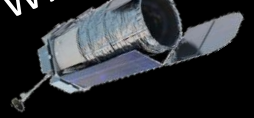
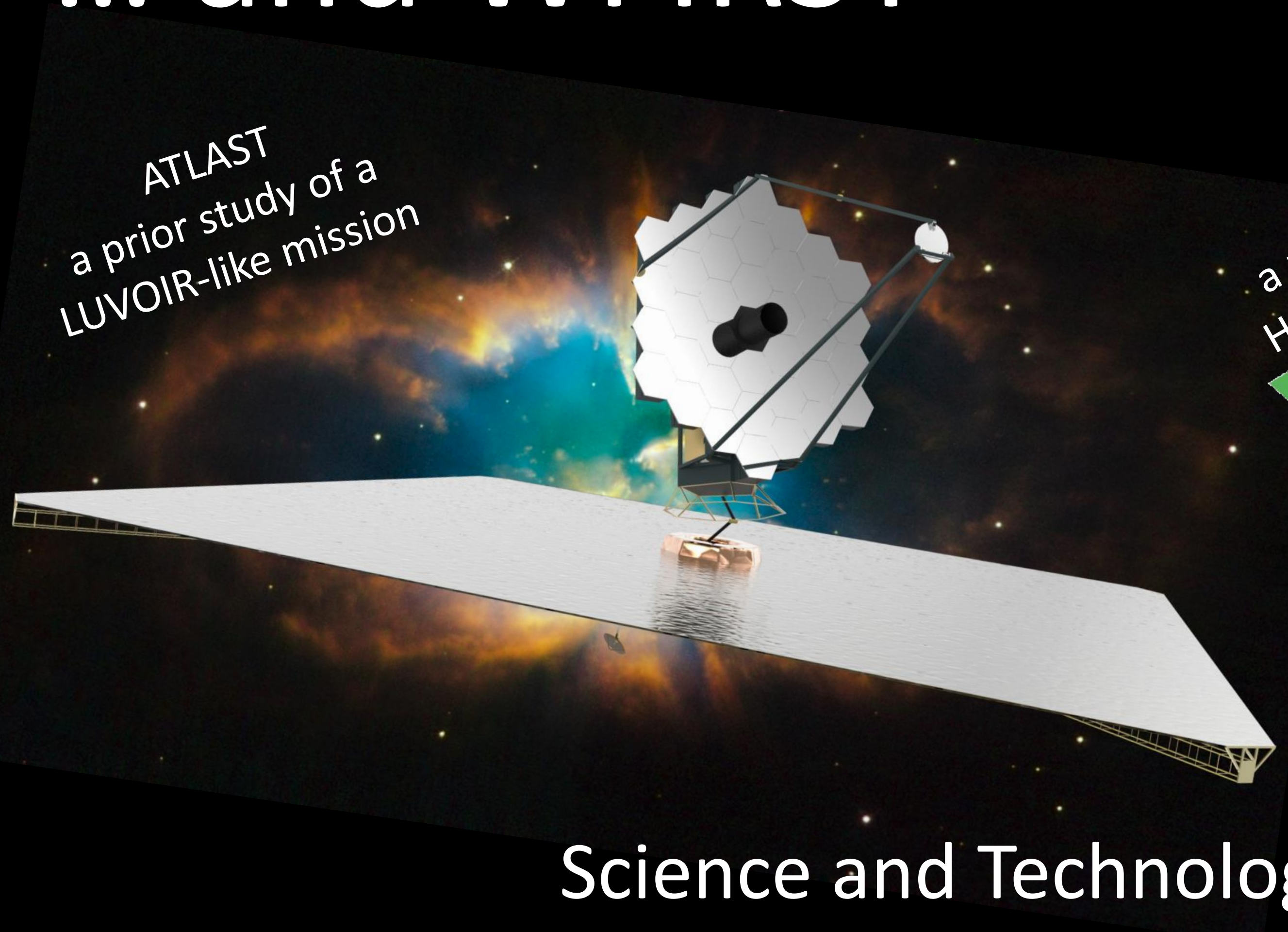
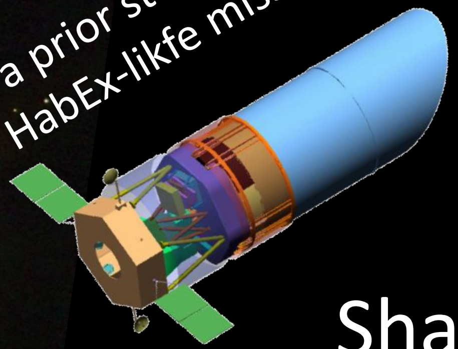
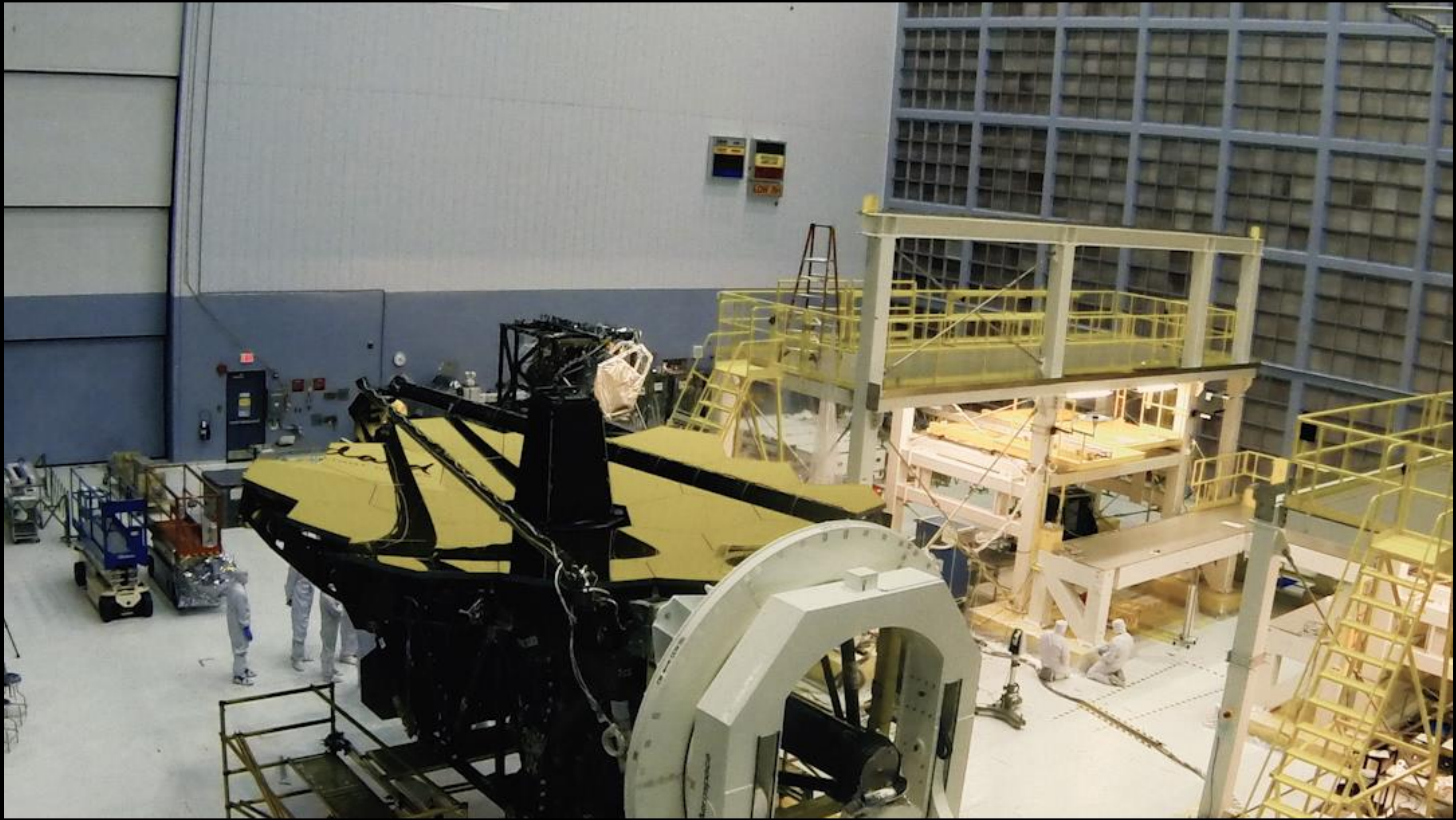
life detection capabilities of LUVOIR and HabEx … and WFIRST







Shawn Domagal-Goldman
NASA Goddard Space Flight Center
Deputy Study Scientist, LUVOIR
Science and Technology Definition Team member, HabEx



