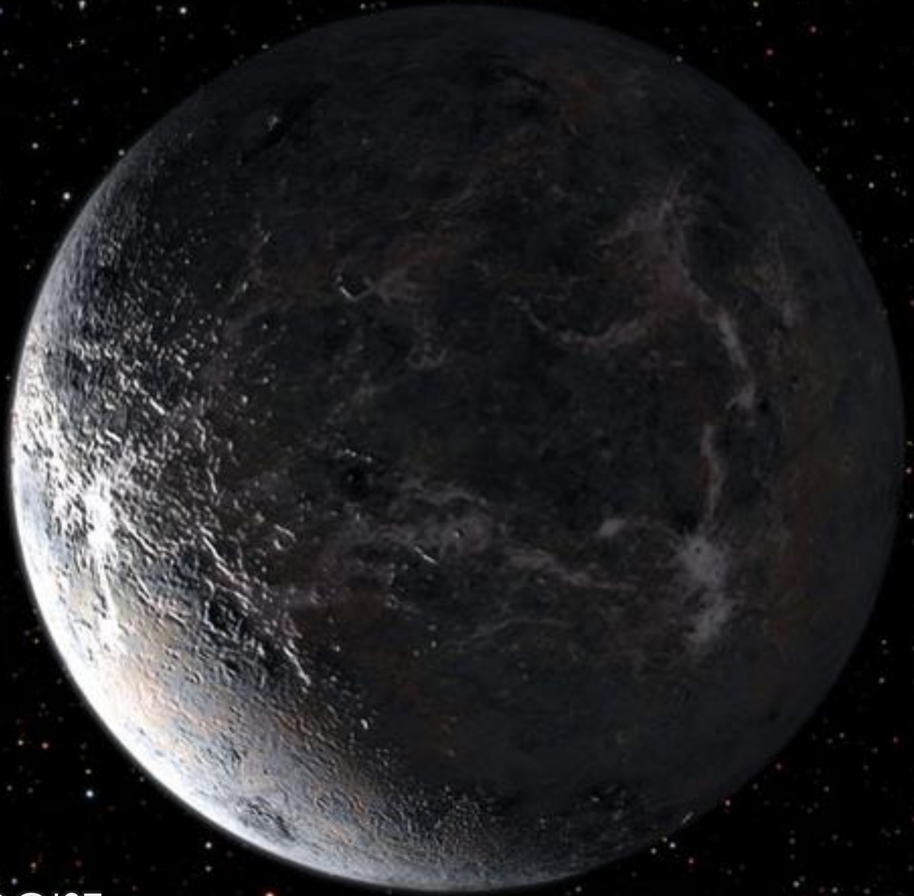
NASA ASTROPHYSICS CAPABILITY NEEDS FOR EXOPLANET SCIENCE



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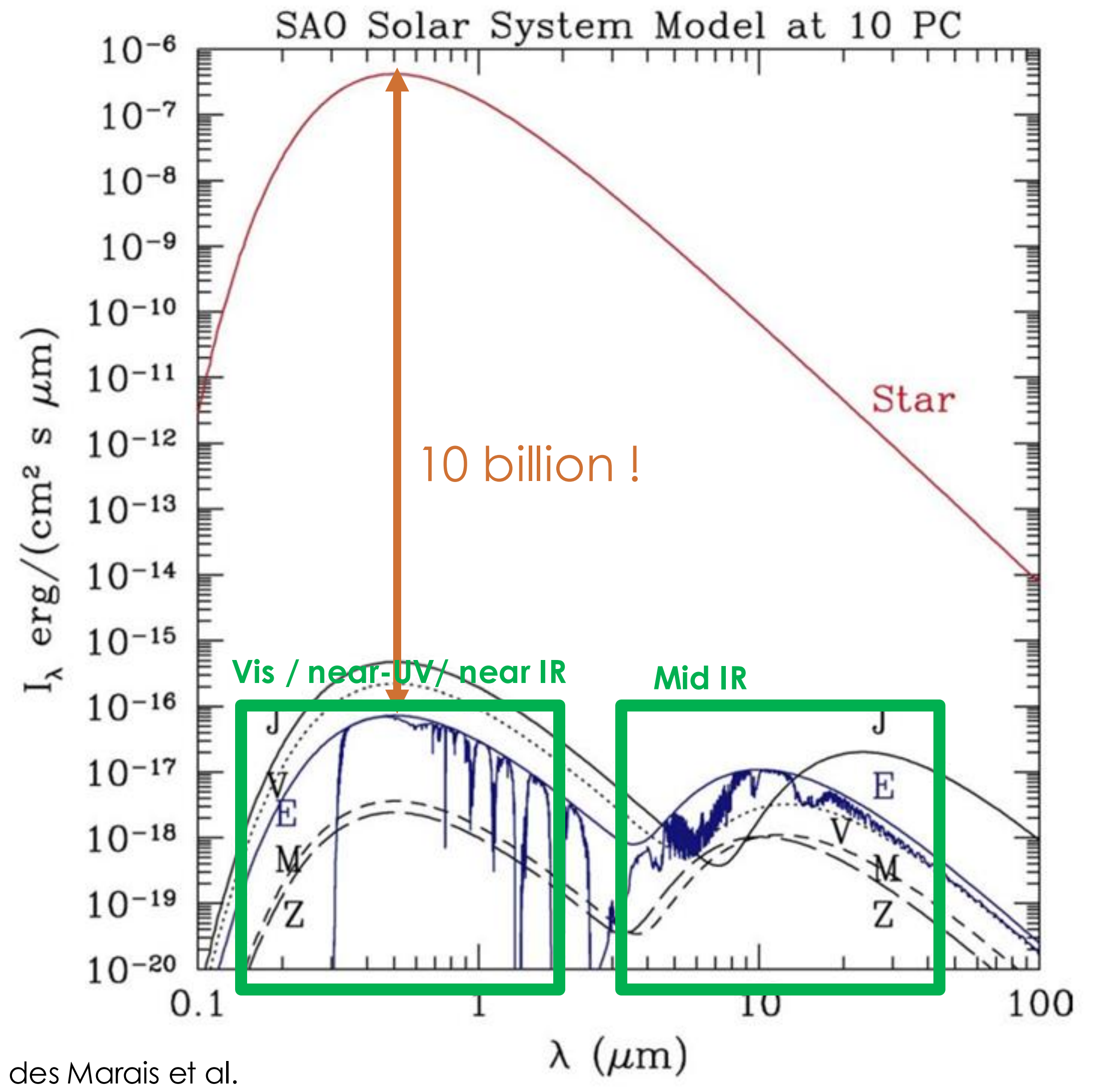
MARCH 4, 2025

