The Mirror

Issue 3 | June 2022

NSF's NOIRLab

The overdeveloped spiral arm of the galaxy NGC 772, which was created by tidal interactions with an unruly neighbor, dominates this observation made by astronomers using the Gemini North telescope located near the summit of Maunakea in Hawai'i. *Credit: International Gemini Observatory/NOIRLab/NSF/AURA*

THE MIRROR

ISSUE 3 | JUNE 2022

On the Cover

The Dark Energy Spectroscopic Instrument (DESI) has cataloged more galaxies than all other previous three-dimensional redshift surveys combined, measuring 7.5 million galaxies in only seven months since beginning science operations. The US Department of Energy's Lawrence Berkeley National Laboratory leads DESI, which is installed at Kitt Peak National Observatory, a program of NSF's NOIRLab, on the Nicholas U. Mayall 4-meter Telescope. See science highlight on DESI science on page 7. *Credit: D. Schlegel/Berkeley Lab using data from DESI*

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The 2020 Decadal Report and Its Meaning for the NOIRLab User Community

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In early November of last year, the National Academies released the report of the 2020 Decadal Survey (Figure 1). The report, *Pathways to Discovery in Astronomy and Astrophysics for the 2020s* (hereinafter *Pathways to Discovery*), will shape our field in this decade and beyond. Since the 1960s the decadal surveys have identified key scientific questions and led to the development of major observational facilities. The 4-meter telescopes at Kitt Peak, CTIO, the Gemini 8-meter telescopes, and Vera C. Rubin Observatory all have their origins in decadal surveys.

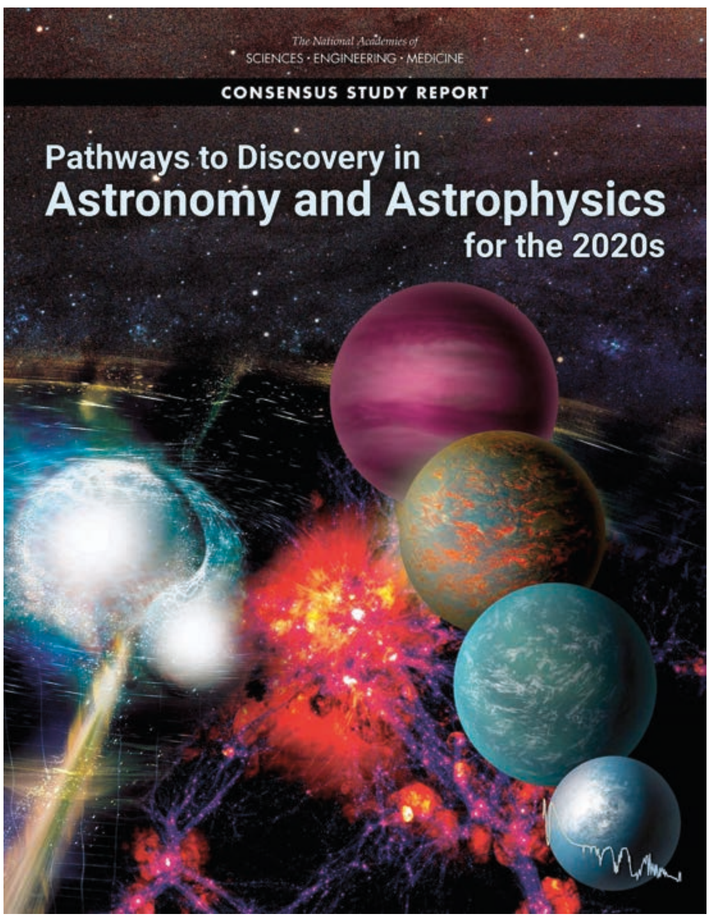

Figure 1. Cover of the Decadal Survey of Astronomy and Astrophysics (Astro2020) publication. *Credit: National Academy of Sciences*

Pathways to Discovery lays out an exciting scientific landscape for the decade and an ambitious agenda both on the ground and in space. The science themes identified in the report — *Worlds and Suns in Context, New Messengers and New Physics*, and *Cosmic Ecosystems* — span an enormous range of astrophysics and touch on areas ripe for new discoveries. The report builds on these themes to develop three priority science areas: *Pathways to Habitable Worlds, New Windows on the Dynamic Universe,* and *Unveiling the Drivers of Galaxy Growth*. These in turn drive key areas for investment in capabilities. The portfolio that the report recommends — in space and on the ground, from radio to high energies — has the power to transform our understanding of the Universe and our place in it.

The decadal themes map well to the capabilities currently offered and those under development at NOIRLab and other observatories within the US optical-infrared (OIR) community. The mid-decade launch of Rubin's Legacy Survey of Space and Time (LSST), the deployment of new instruments and adaptive optics systems on the International Gemini Observatory, and the ongoing DOE-, NASA-, and NSF-supported surveys on the 4-meter telescopes all answer the call of the recommendations in *Pathways to Discovery* for studies of the dynamic Universe on large and small scales. The top priority for new ground-based facilities, the US ELT Program, addresses a large fraction of the *Pathways to Discovery* detailed science goals, as noted in the body of the report and in the report's Table K.1.

The US Extremely Large Telescope Program

Many of the key advances in astronomy and astrophysics can be traced to large OIR telescopes on the ground. From Edwin Hubble's discovery of the cosmic expansion to the discovery of the cosmic acceleration, from SNe light curves, and the detection of the extrasolar planets through Doppler spectroscopy, large-aperture telescopes on the ground have driven discovery for centuries. *Pathways to Discovery* makes the case for a *system of extremely large telescopes* — grounded in the Thirty Meter Telescope and the Giant Magellan Telescope.

Those two telescope projects are very advanced in their design and development, and much of the technical risk has been reduced through years of investment in analysis and prototyping. The road to completion of the telescopes will be long, and there are many issues to resolve. *Pathways to Discovery* presents a set of recommendations that will help the community and agencies navigate the many steps leading to the start of construction. At NOIRLab we look forward to working with the community and the two projects to turn the goals in *Pathways to Discovery* into reality.

The Role of NOIRLab in US Astronomy

The [Report of the Panel on Optical and Infrared Observations from the Ground](#) in appendix K of *Pathways to Discovery* lays out six critical leadership roles for NOIRLab in US astronomy. These include leadership of the US ELT Program, execution of Rubin's LSST, coordination of NOIRLab facilities into a time-domain system, operation of unique capabilities in survey and precision astronomy (e.g., DES, NEID), execution of regular community-based strategic planning exercises, and, lastly, contributions to a healthy program of technical development for astronomical instrumentation. Many of the tasks relating to these roles are well underway; others will require new investments of time and effort along with substantial creativity.

As we head into 2022, we continue to develop the time-domain system with new hardware and software tools. Much of this development is being done in anticipation of the start of Rubin Observatory operations, but there are many interesting time-domain surveys underway now for which rapid follow-up is essential. New instruments coming to Gemini will help us expand our suite of capabilities offered to the community. *Pathways to Discovery* called for better connectivity between ground- and space-based data archives and for greater attention to pipelines that produce science-ready data and support integrated science platforms. Rubin and Gemini each address this issue: Rubin's science platform will provide a one-stop shop for Rubin data products and connectivity to supporting datasets, while Gemini's DRAGONS software packages will continue to grow and will ultimately replace all of the IRAF-based Gemini tools with modern Python-based pipelines. The work done by the DOE, NOIRLab, and university teams leading the Dark Energy Survey and the Dark Energy Spectroscopic Instrument survey enables a wide range of science. These surveys' tools have broader application and have garnered accolades in the professional software development community. NOIRLab's Community Science and Data Center is our clearinghouse for ground-based data archives and connectivity to archives from space-based observatories. There is much work ahead of us and opportunities for better coordination between ground and space.

The most important, and most challenging, of the roles identified in *Pathways to Discovery* related to strategic planning and technical developments. Now that the report is out and agencies are developing plans, we will engage the community in strategic planning. Topics that we expect to address in 2022 include the US ELTs, adaptive optics, time-domain astronomy, and instrumentation. Naturally, we will continue to support science-focused meetings (Figure 2), as these underpin the community's needs and aspirations. The January AAS meeting was to be our first opportunity to engage the

Figure 2. Virtual meetings have a silver lining. The number and diversity of participants at the 2021 Gemini Science Meeting (GSM) were higher than ever. Those who might not be able to travel to in-person meetings at remote locations can participate virtually. The montage shows a sample of the participants at one session of the 2021 GSM. *Credit: International Gemini Observatory/NOIRLab/NSF/AURA*

community about *Pathways to Discovery*; we will have to find other channels while the global pandemic remains a force.

Diversity and Inclusion

The 2020 Decadal Survey was the first to include a formal panel on the state of the profession. *Pathways to Discovery* called for greater attention to, and investment in, diversity and inclusion and for demographic data to provide the ability to trace actions to outcomes. *Pathways to Discovery* asked us to "reimagine leadership."

In 2022 we will implement our dual-anonymous proposal review process. The new proposal development and TAC software support anonymous reviews that include safeguards to protect student thesis projects and other programs that require continuity. Additionally, NOIRLab is sharpening our focus on interactions with our Indigenous communities where our facilities operate and adopting a Community Based Science model as described in the report.

NOIRLab is hiring — into the scientific staff, the engineering teams, and the operations support teams. We are approaching this with an integrated approach to hiring at NOIRLab that aims to build a skilled and diverse workforce — a team of teams driven by values that reflect those of the astronomical community as expressed in *Pathways to Discovery* and other community-derived plans.

In this image it appears as though the telescopes of the Cerro Tololo Inter-American Observatory (CTIO), a Program of NSF's NOIRLab, are growing around the edge of a deep well of stars in this fisheye lens view. Several of the telescopes housed at CTIO are visible around the edge of this image, including (clockwise from the top): the SMARTS 0.9-meter Telescope, the SMARTS 1.5-meter Telescope, the Víctor M. Blanco 4-meter Telescope, the Curtis Schmidt Telescope, the SMARTS 1.0-meter Telescope and the decommissioned DIMM1 Seeing Monitor. *Credit: CTIO/NOIRLab/NSF/AURA/B. Tafreshi*

10.5281/zenodo.667164

Detection of a $10^5\,M_\odot$ Black Hole in M31's Most Massive Globular Cluster

Renuka Pechetti (Liverpool John Moores University) and Anil Seth (University of Utah)

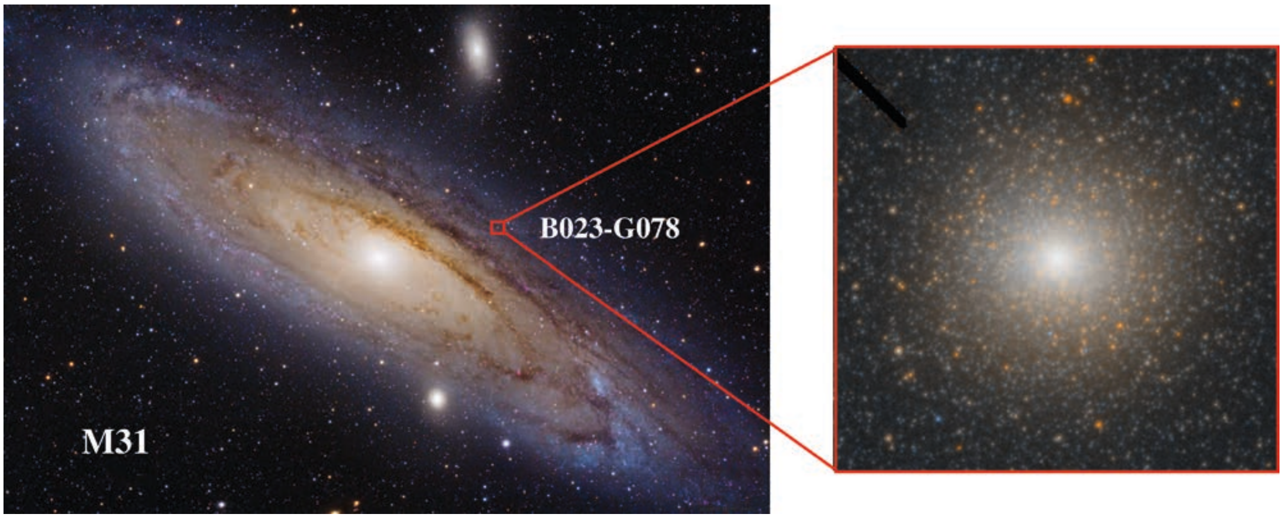

Figure 1. The location of the cluster in the Andromeda galaxy. The HST image of B023-G078 on the right is composed from the F814W and F606W filters. *Credit:* **(left)** *Iván Éder, https://ui.adsabs.harvard.edu/abs/2022ApJ...924...48P/abstract*, **(right)** *STScI/HST.*

Intermediate-mass black holes (IMBHs) are elusive objects that fall within the mass range $\geq 10^2\,M_\odot$ and $\leq 10^5\,M_\odot$, bracketed by stellar-mass black holes (BHs) at the low end and supermassive BHs at the high end. They are most likely to exist in the centers of globular clusters or nuclei of dwarf galaxies. Theoretically, IMBHs can be formed through different formation mechanisms including the direct collapse of gas, mergers and accretion of stellar-mass BHs, or the collapse of high-mass stars in the early Universe. Finding and weighing IMBHs can help us constrain their formation; this can be done either by detecting accretion emission or through dynamical detection. However, observations of IMBHs are challenging, due to the lack of unique signatures of BH accretion in many accretion cases and the ambiguity in distinguishing whether the central dark mass is an IMBH or a collection of stellar-mass BHs in the dynamical case. Dynamical measurements are also limited by our ability to resolve the velocity dispersions within the sphere of influence of the BH, which drives us to the closest targets. Here we discuss our recent detection [1]) of an IMBH in a massive star cluster in M31. At just $10^5\,M_\odot$, this object is the strongest candidate for an IMBH in this mass regime and a potentially valuable clue for understanding the formation of massive BHs.

Using Gemini North's adaptive-optics Near-Infrared Integral Field Spectrometer (NIFS), we were able to obtain data at the center of B023-G078, the most massive cluster in the Andromeda galaxy (Figure 1). The high resolution of these observations (0.13″) was made possible using laser guide star adaptive optics with the ALTAIR system. This resulted in detection of some individual stars in this cluster, which were removed before deriving the kinematic maps shown in Figure 2. We received these data under Director's Discretionary Time shortly after the discovery of supermassive BHs in very massive stripped nuclei in the Virgo cluster by our team. B023-G078, as the most massive cluster in the Andromeda galaxy and with a visible spread in the color of its RGB stars, seemed likely to be a stripped galaxy nucleus. However, it was much less massive than the other stripped nuclei where we had detected BHs. If these lower-mass stripped galaxy nuclei host BHs, they will contribute substantially to the number density of massive BHs in the Universe.

To test whether B023-G078 hosts a central BH and to estimate its mass, we created a stellar mass model of the cluster using the light of the stars from the HST data (Figure 1). By deprojecting this mass model, we can estimate the velocity dispersion profile of the stars around the center. Using Jeans models, we found that the velocity dispersion at the center of the cluster in the observed kinematics from Gemini/NIFS was higher than what was expected based on the stellar mass model. This high-velocity dispersion indicated

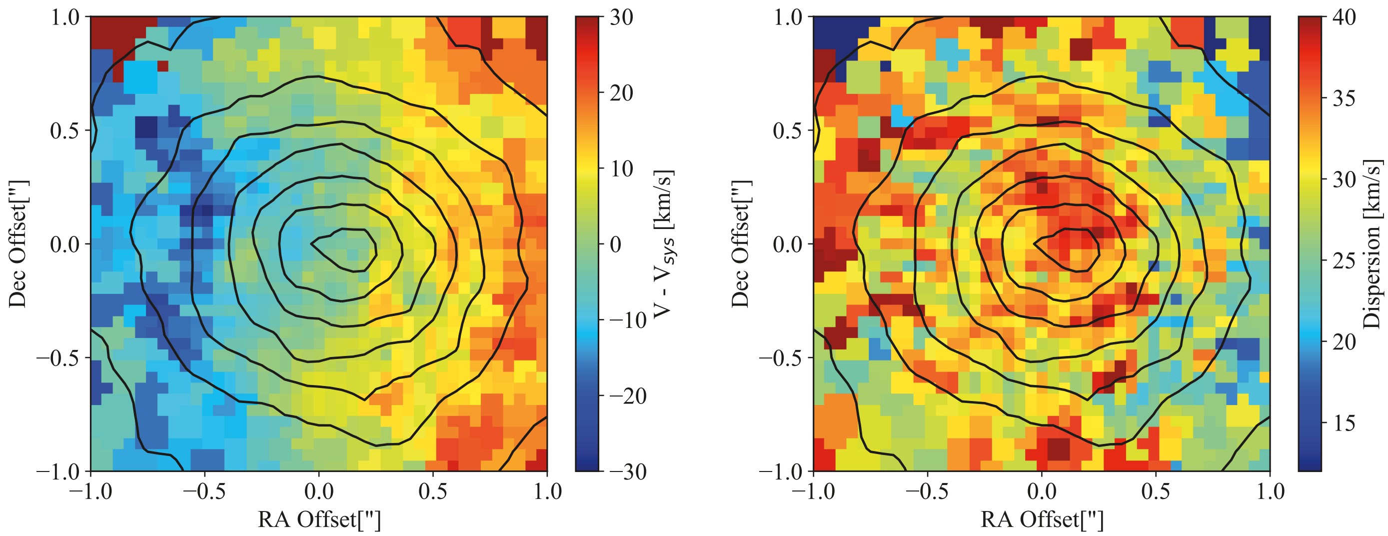

Figure 2. The radial velocity and velocity dispersion maps from the Gemini/NIFS kinematic data with a spaxel size of 0.05″. *Credit: The Astrophysical Journal [1]*

some kind of dark mass, which could either be explained by a single IMBH or by a distribution of stellar-mass BHs. The best-fit models favored the case of an IMBH with a mass of ~105 $M_{\odot}$ (Figure 3). We also modeled the cluster with an extended collection of stellar-mass BHs at the center, but our best-fit models suggest that the source is unresolved. We also found additional evidence that this object was a stripped galaxy nucleus, which supported the case for an IMBH:

(1) The cluster has a two-component profile with varying flattening as would be expected for the nucleus of a stripped dwarf galaxy.

