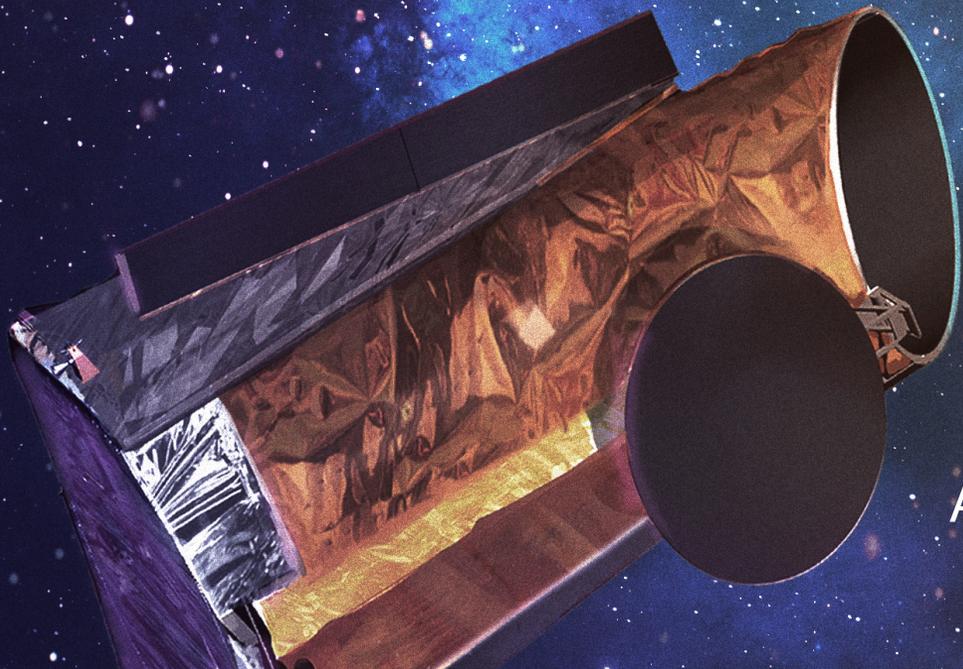


HabEx



The Habitable Exoplanet Observatory

Exploring planetary systems around our neighboring sunlike stars and enabling a broad range of observatory science in the UV through the near-IR



Scott Gaudi (OSU – Co-Community Chair)

Sara Seager (MIT – Co-Community Chair)

Bertrand Mennesson (JPL – Center Study Scientist)

Alina Kiessling (JPL – Deputy Center Study Scientist)

Keith Warfield (JPL – Study Manager)





The HabEx STDT (mostly).



HabEx STDT Meeting, May 16-17 2016, Washington, DC. Team members from left to right: Rachel Somerville, David Mouillet, Shawn Domagal-Goldman, Leslie Rogers, Martin Still, Olivier Guyon, Paul Scowen, Kerri Cahoy, Daniel Stern, Scott Gaudi, Bertrand Mennesson, Lee Feinberg, Karl Stapelfeldt, Sara Seager, Dimitri Mawet. Missing STDT members (unable to attend meeting in person): Jeremy Kasdin, Tyler Robinson and Margaret Turnbull.

...also added John Clarke, Chris Stark.



HabEx Study Goals:

“Develop an optimal* mission concept for characterizing our nearest planetary systems, and detecting and characterizing a handful of ExoEarths.”

“Given this optimal* concept, maximize the general astrophysics science potential without sacrificing the primary exoplanet science goals.”

What does optimal mean?

- Maximizing the science yield while maintaining feasibility, i.e., adhering to expected constraints.
- Constraints include: Cost, technology (risk), time to develop mission.

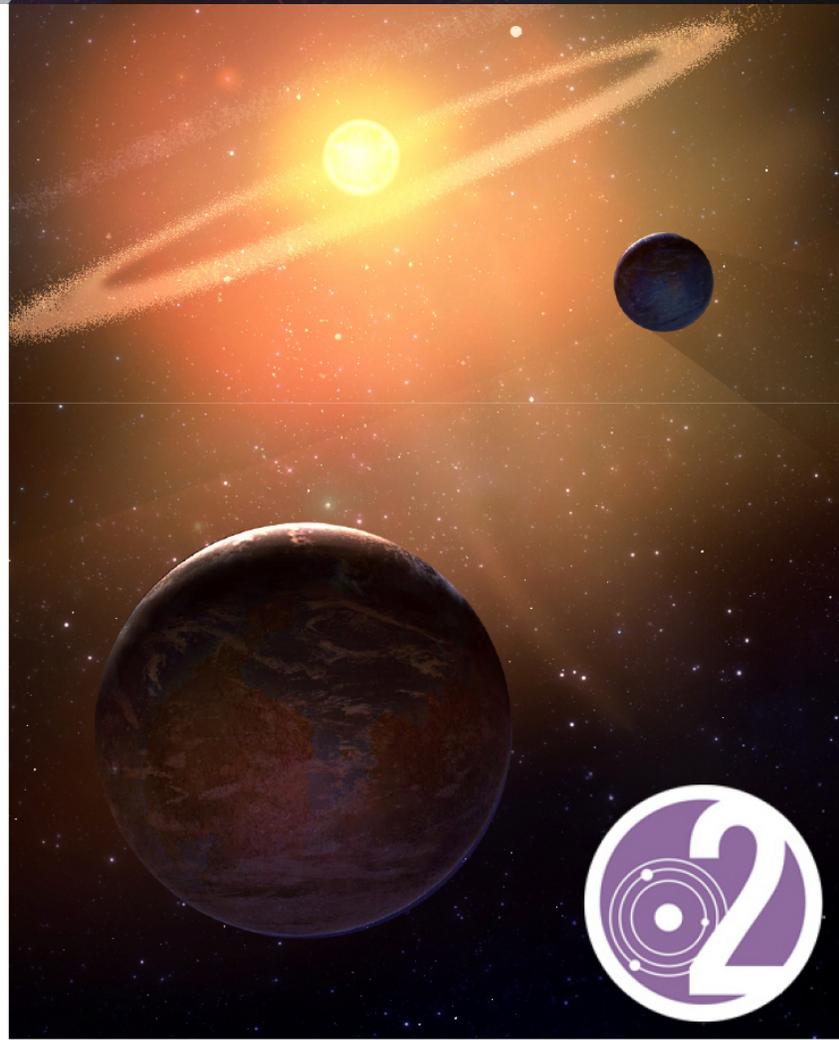
HabEx



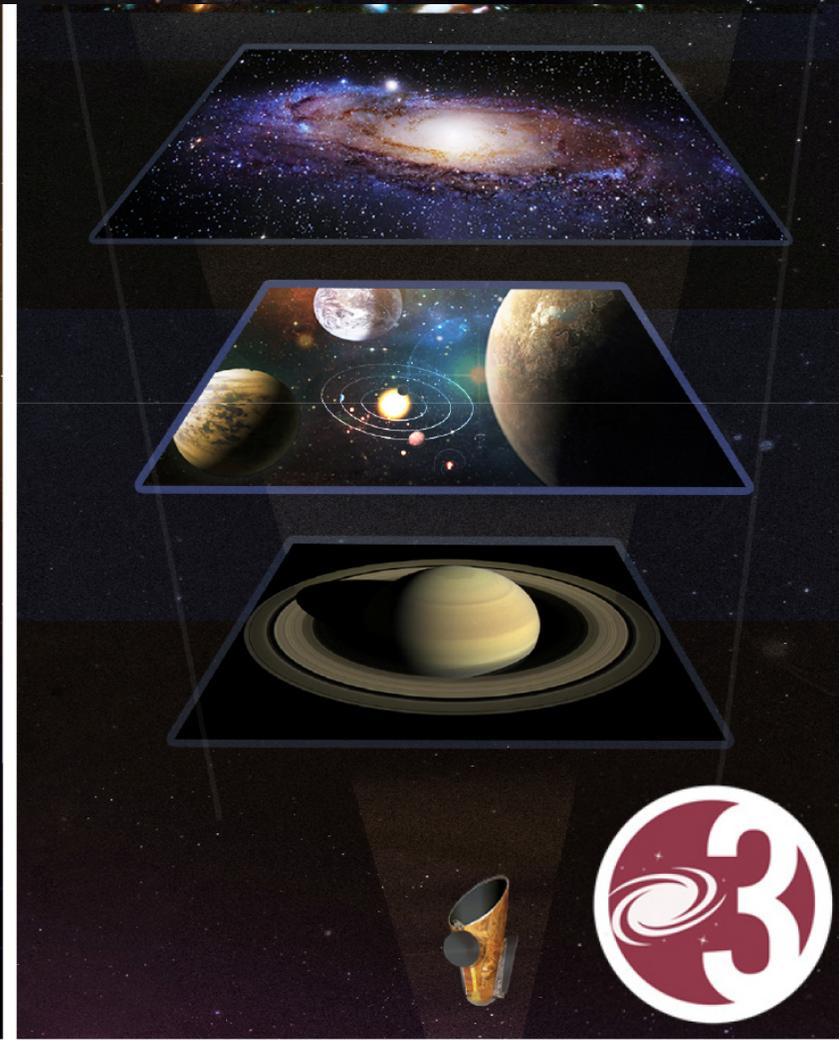
HabEx Science Goals



Seek out nearby worlds and explore their habitability



Map out nearby planetary systems and understand their diversity.

