Exoplanet Exploration Program Technology Update

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ExoPAG 22
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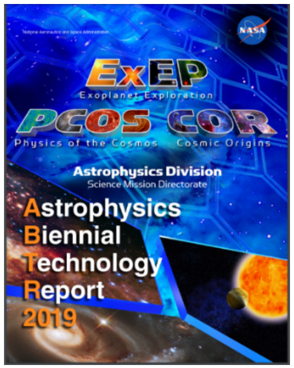
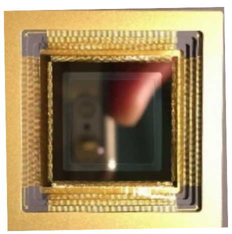
Image Credit:
NASA/Ames/JPL-Caltech/T. Pyle
astropix.ipac.caltech.edu

Technology Activities

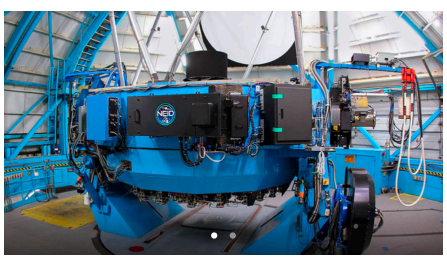
Technology Gaps

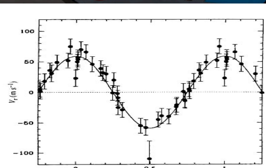


Deformable Mirror Survey

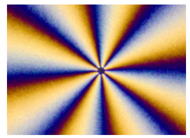


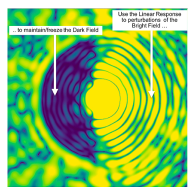
Extreme Precision Radial Velocity





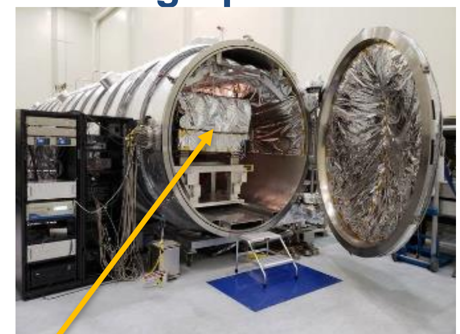
Strategic Astrophysics Technology Grants



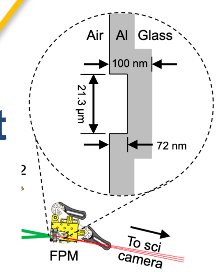


- *Coronagraph architectures: modeling and demonstrations*
- *Wavefront control*
- *Extreme Precision Radial Velocity*
- *Detectors*

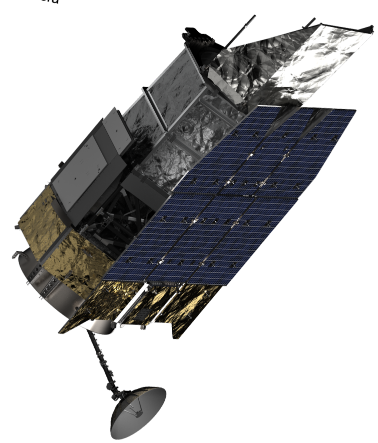
Ultra-Stable Coronagraph Testbeds



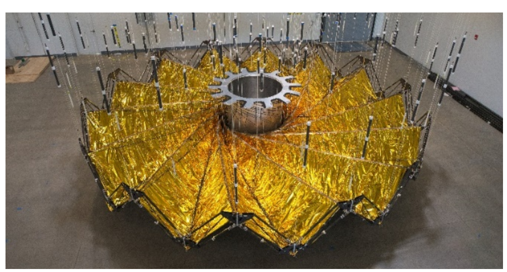
Zernike Wavefront Sensor



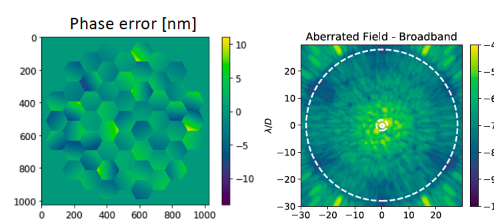
Roman/CGI



Starshade Technology Development



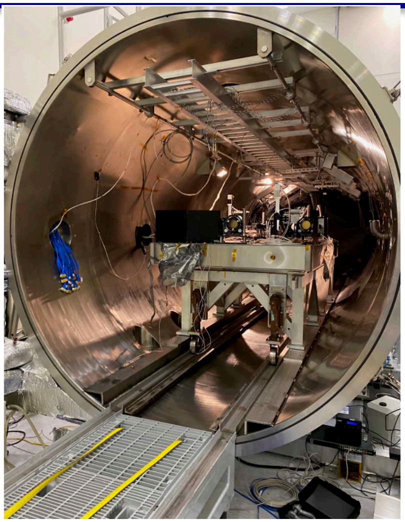
Segmented Coronagraph Design & Analysis Study



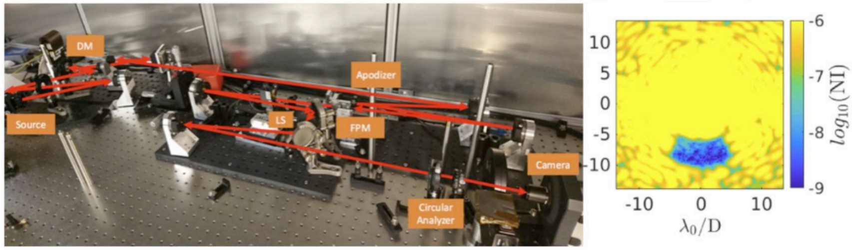
Strategic Astrophysics Technology (1/2)

- **4 coronagraph masks/architectures**
  - Vortex Coronagraph (Serabyn/NASA-JPL)
  - Phase Induced Amplitude Apodization Complex Mask Coronagraph (Belikov/NASA-ARC)
  - Apodized Pupil Lyot Coronagraph (Soummer/STScI)
  - Super-Lyot Coronagraph (Trauger/NASA-JPL)

PIAACMC in vacuum chamber now

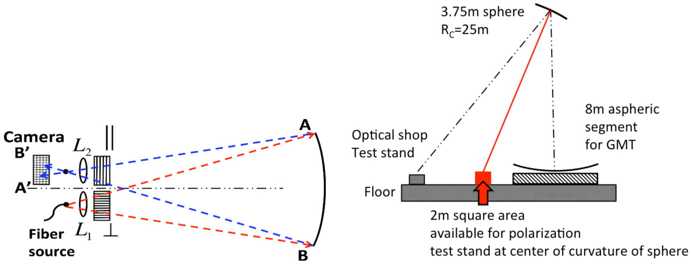


- **4 wavefront-control techniques**
  - Single mode fiber and optimization for spectroscopy (Mawet/Caltech)
  - Multi-star wavefront control demos (Belikov/NASA-ARC)
  - WFC using light outside the dark field (Guyon/UA)
  - MEMS deformable mirrors (Bierden/BMC)



Mawet SAT-2018

- **Polarization & Coronagraphy (Breckinridge/UA)**

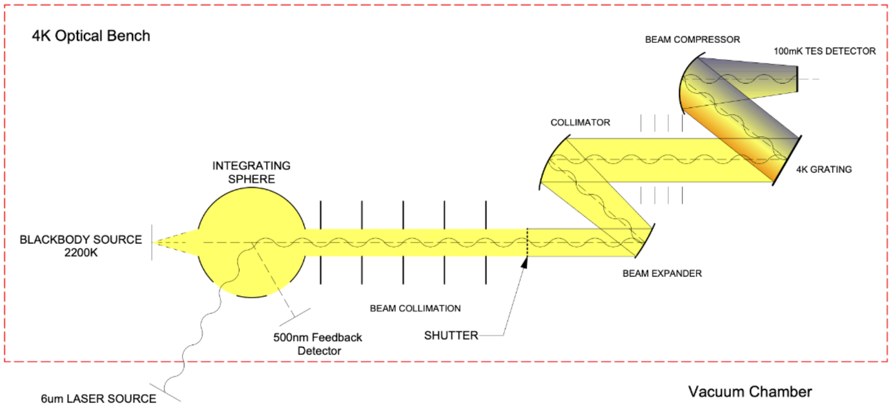


Breckinridge Final Report under review

Strategic Astrophysics Technology (2/2)

