Overview of the 4m baseline architecture concept of the habitable exoplanet imaging mission (HabEx) study

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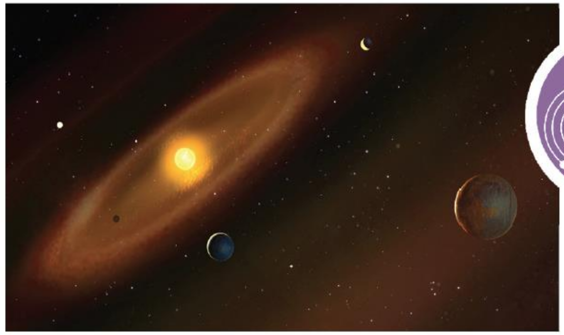
Purpose of HabEx

HabEx

EXPLORING PLANETARY SYSTEMS *AROUND NEARBY SUNLIKE STARS AND ENABLING OBSERVATORY SCIENCE FROM THE UV THROUGH* **NEAR-IR**

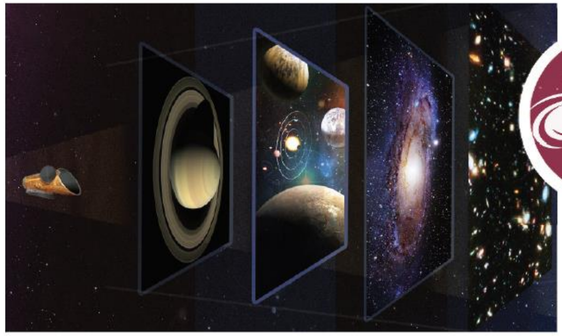
GOAL 1

To seek out nearby worlds and explore their habitability, *HabEx* will search for habitable zone Earth-like planets around sunlike stars using direct imaging and will spectrally characterize promising candidates for signs of habitability and life.



GOAL 2

To map out nearby planetary systems and understand the diversity of the worlds they contain, *HabEx* will take the first "family portraits" of nearby planetary systems, detecting and characterizing both inner and outer planets, as well as searching for dust and debris disks.



GOAL 3

To carry out observations that open up new windows on the universe from the UV through near-IR, *HabEx* will have a community driven, competed Guest Observer program to undertake revolutionary science with a large-aperture, ultra-stable UV through near-IR space telescope.

from HabEx interim report
URS273294

HabEx Presentations & Posters

Title	Presenter	Date • Time
HabEx uUltraviolet spectrograph design and DRM	Paul A. Scowen	10 June 2018 • 10:00 - 10:20 AM
Solid state detectors for the Habitable Exoplanet imaging mission (HabEx) and the large UV/optical/infrared (LUVOIR) surveyor mission concepts	Shouleh Nikzad	10 June 2018 • 11:10 - 11:30 AM
The habitable exoplanet imaging mission (HabEx)	Bertrand Mennesson	11 June 2018 • 1:20 - 1:40 PM
Overview of the 4m baseline architecture concept of the habitable exoplanet imaging mission (HabEx) study	Gary M. Kuan	11 June 2018 • 1:40 - 2:00 PM
The habitable exoplanet imaging mission (HabEx): science goals and projected capabilities	Bernard Gaudi	11 June 2018 • 10:30 - 10:55 AM
The HabEx workhorse camera	Paul A. Scowen	11 June 2018 • 2:00 - 2:20 PM
Technology maturity for the habitable-zone exoplanet imaging mission (HabEx) concept	Rhonda M. Morgan	11 June 2018 • 2:20 - 2:40 PM
HabEx Space telescope exoplanet instruments	Stefan R. Martin	11 June 2018 • 2:40 - 3:00 PM
HabEx: high precision pointing architecture using micro-thrusters and fine steering mirror	Oscar S. Alvarez-Salazar	11 June 2018 • 3:30 - 3:50 PM
Numerically optimized coronagraph designs for the habitable exoplanet imaging mission (HabEx)	A J Eldorado Riggs	11 June 2018 • 3:50 - 4:10 PM
Overview and performance prediction of the baseline 4-meter telescope concept design for the habitable-zone exoplanet direct imaging mission	H. Philip Stahl	11 June 2018 • 4:10 - 4:30 PM
HabEx Lite: a starshade-only habitable exoplanet imager alternative	David Redding	11 June 2018 • 4:30 - 4:50 PM
Terrestrial exoplanet coronagraph image quality: study of polarization aberrations in Habex and LUVOIR update	James Breckinridge, Russell A. Chipman	13 June 2018 • 10:30 - 10:50 AM

Poster Title	Presenter	Date • Time
HabEx polarization ray trace and aberration analysis	**Jeffrey Davis**	**11 June 2018 • 5:30 - 7:00 PM**
HabEx space telescope optical system overview	**Stefan R. Martin**	**11 June 2018 • 5:30 - 7:00 PM**
HabEx telescope WFE stability specification derived from coronagraph starlight leakage	**Bijan Nemati**	**11 June 2018 • 5:30 - 7:00 PM**
Mirror design study for a segmented HabEx system	**James T. Mooney**	**11 June 2018 • 5:30 - 7:00 PM**
Overview and performance prediction fo the alternative 6.5-meter telescope concept design for the habitable-zone exoplanet direct imaging mission	**H. Philip Stahl**	**11 June 2018 • 5:30 - 7:00 PM**

