



**Jet Propulsion Laboratory**  
California Institute of Technology



Exoplanet Exploration Program

# **Exoplanet Exploration Program Technology Update**

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**Exoplanet Exploration Program**

**Jet Propulsion Laboratory / California Institute of Technology**

**ExoPAG EC Telecon**

**7 January 2018**

Cleared for public release



# Program Technology Updates since Last ExoPAG

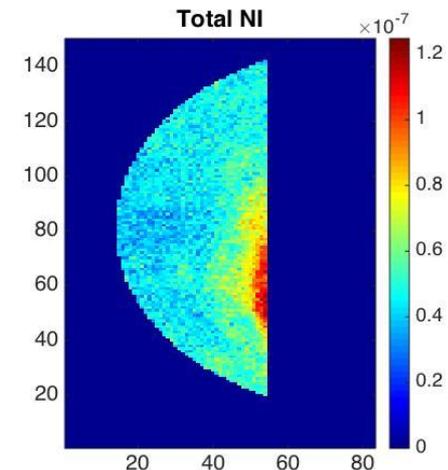
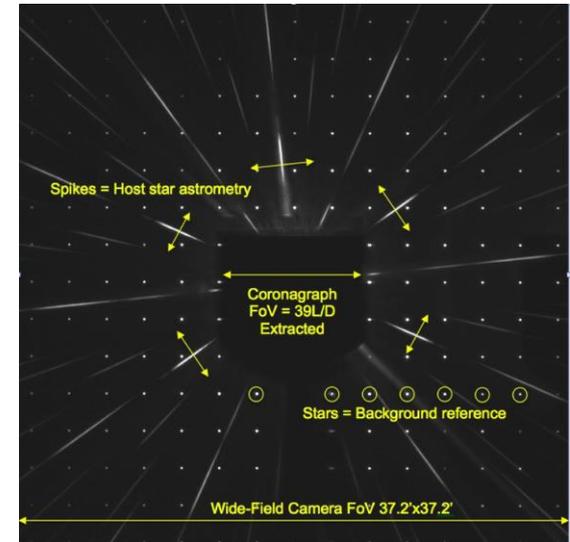


Exoplanet Exploration Program

## 1. Active TDEM news

<https://exoplanets.nasa.gov/exep/technology/TDEM-awards/>

- TDEM-13 PI Eduardo Bendek completed: Demonstrated microarcsecond astrometry with a diffractive pupil and demonstrated an in-air PIAA coronagraph with same pupil [Final report](#) reviewed and approved by ExoTAC
- TDEM-14 PI Gene Serabyn first light in HCIT: first round of testing a charge-4 vortex coronagraph achieved  $5.1 \times 10^{-8}$  contrast at 2% band around 550 nm, centered at 550 nm spanning  $3-9 \lambda/D$ ; incoherent light leak identified, aiming for  $10^{-9}$  contrast in next run





# Program Technology Updates since Last ExoPAG



Exoplanet Exploration Program

## 1. Active TDEM news (cont'd)

- TDEM-15 Jim Breckinridge providing input to WFIRST-CGI, HabEx, and LUVOIR regarding effects of polarization aberration on coronagraph performance.

## 2. New TDEM awards

- TDEM-16 PI John Trauger: Super Lyot Coronagraph
- TDEM-16 PI Rus Belikov: PIAACMC
- TDEM-16 PI Rus Belikov: Multi-star wavefront control
  - Belikov Milestone Whitepapers currently under review by ExoTAC



