Habitable Worlds Observatory

Laurent Pueyo, STScI

Journees SF2A

June 21st 2023

Programmatic update

Key science

Key technologies

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Key science

Key technologies

NASA official posture can be found at

https://science.nasa.gov/science-pink/s3fs-public/atoms/files/AAS_Jan2023_final_online.pdf

National Aeronautics and Space Administration

NASA

EXPLORE SCIENCE

NASA Townhall

Dr. Mark Clampin

Astrophysics Division Director

NASA Science Mission Directorate

241st AAS Meeting

Seattle / January 9, 2023

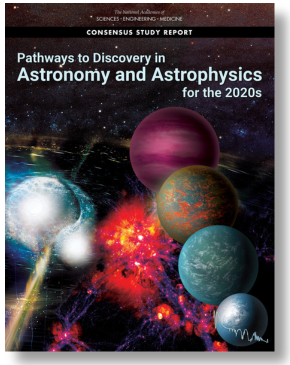
Astro2020 Primary Recommendation

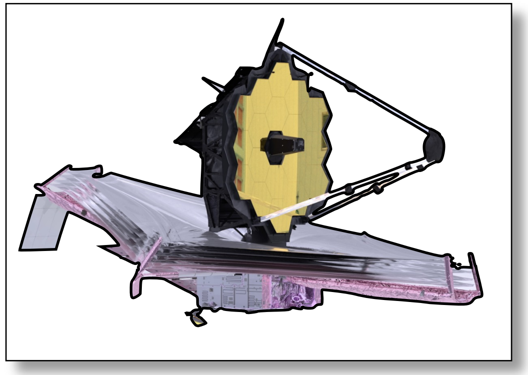
- Infrared / Optical / UV space telescope with ~ 6-m inscribed diameter to search for life on exoplanets and enable transformative astrophysics

The Habitable Worlds Observatory

- Primary technical requirements for coronagraphic survey are:
  - System-level stability at ~ picometer-level
  - Coronagraphic contrast ≥ 10^{10}

- Strategic guidance





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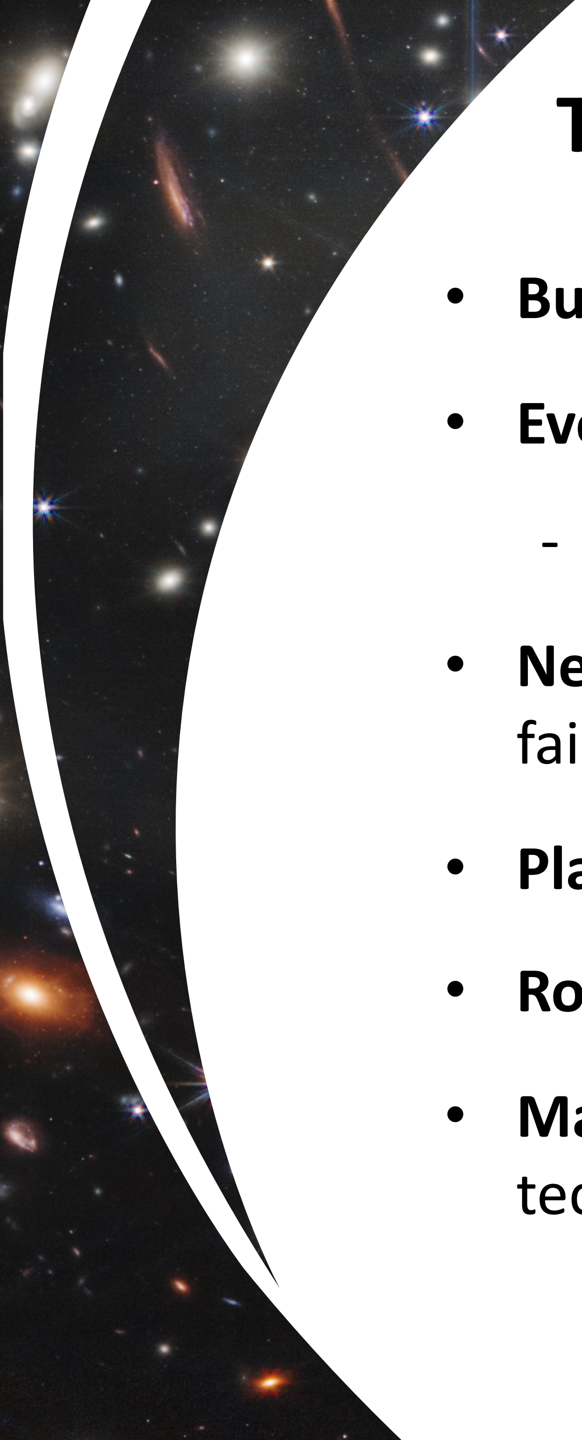

The Habitable Worlds Observatory: *The Big Picture*

- **Build to schedule**: Mission Level 1 Requirement e.g Planetary missions
- **Evolve technology**: Build upon NASA investments i.e.
  - JWST segmented optical system, Roman coronagraph, & Sensors
- **Next Generation Rockets**: Leverage opportunities offered by large fairings to facilitate mass & volume trades
- **Planned Servicing**: Robotic servicing at L2
- **Robust Margins**: Design with large scientific and technical margins
- **Mature technologies first**: Reduce risk by fully maturing the technologies prior to development phase.

https://science.nasa.gov/science-pink/s3fs-public/atoms/files/AAS_Jan2023_final_online.pdf

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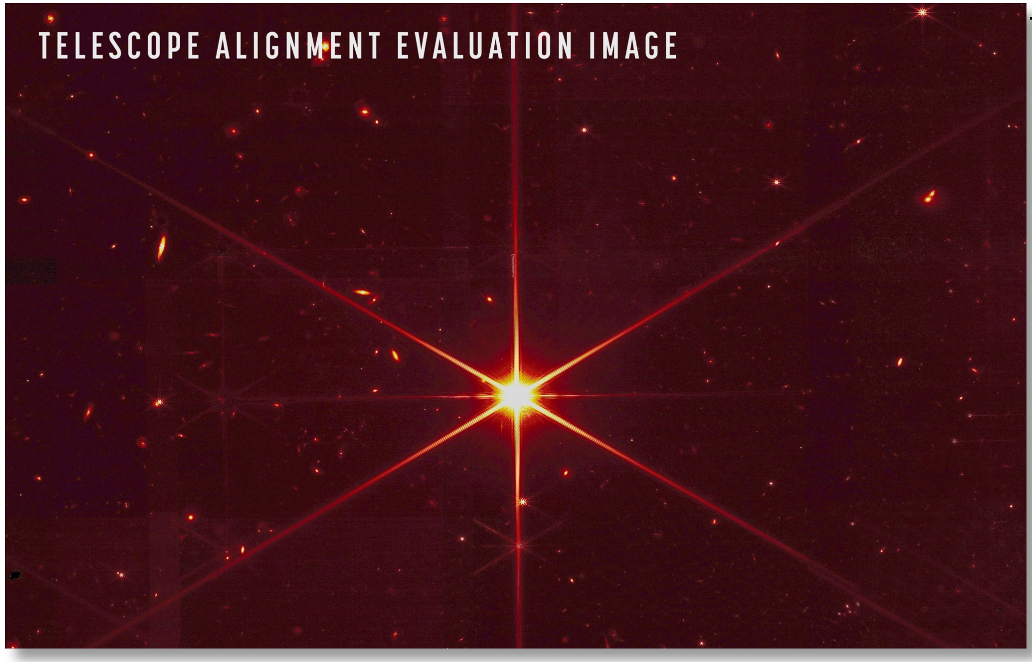
One year from JWST Launch

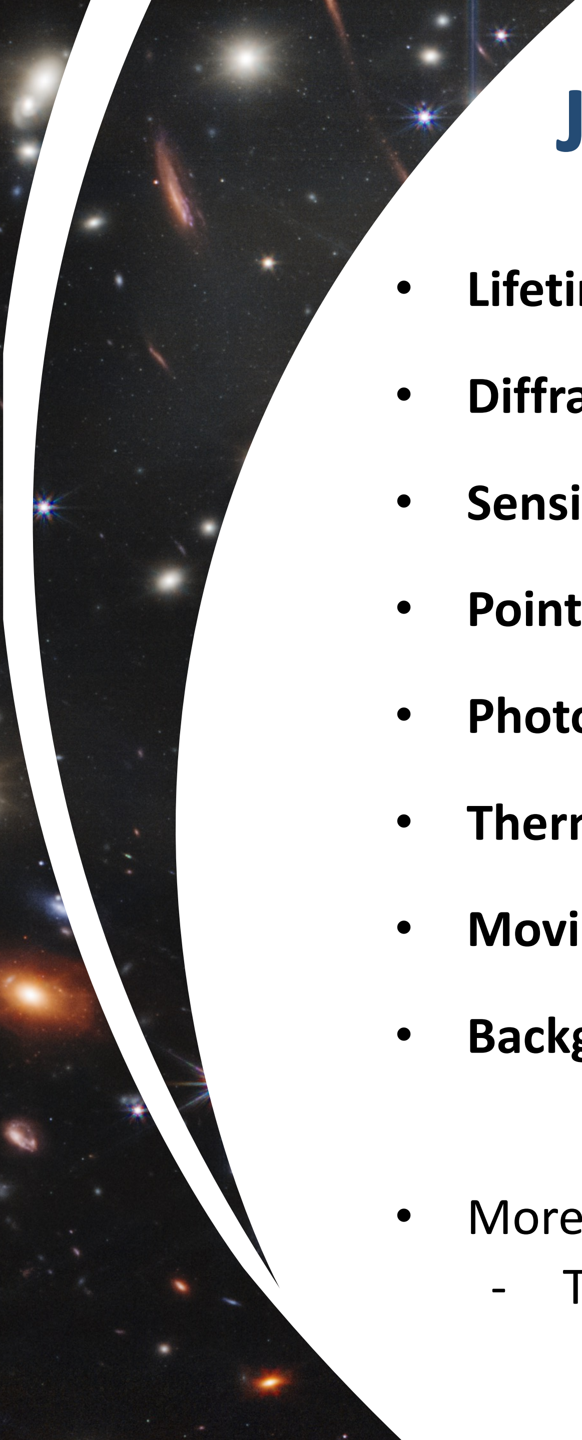
JWST was launched on an Ariane 5 Dec 25, 2021. Credit: NASA/Chris Gunn



JWST's first light image with 18 mirror segments phased

2023 Plans

- Science Operations
- 15-Jan-2023 Cycle 2 proposals due
- 15-Nov-2023 Cycle 3 proposal call release



JWST Performance Metrics

https://science.nasa.gov/science-pink/s3fs-public/atoms/files/AAS_Jan2023_final_online.pdf

- **Lifetime**: > 2x initial goal (10 yr), 4x requirement based on propellant
- **Diffraction limit**: 1.1 µm vs 2 µm requirement
- **Sensitivity**: ~35% better than requirement (NIRCam W)
- **Pointing Stability**: Factor of ~6-7 better than requirement (achieving 1 mas
- **Photometric Stability**: better than 1%
- **Thermal Stability**: within 40mK noise of the sensors
- **Moving Target Tracking**: > 2x required rate (req:30 mas/sec)
- **Backgrounds**: NIR (lower than predicted), MIR (as predicted)

- More details of observatory performance will be discussed in the JWST Town Hall
  - Tonight at 6:30pm

