Final Technology Readiness Level

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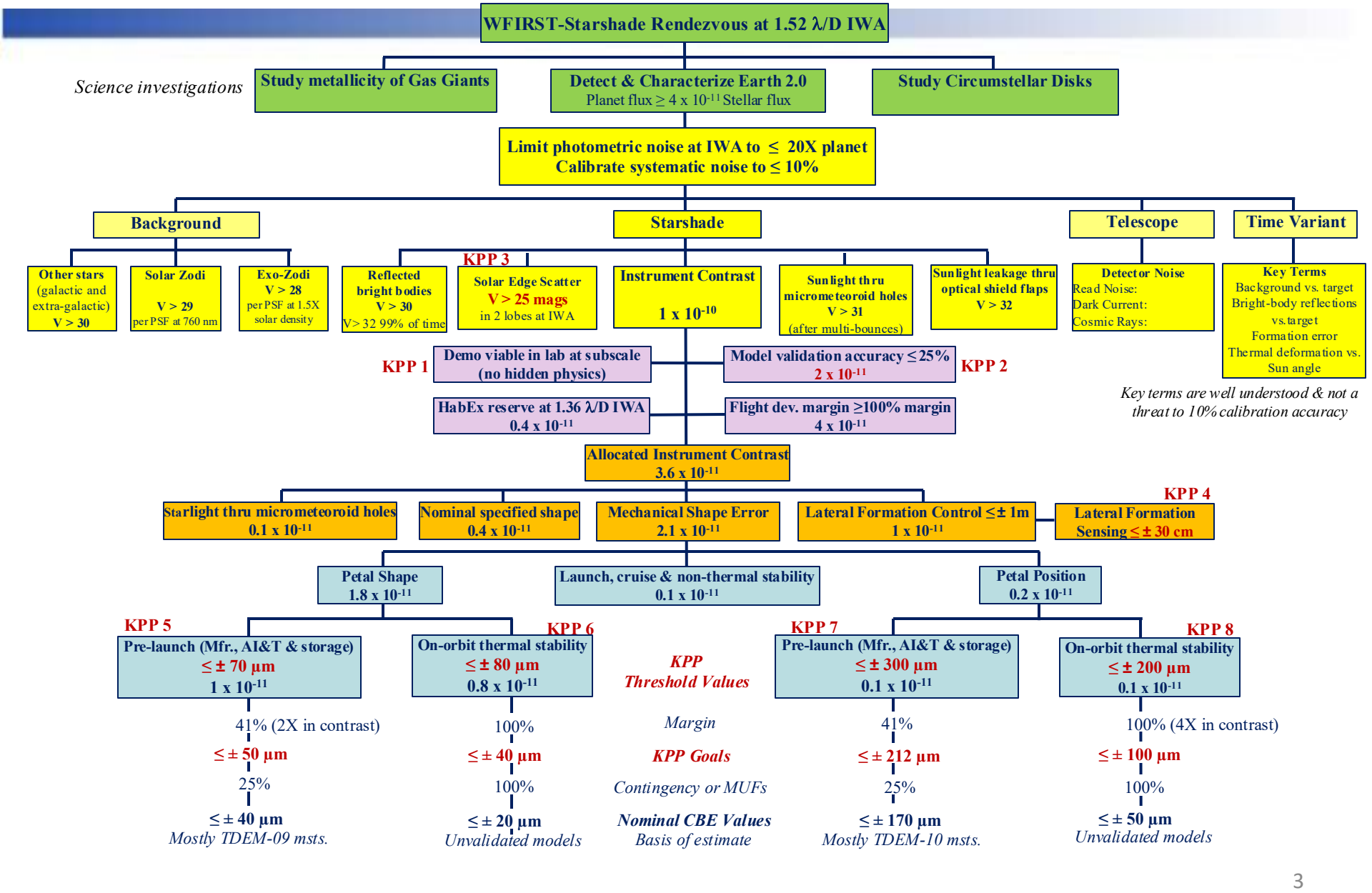
Starshade S5 Closeout Briefing
April 14, 2025

TRL 5 Definition

NASA Technology Readiness Approval, Best Practices Guide; SP-20205003605

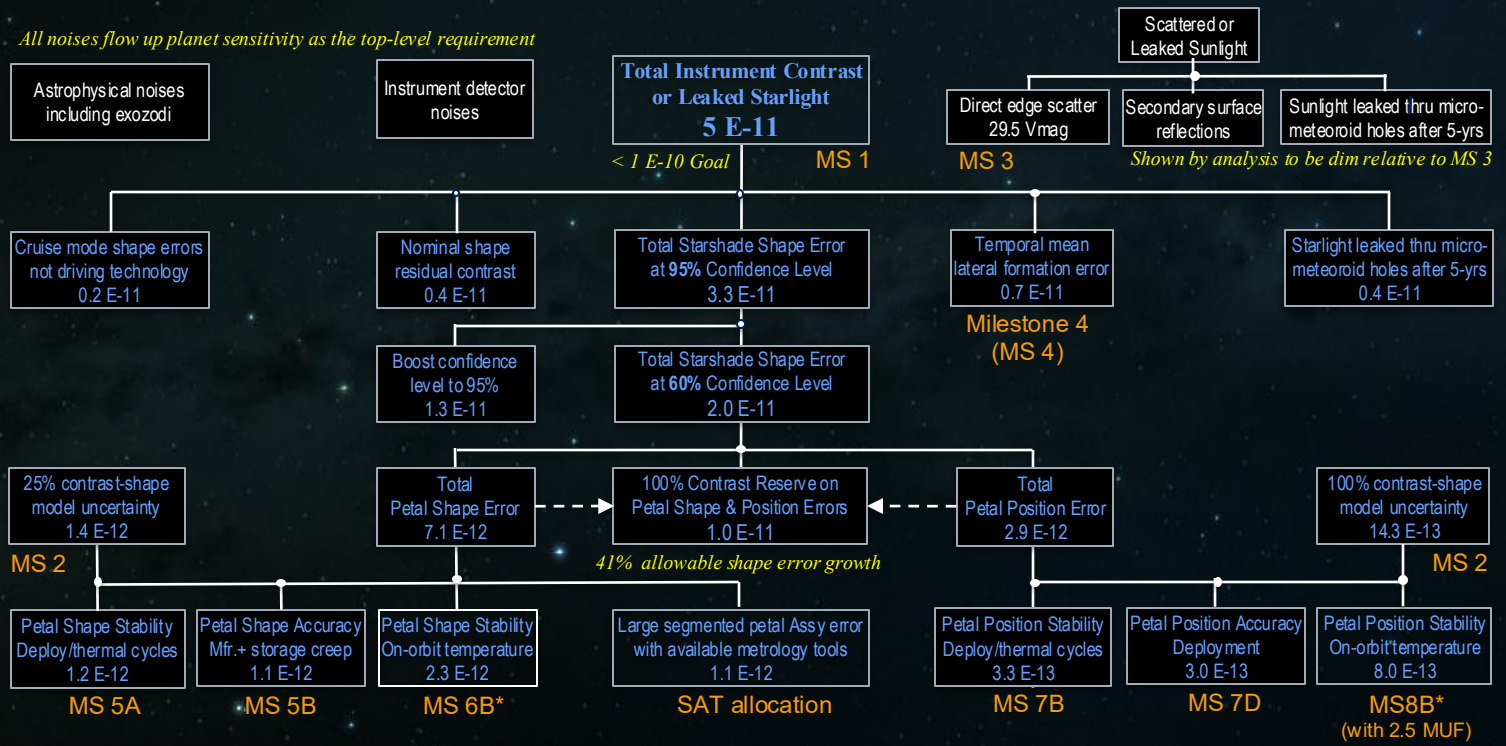
TRL	Definition	Completion Criteria	Mission Req.	Performance/ Function	Fidelity of Analysis	Fidelity of Build	Level of Integration	Environment Verification
5	Component and/or brass-board validated in relevant environment	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.	Generic or specific class of missions	Basic functionality/ performance maintained	Medium fidelity: to predict key performance parameters and life limiting factors as a function of relevant environments	Medium fidelity: brass-board with realistic support elements	Component/ Assembly	Tested in relevant environments Characterize physics of life-limiting mechanisms and failure modes.

S5 Error Budget Tree from S5 Tech Dev Plan



INSTRUMENT CONTRAST ROLLUP FOR 2.4M ROMAN TELESCOPE (FINAL S5 VERSION)

Prime bandpass = 615-800 nm (26%)
IWA at tips = 103-mas = 1.5 λmax / D



These are mean contrasts from milestone reports, unless otherwise specified, and per max expected shape errors including MUFs.
** Contrast is relative to MS8A results.*

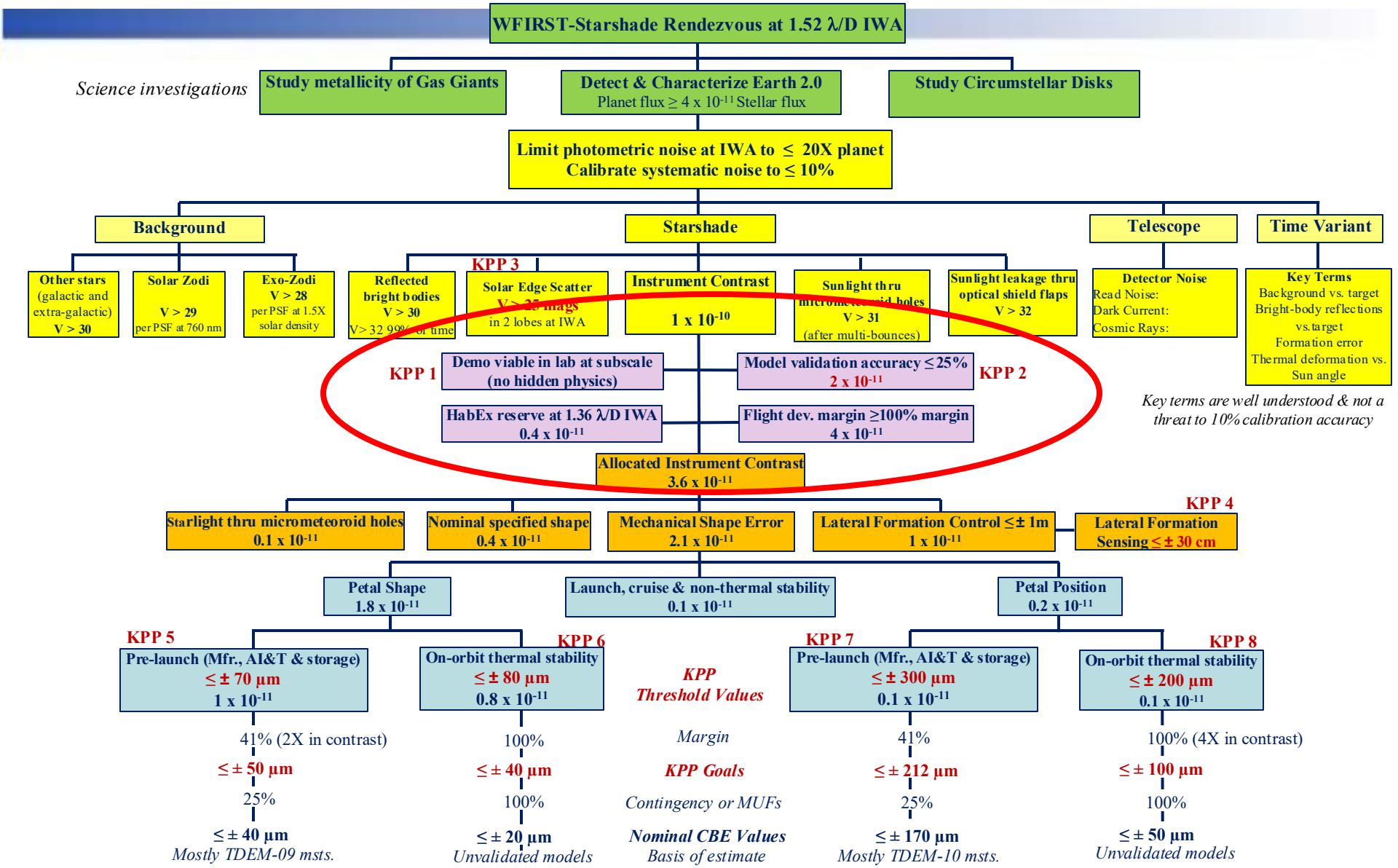
S5 Key Technology Milestones

Advancing 5 technologies to TRL 5

	MS #	Milestone
(1) Starlight Suppression Technology	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.
	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.
	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}.
(2) Scattered Sunlight Technology	3	Optical edge segments demonstrate scatter performance consistent with solar glint lobes fainter than visual magnitude 25 after relevant thermal and deploy cycles.
(3) Formation Flying Sensing Technology	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.
(4), (5) Petal Position and Shape: Accuracy and Stability Technologies	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.
	5B	Petal subsystem with *all features* demonstrates total pre-launch shape accuracy (manufacture, deploy cycles, thermal cycles deployed, & storage) to within ± 70 μm.
	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.
	6B	Petal subsystem with *all features* demonstrates on-orbit thermal stability within ± 80 μm using a validated model of critical dimension vs. temperature.
	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)
	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.
	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)
	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.
	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.
	8B	Truss Bay *assembly* demonstrates on-orbit thermal stability within ± 200 μm by analysis using a validated model of critical dimension vs. temperature.

