Technology Needs and Prioritization Process

Nick Siegler

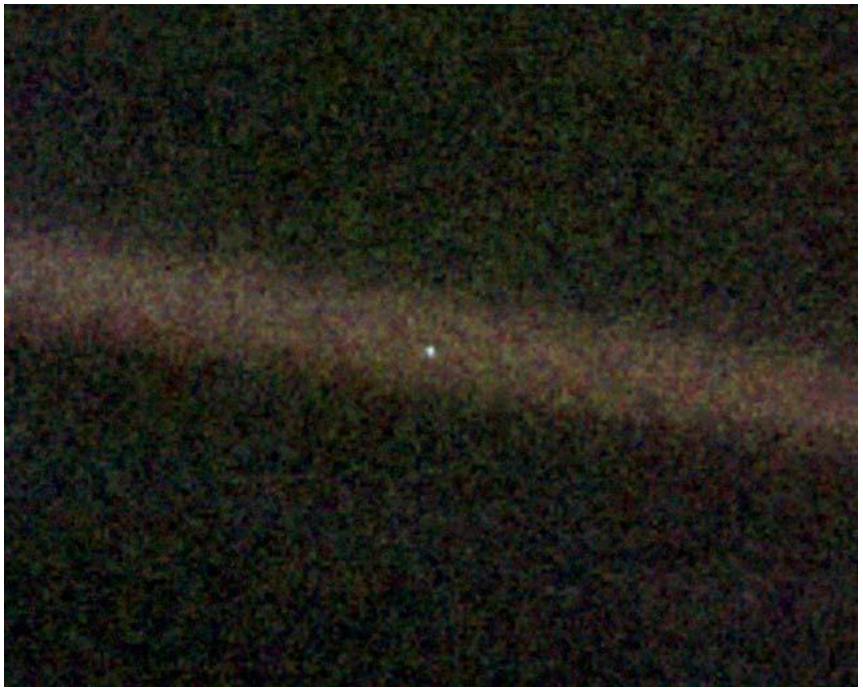
ExoPAG Executive Council Telecon

06/07/16

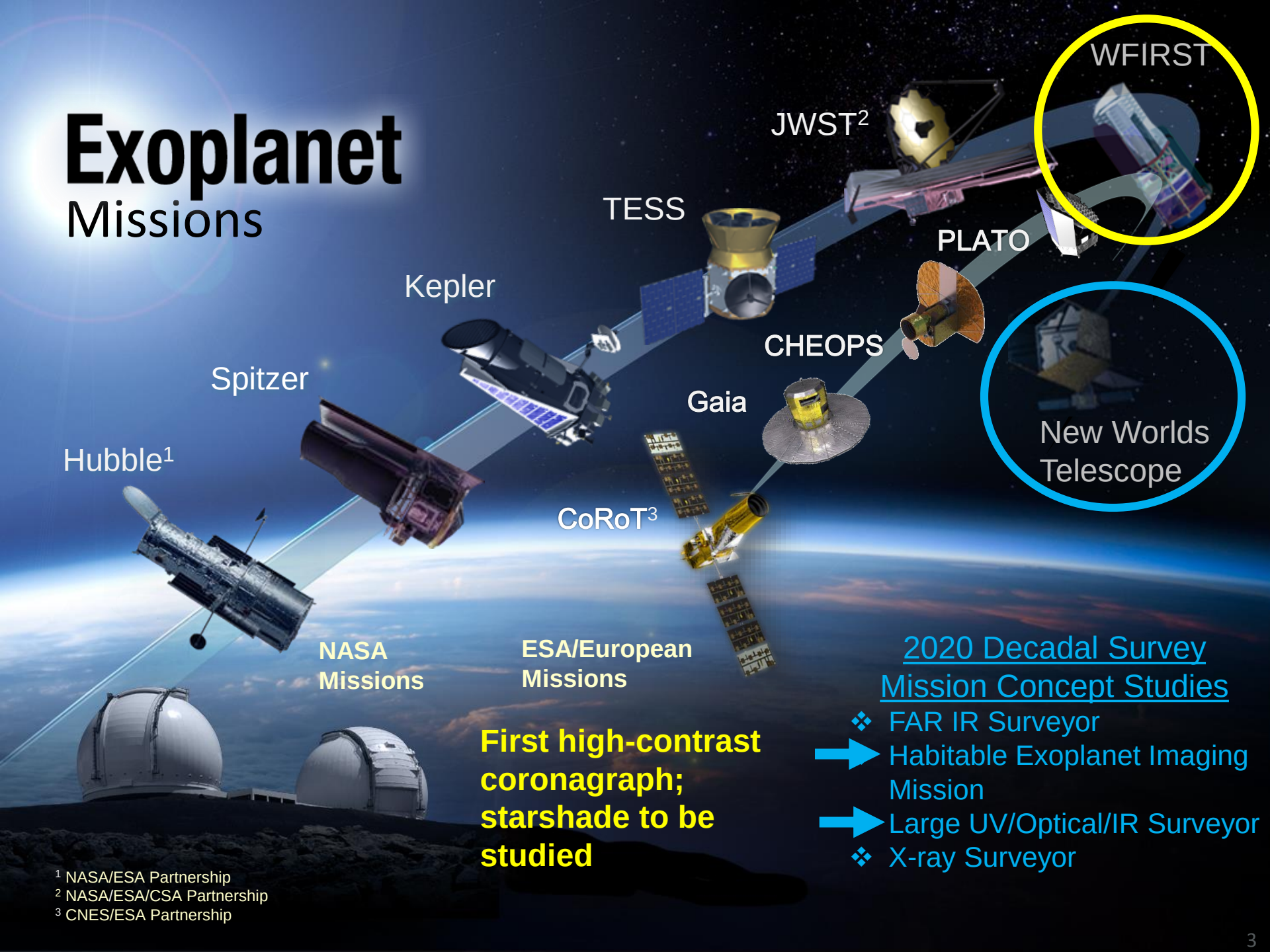
The ExEP Technology Focus

The ExEP technology goals are driven by and focused on enabling the science capability to directly image and spectrally characterize exo-earths in the HZ of Sun-like stars and beyond.

