Exoplanet Exploration Program Technology Selection and Prioritization Process: 2018 Technology List

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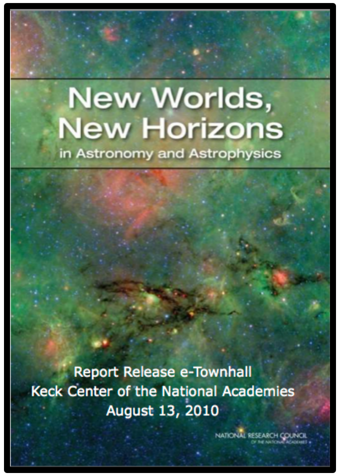
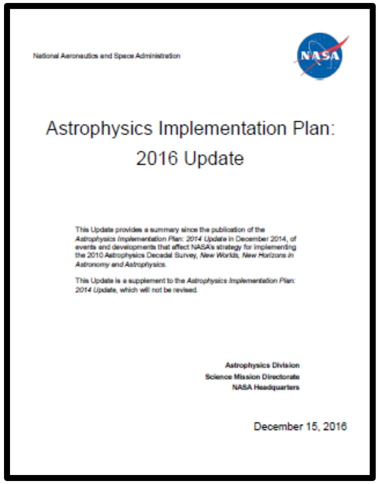
ExEP's Technology Focus

- **The driving ExEP science goals are to:**
  1. Discover planets around other stars
  2. Characterize their properties
  3. Identify candidates that could harbor life

- **As recommended in the 2010 Astrophysics Decadal Survey and planned in NASA's Astrophysics Implementation Plan, the ExEP develops technologies that will enable the direct imaging and characterization of exoplanets in the habitable zone of Sun-like stars.**




National Aeronautics and Space Administration

Astrophysics Implementation Plan:
2016 Update

This Update provides a summary since the publication of the *Astrophysics Implementation Plan: 2014 Update* in December 2014, of events and developments that affect NASA's strategy for implementing the 2010 Astrophysics Decadal Survey, *New Worlds, New Horizons in Astronomy and Astrophysics*.

This Update is a supplement to the *Astrophysics Implementation Plan: 2014 Update*, which will not be revised.

Astrophysics Division
Science Mission Directorate
NASA Headquarters

December 15, 2016

2018 ExEP Prioritized Technology List

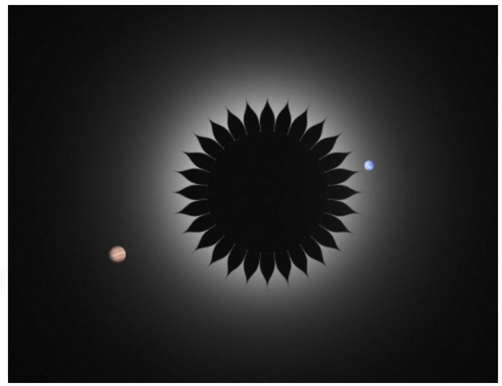
Exoplanet Exploration Program

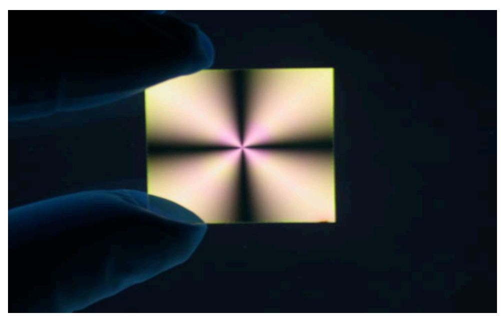
The 2018 Exoplanet Exploration Program Technology List

Compiled by: Dr. Brendan Crill, Deputy Program Chief Technologist, NASA Exoplanet Exploration Program, Jet Propulsion Laboratory, California Institute of Technology

