Jet Propulsion Laboratory
California Institute of Technology

In-Space Assembled Telescope (iSAT) Study

Steering Committee Telecon 5

September 28, 2018

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Jet Propulsion Laboratory, California Institute of Technology

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Today's Agenda

1. **What's new?**
   a) New members
      i. New SC and SM members
   b) Concluded Activity 1a
      i. deliverables
   c) Kicked off Activity 1b
      i. status
   d) Many heading to VA
      i. Agenda, goals

2. **Next Steps**
   a) Advance 1b to conclusion
   b) Plan Activity 2

3. **Miscellaneous**
   a) Briefed Hertz
   b) Scientific American article
   c) Interagency Science and Technology Partnership - Open Forum Event

4. **Open Discussion**

What’s New?

New iSAT Study Members

New Steering Committee Study Members

Transitioning from telescope focus to robotic assembly and systems focus

1.	Dave Redding	JPL
2.	Joe Pitman	consultant
3.	Scott Knight	Ball
4.	Bill Doggett	NASA LaRC
5.	Matt Greenhouse	NASA GSFC
6.	Ben Reed	NASA GSFC
7.	Gordon Roesler	DARPA (ret)
8.	John Grunsfeld	NASA (ret)
9.	Keith Belvin	NASA STMD
10.	Brad Peterson	STScI/OSU
11.	Florence Tan	NASA SMD
12.	Ray Bell	Lockheed
13.	Nasser Barghouty	NASA APD
14.	Dave Miller	MIT
15.	Keith Warfield	NASA ExEP
16.	Bill Vincent	NRL
17.	Bo Naasz	NASA GSFC
18.	Erica Rogers	NASA OCT

Confirmed Study Members for Activity 1b

Telescope Systems
Lynn Allen (Harris)
Dave Redding (JPL)
Scott Knight (Ball)
Allison Barto (Ball)
Keith Havey (Harris)
Doug McGuffy (GSFC)
Ron Polidan (consultant)
Bob Hellekson (Orbital)
Ray Bell (LMC)
David van Buren (JPL)
Kimberly Mehalick (GSFC)

Structures
Kim Aaron (JPL)
John Dorsey (LaRC)
Bill Dogget (LaRC)
Joe Pitman (consultant)
Keith Belvin (LaRC)
Monica Rommel (Harris)
Eric Komendera (VA Tech)

Orbital Mechanics/ Environments
David Folta (GSFC)
Ryan Whitley (JSC)

Launch Systems/AI&T
Diana Calero (KSC)
Roger Lepsch (LaRC)
Mike Fuller (Orbital)

GNC
Bo Naasz (GSFC)

Architectural Systems
Paul Lightsey (Ball)
Bo Naasz (GSFC)

Gateway
Nate Schupe (LMC)
Sharon Jeffries (LaRC)
Mike Elsperman (Boeing)
Mike Fuller (Orbital)

Rendezvous & Proximity Operations
Bo Naasz (GSFC)
Greg Lange (JSC)

Manufacturing
Kevin DiMarzio (MIS)
Max Fagin (MIS)
Bobby Biggs (LMC)
Alex Ignatiev (U Houston)
Rob Hoyt (Tethers)

Robotics and Robotic Servicing and Assembly
Jason Herman (Honeybee)
Atif Qureshi (SSL)
John Lymer (SSL)
Paul Backes (JPL)
Glen Henshaw (NRL)
Rudra Mukherjee (JPL)
Gordon Roesler (ex-DARPA)
Mike Renner (DARPA)
Mike Fuller (Orbital)
Adam Yingling (NRL)
Hsiao Smith (GSFC)
Dave Miller (MIT)
Ken Ruta (JSC)
Kim Hambuchen (JSC)

Controls
Larry Dewell (LMC)

Sunshade
Kim Mehalick (GSFC)
Jon Arenberg (NG)

Thermal
Carlton Peters (GSFC)

SMEs/Observers
Keith Warfield (JPL)
Lynn Bowman (LaRC)
Erica Rodgers (NASA OCT)
John Grunsfeld (NASA retired)
Phil Williams (LaRC)
Alison Nordt (LMC)
Hosh Ishikawa (NRO)
Howard MacEwen (consultant)
Kevin Foley (Boeing)
Evan Linck (IDA)
Richard Erwin (USAF)

Scientist
Brad Peterson (OSU)
Eric Mamajek (NASA ExEP)
Matt Greenhouse (GSFC)

- 5 NASA Centers
- 14 private companies
- 4 gov't agencies
- 4 universities (several grad students not shown here)

Conclusion of Activity 1a

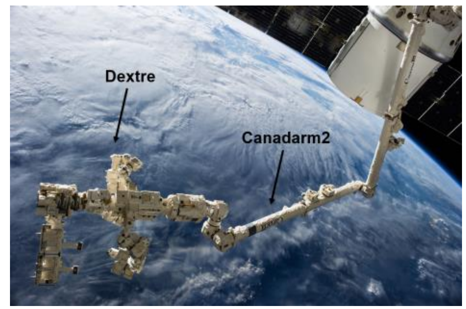
(Telescope Modularization)

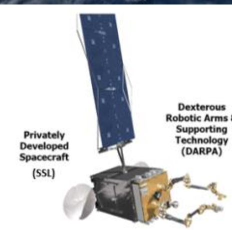
Process Activities

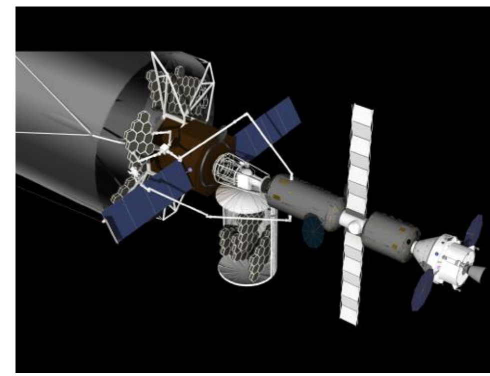
Activity 3: Write and deliver a whitepaper to APD and the Decadal

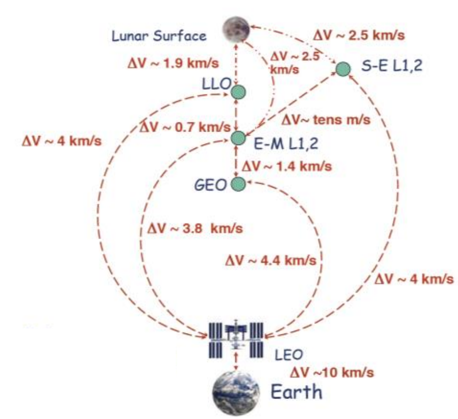
Activity 2: Estimate the costs and assess the risks of a reference iSAT

Activity 1b: Assembly and Infrastructure

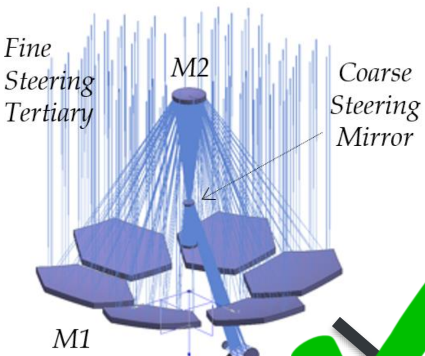




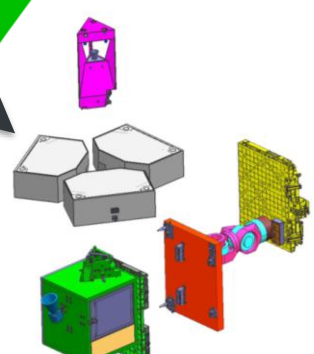




Activity 1a: Modularization and Testing



3 Mirror Anastig
Telescope
(1.45 m aperture)



6 launch modules for assembly

Problem Statement (Activity 1a): Prioritize concepts of modularized designs and architectures for a 20 m in-space assembled telescope.

Musts

M1	Enable necessary adjustability and correctability of key optical components.
M2	Permit module servicing (repair, replacement, refueling) of all instruments and key spacecraft elements.
M3	Prevent failures within a module from propagating to other parts of the system
M4	Enable all modules to be testable and verifiable, including their interfaces.
M5	Fit into the selected LV
M6	Enable the direct imaging and spectral characterization of exoplanets with a coronagraph at contrast levels of 1e-8 or better.

Wants

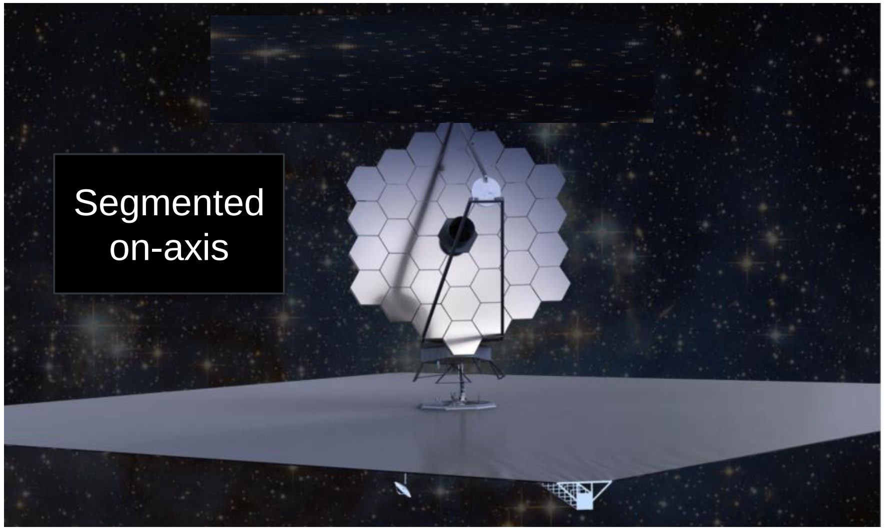
ID			COMMENTS		Reference Option A	Reference Option B
	Programmatic					
	WANTS		COMMENTS			
	Technical					
W1	Few requirements for technologies exceeding the SOA.		The more mature the concept the better, the fewer "Miracles" the better; the larger the number of low TR subsystems the worse, reach TRL 5 at earliest possible date			
W2	Clear and simple architectures and interfaces.		This speaks to the level of complexity. Clear, simple architectures and interfaces are preferred over those that require unique tools, infrastructure, large number of non-identical modules, large number of interfaces.			
W3	Robust architecture		Modularization concept is robust to localized failures, LV failures			
W4	Enables the direct imaging and spectral characterization of exo-Earths at contrast levels of 1e-10 or better		Exo-Earth imaging and characterization is expected to require a greater level of stability on the observatory. WFE stability is expected to be 10s of pm over 10 min time scales			
W5	Enables in-space access to all servicable modules for repairing or replacing.		Architectural flexibility - the more access the better but perhaps not all modules need accessing; just the critical ones.			
W6	Testable and verifiable at interfaces		The more modules that can be testable and verifiable the better. This implies module-level tests on the ground. But is a full assembly on the ground required? Could be a candidate for a Must.			
	Cost					
W7	Minimize cost		The less expensive the better. Common elements/standarization. Size of modules consistent with industry capabilities - use of existing facilities. The greater the consistency with industry capabilities the lower expected cost.			
	Schedule					
	Programmatic					
W8	Flexibility to serve more science communities		If the modularized design reduces the size of the science community then it would be weighted less. An example is narrow FOV, another is only a narrow wavelength.			
W9	Life span		Would like at least a 30 yr life time which will require servicing both the instruments and the spacecraft.			
W10	Modularized design does not preclude an evolvable architecture.		Evolvability may be an important feature but not a Must.			