STARLIGHT SUPPRESSION

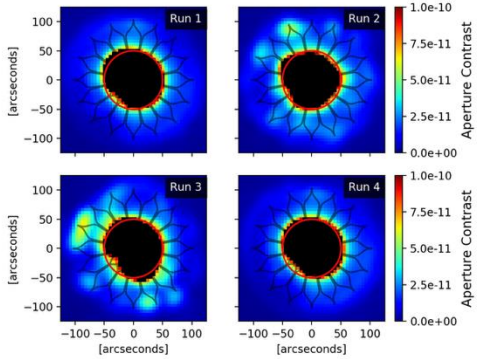
S5 Error Budget Tree

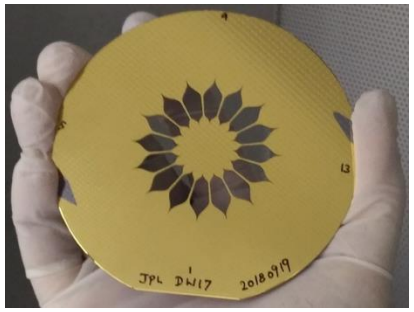


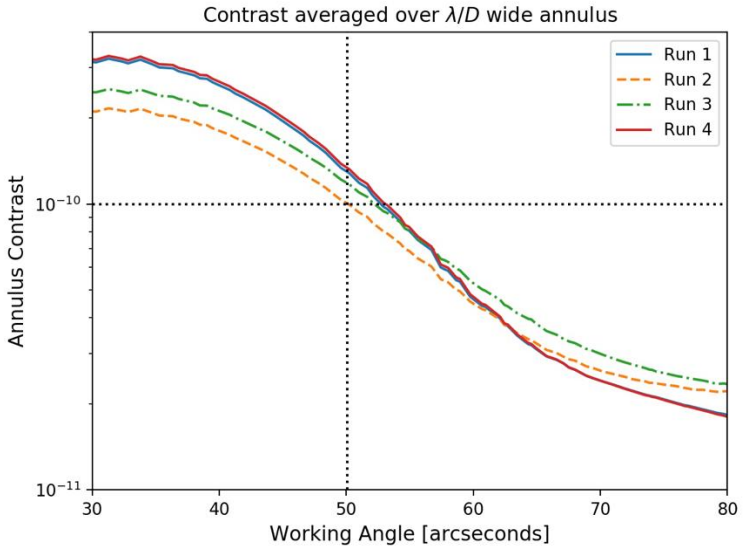
Verifying High Contrast

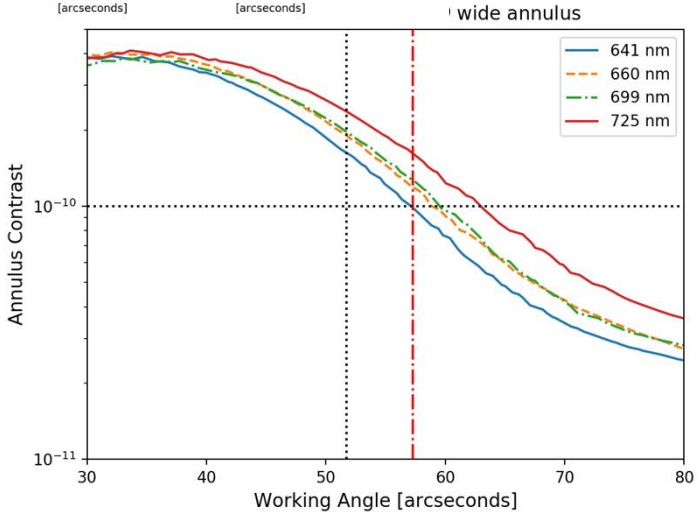
Milestones 1A and 1B

MILESTONE 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.







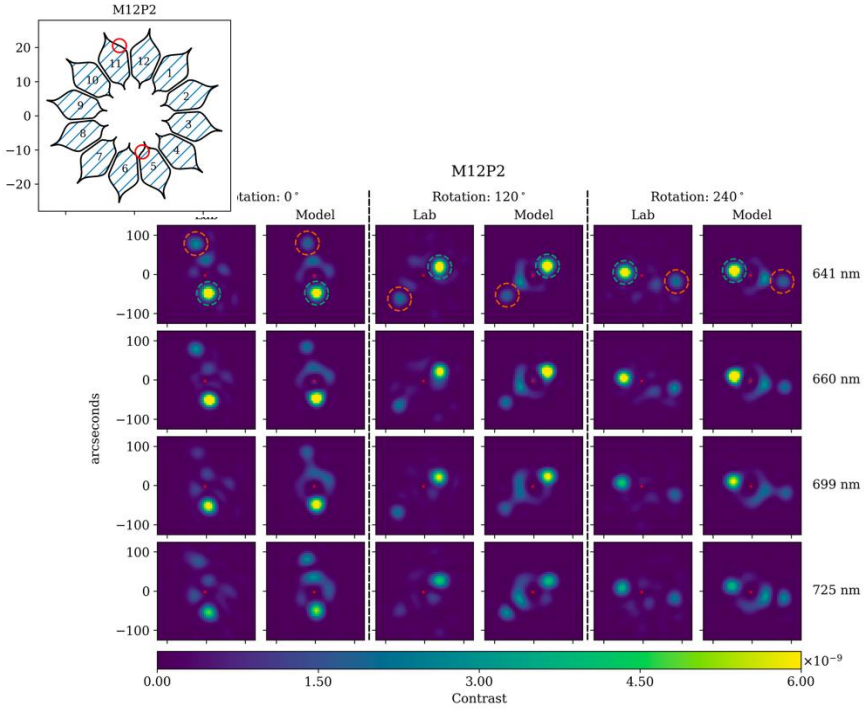


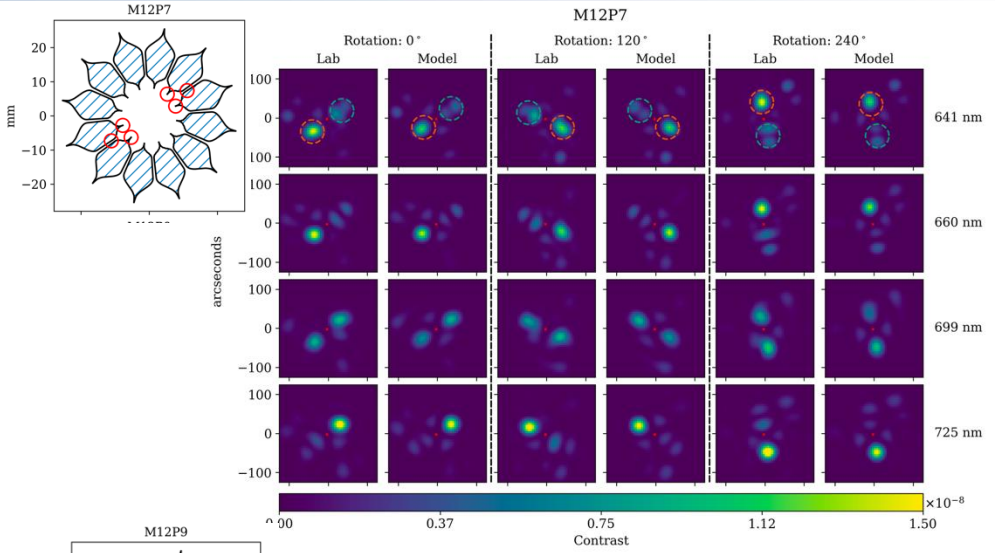
MILESTONE 1B: Small-scale starshade mask in the Princeton Testbed demonstrates $1x10^{-10}$ instrument contrast at the inner working angle at multiple wavelengths spanning ≥ 10% bandpass at Fresnel number ≤ 15 at the longest wavelength.