ID	Technology	Technology Gap	Technology Description	Current Capabilities	Needed Capabilities
CG-2	**Coronagraph Demonstrations and Modeling**	Coronagraph Contrast	Coronagraph optics and architecture that suppress diffracted starlight by a factor of < 10^{-9} at visible and infrared wavelengths	Lab: 6×10^{-10} raw contrast at 10% bandwidth across angles of 3-15 λ/D demonstrated with a linear mask and an unobscured pupil in a static vacuum lab environment (Hybrid Lyot) < 1.6×10^{-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 environment (WFIRST) Flight: 10^{-4} raw contrast 540 nm at 10 λ/D (HST)	Coronagraph masks and optics capable of creating circularly symmetric dark regions in the focal plane enabling raw contrasts ≤ 10^{-10}, with minimal contribution from polarization aberration, IWA ≤ 3 λ/D, throughput ≥ 10%, and bandwidth ≥ 10% on obscured and segmented pupils in a simulated dynamic vacuum environment.
S-1	**Controlling Scattered Sunlight**	Starshade Contrast	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 μm); 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 limit solar glint contributing < 10^{-10} contrast at petal edges.
S-2	**Starlight Suppression and Model Validation**	Starshade Contrast	Experimentally validate at flight-like Fresnel numbers the equations that predict the contrasts achievable with a starshade.	Validated optical model with demonstrated 10^{-6} suppression at white light, 58 cm mask, and Fresnel number F (at the starshade tips) ≈210; 6×10^{-6} suppression demonstrated at F ≈15; 1.3×10^{-7} suppression demonstrated at F~50	Experimentally validated models with total starlight suppression ≤ 10^{-8} in scaled flight-like geometry, with F between 5 and 40 across a broadband optical bandpass. Validated models are traceable to 10^{-10} contrast system performance in space.
S-3	**Lateral Formation Sensing**	Starshade Contrast Stability	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 and lab demos for WFIRST-starshade accommodations have shown that sensing and GN&C is tractable, though sensing demonstration of lateral control has not yet been performed.	Demonstrate sensing lateral errors ≤ 0.20 m accuracy at scaled flight separations (± 1 mas bearing angle). Control algorithms demonstrated with scaled lateral control errors corresponding to ≤ 1 m.
S-5	**Petal Positioning Accuracy and Opaque Structure**	Starshade Deployment	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 12 m 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**	Starshade Deployment	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 6 m 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 for 34 m-diameter Exo-S design; tolerances scale roughly linearly with starshade diameter) with flight-like, minimum half-scale petal fabricated and maintains shape after multiple deployments from stowed configuration.

https://exoplanets.nasa.gov/exep/technology/gap-lists/





Details to be published in annually updated Technology Plan Appendix

Technology Selection and Prioritization Process for 2018

Exoplanet Exploration Program

ID	Activity	
1	Technology needs input window opens ✓	06/18/17
	email ExoPAG announce: Technology Gap Lists, input forms, process explanation	06/09/17
	presentation at June ExoPAG	06/18/17
2	Technology window closes ✓	08/28/17
3	Technology Selection and Prioritization Criteria Review by APD Program Offices ✓	08/25/17
4	Selection and Prioritization Criteria Review by ExoTAC ✓	09/15/17
5	Technology List Assessment Review by APD Program Offices ✓	09/25/17
6	Technology List Assessment Review by ExoTAC ✓	10/16/17
7	Technology Lists inform TDEM Amendment ✓	Early Nov
8	Technology Amendment released through NSPIRES ✓	11/16/18
9	ExEP Technology Plan Appendix updated and released	01/06/18
	Presentation at January ExoPAG	01/06/18
10	TDEM Proposal Deadline	03/15/18
11	TDEM Awards Selected	Aug 2018

Inputs from the community

- **In the 2017 Technology Plan Appendix, we had 18 items on the prioritized list and 4 on the watch list**

- **This summer, we received 37 technology inputs**
  - 14 from LUVOIR STDT
  - 15 from HabEx STDT
  - 4 from OST STDT
  - 2 from community at large
  - 2 redirected from COR

- **After consolidating the inputs with those items already on the List or with each other, there were 7 new additions to the Technology List for 2018.**
  - None were rejected
  - Mid-IR Coronagraph listed in 2017 is split into 3 technologies, so we removed the integrated instrument from the list.
  - Ultra low-noise mid-IR detectors moved from watch list to prioritized list
  - “Astrometry” moved from the watch list to the prioritized list by the Program Chief Technologist