HabEx Architecture A Concept

- The HabEx STDT chose these parameters for Architecture A:
  - Telescope with a 4m aperture
  - 72-m diameter, formation flying external Starshade occulter
  - Four instruments:
    - Coronagraph Instrument for Exoplanet Imaging
    - Starshade Instrument for Exoplanet Imaging
    - UV– Near-IR Imaging Multi-object Slit Spectrograph for General Observatory Science
    - High Resolution UV Spectrograph for General Observatory Science

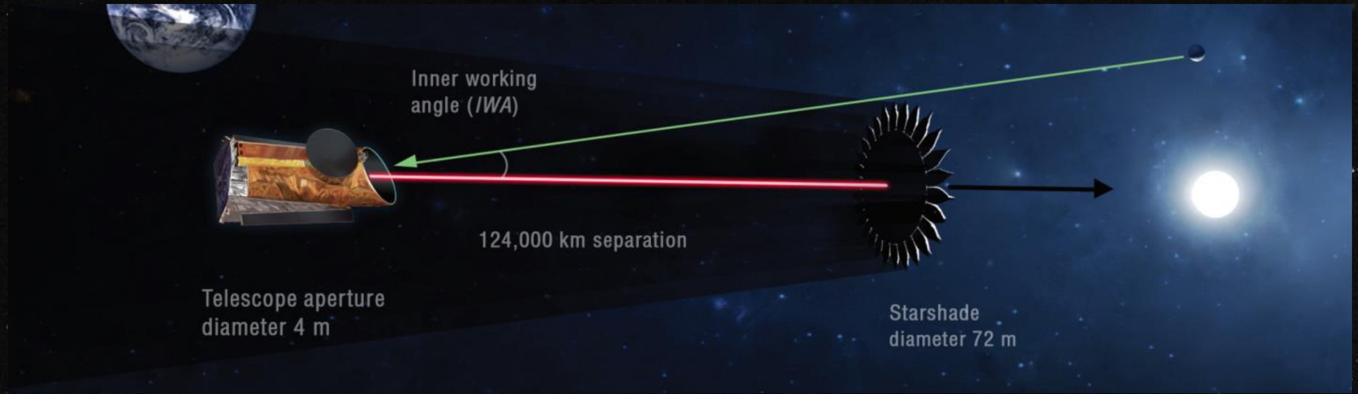


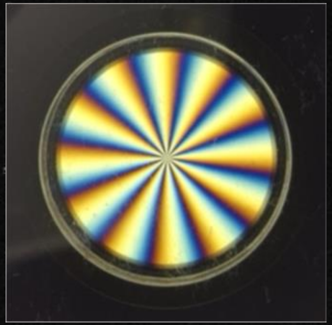
Image from HabEx interim report URS273294

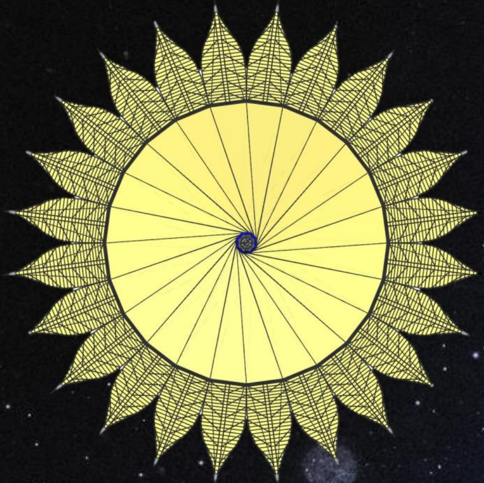
Design Philosophy

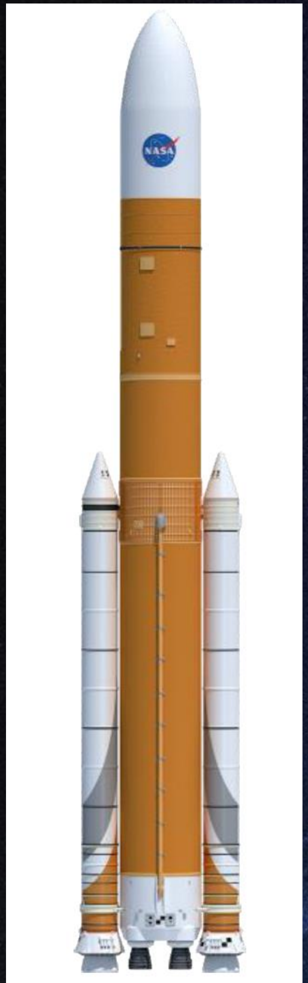
- The HabEx architecture must be:
  - Executable:
    - Within technical capability
    - At reasonable cost
  - Minimize technical risk:
    - Likely Class A Mission
    - Use existing technologies, or
    - Minimize need for developing technologies
- Keep it simple
  - Use mass and volume to reduce complexity
- Avoid problems from the start
  - Don’t fight symptoms