Telescope Modularization Workshop

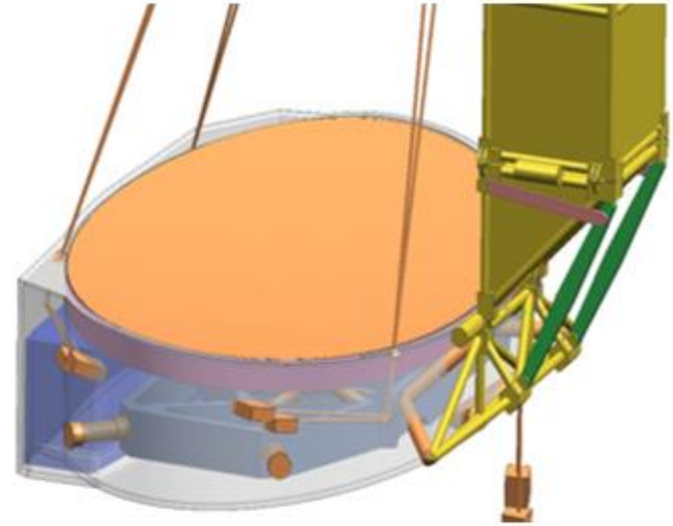
Caltech, June 5-7

47 invited participants from government, industry, and academia spanning the fields of astrophysics, engineering, and robotics.

Telescope Concepts Considered

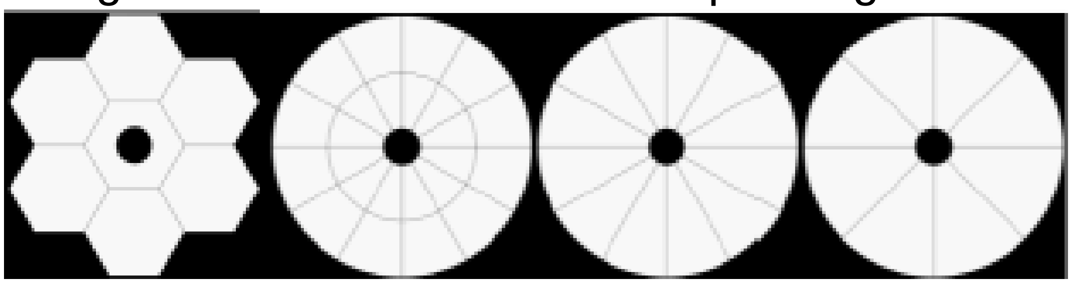


Elliptical, off-axis

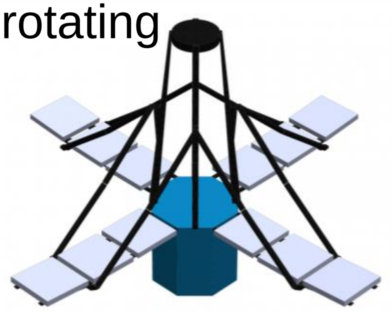


5 m segments

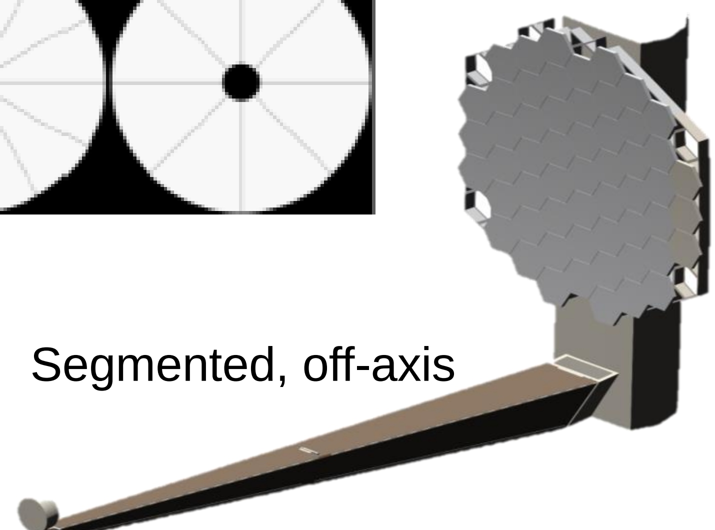
Pie-shaped segments



Sparse, rotating

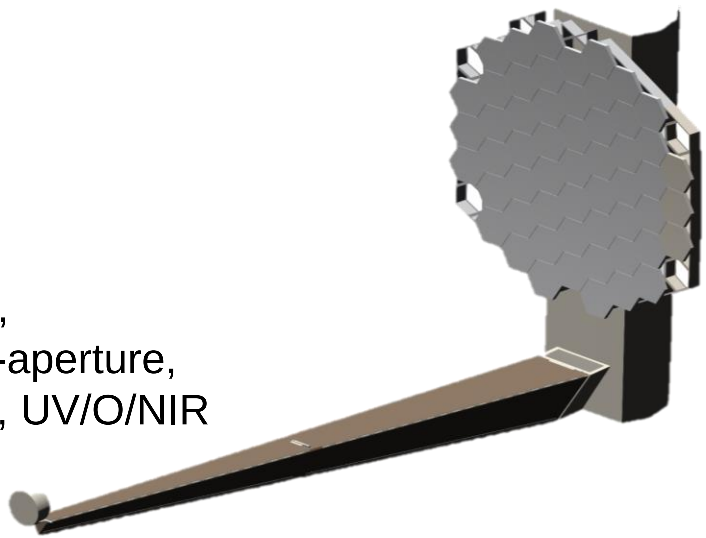


Segmented, off-axis



Telescope Modularization Concepts

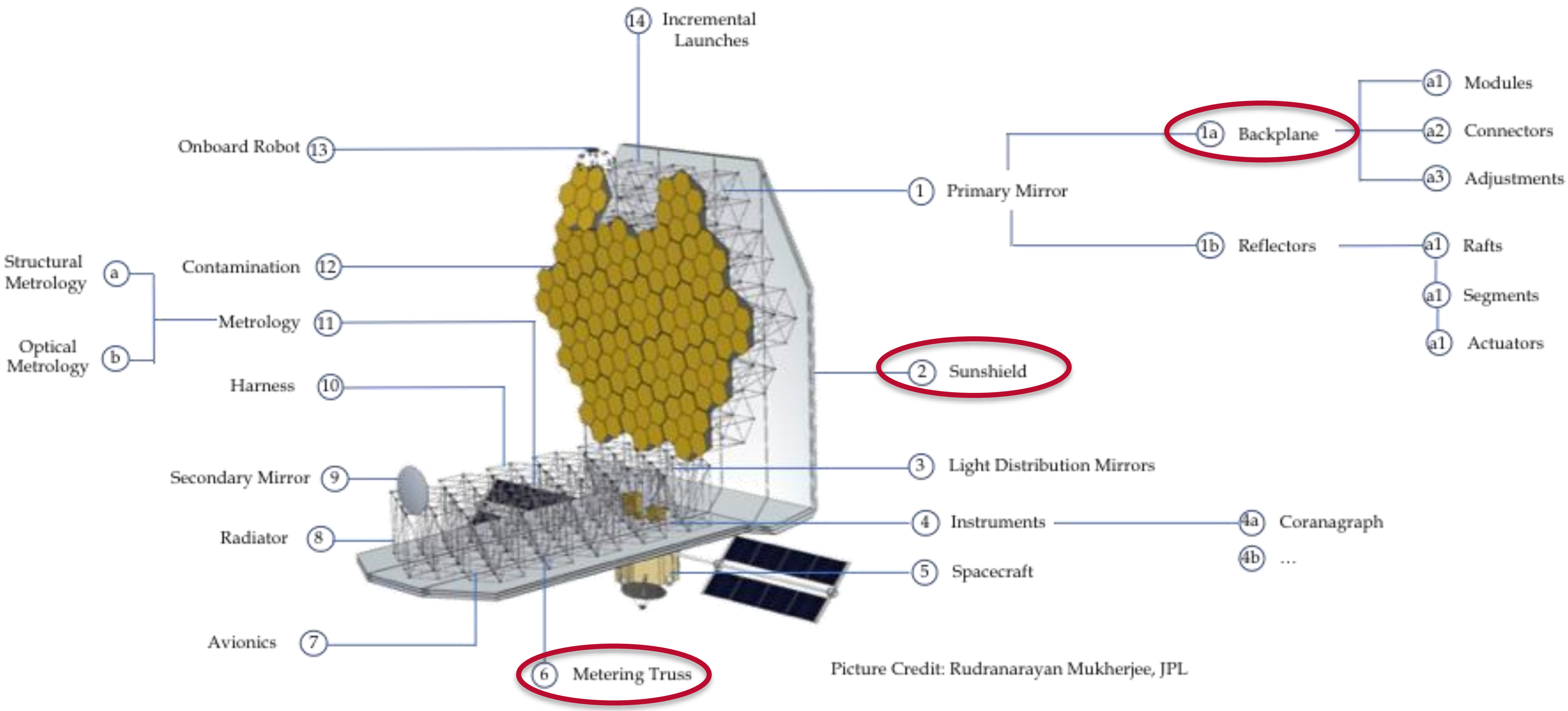
- **A 20 m off-axis f/2 telescope would serve as a good reference for the Study**
- **No better compelling alternatives for this study.**
- **No major show stoppers were found.**
- **The consensus was that modularizing this reference telescope would be feasible with current and anticipated technology and processes.**



20 m, f/2, off-axis,
segmented, filled-aperture,
with coronagraph, UV/O/NIR

Modularized Telescope Sub-Elements

(all were discussed during the Workshop)

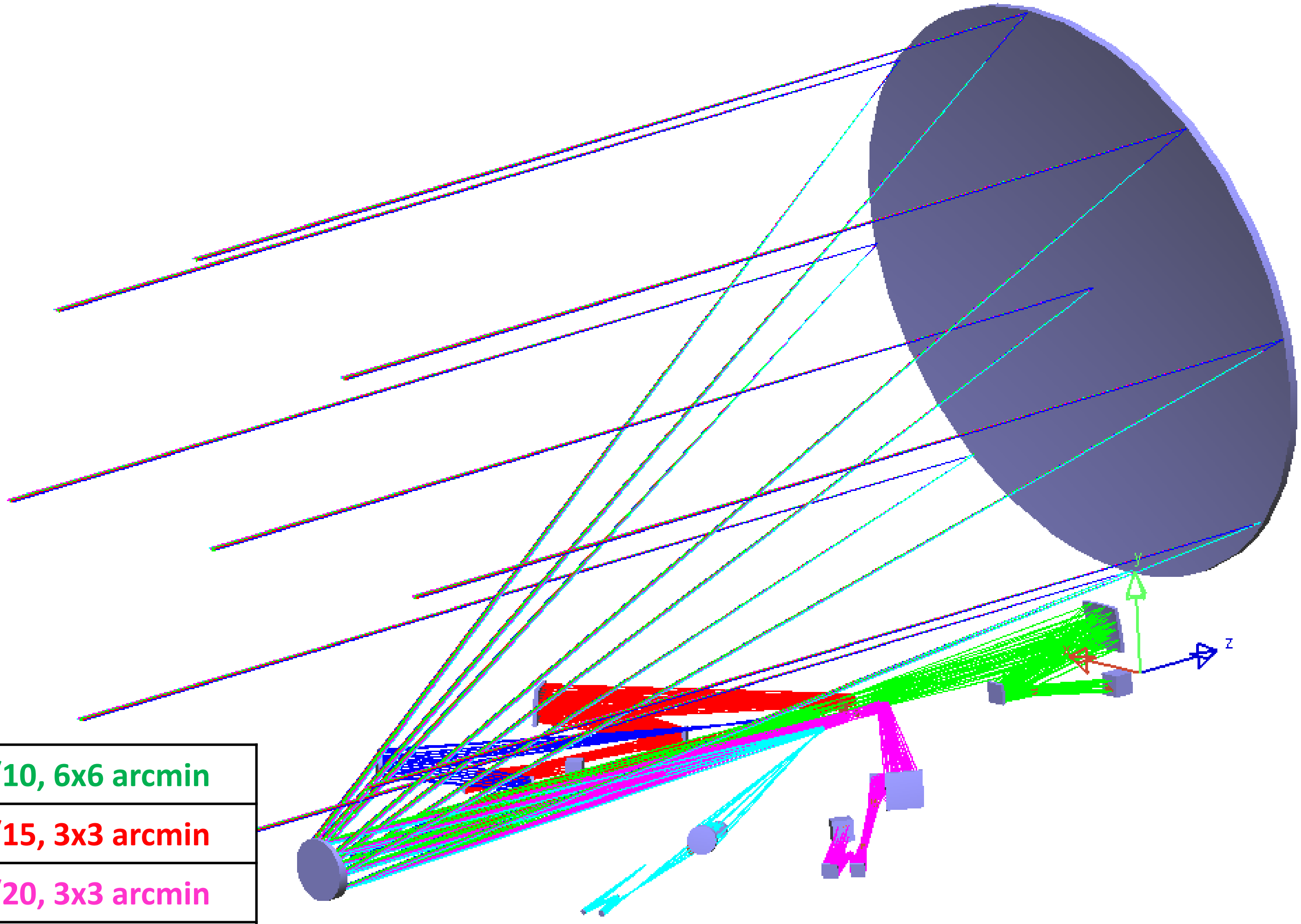


Picture Credit: Rudranarayan Mukherjee, JPL

Telescope architecture and modularization are notional.

