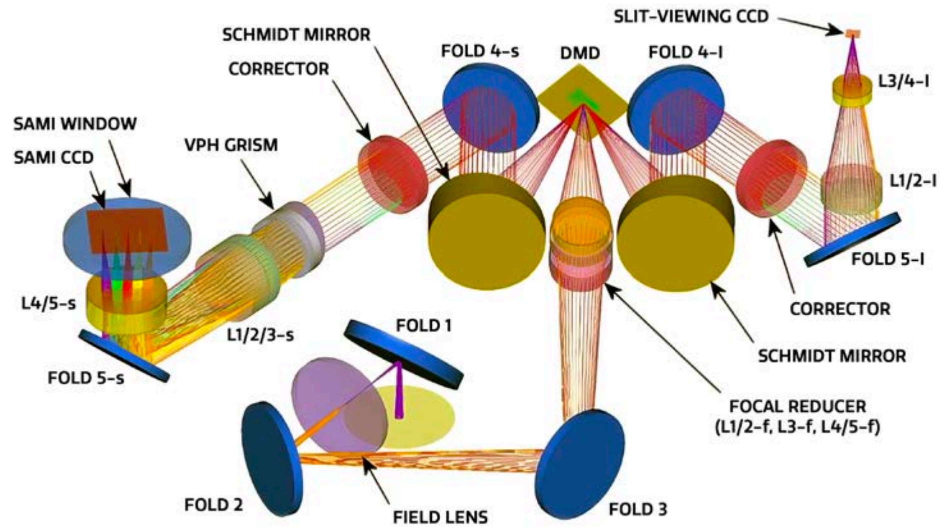

Figure 7: SAMOS optical layout. The overall design needed to be compact enough to fit within volume and weight constraints, as the additional module must fit on top of SAM itself. A detailed explanation of the design and layout is provided in Robberto et al. (2016).

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Robberto, M., Donahue, M., Ninkov, Z., et al. 2016, Proc SPIE, 9908, 99088V

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Rubin Observatory and Citizen Science — Engaging People-Power to Address Rubin's Massive Data Set

Kristen Metzger and Clare Higgs (Vera C. Rubin Observatory/NSF NOIRLab)

The start of Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST) is quickly approaching, which means that many researchers will soon be working with the largest astronomical data set they've ever encountered. Using an 8.4-meter telescope and a 3200-megapixel camera equipped with six color filters, Rubin will image the entire visible southern hemisphere sky over and over for 10 years, generating about 20 terabytes of data per night. The scientific community is developing many approaches to exploring Rubin's enormous data set, and one powerful way that scientists will discover unusual or unexpected phenomena in Rubin data is by drawing on the power of humans around the world through citizen science projects. Citizen science projects invite enthusiastic volunteers from the diverse, worldwide public to participate in the scientific process. Rubin is developing a citizen science project-building infrastructure that will make it easy for researchers to enlist their help.

Rubin Observatory is set to advance science in many areas, including mapping the Milky Way, surveying our Solar System, exploring the nature of dark matter and dark energy, and observing the transient and variable sky. There's no question that Rubin data from the LSST will contain countless treasures in all these areas and beyond. Finding these treasures in such a large data set will require many methods of analysis — methods that go far beyond what can be accomplished by a lone scientist or small team trying to pore through the enormous data set. As an example, Rubin is anticipated to produce 10 million alerts of variable, transient, and moving sources every night. Hypothetically, if an individual were to visually assess even 1% of these alerts, at a rate of 1 per second, it would take about 28 hours to complete — more hours than there are in a day. Automated methods will be essential for working with Rubin data, but the ability of humans to recognize patterns and features — and to notice when something is unusual — makes citizen science a critical complement to automation when it comes to maximizing Rubin's scientific output.

Rubin's citizen science team is developing tools and resources that will enable principal investigators with Rubin data rights to easily build and run citizen science projects using Rubin data. These projects will be mutually beneficial, providing astronomers and astrophysicists with the collective insights of many and welcoming the general public into the scientific process in a meaningful way. The Rubin team will not build or manage citizen science projects, but will instead provide documentation, tools, and support for scientists to build and run their own projects. Additionally, Rubin will promote projects on its public-facing website and on Rubin social media accounts.

Rubin's citizen science initiative is an Education and Public Outreach (EPO)–led effort in collaboration with Rubin's Community Science Team and Zooniverse, one of Rubin's in-kind contributors. Zooniverse is a well-known citizen science platform, which hosts projects in many fields — from astronomy and biology to history and social sciences — and has more than 2.5 million registered users.

