
The Mirror
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THE MIRROR

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On the Cover

This image shows the Simonyi Survey Telescope taking on-sky observations with a 144-megapixel test camera called the Rubin Commissioning Camera on 24 October 2024.

Credit: RubinObs/NSF/DOE/NOIRLab/SLAC/AURA/H. Stockebrand

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Director's Message

Patrick J. McCarthy

As we wrap up 2024 and look ahead to 2025, we can be proud of what we have accomplished, excited about the future, and yet still daunted by the challenges ahead of us. Our field continues to make enormous strides and remains discovery rich. The new year promises the start of a new era for astrophysics as the NSF–DOE Vera C. Rubin Observatory comes online and begins its Legacy Survey of Space and Time (LSST).

As we look ahead to the exciting year to come, we also pause to remember key people who brought the national observatory to fruition but have left us recently. In this edition of *The Mirror* we celebrate the life of our colleague Helmut Abt and all that he did for astronomy — in the U.S. and abroad. Few people have lived a life so full and left such a lasting impact on their field.

We reached some major milestones in 2024 on behalf of our user community. The Gemini High-Resolution Optical Spectrograph (GHOST) went into routine operation in 2024. *This is the first optical echelle spectrograph on a fully open-access 8m telescope for the U.S. community*. This milestone has been more than 20 years in the making. Demand for GHOST is high and exciting science results are now appearing in the literature. NOIRLab's US National Gemini Office provides fully reduced science-ready 1-D spectra to users of GHOST, removing barriers associated with reducing complex 2-D echelle spectra. This is the trend for the future — delivery of science-ready data from complex instruments on our front-line telescopes.

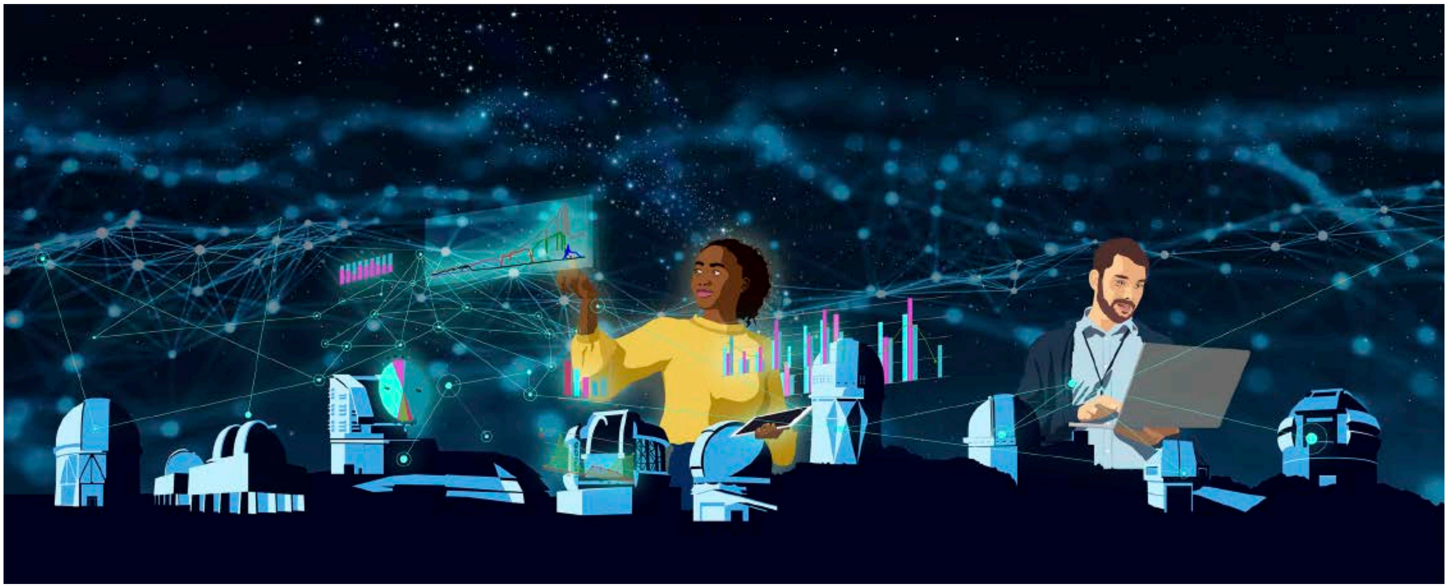
GHOST is complemented by the newly commissioned near-IR echelle spectrograph IGRINS-2 on Gemini North. Built by a team based at KASI in Korea, IGRINS-2 builds on the very successful IGRINS visiting instrument. As described in this edition of *The Mirror* by Hyewon Suh, IGRINS-2 provides R ~ 45,000 spectra across the H and K bands in a single exposure. It is now available for all users.

We continue to build out our instrument and software for time-domain astronomy in anticipation of the start of Rubin's LSST. The upgraded NEWFIRM instrument is available on the Blanco telescope at CTIO along with DECam and an upgraded ISPI near-IR imager that will be deployed on SOAR in 2025. CSDC's ANTARES was adopted as the Rubin Observatory alert filtering service and will serve as a full service alert broker for Rubin along with six other brokers. ANTARES is presently processing roughly ten thousand events per night from the Zwicky Transient Facility; it stands ready to process ten million alerts each night from Rubin. Our premier time-domain follow-up instrument, the SCORPIO eight-channel imaging spectrograph for Gemini South, will move into the assembly, integration, and test phase in Madrid in January, just as this edition of *The Mirror* goes to press.

In April 2024 the Dark Energy Spectroscopic Instrument (DESI) survey released results from their analysis of the first year's data; results from the first three years are expected to be announced at the spring meeting of the American Physical Society. The year one DESI results point to a time variable dark energy parameter — suggesting that dark energy is *not* Einstein's cosmological constant. This still tentative ~3-sigma result furthers the growing "crisis" in cosmology driven by the discordant measurements of the Hubble Constant — the present rate of expansion of the Universe. Measurements of the Hubble Constant from the local Universe differ from those derived from the cosmic microwave background some 100,000 years after the Big Bang by roughly 5-sigma. This "Hubble Tension" and the early indications of variable dark energy suggest that we are missing something fundamental in the standard model of cosmology.

The Rubin Observatory with its unprecedented survey power was designed to probe dark matter and dark energy on the largest scales. Rubin's LSST will probe the evolution of dark energy through multiple experiments. As described in Bob Blum's article in this volume ("Rubin Observatory: It Is Happening!") the Rubin construction team has been busy finishing the telescope and getting it on-sky. The commissioning camera has shown that the telescope works beautifully "out of the box" and shows that the telescope with the full LSST camera will be awesome in the true sense of the word. Exciting discoveries in cosmology, time-domain astronomy, and astrophysics await us as the Rubin era starts later this year.

Introducing the Users Committee for NOIRLab



Letizia Stanghellini (NSF NOIRLab)

The NOIRLab users community is as diverse as its facilities. Active users of NOIRLab's telescopes and data archives benefit from ad hoc support systems tailored to their specific needs. While individual NOIRLab programs have established dedicated Users Committees to address their unique requirements, we are excited to announce the formation of the broader Users Committee for NOIRLab (UCN). This new committee will evaluate the overall services provided to the user community and offer feedback to improve facilities and services, ensuring they meet community expectations.

The UCN will closely follow updates from other Users Committees and Advisory Groups at NOIRLab, gather community feedback, and stay informed about NOIRLab operations, new modes, and relevant special topics. The committee will emphasize issues related to telescope usage and data archives across multiple NOIRLab Programs, as well as common challenges faced by users.

The UCN consists of a Committee Chair and eight members, all appointed by the NOIRLab Director. Its members represent a diverse range of expertise and experience across NOIRLab's various Programs. The standard term of service is two years, with a potential third-year extension at the Director's discretion to ensure continuity. Both the UCN Chair and members are recognized scientists with a demonstrated commitment to the NOIRLab community.

The UCN's first meeting took place 21–22 November 2024. The agenda included two key inter-program topics: Time-domain Issues and Tools, focusing on time-domain follow-up using NOIRLab observatories, and NOIRLab Data Archives and the Community, which provided an opportunity to discuss improving community access to NOIRLab's data archives.

Information about the UCN, including its charter and current membership, is available at Users Committee for NOIRLab.

Helmut Abt and His Stellar Legacy

Abi Saha (NSF NOIRLab), Ethan Vishniac (Johns Hopkins University/ AAS Journals Editor in Chief) & NOIRLab Staff

Top row, left to right: Helmut amidst trees at one of the potential sites for the national observatory; Helmut at his 90th birthday celebration at NOAO Headquarters, 2015; (left to right): Aden Meinel, Don Loomis, Helmut, and Harold Thompson at KPNO 50th Anniversary event in Tucson, 2009. **Bottom row, left to right:** Chinese Government Friendship Award bestowed on Helmut. *Credit: D. Willmarth*; Research collaborator Daryl Willmarth with Helmut, 2024. *Credit: D. Harmer; Helmut in 1960.*

Our staff grieves at the passing of Dr. Helmut A. Abt and on this sad occasion reflect on his remarkable career and scientific legacy. He was a towering figure in U.S. astronomy: on top of his scientific research, he contributed in several critical ways to the formation and evolution of the national observatories and, of course, as the longest serving editor of *The Astrophysical Journal*, which has been a premier journal for astronomy and astrophysics. He was awarded the George Van Biesbroeck Prize (given by the American Astronomical Society [AAS] "for long-term extraordinary or unselfish service to astronomy") in 1997.

Dr. Abt emigrated with his parents to the U.S. from Germany when he was two years old. He grew up first in Jamestown, New York, and then in the Chicago area. After obtaining a BS in mathematics and MS in Physics, both from Northwestern University, he was the very first astronomer to earn a PhD from the then newly formed Astronomy program at the California Institute of Technology. His thesis on W Virginis stars elucidated the detailed dynamical processes in the atmospheres of pulsating stars.

He continued this line of work on RV Tauri stars during his subsequent position at Lick Observatory, expanding on the cyclical propagation of shocks in pulsating stars of old stellar populations. His detailed results were not universally accepted at the time, but were validated some 50 years after his work on this topic. He next had a position at the Yerkes Observatory, then operated by the University of Chicago, where he went on to be appointed as Assistant Professor. Carl Sagan was among the students he taught. During this period he was also involved with the McDonald Observatory in Texas. He continued his observational work with the telescopes there, directing his focus on the variability of supergiant stars.

At this time he also joined the effort established by the McMath Committee and led by Aden Meinel to search for a suitable site in the continental U.S. for establishing a national observatory that would provide observational access to astronomers from any institution. He was part of a small team that surveyed several sites in Texas, New Mexico, and Arizona — sometimes the visits to the mountain peaks (as for Kitt Peak) had to be done on horseback. A lively first person account of this work is available in chapter 5 of his autobiography, *A Stellar Life*. This is how the Kitt Peak site was eventually selected and how Dr. Abt's efforts are directly linked to the genesis of the national observatories, which have evolved to become today's NOIRLab.

Dr. Abt was hired by AURA in 1959 and became full Astronomer in 1963. One of the tasks he took on was to build up the library for what was then the Kitt Peak National Observatory (KPNO), headquartered in Tucson, and its sister observatory in Chile, the Cerro Tololo Inter-American Observatory (CTIO). To find back issues of journals, he tapped the private collections of astronomers. The holdings of the NOIRLab libraries today rival other excellent astronomy collections. Dr. Abt's enthusiasm and efforts contributed greatly to this achievement.

Following better understanding of the Kodak photographic emulsions and uniform dispersion from the new grating spectrographs at the Kitt Peak 84-inch telescope, Dr. Abt obtained new data for a photographic spectral classification atlas, which he compiled in 1968. This was incorporated in 1978 into The Revised MK Spectral Atlas for Stars Earlier than the Sun by Morgan, Abt, and Tapscott. It serves as the seminal reference for photographic spectral classification using grating spectrographs, which provide linear dispersions.

His work on the binary frequency among stars of different types, which appears to have originated with his work in the 1960s on Am and Ap stars, was carried out over several decades. Publications by him on these topics can be found as late as 2018. His result that over 55% of solar type stars show multiplicity came as a surprise at the time, even as it paved the way for the discovery of the first planets by others.

Dr. Abt was a prolific author, publishing 219 refereed science articles as first author and 26 as co-author. In addition, he published 146 non-refereed articles as first author and 16 as co-author. His latest publication appeared in October 2024. A listing of his publications are available in an ADS public library.

Dr. Abt took over as Editor in Chief of *The Astrophysical Journal* (ApJ) in 1971 from S. Chandrasekhar and continued in this position until 1999, past his formal retirement from NOAO in 1996. As his final act as Editor in Chief, Chandrasekhar had arranged for the ownership of the ApJ to pass to the AAS, so Dr. Abt was the first to serve in this capacity under the auspices of the AAS. This was a period of rapid growth in publications, and the ApJ family (including the *Supplements* and the *Letters*) grew by more than a factor of three under his leadership. To cope with this growth, he initiated the practice of enlisting Science Editors from the community. He also became engaged in bibliometrics, parsing the history of publications in astronomy and astrophysics in ways that have, among other things, informed management decisions at the national level. Towards the end of his tenure at the ApJ, he managed the transition to electronic peer review and publication. A detailed account of his tenure as Editor in Chief can be found in chapter 12 of *A Stellar Life*.

During this period, he would be seen in his office late in the night, with classical music from his stereo wafting down the hallways (he was a lifetime patron of the Arizona Friends of Chamber Music). His cat would often accompany him at night and roam the hallways.

He loved his visits to China. He loved his role as an advisor to Chinese colleagues, and they in turn loved his inspiring presence. True to his faith in the importance of libraries, he donated his own personal complete collection of the ApJ to Tsinghua University in Beijing. His work in stimulating astronomy there was recognized by the Chinese Friendship Award, the highest award bestowed by the People's Republic of China for "foreign experts who have made outstanding contributions to the country's economic and social progress."

Helmut Abt will be remembered by staff in Tucson, and the many many postdocs and other early career visitors who have passed through Tucson, as an avuncular mentor, quick with his smile and laugh and encouragement. His breadth of knowledge was breathtaking. Even after he stepped down as editor of the ApJ, he would come in to work daily when he was not traveling, driven by his passion for astronomy and the work that he loved. His presence will be missed, but his passion, integrity, and hard work will continue to inspire us into the future.

In addition to his autobiography *A Stellar Life*, additional accounts about Dr. Abt can be found at the following links:
Personal Interview: https://www.aip.org/history-programs/niels-bohr-library/oral-histories/23364

NOIRLab staff reflections: https://noirlab.edu/public/blog/reflections-helmut-abt/

Wikipedia: https://en.wikipedia.org/wiki/Helmut_Abt

Noisy Stars and the Hunt for Earth–Like Planets

Sarah Logsdon & Jayadev Rajagopal (NSF NOIRLab)

Detecting and characterizing an Earth-like planet around a Sun-like star is a major goal of modern astrophysics. However, with radial velocity signals of ~10 cm/s, detecting and measuring the mass of a so-called "Earth analog" is extremely challenging. The current generation of extreme precision radial velocity (EPRV) spectrographs, including WIYN/NEID and Gemini-N/MAROON-X, are pushing the limits of what we can currently measure, but what really sets those limits? Historically, the limiting factor to making precise RV measurements was the stability of the instrument itself. However, instruments like NEID are stable enough that the new tall pole is often variability in the spectrum of the exoplanet host star. Stars are not quiet and stable over time. Instead, they display a plethora of time-variable behavior or "stellar activity" — they have spots, they flare, they oscillate — and all this activity effectively appears as a form of noise that can mask the radial velocity signal generated by a planet.