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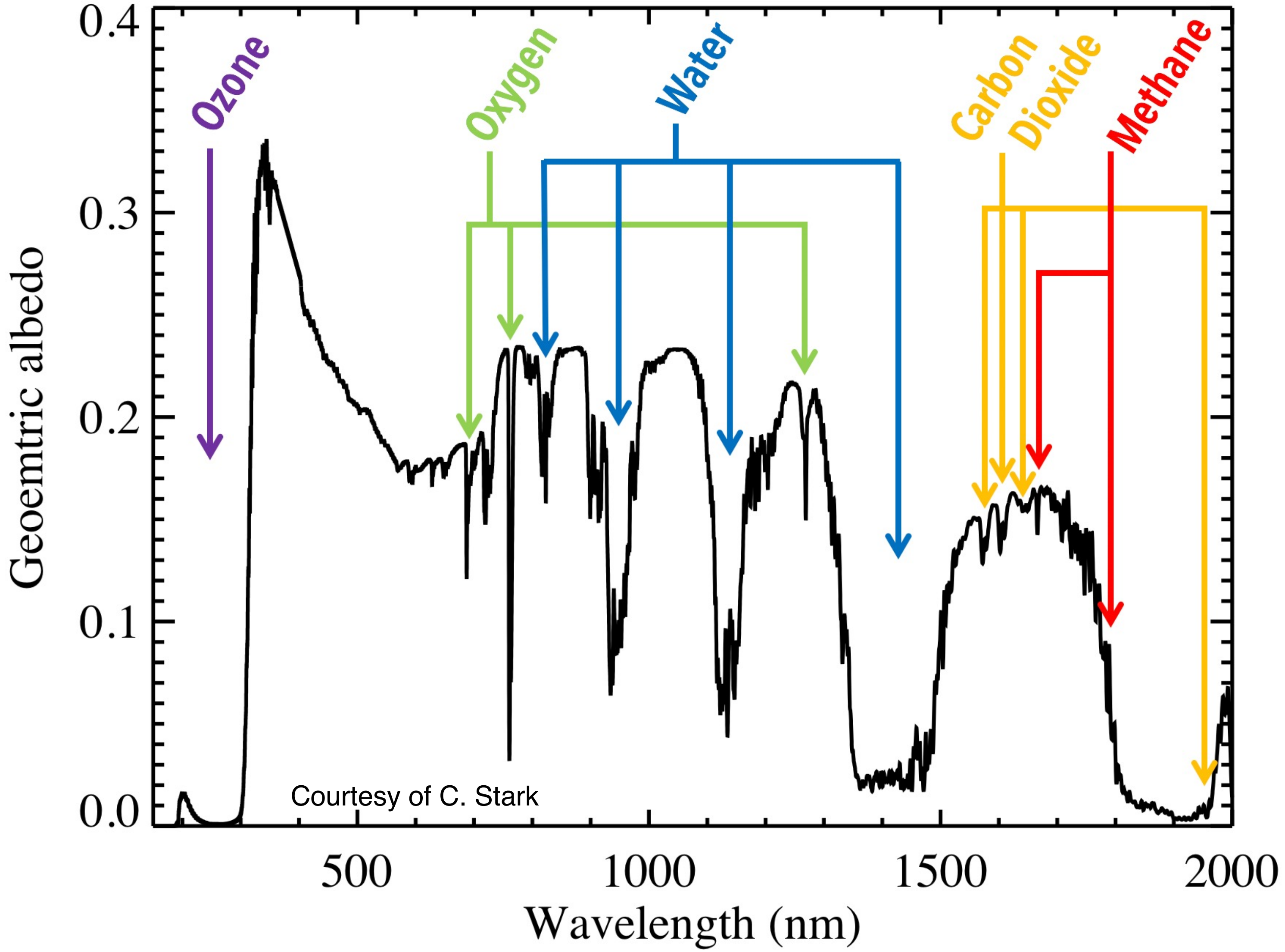
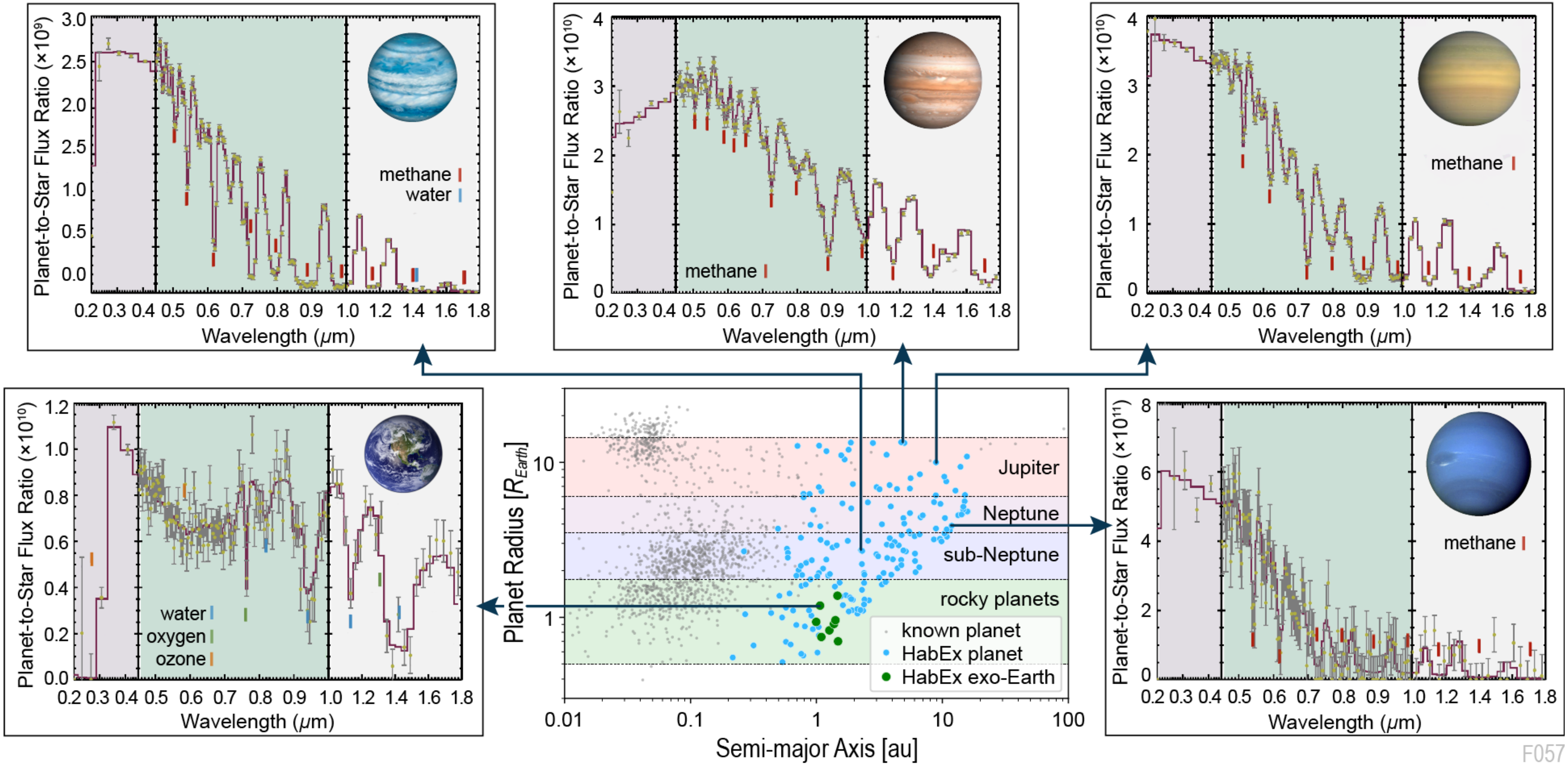
Astro 2020 goal: complete survey of 100 nearby habitable zones.



HabEx concept, Astro 2020 input:

- Multi-epoch reconnaissance of nearby stars using a coronagraph between 0.6 and 0.8 microns
- Dedicated follow up with UV-Vis-nearIR starshade

What can we do with HabEx?



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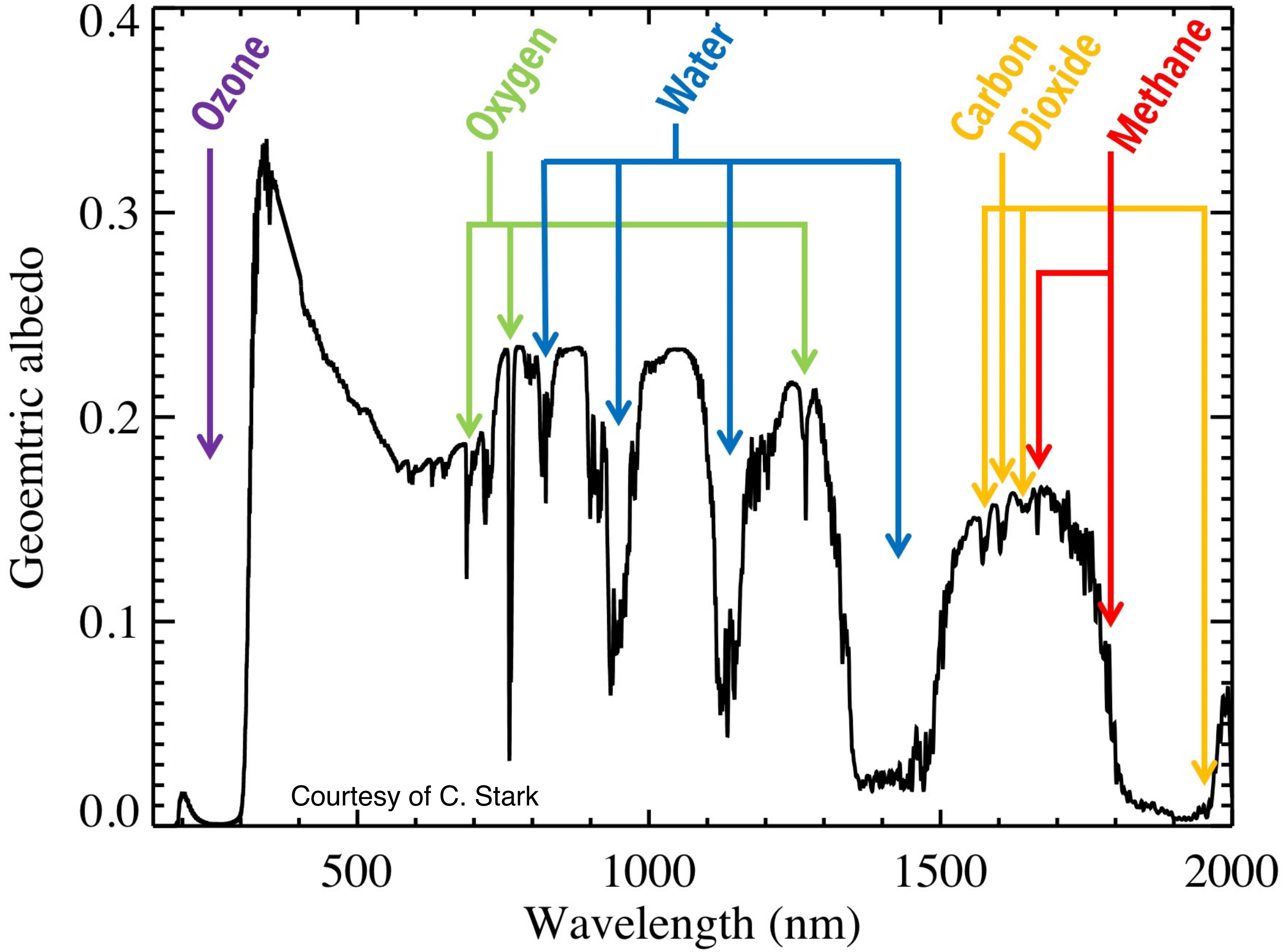
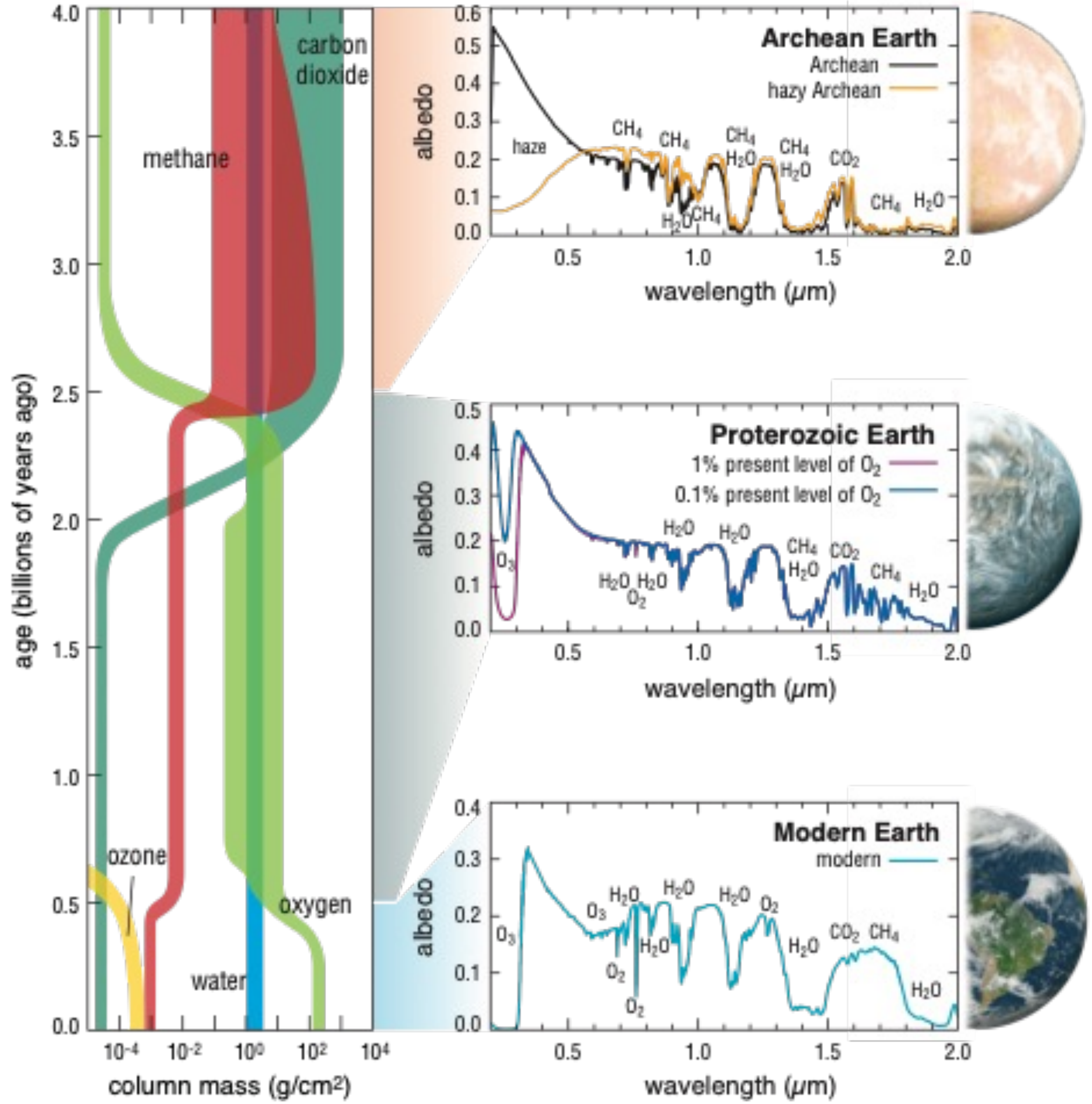
Astro 2020 goal: complete survey of 100 nearby habitable zones.