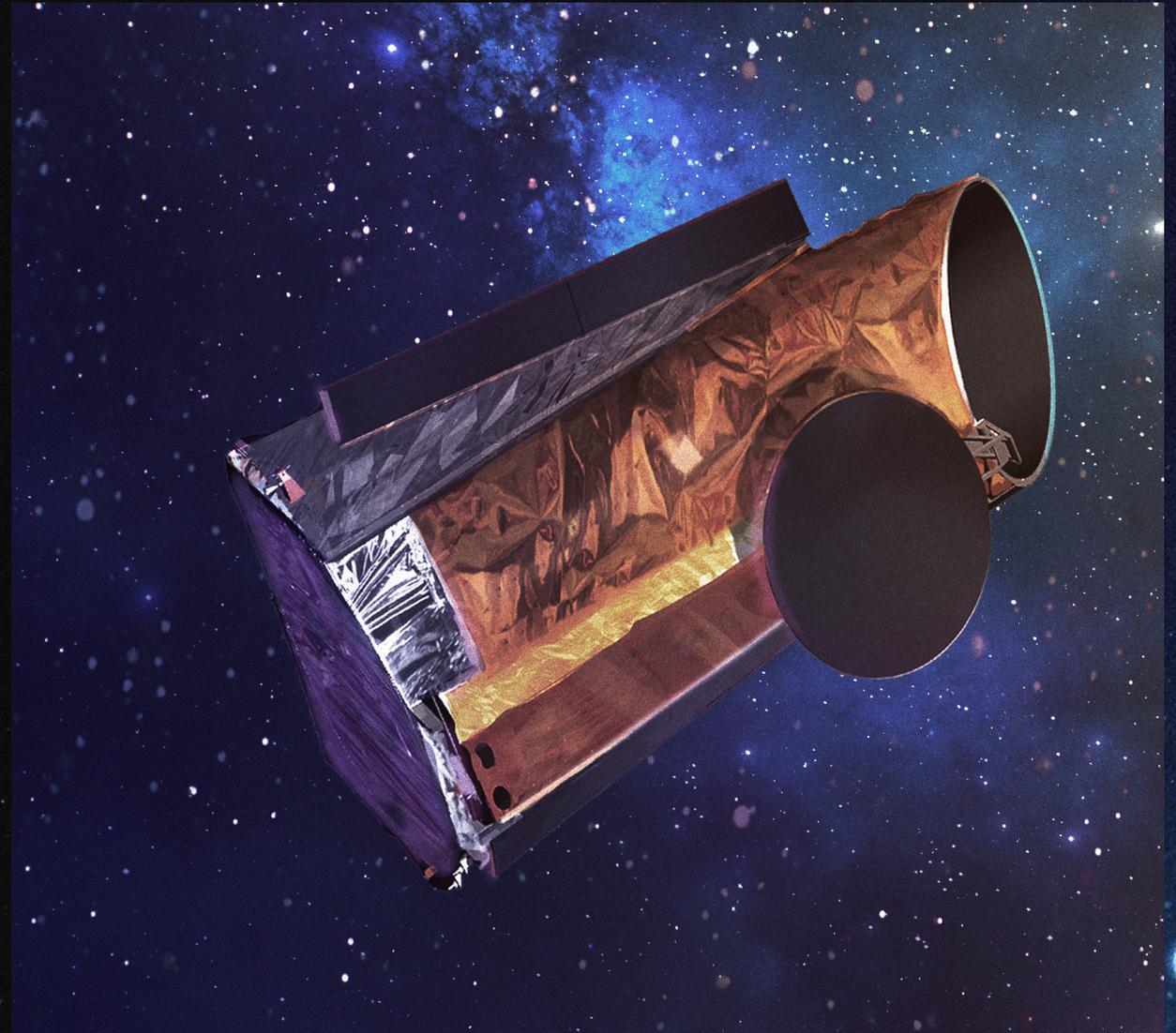


Open up new windows in the Universe from the UV to NIR.



Architecture:

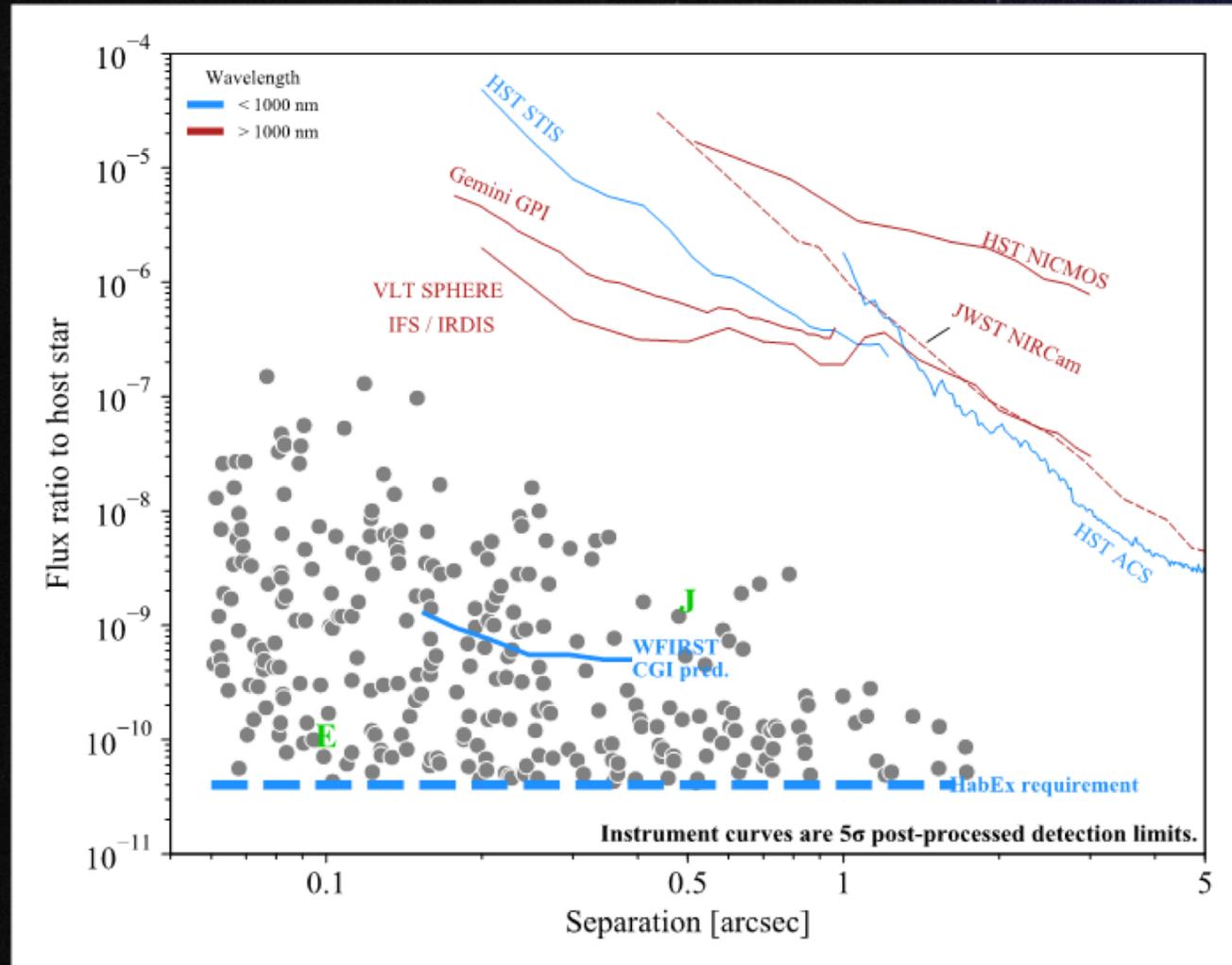
- 4m off-axis f/2.5 aluminum monolith
 - preliminary design completed.
- Four Instruments:
 - Coronagraph Instrument
 - Starshade Instrument
 - UV Spectrograph (UVS)
 - HabEx Workhorse Camera (HWC)
- Launch vehicle
 - SLS Block 1B
- 72m (tip-to-tip) starshade
 - Co-launched with telescope
- Orbit
 - L2
- Launch date and mission length
 - ~ mid-2030s
 - 5 year mission





Capabilities: Direct Imaging

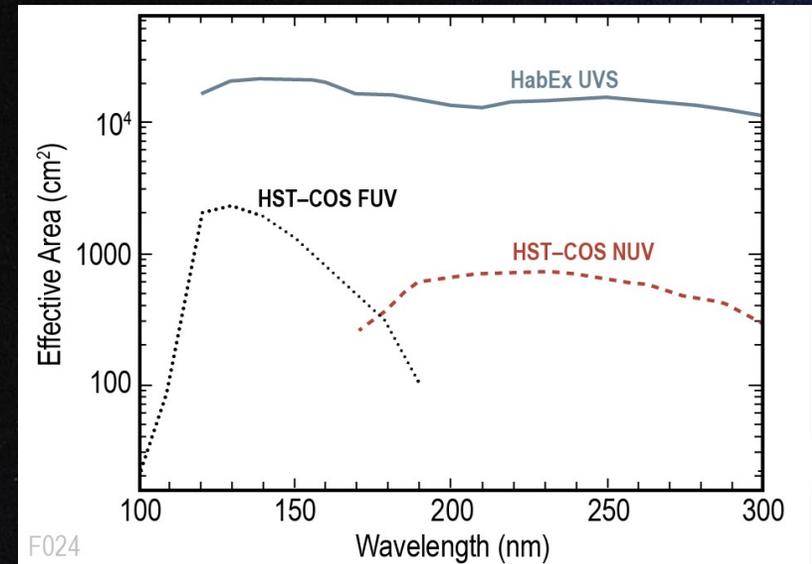
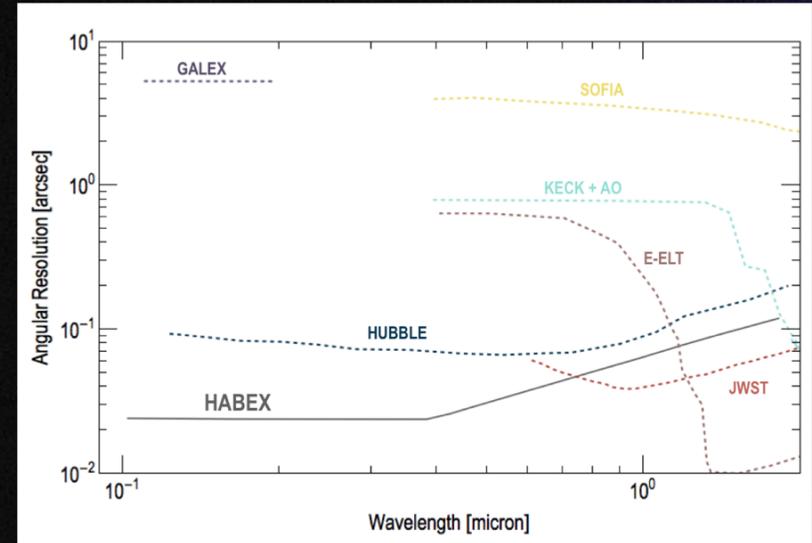
- Minimum contrast: 4×10^{-11}
- Inner Working Angles:
 - 0.06" at 0.3-1 μm (starshade, λ dependent)
 - 0.062" at V band (coronagraph)
- Outer Working Angles:
 - 6" (imaging, starshade)
 - 1.5" (spectra, starshade)
 - 0.72" (@ 0.5 μm imaging+spectra, coronagraph)
- Spectroscopy
 - R=7 from 200 to 450 nm (starshade)
 - R=140 from 450 to 1000 nm
 - R=40 from 1 to 1.8 μm





