Jet Propulsion Laboratory
California Institute of Technology

Exoplanet Exploration Program Technology Update

Nick Siegler (Chief Technologist)

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Exoplanet Exploration Program

Jet Propulsion Laboratory / California Institute of Technology

ExoPAG 21, Honolulu, HI 3 January 2020

CL# 20-0155

Current Technology Activities

NASA EXOPLANET EXPLORATION PROGRAM

Technology Gaps


National Aeronautics and Space Administration

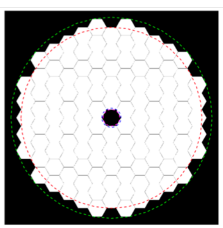
NASA

EXOPLANET EXPLORATION PROGRAM
2019 Technology Plan Appendix

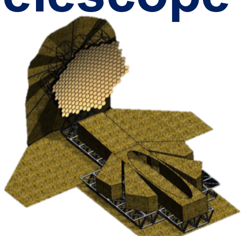
Brendan Crill, Deputy Program Chief Technologist
Nick Siegler, Program Chief Technologist

JPL Document No: D-102506

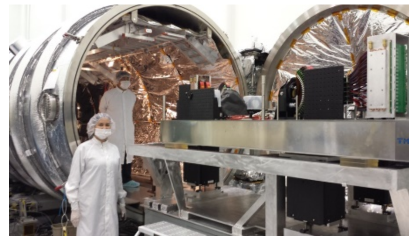
Segmented Coronagraph Design & Analysis Study



iSA Telescope Study

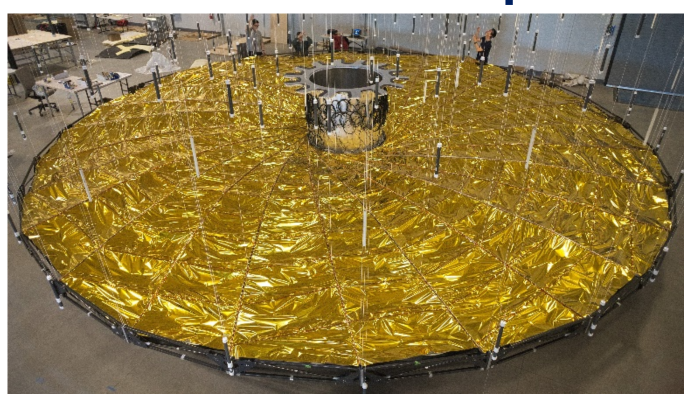


SAT Grants

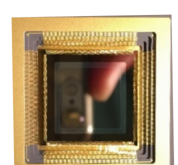


- Coronagraphy
- Detectors
- Wavefront control
- Polarization
- EPRV

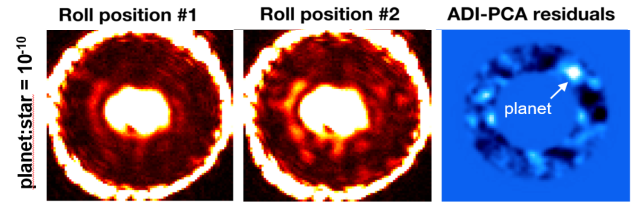
Starshade Development



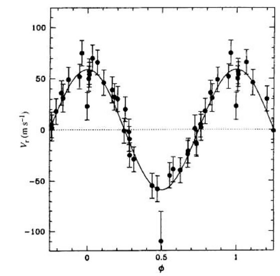
DM Survey



Ultra-Stable Testbed

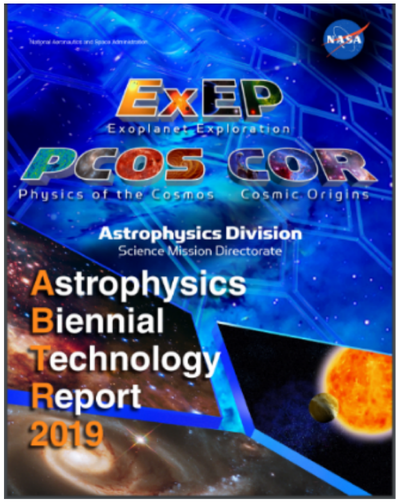


EPRV Initiative



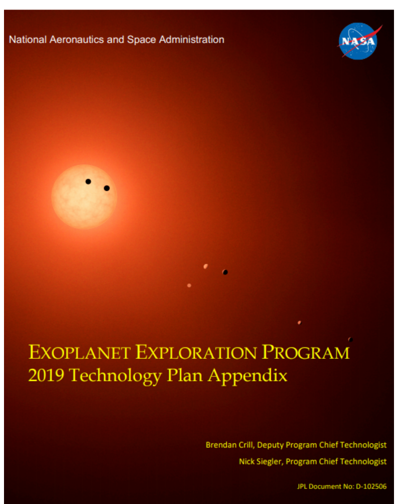
RV Spectrograph (NEID at WIYN)

Technology Gap List



Unified Technology Gap List

- includes gaps within all of NASA's three programs
- single, biennial Technology Report
- common database of past activities (one-stop-shop for proposers)

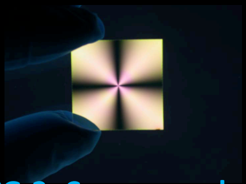


Exoplanets Technology Gap List

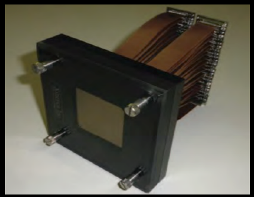
- annual report
- subset of the Unified report
- most up to date single report for all exoplanet technology supporting NASA's space missions