Key Features:

- These features are “game changers” that enable this observatory concept:
  - SLS Block 1B Launch Vehicle with 8.4m x 27.4m Fairing
    - *Characteristic*: Increased mass and volume launch capability over existing LVs
    - *Benefit*: Allows the use of mass and volume to minimize complexity and therefore reduce risk and cost
  - Microthrusters
    - *Characteristic* : Extremely low mechanical disturbance noise
    - *Benefit* : Significantly improves pointing stability, simplifies structural dynamics design, improves telescope wavefront stability
  - Vector Vortex Coronagraph (VVC)
    - *Characteristic* : much less sensitive to low order wavefront aberrations with high throughput
    - *Benefit* : Reduces the need for an ultra stable telescope.
  - Starshade occulter
    - *Characteristic* : allows for a small inner working angle (IWA) over a broad spectral band
    - *Benefit* : Allows a 4m telescope to have an IWA equivalent to an 8m telescope @ λ=1μm







SLS Block 1B Cargo

HabEx Why the SLS?

- Keep it simple!
- Use mass and volume to minimize complexity:
  - Co-launch in a single fairing
  - Minimal deployments
    - Fewer mechanisms and control electronics.
  - Use volume for a 4m unobscured, off-axis telescope with Instruments on the side (not under the PM).
  - Use mass for a monolithic Zerodur® primary mirror.
    - CBE: 1295kg, 80Hz first mode
    - very high thermal inertia for stability

Less complexity = less risk & less cost

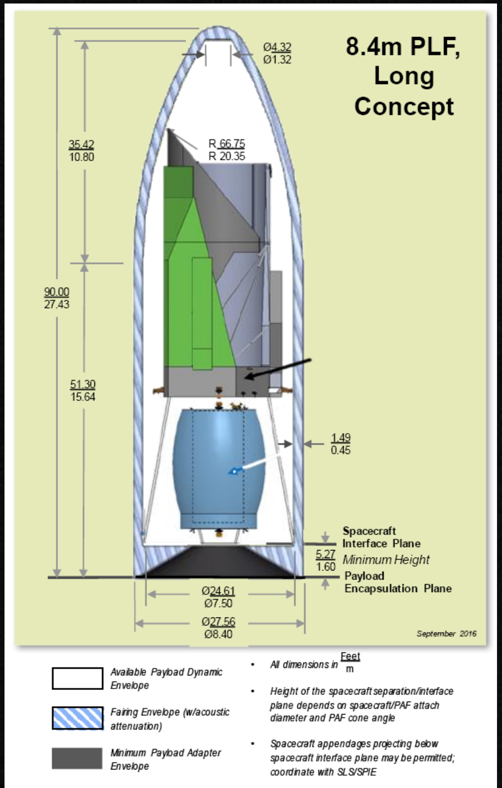
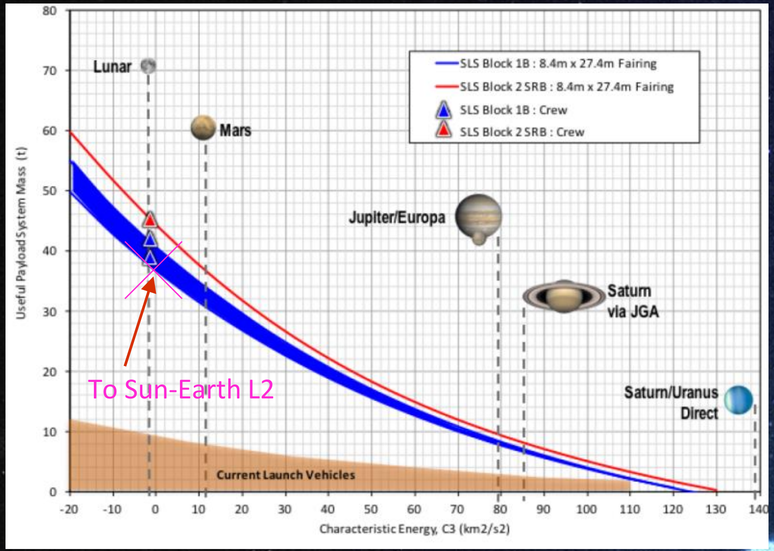


