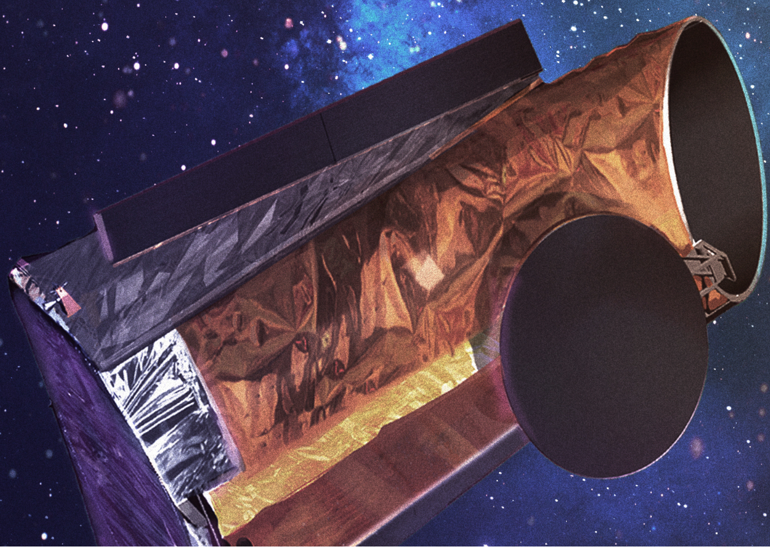
HabEx

The Habitable Exoplanet Observatory

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



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)

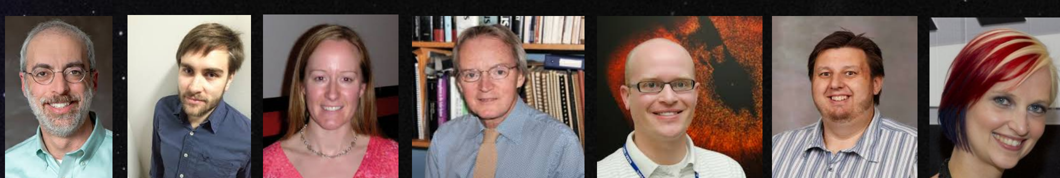
Keith Warfield (JPL – Study Manager)

The HabEx Study Team

HabEx

Science and Technology Definition Team

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.



19 STDT Members

6 International Observers (ESA, JAXA, DLR, CNES, CSA, SRON)

HabEx Study Philosophy

- The HabEx study was guided by the philosophy of developing a mission capable of the most compelling science possible, while still adhering to likely cost, technology, risk, and schedule constraints.
- HabEx is built on two equal science pillars:
  - HabEx must be capable of *discovering* and *characterizing (spectra and orbits)* habitable planets like Earth orbiting nearby bright sunlike stars.
  - HabEx must also be equipped with instrumentation with unique capabilities that will enable broad and exciting general astrophysics and planetary science not possible from current or planned ground-based or space-based facilities.
- All of the enabling technologies for HabEx are TRL 4 or above. The twelve TRL 4 technologies are related to coronagraphy, the starshade, low-noise detectors, and large mirrors.
- The HabEx study also considers eight other lower-cost architectures, each with fewer enabling technologies requiring development than the preferred architecture.

HabEx Science Goals

Seek out nearby worlds and explore their habitability.

Map out nearby planetary systems and understand the diversity they contain.

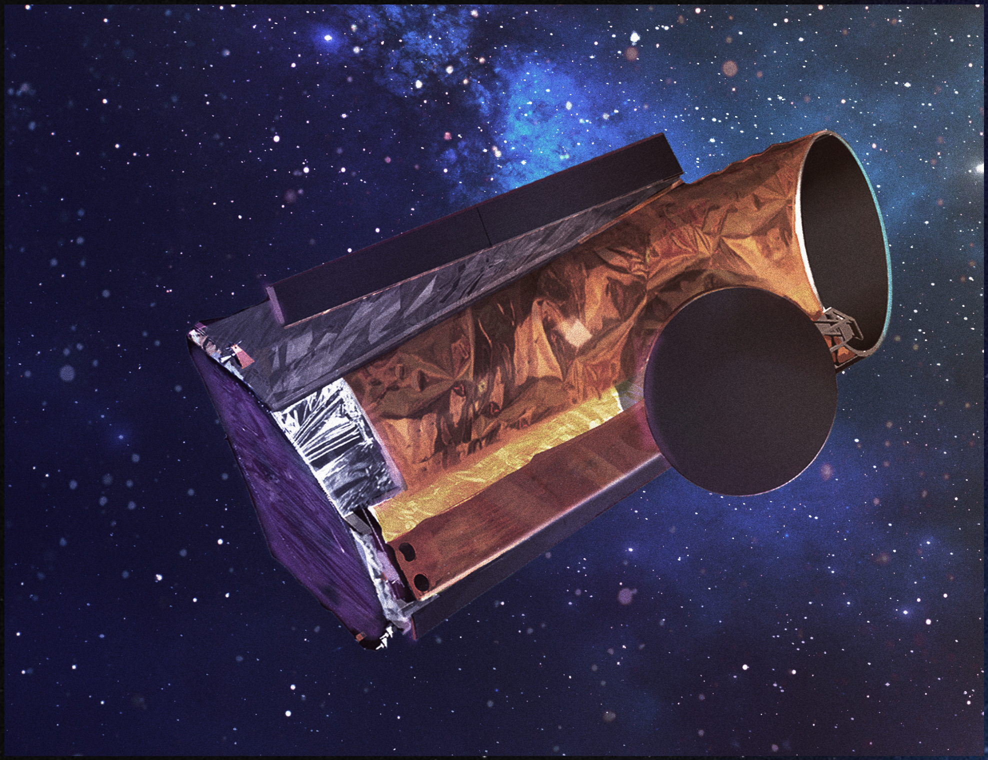
Enable new explorations by extending our reach from the UV to the near-IR.

HabEx Preferred Architecture

- **Telescope:**
  - 4m Off-Axis f/2.5 Al-Coated Monolith
- **Instruments**:
  - Coronagraph Instrument
  - Starshade Instrument (52m)
  - UV Spectrograph (UVS)
  - HabEx Workhorse Camera (HWC)

Will be on all architectures

- **Launch**:
  - SLS Block 1B (Telescope)
  - Falcon Heavy (Starshade)
  - L2 orbit
- **Timeline**:
  - Launch: Mid-2030s
  - Nominal operation: 5 years, Capability: 10 years

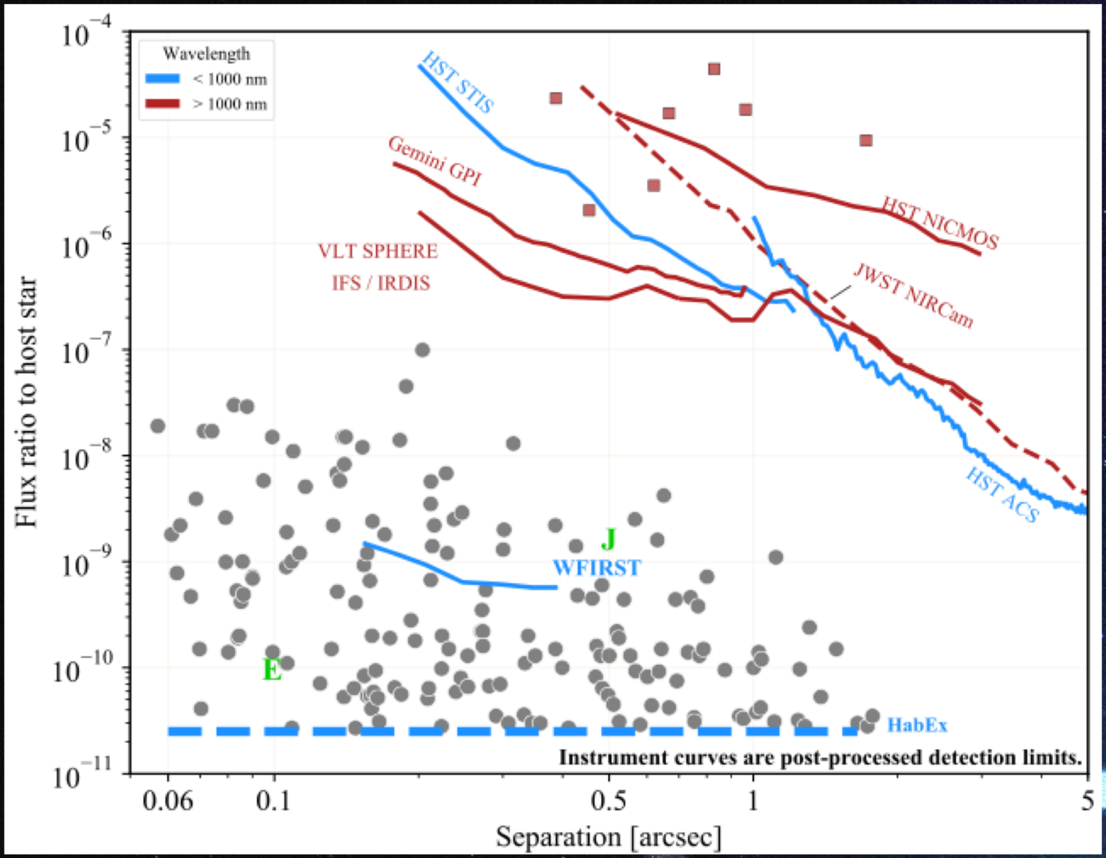


In Total Studying 9 Architectures: 4m/3.2m/2.4m x Hybrid/Starshade-Only/Coronagraph-Only