Image Credit: NASA Hubblesite.org

Earth from Voyager 1 (6 billion km) with a 17cm telescope, Feb 14, 1990

Image Credit: NASA

Earth-like exoplanets are dim



des Marais et al.
Astrobiology (2002)

Figure 1. Model spectrum of the sun and planets as seen from a distance comparable to that of a nearby star (10 pc), shown in physical units. Simple Planck emission and wavelength-independent albedo reflectance components are shown. For Earth, a pure molecular absorption spectrum is superposed for reference.

Fluxes are measured in photons per few minutes

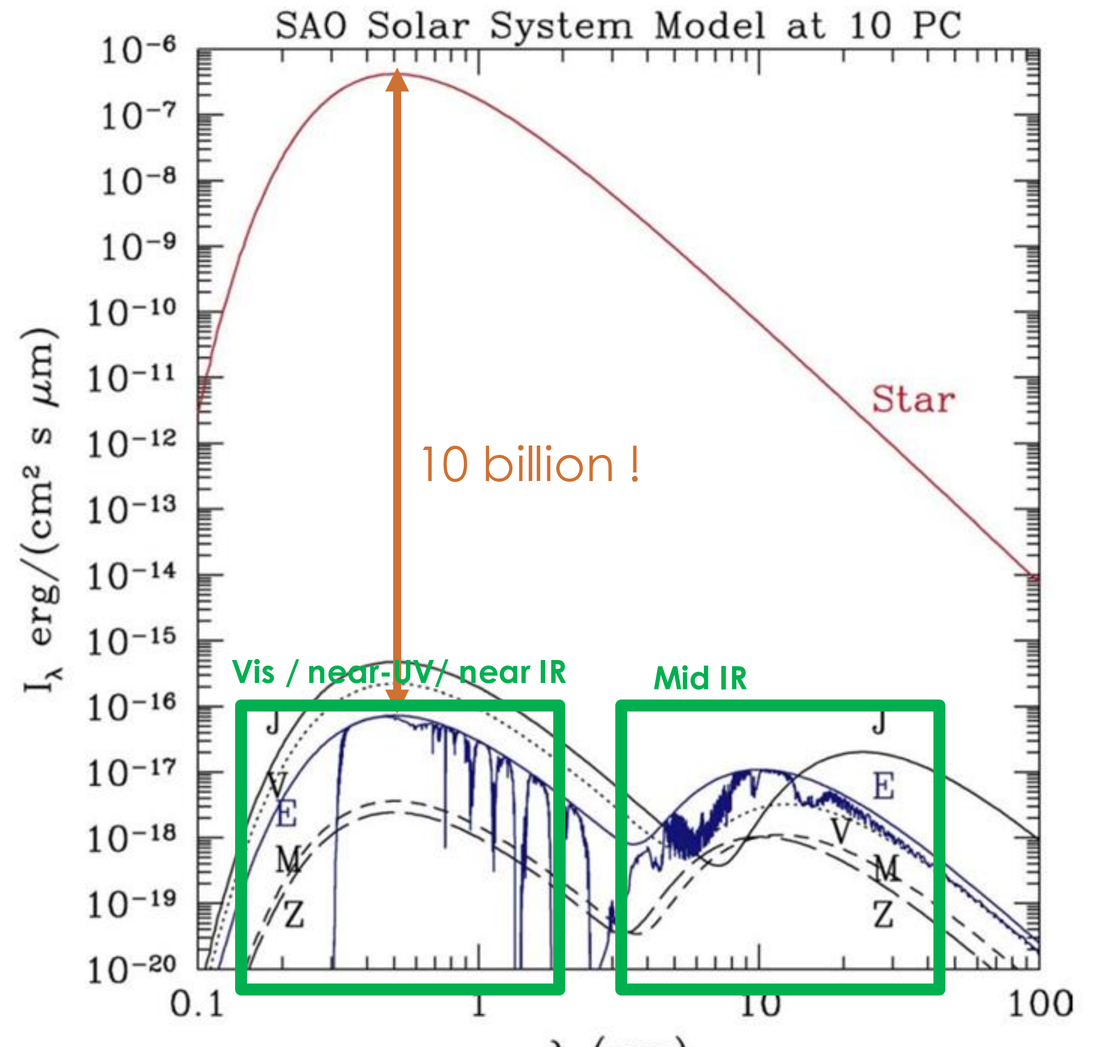
For spectroscopy, photons per hour

Can take months to characterize a single exoplanet using a space telescope (Menneson et al 2024)