Optical Layout with Five Instruments

Perspective view



JPL/Caltech

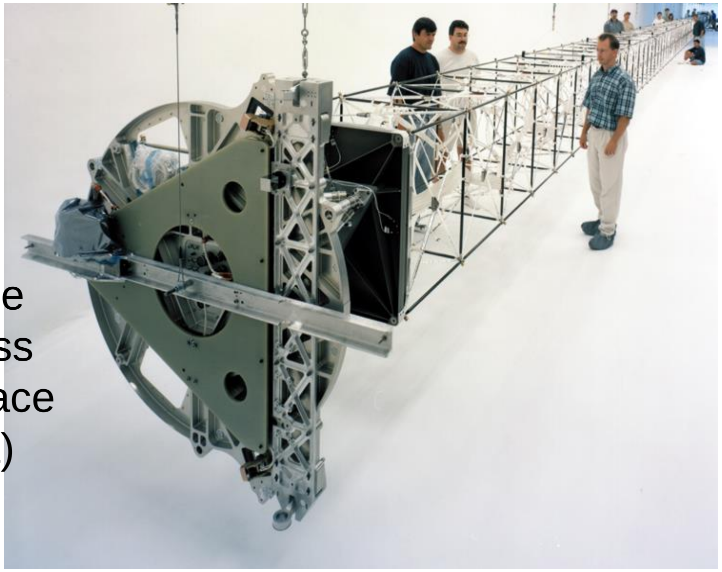
Green	F/10, 6x6 arcmin
Red	F/15, 3x3 arcmin
Magenta	F/20, 3x3 arcmin
Cyan	F/30, 9x9 arcsec
Blue	F/30, 9x9 arcsec

Three Analyses

1. Truss architecture (LaRC)

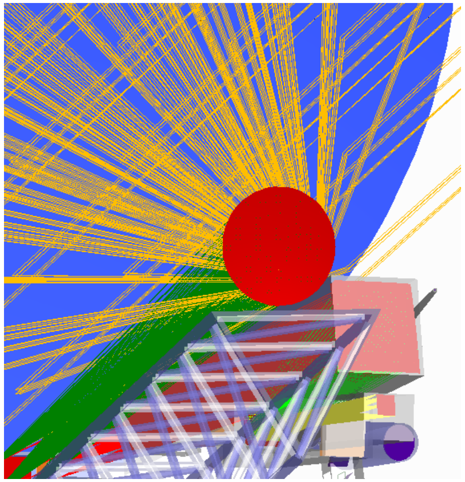
Deployable truss module for the backplane truss

Large deployable booms for the metering truss (made in space not ruled out)



2. Stray light analysis (GSFC)

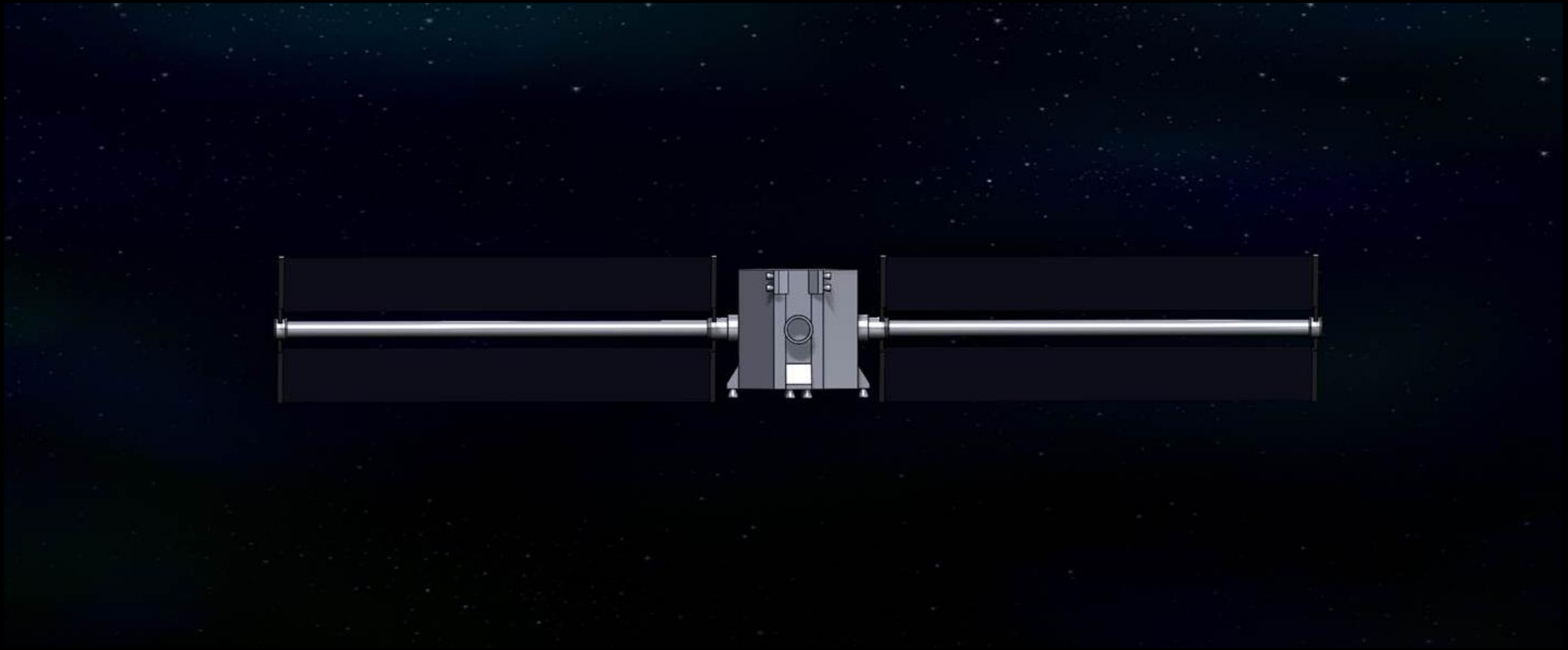
Stray light analysis for multiple sun angles



3. Sunshade architectural concept

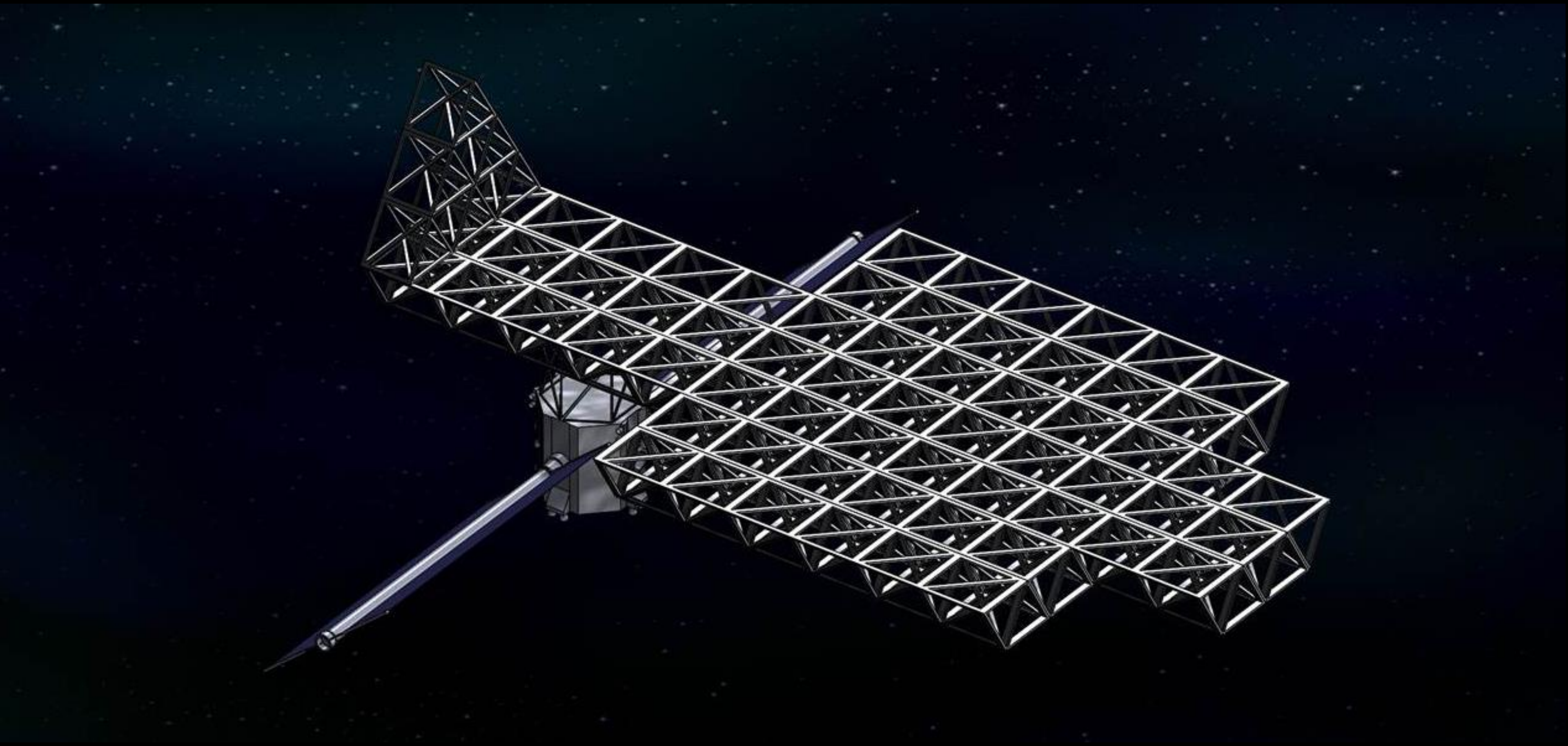
- L-shape sunshade concurred and enlarged

