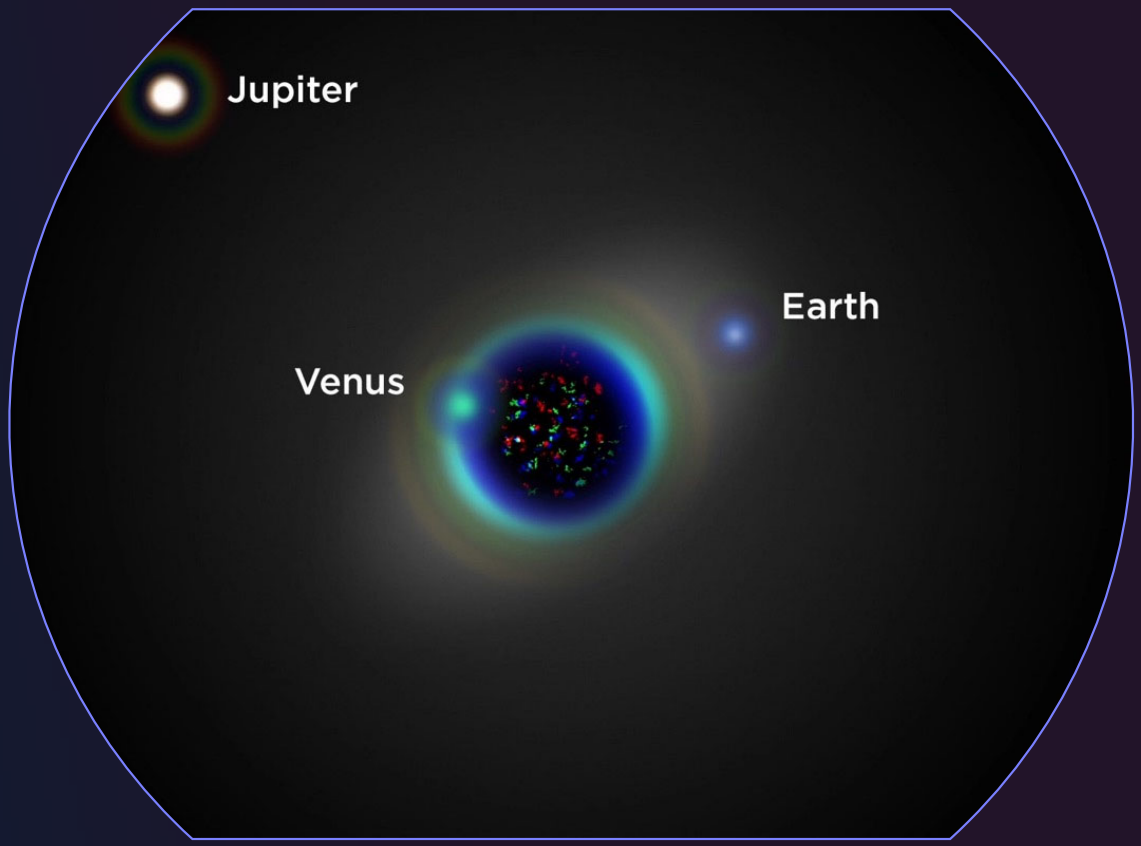
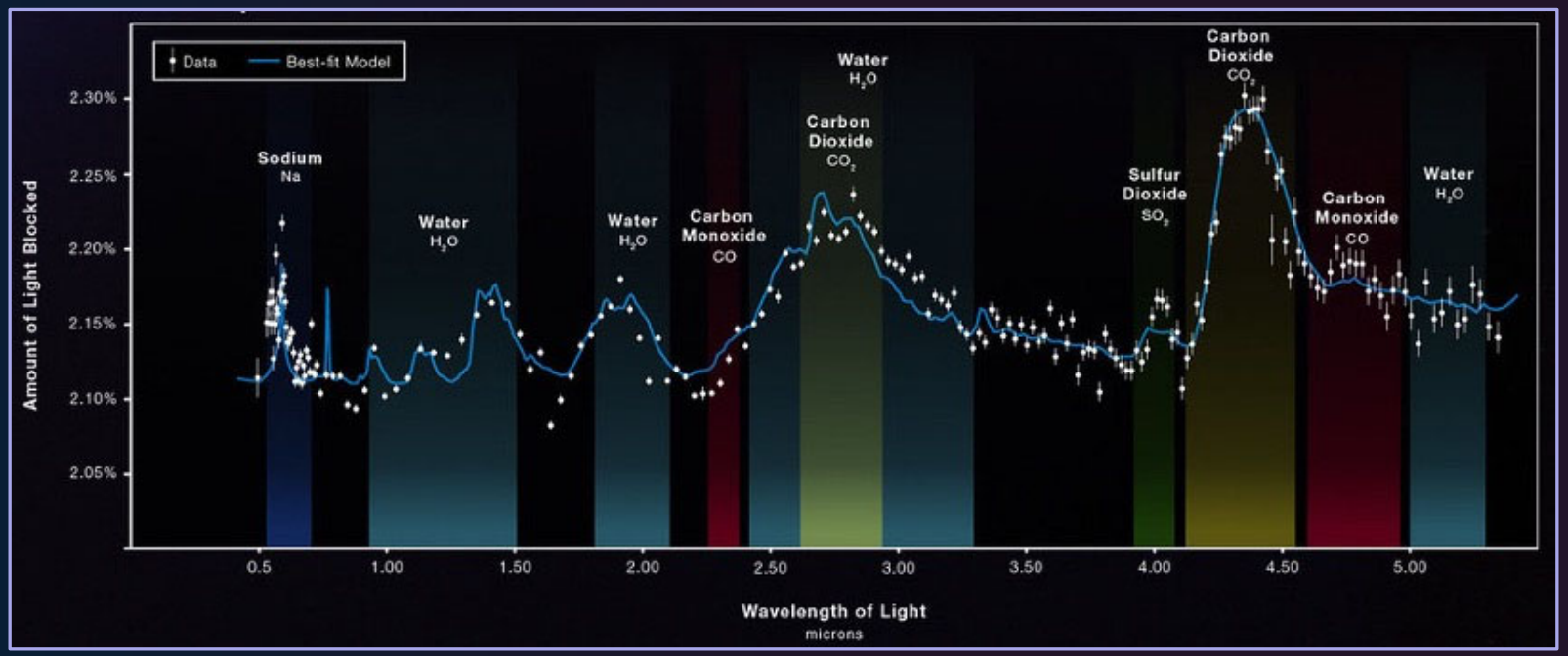
Habitable Worlds Observatory



