Observing with the Roman Coronagraph Instrument (CGI)

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(she/her/hers)
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With support from many at the Jet Propulsion Laboratory, Goddard Space Flight Center

Observing Modes

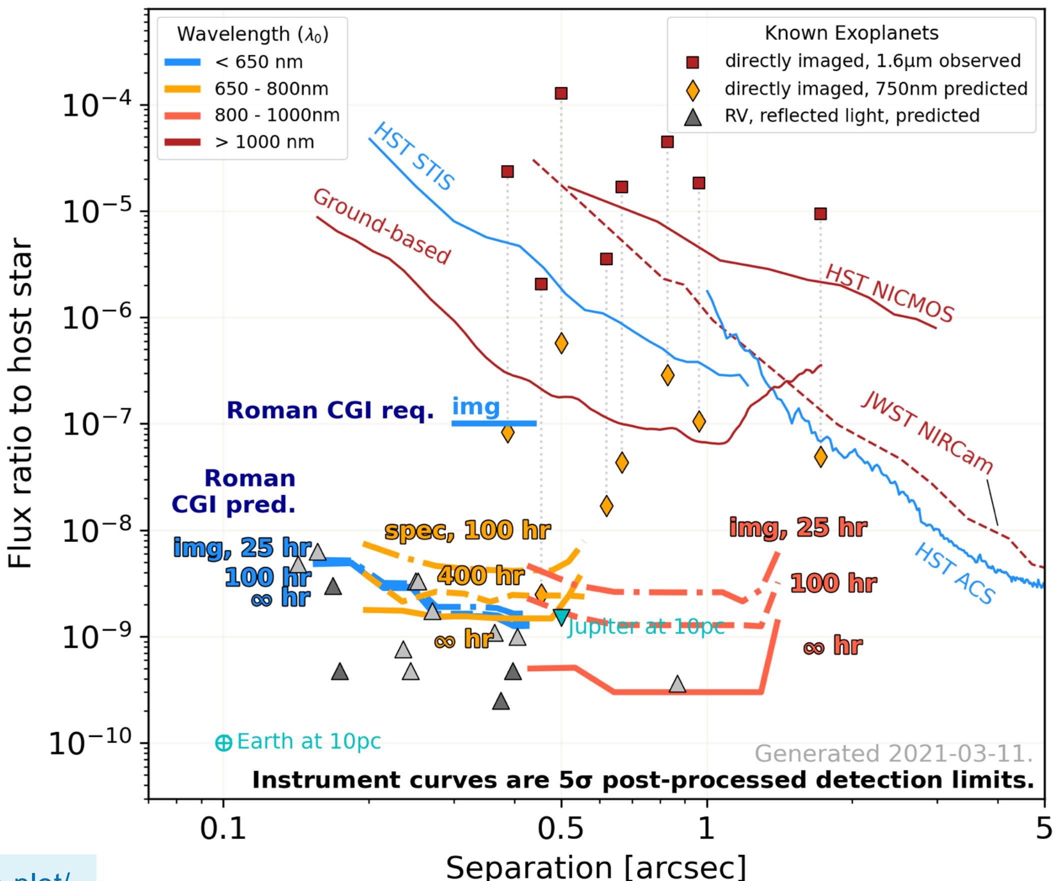
Band	λ_{center}	BW	Mode	FOV radius	FOV Coverage	Pol.	Coronagraph Mask Type	TTR5
1	**575 nm**	**10%**	**Narrow FOV Imaging**	**0.14” – 0.45”**	**360°**	**Y**	**Hybrid Lyot**	**Y**
2	**660 nm***	17%	Slit + R~50 Prism Spectroscopy	0.17” – 0.52”	2 x 65°	-	Shaped Pupil	-
3	**730 nm**	17%	Slit + R~50 Prism Spectroscopy	0.18” – 0.55”	2 x 65°	-	Shaped Pupil	-
4	**825 nm**	11%	“Wide” FOV Imaging	0.45” – 1.4”	360°	Y	Shaped Pupil	-

All masks for Band 1 Hybrid Lyot are fabricated. Masks for Shaped Pupil modes have begun fabrication.

*** 660 nm spectroscopy** is the lowest priority for fabrication, implementation, and on-sky testing. If resources are limited, this mode may not be exercised during the Technology Demonstration Phase.

“Best effort” (Bands 2, 3, 4) modes will not be end-to-end performance tested prior to launch. They will be tested at component and assembly level (eg: are masks aligned in their mounting plates?). Prioritize hardware and fixed firmware over software that could be completed after CGI delivery. Most key hardware for the ‘best effort’ modes is in hand already. Software development is prioritizing Band 1 + HLC. It is possible that there will not be time to complete all software for one or more of the “best effort” modes prior to CGI delivery to payload integration and test, though nothing other than resources would preclude completing later.

Predicted detection limits are strongly speckle-limited at shorter wavelengths



Based on lab demonstrations as inputs to high-fidelity, end-to-end thermal, mechanical, optical models.