- *all other valuable exoplanet science goals, it is assumed, can be achieved along the way (study of larger planets, disk science, planetary orbits, etc)*



Exoplanet Missions



NASA Missions

ESA/European Missions

First high-contrast coronagraph; starshade to be studied

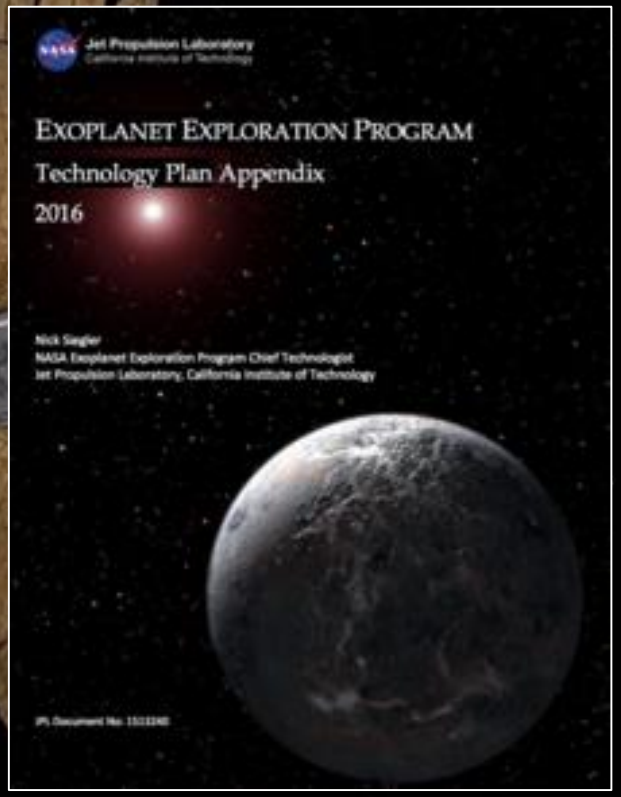
[2020 Decadal Survey Mission Concept Studies](#)