Need:

- Photon-counting detectors that are highly efficient
- A light bucket to collect more photons (a huge telescope)

Earth-like exoplanets are close to their host star



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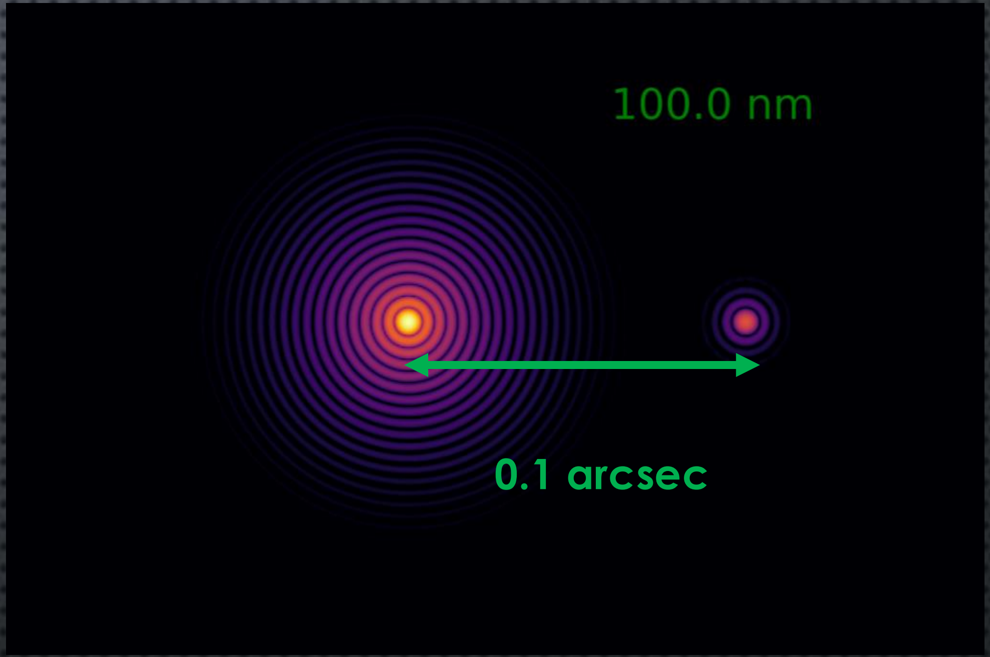
Astrobiology (2002)

Figure 1. Model spectrum of the sun and planets as seen from a distance comparable to that of a nearby star (10 pc), shown in physical units. Simple Planck emission and wavelength-independent albedo reflectance components are shown. For Earth, a pure molecular absorption spectrum is superposed for reference.

Star and planet through a 6m telescope:
λ/D scaling of resolution

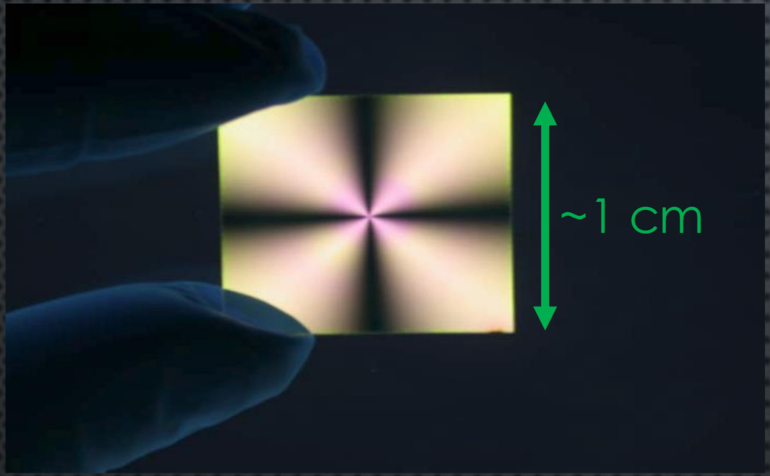


Need:

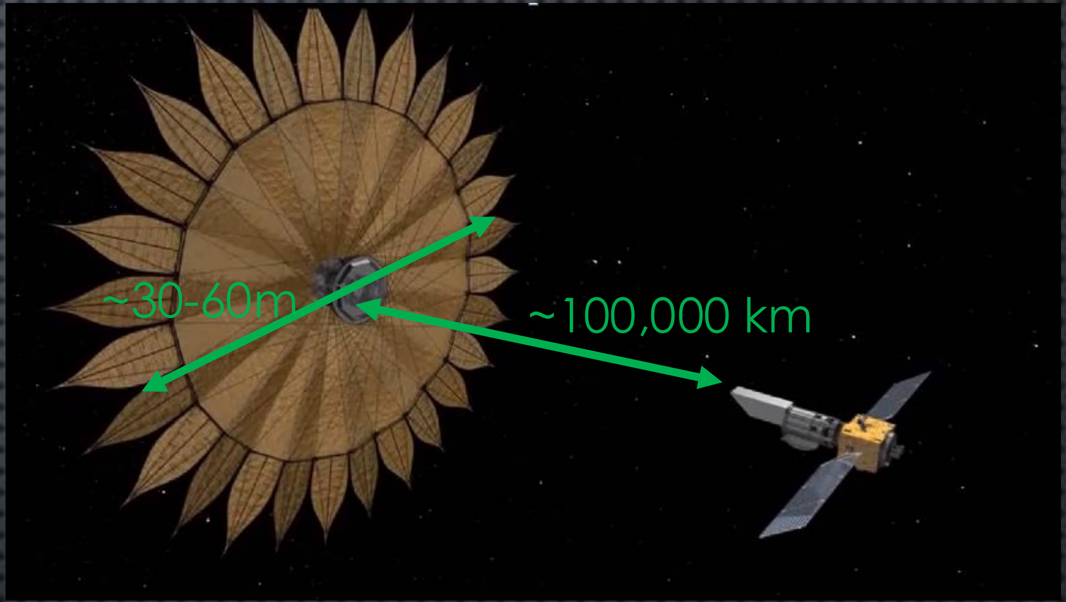
- High Contrast Imaging: coronagraph, starshade
- large ultrastable telescopes, interferometry