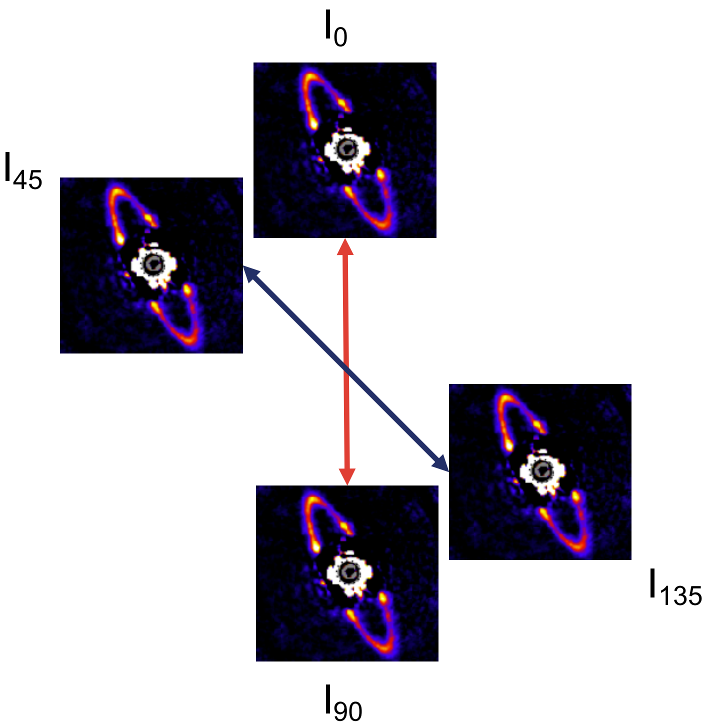
Most Model Uncertainty Factors set to ~1

See also Hildebrandt Rafels talks today and Thursday

github.com/nasavbailey/DI-flux-ratio-plot/

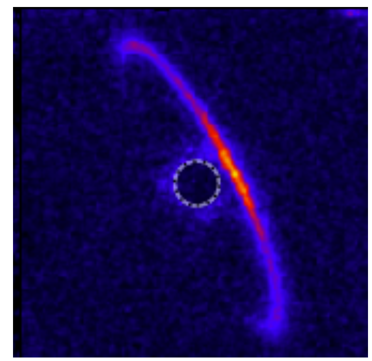
Brian Kern (JPL)
John Krist (JPL)
Bijan Nemati (UA Huntsville)
A.J. Riggs (JPL)
Hanying Zhou (JPL)
Sergi Hildebrandt-Rafels (JPL)

Wollaston Prism Polarimetry (Band 1 or 4 imaging)



1 pair at a time
Pairs separated by 7.5” on chip

Linear polarized fraction (LPF) goal:
RMSE < 3% *per resel*

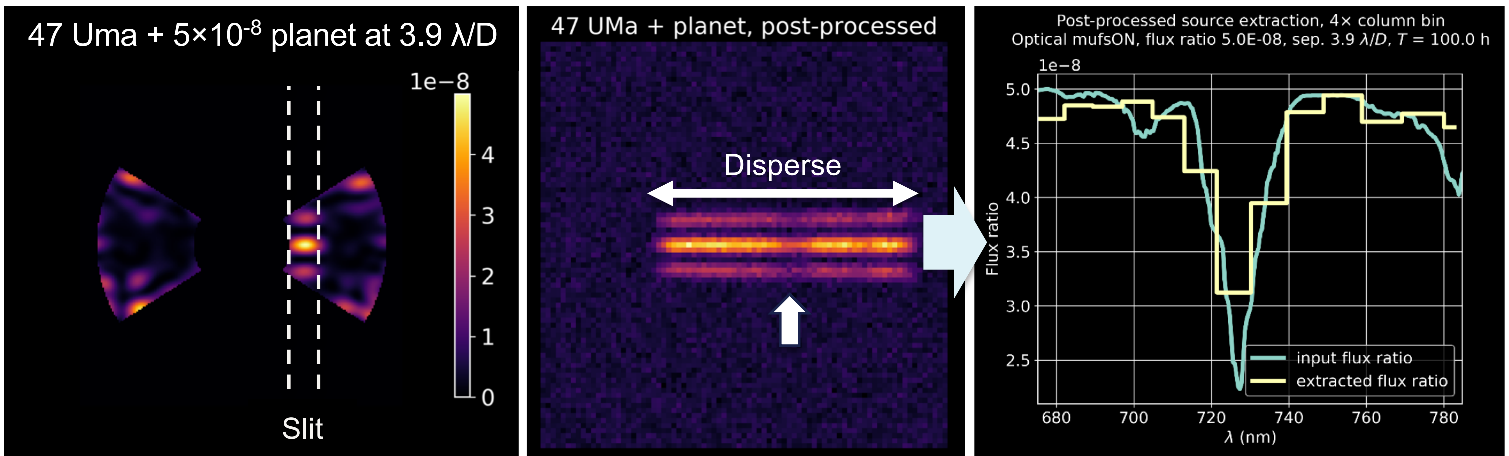


LPF = sqrt $\{(I_0 - I_{90})^2 + \{(I_{45} - I_{135})^2\}$ / I_{tot}

See “Disks and Exozodi” talk

R~50 Spectroscopy w/ Slit Spectrograph (Band 3 or 2)

IFS -> Slit + Prism descope taken in 2019



- Slit is deployed to planet position
- Prism disperses the Shaped Pupil PSF
- Spectrum is extracted from image after post-processing (Reference Star Subtraction)
- Variable resolution. R=50 at bandpass center, ±~10

See Zimmerman “Spectroscopy Data Simulations” talk & backup slide

Filter requirements
(final curves will be posted after fabrication)

