Jet Propulsion Laboratory
California Institute of Technology

Starshade Science and Industry Partnership

Informational Telecon

NASA Exoplanet Exploration Program

Gary Blackwood
Kendra Short
Yuriy Tsurkan
Renyu Hu

December 18, 2018

Purpose of Telecon

- The Exoplanet Exploration Program of the NASA Astrophysics Division will be chartering a Starshade Science and Industry Partnership (SIP)
- This telecon will discuss the Starshade SIP charter, the Starshade Technology Development Plan, and mechanisms for continued participation by the community in NASA's starshade development activities
- The draft charter and the released Technology Development plan are posted at

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

Telecon Agenda

- Introduction to ExEP and Starshade SIP - **Gary Blackwood**
- Starshade Technology Development Activity to TRL5 (S5) – **Kendra Short**
- Expected Outcomes and Participation in the Starshade SIP – **Gary Blackwood**
- Small Business Subcontracts – **Yuri Tsurkan**
- Technology and Science Working Group – **Renyu Hu**
- Work Structure and Schedule - **Gary Blackwood**
- Q&A

Request: hold questions until end

Program Office – Key Participants

NASA Exoplanet Exploration Program (ExEP)

Science and Industry Partnership

- **Gary Blackwood**, NASA ExEP Manager, Starshade SIP Chair
- **Yuriy Tsurkan**, Subcontract Manager
- **Renyu Hu**, ExEP Scientist for Starshade Technology

Starshade Technology Development Activity (S5)

- **Kendra Short**, acting Manager of S5, NASA ExEP Deputy Manager,
- **Phil Willems**, acting Deputy Manager of S5, LBTI Project Manager

NASA Headquarters Leadership

Astrophysics Division

- **Shahid Habib**, Program Executive for ExEP
- **Douglas Hudgins**, Program Scientist for ExEP
- **Martin Still**, Deputy Program Scientist for ExEP
- **Nasser Barghouty,** Division Technology Lead
- **Jeff Volosin**, Deputy Division Director
- **Paul Hertz**, Division Director

NASA Exoplanet Exploration Program

Astrophysics Division, NASA Science Mission Directorate

NASA's search for habitable planets and life beyond our solar system

Program purpose described in 2014 NASA Science Plan

1. Discover planets around other stars
2. Characterize their properties
3. Identify candidates that could harbor life

ExEP serves the Science Community and NASA:

- Focal point for exoplanet science and technology
- Integrated cohesive strategy for future discoveries

https://exoplanets.nasa.gov

NASA Exoplanet Exploration Program

Space Missions and Concept Studies

Kepler K2

Large- and Probe-Scale Mission Concepts

Coronagraph

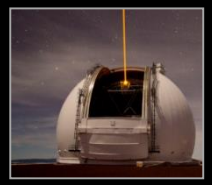
Starshade

Exoplanet Communications

Science Research & Technology

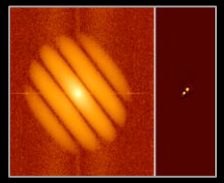
Key Sustaining Research

NN-EXPLORE



Keck Observatory

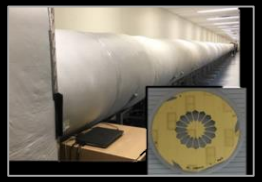
Large Binocular Telescope Interferometer



High Resolution Imaging

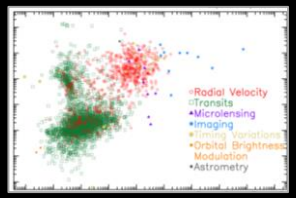
Technology Development

Coronagraph Technology Development



Starshade Technology Development (S5)

NASA Exoplanet Science Institute (NExScI)



Archives, Tools, Sagan Program, Professional Engagement

Motivation for Starshade SIP

- Starshades (or External Occulters) are **one of the starlight suppression technologies** for high contrast imaging of exoplanets and are baselined for large- and probe-class mission concept studies funded by the NASA Astrophysics Division for submission to the Astro2020 Decadal Survey.
- Recently the Astrophysics Division authorized the Exoplanet Exploration Program (ExEP) to **execute a directed technology development activity** to advance starshades to Technology Readiness Level (TRL) 5 to enable **potential future exoplanet science missions**.
- The Starshade Technology Development Activity to TRL5, or S5, follows an **approved Technology Development Plan** with technology milestones that respond to documented mission performance requirements.
- The ExEP recognizes that robust and impactful technology maturation requires **ongoing consideration** of new technology approaches and new mission concept drivers.
- **The purpose of the Starshade SIP is to maximize the technology readiness level of starshades to enable potential future exoplanet science missions**.

