The Habitable Exoplanet Imaging Mission (HabEx): Exploring our neighboring planetary systems.

Scott Gaudi (OSU – Community Chair)

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(Figures and slides stolen from Maggie Turnbull, Paul Hertz, Ty Robinson, Chris Stark, Paul Scowen, and probably others…)

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.

16 STDT Members, 3 Ex-officio Members, 5 International Observers, 8 Working Groups.

http://www.jpl.nasa.gov/habex/

HabEx Study Goals.

- Highest-level goals:

"Develop an optimal mission concept for characterizing the nearest planetary systems, and detecting and characterizing a handful of ExoEarths."

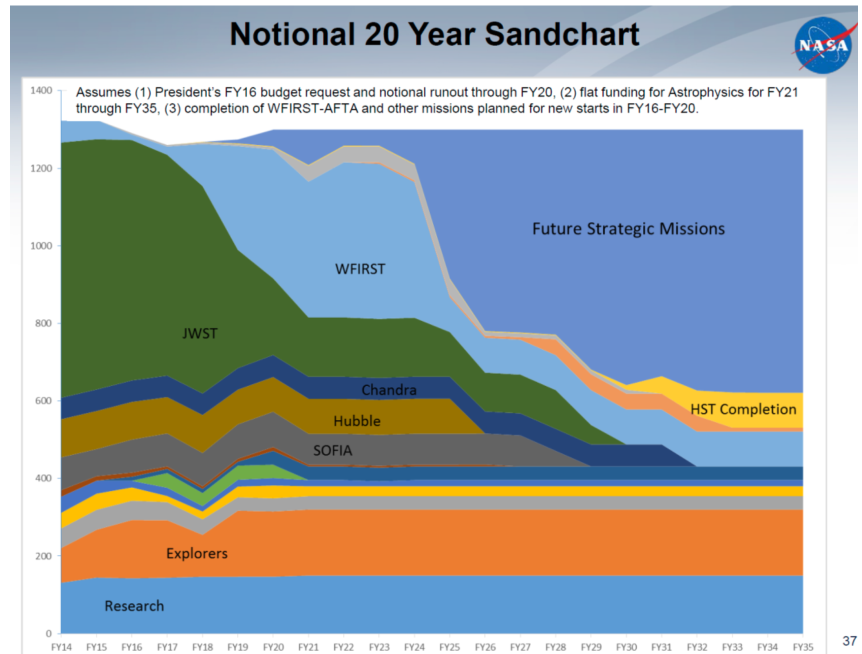
"Given this optimal concept, maximize the general astrophysics science potential without sacrificing the primary exoplanet science goals."

- Optimal means:
  - Maximizing the science yield while maintaining feasibility, i.e., adhering to expected constraints.
- Constraints include:
  - Cost, technology (risk), time to develop mission.
- Thus some primary lower-level goals include:
  - Identify and quantify what science yields are desired and optimal.
  - Identify and quantify the range of potential constraints.

Previous Decadal Recommendations

From Keith Warfield’s study of past decadal missions:

- “All past missions prioritized by the Decadal Survey were thought to be under $3B”
- Only allowed ~3 tooth fairies.