(2) The rotation of the cluster was similar to that of the nuclear star clusters in galaxies, which are dense clusters at the centers of galaxies.

(3) The metallicity of the cluster had a spread similar to that of Omega-Cen and M54, which are globular clusters or stripped nuclei bound to the Milky Way. It also varied along with the radius, with the stars at the center being more metal-rich than those in the outskirts.

All of this evidence strongly suggested that B023-G078 was a stripped nucleus. Therefore, we prefer an IMBH interpretation of the data.

Although many potential IMBH candidates exist, the kinematic data for B023-G078 suggest a strong, >3σ detection. There is no evidence in existing archival radio and X-ray data

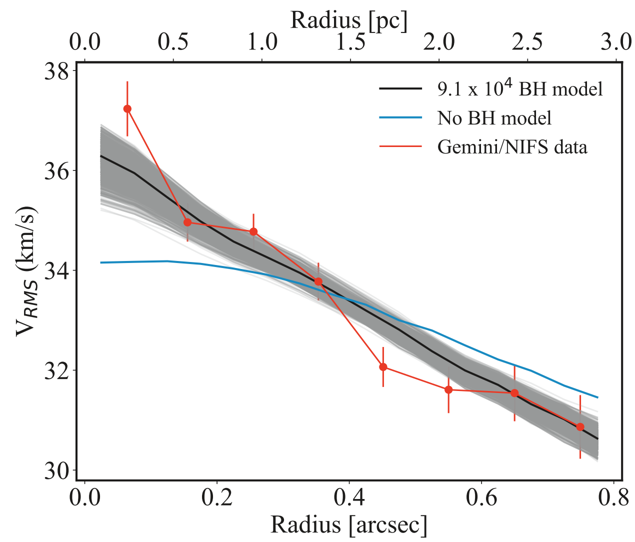

Figure 3. The best-fit models suggest an IMBH with a mass of ~10^5 $M_{\odot}$. These are the Jeans models that model the velocities of the stars using the light profile and then compare them with the kinematics. *Credit: The Astrophysical Journal [1]*

for any BH accretion, but a detection at these wavelengths could confirm the presence of a single IMBH instead of a collection of stellar-mass BHs.

Our future work includes observations with Gemini/NIFS to look at three other clusters in the Andromeda galaxy using a similar analysis to find any potential IMBHs.

Reference:

[1] Pechetti, R., et al. 2022, ApJ, 924, 48

10.5281/zenodo.6643888

Dark Energy Survey Gold

Richard Kron (University of Chicago)

Back in 2018 the Dark Energy Survey (DES) released DR1, the images and catalogs from the first three years of survey operations (Y3) with the Dark Energy Camera (DECam) on the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory. Over the past several months, 30 papers are in the publication stream that collectively constrain cosmological parameters based on DR1. This major undertaking has required years of development to generate precise estimates of photometric redshift and shape for each galaxy. These, and many other value-added products derived from DR1, were made public on 12 January 2022 to support the conclusions of the cosmology papers. The DES Collaboration has documented the methods and the data products for what we call "Y3 Gold" in the paper Sevilla-Noarbe et al. 2021, ApJS, 254, 24. The release is hosted by the National Center for Supercomputer Applications. Much information to help users can be found at DES Data Management: Y3 Cosmology Data Release.

While the data products in the Y3 Gold release support the DES cosmology analyses, we expect that they will have general utility for many other astrophysical applications. The photometric depth, uniformity, and precision are improved over previous releases, as are the object classifications.

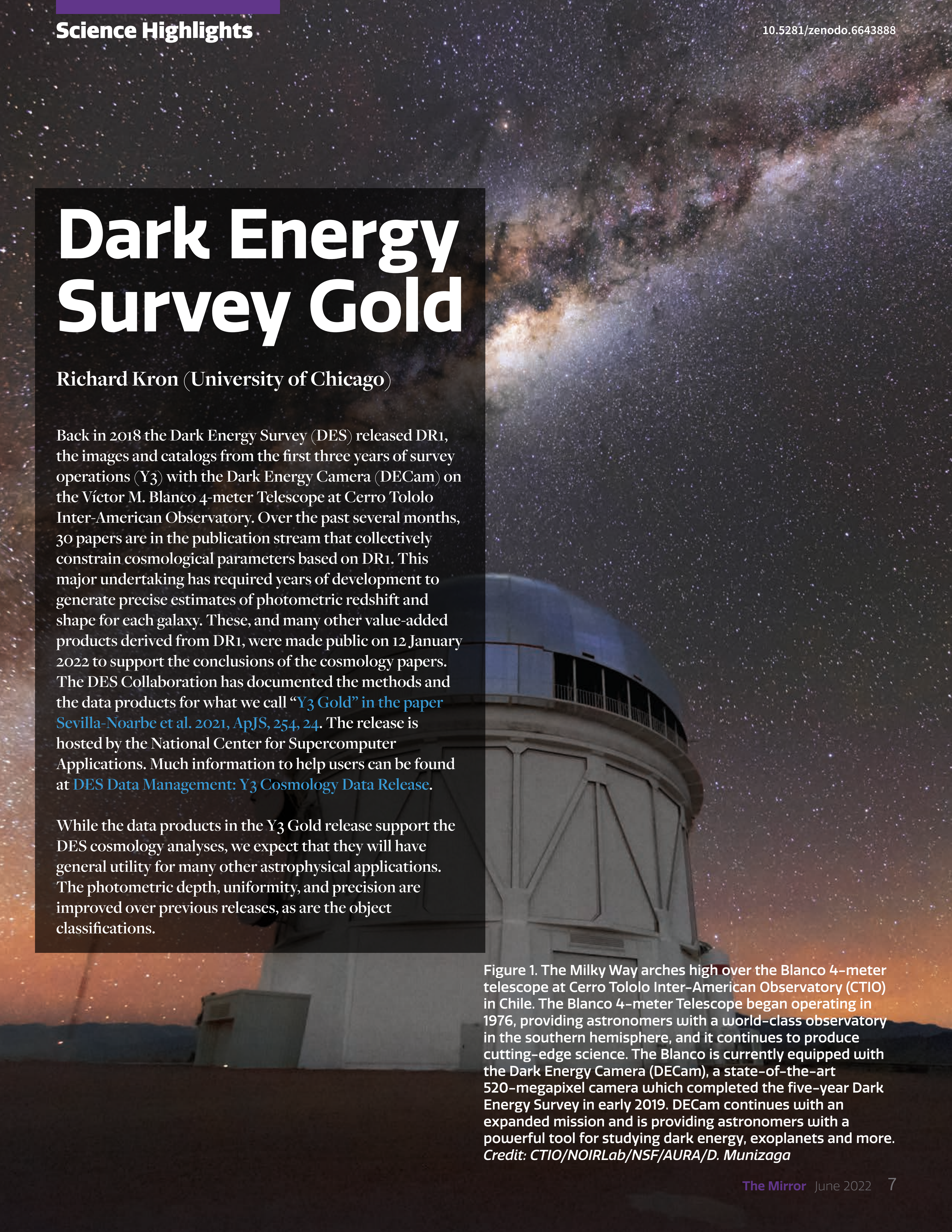

Figure 1. The Milky Way arches high over the Blanco 4-meter telescope at Cerro Tololo Inter-American Observatory (CTIO) in Chile. The Blanco 4-meter Telescope began operating in 1976, providing astronomers with a world-class observatory in the southern hemisphere, and it continues to produce cutting-edge science. The Blanco is currently equipped with the Dark Energy Camera (DECam), a state-of-the-art 520-megapixel camera which completed the five-year Dark Energy Survey in early 2019. DECam continues with an expanded mission and is providing astronomers with a powerful tool for studying dark energy, exoplanets and more. *Credit: CTIO/NOIRLab/NSF/AURA/D. Munizaga*

In addition to the wide-field data products, the Y3 Gold release includes deep-field images and catalogs based on the fields that had been visited weekly for discovery of supernovae. Including the area also covered in near-infrared bands by VISTA, the release contains 8-band photometry (*ugrizJHKs*) over 5.88 square degrees with an exposure of at least 10 times that of the wide-field survey.

In summary, the wide-field release features the following:

- 390 million objects with *grizY* photometry in nearly 5000 deg^2
- S/N ~ 10 for extended objects to *i* ~ 23.0 AB
- *i*-band PSF 0.9" FWHM
- photometric uniformity < 0.003 magnitude
- astrometric residuals compared to Gaia DR2: 0.158" rms

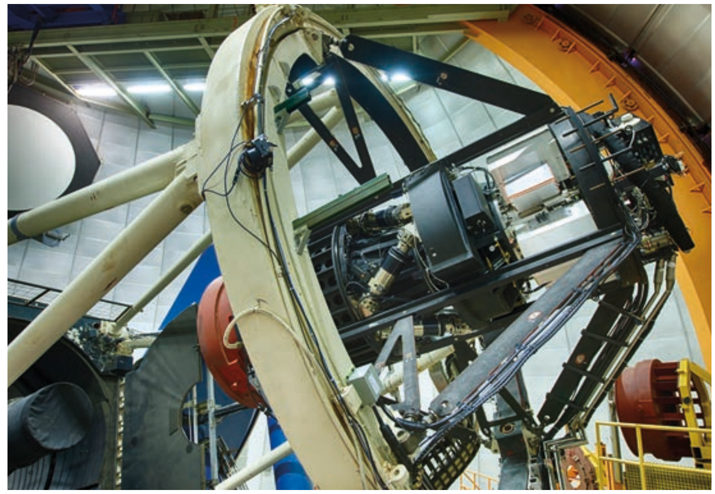

Figure 2. DECam on the Víctor M. Blanco 4-meter Telescope. *Credit: Reidar Hahn, Fermilab*

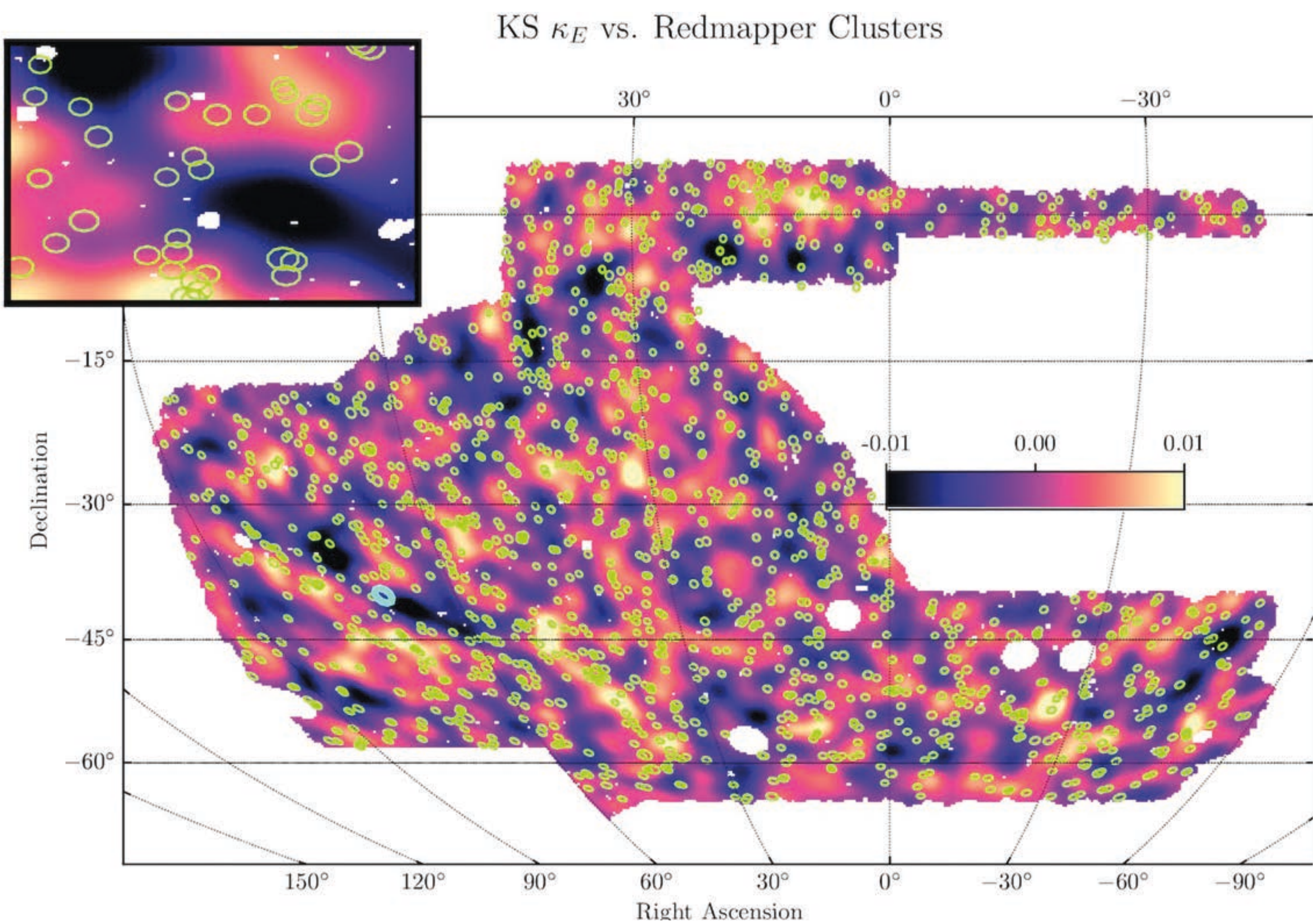

Figure 3. Mass map based on the weak lensing signal, where the circles show the positions of independently identified rich clusters of galaxies. These data reveal a correlation between the visible mass (the clusters) and the dark matter (detected via weak lensing). *Credit: N. Jeffrey et al. Monthly Notices of the Royal Astronomical Society, Volume 505, 4626*

The interacting galaxy pair NGC 1512 and NGC 1510 take center stage in this image from the Dark Energy Camera on the Victor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory, a Program of NSF's NOIRLab. NGC 1512 has been in the process of merging with its smaller galactic neighbor for some 400 million years, and this drawn-out interaction has ignited waves of star formation and warped both galaxies. *Credit: Dark Energy Survey/DOE/FNAL/DECam/CTIO/NOIRLab/NSF/AURA*

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Ninth Data Release of the DESI Legacy Surveys Available at the Astro Data Lab

Stéphanie Juneau & Arjun Dey (NSF's NOIRLab)
on behalf of the DESI Legacy Imaging Surveys & Astro Data Lab teams

The DESI Legacy Imaging Surveys Data Release 9 (LS DR9) is publicly available through the Astro Data Lab, and we invite the community to use its products, including images and catalogs. This release marks the official imaging dataset for target selection for the ambitious cosmological survey being conducted with the Dark Energy Spectroscopic Instrument (DESI;[1], [2]).

Begun in 2014, the Legacy Imaging Surveys are a combination of three imaging surveys and archival data covering more than 20,000 square degrees of extragalactic sky in the *g*, *r*, and *z* bands [3]. The survey data were obtained using the Dark Energy Camera (DECam) on the Víctor M. Blanco 4-meter telescope at Cerro Tololo, the Mosaic-3 camera on the Nicholas U. Mayall 4-meter telescope at Kitt Peak, and the 90Prime camera on the Steward Observatory's Bart Bok 2.3-meter telescope. Beyond the primary goal to produce a uniform dataset for the selection of DESI targets, the imaging and catalog data enable a very wide diversity of astrophysics projects. They are already being used in studies of faint stars, stellar streams, faint ultra-diffuse galaxies, gravitational lenses, high redshift quasars, and galaxy clustering.

