The Palomar Observer

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Palomar Observatory

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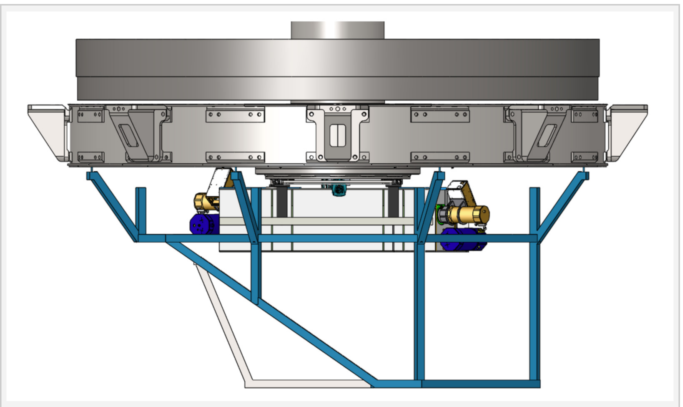
NSF Support Success

By Andy Boden (Caltech)



NGPS mounted on the 200-inch cass rotator. (R.Smith/Caltech)

Palomar Observatory is excited to report that a number of new and/or recurring initiatives have been successful in obtaining National Science Foundation (NSF) support in the most current round of awards.

First we are excited to advise that the Zwicky Transient Facility will be supported by the NSF Mid-Scale Innovations Program (MSIP) for a second phase of operation, again under the leadership of Shri Kulkarni. ZTF saw first light in 2017 with a custom 600-Mpix camera, operates on the Samuel Oschin Telescope and the Palomar 60-inch telescope, and uses the Hale and other large telescopes for transient event follow up.

Next we are excited to announce that the new Hale Telescope facility optical spectrograph concept, the Next Generation Palomar Spectrograph (NGPS), received NSF development support. The proposal effort was led by Evan Kirby, and was selected for funding by the NSF Major Research Instrumentation (MRI) program. NGPS is envisioned as a replacement for the venerable facility Double Spectrograph, and is being jointly developed by Caltech and the National Optical Observatories of China (NAOC). We anticipate first light with NGPS in 2023.

We are similarly excited to announce that a novel ground-layer adaptive optics (GLAO) system called SIGHT was also selected for NSF Advanced Technologies and Instrumentation (ATI) funding under the leadership of Richard Dekany. SIGHT will demonstrate a new paradigm for compact ground-based AO in its LGS mode: non-diffraction-limited panchromatic image improvement spanning 330 – 2400 nm wavelengths. Coupled with NGPS the addition of SIGHT promises to provide Hale Telescope observers with a total spectroscopic observing efficiency 5 – 10X that of DBSP when SIGHT becomes operational in 2023.

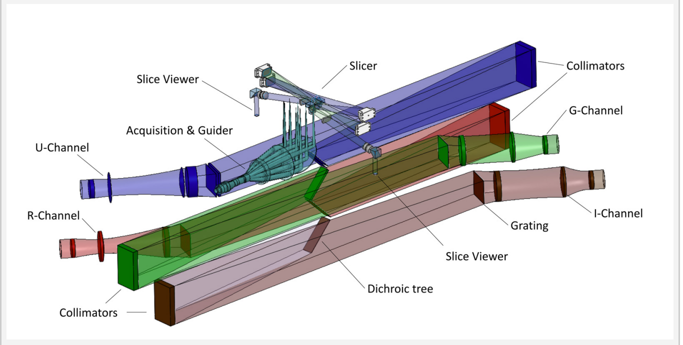
Finally, CryoScope, a novel wide-field near-IR telescope development effort led by Roger Smith has been selected for NSF ATI funding. This cryogenic telescope, operating at −100 °C, will be a proof-of-concept development fielded at Palomar, a pathfinder for future near-IR transient survey instruments complementary to both ZTF and the Simonyi Survey Telescope at the Vera Rubin Observatory.