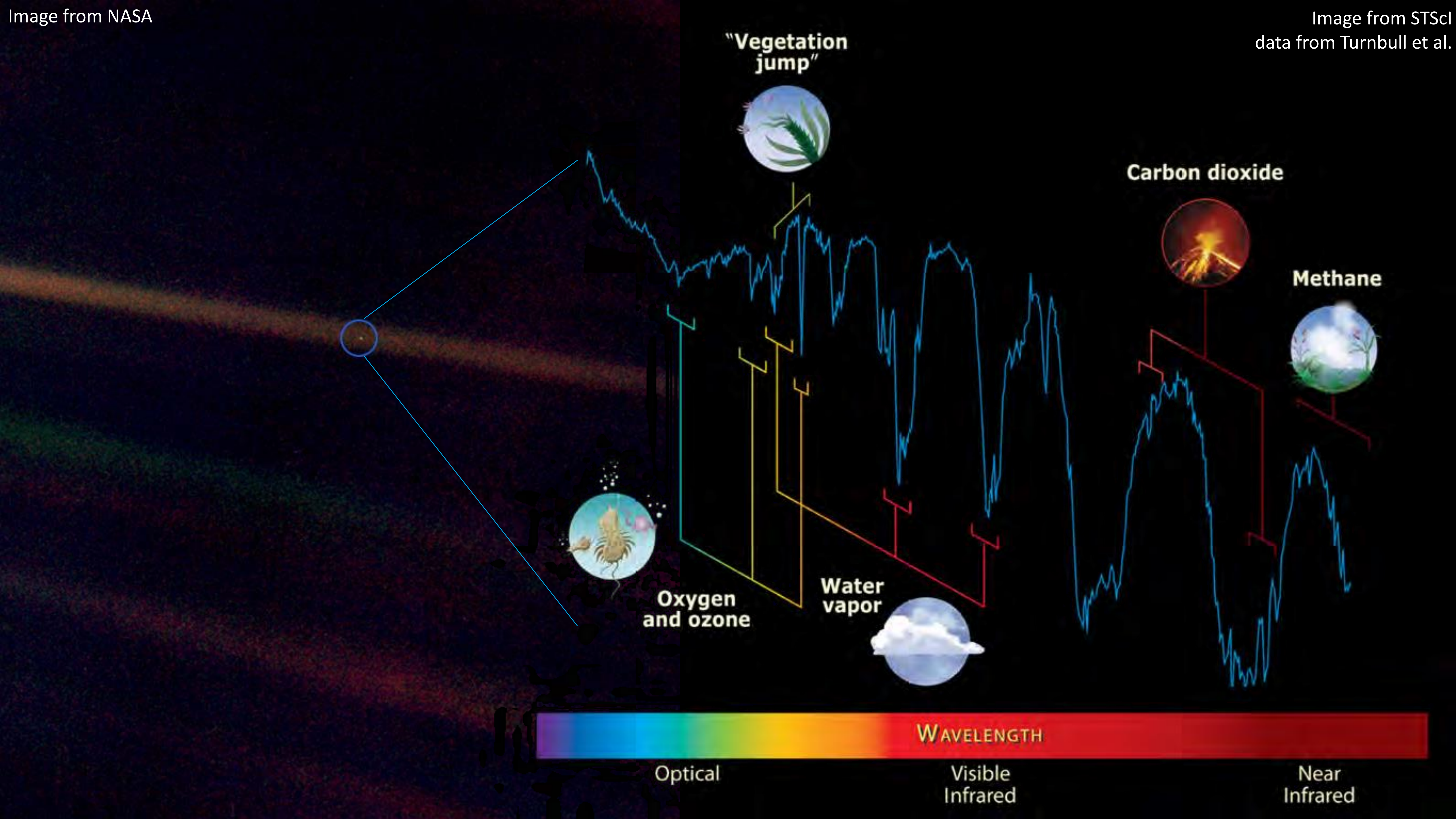
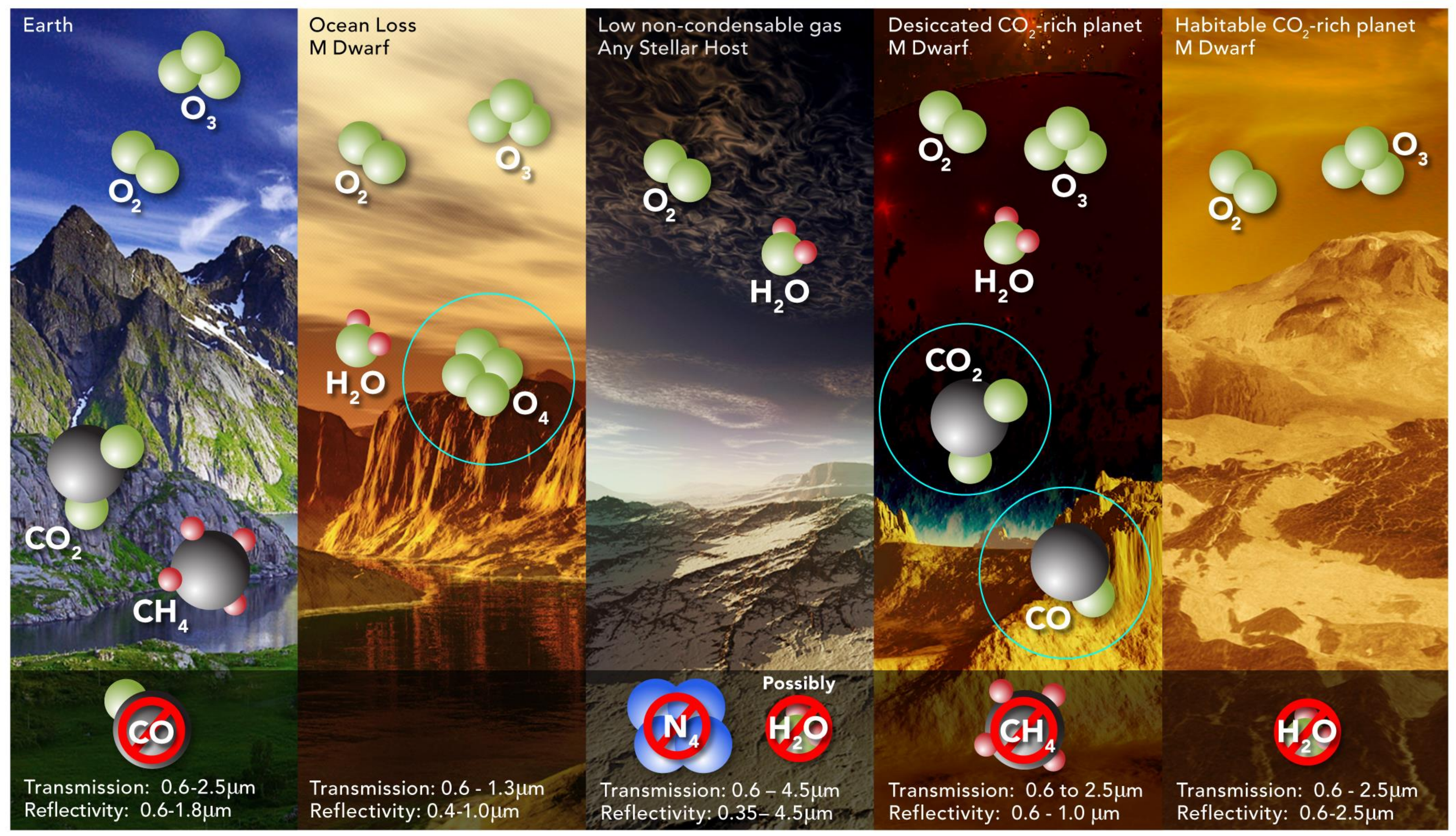


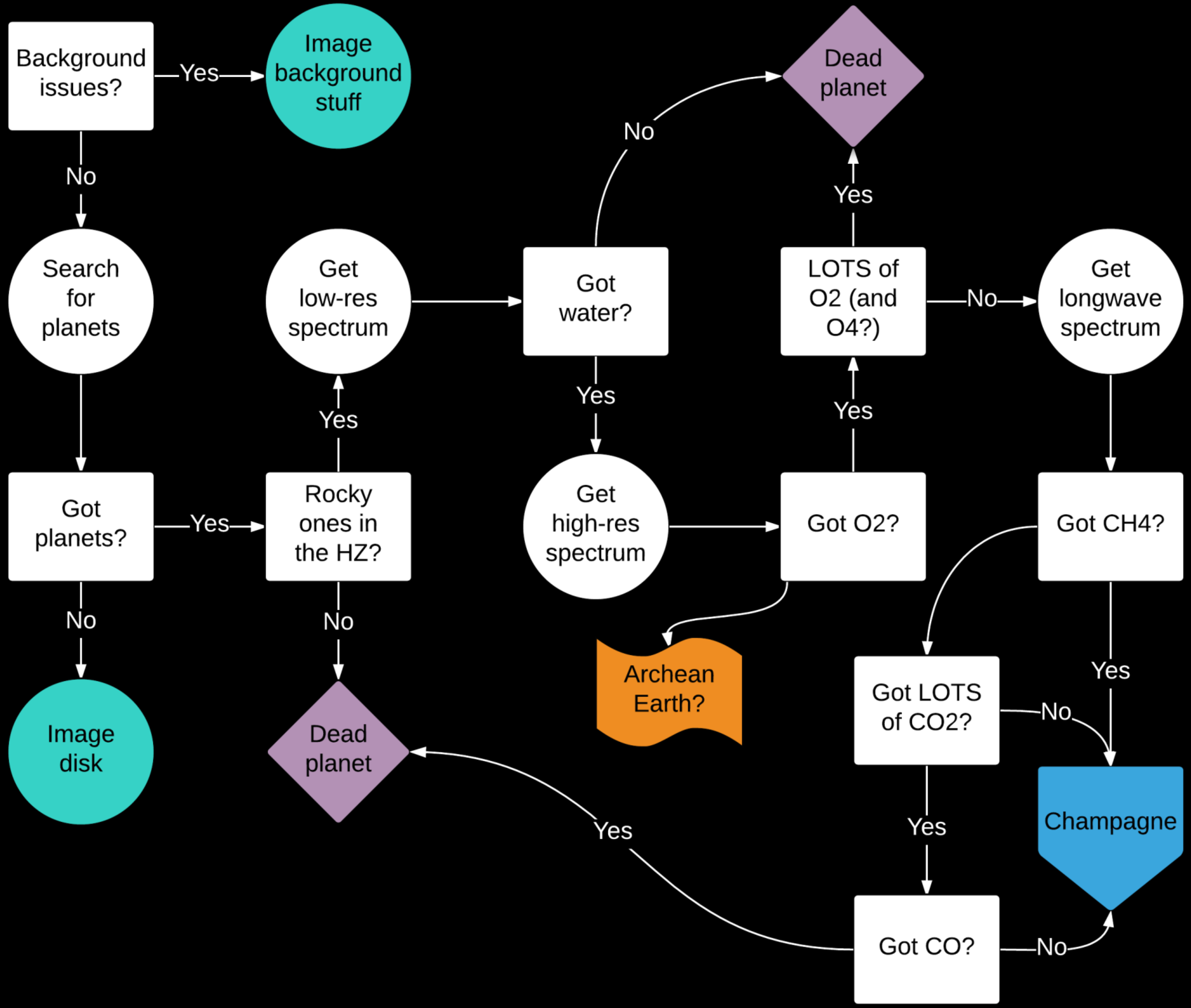
Image from NASA
Image from STScI
data from Turnbull et al.
"Vegetation jump"
Carbon dioxide
Methane
Oxygen and ozone
Water vapor
Wavelength
Optical
Visible Infrared
Near Infrared