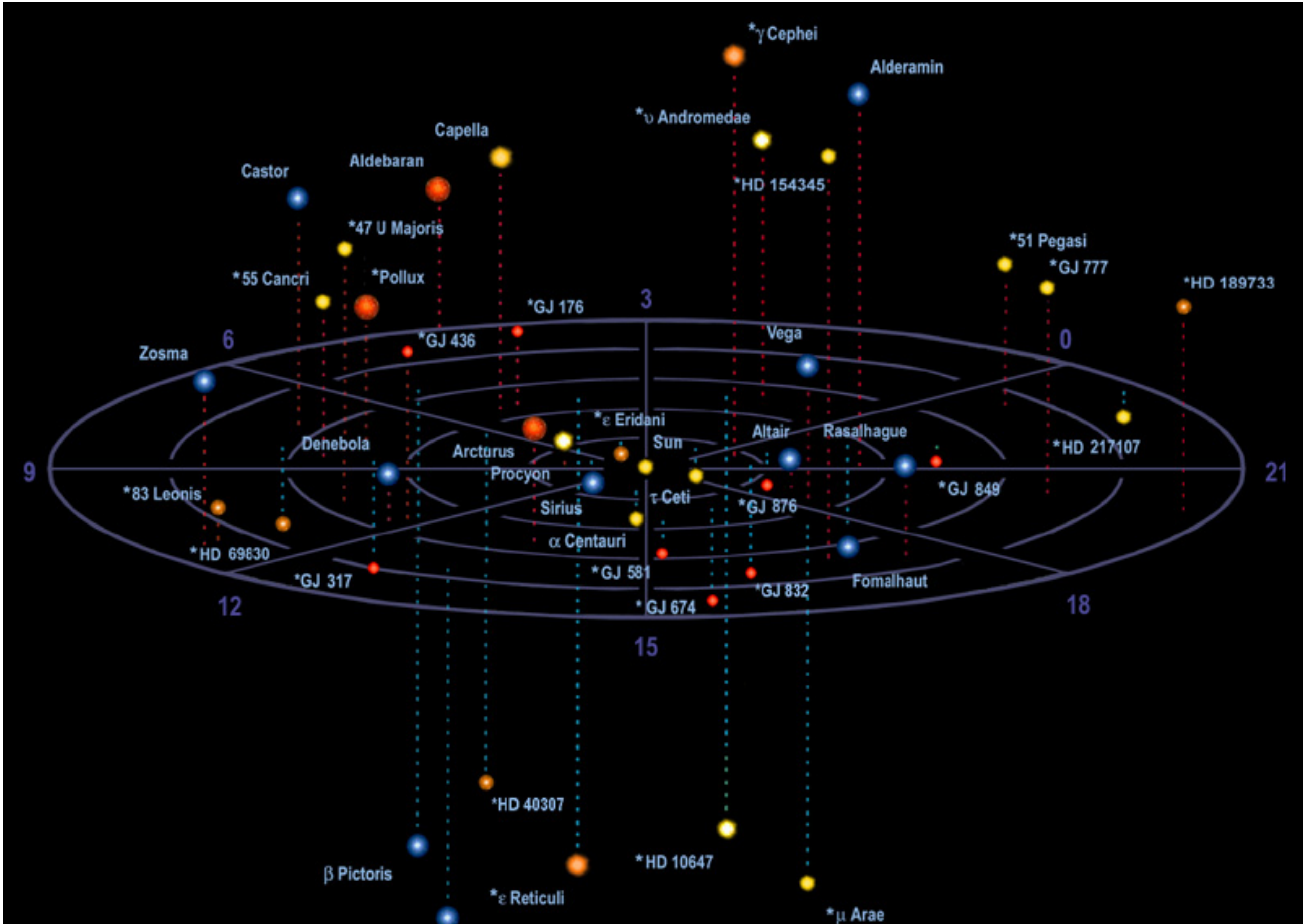


Paul Hertz

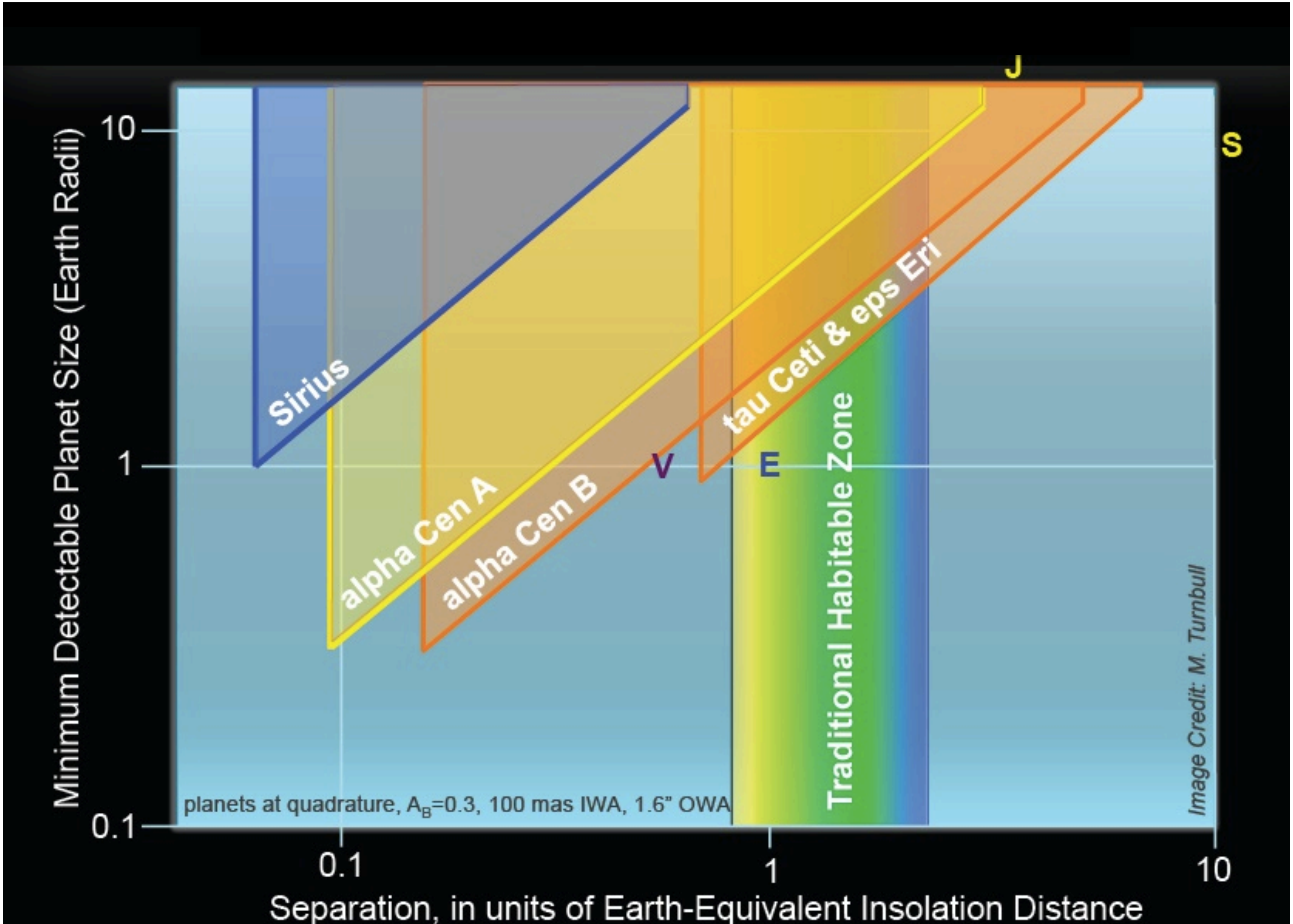
$7.0B by 2035

HabEx Science Goals.