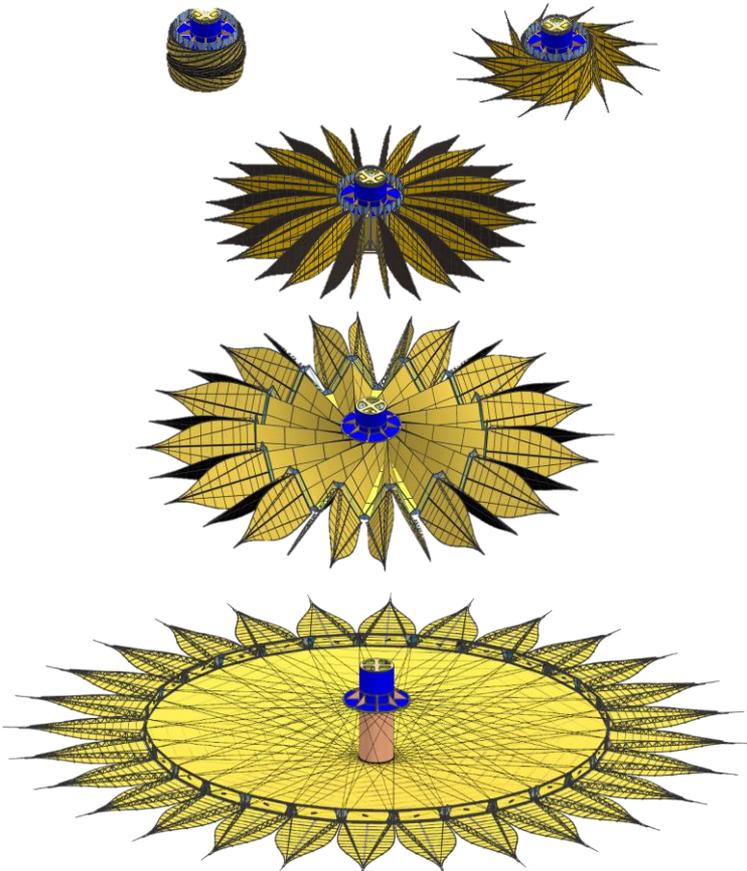
# Program Technology Updates since Last ExoPAG