Detectors

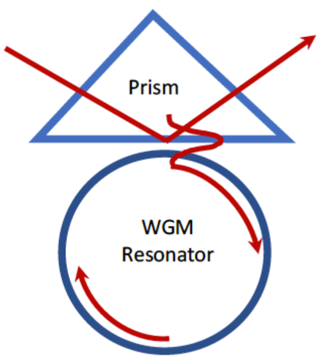
- **Vis-band rad-hard photon-counting detectors (Rauscher/NASA-GSFC)**
- **Ultra-stable mid-IR detector array (Staguhn/JHU)**

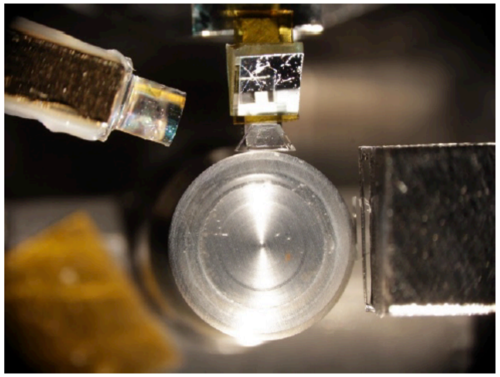


Staguhn SAT2018

Extreme Precision Radial Velocity

- **Micro-resonator optical etalon for radial velocity measurements (Leifer/NASA-JPL)**





Leifer SAT2018

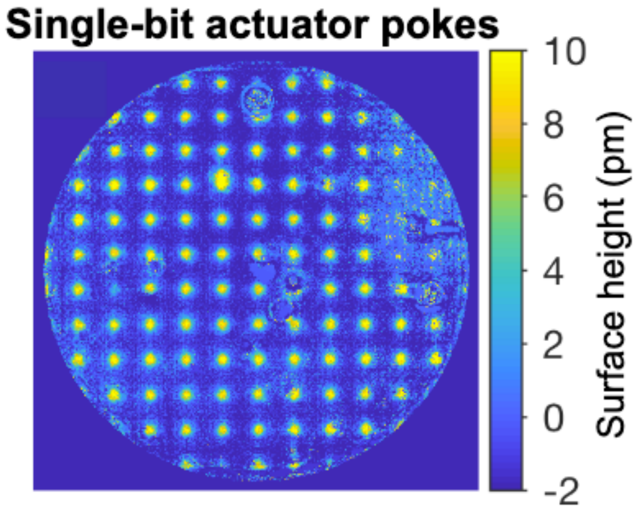
https://exoplanets.nasa.gov/exep/technology/TDEM-awards/

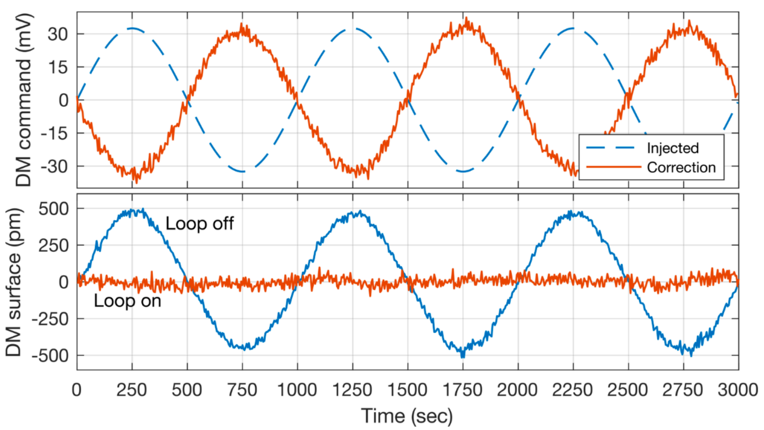
Decadal Survey Testbed (DST)

- **Coronagraph testbed specifically designed for opto-mechanical stability permitting demonstration of 10^{-10} contrast**

- **Zernike wavefront sensor commissioned in DST, achieving picometer sensitivity, and available to investigators**

ExEP's HCIT-2 Vacuum Chamber and the DST at JPL



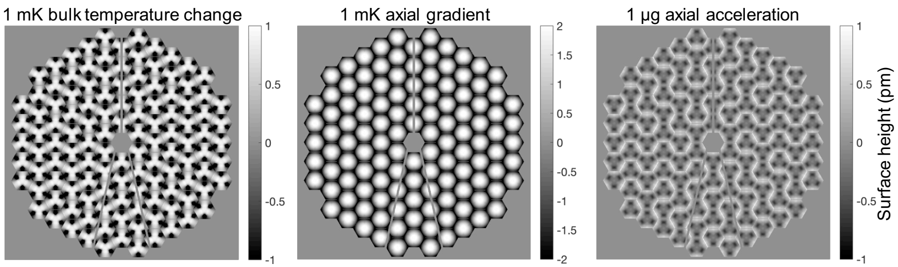


- **Segmented pupil (static) will commence later in 2020, targeting large space telescope concepts; also installing EMCCD**

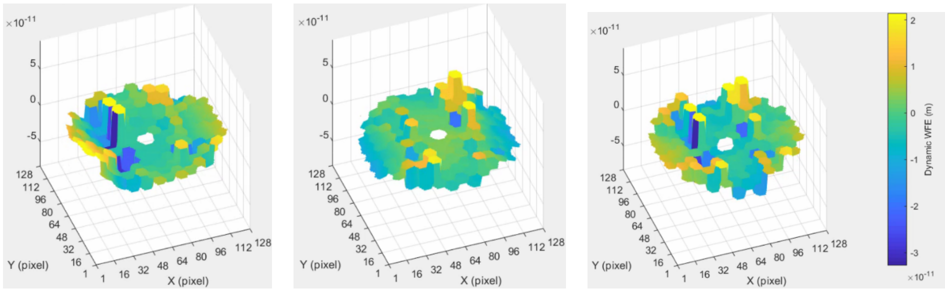
Segmented Coronagraph Design & Analysis

- **2020 Objectives:**
  - Investigate sensitivity of science yield to telescope aberrations/instabilities
  - investigate how coronagraph requirements drive telescope requirements

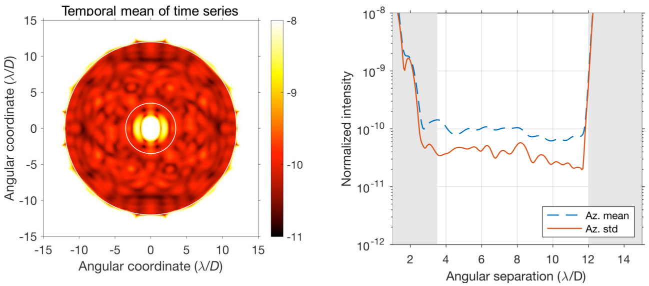
- **Year-to-Date Accomplishments**
  - Produced end-to-end propagation model
  - Incorporated quasi-static and dynamic telescope aberrations



Quasi-Static Segment Deformations (Coyle, East)



Snapshots of Dynamic Wavefront Errors (Chopra, Dewell, Nordt)



Preliminary Contrast Result,
APLC w/ Angular Differential Imaging (Ruane, JPL)

Deformable Mirror Survey

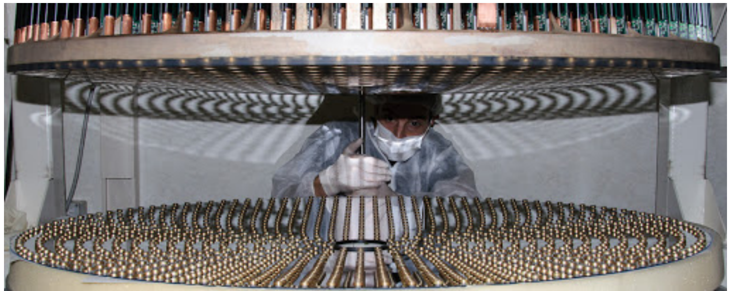
- ***Have we identified all candidate deformable mirrors that might be suitable for a future exoplanet direct imaging mission?***

