A Future Large-Aperture UVOIR Space Observatory: Key Technologies and Capabilities

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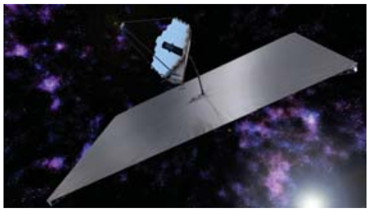
We identify six key technologies that will enable a future, large-aperture ultraviolet/optical/infrared (UVOIR) space observatory:

- Starlight Suppression Systems
- Lightweight Mirror Segments
- Sensing & Control Systems
- Vibration Isolation
- Detectors
- Mirror Coatings

These capabilities will provide major advances over current and near-future observatories for sensitivity, angular resolution, and high-contrast imaging.



We present the top-level science requirements flow-down to both the telescope and a notional instrument suite (Tables 1 & 2), pending engineering trade studies and further definition of the mission science goals and requirements.

For each technology area, a gap analysis is presented in the context of a design reference missions consisting of a 10-m class segmented aperture telescope with an internal coronagraph for exoplanet science.

Table 1 – Science Requirements Flow-Down to Telescope

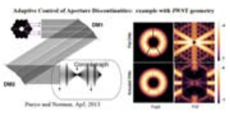
Parameter		Requirement	Stretch Goal	Traceability
Primary Mirror Aperture		≥ 8 meters	12 meters	Sensitivity Exoplanet Yield
Telescope Temperature		273 K – 293 K	-	Thermal Stability Ground Testing
Wavelength Coverage	UV	100 nm – 300 nm	90 nm – 300 nm	
	Vis	300 nm – 950 nm	-	
	NIR	950 nm – 1.8 μm	950 nm – 2.5 μm	
	MIR	-	Capability Under Evaluation	
Image Quality	UV	< 0.20 arcsec at 150 nm		
	Vis/NIR/MIR	Diffraction-limited at 500 nm		
Stray Light		Zodi-limited between 400 nm – 1.8 μm		
Wavefront Error Stability (for Exoplanet Science)		< 10 pm RMS uncorrected WFE per control step		
Pointing		1 milli-arcsec		

Table 2 – Science Requirements Flow-Down to *Notional* Instrument Suite, pending engineering trade studies and further definition of the mission science goals and requirements.

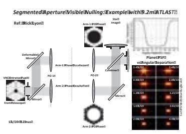
Science Instrument	Parameter	Requirement
UV Imager / Multi-Object Spectrograph	Wavelength Range	100 nm (90 nm goal) – 300 nm
	Field-of-View	1 – 2 arcmin
	Image Resolution	< 0.20 arcsec
	Spectral Resolution	R = 20,000 – 300,000 (selectable modes)
Vis Imager / Multi-Object Spectrograph	Wavelength Range	300 nm – 950 nm
	Field-of-View	4 – 8 arcmin
	Image Resolution	Nyquist sampled at 500 nm
	Spectral Resolution	R = 100 – 10,000 (selectable modes)
NIR Imager / Multi-Object Spectrograph	Wavelength Range	950 nm – 1.8 μm (2.5 μm goal)
	Field-of-View	3 – 4 arcmin
	Image Resolution	Nyquist sampled at 950 nm
	Spectral Resolution	R = 100 – 10,000 (selectable modes)
MIR Imager / Spectrograph	Wavelength Range	2.5 μm – 8 μm
	Field-of-View	3 – 4 arcmin
	Image Resolution	Nyquist sampled at 2.5 μm
	Spectral Resolution	R = 5 – 500 (selectable modes)
Starlight Suppression System	Wavelength Range	400 nm – 1.8 μm
	Raw Contrast	10^{-10}
	Contrast Stability	10^{-11} over an observation
	Inner-working Angle	20 milli-arcsec @ 400 nm
	Outer-working Angle	1 arcsec @ 400 nm
Multi-Band Exoplanet Imager	Field-of-View	~ 1 arcsec
	Image Resolution	Nyquist sampled at 500 nm
Exoplanet Spectrograph	Field-of-View	~ 1 arcsec
	Spectral Resolution	R = 70 – 500 (selectable modes)