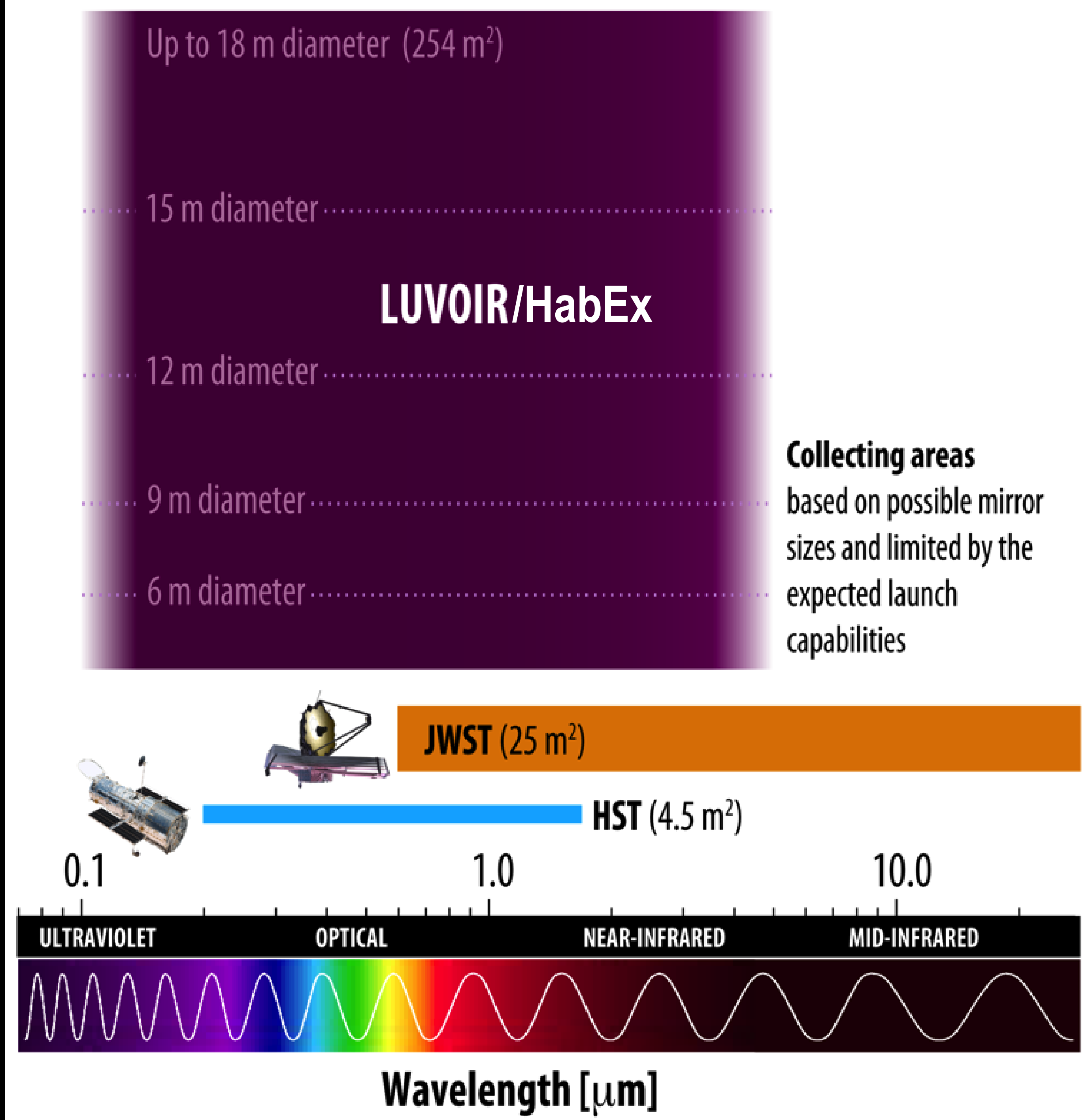
Meadows, 2016

Is the flux our biosignature?

O_2 Generation Mechanism	Stellar Host	O_2 Column Depth (molecules/cm^2)	O_3 Column Depth (molecules/cm^2)	O_2 production rate (molecules/cm^2/s)
Modern Earth Biology	G-type star	$\sim 5\times10^{24}$	$\sim 6\times10^{18}$	$\sim 1\times10^{19}$
Archean Earth Biology	G-type star	$\sim 4\times10^{16}$	$\sim 8\times10^{11}$	$\sim 3\times10^{11}$
Photochemistry (Harman et al.)	G-type star	$\sim 2\times10^{19}$	$\sim 7\times10^{14}$	$\sim 1\times10^{12}$
Photochemistry (Harman et al.)	M-type star	$\sim 2\times10^{23}$	$\sim 3\times10^{18}$	$\sim 3\times10^{11}$
H escape (Luger et al., Schwieterman et al.)	M-type star	$\sim 1\times10^{26}$	$\sim 2\times10^{19}$	$\sim 3\times10^{12}$



Background issues?
Yes
Image background stuff
No
Search for planets
Got planets?
Yes
No
Image disk
Rocky ones in the HZ?
Yes
No
Dead planet
Get low-res spectrum
Got water?
No
Dead planet
Yes
Get high-res spectrum
Got O2?
Archean Earth?
Yes
LOTS of O2 (and O4?)
Yes
No
Get longwave spectrum
Got CH4?
Yes
Got LOTS of CO2?
No
Yes
Champagne
Got CO?
Yes
No


Up to 18 m diameter (254 m²)
15 m diameter
LUVOIR/HabEx
12 m diameter
9 m diameter
6 m diameter
Collecting areas
based on possible mirror sizes and limited by the expected launch capabilities
JWST (25 m²)
HST (4.5 m²)
0.1
1.0
10.0
ULTRAVIOLET
OPTICAL
NEAR-INFRARED
MID-INFRARED
Wavelength [μm]

NASA/JPL

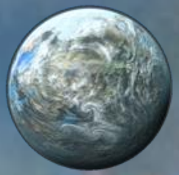
NASA/JPL

Crab Nebula with HST ACS/WFC, Credit: NASA / ESA

Difference between LUVOIR and HabEx ?

