4-meter Space Telescope Design Concepts for a UVOIR / ExoPlanet Mission

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Ground Rules and Assumptions

- 4-meter class UVOIR telescope – consistent with decadal survey recommendations:
  - *"as much could be learned about the universe at ultraviolet wavelengths as motivated the proposal and development of JWST for observations at infrared wavelengths."*
  - *"Key advances could be made with a telescope with a 4-meter-diameter aperture with large field of view and fitted with high-efficiency UV and optical cameras/spectrographs operating at shorter wavelengths than HST. This is a compelling vision that requires further technology development.“*
- Telescope compatible with coronagraphs and starshades for ExoPlanet detection and characterization
  - "*The committee highly recommends a modest program of technology development to begin mission trade-off studies, in particular those contrasting coronagraph and star-shade approaches, and to invest in essential technologies such as detectors, coatings, and optics, to prepare for a mission to be considered by the 2020 decadal survey. A notional budget of $40 million for the decade is recommended."*

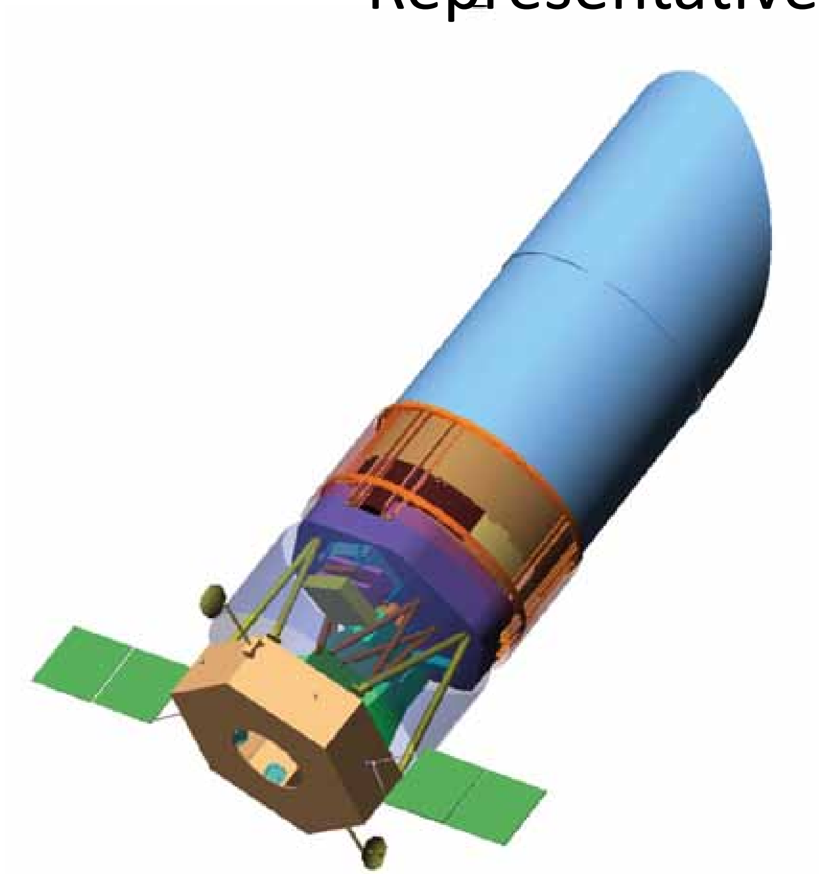
UVOIR Telescope Requirements

Parameter	**Value**	**Comment**
Aperture:	4-meters	consistent with decadal recommendation, could be larger
Mirror Type	Monolithic	permits wide range of starlight suppression options
Telescope Type	On-axis Cassegrain/ Off-axis Gregorian	On-axis Cassegrain is lower cost, lighter. Off-axis Gregorian is best for internal coronagraph. Both options should be
Short wavelength limit:	0.1 μm	No larger than 0.1 μm
Long wavelength limit:	2.4 μm (TBR)	No longer than 5 μm to minimize cooling and test requirements. The long wavelength limit may not be much of a driver on the telescope per se. The main emphasis overall should be on the uv-optical- and near ir
Diffraction-limited wavelength	0.2 μm	shortward of 0.5 μm
Image/surface quality	2 Å rms (TBR)	PSD ≤ HST/TDM to permit internal coronagraphy
Wavefront stability	< 1% (TBR) change in WF abberations in 24 hrs	must be consistent with internal coronagraphy
Actuator density	~360/m^2 (TBR)	as for AHM, but must be consistent with internal
Coatings/reflectivity	Al overcoated w/MgF_2	consistent with high efficiency across the wavelength band
Field of view	15 arcmin	as for THEIA, NWO 4-m telescopes