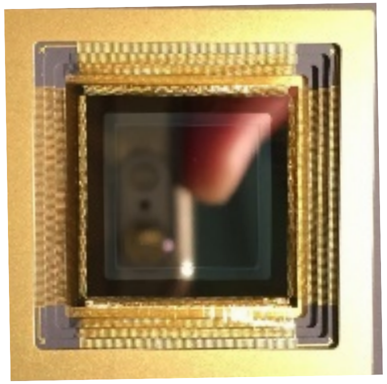
- **A 1-year survey to assemble a Subject-Matter Expert team, define requirements, perform a global fact-finding effort, and write a report.**

- **Identify novel wavefront control technologies that could mature rapidly.**

- **Current Status: Defined requirements with Subject Matter Experts, fact finding ongoing with vendors.**

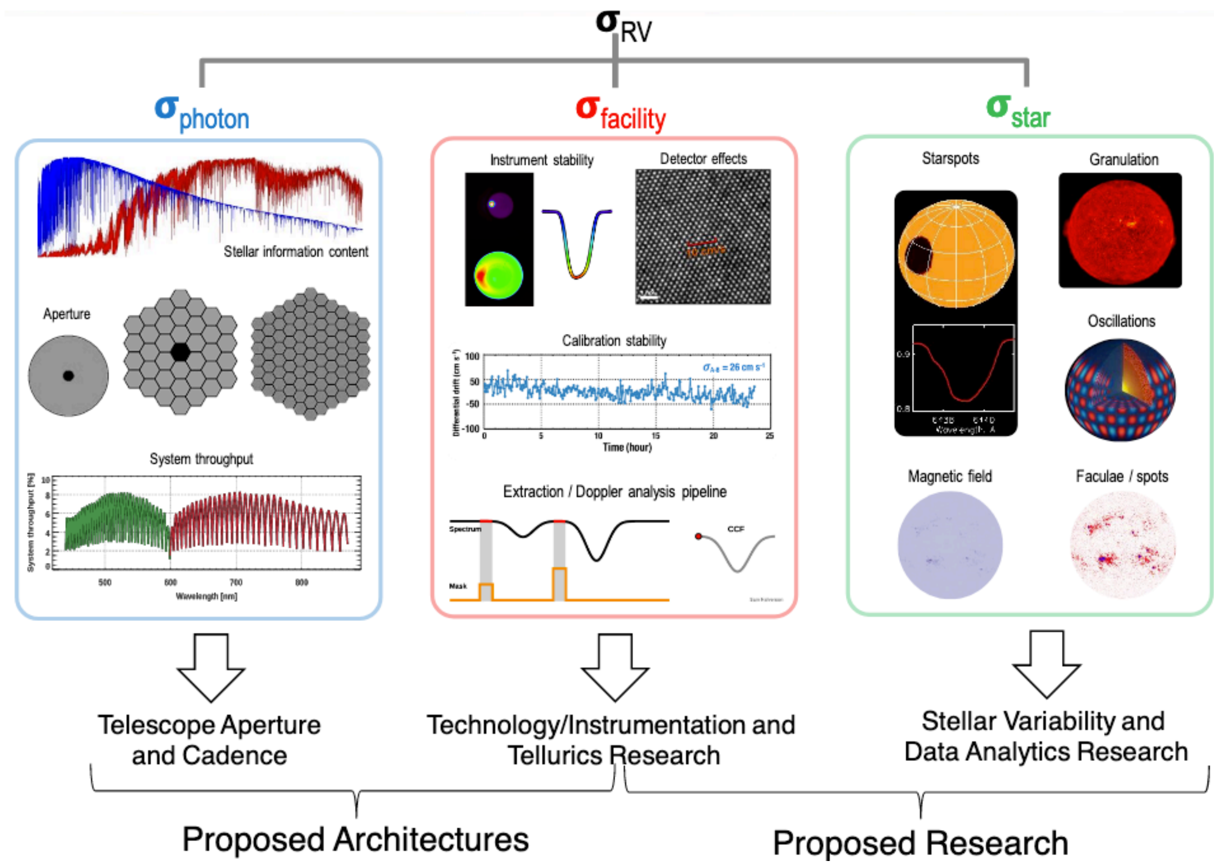
- **Report to be made public at the end of the year**





Extreme Precision Radial Velocity

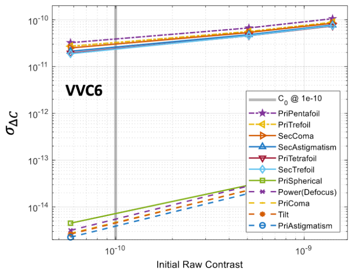
- **Extreme Precision Radial Velocity Initiative Plan delivered to NASA and NSF in March 2020**
- **See upcoming talk by Scott Gaudi and Jenn Burt for the details!**



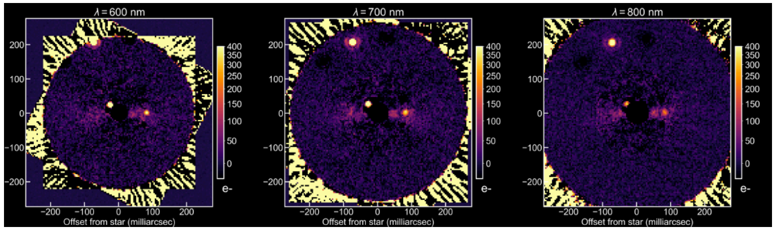
EPRV working group

Exoplanet Exploration Technology Colloquium Series

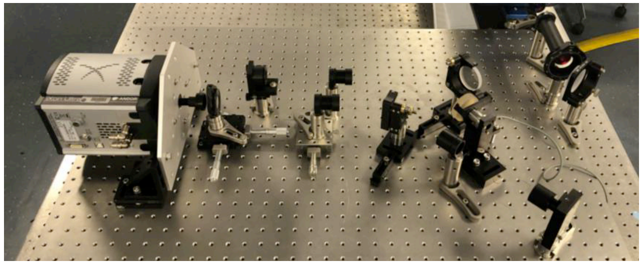
- **Telescope Stability + Coronagraph modeling**

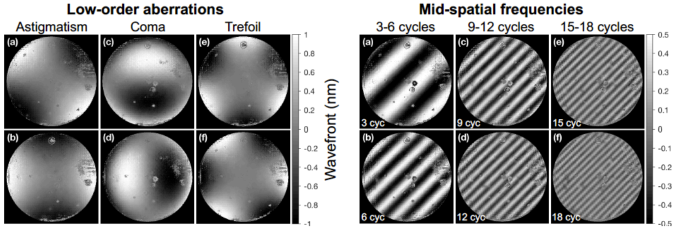


4-m Off-Axis Monolithic with VVC-6			
Perturbation Mode	Sensitivity	Allocations (auto)	Tolerance
	ppt/pm	40.00	pm
Tip/Tilt	0.00091	0.21	235
Defocus	0.0011	0.21	194
Astigmatism	0.00	0.2	276
Coma	0.00	0.2	231
Trefoil	6.06	18.0	3.0
Spherical	0.00	0.2	156
Secondary Atigmatism	4.82	14.3	3.0
Tetrafoil	4.44	13.2	3.0
Secondary Coma	5.62	16.7	3.0
Secondary Trefoil	4.34	12.9	3.0
Pentafoil	7.21	21.4	3.0

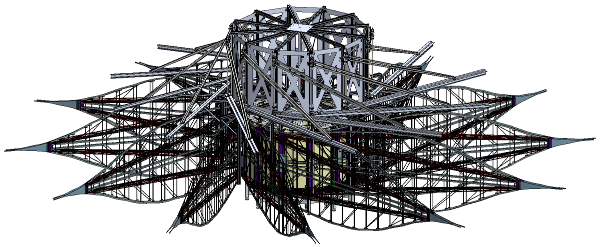


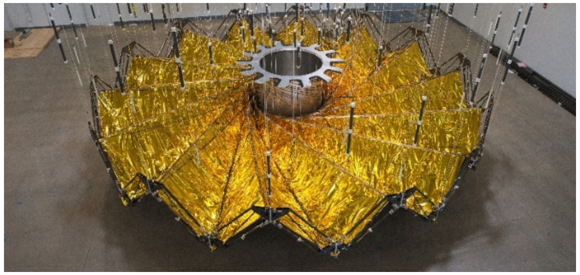
- **Workshop on Advanced Wavefront Sensing for Coronagraphy**

