Technology Maturity for the HabEx Observatory Concept

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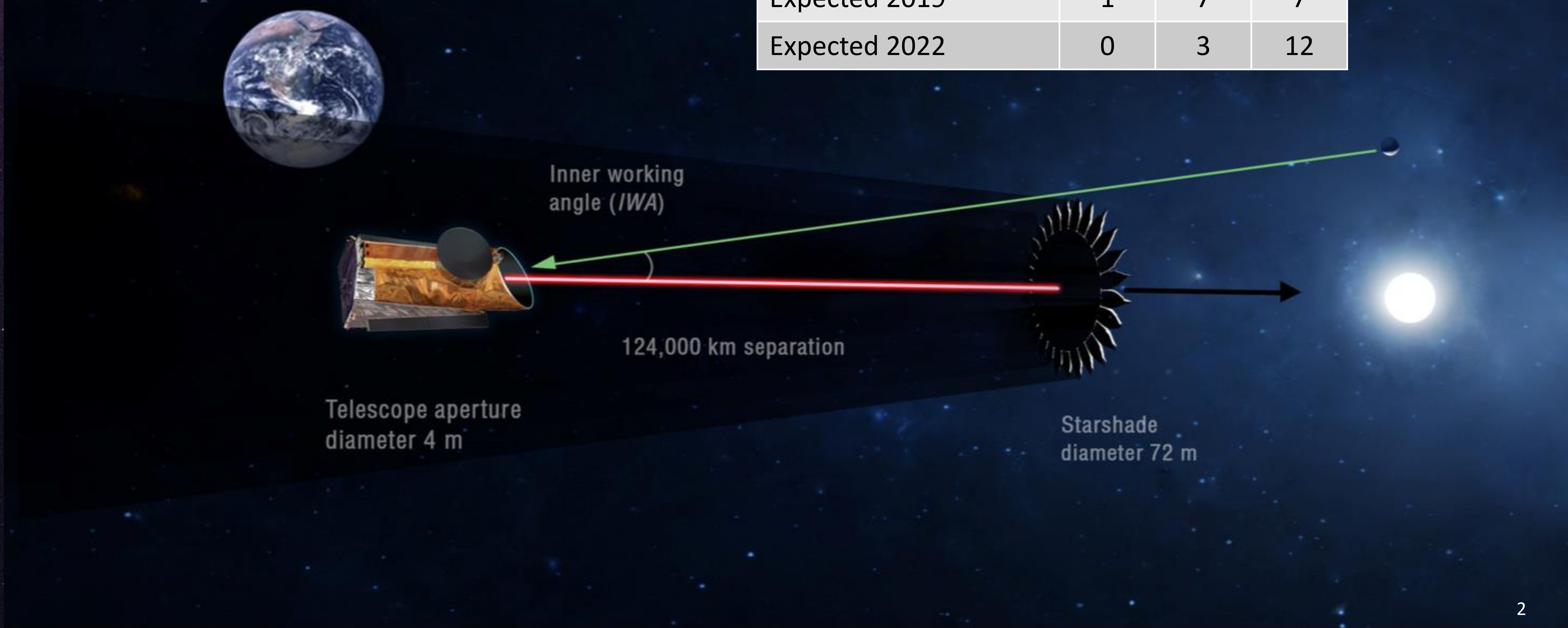
Technology Maturity