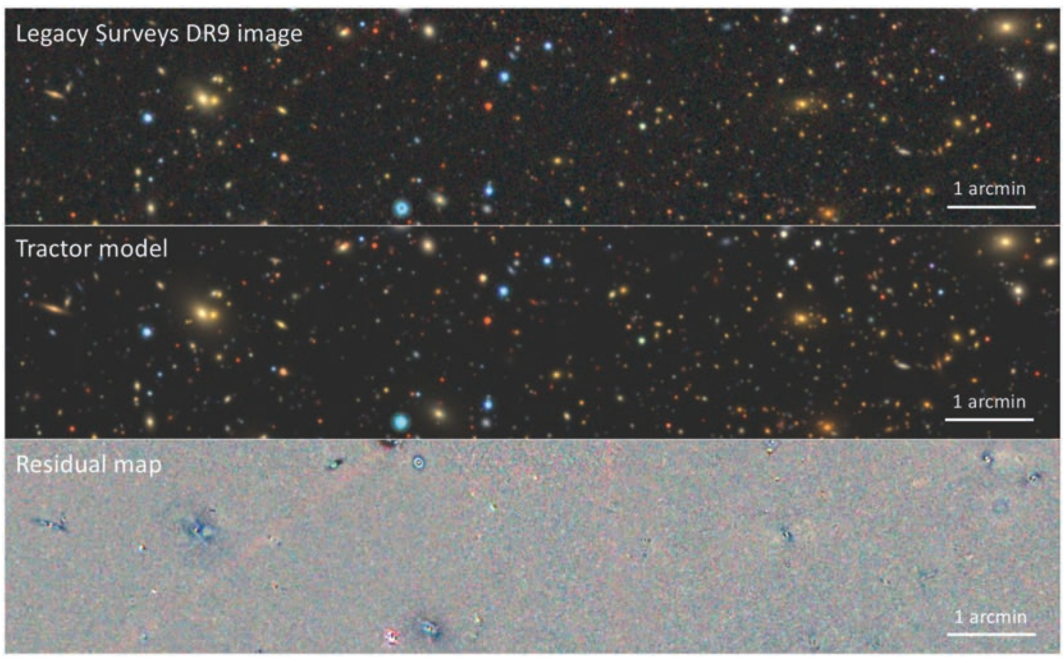

Figure 1. From top to bottom: LS DR9 color image in the combined *grz* bands, the DR9 Tractor model of the same region of the sky, and the DR9 residual map (image minus model) shown with enhanced brightness and contrast to highlight faint features. To interactively explore this region, visit the Sky Viewer around RA=215.1137 and Dec=0.9736 *Credit: Legacy Surveys/D. Lang (Perimeter Institute)*

The Legacy Imaging Surveys project was unusual in three ways. First, it introduced a novel approach to data collection: it implemented a dynamic observing strategy, where each frame was analyzed for seeing, throughput, and depth as soon as it was taken, and exposure times of future observations were adjusted accordingly [4]. Second, the LS team pioneered a new cataloging technique ("the Tractor," created by Dustin Lang) where the sky was "forward modeled" (i.e., in each region of sky, unique models for each source were derived by fitting all of them simultaneously to all the individual sky images [5]). The result is a two-dimensional model of the sky in each band (Figure 1). Third, the project was executed as a completely public endeavor: all data taken for the survey, all data products, and all the software (for observation planning, scheduling, data reduction) were made available publicly as the survey was in progress. The project published eight data releases in five years.

LS DR9 includes not only data from the 3 suery.rveys described above (the DECaLS Survey, NOAO Proposal IDs 2014B-0404 and 2016A-0190; the MzLS Survey, 2016A-0453; and the BASS Survey, 2015A-0801) but also archival images from the NOIRLab Astro Data Archive from other projects, most notably public data from the Dark Energy Survey (DES) project. LS DR9 also reports mid-infrared photometry measured at 3.4, 4.5, 12, and 22 microns by NASA's WISE satellite for all optically detected sources. The mid-infrared photometry was measured (using the LS source positions and shapes as priors) from the single-band unWISE coadds [6] which includes data from the original WISE survey and the NEOWISE phase of the WISE mission. The LS DR9 footprint covers over 20,000 square degrees (Figure 2) and reaches depths (in AB magnitudes) of g=24.7, r=23.9, z=23.0, $W1$=20.72, and $W2$=19.97. The survey is notable for its uniformity across its footprint, lending itself to cosmological analyses.

The data products from the survey are available through NOIRLab's Astro Data Lab and through the Legacy Surveys project website. In addition to the main Tractor photometric catalog, DR9 also includes single-epoch forced photometry catalogs, which report photometry from each individual image that contributed to the survey, as well as a photometric redshift catalog [7]. Astro Data Lab provides users with Python and Table-Access-Protocol (TAP) interfaces to these data as well as web-based queries and Jupyter notebooks. A new scientific example notebook demonstrates an investigation of large-scale structures using photometric redshifts to augment the census of member galaxies in spectroscopically identified overdensities such as galaxy clusters and superclusters (Figure 3). Astro Data Lab users can easily join the LS DR9 catalogs with other holdings such as catalogs from Gaia, WISE, or selected Sloan Digital Sky Survey (SDSS) spectroscopic and photometric tables.

The imaging surveys can be explored visually using the Imagine Sky Viewer tool, written by Dustin Lang, which includes views of the stacked images, the Tractor models, and the residual maps and provides the ability to download FITS and JPEG cutouts. Various catalogs of astrophysical interest (e.g., *Gaia* DR2, SDSS spectroscopy, DESI target lists) can be overlaid on the images.

The Legacy Imaging Surveys project is the result of the efforts of an international team working together to create one of the largest and most uniform surveys ever conducted of the night sky (see the project acknowledgments). Support was provided by the National Science Foundation, the Department of Energy's Office of Science, Steward Observatory, the Chinese Academy of Sciences, and partner universities around the world, including staff at three observatories and observers

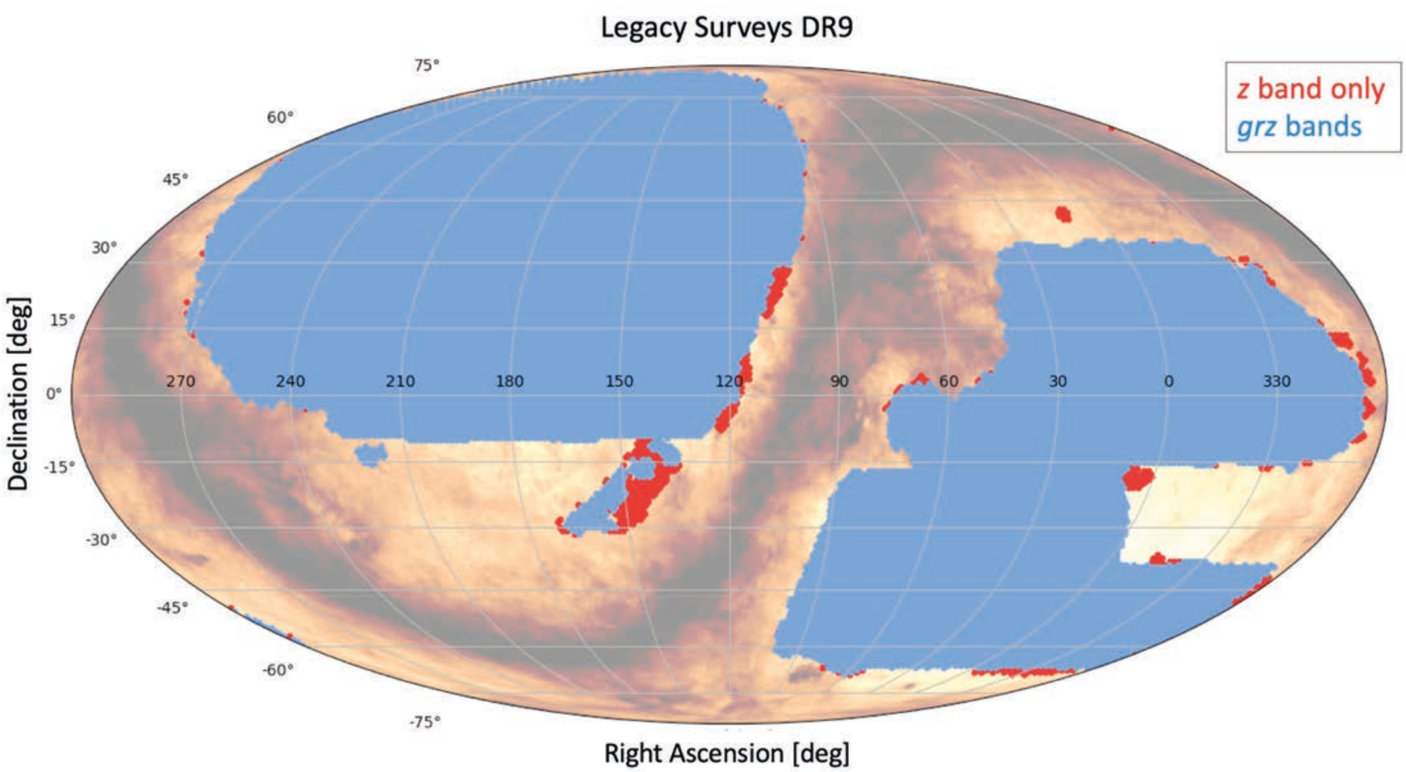

Figure 2. Sky map showing the >20,000-square-degree coverage of LS DR9 (*g,r,z* bands in blue, *z*-band only in red). The footprint avoids regions of high dust attenuation displayed by the underlying dust map, which is the darkest along the Galactic Plane. DESI spectroscopy will target the region north of declination -30 degrees.
Credit: A. Raichoor/EPFL/LBL and the DESI Collaboration

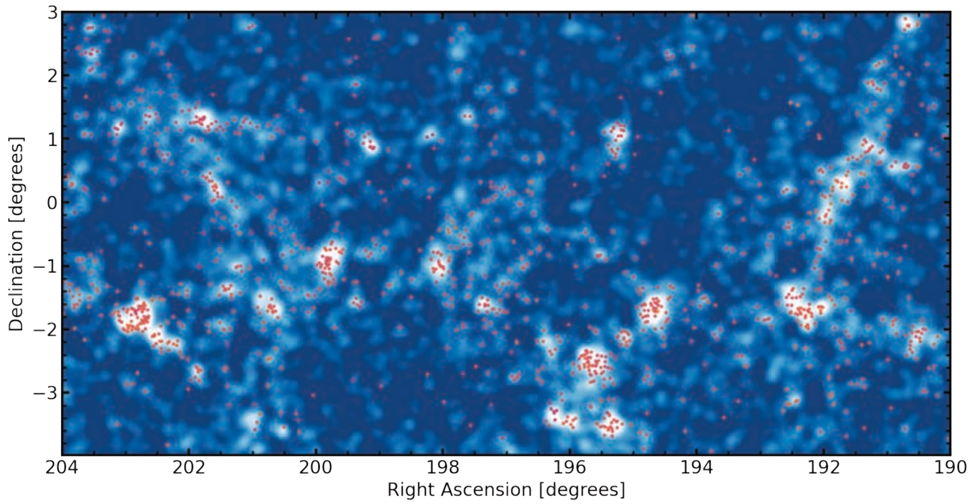

Figure 3. Large-scale galaxy overdensities from LS DR9 photometric redshifts clearly show several clusters and filaments (blue color map), and the most prominent features correspond to the presence of red sequence galaxies with spectroscopic redshifts (red dots). This analysis is conducted in one of the latest Jupyter notebook scientific examples available to all Astro Data Lab users. *Credit: S. Juneau/NOIRLab and the Astro Data Lab team.*

who traveled to Kitt Peak and Cerro Tololo to collect the data. The initial detrending of the data was performed at NOIRLab in Tucson, and the cataloging and data analyses used the substantial computing resources of the National Energy Research Scientific Computing Center. This team has now shifted its gaze to the next horizon: using the DESI instrument at the Mayall telescope to obtain 30 million galaxy redshifts and nearly 10 million stellar spectra. Together, the Legacy Imaging Surveys and DESI will represent one of the largest cosmic cartography projects ever attempted.

DESI saw first light in October 2019 and was fully commissioned in 2020 (Figure 4). The Survey Validation phase took place in early 2021, yielding over one million successful redshifts even before starting its five-year survey on 17 May 2021. DESI's ambitious survey aims to measure the expansion history of the Universe over the last 10 billion years and provide measurements of cosmological parameters with unprecedented precision. As probes of the expansion of the Universe, DESI has selected four classes of extragalactic targets: bright (r<19) galaxies that lie primarily at low-redshift; luminous red galaxies, the progenitors of present-day ellipticals; emission line galaxies; and quasars. The DESI target lists, selected from LS DR9, will also be publicly accessible through Astro Data Lab. While we wait for DESI spectroscopy to open new vistas into the cosmos, the Legacy Imaging Surveys imaging data are ready for exploration.

References:

[1] DESI Collaboration, et al. 2016a, arXiv:1611.00036

[2] DESI Collaboration, et al. 2016b, arXiv:1611.00037

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

[4] Burleigh, K., et al. 2020, AJ, 160, 61

[5] Lang, D., Hogg, D. W., & Mykytyn, D. 2016, Astrophysics Source Code Library

[6] Meisner, A. M., et al. 2019, PASP, 131, 124504

[7] Zhou, R., et al. 2021, MNRAS, 501, 3309

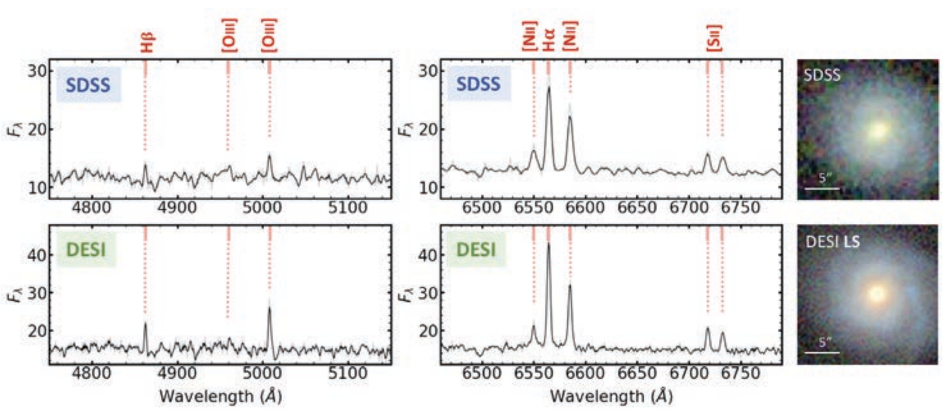

Figure 4. Comparison of SDSS DR16 (top) and DESI (bottom) spectra (taken during commissioning) and three-band color images for the same galaxy (*gri* bands for SDSS; *grz* bands for DESI). Only spectral regions around typical emission lines of interest are shown. The LS data are deeper with better image quality than SDSS, and the DESI spectra have higher spectral resolution and signal-to-noise ratio. Images span 20 arcseconds on a side. *Credit: R. Pucha/University of Arizona, S. Juneau/NOIRLab, and the DESI Collaboration*

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The US NGO GMOS Data Reduction Cookbook: Version 2.0

Brian Merino, Vinicius Placco, and Letizia Stanghellini
(US NGO, CSDC/NSF's NOIRLab)

The twin Gemini Multi-Object Spectrographs (GMOS) are among the most subscribed capabilities at the International Gemini Observatory. In 2016, the National Gemini Office (NGO) released the first version of the GMOS data reduction cookbook to guide users in GMOS data reduction with the Gemini IRAF routines. The cookbook included an introduction to the instrument and its observing modes, a description of specific data structure, and detailed instructions for data reduction for the individual GMOS modes, with examples and tutorials.

In the future the majority of GMOS Gemini data will likely be reduced with the Python-based DRAGONS routines that are already available for Imaging mode and are under development for all GMOS modes. In the interim, users rely on IRAF/PyRAF to reduce their GMOS data.

We analyzed the needs of the users and realized that there was a great deal of interest in a guide to GMOS data reduction with IRAF/PyRAF, as seen in the volume of traffic directed to the GMOS Data Reduction Cookbook web page through the US NGO Portal (Figure 1). The US NGO therefore made it a priority to revise and maintain user access to GMOS data reduction with IRAF/PyRAF by updating the cookbook.

The new version (v2.0) of the cookbook is now available online. All parts of the document have been updated and for all of the GMOS modes — Imaging, Long Slit Spectra, Long Slit Nod and Shuffle, Multi-Object Spectra, and IFU Spectral Images.

