Roman Coronagraph Primer

Community Participation Program

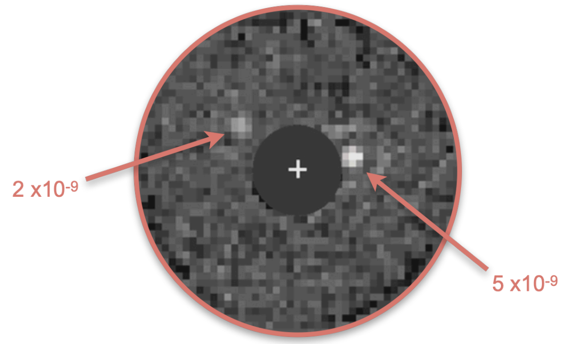
January 8 2025

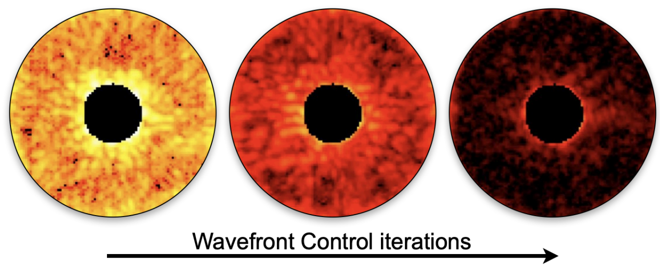
A TECHNOLOGY PATHFINDER ONBOARD ROMAN

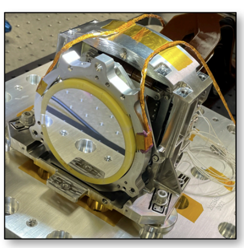
The Nancy Grace Roman Space Telescope (Roman) will start science operations in 2027. The Roman telescope will spend most of its time surveying large areas of the sky with a transformative wide field instrument.

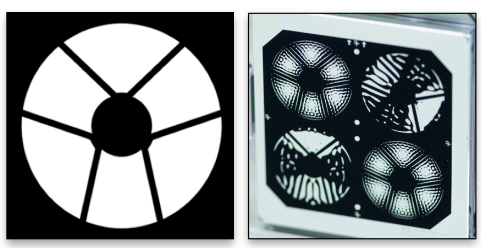
However, Roman will also test new technologies for space-based planet hunting through direct imaging, using the novel Roman Coronagraph Instrument (the Coronagraph hereafter).

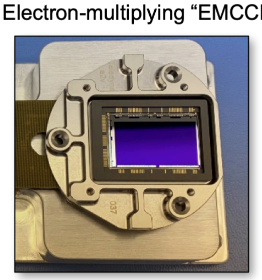
The Coronagraph onboard Roman is a system of masks, prisms, detectors, and deformable mirrors built to block out the glare from distant stars and reveal the planets in orbit around them. The Roman Coronagraph will demonstrate that direct imaging technologies can perform even better in space than they have with ground-based telescopes. As it captures light directly from large, gaseous exoplanets, and from disks of dust and gas surrounding other stars, it will pave the way towards high-contrast imaging with even larger and more advanced space telescopes like the recently announced Habitable Worlds Observatory (HWO) mission concept.

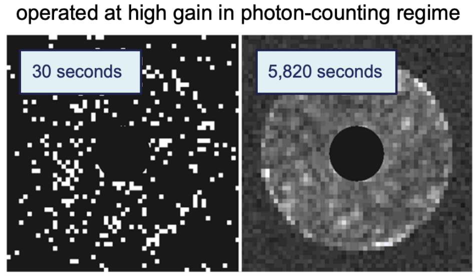












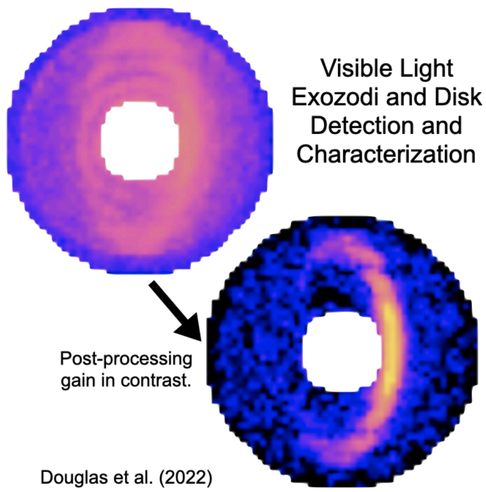
The main goal of the Coronagraph Instrument is to validate technologies in space (wavefront control, high performance coronagraphs and ultra-low noise photon-counting detectors).