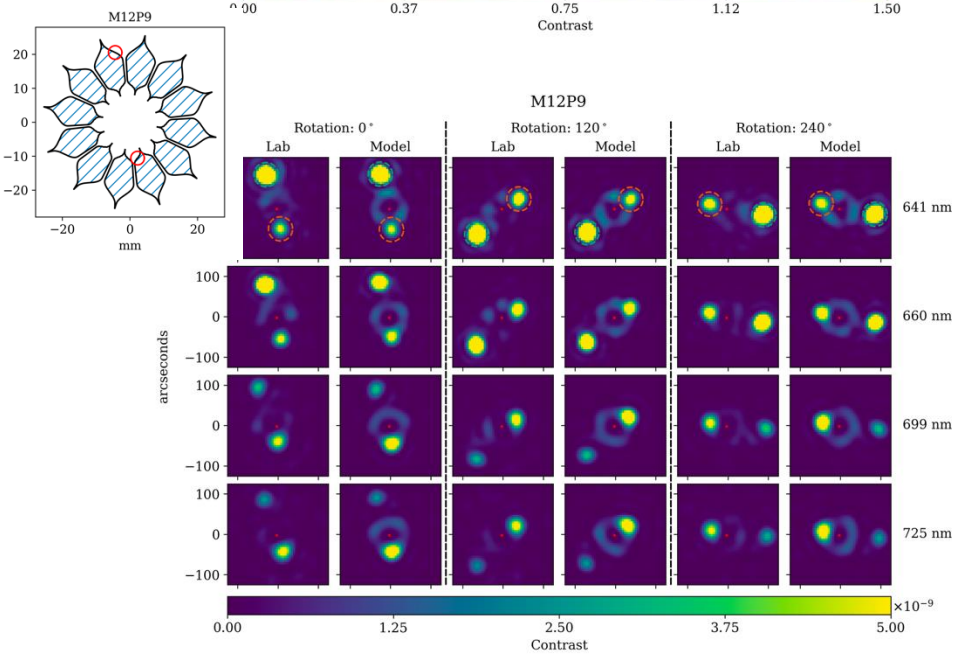
Validating the Contrast Model

Milestone 2

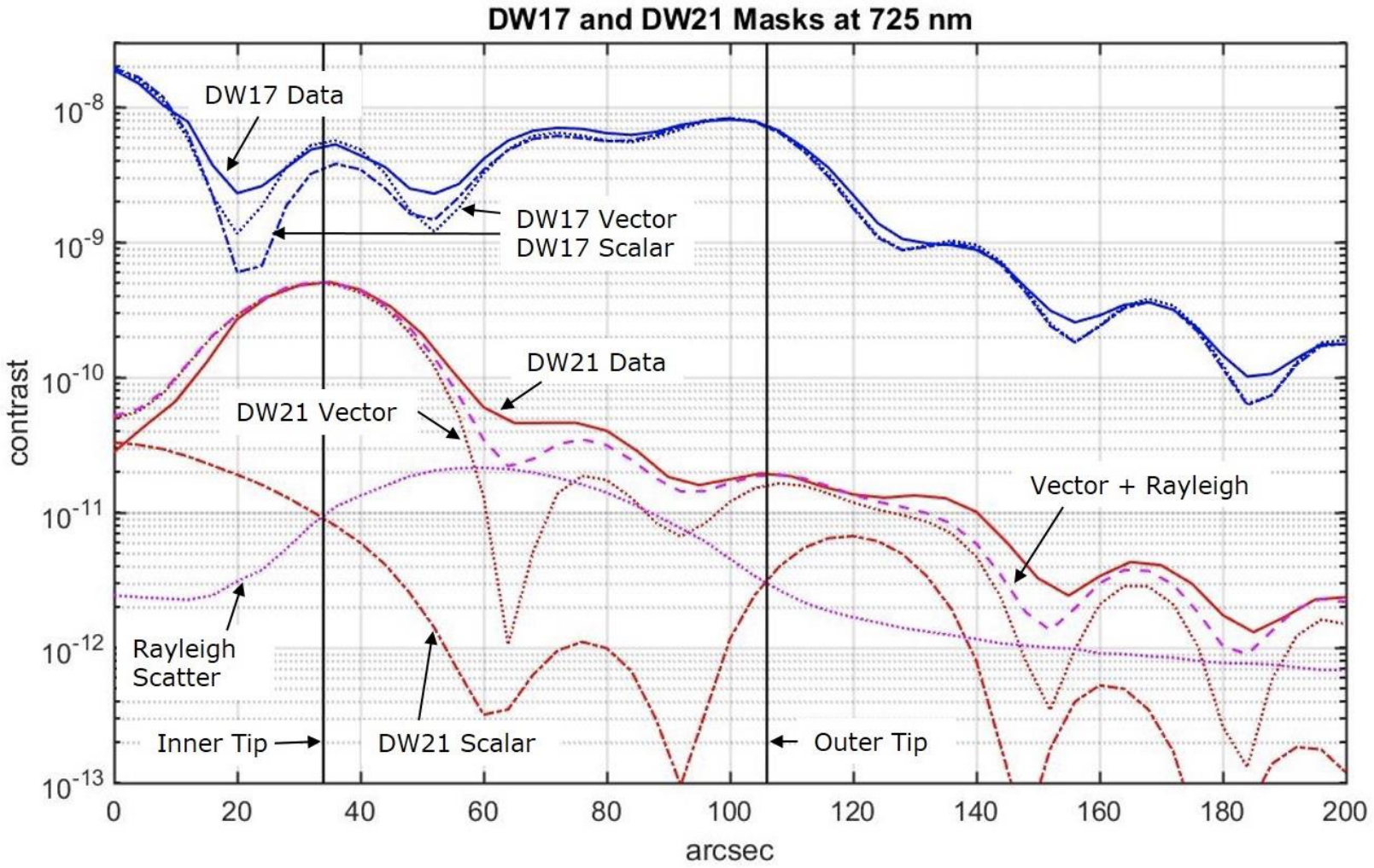
MILESTONE 2: Small-scale starshade masks in the Princeton Testbed validate contrast vs. shape model to within 25% accuracy for petal shape and 100% for petal position for induced contrasts between 10^{-9} and 10^{-8}.







Starlight Suppression Demonstration Results

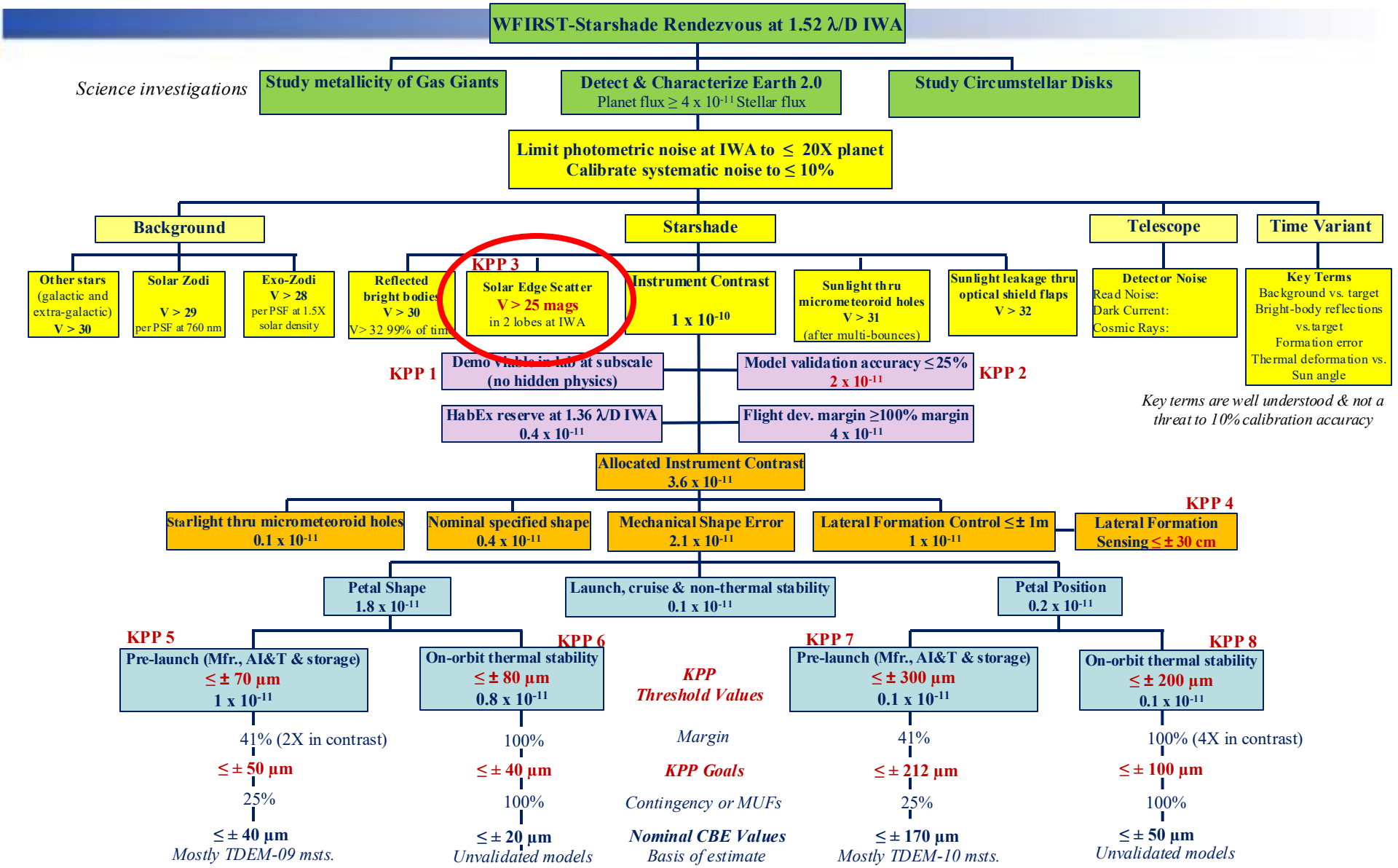


TRL 5 Achieved for Starlight Suppression Technology

TRL	Definition	Completion Criteria	Mission Req.	Performance/ Function	Fidelity of Analysis	Fidelity of Build	Level of Integration	Environment Verification
5	Component and/or brass-board validated in relevant environment	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements. ✓	Generic or specific class of missions ✓ 2-4 meter telescope	Basic functionality/ performance maintained ✓	Medium fidelity: to predict key performance parameters and life limiting factors as a function of relevant environments ✓✓ High fidelity: subscale effects modeled and understood	Medium fidelity: brass-board with realistic support elements ✓ Medium fidelity mask shape and testbed scaled to preserve Fresnel number	Component/ Assembly NA	Tested in relevant environments Characterize physics of life-limiting mechanisms and failure modes. NA

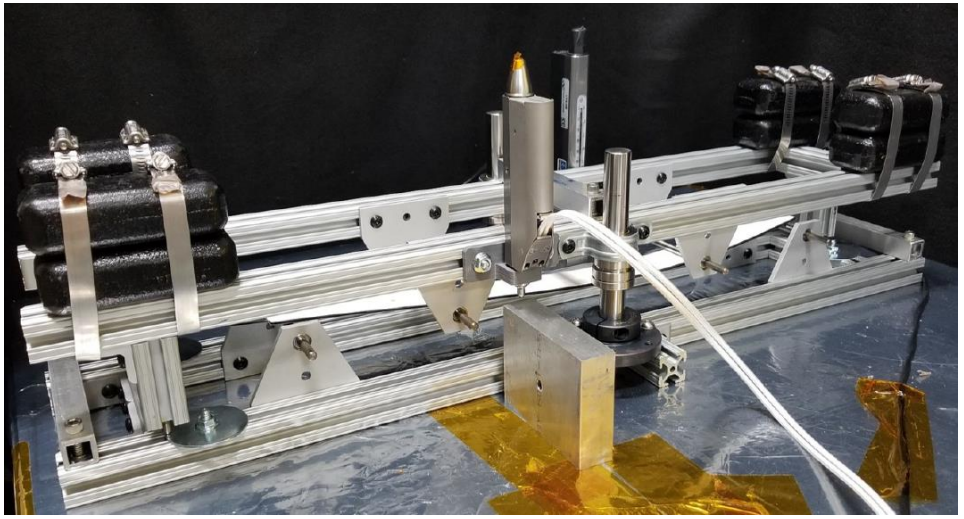
SOLAR SCATTER OFF PETAL EDGES

S5 Error Budget Tree



TRL 5 Achieved for Solar Scatter Technology

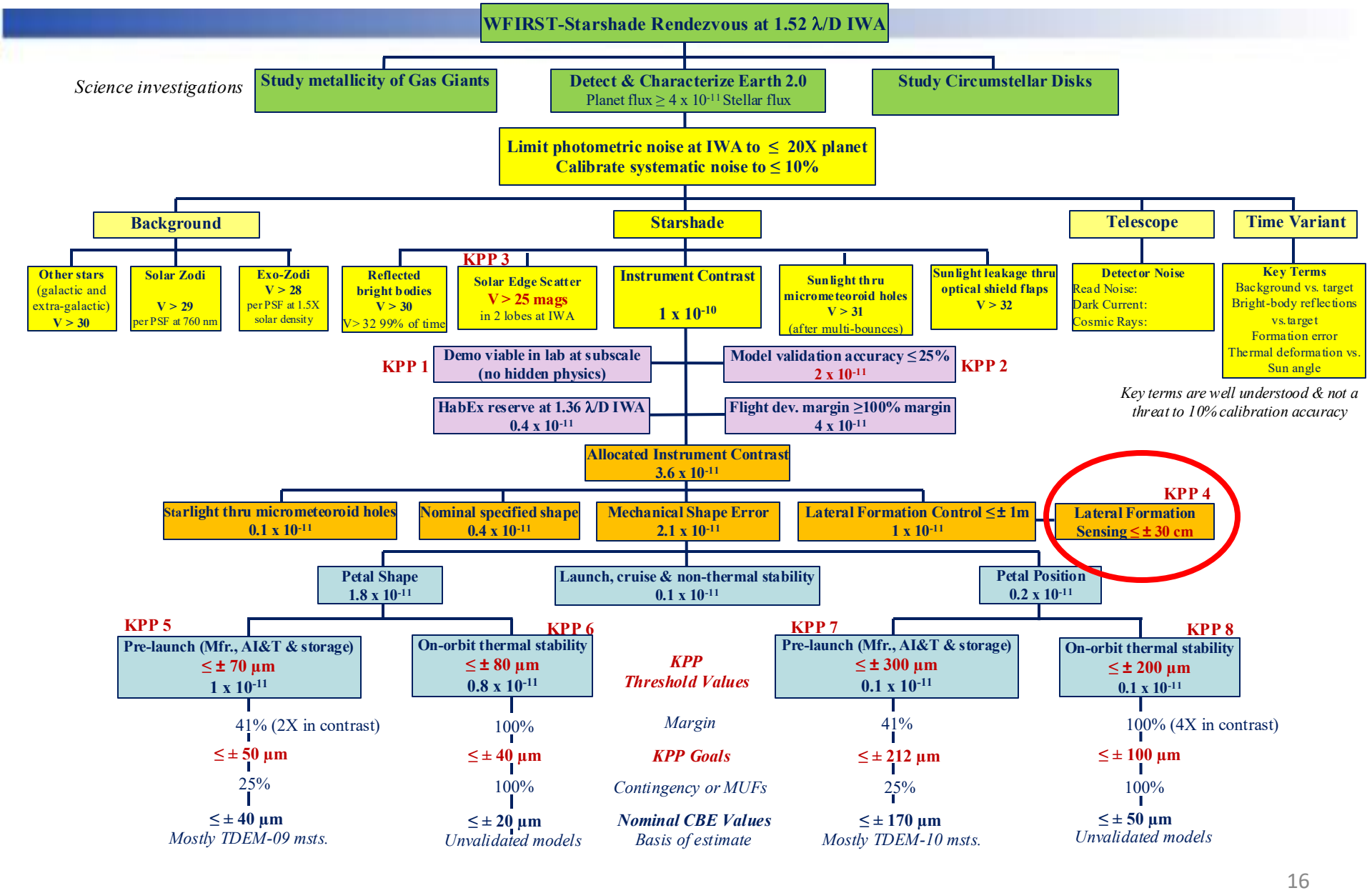
MILESTONE 3: Optical edge segments demonstrate scatter performance consistent with solar glint lobes fainter than visual magnitude 25 after relevant thermal and deploy cycles.



