Roman Coronagraph Instrument*: overview and observing capabilities

*formerly AKA: CGI

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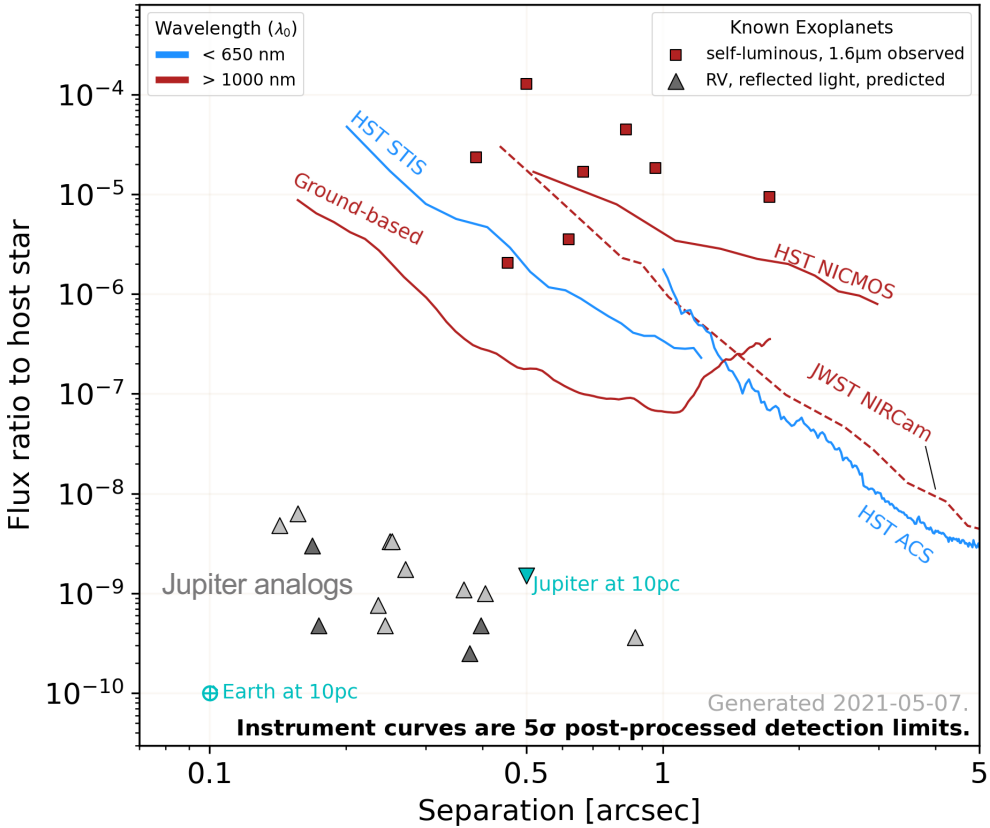
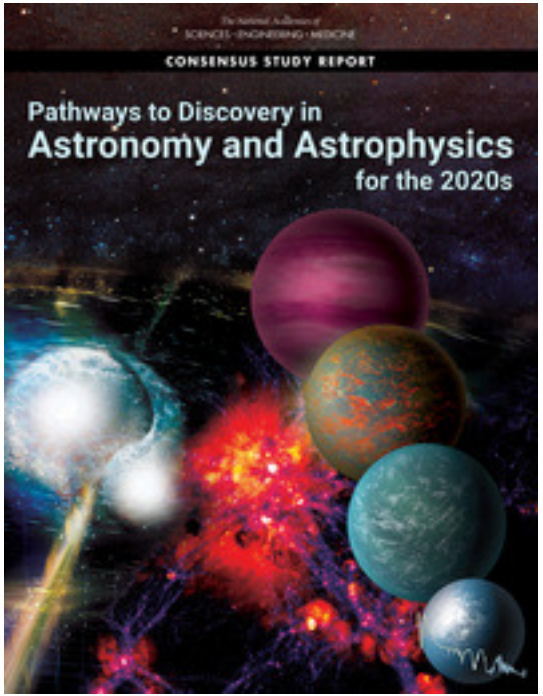
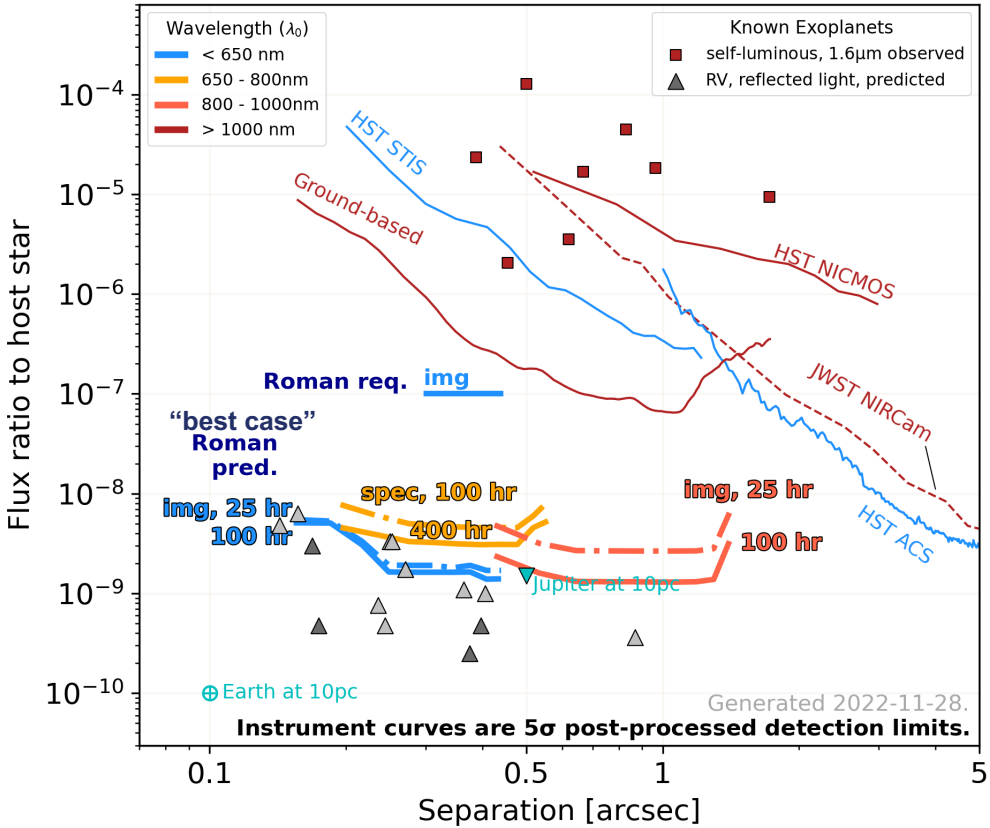
On behalf of the Roman Coronagraph team