Jet Propulsion Laboratory
California Institute of Technology

Starshade Technology Development Activity (S5) Overview and Status

Kendra Short, S5 Manager (acting)
Phil Willems, S5 Deputy Manager (acting)

December 18, 2018

NASA Approves Starshade Technology Activity (Sept 2018)

Technology Activity Goals:

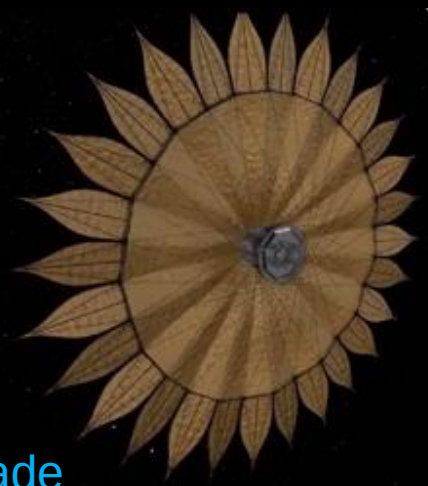
- "to mature the required techniques to the point at which starshades could be integrated into potential future exoplanet detection and characterization missions"

- *The goal of S5 is to advance critical capabilities to TRL5 in the following technology focus areas*:*
  - *Starlight suppression*
  - *Formation flying*
  - *Deployment of large-scale, precision structures*

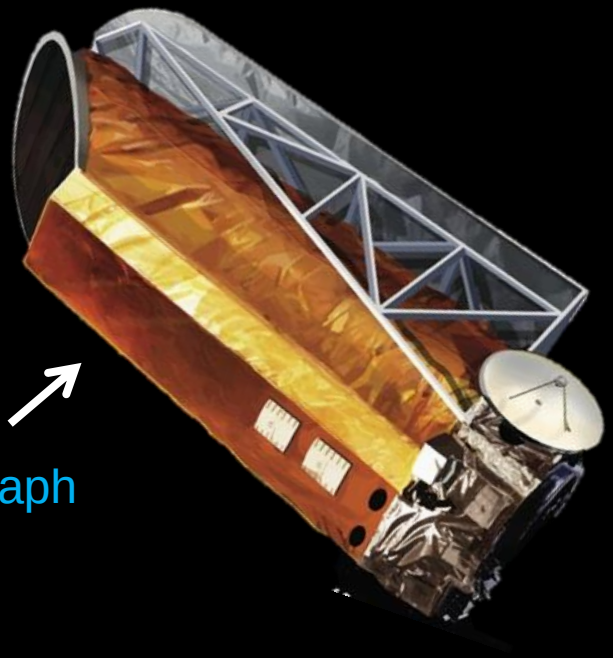
** reference ExEP Technology Plan Appendix*

Possible Starshade Mission Concepts

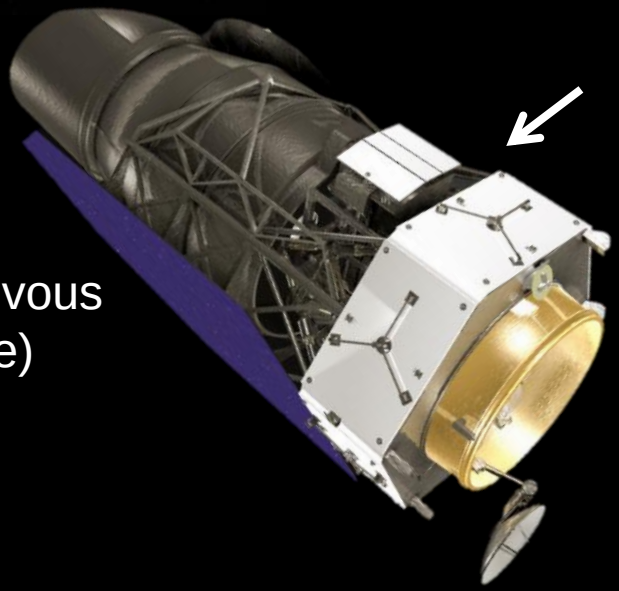
Pending 2020 Decadal Survey



starshade



coronagraph



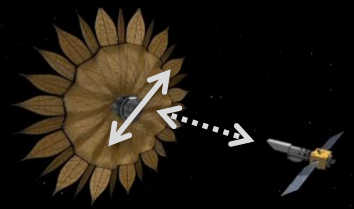
WFIRST Rendezvous
(26m starshade)

Habitable Exoplanet
Imaging Mission
(HabEx)

(52m starshade)

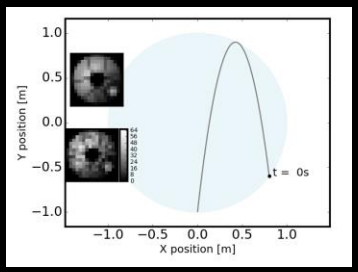
Starshade Technology Development Activity

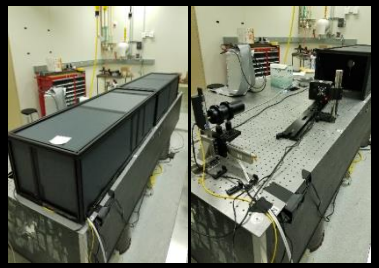
Formation Flying



+/- 30 cm sensing accuracy
+/- 1 m control

Testbed validated model of sensing accuracy; simulated control performance under flight-like conditions.

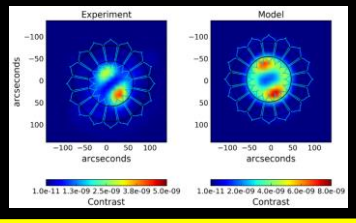




TGL S-3

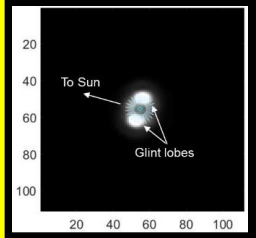
Starlight Suppression

Subscale demonstration of 1e-10 contrast at both narrow and broadband; optical model validation to 25% accuracy.