V-NIR Coronagraph/Telescope Technology Gaps

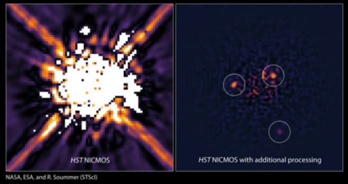
Contrast



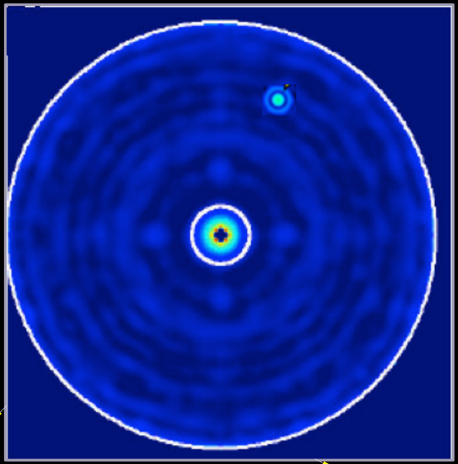
CG-2: Coronagraph Architecture



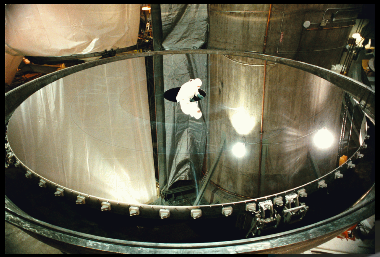
CG-3: Deformable Mirrors



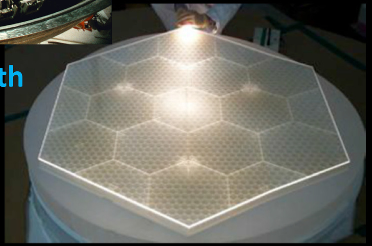
CG-4: Data Post-Processing



Angular Resolution

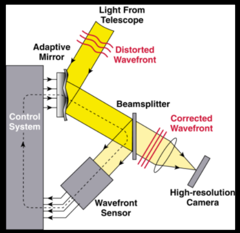


CG-1: Large Monolith Mirrors



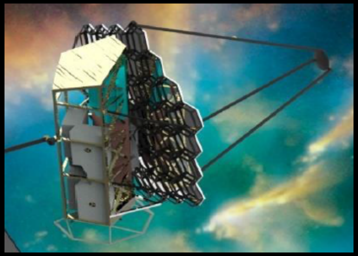
CG-1: Segmented Mirrors

Contrast Stability



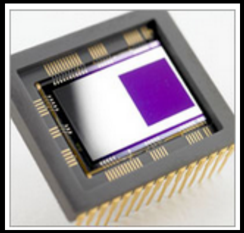
CG-5: Wavefront Sensing and Control

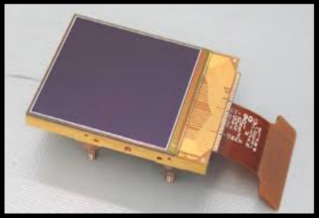
CG-6: Mirror Segment Phasing



CG-7: Telescope Vibration Sensing and Control or Reduction

Detection Sensitivity

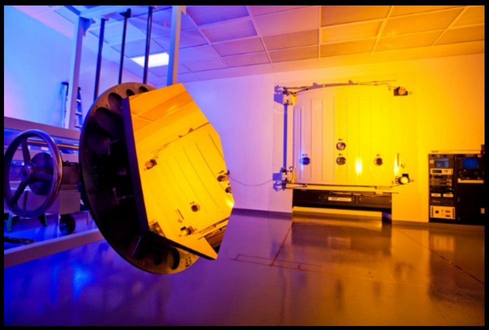




Ultra-low Noise Visible (CG-8) and Infrared (CG-9) Detectors

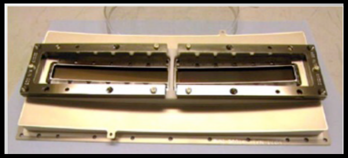
Other Technology Gaps

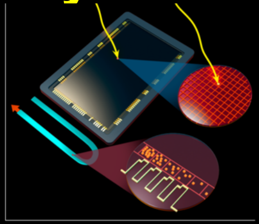
UV Contrast



CG-10 UV/V/NIR Mirror Coatings

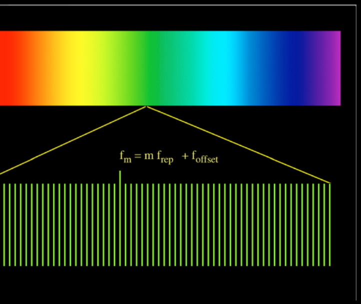
UV Detection Sensitivity



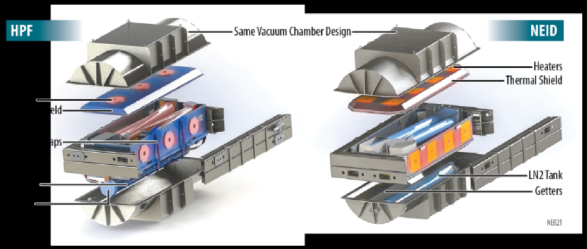


CG-12: Ultra-low Noise UV Detectors

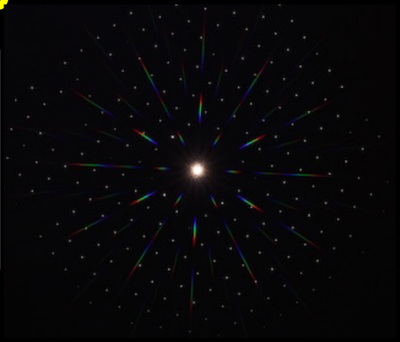
Stellar Reflex Motion Sensitivity



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

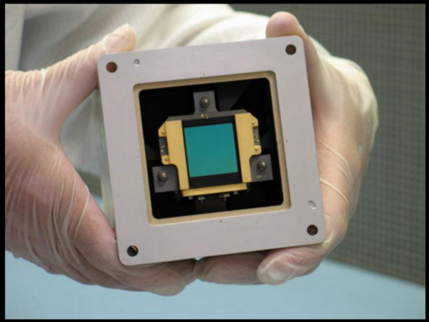


M-1: Ground-based Ultra-high Precision Radial Velocity



M-3: Astrometry

Transit Spectroscopy Sensitivity

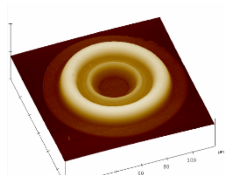


M-4: Ultra-stable Mid-IR Detectors for Transit Spectroscopy

WFIRST Coronagraph Instrument
Technology Demonstration

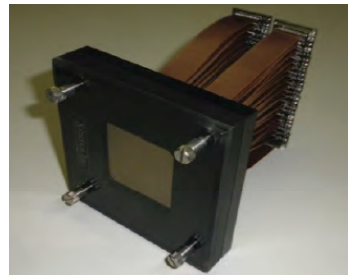
NASA EXOPLANET EXPLORATION PROGRAM

High-contrast coronagraph masks with a highly obscured pupil



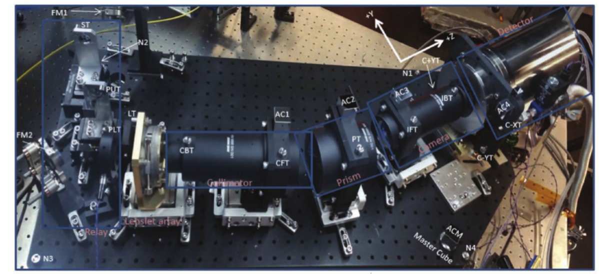
- Narrow FoV, HLC (360° az.) & SPC (2x65° az.): 3-9 λ/D, 4×10^{-9} contrast, 10% BW.
- Wide FoV, SPC: 6-20 λ/D, 4×10^{-9} contrast, 10% BW