- **There are 24 technologies on the 2018 prioritized list and 2 on the watch list**

2018 ExEP Prioritized Technology List

Exoplanet Exploration Program

Tech. ID	Technology Title	Impact	Urgency	Trend	2018 Score	2017 Score
	weight:	10	10	5		
CG-2	Coronagraph Architecture	4	4	2	**90**	85
S-2	Starlight Suppression and Model Validation	4	4	2	**90**	90
S-1	Controlling Scattered Sunlight	4	4	2	**90**	90
S-3	Lateral Formation Sensing	4	4	2	**90**	90
S-5	Petal Positioning Accuracy and Opaque Structure	4	4	2	**90**	90
S-4	Petal Shape and Stability	4	4	2	**90**	90
CG-3	Deformable Mirrors	4	4	2	**90**	80
CG-1	Large Aperture Primary Mirrors	4	3	3	**85**	85
CG-6	Mirror Segment Phasing	4	3	3	**85**	85
CG-7	Telescope Vibration Sense/Control or Reduction	4	3	3	**85**	85
CG-9	Ultra-Low Noise Near-Infrared Detectors	4	3	3	**85**	85
CG-5	Wavefront Sensing and Control	4	3	2	**80**	80
CG-8	Ultra-Low Noise Visible Detectors	4	3	2	**80**	80
M-4	Ultra-Stable Mid-IR detector	3	3	4	**80**	
M-3	Astrometry	3	3	3	**75**	
CG-4	Data Post-Processing Algorithms and Techniques	4	2	2	**70**	70
CG-10	Mirror Coatings for UV/NIR/Vis	3	3	2	**70**	70
M-2	Space-based Laser Frequency Combs	3	3	2	**70**	
CG-13	Ultra Low-noise Mid-IR detectors	2	3	4	**70**	
M-1	Extreme Precision Ground-based Radial Velocity	2	3	3	**65**	75
CG-14	Mid-IR Large Aperture Telescopes	2	3	3	**65**	
CG-15	Mid-IR Coronagraph Optics and Architecture	2	3	3	**65**	
CG-16	Cryogenic Deformable mirror	2	3	3	**65**	
CG-12	Ultra-Low Noise UV Detectors	2	3	2	**60**	60

Carried over from 2017

New to list in 2018

Investments in ExEP Technologies

Tech. ID	Technology Title	SAT / APRA	directed	mission or mission concept	Funded to TRL 5	List status
	weight:					
CG-2	Coronagraph Architecture	✓	✓	✓	funded to TRL 5 *	Carried over from 2017
S-2	Starlight Suppression and Model Validation	✓	✓		funded to TRL 5 *	Carried over from 2017
S-1	Controlling Scattered Sunlight	✓	✓		funded to TRL 5 *	Carried over from 2017
S-3	Lateral Formation Sensing	✓	✓	✓	funded to TRL 5 *	Carried over from 2017
S-5	Petal Positioning Accuracy and Opaque Structure	✓	✓		funded to TRL 5 * for some mission architectures	Carried over from 2017
S-4	Petal Shape and Stability	✓	✓		funded to TRL 5 * for some mission architectures	Carried over from 2017
CG-3	Deformable Mirrors	✓		✓	funded to TRL 5 * for some mission architectures	Carried over from 2017
CG-1	Large Aperture Primary Mirrors	✓	✓	✓	funded to TRL 5 * for some mission architectures	Carried over from 2017
CG-6	Mirror Segment Phasing		✓	✓		Carried over from 2017
CG-7	Telescope Vibration Sense/Control or Reduction		✓	✓	funded to TRL 5 * for some mission architectures	Carried over from 2017
CG-9	Ultra-Low Noise Near-Infrared Detectors	✓			funded to TRL 5 * for some mission architectures	Carried over from 2017
CG-5	Wavefront Sensing and Control			✓	funded to TRL 5 * for some mission architectures	Carried over from 2017
CG-8	Ultra-Low Noise Visible Detectors	✓		✓	funded to TRL 5 * for some mission architectures	Carried over from 2017
M-4	Ultra-Stable Mid-IR detector			✓		New to list in 2018
M-3	Astrometry	✓				New to list in 2018
CG-4	Data Post-Processing Algorithms and Techniques			✓	funded to TRL 5 *	Carried over from 2017
CG-10	Mirror Coatings for UV/NIR/Vis	✓	✓			Carried over from 2017
M-2	Space-based Laser Frequency Combs					New to list in 2018
CG-13	Ultra Low-noise Mid-IR detectors					New to list in 2018
M-1	Extreme Precision Ground-based Radial Velocity	✓	✓			Carried over from 2017
CG-14	Mid-IR Large Aperture Telescopes					New to list in 2018
CG-15	Mid-IR Coronagraph Optics and Architecture					New to list in 2018
CG-16	Cryogenic Deformable mirror					New to list in 2018
CG-12	Ultra-Low Noise UV Detectors	✓				Carried over from 2017