Capabilities: Direct Imaging

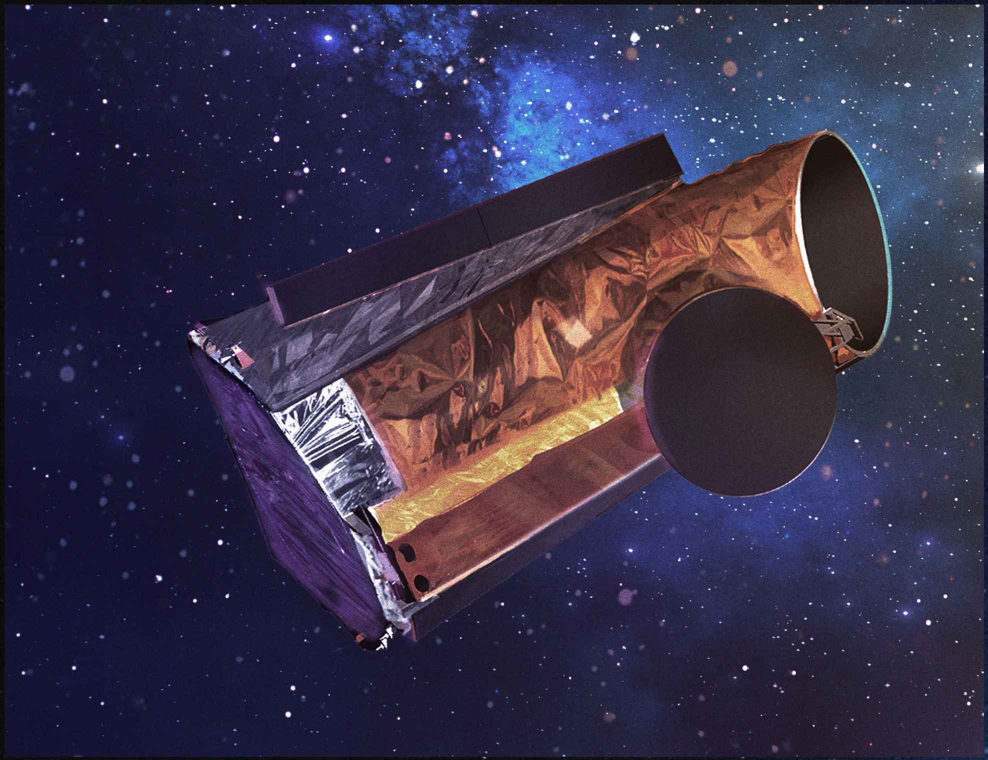
- **Raw Contrast:**
  - 1 x 10^{-10} (at IWA)
- **Inner Working Angles:**
  - 0.058” at 0.3-1 µm (ss)
  - 0.062” at V band (cg)
- **Outer Working Angles:**
  - 6” (ss-imaging)
  - 1” (ss-spectra)
  - 0.83” (@ 0.5 µm, cg-imaging/spectra)
- **Spectroscopy**:
  - R=7 from 200 to 450 nm (ss)
  - R=140 from 450 to 1000 nm (ss/cg)
  - R=40 from 1 to 1.8 µm (ss/cg)

ss = starshade | cg = coronagraph



HabEx Preferred Architecture

Why starshade *and* coronagraph?

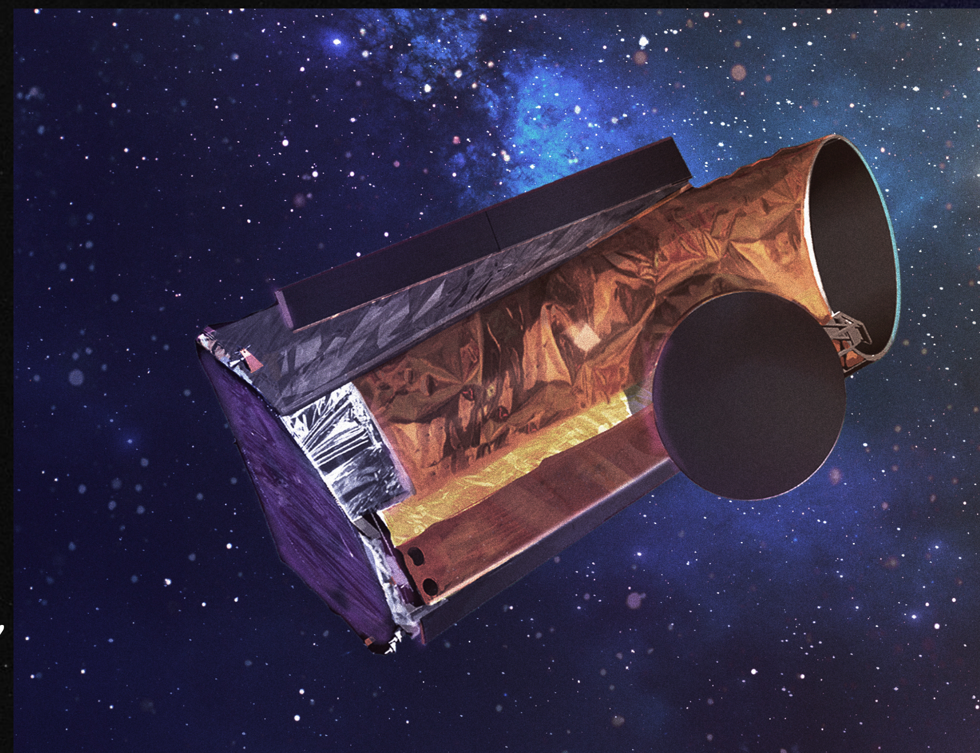


Preferred Architecture

Why starshade *and* coronagraph?

- **Coronagraph:**
  - **Pro**: nimble, on-board, good for blind searches and orbit determination.
  - **Con**: narrow instantaneous bandpass, not optimal for obscured primaries, typically limited OWA.

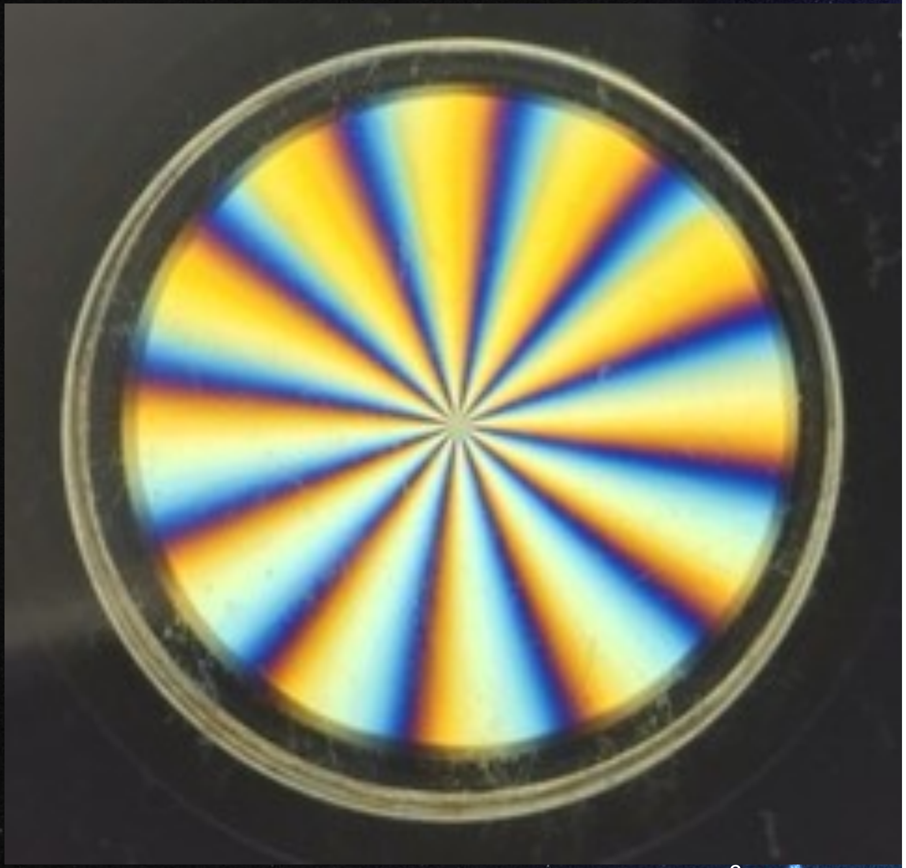
- **Starshade**:
  - **Pro**: wide bandpass, high throughput, large OWA, small IWA, good for spectral characterization.
  - **Con**: slow, fuel limited, require a separate launch



Baseline Coronagraph

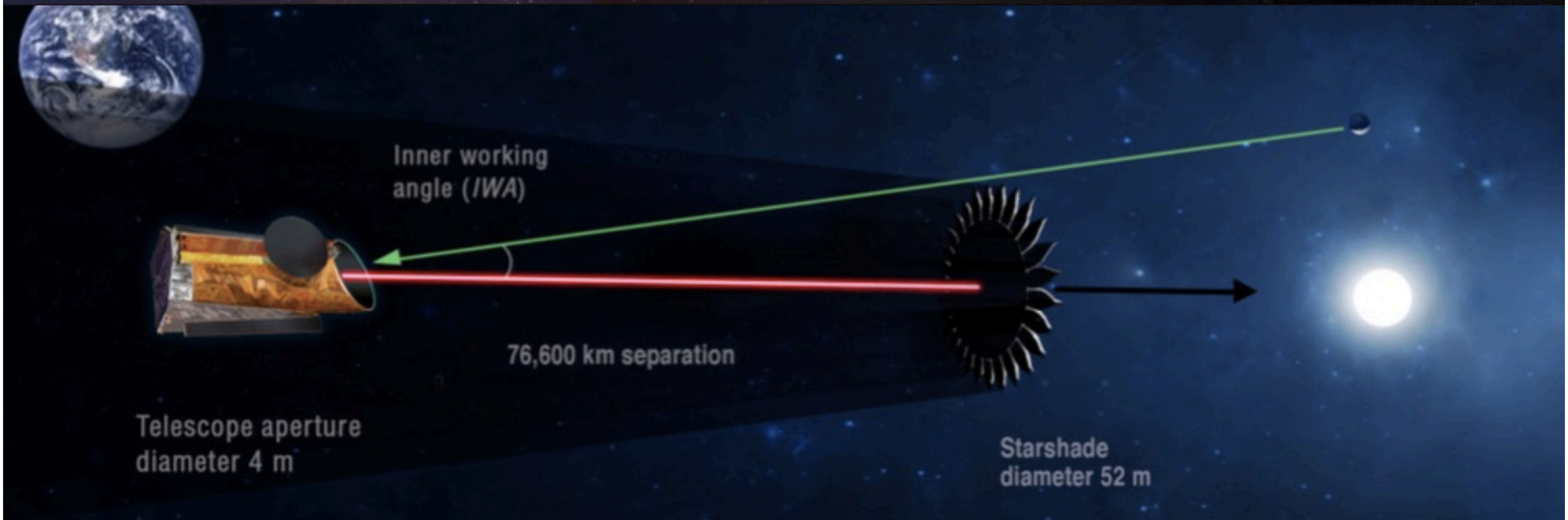
- **Vector Vortex Charge 6**
  - mostly insensitive to low order aberrations
  - achieved 5 x 10^{-10} contrast (monochromatic) in 2013
  - 10% bandwidth currently tested in HCIT

- **Hybrid Lyot Coronagraph**
  - more mature technology
  - achieved 5 x 10^{-10} contrast (10% bandwidth) in 2018 at DCT



Potential heritage from *WFIRST*/CGI (for HLC)!