Deformable mirrors

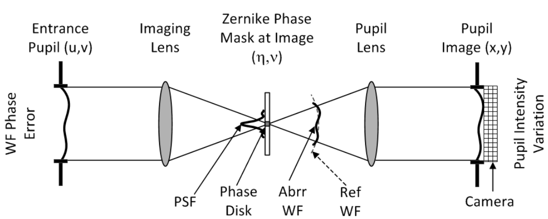


- Implementing connector solutions to reach TRL 6 by mid-2020

Integral field spectrograph + coronagraph

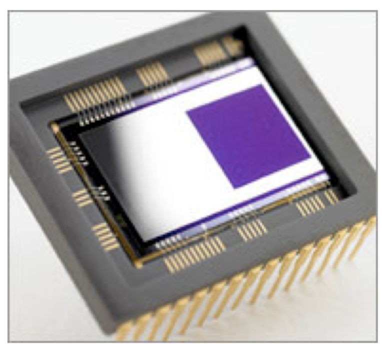


Low order wavefront sense / control



- Zernike LOWFS applies Z5-Z11 corrections to DM1 and Z4 to FCM.
- FSM corrects LOS jitter to 0.8 mas

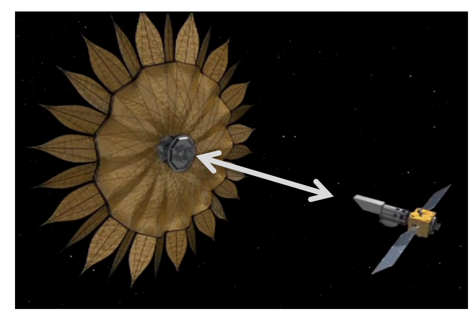
Ultra-low noise EMCCD for space



- Flight design meets the 5 year instrument lifetime requirement
- ESA contribution.

Starshade accomodation for possible rendezvous mission

(pending 2020 Decadal Survey)

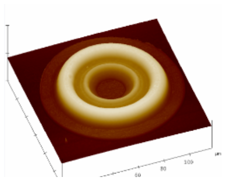


- Full set of detailed interface requirements captured in Lvl 2 Project IRD

WFIRST Coronagraph Instrument

Technology Demonstration

High-contrast coronagraph masks with a highly obscured pupil



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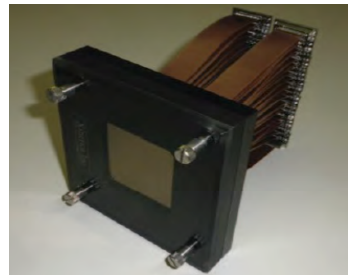
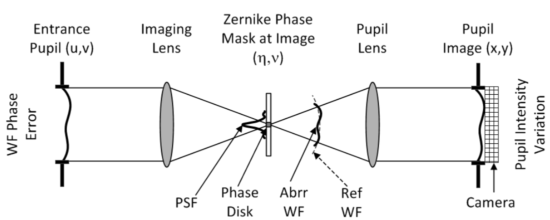


- Implementing connector solutions to reach TRL 6 by mid-2020

- **Passed Instrument PDR!!!**
- **Recent NASA Tiger Team identified options to deliver required capabilities within cost and schedule constraints**

Low order wavefront sense / control



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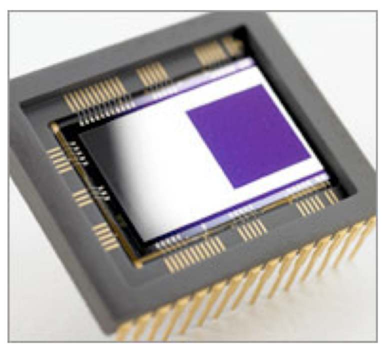
Ultra-low noise EMCCD for space



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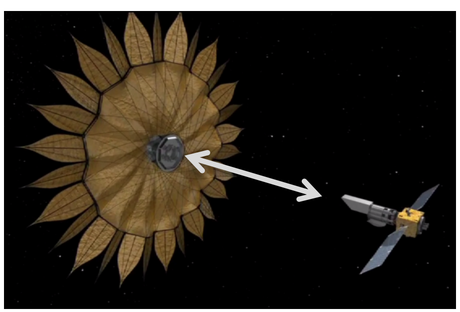
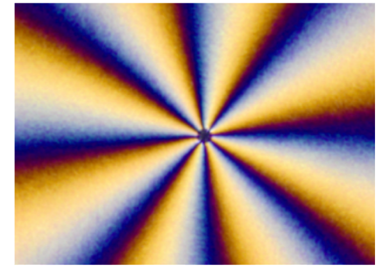
(pending 2020 Decadal Survey)



- Full set of detailed interface requirements captured in CGI Lvl 2

Active SAT Grants (1/2)

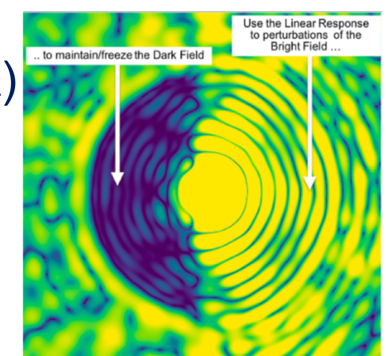
- **4 coronagraph masks/architectures**
  - Vector Vortex (Serabyn/NASA-JPL)
  - Phase Induced Amplitude Apodization Complex Mask Coronagraph (Belikov/NASA-ARC)
  - Apodized Pupil Lyot Coronagraph (Soummer/STScI)
  - Super-Lyot Coronagraph (Trauger/NASA-JPL)



Vector Vortex (Serabyn)

APLC (Soummer)

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



Linear Dark Field Wavefront Control (Guyon)

- **Polarization technique** (Breckenridge/UA)