Capabilities: Imaging and Spectra

- Diffraction limited at 0.4 μm
 - Better than all current or planned facilities for $\lambda < 0.7 \mu\text{m}$
- Non-sidereal tracking.
- Wavelength coverage
 - 115nm-1.8 μm
- Effective Area
 - >10x better than HST for 115nm-300nm
- UVS
 - Area 3' x 3', 115-300nm, resolution up to R=60,000
- HWC
 - Area 3' x 3'
 - 150-400nm, 400-950nm, 950-1.8nm
 - R=2000





Starlight suppression at the level of 10^{-10} within ~ 0.1 arcseconds: *easy!*

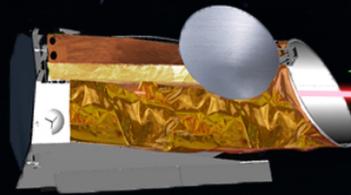
- Analogy: detecting a firefly a few feet from a searchlight at a distance of ~ 3000 miles (NY to LA)
- HabEx uses two promising technologies:
 - Coronagraph:
 - Pros: Nimble, advanced technology demonstrations, one spacecraft, yield limited by time (not fuel), multiple pointings.
 - Cons: Narrow bandpass, polarization issues, not optimal for obscured primaries, limited OWA.
 - Starshade:
 - Pros: Wide instantaneous bandpass, high throughput, no polarization issues, independent of pupil, deep contrast, large OWA, IWA \sim independent of aperture.
 - Cons: Slow, limited number of slews, lower TRL, may require two spacecrafts.



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Starshade



Inner working angle (IWA)

124,000 km separation

Telescope aperture diameter 4 m



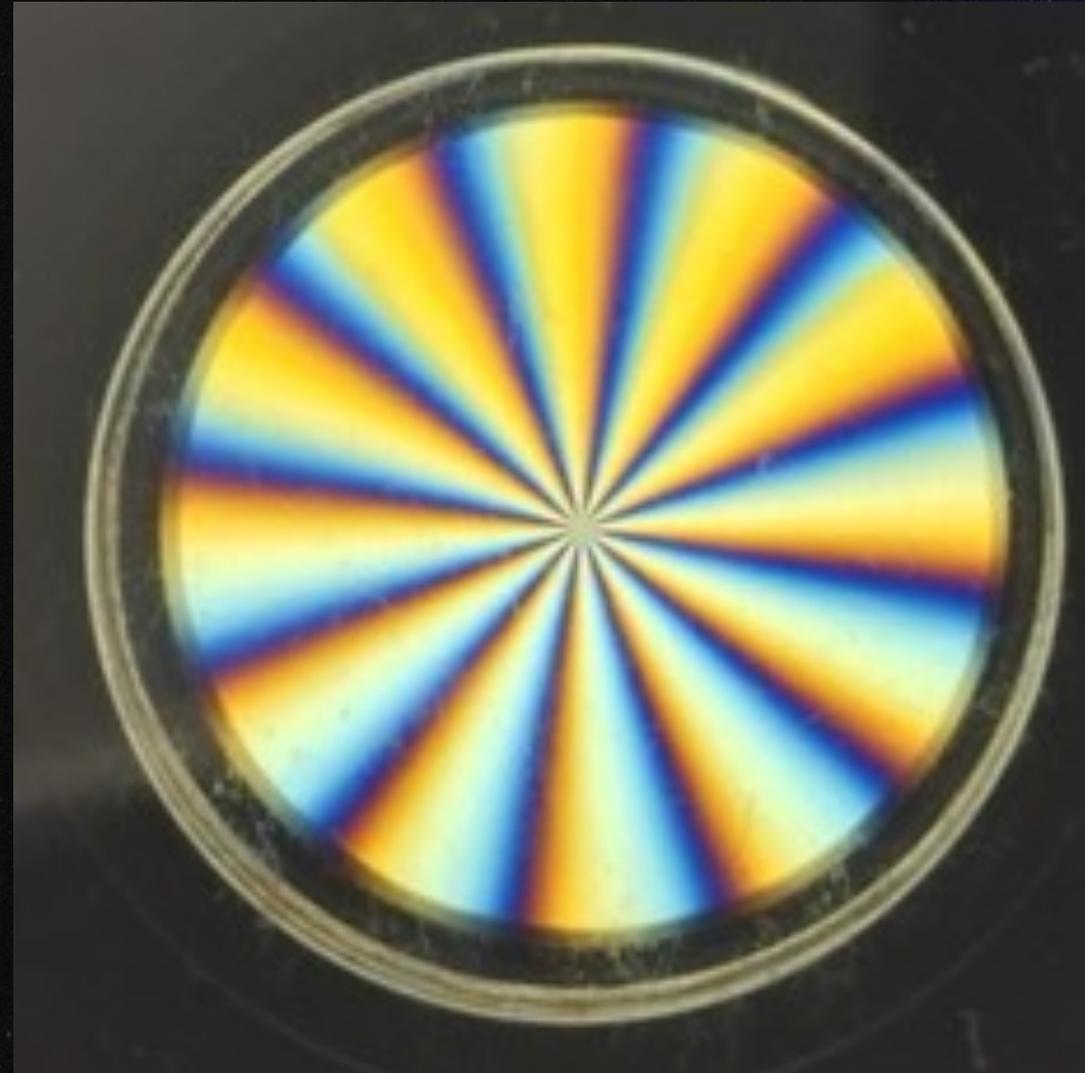
Starshade diameter 72 m





Coronagraph:

- Much more mature technology
- Base lining two types:
 - Vector Vortex Charge 6 coronagraph (shown)
 - Mostly insensitive to low order aberrations.
 - Hybrid Lyot Coronagraph
 - More mature.
- Hybrid Lyot Coronagraph
 - Demonstrated $<10^{-8}$ suppression in the laboratory
- Heritage with WFIRST CGI (potentially).



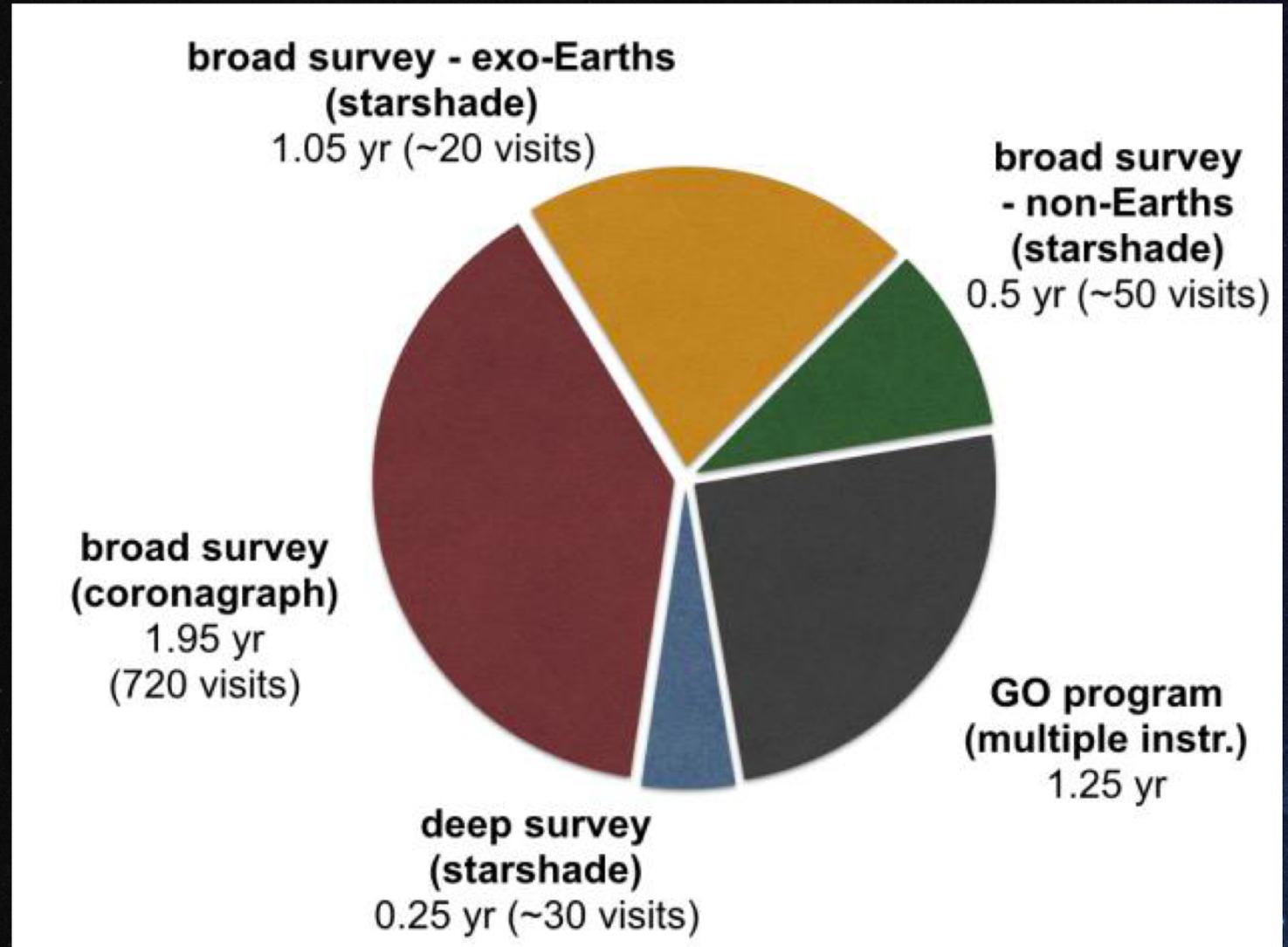


Deep Survey

- Nine nearby high-priority sunlike stars
- 3 months total time
- Deep broadband image to the systematic floor
- Spectra
 - R=7 (grism) 0.3-0.45 μm
 - R=140 (IFS) 0.45-1.0 μm

