The Mirror

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The tattered shell of the first-ever recorded supernova was captured by the US Department of Energy-fabricated Dark Energy Camera, which is mounted on the National Science Foundation's (NSF) Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory in Chile, a Program of NSF's NOIRLab. A ring of glowing debris is all that remains of a white dwarf star that exploded more than 1800 years ago when it was recorded by Chinese astronomers as a "guest star." This special image, which covers an impressive 45 arcminutes on the sky, gives a rare view of the entirety of this supernova remnant. *Credit: CTIO/NOIRLab/DOE/NSF/AURA*

T.A. Rector (University of Alaska Anchorage/NSF's NOIRLab), J. Miller (Gemini Observatory/NSF's NOIRLab), M. Zamani & D. de Martin (NSF's NOIRLab)

THE MIRROR

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Editor-in-Chief
Tod R. Lauer

Design & Layout
Joy Pollard
Pete Marenfeld

Production Manager
Peter Michaud

Associate Editor
Sharon E. Hunt

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On the cover:

In this montage, the background image is a visual representation of the galaxies observed during the Dark Energy Spectroscopic Instrument (DESI) Survey Validation and published in the first DESI Data Release. The "rays" represent different lines of sight along which the galaxy redshifts were measured, showing the clustering of galaxies with distance. In the foreground, an image of the Mayall 4-meter Telescope on Kitt Peak showing DESI mounted on the top end of the telescope. See the collection of Science Highlights that focus on Dark Energy research at NOIRLab. *Credit: Background: David Kirkby, UC Irvine; Foreground Image: NSF's NOIRLab/DOE photograph by P. Marenfeld (NSF's NOIRLab); Montage: Joy Pollard (NSF's NOIRLab)*

Directorate Perspective

Science Highlights

CSDC

Gemini

MSO

Vera C Rubin

US-ELTP

CEE

In Memoriam

10.5281/zenodo.8284424

Director's Message

Patrick McCarthy

In this edition of *The Mirror*, we mark the 25th anniversary of the discovery of Dark Energy with a number of contributions from the key people, and NOIRLab facilities, involved in its discovery and follow-ups. We are privileged to have their contributions and to share in their recollections of key events in the history of cosmology and astrophysics. Only in astronomy will one see a celebration of the 25th anniversary of the discovery of … *we don't really know what!* Dark Energy drives the acceleration of the cosmic expansion and will play an increasingly dominant role in the future of the Universe on the largest scales. The nature of dark energy, however, is still poorly understood. How we got to this point in science is an interesting story that our guest authors share with us.

Behind this landmark scientific breakthrough is a story of decades of hard work, innovation, creativity, and perseverance. Many people over many years helped set the stage for this discovery, and much work was needed to bring it to fruition. This story is told in the pages of this issue, and the facilities and staff of NOIRLab's predecessor organizations feature prominently in the narrative.

There were many steps on the path to making supernova cosmology a reality. A key first requirement was a wide-field imaging capability powerful enough to allow large areas of the sky to be surveyed for supernovae. The survey needed large blocks of nights, only available through the survey/long-term proposal option offered by NOAO at the time. It required large-format linear detector arrays in cameras with large and well-corrected fields of view. The surveys needed to reach faint levels to allow access to SNe at interesting redshifts. While Type 1a SNe are luminous, they are faint when seen at cosmological distances.

The 4m telescopes at KPNO and CTIO were just the right tools for this work. The Mosaic camera at the prime focus of the Blanco 4m telescope was the engine for the supernova cosmology project of Schmidt et al. and the program by Perlmutter et al. Discovering faint SNe is not easy. In addition to the primary survey, one needs follow-on observations to detect transient objects. Sophisticated software is needed to find SNe amongst the light of their host galaxies. Image subtraction is the technique of choice – but quite a bit of software is needed to match the point-spread-functions and avoid thousands of false positives that would swamp true SNe transients.

Making sense of the SNe detections requires a deep familiarity with the spectra and lightcurves of the many varieties of supernovae. Type 1a SNe are not *standard candles,* rather they are *calibratable candles*, and one needs precise and dense sampling of the lightcurves to perform the necessary calibrations. The correlation between the rate of decline and absolute magnitude was key to making Type 1a SNe useful for cosmology. All of this was made possible through the early development of *time-domain astrophysics*. Spectroscopy is the complement of time-domain imaging – it allows classification of the phenomena and was essential to bringing clarity to the Type 1a phenomenon. None of this is possible without a suitable communications infrastructure that alerts observers, and observatories, to candidate transients in time to allow follow-up observations before they fade beyond reach.

It is remarkable that much of the mission of NOIRLab in the 21st century is rooted in the discovery of Dark Energy and the techniques that made it possible in the last century. The Dark Energy Camera took up the challenge where the Mosaic cameras left off to survey a large fraction of the southern sky to faint levels with good time coverage. The GMOS spectrographs on Gemini North & South proved to be powerful tools for low-resolution SNe spectroscopy and classification.

The Rubin Observatory will take dark energy research to the next level with both a next-generation wide-field deep time-domain survey, plus an ambitious full southern-sky weak lensing survey. Sophisticated detection algorithms, real-time alerts, and a network of telescopes and instruments will enable the detection and characterization of thousands of SNe to be used as probes of the expansion history of the Universe. Exquisitely precise image-shape analysis will isolate the subtle large-scale weak lensing signal that will testify to the effects of Dark Energy on the growth of structure over cosmological time. Photometric redshifts will allow us to measure peaks in the power spectrum imprinted by baryonic acoustic oscillations. Decades of development have gone into building the telescope, the powerful camera, the software, the science platform, and the community of scientists needed to make this a reality.

NOIRLab and the community of users have created powerful event brokers (including ANTARES) and a network of follow-up capabilities linked by sophisticated software (AEON) to allow scientists to follow up on all manner of transients from Rubin's LSST. Gemini, SOAR, and other telescopes with powerful spectrographs will be the key astrophysics machines for Rubin follow-up.

As we reflect on 25 years of Dark Energy, we can look forward to another 25 years of discovery with Rubin, Gemini, and the 4m telescopes (and software!) playing key roles. Before the Rubin Observatory was "Rubin" or "LSST," it was the *Dark Matter Telescope;* it may well turn out to be the *Dark Energy Telescope*.

10.5281/zenodo.8284490

Rapid Rise in Light Pollution Estimated by NOIRLab's Citizen-Science Program

Connie Walker (NSF's NOIRLab)

As astronomers, we are inherently concerned about light pollution affecting our research as well as the environment around us, our health, and our level of energy consumption.

The artificial glow of the night sky is a form of light pollution; its global change over time is not well known. Developments in lighting technology complicate any measurement because of changes in lighting practice and emission spectra.

NOIRLab has had an international citizen-science campaign running for the last 17 years, Globe at Night. Globe at Night invites people from around the world to compare the campaign's monthly featured constellation with the charts shown in its app. The charts represent different limiting stellar magnitudes. Hence charts with fainter magnitudes represent less light-polluted skies because more stars are seen.

In a recent paper by Kyba et al. (2023), we investigated the change in global sky brightness from 2011 to 2022 using 51,351 Globe at Night citizen-scientist observations of naked-eye stellar visibility (Figure 1). The number of visible stars decreased by an amount that can be explained by an increase in sky brightness of 9.6% worldwide per year (10.4% in North America) in the human-eye visible band (Figure 2). This is equivalent to doubling the sky brightness every eight years! This increase is faster than emissions changes indicated by satellite observations (2%). This is mainly because the satellites are not sensitive to the wavelengths (shorter than 500 nm) at which white LEDs (primarily from cities) peak or to light emitted horizontally. In addition, blue light is more effectively scattered in the atmosphere than other colors. These two effects give a possible reason for the lower estimate from orbital-based light pollution measurements versus the ground-based estimates studied by Kyba et al.

We draw two conclusions from these results. First, the naked-eye visibility of stars is deteriorating rapidly despite (or perhaps because of) the introduction of LEDs in outdoor lighting applications. Existing lighting policies are not preventing increases in skyglow, at least on continental and global scales. Second, the use of

Figure 1: The light pollution of Tucson, Arizona, can be seen in the backdrop of this photo of Kitt Peak National Observatory, with the Nicholas U. Mayall 4-meter Telescope featured prominently. In addition to being an aesthetic blight, light pollution poses one of the greatest risks to astronomical research at Kitt Peak, drowning out the natural starlight and the light from distant asteroids, comets, galaxies, quasars, and other objects in the night sky.
Credit: KPNO/NOIRLab/NSF/AURA/B. Tafreshi

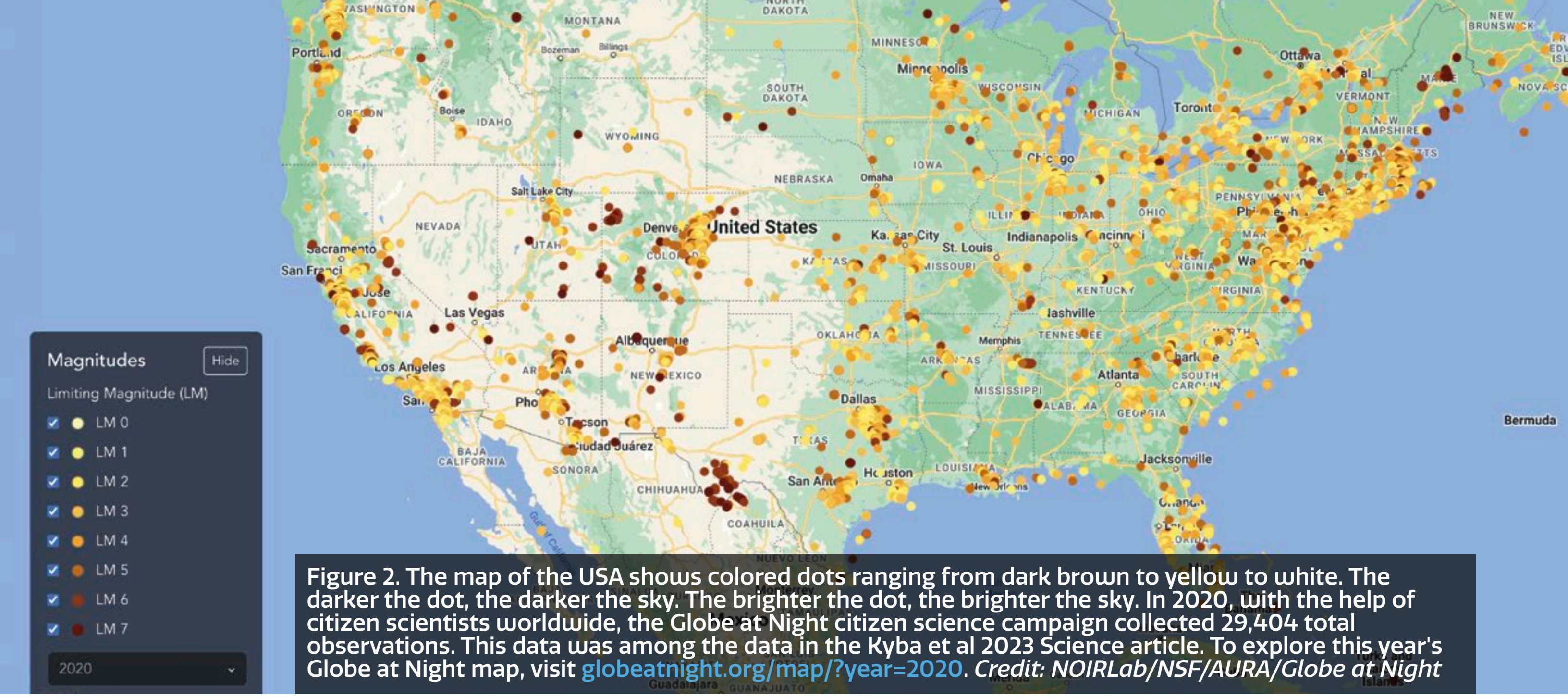


Figure 2. The map of the USA shows colored dots ranging from dark brown to yellow to white. The darker the dot, the darker the sky. The brighter the dot, the brighter the sky. In 2020, with the help of citizen scientists worldwide, the Globe at Night citizen science campaign collected 29,404 total observations. This data was among the data in the Kyba et al 2023 Science article. To explore this year's Globe at Night map, visit globeatnight.org/map/?year=2020. *Credit: NOIRLab/NSF/AURA/Globe at Night*

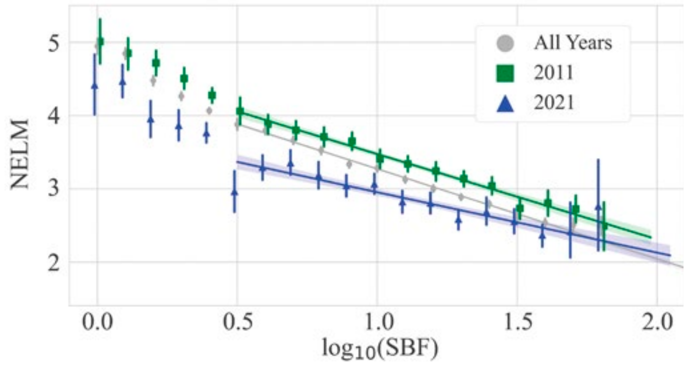


Figure 3: Relationship between naked-eye limiting magnitude estimated by Globe at Night participants and the modeled artificial brightness of the night sky in 2014. "Sky brightness factor" (SBF) is the ratio of total radiance to natural sky radiance, so a factor of 1 here means the sky is 10 times brighter than starlight. The relationship is shown for two separate years (green, blue) and all years together (gray). Smaller naked-eye limiting magnitude (NELM) values mean a brighter sky. The fit lines are calculated only for log10SBF>0.5, which corresponds to about 3 times brighter than starlight. *Credit: Kyba et al. 2023*

naked-eye observations by citizen-scientists provides complementary information to datasets from satellites.

Skyglow from light pollution can be reduced. The DarkSky strategies for cutting light pollution are straightforward: use outdoor lighting only when, where, and how it is needed; minimize blue light content; and use fully shielded fixtures. As the results from the Kyba et al. study indicate, more effort is needed to put these recommendations into ordinances, bylaws, and other regulations to slow down and hopefully reverse the degradation of our shared night sky.

Reference

Kyba, C. C. M., Altıntaş, Y. Ö., Walker, C. E., Newhouse, M. 2023, Sci, 379(6629), 265. doi.org/10.1126/science.abq778

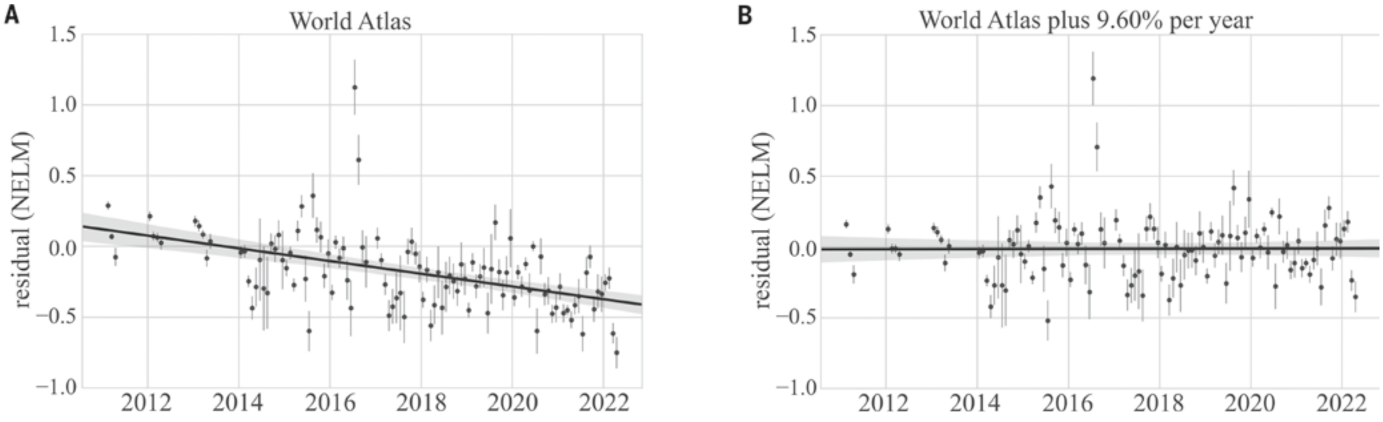


Figure 4: The fit residuals (observed minus expected) for naked-eye limiting magnitude are shown with (a) the standard World Atlas prediction and (b) the Atlas adjusted for an annual exponential growth of 9.60% per year. Larger values mean observers reported more stars than expected. Note that data points before 2014 include a larger number of observations than those after 2014. Error bars show the standard error. *Credit: Kyba et al. 2023*

10.5281/zenodo.8284511

IAU Symposium #385

"Astronomy and Satellite Constellations: Pathways Forward"

La Palma, Canary Islands, Spain, 2–6 October 2023

Connie Walker (NSF's NOIRLab)

Regarding astronomy and satellite constellations, are you interested in

- the latest news on the impact of satellite constellations on astronomy?
- meeting the people at the forefront of this work?
- sharing your knowledge and efforts in this area through networking or contributed talks?
- helping to shape the next steps in protecting our dark and quiet skies from satellite constellation interference?

Then please join us online or in-person for the IAU Symposium on Astronomy and Satellite Constellations: Pathways Forward on the island of La Palma in the Canary Islands of Spain from 02 to 06 October 2023.

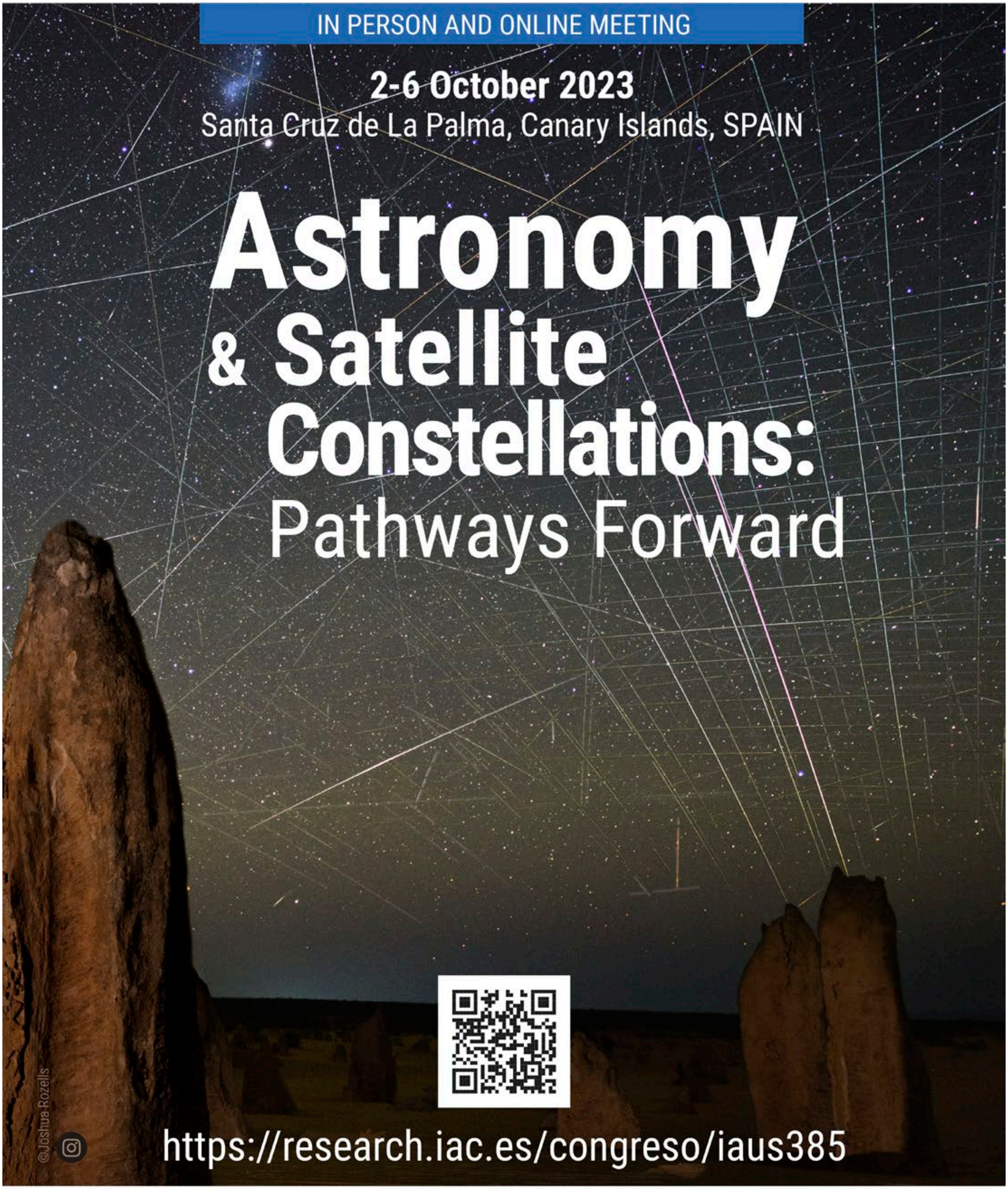
The proliferation of satellites launched into orbit around the Earth has improved our ability to instantly communicate globally; however, there are concerns about the impact these technologies have on astronomical observations and the preservation of dark and quiet skies. The rapid growth in light pollution, which is exacerbated by the new satellites, affects the entirety of society. Many people have never seen a truly dark night sky, and over a third of humanity cannot see the Milky Way. These new satellites are encroaching on the few remaining dark-sky reserves and radio-quiet zones.

To address these challenges, IAU Symposium 385 is being held with the support of the International Astronomical Union (IAU)'s newest specialist center, the Center for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference (CPS), and co-hosted by NSF's NOIRLab and the Square Kilometer Array Observatory (SKAO). The symposium's local organizer is the Instituto de Astrofísica de Canarias. Information on the members of the local and scientific organizing committees is available on the symposium organizers web page.

The symposium is planned as a dedicated space where astronomers, industry, space lawyers, and other interested stakeholders can share the current status of their work with respect to large satellite constellations and the impact on astronomy and the night sky. Through presentations, panel discussions, and networking, the current status of studies, observations, and mitigations will be explored, and gaps will be addressed to help define further the pathways forward.

Visit the symposium website for more information, including details on registration and fees payment.

IAUS385 SYMPOSIUM



IN PERSON AND ONLINE MEETING

2-6 October 2023

Santa Cruz de La Palma, Canary Islands, SPAIN

Astronomy & Satellite Constellations:

Pathways Forward

https://research.iac.es/congreso/iaus385

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CPS IAU NOIRLab SKAO

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The Past, Present, and Future of Dark Energy Research with NOIRLab Facilities

Tod R. Lauer (NSF's NOIRLab)

This year marks the 25th anniversary of the discovery of the accelerating expansion of the Universe and the implication that it was being powered by some mysterious form of "dark energy." There is no question that this is the most startling discovery in cosmology since 1965, when Arno Penzias and Robert Wilson discovered the cosmic microwave background, thus almost instantly establishing the Big Bang as the dominant theory of the origin of the Universe.

It has been a particular delight to me as a member of the NSF's NOIRLab scientific staff that the discovery was made by teams using NOAO telescopes and instruments.[1] Both the High-Z Supernova Search Team, led by Brian Schmidt, and the Supernova Cosmology Project, led by Saul Perlmutter, requested time through the standard open NOAO time allocation process. The famed searches for SN Ia and their photometric follow-up took place on the Cerro Tololo Inter-American Observatory (CTIO) Víctor M. Blanco 4-meter Telescope, enabled by a wide-field CCD camera. But well before that, both teams benefited from a plethora of precursor programs done with a variety of NOAO telescopes at both Kitt Peak National Observatory (KPNO) and CTIO, again using time awarded by the standard open time allocation process.

As they say, the rest is history. In this issue of *The Mirror*, we offer a set of science highlight articles to celebrate the role of NOAO in the discovery of dark energy as well as to describe the observational work supported by NOAO that followed, work that continues now using NOIRLab facilities. The first two articles are informal first-person histories of the High-Z Supernova Search Team by Adam Riess and Brian Schmidt and of the Supernova Cosmology Project by Saul Perlmutter, all of whom in 2011 were awarded the Nobel Prize in Physics for their discovery of the accelerating expansion of the Universe. Follow-up work in the first decade of this century drew heavily on NOAO facilities, and Michael Wood-Vasey recounts an ambitious program, done through the NOAO survey program, that provided some of the first observations tightening our understanding of the dark energy equation of state.

As was quickly realized, high-precision studies of the evolution of the dark energy equation of state over cosmological time would require new instrumentation and dedicated long-term surveys covering large fractions of the sky. The resulting Dark Energy Survey (DES) is one such example of this. The DES was a partnership between the Department of Energy (DOE)'s Fermilab and NOAO, which led to the deployment of the Dark Energy Camera at the Blanco telescope. The DES is described in the article by Chihway Chang et al.

The soon-to-be commissioned Vera C. Rubin Observatory Simonyi Survey Telescope, which will be operated by NOIRLab, was justified because of its ability to test the evolution of the dark energy equation of state over cosmological time. The Dark Energy Spectroscopic Instrument (DESI), developed and operated by DOE's Lawrence Berkeley National Laboratory, has begun operating on the KPNO Nicholas U. Mayall 4-meter Telescope. NOIRLab is providing access to DESI data to the community. NOIRLab astronomers Stéphanie Juneau and Adam Bolton summarize the DESI Early Data Release, now available for archival research. Meanwhile, Katrin Heitmann et al. describe the LSST Dark Energy Science Collaboration, which will use the Telescope in a multi-pronged approach to achieve this goal.

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[1] The National Optical Astronomy Observatory (NOAO) joined with the International Gemini Observatory and Vera C. Rubin Observatory Operations, to become NSF's NOIRLab in 2019.

10.5281/zenodo.8284543

The Origins of the High-Z Supernova Search Team and the Discovery of the Accelerating Universe

Adam Riess (STScI/JHU) and Brian Schmidt (ANU)

The National Optical Astronomy Observatory (NOAO), and specifically its southern hemisphere facility the Cerro Tololo Inter-American Observatory (CTIO), now both part of NSF's NOIRLab, played a key role in the discovery of the accelerating Universe. On the occasion of the 25th anniversary of the publications that announced this unexpected finding, we discuss the role our High-z Supernova Search Team and CTIO played in this startling discovery.

In 1986, the nearest supernova discovered since 1972 (SN 1986G), which fell into the then newly designated Type Ia class, appeared in Centaurus A. It was a time of peak *Hubble* Constant controversy, with camps polarized between values of H_0=50 and 100 km/s/Mpc. Work in 1984 and 1985 separated the type I class of supernovae in two, with one class clearly resulting from the demise of stripped massive stars (SN Ib/Ic) and the other, SN Ia, presumed to be some form of Chandrasekhar mass thermonuclear detonation of a white dwarf. Quality data were sparse, but were consistent with SN Ia being a highly uniform group of objects that held great promise for measuring accurate distances over cosmologically large scales.

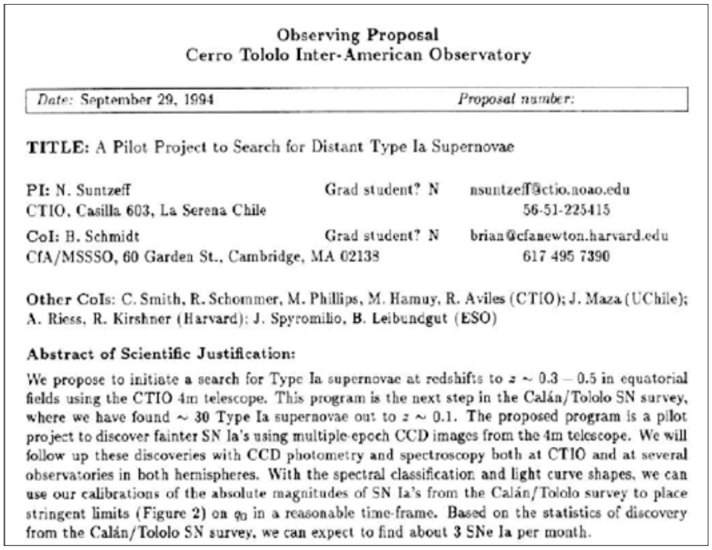
Mark Phillips led a program to observe SN 1986G from CTIO, with spectra and photometry from the optical through IR. It was one of the first digital datasets, using state-of-the art equipment that had recently been deployed at CTIO. SN 1986G was highly obscured by dust. There wasn't that much to compare it to, but Brian remembers Mark telling him that it did seem odd relative to what a SN Ia was supposed to be. This observing campaign was the beginning of CTIO's major role in producing and analyzing the digital datasets that underpin modern supernova studies.