name	λ_0 [nm]	FWHM [%]	Primary Purpose
1F (1) *	575	10.1%	Obs
2F (2)	660	17.0%	Obs
3F (3)	730	16.7%	Obs
4F (4)	825	11.4%	Obs
1A	555.8	3.5%	WFS **
1B	575	3.3%	WFS
1C	594.2	3.2%	WFS
2A	615	3.6%	WFS
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2C	656.3	1.0%	Wavecal ***
3A	681	3.5%	WFS
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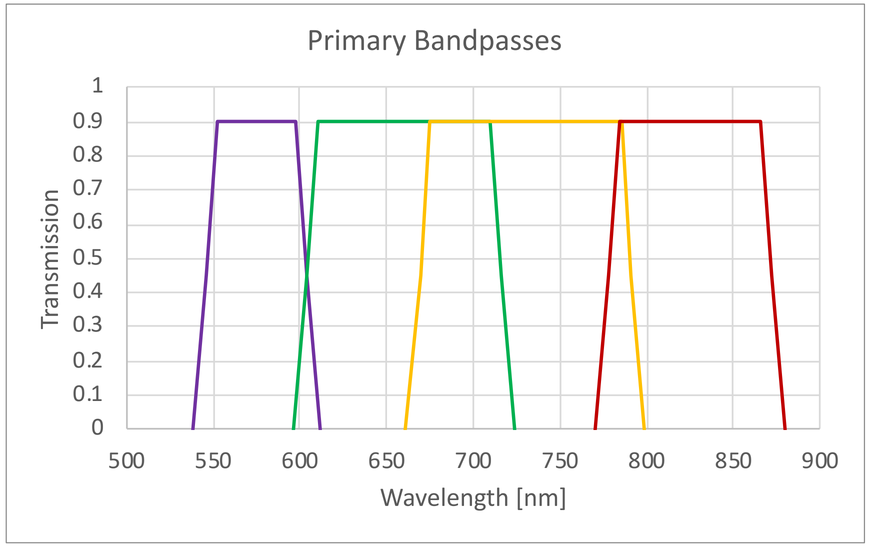


* Bands 1, 2, 3, 4 are shorthand for Band 1F, 2F, 3F, 4F

** WFS = High-order wavefront sensing
*** Wavecal = spectroscopy wavelength calibration

See backup slide for more info

https://roman.ipac.caltech.edu/sims/Param_db.html

Not all mask+filter combinations are valid

- High-Contrast masks are designed to operate at a specific wavelength (Band 1, 2, 3, or 4).
  - In principle, can be used with sub-bands of primary band (eg: SPC bowtie for Band 2 would also work for Band 2A, 2B, 2C, 3A, 3B, because they're all subsets of band 2).
- Combinations other than the supported ones (slide 4) may not be commissioned during the Tech Demo Phase

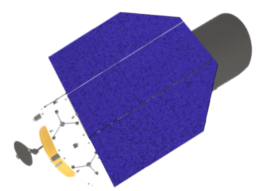
Unsupported observing modes

- Additional masks contributed by NASA's Exoplanet Exploration Program to fill empty slots in mechanisms.
  - Bands 2 and 3 spectroscopy with 60˚ rotated slit
  - Bands 1 and 4 Wide FOV with grid dot mask for multi-star WFC
  - Bands 2, 3, 4 HLC
  - "low contrast" classical Lyot stops with large inner working angles for "outside the dark hole" observations
  - Transmissive Zernike WFS dimples for focal plane WFS demo
- Caveat: No funding for on-sky commissioning identified at this time. Analogous to HST/STIS Bar5.
- For more info: see backup slide & [Riggs+ SPIE O&P 2021]

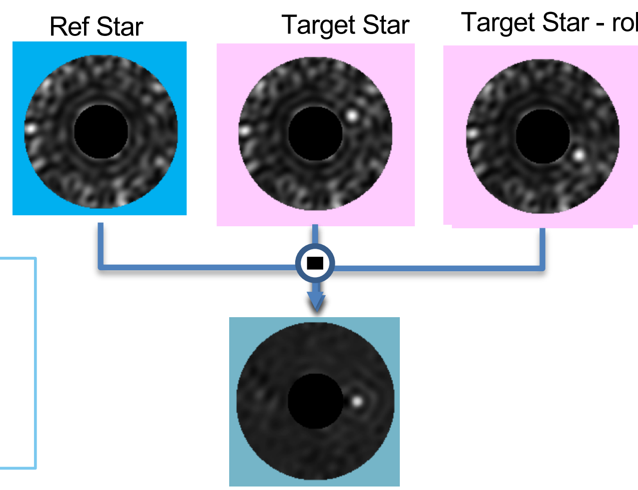
Target constraints for coronagraphic observations

Reference Star
V < 3
<~ 1 mas angular diameter
Hot O/B
WFSC & PSF reference

Target Star
V < 5 (maybe V<7; TBD)
< 2 mas strongly preferred



All stars must be **single**
Nothing equally bright within ~45”; increasingly stringent at smaller separations

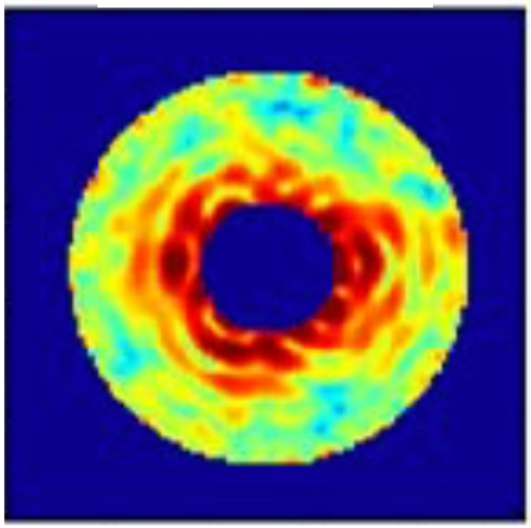


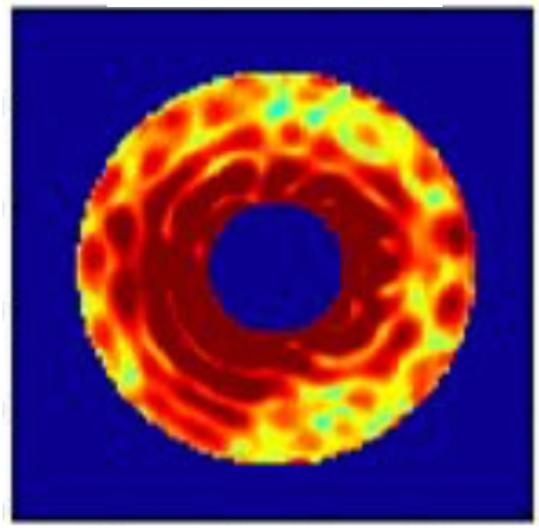
Target vs Reference should have small delta (spacecraft) pitch for better thermal stability