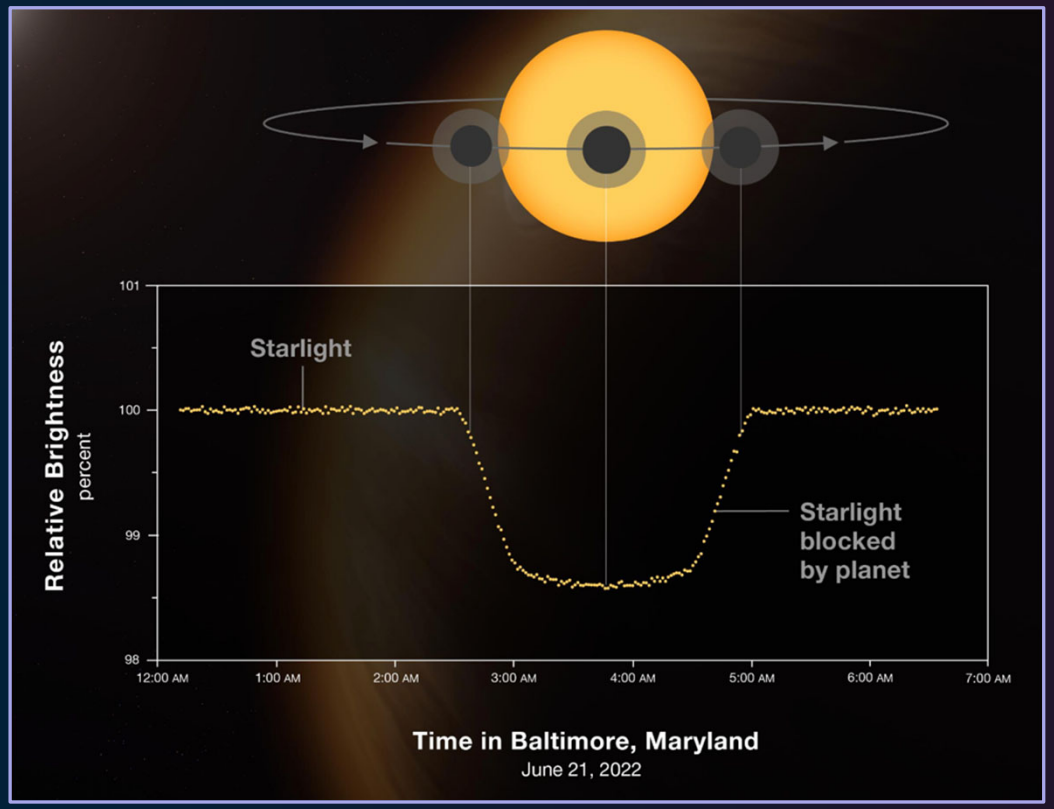
Dr. Mark Clampin
Astrophysics Director
Science Mission Directorate

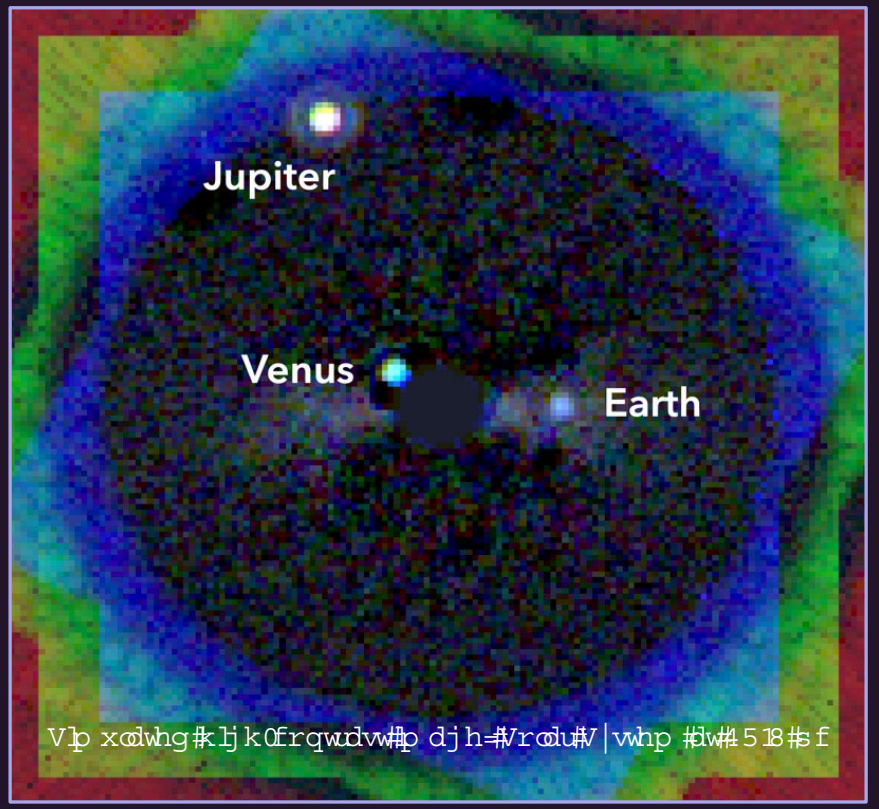
JWST Exoplanet First Science Results



JWST spectrum of the gas giant exoplanet WASP-39b showing the first molecular and chemical profile of an exoplanet's atmosphere, revealing the presence of H_2O, SO_2, CO, Na and K, as well as signs of clouds, and the first clear evidence of carbon dioxide in a planet outside our solar system. This planet is what is known as a "hot Saturn". The data shown here provide the first concrete evidence of photochemistry.
Credits: NASA, ESA, CSA, J. Olmsted (STScI)

