Jet Propulsion Laboratory
California Institute of Technology

In-Space Assembled Telescope (iSAT) Study

Study Members Telecon 8

September 12/13, 2018

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NASA Jet Propulsion Laboratory, California Institute of Technology

CL#18-5005

Today's Agenda

1. **Review of Study Goals and Activities**
2. **Face-to-Face Meeting Update**
3. **Exploring the Assembly and Infrastructure Parameter Space** *(Rudra Mukherjee/JPL)*
4. **Short Tutorial on Decision-Making Process**
5. **Begin Selection Criteria Assessment**

Activity 1b Kick-Off Telecon presentation slides:
https://exoplanets.nasa.gov/exep/technology/in-space-assembly/iSAT_working_group_telecons/

Study Charter (original):
https://exoplanets.nasa.gov/internal_resources/864

Review of Study Goals and Activities

Study Objective and Deliverables

- **Study Objective:**
  - *"When is it advantageous to assemble space telescopes in space rather than to build them on the Earth and deploy them autonomously from individual launch vehicles?"*

- **Deliverables:**

A whitepaper by May 2019 assessing:

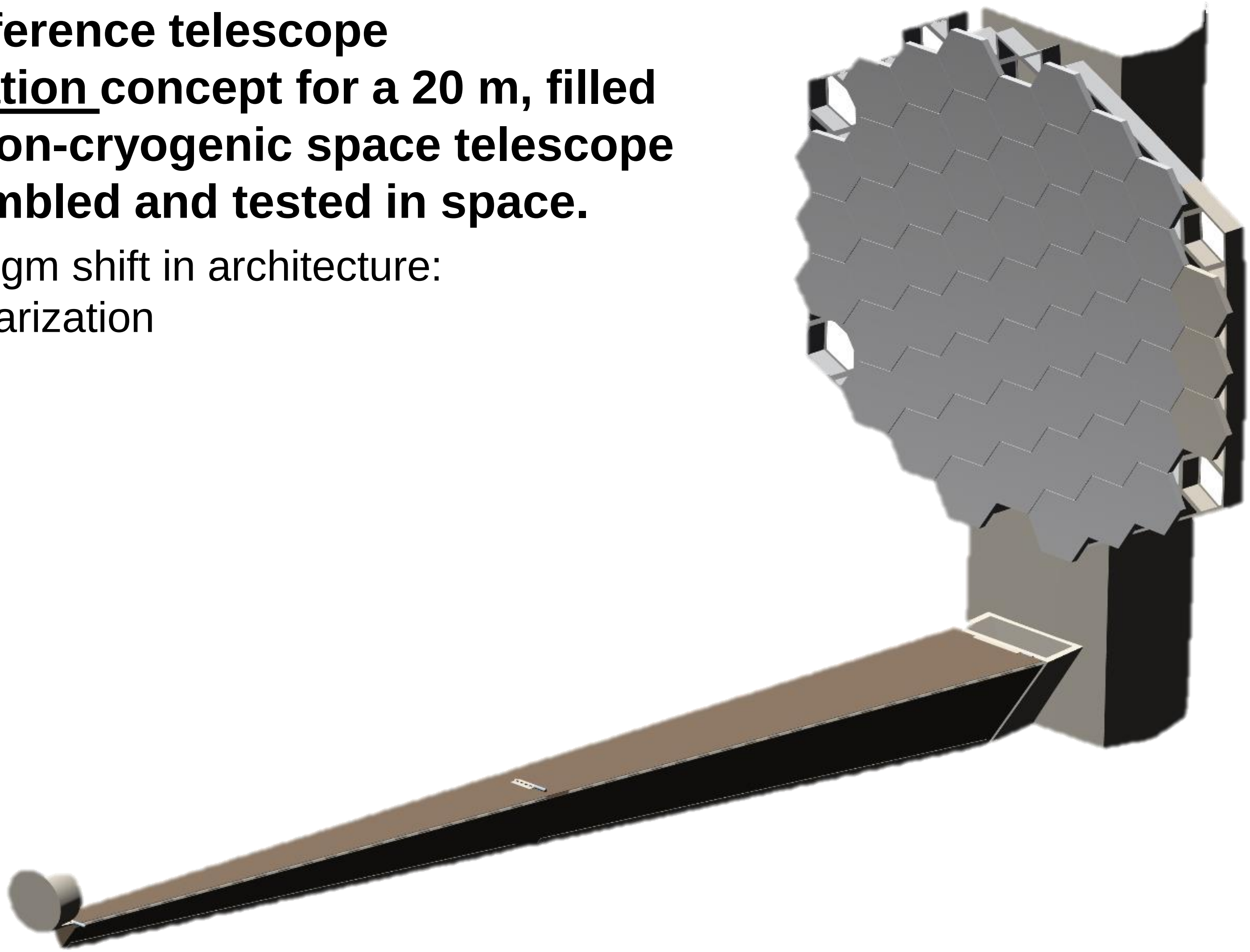
1. the telescope size at which iSA is necessary (*an enabling capability*)
2. the telescope size at which iSA is cheaper or lower risk with respect to traditional launch vehicle deployment (*an enhancing capability*)
3. the important factors that impact the answers (e.g., existence of HEO-funded infrastructure, architecture of space telescope (segments or other), cryogenic or not, coronagraph capable (stability) or not, etc.)
4. A list of technology gaps and technologies that may enable in-space assembly

The intention of the whitepaper is to inform NASA and the 2020 Decadal Survey of the cost and risk benefits of the iSA of telescopes.

Activity 1a
Concept Telescope Modularization for the iSAT

Select a reference telescope modularization concept for a 20 m, filled aperture, non-cryogenic space telescope to be assembled and tested in space.

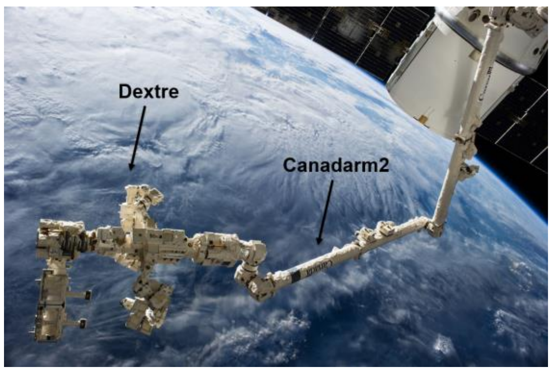
- Paradigm shift in architecture: Modularization