TRL	Definition	Completion Criteria	Mission Req.	Performance/ Function	Fidelity of Analysis	Fidelity of Build	Level of Integration	Environment Verification
5	Component and/or brass-board validated in relevant environment	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements. ✓	Generic or specific class of missions ✓ 2-4 meter telescope missions	Basic functionality/ performance maintained ✓	Medium fidelity: to predict key performance parameters and life limiting factors as a function of relevant environments ✓ Life limiting factors expected to be stowed stress and thermal cycles	Medium fidelity: brass-board with realistic support elements ✓ ✓ High fidelity edge	Component/ Assembly ✓ Component	Tested in relevant environments Characterize physics of life-limiting mechanisms and failure modes. ✓

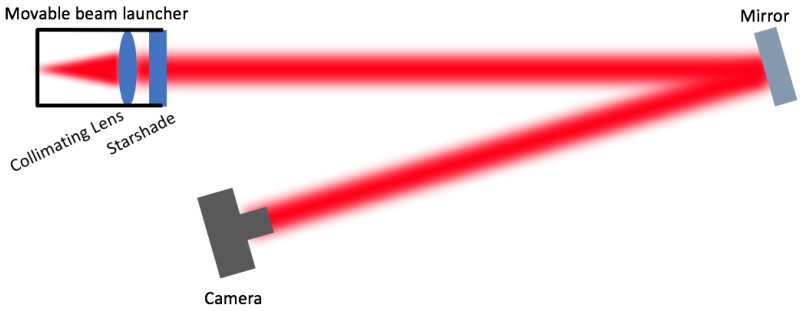
LATERAL FORMATION FLYING SENSING AND CONTROL

S5 Error Budget Tree

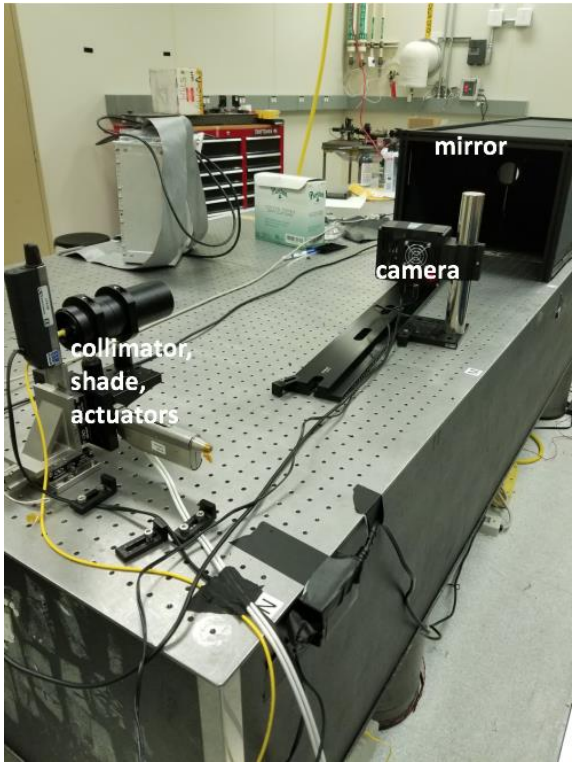


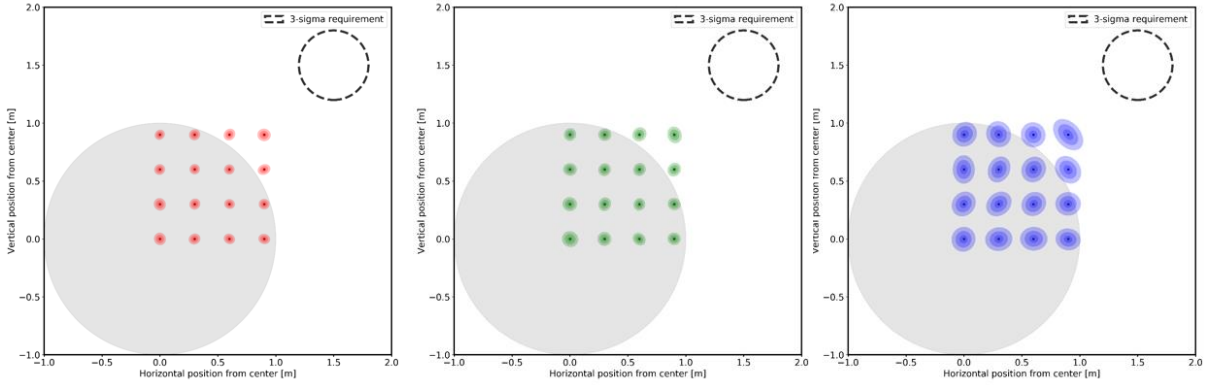
Lateral Formation Sensing and Control

Milestone 4



MILESTONE 4: Starshade Lateral Alignment Testbed validates the sensor model by demonstrating lateral position offset sensitivity to a flight equivalent of 30cm. Control system simulation using validated sensor model demonstrates on-orbit lateral position control to within ±1m.