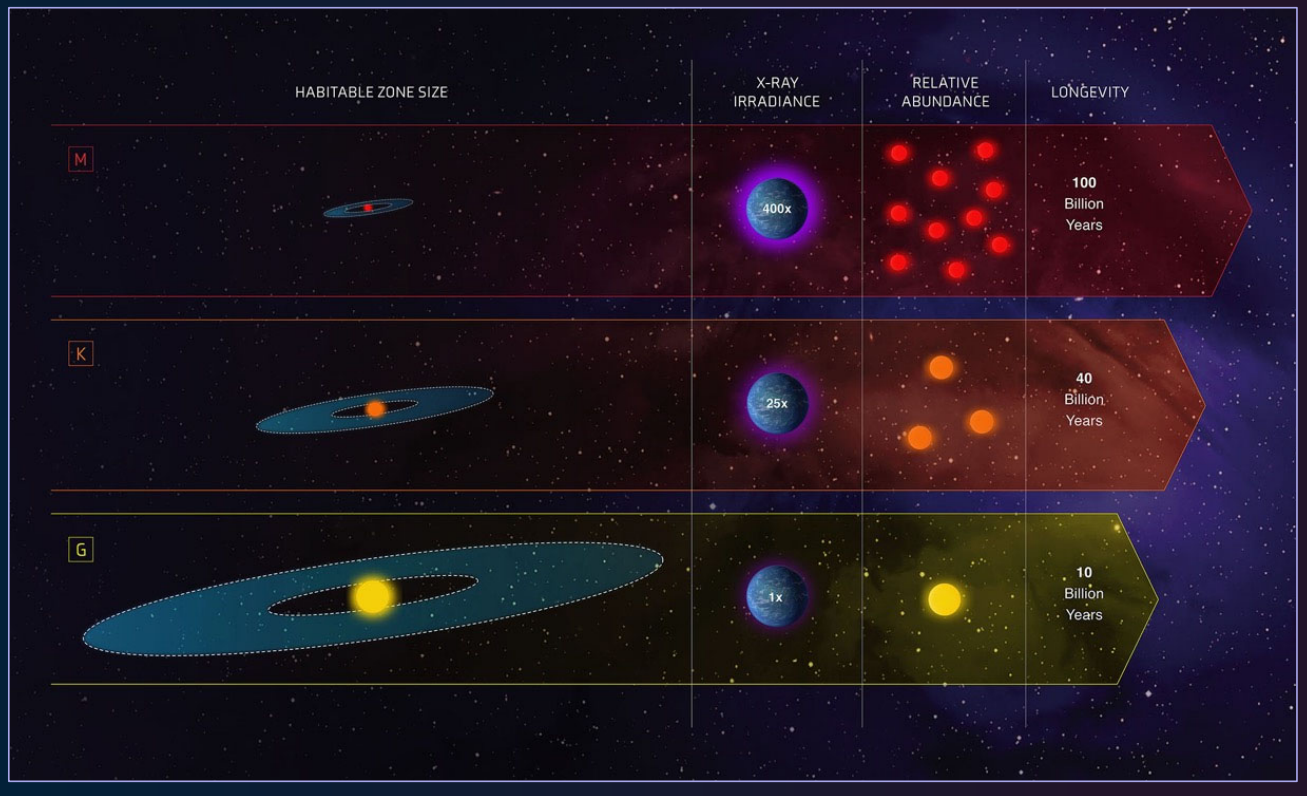
Transit Observations to Direct Imaging





Exoplanet Populations

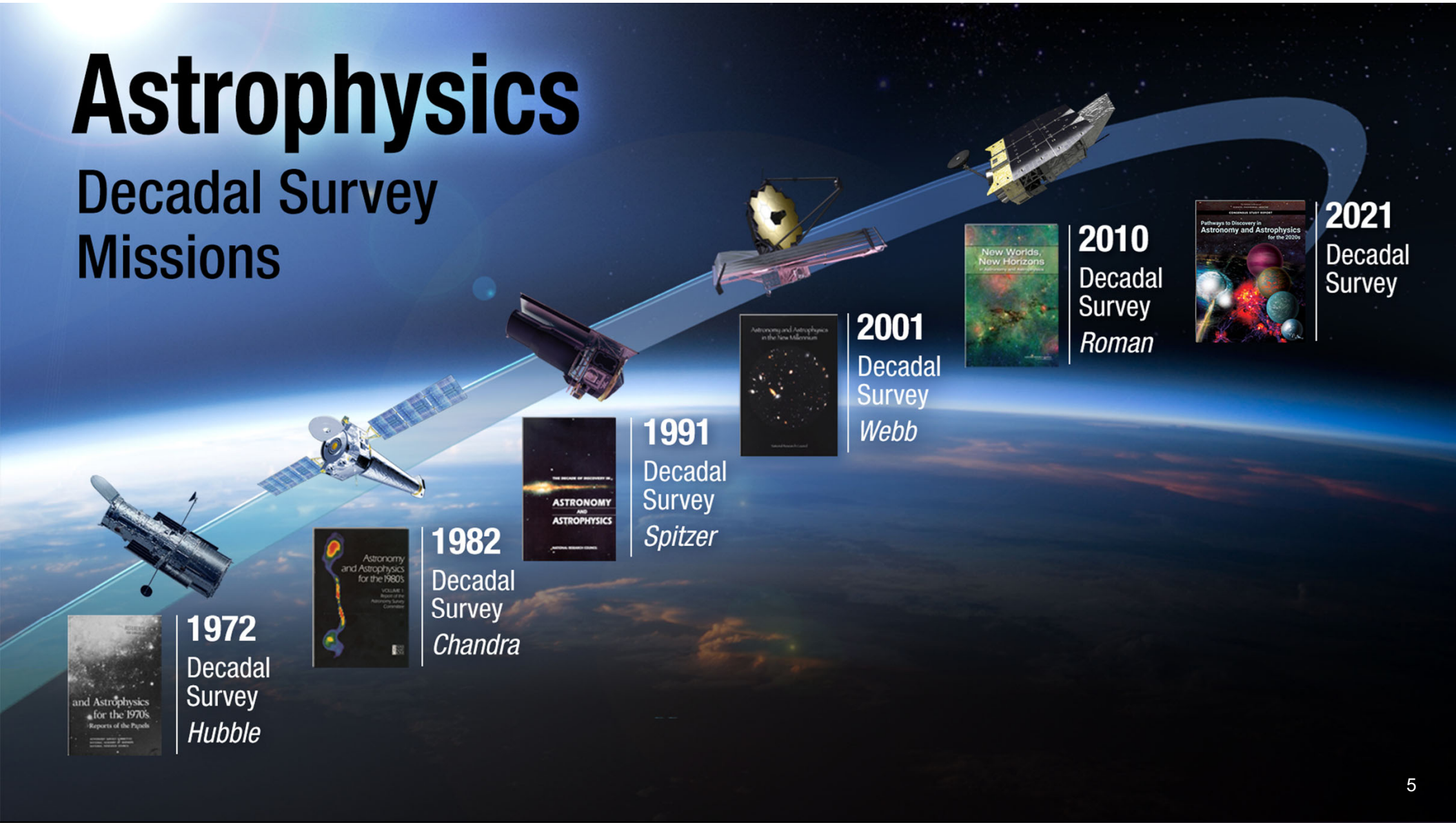
- Fraction of systems with transiting exoplanets < 10% for small orbits
- Solar-type star with planet at 1 AU, fraction is < 1%