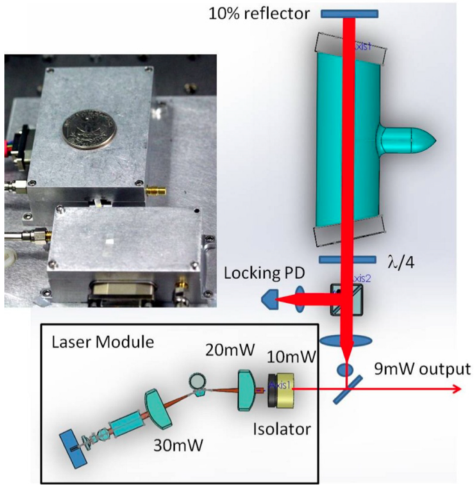
Active SAT Grants (2/2)

Detectors

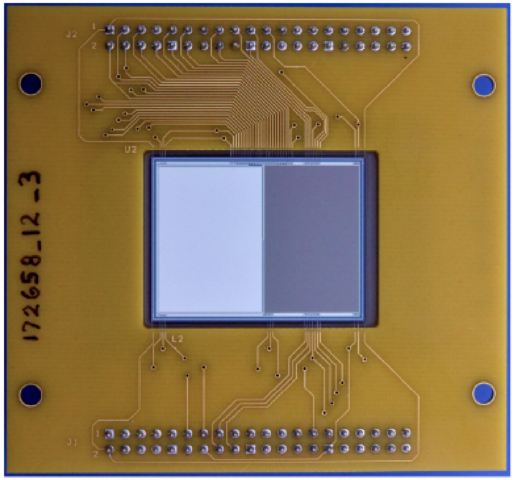
- Vis-band rad-hard photon-counting detectors (Rauscher/NASA-GSFC)
- Ultra-stable MIR detector array (Staguhn/JHU)

Extreme Precision Radial Velocity Observations

- Optical etalon for radial velocity measurements (Leifer/NASA-JPL)



Etalon for EPRV (Leifer)



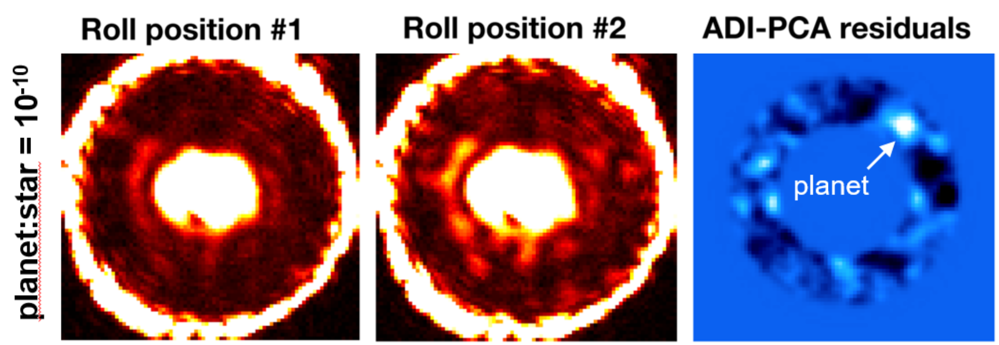
Photon-counting Vis-Band Detectors (Rauscher)

Ultra-Stable Coronagraph Testbed

Decadal Survey Testbed (DST)

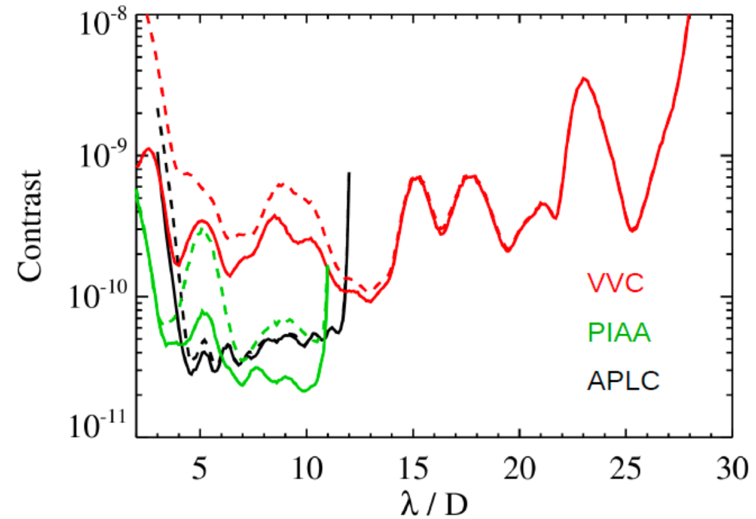
- Specifically designed for opto-mechanical stability permitting demonstration of 10^{-10} contrast
- DST established during commissioning 3.8×10^{-10} contrast @ 550 nm, 10% bandpass, 3-8 λ/D angular zone
- With post-processing: contrast of 1×10^{-10} can be reached for sensitivity w.r.t. Earth-size planets in habitable zone of Sun-like stars
- Commissioning phase complete - facility ready for SAT investigations.
- Segmented pupil (static) will commence in FY20, targeting large space telescope concepts

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



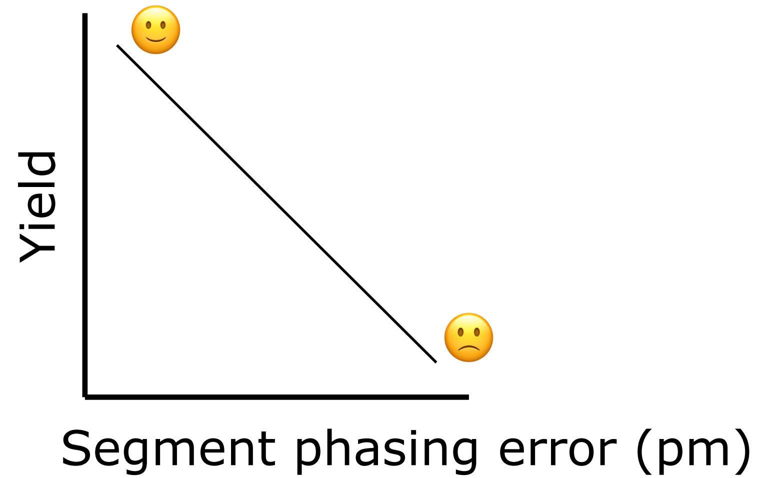
Segmented Coronagraph Design & Analysis Study

- **Objective: Determine if there is at least one coronagraph architecture that can reach 1×10^{-10} contrast on a segmented telescope.**
  - Four architectures appear to be promising
    - Vector Vortex, PIAA, Hybrid Lyot, Apodized Pupil Lyot Coronagraph
  - Whitepaper submitted to Astro2020 Decadal Survey (Shaklan et al.)