In 1990, Brian travelled with his PhD supervisor, Bob Kirshner (later Adam's as well), to Les Houches to attend a five-week supernova workshop. There, they met Mario Hamuy, who was working at CTIO as a research assistant for CTIO astronomer Nick Suntzeff. Mario was well known for the photometric data that he and Nick had amassed on SN 1987A in the Large Magellanic Cloud.

Mario told the workshop of a new project, the Calán/Tololo Supernova Survey, which would use the Curtis Schmidt telescope at CTIO to discover objects at redshifts more distant than the objects we were all studying. By discovering SN at 0.02 < z < 0.1, the Calán/Tololo survey aimed to rigorously test SN Ia as standard candles, using the redshift as an accurate proxy for relative distance. The members of this group — Mario, Nick, and Mark at CTIO, and José Maza at the University of Chile — were starting their program that year.

When Brian visited CTIO in 1991 to work with the group on his thesis for a month, the Calán/Tololo survey was well underway. A few days after arrival, Mario showed off some of his first couple of objects. One of them, SN 1990af, looked pretty normal with respect to its spectrum, but compared to the average Leibundgut SN Ia template, it clearly rose and fell more quickly. More significantly, SN 1990af was fainter than the other objects, despite being at the same redshift. Mario was a bit depressed, because he felt that the Calán/Tololo program to use SN Ia to measure H_0 might be a dead end. But 1991 was a transformational year for SN Ia, being the year that 1991bg (faint, fast-evolving) and SN 1991T (bright, slow-evolving) appeared, which made it clear that SN Ia were definitely not identical photometrically or spectroscopically.

In 1993, based on the range of objects being studied in the nearby universe including SN 1991T and SN 1991bg, and consistent with the picture that was emerging from the Calán/



Observing Proposal
Cerro Tololo Inter-American Observatory

Date: September 29, 1994	*Proposal number:*

TITLE: A Pilot Project to Search for Distant Type Ia Supernovae

PI: N. Suntzeff — Grad student? N — nsuntzeff@ctio.noao.edu
CTIO, Casilla 603, La Serena Chile — 56-51-225415

CoI: B. Schmidt — Grad student? N — brian@cfanewton.harvard.edu
CfA/MSSSO, 60 Garden St., Cambridge, MA 02138 — 617 495 7390

Other CoIs: C. Smith, R. Schommer, M. Phillips, M. Hamuy, R. Aviles (CTIO); J. Maza (UChile); A. Riess, R. Kirshner (Harvard); J. Spyromilio, B. Leibundgut (ESO)

Abstract of Scientific Justification:

We propose to initiate a search for Type Ia supernovae at redshifts to $z \sim 0.3 - 0.5$ in equatorial fields using the CTIO 4m telescope. This program is the next step in the Calán/Tololo SN survey, where we have found ~ 30 Type Ia supernovae out to $z \sim 0.1$. The proposed program is a pilot project to discover fainter SN Ia's using multiple-epoch CCD images from the 4m telescope. We will follow up these discoveries with CCD photometry and spectroscopy both at CTIO and at several observatories in both hemispheres. With the spectral classification and light curve shapes, we can use our calibrations of the absolute magnitudes of SN Ia's from the Calán/Tololo survey to place stringent limits (Figure 2) on q_0 in a reasonable time-frame. Based on the statistics of discovery from the Calán/Tololo SN survey, we can expect to find about 3 SNe Ia per month.

Figure 1: Our first proposal to measure q_0

Tololo survey, Mark Phillips wrote his seminal paper that compared the amount that a SNIa faded over 15 days after peak (Δm_{15}) to its luminosity, finding that faster-falling objects were systematically fainter than their slower-falling counterparts. Adam, then a first-year graduate student working with Bob Kirshner and Bill Press, began a monitoring campaign at the Fred Lawrence Whipple Observatory to classify SN reports and collect SN Ia light curves in the North, the Center for Astrophysics (CfA) I sample (1993–1996), while developing a method to correlate the whole SN Ia light curve shape with luminosity.

In 1994, Mario visited Harvard where Brian was now a postdoc and Adam a second-year graduate student. Using the Δm_{15} relation on the completely independent Calán/Tololo dataset, he showed us that the scatter of the SN Ia distances around the *Hubble* line was 7% — a massive improvement on any other distance measure at the time that could probe the *Hubble* flow. This dataset (29 SN Ia) and the CfA I sample (22 SN Ia) underpinned Adam's development of his Multi Light Curve Shape (MLCS) method for SN Ia distances, which also combined corrections for the Phillips relation with color corrections to account for reddening by dust. In March of 1994, Saul Perlmutter of the Supernova Cosmology Project (SCP) enlisted the help of Bob, Adam, and Peter Challis on an observing run at the MMT to classify the highest redshift SN Ia yet observed at that time, SN 1994G at $z=0.425$ (IAUC 5956), which the SCP discovered at Kitt Peak National Observatory (KPNO), NOAO's northern-hemisphere facility.

In mid-1994, Brian once again returned to CTIO for an unrelated observing program on the 1.5m telescope. Based on the accuracy of SN Ia distances from the CTIO and CfA work, and the demonstration by the SCP and collaborators that SN Ia could be discovered and classified, he and Nick hatched a plan to use the CTIO 4m (named the Víctor M. Blanco 4-meter Telescope in 1995) to extend the approach of the Calán/Tololo survey to $z > 0.3$ while adding digital image subtraction methods. The advantage of the CTIO 4m is it had an extremely good 2k × 2k imager (covering 15′ × 15′) at a site that offered 95% clear weather for parts of the year. The High-Z team was formed in the second half of 1994, and our first proposal was submitted on 29 September 1994.

Brian moved to Australia at the end of 1994 and began developing a data reduction pipeline to process SN-search images. As we started to implement the pipeline at CTIO, it became clear we had a problem or two. The CTIO computing system had substantial differences from the system Brian was using in Australia, which prevented the software from running. To confound matters, the internet connection between Australia and Chile was about 1 character per second.

Our first observations were taken on 25 February 1995, and we had another night's data on 06 March. The processing of this data was an unmitigated disaster—nothing seemed to work, and Brian could not get the data to Australia to diagnose what was going wrong. We resorted to emailing tiny 16 × 16 pixel stamps of interesting things to Australia (the only method at the time to get data across the slow connection). These little mini images, combined with as vivid descriptions as could be mustered by telephone, were the basis of the entire team at CTIO working together to slowly fix the pipeline.

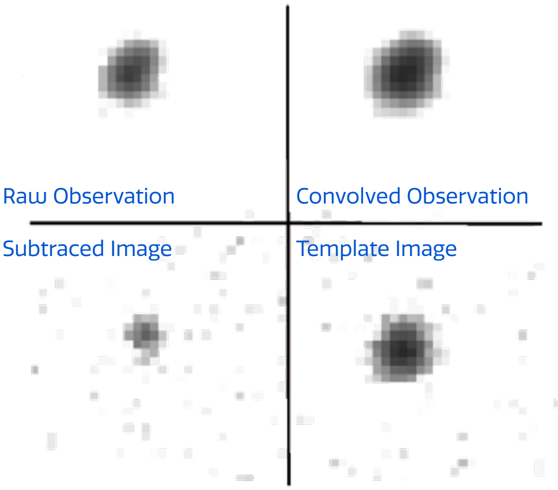


Figure 2: Object C14 – actual finding chart
(complete with typo)

We had two more nights on 24 and 29 March 1995, while having a proposal to write for a continuation of our program due on 30 March. Around 27 March, the pipeline started to produce interesting objects, and searching the data from 29 March, we discovered a single object, C14, later named SN 1995K, that got everyone excited. It was a new object, buried in a spiral galaxy. It didn't move, and it appeared to be possibly fainter in our poor data from 24 March.

Using the CTIO 4m spectrograph, Mark was able to obtain a spectrum of the galaxy — it was at a redshift of $z = 0.48$ — making it potentially the most distant SN yet detected. This was followed up with confirmation of it being a SN Ia at ESO a few days later by Bruno Leibundgut and Jason Spyromilio.

For the next five years, twice a year, we would converge in Chile (and starting in 1997, in Hawai'i to use the Canada France Hawaii Telescope 4m) to use the CTIO 4m Blanco telescope to find supernovae, which would then be classified and followed-up with telescopes across Chile, and in Hawai‘i (including Alex Fillipenko, his group, and Adam at Keck). The Blanco imager was upgraded to the BTC (Big Throughput Camera) through the efforts of Tony Tyson and colleagues, and the CTIO 4m telescope remained the workhorse of both the High-Z and SCP teams. Group members of both High-Z and SCP passed each other at airports and observatory control rooms like ships in the night.

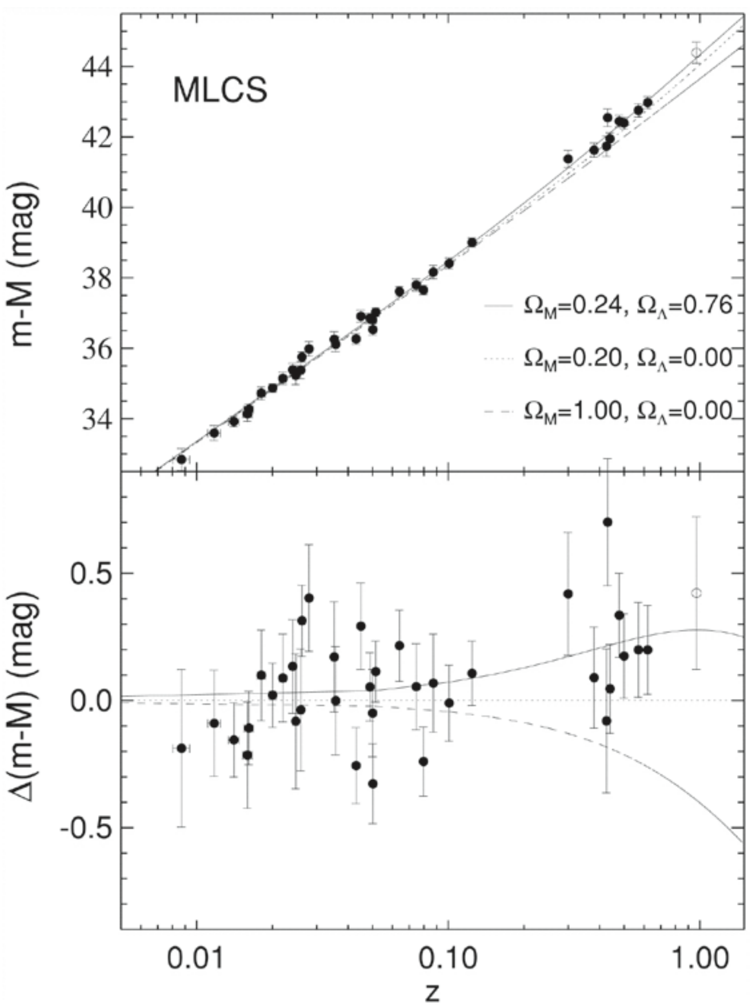


Figure 3: The top panel shows a *Hubble*-diagram of SN Ia photometrically-estimated distance modulii as a function of redshift, with the predictions from three different cosmological models shown. The bottom panel shows the residuals from the $\Omega_M = 0.2$, $\Omega_\Lambda = 0.0$ model, which had been the observationally favored cosmological model at the time. The high-redshift SN are markedly fainter than expected. With the $\Omega_\Lambda = 0.7$ model, which implies accelerating expansion over the redshift interval shown, the data are now explained. *Figure from Riess et al. (1998).*

Only in 1996 did we apply to use the KPNO 4m telescope, which we were rejected for in favor of the SCP. Informal feedback to Brian from a member of the KPNO Time Allocation Committee (TAC) at the time was the complaint that SCP had seven objects consistent with Ω_M~1, while we had only one. And while ours had the smallest uncertainty, it was deeply in negative q_0 territory — feedback indicated that the TAC didn't think we had our act together. While Brian was not very unhappy at the time with that feedback — we dodged a bullet. The importance of consistent clear weather with good seeing cannot be understated. When discoveries require two epochs to be made, success is proportional to P(good weather).[2] For CTIO P ~95% compared to KPNO where P ~60%, a huge difference for the success of our project. The High-Z team simply did not have the human power to discover SN at both KPNO and CTIO simultaneously and could not afford following up a search run that only had a 1/3 chance of success.

Each observing run was organized chaos. Brian would arrive a week before observations were scheduled, with the latest version of the software. Since we did not have dedicated equipment, the whole pipeline would be re-built at the beginning of each run. Due to the size of our dataset, we needed to operate across essentially all available machines and disks of the observatory — and this was hardware that changed with each run. The week inevitably ended with the entire team working 20-hour days to ensure that we were able to promptly discover supernovae. Probably the best sense of an observing run was captured in the 2000 PBS documentary, “Runaway Universe.” Adding to the stress was a hard deadline set by the Space Telescope Science Institute (STScI) to provide targets for our nascent *Hubble Space Telescope* (*HST*) Program. A slot in the *Hubble* schedule was held for us within a ~1 degree search radius, with final coordinates to be provided on the first Tuesday by noon following the search. At the time, *HST* was so new that failing to find a target, and shooting blank sky, was unthinkable.

Despite the chaos, through 1995 to 1997, we did manage to discover, spectroscopically confirm, and photometrically follow 16 distant SN Ia — enough to, in theory, make a statistically robust measurement of the deceleration parameter.

But analysis of high-redshift SN Ia data was not straightforward. Undertaking the K-corrections to convert the redshifted data to a common frame was hard, and here, CTIO led the way. Accurate K-corrections require accurate understanding of bandpasses and accurate spectrophotometry of SN Ia as they evolve. Nick and Mario went through the process of re-observing spectrophotometric standards with the new instrumentation to provide higher quality standards. This spectrophotometry was used by the CTIO group, the High-Z team, and people around the world to improve the quality of spectrophotometry of SN Ia, and it was also a key ingredient to understand the bandpasses we were using to calculate the K-corrections. Likewise, the use of SN colors to account for extinction was a tricky task, with the team using an early-for-the-day Bayesian formalism developed by Adam in MLCS to infer extinction from colors. An initial analysis from just 4 SNe Ia led by Peter Garnavich in late 1997/early 1998 reached a landmark conclusion that the Universe was at least not strongly decelerating ($\Omega_M < 1$).

Adam then led the analysis of the full sample. When the calibrated photometry was in, Adam's MLCS and the Mark Phillip's Δm_{15} were used to derive the light curve shape corrections, which along with the redshifts, color-based extinction measures, K-corrections, and the local sample of SNe from Calán-Tololo and CfA I, provided the foundational ingredients to making the cosmological measurements. The initial analysis perplexed Adam, who couldn't understand why the data preferred a negative value for Omega matter (without the option of a Cosmological constant offered). Further analysis found, no matter what we did, that the Universe was accelerating with > 99.9% confidence. It was not easy for the team to come to terms with such an outlandish proposition. Our strongest test against our biggest concern, SN Ia evolution, was our finding that local SN Ia distances were consistent (i.e., same expansion rate) between old, elliptical hosts and young spirals.

Ultimately we agreed that it was what the data showed, and we needed to publish. We submitted "Observational Evidence for an Accelerating Universe and a Cosmological Constant" to *The Astronomical Journal* on 13 March 1998 (accepted 06 May), a paper which is now the most cited science paper in the field of astronomy and astrophysics (as of last check, over 23,000 citations to date). The fact that the SCP arrived at the same answer independently and in the same time frame made the broader acceptance perhaps a bit easier and faster than most of us expected.

The High-Z SN Search team's discovery of the accelerating Universe was founded with people and instrumentation of CTIO. Twenty-five years on, despite better understanding of dust and the diversity of SN Ia, the data collected largely at CTIO in the 1990s that led to the discovery of the accelerating Universe have held up to a dramatic increase in scale and ever-improving instrumentation. It also marked the start of an important transition where NOAO started supporting large-scale projects, rather than just individual small-N investigator-lead programs. That transition continues apace, leaving many of us feeling nostalgic for the days of the past. But such is the progress of astronomy!

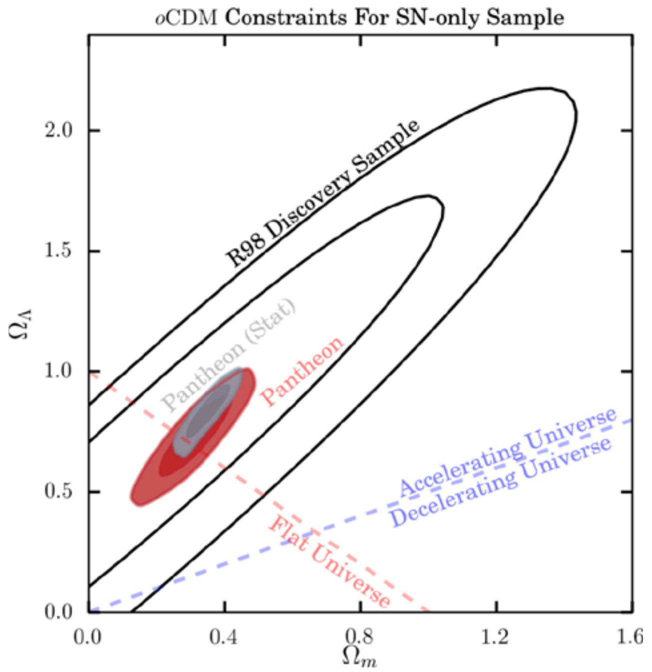


Figure 4: The evidence for dark energy, just using SN Ia alone, has gotten tremendously stronger with each passing year since 1998. This figure shows the recent cosmological parameter constraints provided by the "Pantheon" SN sample of Scolnic et al. (2018). The outer black contours show the original 68% and 85% confidence-interval constraints provided by Riess et al. (1998)

10.5281/zenodo.8284559

NOAO Accelerates the Universe

Saul Perlmutter (University of California, Berkeley and
Lawrence Berkeley National Laboratory)

The NOAO celebration of 25 years of dark energy takes me right back in time to a night in early 1994 in the control room of the Mayall 4-meter Telescope on Kitt Peak, observing deep, wide fields in the I band with Marc Postman and Tod Lauer. We were combining our observing nights since my team's deep supernova search program (the Supernova Cosmology Project), and Marc and Tod's Deep, Wide Galaxy Survey (with Bill Oegerle and John Hoessel) both needed as much deep, wide data as we could get. Observing with Marc and Tod was a new experience: they were past masters at the game and by this point had their patter tuned as they kept themselves amused through the long night of careful work by issuing what I took as Star Trek-style commands to each other (*is that right, Tod?*) as they monitored and adjusted the observations in what they called the Deeprange Project.

For my team, the Supernova Cosmology Project, the stakes were also high, because we had invested a large collection of hard-won telescope nights at multiple telescopes around the world, all scheduled (after much time-trading and cajoling of telescope schedulers) around a new approach to systematizing high-redshift supernova discovery-and-follow-up. In our previous stage of the project, we had managed to demonstrate the ability to discover at least one supernova at very high redshift (z = 0.48), but the follow-up of such a faint object was extremely difficult to obtain through the response to an IAU telegram and calls to observers at the larger telescopes; such a follow-up observation was a much bigger ask than the usual, much brighter, nearby supernova. But now with this coordinated telescope campaign, we were going to show that it was possible to find a whole "batch" of such high-redshift supernova on demand, not just one, and this time discover them all on the rising part of their lightcurves, and all just before New Moon, so that *pre-scheduled* spectroscopy could identify the Type Ia supernova and obtain their redshifts.

We had learned our lesson from the previous observing work, most of which had been clouded out, so this time we were doing the search with double the observing time ostensibly required, scheduling two telescopes back-to-back to observe the same fields from the entirely separate sites on Earth in case either one was clouded (the Isaac Newton Telescope on La Palma was the other site). We also developed a new observing strategy where we would compare observations taken just before New Moon to observations taken just after

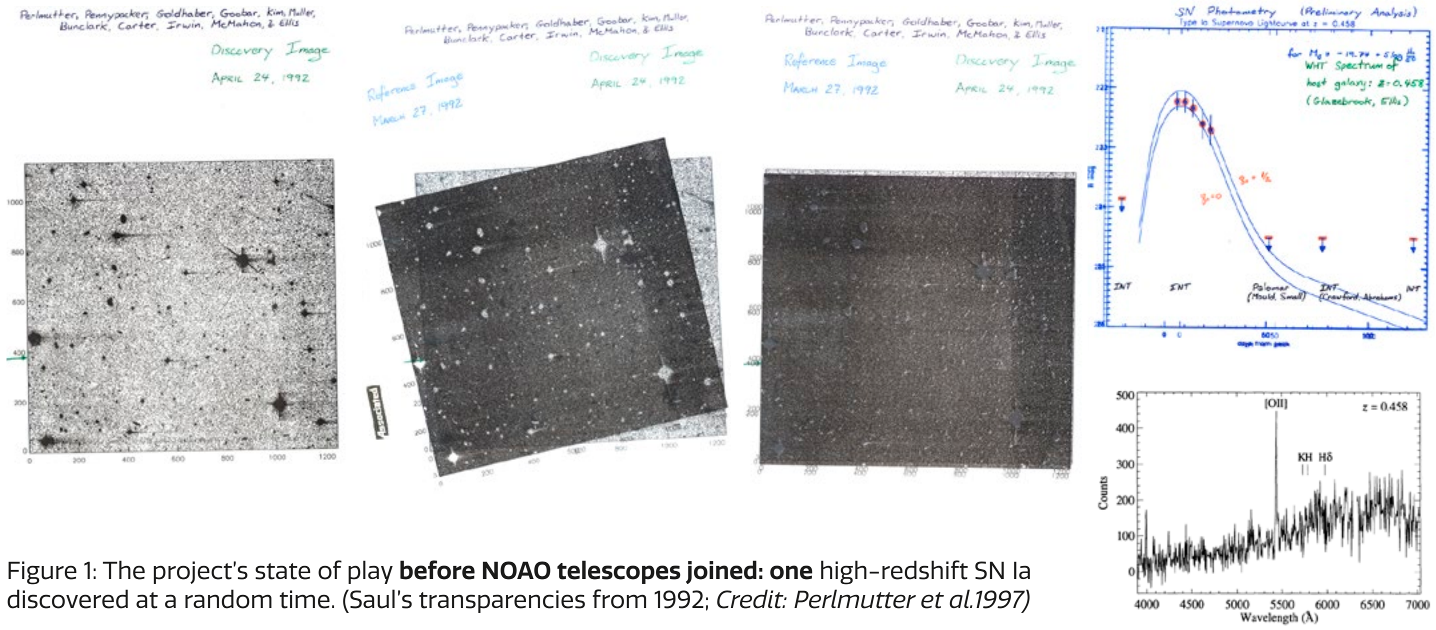


Figure 1: The project's state of play **before NOAO telescopes joined: one** high-redshift SN Ia discovered at a random time. (Saul's transparencies from 1992; *Credit: Perlmutter et al.1997)*

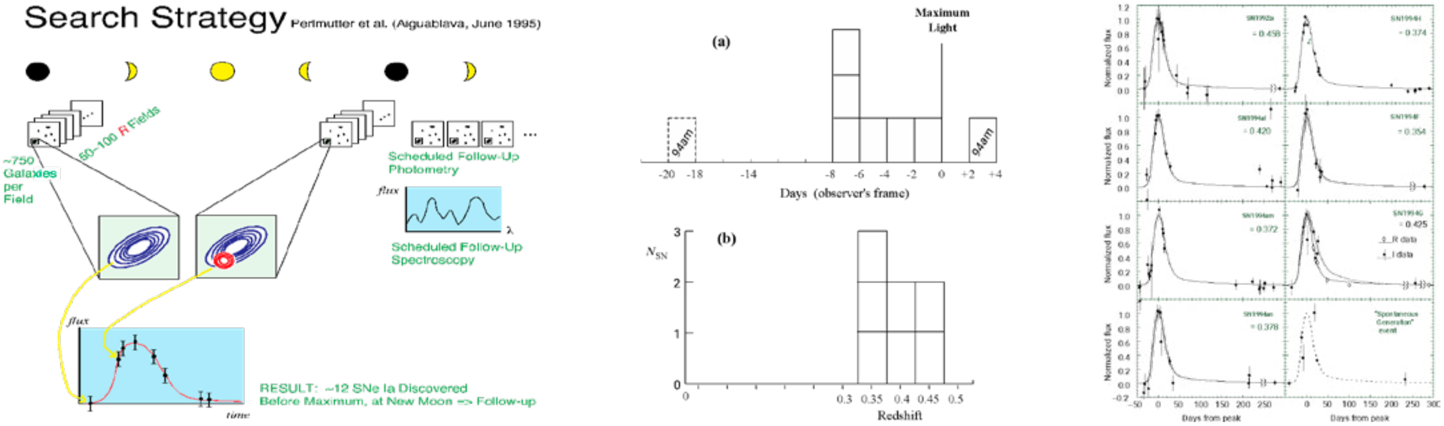


Figure 2: **The KPNO Mayall 4-meter Telescope joins** the project, using the new "batch" search strategy: a half-a-dozen high-redshift SNe Ia discovered at a pre-scheduled date, just before New Moon, and all before their maximum light. (Slides from Saul's Aiguablava presentation to SN community, June 1995; *Credit: Perlmutter et al. 1995)*

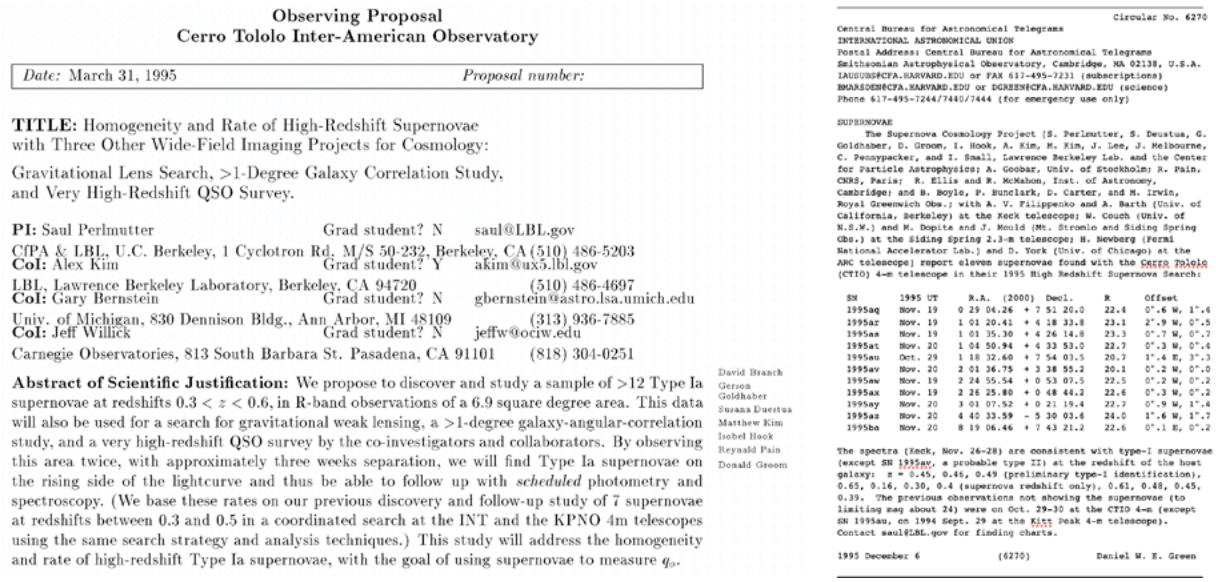
the previous New Moon, thus guaranteeing that a Type Ia supernova discovered in the second observation but not present in the first would not have had time to reach its peak before the following dark time. If we could find and study a few dozen supernovae at redshifts of order z ~ 0.4, we could measure the expected deceleration of the universe's expansion with sufficient accuracy to determine if we live in an open or closed universe, and whether the Universe would last forever or end in a big crunch.

The plan worked, and starting in March of 1994 we were able to send out IAU telegrams with a batch of half-a-dozen newly discovered Type Ia supernovae, all with extensive follow-up observations over their lightcurves. (I'm pretty sure that Marc and Tod had a good Deeprange run, too.) From then on, we could apply for telescope time with a clear demonstration of a successful approach to systematic studies of distant supernovae – and we turned our attention to the new Big Throughput Camera that Gary Bernstein was building with Tony Tyson for NOAO's Cerro Tololo Inter-American Observatory (CTIO) Víctor M. Blanco 4-meter Telescope.

This NOAO facility was the perfect match to our program: the wider-field camera guaranteed more supernova discoveries from each observing run, and the extremely stable, clear Chilean summer weather meant that we had much higher odds of a successful search, so our extensive follow-up campaign at many telescopes wouldn't be wasted. In practice, starting in 1995 we could discover and follow about 10 or more distant supernovae each semester, and other NOAO telescopes and observers in Chile and Kitt Peak were active in these follow-up campaigns. I still am grateful to the great efforts of all the NOAO schedulers and queue-observers to make it possible to systematically catch these live supernovae in action. And NOAO's WIYN queue observing, a novelty at the time, made this work much more efficient. (Thank you Di Harmer, Paul Smith, and Daryl Willmarth, the WIYN queue observers!)