Starlight Suppression Techniques

Internal Occulter (Coronagraph)



External Occulter (Starshade)



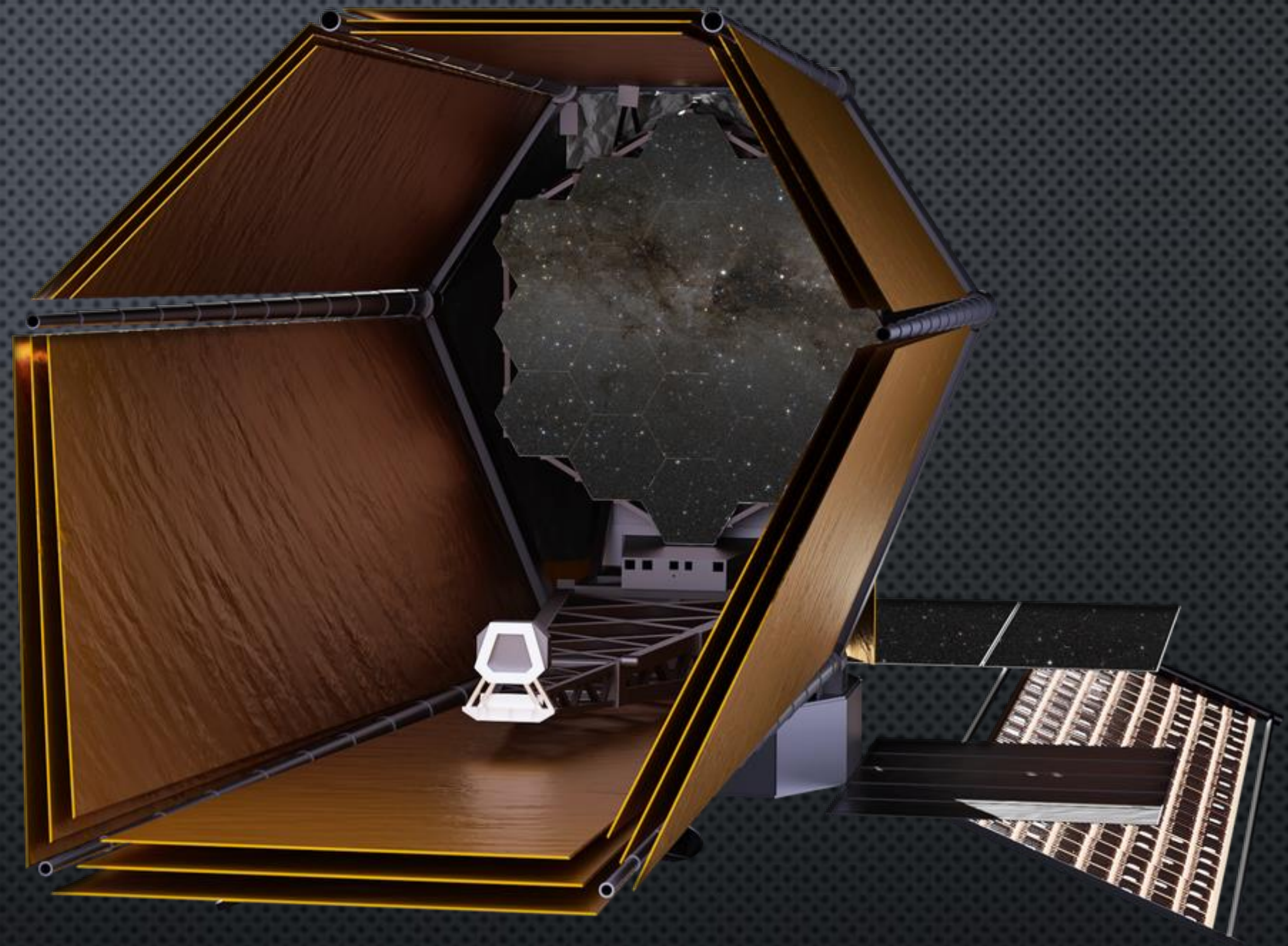
Nulling Interferometry

HABITABLE WORLDS OBSERVATORY

- A flagship mission with a ~6m IR/Vis/UV telescope designed to detect and characterize Terrestrial Exoplanets
- Currently developing technology
- aiming for maturity by ~2030; launch would be ~2040s
- Will be serviceable

Key Technology Challenges

- Starlight suppression with a coronagraph
- Ultrastable telescope
- UV Instrumentation



One architecture concept for HWO

Current Gaps – Coronagraph System

1. Starlight Suppression

Overall ability to achieve desired raw contrast, bandwidth, inner working angle, etc.