See also these presentations:
- “Working with Simulated Datasets” (Ygouf)
- “Overview of Observing Scenarios and Their Simulated Datasets” (Krist)
- “Target vetting” (Bailey)

Adapted from J. Krist

Residual tip/tilt jitter impacts contrast, sets V<5 host star requirement

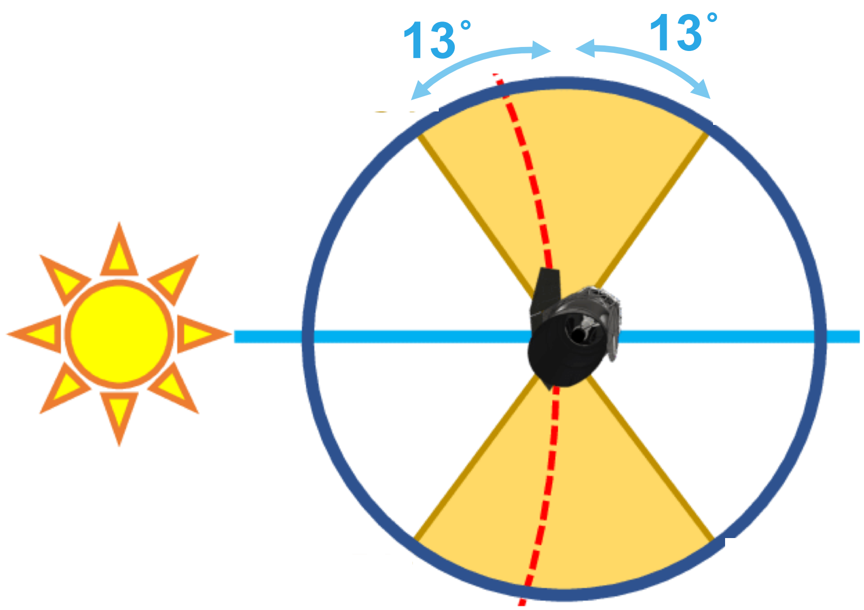


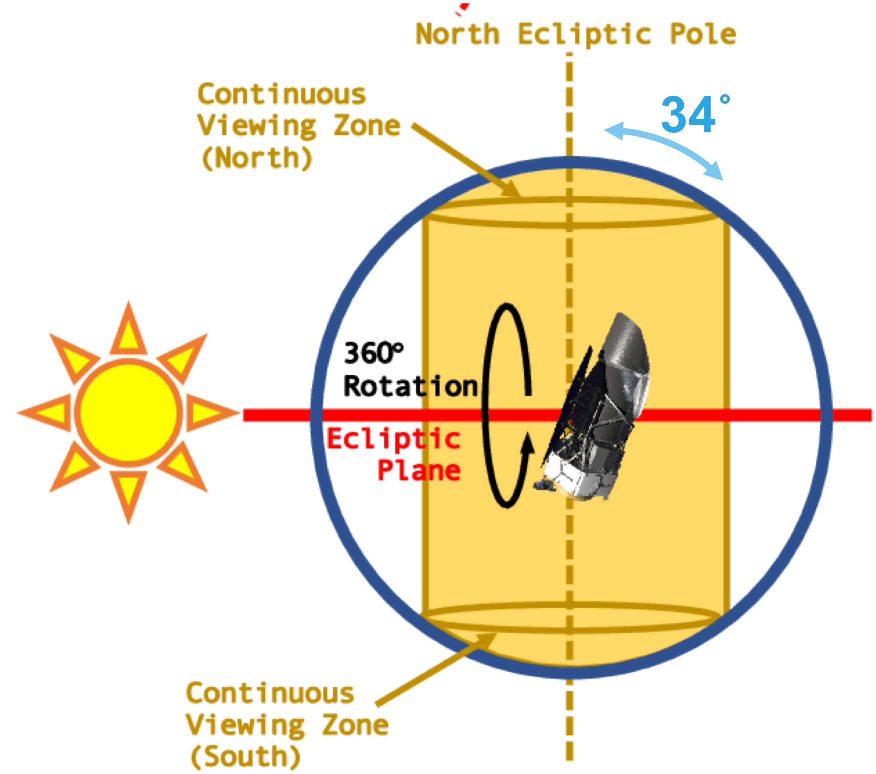


Probably graceful degradation at V>5, but TBD. Project is using V~7 cutoff for coronagraphic target lists.
See backup slide about faint star and non-coronagraphic pointing/jitter performance

Shi, F., et al., SPIE, Vol 10698, p 106982O-5 2018 ; flight-like jitter tests on V=5 ”star”
Note: feed-forward will NOT be implemented in flight (ie: tip/tilt control will be feedback only)

Pointing constraints: ±34˚ pitch, ±13˚ roll vs. sun, 22˚ Earth avoidance; 11˚ Moon avoidance





Telescope slew rate for long slews is ~0.05dgr/sec

See Hildebrand Rafels Talk

JPL “Coronagraph Technology Center” (CTC) responsibilities

- **Collaborate closely w/ Community Participation Program (CPP) & Science Support Center (SSC) in any/all aspects**
- Assist analysis of CGI integration and test data; assist test definition/execution where appropriate
- Top priority: Ensure Coronagraph Instrument (CGI) meets TTR5 requirement on sky (HLC+Band 1)
  - 2nd priority: also meet CGI “Objectives” and deprecated requirements (spec, pol, wide FOV, WFSC)
  - Best effort basis: push performance limits
- Target selection: Choose scientifically interesting targets for tech demo tests whenever possible
- Observation planning: high-contrast and calibration targets
- Data processing: analysis software development & prompt delivery to public archive
  - Up through PSF subtracted images, extracted spectra, etc., in astrophysical
- Anomaly diagnosis and response
- Document on-sky performance