Goal: bridge gap between massive self-luminous planets (IR) and reflected light exo-Earths (visible)





Coronagraph is expected to significantly advance key technologies & be capable of imaging exoplanets



github.com/nasavbailey/DI-flux-ratio-plot/
NEW: more options for conservatism & exposure time

Exoplanet Exposure Time Calculator
https://roman.ipac.caltech.edu/sims/ETC.html
Built on EXOSIMS

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Ewan Douglas
Brianna Lacy
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Dean Keithly
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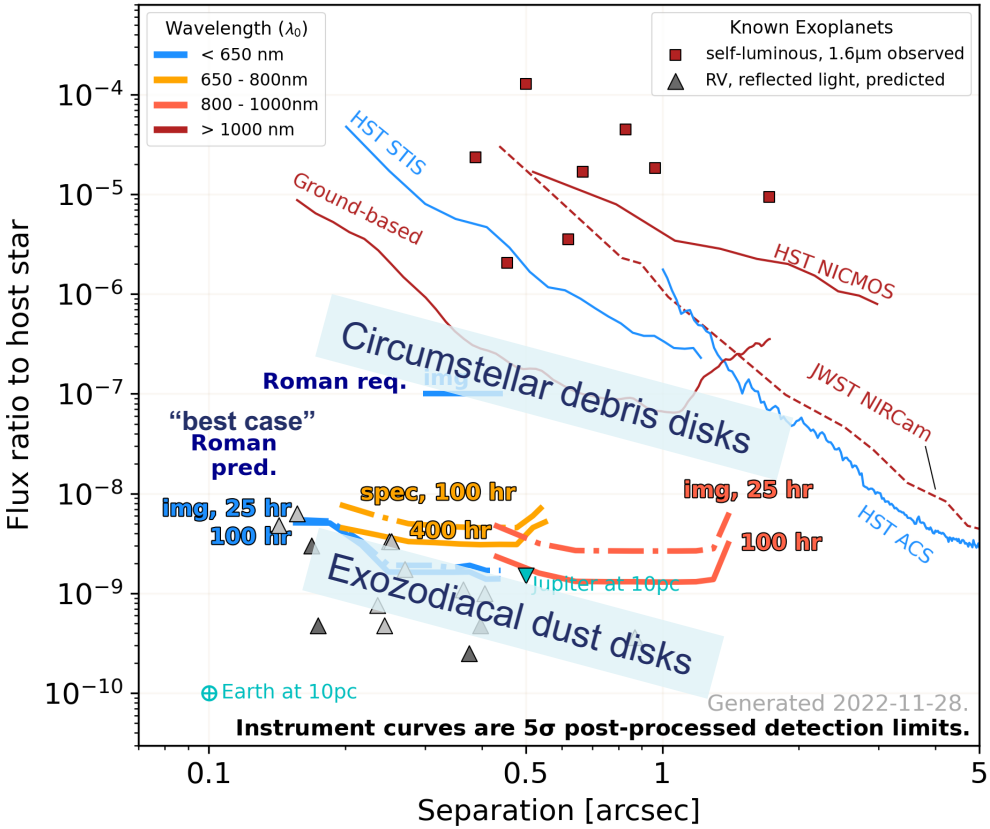
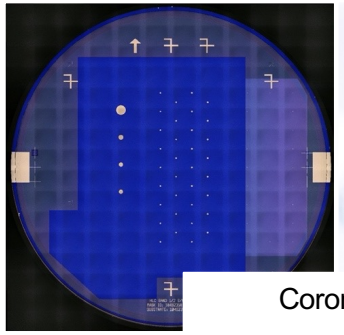
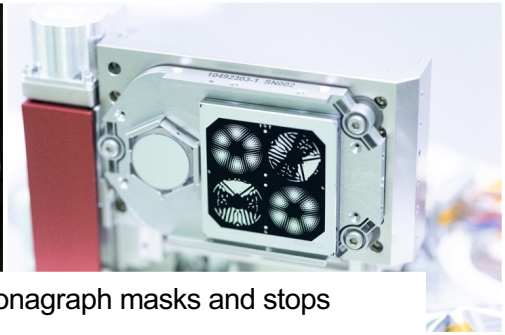
John Krist
Bijan Nemati
Dmitry Savransky
Leah Sheldon
Corey Spohn
Sergi Hildebrandt Rafels
A.J. Riggs
Hanying Zhou

