The Mirror

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THE MIRROR

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On the Cover

NSF–DOE Vera C. Rubin Observatory, located on Cerro Pachón in Chile, is now a complete system. Rubin began its on-sky commissioning campaign in April 2025 and is preparing to release its first imagery on 23 June 2025 in a global, online event called Rubin First Look.

Credit: RubinObs/NOIRLab/SLAC/DOE/NSF/AURA/W. O'Mullane

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Director's Letter

As this edition of *The Mirror* goes to press, the NSF–DOE Vera C. Rubin Observatory team is preparing to release their first set of images following first light. The Rubin *First Look* event is just weeks away, and the start of operations lies only five months in the future. Rubin *First Look* watch parties are planned for Tucson, Palo Alto, La Serena, and more than a hundred other locations around the world.

The rapid progress over the past few months is a testament to the expertise and dedication of the project team — see the article in this issue detailing work over the past year. By all accounts the telescope and camera are meeting or exceeding their performance requirements and have worked "out of the box" with very little fine tuning needed. We have every expectation that the transition to operations will also be smooth and reflect the high degree of preparation within the operations team. The Legacy Survey of Space and Time (LSST) is expected to start just a few months after the operations phase begins in October. When the Rubin Community Workshop meets in August, there will be much to celebrate — and much to plan in the year ahead.

The success of the Rubin enterprise depends on more than just the telescope and camera. A vast distributed network of software, computing resources, data management, science teams, and supporting observations must be ready to harness the flood of data coming from Rubin. The data systems are up and running and the Rubin Science Platform is being exercised with the first images. Teams around the world have developed event brokers, and long-standing science collaborations are ready for the first data release a few months after the survey start. We are working to bring the AEON observatory network software up to full speed to support follow-up observations from a range of telescopes and instruments.

The emphasis on large survey programs at NOIRLab is not confined to Rubin. As presented in recent editions of *The Mirror*, the DESI project is demonstrating the power of large homogenous datasets. Last month at the annual meeting of the American Physical Society, the DESI and Dark Energy Survey teams presented new results strengthening earlier indications that dark energy may be weakening over time.

Early this year we issued a call for survey proposals with an adjustment in the balance between survey and normal proposals — up to 50% of the time is now available for survey programs. The response was enthusiastic: demand for survey time was very high. In addition, the number of proposals for Gemini Large and Long programs was twice that in past semesters. The community is asking for more opportunities to conduct large programs spanning several semesters, and we are responding.

NOIRLab is in the midst of a comprehensive review of our performance since inception. By the time this edition of *The Mirror* has gone to press, we will have met with the expert panel assembled by NSF to assess our management of their center for nighttime optical IR astronomy. Preparation for this review has consumed a great deal of attention for the past several months. It has led us to take stock of what is working and what needs adjustment. At the review we will describe the origin of NOIRLab and our vision for the role of a national center, our present approach to management, what we have learned over the past three years, and how we have evolved in response to that experience. Lastly, we will present our vision for the next five, ten, and twenty years of NOIRLab.

We are presently in a time of uncertainty around the structure and priorities for federally funded research in the US. The news media report changes on a nearly daily basis. We know little more than what we read in the news, and we realize that this uncertainty creates stress for our staff, our users, and the scientific community as a whole. The component programs of NOIRLab have been through many periods of change since their inception and have emerged stronger. We are keeping our focus on the future and the many powerful capabilities that we are bringing to our community.

Hubert Condoretti Is New Chief Technology Officer and Director for Software

We are excited to welcome Hubert Condoretti as NSF NOIRLab's new Chief Technology Officer (CTO) and Director for Software. Hubert started in his role on 6 January 2025.

Hubert will play a pivotal role in forming the new Software and Data Management (DMS) Division where he will lead the integration and alignment of NOIRLab's software, data management, infrastructure, and IT initiatives. His responsibilities include the following:

- Evolving our dispersed software, data, and infrastructure efforts into a cohesive and efficient group
- Identifying opportunities for synergies among new requirements while optimizing the reuse or generalization of existing tools
- Establishing the structures, processes, and frameworks needed to manage these efforts effectively
- Overseeing the implementation, execution, and continuous improvement of NOIRLab's software, data management, and IT initiatives — from high-level user tools to foundational infrastructure

Hubert brings over 25 years of tech industry experience as a senior executive and technology leader, with a passion for fostering innovation, building high-impact organizations, and driving strategic growth. His impressive career spans leadership roles at Microsoft, Amazon, Twitch, Ellie Mae, and several startups, where he successfully launched and managed products such as Windows, Office, Azure, OneDrive, Xbox, Alexa, and Twitch.tv — tools and platforms used globally. He has spearheaded cloud migration initiatives, scaled businesses during periods of significant growth, and implemented advanced technologies like AI and machine learning to drive efficiency, optimize workflows, and transform businesses in regulated industries.

Beyond his professional achievements, Hubert contributes to the community through his role on the Board of Directors for the US Math Recovery Council, where he shapes strategies to enhance math education outcomes for students and educators.

Born in La Paz, Bolivia, Hubert is fluent in Spanish and immigrated to the US, where he earned dual Bachelor of Science degrees in Computer Engineering and Computer Science, graduating summa cum laude from the University of Southern California.

The Only Constant Is Change

DESI Shakes Up Our Understanding of Nature and the Fate of the Universe

Joan Najita (NSF NOIRLab)

What is the nature of the mysterious thing called dark energy and how is the Universe fated to evolve? Surprising new insights into these big questions are arriving from the Department of Energy-funded Dark Energy Spectroscopic Instrument (DESI) experiment, currently underway at Kitt Peak. On 19 March 2025, the DESI Collaboration announced results from their first three years of data, finding stronger evidence that dark energy, once thought to be a cosmological constant, is instead evolving, becoming weaker (i.e., "less pushy") with time. The finding opens up the possibility of other, cheerier outcomes for the fate of the Universe.

DESI's result is based on its spectra of nearly 15 million galaxies and quasars, which combine to yield the largest 3D map of the Universe ever made. The experiment's ability to collect such huge samples in only a few years of observing is a result of its high multiplex (the DESI instrument can measure spectra of 5000 objects simultaneously), the high end-to-end efficiency of the entire DESI observing system, and the light-gathering power of the U.S. National Science Foundation Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory.

Using the 3D map, astronomers are able to track the influence of dark energy over time using subtle features in the matter distribution, as traced by galaxies, quasars, and the Lyman alpha forest. The map charts the subtle pattern of ripples or bubbles in the matter distribution, the baryon acoustic oscillations (BAO) signal, which is a frozen relic from the early Universe and a standard cosmological ruler. By measuring the size of the BAO signal as a function of redshift, the strength of dark energy can be measured throughout history (Figure 1).

When DESI's constraints on BAO are combined with constraints from other cosmological probes (the cosmic microwave background, supernovae, and weak lensing), the DESI Collaboration finds that the data are best fit when the standard model of the universe, Lambda CDM, is tweaked so that the strength of dark energy is no longer a constant (Figure 2).

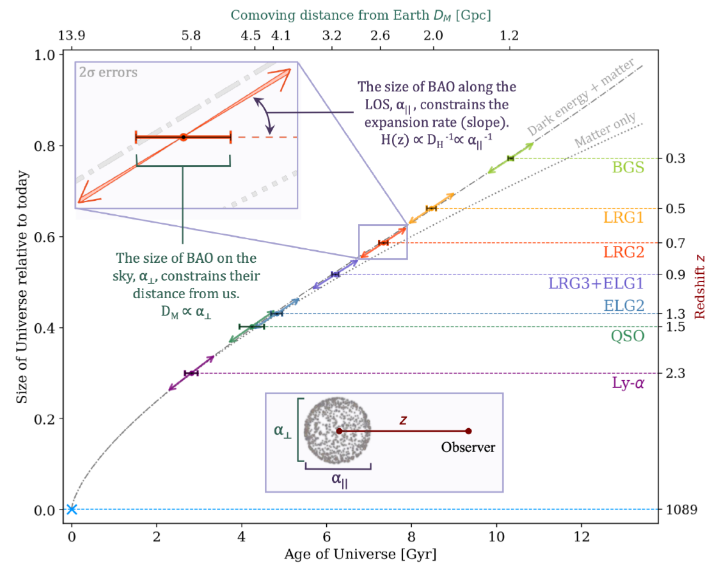

Figure 1: DESI's BAO measurements constrain the expansion history of the Universe, shown here as the scale factor versus time. The angular size of the BAO signal measures the comoving distance to the sample (top horizontal axis). The size of BAO along the line-of-sight measures the Hubble distance, and therefore the expansion rate, or the slope on the curve. The scale factor is inferred from the effective redshift of the sample. DESI measures the BAO signal for seven tracer samples between redshifts of 0.5 to 2.3. The constraint from the CMB acoustic scale is plotted as a light blue cross. The late-time acceleration caused by dark energy is easily seen as favored by the BAO data. The bottom axis shows the age of the Universe as a function of comoving distance in a flat ΛCDM universe. DESI-fitted models with evolving dark energy are not visually distinguishable from the ΛCDM model on this plot. (Credit: Figure 1 from DESI Collaboration 2025)

The March 2025 results represent a major improvement on DESI's announcement a year ago, which hinted that dark energy is likely to be dynamic (i.e., evolving with time). By doubling the size of the dataset used in the analysis, the early hints are now on firmer ground. The results have been heralded as the first new clue about the nature of dark energy in the 25 years since its discovery.

The results upend cosmology and open up a wide range of possible futures for the Universe. If dark energy isn't a strict constant, it's unclear how it will evolve. It may weaken

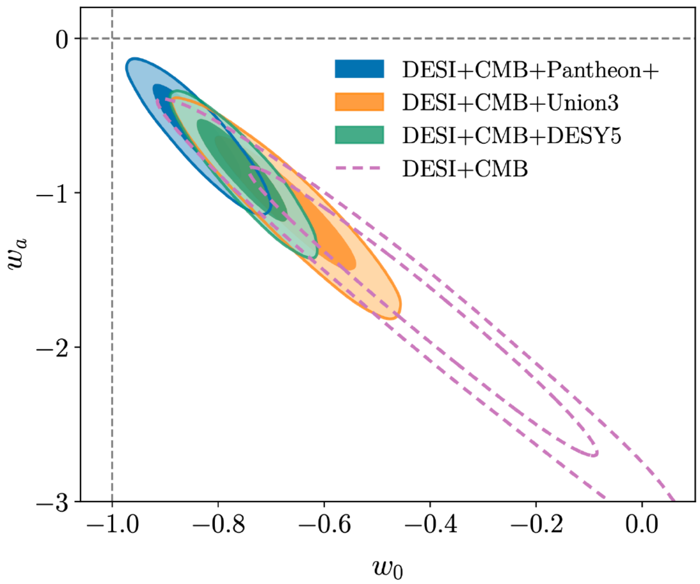

Figure 2: Best fit quantities describing the dark energy equation of state parameter ω in a model that evolves as $\omega(a) = \omega_0 + \omega_a(1–a)$, where $a = 1/(1+z)$, from fits to DESI data in combination with constraints from the CMB and three supernova datasets. The contours enclose 68% and 95% of the posterior probability. The intersection of the gray dashed lines indicates the ΛCDM limit (ω_0 + –1, ω_a = 0). ΛCDM is rejected at 2.8σ, 3.8σ, and 4.2σ significance for DESI combined with the Pantheon+, Union3, and DESY5 supernova samples, respectively, and 3.1σ for DESI+CMB without any supernovae. (Credit: Figure 11 from DESI Collaboration 2025)

further over time, becoming not only "less pushy" but perhaps even "sucky," inducing the Universe to contract rather than expand. Alternatively, it could grow stronger or fade away.

As humans, we may welcome the news. Constant dark energy would predict that the accelerating expansion of the Universe would continue unabated into the future, eventually driving galaxies so far apart that no other galaxies would be visible to us. In other words, it would forecast a dark and lonely future. If dark energy is instead not a constant, cheerier outcomes are still on the table.