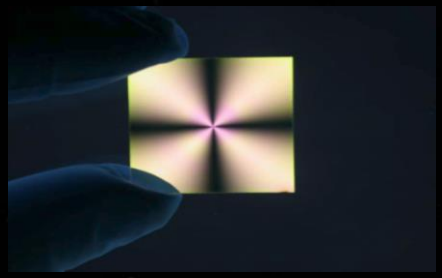
- FAR IR Surveyor
- Habitable Exoplanet Imaging Mission
- Large UV/Optical/IR Surveyor
- X-ray Surveyor

[1] NASA/ESA Partnership
[2] NASA/ESA/CSA Partnership
[3] CNES/ESA Partnership

ExEP Technology Gap Lists

Enabling Technologies Only





Starshade Technology Gap List

Table A.3 Coronagraph Technology Gap List.

ID	Title	Description	Current	Required
C-1	Specialized Coronagraph Optics	Masks, apodizers, or beam-shaping optics to provide starlight suppression and planet detection capability.	A linear mask design has yielded 3.2×10^{-10} mean raw contrast from 3–16 λ/D with 10% bandwidth using an unobscured pupil in a static lab demonstration.	Circularly symmetric masks achieving $\leq 1\times10^{-10}$ contrast with IWA $\leq 3\lambda/D$ and $\geq 10\%$ bandwidth on obscured or segmented pupils.
C-2*	Low-Order Wavefront Sensing & Control	Beam jitter and slowly varying large-scale (low-order) optical aberrations may obscure the detection of an exoplanet.	Tip/tilt errors have been sensed and corrected in a stable vacuum environment with a stability of 10^{-3} λ rms at sub-Hz frequencies.	Tip/tilt, focus, astigmatism, and coma sensed and corrected simultaneously to 10^{-4} λ (~10's of pm) rms to maintain raw contrasts of $\leq 1\times10^{-10}$ in a simulated dynamic testing environment.
C-3*	Large-Format Ultra-Low Noise Visible Detectors	Low-noise visible detectors for faint exoplanet characterization with an Integral Field Spectrograph.	Read noise of < 1 e^-/pixel has been demonstrated with EMCCDs in a 1k × 1k format with standard read-out electronics	Read noise < 0.1e^-/pixel in a ≥ 4k × 4k format validated for a space radiation environment and flight-accepted electronics.
C-4*	Large-Format Deformable Mirrors	Maturation of deformable mirror technology toward flight readiness.	Electrostrictive 64x64 DMs have been demonstrated to meet $\leq 10^{-9}$ contrasts in a vacuum environment and 10% bandwidth.	≥ 64x64 DMs with flight-like electronics capable of wavefront correction to $\leq 10^{-10}$ contrasts. Full environmental testing validation.
C-5	Efficient Contrast Convergence	Rate at which wavefront control methods achieve 10^{-10} contrast.	Model and measurement uncertainties limit wavefront control convergence and require many tens to hundreds of iterations to get to 10^{-10} contrast from an arbitrary initial wavefront.	Wavefront control methods that enable convergence to 10^{-10} contrast ratios in fewer iterations (10-20).
C-6*	Post-Data Processing	Techniques are needed to characterize exoplanet spectra from residual speckle noise for typical targets.	Few 100x speckle suppression has been achieved by HST and by ground-based AO telescopes in the NIR and in contrast regimes of 10^{-5} to 10^{-6}, dominated by phase errors.	A 10-fold improvement over the raw contrast of ~10^{-9} in the visible where amplitude errors are expected to no longer be negligible with respect to phase errors.

*Topic being addressed by directed-technology development for the WFIRST/AFTA coronagraph. Consequently, coronagraph technologies that will be substantially advanced under the WFIRST/AFTA technology development are not eligible for TDEMs.

