Technology Selection and Prioritization Process: 2017 Technology Gap List

Brendan Crill
Deputy Technology Development Manager
Exoplanet Exploration Program
Jet Propulsion Laboratory / Caltech

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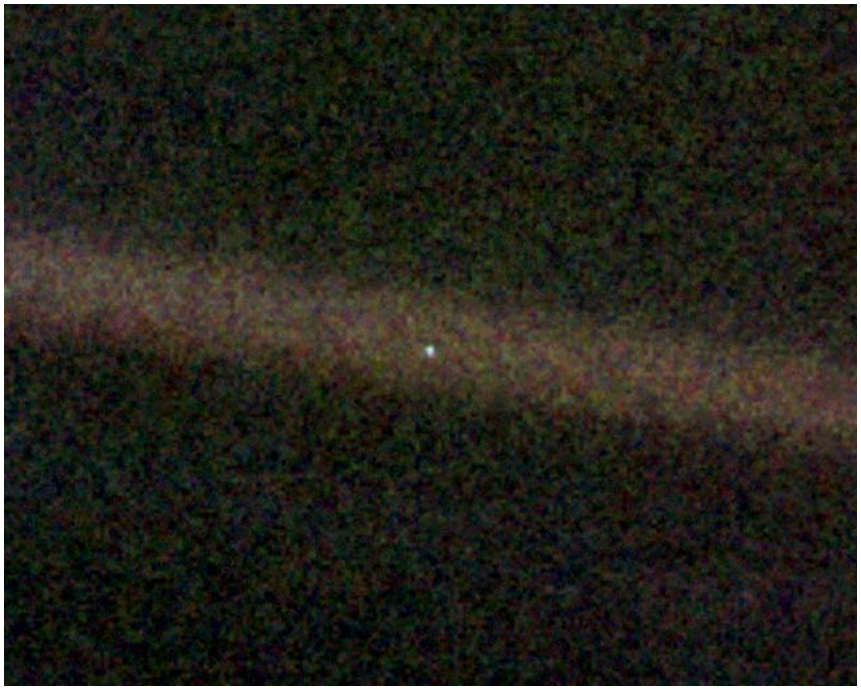
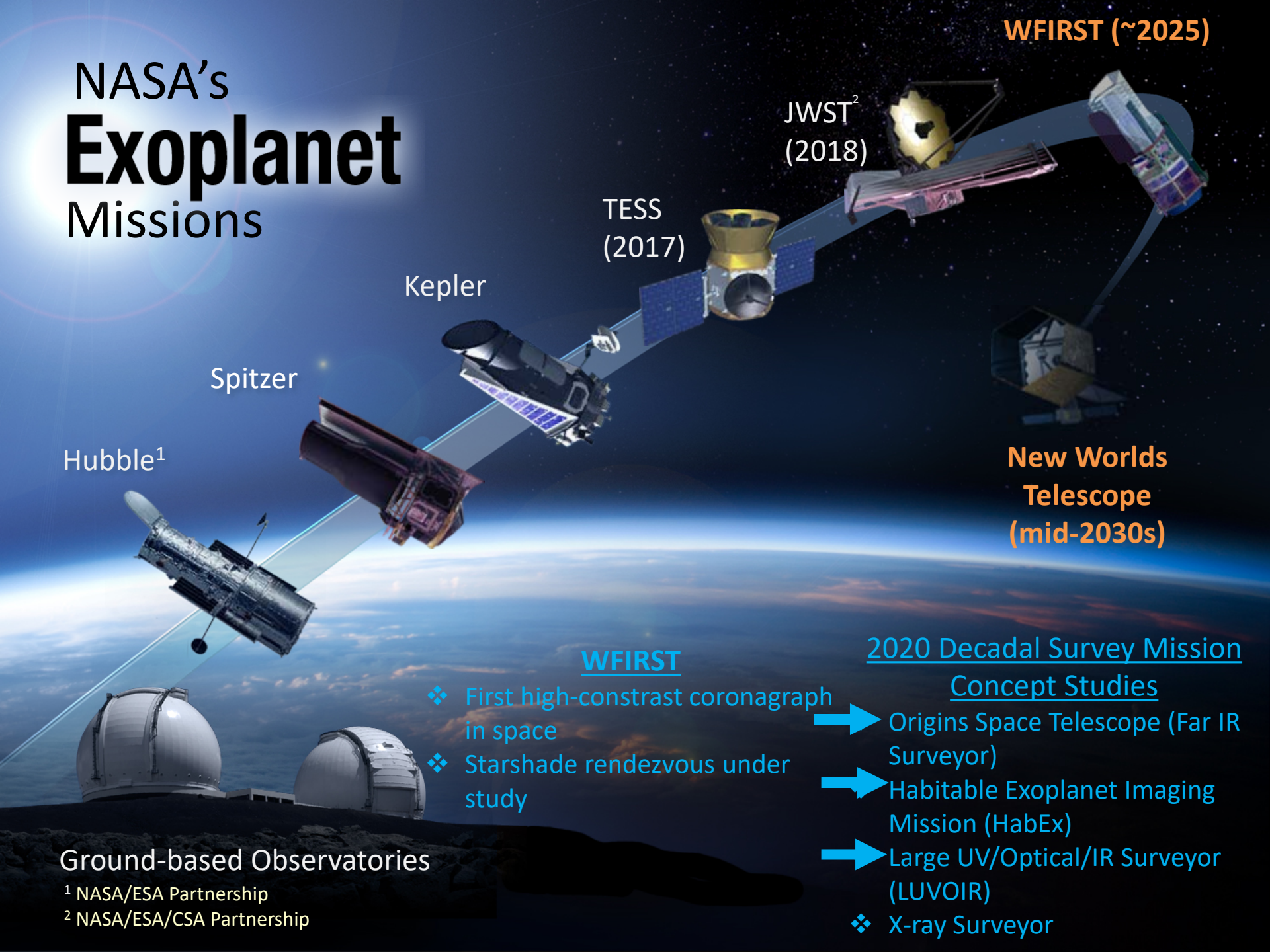
ExEP's Technology Focus