The discoveries were becoming so predictable that we were able to add the *Hubble Space Telescope* (*HST*) to the suite of scheduled follow-up. We realized that we could tell them well in advance which square degrees on the sky would have supernovae discoveries in them, so that the *HST* observing schedule could be laid down in advance, and then we would tweak the coordinates just the week before the observation once we had actually made the discoveries.

Now that we were observing at CTIO with this standardized approach, we began having company in the high-redshift-supernova game. Brian Schmidt, working with NOAO's Nick Suntzeff, began developing a competing team (the High-Z Supernova Team), also using CTIO for searching, building on an experienced group of supernova experts, including members of the earlier Calan/Tololo Supernova Survey. The Calan/Tololo survey was a highly successful low-redshift



Observing Proposal
Cerro Tololo Inter-American Observatory

Date: March 31, 1995	*Proposal number:*

TITLE: Homogeneity and Rate of High-Redshift Supernovae with Three Other Wide-Field Imaging Projects for Cosmology:

Gravitational Lens Search, >1-Degree Galaxy Correlation Study, and Very High-Redshift QSO Survey.

PI: Saul Perlmutter Grad student? N saul@LBL.gov
CfPA & LBL, U.C. Berkeley, 1 Cyclotron Rd. M/S 50-232, Berkeley, CA (510) 486-5203
CoI: Alex Kim Grad student? Y akim@ux5.lbl.gov
LBL, Lawrence Berkeley Laboratory, Berkeley, CA 94720 (510) 486-4697
CoI: Gary Bernstein Grad student? N gbernstein@astro.lsa.umich.edu
Univ. of Michigan, 830 Dennison Bldg., Ann Arbor, MI 48109 (313) 936-7885
CoI: Jeff Willick Grad student? N jeffw@ociw.edu
Carnegie Observatories, 813 South Barbara St. Pasadena, CA 91101 (818) 304-0251

Abstract of Scientific Justification: We propose to discover and study a sample of >12 Type Ia supernovae at redshifts $0.3 < z < 0.6$, in R-band observations of a 6.9 square degree area. This data will also be used for a search for gravitational weak lensing, a >1-degree galaxy-angular-correlation study, and a very high-redshift QSO survey by the co-investigators and collaborators. By observing this area twice, with approximately three weeks separation, we will find Type Ia supernovae on the rising side of the lightcurve and thus be able to follow up with *scheduled* photometry and spectroscopy. (We base these rates on our previous discovery and follow-up study of 7 supernovae at redshifts between 0.3 and 0.5 in a coordinated search at the INT and the KPNO 4m telescopes using the same search strategy and analysis techniques.) This study will address the homogeneity and rate of high-redshift Type Ia supernovae, with the goal of using supernovae to measure q_o.

David Branch
Gerson Goldhaber
Susana Duestua
Matthew Kim
Isobel Hook
Reynald Pain
Donald Groom

Circular No. 6270

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SUPERNOVAE

The Supernova Cosmology Project [S. Perlmutter, S. Deustua, G. Goldhaber, D. Groom, I. Hook, A. Kim, M. Kim, J. Lee, J. Melbourne, C. Pennypacker, and I. Small, Lawrence Berkeley Lab. and the Center for Particle Astrophysics; A. Goobar, Univ. of Stockholm; R. Pain, CNRS, Paris; R. Ellis and R. McMahon, Inst. of Astronomy, Cambridge; and B. Boyle, P. Bunclark, D. Carter, and M. Irwin, Royal Greenwich Obs.; with A. V. Filippenko and A. Barth (Univ. of California, Berkeley) at the Keck telescope; W. Couch (Univ. of N.S.W.) and M. Dopita and J. Mould (Mt. Stromlo and Siding Spring Obs.) at the Siding Spring 2.3-m telescope; H. Newberg (Fermi National Accelerator Lab.) and D. York (Univ. of Chicago) at the ARC telescope] report eleven supernovae found with the Cerro Tololo (CTIO) 4-m telescope in their 1995 High Redshift Supernova Search:

SN	1995 UT	R.A. (2000)	Decl.	R	Offset
1995aq	Nov. 19	0 29 04.26	+ 7 51 20.0	22.4	0".6 W, 1".4 S
1995ar	Nov. 19	1 01 20.41	+ 4 18 33.8	23.1	2".9 W, 0".5 S
1995as	Nov. 19	1 01 35.30	+ 4 26 14.8	23.3	0".7 W, 0".7 N
1995at	Nov. 20	1 04 50.94	+ 4 33 53.0	22.7	0".3 W, 0".4 S
1995au	Oct. 29	1 18 32.60	+ 7 54 03.5	20.7	1".4 E, 3".3 N
1995av	Nov. 20	2 01 36.75	+ 3 38 55.2	20.1	0".2 W, 0".0 N
1995aw	Nov. 19	2 24 55.54	+ 0 53 07.5	22.5	0".2 W, 0".2 S
1995ax	Nov. 19	2 26 25.80	+ 0 48 44.2	22.6	0".3 W, 0".2 S
1995ay	Nov. 20	3 01 07.52	+ 0 21 19.4	22.7	0".9 W, 1".4 S
1995az	Nov. 20	4 40 33.59	- 5 30 03.6	24.0	1".6 W, 1".7 N
1995ba	Nov. 20	8 19 06.46	+ 7 43 21.2	22.6	0".1 E, 0".2 N

The spectra (Keck, Nov. 26-28) are consistent with type-I supernovae (except SN 1995av, a probable type II) at the redshift of the host galaxy: z = 0.45, 0.46, 0.49 (preliminary type-I identification), 0.65, 0.16, 0.30, 0.4 (supernova redshift only), 0.61, 0.48, 0.45, 0.39. The previous observations not showing the supernovae (to limiting mag about 24) were on Oct. 29-30 at the CTIO 4-m (except SN 1995au, on 1994 Sept. 29 at the Kitt Peak 4-m telescope). Contact saul@LBL.gov for finding charts.

1995 December 6 (6270) Daniel W. E. Green

Figure 3: **The CTIO Blanco joins** the project, using the new "batch" search strategy: 11 high-redshift SNe Ia discovered at a pre-scheduled date, just before New Moon, and all before their maximum light. Shown are the CTIO proposal and the resulting IAU telegram.

supernova project (and another collaboration with NOAO people and facilities) that provided some of the best-observed low-redshift Type Ia supernovae, making it possible to calibrate the supernovae for the distance measurements at high redshift — the later results all depended on this. (Our Supernova Cosmology Project team and the new High-Z team were now often scheduled one right after the other at CTIO, and we would pass each other coming and going in the La Serena offices on our way to and from the mountaintop.)

Two years later, our Supernova Cosmology Project team was analyzing 42 Type Ia supernovae (an auspicious number for

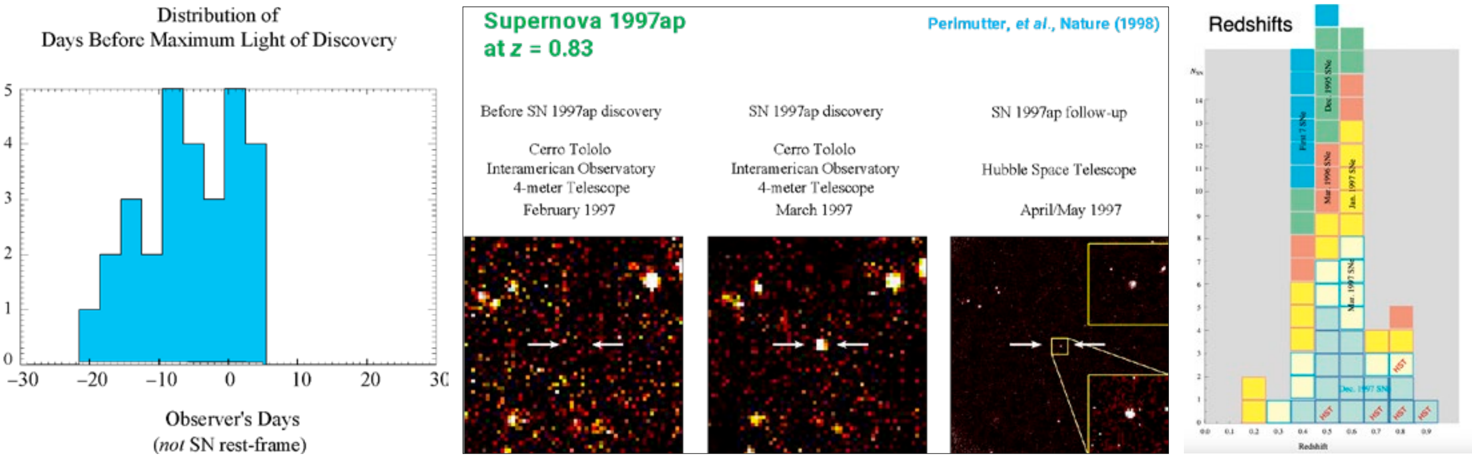

Figure 4: **The Blanco searches become routine:** Our set of well-observed high-redshift SNe Ia becomes big enough to measure the deceleration/acceleration of the universe, and HST follow-up can also be scheduled. (Saul's transparencies from 1997)

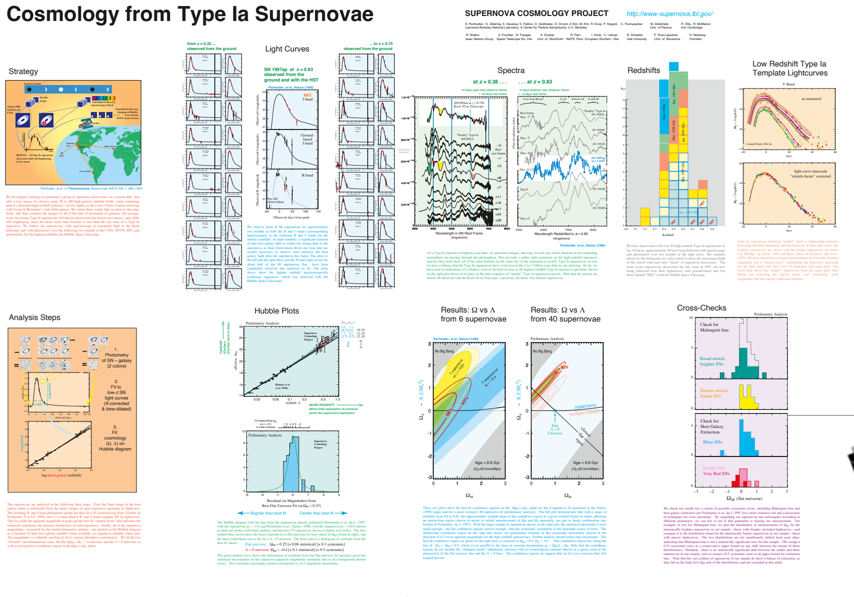

Figure 5: The results: 42 SNe analyzed – **almost all discovered at NOAO telescopes** – showing a Universe dominated by dark energy. (Supernova Cosmology Project poster from January 1998 AAS meeting and newspaper report the next morning)

San Francisco Chronicle

FRIDAY, JANUARY 9, 1998

Scientists See Cosmic Growth Spurt

Universe getting bigger and bigger, faster and faster—forever

By Charles Petit
Chronicle Science Writer

Washington, D.C.
Call it the runaway universe,
and we are on board.
A new, detailed study of ex-
ploding stars and immense galaxy
clusters billions of light-years
away seems to indicate that the
universe not only will expand for-
ever, contrary to some theories,
but that its outward expansion is
starting to speed up.
The startling conclusion that
the entire cosmos is running away
from itself at ever faster rates
strengthens some versions of the
Big Bang theory about the birt
the universe. But it also confo
certain explanations of hov
many kinds of energy and
emerged from that explos
-ment of creation.
Not only that, the runaway uni-
verse conclusion seems to endorse
an idea first developed, then re-
jected, by Albert Einstein in his
general theory of relativity early
in the century. Einstein concocted
what he called a "cosmological
constant" to balance his equations

UNIVERSE

From Page 1

will exist forever," said Saul Perl-
mutter. "And we seem to be see-
ing, for the first time, direct evi-
dence that the cosmological con-
stant is real."
Perlmutter, an astronomer at
the Lawrence Berkeley Laborato-
ry operated by the University of
California, is a leader of an ambi-
tious program, using telescopes in
Hawaii, the eastern Atlantic, Arizo-
na, Chile and in space, to chart the

fans of another sci fi series), with data anchored by our NOAO discoveries and follow-up but now also with our extensive Keck spectroscopy and even some *HST* photometry. The measurement of deceleration turned out to be a discovery of current acceleration – both competing teams agreed! – and we are now celebrating the 25-year anniversary of what Mike Turner dubbed Dark Energy.

NOAO telescopes, both old and new, have remained in the game ever since, with further supernova work – over 2,000 SNe Ia are in our most recent compilation study! – and with other measurement approaches triangulating in on this mystery; notably the weak lensing measurements with the Dark Energy Survey (DES) project at the Blanco, and the baryon acoustic oscillation (BAO) measurements with the Dark Energy Spectroscopic Instrument (DESI) project at the Mayall. Two other long-planned efforts to address dark energy are now coming to fruition, with NOIRLab's Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST) and NASA's Nancy Grace Roman Telescope.

Well before the 50-year anniversary of dark energy, we hope to have accomplished our next major step in understanding this acceleration of the Universe's expansion and the putative dark energy that powers it. Meanwhile, congratulations to all the NOAO staff for more than a quarter century of unparalleled work, carrying us into the discovery and study of dark energy!

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[2] Perlmutter, S. et al. 1997, NATO Advanced Study Institute (ASI) Series C, vol. 486, Thermonuclear Supernovae, Proceedings of the NATO Advanced Study Institute, held in Begur, Girona, Spain, June 20-30, 1995, ed. P. Ruiz-Lapuente, R. Canal, & J. Isern (Dordrecht: Kluwer Academic Publishers), 749

10.5281/zenodo.8284565

The ESSENCE Survey 15 Years Later

Michael Wood-Vasey (University of Pittsburgh)

In three successive months of 2004, I finished my dissertation, got married, and went down to Chile for my first observing run with the ESSENCE project. I had spent my graduate career at the University of California, Berkeley, under the guidance of Saul Perlmutter and George Smoot. I joined the Supernova Cosmology Project in the spring of 1999, just after the first papers reporting on the discovery of dark energy with Type Ia supernovae (SNeIa) had come out. To take the next steps in SN Ia cosmology, it was clearly time to build on the 18 low-redshift SNeIa from the Calán/Tololo Supernova Survey, the 42 high-redshift supernovae from the Supernova Cosmology Project and 16 nearby SNeIa from the Center for Astrophysics(CfA) sample, and the 10 high-redshift from High-z Supernova Team.

I spent my graduate career developing the supernova search pipeline for the Nearby Supernova Factory to grow and improve the nearby SN Ia sample. In the last years of my graduate career, two groups assembled to build and improve samples of higher-redshift SNeIa. One group would use the 3.6m Canada France Hawaii Telescope (CFHT), and the other the 4m NOAO CTIO Blanco telescope through the NOAO survey program. This was the era where useful, largely contiguous, cosmetically clean mosaic CCD arrays had just become available on 4m-class telescopes, with Mosaic-II on CTIO and MegaCam on CFHT. Each telescope+instrument was designed for large surveys, and there were specific efforts to organize such programs to realize the potential of these new technological capabilities. Many of the members of the Supernova Cosmology Project joined the Supernova Legacy Survey (SNLS), while the ESSENCE team, which used NOAO facilities, was largely from the High-z Supernova team. In broad strokes the plans were the same: use 4m-class telescopes with wide-field cameras to take repeated observations of a field, find and monitor supernovae photometrically, and then use 6- to 10m-class telescopes to take spectra to confirm the supernova type and to obtain the redshift.

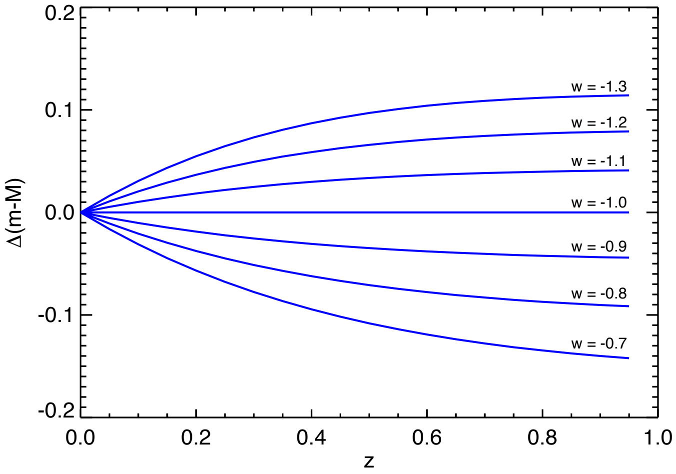

Figure 1: Delta m vs. ω. This figure shows the size of the effect we were trying to observe. *Credit: Miknaitis et al. 2007*

When I took my postdoc with Christopher Stubbs and the ESSENCE survey, I was switching sides. There was some teasing and joking about that, but it turned out to be great. I ended up knowing essentially all of the people doing supernova cosmology during that decade, and it was great to meet people with different perspectives on supernovae and the history of the earlier investigations.

The ESSENCE survey was paired with the SuperMacho NOAO survey to make effective use of half nights. SuperMACHO was observing the Large Magellanic Cloud (LMC; RA 05:20, Dec -70:00) to look for microlensing events due to massive compact bodies in the halo of the Milky Way along the line of sight to the LMC. The ESSENCE survey focused on four large fields at Right Ascensions 23:30, 01:10, 02:10, and 02:30 between Declinations of -10 to 0 degrees, so as to be accessible by telescopes in both the northern and southern hemispheres.

ESSENCE would observe in the first half of the nights through September through January, gradually rolling through the fields, with SuperMACHO using the second half of the nights. Working together, both programs brought sustained remote observing to the Blanco telescope. We would observe from a remote observation booth in La Serena, Chile, at the NOAO compound — this was much more sustainable than being up on the mountain to observe only every 2–3 nights. We ran the image subtraction on a cluster in the computing room on the compound, with a goal of finishing the image subtractions and scanning for supernovae by the following morning.

For spectroscopy, ESSENCE used Keck I and II, the VLT, Gemini North and South, Magellan Clay and Baade, and the MMT [1]. This was the beginning of queue observing time at Gemini. We found that queue mode worked great, as long as one of our team members (often Isobel Hook) was on the mountain. Part of it was morale and focus, and part of it was to provide detailed information on what we needed for SN cosmology. Most spectroscopic systems were focused on obtaining observations of galaxies and would often explicitly center up on the brightest nearby source to get the center of the galaxy. But for supernova observations, we instead needed the offset location of the supernova and required exact knowledge of where the slit was placed,

More broadly, this was a case where having the observing and scientific staff of observatories as active members of science projects yielded better results than more independent teams. And I found it beneficial to have both experts who used the instruments every day and people super-focused on getting the best science. Weekly soccer games with the observatory staff and the inter-observatory olympics were helpful for building teamwork and camaraderie.

The ESSENCE survey was focused on getting two bands, R and I, for 200 SNeIa in a redshift range from $0.2 < z < 0.8$. At the start of the survey it really wasn't clear whether w, the dark energy equation of state parameter, was truly constant with redshift. I certainly was pretty interested in that question when I started the postdoc. I (unfortunately?) remain interested in the question — but in the present day we're looking for little things and small changes in the equation of state over cosmological time. At the time of the ESSENCE survey we didn't know that, and I think that many of us thought we might actually find something measurably different than $w=-1$.

Our major first papers [2, 3] were based on 60 SNeIa from the first part of the survey. These first results from SNLS and ESSENCE introduced detailed systematic error tables, as the field started focusing on the limitations of combining large numbers of supernovae from different surveys and at different redshifts. Since then the evidence overwhelmingly points to something very well approximated by a constant $w=-1$ model. But the mystery of dark energy remains. As we look forward to an explosion in numbers from the Vera C. Rubin Observatory Legacy Survey of Space and Time, which should find, during the life of survey, at least 100,000 well-studied SNeIa, and the Nancy Grace Roman Observatory, which will take us securely out to redshifts of ~1.5, the field of supernova cosmology continues to be rich with excitement and potential.

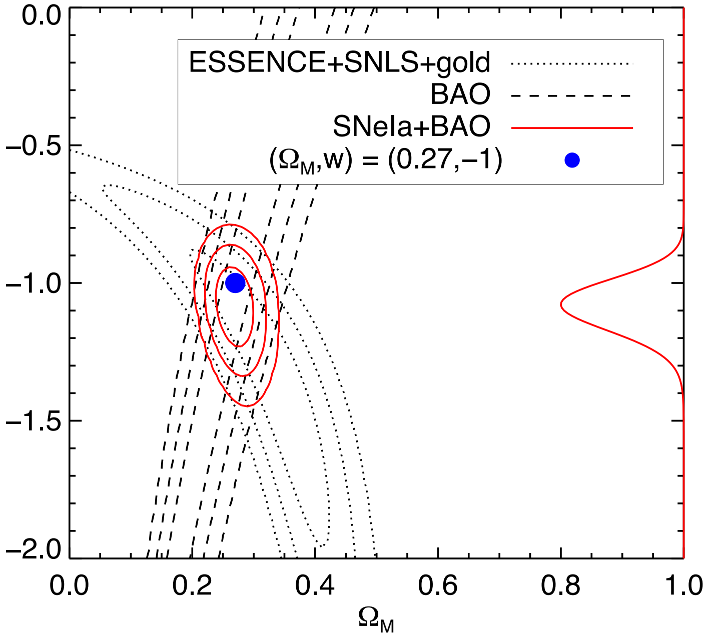

Figure 2: Cosmology OM vs. OL. This figure presents the first ESSENCE+SNLS constraints. The SNLS constraints had been published prior to the SNLS results. *Credit: Wood-Vasey et al. 2007*

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10.5281/zenodo.8284578

Exploring the Dark Energy Phenomenon: The Impact of the Dark Energy Survey

Chihway Chang (University of Chicago/KICP), Tamara Davis (University of Queensland), Giulia Giannini (University of Chicago/KICP), Anna Porredon (University of Edinburgh), Judit Prat (University of Chicago/KICP), Simon Samuroff (Northeastern University), Michael Troxel (Duke University), and Yuanyuan Zhang (NSF's NOIRLab)

The Dark Energy Survey (DES) was enabled by the construction of the Dark Energy Camera (DECam), the prime focus instrument on the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory (CTIO), a program of NSF's NOIRLab. The scientific motivation for DES — constraining the properties of dark energy by deep images — was developed in the early 2000s and drove the initial concept for the camera. The camera needed to have a wide field of view, which implied large correcting lenses and tight control of aberrations and flexure. This in turn implied the camera would have to be massive

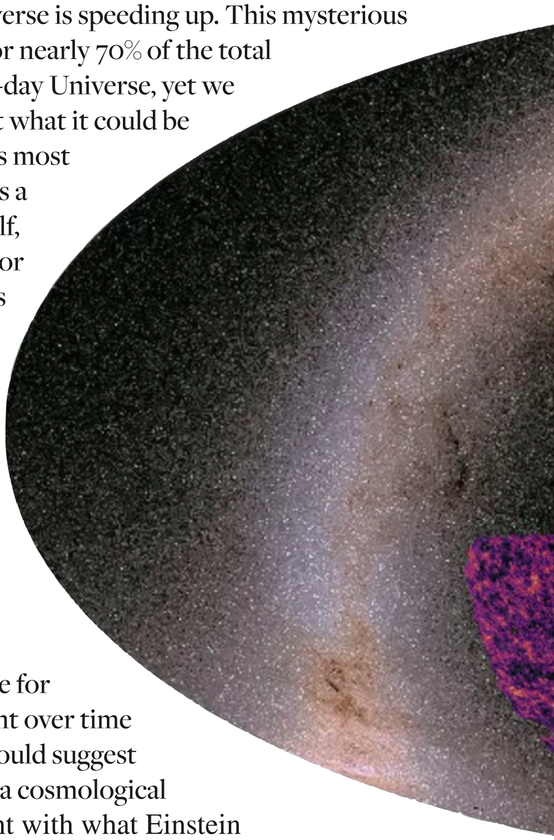
At the same time, in the early 2000s, NOIRLab (then NOAO) was exploring what role the Kitt Peak National Observatory (KPNO) and CTIO 4m telescopes could have in the era of modern 6- to 8-meter telescopes. Using the telescopes to investigate the then newly discovered phenomenon of dark energy was at the top of the list.

Astronomers realized that the older massive steel equatorial mounts of the Mayall 4-meter Telescope at KPNO and the Blanco at CTIO were ideal for mounting heavy instruments at the prime focus — a perfect match of scientific need with practical capabilities. Thus was born the partnership where the construction of DECam was the responsibility of Fermilab, assisted by many DES international institutional partners, while the team at CTIO was responsible for fitting DECam to the Blanco, replacing its entire top end. The data system was also a joint project, involving the National Center for Supercomputing Applications (NCSA) and other DES institutions, as well as NOIRLab.

The agreement among the various agencies was that DES would be granted 30% of the observing time for five years, in return for supporting public access to the instrument during this period, including a data processing pipeline and other tools. At the end of DES observing, DECam was then to become a facility instrument for CTIO, completing NOIRLab's early vision for a world-class wide-field imager available to the general community.

What Is Dark Energy?

The discovery of the accelerated expansion of the Universe just before the turn of the millennium (see the Perlmutter and the Riess & Schmidt articles in this Science Highlights section) revolutionized our understanding of the cosmos, leading to the reintroduction of the cosmological constant or some other unknown form of energy to justify why the expansion of the Universe is speeding up. This mysterious substance accounts for nearly 70% of the total energy in the present-day Universe, yet we know very little about what it could be or how it behaves. It is most commonly modeled as a property of space itself, rather than a particle or field. Its existence was first proposed to justify the observed accelerated expansion of the Universe discovered from constructing *Hubble* diagrams using Type Ia supernovae.



If the equation of state for dark energy is constant over time with a value of -1, it would suggest dark energy is simply a cosmological constant Λ, consistent with what Einstein proposed in 1917. However, some cosmologists have suggested that the dark energy equation of state may be changing with cosmological time, such that dark energy is something other than Λ. This would have significant implications for our understanding of the Universe and its future. To help unravel this cosmic enigma, cosmologists are building and conducting an amazing array of experiments to measure the properties of dark energy, and one of the most powerful to date is the DES.

The Dark Energy Survey

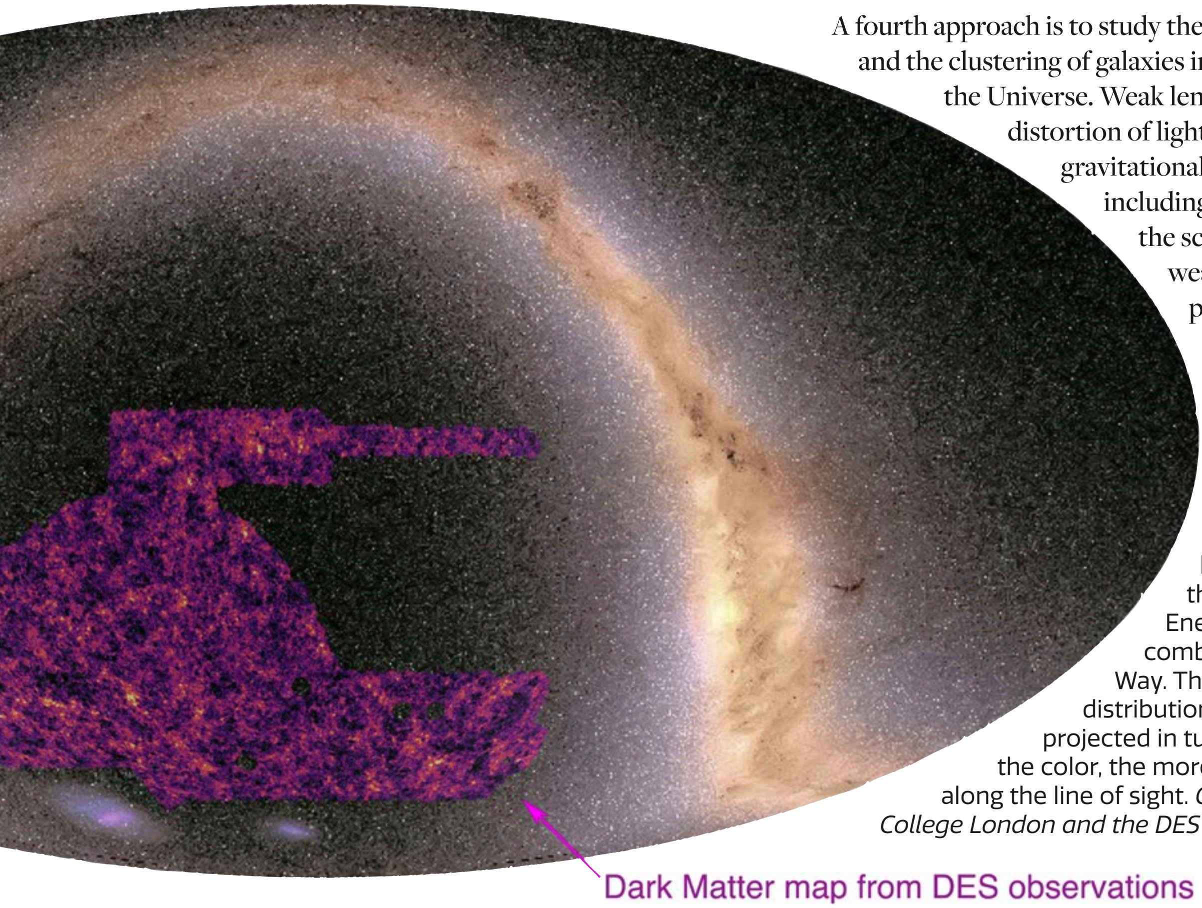
DES is an international collaboration of scientists who are studying dark energy using data taken with the powerful 570-megapixel DECam mounted on the Blanco telescope at CTIO in Chile. DES is capable of capturing images of up to 100,000 galaxies in a single snapshot, allowing cosmologists to study the distribution of galaxies and their properties in unprecedented detail. The primary goal of DES is to measure the equation of state for dark energy, which describes how dark energy changes over time. To achieve this, DES scientists use many different methods to study the Universe and how it changes over time, including the main four methods described below.