Coronagraph Technology Gap List

Table A.4 Starshade Technology Gap List

ID	Title	Description	Current	Required
S-1	Control Edge-Scattered Sunlight	Limit edge-scattered sunlight with optical petal edges that also handle stowed bending strain.	Graphite edges meet all specs except sharpness, with edge radius ≥10 µm.	Optical petal edges manufactured of high flexural strength material with edge radius ≤ 1 µm and reflectivity ≤ 10%.
S-2	Contrast Performance Demonstration at Optical Model Validation	Experimentally validate the equations that predict the contrasts achievable with a starshade.	Experiments have validated optical diffraction models at Fresnel number of ~500 to contrasts of 3×10^{-10} at 632 nm.	Experimentally validate models of starlight suppression to $\leq 3\times10^{-11}$ at Fresnel numbers ≤ 50 over 510-825 nm bandpass.
S-3	Lateral Formation Flying Sensing Accuracy	Demonstrate lateral formation flying sensing accuracy consistent with keeping telescope in starshade's dark shadow.	Centroid accuracy ≥ 1% is common. 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 ≤ 0.20m at scaled flight separations and estimated centroid positions ≤ 0.3% of optical resolution. Control algorithms demonstrated with lateral control errors ≤ 1m.
S-4	Flight-Like Petal Fabrication and Deployment	Demonstrate a high-fidelity, flight-like starshade petal and its unfurling mechanism.	Prototype petal that meets optical edge position tolerances has been demonstrated.	Demonstrate a fully integrated petal, including blankets, edges, and deployment control interfaces. Demonstrate a flight-like unfurling mechanism.
S-5	Inner Disk Deployment	Demonstrate that a starshade can be autonomously deployed to within the budgeted tolerances.	Demonstrated deployment tolerances with 12m heritage Astromesh antenna with four petals, no blankets, no outrigger struts, and no launch restraint.	Demonstrate deployment tolerances with flight-like, minimum half-scale inner disk, with simulated petals, blankets, and interfaces to launch restraint.

http://exep.jpl.nasa.gov/technology/

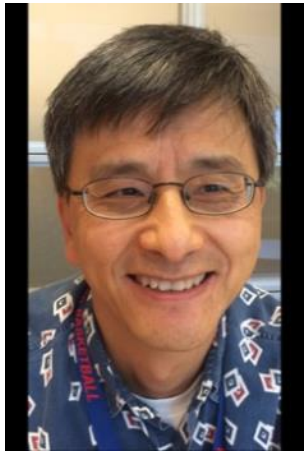
ExEP Technology Development Team

Nick Siegler
Program Chief Technologist

Brendan Crill
Technology Development Manager

David Breda
TDEM Engineer

Stuart Shaklan
SME for coronagraphs and starshades; task lead for the Segmented Coronagraph Design & Analysis



Hong Tang
HCIT Manager

Karl Stapelfeldt
Program Chief Scientist

Technology Needs and Prioritization Process

ID	Activity	Date
1	Technology Input Needs Window Opens	06/08/16
	with email to all three PAGs: Technology Gap Lists, Input Forms, process explanation	
	presentation at June ExoPAG	06/12/16
2	Technology Window Closes	08/26/16
3	Prioritization Criteria Concurred by the ExEP	09/15/16
4	Technology Gaps Prioritized by the ExEP	10/20/16
5	Technology Gap Lists Inform TDEM Amendment	mid-Nov
	Technology Amendment released through NSPIRES	mid-Dec
6	ExEP Technology Plan Appendix Updated and Posted	12/22/16
	Presentation at January ExoPAG	01/02/17
7	TDEM Proposal Deadline	03/17/17
8	TDEM Awards Selected	Aug 2017

- Enabling technologies only - requires ExEP iteration with community members
- PCOS/COR Technology team involved in every step