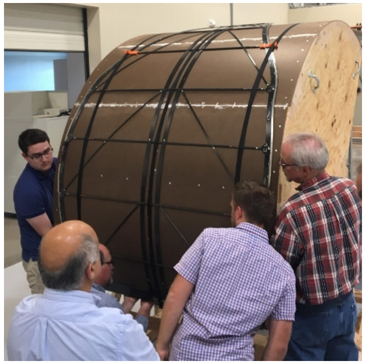




- **Update on Starshade Technology Development**





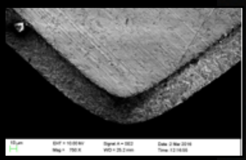


- **Recordings and slides available here:**
  - https://exoplanets.nasa.gov/exep/technology/tech_colloquium/

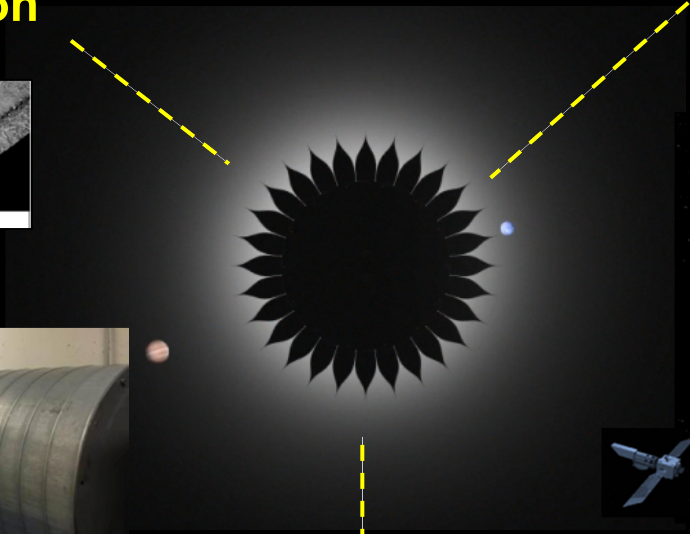
The Three Starshade Technology Gaps

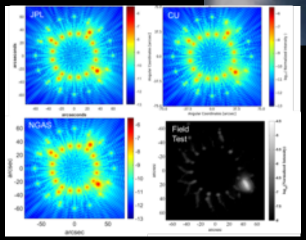
https://exoplanets.nasa.gov/exep/technology/starshade/

(1) Starlight Suppression



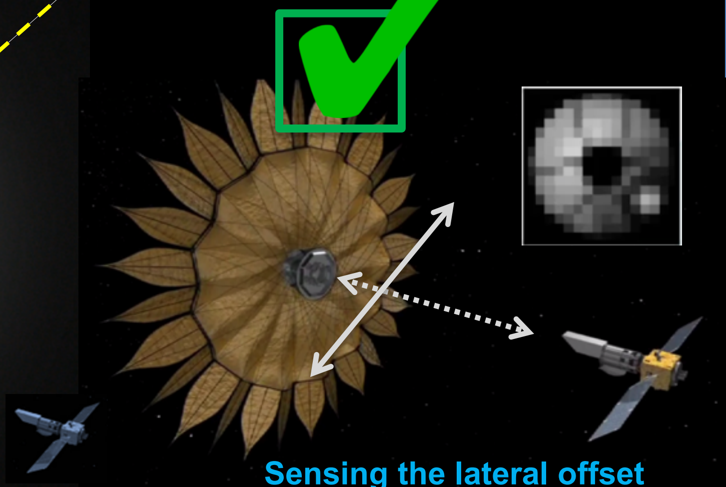
Suppressing scatted light off petal edges from off-axis Sunlight (S-1)





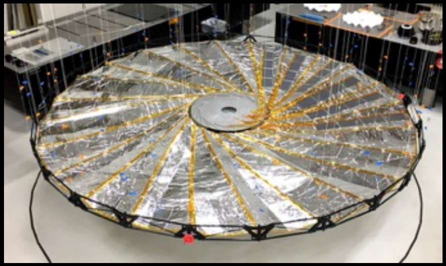
Suppressing diffracted light from on-axis starlight and optical modeling (S-2)

(2) Formation Sensing

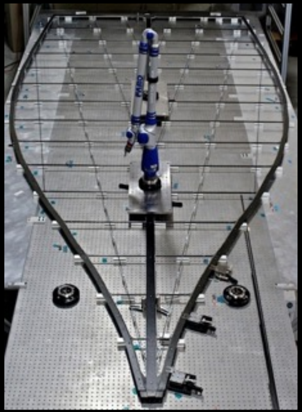


Sensing the lateral offset between the spacecraft (S-3)

(3) Deployment Accuracy and Shape Stability



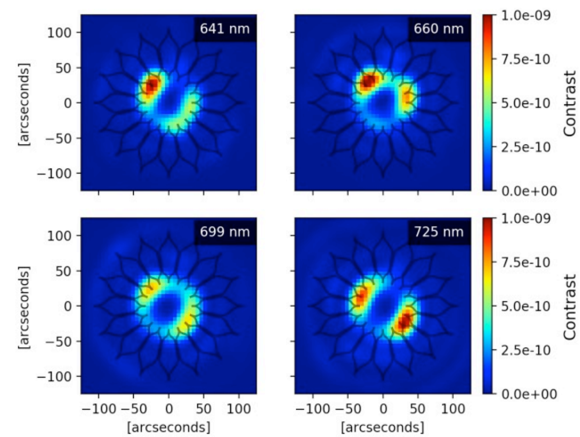
Positioning the petals to high accuracy, blocking on-axis starlight, maintaining overall shape on a highly stable structure (S-5)



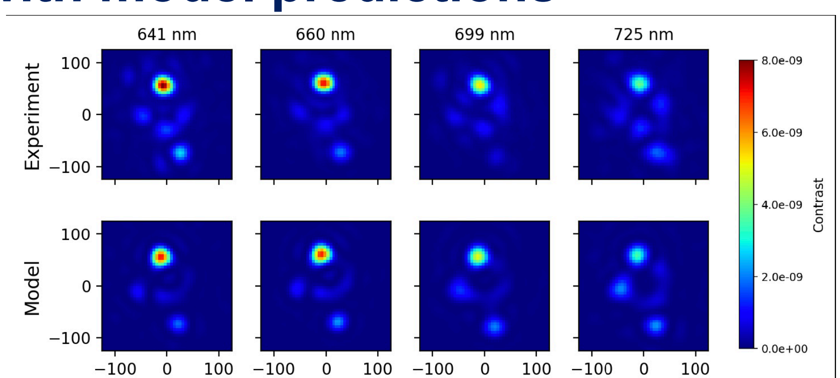
Fabricating the petals to high accuracy (S-4)

Starlight Suppression and Edge Scatter

- **Validate models of starshade performance**
- **Princeton testbed has been used to demonstrate starlight suppression to $< 10^{-10}$ over a 10% band of sub-scale starshade**