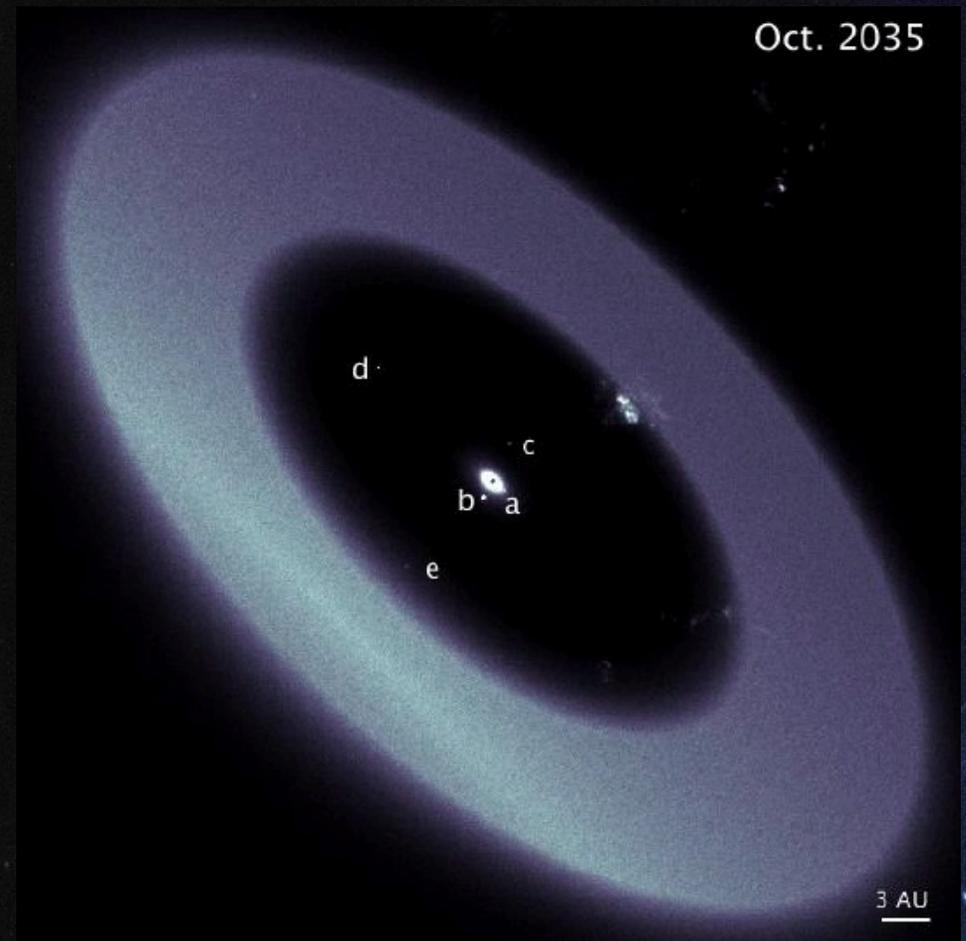
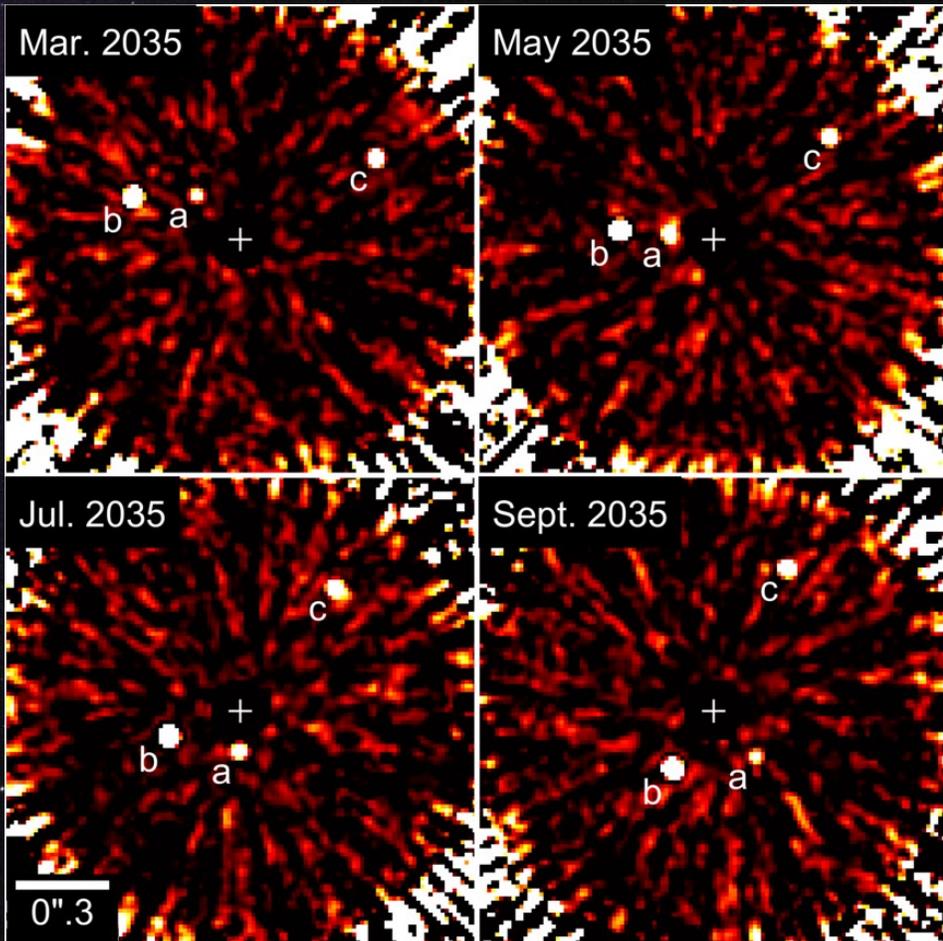
Broad Survey

- Roughly 110 stars
- Roughly 6 observations of each
- 50% completeness for exo-Earths
- Spectra
 - 0.3-1.0 μm at once with starshade





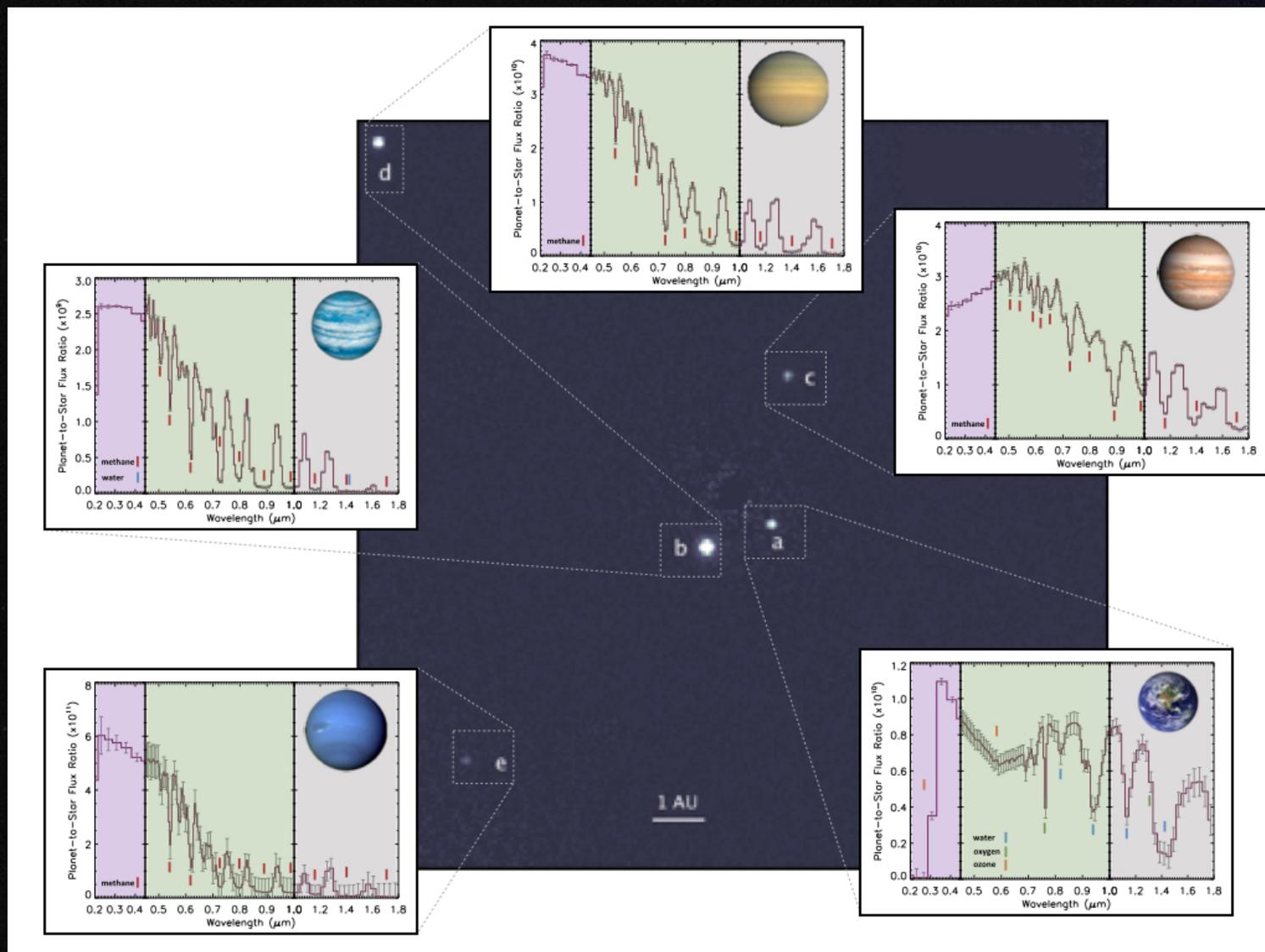
- HabEx will survey ~110 stars with the coronagraph to search for potentially habitable worlds.
- Promising systems will be studied by further with the coronagraph and starshade.