Figure 6-9. Composite 8.4 m PLF, Long Concept

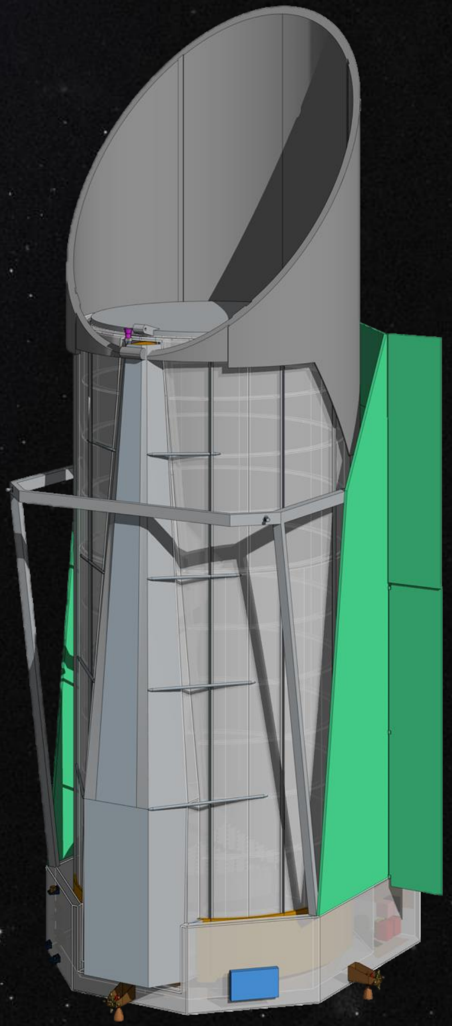
from HabEx interim report URS273294

Key Specifications of Block 1B Cargo with 8.4m PLF, Long Concept:

- 7.5m inner diameter fairing
- 25.83m total useable inner height
- ~36,000kg (minimum) to Sun-Earth L2



Telescope Flight System (Baseline)



- 4-meter diameter aperture
- Off-axis, Three-mirror anastigmat telescope (unobscured)
- Four Instruments:
  - Coronagraph Imager/Spectrograph (CG)
  - Starshade Imager/Spectrograph (SS)
  - UV Spectrograph (UVS)
  - Workhorse Camera Imager/Spectrograph (HWC)
- Fine Guidance Sensor (FGS)
- ACS Thrusters
- Microthrusters
- Solar Array/Sunshield
- Phased Array Antenna
  - Ka-band data downlink
  - S-band cross-communications with Starshade

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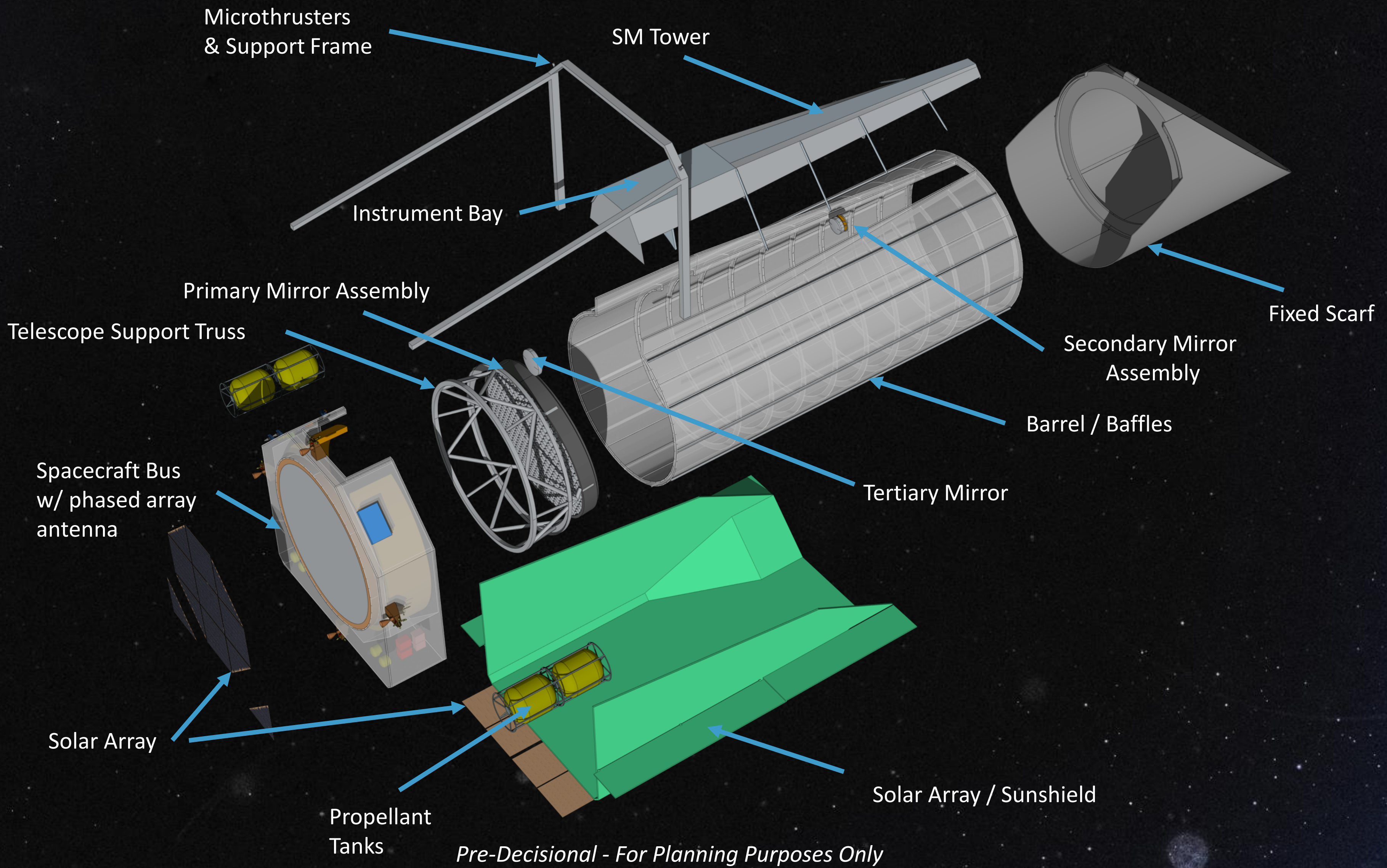
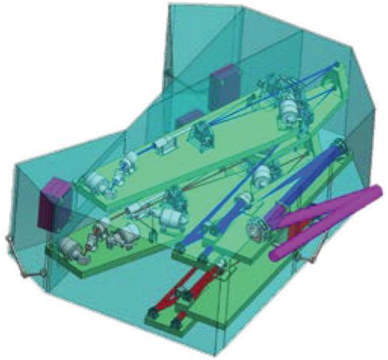
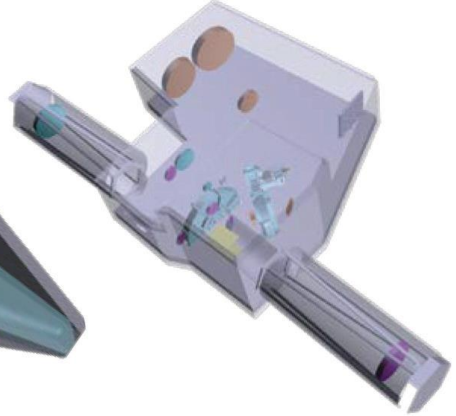
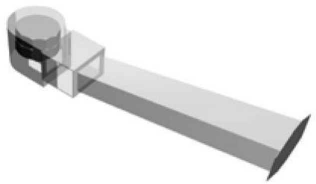
Telescope Flight System: Exploded View (Baseline)