Both LUVOIR and HabEx have two primary science goals

- Habitable exoplanets & biosignatures
- Broad range of general astrophysics



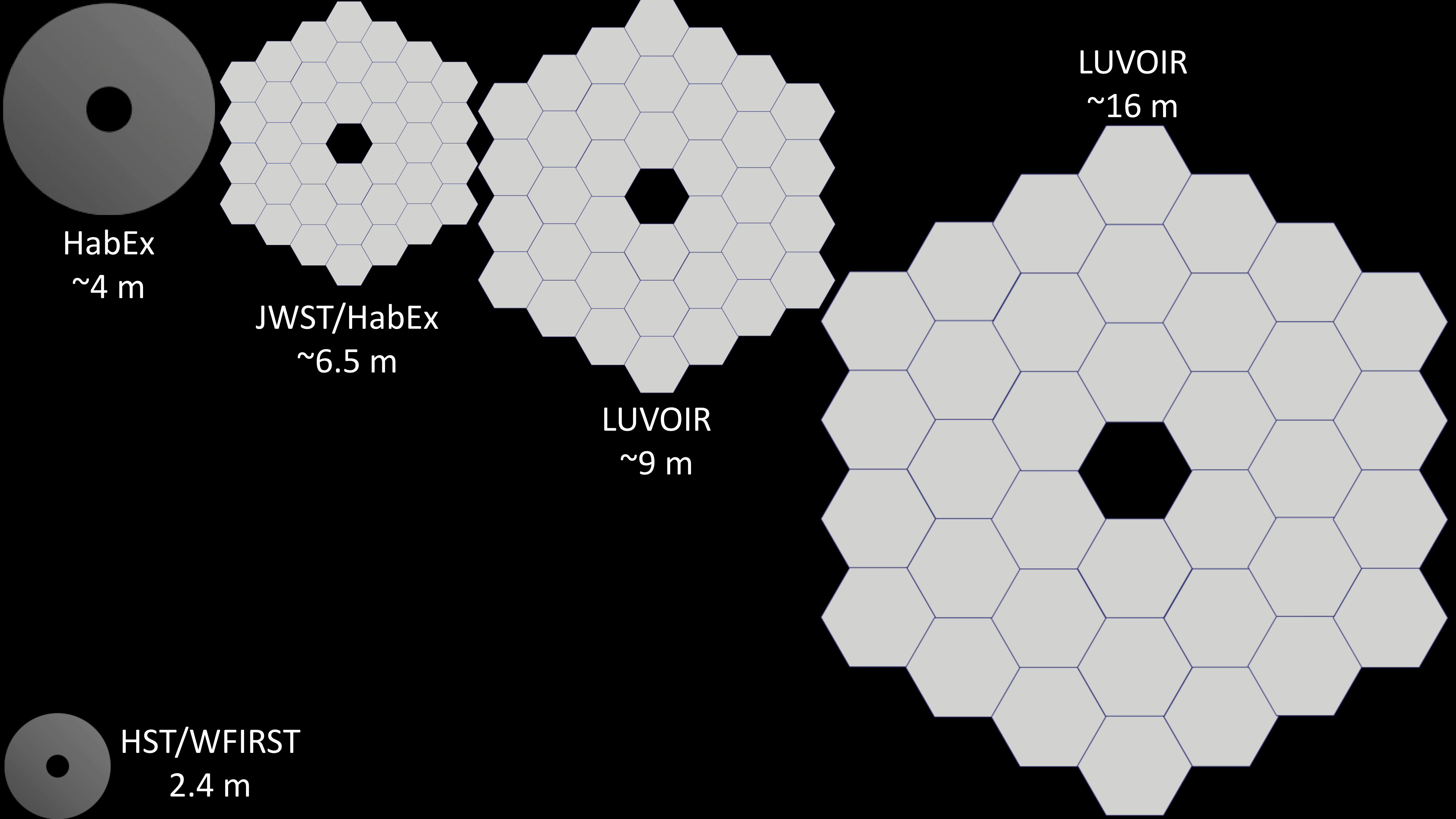
The two architectures will be driven by difference in focus

- For LUVOIR, both goals are on equal footing. LUVOIR will be a general purpose “great observatory”, a successor to HST and JWST in the ~ 8 – 16 m class
- HabEx will be optimized for exoplanet imaging, but also enable a range of general astrophysics. It is a more focused mission in the ~ 4 – 8 m class

Similar exoplanet goals, differing in quantitative levels of ambition

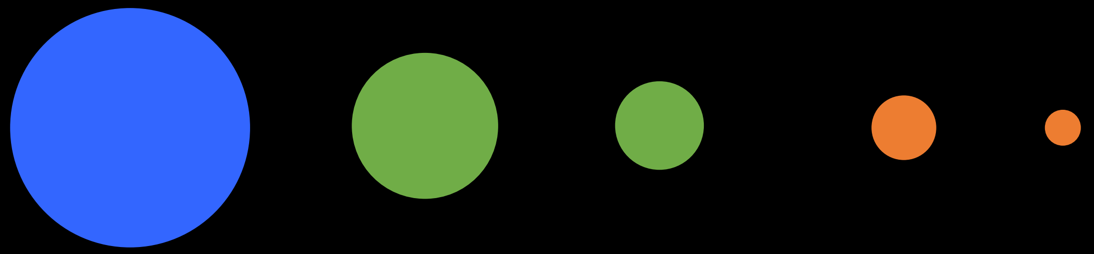
- HabEx will *explore* the nearest stars to “search for” signs of habitability & biosignatures via direct detection of reflected light
- LUVOIR will *survey* more stars to “constrain the frequency” of habitability & biosignatures and produce a statistically meaningful sample of exoEarths