Technology Needs and Prioritization Process Timeline

Exoplanet Exploration Program

			TDEM Year							
Activity	Intended Result	Resp	J	J	A	S	O	N	D	J
ExEP Technology Needs and Prioritization Process										
TNPP and TGL Presented to ExoPAG EC	EC understands the TNPP, the current TGL, any changes from the previous year, and has opportunity to provide feedback and make requests.	TDM	1st Tue							
TGL Window Opens (ExoPAG receives email request for technology need inputs)	ExoPAG understands the current TGL, how to make technology gap recommendations to the ExEP, how long input window is, what the TNPP is	TDM	day after 1st Tue							
TGL Presented at Summer ExoPAG	ExoPAG understands the TNPP, the current TGL, any changes from the previous year, how to make technology gap recommendations to the ExEP, and has the opportunity to provide feedback and make requests.	TDM	mid-month							
TGL Window Closes					last Fri					
TGL Prioritization Criteria Concurred	Technology gap prioritization criteria is concurred by ExEP techncial leadership team (PM, PS, PCT, PCS, PCE)	TDM				2nd week				
TGL Prioritization	Technology gaps are prioritized by ExEP science and techncial staff	TDM					mid-month			
Present Final TGL to ExoPAG EC and PS	ExoPAG and PS understand final TGL results	TDM						1st Tue		
Provide Input to TDEM Amendment	ExEP PS has received recommendations to the TDEM Amendment	PCT, PS, TDM						mid-month		
Update Technology Plan Appendix	Updated Technology Plan Appendix is posted to the ExEP Technology website	TDM							mid-month	
TGL Presented at Winter ExoPAG	ExoPAG understands the updated TGL and the changes from the previous year	TDM								1st week

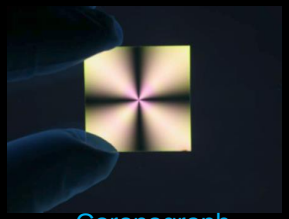
TDEM Timeline

Exoplanet Exploration Program

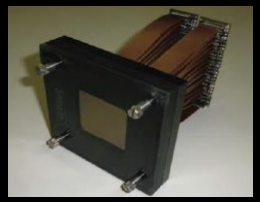
		TDEM Year											TDEM Year plus 1							
Activity	Resp	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
TDEM Process																				
Solicitation Released	PS	mid-month																		
Amendment Posted	PS											mid-month								
Pre-Proposal Briefing Telecon	PS												mid-month							
Proposal Due															mid-month					
Proposals Selected	PS																			by month end

Coronagraph Technology Gaps

Starlight Suppression



Coronagraph Architectures (CG-2)



Deformable mirrors (CG-3)

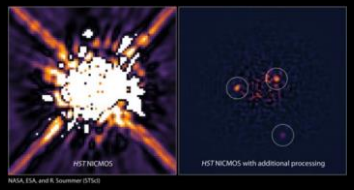
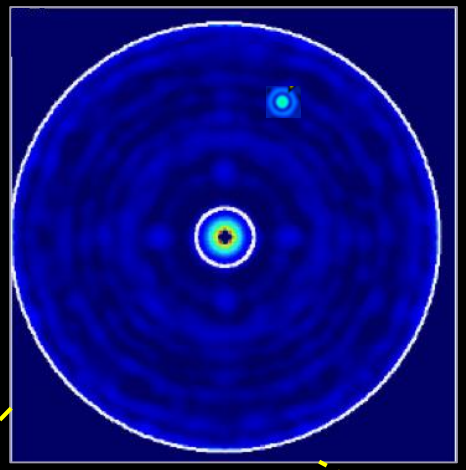
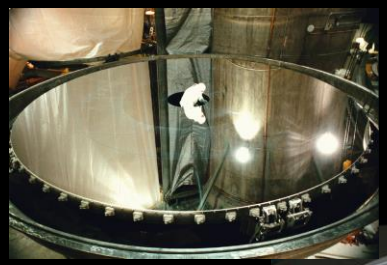


Image post-processing (CG-4)



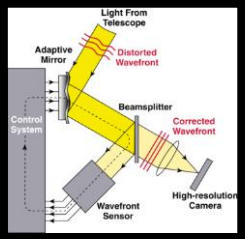
Mirrors



Large monolith (CG-1)

