Jet Propulsion Laboratory
California Institute of Technology

In-Space Assembled Telescope (iSAT)

Study Members Telecon 4

August 2, 2018

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CL#18-4215

Today's Agenda

1. Summary of the June Cambridge Workshop
2. Where are We Now?
3. What's New?
4. Next Steps
5. Advance Selection Criteria

Summary of the June Cambridge Workshop

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)

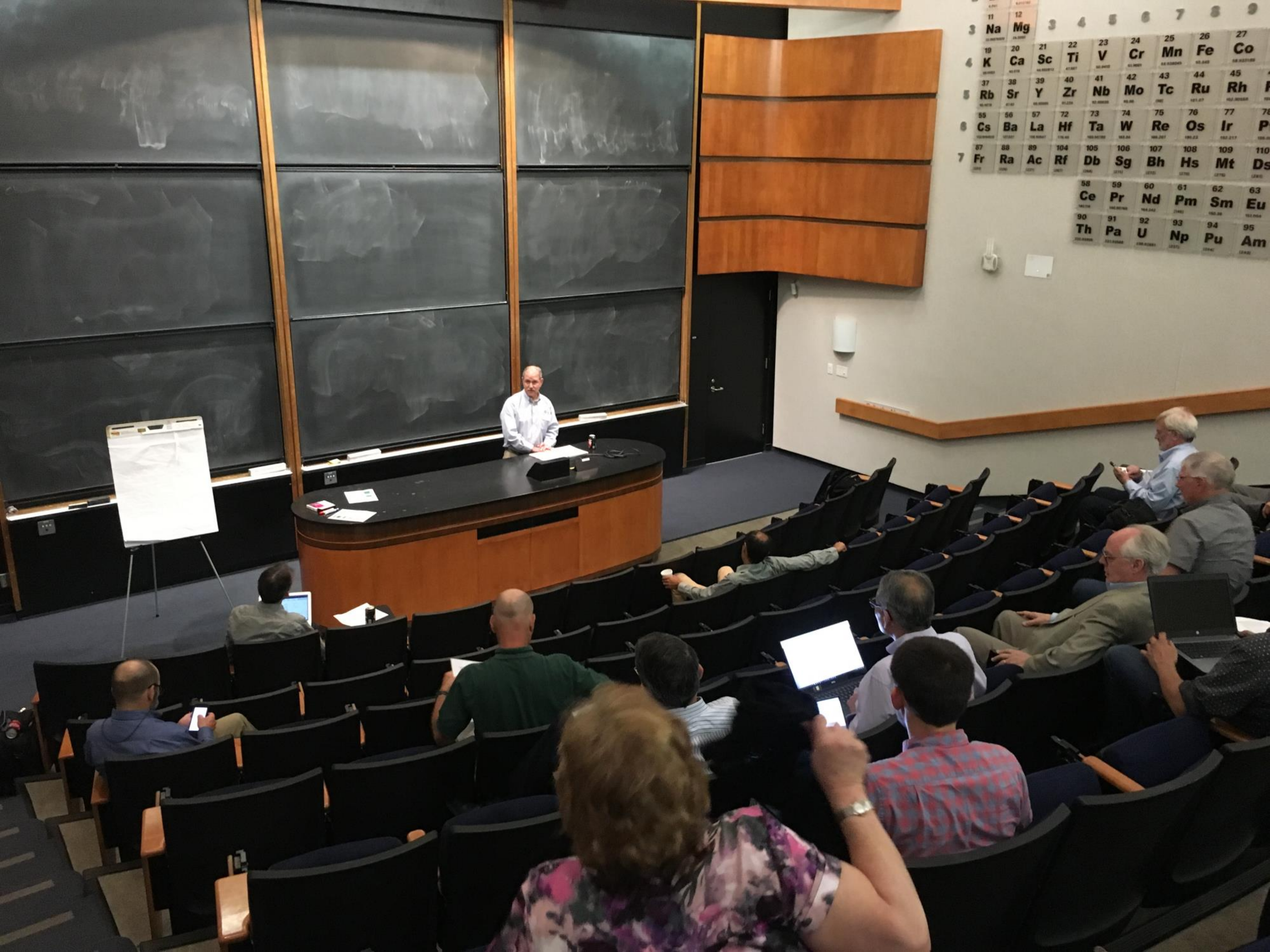
- **The goals of the Workshop were to:**
  1) Create concepts (Options) for modularized telescope designs
  2) Advance the Selection Criteria
  3) Build a community of experts to advance in-space assembly