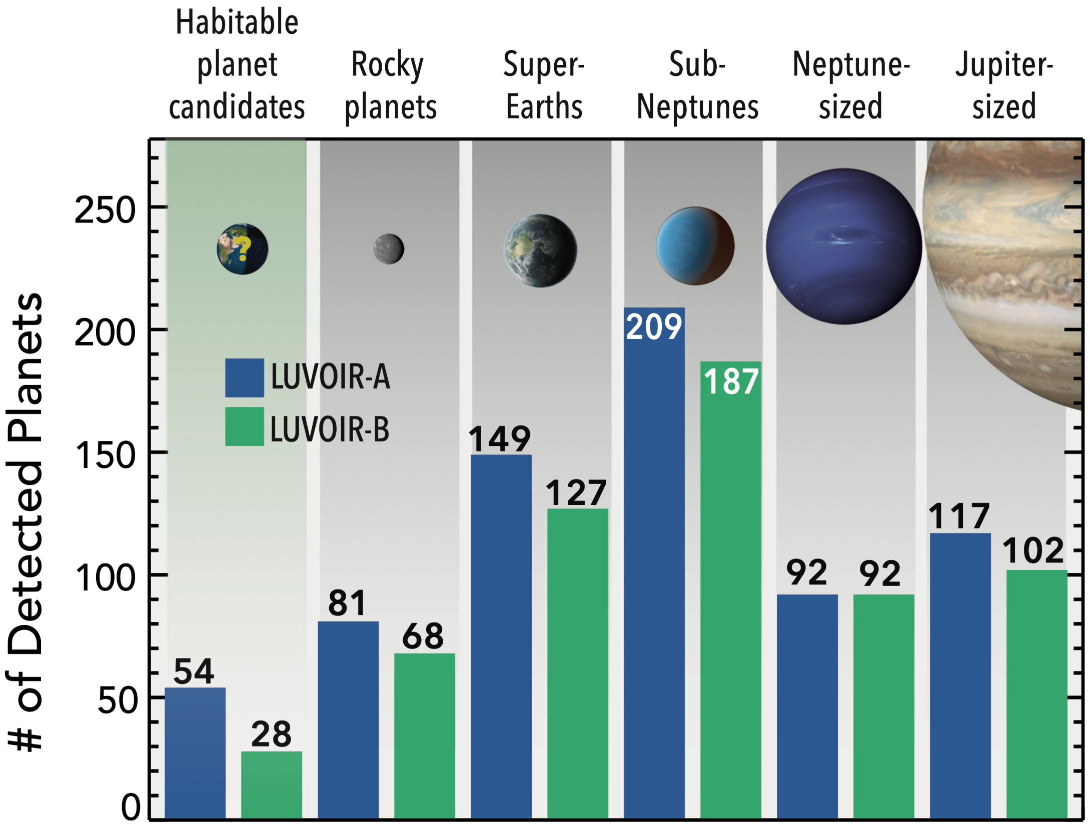


LUVOIR concept, Astro 2020 input:

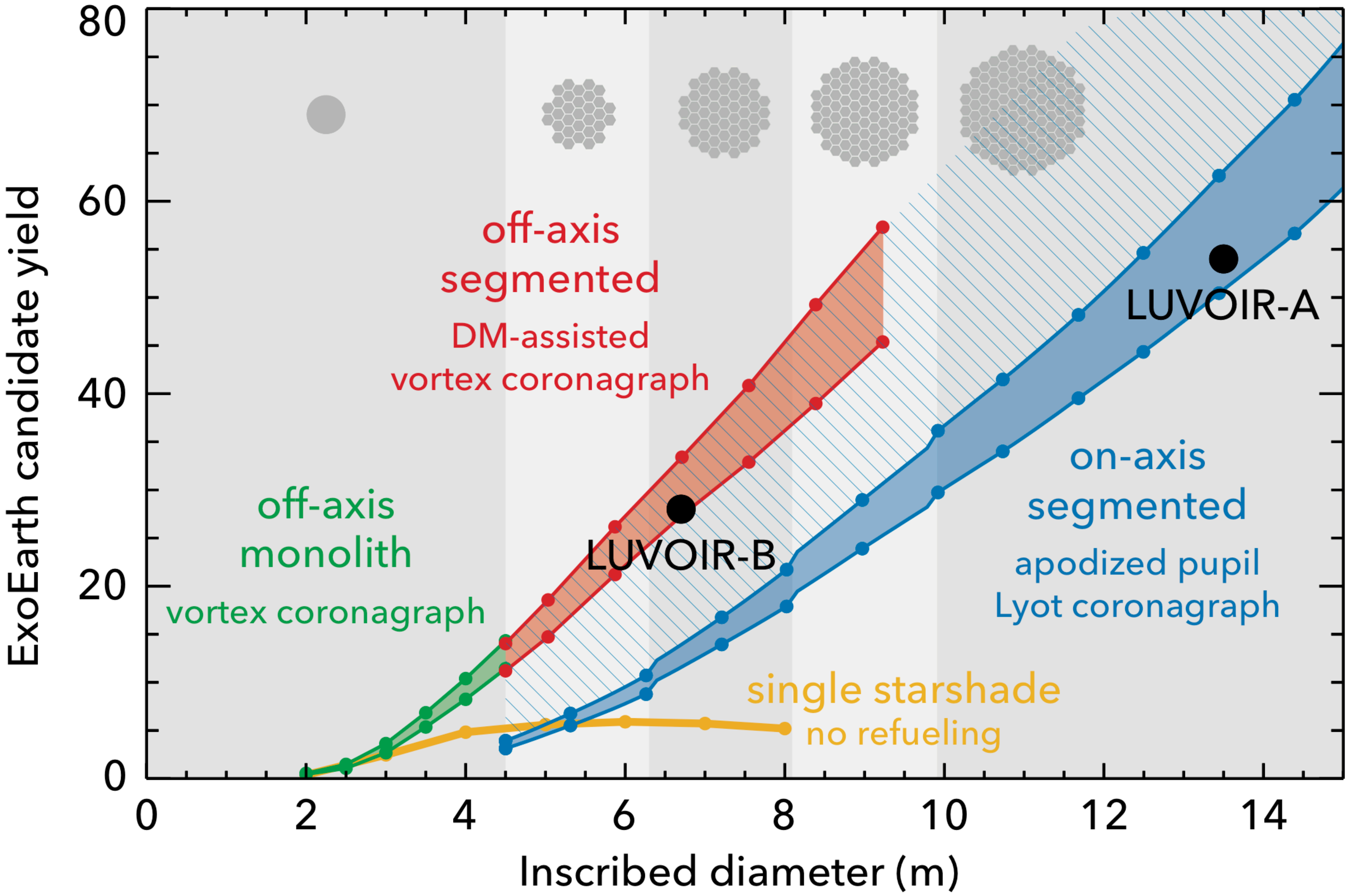
- Multi-epoch reconnaissance of nearby stars using a coronagraph between 0.6 and 0.8 microns
- Dedicated follow up for water feature at 0.9 microns
- Most promising systems further observed using near-IR and UV coronagraph capabilities.

What can we do with LUVOIR?





Yield to telescope size relationship



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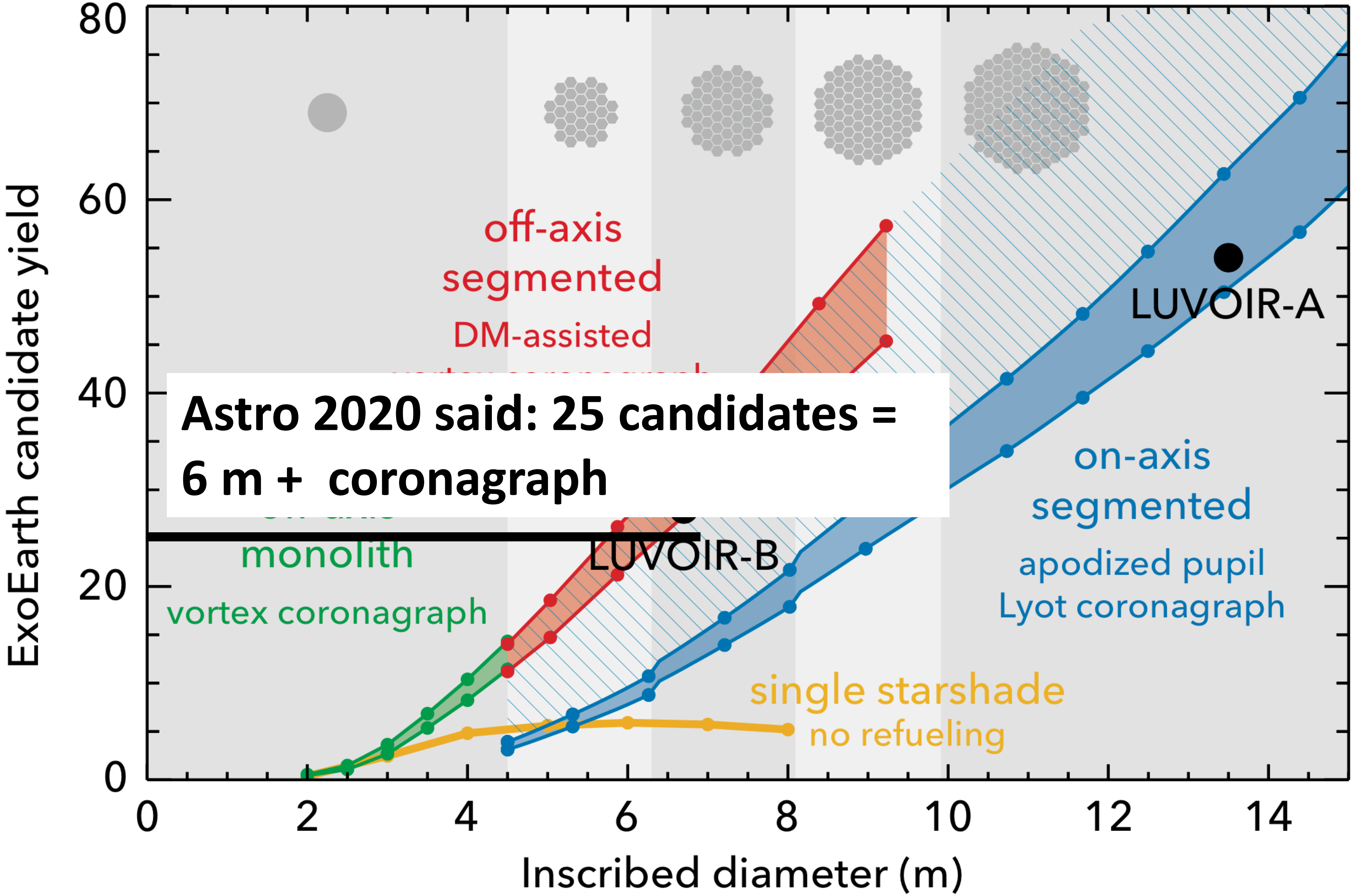
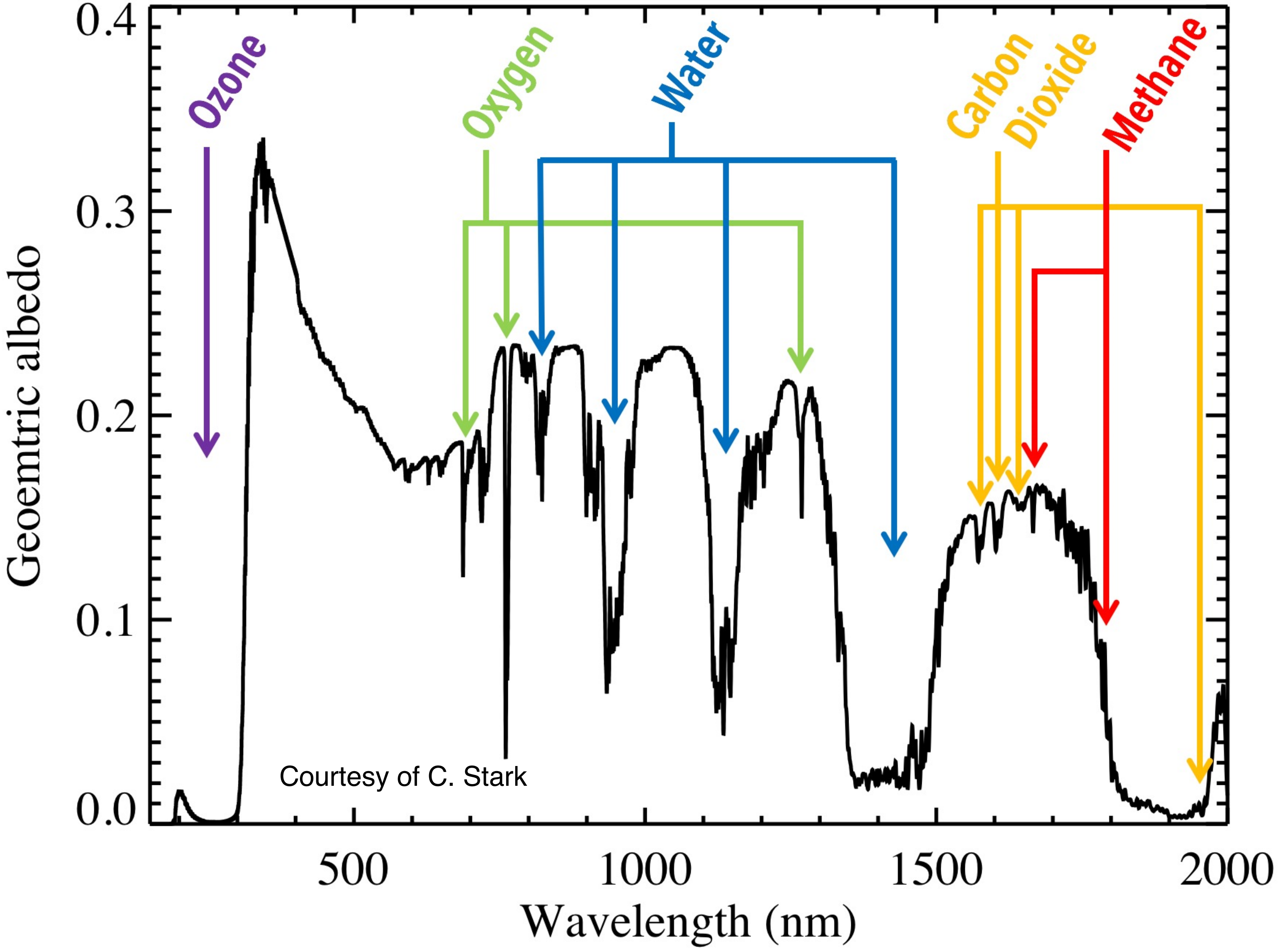