One approach is to use Type Ia supernovae (SN) as cosmic distance markers to infer the distances to galaxies. Their brightness tells us their distance, and their spectral properties tell us their recession velocity, which together let us infer the evolution of the Universe's expansion rate to constrain the properties of dark energy.

A second approach is to use Baryon Acoustic Oscillations (BAO), a feature imprinted in the large-scale distribution of galaxies that originated from acoustic waves in the baryons of the early universe. DES measures this feature on the sky from the galaxies, allowing us to probe the expansion rate of the Universe in an independent way.

A third approach is to investigate the abundance of massive galaxy clusters. The tug of war between gravity and dark energy means that the sizes of those galaxy clusters are sensitive to the evolution of dark energy over time. More dark energy means faster expansion, which means fewer massive clusters can form. Thus, the abundance of massive galaxy clusters over time can also expose the properties of dark energy.

A fourth approach is to study the weak gravitational lensing and the clustering of galaxies in the large-scale structure of the Universe. Weak lensing involves measuring the distortion of light from distant galaxies by the gravitational pull of intervening matter, including dark matter. Measured on the scale of modern galaxy surveys, weak lensing provides a direct probe of the structure and history of the low-redshift



This figure shows the weak lensing convergence map in the footprint of the Dark Energy Survey (purple), combined with stars in the Milky Way. This map shows the matter distribution along the line of sight projected in two dimensions. The lighter the color, the more matter is accumulated along the line of sight. *Credit: N. Jeffrey/University College London and the DES Collaboration*

Universe. Alternatively, one could map the positions of the same galaxies on the sky; tracing the correlations in galaxy density provides an alternative measurement of the large scale matter distribution. The combination of these two effects is typically known as the "3x2pt" probes, since it consists of three two-point measurements.

Although each of the four approaches is powerful in their own right, weak lensing and galaxy clustering are the most sensitive to different cosmological parameters and to different systematic effects than supernovae and BAO. Combining all four observational techniques allows for much more robust measurements of dark energy parameters and helps reduce the impact of systematic uncertainties.

The Impact of the Dark Energy Survey

DES has achieved a significant leap in the quality and quantity of data available to study dark energy. We have already released a catalog of over 800 million objects in the sky, including over half a billion galaxies, and we will soon be releasing data that approximately doubles the number of distant supernovae ever measured. Our preliminary results using half of this data achieve a 10% constraint on w, and our final analysis of our full dataset is currently underway, with results expected in 2024.

The most important aspect of this experiment is that it is the first to use a combined-probes approach. This approach has the potential to reveal new physics and cosmic mysteries that may lead to an even deeper understanding of our Universe, because it is when different measurements of the same thing disagree that new physics can be revealed. In particular, by combining 3x2pt with BAO and supernova (SN) from DES, we found an improvement of about 40% in the constraining power compared to 3x2pt alone, allowing to constrain the dark energy equation of state, at a precision of 10% with half our final data. This is about twice as constraining as the Cosmic Microwave Background alone can do currently, and only a factor of two less constraining than the combined power of most other low-redshift data together. The probes DES is using are entirely independent from previous early-Universe-based studies, yet this result is in agreement with previous measurements, suggesting that the equation of state for dark energy is indeed consistent with a cosmological constant. This result is significant, as it supports the standard cosmological model and our understanding of the Universe's evolution and future.

In addition to the four dark energy probes described above, DES provides the data to perform a variety of other tests on dark energy and cosmology, as well as studies beyond cosmology. For example, combining gravitational waves and galaxies from DES data allows us to constrain the expansion rate of the Universe. Similar constraints can be achieved using strong gravitational lensed galaxies in DES, followed up by space-based telescopes. DES has also enabled new opportunities to study other astrophysical phenomena besides dark energy. Throughout the years, we have measured how galaxies form and evolve, discovered rare solar system objects including the most distant and massive comet, and even offered insights on what properties dark matter particles could possess.

Another significant and lasting impact of the DES project has been the development of new techniques for cosmological observations and calibration. DES has pioneered new methods for measuring galaxy shapes and photometric redshifts and has developed new algorithms for managing and analyzing large datasets. The primary DES cosmological analyses have also sustained a commitment to developing the first uniformly blinded multi-probe experiment — that is, DES scientists hide the true information about the Universe in their data even from themselves, until they are sure the data are robust. This protects us from confirmation bias in what we learn about the Universe in DES. These advancements have important implications for future cosmological projects and will pave the way for further discoveries.

A final important aspect of DES is its commitment to open data sharing. Nearly all of the DES data is publicly available to anyone who wishes to use it, and cosmologists from around the world have already made use of this data to carry out new studies and make new discoveries. This open approach to data sharing is critical for advancing our understanding of the Universe, as it enables more cosmologists to participate in the scientific process and collaborate on new ideas and discoveries.

As we wrap up the main DES dark energy analyses in the coming years, we look forward to sharing more about what we learn from the Universe, both through fundamental discoveries and via our legacy of technical advances. DES's legacy will also continue for many years to come, with future surveys and missions building on its findings and methods and pushing the boundaries of our understanding of the Universe even further.

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The Dark Energy Spectroscopic Instrument Survey Early Data Release

Is Available at the Astro Data Lab

Stéphanie Juneau & Adam Bolton (NSF's NOIRLab) on behalf of the
Astro Data Lab Team

The Early Data Release (EDR) of the Dark Energy Spectroscopic Instrument (DESI) survey comprises nearly two million spectra of galaxies, quasars, and stars obtained during the commissioning and survey validation phases of the observing campaign [1]. While DESI is designed primarily to be a world-leading cosmological experiment, the rich dataset from the EDR can enable a slew of scientific discoveries across a broader range of astrophysics.

The release of DESI data to the astronomical community is a major milestone in the ongoing tradition of collaboration between astronomy and particle physics, which has delivered great scientific benefits to both fields of research. The large sky surveys that are necessary to measure the signatures of dark energy also deliver massive samples of objects for astronomical data mining. NOIRLab facilities have been at the center of this mode of research from the original discovery of dark energy, to the Dark Energy Camera (DECam) and associated Dark Energy Survey, through DESI, and on to the Vera C. Rubin Observatory's forthcoming Legacy Survey of Space and Time (LSST).

The Dark Energy Spectroscopic Instrument (DESI) making observations in the night sky on the Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory in Arizona *Credit: KPNO/NOIRLab/NSF/AURA/T. Slovinský*

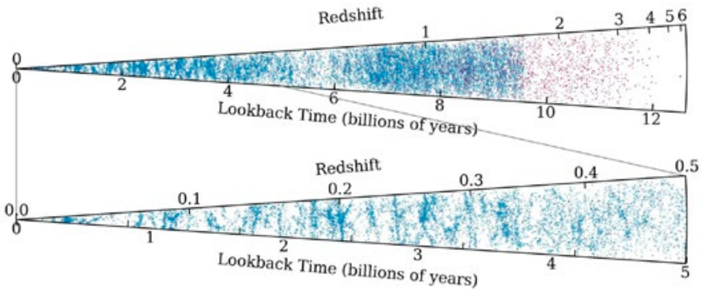


Figure 1: Early DESI data showing the location of galaxies (blue dots) and quasars (red dots) in a small slice of the survey. The top wedge shows a high sampling with galaxies out to redshift 1.6 and distant quasars reaching redshifts 4–5, corresponding to light-travel time of 12 billion years. The bottom wedge zooms in to reveal more details of the large scale structures such as galaxy filaments, clusters, groups and interspersed voids. *Credit: E. Downing/DESI Collaboration*

The DESI Collaboration has published a series of papers, including technical papers as well as a variety of scientific studies [2]. Given the vast applications, these works have barely scratched the surface, and much remains to be discovered. Of interest, some of the commonly studied extragalactic fields, such as the *Hubble* Deep Field and COSMOS, have been covered [3].

With its 5000 robotic fibers, and a nine-square-degree field of view, DESI is currently astronomy's most powerful optical spectrograph. It can obtain up to 100,000 spectra in a single night of observing. This technological capability will enable the DESI Collaboration to reach its five-year goal of 40 million spectra of galaxies and quasars to create the largest-ever 3D map of the Universe [4]. The EDR gives us a glimpse of cosmic large-scale structures such as impressive galaxy filaments, clusters, and voids (Figure 1).

The DESI EDR includes catalogs of spectroscopic and photometric quantities as well as fully processed, flux-calibrated, and extracted spectra from the automated pipeline run at the National Energy Research Computing Center (NERSC). Each spectrum comes with a best-fit template model and redshift measurement. The public data release at NERSC comprises primarily serving files. To augment this, the Astro Data Lab at the Community Science and Data Center (CSDC), a program of NSF's NOIRLab, hosts a searchable **desi_edr** catalog database for efficient data discovery and retrieval. The database is accessible via methods such as a web query interface, Table Access Protocol (TAP) handle for tools such as TOPCAT, or a Jupyter notebook server [5]. In addition, the DESI spectra themselves can be obtained through CSDC's new SPectra Analysis and Retrievable Catalog Lab (SPARCL). To facilitate data exploration, the Astro Data Lab team has developed several tutorial Jupyter notebooks in collaboration with the DESI team [6].

One example notebook demonstrates how to search a region of the sky for available spectra from the Sloan Digital Sky Survey (SDSS) DR16 [7] and from the DESI EDR and how to use a value-added catalog with emission-line measurements to select an interesting galaxy with copious ionized gas traced by an Oxygen transition ([OII] doublet at 3726 & 3729 Angstroms). The notebook then shows how to combine Astro Data Lab databases together with the SPARCL spectrum-access service to quickly retrieve spectra of interest in a fraction of a second. Finally, zooming in on the spectra around the Oxygen lines highlights that the spectral resolution of DESI is sufficient to resolve the doublet (Figure 2). This capability is key to the DESI experiment, as it allows easy differentiation of [OII] from single emission lines in a large number of faint emission-line galaxies (ELGs), which are used as cosmological tracers of the underlying distribution of matter in the Universe.

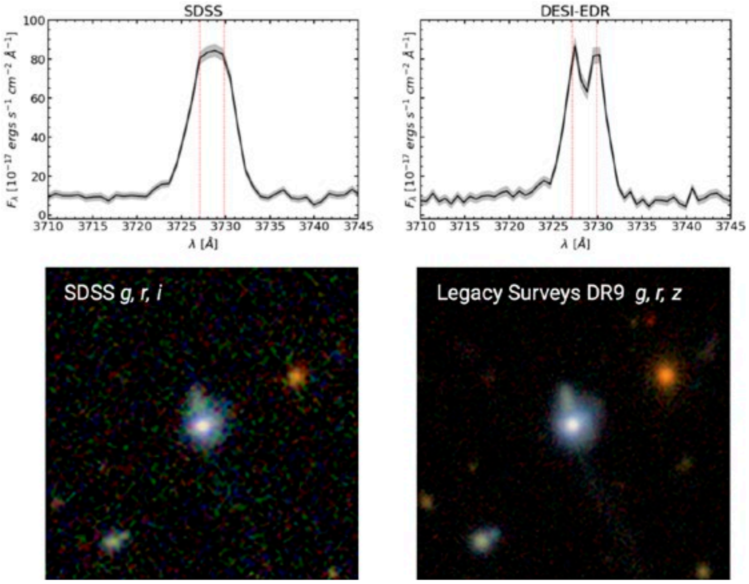
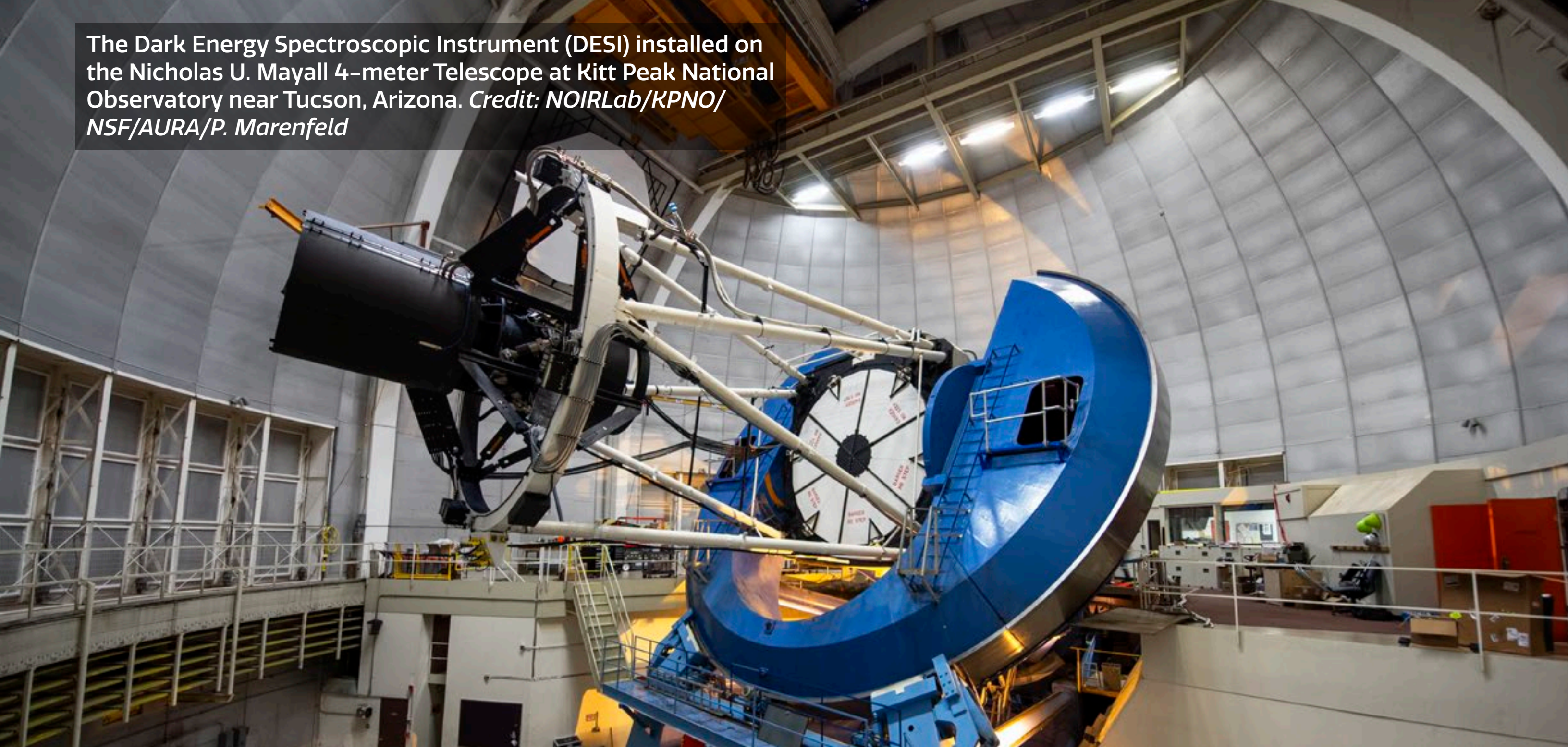


Figure 2: (Top) Comparison of the [OII] 3726 & 3729 Å doublet in SDSS (L) and DESI EDR (R) spectra of the same galaxy made with an example Jupyter notebook available on the Astro Data Lab platform [4]. DESI's comparatively higher spectral resolution is key to splitting the doublet components, allowing [OII] to be used to obtain accurate redshift measurements. (Bottom) Images from the Legacy Surveys Sky Viewer of the SDSS layer and LS DR9 layer used for DESI targeting. *Credit: R. Pucha/University of Arizona, NOIRLab/AURA/NSF/S. Juneau, NOIRLab/AURA/NSF/Astro Data Lab team*



The Dark Energy Spectroscopic Instrument (DESI) installed on the Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory near Tucson, Arizona. *Credit: NOIRLab/KPNO/NSF/AURA/P. Marenfeld*

The DESI Collaboration continues to grow its dataset, having obtained spectra of over 26 million galaxies, quasars, and stars thus far. Within this context, the early release of 2 million spectra might seem like only the tip of the cosmic iceberg, but it also represents a treasure trove of data available for exploration. The astronomy community is invited to join in this exploration as discoveries await to be made.

DESI is supported by the DOE Office of Science and by the National Energy Research Scientific Computing Center, a DOE Office of Science user facility. Additional support for DESI is provided by the U.S. National Science Foundation, the Science and Technology Facilities Council of the United Kingdom, the Gordon and Betty Moore Foundation, the Heising-Simons Foundation, the French Alternative Energies and Atomic Energy Commission (CEA), the National Council of Science and Technology of Mexico, the Ministry of Science and Innovation of Spain, and by the DESI member institutions. See the DESI data license and acknowledgments page for more information.

Kitt Peak National Observatory is a program of NSF's NOIRLab. The DESI collaboration is honored to be permitted to conduct scientific research on Iolkam Du'ag (Kitt Peak), a mountain with particular significance to the Tohono O'odham Nation.

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[6] Juneau, S. et al. 2021, CiSE, 23, 15
[7] Ahumada, R. et al. 2020, ApJS, 249, 3

Useful Links

SPARCL: https://astrosparcl.datalab.noirlab.edu
Astro Data Lab: https://datalab.noirlab.edu
DESI Landing page: https://datalab.noirlab.edu/desi

Tutorial Jupyter Notebooks

Introduction to DESI EDR notebook
https://github.com/astro-datalab/notebooks-latest/blob/master/03_ScienceExamples/DESI/01_Intro_to_DESI_EDR.ipynb

How to use the SPARCL notebook
https://github.com/astro-datalab/notebooks-latest/blob/master/04_HowTos/SPARCL/How_to_use_SPARCL.ipynb

SDSS vs. DESI EDR Comparison notebook
https://github.com/astro-datalab/notebooks-latest/blob/master/03_ScienceExamples/DESI/02_DESI_EDR_SDSS_Comparison.ipynb

How to query the desi_edr database notebook
https://github.com/astro-datalab/notebooks-latest/blob/master/04_HowTos/QueryClient/How_to_query_DESI_EDR_Data.ipynb

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The LSST Dark Energy Science Collaboration

Katrin Heitmann (Argonne National Laboratory), Chihway Chang (University of Chicago), and Joe Zuntz (University of Edinburgh) on behalf of the LSST DESC

More than one thousand scientists from around the world have come together in the Legacy Survey of Space and Time (LSST) Dark Energy Science Collaboration (DESC) to explore the secrets of the dark Universe. Many questions demand answers: What is the cause of the late-time accelerated expansion of the Universe? Is dark energy a static vacuum energy (a cosmological constant), or does it have a dynamical component? What is its origin and how does it fit into the Standard Model of particle physics? What does the comparison between the expansion history and the growth rate of large-scale structure tell us about possible modification of General Relativity on the largest scales? What is the nature of dark matter? What happened during the very first moments of the Universe? What is the neutrino mass scale?

DESC is hoping to answer many of these questions with the unprecedented dataset to be collected by the Vera C. Rubin Observatory (Rubin). LSST will deliver data in area and depth that will dwarf what any previous cosmology survey has achieved. This highly anticipated dataset offers exciting scientific opportunities but also many technical challenges. To prepare for data arrival, LSST DESC has established a comprehensive program to investigate different cosmological probes and avoid possible systematics pitfalls from both the astrophysical and data analysis perspective, relying on simulated and precursor data.

Forecasting the power of LSST: To predict how well the data will constrain the nature of dark energy and to address the impact of a range of systematics and the requirements on how well they need to be understood, LSST DESC has undertaken a major program to forecast constraints for a dynamical dark energy equation of state, described by two parameters (w_0, w_a), where w_0 is a constant term valid for all time, while w_a describes a linear change in the equation of state (EOS) with the cosmological scale factor. LSST DESC is planning to use a range of cosmological probes: supernovae, clusters of galaxies, strong and weak lensing, and clustering of galaxies. The combination of these probes will provide the best-ever constraints on the dark energy equation of state parameters (w_0, w_a).

To fully realize the potential of LSST, DESC is busy preparing for data arrival in many different ways.

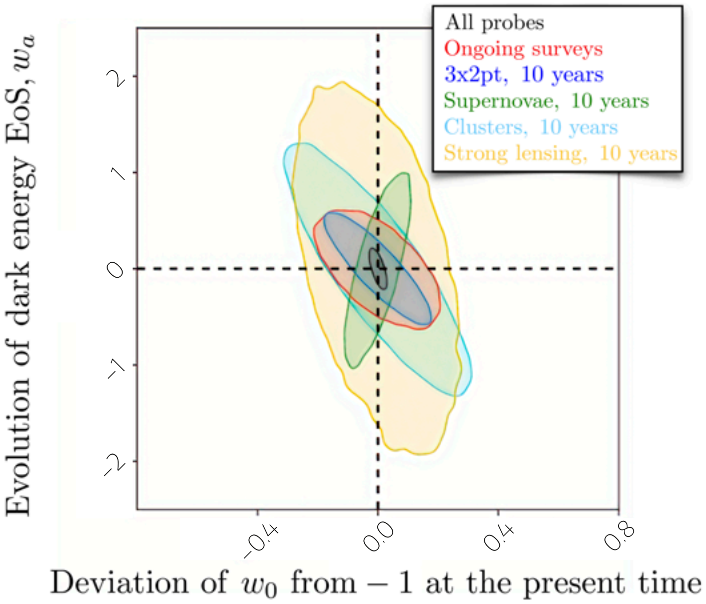

Figure 1: This figure shows the forecast for (w0, wa) after 10 years of LSST data taking. The black contour in the center demonstrates the constraining power of all cosmological probes combined while the red contour shows constraints from contemporary surveys. *Figure reproduced from LSST DESC 2021a [4].*

Preparing for data with simulations: In 2017, DESC embarked on an exciting endeavor to create a simulation that looks as closely as possible like the actual data to be collected by Rubin. The collaboration created a five-year synthetic survey in six optical bands covering a region of 300 square degrees in a wide-fast-deep area and a deep drilling field of approximately one square degree [1]. The simulation, named Data Challenge 2 or DC2, was set up to follow a reference LSST observing cadence, and the simulated images were processed with the LSST Science Pipelines. The DC2 sky includes variable observing conditions and CCD image artifacts as well as a range of astrophysical objects, among them lensed AGN host galaxies (Figure 2), stars in the Milky Way, and supernovae. Figure 3 shows the placement of DC2 on the sky and two zoom-ins to show the exquisite detail that was achieved in the simulation. The Deep Drilling Field is in the upper right corner of the DC2 area shown in Figure 2.

The DC2 dataset has provided many opportunities to aid the preparation for Rubin data. It has been used to test the LSST Science Pipelines, to carry out a Supernova Type Ia-

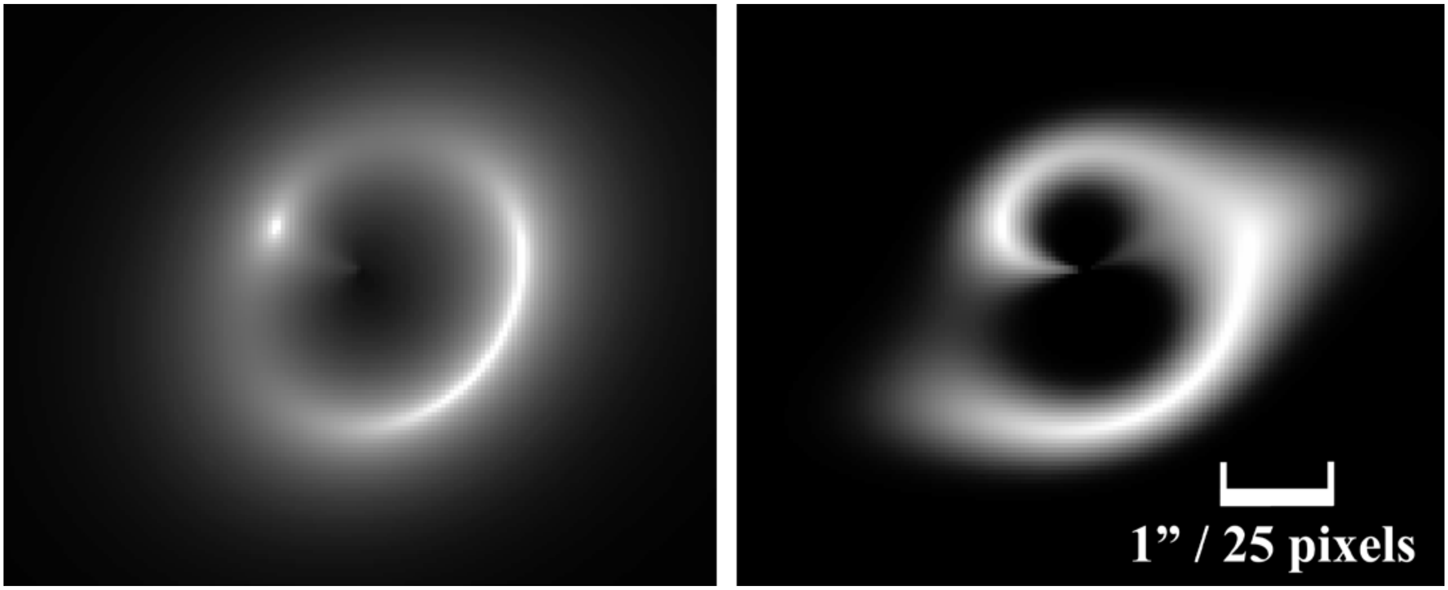

Figure 2: High-resolution (250x250 pixels, 0.04"/pixel) postage stamps of a lensed AGN host galaxy bulge **(left)** and disk **(right)**. *Figure reproduced from LSST DESC 2021b [1].*

cosmology analysis [2], and to test LSST DESC analysis pipelines, for example. The dataset has also been made available to the larger Rubin community. As part of the Rubin Observatory Data Previews, DC2 data can be accessed by a set of "delegates" via the Rubin Science Platform (RSP), facilitating exploration of the functionalities of the RSP. And, while a synthetic sky has the advantage that all ingredients – including the nature of dark energy – are known and analyses can be validated against the known truth, data from the real Universe are as important for the preparation of data arrival.

Preparing for data with precursor data: Many aspects of the data from precursor surveys provide valuable tests for DESC analysis tools that would be challenging to achieve via simulations. Analyzing real observational data ensures that tools are up to date with state-of-the-art approaches currently deployed in the community. An additional motivation for the reanalysis projects is to bring together experts from ongoing surveys, many of whom will be working together in the Rubin era within DESC. In DESC, a coherent program has been established for performing these reanalyses, mostly from galaxy catalogs to cosmological constraints. Different projects are designed to test different parts of the pipelines. Most recently, three precursor datasets were examined — DES Y3, HSC Y1, KiDS-1000 — with an analysis focused on cosmic shear measurements [3]. Fortunately, the conclusion from the unified analysis was that the precursor datasets yield consistent results. The combined power is fairly impressive and sets a high bar for DESC endeavors in exploring the underlying cause of the accelerated expansion of the Universe. The effort motivated significant development of the DESC software tools, to ensure that published results were reproducible.

