Mechanical Group Report

Paris 2025

Thursday, June 5th 2025

Engineers: Paul Degarate, Neville Dewitt Pierrat, William Finch, Derek Lapp, Josh Moses, Ben Stillwell

Students: Levi Barr-On, Julia Burton-Heibges, Trenton Frederik, Auston Froid, Conrad Shay, Luke Wanner

Faculty: Austin Cummings, Johannes Eser, George Filappatos, Tobias Heibges, Eric Mayotte*, Stephen Meyer, Tom Paul, Lawrence Weincke

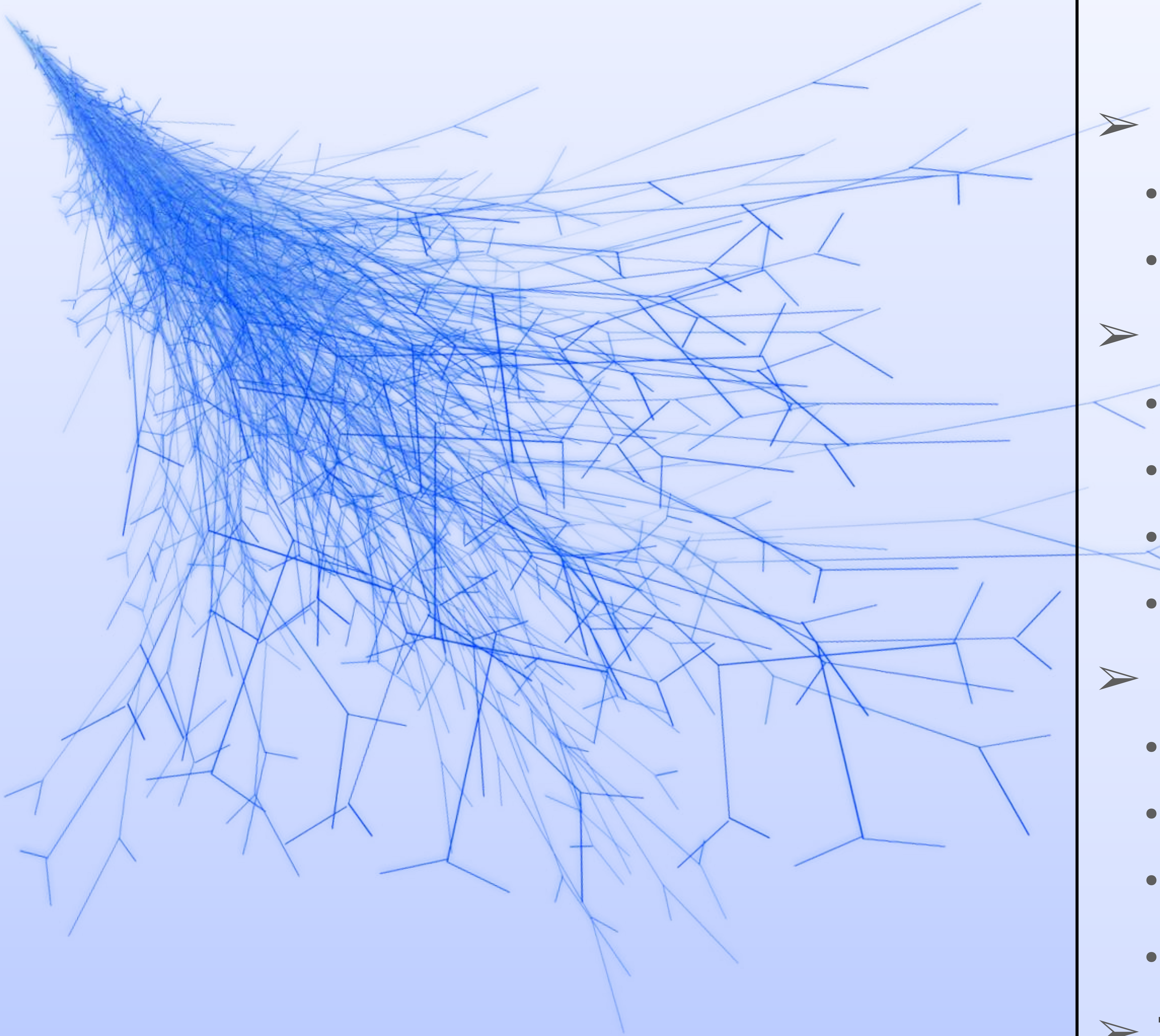
Summary

➢ Very near to the design completion
➜ Moving from design phase to construction phase

➢ Procurement has already started on some components
- Mirror cell components are already underway
- Ready for a large procurement order for Gondola and Telescope
- 50% Tariffs on Al may cause problems as they were not accounted for in the original budget
➜ In effect, as of yesterday…

➢ On schedule, but the timeline is tight
➜ It will be a very busy fall

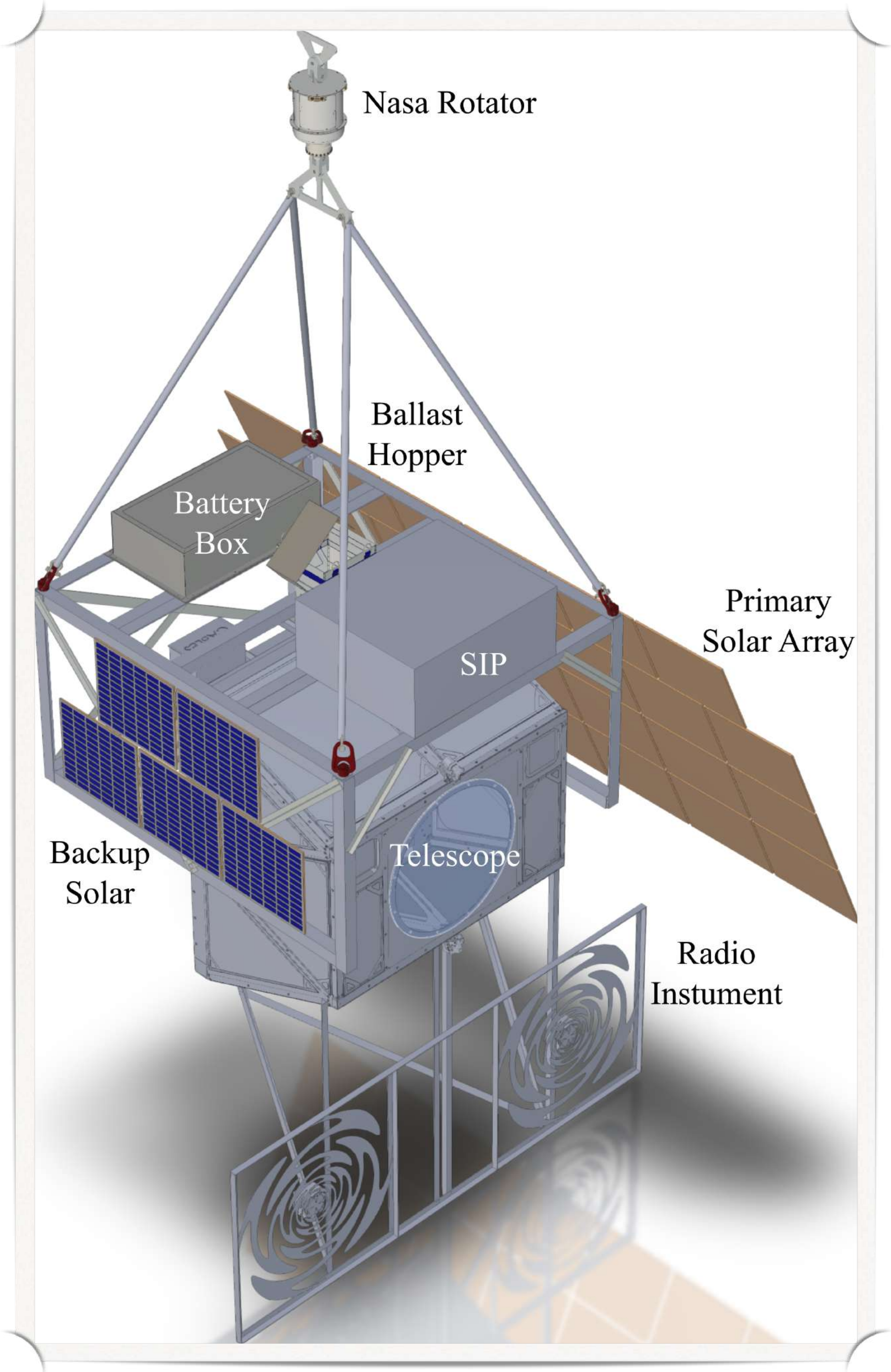
➢ Last chance for any major design change requests passes after this meeting



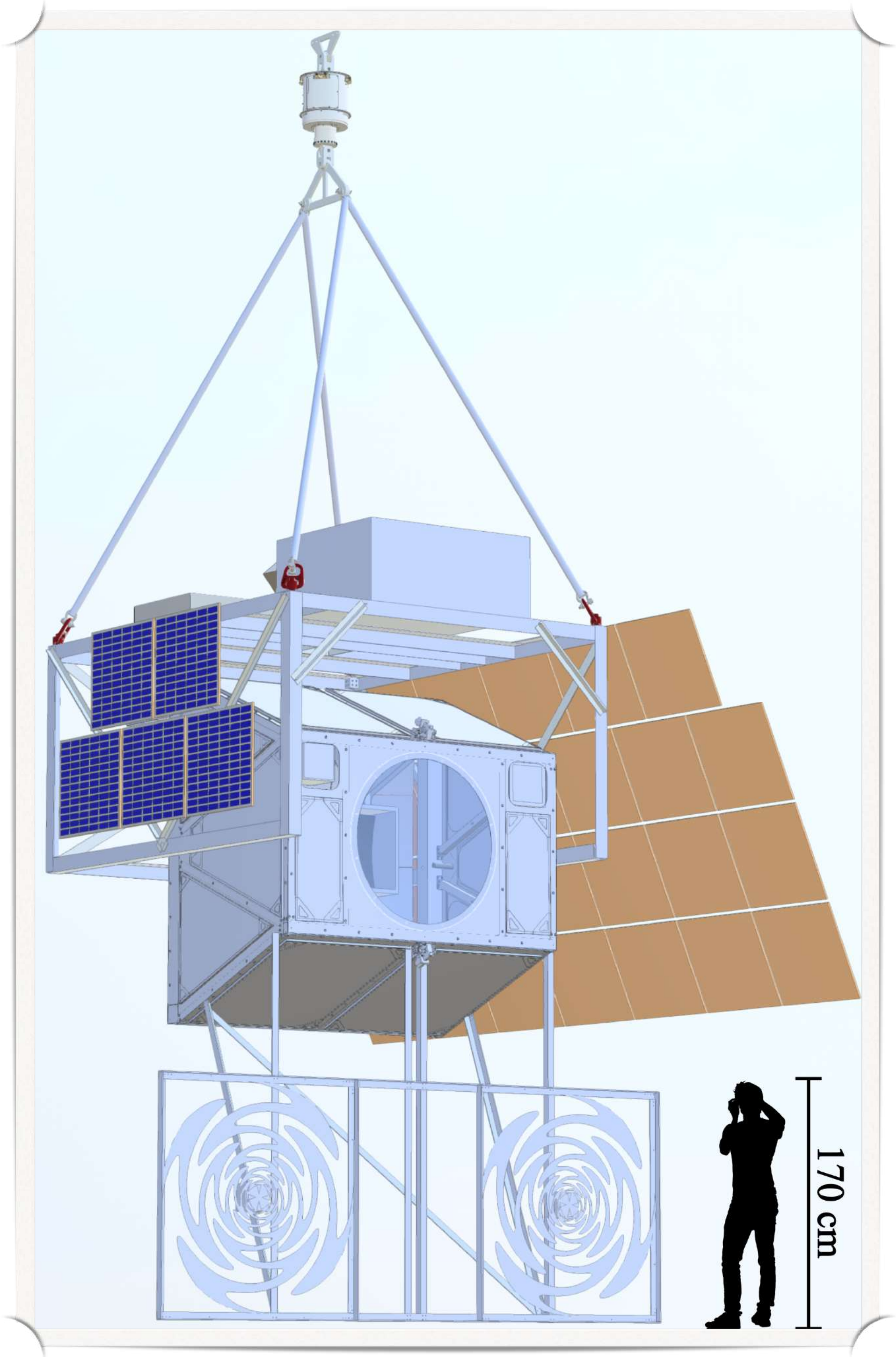
Outline

- ➢ New Figures for Conferences
  - Payload
  - Telescope
- ➢ Mechanical Design Status
  - Gondola
  - Telescope
  - Mirror Assembly
  - Radio Frame and Mast
- ➢ FEA and Testing Status
  - Gondola and Telescope
  - Radio Mast
  - Bonded Joints
  - Mirror Assembly
- ➢ Timeline and Outlook

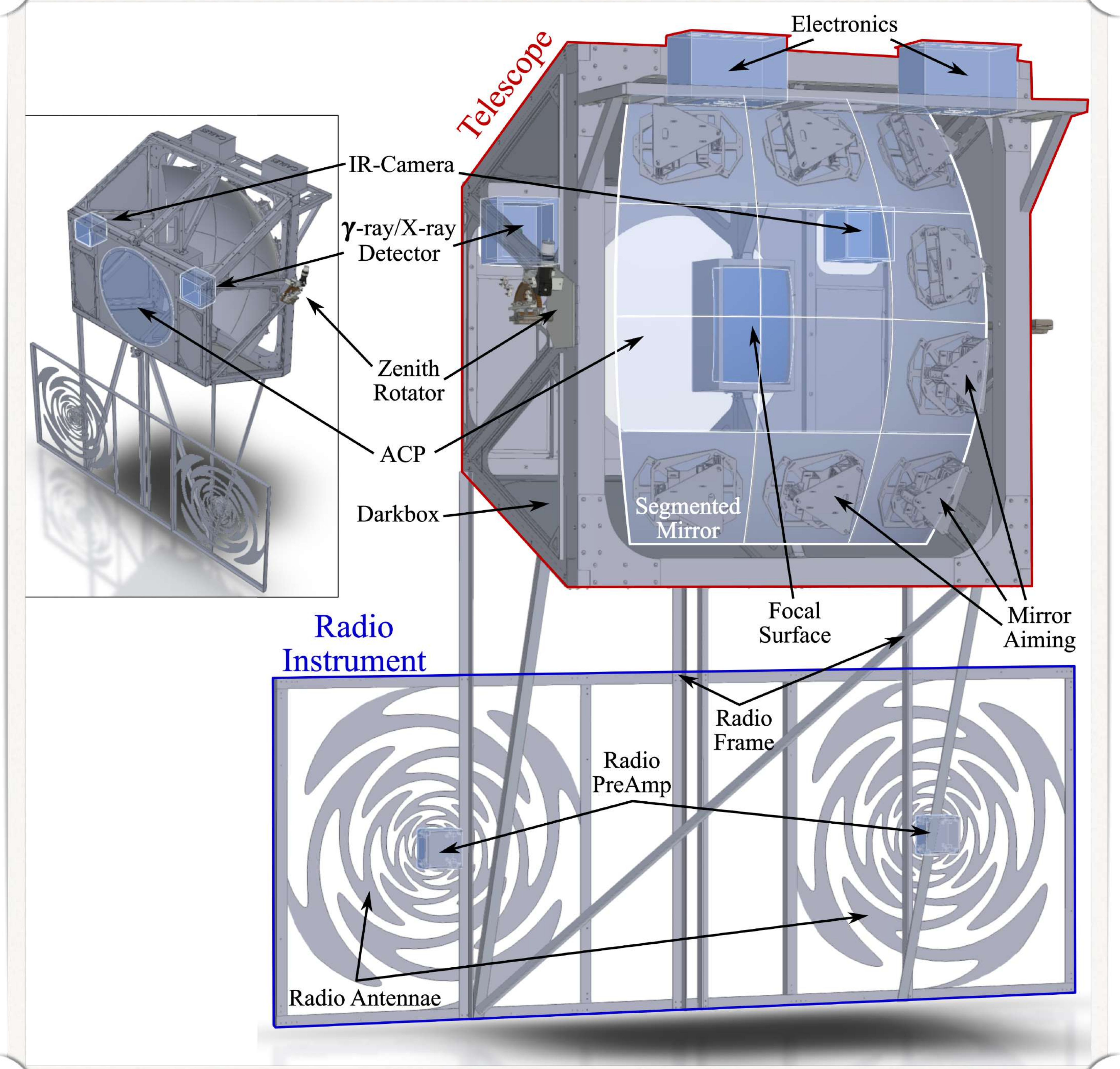
Payload



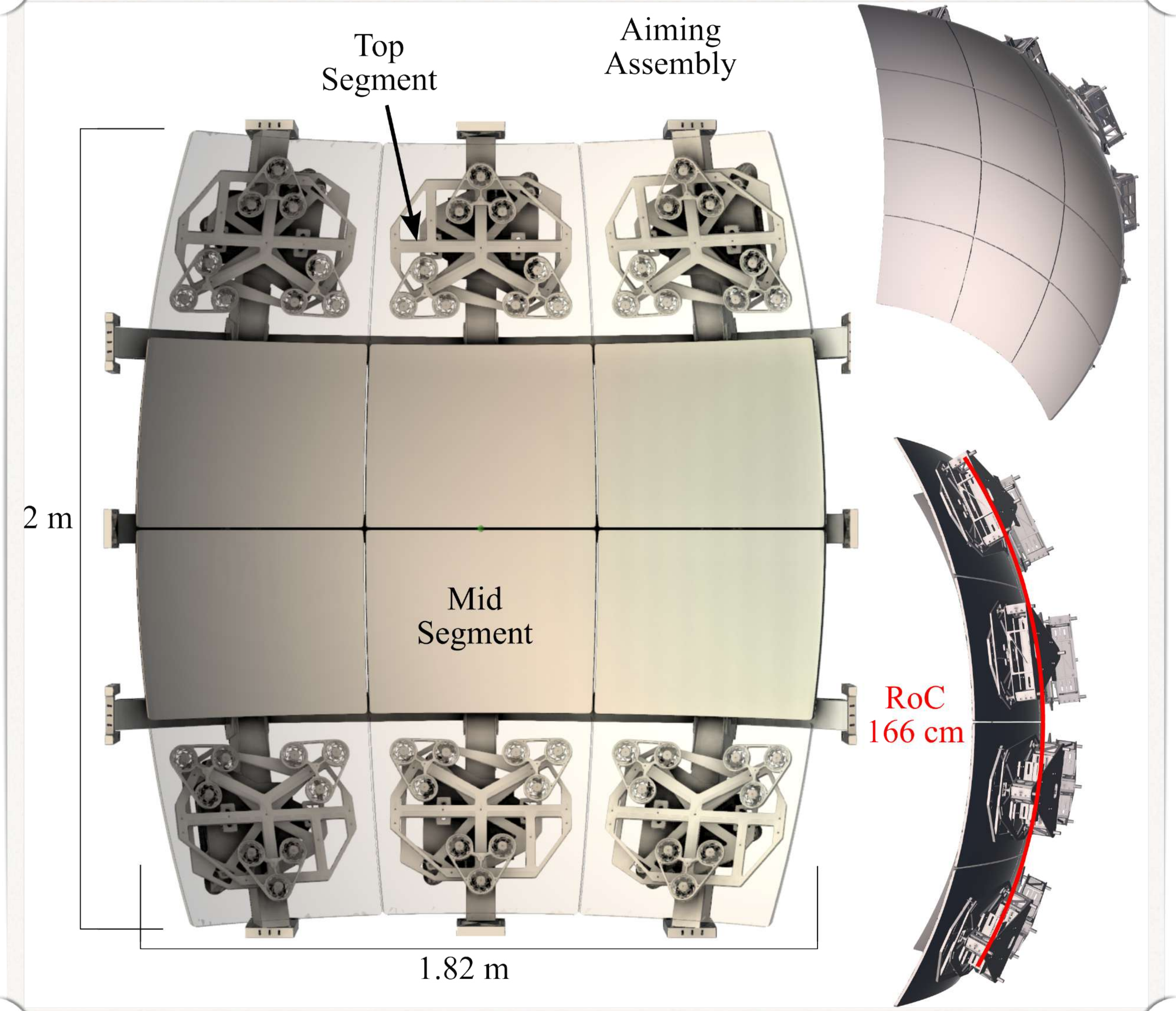
Payload Scaled

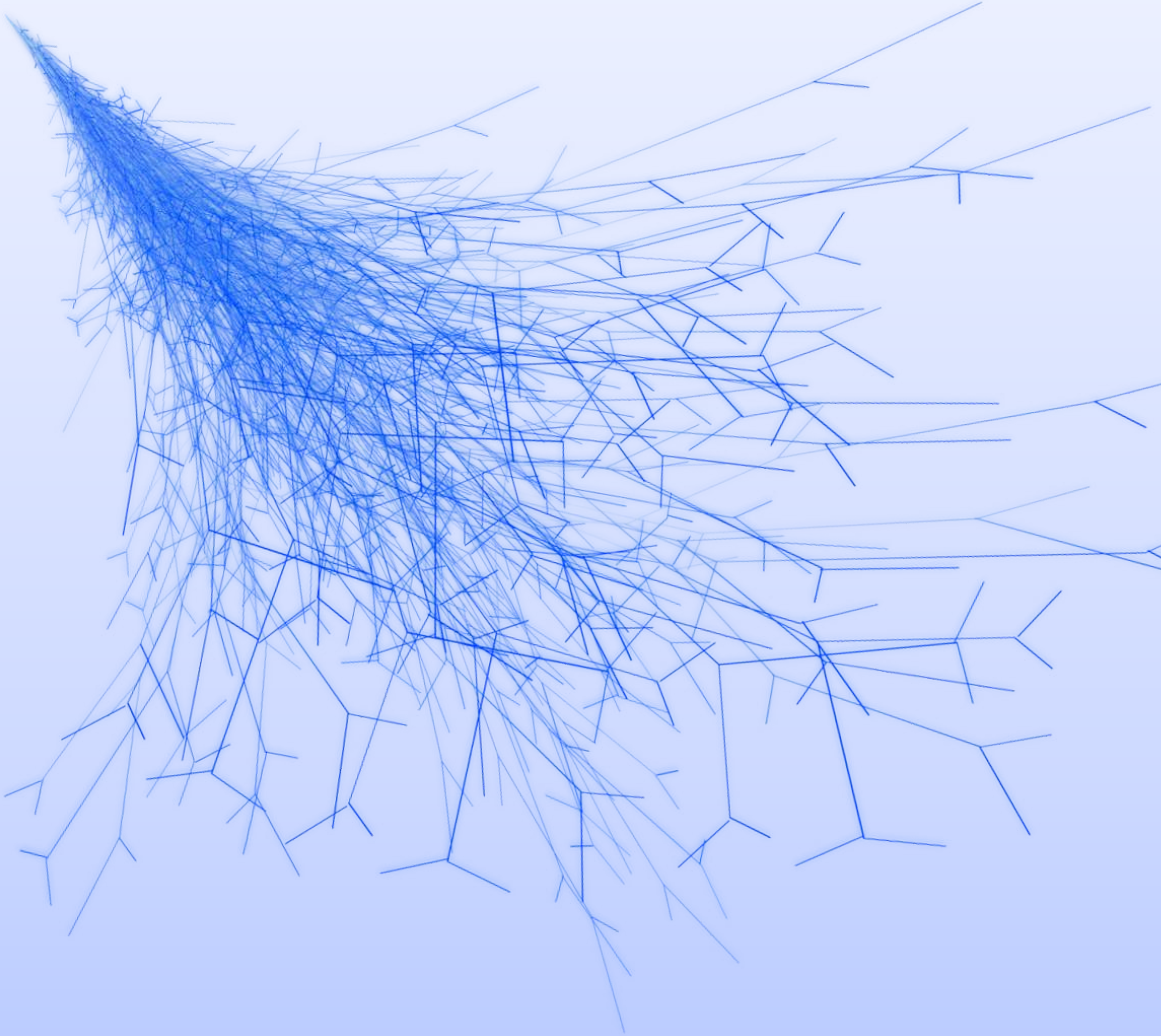


PBR Telescope



Primary Mirror Assembly



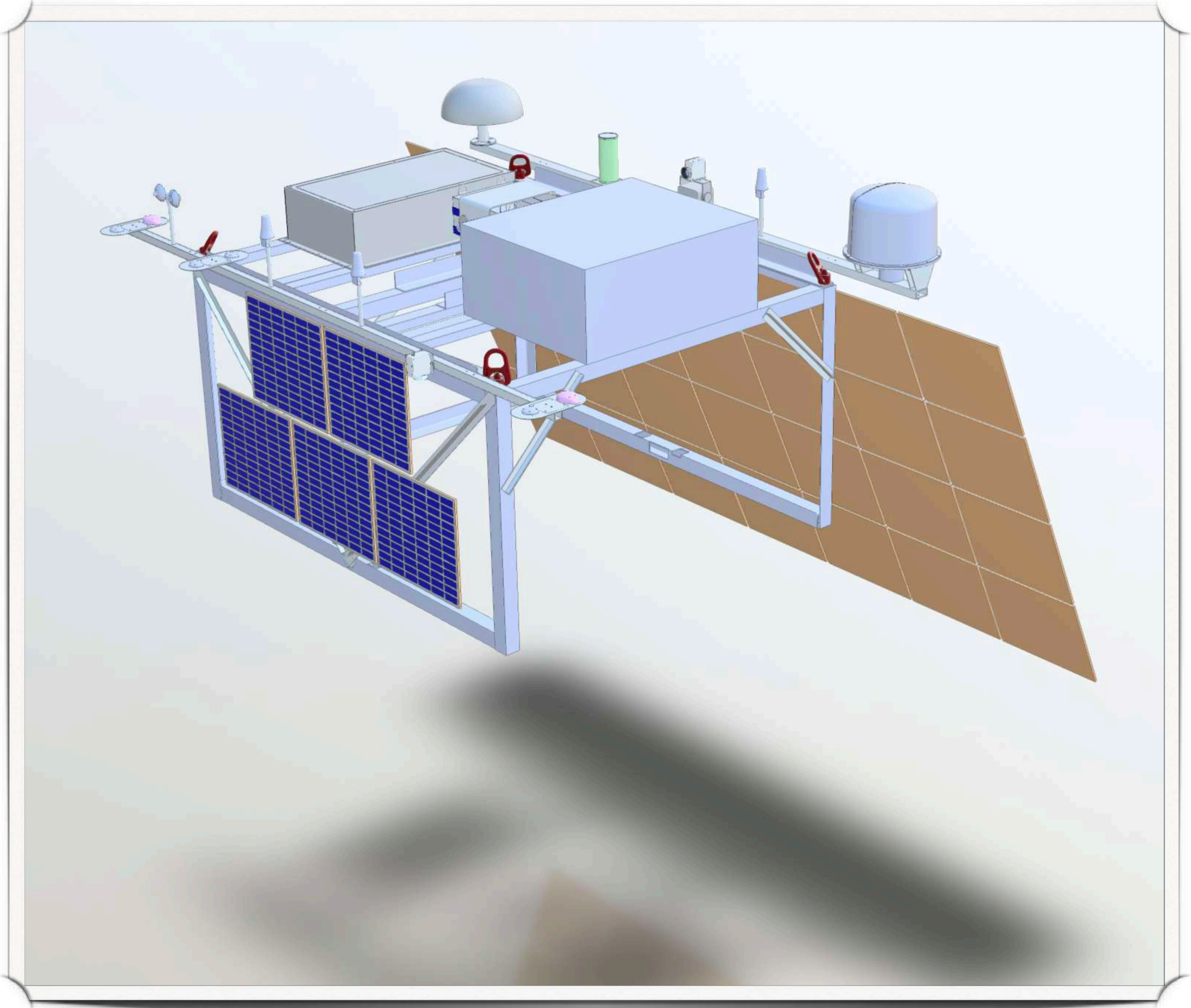


Mechanical Design Status

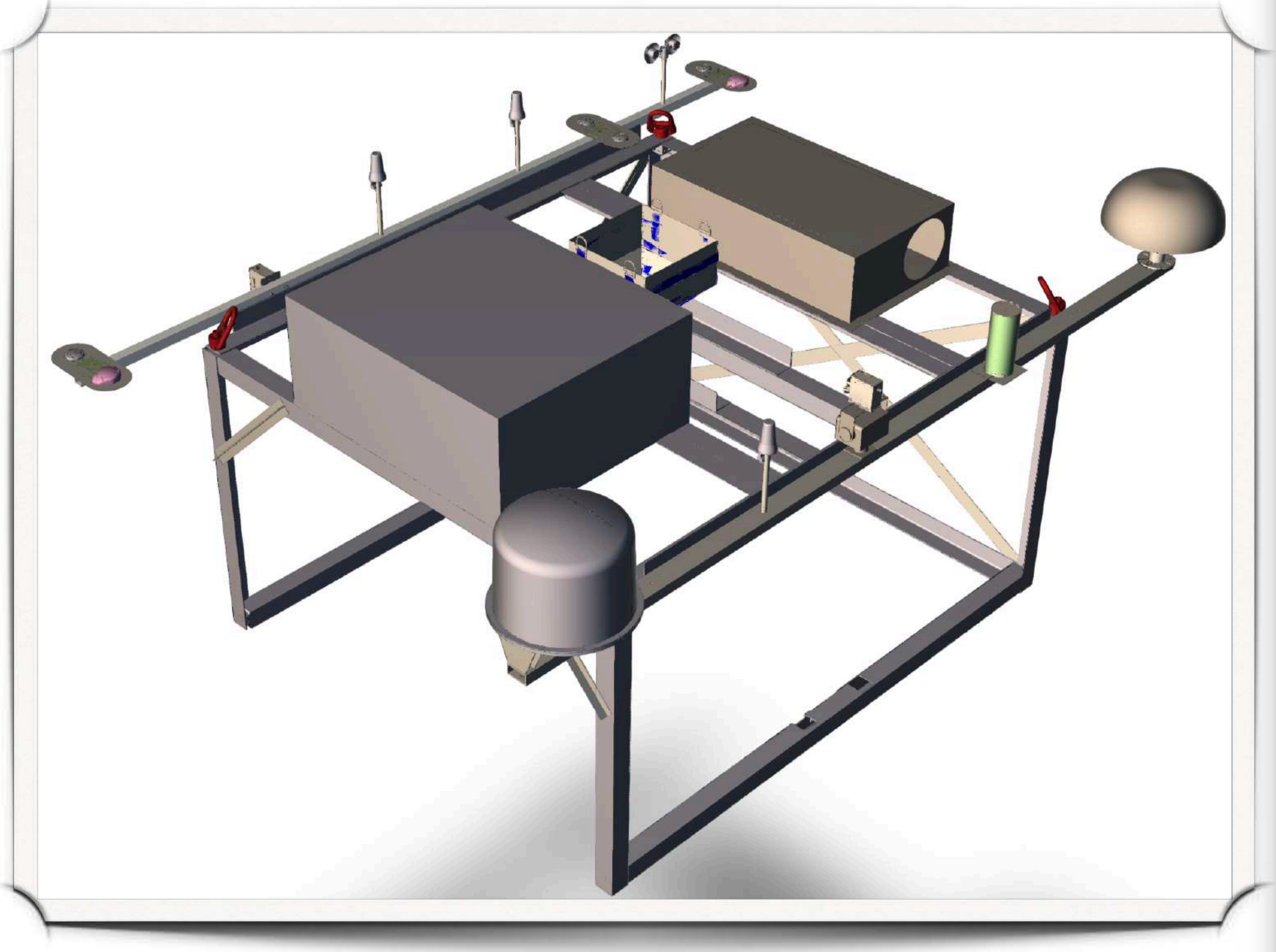
- Gondola
- Telescope
- Mirror Assembly
- Radio Frame and Mast
- Payload

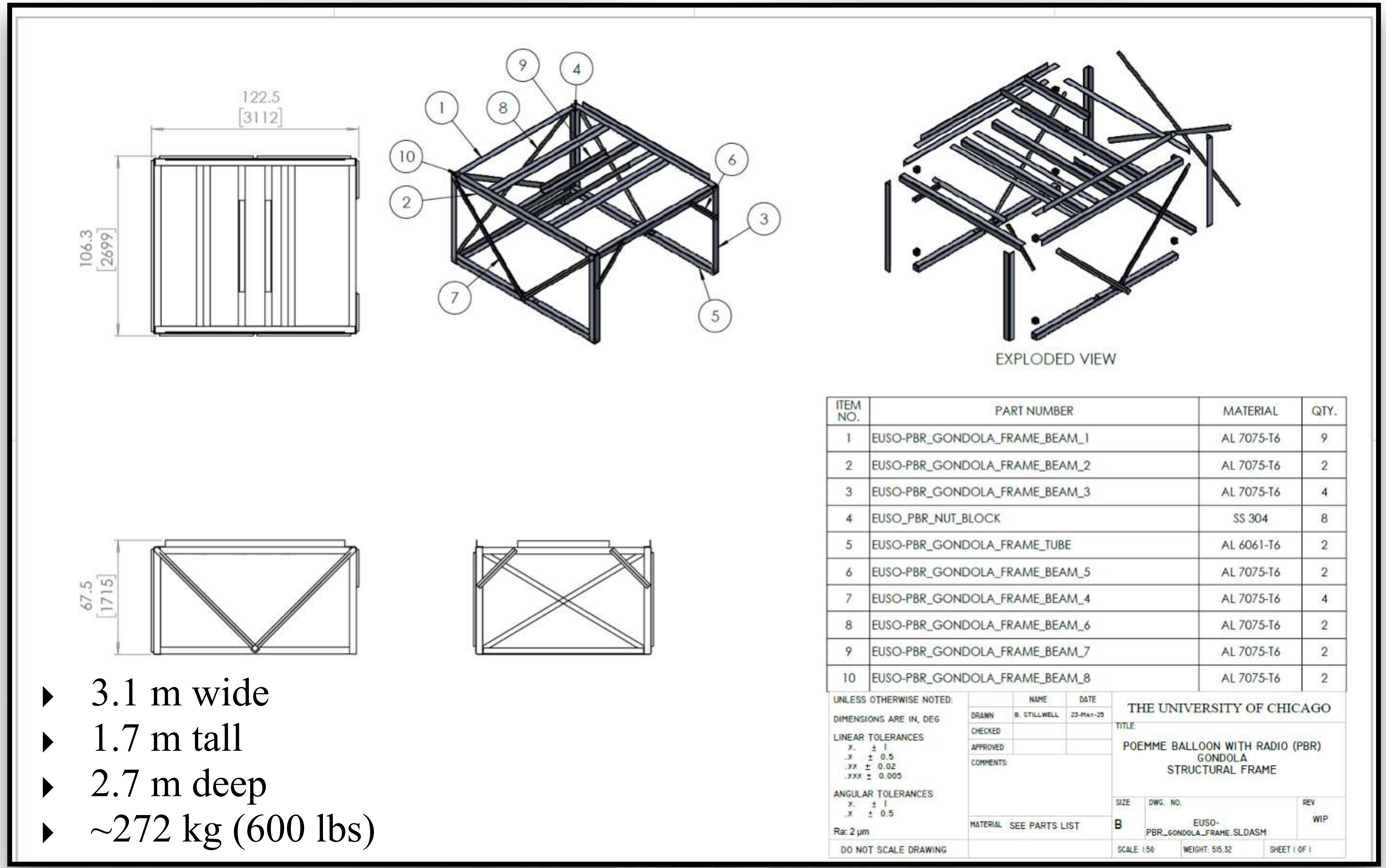
PBR Gondola

Engineer: Ben Stillwell
Univerisity of Chicago



PBR Gondola



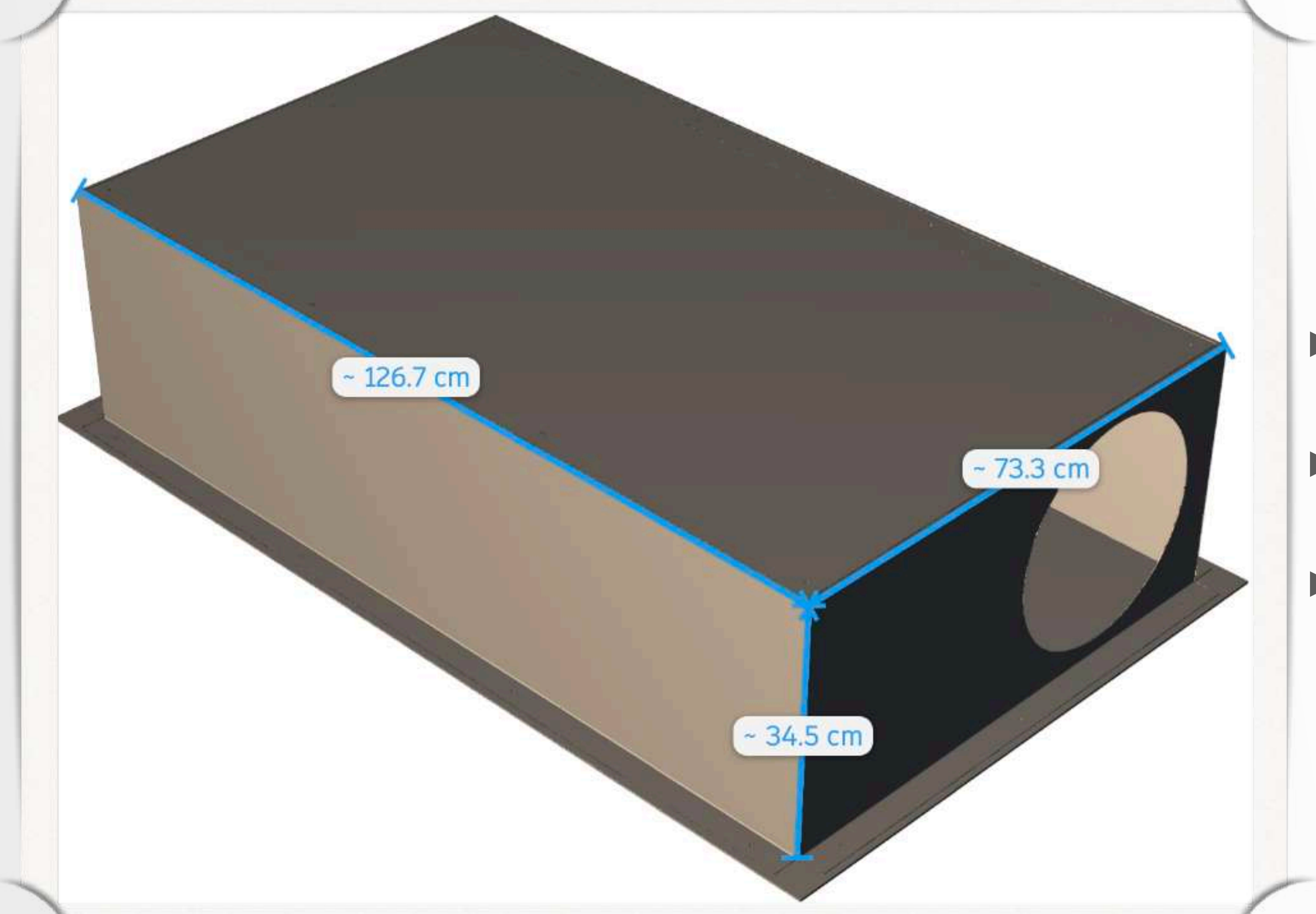


ITEM NO.	PART NUMBER	MATERIAL	QTY.
1	EUSO-PBR_GONDOLA_FRAME_BEAM_1	AL 7075-T6	9
2	EUSO-PBR_GONDOLA_FRAME_BEAM_2	AL 7075-T6	2
3	EUSO-PBR_GONDOLA_FRAME_BEAM_3	AL 7075-T6	4
4	EUSO_PBR_NUT_BLOCK	SS 304	8
5	EUSO-PBR_GONDOLA_FRAME_TUBE	AL 6061-T6	2
6	EUSO-PBR_GONDOLA_FRAME_BEAM_5	AL 7075-T6	2
7	EUSO-PBR_GONDOLA_FRAME_BEAM_4	AL 7075-T6	4
8	EUSO-PBR_GONDOLA_FRAME_BEAM_6	AL 7075-T6	2
9	EUSO-PBR_GONDOLA_FRAME_BEAM_7	AL 7075-T6	2
10	EUSO-PBR_GONDOLA_FRAME_BEAM_8	AL 7075-T6	2

- 3.1 m wide
- 1.7 m tall
- 2.7 m deep
- ~272 kg (600 lbs)

PBR Deck Components

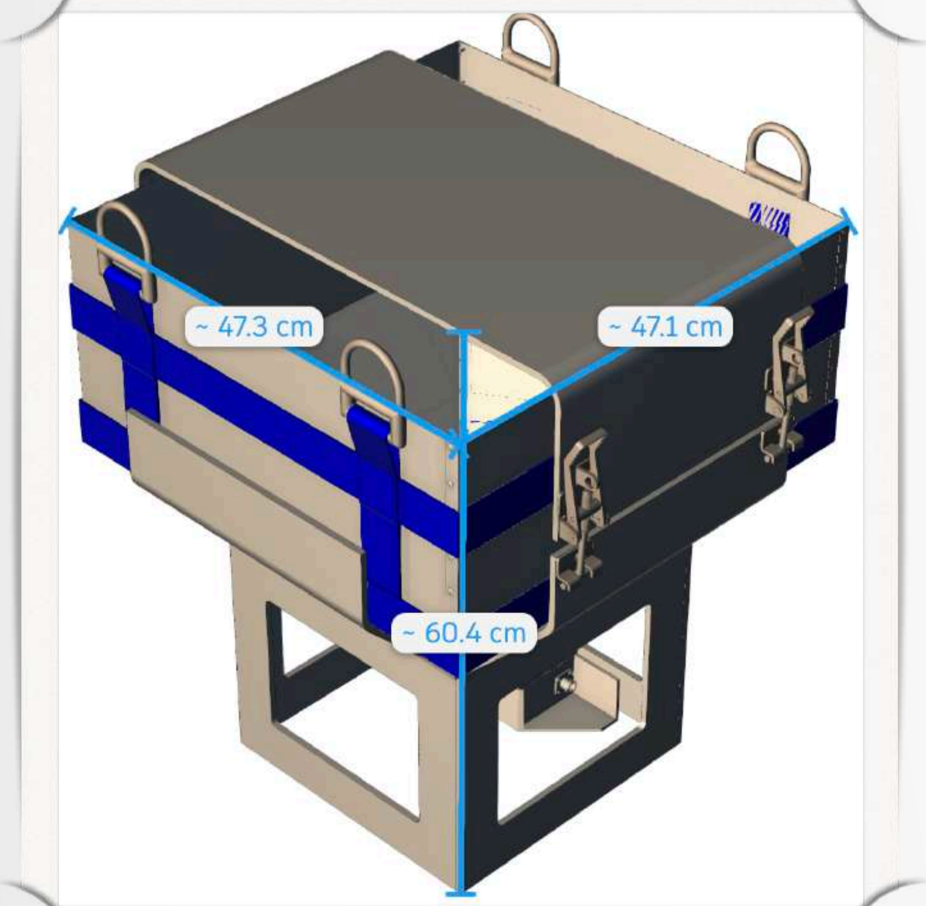
Battery Box



- Holds 7 Batteries
- 2 Charge Controllers
- PDU

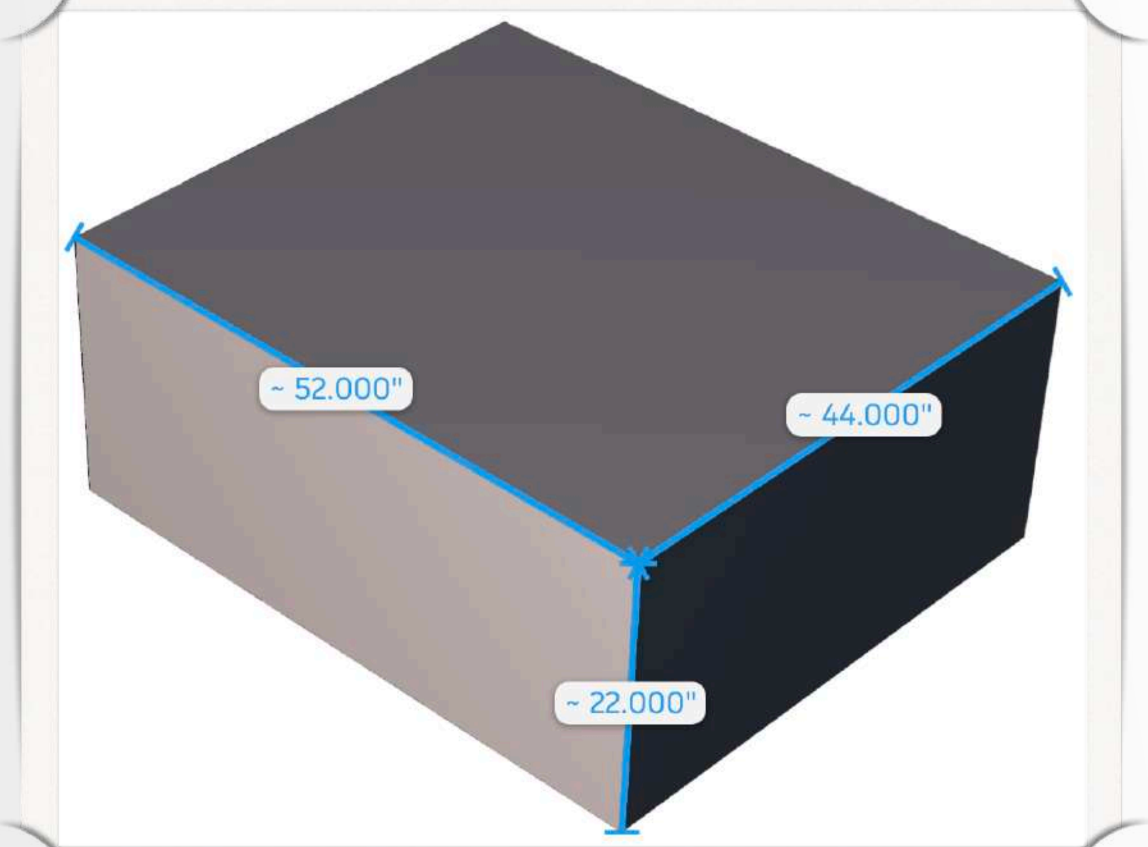
See Julia’s Talk

Ballast Hopper



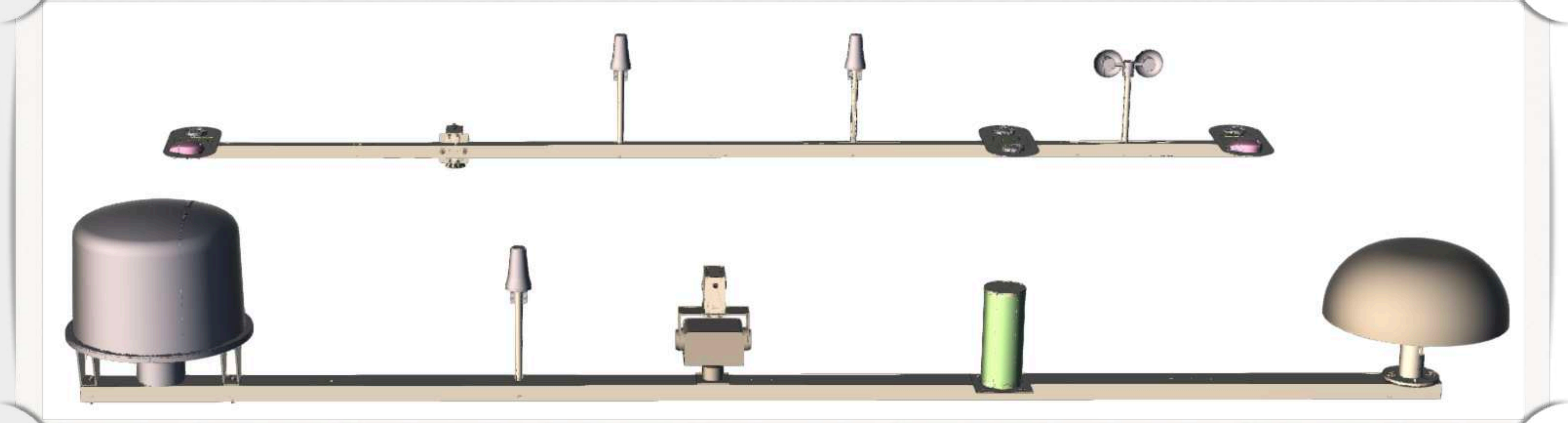
- Only 1 Hopper on PBR
- 600 lbs Balast Max
- Mounted at CoM
- Weight metered from below

SIP (Support Instrumentation Package)



- TRDSS
- Iridium
- Starlink
- Science Stack
- Insulation needs to be determined

Antenna Booms



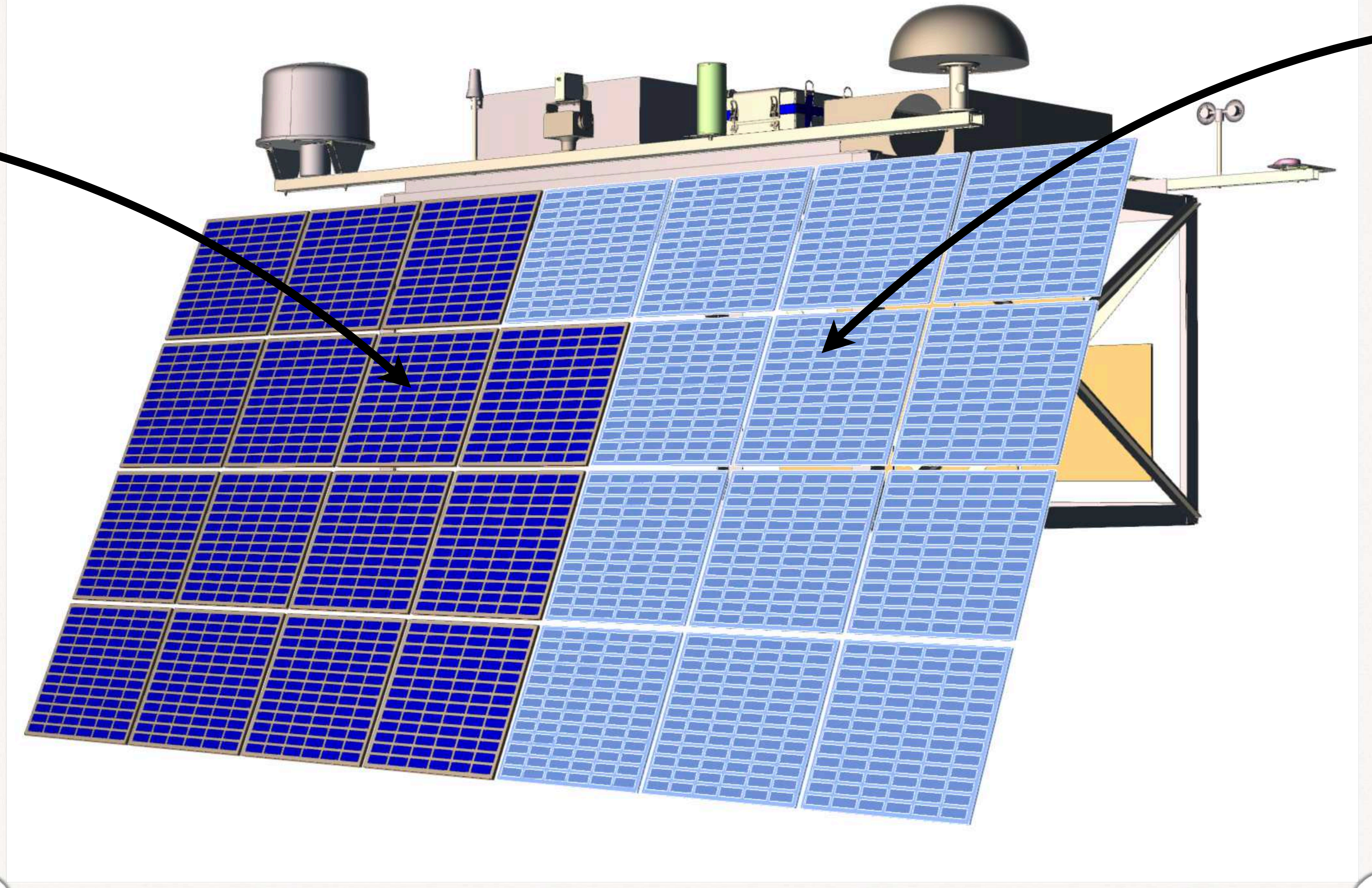
- Currently a carbon copy of SPB2

PBR Main Solar Array

➢ Single side (no skirt) confirmed as rotator is considered qualified

PBR Panels

➢ 15 panels in total



CSBF Panels:

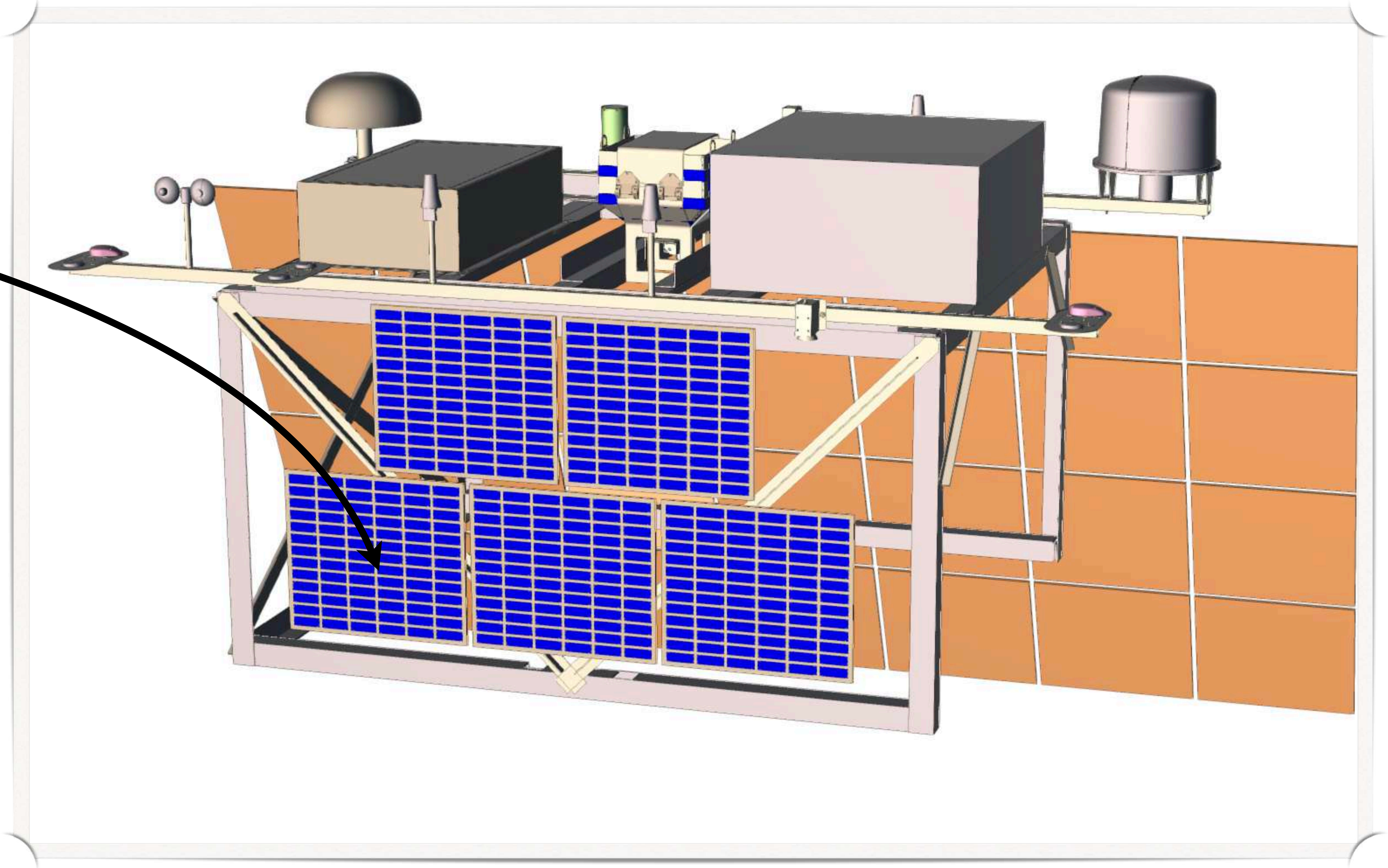
➢ 13 panels in total as extra, are needed for Starlink

See Julia's talk for details on power system

PBR Backup CSBF Solar Array

Backup CSBF Solar Array

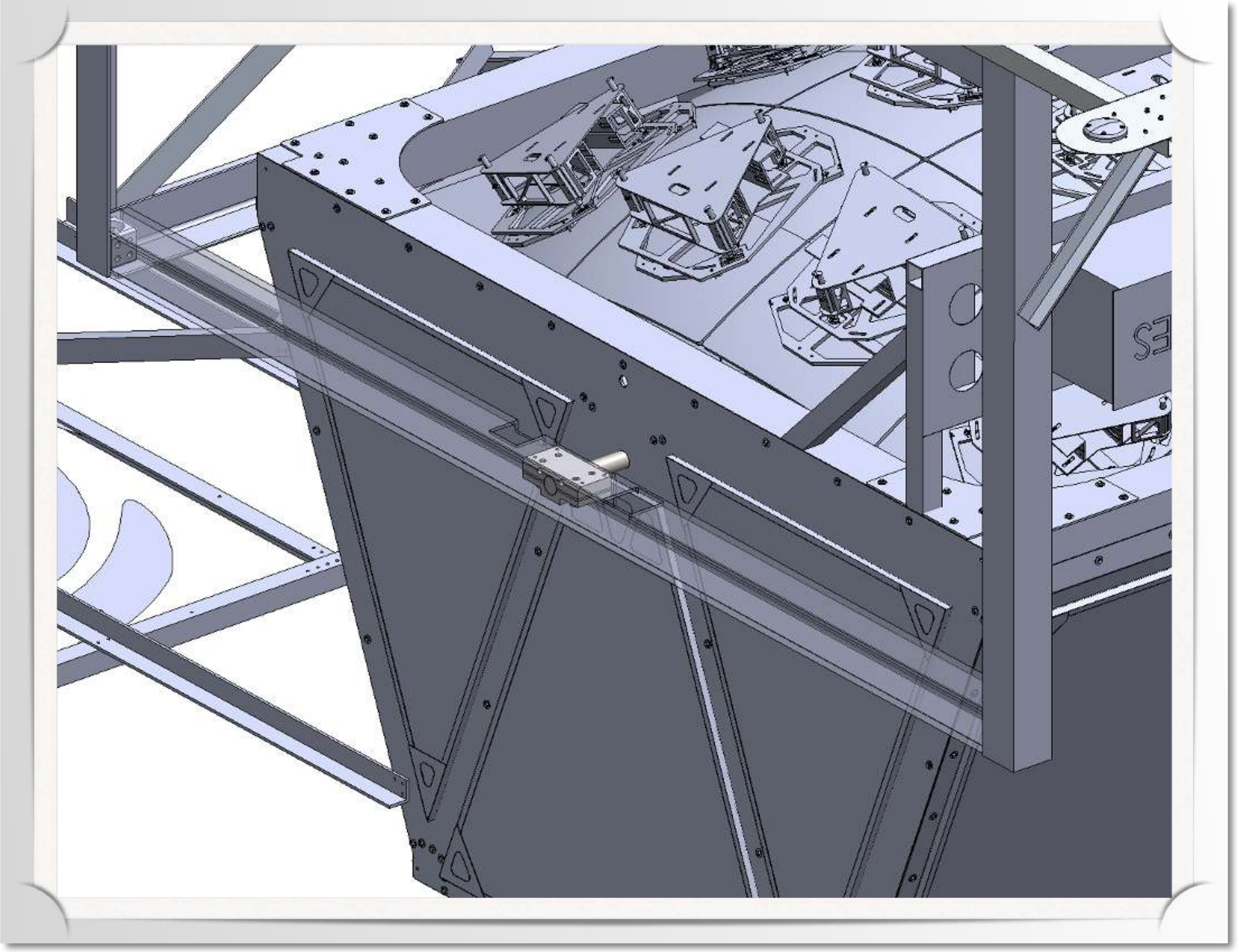
- ➢ 5 panels in total
- ➢ For control of the Payload if the rotator fails
- ➢ If needed balloon mission terminates

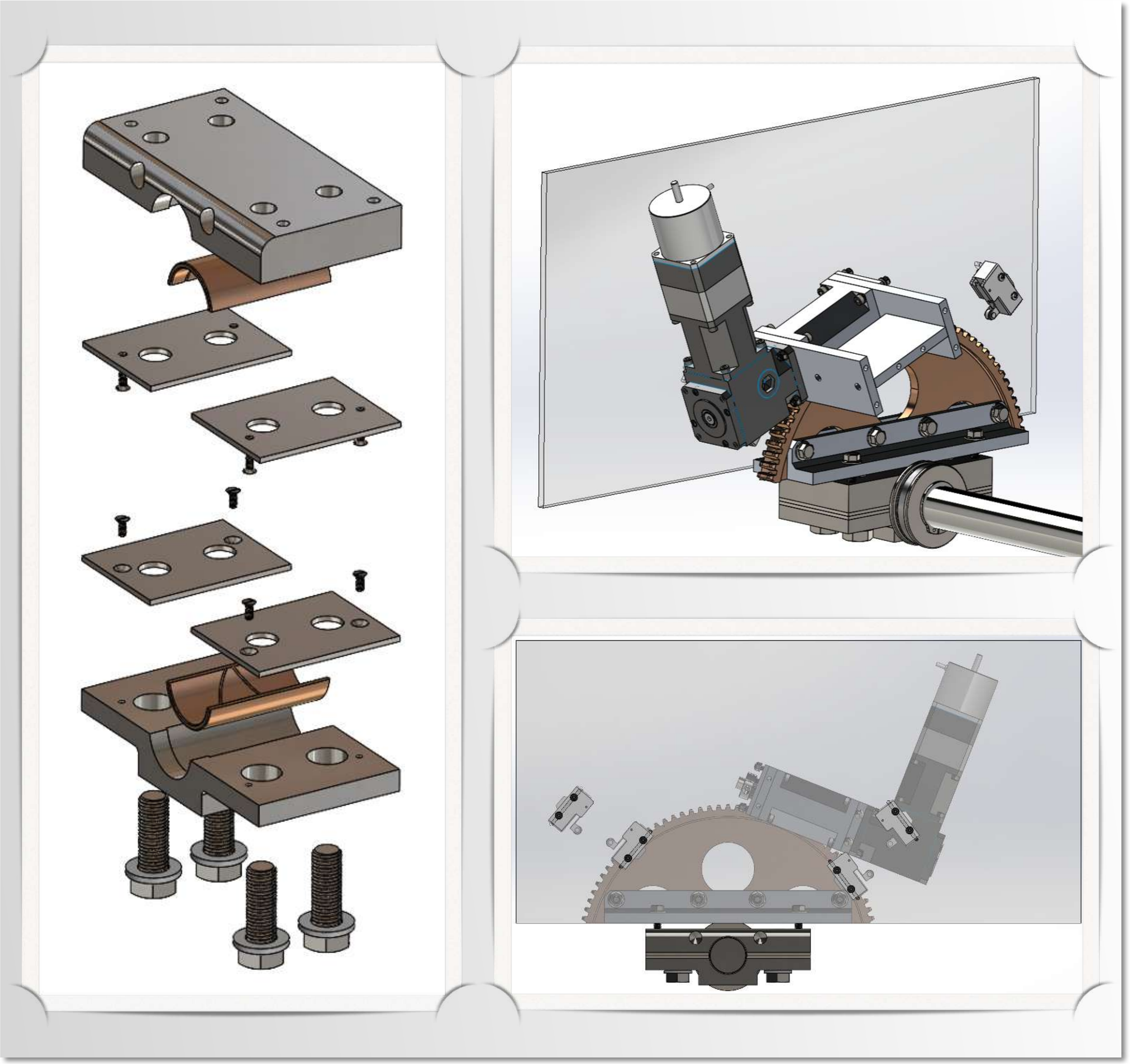


See Julia's talk for details on power system

Rotator

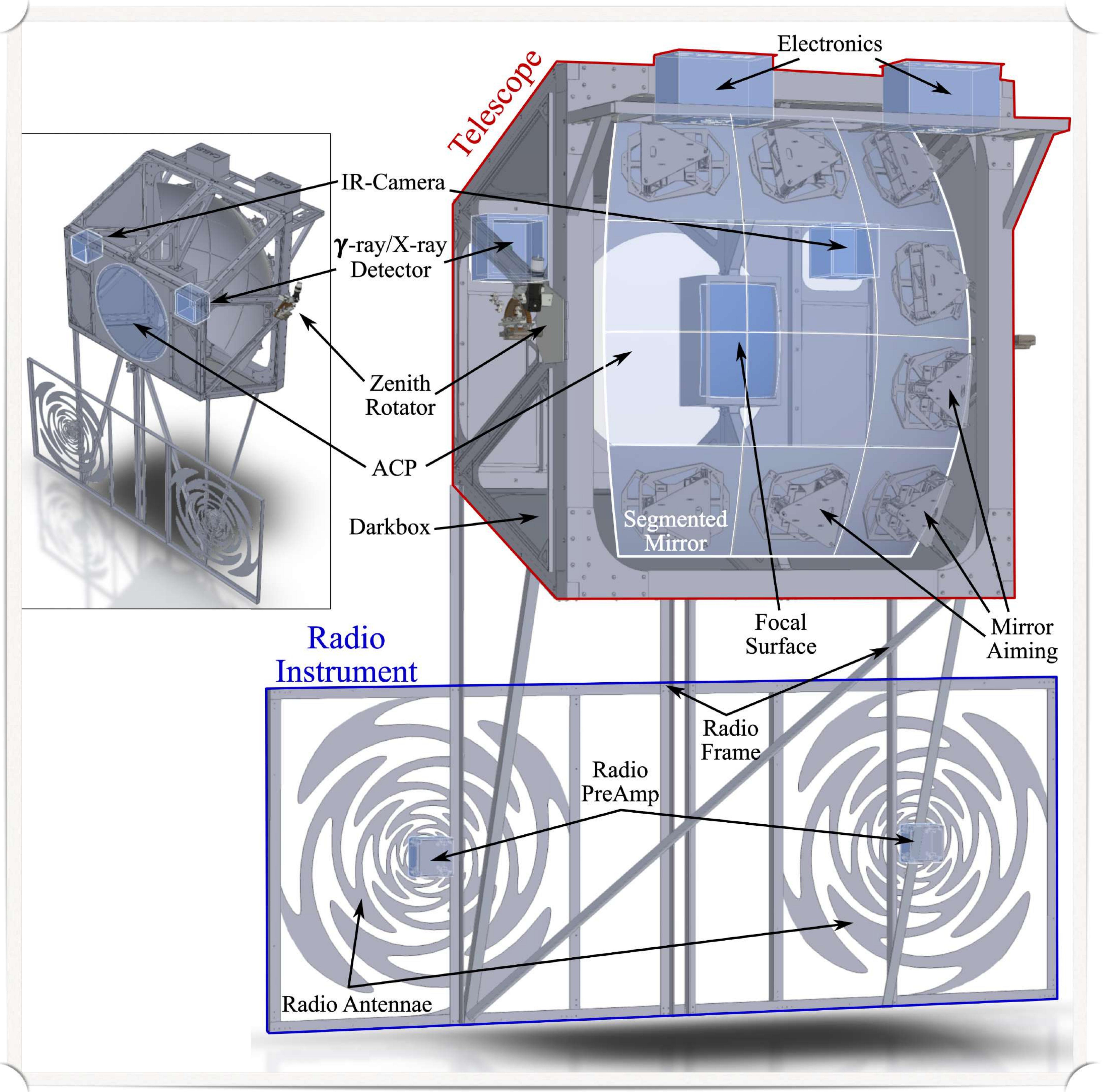
Good progress is being made





See Lawrence's Talk for Details

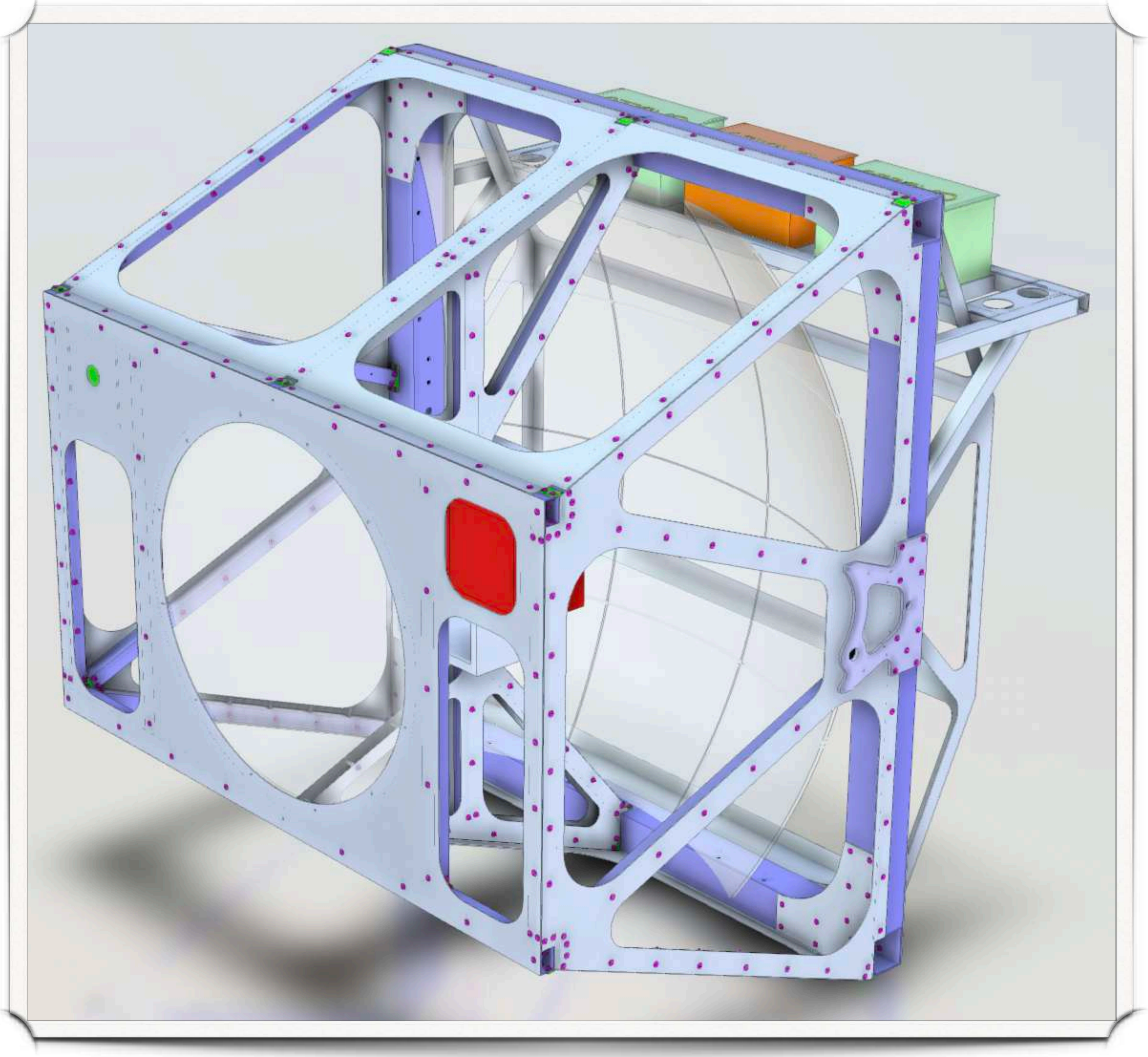
PBR Telescope



Telescope Structure and Darkbox

Engineer: Paul Degarate
Halley Tech Engineering

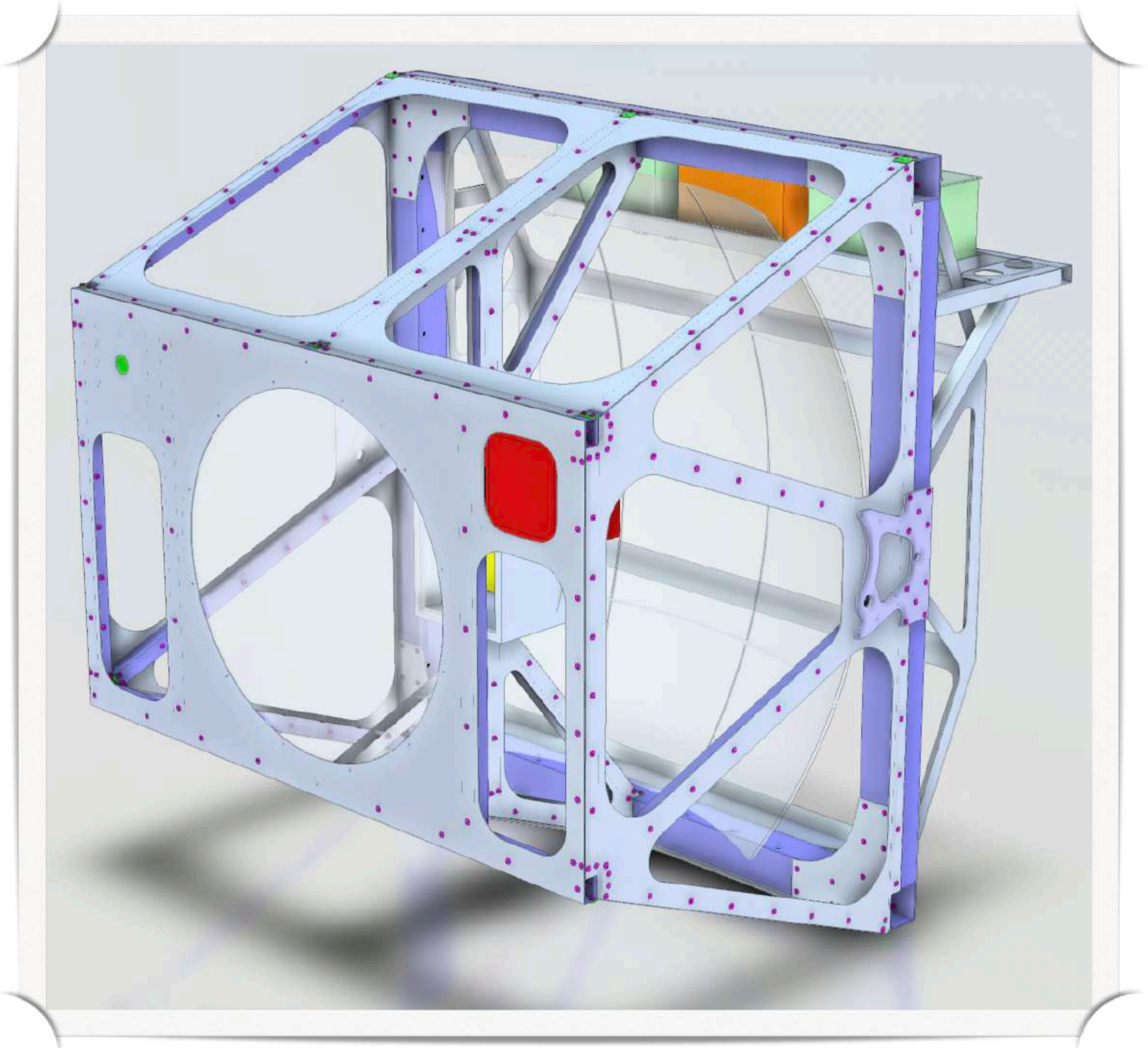
Engineer: William Yitz Finch
Colorado School of Mines

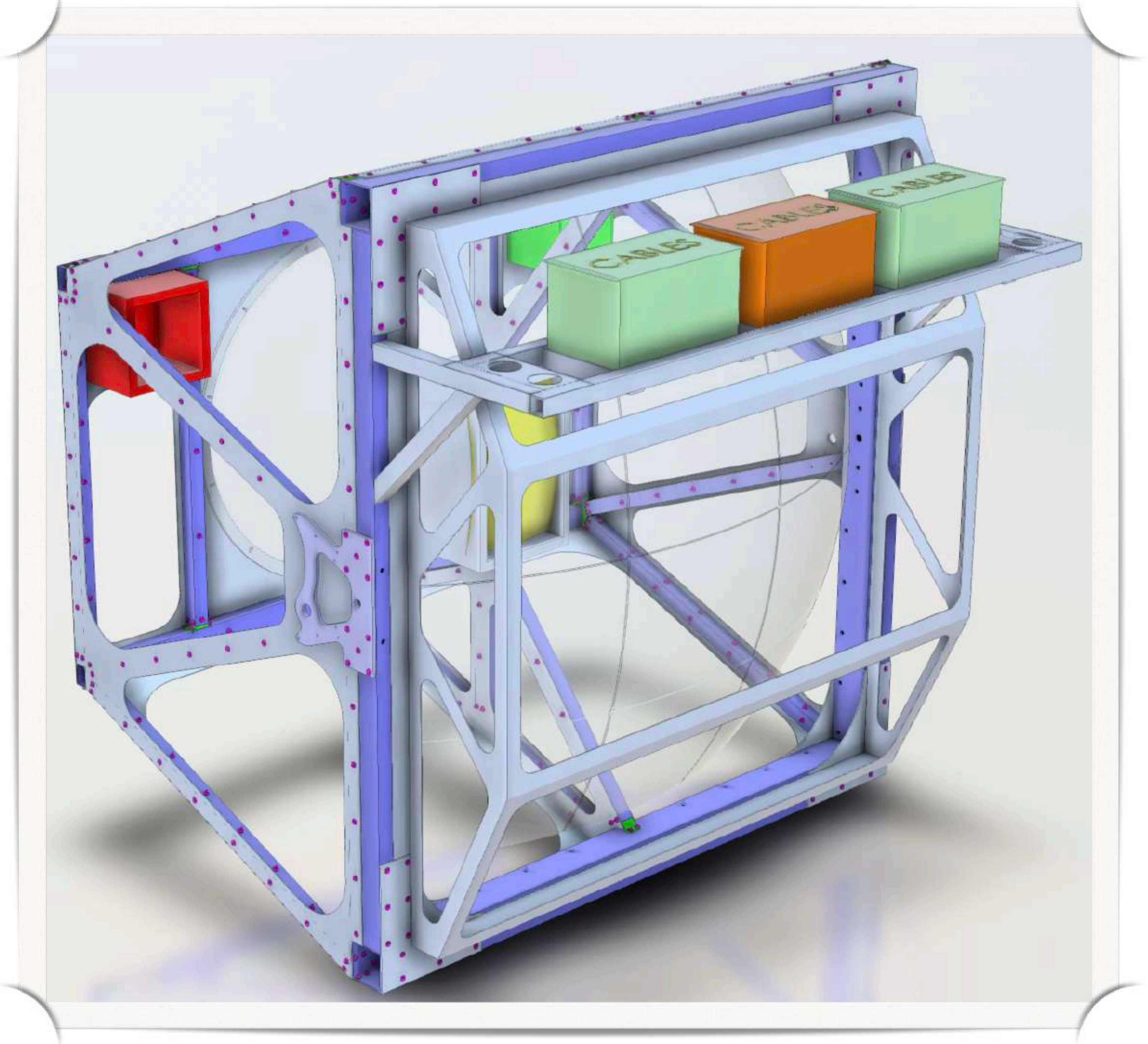


Telescope Frame

Telescope Structural comlete!

- ➢ Full frame in place with Fasteners, gussets, and major interfaces.
- ➢ Feature complete with:
  - Movable Ekit shelf
  - Dark box paneling
  - Shutters
  - ACP mounting
- ➢ Optically, we are hitting Takky's prescription
- ➢ Still only have the large blocky stand in the camera shelf
  - With up-to-date designs of FC and CC mechanics, we can make the shelf
  - Planing for CC FC separately adjustable ± 2.5 cm toward / away from the mirror





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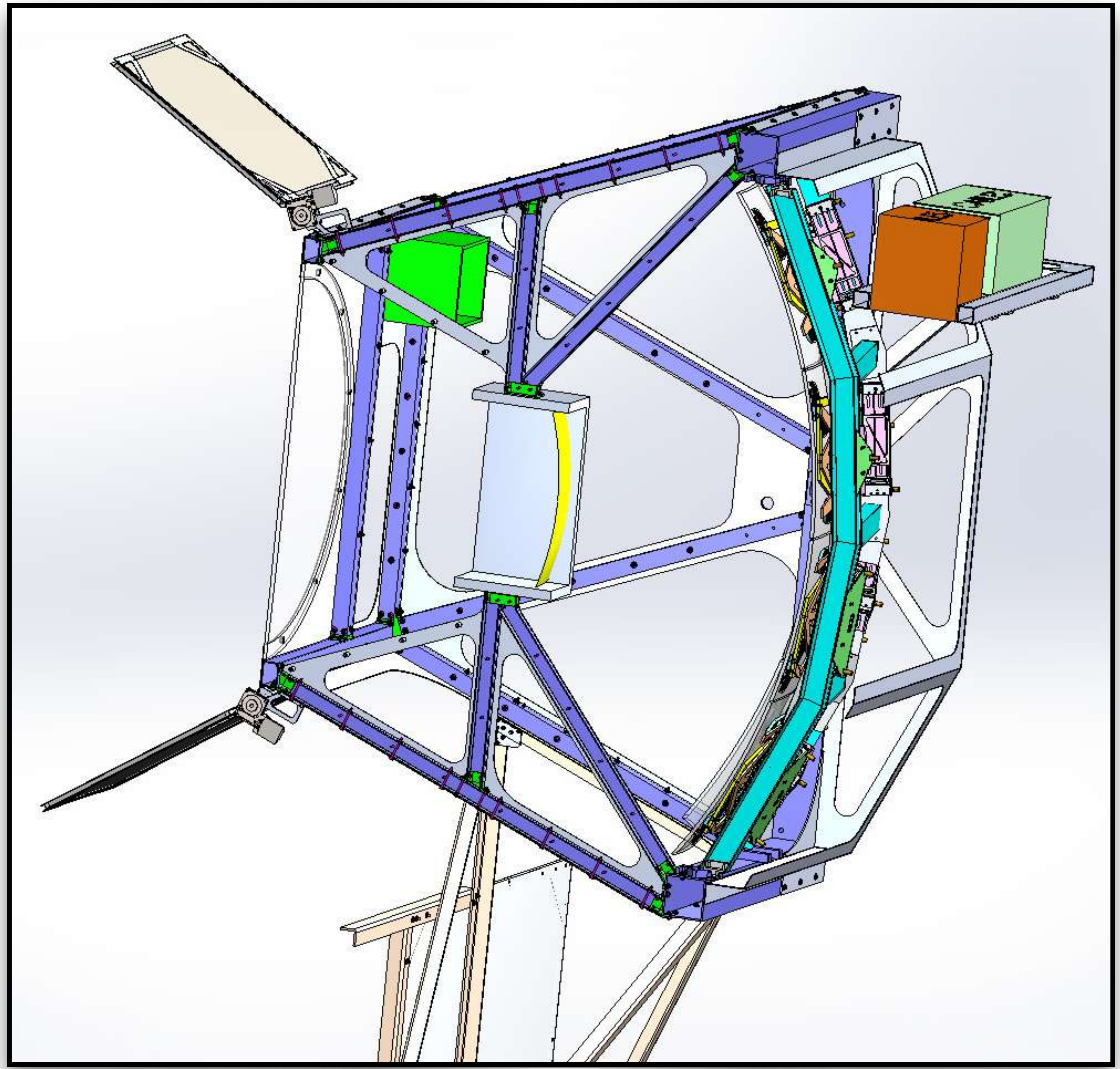
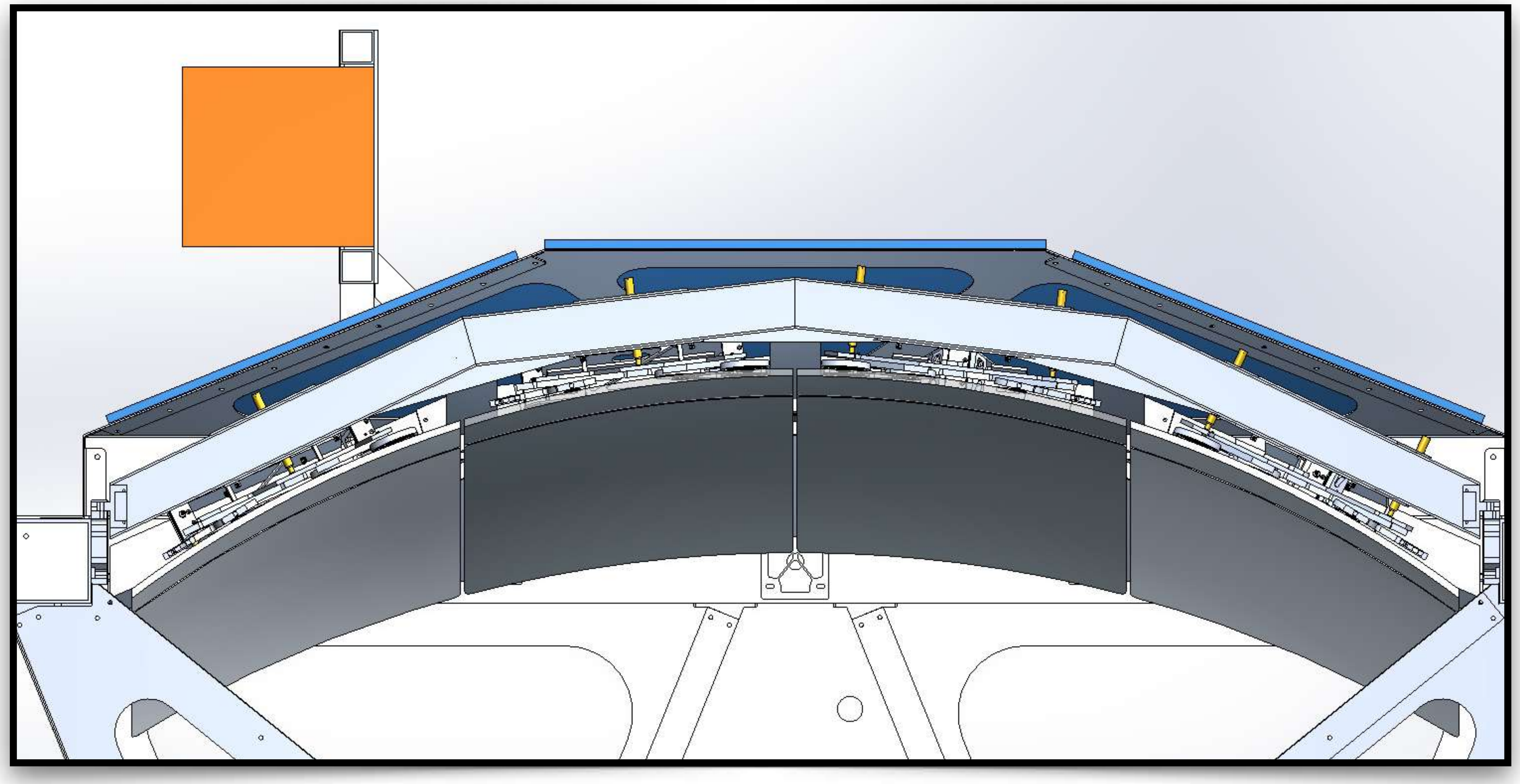
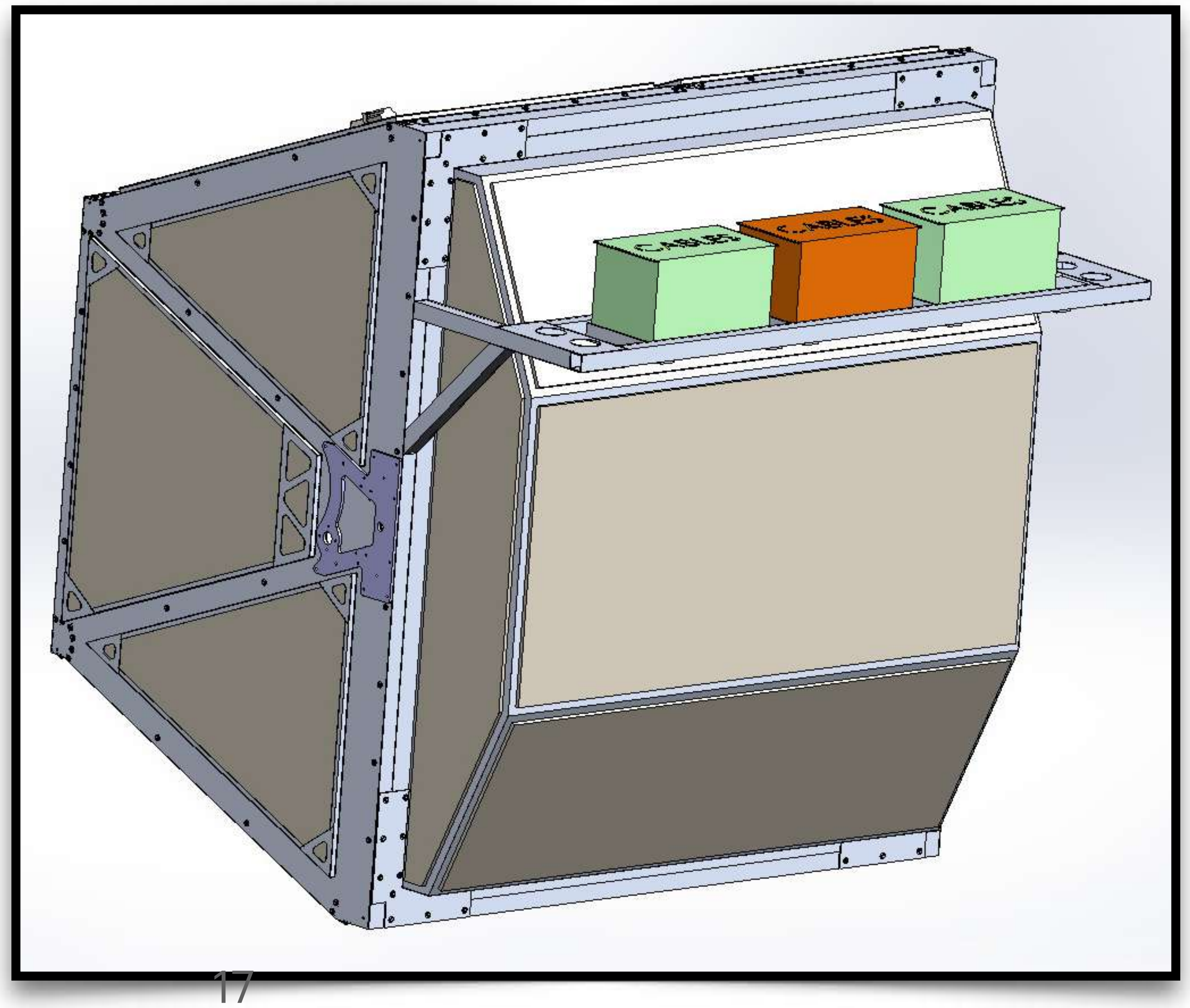


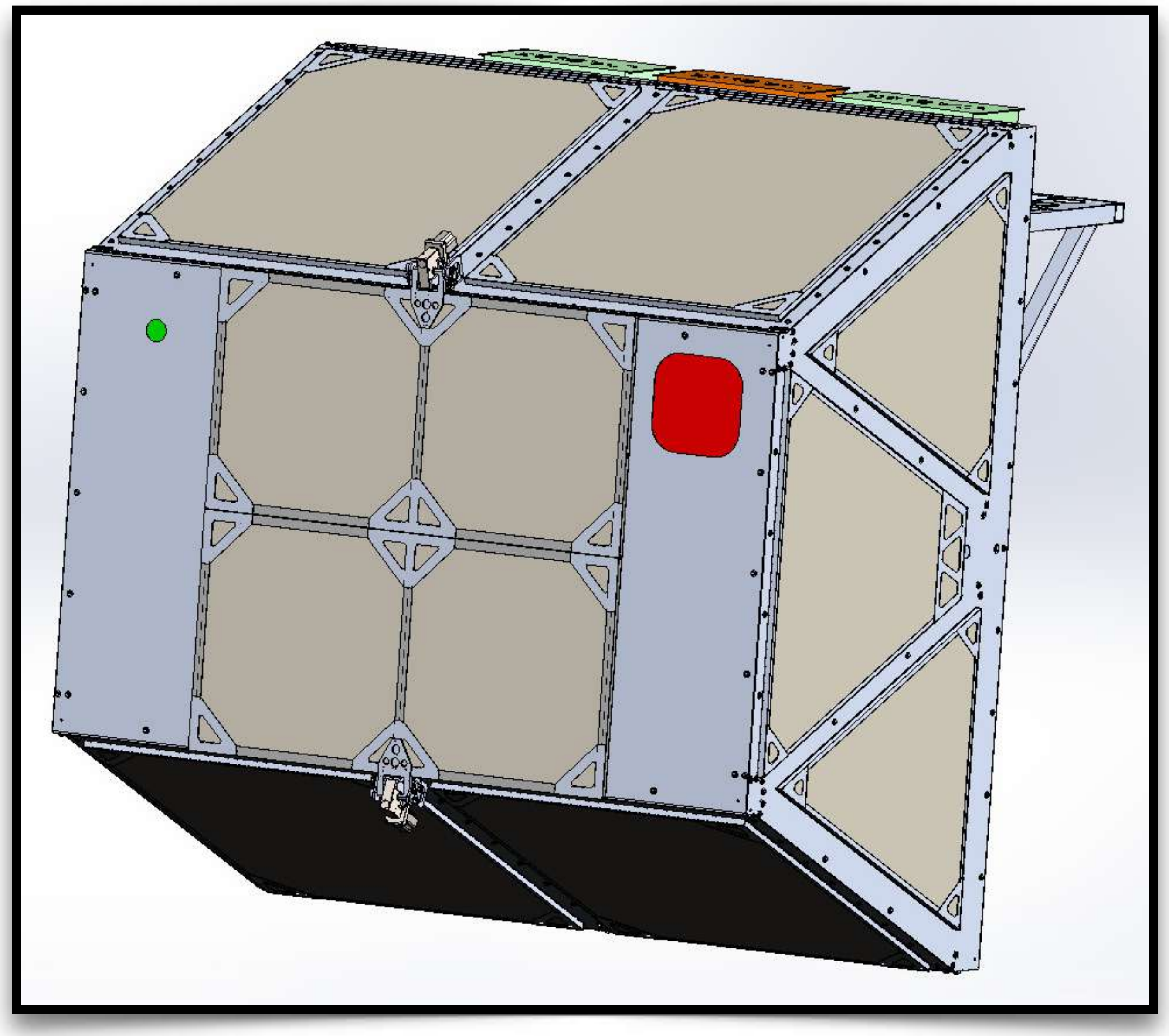
Telescope Darkbox



Conceptual Darkbox is finished.

- ➢ Paneled design slotting into aluminum bracing.
- ➢ Panels likely needing removal during integration are planned to use quick release bolts + regular bolts (installed for flight)
- ➢ The rear box is designed to maintain access to the mirror cells after the rear darkbox frame is installed by removing panels.