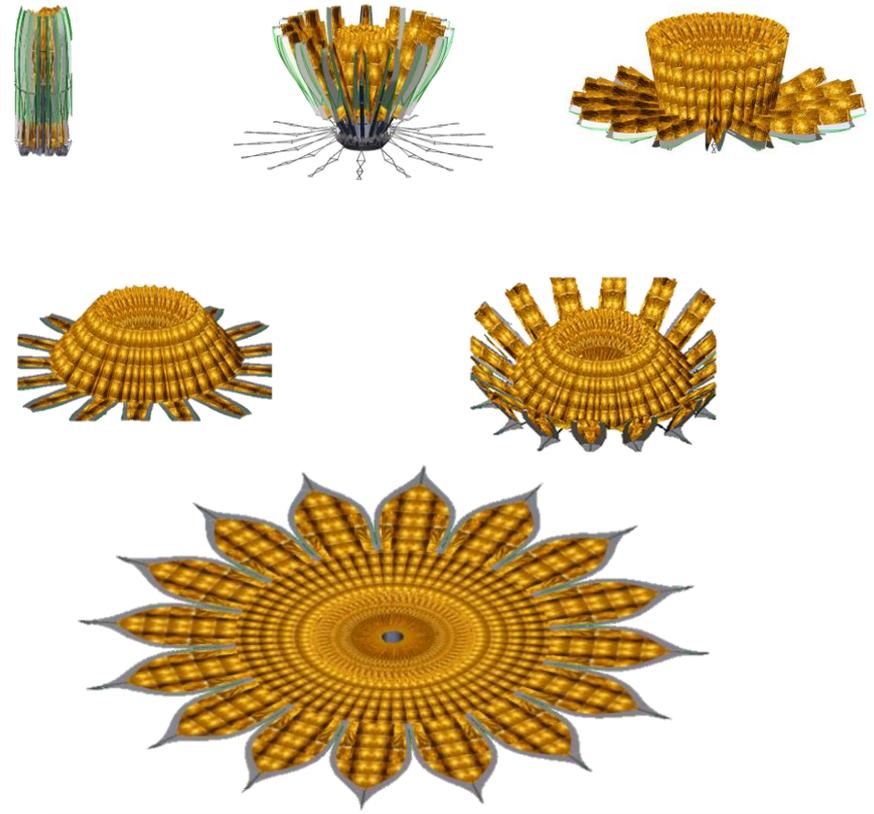
Exoplanet Exploration Program

## 3. Starshade technology activity

- Plan for TRL 5 expected April 2018
- Deployment trade study kicked off



Wrapped petals



Folded petals



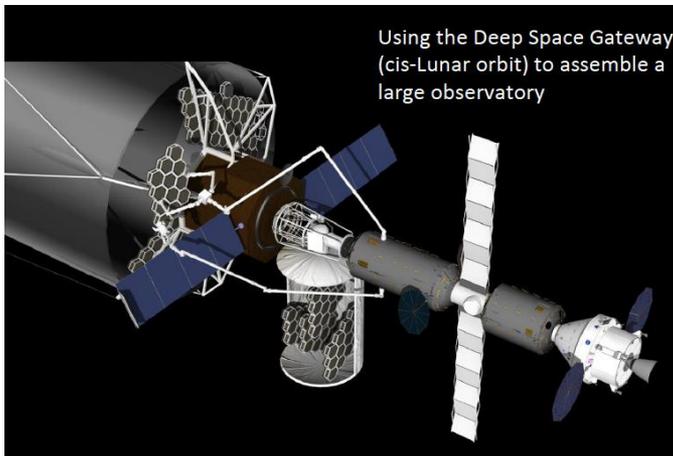
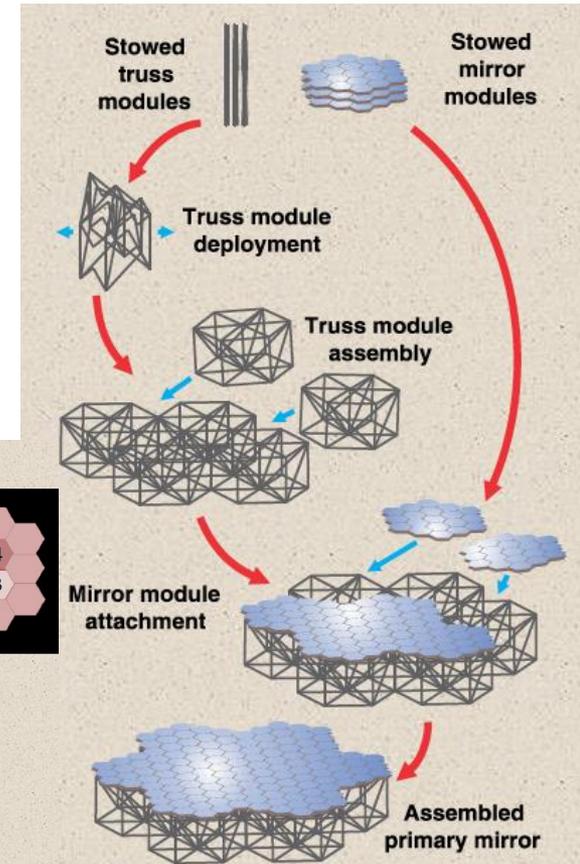
# Program Technology Updates since Last ExoPAG



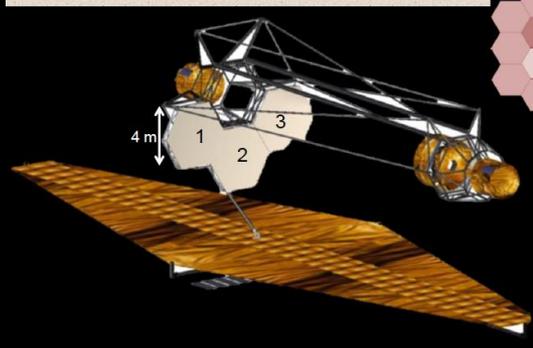
Exoplanet Exploration Program

## 4. in-Space Service and Assembly

Technical Interchange Meeting held at Goddard Nov 1-3 brought together 70+ representatives of gov't, industry, and academia to discuss potential iSSA for future large space observatories