The GMOS cookbook improvement and modernization process has been multipronged. The cookbook has a new

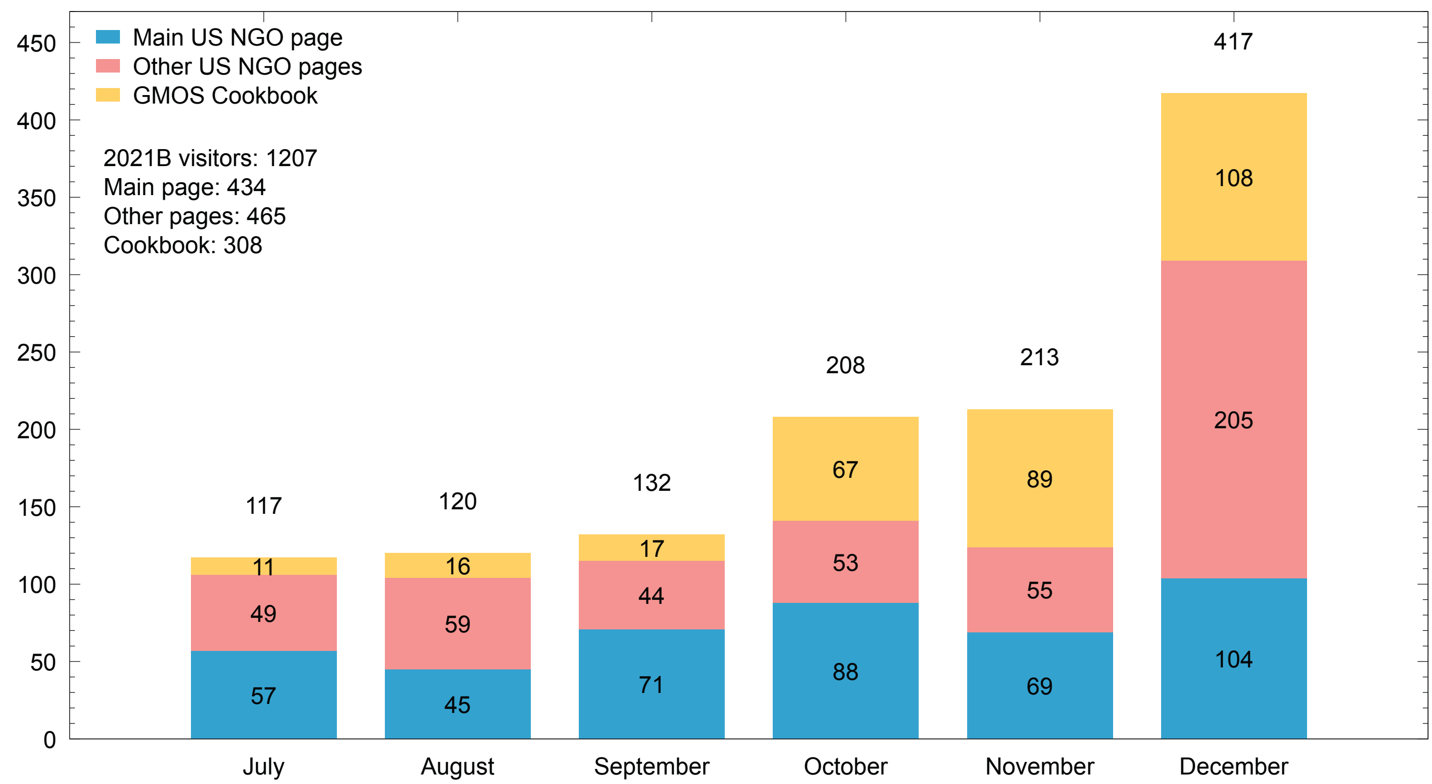


Figure 1. The number of unique visitors to the US NGO Portal during Semester 2021B, by month. The block colors refer to specific sections of the Portal. The GMOS Cookbook in particular has seen a great deal of traffic. The Portal is accessed by the entire Gemini community. *Credit: US National Gemini Office*

look, a new address, and updated processing tutorials. We have completed the following revision steps:

(1) *We revised the five existing PyRAF processing cookbooks (i.e., the cookbooks for the individual GMOS modes) by verifying that the code is compliant with the latest software provided by the observatory (including native astroconda installation and version 6.1.28 of the virtual machine with the Gemini IRAF packages).*

(2) *We moved the cookbook to a GitLab repository, allowing for version control and real-time collaboration.*

(3) *We improved the overall clarity.*

The GMOS cookbook consists of a general section describing the instrument (including its observing modes, the data properties, and general reduction issues) and five individual PyRAF tutorials.

The tutorial modernization portion of the project involved analyzing the existing documentation for the five PyRAF processing tutorials to correct errors and determine areas that could benefit from further explanation. For example, code was added to help users reproduce the outputs featured in the tutorials (Figure 2). The improvement portion of the project involved verifying that every line of code listed in the individual mode cookbooks would run without crashing, solving any line order issues in the code, and correcting

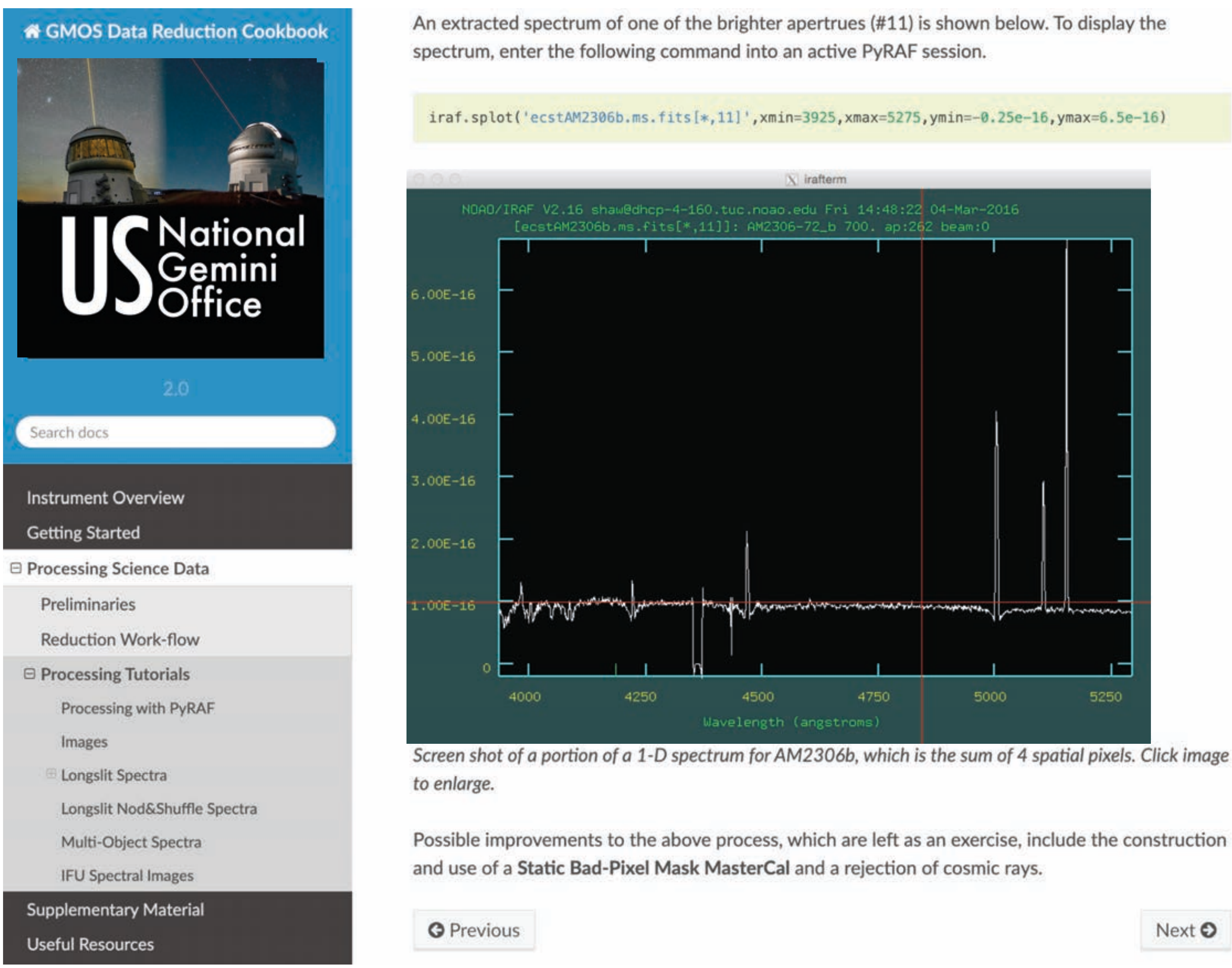


Figure 2. An example of code added to the Reduction of Long-Slit Spectra with PyRAF that users can use to verify that they have successfully reduced their data. *Credit: US National Gemini Office*

punctuation to avoid errors. We added informative and warning boxes as appropriate throughout the tutorials.

We also corrected grammatical errors and punctuation. Broken links that resulted from the retirement of the noao.edu domain were updated. Any updates to the pages and changes to the code are automatically published on the new website.

We revised the cookbook's text to improve the overall clarity of the instructions and added informative notes. We inserted a box on the main cookbook web page with information on the v2.0 release and a link to the "Getting Started" section, which in turn has been updated with the latest software instructions. We added a prominent box in this section, with software installation procedure links for all available products (astroconda/PyRAF and the Gemini Virtual Machine). We corrected the broken links and updated the instructions and references to bring the cookbook up to date. We also revised the supplemental materials and resources.

We plan to keep abreast of any software issues and changes and revise the cookbook periodically so users can have a seamless experience when reducing their GMOS data.

The US NGO welcomes suggestions from the GMOS user community! Please contact us at usngo@noirlab.edu or via our Twitter account. Visit our Users Support Portal for information on the US NGO and links to important information on our activities.

A view of the partial lunar eclipse of 19 November 2021 as seen from Kitt Peak National Observatory. This image captures the eclipse above the Nicholas U. Mayall 4-meter Telescope in the Arizona-Sonoran Desert of Arizona and despite being dimmed in the eclipse, the Moon still brightens the dome of the Mayall telescope with a red glow. *Credit: KPNO/NOIRLab/NSF/AURA/R. T. Sparks*

Gemini South, one half of the International Gemini Observatory, is seen here with its laser guide star in action. Both of the Gemini telescopes use laser guide stars to provide data for the calibration of their adaptive optics systems. *Credit: International Gemini Observatory/NOIRLab/NSF/AURA/T. Slovinský*

10.5281/zenodo.6643900

The Next–Generation Adaptive Optics Facility for Gemini North

Gaetano Sivo (NSF's NOIRLab), Julia Scharwächter (NSF's NOIRLab), and Suresh Sivanandam (University of Toronto)

Adaptive optics (AO) has been used for more than two decades at major observatories to obtain high-spatial-resolution observations from the ground. The basic principle of AO involves correcting the wavefront disturbances induced by Earth's atmosphere in real time using deformable mirrors. The Gemini North Adaptive Optics (GNAO) project will provide the Gemini North telescope with a state-of-the-art AO facility for survey, time-domain, and general-purpose science in the era of Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST) and *James Webb Space Telescope* (*JWST*) operations. GNAO is supported by the Gemini in the Era of Multi-Messenger Astronomy (GEMMA) program funded by NSF to advance the leadership role of the Gemini telescopes in high-resolution, time-domain, and multi-messenger astronomy. By building on the legacy of Gemini Multi-Conjugate Adaptive Optics System (GeMS) at Gemini South, the GNAO project aims primarily at revitalizing the Gemini North AO capabilities with a flexible queue-operated facility. This will take full advantage of Maunakea's outstanding characteristics as a premier site for high-angular-resolution observations from the ground.

GNAO is expected to replace the aging single-conjugate AO facility ALTAIR on the AO port of the Gemini North telescope. The GNAO design will be optimized to feed the Gemini InfraRed Multi-Object Spectrograph (GIRMOS), an innovative near-infrared imager and multiplexed integral field unit (IFU) spectrograph [1] developed by a Canadian

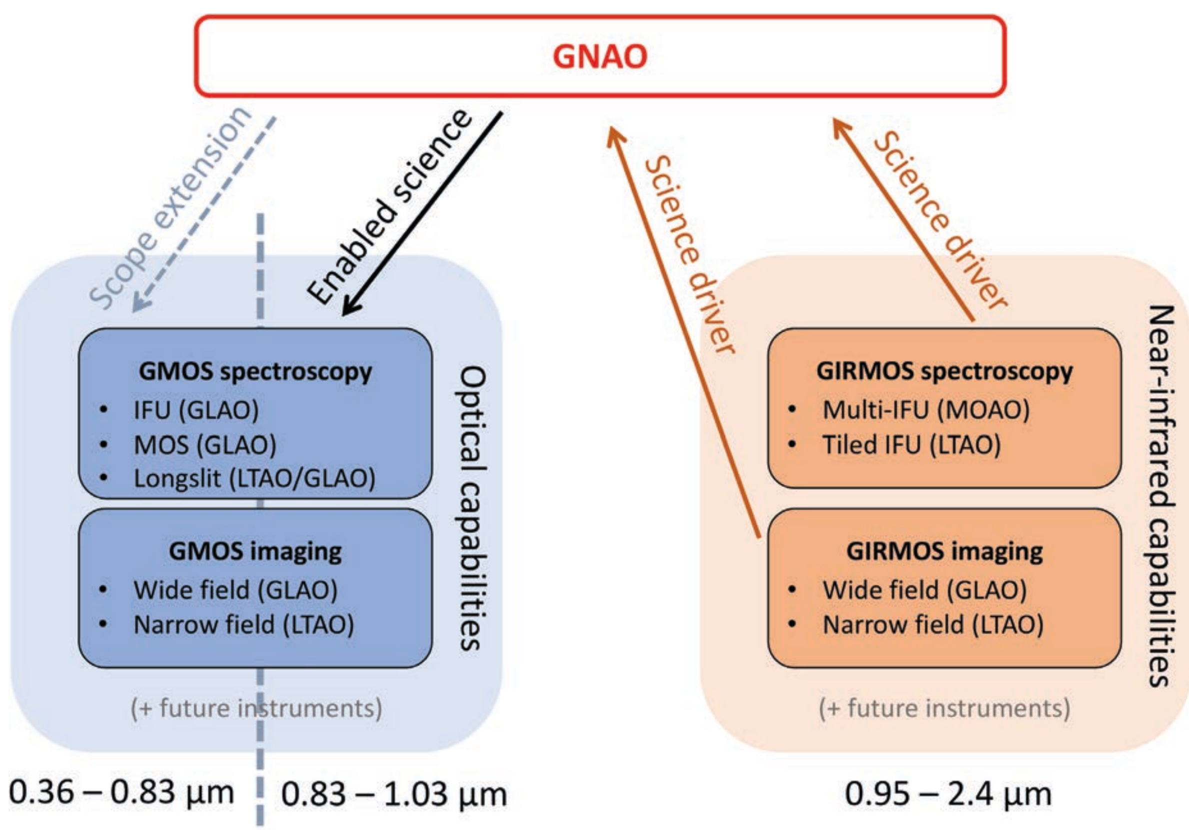


Figure 1. Schematic overview of the primary GNAO-enabled instrument modes. GNAO will provide a baseline science wavelength coverage in the NIR reaching down to 0.83 µm.