2. Deformable Mirrors

High actuator count; stable smooth surface; robust, precision electronics and interconnects

3. Coronagraph Sensing & Control

Achieve and maintain contrast stability during observations

4. Low-noise/Noiseless Detectors

Photon-counting, low-noise, rad-hard capability with high QE at biomarker wavelengths

5. Spectroscopy

Resolve questions about speckle chromaticity; achieve desired R for key biomarkers

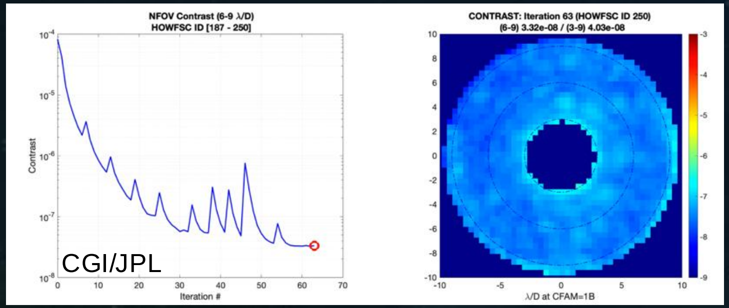
6. Near-UV Capability

Achieve high contrast between 250-450 nm for key ozone features

7. Post-processing

Achieve desired SNR in context of observatory stability and sensing & control

State-of-the-Art: Roman CGI



4.0e-8
Raw Contrast
3-9 λ/D

48x48 Deformable Mirror

Con-ops and Post Processing:
Reference Differential Imaging (RDI)
➔ **FRN = 3.94×10^{-9}**
(Courtesy of B. Kern)

Current Gaps – Ultra-Stable Telescope

8. Ultra-stable Mirrors

Mirror cell that meeting required stability and optical performance

9. Ultra-stable Structures

Composites and joints with low creep and high-stiffness

10. Thermal Control System

Milli-kelvin control with compact Flight electronics, low-vibe thermal control systems

11. Telescope Sensing & Control

Sense and control segment-level and global telescope alignment at picometer level

12. Low-disturbance Systems

Active and passive isolation, Microthrusters, and low-disturbance mechanisms

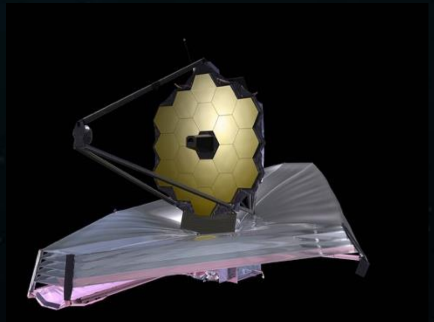
13. Deployable Systems

Large deployable baffle, stable hinge and latch systems

State-of-the-Art: JWST, Roman

Roman Instrument Carrier achieves 10 mk stability

Roman Telescope thermal vacuum test results consistent with 10s of pm wavefront error stability.



JWST continues to exhibit extraordinary on-orbit passive stability.

Current Gaps – High-Sensitivity UV/VIS Instruments

14. Far-UV Mirror Coatings

Broadband with high reflectivity down to 100 nm; high-uniformity and low scattering

15. Near UV/VIS Detectors

Large format, low noise, high-QE

16. Far-UV Detectors

Large format and high-QE, with high solar-blindness

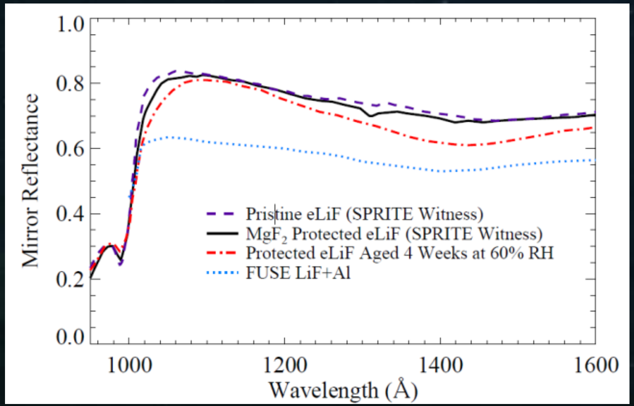
17. Multi-object Selection

Microshutters, micro-mirrors, or slicers for multi-object or integral field spectroscopy