- **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
NASA
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
AED


Na Mg
K Ca Sc Ti V Cr Mn Fe Co
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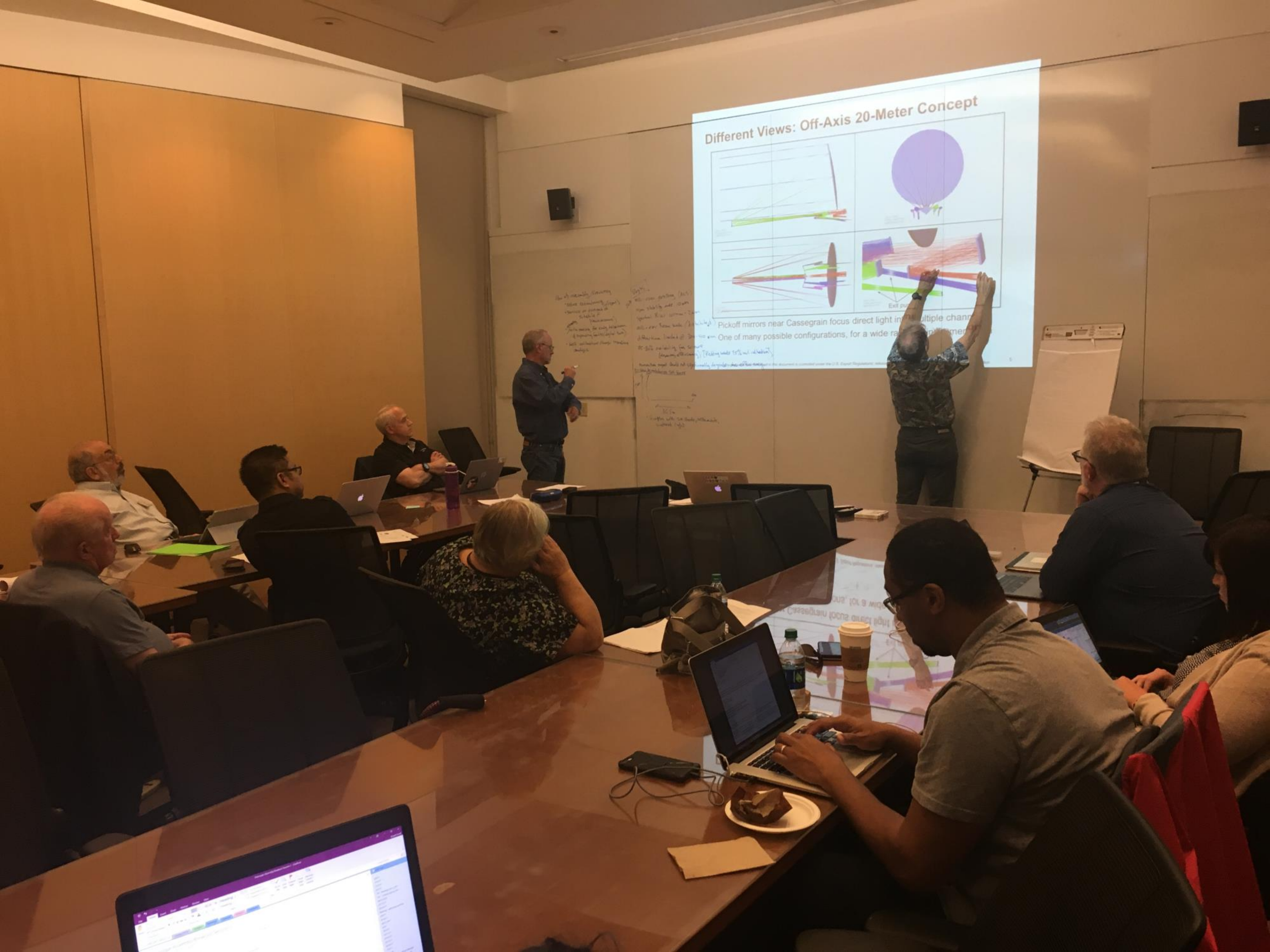
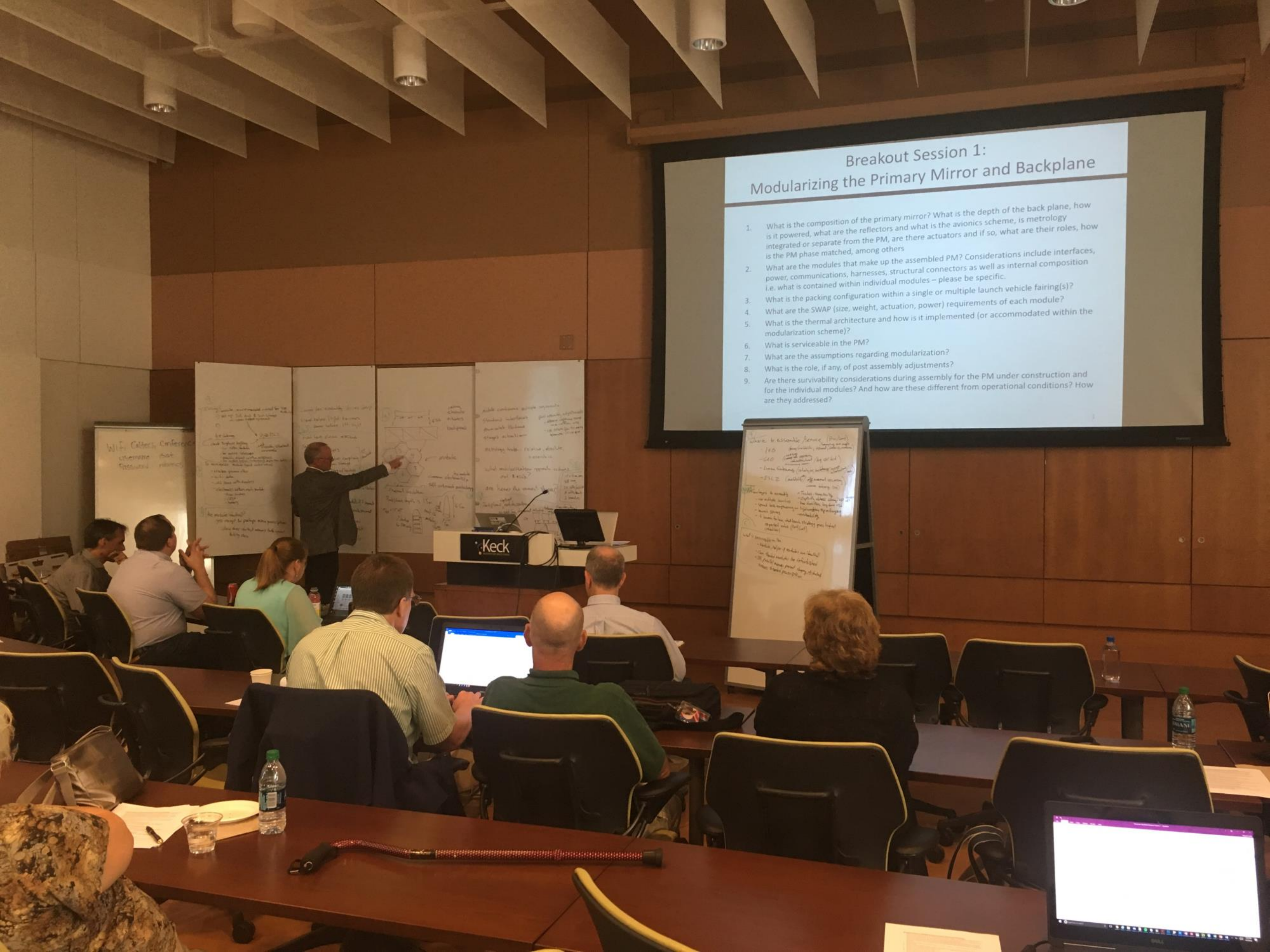