Next Generation Palomar Spectrograph

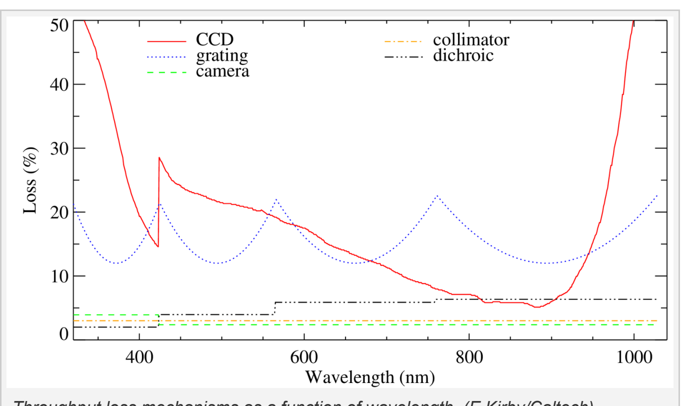
By Roger Smith (Caltech)

COO and NAOC/NIAOT are collaborating on the construction of a general-purpose spectrograph to replace DBSP which has been the most scheduled instrument on the 200-inch since it was commissioned in 1982. NGPS will employ every available method to maximize both sensitivity and operational efficiency.

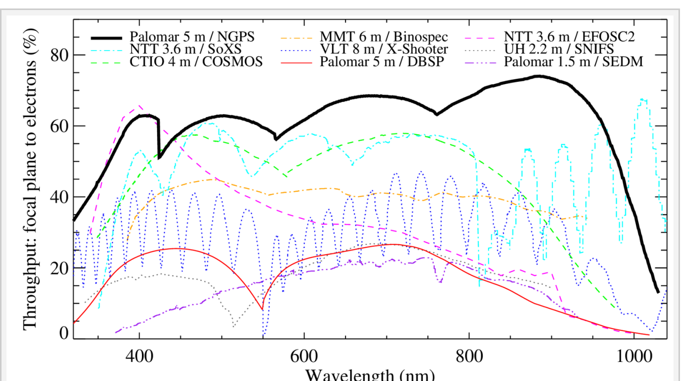
Financial support from the Heising-Simons Foundation and the NSF has enabled the implementation of a four-channel design which makes use of the existing 4K × 2K CCDs from DBSP and SWIFT to provide 16K pixels in the spectral direction. The fixed grating configuration provides simultaneous wavelength coverage from 320 nm to 1030 nm with R = 4600 in the center of each for four bands when slit width projects to 2.7 pixels, as would be appropriate in median seeing.



Optical path for NGSP. (R.Smith/Caltech)



Throughput loss mechanisms as a function of wavelength. (E.Kirby/Caltech)



Predicted open-slit optical throughput of NGPS compared to the measured optical throughput of selected spectrographs. (E.Kirby/Caltech)

A 60" wide rectangular section of the telescope focal plane is subdivided into three slices by two moveable pickoff mirrors. Light falling between the pickoff mirror passes directly to the spectrograph without losses. The lateral slices are then re-imaged to the sides, reformatting the image as a single “slit” with slightly more than 3 times the spatial extent. The new slicer design keeps the entire 60 arcsecond pickoff mirror edge in focus and allows the width of all slices to be adjusted to maintain the best trade-off between resolution and slit losses under varying seeing conditions. When fed by a new adaptive optics system (see companion article on SIGHT), the slit width can be reduced to 2 pixels delivering R = 6000 while also improving SNR by concentrating light in the central image slice.

In addition to reducing slit losses, the 3-way slicer achieves R = 4600 with a relatively small (100 mm) beam which in turn allows a single element off-axis collimator to be used. Dichroics just behind the slicer direct light radially to separate collimators to produce a short-wide layout, which is expected to exhibit lower flexure than axial layouts like DBSP.

Like most modern spectrographs, volume phase holographic gratings are used for high efficiency. The small beam size leads to refractive cameras with few optical surfaces and low absorption losses. Each channel employs highly optimized AR coatings and high reflectivity dichroic coatings and suffer relatively low roll-off in grating efficiency due to the restricted wavelength range. These factors combine to deliver very competitive throughput (see accompanying figures), even without accounting for the reduction of slit losses afforded by the slicer. Throughput could be improved further by upgrading U and G band CCDs, but this is beyond the scope of the current project.