Astro 2020 said: 25 candidates = 6 m + coronagraph

What did Astro 2020 not decide



“Candidate” is defined by 0.9 microns water feature in previous calculation. Open questions:

- How blue in UV to robustly measure O3 and hazes?
- How deep does the contrast need to be in the visible for accurate abundance determination?
- How red in the near IR? Methane is key for non earth twin science.
- How many of the notional ~25 candidates can actually be detected in UV and near-IR?

Programmatic update

Key science

How blue, how red, how deep, can we see planets at all?

Key technologies

Programmatic update

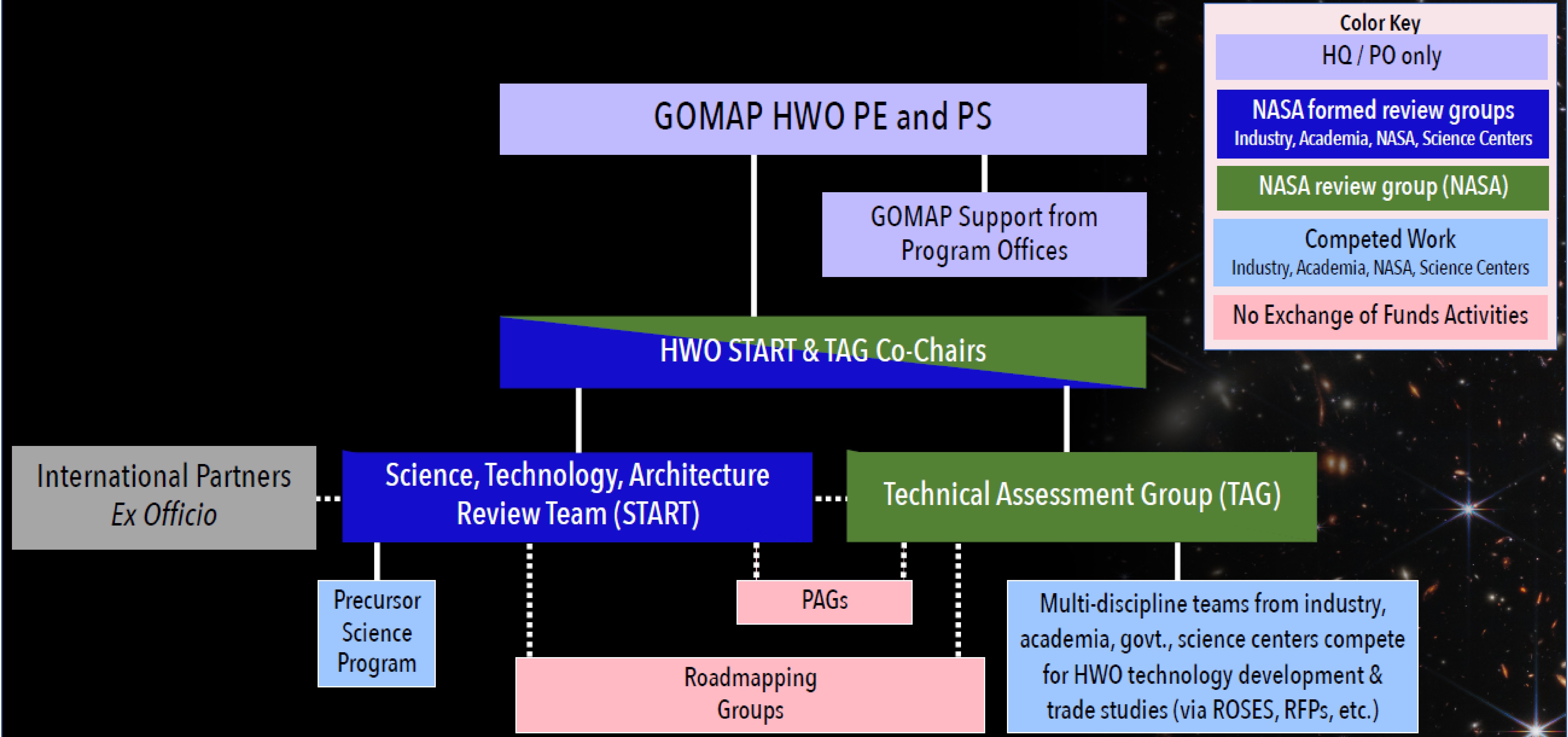
Key science

How blue, how red, how deep, can we see planets at all wavelengths?

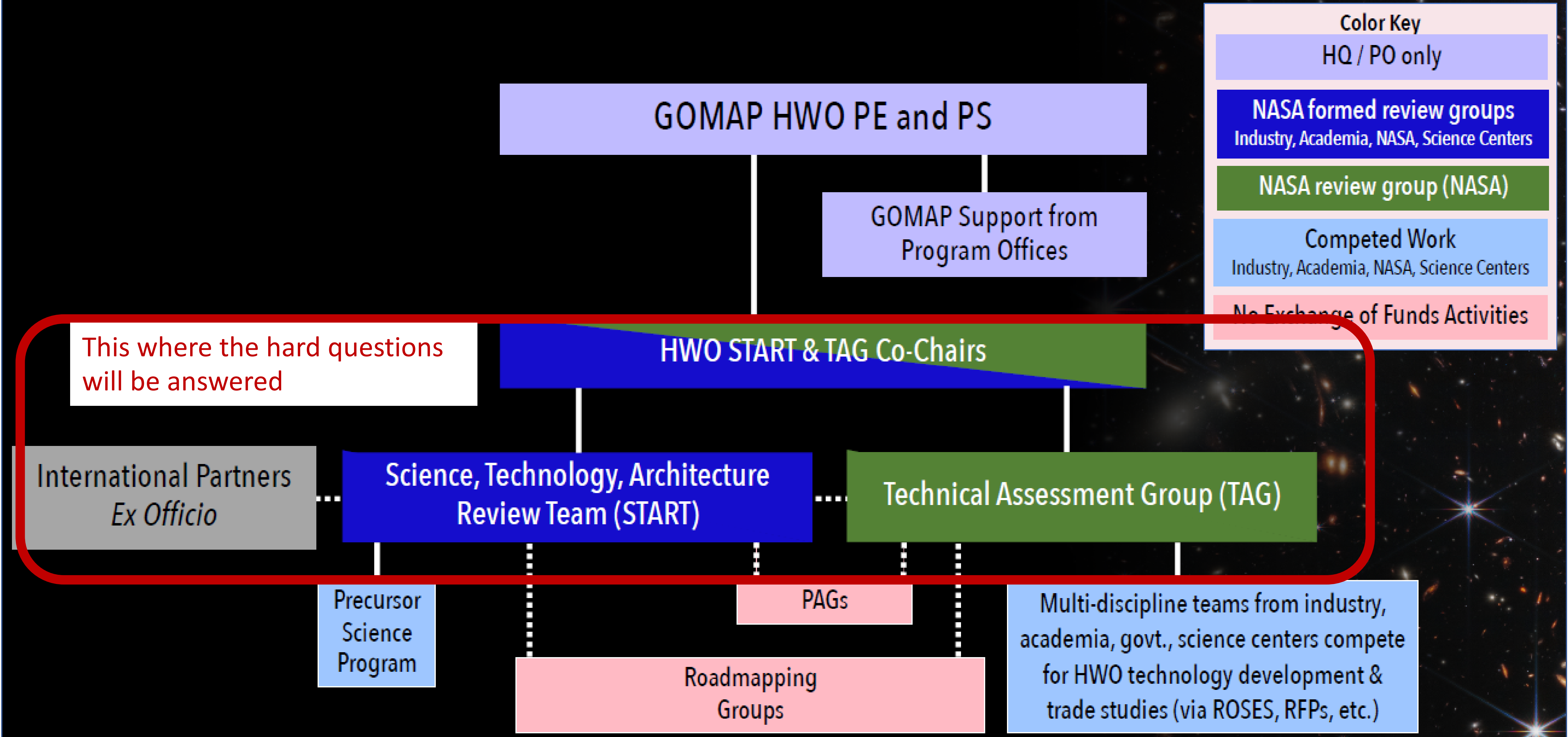
Key technologies

A UV coronagraph? A cold telescope? A stable wavefront? Is 6 m big enough?

HWO Technology Development and Concept Maturation Phase



HWO Technology Development and Concept Maturation Phase



US community organization around HWO as of today

Physics of the Cosmos / Cosmic Origins Groups for Habitable Worlds Observatory

Do you love ultraviolet technology and are you interested in HWO?

UV Working Group - Technology Roadmap. Contact Sarah Tuttle, tuttlese@uw.edu

UV Science & Technology Interest Group - ongoing events.