Starlight Suppression System

Gap Title	Capability Needed	Capability Today
Contrast Performance	1×10^{-10} raw contrast, 1×10^{-11} contrast stability between 2λ/D and 100λ/D.	1.3×10^{-10} raw contrast between 3λ/D and 16λ/D for an internal coronagraph. 4×10^{-10} raw contrast prediction for starshade at non-Flight Fresnel number, excluding edge reflections.
Bandpass	Meet contrast requirement between 400 nm – 1.8 μm.	1.3×10^{-10} raw contrast between 700 nm – 880 nm.
Segmented Aperture Performance	Meet contrast requirement with obscured, segmented aperture.	5.7×10^{-9} narrowband raw contrast with a hexagonally-segmented deformable mirror. Active Control of Aperture Discontinuities (ACAD) simulations indicate 3×10^{-9} contrast over 30% bandwidth with apodizing masks.
Starshade Edge Scatter	Edges manufactured of high flexural strength material with edge radius ≤ 1 μm.	Graphite edges meet specs except for edge radius at ≥ 10 μm. Razor blades meet optical requirements but are not stowable.
Starshade Formation Flight	Sensors demonstrated with errors ≤ 0.25 m. Control algorithms demonstrated with lateral control errors ≤ 1m.	Simulations have shown that sensing and GN&C is tractable, though sensing demonstrations of lateral control has not yet been performed.
Starshade Petal Construction & Deployment	Demonstrate a fully integrated petal, including blankets, edges, and deployment control interfaces.	Low-fidelity petals have been assembled and precision petal manufacturing has been demonstrated.
Starshade Truss Construction & Deployment	Demonstrate the budgeted in-plane deployment tolerances (~1 mm to < 1 mm) using a half-scale or larger prototype.	Millimeter-wave mesh antennas have been deployed in space with diameters up to 17 m × 19 m and a out-of-plane accuracy of 2.4 mm.
Model Validation	Models and error budgets of starlight suppression architectures, validated to the 1×10^{-11} raw contrast level, including thermal & dynamic effects, relevant Fresnel numbers, and a dynamic wavefront control system.	Error budget tool that incorporates apodizing coronagraphs, but not nullers. Does not include segment-to-segment dynamics. Models for various architectures exist, but are not yet fully correlated to testbed results to the 1×10^{-11} level

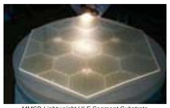


Starshade Petal
Structural Prototype & Deployment Experiment

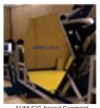


Lightweight Mirror Segments

Gap Title	Capability Needed	Capability Today
Mirror Static Surface Figure Error	< 7 nm RMS Total: 5 nm RMS Low Spatial Freq. 5 nm RMS Mid Spatial Freq. 1.5 nm RMS High Spatial Freq. 1 nm RMS Surface Roughness	~25 nm RMS total (JWST) ~7 nm RMS total (HST)
Wavefront Error Stability	< 10 pm RMS total per control step: < 7 pm RMS mechanical < 7 pm RMS thermal	~70 nm RMS total per 14 days (JWST)
Areal Density	< 36 kg/m² for existing launch vehicles < 500 kg/m² for planned (SLS)	70 kg/m² (JWST) 460 kg/m² (HST)
Areal Cost	< $2M/m²	~$6M/m² (JWST) ~$12M/m² (HST)
Areal Production Rate	> 10 m²/year	~4 m²/year (JWST) ~1 m²/year (HST)



MMSD Lightweight ULE Segment Substrate



AHM SiC-based Segment Substrate

Sensing & Control Systems

Gap Title	Capability Needed	Capability Today
Mirror Thermal Control System	0.01 mK sensor precision < 1 mK heater precision	???
Autonomous Onboard Processing	Control bandwidths ~ Hz > 100 GFLOPS/W	Control once per 14 days (JWST) < 20 GFLOPS/W (SpaceCube 1.0)
Deformable Mirrors	> 4000 actuators (DOFs) Routine 100% yield Environmentally qualified	4096 actuators (continuous) 501 actuators (segmented) < 100% yield Some environmental testing performed
Mirror Position Metrology	<1 pm accuracy	~1 nm accuracy
Mirror Actuators	~1 pm accuracy	~5 nm accuracy

IrisAO 167-Segement Piston-Tip-Tilt Deformable Mirror

Xinetics 48x48 Continuous Face-Sheet Deformable Mirror

Vibration Isolation

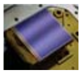
Gap Title	Capability Needed	Capability Today
Active Vibration Isolation	140 dB attenuation > 40 Hz	80 dB attenuation > 40 Hz (JWST)
Low Disturbance RWA & Mounts		0.48 g-cm static 13.7 g-cm² dynamic
Integrated Modeling	High-fidelity, multidisciplinary design & modeling tools, supporting efficient analysis methods	Cross-discipline modeling tools are incompatible. Multi-week/month turn-around time on design iterations.

Lockheed 5-DOF DFP Testbed

Rockwell-Collins RDR68 Reaction Wheel

Detector Systems

Gap Title	Capability Needed	Capability Today
UV, Visible-Blind Detectors	>50% Q.E. between 90 nm – 350 nm <5 e⁻ read noise >4 Mpixel	5-20% Q.E. between 150 nm – 300 nm <5 e⁻ read noise 1 Mpixel
Visible/NIR Photon Counting Detectors	>80% Q.E. between 400 nm – 1.7 μm <1 e⁻ read noise <0.001 e⁻/pix/s dark current	> 60% Q.E. between 300 nm – 750 nm ~1 e⁻ read noise ~0.001 e⁻/pix/s dark current



Teledyne H4RG

Mirror Coatings

Gap Title	Capability Needed	Capability Today
UV Coating Reflectivity	>90% at wavelengths ≥ 90 nm	85% at wavelengths 180 nm – 300 nm 60% at wavelengths 90 nm – 180 nm
UV Coating Uniformity	<1 – 0.1% at wavelengths ≥ 90 nm	1% at wavelengths ≥ 90 nm
UV Coating Polarization	<1% at wavelengths ≥ 90 nm	1% at wavelengths ≥ 90 nm