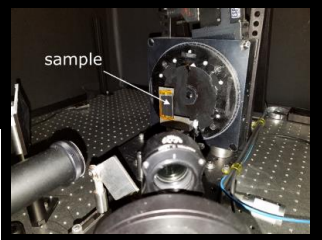


TGL S-1

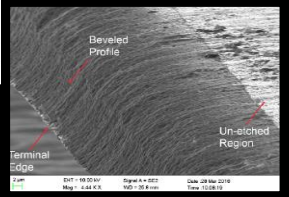
Scattered Sunlight



TGL S-2



Amorphous Metal

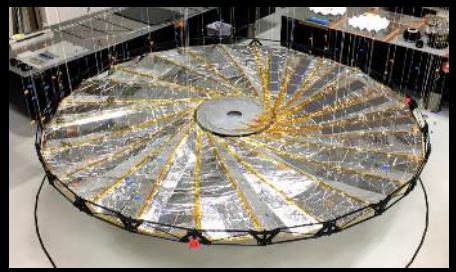


Scatterometer measurements of half-scale petal edge segments show scattered sunlight less than Vmag 25 in image simulations.

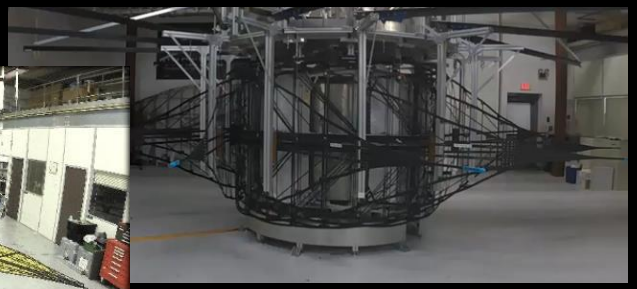
Petal Shape and Position Accuracy
Petal Shape and Position Stability

Fabricate petals shape to a pre-launch accuracy of +/- 70um and demonstrate by analysis an on-orbit shape stability of +/- 80um

Perform petal deployment to a position accuracy of +/- 300um and demonstrate by analysis an on-orbit position stability to +/- 200 um



TGL S-4 TGL S-5



TGL S-# is the ExEP Technology Gap List reference number

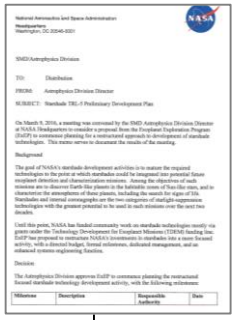
Keys to Success

- Must be ready for 2020 Astrophysics Decadal
  - Key technologies need to be mature enough to enable a starshade to be considered for possible WFIRST Rendezvous and future large telescope missions
  - Complete near-term milestones of an approved TRL 5 Plan
  - Reach TRL 5 on several key technologies before end of decade

- Starshade will live and flourish by its model validation
  - Performance models: optical diffraction, light scattering, mechanical, thermal and dynamic deformation, etc.
  - Ground based tests must focus on validating performance models and the error budget as well as demonstrations of meeting requirements that are derived from reasonable error budgets

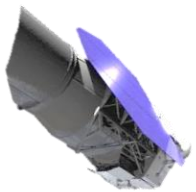
- Independent reviews of the technology plan and technical progress

Two Years of Planning (and technical progress)



Mar'16

Sara Seager/Massachusetts Institute of Technology
Starshade Rendezvous Mission



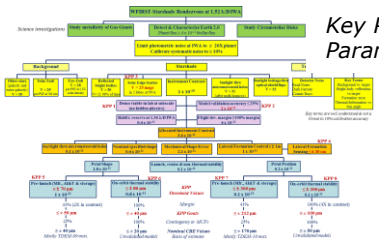
Jun'17

Status Review

Dec'17

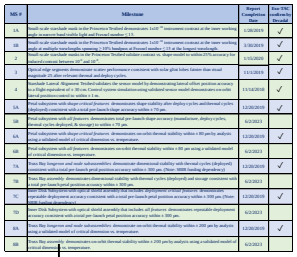
(FF, scatter, suppression)