Starshade


Inner working angle (IWA)
76,600 km separation
Telescope aperture diameter 4 m
Starshade diameter 52 m

HabEx

HabEx Science Goals

Seek out nearby worlds and explore their habitability.

Map out nearby planetary systems and understand the diversity they contain.

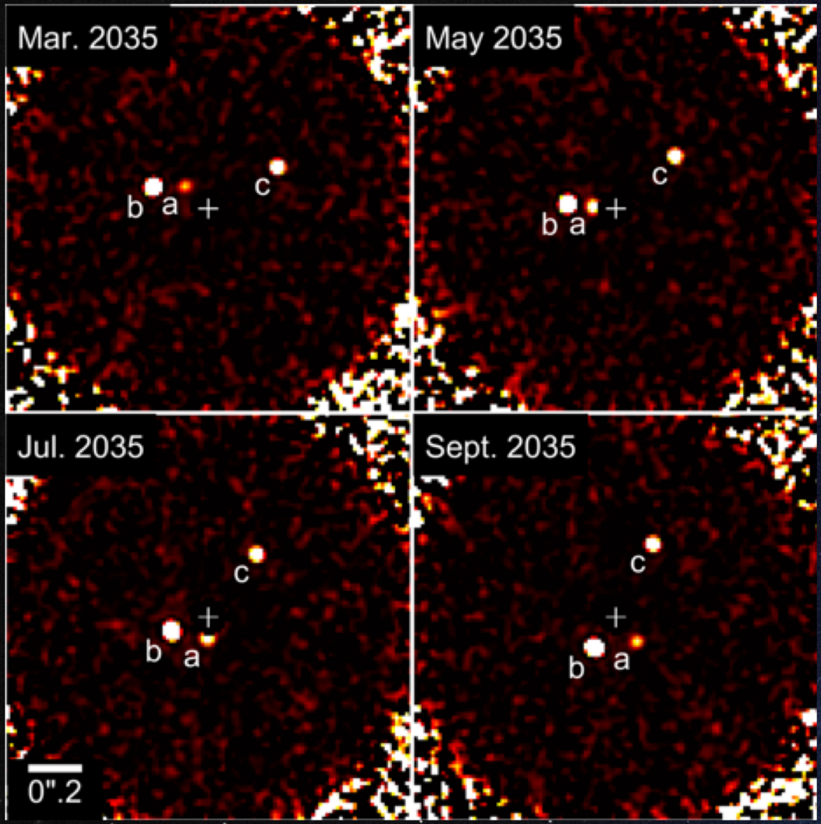
Enable new explorations by extending our reach from the UV to the near-IR.

HabEx

Broad Survey for Potentially Habitable Worlds

Seek Out Habitable Worlds

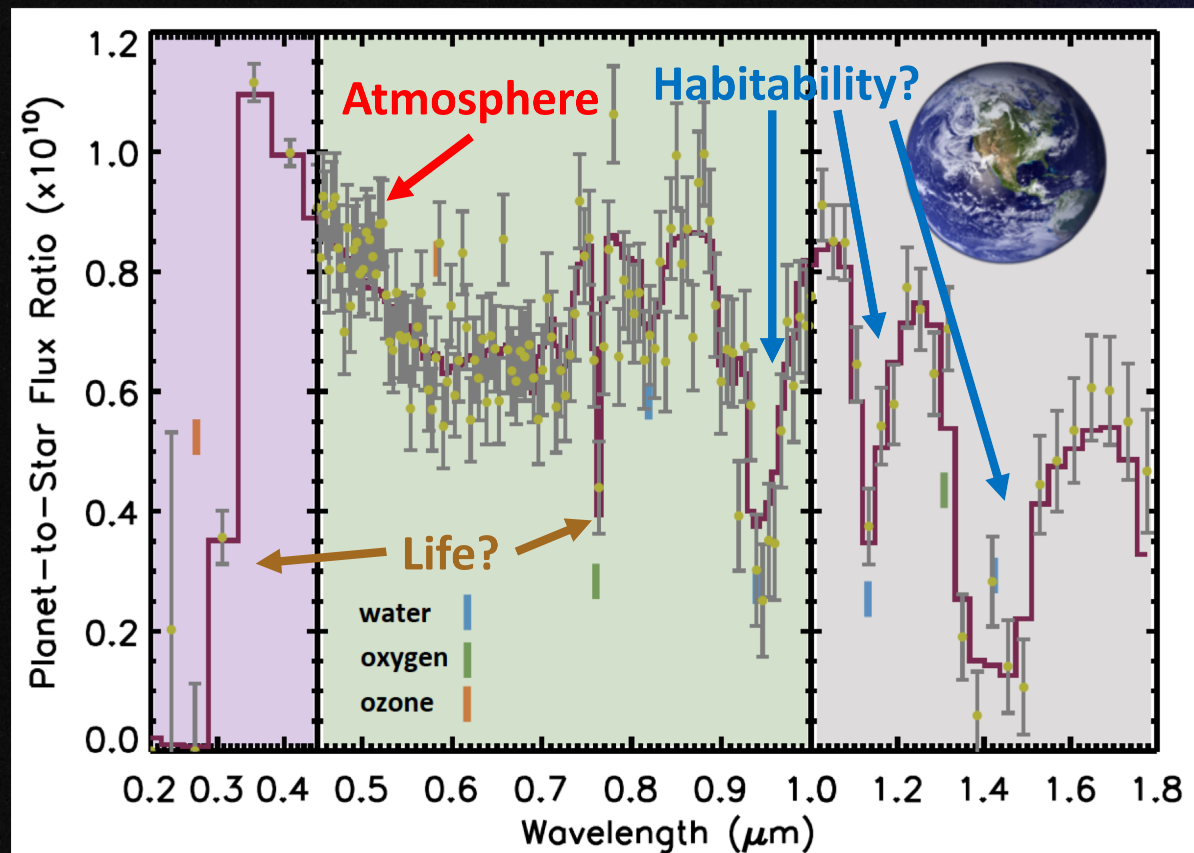
- HabEx will survey ~50 stars with the coronagraph to search for potentially habitable worlds.
- HabEx will measure their orbits to determine if they are in the Habitable Zone.
- Promising systems will be studied in further detail with the coronagraph and starshade.



Simulated ExoEarth Spectrum

Characterize Earths

- Potentially rocky planets with orbits in the HZ of their stars will be characterized by the starshade.
- Simulated HabEx spectrum of exo-Earth around Beta CVn (Chara), a G0V star at 8.4 pc assuming 230h of observations (SNR=10 @ 0.55 mm & R=140)




HabEx
HabEx Science Goals
NASA
Seek out nearby worlds and explore their habitability.
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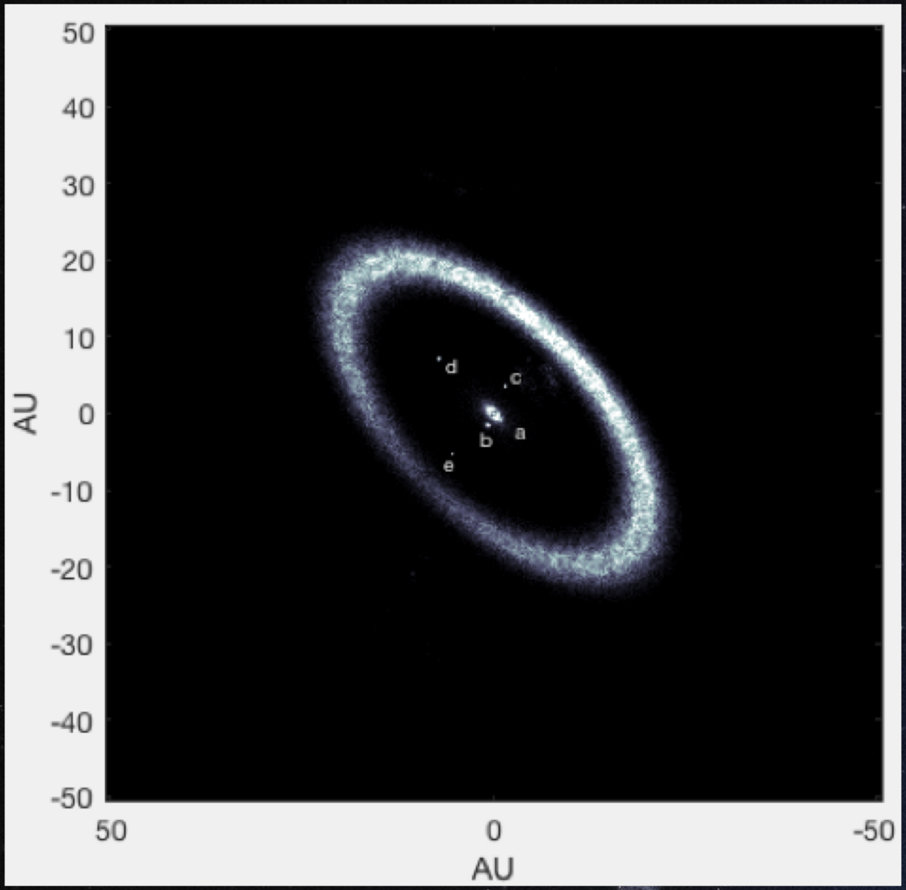
Deep Survey of our Nearest Neighbors