Pre-Decisional - For Planning Purposes Only

Instruments (Baseline)



	Coronagraph	Starshade	Workhorse Camera	UV Spectrograph
Purpose	Exoplanet imaging and characterization	Exoplanet imaging and characterization	Multipurpose, wide-field imaging camera and spectrograph for general astrophysics	High-resolution, UV spectroscopy for general astrophysics
Instrument Type	Vortex charge 6 coronagraph with: - Raw contrast: 1×10^{-10} at IWA - Δmag limit = 26.0 - 20% instantaneous bandwidth Imager and spectrograph	72 m dia starshade occulter with: - 124,000 km separation - Raw contrast: 1×10^{-10} at IWA - Δmag limit = 26.0 - 107% instantaneous bandwidth Imager and spectrograph	Imager and spectrograph	High-resolution spectrograph
Channels	Vis, Blue: 0.45–0.67 µm Imager + IFS with R = 140 Vis, Red: 0.67–1.0 µm Imager + IFS with R = 140 NIR: 0.95–1.8 µm, Imager + slit spectrograph with R = 40	UV: 0.2–0.45 µm Imager + grism with R = 7 Vis: 0.45–1.0 µm Imager + IFS with R = 140 NIR: 0.95–1.8 µm Imager + IFS with R = 40	UV: 0.15–0.4 µm Imager + grism with R = 2,000 Vis: 0.4–0.95 µm Imager + grism with R = 2,000 NIR: 0.95–1.8 µm Imager + grism with R = 2,000	UV: 0.115–0.3 µm (20 bands), R = 60,000; 25,000; 12,000; 6,000; 3,000; 1,000; 500
Field of View	FOV: 1.5×1.5 $arcsec^2$ @ 0.5 µm IWA: 2.4 λ/D = 62 mas @ 0.5 µm OWA: 0.74 arcsec @ 0.5 µm	FOV: 11.9×11.9 $arcsec^2$ (Vis) IWA: 60 mas (0.3–1.0 µm) OWA: 6 arcsec (Vis)	3×3 $arcmin^2$	3×3 $arcmin^2$
Features	64×64 deformable mirrors (2) Low-order wavefront sensing & control	Formation flying sensing & control	Microshutter array for multi-object spectroscopy 2×2 array, 171×365 apertures	Microshutter array for multi-object spectroscopy 2×2 array, 171×365 apertures

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Why Vector Vortex Coronagraph?

- Purpose:
  - to maximize planet light throughput and contrast and minimize requirements on the telescope
- Benefit:
  - Much less sensitive to low order telescope WFE
- Rationale:
  - Very good throughput and contrast:
    - on par (theoretically) with Hybrid-Lyot Coronagraphs (HLC) or other coronagraph types
  - Forgiving:
    - rejects low order Zernike WFE terms in its null space.
    - ~500pm rms instead of ~10pm rms stability
  - Demonstrated in the lab (though not to the level required for space)
  - Demonstrated on ground-based telescopes (Subaru, Palomar, VLT, Keck)
  - Further development on-going in HCIT at JPL