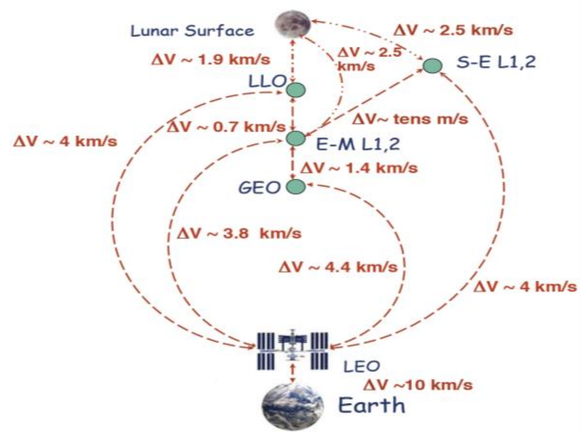


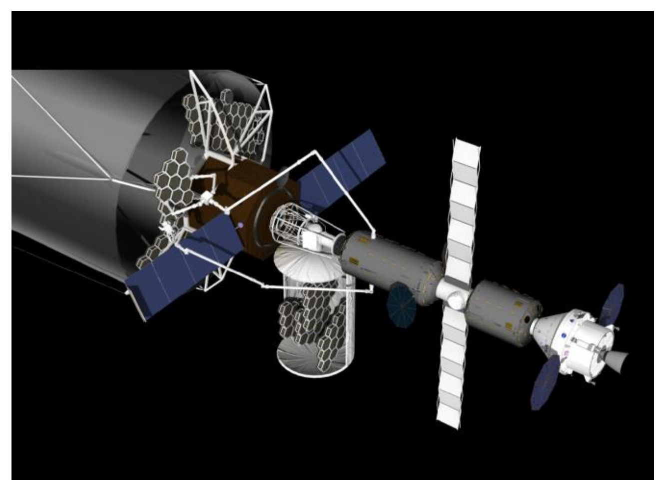
Activity 1b:

Concept for Assembly and Infrastructure for the iSAT

Select a reference in-space assembly and infrastructure concept for the "assemble-able" space telescope architecture, defining robotics, orbit, launch vehicle, and assembly platform.







Activities 2a and 2b
Detailed Engineering Design and Costed

Activity 2a: Advance the engineering fidelity of the concepts sufficiently so that they can be costed.

a) Inputs from Activity 1a and 1b
b) Select a team of NASA engineers, academia, government labs, and commercial companies to conduct the work.

Activity 2b: Estimate, through an independent body, the cost of designing, architecting, assembling, and testing the reference 20 m space telescope?

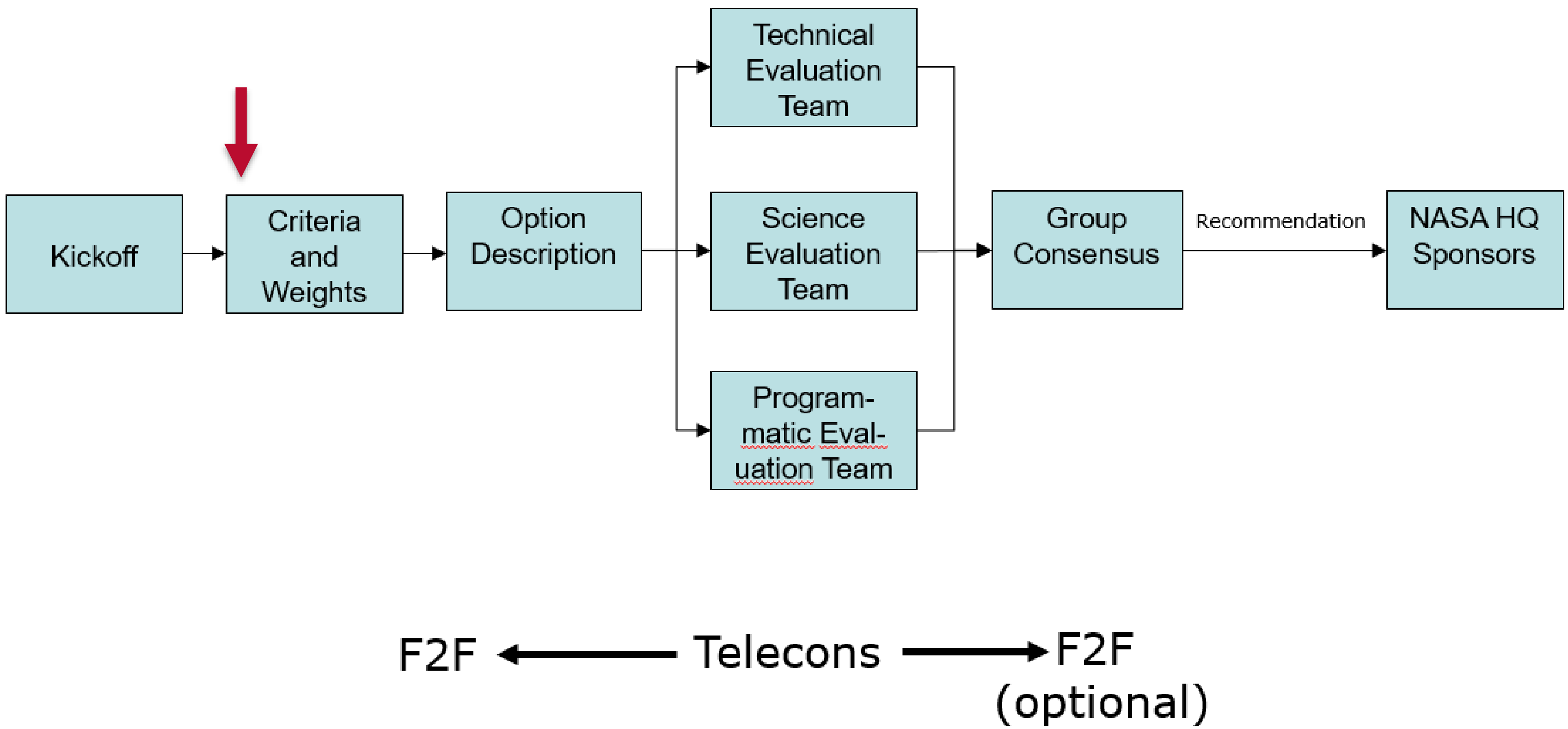
a) Input designs/final architecture from Activity 2a
b) Identify risks
c) Parameterize the cost to smaller apertures

Activity 3
Deliver Final Whitepaper

Write and deliver the Final Whitepaper

a) Submit to APD Director who submits to 2020 Decadal Survey (June 2019)

How will iSAT Study WG Produce a Recommendation?



Confirmed Participants 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)
Kimberly Mehalick (GSFC)

Structures
Kim Aaron (JPL)
John Dorsey (LaRC)
Bill Dogget (LaRC)
Joe Pitman (consultant)
Keith Belvin (LaRC)
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)

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

GNC
Bo Naasz (GSFC)

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)
Joe Parrish (DARPA)
Michael Fuller (Orbital)
Adam Yingling (NRL)
Hsiao Smith (GSFC)
Dave Miller (MIT)
Ken Ruta (JSC)
Kim Hambuchen (JSC)

Architectural Systems
David Kang (NG)
Paul Lightsey (Ball)
Bo Naasz (GSFC)

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

Manufacturing
Kevin DiMarzio (MIS)
Bobby Biggs (LMC)
Rob Hoyt (Tethers)

Controls
Larry Dewell (LMC)

Sunshade
Jon Arenberg (NG)

Thermal
Carlton Peters (GSFC)

SMEs/Observers
Keith Warfield (JPL)
Lynn Bowman (LaRC)
Erica Rodgers (STMD)
John Grunsfeld (NASA retired)
Phil Williams (LaRC)
Alison Nordt (LMC)
Hosh Ishikawa (NRO)
Howard MacEwen (consultant)
Mike Elsperman (Boeing)

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

Face-to-Face Update

Assembly and Infrastructure Face-to-Face

October 2-4, NASA LaRC, Hampton, VA

- **Goal:**
  1. advance and generate concepts to assemble the reference telescope and define its needed infrastructure,
  2. advance the selection criteria in which we will prioritize these concepts.