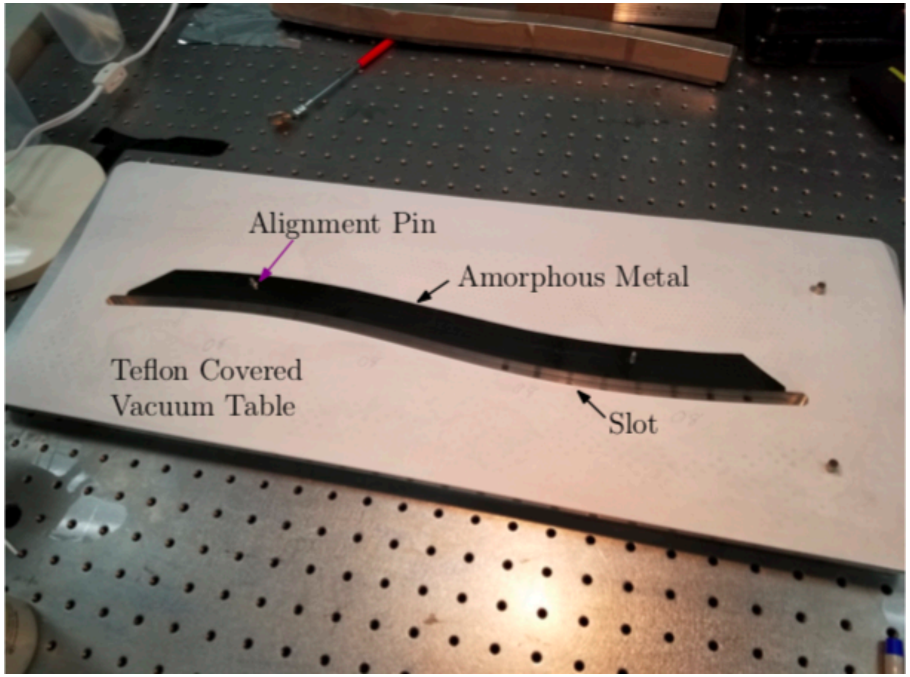


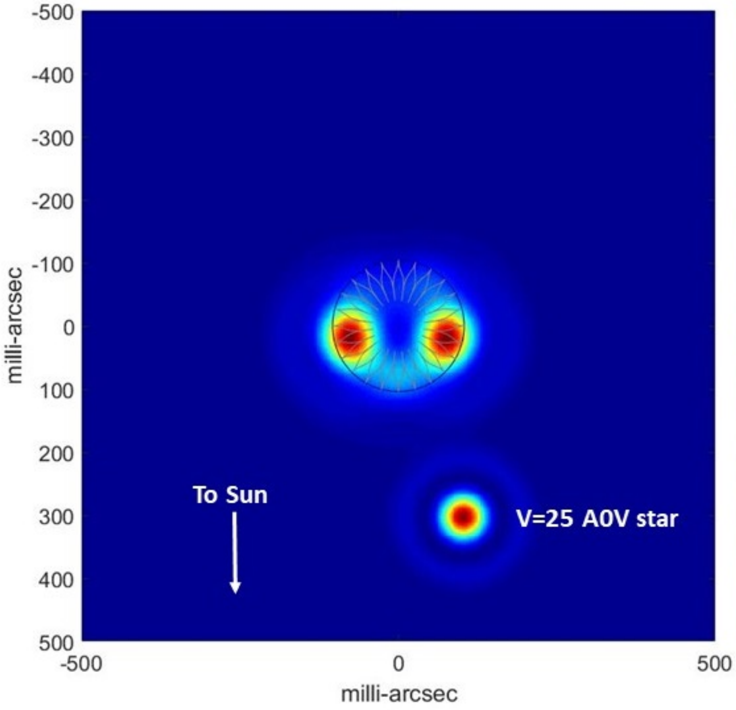
- **Last step: measure deliberately misshapen subscale starshades and compare with model predictions**



Starlight Suppression and Edge Scatter

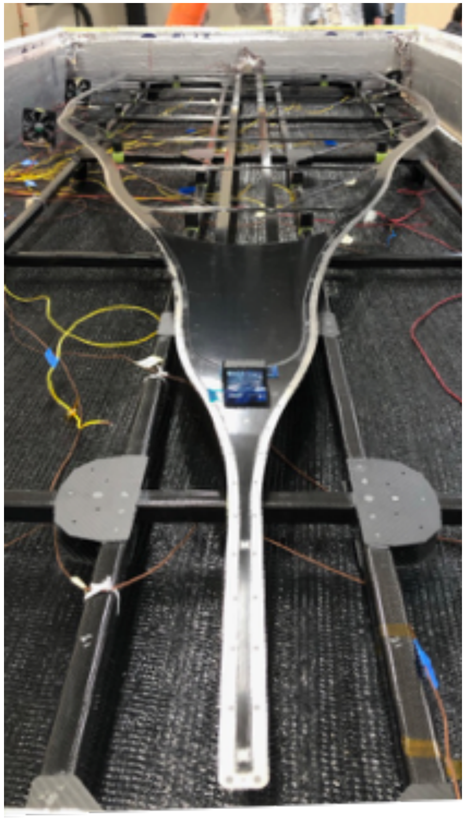
- **Demonstrated starshade optical edge limits Solar scatter performance to lobe dimmer than mag 25 and maintains performance after thermal cycling**



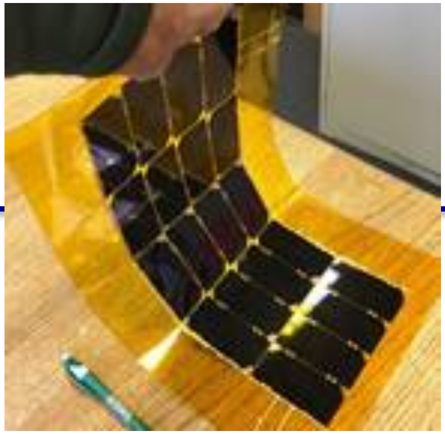


Shape Accuracy: Critical Features demonstrated

- **Starshade Petal System successfully demonstrated to maintain prelaunch shape within +/- 70 μm after deploy and thermal cycles**