Telescopes that incrementally evolve





# Program Technology Updates since Last ExoPAG

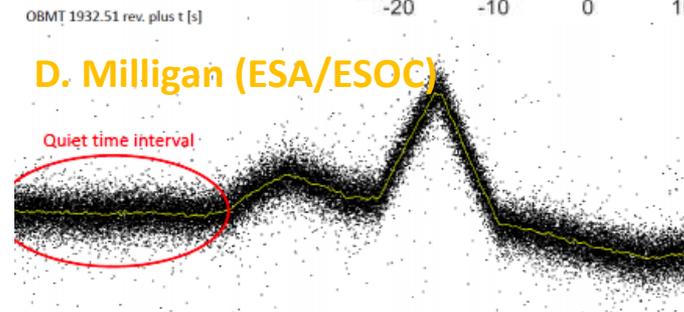
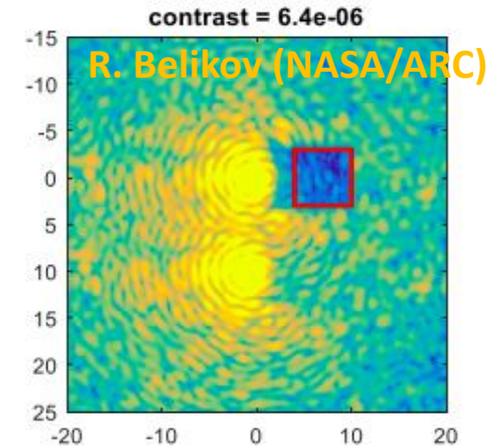
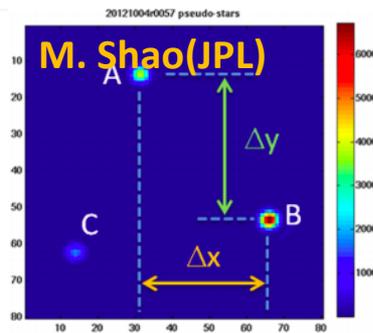


Exoplanet Exploration Program

## 5. ExEP Technology Colloquium Series continues

[https://exoplanets.nasa.gov/exep/technology/tech\\_colloquium/](https://exoplanets.nasa.gov/exep/technology/tech_colloquium/)

- Astrometry, GAIA design and on-orbit lessons learned, Multi-star wavefront control



## 6. Technology Selection and Prioritization Process concluded

- 2018 Technology List is online

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



# 2018 Technology Selection and Prioritization Process Results

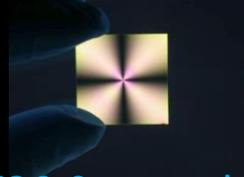


Exoplanet Exploration Program

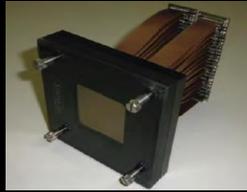
- **In the 2017 Technology Plan Appendix, we had 18 items on the prioritized Technology List and 4 on the Watch List**
- **This summer, we received 37 technology inputs from the community**
  - 14 from LUVVOIR STDT
  - 15 from HabEx STDT
  - 4 from OST STDT
  - 2 from community at large
  - 2 redirected from COR
- **Results:**
  - None were rejected
  - 32 were consolidated into existing technologies already on the List
  - 5 new additions to the Technology List
  - 2 from Watch List upgraded to the Technology List
  - 0 additions to the Watch List
  - 1 listed technology was broken down into 3 finer component/subsystem technologies
- **There are now 24 technologies on the 2018 prioritized list and 2 on the Watch List** <https://exoplanets.nasa.gov/exep/technology/gap-lists/>