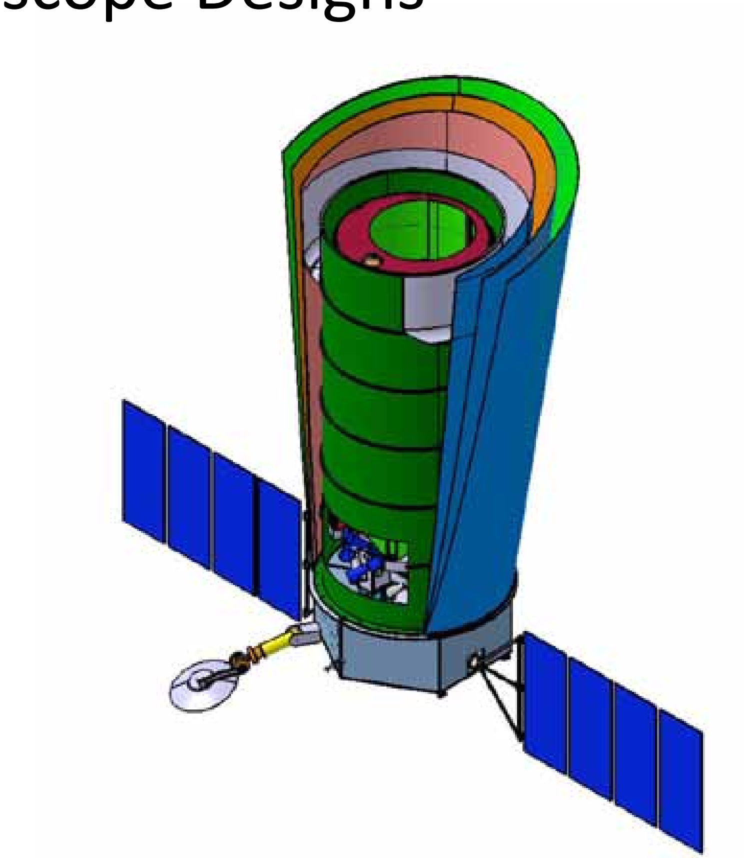
ExoPlanet Mission Requirements

	MUSTS
No.	**Exoplanet capability**
M.1	Able to detect an Earth twin at quadrature in a Solar System twin at a distance of 10 pc
M.2	Able to detect a Jupiter twin at quadrature in a Solar System twin at a distance of 10 pc
M.3	Examine at least 14 Cumulative Habitable Zones with $D_{mag} \geq 26$ sensitivity
M.4	Examine at least 3 Cum HZs with $D_{mag} \geq 26$ sensitivity
M.5	Characteriz discovered exoplanets by R>4 spectroscopy from 0.5 to 1.1µm
M.6	Characterize discovered TXPs by R>70 spectroscopy from 0.5 to 1.1µm
M.7	Characterize discovered TXPs by R>70 spectroscopy from 0.5 to 0.85µm
M.8	Determine Size, Mass, Albedo for found planets
M.9	Determine Size, Mass, Albedo to 10% for an Earth twin in a Solar System twin at 10 pc
M.10	Absolute photometry of Earth twin to 10%
M.11	Able to measure O_2 A-band equivalent width to 20% for Earth twin at 10 pc
M.12	Able to measure H_2O equivalent width to 20% for Earth twin at TBD pc
M.13	Able to guide on stars as faint as V_{AB}= 16.
M.14	Able to detect disk emission lines of Na I, Hα, [S II], and K I.
M.15	Capable of optical imaging at half the normal inner working angle at contrast levels of 1e-6