Nov17-Mar18



Key Performance Parameter Review

Milestone Review with ExoTAC

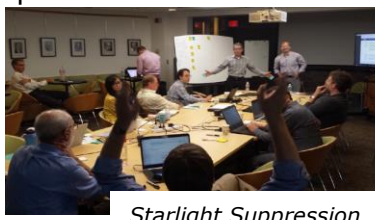


Jul18

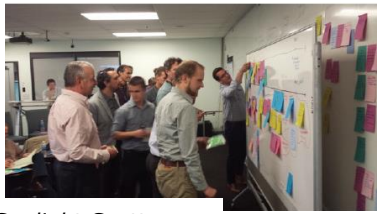
Aug18

Dec'16 Mar'17 Apr'17 Oct'17

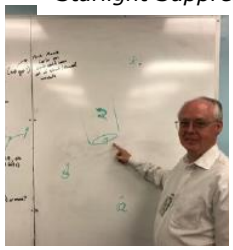
Community Kickoff



Starlight Suppression

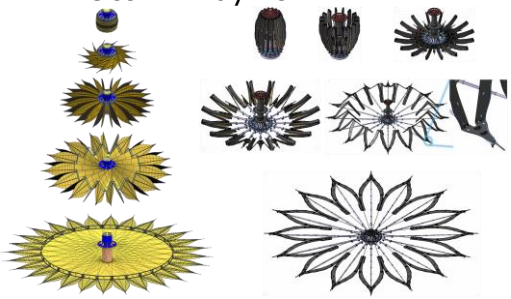


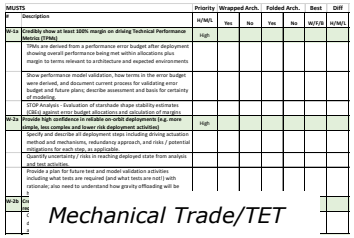
Sunlight Scatter



Mechanical

Oct'17-May'18





Mechanical Trade/TET

Aug18

Cost Review

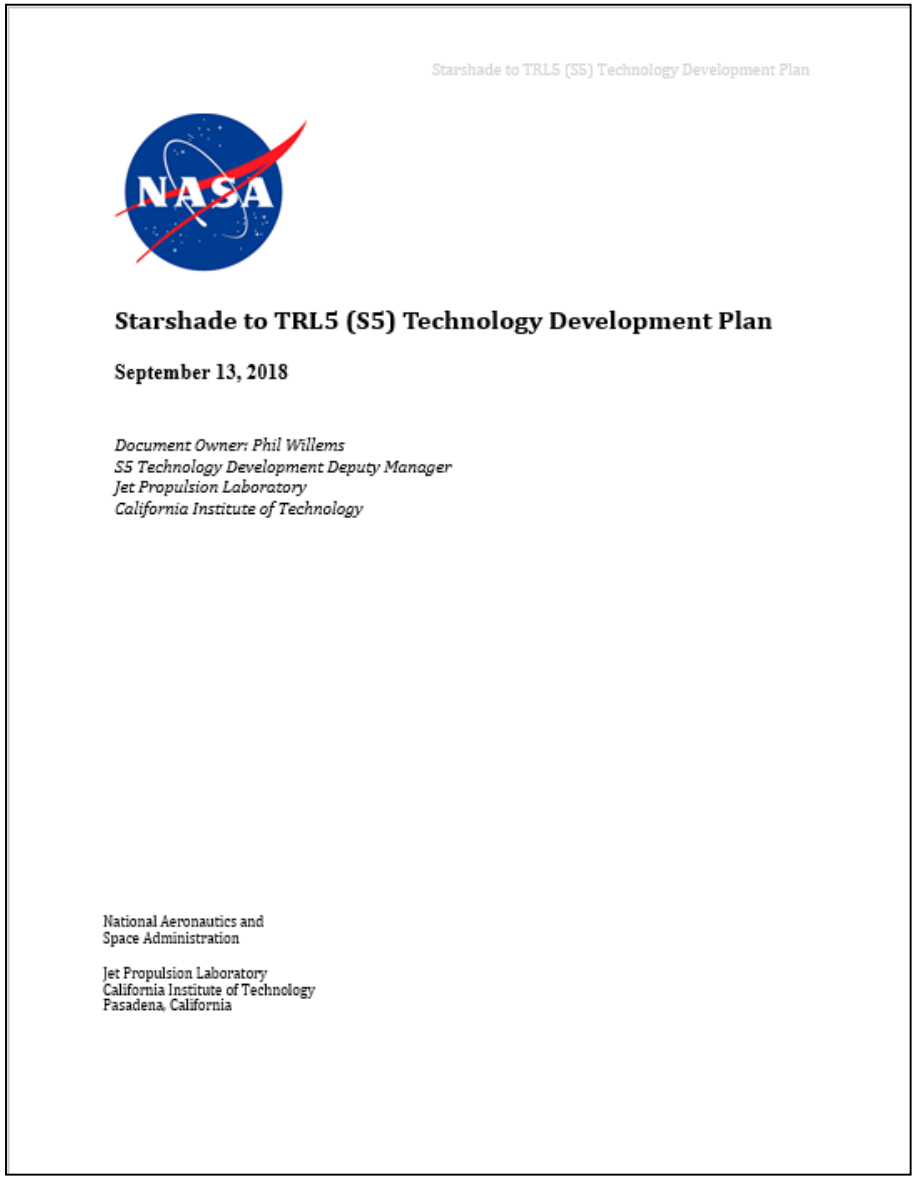
Aug18

Sep 2018

APPROVED

Technology Development Plan

- Signed and released. Approved for public distribution. Posted on S5 website.
- Contains in-depth description of technology baseline, performance parameters, development and test plans.
- Specifically refer you to:
  - the comprehensive error budget based on the mission key performance parameters
  - the specific milestones defined as necessary to meet TRL 5



Starshade to TRL5 (S5) Technology Development Plan

Starshade to TRL5 (S5) Technology Development Plan

September 13, 2018

Document Owner: Phil Willems
S5 Technology Development Deputy Manager
Jet Propulsion Laboratory
California Institute of Technology