# V-NIR Coronagraph/Telescope Technology Gaps

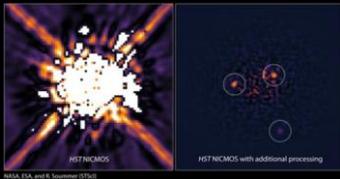
## Contrast



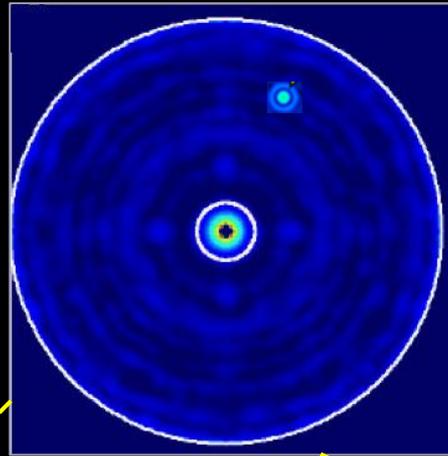
CG-2: Coronagraph Demonstrations and Modeling



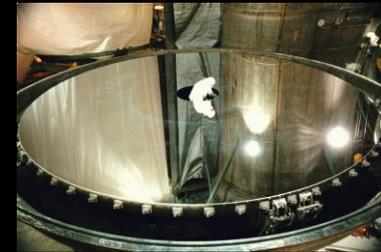
CG-3: Deformable mirrors



CG-4: Data post-processing



## Angular Resolution

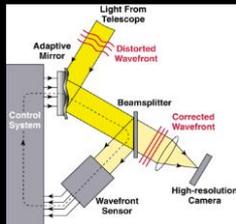


CG-1: Large monolith mirrors



CG-1: Segmented mirrors

## Contrast Stability



CG-5: Wavefront sensing and control

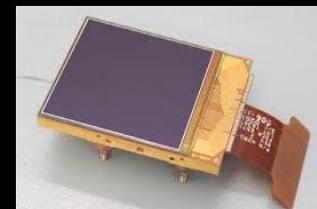
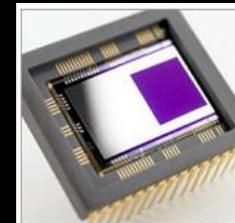


CG-6: Segment phasing and rigid body sensing and control



CG-7: Telescope vibration sensing and control or reduction

## Detection Sensitivity



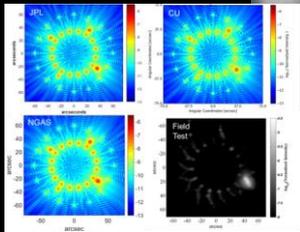
Ultra-low noise visible (CG-8) and infrared (CG-9) detectors

# Starshade Technology Gaps

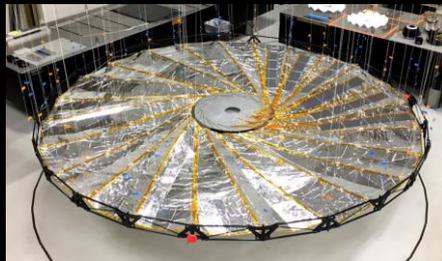
## Contrast (Starlight Suppression)



S-1: Controlling Scattered Sunlight



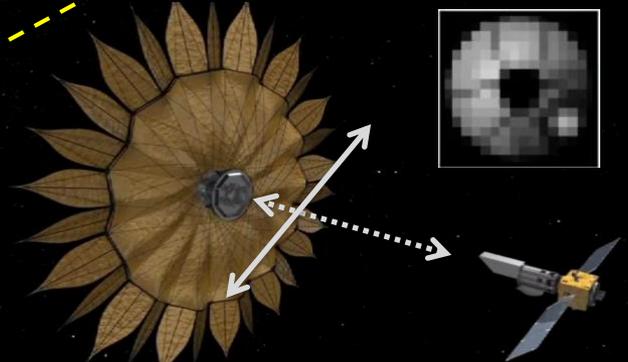
S-2: Starlight Suppression and Model Validation