In parallel with the announcement of these cosmological results, DESI data were also made public, with Data Release 1 (DR1) now freely available for all to explore. Based on data obtained in the first year and the survey validation period of the DESI survey, the DR1 main catalogs and full-depth spectra are available through NSF NOIRLab's Community Science and Data Center's Astro Data Lab and SPARCL services. In addition, the full set of DR1 files are available through the National Energy Research Scientific Computing Center (NERSC), the Berkeley Lab facility that stores and processes DESI data. The DR1 catalogs contain information on 13.1M galaxies and 1.6M quasars, more than twice as many objects as in all previous extragalactic spectroscopic surveys combined. The public data also include spectra of more than 4M stars.

These remarkable advances continue the tradition of cosmological exploration at the US National Observatory and its advocacy for highly multiplexed wide-field spectroscopy as a powerful tool for discovery. National Observatory (then NOAO) facilities played a leading role in the discovery of the accelerating expansion of the Universe. Both the High-z Supernova Search team and the Supernova Cosmology Project (SCP) relied on the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory (CTIO) and the WIYN 3.5-meter Telescope at Kitt Peak National Observatory (KPNO) for their work. The SCP also used the Mayall Telescope and the KPNO 2.1-meter Telescope at Kitt Peak. The National Observatory's advocacy for highly multiplexed wide-field spectroscopy dates back to the 1999 NOAO white paper on SWIFT (Spectroscopic WIde field Telescope) and numerous activities since then.

From a facilities perspective, another notable aspect of the DESI results is the remarkable scientific longevity of well-maintained facilities that are matched to compelling science opportunities. In the case of DESI, the incredible teamwork and scientific energy of the collaboration and its dedication to end-to-end efficiency has engaged the Mayall Telescope, now more than 50 years old, in a vibrant new mission and world-leading science.

DESI is an international experiment with more than 900 researchers from over 70 institutions around the world. 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.

Additional Information

DESI Collaboration, 2025, arXiv:2503.14738
Access DR1 through Astro Data Lab
DESI public webpages (provide more background on DESI's science)
DESI's YouTube channel (features playlists of DESI talks from the March 2025 APS meeting and additional talks showcasing the BAO results)
A guide to the 19 March 2025 DESI publications
NSF NOIRLab press release, 19 March 2025
Seo, H.-J., *The Mirror*, 7, 11

Figure 1: (Credit: DESI Collaboration/C. Lamman/M. Sargent)

A Treasure Trove of Dark Energy Spectroscopic Instrument Data

Stéphanie Juneau (NSF NOIRLab)

Sitting atop Kitt Peak and mounted on the Nicholas U. Mayall 4-meter Telescope, the Dark Energy Spectroscopic Instrument (DESI) has been conducting its cosmic cartography experiment since 2021. Funded by the U.S. Department of Energy (DOE) to conduct a Stage IV cosmology measurement of dark energy, it aims to gather spectra of 50 million galaxies and quasars over the course of its five-year spectroscopic observational campaign. The DESI multiplex of 5000 robotically positioned fibers combined with its large field of view of 8 square degrees make it the most productive spectroscopic machine ever built.

On 19 March 2025, the DESI collaboration published a new data release encompassing the first 13 months of the main survey and a reprocessing of the previous survey validation observations. DESI DR1 is more than 10 times larger than the early data release (EDR) and includes optical spectra for an unprecedented 13.1 million galaxies and 1.6 million quasars. This tally amounts to more than twice the number of extragalactic redshifts from all previous optical spectroscopic surveys to date. The data release additionally includes spectra and radial velocities for about four million stars. Altogether, this rich dataset can enable a wide array of astrophysical studies spanning galaxy evolution, physics and demographics of active black holes, dark matter distribution, stellar populations, the formation history of the Milky Way, and more.

Example composite spectra are shown in Figure 2 to illustrate the variety in spectral shape and features among galaxies and quasars from the DESI extragalactic target

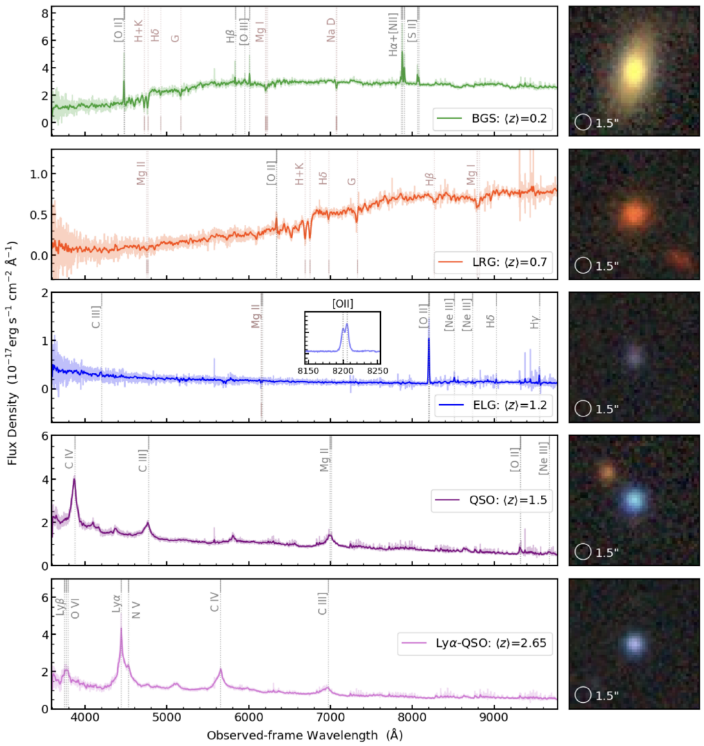

Figure 2: Composite spectra and example images of the DESI extragalactic target classes: Bright Galaxy Survey (BGS), Luminous Red Galaxy (LRG), Emission-Line Galaxy (ELG), and Quasi Stellar-Object (QSO). The latter are divided into tracer QSOs (z<2.1) and Lyman-alpha QSO (z>2.1). Each row shows the average of 75–100 spectra in a narrow redshift range around the labeled mean redshift value (left) and an image from the Legacy Surveys Sky Viewer for one representative example object (right). For the spectra, the faint colored lines represent the inverse-variance weighted average spectra, while the darker lines are the same spectra smoothed with a five-pixel Gaussian kernel. The vertical dotted lines indicate the expected wavelengths of key emission and absorption lines, and for the ELG class, the inset shows the resolved [O II] λλ3726, 29 Doublet. On the image panels, the 1.5 arcsecond diameter circles represent the size of the DESI fiber. Figure created using the Astro Data Lab and SPARCL, and reproduced from the DESI DR1 paper (DESI Collaboration et al. 2025).

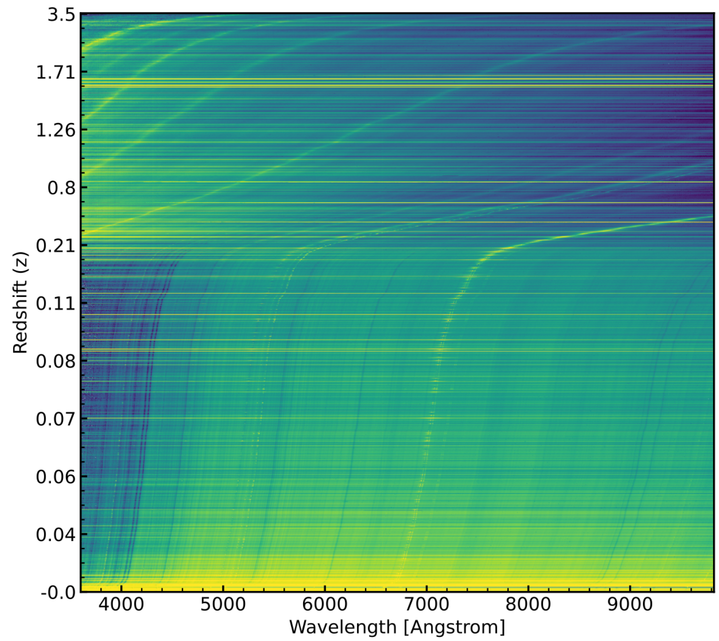

Figure 3: DESI spectra of 5687 primarily extragalactic sources from the Milky Way Backup Program, arranged in increasing redshift. Several emission and absorption features typical of galaxy and QSO spectra are seen tracking diagonally across the image with increasing redshift. Emission features appear lighter toward yellow colors while absorption features appear darker toward blue colors. A small number of the brightest horizontal lines are spectra of stars that are mis-classified as spectral type GALAXY by the default DESI pipeline. This figure was made by retrieving the spectra using CSDC's SPARCL and will be published as part of the DESI Backup Program Overview paper (Dey et al. 2025).

classes. This montage offers a glimpse of typical objects but does not encapsulate the full extent of the parameter space, which further covers various subtypes of stellar spectra as well as rare objects of all kinds. Another illustrative example of DESI spectra is shown in Figure 3, encapsulating nearly 6000 spectra stacked in order of increasing redshift. This particular set of spectra showcases targets from the backup program — when conditions are subpar for both the regular dark time and bright time programs of DESI.

The complete 270-terabyte dataset is published through the National Energy Research Scientific Computing Center (NERSC), the same supercomputing facility used to process the raw data and estimate object redshift and classification. The DESI DR1 dataset includes redshift catalogs, targeting and photometry catalogs, one-dimensional spectra, and over 20 value-added catalogs (VACs) produced by DESI collaborators. For additional convenience and reach, the NSF NOIRLab Community Science and Data Center (CSDC) prepared powerful public data access methods including searchable databases on the Astro Data Lab science platform for all main DESI catalogs and a searchable spectral database as part of the Spectra Analysis and Retrievable Catalog Lab (SPARCL) serving both Sloan Digital Sky Survey (SDSS) and DESI spectra for a combined 30 million spectra.

The Astro Data Lab Science Platform features functionality such as an online cross-matching tool and an online query interface as well as a Jupyter notebook server. The latter is equipped with pre-installed Python software covering general purpose and astronomy-specific libraries, the DESI software, and the SPARCL client. This allows users to discover and access DESI spectra within the JupyterLab environment. Astro Data Lab and SPARCL are also available as installable command-line packages for users to work locally while alleviating the need to download large volumes of data.

With millions of spectra and billions of objects in the DESI Legacy Imaging Surveys campaign, researchers are tasked with navigating an immense sea of data. To guide them, a close collaboration between the DESI data team and the NOIRLab Astro Data Lab and SPARCL teams has produced a suite of tutorials and documentation tailored to each entry point. The NOIRLab Astro Data Lab tutorials and the NERSC tutorials range in complexity and topics to maximize the scientific impact of this revolutionary dataset.

Following in the footsteps of the highly successful predecessor SDSS, members of the DESI collaboration created more than 20 VACs covering a range of topics from general purpose (photometry, sky spectra) to supporting Milky Way science, extragalactic science, quasar science, and Lyman-alpha forest studies. The VAC collection is growing and is documented alongside the main data products on the DESI Data Documentation page. The original set of 24 VACs released concurrently with DR1 are also documented in the DESI DR1 paper (DESI Collaboration et al. 2025). The astronomy community is invited to dive in and make use of DESI data for a wide array of research topics, noting the data license and official acknowledgements.

What comes next? The DESI collaboration has processed the first three years of survey data and recently announced the first batch of cosmology results strengthening the hint for an evolving dark energy previously reported with the first year data). Other cosmological measurements are underway, but this even larger dataset will eventually be released as DESI DR2. To be continued…

References

DESI Collaboration et al., 2025, arXiv:2503.14745

Dey, A., et al. 2025, in preparation

Nearly a Decade of Speckle Interferometry at the International Gemini Observatory

Steve B. Howell (NASA) & Clara E. Martínez-Vázquez (NSF NOIRLab)

In 2018, a pair of speckle interferometry instruments (‘Alopeke and Zorro) were installed at the twin 8.1-meter Gemini North and South telescopes in Hawai‘i and Chile. ‘Alopeke and Zorro deliver high-resolution imaging across the optical bandpass from 350 to 1000 nm (Scott et al. 2021), which has led to crucial discoveries in stellar multiplicity, exoplanetary science, and more.