“Family Portraits”

- Broadband 12" x 12" image
- Simultaneous spectra for 0.3-1.0 μm at once with starshade for planets within 3"
 - R=7 (grism) 0.3-0.45 μm
 - R=140 (IFS) 0.45-1.0 μm



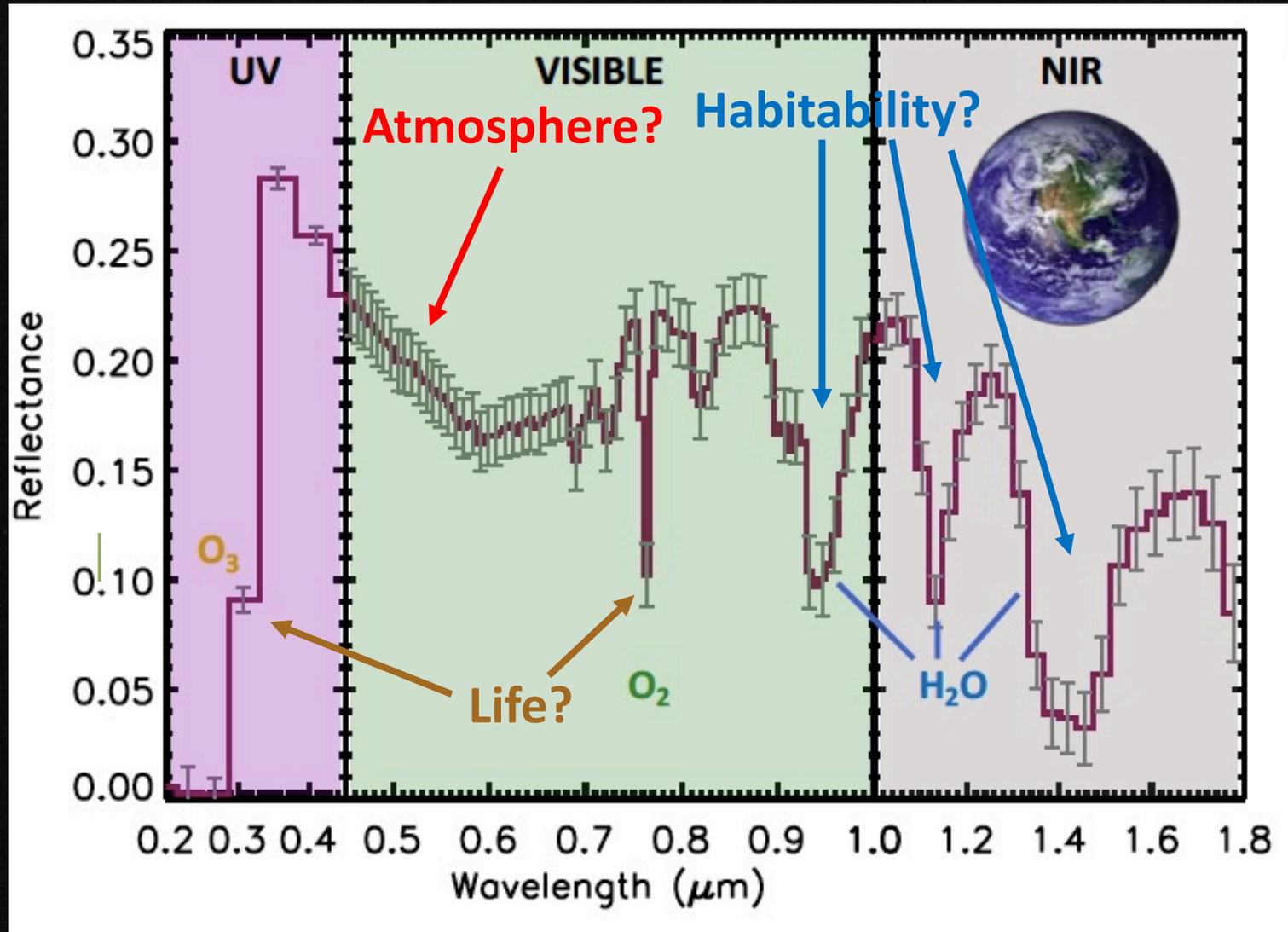


Star	Type	Dist. (pc)	V-mag	Age (Gyr)	Notes
τ Ceti	G8V	3.7	3.5	5.8	Astronomy: closest solitary G-star, 4 confirmed planets (2 in HZ) plus debris disk Popular culture: homeport of <i>Kobayashi Maru</i> in <i>Star Trek</i> and location of <i>Barbarella</i> (1968)
82 Eridani	G8V	6.0	4.3	6.1–12.7	Astronomy: 3 confirmed planets (all super-Earths) plus dust disk
ϵ Eridani	K2V	3.2	3.7	0.4–0.7	Astronomy: 1 unconfirmed planet (<i>Ægir</i>) plus dust disk Common name: Ran Popular culture: location of <i>Babylon 5</i> (1994-1999)
40 Eridani	K1V	5.0	4.4		Astronomy: triple-system, with white dwarf and M-dwarf Common name: Keid Popular culture: in <i>Star Trek</i> , host star to Vulcan
GJ 570	K4V	5.8	5.6		Astronomy: quadruple-system, with 2 red dwarfs and brown dwarf
σ Draconis	K0V	5.8	4.7	3.0 ± 0.6	Astronomy: 1 unconfirmed planet (Uranus-mass) Common name: Alfasi Popular culture: visited in <i>Star Trek</i> episode “ <i>Spock’s Brain</i> ” (1966)
61 Cygni A	K5V	3.5	5.2	6.1	Astronomy: wide-separation binary Common name: Bessel’s star
61 Cygni B	K7V	3.5	6.1		Popular culture: home system of humans in Asimov’s <i>Foundation</i> series
ϵ Indi	K5V	3.6	4.8	1.3	Astronomy: triple-system, with 2 brown dwarfs 1 unconfirmed planet (Jupiter-mass)

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Nobel Prize!



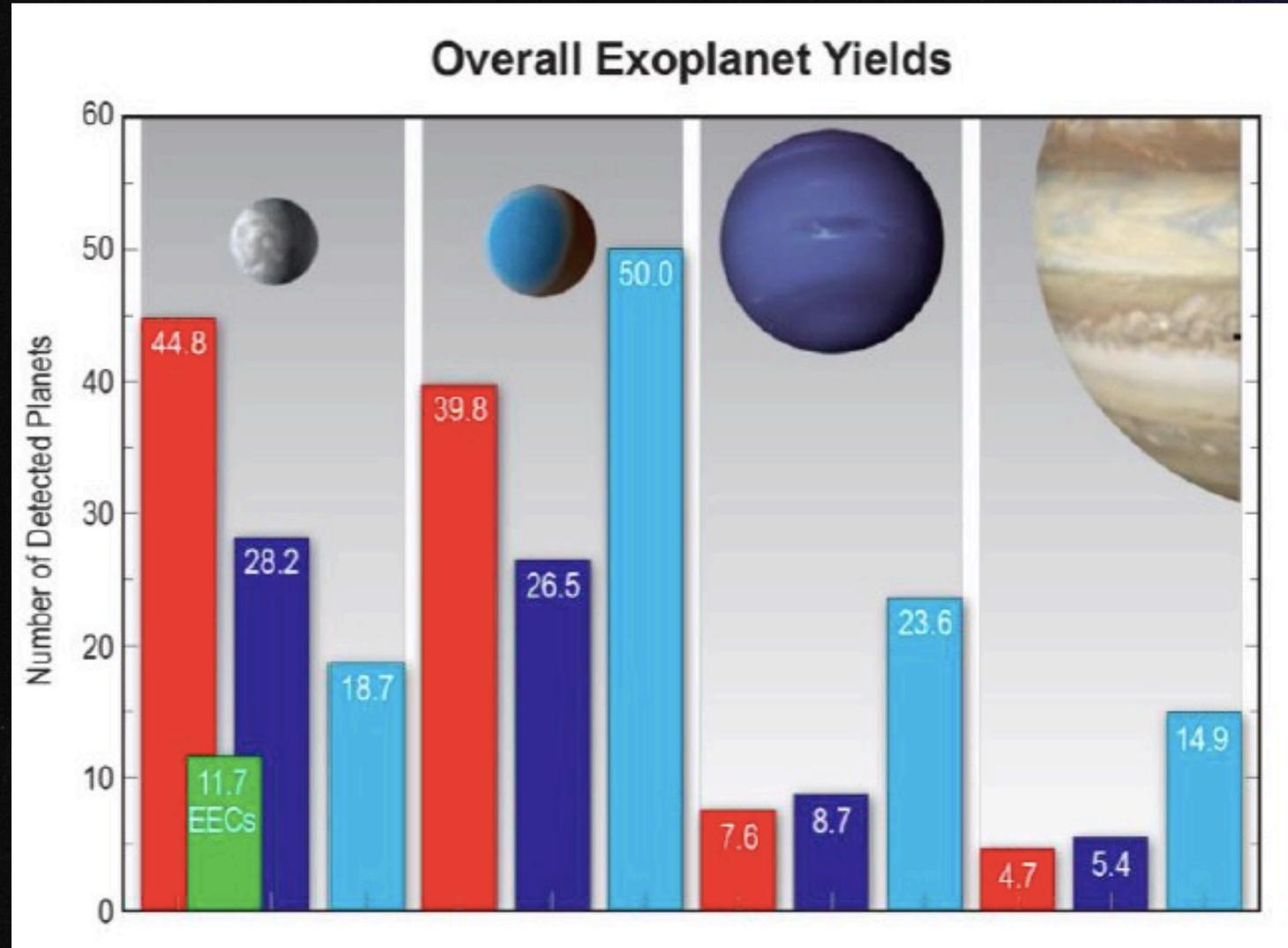


Yields*

Detect and characterize the orbits and atmospheres of:

- Rocky planets:
 - 92 rocky planets (0.5-1.75 R_E)
 - Includes 12 Earth Analogs (0.5-1.4 R_E)
- Sub Neptunes:
 - 116 sub-Neptunes (1.75-3.5 R_E)
- Gas Giants
 - 62 gas giants (3.5-14.3 R_E)

*Assumes SAG13 Occurrence Rates – uncertain!