To better understand, characterize, and ultimately correct for stellar activity, astronomers are turning to our closest star — the Sun — to obtain high cadence, high signal to noise observations during the day, using the same instruments used to hunt for exoplanets at night. Ford et al. (in review) analyze 3.5 years of solar data observed with the NEID spectrograph and show that the daily-averaged, *uncorrected* RV scatter for the Sun is 2.11 m/s – much higher than the signal from an Earth-like planet, but consistent with the expected activity levels for the Sun based on observations from other solar telescopes. The paper focuses on probing how well we can correct for the Sun's activity-induced RV scatter or, in other words, how close astronomers can get to the ~10 cm/s signals from Earth-like planets with our current tools. The authors use a broad range of techniques from classical stellar activity indicators to more sophisticated numerical analyses to visualize, measure, and correct for the stellar activity. An algorithm called SCALPELS (Collier Cameron et al. 2021) gave the best results (Figure 1). SCALPELS

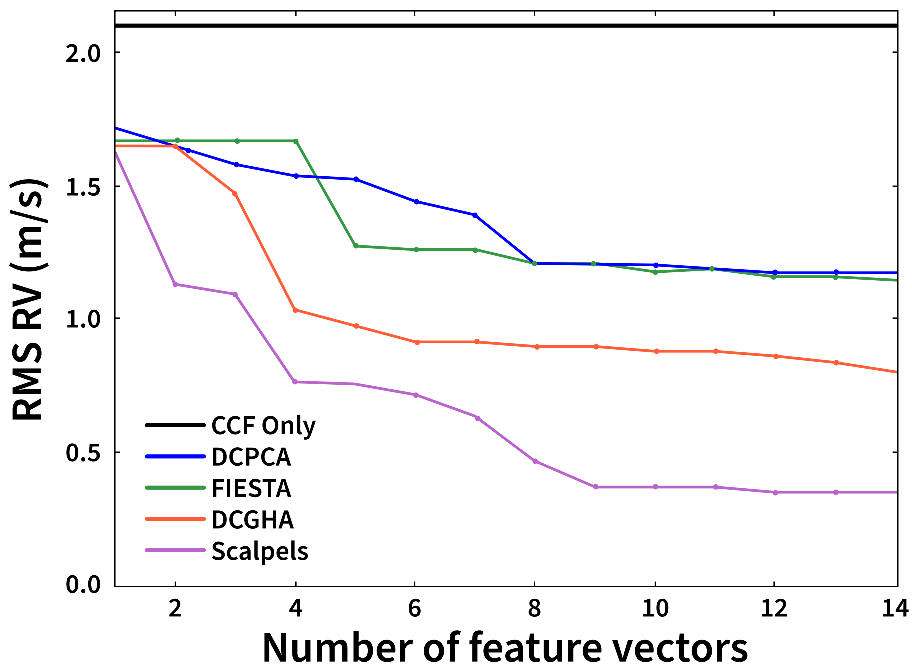


Figure 1: The radial velocity scatter for the NEID solar data before (black line) and after (colored lines) different stellar activity mitigation techniques are applied. The mitigation techniques are plotted as a function of the number of "feature vectors" (e.g., mathematical representations of stellar activity and instrumental noise characteristics) that each technique accounts for. The pink line shows the results from the SCALPELS technique, which is successfully reducing the RV scatter from the Sun from ~2 m/s to ~30 cm/s. (Ford et al., Figure 12 left)

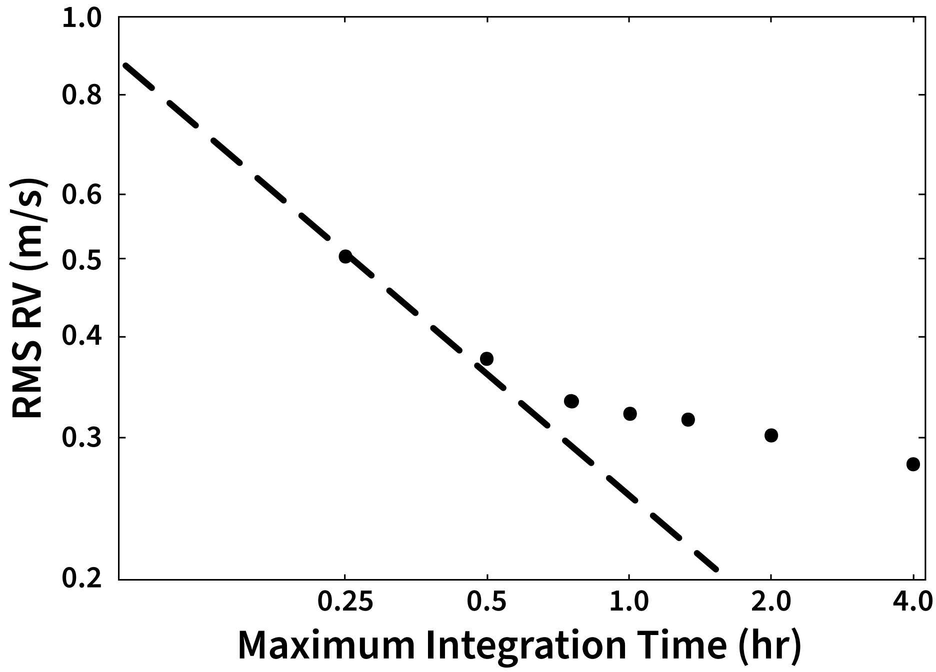


Figure 2: Solar radial velocity scatter as a function of integration time. With 1 hr exposures, NEID's solar data can be corrected to ~30 cm/s, suggesting that the same exquisite RV precision could be obtained at night with Sun-like stars. (Ford et al., Figure 13)

leverages the fact that an RV signal from a planet will shift all of the lines in a stellar spectrum whereas stellar activity affects the shapes of lines. SCALPELS-based activity-corrected solar data gives an RV scatter of 28 cm/s, nearly an order of magnitude reduction over the raw scatter.

The data-driven activity mitigation on the Sun is striking and begs the question – can we reach this level of precision on other solar-twin stars? The authors probe this question by limiting the amount of Solar data each day to time spans that are reasonably observable for a single star at night — 30 min, 1 hr, 2 hr, etc. — and repeating their activity analysis. They find that the RMS scatter decreases rapidly from 30 minutes (~50 cm/s) to 1 hr (~30 cm/s) of integration time and then falls off slowly after that (Figure 2). This result suggests that, with enough signal to noise and enough 1 hr observation windows, we are potentially on the cusp of detecting an Earth-like planet around a Sun-like star!

You can see the data too! The NEID solar data is made publicly available immediately upon data reduction. If you want to try your hand at mitigating solar activity yourself, please visit the Solar Radial Velocity Archive (https://neid.ipac.caltech.edu/search_solar.php).

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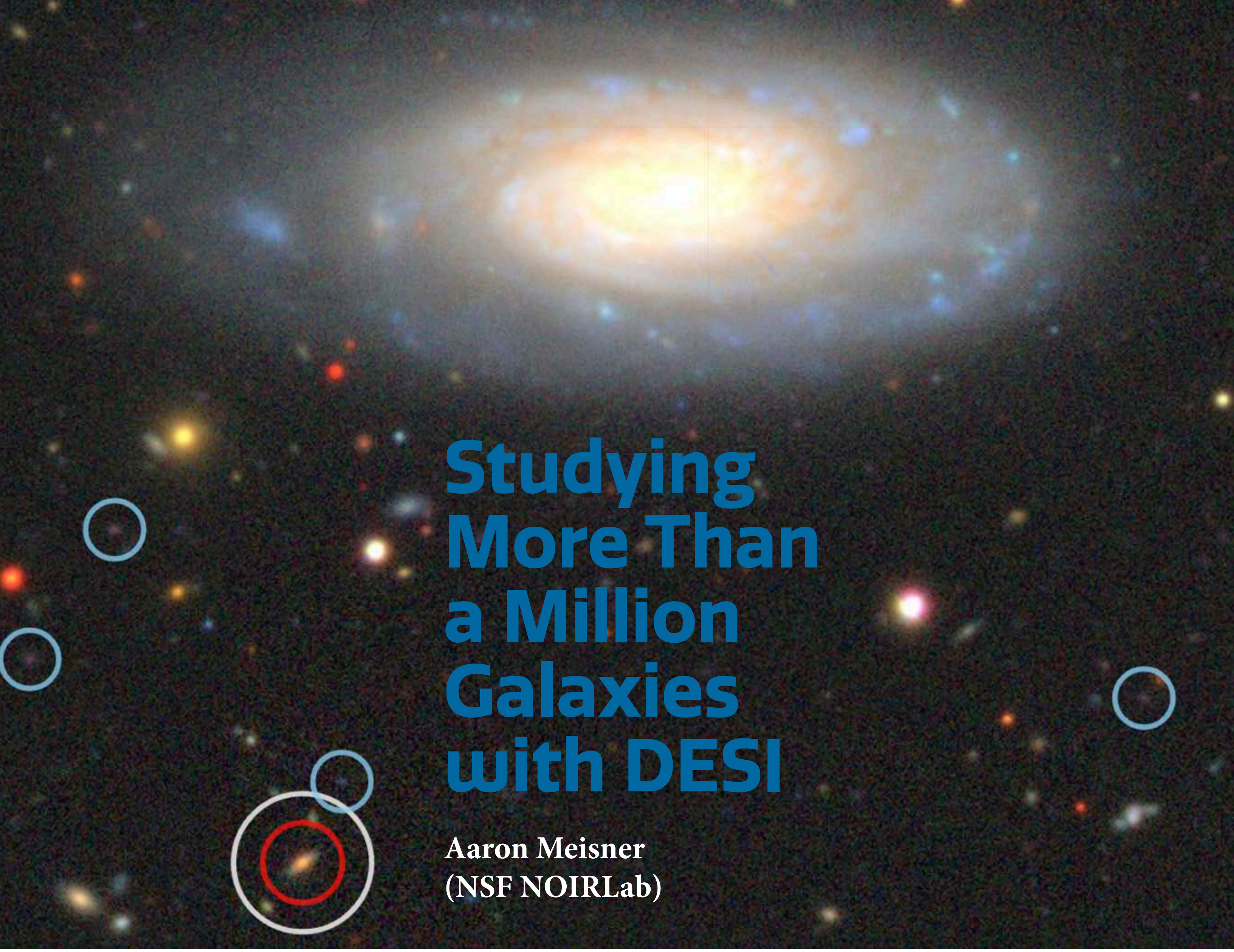

Studying More Than a Million Galaxies with DESI

Aaron Meisner
(NSF NOIRLab)

Figure 1: DESI's new value-added catalog of galaxy properties contains diverse classes of galaxies, illustrated in this color-composite image from the DESI Legacy Imaging Surveys (Dey et al. 2019). Blue circles are emission line galaxies, which are faint and distant. The orange-ish galaxy near the bottom left surrounded by red and white circles is a luminous red galaxy. For comparison, an apparently large galaxy (NGC 4193) is shown near the top. *Credit: Legacy Surveys/D. Lang/Perimeter Institute*

The Dark Energy Spectroscopic Instrument (DESI) installed on the Nicholas U. Mayall 4-meter telescope at Kitt Peak National Observatory is the world's premier massively multiplexed spectrograph. DESI can simultaneously obtain roughly 5,000 spectra across its eight-square-degree field of view and is capable of accurately measuring nearly 200,000 galaxies in a single night of observations. DESI is operating efficiently and acquiring new data essentially every night, having begun its initial five-year mission to make the best ever 3-dimensional map of the Universe in mid-2021.

DESI is revealing new insights about cosmology (DESI Collaboration 2024), the study of the Universe on its largest scales much bigger than the size of an individual galaxy. To this end, DESI has become highly efficient at extracting the "redshift" from each galaxy spectrum it obtains, as the redshift — which can be thought of as a measure of distance to the galaxy — encodes much of the information DESI needs to map the Universe in three dimensions and thereby interrogate the nature of dark energy. But in the process of collecting vast numbers of redshifts, DESI also gathers detailed spectra of millions of galaxies. These spectra contain a wealth of additional information about the galaxies' physical properties, such as the rates at which they're forming stars, the number of stars they contain, and the behavior of the black holes at their centers.

Astronomers within the DESI Collaboration have now published such measurements for more than 1 million galaxies with DESI spectra (Siudek et al. 2024). This "value-added" catalog will enable yet more research investigations in the realms of galaxy formation and evolution with DESI data, illustrating the power of archival data analysis in combination with large survey data sets such as DESI. The new DESI catalog incorporates multiple different classes of galaxies, such as passive "luminous red galaxies," star-forming "emission line galaxies," and quasars. By comprehensively measuring physical parameters across these diverse galaxy types, the new DESI catalog spans a remarkably wide range of redshifts from z = 0 to z = 6.

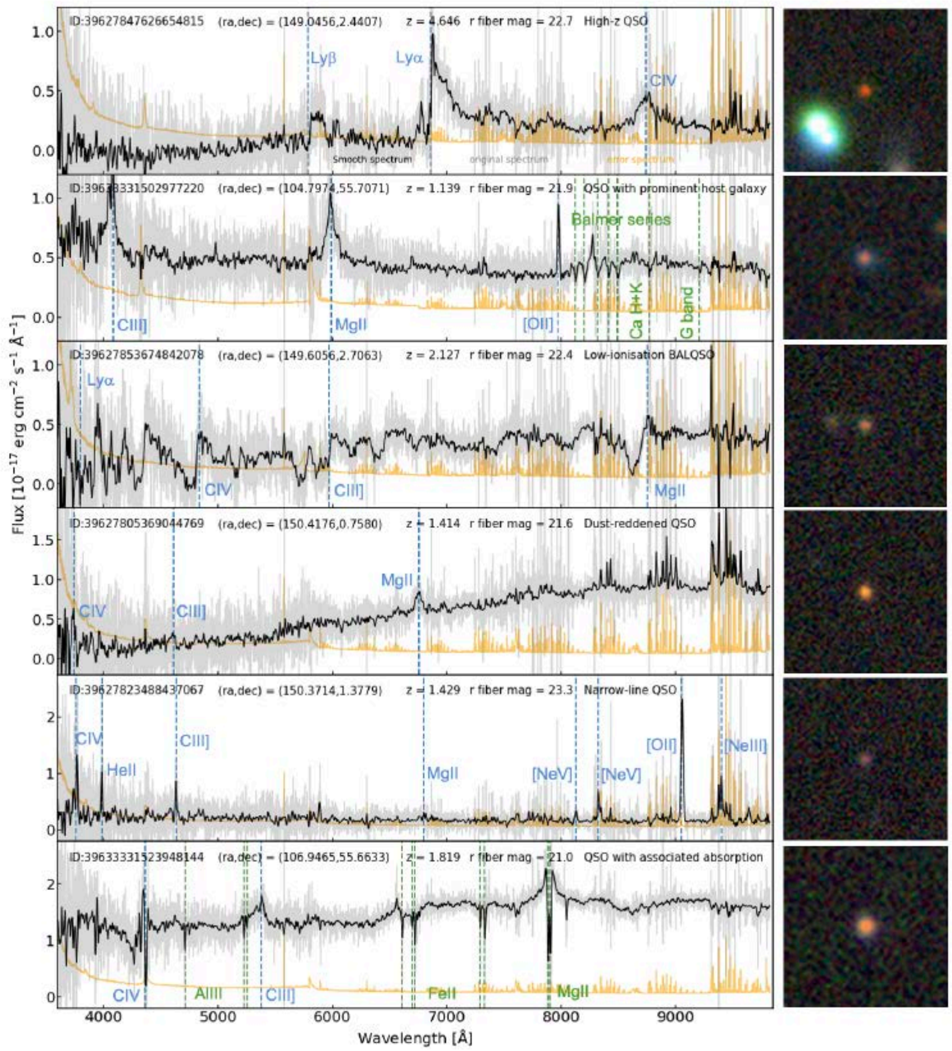

Figure 2: A diverse set of DESI quasar spectra (left column) with corresponding Legacy Surveys image cutouts (right column) from Alexander et al. 2023.

References

Alexander, D. M., et al. 2023, AJ, 165, 124

DESI Collaboration, et al. 2024, arXiv:2404:03002

Dey, A., et al. 2019, AJ, 157, 168

Siudek, M., et al. 2024, A&A, 691, 308

A Substantial Increase in the Census of Dwarf AGN Candidates from DESI Early Data

Ragadeepika Pucha (University of Utah) & Stéphanie Juneau (NSF NOIRLab)

By analyzing early spectral data from the Dark Energy Spectroscopic Instrument (DESI) on the KPNO Nicholas U. Mayall 4-meter Telescope, our latest research (Pucha et al. 2024) has unveiled an astonishing ~2,500 dwarf AGN candidates, the largest sample ever identified. Additionally, we have identified ~300 Intermediate-Mass Black Hole (IMBH) candidates, creating the most extensive collection of such candidates to date. Interestingly, only 70 of these IMBH candidates overlap with the dwarf AGN population, revealing that not all dwarf AGN host IMBHs, nor do all IMBH candidates reside within dwarf galaxies. This dual discovery not only expands our understanding of the black hole (BH) populations in the Universe but also lays the groundwork for future investigations into the formation of the first black holes and their role in galaxy evolution.