Contact Stephen McCandliss, stephan.mccandliss@jhu.edu

Technology

Ultra-Stable Observatory Roadmap Contact Lee Feinberg lee.d.feinberg@nasa.gov, Laura Coyle laura.coyle@ballaerospace.com

For more opportunities to participate, see here:

Cosmic Origins Science (& Technology) Interest Groups: https://cor.gsfc.nasa.gov/sigs/sigs.php

Physics of the Cosmos Science Interest Groups: https://pcos.gsfc.nasa.gov/physpag/sigs-sags.php

US community organization around HWO as of today

ExEP Working Groups for Habitable Worlds Observatory

exoplanets.nasa.gov

Technology

- **Coronagraph Design Survey** (Belikov, Stark) **Design Solicitation Open Until June 9**
- **Coronagraph Technology Roadmap** (Chen, Pueyo)
- **Deformable Mirror Technology Roadmap** (Bendek, Groff)

Science

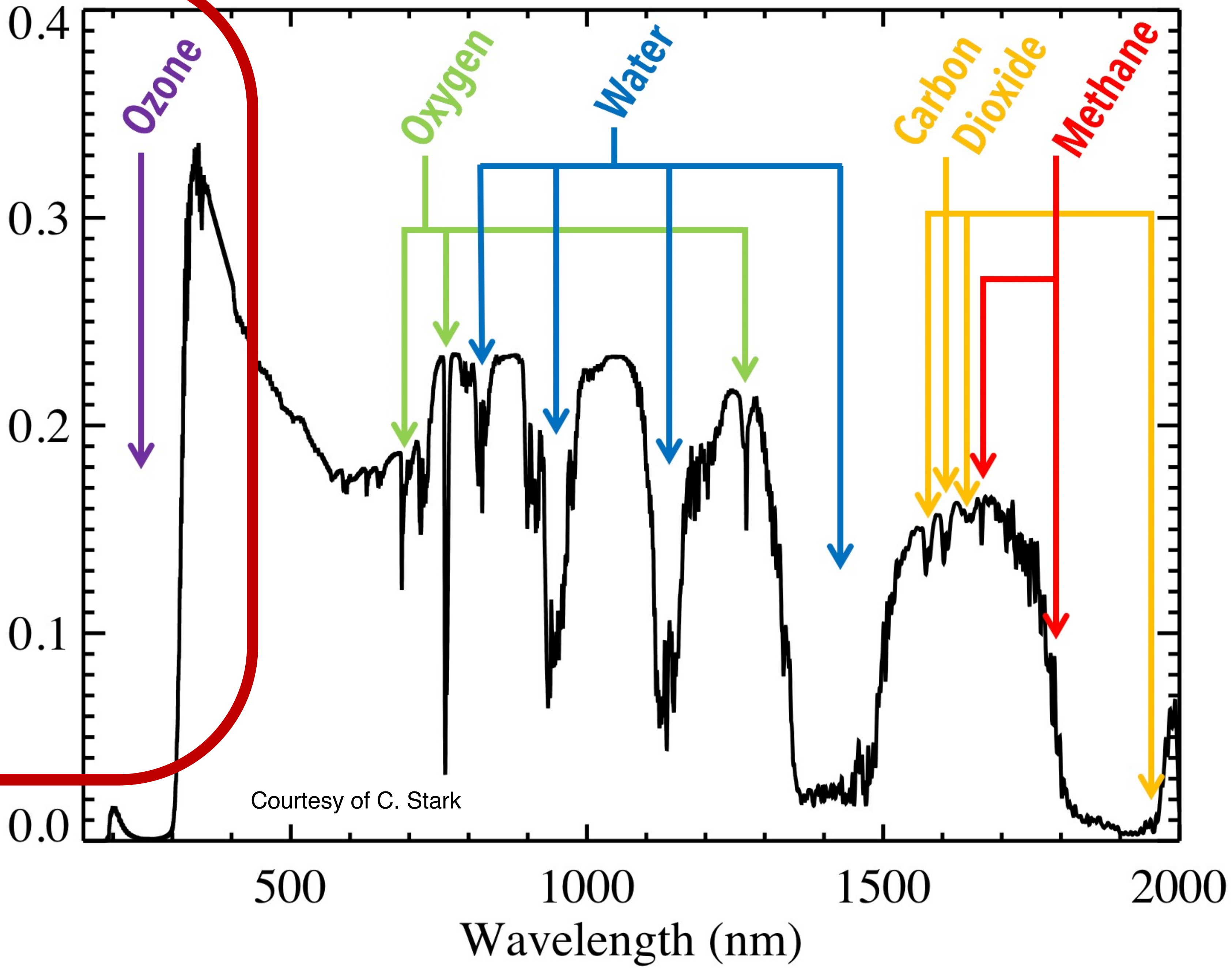
- **Mission Stars List for the Habitable Worlds Observatory** (Mamajek, Stapelfeldt)
- **Exoplanet Science Metrics** (Stapelfeldt) **Splinter: Tue 2-3:30**

Science Evaluation & Modeling

- **Exoplanet Yield Modeling** (Morgan, Savransky) **Splinter: Thu 9-11, 12:30-3**
- **Integrated Modeling** (Levine, Liu)

Workshop: **Towards Starlight Suppression for HWO** **August 8-10, 2023; Pasadena, hybrid**

- Do we have enough photons to probe ozone feature given that UV throughput is low? On how many targets?
- Can we design a UV coronagraph with a minimal number of reflections to bolster throughput?
- Is photometry sufficient?
- Do we need UV capabilities for outer solar system scales? (drives Deformable mirrors actuator count)



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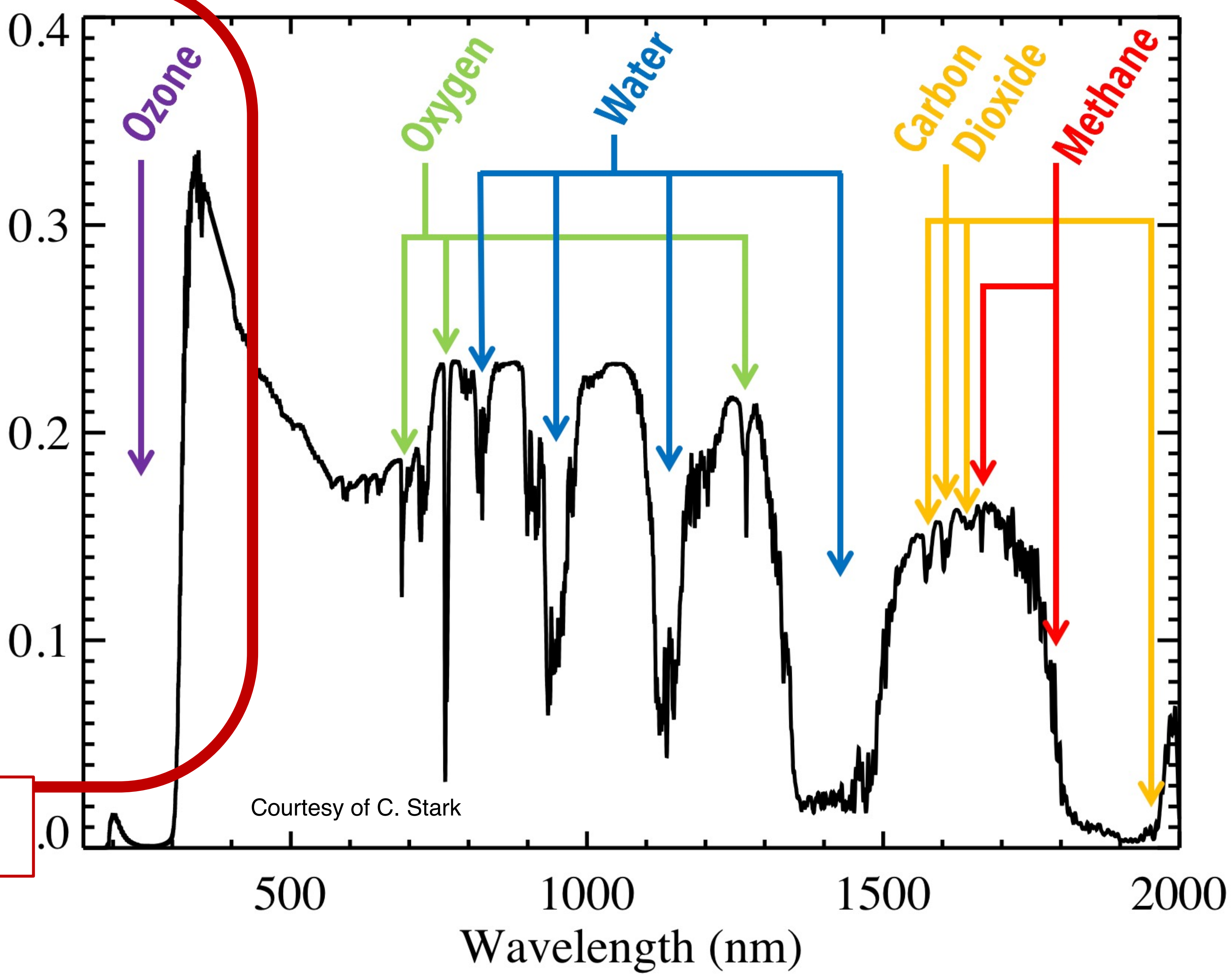
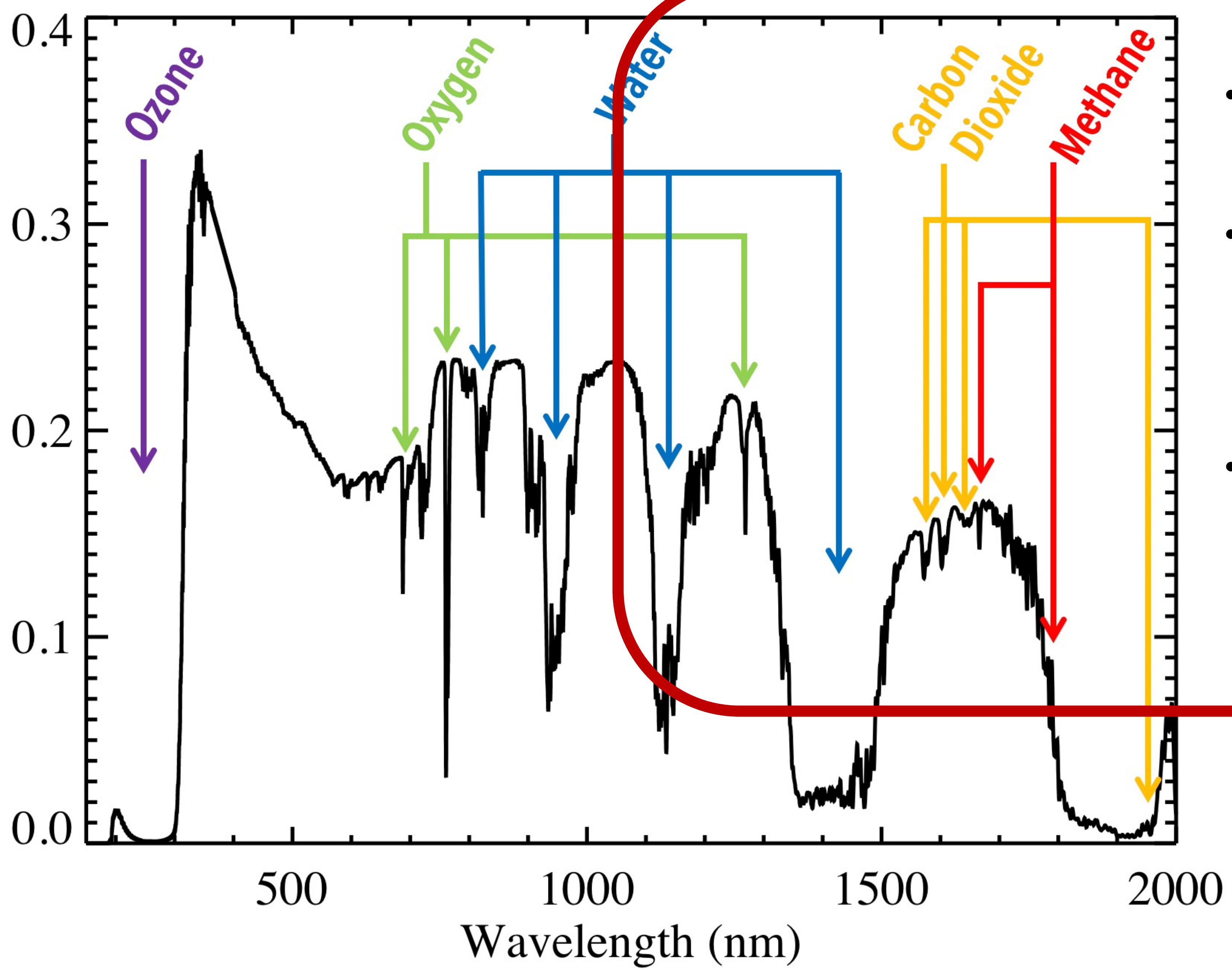
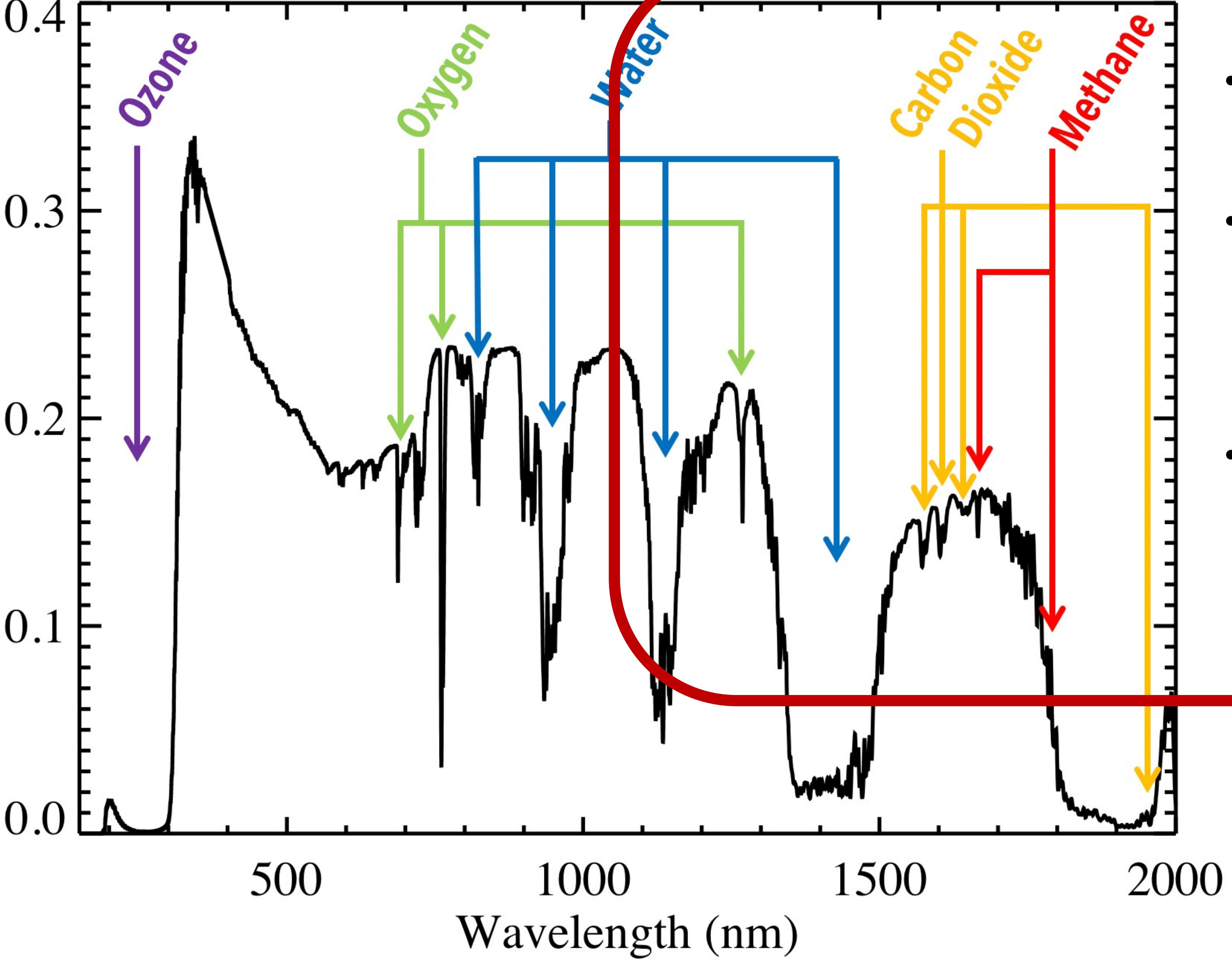
Back up option: starshades as second generation instrument