- **Do these coronagraphs put unrealistic requirements on the telescopes?**

Notional example



New Initiative: Deformable Mirror Survey

- **Are there other DM technologies that may be better suited for flight qualification? Can they meet the $1x10^{-10}$ contrast goal. Are they scalable? Can they be matured in time for future exoplanet space missions?**

  - *Or should NASA continue its focus on the current two technology approaches (electrostrictive PMN and electrostatic MEMS)?*

- **Survey deliverables:**
  1. Survey and document viable DM technologies across the world to inform future exoplanet missions about their capabilities and technology readiness.
  2. Make recommendations for DM technologies based on an assortment of success criteria and recommend how best to advance (directed vs competed).

The Three Starshade Technology Gaps

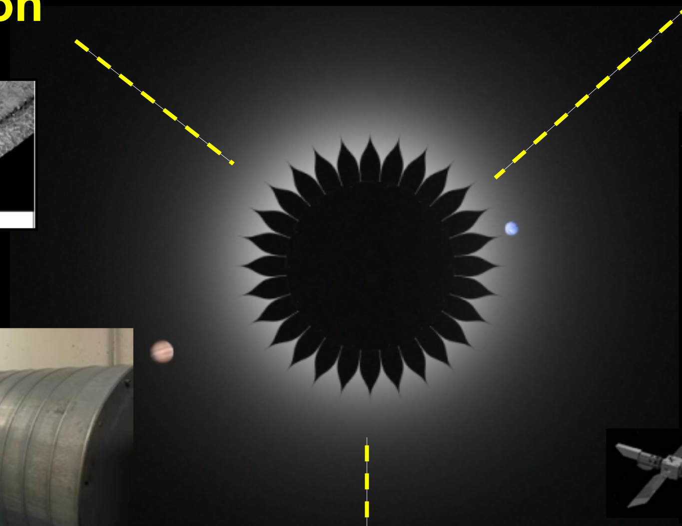
(1) Starlight Suppression

Final Report Submitted

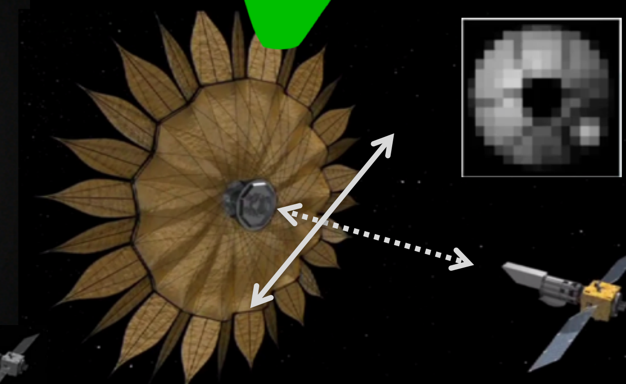
Supp… edge… …etal …(S-1)

2 of 3 Milestones Met

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

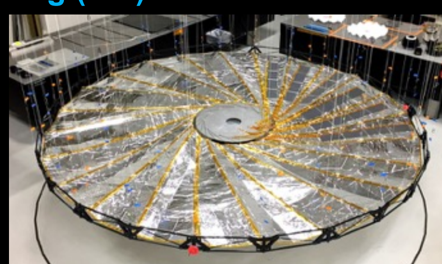


(2) Formation Sensing



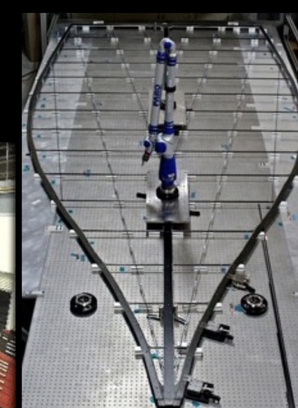
Sensing the lateral offset between the spacecraft (S-3)