‘Alopeke and Zorro are permanently mounted at Gemini, residing in a very small space at the facility calibration unit (GCAL) port. Figure 1 shows some details of the small instruments. Speckle imaging of a target requires many thousands of short exposures (10 to 60 milliseconds) to be obtained and processed. Random microfluctuations of temperature and pressure in the Earth’s atmosphere cause fluctuations of the phase of an incoming wavefront, producing a degraded image, consisting of bright and dark spots called speckles, at the focus of the telescope. Rapid sampling of this image “freezes” the atmosphere and provides an instantaneous interferogram of the observed source. Fourier analysis of this large set of frozen images allows one to reconstruct the scene as if the atmosphere was essentially absent. The large number of images is required to build up sufficient S/N, especially at contrasts greater than 4 or 5 magnitudes (~10−2), at very close angular separations, and/or for fainter targets. Although this large number of exposures may seem daunting, typical speckle observations last only a few minutes per target. Targets as faint as R = 19 mag can be observed by using ~50 minutes of on-source time. Reaching the diffraction limit and providing deep magnitude contrasts, these instruments are unmatched by any single telescope in terms of angular resolution.

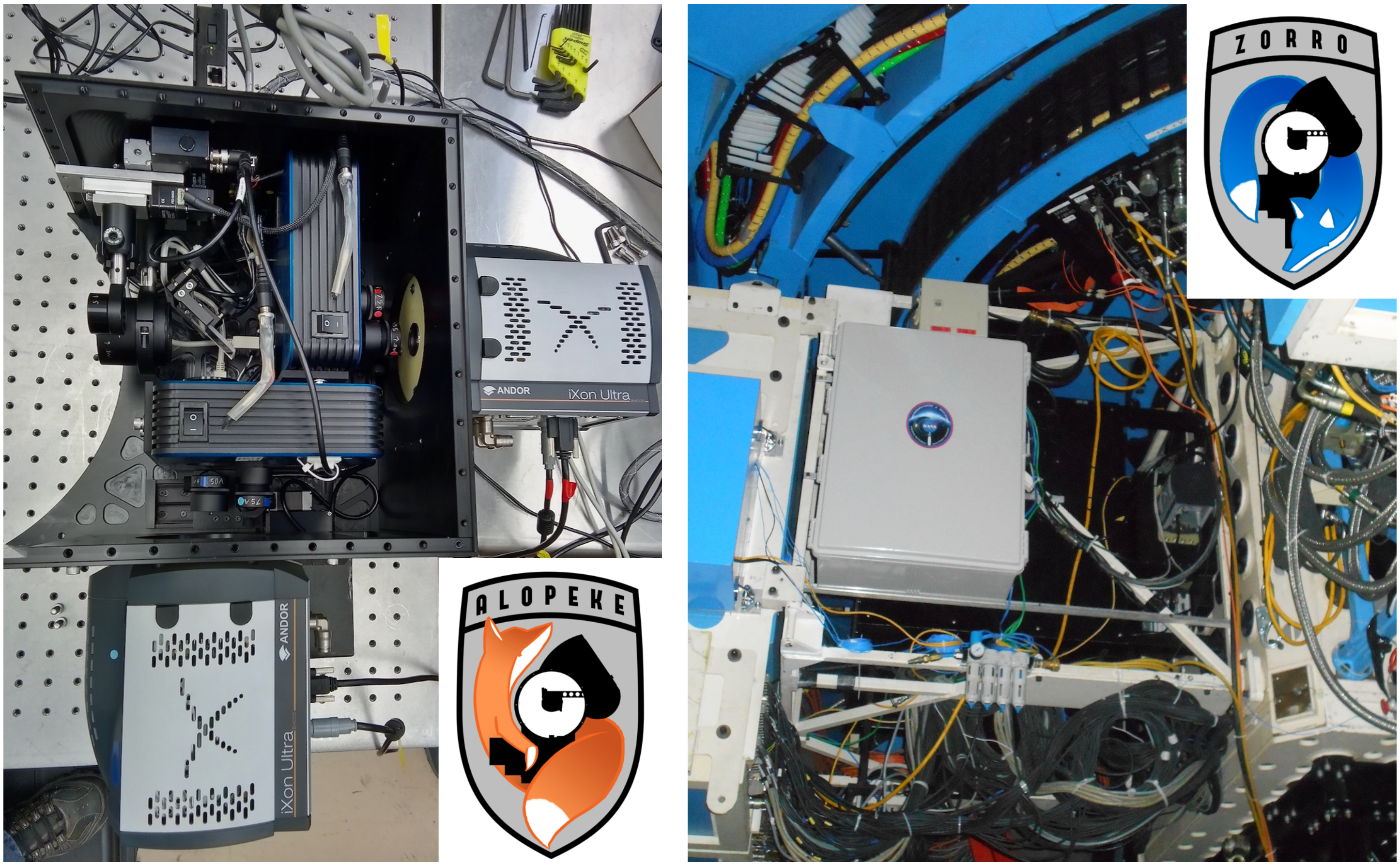

Figure 1: ***Left*:** The 'Alopeke instrument components were visible during a routine maintenance inspection at the Gemini North base facility. With the covers removed, one can see the tightly packed innards that contain two filter wheels, the optical elements, and the two ANDOR EMCCD cameras extending from the box. ***Right*:** Zorro mounted on the Gemini South telescope, in its permanent mount location at the GCAL port, attached underneath the primary mirror. The black box with one ANDOR EMCCD camera seen extending from it contains the instrument, while the larger white box to the left contains the electronic power supplies and instrument computer.

Through community access, the Gemini speckle imagers have supported a wide range of scientific investigations, from Solar System bodies to morphological studies of stellar remnants and quasars to evolved stars to transient phenomena. Stars have been the main target of speckle imaging: in particular, a number of large programs to image exoplanet host stars providing validation, characterization, and searching for multiplicity. Figure 2 presents a typical result for a stellar observation, here showing a close companion discovered for the exoplanet host star TOI-5873. The astrometric precision for binary stars observed at Gemini yields stellar separations to ±1 milli-arcseconds (mas) and ±1 degree in position angle (Lester et al. 2021). Photometric magnitude differences for stars in multiple systems typically have uncertainties of ±0.25 magnitudes. With the superior angular resolution obtained at the Gemini telescopes, extended objects can be resolved enabling additional astrophysics to be performed. For example, the classical nova V906 Car was observed about 1000 days after its explosion, revealing an extended shell of 90 mas (Figure 3). Closer to

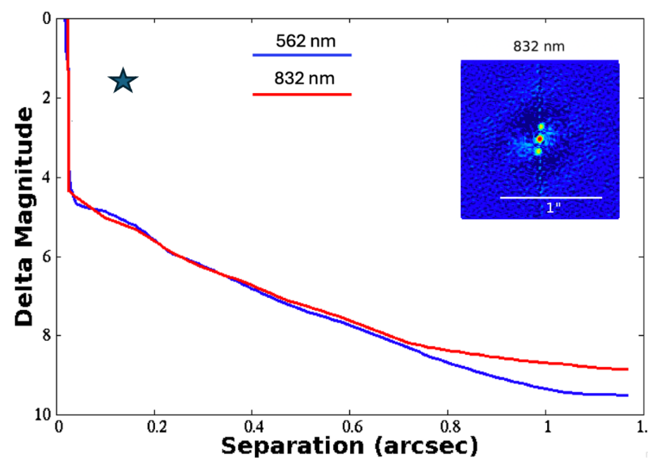

Figure 2: A typical speckle imaging result for an 8th magnitude star (TOI-5873). The red and blue curves show the 5-σ contrasts achieved as a function of angular separation, from the diffraction limit out to 1.2 arcsec, and the inset shows the reconstructed image for the 832-nm observation. The star symbol shows the location of the companion. The speckle observations reveal that the target star is binary, with a very close (0.14 arcsec separation) companion that is 1.6 mag fainter than the primary at a position angle of 176 degrees.

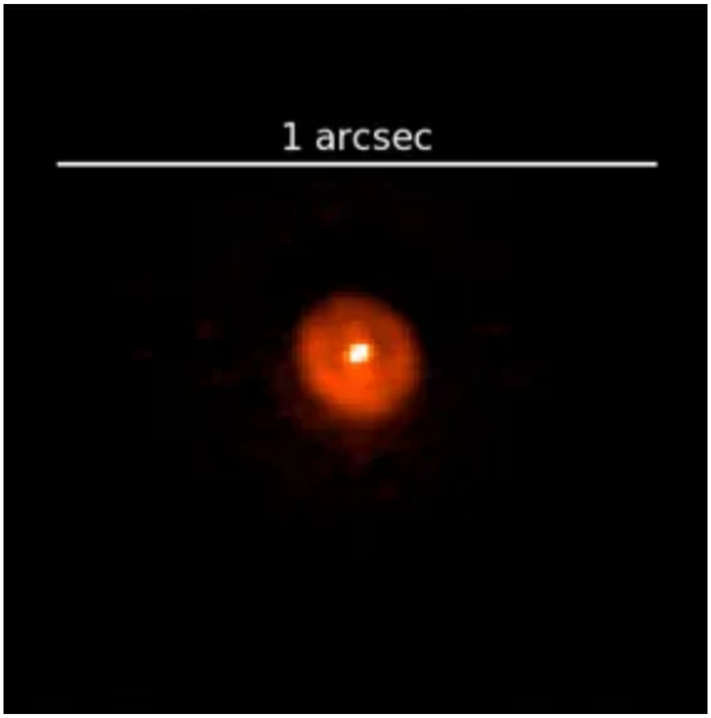

Figure 3: Nova V906 Car observed 978 days after its explosion. The image shows a resolved nova shell with a radius of 90 mas.

home, time-series imaging of Near Earth Asteroids (NEAs) such as Eros allow the shape and rotation axis to be determined. Figure 4 shows five selected frames from a 5-hour time series of Eros revealing its changing shape during one rotation period.

‘Alopeke and Zorro proposal demand varies semester by semester, but on average it is 5–10%, exceeding the Gemini South Adaptive Optics Imager (GSAOI) demand and nearing the demand for other visiting instruments (e.g., Immersion Grating Infrared Spectrometer [IGRINS]) or even facility instruments (e.g., Gemini Near-Infrared Spectrograph [GNIRS]). Any user can request time on these instruments using the regular Call for Proposals, or Director's Discretionary Time (DDT) when needed. Principal Investigators (PIs) from Gemini partner countries can also propose for ‘Alopeke and Zorro time using Fast Turnaround (FT) proposals.

Raw and fully reduced archival data from Zorro and ‘Alopeke can be found in the Gemini Observatory Archive (Hirst & Cardenes 2017) or the Exoplanet Follow-up Observing Program Archive. The full story of scientific applications using speckle imaging at the International Gemini Observatory is available at Howell et al. (2025).

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Lester, K. V., et al., 2021, AJ, 162, 75
Scott, N. J., et al., 2021, FrASS, 8, 138

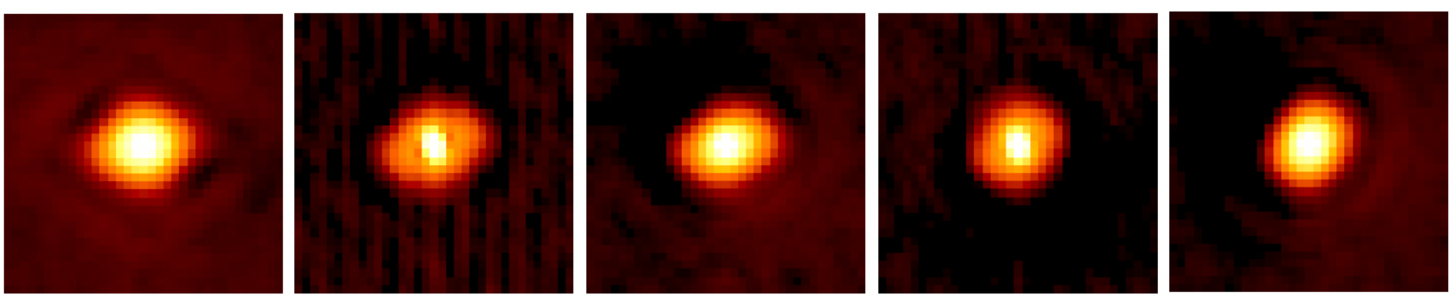

Figure 4: Speckle imaging time series of the asteroid Eros covering one rotation period (5.3 hours). During the series, the resolved shape of the non-spherical body is seen changing with time.