Ground System Architecture

HOWFS = high-order wavefront sensing
GITL = Ground In The Loop

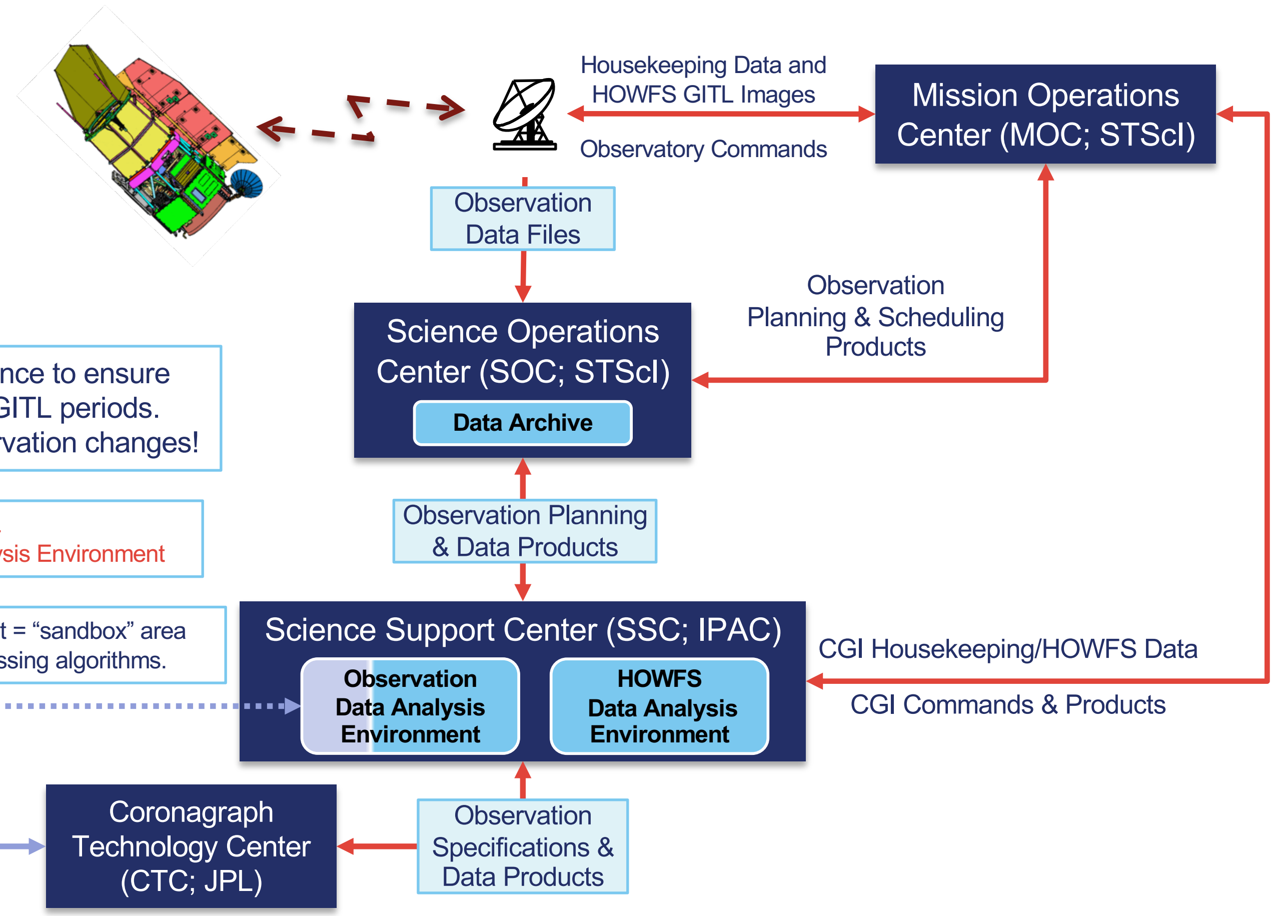
Data Downlink:
Ka-Band (observation data)
S-Band (commands, housekeeping and HOWFS data)

Raw observation image files ("L1 data products") will be in STScI Archive < 72hr after observation.

CGI scheduling done weeks or months in advance to ensure ground station contact during critical HOWFS GITL periods. CGI does not support 'joysticking' or mid-observation changes!

See Zimmerman HOWFS talk for more details about GITL
See Lowrance talk for more details about SSC Data Analysis Environment

Purple area of the Observation Data Analysis Environment = "sandbox" area available to CPP and CTC to develop and test data processing algorithms.