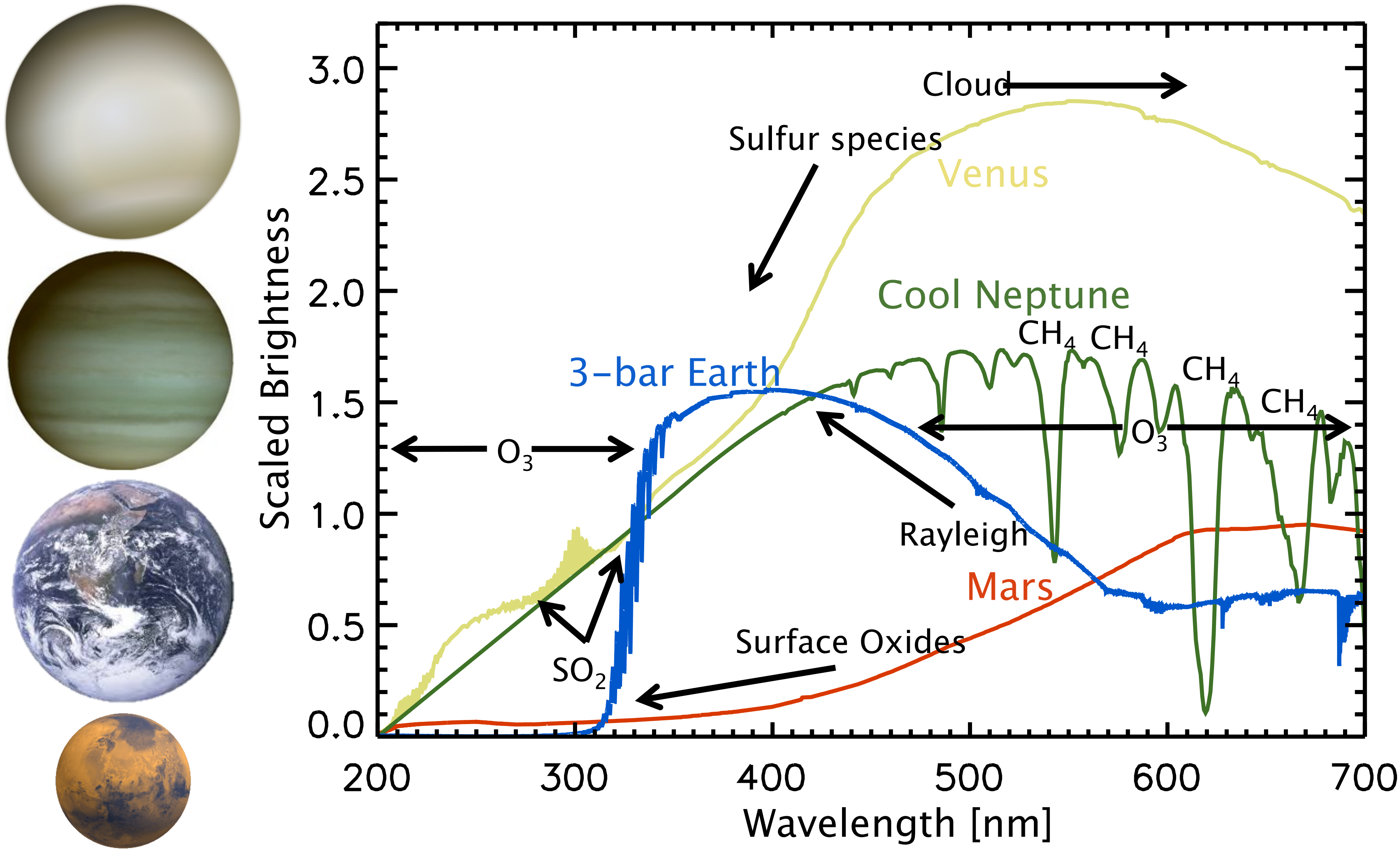
- Exploration-based:
  - How many unique planetary systems can we explore in great detail, determine "their story", including finding and characterizing potential habitable worlds?
  - HabEx will explore N systems as systematically and completely as possible.
  - Leverage abundant pre-existing knowledge about our nearest systems, acquire as much additional information as possible.
  - Take the first step into the unknown!
- Search for Potentially Habitable Worlds
  - Detect and characterize a handful of potentially habitable planets.
  - Search for signs of habitability and biosignatures.
- Optimized for exoplanet imaging, but will still enable unique capabilities to study a broad range of general astrophysics topics.