Full Scale Inner Disk



Integrated solar cells

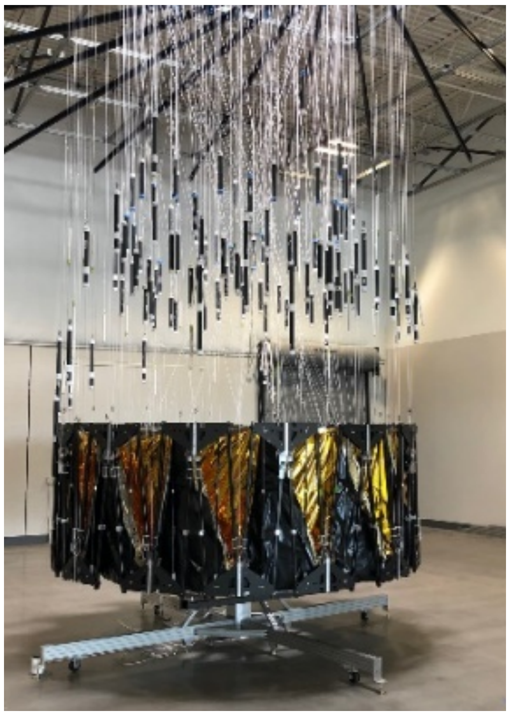
Gravity offloading

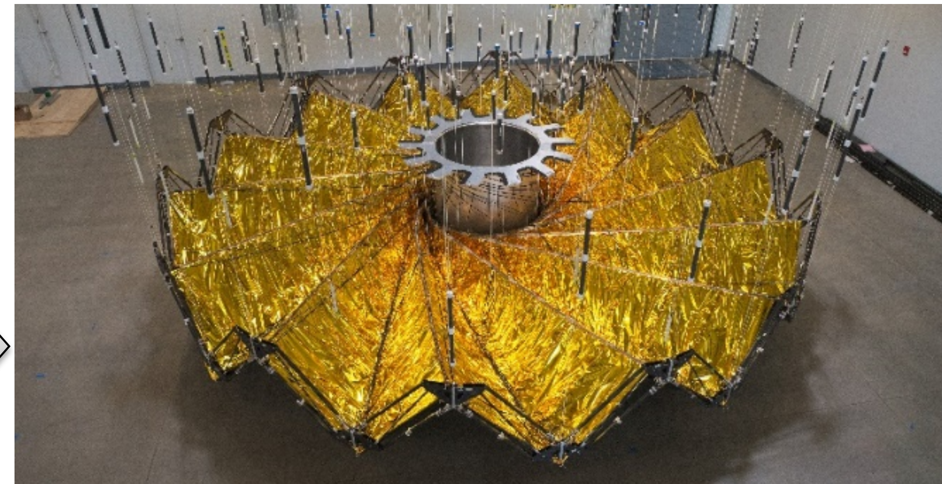
(a) Deployed

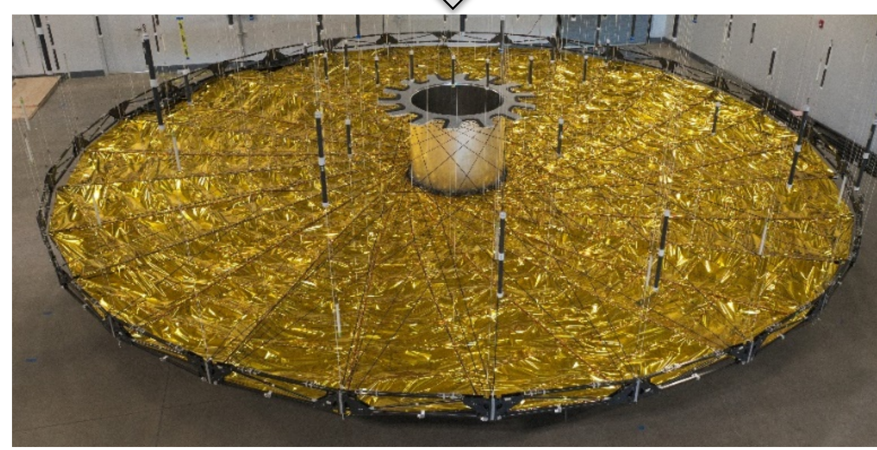
(b) Stowed

Shape Accuracy: Critical Features demonstrated

- **Full Scale Prototype Tested**



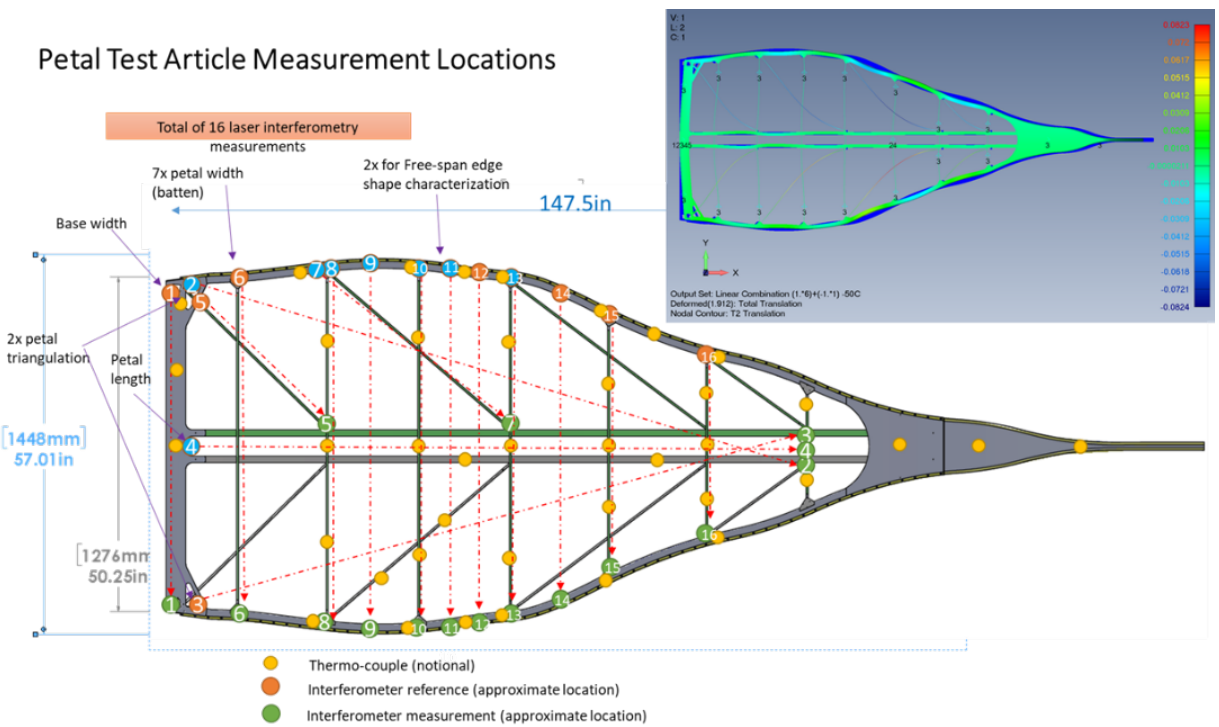




- **Inner disk deployment dimensional stability with thermal cycles and storage successfully demonstrated to +/- 300 μm**

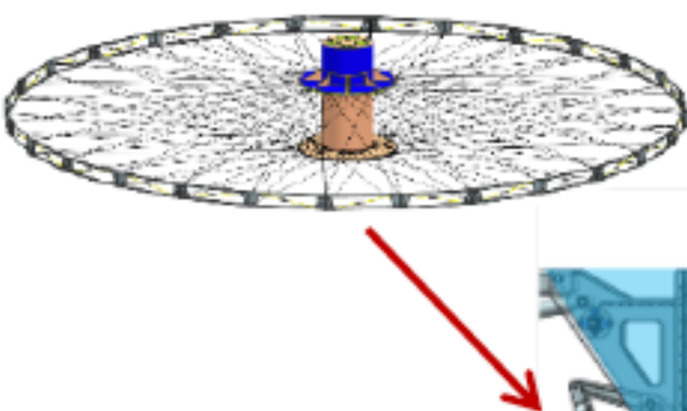
Starshade Shape Stability: critical components demonstrated

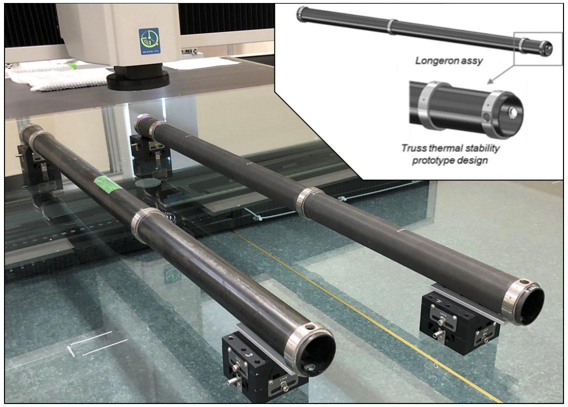
- **On-orbit thermal stability on-orbit of petal critical dimensions demonstrated to +/- 80 μm through measurement and models**

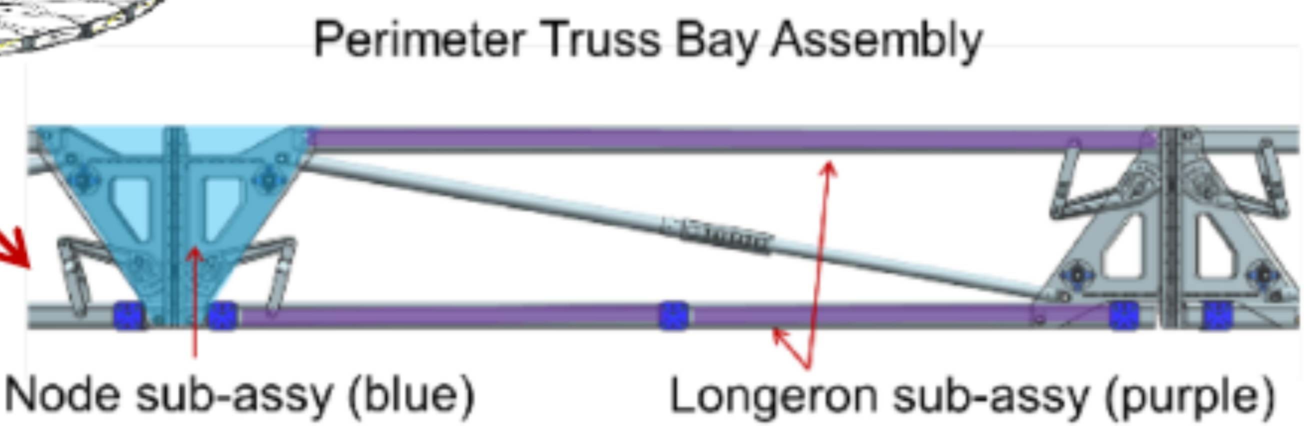


Starshade Shape Stability: critical components demonstrated

- **Thermal stability on-orbit of critical parts of inner disk demonstrated to +/- 200 μm**





