G@M: Design of the Giant Magellan Telescope Consortium Large Earth Finder (G-CLEF) for Operations at the Magellan Telescopes

Colby Jurgenson[a], Andrew Szentgyorgyi[a], Mark Mueller[a], Stuart McMuldroch, Sagi Ben-Ami[c], Kang-Min Kim[b], Chan Park[b], Daniel Baldwin[a], Daniel Catropa[a], Moo-Yung Chun[b], Jeffrey D. Crane[d], Daniel Durusky[a], Jason Eastman[a], Harland Epps[e], Ian N. Evans[a], Thomas Gauron[a], Ofir Hershko[c], Kenneth McCracken[a], Cem Onyuksel[a], William Podgorski[a], Matthew Smith[a], Alan Uomoto[d]

[a]Center for Astrophysics | Harvard and Smithsonian, 60 Garden St., Cambridge, MA 02140
[b]Korean Astronomy and Space Science Institute (KASI) 776, Daedeokdae-ro, Yuseong-gu, Daejeon, Republic of Korea
[c]Weizmann Institute of Science, Herzl St 234, Rehovot, 7610001, Israel
[d]The Observatories of the Carnegie Institution for Science, 813 Santa Barbara St., Pasadena, CA 91101
[e]UCO/Lick Observatory, University of California, Santa Cruz, CA 95064

INTRODUCTION

In late 2025 the GMT-Consortium Large Earth Finder (G-CLEF) spectrograph will be deployed on the 6.5-meter Magellan Clay Telescope prior to being relocated to the Giant Magellan Telescope (GMT) for the start of science operations in the early 2030's. Operation at the Magellan Clay is referred to as G-CLEF@Magellan (G@M). G@M will have two distinct telescope interfaces:

i) The "standard" natural seeing front end that feeds optical fibers for high resolution and extreme-high resolution modes.

ii) A second interface untilizes the Magellan extreme Adaptive Optics (MagAO-X) instrument under development at Steward Observatory.

G@M will carry out many high-priority astrophysics programs, however the primary design drivers are two exoplanet science areas:

i) The measurement of small mass exoplanets orbiting Solar-type stars in those star's habitable zones by measuring precision radial velocities.

ii) The search for biomarkers and the characterization of the atomic and molecular constituents of exoplanet atmospheres.

Figure 1. The twin 6.5-meter Magellan Telescopes at Las Campanas Observatory. G-CLEF will be deployed on the Clay in late 2025 until the Giant Magellan Telescope is ready for science operations in the early 2030's. The G-CLEF spectrograph will be installed in the auxilliary building, while the calibration systems will be located in the interferometry tunnel that connects the two telescopes. A solar telescope will be retrofitted to a structure across from the auxilliary building.

G@M DEPLOYMENT

Figure 2 is a system-level view of the G@M deployment. The spectrograph will be housed in the auxilliary building connecting the Clay and Baade telescopes, and the calibration systems. The spectrograph is vacuum-enclosed and temperature stabilized to +/-0.001K. Table 1 lists the different fiber resolution modes that will be deployed with G@M.

The calibration systems will be housed in the interferometry tunnel beneath the auxilliary building. These will consist of heritage flux and wavelength calibrators, and an advanced calibration system that uses a laser frequency comb and two etalons. G@M will also be coupled to a robotic solar telescope that will permit the collection of calibrated spectra during the day.