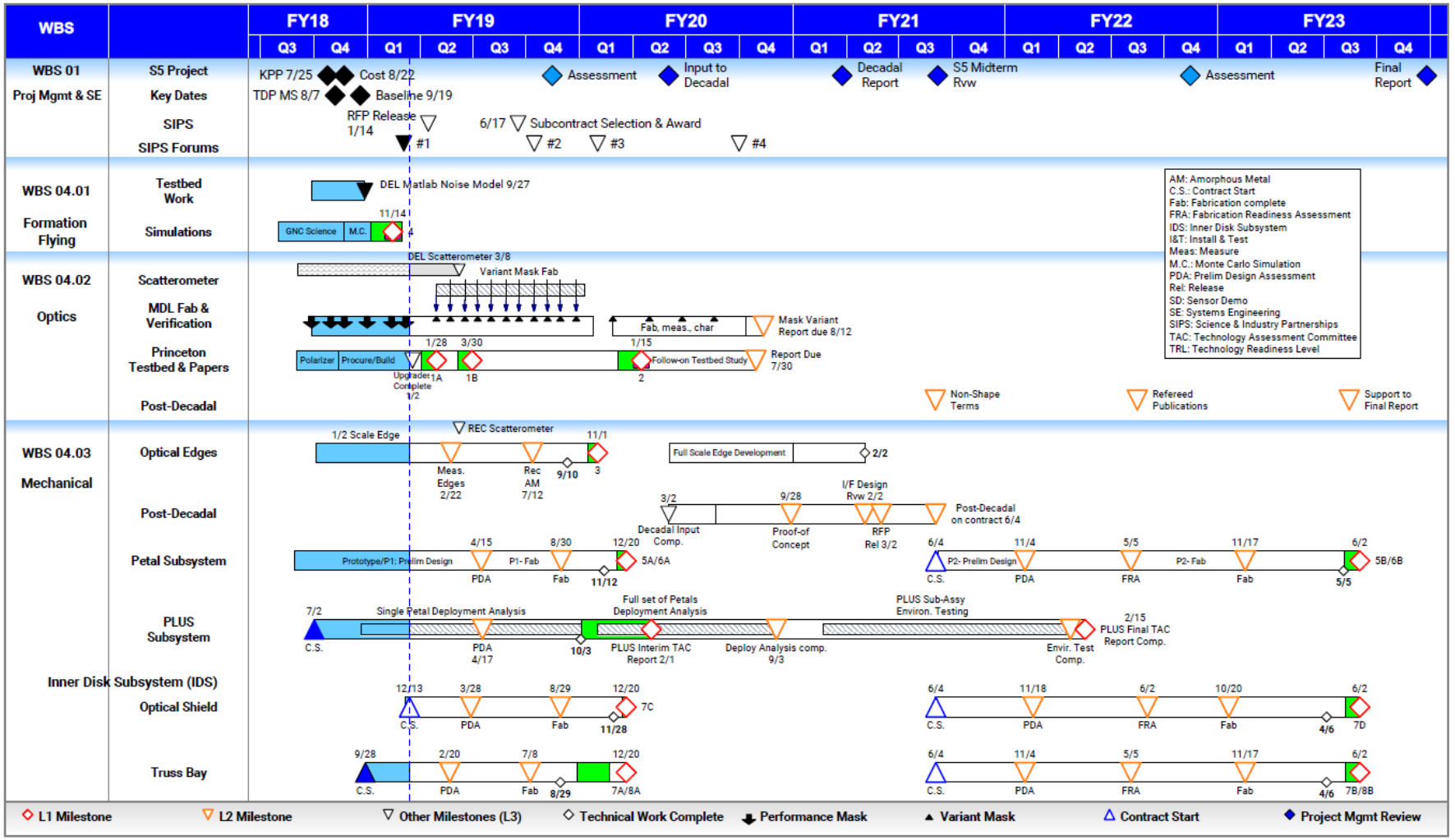
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

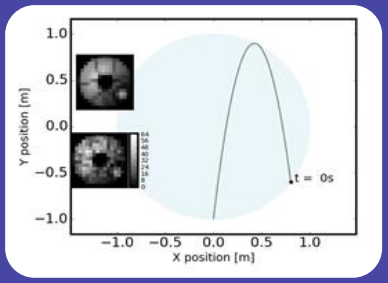
S5 Top Tier Schedule

Starshade Technology Development Project
Tier 1

12/12/18

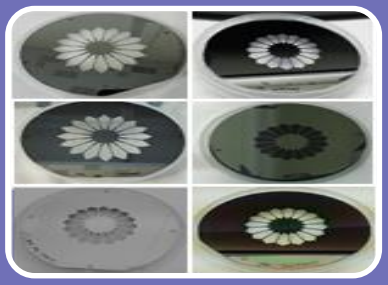


Future Opportunities within S5



Formation Flying

- Complete pending review by ExoTAC
- Future opportunities are limited but may include updated simulations.



Optical Performance

- Expected demonstration of 10-10 contrast narrow and broadband between Dec – March
- Current and past partners include: Princeton, UCSD, NGAS
- Future opportunities include: mask fabrication, optical modeling, next generation test facilities

Mechanical Performance

- Driving near term to TRL4 and risk reduction for later TRL5
- Current and past partners include: Tendeg, Roccor, NGAS
- Future opportunities include: optical edge material and testing, optical shield opacity testing, composite structure fabrication, thermal testing, deployment analysis, shield material and design

To learn more: contact Kendra Short

Expected Outcomes of the Starshade SIP

1. Identify solutions to challenges faced by the S5 development activity;
2. Propose new approaches, techniques, and research beyond planned S5 activities that can maximize starshade technology readiness;
3. Document new mission concept drivers for starshade technology performance requirements;
4. Maintain alignment between S5 technology development activities and future mission needs;
5. Facilitate groups of investigators to communicate research, new technology, and new mission concepts across disciplinary, organizational, and geographic boundaries;
6. Enable continued participation of the community in NASA's starshade technology development activities.