The two studies will provide a continuum of options for a range of futures


HabEx
~4 m
JWST/HabEx
~6.5 m
LUVOIR
~9 m
LUVOIR
~16 m
HST/WFIRST
2.4 m

UV oxygen emission from Europa water vapor jets observed with HST

For illustration …

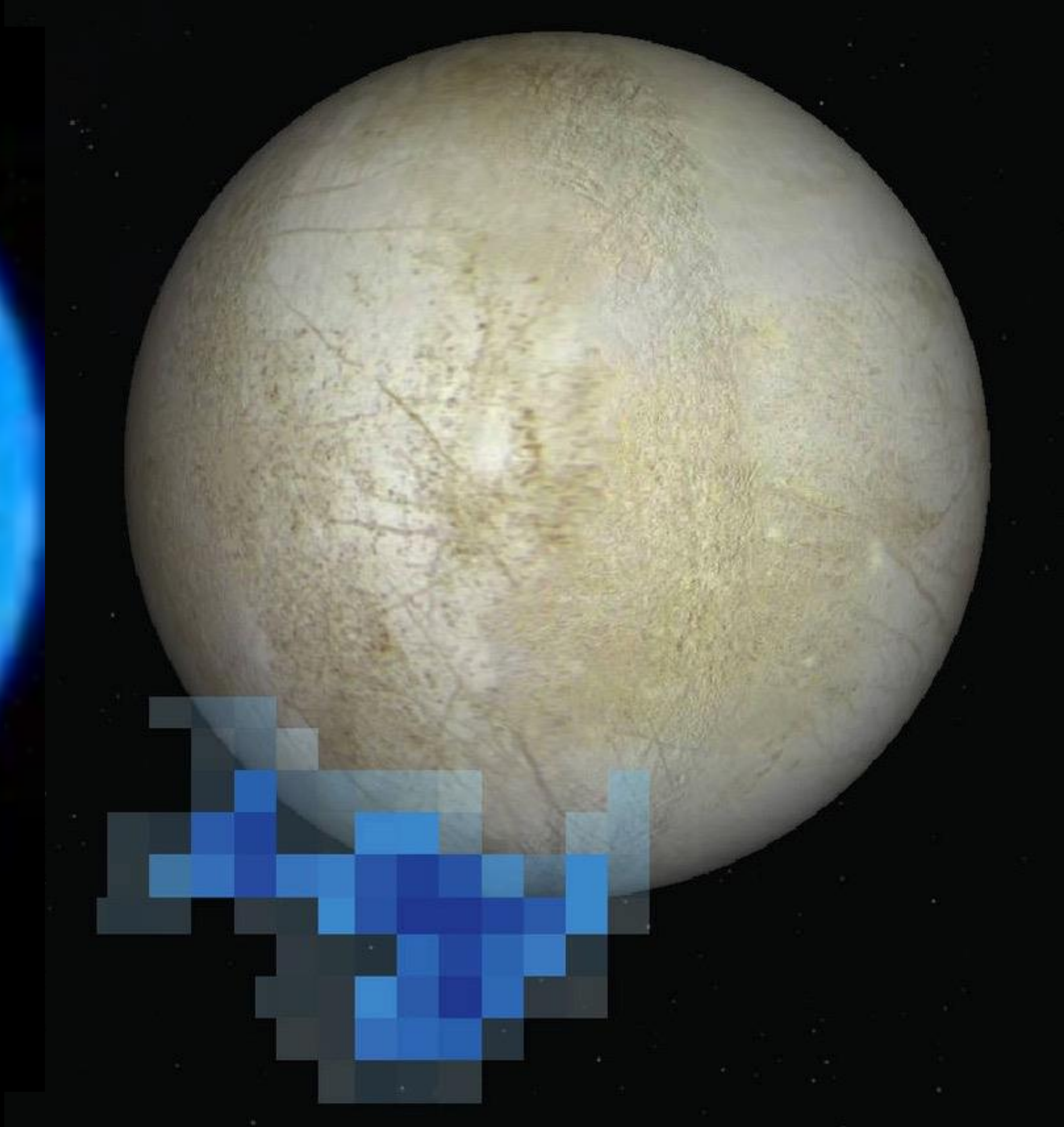


HST resolution 2.4-m

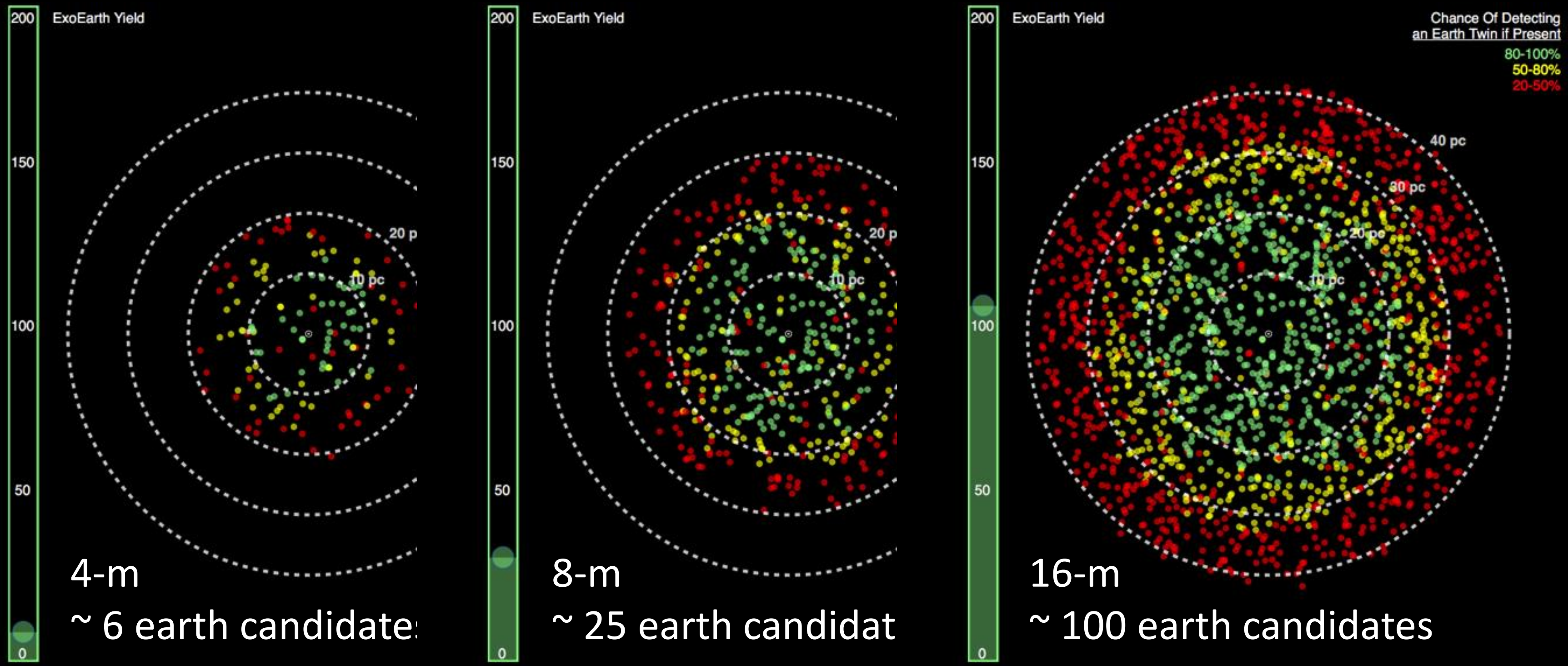
HabEx resolution 4-m 6.5-m

LUVOIR resolution 9-m 16-m

Credit: NASA/ESA/L. Roth/SWRI/University of Cologne



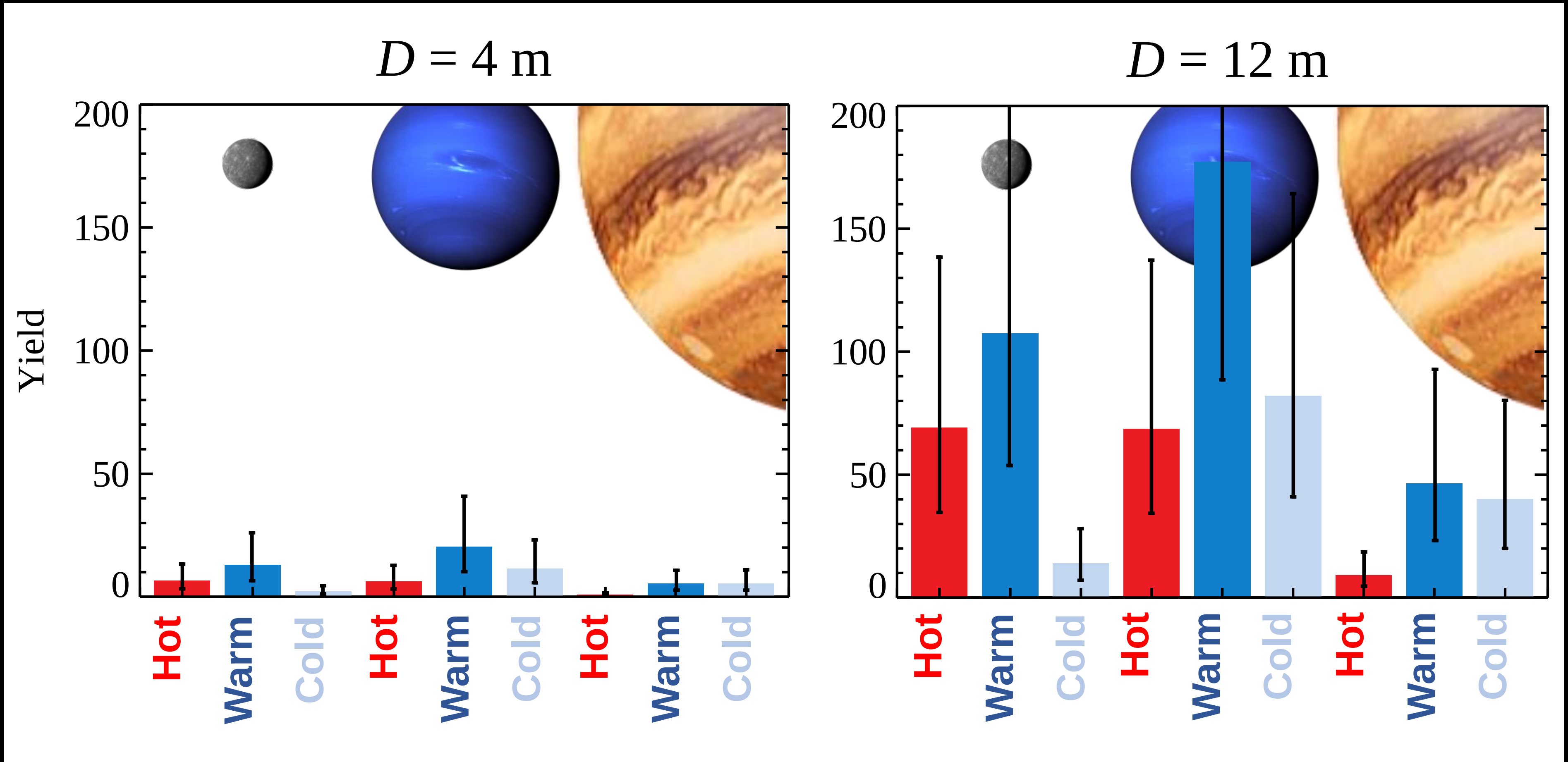
ExoEarth candidates as function of aperture



Stark et al. (2014)

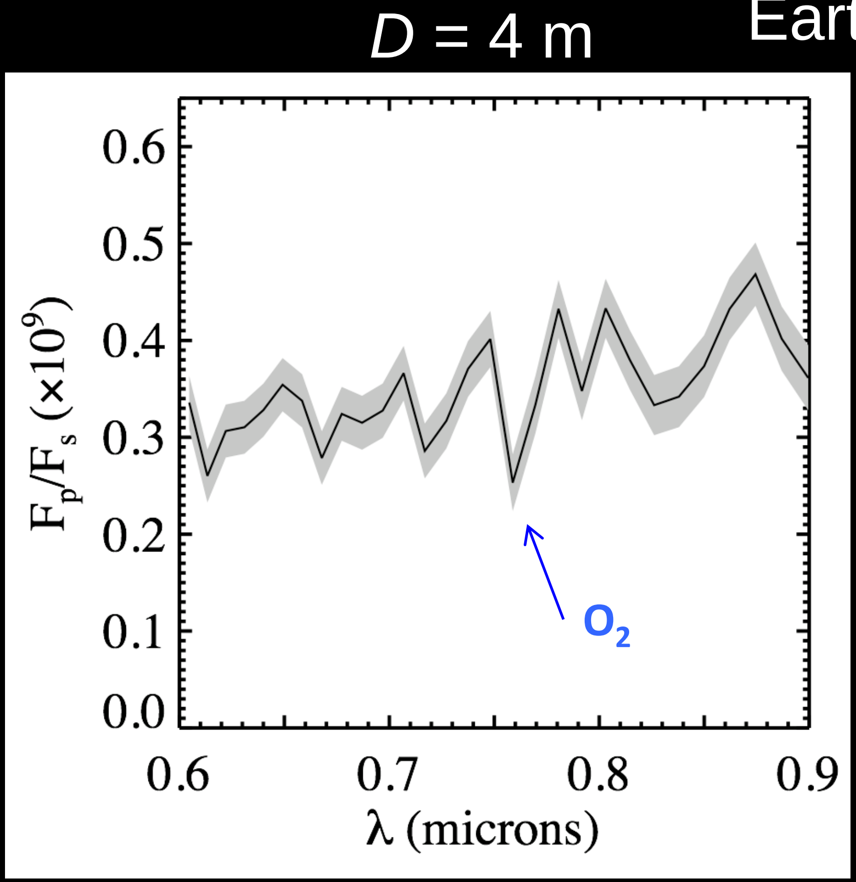
If frequency of habitable conditions is 10%,
need 30 candidates to guarantee seeing one true exoEarth
(at 95% confidence)