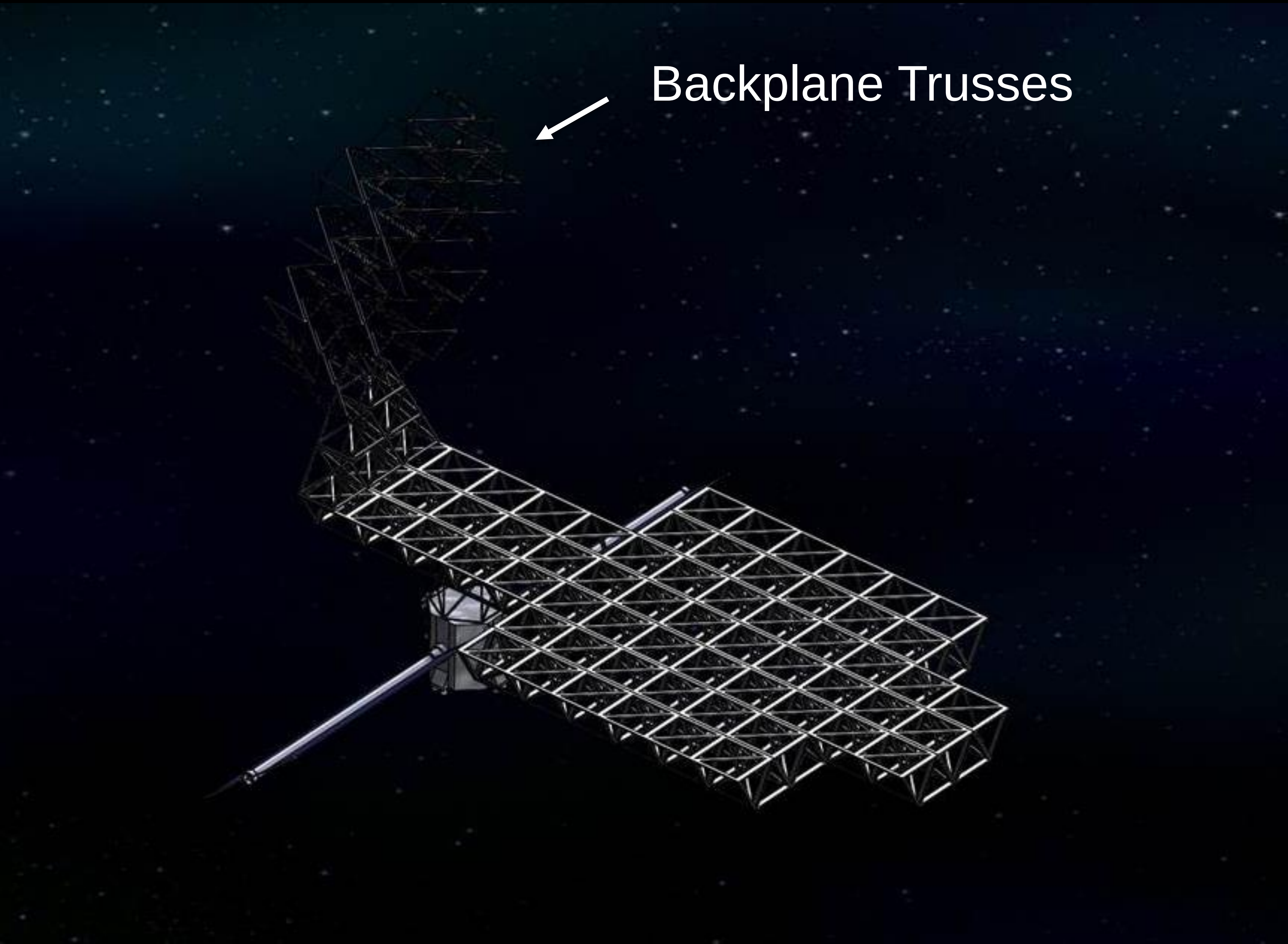
Telescope Bus and Solar Arrays

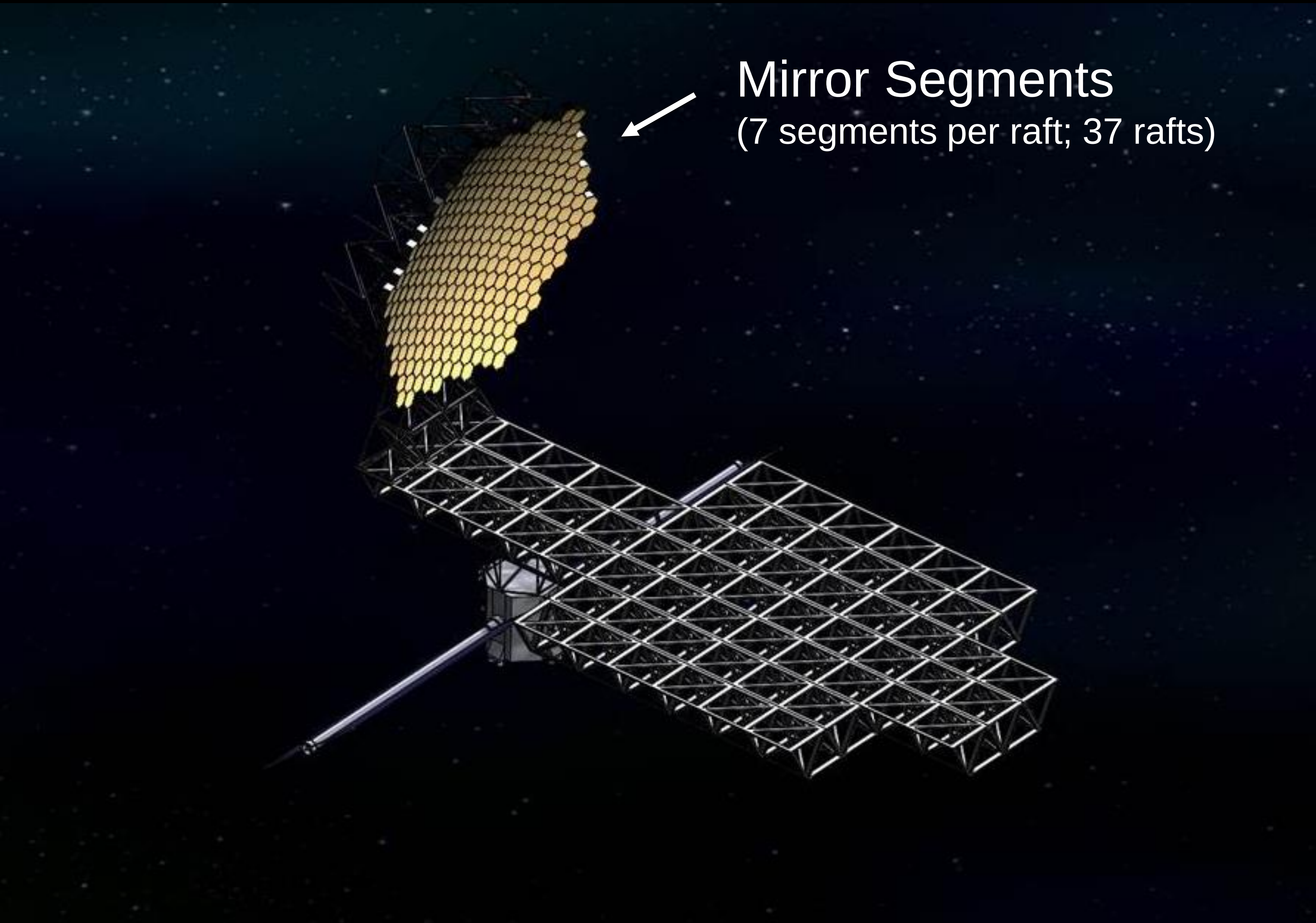


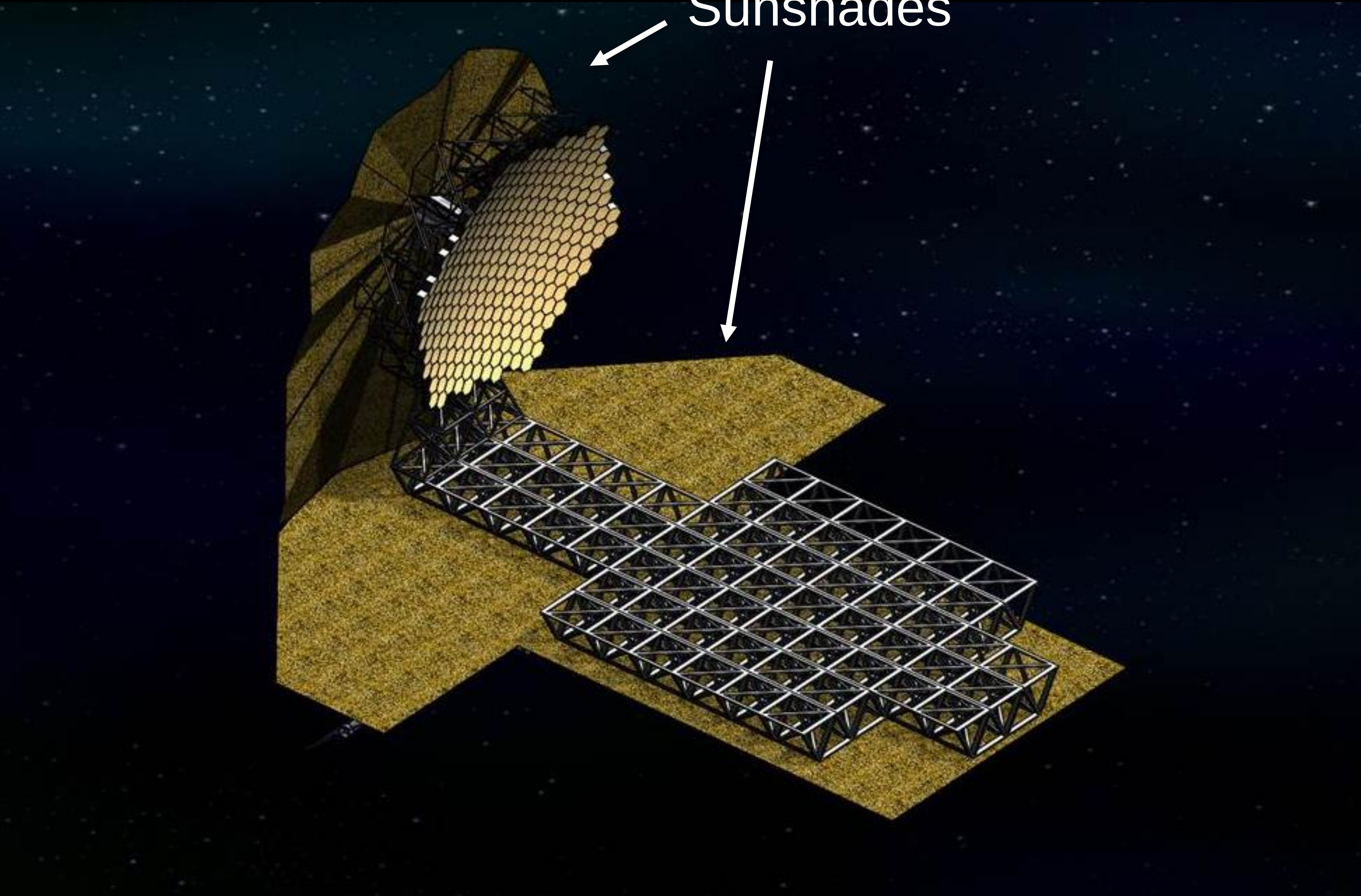
Following drawings all come from R. Mukherjee et al. 2018

