Jet Propulsion Laboratory
California Institute of Technology

In-Space Assembled Telescope (iSAT)

Steering Committee Telecon 4

July 25, 2018

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Today’s Agenda

1. **Update on Study activities**
   - Caltech Workshop
2. **What’s new?**
3. **Next Steps**
   - Need help
4. **Open Discussion**

But first, any general questions?

Update on Study Activities

Last Telecon's Next Steps

- **Advance Selection Criteria**
  - Will continue advancing them at the Workshop and through telecons post-Workshop
- **First Face-to-Face Workshop for the Working Group**
  - June 5-7 at Caltech
  - Focus is on Activity 1a: Designing and Architecting a Modularized Telescope

The first face-to-face meeting for the iSA Telescope Study was held on June 5-7, 2018 at Caltech, hosted by the NASA Exoplanet Exploration Office.

Invited participants only:

- 46 from government, industry, and academia spanning the fields of astrophysics, engineering, and robotics.
- 29 NASA, 12 industry, 4 academia, and 1 government agency

Caltech Workshop (June 5-7)

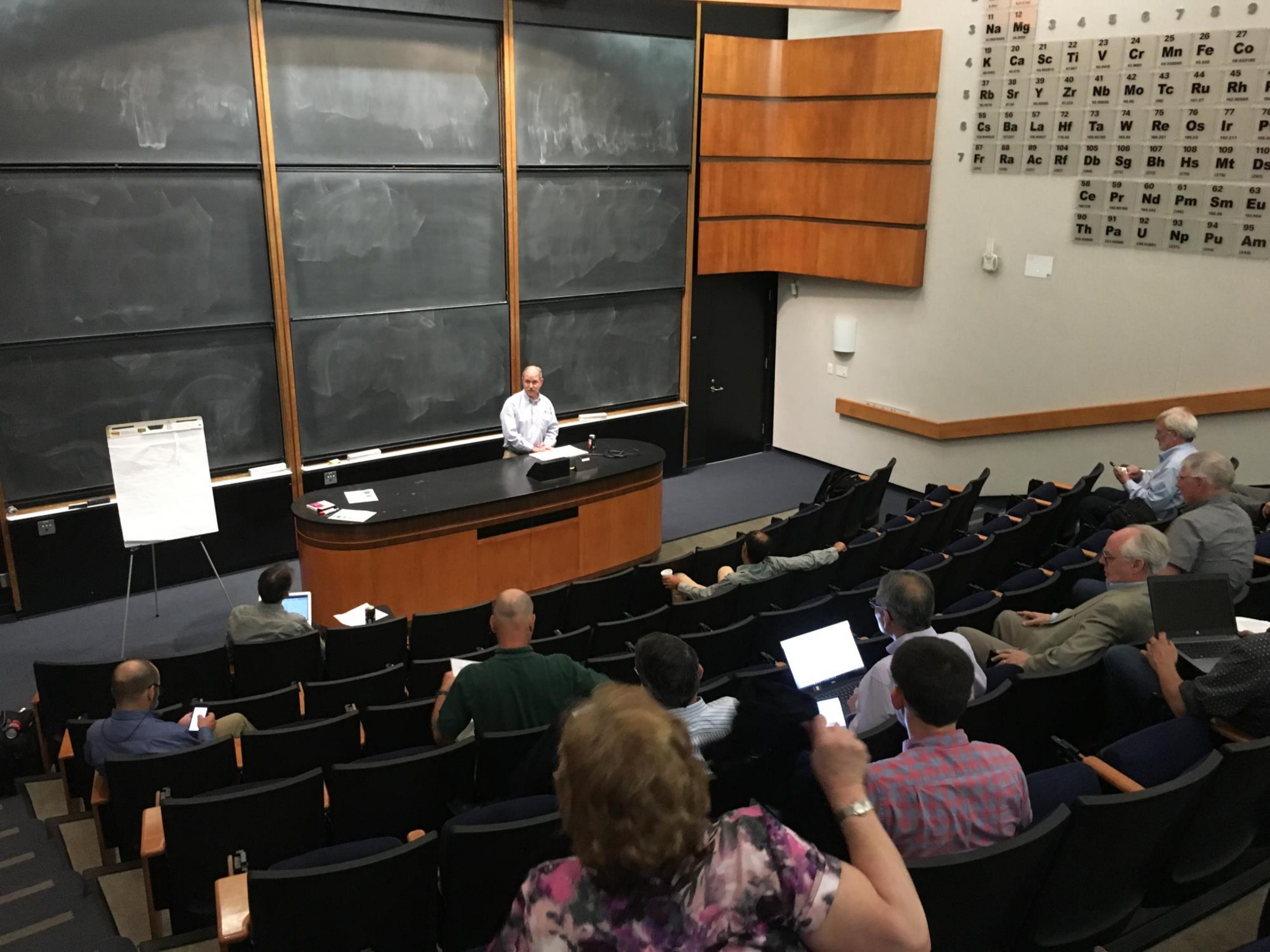
- **The goals of the Workshop were to:**
  1) Create concepts (Options) for modularized telescope designs
  2) Advance the Selection Criteria
  3) Build a community of experts to advance in-space assembly

- **Initial conditions for the reference telescope included:**
  – A 20-m, filled-aperture, off-axis, non-cryogenic telescope operating in the UV/V/NIR, located at Sun-Earth L2.
  – The instrument suite would include a coronagraph
  – Astronaut- and robotic-enabled assembly/servicing is available
  – 5-m class LV fairing

- **Participants broken into two breakout teams charged with:**
  – Modularizing the Primary Mirror and Backplane
  – Modularizing the Rest of the Telescope
  – Assembly, Integration, and Testing (on the ground and in space)


THE KECK CENTER
IN HONOR OF W.M. KECK JR.