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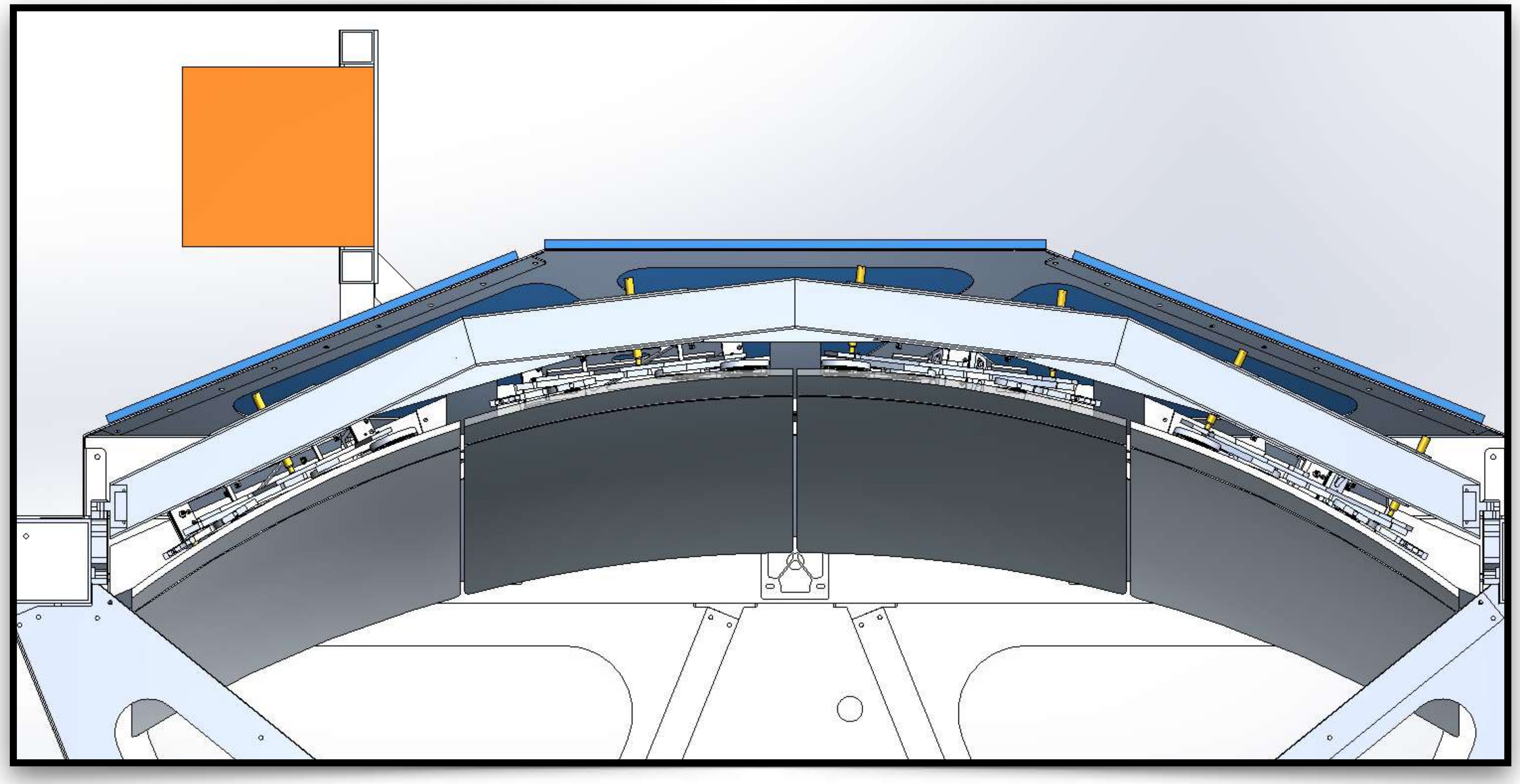

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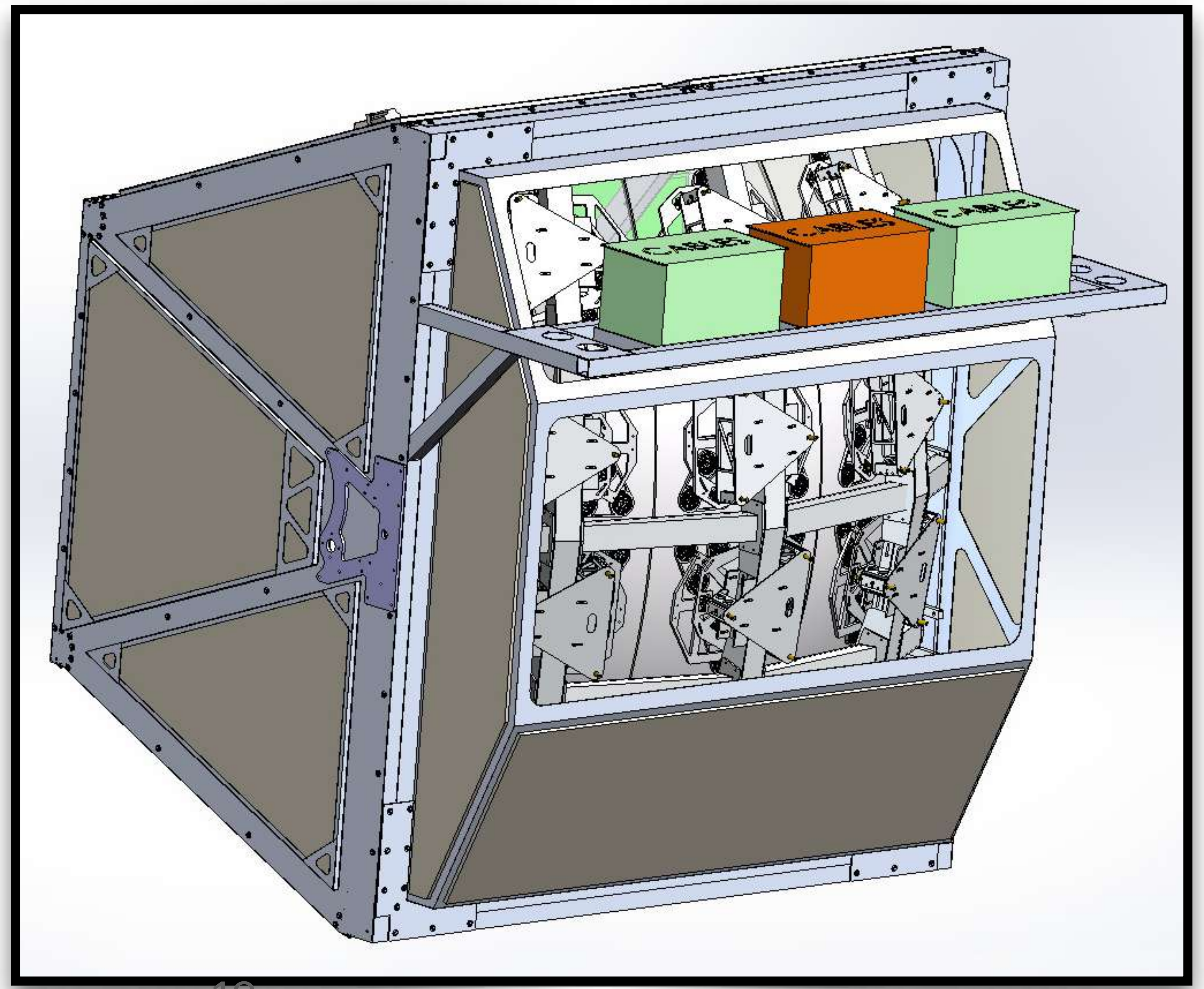
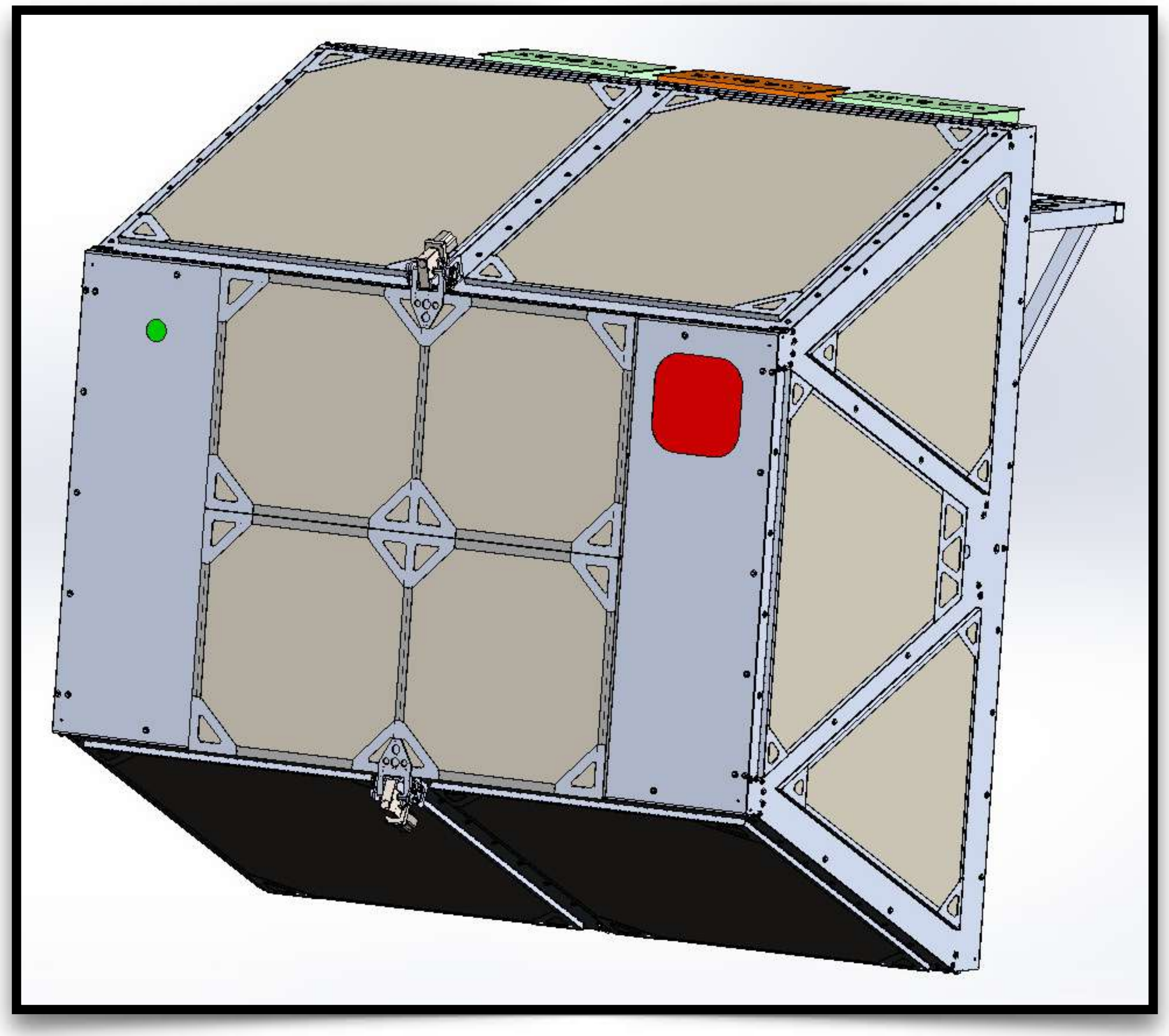
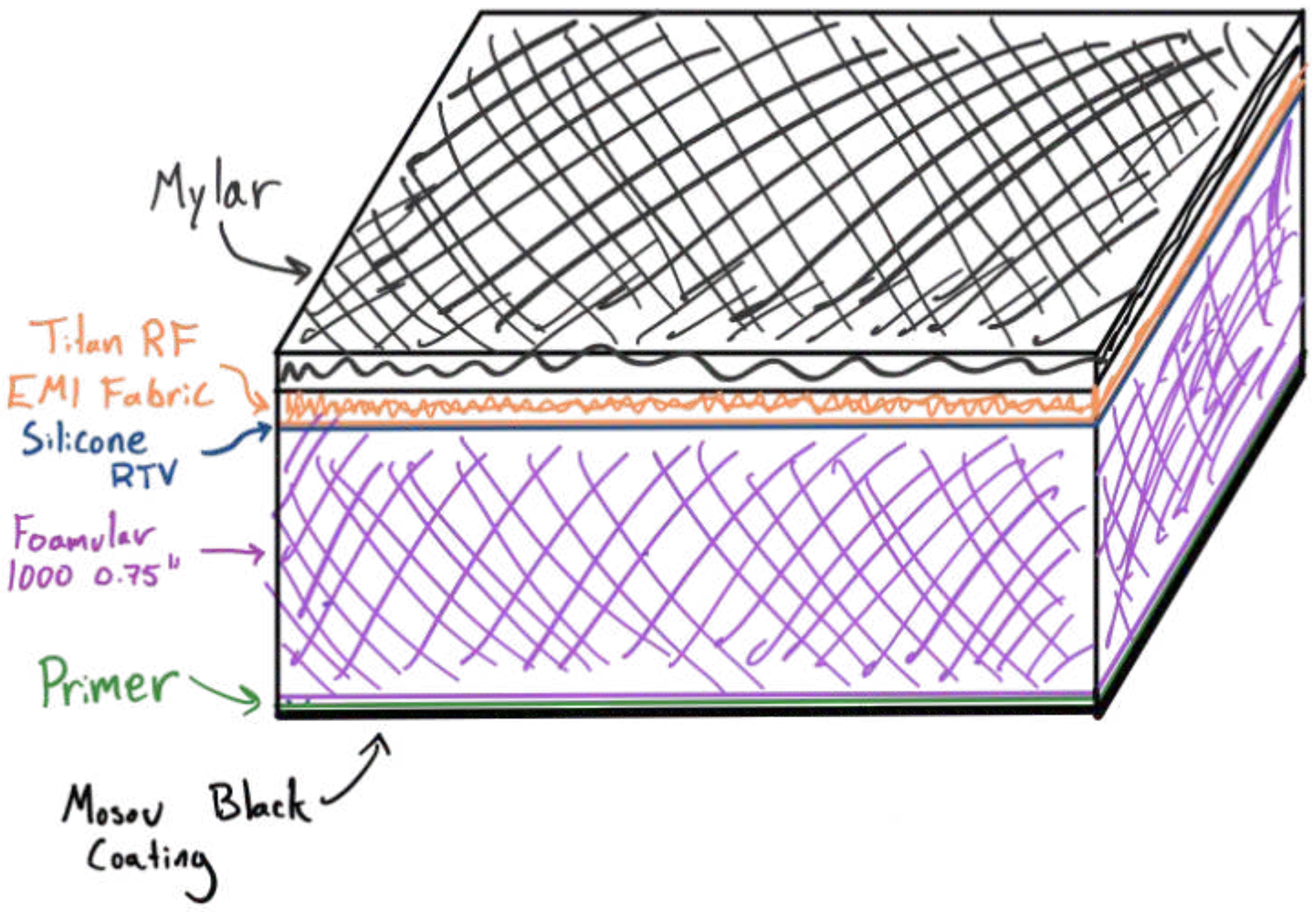
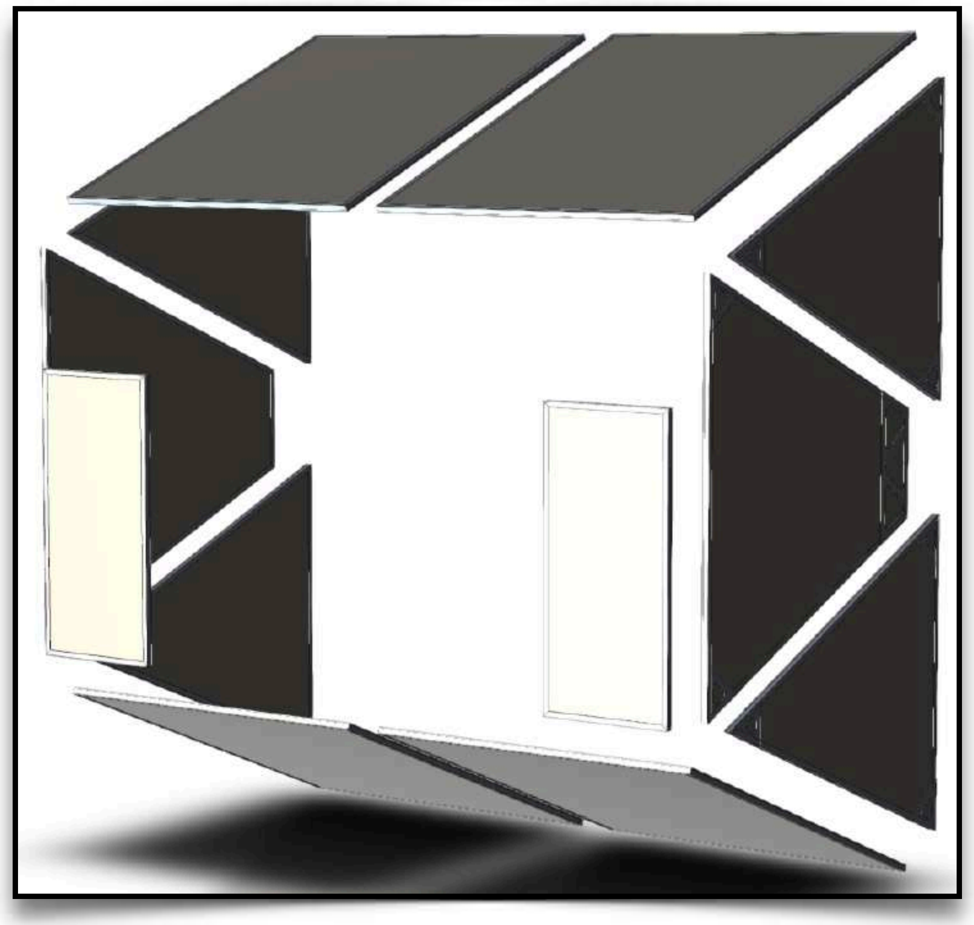




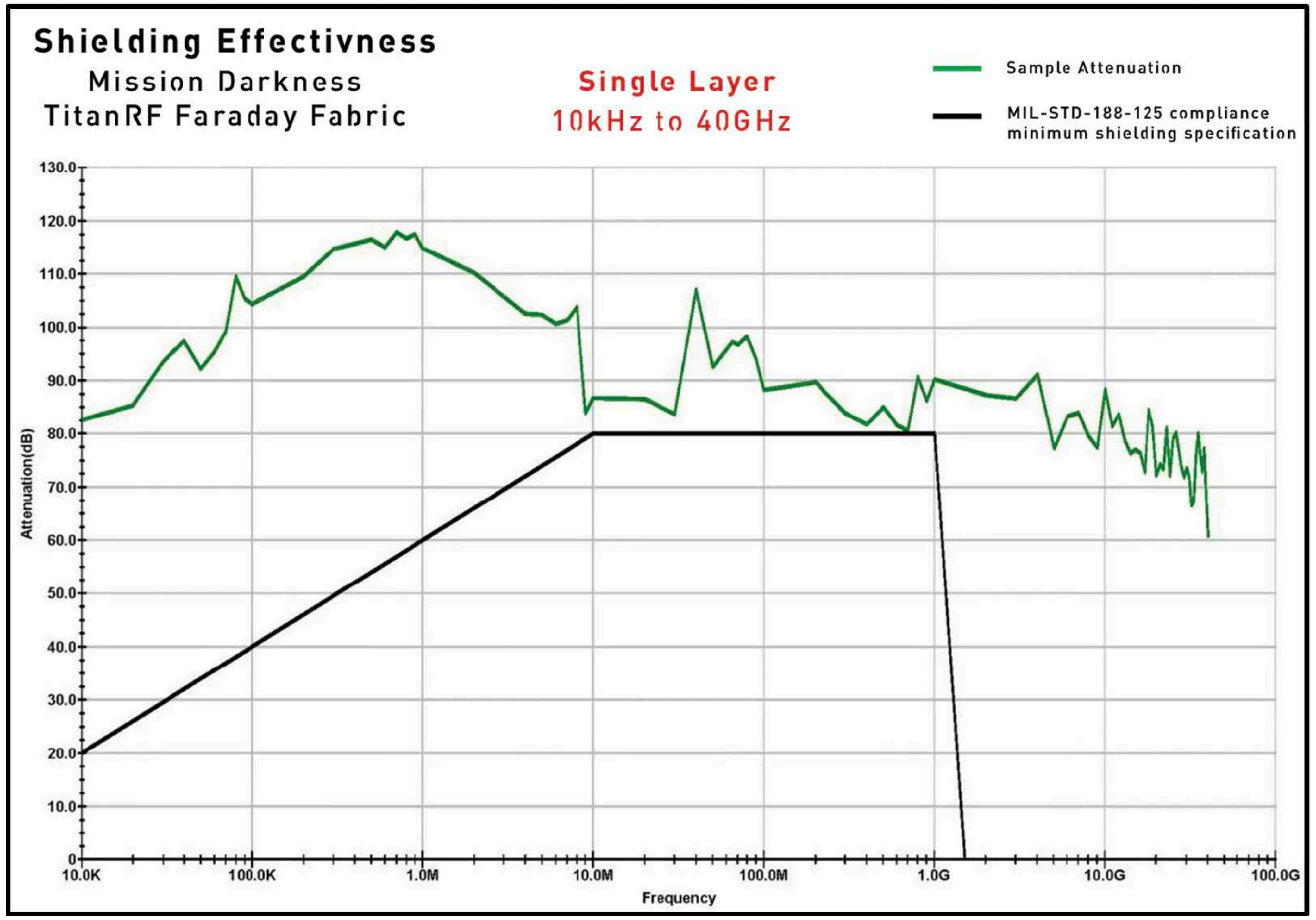
Telescope Darkbox Layers

Dark box to be constructed out of multi-layer panels consisting of:





- ➢ 6.7 mil Mylar: 24 m^2 ➜ 5.7 kg
- ➢ Titan RF for EMI shielding 24 m^2
  - ~2 kg (Verified by company as 80g/m^2)
  - A Second layer is a possibility if needed
  - Need a good way to ensure a conductive connection to the Al Frame.
- ➢ -100°— 200°C RTV to bond Mylar / Titan RF
- ➢ ¾-inch thick Foamular 400 polystyrene foam
- ➢ Musou black for internal reflectance ~ 1kg



Total weight ~20kg (44 lbs)

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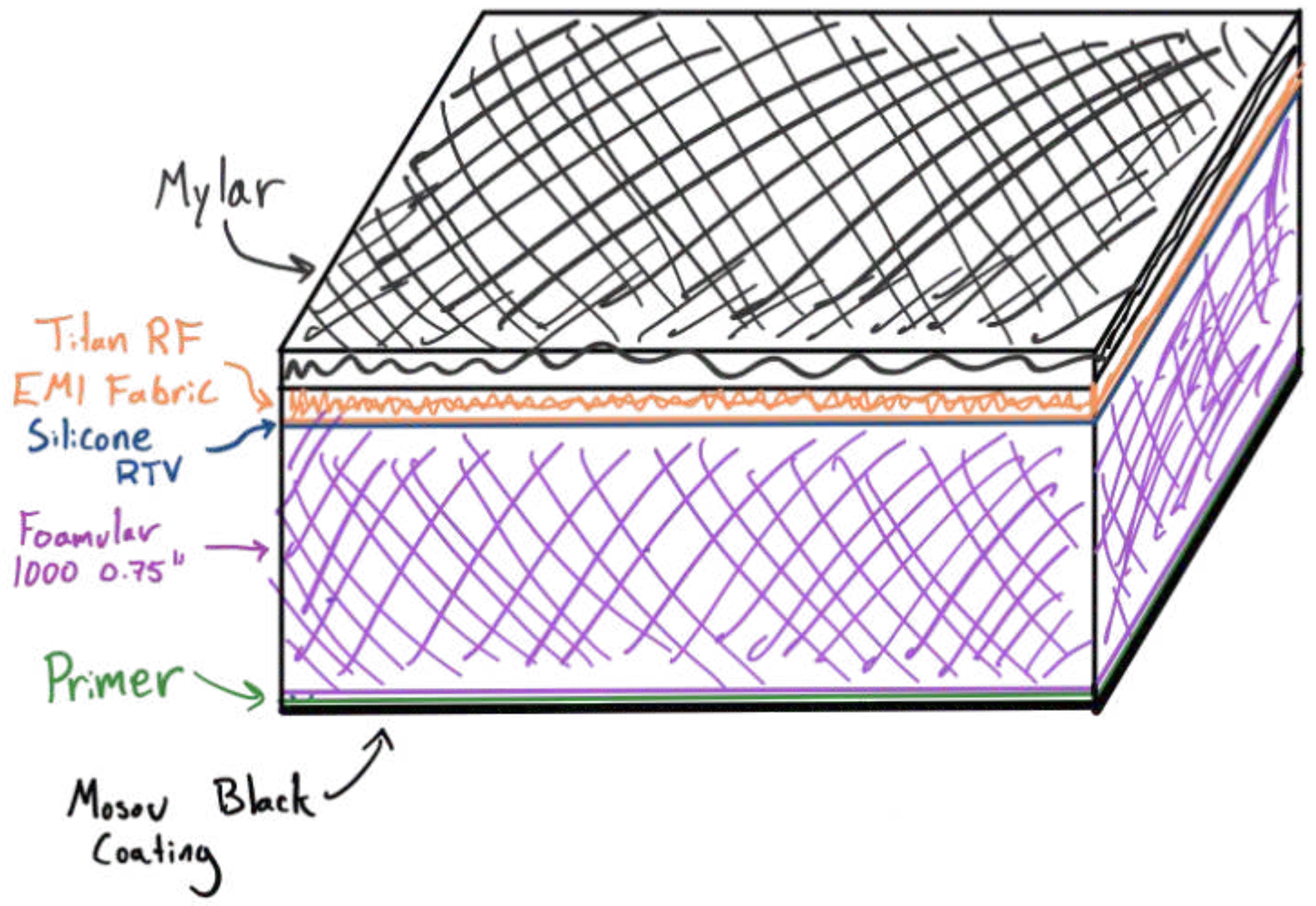
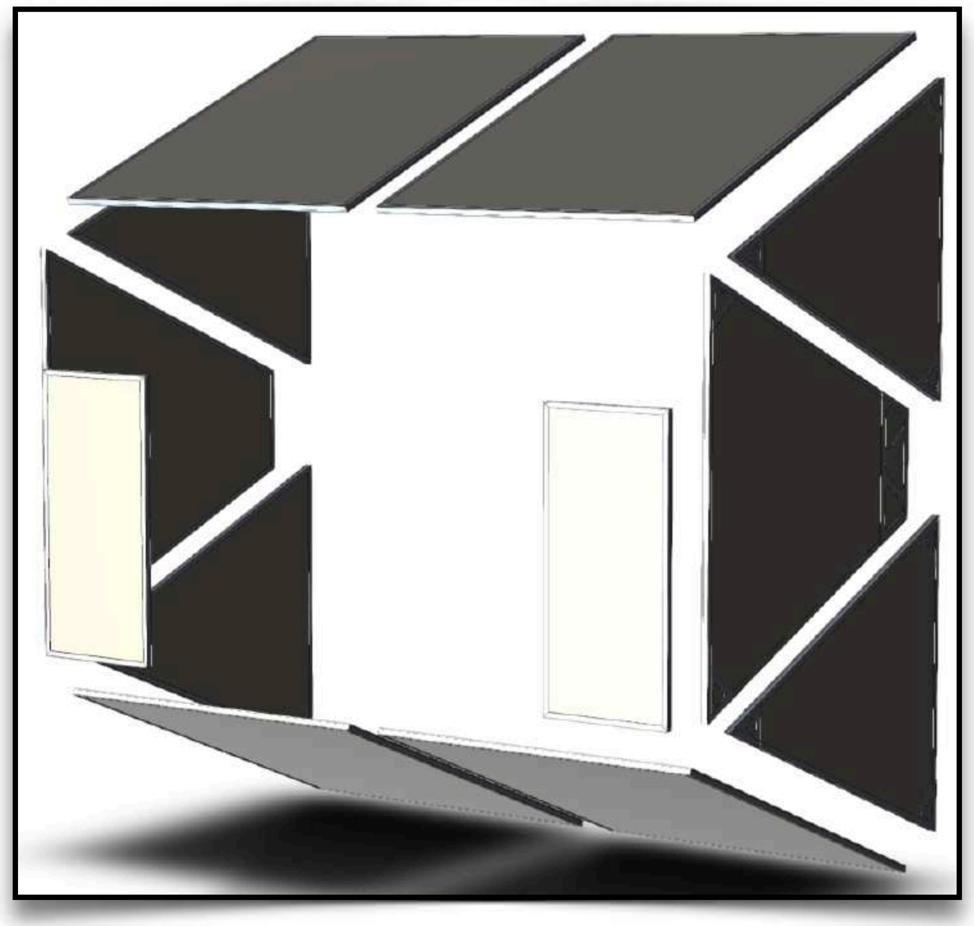
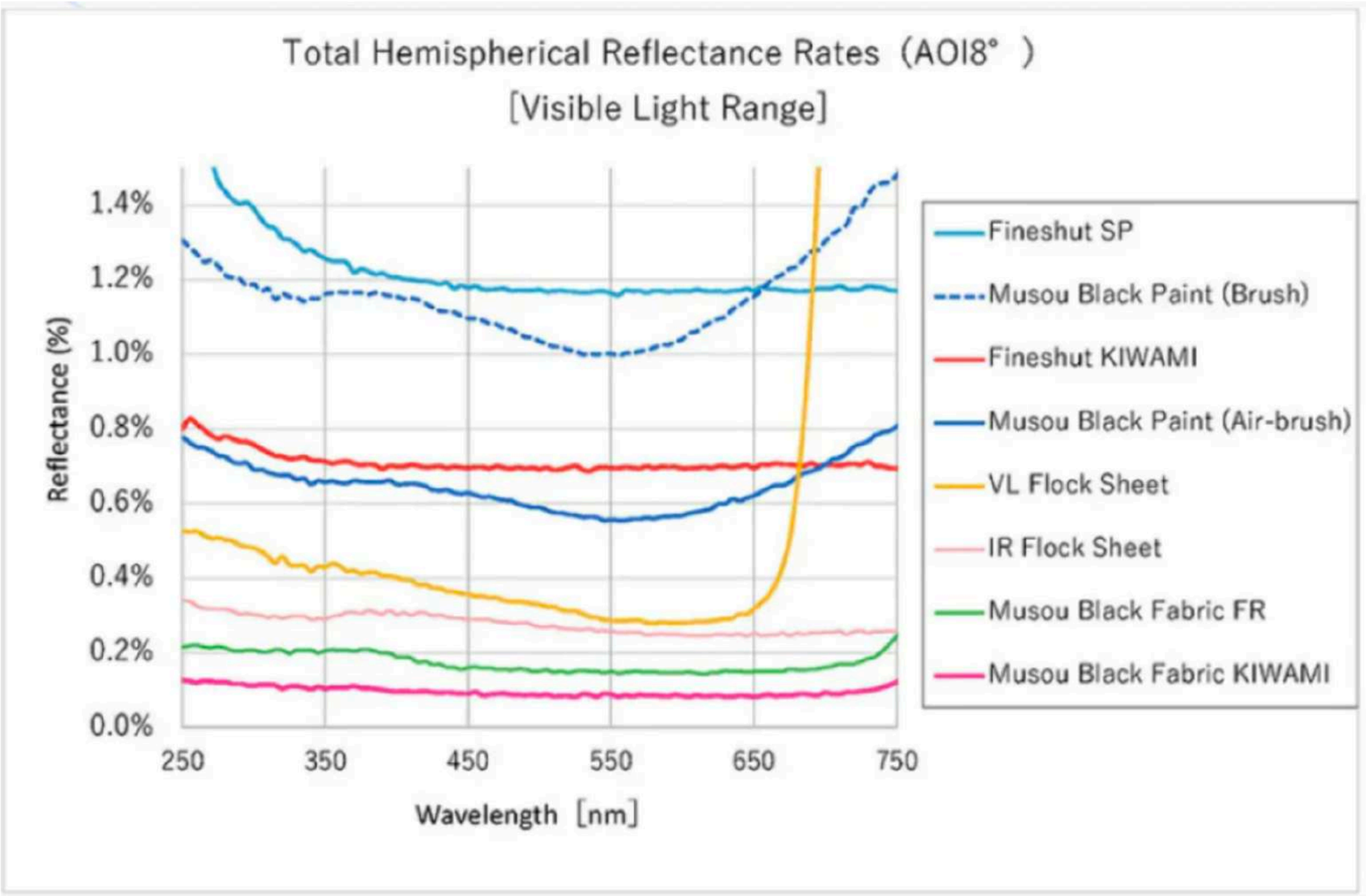
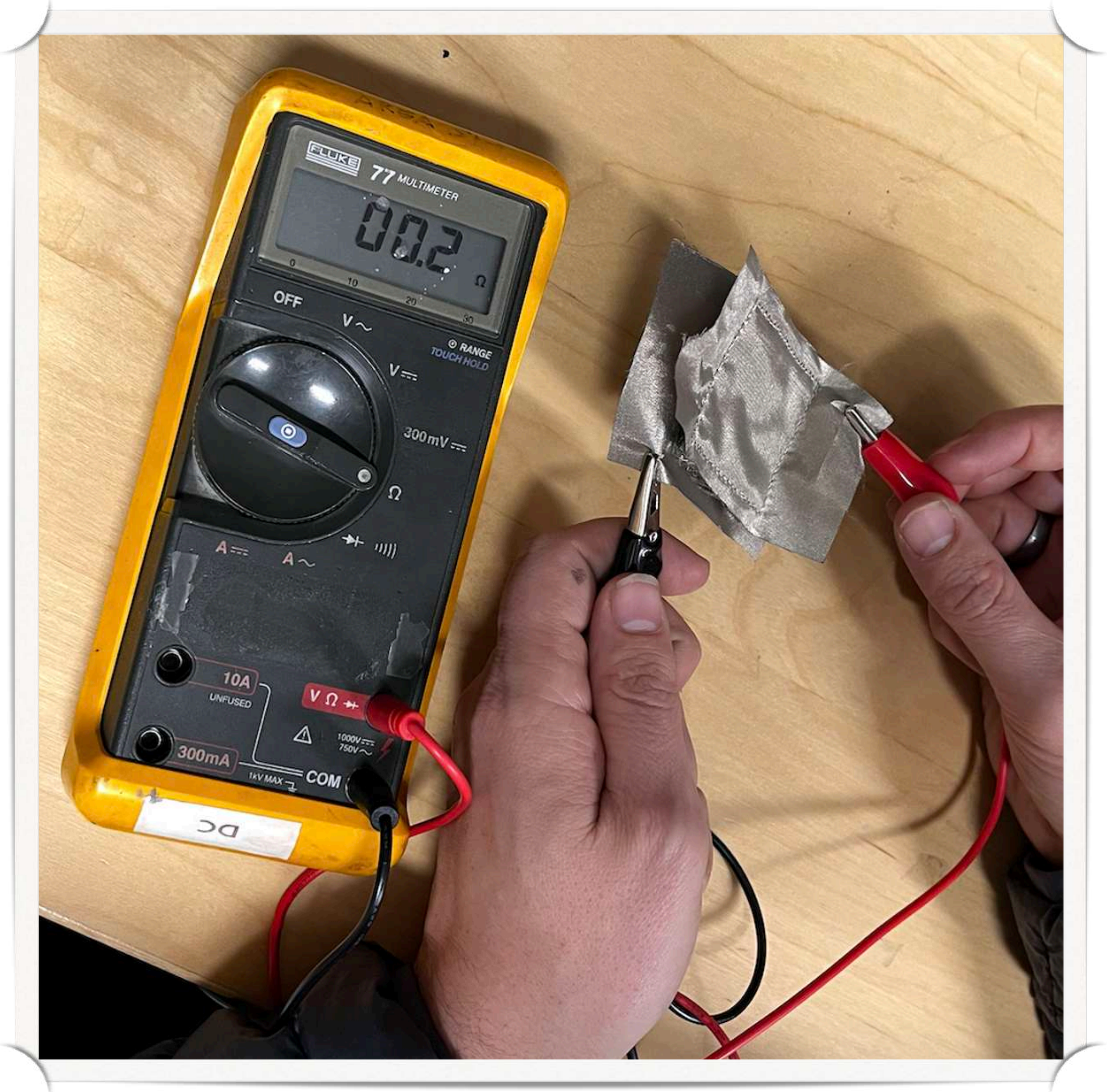






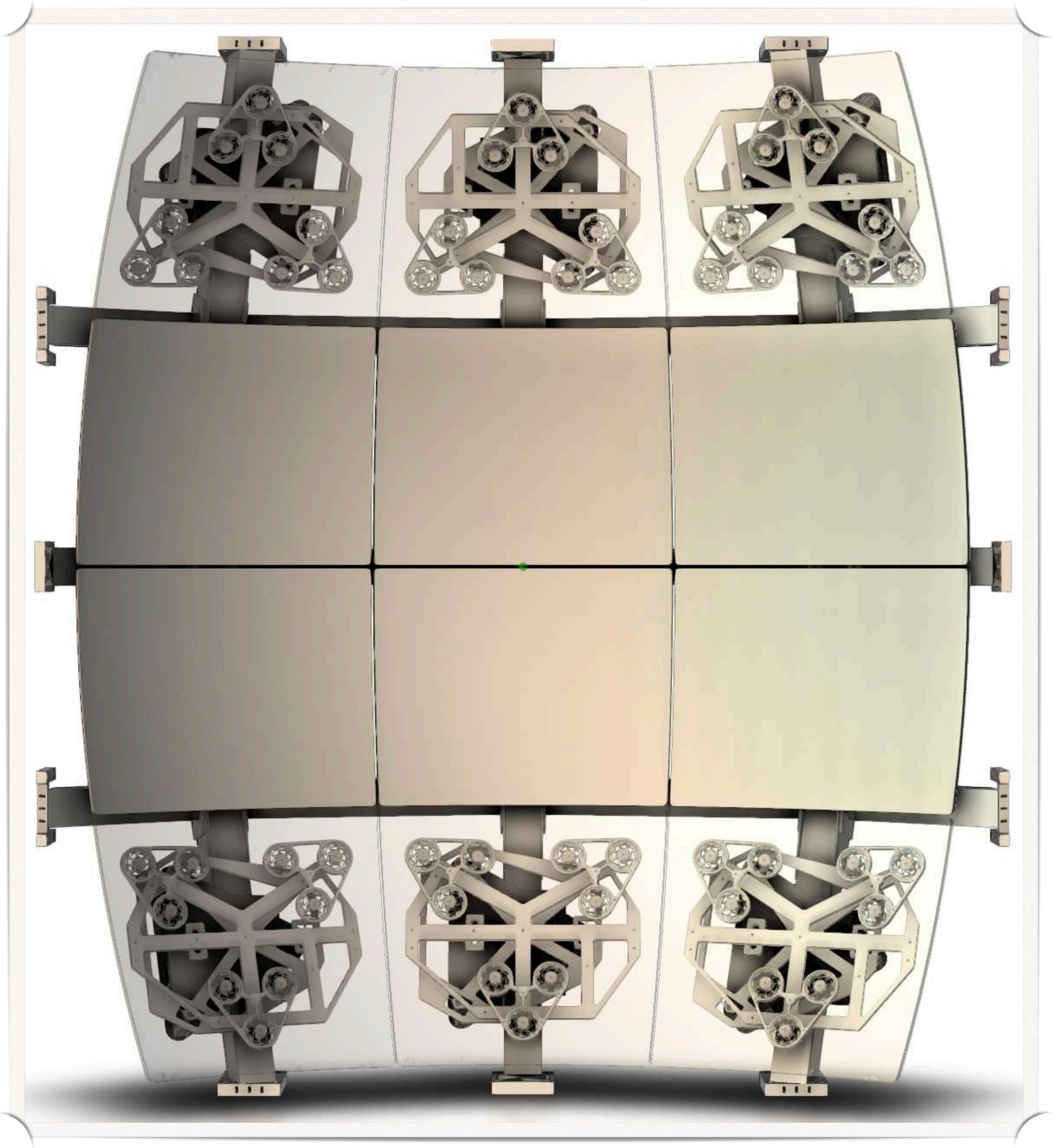
Hook and Loop and Conductive Thread

➢ Conductive thread and hook-and-loop are being considered to provide a conductive bond between the Faraday fabric of panels and the Aluminum Frame



Primary Mirror Assembly

Engineer: William Yitz Finch
Cotopaxi Engineering /
Colorado School of Mines



Mirror Cell Assembly

➢ **Mirror:**
- 11mm thick Borosilicate glass, 18 lbs per segment, RoC 1660 mm

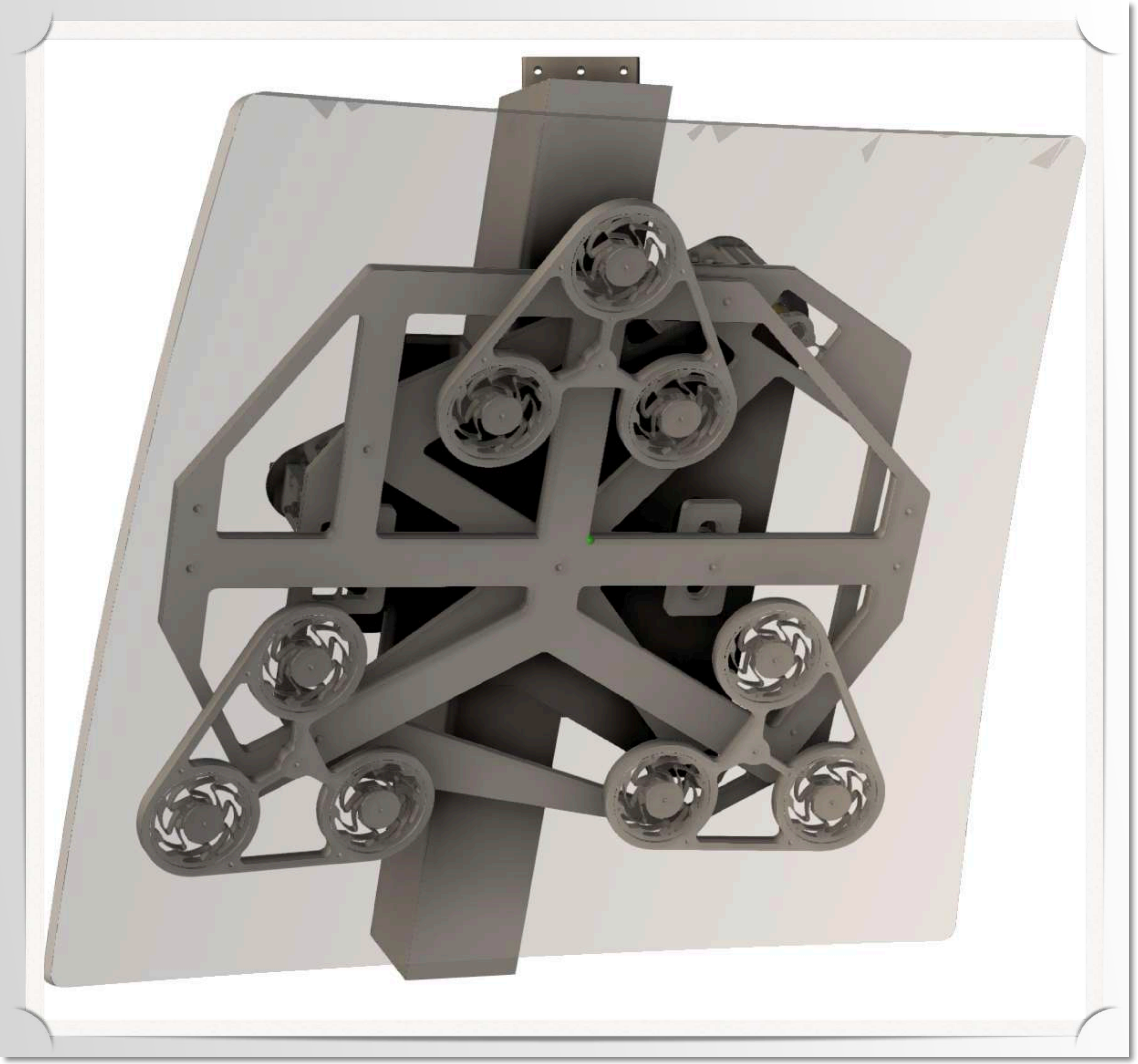
➢ **Glue Bond:**
- Epoxy Bond of the mirror cell and pads

➢ **2.5 cm Kovar Glue Pads:**
- Kovar has the same thermal properties as the mirror glass
- 9 pads per mirror cell

➢ **Flexure Assembly**
- 6061 Al springs to absorb thermal loads

➢ **Whipple Tree**
- Aluminum the assembly to map pads to the glass and evenly distribute loads

➢ **Aiming and Frame Mounting**
- Aluminum assembly for precision alignment of mirrors



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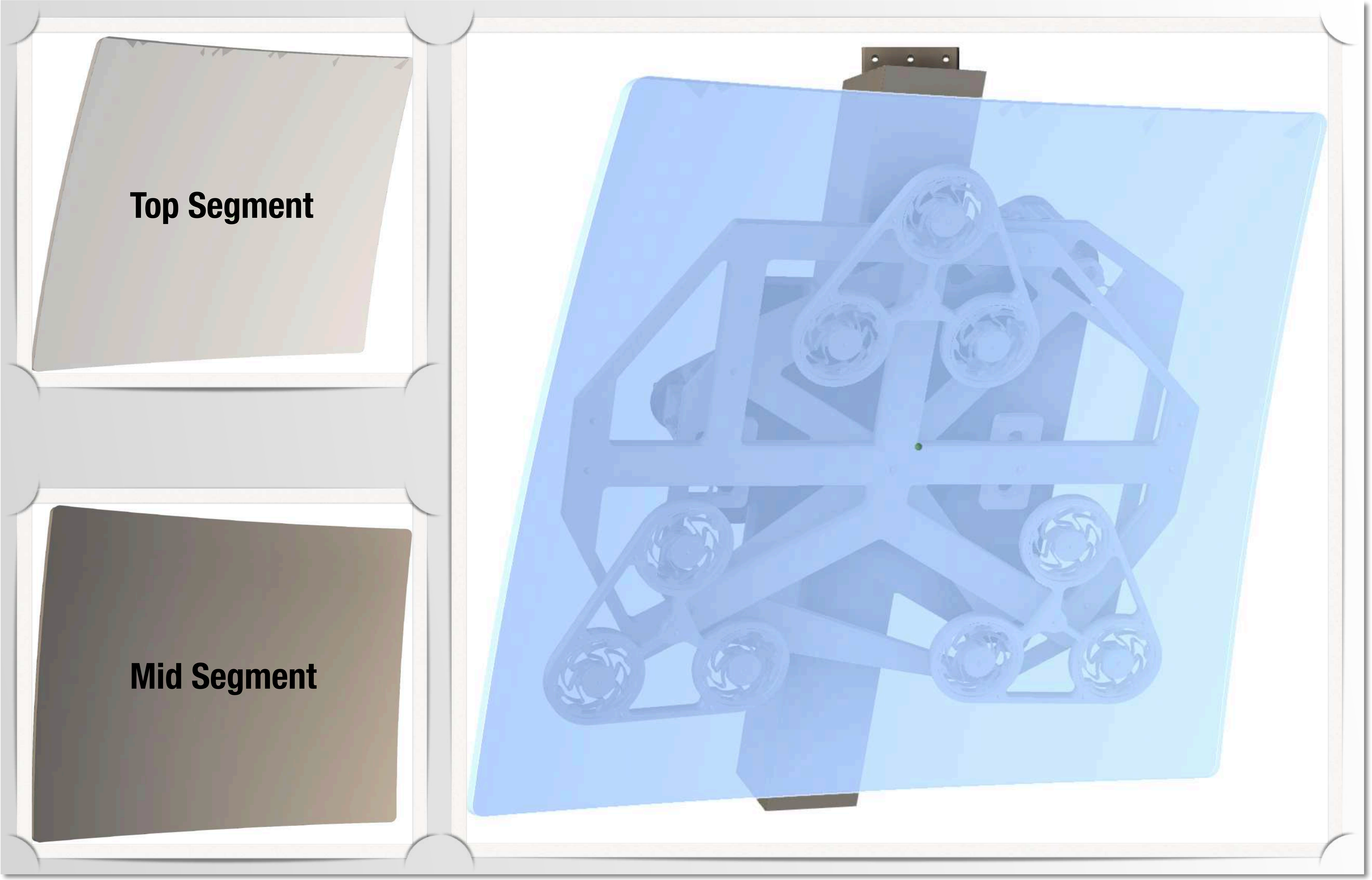

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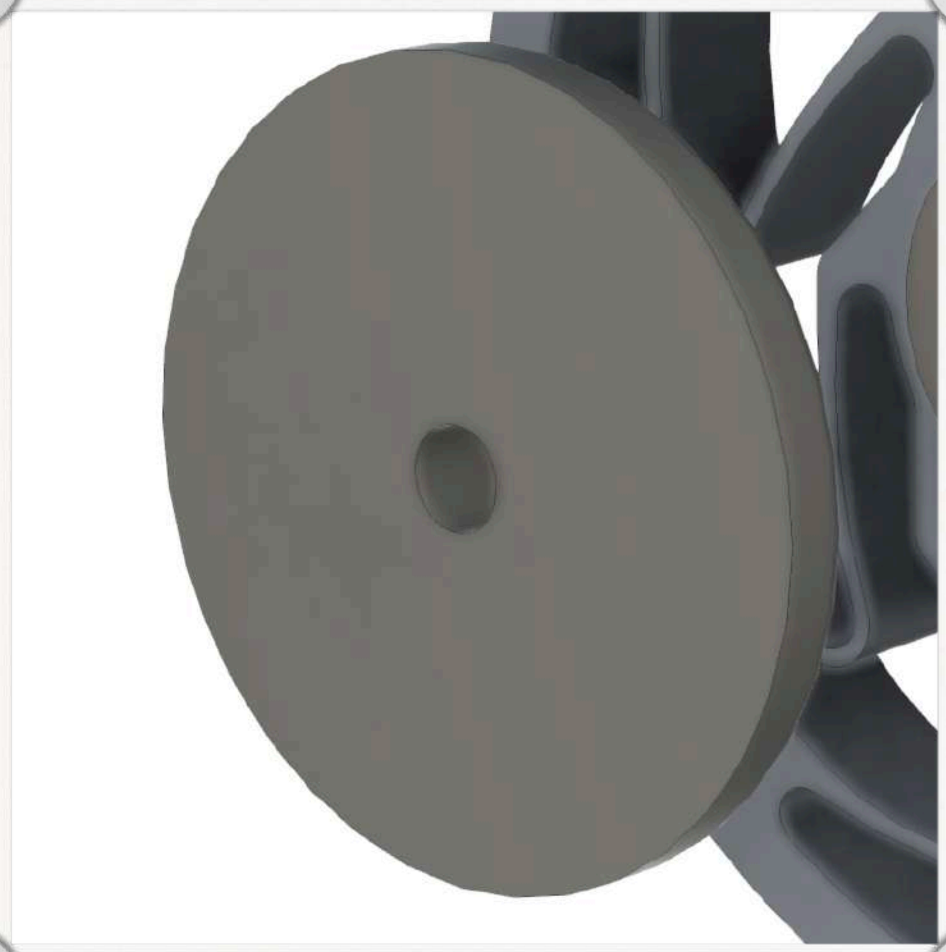

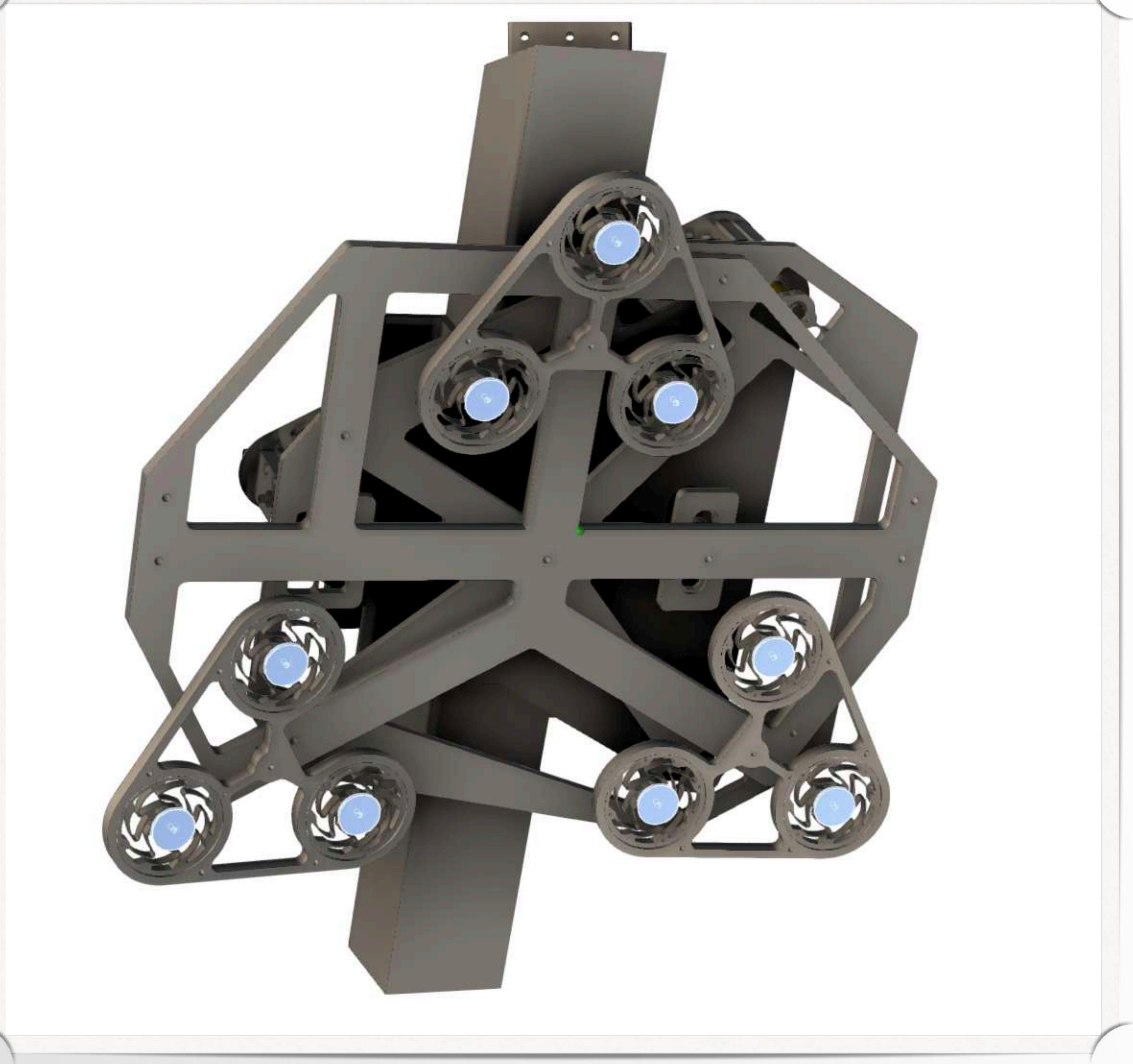

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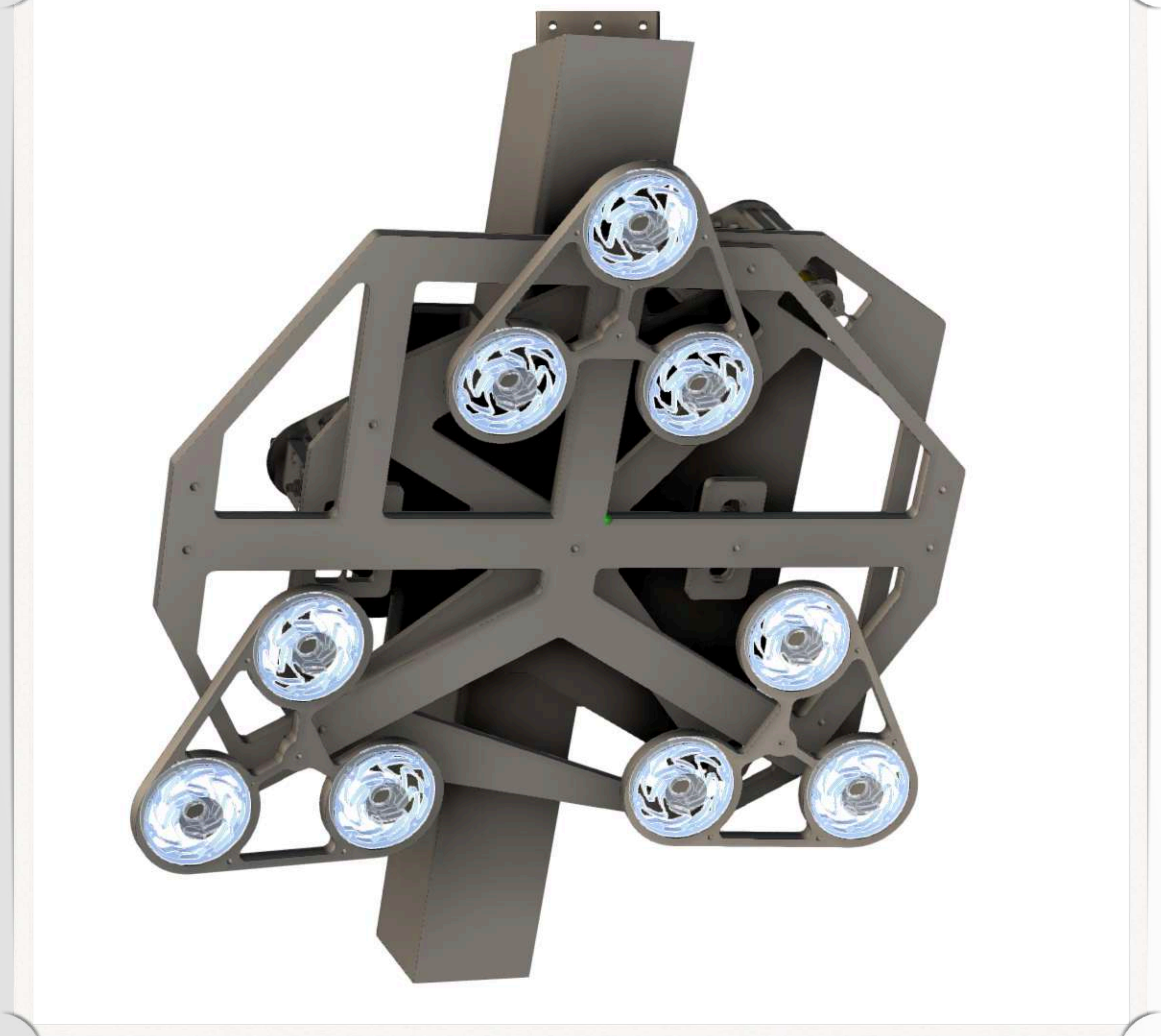