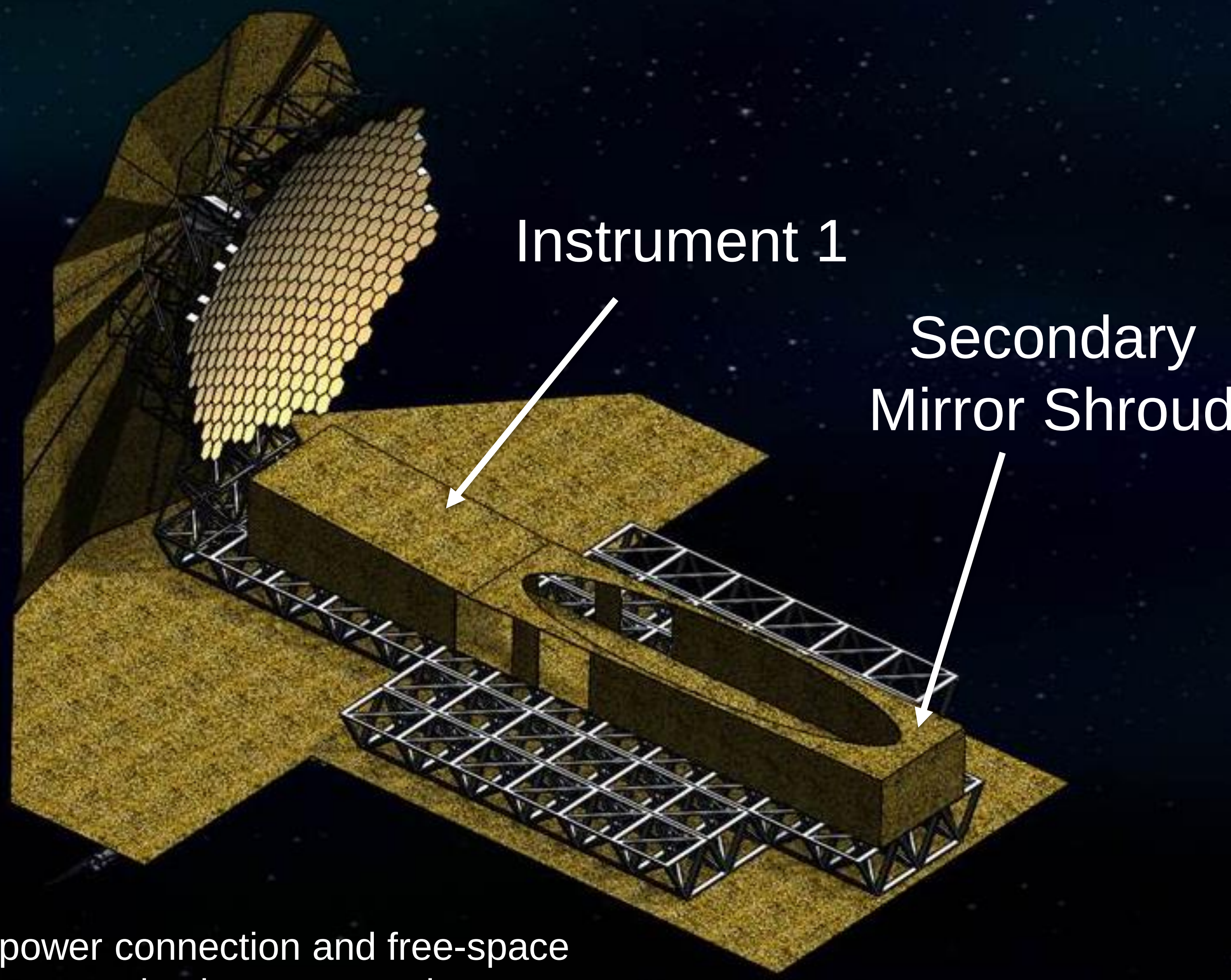
Telescope Deployed Trusses



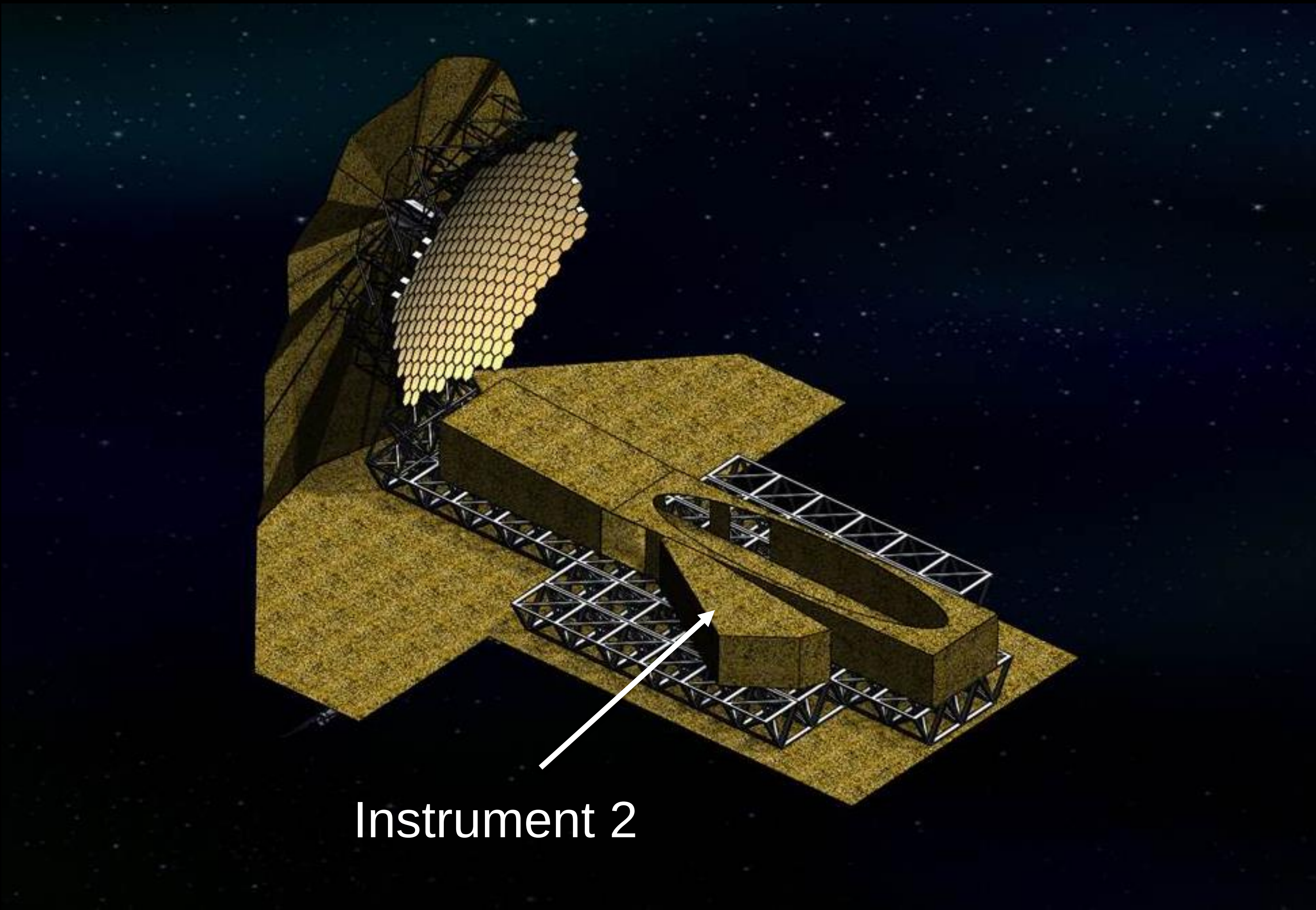

Backplane Trusses

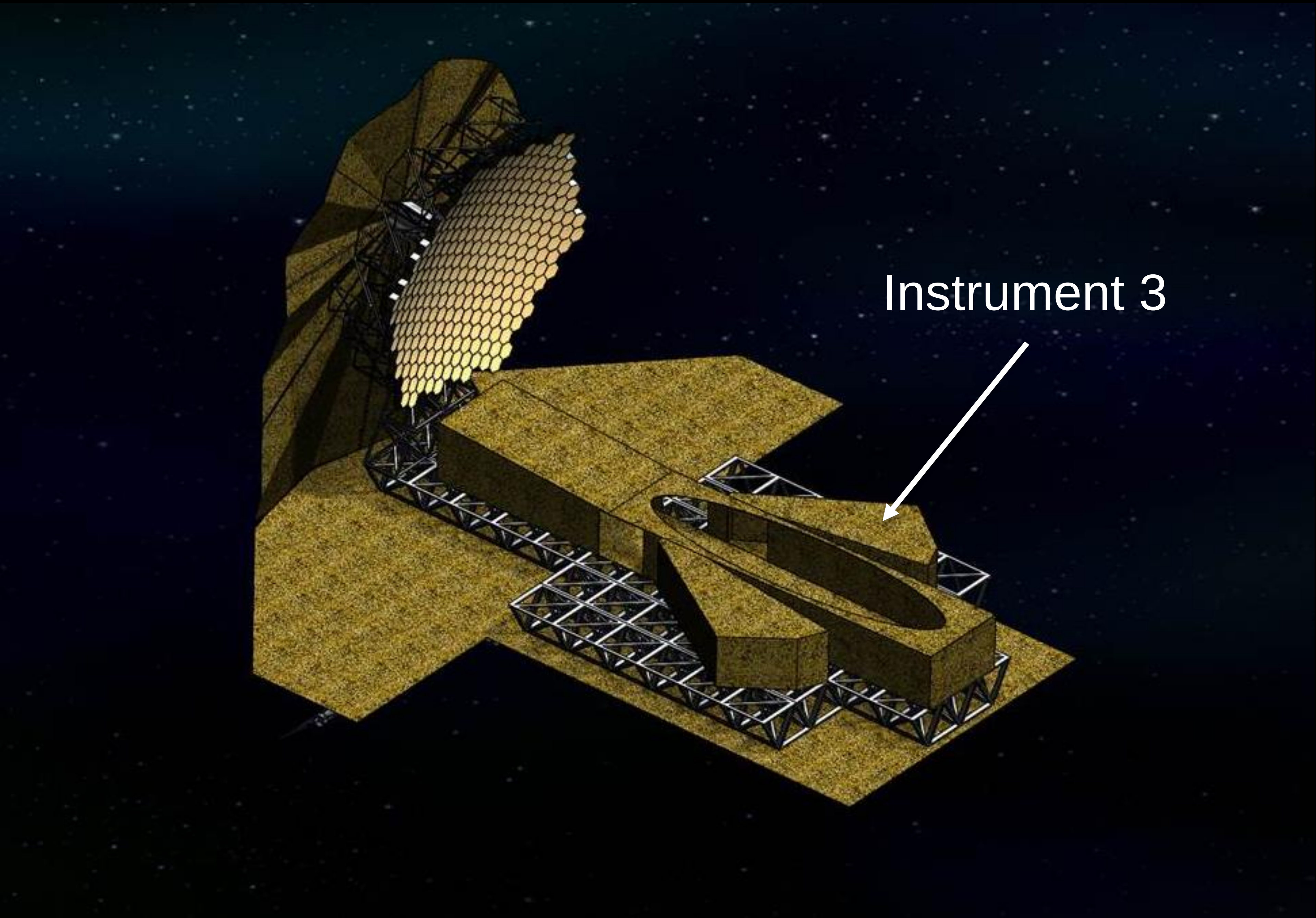

Mirror Segments
(7 segments per raft; 37 rafts)