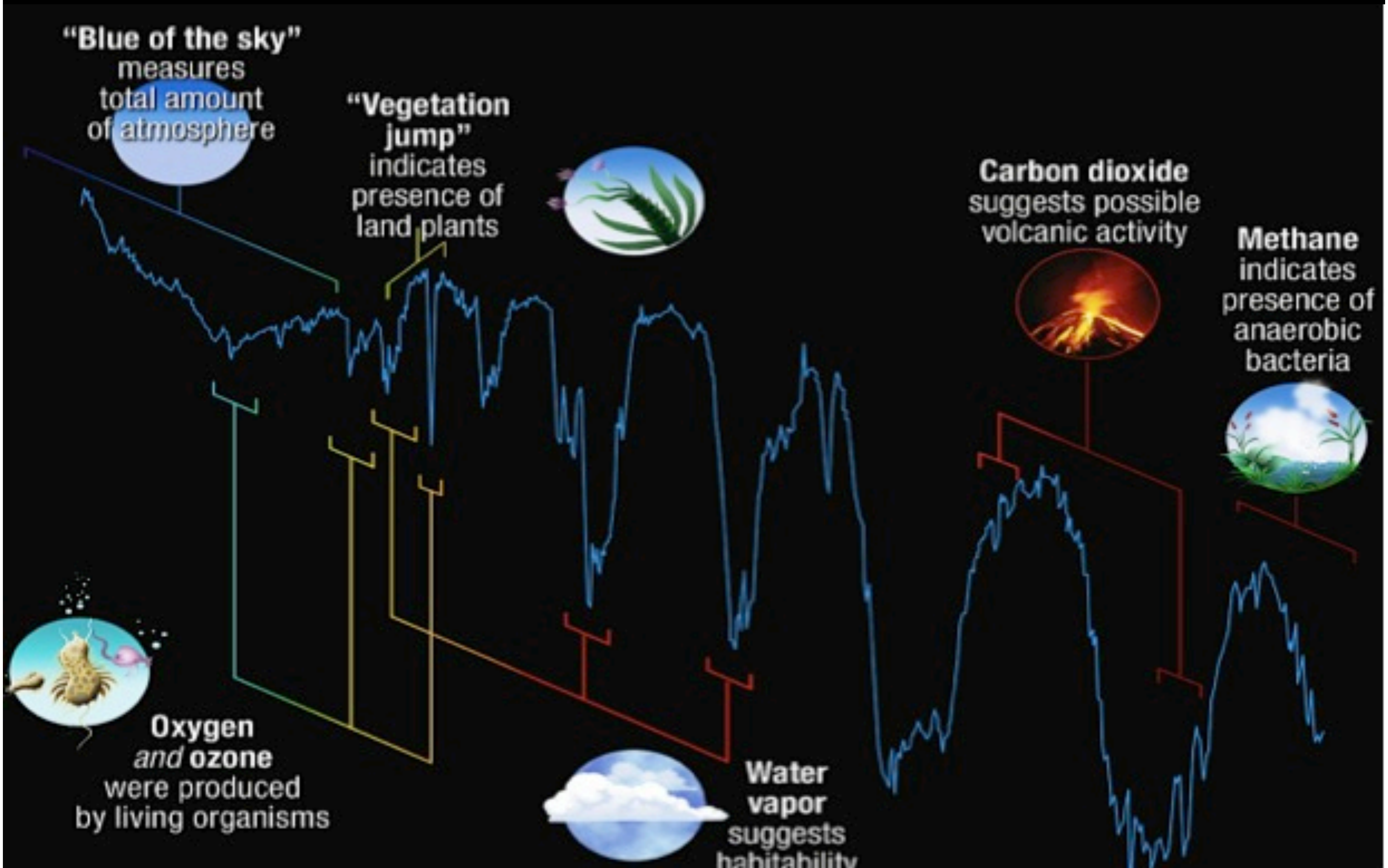
Random Internet Figure



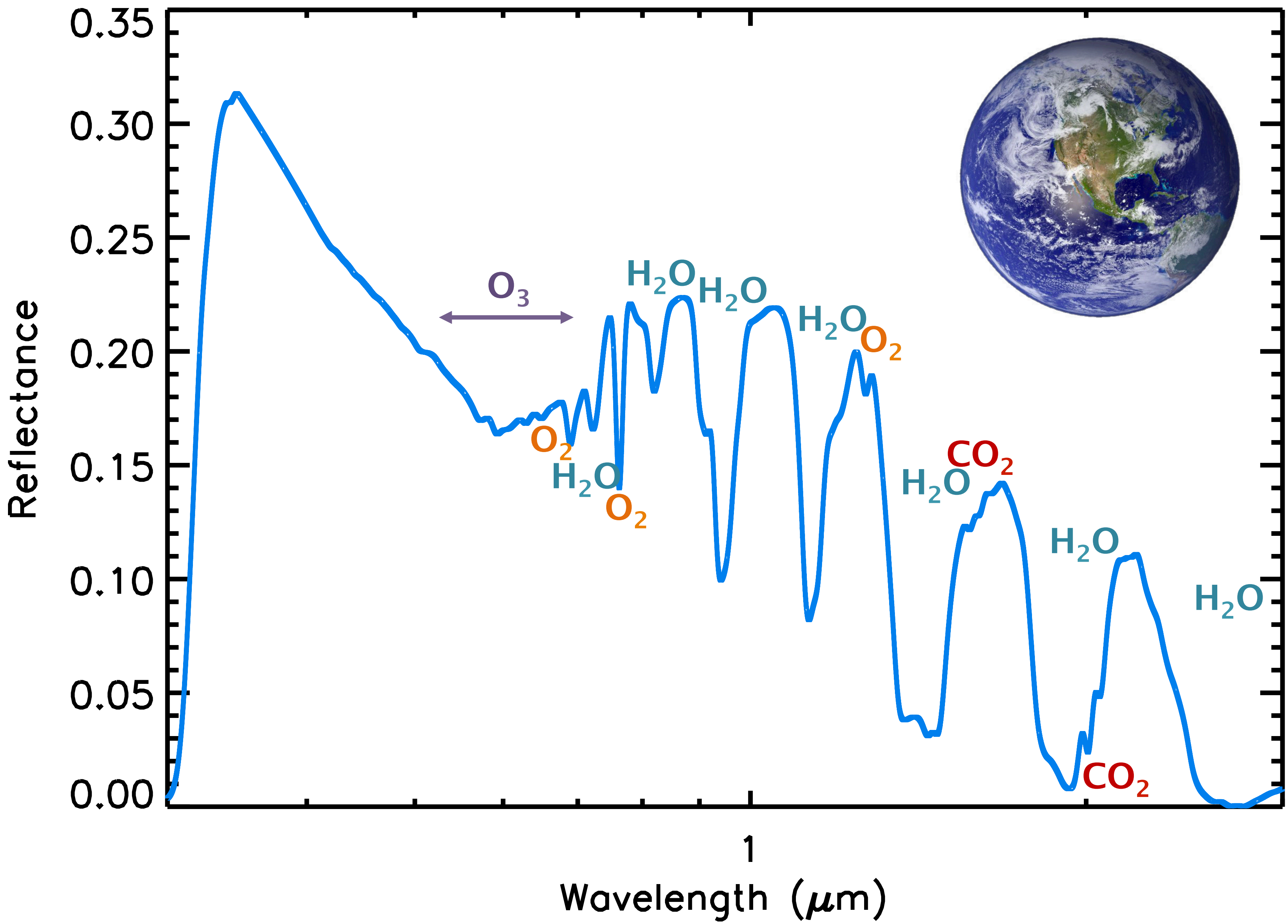
Courtesy of Maggie Turnbull



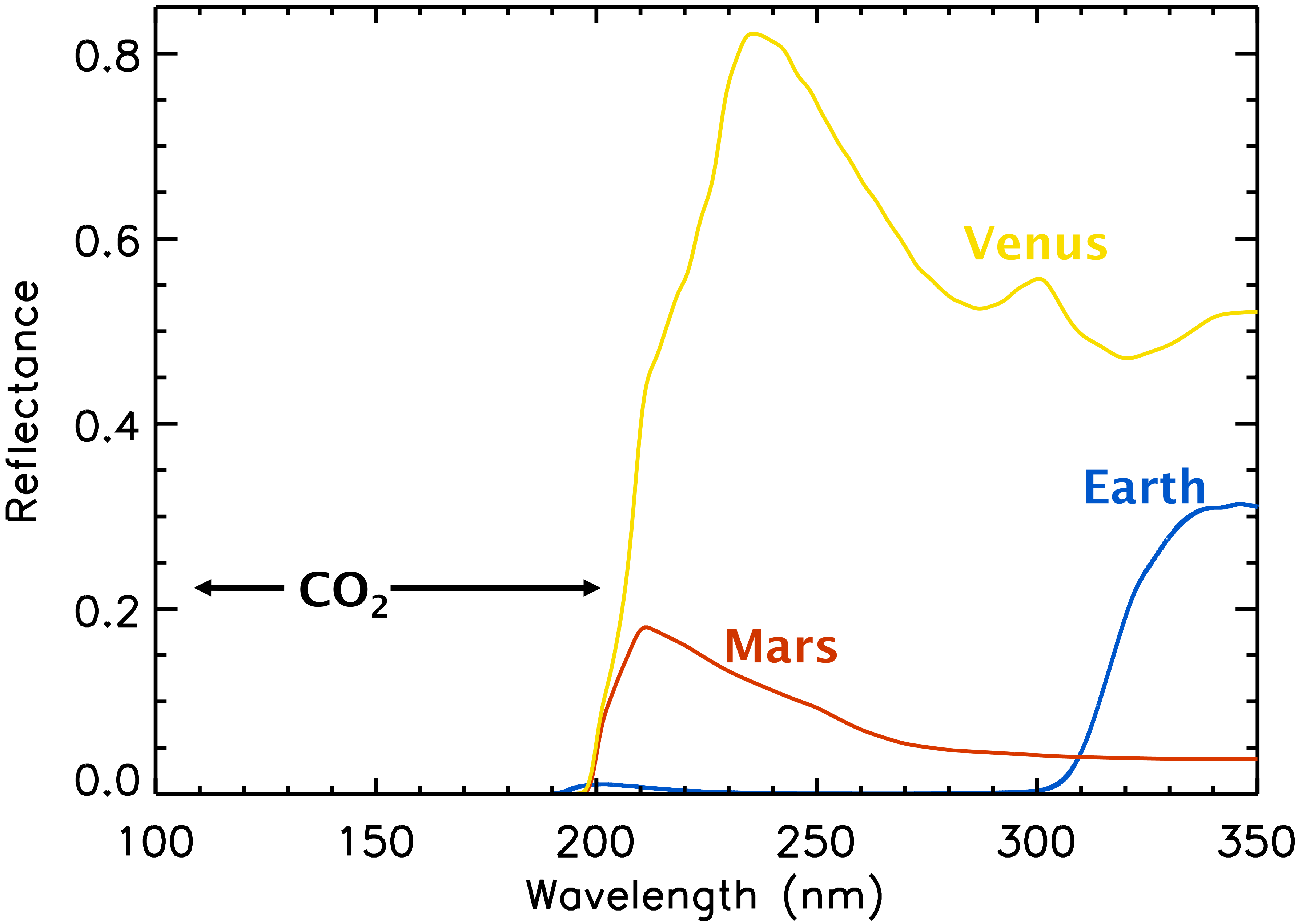
Courtesy of Ty Robinson



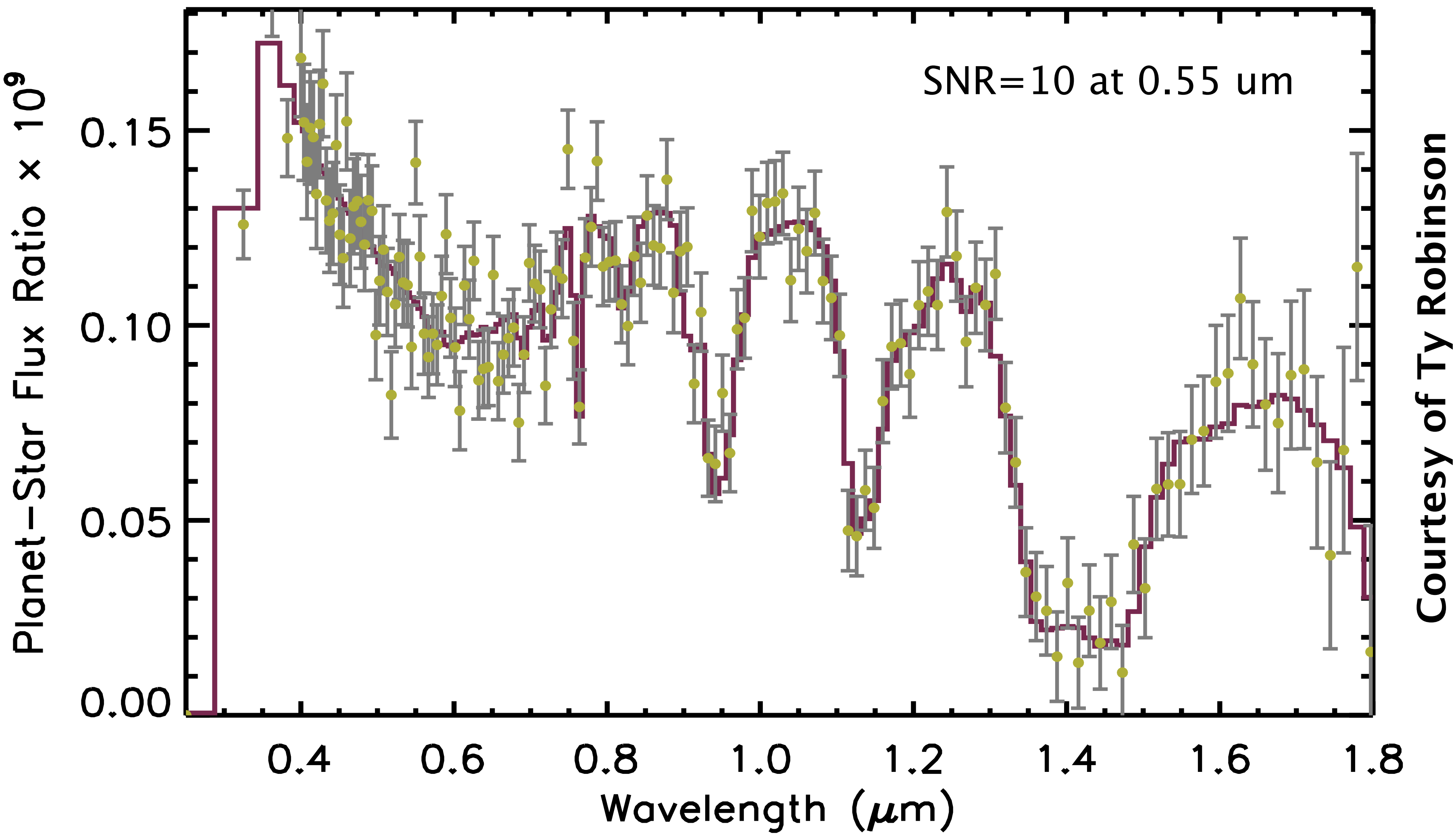
Courtesy of Maggie Turnbull