- **Draft Agenda and Logistics Package:**
  - https://exoplanets.nasa.gov/exep/technology/in-space-assembly/iSAT_study_workshops/
  - Hotel information and meeting location
  - Please arrive early to deal with badging

- **Logistics questions:**
  - Jennifer Gregory (jgregory@jpl.nasa.gov)
  - Lynn Bowman (lynn.m.bowman@nasa.gov)

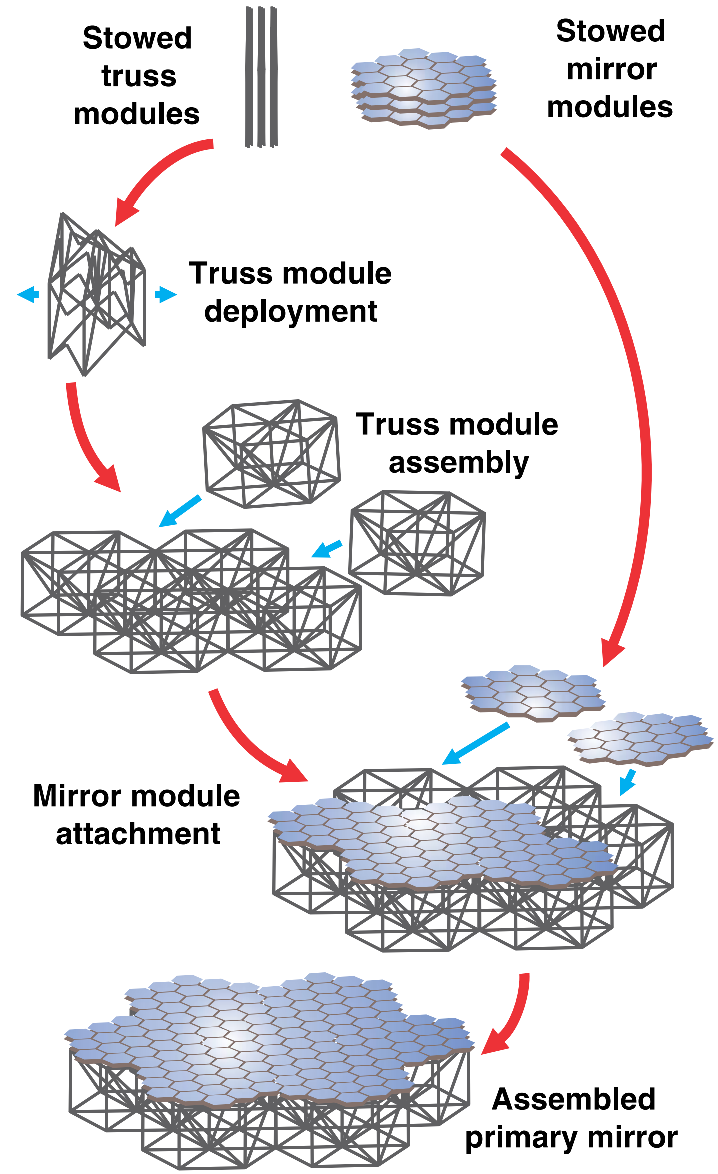
A Brief Exploration of the Parameter Space