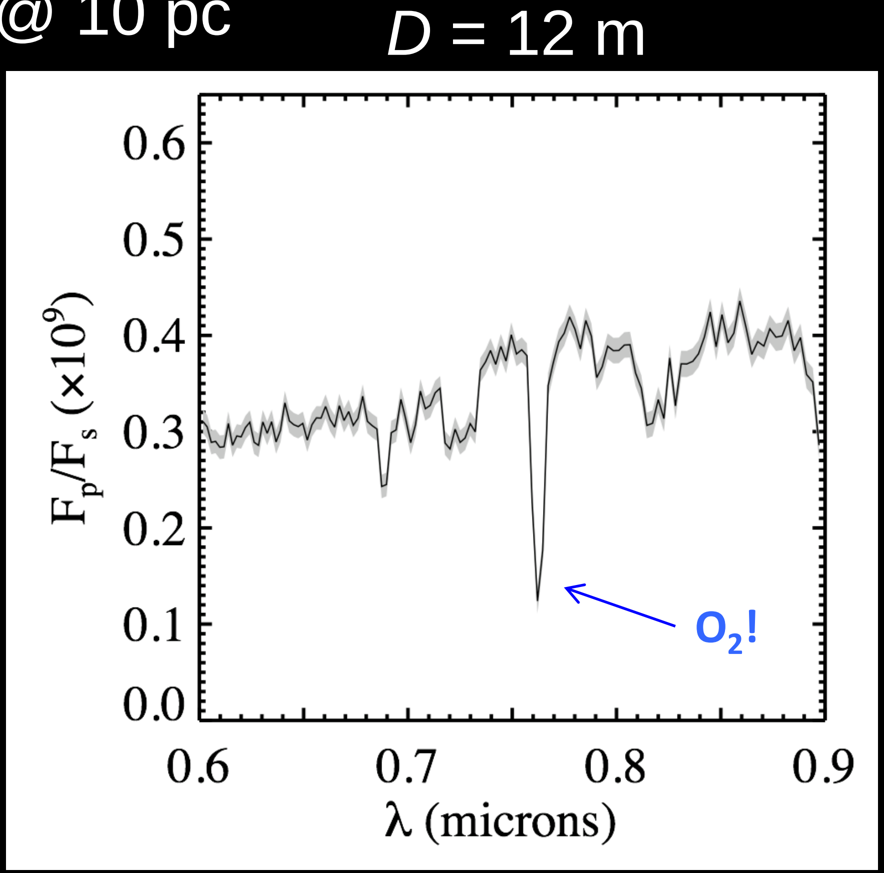
Planet Diversity Yields



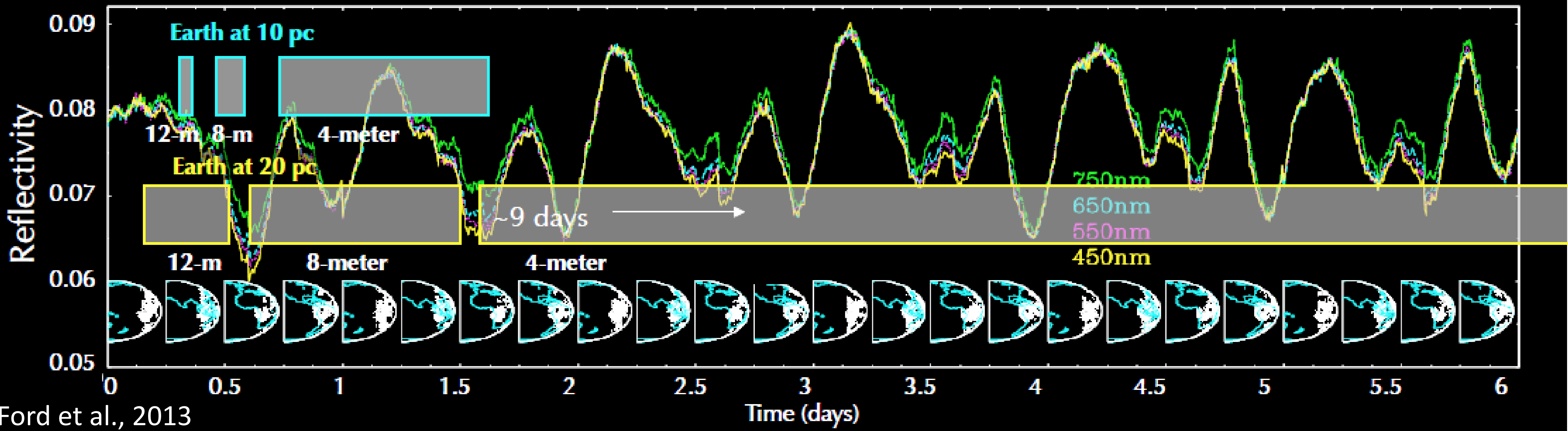
C. Stark, Using SAG13 Occurrence Rates

200 hr observations of Earth @ 10 pc

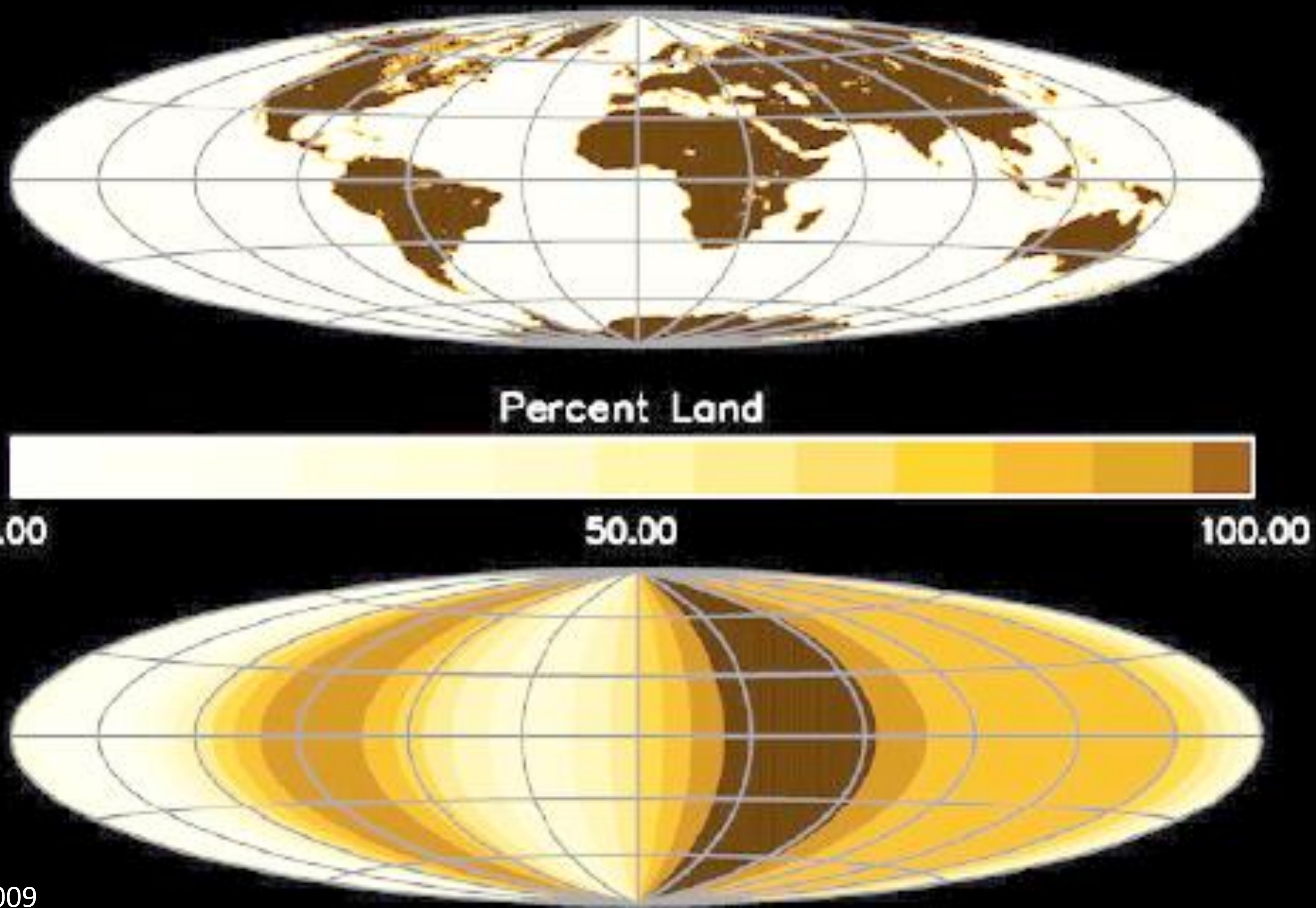




J. Tumlinson's Online Spectra Tool (Tumlinson, Robinson, Arney, et al)



Ford et al., 2013

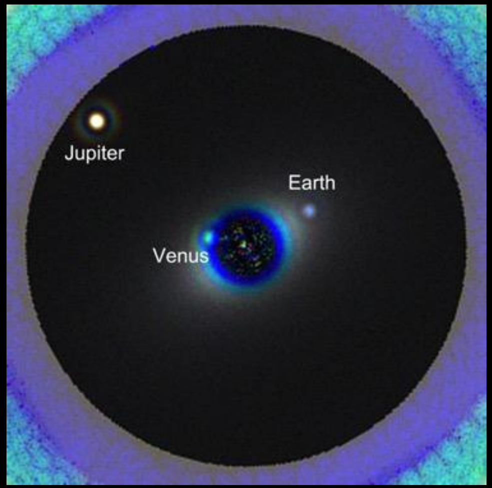


Cowan et al., 2009

Notional LUVOIR/ HabEx instruments

Observational challenge

Faint planets next to bright stars



Solution

OBSCURA

Optical-IR Band Spectroscopy and Coronagraph for Rocky Atmospheres

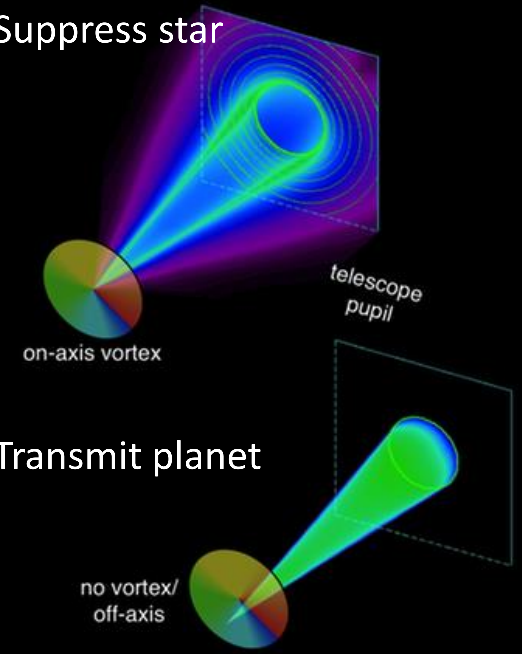
Contrast < 10^{-10} to observe exoEarths