Different Views: Off-Axis 20-Meter Concept
Pickoff mirrors near Cassegrain focus direct light in
One of many possible configurations, for a wide ra

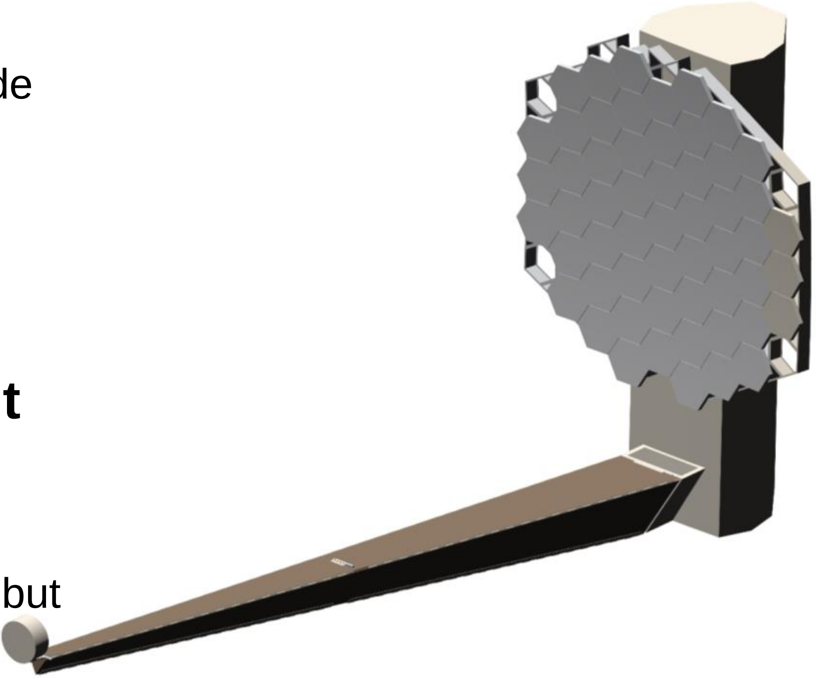

Breakout Session 1:
Modularizing the Primary Mirror and Backplane
1. What is the composition of the primary mirror? What is the depth of the back plane, how is it powered, what are the reflectors and what is the avionics scheme, is metrology integrated or separate from the PM, are there actuators and 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