Coronagraph will be able to observe circumstellar disks at a range of surface densities

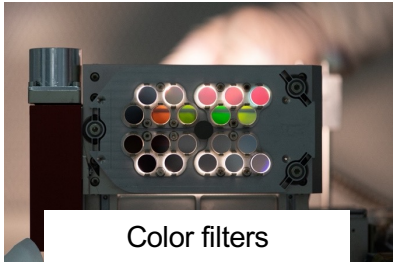


Instrument delivery ~1 yr away

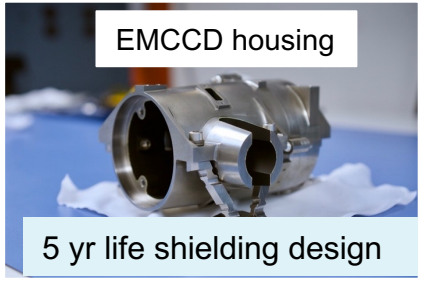




Coronagraph masks and stops

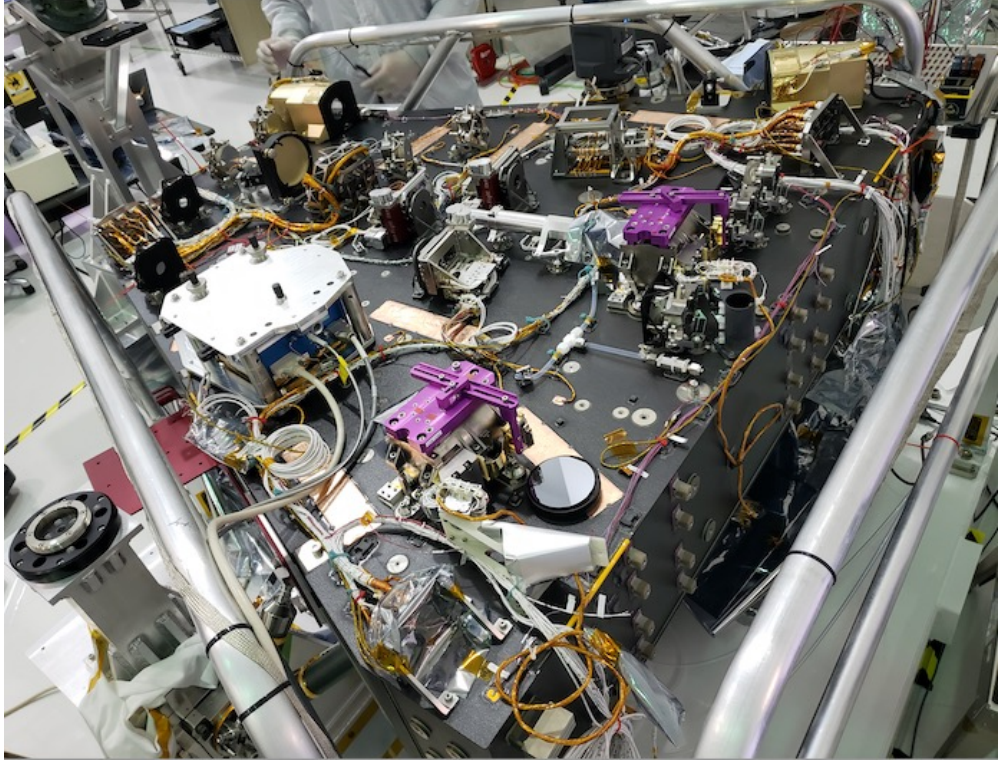


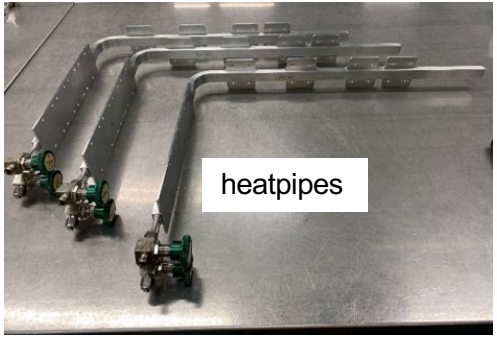
Color filters



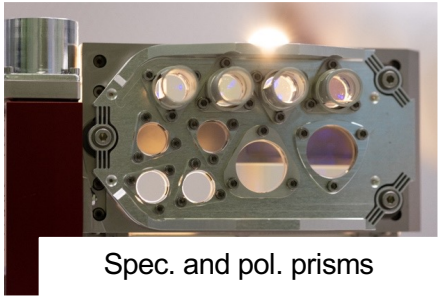
EMCCD housing

5 yr life shielding design

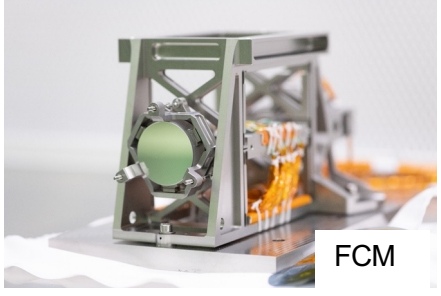




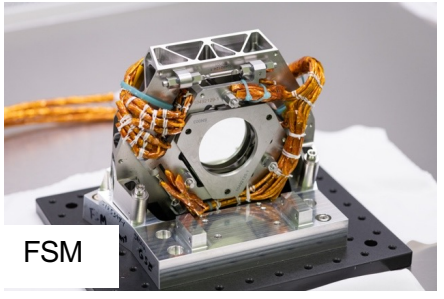
heatpipes



Spec. and pol. prisms



FCM



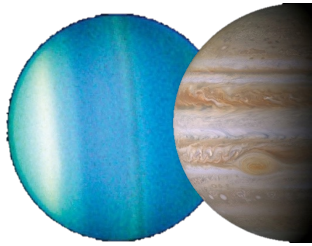
FSM

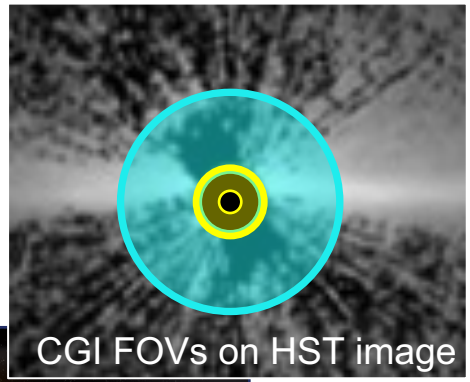
Coronagraph “Technology Demonstration Phase”

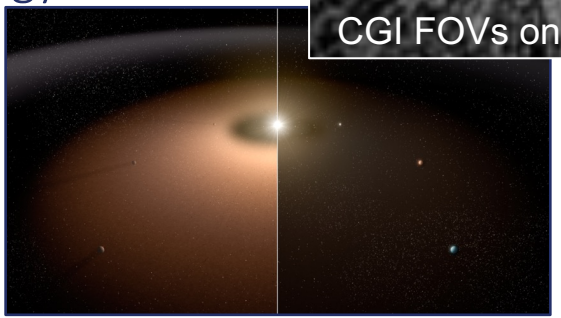
- Baseline: 2200hr (90 days) during first 18mo of Mission
- Top priority: achieve L1 Technology Requirement
  - Flux ratio of at least 10^{-7} on a V~5 star in Band 1
- Then, as time/resources allow, push performance limits
  - Maximize long-term value to Habitable Worlds Observatory