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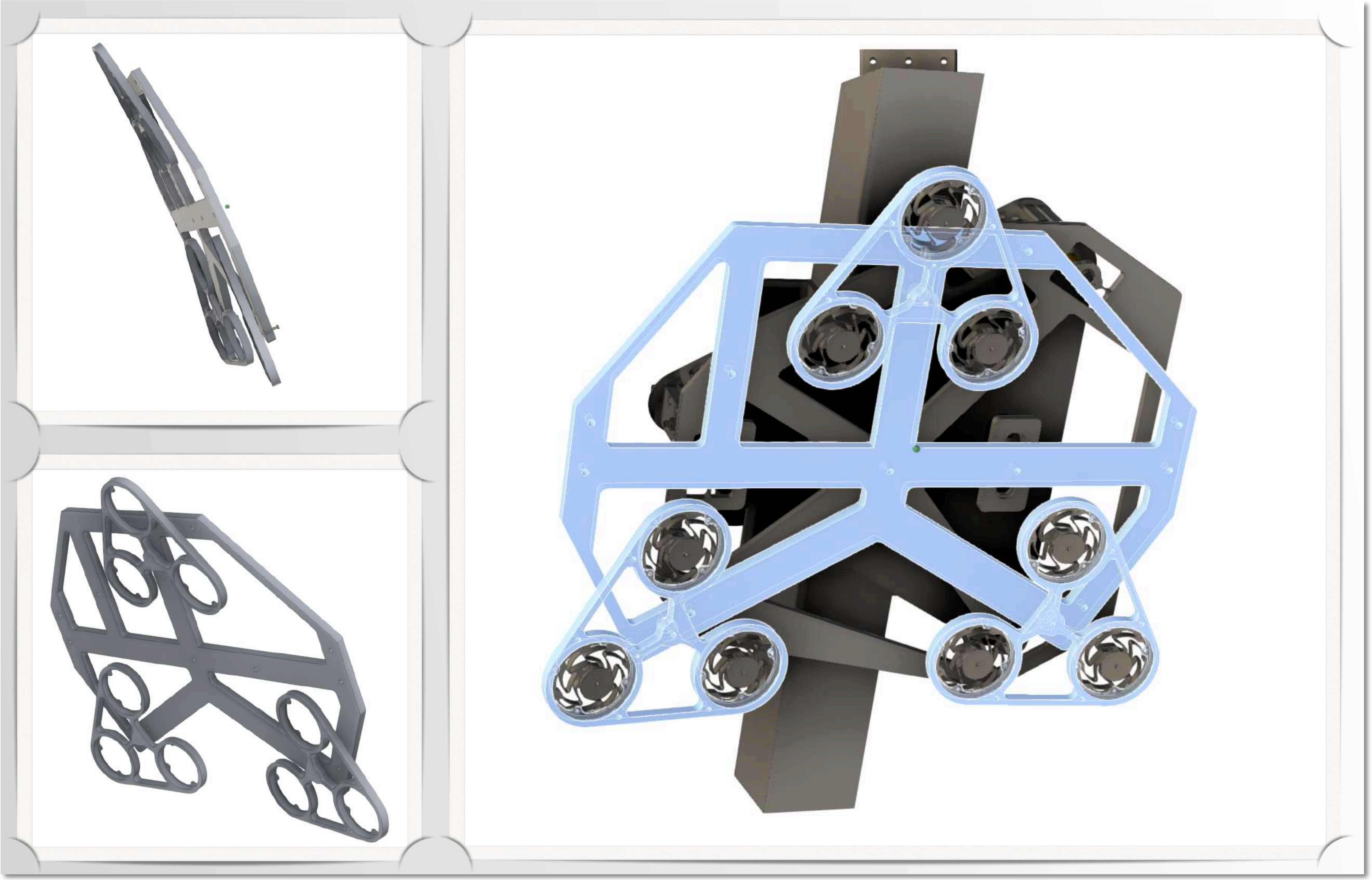

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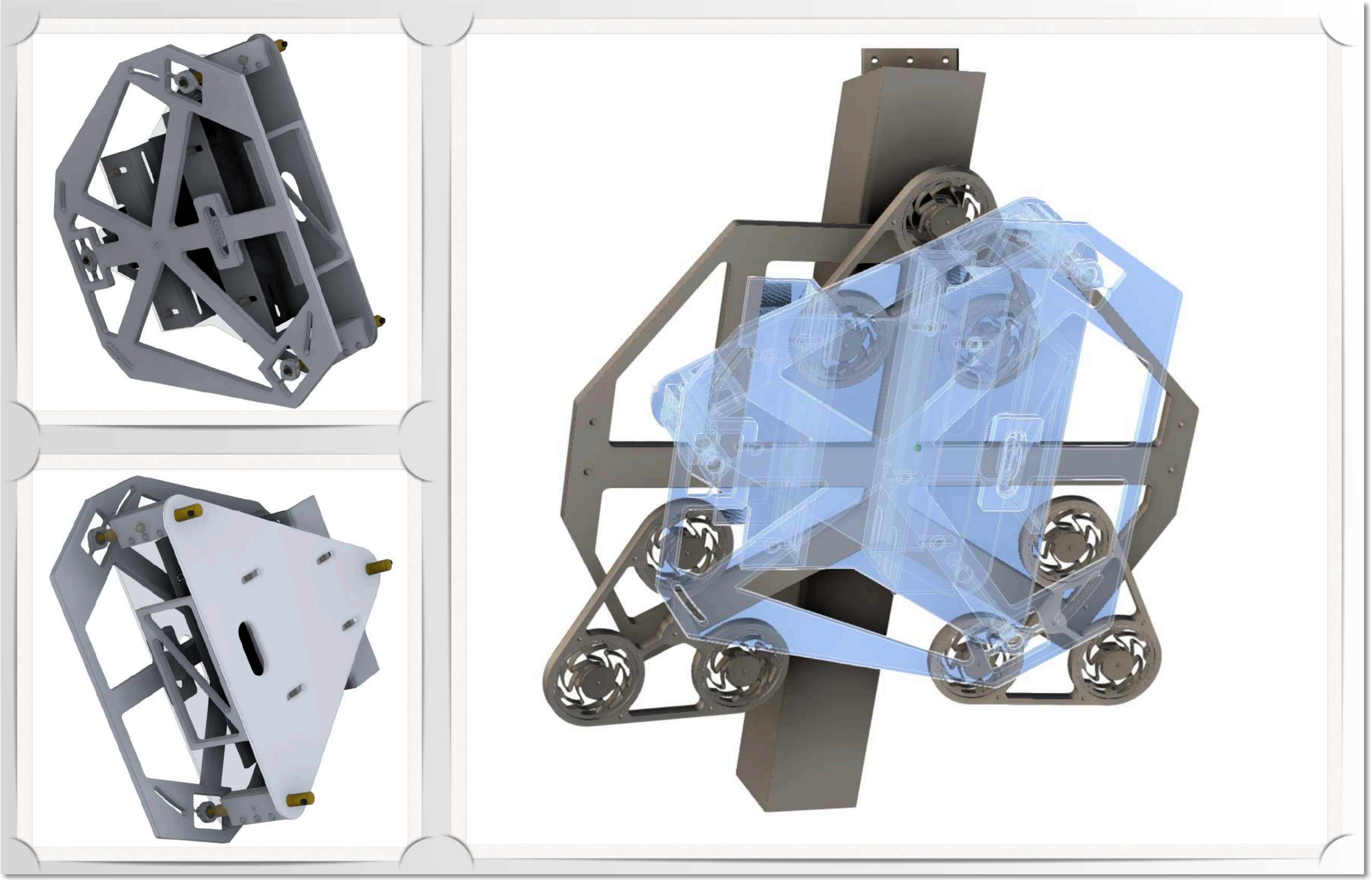
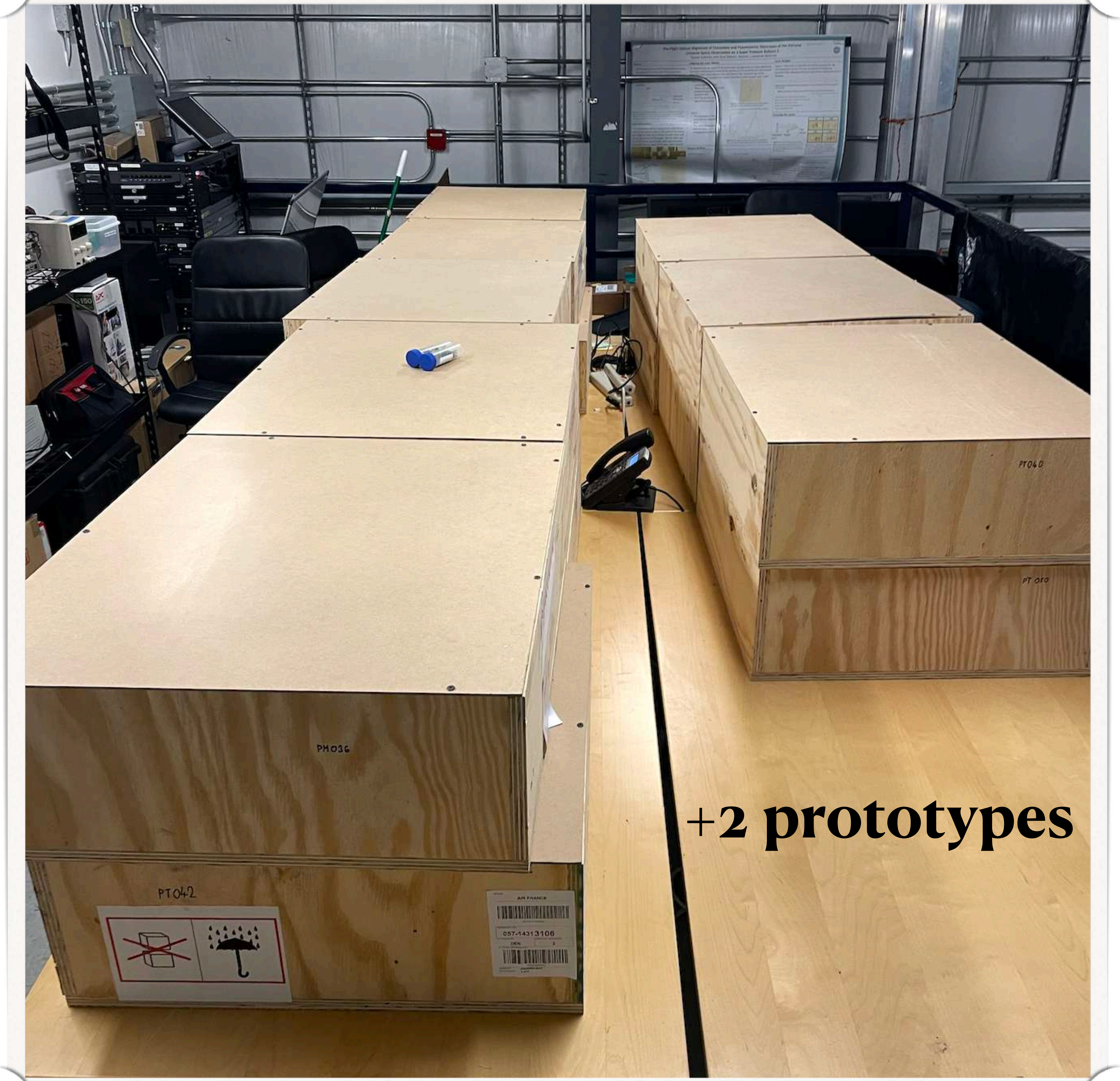


Mirrors Delivered by Olomouc

- ➢ All 18 Mirrors arrived safely at Mines
  - 2 prototypes + 16 production (9 Top, 9 Mid)
- ➢ Full Surface inspection of Prototypes
- ➢ Production mirrors were inspected to ensure they were undamaged in transit
- ➢ Boxes large enough to ship mirrors to NZ with full Whipple-Tree and mating assembly



Mirrors Measurments

Mirror shape	Nominal dimensions A [mm]	B [mm]	C [mm]	D [mm]	E [mm]	F [mm]
TOP	596.83	503.98	555.44	555.44	772.79	772.77
MID	627.70	599.94	500.97	500.97	783.32	783.31

18ks (9+9)

1659.8

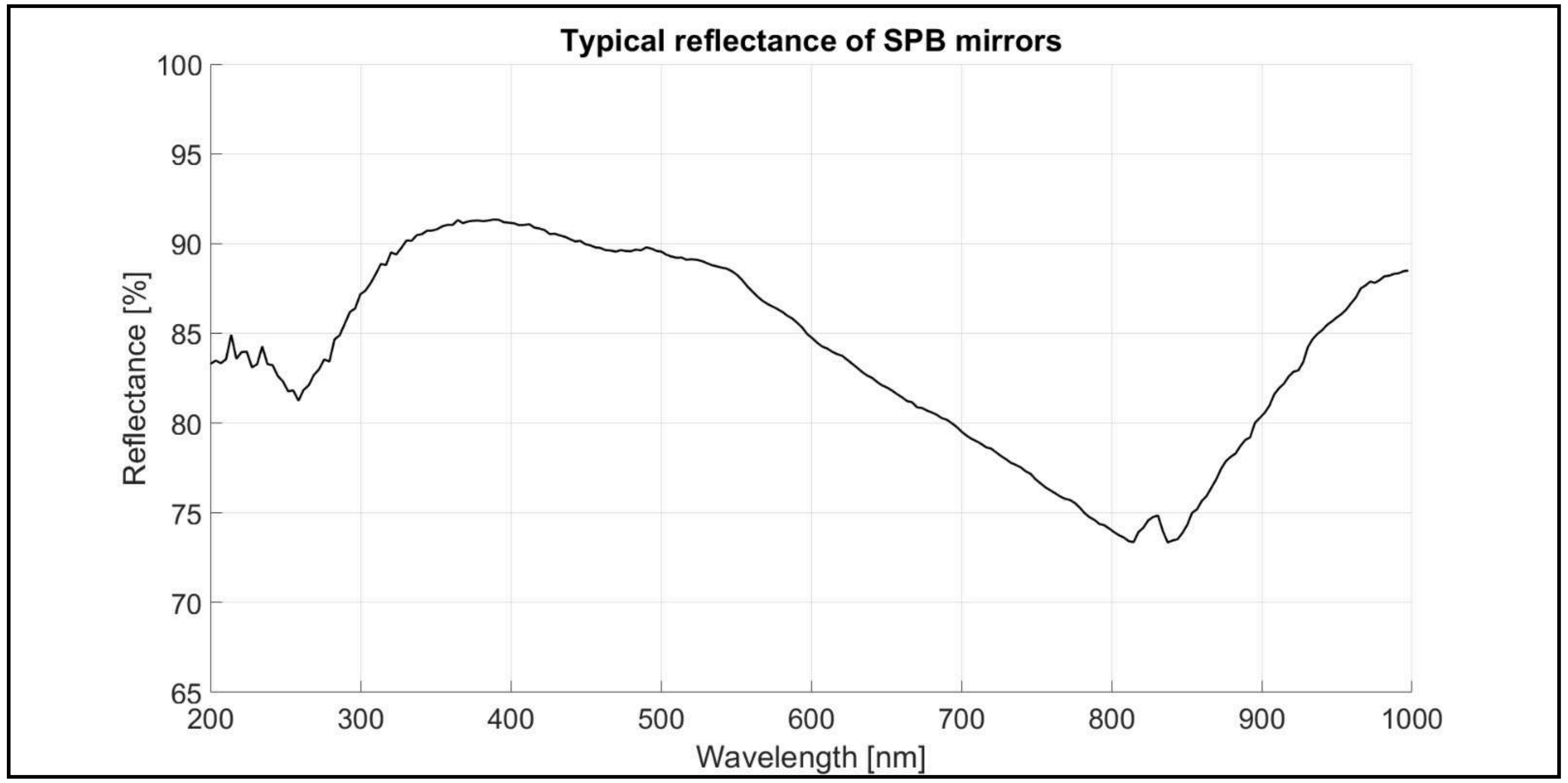
ROC = 1659.8 mm +-2.5 mm

Rmin>80%

	T	M	After CNC	After polishing	After coating	After measuring	In box		shipped	ROC [mm]		hickness in corners [mm				SF D95 [mm]2	Reflectance 300-600nm min R [%]	max R [%]	mean R [%]
PM30	M	M	1	1	1	1	1		0	1659.0	-0.80	####	####	####	####	1.1	83.3	91.2	88.6
PM31	M	M	1	1	1	1	1		1	1659.0	-0.8	####	####	####	####	2.2	82.8	91.3	88.0
PT32	T	T	1	1	1	1	1		1	1659.0	-0.8	####	####	####	####	1.5	84.3	91.8	89.4
PT33	T	T	1	1	1	1	1		0	1661.0	1.20	####	####	####	####	1.4	82.7	90.9	88.2
~~PT34~~	~~T~~	~~T~~	~~1~~	~~1~~	~~1~~	~~1~~	~~0~~		~~0~~	~~1662.0~~	~~2.20~~	~~####~~	~~####~~	~~####~~	~~####~~	~~1.2~~	~~83.0~~	~~91.4~~	~~88.0~~
PM35	M	M	1	1	1	1	1		0	1661.0	1.20	####	####	####	####	2.0	82.7	90.8	87.8
PM36	M	M	1	1	1	1	1		0	1662.0	2.20	####	####	####	####	2.0	83.1	91.3	88.2
PT37	T	T	1	1	1	1	1		0	1660.0	0.20	####	####	####	####	1.1	82.5	90.6	87.3
~~PT38~~	~~T~~	~~T~~	~~1~~	~~1~~	~~1~~	~~1~~	~~0~~		~~0~~	~~1661.0~~	~~1.20~~	~~####~~	~~####~~	~~####~~	~~####~~	~~2.0~~	~~82.8~~	~~90.8~~	~~87.7~~
PM39	M	M	1	1	1	1	1		0	1660.0	0.20	####	####	####	####	2.4	83.1	91.5	88.3
PT40	T	T	1	1	1	1	1		0	1659.0	-0.80	####	####	####	####	1.3	82.5	90.6	87.5
PM41	M	M	1	1	1	1	1		0	1660.0	0.20	####	####	####	####	1.2	83.0	91.3	87.8
PT42	T	T	1	1	1	1	1		0	1660.0	0.20	####	####	####	####	1.4	83.2	91.6	88.5
PM43	M	M	1	1	1	1	1		0	1660.0	0.20	####	####	####	####	1.7	83.2	91.4	88.3
PT44	T	T	1	1	1	1	1		0	1660.0	0.20	####	####	####	####	1.3	82.7	90.6	87.2
PM45	M	M	1	1	1	1	1		0	1660.0	0.20	####	####	####	####	1.4	82.3	90.1	87.3
PT46	T	T	1	1	1	1	1		0	1658.0	-1.80	####	####	####	####	1.3	82.7	90.0	87.2
~~PM47~~	~~M~~	~~M~~	~~1~~	~~1~~	~~1~~	~~1~~	~~0~~		~~0~~	~~1660.0~~	~~0.20~~	~~####~~	~~####~~	~~####~~	~~####~~	~~1.4~~	~~82.9~~	~~90.5~~	~~87.5~~
PT48	T	T	1	1	1	1	1		0	1658.0	-1.80	####	####	####	####	1.7	83.1	90.4	87.4
PM49	M	M	1	1	1	1	1		0	1659.0	-0.80	####	####	####	####	1.3	83.2	90.6	87.8
PT50	T	T	1	1	1	1	1		0	1658.0	-1.80	####	####	####	####	1.3	83.2	90.4	87.6

		Dimension diference from nominal A [mm]	B [mm]	C [mm]	D [mm]	E [mm]	F [mm]	pozn	Dimensions A [mm]	B [mm]	C [mm]	D [mm]	E [mm]	F [mm]
PM30	M	-0.80	-0.34	-0.37	-0.17	0.08	-0.11		626.9	599.6	500.6	500.8	783.4	783.2
PM31	M	0.20	0.36	0.03	-0.27	-0.02	-0.01	shipped	627.9	600.3	501.0	500.7	783.3	783.3
PT32	T	-0.93	1.42	1.36	0.76	-0.49	-0.97	shipped	595.9	505.4	556.8	556.2	772.3	771.8
PT33	T	-1.13	-0.08	1.36	1.76	-0.59	-0.67		595.7	503.9	556.8	557.2	772.2	772.1
~~PT34~~		~~-1.83~~	~~-0.98~~	~~0.56~~	~~0.96~~	~~-0.79~~	~~-0.97~~	~~2x zaštípnuto hrana X+~~	~~595.0~~	~~503.0~~	~~556.0~~	~~556.4~~	~~772.0~~	~~771.8~~
PM35	M	0.20	-0.04	-0.27	-0.27	-0.12	-0.01		627.9	599.9	500.7	500.7	783.2	783.3
PM36	M	-0.60	0.06	-0.67	-0.57	-0.02	-0.01		627.1	600.0	500.3	500.4	783.3	783.3
PT37	T	-0.83	1.22	0.56	0.16	-0.79	-0.57		596.0	505.2	556.0	555.6	772.0	772.2
~~PT38~~		~~-0.83~~	~~-0.28~~	~~1.46~~	~~-0.24~~	~~-0.69~~	~~-0.77~~		~~596.0~~	~~503.7~~	~~556.9~~	~~555.2~~	~~772.1~~	~~772.0~~
PM39	M	-0.30	0.16	-0.37	-0.17	0.18	0.19		627.4	600.1	500.6	500.8	783.5	783.5
PT40	T	-0.43	-0.98	0.36	1.36	-0.79	-0.57		596.4	503.0	555.8	556.8	772.0	772.2
PM41	M	-0.10	0.06	-0.17	-0.07	0.18	0.19		627.6	600.0	500.8	500.9	783.5	783.5
PT42	T	-1.83	-0.98	0.56	0.96	-0.79	-0.97		595.0	503.0	556.0	556.4	772.0	771.8
PM43	M	-0.10	0.06	-0.67	0.03	0.28	0.29		627.6	600.0	500.3	501.0	783.6	783.6
PT44	T	-0.63	-0.58	0.76	1.76	-0.49	-0.37		596.2	503.4	556.2	557.2	772.3	772.4
PM45	M	-0.40	0.86	-0.37	-0.47	-0.22	-0.01		627.3	600.8	500.6	500.5	783.1	783.3
PT46	T	-0.83	0.72	1.76	1.56	-0.39	-0.57		596.0	504.7	557.2	557.0	772.4	772.2
~~PM47~~		~~-0.20~~	~~0.36~~	~~-0.37~~	~~0.03~~	~~0.08~~	~~0.09~~	~~rysky na funkční ploše~~	~~627.5~~	~~600.3~~	~~500.6~~	~~501.0~~	~~783.4~~	~~783.4~~
PT48	T	-0.13	-0.18	1.76	1.76	-0.39	-0.37		596.7	503.8	557.2	557.2	772.4	772.4
PM49	M	-0.10	0.76	0.03	0.03	0.08	0.09		627.6	600.7	501.0	501.0	783.4	783.4
PT50	T	-0.23	-0.78	1.36	0.96	-0.49	-0.37		596.6	503.2	556.8	556.4	772.3	772.4

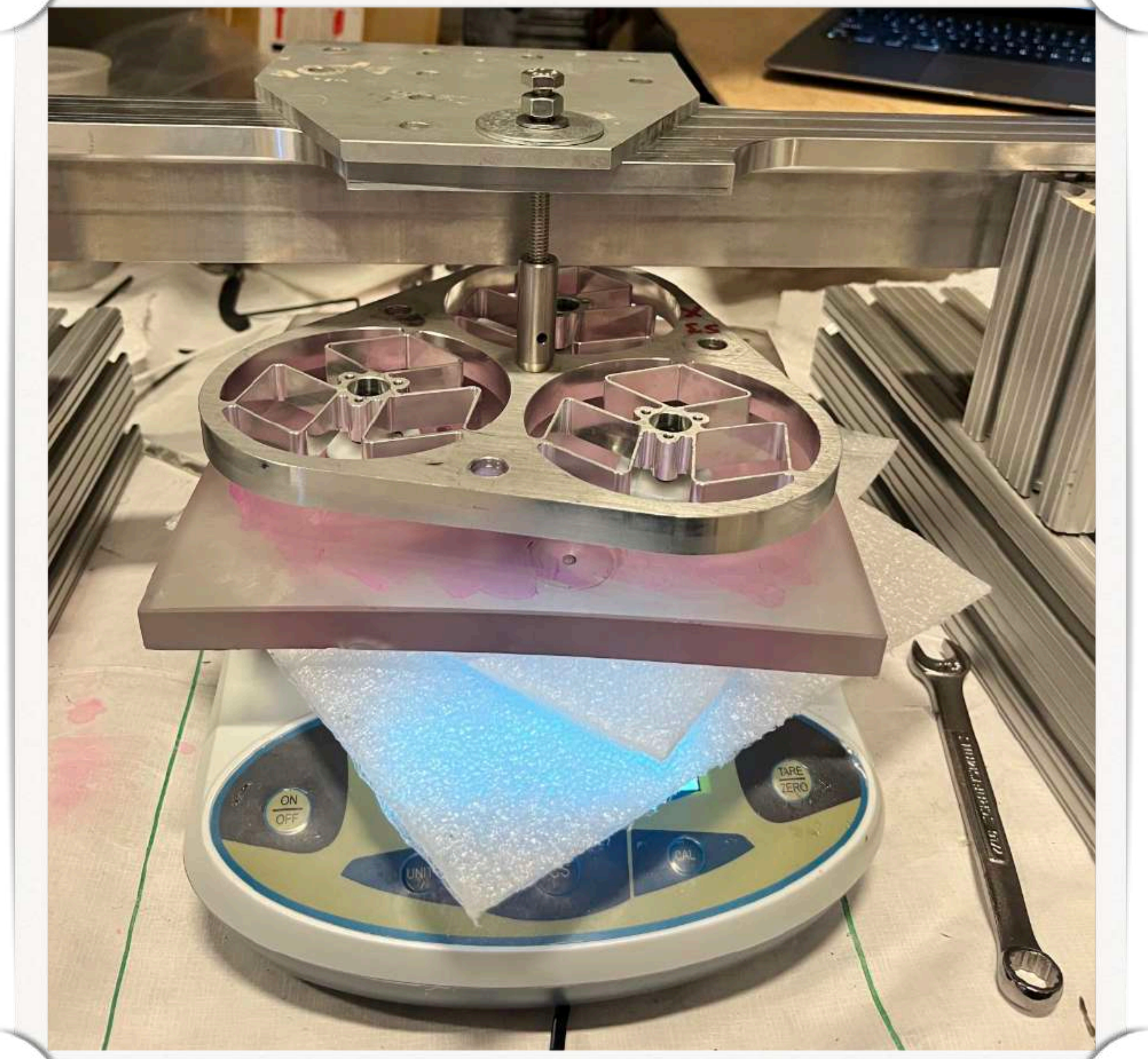
- ➢ Measurements of all 18 mirrors provided
  - RoC + Sizes all within spec
  - Size varies ±1.5mm
  - 6mm inter-mirror gaps, which means choosing which mirror to use where is nontrivial
- ➢ Mirror reflectivity is same as SPB2
- ➢ All data on Mech Wiki

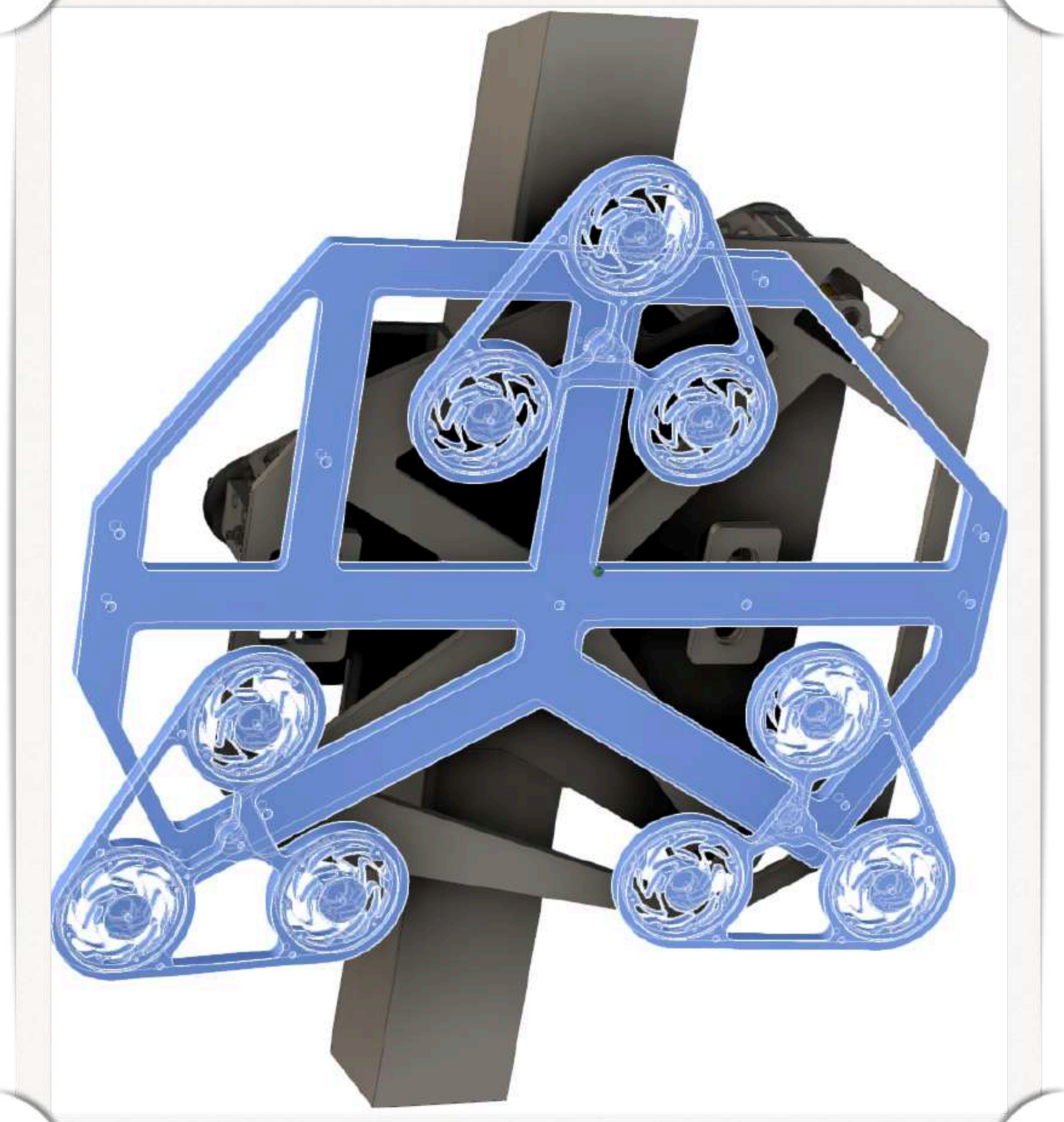


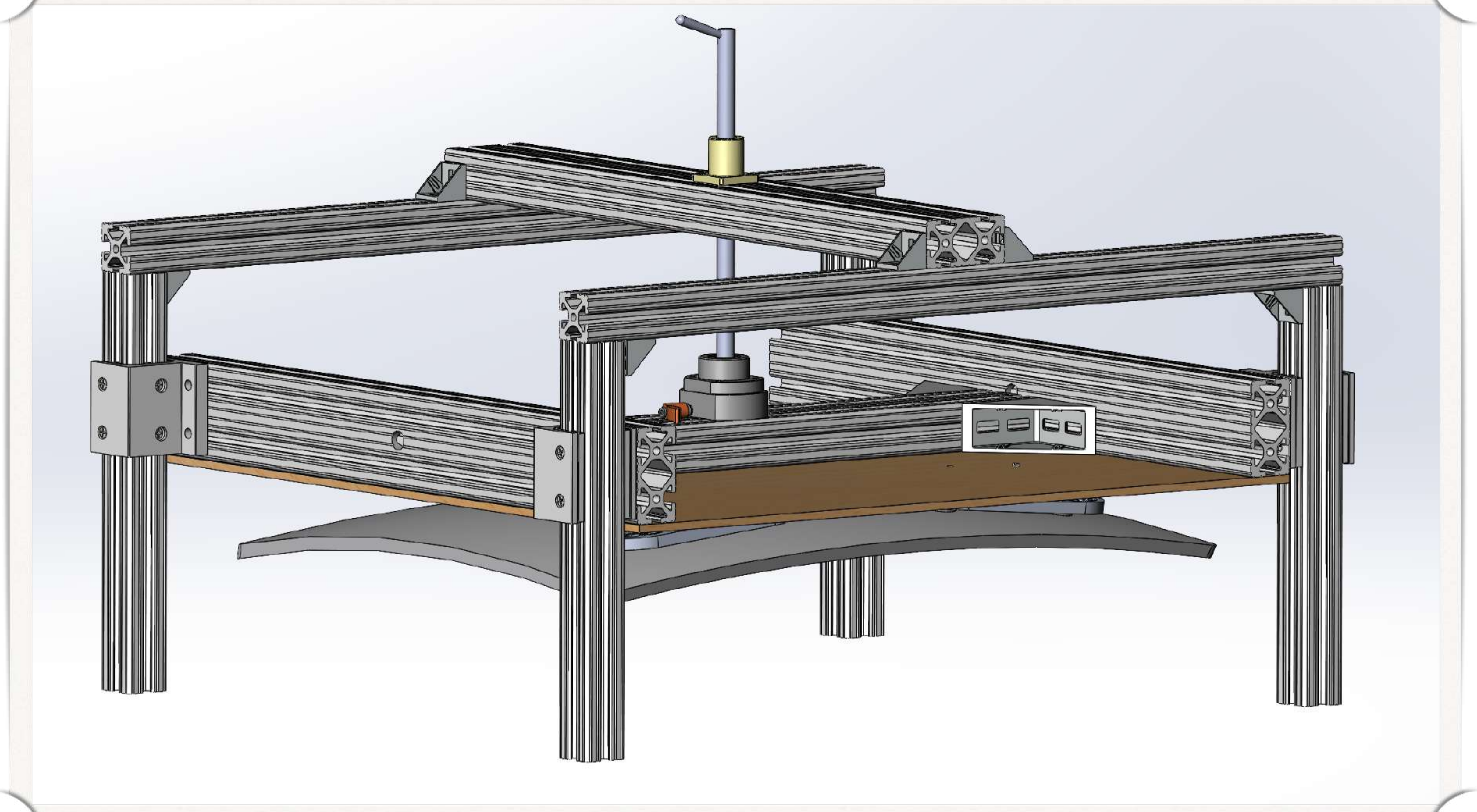
Mirror Gluing Procedure

Conrad Shay, Luke Wanner, Viktoria Kungel

- ➢ PBR Gluing procedure largely follows SPB2 procedure developed by Viktoria, with some significant changes
  - Revision of the priming procedure
  - Glue quantity is higher and metered by weight
  - Thickness not controlled by the spacer
- ➢ Results in very high bond strengths
  - No glue bond failures under 400 lbs (181 kg)
  - Demonstrably now stronger than the glass
- ➢ Mirror Gluing stand is under development to port the single pad gluing procedure to the full mirror procedure
  - Will use the actual Whipple tree that will live with the mirror as the template
  - Will test to ensure accurate, strong bonding

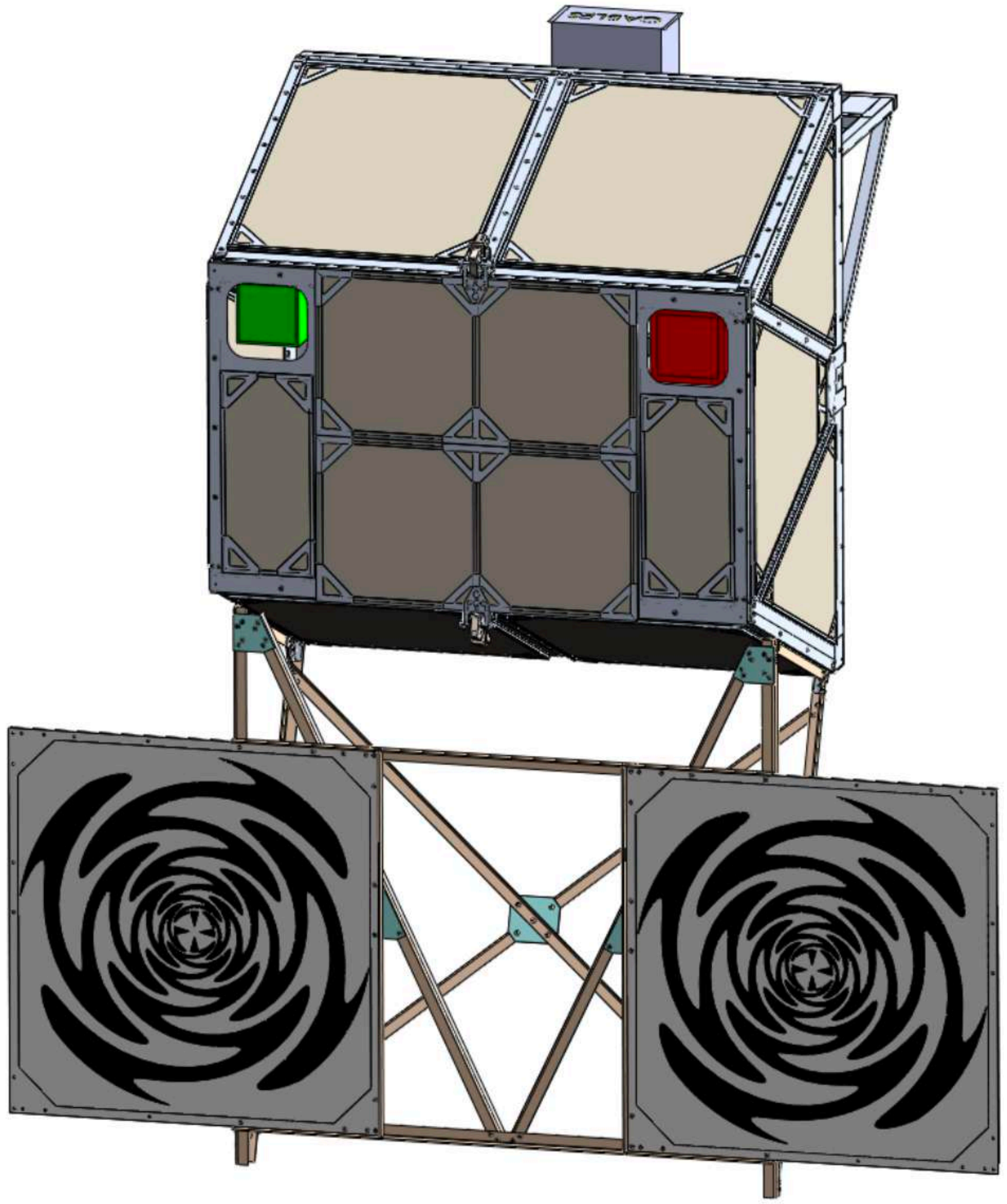






RI Frame and Mast

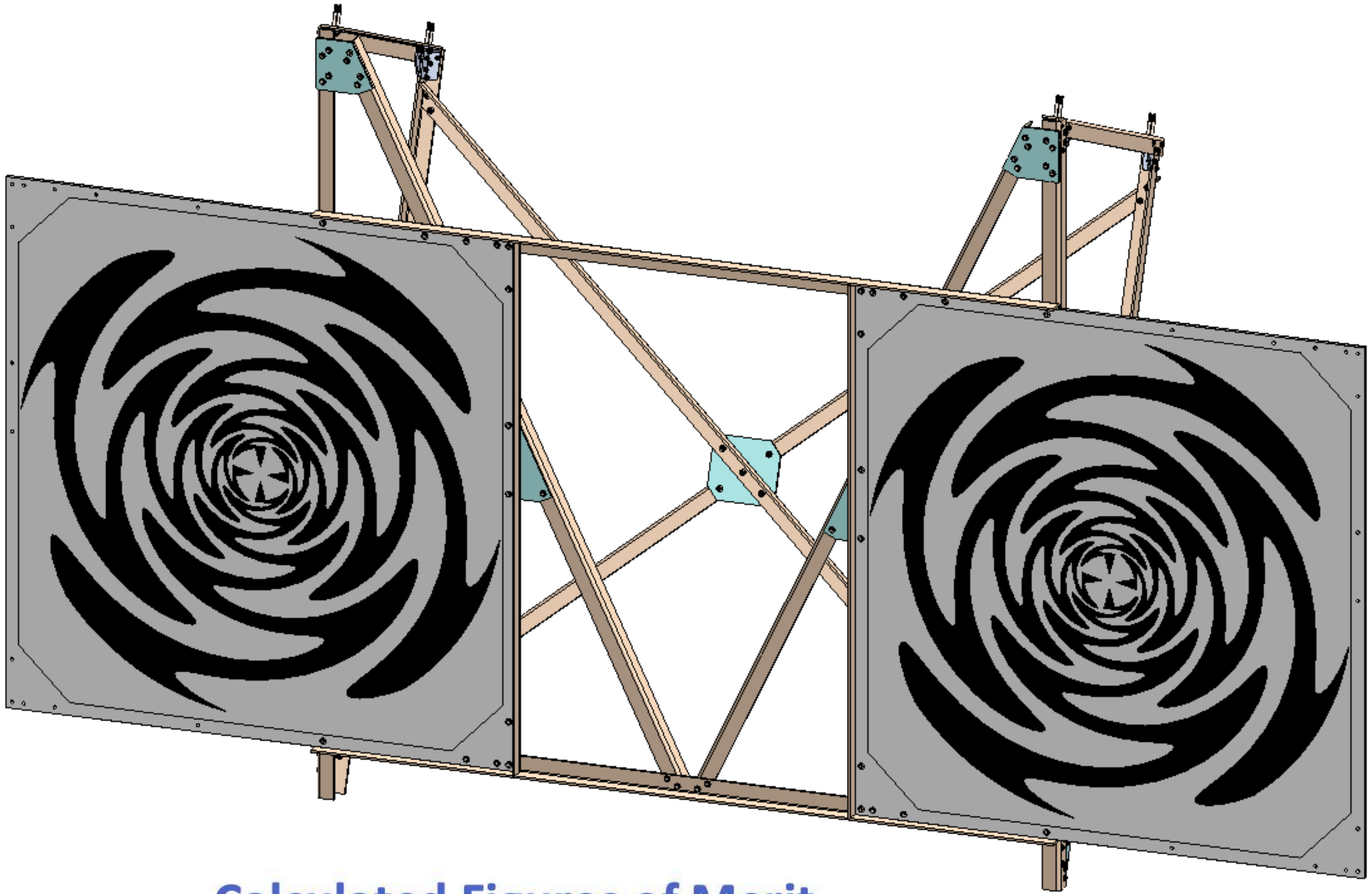
Engineer: Neville DeWitt Pieratt
Firebrand Engineering



RI Antenna, Frame, and Mast

Design Requirements:

- Antenna separation from telescope: 0.5 m minimum
- RF transparent materials
- Metallic fasteners and brackets permitted if <10cm and not in antenna LOS
- Alignment tolerance with telescope: ±1°
- Panel size: 60" x 62" (1.52 m x 1.57 m)
- Weight limit: 150 lbs total
- Survive 8G shock load with 1.25 safety factor
- Survive 15kt wind gust at launch conditions
- Temperature range: -70°C to +100°C
- Survive UV exposure for 100 days
- Target cost: $10k



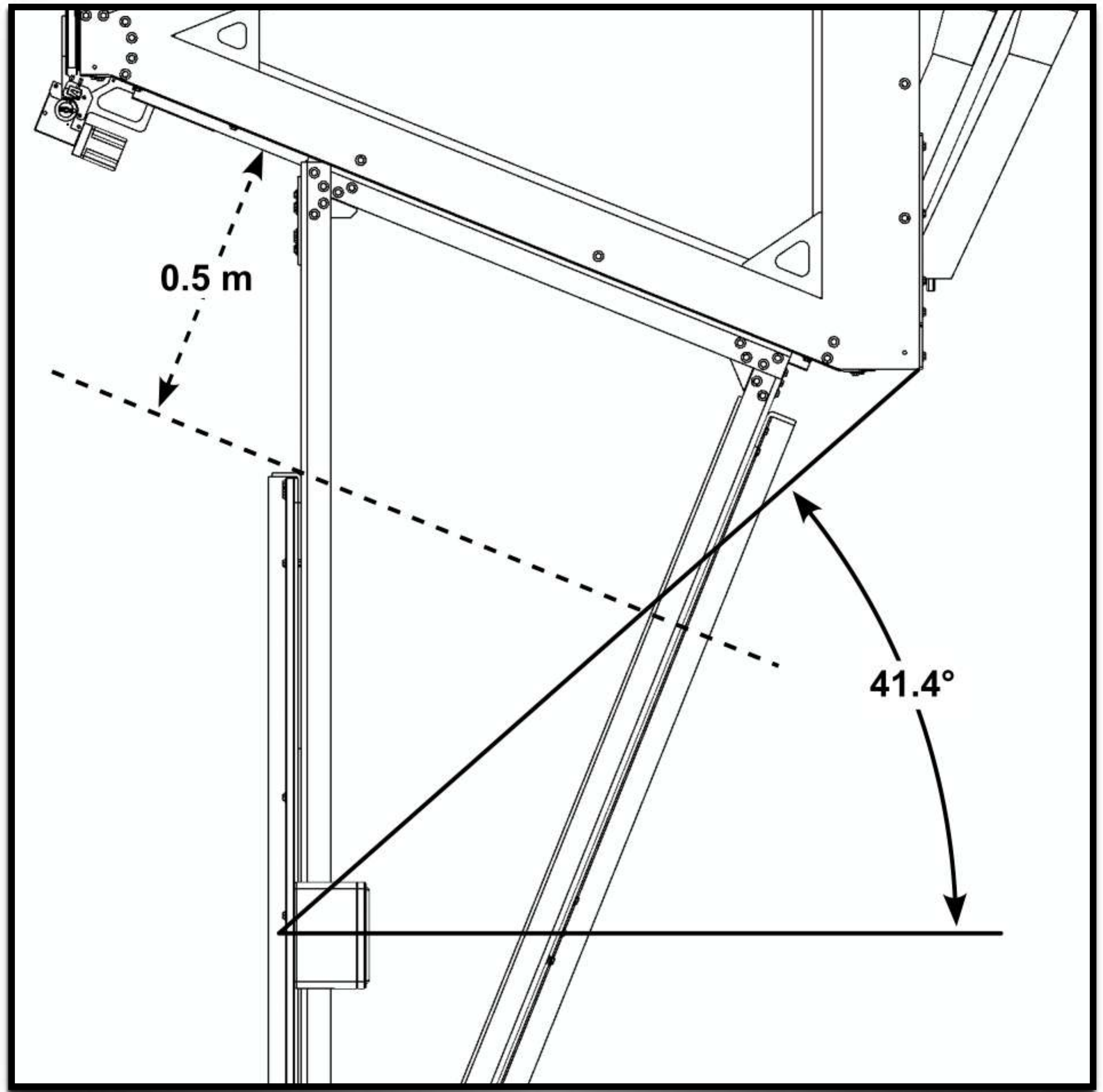
Calculated Figures of Merit

Figure	Value
Assembly Weight	147 lbs*
Ultimate Design Load	3300 lbf
Ultimate Safety Factor – 8G shock load	2.8
Required Safety Factor – 8G shock load	1.25

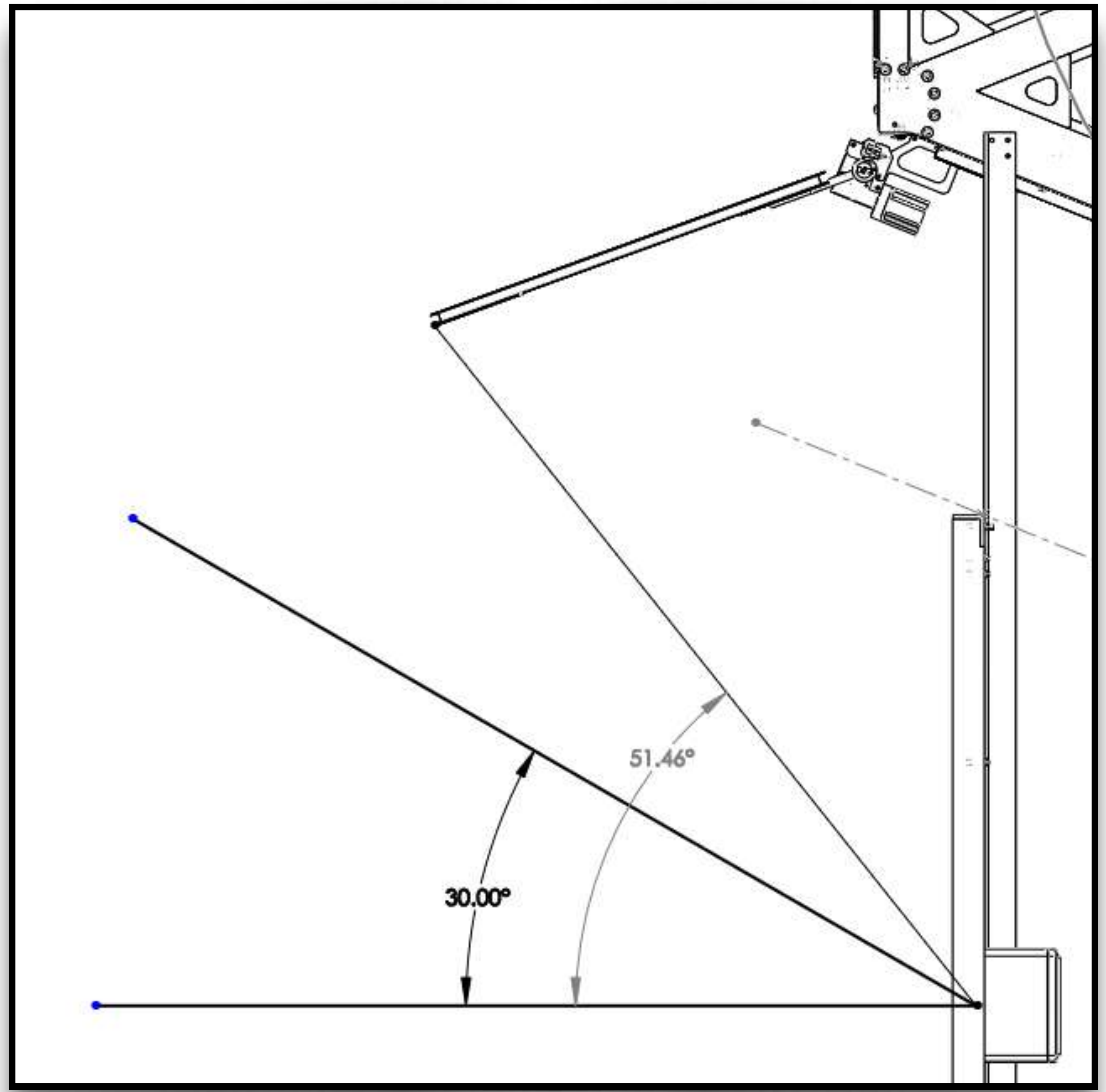
*Excludes cables and electronics

RI Clearance from Telescope

➢ **Telescope Clearance:**
- 0.5 m from the nearest Aluminum member
- Telescope nearest angle 41.4°