Low resolution spectroscopy (R > 150)

Baseline bandpass: 0.4 μm to 1.8 μm

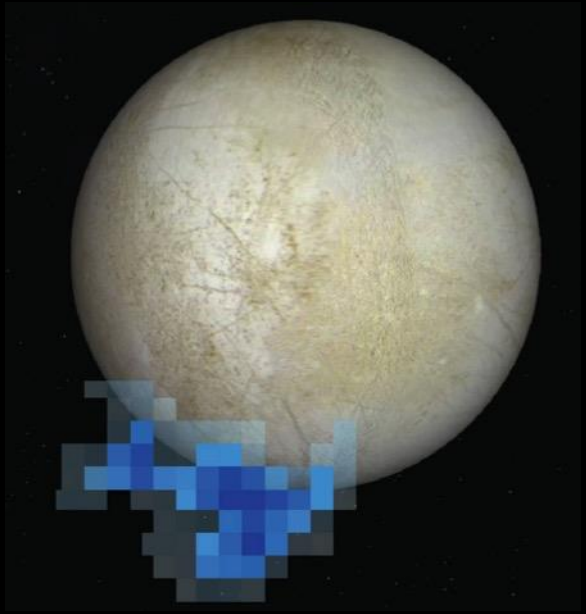
Ambitious bandpass: 0.2 μm to 2.4 μm

No space-based analog



Vector vortex coronagraph (Credit: D. Mawet)

Notional LUVOIR/ potential HabEx instruments



Observational challenge

No UV through Earth's atmosphere

Solution

LUMOS
(LUVOIR UV Multi-Object Spectrograph)

Far-UV to near-UV spectroscopy

High resolution (R ~ 10^5) spectroscopy

Med. res. multi-object spectroscopy

Near-UV imaging

Major upgrade of HST STIS

HST STIS UV instrument

Notional LUVOIR/ potential HabEx instruments

Observational challenge

Imaging wide fields at high resolution

Solution

High-Definition Imager

4 – 6 arcmin field-of-view

Optical to near-IR bandpass

Possibly high precision astrometry to measure planet masses

Major upgrade of HST WFC3

HST Wide Field Camera 3

Notional LUVOIR instruments

Observational challenge

Measuring warm molecules present in Earth's atmosphere

Solution

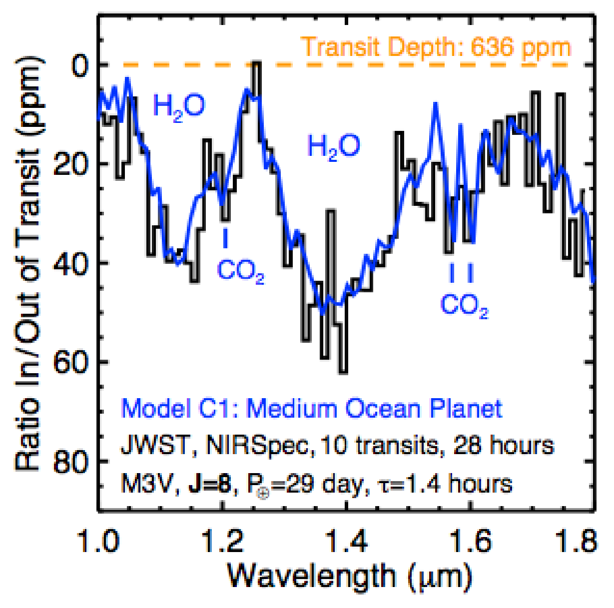
Optical / Near-IR Spectrograph

Multiple resolutions up to R ~ 10^5

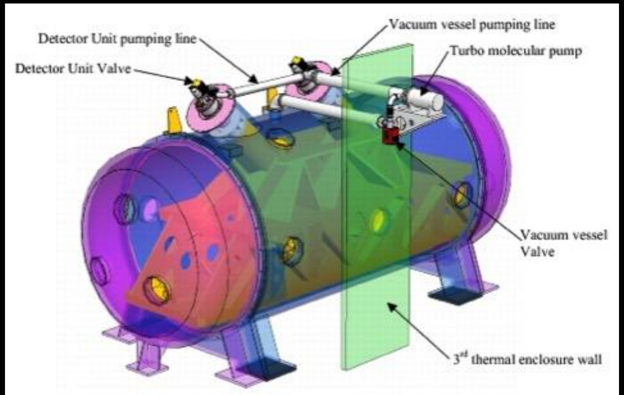
High photometric precision for transits

Possibly high precision RV to measure planet masses

No space-based analog



Credit: Natasha Batalha



ESPRESSO spectrograph for VLT (Credit: ESO)

Technological challenges

Need heavy lift launch vehicle with large fairing

Suitable vehicles (SLS and commercial) in development

Compatibility of UV and coronagraphy

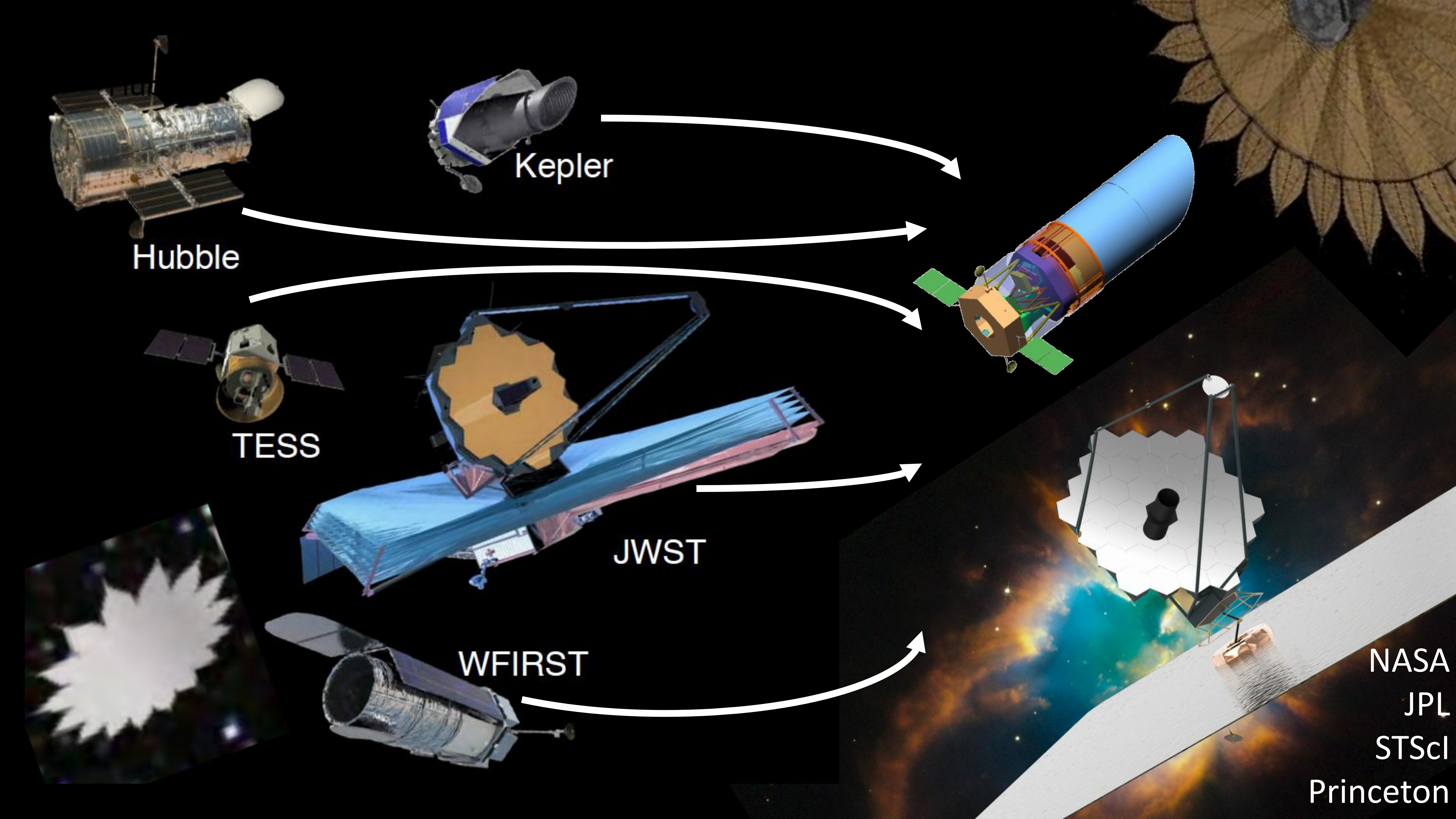
New lab work shows UV reflective mirrors are just fine for coronagraphy