Representative Telescope Designs



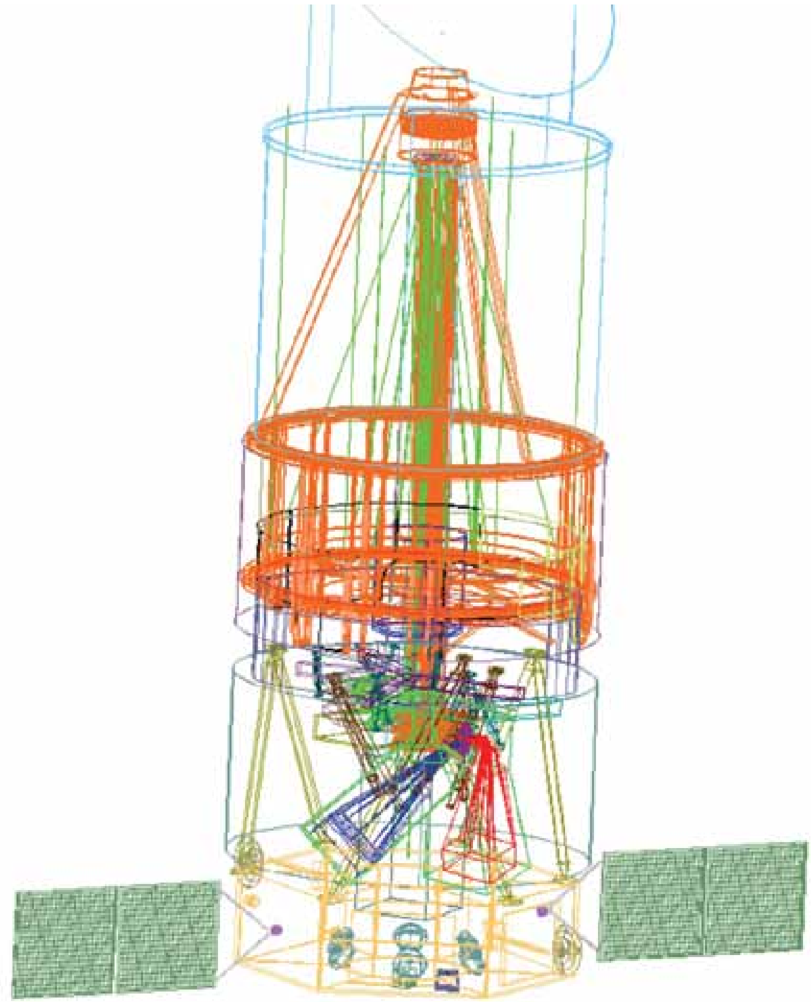
Telescope for Habitable Exoplanets and Intergalactic/Galactic Astronomy (THEIA)



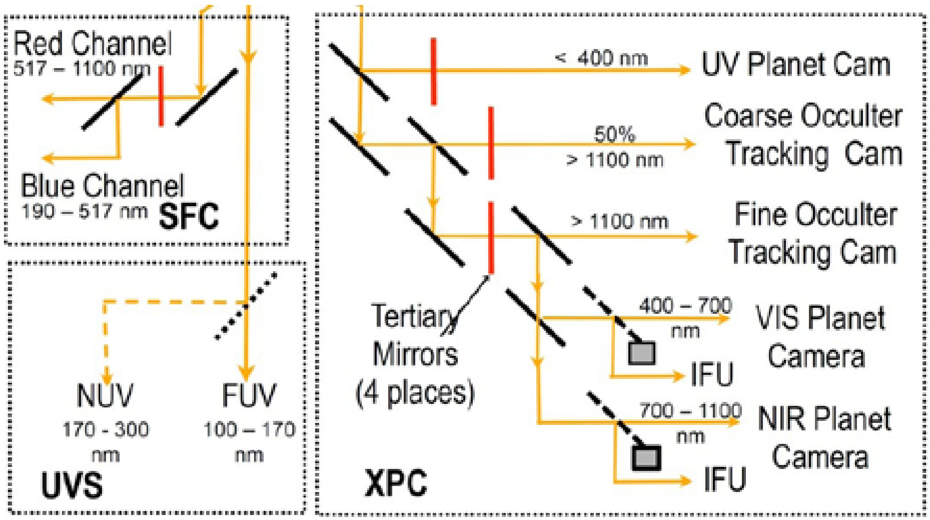
Actively-corrected Coronagraph Concepts for Exoplanetary System Studies (ACCESS)