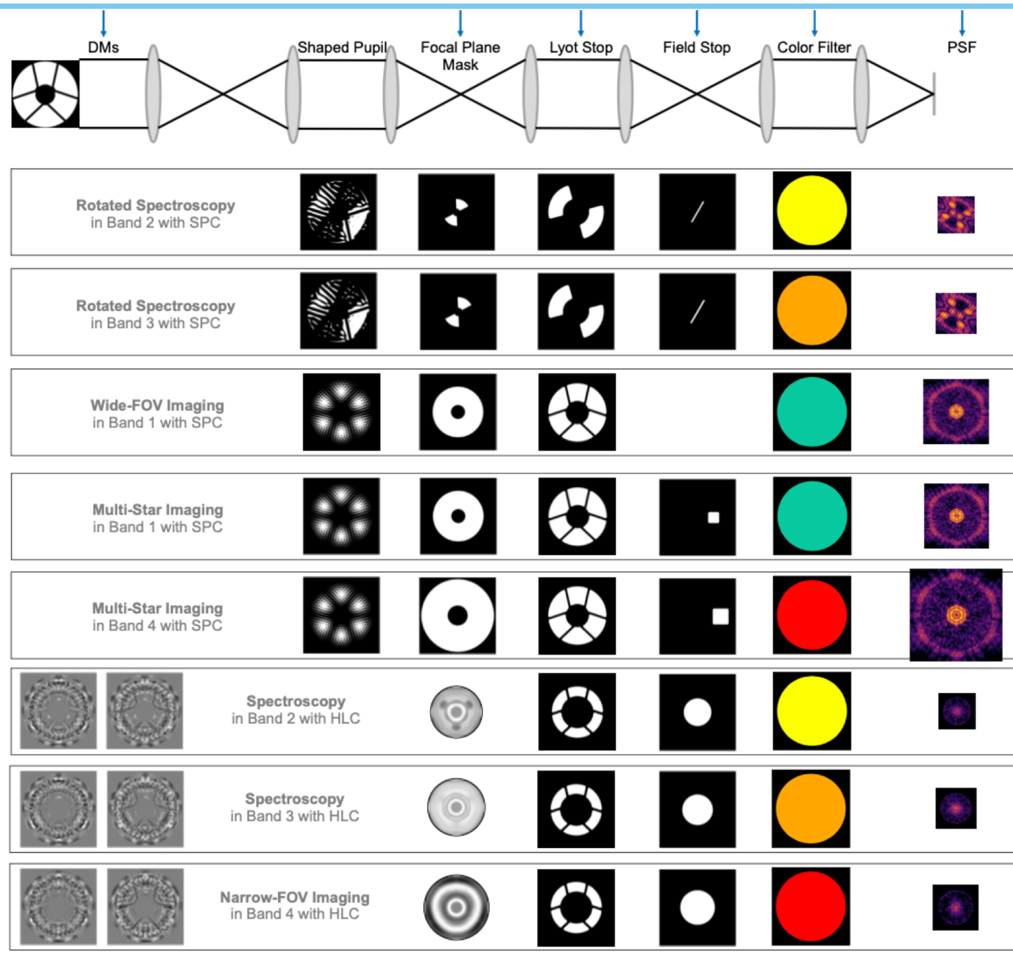
Resources

Vanessa Bailey vanessa.bailey@jpl.nasa.gov

- Roman IPAC website
  - Instrument parameters https://roman.ipac.caltech.edu/sims/Param_db.html
  - “Observing Scenario #N” Image simulations and reports https://roman.ipac.caltech.edu/sims/Coronagraph_public_images.html
  - Roman Virtual Lecture Series https://roman.ipac.caltech.edu/Lectures.html
- https://www.jpl.nasa.gov/missions/the-nancy-grace-roman-space-telescope
- https://roman.gsfc.nasa.gov/
- SPIE proceedings: 2018 Vol 10698; 2019 Vol 11117; 2020 Vol 11443; 2021 Vol 11823
  - Caveat: performance predictions have degraded over time; you should sanity check older papers’ conclusions against the latest contrast curves!

Questions?

Unsupported mask configurations



Additional masks contributed by NASA's Exoplanet Exploration Program to fill empty slots in mechanisms.

No funding for on-sky commissioning identified at this time. Analogous to HST/STIS Bar5.

Not shown: unsupported "low-contrast" classical Lyot spots (analogous to HST) for very wide FOV imaging (~1-3.5")

For complete list of masks see [Riggs+ SPIE O&P 2021]

Filter requirements
(final curves will be posted after fabrication)

name	λ$_0$ [nm]	FWHM [%]	FW Trans. Band [≥%] ***	Primary Purpose
1F (1) *	575	10.1%	8.0%	Obs
2F (2)	660	17.0%	15.2%	Obs
3F (3)	730	16.7%	15.1%	Obs
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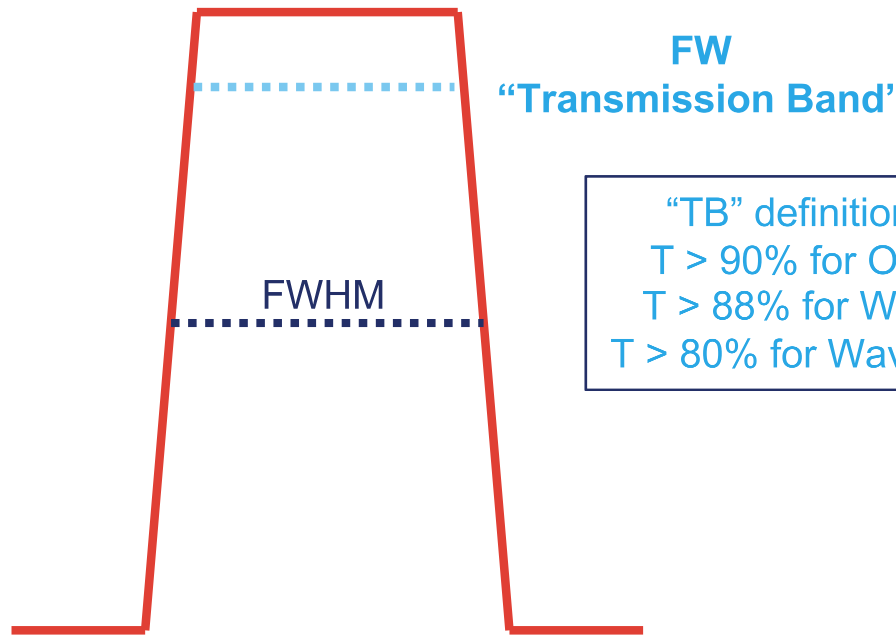

"TB" definition:
T > 90% for Obs
T > 88% for WFS
T > 80% for Wavecal

* Bands 1, 2, 3, 4 are shorthand for Band 1F, 2F, 3F, 4F
** WFS = High-order wavefront sensing
*** FWTB listed is minimum %; likely to be closer to FWHM value