- Transit Observation
- Direct Imaging
- Direct Imaging
- Direct Imaging

Astrophysics

Decadal Survey Missions



1972 Decadal Survey *Hubble*

1982 Decadal Survey *Chandra*

1991 Decadal Survey *Spitzer*

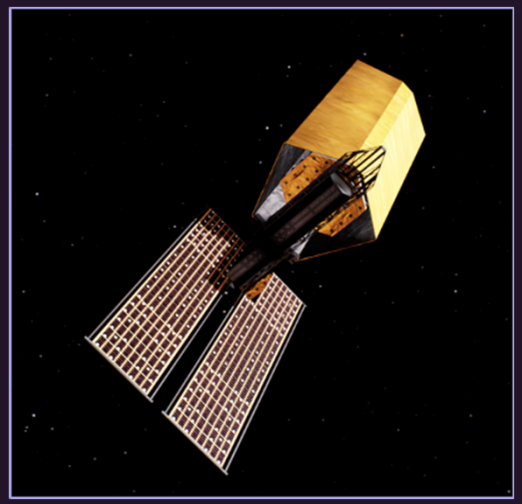
2001 Decadal Survey *Webb*

2010 Decadal Survey *Roman*

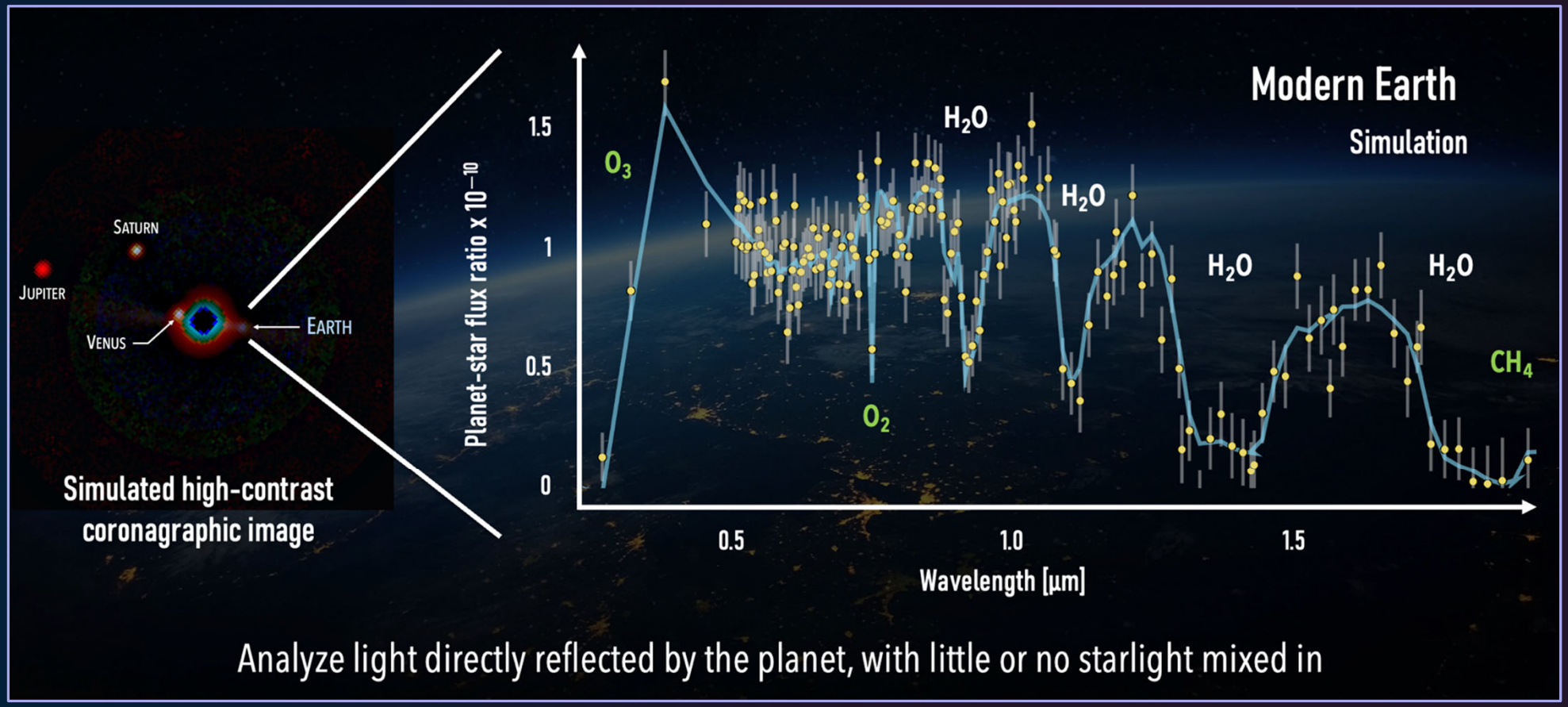
2021 Decadal Survey

Response to Decadal Survey
Habitable Worlds Observatory

- **Decadal Survey (ASTRO2020) priority science areas**
  - Are there habitable planets harboring life elsewhere in the universe?