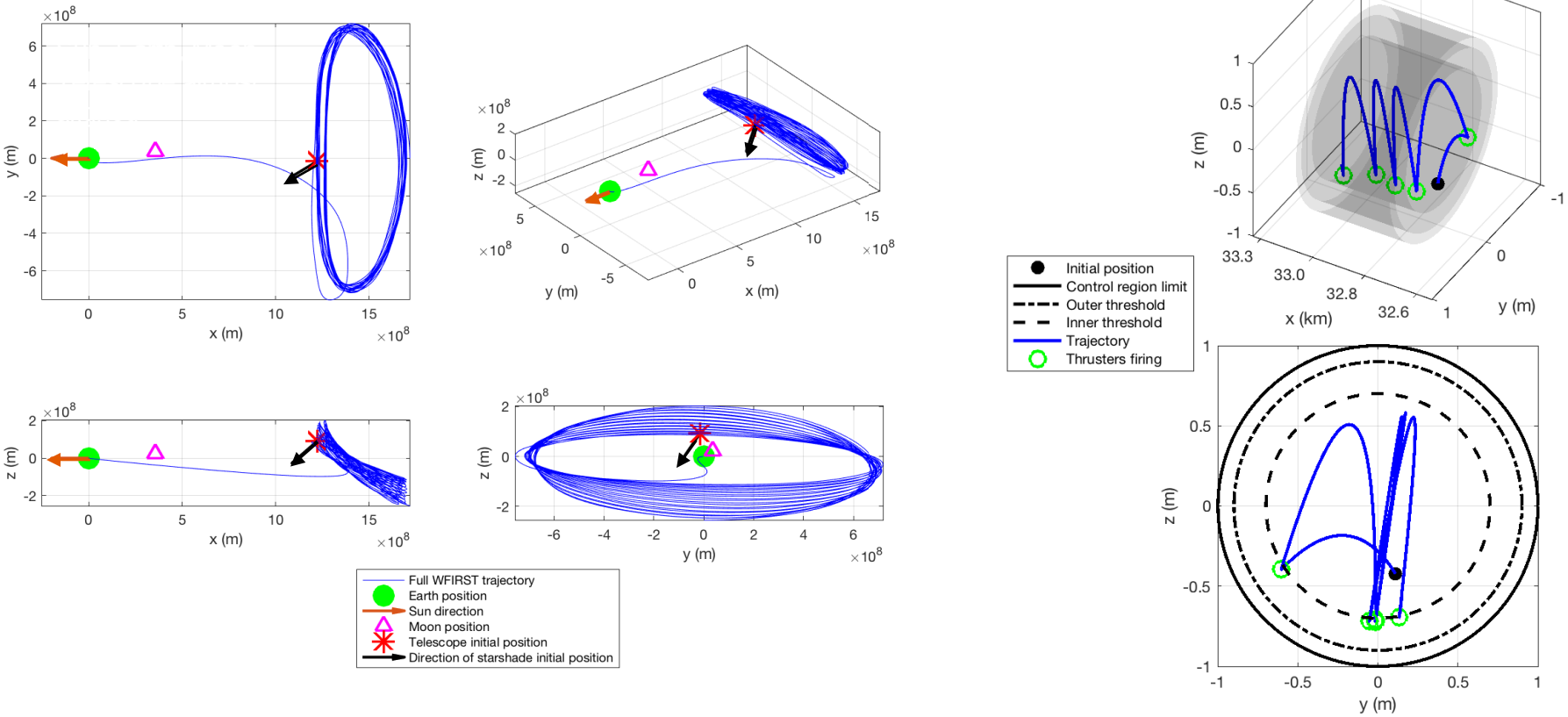




Measurements scaled to flight dimensions well within 30 cm milestone requirement

Lateral Formation Sensing and Control

Milestone 4



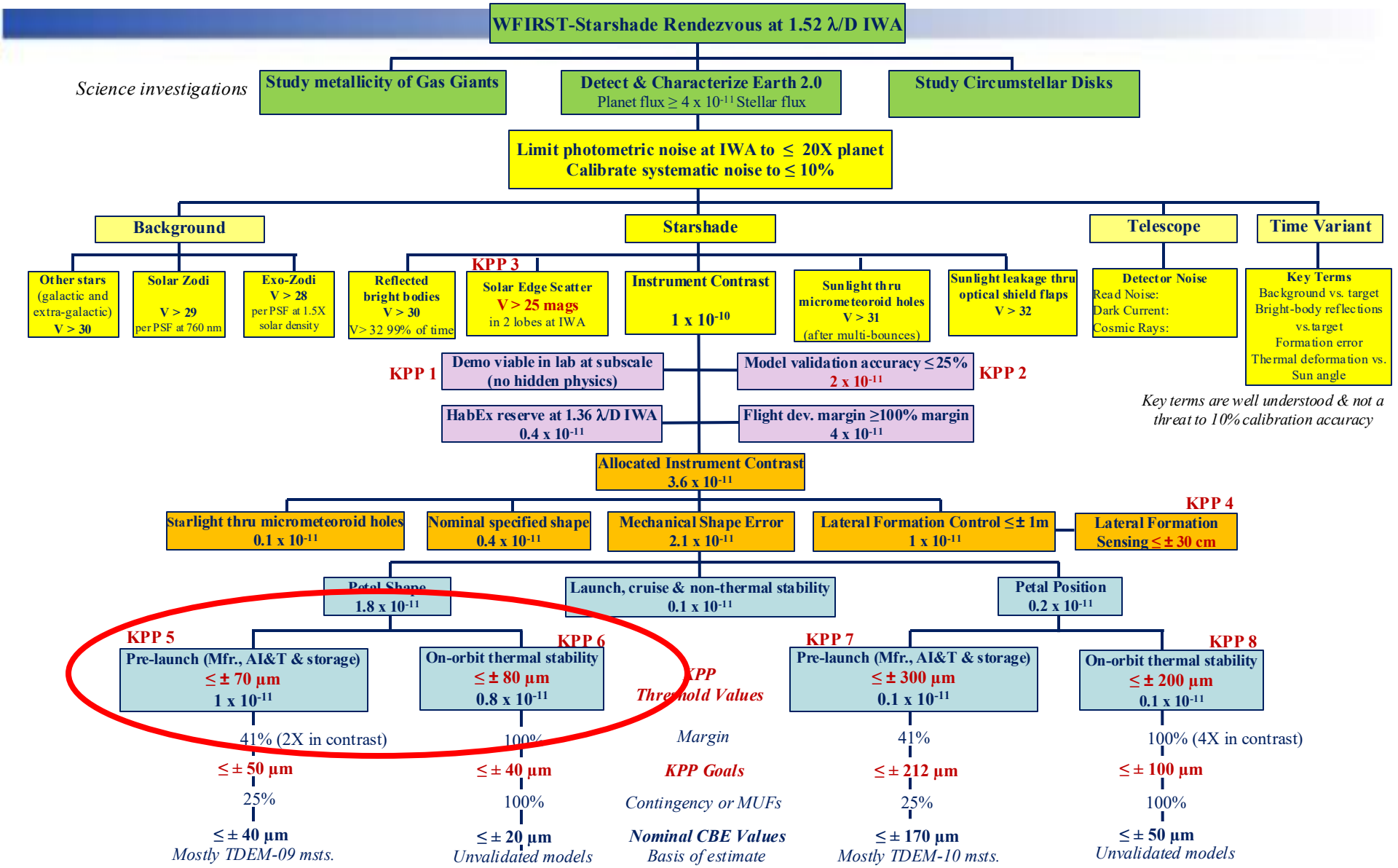
Formation flying model assumes realistic worst-case orbital configuration and position sensing only at 30 cm requirement.

TRL 5 Achieved for Lateral Formation Sensing and Control

TRL	Definition	Completion Criteria	Mission Req.	Performance/ Function	Fidelity of Analysis	Fidelity of Build	Level of Integration	Environment Verification
5	Component and/or brass-board validated in relevant environment	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements. ✓ Testbed scaled to reproduce Arago spot size w.r.t. pupil	Generic or specific class of missions ✓ 2-4 meter telescope missions at L2	Basic functionality/ performance maintained ✓	Medium fidelity: to predict key performance parameters and life limiting factors as a function of relevant environments ✓ KPP validated with Roman formation flying model	Medium fidelity: brass-board with realistic support elements ✓ Algorithm compatible with flight CDS and LOWFS array size	Component/ Assembly ✓	Tested in relevant environments Characterize physics of life-limiting mechanisms and failure modes. NA

PETAL SHAPE ACCURACY AND STABILITY

S5 Error Budget Tree



How the Mechanical Milestones Were Split Up

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.
5B	Petal subsystem with *all features* demonstrates total pre-launch shape accuracy (manufacture, deploy cycles, thermal cycles deployed, & storage) to within ± 70 μm.
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.
6B	Petal subsystem with *all features* demonstrates on-orbit thermal stability within ± 80 μm using a validated model of critical dimension vs. temperature.

The mechanical milestones were divided in several ways:

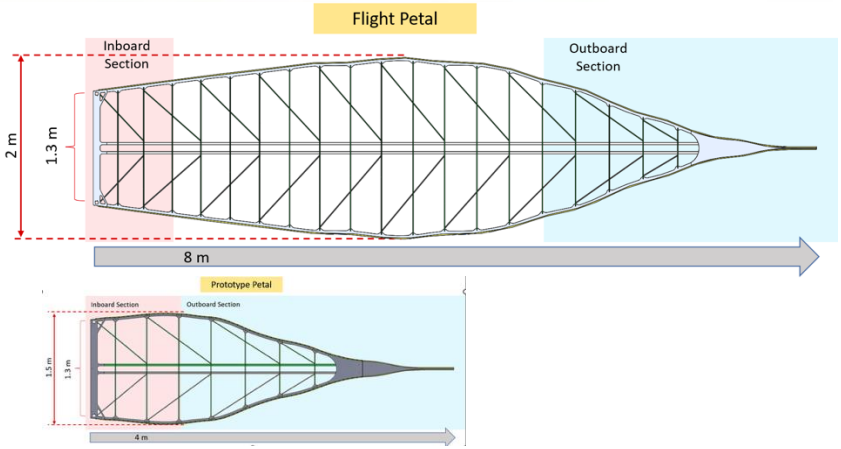
- **Technical split** – the technology to position the petal is not the same as what gives it its shape → shape vs. position milestones
- **'Stage of mission' split** - the technologies to give a petal its shape and to keep the shape stable against temperature changes differ and are tested differently → accuracy vs. stability milestones
- **Fidelity split** – tests were performed first at low fidelity, then finally at medium fidelity incorporating lessons learned → 'A' vs 'B' and 'C' vs 'D' milestones

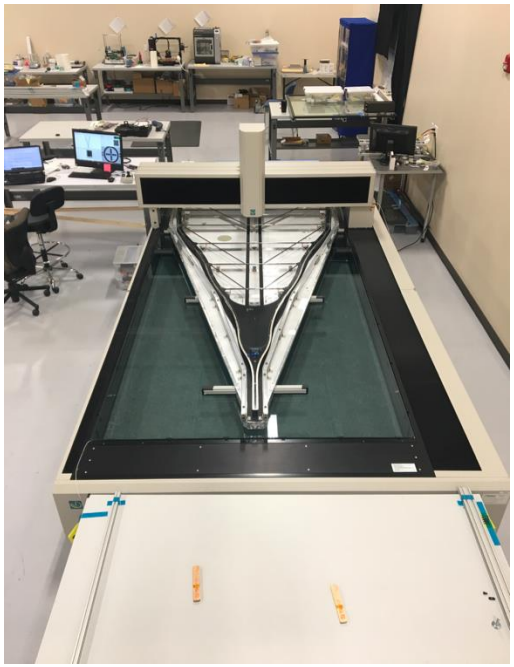
All milestones listed above must be met to reach TRL 5 for the petal shape accuracy and stability technology; likewise all 7 and 8 milestones are needed to reach TRL 5 for petal position technology

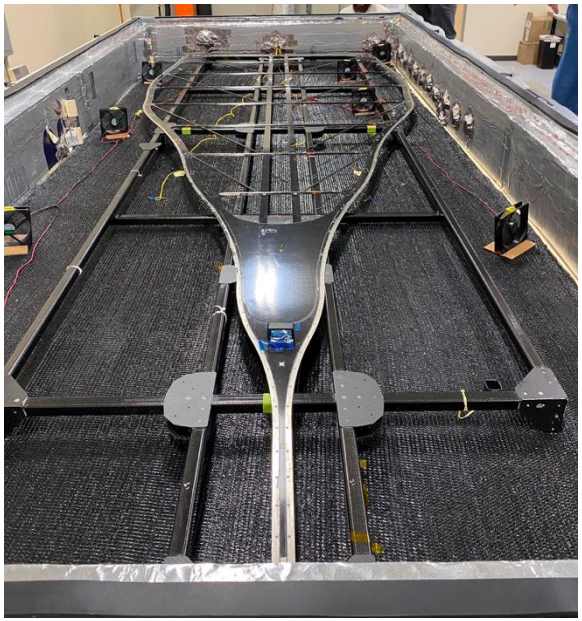
Petal Shape Accuracy

Milestones 5A and 5B

MILESTONE 5A: Petal subsystem with *shape critical features* demonstrates shape stability after deploy cycles (deployed) consistent with a total pre-launch shape accuracy within ± 70 µm.