S-5: Petal Positioning Accuracy and Opaque Structure

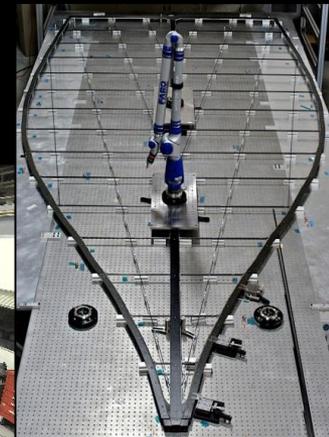


## Contrast Stability (Formation Sensing)



S-3: Lateral Formation Sensing

## Deployment Accuracy and Shape Stability



S-4: Petal Shape And Stability

# Mid-IR Coronagraph/Telescope Technology Gaps

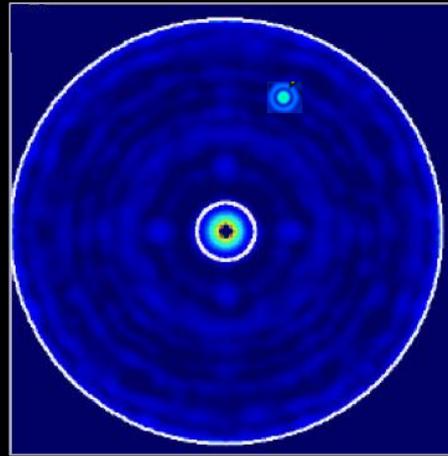
## Contrast



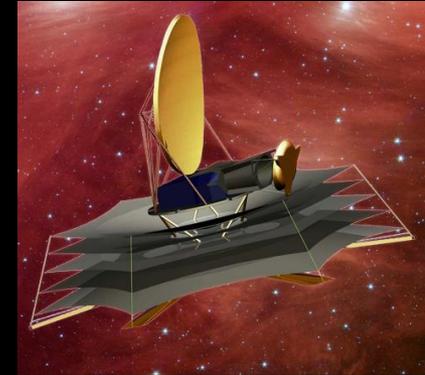
CG-15: Mid Infrared  
Coronagraph Optics and Architecture



