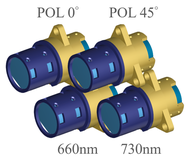
WFIRST CGI: Prism and Polarizer Characterization Modes

Tyler D. Groff[1], Neil Zimmerman[1], Hari Subedi[1], Maxime Rizzo[2], John Titus[2], Jim Lyons[3], Dylan Bell[4], Samuel Gaylin[4], Guangjun Gao[1], Bert Pasquale[1], Nicholas Nicolaeff [2], Motohide Tamura[5], Fang Shi[6]
1- NASA Goddard Space Flight Center, 2- Conceptual Analytics, 3 - ATA Aerospace, 4 - Genesis ESI, 5- Astrobiology Center, 6- Jet Propulsion Laboratory, California Institute of Technology

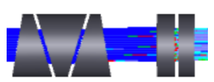
The CGI Spectral Characterization and Polarization Modes:

The WFIRST coronagraphic instrument (CGI) will demonstrate exoplanet spectroscopy and disk polarization measurements using a set of Amici and Wollaston prisms. The CGI spectral characterization mode, being designed and built and Goddard Space Flight Center (GSFC), has a spectral resolution of R50 and is designed to accommodate a 20% bandpass spanning 610-785nm. The CGI polarization mode is two sets of Wollaston prisms clocked 45 degrees from one another in order to recover Stokes information that would be otherwise unmeasurable in the current instrument configuration. The Wollaston design and optical elements are a contribution by the Japanese Aerospace Exploration Agency, with final alignment and testing being done at GSFC. The Wollaston mode targets disk imaging science cases. The spectrograph mode is designed to target Methane features, with the primary coronagraph band being centered around 730nm. We highlight the requirements for both modes and how the on-orbit calibration for a deployable spectrograph slit is handled. We also provide further detail on the optomechanical design, its stability based on thermal and structural predictions, anticipated performance, and operations concept. The impact of these performance metrics are projected into simulated data products, demonstrating that with a deployable slit and prism the planet spectrum can be taken with the required wavelength accuracy to perform spectral retrieval.

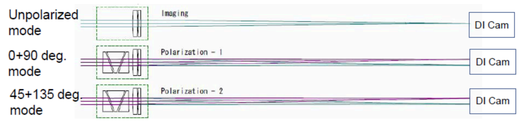
General Prism and Polarizer Design:



Zero Optical Deviation Prism Optical Design



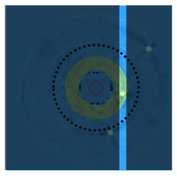
Wollaston Optical Design



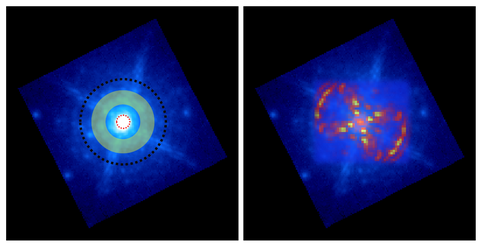
Prism and Polarizer Bandpasses, Inner Working Angles, and Fields of View:

- CGI Spectroscopy FOV overlaid onto CHARIS images of M5 and HR8799 from Subaru Telescope
  - Single Shaped Pupil Coronagraph in CGI Band 3 available
- CGI Polarization FOV overlaid onto CHARIS images of AB Aur from Subaru Telescope
  - CGI Band 1 and CGI Band 4 FOV shown

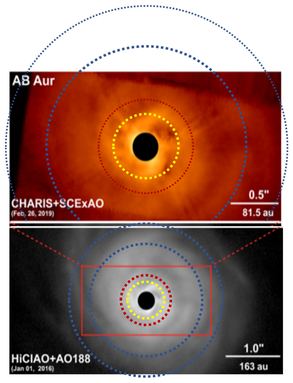
HR8799 w/Post-Processing



M5 Globular Cluster



Wollaston Polarization Image Separation



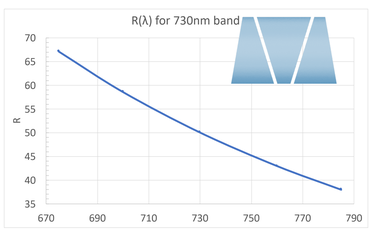
HiCIAO and CHARIS+SCExAO Images Courtesy of Lozi et al.

