NASA's future direct imaging facilities: Nancy Grace Roman Space Telescope &

the Habitable Worlds Observatory mission concept

Vanessa Bailey

Jet Propulsion Laboratory

California Institute of Technology

Sagan Summer Workshop - July 25, 2025

How do we **characterize** solar system twins?

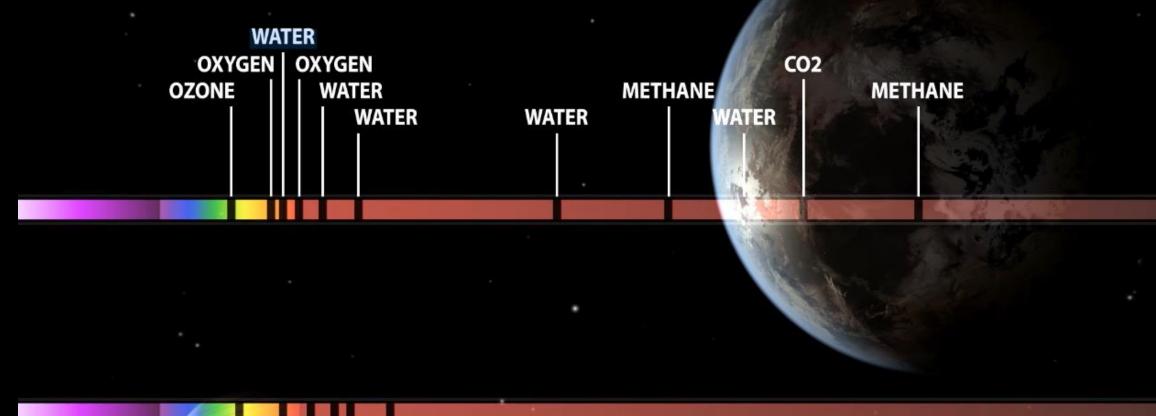
(similar planet masses/orbits, Sun-like host)

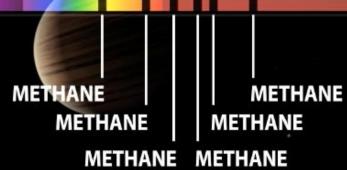
What will it take to find Earth 2.0?

(Earth-like planet orbiting Sun-like host)

Caution: smaller sample sizes ahead!

Atmospheric composition with reflected light spectroscopy







Living Worlds Working Group

Explore finding & characterizing potentially habitable exoplanets and searching them for the

possibility of life with HWO

Co-Chairs



Giada Arney (GSFC)



Niki Parenteau (Ames)







Ravi Kopparapu



Jake Lustig-



Mark



Garima Singh



Biosignature Possibilities

Eddie Schwieterman (UC Riverside)

Sara Walker (ASU)

Sukrit Ranjan



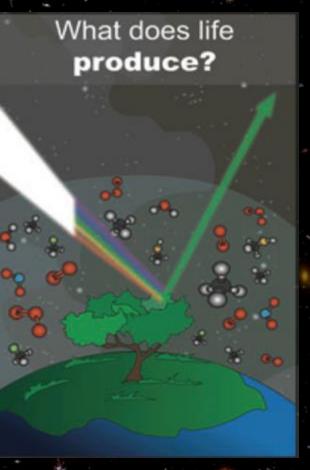
Clara Sousa-Silva

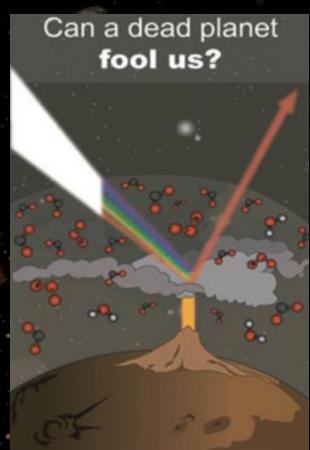


Biosignature Interpretation Stephanie Olson (Purdue) Josh Krissansen-Totton (U of Washington



Target Stars & Systems Eric Mamajek (JPL) Natalie Hinkel (Lousiana State)