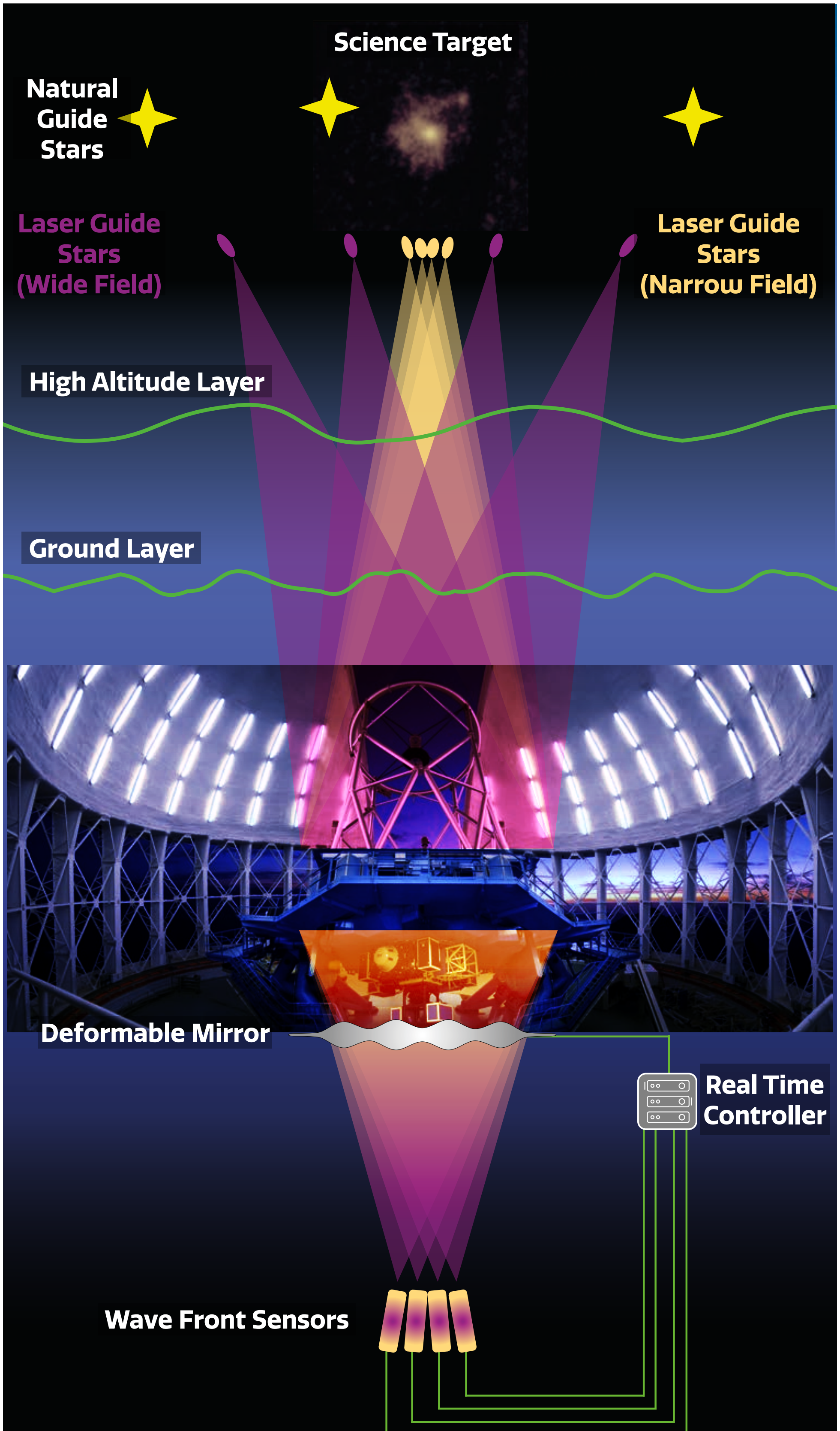


Figure 2. GNAO optical schematic, including on-sky configuration, conjugated atmospheric layers and stylized deformable mirror, wavefront sensor, real time controller, and feedback loop. Also shown are laser guide star configurations and natural guide stars. *Credit: International Gemini Observatory/NOIRLab/NSF/AURA/J. Pollard*

consortium (P.I. S. Sivanandam, University of Toronto) in close collaboration with the GNAO team. While GIRMOS is the primary driver for defining the capabilities of GNAO, the new AO system will be available as a general facility for backend instruments operable with GNAO's f/32 output beam in the 0.83 to 2.5 µm wavelength range. Among the current Gemini North facility instruments, the optical workhorse instrument Gemini Multi-Object Spectrograph (GMOS) will be able to take advantage of the GNAO-corrected beam at the red end of the GMOS wavelength coverage.

The GNAO project includes the development of a new laser guide star facility, which will consist of four side-launched laser beams supporting the two primary AO modes of GNAO as well as a wide-field mode providing improved image quality over natural seeing for a 2′ circular field of view and a narrow-field mode providing near diffraction-limited performance over a 20″ × 20″ square field of view. The GNAO wide-field mode will enable GIRMOS's multi-IFU configuration in which the science beam to each individual IFU will be additionally corrected using multi-object AO within GIRMOS. The GNAO narrow-field mode will feed the GIRMOS-tiled IFU configuration in which all IFUs are combined into a 'super-IFU' in the center of the field. The GIRMOS imager will have a 85″ × 85″ square field of view and can be operated with either the GNAO narrow-field or wide-field correction at a fixed plate scale, depending on the angular resolution and field size required for specific science goals.

Imaging	FoV	K-band (2.2μm) Performance	H-band (1.65μm) Performance	J-band (1.25μm) Performance
GNAO WFM (GLAO) 60% sky coverage	85″ × 85″	120 mas FWHM	150 mas FWHM	200 mas FWHM
GNAO NFM (LTAO) 60% sky coverage	20″ × 20″	SR 35%	SR 20%	SR 10%
GNAO on-axis (LTAO) 12 mag R-band limit	On-axis	SR 60%	SR 45%	SR 25%
Detector	HAWAII-4RG 4k × 4k			
Plate Scale	0.021″			
Wavelength (μm)	0.83 – 2.4			

Table 1: GIRMOS Imager characteristics and Image Quality (SR: Strehl Ratio) performance requirements in *J*, *H* and *K*-bands.

Spectroscopy			
Wavelength (μm)	0.95–2.4	# of IFS	Up to 4
Spectral Resolving Power	3000 and 8000	Spectral Bands	0.95–1.35, 1.25–1.8, 1.63–2.35 μm for R~3000 1.194–1.35, 1.5–1.706, 2.11–2.379 μm for R~8000
FoV for MOAO arms	2′ Patrol field		
IFS FoV (100% coverage)	1.0″ × 1.0″ 2.0″ × 2.0″ 4.0″ × 4.0″	Spaxel Sampling	0.025″ 0.05″ 0.1″
Single Object IFS FoV (Tiled mode)	2.0″ × 2.0″ 4.0″ × 4.0″ 8.0″ × 8.0″	Spaxel Sampling	0.025″ 0.05″ 0.1″
Throughput	35%	Detectors	4 × HAWAII-2RG 2k × 2k
GNAO+GIRMOS AO Image quality	50% EE in 0.05″ in H band (LTAO mode) 50% EE in 0.1″ in H band (MOAO mode) 50% EE in 0.4″ in H band (GLAO mode)		

Table 2: GIRMOS spectroscopic characteristics and image quality performance requirements.

The GNAO project also includes the development of the following:

- The Adaptive Optics Bench, including the low-order natural guide star wavefront sensor, the high-order laser guide star wavefront sensor, and the fast-moving active element to correct for the aberrations induced by the atmosphere
- The Real Time Controller to compute and apply in real time the correction to the deformable mirrors
- The System Controller, including the operational software and AO software tools to calibrate and optimize the system and the logical sequencing of the observations

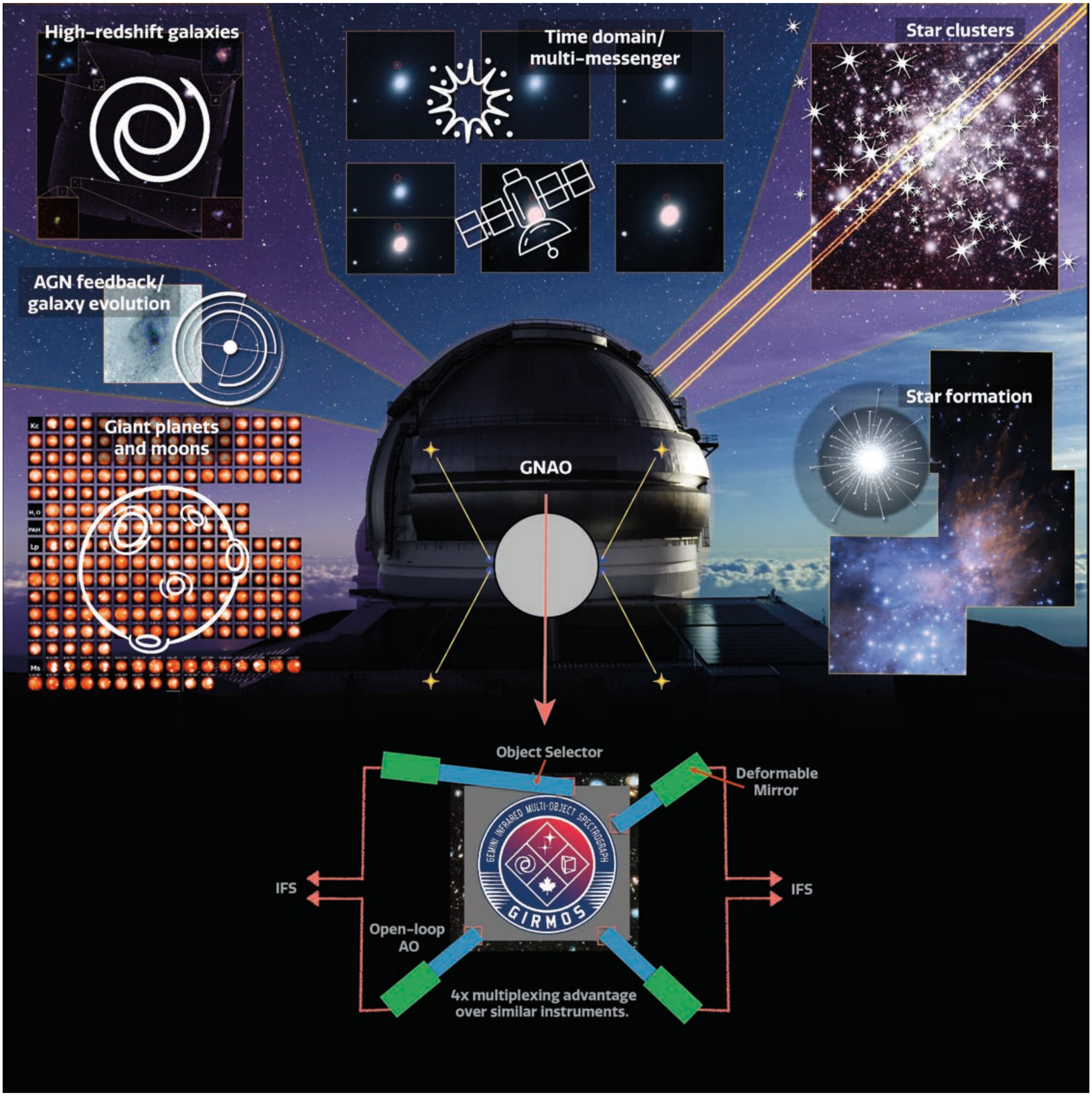


Figure 3: Science Case categories enabled with GNAO+GIRMOS
Credit: International Gemini Observatory/NOIRLab/NSF/AURA/J. Pollard

The design of the new AO facility for Gemini North is driven by a broad range of science cases, ranging from Solar System to extragalactic science. The overall science drivers include science cases developed by both the GNAO and GIRMOS science teams.

High-resolution facility for multi-messenger events

The example of the famous 2017 gravitational wave event GW170817 has demonstrated the power of multi-messenger astronomy as an important driver of astrophysical discoveries. GW170817 was the first gravitational wave event detected with an electromagnetic counterpart through a major world-wide observing campaign [2]. The gravitational wave signal together with the subsequent short gamma-ray burst (GRB) and follow-up detections across the electromagnetic spectrum have provided unprecedented insights into the physics of neutron star mergers, including their association with short GRBs as well as kilonova emission from radioactive decay during the synthesis of heavy elements. Characterizing the kilonova emission after a short GRB is a high-priority science driver for the GNAO narrow field mode, where high angular resolution will improve the detection of the transient against the background host galaxy light. As a queue-operated facility, GNAO is being developed to offer a rapid response mode to support this science case and early follow-up of other targets of opportunity, such as Solar System transients or new, unknown transients discovered with Rubin Observatory's Legacy Survey of Space and Time.

Powerful capabilities for survey science

GNAO, in conjunction with GIRMOS, will provide powerful capabilities for spectroscopic surveys at high angular resolution. The multiplexing capabilities offered by the GIRMOS spectroscopic modes will be complementary to many aspects of galactic and extragalactic research conducted with the *JWST*. The GIRMOS spectroscopic modes are well suited to study targets such as star clusters, galaxy nuclei and supermassive black holes, lensed galaxies, and in the study of galaxy evolution from low to high redshift. Two of the primary science drivers for GIRMOS are a survey of galaxies between redshifts of 0.7 and 2.7 and a survey of globular clusters, taking advantage of the multi-IFU and tiled-IFU configurations, respectively. The galaxy survey will provide unprecedented sample sizes of high-angular-resolution IFU data to study the role of mergers, star formation, and feedback processes in the build-up of galaxy mass around redshift 2. Globular clusters are candidates for hosting intermediate-mass black holes, which are expected to exist in the mass range between stellar-mass and supermassive black holes but have remained difficult to detect. The spatially resolved spectroscopy obtained with the GIRMOS globular cluster survey will provide new opportunities to systematically search for observational signatures of the much sought-after intermediate-mass black holes.

Flexibility for Solar System science and multi-epoch studies

AO-assisted observations from ground-based telescopes have traditionally been an important technique for advancing our knowledge of the Solar System. Ground-based observations play a major part in studying the atmospheres of the giant planets (e.g., wind shear, convection, seasonal variations) or variable phenomena on their moons, such as the volcanic activity on Io [3]. Science cases focusing on multi-epoch observations to monitor Solar System objects or to characterize the time evolution of protostellar jets and outflows at high angular resolution require an AO facility that is available on a virtually nightly basis. By supporting Solar System studies through a non-sidereal tracking option and by operating as a queue-scheduled facility, GNAO will provide exciting new opportunities for such high-angular-resolution work in the time domain within and beyond the Solar System.

The GNAO project is fully managed in-house under the leadership of Gaetano Sivo (Principal Investigator), Manuel Lazo (Project Manager), Julia Scharwächter (Project Scientist), Stephen Goodsell (Project Director), William Rambold (Lead Systems engineer), and Jennifer Lotz (Gemini Director). The Laser Guide Star Facility is designed and built in-house except for the Laser Launch Telescopes that are contracted out to Officina Stellare in Vicenza (Italy). The Real Time Controller is developed by Herzberg Astronomy and Astrophysics in Victoria (Canada). The Adaptive Optics Bench is currently under a call for tenders / bid selection process. The project timeline currently foresees first light of GNAO during the first quarter of 2028.

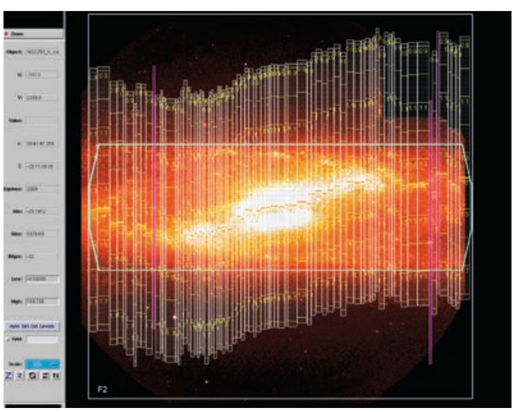
References:

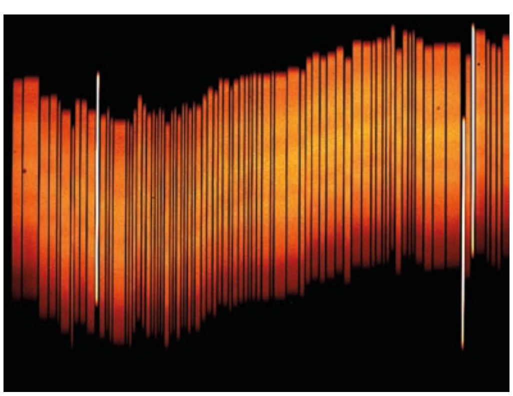
[1] Sivanandam, S., et al. 2020, Proc. SPIE, 11447, 114471A
[2] Abbott, B. P., et al. 2017, Phys. Rev. Lett., 119, 161101
[3] de Kleer, K., et al. 2019, AJ, 158, 29

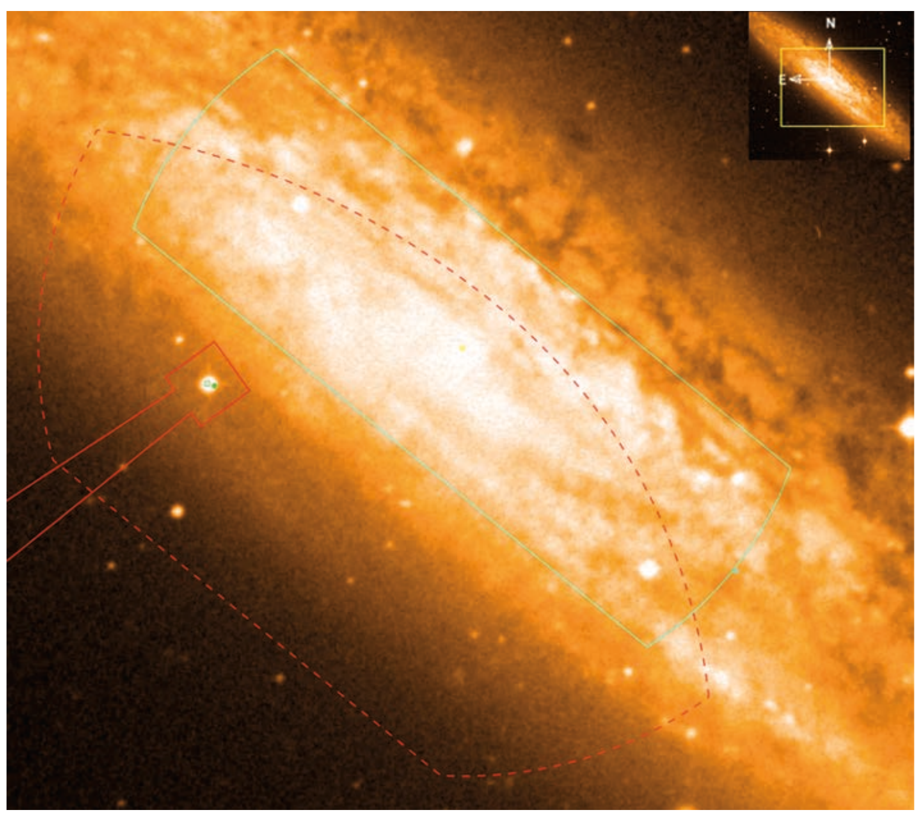
10.5281/zenodo.6643913

Flamingos-2 at Gemini South: Ongoing Upgrades and Upcoming Support of Multi-Object Spectroscopy

Ruben Diaz, Andy Adamson, Janice Lee, Jennifer Lotz (NSF's NOIRLab)







Flamingos-2 (F-2) is a wide-field, near-infrared imager, and long-slit and multi-object spectrograph built by Stephen Eikenberry and his team at the University of Florida [1] that operates on the Gemini South 8m telescope. After a series of refurbishments, F-2 achieved its nominal performance in 2017. Since then it has become the most used near-infrared (NIR) spectrograph at Gemini, with more than 90 refereed publications since 2016, a number growing at the pace of other workhorse NIR instruments in their first years of regular operation.