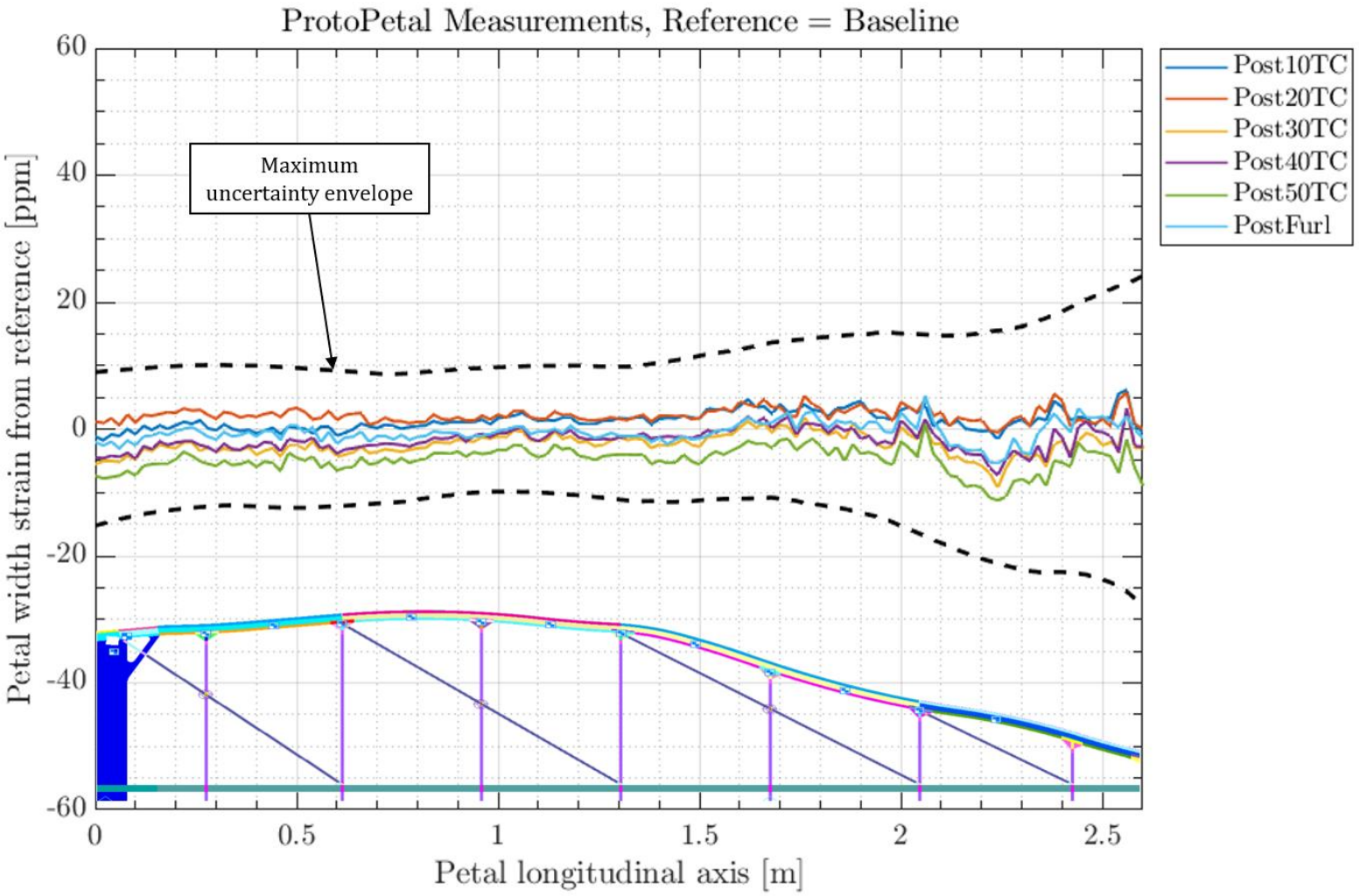






Petal Shape Accuracy

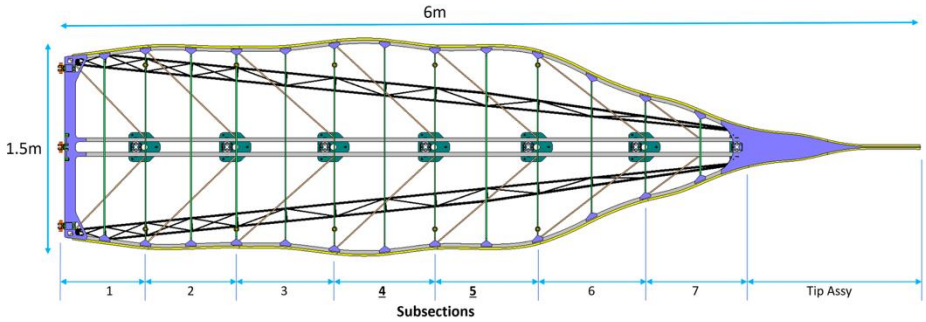
Milestones 5A and 5B

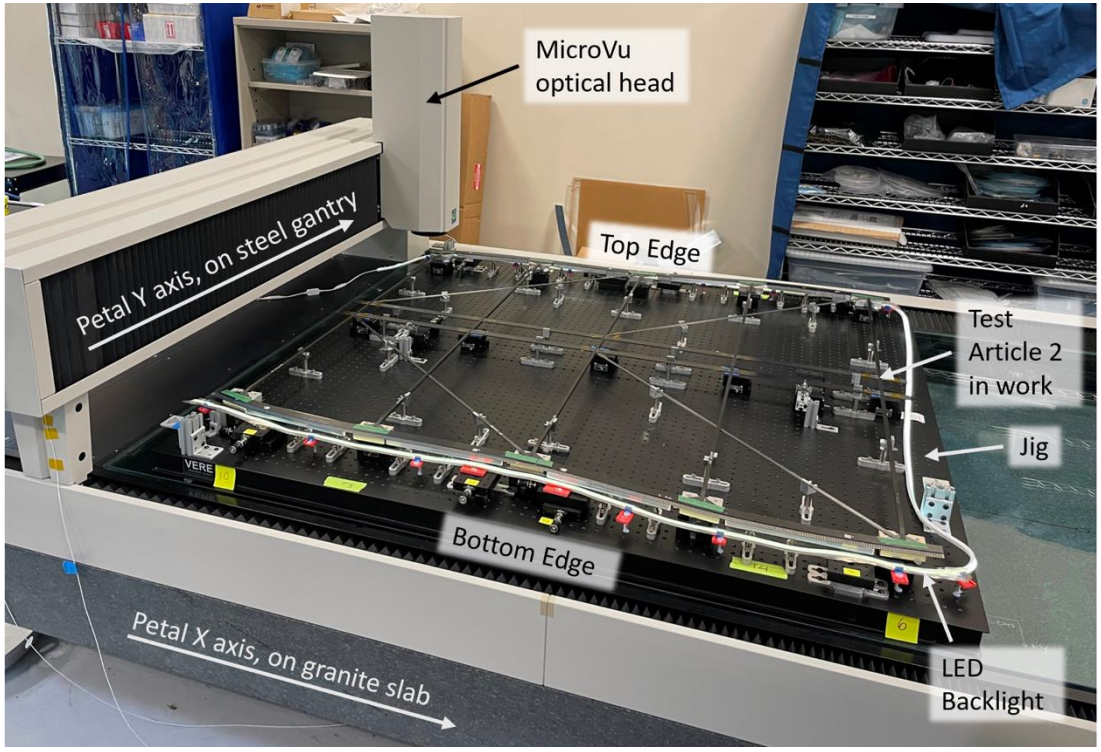


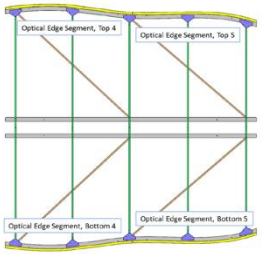
Petal Shape Accuracy

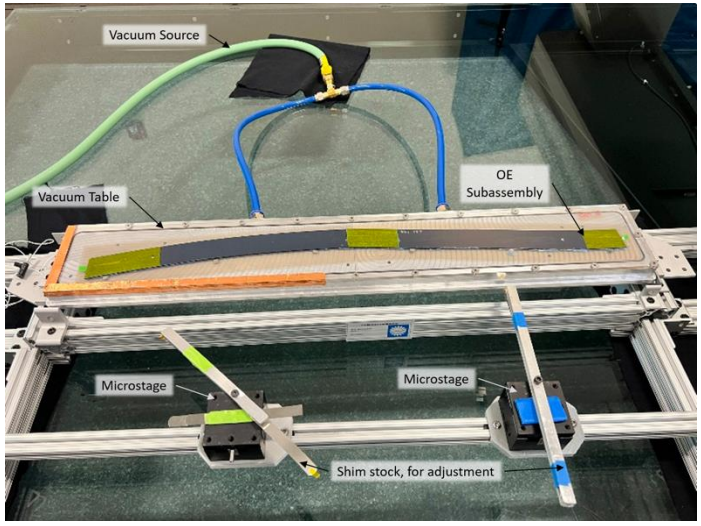
Milestones 5A and 5B

MILESTONE 5B: Petal subsystem with *all features* demonstrates total pre-launch shape accuracy (manufacture, deploy cycles, thermal cycles deployed, and storage) to within ± 70 µm.



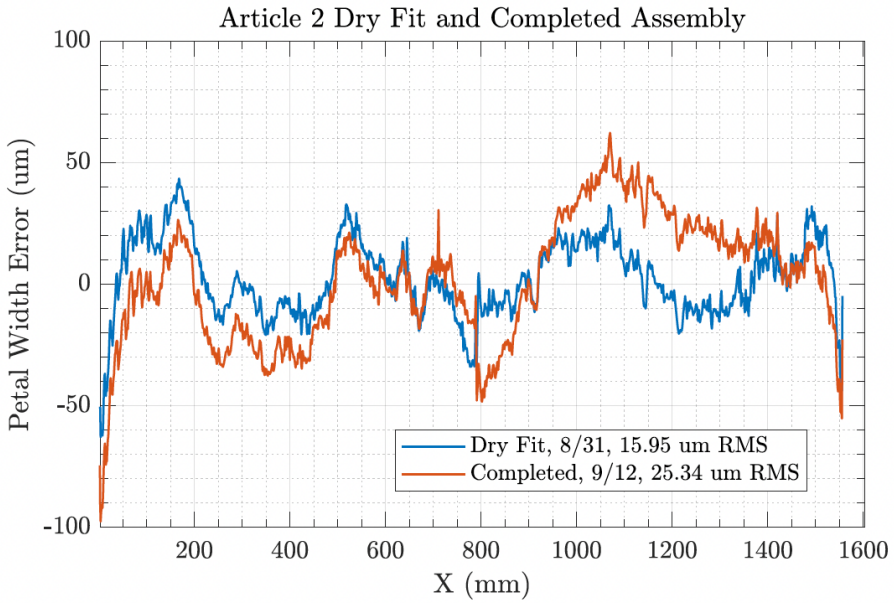


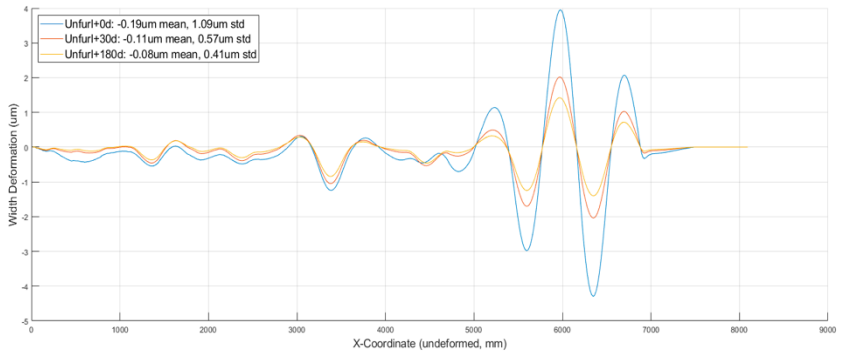


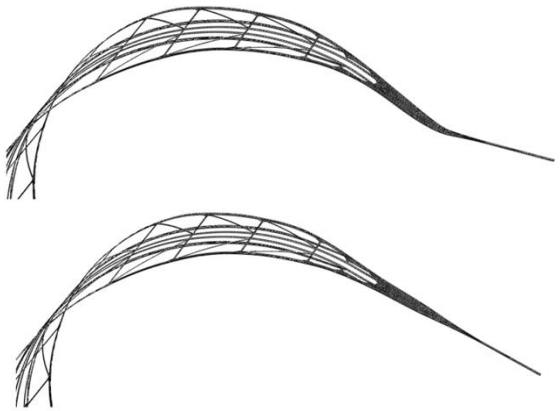


Petal Shape Accuracy

Milestones 5A and 5B



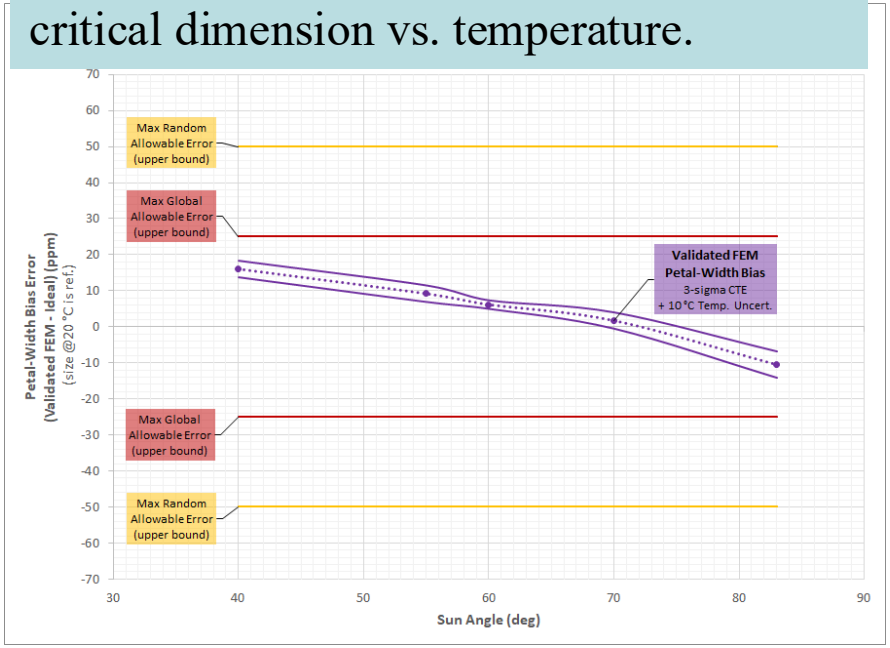


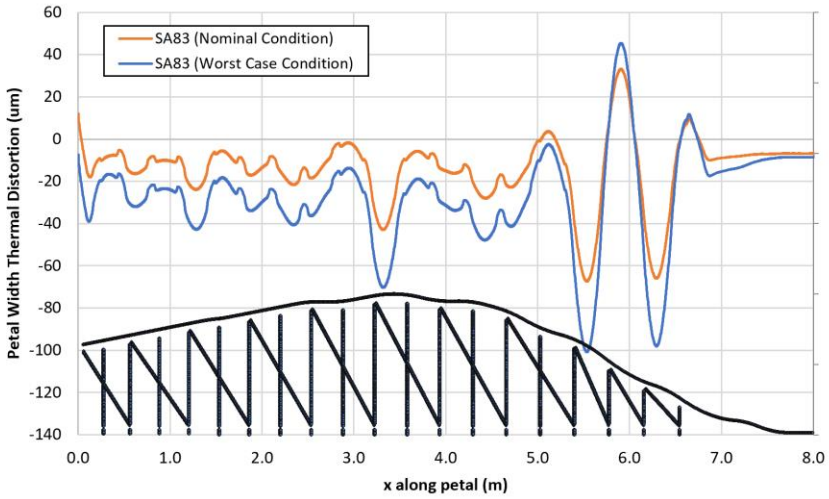


Petal Shape Stability

Milestones 6A and 6B

MILESTONE 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.