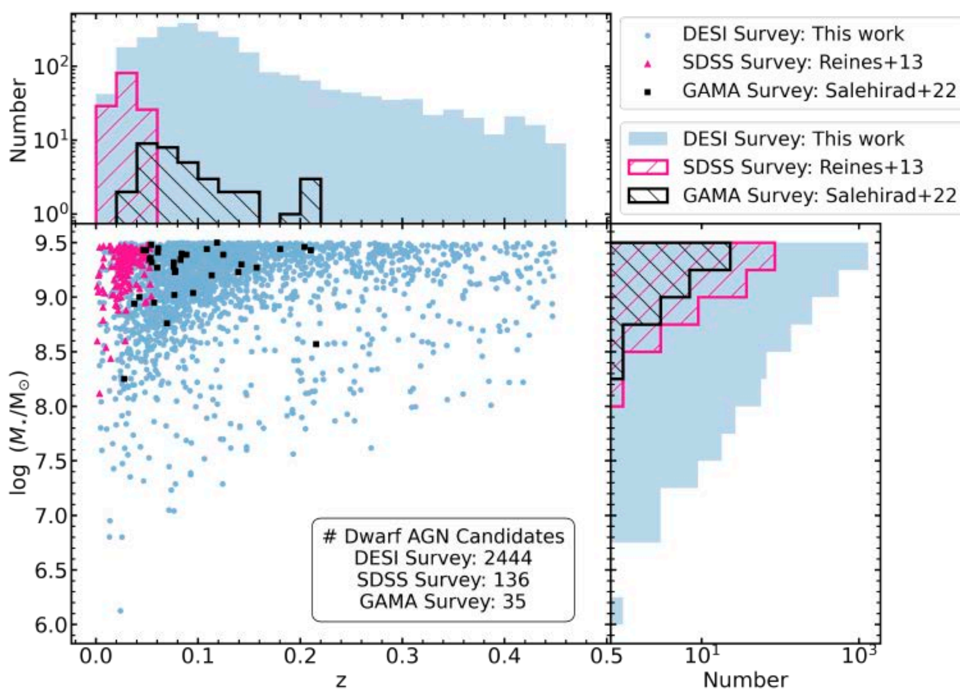

Figure 1: Comparison of dwarf AGN candidates from DESI early data (shown in blue) with those from previous single-fiber spectroscopic surveys such as SDSS (in pink; Reines et al. 2013) and GAMA (in black; Salehirad et al. 2022) in the stellar mass (log M_*) – redshift (z) space. The DESI survey significantly expands the discovery space for dwarf AGN, uncovering candidates down to lower galaxy masses and higher redshifts.

Dwarf galaxies (stellar mass, $M_* \leq 3 \times 10^9\ M_\odot$) are considered to be fundamental building blocks in the formation of larger galaxies, and understanding their growth is essential to unraveling the broader puzzle of galaxy formation and evolution. While the presence of black holes in dwarf galaxies has been known for over a decade, their numbers have ranged from ~200 to 1000, depending on the selection criteria. When a black hole begins to accrete matter, it releases vast amounts of energy, transforming into an Active Galactic Nuclei (AGN). This energy ionizes the surrounding gas and acts as a beacon to identify the central black holes (BHs).

Using the traditional [NII]-BPT emission-line ratio diagnostic (Baldwin, Phillips, and Terlevich 1981) on

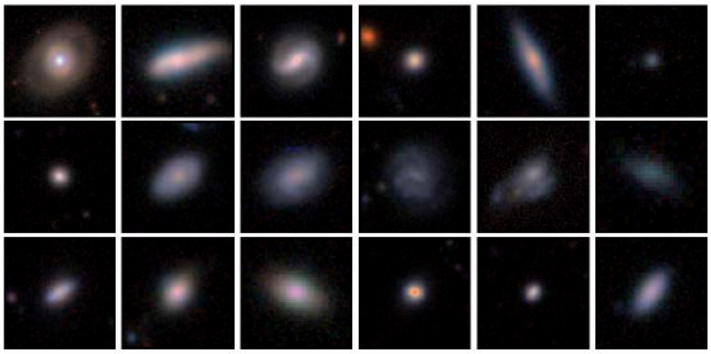

Figure 2: Example color images of dwarf galaxies with AGN signatures. The first three galaxies have a detectable broad Hα component used to estimate the Black Hole masses (log (M_{BH}) = 7.1, 6.4, and 5.2, respectively). The rest of the example dwarf galaxies are narrow-line AGN hosts. Each image cutout spans a size of 30 kpc on the side at the redshift of the galaxy. *Credits: Legacy Surveys/D. Lang (Perimeter Institute)/NAOJ/ HSC Collaboration*

~115,000 dwarf galaxies from the early DESI data (covering Survey Validation and 20% of Year 1 data), we detected AGN signatures in ~2,500 galaxies — more than tripling the current census of dwarf AGN candidates. This observed fraction of 2.1% AGN among dwarf galaxies is nearly four times higher than the previous estimates from similar studies using Sloan Digital Sky Survey (SDSS) data (0.5%; Reines et al. 2013). This substantial increase is primarily due to DESI's smaller fiber size, which focuses on the central regions of galaxies, reducing stellar contamination and enabling the detection of lower-luminosity AGN candidates.

The role of AGN in the evolution of dwarf galaxies is a topic of ongoing debate. The immense energy released by AGN can significantly influence the growth of dwarf galaxies, which have lower gravitational potentials, making it challenging for them to retain gas compared to their more massive counterparts. This raises important questions about the balance between star formation and AGN activity and their broader impact on galaxy evolution. With our expanded census of dwarf AGN candidates, we now possess a comprehensive dataset for statistical analysis of the co-evolution of dwarf galaxies and their central BHs. Notably, the DESI survey has extended the discovery space for dwarf AGN candidates to lower galaxy masses and higher redshifts compared to previous single-fiber spectroscopic surveys (Figure 1). We anticipate detecting over 10,000 dwarf AGN candidates by the end of the five-year survey.

Dwarf galaxies are expected to harbor IMBHs (MBH = 10^2 - 10^6 $M_\odot$), which serve as a crucial link between stellar mass BHs (< 100 $M_\odot$) and supermassive BHs (> 10^6 $M_\odot$). IMBHs are theorized to be the primordial seeds of SMBHs and remnants of the earliest black holes in the Universe. To identify these elusive IMBHs, we searched for broad Hα components in the DESI spectra of BPT-AGN candidates across a broad range of stellar masses ($6 \leq \log M_* \leq 12$), which can be used to estimate BH masses via virial methods. We identified ~300 candidates with a statistically significant broad Hα component, indicative of IMBHs. Intriguingly, only 70 of these candidates reside in dwarf galaxies, while the remaining candidates are likely under-massive BHs in more massive galaxies. These under-massive BHs may be struggling to grow due to a lack of sufficient gas reservoirs. Alternatively, some of these objects could be remnants of recent galaxy mergers, where an SMBH is merging with a lower-mass BH. In such cases, we could be detecting the accreting activity from the lower-mass BH, with minimal accretion occurring at the SMBH.

The finding that there is only a partial overlap between dwarf AGN and IMBH candidates raises key questions about BH formation and growth and the relationship between BHs and their host galaxies. These results open new avenues for exploring the formation and evolution of BHs in the early Universe and their profound impact on the evolution of galaxies.

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Pucha, R., Juneau, S., Dey, A., et al. 2024, arXiv:2411.00091, submitted to AJ

Reines, A. E., Greene J. E., Geha, M, 2013, ApJ, 775, 116

Salehirad, S., Reines, A. E., Molina, M. 2022, ApJ, 937, 7

Data Reduction Tutorials with DRAGONS Are Now Available as Jupyter Notebooks

Brian Molina Merino & Vinicius Placco (NSF NOIRLab)

Data **R**eduction for **A**stronomy for **G**emini **O**bservatory **N**orth and **S**outh, or **DRAGONS**, is a Python-based meta-package designed by NOIRLab/Gemini scientists to reduce astronomical data. Currently, DRAGONS can reduce imaging and spectroscopic data taken with various Gemini facility instruments. Instructions for downloading the latest version of DRAGONS (v.3.2.2) can be found in the DRAGONS User Manual.

Gemini users interested in using DRAGONS to reduce their data can follow the examples on the Read the Docs web page. Because DRAGONS was designed to perform most of the heavy lifting behind the scenes, knowing what happens at each step can sometimes be challenging. To remedy this, the US National Gemini Office (US NGO) has translated the tutorials into Jupyter Notebooks hosted on the Astro Data Lab science platform. The Astro Data Lab offers a custom kernel called DRAGONS-3.2.2 (Py3.10.14), which contains the entire DRAGONS package. This means that each tutorial can be run completely on the Astro Data Lab servers, allowing the user to use DRAGONS to reduce data without ever needing to install the software or download data on their computer. The science and calibration files required to run the tutorial can be downloaded directly from the Gemini Observatory Archive to the Astro Data Lab server, saving storage space on the user's computer.

A major benefit of the Jupyter Notebook format is that you can run each cell individually to see what intermediate files are created at each step. If there is a variable you are unsure of, you can add new cells to the notebook and investigate it without affecting the rest of the processing. You can also experiment and change the notebook by changing the default presets to see how it affects the final result. If some changes break the code, you can simply download a fresh copy of the notebook.

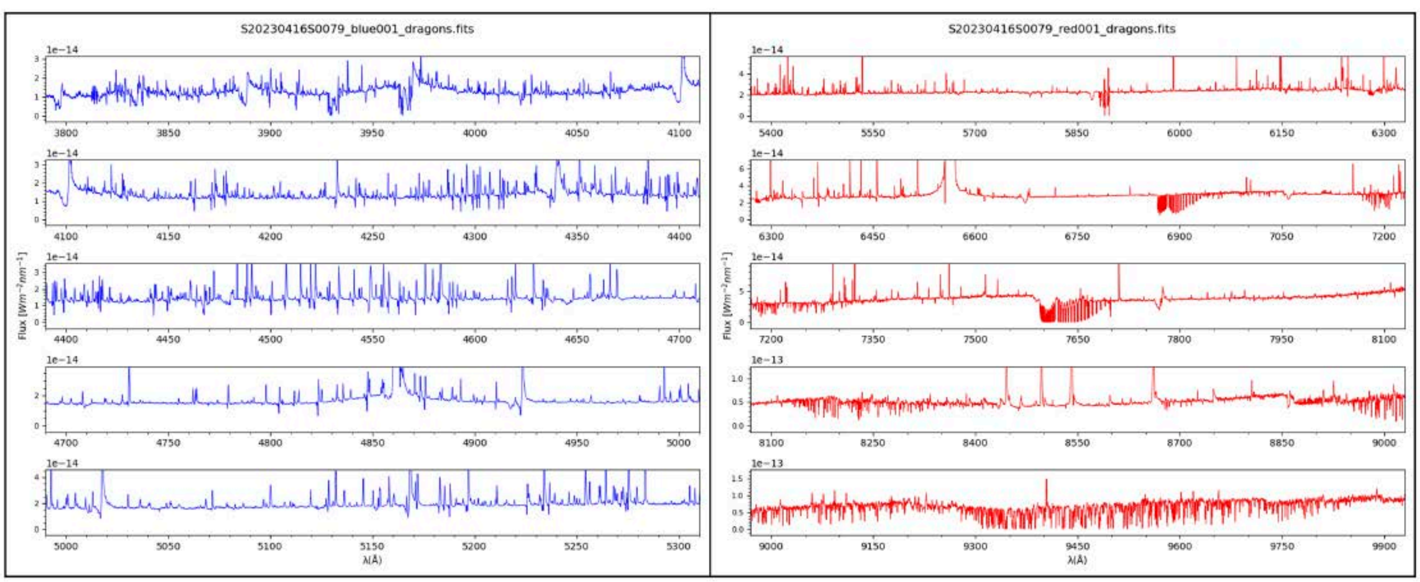


Figure 1: Reduced GHOST blue and red IFU data for the star XX Oph from the GHOST_IFU_Star notebook

All eight tutorials will walk the user through downloading the datasets, reducing the data, and displaying the finished product for multiple Gemini instruments, including FLAMINGOS-2, GMOS, GHOST, GNIRS, GSAOI, and NIRI. Six notebooks reduce imaging data from astronomical sources such as a star field, brown dwarf, galaxies, gamma-ray burst, and a supernova. The remaining two notebooks demonstrate how to reduce long-slit spectroscopic data of a white dwarf taken with GMOS and IFU data of a star taken with GHOST.

Each notebook is available to all Gemini and Astro Data Lab users. To access the notebooks on the Astro Data Lab platform, follow these steps:

- Go to the web page and create a free account.
- Once a new account has been approved, click "Launch a Jupyter Notebook" and follow the path /notebooks-latest/04_HowTos/DataReduction/DRAGONS_reduction_examples/ to access the notebooks.
- Select the notebook you would like to run and begin exploring DRAGONS.

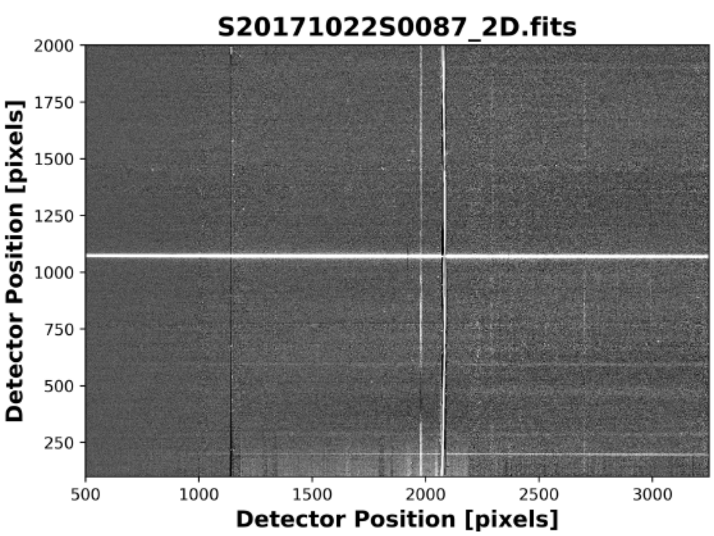


Figure 2: Reduced long-slit spectrum for the DB white dwarf candidate J2145_0031 from the GMOS_Longslit_WhiteDwarf tutorial

Alternatively, you can also access these notebooks on the US NGO GitLab repository:

- FLAMINGOS2_Imaging_BrownDwarf [Y-band imaging]
- GHOST [red and blue IFU spectroscopy]
- GMOS_Imaging_Galaxy [G-band imaging]
- GMOS_Imaging_StarryField [I-band imaging]
- GMOS_longslit_WhiteDwarf [Long-slit spectroscopy]
- GNIRS_Imaging_GammaRayBurst [J-band imaging]
- GSAOI_Imaging_EllipticalGalaxy [Kshort-band imaging]
- NIRI_Imaging_Supernova [H-band imaging]

Have questions or need help running the notebooks? The US NGO is here to help. You can contact the US NGO via our Portal or by email at usngo@noirlab.edu. For assistance with DRAGONS, users can submit a ticket to the Gemini Helpdesk (Partner Country: US; Topic: DRAGONS).