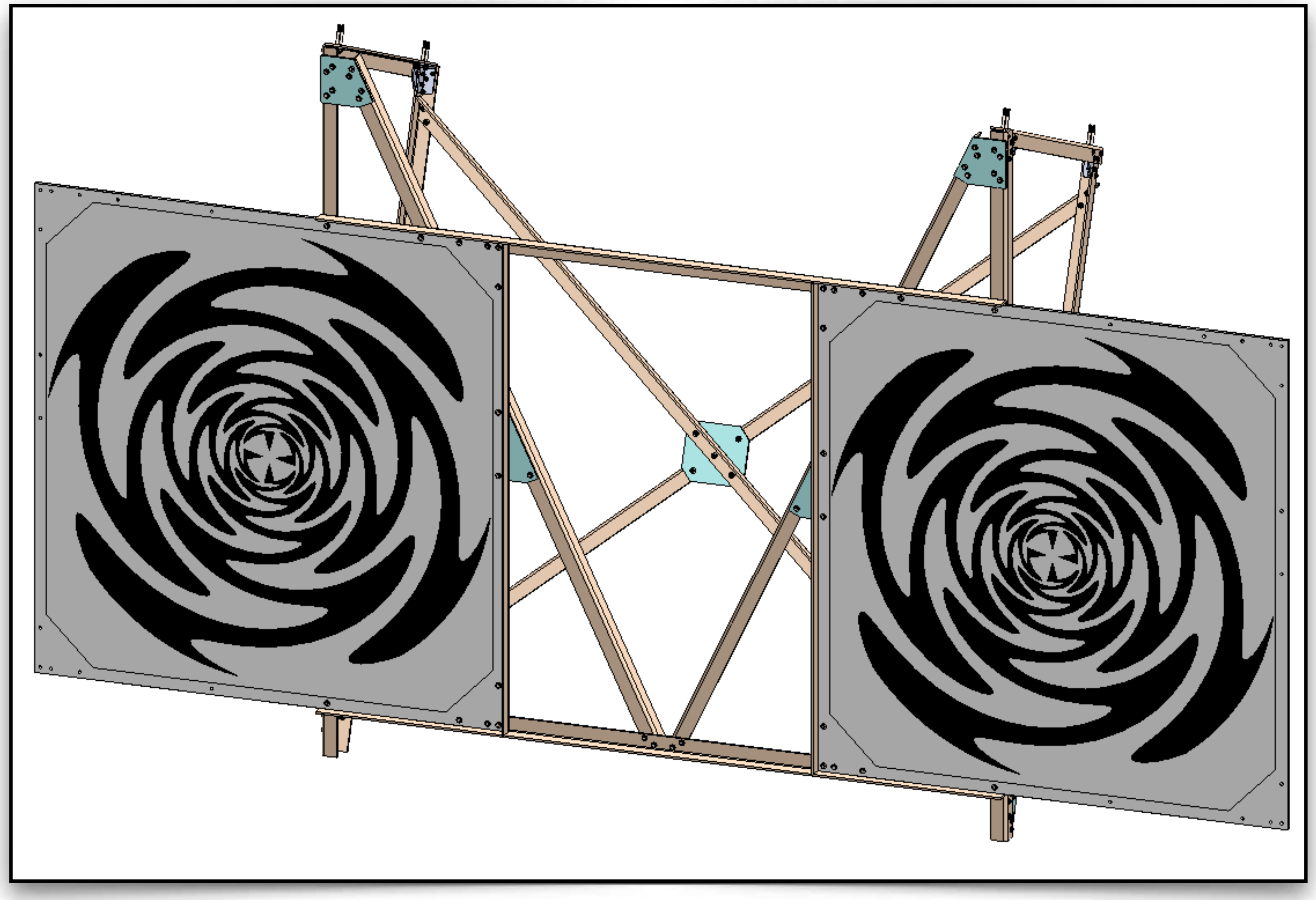
➢ **Shutter Clearance:**
- When open Al shutter edge: 51.5°
- Can shorten shutter or use fibrglass frame

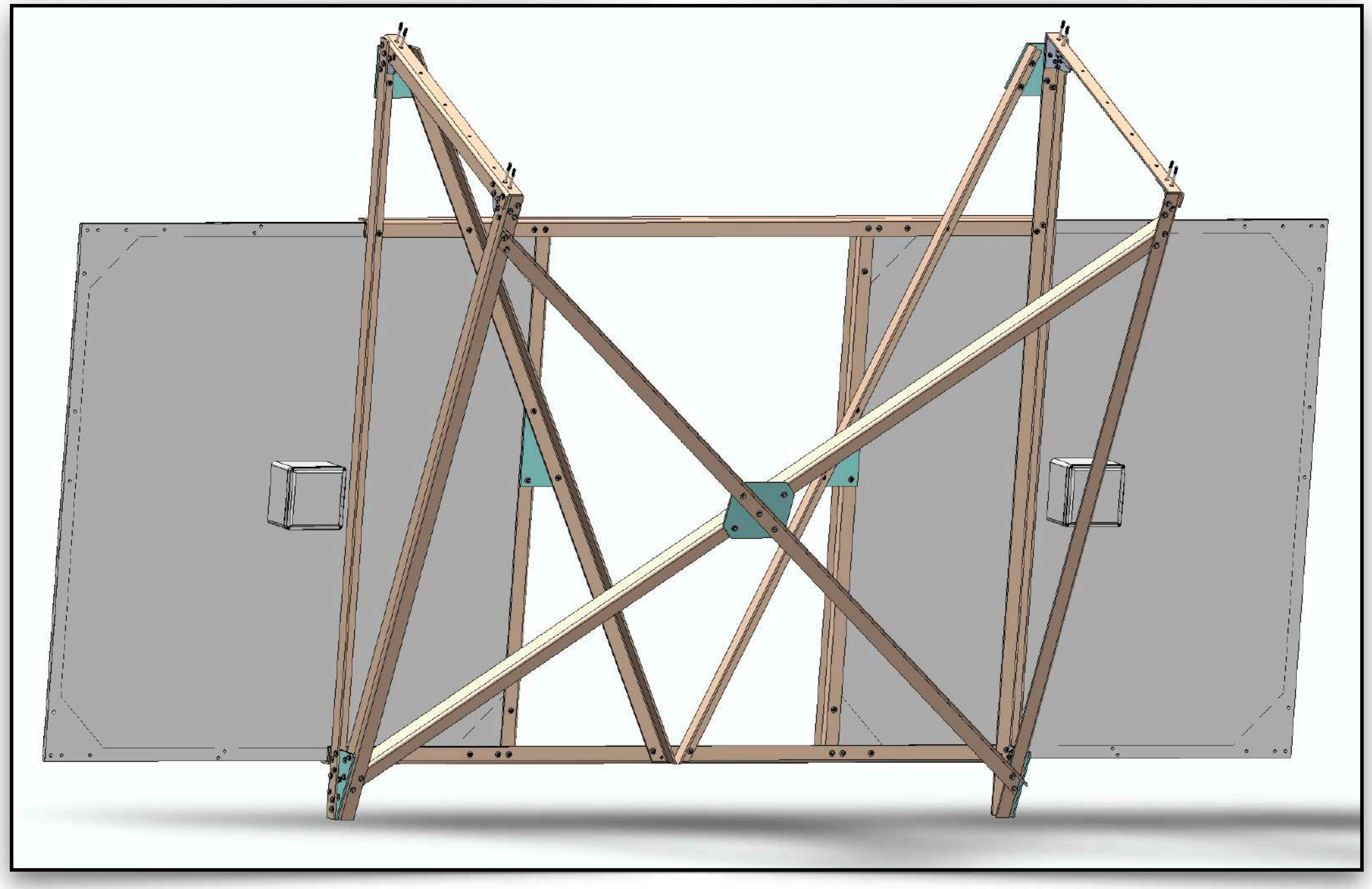


RI Mast: Materials

➢ Frame Members:
- Mainly Fiberglass L-Bar up to 12’
- G10 ideal composite, but only 3’ max
- Glass Fiber Reinforced Vinyl-Ester (GFRV) chosen as a G10 replacement
  ➜ Pultex 1625 Series Thermoset Vinyl Ester Class 1 FR composite, manufactured by Creative Pultrusions, Inc
  ➜ Precut, formed, drilled, and UV-white coated
- More than strong enough at 100°C
- Testing needed to confirm performance @ -70°C
  ➜ Will be performed at a Testing lab

➢ Joints and fasteners
- Steel bolts (not behind or in front of RI)
- Aluminum blocking for telescope mounting
- G10 Plate as gussets to reinforce Joints near RI





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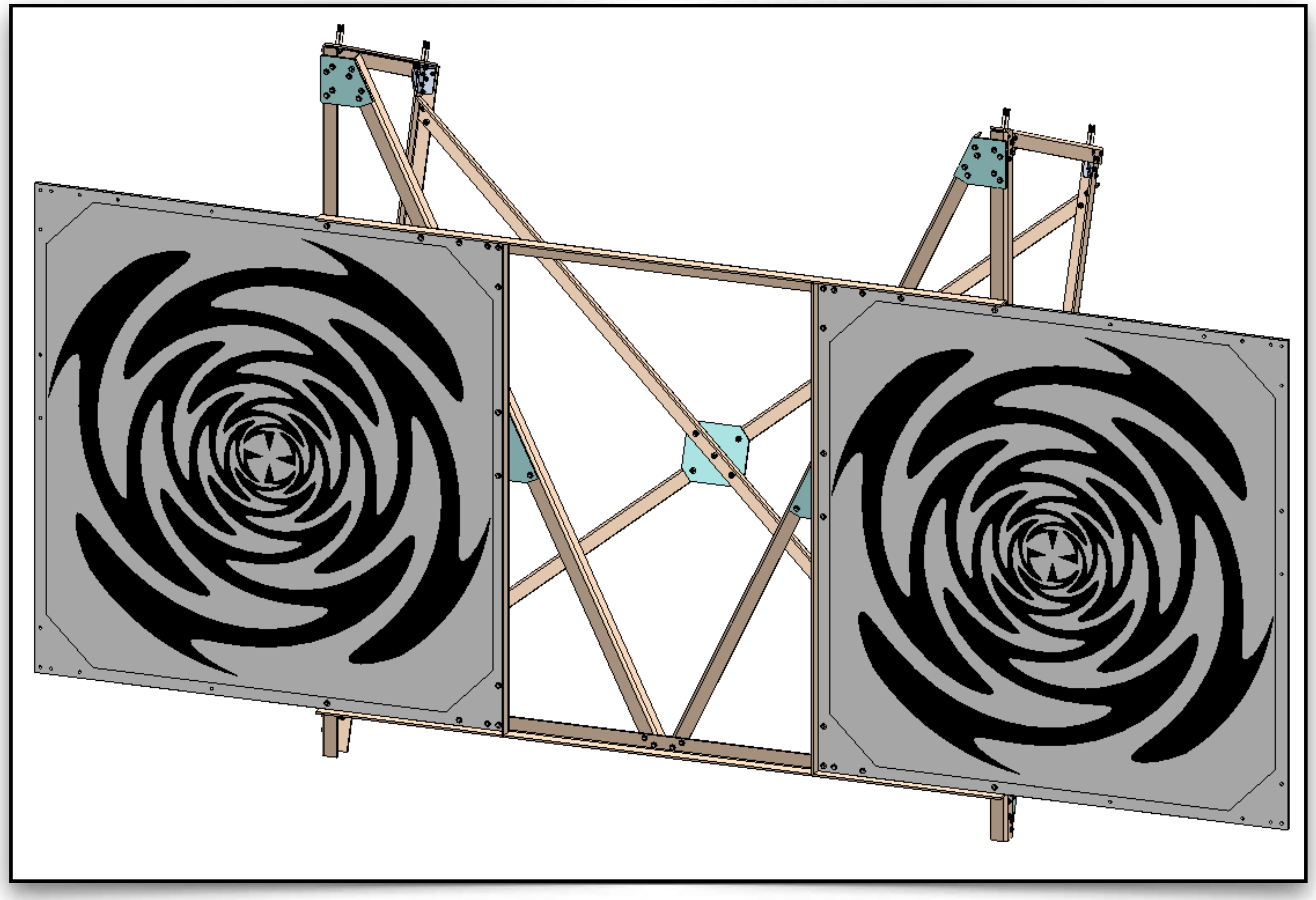
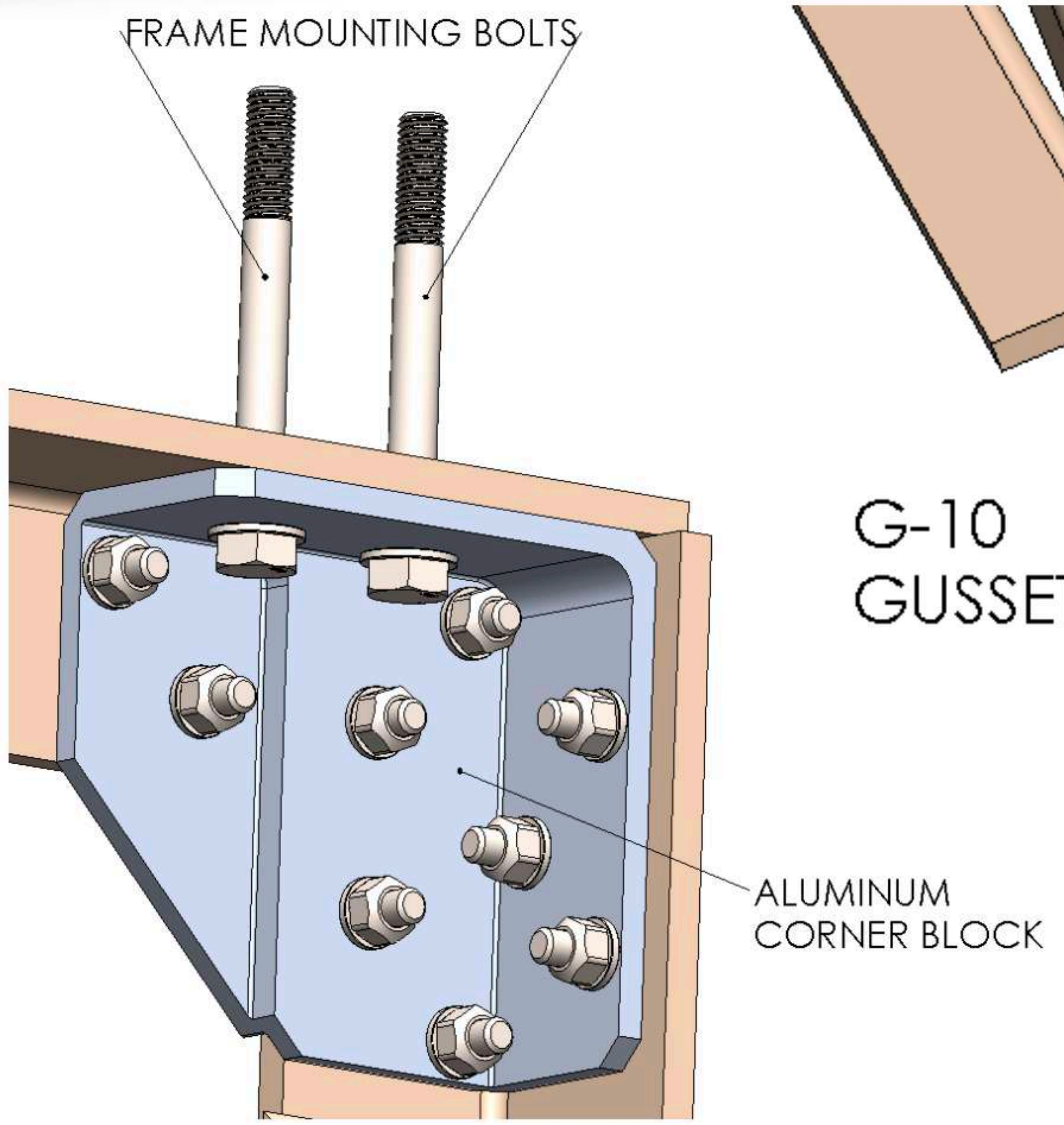
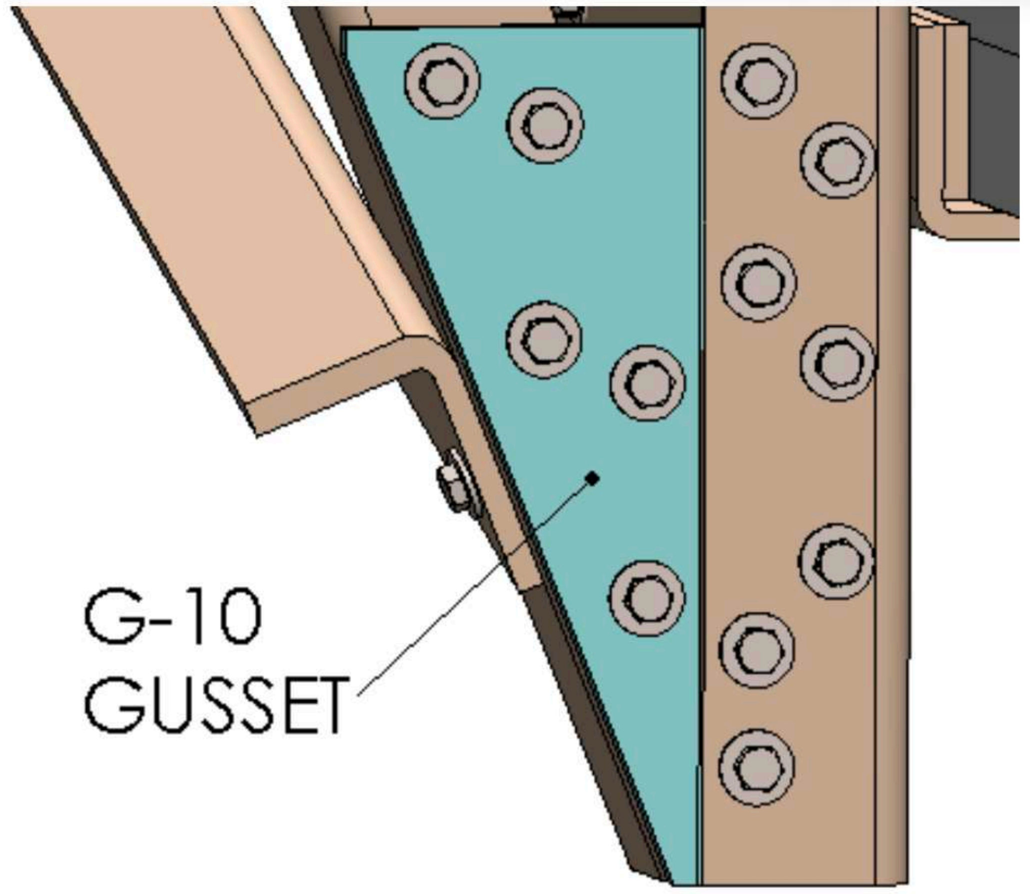






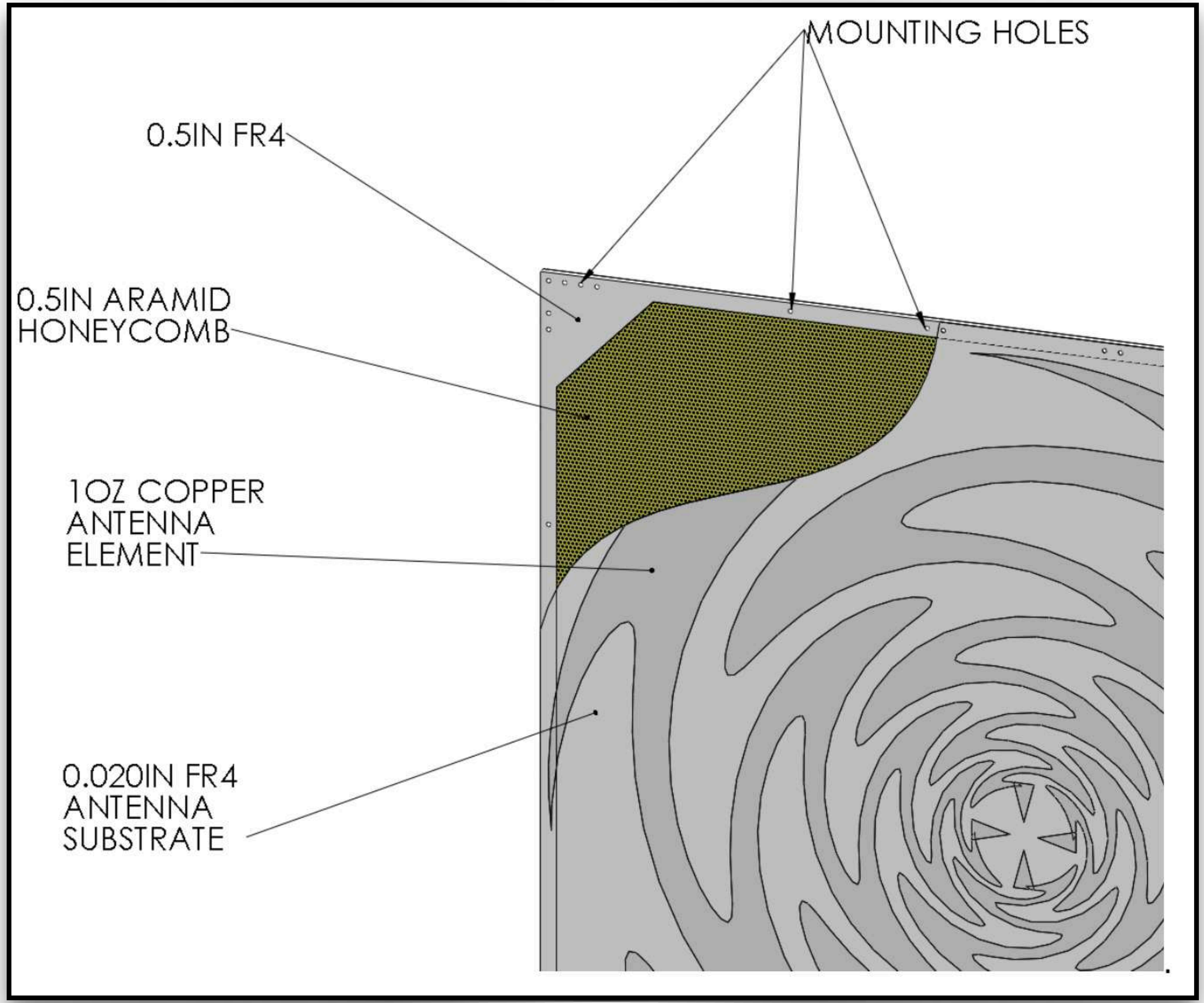
➢ **Joints and fasteners**

- **Steel bolts (not behind or in front of RI)**
- **Aluminum blocking for telescope mounting**
- **G10 Plate as gussets to reinforce Joints near RI**

RI Antenna and Frame

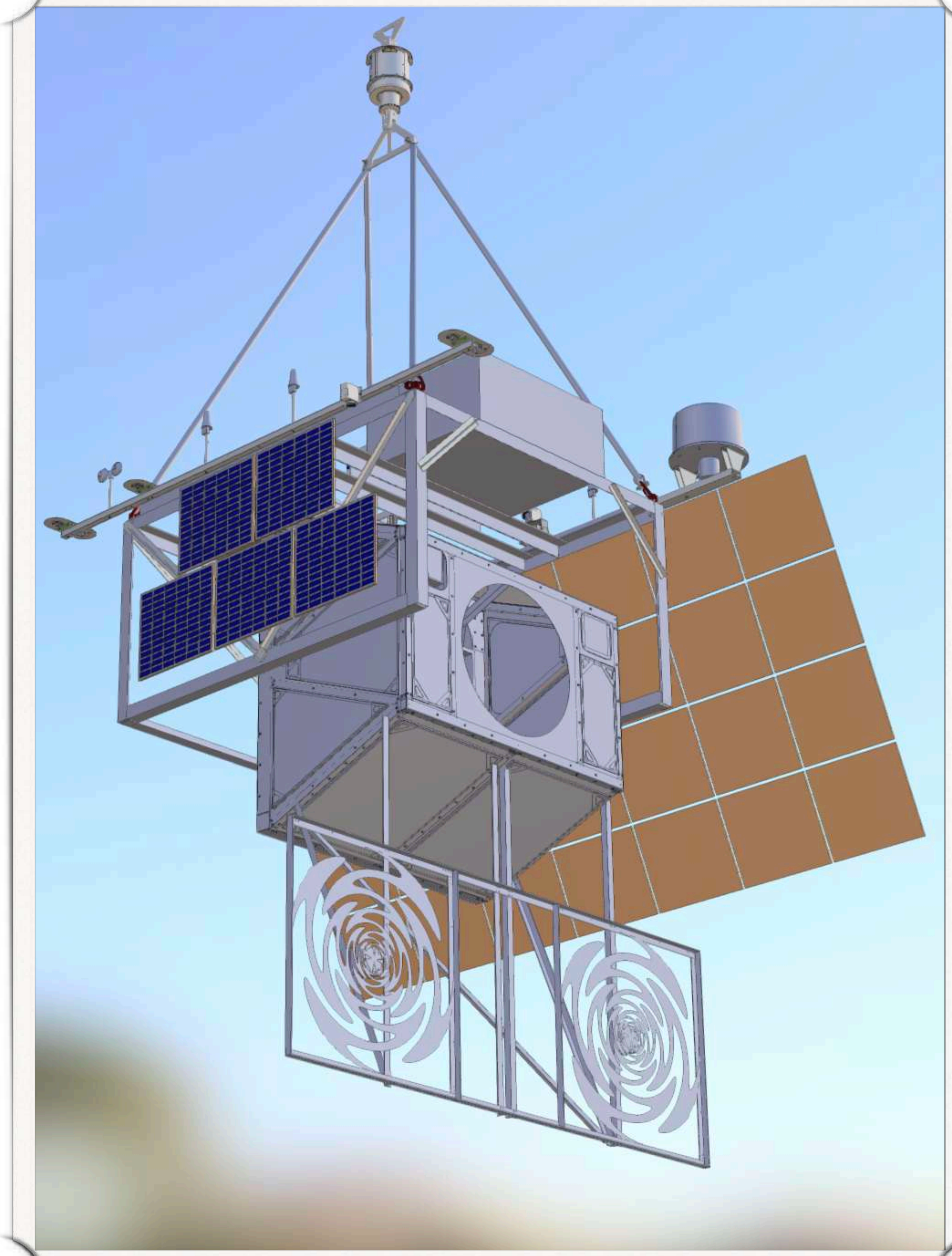
➢ **Antenna**
- Antenna Substrate: FR4 ~0.51 mm
- Antenna printed in Copper
- Gold-plated feedthroughs to electronics

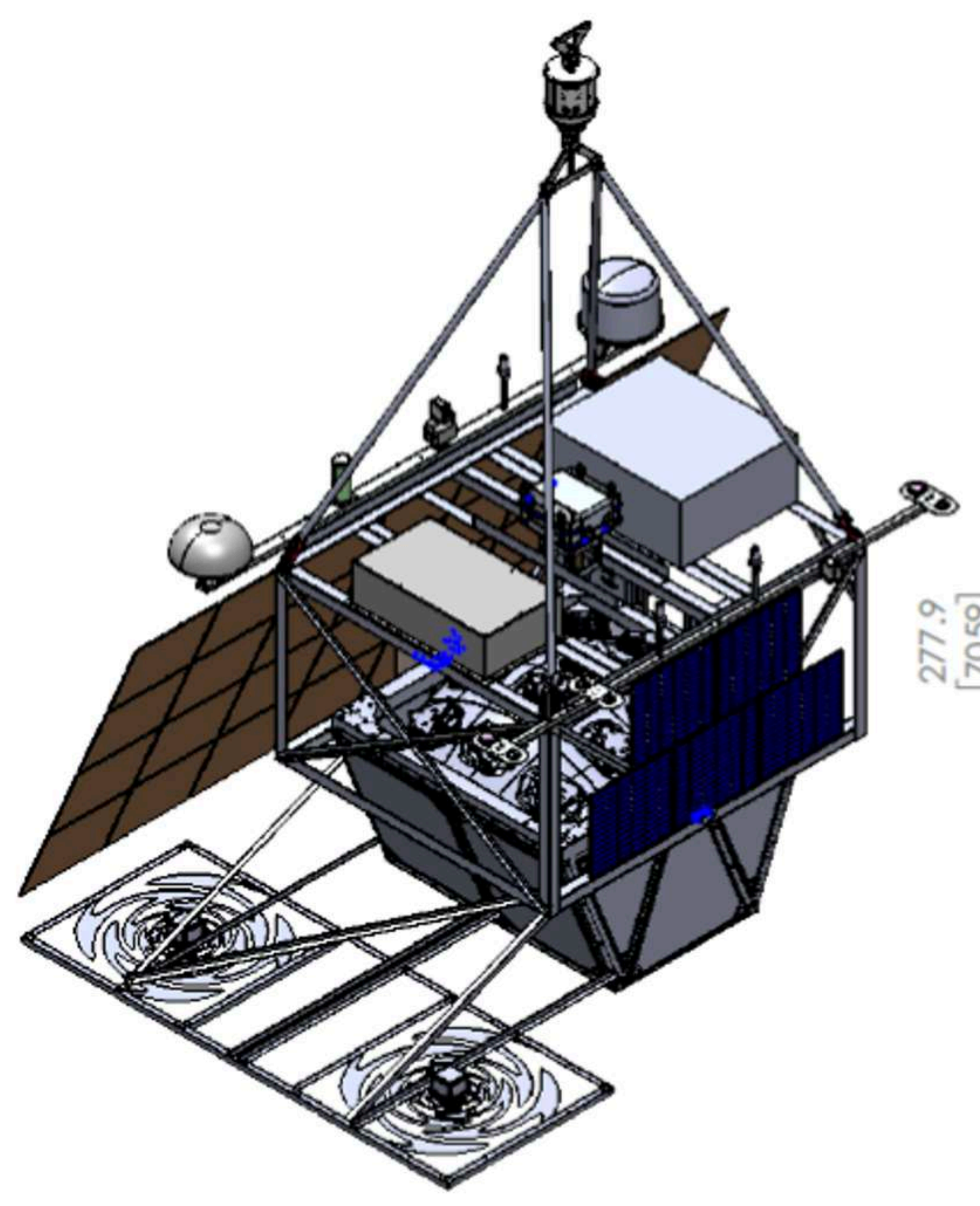
➢ **Frame**
- Frame of FR4 blocking incorporated into the Antenna assembly
- Antenna structure is 2 layers of FR4 with an infill of 0.5 in Aramid honeycomb
- Safety strapping to the FR4 frame planned via a slot cut into the FR4 front plate.

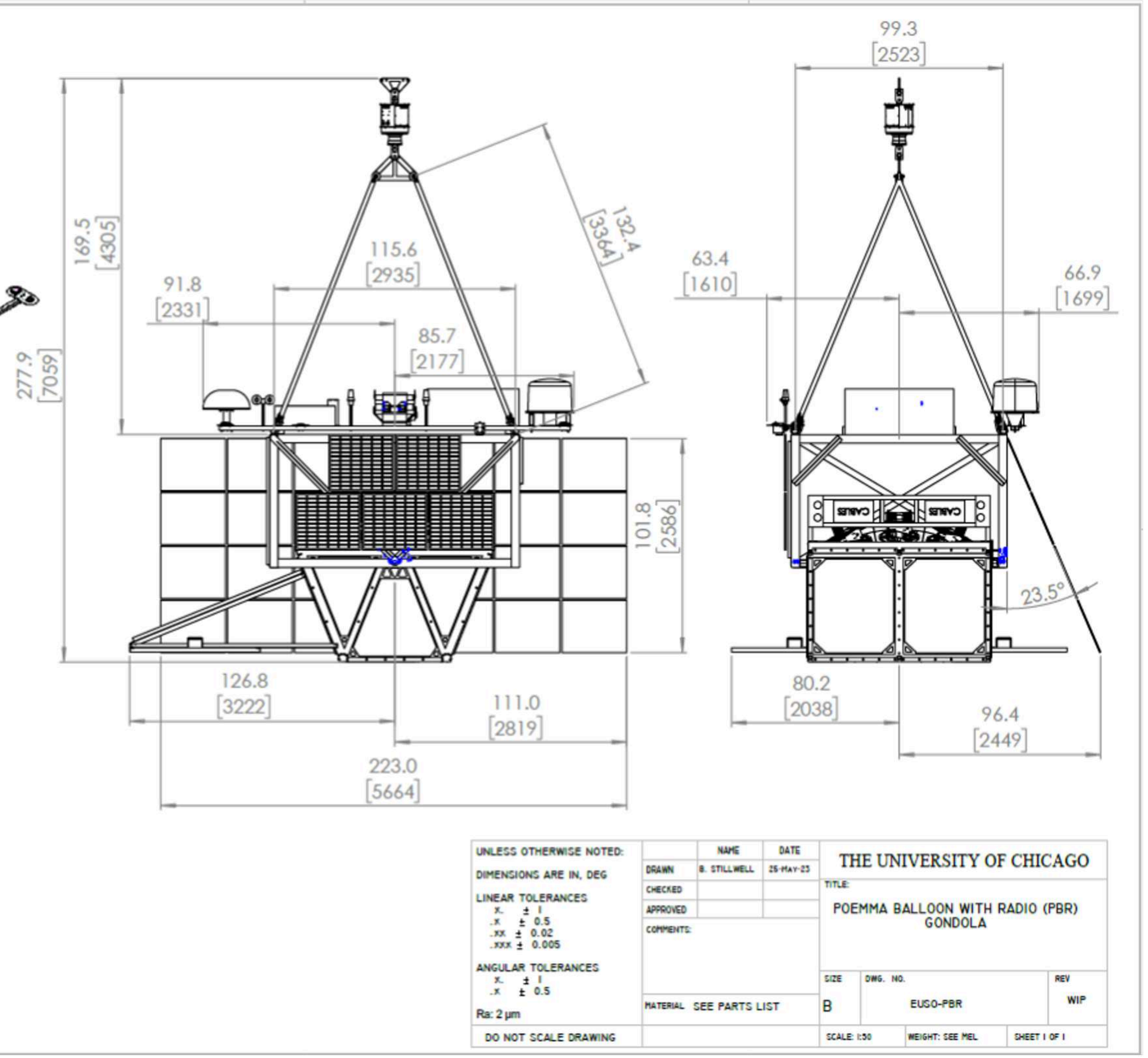


See Austin's Talk for more Details

Payload







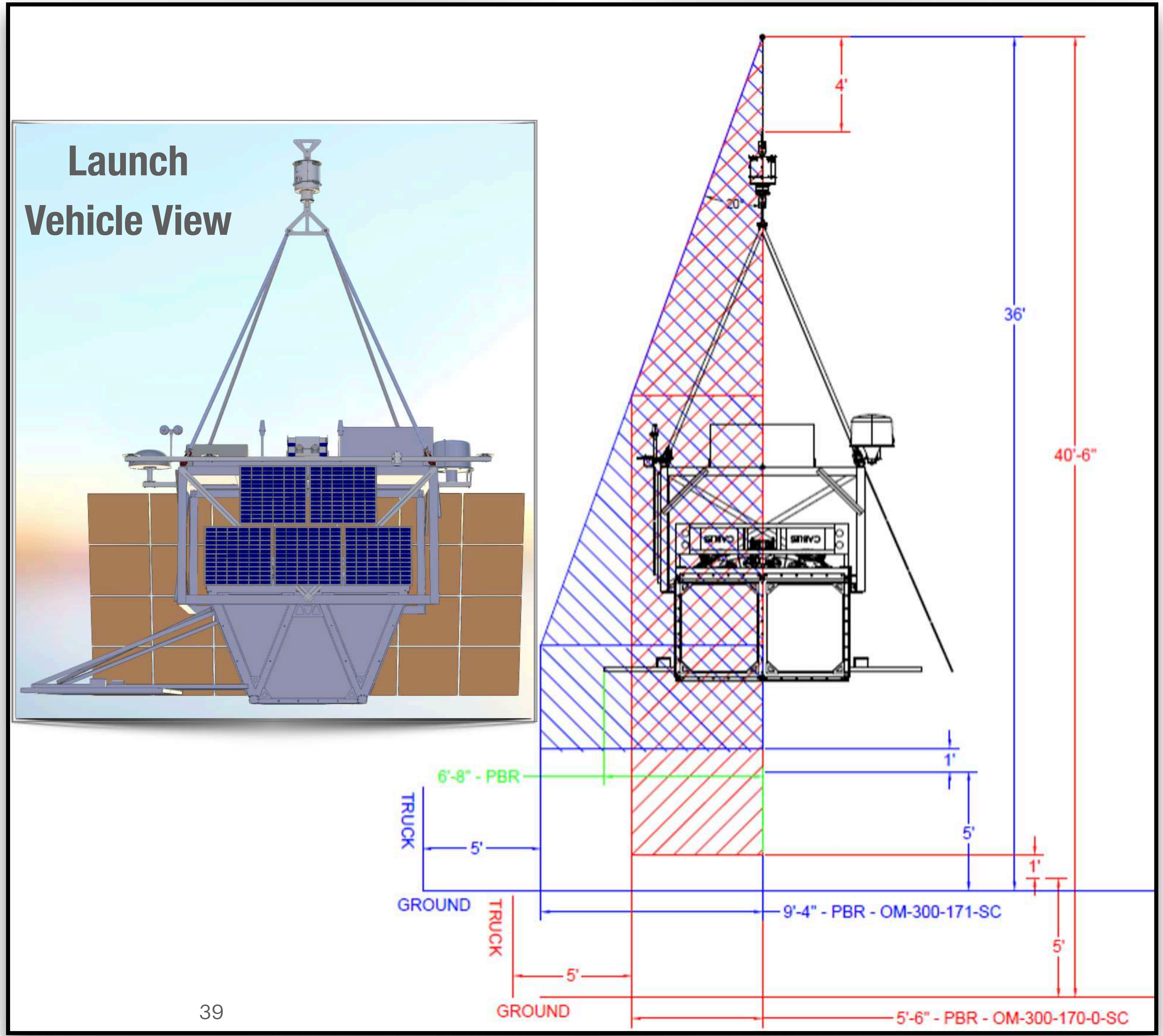
Key Parameters:

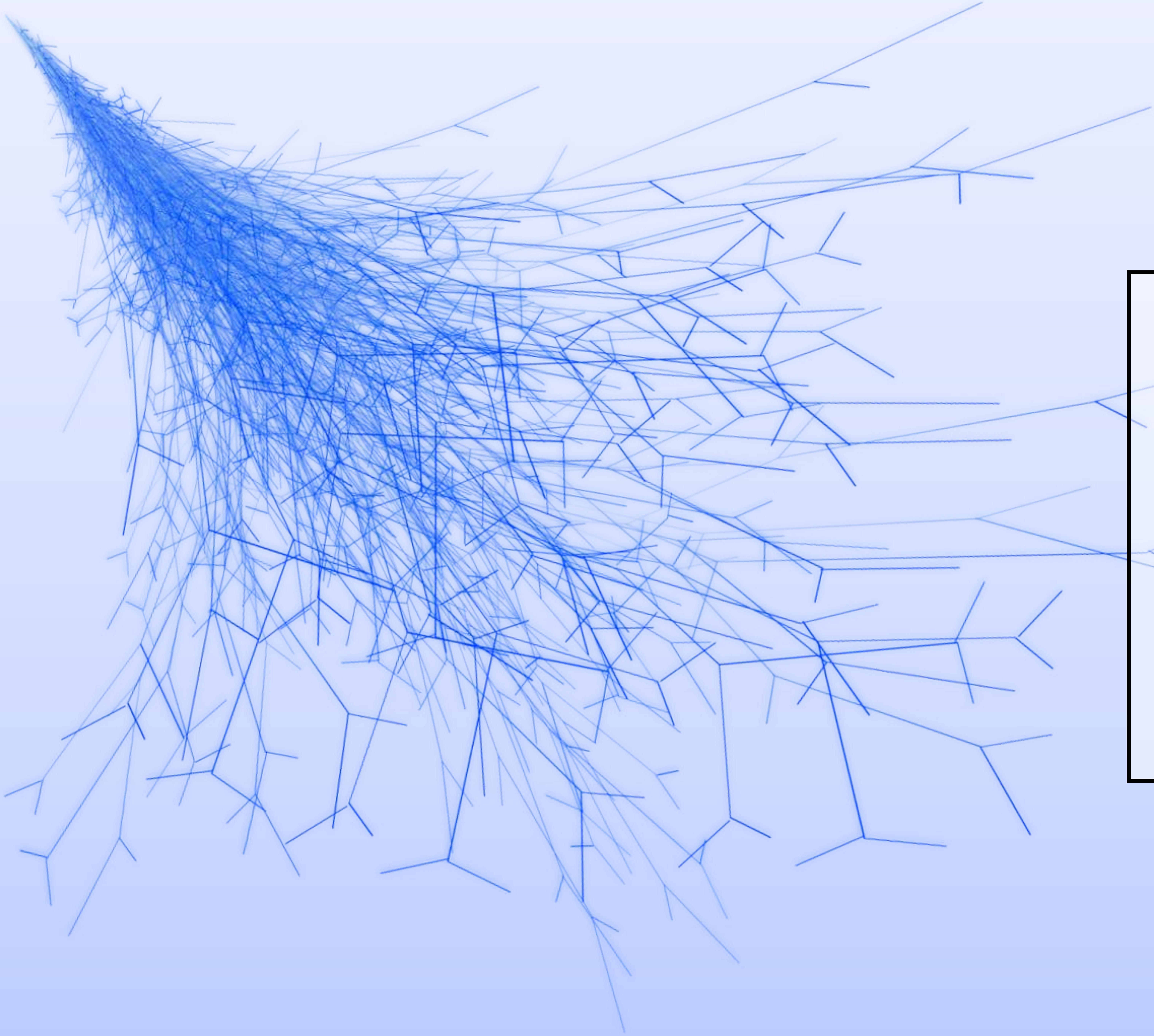
- 6.0 m wide
- 3.3 m tall
- 4.5 m deep
- ~1361 kg (3000 lbs)

Launch Configuration

For launch, the payload will be pointed downward, and we will use the "Wide-short" launch configuration:

- ➢ The Radio Frame is too wide to fit in the tall configuration when pointed to Hz
- ➢ This configuration provides the highest ground clearance
- ➢ Since the Radio is pointed down, it has a very low wind cross-section at ground level
  - During ascent, it has a higher cross-section to vertical wind loads.





Mechanical FEA / Testing

- Gondola and Telescope
- Radio Mast
- Bonded Joints
- Mirror Assembly

NASA mechanical requirements

TYPE OF HARDWARE	DESIGN FACTOR OF SAFETY		
	Yield	Ultimate	Proof Test
Metallic Structures			
Flight Structure - metallic only	1.25	1.4	N/A
Preloaded Joints	1.25	1.4	N/A
Fasteners	1.25	1.4	N/A
Welds	N/A	1.5	1.2
Suspension Systems			
Wire Rope Cables, Slings, Cable assemblies, Shackles, Turnbuckles, etc.	N/A	1.4	*
Soft-body Structures			
Slings, Webbing	N/A	2.0	*
Composite Flight Structure			
Uniform Material	N/A	1.5	1.2
Bonded Joints/Inserts	N/A	2.0	1.2
Stability/Buckling			
Stability/Buckling – metallic only	N/A	1.4	N/A
Stability/Buckling – composite	N/A	1.5	N/A
Pressure Vessel Systems	Ref: GSFC-STD-8009, ANSI/AIAA S-080A-2018		
*: based upon NASA review of GP hardware			

The strength of the gondola system shall be demonstrated by showing a positive margin of safety (MS) for individual components and assembly interfaces for the given loading environment when the factors of safety given in Table 3 are applied.

The margins of safety are determined by multiplying the design limit load (or stress) by the appropriate factor of safety and comparing it to either the yield or ultimate material allowable strength as shown in the following equations:

$$MS_u = \frac{P_u}{FS_u P} - 1$$

and

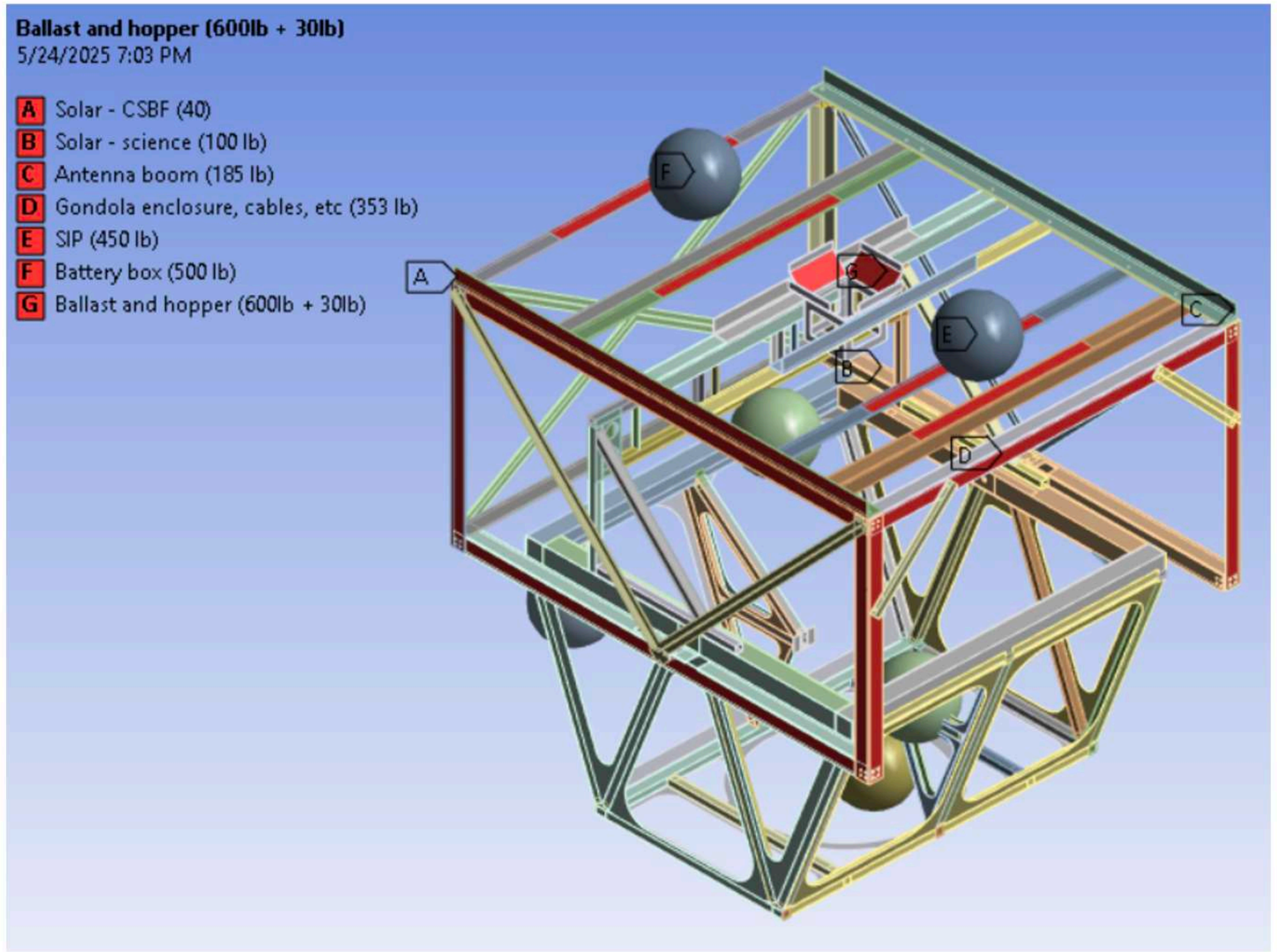
$$MS_y = \frac{P_y}{FS_y P} - 1$$

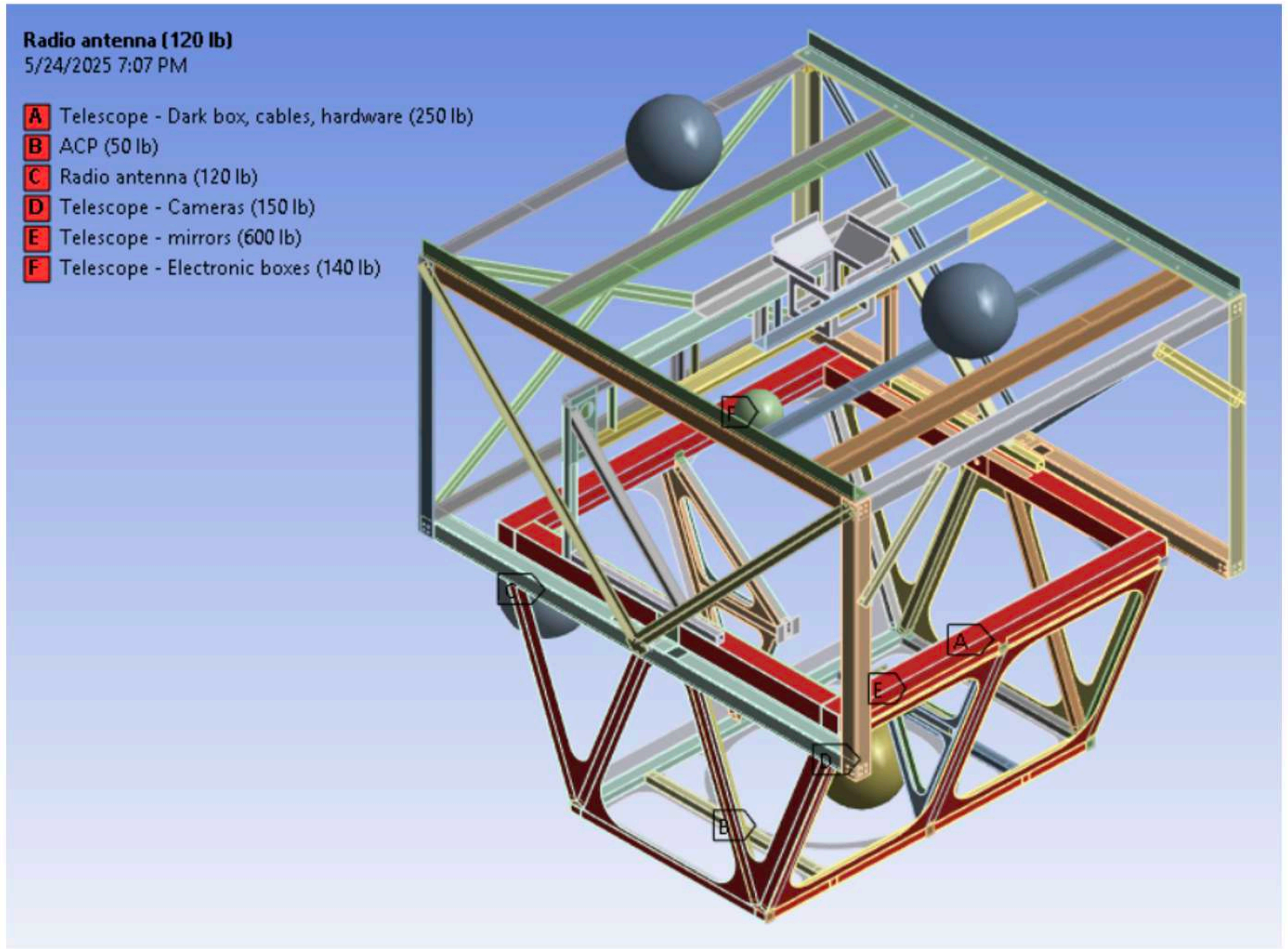
where

- FS_u is the ultimate Factor of Safety
- FS_y is the yield Factor of Safety
- P is the limit load (or stress) calculated in the analysis
- P_u is the load (or stress) at which material failure will occur
- P_y is the load (or stress) at which material yielding will occur
- MS_u is the Margin of Safety against ultimate failure
- MS_y is the Margin of Safety against material yielding

At pre-loaded interfaces, the analysis shall show positive margins for all components which comprise the interface – fittings, bolts, rivets, etc., when subjected to the loads given in Section 3.3 and the margins given in Section 3.4. Fitting analysis of critical components shall meet Section 4.4.2, Certification of Fasteners.