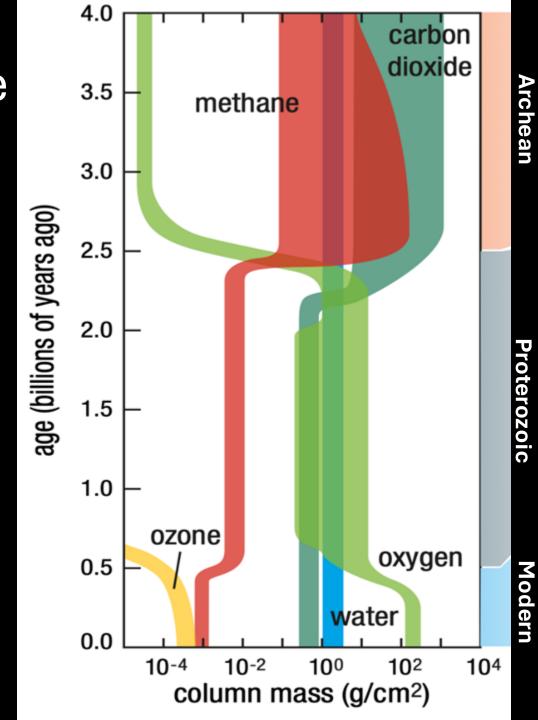




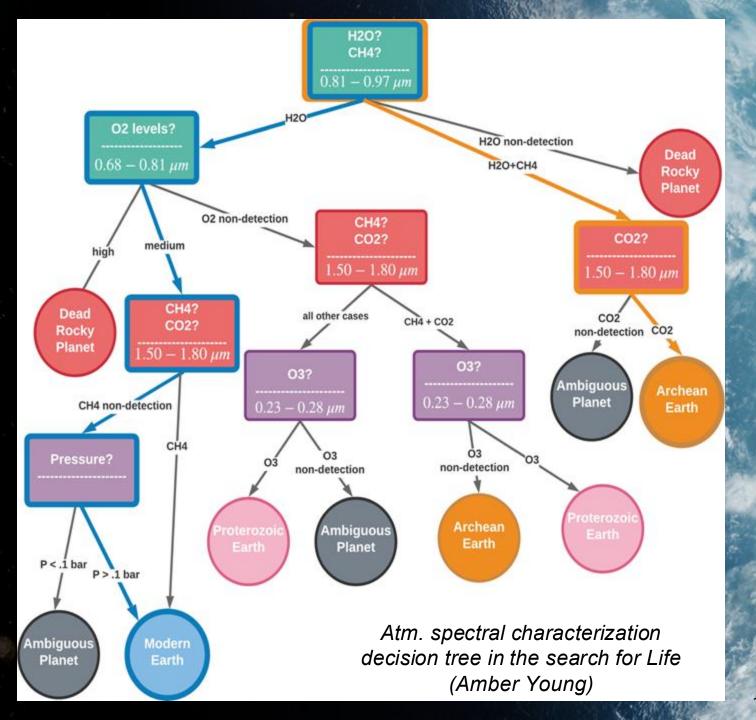


Ratio of key gases changed dramatically over Earth's lifetime

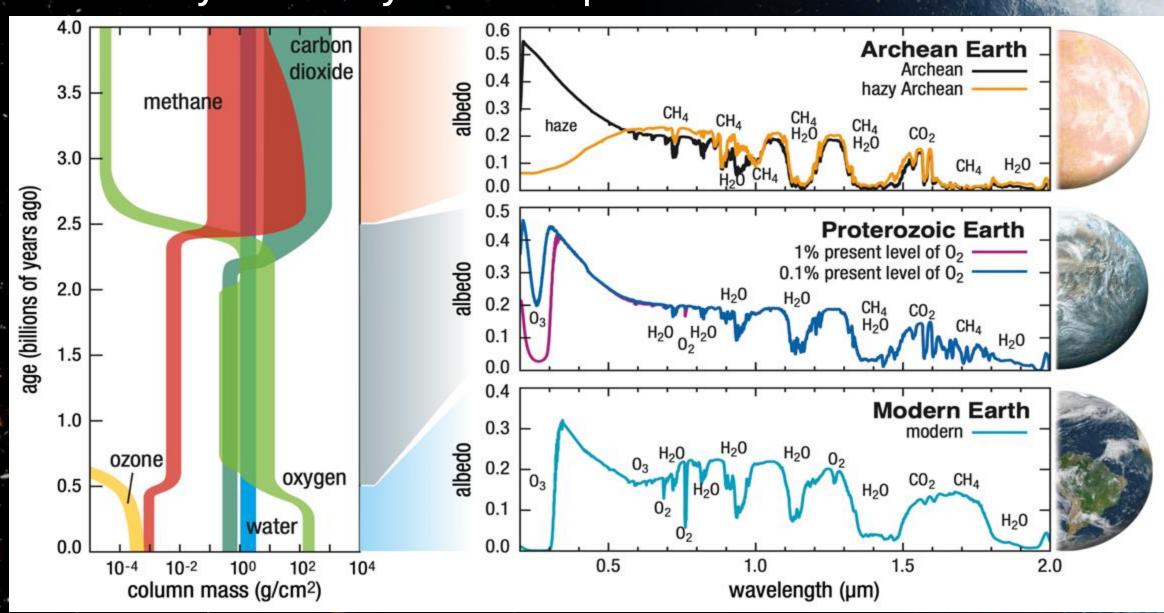
- Archean (prokaryotes & early photosynthesis): CO2 + CH4 rich
- **Proterozoic**: eukaryotes & early multicellular organisms begin to oxygenate atmosphere
- Modern: abundant multicellular life further raises oxygen