10 λ/D (~0.5") Spectroscopy outer working angle (20 Disk)
3 λ/D Spectroscopy radial inner working angle (6.5 Disk)
Angular separation where requirements are set

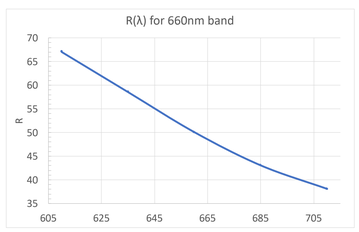
Baseline Filter Bands	Center	Cut-on	Cut-off	Bandwidth %
CGI Band 1 (HLC Disk Imaging)	575	546	604	10.1
CGI Band 2 (Spectroscopy Shaped Pupil)	660	610	710	15.2
CGI Band 3 (Spectroscopy haped Pupil)	730	675	785	15.1
CGI Band 4 (Disk Shaped Pupil)	825	784	866	9.8

Prism and Polarizer Performance Standards:

730nm Band 3 Spectral Resolution

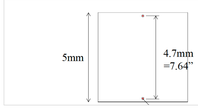


660nm Band 3 Spectral Resolution



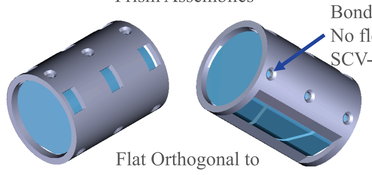
Wollaston Polarization Image Separation

Plate Scale	615 μm/"
Airy Disk Radius 1.22λ/D	32.5 μm = 0.053" @ λ0.5μm 58.5 μm = 0.095" @ λ0.9μm
Separation	4.70 mm = 7.64" = 80 × Airy Disk Rad. (λ0.9μm)

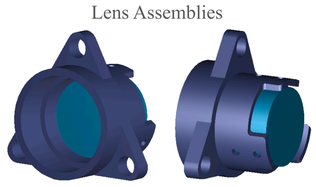


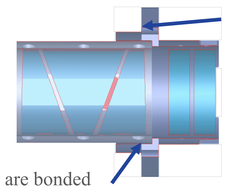
Optomechanical Design for Prism and Polarizer Optics

Prism Assemblies



Lens Assemblies

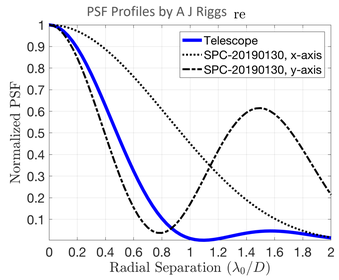




- Prism materials SiO2 + S-TIH1
  - Known Radiation Tolerance
- Lenses are JAXA provided Ohara rad-hard materials
- No-flexure Design, with low-outgassing RTV
- Prism and Lenses can be clocked against each other, simplifying the orientation on DPAM
- Tubes are common to prism and polarizer
- Front-to-Back symmetry

Spectral Resolution:

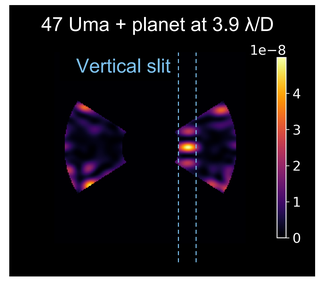
- The slit size is a function of PSF core
- Shaped Pupil FWHM is assymmetric
  - Nyquist sampled at 500nm
- R=50 is **nominal** at central wavelength 730nm
- Core = 1.9 x 0.8 FWHM area in λ/D
  - 5 pixels / FWHM in X direction @ 660nm



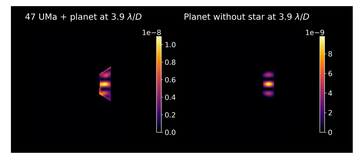
- Slits are integrated into the upstream field stop mechanism
- Several slits per mode
  - No slit
  - FWHM slit widths
  - Slit to first null
- After planet is detected
  - Slit deployed over the planet
  - Prism is engaged

Instrument Simulations of Dispersion Mode:

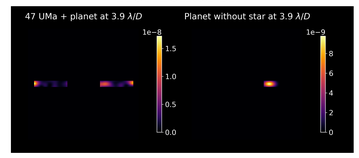
- Primary Trades in Simulations
  - Slit Size
  - Slit Orientation
- OS6 SPC model (2018) by John Krist
- Two cases simulated:
  - Requirements performance
    - Optical Model Uncertainty Factors applied
    - Fiducial 5x10^{-8} flux ratio @ 4 λ/D
  - Science performance case
    - 5x10^{-9} flux ratio planet
    - Optical MUFs turned off