- Use scientifically-interesting targets whenever possible
  - No GO program; will solicit community input on target selection
  - Roman data has no proprietary period

Capable of exciting exoplanetary system science

- After demonstrating our Level 1 requirement…
- Known, self-luminous planets at visible wavelengths
  - (eg: Lacy & Burrows 2020)
- Potential for first images and spectrum of true Jupiter analog
  - Known RV planet
  - (eg: Batalha+2018, Saxena+2021)
- Low surface brightness disks, improved morphology
  - (eg: Mennesson+2018)
- Potential for first visible light images of exozodi
  - (Douglas+2022)







Observing Modes

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

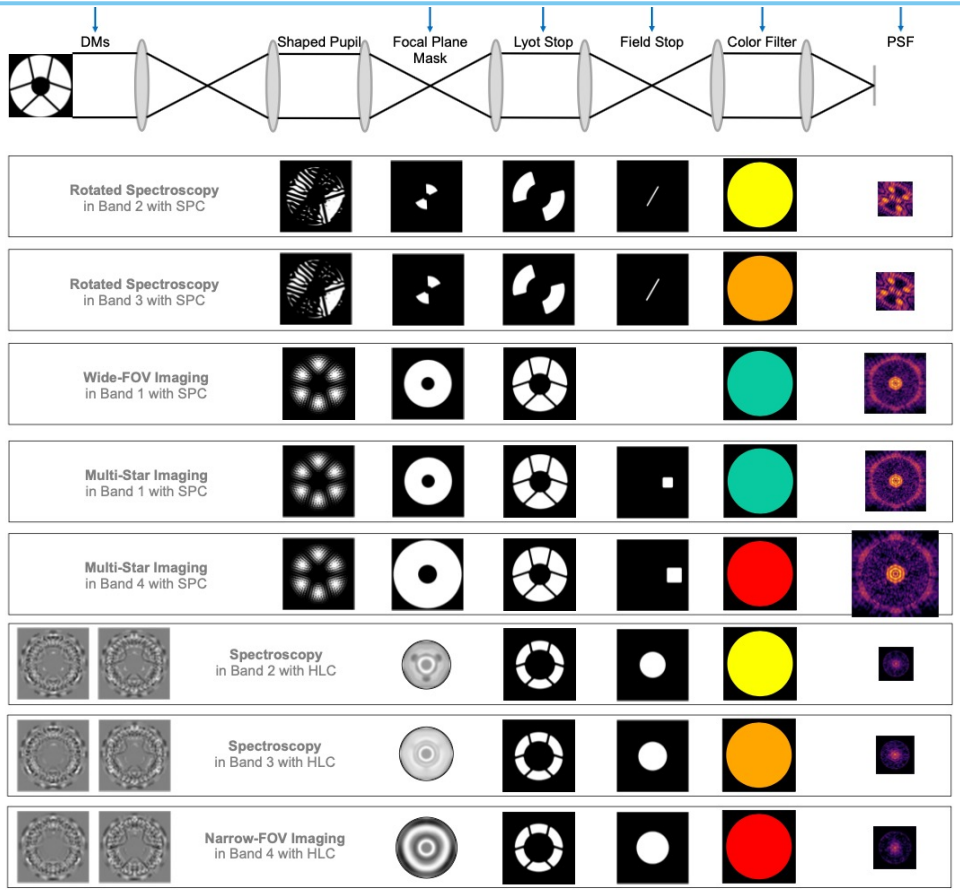
“Best effort” modes will not be end-to-end performance tested prior to launch and do not have guaranteed support on-orbit. They will be tested at component and assembly levels (eg: Do the masks meet their acceptance criteria? Are masks aligned in their mounting plates?)