- How cold does the telescope need to be?
- Is the angular resolution sufficient with a ~6m? Do new coronagraph concepts need to be developed?
- What near IR resolution is needed? What does it mean in terms of IR detector development?



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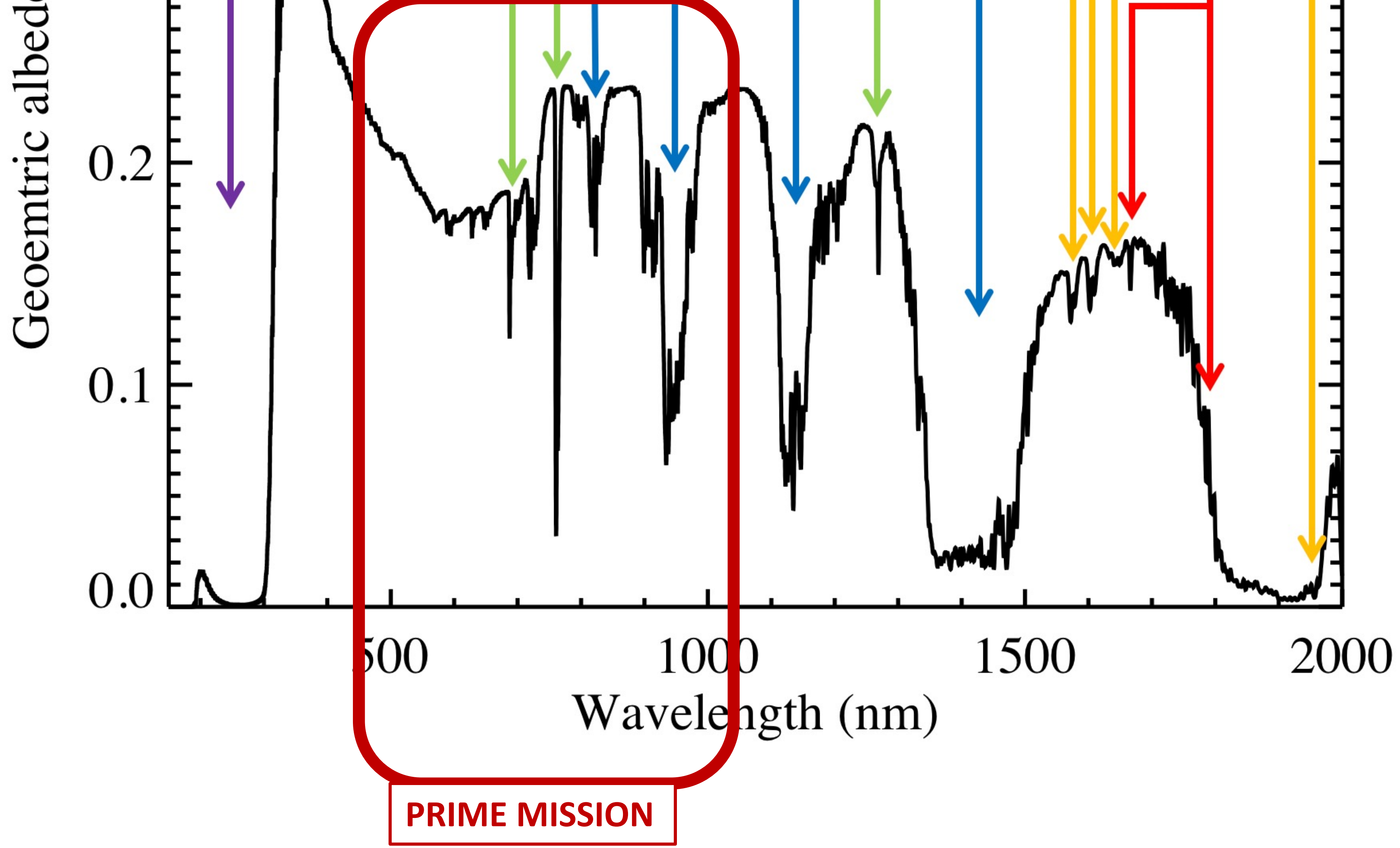
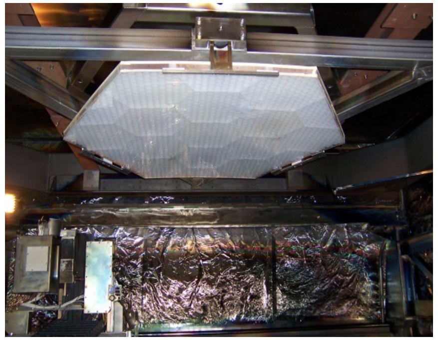


Geoemtric albedo
0.2
0.1
0.0
500
1000
1500
2000
Wavelength (nm)
PRIME MISSION

Astrophysics Technology Investments

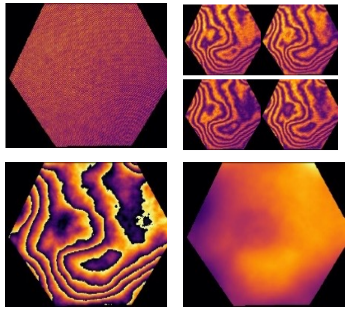
- **System-level picometer stability**

Lightweight ULE mirror segment



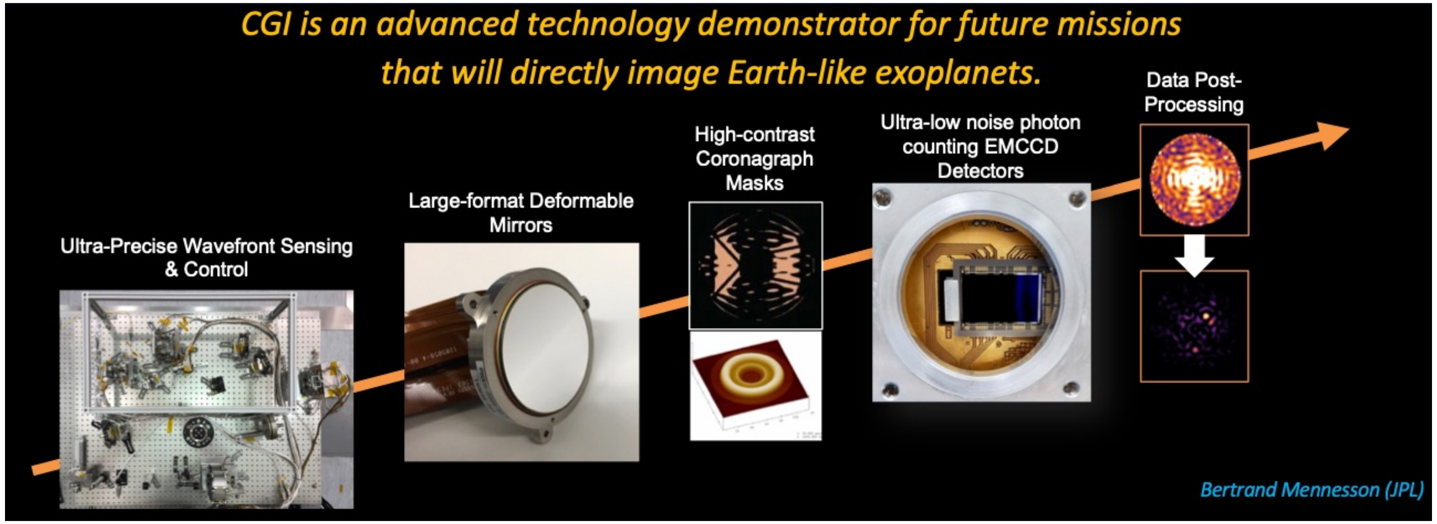
Credit: L3/Harris

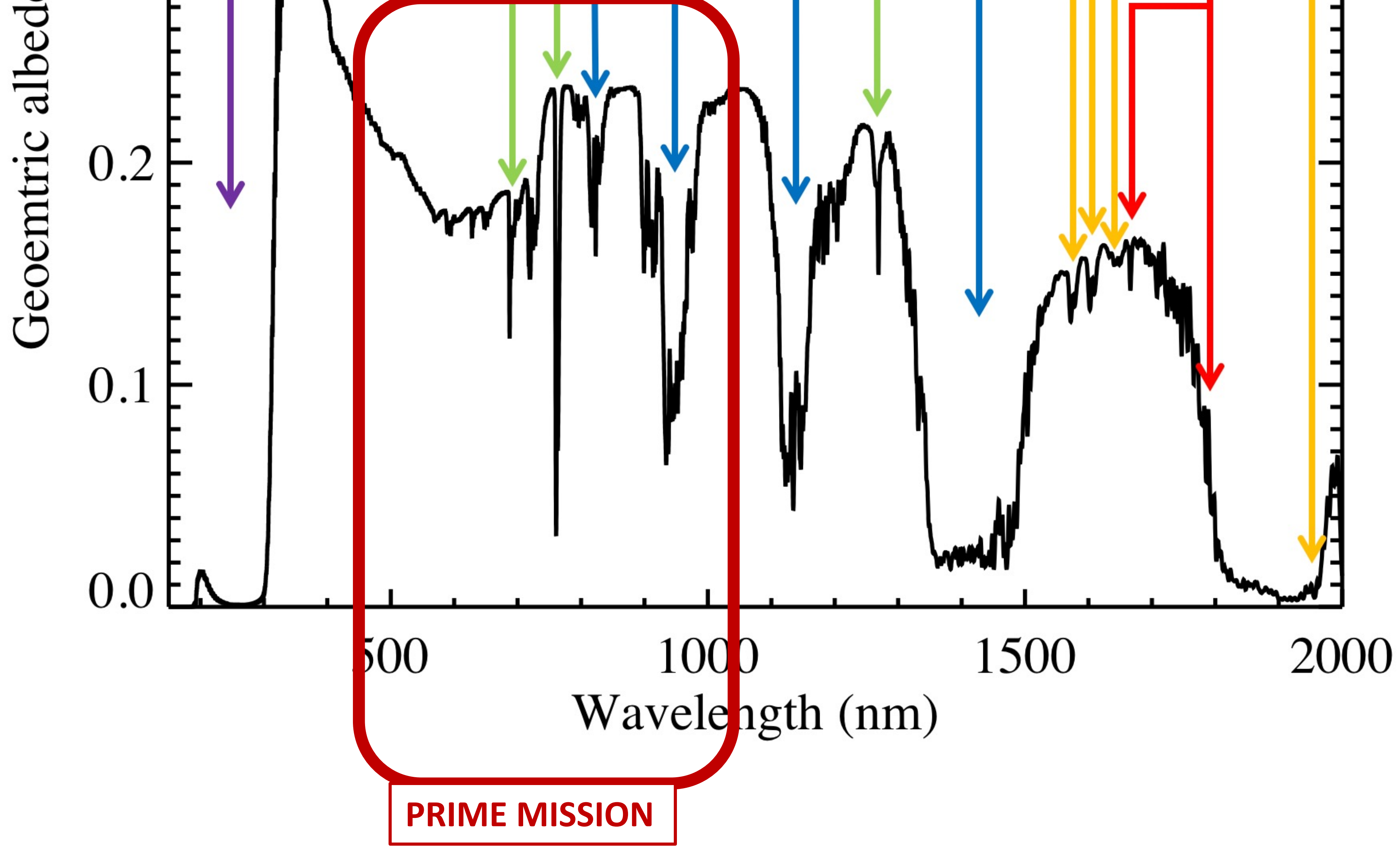
Picometer-scale dynamics measured with high-speed interferometry