	Number of Gaps		
	TRL 3	TRL 4	TRL 5
Expected 2019	1	7	7
Expected 2022	0	3	12



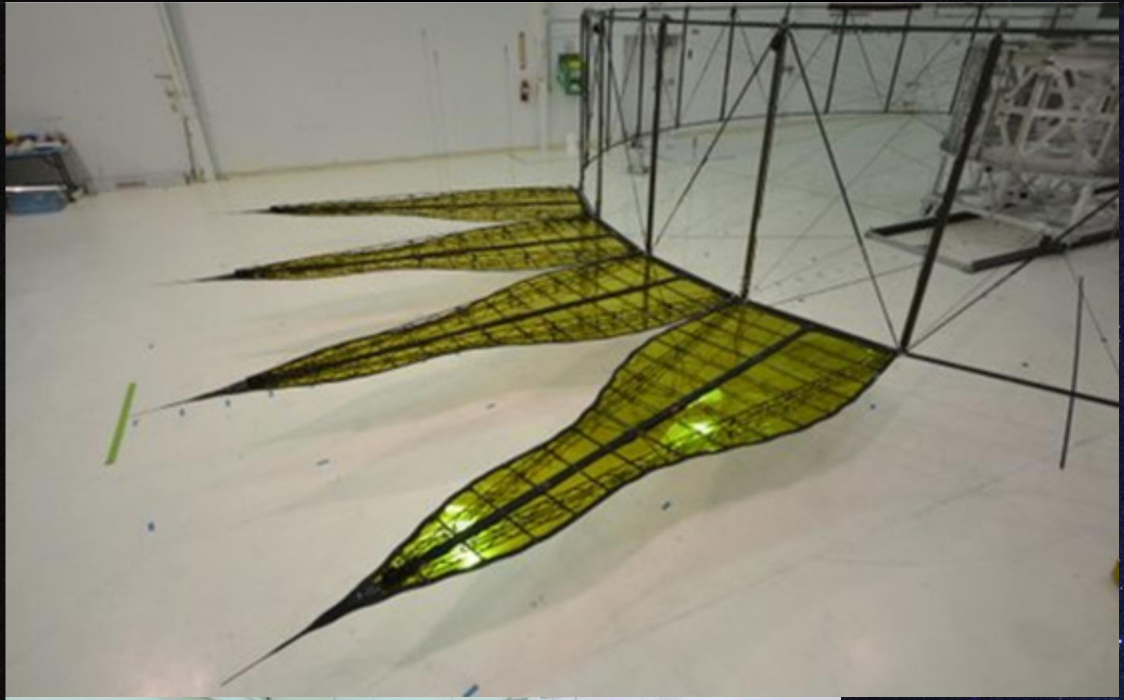
Starshade Deployment

Truss Deployment Test

HabEx

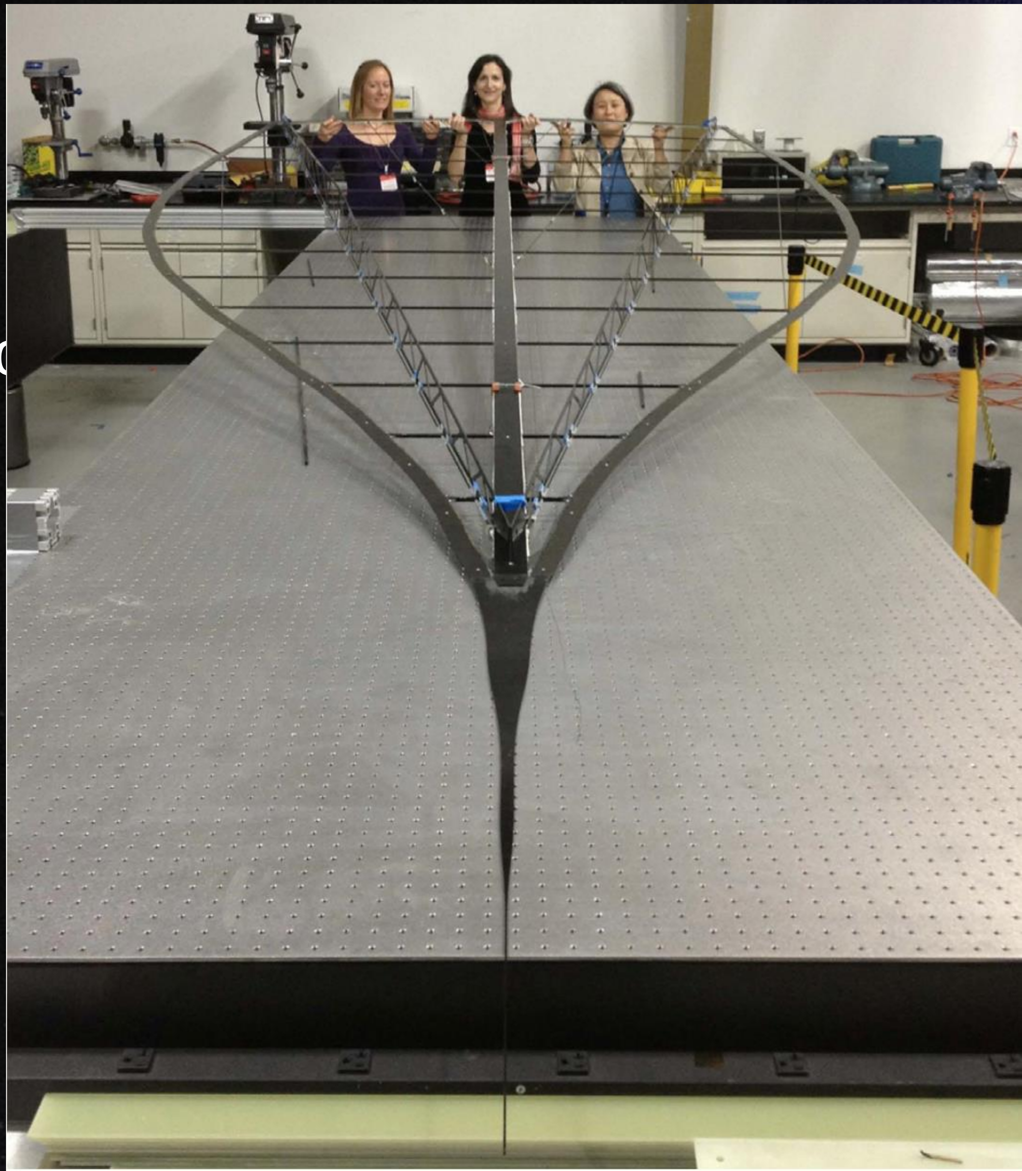
Petal deployment accuracy

- Starshade tolerances scale linearly
- SOA
  - 12 m flight-like truss
  - Petal deployment tolerance <0.15 mm
- Requirement for 40 m truss
  - +- 0.5 mm (3σ) bias
  - +- 1.5 mm (3σ) stability
  - In operational environment
- Path
  - S5 5m truss half-scale demo for 10 m truss
  - HabEx 72m starshade requires 20m half-scale demo truss
    - Starshade size reductions under consideration to more closely match S5 truss demo size



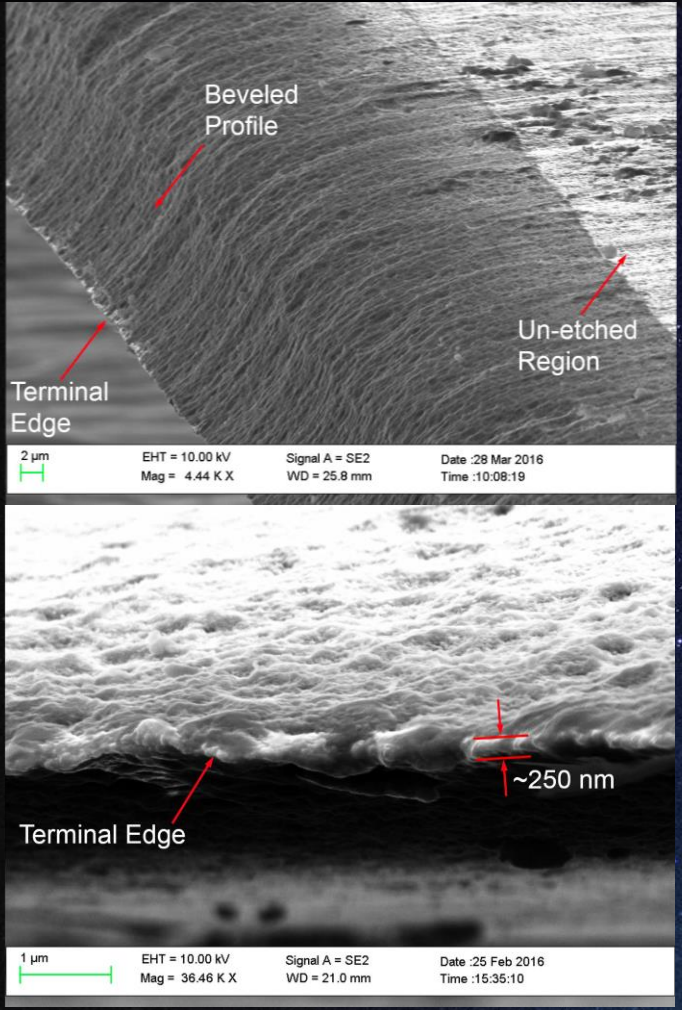
Petal shape and stability.

- SOA
  - 6m prototype petal manufactured to <100 um to
- Requirement for 16m petal
  - Shape manufacture to +-115 um (3σ)
  - Deployed shape to < +- 230 um (3σ)
  - Stability (thermal)
    - Disk to petal strain < 30 ppm
    - 1-5 cycle petal width <20 ppm
- Path
  - 8 m half-scale petal for S5 applies to HabEx



Solar Edge Scatter

- SOA
  - Metal edges (coupons)meet all specs but in-plane shape tolerance
  - Graphite edges produce low reflectance of 25 Vmag in two main lobses
- Requirement
  - Petal-edge in-plane shape tolerance 40 um
  - Solar glint at 25 Vmag in two main lobes
- Path
  - S5 to demonstrate performance at edge segment level
  - Sufficient demonstration for HabEx



SEM images of the beveled edge and terminal edge

Formation Sensing

- SOA
  - Out-of-band sensing of pupil plane images show structure in the low-contrast starshade shadow
  - Simulations show ample star flux for control loop and < 0.15 cm lateral displacement (0.01 pixel star positions)
- Requirements
  - Demonstrate sensing lateral errors to 0.20 m accuracy, =< 1 mas bearing angle
  - Demonstrate control algorithms to scaled lateral errors =< 1m
- Path
  - S5 testbed demonstration is sufficient for HabEx FY2018