Speckle Interferometry at SOAR

Andrei Tokovinin (NSF NOIRLab)

Current interest in binary and multiple stars is driven by several factors in addition to the classical topic of measuring masses. Mergers of compact objects leading to the supernova explosions and gravitational wave bursts are at the forefront of astrophysics. Such mergers happen more frequently in triple systems (Toonen et al. 2020), and the population synthesis requires a knowledge of the binary- and triple-star statistics at birth time. On the other hand, exoplanets in binary and triple star systems pose the same questions: Why does Nature produce single, binary, and hierarchical stars with and without planets, and what are the typical properties of these systems? Another powerful driver is the wealth of information on stars coming from the Gaia and TESS space missions; these data open new lines of research and require ground-based follow-up (El-Badry 2024).

Speckle interferometry at the 4.1-meter Southern Astrophysical Research (SOAR) Telescope is used for the multiplicity surveys and for monitoring orbital motions for more than a decade (Tokovinin 2018). Typically, 10 nights per year are allocated, also using the available hours of the bright-time engineering nights. The observations are organized in an efficient way, visiting 300 objects per night and yielding 3000–5000 visits per year; a total of 44,061 observations have been accumulated to date.

The observational capabilities of the SOAR speckle instrument, the High-Resolution Camera (HRCam), are best illustrated by the actual data. Figure 1 plots the magnitude difference (or contrast) delta-m vs. angular separation \rho for all pairs measured in 2023. Some binaries are resolved below the formal diffraction limit of 40mas. The 1m aperture of Gaia sets its diffraction limit at 100mas (the green shading), but these measurements will be available only in the final data release, expected in the 2030s. The 11-year duration of the Gaia mission restricts its capability to determine orbits with longer periods. So, speckle interferometry at SOAR substantially complements and extends the information on binaries provided by Gaia in terms of angular resolution and time coverage.

The wealth of speckle-interferometric observations collected at SOAR is being used in a variety of projects that can be classified in two broad groups: surveys, where one visit per target is sufficient, and monitoring of orbital motion vs. time. For example, the follow-up of TESS exoplanet candidates, started in 2018, has so far collected 2944 observations. Apart from testing the absence of companions around most exohosts, the follow-up campaign provided statistical proof that planet formation in binaries closer than 100 au is suppressed (Ziegler et al. 2021). Another example of the single-visit science is the survey of binary stars in the young association Upper Scorpius (Tokovinin & Briceño 2020). By combining the data from HRCam and Gaia, 250 physical binaries among 614 targets were uncovered, and the distributions of their periods and masses were studied. The surveys of accelerating stars (K. Franson, B. Bowler) and wide binaries (J. Chanamé) conducted 2021–2022 will be published soon.

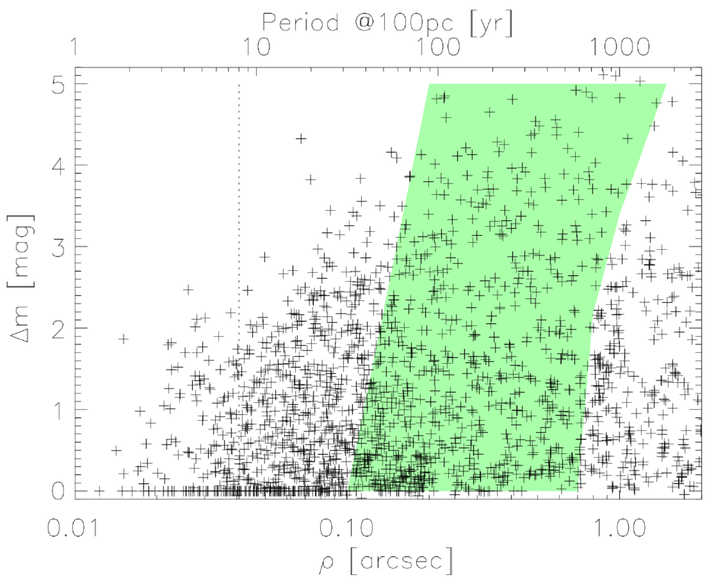

Figure 1: Magnitude difference m vs. separation for 1533 pairs measured at SOAR in 2023 (crosses). The upper axis indicates approximate periods of binaries with such separations located at 100 pc distance. The green shading highlights the expected future measurements from Gaia, the vertical dotted line shows the SOAR diffraction limit of 40mas in the I band (from Tokovinin et al. 2024).

For the nearby stars, the resolution limit of HRCam allows discovery and study of binaries with periods as short as a few years. Quite naturally, many HRCam projects are focused on the solar neighborhood. The survey of M dwarfs within 25 pc has been conducted by Vrijmoet et al. (2022). Potential binary candidates were selected on the basis of the

Gaia and ground-based astrometry, and 63% of the 333 targets were resolved. Monitoring of their orbital motion continues with the aim to determine orbits. The first batch of 50 orbits with periods under 30 yr is ready for publication in 2025. The ultimate goal is to pinpoint the binary statistics in the low-mass regime. The total number of M-dwarf observations at SOAR approaches 2000.

The synergy between Gaia and speckle can be illustrated by the survey of low-mass hierarchical triples within 100 pc (Tokovinin 2023). Among the 1243 wide binaries where Gaia suspected a presence of inner subsystems, 503 close pairs were actually resolved. Knowledge of their separations and contrasts allows evaluation of the periods and mass ratios — the information not provided by Gaia. The closest pairs move fast, and their orbits are being determined from subsequent monitoring at SOAR. As noted above, even the final Gaia data release will be restricted to periods below 10 years, and only photocentric orbits will be available owing to the limited angular resolution of Gaia.

Monitoring of orbital motions in hierarchical systems is time-consuming but rewarding, uncovering their architecture. Figure 2 highlights one such triple, HIP 9497. The faint companion B, detected by Hipparcos in 1991.25 at a separation of 0.57″, was revealed as a close pair B,C by its first observation in 2008 (over 100 hierarchical systems were discovered at SOAR in this way, by targeting known binaries and finding them to contain more than two stars). Patient monitoring defines the inner orbit accurately and gives a good idea of the long-period outer orbit. Both orbits are located in one plane and are nearly circular; the ratio of periods, 1:9, suggests that the two orbits might be in resonance. Furthermore, the masses of the three stars (1.2, 0.6, and 0.6 solar) make this system a "double twin" where both inner and outer pairs have nearly equal masses. Obviously, such configuration (typical for many other low-mass triples) cannot be created randomly; it suggests a special formation mechanism and contrasts with the predictions of N-body dynamics. Accumulation of data on the architecture of stellar hierarchies leads to understanding the pathways and mechanisms of their formation.

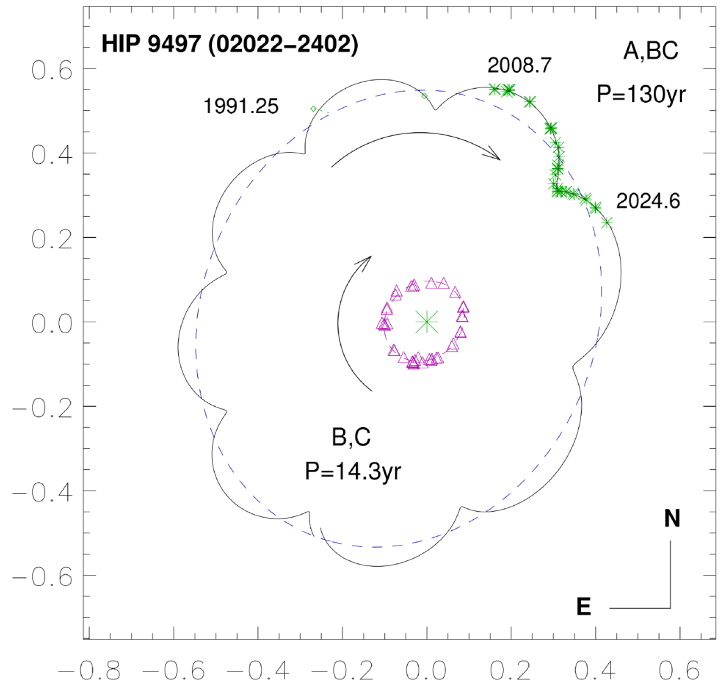

Figure 2: Orbital architecture of the hierarchical triple system HIP 9497 discovered at SOAR in 2008. The 14.3-yr orbit of the inner pair B,C is now fully covered (magenta symbols and ellipse), while the outer orbit (blue dash and black solid lines, green asterisks) with a period of 130 yr is known approximately. Both orbits are nearly circular and coplanar. The mass ratios in the inner and outer pairs are close to one. Such configuration is typical for many (but not all) low-mass triples.

Speckle interferometry at SOAR has provided a rich harvest of discoveries and insights. Its synergy with space missions promises new exciting results in the future. To support this work, an upgrade of the HRCAM to a new CMOS detector, also enabling its use for fast photometry, has started.

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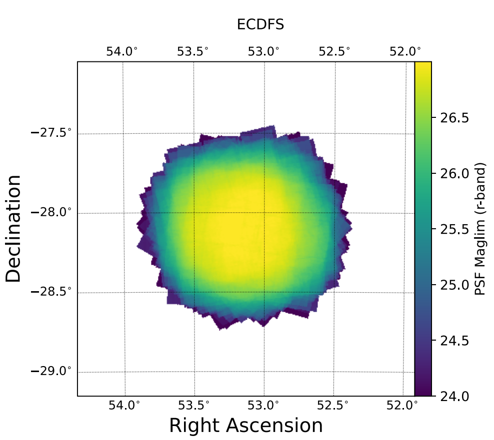
NSF–DOE Vera C. Rubin Observatory On Sky Commissioning!

Robert Blum (NSF–DOE Vera C. Rubin Observatory)

As you read this in June, perhaps right before the American Astronomical Society (AAS) meeting in Alaska, you probably already know that NSF–DOE Vera C. Rubin Observatory has begun observing on sky and is taking data like crazy. You probably also know the team is rushing to finish the construction project and transfer Rubin into Operations so we can start the Legacy Survey of Space and Time (LSST). In mountaineering speak, we talk about moving with "unhurried haste." That's what rushing means here. After more than 20 years of conceptualizing, designing, developing, and building, Rubin and the LSST are almost here.

It's amazing to consider that children born when Rubin's Chief Scientist, Tony Tyson, was observing on the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory and dreaming up the Dark Matter Telescope are now old enough to begin thesis projects or other research using a science platform on the Google cloud connected to a data facility at SLAC National Accelerator Lab.



Target	u	g	r	i	z	y
47 Tuc	6	10	33	19	0	5
Rubin SV 38 7	0	44	55	57	27	0
Fornax dSph	0	5	26	13	0	0
ECDFS	53	230	257	177	177	30
EDFS ComCam	20	61	90	42	42	20
Rubin SV 95 -25	33	86	97	29	60	11
Seagull	10	37	49	3	13	0

Figure 1: **Left:** limiting 5 sigma magnitude depth in the Extended Chandra Deep Field South from ComCam in late 2024. **Right:** seven fields used for pipeline testing in the ComCam on-sky campaign with number of visits for each filter. Field centers are given in the ComCam report sitcomtn-149. *Credit: Vera C. Rubin Observatory Team*

With the construction project nearing completion, Project Manager Victor Krabbendam can now realistically foresee a night's sleep longer than four hours (I actually don't know how long Victor sleeps now, but it's not long). As you read this, he is seeing the biggest project in his career reach the precipice of completion. Željko Ivezić will happily see his time as Director of Rubin Construction coming to an end in anticipation of the science to come. And thousands of dedicated colleagues — scientists, engineers, administrative staff, and communicators, not to mention leadership at the U.S. National Science Foundation, the U.S. Department of Energy, NSF NOIRLab, SLAC National Accelerator Laboratory, AURA, and our international collaborators — will be incredibly excited as we get closer to showing the world Rubin's first images in a worldwide media and public outreach event called "Rubin First Look." This event should happen very soon after you read this!