Credit: NASA GSFC

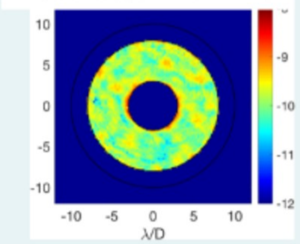
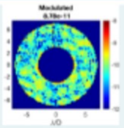
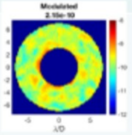
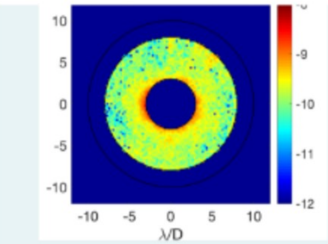
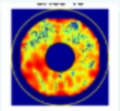
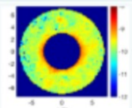
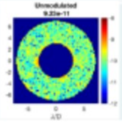
- **High Contrast Imaging**

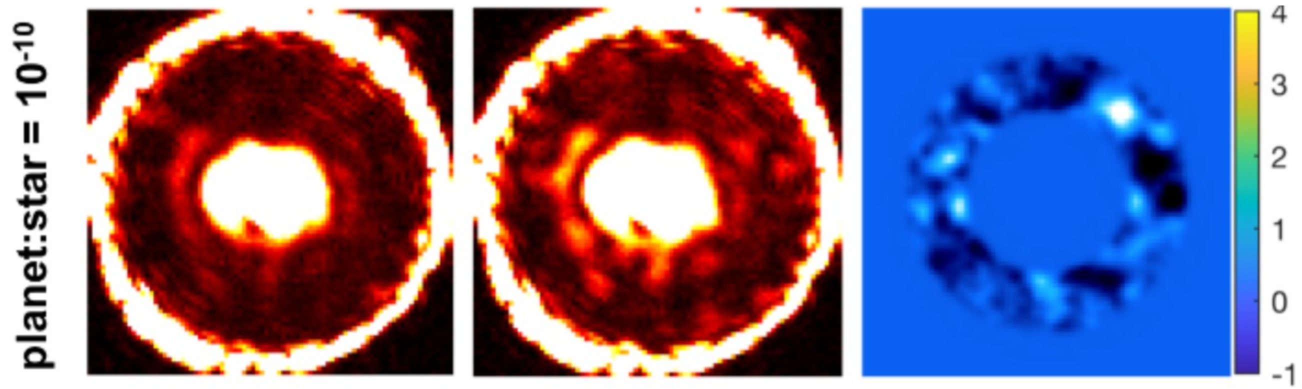




- Deep spectral characterization requires to go deeper than the canonical “ten to the ten” contrast.
- How do we build a telescope + coronagraph that are stable enough for this science?

Can we reach the raw contrast? (yes on a clear aperture)

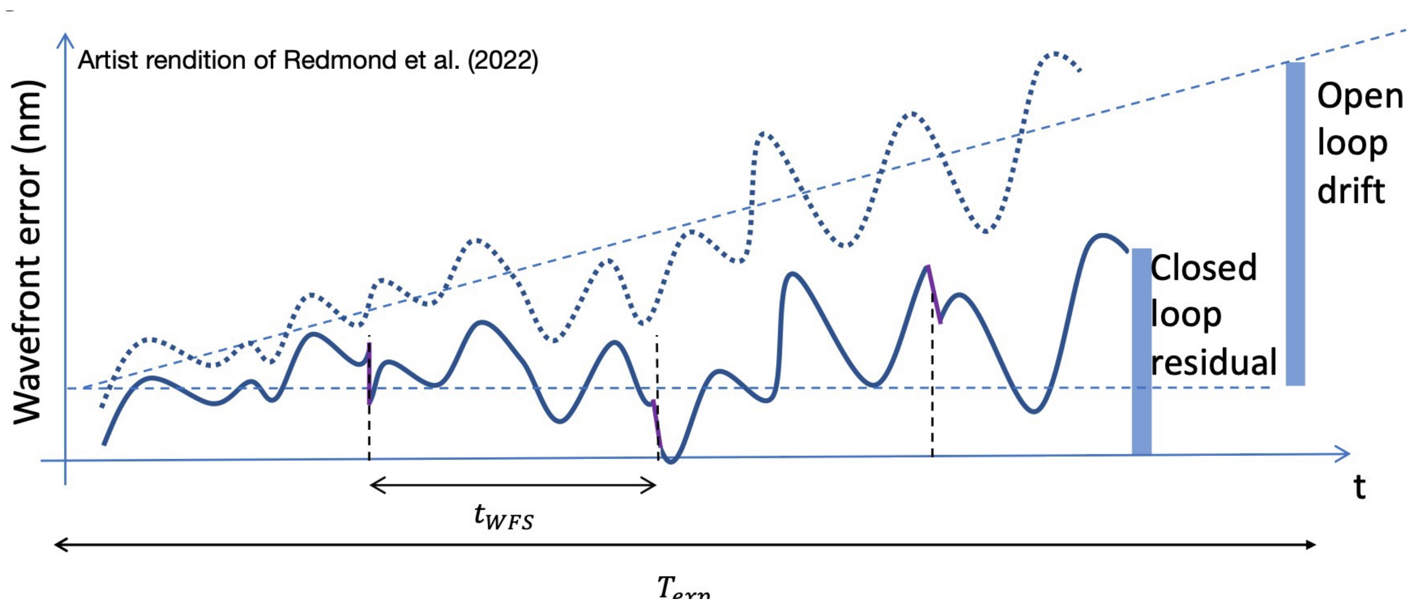
Contrast, 3.82E-10 Total		Measured	Model/Indirect Expectation	Morphology
Modulated 1.81E-10 	LSB effect of DM actuators	8.78E-11	~1E-10	Specklish 
	Chromatic Control Residual	9.32E-11	~4E-11	Specklish 
Unmodulated 2.01E-10 	Occulter Ghost (+Chromatic Residual)	1.01E-10	~1E-10	Patterned March with wavelength 
	Testbed LoS Jitter impact	4.19E-11	< 1E-11	Centered 
	Unknown	5.04E-11	N/A	Diffused 

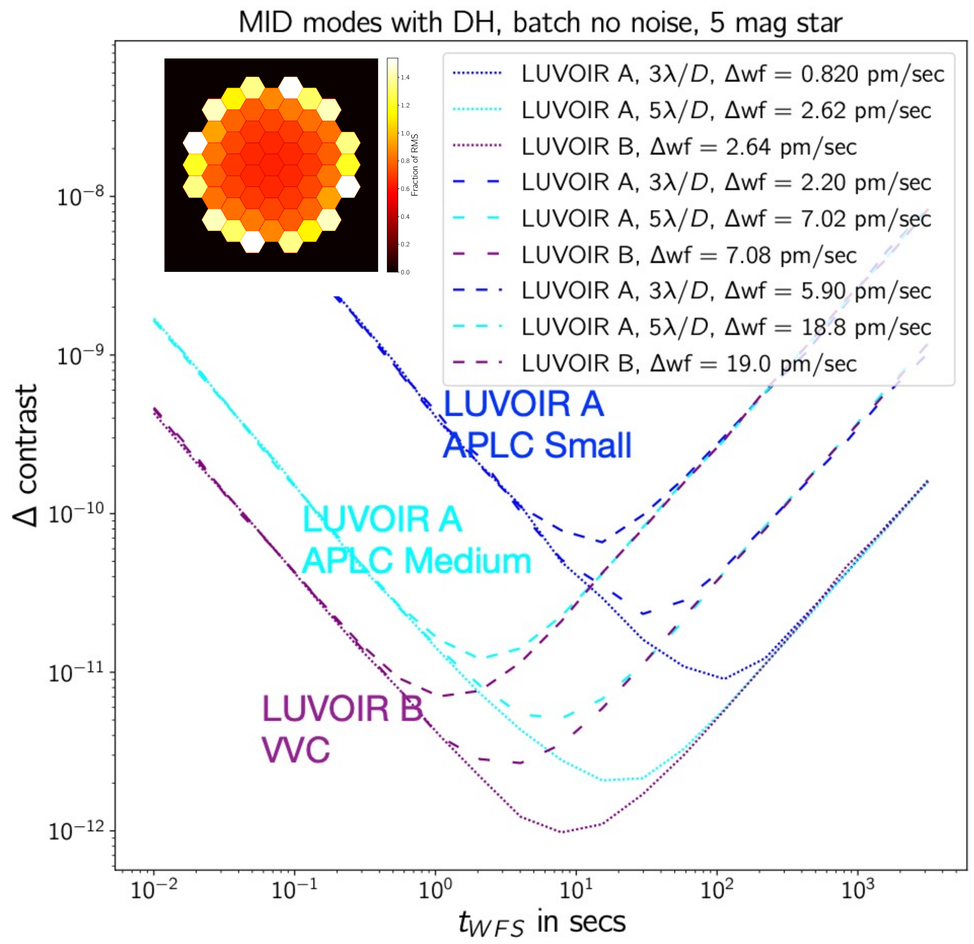


- Demonstrates static contrast at ~4e-10.
- Demonstrates contrast stability at 1e-10 (5 sigma), 2e-11 (1 sigma).
- Breaks down empirical allocations of contributions to static contrast error budget.
- Does not breaks down empirical allocations of contributions to noise floor.

Seo et al. (2019)

Can we keep the contrast stable? (working on it)