Far-UV Imaging / Spectroscopy
Minimizing the number of reflections drives the telescope design
Need the telescope to deliver the appropriate resolution and performance so that relay and corrective optics are not needed
Keck



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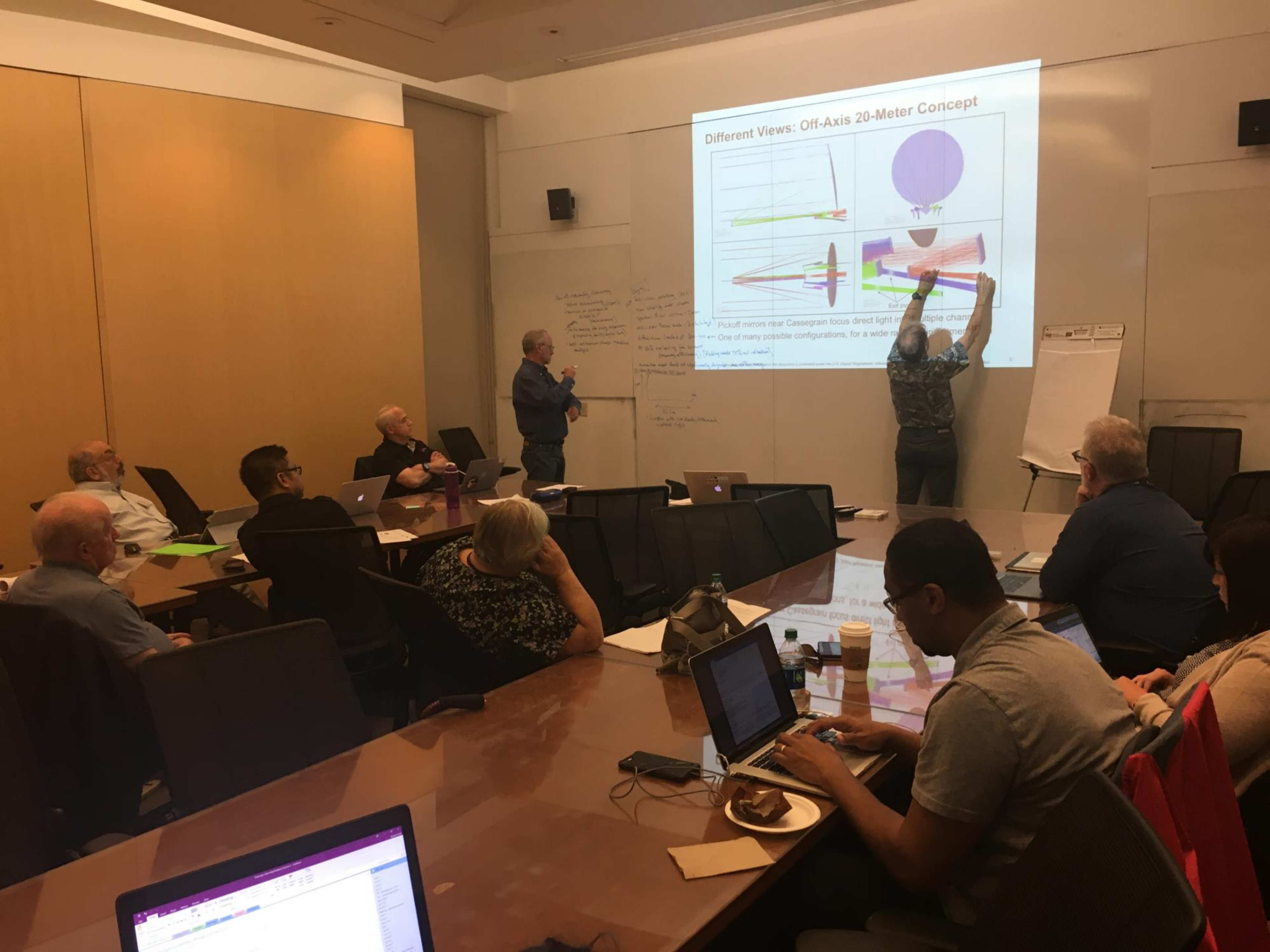
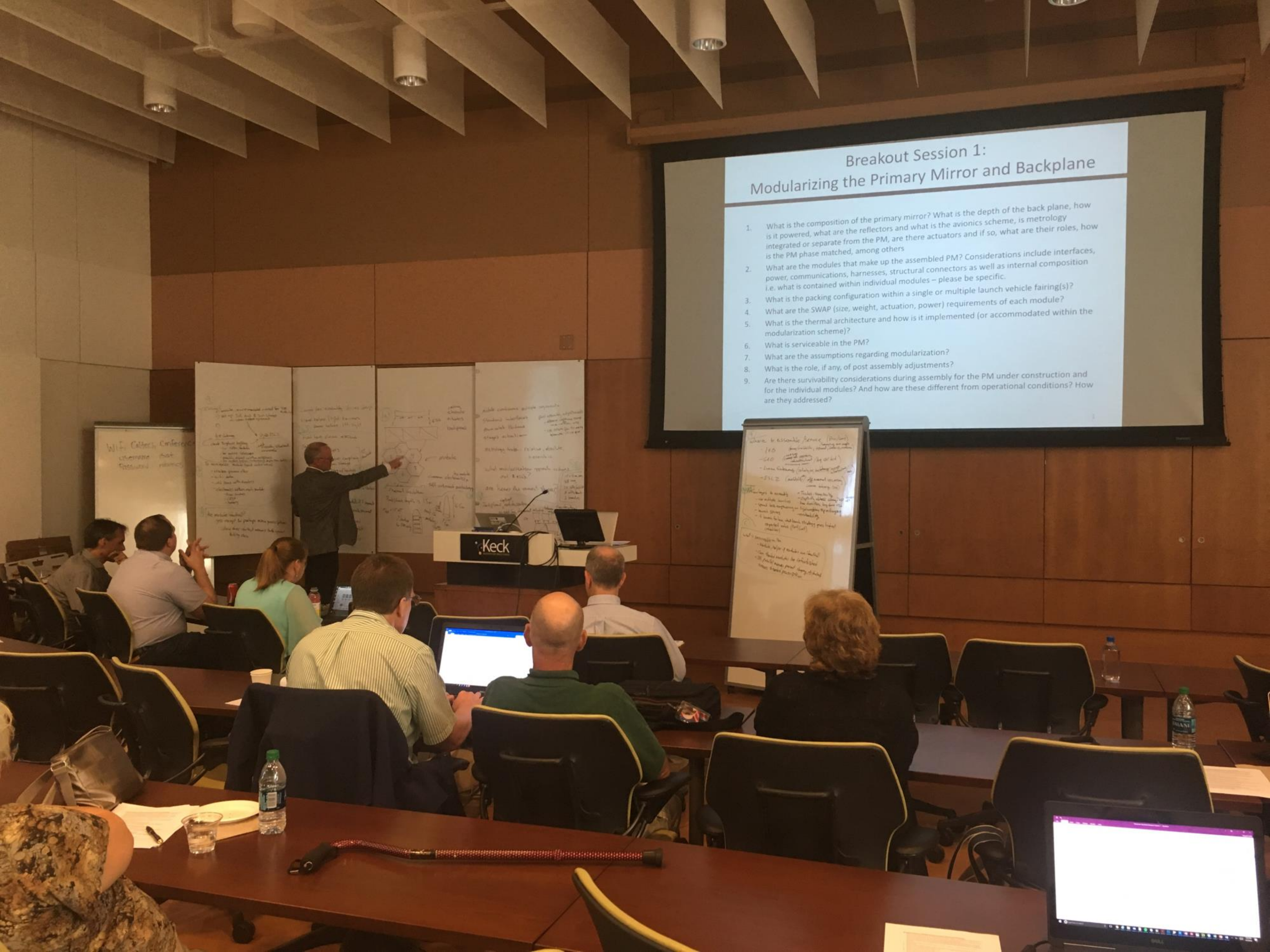