None of this is guaranteed, or happened by chance (yes, my tenses here are mixed — it's not easy to write about events that haven't happened yet but will by the time this article is published). In our last update in these pages, the Rubin Observatory system was going through early end-to-end testing with Rubin's Commissioning Camera (ComCam). That campaign went smashingly well, and the data we took during that time will be available soon after you read this. The phase of commissioning with ComCam on sky showed that the system worked exceedingly well, with a reasonable number of items to improve upon — and, of course, significant work

Figure 2: The LSST Camera mounted on the transportation cart (yellow) and installed on the integrating structure (teal). Looking from the lens toward the back, the hexapods that hold the camera to the rotator are visible behind the camera body, then comes the rotator itself, and finally the bulkhead plate that attaches the assembly to the telescope. The camera is parked in this view on level 3 in front of the white room. The lens cap is off of the 1.6 m first lens (L1), and one can see the shutter is closed. *Credit: RubinObs/NOIRLab/SLAC/NSF/DOE/AURA*

still to do with the LSST Camera. Figure 1 shows the multiyear depth achieved in the Extended Chandra Deep Field as well as data collected in other fields. These data reflect a system that worked very well "out of the box" and was improved over the course of a few months.

Following ComCam work, the team took a well-deserved holiday break in late December and returned refreshed and ready for the work of installing LSSTCam on the telescope and going on sky.

In January, the LSSTCam was painstakingly moved from the white room on Cerro Pachón and exchanged with the ComCam on the integrating structure. The integrating structure is the part of the system that allows the camera to be installed on the top end of the telescope. Figure 2 shows the LSSTCam on this structure — which, in turn, is on the cart that transported it from the relative calm of the assembly and maintenance level of the facility (also known as Level 3) to the observing floor where all the action is now.

The camera was tested in some functional modes on its cart at Level 3. These tests included rotating it using the camera rotator, which is integral to the assembly. The rotator fixes the image on the sky in normal operations (common to all telescopes) by countering the effect of the rotating Earth — in fact it might better be called the "anti-rotator." The consequence of not rotating is, of course, star trails. The LSSTCam rotator is thus a key component of the system. It provides one of three primary axes of motion of the system along with the azimuth and elevation. The latter two are used to point the telescope at any point on the sky or in the dome (to do calibrations, for example). Another important activity between ComCam

Figure 3: Rubin's large, reflective calibration screen mounted inside the dome. The screen is precision-made and aligned to provide a flat illumination of the focal plane used to calibrate LSSTCam images. Light sources project through the central hole toward the telescope, where a reflector sends the light back to fill the screen. This light then illuminates the telescope's mirrors and is directed into the camera. *Credit: RubinObs/NOIRLab/SLAC/NSF/DOE/AURA*

installation and LSSTCam installation was finishing (almost) the calibration system.

Rubin uses a combination of data and inputs to calibrate its images (including the images themselves, but that is a story for another day). The calibration system includes broad spectrum light and a calibration screen as well as monochromatic light sources and an off-axis beam projector to interrogate sensor response. The calibration screen is very large and has precision-made panels that allow for a flat field illumination to be captured by the full focal plane of sensors. Figure 3 shows the installed screen inside the Rubin dome. Calibration light sources emit light through the central hole of the screen toward the telescope, where a reflector mounted at the top end bounces the light back to the screen. The light uniformly illuminates the camera focal plane, producing calibration images for the data reduction pipeline.

A flurry of activity preceded on-sky work — including further tuning of the primary/tertiary mirror's (M1M3) active control and thermal control, various dome work activities, and nighttime observing runs with the Rubin Auxiliary Telescope (AuxTel). The highlight of this period, however, was the much anticipated and thrilling installation of the LSST Camera on the telescope, which happened on 6 March 2025. The assembly with LSSTCam and the

Figure 4: LSSTCam arrives at Level 8 (observing floor) on the vertical platform lift. The lift roof raises up, exposing the lift to daylight, when the lift reaches Level 8. The lift also provides a stunning view of the Chilean Andes on a typically clear and calm day. *Credit: RubinObs/NOIRLab/SLAC/NSF/DOE/AURA*

integrating structure were moved using the vertical platform lift from Level 3 to Level 8 the day prior to installation on the telescope (see Figure 4).

Once moved inside on Level 8, the camera integrating structure was attached to the massive lifting fixture at the bulkhead and lifted off the cart. The lifting fixture is raised by an overhead dome crane. In this case, Rubin's lead mechanical engineer in Chile, Freddy Muñoz, rode above the camera in an independent boom lift, guiding the camera into the top end assembly. The camera points at the primary mirror, and so it is installed in a down-facing position on the telescope while observing. Only a few millimeters of space exist between the secondary mirror central hole — through which the camera is inserted — and the camera body. Prior to the LSSTCam installation, this delicate and deliberate maneuver was undertaken multiple times — with the commissioning camera and also with a surrogate structure of the same shape and mass as the LSSTCam. Thanks to extremely careful planning and the practice gained from those prior installations, lifting the LSSTCam into place went off without a hitch.

Once installed, the team spent a few weeks installing the multitude of service lines to the LSST Camera, including fibers, electrical, air to circulate in the camera body (outside the cryostat but within the body volume), and cooling for the camera electronics and focal plane. In early April, the cryostat was evacuated and the cooling turned on. Then, on 15 April, just before 9 pm local time, the first photons — some of which left their celestial sources millions or even billions of years ago — were captured by the Rubin system. The team took a moment to celebrate (the author of this article was following along on Zoom, joyful and proud of his colleagues, from 5000 miles away) and then went quickly to work. Within just a few frames, the Simonyi Survey Telescope and LSSTCam were producing in-focus images, a great sign that things were again working "out of the box" and that we would soon be surveying the sky. More than 20 years after embarking on this journey, this is an amazing milestone well-earned by the Rubin team!

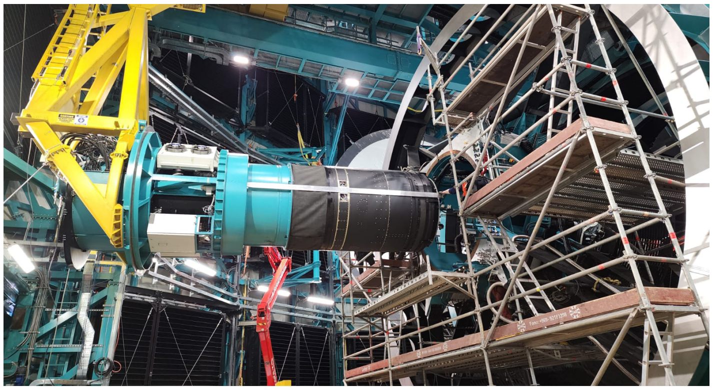


Figure 5: LSSTCam being lifted up for installation on the Simonyi Survey Telescope top end. The yellow lifting fixture is attached to the overhead dome crane and is being operated by lead mechanical engineer Freddy Muñoz in the boom lift (orange) behind the camera in this view (the person basket is not visible). The long aluminum bar (one of two) along the camera body is used to guide the camera through the secondary mirror (M2) hole visible at the center of the scaffolding. *Credit: RubinObs/NOIRLab/SLAC/NSF/DOE/AURA*

This night marked the wonderful start to the end of the beginning for Rubin Observatory and its partners, stakeholders, and community. When you read this, we will be very close to sharing Rubin's remarkable images with the world, completing the last activities of construction, and turning fully towards Operations and the LSST.

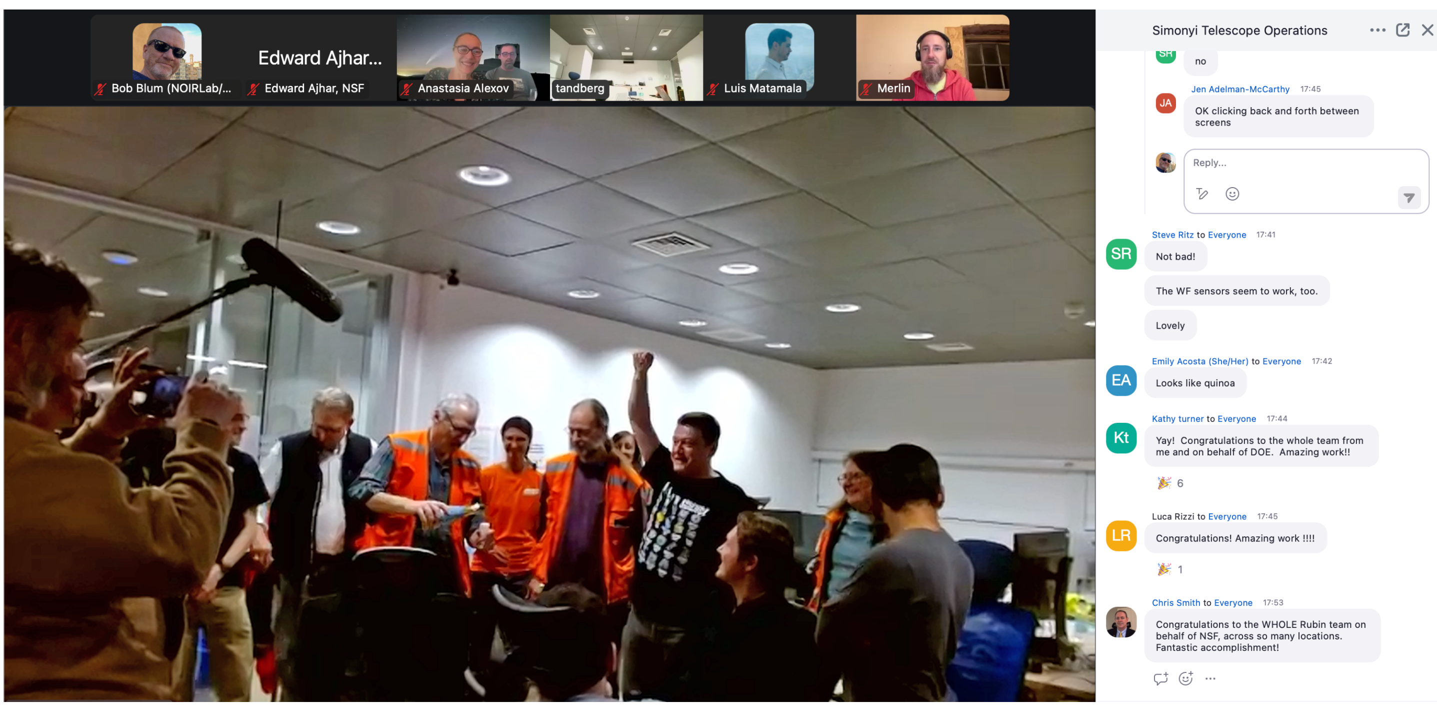


Figure 6: Joy in the summit facility control room on Cerro Pachón on the evening of 15 April at approximately 9 pm local time. Colleagues from around the world joined the on-site team via Zoom and celebrated the shared success of so many who contributed over the more than 20 years it took to reach this point. Messages from NSF and DOE colleagues who have supported the project over many years, along with staff working remotely and those just observing, are evident in this historic screenshot. Among those on-site are the Rubin Project Manager, Victor Krabbendam (head down); the PI for LSSTCam, Aaron Roodman (pouring a non-alcoholic beverage); Project Deputy Director and Telescope Scientist Sandrine Thomas (right of A. Roodman); the Project Director, Željko Ivezić (arm raised); and Commissioning Scientist Robert Lupton (between S. Thomas and Ž. Ivezić). *Credit: RubinObs/NOIRLab/SLAC/NSF/DOE/AURA*

Getting Ready to Commission Gemini Planet Imager 2.0 at Gemini North

Garima Singh (NSF NOIRLab)

We are looking forward to the arrival of the direct imaging instrument, Gemini Planet Imager 2.0 (GPI2.0), in early 2026, alongside its sub-instrument, Calibration Unit 2.0 (CAL2.0), in mid-2026 at the Gemini North Observatory in Hawaiʻi, one half of the International Gemini Observatory, partly funded by the U.S. National Science Foundation and operated by NSF NOIRLab. The combined efforts of these instruments will enable the near-infrared direct imaging and atmospheric characterization of older and lower-mass exoplanets on Solar System-scale orbits, i.e., between 4 and 10 Astronomical Units (AU), around young, nearby stars.

Direct Imaging

Direct Imaging or High-Contrast Imaging (HCI) technology requires high angular resolution to access the immediate surroundings of stars and high contrast to enable imaging of the faintest planetary companions at close separations.