Segmented (CG-1)

WFE Stability

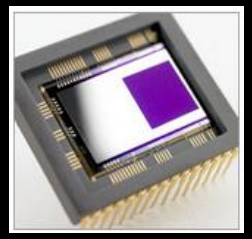


Wavefront sensing and control (CG-5)

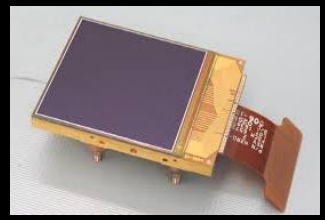
Segment phasing and rigid body sensing and control (CG-6)

Telescope vibration sensing and control (CG-7)

Detection Sensitivity



Ultra-low noise visible detectors (CG-8)

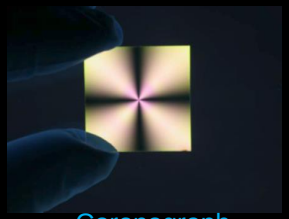


Ultra-low noise infrared detectors (CG-9)

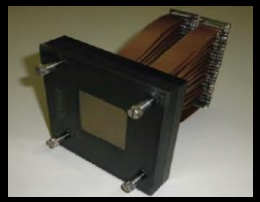
Coronagraph Technology Gaps

TDEM-14, -15

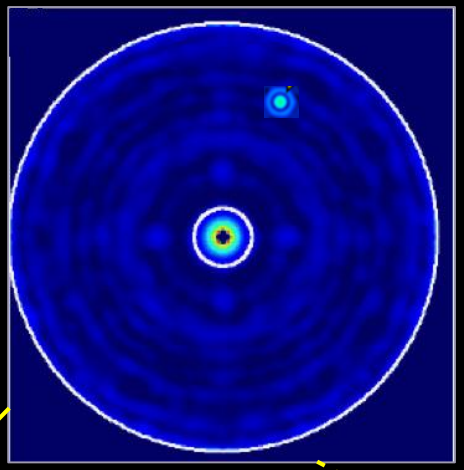
Starlight Suppression



Coronagraph Architectures (CG-2)



Deformable mirrors (CG-3)



WFIRST

Image post-processing (CG-4)

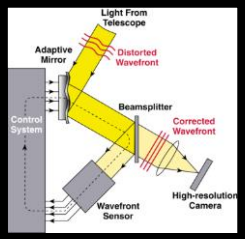
Mirrors

COR/PCOS

Large monolith (CG-1)

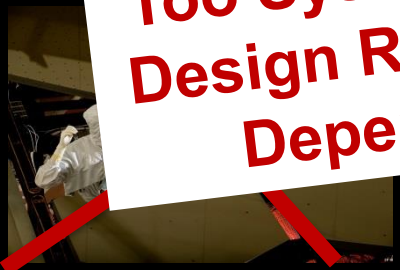
Segmented (CG-1)

WFE Stability



Wavefront sensing and control (CG-5)

Too Systems and Design Reference Dependent



Segment phasing and rigid body sensing and control (CG-6)

Telescope vibration sensing and control (CG-7)

Detection Sensitivity

WFIRST

COR/PCOS

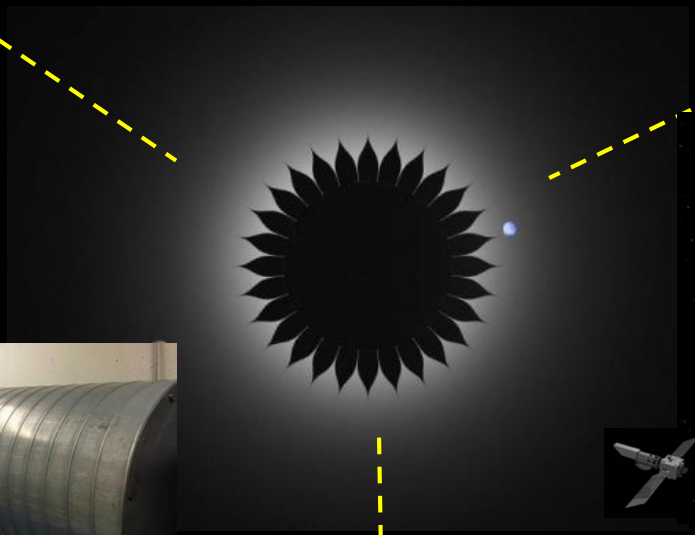
Ultra-low noise visible detectors (CG-8)