Plans for Rubin and citizen science were initiated as part of the EPO construction effort, and the seamless integration of citizen science projects with Rubin data has been considered throughout development of the EPO program. Ivezić et al. (2019) state that "*EPO anticipates that the number of citizen science projects in the astronomy field will increase dramatically when LSST is operational, giving a whole new generation of citizen scientists the opportunity to deepen their engagement with astronomy using authentic data from LSST.*"

For the science community, the focus of Rubin's citizen science team is to support project leads and teams by reducing the learning curve necessary to run a project and by providing resources to manage their projects. Lowering barriers to entry will broaden participation by researchers using Rubin data — early-career scientists or those who don't have extensive experience building citizen science projects will find that the process is more manageable and that support is readily available.

Scientists wanting to run a citizen science project will find a suite of citizen science notebooks on the Rubin Science Platform (RSP), the same place they access Rubin data. Documentation and resources for building projects will be available along with the other tools on the RSP, as well as focused support from the citizen science team.

The citizen science notebooks are intended to be launching points for a variety of project and data types. A "basic" notebook demonstrates sending cutout images to the Zooniverse and retrieving the classified data, while other notebooks in development show ways to use Zooniverse features, such as "flipbooks" that show multiple images of a single source or use the Rubin alert stream as a data source. These notebooks replace the need to upload or download large volumes of data. In addition, the Rubin citizen science pipeline stores and secures the data for the project leads. The notebooks and documentation greatly reduce the learning curve for understanding the Zooniverse Python package (panoptes) and how to implement it. Project leads are also encouraged to contact Rubin's citizen science team with questions or for help addressing the unique challenges of working with Rubin data.

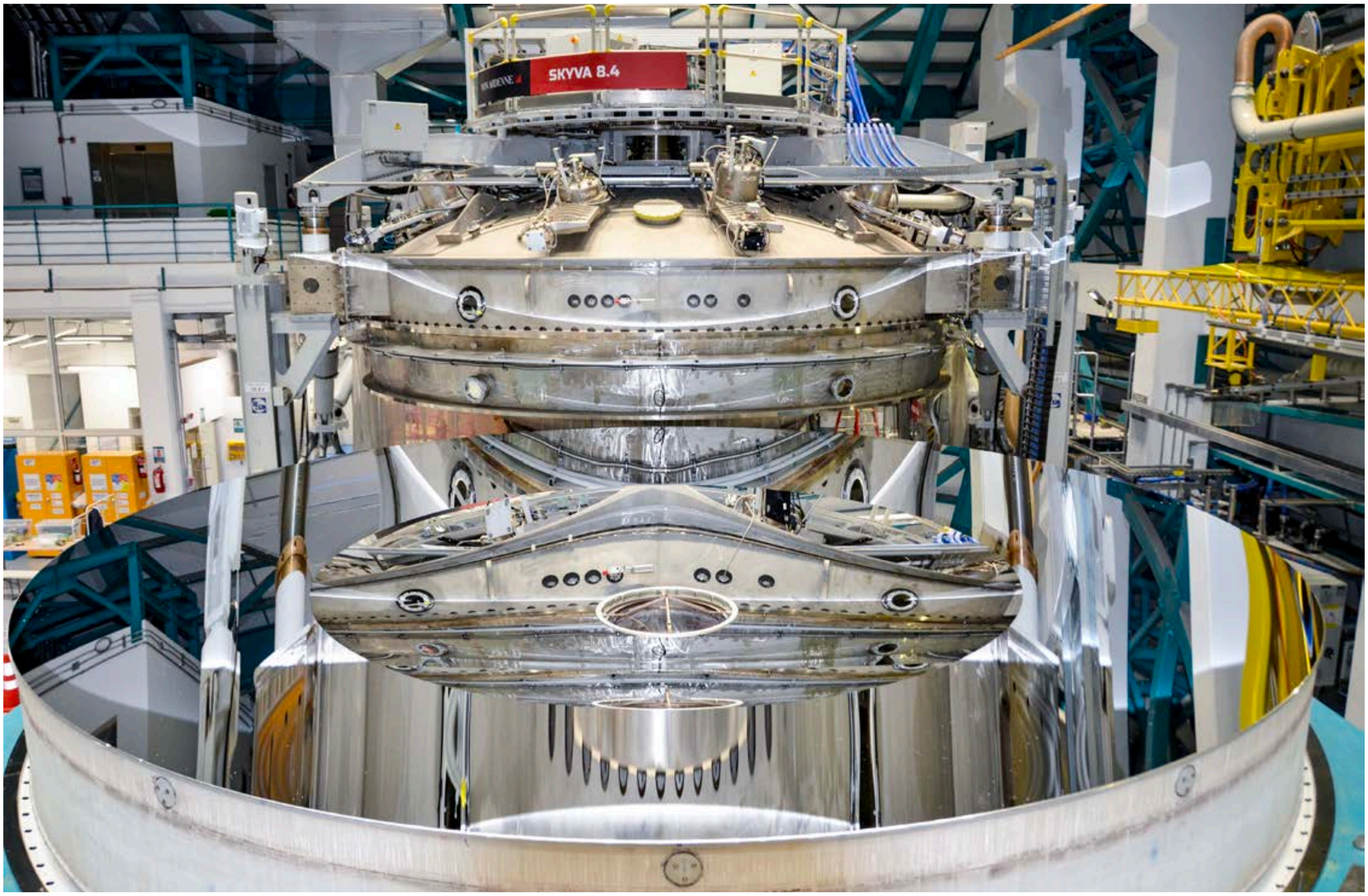
In addition to providing resources and support, the Rubin EPO team will promote citizen science projects that use Rubin data through various channels. Projects can be connected to Rubin's classroom investigations, featured on rubinobservatory.org, and promoted on Rubin's social media accounts. As part of EPO's overall commitment to reaching a broad audience, including those not traditionally served by astronomy outreach programs, EPO will connect Rubin citizen science projects with volunteers from all over the world who want to participate in authentic astronomical research.