*** 660 nm spectroscopy** is the lowest priority ‘Best Effort’ mode.
** Polarimetry in Band 1 is ‘best effort’

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 ones shown in the previous slide may not be commissioned during the Tech Demo Phase
- For complete list of installed masks see Riggs+ SPIE O&P 2021

Unsupported mask configurations



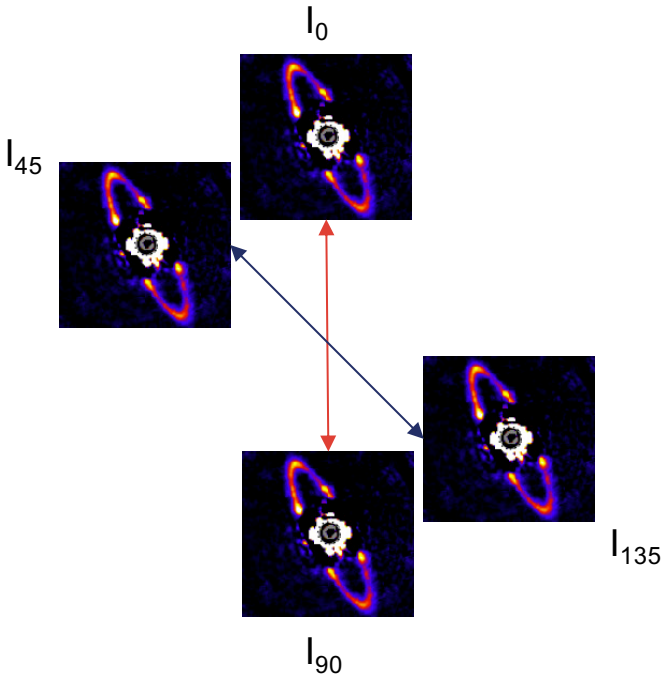
Additional masks contributed by NASA's Exoplanet Exploration Program to fill empty slots in mechanisms.

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")

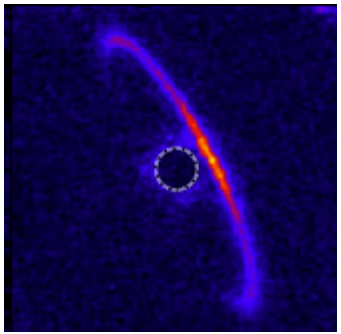
For complete list of masks see Riggs+ SPIE O&P 2021

Best Effort:
Wollaston Prism Polarimetry (Band 1 or 4 imaging)



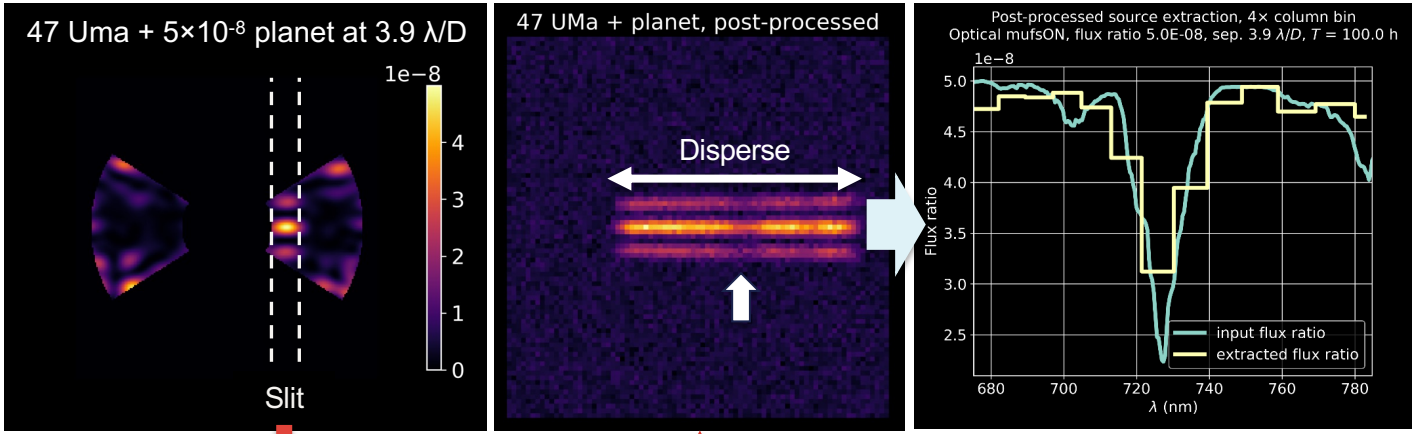
1 pair at a time
Pairs separated by 7.5” on chip