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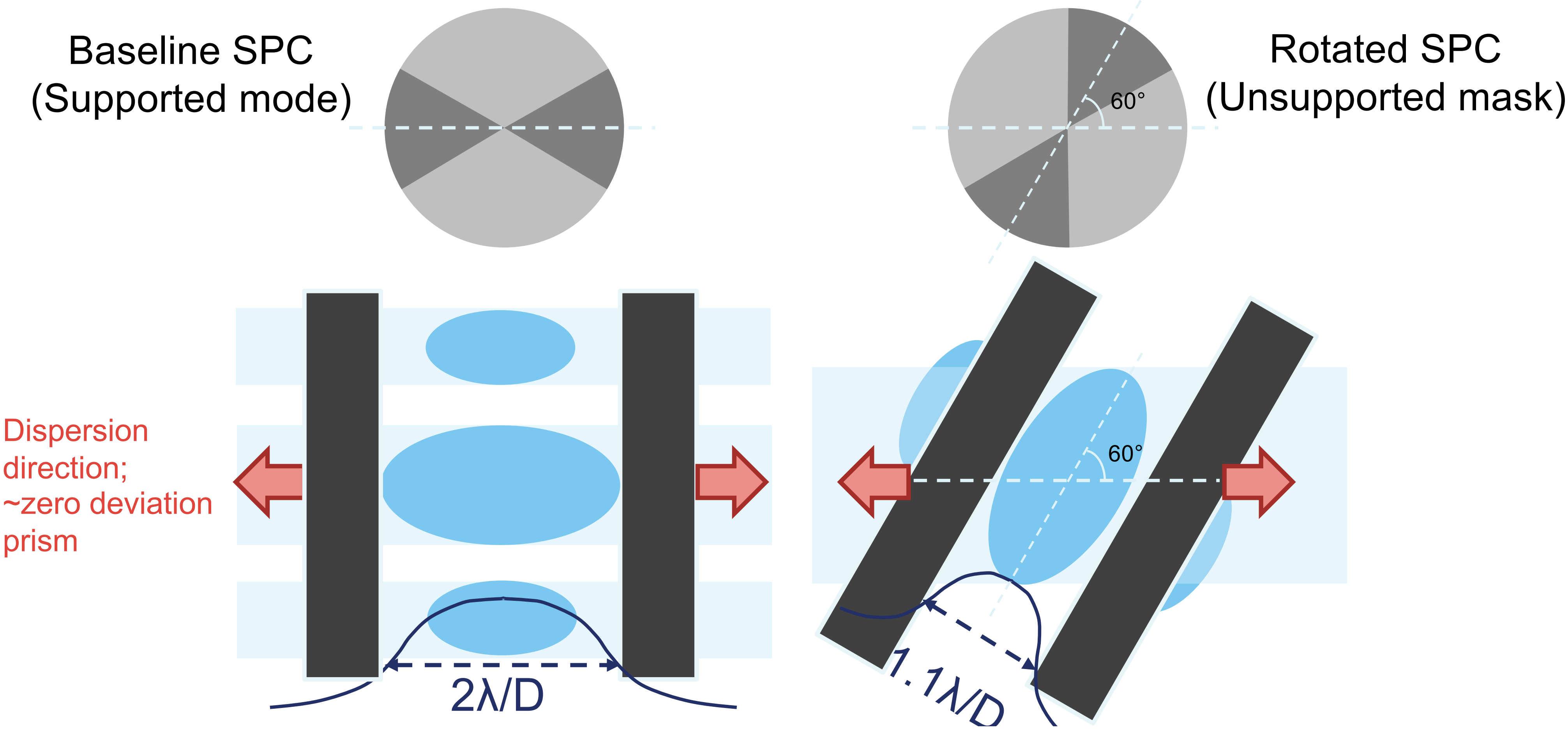
SPC "bowtie" slit orientations



Pointing control

Initial acquisition

- Roman observatory: 100 mas RMSE
- EXCAM acquisition (single stars only): 18 mas RMSE

Pointing errors during coronagraphic observations of bright stars (V≤5)