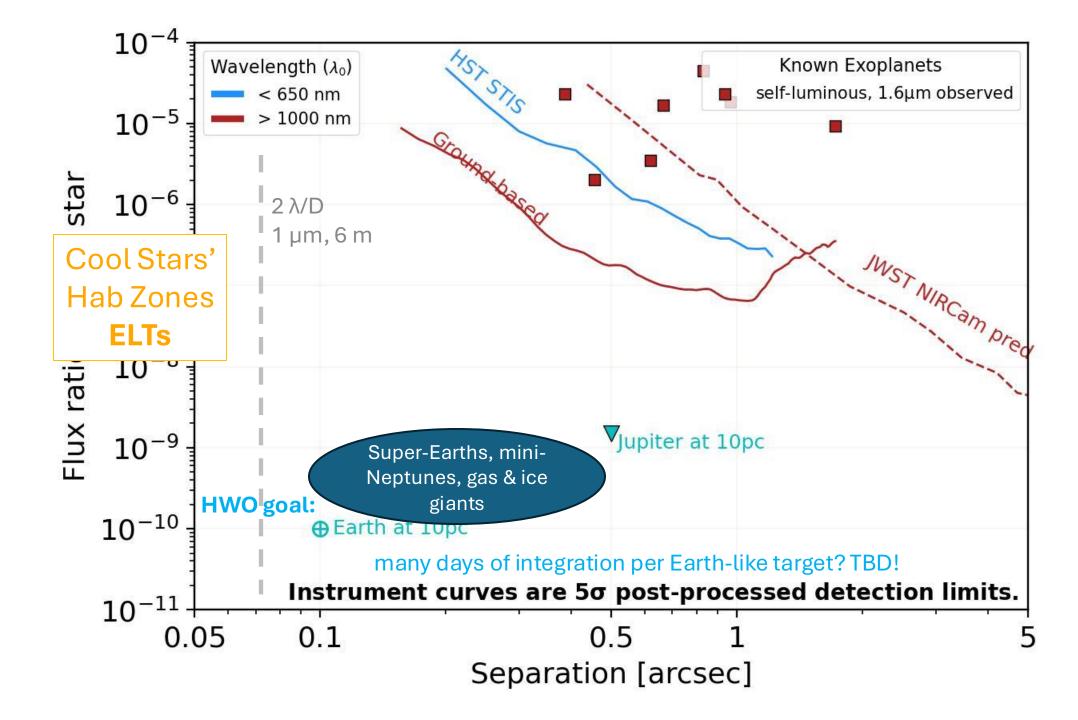


Earth-like planet atmosphere characterization is complex & requires multiwavelength observations



sensitivity to variety of atmospheres: UV – NIR





SOLAR SYSTEMS IN CONTEXT WORKING GROUP

Explore UVOIR imaging and spectroscopy of Solar System objects at all scales, along with exoplanet observations to understand the full range of planet possibilities and histories

Co-Chairs



Evgenya Shkolnik (Arizona State)



Tyler Robinson (U of Arizona)

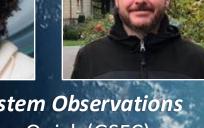


Characterizing Exoplanets Renyu Hu (JPL) Michiel Min (SRON)



Birth & Evolution Meredith MacGregor (JHU) Yasuhiro Hasegawa (JPL)





Solar System Observations Lynnae Quick (GSFC) Richard Cartwright (JHU-APL)





Demographics & Architectures Jessie Christiansen (NExScI) Malena Rice (Yale)

UV-NIR imaging + spectroscopy capabilities would also enable comparative planetology

What is the nature of planets in the 1.4 – 2.6 Re size range?