F-2 provides the widest-field near-infrared imaging capability at Gemini, with a circular field of view (FOV) of 6.1′. The achieved image quality across the whole FOV is on par with the telescope-delivered image quality in the NIR (0.4″ FWHM in the *H* band under 20-percentile seeing conditions; Figure 1). The standard *JHKs* set of filters was recently upgraded, adding *Kb* and *Kr*, two high-throughput filters splitting the *K* band to allow demography studies of high-redshift galaxies and young stellar objects.

Figure 1 (previous page). Top: F-2 *JHKs* pseudo-color image of NGC 253's central region, showing a 6′ x 2.5′ part of the circular FOV. The average FWHM is 0.43″ across the 6′ FOV, meaning that the instrumental PSF permits exploitation of the 20-percentile image quality delivered by the telescope. **Mid-left**: GMMPS (mask design program) showing a mask design on the *Ks* pre-image of NGC 253, including wavelength display. **Bottom Left:** Actual *K*-band flat field taken with the same mask, showing 77 slits of lengths 2–10″ and the three alignment star boxes. **Bottom right**: Observing Tool program view on a Digitized Sky Survey red image of NGC 253, marking in red the OIWFS and its patrol field, and in blue the mask FOV. *Credit: International Gemini Observatory/NOIRLab/NSF/AURA*

F-2 also provides the longest long-slit spectroscopic capability in the NIR at Gemini. The 4.4′ long-slit spectroscopic mode provides average spectral resolution of 2800 over the single bands *J*, *H*, and *K*-long (1.9–2.5 μm) and 1000 with simultaneous coverage on the wider spectral ranges *YJH* and *HK*. As per instrument design, the spectral resolution changes relatively quickly across each spectral range; however, the relatively low internal flexure plus the availability of many OH emission lines in the NIR sky allows accurate wavelength calibration and radial velocity uncertainties of ~5 km s^{-1} for a single emission line at S/N~25.

In addition to supporting diverse science cases, F-2 is well suited to time-domain astronomy. Gemini's queue operation allows slewing the telescope and acquiring data with F-2 in times as short as three minutes (images) or five minutes (spectra) after a Target of Opportunity has been triggered. For example, F-2 near-infrared images and spectra allowed multiple research teams to form the most complete NIR picture of the gravitational wave event GW170817, covering 25 nights of its aftermath [2]. On the evening twilight of the first day after the researchers pinpointed the location of the optical afterglow, the 8m Gemini South telescope successfully captured some of the first infrared photons ever seen from the merger of two neutron stars.

As part of its Instrument Upgrade Program [3], Gemini started commissioning the Multi-Object Spectroscopy (MOS) mode in 2018. However, a series of mechanical faults due to aging of the On Instrument Wave Front Sensor (OIWFS) mechanism, plus other faults (the most important one related to the closed-cycle refrigeration system), precluded completion of the MOS commissioning in 2019. The final phase of the commissioning was completed in 2021, and we plan to offer the mode in mid-2022.

The MOS mode currently allows the simultaneous observation of up to 150 targets over an area of 6′ × 2′, with a maximum of nine masks installed on the instrument per thermal cycle. The OIWFS minimizes spectral losses due to flexure between the focal plane unit and the telescope guiding system, allowing a minimum slit width of 0.54″ for zenith distances up to 60 degrees. This allows observing with average spectral resolution of 2000 over the single bands *J*, *H*, and *K*-long (1.9–2.5 μm) and 700 with simultaneous coverage on the wider spectral ranges *YJH* and *HK*. Observing overheads are similar to those in the long-slit mode: maximization of the number of slits on point-source targets or the observation of extended targets require an overhead larger than 100% of the on-source time due to the need for offsetting to obtain sky frames.

F-2 masks (Figure 2) can be designed with targets selected from pre-images or catalog pseudo-images and can be cut with the lasers at either the Gemini North or the Gemini South site. The current public Gemini IRAF package includes recipes and examples for MOS and long-slit data reduction, and imaging data can be processed within the Gemini DRAGONS Python-based platform.

Gemini continues to upgrade its operations, instrumentation, and user support to provide its community with essential scientific capabilities for the 2020s and to preserve and enhance diverse science, ensuring benefits to the broadest possible set of users, as outlined in its Scientific Strategic Plan [4]. The next F-2 upgrades, ongoing in the CP instrument laboratory, will improve its overall spectroscopy performance (including the MOS mode). The *YJH/HK* broadband spectroscopic filters will be replaced by new versions, increasing the spectroscopic throughput in the *R*~1000 modes by ~9% (*HK*) and ~12% (*YJH*) and making the response function significantly flatter. Another ongoing upgrade will increase by two the number of filter slots, allowing us to offer the *J*-low and *Y* filters permanently, as requested by several user teams. In addition, the instrument's thermal insulation will be improved to allow more thermal stability, especially in the MOS dewar. Finally, we have initiated a study to probe the performance of the F-2 spectroscopic modes when used with the multi-conjugate adaptive optics system GeMS and plan to issue a feasibility report in 2023.

References:

[1] Eikenberry, S., et al. 2008, Proc. SPIE, 7014, 70140V
[2] Chornock, R., et al. 2017, ApJL, , 848, L19
[3] Diaz, R., et al. 2018, Proc. SPIE, 10702, 107023R
[4] Blakeslee, J. P., et al. 2019, arXiv:1909.09196

The contributors to F-2 MOS commissioning are Andy Adamson, Gonzalo Diaz, Ruben Diaz, Stephen Eikenberry, German Gimeno, Percy Gomez, Scot Kleinman, Janice Lee, Jennifer Lotz, Bryan Miller, Marcelo Mora, Gabriel Perez, Pablo Prado, Steven Raines, Rolando Rogers, Roberto Rojas, Rene Rutten, Ricardo Salinas, Mischa Schirmer, Karleyne Silva, Chris Simpson, Andrew Stephens, and James Turner.

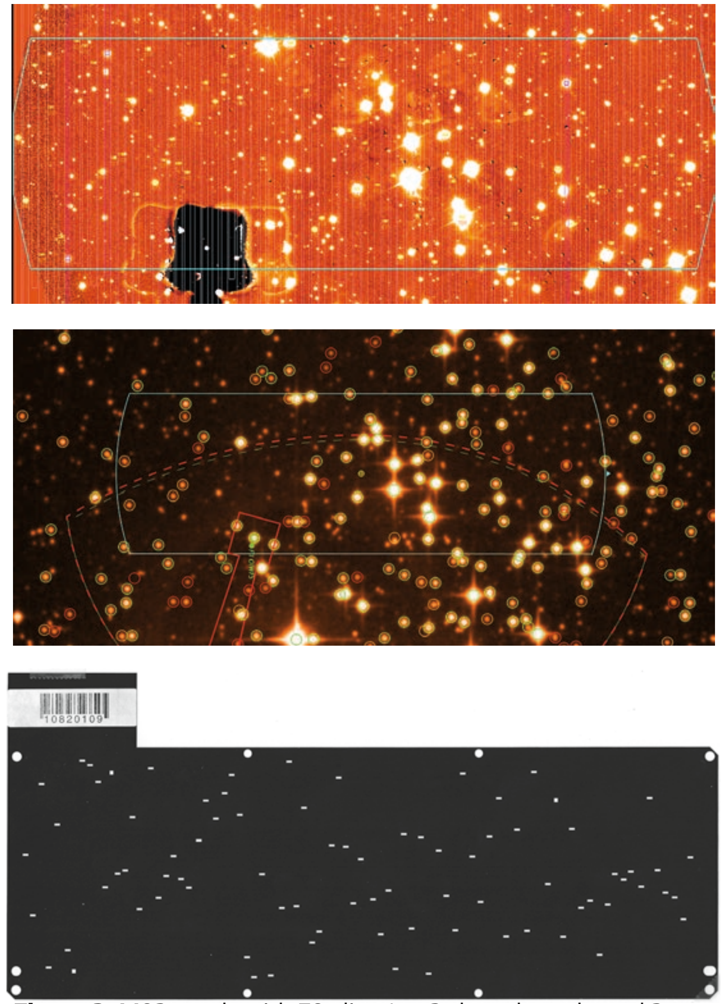


Figure 2. M93 mask with 78 slits, 1″ × 3″ length each, and 3 alignment star boxes. **Top:** GMMPS mask design and *Ks* pre-image. Note that the intensity level display is non-linear and shows the low-level artifacts in the processed image, due to the pre-image dithering pattern and the presence of many bright stars in the observed field. **Center:** OT configuration. **Bottom:** The mask (anodized Al) with the slits cut with the Gemini South laser cutter. *Credit: International Gemini Observatory/NOIRLab/NSF/AURA*

Mask Field of View	6′ × 2′	Targets from F-2 pre-image or catalog
Number of 4.5" length slits	72	Nodding along the slits (100% on source)
Number of 1.8" length slits	153	Offsetting to sky position (50% on source)
Spectral coverage	0.97–2.48 µm	*YJH*, *HK*, *J*, *H*, *K*-long band modes
Spectral Resolution	700 / 2000	Single / Broadband, 0.54″ slit
Spatial image quality	0.4″	*H* band, IQ 20-percentile observing conditions

Table 1. MOS capability

The Gemini North telescope with the Southern Cross to its left as the Milky Way rises. The glow of Kīlauea volcano can be seen to the left with the summit of Maunakea between the volcano and the Gemini telescope. *Credit: International Gemini Observatory/NOIRLab/AURA/NSF/ P. Horálek*

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A Strong Start for Rubin Observatory Data Previews

Kristen Metzger
(AURA/Rubin Observatory)

In 2021 Vera C. Rubin Observatory began Data Preview Zero (DP0), the first of three data previews leading up to the start of Rubin Observatory's Legacy Survey of Space and Time (LSST). In its first few months, DP0 has proven successful with regard to its primary goals: 1) to train the operations team and test the functionality of Rubin's developing data infrastructure in the operations context; and 2) to introduce a diverse group of scientists to the tools and interfaces they'll use to access and analyze Rubin data. Community feedback obtained during DP0 is being used to guide the continued development of Rubin's data infrastructure and support materials.

Rubin Observatory is committed to research inclusivity, and one of the highest priorities for DP0 was to ensure that the DP0 participants, referred to as delegates, represent the full range of diversity in the science community. The call for delegate applications was broadly advertised, and the Rubin Observatory Community Engagement Team (CET) worked with Rubin leadership to identify and reach out directly to individuals at small or under-resourced institutions. The initial selection process, in May 2021, relied on an algorithm designed to prioritize participation from scientists and students who are under-represented in astronomy and to build a network of delegates from a variety of global locations, institutional types, career stages, and astronomical fields. The first couple of months of DP0 went so well that by November 2021 all the applicants were invited to become DP0 delegates, and an additional limited number of invitations have now been extended to delegates' students as well.

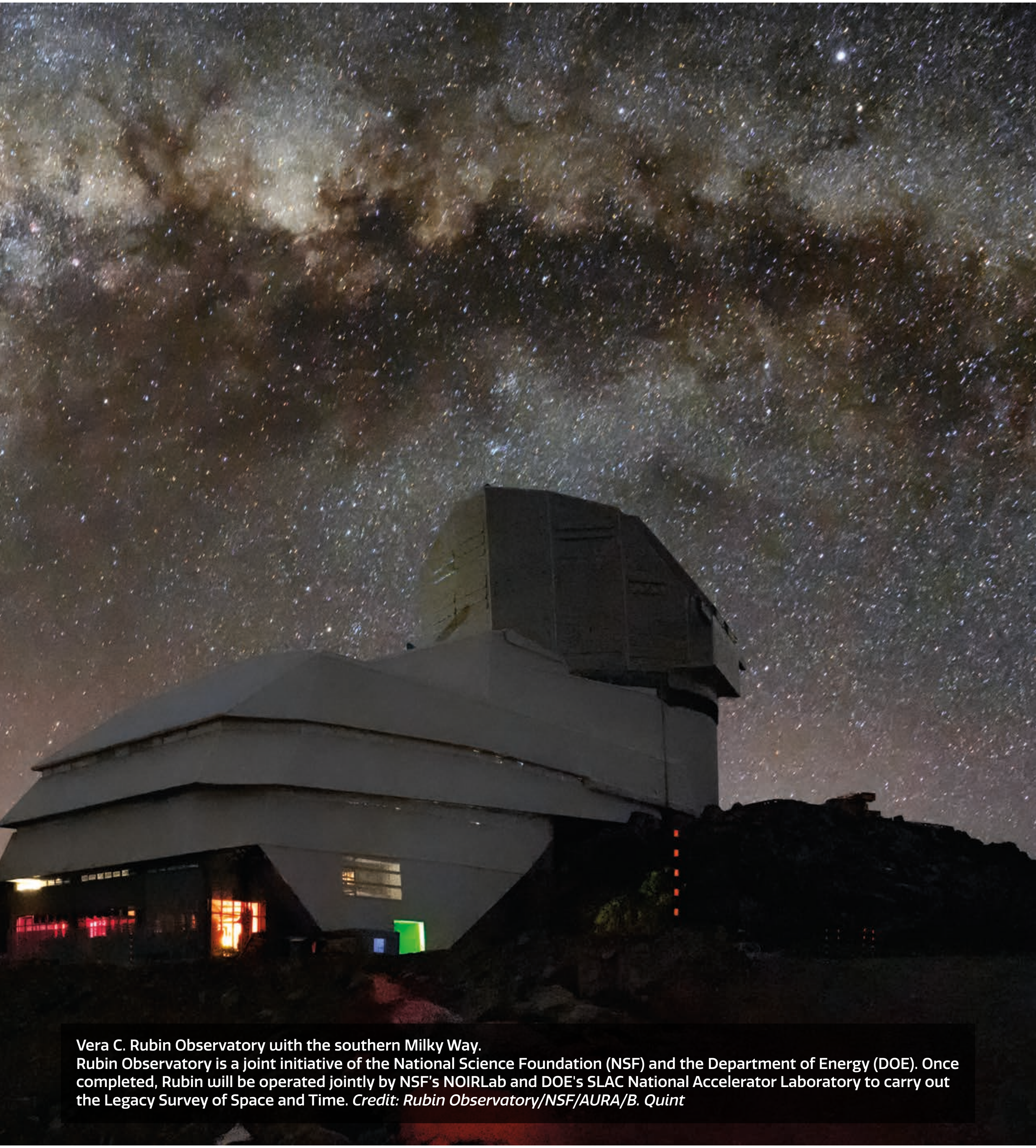
The several hundred delegates have now spent a few months using the Rubin Science Platform (RSP) to access simulated data products that are similar to those that will be produced during the LSST. Frossie Economou, who leads the development of the RSP, notes that the developers are gratified to see astronomers using the products they've been working on ahead of Rubin Observatory's first light. "*This first cohort of external users is a great opportunity for us to test our ideas out in the wild,*" notes Frossie. "*We have had internal RSP users for quite some time now, but there was always the possibility that in-project users were suffering from some form of Stockholm Syndrome. But more seriously, it's great for our developers to start settling into the mixed development-operations mode that will be the norm during the LSST campaign. While it is a challenge to balance the two with so much construction work remaining, there is great satisfaction in remembering the point of all this, and we can't wait for our own telescope's data to start flowing.*" In addition to exploring new query, visualization, and analysis tools in the RSP, delegates are also learning to use the Rubin Observatory Community Forum to get help from their peers and colleagues. The Forum is intended to provide a sustainable support model where publicly shared ideas and solutions benefit the whole science community. The Rubin CET has also provided an extensive suite of documentation, tutorials, and other resources for delegates and has hosted online information sessions and delegate assemblies. In September 2021 the CET invited DP0 delegates to provide feedback about their experiences using the initial support resources provided by the CET. Overall, the survey results were

(left) *Credit: Rubin Observatory/NSF/AURA*

extremely positive, and most respondents affirmed that the Community Forum and other core DP0 support resources were serving them well. DP0 Delegate Kristen Larsen, associate professor of astronomy and physics at Western Washington University, credits the CET and the support they've provided for her positive experience with DP0, adding, "*I feel much more confident and enthusiastic about jumping in to use real Rubin Observatory data when they arrive.*"

The first few months of DP0 have gone so well that Rubin Observatory leadership plans to allocate 300 new RSP accounts in the second phase of DP0, bringing the total number of DP0 delegates to 600 by 30 June 2022. "*Our goal is to scale up sustainably,*" says Melissa Graham, Lead Community Scientist for Rubin Observatory, "*so we can protect our still-developing infrastructure and continue to provide adequate support for all delegates.*" This deliberate and incremental growth will continue through the data preview process, and all Rubin data rights holders will be able to obtain RSP accounts by the time science operations begin. Meanwhile, DP0 delegates are playing an important role in building and strengthening the community of scientists using Rubin data for their research. Delegate Louise Edwards, assistant professor of physics at California Polytechnic State University, says DP0 "*has motivated me to reach out to other LSST scientists, and I have been communicating regularly with folks at SLAC, NOIRLab, and across my university system about potential projects involving DP0 data.*"

The second phase of DP0 is scheduled to begin on 30 June 2022. It will include a new dataset that has been reprocessed using a more recent version of the LSST Science Pipelines, and data products will be available in a format that is consistent with planned LSST data products. Additional data products, such as light curves, will also be available. The application form for new DP0 delegates will open in early March and close on 30 April 2022. See the Community Forum topic: Early announcement for Phase 2 of Data Preview 0 (DP0.2) for more information about how to participate.