Preparing for data via collaboration-wide challenges: While eagerly awaiting the arrival of data from Rubin, data challenges have been one of the most productive approaches to engage members across DESC, and in the broader LSST science community, in the preparations. Casting analysis problems as competitions creates added impetus for everyone involved. For example, one step in analyzing photometric galaxy lensing and clustering correlations is tomography — splitting galaxies into approximate redshift bins based on their magnitudes. While this is usually considered a photometric redshift problem, it can also be cast as a classic machine learning problem: we want to predict labels (bins) based on features (magnitudes) with some training data (spectroscopic redshifts). In the DESC tomography challenge [5], an easy-to-use dataset and metric calculator were created, and groups were asked to submit their best code for the analysis. Twelve teams submitted 22 methods, including a wide range of machine learning approaches, and demonstrated the general tractability of the problem. In particular, several methods showed how switching to alternative target tomographic bins can greatly improve the constraining power of the result measurements but also that this was highly dependent on which science case we were considering: optimal bins for varying dark energy models were not the same as those for LCDM, for example. This has pushed DESC to think more about supporting multiple samples in our analysis process. The most effective methods that did well in multiple branches of the challenge are now

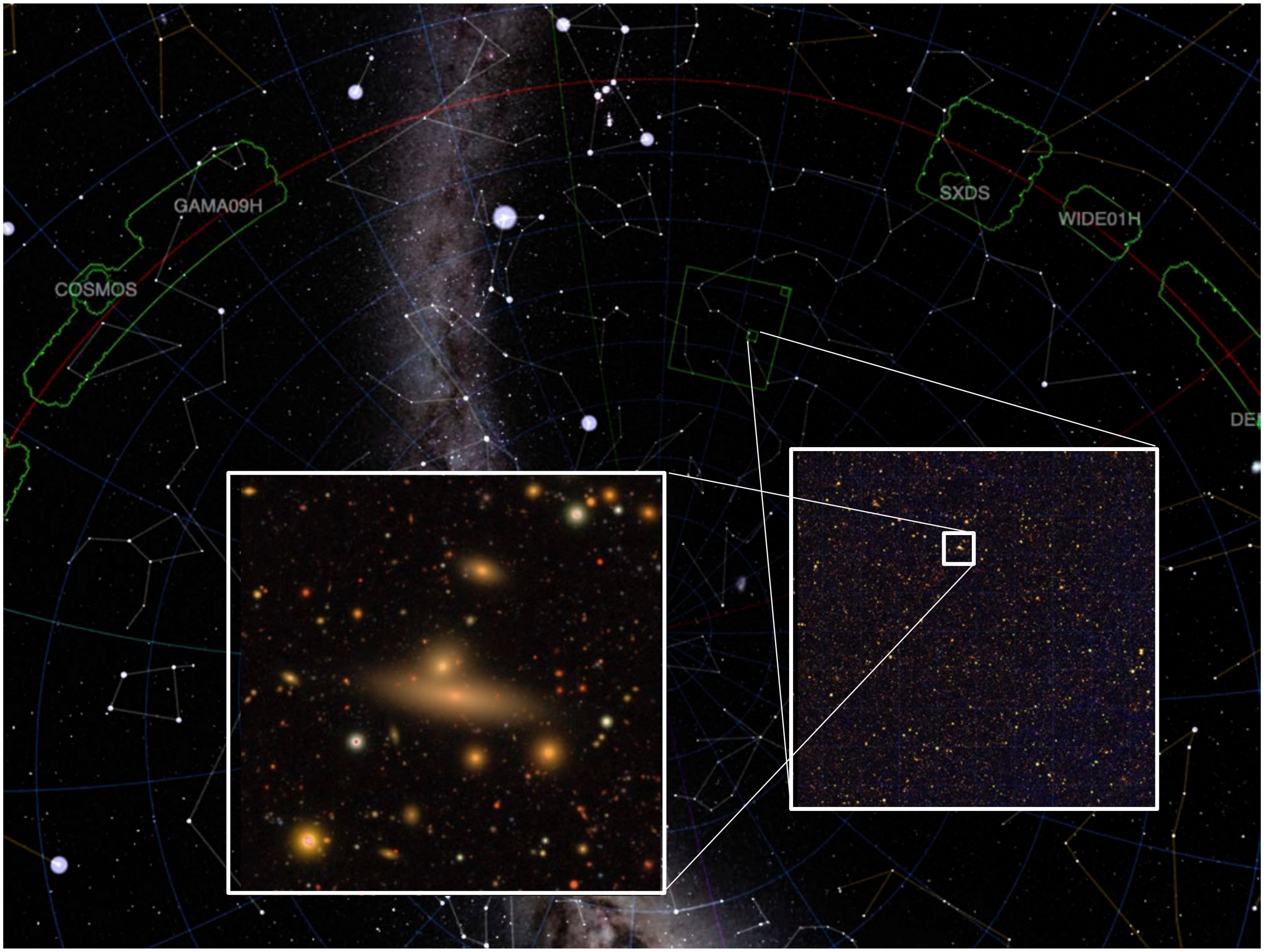

Figure 3: Data Challenge 2 (DC2) simulation region plotted on the ESO Milky Way Panoramic Image along with Subaru HSC Survey PRD2 regions. Two zoom-ins are shown to demonstrate the details and depth of the simulated dataset.
Credit: J. Cohen-Tanugi, J. Chiang

being incorporated into DESC official pipelines. Overall this "challenge" approach has been both effective and a positive experience, and DESC has used it in a range of complete and in-progress papers, including a bias modeling challenge, a competition of methods for calculating 2D spectra beyond the Limber regime, and an exploration of models for baryonic effects on small-scale matter power spectra.

The path ahead: With every report "from the summit" about Rubin getting closer to first light, the excitement in the DESC community rises. What new insights will we gain about the physics of the dark Universe, will our analysis pipelines perform at the required levels, will we be able to disentangle systematic effects from new physics, what unexpected results will Rubin deliver? DESC is preparing in many ways to take full advantage of the unprecedented data from Rubin and is excited by the power, and the discovery potential, of LSST for cosmology.

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The US National Gemini Office at NSF's NOIRLab

Vinicius Placco and Letizia Stanghellini (NSF's NOIRLab)

The US National Gemini Office (US NGO) is a group within the Community Science and Data Center (CSDC) at NSF's NOIRLab. The goal of the US NGO is to support US Gemini users in all phases of the astronomical observing cycle, from proposal preparation to data analysis.

The US NGO recently published an article on its history and services in SPIE's *Journal of Astronomical Telescopes, Instruments, and Systems* (*JATIS*) [1]. The article provides a brief historical overview of the US NGO through its almost 30 years of existence and its evolving role within the International Gemini Observatory partnership, NOAO, and, more recently, NOIRLab. The article provides a thorough discussion of the efforts and products currently being developed by the US NGO staff and how those help increase engagement with the user community in the US and with the other Gemini partners. These efforts and products include data reduction cookbooks, helpdesk support, and engagement through social media, among others. In addition, the article describes how the US NGO quantifies user engagement and outreach through website analytics and metrics, which help focus the effort allocation and distribution within the team. An example of these analytics is given in the figure, showing the number of unique visitors to the GMOS Data Reduction Cookbook in a 18-month period.

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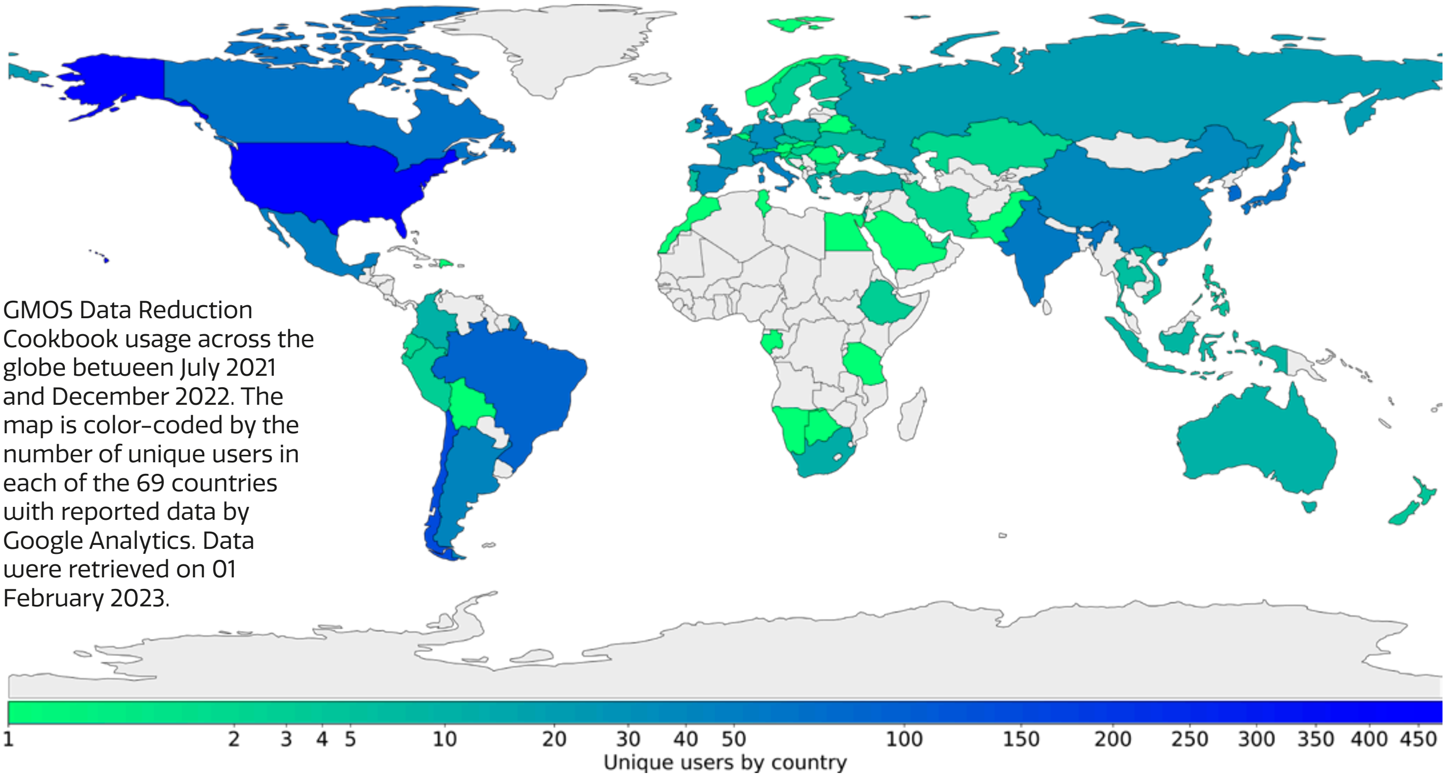
US NGO website

GMOS Data Reduction Cookbook

US NGO on Twitter



GMOS Data Reduction Cookbook usage across the globe between July 2021 and December 2022. The map is color-coded by the number of unique users in each of the 69 countries with reported data by Google Analytics. Data were retrieved on 01 February 2023.

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Gemini North Returns to Operations Following the Repair of Its Primary Mirror

Jennifer Lotz (International Gemini Observatory Director, NSF’s NOIRLab)

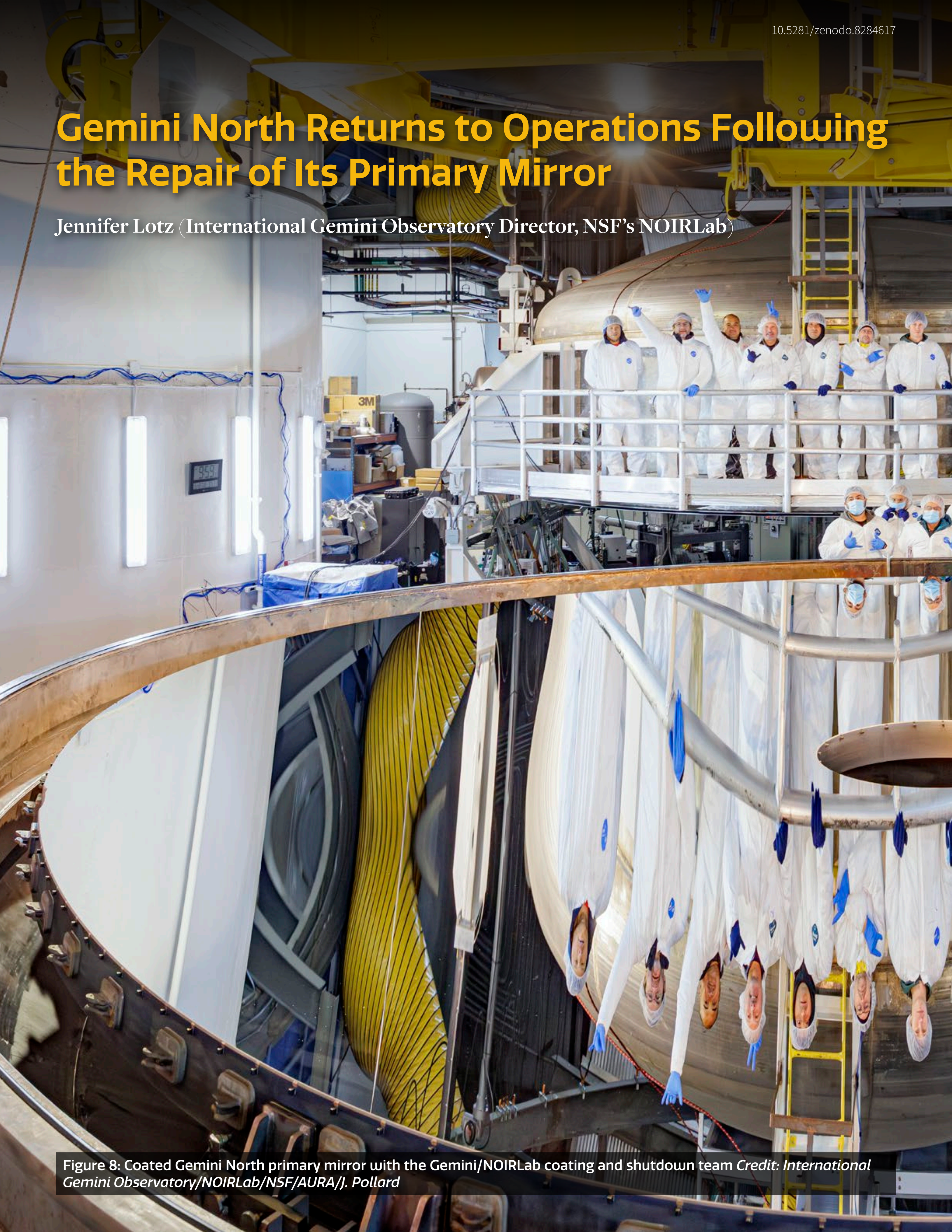

Figure 8: Coated Gemini North primary mirror with the Gemini/NOIRLab coating and shutdown team *Credit: International Gemini Observatory/NOIRLab/NSF/AURA/J. Pollard*


EMERGENCY SHOWER

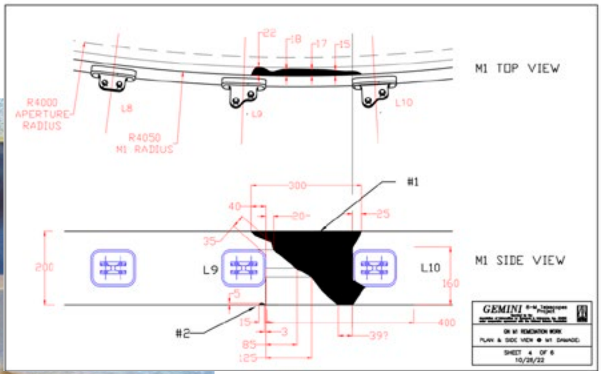

Figure 1: GN M1 Top & Side View of M1 Damage (measurements in mm). M1 was impacted at two locations by the earthquake restraint (Damage Area #1) and a nearby bolt (Damage Area #2). Damage Area #1 was a roughly triangle-shaped chip extending ~20 cm along the full vertical edge of the mirror and ~30 cm between lateral pads 9 and 10. Damage Area #2 was a smaller chip a few cm in diameter at the underside (non-reflective) of the mirror. *Credit: Safran-Reosc*

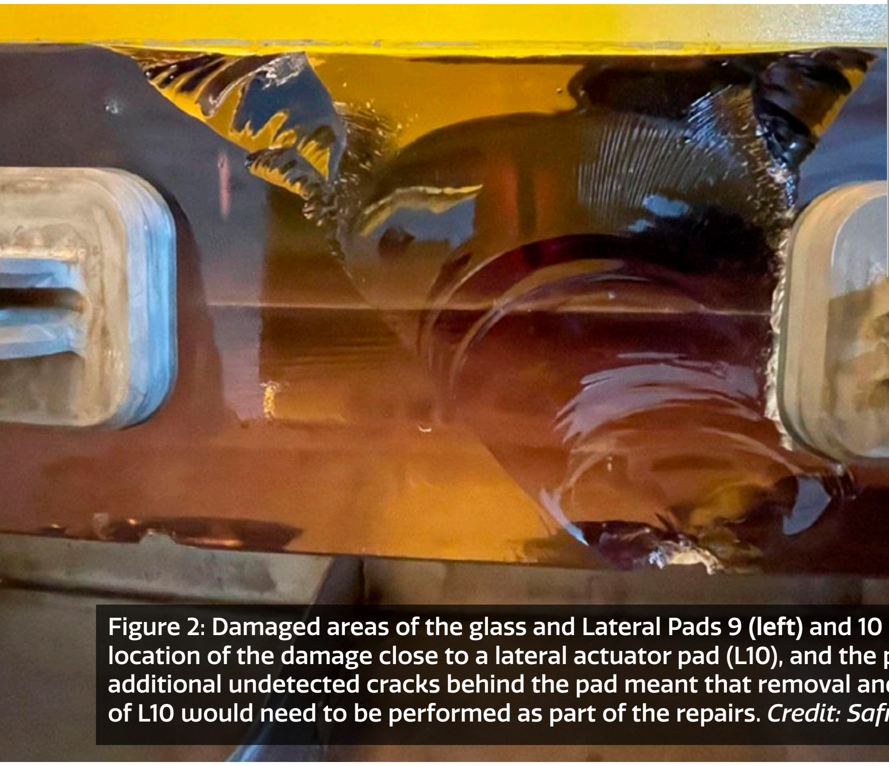

Figure 2: Damaged areas of the glass and Lateral Pads 9 (left) and 10 (right). The location of the damage close to a lateral actuator pad (L10), and the potential for additional undetected cracks behind the pad meant that removal and replacement of L10 would need to be performed as part of the repairs. *Credit: Safran-Reosc*

On the evening of 02 June 2023, the Gemini North telescope restarted operations for the first time since October 2022. The telescope performed beautifully after an almost eight-month hiatus, with a newly repaired and coated primary mirror achieving its full performance. The Gemini North science operations team kicked off the first science observations with a staff-led Director's Discretionary program to observe SN2023ixf in the nearby galaxy M101.

Figure 3: Removal of the Pad L10 from GN M1 by *Jean-Benoît de Vanssay*. *Credit: Safran-Reosc*

This successful outcome followed a challenging and intense program by NOIRLab to recover from the damage to the primary mirror incurred on 20 October 2022 during preparations to recoat the mirror with its reflective silver layer. While lowering the M1 onto the washcart used to hold the mirror during stripping of the old coating, the mirror impacted an earthquake restraint on the side of the cart. Fortunately, there were no injuries associated with the incident, and the damage was limited to two chips on the outer edge of the mirror, in a section that is outside the area collecting light for observations.

Although the damage to M1 was limited, careful planning for the repairs was needed to ensure that the damage would not propagate or cause additional issues with the telescope performance. The immediate cause of the accident was human error, due to a radio communications mishap between the crane operator and the team lowering the mirror. However, there were multiple factors contributing to the event. These included insufficient management and safety oversight, unclear mirror handling procedures at the point of the incident, perceived time pressure, and the long interval between M1 coatings. Immediately following the

Figure 4: Thierry Lagrange grinding of Damage Area #1. *Credit: Safran-Reosc*

accident, it was necessary to take the needed time to understand the root causes and address them before the mirror was handled again.

The Gemini North telescope undergoes regular maintenance work to maintain the performance of its complex systems. Its primary mirror is a 8.1m diameter monolithic piece of ultra-low expansion glass, actively controlled by a series of actuators and coated with silver to provide high reflectivity at optical-infrared (OIR) wavelengths. While the mirror is regularly cleaned, the reflective coating degrades over time and must be stripped off and reapplied to maintain the telescope's optimal light-collecting power. This is a significant, high-risk activity that requires removing the 25-ton mirror from its mounting on the telescope structure and lowering it several floors to the coating area. The mirror is stripped of its old coating and then moved into the coating chamber for application of the new coating. Finally, the primary mirror is raised up to the telescope level, reconnected to the mirror cell, and reinstalled onto the telescope. In normal times, this activity is performed every five years, with the other mirrors (secondary mirror, science fold) coated in off-years in between.


Figure 5: NOIRLab GN M1 team members Gary Pozculp, Tom Schneider, and Heather Carr prepare witness samples to test the L10 epoxy application and bonding to ULE glass block. *Credit: NOIRLab/NSF/AURA/ Katie Smither*


Figure 6: NOIRLab M1 repair team members placing the new L10 lateral pad into position on the Gemini North primary mirror. *Credit: NOIRLab/NSF/AURA/Katie Smither*

The last time the Gemini North primary mirror (GN M1) was coated was in 2014, a long hiatus due to a series of unplanned events. This work was originally planned for July 2019, which ended up coinciding with the Thirty Meter Telescope protests on the Maunakea access road. Given the challenges with access to the telescope, Gemini management decided to defer the primary mirror coating until the summer of 2020. In 2020, NOIRLab halted all nighttime operations in response to the global COVID-19 pandemic. While Gemini North resumed observations in May 2020, in-person work at the telescope was limited in order to minimize the potential COVID exposure of critical staff. In 2021, we successfully recoated the smaller, easier to handle Gemini North secondary mirror, gaining 8% improvement in overall telescope throughput. With COVID-19 in decline and the majority of staff vaccinated, we planned a six-week shutdown of the Gemini North telescope to include the GN M1 coating to start in October 2022. The GN M1 incident occurred ten days into the shutdown, following the removal of the primary mirror from the telescope support structure and transport of the mirror to the pier support level.

The months-long effort to recover from the incident, repair the mirror, and


Figure 7: M1 after repairs and installation of new L10 pad. *Credit: NOIRLab/NSF/ AURA/Katie Smither*

Figure 8: GMOS imaging observations of the M101 supernova 2023ixf taken 02–05 June 2–5 2023. *Credit: International Gemini Observatory/NOIRLab/NSF/AURA/J. Miller/M. Rodriguez/M. Zamani/T.A. Rector & D. de Martin.*

complete the Gemini North mirror coating and engineering shutdown was supported by a team of internal and external experts. Shortly after the incident, an Independent Review Board (IRB) was convened to review the incident report and the repair plans. During the initial recovery period, the internal NOIRLab team performed a detailed damage assessment and worked with the IRB to develop the detailed M1 repair plan. Concurrently, the root-cause investigation was conducted, and the findings were addressed with improved mirror handling procedures, clarified roles and responsibilities, and strengthened oversight. The on-site mirror repair work by external contractors from Safran-REOSC and the NOIRLab repair team began in late February 2023 and was completed in April 2023. Following the completion of the repairs, the M1 stripping and coating was executed in April–May 2023, using the improved set of procedures and after providing additional managerial support to the team. Additional work in May 2023 was required to reassemble the telescope and test its performance following the repairs. On 02 June, the Gemini North telescope returned to on-sky observations, with the primary mirror achieving its full performance and ~10% improved reflectivity following the recoating.

For more details see: GN M1 2022 incident and repairs final report.

We would like to thank the Gemini/NOIRLab M1 repair team, led by NOIRLab Engineering Services Head of Optical & Mechanical Engineering Slawomir Bucki and supported by the NOIRLab Optical Engineering team and other experts within NOIRLab. On-site preparations and repair work and the engineering shutdown were led by Andrew Galvan, Andy Adamson, Steve Hardash, and Michiel van der Hoeven, with support from the cross-NOIRLab and Gemini/NOIRLab summit and engineering teams. The Independent Review Board was led by Jim Oschmann (retired, former Gemini construction project manager) and included Larry Stepp (retired), Eric Hansen (Thirty Meter Telescope), John Hill (University of Arizona), Dennis McBride (W.M. Keck Observatory), and Scott Roberts (NRC Herzberg Astronomy and Astrophysics Research Centre). External contractors from Safran-REOSC (France) provided preparatory work and on-site repair work.

10.5281/zenodo.8284624

The First Public Data from the Gemini High-Resolution Optical Spectrograph

David Jones (NSF's NOIRLab)

In the next few years, the International Gemini Observatory, a program of NSF's NOIRLab, is pursuing an ambitious plan for new instrumentation. That plan includes the Gemini Infrared Multi-Object Spectrograph (GIRMOS), the IGRINS-2 high-resolution near-infrared spectrograph, the SCORPIO optical and near-infrared imager, and the upgraded Gemini Planet Imager 2.0. The first of these new instruments — and the first facility instrument that Gemini has commissioned in more than a decade — is the Gemini High-Resolution Optical Spectrograph (GHOST), a new workhorse high-resolution spectrograph that will be available to the community in shared-risk mode in Semester 2023B. GHOST is a fiber-fed, echelle spectrograph with coverage from 363 to 950 nm; it provides two-target spectroscopy at resolutions of greater than 50,000 and single-target spectroscopy at resolutions of more than 75,000.

Over the last few months, GHOST has finished its commissioning work, and the team is now preparing for the first call for proposals. The final step in this process was the end-to-end system verification (SV) conducted in mid-May, in which proposals were selected to go through the full process of proposal submission, observation preparation, and data reduction. Targets were chosen by the instrument science team. This group was selected by the Gemini Directorate, in consultation with the Science and Technology Advisory Committee (which advises the Gemini Board on scientific and instrumentation priorities for Gemini), and the GHOST instrument team. The goals of the SV were to test the full set of GHOST software, documentation, and operational procedures in advance of offering the instrument to the community; to demonstrate to the community the science possible with GHOST; and to provide public, reduced data

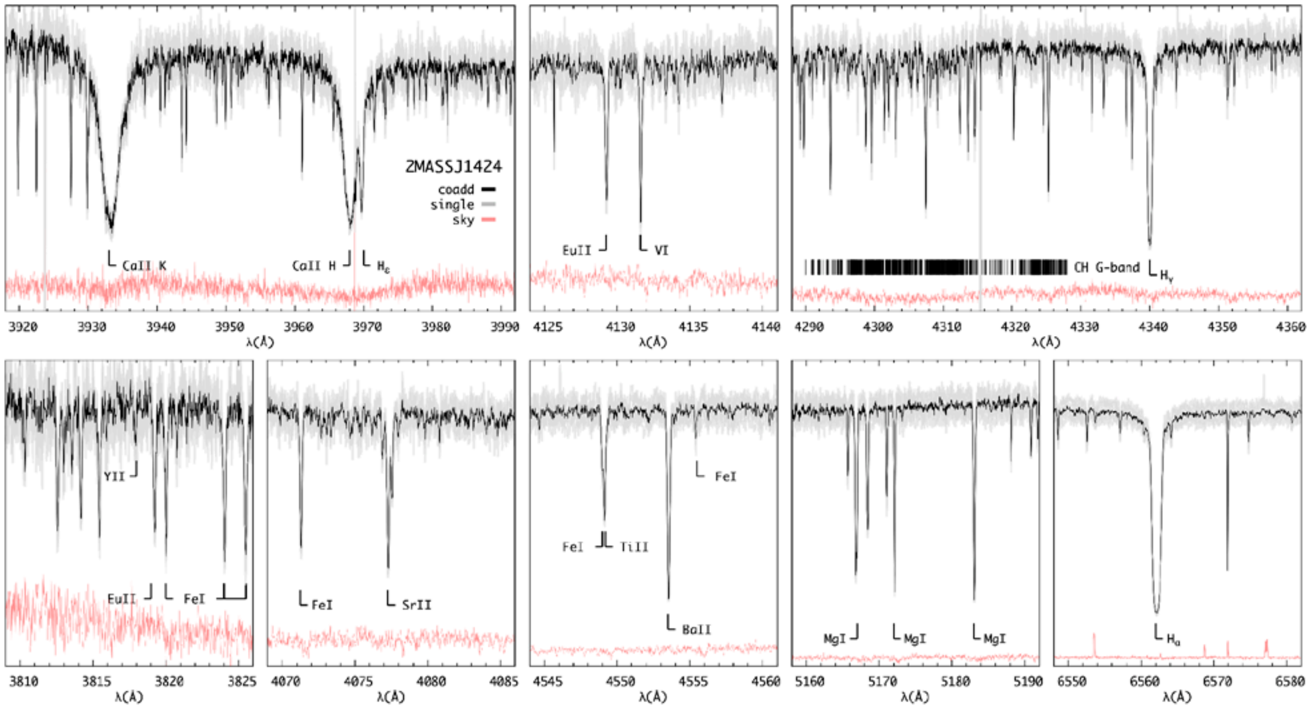

Figure 1: Example data from a 1.5-hour GHOST SV observation of 2MASSJ1424, an extremely metal-poor star with enhancements in r-process elements. The panels highlight atomic and molecular absorption features used for the determination of atmospheric parameters (Teff, logg, and [Fe/H]) and chemical abundances. These data will allow for a more complete chemical inventory of this star's atmosphere and a chemo-dynamical analysis that can further constrain its progenitor. *Credit: NOIRLab/AURA/NSF/V. Placco*

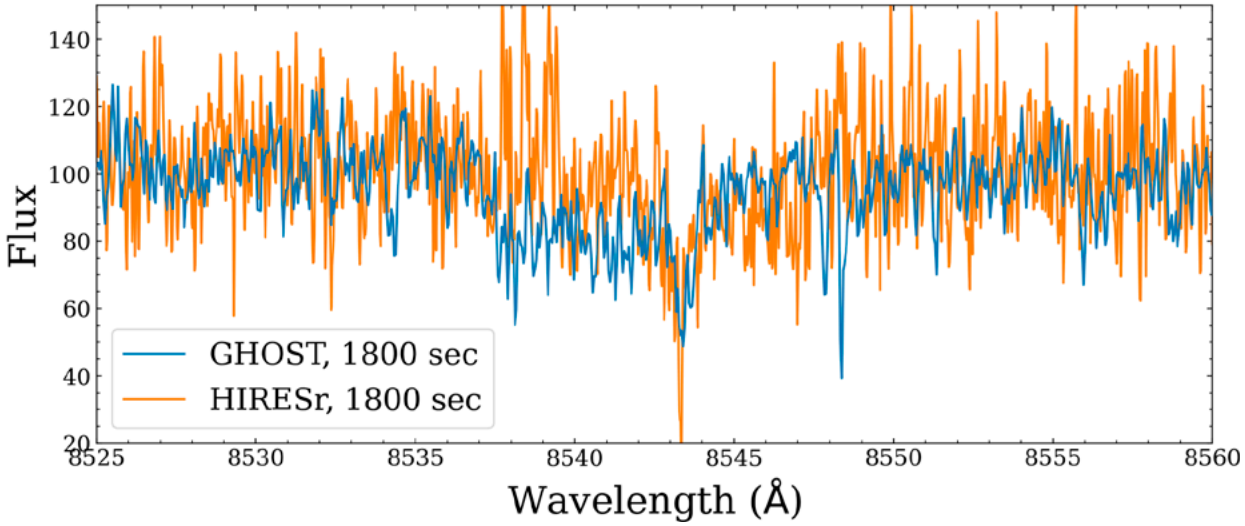

Figure 2: An example spectral comparison for the White Dwarf WD 1145+017 from GHOST and the High Resolution Echelle Spectrometer (the long-wavelength configuration; HIRESr) on Keck I. WD 1145+017 is the first white dwarf discovered to show transits from a disintegrating asteroid [2]. Its atmosphere is heavily polluted from accretion of the circumstellar material and GHOST SV data will be used to constrain the evolution of that material over time. *Credit: NOIRLab/AURA/NSF/S. Xu*

that showcase the capabilities of GHOST and in turn helps users to prepare for GHOST's first open call for proposals.