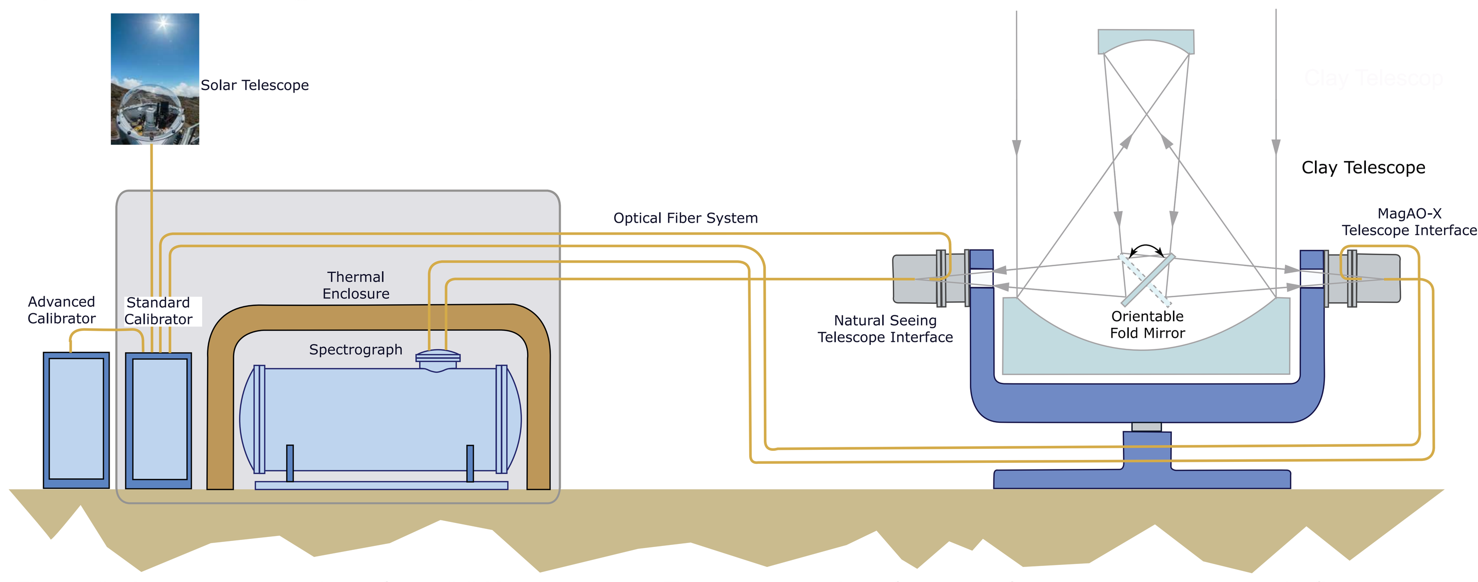


Figure 2. A system level view of the G@M deployment. Two telescope interfaces will feed the spectrograph via fibers, the standard natural seeing interface, and an interface to MagAO-X. The standard interface will offer three resolution modes of observation, while the MagAO-X interface will enable direct spectroscopy of exoplanets.

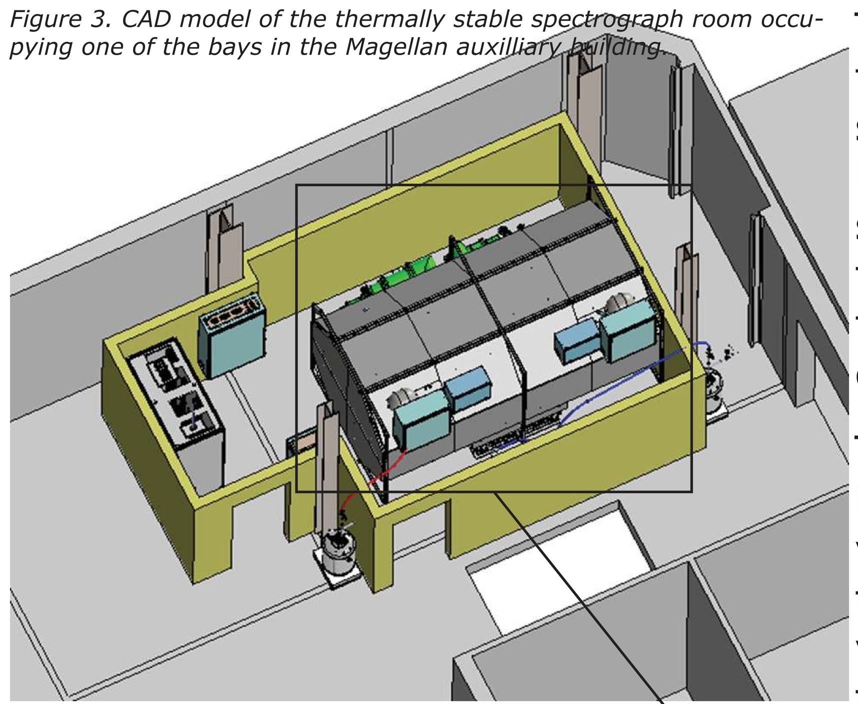
Mode	Slit FOV (")	Resolution	# Fibers	Comments
Medium Resolution (MR)	1.12	100,000	1 x 2	Science + Sky Fiber
High Resolution (HR)	0.8	140,000	1 x 2	Science + Sky Fiber
Pupil-Sliced Extreme HR	1.05	>300,000	4 x 2	Science + Sky Fiber
MagAO-X	0.8	140,000	1	Enhanced throughput over HR mode
MagAO-X IFU	0.12 x 0.12	>200,000	16	Divided into 16 spaxels