  - Survey sun-like, nearby stars for habitable planets and search for evidence of life
  - Transformational astrophysics program (UV)
- **Primary Technical Approach**
  - ≥ 6 meter Segmented mirror telescope
  - Active control of telescope/coronagraph system for stability at level of ~10 pm over control cycle
  - Coronagraph achieving contrast levels of 10^{-10}
- **Habitable Worlds Observatory**



How Will it Search for Life?



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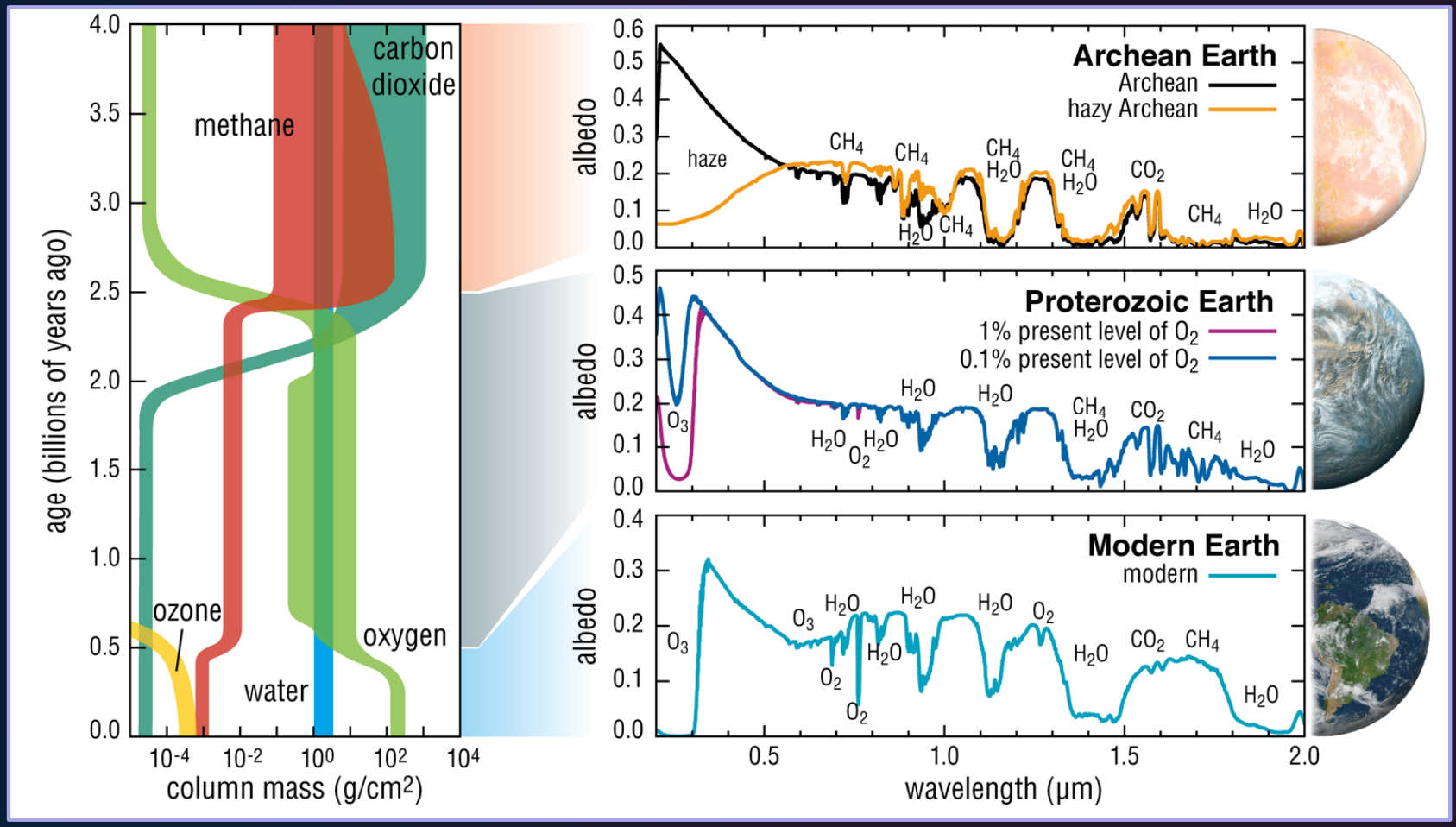
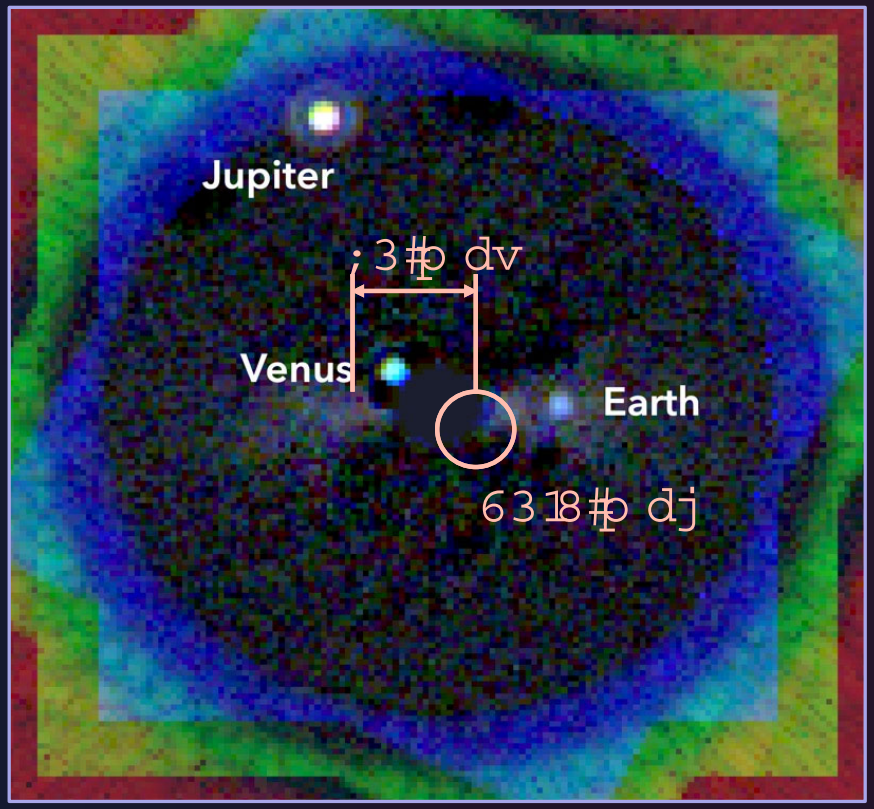