Participation (1 of 2)

- The Starshade SIP is open to all participants from NASA, industry, academia, and any organization or individual with research, technology, or science capabilities and contributions in starshade-related technology. Non-US participation is welcome.
  - Export-controlled topics, if any, will be covered in a separate forum.
- The Starshade SIP will be chaired by the ExEP Manager.
- A Steering Committee will be comprised of representatives from participating NASA Centers, industry, and academia.
  - Purpose: assist Chair in setting agendas and reporting to NASA APD

Participation (2 of 2)

To maximize participation of small businesses and academia in the Starshade SIP within limited program funds the following opportunities are planned:

1. Up to three cost-sharing contracts set aside for small business to be announced on FedBizOps by the Jet Propulsion Laboratory.
2. A Technology and Science Working Group (TSWG) of approximately 8 members solicited through a NASA *Dear Colleague* letter. Travel expenses will be reimbursed to TSWG members.
3. Up to four graduate students and post-doc will be selected by the TSWG to attend and present at Starshade SIP events. Travel expenses will be reimbursed to these students.

Small Business Set Aside Subcontracts

- Proposals solicited only from small businesses and any resulting award will be made to a small business
- Up to three cost-sharing contracts are planned by the Jet Propulsion Laboratory
- Contract type is cost type
- Procurement Schedule Milestones:
  - RFI release in FedBizOpps 7/25/2018 Complete
  - RFI responses due 9/05/2018 Complete
  - RFP release in FedBizOpps 1/14/2019
  - Proposals due 2/13/2019
  - Target Award Date 6/17/2019

- Only responsive, responsible proposers will be considered for award

Technology and Science Working Group

- A Technology and Science Working Group (TSWG) of approximately 8 technologists and scientists will be formed
  - Nomination solicited through a NASA *Dear Colleague* letter
  - Selection by the ExEP Program Executive and Program Scientist
  - Applications are solicited from individuals at U.S.-based research and academic institutions, Government laboratories, and industry, and from private individuals
  - TSWG will self-organize and report to the SIP chair
  - Travel expenses will be reimbursed to TSWG members
- TSWG members will:
  - Identify new science parameters and mission drivers that are relevant to S5
  - Keep S5 informed of technology innovations to solve S5 challenges
  - Provide scientific studies needed to support achievement of S5 objectives
  - Document findings in annual Starshade SIP reports to NASA APD
- The TSWG will select up to four graduate students and postdocs to attend and present at each SIP forum (travel expenses reimbursed)

Starshade SIP Work Structure

- The Starshade SIP will convene periodically by telecon (approximately bimonthly, 90 min WebEx) and semi-annually in face-to-face Starshade SIP Forums facilitated for remote participation.
- Telecons nominally 10 am, first Thursday in scheduled month (exept Feb), pending doodle poll
- Small-business awardees and TSWG members, when selected, are expected to participate in the Starshade SIP telecons and Forums.
- Agendas for telecons and Forums will include status from the S5 Project and presentations from Starshade SIP participants recommended by the Steering Committee.
- Annual briefing to HQ APD (by Chair, Steering Group, TSWG Chair)
- The Starshade SIP, TSWG, and contracts will conclude in December 2020 and may be renewed pending the outcome of the Astro2020 Decadal Survey.

Starshade SIP Schedule

- Dec 18 2018 — Telecon 1: SIP informational telecon

- Jan 14 2019 — Request for Proposal for cost-sharing contracts
- Feb 13 2019 — Proposals due
- Feb 21 2019 — Telecon 2: Mechanical technology
- Feb 28 2019 — *Dear Colleague* letter for the TSWG
- Apr 4 2019 — Telecon 3: Optical technology
- Jun 3 2019 — Announce TSWG membership
- Jun 17 2019 — Award of small business contracts
- Jun 6 2019 — Telecon 4: Formation flying technology
- Jul 2019 — Starshade SIP Forum #1 (date TBC)

- Nov 2019 — Starshade SIP Forum #2
- July 2020 — Starshade SIP Forum #3
- Nov 2020 — Starshade SIP Forum #4

Contact Information

Starshade Science and Industry Partnership

- **Gary Blackwood**, NASA ExEP Manager, Starshade SIP Chair
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  - M: 818 458 0507
- **Yuriy Tsurkan**, Subcontract Manager
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  - W: 818 393-8052
  - M: 747 261-8928
- **Renyu Hu**, ExEP Starshade Scientist
  - Renyu.Hu@jpl.nasa.gov
  - W: 818 354 6090
  - M: 818 281-9459
- **Kendra Short**, S5 acting Manager, NASA ExEP Deputy Manager
  - Kendra.Short@jpl.nasa.gov
  - W: 818 354 9286
  - M: 818 634 3918