The HCI technology typically includes a high-order Adaptive Optics (AO) system that provides images of star-planet systems close to the telescope's diffraction limit; a coronagraphic system that optically attenuates on-axis starlight while allowing the off-axis exoplanetary signal to pass through the optical system; a Focal-Plane WaveFront Sensor (FPWFS) for calibrating and correcting residual wavefront errors or speckle noise both in real-time and during post-processing, also referred to as differential imaging; and a scientific instrument equipped with near-infrared imaging and spectro-polarimetric capabilities for characterizing exoplanetary atmospheres and dusty circumstellar disks. The success rate of such instruments depends significantly on the post-processing techniques used to calibrate and subtract the post-AO stellar residuals, thereby improving the signal-to-noise ratio and the detection sensitivity of faint companions.

The current state-of-the-art ground-based HCI instruments, including the predecessor of GPI2.0 (GPI1.0), routinely provide raw contrast in the range 10^{-5}–10^{-6} at separations between ~150 and 400 milli-arcseconds (mas). As a result, they are only sensitive to self-luminous giant exoplanets in wide orbits.

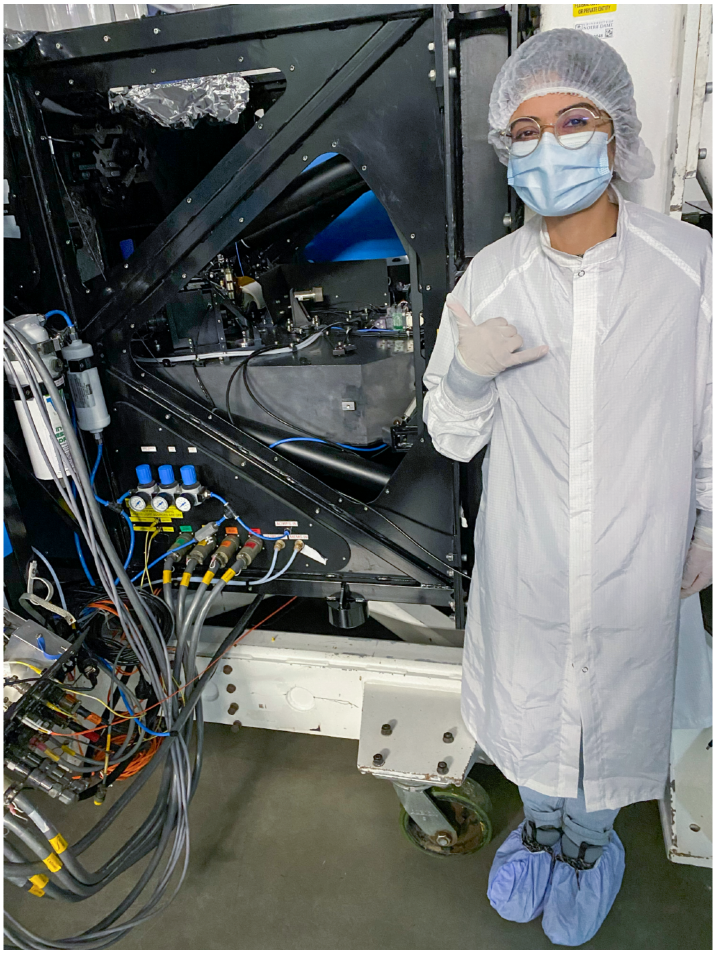
Gemini Planet Imager 1.0

GPI1.0 operated at Gemini South from Semesters 2014B to 2020A. It characterized dozens of circumstellar disks in polarized and unpolarized light. The GPI1.0 exoplanet survey concluded that massive planets (5–13 M_{Jup}) in wide orbits (10–100 AU) are more frequently found around higher-mass stars (1.5 $M_{\odot}$) compared to Solar-type stars. GPI1.0 proved scientifically productive; however, it needed an upgrade to enhance its decade-old technology and improve its robustness against the observatory's vibrations to increase its scientific yield. The ongoing instrument upgrade efforts (see Figure) are led by the University of Notre Dame (UND) in collaboration with Cornell University and the University of California, San Diego. The CAL2.0 instrument, which will be integrated into the GPI2.0 system by late 2026, is being developed by the National Research Council Canada's Herzberg Astronomy and Astrophysics (HAA) Research Centre in Victoria, British Columbia, Canada.

Gemini Planet Imager 2.0

Technologically, GPI2.0 will reuse GPI1.0's Woofer-Tweeter deformable mirror (DM) configuration, which includes a CILAS 11-actuator diameter piezoelectric DM and a 4096-actuator MEMS DM. GPI2.0 will implement a new highly sensitive Pyramid wavefront sensor (PyWFS) coupled with a custom low-noise HNü240 Electron-Multiplying CCD. This will allow faster operations (at 2KHz) on brighter targets while ensuring graceful degradation for stars with an I-magnitude fainter than 13.

The instrument will also integrate a new generation of the Apodized Pupil Lyot Coronagraph, enabling deeper con-



Garima Singh, the Project Scientist of GPI2.0 at Gemini North, stands in front of GPI2.0's AO bench during her visit to the University of Notre Dame in November 2024.

trast at small angles through the carbon nanotube-patterned transmissive apodizers, a technology currently being explored for the Habitable World Observatory's coronagraphs. GPI2.0's apodizers will feature enhanced diffraction suppression and improved robustness against low-order aberrations. CAL2.0 will strengthen GPI2.0's robustness toward vibrations by employing a dedicated low-order wavefront sensor for actively correcting low-order aberrations and an FPWFS for addressing non-common path aberrations, thus actively suppressing quasi-static speckle noise directly in the science image. GPI2.0 will also reutilize its Integral Field Spectrograph (IFS), which has a field of view of 2.7" × 2.7" and a resolving power of R=~30–100. IFS will have upgraded prisms and filters to enhance GPI2.0's sensitivity for detecting faint companions. Finally, GPI2.0's newly developed low-latency (~1.1 milliseconds) Real-Time Computer by HAA will significantly boost GPI2.0's science execution rate.

With the new upgrades, the GPI2.0 and CAL2.0 instruments will improve the current contrast limit by a factor of 10 to 100 at angular separations below 200 mas (10 AU at 50 parsecs). This technological advancement signifies the anticipated arrival of the GPI2.0 and CAL2.0 instruments at GN as an exciting opportunity, as it will bolster NOIRLab's standing in direct imaging exoplanetary discoveries. Alongside new exoplanet detections, these instruments will impose stricter constraints on planet formation and evolution theories and image protoplanets and circumstellar disks around young (~1–3Myr) bright stars. They will also characterize the physical properties of Solar System objects, such as asteroids, and examine outflows from evolved stars and the inner regions of nearby Active Galactic Nuclei.

Challenges Foreseen

Successfully demonstrating the new technical capabilities of GPI2.0 and CAL2.0 on-sky will pave the way for new exciting science; however, challenges such as the Gemini North vibration environment and the notorious M2 print-through of Gemini North will impact the instrument's performance. The encouraging news is that the external GPI2.0 and CAL2.0 teams, in collaboration with the Gemini Project Scientist, demonstrated through simulations to Gemini's Science and Technical Committee in December 2024 that with faster AO, better suppression of quasi-static speckles, and improved post-processing techniques, the GPI2.0 and CAL2.0 instruments will remain capable of producing the promised science.

Ongoing Work

The GPI2.0 team is currently testing the PyWFS at UND, while the CAL2.0 team is focused on procuring and assembling its components at HAA. At the same time, the internal GPI2.0 project staff at Gemini North is actively preparing documents, including the Concept of Operation, Acceptance Test and Planning, Telescope Integration Planning, and Verification and Commissioning Planning. GPI2.0 is set to be commissioned between the 2026A and 2027A Semesters. For further information on the GPI2.0 and CAL2.0 projects, readers can contact the Gemini Project Scientist at garima.singh@noirlab.edu.

Scott Dahm Appointed Director of the International Gemini Observatory

NSF NOIRLab has announced the appointment of Scott Dahm as the new Director of the International Gemini Observatory, which is funded in part by the U.S. National Science Foundation and operated by NOIRLab. This leadership change is poised to steer the observatory into a new era of scientific discovery and operational excellence.

In February 2024 former Gemini Director Jennifer Lotz was appointed Director of the Space Telescope Science Institute. Scott, who was the Gemini Deputy Director at the time, was appointed Interim Director for Gemini while the search for a permanent director was conducted. In the spring of 2024, NOIRLab assembled an international search committee with members from the Gemini partner countries, including Canada, Korea, and the US, along with staff working in Hawai'i and Chile. Most of the committee members were in observatory leadership positions and two were affiliated with the Gemini Observatory. The committee conducted a worldwide search and considered a large number of candidates.

Given Scott's background in astronomy research and his experience in positions of leadership, he was the unanimous selection of the search committee. He received his PhD in astronomy from the University of Hawai'i at Manoa under George Herbig on the study of young stellar clusters. He subsequently served as an NSF Postdoctoral Fellow at Caltech, a staff astronomer at W. M. Keck Observatory, and as the Chief Scientist and acting Station Director for the U.S. Naval Observatory Flagstaff Station. He is also a retired US Naval Officer.

With extensive experience in observatory operations, working with government agencies, engagement with the local community, and interacting with the other observatories on the island of Hawai'i, Scott is exceptionally well prepared for the role. He is also highly attuned to the needs of the international Gemini partners and their funding agencies.

In July of this year Scott will relocate to the island of Hawai'i where he will work from the Gemini North Hilo Base Facility in Hilo. Under his leadership, the International Gemini Observatory is set to continue its tradition of excellence in astronomical research as it serves as a critical tool for astronomers worldwide. Scott plans to strengthen existing partnerships and forge new collaborations with international research institutions. By doing so, he seeks to enhance the observatory's global impact and ensure that it remains at the forefront of astronomical research.

As the new director, Scott is poised to lead the International Gemini Observatory into a future marked by significant scientific achievements and international cooperation. His appointment underscores NOIRLab's commitment to advancing the frontiers of astronomical research and maintaining its position as a leader in the global scientific community.

US-ELTP team at the 245th AAS meeting booth
Credit: NOIRLab/NSF/AURA/P. Marenfeld

The US Extremely Large Telescope Program

Lucas Macri, Marie Lemoine-Busserolle & Eric Peng (NSF NOIRLab)

NSF Site Visit. The NOIRLab US-ELTP project had its NSF site visit 29–30 April. We delivered about a dozen presentations and shared over 30 documents and artifacts covering all aspects of the project, which is currently at the Conceptual Design stage. Also participating in the review were Pat McCarthy, NOIRLab Director, and Hubert Condoretti, NOIRLab Chief Technology Officer and Director for Software, who leads the new Data Management & Software division. We thank our NSF Program Officers for their continued support of the project and the panelists for their valuable suggestions and comments.

New US-ELTP Director. Eric Peng has been appointed as NOIRLab US-ELTP Director effective 2 June. Eric previously served as US-ELTP Project Scientist. His experience with ELTs also include being a member of the Thirty Meter Telescope Science Advisory Committee and being the Project Scientist for TMT/WFOS. Eric's research interests include observational studies of galaxy evolution and stellar populations, and he was an Associate Professor at Peking University before joining NOIRLab in 2022. He takes over the position from Lucas Macri, now Dean of the College of Sciences at the University of Texas – Rio Grande Valley.

AAS Meetings. The tripartite US-ELTP team participated in the winter AAS meeting in Washington, DC, where we held a joint open house with NOIRLab. Our booth was very well attended, and we left the meeting energized by all the enthusiasm and support of the community. We are in final preparations for the summer AAS meeting and hope to see many of you in Anchorage!

NOIRLab Program Platform. Over the past year, the NOIRLab US-ELTP team continued to refine our scope within the broader NOIRLab Program Platform (NPP), which we highlighted in issue 7 of *The Mirror*. We have completed the elaboration of our technical requirements within each phase of the *End-to-End Support of Scientific Discovery* that NOIRLab plans to offer its users. Two of our team members, Chief Software Architect François Pradeau and Principal Software Engineer Mike Fitzpatrick, transitioned from our project to the DMS division where they will continue to contribute to NPP development. The NOIRLab US-ELTP team will work to refine the NPP technical requirements for the ELTs, with ultimate development and implementation to be led by DMS.