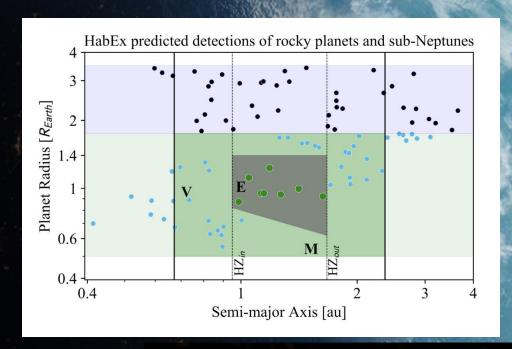
How do planets form and grow within their birth environments?

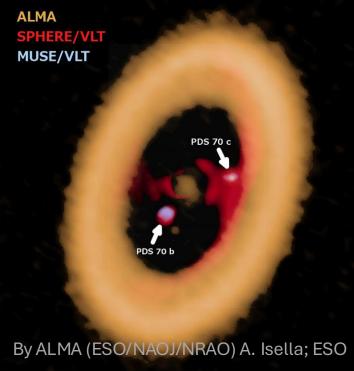
...and more!

adapted from slides from SSIC WG & B. Mennesson



Credit: NASA, ESA, A. Simon

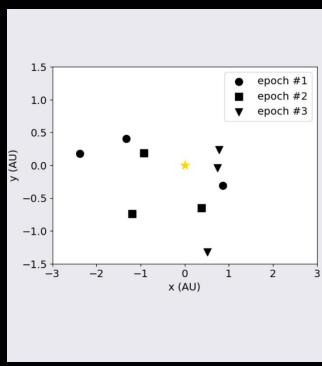




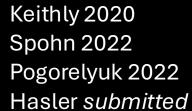
Habitable Worlds Observatory Simulated Solar System Time-lapse Observed from 33 light-years away Time = 10 years, 1 second = 72 days

New observing challenges for reflected light multi-planet systems: phase functions & confusion

New observing challenges for reflected light multiplanet systems: confusion & observation scheduling



- Multi-epoch imaging needed to increase likelihood of detection in blind search
 - Multi-band photometry and self-consistent orbit fitting needed for deconfusion
 - RV constraints





Some of the technology challenges ahead

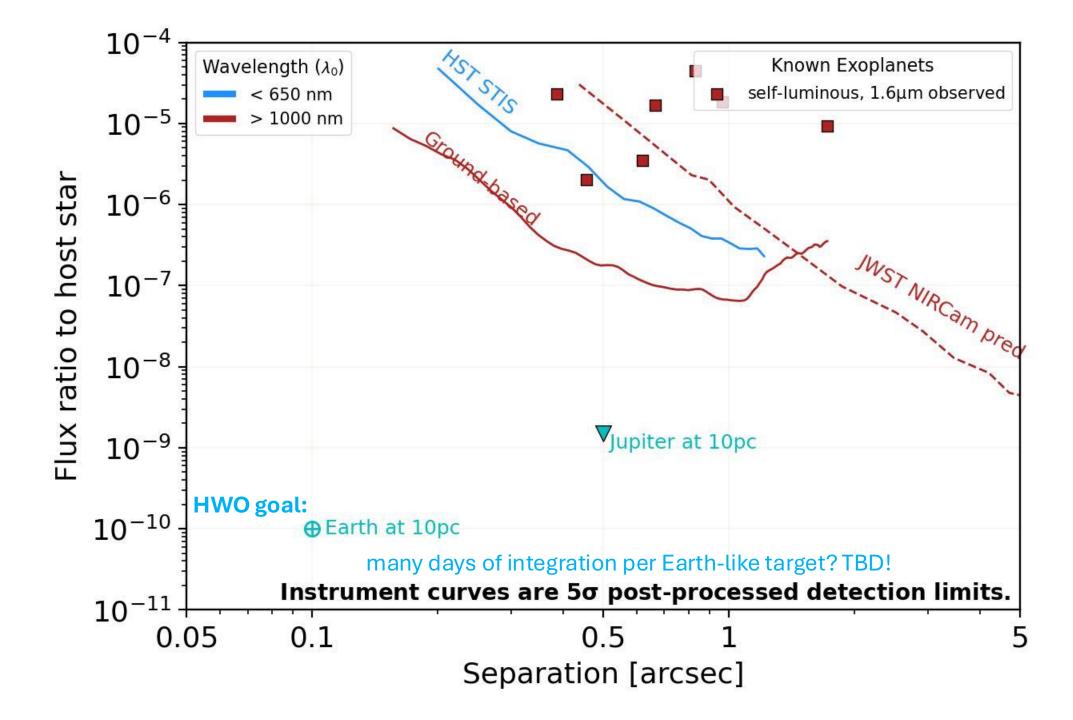
- No single direct imaging instrument can collect UV NIR imaging and spectra. 3-instrument/channel concept:
 - visible light imager + R~140 spectrograph
 - UV imager
 - NIR R~70 spectrograph
- Starlight suppression ~1E-10 at <~2 lambda/D
 - Ultrastable telescope
 - Advanced coronagraph masks and wavefront control
 - see Mennesson 2024 and Kenworthy 2024 review articles
 - Ultra low noise detector (planets are VERY faint)