Vera C. Rubin Observatory with the southern Milky Way.
Rubin Observatory is a joint initiative of the National Science Foundation (NSF) and the Department of Energy (DOE). Once completed, Rubin will be operated jointly by NSF's NOIRLab and DOE's SLAC National Accelerator Laboratory to carry out the Legacy Survey of Space and Time. *Credit: Rubin Observatory/NSF/AURA/B. Quint*

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The US Extremely Large Telescope Program

Mark Dickinson (NSF's NOIRLab)

Many of today's forefront astronomical problems demand higher angular resolution and greater sensitivity than 8–10m optical–infrared telescopes can provide. The US Extremely Large Telescope Program (US-ELTP) will deliver those capabilities, opening new frontiers in nearly all areas of astrophysics, from solar systems (our own and around other stars) to cosmology. The large apertures and small diffraction limits of Extremely Large Telescopes (ELTs) will enable dramatic advances in the investigation of the forefront problems of the decades to come and open tremendous potential for new discoveries. For diffraction-limited observations, sensitivity[1] scales with telescope primary mirror diameter (D) as D^4, or even more steeply for observations in crowded fields, so the potential gains from telescopes with D > 20m are enormous.

The US-ELTP is a partnership between NSF's NOIRLab and the organizations building the Giant Magellan Telescope (GMT) and the Thirty Meter Telescope (TMT). Our aim is to complete construction of a bi-hemispheric ELT system available to all US scientists, regardless of their institutional affiliations. We seek to provide 25% or greater shares of national open-access observing time on both the TMT and the GMT, available via NOIRLab's peer-reviewed time allocation process. Any US astronomer with a great idea will be able to propose to use these world-class facilities to study objects anywhere on the sky, using a broader suite of instruments than a single observatory could provide. The observing time available to US astronomers will enable Key Science Programs (KSPs) to tackle fundamental problems requiring dedicated effort using large, multiyear allocations of GMT and TMT observing time, as well as smaller, focused Discovery Science Programs allocated on a more frequent cadence, nimble and responsive to new opportunities and new ideas. NOIRLab will provide a suite of user services spanning the full research life cycle from proposal preparation through data analysis and publication, ensuring inclusive support for a broad community of observers and archival researchers.

The recent Decadal Survey report, *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*, wrote: "*Because of the transformative potential that large (20–40m) telescopes with diffraction-limited adaptive optics have for astronomy, and because of the readiness of the projects, the survey committee's top recommendation for frontier ground-based observatories is investment in the US ELT Program. [...] These observatories will create enormous opportunities for scientific progress over the coming decades and well beyond, and they will address nearly every important science question across all three priority science themes.*" The three Decadal Survey science themes and the importance of US-ELTP capabilities for addressing each are as follows:

- ***Worlds and Suns in Context:*** The study of exoplanetary systems including their formation and evolution and the interconnections between planets and their host stars.
    - **Priority science area:** *Pathways to Habitable Worlds* — the quest to identify and study potentially habitable planets and to seek atmospheric chemical indicators of habitability and perhaps life itself.
    - **Role of the US-ELTP:** Resolving forming and mature planetary systems, spectroscopic analysis of those systems and of exoplanet atmospheres, and the search for chemical biosignatures.
- ***New Messengers and New Physics:*** The application of multi-messenger astrophysics and time-domain astronomy to address fundamental questions in cosmology and physics.
    - **Priority science area:** *New Windows on the Dynamic Universe* — using temporal observations of gravitational waves and electromagnetic radiation to address fundamental questions about black holes, neutron stars, and the explosive consequences of their interactions and mergers.
    - **Role of the US-ELTP:** Precision measurements to resolve the physics of dark matter and accelerating cosmic expansion, test the nature of gravity near supermassive black holes, and conduct time-resolved and time-critical measurements of the faint electromagnetic counterparts to gravitational wave beacons created by merging compact objects.

[1] Here, sensitivity is defined as the reciprocal of the exposure time required to attain a given signal-to-noise ratio for observations of a point source with a given flux in the background-limited regime.

- ***Cosmic Ecosystems:*** The integrated study of gas, stars, and black holes within galaxies and their interconnections over a huge dynamic range of scale and density — processes that shape the evolving life cycle of galaxies, their contents, and the intergalactic medium.
  - **Priority science area:** *Unveiling the Hidden Drivers of Galaxy Growth* — direct observations of galaxies and circum- and inter-galactic gas to understand the cosmic "baryon cycle" that governs the growth and evolution of galaxies and their component structures over cosmic history.
  - **Role of the US-ELTP:** Spatially resolved observations of early galaxies and their intersellar and circumgalactic gaseous media, and analysis of today's fossil record using resolved stellar populations in galaxies throughout the Local Volume.

The bi-hemispheric US-ELTP supporting these next-generation observatories and their state-of-the art instrumentation will enable research breakthroughs in all of these science areas, as well as capability for unexpected discoveries anywhere on the sky. Two telescopes will ensure full sky coverage with approximately 50% sky overlap where the complementary capabilities and instruments of the GMT and TMT can be used together. The longitudinal separation of the telescopes will support and enhance critical time-domain science programs. Two telescopes will ensure that more observing nights are available to enable US astronomers to carry out large-scale KSPs. US-ELTP capabilities will work together with all-sky space observatories on the problems of the future, as well as with other forefront observatories operating at all wavelengths in both hemispheres, and all-sky multimessenger facilities such as the next generation of gravitational wave detectors. The US-ELTP leverages the past

Figure 1. The US Extremely Large Telescope Program will enable US astronomers to observe objects anywhere in the sky using the Thirty Meter Telescope (left) in the northern hemisphere and Giant Magellan Telescope (right) in the southern hemisphere. ***Credit: US-ELTP (Giant Magellan Telescope/NOIRLab/TMT)***

and present capital and intellectual investment by the current TMT and GMT partners and integrates the whole US research community into these trans-Pacific, multi-continental, international partnerships, establishing an unparalleled worldwide ELT collaboration.

In addition to serving as a gateway for US community observing proposals for the GMT and TMT, NOIRLab will provide a full suite of user support services and tools, drawing on the extensive heritage of all of NOIRLab's programs and observatories and building new capabilities optimized for the needs of the TMT, GMT, and US-ELTP user community. NOIRLab's US ELT Program Platform will span all stages of the "science data life cycle," including observing proposal preparation, observing time allocation, observing program planning, dynamic and adaptive observation scheduling, data archiving, data reduction, and data analysis. All GMT and TMT data will be archived at NOIRLab and will be available after agreed-upon proprietary periods. Science data obtained using standard observing procedures and calibrations will undergo pipeline processing, and reduced, calibrated data products will be archived. NOIRLab will provide and support data analysis tools in a science platform environment that facilitates collaboration within teams and archival research using TMT/GMT data.

NOIRLab has established a small but dynamic team that is working closely with the GMT and TMT projects and the US science community to bring the US-ELTP to fruition. The current Project Director is Beth Willman, and the Project Manager is Steven Berukoff, who recently joined NOIRLab from the National Solar Observatory. Mark Dickinson and Marie Lemoine-Busserolle are the Project Scientist and Systems Scientist, respectively. In a nutshell, they are responsible for ensuring that NOIRLab's user services and tools will meet the research needs of a diverse astronomical community. Dara Norman (also deputy director of NOIRLab's Community Science and Data Center, CSDC) and research associate Tim Sacco are the US-ELTP's Research Inclusion Team, guiding NOIRLab's plan to ensure that NOIRLab's US-ELTP policies and user services will provide outstanding and equitable support for a community of users from a wide variety of institutional backgrounds, including scientists at small and under-resourced institutions. The newest team member is André-Nicolas Chené, Community Engagement Scientist, who will oversee NOIRLab's efforts to inform, consult, and involve the scientific community in planning and development of the US-ELTP, working closely with the Research Inclusion Team. Andrew Serio is the Project Systems Engineer, responsible for developing and maintaining the project's formal requirements and their traceability from use cases and for developing and overseeing verification and validation of the user support software systems. Other US-ELTP team members include Sharon Hunt (Document Manager), Kevin Long (Project Controls Specialist), Mark Newhouse (Communications, Education & Engagement Liaison), and Stephen Ridgway (Technical Monitor). The core team also draws on the tremendous resource of expertise in other NOIRLab programs, particularly in CSDC and Gemini.

In recent years, community scientists have contributed enormously to the development of the US-ELTP, formulating KSP concepts that demonstrate the potential of a bi-hemispheric ELT system, and writing white papers on the transformational science that the system will enable. The Decadal Survey endorsement is, in no small part, a consequence of our community's enthusiasm and effort. With that endorsement, the US-ELTP partnership is now preparing proposals for peer review at the National Science Foundation to support the development and construction of the observatories and NOIRLab's suite of user services. NOIRLab and the TMT and GMT projects will continue to work with the astronomical community to understand its needs for observatory capabilities, future instrumentation, and user support, and to inform the community about scientific opportunities and the status and progress of the program and the observatories. The upcoming June AAS meeting #240 in Pasadena, California, home to both the GMT and TMT project offices, will be one of many future opportunities to learn about the US-ELTP and to meet staff from both observatories and NOIRLab. Look for more information about the US-ELTP in e-News for the NOIRLab Community.

A spectacular portrait of the galaxy Centaurus A is captured using the Dark Energy Camera mounted on the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory in Chile. This galaxy's peculiar appearance — cloaked in dark tendrils of dust — stems from a past interaction with another galaxy, and its size and proximity to Earth make it one of the best-studied giant galaxies in the night sky. *Credit: CTIO/NOIRLab/DOE/NSF/AURA*

Acknowledgment

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Eighteen Years Young

Journey Through the Universe celebrates 18 years of community engagement — with a bright future ahead under NOIRLab

Peter Michaud (NSF's NOIRLab)

If you haven't heard of NOIRLab's flagship annual outreach program *Journey Through the Universe* (*Journey*), it's not for lack of persistence! Just completing 18 consecutive years of local community engagement in Hawai'i, *Journey* continues to grow and develop in new and exciting ways.

One of the most significant changes to *Journey* has happened in the past two years, due to the COVID-19 pandemic. For most of its long history, *Journey*, managed by Gemini North staff (and led by Janice Harvey, see sidebar on page 37), focused mostly on in-classroom, in-person programming. In a typical year *Journey* programming reaches 300+ classrooms and over 8000 individual students. However, because of COVID, for the past two years *Journey* pivoted to virtual programming, which has proven to be a challenge in many ways, but also presented a number of unexpected opportunities.

First, a little background for those who are not familiar with the program. The *Journey* program in Hawai'i began in 2004 as part of a national initiative started in 1999, led by Jeff Goldstein at NASA's National Center for Earth and Space Science Education (NCESSE) and managed by USRA (the NCESSE *Journey Through the Universe* webpages can be found here). Over the years, about 20 communities around the US participated in the program, with Gemini joining in 2005. Then, in 2006, the NASA funding came to a close and the program began operating in cost recovery mode. Since then most of the original participating communities have been unable to sustain the program (according to the website, only Hawai'i and Washington DC continue running the program). As the national program shrank, the Hawai'i program was just hitting its stride!

The release of the Decadal Survey report (*Pathways to Discovery in Astronomy and Astrophysics*) in November of 2021 included a focus on Community Based Science. This concept is not new; in fact the *Journey* program incorporated this principle since its inception, with immersion of STEM professionals and resources in local host communities. A major factor contributing to the success of the Hawai'i *Journey* program is a strong partnership with the local Department of Education (DOE). It cannot be overstated that a program like *Journey* needs the full support of local educators to succeed. For the past 18 years the Gemini-DOE partnership has been a model of effective community engagement and synergy.

So how does *Journey* exemplify the Community Based Science model highlighted in the Decadal Survey report?

At its very core *Journey* immerses observatory staff in the community (Figures 1 & 2). Each year during "*Journey* week," which generally happens in late February/early March, up to 60 staff from Gemini/NOIRLab, most of the Maunakea Observatories, NASA, and beyond, converge on Hawai'i Island schools. These astronomy educators each prepare a

Figure 1. The author gets help from students using carbon dioxide snow to wash dust off a mirror much like is done with the Gemini telescope mirrors. *Credit: International Gemini Observatory/NOIRLab/NSF/AURA/ J. Pollard*

presentation and are encouraged to include a hands-on activity to lead with students. To this end, an annual workshop for astronomy educators is held which shares best practices, how to align with the Next Generation Science Standards that teachers are required to adhere to, and ideas and activities that work effectively for elementary through high school students. At the end of a typical *Journey* week over 300 local classrooms are engaged in the science of astronomy and STEM disciplines.

In addition to classroom visits, *Journey* week includes multiple career panels where STEM professionals share their career experiences with students and describe what inspired them to devote their careers to astronomy (or other STEM careers such as engineering or support roles at observatories). These career panels have become an integral part of the *Journey* activities and provide fascinating and inspiring perspectives on careers in STEM that students can relate to and identify role models for their own aspirations.