(3) Deployment Accuracy and Shape Stability

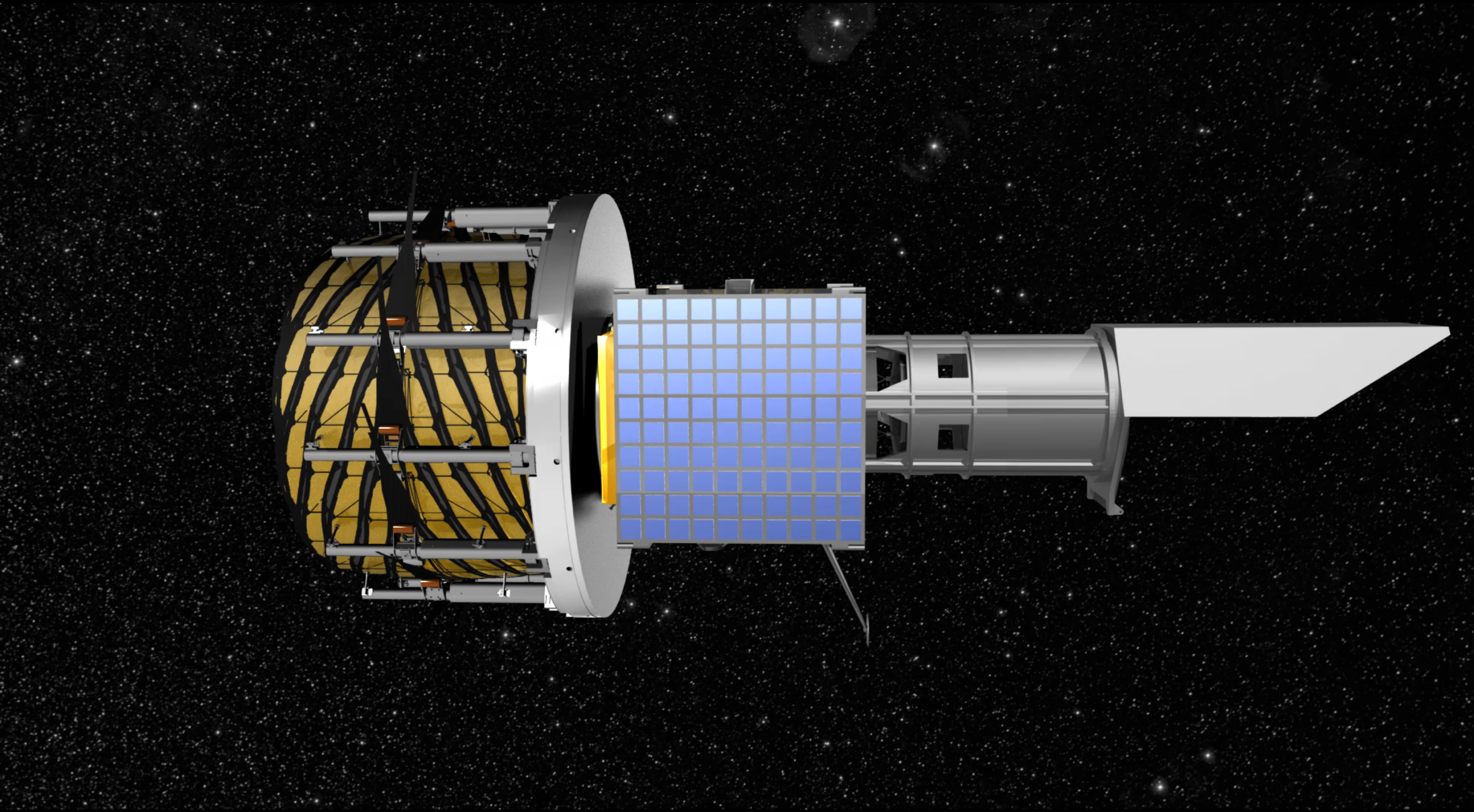


10 Milestones, 2 Submitted

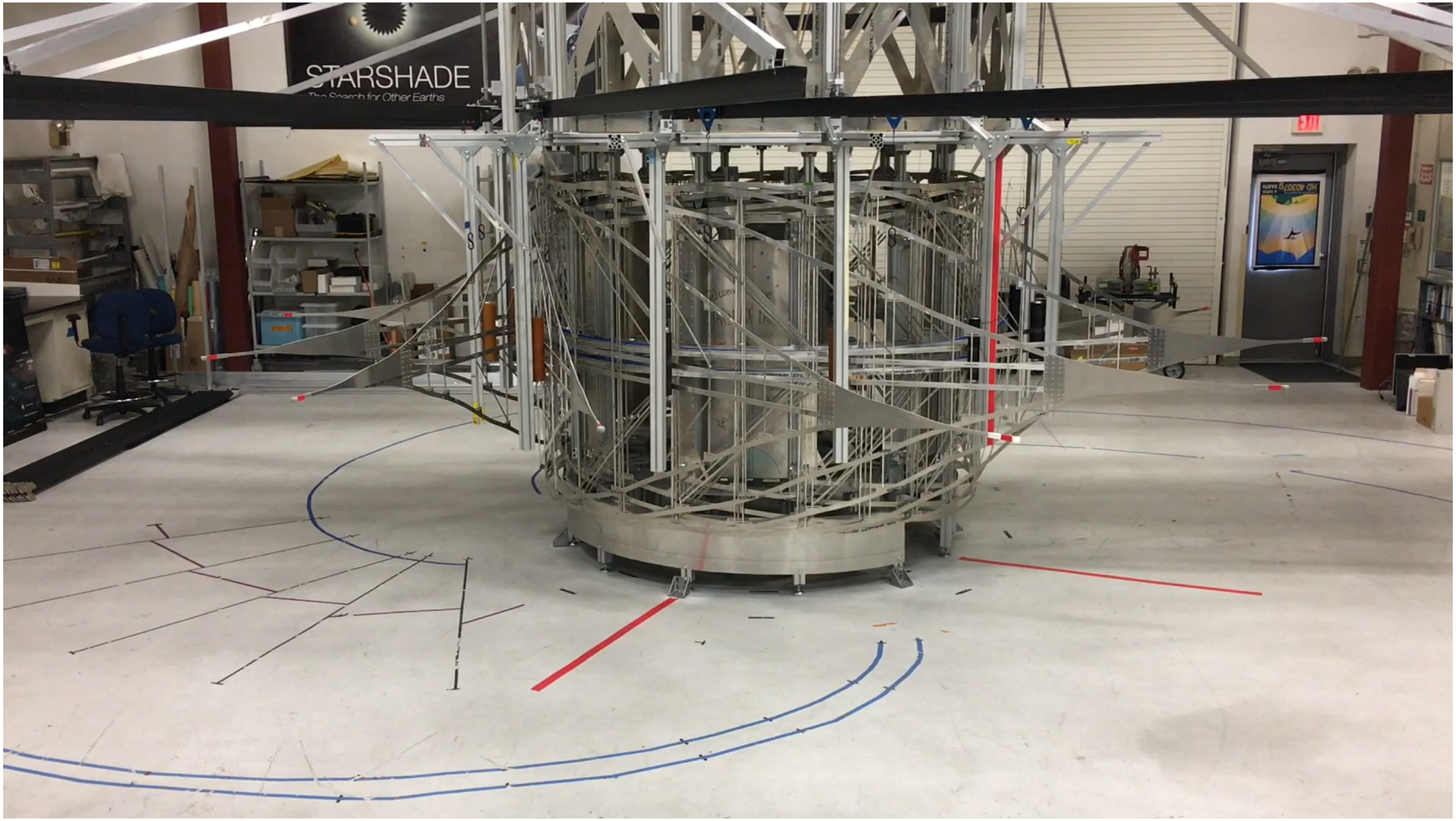
Positioning the petals to high accuracy, blocking on-axis starlight, maintaining overall shape on a highly stable structure (S-5)



Fabricating the petals to high accuracy (S-4)