Response to Decadal Survey

Habitable Worlds Observatory



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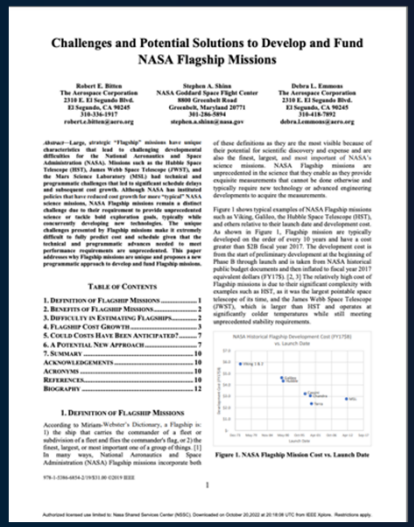
The Habitable Worlds Observatory
Big Picture Strategy

- **Build to schedule**: Mission Level 1 Requirement e.g. Planetary mission strategy
- **Evolve technology**:
  - Build upon current NASA investments and TRL-9 technology
  - Segmented optical telescope system from JWST
  - Coronagraph from Roman ‘s coronagraphic imager program
- **Next Generation Rockets**:
  - Larger telescope aperture sizes
  - Leverage opportunities offered by large fairings to facilitate mass & volume trades
- **Planned Servicing**: Robotic servicing at L2
- **Robust Margins**: Design with large scientific, technical, and programmatic margins
- **Mature technologies first**: Reduce risk by maturing the technologies prior to formulation

Strategic Approach

Decades of research-based consensus on megaprojects

Independent Research Papers


Challenges and Potential Solutions to Develop and Fund NASA Flagship Missions

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Abstract—Large, strategic "Flagship" missions have unique characteristics that lead to challenging developmental difficulties for the National Aeronautics and Space Administration (NASA). Missions such as the Hubble Space Telescope (HST), James Webb Space Telescope (JWST), and the Mars Science Laboratory (MSL) had technical and programmatic challenges that led to significant schedule delays and subsequent cost growth. Although NASA has instituted policies that have reduced cost growth for more "typical" NASA science missions, NASA Flagship missions remain a distinct challenge due to their requirement to provide unprecedented science or tackle bold exploration goals, typically while concurrently developing new technologies. The unique challenges presented by Flagship missions make it extremely difficult to fully predict cost and schedule given that the technical and programmatic advances needed to meet performance requirements are unprecedented. This paper addresses why Flagship missions are unique and proposes a new programmatic approach to develop and fund Flagship missions.

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1. DEFINITION OF FLAGSHIP MISSIONS

According to Miriam-Webster's Dictionary, a Flagship is: 1) the ship that carries the commander of a fleet or subdivision of a fleet and flies the commander's flag, or 2) the finest, largest, or most important one of a group of things. [1] In many ways, National Aeronautics and Space Administration (NASA) Flagship missions incorporate both of these definitions as they are the most visible because of their potential for scientific discovery and expense and are also the finest, largest, and most important of NASA's science missions. NASA Flagship missions are unprecedented in the science that they enable as they provide exquisite measurements that cannot be done otherwise and typically require new technology or advanced engineering developments to acquire the measurements.

Figure 1 shows typical examples of NASA Flagship missions such as Viking, Galileo, the Hubble Space Telescope (HST), and others relative to their launch date and development cost. As shown in Figure 1, Flagship mission are typically developed on the order of every 10 years and have a cost greater than $2B fiscal year 2017. The development cost is from the start of preliminary development at the beginning of Phase B through launch and is taken from NASA historical public budget documents and then inflated to fiscal year 2017 equivalent dollars (FY17$). [2, 3] The relatively high cost of Flagship missions is due to their significant complexity with examples such as HST, as it was the largest pointable space telescope of its time, and the James Webb Space Telescope (JWST), which is larger than HST and operates at significantly colder temperatures while still meeting unprecedented stability requirements.