Rubin's support for project leads will continue throughout the life of their citizen science projects. The Rubin citizen science team is committed to creating strong and inclusive communities of project leads and volunteers, where project leads of all career stages are confident and able to leverage the Rubin's citizen science team's support where needed, and citizen science project volunteers see themselves as an integral part of the Rubin discovery space.

References

Ivezić, Ž. et al. 2019, ApJ, 873, 111

The LSST Camera Arrives in Chile, and the Rubin Primary Is Silvered



Rubin Observatory's 8.4-meter combined primary/tertiary (M1M3) mirror was coated with protected silver in April 2024 using the observatory's on-site coating chamber. This image shows the M1M3 mirror in the foreground with the silver coating chamber behind (and reflected in) it. The different curvatures of the two optical surfaces of the M1M3 are clearly visible — the annular 8.4-meter primary mirror (M1) and 5.0-meter tertiary mirror (M3) share a single monolithic substrate. This substrate is a cast borosilicate hexagonal honeycomb sandwich, fabricated by the Richard F. Caris Mirror Lab of the University of Arizona. Integrating the two mirrors in this way reduces the engineering and control complexity for the telescope while maintaining its light-collecting capacity. The coating chamber, which uses magnetron sputtering technology, can be configured for either the M1M3 or the secondary (M2) mirror, and it was also used to coat the 3.4-meter M2 with protected silver in mid-2019. *Credit: RubinObs/NSF/AURA/T. Vučina*

The LSST Camera arrives at Rubin Observatory, paving the way for cosmic exploration. *Credit: Olivier Bonin/SLAC National Accelerator Laboratory*

US–ELTP Moving Forward

André-Nicolas Chené (NSF NOIRLab)

The NOIRLab component of the U.S. Extremely Large Telescope Program (US-ELTP) is steadily advancing towards its Conceptual Design Review by the U.S. National Science Foundation (NSF) in December 2024. Here we highlight recent progress in the technical development and community engagement aspects of the program.

US-ELT NOIRLab Program Platform

The NOIRLab US-ELTP team is developing a platform (hereafter, NPP) to provide access to all phases of the Scientific Data Life Cycle, guided and inspired by other services and platforms currently deployed and under development at NOIRLab. We have recently completed the first set of NPP mockups (Figure 1), which represent a substantial refinement of the interface with enhanced usability and efficiency, promising to transform the support provided to science users in optical and infrared ground-based observatories.

The NPP offers a portal that accommodates users based on their specific requirements. Archive researchers can start their journey by exploring the data archive, while principal investigators of observing programs will use it to prepare their proposals.

Taking inspiration from the Gemini Program Platform in pre-observing services, the NPP will allow researchers to focus on critical criteria while streamlining other processes through software automation (Figure 2). For instance, observations are generated by combining targets with configurations, each defined within its dedicated environment. Users are presented with versatile options, including starting from provided examples, utilizing customizable forms, or importing their own information when selecting targets and configurations (Figure 3).