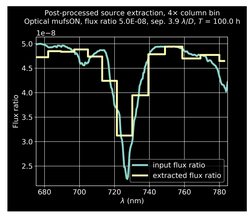
Vertical slit



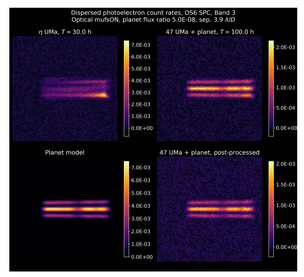
Horizontal slit

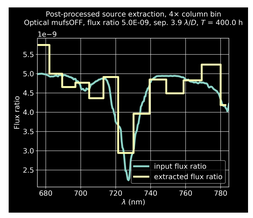


Perfectly Aligned Slit



Albedo spectrum model by Nikole Lewis
Simulation by Neil Zimmerman





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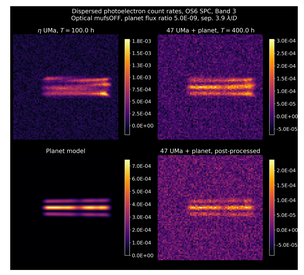
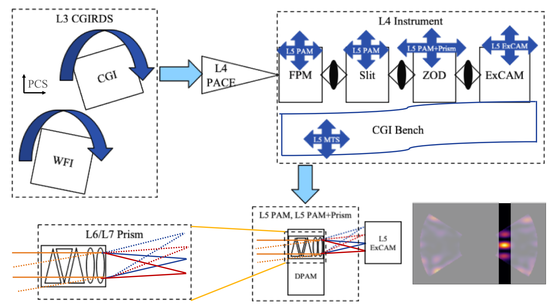
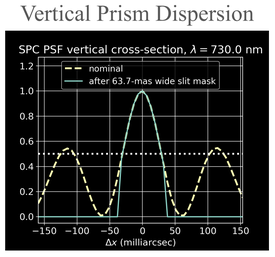


Modeling Pointing Error on Spectroscopy

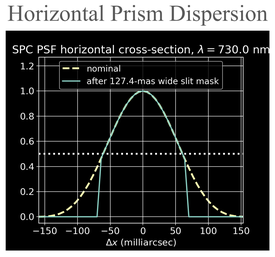
- Primary Trade on Slit Orientation was driven by pointing error
  - Single Orientation Shaped Pupil with elliptical PSF
  - Sharper slits create less favorable on-sky plate scale compared to the effective bandpass per pixel when dispersed
- Error budget includes errors from observatory to detector

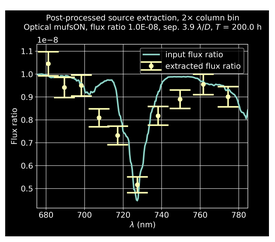


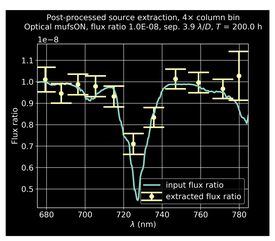
Horizontal Slit
Vertical Prism Dispersion

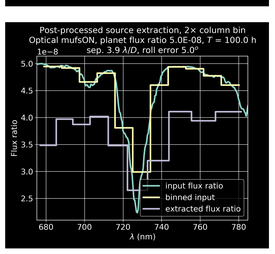


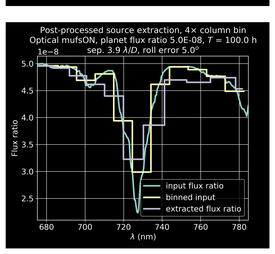
Vertical Slit
Horizontal Prism Dispersion











Horizontal slit

- PROS
  - SNR (higher count rate per pixel due to lower prism dispersion)
  - Wider speckle cross-section – more context for post-processing
- CONS
  - Greater sensitivity to roll and boresight error
    - More difficult to meet 2 nm wavelength accuracy
  - For wide slit or no slit, the PSF lobes create confusion

Vertical slit

- PROS
  - Less sensitivity to roll and boresight error
  - For starshade, spectral resolution above R=50 at all wavelengths
- CONS
  - Lower SNR than a horizontal slit dispersion optimization (lower count rate per pixel due to higher prism dispersion)
  - Limited speckle cross-section – less context for post-processing

Ultimately, drifts and mechanism repeatability drove us to using the vertical slit.