Family Portraits

- Broadband 12” x 12” image
- Simultaneous 0.3-1.0 µm spectra with starshade for all planets within 2”x2” square.
  - R=7 (grism) 0.3-0.45 µm.
  - R=140 (IFS) 0.45-1.0 µm.
- Also NUV and NIR spectral extensions:
  - R=7 (grism) 0.2 - 0.3 µm
  - R=40 (IFS) 1.0 – 1.8 µm



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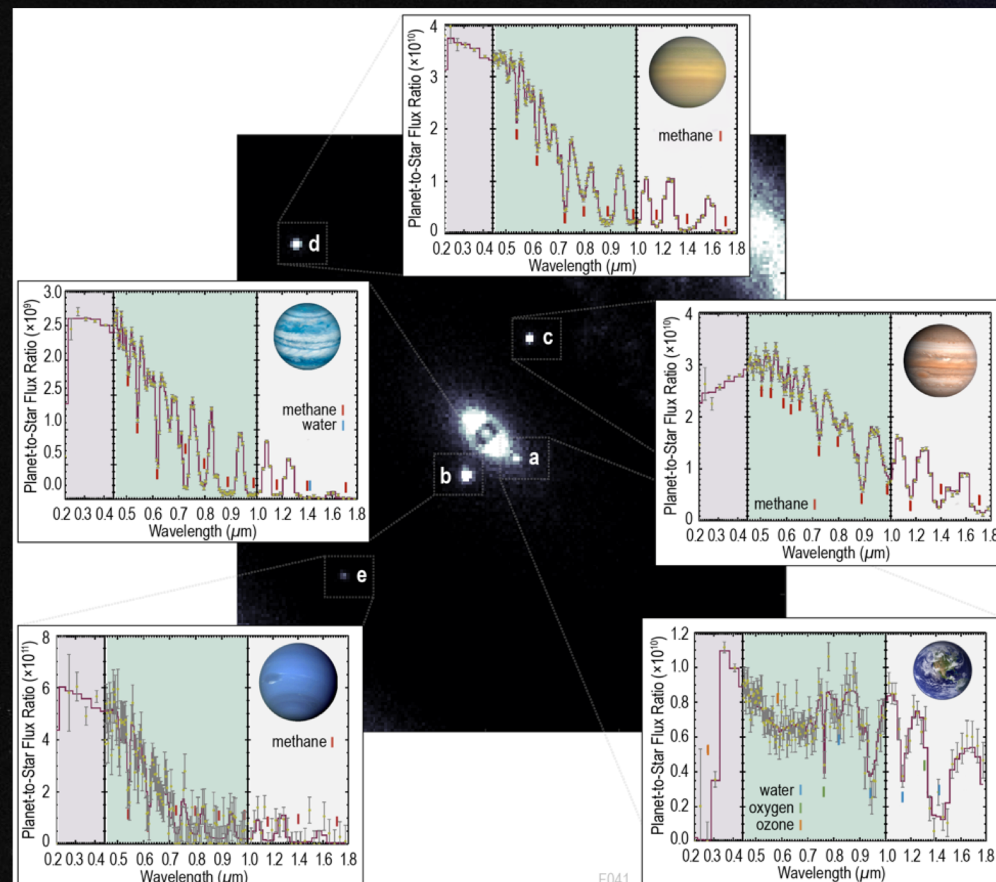


HabEx — Deep Survey Targets

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 *Kobayashi Maru* in *Star Trek* and location of *Barbarella* (1968)
82 Eridani	G8V	6.0	4.3	6.1–12.7	**Astronomy:** 3 confirmed planets (all super-Earths) plus dusk disk
40 Eridani	K1V	5.0	4.4		**Astronomy:** triple-system, with white dwarf and M-dwarf **Common name:** Keid **Popular culture:** in *Star Trek*, 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 *Star Trek* episode "*Spock's Brain*" (1966)
61 Cygni A	K5V	3.5	5.2	6.1	**Astronomy:** wide-separation binary **Common name:** Bessel's star **Popular culture:** home system of humans in Asimov's *Foundation* series
61 Cygni B	K7V	3.5	6.1		
ε Indi	K5V	3.6	4.8	1.3	**Astronomy:** triple-system, with 2 brown dwarfs 1 unconfirmed planet (Jupiter-mass)

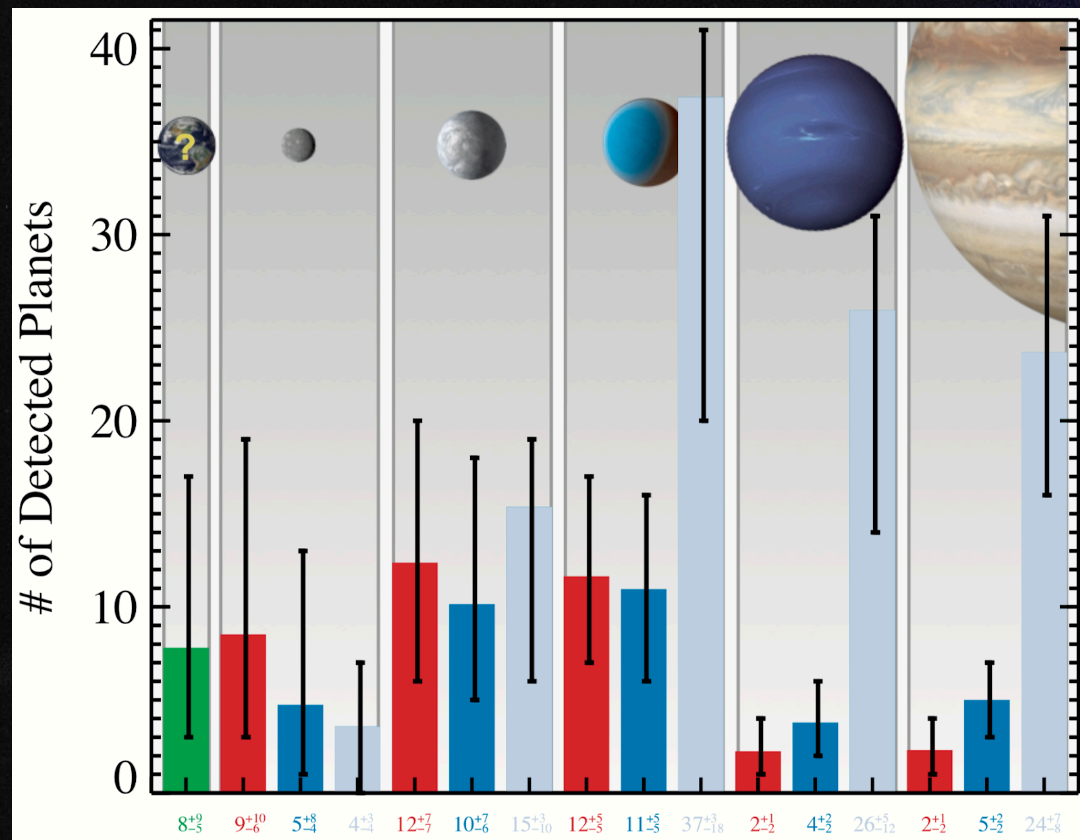
Yields of Characterized Planets

Yields*

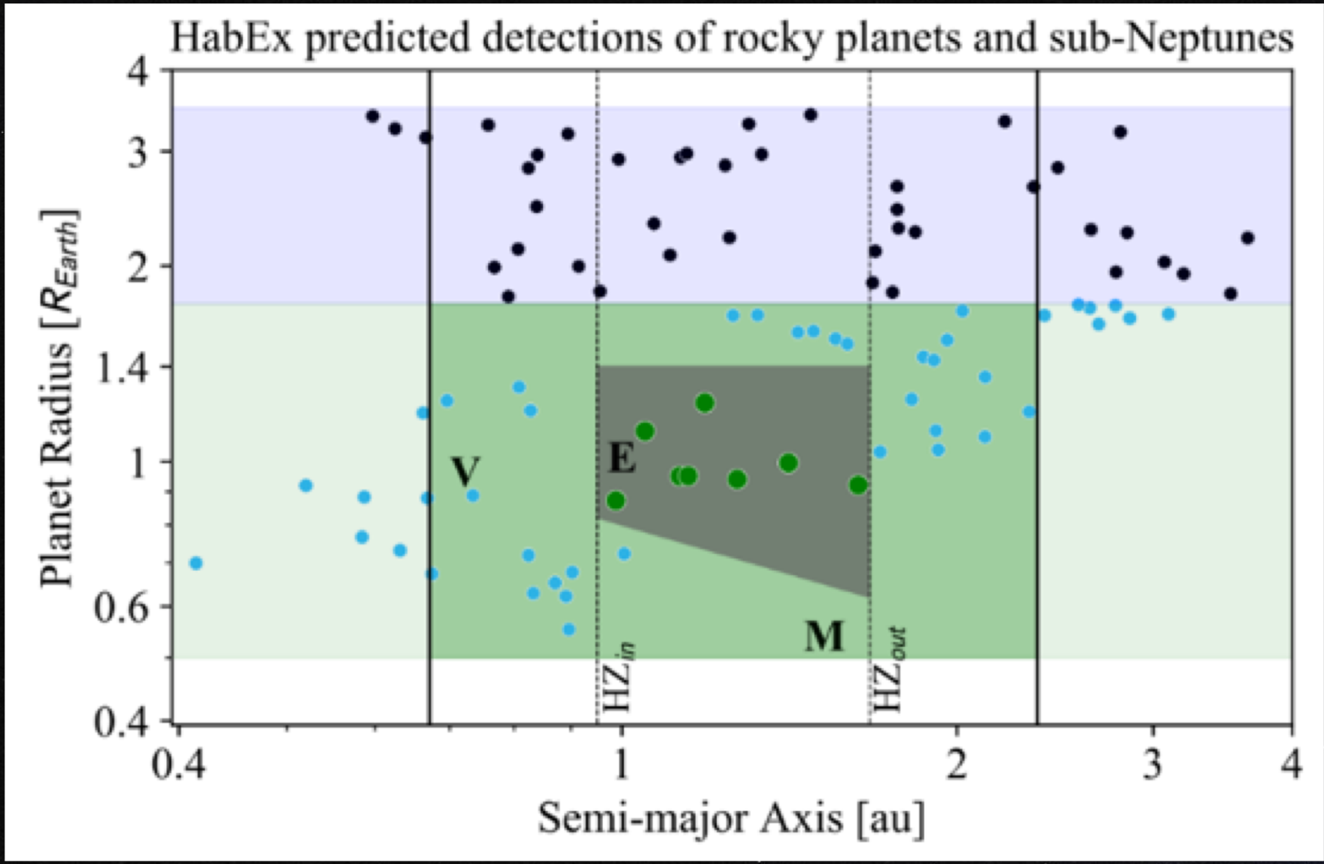
Detect and characterize orbits and atmospheres of:

- **Rocky planets**:
  - ~55 rocky planets (0.5-1.75 R_E)
  - Includes ~17 in the HZ and ~8 Earth Analogs (~0.6-1.4 R_E)
- **Sub Neptunes**:
  - ~60 sub-Neptunes (1.75-3.5 R_E)
- **Gas Giants**:
  - ~63 gas giants (3.5-14.3 R_E)

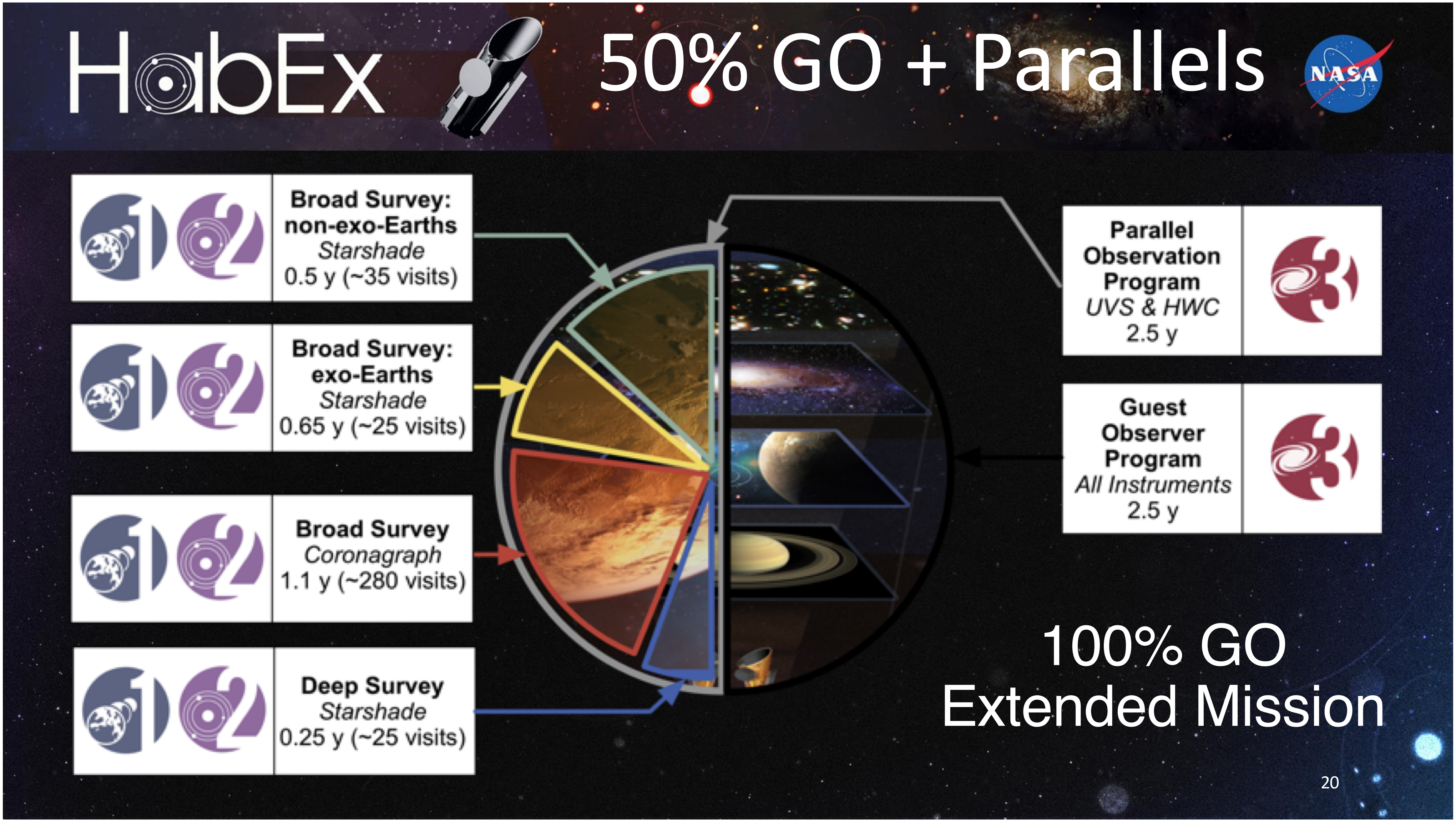
*Assumes Belikov 2017, Dultz & Plavchan 2019 Occurrence Rates; uncertain, particularly for cold planets.