The Coronagraph technology demonstration has a 3 month observing allocation (2,200 hours) within the first 18 months of the mission.

The community is being engaged to define a program that will verify baseline technology requirements and demonstrate technologies relevant to the future HWO coronagraph(s) while potentially providing cutting-edge exoplanet, circumstellar disk, and other high-contrast science results.

CORONAGRAPH SCIENCE CASES

The Roman Coronagraph science cases span from the direct imaging of young to mature Jupiter analogs in visible reflected light to circumstellar disks. The Coronagraph will yield valuable community data for several classes of exoplanets and circumstellar disks.



The Roman Coronagraph could potentially yield the first images of mature Jupiter analogs in reflected light. Combining these images with priors from Gaia astrometry and/or radial velocity would yield significantly improved orbital constraints and hence accurate mass estimates. The Coronagraph may also collect optical spectra of up to two of these exoplanets, providing a window into their atmospheric properties for the first time. For young, self-luminous giant planets already imaged in the infrared, Coronagraph spectroscopy could complete the short wavelength spectral energy distributions for these planets, producing stronger constraints on their atmospheric properties than is possible with infrared observations alone. The Coronagraph can also be transformative for disk science, potentially obtaining the first visible light images of exozodiacal dust as well as providing additional optical imaging and polarimetry of known warm debris disks.

IMPORTANT FACTS ABOUT THE OBSERVING PLAN

Launch: No later than May 2027.

Baseline: 2,200 hours (90 days) during the first 18 months of the mission.

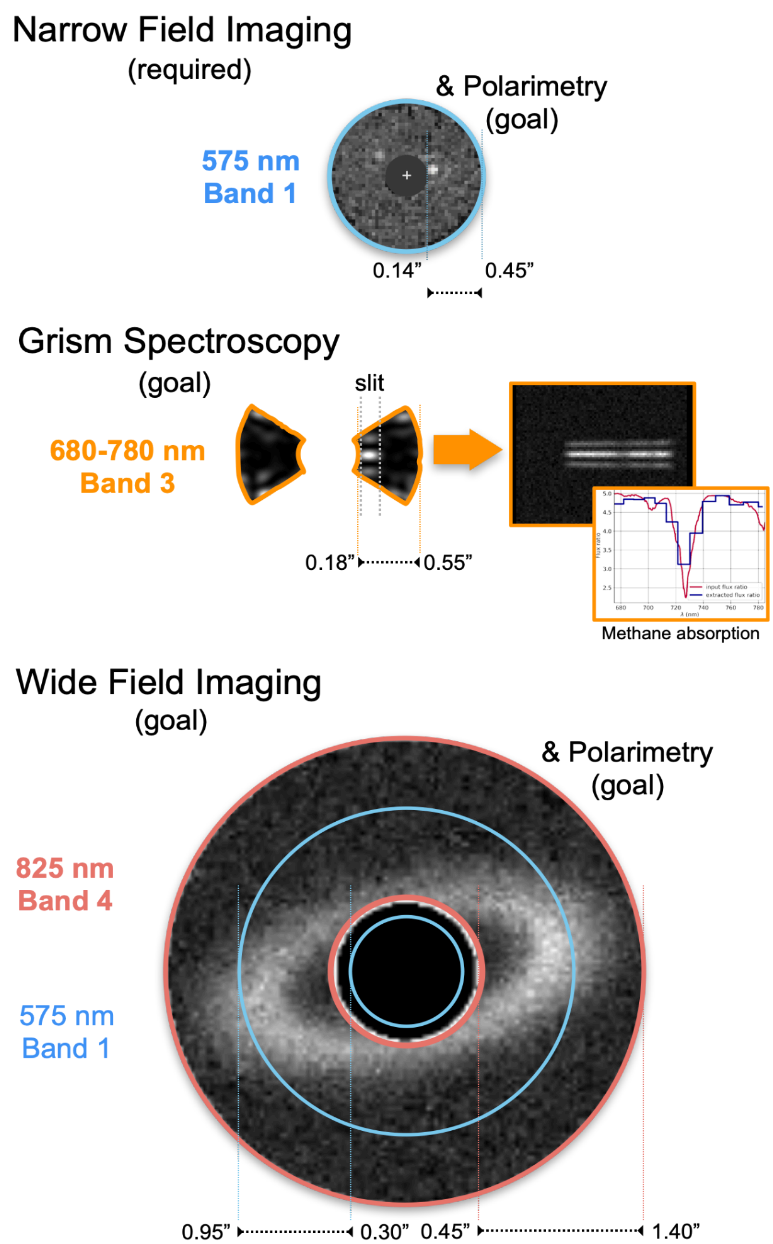
Top priority: Achieve Project Level 1 Requirement (L1): Demonstrate the capability to measure, with a signal to noise ratio (SNR) of ≥ 5, the brightness of an astrophysical point source located between 6 and 9 λ/D from the central star with a V_{AB} magnitude ≤ 5, with a flux ratio $\leq 10^{-7}$ in Band 1 (575 nm). This can only be done by fulfilling the objective of performing active wavefront control, demonstrating in-space operations the Coronagraph elements.