Equal attention is being paid to *operational* efficiency. Focus and flexure compensation will occur automatically during observations. Calibration light will be delivered to the ends of slices during science exposures to track residual flexure. With frame-transfer CCD readout, inter-exposure delay can be reduced to just the telescope slew time. Field acquisition and placement of target on the slit will occur automatically within seconds of end of slew. As the exposure progresses, EMCCD cameras will integrate the image immediately adjacent to the slicer to confirm that that target is correctly positioned. An Exposure Time Calculator will recommend the time required to reach desired SNR, taking into account the source brightness, slice width, extinction and seeing, all measured by the guide camera. An “Observation Timeline Calculator” will predict the time and position (track) on sky for the list of planned observations, modelling observation overheads and expected exposure time for the source magnitude, slice width and requested SNR, given current seeing and extinction, and predicted airmass. A near real time data reduction pipeline is also planned.

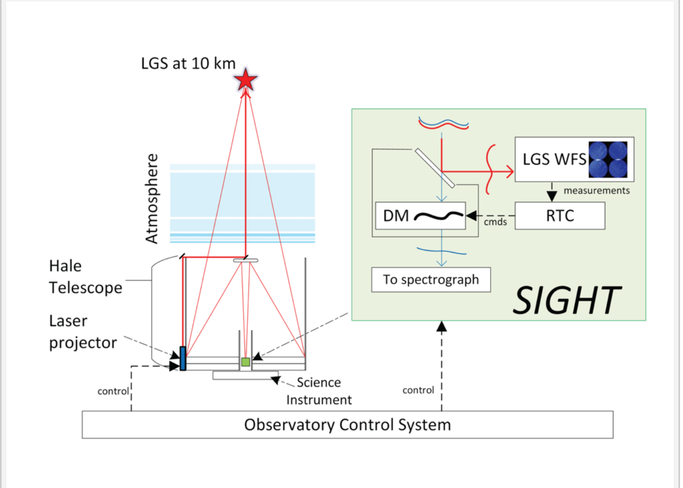
Our expectation is that NGPS will transform optical spectroscopy at Palomar by greatly improving throughput and operational efficiency, while providing tools which allow observers to focus on their science.

SIGHT to Improve Hale Telescope Image Quality Utilizing Novel UV Laser Guide Star Adaptive Optics

By Richard Dekany (Caltech)

The National Science Foundation (NSF) program for Advanced Technologies and Instrumentation (ATI) has issued a grant to Caltech for the development of an innovative, extremely compact laser guide star (LGS) adaptive optics (AO) pathfinder known as SIGHT (Sharpening Images using Guide stars at the Hale Telescope).

Under the leadership of Principal Investigator Richard Dekany of Caltech Optical Observatories, SIGHT will be permanently installed in the 200-inch telescope’s primary mirror central baffle tube and, when operational in 2023, routinely improve 200-inch image quality by 30 – 50% across optical and infrared wavelengths from 330 – 2500 nm. Because the faint-object sensitivity is proportional to Point-Spread-Function (PSF), the improvement from SIGHT will have the equivalent scientific benefit of increasing the telescope aperture from 5 meters to over 7 meters diameter. As a facility resource, SIGHT will bring improved image quality to current and future Cassegrain instruments, including the transformative Next Generation Palomar Spectrograph (NGPS) scheduled to replace DBSP in 2023. Excluding the wide-field prime focus imaging instruments, SIGHT is expected to be used up to 80% of all observing nights on the Hale Telescope.



Functional block diagram for SIGHT, highlighting the instrument installed above the Cassegrain focus and laser projection path. (R.Dekany/Caltech)

Key members of the SIGHT team include COO optical engineer Mitsuko Roberts, instrument scientists Nem Jovanovic, Reed Riddle, Dan McKenna, and Palomar Chief Engineer Jeffry Zolkower.

The technology of SIGHT follows key strategies pioneered at the Palomar 60-inch telescope, using an invisible, ultraviolet (UV) laser broadcast to form a wavefront sensing beacon. SIGHT will build on the success of Palomar’s Robo-AO program by additionally cooling its own internal optics to −30 °C, in order to reduce thermal self-emission, and maintain maximum sensitivity for infrared instruments.