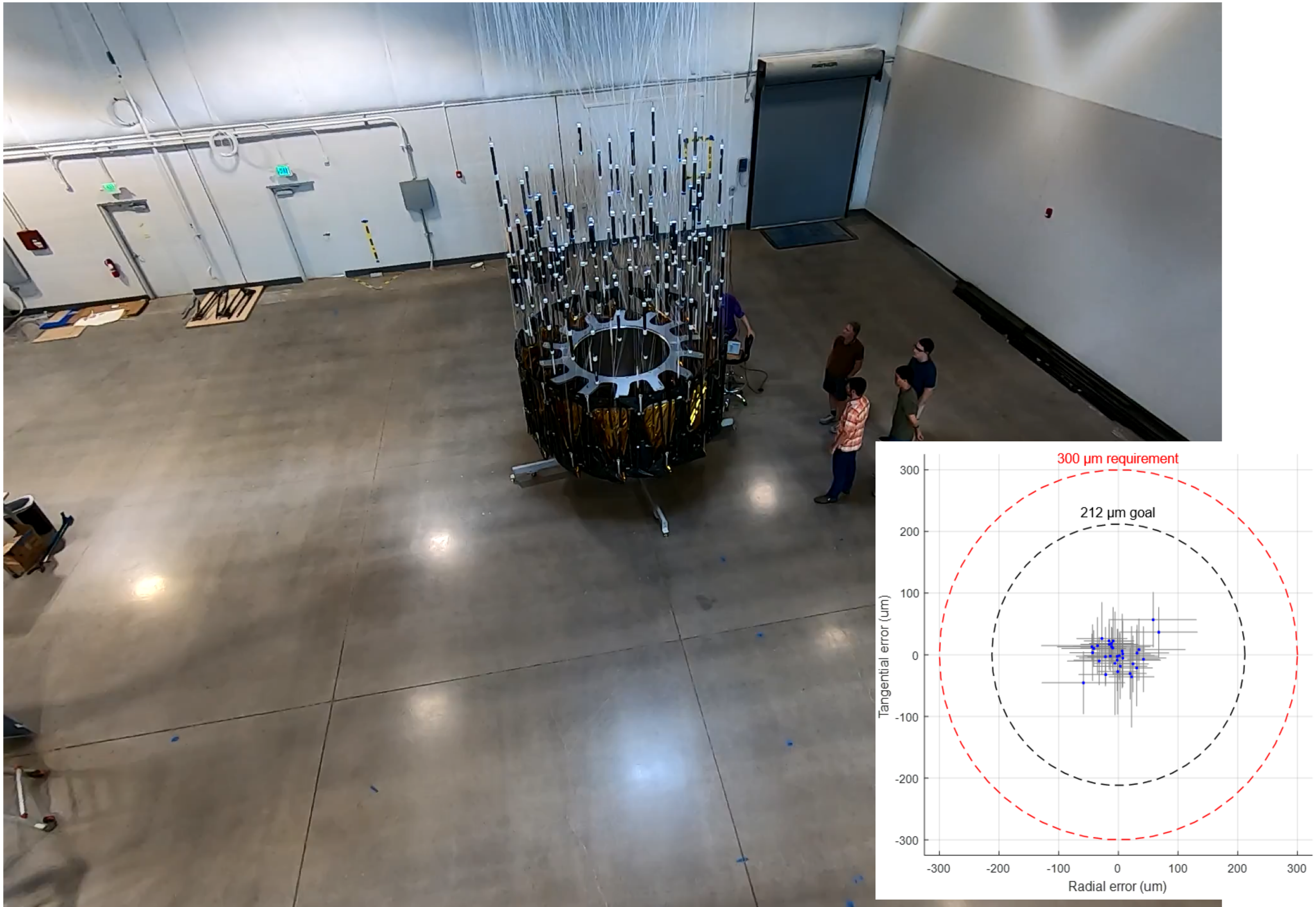


Petal Unfurling Demonstration



Tendeg/Roccor/NASA/JPL-Caltech

Starshade Inner Disk Deployment

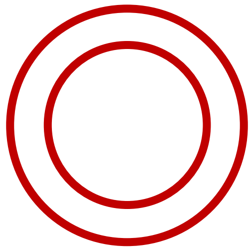


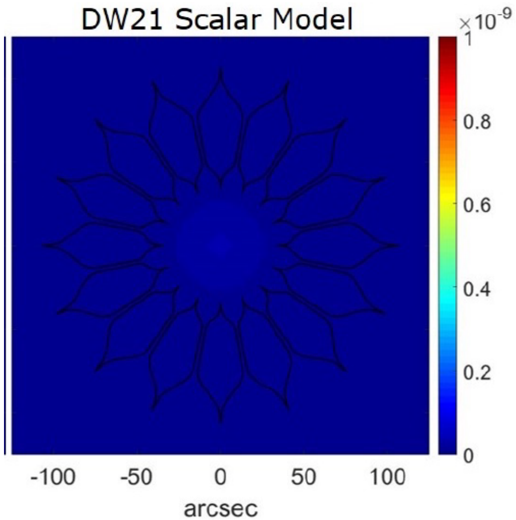
Tendeg/Roccor/NASA/JPL-Caltech

Starlight Suppression and Model Validation

Frick Testbed, Princeton University
Lead: Anthony Harness

Optical Demonstration





725 nm

Best performance to date of a starshade at a flight-like Fresnel number!

- Demonstrated 10^{-10} contrast over a fraction of the IWA in multiple wavelengths across 10% bandpass.
- However, need to prove this vector diffraction behavior disappears at larger sizes.

λ	Fraction at IWA	Fraction of Search Space
641 nm	18 ± 4 %	83 ± 4 %
660 nm	34 ± 6 %	77 ± 3 %
699 nm	2 ± 2 %	74 ± 5 %
725 nm	6 ± 2 %	65 ± 5 %

$$Vector\ Effect \propto \left(\frac{\gamma \times perimeter}{area}\right)^2 \propto \left(\frac{\gamma}{radius}\right)^2$$

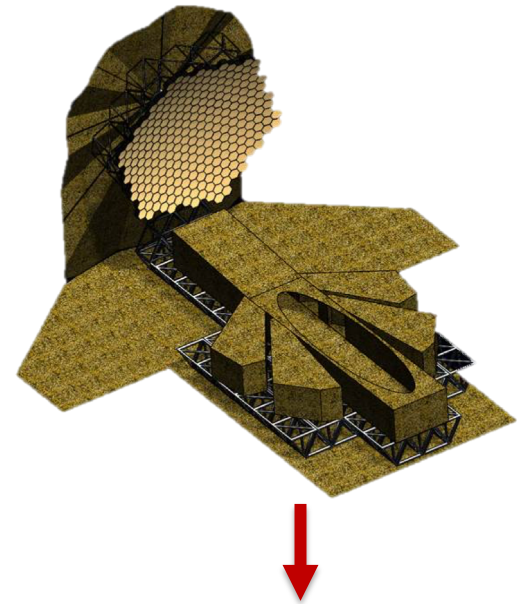
Effect $\sim 10^6 \times$ lower for space case