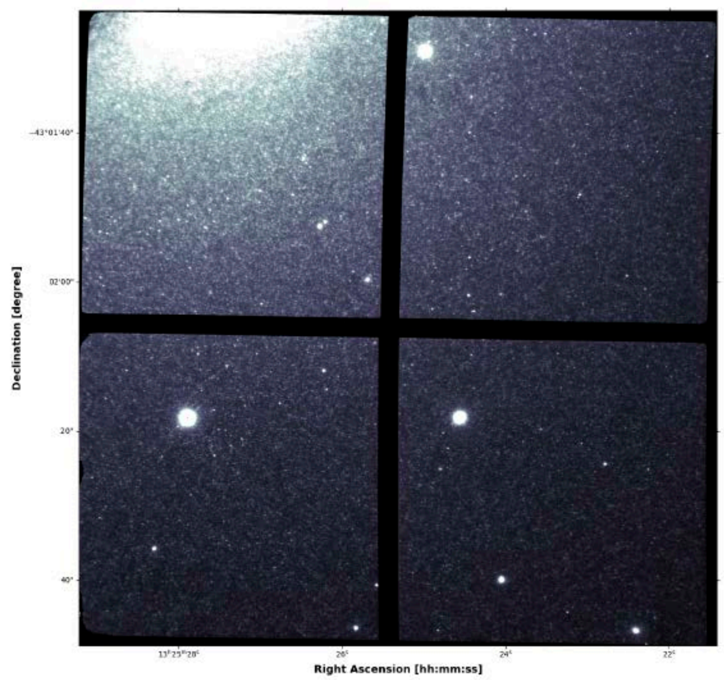


Figure 3: Reduced Kshort image of the galaxy NGC 5128 from the GSAOI_Imaging_EllipticalGalaxy tutorial

IGRINS-2: High-Resolution Near-Infrared Spectrograph at Gemini North

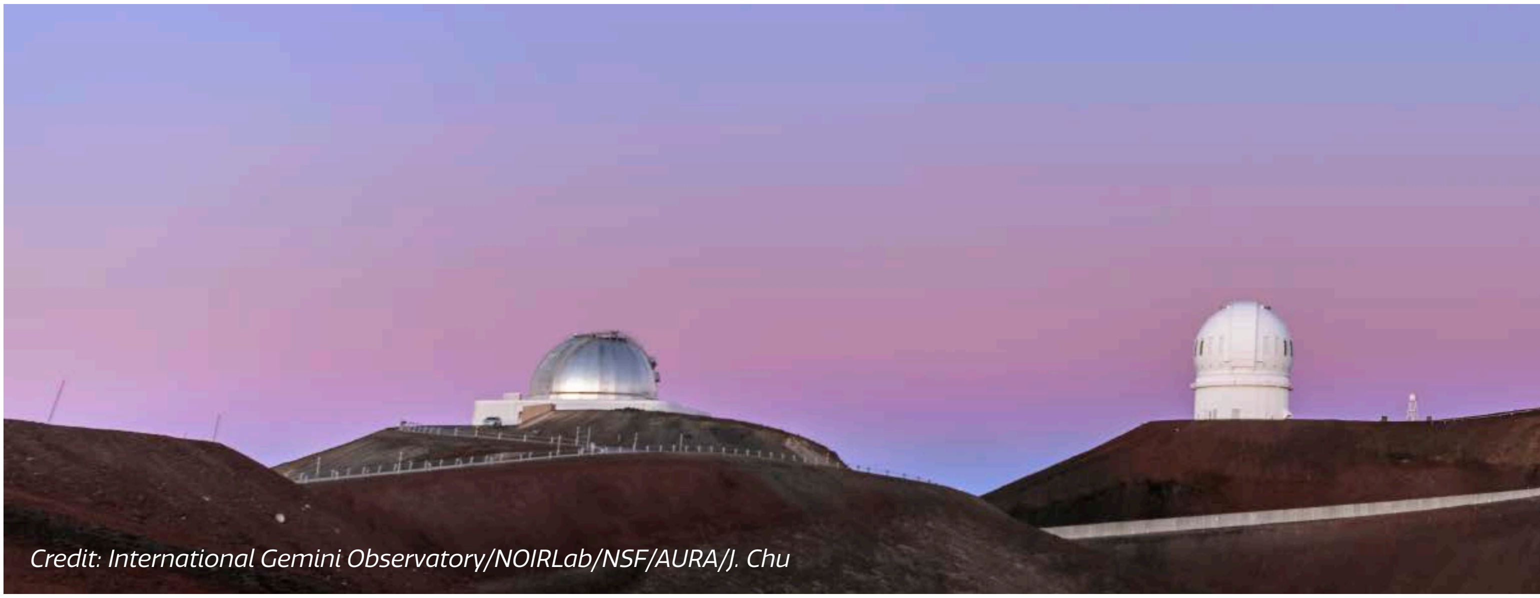
Hyewon Suh (NSF NOIRLab)

IGRINS-2 (the Immersion GRating INfrared Spectrograph 2) is the first new facility instrument at Gemini North since 2005. This compact, high-resolution near-infrared spectrograph utilizes a silicon immersion grating as its primary disperser, complemented by two VPH (volume-phase holographic) gratings as cross-dispersers. IGRINS-2 operates across both the H and K bands simultaneously, achieving a resolving power of R ~ 45,000 in a single configuration.

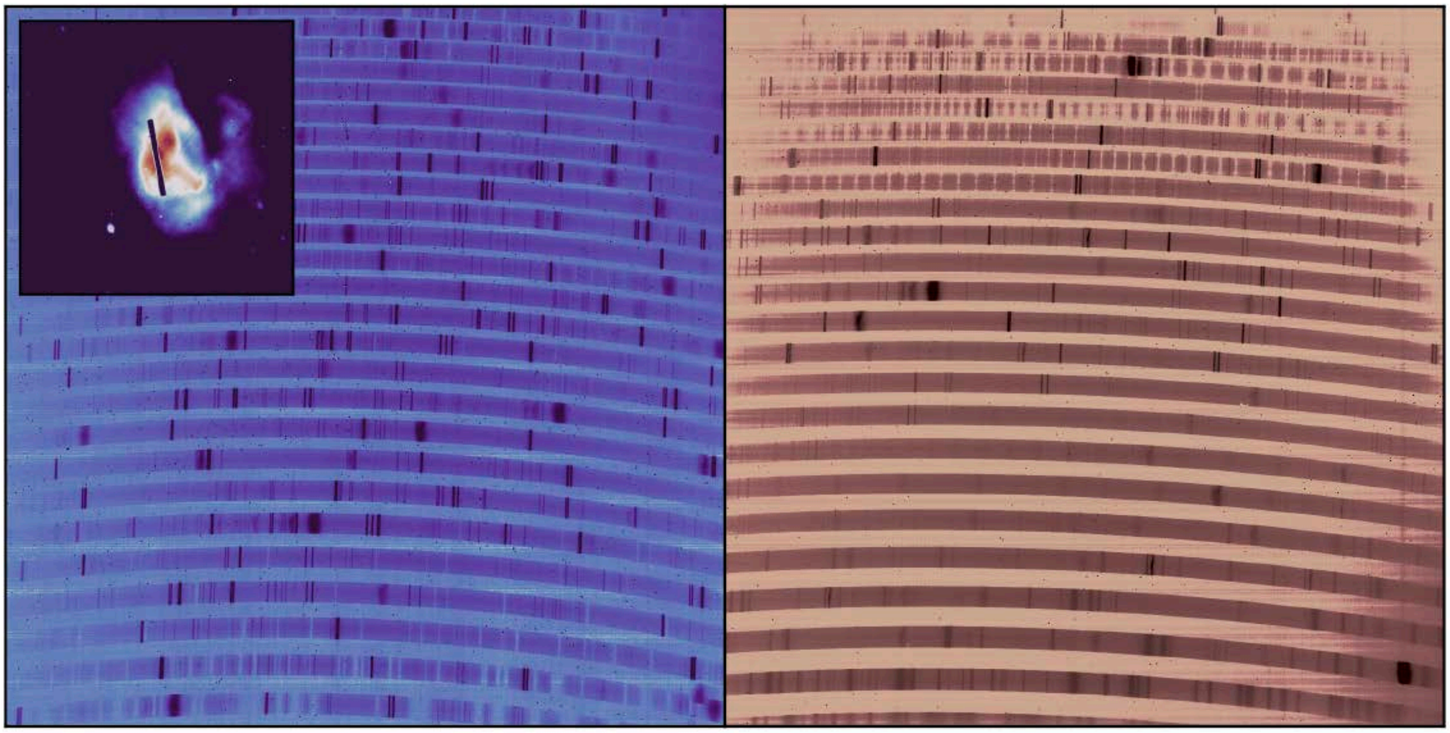
The design of IGRINS-2 builds on the original IGRINS (see "IGRINS Completes Its Mission at Gemini South" in *The Mirror*, June 2024) concept, incorporating updated electronics and a slit viewing camera with a larger field of view. Developed through a collaboration between the Korea Astronomy and Space Science Institute (KASI) and the International Gemini Observatory, IGRINS-2 achieved first light in October 2023, and its commissioning was successfully completed in April 2024.

IGRINS-2 underwent its System Verification (SV) process during May to August 2024. This was a crucial phase for comprehensive testing of the International Gemini Observatory system and operational procedures. This phase also aimed to demonstrate the instrument's capabilities across a variety of science cases, preparing for the first open calls for proposals. The SV team, composed of International Gemini Observatory staff and community representatives, was responsible for preparing observations, reducing and analyzing data, and evaluating the instrument's performance from the user's perspective.

During the SV period, 40 hours of observing time were allocated for IGRINS-2, including any time lost due to faults, weather, or other operational issues. The SV observing run, which took place 17–23 July 2024, yielded valuable scientific data, including observations of supernova remnants, exoplanet atmospheres, wide binary stars, gaseous disks around massive stars, planetary nebulae, and young stellar



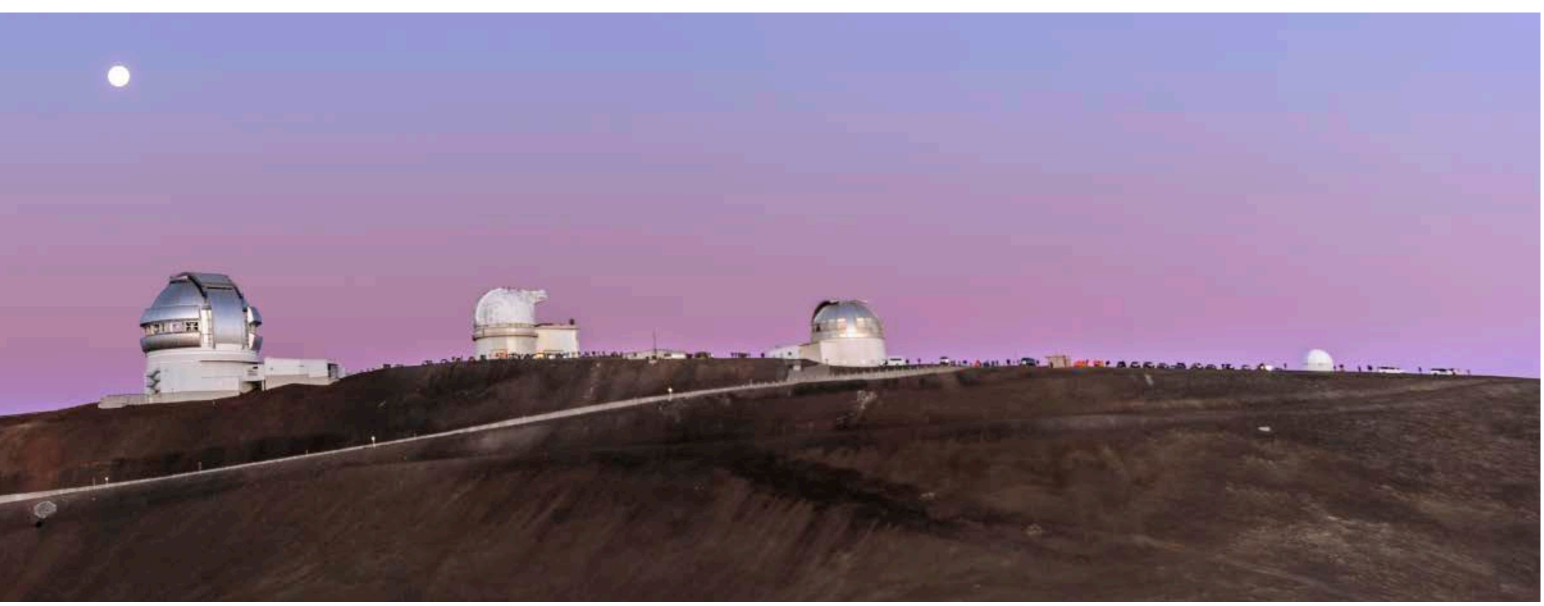
Credit: International Gemini Observatory/NOIRLab/NSF/AURA/J. Chu

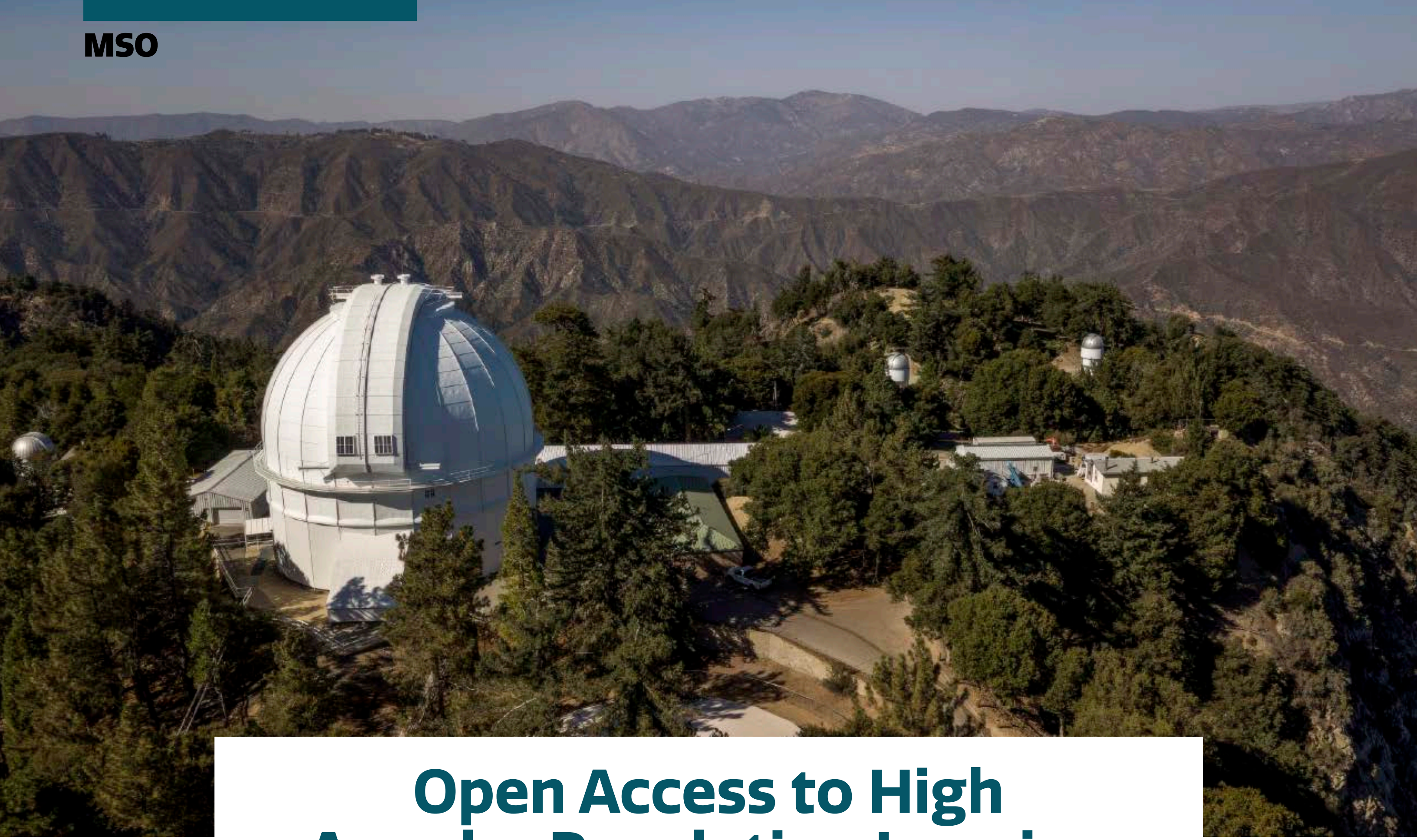


Raw spectrum obtained with IGRINS-2 for the planetary nebula NGC 6302. *Credit:NOIRLab/NSF/AURA/B. Vacca and the IGRINS-2 SV team*

objects. Raw data from the SV run were made publicly available in the Gemini Observatory Archive in mid-August, and the reduced data is now accessible as well. Detailed information about the observations conducted during the SV run can be found on the IGRINS-2 SV web page, providing the Gemini community with essential data to support proposal preparation.

IGRINS-2 was offered in shared-risk mode for the 25A semester and is also available through the Fast Turnaround program in the Call for Proposals. Preliminary information indicates that the requested time for IGRINS-2 is the second highest among all the requests for Gemini North, highlighting the strong demand for this powerful new instrument.





Open Access to High Angular Resolution Imaging at the CHARA Array

Gail Schaefer (CHARA Array of Georgia State University)

Located at Mount Wilson Observatory in California, the CHARA Array of Georgia State University combines the light from six 1-meter telescopes (Figure 1). With 15 baselines ranging from 34 to 331 meters, the CHARA Array interferometer achieves sub-milliarcsecond resolution at visible and near-infrared wavelengths. A new $3.5 million grant from the U.S. National Science Foundation awarded to Georgia State University continues to offer open access at the CHARA Array over the next three years through the NSF NOIRLab time allocation process.

It has been nearly 15 years since CHARA first offered access to the array to the broader astronomical community. Initially, only a limited number of 10 nights per year were available through a trial program. Thanks to its success, CHARA has expanded the program to offer 100 nights per year for open competition. To date, more than 400 open access proposals for CHARA time have been submitted by over 100 principal investigators and more than 300 co-investigators.