Different Views: Off-Axis 20-Meter Concept

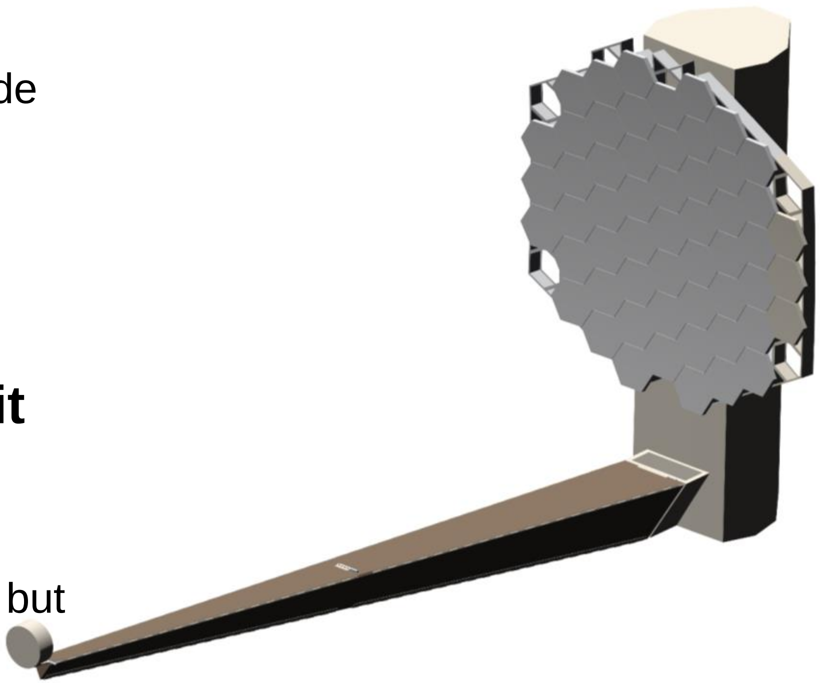

Breakout Session 1:
Modularizing the Primary Mirror and Backplane
1. What is the composition of the primary mirror? What is the depth of the back plane, how is it powered, what are the reflectors and what is the avionics scheme, is metrology integrated or separate from the PM, are there actuators and if so, what are their roles, how is the PM phase matched, among others
2. What are the modules that make up the assembled PM? Considerations include interfaces, power, communications, harnesses, structural connectors as well as internal composition i.e. what is contained within individual modules – please be specific.
3. What is the packing configuration within a single or multiple launch vehicle fairing(s)?
4. What are the SWAP (size, weight, actuation, power) requirements of each module?
5. What is the thermal architecture and how is it implemented (or accommodated within the modularization scheme)?
6. What is serviceable in the PM?
7. What are the assumptions regarding modularization?
8. What is the role, if any, of post assembly adjustments?
9. Are there survivability considerations during assembly for the PM under construction and for the individual modules? And how are these different from operational conditions? How are they addressed?
Keck


MOUSTAKAS

Generating Modularization Design Options

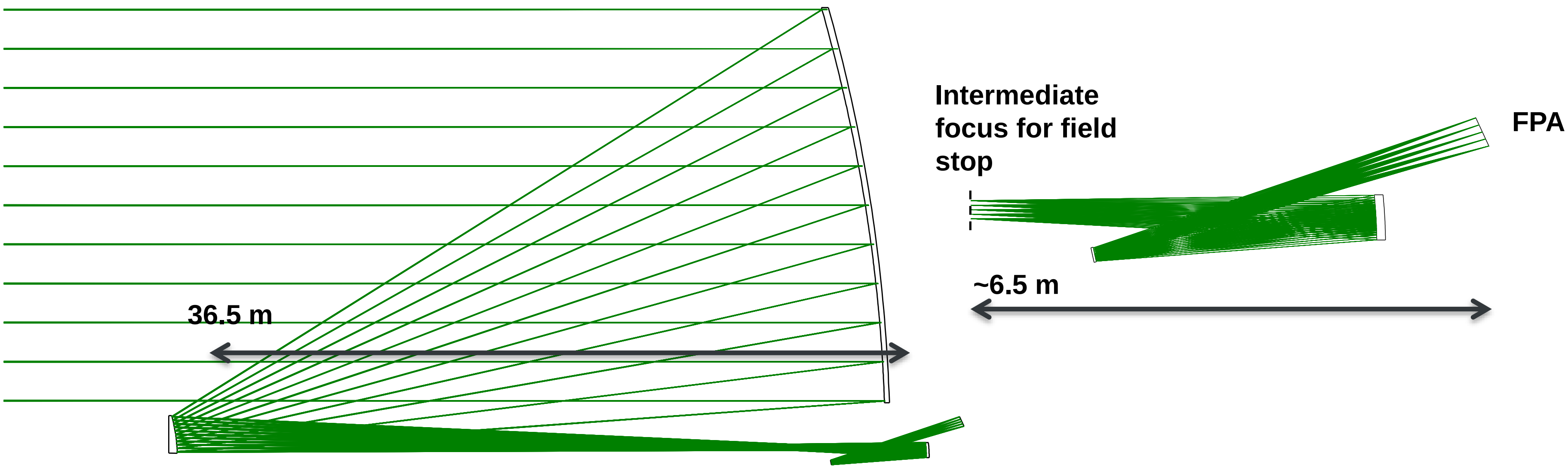
- **Trade space for <u>modularization</u> is very open**
  - Number of modules
  - Segment size, segment carriers, sun shade
  - Backplane architecture
  - Power, latching, harnessing
  - Instrument carriers, thermal