The science encompassed by GHOST's initial targets includes the following:

1. **Observations of Galactic metal-poor stars:** Chemical abundances of stars in the Milky Way will be used to constrain the progenitors of extremely metal-poor stars, understand star formation at the lowest metallicities, and study the accretion history of the Milky Way disk and the origins of substructures in the Milky Way halo (Figure 1).

2. **Transmission spectroscopy of hot exoplanet atmospheres:** GHOST spectroscopy of atomic, ionic, and molecular species in the atmospheres of exoplanets transiting their host stars will be used to study the physical and chemical processes at work in those atmospheres.

3. **White dwarfs and symbiotic stars:** GHOST observed O IV line profiles in symbiotic star systems to provide insights into their kinematics, geometry, and evolutionary stages. GHOST also observed a white dwarf with a disintegrating, transiting asteroid and will study the evolution of its circumstellar material (Figure 2).

4. **Binary star systems:** GHOST observations of single-lined spectroscopic binaries will reveal their hidden companion stars, allowing the team to investigate accretion processes that shed light on massive star formation. GHOST observations of candidate co-natal stars will be used to study the correlation of metallicity with binary star separation.

5. **Chemical abundances of ultra-faint dwarf Milky Way satellites:** Chemical abundance patterns of stars in ultra-faint dwarf galaxies (UFDs), some of the oldest and most metal-poor stellar systems in the local Universe, will be used to explore the star formation and chemical enrichment in environments like those of the first galaxies (Figure 3). GHOST also observed early-type stars in the nearby dwarf galaxy Sextans A.

6. **Extragalactic compact systems:** GHOST observations will reveal the chemical compositions of ultra-compact dwarfs — massive, compact star clusters — in order to understand their evolutionary histories. GHOST also observed luminous quasars to study absorption from galaxies along the line of sight to probe galaxy evolution and the formation and distribution of metals in the circumgalactic medium.

Simultaneously, a manuscript with the first science results from GHOST from the commissioning data — spectroscopy

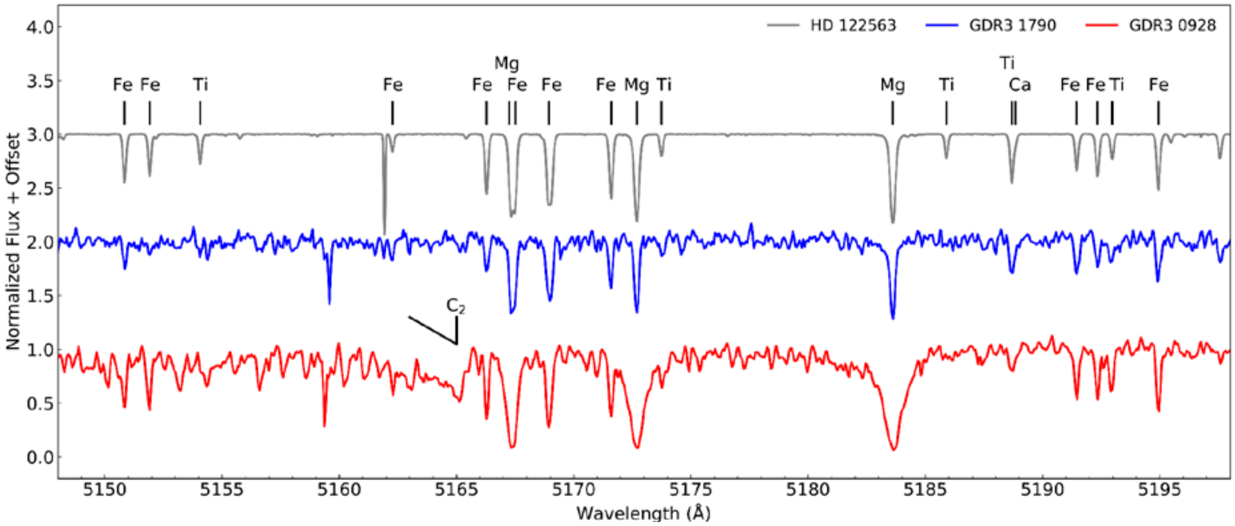

Figure 3: Spectroscopy of metal-poor stars from GHOST's first science results (Hayes et al., 2023). GHOST commissioning data clearly show the enhancement in Mg and C abundances for the star GDR3 0928 (red), allowing it to be identified as a carbon-enhanced metal-poor star in the ultra faint dwarf galaxy Ret II. These data demonstrate how GHOST will help to constrain the metal enrichment, star-formation histories, and evolutionary processes of some of the faintest and oldest galaxies in the Universe. *Credit: C. Hayes/NRC Herzberg Astronomy & Astrophysics*

of metal-poor stars in a nearby UFD — has recently been submitted to AAS Journals [1] (Figure 3). The data allowed the GHOST commissioning team to constrain chemical abundances in the galaxy Ret II, in turn placing constraints on the metal enrichment processes of one of the closest UFDs.

In addition to showcasing the potential science from GHOST, the goal of these data is to help the community prepare for 61 hours of shared-risk observations in Semester 2023B. The first GHOST raw data was made available to the community in June, and the reduced data will be available by the end of August. The call for proposals will be announced in late August, and Gemini is hosting multiple webinars for the community to prepare for the new instrument.

Our hope is that these data will be the starting point for engaging the community in Gemini's new instrumentation. Over the coming years, observatory staff will be streamlining the process from instrument commissioning to system verification to community engagement and accessibility. We're excited to be at the beginning of a new era for Gemini instrumentation and new science frontiers.

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10.5281/zenodo.8284634

The NOIRLab/CHARA Connection Marks Decadal Milestones Up to 40 Years

Steve Ridgway (NSF's NOIRLab) and Gail Schaefer (GSU and CHARA)

Just one decade ago, the Georgia State University (GSU) Center for High Angular Resolution Astronomy (CHARA) first offered open access to the CHARA Array, making time available through the NOAO Telescope Allocation Committee (TAC) twice per year (Figure 1). GSU absorbed the associated costs, thus taking leadership in developing the science community of interferometer users. Starting at about 10 nights per year, that allocation has increased. Thanks to NSF grant support through the Mid-Scale Innovations Program (MSIP), CHARA now offers up to 100 nights per year through open competition.

The 10-year mark on open access recalls other milestones. The Array was dedicated two decades ago. At that time, its 300-meter telescope baselines provided the highest optical resolution available to astronomers. After 20 years, with the same telescopes and baselines, this is still true.

The CHARA and National Observatory links go back even further. Approximately 40 years ago, Harold McAlister, while working as a postdoc for Kitt Peak astronomer Roger Lynds, matured speckle interferometry as a methodology. Hal departed Tucson with the immediate goal of pursuing speckle methods and with the germ of an idea for an optical array. In the succeeding years he formed CHARA as a major GSU initiative. While conducting and fostering modern binary star research, he prepared the ground for the CHARA Array, motivating, promoting, and shepherding the program to success. NOAO engaged substantially in the Array design and construction. In addition to scientific and technical staff participation, NOAO was the second-largest Array contractor, mainly for design, fabrication, and implementation of specialized array elements.

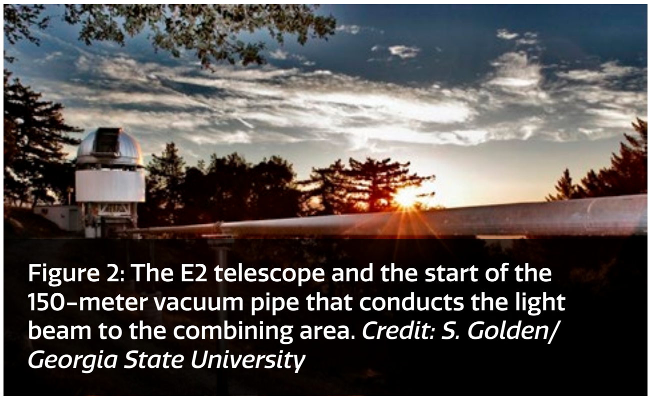

Figure 2: The E2 telescope and the start of the 150-meter vacuum pipe that conducts the light beam to the combining area. *Credit: S. Golden/ Georgia State University*

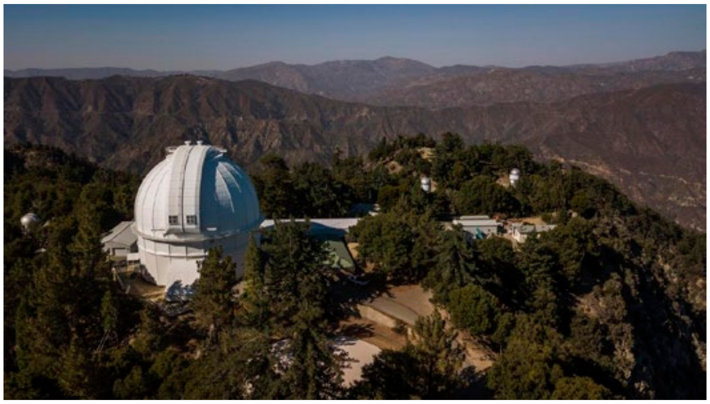

Figure 1: The Mt. Wilson 100" Hooker dome, surrounded by the CHARA Array. Key to Array elements: at 2:30, the E1 and E2 domes; at 3:00, the central laboratory and the offices; at 7:00, light pipes to the S1 and S2 telescopes; at 9:00, the W1 dome. *Credit: Georgia State University*

Now 22 years after the Array dedication, succeeding development of beam combiners and detectors extend the Array performance in sensitivity, spectral coverage, and imaging power (Figures 2–3). Major recent or in-progress developments include higher-performance visible and infrared beam combiners and adaptive optics on all telescopes. Programs in preparation include addition of a movable telescope with an optical fiber link to the fixed array and continuing design work on possible future Array upgrades to larger apertures.

Open access is now an essential feature of the CHARA Array operation. Records show that during the decade, the NOAO/NOIRLab TACs have processed 303 proposals representing over 350 distinct participating observers (PI + CoI). Community proposals span a broad range of science goals (see sidebar).

A sample of community science programs conducted with the CHARA Array

One main focus is measuring the angular diameters of stars across the H-R diagram, from low- to high-mass stars along the main sequence and for stars at different evolutionary stages. Tyler Ellis [1] recently used the CHARA Array to measure the radius of the exoplanet host star HD 97658. These results were used to refine the physical properties of the transiting super-Earth HD 97658 b. In a similar analysis, José Caballero [2] measured the radius of the host star Gl 486 to help derive the properties of the rocky transiting exoplanet Gl 486 b.

Matthew De Furio [3] conducted a multiplicity survey of 26 intermediate mass A-type stars within 80 pc and found a companion frequency of 0.19 at separations between 0.29 and 5.48 au. At the higher masses, Cyprien Lanthermann [4] surveyed 29 O-stars to search for companions at angular separations between 0.5 to 50 mas and found a higher companion frequency of 0.66 ± 0.13.

Noel Richardson [5] measured the first dynamical mass of a nitrogen-rich Wolf-Rayet star by mapping the visual orbit of WR 133 with the CHARA Array and combining his data with radial velocity measurements. The results suggest that WR 133 might have formed through binary interactions. Leslie Morales and Eric Sandquist [6] mapped the orbit of the brightest member of the Praesepe cluster, ε Cnc, to determine precise dynamical masses. Comparison with evolutionary tracks yielded an age of 637 ± 19 Myr. Willie Torres [7] spatially resolved the orbits of the close, faint companions to Castor A and B for the first time. Combined with historical observations spanning the past three centuries, he measured the three-dimensional orbits of the four stars in Castor A and B and determined the stellar masses with a precision better than 1%. The interferometric radii of the primary stars in each subsystem were used to infer an age of 290 Myr.

Makoto Kishimoto [8] resolved the inner dusty region around the supermassive black hole at the center of the active galaxy NGC 4151. The results show an elongation perpendicular to the emerging jet, consistent with emission from an equatorial dusty ring. A flaring disk geometry could explain differences in the inner region probed by the near-infrared wavelengths and the outer region studied by high-angular-resolution observations in the mid-infrared.

Elias Aydi and Laura Chomiuk [9] obtained target-of-opportunity observations of five bright novae outbursts to monitor the angular expansion of the ejecta and the development of asymmetries over time.

A major development of recent years is the capability to record resolved stellar images, giving greater insight into the physics of surface activity. Rachael Roettenbacher [10] (Figure 4) studied the rapidly rotating, magnetically active giant Zeta And, with time evolution confirming a persistent polar spot and variable lower latitude spots. Ryan Norris [11] followed convective structures on the supergiant AZ Cyg, finding large structures observed for five years and a smaller structure that was more transient.

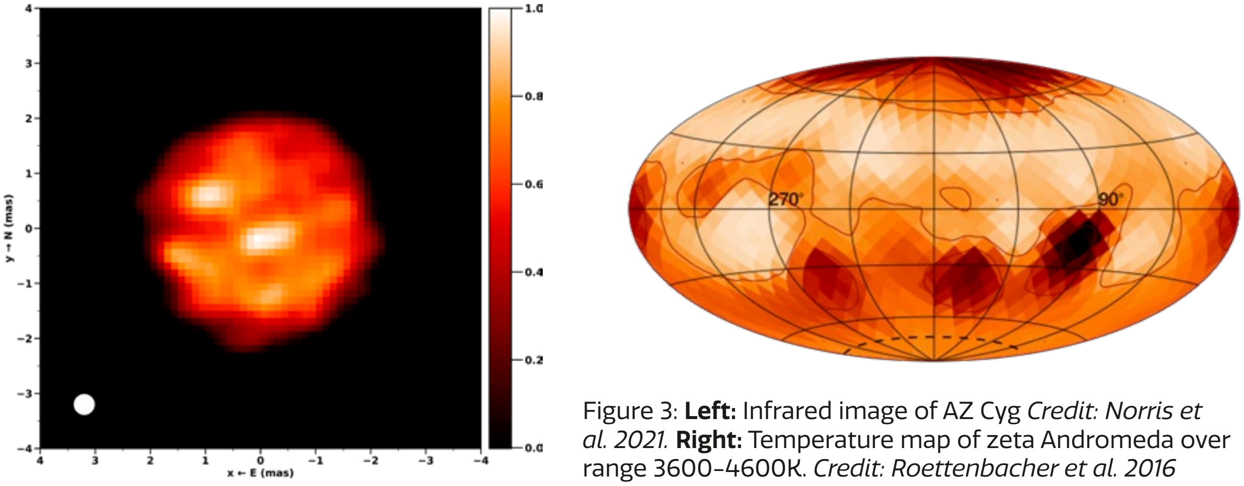

Figure 3: **Left:** Infrared image of AZ Cyg *Credit: Norris et al. 2021.* **Right:** Temperature map of zeta Andromeda over range 3600-4600K. *Credit: Roettenbacher et al. 2016*

The next generation of instrumentation at the CHARA Array offers improved sensitivity and options for combining all six telescopes across multiple wavelength regions. The MIRC-X and MYSTIC instruments operate simultaneously and combine the light from all six telescopes in the near infrared H and K bands. They provide sensitivity down to H=7.5 mag

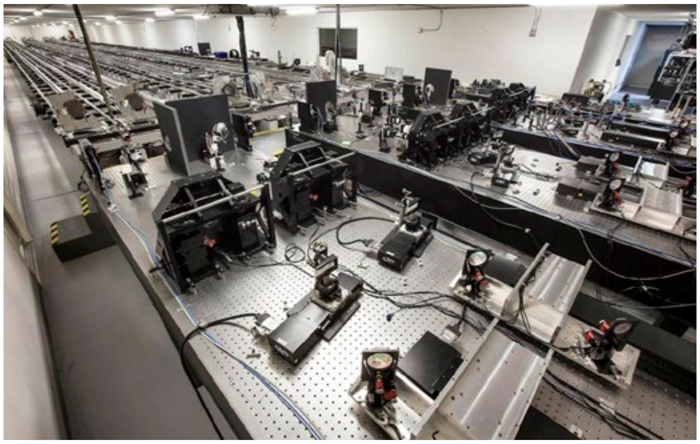

Figure 4: Beam synthesis facility. Optical delay room. The variable delay lines extend toward the upper left. Metrology, beam compression, switching, and dispersion compensation are on the tables in the foreground. *Credit: S. Golden/ Georgia State University*

and a range of spectral resolutions from R=50 to R=1700. The MIRC-X and MYSTIC beam combiners were built and commissioned by teams at the University of Michigan and Exeter University, led by John Monnier and Stefan Kraus. The main science drivers include imaging stellar surfaces and circumstellar disks around young stars to better understand planet formation.

A new visible light, 6-telescope combiner called Stellar Parameters and Images with a Cophased Array (SPICA) has been installed at the CHARA Array by a team from the Observatoire de la Côte d'Azur led by Denis Mourard. The instrument features low (R=150), medium (R=4300), and high (R=13,200) spectral resolution modes. One of the main science goals of SPICA is to conduct a survey of 1,000 stars to provide a large and homogeneous set of angular diameter measurements and stellar parameters across the HR-diagram. The higher spectral resolution modes will be available for spectral imaging of stellar surfaces and environments and kinematic studies of brighter stars. Time on SPICA is expected to be offered to the community starting in 2024.

Development work is underway on a new, near-infrared, 3-beam combiner called SILMARIL that seeks to extend the sensitivity of the Array down to 10–11 mag in the H and K bands. The SILMARIL project is led by Theo ten Brummelaar of GSU. The improved sensitivity will help astronomers resolve the inner cores of a larger sample of active galaxies.

Open-access time at the CHARA Array is available through the NOIRLab time allocation system. CHARA staff provides assistance to new observers to help with developing science programs, planning observations, collecting data, and providing reduced and calibrated data files. Guest observers are encouraged to participate in the observations, and travel support is available for those who wish to visit the Array. CHARA also offers the option to participate in observations remotely through a VNC connection to a virtual machine that runs the control software.

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10.5281/zenodo.8284646

NEID: Back On–Sky and Delivering Science Led by Early Career Researchers

Sarah Logsdon (NSF's NOIRLab)

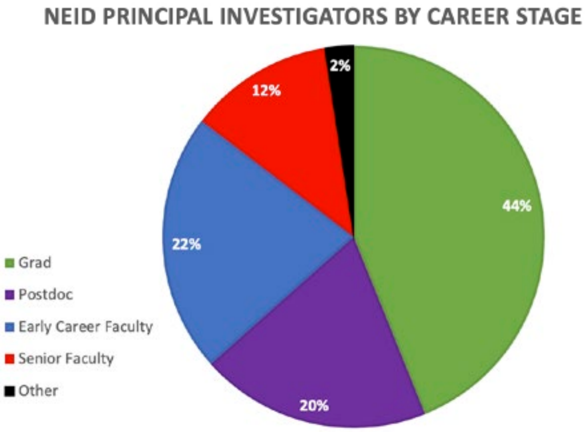

Figure 1: Breakdown of unique NEID PIs by career stage at the time of their first successful NEID proposal from Semesters 2021B–2023A. This does not include successful repeat proposals. Over 85% of NEID PIs are either graduate students, postdoctoral researchers, or early career faculty/staff (defined as being within 10 years of their PhD). *Credit: Figure provided by author.*

NEID is an extreme precision radial velocity (EPRV) spectrometer at the WIYN 3.5m Telescope at Kitt Peak National Observatory. It resumed science operations in November 2022, following a shutdown due to the June 2022 Contreras Fire at Kitt Peak National Observatory. We are pleased to report that NEID is still delivering radial velocities at the sub-m/s precision levels that it achieved before the fire.

NEID continues to be WIYN's flagship newest instrument, utilizing more than 75% of the available WIYN 3.5m Telescope time in Semester 2023A. It is scheduled for a similar percentage of Semester 2023B time after the NN-EXPLORE (NASA-NSF Exoplanet Observational Research) program received the largest number of NEID proposals to date.

Much of the awarded NEID time is being led by early career principal investigators (PIs). As shown in Figure 1, over 85% of the NEID PIs through Semester 2023A were either graduate students, postdoctoral researchers, or early career faculty/staff (defined as being within 10 years of their PhD) when they were first awarded time with NEID.

In early 2023, these early career PIs published several articles presenting NEID science results. These publications have reported on the usage of NEID to confirm and measure the masses of hot Jupiter-sized exoplanets discovered using NASA's *Transiting Exoplanet Survey Satellite* (*TESS*) around both low-mass and solar-type stars [1, 2], to confirm and characterize a *TESS*-discovered and highly eccentric warm Jupiter (Figure 2, TOI-4127b; 3), and to probe the formation mechanism(s) of a warm sub-Saturn (TOI-1842b; 4) and a young, warm Neptune (TOI-1842b; 5).

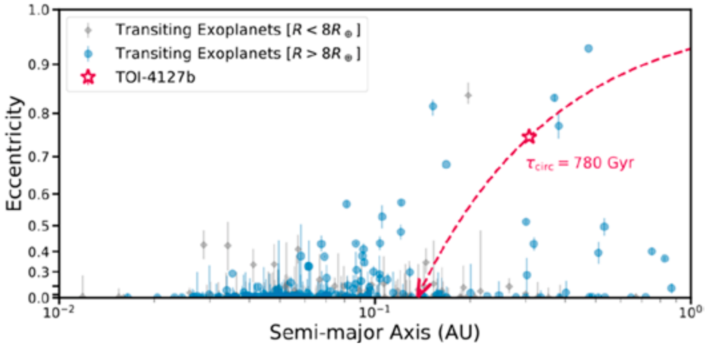

Figure 2: This plot shows planet eccentricity for all known transiting planets with well-defined mass measurements vs. distance from the host star. TOI-4127b is indicated with a red star and is one of only a few known transiting planets at high eccentricity. The dashed red line shows how the orbit of TOI-4127b would become circular, assuming a constant angular momentum. The planet is not expected to reach a circular orbit during the main-sequence lifetime of its host star. *Credit: Gupta et al. 2023*

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10.5281/zenodo.8284658

Rubin Observatory and Facilitated DEI Training

Federica Bianco (Rubin Observatory)

The following people contributed to this write-up and to the organization of the facilitated sessions described in this article: Keith Bechtol (Rubin Observatory), Sara Bonito (INAF – Osservatorio Astronomico di Palermo), Ranpal Gill (Rubin Observatory), Xiaolong Li (University of Delaware), Andres A. Plazas Malagón (SLAC), Kristen Metzger (Rubin Observatory), Brian Nord (Fermilab), Alysha Shugart (NSF's NOIRLab), Rachel Street (Las Cumbres Observatory).

The Vera C. Rubin Observatory community has made a commitment to equity and inclusivity. We have been active in the Equity, Diversity, and Inclusion (EDI) sphere, offering EDI activities and training as well as forming committees focused on promoting equity in all our spaces. In this article, we describe our experiences organizing facilitated and moderated EDI training opportunities for the Rubin community, including a discussion of advantages and challenges of various approaches. While facilitated EDI activities require financial resources as well as a non-negligible amount of work from internal teams, we believe that their advantages outweigh the costs, and we share lessons learned in the organization of facilitated EDI training.

In addition to the more than 1000 individuals working as Rubin Observatory staff, there are more than 2500 scientists based in more than 30 countries around the world preparing to generate science from the Rubin Legacy Survey of Space and Time (LSST). These scientists are organized within the Rubin LSST Science Collaborations. Hereafter, we will use "Rubin" to refer to this global ecosystem.

While we feel confident saying, unequivocally, that Rubin at large shares the ideals of equity and inclusivity, making these principles a reality requires financial resources, work, and effort. There is little doubt that the vast majority of the Rubin community values and intends to support diversity and practice equity and inclusivity, yet statistics confirm the aspirational nature of these principles in Rubin: the representation of scholars of color remains painfully small, the engagement service roles rest disproportionately on the shoulders of minority scholars, and currently, observatory staff in leadership positions are predominantly senior white males (McBride 2019). These few examples show that equity remains something we strive for, but cannot say we have achieved. To continue to improve our capacity for putting into practice our shared principles, Rubin regularly provides opportunities for EDI training. Recently, some of these activities have been facilitated by external organizations.

> **"LSST Corporation recently selected a cohort of postdoc fellows for the LSSTC Catalyst Fellowship, and I leveraged what I learned in the workshop as I helped oversee and explain the selection process"**
>
> *–Jeno Sokoloski Director of LSSTC's LINCC initiative, including directorship of the LSSTC Catalyst Fellowship Funded by the John Templeton Foundation*

Hiring an organization for facilitated EDI training requires an outlay of resources. The first facilitated EDI training in Rubin was supported by a grant awarded to PI Plazas Malagón by the LSST Corporation (LSSTC Enabling Science Award #2020-07) to organize an anti-racism workshop during the Rubin Project & Community Workshop (PCW). The organizers felt the urgency of offering an opportunity for reflection on racism in the social environment that was emerging in the early days of the pandemic, a racial reckoning triggered by disparities enhanced by the pandemic and catalyzed in the US by the murder of George Floyd, with the Black Lives Matter movement gaining ground on raising awareness and outrage about systemic anti-Black racism. We recruited The BIPOC Project for anti-Black racism on-line training[1] during the 2021 PCW. The most recent Rubin-facilitated EDI training was organized by the Transient and Variable Stars Science Collaboration Justice Equity Diversity and Inclusion team

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[1] Notably, the EDI landscape had changed worldwide, and, accordingly, demand on organizations had increased and prices have risen. Ultimately, the original grant request based on pre-pandemic prices for typical moderated EDI sessions fell short by nearly one-half of the total cost, and AURA stepped in to supply the additional funds with funds from NSF Cooperative Support Agreement 2211468.