On-Axis Telescope for General Astrophysics

- 4m, On-axis, F16 TMA Telescope
- 300 nm diffraction limited
- F1.5 primary
- Al+MgF_2 coated primary
- Al+LiF coated secondary
- 45 degree Sugar-Scoop Sunshade
- Active Isolation Struts to 30 mas
- 3-axis Pointing to 3 arcsec
- HR-16 Reaction wheels
- 5 kw Solar Array
- S-Band occulter and Earth link
- Ka-Band High-rate Downlink
- 2 Gimbaled High Gain Antennas



Instruments



SFC Instruments

- **Dual-Channel, Wide Field Imager**
- **19' x 15' FOV**
- **3.3 Gpixel FPAs, 66 x 55 cm**
- **517 nm Dichroic split**
- **4 mas pointing with FSM**

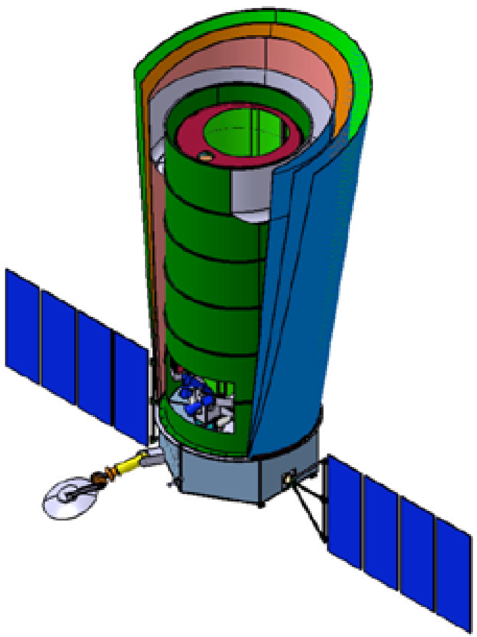
UVS Instruments

- **Multi-Purpose Ultraviolet Spectrograph (100-300 nm),**
  - **30,000 - 100,000 Spectral Resolution**
  - **Fed direct from secondary**
- **Photon-counting, 50k x 1k micro-channel array (100-170 nm)**
- **Photon counting 8k x 8k CCD (170-300 nm)**