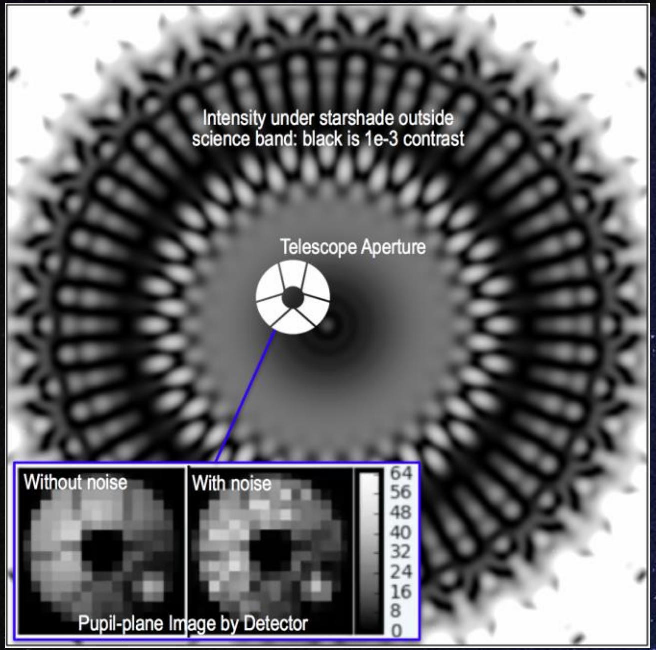
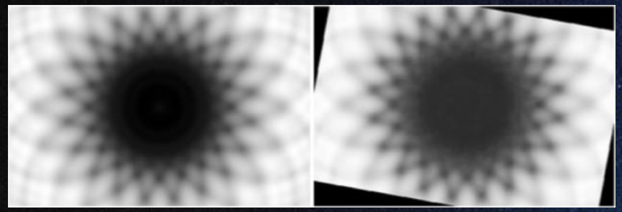


Illustration of lateral sensing using pupil-plane image matching



Preliminary results

Simulation Testbed

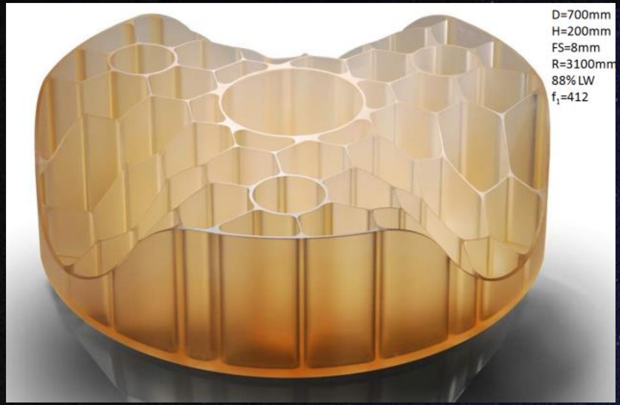
Optical Performance and Model Validation

- SOA
  - 6E-6 suppression in pupil plane at Fresnel No. 15 broadband
  - 4.8E-8 suppression in pupil plane, 5E-10 constrast at Fresnel No. 27, monochromatic
- Requirements
  - Experimentally validated models
    - with suppression <1E-8, F1.0 between 5 and 40 (broadband)
    - Traceable to 1E-10 contrast system performance
- Path
  - S5 testbed at Princeton expected TRL 5 2018 is sufficient for HabEx

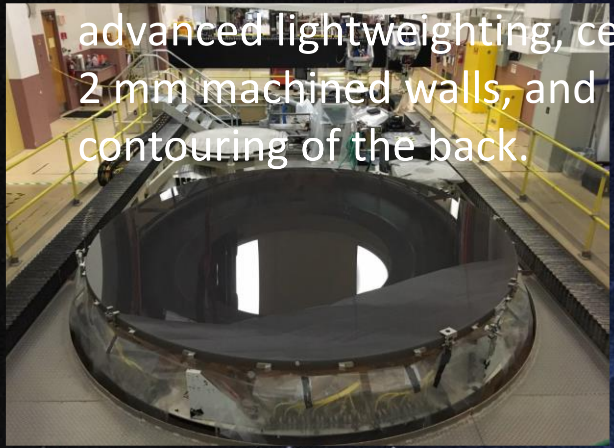
S5's starshade model validation testbed at Princeton.

HabEx Large Mirror Fabrication

- SLS allows for moderate lightweighting
- Microthrusters allow for low first frequency
- SOA
  - 4.2m DKIST primary mirror by Schott, UA (2nm surface roughness)
  - 4m ELT M2 by Schott
  - Zerodur CTE homogeneity 10 ppb/K
  - Lightweight cell 340 mm deep, 2mm wall
- Requirements
  - Wavefront thermal stability ~1 nm over 100s of seconds
  - First mode > 60 Hz
- Path
  - 4m demonstrator for TRL 5



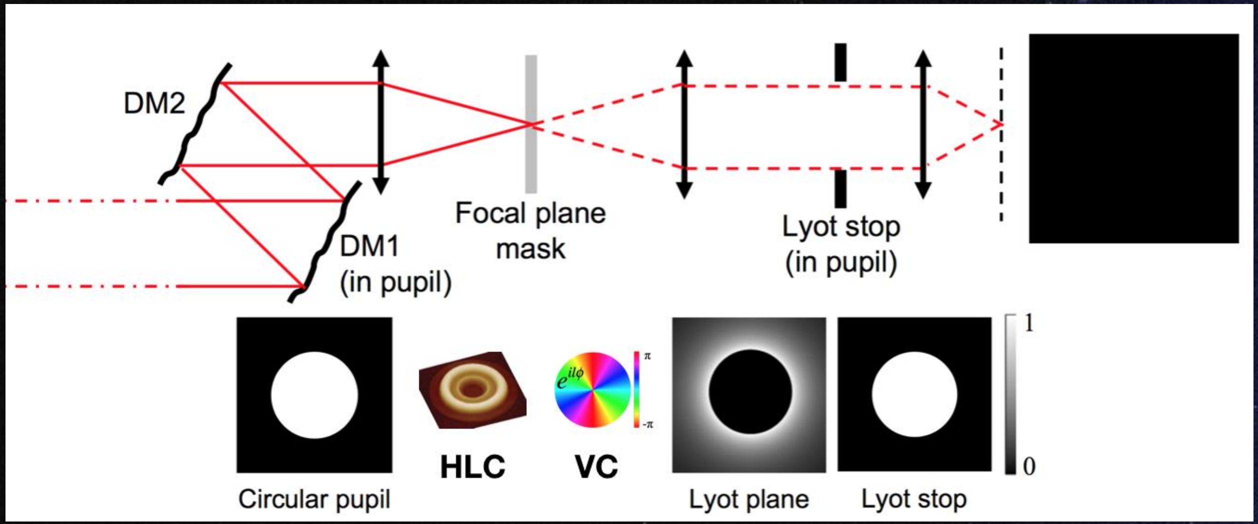
SCHOTT 700 mm diameter and 200 mm high Zerodur® demonstration piece showing advanced lightweighting, cells with 2 mm machined walls, and contouring of the back.