CHARA staff supports new users with help in planning observations, collecting data, and providing reduced and calibrated interferometric data files. Open access observers are encouraged to participate in the observations, either remotely through a virtual connection or by visiting the mountain in person.

Starting in 2025, CHARA will initiate a new fast-turnaround snapshot imaging mode. Up to one night per month will be reserved to provide spatially resolved confirmation of high-impact findings and to encourage new investigations by providing an initial exploratory

Figure 1: Photo of Mount Wilson Observatory showing the historic 100-inch telescope dome. Three of the smaller CHARA telescopes with silver domes are visible in the distance (one on the far left and two in the upper right). The long building immediately behind the 100-inch telescope houses the long delay lines and beam combining facility for the CHARA Array. *Credit: T. Traynor*

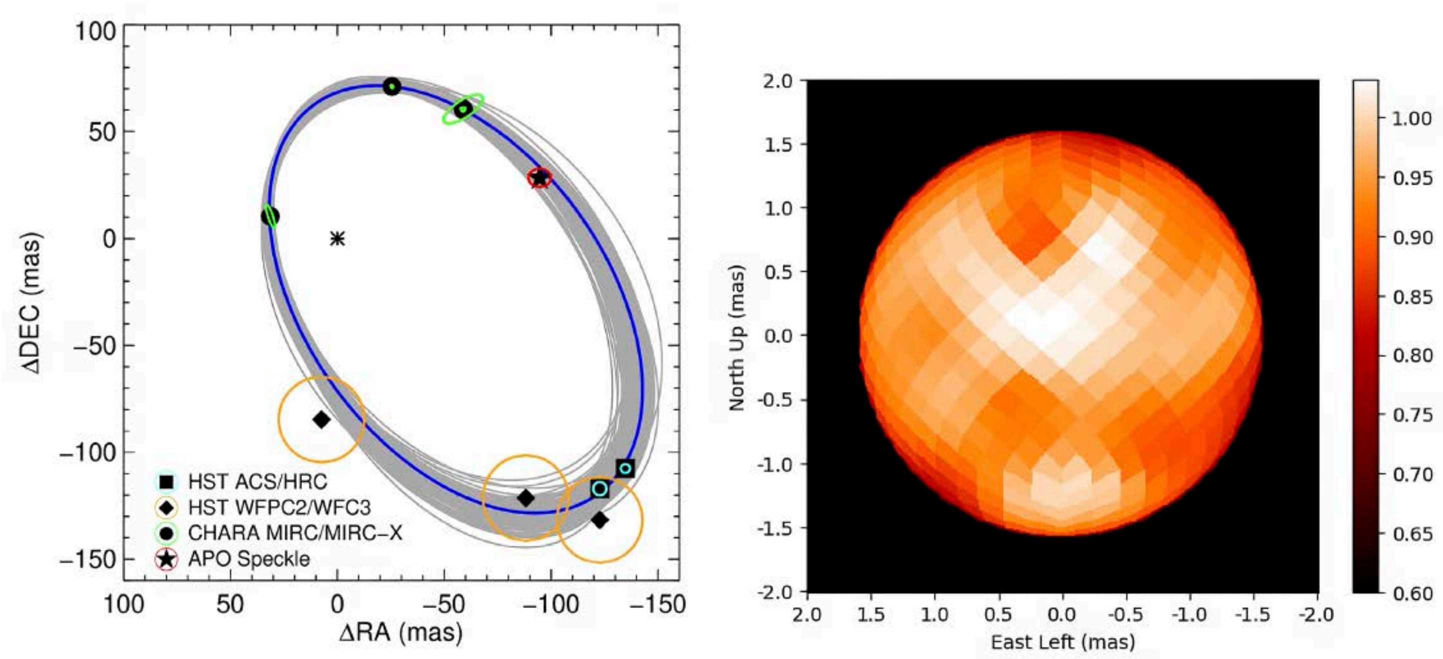


Figure 2: ***Left:*** Orbital motion of the close companion of Polaris. The symbols show the new measurements with the CHARA Array and speckle imaging at Apache Point, along with previously published measurements from the Hubble Space Telescope (HST). The best-fit orbit is plotted in blue, while the gray orbits show a sample of orbits selected at random to compute bootstrapped uncertainties. ***Right:*** Surface image of the Cepheid Polaris Aa reconstructed from data collected with the CHARA Array in April 2021. Both panels are reprinted from Evans et al. (2024).

observation as a check on feasibility before applying for a detailed follow-up proposal.

Science at High Angular Resolution

The CHARA Array can measure the sizes of stars across the H-R diagram, from massive O and B type stars down to cool, low-mass M stars. It can explore how stellar diameters change as main sequence stars evolve into giant and supergiant stars. CHARA can measure the oblate shapes of rapidly rotating stars. Stellar surface imaging resolves directly the effects of limb-darkening and gravity darkening, the motion of starspots on magnetically active stars, and changes in convection cells on supergiant stars.

Multiplicity surveys using long baseline interferometry can reveal binary companions with sub-milliarcsecond separations, well below the resolution limits of adaptive optics and speckle imaging. By mapping the spatially resolved orbits of spectroscopic binaries, the CHARA Array can be used to measure precise stellar masses and distances to binary systems.

Resolving the environments around stars using CHARA Array can probe the innermost structure of circumstellar disks around young and old stars, mass loss from massive stars, and mass transfer in interacting binaries. The array can also resolve the structure of the core in active galactic nuclei.

New CHARA Images Reveal Spots on the Surface of Polaris

An open access program led by Evans et al. (2024) conducted a multiyear observing campaign of the nearest and brightest Cepheid variable star Polaris. The goal of the investigation was to map the orbit of the inner, close, faint companion, which orbits Polaris every 29.4 years. The companion, Polaris Ab, was initially detected spectroscopically and has a long compilation of radial velocities collected over the past 100 years (see Torres et al. 2023 and references therein). Polaris Ab was spatially resolved for the first time using the *Hubble Space Telescope* (Evans et al. 2008, 2018). However, given the high orbital eccentricity and the large contrast in brightness, the binary system is extremely challenging to resolve during closest approach. This motivated the program at the CHARA

Array — to resolve the close companion of Polaris as it passed through periastron.

The team successfully tracked the orbit of the close companion with the CHARA Array, as shown in Figure 2. The revised mass of the Cepheid of 5.13 ± 0.28 $M_\odot$ indicates that Polaris Aa is more luminous than predicted from evolutionary tracks. The stellar radius of 46.3 ± 0.4 $R_\odot$ shows a 2% change in size over the pulsation cycle.

Surprisingly, the CHARA data show large asymmetries that could not be accounted for by the companion. Reconstructing images of the stellar surface revealed large bright and dark spots on Polaris Aa, as shown in Figure 2. The distribution of these spots changed over the five years of observations. Continued monitoring in the future could indicate whether the changes in the distribution of spots could be related to rotation, pulsation, or convection.

New Instrumentation and Future Directions at the CHARA Array

Recent advances to the instrument suite at the CHARA Array provide expanded access to imaging capabilities using all six telescopes in multiple wavelength bands and improved sensitivity to fainter targets. The MIRC-X (Anugu et al. 2020) and MYSTIC (Setterholm et al. 2023) instruments combine the light from all six telescopes simultaneously in the *H*- (1.6 μm) and *K*-bands (2.3 μm), respectively, with spectral resolutions ranging from R = 50 to 1,700, reaching a sensitivity of $H = 8$ mag. The SPICA instrument (Mourard et al. 2024) combines the light from all six telescopes in the *R*-band (650–950 nm) with low (R = 150), medium (R = 4,300), and high (R = 13,200) spectral resolving power options; shared-risk time is currently available with SPICA.

A new high-sensitivity 3-beam combiner, Silmaril, is being commissioned and expected to achieve a limiting magnitude of $H = 10$–11 mag (Lanthermann et al. 2024).

A new pathfinder project is underway to add a seventh mobile telescope to the Array that will be connected by fiber optics (Koehler et al. 2024). The new telescope will be moved between a distant site to extend the longest baseline out to 550 m to improve the spatial resolution by almost a factor of two and a site near the closest pair of telescopes to create additional short baselines for imaging large stars.

CHARA welcomes new investigations through the open access program to explore the local Universe at milliarcsecond resolution.

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Figure 1: Day Crew with outgoing and incoming directors on the SOAR telescope. Left to right: Ignacio Roco (Electronics Tech), Sebastian Nuñez (Mechanic), Mauricio Araya (Mechanic), César Briceño (new Director), Jay Elias (outgoing Director), Juan Pablo Burgos (Electronics Tech), Eduardo Aguirre (Mechanic), Diego Fabrega (Mechanic), Carlos Corco (Observer Support)

Ten Years of Innovation: Jay Elias at SOAR

César Briceño, Steve Heathcote & Nicole van der Bliek (NSF NOIRLab)

With Jay Elias stepping down as director of the Southern Astrophysical Research (SOAR) telescope, and the facility approaching its 20-year anniversary, it is a good time to look back at the past decade, during which Elias steered SOAR into new areas of astronomical exploration and technological advancement. As director, he promoted a series of transformative upgrades and introduced innovative operational modes that have significantly enhanced the telescope's capabilities.

Telescope and Subsystems Improvements

One improvement has been the upgrade of the Mount Control Unit (MCU; Cancino et al. 2018, 2024). The new control unit is based on the National Instruments cRIO-9039 controller, which provides better telemetry and improved fault detection and uses new digital control techniques, allowing for a more compact and robust MCU. In parallel, the mount power cabinets were also upgraded. Done entirely in-house by NOIRLab/Cerro Tololo Inter-American Observatory (CTIO) engineering staff, it has been not only an improvement in the general control of the telescope mount but also a major step towards obsolescence mitigation and continued telescope operations for the next decade. Failures traceable to mount issues have gone down significantly and have been almost zero during the past six months. Other improvement projects include the upgrade to the Calibration Wavefront Sensor (David et al. 2020), resulting in a more robust system for configuring the telescope active optics.

Instrumentation and Technological Innovation

The period during which Jay was director was a time for SOAR to grow into a mature astronomical facility, coming into its full potential. During Jay's tenure, SOAR has not only improved its science capabilities but also made new tools available for its users. The workhorse Goodman imaging spectrograph (Clemens et al. 2004) was fitted with a red-sensitive camera, in addition to its existing blue-sensitive one. Equipped with an e2v Deep-Depletion CCD, the new Goodman red camera provides improved sensitivity out to 0.9 μm with minimal fringing, which is a severe issue with the blue camera. This vastly improved the performance of Goodman for imaging and spectroscopy redward of ~6000 Å,

Figure 2: Reduced spectrum of a T Tauri star, obtained at SOAR using the Goodman spectrograph controlled by the AEON Observation Schedule Manager (OSM) software (Gómez et al. 2020) and processed automatically with the live Goodman Spectroscopic Pipeline (GSP; Torres-Robledo and Briceño 2019). The user interface is web based, so it can be launched from any computer and browser with access.

to the point that this is the default choice of detector for the majority of programs. The blue camera remains the best choice for science that requires high sensitivity below ~4500 Å. Another improvement to Goodman was the addition of a slit-viewing camera (Goodman Acquisition Camera; GACAM), which uses a deployable arm that can be moved into the optical path, just behind the long slit. This has made on-slit target acquisition much faster and is now the method of choice for most users. Imaging acquisition in Goodman is still available, but mostly restricted to faint targets ($V \gtrsim 19$). Over this period, the maintenance of the Goodman hardware has progressively transferred from the instrument creators at the University of North Carolina (UNC) to the SOAR day crew and NOIRLab engineering staff. Upgrades to the instrument control software are now done entirely by NOIRLab's software engineers at CTIO, which has allowed us to incorporate more features and adapt it to the automation initiative we are implementing across the facility.

A key addition to SOAR has been the TSpec near-IR spectrograph (R ~ 3500; Schlawin et al. 2014; Herter et al. 2020), which replaced the aging OSIRIS spectrograph. First installed at the Víctor M. Blanco 4-meter Telescope (where it was named ARCoIRIS), TSpec on SOAR offers the distinct advantage of always being available. With its rapid switching between instrument ports, SOAR allows changing from optical spectroscopy with Goodman to near-IR with TSpec in just under 30s, effectively providing the possibility of back-to-back spectra from the UV cutoff out to 2.4 μm. Now the SOAR user community has a capable and tested near-IR spectrograph permanently available on a 4m-class telescope.

Another important instrument upgrade has been the SAMPLus project (Faes et al. 2018). Developed and carried out by a collaboration between Brazil and NOIRLab, SAMPlus upgraded the SOAR Laser-assisted, Ground Layer Adaptive Optics (GLAO) Module SAM by retrofitting the instrument with a new, larger deformable mirror (DM) with more actuators, a new wavefront sensor, and upgraded software that together provide higher-order corrections and improved image quality at shorter optical wavelengths. A new instrument designed to be fed by the SOAR AO system is SAMOS (Robberto et al. 2016), a novel configurable multi-object spectrometer that uses a digital micromirror device (DMD), built by Johns Hopkins University, the Space Telescope Science Institute, Michigan State University, and SOAR. The unique layout of the instrument allows for the spectroscopic and imaging channels to operate in parallel. While integrating spectral targets, the observer can simultaneously perform photometry on the remainder of the field, improving the spectro-photometric calibration compared to a conventional multi-object spectrograph. In SAMOS, the DMD is used as a reconfigurable slit mask that redistributes slits near-instantaneously. Both SAMPlus and SAMOS were tested on-sky during 2024, first on May 24 and then on the engineering run of 14–17 October (Piotrowski et al. 2024). More details are provided in Elias (2024).

Two new instruments are being commissioned during 2025. The STELES optical echelle spectrograph was built by Brazil (LNA/MCTIC) in collaboration with NOIRLab. The ISPI near-IR imager, which is an upgrade funded by supplemental funds from NSF, was built at NOIRLab. It will replace the aging SPARTAN instrument.

SOAR is also a test bed for new and cutting edge technologies. In addition to the DMD device used in SAMOS, Skipper CCDs are being tested using the SOAR Integral Field Unit spectrograph (SIFS).[1] Modern Skipper CCD technology has been used in particle physics experiments since its first successful demonstration in 2017.

[1] SIFS was developed and constructed in Brazil by the Laboratório Nacional de Astrofísica (LNA/MCTIC) in collaboration with the Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo. SIFS provides spectral resolution R ~ 4200 at a scale of 0.3 arcsec/fiber over the range ~4000 Å to 7800 Å.

This technology has been demonstrated to achieve extremely low readout noise (0.039 e-rms/pix), while maintaining the benefits of conventional CCD detectors. The extremely low noise of Skipper CCDs brings great potential for observations where photon shot noise does not dominate. The ability of Skipper CCDs to be tuned for a desired readout noise further allows for a wide range of applications. This work is being performed in the context of a NOIRLab/LNA/Fermilab/U. Chicago/LBNL collaboration for testing Skipper devices for astronomy. The first-ever on-sky astronomical observation with Skipper CCDS took place the night of 31 March 2024, achieving readout noise levels of less than 0.25 electrons (Bonati et al. 2024).

New Paths into Operations and Data Processing

New capabilities have been developed during this decade that offer users novel observing modes and improved data processing tools. Such efforts have been part of a systematic plan to increase automation (Elias and Briceño 2016, 2020; Elias et al. 2018) to prepare SOAR for playing a pivotal role in the era of the NSF–DOE Vera C. Rubin Observatory Legacy of Space and Time Survey (LSST). This approach was recommended by the National Research Council (2015) report, Najita et al. (2016) study, and Astro2020 Decadal Survey (National Academies of Sciences, Engineering, and Medicine 2023). The main result has been the creation of the Astronomical Event Observatory Network (AEON), a collaboration between NOIRLab and Las Cumbres Observatory to develop an ecosystem of programmatically accessible telescopes that can provide fast and efficient followup when the Legacy Survey of Space and Time (LSST) gets underway (Briceño 2020; Street et al. 2020). SOAR was the pathfinder facility for setting up a 4m-class telescope that could automatically receive observation requests from an unsupervised, robotic software running at Las Cumbres and execute the corresponding observation requests with minimal intervention from the operator at the telescope. This has evolved into the AEON-queue mode at SOAR, which has enabled many Time Domain and transient programs that are difficult or impossible to schedule in classical mode. At present, AEON at SOAR accounts for ~28% of the total science time and ~70% of the NOIRLab open access time. Not only does AEON bring a new operation mode to SOAR but also, by running in a highly automated way, it allows us to avoid incurring the additional staffing costs typically associated with running traditional manual queues or service observing.