Learn more next week!



https://habitableworldsobservatory.org/resources/events

Plenary sessions will live stream on the STScI Research YouTube Channel



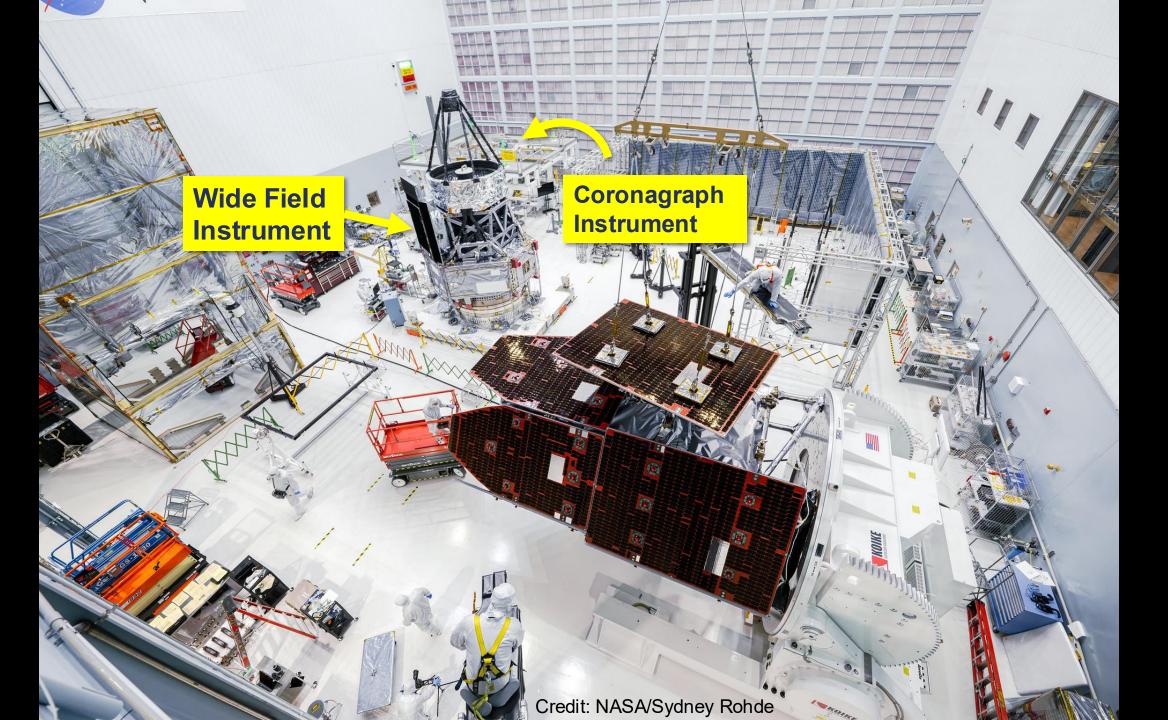
NANCY GRACE ROMAN

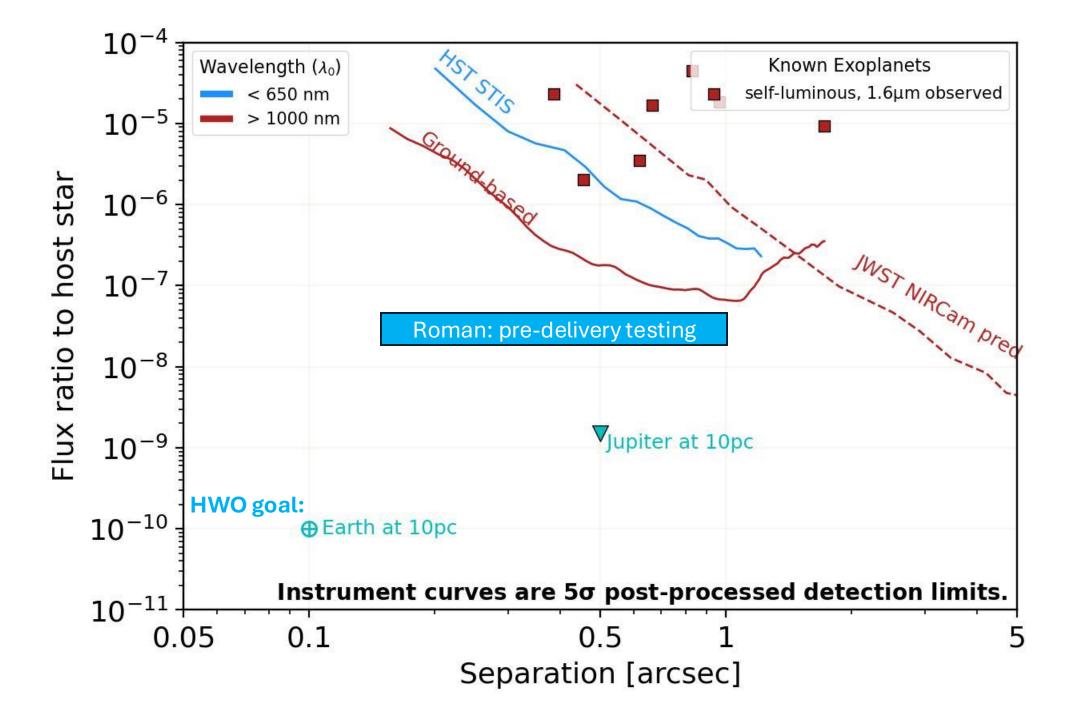
SPACE TELESCOPE