NASA Historical Flagship Development Cost (FY17$) vs. Launch Date

Figure 1. NASA Flagship Mission Cost vs. Launch Date

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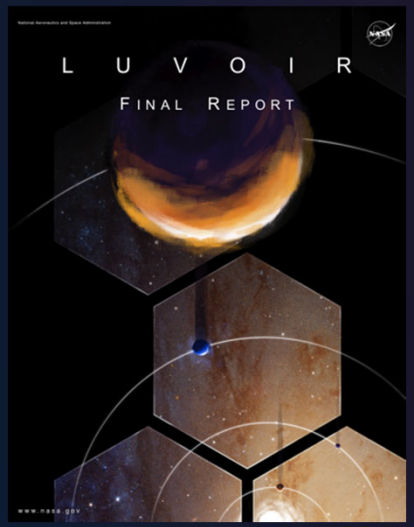
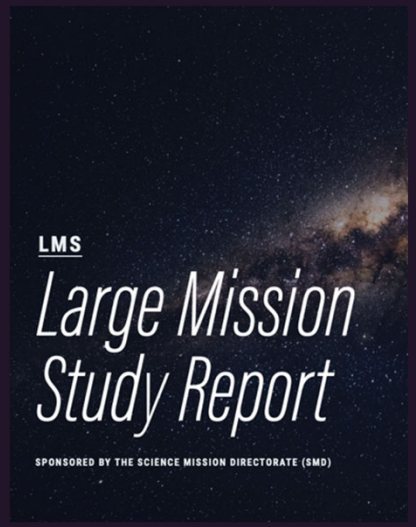
Mission Concept Reports

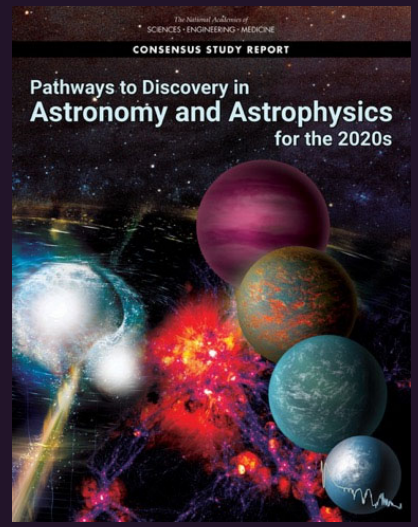


GAO Report on Major Projects

SMD Internal Study on Flagship Projects



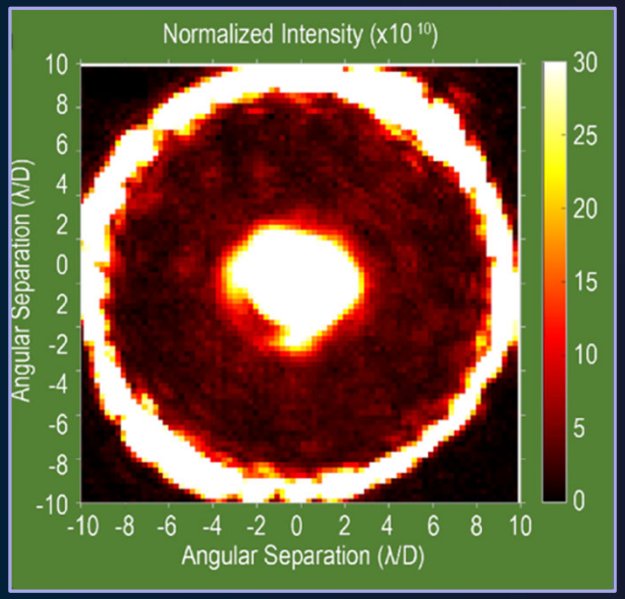
National Academy Recommendations



Coronagraph: Current State of the Art

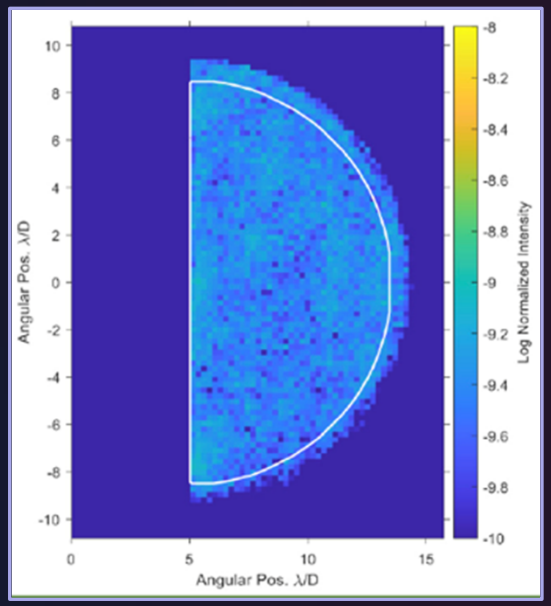
- **Unobscured simple Lyot Coronagraph**
  - **$4x10^{-10}$ contrast, 10% BW**
  - **3 – 10 λ/D**

  Credit: JPL HCIT Team



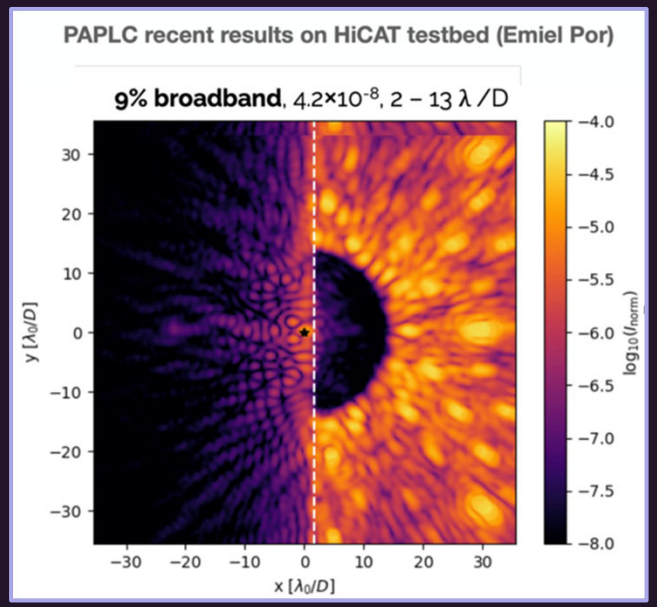
- **$4x10^{-10}$ contrast, 20% BW**
- **5.5 – 13 λ/D**