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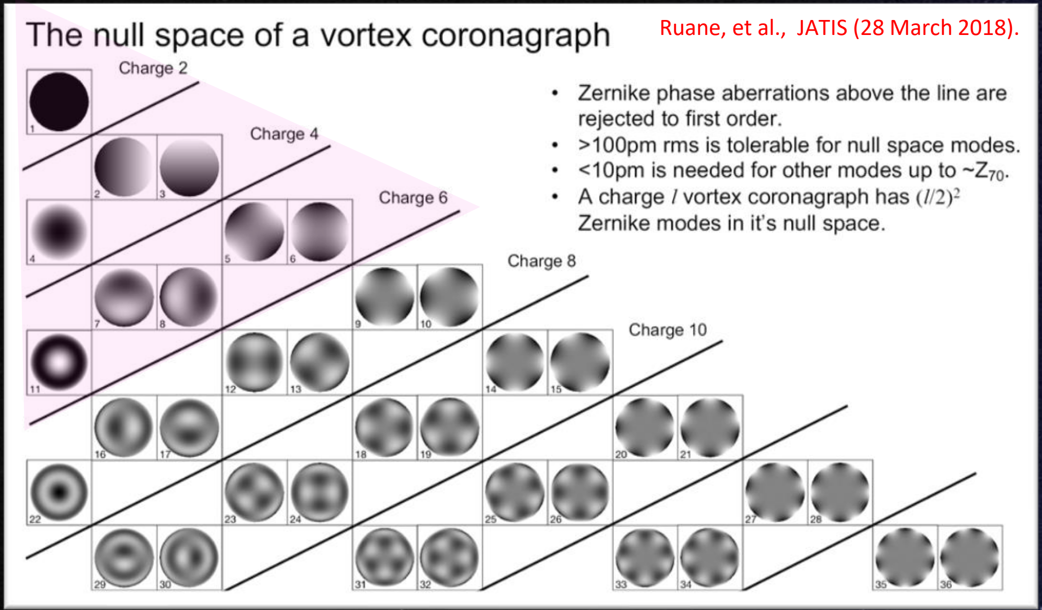
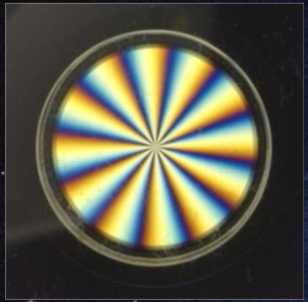


VVC6 IWA = 2.4λ/D = 62mas @ 500nm

from HabEx interim report URS273294



A charge 6 liquid crystal polymer vector vortex mask as seen through crossed polarizers.

Key Telescope Requirements

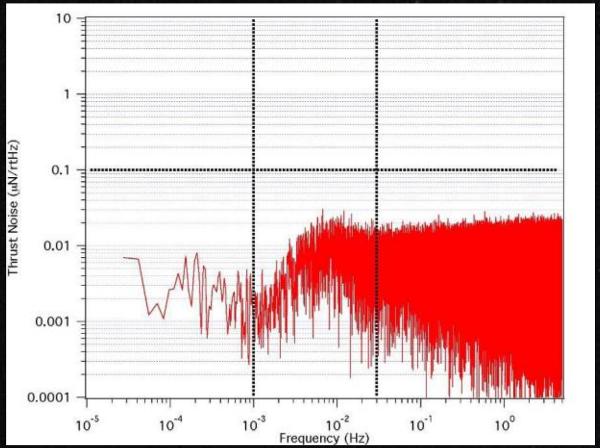
- The coronagraph instrument drives telescope requirements:

Coronagraph Requirement		Telescope Requirement	
Inner working angle (IWA) @ 500nm	62mas	Aperture diameter	4m
Contrast	$\leq 1 \times 10^{-10}$	Primary mirror f/#	f/2.5
		Diffraction limit wavelength	400nm
		Quasi-static WFE	30nm rms
Maximize throughput		Primary mirror type	monolith
		Unobscured pupil	off-axis TMA
Contrast stability	$\leq 2 \times 10^{-11}$	Pointing stability	≤2mas/axis
		WFE stability	<1nm rms / 50hrs

HabEx Why Microthrusters?

- Purpose:
  - To maintain pointing during observations
  - To offset solar pressure induced torque on the telescope.
- Background:
  - Solar pressure is 0.5µN/m^2 at Sun-Earth L2.
  - HabEx has ~100m^2 projected area,
  - Solar pressure is ~50µN, with ~3m offset of the center of pressure from the center of mass.
- Rationale:
  - Two flight proven microthrusters to choose from: cold gas and colloidal electrospray
    - Colloidal electrospray thrusters (NASA ST7) have flown on ESA LISA Pathfinder and are planned for ESA's LISA mission.
    - Cold gas thrusters are currently flying on ESA Gaia.
  - Colloidal Microthrusters (baselined) have sufficient thrust capability:
    - 5-30µN for each thruster head on ST7
    - thrust resolution ≦0.1µN
  - Significantly less noise than reaction wheels (≦0.03µN/rtHz over all frequencies)
  - Potentially higher reliability than reaction wheels
  - Simplifies structural dynamics design, analysis, and testing
  - Potentially no payload/spacecraft isolation.