The NPP will also offer a science platform for post-observing data reduction, analysis, and publications, inspired by the NOIRLab Community Science and Data Center Astro Data Lab and the Rubin Science Platform. It is presently based on the virtual platform CoCalc and will provide an environment for users to share a common workspace and collaborate in real-time, fostering efficient development and refinement of their research. The NPP promises to significantly improve the user experience within the US-ELTP community and beyond.

New US-ELTP Website

The US-ELTP has launched its new website, useltp.org! A collaborative effort between NOIRLab, GMTO, and TIO, this digital hub serves as a comprehensive resource center for all things US-ELTP. From technical documentation tailored for public consumption to insightful overviews of US-ELTP science, the website offers a wealth of information accessible to both scientists and enthusiasts. Visitors can learn more about the program's science cases and expectations for user support services and instrumentation and browse through our gallery of images and videos. With its user-friendly interface and engaging content, the site aims to illuminate the program's opportunities and capabilities.

Meetings

Looking ahead, the US-ELTP will participate in three upcoming events: the second meeting on "ELT Science in Light of JWST" (to be held 3–7 June in Sendai, Japan); the 244th meeting of the AAS (to be held 9–13 June in Madison, Wisconsin), and the SPIE meeting on Astronomical Telescopes + Instrumentation (to be held 16–21 June in Yokohama, Japan). These gatherings provide invaluable opportunities for networking, knowledge sharing, and showcasing the latest advancements in astronomical research. Attendees can anticipate engaging discussions and demonstrations at the US-ELTP booth, where they will have the opportunity to delve deeper into the program's mission and initiatives.

The Future

In the realm of policy and funding, the National Science Board (NSB) endorsed the US-ELTP at their February 2024 meeting, but with a recommendation to NSF for a total investment not to exceed $1.6B and a request to NSF to present a plan at their next meeting for the eventual selection of only one project. However, just a few days later,