Courtesy of Ty Robinson



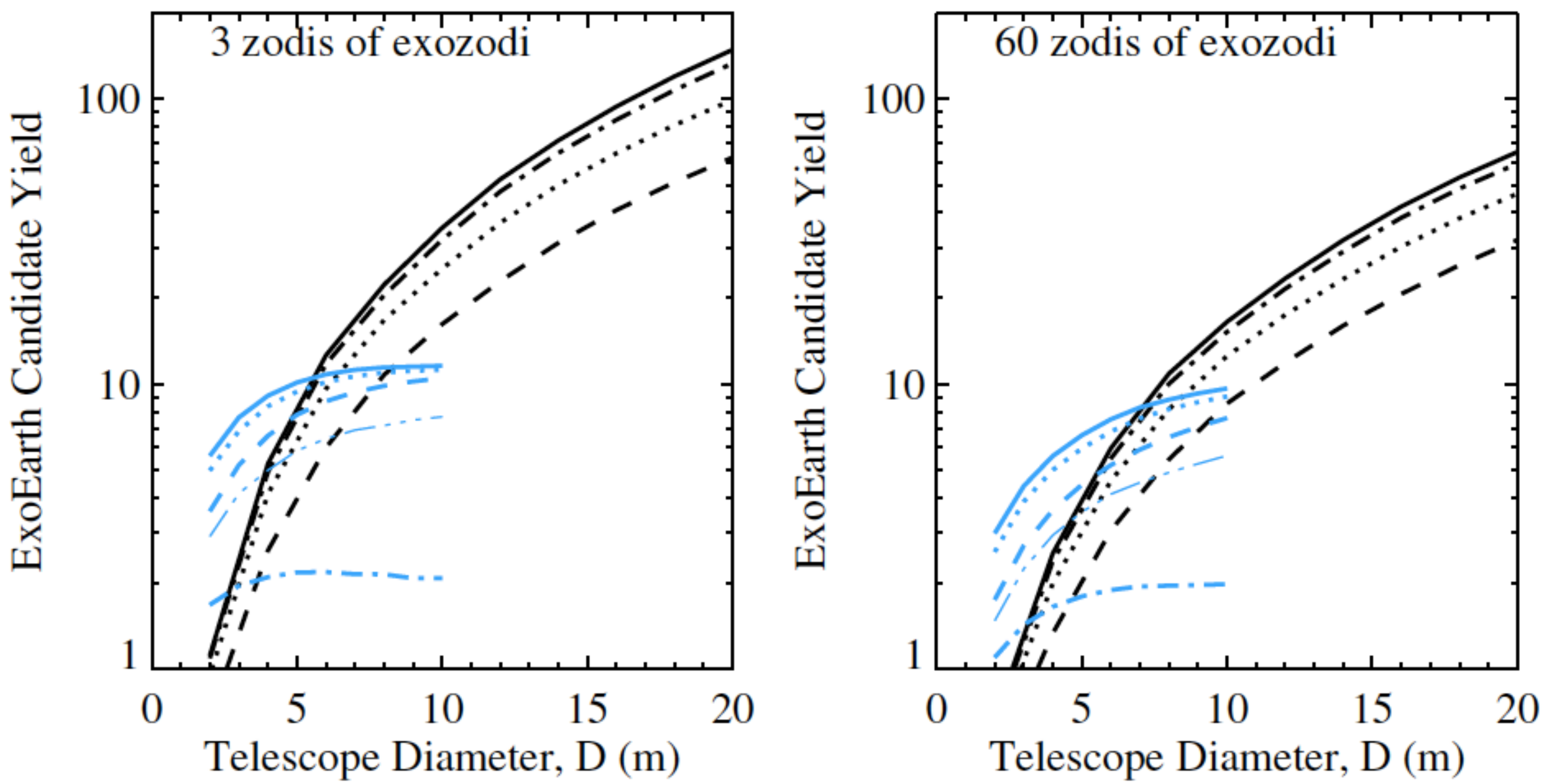
Courtesy of Ty Robinson



SNR=10 at 0.55μ,m
10^{-10} raw contrast
Constant 30% throughput
Integration time *per* bandpass

5m HabEx: 10 hr for a Earthlike planet at 5 pc
12m LUVOIR for a target at 12 pc.