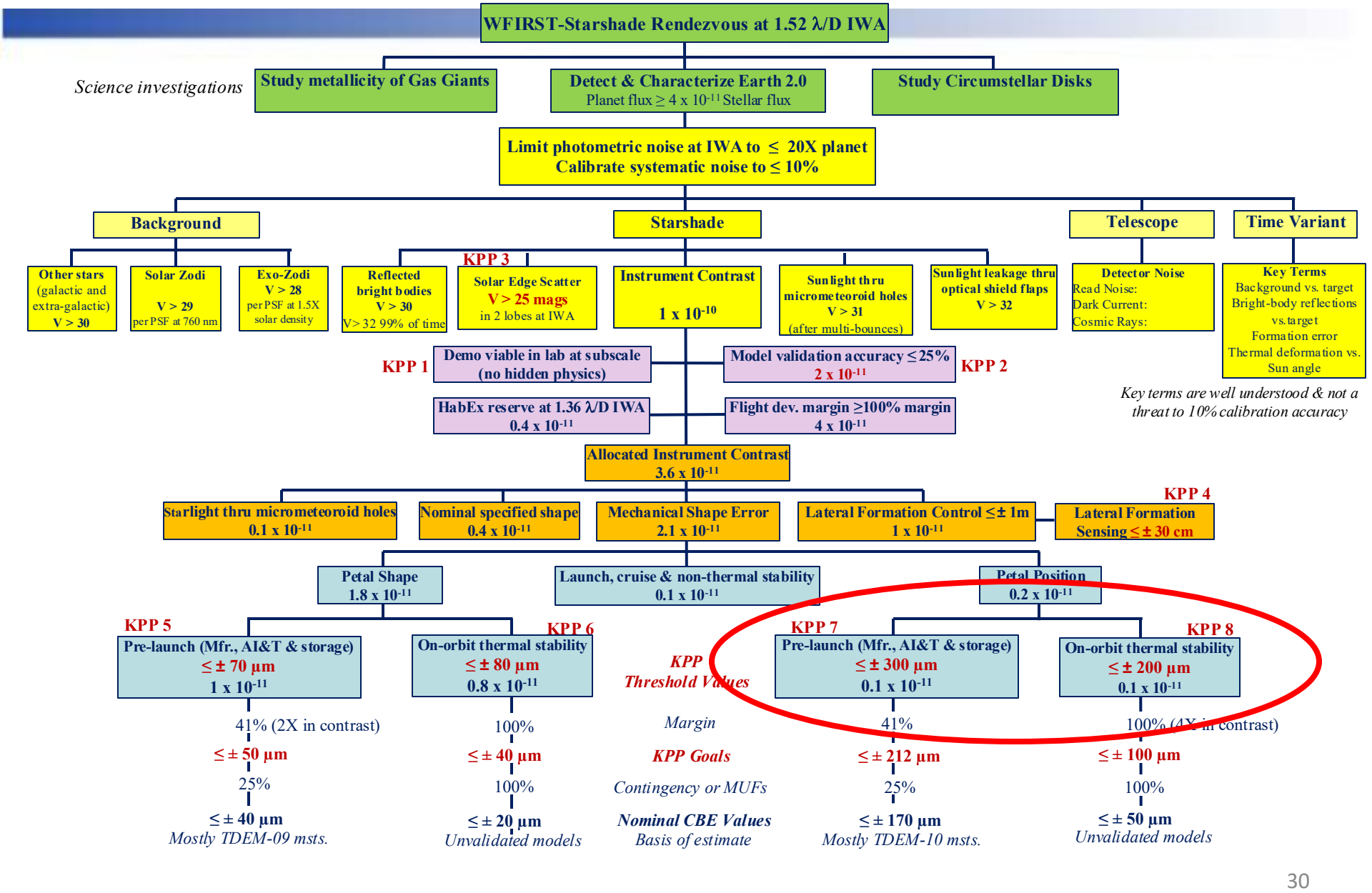
MILESTONE 6B: Petal subsystem all *features* demonstrates on-orbit thermal stability within ± 80 µm by analysis using a validated model of critical dimension vs. temperature.

TRL 5 is Achieved for Petal Shape Technology

TRL	Definition	Completion Criteria	Mission Req.	Performance/ Function	Fidelity of Analysis	Fidelity of Build	Level of Integration	Environment Verification
5	Component and/or brass-board validated in relevant environment	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements. ✓ Good agreement between analysis and test	Generic or specific class of missions ✓ 2-4 meter telescope missions	Basic functionality/ performance maintained ✓	Medium fidelity: to predict key performance parameters and life limiting factors as a function of relevant environments ✓ Life limiting factors expected to be stowed stress and thermal cycles	Medium fidelity: brass-board with realistic support elements ✓ Medium fidelity test articles at ≥ half scale	Component/ Assembly ✓ Assembly	Tested in relevant environments Characterize physics of life-limiting mechanisms and failure modes. ✓ Functions and survives over operating full temperature range

INNER DISK ACCURACY AND STABILITY

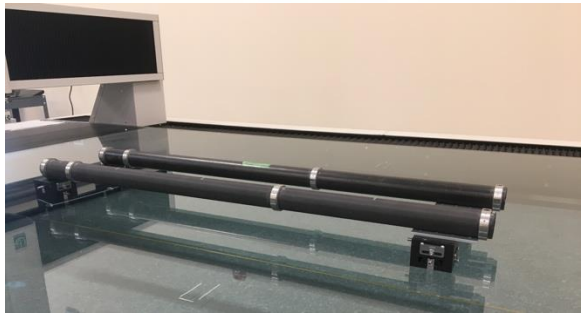
S5 Error Budget Tree

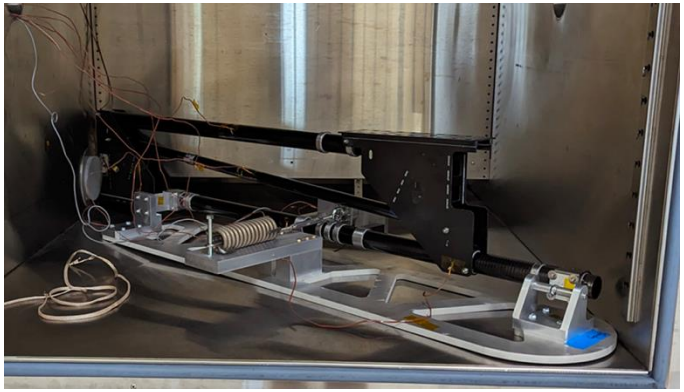


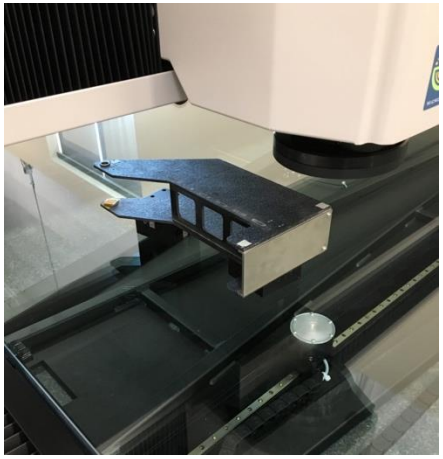
Truss Bay Shape Accuracy

Milestones 7A and 7B

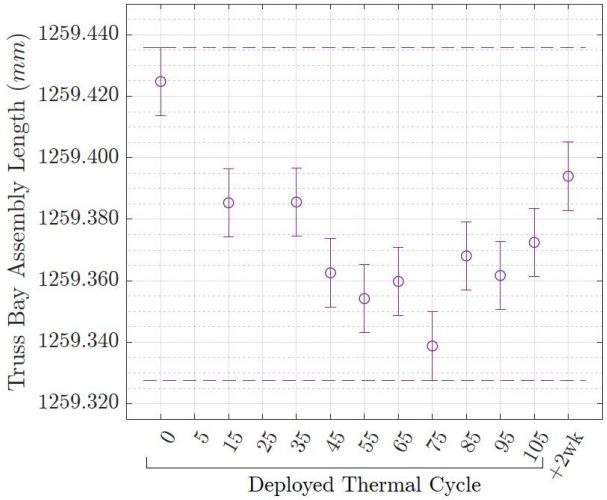
Milestone 7A: Truss Bay *longeron and node subassemblies* demonstrate dimensional stability with thermal cycles (deployed) consistent with a total pre-launch petal position accuracy within ± 300 µm.







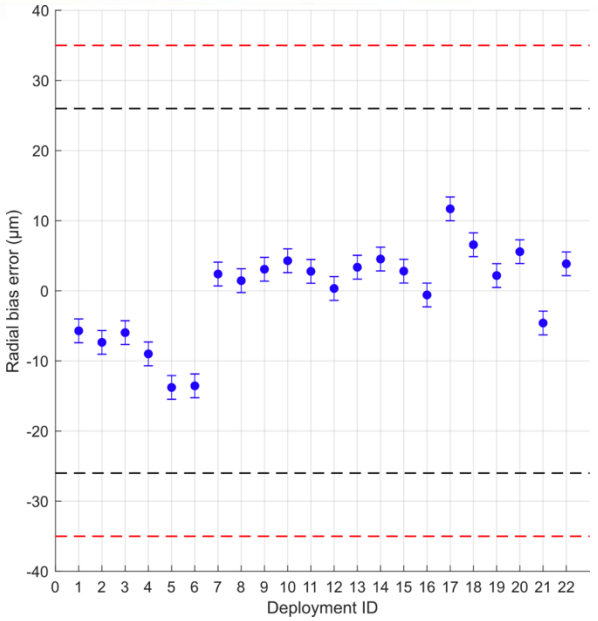
Milestone 7B: Truss Bay *assembly* demonstrates dimensional stability with thermal cycles (deployed) and storage consistent with a total pre-launch petal position accuracy within ± 300 µm.

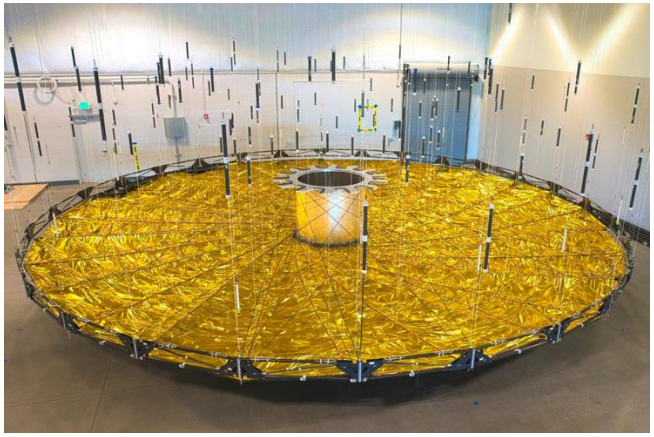


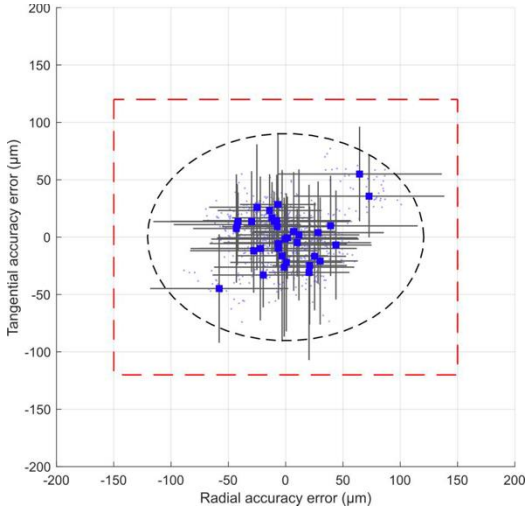
Inner Disk Deployment Accuracy

Milestones 7C and 7D

Milestone 7C: Inner Disk Subsystem with optical shield assembly that includes *deployment critical features* demonstrates repeatable accuracy consistent with a total pre-launch petal position accuracy within ± 300 µm.