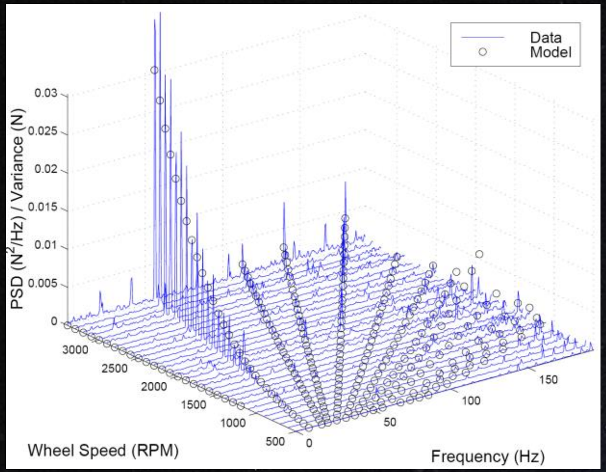
Units: µN/rtHz



Thruster noise PSD plot for colloidal microthrusters. Max noise above 10^{-3} is likely due to thrust-balance sensor noise limits.

(ref: *"Colloid Micro-Newton Thrusters For Precision Attitude Control", John Ziemer, et. al, April 2017, CL#17-2067*)

Units: N^2/Hz



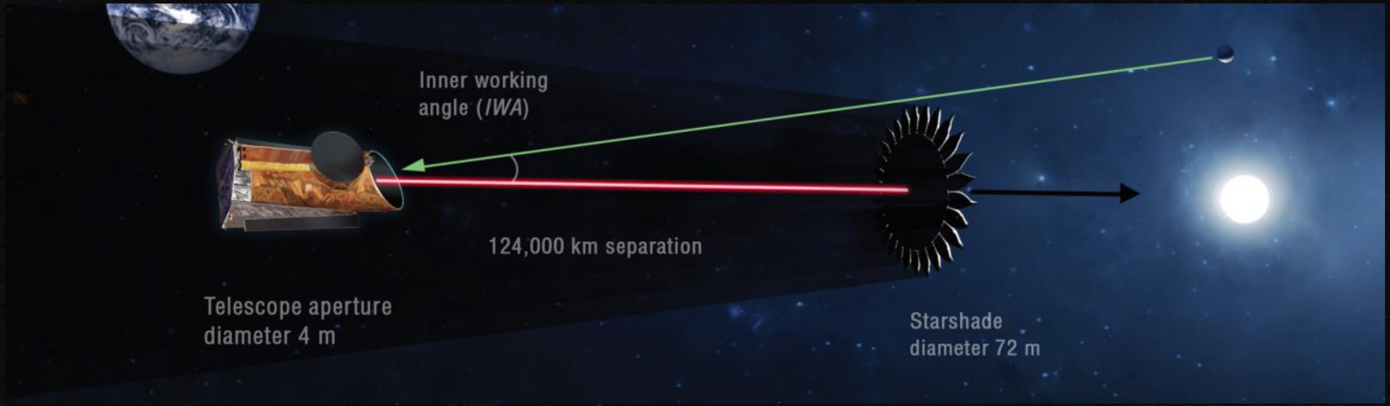
Waterfall plot derived from measured data showing Ithaco B-wheel Fx data and the radial force model
(reference: *"Conditioning, Reduction, and Disturbance Analysis of Large Order Integrated Models for Space-Based Telescopes" By Scott Alan Uebelhart, MIT 2001*)

Why a Starshade?

- A starshade is designed for $<1\text{x}10^{-10}$ contrast from the IWA+ over a wide spectral band.
- For HabEx:
  - Coronagraph @ 500nm, D=4m (Tel dia)
    - IWA = 2.4λ/D = 62mas
  - 72m Starshade @ 124,000km
    - IWA = 60mas over 300nm – 1000nm
  - For Coronagraph IWA=62mas @1000nm would require D = 8m.

- The Starshade is slow to retarget, but is very good at deep spectral characterization at IWA with no OWA.
- The coronagraph is fast to retarget, but is only able to detect 500nm at IWA, and is limited by OWA
- These two exoplanet instruments are complimentary.

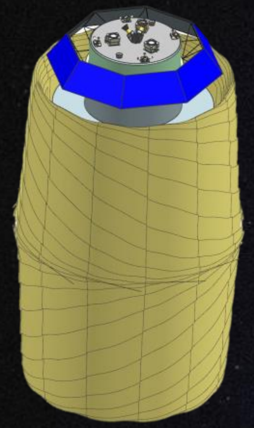
- Starshade technologies are being developed by the Exoplanet Exploration Program
- A Starshade is planned for a rendezvous with WFIRST