4.2 m Daniel K. Inouye Solar Telescope primary mirror

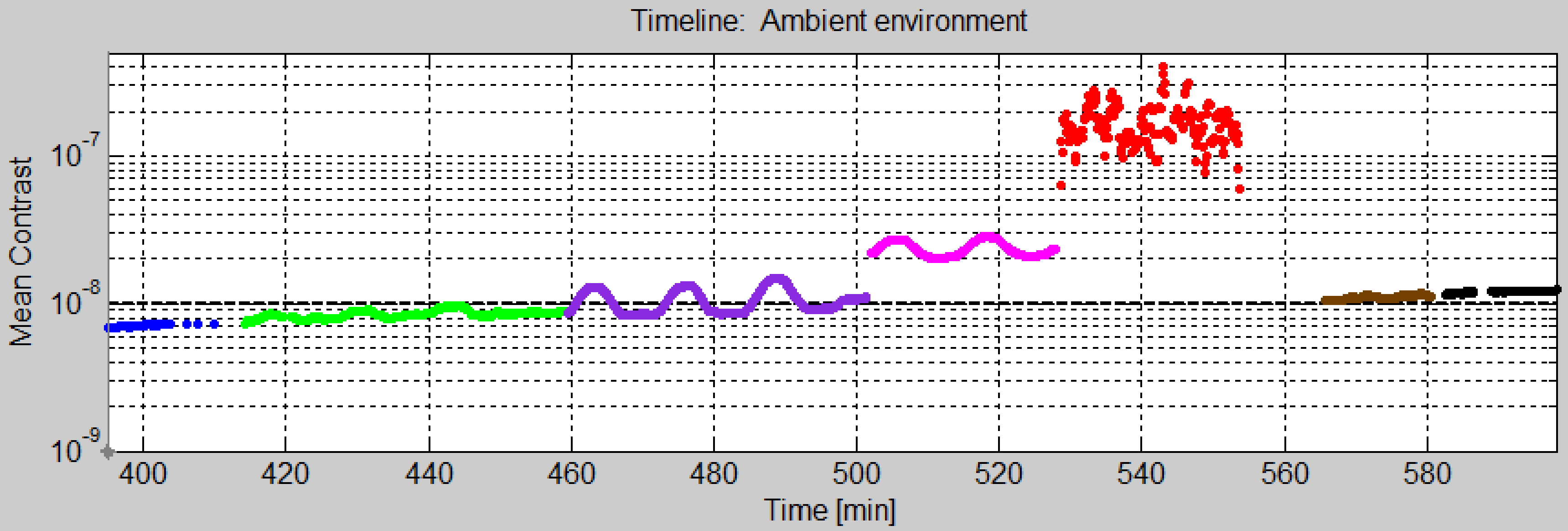
Coronagraph Architecture

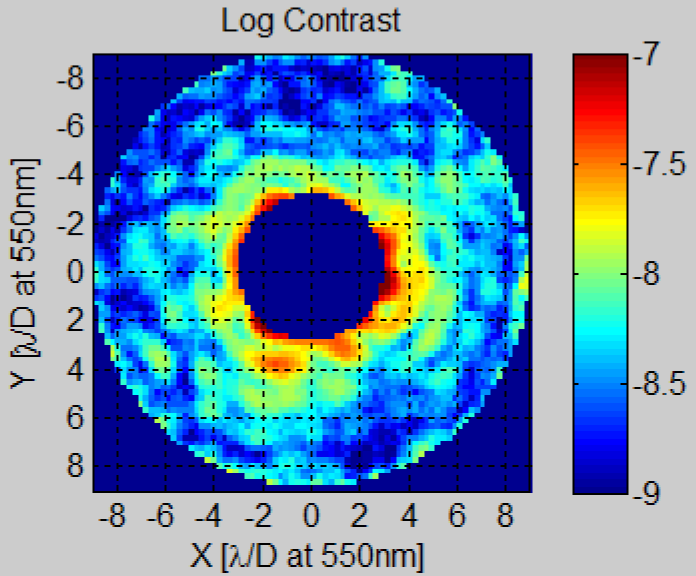
- Requires 10^{-10} raw contrast from 2.4 to 32 λ/D for 20% bandwidth
- SOA
  - VVC 5E-10 monochromatic,
    - 3-8 l/D, 2-7 λ/D
    - 1E-8 10% BW
  - HLC linear mask
    - 6E-10, 10% BW, 3-16 λ/D
- Requirement
  - 1E-10 raw contrast, 20% BW,
  - 1E-11 contrast stability
  - IWA = 2.4 λ/D
  - Coronagraph throughput >= 10%
  - Dual polarization operation
- Path
  - ExEP Decadal Studies Testbed seeks to show 1E-10 raw contrast with VVC in static environment by 2019

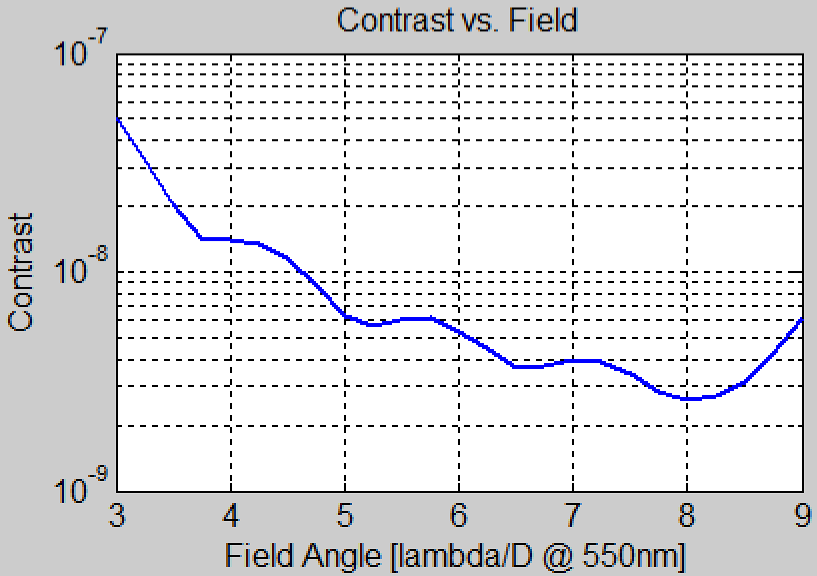


The ExEP Decadal Studies Testbed (DST) strives to achieve 10^{-10} raw contrast for an unobscured aperture.