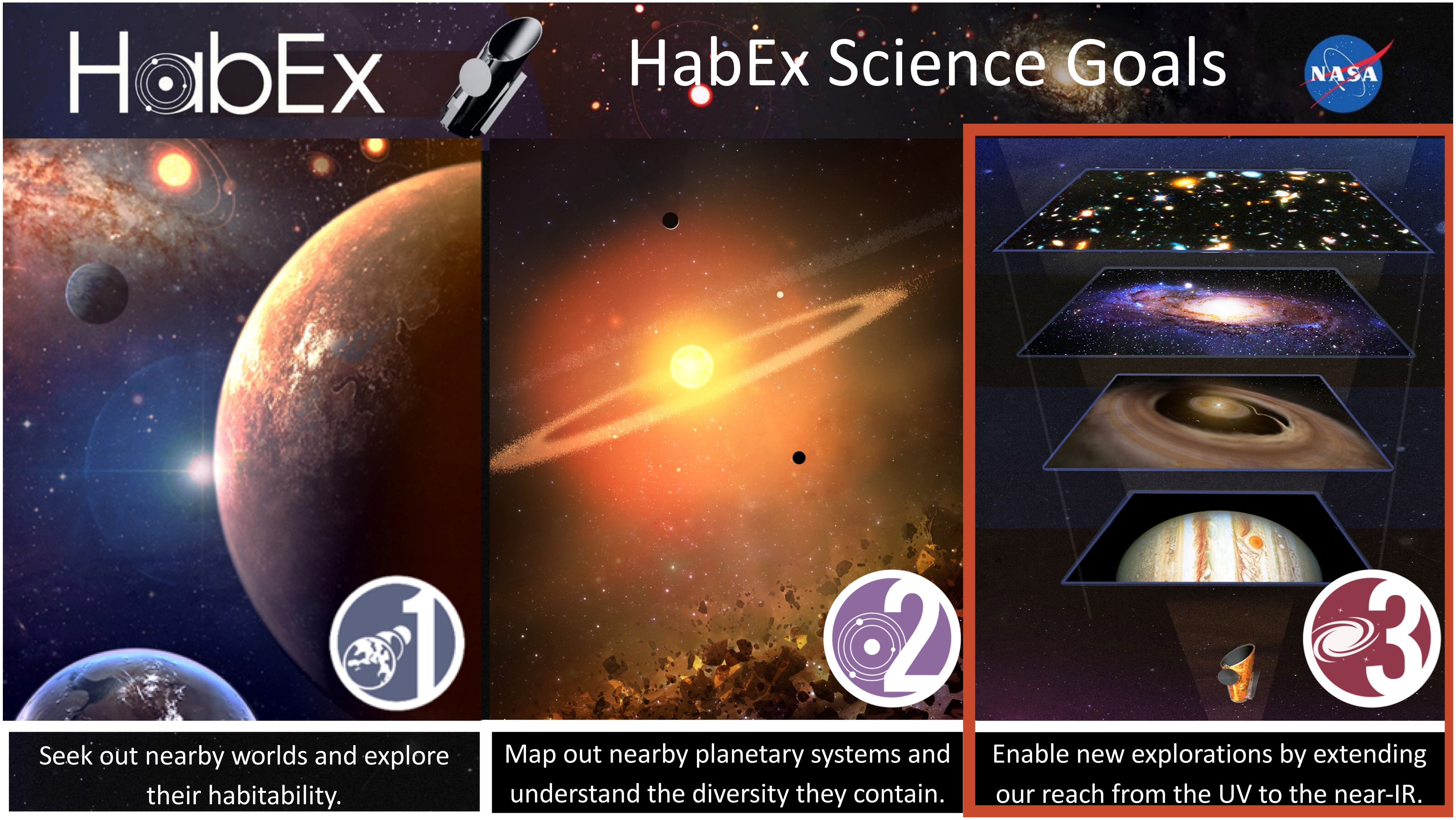


Empirically Defining the Habitable Zone



Credit: T. Meshkat and C. Stark

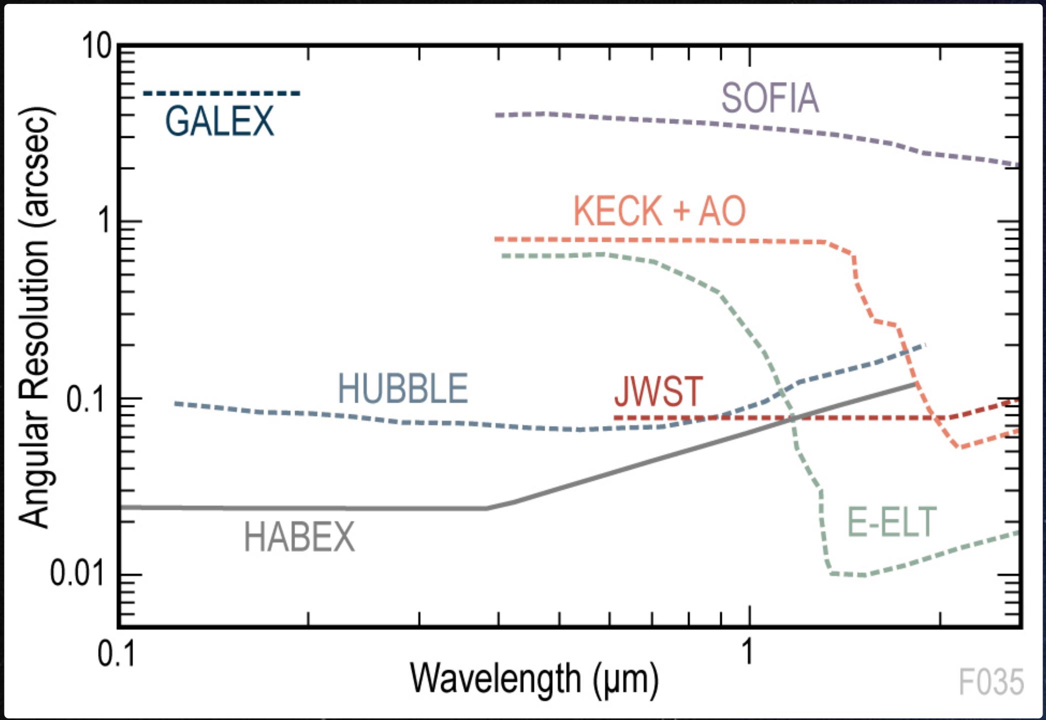

HabEx
50% GO + Parallels
NASA
Broad Survey: non-exo-Earths
Starshade
0.5 y (~35 visits)
Broad Survey: exo-Earths
Starshade
0.65 y (~25 visits)
Broad Survey
Coronagraph
1.1 y (~280 visits)
Deep Survey
Starshade
0.25 y (~25 visits)
Parallel Observation Program
UVS & HWC
2.5 y
Guest Observer Program
All Instruments
2.5 y
100% GO
Extended Mission
20


HabEx
HabEx Science Goals
NASA
Seek out nearby worlds and explore their habitability.
Map out nearby planetary systems and understand the diversity they contain.
Enable new explorations by extending our reach from the UV to the near-IR.

Capabilities: Resolution and Effective Area

Capabilities: Imaging and Spectra

- **Key Details**
  - diffraction limited at 0.4 µm
  - non-sidereal (e.g., SS objects) tracking
  - wavelength coverage: 115 nm - 1.8 µm
- **UVS**
  - 3’ x 3’ FOV
  - 115-320 nm
  - spectral resolution up to 60,000
- **HWC**
  - 3’ x 3’ FOV
  - 450-950 nm and 950 nm - 1.8 µm
  - spectral resolution of 1000



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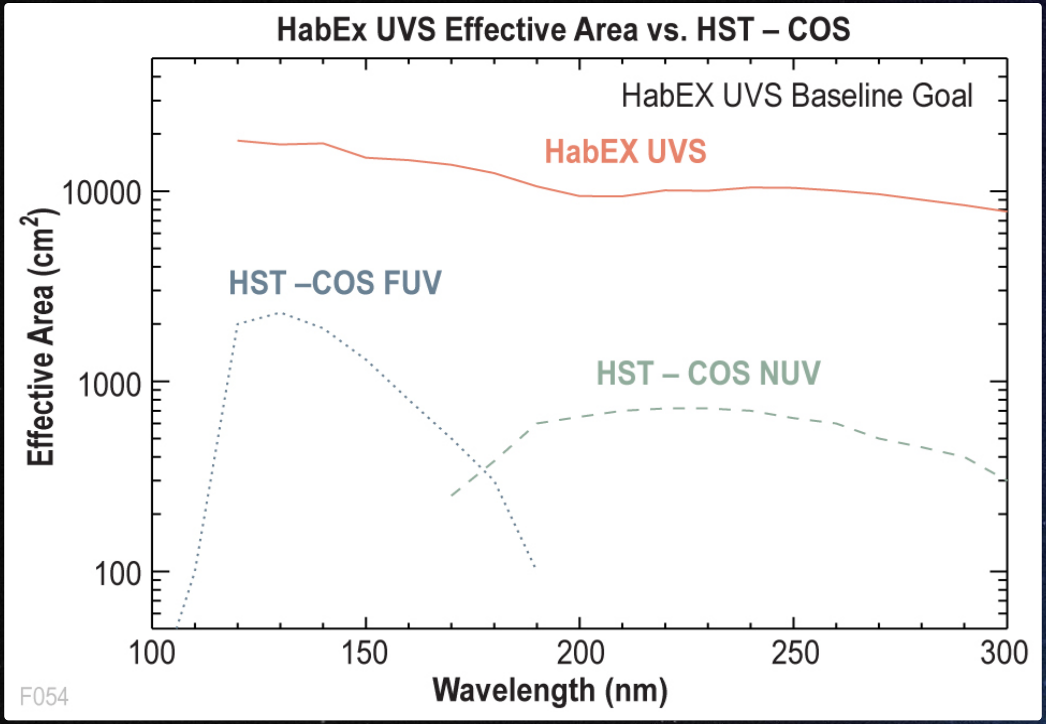


GO Science: Key Themes

- 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.
- Gas and Ice Giant Aurorae and Stellar Wind-Magnetosphere Interactions.
- Wind Dynamics of Gas and Ice Giant Atmospheres.
- Exoplanet Transit Spectroscopy.

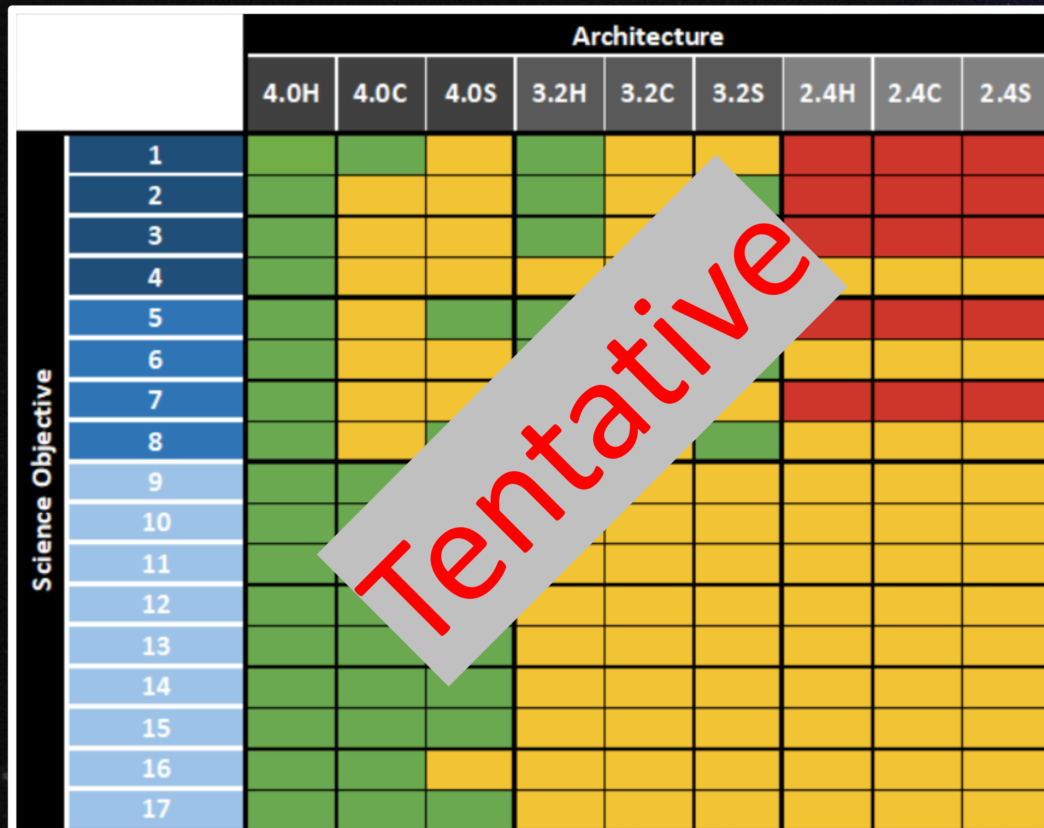
But! The “killer science” applications will be determined by the public, i.e., YOU!

The Three Graces: John Clarke, Paul Scowen, Dan Stern

Trade of 9 Architectures

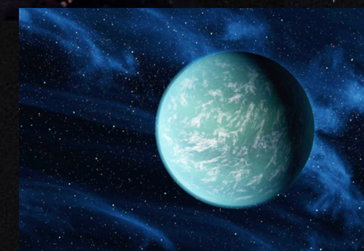
Studying 9 Architectures

- Total of 17 Science Objectives in the STM that define our baseline and threshold requirements.
- Color code.
  - Green = meets baseline
  - Yellow = meets threshold
  - Red = does not meet threshold
- All 9 are significant improvements over Hubble and can directly detect and characterize planets.