Table 1. The fiber modes that will be installed with G@M at the two telescope interface ports.

G-CLEF SPECTROGRAPH DESIGN

The optomechanical design of the G-CLEF spectrograph for the G@M deployment is unwrapped in Figures 3 through 7. An environmentally controlled room will be constructed in one of the bays of the Magellan auxilliary building. The room will be controlled to +/-1K.

Figure 3. CAD model of the thermally stable spectrograph room occupying one of the bays in the Magellan auxilliary building

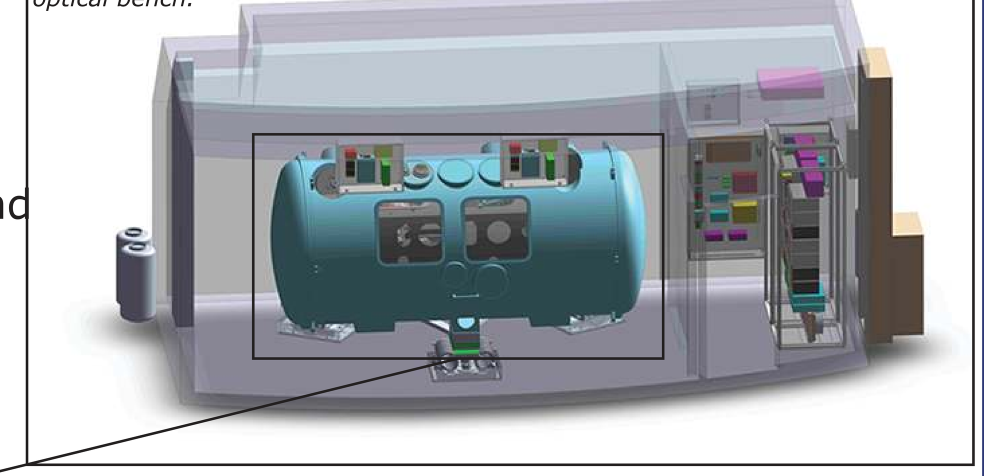


The spectrograph room maintains its temperature to ensure the +/-0.001K optical bench stability. The f/11 telescope beam is converted to f/3 upon injection into the fibers that feed the spectrograph.

The spectrograph is enclosed in an aluminum, high-vacuum vessel continuously pumped to maintain high vacuum. The vessel exterior is shrouded in thermal control panels with temperature sensors.

The optical bench is being fabricated out of carbon fiber reinforced polymer by Northrup Grumman Innovation Systems. The panels and are joined by machined Invar 36. Active vibration isolation is implemented between bench and vessel.

Figure 4. Thermal enclosure that houses the spectrograph vacuum vessel and optical bench.