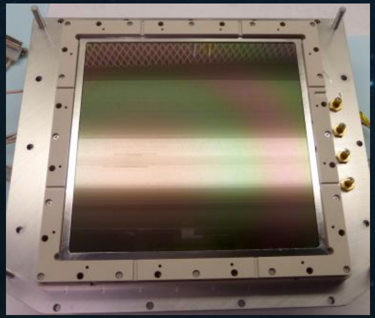
18. UV Gratings and Filters

High out-of-band rejection; curved substrates for aberration control

State-of-the-Art: Sub-orbital & Lab



SPRITE mirror coating

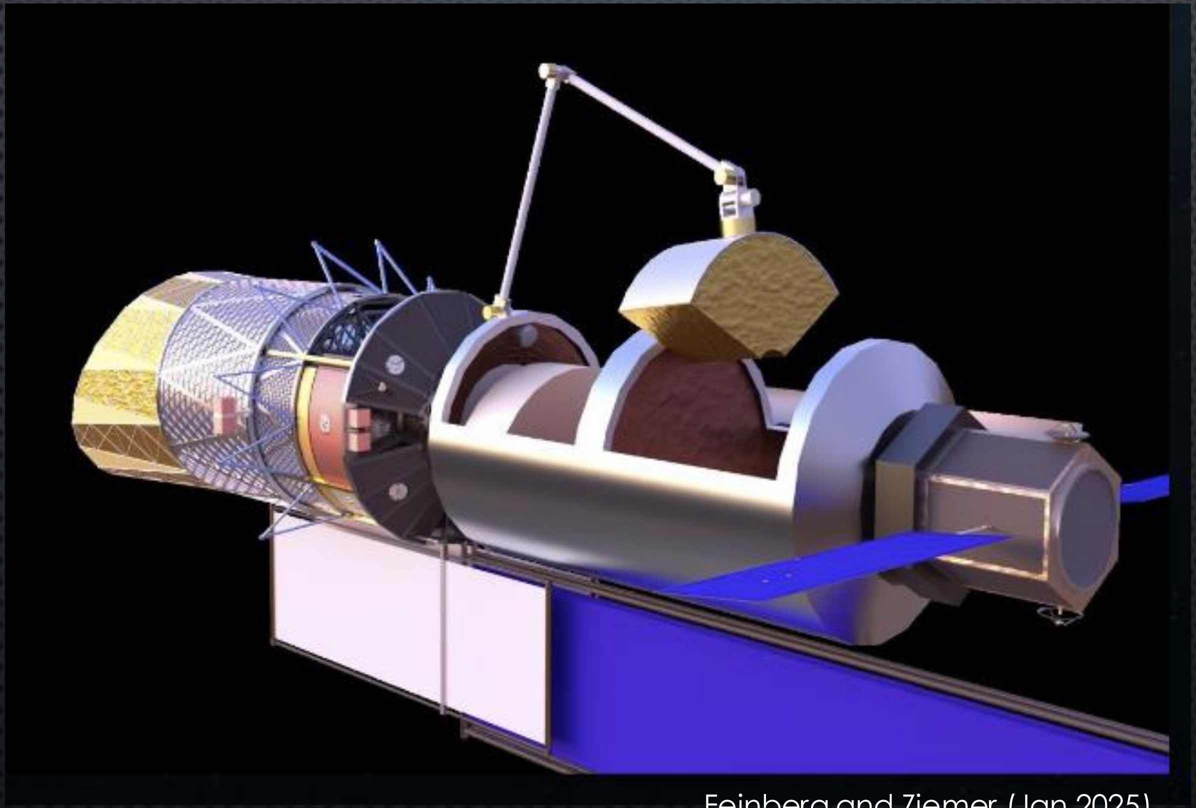


20x20 cm MCP for DEUCE

FORTIS & JWST microshutters (left) with next gen devices (right)

See: Tuttle, et al. 2024 for comprehensive review of state-of-the-art.

HWO IS PLANNED TO BE AN IN-SPACE ROBOTIC-SERVICEABLE MISSION AT EARTH-SUN L2

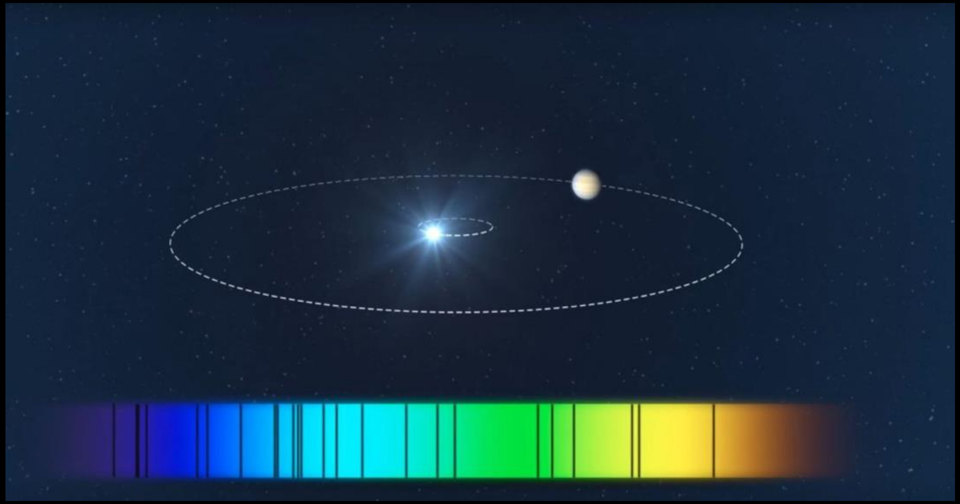


Feinberg and Ziemer (Jan 2025)

Exoplanet Mass Measurement Technology Gaps

Challenge:

- Measuring recoil motion of stars to detect an orbiting Earth-mass planet



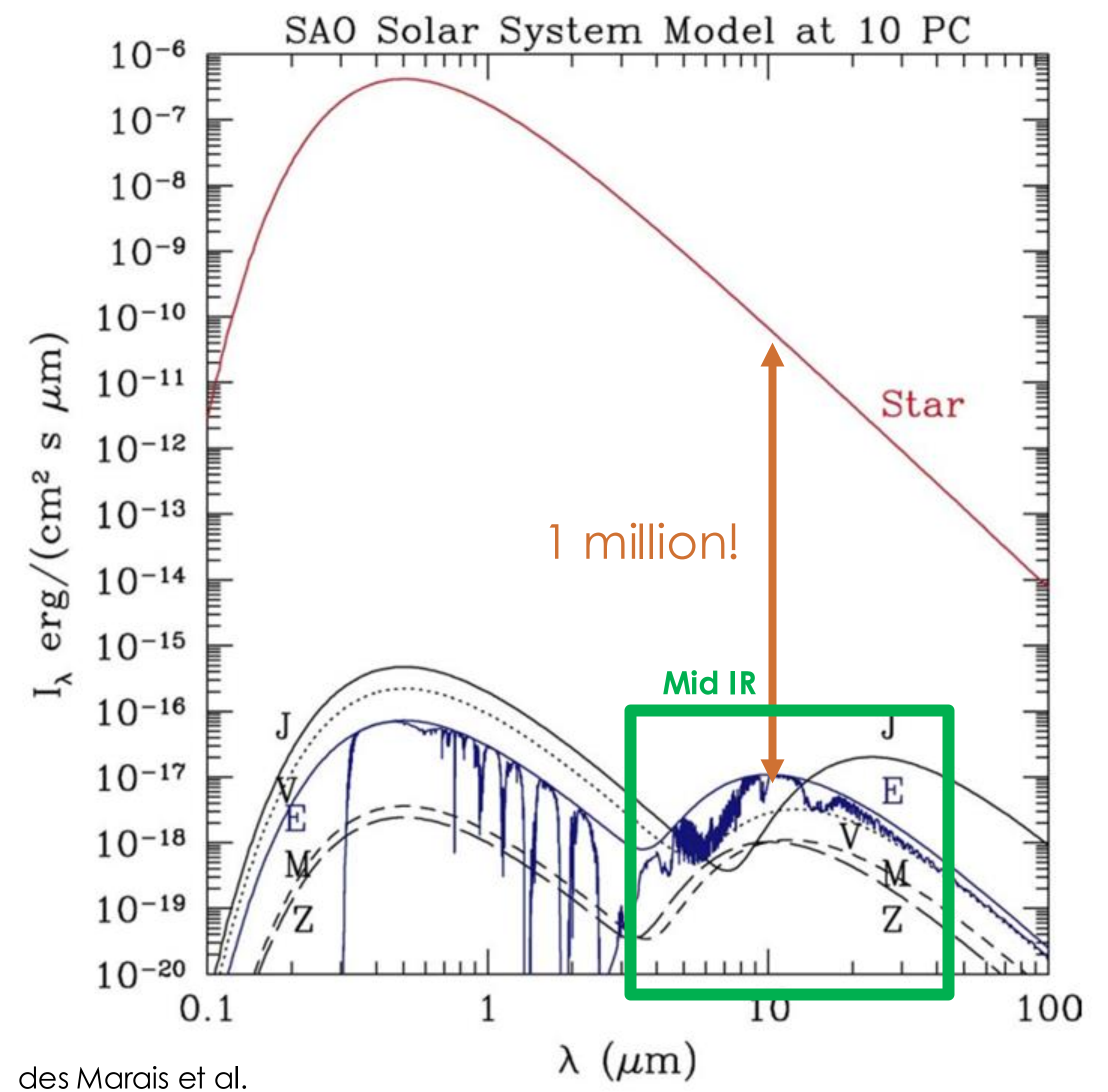
Extreme Precision Radial Velocity ~1 cm/s precision

- Detectors for High-res Spectrographs
- Dispersive Optics
- Advanced Photonics
- Ground-based Visible-light Adaptive Optics
- Precision Calibration

Astrometry ~ 1 microarcsecond precision

- Detector Metrology
- Optical Field Distortion Stability and Metrology

Mid-Infrared



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In mid-IR:

Richer biosignatures

Contrast is more 10^4 times favorable than in Visible

BUT:

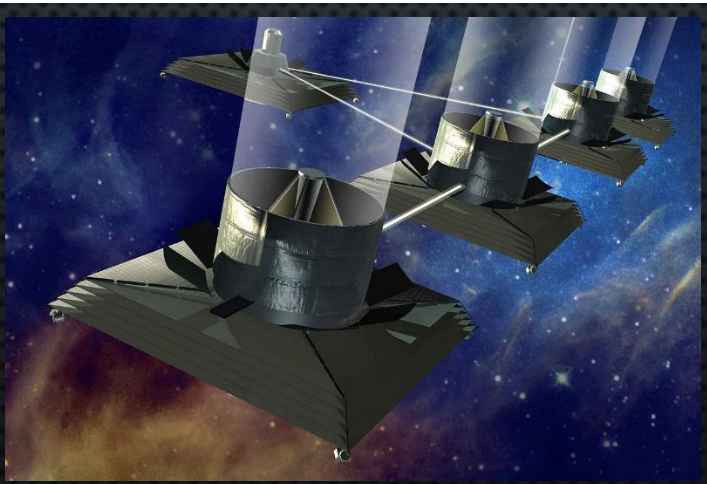
Angular resolution is a problem

Challenges:

- Enormous telescope
  or Interferometer
- Optics/detectors must be cold

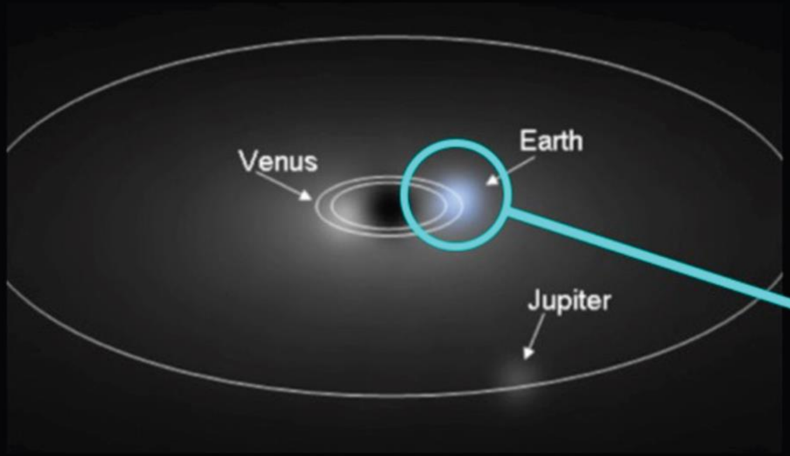
Mid-Infrared Interferometer Technology Gaps