- **Do some telescope designs benefit from iSA more than others?**
  - Let's find out
  - Option generation starts at the Workshop but can continue after
  - Recommendation for Workshop Breakout sessions for Reference Telescopes:
    1) (a) 20 m off-axis and (b) 20 m off-axis with opportunities to move to a different configuration if benefits noted
    2) Max 5-m class fairings



Candidate Reference Telescope Design

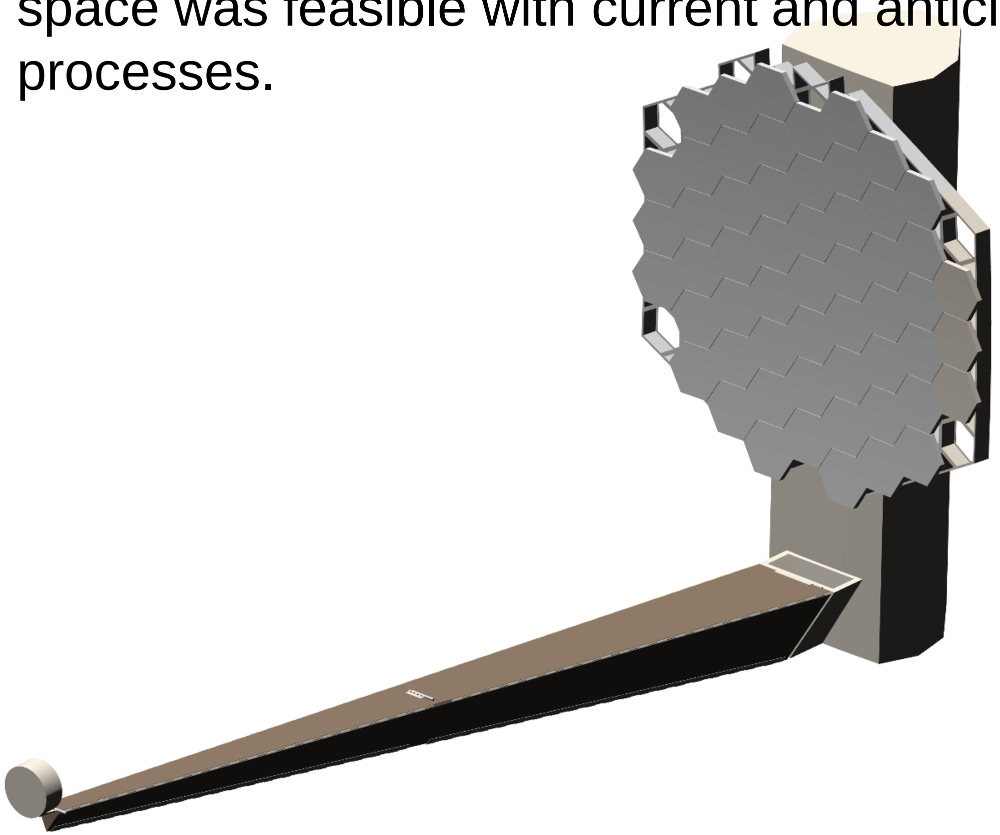
Off-Axis 20-Meter Optical Layout



Parameter	Assumption
Entrance pupil diameter	20 meter
Field of View	3x3 arc-minute
Final F/#	F/30
Image size	530 x 530 mm (implied by EPD, F/#, and FOV)
Primary mirror ROC and F number	80 meter ; F/2.0
Primary-secondary spacing	36.5 meter
AOI, maximum on each mirror	16.0° primary; 17.5° secondary; 5.6° tertiary; 8.4° fold.
RMS WFE (nanometer)	18.6 maximum, 10.4 average

Workshop Progress

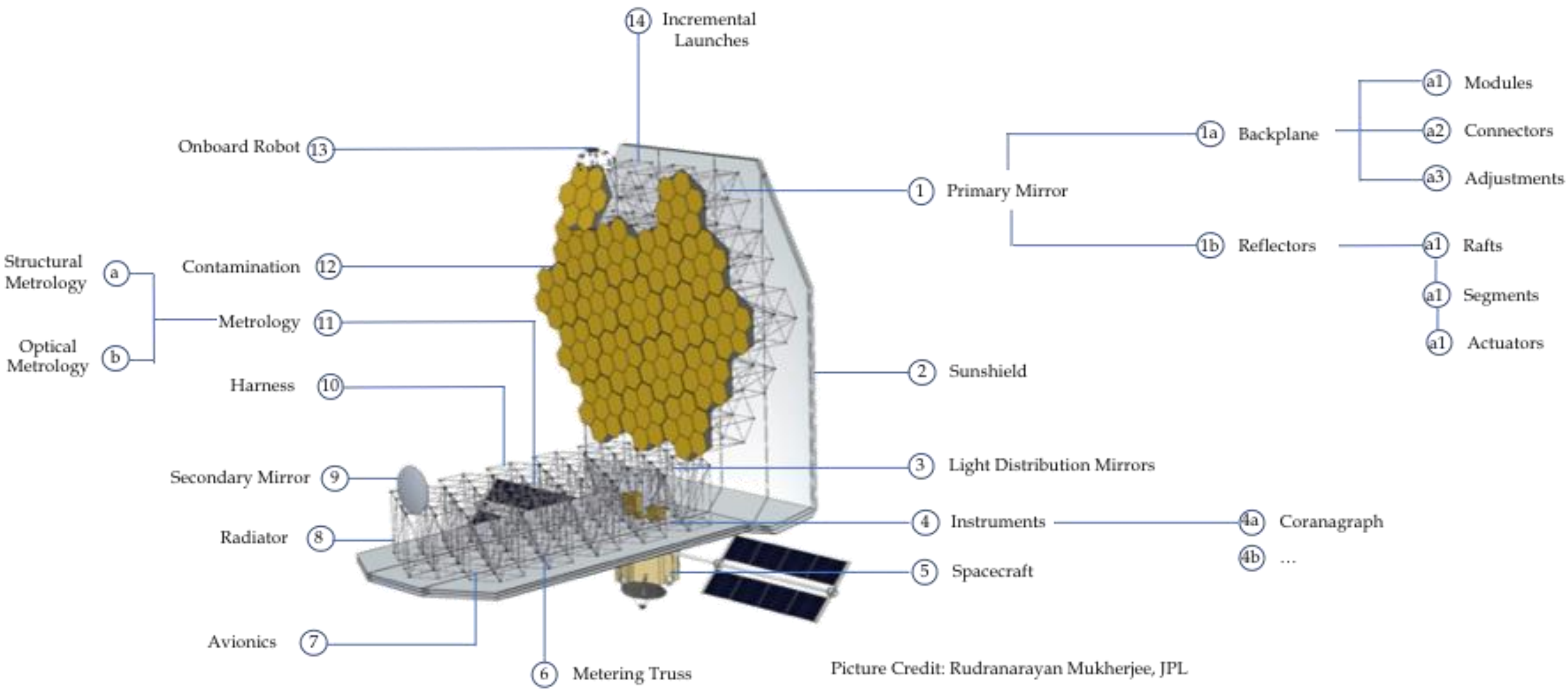
- The 20 m off-axis f/2 telescope would serve as a good reference for the Study
- No major show stoppers were found; no real energy for an alternative.
- The consensus was that assembling the reference telescope in space was feasible with current and anticipated technology and processes.