(JEDI) and supported by a "kickstarter grant" ($7,000; PI Bonito) apportioned from Heising Simons Foundation grant 2021-2975 administered by Las Cumbres Observatory (PI Street). Training was led by Movement Consulting in empathic communication and community building, topics that were chosen by a community vote among those available in the portfolio of the facilitating organization.

Although there are many demands on funding for science, we felt that investing resources in moderated EDI sessions would provide more value to participants, and more benefit to the organization, than providing these sessions "in-house." Organizing in-house EDI sessions has significant hidden costs, often absorbed by members of the community volunteering their time and energy. As an example, the 2020 PCW included a multi-day EDI session led by members of the Rubin community. This session, based on input from the American Institute of Physics TEAM-UP Project, included offline preparatory exercises and reading as well as follow-up activities and required months of preparation by a team of three Rubin members. Organizing moderated training also required significant person-power from Rubin: work directed to fundraising, identifying, contacting, and selecting facilitators and to working with the selected organization to tune their training to the complex Rubin community. We estimate 20 person-hours to prepare a compelling proposal and 25 person-hours to finalize the organization, including ~15 person-hours spent interviewing facilitators. However, there are additional advantages in externally facilitated EDI activities.

There is a level of EDI competence, experience, and professionality in externally facilitated training that cannot be expected to be matched by members of the Rubin community with limited EDI formal training and for whom this work is outside of the scope of their jobs. The activities developed by these teams are based on evidence, tested, and optimized for impact on the targeted community. Just as important, however, is the perception of the audience. While in grassroots EDI training some members of the community are necessarily placing themselves in a leadership position, in externally facilitated training, all members of the audience are on the same footing. Furthermore, the moderators do not know the individuals in the audience and do not carry biases and preconceptions about them: they are not deferential to people in leadership positions nor do they have assumptions on who may hold more progressive or knowledgeable views on EDI; the community as a whole is able to reassess their position with respect to equity; and external facilitators can afford to be provocative, even disruptive, without fear of consequences.

The following are some of the lessons we have learned during this process.

Participation statistics for two externally facilitated EDI training experiences

Participants	Demand	Seniority	Demographic Breakdown	Hours of facilitated work	Preparatory material	Follow-up	Organization
~65 (all required to participate in both sessions)	Demand slightly exceeded the original session limit. All applicants were allowed to participate after consulting with facilitators.	30% junior 37% mid 33% senior	Pronouns: 59% he-him 39% she-her 2% other ==== Racial or ethnic identity not identified	2x2 hour session, consecutive days	Reading material was prepared and shared with prospective participants by Rubin over the course of months prior to the PCW. Part of this training isolated sections of *The Time is Now* (APS 2020) and suggested them as reading material. A pamphlet on systemic racism and anti-Black racism in STEM and in academia was also offered by the facilitators closer to the time of the workshop with additional references and reading suggestions.	A community session was organized at the five-month benchmark to discuss the impact of the workshop.	The BIPOC Project
Session 1: 17 Session 2: 35	67 (not required to participate to both sessions) Demand did not exceed the per-session limit.	Information not collected	Identifies with a STEM gender minority 52% no 40% yes 8% maybe / prefer not to answer ==== Identifies with a STEM Race-Ethnic minority 75% no 20% yes 6% maybe / prefer not to answer	2x2 hour session, one month apart. Session 1 "Power Dynamics & Empathic Communication" Session 2 "Collective Principles & Community Building"	Topics were selected by pooling the Rubin Science Collaborations.	Participants were sent an anonymous follow-up survey asking about their impressions from the sessions they attended, how to improve them (as organizers and as participants), and what topics they would want future training to focus on. Outcomes will help us organize future EDI training.	Movement Consulting

Selection of an Organization

It is critical to engage thoroughly with the organization providing the training. The recruitment and selection process includes interviews to understand what activities can be developed for the available funds and ensure that the constraints on dates and modality of delivery will be respected. The Rubin organizing teams considered a representation of marginalized communities among the facilitators a requirement. For example, it was critical for us to ensure that Black people would be leading the anti-Black racism workshop to speak from an experiential and not exclusively scholarly perspective. Familiarity with the world of STEM is important: STEM has specific EDI issues, including severe historical marginalization with lingering effects on diversity and climate, and STEM people tend to be prone to problem-solving, rather than to abstract reflection, which needs to be taken into account in planning a strategy for engagement. We preferred training organizations that would provide preparatory and follow-up material, particularly in the context of training offered at the PCW where we had an opportunity to emphasize and coordinate preparatory work. Facilitated training sessions have limits to the number of participants which vary significantly from one organization to another. This proved to be an important factor in the selection of an organization. See table.

Working with the Organizations Providing Training

Once an organization is selected, it is critical to familiarize them with the audience. The Rubin community offers significant complexity. We are a highly international community, while EDI topics intersect with cultural and situational frameworks. Organizations that provide EDI training tend to specialize in working within a specific cultural context.

For example, The BIPOC Project indicated that their focus was going to be unequivocally on anti-Black racism, and particularly on anti-Black racism as it is understood in the US context. While anti-Black racism is a global problem, it has different nuances in different cultural contexts, and it proved important to prepare the facilitators and the community to understand the topic of the training and the lens through which the organization was approaching it. In the instances in which we failed to do that effectively, we failed to reach members of the audience who complained about the specificity of the topic and lack of applicability to their direct environment.

> **This meeting opened my eyes. My thinking on this topic had been focused on the “pipeline” question. The discussion over the past two days showed clearly that there is much more at work.**
>
> *- Patrick McCarthy, director of NSF's NOIRLab*

Movement Consulting is a multicultural organization accustomed to working with international audiences. However, communicating the profile of the Observatory, with the PI of the grant that financed the training affiliated with an Italian organization, the physical facility occupying Chilean land, the majority of the employees who participated in the training from the US, and community members participating from a variety of countries in North and South America and Europe required multiple iterations and refinements between the two sessions. An additional complexity of the Rubin community is that it is composed of employees of the Observatory, for whom rules of engagement can be enforced by contractual obligations and Human Resources, and scientists with volunteer associations with Rubin that are not bound by rules enforceable by consequences on their employment. This should be communicated clearly or facilitators may offer solutions that are not applicable to the community at large.

Participation of People in Decision-Making Positions

We believe it is critical that the leadership of all Observatory and community teams participates in this training. Their participation is a sign of commitment to EDI. Their decision-making power is necessary to turn learned lessons into actionable plans. However, it is also important to ensure that facilitators control social dynamics and prevent people in prominent and decision-making positions from centering themselves or being centered in the discussion. EDI training should be for everyone, and the space where EDI training happens needs to be exemplary in equity.

The last point we want to make is that our EDI training sessions have been disproportionately populated by people from historically marginalized communities: people of color, gender minorities, and people on all axes of disadvantage have been interested in participating and in increasing equity in our spaces for themselves and the other marginalized groups. While we are not qualified to speculate on the reasons for this, we want to stress some of its consequences. These sessions are intended as an opportunity to learn and organize action for everyone, not an opportunity to learn and reflect for some and a request to teach and share experiences about (in)equity for others. It can be very frustrating for people who regularly experience oppression to have to explain oppressions to the newcomers in EDI. We want to protect our colleagues from the risk of retraumatization and the burden of shepherding those with privilege into a new appreciation of the magnitude and importance of EDI issues. Facilitated training removes some of the burden of the organization and some of the potentially onerous spotlight from people from marginalized groups in our community, but the need to protect marginalized identities from harm within the EDI training is a critically important point that should be discussed with the facilitators in depth before finalizing a contract for EDI training.

We received powerful testimonies of the impact of the workshops we organized, including from people in key decision-making positions, and we are progressively improving plans to sustain the outcome of activities and we continue to invite the community to meet and discuss how they are implementing what they learned in training. We hope and believe that collectively we are moving towards Equity and Inclusivity, and we do see improvements, however slow, in becoming more diverse.

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10.5281/zenodo.8284664

Update on the US Extremely Large Telescope Program

Richard Green (NSF's NOIRLab)

The US Extremely Large Telescope Program (US-ELTP) is a partnership among the Giant Magellan Telescope (GMT) and Thirty Meter Telescope (TMT) observatory projects and AURA/NOIRLab. The goal of the US-ELTP is to complete the construction of the two observatories and ensure US community access to full-sky data from the next-generation state-of-the-art telescopes. The role of NSF's NOIRLab is to provide the end-to-end system for proposal submission and evaluation; generation of observing programs for adaptive, integrated scheduling; robust automated standard data reduction pipelines; complete curation of all data; and support of a data science platform, based on the heritage of its efforts for the Gemini and Rubin Observatories and the Community Science and Data Center.

The plan is to provide high-quality, easy-to-use tools accessible by any community user and to support a means for fostering collaborations to lower the barrier to participation in cutting-edge science with these telescopes, enabling high-impact investigations and furthering community goals

US–ELTP exhibit at AAS Meeting #241 in Seattle, Washington, with staff from the three partners. *Credit: NOIRLab/NSF/AURA* for research inclusion. The three partners (GMT, TMT, and AURA/NOIRLab) communicate closely and often at management and technical levels to assure that the parallel developments are mutually supportive in realizing the US-ELTP's goals.

Considerable progress has been made over the last several months. The NSF Astronomy Division conducted preliminary design reviews for the two telescope projects in December and January. The projects used the opportunity to demonstrate their technical innovation and readiness, risk mitigations, and rigorous management and business practices. At NOIRLab, under the guidance of Steve Berukoff, the Program Manager, and Marie Lemoine-Busserolle, the Systems Scientist, the US-ELTP team has advanced the flow-down from scientific and operational needs to (over 700) system requirements, and work is underway on an integrated conceptual design. André-Nicolas Chené, the Community Engagement Scientist, worked with the telescope projects and NOIRLab's Communications, Education, and Engagement Service to create an eye-catching US-ELTP exhibit at the Seattle AAS meeting in January and the Albuquerque AAS meeting in June. He is also updating the US-ELTP website. Dara Norman and her postdoc, Tim Sacco, have produced an initial version of the Toolkit of Collaborative Practice, which is an important step on the road to having a large community ready to benefit from ELT data as soon as the observatories begin their scientific operations. Eric Peng has now joined the team as Project Scientist, while Mark Dickinson is taking a well-earned sabbatical. We particularly welcome Lucas Macri, who is the new NOIRLab US-ELTP Director as of 01 May.

It has been a privilege for me to serve as Interim Program Director during these last months. By mutual agreement, I will be continuing to advise the program leadership. At the time of this writing, our astronomy colleagues at NSF are confronting the challenge of gaining approval and the financial resources necessary for the telescopes and the user support development to advance to construction. NOIRLab works with them closely in the spirit of the Cooperative Agreement to support their efforts to make the highest recommendation of the Decadal Survey for ground-based astronomy a reality.

New NOIRLab US ELT Program Director

Lucas Macri became the Program Director of the US Extremely Large Telescope Program (US-ELTP) on 01 May. The Program Director has overall leadership responsibility for the execution of the work and for meeting the science requirements within schedule and budget. Lucas is responsible for setting the strategic vision and priorities for the project. He acts as the main point of contact with NSF, AURA Corporate, and the NOIRLab Director's Office and represents the program in both internal and external committees and in public settings.

Lucas brings recent valuable experience as Professor of Physics and Astronomy and Associate Dean in the College of Science (later Arts & Sciences) of Texas A&M University, as Chair of the Executive Board of the LSST Corporation, and as a member of the Space Telescope Science Institute Council. He received a BS in Physics from MIT and a PhD in Astronomy from Harvard. He held Hubble and Goldberg Fellowships at NOAO, so his new appointment is a welcome return back to Tucson. The primary focus of his research has been in the extragalactic distance scale, using Cepheids and Miras to calibrate SNe Ia and measure the Hubble constant with increasing accuracy and precision.

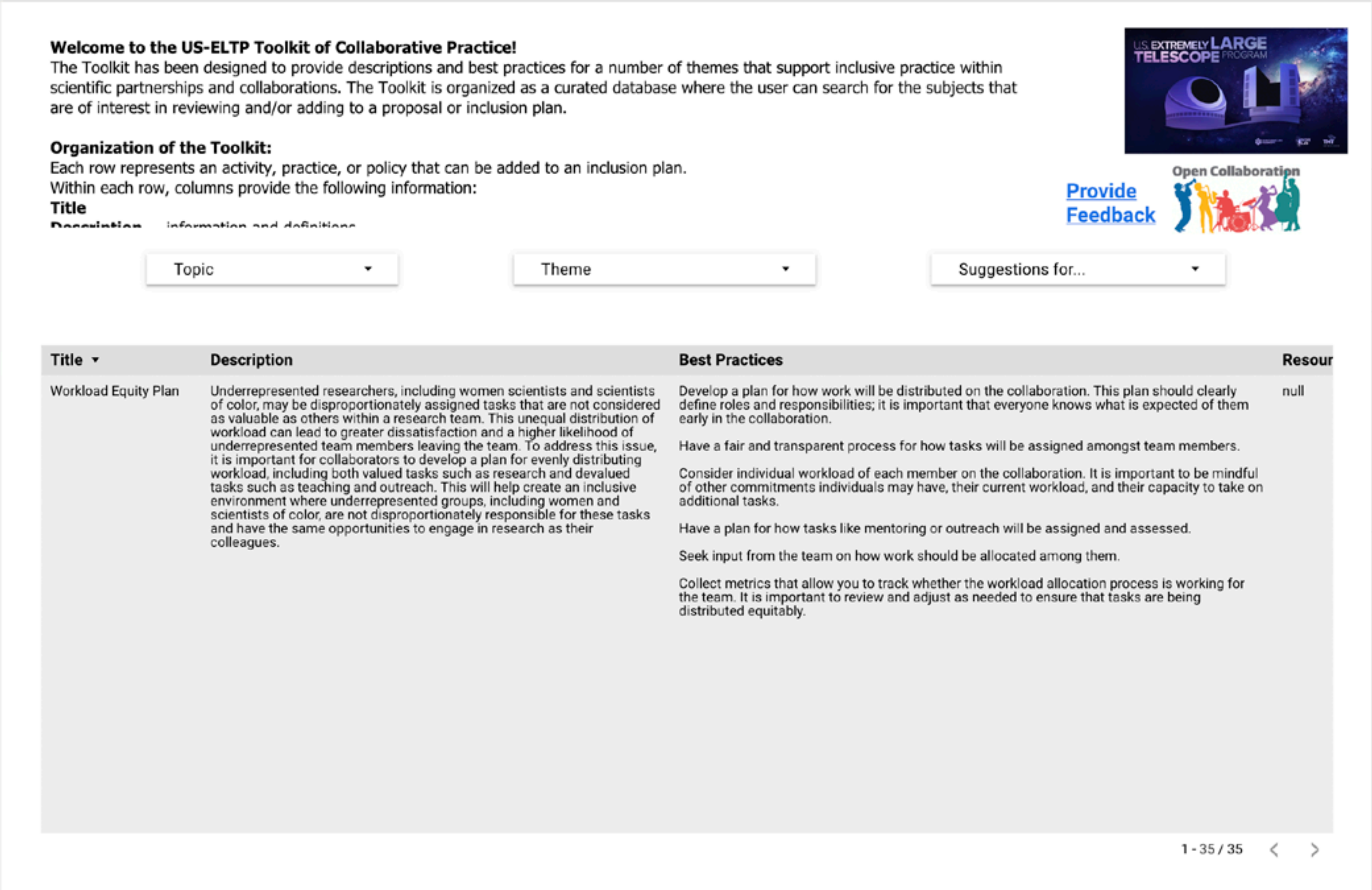
10.5281/zenodo.8284670

Helping Researchers Write Better Inclusion Plans

Dara Norman and Tim Sacco (NSF's NOIRLab)

The Astro2020 Decadal Survey report laid out an unprecedented number of recommendations for improving the workplace culture of the field. In response to these inclusion priorities, federal agencies, such as NASA and the Department of Energy (DOE), have signaled that topics around diversity, equity, inclusion, and accessibility (DEIA) are important to the development of the workforce going forward. For instance, NASA has adopted inclusion as one of its five pillars of mission success, and several of its divisions require an Inclusion Plan as part of proposals. Similarly, the DOE has introduced Promoting Inclusive and Equitable Research (PIER) Plans as an appendix to their proposal narrative that "will be evaluated as part of the merit review process and will be used to inform funding decisions."

As part of the US Extremely Large Telescope Program (US-ELTP), the staff at NSF's NOIRLab have developed a Toolkit of Collaborative Practice (Toolkit). The Toolkit originally was designed to be a product of the US-ELTP Research Inclusion Initiative and had been scheduled to be



Welcome to the US-ELTP Toolkit of Collaborative Practice!
The Toolkit has been designed to provide descriptions and best practices for a number of themes that support inclusive practice within scientific partnerships and collaborations. The Toolkit is organized as a curated database where the user can search for the subjects that are of interest in reviewing and/or adding to a proposal or inclusion plan.

Organization of the Toolkit:
Each row represents an activity, practice, or policy that can be added to an inclusion plan.
Within each row, columns provide the following information:
Title
Description information and definitions

Title	Description	Best Practices	Resour
Workload Equity Plan	Underrepresented researchers, including women scientists and scientists of color, may be disproportionately assigned tasks that are not considered as valuable as others within a research team. This unequal distribution of workload can lead to greater dissatisfaction and a higher likelihood of underrepresented team members leaving the team. To address this issue, it is important for collaborators to develop a plan for evenly distributing workload, including both valued tasks such as research and devalued tasks such as teaching and outreach. This will help create an inclusive environment where underrepresented groups, including women and scientists of color, are not disproportionately responsible for these tasks and have the same opportunities to engage in research as their colleagues.	Develop a plan for how work will be distributed on the collaboration. This plan should clearly define roles and responsibilities; it is important that everyone knows what is expected of them early in the collaboration. Have a fair and transparent process for how tasks will be assigned amongst team members. Consider individual workload of each member on the collaboration. It is important to be mindful of other commitments individuals may have, their current workload, and their capacity to take on additional tasks. Have a plan for how tasks like mentoring or outreach will be assigned and assessed. Seek input from the team on how work should be allocated among them. Collect metrics that allow you to track whether the workload allocation process is working for the team. It is important to review and adjust as needed to ensure that tasks are being distributed equitably.	null

The Toolkit of Collaborative Practice is a filterable database that contains curated materials, including descriptions of DEIA themes and best practices. Researchers can use the information to tailor their own DEIA plans to the size and resources of their collaborations.

used to eventually support applications for broad community access to time on 30m telescopes. However, it is clear that there is a more immediate need for the Toolkit due to the new requirements for NASA and DOE proposal plans, which explicitly require principal investigators (PIs) to discuss DEIA.

The Toolkit is intended to provide principal investigators direct support in the designing and building of more effective activities that best suit their collaboration's size and readiness to engage in DEIA goals. In addition to providing links to web pages and articles, the Toolkit contains materials curated with the input and expertise of social scientists. It provides descriptions of themes that the PI may be interested in and provides a comprehensive list of good and better practices that proposers can adjust to their own needs and resources. Although many suggestions for good practice are provided, proposers are not expected to adopt every entry, but rather are encouraged to tailor their unique plan based on the best practice recommendations. Information on additional resources and citations are also available through the Toolkit portal and allow the PI to dive deeper into each theme as desired.

The Toolkit is set up as a filterable database that can be fully "opened," with all entries available, if the PI is interested in exploring all possible options, or that can be filtered to highlight specific recommendations, if the PI already has a theme in mind that they would like to know more about. This allows proposers to spend more time fully concentrating on the planning of the activities that they are most interested in supporting.

The first version of the Toolkit includes 35 topical entries with themes that have been selected based on our report analyzing the review of Inclusion Plans written for the NASA Astrophysics Theory Program Research Opportunities in Space and Earth Sciences (ATP ROSES) call in 2021. The report identifies common (and less common) DEIA themes and provides an analysis of the grades that proposals received from diversity, equity, and inclusion expert panel members [1]. The Toolkit team used results from the report to select the initial themes that would be most useful to the community for version 1. We anticipate releasing version 2 in the summer of 2023, which will include additional themes and information about metrics for success, as well as enhanced guidance for panel members who want to use the Toolkit to better understand how best to grade proposals.

The release of the Toolkit enables staff to obtain feedback on Toolkit use and content from the community well in advance of when this resource is needed for investigators proposing for time on the US ELTs. The "Provide Feedback" link in the Toolkit offers a means for obtaining community input.

Reference

[1] Sacco, T., & Norman, D. 2022, BAAS 54(1). doi:10.3847/25c2cfeb.19262acc

US EXTREMELY LARGE TELESCOPE PROGRAM

10.5281/zenodo.8284674

Moving Forward with the Windows on the Universe Center for Astronomy Outreach

Josie Fenske & Lars Lindberg Christensen (NSF's NOIRLab)

Arizona's signature desert air and wide-open skies make it a state with a large, astronomy-interested resident community as well as a destination of choice for national and international travelers interested in exploring the night sky. From casual tourists to science enthusiasts to advanced amateur astronomers, the region offers an abundance of night-sky wonders and discovery for all levels of knowledge. In the summer of 2024, a new attraction will be added to the list of must-see Arizona locations: the Windows on the Universe Center for Astronomy Outreach, or Windows Center for short, will open in the retired McMath-Pierce Solar Telescope (McMath-Pierce), located at Kitt Peak National Observatory (KPNO), a Program of NSF's NOIRLab. It will be operated as a part of the Kitt Peak Visitor Center (KPVC), which was established in 1964.

For many years, the McMath-Pierce was the largest solar telescope in the world. Equipped with three heliostats, the

Figure 1: The recently retired McMath-Pierce Solar Telescope located at Kitt Peak National Observatory, soon to host the Windows on the Universe Center for Astronomy Outreach. *Credit: KPNO/NOIRLab/NSF/AURA/P. Horálek (Institute of Physics in Opava)*

reflecting solar telescope was used to study the structure of sunspots and to obtain solar spectra. The telescope was decommissioned in 2017, but the approximately 8000-square-foot interior has been given a new life through funding from the National Science Foundation (NSF) as the future home of a dynamic astronomy visualization and presentation center focused on astronomy.

The McMath-Pierce's unique environment and its rich history of scientific discovery make for an experience that combines a historical retrospective of the facility with an overview of modern astronomy. By exploring the interactive exhibits and educational programs offered in the Windows Center, visitors will gain a deeper understanding of the history of astronomy research and how it has led to humanity's current understanding of the cosmos. The Sun will also play an integral role in the Windows Center exhibits and content with solar themes woven throughout as visitors experience the iconic McMath-Pierce architecture and participate in unique live daytime solar disk viewing, interactive spectroscopy, and nighttime viewing of celestial showpieces.

All Windows Center programs and exhibits are designed to enhance participants' knowledge and perspective of science and will be presented in visitors' predominant languages: English, Spanish, and O'odham. Staff will have training in both content and presentation skills to deeply connect with and engage visitors. Rather than just delivering facts, staff will tell stories and offer views that are challenging, honest, and provocative — all the while appreciating the responsibility of communicating at and about a national research institution. Through effective communication by exhibits and staff,

History of the McMath-Pierce Solar Telescope

The concept of a national optical observatory was born at a conference at Lowell Observatory in Arizona in 1953 as ideas were developing to strengthen science in the United States. A few years later, in 1957, around the time of the launch of the Soviet Sputnik satellite, civil engineer William F. Zabrinskie was commissioned to prepare three preliminary designs for a solar telescope building. Following Zabrinskie's preliminary design work, the Association of Universities for Research in Astronomy (AURA) contracted with the Chicago engineering firm of Skidmore, Owings, & Merrill, which developed 10 designs, 2 of which were recommended for final consideration. The striking building design was constructed in 1962 using designs by American architect Myron Goldsmith and Bangladeshi-American structural engineer Fazlur Rahman Khan.

The Arizona Sky Islands — part of a collection of isolated mountain ranges that stretch from southeastern Arizona to northern Mexico — proved to be a favorable location for a new solar telescope, given their high altitude and relatively isolated "ecozone" in the midst of the Sonoran Desert. Kitt Peak, whose original O'odham name is Iolkam Du'ag, is located on the ancestral lands of the Tohono O'odham. A lease was signed in 1958 with the Tohono O'odham Nation, formerly known as the Papago Tribe of Southern Arizona, that allowed construction of Kitt Peak National Observatory. This national observatory became the home to a large collection of optical, infrared, and radio telescopes, with a rich legacy of discovery and pioneering advancement in technology. The solar telescope — now called the McMath-Pierce Solar Telescope after solar astronomers Robert Raynolds McMath and A. Keith Pierce — was opened in 1962 for scientists and technicians to perform observations and develop instruments. Astronauts from the Mercury, Gemini, Apollo, Skylab, and even Space Shuttle missions used the telescope's 1.5-, 1.6-, and 2.1-meter heliostat mirrors during the 1960s and 1970s for their unique capability to project large-scale images of the Moon.

Now that the McMath-Pierce Solar Telescope has finished its science mission, it is being transformed into an outreach center.

Figure 2: 1964 view of several of the Apollo astronauts in the Control Room of the McMath-Pierce. Left to right: Astronaut Donn Eisele, Don Wilhelms (USGS), Spencer Titley (UA), Ray Zedekar (NASA), Astronaut Theodore Freeman, Astronaut Frank Borman, Astronaut Eugene Cernan, and Harold Masursky (USGS). ***Credit: USGS***

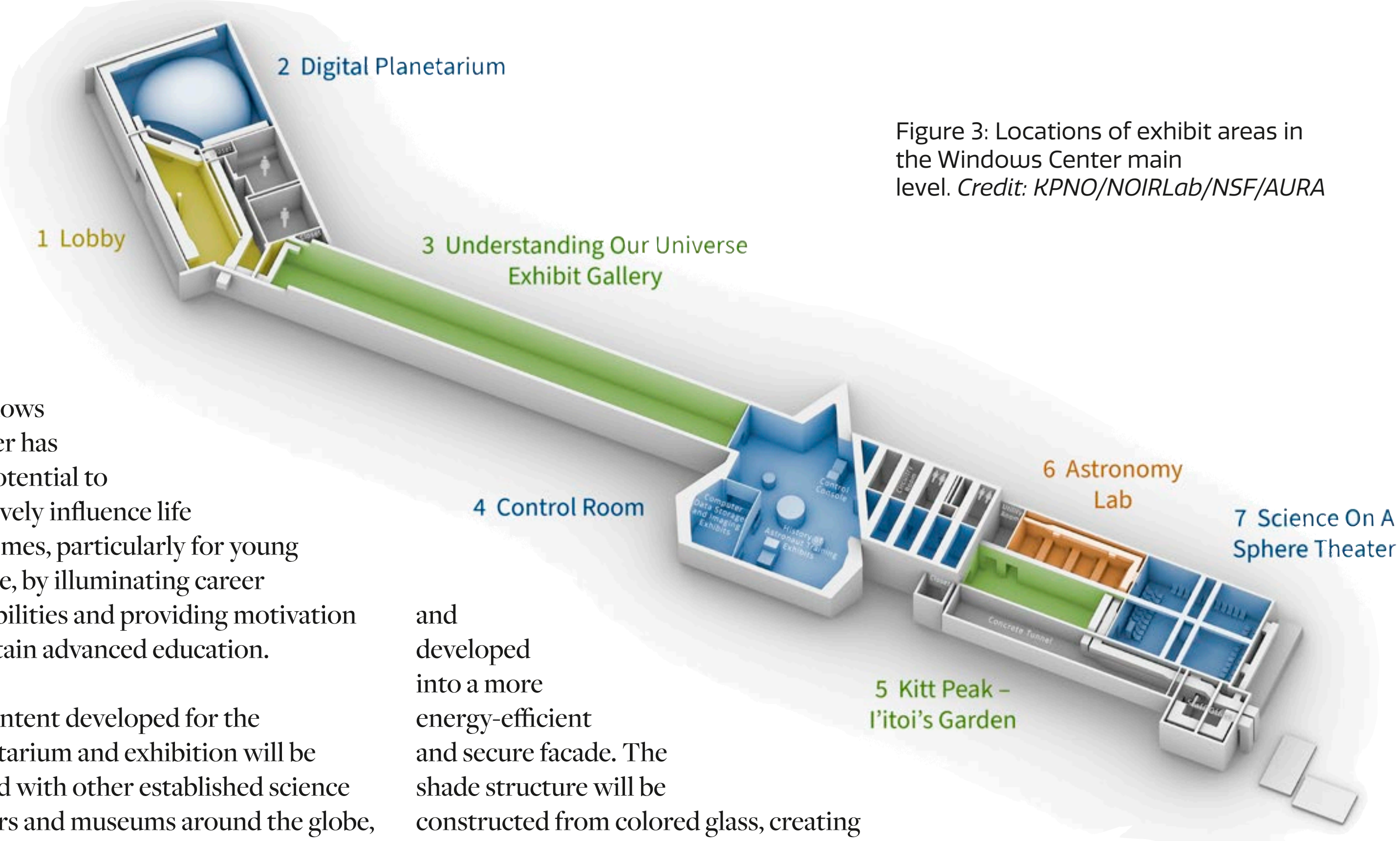


Figure 3: Locations of exhibit areas in the Windows Center main level. *Credit: KPNO/NOIRLab/NSF/AURA*

the Windows Center has the potential to positively influence life outcomes, particularly for young people, by illuminating career possibilities and providing motivation to obtain advanced education.