CG-16: Cryogenic  
Deformable Mirror

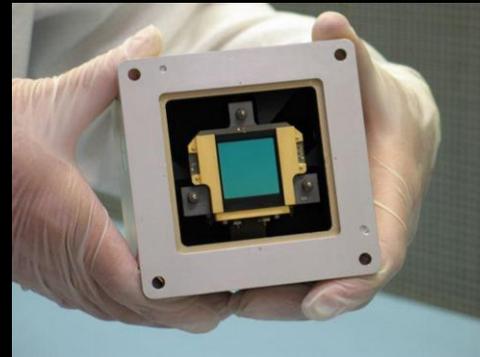


## Angular Resolution



CG-14: Mid-IR Large  
Aperture Telescopes

## Detection Sensitivity

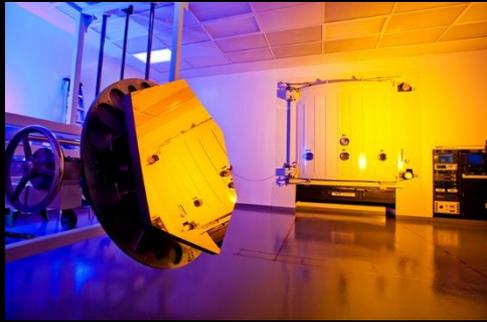


CG-13: Low noise Mid-IR detectors

M-4: Ultra-stable Mid-IR detectors for transit spectroscopy

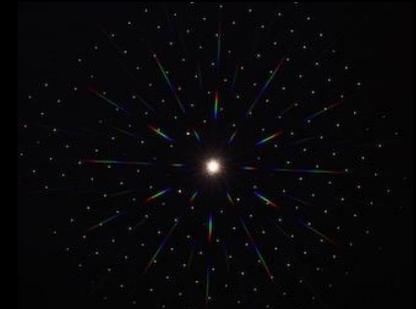
# Other Technology Gaps

## UV Contrast

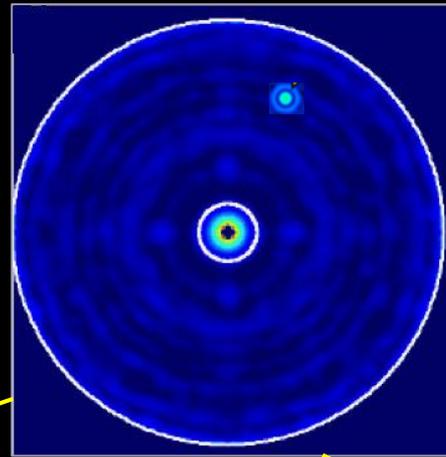


CG-10 UV/V/NIR  
mirror coatings

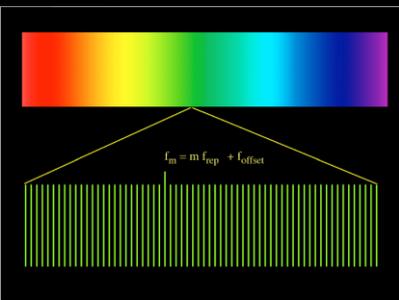
## Tangential Stellar Motion Sensitivity



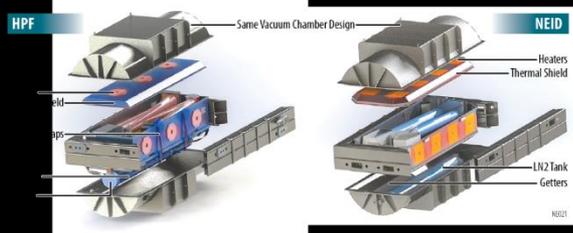
M-3: Astrometry



## Radial Stellar Motion Sensitivity



M-2: Laser Frequency Combs  
for Space-based EPRV

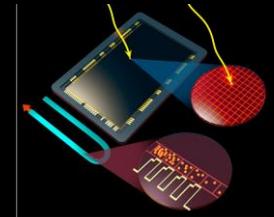


M-1: Ground-based Ultra-high  
precision Radial Velocity

## UV Detection Sensitivity



CG-12: Ultra-low noise UV detectors





# Investments in ExEP Technologies



Exoplanet Exploration Program

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

- ✓ SAT / APRA
- ✓ directed
- ✓ mission or mission concept

**funded to TRL 5 \***

**funded to TRL 5 \*  
for some mission architectures**

Carried over from 2017  
New to list in 2018

\* for an exo-Earth imaging mission

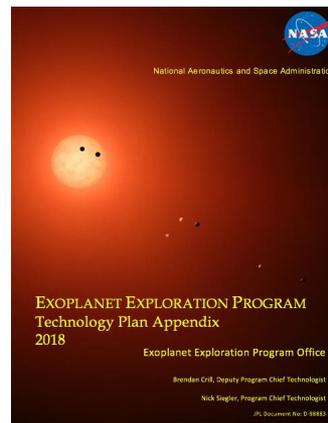


# Reminders



Exoplanet Exploration Program

- **2018 Technology List published on ExEP website**  
<https://exoplanets.nasa.gov/exep/technology/gap-lists/>
- **SAT Amendment was released on NSPIRES on Nov. 19**
- **Please note that there is a Mandatory NOI for SAT proposals due January 25, 2018**
- **Draft 2018 update to ExEP Technology Plan Appendix coming**





# ADDITIONAL SLIDES

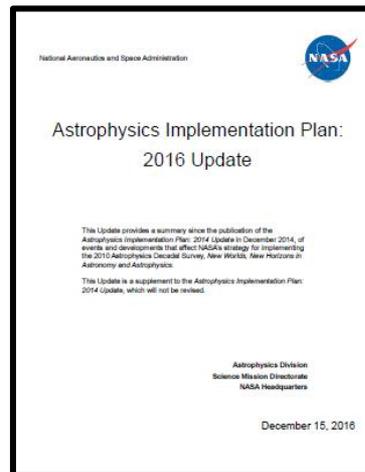
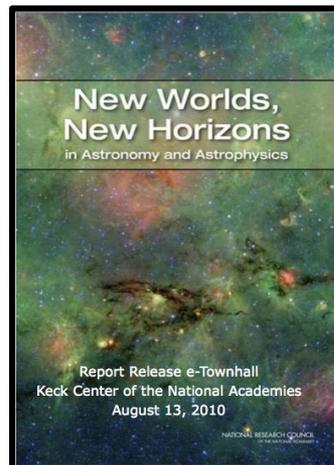