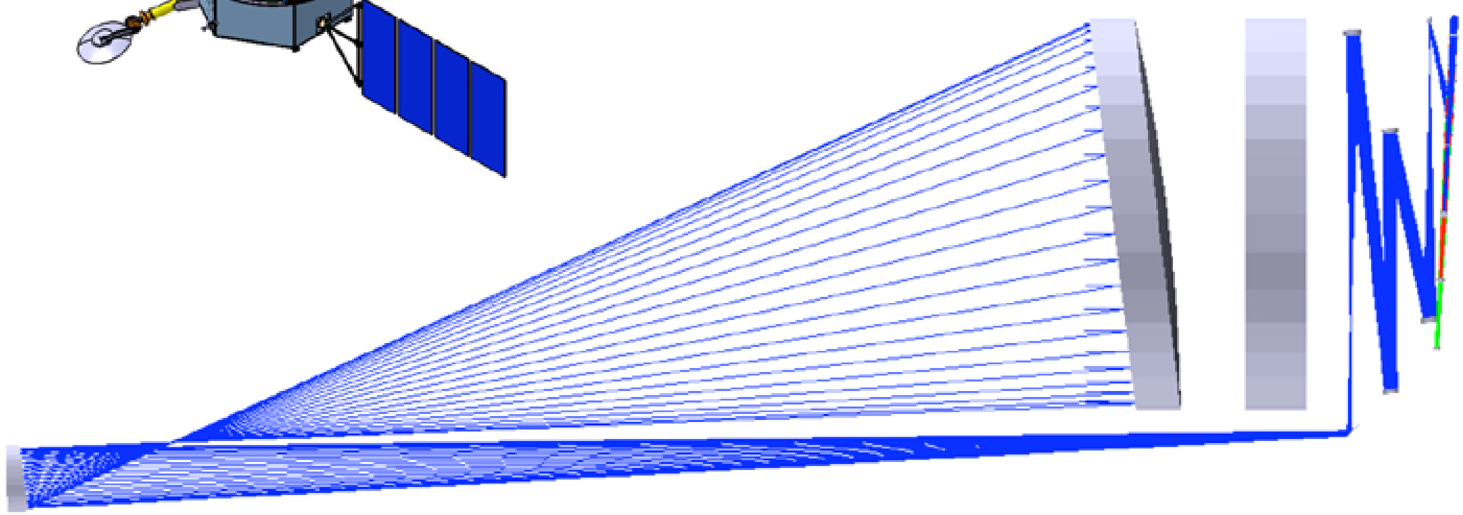
XPC Instruments

- **3 Science Cameras (250-400, 400-700, 700-1000)**
- **2 Integral Field Units**
- **Coarse and Fine IR Occulter Tracking Camera**
  - **Fine 20 arcsec field with 2k x 2k detectors**
  - **Coarse with 200 arcsec field**