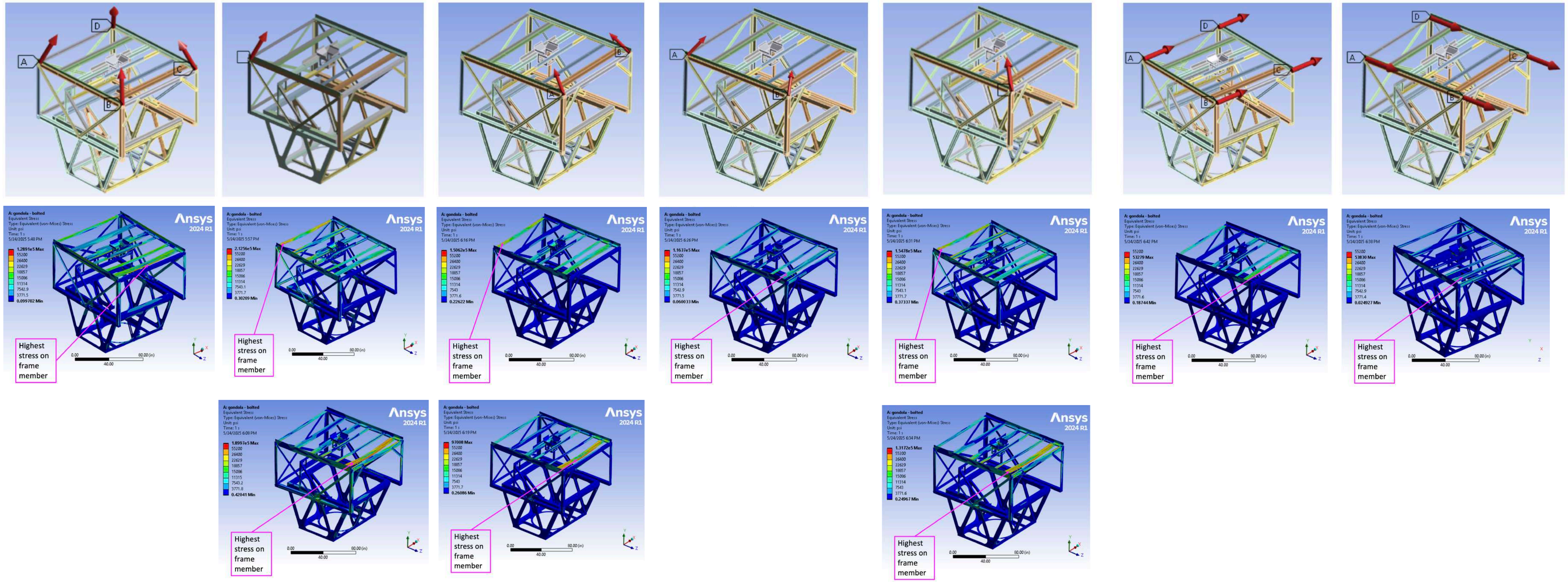
Payload Loading model





- Total mass = maximum allowable payload mass
  = CSBF MPV of 5500 lb - 915 lb (min) above pin = 4585 lb
- Analysis mass = 4585 lb - flight rigging (95 lb) = 4490 lb ≈ **4500 lb**
- Modelled subsystem masses are greater than estimated values for those components to reflect MPV.

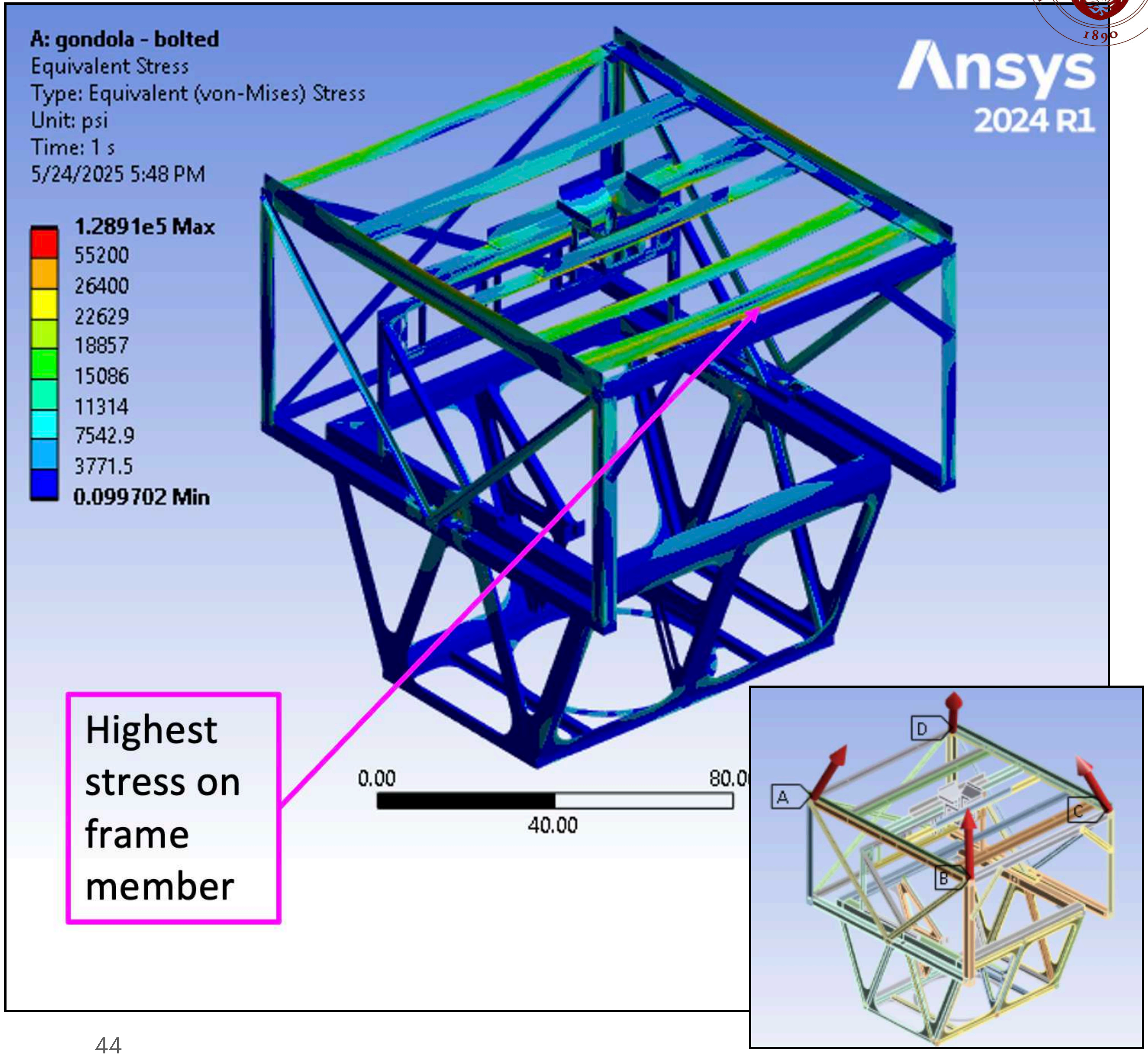
Payload Load Cases and FEA



Payload FEA Results

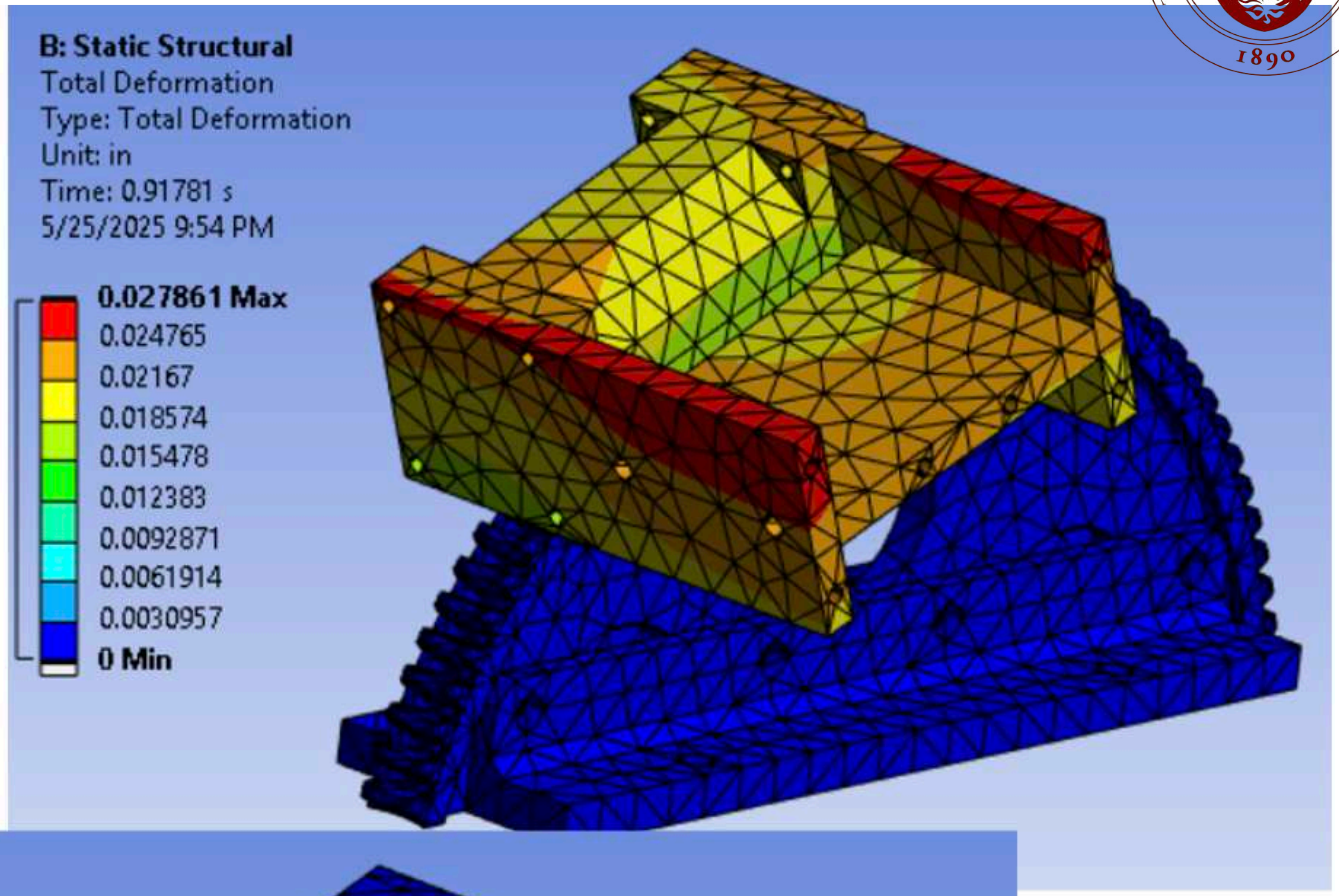
➢ Plot Reading
- 6061 yeild + 1.25 SF @ 26.4 ksi Orange
- 7075 yeild + 1.25 SF @ 55.2 ksi Red
- Some artifact stress (usually max) not usually significant if isolated and far from significant stresses

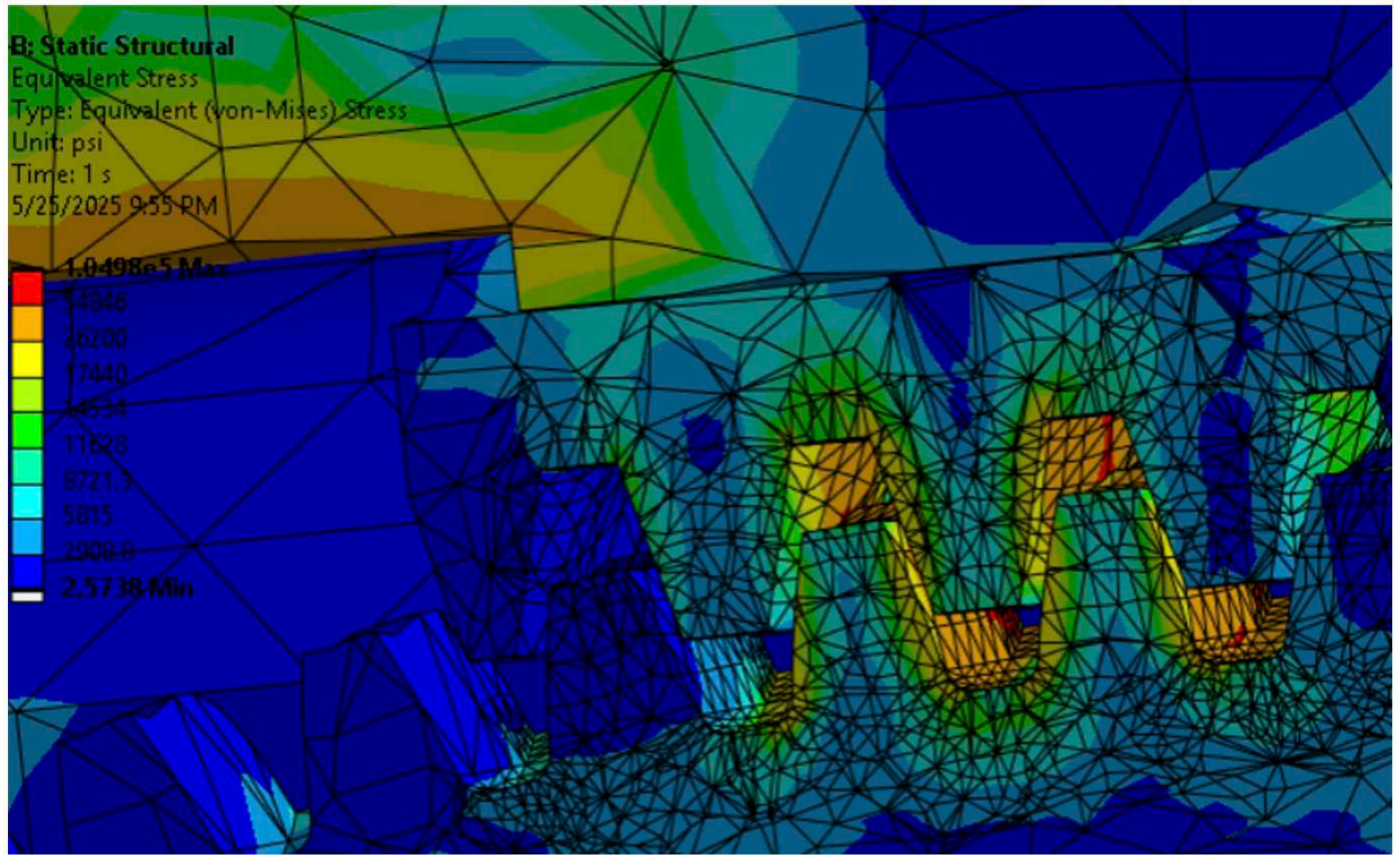
➢ Interpretation
- Gondola requires 7075 Al but has a good margin with its use
- 6061 would hit yeild so if used members would need to be thickened
- The telescope and rotator are more than strong enough to bear loads.

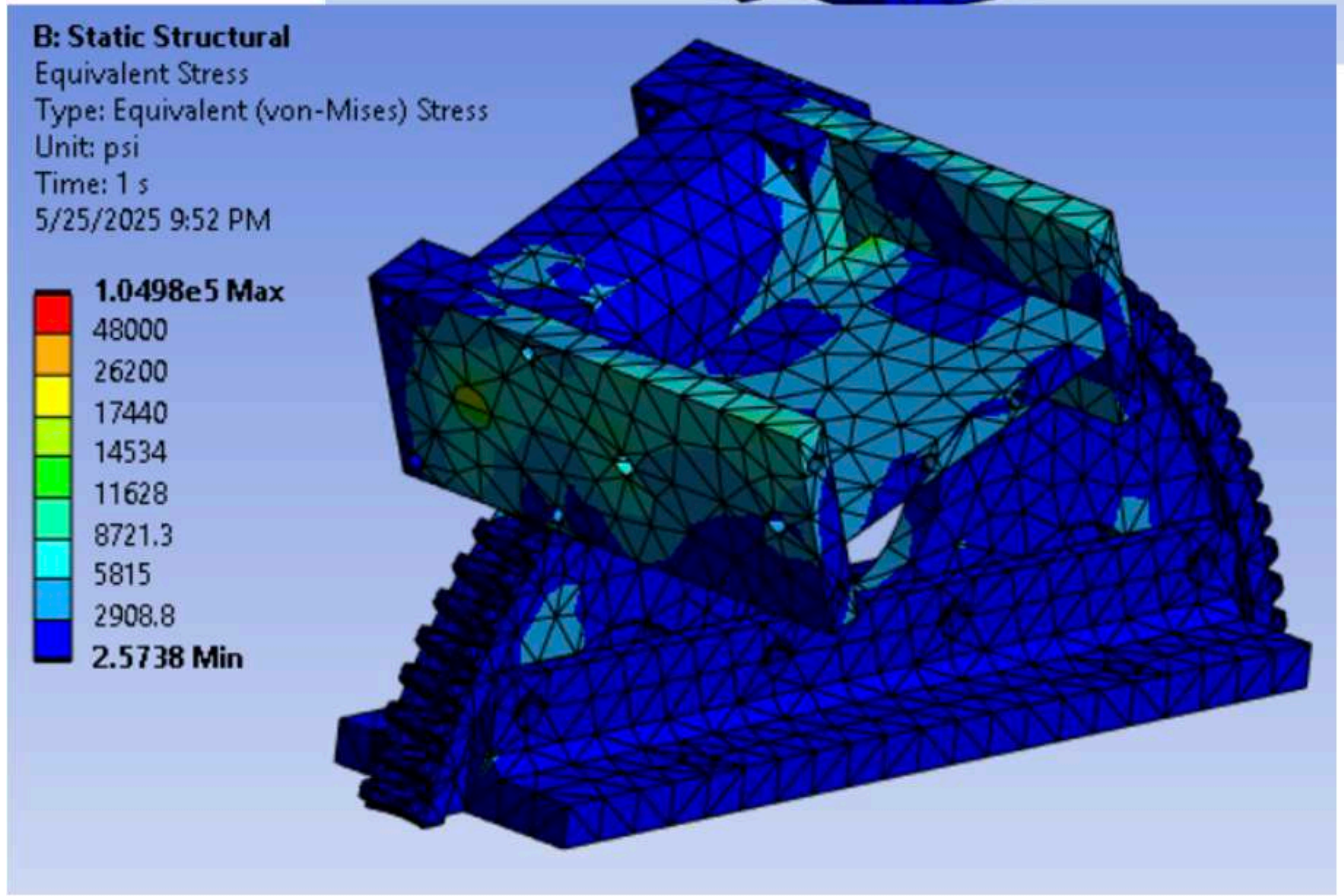


Rotator FEA Results

➢ Some trouble with the rotator
- Teeth on the gear may fail under acceleration as low as 3.6g
- Only a few teeth would fail, but rotation would be gone
- Some NASA concerns on a cascading failure of more and more teeth being removed, causing catastrophic failure.
- Solutions are not yet known. Maybe steel gearing?







See Lawrence's talk for more details

RI Frame and Mast: Strength and Testing

Table 2: Design Limit Loads

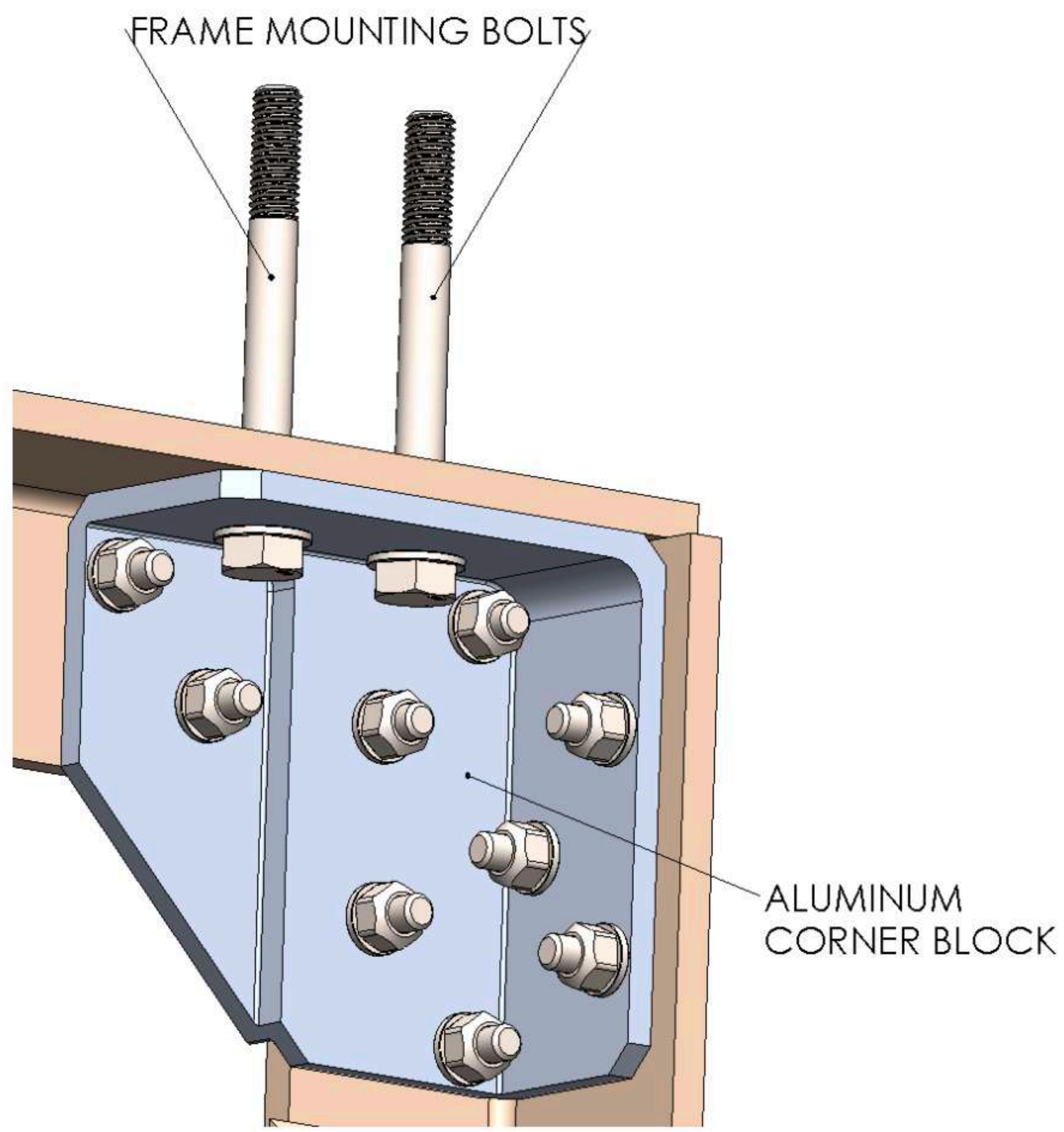
Structural Flight Hardware	Design Limit Loads (DLL) G's		
	Vertical	45 Deg	Horizontal
	8	4	4

Table 3: Design Factors of Safety

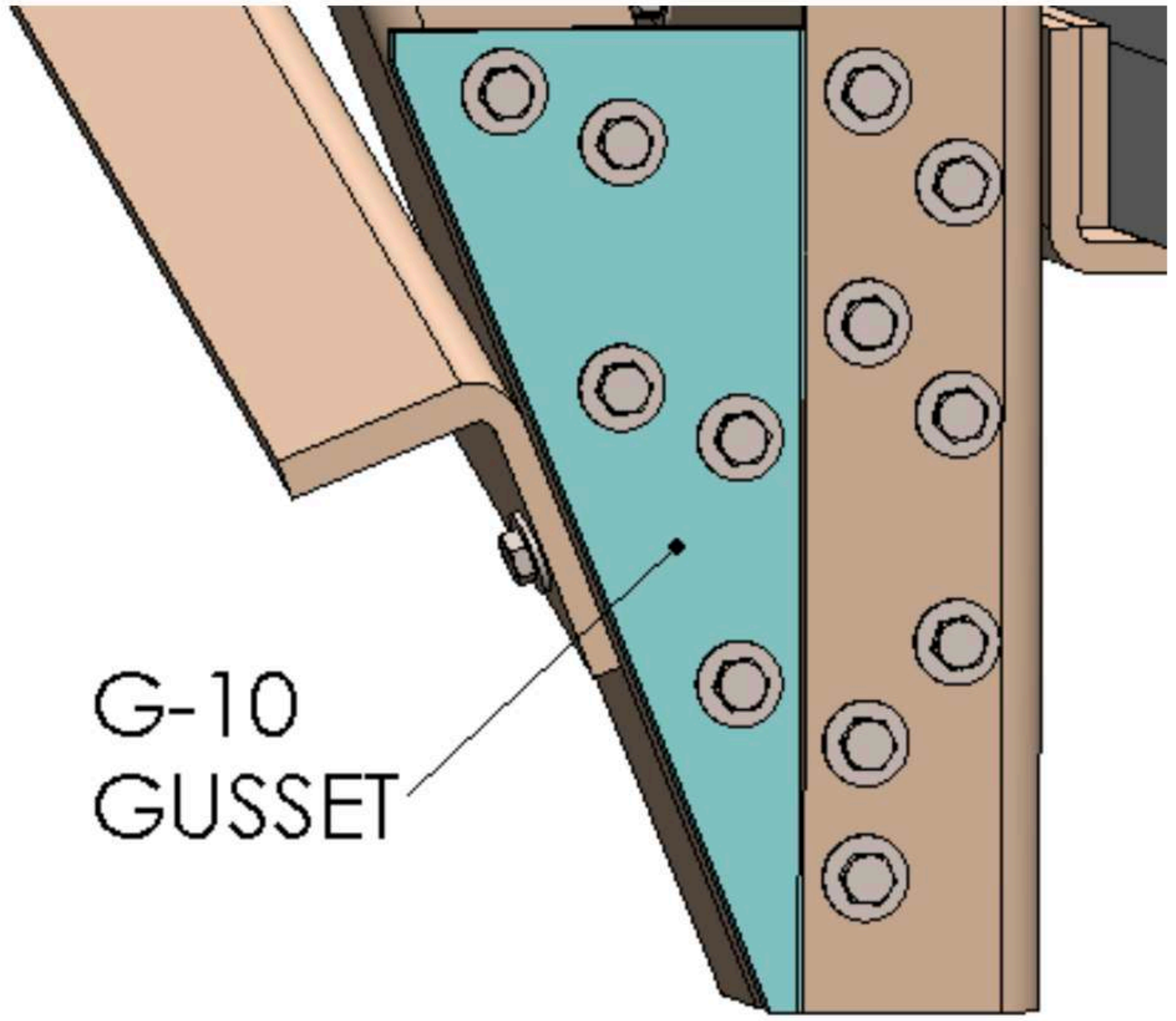
TYPE OF HARDWARE	DESIGN FACTOR OF SAFETY		
	Yield	Ultimate	Proof Test
Composite Flight Structure			
Uniform Material	N/A	1.5	1.2

Calculated Figures of Merit

Figure	Value
Assembly Weight	147 lbs
Ultimate Design Load	3300 lbf
Ultimate Safety Factor – 8G shock load	2.8
Required Safety Factor – 8G shock load	1.25

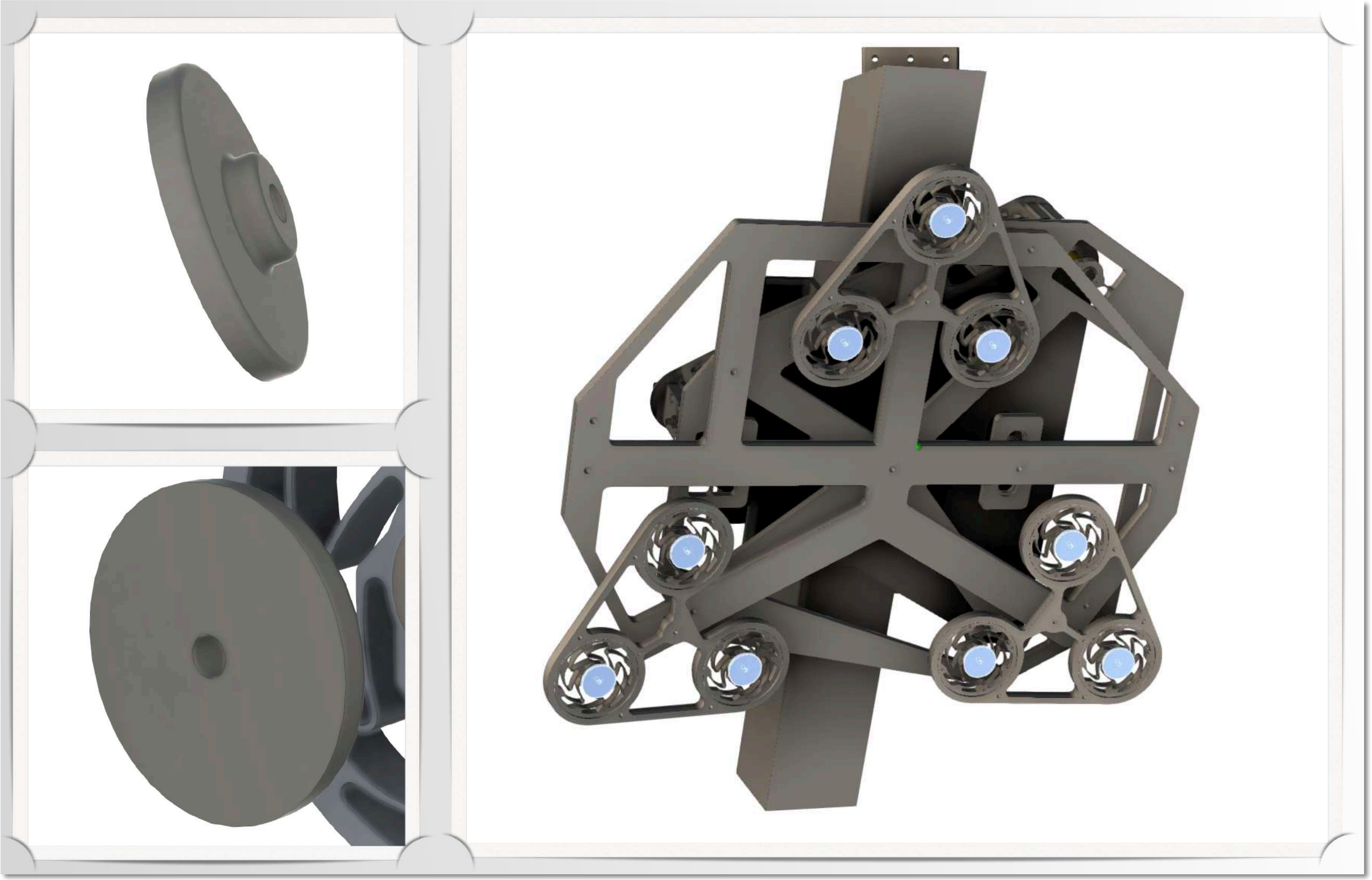


- Bearing Failure at joints determines overall strength
  ➜ Strength per bolt: G10 1100lbs, GFRV 200lbs
- Addressed with G10 Gussets, Aluminum blocking
- Samples will be professionally tested at high/low temperatures
- Safety straps to be added anyway



Mirror Cell Assembly

- **Mirror:**
  - 11mm thick Borosilicate glass, 18 lbs per segment, RoC 1660 mm
- **Glue Bond:**
  - Epoxy Bond of the mirror cell and pads
- **2.5 cm Kovar Glue Pads:**
  - Kovar has the same thermal properties as the mirror glass
  - 9 pads per mirror cell
- **Flexure Assembly**
  - 6061 Al springs to absorb thermal loads
- **Whipple Tree**
  - Aluminum the assembly to map pads to the glass and evenly distribute loads
- **Aiming and Frame Mounting**
  - Aluminum assembly for precision alignment of mirrors



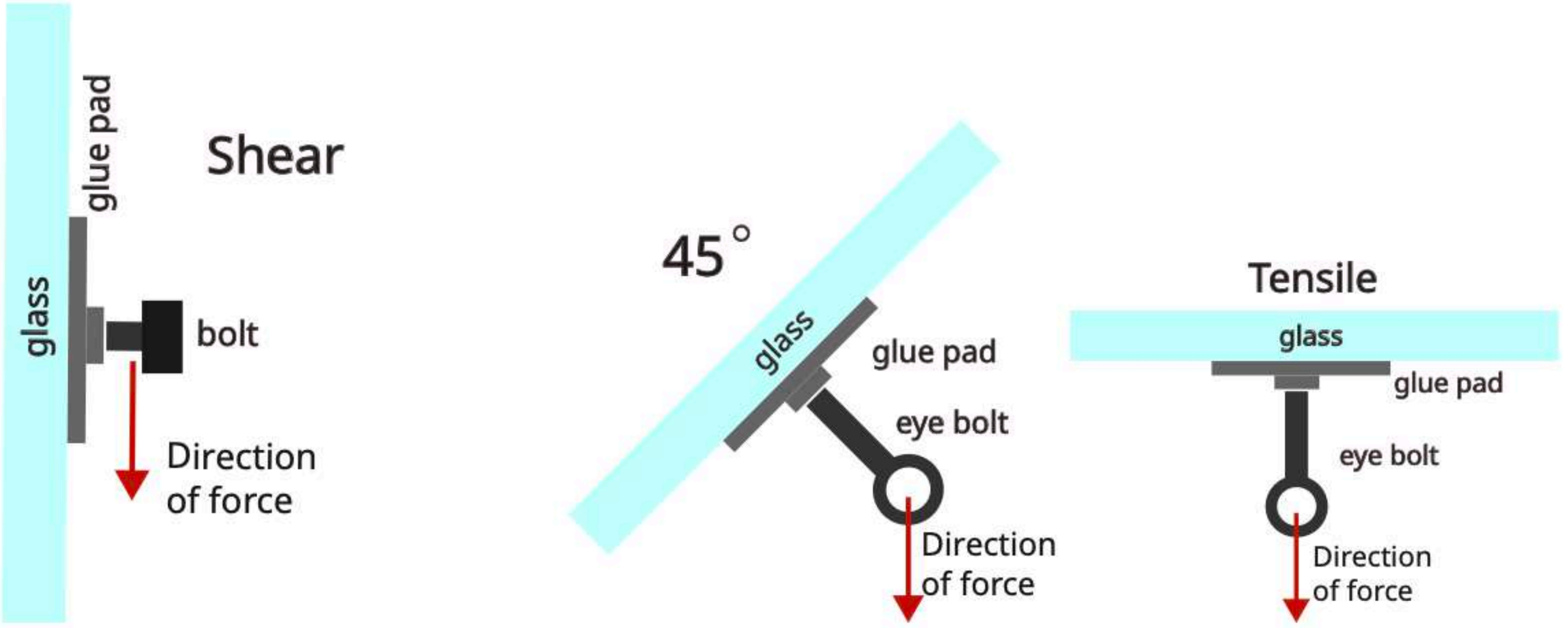
Bonded Joint Requirements

Table 2: Design Limit Loads

Structural Flight Hardware	Design Limit Loads (DLL) G's		
	Vertical	**45 Deg**	**Horizontal**
	8	4	4

Table 3: Design Factors of Safety

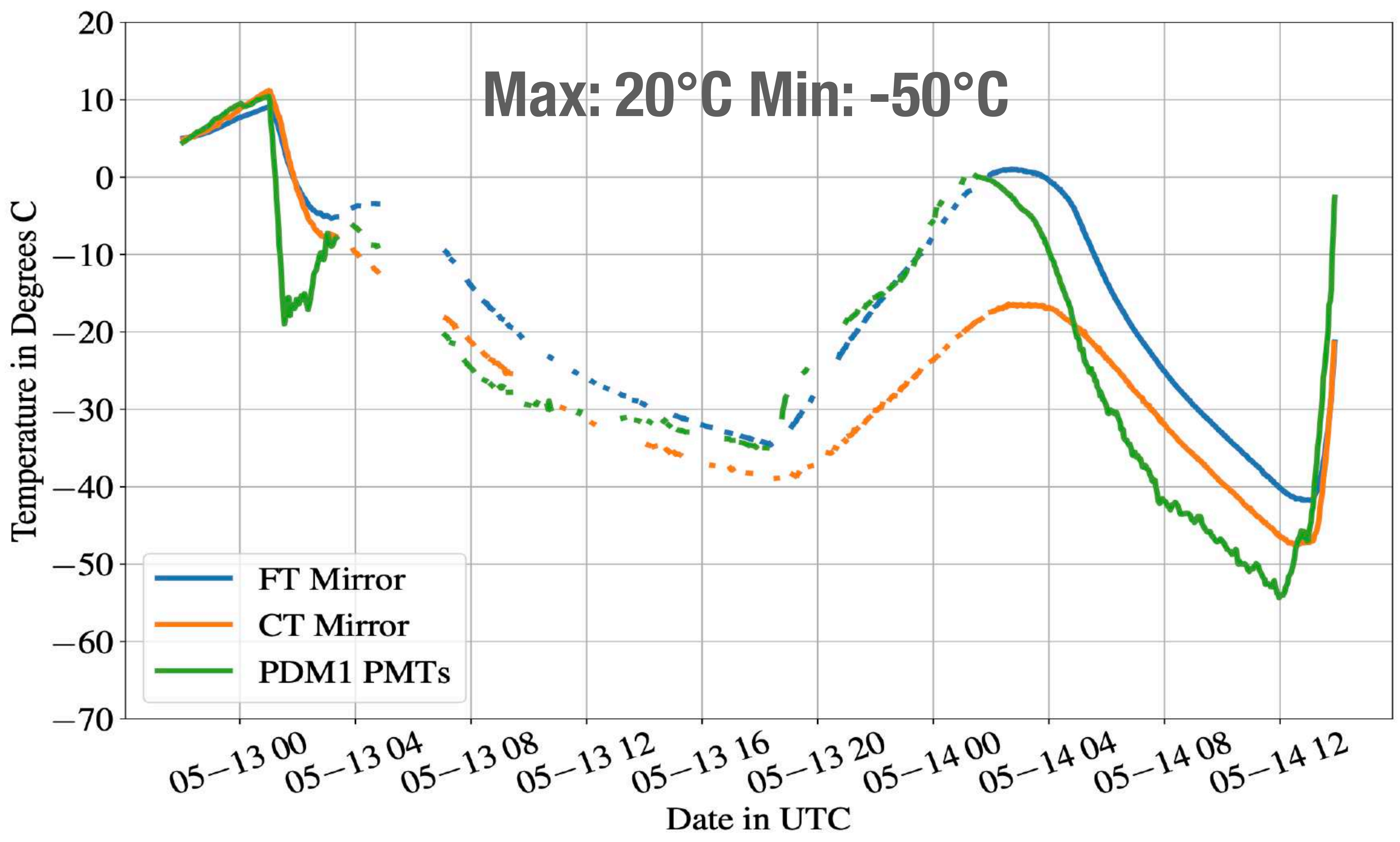
TYPE OF HARDWARE	DESIGN FACTOR OF SAFETY		
	Yield	**Ultimate**	**Proof Test**
Composite Flight Structure			
Uniform Material	N/A	1.5	1.2
Bonded Joints/Inserts	N/A	2.0	1.2
Stability/Buckling			