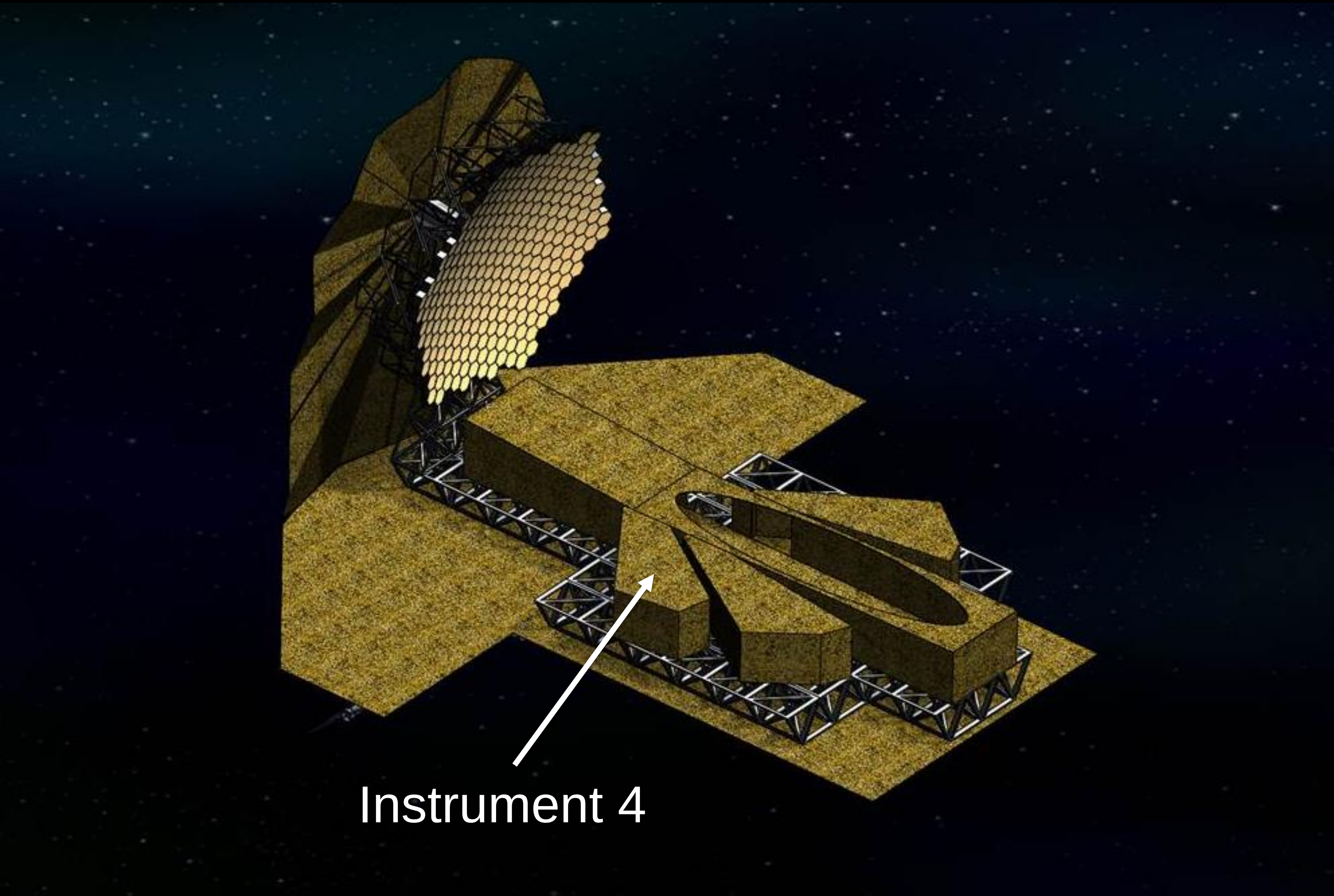

Sunshades

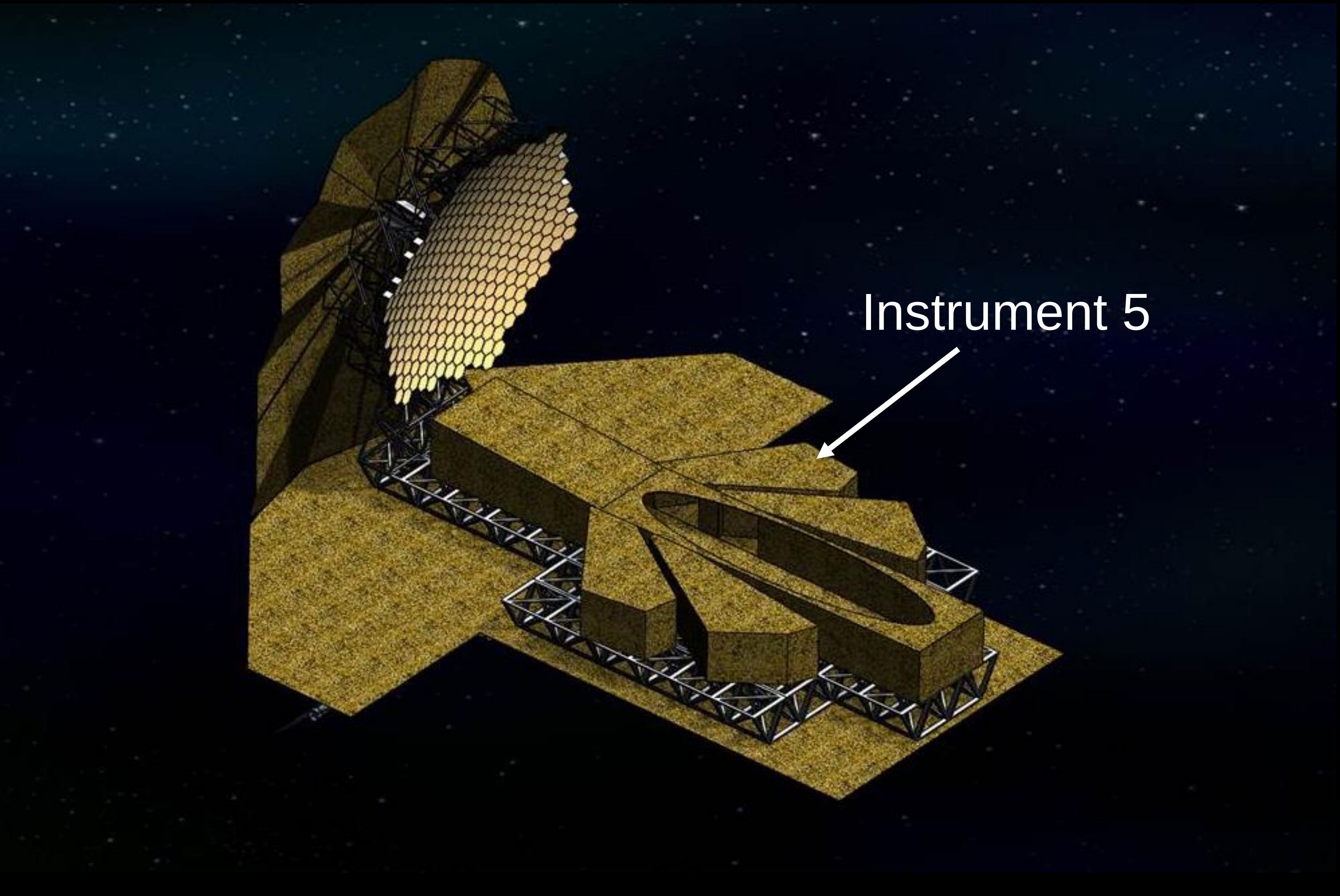


Simple power connection and free-space optical communications across short gap using a standard interface for all modules