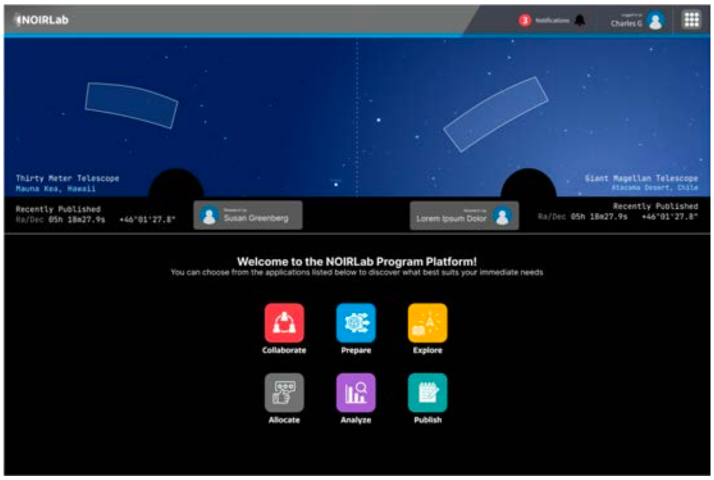


Figure 1: Mockup of the NPP portal

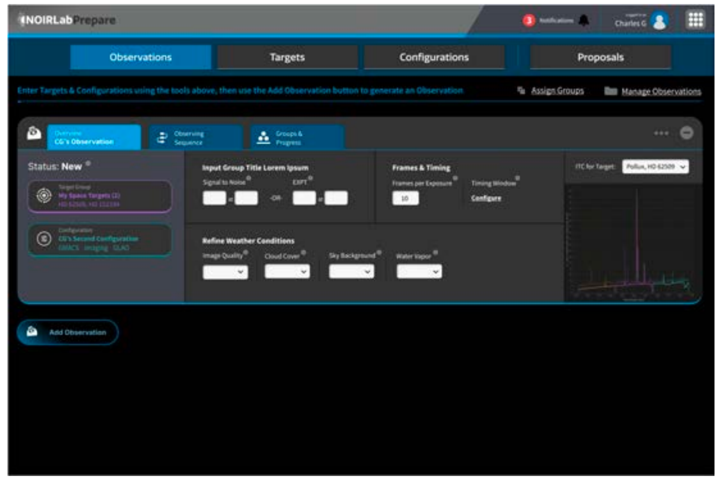


Figure 2: Example of an observation in the NPP

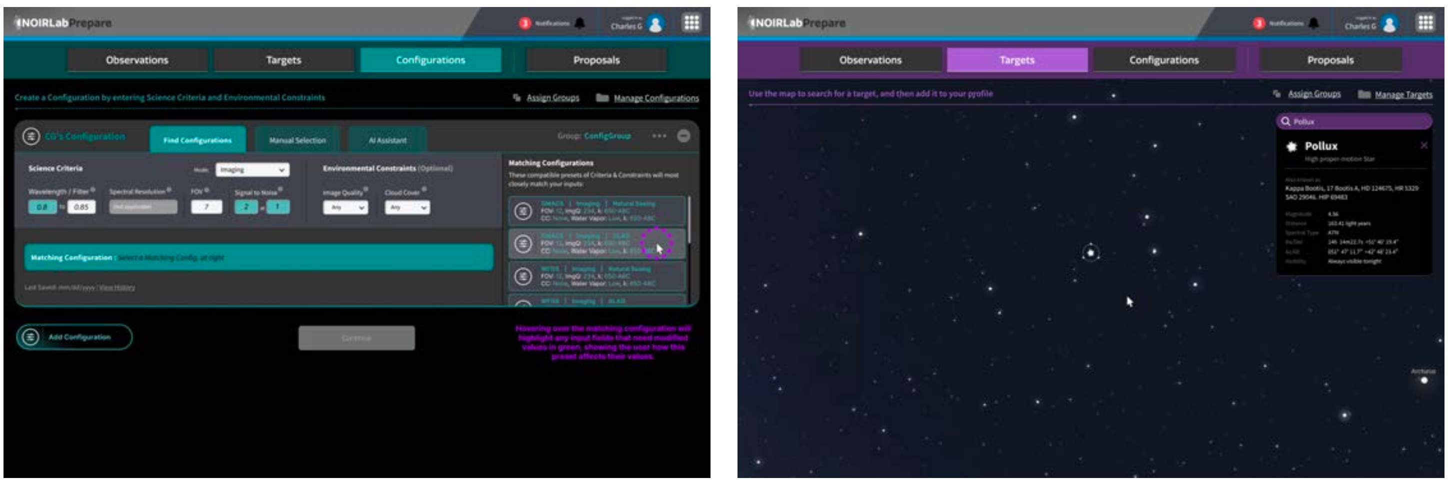


Figure 3: Examples of tabs where configurations (a) and targets (b) are selected

and as part of the final FY24 appropriations bill, Congress strongly encouraged the NSB and NSF to "ensure that the US-ELTP includes a two-observatory footprint with a mechanism to guarantee robust community access" (from the explanatory statement accompanying HR 4366, published in the Congressional Record).

At the May 2024 NSB meeting, the NSF Director announced his decision to convene an external panel to provide him with input on advancing either of the two candidate projects for the US-ELTP. This panel will assess, among other things, progress since the preliminary design reviews, partnerships, risks mitigation, governance models, scientific complementarity with the European ELT, opportunities for early career scientists, and engagement with the public. The NSF Director made it clear that this was not a decision to build either telescope, but a process to gather critical information to help him decide whether to advance either project to the final design phase. His decision is expected during the first quarter of FY25.

As the US-ELTP continues to evolve, we will keep you posted on further updates and discoveries. With each milestone achieved, the program edges closer to realizing its vision of revolutionizing ground-based optical and infrared telescope support, propelling astronomical research to new heights.

Beyond Numbers: Using Data to Improve Education Programs

Justine Schaen (NSF NOIRLab)

Engaging with the local communities of our facilities in Arizona, Hawaiʻi, and Chile to share the thrill of discovery and inspire the next generation is a core value of NSF NOIRlab. Our education programs are more than just one-off events: they are designed to grow and evolve with the unique needs of each community while building lasting relationships.

Why Evaluate?

To ensure each program is relevant and stands the test of time, the NOIRLab Communication, Education, and Engagement (CEE) team conducts evaluations. This process is a team endeavor upholding NOIRLab to deliver valuable experiences that not only meet the audience's needs but also reflect the cutting-edge research and technologies that are happening in our facilities. The seamless incorporation of evaluation into program planning leads to quality data collection and informed decision-making.