(a) Shear setup (b) 45° setup (c) Tensile setup

Figure 6: Three configurations of load cases that need to be tested

EUSO-SPB2 Telescope Temperatures



Mirrors Glued at ~25°C

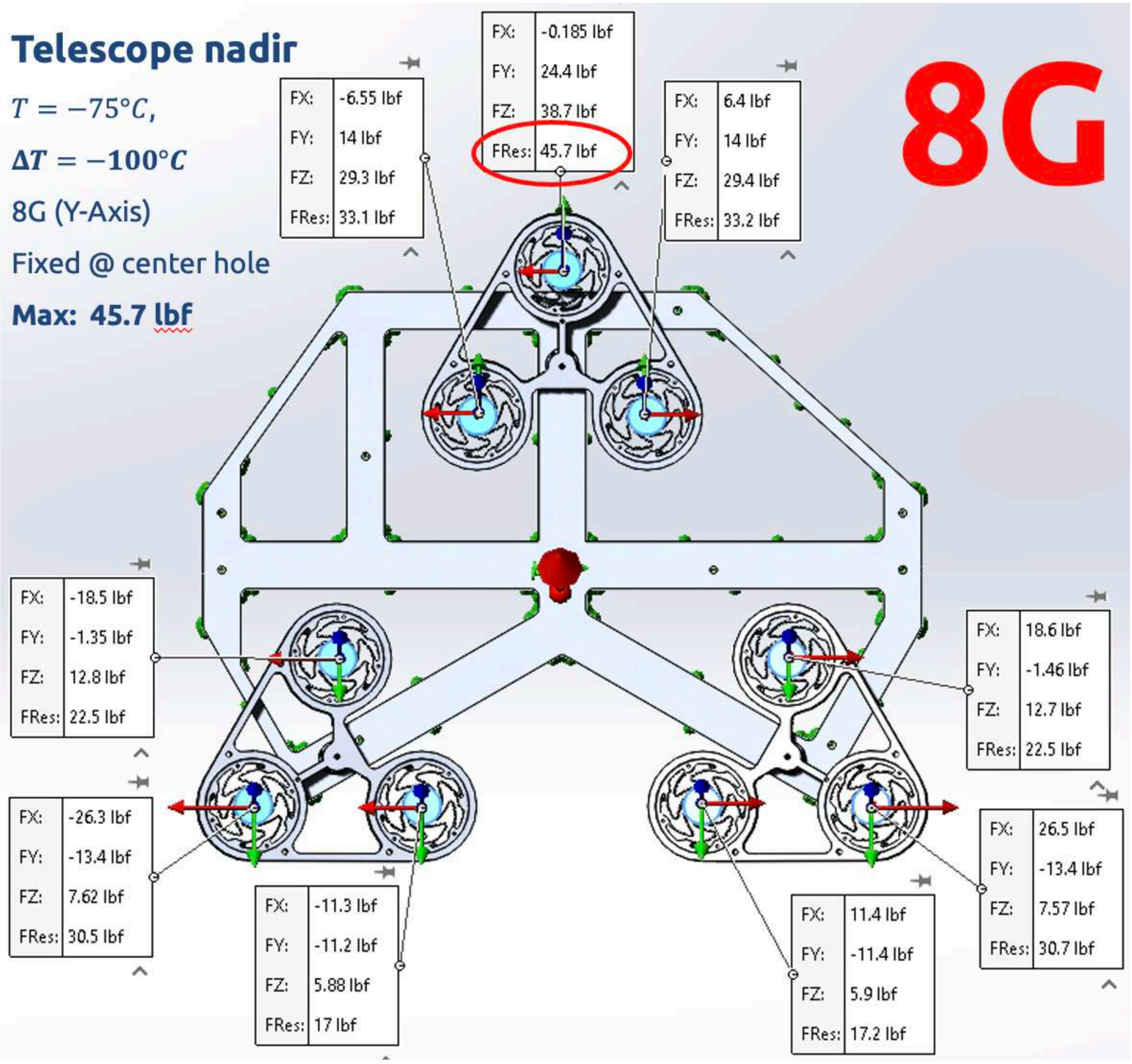
Flight as cold as -50°C

➜ Glue bond must also handle load from ΔT = -75°C

Bonded Joint FEA @ 8G / -100°C ΔT

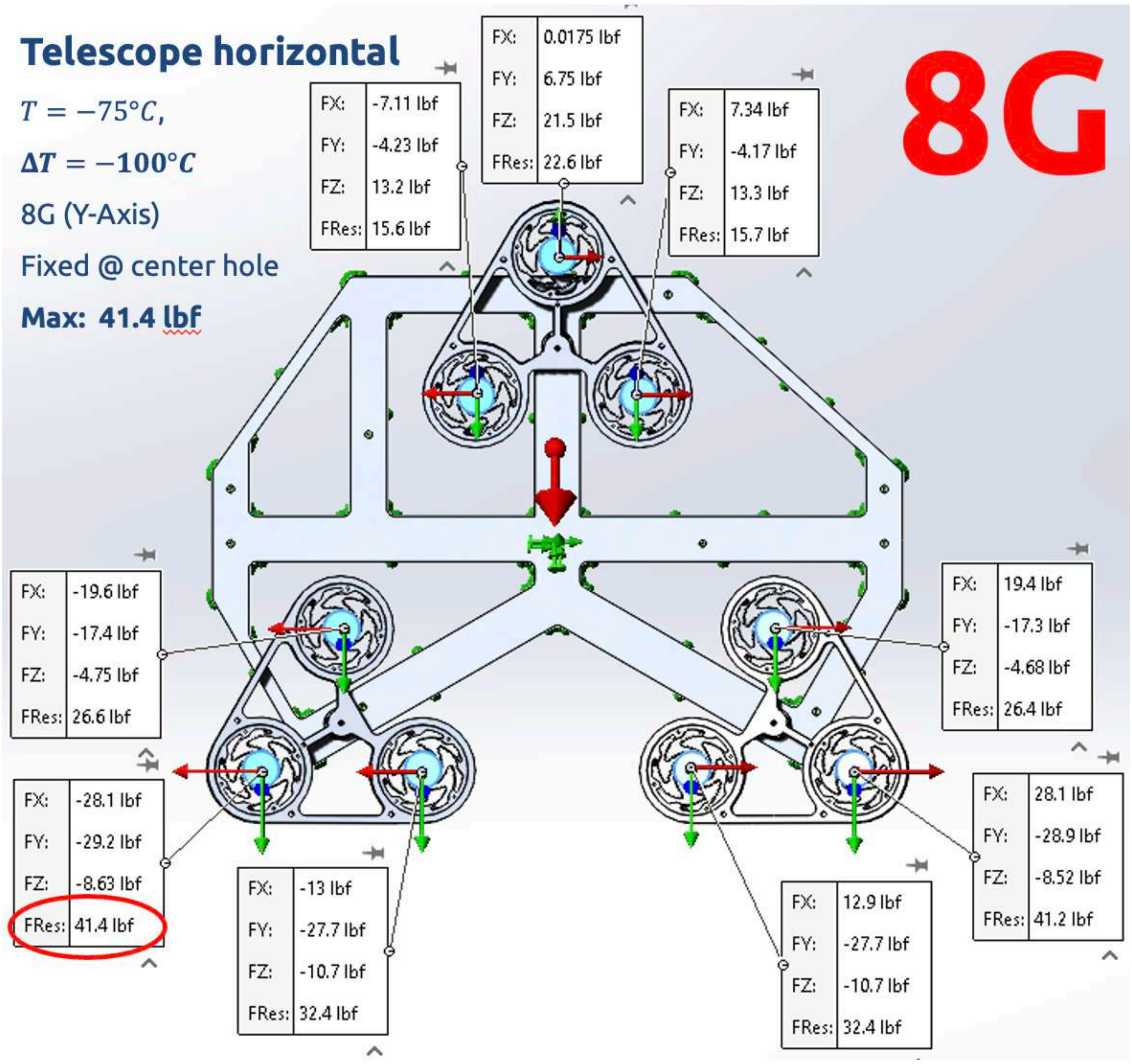
Tensile

Tensile

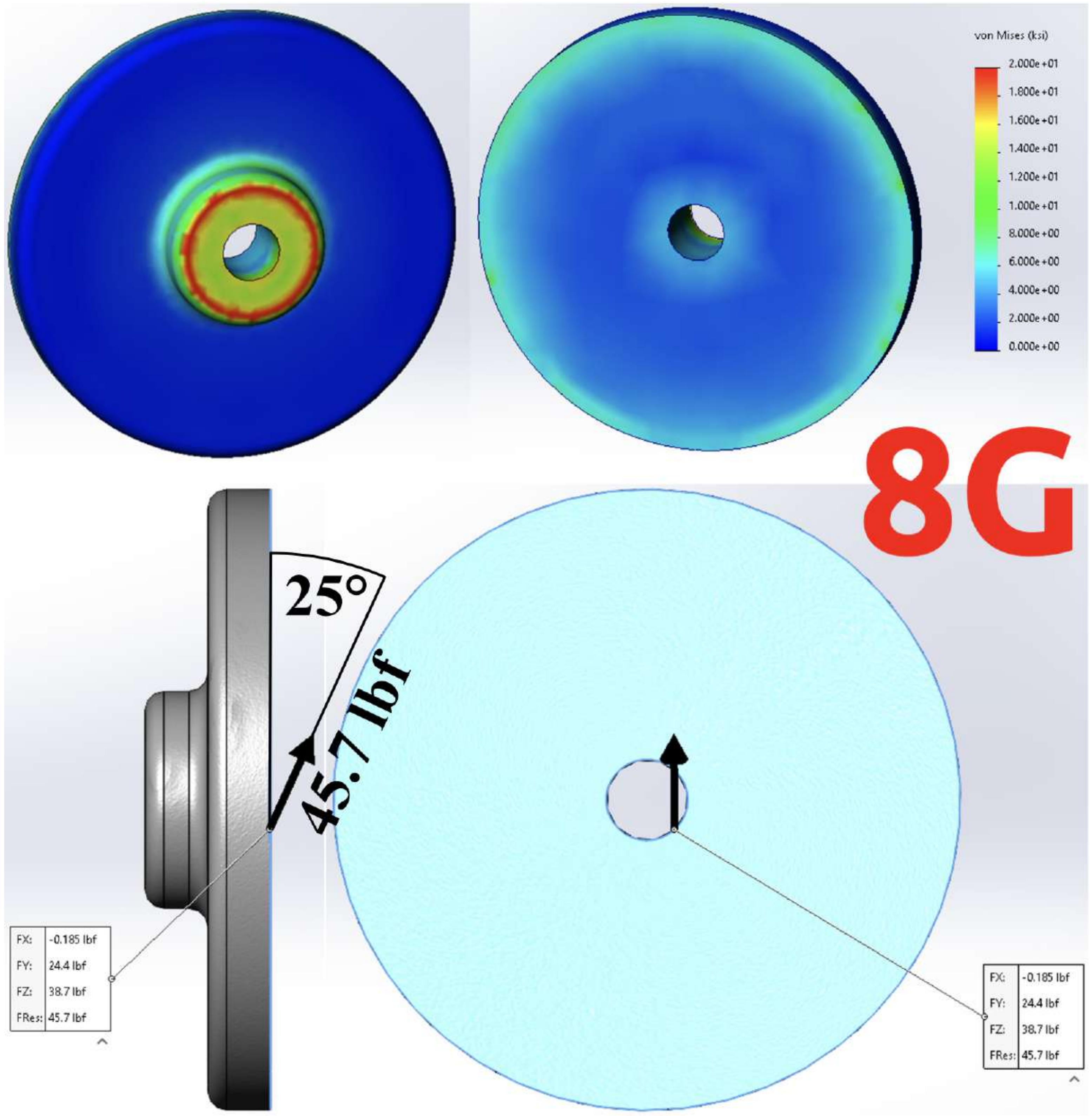


Max Single Pad 45.7 lbs

Shear



Max Single Pad 41.4 lbs

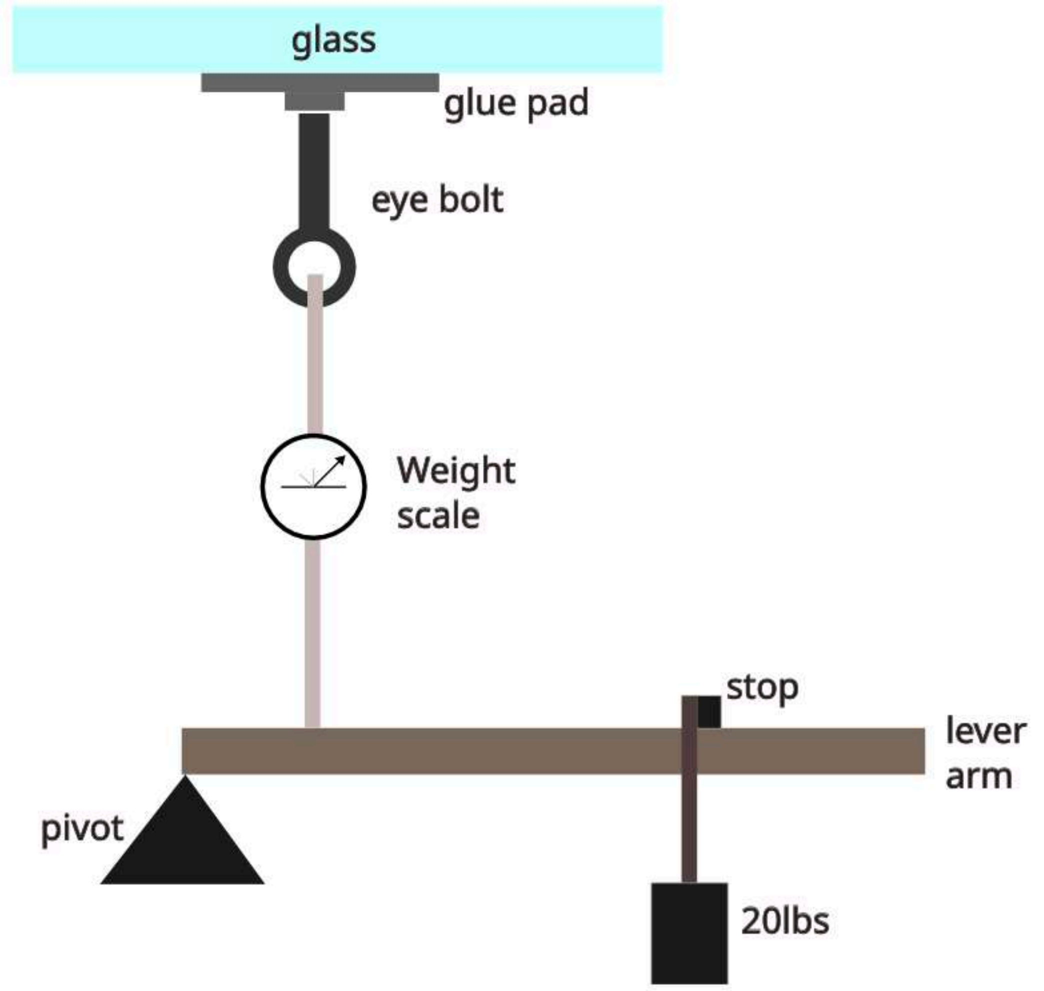


Majority of Pad Force is Shear

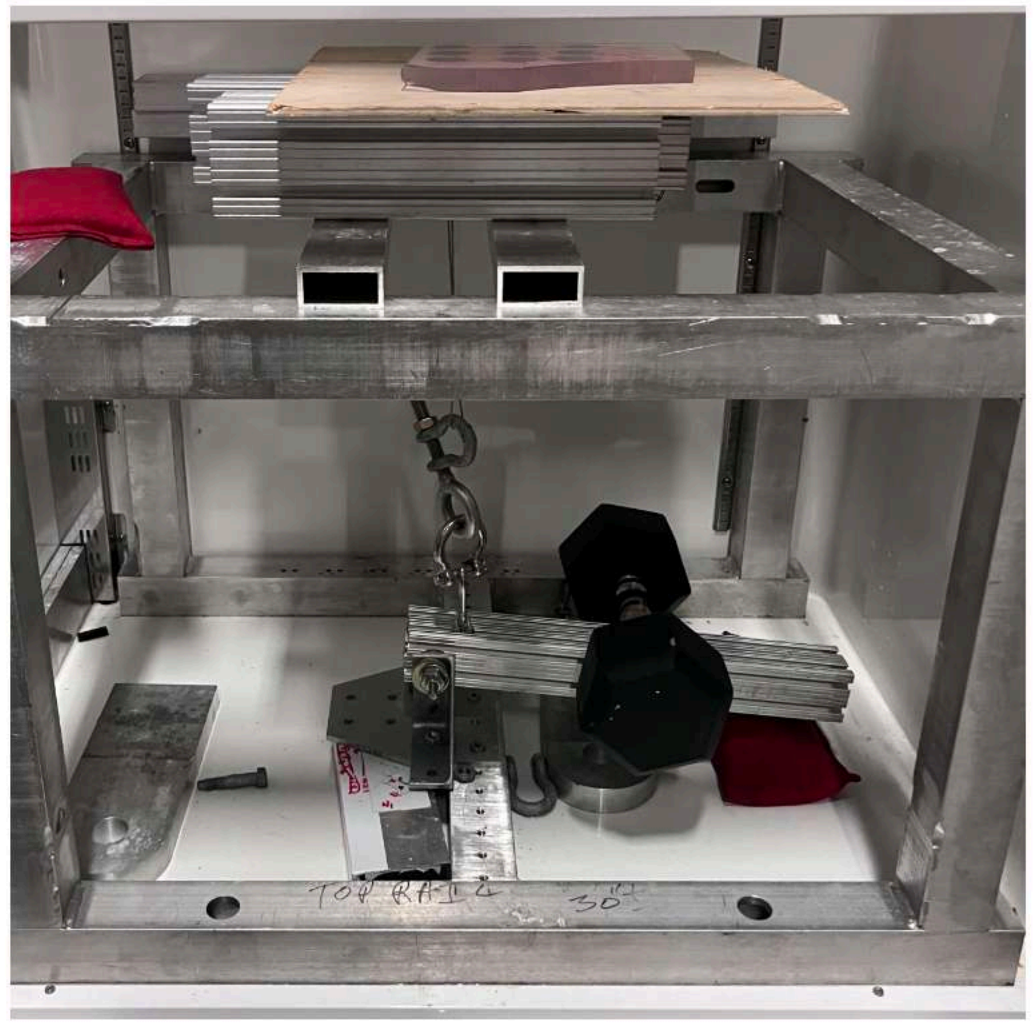
NASA requires 8G with SF of 2.0

Pads must bear 45.7 lbs * 2.0 = 91.4 lbs

Bonded Joint Testing Setups



(a) sketch of lever arm setup



(b) Low-temperature testing setup, undergoing tensile testing. Utilizes a 20 lbs weight on a roughly 10:1 lever arm.

Figure 9: Lever arm testing setup

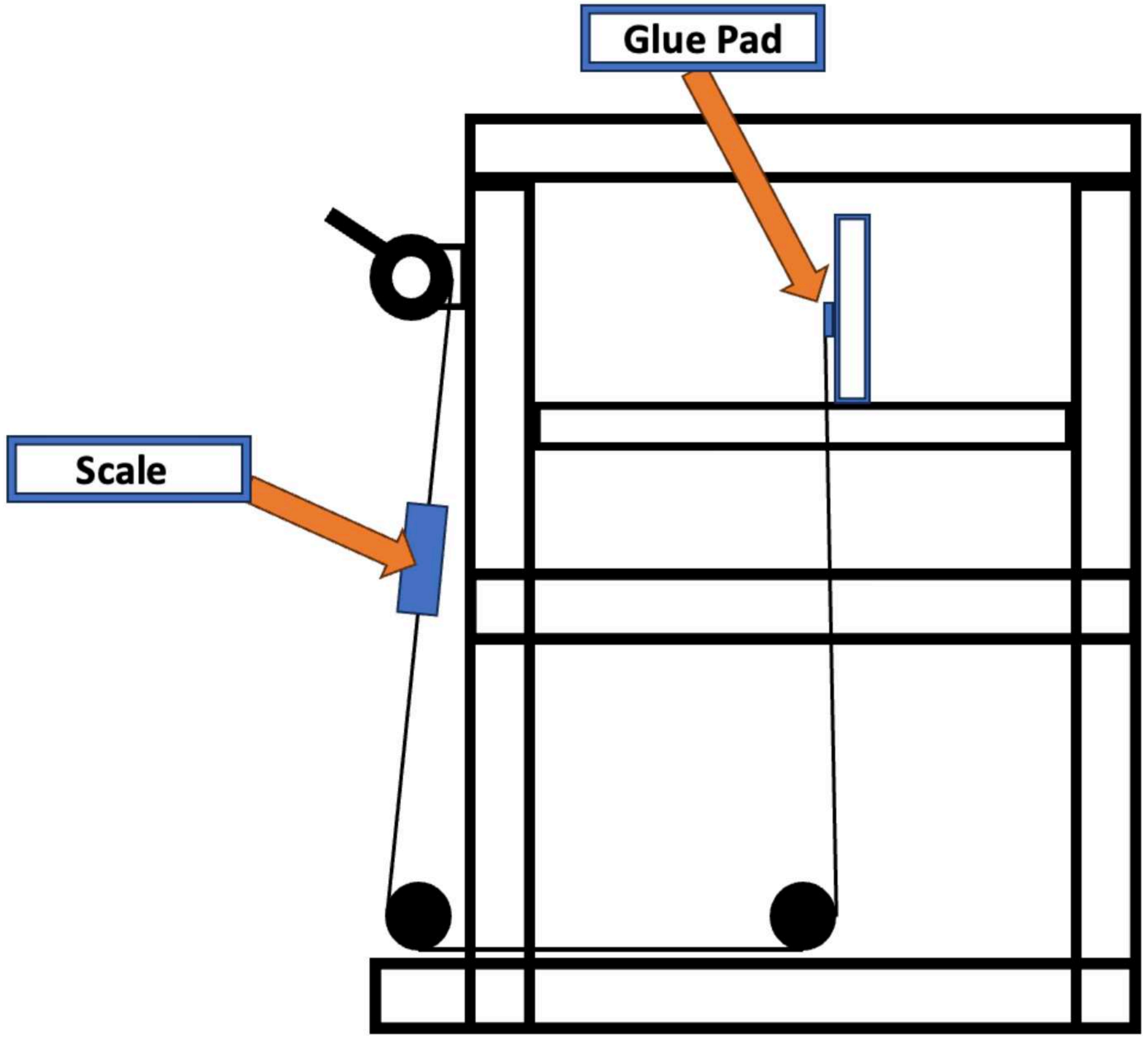


Figure 8: Diagram of Pully System

(a) Shear testing stand. Allows parallel force on the glue pad while protecting the glass piece.

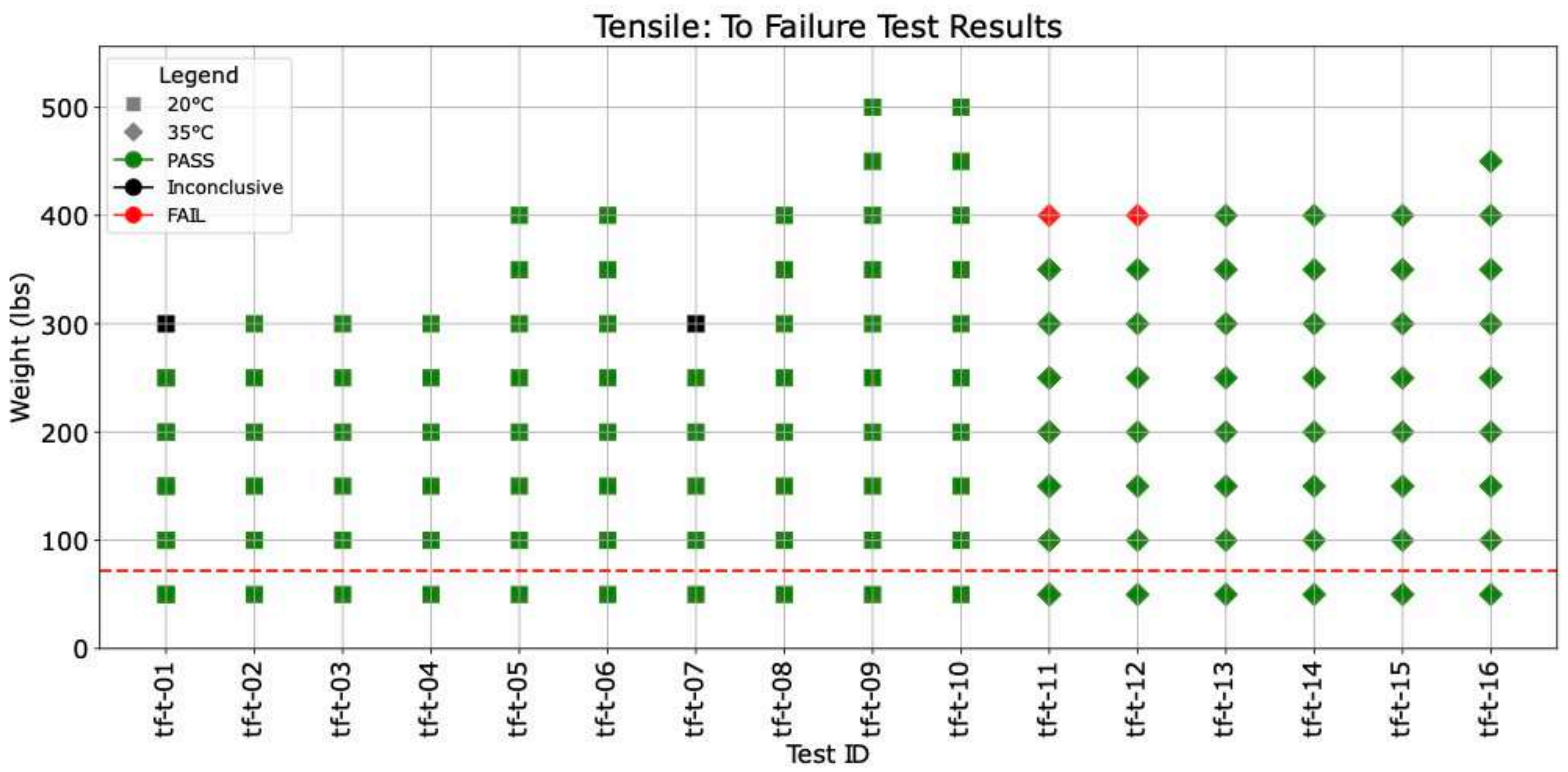
(b) Tensile testing stand. The foam was used to soften the load and lead bags were used to counterweight the pulling of the cable.

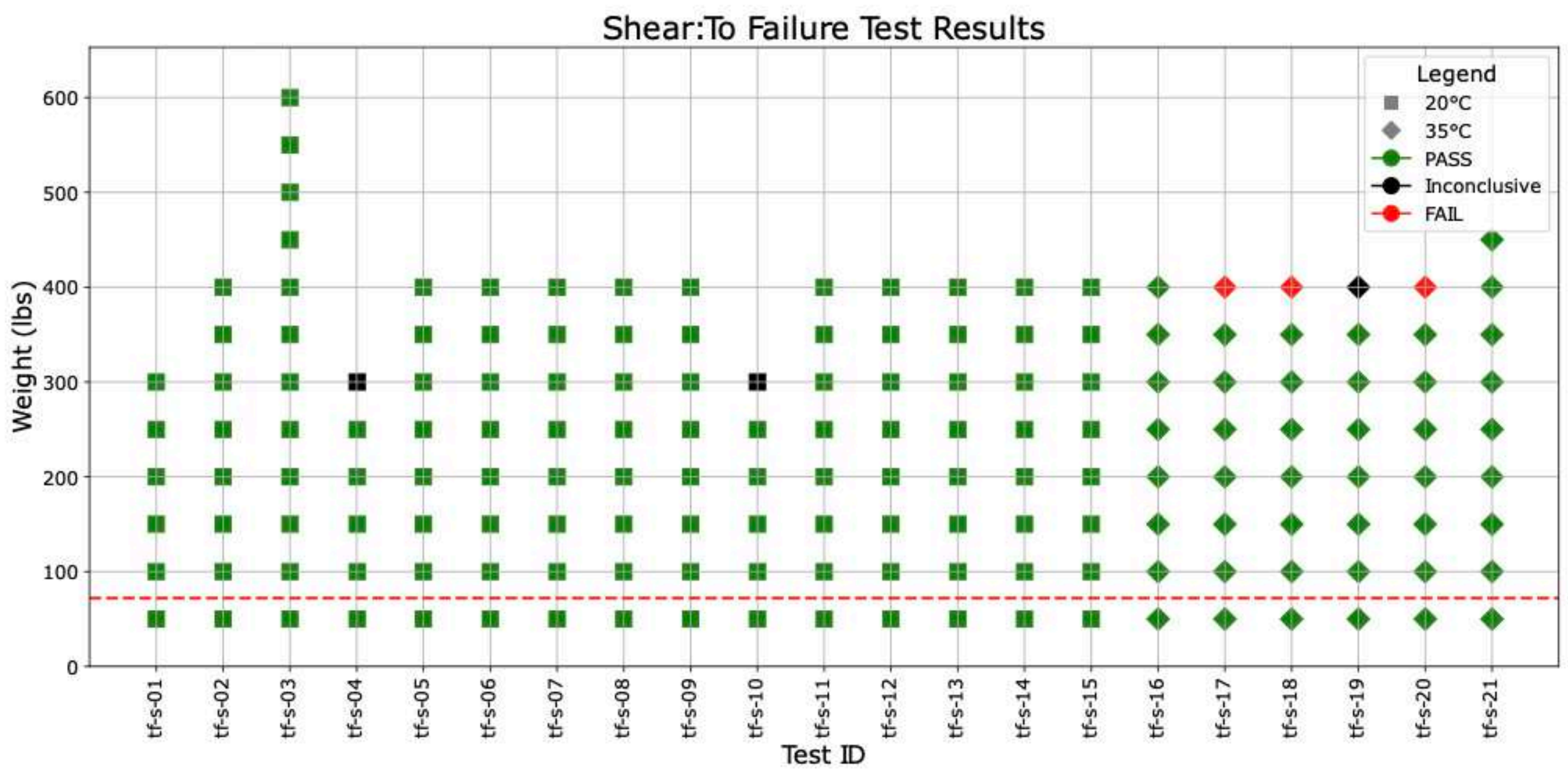
Bonded Joint Tests

Tensile

Shear

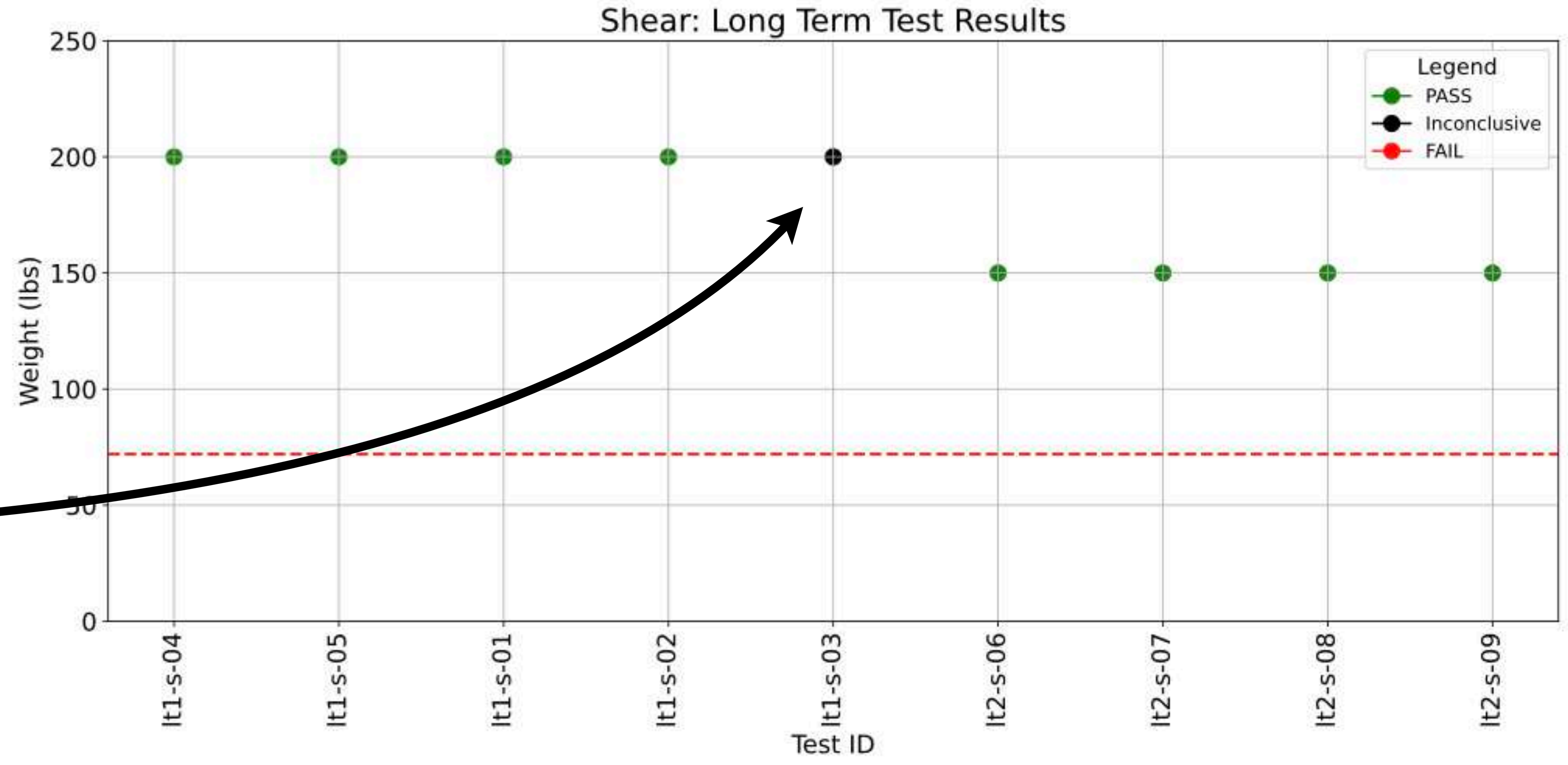
To Failure





Cold Longterm

Glass Breakage



NO BOND FAILURES UNDER 399 lbs ➜ MSu = 3.37

Question on Proof Testing

Table 2: Design Limit Loads

Structural Flight Hardware	Design Limit Loads (DLL) G's		
	Vertical	45 Deg	Horizontal
	8	4	4

Table 3: Design Factors of Safety

TYPE OF HARDWARE	DESIGN FACTOR OF SAFETY		
	Yield	Ultimate	Proof Test
Composite Flight Structure			
Uniform Material	N/A	1.5	1.2
Bonded Joints/Inserts	N/A	2.0	1.2
Stability/Buckling			

(a) Shear setup (b) 45° setup (c) Tensile setup

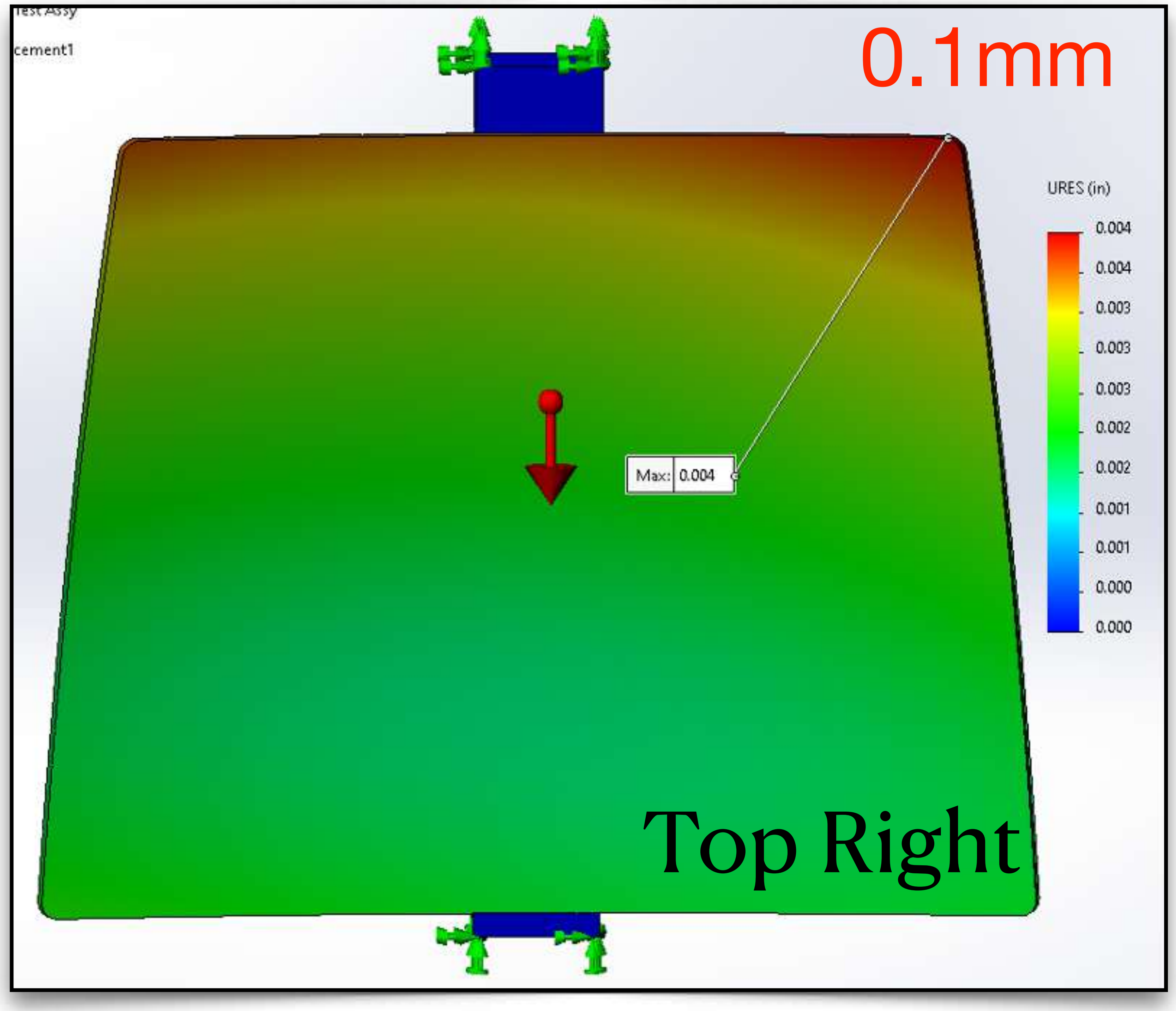
Figure 6: Three configurations of load cases that need to be tested

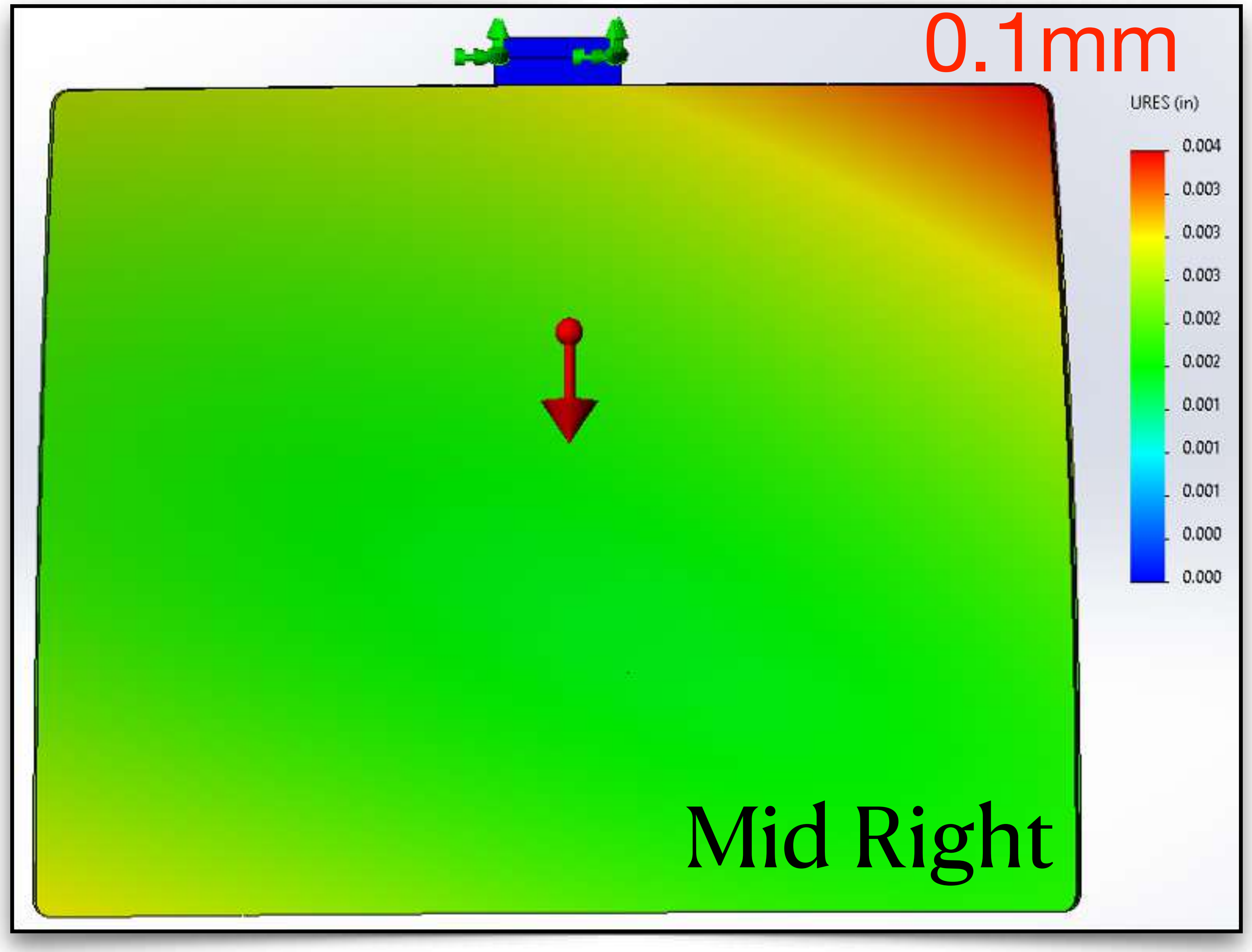
- ➢ **Proof Test would require pulling of pads at 55 lbs**
  - No Glue bond failures under 400 lbs thus far (MSp = 6.25)
- ➢ **Proof Test requires a high degree of mirror handling**
  - Increases the possibility of damage to the reflective surface
  - Provides the possibility of weakening glass around pad without failing proof test
- ➢ **Question:**
  - Is repeatability as done in SPB2 testing a viable alternative for PBR?
  - If yes, how many pads are needed and in what configuration
  - 58 Pads already tested with no bond failures under 400 lbs
  - Will easily surpass 80 pads while finishing 45° and cycling tests

Resolved: NASA Eng/Saftey "Testing already described is sufficient"

Mirror Movement/Distortion: Hz to Nadir

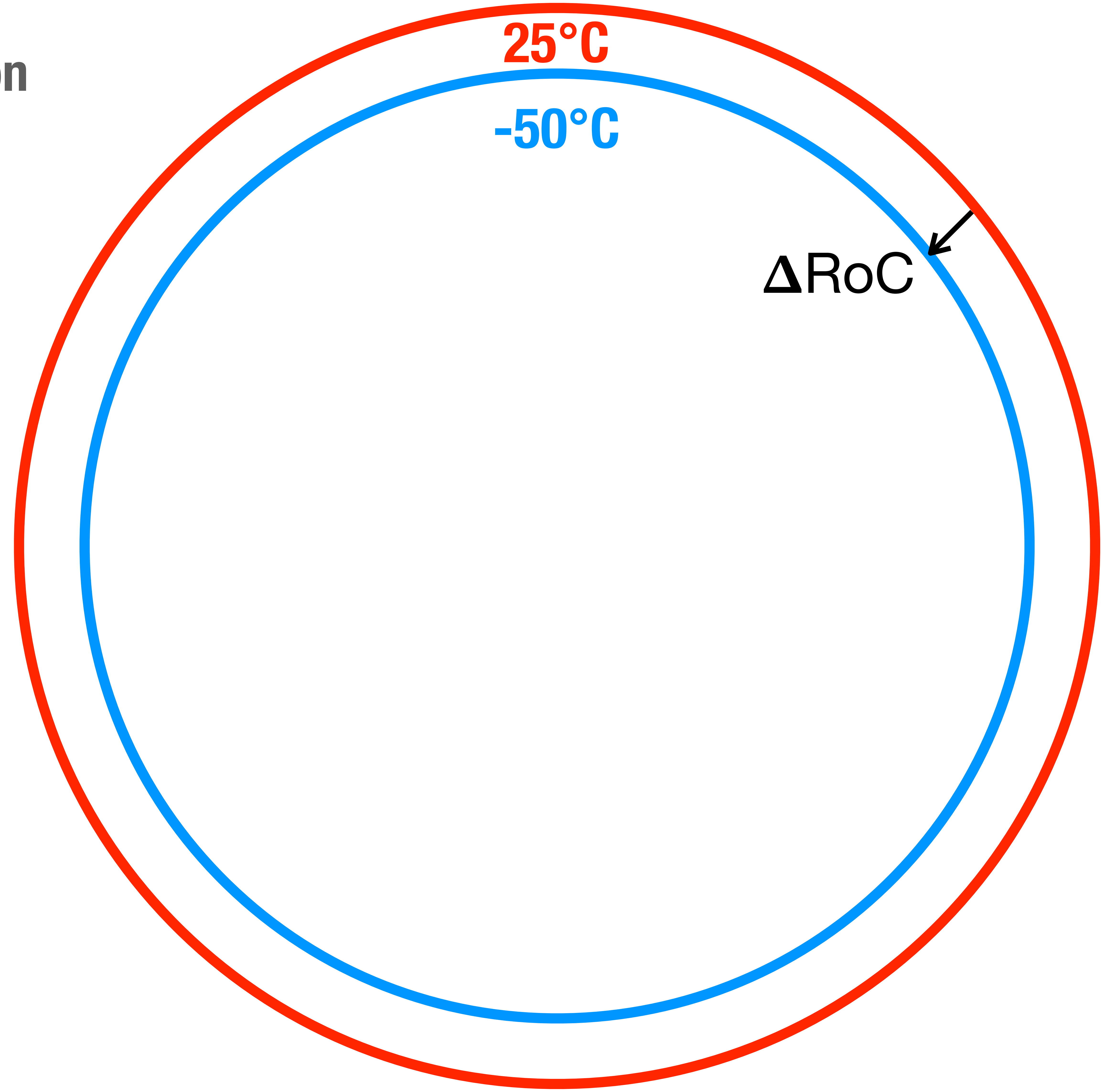
- ➢ Mirrors aligned and PSF known only in Hz configuration
  - For practical reasons, it is the only option for assembly
  - Very difficult to measure PSF at Nadir configuration
- ➢ The primary mech constraint on the telescope is stiffness
  - Stiffness requires more Al than yield strength
  - Satisfying stiffness req essentially guarantees strength
- ➢ Stiffness Req limits opportunities for lightening Tel
  - 7000 Series Al: Yield 400 MPa, Young's Mod 71 GPa
  - 6000 Series Al: Yield 240 MPa, Young's Mod 69 GPa
- ➢ Mirror deflection (Mirror Assy only) under rotation from Hz to Nadir
  - Top Row ➜ 0.025 to 0.1 mm
  - Mid row highest in corners ➜ 0.025 to 0.1 mm
  - Effect on RoC ➜ Negligible
- ➢ Movement of ACP and Camera not yet known





Mirror Distortion Estimate: -70°C ΔT

- ➢ PSF will depend on Temperature due to thermal contraction
- ➢ Mirrors aligned and PSF known only at ~20°C
  ➜ Mirrors will be as cold as -50°C
  - For practical reasons, it is the only option for assembly
  - No current plan to measure PSF at low temperatures
  - Maybe possible (very difficult) if important
    ➜ NSF Ice Core Facility
- ➢ Glass distortion minor @ ΔT = -70°C
  - ΔRoC ≃ -0.4 mm ignoring Al frame effects
- ➢ Aluminum distortion is more significant
  - Much harder to extract as it depends on the final design
  - Change in a full Al sphere ΔRoC ≃ -2.6 mm

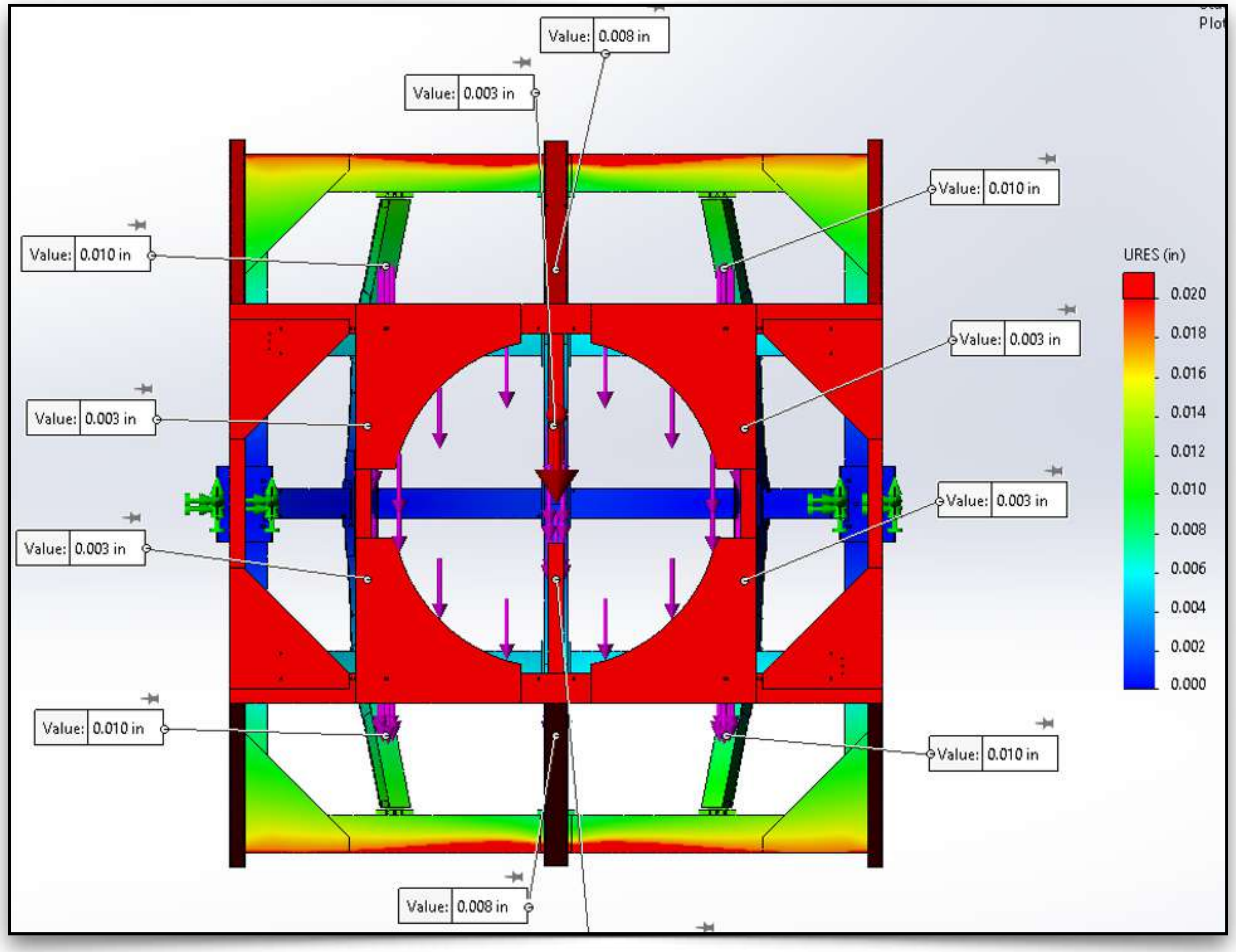


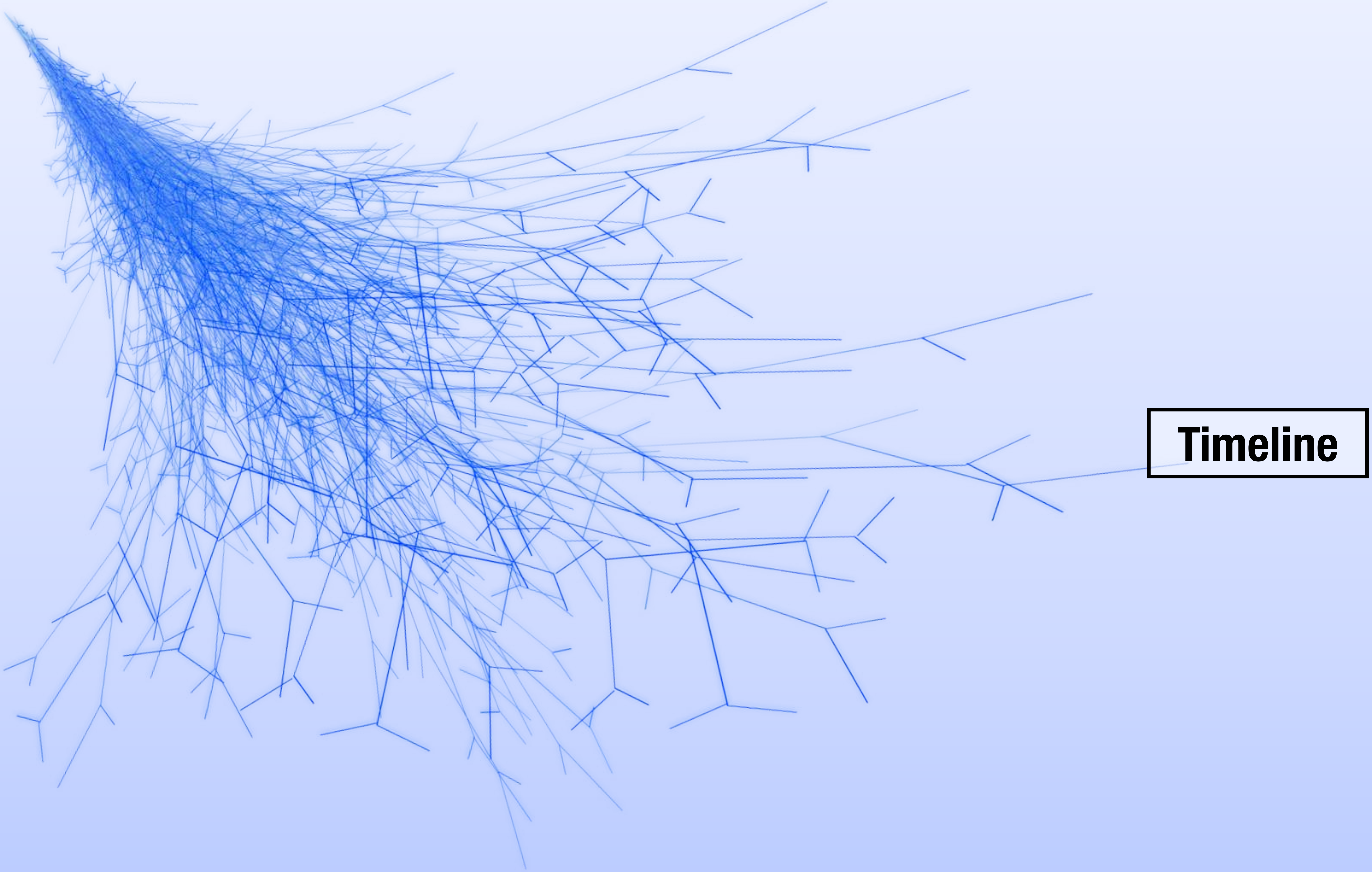
PSF Destortion TODO:
Temp + Pointing with Full telescope

- Need to extract the movement of optical components for ΔT = -100°C and pointing 0° ➜ -90° and 0° ➜ +15°
  - 0° ➜ -90° for UHECR measurement
  - 0° ➜ +15° for potential stellar alignment studies

- Approach: SolidWorks + G4/Offline or Zemax
  - Once the design is complete measure the position changes of ACP, Camera and Mirror Segments with Solidworks
  - Extract size changes of ACP and Mirror segments
  - Feed to ZeMax or G4 in offline to get effects

- Hope to set up for fast turnaround as design tweaks difficult at this late stage




Timeline

Timeline Chicago

Month	Opto-Mechanical	Gondola / Carts	Rotator /Shutter	Radio Frame/Mast
Jan	•Aiming Assembly Design Complete •Fabrication of Whipple Trees for tests	•**Ballast hopper load cell solution** •Gondola design polishing	•Procurement	•
Feb **MIC**	•**Telescope Design Complete** •Preliminary FEA	•**Gondola Design Complete** •Preliminary FEA	•Preliminary Rotator Design	•**Preliminary Mast Design** •**Preliminary Frame Design**
Mar	•Design Iteration using NASA Feedback •Finish Flight Pad and flexure tests	•Design Iteration using NASA Feedback •**Procurement LLT and Solar Power**	•Design Iteration •**Thermal Vac Testing of Primary Components**	•Design Iteration using Feedback •Finalization of interface
April **ORDM**	•**Final Telescope Design & FEA** •**Glue Testing Doc Ready**	•**Final Gondola Design & FEA** •**Preliminary Cart Design**	•**Final Rotator Design & FEA**	•**Radio Mast Design Ready** •**Radio Frame Design Ready**
May **BTC**	•**Final Mass Estimate** •Procurement •Fabrication Start	•**Final Mass Estimate** •Procurement •Cart Design / Ground Support Design	•**Final Mass Estimate** •Software Hardware/Testing •Balloon Tech Conference	•**Final Mast Estimate** •Antenna and electronics integration design
June	•Procurement •Fabrication	•Procurement •Cart / Ground Support Design	•Software Hardware/Testing •Fabrication •	•Procurement
July	•**Mirror Frame Ready with T/M mirrors** •**Optical Characterization Start**	•**Gondola Fabrication Start**		•Prototype Frame Fabrication and Assembly
Aug	•Telescope Structural Frame Fabrication •Optical Characterization •Finalization of Camera Shelf •Finalization of Cable routing	•Gondola Fabrication •Cart / Ground Support Design		
Sept				•Prototype Frame to Penn
Oct		•Gondola Assembly •Cart / Ground Support Design Finalized	•Software Hardware/Testing •Assembly	•Mast Fabrication & Assembly
Nov		•Gondola Assembly •Cart / Ground Support procurement		
Dec **Pre-Int**	•Telescope Structural assembly complete •Optical characterization ongoing •**Ready for integration**	•Gondola Assembly Complete •Disassembly for shipping begins •**Ship to Mines for integration**	•Rotator Components Assembled •Rotator Testing Ongoing •**Ready for integration**	•Radio Frame Ready for Antenna •Radio Mast Assembled •**Ready for integration**

Timeline Today

Month	Telescope and Mirror Assemblies	Gondola / Carts	Rotator /Shutter	Radio Frame/Mast
May **ORDM**	• **Preliminary Telescope Design & FEA** • **Preliminary Glue Testing Doc Ready**	• **Preliminary Gondola Design & FEA** • **Preliminary Cart Design**	• **Preliminary Rotator Design & FEA**	• **Preliminary Mast Design Ready** • **Preliminary Frame Design Ready**
→ June **Paris**	• **Finish Glue Testing** • Prototype Whipple Tree Fabrication starts • Design Complete	• **Firm Mass Estimate** • Gondola Procurement Start • Cart Design / Ground Support Design	• **Sort out the Gear strength issue** • Finish the design of test stand	• **Final Concept** • **Firm Mass Estimate** • Prototype / Sample Procurement
July	• Optical FEA Work Start • Mirror Glue Bench Fabrication • Flexure Mechanical Testing • **Prototype Mirror Glue-up**	• Procurement • Cart Design • Gondola Design Finalization	• Test bench fabrication • Rotator component procurement	• Materials Testing and Validation • Prototype Antenna Testing @ Penn
Aug	• Optical FEA Finish • **Telescope and Mirror Assembly Finalization** • Mirror Assembly Fabrication	• Procurement • Cart Design Continues • **Gondola Fabrication Start**	• Rotator component procurement • Testing organization	• RI Frame and Mast Finalization • **Final Mass Estimate** • Antenna Procurement
Sept	• **Location of CoM** • Mirror Gluing • Telescope Structural Frame Fabrication Start • Design of Camera Shelf • **Final FEA** • **Final Mass / CoM Estimation**	• Procurement • Gondola Fabrication continues • Cart Design Continues • **Final FEA**	• Rotator component procurement • Fabrication • Software testing	
Oct			• **Test setup fabrication finish** • Software testing	• Antenna Testing @ Penn • **Final FEA**
Nov	• Hanging of Mirrors • Installation of ACP • Optical Characterization Start	• Gondola Assembly • Cart Design Finalized • Cart Procurement Start @ Mines	• Hardware testing at BEMCO • **Design Finalization** • Final Procurement	• Final Mast Procurement @ Mines • Final Antenna Test @ Penn • Ship Antenna to Mines
Dec **Japan**	• **Assembly Cart Design Finalization** • Telescope Structural assembly ongoing • Optical characterization ongoing	• **Final Mass Estimate** • Cart Procurement Finish @ Mines • Cart Assembly @ Mines	• Rotator Assembly • Full Assembly Testing • **Final FEA**	• **Trial RI assembly** • **RI disassembly**
Jan **Pre-Int**	• **Telescope Structural assembly complete** • PSF characterization • **Cart Fabrication**	• Gondola Test Assembly Complete • Disassembly for shipping begins • **Ship to Mines for integration**	• Rotator Assembly • Full Assembly Testing	• Sitting in the corner???
Feb	• Absolute Calibration • Dark box fabrication • Camera Shelf fabrication	• Receiving at Mines • Assembly start	• **Ready for integration**	
March **BTC**	• **Telescope Integration**	• Assembly Continues • **Gondola Installation on Trailer**	• **Integration on Gondola / Telescope**	

Summary

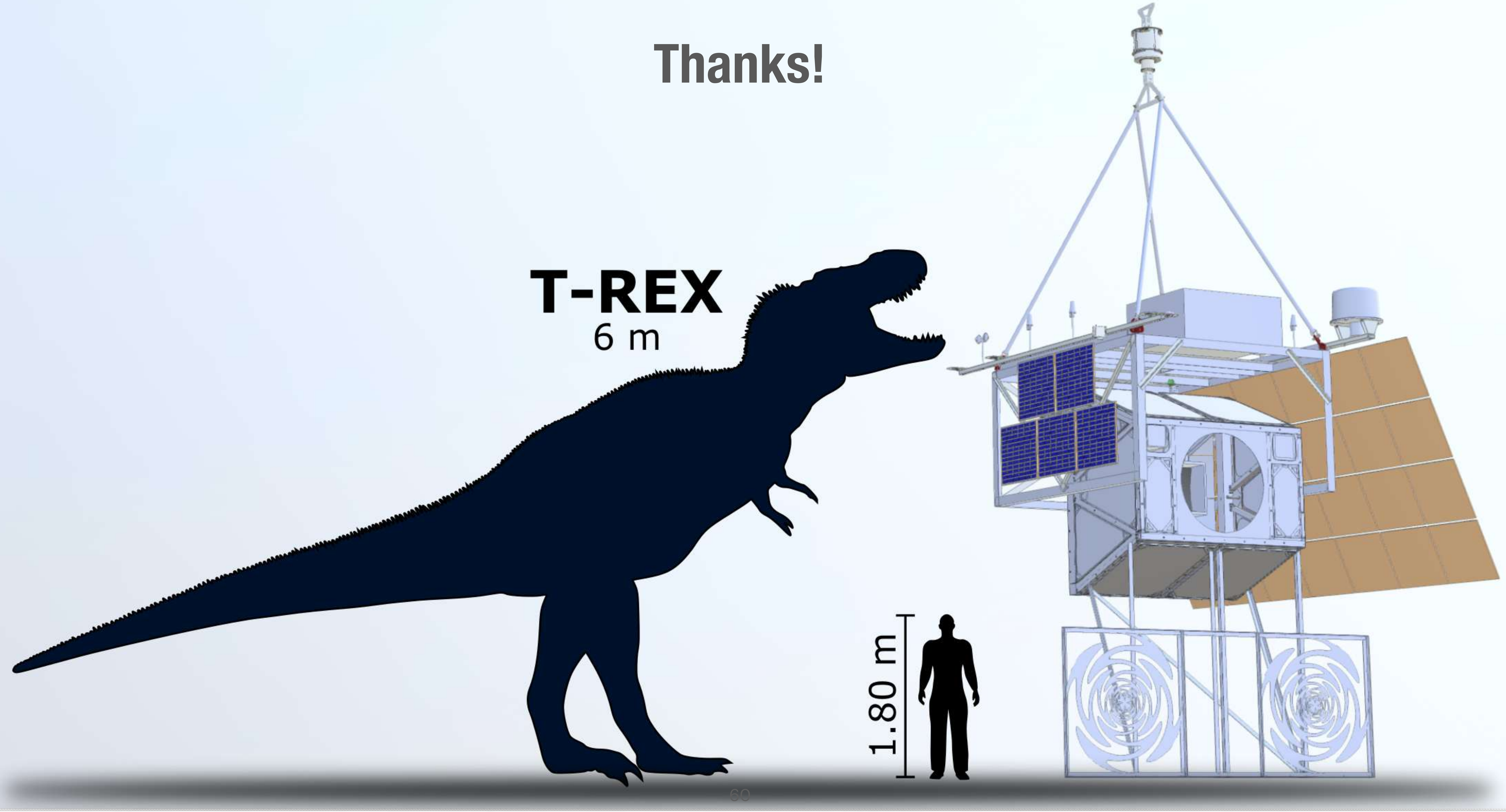
➢ Very near to the design completion
➜ Moving from design phase to construction phase

➢ Procurement has already started on some components
- Mirror cell components are already underway
- Ready for a large procurement order for Gondola and Telescope
- 50% Tariffs on Al may cause problems as they were not accounted for in the original budget
➜ In effect, as of yesterday…

➢ On schedule, but the timeline is tight
➜ It will be a very busy fall

➢ Last chance for any major design change requests passes after this meeting

Thanks!