International Gemini Observatory Stars in *Messengers of Time and Space* Planetarium Show

Phoebe Dubisch & Nicole Kuchta (NSF NOIRLab)

Messengers of Time and Space, a fulldome planetarium show, is now available online for free download. The show is an immersive, dome-based video, utilizing the industry-adopted standard 4K planetarium format (4096 × 4096 pixels) to create a high-quality, full-screen experience in the planetarium. The first of its kind at NSF NOIRLab, it was produced entirely in-house as part of the Gemini in the Era of Multi-Messenger Astronomy (GEMMA) program.

Messengers of Time and Space demonstrates how the substantial influx of time-variable data from the NSF–DOE Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST) will position Gemini as a global leader in time-sensitive follow-up observations. This immersive experience invites audiences to explore the transformative impact of time-domain data on our understanding of the Universe and to learn how information can reach us through messengers like cosmic rays, neutrinos, and gravitational waves.

As an example, the show demonstrates the increasing importance of rapid-response observations by highlighting the 2017 discovery of ʻOumuamua. The Gemini North and Gemini South telescopes provided key observations in characterizing ʻOumuamua, finding that it had a composition similar to Kuiper Belt objects, organic-rich comets, and trojan asteroids. Yet, its shape was unlike any other Solar System object, being 10 times as long as it was wide. As this

The GEMMA program is funded by an award from the U.S. National Science Foundation (NSF) aimed at advancing the leadership role of the International Gemini Observatory in time-domain and multi-messenger follow-up observations. The projects within GEMMA include upgrading the Gemini North adaptive optics facilities and incorporating Gemini into the Astronomical Event Observatory Network (AEON). This new instrumentation and infrastructure will better support high-spatial-resolution and rapid-response astronomy at Gemini. The GEMMA program has also led several educational and communications initiatives, which, in addition to this planetarium show, include classroom materials to promote careers in science and technology fields, training workshops for science writers, and a white paper on best practices for multi-institution astronomy communication.

unique object rapidly drifted farther from Earth, time was of the essence in exploring this first known interstellar visitor to the Solar System.

The show also features exciting examples of multi-messenger astronomy, such as Gemini's 2017 follow-up observations of the gravitational wave event, GW170817, localized by LIGO (Laser Interferometer Gravitational-Wave Observatory). The first-ever detection of optical and infrared light linked to a gravitational wave event, in this case a merger of two neutron stars, initiated a time-critical sequence of observations at the Gemini South telescope in Chile. The data directly demonstrated that the much-speculated mechanism of a neutron star binary merger caused a ripple in space and time and that the event formed and dispersed heavy elements, like gold, into space. This discovery was only made possible by coordinated multi-messenger observations.

"New data are inviting exciting changes to the field of astronomy, from the Vera C. Rubin Observatory survey data to the fleeting gravitational wave signals from LIGO," says Peter Michaud, former NOIRLab Education and Engagement Manager and director of the show. *"Both multi-messenger and time-domain astronomy are revealing new cosmic mysteries every night."*

By making *Messengers of Time and Space* available for free, NOIRLab and NSF aim to empower planetariums worldwide to provide high-quality programming and engage audiences with state-of-the-art fulldome content. *"It's a joy to be able to bring this show to the planetarium community,"* says Ron Proctor, NOIRLab Motion Graphics Designer and producer of the show. In addition to the full show, individual clips and frames will be available to download online.

The world premiere of *Messengers of Time and Space* was held at Flandrau Science Center & Planetarium in Tucson, Arizona, and ʻImiloa Astronomy Center in Hilo, Hawaiʻi, on 22 May 2025.

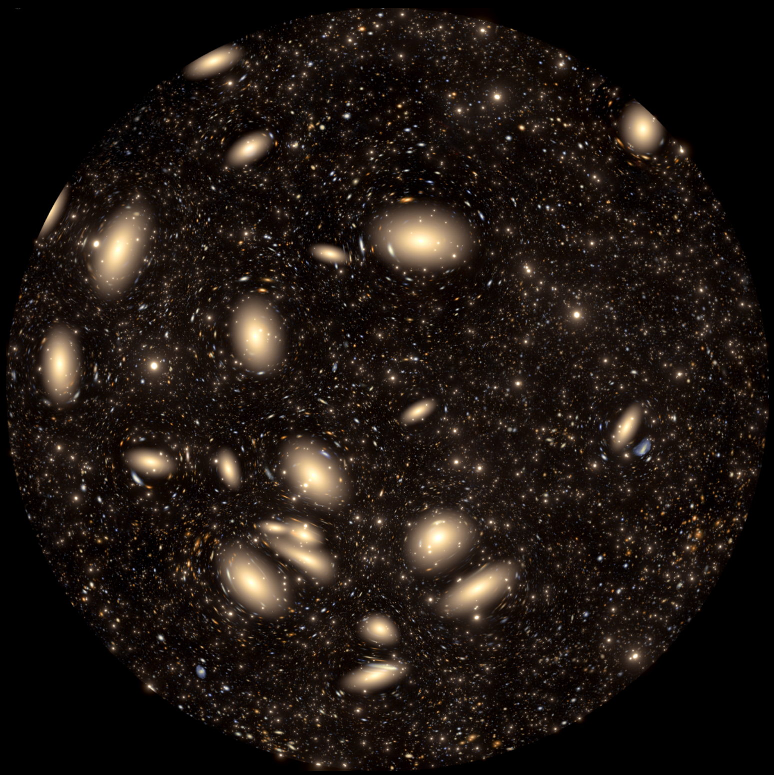


Figure 1: A frame from the planetarium show, *Messengers of Time and Space*, visualizing gravitational lensing of background galaxies. *Credit: International Gemini Observatory/NOIRLab/NSF/AURA/R. Proctor*

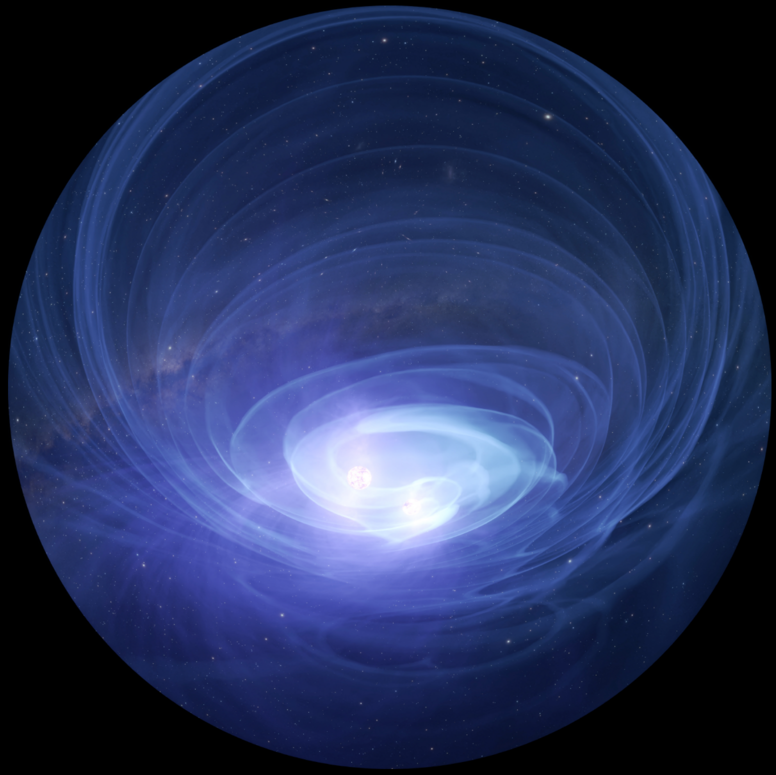


Figure 2: A frame from the planetarium show, *Messengers of Time and Space*, visualizing two neutron stars colliding. *Credit: International Gemini Observatory/NOIRLab/NSF/AURA/Double Dome Films*

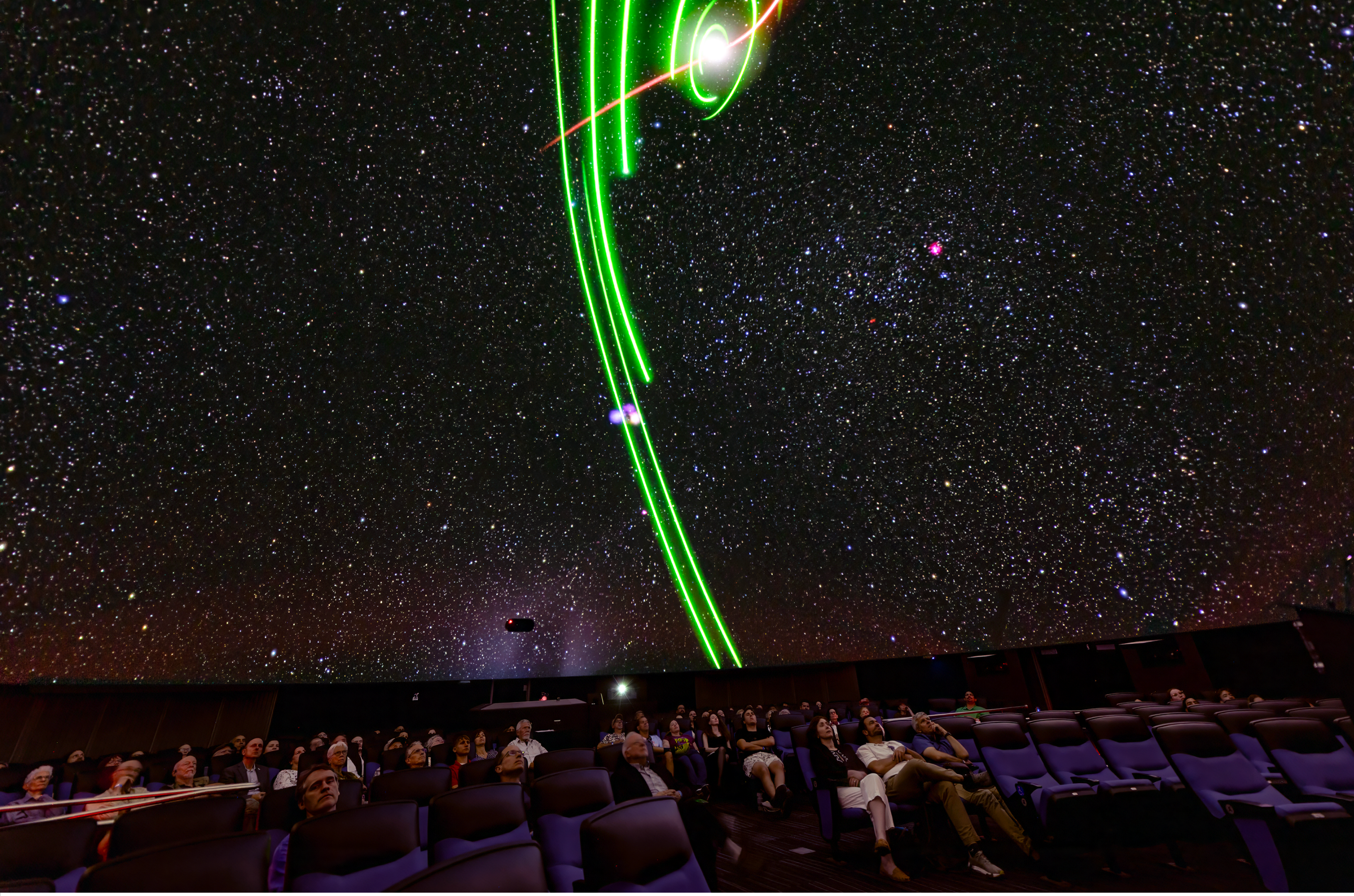
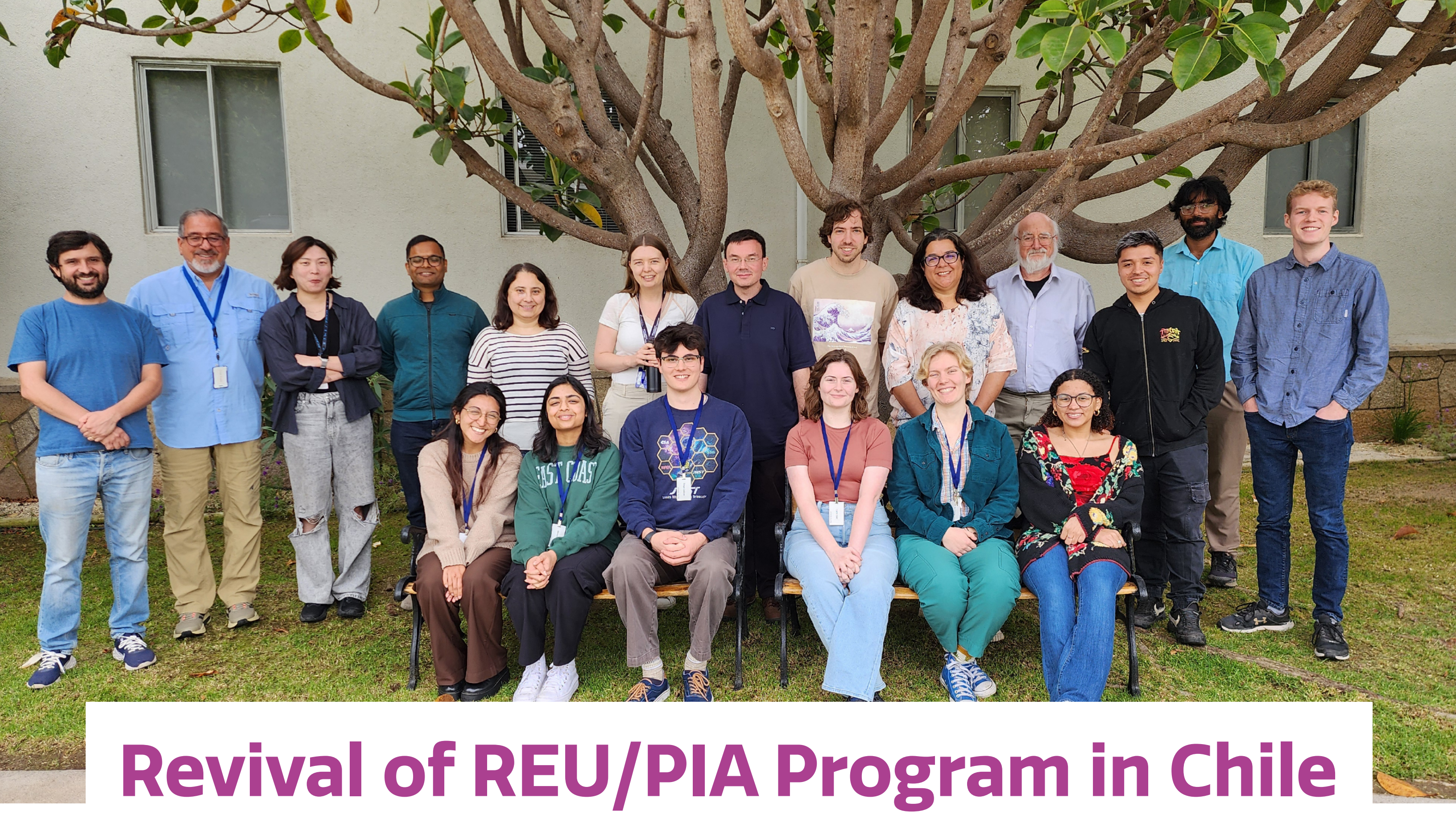