Overcoming Challenges

To make valid claims of any program's impact, a variety of data is needed within a certain time frame, and getting enough feedback can be a challenge, even for well-attended events such as *AstroDay Chile*. This popular science and astronomy event brings together over 1800 people from Coquimbo to participate in hands-on astronomy activities, planetarium shows, workshops, and a star party (Figure 1). As an incentive for attendees to provide feedback via a digital survey, the CEE team in Chile was creative and

Figure 1: (Above) *AstroDay Chile* 2024 drew in over 1800 people from the Coquimbo Region and featured science-themed booths and activities.

raffled a small telescope. This led to over 200 survey responses and valuable insights about the demographics of the attendees along with their favorite activities.

To overcome last-minute data scrambling, the evaluation process of a program is planned in advance. The CEE team leading the program outlines the scope and purpose of the education program's evaluation. This upfront planning optimizes our time during the event and reduces the risk of compromising the data's relevance.

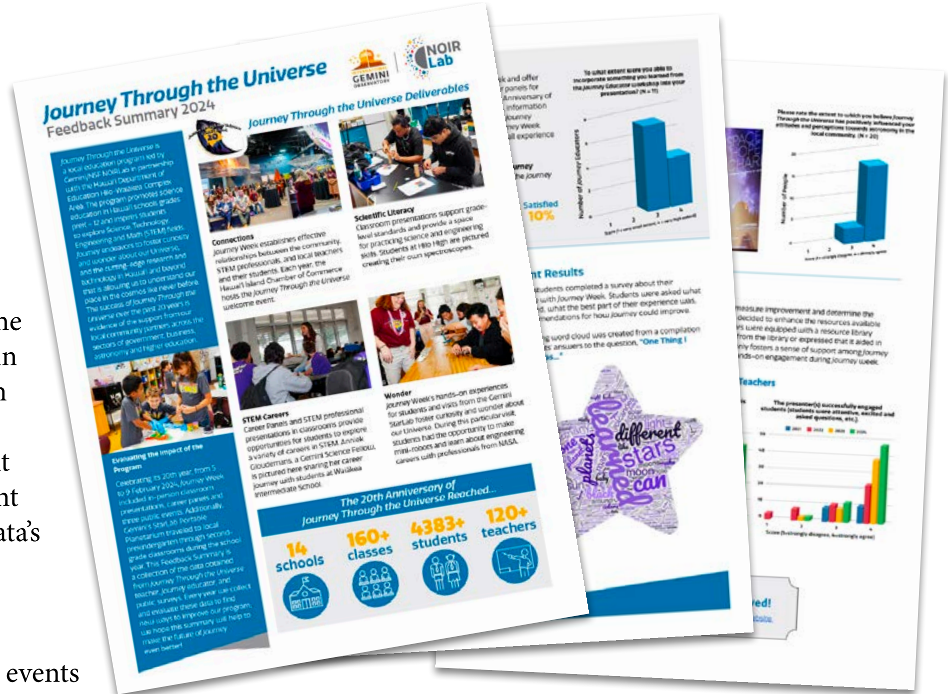


Figure 2: Results of the evaluation of NOIRLab's education programs are summarized into short reports and made publicly available on the NOIRLab public website.

NOIRLab Best Practices

NOIRLab's current education programs and events use a mixed-method approach to collect data. The balanced blend of quantitative and qualitative data enables a more holistic analysis. *Journey Through the Universe*, an education and outreach program in Hilo, Hawai‘i, brings STEM professionals into local classrooms to engage students with hands-on activities and careers. For this year's milestone 20th anniversary of the program, we collected numerical data on the total number of students, teachers, and volunteers to provide an overview of who was impacted. Additionally, participants' experiences and perceptions were captured through classroom observations, interviews, and surveys to gather feedback on the quality of the program. This comprehensive approach minimizes the risk of bias and enhances the reliability of the evaluation.

As we have a variety of partners that play a key role in the success of our programs, it is crucial they feel invested and can contribute their recommendations and insights throughout the evaluation process. The Hawai‘i CEE team consults and collaborates with the Hawai‘i Department of Education in evaluating *Journey Through the Universe*. Other partners or stakeholders include local school districts, teachers, and even students. This practice holds NOIRLab accountable for collecting high-quality data and for being responsive to these results.

Transparency in communicating results internally and externally to our partners and the public is vital for building trust and upholding reputation. To ensure openness, most NOIRLab education programs publicly provide a concise summary of the annual evaluation results on the public website (Figure 2). Additionally, in-depth documentation is developed and shared with partners to foster higher-level collaborative decision-making.