Rudra Mukherjee
Jet Propulsion Laboratory, California Institute of Technology

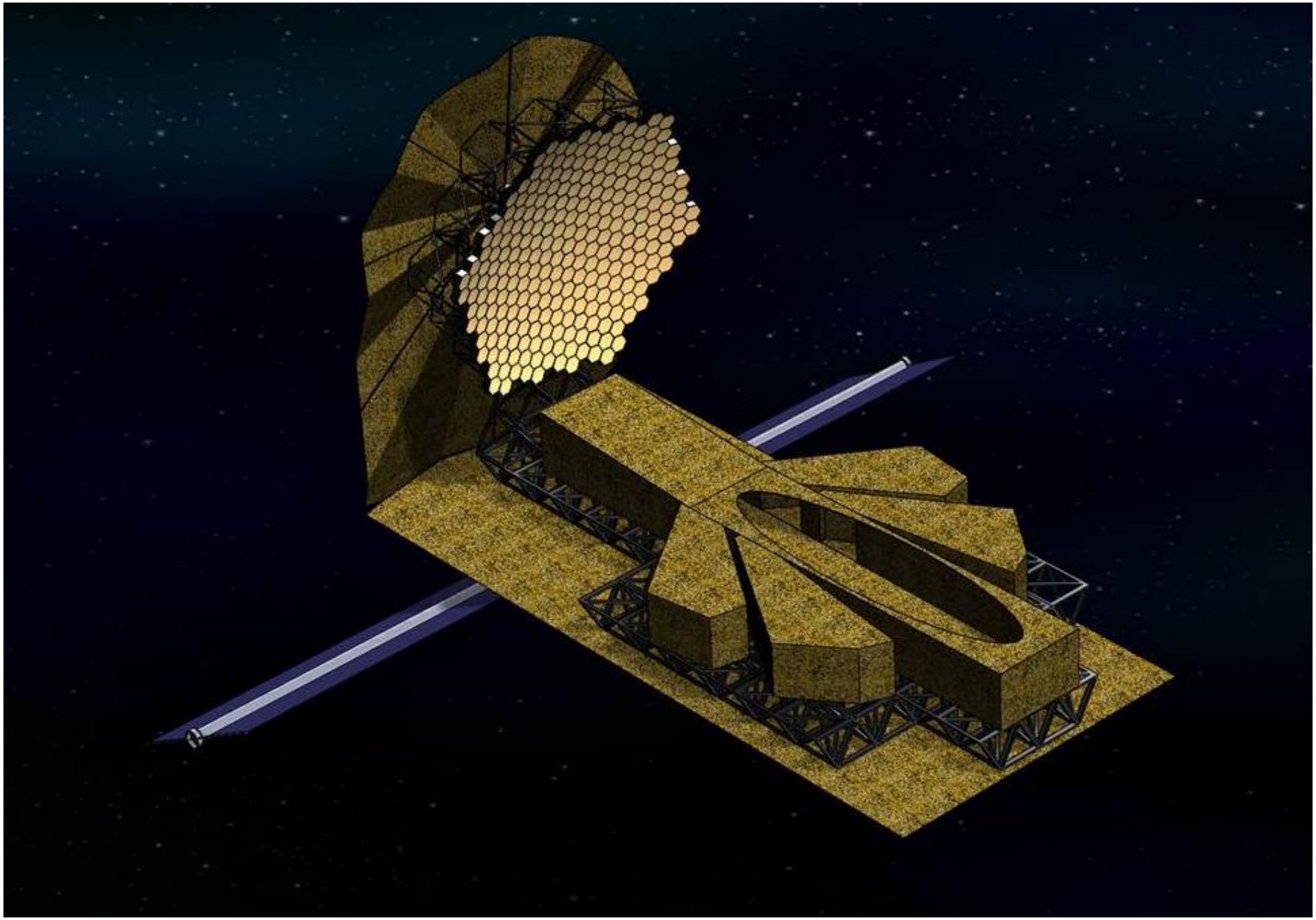
The Job At Hand

Activity 1b Briefing
Sep 12, 2018

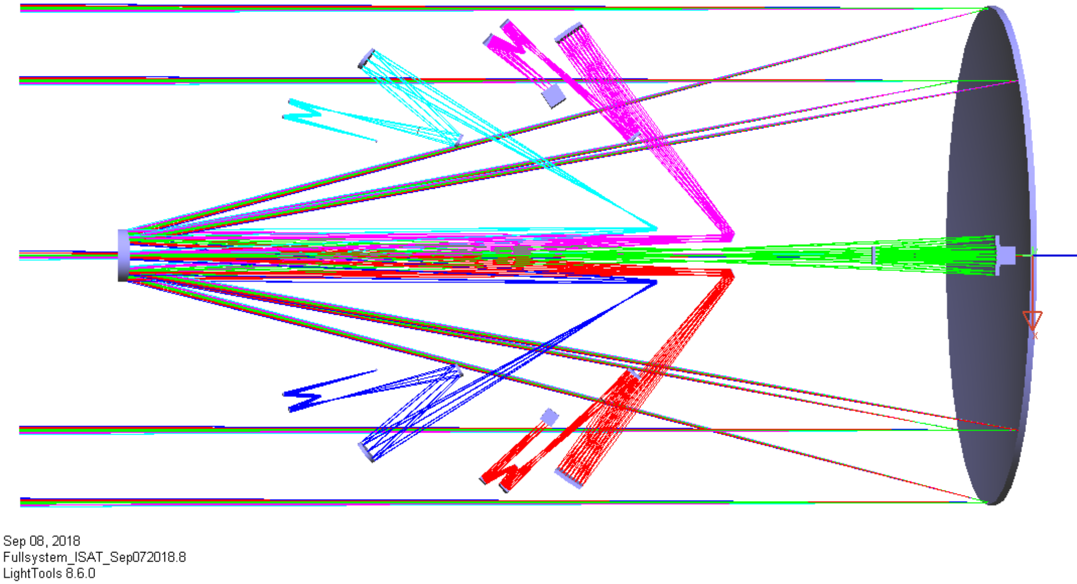
Rudranarayan Mukherjee Ph.D.

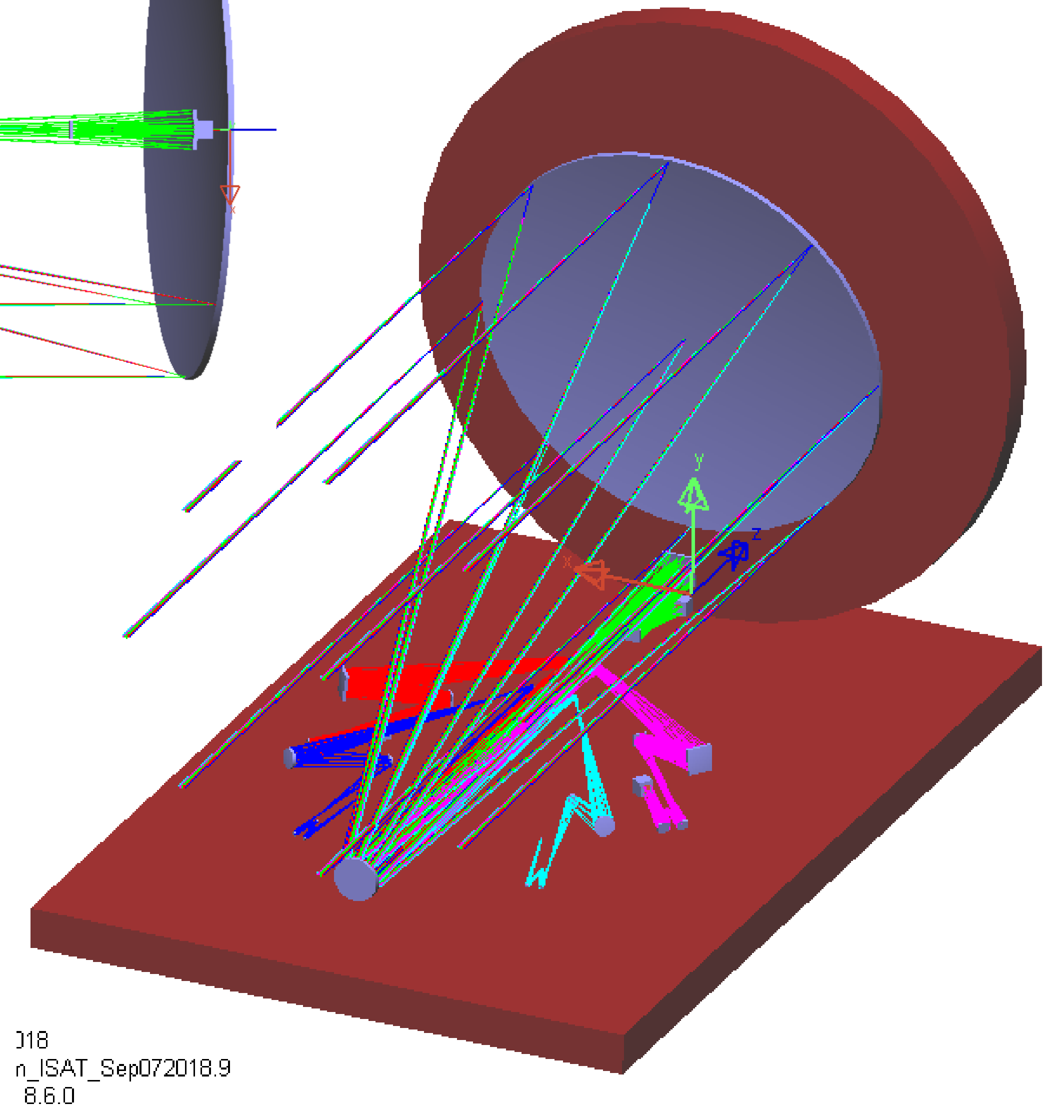


The Whole (Notionally)