LOWFS/C



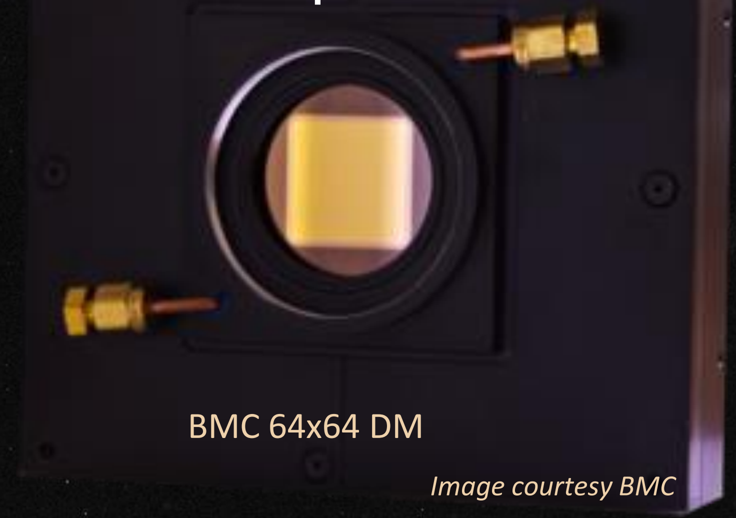




- Low Order Wavefront Sensing and Control (LOWFS/C) demonstrated in testbed for WFIRST with jitter and focus input disturbance.
- The HabEx jitter environment is much more benign due to microthrusters.
- Path
  - Demonstrate in full coronagraph testbed with WFIRST CGI like progression

DMs and visible detectors

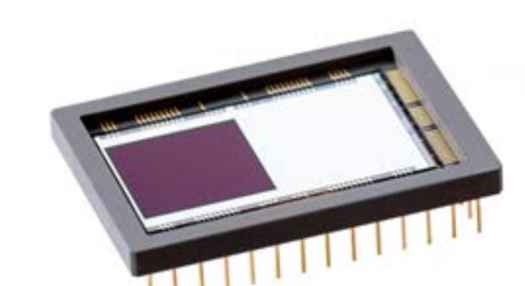
- Boston Micromachines Corp (BMC) Deformable Mirrors (DMs)
  - 0.4 mm pitch
  - Micro Electrical Mechanical System (MEMS)
  - 64 x 64 actuators (4096 actuators)
- Under test in the DST
- Environmental testing in progress (TDEM)
- Phase 2 SBIR to improve residual WFE



BMC 64x64 DM

Image courtesy BMC

- Visible detectors are EM-CCDs
  - CCD201: 1024 pixels for cameras
  - CCD282: 2048 pixels for coro. IFS
  - CCD282: 4096 pixels for Starshade IFS
- WFIRST-CGI lab results for dark current meet HabEx requirements
- WFIRST-CGI EMCCD requirements meet HabEx needs



E2v CCD201, 1024 pixels wide

Image courtesy e2v

Enhancing Technologies

- Delta-Doped UV EMCCD
- SOA (TRL 4)
  - Same noise performance as Visible EMCCDs, reduced performance at 4k x 4k format
- Requirement
  - 4kx4k format for UV Spectrograph
- Path
  - Adopt if mature in time

- Far-UV Enhanced coatings for 100 nm cutoff
- SOA (TRL 3)
  - Al+LiF+AlF3 proof of concept show 3 year stability
- Requirement
  - Operational life >10 years
- Path
  - Adopt if mature in time

Maturation Timeline

task	start	end
Petal Shape	2019	2022
Petal deployment		
S5	2019	2021
HabEx	2022	2025
Starshade Edge Scatter	2018	2020
Large Mirror Fab		
Mirror Fab & Test	2022	2024
Coating Chamber Fab & Coupon Tests	2022	2024
Mirror Coating	2024	2026
Coronagraph Instrument Testbed		
LOWFS (WFIRST)	2018	2018
VV6 Design	2019	2019
HCIT Modification	2020	2020
1E-10 Contrast, 20% BW, Dynamic	2021	2022
DM		
Environment Testing	2018	2018
Performance in DST	2019	2019

HabEx Talks and Posters

Title	Presenter	Date • Time
HabEx Ultraviolet spectrograph design and DRM	Paul A. Scowen	10 June 2018 • 10:00 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 AM
The habitable exoplanet imaging mission (HabEx): science goals and projected capabilities	Scott B. Gaudi	11 June 2018 • 10:30 AM
The habitable exoplanet imaging mission (HabEx)	Bertrand Mennesson	11 June 2018 • 1:20 PM
Overview of the 4m baseline architecture concept of the habitable exoplanet imaging mission (HabEx) study	Gary M. Kuan	11 June 2018 • 1:40 PM
The HabEx workhorse camera	Paul A. Scowen	11 June 2018 • 2:00 PM
Technology maturity for the habitable-zone exoplanet imaging mission (HabEx) concept	Rhonda M. Morgan	11 June 2018 • 2:20 PM
HabEx Space telescope exoplanet instruments	Stefan R. Martin	11 June 2018 • 2:40 PM
HabEx: high precision pointing architecture using micro-thrusters and fine steering mirror	Oscar S. Alvarez-Salazar	11 June 2018 • 3:30 PM
Numerically optimized coronagraph designs for the habitable exoplanet imaging mission (HabEx)	A J Eldorado Riggs	11 June 2018 • 3:50 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 PM
HabEx Lite: a starshade-only habitable exoplanet imager alternative	David Redding	11 June 2018 • 4:30 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 AM

Poster Title	Presenter	Date • Time
HabEx polarization ray trace and aberration analysis	Jeffrey Davis	11 June 2018 • 5:30 PM
HabEx space telescope optical system overview	Stefan R. Martin	11 June 2018 • 5:30 PM
HabEx telescope WFE stability specification derived from coronagraph starlight leakage	Bijan Nemati	11 June 2018 • 5:30 PM
Mirror design study for a segmented HabEx system	James T. Mooney	11 June 2018 • 5:30 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 PM

BACKUP

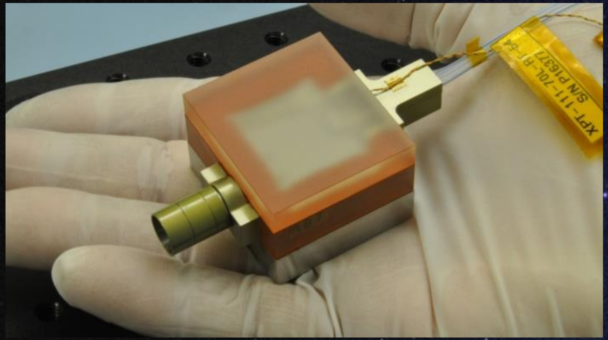
Microthrusters

- SOA
  - Colloidal (CMT): 5-30 uN thrust, 0.1 uN resolution
    - 100 days on ESA/NASA LISA Pathfinder
  - Cold Gas: 1mN max thrust, 0.1 uN resolution
    - 4 years on orbit operations on ESA Gaia
  - *May be on Euclid*
- Requirement
  - Thrust capability of 0.35 mN
  - Operating life of 5 years
- Path:
  - PCOS maturing TRL7 CMT to TRL6 for ESA-led LISA mission
  - Trade Colloidal with cold gas microthrusters
  - Trade: active isolation + RCS with monoprop + microthrusters

A single cluster of four Busek Co. CMTs integrated on the LISA Pathfinder Spacecraft just prior to launch.