As time/resources allow: Push performance limits, perform transformative science and **maximize long-term science and technical value** to the astronomy community.

Observing Program: Community input on target selection is encouraged through the Community Participation Program (CPP, see below).

No proprietary period: Roman data will be made **immediately available**.

OBSERVING MODES



The Coronagraph Instrument has imaging, spectroscopic (R~50), and polarimetric capabilities. The current required and best effort "goal modes" of the Coronagraph are listed in the table below and respective modes, fields of view (to scale) and inner/outer working angles are represented with colored circles. All images and spectra are simulations.

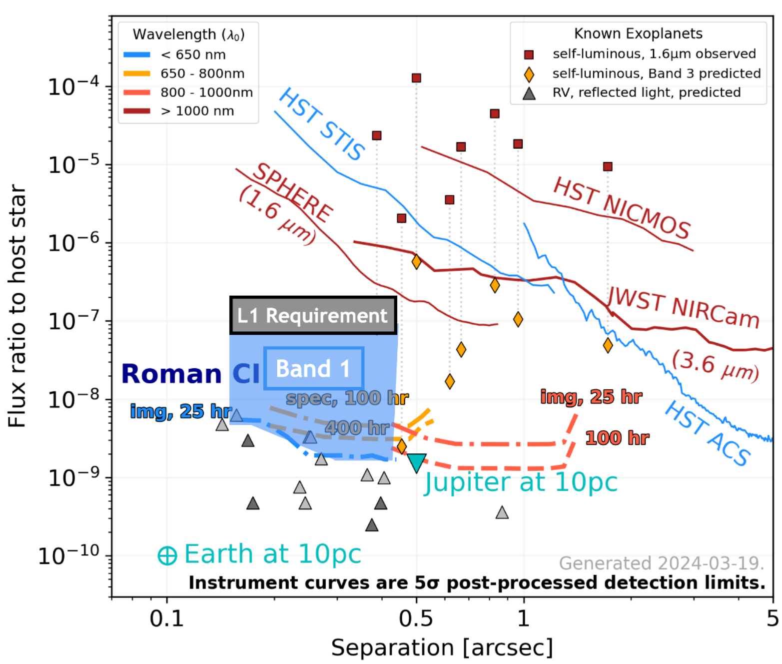
The only formal performance requirement for the Coronagraph Instrument is to be able to image a point source with a flux ratio of at least 10^{-7} at a separation of 6 – 9 λ/D from a star as faint as V = 5 in a 10% bandpass centered < 600 nm (Band 1). Thus, in order to reach this requirement, only observations in Band 1 with the hybrid Lyot coronagraph are formally supported; all other modes listed in the table below will be supported on a "best effort" basis.

Optical elements to enable potential additional "unsupported modes" exist (*e.g.*, Riggs et al. 2022, 2025) but currently there is no guarantee that any of these modes will be commissioned during the baseline observing phase.

Band	Central wavelength	Bandwidth	Mode	Mask Type	Azimutal Coverage	Support
1	**575 nm**	**10%**	**Narrow FoV Imaging**	**Hybrid Lyot**	**360º**	**Required** **(Imaging)** Best Effort (Polarimetry)
1	575 nm	10%	Wide FoV Imaging	Shaped Pupil	360º	Best Effort (Imaging & polarimetry)
3	730 nm	15%	Slit + R~50 Prism Spectroscopy	Shaped Pupil	2x65º	Best Effort
4	825 nm	10%	Wide FoV Imaging	Shaped Pupil	360º	Best Effort (Imaging & polarimetry)

CONTRAST REGIME

The Roman Coronagraph expected performance is highlighted in the blue region shown in the contrast curve plot below. The L1 Requirement (contrast better than 10^{-7} in Narrow-field Band 1 / 575 nm) is at the top of the blue region. The Coronagraph should yield contrasts 100 to 1000 times better than that obtained with current facilities and potentially enables imaging of mature Jupiters at 10-50 pc in reflected light.