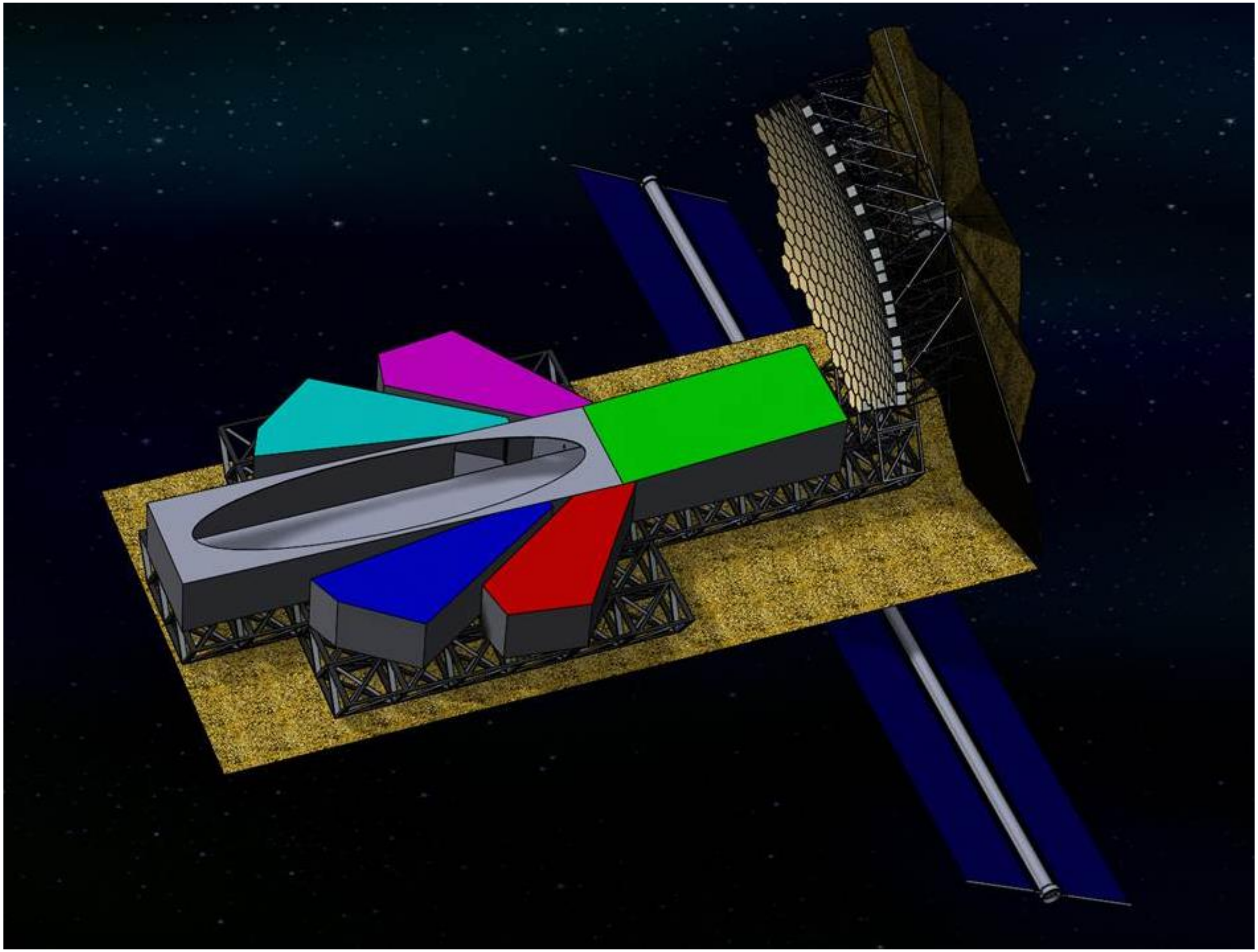


Optical Design

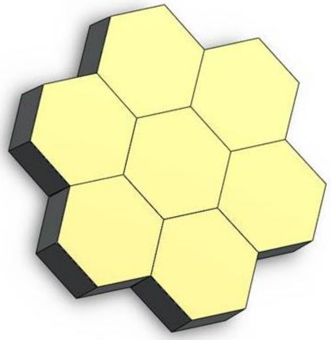




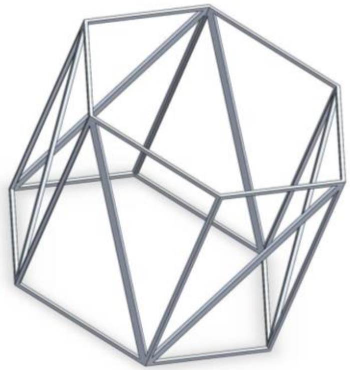
The Instrument Modules



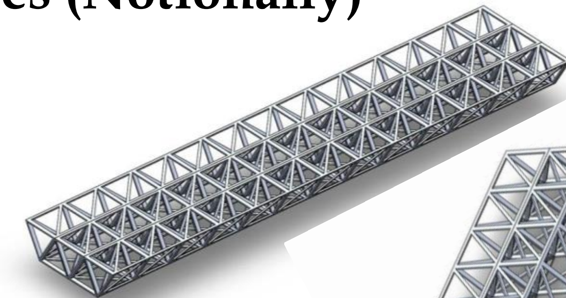
The Pieces (Notionally)



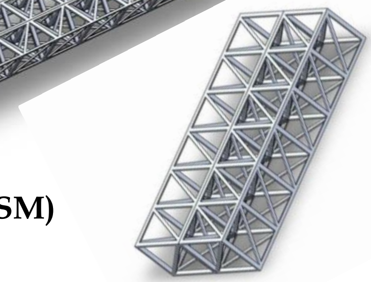
Primary Mirror Rafts
37 units



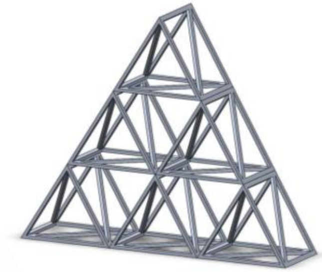
Deployable Truss Modules
24 units



Metering Truss (PM-SM)
1 unit

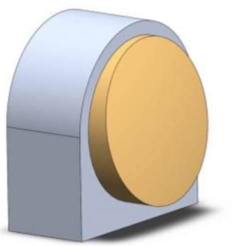


Instrument Support Truss
1 unit

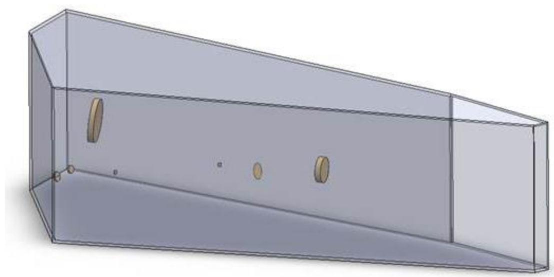


Transition Structure
1 unit

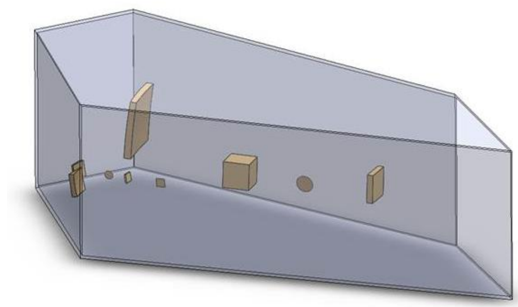
Bottom Sunshade
1 unit



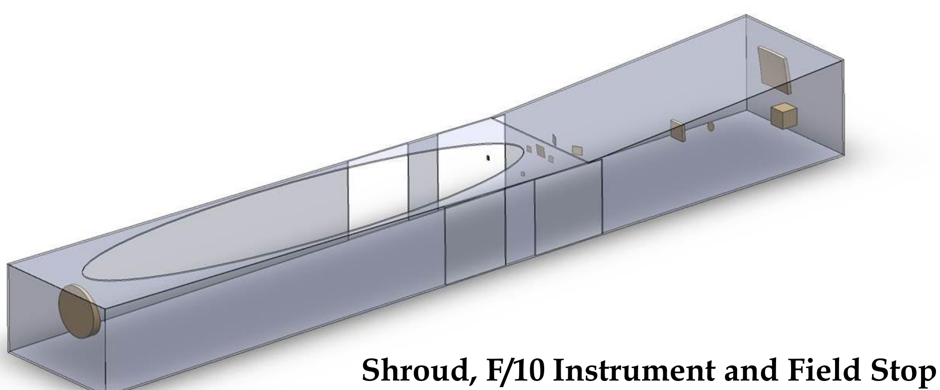
Secondary Mirror
1 unit



F/30 Instrument Module
2 units



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



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

Back Sunshade
1 unit

Job At Hand

- **Someone stacked multiple fairings with the modules and gave us a manual of what goes where and in what order**

- **Need a working observatory at Sun-Earth L2**

Now what?