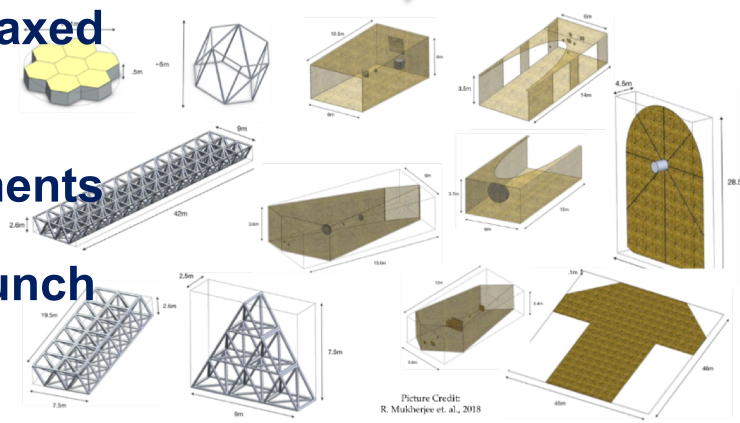
In-Space Assembled Telescope Study

- **NASA-chartered study answered the question:**

  When is it advantageous assembling space telescopes in space rather than building them on Earth and deploying them autonomously from single launch vehicles?

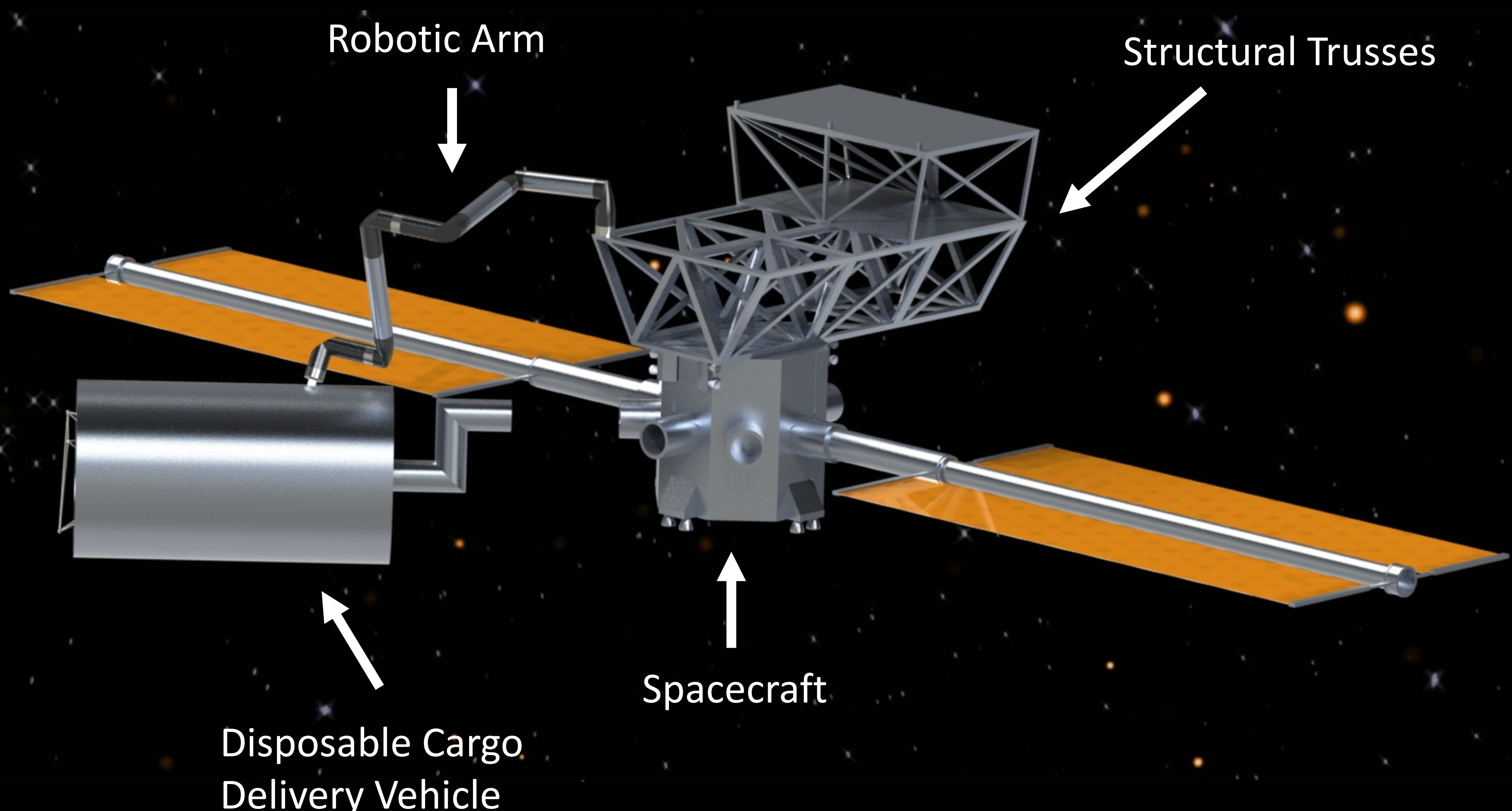
- **Concluded <u>all</u> large future space telescope should consider iSA as the implementation approach separately or as part of a potential hybrid solution.**
- **No “tyranny of the launch vehicle fairing” - relaxed mass and volume constraints**
- **Eliminates complex autonomous self-deployments**
- **Mitigates the risks associated with a single launch vehicle or deployment anomaly**
- **Reduces large standing army I&T costs**





Picture Credit: R. Mukherjee et. al., 2018

iSA Solves Servicing Dilemma



Iillustration from R. Mukherjee and D. Mick (NASA/JPL/Caltech)

Welcome Baby-CAT

- Remi Soummer (STScI) delivered a coronagraph demonstration unit to the ExEP enabling demonstrations to the public and at scientific conferences.
- Unit is portable and can be shipped anywhere.
- Come see it at the NASA booth!

Looking Forward

Wiki Commons: https://foto.wuestenigel.com/empty-crystal-ball-on-white-background/

- **We hope exoplanet space missions fare well in Astro 2020 as it did in both the Exoplanet Science and Astrobiology Science Strategy reports.**
  - ***A large reflected light direct imaging/spectroscopy mission***
- **Come hear our AAS Splinter Session on Sunday (1:55 pm, 306AB): *"Are we Ready"?***
- **Will Astro 2020 say anything about mid-IR interferometry?**
- **And, one day, quantum telescopes (arrays)?**