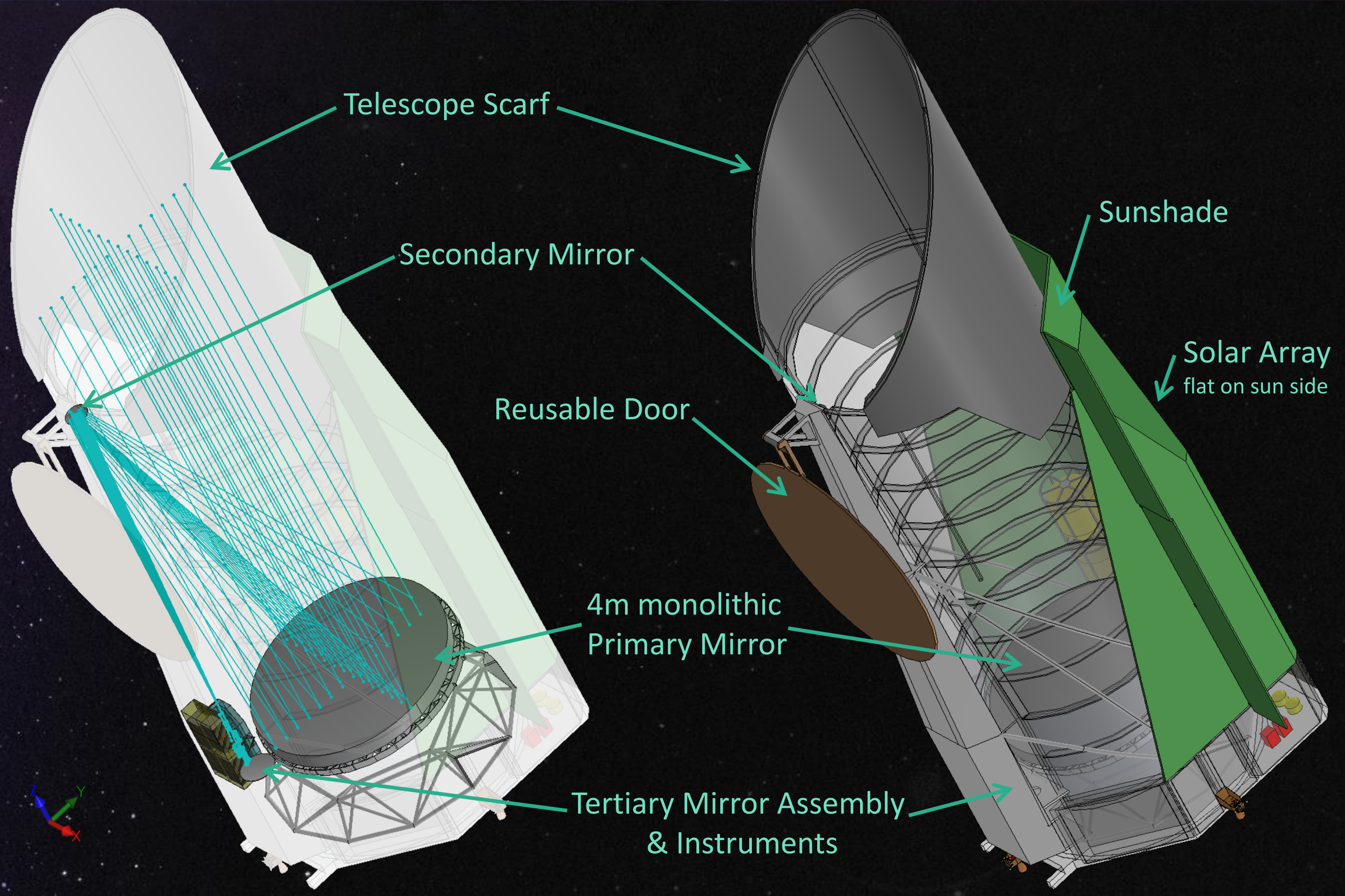
Laser Metrology

- SOA
  - Laser: Nd:YAG ring laser and modulator on LISA Pathfinder
  - Thermally stabilized Planar Lightwave Circuit fully tested
- Requirements
  - Sense at 1 kHz BW
  - Uncorrelated per gauge error of 0.1nm
- Path
  - At TRL 5 for HabEx