Ultra-low noise infrared detectors (CG-9)

Starshade Technology Gaps

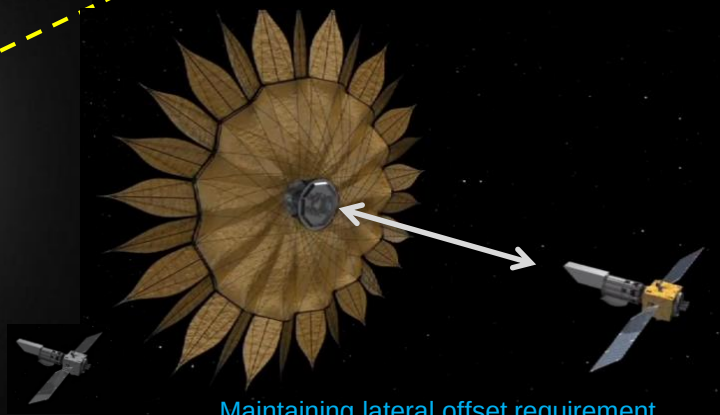
Starlight Suppression

Controlling Sunlight scattering off petal edges (S-2)



Suppressing starlight and validating optical model (S-1)

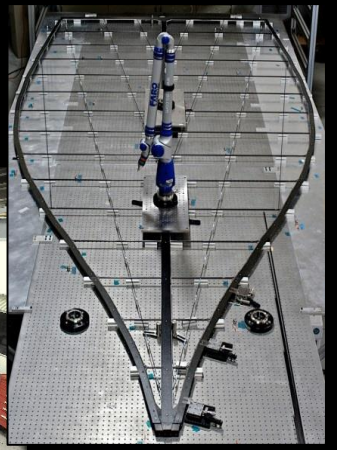
Formation Sensing and Control



Maintaining lateral offset requirement between the spacecrafts (S-3)

Deployment Accuracy and Shape Stability

Positioning the petals to high precision, blocking on-axis starlight, maintaining overall shape on a highly stable structure (S-5)



Fabricating the petal to high precision (S-4)

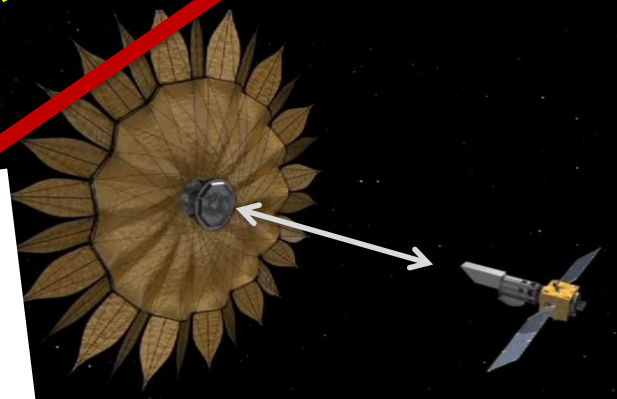
Starshade Technology Gaps

TDEM-16

Starlight Suppression

Controlling Sunlight scattering off petal edges (S-2)

Formation Sensing and Control



Maintaining lateral offset requirement between the spacecrafts (S-3)

Starshade Technology Project

Suppressing starlight and validating optical model (S-1)