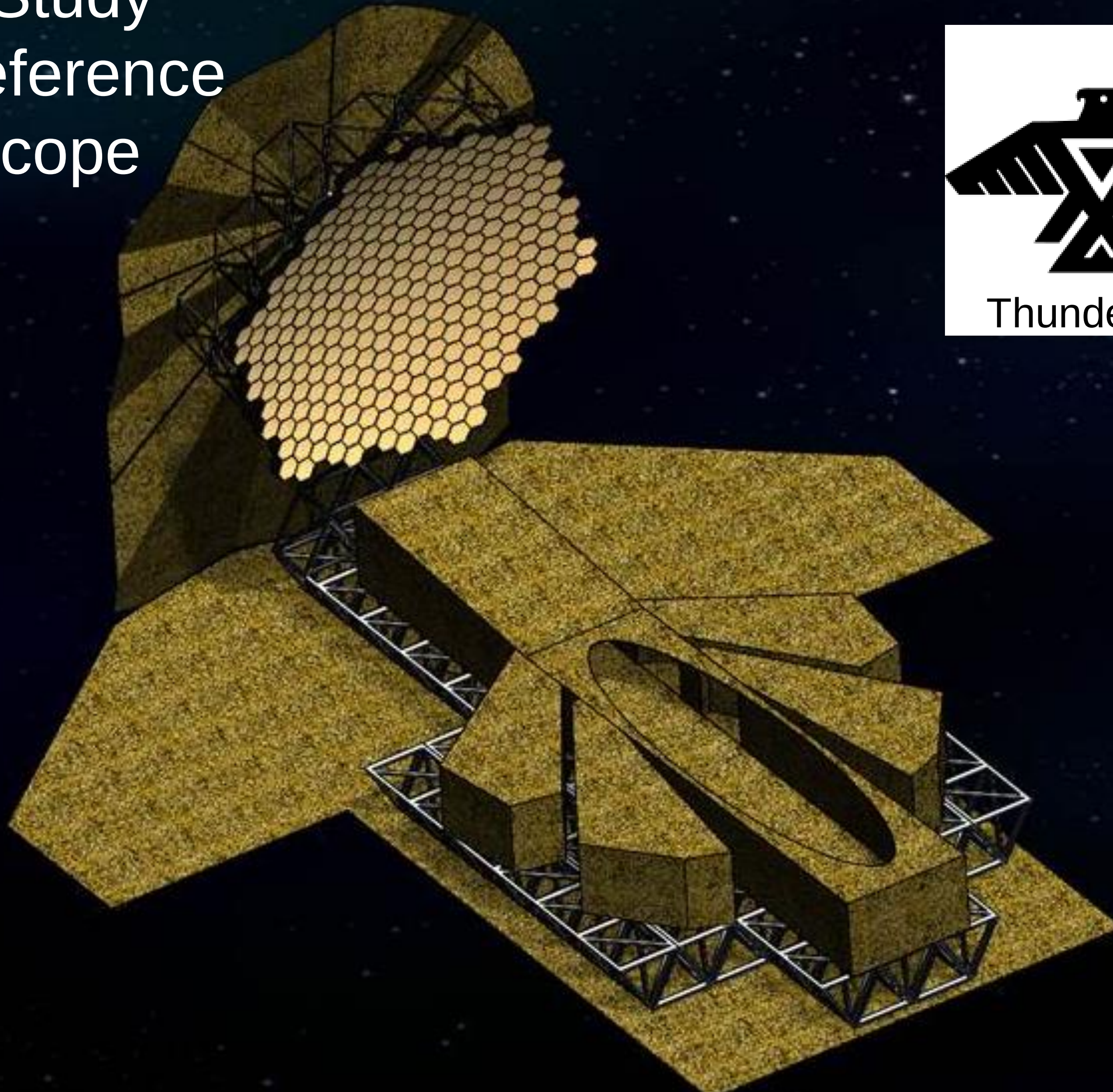

Instrument 2


Instrument 3


Instrument 4

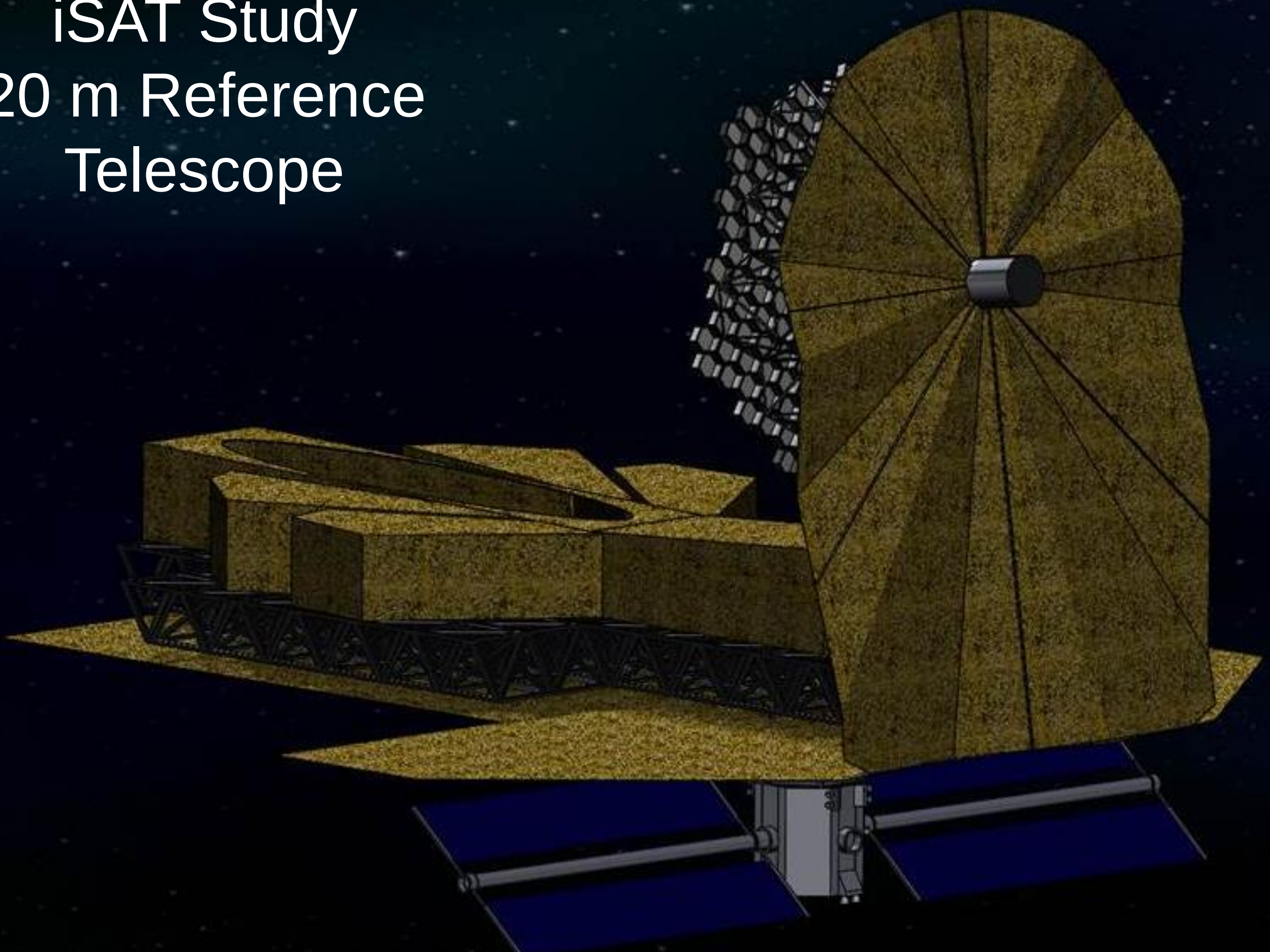

Instrument 5

iSAT Study
20 m Reference Telescope



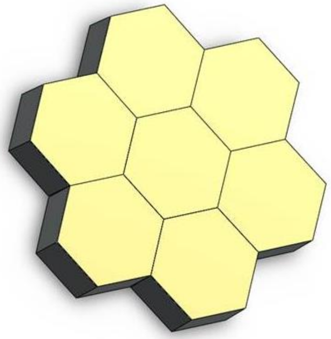
Thunderbird

iSAT Study
20 m Reference Telescope

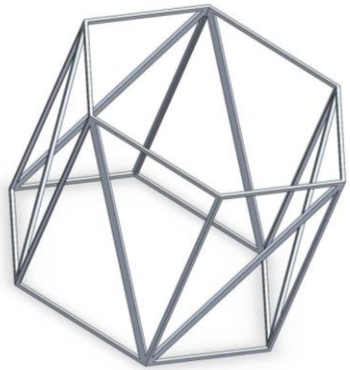


Will parametrize downward to
15, 10, and 5 m apertures

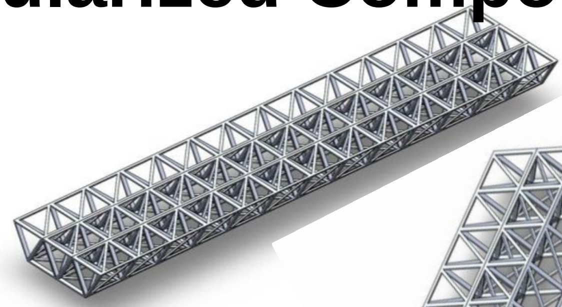
The Notional Modularized Components



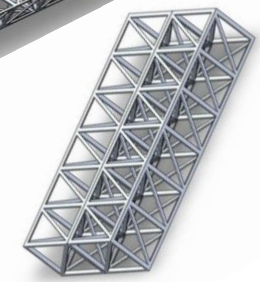
Primary Mirror Rafts
37 units



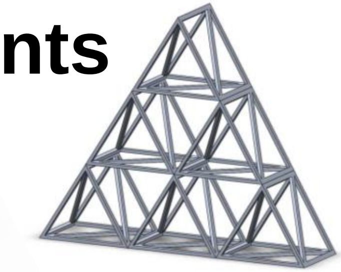
Deployable Truss Modules
24 units



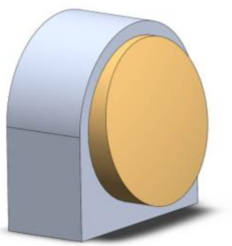
Metering Truss (PM-SM)
5 units



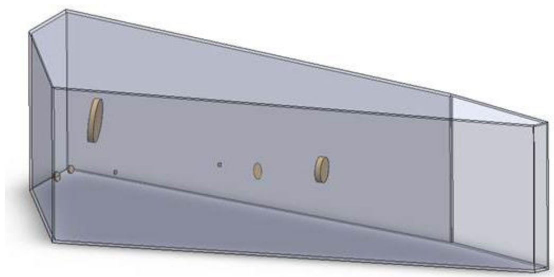
Instrument Support Truss
4 units



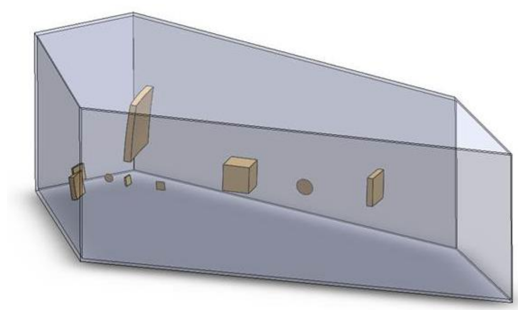
Transition Structure
1 unit



Secondary Mirror
1 unit

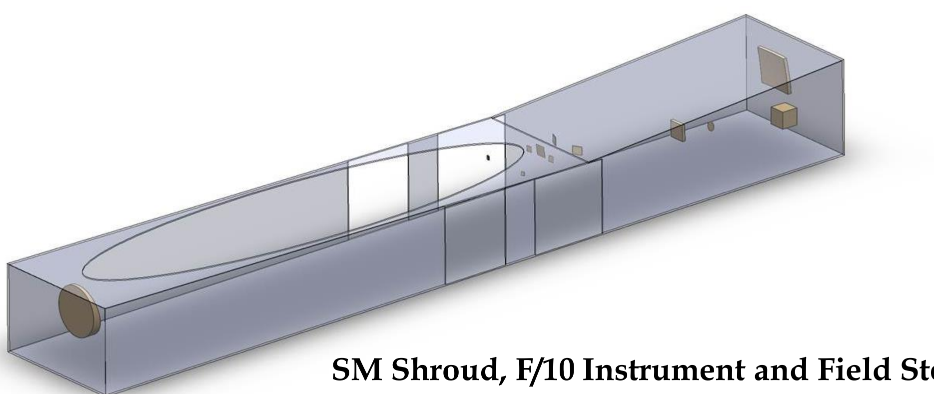


F/30 Instrument Module
2 units



F/15 & F/20 Instrument Module
1 unit each

Bottom Sunshade
1 unit



SM Shroud, F/10 Instrument and Field Stop
1 unit each

Back Sunshade
1 unit

Problem Statement (Activity 1a): Prioritize concepts of modularized designs and architectures for a 20 m in-space assembled telescope.

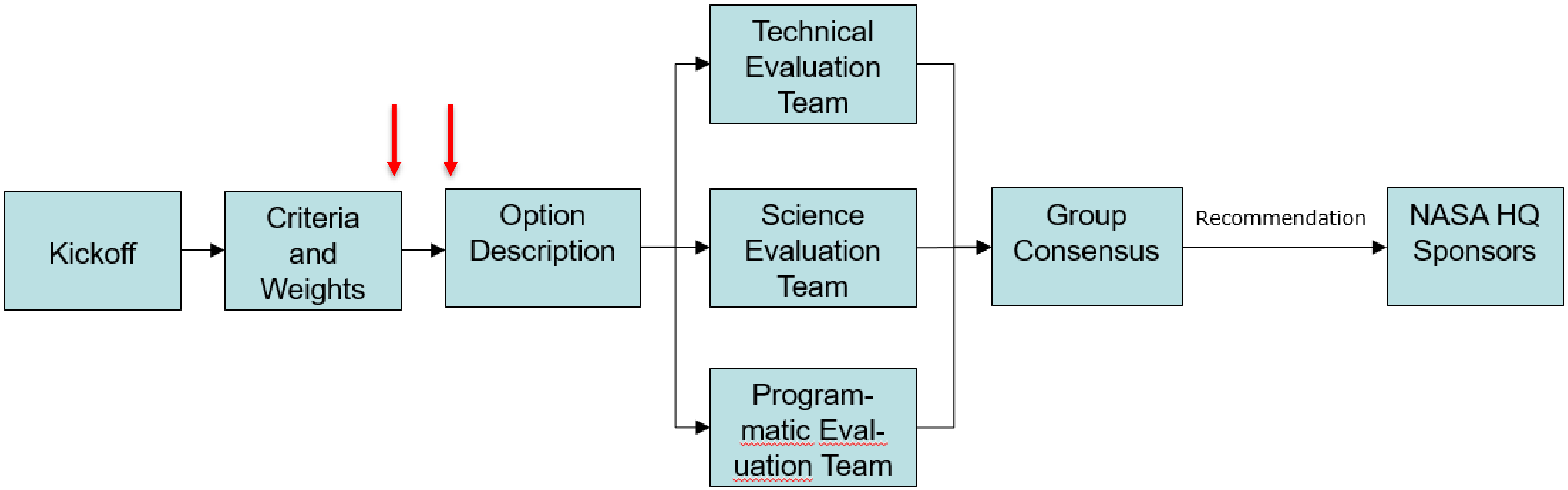
Musts		20 m Off-Axis
M1	Enable necessary adjustability and correctability of key optical components.	✓
M2	Permit module servicing (repair, replacement, refueling) of all instruments and key spacecraft elements.	✓
M3	Prevent failures within a module from propagating to other parts of the system	✓
M4	Enable all modules to be testable and verifiable, including their interfaces.	✓
M5	Fit into the selected LV	✓
M6	Enable the direct imaging and spectral characterization of exoplanets with a coronagraph at contrast levels of 1e-8 or better.	✓

Actual assessment: *The Study Members did not identify anything within the 20 m off-axis modularized reference telescope that preempted these Musts from being met.*

Activity 1b Kicked Off

(Telescope Assembly and Infrastructure)

Process


Kickoff
Criteria and Weights
Option Description
Technical Evaluation Team
Science Evaluation Team
Program-matic Eval-uation Team
Group Consensus
Recommendation
NASA HQ Sponsors

Musts

	MUSTS: *Assembly and infrastructure concept must …*		COMMENTS
	Technical		
M1	Have a useful lifetime of ≥ 30 years	Must	Useful refers to obtaining science data. To meet this Must the Concept must demonstrate it can service the observatory and spacecraft for repairs and refueling. Examples of servicing includes replacing segmented mirror rafts, avionics, sunshades, and truss infrastructure.
M2	Be able to replace the observatory's instruments and select modules with newer ones	Must	It is important that next generation science instruments replace older units as technologies change and new science questions arise.
M3	Enable the observatory to "relocate" from its assembly point to SE-L2 (if not already assembled in SE-L2)	Must	Orbital re-positioning capabilities
M4	Access the payload stowage location of the resupply vehicles	Must	
M5	Not violate the expected contamination allocation budget for each module as well as the system	Must	The entire telescope needs to be designed such that there is a docking station well clear of the optics, to avoid pluming.
M6	Enable incremental and end-to-end in-situ V&V of payload	Must	
M7	Tolerate micro-meteroid and orbital debris requirements at the assembly location	Must	

Wants

24 so far

	WANTS: *The assembly and infrastructure concept can…*	**Must, Want, or Neither**	**COMMENTS**
	Technical		
W1	Have a lifetime exceeding 30 years	Want	The longer the lifetime the better. This is a reflected Must (M1)
W2	Enable refueling	Want (high)	
W3	Go unserviced for a minimum of 5 yr	Want	Servicable interval to be as long as possible
W4	Manipulate all modules (size, materials, etc) by the assembling agent(s)	Want (high)	We may have a base platform which faciliates the assembly on it but is not itself manipulatable
W5	Access all regions of the observatory	Want	Might not want to access certain regions post assembly
W6	Use common assembly and verification tools (like laser trackers)	Want	Unique tools/tooling will fare less well as those that are more common and standardized.
W7	Allow select assembly components to be adjustable	Want	Instrument, trusses, mirror rafts alignment to mitigate I&T positioning risks
W8	Permit assembling agents' behaviors to be pre-verified	Want	There cannot be a part of the system (whether it is a robotic artificial vision system, or a dexterous manipulation system, or a planner) whose behavior isn't predictable and deterministic over all the operational environments. Astronauts can fit into this as well given their training and scripts.