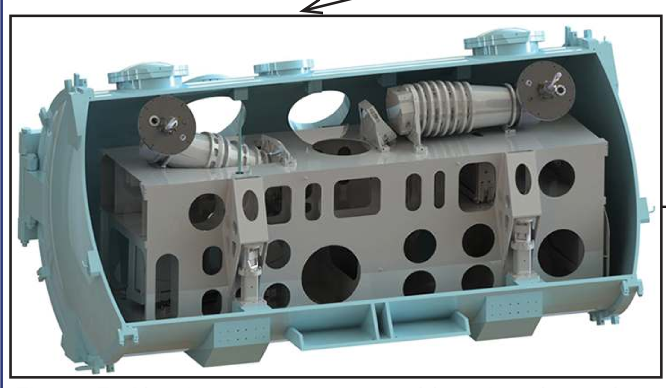


Figure 5. Aluminum vacuum vessel housing the carbon fiber optical bench.

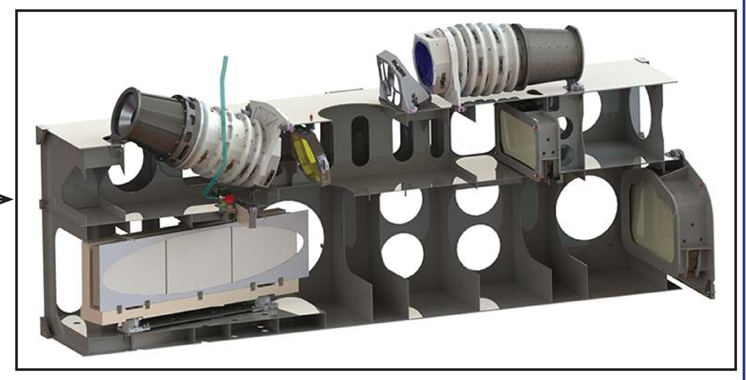


Figure 6. Carbon fiber optical bench with the internal optical mounts exposed.

Figure 7 shows the optical layout of the spectrograph. It is an asymmetric white pupil design. Light enters the spectrograph through the fiber slits and the f/3 beam is converted to an f/8. The beam is then collimated by M1 and reflected from the mosaic R4 echelle grating. The three facets are co-aligned on a monolithic Zerodur structure.