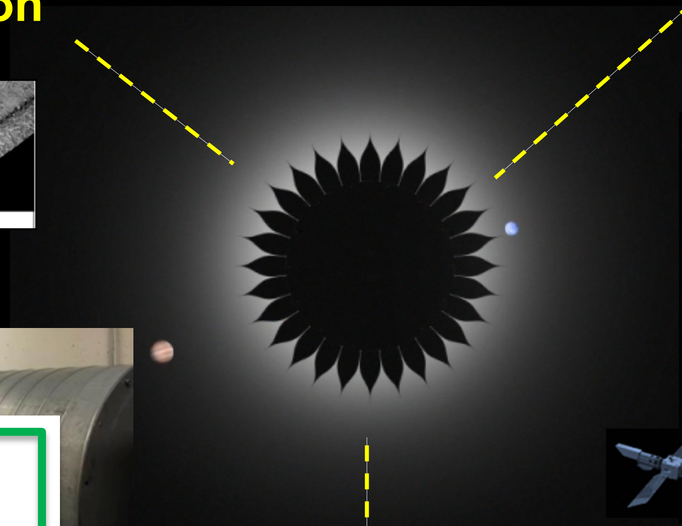


Starshade Technology Gaps Scorecard

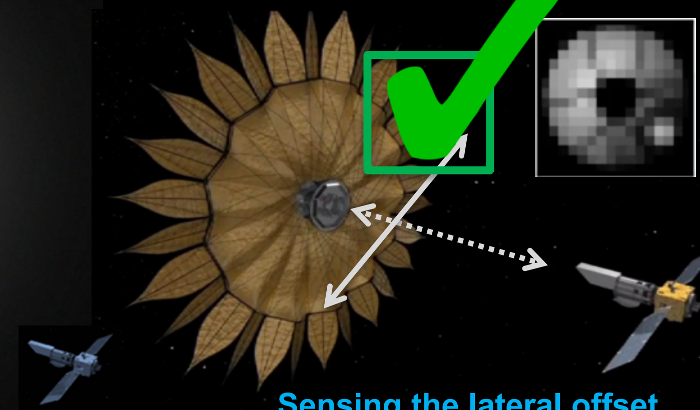
https://exoplanets.nasa.gov/exep/technology/starshade/

(1) Starlight Suppression

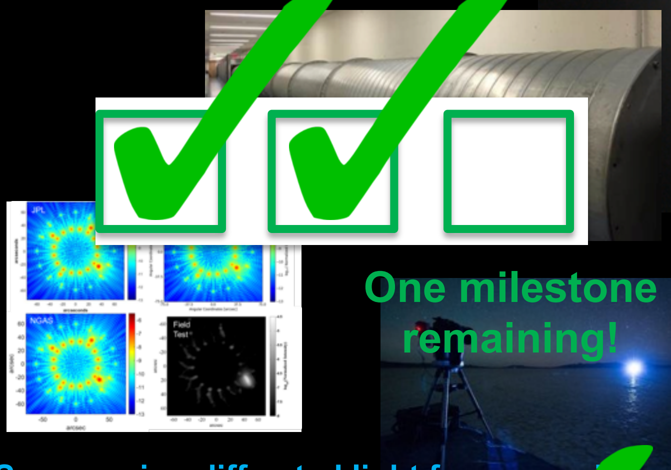
Suppressing scatted light off petal edges from off-axis Sunlight (S-1)



(2) Formation Sensing



Sensing the lateral offset between the spacecraft (S-3)

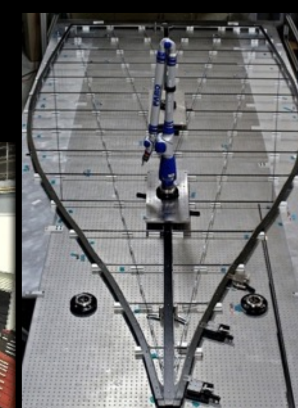


One milestone remaining!

Suppressing diffracted light from on-axis starlight and optical modeling (S-2)

(3) Deployment Accuracy and Shape Stability

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



Fabricating the petals to high accuracy (S-4)

Remaining accuracy and stability milestones complete by 2023

Looking ahead..

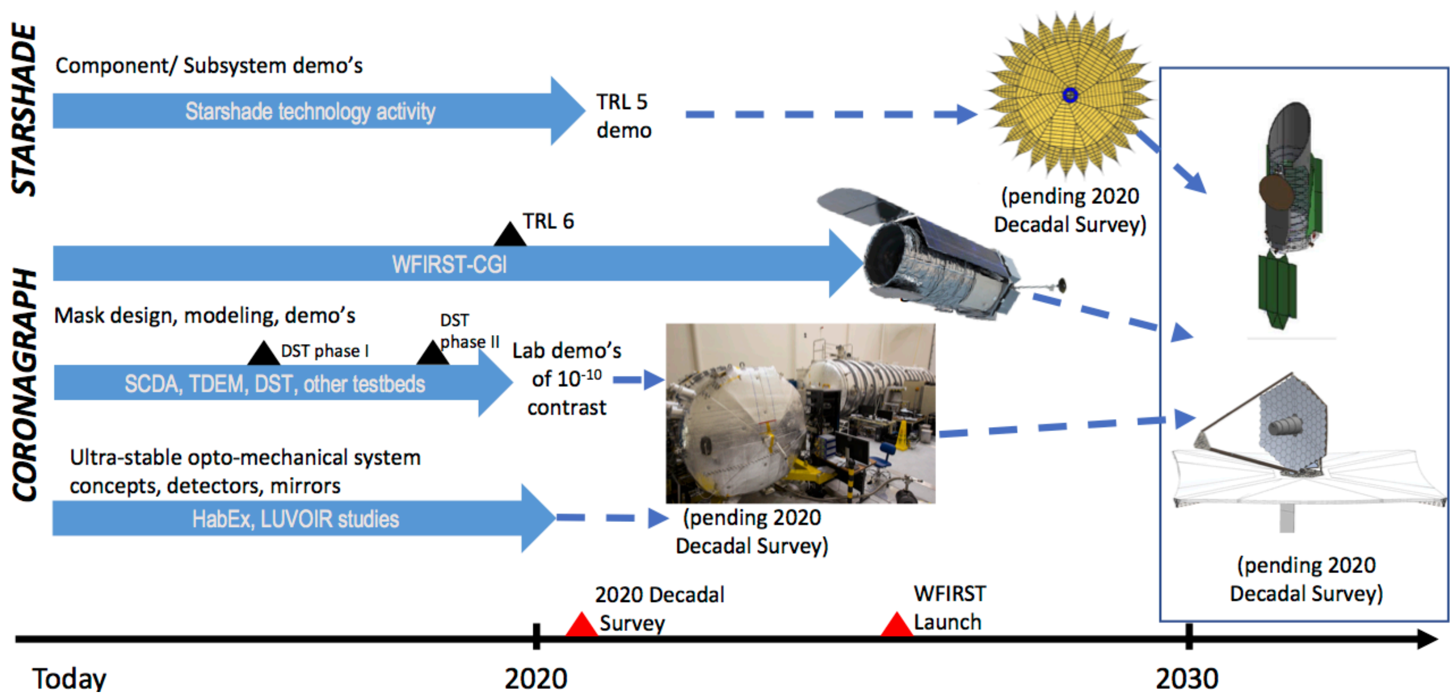
- **SAT Results coming:**
  - Final Reports on Polarization, MEMS DMs
  - Lab Coronagraph demonstrations of PIAACMC, Vortex, HLC
  - Further upgrades to DST – segmented pupil, EMCCD
- **Starshade work continues: subscale optical demos, deployment shape and stability demos**
- **Segmented Coronagraph Design and Analysis: telescope tolerancing results**
- **Roman/CGI: Zernike Wavefront Sensor and Multi-Star Wavefront Control masks in spare slots**
- **Extreme Precision Radial Velocity solicitation coming in August**
- **Astro2020 coming 2021**

Want to get involved?