- **ExEP technology goals are focused on enabling or enhancing the capability to directly image and spectrally characterize exoplanets from space**



NASA's Exoplanet Missions



WFIRST

- First high-constrast coronagraph in space
- Starshade rendezvous under study

2020 Decadal Survey Mission Concept Studies

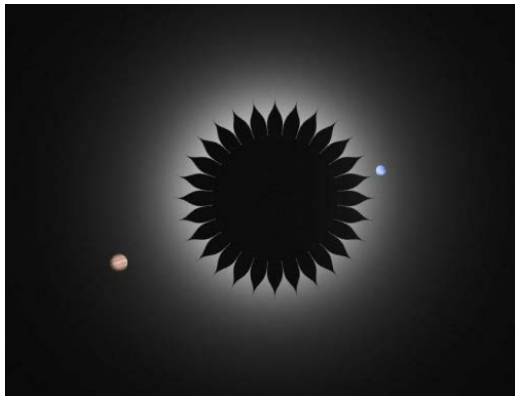
- Origins Space Telescope (Far IR Surveyor)
- Habitable Exoplanet Imaging Mission (HabEx)
- Large UV/Optical/IR Surveyor (LUVOIR)
- X-ray Surveyor

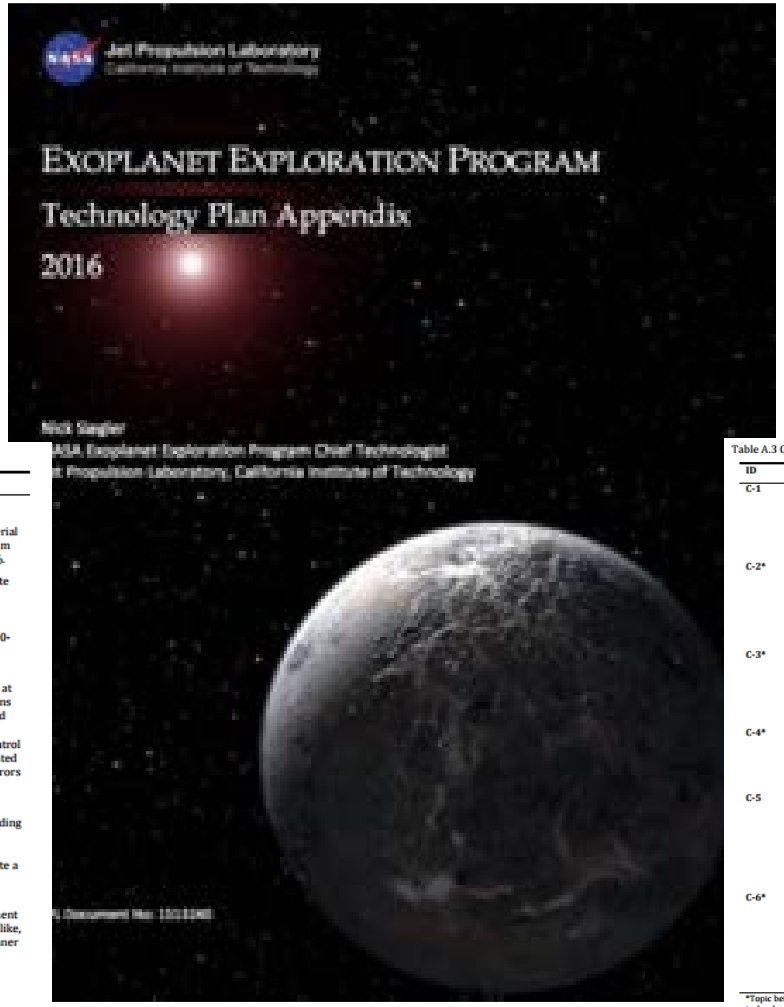
Ground-based Observatories

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

ExEP Technology Gap Lists

Exoplanet Exploration Program





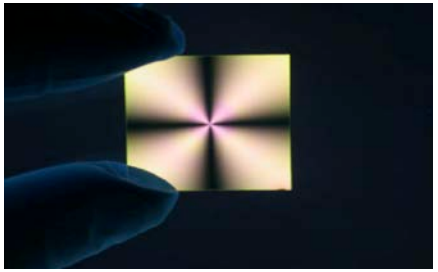


Table A.4 Starshade Technology Gap List

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 and 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.

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 ≤ 3λ/D and ≥ 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^{-1}'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 ≤ 10^{-9} contrasts in a vacuum environment and 10% bandwidth.	≥ 64x64 DMs with flight-like electronics capable of wavefront correction to ≤ 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^{-4}, 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.

https://exoplanets.nasa.gov/exep/technology

This year's New Selection Criteria

1. **Technology Gaps considered for tracking and development by the ExEP must support APD exoplanet science missions:**
   - as described in the Astrophysics Implementation Plan
   - directed through the Science Mission Directorate
   - selected through open competition
   - or described in the APD 30-year roadmap

2. **The subset of these gaps that either <u>enables</u> or <u>enhances</u> the direct detection and characterization of exoplanets, are prioritized onto the ExEP Technology Gap List.**
   - Technologies that address these gaps are the ones prioritized for development and considered for resource allocation
   - The list is published in the annual Technology Plan Appendix
   - Some of these technologies may be funded outside of the ExEP and will require collaboration amongst programs.

3. **The remaining technology gaps are considered to benefit exoplanet science and will be captured onto a second list: "List of Other Technology Opportunities That May Benefit Exoplanet Science" in the annual Technology Plan Appendix**