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



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

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

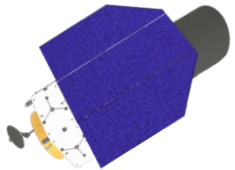


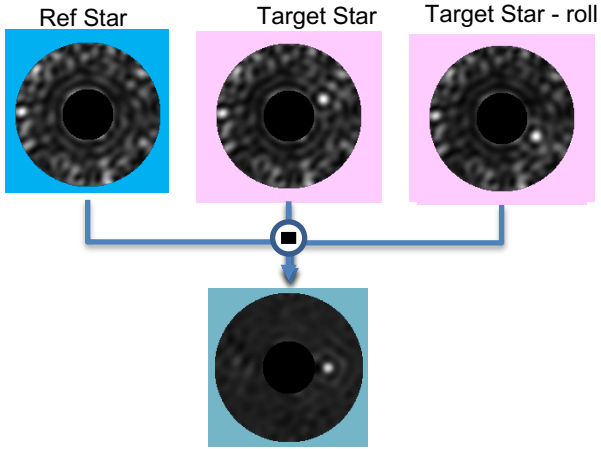
- Slit is deployed to planet position
- Prism disperses the Shaped Pupil PSF
- Spectrum is extracted from image after post-processing (Reference Star Subtraction)
- Variable resolution. R=50 at bandpass center, ±~10

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 diameter strongly preferred





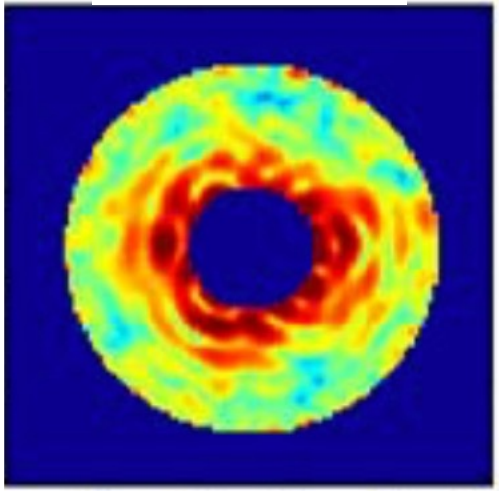
All stars must be **single**
Nothing equally bright within ~45";
increasingly stringent at smaller separations