5m HabEx: 30 hr at 7pc
12m LUVOIR: for a target at 17 pc.

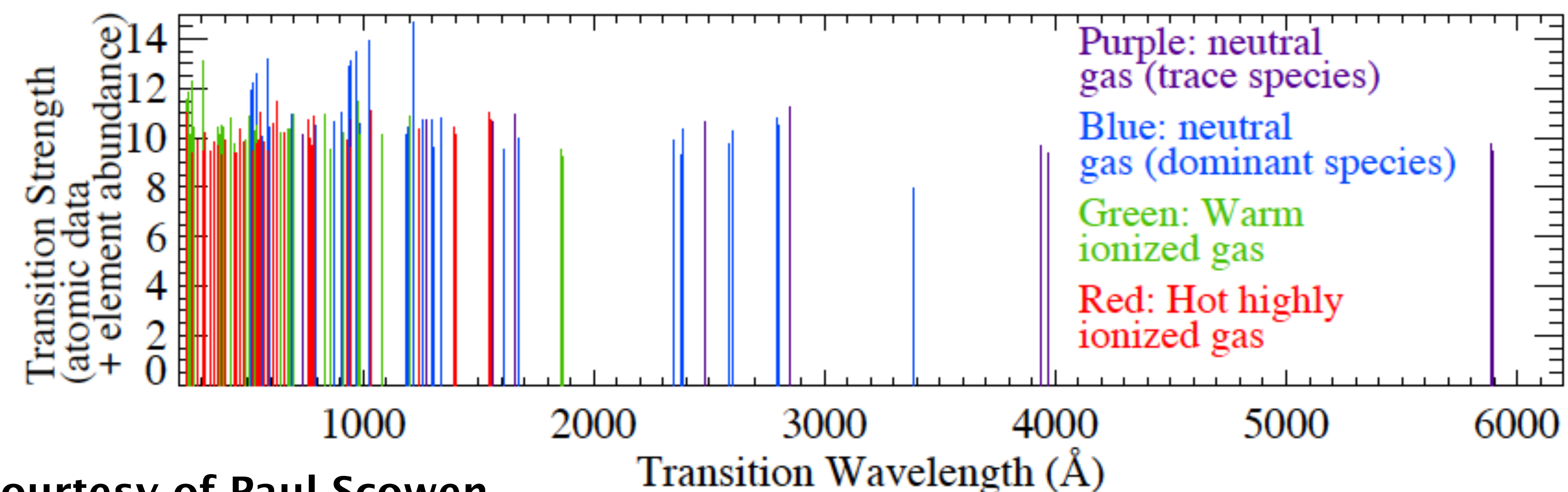
Yields: ExoEarths



From Stark et al. 2016

General Astrophysics

- Consider what will be or has been available:
  - HST
  - JWST
  - Ground-based ELTs
- UV for >2.5m provides a novel capability



Courtesy of Paul Scowen

General Astrophysics Themes.

- Hubble Constant
- Escape Fraction
- Cosmic Baryon Cycle
- Massive Stars & Feedback
- Stellar Archaeology
- Dark Matter

The Three Graces: Paul Scowen, Rachel Somerville, Dan Stern

Capabilities Matrix.