   - These gaps will be tracked and re-evaluated annually for potential prioritization

Technology Selection and Prioritization Process

Exoplanet Exploration Program

ID	Activity	Date
1	Technology needs input window opens ✓	06/08/16
	email 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	Technology Gap Selection and Prioritization Criteria Peer Review ✓	09/08/16
4	Selection and Prioritization Criteria Review by independent review board convened by ExoTAC ✓	09/21/16
5	Technology Gap Assessment Peer Review ✓	10/07/16
6	Technology Gap Assessment Review by review board convened by ExoTAC ✓	10/21/16
7	Technology Gap Lists inform TDEM amendment ←	mid-Nov
	Technology amendment released through NSPIRES	mid-Dec
8	ExEP Technology Plan Appendix updated and posted ←	12/22/16
	Presentation at January ExoPAG	01/02/17
9	TDEM Proposal Deadline ←	03/17/17
10	TDEM Awards Selected ←	Aug 2017

Input from the community

- **Received 21**
  - 7 from LUVOIR STDT
  - 2 from HabEx STDT
  - 8 from Far-IR Surveyor STDT
  - 4 from community at large
- **Most can be consolidated with existing gaps or each other**
- **Four enhancing technology gaps added to the gap list**
  - UV Ultra-low Noise Detector (LUVOIR)
  - UV/NIR/Vis Mirror Coatings (LUVOIR/HabEx)
  - Extreme Precision Ground-based Radial Velocity (HabEx)
  - Mid-IR Spectral Coronagraph (OST)
- **Four items for the Watch List**
  - Sub-Kelvin Coolers (OST)
  - Advanced Cryocooler (OST)
  - mid-IR ultra-low noise detectors (LUVOIR)
  - Astrometry

2017 Prioritization Criteria

Impact (weight: 10)	4: Critical technology - required to meet mission concept objectives; without this technology, applicable missions would not launch
	3: Highly desirable - not mission-critical, but provides major benefits in enhanced science capability, reduced critical resources need, and/or reduced mission risks; without it, missions may launch, but science or implementation would be compromised
	2: Desirable - not required for mission success, but offers significant science or implementation benefits; if technology is available, would almost certainly be implemented in missions
	1: Minor science impact or implementation improvements; if technology is available would be considered for implementation in missions