Credit: JPL HCIT Team

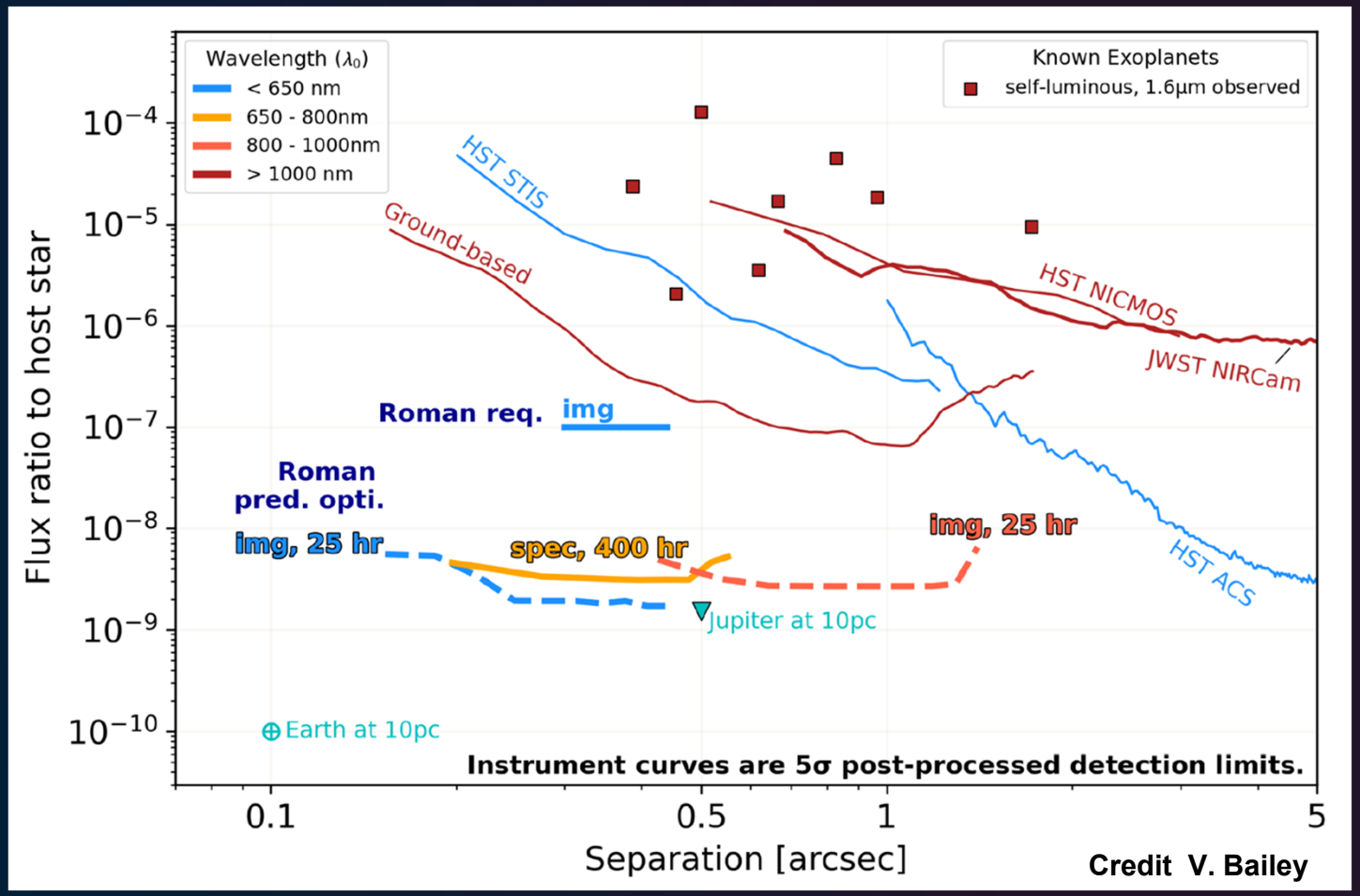


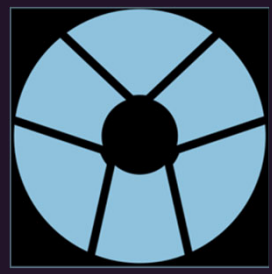
- **Segmented Mirror Aperture**
  - **$4.2x10^{-8}$ contrast, 9% BW**
  - **2 – 13 λ/D**

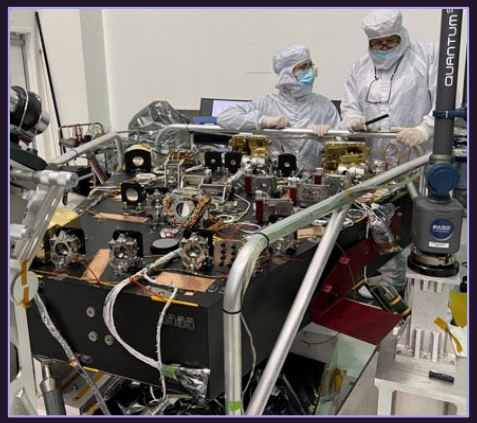
  Credit: Por et al. 2022



Roman Coronagraph







Credits: Jet Propulsion Laboratory

Contrast vs Stability Trade

The Habitable Worlds Observatory will be the first mission where the interface between coronagraph and observatory will be key to meeting the science requirements

Vis Science Case 1: Search for Planet Candidates

- By definition, static raw contrast ($|E|^2$) is constant → removed by reference subtraction (w/ residual shot noise)
- The mixing term ($2\mathrm{Re}\{E^* \Delta E\}$) is usually the dominant term impacting exoplanet detectability (noise floor)
- The table shows that raw contrast can be 10x worse, but a 3x improvement in wavefront stability returns the same detection limit
- Contributors to instability include movements of primary-mirror segments, telescope alignment drifts, and changes in DM surface figure
- **Observatory stability and coronagraph instrument performance are inextricably coupled (via the cross term)!**

Residual WFE & instability	$\|E\|^2$ raw contrast	$\|\Delta E\|^2$	$2\mathrm{Re}\{E^* \Delta E\}$	ΔI
$E = 7\times10^{-6}$, $\Delta E = 7\times10^{-7}$	5×10^{-11}	5×10^{-13}	1×10^{-11}	1×10^{-11}
$E = 2.3\times10^{-5}$, $\Delta E = 2.3\times10^{-7}$	5×10^{-10}	5×10^{-14}	1×10^{-11}	1×10^{-11}