Due to the Hale Telescope’s wide aperture and long focal length, SIGHT will also require an innovative high-dynamic-range, open-loop LGS AO architecture based on a new technology called Optical Differentiator Wavefront Sensor (ODWFS). This new approach encodes the aberrations induced by Earth’s atmosphere as left-handed and right-handed polarization signals, which are then analyzed in a photon-efficient optical arrangement to provide wavefront gradient measurements.

Despite steady advances over the past 20 years, adaptive optics has heretofore remained the nearly exclusive tool at infrared wavelengths. SIGHT will demonstrate an entirely new AO modality that consistently sharpens images at *all optical/infrared (O/IR)* wavelengths, under any seeing conditions, anywhere on the sky (good Palomar seeing of 1" FWHM will become 0.5" FWHM, comparable to be very best astronomical sites in the world, while an unfortunately Palomar seeing night of 2" FWHM is expected to become 1" FWHM, saving an otherwise marginal night for high scientific productivity).

The Palomar 60-inch Robo-AO LGS system has demonstrated its capacity to consistently and routinely achieving visible-light image quality < 0.4" FWHM, even in moderately-poor seeing condition (~1.3"). The utility of the Rayleigh Laser Guide Star system to feed a workhorse single-object spectrograph is an obvious step forward. We will reuse the successfully automated system developed for Palomar 60-inch Robo-AO to manage laser deconfliction. The reliability and efficiency of all of these Robo-AO elements has been demonstrated by over 45,000 scientific observations to date, at rates of up to 240 targets per night with multiple science programs completed.

As the first-of-its-kind panchromatic image sharpener, SIGHT will demonstrate new science gains for a diverse range of science topics, ranging from galaxy clusters, galaxies, stars, transients, and exoplanets. To demonstrate SIGHT’s broad applicability, we have assembled a nationwide team with broad science interest, who are committed to demonstrating and disseminating complementary modes of SIGHT usage.

Cryoscope

By Roger Smith (Caltech)

COO recently received an NSF ATI award (PI: Roger Smith, PS: Mansi Kasliwal) to build a quarter scale prototype of a new kind of telescope which will make time domain astronomy possible in the thermal infrared for the first time. The prototype will be the first example of an optical design devised by Jason Fucik which performs extremely well over a very large field of view: 88% Strehl at edges of 10 degree field even at f1.2. The Fucik design is adaptable to any wavelength where fused silica is transmissive and was in fact conceived for a transient survey proposal in the vacuum ultraviolet.

The convex corrector can support vacuum even when scaled to > 1m aperture. This allows us to cryogenically cool the entire optical path, eliminating the need for the reimaging optics and cold Lyot stop normally required to block radiation from a warm telescope. This allows us to increase field of view by more than two orders of magnitude compared the current widest field instrument operating in K band (VISTA with 0.6 deg^2) while reducing foreground radiation below that achieved by cryogenic re-imaging systems.

Our ultimate goal is to deploy a meter class cryogenic telescope in the Antarctic to conduct a wide field survey in the K_{dark} bandpass (2.35 – 2.5 μm) where the sky is 25 – 40 times darker than at temperate latitudes. Above the 25 m thick inversion layer at Dome C, median seeing is 0.25" so our telescope will be diffraction limited most of the time.

CryoScope, the quarter scale prototype, will demonstrate the new Fucik optical design, confirm thermal foreground suppression, and validate the baffling scheme devised to reduce radiative cooling of the window to avoid condensation. Beyond CryoScope, the full scale telescope will require a gigapixel focal plane, setting a record in the infrared. Fortunately, a new technology (funded by the ATI program) is yielding suitable sensor material at much reduced cost per pixel, while a NASA SBIR grant has produced a 4K × 6K readout IC with the desired 10 μm pixel size, making such large IR focal planes economically feasible in the near future.

There are challenges on many other fronts such as humidity control, image stabilization, data processing and communications bandwidth, but there are plausible technical solutions and the science is very compelling.

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