In connection with the AEON-queue at SOAR, we have also developed a fully automated Python-based data processing pipeline for the Goodman spectra and images (Torres-Robledo and Briceño 2019). It produces 1-D wavelength-calibrated spectra seconds after the shutter closes. It runs in a completely unsupervised form. These added-value products are provided together with the raw data to our AEON users. As of this writing, we have implemented a module that produces a full astrometric and photometric solution for every single image frame, using the Gaia DR3 catalog together with a photometric zero point and image quality flags. This new feature will be rolled out in the next months and will enable us to provide a fully automated image quality control system for SOAR.

As a result of the sustained work carried out by scientific and technical staff from SOAR and NOIRLab, working together with colleagues from SOAR partners and other institutions, SOAR under the leadership of Jay Elias has become a forefront facility with effective, modern instrumentation and capabilities. It is one of the most oversubscribed of the NOIRLab suite of telescopes, and its publication record has steadily increased to over 100 papers per year, on par with similar- or larger-aperture facilities worldwide (Crabtree 2023). SOAR is now a mature facility, a key multipurpose 4m-class telescope for the U.S. community that is well prepared to tackle the challenges of the next decade.

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Figure 1: The M1M3 mirror, the last major element of the telescope, is towed to the summit facility in March 2024. It had been stored a short distance away for several years awaiting final integration. *Credit: RubinObs/NOIRLab/SLAC/NSF/DOE/AURA/O. Rivera*

Rubin Observatory: It Is Happening!

Bob Blum, Rubin Operations Director (NSF NOIRLab)

As of this writing, NSF–DOE Vera C. Rubin Observatory has been on-sky for the first time! A successful commissioning phase with the full Simonyi Survey Telescope and the Rubin Commissioning Camera (ComCam) has been completed. By the time you read this, the Rubin team will be working hard on moving the LSST Camera to the telescope for the final system integration and commissioning. A short time later — about September–October 2025 — we will start the formal operations phase and be on the brink of starting the Legacy Survey of Space and Time (LSST). Wow! After more than 20 years of work by hundreds of engaged staff, community scientists, and stakeholders it is still hard to imagine getting to this point. But it is true. It is happening!

Let's back up a few months. The Rubin team had made steady progress throughout the construction phase, but early in 2024 big things started happening.

In March, the 8.4-meter primary/tertiary mirror (M1M3) was removed from its bodega (warehouse) on Cerro Pachón in Chile and moved up the short distance to the Rubin Observatory summit facility (Figure 1). In the picture, it almost seems like it is hanging off the road! A careful and slow time later (hours), the truck carrying the mirror was backed into the third level of the summit facility. Home at last! Once inside, the Rubin team unpacked the mirror and lifted it carefully onto its cell — the combined cell and mirror assembly were designed to attach directly to the telescope. Once on the cell, the mirror was stripped by an expert team from the University of Arizona Richard F. Caris Mirror Lab (which made the mirror) and then coated with a protected silver (Ag) coating by the Rubin coating team in late April (Figure 2). This amazing coating appears to be one of the best ever done on a large astronomical mirror — optimizing reflectivity from the ultraviolet to the near-infrared.

In the meantime, the camera team at SLAC National Accelerator Laboratory in Menlo Park, California, finished testing the LSST Camera for pre-ship, packed it up along with all its gear in 12 truckloads, and flew it (with a little

Figure 2: The freshly coated M1M3 mirror on level three and in front of its coating chamber. The telescope has a three mirror design. M1 (primary) and M3 are built on the same glass casting but have notably different curvatures. M2 is mounted at the top of the telescope, facing down toward M1. *Credit: RubinObs/NOIRLab/SLAC/NSF/DOE/AURA/T. Vučina*

help from an Atlas Boeing 747) to Santiago, Chile. Rubin, SLAC, NOIRLab, and AURA staff helped the caravan of trucks get from Santiago to the summit facility on Cerro Pachón in under two days. The LSSTCam arrived in its new home on 16 May 2024 (Figure 3). As of this writing, the LSSTCam is under vacuum and cold, having made the 10,000 km journey in excellent shape and without incident (Figure 4). In late October 2024, the camera was undergoing final electro-optical tests. The next step is to conduct scheduled maintenance on the filter exchange mechanism. The camera team will warm up the camera in preparation for putting it on the top end of the telescope (planned for early 2025). Once that's completed, the Rubin team will be running hard and fast and safely to First Light. But that's a story for another day.

Three other big events rounded out the last exciting seven months. First, the 3.5-meter secondary mirror (M2) was unpacked, placed on its cell, and installed on the top end of the telescope (Figure 5). Next, the 144-megapixel ComCam was installed on the top end and hooked up to its utilities (Figure 6). In the last days before going on-sky, it was cooled down and checked out for its first flight. Finally, in early October, a ceremony was held following the installation of M1M3 on the telescope (completing it as a full system, if not the final one). The ceremony was to honor the Simonyi family by revealing the name of the telescope: the Simonyi Survey Telescope (Figure 7). Charles Simonyi, the chief architect of Microsoft Office, generously donated funds in the early 2000s to kick off the procurement of M1M3, one of the long lead items. While the observatory and everything in it are named for Vera C. Rubin, the telescope itself holds the name Simonyi in honor of the Simonyi family's support.

To close out this chapter, as I write this our team is celebrating going on-sky with a fully functional Simonyi Survey Telescope and ComCam. The latter is one 1/21st of the field of LSSTCam (no slouch) and will take the team one step closer to the start of the LSST and beyond. The final picture below shows a wide angle of the full system. In view are the telescope, M1M3 assembly, ComCam, and M2.

Figure 3: **Left**: Members of the Rubin team welcome the LSST Camera to Chile; **Right**: The shipping crate holding the LSST Camera is transported the final 35 kilometers (21.7 miles) up the winding dirt road to the observatory on the summit of Cerro Pachón. *Credits: Left: SLAC National Accelerator Laboratory/O. Bonin; Right: SLAC National Accelerator Laboratory/T. Lange*

Figure 4: The LSST Camera, built at SLAC and funded by DOE, in the clean room at the summit facility. Once safely on its stand, the team began hooking up all the utilities including two independent systems to cool the focal plane and the onboard electronics, fibers, and power. The cooling system compressor/chiller cabinets are on level 1 of the facility and represent a complete copy of the telescope systems, which are installed under the azimuth floor. *Credit: SLAC National Accelerator Laboratory/T. Lange*

Figure 5: The secondary mirror, M2, on its assembly cart and placed on its cell. Like the M1M3 assembly, M2 has force actuators to control its shape under gravity. *Credit: RubinObs/NSF/AURA/W. O'Mullane*

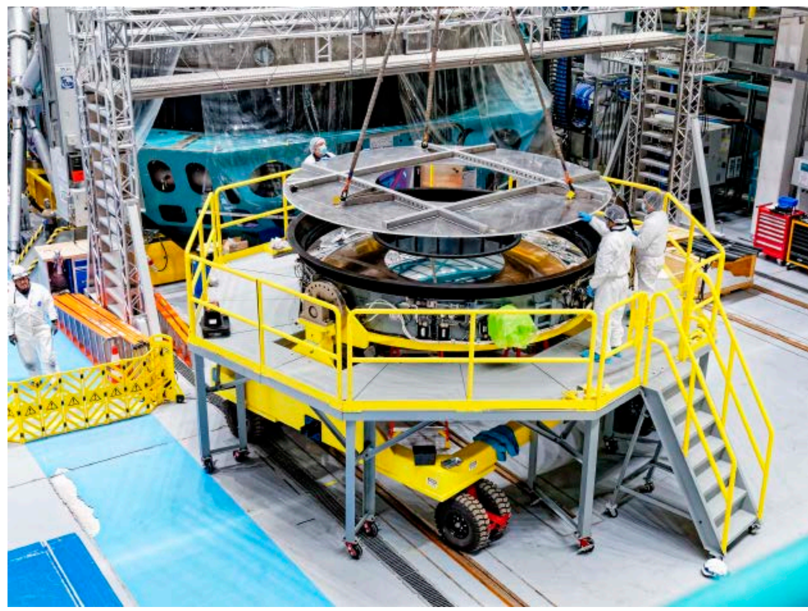


Figure 6: The commissioning camera, ComCam, on level 3 of the summit facility. The entire assembly mimics the mass and moment of inertia of LSSTCam. In the view, ComCam is the black structure to the right and the actual vacuum vessel with the imaging sensors and front window face away from us. ComCam attaches to the camera (image) rotator which ensures the rotation of the field on sky is taken out, so each image is fixed on the sky as the telescope tracks. The camera cable wrap is on the left end of the assembly. Everything attaches to the large circular bulkhead which, in turn, is fixed to the yellow integration cart. When it is LSSTCam's turn, ComCam will be removed and LSSTCam installed on this same cart. *Credit: Rubin Obs/NSF/AURA/H. Stockebrand*

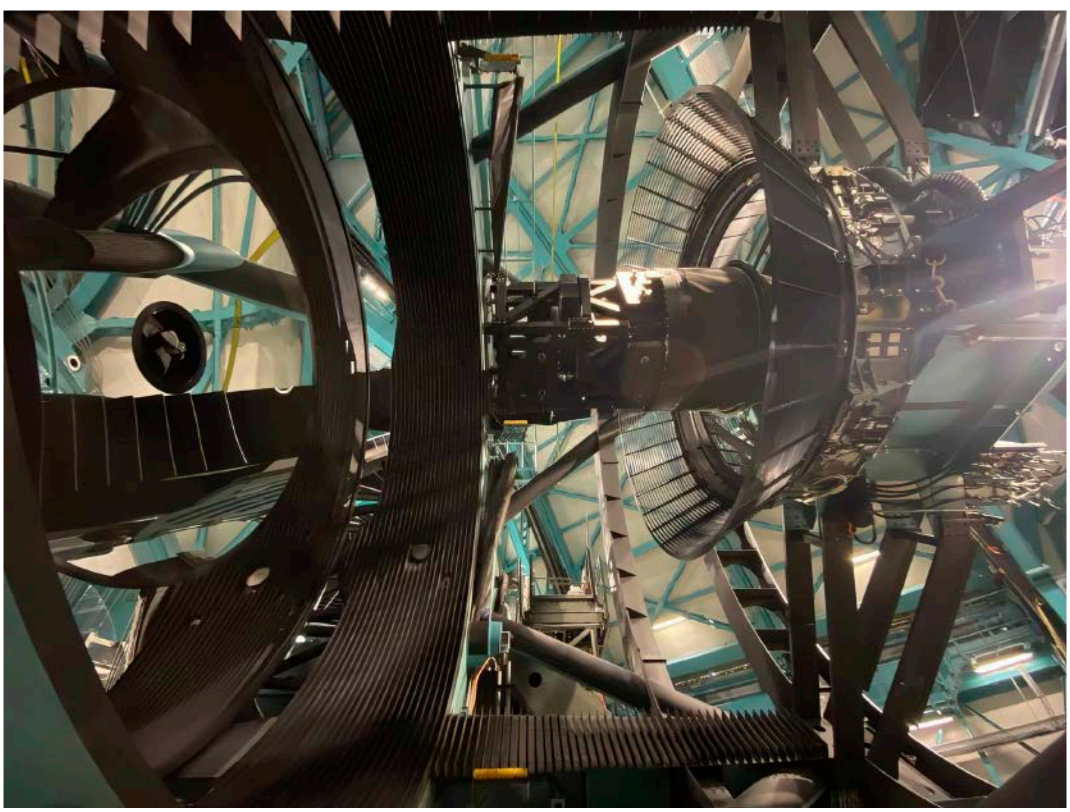


Figure 7: Rubin Observatory, SLAC, NOIRLab, AURA, NSF, and DOE representatives join Charles Simonyi at the ceremony to honor his family by naming the Rubin telescope for them. *Credit: RubinObs/NOIRLab/SLAC/NSF/DOE/AURA/M. Paredes*

Figure 8: Parting shot, the fully functional system pointed at horizon. **From left to right**, M1M3, ComCam, M2 light baffle, M2 mirror and mirror cell. The central hole in M1M3 allows for cleaning and stripping chemicals to be captured and removed and provides access to the volume above the mirror when it is installed. Visible in the picture is a laser tracker mounted in the central hole that is used to align the telescope optics and camera. *Credit: Rubin Obs/AURA/NSF/B. Blum*

Rubin Community Workshop 2024

Rubin Observatory staff and scientists gathered at SLAC National Accelerator Laboratory for the 2024 Rubin Community Workshop, held from 22–26 July. *Credit: SLAC National Accelerator Laboratory/J. Ramseyer Orrell*

Kristen Metzger (NSF-DOE Vera C. Rubin Observatory/NSF NOIRLab)

This year's Rubin Community Workshop (Rubin 2024), held from July 22–26 at SLAC National Accelerator Laboratory in Menlo Park, California, marked another productive and inspiring annual meeting. This was NSF–DOE Vera C. Rubin Observatory's 15th annual gathering, and it featured some significant changes from past years' meetings. These changes included a shift in physical location — most years' meetings have been held in Tucson, Arizona — and being fully hybrid for the first time, with the option to connect virtually with all plenary and breakout sessions. This year's meeting focused on boosting engagement with the science community while maintaining strong participation from Rubin project members as Rubin moves closer to Operations. By this time next year, Rubin Observatory will have achieved first light and will be preparing for the launch of the 10-year Legacy Survey of Space and Time (LSST)!

The five-day meeting had a packed agenda of daily plenary and parallel sessions, beginning with a welcome and overall status update on Monday morning from Bob Blum, Rubin

Operations Director. Breakout sessions followed, as well as the first of several "brown bag" lunch opportunities for informal networking and a themed discussion. Monday's lunch was a LGBTQIA+ social; other lunches throughout the week included a student social, an open house hosted by the Informatics and Statistics Science Collaboration, and a discussion about reducing Rubin's carbon footprint.

On Tuesday morning, meeting participants were invited to gather before the plenary session for a virtual tour of the summit. Rubin team members Yijung Kang, Craig Lage, and Kevin Reil connected via Zoom to show off the Observatory facility, Auxiliary Telescope, and sweeping views of the Chilean Andes. The following plenary featured a talk from Jeno Sokowloski about the role and benefits of joining the LSST Discovery Alliance (LSST-DA). Then came four excellent "Lightning Story" talks from Rubin team members Azalee Bostroem, Mark Pitts, Fernanda Urrutia, and Orion Eiger. The plenary session concluded with 30-second flash talks from the meeting's LSST-DA–sponsored student participants, encouraging attendees to visit their posters during the week's afternoon breaks.

On Tuesday evening, the SLAC Café provided the venue and refreshments for a lively indoor/outdoor reception. Then, once the sun went down, the LSST-DA and the SETI Institute partnered to offer a Rubin/LSST–themed Star Party, with Unistellar smart digital telescopes (eVscopes) set up to observe deep space objects and transient phenomena. Thanks to the volunteers who stayed at their telescopes until the last stargazers called it a night.

The Wednesday morning plenary featured short presentations from each of Rubin's eight science collaborations, followed by a full day of breakout sessions. The day's session agenda concluded with what has become a regular feature at Rubin's annual meetings: parallel "Unconference" sessions on topics proposed and voted on by conference attendees. In the early evening, people were invited to drop in at an open house in SLAC's Rubin Control Room and chat with the team remotely operating and observing with the Rubin Auxiliary Telescope on Cerro Pachón.