Closing

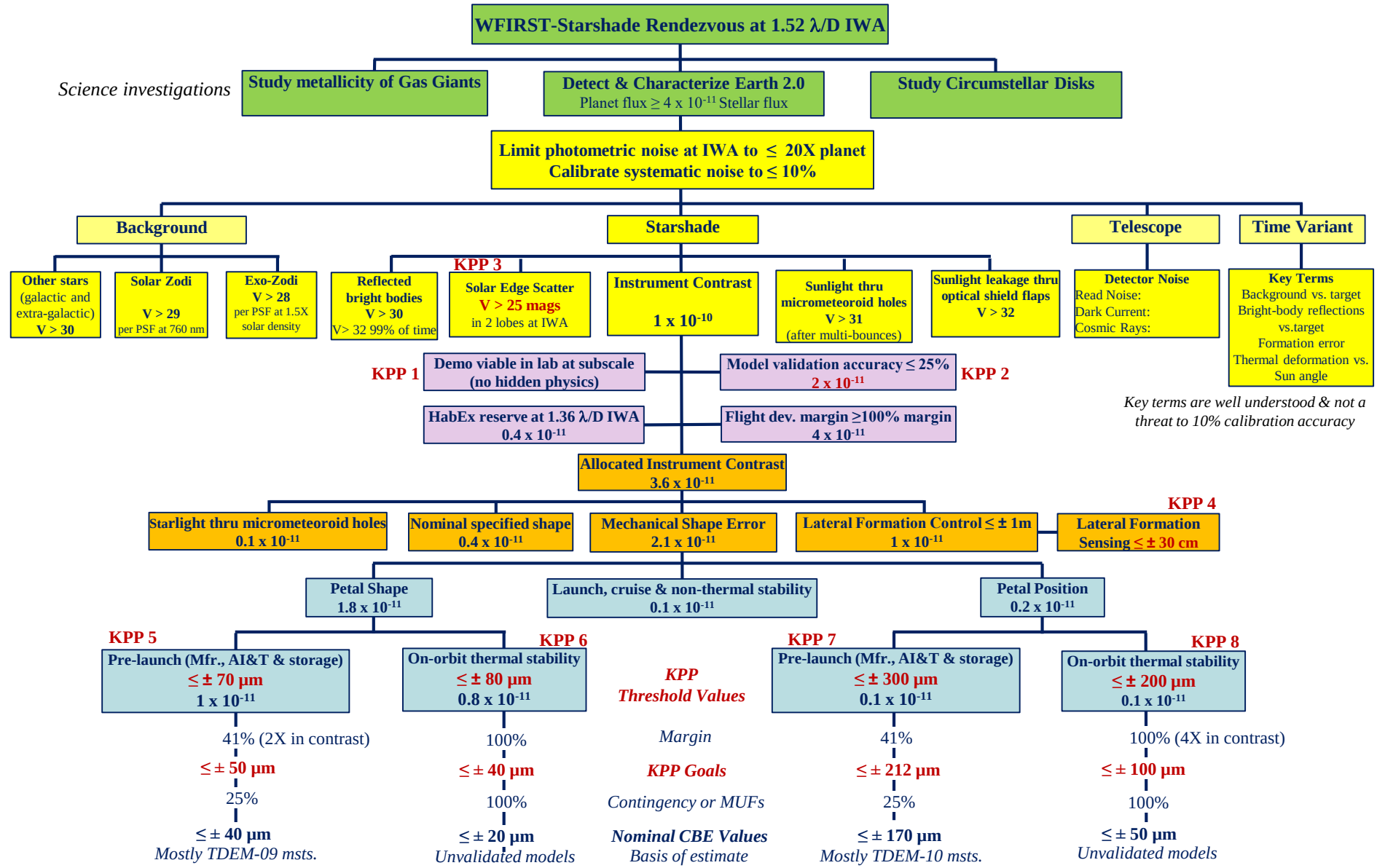
- **To receive further announcements of the Starshade SIP**, please send an email message to sympa@list.jpl.nasa.gov with the subject “subscribe starshadesip” and your name in the body. You will need to reply to email from JPL to confirm your membership.

- Please send and questions regarding:
  - Draft Charter: to Gary Blackwood
  - Request for Proposal for Starshade SIP: to Yuriy Tsurkan
  - TSWG: to Renyu Hu
  - S5 Technology Implementation: Kendra Short