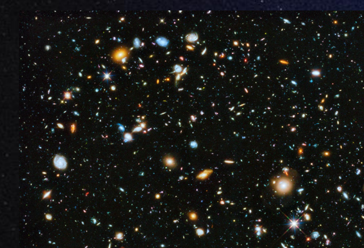
HabEx Summary

Preferred Architecture Design Nearly Complete:



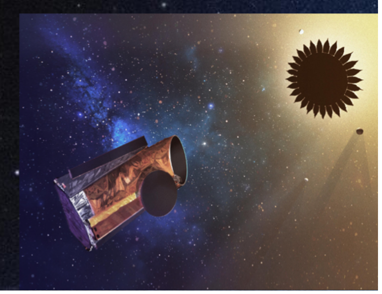
- 4m off-axis monolith.
- Four instruments:
  - Coronagraph and Starshade.
  - UV Spectrograph and Workhorse Camera.

Science Goals:



- To seek out nearby worlds and explore their habitability.
- To map out nearby planetary systems and understand the diversity of the worlds they contain .
- To carry out observations that open up new windows on the universe from the UV through near-IR.

The HabEx Final Report Includes:

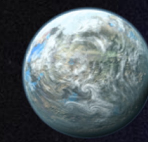


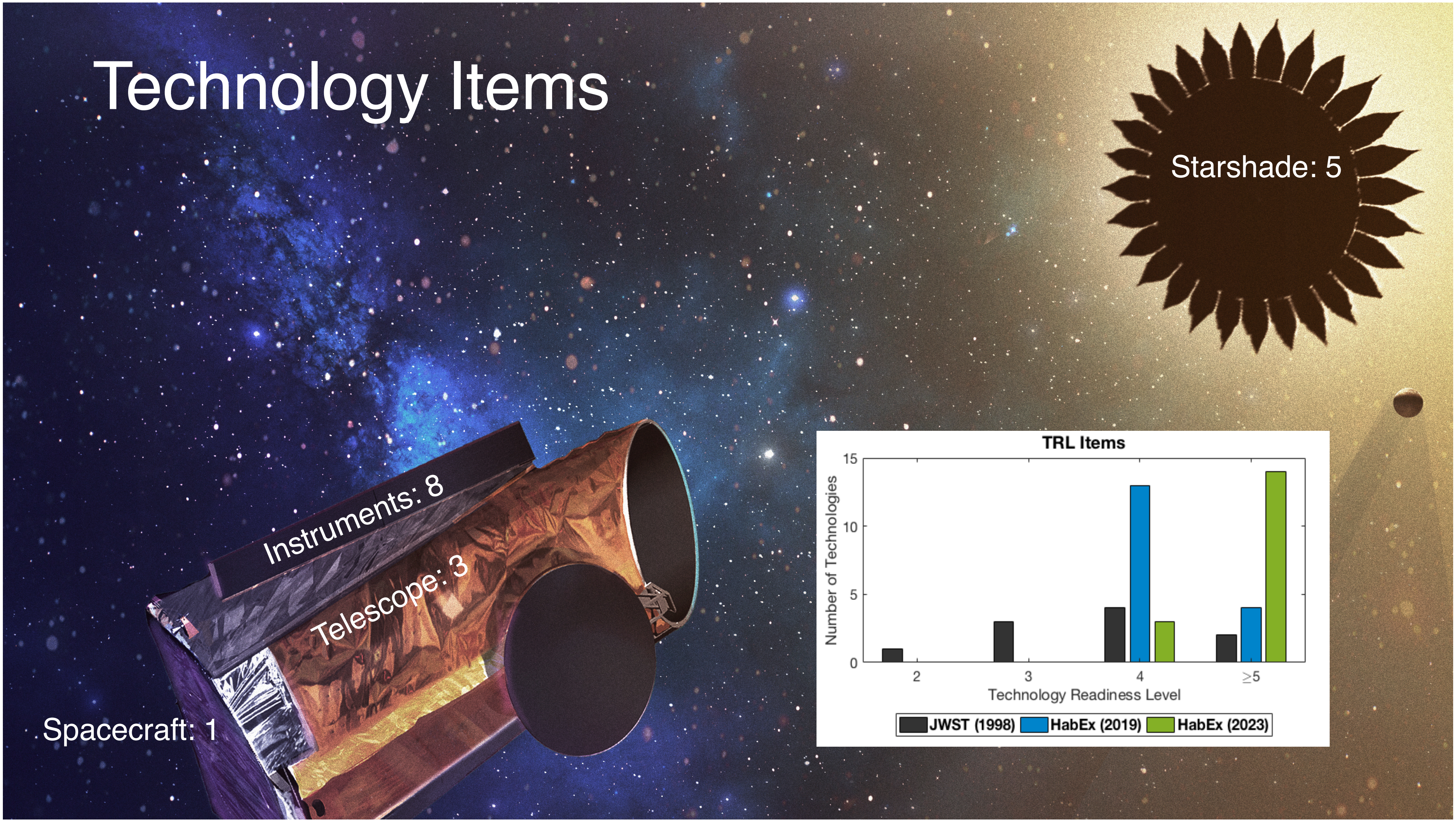
- A complete science traceability matrix (STM).
- Heavily polished primary architecture.
- Robust descriptions of technologies and the path to TRL 6.

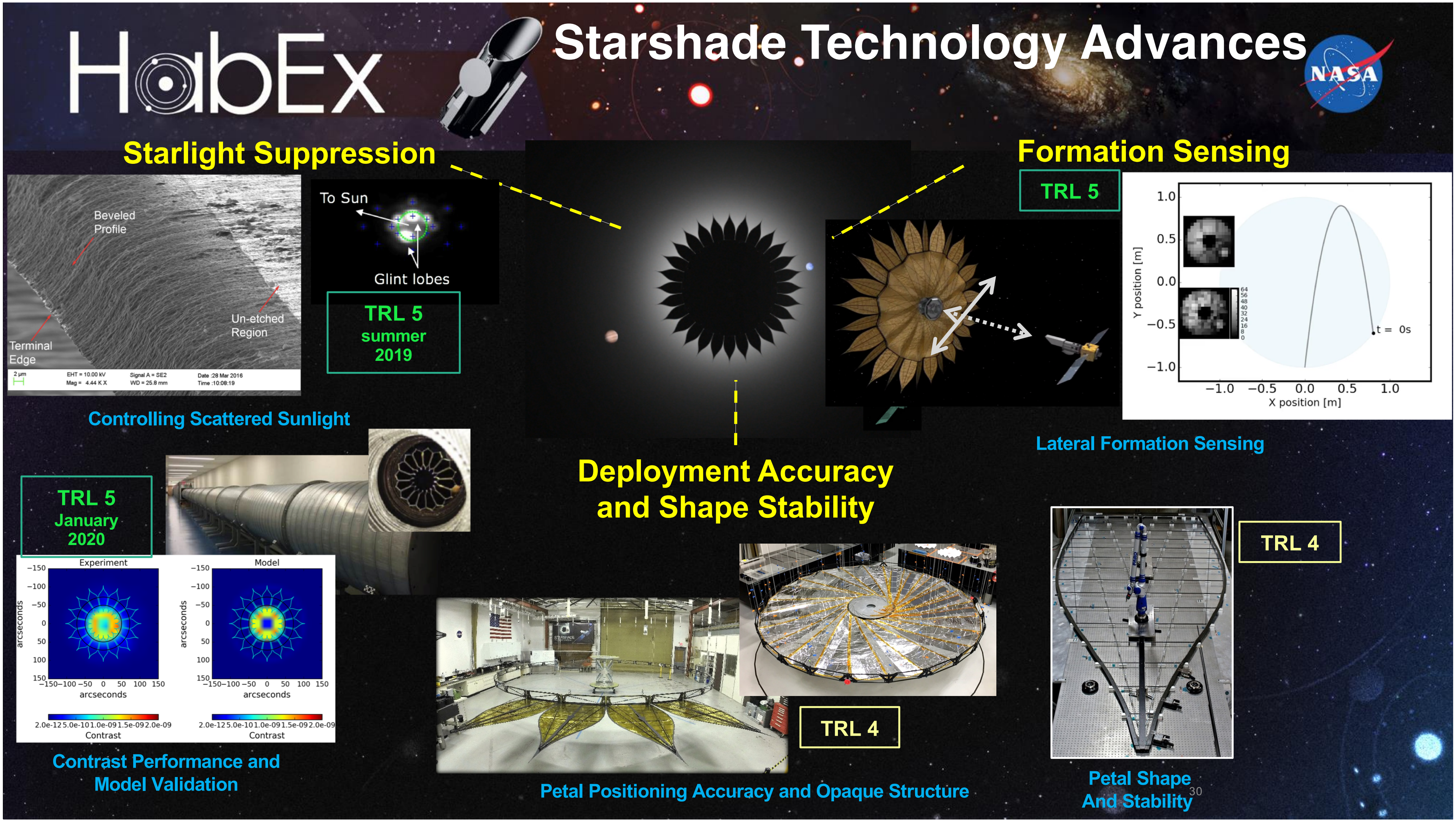
Thank you!

Two Teams, One Vision
Statement by the LUVOIR & HabEx STDTS

- The HabEx and LUVOIR (and Lynx and *Origins*) Science and Technology Definition Teams have devoted over three years and many thousands of person-hours to studying future large strategic space mission concepts.
- Together, HabEx and LUVOIR will present eleven different architectures.
- ***The HabEx and LUVOIR teams have collaborated since their initiation,*** and as a result are offering a ‘buffet’ of options, with corresponding flexibility in budgeting and phasing.
- The studies agree that a joint astrophysics – exoplanet UV/optical/near-IR space observatory provides a bold, compelling, and achievable vision for space astronomy.