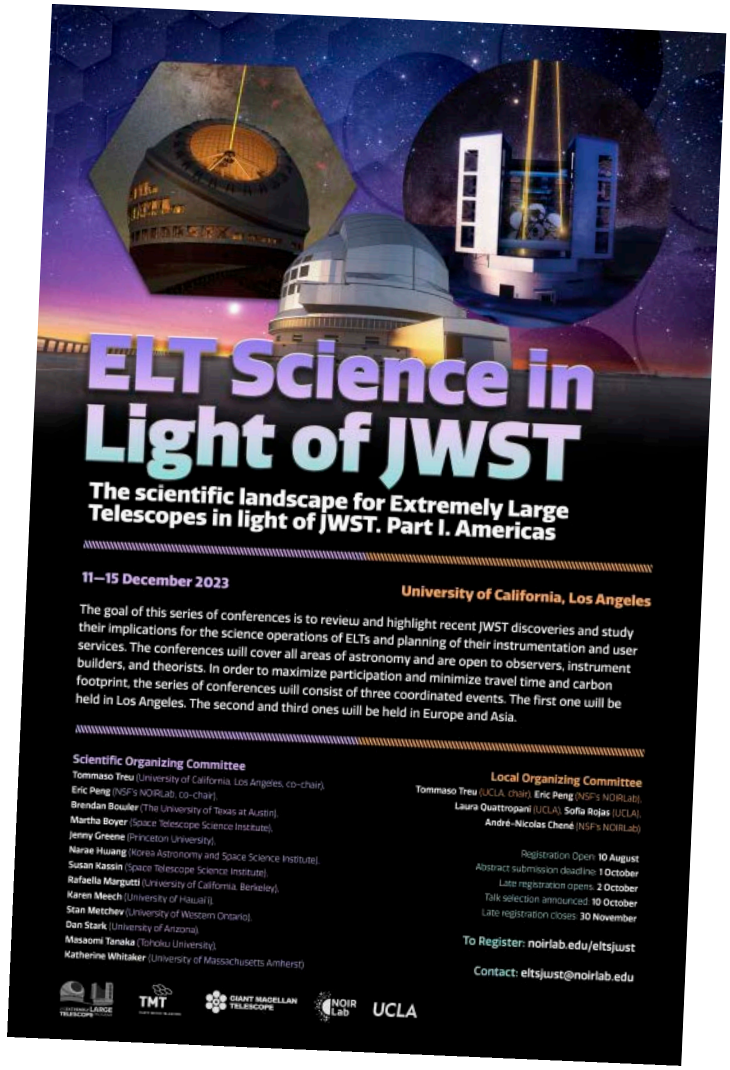
On Thursday, a plenary titled, "Rubin Research Spotlights" featured four speakers invited by the Science Organizing Committee to present on timely Rubin research projects. Louise Edwards (Cal Poly), Jamie Robinson (Princeton), Ashley Villar (Harvard), and Nikki Arendse (Stockholm University) gave well-received talks in this session. In addition to the day's following breakout sessions, Hannah Pollek and Travis Lange from Rubin's LSST Camera team hosted a lunchtime "show and tell" of a spare raft tower module for the 3200-megapixel LSST Camera, which shipped to Chile from SLAC in May 2024.

The last day of the meeting was scheduled as a half day, which kicked off with the Rubin Project Keynote talk, in which Phil Marshall, Lynne Jones, and Federica Bianco presented on the collaborative efforts of the Rubin Survey Strategy team, the Survey Cadence Optimization Committee (SCOC), and the Rubin community to converge on the LSST baseline survey strategy. The day's agenda concluded with a final block of parallel sessions, after which participants who had traveled to SLAC began their journeys home.

Thanks to SLAC for hosting this memorable event, and to the Scientific Organizing Committee and Local Organizing Committee for their hard work on a very successful Rubin 2024! Additional photos are available at this link, and recordings of sessions are available on Rubin's YouTube channel.

The Scientific Landscape for Extremely Large Telescopes in Light of JWST

Eric Peng (NSF NOIRLab)



The Extremely Large Telescopes (ELTs) will be the premier ground-based optical-infrared facilities from the 2030s onward. The three telescopes currently planned — the Giant Magellan Telescope (GMT), the Thirty Meter Telescope (TMT), and the European Southern Observatory's Extremely Large Telescope (ESO ELT) — will provide diffraction-limited spatial resolution, unrivaled from the ground or space, as well as sensitivity commensurate with their large apertures.

In the years since its launch, JWST has enabled breakthroughs in virtually all areas of astrophysics, by virtue of its wavelength coverage, sensitivity, and angular resolution. The experience of Hubble and Spitzer, coupled with ground-based 8–10-meter telescopes, demonstrates the power of combining space- and ground-based observatories to carry out unprecedented, complementary, and even unexpected science. Similarly, we expect the upcoming ELTs will be the ideal complement and successors to JWST.

To facilitate discussion on ELT synergies with JWST science, the US Extremely Large Telescope Program (US-ELTP) at NOIRLab was involved in the organization of two conferences on the topic, "The Scientific Landscape for Extremely Large Telescopes in Light of JWST." The first conference ("Americas") was co-organized by UCLA and NOIRLab and held at the UCLA Faculty Center, 11–15 December 2023. The second conference ("Asia") was co-sponsored by Tohoku University and the Korea Astronomy and Space Science Institute (KASI), and held at Tohoku University in Sendai, Japan, 3–7 June 2024. Holding multiple conferences on the same theme in different geographic regions allowed for inclusive participation cross the global partnerships in the ELT projects.

Each conference had over 100 in-person attendees, with agendas that included both invited and contributed talks, discussion panels, and posters. The goal of these two conferences was to review and highlight recent JWST discoveries and discuss their implications for the science operations of ELTs and planning of their instrumentation and user services. The conferences covered all areas of astronomy, and included observers, instrument builders, and theorists.

Both conferences had talks from members of the three telescope projects — GMT, TMT, and ESO's ELT — and from the US-ELTP, providing descriptions and status updates. The highlighted strengths of the ELTs included their large

Figure 1: "The Scientific Landscape for Extremely Large Telescopes in Light of JWST" conference, held at UCLA Faculty Center, 11–15 December 2023

aperture, adaptive optics-enabled diffraction-limited spatial resolution that will surpass anything in space or on the ground, instruments with high spectral resolution, the ability to upgrade and develop new instrumentation, and an operational model that will enable rapid response for time domain and multi-messenger (TDAMM) follow-up. The US-ELTP highlighted the advantages of a bi-hemispheric, two-telescope system with end-to-end support for scientific discovery (EESSD).

The presentations and discussions on science touched on the full range of astrophysical inquiry, from the Solar System to cosmology. We include a few highlights below.

Exoplanets

The landscape of exoplanet science is expected to change rapidly over the next decade. Open questions include the range of exoplanetary system architectures, the processes that lead to planetary diversity, the evolution of habitable planets, and the markers by which we can identify and interpret signs of life. By the early 2030s, JWST will likely have devoted thousands of hours to exoplanet science. One consensus at these conferences was that with JWST, we have the opportunity to answer the question of whether rocky planets around M dwarfs have atmospheres and, if so, which ones are the best targets for further study. (These conferences were both held before STScI announced a 500-hour Director's Discretionary Time program on JWST to focus on this topic.) The ELTs, with their spatial and spectral resolution enabling both direct imaging and high-resolution spectroscopy of exoplanets, will present a leap in observational capability. In the US-ELTP system, instruments such as GMT/G-CLEF, TMT/MODHIS, and GMT/GMTNIRS will provide high (R ~ 100,000) spectral resolution, with TMT/IRIS, GMT/GMTIFS, and GMT/GMagAO-X providing diffraction-limited imaging and low resolution spectroscopic capabilities. These instruments will be used to directly characterize exoplanetary properties, including the measurement of potential biosignatures, like molecular oxygen, water, methane, and carbon dioxide. Measuring isotopologue ratios, like $^{13}C/^{12}C$, may also be important in the search for biosignatures, as the presence of life can alter these ratios. This is already possible in giant exoplanets with JWST (Esparza-Borges et al. 2023), but will require the ELTs for smaller exoplanets.

Multi-messenger astrophysics

With the expected improvements in the sensitivity of gravitational wave (GW) detectors over the next decade, the volume within which we will be sensitive to GW events will increase dramatically. Future GW observatories will detect neutron star – neutron star (NS–NS) mergers out to $z > 2$ (Evans et al. 2021), but their kilonovae will be faint. It was discussed how the optical-infrared spectroscopic characterization of kilonovae will require ELTs for any distance beyond $z = 0.1$. Furthermore, the operations of the ELTs are already planning to support rapid follow-up of TDAMM events, including rapid instrument changes, dynamic scheduling, and ways to facilitate real-time communication between PIs and the observatories, something which is more difficult to do with current flagship space-based missions.

Figure 2: Participants in the "ELT Science in Light of JWST" Conference held in Sendai, Japan, 3–7 June 2024. *Credit: I. Ko*

Cosmology and dark matter
Both JWST and the ELTs are well-suited to making advances in cosmology. One way that was highlighted is by refining the extragalactic distance ladder using infrared surface brightness fluctuations (Anand et al. 2024). High spatial-resolution imaging of multiply lensed QSOs can also constrain both H_0 (using time delays) and the nature of dark matter (flux anomalies).

Galaxy evolution and black holes
Both conferences highlighted the complementarity between JWST and the ELTs for studies of galaxy evolution (both nearby and distant), as well as for supermassive black holes (from the one at the Milky Way center to ones at high redshift). In the early Universe, the galaxies and AGN now being discovered with JWST will be studied in detail using IFUs on ELTs at physical scales of 100 pc. At the same time, the much wider field enabled by the ELTs will enable a more comprehensive picture of the gaseous environment within which galaxies evolve, mapping the intergalactic medium and circumgalactic medium. ELT imaging and spectroscopy will also push resolved stellar population studies to even larger distances, well beyond the Local Group.

The two conferences showed how the current excitement and opportunities with JWST science are directly informing how the community envisions using the unique capabilities of the upcoming ELTs. The meetings on two continents also highlighted how the ELT era will be an internationally collaborative era for optical-infrared astronomy. We thank the organizing committees for both the UCLA and Tohoku meetings for putting together two very successful conferences.

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The Age of Skyviewers

Lars Lindberg Christensen, Mahdi Zamani, Clare Higgs, Robert Nikutta, Alexandra Goff & Mark Newhouse (NSF NOIRLab)

Many sciences have become reliant on large datasets to make progress towards answering big questions, and astronomy is no exception. Large sky surveys and spectroscopic projects such as the NSF–DOE Vera C. Rubin Observatory or the Dark Energy Spectroscopic Instrument (DESI) produce terabytes, or even petabytes, of data.

When faced with data avalanches, our human senses in many ways act as a bottleneck to see, grasp, analyze, and understand the data. Data visualization helps present the data in ways that enable exploration, and ultimately insights.

A convergence of fast internet speeds, computing power, javascript, modern browser technologies, and clever minds has enabled the emergence of a series of *extremely* fast and smoothly functioning tools for imaging data, so-called Skyviewers. Skyviewers give the user a seamless exploration vehicle for navigating high-resolution images of giga- or even terapixel datasets that are many degrees wide (or even the entire 40,000+ square degrees of the sky).

By now most computers and handheld devices seamlessly display video in 2000–4000 pixels resolution (2–4K). Streaming video apps effectively display a series of such images at a high frame rate (typically 30 frames per second), and these are rendered back with ease on modern devices.[1] Similarly, the Skyviewers show a rendering adapted to the display resolution of the user (typically 2–4K) at a given magnification level and allow the user to zoom, pan, and explore the image with ease. The Skyviewers effectively show just a tiny fraction of the data, displaying a "funnel," or viewport, into the data in the image as you zoom in.

How do skyviewers work?

Skyviewers are multi-resolution image viewers that use sophisticated tiling methods such as the HiPS and ST-MOC International Virtual Observatory Alliance (IVOA) standards. These standards are based on HEALPix tesselation of the sphere and TOAST (Tessellated Octahedral Adaptive Subdivision Transform; McGlynn et al. 2019) in the Montage Engine based on Hierarchical Triangular Mesh (HTM).

[1] Technically, the comparison between such apps and rendering of still images has limitations. Netflix and similar apps use highly sophisticated run-time encoding algorithms that use advanced methods to take advantage of the near-duplication of content in one frame to the next.

HiPS is a hierarchical tiling mechanism that allows one to access, visualize, and seamlessly browse image, catalog, and cube data. It was developed by CDS in 2009 (Fernique et al. 2015). Based on the growing number of Skyviewers supporting HiPS implementation, it is one of the most used tiling method in astronomy.

ST-MOC is a hierarchical tiling mechanism developed by CDS in 2019 that, by adding an axis for time, allows representation of the time evolution of a spatial coverage, querying it by time and space and filtering a catalog (see Baumann et al. 2019; Fernique et al. 2019).

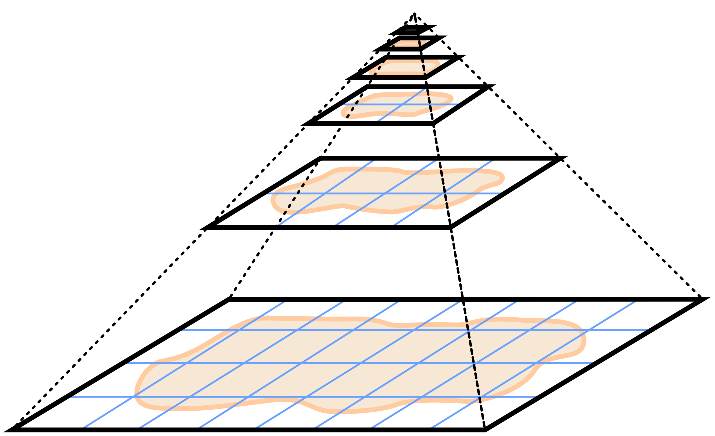


Figure 1: Illustration of the "funnel" with a series of 2K image "slices" in different resolutions as the user zooms down in the image

In all of the Skyviewer tiling methods, thousands, or even millions, of tiny JPEG, FITS (Hayashi et al. 2016), TIFF, or PNG files with different fields of view are generated in a pyramid fashion; the shape and size of which determines the possible projections of the output image. Only a subset of these typically 256 × 256 pixel tiles are downloaded by the Skyviewer based on the field of view (or pyramid-level) set by the user. This minimizes the amount of downloaded data and provides a fast response for the user, while maintaining consistent image quality. Tiling the image allows the viewer to only display the pixels needed for a particular view on the screen (as well as some neighboring pixels), resulting in effective use of bandwidth and computer resources. This also means that the amount of data needing to be transferred at any one time is proportional to the number of pixels on the screen and not to the actual huge image. This is an alternative to loading all the pixels of an image at once. It is the "secret sauce" that allows for the seamlessly smooth transition between the layers during the zooming process, empowering anyone to enjoy gigapixel images. The price to pay for this speed and convenience lies in a significantly increased storage volume on disk.

A Skyviewer renders only the pixels needed on the screen at the given zoom level, without the need to touch data that are not relevant for the final image because they cannot be seen:

1. Calculate what the user can see on their screen.
2. Access the data needed to fill *only* the viewable area (and possible neighbors) at the current zoom-level.
3. Deliver the tiles quickly to the user's buffer.

Example tools

The following are four selected example Skyviewers with different use cases.

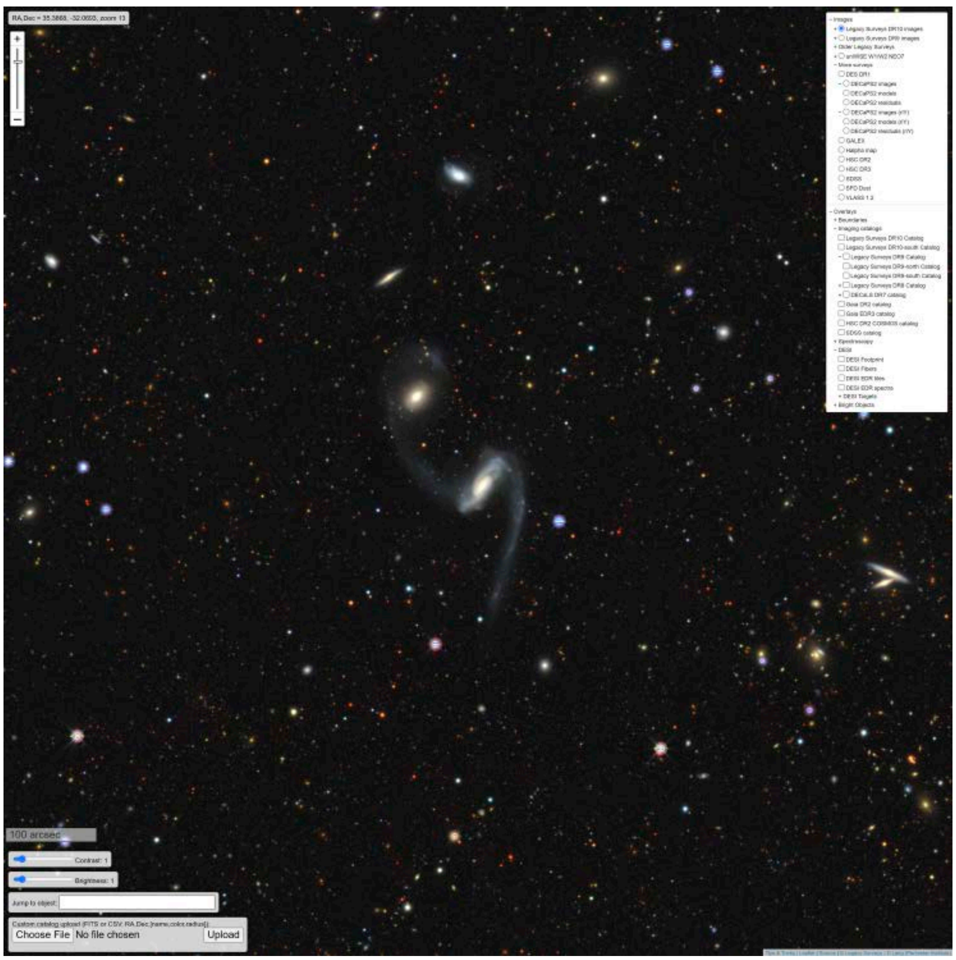


Figure 2: The DESI Legacy Survey Skyviewer gives one-click browser-based access to exceptionally deep images of ⅓ of the sky (soon to be expanded to ½). *Credit: DESI Legacy Survey Skyviewer.*

DESI Legacy Survey Skyviewer

The DESI Legacy Survey (Dey et al. 2019) is a very deep dataset of ~14,000 square degrees of extragalactic sky visible from the northern hemisphere in three optical bands and other datasets taken with the Department of Energy's Dark Energy Camera (DECam) at the Víctor M. Blanco 4-meter Telescope, Cerro Tololo Inter-American Observatory; Nicholas U. Mayall 4-meter Telescope, Kitt Peak National Observatory; and the Bok telescope, Steward Observatory, University of Arizona, Kitt Peak National Observatory. The **DESI Legacy Survey Skyviewer** was created by Dustin Lang and is designed to work with a specifically adjusted version of Leaflet javascript. It uses a smoothly running and well-developed open-source JavaScript library for interactive maps. This JavaScript library uses a rectangular-shaped tiling method, which limits it to produce output images in certain flat projections, making it difficult to project into a spherical viewer.