# ExEP's Technology Focus



Exoplanet Exploration Program

- **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.**



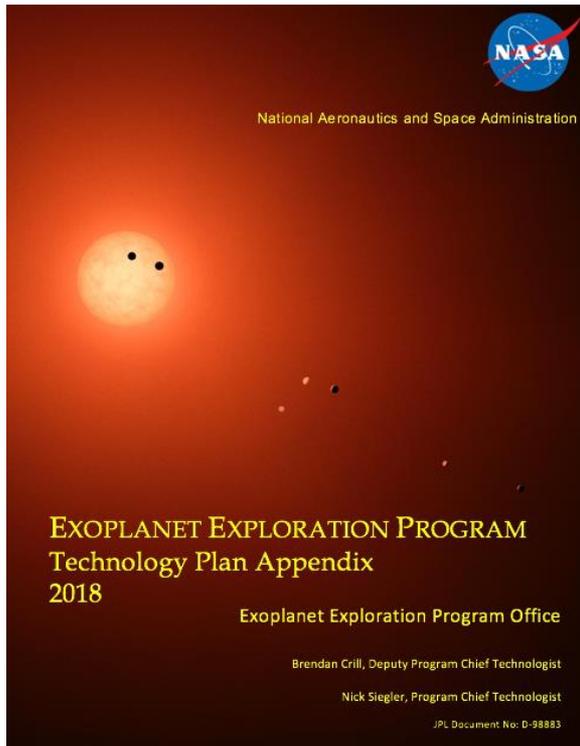


# ExEP Technology List



Exoplanet Exploration Program

ID	Technology	Technology Gap	Technology Description	Current Capabilities	Needed Capabilities
S-1	<b>Controlling Scattered Sunlight</b>	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 ( $\geq 10 \mu\text{m}$ ); 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.



- **24 technologies currently tracked**
- **Technology List posted here:**  
<https://exoplanets.nasa.gov/exep/technology/gap-lists/>
- **More detail coming soon in the Technology Plan Appendix**



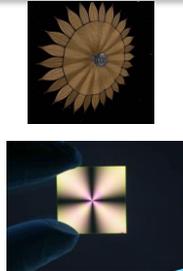
# ExEP Technology Selection and Prioritization Process



Exoplanet Exploration Program



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

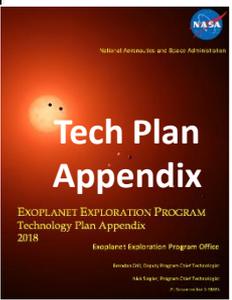
Yes  
**Accepted and Prioritized:** (Impact, Urgency, and Trend)

**Watch List**

Informs SAT/TDEM Call

**ExEP Technology List**

Reviewed by Exo-TAC





# 2018 ExEP Prioritized Technology List



Exoplanet Exploration Program

Tech. ID	Technology Title	Impact weight:	Urgency	Trend	2018 Score	2017 Score
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



# Impact, Urgency, Trend Prioritization Scoring



Exoplanet Exploration Program

<b>Impact:</b> (weight: 10)	4: Critical strategic technology for the New Worlds Technology Development Program envisioned in <i>New Worlds, New Horizons</i> (2010 Decadal Survey) and in the NASA Astrophysics Implementation Plan; without this technology, the mission would not launch
	3: Highly desirable but not mission-critical, but provides major benefits and 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 but 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
<b>Urgency</b> (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 RRL but reduced risk.
	2: Earliest projected launch date < 1.5 yr (< 2033)
	1: Earliest projected launch date > 1.5 yr (> 2033)
<b>Trend</b> (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



# 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