Science driver	observation	wavelength	spatial resolution	spectral resolution	FOV	aperture	effective aperture	exp. time	other
Hubble Constant	image Cepheid variable stars in SN Ia host galaxies	optical-near-IR (!.6 micron)	diffraction limited	N/A	3'	>=4m		20 ks/galaxy	
Escape Fraction	UV imaging of star forming galaxies	UV, preferably down to 912A	diffraction limited preferred	R ~ 1000-3000	few arcmin	>=4m		few ks/galaxy	
Cosmic Baryon Cycle	spectroscopy of absorption lines in background QSO or galaxies; UV imaging	UV, imaging down to 115nm sufficient, spectroscopy down to 92nm preferred	10mas	R=1,000-40,000 (grating turret)	10'	>6m	>3x10^4 cm^2 in the UV - implies 10% (throughput + DQE) in the UV for a 6m telescope	300-2000s	MOS capabilities beneficial over a field as large as 20x20'
Massive Stars/Feedback	UV imaging and spectroscopy of massive stars in the Galaxy and nearby galaxies	UV, 120-160nm spectroscopy; 110-1000nm imaging	diffraction limited; 0.04" at 300nm	R=10,000	10-30'	>4m			large number of broad, medium and narrow filter bands; spectroscopic angular resolution 5 mas
Stellar Archaeology	resolved photometry of individual stars in nearby galaxies	optical (500-1000nm)	diffraction limited	N/A	10'	4-8m		100 hours/galaxy	this science can be done with smaller aperture telescopes, but a significant jump in capability occurs at around 8m
Dark Matter	integrated photometry + radial velocities and proper motions of stars in Local Group dwarf galaxies	optical (500-1000nm)	diffraction limited	?	10'	>=8m			astrometric accuracy of <40 m arcsec/yr

-> UV Spectrometer and UVOIR imager.

The Three Graces: Paul Scowen, Rachel Somerville, Dan Stern

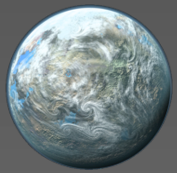
HabEx Design Team

Name	Role
Keith Warfield	Study Lead
Bertrand Mennesson	Study Center Scientist
Gary Kuan	Design Lead
Stefan Martin	Optics Lead
Joel Nissen	Systems & Structures; Stability
Rhonda Morgan	DRM & science yield
Stuart Shaklan	starshade & coronagraph expert
Doug Lisman	Starshade expert
David Webb	Starshade expert
Eugene Serabyn	coronagraph expert
John Krist	coronagraph expert
Alina Kiessling	associate center scientist
Bala Balasubramanian	coatings expert
Phil Stahl	MSFC – Telescope
Steve Warwick	Northrup Grumman – Starshade expert
Shouleh Nikzad	Detectors Lead
John Hennessy	detectors expert
Fang Shi	LOWFSC expert consultant

Architectures.

Property (Baseline)	Architecture #1	Architecture #2
Aperture	4m	6.5m
Primary Mirror	Monolithic, Al, f/2.5	Segmented (TBD)
Secondary Mirror	Off-axis	Off-axis (TBD)
Stabilization	Laser Metrology (M2)	TBD
Coatings	M1, M2, M3: Al	TBD
Coronagraph Instrument	HLC/VV6 Al (UV ?), Ag (OIR)	TBD
Wavelength (high contrast)	250nm–1.8μm	TBD
Wavelength (GA)	120nm–1.8μm (stretch 90nm–2μm)	TBD
Starshade	Yes, 75m (TBR) UVOIR	TBD
General Astrophysics Instrument #1	Workhorse UVOIR Camera (10 arcmin^2 FOV, diff. limited at 400nm)	TBD
General Astrophysics Instrument #2	High Res; 60k UV Spectrograph, Microshutter arrays	TBD

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

Enhancing and Enabling Technologies for HabEx and LUVOIR

Technology	HabEx (4m)	HabEx (6.5m)	LUVOIR (9m/16m)
High-contrast Coronagraph on Segmented and/or Obscured Apertures	NR=Not Relevant	Enabling	Enabling
Ultra-low-noise UV Detectors	Enhancing	Enhancing	Enabling
Ultra-low-noise Visible Detectors	Enabling	Enabling	Enabling
Ultra-low-noise Near-IR Detectors	Enabling	Enabling	Enabling
UV-to-NIR Coatings	Enhancing	Enhancing	Enhancing
Large Optics Fabrication	Enabling	NR	NR
Starshade Technologies	Enabling	Enhancing	Enhancing
Large Format Deformable Mirrors	Enhancing	Enhancing	Enhancing
Thin Solar Films	Enhancing	Enhancing	Enhancing
Sub-nanometer Wavefront Stability	Enabling	Enabling	Enabling

Launch Vehicles Likely Required for HabEx and LUVOIR Designs

Mission Design	Falcon Heavy 5 m*	SLS 8.4 m
HabEx 4m	No?	Yes
HabEx 6.5m	Yes	No?
LUVOIR 9m	Yes	No
LUVOIR 16m	No	Yes

*Or similarly capable heavy-lift vehicle with an industry-standard 5-meter fairing.

Progress on 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 and/or obscured telescope

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

Starshade technology development

Successful lab demonstrations of petal manufacturing accuracy and deployment, small scale field testing and model validation across various institutions.

https://exoplanets.nasa.gov/exep/technology/TDEM-awards/

Summary

Primary HabEx Science Goals:

- Develop an optimal mission concept for characterizing the nearest planetary systems, and detecting and characterizing a handful of ExoEarths.
- Enable a broad range of solar system and general astrophysics.

Our overall Approach:

- Maximizing the science yield while maintaining feasibility, i.e., adhering to expected constraints: cost, technology, risk, time to develop mission.

Considering Two Architectures:

- 4m monolith.
- 6.5m segmented.
- This is a complex region of trade space.

For the 4m Architecture:

- Three enabling technologies that need to be matured: starshade, low-noise IR detectors, sub-nm wavefront stability.