HabEx



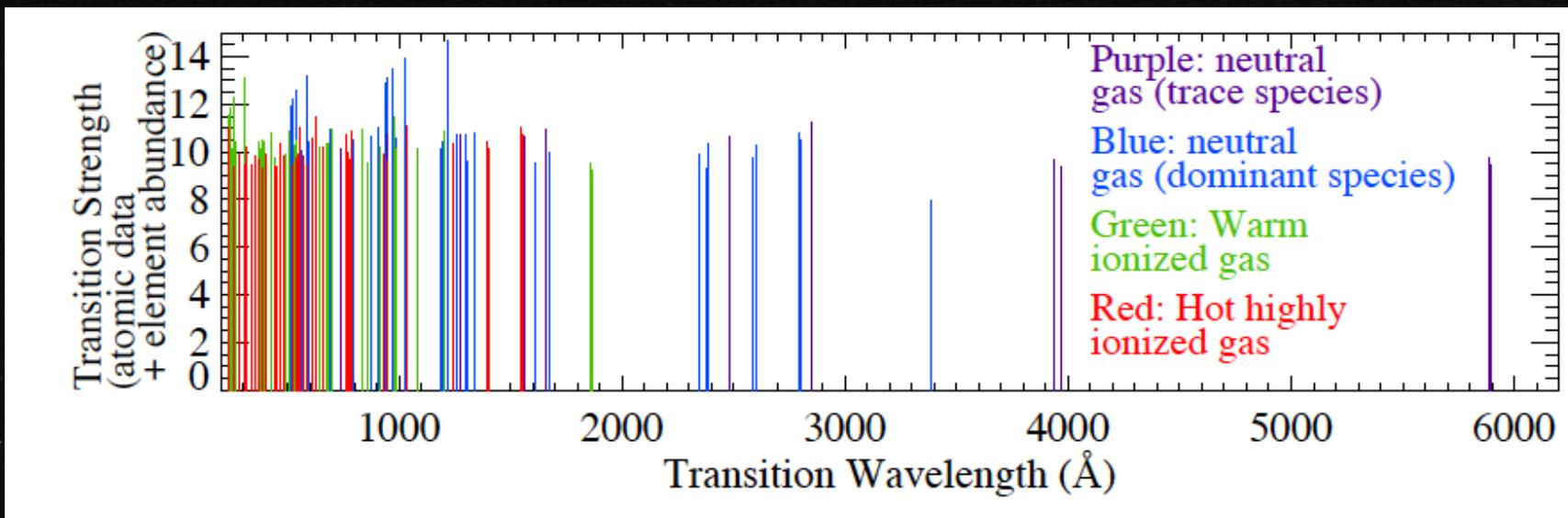
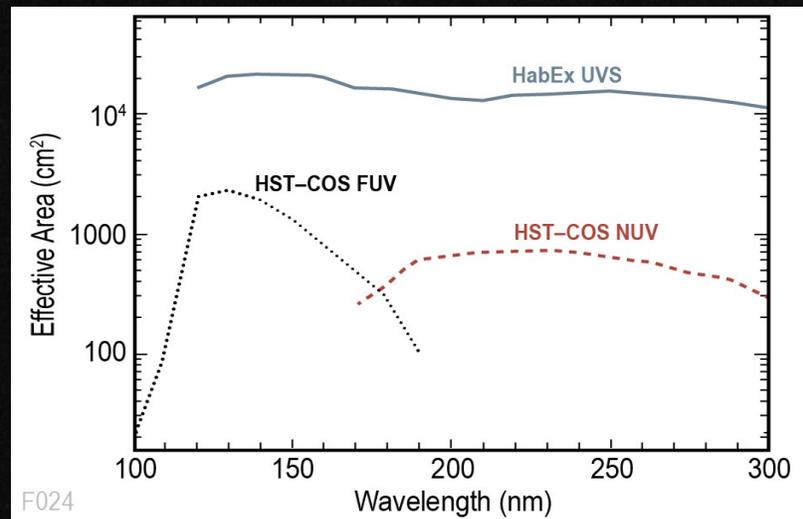
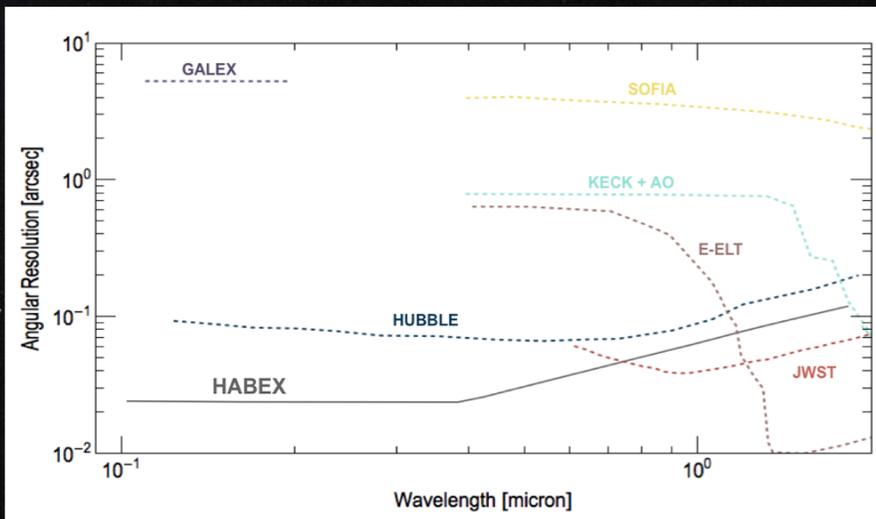
Just exoplanets, right?

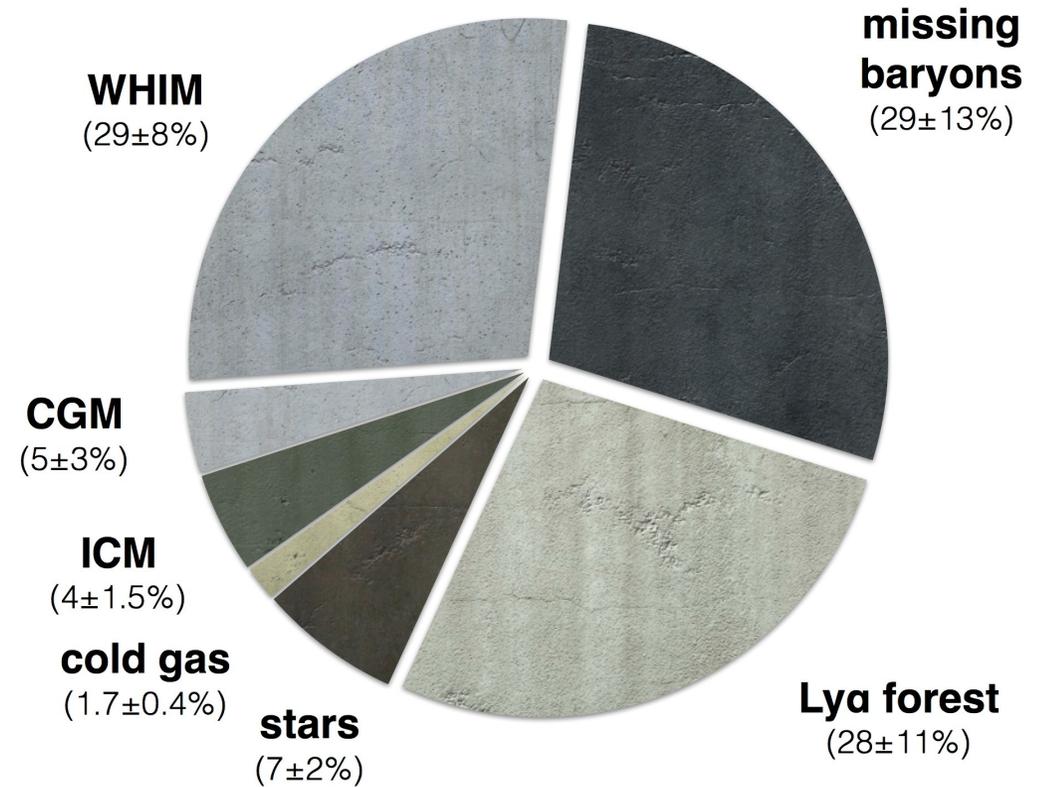
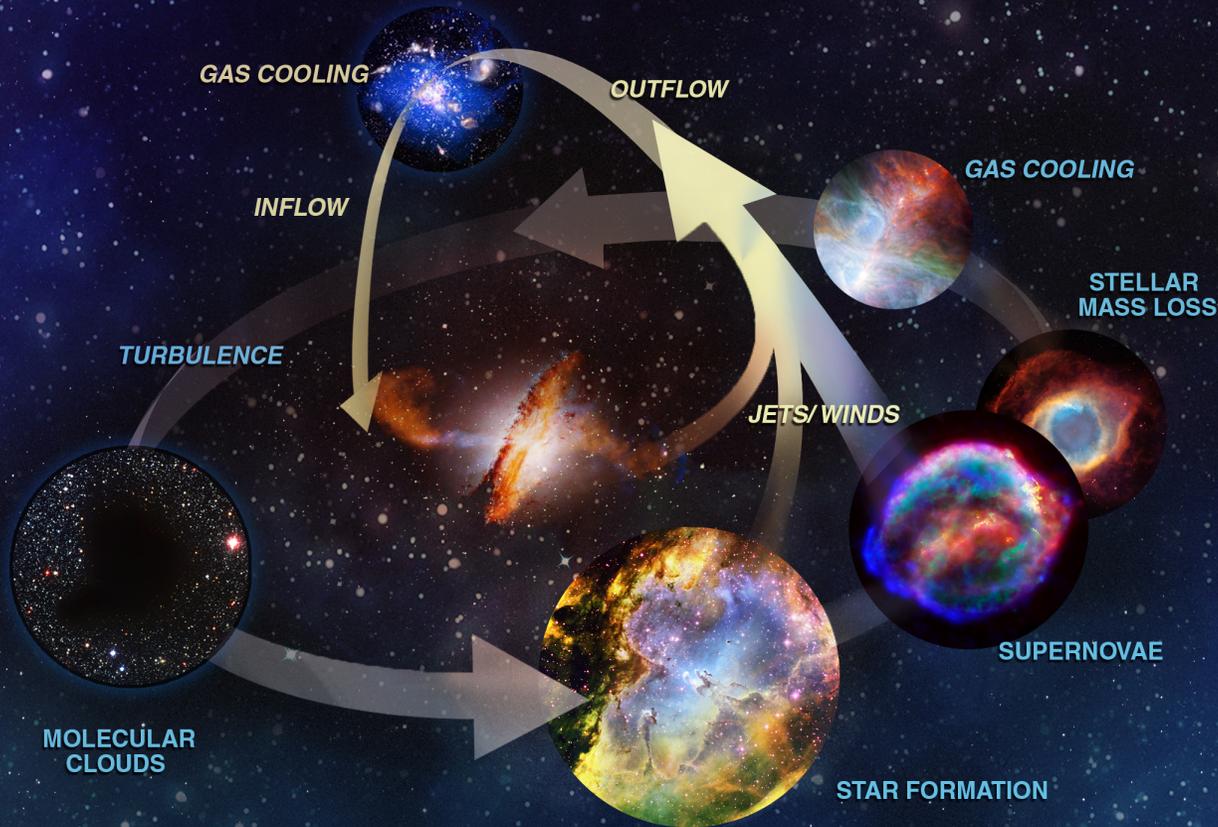
NO!