LUVOIR B architecture scaled to 20 m, f/2.5, off-axis

Modularized Telescope Sub-Elements

(all were discussed during the Workshop)



Telescope architecture and modularization are notional.

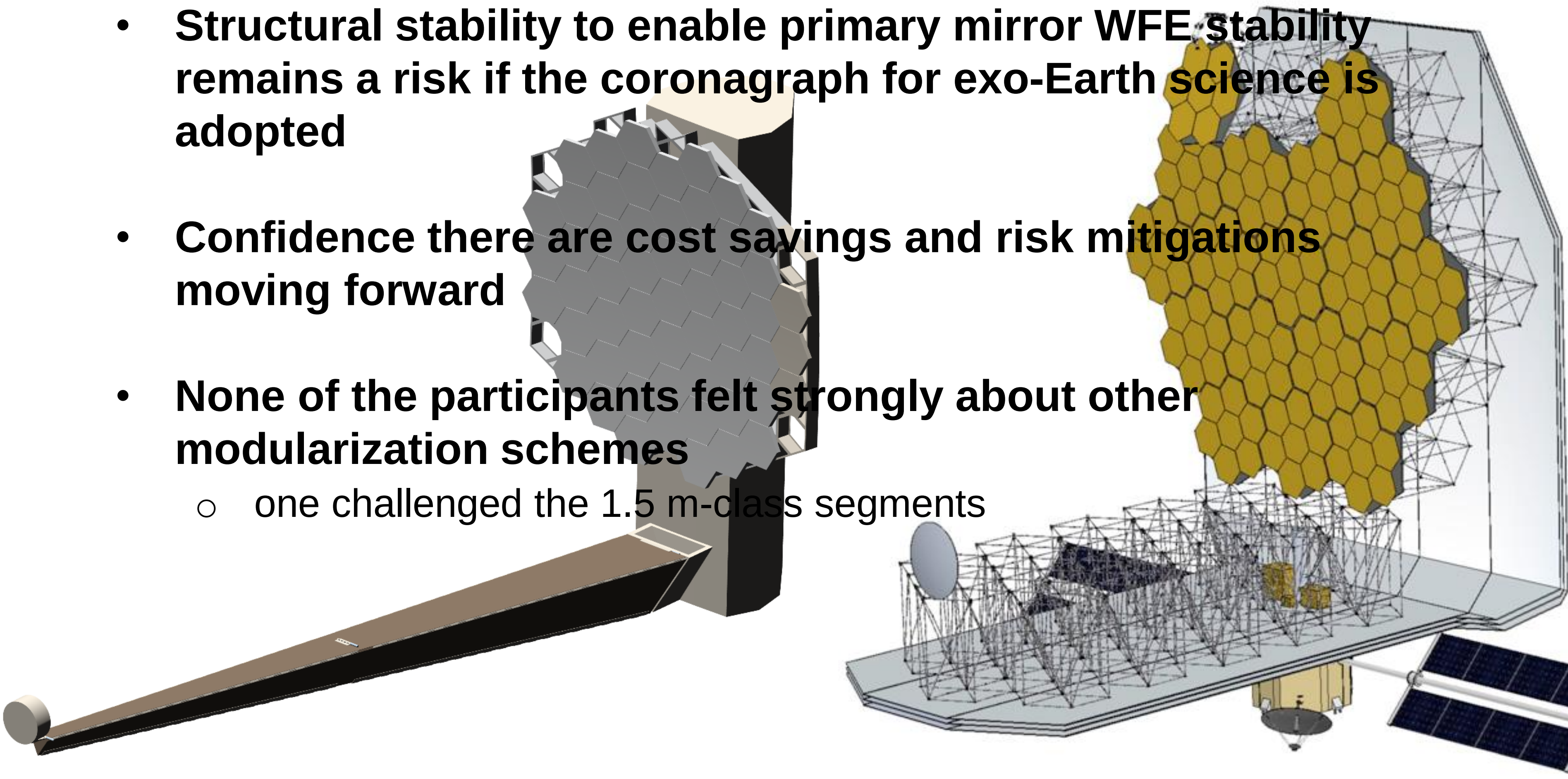
Workshop Progress

- **Three analyses requiring additional work**
  - Primary mirror truss height and structure
  - Stray light analysis
  - Sunshade architectural concept

- **Structural stability to enable primary mirror WFE stability remains a risk if the coronagraph for exo-Earth science is adopted**

- **Confidence there are cost savings and risk mitigations moving forward**

- **None of the participants felt strongly about other modularization schemes**
  - one challenged the 1.5 m-class segments



Features of Kepner-Tregoe Decision Process

				Option 1		Option 2		Option 3	
Decision Statement									
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

plus Assumptions

In-progress

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

ID	OPTION DESCRIPTORS	COMMENTS	Reference Option A	Reference Option B
D1	Architecture	on- or off-axis, segmented or monolith	off-axis, segmented	
D2	Size of primary mirror segments	1.3-1.5 m segments are industry SOA; all have RBAs, but need for figure control actuators are TBD at this time.	1.3-1.5 m class	
D3	Number of primary mirror segments per module		6-7 (This minimizes number of interfaces during final assembly as compared to single segment per module; good heritage in testing this size module on the	
D4	ROC and segment-to-segment control		Combination of laser metrology and edge sensors	
D5	Electronics and thermal architecture		Common electronics run the segments self-contained metrology system and actuators, includes simple thermal management - cold bias with heaters and thermal	
D6	Fairing size needed	Related to module sizes. Look out for fairing sizes that do not yet exist (> 5-m class); larger is in play but may score poorly in some areas and may carry shedule and cost risks.	5-m class	Would fairing sizes greater than 5 m pose opportunities worth considering?
D7	Module packing within LV fairing		nominal vertical packing (5x16.5 m)	
D8	Number of modules			
D9	Use of space infrastructure and resources (existing, projected, or	Includes assembly platforms, robotics, astronauts		
D10	Assembled robotically or robotically with astronaut support		Assembled robotically	
D11	Number of new technologies			
D12	Type of LV needed	Look out for unique launchers		
D13	Number of LVs to complete system assembly			
D14	Serviceability	What modules can and can't be serviced?	All modules are serviceable?	
D15	Need for new industry facilities	vacuum chambers, test facilities, etc		