For V~ 5 stars

The expected contrast is
< 10^{-7} (L1 requirement)
~ 10^{-8} - 10^{-9} (predicted/goal)

100 to 1,000 times better than current facilities. Optimistically, image mature "Jupiters" @ 10-50pc in reflected light!

TARGETS

The Roman Coronagraph targets will be selected to facilitate both technology demonstration and science cases across all available modes (imaging, spectroscopy, and polarimetry) with a target database maintained by the CPP. Target stars are required to have V magnitudes ≤ 5, though several magnitudes fainter may be possible. Stellar diameters < 2 mas are required to achieve the baseline contrast performance.

WAVEFRONT SENSING REFERENCE STARS

Roman Coronagraph Wavefront Sensing Reference stars are used to dig and maintain the dark hole to achieve the deepest possible contrast. They are also used to perform PSF subtraction and remove residual speckles via high-contrast data processing.

These Reference Stars must meet several criteria to mitigate performance degradation:

- **Single stars**: Otherwise, contaminants (stellar, substellar or extragalactic) in the vicinity of the reference star add photon noise and degrade the contrast performance.
- **Bright** (V mag < 3): To accelerate the "dark hole digging" and maximize the efficiency of the Coronagraph.
- **Small angular diameter**: Though spatially unresolved, the angular stellar diameter has to be small (typically < 2 mas) in order to not limit contrast performance (Krist et al., 2023).
- **Proximity** to the science target: There are observing and scheduling limitations to preserve thermal and hence, wavefront stability throughout the whole observing sequence.

As a result, the current suitable reference stars are dominated by B-type stars, whose measured binary fraction is of the order of 90%.

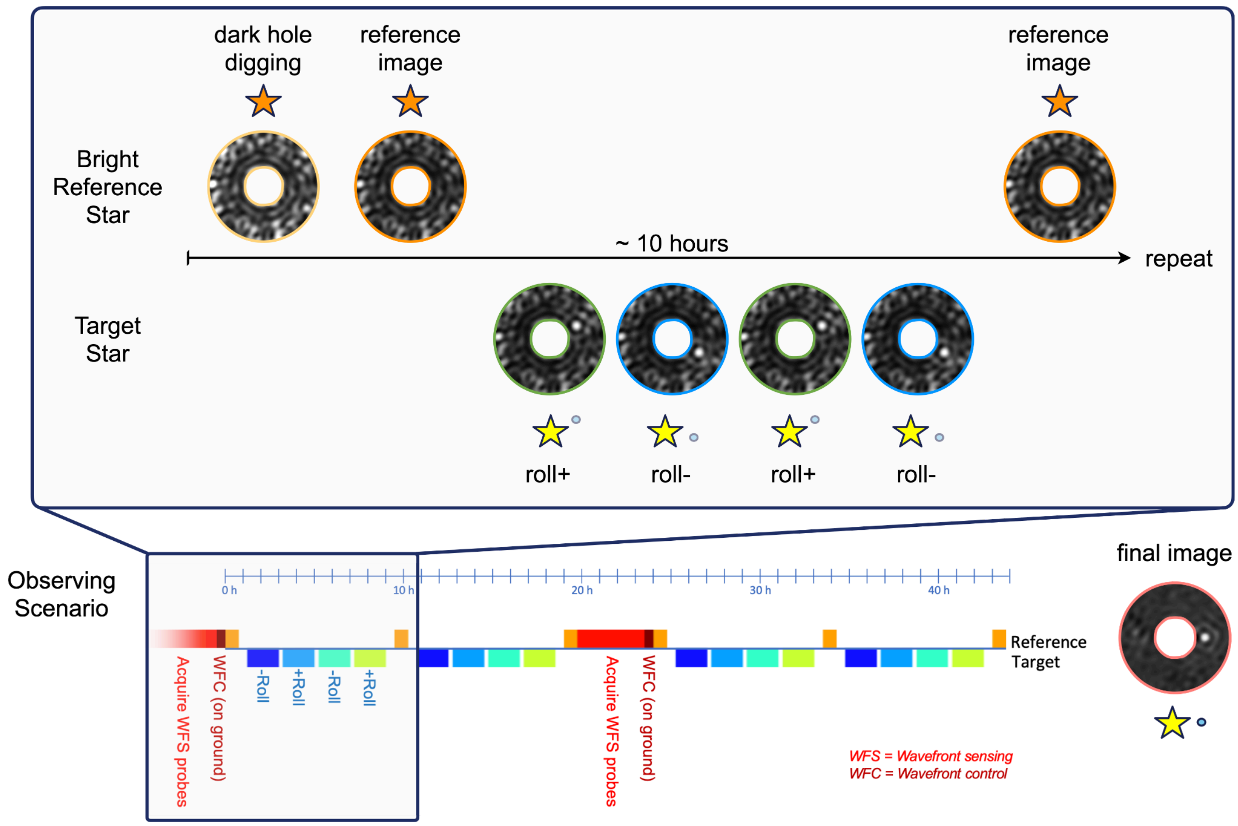
The CPP is conducting several vetting campaigns using adaptive optics and interferometric facilities to assess the suitability of about 50 stars that have been preselected.