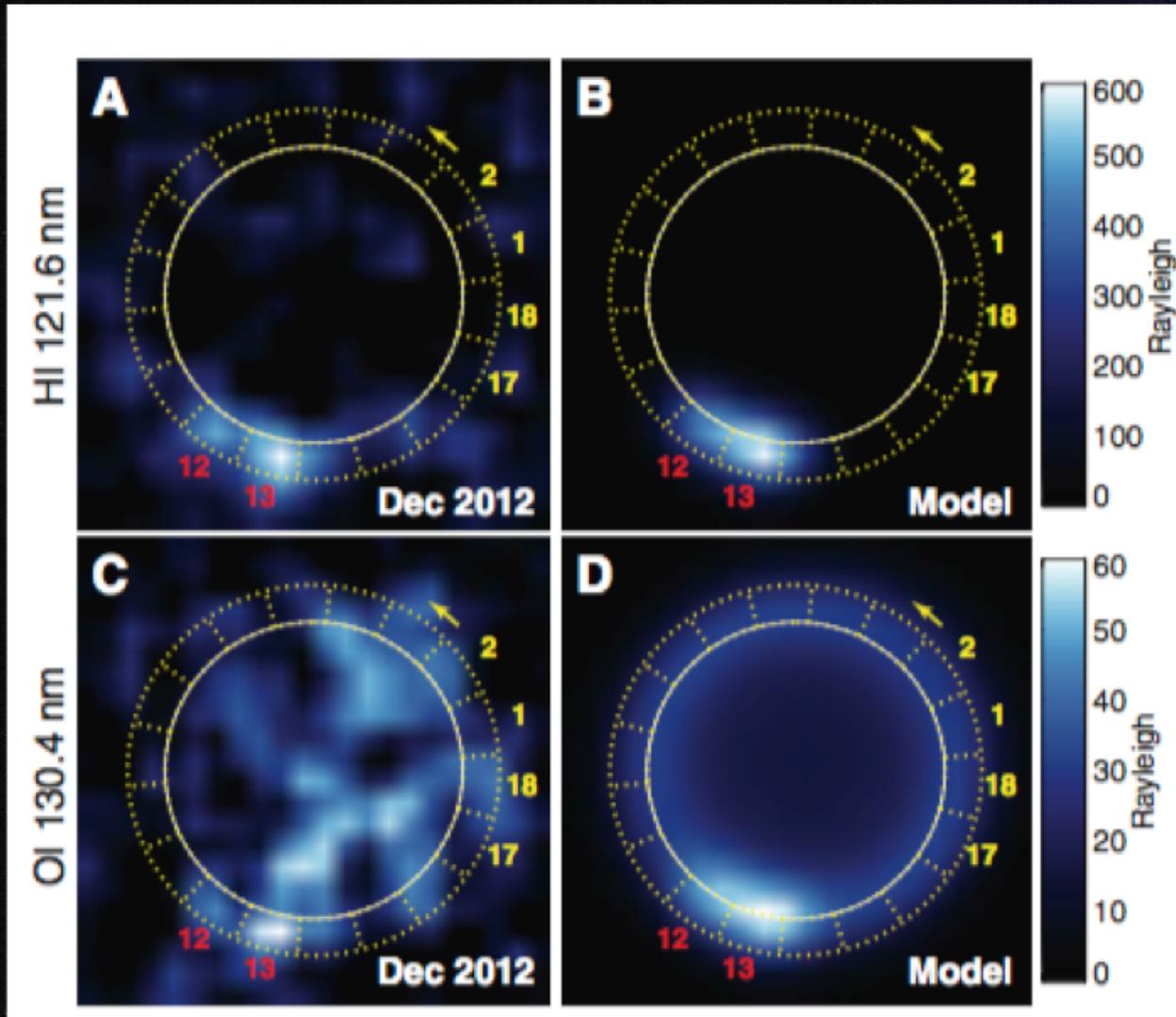
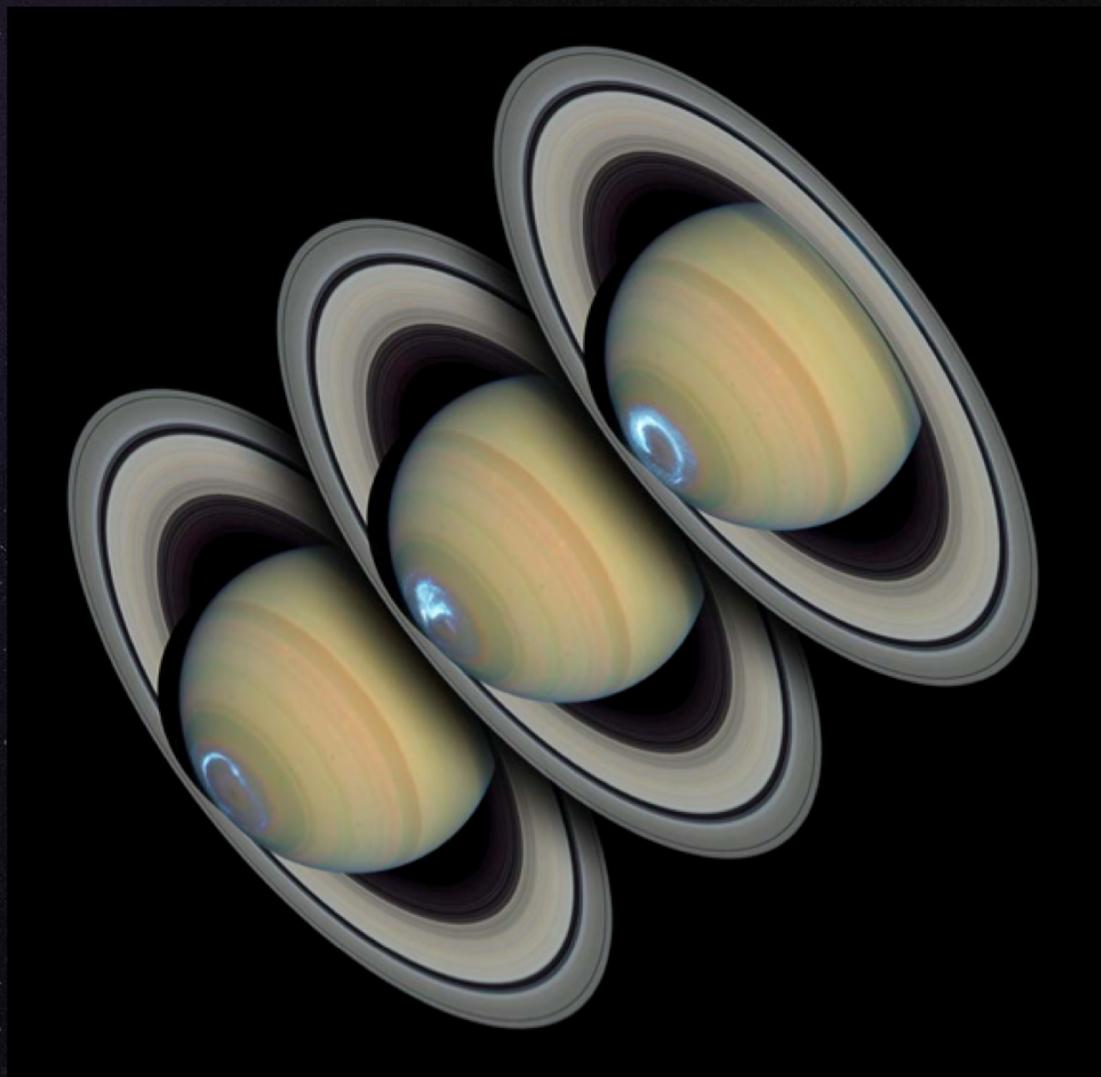
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General Observatory Science







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General Astrophysics and Solar System Science Themes