Being Responsive and Innovative

With baseline data established for our education programs, annual evaluations serve as checkpoints for consistency and ensure growth. For example, in preparation for the 20th anniversary of *Journey Through the Universe*, the previous year's evaluation was used to inform planning and decision-making. The 2023 teachers' survey emphasized a need to broaden the program's scope by adding ‘Ohana events for families to engage in astronomy education together. In response, the *Journey* team added two events to the 2024 program that were open to the public including a lecture, "From Hollywood to the Moon and Beyond," and a free screening of the independent film, *Space, Hope, and Charity.* The *Journey* team created and administered a survey to measure the impact of these new events and to broadly gather feedback on the International Gemini Observatory's effort toward supporting community engagement in astronomy.

Additionally, the *Journey* team improved the resources available to the *Journey* educators (classroom presenters) in response to last year's results. This year, *Journey* educators

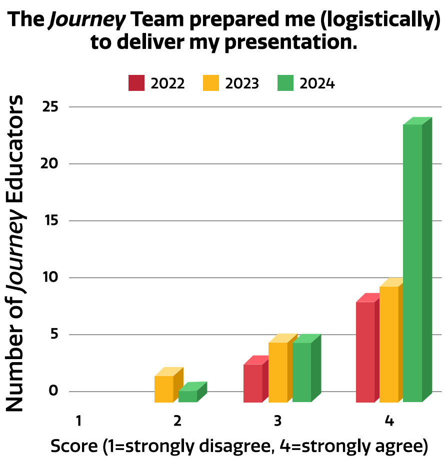
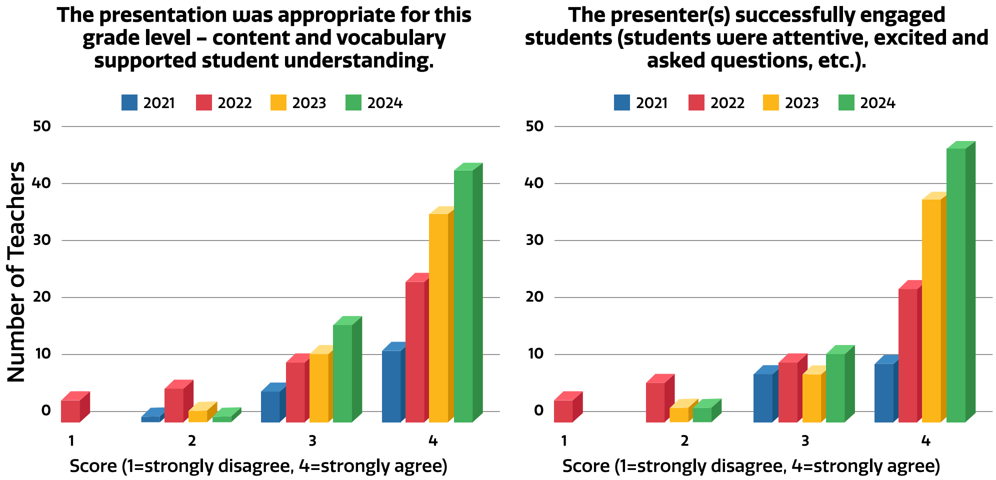


Figure 3: *Journey* educators felt more prepared in 2024 to deliver their presentations compared to previous years.



Figures 4 and 5: Teachers indicated more quality *Journey* presentations in 2024 than in previous years.

were equipped with a resource library containing a variety of sample lessons. Many *Journey* educators utilized lessons from the library or expressed that it aided in developing their own presentations. As a result of this change, there was an increase in *Journey* educators feeling better supported (Figure 3), and teachers noted an increase in the quality of classroom presentations (Figures 4 and 5).

Lasting Impact

As we have learned from the evaluation of our education programs and events, responsive evaluation is key for addressing pre-conceived and emerging issues. By listening and learning from various perspectives, together we can grow and build a more dynamic and meaningful presence in our communities.

Journey Through the Universe is a local education and outreach program in Hawaiʻi that brings STEM professionals into classrooms for presentations and hands-on activities with students. The program held its 20th annual program earlier this year.

Previous *The Mirror* articles on *Journey Through the Universe*

“Eighteen Years Young,” *The Mirror* #3, p. 34

“Education and Engagement in the Era of Social Distancing,” *The Mirror* #2, p. 68

“Journey Through the Universe Celebrates 16 Years (and Counting!),” *The Mirror* #1, p. 68

AstroDay Chile: A Public Event for Families

Manuel Paredes and Peter Michaud
(NSF NOIRLab)

On 15 March 2024, NSF NOIRLab and AURA led *AstroDay Chile* 2024 to kick off celebrations for the National Day of Astronomy in Chile. This event is one of NOIRLab's core programs in Chile and one of the favorites of the public and staff!

