	ID	Title	Description	Current Capabilities	Needed Capabilities
Contrast	CG-2	Coronagraph Optics and Architecture	Coronagraph optics and architecture that suppress diffracted starlight by a factor of ≤ 10^{-9} at visible and infrared wavelengths.	$6x10^{-10}$ raw contrast at 10% bandwidth across angles of 3-16 λ/D demonstrated with a linear mask and an unobscured pupil in a static vac lab env't (Hybrid Lyot) < $8.8x10^{-9}$ raw contrast at 10% bandwidth across angles of 3-9 λ/D demonstrated with a circularly-symmetric mask and obscured pupil in a static vacuum lab env't (WFIRST)	Coronagraph masks and optics capable of creating circularly symmetric dark regions in the focal plane enabling raw contrasts ≤ 10^{-9}, IWA ≤ 3 λ/D, throughput ≥ 10%, and bandwidth ≥ 10% on obscured/segmented pupils in a simulated dynamic vacuum lab environment.
Angular Resolution (plus sensitivity, integration time, and planet yield)	CG-1	Large Aperture Primary Mirrors	Large monolith and multi-segmented mirrors that meet tight surface figure error and thermal control requirements at visible wavelengths.	**Monolith:** 3.5m sintered SiC with < 3 um SFE (Herschel) 2.4m ULE with ~ 10 nm SFE (HST) Depth: Waterjet cutting is TRL 9 to 14", but TRL 3 to >18". Fused core is TRL 3; slumped fused core is TRL 1. **Segmented:** 6.5m Be with 25 nm SFE (JWST) Non-NASA: 6 dof, 1-m class SiC and ULE, < 20 nm SFE, and < 5 nm wavefront stability over 4 hr with thermal control	Aperture: 4m - 12m; SFE < 10 nm rms (wavelength coverage 400 nm - 2500 nm) Wavefront stability better than 10 pm rms per wavefront control time step. Segmented apertures leverage 6 DOF or higher control authority meter-class segments for wavefront control. Environmentally tested.
Detection Sensitivity	CG-8	Ultra-Low Noise, Large Format Visible Detectors	Low-noise visible detectors for faint exoplanet characterization with an Integral Field Spectrograph	1kx1k silicon EMCCD detectors provide dark current of $8x10^{-4}$ e-/px/sec; effective read noise < 0.2 e- rms (in EM mode) after irradiation when cooled to 165.15K (WFIRST). 4kx4k EMCCD fabricated but still under development.	Effective read noise < 0.1e- rms; CIC < $3x10^{-3}$ e-/px/fram; dark current < 10^{-4} e-/px/sec tolerant to a space radiation environment over mission lifetime. ≥ 2kx2k format
Detection Sensitivity	CG-9	Ultra-Low Noise, Large Format Near Infrared Detectors	Near infrared wavelength (900 nm to 2.5 μm), extremely low noise detectors for exo-earth spectral characterization with Integral Field Spectrographs.	HgCdTe photodiode arrays have read noise <~ 2 e- rms with multiple non-destructive reads; dark current < 0.001 e-/s/pix; very radiation tolerant (JWST). HgCdTe APDs have dark current ~ 10-20 e-/s/pix, RN << 1 e- rms, and < 1kx1k format Cryogenic (superconducting) detectors have essentially no read noise nor dark current; radiation tolerance is unknown.	Read noise << 1 e- rms, dark current < 0.001 e-/pix/s, in a space radiation environment over mission lifetime. ≥ 2kx2k format

	ID	Title	Description	Current Capabilities	Needed Capabilities
Contrast Stability	CG-6	Segment Phasing Sensing and Control	Multi-segment large aperture mirrors require phasing and rigid-body sensing and control of the segments to achieve tight static and dynamic wavefront errors.	6 nm rms rigid body positioning error and 49 nm rms stability (JWST error budget) SIM and non-NASA: nm accuracy and stability using laser metrology	Systems-level considerations to be evaluated but expect will require less than 10 pm rms accuracy and stability.
Contrast Stability	CG-7	Telescope Vibration Control	Isolation and damping of spacecraft and payload vibrational disturbances	80 dB attenuation at frequencies > 40 Hz (JWST passive isolation) Disturbance Free Payload demonstrated at TRL 5 with 70 dB attenuation at "high frequencies" with 6-DOF low-order active pointing.	Monolith: 120 dB end-to-end attenuation at frequencies > 20 Hz. Segmented: 140 dB end-to-end attenuation at frequencies > 40 Hz. End-to-end implies isolation between disturbance source and the telescope.