All content developed for the planetarium and exhibition will be shared with other established science centers and museums around the globe, creating international impact and visibility. The Windows Center will be one of only a few facilities in the world with free, openly accessible materials for other science centers.

Windows Center Spaces

Building modifications are currently underway, and once they are completed, the individual spaces within the facility will be filled in phases. Phase I includes a revamped front entrance, the first iteration of the Lobby area, a fully revamped Control Room, first-iteration exhibits throughout the rest of the space, and a Science On a Sphere (SOS) data visualization system. Visitors can expect an experience built on NOIRLab's foundational principle of Discovering Our Universe Together.

Entrance

The visitor experience begins at the original entrance to the telescope's main floor. The old glass storefront design has been completely replaced and developed into a more energy-efficient and secure facade. The shade structure will be constructed from colored glass, creating ever-evolving rainbow shadows that change depending on the Sun's location throughout the day. The placements and colors of the glass blocks are inspired by the spectrum of our Sun, created using the very spectrometer that still lives in the Control Room. Benches near the entrance will allow for rest, interaction, and snack breaks.

Lobby

The Lobby establishes a sense of place for visitors, orienting them to the telescope by providing an overview of some of the accomplishments of astronomers who have used the facility over the years. Displays describe the mission and priorities of NSF and its role in astronomy research, in funding the construction and operation of the McMath-Pierce as an observatory, and in funding the development of the Windows Center. The Lobby also serves as the gathering place for arriving groups or individuals and the location for volunteers and staff to welcome and orient visitors. Near the Lobby, large, aesthetically pleasing wall graphics serve as photo opportunities for visitors.

A primary focus of the Lobby area is KPNO's location on the lands of the Tohono O'odham Nation, specifically on Iolkam Du'ag (the original O'odham name for the mountain), as well as the relationship between the observatory and Nation members. The Windows Center makes it a high priority to foster partnerships with Nation members both in the development of content and in O'odham staff working as interpretive guides to the space. Working with Tohono O'odham staff members and representatives from the Himdag Ki: Hekĭhu, Hemu, Im B I-Ha'ap (the O'odham name for the Tohono O'odham Nation Cultural Center & Museum), content is being developed to provide visitors with an understanding of the O'odham culture and their important part in the history of KPNO. By implementing features such as a welcome message by a Tohono

O'odham tribal member, architecture reflecting the Tohono O'odham building styles, and a garden showcasing culturally important plants, the Windows Center recognizes the Nations history, their longstanding connection with the night sky, and the land they consider sacred.

Understanding Our Universe Exhibit Gallery

Visitor flow naturally progresses from the Lobby into the Understanding Our Universe Exhibit Gallery, which provides a blend of static and interactive exhibits covering modern astronomy and physics, the electromagnetic spectrum, and the instruments astronomers use to probe the Universe. In this area, visitors can better understand our place in the Universe, how we know what we know about the cosmos, and why that knowledge is relevant to visitors.

Beginning with a You Are Here display, visitors take a journey across the Universe starting in southern Arizona and moving progressively out from Earth, across the Solar System, through the Milky Way, and into the realm of the galaxies. Throughout the exhibit, the nature of planets, stars, nebulae, and other common and more exotic objects is explained. Next, to address the question of "How do we know?" the visitor is introduced to light and the electromagnetic spectrum to understand how nature transmits information across vast distances of space. Woven into the messages of each exhibit is the answer to the question "How does this relate to me?" By showcasing the personal stories of past and present scientists, the exhibits show relevance, applications to daily life, and the benefits gained by humanity from having a clear, in-depth understanding of how the Universe works.

Control Room

Beyond the Understanding our Universe Exhibit Gallery, visitors enter the Control Room. This room is where astronomers operated the heliostats and observed the Sun for decades, and several vintage aspects of the room have been preserved and incorporated into the experience. With its restored computers and analog control panel, the room evokes a sense of nostalgia. Here, during observing sessions with the three original heliostats, visitors can witness firsthand what the Sun looks like through a large solar telescope and learn to identify features like sunspots and granulation. The room also features a large live solar spectrum on a touch screen interactive panel so visitors can explore the details of the spectrum and identify the elements behind its absorption lines.

Astronomy Lab

As they exit the Control Room, visitors enter a gallery tentatively named Kitt Peak — I'itoi's Garden, which features images and information about nature on the Sky Island and the Tohono O'odham Tribe's culture and connection with the cosmos. Adjoining this gallery is the Astronomy Lab, which will be used for scheduled educational programs and multi-use events, especially those that engage students from the Tohono O'odham Nation.

Science On a Sphere Theater

At the far end of the exhibit area is the SOS Theater with an exhibit that projects myriad videos and images on a spherical multimedia screen where visitors, together with a guide, can virtually explore planetary data from our Solar System and beyond. Global phenomena and issues such as climate change will also be shared by using

Key Takeaways for Visitors

- We are all connected to the night sky.
- You too can be an astronomer through citizen astronomy.
- Light that we capture through our eyes and instruments tells us about our place in the Universe.
- Every tool we have developed was inspired by questions that astronomers wanted to answer.
- We are guests of the Tohono O'odham Nation and honor this special place.

Key Learning Objectives of the Windows Center

- Visitors will understand the context of the collaboration between KPNO and the Tohono O'odham Nation that allows astronomical facilities to operate at KPNO.
- Visitors will be inspired and awed by the Universe, our current understanding of it, and the role that the facilities at KPNO have played in conjunction with NSF's astronomy facilities around the world.
- Visitors will appreciate the history of the McMath-Pierce and be transported back in time to experience the operation of the facility since the 1960s.
- Visitors will exit the Windows Center with a sense of the form and function of the McMath-Pierce through restored instruments and facilities that, wherever possible, will function as they did in the past to provide exceptional observations of the Sun and other objects in space.

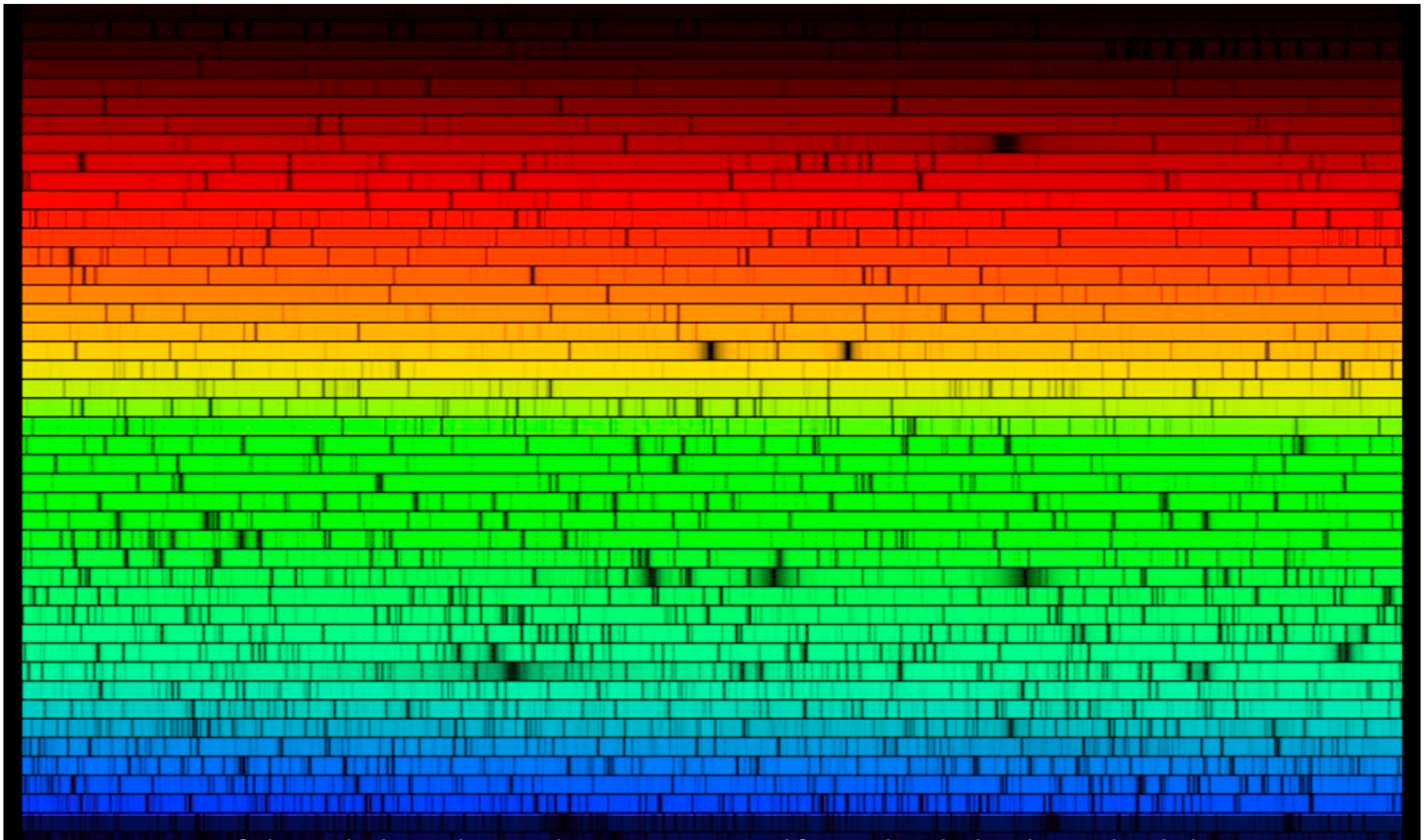


Figure 4: A state-of-the-art high-resolution solar spectrum created from a digital atlas observed with the Fourier Transform Spectrometer at the McMath-Pierce by Robert L. Kurucz, Ingemar Furenlid, James Brault, and Larry Testerman. *Credit: KPNO/NOIRLab/NSO/NSF/AURA/N. A. Sharp*

compelling representations of real data and timely science. The focus of this exhibit is to provide visual context for understanding complex scientific concepts to give visitors a better understanding of modern astronomy and climate science.

Development Phases

With the completion of Phase I, the Windows Center will already be a place that evokes a sense of wonder for visitors, inspiring and encouraging them to pursue a deeper connection with the Universe.

NOIRLab can neither successfully complete the Windows Center exhibits nor run the KPVC operations without supporting funding beyond that provided by visitors. Membership programs, events, naming sponsorships, endowments, and fundraising campaigns are all strategies that NOIRLab will pursue to obtain needed funds.

With the execution of subsequent phases — as funds allow — the Windows Center experience will be further enhanced with a facility-wide audio system, outdoor exhibits, and a gallery inside the hulking metal tower of the McMath-Pierce where visitors will be able to enter the facility's optical viewing tunnel and learn how sunlight is collected by the telescope. Interactive exhibits and a planetarium adjacent to the lobby will allow visitors to immerse themselves in the cosmos as revealed by KPNO and NSF observatories around the world. Planetarium shows will include voyages across space, recountings of significant moments of discovery, and virtual tours of NOIRLab sites, giving visitors a better sense of how contemporary astronomy impacts humanity's understanding of the Universe. The digital planetarium comes with an extraordinary 3D astronomical database, projection system, and well-designed user interface.

The unique experience offered by the Windows on the Universe Center for Astronomy Outreach will leave visitors with an expanded understanding of the history of astronomy research and how it has led to our modern view of the cosmos. With a probing look into the physical wonders of the Universe, set against a backdrop of the McMath-Pierce Solar Telescope facility's history of scientific achievement, visitors will be inspired to continue their journey of discovery beyond their visit to the Tohono O'odham Nation and Kitt Peak National Observatory.

10.5281/zenodo.8284680

With Fond Memories of Ron Probst, Tom Kinman, and Roger Lynds

Based on contributions by Abi Saha, Bob Blum, David Sprayberry, Dick Joyce, Jay Elias, Alistair Walker (NSF's NOIRLab), Beverly Lynds (formally NOAO)

Compiled by Katy Garmany

NSF's NOIRLab lost three giants in the past six months, each of who contributed enormously to making the observatories what they are today. Ron Probst passed away on 05 December 2022, Tom Kinman on 20 March 2023, and Roger Lynds on 16 April 2023. All three spent many years working at what began as Kitt Peak National Observatory (KPNO), staying on to the transition to the National Optical Astronomy Observatory (NOAO) and later to NSF's NOIRLab. All attained emeritus status following their retirements.

Ron Probst

Ron Probst came to KPNO in 1983 to take a scientist position. He had completed his PhD at the University of Virginia: his thesis data were obtained with the IR photometers at Kitt Peak. He was deeply involved in many NOAO developments in infrared instruments and detectors at a time when two-dimensional infrared arrays were just arriving on the astronomical scene. Most recently, he was the Principal Investigator on two heavily used infrared imagers: ISPI on the Víctor M. Blanco 4-meter Telescope in Chile and NEWFIRM on the Nicholas U. Mayall 4-meter Telescope at KPNO. NEWFIRM was so popular that it is the only instrument to have been moved from the Mayall to the Blanco, then back to the Mayall, then (after the DESI installation) back again to the Blanco to satisfy user demand. NEWFIRM on 11 January 2023 achieved "first light for the second time" on the Blanco.

Ron Probst, 2009. *Credit: NOIRLab/NSF/AURA/K. Garmany*

One of Ron's significant but often unrecognized contributions to NOAO was promoting, implementing, and supporting significant collaborative efforts between the Cerro Tololo Inter-American Observatory (CTIO) and KPNO. Many staff members (not just scientists) owe Ron a debt of gratitude for drawing them into rewarding and productive collaborations with their colleagues from the Southern Hemisphere. Ron was committed to science education. He helped design an astronomy course for schoolchildren in Chile and supported public events while he lived there. A memorable event was the transit of Mercury across the disk of the sun in the late 1990s when Ron set up telescopes and spoke to students and the public about the transit at the University of La Serena. In Tucson, Ron was an active member of the Tucson Amateur Astronomy Association.

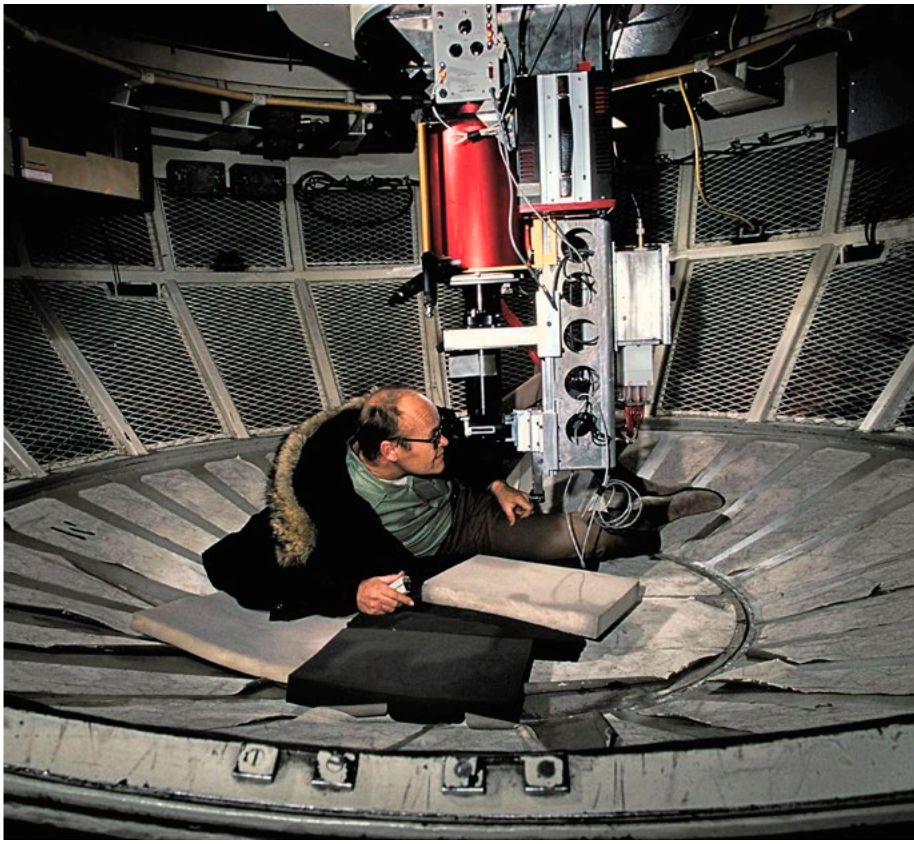
Tom Kinman

Tom Kinman came to KPNO in 1969, having completed his PhD at the University of Oxford in 1953. He was a towering figure in the early studies of the diffuse halo of stars that surround our Galaxy: illuminating the nature of and distribution of globular clusters in the Milky Way halo and conducting one of the earliest systematic searches for RR Lyrae stars in the Milky Way halo. To analyze periods and light curves, he invented the so-called Lafler-Kinman algorithm, a simple but effective form of the "period dispersion minimization" class of methods, which remains in use to this day, with over 700 citations in ADS. During the 1960s and onwards, Kinman also became interested in the study of quasi-stellar objects (QSOs), with a focus on their variability and on polarimetry. He continued his exploration of the Galactic halo using blue horizontal branch and other A and F stars, in addition to the RR Lyraes. His studies included exploring the extended structure of the Large Magellanic Cloud (LMC) and studying long period variables in M33. He was a mentor to many students and postdocs — especially those who passed through KPNO. After retirement, Tom was ordained a Deacon at St. Michael's and All Angels Episcopal Church in Tucson, and he took great pleasure in serving as a hospital chaplain at the University Medical Center in Tucson.

Tom Kinman in his office in 2004. *Credit: J. Kinman*

Roger Lynds

Roger Lynds received his PhD from the University of California, Berkeley, in 1955 and joined the staff of KPNO in 1961. Roger's primary interest was in optical astronomy and the development of detectors to be used on optical telescopes. Working with his friend Bill Livingston (an astronomer with the National Solar Observatory), Lynds published several papers on their experiments with electronic image intensifiers. The development of such systems allowed the KPNO 2.1-meter Telescope at Kitt Peak to compete on equal terms with larger telescopes using traditional photographic detectors. Notably, Roger used spectra obtained with the 2.1-meter to discover what he described as "the Lyman-alpha forest" in the far UV spectra of QSOs, which is a dense ensemble of hydrogen lines generated by gas between us and the QSOs. Studies of the Lyman-alpha forest have subsequently emerged as a critical tool for understanding the formation and evolution of galaxies over cosmological history. In 1974 Roger was accepted as a member of the National Academy of Sciences. Also in 1974, Roger used the technique of speckle interferometry on the then-new Mayall telescope to obtain the first image of the surface of Betelgeuse, the first time anyone obtained resolved images of another star besides our Sun. When plans were being made for the *Hubble Space Telescope* (*HST*), Jim Westphal (a professor of planetary astronomy at Caltech) invited Roger to join his team in developing and using the Wide Field and Planetary Camera (WPFC), which was designed to be *HST*'s primary camera. Roger had a special interest in "strange objects" in the Universe, which defined a portion of the WPFC team's scientific investigation. As a footnote to history, shortly after the launch of *HST* in 1990, Roger was the first to recognize that the *Hubble* primary mirror suffered from spherical aberration (although his assessment wasn't accepted at first). In 1989 he and Vahe Petrosian published the discovery that the mysterious arcs seen in clusters of galaxies were really background galaxies lensed by the clusters. As with his discovery of the Lyman-alpha forest, this has turned into a vital tool for understanding the Universe over all.



Roger Lynds lying on the floor of the Cassegrain cage at the Kitt Peak Nicholas U. Mayall 4-meter Telescope (1975). *Credit: NOIRLab/NSF/AURA*

The entire NOIRLab staff is honored to have worked with each of these remarkable individuals during careers that spanned the history of the observatory.

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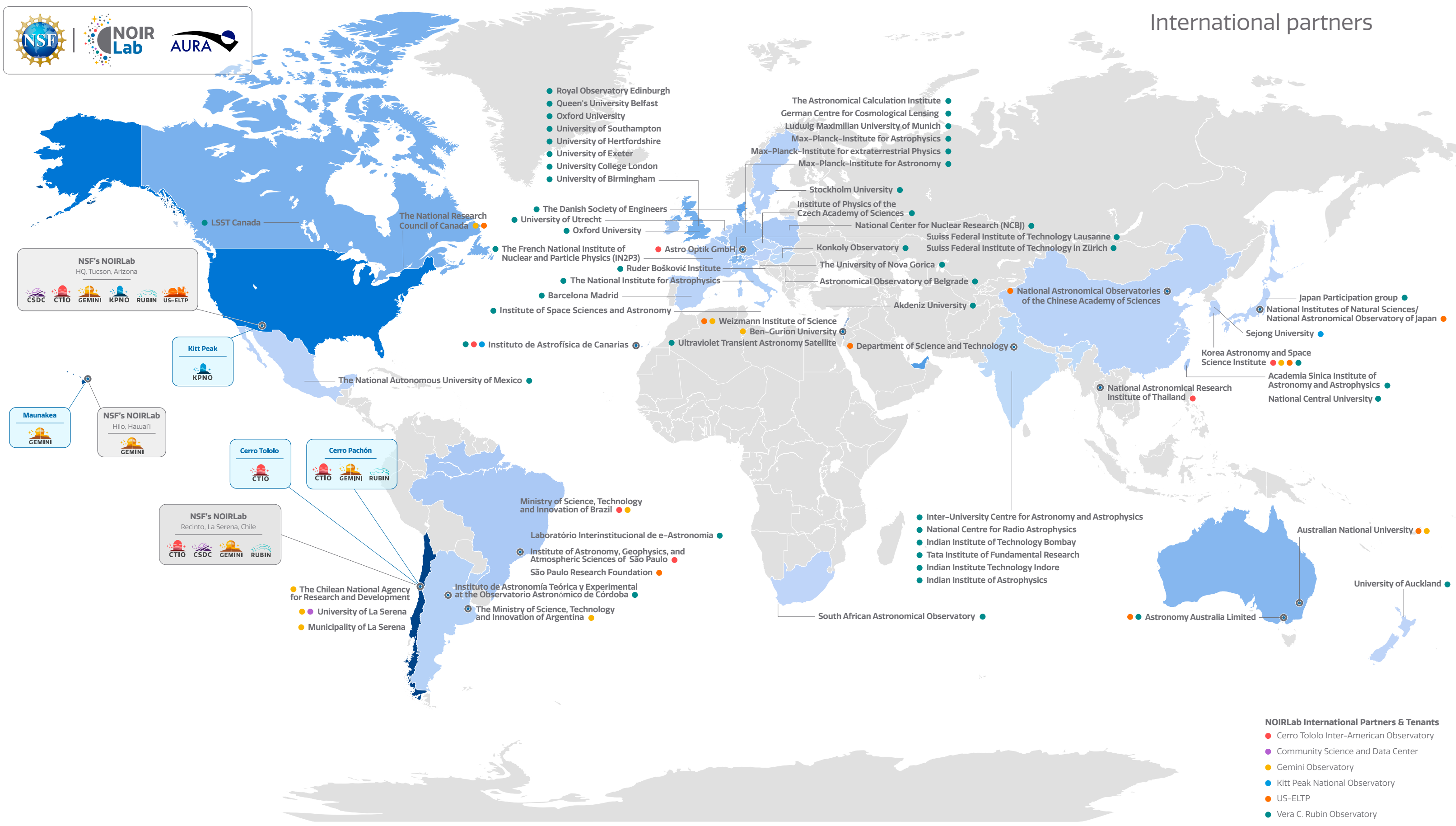
International partners



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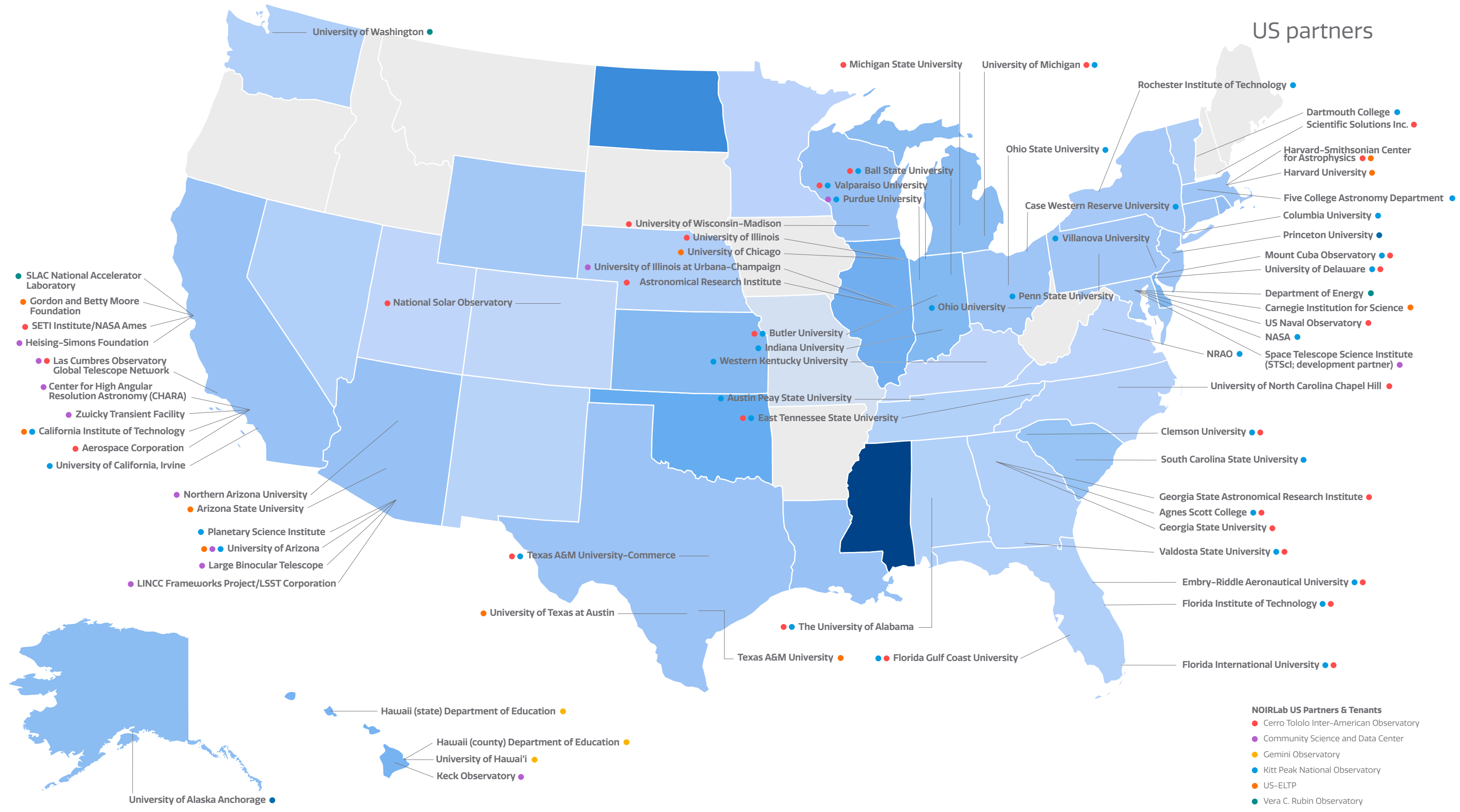

Discovering Our Universe Together

NOIRLab Headquarters
950 North Cherry Avenue
Tucson, AZ 85719 USA

General Inquiries
+1 520 318 8000
noirlab.edu
info@noirlab.edu

Cerro Tololo Inter-American Observatory
Recinto de AURA
Avda. Juan Cisternas 1500
La Serena, Chile

User Support
+56 51 205200
ctio@noirlab.edu

Community Science and Data Center
950 North Cherry Avenue
Tucson, AZ 85719 USA

User Support
+1 520 318 8421
csdc@noirlab.edu

Gemini North Base Facility
670 N. A'ohoku Place
Hilo, Hawai'i, 96720 USA

User Support
+1 808 974 2500
gemini@noirlab.edu

Gemini South Base Facility
Recinto de AURA
Avda. Juan Cisternas 1500
La Serena, Chile

+56 51 2205 600
gemini@noirlab.edu

Kitt Peak National Observatory
950 North Cherry Avenue
Tucson, AZ 85719 USA

User Support
+1 520 318 8135 & 8279
kpno@noirlab.edu

Visitor Center / Public Programs
+1 520 318 8726
www.visitkittpeak.org

Vera C. Rubin Observatory
950 North Cherry Avenue
Tucson, AZ 85719 USA

+1 520 881 2626
lsst.org
contact@lsst.org