Urgency (weight: 10)	4: reduced risk needed for missions currently in pre-formulation or formulation.
	3: In time for the Decadal Survey (2019); not necessarily at some TRL but reduced risk by 2019.
	2: Earliest projected launch date < 15 yr (< 2030)
	1: Earliest projected launch date > 15 yr (> 2030)

Trend (weight: 5)	4: (a) no ongoing current efforts, or (b) little or no funding allocated
	3: (a) others are working towards it but little results or their performance goals are very far from the need, (b) funding unclear, or (c) time frame not clear
	2: (a) others are working towards it with encouraging results or their performance goals will fall short from the need, (b) funding may be unclear, or (c) time frame not clear
	1: (a) others are actively working towards it with encouraging results or their performance goals are close to need, (b) it's sufficiently funded, and (c) time frame clear and on time

Footnote: to be deemed “ready,” the technology is available to NASA at TRL 6 by the earliest possible Preliminary Design Review (PDR) of a mission; or at TRL 5 by the start of Phase A

2017 ExEP Technology Gap List

Exoplanet Exploration Program

Prioritized List

Gap ID	Gap Title	Impact	Urgency	Trend	Total
S-2	Optical Performance Demonstration and Optical Modeling	4	4	2	90
CG-1	Large Aperture Mirrors	4	3	3	85
CG-2	Coronagraph Architecture	4	3	3	85
CG-6	Mirror Figure (Segment Phasing) Sense & Control	4	3	3	85
CG-7	Telescope Vibration Control	4	3	3	85
CG-9	NIR Ultra-Low Noise Detector	4	3	3	85
S-1	Control Edge-Scattered Sunlight	4	4	1	85
S-3	Lateral Formation Flying Sensing	4	4	1	85
S-4	Petal Shape	4	4	1	85
S-5	Inner Disk Deployment	4	4	1	85
S-6	Petal Deployment	4	4	1	85
CG-3	Low-Order Wavefront Sensing and Control	4	3	2	80
CG-5	Deformable Mirrors	4	3	2	80
CG-8	Visible Ultra-Low Noise Detector	4	3	2	80
M-1	Extreme Precision Radial Velocity	3	3	3	75
CG-4	Post-Data Processing	4	2	2	70
CG-9	UV/NIR/Vis mirror coatings	3	3	2	70
CG-10	Mid-IR Spectral Coronagraph	2	3	3	65
CG-11	UV Ultra-low noise detector	2	3	2	60

Enabling Gap
Enhancing Gap
Watch List

Watch List

Sub-Kelvin Coolers
Advanced Cryocooler
Mid-IR Ultra-low Noise Detector
Astrometry

Changes to Existing Gaps

- **Technology gap CG-6: “Mirror Segment Phasing Sensing and Control” -> “Mirror Figure Sensing and Control”**
- **Control of polarization aberration explicitly added to language of gap CG-2 ”Coronagraph Architecture and Optics”**

Conclusions

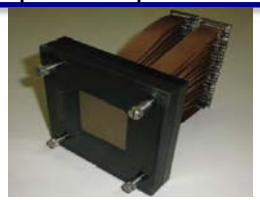
- **Final 2017 Technology Gap List to come with updated ExEP Technology Plan Appendix**
  - Pending iteration with STDT's for better SOA
  - TDEM amendment later this year
- **Presentation at Winter ExoPAG meeting in Grapevine TX**

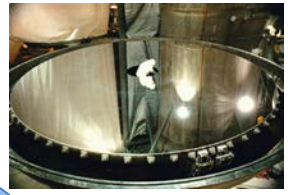
BACKUP SLIDES

ExEP Technology Selection and Prioritization Process

21 New Technology Gaps from Exoplanet Community

14 Technology gaps carried over from 2016





Selection: enables or enhances direct detection and characterization of exoplanets?

Neither enhancing nor enabling

not accepted

No, but could benefit exoplanet science

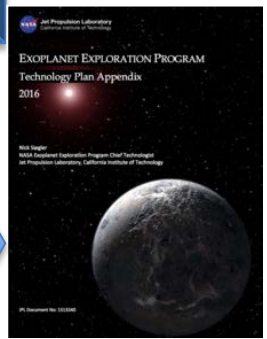
List of Technologies that Benefit Exoplanet Science, aka "Watch List"

Yes

Selection and Prioritization Criteria:

- Peer reviewed
- Exo-TAC reviewed

Prioritize technologies according to criteria (Impact, Urgency, and Trend)

ExEP Technology Gap List

Reviewed by Exo-TAC