This year, the event was held at the Biblioteca Regional Gabriela Mistral in La Serena, a public library under the Ministry of Culture, Arts and Heritage of the Chilean government. This new location provided NOIRLab with more opportunities than the previous location to interact with a diverse public of all ages and from different areas of the Region de Coquimbo.

More than 1800 people attended the all-day event. The public participated in various activities organized by NOIRLab, and the event was supported by 22 exhibitors and more than 24 NOIRLab staff, along with 8 instructors from Explora Coquimbo.

The public was asked to participate in a contest by answering a survey that allowed us to learn about some of the preferences of the event's attendees. The results of this survey showed that *AstroDay Chile* achieved its goal of being an event primarily for families, with 62.8% of visitors attending as family groups. The survey also confirmed that the new venue helped to achieve our goal for attracting new participants, with 87.8% of people attending the event for the first time, most of whom (27.6%) learned of the event through social media.

The public also rated the science workshops and the exhibitions highly. These activities were supported mostly by NOIRLab staff members, who were crucial for the success of the event.

Figure 1: Left to right: Luis Padilla, Peter Moore, Adriana Gutiérrez, Pedro Gigoux, and Carola González in the NOIRLab booth at *AstroDay Chile* 2024. *Credit: NOIRLab/NSF/AURA/ D. Munizaga*

Figure 2: University of La Serena astronomy students explaining to children why stars have different colors at *AstroDay Chile 2024*. *Credit: NOIRLab/NSF/AURA/D. Munizaga*

Figure 3: NOIRLab astronomer Kathy Vivas gives a talk about the Dark Energy Camera to the public during *AstroDay Chile* 2024. *Credit: NOIRLab/NSF/AURA/D. Munizaga*

NOIRLab organized mobile planetarium sessions (thanks to the partnership with the Corporación Municipal Gabriel González Videla, which manages public schools in La Serena); workshops about the Moon, astronomical origami, and galaxies; solar observations with telescopes equipped with solar filters for safely viewing the Sun; 3D films about astronomy; and the acclaimed international planetarium show from the California Academy of Sciences, Big Astronomy.

One of the most popular workshops was the paper rocket-building workshop led by the amateur astronomy group Astronor. Hundreds of children learned the science of rockets and enjoyed launching the models themselves, using launchpads and compressed air.

NOIRLab's Dark Sky Protection group in Chile also participated, hosting a booth and an immersive experience that helped the public understand how light pollution affects our dark skies heritage and the importance of shielding lights.

The Universidad Central de Chile, La Serena, and the Universidad de La Serena booths offered fun hands-on activities for the youngest participants, and adults were able to join in panel discussions on light pollution and the latest astronomical advances in the Coquimbo Region. Visitors also enjoyed taking selfies with Star Wars characters. The Biblioteca took the opportunity to launch The Kamishibai experience, *Illari, the Girl Who Looked at the Stars*, a video made with the sponsorship and advice of NOIRLab that addresses the local Indigenous views of the Universe and the impact of the night sky on the lives of Native people for centuries

The event ended with a star party with telescopes provided by Astronor, Colegio Seminario Conciliar, and the Mamalluca, Collowara and Roan Jasé tourist observatories. The star party featured views of the Moon, which many attendees attempted to photograph using their cell phones!

Events such as *AstroDay Chile* attract a significant number of people. The new location at the public library provided an opportunity for the organizers and hosts to hold the event where we were able to interact with a diverse range of individuals. The impact on the public was inspiring.

We are already planning the 2025 *AstroDay Chile* and hope many staff and local families will join us again!

Figure 4: A group of kids waiting for the launching of their own paper rockets during *AstroDay Chile* 2024. *Credit: NOIRLab/NSF/AURA/D. Munizaga*

Figure 5: Isabel Cortés Ramos, from the Biblioteca Regional Gabriela Mistral, offers a public reading of the Kamishibai experience, *Illari, The Girl Who Looked at the Stars*, as part of the *AstroDay Chile* 2024 activities. *Credit: NOIRLab/NSF/AURA/D. Munizaga*

Figure 6: Dark Sky Protection group during *AstroDay Chile* activities. Top left: Camila Ibarlucea, Constanza Muñoz, Carolina Vargas, and Loreto Troncoso. *Credit: NOIRLab/NSF/AURA/C. Vargas/C. Ibarlucea/L. Troncoso*

Discovering Our Universe Together

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