The current list of wavefront sensing reference stars in the process of vetting is available in this table. They are distributed nearly in all directions of the sky (with some gaps) and a few are located in the continuous viewing zones (100% observability).

OBSERVING SCENARIO

In order to correct the wavefront and dig the high-contrast dark hole, each observing sequence incorporates a series of observations of both the target and a bright reference star. Both target and reference stars are also observed at different telescope roll angles to decorrelate real companions from instrumental speckles.

What a typical observation sequence looks like for reflected light planets:



The observatory can roll up to ±15º and allow for angular differential imaging (ADI). A reference star image (with the same speckle residual pattern) is subtracted from each roll and the final image is a combination of ADI and reference differential imaging (RDI). The wavefront sensing is performed on a bright reference star and the "dark hole" (deepest contrast) is obtained via wavefront control with the deformable mirrors. The high order control commands are calculated on the ground. In the notional observing scenario shown above, the Roman Coronagraph will achieve ~ 14 hrs of integration time on the science target per 24 hrs (Krist et al. 2023), not accounting for the initial dark hole digging but only wavefront correction "touch up" rounds.

COMMUNITY PARTICIPATION PROGRAM (CPP)

In preparation for the operational phase of the Nancy Grace Roman Space Telescope, NASA has created the Coronagraph Community Participation Program (CPP) to prepare for and execute Coronagraph Instrument observations. The CPP is currently composed of 7 small, US-based teams, members of the Roman Project Team, and international partner teams from ESA, JAXA, CNES, and the Max Planck Institute for Astronomy. The primary goals of the CPP are to prepare tools, target databases, and data reduction software for the execution of the Coronagraph Instrument observation phase. The CPP's core working groups focus on Observation Planning and Calibration, Data Reduction Pipeline (DRP) and Simulations, Hardware and Polarimetry.

POINTS OF CONTACTS / QUESTIONS

Vanessa Bailey (JPL / CTC / CPP co-chair)
& Maxwell Millar-Blanchaer (UCSB / CPP co-chair) - cpp-co-chairs@jpl.nasa.gov

Alexandra Greenbaum (IPAC / SSC) - azg@ipac.caltech.edu

Julien Girard (STScI / SOC) - jgirard@stsci.edu

Schuyler Wolf (U. of Arizona / CPP Observation Planning) - sgwolff@arizona.edu

LINKS & RESOURCES

Roman Coronagraph at NASA
science.nasa.gov/mission/roman-space-telescope/coronagraph/

Key Technical Resources about Roman:
roman.gsfc.nasa.gov/science/technical_resources.html

Research and Support Participation Opportunities (ROSES) Document Library and Additional Resources: https://roman.gsfc.nasa.gov/science/roses.html

Simulations at IPAC roman.ipac.caltech.edu/sims/Simulations_csv.html

Target Database curated by the Space Imaging and Optical Systems Lab (Cornell):
plandb.sioslab.com

Current list of wavefront sensing reference stars in the process of vetting:
https://docs.google.com/spreadsheets/d/1p5r0VmjBCjXU25daJl5oJOPoPh1V79nuESbnwmca0s0/edit?gid=881077142#gid=881077142

The Roman Exoplanet Imaging Data Challenge exoplanetdatachallenge.com
and legacy tutorial https://www.exoplanetdatachallenge.com/tutorial

Roman Coronagraph Technical Parameters:
https://roman.ipac.caltech.edu/sims/Param_db.html#coronagraph_mode

DEFINITIONS & ACRONYMS

FoV= Field of View
IWA = Inner Working Angle
OWA = Outer Working Angle
Dark hole = The deepest contrast FoV of a given mode, the zone defined by IWA and OWA and where the wavefront control is effective.