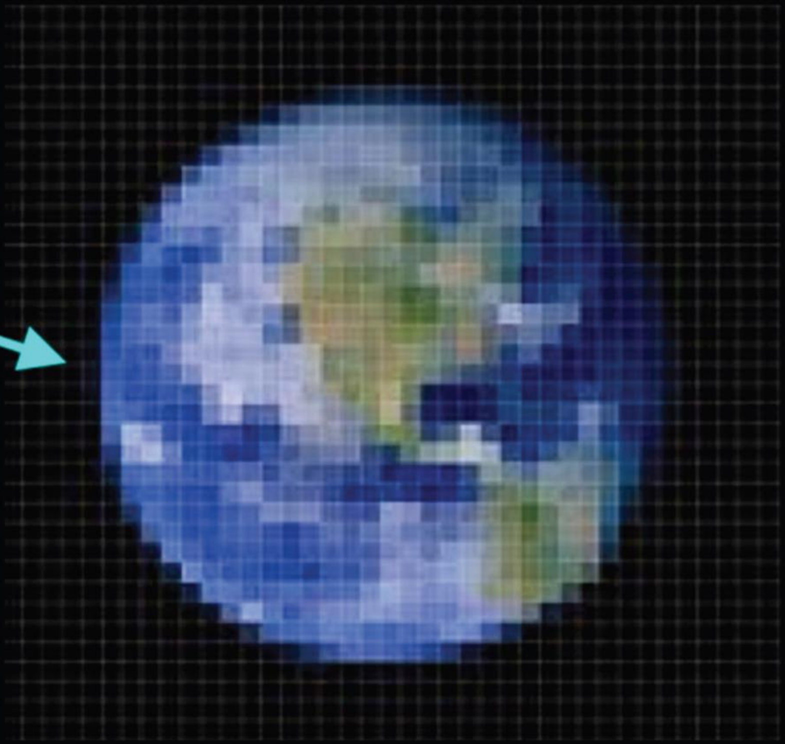
#	Gap Name	#	Gap Name
Gap #1	Cryogenic single mode spatial filters	Gap #6	Cryogenic four-beam nulling
Gap #2	Cryogenic deformable mirrors	Gap #7	Cooling
Gap #3	Cryogenic delay lines	Gap #8	Detector technology
Gap #4	Laser metrology systems	Gap #9	Mirror technology
Gap #5	Cryogenic broadband nulling at N-band	Gap #10	Formation flying technology

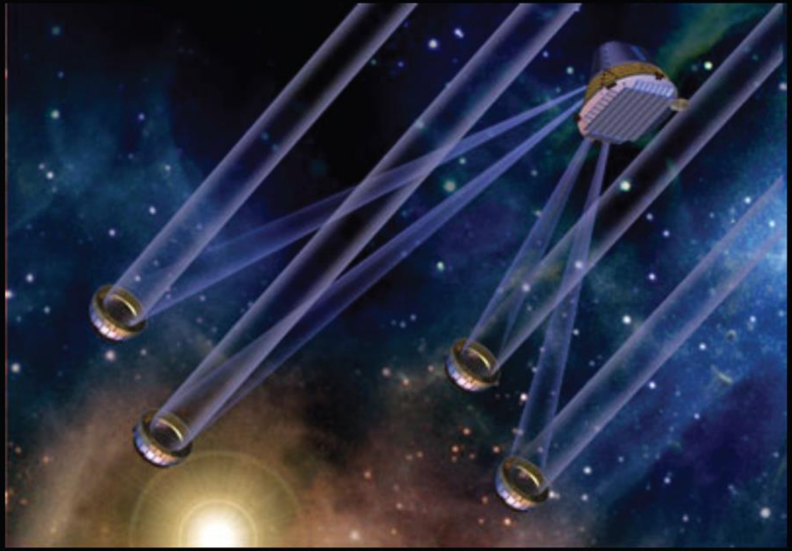


Martin, Mennesson, Serabyn, Danchi, Chen, Siegler priv. comm (2021)

Mapping Earths.







NEW SOLUTIONS TO OLD PROBLEMS?

- CONVENTIONAL TECHNOLOGIES DRIVE US TOWARDS EXPENSIVE, COMPLEX SOLUTIONS THAT TAKE A LONG TIME TO DEVELOP AND IMPLEMENT
- ***USING EMERGING TECHNOLOGIES CAN WE FIND BETTER WAYS TO SEARCH FOR LIFE IN THE UNIVERSE?***

BACKUP

Links to More Information

- NASA Astrophysics Technology Gap List
- NASA Astrophysics biennial Technology Report (2024)
- NASA Exoplanet Exploration Program Technology Gap List (including Subgaps)

- Whitepapers and Final Reports for Exoplanet Related Strategic Astrophysics Technology awards
- Progress in Technology for exoplanet missions (2023)