Contrast	CG-3	Deformable Mirrors	Environment-tested, flight-qualified large format deformable mirrors	Electrostrictive 64x64 DMs have been demonstrated to meet ≤ 10^{-9} contrasts and < 10^{-10} stability in a vacuum environment and 10% bandwidth; 48x48 DM passed random vibe testing.	4 m primary: ≥ 96x96 actuators 10 m primary: ≥ 128x128 actuators Enable raw contrasts of ≤ 10^{-9} at ~20% bandwidth and IWA ≤ 3 λ/D Flight-qualified device and drive electronics (radiation hardened,environmentally tested, life-cycled including connectors and cables) Large segment DM needs possible for segmented telescopes.
Contrast Stability	CG-5	Low-Order Wavefront Sensing and Control	Sensing and control of line of sight jitter and low-order wavefront drift	< 0.5 mas rms per axis LOS residual error demonstrated in lab with a fast-steering mirror attenuating a 14 mas LOS jitter and reaction wheel inputs; ~ 100 pm rms sensitivity of focus (WFIRST). Higher low-order modes sensed to 10-100 nm WFE rms on ground-based telescopes.	Sufficient fast line of sight jitter (< 0.5 mas rms residual) and slow thermally-induced (≤ 10 pm rms sensitivity) WFE sensing and control to maintain closed-loop < 10^{-9} raw contrast with an obscured/segmented pupil and simulated dynamic environment.
Contrast	CG-4	Post-Data Processing	Post-data processing techniques to uncover faint exoplanet signals from residual speckle noise at the focal-plane detector.	Few 100x speckle suppression has been achieved by HST and by ground-based AO telescopes in the NIR and in contrast regimes of 10^{-4} to 10^{-5}, dominated by phase errors.	A 10-fold contrast improvement in the visible from 10^{-9} raw contrast where amplitude errors are expected to be important (or a demonstration of the fundamental limits of post-processing)

	ID	Title	Description	Current Capabilities	Needed Capabilities
Optical Performance and Model Validation	S-2	Optical Performance Demonstration and Validated Optical Model	Experimentally validate the equations that predict the contrasts achievable with a starshade.	3×10^{-10} contrast at 632 nm, 5 cm mask, and ~500 Fresnel #; validated optical model 9×10^{-10} contrast at white light, 58 cm mask, and 210 Fresnel #	Experimentally validate models predicting contrast to ≤ 10^{-10} just outside petal edges in scaled flight-like geometry with Fresnel numbers ≤ 20 across a broadband optical bandpass.
	S-1	Controlling Scattered Sun Light	Limit edge-scattered sunlight and diffracted starlight with optical petal edges that also handle stowed bending strain.	Machined graphite edges meet all specs but edge radius (10 um); etched metal edges meet all specs but in-plane shape tolerance (Exo-S design).	Integrated petal optical edges maintaining precision in-plane shape requirements after deployment trials and limiting contrast contribution of solar glint to < 10^{-10} at petal edges.
Formation Sensing and Control	S-3	Lateral Formation Sensing	Demonstrate lateral formation flying sensing accuracy consistent with keeping telescope in starshade's dark shadow.	Centroid star positions to ≤ 1/100th pixel with ample flux. Simulations have shown that sensing and GN&C is tractable, though sensing demonstration of lateral control has not yet been performed.	Demonstrate sensing lateral errors ≤ 0.30 m accuracy at scaled flight separations (±1 mas bearing angle). Estimated centroid positions to ≤ 1/40th pixel with limited flux from out of band starlight. Control algorithms demonstrated with scaled lateral control errors corresponding to ≤ 1 m.
Deployment Accuracy and Shape Stability	S-5	Petal Positioning Accuracy and Opaque Structure	Demonstrate that a starshade can be autonomously deployed to within its budgeted tolerances after exposure to relevant environments.	Petal deployment tolerance (≤ 1 mm) verified with low fidelity 12m prototype and no optical shield; no environmental testing (Exo-S design).	Deployment tolerances demonstrated to ≤ 1 mm (in-plane envelope) with flight-like, minimum half-scale structure, simulated petals, opaque structure, and interfaces to launch restraint after exposure to relevant environments.
	S-4	Petal Shape and Stability	Demonstrate a high-fidelity, flight-like starshade petal meets petal shape tolerances after exposure to relevant environments.	Manufacturing tolerance (≤ 100 µm) verified with low fidelity 6m prototype and no environmental tests. Petal deployment tests conducted but on prototype petals to demonstrate rib actuation; no shape measurements.	Deployment tolerances demonstrated to ≤ 100 µm (in-plane envelope) with flight-like, minimum half-scale petal fabricated and maintains shape after multiple deployments from stowed configuration.