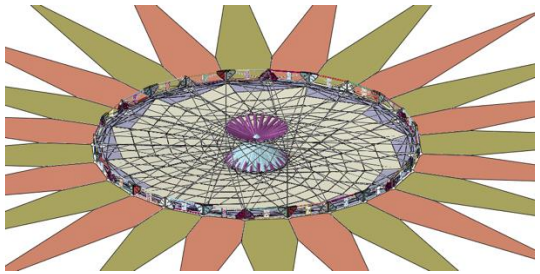


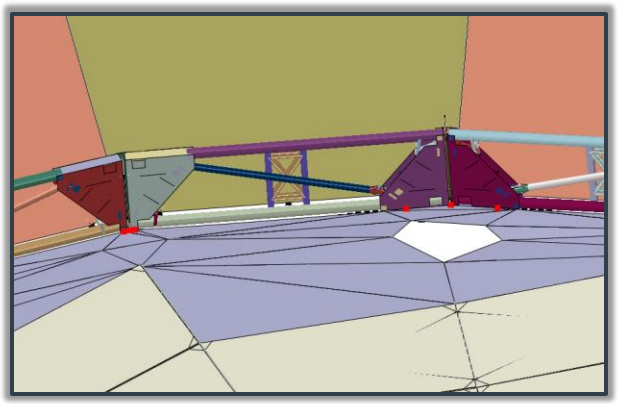


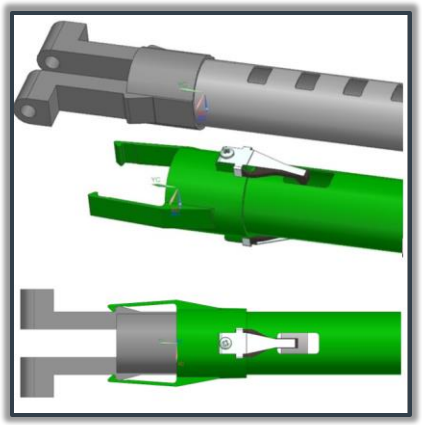
Inner Disk Deployment Accuracy

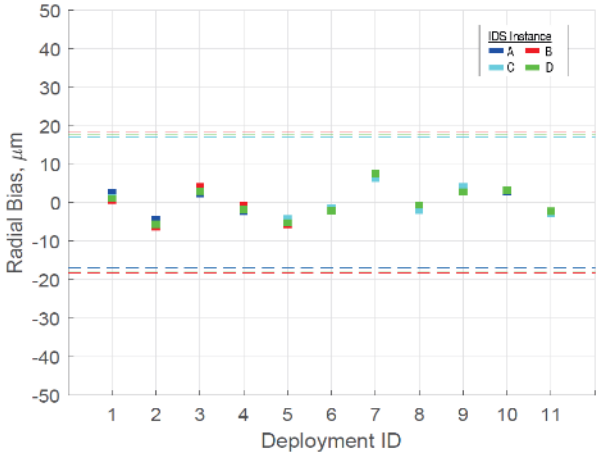
Milestones 7C and 7D

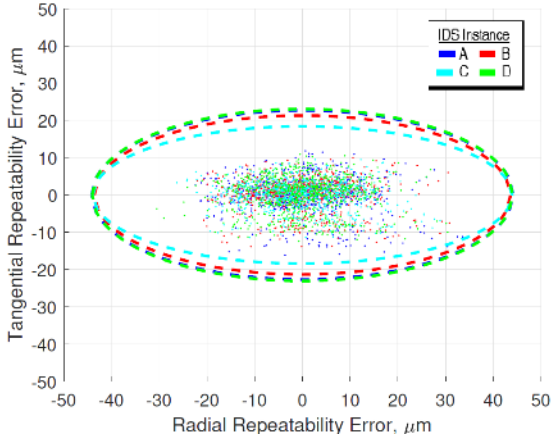
Milestone 7D: Inner Disk Subsystem with optical shield assembly that includes *all features* demonstrates repeatable accuracy consistent with a total pre-launch petal position accuracy within ± 300 µm.

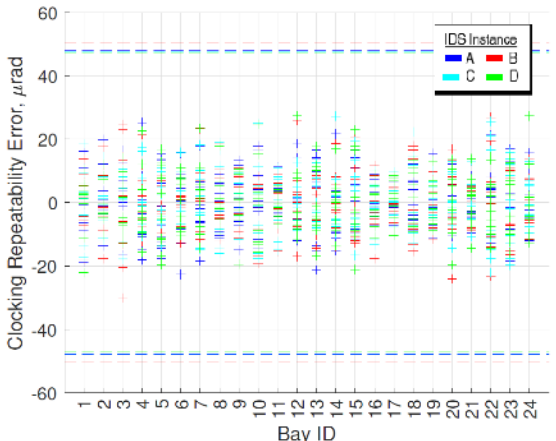








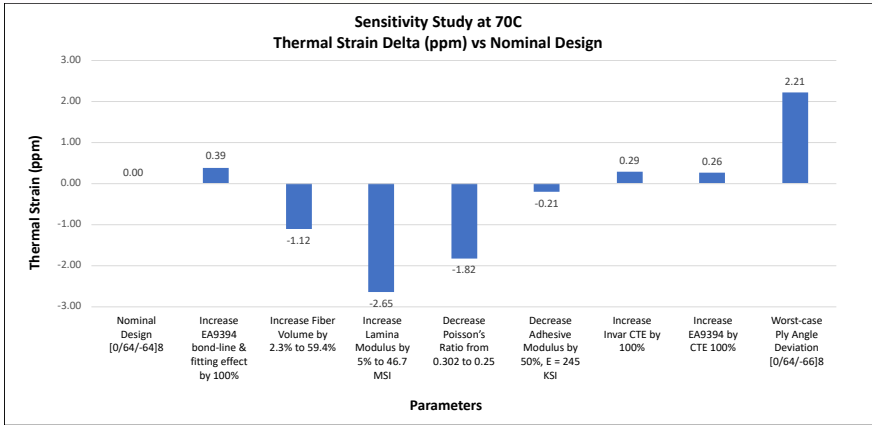


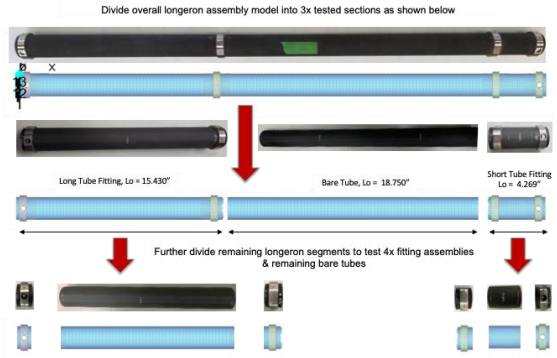


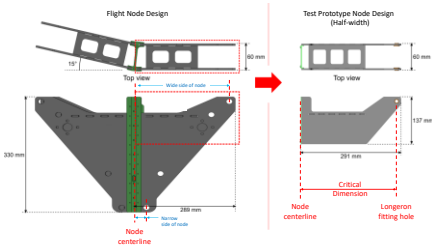
Inner Disk Thermal Stability

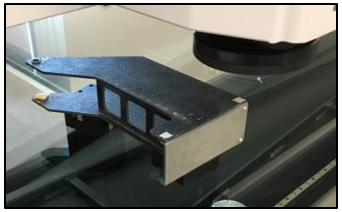
Milestones 8A and 8B

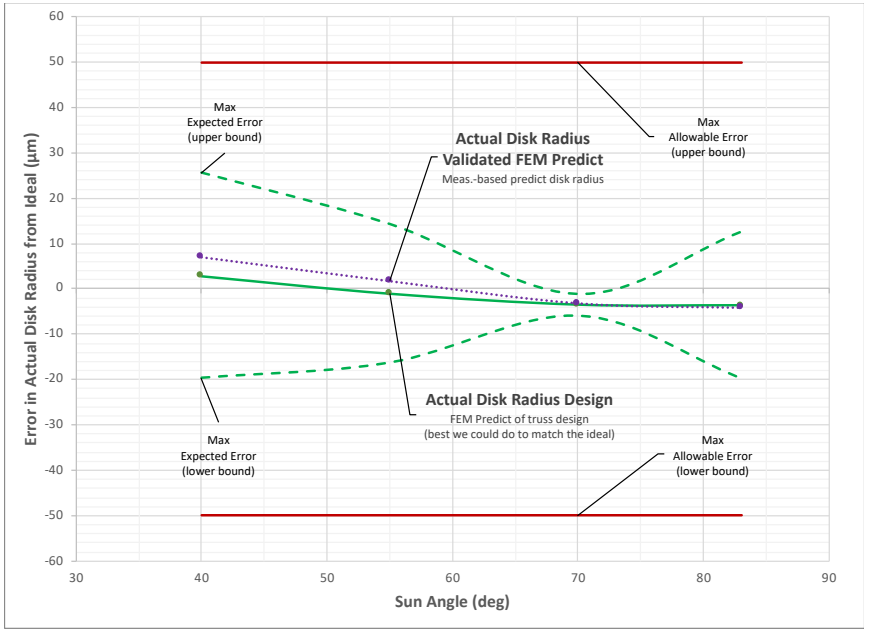
Milestone 8A: Truss Bay *longeron and node subassemblies* demonstrate on-orbit thermal stability within ± 200 µm by analysis using a validated model of critical dimension vs. temperature.







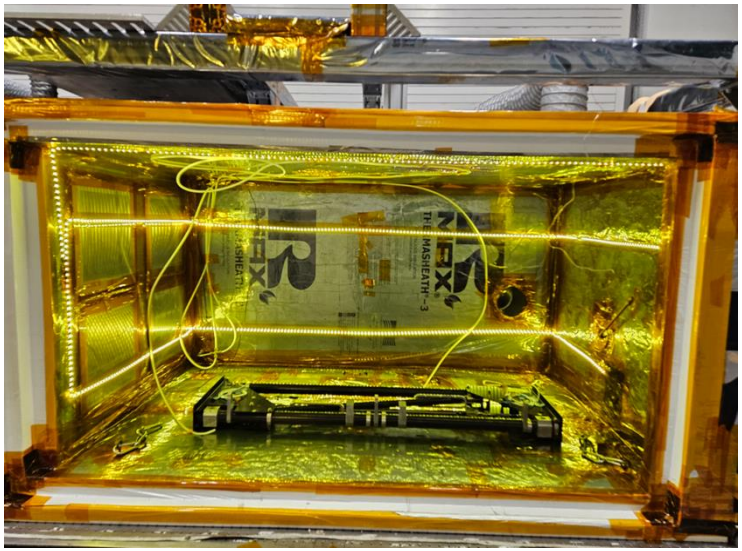


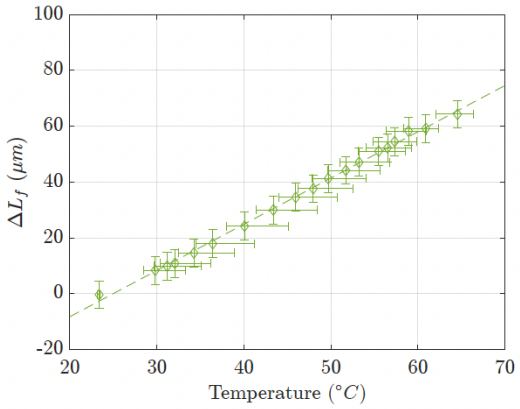


Inner Disk Thermal Stability

Milestones 8A and 8B

Milestone 8A: Truss Bay *assembly* demonstrates on-orbit thermal stability within ± 200 µm by analysis using a validated model of critical dimension vs. temperature.





TRL 5 is Achieved for Petal Position Technology

TRL	Definition	Completion Criteria	Mission Req.	Performance/ Function	Fidelity of Analysis	Fidelity of Build	Level of Integration	Environment Verification
5	Component and/or brass-board validated in relevant environment	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements. ✓	Generic or specific class of missions ✓ 2-4 meter telescope missions	Basic functionality/ performance maintained ✓	Medium fidelity: to predict key performance parameters and life limiting factors as a function of relevant environments ✓ Life limiting factors expected to be stowed stress and thermal cycles	Medium fidelity: brass-board with realistic support elements ✓ Medium fidelity test articles at full scale for Roman	Component/ Assembly ✓ Subassembly/ Assembly	Tested in relevant environments Characterize physics of life-limiting mechanisms and failure modes. ✓ Functions and survives over operating full temperature range