ID	**Modular design option MUST...**	**COMMENTS**	
	Technical		
M1	Enable necessary adjustability and correctability of key optical		Expected
M3	Permit module servicing (repair, replacement, refueling) of instruments and spacecraft.		Expected
M4	Not enable a failure within a module to propagate through to the system		Expected
M5	Fit into the selected LV	Sanity check	Expected
M6	Enable the direct imaging and spectral characterization of exoplanets with a coronagraph at contrast levels of 1e-8 or less	Contrast performance worse than 1e-10 (but better than 1e-8) due to inability to achieve needed observatory stability will not acquire exo-Earths, but may acquire larger planets. Acquiring exo-Earths would then require a starshade.	Expected

Under review

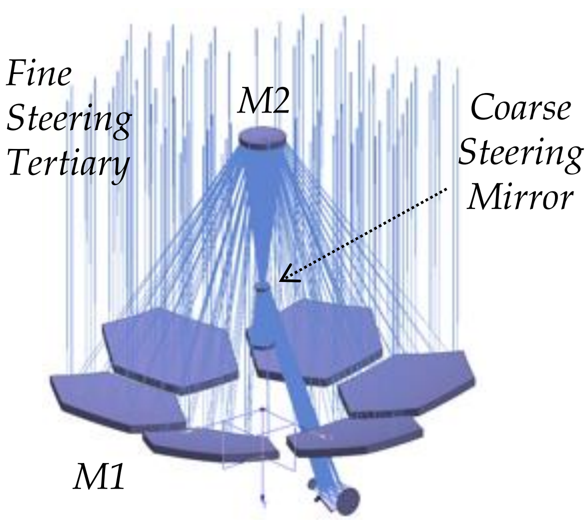
ID		COMMENTS	Reference Option A	Reference Option B
	Programmatic			
	WANTS	**COMMENTS**		
	Technical			
W1	Few requirements for technologies exceeding the SOA.	The more mature the concept the better, the fewer "Miracles" the better; the larger the number of low TR subsystems the worse, reach TRL 5 at 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.		

Activity 1a

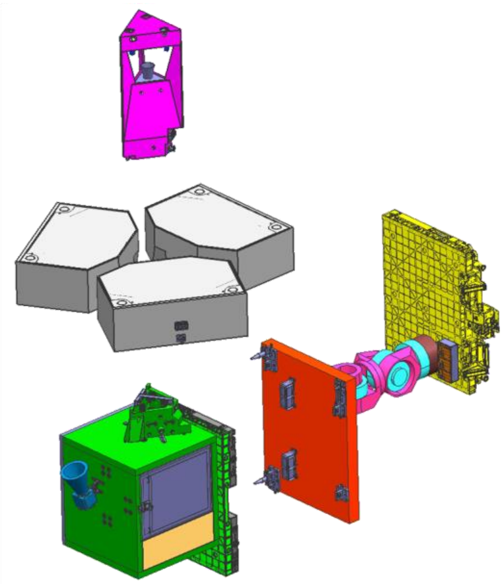
Concept Design and Architecture for the iSAT

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

- Paradigm shift in architecture: Modularization
- An example, from the 2012 OpTIIX study (NASA JSC/GSFC/JPL/STScI):



3 Mirror Anastigmat Telescope (1.45 m aperture)



6 launch modules for assembly

What's New?

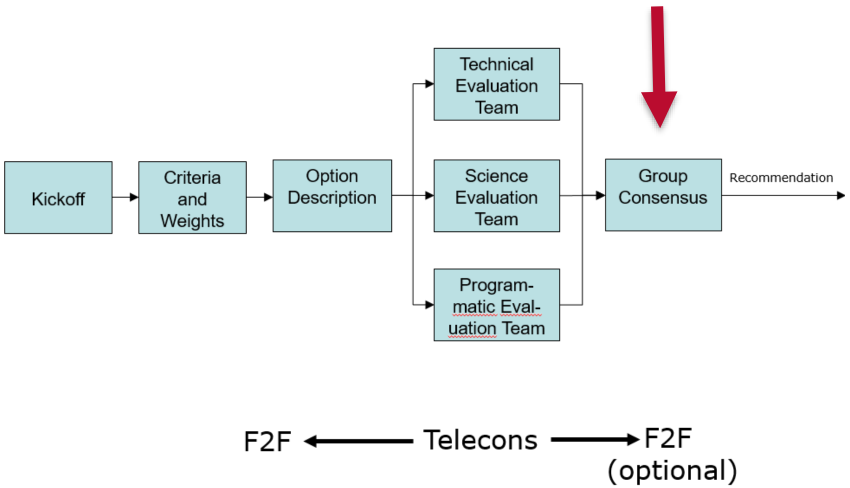
What's New?

- **Activity 2 Funding**
- **Workshop III at NASA Langley Research Center**
  - Oct 2-4
  - Focus will be on Activity 1b: Assembly, Testing, Robotics, Assembly Platforms, Launch Vehicles
  - Another Musts and Wants List and expect several concepts

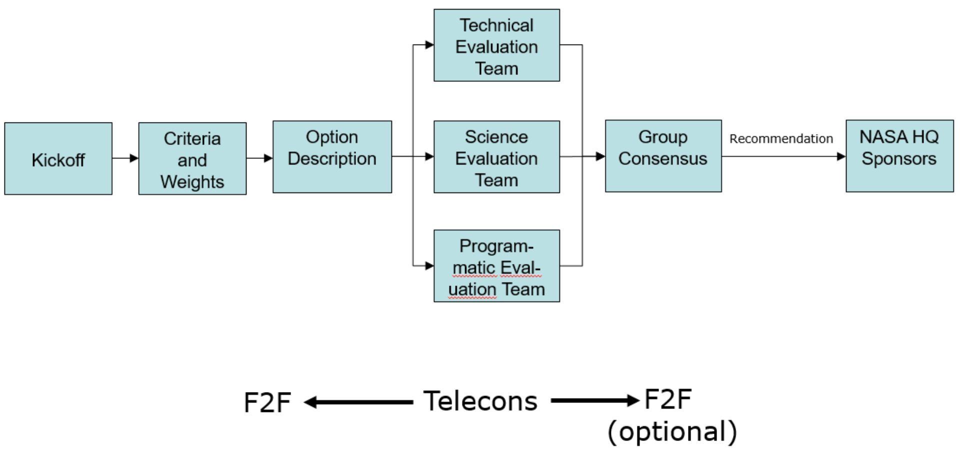
Next Steps

iSAT Study Process

(Activity 1a – Telescope Modularization)