- **Please contact me**

- **in July or August 2020, I plan to offer a 1-hour ExEP Technology Primer briefing: a deeper dive into our technology activities**

  – *look for an email on ExoPAGannounce*



BACKUP

Starshade Technology Activity (S5) Technology Milestones Scorecard

Complete 2020

Complete 2023

Milestone Completed

Report under Review

In Progress

Not Started

Starlight Suppression

Contrast NB 1A

Contrast BB 1B

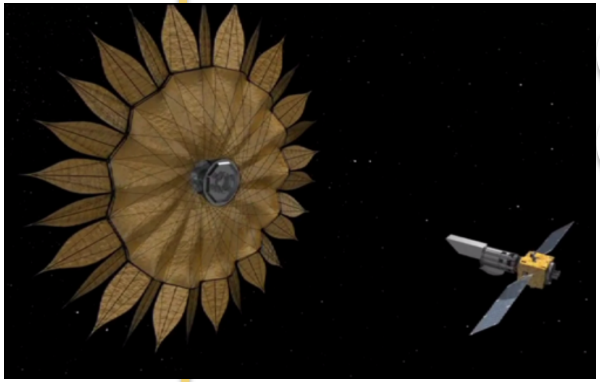
Modeling 2

Scattered Sunlight

Edges 3

Formation Flying

Sensing 4



Critical Features

All Features

Shape Accuracy

Petal 5A

Truss Bay 7A

Inner Disk 7C

Petal 5B

Truss Bay 7B

Inner Disk 7D

Shape Stability

Petal 6A

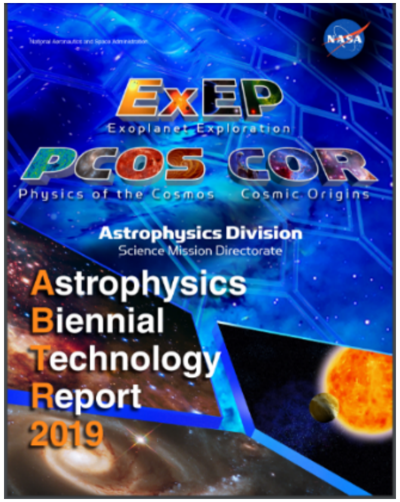
Inner Disk 8A

Petal 6B

Inner Disk 8B

from Phil Willems

Technology Gap List

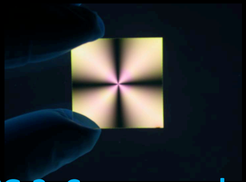


- **Astrophysics Technology Gap List**
  - Technology gaps for all three NASA Astrophysics Division (APD)'s programs
  - Database of technology activities:
    - http://astrostrategictech.us/
  - Update coming in 2021, post-decadal

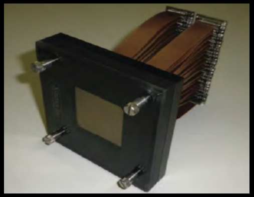
- **Exoplanet Technology Gap List**
  - Subset of APD gap list corresponding to exoplanet science:
    - https://exoplanets.nasa.gov/exep/technology/gap-lists/

V-NIR Coronagraph/Telescope Technology Gaps

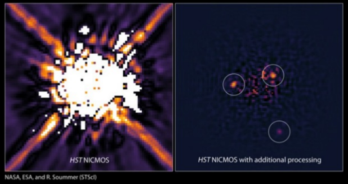
Contrast



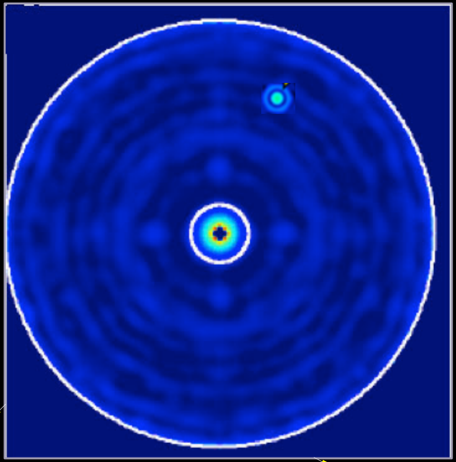
CG-2: Coronagraph Architecture



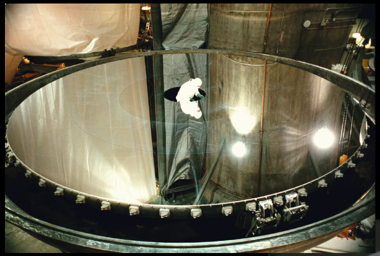
CG-3: Deformable Mirrors



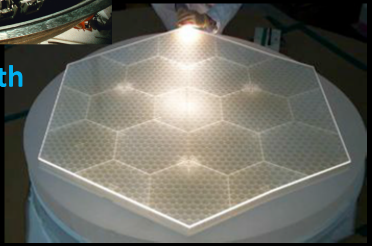
CG-4: Data Post-Processing



Angular Resolution

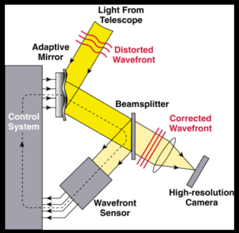


CG-1: Large Monolith Mirrors



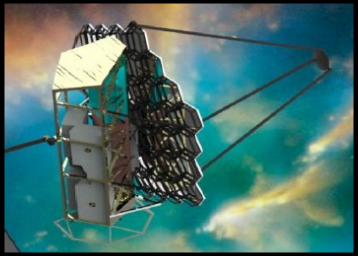
CG-1: Segmented Mirrors

Contrast Stability



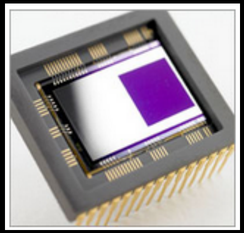
CG-5: Wavefront Sensing and Control

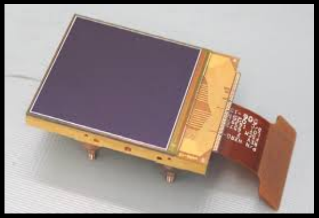
CG-6: Mirror Segment Phasing



CG-7: Telescope Vibration Sensing and Control or Reduction

Detection Sensitivity

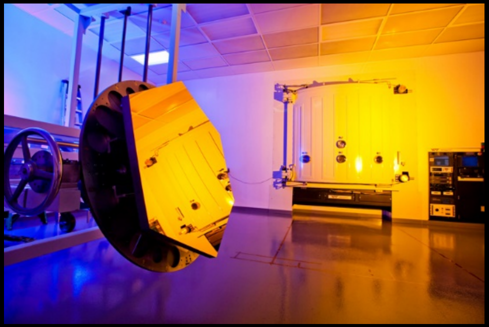




Ultra-low Noise Visible (CG-8) and Infrared (CG-9) Detectors

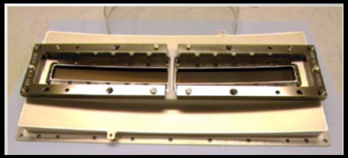
Other Technology Gaps

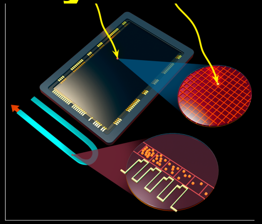
UV Contrast



CG-10 UV/V/NIR Mirror Coatings

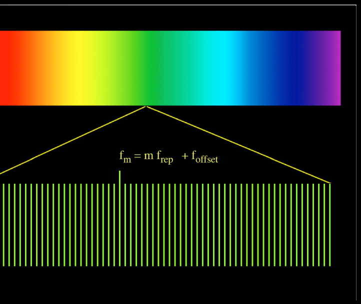
UV Detection Sensitivity



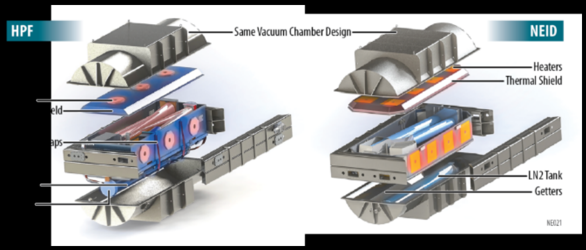


CG-12: Ultra-low Noise UV Detectors

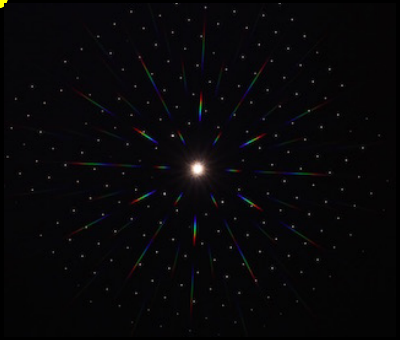
Stellar Reflex Motion Sensitivity



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

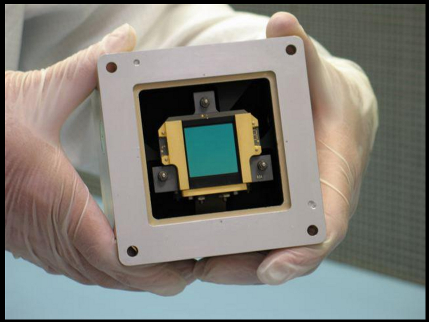


M-1: Ground-based Ultra-high Precision Radial Velocity



M-3: Astrometry

Transit Spectroscopy Sensitivity



M-4: Ultra-stable Mid-IR Detectors for Transit Spectroscopy