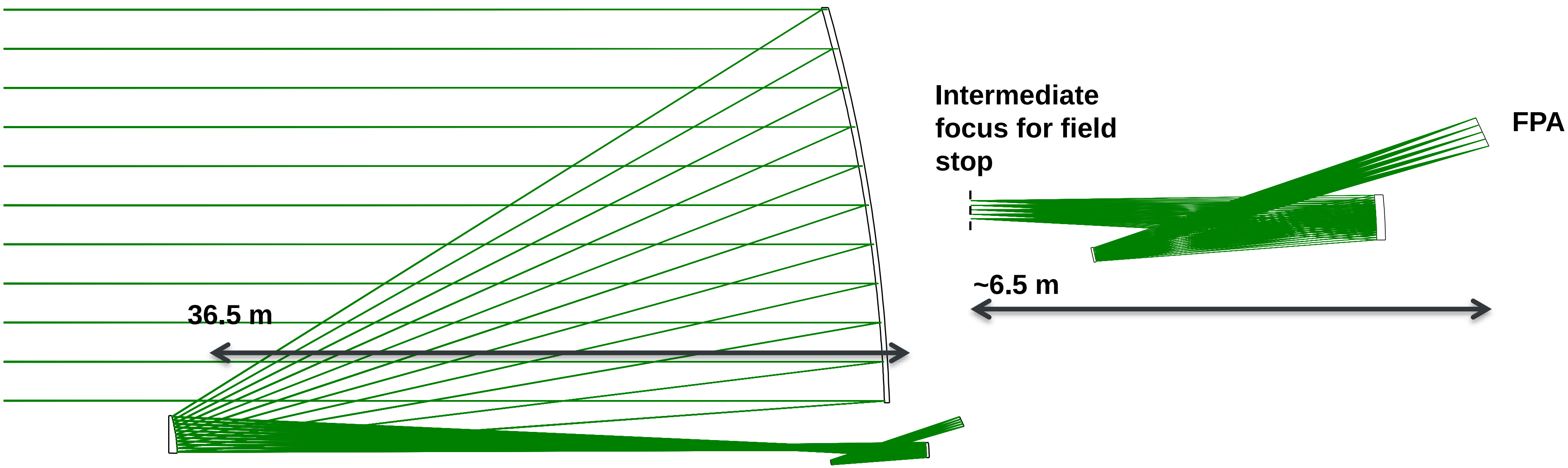
- **Trade space for <u>modularization</u> is very open**
  - Number of modules
  - Segment size, segment carriers, sun shade
  - Backplane architecture
  - Power, latching, harnessing
  - Instrument carriers, thermal