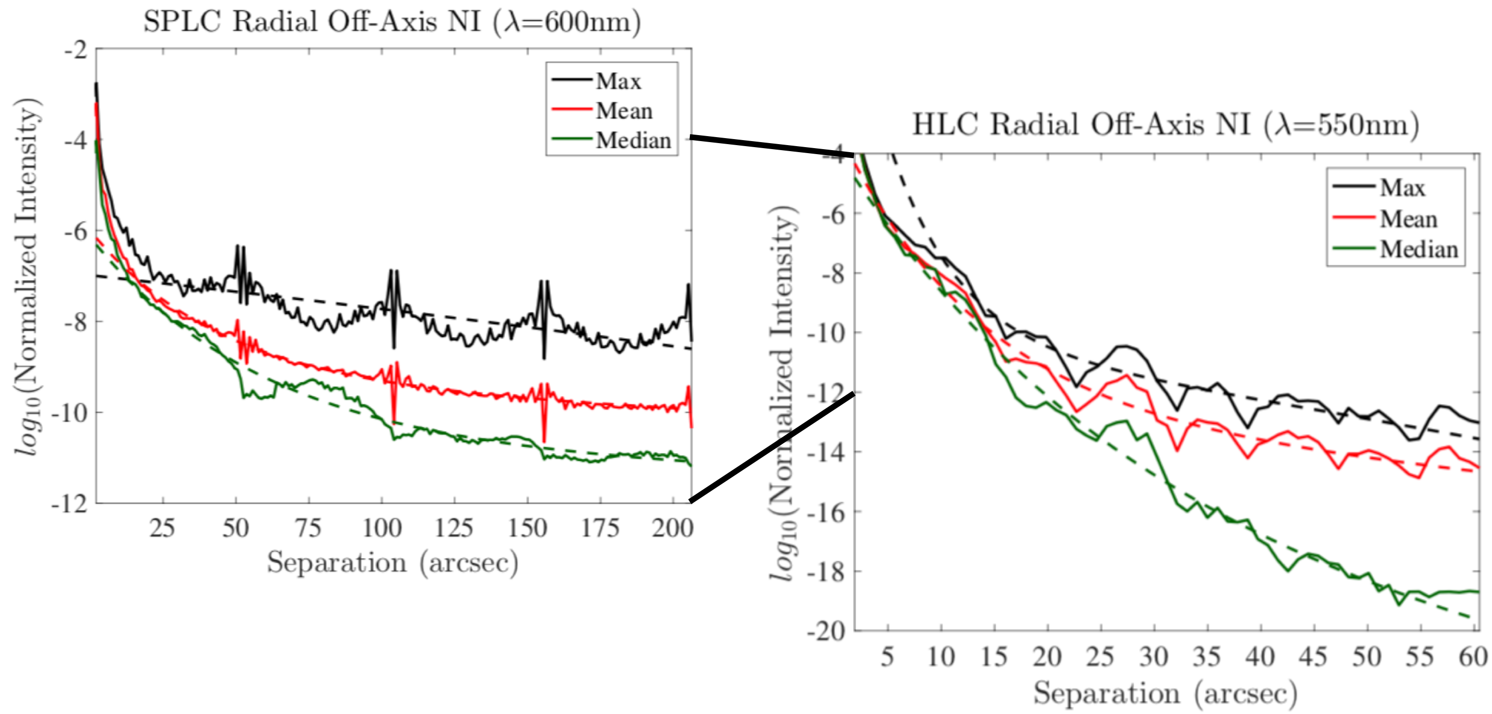
- LOWFS maintains star-to-focal plane mask alignment; controls tip & tilt to < 1 mas

Pointing errors during non-coronagraphic and/or faint star observations

- No LOWFS tip-tilt control
- Conservative assumption: star is aligned to focal plane mask only to EXCAM acquisition accuracy (18 mas)
- Slow pointing drift (up to 20mas/hr, typically ≤10mas/hr)
- Fast jitter: 12 mas RMS, > 1Hz
- Attitude Control System (ACS) wander: 10 mas RMS, ~0.05Hz

Far-off-axis PSF profiles used in original analysis

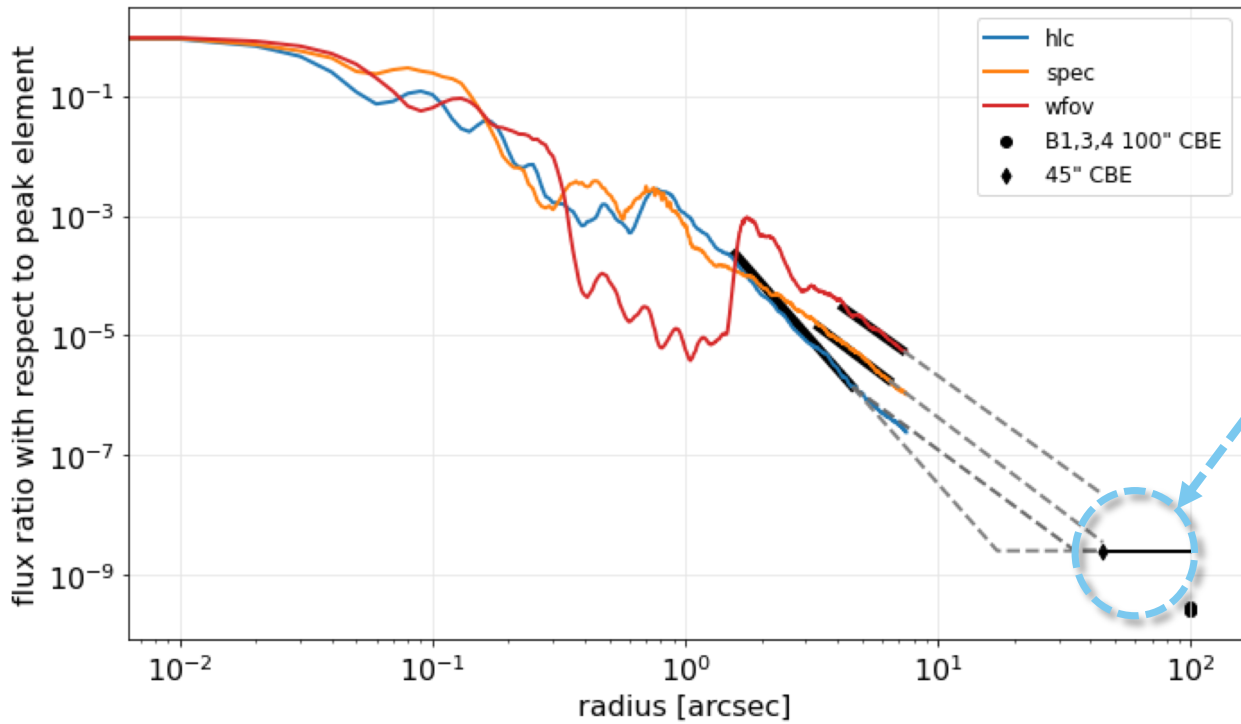
Incomplete model, but best available at the time (2018/19)



From AJ Riggs' presentation "Effects of Nearby Stars on Wavefront Correction for the WFIRST CGI" (Oct 13th, 2016)

Updated far-off-axis profile

Not incorporated into background star simulations / target vetting yet



Far off-axis value (≥45”) is work in progress… Will post to IPAC Instrument Parameters page when complete.