  - **Where to assemble?**
  - **How to get there?**
  - **How to bring them together?**
  - **What robotic system(s)?**
  - **How to assemble?**
  - **How to verify and validate?**
  - **How to service?**

- **Optimize cost and risk posture**

- **Understand tall tent poles**

- **Identify one or two concepts that seem most favorable**
  - **Not a down select: a reference approach to evaluating ISA implications**

Manual Says (Cliff Notes version)

- Assemble the truss work,
  - Use metrology to show it meets requirements – adjust as needed
- Block out the sun
- Assemble the optics
- Assemble the instruments
- Assemble final stray light blocks
- Use metrology and show optics are aligned and stable
  - Adjust as needed and loop till fully operational
- With time, service select modules
  - Instruments, reflectors etc.
- There are some hard constraints, e.g.:
  - Micron level structural stability, Nano-meter level optical stability
  - Gaping or spacing constraints
  - Block all stray light

The Doer Based Phase Space

	Free Flyer	Station	Embedded Robot	Astronaut
LEO	X	X	X	X
GEO	X		X	
CisLunar		X	X	X
SE-L2			X	

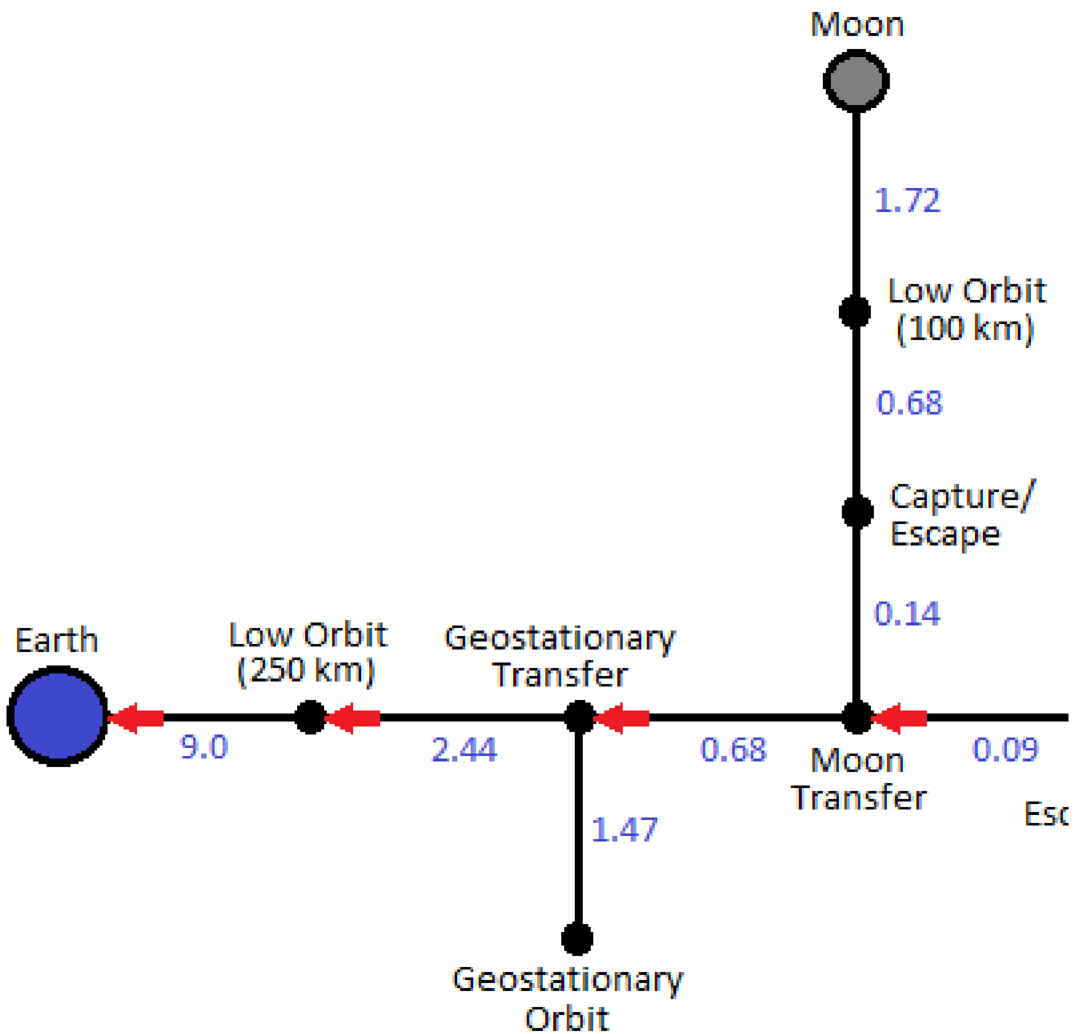
- **Free Flyer Examples: RSGS, RESTORE-L**
- **Station Examples: ISS, Gateway**
- **Embedded Robot Example: Canada Arm**
- **Astronaut Example: HST Style Assembly**

- **Please email any additional columns or rows (i.e. concepts and orbits) to Nick and Rudra**
  - **Keep it real – missions or concepts or technologies that are currently being developed**
  - **Need good coverage of the phase space: seeking diverse options**

Notional Launch Vehicles

LEO	GEO	CIS LUNAR	L2
SLS	SLS	SLS	SLS
New Glenn	New Glenn	New Glenn	New Glenn
Delta 4 H	Delta 4 H	Delta 4 H	Delta 4 H
FH	FH	FH	FH
Vulcan	Vulcan	Vulcan	Vulcan
Ariane	Ariane	Ariane	Ariane
Atlas 5	Atlas 5	Atlas 5	Altas 5
F9	F9		
H3	H3		
Angara	Angara		
GSLV	GSLV		
Antares	Antares		
Pegasus			
Athena 1			
Athena 2c			
Firefly			
Vector			
Pegasus			
Electron			
Minotaur C			
Launcher One			
PSLV			

Delta V Map



Moon
1.72
Low Orbit
(100 km)
0.68
Capture/
Escape
0.14
Earth
Low Orbit
(250 km)
Geostationary
Transfer
9.0
2.44
0.68
Moon
Transfer
0.09
1.47
Geostationary
Orbit

Notional Function Based Phase Space

	Free Flyer	Station	Embedded Robot	Astronaut
LEO	R, A, T, I, S	V	A, I	V, A, I
GEO	V, (RATIS)*		(AI)*	
Cislunar	R, A, T, I, S	V	A, I	V, A, I
SE-L2	R, S		A, M, I	

Ref: Gordon Roesler

R = rendezvous and capture of upcoming payloads, handoff to embedded robots
A = assembly of telescope from component modules
M = in-service maintenance, upgrade
V = verification of assembly concepts, robotics, etc. (risk reduction prior to go-ahead)
I = inspection of assembled systems/subsystems
T = tugging of components, subassemblies, or fully assembled telescope between orbits
S = station-keeping, attitude adjustment, wheel desaturation
* The starred options represent assembly in GEO by renting a commercial free-flyer there.