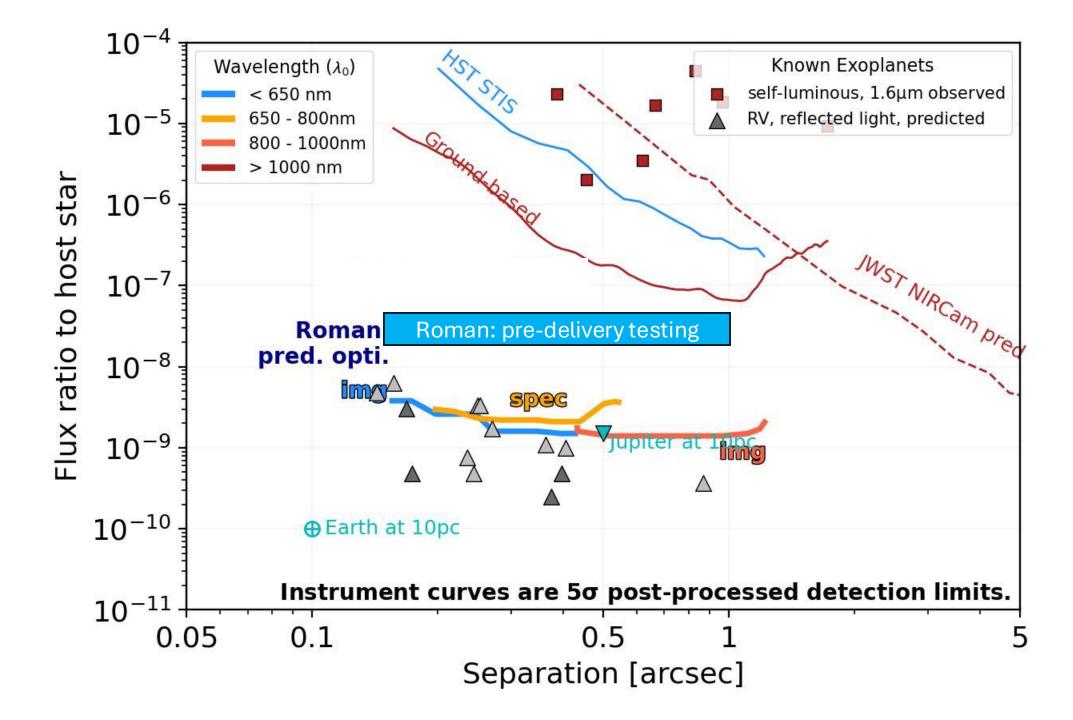
Formerly **WFIRST**

Launch ≤ May 2027; planning for Sept/Oct 2026









Roman Coronagraph is a "technology demonstrator" stepping stone to HWO

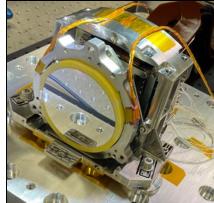
See 2025 JATIS special issue(s)