Figure 3: Premiere of *Messengers of Time and Space* at Flandrau Planetarium and Science Center, Tucson, Arizona, 22 May 2025.
Credit: NOIRLab/NSF/AURA/P. Marenfeld

Astrovisualization in Messengers of Time and Space

Parts of *Messengers of Time and Space* were made using Blender, a free and open-source 3D computer graphics software. *"Blender is free to the public, sharing the NOIRLab value of distributing scientific visualization resources and allowing us to broaden the reach of scientific understanding,"* says Ron Proctor, NOIRLab Motion Graphics Designer and producer of *Messengers of Time and Space*.

Blender's advanced rendering capabilities and data processing functions enable artists to design transformative educational experiences that captivate and inspire audiences. In particular, the software provides Proctor a way to simulate astronomical events, model large quantities of cosmic data, and animate events that aren't directly observable.



Revival of REU/PIA Program in Chile Kicks Off with a Flourish

Joan Najita & Guillermo Damke (NSF NOIRLab)

NOIRLab's revival of the REU/PIA program in Chile recently concluded its first year as a joyful success. In an experience described by the participants as "a unique immersive research opportunity" that was "invaluable and unforgettable," eight students from the US and Chile worked together January–March 2025 on a suite of activities designed to develop their interest in astronomy and foster lifelong interest in STEM and STEM-related careers. Funded by NSF's Research Experiences for Undergraduates (REU) program, which supported six students from the US, and the NOIRLab Research Practices in Astronomy (PIA) program, which supported two students from Chile, the NOIRLab REU/PIA program revolved around the following activities:

Forefront astrophysical research. Each student, working closely with a NOIRLab mentor, developed an individual research project on a topic ranging from exoplanets and stars to AGN and light pollution. Making use of existing datasets, their research projects cultivated their data reduction and analysis skills; utilized machine learning, data wrangling, and visualization techniques; and developed detailed astrophysical analysis skills.

Experiencing professional astronomy observing first hand. As one of the major highlights of the program, the students continued the long-standing REU tradition of designing and carrying out their own in-person observing program, this year at the SMARTS-GSU 0.9-meter Telescope at NSF Cerro Tololo Inter-American Observatory (CTIO). They also got a glimpse of how a lot of observing is carried out today, by eavesdropping on remote observing at the Gemini South telescope.

Observatory visits. At CTIO, the students explored the wide range of activities and extensive technical work required to keep the NOIRLab and tenant facilities operating reliably for the global astronomical community. Delving

Figure 1: **(back row, left to right)** Guillermo Damke, Cesár Briceño, Jeong-Eun Heo, Swayamtrupta Panda, Konstantina Boutsia (REU/PIA program coordinator), Emily Deibert, Aleksandar Cikota (REU/PIA program coordinator), Pol Massana, Kathy Vivas, Steve Heathcote (CTIO Director), David Fernández, Venu Kalari, Peter Jensen. **(front row, left to right)** Catalina Sáez, Shreya Sareen, Diego Lockyer, Caitlin Bell, MJ Cooke, Jacinda Byam (Credit: NOIRLab/NSF/AURA/N. Auza)

Figure 2: 2025 REU/PIA students observing from the control room of the SMARTS-GSU 0.9-meter Telescope (Credit: NOIRLab/NSF/AURA/G. Damke)

into the intricacies of daytime telescope commissioning and operations at Cerro Pachón, the students were impressed by the Rubin Construction Team's ability to overcome technological challenges, the versatility of the SOAR Telescope, and the sheer size of the Gemini South mirror.

Professional development program. To help chart out their future careers, the students explored the wide range of activities that NOIRLab staff conduct and the many career paths that an interest in astronomy can lead to: careers ranging from research, observatory operations, instrumentation, science education and public outreach, and software and data science to industry and dark skies protection. They also developed practical skills — related to impostor syndrome, responsible conduct in research, and science communications — and explored the broader societal context for astronomy, learning about sustainability in astronomy and engagement with local and indigenous communities. Finally, led by an REU Chile alum, Colette Salyk, now a professor at Vassar College, the students had the opportunity to think about grad school as a possible next step.

Astronomy-related enrichment activities. To enhance their understanding and appreciation of the local and cultural context in which astronomy operates, the students joined the local journal club and presented papers of interest from the literature. They also learned about light pollution and dark skies protection in Chile as well as Chilean cultural astronomy from local experts Juan Pablo Uchima and Ricardo Moyano.

Project presentations: At the conclusion of the program, the students presented their research projects to NOIRLab colleagues and friends.

- **Caitlin Bell** (East Texas A&M University), mentored by Emily Deibert, on "High-Resolution Spectroscopy of Ultra-Hot Jupiter WASP-178b"

- **Jacinda Byam** (Agnes Scott College), mentored by Guillermo Damke, on "Data Visualization of Sky Brightness"
- **MJ Cooke** (UT Austin), mentored by Kathy Vivas, on "Anomalous Cepheids in Crater II"
- **David Fernández** (Universidad de La Serena), mentored by Pol Massana, on "Heartbeats of the Universe: Analyzing Cepheid Variability"
- **Peter Jensen** (Brigham Young University), mentored by Sean Points, on "A New Look at Planetary Nebulae in the Large Magellanic Cloud"
- **Diego Lockyer** (Cal Poly San Luis Obispo), mentored by Jeong-Eun Heo, on "Dancing in the Dark – Understanding Symbiotic Stars with High-Resolution Spectroscopy"
- **Shreya Sareen** (Folsom Lake College), mentored by Swayamtrupta Panda, on "Identifying Doppelganger Active Galactic Nuclei"
- **Catalina Sáez** (Universidad de Valparaíso), mentored by Venu Kalari, on "Constraining the Role of Hierarchical Triplets in Hot Subdwarf Formation"

Through these activities, the students gained experience with front-line techniques of modern astrophysics and also developed critical thinking, data analysis, teamwork, science communication, and other professional skills that are applicable to a wide array of careers in STEM. Many of the students intend to continue their projects beyond the conclusion of the program and to present their results at the next winter AAS meeting.

Reflecting on the program, the students described their experience as "amazing," "incredibly valuable," "life changing," and an experience they'll remember for the rest of their lives. Experiencing the southern sky, visiting and using professional telescopes, and engaging in all aspects of the research process were particular highlights, as was the opportunity to develop ideas about their future careers. The international aspect, of experiencing a new country and meeting new people, was also very meaningful.

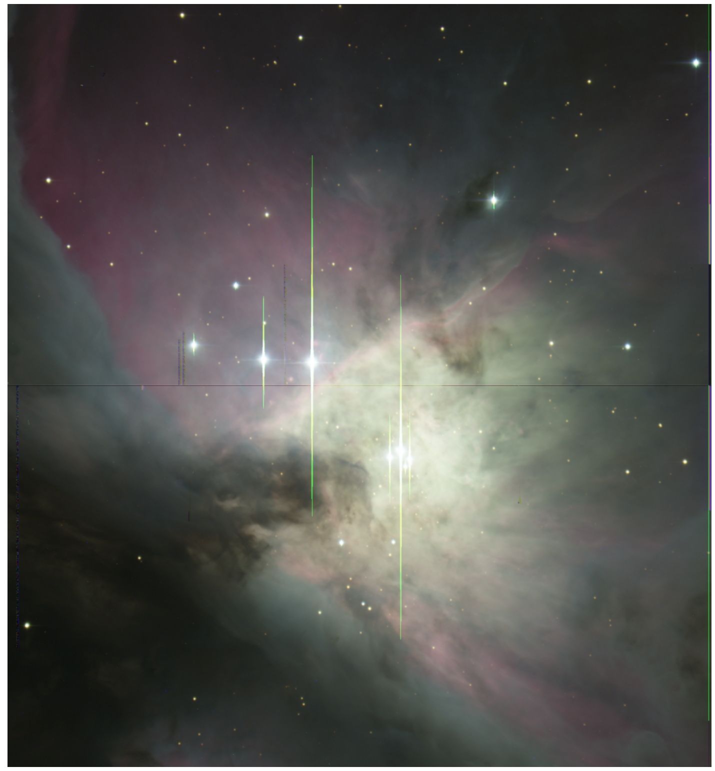


Figure 3: Image of the Orion Nebula, created by the 2025 REU/PIA students using the SMARTS-GSU 0.9-meter Telescope. (Credit: NOIRLab/NSF/AURA/2025 NOIRLab REU-PIA students/G. Damke)

The NOIRLab REU/PIA program continues a long tradition dating back several decades. More than 120 US students participated previously through NOAO's REU Chile program (1995–2016), and more than 40 Chilean students are alumni of the PIA program, previously funded by CTIO. We will soon begin advertising for next year's REU/PIA program. If you know of a student who might be interested in this program, please point them to https://noirlab.edu/science/resources/REU-PIA/REU-Chile
Or contact any of the REU/PIA organizers for further information.

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