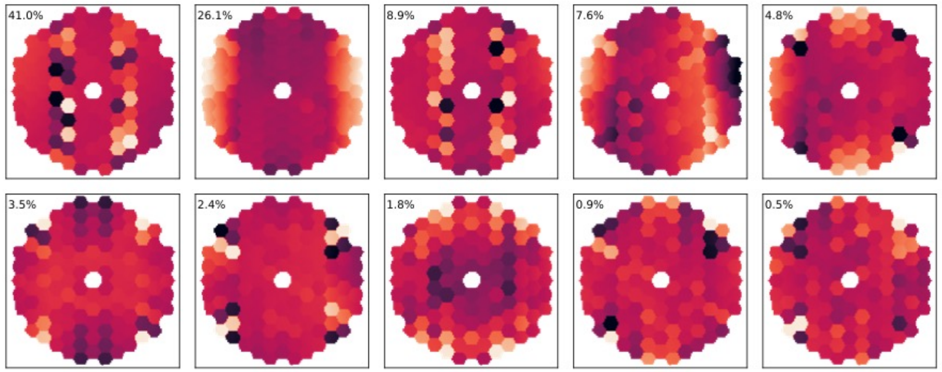


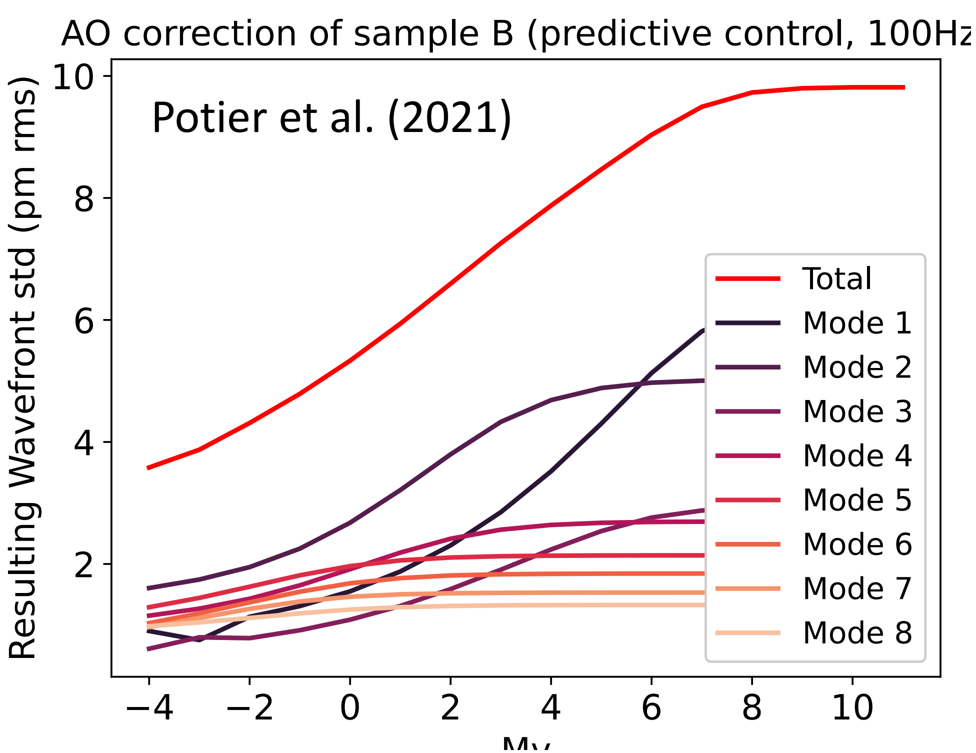


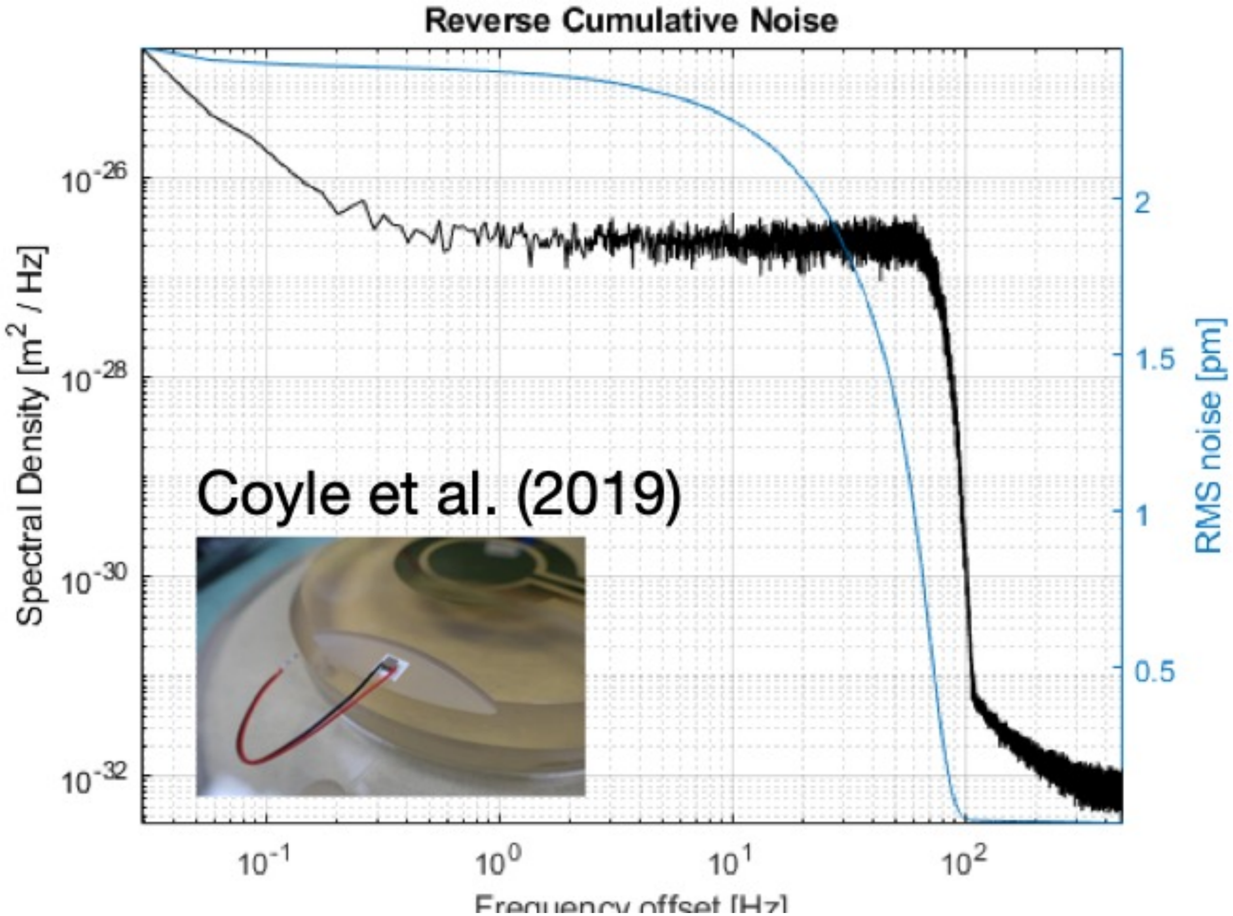
- **Using the coronagraph instrument we can compensate telescope drifts at the ~10s-1 minute timescale**
- **Outer segments can drift significantly more than inner segments**
- **In theory, we can correct thermal drifts with Deformable Mirrors in instrument**

Based on
Leboulleux et al. (2017)
Laginja et al. (2020)

Can we keep the contrast stable? (working on it)

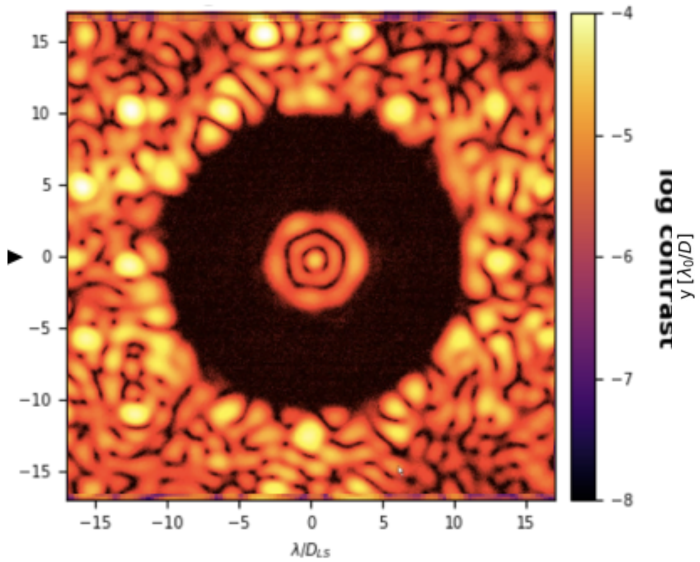


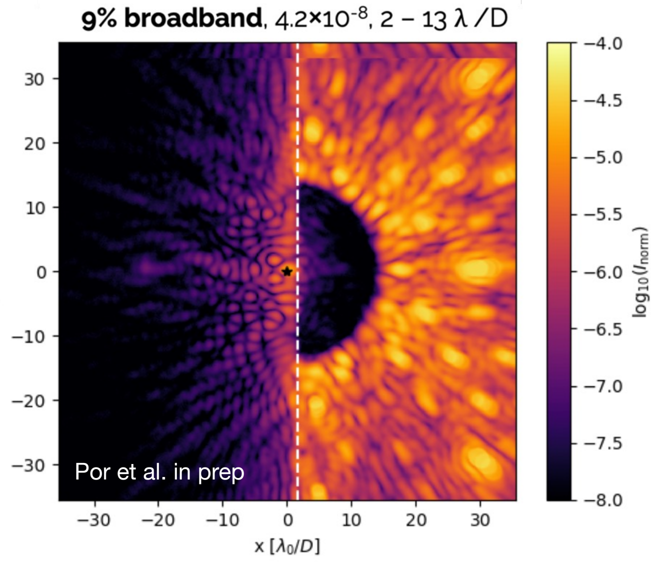


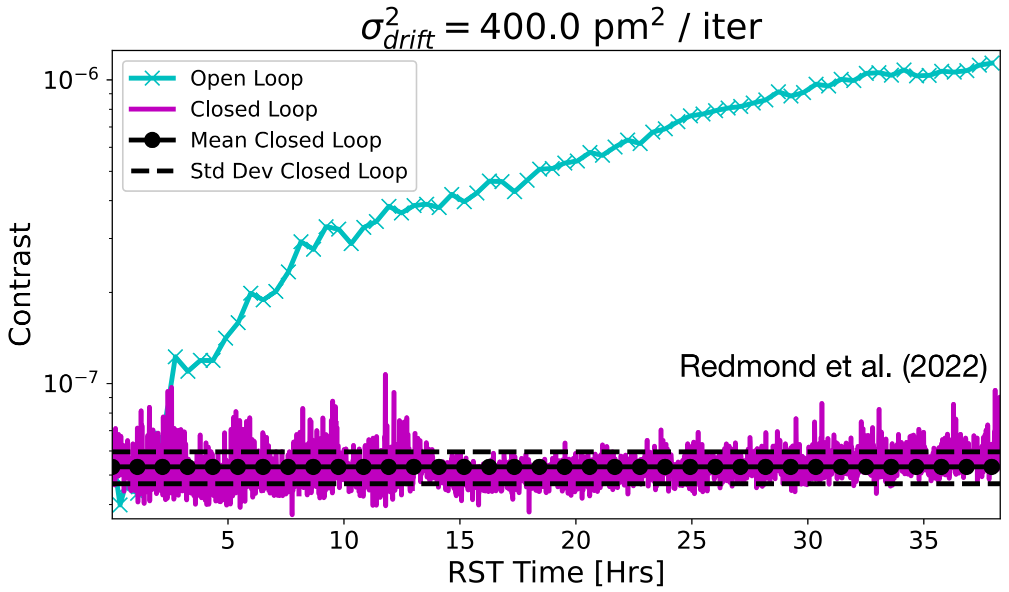


Faster timescales can be corrected either using better controllers or edge sensors at telescope

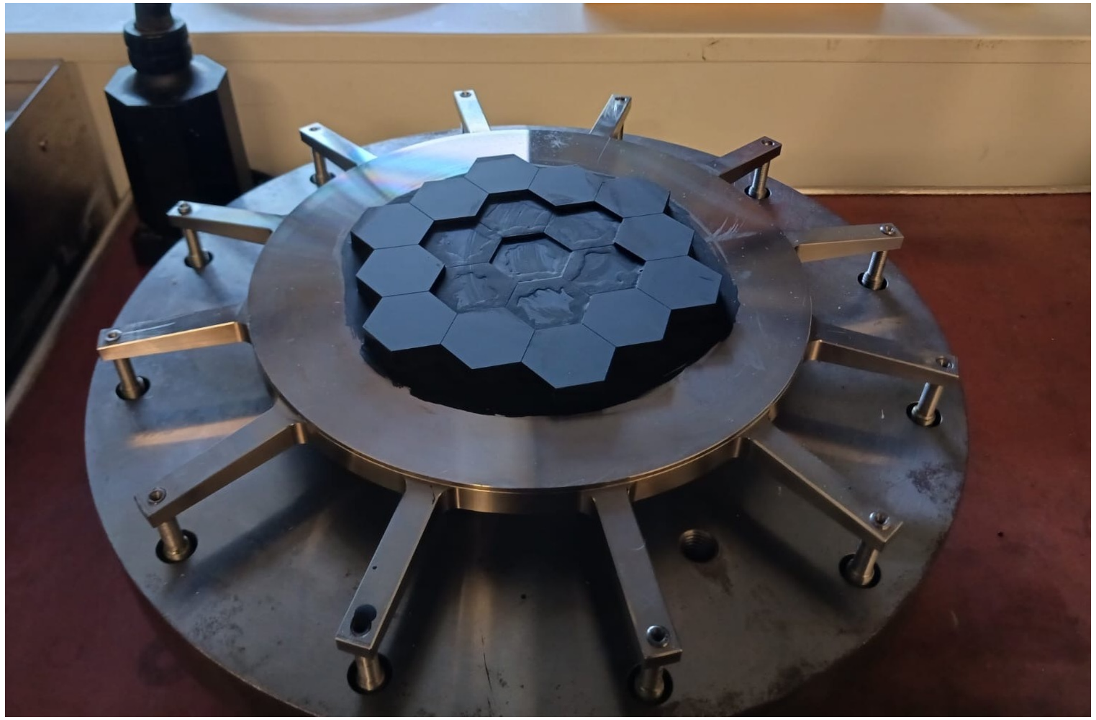
Can we keep the contrast stable? (working on it)







STScI HiCAT results with synthetic segment drifts.



Prototype of a segmented telescope surrogate for high-contrast drift experiments build using stress polishing (Courtesy of M. Ferrari, LAM).

Thank you