(Activity 1b – Telescope Assembly and Testing)



Next Steps

- **Complete Selection Criteria**
  - Through upcoming telecons and emails
  - Bi-weekly cadence
- **Complete Activity 1a (Telescope Modularization)**
  - Complete the three analyses
  - Canvas the Study Members for other modularization concepts for the reference telescope
  - Complete description of Concept A including module definitions and Musts
- **Start planning Activity 2 (concept definition - cost and risk benefits)**
  - Rudra will propose a plan next week for review; may need help
- **Start Activity 1b (Module Assembly, Testing, etc)**
  - Membership (and Steering Committee) will morph towards more assembly/robotics focused
  - Need names

Candidate Participants for Activity 1b

Telescope

Dave Redding (JPL)
Scott Knight (Ball)
Lee Fienberg (GSFC)
Allison Barto (Ball)
Keith Havey (Harris)
Doug McGuffy (GSFC)
Dave Miller (MIT)
Joe Pitman (Consultant)
Keith Warfield (JPL)
Bob Hellekson (Orbital)

Robotics

Al Tadros (SSL)
John Lymer (SSL)
Paul Backes (JPL)
Bo Naasz (GSFC)
H Smith (GSFC)
Gordon Roesler (ex-DARPA)
Joe Parrish (DARPA)
Someone from NG robotics
William Vincent (NRL)
JSC robotics POC
Michael Fuller Orbital
Motiv

Structures

John Dorsey (LaRC)
Bill Dogget (LaRC)

Keith Belvin (LaRC)

Autonomy

CLT Leadership

Academia

MIT
Stanford
CMU etc

Gateway

John Guidi (NASA HQ)
Ben Bussey (NASA HQ)

Sunshade

Kimberly Mehalick (GSFC)
Jon Arenberg (NG)
One more ?

Orbital Mechanics/ Environments

Ryan Whitley (JSC)
Speaker to describe the environments

RPO

James Lewis JSC
Scott Cryan JSC

ISS

James Lewis JSC
Atif Qureshi (SSL)

Programmatic

Keith Belvin (STMD)
Rob Ambrose (STMD)
Dan Coulter (JPL)
Jon Guidi (NASA HQ)
Ben Bussey (NASA HQ)
Erica Rodgers (STMD)
Ben Reed (Space Council)
Dave Miller (MIT)

Launch Systems/AI&T

LaRC/JSC expertise

GNC

George Chen (JPL)

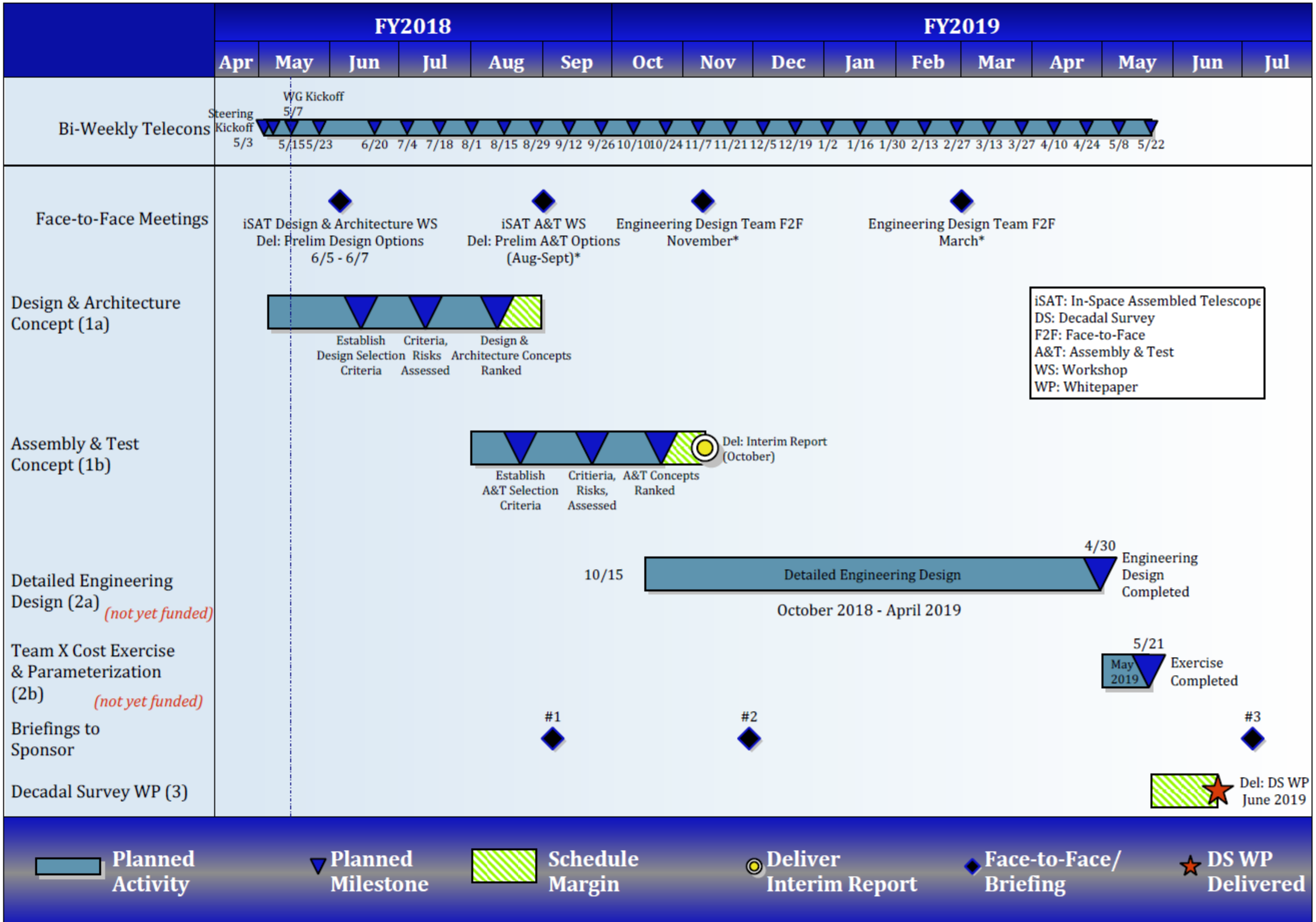
Manufacturing

Rob Hyot (Tethers)
Made In Space
?