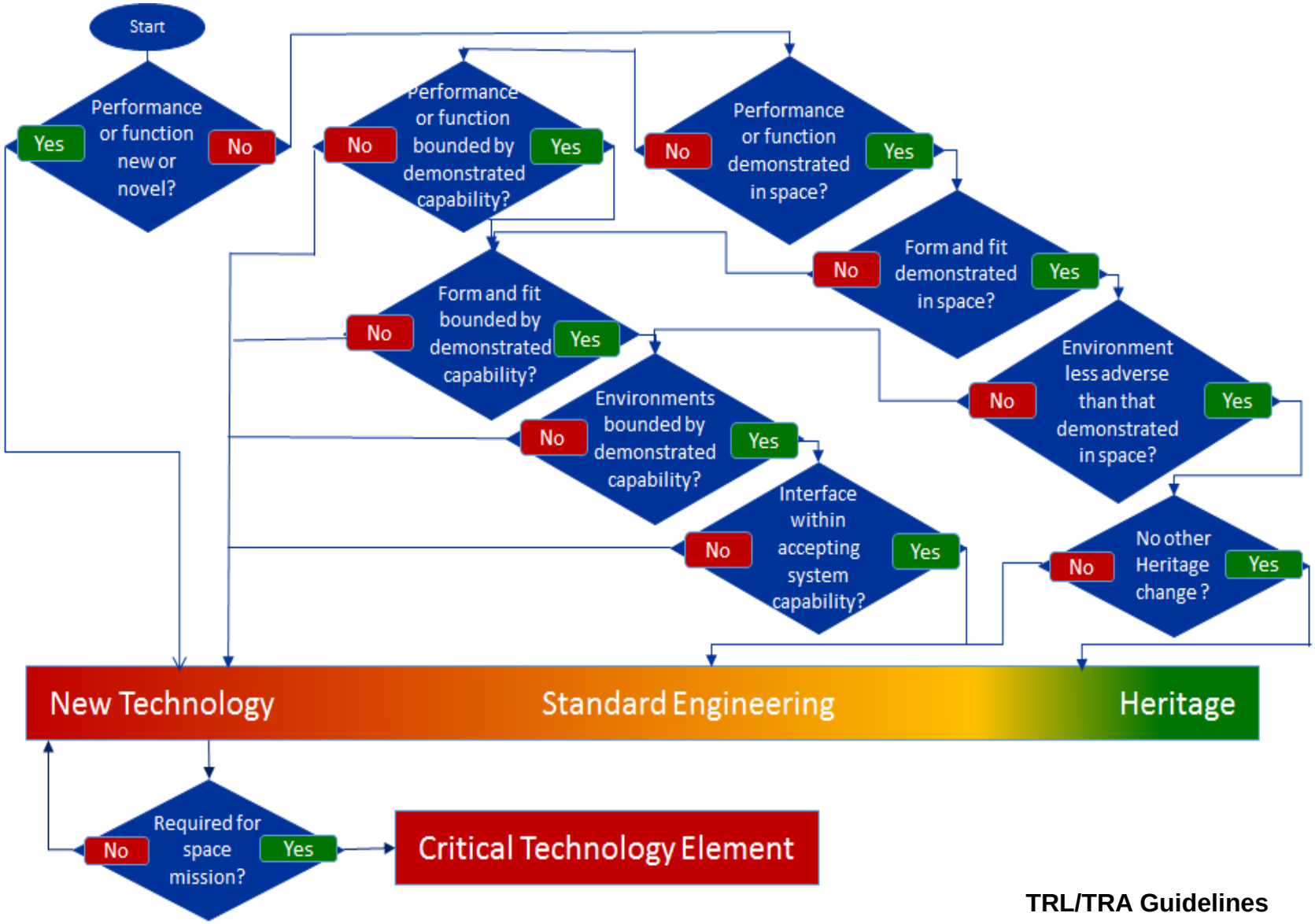
Deployment Accuracy and Shape Stability

Positioning the petals to high precision, blocking on-axis starlight, maintaining overall shape on a highly stable structure (S-5)

Fabricating the petal to high precision (S-4)

Backup Slides

Technology or Engineering?



TRL/TRA Guidelines
Frerking et al (JPL) in review