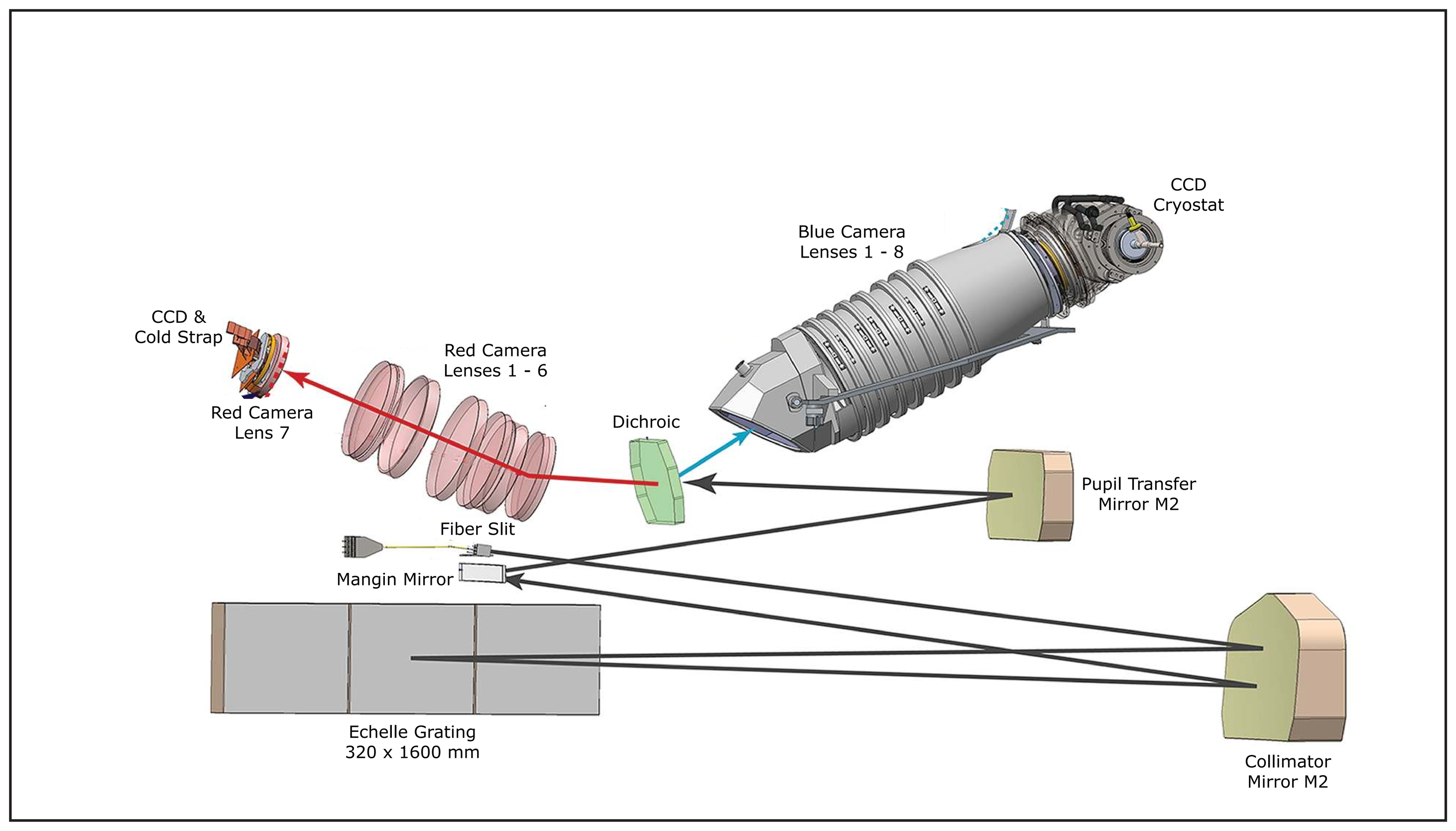


Figure 7. The G-CLEF spectrograph optical component layout.

Following the grating, M1 refocuses the beam onto a Mangin mirror that compensates for cylindrical aberrations intrinsic to the spectrograph. The beam diverges until it is reflected by the M2 pupil transfer mirror which recollimates the beam where the dichroic splits the beam into red and blue arms. Each beam is then cross dispersed by VPH gratings. The red camera is a 7-lens design and the blue camera is an 8-lens design. Each camera has a single, polynomial aspheric surface.

G-CLEF CALIBRATION SYSTEM

G-CLEF will be instrumented with two calibration systems – a standard calibration system that incorporates heritage flux and wavelength calibrators, a laser frequency comb and two etalons, one that extends into the UV and the other into the infrared. The advance calibrator couples into the standard calibrator, which in turn feeds a pair of calibration fibers that convey the light from the calibration system to the input of the science fibers at the front end. These fibers illuminate various pairs of science object and sky fibers.