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

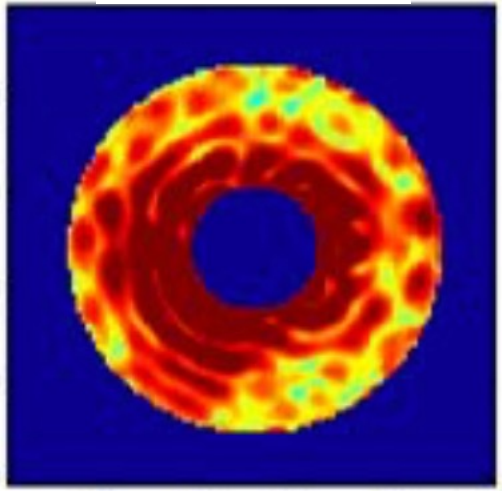
Adapted from J. Krist

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

Tip/tilt control on



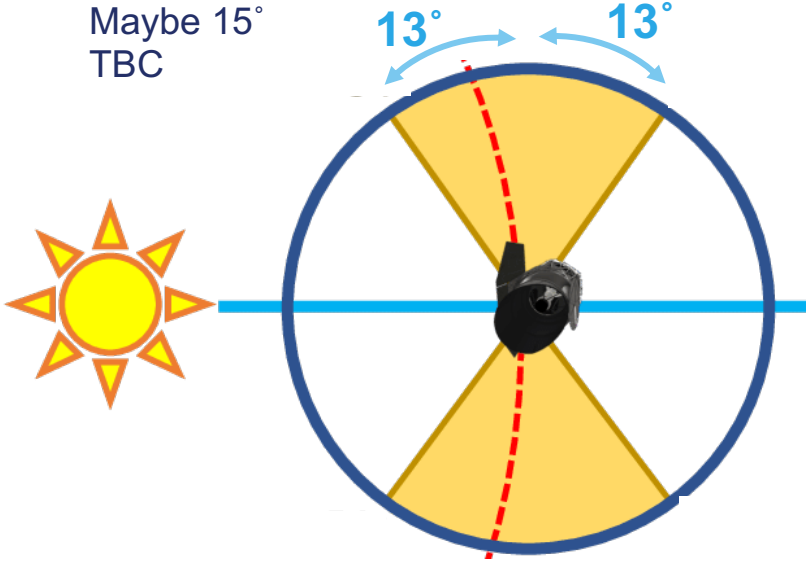
Tip/tilt control off

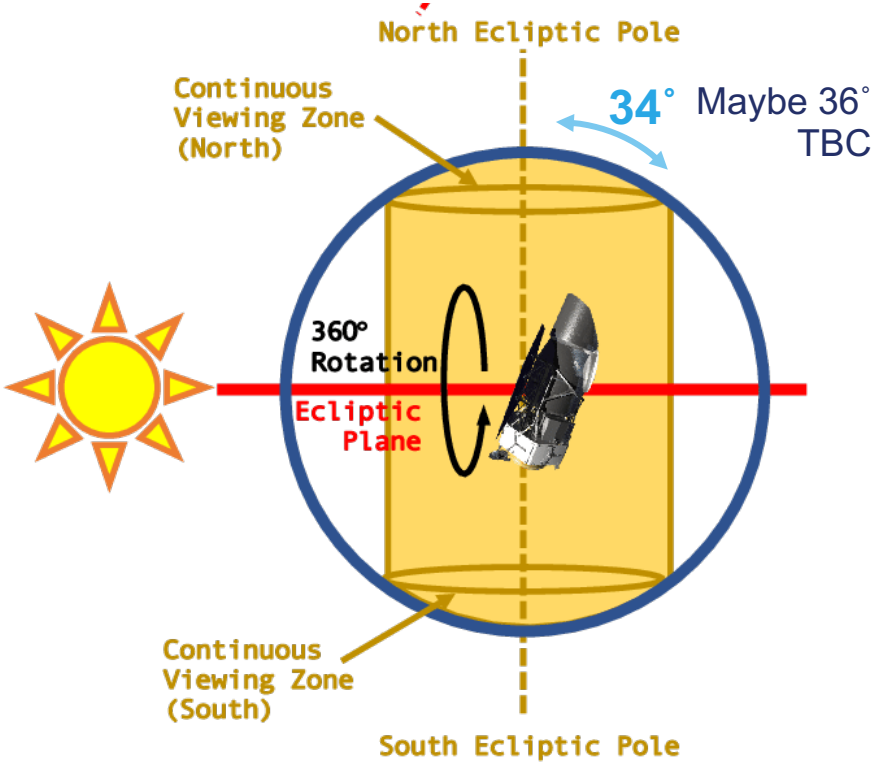


Probably graceful degradation at V>5, but TBD.
Project is considering V~7 cutoff for coronagraphic target lists, pending performance.

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

Resources

Vanessa Bailey vanessa.bailey@jpl.nasa.gov

- Resources for proposers https://roman.gsfc.nasa.gov/science/roses.html
- Roman IPAC website https://roman.ipac.caltech.edu/
  - 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
  - Recordings & slides from 2-day Coronagraph information session
    - https://roman.ipac.caltech.edu/mtgs/Roman_CGI_workshop.html
  - Roman Virtual Lecture Series https://roman.ipac.caltech.edu/Lectures.html
  - …and more!

Questions?

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)

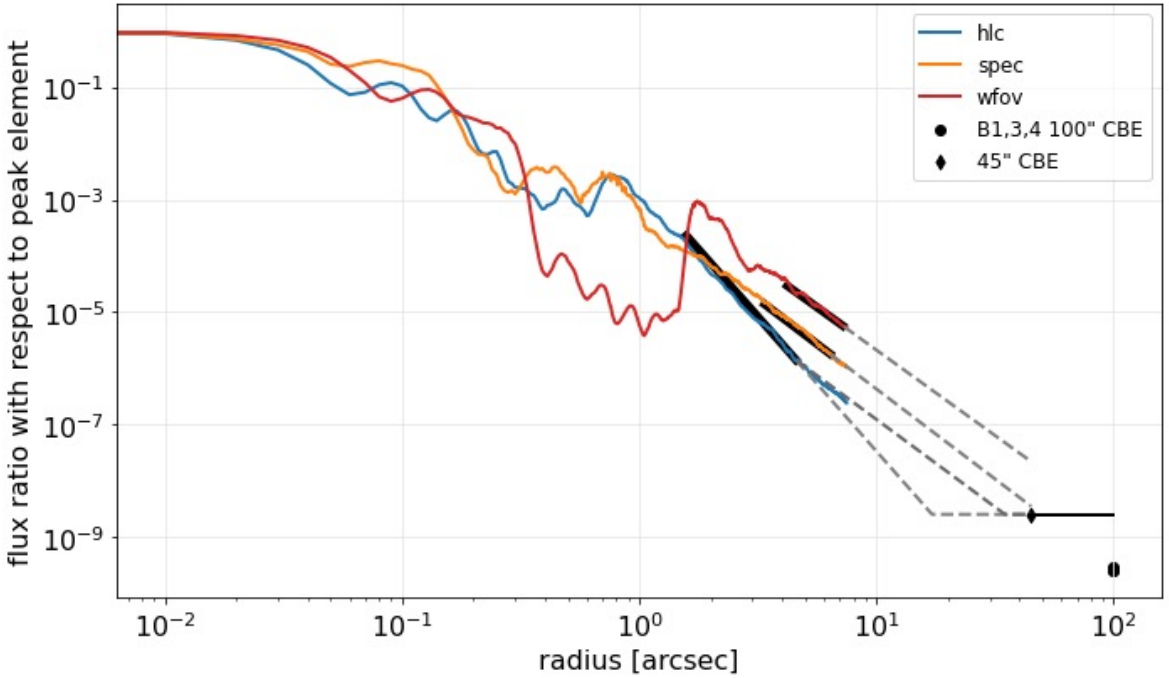
- LOWFS maintains star-to-focal plane mask alignment; controls tip & tilt to < 1 mas