Face-to-Face Meeting
NASA Langley Research Center

- Oct 2-4
- Expecting out 60 Study Members and Observers; local guests
- Goals will be:
  - advancing robotic assembly and infrastructure concepts
  - advancing the Must and Wants

Features of Kepner-Tregoe Decision Process

Decision Statement										
					Option 1		*Option 2*		*Option 3*	
Description		*Feature 1*								
		Feature 2								
		Feature 3								
Evaluation	**Musts**									
		M1			✔		✔		✔	
		M2			✔		**?**		**?**	
		M3			✔		✔		✕	
	Wants		*Weights*							
		W1	*w1%*		*Rel score*		*Rel score*		*Rel score*	
		W2	*w2%*		*Rel score*		*Rel score*		*Rel score*	
		W3	*w3%*		*Rel score*		*Rel score*		*Rel score*	
			100%	Wt sum =>	*Score 1*		*Score 2*		*Score 3*	
	Risks				C	L	C	L	C	L
		Risk 1			M	L	M	L		
		Risk 2			H	H	M	M		
Final Decision, Accounting for Risks										

C = Consequence, L = Likelihood

Day 1 Agenda

	Topic	Presenter	Start	Duration	Intended Result
1	Sign in and Refreshments		**8:30**	0:30	
2	Welcome	Siegler	9:00	0:05	
3	Logistics overview	Bowman	9:05	0:05	
4	LaRC Welcome	Cathy Mangum	9:10	0:05	
5	Sponsor Comments	Paul Hertz (remotely)	9:15	0:10	
6	Opening Remarks	Siegler	9:25	0:20	Study Members gain understanding of the rationale, process, and goals of the 3-day meeting.
7	Introductions	All	9:45	0:15	
8	Technical Overview	Mukherjee	10:00	1:00	Study Members are presented with a recap of the Activity 1a telescope modularized architecture. Members are also presented with the different concepts for Activity 1b and overview of the process for the breakout sessions
9	Musts and Wants Overview	Siegler	11:00	0:45	Study Members receive a status of the Decision Matrix Musts and Wants
10	Lunch- NACA room	All	11:45	1:15	
11	Environments Overview	Dave Miller	13:00	0:45	Study Members are presented a systems level discussion of the various space environments for assembly and operations
12	Brief Introduction to Breakout sessions	Mukherjee	13:45	0:15	Study Members get a quick primer on the breakout sessions
13	Breakout Session 1	Breakout Leads	14:00	1:45	The break-out groups have their first discussion
14	Break		15:45	0:15	
15	Breakout Session 2	Breakout Leads	16:00	1:45	The break-out groups have their second discussion
16	Outbrief	Breakout Leads	17:45	0:15	Breakout leads provide quick updates on the two breakout sessions
17	Adjourn		18:00	0:00	Facilitators provide a quick recap of the breakout sessions
	End Day 1		18:00		
18	No Host Group Dinner @ "The Vanguard"		19:30		https://www.thevanguard757.com/

Day 2 Agenda

	Topic	Presenter	Start	Duration	Intended Result
1	Sign in and Refreshments		**8:00**	0:30	
2	Recap	Siegler	8:30	0:15	Quick recap of day 1
3	Breakout session 3	Breakout Leads	8:45	1:30	2 groups evaluate the concepts
4	Break		10:15	0:15	
5	Breakout session 4	Breakout Leads	10:30	1:30	2 groups evaluate the concepts
6	Group Photo	All	12:00	0:15	
7	Lunch- NACA room (Guest Speaker: Debi Tomek, Deputy Director of Space Technology and Exploration at LaRC)	All	12:15	1:00	
8	Breakout session 5	Breakout Leads	13:15	1:30	2 groups evaluate the concepts
9	Break		14:45	0:15	
10	Breakout session 6	Breakout Leads	15:00	1:30	2 groups evaluate the concepts
11	Outbrief		16:30	1:30	Facilitators provide detailed recap of their group's findings on the different concepts (including day 1 and 2)
12	Adjourn		18:00		
	End Day 2		18:00		

Day 3 Agenda

	Topic	Presenter	Start	Duration	Intended Result
1	Sign in and Refreshments		**8:00**	0:30	
2	Recap	Mukherjee	8:30	0:15	Recap of findings from days 1 and 2
3	Hybrid Concepts	Siegler	8:45	0:30	Study Members discusses any new concepts hybridizing the concepts from day 1 and 2
4	Map Concepts to KT Matrix	Siegler	9:15	2:45	Study Members discuss relative merits for the different concepts per the criteria in the Musts and Wants
5	Summary/Wrap Up	Siegler/Thronson/ Mukherjee	12:00	0:30	Next steps and action items are identified
	Adjourn		12:30		
	End Day 3		12:30		

Sample Questions

Intended to help describe and compare the Assembly and Infrastructure Concepts

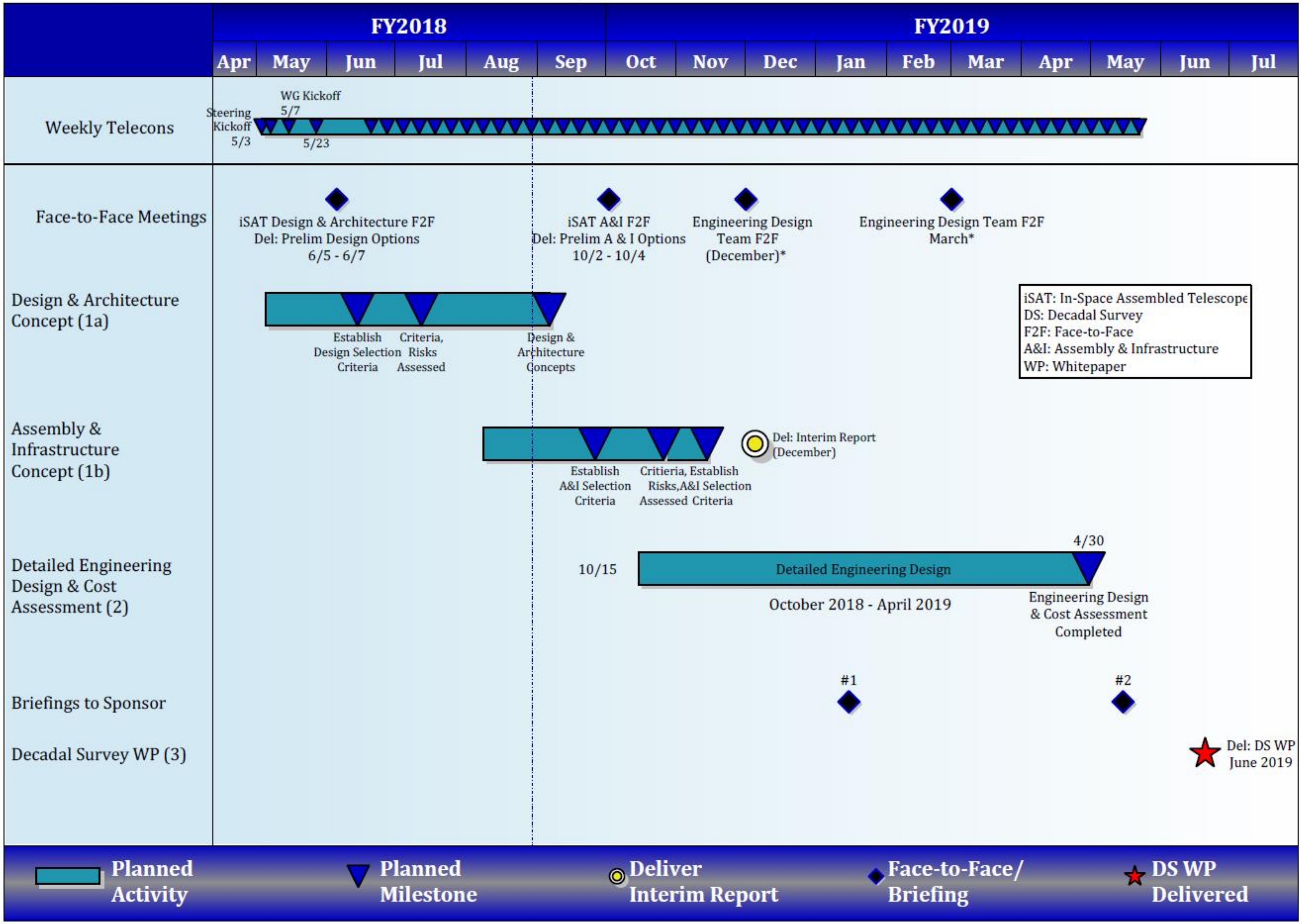
1. *Describe the RPO con-ops of the assembly agent, resupply vehicle, sensing and spacecraft control authority.*
2. *Describe the assembly agent (single or multiple) and their roles.*
3. *Describe the assembly sequence (i.e. how do we go from the modules to the observatory)*
4. *Describe mobility or accessibility to different regions of the observatory for assembly – estimate precision and accuracy*

Next Steps

Next Steps

- **Complete Activity 1b**
  - Planning for mid-Nov
  - Expect forward analyses needing to be work out
- **Activity 2: Assess Cost and Risk Impacts of iSA Paradigm**
  - Develop Product Life Cycle factoring in:
    - More parallel activities
    - Less systems-level testing; take advantage of increased adjustability and correctability of final integrated system
    - Mass and volume relief
    - Deferred I&T stage (in space, with numerous LVs)
  - Feeds into a costing exercise for each of the four aperture sizes
  - Focused engineering design/analyses sprints as needed
- **Costing approaches:**
  1) **Identify cost and risk deltas with respect to the current paradigm**
  2) **Costing exercise - combination of grass roots plus heritage**
     - Some subsystems will have heritage and some will require new costing
  3) **Parameterize to 5, 10, 15, 20 m apertures**

Top-Level Schedule



*tentative date

Miscellaneous Topics

Miscellaneous iSA Topics

1. **Briefed Paul Hertz at NASA HQ in September**

2. **Scientific American article on iSSA should be out in next few months**

3. **Interagency Science and Technology Partnership - Open Forum Event**
   - *The purpose of the Open Forum is to understand the current state of commercial investments in in-space assembly related systems and capability developments and how they may fit with the in-space assembly capability needs of any of the partners.*
   - Nov 6 at NASA HQ
   - https://www.fbo.gov/index.php?s=opportunity&mode=form&id=521f240a66d117dfc929bde17d427791&tab=core&_cview=0

Open Discussion

Jet Propulsion Laboratory
California Institute of Technology