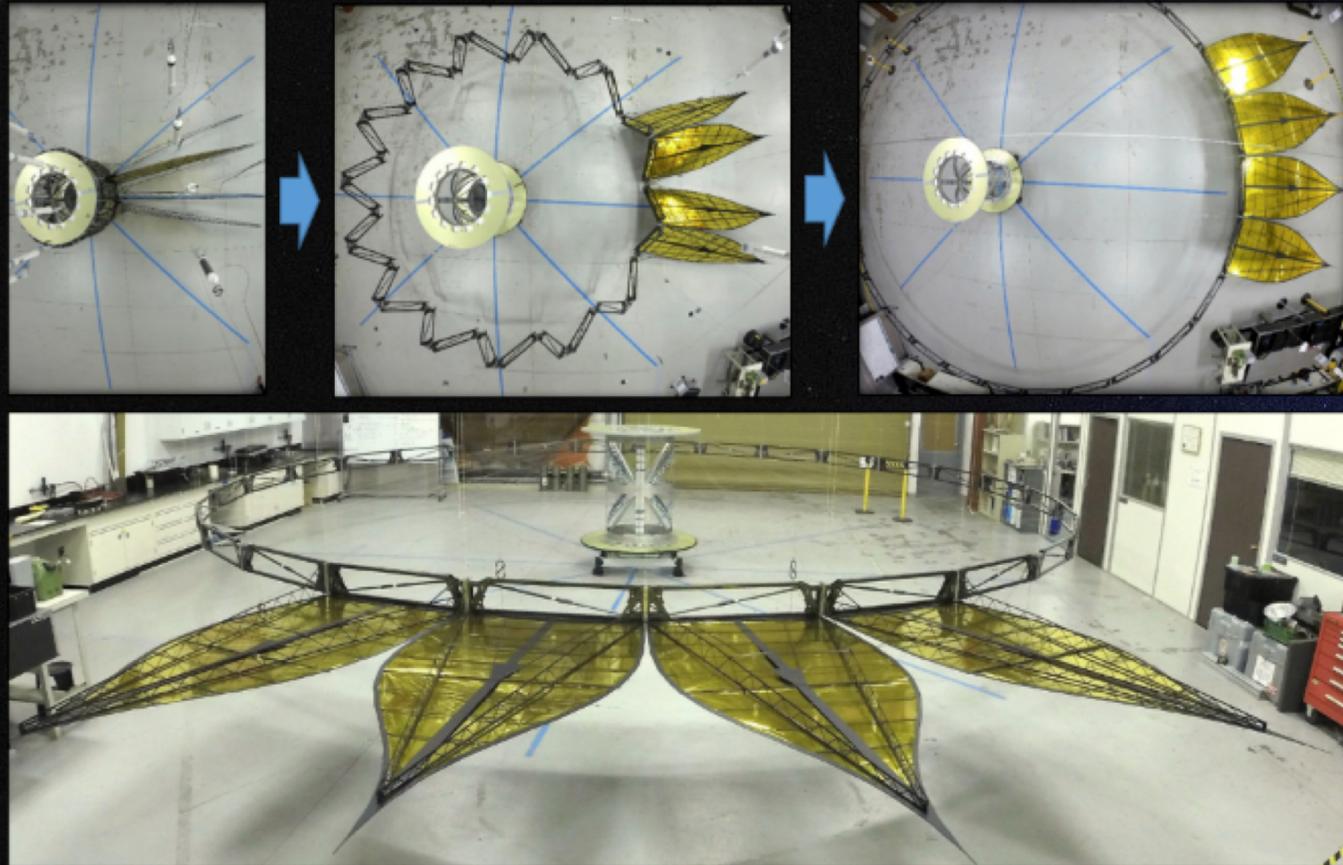


- The Life Cycle of Baryons and the Missing Baryons Problem
- Resolved Stellar Populations of Nearby Galaxies.
- Planetary Aurorae and Exospheres
- Cryovolcanism and Potentially Habitable Icy Worlds
- The Hubble Constant
- The Nature of Dark Matter Using Dwarf Galaxies



Enabling technologies currently at TRL 3 for the 4m architecture to be matured.

- Expected to be TRL >3 by Final Report
 - LOWFS and control
 - Starshade starlight suppression
 - Starlight age suppression and edge scattering
 - Microthrusters
- Needs investment to reach TRL >3 by Final Report
 - Petal shape stability and shape accuracy



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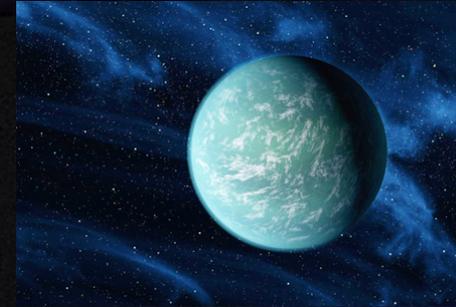


Summary



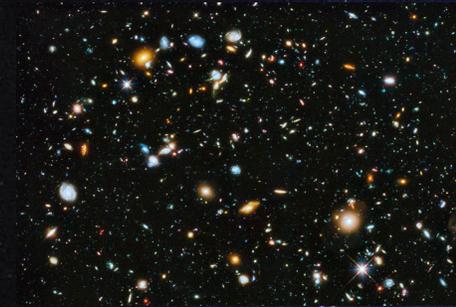
Architecture studied:

- 4m off-axis monolith: preliminary design completed.
 - Four instruments:
 - Coronagraph and Starshade Cameras
 - UV spectrograph and Workhorse Camera.



Science Goals:

- Seek out nearby worlds and explore their habitability
- Map out nearby planetary systems and understand their diversity.
- Open up new windows in the Universe from the UV to NIR.

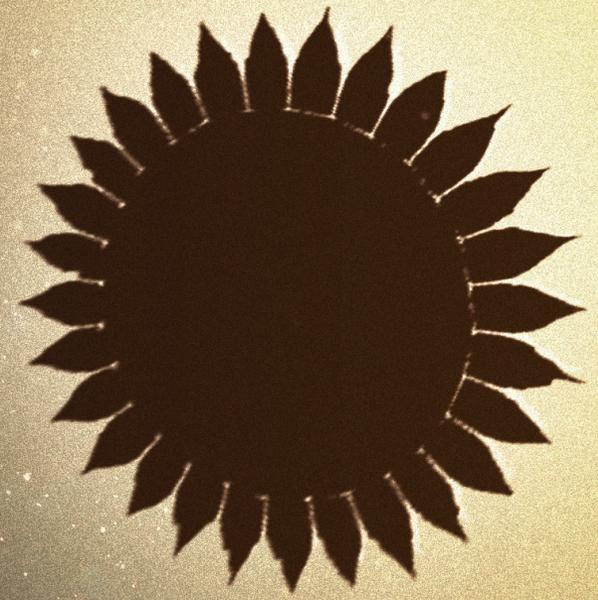
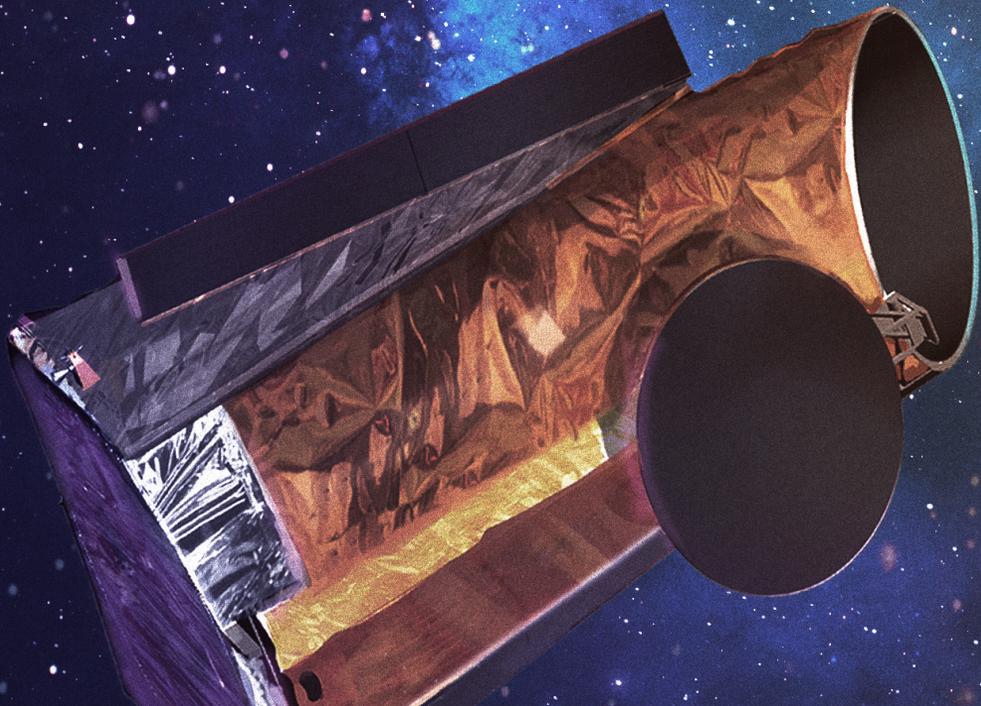


Next Steps:

- Refine our observing strategy
- Create a full Design Reference Mission
- Decide on near-IR capabilities
- Decide on and develop a second architecture



Thank you!



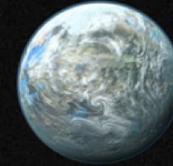


	Starshade	Coronagraph	Technology Gap	ExEP TRL Assessment at P&L	Our Assessment at Final Report	
Enabling			Petal Shape stability	3	3	High priority. Needs a plan.
			Petal Position Accuracy	3	3	High priority. Needs a plan.
			LOWFS and control	3	4	High Priority. Once we can demonstrate that we need only the same LOWFS implementation as WFIRST we can move to TRL 4.
			Starshade Starlight Suppression	3	4	Technology being advanced in the S5 project
			Starshade Edge Scattering	3	4	Technology being advanced in the S5 project
			Micro-Thrusters	3	5	ExEP needed analysis that demonstrated that the existing thrusters would work for HabEx. We are doing this now. Once complete, the technology moves to TRL 5 since already demonstrated in space.
			Coating Uniformity on Large Optics	4	4	High priority. Needs a plan.
			Coronagraph Architecture	4	4	
			Large Aperture Primary	4	4	
			Formation Flying	4	5	Technology being advanced in the S5 project.
			Deformable Mirrors	5	5	
		Visible Detectors	5	5		
Enhancing			NIR Detectors	3	4 or 5	ExEP needs analysis showing that the current SOA will meet HabEx needs. May be able to leverage work in JWST to show HgCdTe detectors are suitable for the HabEx environment.



Both LUVVOIR 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 LUVVOIR, both goals are on equal footing. LUVVOIR will be a general purpose “great observatory”, a successor to HST and JWST in the $\sim 8 - 16$ 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 $\sim 4 - 8$ 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
- LUVVOIR 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



Back-up Slides