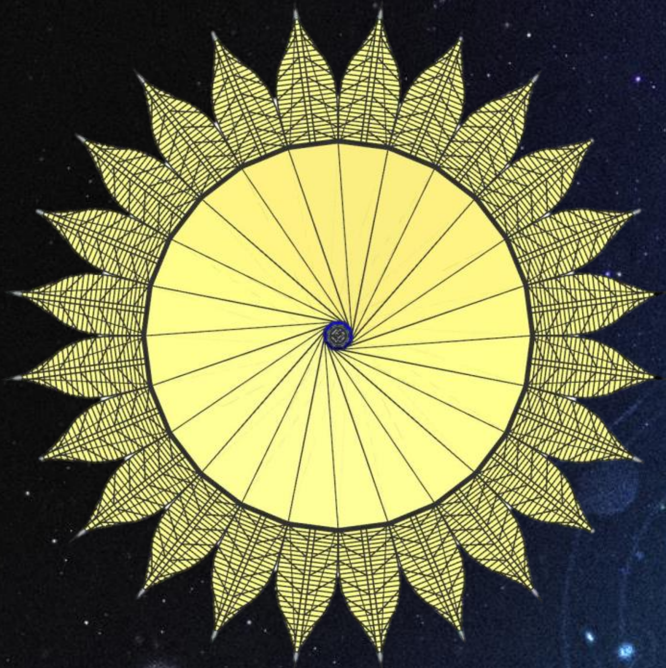


Vis: 300nm – 1000nm, 124,000km
UV: 200nm – 670nm, 182,000km
NIR: 540nm – 1800nm, 69,000km

Starshade Flight System (Baseline)

- 72-meter diameter (tip-to-tip)
- 40-meter diameter central disk
- 16-meter petals (x22)
- Solar Electric Propulsion (SEP) Hall Effect thrusters
  - 2 flight + 1 spare, each side (6 total)
- Bi-prop hydrazine thrusters
  - ACS
  - Orbit maintenance
- Communications
  - X-band to ground, 1kbps, command & ranging
  - S-band to telescope, 100bps, data transfer & ranging





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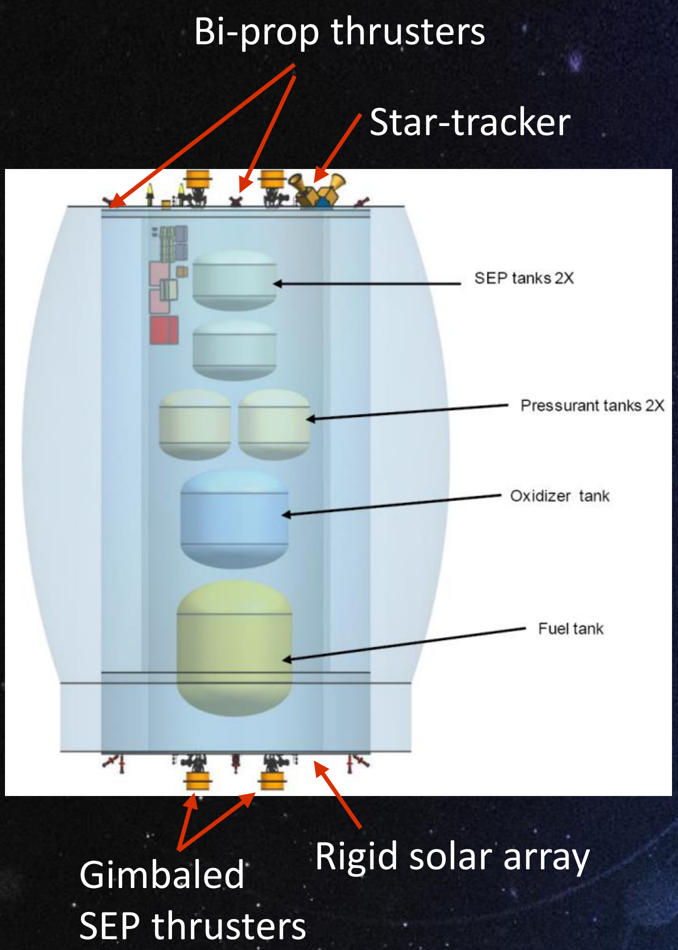
Starshade Flight System (Baseline) Exploded View

- 72m diameter Starshade deploys radially from Hub exterior
- PLUS (Petal Launch Restraint & Unfurler Subsystem)
  - deploys the Starshade occulter (jettisoned after use)
- Starshade Bus fits within the Starshade Hub
- Bus Includes:
  - Solar Electric Propulsion (SEP) Hall effect thrusters
  - 2 Flight / 1 Spare (on each end)
  - Bi-prop chemical thrusters
  - Communications, with ground & telescope
  - Formation Flying beacon
  - Electronics
  - Solar Array (2 sets)
    - 1 rigid array on end of hub
    - 1 flexible CIGS array starshade disc when deployed
  - Thermal Control
- Starshade is spin-stabilized at 0.33 RPM
  - allows starshade occulter temperature to be passively controlled
- Communications same as telescope (w/o extra 1Tb storage)



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Summary

- HabEx takes advantage of existing (or developing) technologies to achieve compelling science:
  - SLS Block 1B launch vehicle
    - Reduces complexity and technical risk (and cost)
  - Vector Vortex Coronagraph Charge 6
    - Relaxes telescope quality and stability requirements compared to other coronagraphs
  - Microthrusters
    - Significantly reduces mechanical noise
    - Simplifies structural dynamics design, analysis and test
  - Starshade
    - Allows for a smaller telescope (4m instead of 8m) to achieve the same level of exoplanet characterization over a broad spectral band
    - A smaller starshade design (~52 m) is being developed to improve technology readiness.