Journal of Astronomical Telescopes,

SPIE

Control wavefront to <10 pm RMS

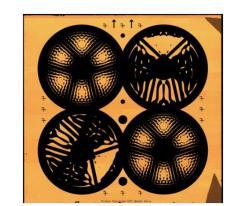
Large-format
Deformable Mirrors



High-contrast Coronagraph Masks

Suppress starlight by

~100 million



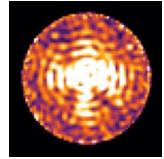
Ultra-low-noise Photon-counting EMCCDs

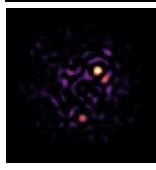


Count individual planet photons as they arrive (1 per 10-100 sec)

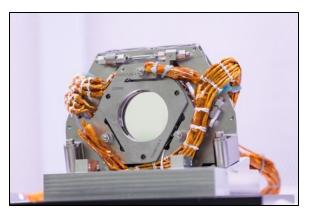
Planets > 100 million x fainter than their stars

Data Post-Processing





Ultra-Precise
Wavefront Sensing
& Control
(now Ground-In-The-Loop)





1 fully supported mode

Additional "best effort" modes: spectroscopy & polarimetry



Band	λ_{center}	BW	Mode	FOV radius	FOV Coverage	Pol?	Coronagraph Mask Type	Support
1	575 nm	10%	Narrow FOV Imaging	0.15" - 0.45"	360°	Υ **	Hybrid Lyot	Req'd
1	575 nm	10%	"Wide" FOV Imaging	0.45" — 1.4"	360°	Υ	Hybrid Lyot	Best Effort
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°	Υ	Shaped Pupil	Best Effort

[&]quot;Best effort" modes will not be end-to-end performance tested prior to delivery & do not have guaranteed support on-orbit.

** Polarimetry in Band 1 is 'best effort'

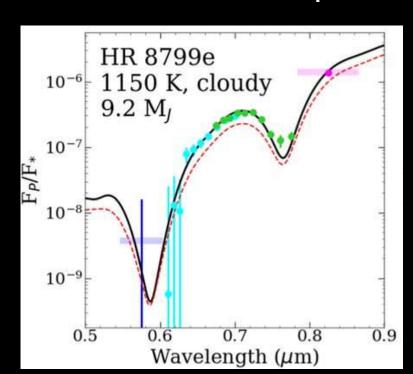
Observation Plan for the Coronagraph "Observation Phase"



- Baseline: 2200hr (90 days) during first 18mo of Mission
 - Launch no later than May 2027, currently expected in Oct. 2026
- 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 and commission additional observing modes
 - Maximize long-term science and technology value
- Prioritize scientifically-interesting targets when possible
- Roman data has no proprietary period

Opportunities in Exoplanet Science Young Jupiters

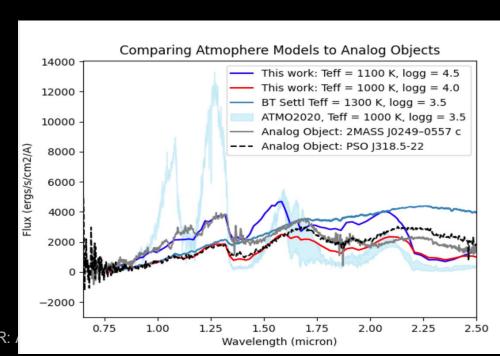
- young, self-luminous super-Jupiters
 - State of the Art (SOTA): Infrared photometry & spectroscopy
 - Roman Coronagraph: add visible light photometry & lowresolution spectroscopy (eg: Lacy & Burrows 2020)



Lacy & Burrows, 2020, *ApJ*, 892, 151

Zarah Brown, in prep

Jupiter thermal IR:



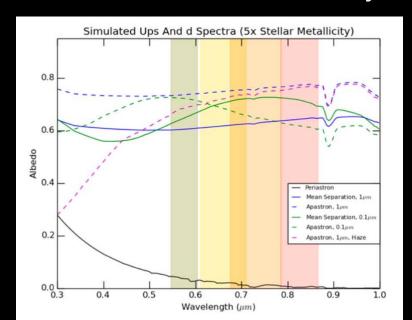
Opportunities in Exoplanet Science Cold, mature Jupiter analogs

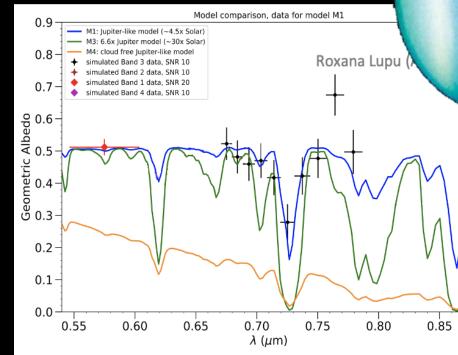
• SOTA: indirect detection only; no characterization

• Roman Coronagraph: potential for 1st images & low-resolution spectrum (eg: Batalha+2018, Saxena+2021)

Cloudy or clear?