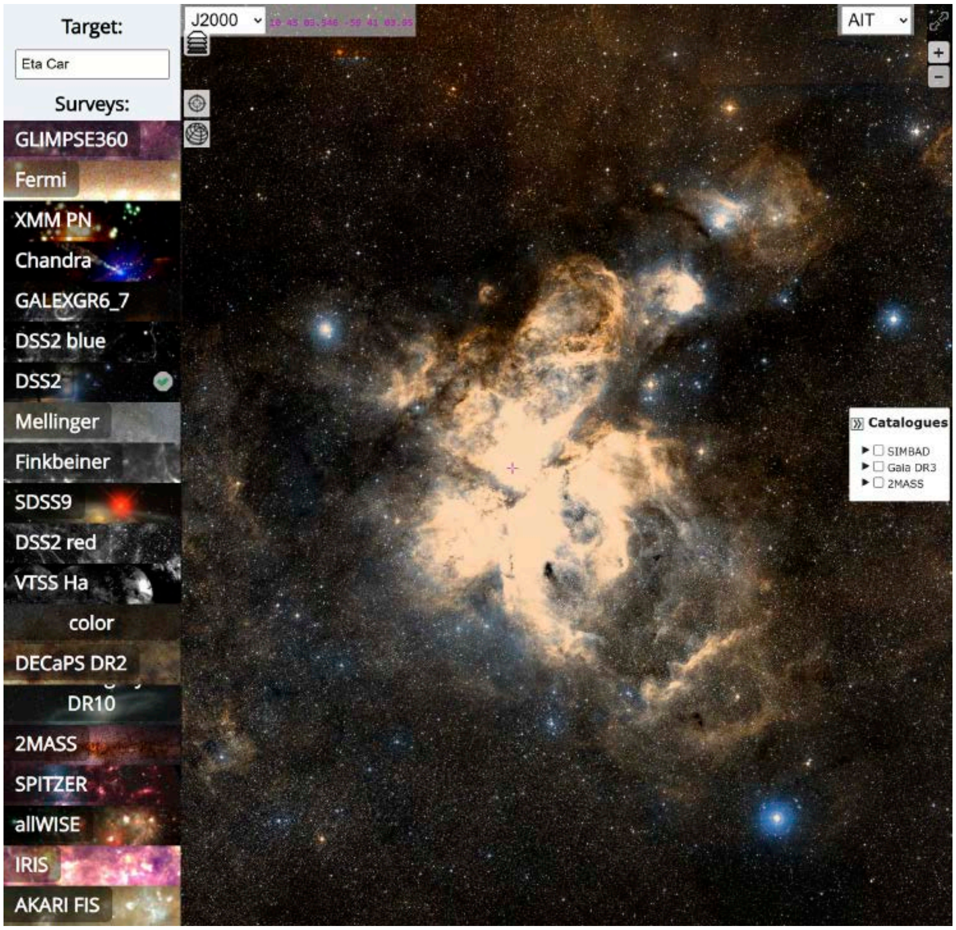


Figure 3: Aladin Lite is a browser-based, hugely versatile, and elegant sky and image exploration tool. *Credit: CDS/Aladin*

Aladin Lite

Aladin Lite (Boch & Fernique 2014; Baumann et al. 2022) is a versatile and elegant sky and image exploration tool that uses HiPS in the JavaScript Canvas 2D rendering. It is lightweight (less than 100 KB when gzipped and minified) and exceptionally easy to embed on any web page (no plugins and just a few JavaScript snippets of code needed). The Skyviewer accepts user-generated HiPS tiles and offers to generate HiPS tiles on Aladin/CDS servers[2] based on tagged standard WCS parameters in the metadata of the image; such as those defined by Astronomy Visualization Metadata Standard (Christensen, Hurt & Gauthier 2006).

The Astro Data Lab science platform at NOIRLab's Community Science & Data Center (CSDC) uses AladinLite as a web-based exploration tool for its datasets. Integration into Jupyter notebooks is underway.

[2] Producing HiPS tiles through the Aladin Lite interface (using the Aladin/CDS servers) may not be an optimal option for gigapixel images and time-sensitive applications, as the tile processing time may vary depending on the CDS server's free bandwidth at the time. For such purposes, it might be faster for the user to produce HiPS locally.

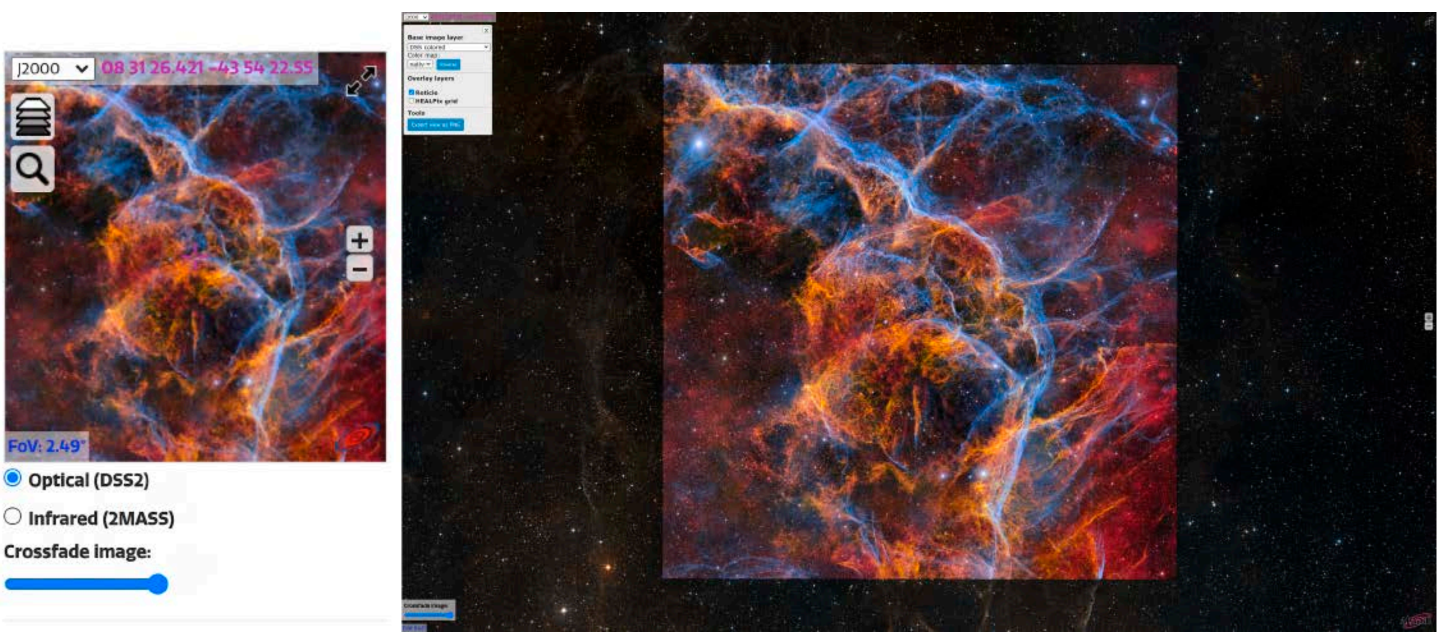


Figure 4: An example of an embedded version of Aladin Lite on a NOIRLab press release web page (left).

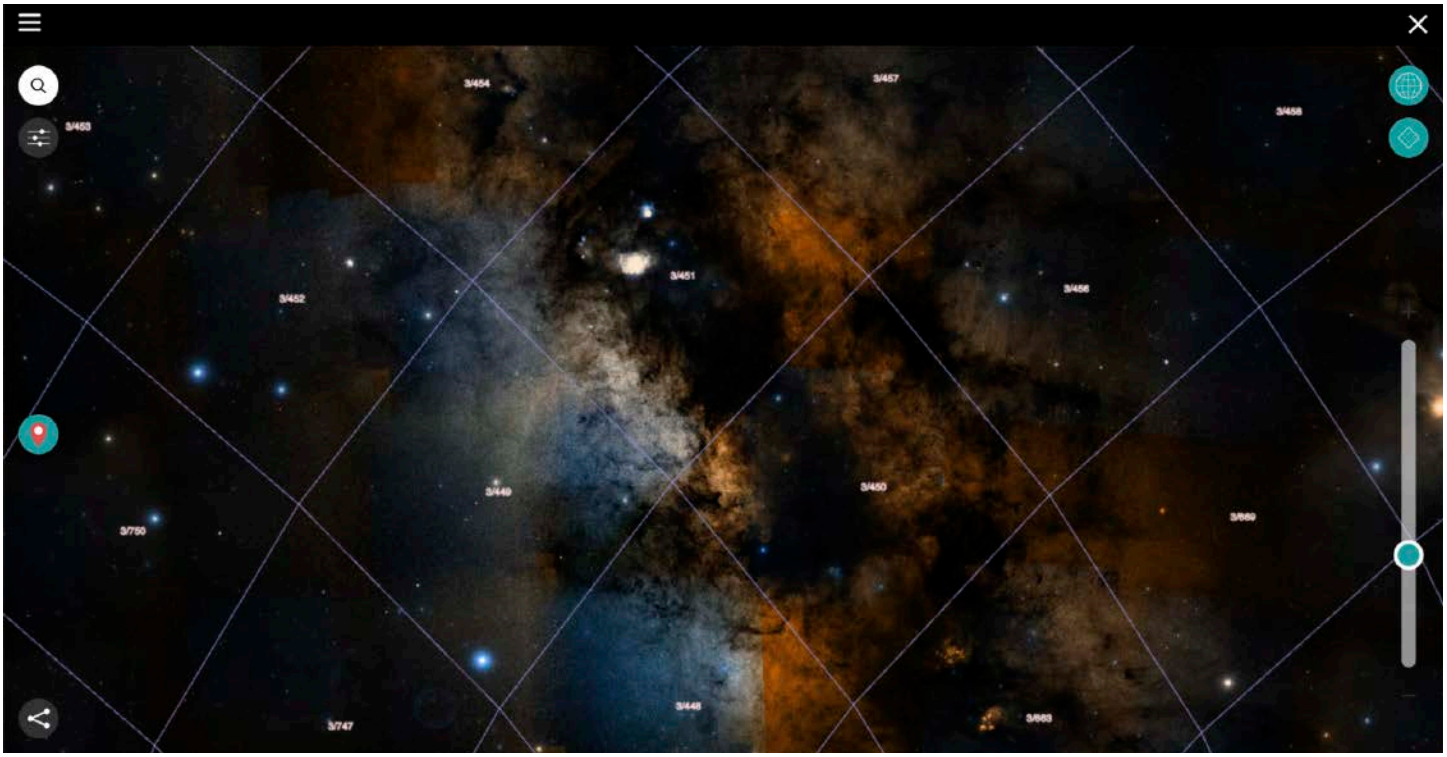
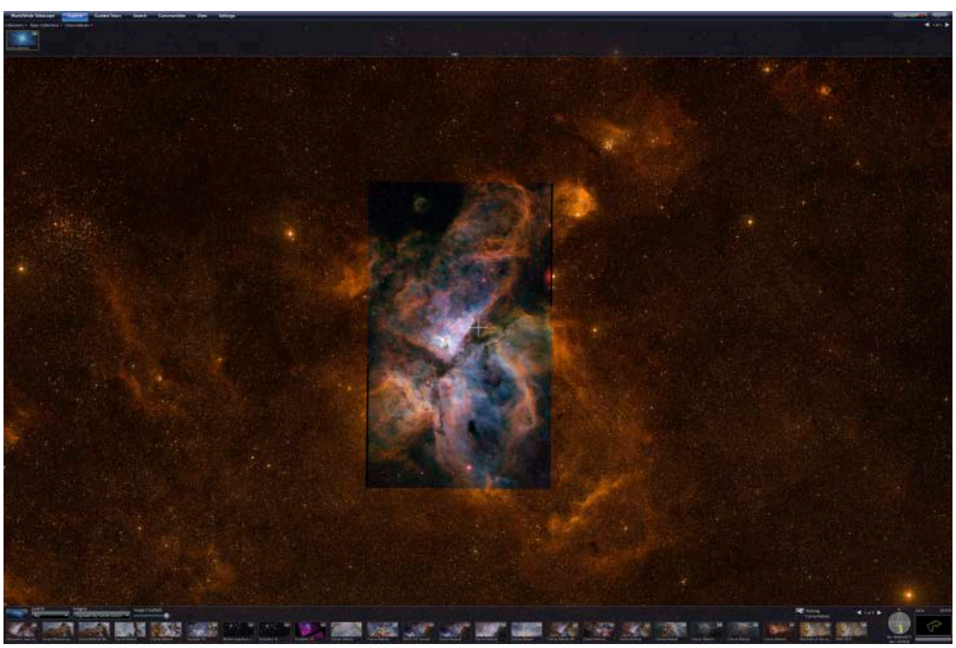


Figure 5: Rubin Skyviewer showing a large field around the center of the Milky Way. *Credit: RubinObs/NOIRLab/SLAC/NSF/DOE/AURA*

The **Rubin Skyviewer** is an implementation of Aladin Lite inside a React.js wrapper. The application is backed by a content management system for creators to make annotations highlighting points of interest or objects in images. The Skyviewer has two modes of operation: free exploration of an all-sky image of Rubin's 18,000-square-degree footprint and guided tours set up by content creators. These two modes of exploration were determined via needs assessment work, which identified a desire for orientation and guidance when users are confronted with a complex dataset. The tours are designed to create a feeling of familiarity and empower the public to feel comfortable exploring independently. The Rubin Skyviewer will be released at the time of Rubin Observatory's first public image release.



WorldWide Telescope

WorldWideTelescope (WWT; Rosenfield et al. 2018) selected Hierarchical Triangular Mesh (HTM) as the standard for data visualization in the early stage of development. WWT has also supported HiPS and FITS imagery and catalogs since 2022.

Figure 6: WorldWideTelescope used to be a stand-alone app, but since 2009 has been offered in a browser-based version seen here. *Credit: AAS/World-Wide Telescope*

Figure 7: A full-screen example of a browser-based embedding of OpenSeadragon tiling used on cosmetically cleaned NOIRLab press release images. It is possible to zoom above 100%, which is helpful on very high resolution screens. The controls are in the upper left. *Credit: CTIO/NOIRLab/DOE/NSF/AURA*

OpenSeadragon

OpenSeadragon offers a fast and smoothly running JavaScript open-source zoomable image viewer with its own rectangular-shaped tiling mechanism for flat projection. At NOIRLab it is used as an interactive exploration tool for all public outreach images. OpenSeadragon is fast, seamless, and easy to work with. As Aery (2015) puts it: *"Arthur C. Clarke's Third Law states, 'Any sufficiently advanced technology is indistinguishable from magic.' And looking at high-res images in OpenSeadragon feels pretty darn magical."*

Conclusion

The advent of sophisticated Skyviewer tools makes it possible to render enormous imaging datasets in a way that makes them ready for exploration.The possibilities for more interactively experiencing datasets should be explored further, especially in presenting time-domain datasets. As the construction of the Rubin Observatory is drawing to a close over the next months, Skyviewers promise to be ever more relevant for the exploration of large astronomical datasets.

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