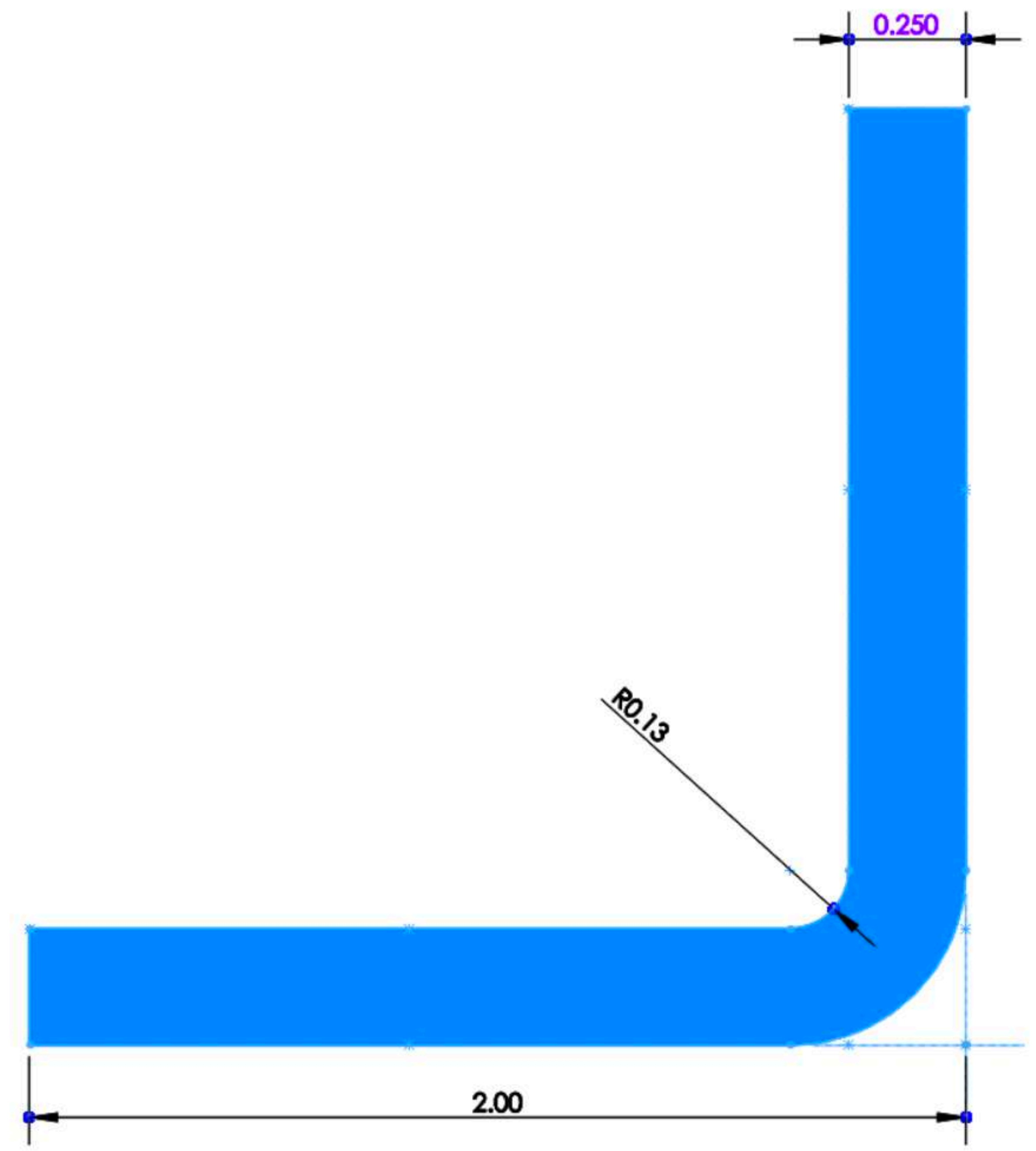


Backup

RI Mast: Pultex GFRV

Material values, Pultex 1625

Strength mode	**Symbol**	**Value @ 25° C (psi)**	**Value @ 100° C (psi)***
LW Tensile	ScxxT	37500	14250
LW Compressive	ScxxC	37500	14250
CW Tensile	ScyyT	8000	3040
CW Compressive	ScyyC	20000	7600
In-plane shear	ScxyS	7000	2660
Through-plane shear	SczzS	6000	2280
Geometry	**Symbol**		**Value (in)**
Bolt hole diameter	d		0.368
Laminate thickness	t_c		0.25
Edge distance (min)	e		varies
Laminate width	w		1.75



Calculated Figures of Merit

Figure	Value
Assembly Weight	147 lbs
Ultimate Design Load	3300 lbf
Ultimate Safety Factor – 8G shock load	2.8
Required Safety Factor – 8G shock load	1.25

Requirements - Gondola Frame

- The gondola structure has been designed in accordance with **NASA document 820-PG-8700.0.1, “Gondola Structural Design Requirements.”**

TYPE OF HARDWARE	DESIGN FACTOR OF SAFETY		
	Yield	Ultimate	Proof Test
Metallic Structures			
Flight Structure - metallic only	1.25	1.4	N/A
Preloaded Joints	1.25	1.4	N/A
Fasteners	1.25	1.4	N/A
Welds	N/A	1.5	1.2
Suspension Systems			
Wire Rope Cables, Slings, Cable assemblies, Shackles, Turnbuckles, etc.	N/A	1.4	*
Soft-body Structures			
Slings, Webbing	N/A	2.0	*
Composite Flight Structure			
Uniform Material	N/A	1.5	1.2
Bonded Joints/Inserts	N/A	2.0	1.2
Stability/Buckling			
Stability/Buckling – metallic only	N/A	1.4	N/A
Stability/Buckling – composite	N/A	1.5	N/A
Pressure Vessel Systems	Ref: GSFC-STD-8009, ANSI/AIAA S-080A-2018		
*: based upon NASA review of GP hardware			

The strength of the gondola system shall be demonstrated by showing a positive margin of safety (MS) for individual components and assembly interfaces for the given loading environment when the factors of safety given in Table 3 are applied.

The margins of safety are determined by multiplying the design limit load (or stress) by the appropriate factor of safety and comparing it to either the yield or ultimate material allowable strength as shown in the following equations:

$$MS_u = \frac{P_u}{FS_u P} - 1$$

and

$$MS_y = \frac{P_y}{FS_y P} - 1$$

where

FS_u	is the ultimate Factor of Safety
FS_y	is the yield Factor of Safety
P	is the limit load (or stress) calculated in the analysis
P_u	is the load (or stress) at which material failure will occur
P_y	is the load (or stress) at which material yielding will occur
MS_u	is the Margin of Safety against ultimate failure
MS_y	is the Margin of Safety against material yielding

At pre-loaded interfaces, the analysis shall show positive margins for all components which comprise the interface – fittings, bolts, rivets, etc., when subjected to the loads given in Section 3.3 and the margins given in Section 3.4. Fitting analysis of critical components shall meet Section 4.4.2, Certification of Fasteners.

Backup: Bonded Tests

Bonded Joint Testing: Tensile

Date	Test ID	Test Type	Pad Type	Temp (C)	Duration	Weight (lbs)	Pass/Fail	Comments
09/26/24	tf-t-01	To Failure	AL-HG	20	N/A	295.5	PASS	**Mech Failure**
09/26/24	tf-t-02	To Failure	AL-HG	20	N/A	300+	PASS	
09/26/24	tf-t-03	To Failure	AL-FG	20	N/A	300+	PASS	
09/26/24	tf-t-04	To Failure	AL-FG	20	N/A	300+	PASS	
11/09/24	tf-t-05	To Failure	KV-Flat	20	N/A	425.5	PASS	Over 400
11/09/24	tf-t-06	To Failure	KV-Flat	20	N/A	412.5	PASS	Over 400
11/09/24	tf-t-07	To Failure	KV-Flat	20	N/A	300+	PASS	**Mech Failure**
11/09/24	tf-t-08	To Failure	KV-Flat	20	N/A	422	PASS	Over 400
11/09/24	tf-t-09	To Failure	KV-Flat	20	N/A	503	PASS	Over 400
11/09/24	tf-t-10	To Failure	KV-Flat	20	N/A	506	PASS	Over 400
02/04/24	tf-t-11	To Failure	KV-Flat	35	N/A	399	PASS	**Bond Failure**
02/04/24	tf-t-12	To Failure	KV-Flat	35	N/A	415	PASS	**Bond Failure**
02/04/24	tf-t-13	To Failure	KV-Flat	35	N/A	430*	PASS	Over 400
02/04/24	tf-t-14	To Failure	KV-Flat	35	N/A	427.5*	PASS	Over 400
02/04/24	tf-t-15	To Failure	KV-Flat	35	N/A	433*	PASS	Over 400
02/04/24	tf-t-16	To Failure	KV-Flat	35	N/A	450*	PASS	Over 400
04/01/25	lt1-t-01	Long Term	KV-Flat	-60	20 min	175	Inconclusive	**Glass Failure**
04/01/25	lt1-t-02	Long Term	KV-Flat	-60	20 min	175	PASS	
04/28/25	lt1-t-03	Long Term	KV-Flat	-60	Overnight	175	PASS	
04/28/25	lt1-t-04	Long Term	KV-Flat	-60	N/A	175	Inconclusive	**Glass Failure**
04/28/25	lt1-t-05	Long Term	KV-Flat	-60	N/A	150	Inconclusive	**Glass Failure**
04/28/25	lt1-t-06	Long Term	KV-Flat	-60	Overnight	150	PASS	
05/08/25	lt2-t-07	Long Term	KV-Flat	-60	Overnight	150	PASS	
05/08/25	lt2-t-08	Long Term	KV-Flat	-60	Overnight	150	PASS	
05/08/25	lt2-t-09	Long Term	KV-Flat	-60	20 min	150	PASS	
05/08/25	lt2-t-10	Long Term	KV-Flat	-60	20 min	150	PASS	
05/08/25	lt2-t-11	Long Term	KV-Flat	-60	Overnight	150	PASS	
05/09/25	lt2-t-12	Long Term	KV-Flat	-60	20 min	150	PASS	

Table 7: Tensile Test Results (Excluding Summer Tests and Flat Pads on Curved Glass), Sorted by Temperature. The lt2 test ID represents pads that were tested using the improved fridge testing procedure.

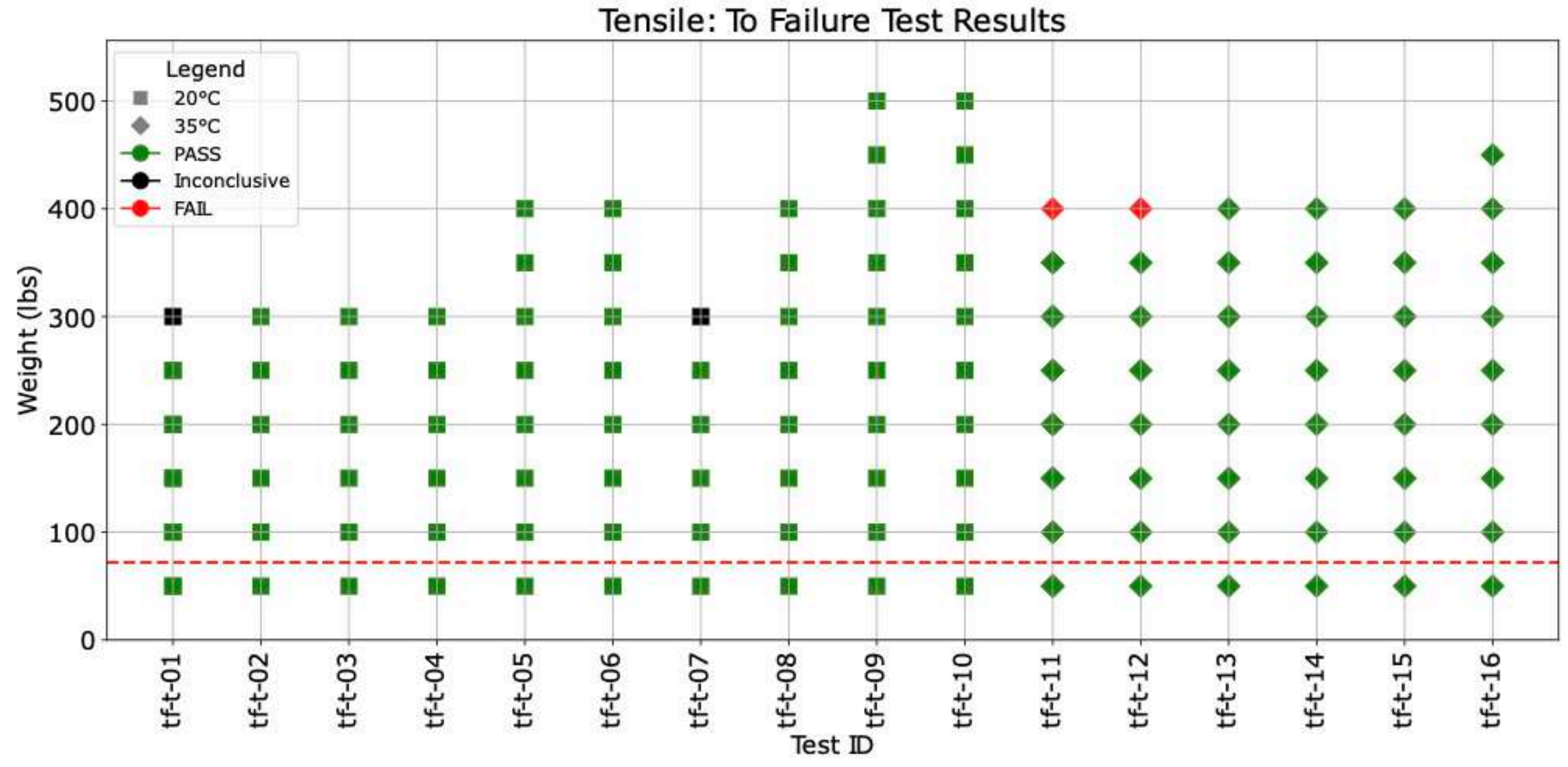


Figure 12: To-failure tests in the tensile configuration. For the to failure tests, a pass is considered if the glue bond does not break before passing the required strength given by the red dashed line. Loads where glue bonds failed are marked in red. Other breakages (mechanical or glass) are marked in black.

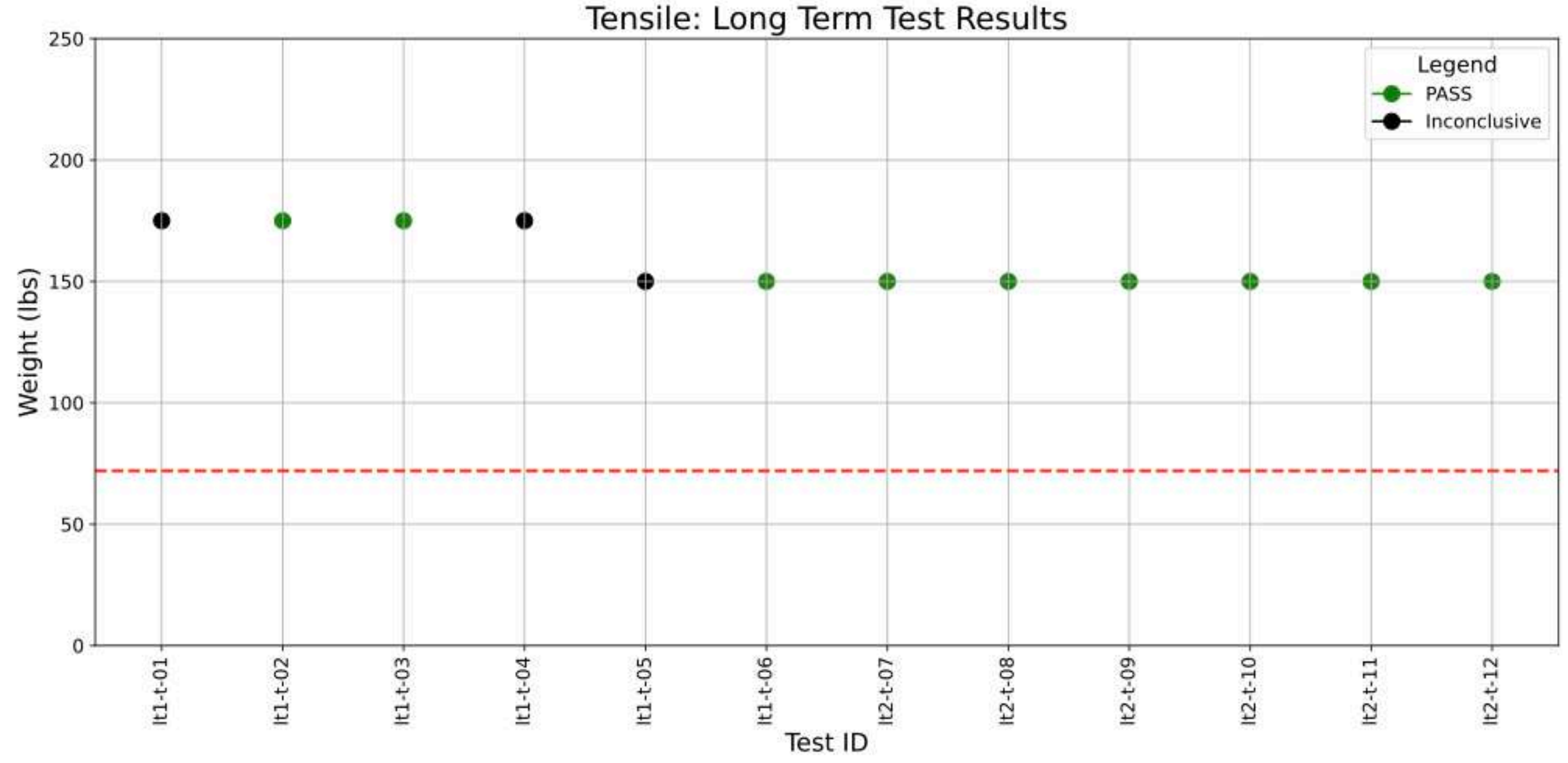


Figure 13: Long-term tests in the tensile configuration. For the long-term tests, a pass is considered if the glue bond does not break a any point in the test duration or during loading or unloading. Failure of the glass due to testing method or during loading/unloading is considered an inconclusive test.

NO BOND FAILURES UNDER 399 lbs ➜ MSu = 3.37

Bonded Joint Testing: Shear

Date	Test ID	Test Type	Pad Type	Temp (C)	Duration	Weight (lbs)	Pass/Fail	Comments
10/03/24	tf-s-01	To Failure	AL-HG	20	N/A	300*	PASS	**Mech Failure**
10/03/24	tf-s-02	To Failure	AL-HG	20	N/A	400*	PASS	**Mech Failure**
10/03/24	tf-s-03	To Failure	AL-FG	20	N/A	603*	PASS	
10/16/24	tf-s-04	To Failure	AL-Flat	20	N/A	311*	PASS	**Mech Failure**
10/16/24	tf-s-05	To Failure	AL-Flat	20	N/A	400*	PASS	Over 400
10/16/24	tf-s-06	To Failure	AL-Flat	20	N/A	400*	PASS	Over 400
10/16/24	tf-s-07	To Failure	AL-Flat	20	N/A	400*	PASS	Over 400
10/16/24	tf-s-08	To Failure	AL-Flat	20	N/A	400*	PASS	Over 400
10/16/24	tf-s-09	To Failure	AL-Flat	20	N/A	400*	PASS	Over 400
10/16/24	tf-s-10	To Failure	KV-Flat	20	N/A	305.5	PASS	**Glass Failure**
10/16/24	tf-s-11	To Failure	KV-Flat	20	N/A	400*	PASS	Over 400
10/16/24	tf-s-12	To Failure	KV-Flat	20	N/A	400*	PASS	Over 400
10/16/24	tf-s-13	To Failure	KV-Flat	20	N/A	400*	PASS	Over 400
10/16/24	tf-s-14	To Failure	KV-Flat	20	N/A	400*	PASS	Over 400
10/16/24	tf-s-15	To Failure	KV-Flat	20	N/A	400*	PASS	Over 400
11/15/24	tf-s-16	To Failure	KV-Flat	35	N/A	425*	PASS	Over 400
11/15/24	tf-s-17	To Failure	KV-Flat	35	N/A	401	PASS	**Bond Failure**
11/15/24	tf-s-18	To Failure	KV-Flat	35	N/A	427.5	PASS	**Bond Failure**
11/15/24	tf-s-19	To Failure	KV-Flat	35	N/A	433*	PASS	**Glass Failure**
11/15/24	tf-s-20	To Failure	KV-Flat	35	N/A	420*	PASS	**Bond Failure**
11/15/24	tf-s-21	To Failure	KV-Flat	35	N/A	450*	PASS	Over 400
11/22/24	lt1-s-04	Long Term	KV-Flat	20	Overnight	200	PASS	Left for 3 days.
11/22/24	lt1-s-05	Long Term	KV-Flat	20	Overnight	200	PASS	Left for 3 days.
02/18/25	lt1-s-01	Long Term	KV-Flat	-60	Overnight	200	PASS	Left over night
02/18/25	lt1-s-02	Long Term	KV-Flat	-60	Overnight	200	PASS	Left over night
02/18/25	lt1-s-03	Long Term	KV-Flat	-60	N/A	200	Inconclusive	**Glass Failure**
05/12/25	lt2-s-06	Long Term	KV-Flat	-60	Overnight	150	PASS	Left over night
05/13/25	lt2-s-07	Long Term	KV-Flat	-60	20 min	150	PASS	20 mins
05/23/25	lt2-s-08	Long Term	KV-Flat	-60	20 min	150	PASS	20 mins
05/23/25	lt2-s-09	Long Term	KV-Flat	-60	20 min	150	PASS	20 mins

Table 8: Shear Test Results (Excluding Summer Tests and Flat Pads on Curved Glass), Sorted by Temperature. The lt2 test ID represents pads that were tested using the improved fridge testing procedure.

NO BOND FAILURES UNDER 399 lbs ➜ MSu = 3.37

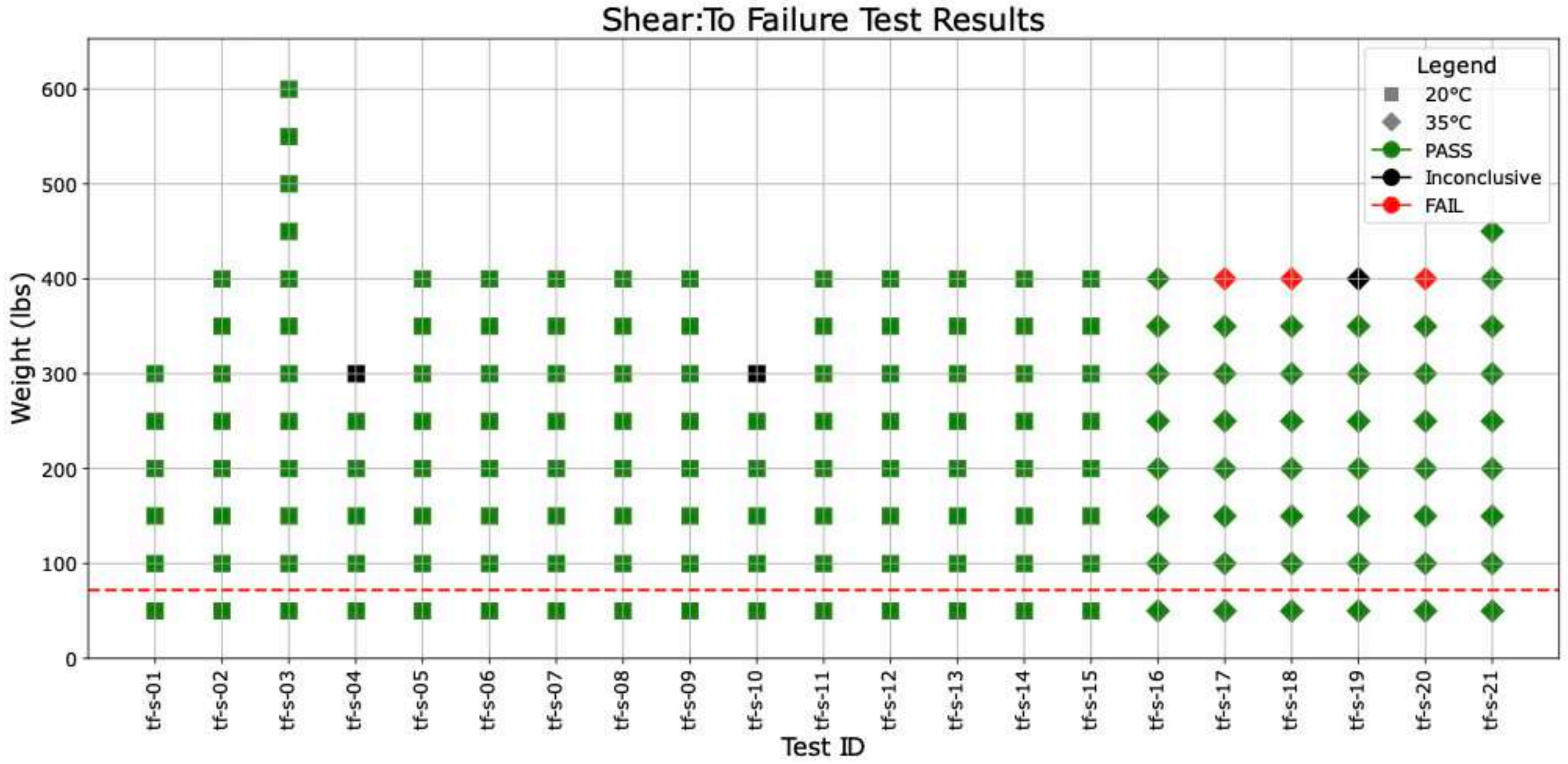


Figure 14: To-failure tests in the shear configuration. For the to failure tests, a pass is considered if the glue bond does not break before passing the required strength given by the red dashed line. Loads where glue bonds failed are marked in red. Other breakages (mechanical or glass) are marked in black.

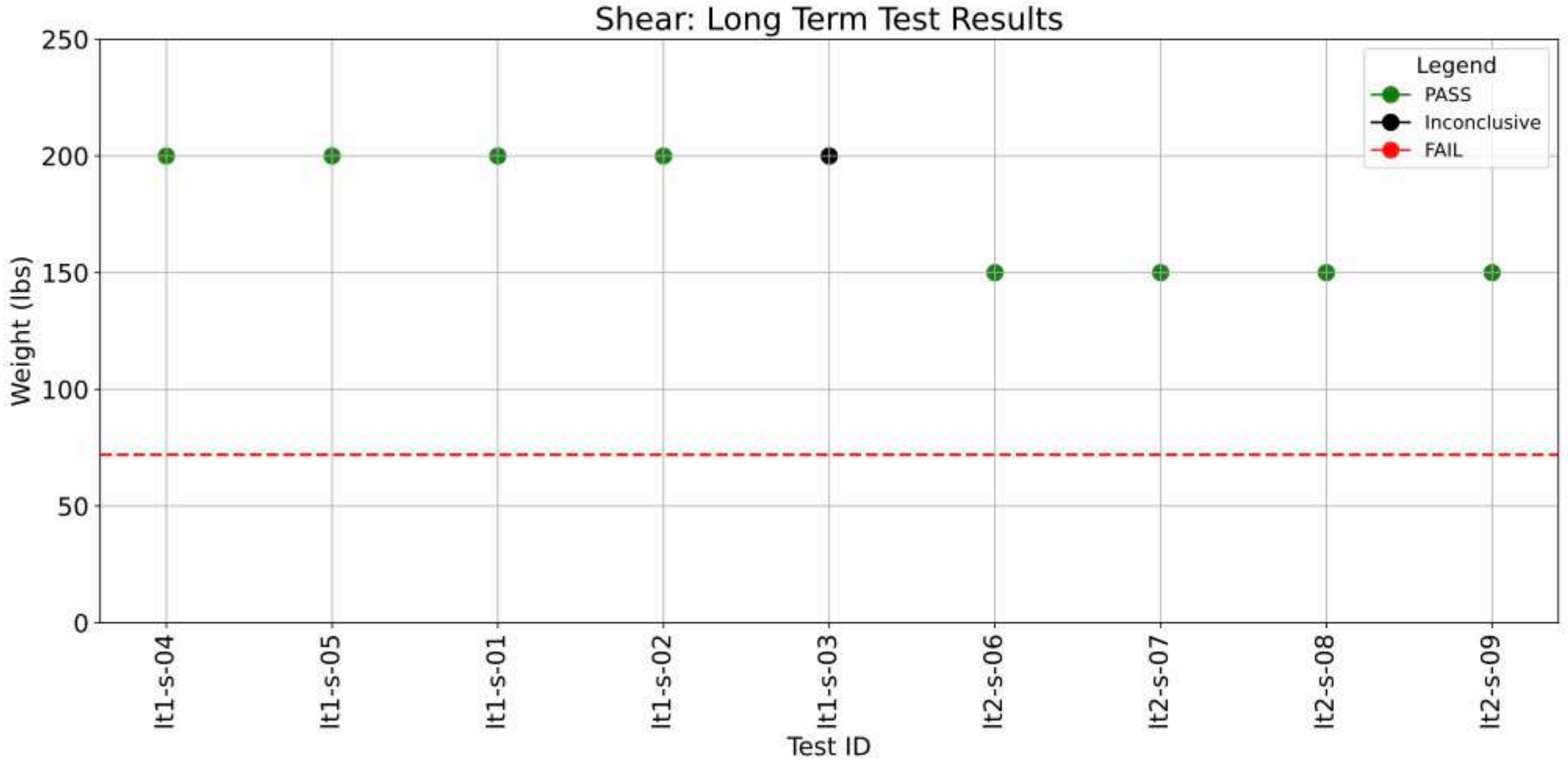


Figure 15: Long-term tests in the shear configuration. For the long-term tests, a pass is considered if the glue bond does not break a any point in the test duration or during loading or unloading. Failure of the glass due to testing method or during loading/unloading is considered an inconclusive test.

Bonded Joint Testing: Status

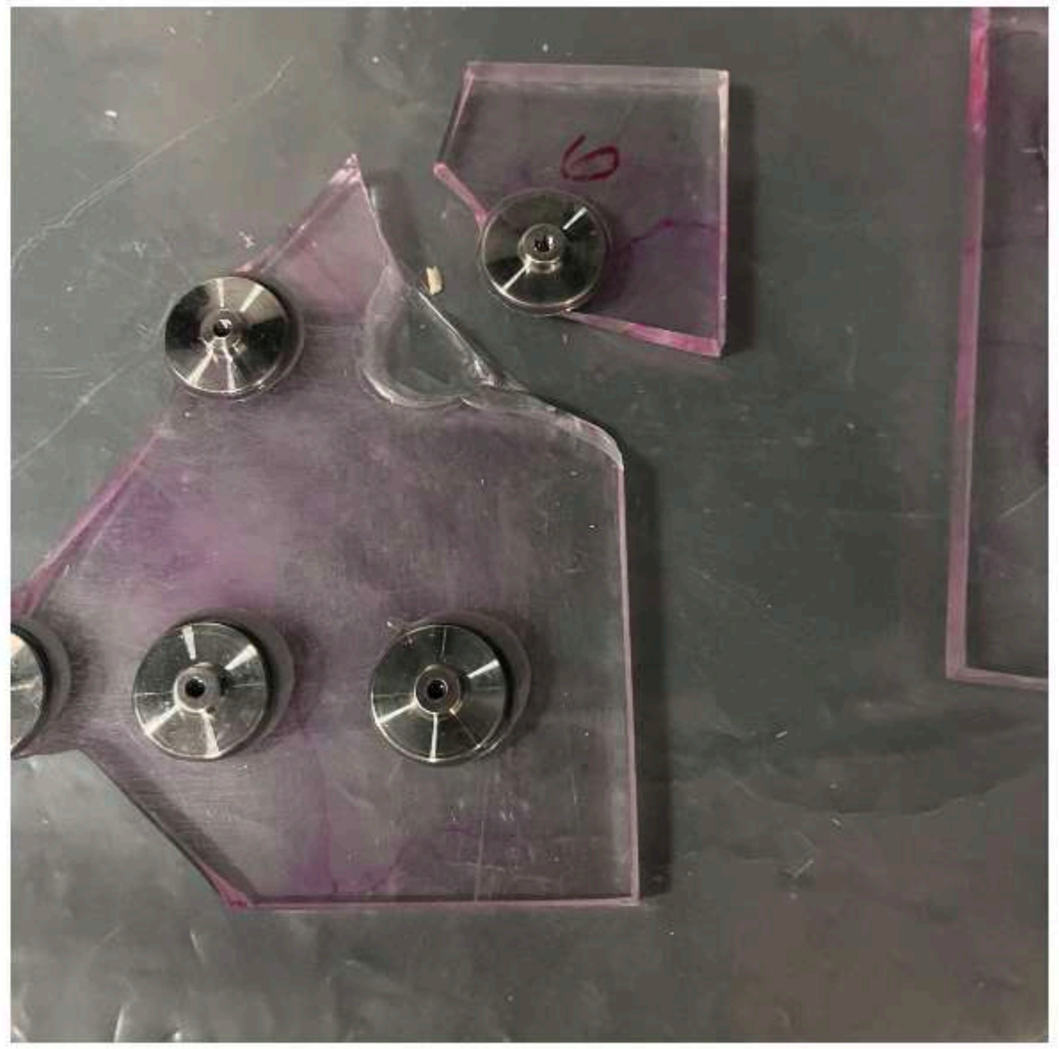
Req Num	Requirement	Objective Req Trace	Test Obj ID	Status
PBR-GB-01	The glue bond shall hold an 8 G load with a $SF = 2.0$ perpendicular to the surface of the mirror at 20°C with	GSDR 3.6.1	5.1.1-1	**PASS**
PBR-GB-02	The glue bond shall hold a an 8 G load with a $SF = 2.0$ perpendicular to the surface of the mirror at -60°C	GSDR 3.6.1	5.1.1-2	**PASS**
PBR-GB-03	The glue bond shall hold a 4 G load with a $SF = 2.0$ 45° to the surface of the mirror at 20°C	GSDR 3.6.1	5.1.2-1	TBD
PBR-GB-04	The glue bond shall hold a 4 G load with a $SF = 2.0$ 45° to the surface of the mirror at -60°C	GSDR 3.6.1	5.1.2-2	TBD
PBR-GB-05	The glue bond shall hold a an 8 G load with a $SF = 2.0$ parallel to the surface of the mirror at 20°C	GSDR 3.6.1	5.1.3-1	**PASS**
PBR-GB-06	The glue bond shall hold a an 8 G load with a $SF = 2.0$ parallel to the surface of the mirror at -60°C	GSDR 3.6.1	5.1.3-2	**PASS**
PBR-GB-07	The glue bond shall withstand an 8 G load with a $SF = 2.0$ perpendicular to the surface of the mirror is applied to the glue pads when temperature cycled from -60°C to 20°C	PBR Team	5.1.4-1	TBD
PBR-GB-08	The glue bond shall withstand an 4 G load with a $SF = 2.0$ 45° to the surface of the mirror when temperature cycled from -60°C to 20°C	PBR Team	5.1.4-2	TBD
PBR-GB-09	The glue bond shall withstand an 8 G load with a $SF = 2.0$ parallel to the surface of the mirror when temperature cycled from -60°C to 20°C	PBR Team	5.1.4-3	TBD

Table 2: Minimum strength specifications to satisfy required ultimate safety factors for bonded joints from GSDR 3.4, 3.5 and 3.6.1

8 End-to-End Trace Table

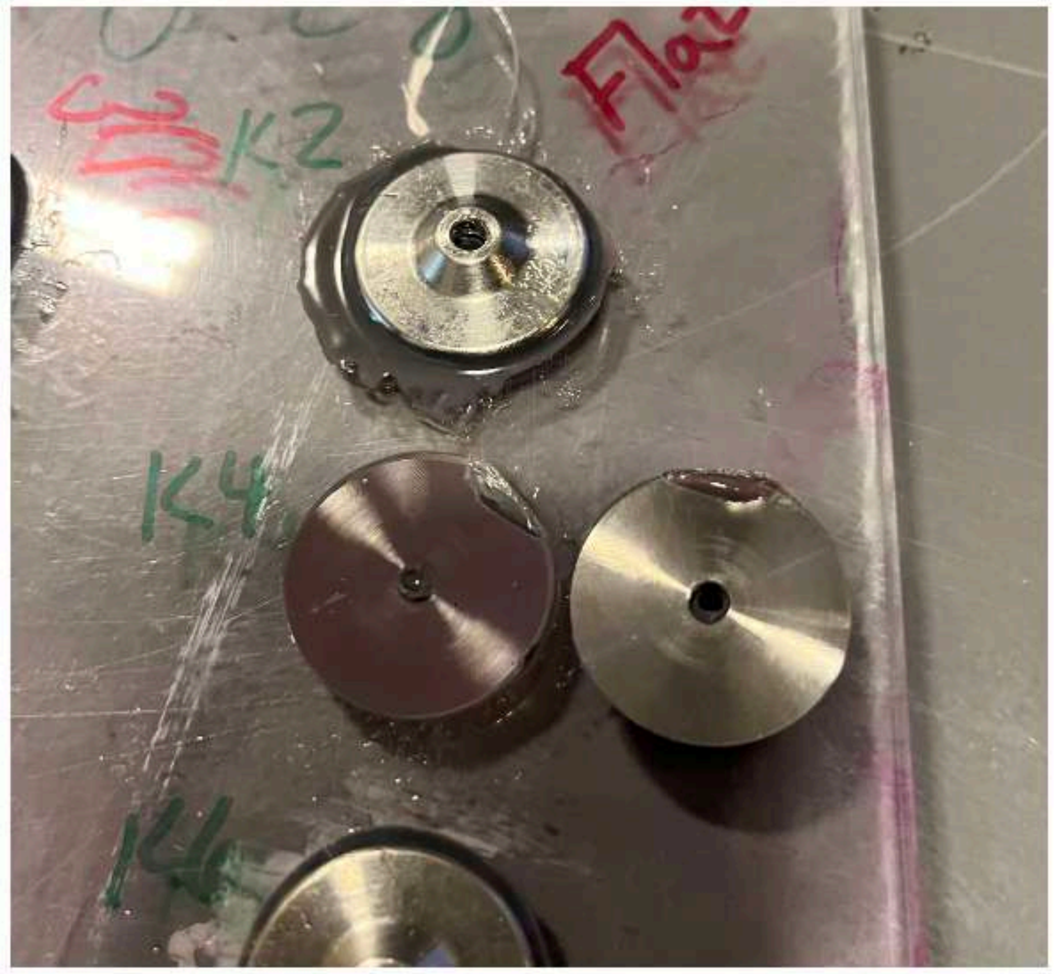
NASA GSDR Req	System Requirement	Test Objective	Test ID	Results
GSDR 3.6.1	PBR-GB-01	5.1.1-1	tf-t-05, tf-t-06, tf-t-07, tf-t-08, tf-t-09, tf-t-10, tf-t-11, tf-t-12, tf-t-13, tf-t-14, tf-t-15, tf-t-16	PASS: 12, FAILED: 0, INC: 0
GSDR 3.6.1	PBR-GB-02	5.1.1-2	lt1-t-01, lt1-t-02, lt1-t-03, lt1-t-04, lt1-t-05, lt1-t-06, lt2-t-07, lt2-t-08, lt2-t-09, lt2-t-10, lt2-t-11, lt2-t-12,	PASS: 9, FAILED: 0 INC: 3
GSDR 3.6.1	PBR-GB-03	5.1.2-1	TBD	TBD
GSDR 3.6.1	PBR-GB-04	5.1.2-2	TBD	TBD
GSDR 3.6.1	PBR-GB-05	5.1.3-1	lt1-s-04, lt1-s-05, tf-s-10, tf-s-11, tf-s-12, tf-s-13, tf-s-14, tf-s-15, tf-s-16, tf-s-17, tf-s-18, tf-s-19, tf-s-20, tf-s-21	PASS: 14, FAILED: 0, INC: 0

Observed Failure Modes



(a) Example of glass failure. Here, the glass broke due to high and uneven loads, but the pad remained firmly fixed to the glass.

(b) Example of Mech Failure. The eye bolt shown here was bent out of place, causing a test termination and an inconclusive result.



(c) Failed glue pad example. Here we see the pad completely separated from the glue joint. The glass chip still attached indicates the glass failed first, which then allowed the pad to peel off.

Figure 11: failure examples

7.4 Comments on Individual Failures.

lt1-s-03 While undergoing testing, the glass piece attached to the pad broke. In this case the pad itself was still glued to the remaining glass. However, we record this as a failure as it was inconclusive as to the strength of the pad.

tf-s-18 This was an actual failure that occurred at 427.5 lbs.

tf-s-19 During this test the glass itself broke in half, causing a failure. Still this was at 433 lbs.

tf-s-20 This was an actual failure that occurred at 420 lbs. Similar to test tf-s-10, a chip came out of the glass as was still glued to the pad.

lt1-t-01 While undergoing testing, the glass piece attached to the pad broke. In this case the pad itself was still glued to the remaining glass. However, we record this as a failure as it was inconclusive as to the strength of the pad.

lt1-t-04 While undergoing testing, the glass piece attached to the pad broke. In this case the pad itself was still glued to the remaining glass. However, we record this as a failure as it was inconclusive as to the strength of the pad.

lt1-t-05 While undergoing testing, the glass piece attached to the pad broke. In this case the pad itself was still glued to the remaining glass. However, we record this as a failure as it was inconclusive as to the strength of the pad.

tf-t-07 While undergoing failure testing, the eye-Bolt attached to the glue pad bent out of form, causing a failure in the test. The joint itself was not broken.

tf-t-11 This was an actual failure recorded at 399 lbs.

tf-t-12 This was also an actual failure. The joint broke at 415 lbs.

Bond Material Information

Kovar Bar Stock

Sold To: COLORADO SCHOOL OF MINE
CBE DEPT/CSM CENTRL RECV
1301 19TH ST.
GOLDEN CO 80401
United States

Material Size	Date Shipped
1in x 81in	2/7/2024
PO Number	**Purchased By**
VERBAL WILLIAM	ERIC MAYOTTE
Control Number	**EFINEA ID Number**
SO026639	062121-421

Material Standards:

ASTM F15-04 TEMPER A REAPPR. 2017	ASTM E45-18A METHOD D
AMS I 23011 CL1 ANNEALED REV C(04/ /17)	

Chemical Analysis:

C	Mn	P	S	Si	Cr	Ni	Al	Cu	Ti	Co
.02	.27	.001	.002	.15	.11	29.12	<.01	.08	<.01	17.37
Fe	**Mg**	**Zr**	**Mo**							
52.63	<.002	<.005	.11							

Mechanical and Physical Analysis:

Tensile	Yield	Elongation	Hardness	Grain Size	No Phase Trans
77,900 psi	53,900 psi	42.7% in 2"	84.0 RB	8	-196°C

Coefficient of Thermal Expansion:

30 to 400°C	450°C
4.99	5.27

3M Primer 3901

Overlap Shear Strength 17-7 Stainless Steel — 10203 lb/in²

Test Name: Overlap Shear Strength
Temp C: -55C
Temp F: -67F
Substrate: 17-7 Stainless Steel

Notes: Adhesive: AF-126, 0.06 wt.

Overlap Shear Strength 17-7 Stainless Steel — 6310 lb/in²

Test Name: Overlap Shear Strength
Temp C: 23C
Temp F: 73F
Substrate: 17-7 Stainless Steel

Notes: Adhesive: AF-126, 0.06 wt.

Overlap Shear Strength 17-7 Stainless Steel — 3600 lb/in²

Test Name: Overlap Shear Strength
Temp C: 82C
Temp F: 180F

3M Epoxy DP2216

	Overlap Shear (psi)		
	3M™ Scotch-Weld™ Epoxy Adhesive		
Test Temperature	**2216 B/A Gray Adhesive**	**2216 B/A Tan NS Adhesive**	**2216 B/A Trans. Adhesive**
-423°F (-253°C)	2440	—	—
-320°F (-196°C)	2740	—	—
-100°F (-73°C)	3000	—	—
-67°F (-53°C)	3000	2000	3000
75°F (24°C)	3200	2500	1700
180°F (82°C)	400	400	140

		Overlap Shear (psi) 75°F (24°C)		
		3M™ Scotch-Weld™ Epoxy Adhesive		
Environment	**Time**	**2216 B/A Gray Adhesive**	**2216 B/A Tan NS Adhesive**	**2216 B/A Trans. Adhesive**
100% Relative Humidity @120°F (49°C)	14 days 30 days 90 days	2950 psi 1985 psi 1505 psi	3400 psi 2650 psi	1390 psi
*Salt Spray@75°F (24°C)	14 days 30 days 60 days	2300 psi 500 psi 300 psi	3900 psi 3300 psi	1260 psi
Tap Water@75°F (24°C)	14 days 30 days 90 days	3120 psi 2942 psi 2075 psi	3250 psi 2700 psi	1950 psi
Air@160°F (71°C)	35 days	4650 psi	4425 psi	
Air@300°F (149°C)	40 days	4930 psi	4450 psi	3500 psi
Anti-icing Fluid@75°F (24°C)	7 days	3300 psi	3050 psi	2500 psi
Hydraulic Oil@75°F (24°C)	30 days	2500 psi	3500 psi	2500 psi
JP-4 Fuel	30 days	2500 psi	2750 psi	2500 psi
Hydrocarbon Fluid	7 days	3300 psi	3100 psi	3000 psi