Super-solar or solar metallicity?



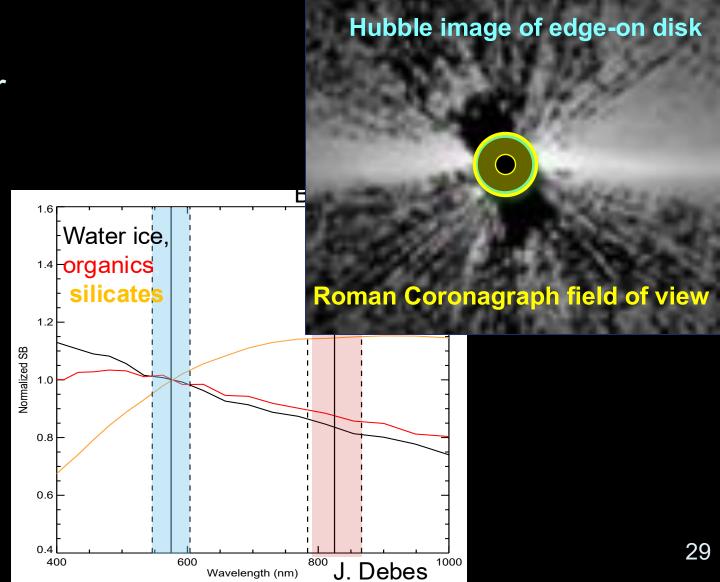


Saxena+2021

Opportunities in circumstellar disk science low surface-brightness debris disks



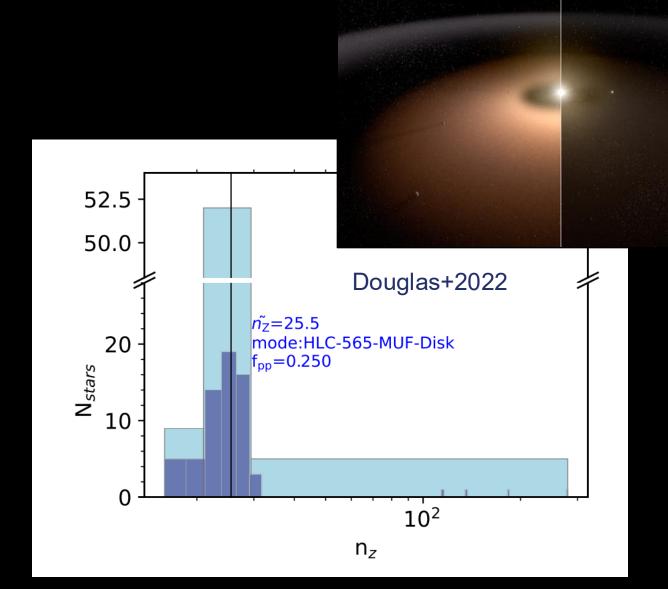
- SOTA: Hubble ~white light imaging (sensitive, worse inner working angle); ground-based AO facilities (high-resolution, less sensitive)
- Roman: Observe closer to the star, in polarimetry, multiple color filters
 - (Mennesson+2018, Anche+2023)



Opportunities in circumstellar disk science Terrestrial zone dust (exozodi)



- terrestrial zone dust
 - **SOTA**: IR excesses
 - Roman: potential for first visible-light image
 - Are any HWO high-priority systems too dusty?
 - (Douglas+2022)



We want your input: whitepapers due Aug 7



- No GO program for Coronagraph Instrument, so this whitepaper call solicits community input into the observing program
 - No proprietary period: observation data will be open to all
- Whitepapers can influence priorities and even suggest specific targets
- https://www.romancoronagraph.space/
 - whitepaper template
 - town hall recordings
 - more information about Roman & the Coronagraph Instrument



Summary

- Long-term vision: survey dozens of Sun-like stars to discover life
- Habitable Worlds Observatory concept aims to image Earth analogs that are
 ~10 billion times fainter than their stars
 - UV NIR offers sweet spot of spatial resolution and sensitivity to biosignature gasses
 - would also be a powerful tool for comparative planetology
 - listen to the HWO livestreamed conference plenaries next week!
- Nancy Grace Roman Space Telescope will launch in <2 years with a visiblelight Coronagraph Instrument onboard
 - capable of imaging planets and circumstellar disks that are 10 100+ million times fainter than their stars
 - data will have no proprietary period; submit your ideas to the whitepaper call by Aug 7
 - romancoronagraph.space