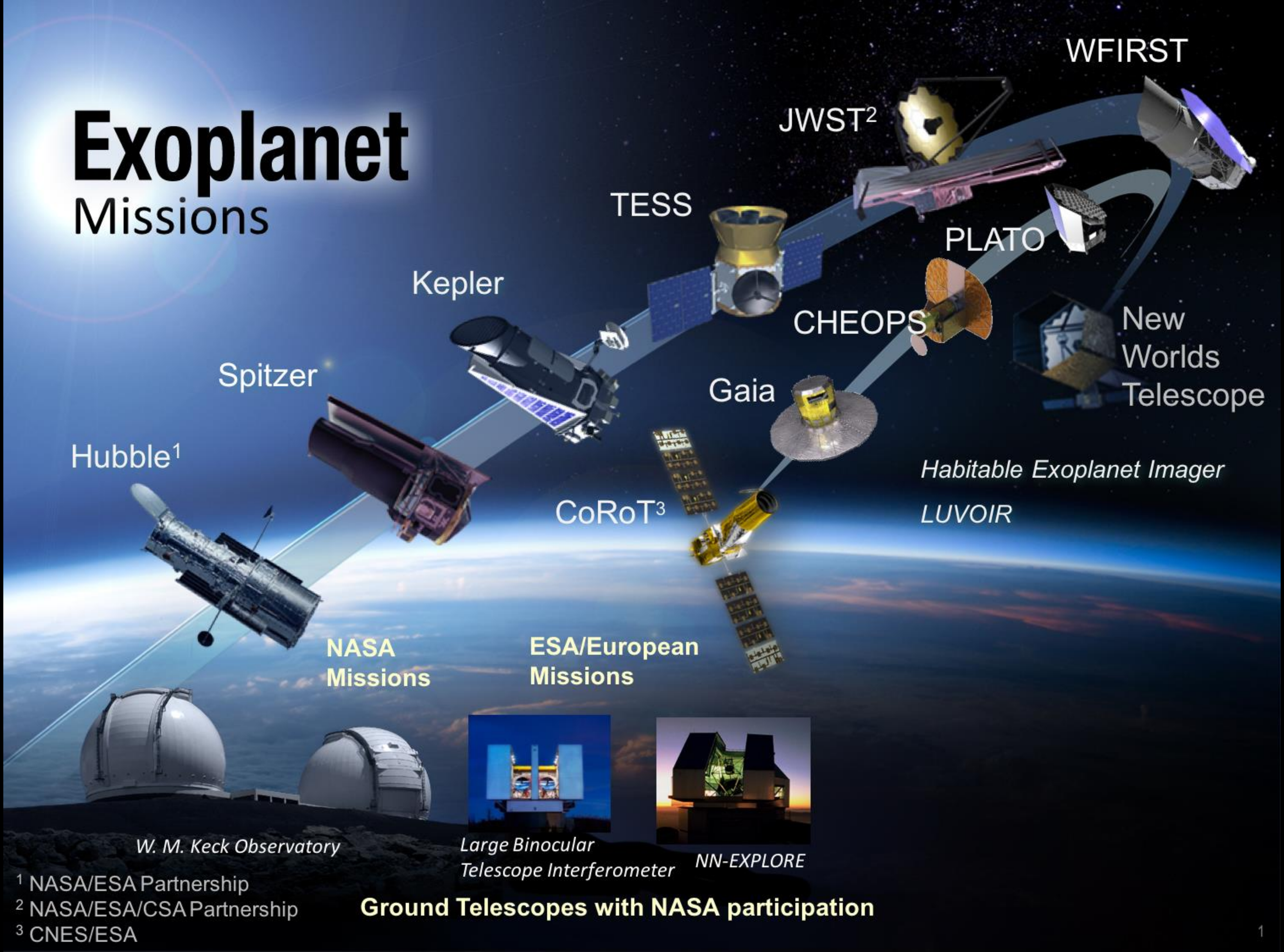
Ultra-high contrast observations with a segmented telescope

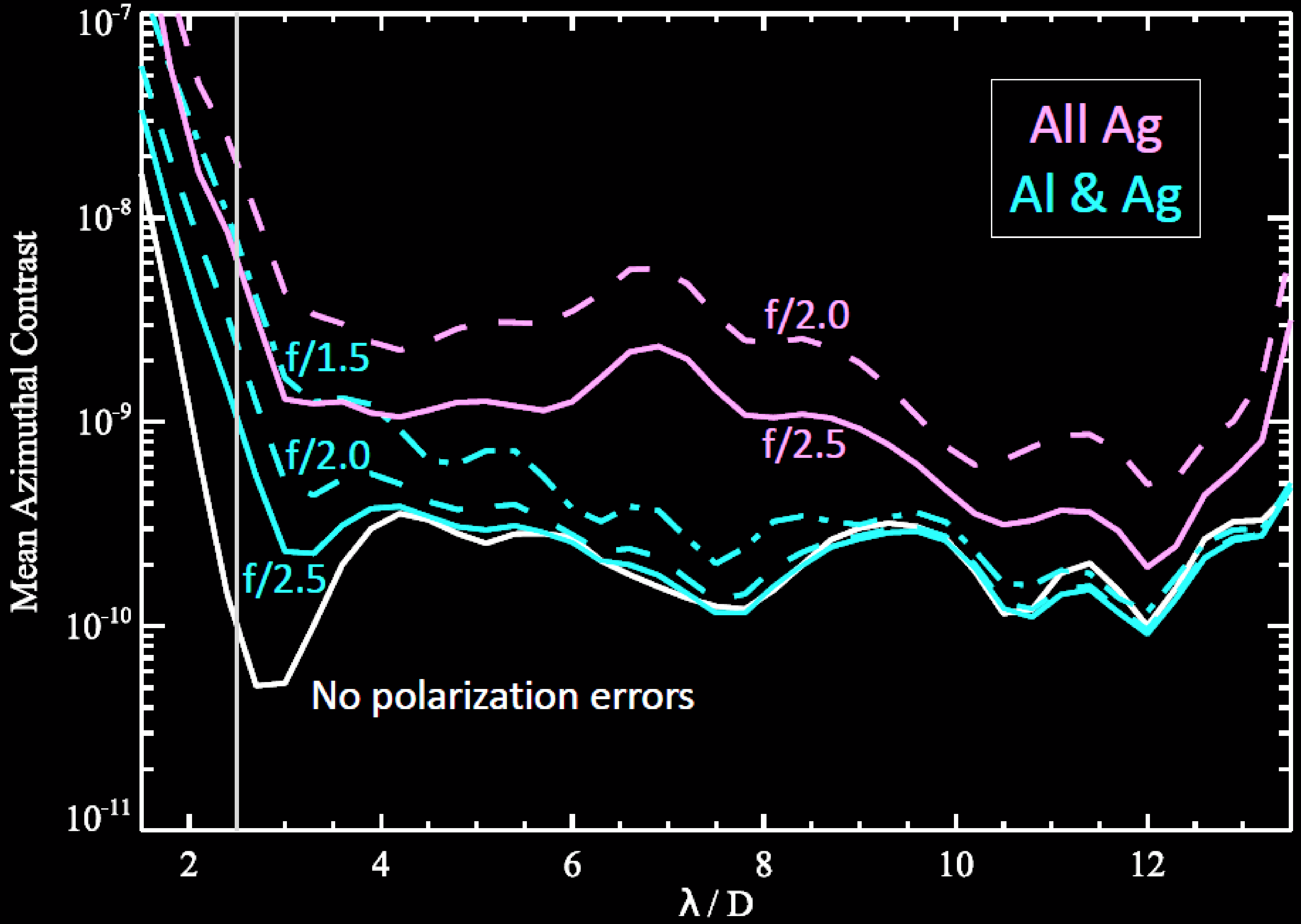
Coronagraphs can be designed for segmented telescopes.
Working hard to demonstrate needed system stability

Starshade Deployment, Edge Tolerance, and Formation Flying

Lots of progress on deployment, both from JPL testbed and via JWST sunshield
Formation flying likely not limiting, but slewing of the starshade may limit # of observations
Edge tolerance currently the one of the biggest challenges for starshades.


Kepler
Hubble
TESS
JWST
WFIRST
NASA
JPL
STScI
Princeton


Exoplanet
Missions
WFIRST
JWST2
TESS
PLATO
Kepler
CHEOPS
New
Worlds
Telescope
Spitzer
Gaia
Hubble1
Habitable Exoplanet Imager
CoRoT3
LUVOIR
NASA
Missions
ESA/European
Missions
W. M. Keck Observatory
Large Binocular
Telescope Interferometer
NN-EXPLORE
1 NASA/ESA Partnership
2 NASA/ESA/CSA Partnership
3 CNES/ESA
Ground Telescopes with NASA participation
1



From J. Crist
via M. Bolcar