Off-Axis Telescope for Coronagraphic Instruments

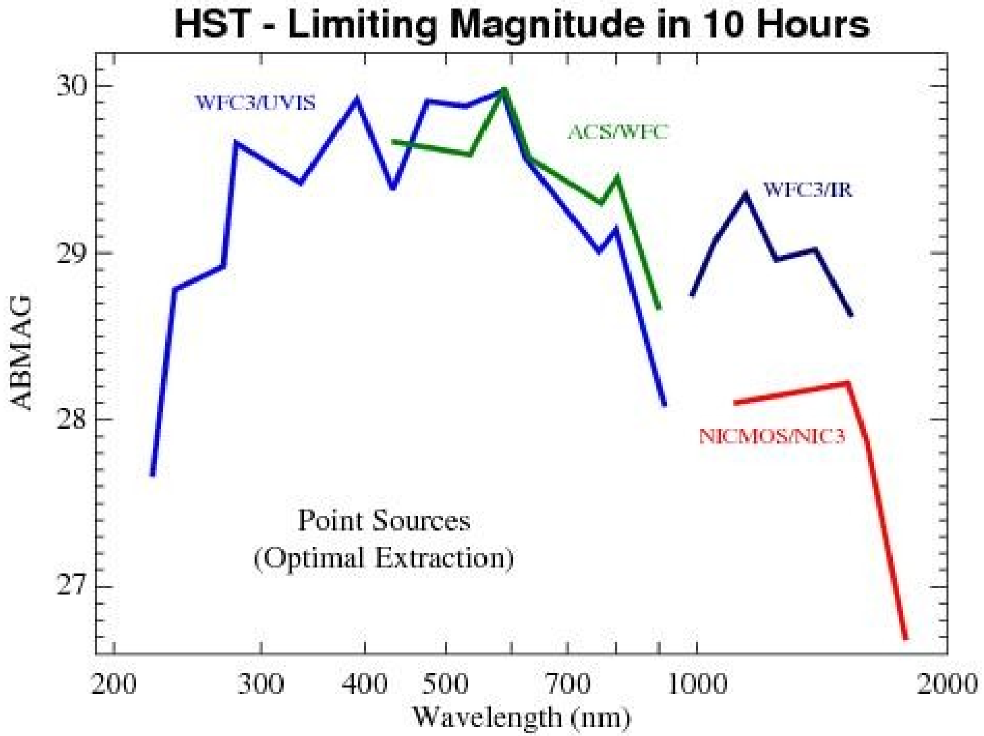


ACCESS observatory:
1.5 meter -
unobscured off-axis
gregorian telescope

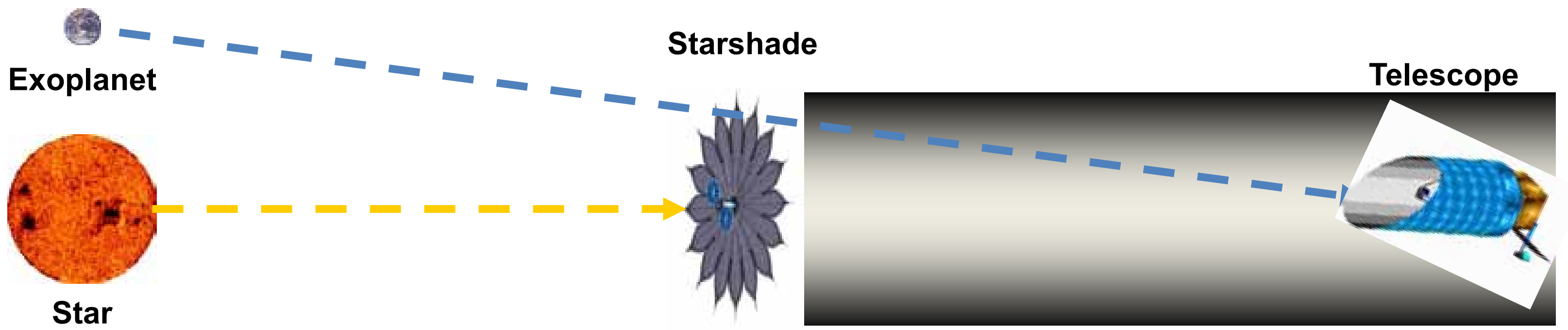


4-m Telescope Performance

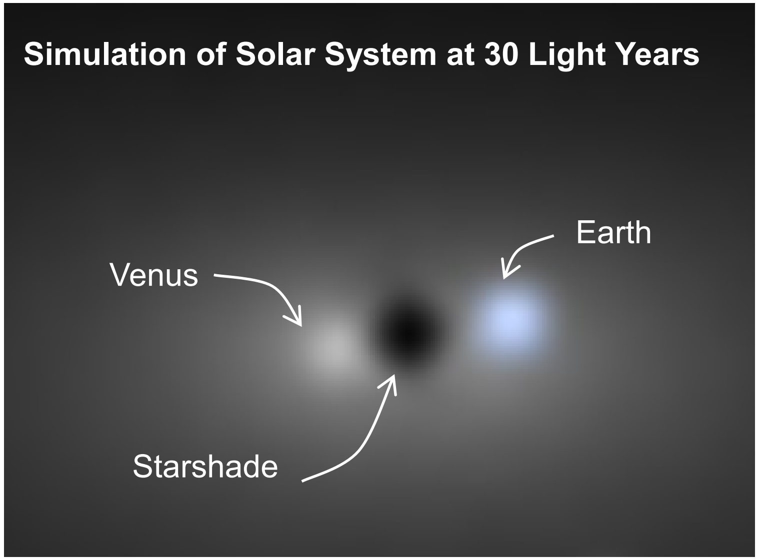
- Compared to he HST, a 4-m telescope will have:
  - Collecting area of 12.37 m^2 versus 4.45 m2 (2.78 X greater)
  - Point Source Sensitivity 7.72 x greater
  - Limiting Magnitude 2.22^m greater (~32 ABMAG in 10 hours)



Starshades: Direct Imaging of ExoPlanets



- “Starshade” blocks out target star’s light
- Allows the planet light to reach the telescope
- No special requirements for the telescope, making it easier to build and friendly for general astrophysics
- Starshade **with hypergaussian petals** deigned by Northrop and Webster Cash



Starshades are Scaled to Meet Mission Requirements

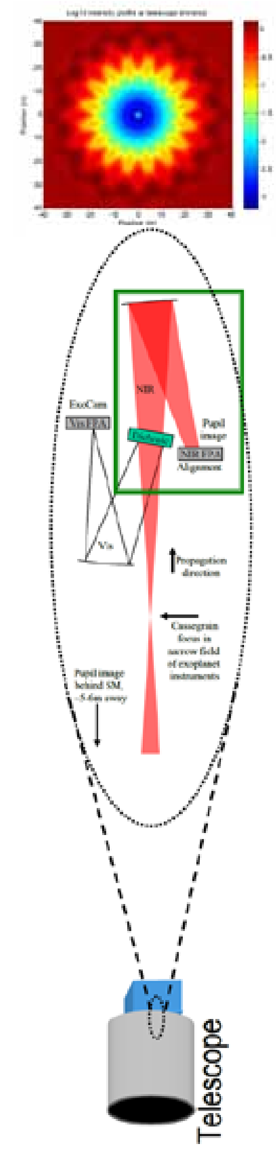
- Starshade sized for various missions:

Case	Telescope Diameter (D_{Tel})	Starshade Diameter (D_{SS})	SS/Tel Distance (z)	D_{Tel}/D_{SS}	IWA	F# at 0.6 [redacted]m
ACCESS	1.5 m	25 m	15,000 km	0.06	170 mas	17
NWO Flagship	4 m	50 m	80,000 km	0.08	65 mas	13
Starshade with JWST – small	6.5 m	30 m	25,000 km	0.22	120 mas	15
Starshade with JWST – large	6.5 m	50 m	55,000 km	0.13	94 mas	19
ATLAST – small	8 m	80 m	165,000 km	0.1	50 mas	16
ATLAST – large	16 m	90 m	185,000 km	0.18	50 mas	18

- Note that starshade is not scaled directly to telescope size, each mission has its own science requirements that were considered

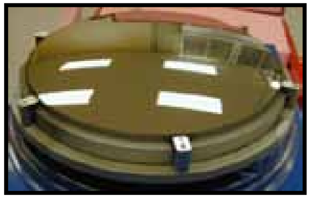
Telescope Enhancements for Use With Starshades

- S-Band Transponder for RF ranging between telescope and occulter
  - Range and range-rate data combined with ground-based tracking locates telescope and occulter within 50 km
- Laser beacon (low-power "pointer") for telescope acquisition by starshade's astrometric camera
  - Camera provides telescope location relative to background stars with 5 milli-arcsecond resolution, 1-sigma (>2-m at 80,000 km)
- Shadow sensor (pupil plane NIR imager) to sense location of the telescope within the shadow of the Starshade and provide error signals for station keeping
  - Sensor (~10 kg) uses IR leakage (Poisson's Spot) to measure distance from enter of shadow with 10 cm accuracy

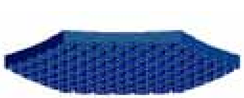
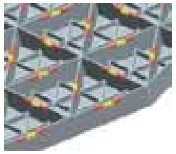
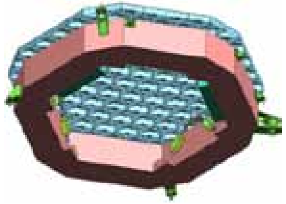


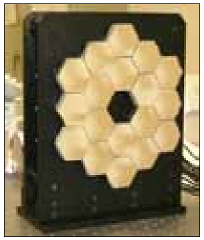
Key Enabling Technologies

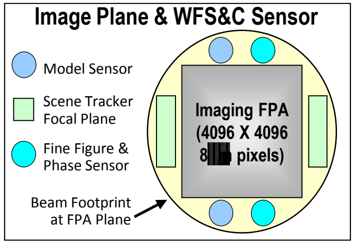
- Rapid, low cost fabrication of ultra-light weight primary mirror segments
  - Eliminates time consuming grinding and polishing
  - Several approaches including vapor deposition of nanolaminates bonded to actuated substrates
- Active figure control of primary mirror segments
  - High precision actuators
  - Surface parallel actuation eliminates need for stiff reaction structure (SMD)
- High speed wavefront sensing and control
  - High density figure control enables very light weight mirror segments
  - High speed, active while imaging WFS&C allows for rapid slew and settle and earth imaging
- Highly-packageable & scalable deployment techniques
  - Deployment architecture that take advantage of light weight mirrors
- Active control for light weight structural elements to supply good stability
  - Reduces weight required for vibration and thermal control