PSF = Point Spread Function
ADI = Angular Differential Imaging
RDI = Reference Differential Imaging

HLC = Hybrid Lyot Coronagraph
SPC = Shaped Pupil Coronagraph
EMCCD = Electron Multiplying CCD

CPP = Community Participation Program
CTC = Coronagraph Technology Center (based at JPL)
SSC = Science Support Center (based at IPAC)
SOC = Science Operations Center (based at STScI)
CorGI-DRP = Coronagraph Instrument Data Reduction Pipeline (in development)
OS11 = Observing Scenario 11, an Observation Cycle Concept, with exposures from Reference and Target Star pairs.

REFERENCES

Here is a list of recent references for the Roman Coronagraph. A special issue in JATIS is anticipated in 2025.

1. Riggs et al. 2025 (Flight Masks for the Roman Coronagraph; submitted)
2. Altinier et al. 2024 SPIE (Roman Simulator for Post-Processing Development) https://ui.adsabs.harvard.edu/abs/2024SPIE13092E..58A/abstract
3. Anche et al. 2024 SPIE (Simulation of Polarimetric Observations) https://ui.adsabs.harvard.edu/abs/2024SPIE13092E..57A/abstract
4. Choquet et al. 2024 SPIE (Novel Observing and Post-Processing Strategies) https://ui.adsabs.harvard.edu/abs/2024SPIE13092E..6IC/abstract
5. Lau et al. 2024 SPIE (Testing of Novel Observing Strategies on a Testbed) https://ui.adsabs.harvard.edu/abs/2024SPIE13092E..6JL/abstract
6. Millar-Blanchaer et al. 2024 SPIE (CPP: Data Reduction and Simulations) https://ui.adsabs.harvard.edu/abs/2024SPIE13092E..56M/abstract
7. Poberezhskiy et al. 2024 SPIE (Status after Instrument Level Test Completion) https://www.spiedigitallibrary.org/conference-proceedings-of-spie/13092/130921H/Roman-coronagraph-status-at-the-completion-of-instrument-level-test/10.1117/12.3033229.short
8. Savransky et al. 2024 SPIE (The Roman Coronagraph CPP) https://ui.adsabs.harvard.edu/abs/2024SPIE13092E..1IS/abstract
9. Wolff et al. 2024 SPIE (CPP: Observation Planning) https://ui.adsabs.harvard.edu/abs/2024SPIE13092E..55W/abstract
10. Anche et al. 2023 (Simulation of polarimetric observations) https://ui.adsabs.harvard.edu/abs/2023PASP..135l5001A/abstract
11. Bailey et al. 2023 SPIE (Coronagraph instrument overview and status) https://ui.adsabs.harvard.edu/abs/2023SPIE12680E..0TB/abstract
12. Krist et al. 2023 JATIS (End-to-End Numerical Modeling) https://ui.adsabs.harvard.edu/abs/2023JATIS...9d5002K/abstract
13. Douglas et al. 2020 PASP (Exozodi Science Yields and Impact) https://ui.adsabs.harvard.edu/abs/2022PASP..134b4402D/abstract
14. Zellem et al. 2022 SPIE (Calibration Plan) https://ui.adsabs.harvard.edu/abs/2022SPIE12180E..1ZZ/abstract
15. Riggs et al. 2022 SPIE (Flight Mask Designs) https://ui.adsabs.harvard.edu/abs/2021SPIE11823E..1YR/abstract
16. Mennesson et al. 2021 SPIE (Current Status and Relevance to Future Missions) https://ui.adsabs.harvard.edu/abs/2021SPIE11823E..10M/abstract
17. Poberezhskiy et al. 2022 SPIE (Engineering Overview and Status) https://ui.adsabs.harvard.edu/abs/2022SPIE12180E..1XP/abstract
18. Girard et al. 2020 SPIE (Imaging Data Challenge) https://ui.adsabs.harvard.edu/abs/2020SPIE11443E..37G/abstract