- Open the floor for Q&A

Backup

S5 Error Budget Tree



S5 Key Performance Parameters

Technology Gap Area	KPP	Fidelity			Relevant Environments	Verification	Model Validation
		Form	Fit	Function			
Starlight Suppression	Demonstrate flight instrument contrast is viable via subscale lab tests at **≤ 1 x 10^{-10}**	Flight-like shape, etched in silicon	1/500th scale, near-flight Fresnel #	Flight-like diffraction perf.	Space, large telescope distance	Measure image plane contrast at multiple wavelengths covering flight bandpass.	Demonstrates all physics are captured
	Validate contrast senstivity to accuracy of **≤ ± 25%**					Introduce precisely known shape errors, measure contrast at the 10^{-8} to 10^{-9} level, extrapolate to flight contrast.	Validates model used to establish all shape error allocations
Lateral formation sensing & control	Verify sensing accuracy to **≤ ± 30 cm** (1/8th pupil dia.) & corresponding control to **≤ ± 1m**, via simulation	Flight-like shape, copper on glass	1/4000th scale, near-flight Fresenel #	Flight-like diffraction perf.	Space, large telescope distance, ≤ 1 µg gravity gradient	Measure lateral shear in pupil plane of Poisson spot from out of band starlight. Verify control perf. via simulations using a validated sensor model.	Validates prototype lateral sensor algorithms.
Solar Scatter	Verify lobe brightness is dimmer than **25 visual magnitudes**	Medium fidelity optical edge segment.	3/4 scale	Flight-like scatter perf., in-plane shape profile accuracy	Deploy cycles, thermal cycles, dust in lab & launch fairing	Measure scatter at discrete Sun angles & measure in-plane profile, after env. Tests	Validates model of scatter vs. Sun angle at edge coupon level.
Petal Shape	Pre-launch shape accuracy (manufacture, AI&T, storage) **≤ ± 70 µm**	Med. fidelity Petal Subsystem, all features & interfaces	3/4 scale	Flight-like	Deploy cycles, thermal cycles, stowed storage, temperature	Measure shape before & after env. tests,	Validates models of: shape vs. temp, shape vs. I/F load, creep vs. time & temperature.
	On-oribt thermal stability **≤ ± 80 µm**					Measure petal critical dimensions in ambient press. "hot box" vs. temperature	
Petal Position	Pre-launch shape accuracy (manufacture, AI&T, storage) **≤ ± 300 µm**	Med. fidility Inner Disk Subsystem, all features & interfaces	Full-scale	Flight-like	0-gravity, space vacuum, stowed storage, temperature	Measure petal position after many quasi-static deployments that min. air drag and imperfect gravity off-loading.	Validates models of: shape vs. temp, shape vs. I/F load, creep vs. time & temperature.
	On-oribt thermal stability **≤ ± 200 µm**					Measure Truss-Bay critical dimensions in ambient press. "hot box" vs. temperature	

The combination of the KPP performance specification and the TRL 5 expectations form the basis for the definitions for comprehensive Technology Milestone demonstrations.

S5 Key Technology Milestones

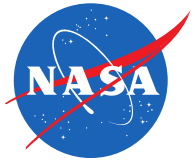
	MS #	Milestone	Report Completion Date
Starlight Suppression S-2	1A	Small-scale starshade mask in the Princeton Testbed demonstrates $1x10^{-10}$ instrument contrast at the inner working angle in narrow band visible light and Fresnel number ≤ 15.	1/28/2019
	1B	Small-scale starshade mask in the Princeton Testbed demonstrates $1x10^{-10}$ instrument contrast at the inner working angle at multiple wavelengths spanning ≥ 10% bandpass at Fresnel number ≤ 15 at the longest wavelength.	3/30/2019
	2	Small-scale starshade masks in the Princeton Testbed validate contrast vs. shape model to within 25% accuracy for induced contrast between 10^{-9} and 10^{-8}.	1/15/2020
Scattered Sunlight S-1	3	Optical edge segments demonstrate scatter performance consistent with solar glint lobes fainter than visual magnitude 25 after relevant thermal and deploy cycles.	11/1/2019
Formation Flying S-3	4	Starshade Lateral Alignment Testbed validates the sensor model by demonstrating lateral offset position accuracy to a flight equivalent of ± 30 cm. Control system simulation using validated sensor model demonstrates on-orbit lateral position control to within ± 1 m.	11/14/2018
Petal Position and Shape: Accuracy and Stability S-4, S-5	5A	Petal subsystem with *shape critical features* demonstrates shape stability after deploy cycles and thermal cycles (deployed) consistent with a total pre-launch shape accuracy within ± 70 µm.	12/20/2019
	5B	Petal subsystem with *all features* demonstrates total pre-launch shape accuracy (manufacture, deploy cycles, thermal cycles deployed, & storage) to within ± 70 µm.	6/2/2023
	6A	Petal subsystem with *shape critical features* demonstrates on-orbit thermal stability within ± 80 µm by analysis using a validated model of critical dimension vs. temperature.	12/20/2019
	6B	Petal subsystem with *all features* demonstrates on-orbit thermal stability within ± 80 µm using a validated model of critical dimension vs. temperature.	6/2/2023
	7A	Truss Bay *longeron and node subassemblies* demonstrate dimensional stability with thermal cycles (deployed) consistent with a total pre-launch petal position accuracy within ± 300 µm. (Note: SBIR funding dependency)	12/20/2019
	7B	Truss Bay *assembly* demonstrates dimensional stability with thermal cycles (deployed) and storage consistent with a total pre-launch petal position accuracy within ± 300 µm.	6/2/2023
	7C	Inner Disk Subsystem with optical shield assembly that includes *deployment critical features* demonstrates repeatable deployment accuracy consistent with a total pre-launch petal position accuracy within ± 300 µm. (Note: SBIR funding dependency)	12/20/2019
	7D	Inner Disk Subsystem with optical shield assembly that includes *all features* demonstrates repeatable deployment accuracy consistent with a total pre-launch petal position accuracy within ± 300 µm.	6/2/2023
	8A	Truss Bay *longeron and node subassemblies* demonstrate on-orbit thermal stability within ± 200 µm by analysis using a validated model of critical dimension vs. temperature.	12/20/2019
	8B	Truss Bay *assembly* demonstrates on-orbit thermal stability within ± 200 µm by analysis using a validated model of critical dimension vs. temperature.	6/2/2023

15 Technology Milestones define the L1 deliverables

Each Milestone documented in Technology Report

ExoTAC serves as independent review and acceptance of milestone completion

Reports to be reviewed for ITAR & made publicly available.



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