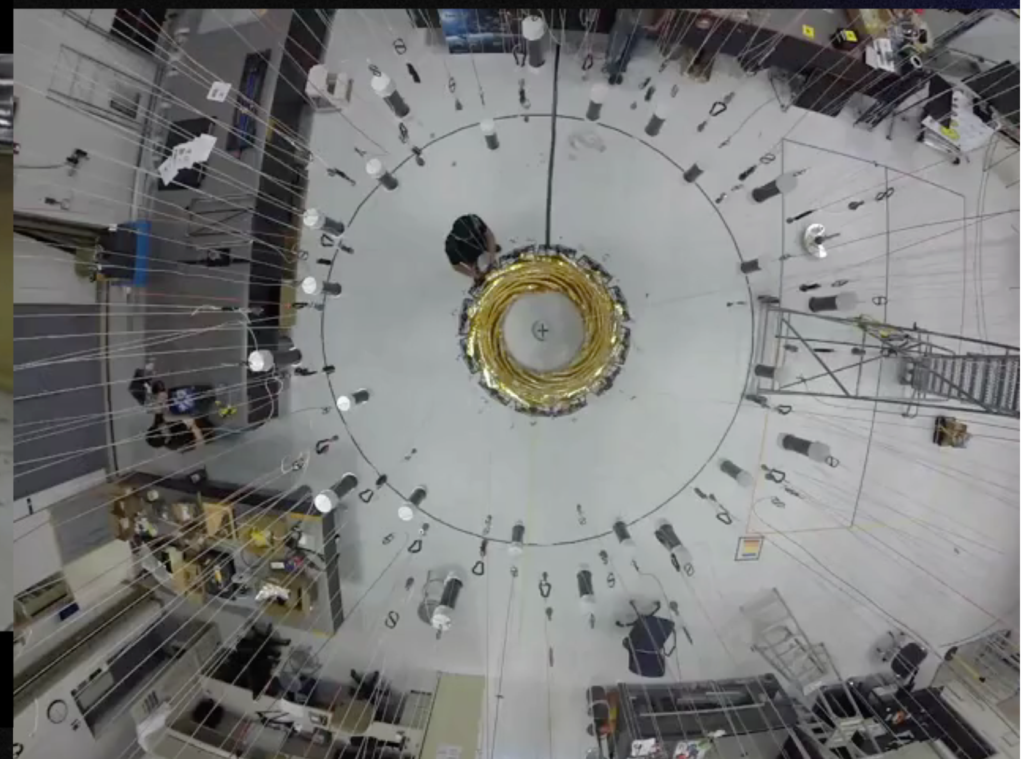



Technology Items
Starshade: 5
Instruments: 8
Telescope: 3
Spacecraft: 1
TRL Items
Number of Technologies
0
5
10
15
2
3
4
≥5
Technology Readiness Level
JWST (1998)
HabEx (2019)
HabEx (2023)


HabEx
Starshade Technology Advances
NASA
Starlight Suppression
Beveled Profile
Un-etched Region
Terminal Edge
To Sun
Glint lobes
TRL 5
summer 2019
Controlling Scattered Sunlight
TRL 5
January 2020
Experiment
Model
arcseconds
Contrast
Contrast Performance and Model Validation
Formation Sensing
TRL 5
Y position [m]
X position [m]
t = 0s
Lateral Formation Sensing
Deployment Accuracy and Shape Stability
TRL 4
Petal Positioning Accuracy and Opaque Structure
TRL 4
Petal Shape And Stability

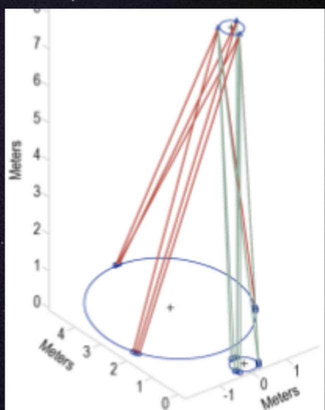
Truss Deployment Test

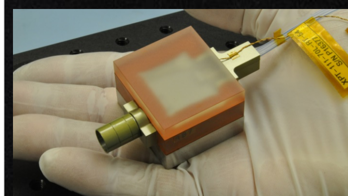
¼ scale for HabEx



HabEx Telescope Technology Advances

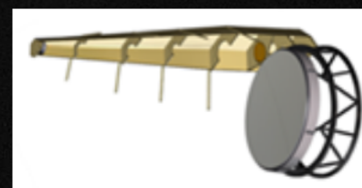
Laser Metrology





TRL 5

Laser Metrology System: Beam launcher, ring laser, and phase meter



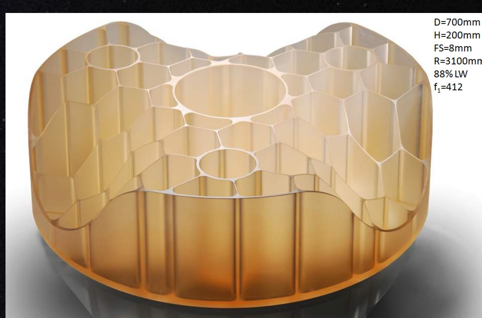
Microthrusters

TRL 5

ESA/LISA Pathfinder

Large Monolith Mirrors

TRL 4

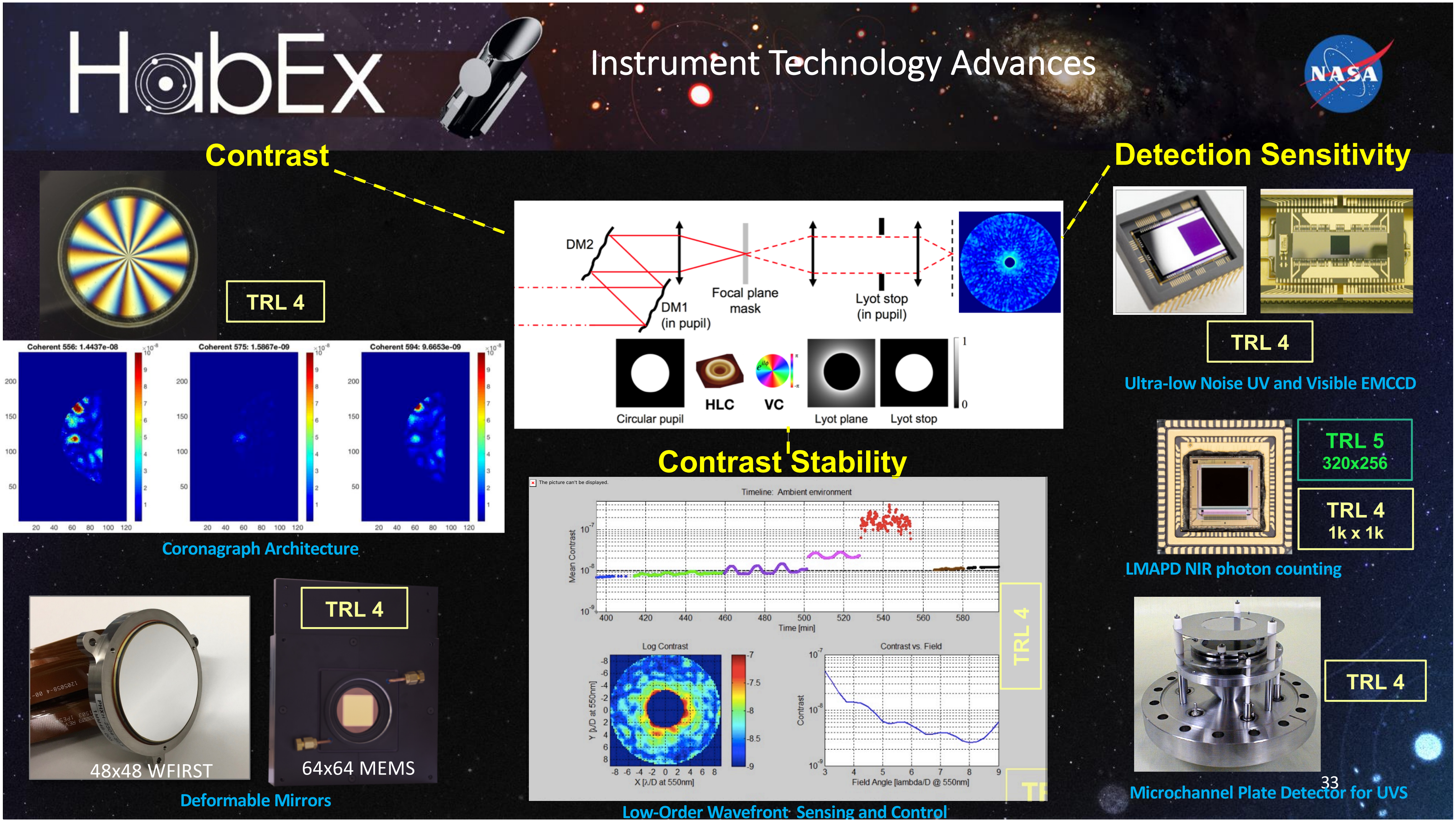


Large Monolith Mirror Fabrication

2.4 m Coating Chamber

TRL 4

Coating Uniformity


HabEx
Instrument Technology Advances
NASA
Contrast
TRL 4
Coherent 556: 1.4437e-08
Coherent 575: 1.5867e-09
Coherent 594: 9.6653e-09
Coronagraph Architecture
DM2
DM1
(in pupil)
Focal plane
mask
Lyot stop
(in pupil)
Circular pupil
HLC
VC
Lyot plane
Lyot stop
Contrast Stability
Timeline: Ambient environment
Mean Contrast
Time [min]
Log Contrast
Y [λ/D at 550nm]
X [λ/D at 550nm]
Contrast vs. Field
Contrast
Field Angle [lambda/D @ 550nm]
TRL 4
Low-Order Wavefront Sensing and Control
TRL 4
48x48 WFIRST
64x64 MEMS
Deformable Mirrors
Detection Sensitivity
TRL 4
Ultra-low Noise UV and Visible EMCCD
TRL 5
320x256
TRL 4
1k x 1k
LMAPD NIR photon counting
TRL 4
Microchannel Plate Detector for UVS
33