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 RMSE)
- 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

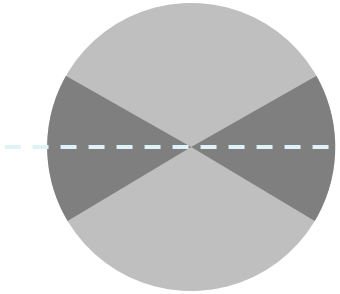
far-off-axis profile

Available on IPAC CGI additional parameters data page

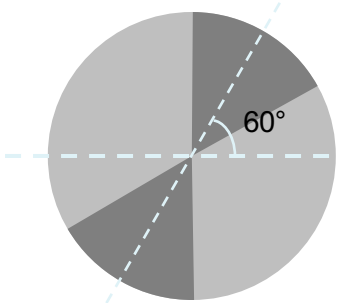


SPC “bowtie” slit orientations

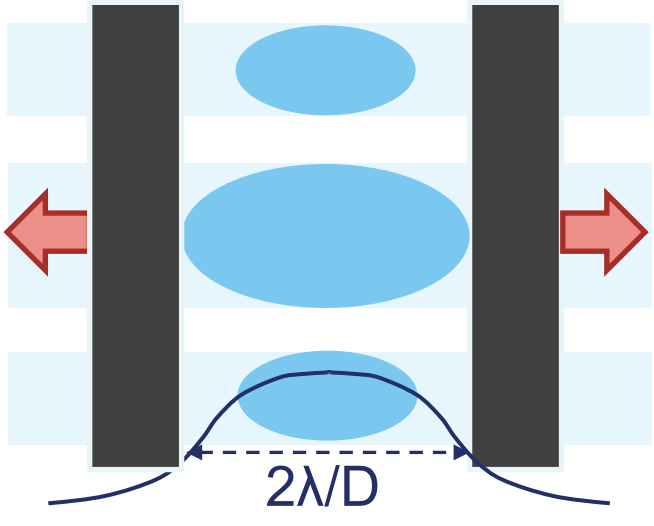
Horizontal SPC
(Best Effort)

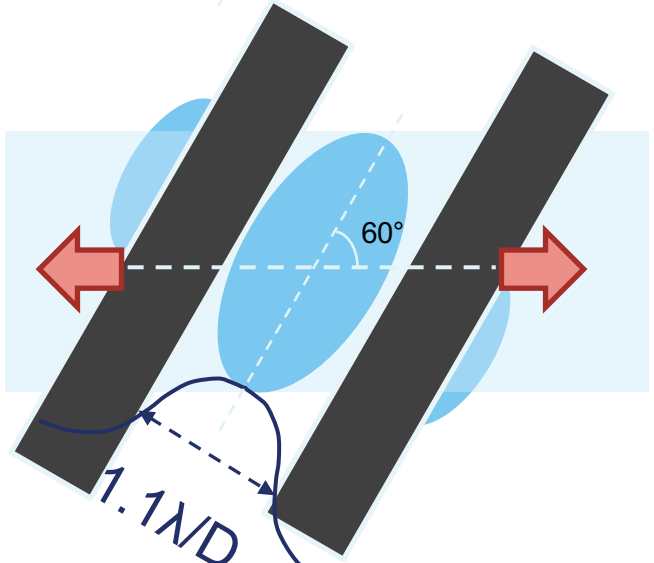


Rotated SPC
(Unsupported mask)



Dispersion direction; ~zero deviation prism





Ground System Architecture

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

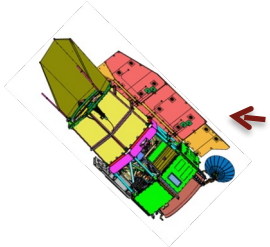
Data Downlink:
Ka-Band (observation data)
S-Band (commands, housekeeping and HOWFS data)

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.



Housekeeping Data and HOWFS GITL Images

Observatory Commands

Mission Operations Center (MOC; GSFC)

Observation Data Files

Science Operations Center (SOC; STScI)

Data Archive

Observation Planning & Scheduling Products

Observation Planning & Data Products

Science Support Center (SSC; IPAC)

Observation Data Analysis Environment

HOWFS Data Analysis Environment

CGI Housekeeping/HOWFS Data

CGI Commands & Products

Coronagraph Community Participation Program (CPP)

Coronagraph Technology Center (CTC; JPL)

Observation Specifications & Data Products

Coronagraph Community Participation Program (CPP)

- Selected teams become integral part of Coronagraph team, *not just end users*
- Draft list of solicited topics are in ROSES D.14
  - Observation design, preparatory work, data analysis, simulations, …
  - **Engaging external research community** to optimize tech demo observations for broad, long-term impact (eg: target selection, …)
  - Add-ons: wavefront sensing and control and/or commissioning modes beyond req'd one
- CPP will be relatively small
  - ~6 US proposals to be selected via ROSES; each annual budget <$200K
  - + 4 selected by CNES, ESA, JAXA, MPIA