Another core principle of *Journey* and Community Based Science is community partnerships. In addition to the DOE, over 50 community businesses, institutions and organizations are active partners in the *Journey* program. These partners include everything from local car dealerships, the local daily newspaper,

Figure 2: Gemini Director Jennifer Lotz participates in a *Journey Through the Universe* classroom presentation. *Credit: International Gemini Observatory/NOIRLab/NSF/AURA/ J. Pollard*


Hilo • Waiākea Complex Area
Department of Education State of Hawai'i
Journey Through the Universe
Hawai'i Island
Astronomy Educators in the Community
2022(*virtually)
Alexis Ann Acohido EAO/JCMT
Andy Adamson Gemini Observatory/NSF's NOIRLab
Tishanna Ben National Solar Observatory/DKIST
Vanshree Bhalotia UH-Manoa Physics & Astronomy
Ravinder Bhatia Thirty Meter Telescope
Christopher Brownewell AURA/KPNO
Lars L. Christensen Gemini Observatory/NSF's NOIRLab
Devin Chu UCLA
Brian Day NASA SERVI
Xinnan Du KIPAC/Stanford
Angelic Ebbers Gemini Observatory/NSF's NOIRLab
Jocelyn Ferrara Gemini Observatory/NSF's NOIRLab
Scott Fisher University of Oregon
Mimi Fuchs Graduate student at Drexel University
Abhimat Gautam UCLA
Tom Geballe Gemini Observatory/NSF's NOIRLab
Kristina Gibbs NASA SERVI
Jeff Goldstein NCESSE
Olivier Guyon Subaru Telescope
John Hamilton UH-Hilo Physics & Astronomy
Janice Harvey Gemini Observatory/NSF's NOIRLab
Saeko S. Hayashi TMT Japan Project & Subaru Telescope
Stephanie Henry NASA Marshall Space Flight Center
Ardis Herrold Rubin Observatory
Matthew Hosek UCLA
Solveig Irvine NASA / PMPO
Paul Jeffers NSO
Russell Kackley Subaru Telescope
Carolyn Kaichi UH Institute for Astronomy
Yuko Kakazu TMT Japan Project & Subaru Telescope
Markus Kissler-Patig European Southern Observatory
Kelly Kosmo O'Neil UCLA
Preethi Krishnamoorthy Subaru Telescope
Mary Beth Laychak Canada-France-Hawaii Telescope
Fengchuan Liu TMT
Alexandra Lockwood Space Telescope Science Institute
Jennifer Lotz Gemini Observatory/NSF's NOIRLab
Julien Lozi Subaru Telescope
Leinani Lozi Gemini Observatory/NSF's NOIRLab
Nadine Manset Canada-France-Hawaii Telescope
Jameeka Marshall Gemini Observatory/NSF's NOIRLab
Callie Matulonis EAO/JCMT
Ameerah McBride AURA (Corporate Office)
Peter Michaud Gemini Observatory/NSF's NOIRLab
Joseph Minafra NASA SSERVI
Brian Mitchell NASA Marshall Space Flight Center
Junichi Noumaru Subaru Telescope
Brialyn Onodera AURA / NSO / DKIST
Emily Peavy Imiloa Astronomy Center
Shelly Pelfrey W.M. Keck Observatory
Joy Pollard Gemini Observatory/NSF's NOIRLab
Claire Raftery National Solar Observatory
Laurie Rousseau-Nepton Canada-France-Hawaii Telescope
Julien Rousselle Subaru Telescope
Therese Sampia Gemini Observatory/NSF's NOIRLab
Tom Schad National Solar Observatory/DKIST
Justine Schaen NSF's NOIRLab
Doug Simons Canada-France-Hawaii Telescope
Robert Sparks Gemini Observatory/NSF's NOIRLab
Chance Spencer CSU Fresno
Marianne Takamiya UH-Hilo Physics & Astronomy
Ichi Tanaka Subaru Telescope
Alex Tetarenko Texas Tech University
Niki Thomas UCSC
Tomo Usuda NAOJ TMT Project
Fuchs Usuda-Sato Subaru Telescope NAOJ
Sebastien Vievard Subaru telescope
Andrea Waiters SMA
Connie Walker Gemini Observatory/NSF's NOIRLab
Cam Wipper CFHT
Siyi Xu Gemini Observatory/NSF's NOIRLab
Michitoshi Yoshida Subaru Telescope
For more information contact Janice Harvey at: janice.harvey@noirlab.edu
noirlab.edu/public/education/journey-through-the-universe/

Figure 4: Journey Through the Universe community ambassador training event. This annual training prepares ambassadors who work with classroom presenters with logistics, introductions, and general assistance. *Credit: International Gemini Observatory/ NOIRLab/NSF/AURA/J. Pollard*

supermarkets and educational institutions such as the ʻImiloa Astronomy Education Center, University of Hawaiʻi, NASA and more (Figure 3). Partnerships like these provide a way for the community to engage in the program in a tangible way and support education in the community. Each year the two local Hawaiʻi Island Chambers of Commerce host a Thank You Reception for all of the *Journey* business partners, teachers, and observatory staff who share their time with students in classroom presentations and career panels.

Also included in *Journey* activities are teacher workshops, public lectures, family science days and more (although these don't all happen during *Journey* week, and COVID has required suspending some of these events temporarily).

For the past two years (during the pandemic) all *Journey* programming has been 100% virtual, with Zoom classroom presentations/activities, virtual Thank You Receptions and career panels. In some cases *Journey* will continue with virtual elements even after the pandemic. One area where virtual presentations make sense is for some career panels and when presenters cannot travel to Hawaiʻi but want to participate and share. In these cases we will continue to keep the virtual option as an alternative for presenters.

A new element of *Journey* for 2022 (which happened in late February/early March) was a virtual education/culture exchange between Hawaiʻi, Arizona and Chile (all three NOIRLab site host communities). Called *Journey Through NOIRLab*, this program enabled students and teachers to share cultural and educational experiences with classes at the other NOIRLab sites in an environment that encouraged sharing questions, dreams, and cultures. NOIRLab plans to continue to expand this event in future years and engage more students from across NOIRLab as participants.

Despite changes ahead, NOIRLab staff are excited to continue and grow the *Journey* program across all NOIRLab sites. We encourage all staff and stakeholders of NOIRLab to consider participating in the *Journey* program; to learn more about participating in future *Journey* programs please contact: peter.michaud@noirlab.edu

Figure 3. **(left)** *Journey Through the Universe* local partner and classroom educators poster for 2022. *Credit: International Gemini Observatory/ NOIRLab/NSF/AURA/J. Pollard*

Those who are familiar with the *Journey Through the Universe* program in Hawaiʻi will know that Janice Harvey is the inexhaustible energy source that keeps the *Journey* engine humming. Janice has managed the program since it began over 18 years ago and has kept a laser-like focus on making sure the program continues to meet the needs of teachers, students, and the community at large.

Janice's commitment and passion for the program are obvious to anyone who knows her, and her concern for students and their futures is at the core of her lifelong commitment to bettering the community. As Janice says, "*It's all about the keiki!*" (keiki being Hawaiian for children).

This year, after 22+ years at Gemini, and more recently NOIRLab, Janice is planning to retire. It is difficult to imagine the program without her and there is no question that it will be a different program without her at the helm. However, NOIRLab is committed to keeping *Journey* alive and vibrant and building on the remarkable legacy that Janice leaves behind. Her exceptional work to make the *Journey* program what it is today sets a very high bar that we will all strive for as the *Journey* continues!

This ethereal image, captured from Chile by the International Gemini Observatory looks as delicate as a butterfly's wing. It is, however, a structure known as the Chamaeleon Infrared Nebula, which is located near the center of the even larger Chamaeleon I dark cloud, one of the nearest star-forming regions in our Milky Way. *Credit: International Gemini Observatory/NOIRLab/NSF/AURA*

10.5281/zenodo.6643938

NOIRLab Library Services

Sharon E. Hunt (NSF's NOIRLab)

NOIRLab's Library Services is a service within Research and Science Services (RSS) that serves all NOIRLab staff. We support the mission and scientific activities of NOIRLab by providing a variety of services. We also collaborate with other observatory librarians to share expertise and to offer collective support to the user community.

The NOIRLab Library Services maintains three physical locations with collections of journals, books, and historical materials: Tucson, Arizona; Hilo, Hawai'i; and La Serena, Chile. We maintain institutional subscriptions to print and electronic journals and purchase books and ebooks on request. To aid in research endeavors, Library Services staff provide assistance in locating and obtaining journal articles, books, and other materials; developing citation lists; and filling information requests.

Following are details on several of the key services provided by the NOIRLab Library Services.

Publications Tracking: Citation analysis and bibliometrics are important tools for measuring the scientific productivity

Figure 1. Tucson Headquarters Library *Credit: NOIRLab/NSF/AURA. R.T. Sparks*

and impact of observatories as well as the return on investment of public and private funds used in advancing astronomical research. One of the main functions of the NOIRLab Library Services is to track publications written by NOIRLab staff and all community publications that make use of our telescopes, data products, and services. We maintain two ADS public libraries: the NOIRLab ADS bibliographic group for refereed NOIRLab telescope publications and the NOIRLab Staff Publications ADS public library for refereed and non-refereed staff publications. The metrics derived from publication tracking are used in NOIRLab reports and proposals. To ensure that NOIRLab is appropriately recognized in scientific publications, we maintain the AAS Facility Keywords for NOIRLab and the NOIRLab Scientific Acknowledgments web page.

Page Charges: Library Services oversees the processing of page charge requisitions for the NOIRLab author portion of publications.

Website: Library Services maintains web pages both on the intranet website for the use of our staff and on the science website.

Archival Materials: Library Services helps to preserve the history of the organization through its archival collections. We preserve, organize, and provide access to this historical material to NOIRLab staff as well as to individuals outside the organization. The Tucson Headquarters Library has a rich collection of historical materials: books, documents, correspondence, images, and glass plates.

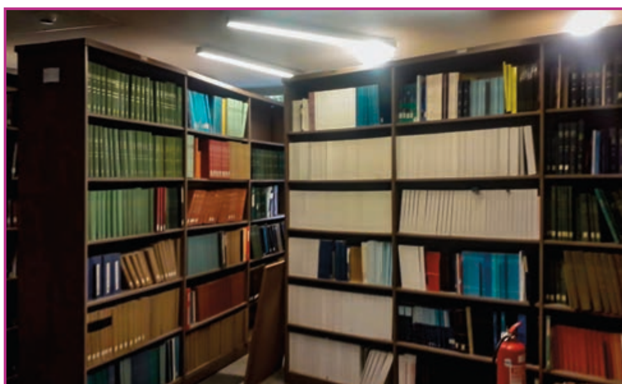
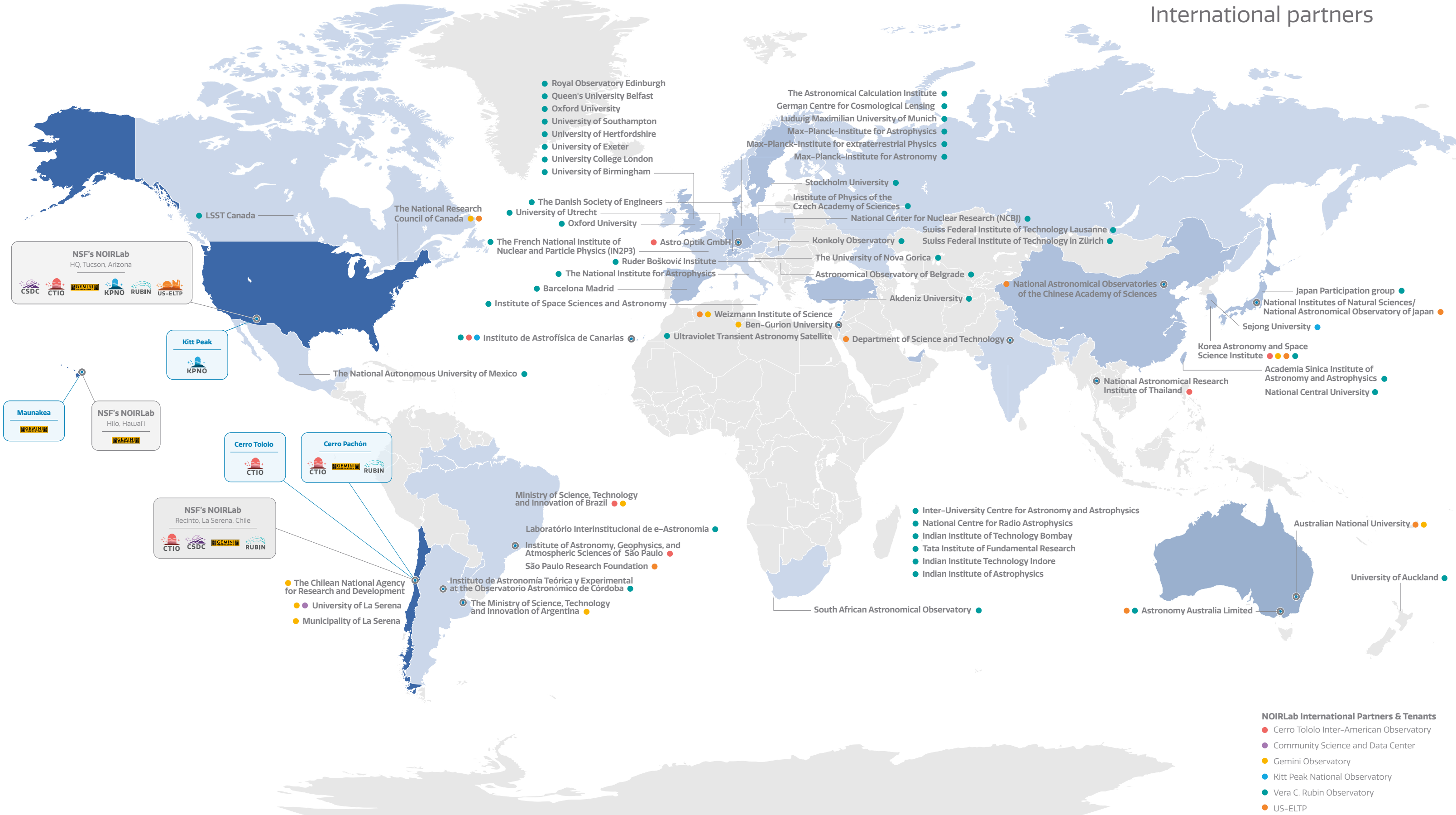
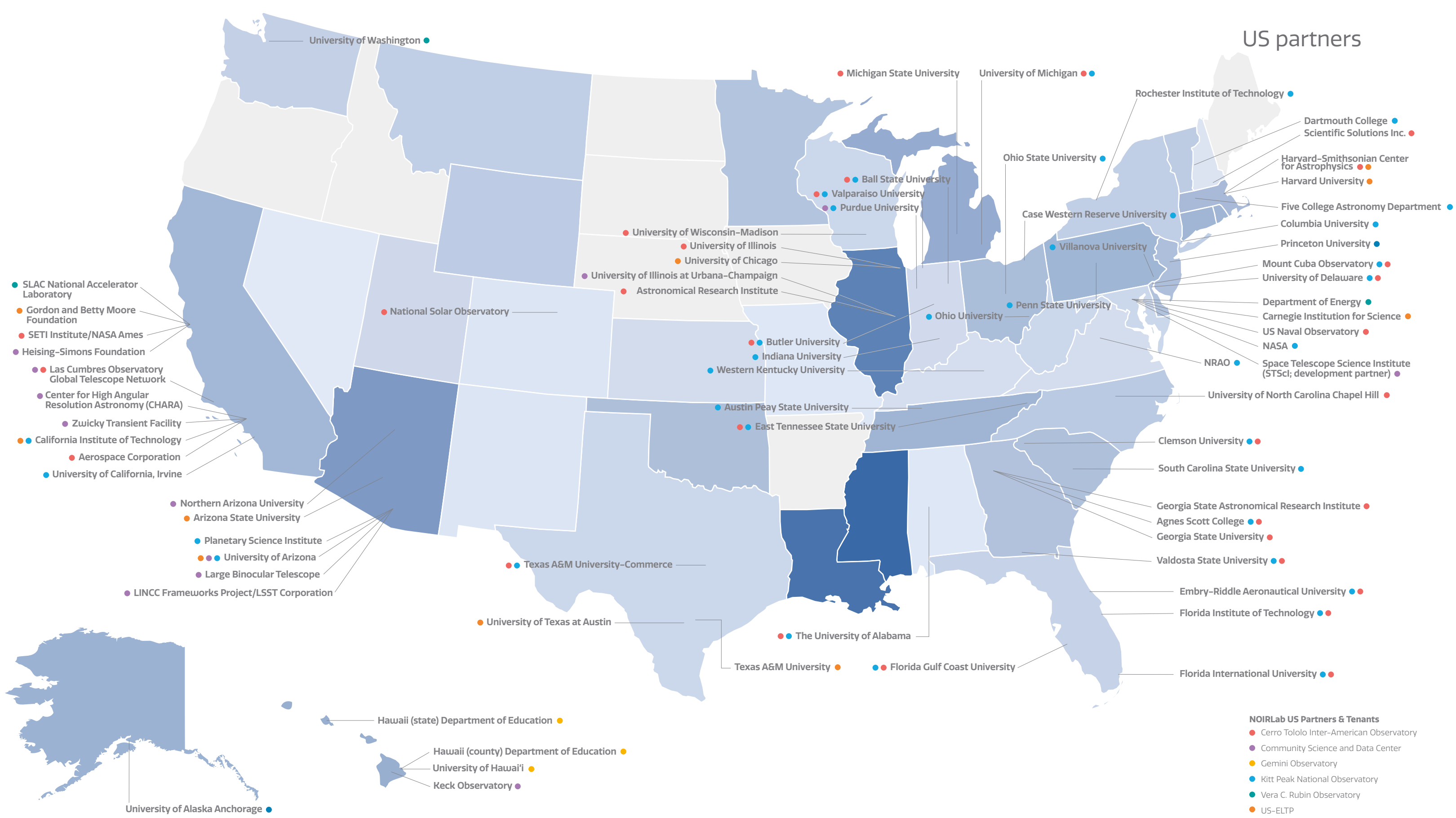


Figure 2. **(right)** Library facilities in Hilo *Credit: International Gemini Observatory/NOIRLab/NSF/AURA/J. Pollard*
(inset above) Library facilities in Chile *Credit: NOIRLab/NSF/AURA*

NOIRLab Partners





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