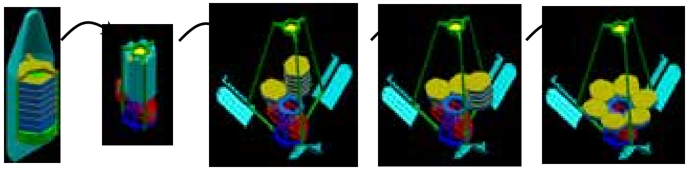


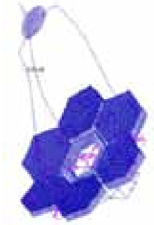
Nanolaminate on Mandrel

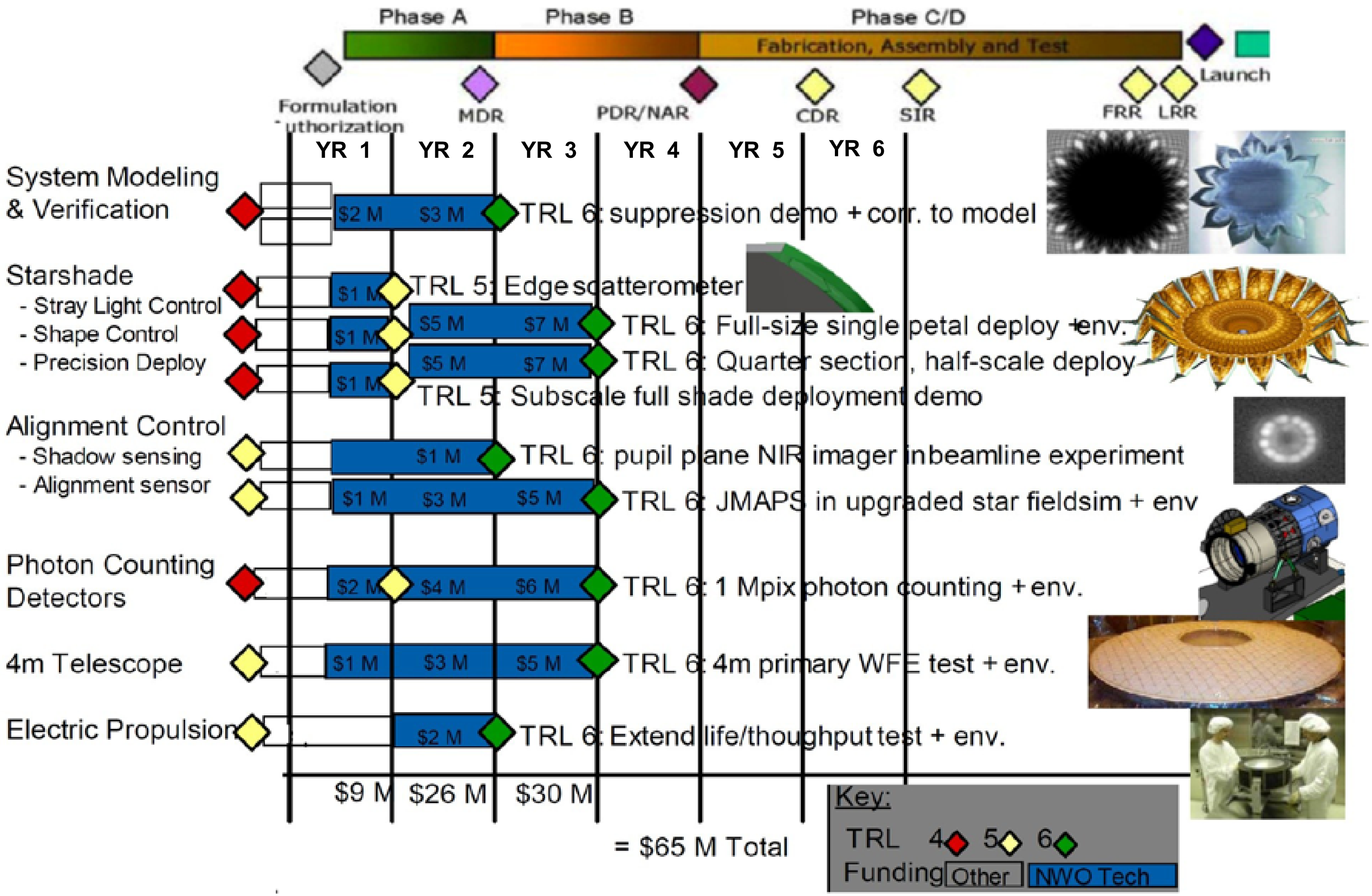









Starshade Technology Development



Summary

- “Key advances could be made with a telescope with a 4-meter-diameter aperture with large field of view and fitted with high-efficiency UV and optical cameras/ spectrographs operating at shorter wavelengths than HST”
- “The EOS panel believes that, if technology developments of the next decade show that a UV-optical telescope with a wide scope of observational capabilities can also be a mission to find and study Earth-like planets, there will be powerful reason to build such a facility.”
- An off-axis 4-m telescope with a coronagraph, the instruments proposed for THEIA, and the enhancements need for operation with a starshade would meet the requirements for ExoPlanet detection and characterization and meet the needs of the general astrophysics community for a UVOIR follow-on to HST.
- This telescope can be developed at an affordable cost if the key enabling technologies, which have been identified, are developed during this decade