PLC beam launcher

Baseline Architecture

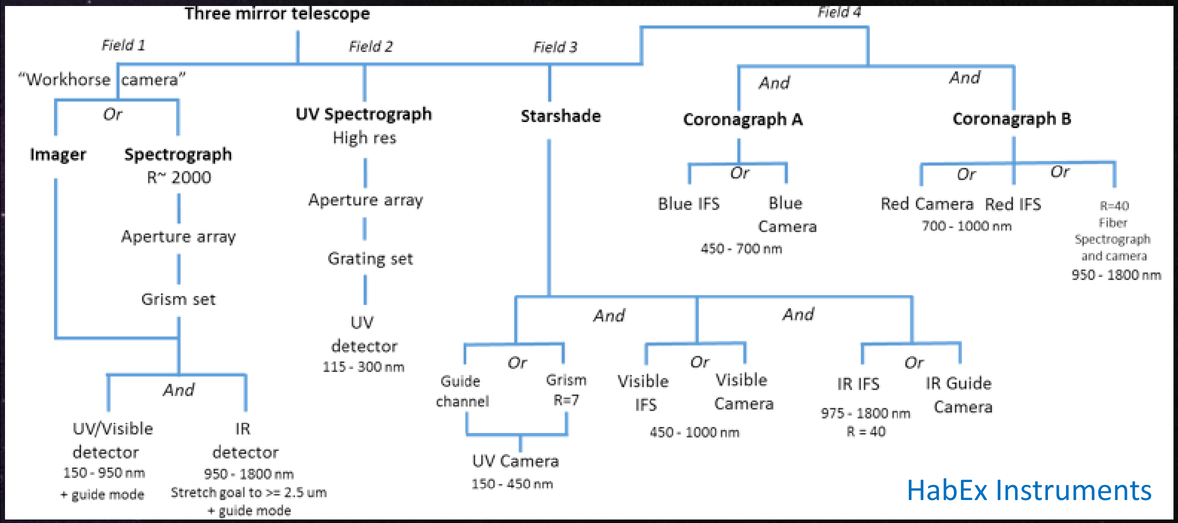


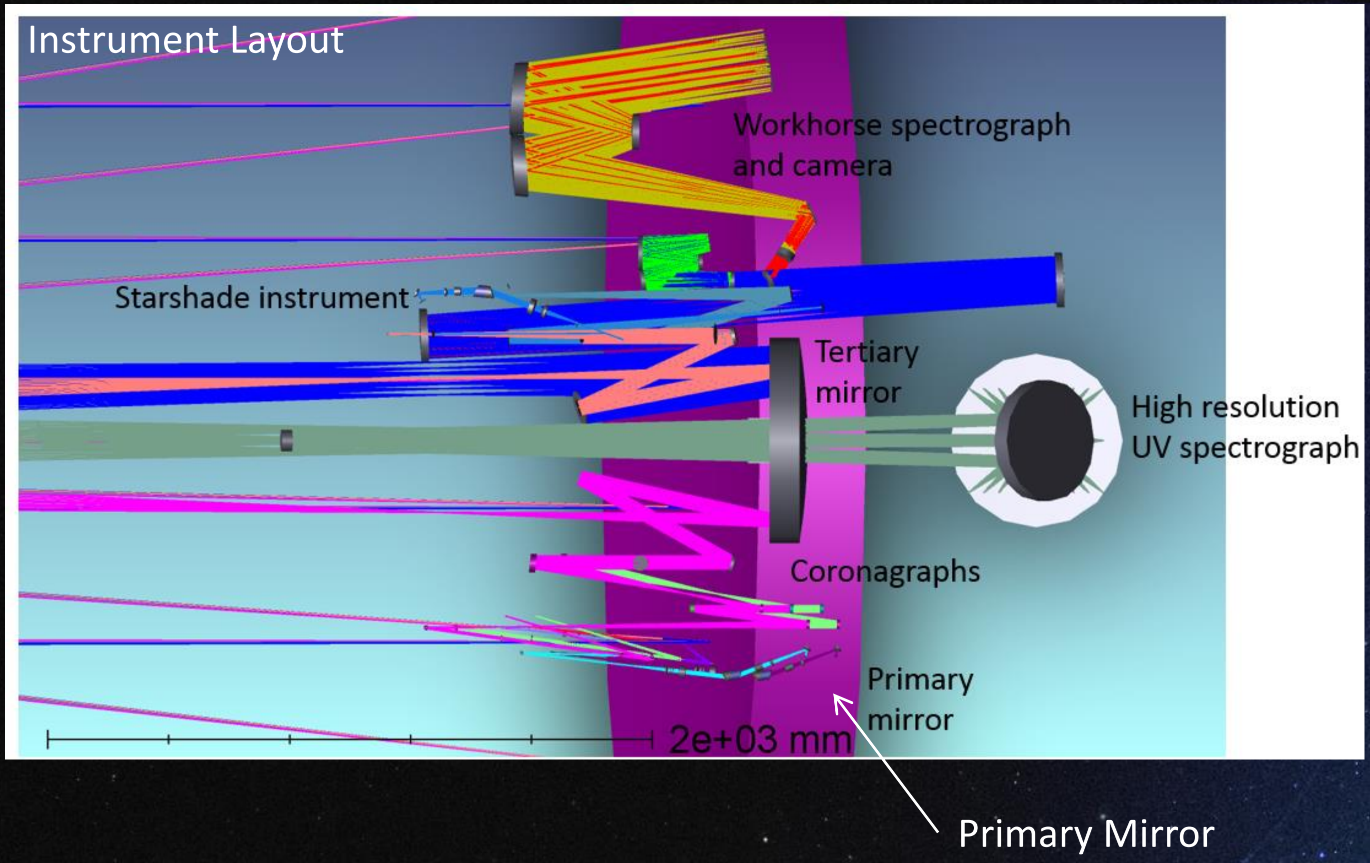
Habitable Exoplanet Imaging Mission	
Mission Duration:	5 years
Orbit:	Earth-Sun L2 Halo orbit
Aperture:	4-meter unobscured
Telescope Architecture:	off-axis, Three Mirror Anastigmat (TMA)
Primary Mirror:	f-number: f/2.5 construction: monolith reflective coating: Al+MgF2
Wavelengths:	115nm – 2500nm (UV, Vis, NIR)
Instruments:	- Coronagraph - Starshade Camera + Starshade Occulter - High-Resolution UV Spectrograph - Multi-purpose, Wide-field Camera & Spectrograph
Starshade	72-meter diameter starshade occulter
Attitude Control System (ACS):	- Fine-Guiding Sensor Instrument - biprop thrusters (slewing) - microthrusters (pointing)
Formation Flying Control System:	- position sensor - local communications
Communications:	phased-array antenna
Serviceability:	- instruments (4) - thrusters - avionics - communications - refueling: telescope + starshade

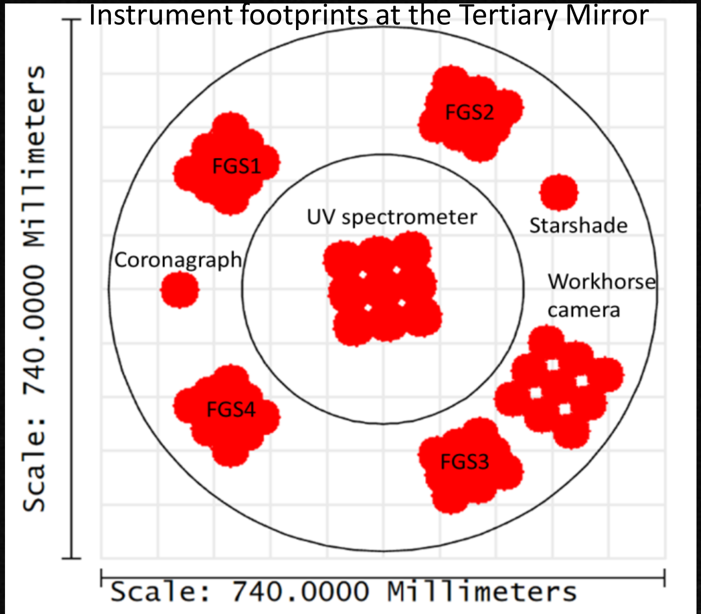
WED 5:30 pm, 246.38. HabEx Optical Telescope Concepts: Design and Performance Analysis *H. P. Stahl*

The 4m monolithic primary TRL of 4 is enabled by microthrusters and the SLS lift capacity