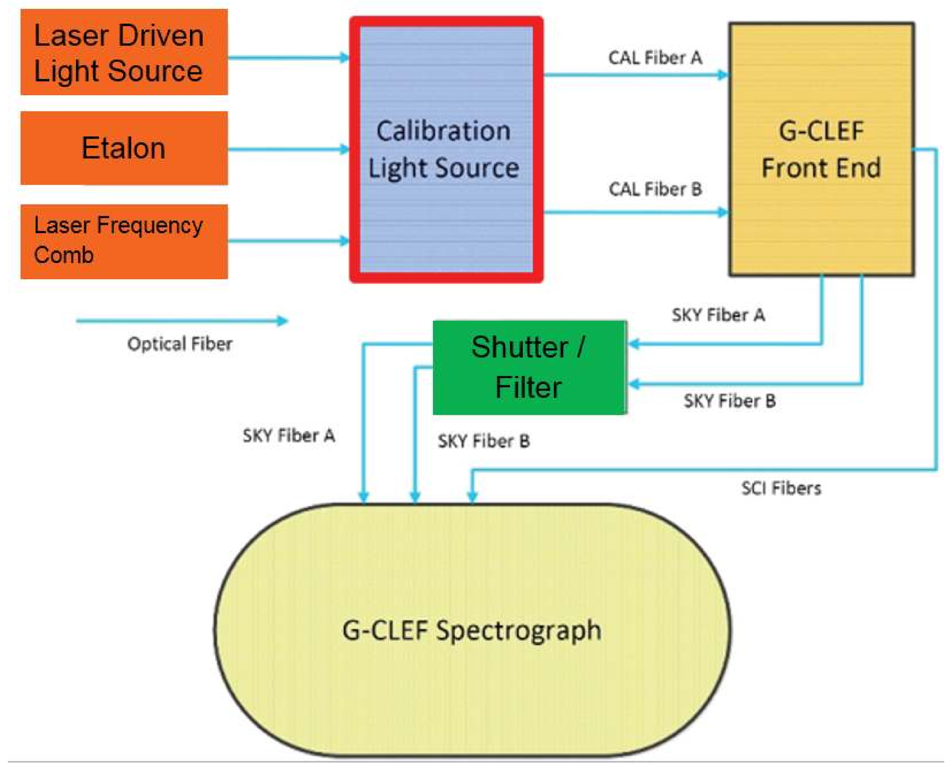


Figure 8. The architecture of the G-CLEF calibration system. The Standard Calibrator is indicated by the blue box with a red surround. The advanced calibrator is indicated by the red-orange boxes. The combined calibration system delivers calibration light through a pair of calibration fibers to the G-CLEF front end, where it is injected into the science fibers. The sky fibers are instrumented with a filter wheel to adjust illumination levels and a shutter.

G@M 2023 STATUS

2023 Assembly, Integration, and Test Activities

- Red Camera Lens Assembly/Test – Under Lab Construction
- Echelle Grating Facet Alignment – Under Lab Construction
- Optical Bench Alignment – Lab Prototyping
- M1, M2, Mangin Mirror/Mount Assemblies – Winter 2023

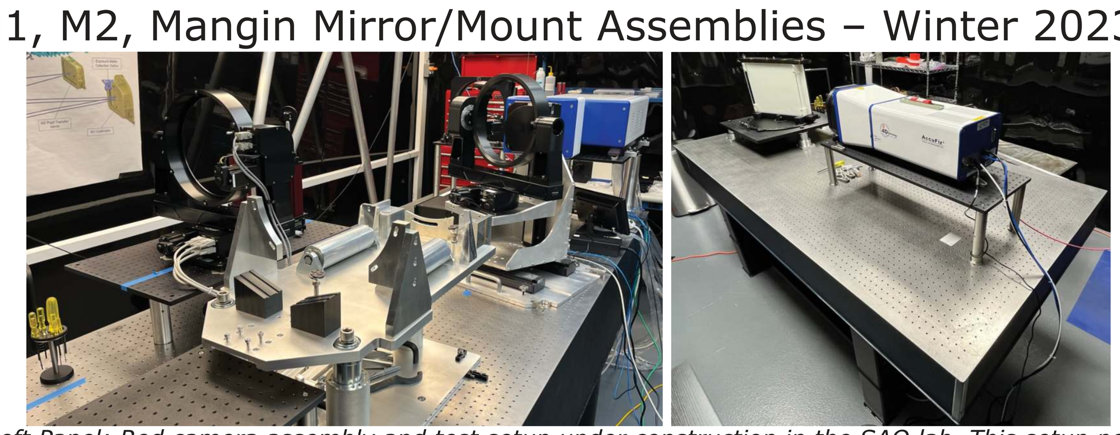


Figure 9. Left Panel: Red camera assembly and test setup under construction in the SAO lab. This setup perform interferometric measurements, and measure wavelength by wavelength aberrations. Right Panel: Facet test and alignment setup under construction at the SAO lab. This setup will perform interferometric measurements on individual facets as well as the entire assembly.