✓ **SAT / APRA**

✓ **directed**

✓ **mission or mission concept**

funded to TRL 5 * (solid box)

funded to TRL 5 * for some mission architectures (dashed box)

Carried over from 2017

New to list in 2018

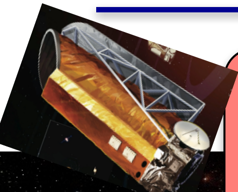
* for an exo-Earth imaging mission

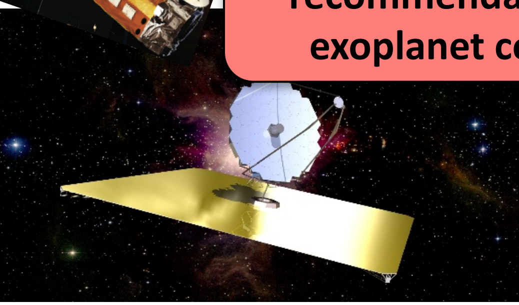
In conclusion

- 2018 Technology List published on ExEP website
- SAT Amendment was released on Nov. 19
- Please note that there is a Mandatory NOIs for SAT due January 25, 2018
- 2018 update to ExEP Technology Plan Appendix in early January
- Presentation at Winter ExoPAG meeting Jan. 7, 2018 in National Harbor, MD

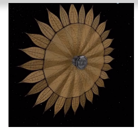
BACKUP SLIDES

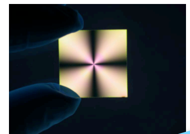
ExEP Technology Selection and Prioritization Process



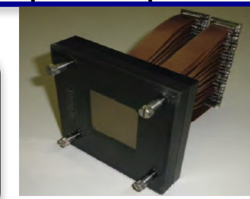


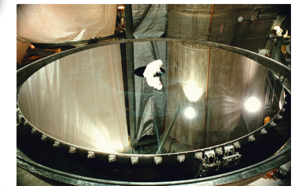
New technology recommendations from exoplanet community





Technologies carried over from previous year





Reviewed by (1) APD Program Offices and (2) Exo-TAC

Selection Criteria: Enables or enhances direct detection and/or characterization of exoplanets?

No → Not accepted

No, but could still benefit exoplanet science → Watch List

Yes → **Accepted and Prioritized:** (Impact, Urgency, and Trend)

ExEP Technology List

Informs SAT/TDEM Call

Reviewed by Exo-TAC

Impact, Urgency, Trend Prioritization Scoring

Impact: (weight: 10)	4: Critical strategic technology for the New Worlds Technology Development Program envisioned in *New Words, New Horizons* (2010 Decadal Survey) and in the NASA Astrophysics Implementation Plan; without this technology, the mission 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: Advances technology or reduces risk needed for missions currently in Pre-Formulation or formulation.
	3: In time to inform the 2020 Decadal Survey; not necessarily at some TRL but reduced risk.
	2: Earliest projected launch date < 15 yr (< 2033)
	1: Earliest projected launch date > 15 yr (> 2033)

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