HabEx Baseline Instruments

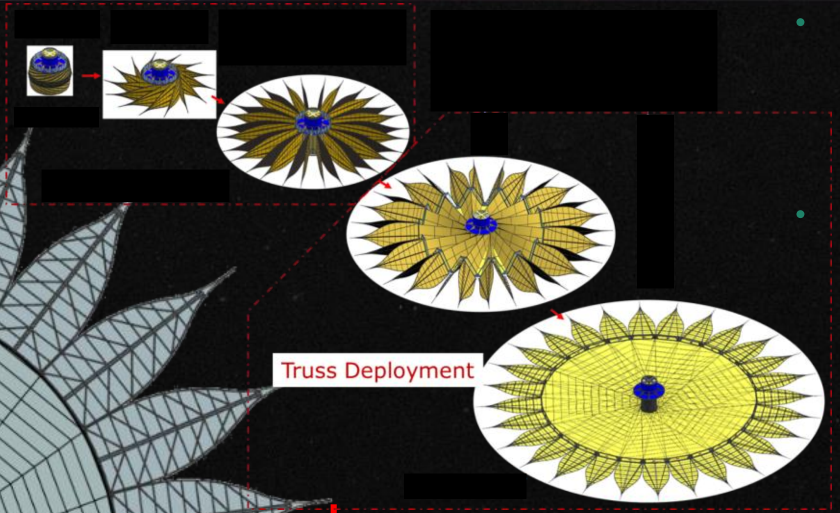




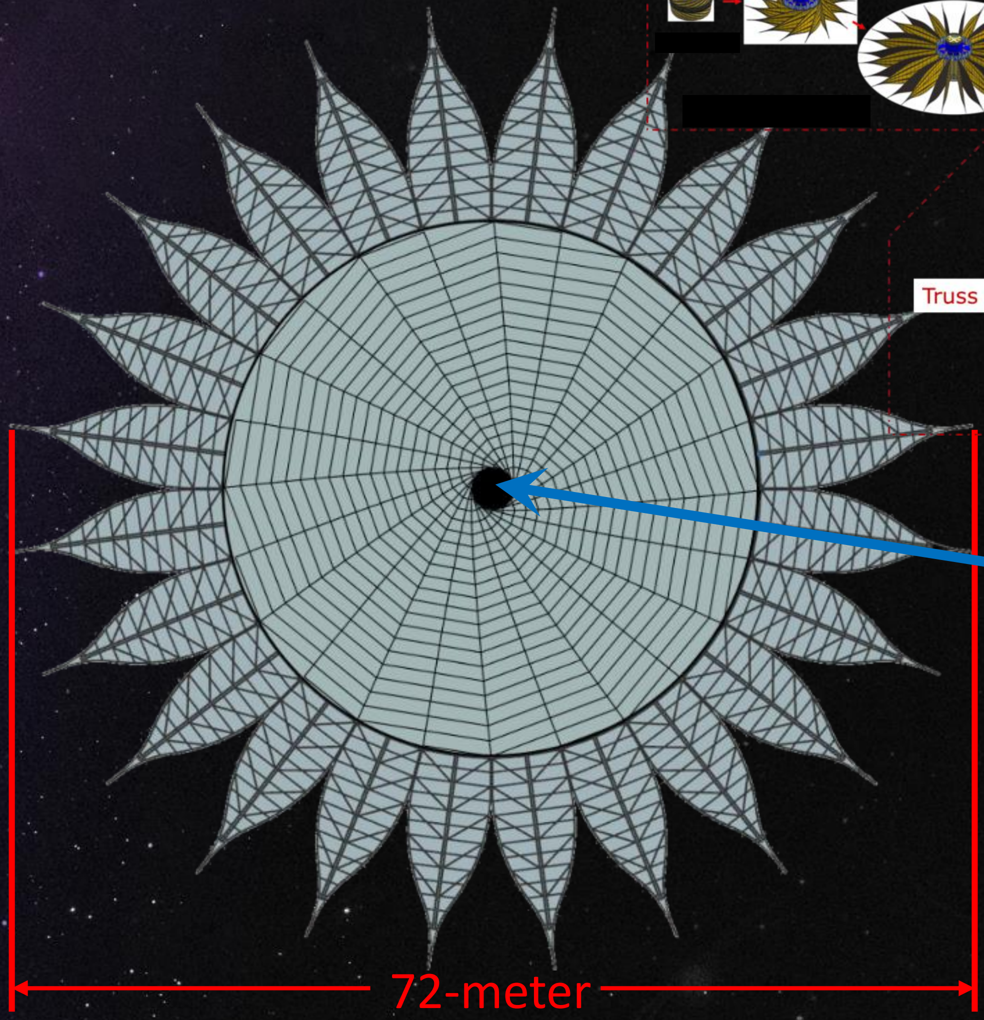


HabEx

Starshade

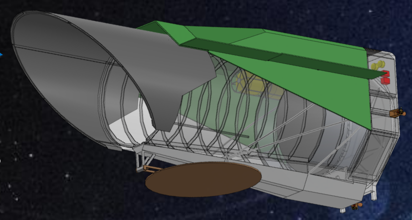


- **Propulsion (Occulter)**
  - Solar Electric Propulsion (SEP) with Hermes Hall effect thrusters for slewing (repositioning)
  - Biprop thrusters for attitude control
  - >100 targets / 5yrs
- **Observing**
  - ≤10^{-10} Suppression
  - 40 – 83 degree sun-angles
  - 450 – 1000nm wavelengths at **nominal** separation
    - IWA = 62 mas
    - IFS, R = 140
  - 150– 300nm wavelengths at farther distance
    - IWA = 28 mas
    - Grism, R = 7
  - 1000 – 1800nm at closer distance
    - IWA = 111 mas
    - Slit spectrograph, R = 140
  - OWA = 1.9 arcsec



Technology Maturity

- The Starshade to TRL 5 (S-5) project is maturing 5 starshade technology gaps to TRL 5: 3 by the end of 2019 and 2 by 2021
- S-5 demonstration on a 26 m starshade achieves HabEx requirements on HabEx 72 m starshade because requirements scale by angle to starshade.



HabEx Workhorse camera, UVS

Workhorse Camera Instrument	
Purpose:	Multi-purpose, wide-field imaging camera and spectrograph for general astrophysics
Waveband: • UV: • Vis: • NIR:	• 150nm – 400nm • 400nm – 950nm • 950nm - 1800nm (2500nm goal)
Telescope Diffraction Limit:	400nm
Field-of-view:	3 arcmin x 3 arcmin
Spectral Resolution:	R = 2000
Detector: • UV/Vis: • NIR:	• 3x3 CCD203 12288x12288 pixels • 2x2 H4RG10 8192x8192 pixels
Multi-Object Spectroscopy (MOS) capable	Micro-shutter array, 2x2 array 200x100 um 171x365 apertures

UV Spectrograph Instrument	
Purpose:	High resolution, UV spectroscopy for general astrophysics
Waveband: • Spectroscopy:	115nm – 360nm (20 bands)
Telescope Diffraction Limit:	400nm
Field-of-view:	3 arcmin x 3 arcmin
Spectral Resolution:	R = 500 – 60,000 (band dependent)
Detector	• 6x6 MCP array, 100mm sq each • 60000x60000 pixels
Multi-Object Spectroscopy (MOS) capable	Micro-shutter array, 2x2 array 200x100 um 171x365 apertures

- UV requirements are met by the state of the art.
- UV Performance can be enhanced by advancements in UV coatings and detectors