2023 Major Optics Arrival

- Red Camera Lenses 1 Through 7 – In House
- Red and Blue VPH Prisms – In House
- M1, M2, and Mangin Mirrors – Fall 2023
- Blue Camera Lenses 1 Through 8 – Fall 2023

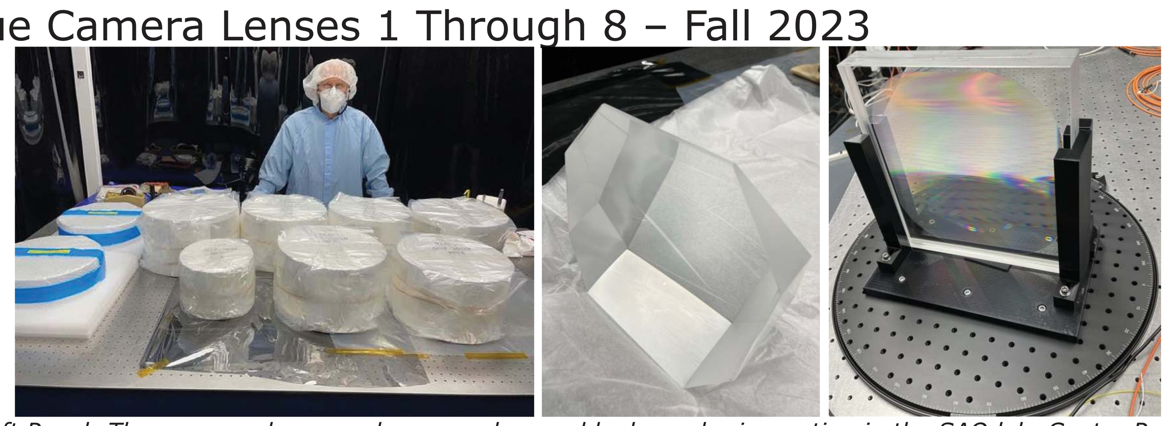


Figure 10. Left Panel: The seven red camera lenses and spare blanks under inspection in the SAO lab. Center Panel: The blue VPH exit prism upon inspection in the SAO lab. Right Panel: The red VPH prism shown in its test fixturing at the SAO lab.

2023 Major Hardware Arrival

- Carbon Fiber Composite Bench – November 2023
- Aluminum Vacuum Chamber – November 2023
- Grating Mount Structure – May 2023
- Red Camera Lens Cells – March 2023
- M1 and M2 Mounting Structures – Fall 2023
- Handling Carts & Fixturing for Above Assemblies

Figure 10. Left Panel: The Invar red camera lens mounts under factory acceptance testing at the manufacturer warehouse, Next Intent in San Luis Obispo. Center Panel: The rolled aluminm central body of the spectrograph vacuum vessel at Redline in Salt Lake City. Right Panel: Carbon fiber optical bench mock-up at SAO currently being used to develop bench alignment.

This work has been supported by the GMTO Corporation, a non-profit organization operated on hefalf of an international consortium of universities and institutions: Arizona State University, Astronomy Australia Ltd, the Australian National University, the Carnegie Institution for Science, Harvard University, the Korea Astronomy and Space Science Institute, the São Paulo Research Foundation, the Smithsonian Institution, the University of Texas at Austin, Texas A&M University, the University of Arizona, and the University of Chicago.