This view is for the Face to Face Meeting

- **One and a half day break out sessions in 2 or 3 groups**
- **Facilitators: David Miller, John Grunsfeld, Harley Thronson**
- **Embedded Scribes: Ron Polidon, Lynn Bowman, Eric Mamajek**

The Sane Moment Before Creative Mayhem

- **We love this stuff: there is going to be the gushing of "what ifs" and "couldn't we just" …**

- **But how to navigate the ideas, possibilities and options?**
  - **The KT Matrix Approach**

The Face to Face Meeting Draft Agenda (Cliff Notes)

- **Day 1 Morning: Introductions and Preamble**
- **Day 1 Afternoon: Break out session**
- **Day 2 Morning: Break out session**
- **Day 2 Afternoon: Break out session**
- **Day 3 Morning: Project it all on to the KT Matrix and see what sticks**

Very Short Tutorial on the Decision-Making Process

Features of Kepner-Tregoe Decision Process

Decision Statement										
Description					*Option 1*		*Option 2*		*Option 3*	
		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

Begin Selection Criteria Brainstorming

(switch to Excel)

Next Steps

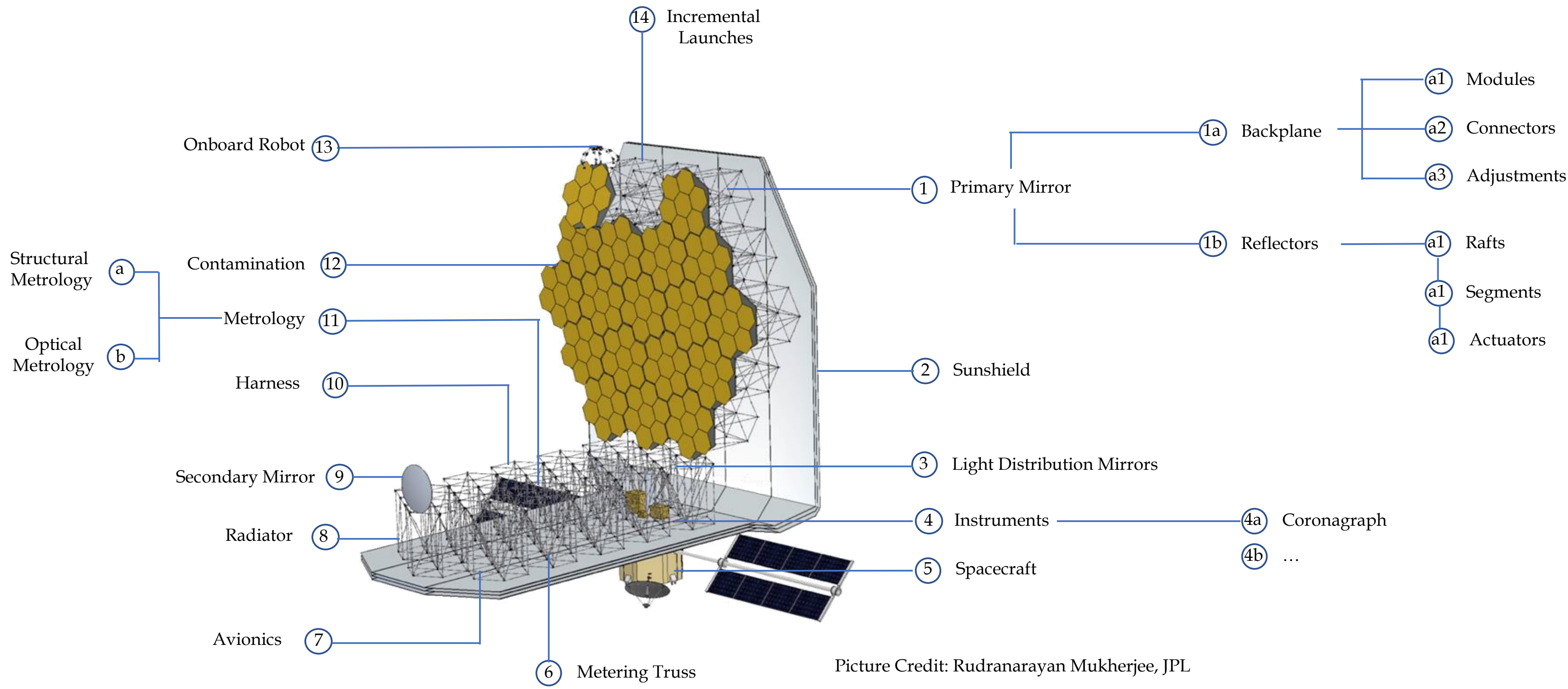
Next Steps

- **Telecons next week with the Study Members**
  - Pick one: Wednesdays at 12:30 pm (EDT) and Thursdays at 2 pm (EDT)
  - Advance work on Selection Criteria

- **Second Face-to-Face Meeting for the Study Members and Observers**
  - Oct 2-4 at NASA LaRC
  - Focus is on Activity 1b: Telescope Assembly and Infrastructure
  - Breakout sessions to advance the concepts