Open Discussion

Additional Slides

Study Schedule



*tentative date

Study Initial Conditions

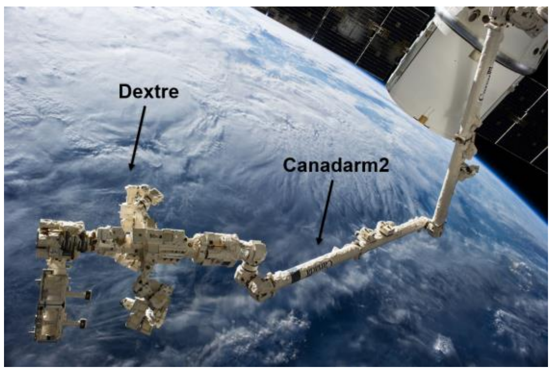
1. 20-meter, filled-aperture, non-cryogenic telescope operating at UV/V/NIR
   - *We will examine parameterized designs so that we can also explore smaller apertures*
2. Off-axis secondary mirror (to assist coronagraph throughput and performance) but can diverge if clearly benefits telescope modularization (and therefore in-space assembly).
3. A high-contrast coronagraph will be an observatory instrument tasked to directly image and spectrally characterize Earth-sized planets. The coronagraph will have the capability to actively sense and control input light wavefront errors due to all reasonable disturbance sources.
4. f/(≥ 2) to reduce polarization effects to coronagraph performance (but identify benefits if a different number is selected)
5. Operational destination is Sun-Earth L2

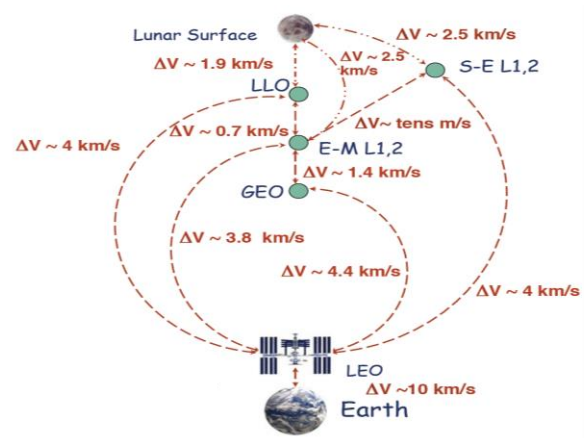
Study Assumptions

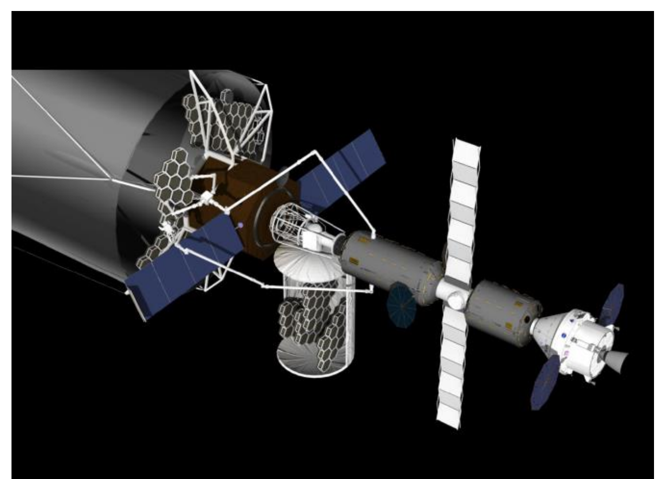
1. Science goals developed from LUVOIR/HabEx concept studies; exoplanet science is the driving science on the reference telescope.
2. The Observatory must provide the stability requirements associated with coronagraphy of Earth-sized planets. These are expected to be on order of 10s of pm wavefront error stability over time periods of ~ 10 minutes.
   - At the end of the telescope modularization activity (Activity 1a) we may assess what would have been the impact if the coronagraph was not assumed but rather a starshade. A starshade would significantly reduce the stability requirements on the telescope as well as eliminate almost all of the active optics. In Kepner-Tregoe speak, we can capture this as an Opportunity.
3. Astronaut- and robotic-enabled assembly/servicing is available
4. ISS is available until 2028 (TBD)
5. The following missions can be assumed but each will carry its own level of capability and risk:
   a. DARPA's RSGS (Robotic Servicing & Geosynchronous Satellites) at GEO (contract with SSL already in place)
   b. NASA's Lunar-Orbital Platform - Gateway at cis-Lunar
   c. Orbital-ATK's Mission Extension Vehicle (MEV) at GEO (contracts in place)
   d. NASA's Restore-L at LEO

Activity 1b:
Concept for Assembling and Testing the ISAT

Select a reference in-space <u>assembly and testing concept</u> 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.
c) Needs funding

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

a) Input design 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

SOA for Primary Mirror Segments

2016 ExEP Study

Table 1 Relative challenges of designs under consideration. Green to red designates least to most challenging. No absolute scale of difficulty is implied, and the relative challenge scale of each row may be different.

	APERTURES						
	4 ring	3 ring	2 ring	1 ring	Keystone 24	Pie wedge 12	Pie wedge 8
Segment Shape	Hex	Hex	Hex	Hex	Keystone	Pie wedge	Pie wedge
Max Segm. Dimension	1.54 m	1.98 m	2.77 m	4.62 m	2.5 m x 3.14 m	5 m x 3.14 m	5 m x 4.71 m
Segments	Green	Yellow	Orange	Red	Orange	Red	Red
Backplane	Green	Green	Orange	Red	Orange	Orange	Red
Stability	Green	Yellow	Yellow	Red	Yellow	Red	Red
Launch Configuration	Yellow	Green	Orange	Red	Orange	Red	Red
SM Support	Green	Green	Green	Yellow	Orange	Red	Red
Overall Ranking	Green	Yellow	Orange	Red	Orange	Red	Red

https://exoplanets.nasa.gov/internal_resources/211/

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