Additional Slides

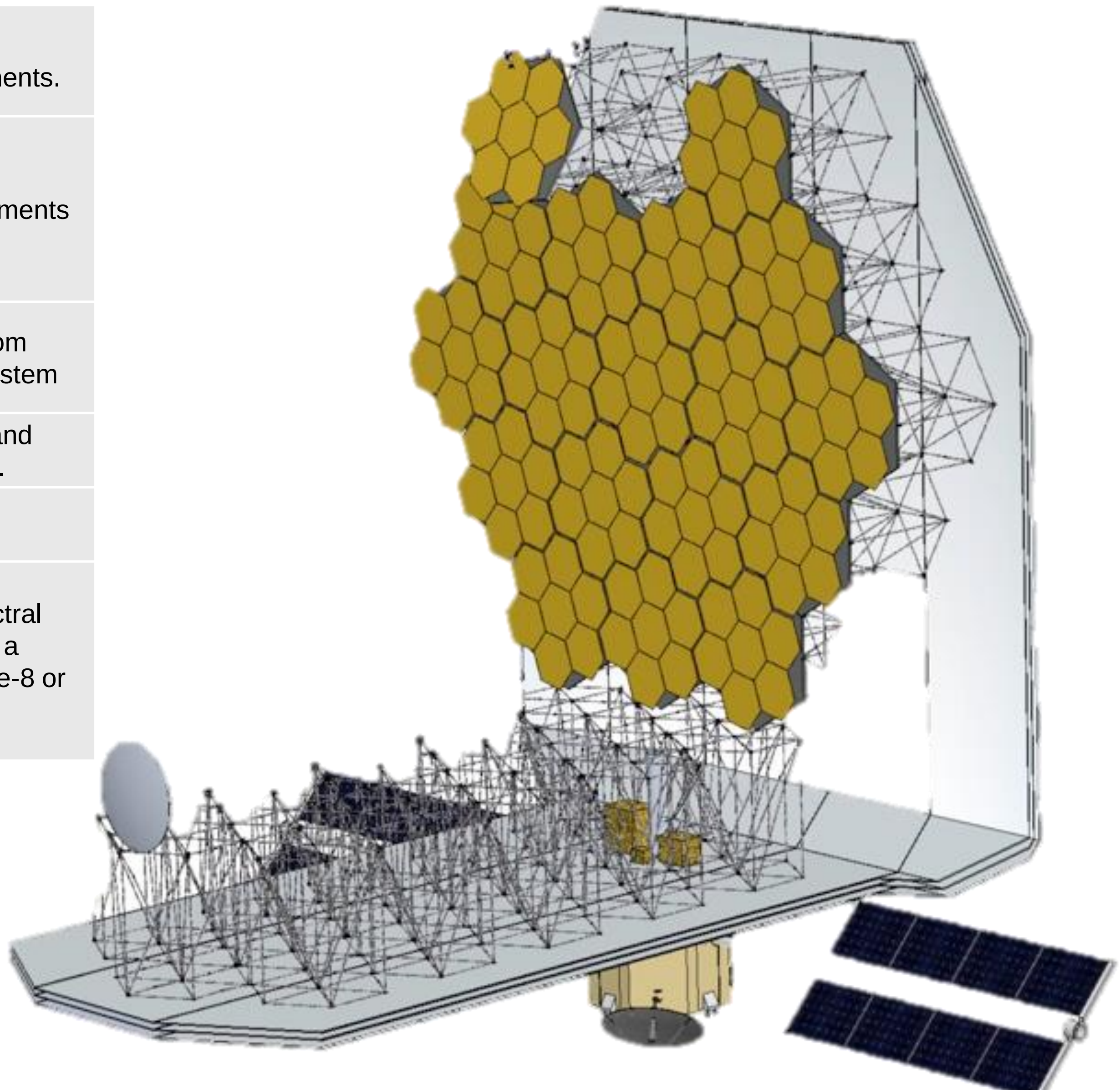
Activity 1A Discussion Space



Picture Credit: Rudranarayan Mukherjee, JPL

Telescope Modularization Design 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.



Example of a Completed Trade Matrix

Decision Statement: Recommend one Primary and one Backup coronagraph *architecture* (option) to focus design and technology development

Descr	Name		Weights	Option 1 SPC	Option 2 PIAACMC	Option 3 HLC	Option 4 VVC	Option 5 VNC - DA	Option 6 VNC - PO	Notes
Musts		Programmatic								
	M1 - T	Science: Meet Threshold requirements? (1.6, x10)		Yes	Yes	Yes	No	No	U	
	M2	Interfaces: Meets the DCIL**?		Yes	Yes	Yes	Yes	Yes	U	
	M3	TRL Gates: For baseline science is there a credible plan to meet TRL5 at start of FY17 and TRL6 at start of FY19 within available resources?		Yes	Yes	Yes	U	No	U	
	M4	Ready for 11/21 TAC briefing		Yes	Yes	Yes	Yes	Yes	No	
	M5	Architecture applicable to future earth-characterization missions		Yes	Yes	Yes	Yes	Yes	U	

Legend: ✓ yes, or expected likely; ? unknown; ✗ no, or expected showstopper

Wants			Weights	SPC	PIAACMC	HLC	VVC	VNC-DA	VNC - PO	Notes
	W1	Science	40							
	a	Relative Science yield (1.6, x10) beyond M1-T		Sm/Sig	Best	Sm/Sig	VL	VL		Range of opinions between "significant and small". For SPC and VNC2 the search area is ~3 times less than 360deg, and that was taken into acct in comparisons
	W2	Technical	30							
	a	Relative demands on observatory (DCIL), except for jitter and thermal stability		Best	Best	Best	Best	Small		
	b	Relative sensitivities of post-processing to low order aberrations		Best	Sig	Sig	VL	U		For n-lambda over D or different amplitudes the designs will have the same relative ranking
	c	Demonstrated Performance in 10% Light		Small	Sig	Best	Sig	VL		Demonstrated Performance (10%) and Prediction
	d	Relative complexity of design		Best	Small	Best	Small	Sig		
	e	Relative difficulty in alignment, calibration, ops		Best	Small	Best	Small	Sig/Sm		
	W3	Programmatic	30							
	a	Relative Cost of plans to meet TRL gates		Best	Small	Best	Sig	Sig		
		Wt. sum =>	100%							

Identify "Best" and others are:
-Wash
-Small Difference
-Significant Difference
-Very Large Difference

Risks		(all judged to be Hgh consequence)	SPC C	SPC L	PIAACMC C	PIAACMC L	HLC C	HLC L	VVC C	VVC L	VNC-DA C	VNC-DA L	VNC - PO C	VNC - PO L	Notes
	Risk 1	Technical risk in meeting TRL5 gate		L		M		M/L		M/H		H			PIAA trend over the last three working days lower, but recommendation to keep M
	Risk 2	Schedule or Cost risk in meeting TRL5 Gate		L		M		M/L		M/H		H			
	Risk 3	Schedule or Cost risk in meeting TRL6 Gate		L		L		L		M		M			
	Risk 4	Risk of not meeting at least threshold science		L		L		L		H		H			
	Risk 5	Risk of mnfr tolerances not meeting BL science		L		L		L		M/L		H			One dissent, previous TDEM performance track record and Bala's assessment should be taken into account.
	Risk 6	Risk that wrong architecture is chosen due to assumption that all jitter >2Hz is only tip/tilt		L		M/H		M		M/H		M			
	Risk 7	Risk that wrong architecture is chosen due to any assumption made for practicality/simplicity	open ended question, spawned evaluations on Risk 5, Risk 6, Risk 8, and Oppty 1												
	Risk 8	Risk that ACWG simulations (by JK and BM) overestimate the science yield due to model fidelity	discussed; not enough understanding at this time to make an evaluation.												Model validation is a risk that needs to be evaluated in the future

Opportunities		(judged to be High benefit)	SPC B	SPC L	PIAACMC B	PIAACMC L	HLC B	HLC L	VVC B	VVC L	VNC-DA B	VNC-DA L	VNC - PO B	VNC - PO L
	Oppty 1	Possibility of Science gain for 0.2marcsec jitter, x30		L		M/H		M		L		H		

Final Decision, Accounting for Risks and Opportunities:

C = Consequence, L = Likelihood, B=Benefit
**DCIL = Dave Content Interface List

(yellow) indicates those few areas where consensus was not achieved
(white) consensus achieved on balance of matrix

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