- **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

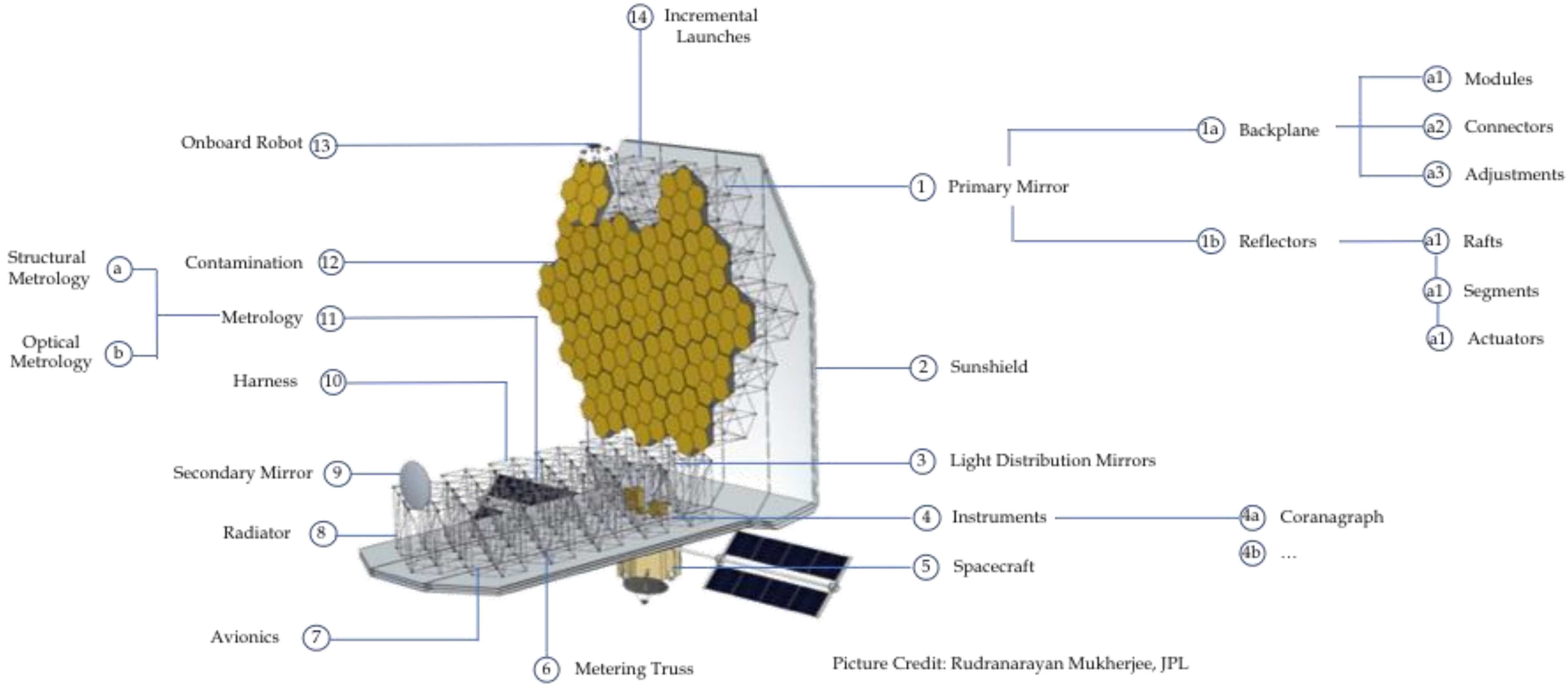
Off-Axis 20-Meter Optical Layout



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

Modularized Telescope Sub-Elements

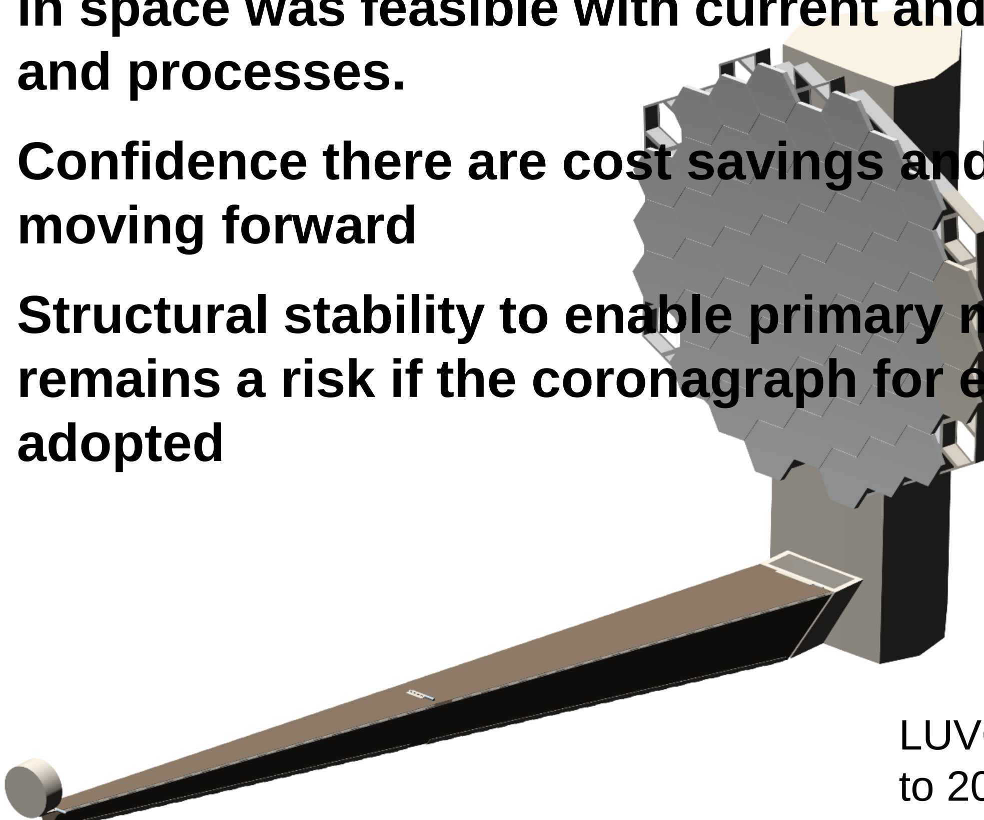
(all were discussed during the Workshop)



Telescope architecture and modularization are notional.

Workshop Conclusions

- The 20 m off-axis f/2 filled 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.
- Confidence there are cost savings and risk mitigations moving forward
- Structural stability to enable primary mirror WFE stability remains a risk if the coronagraph for exo-Earth science is adopted

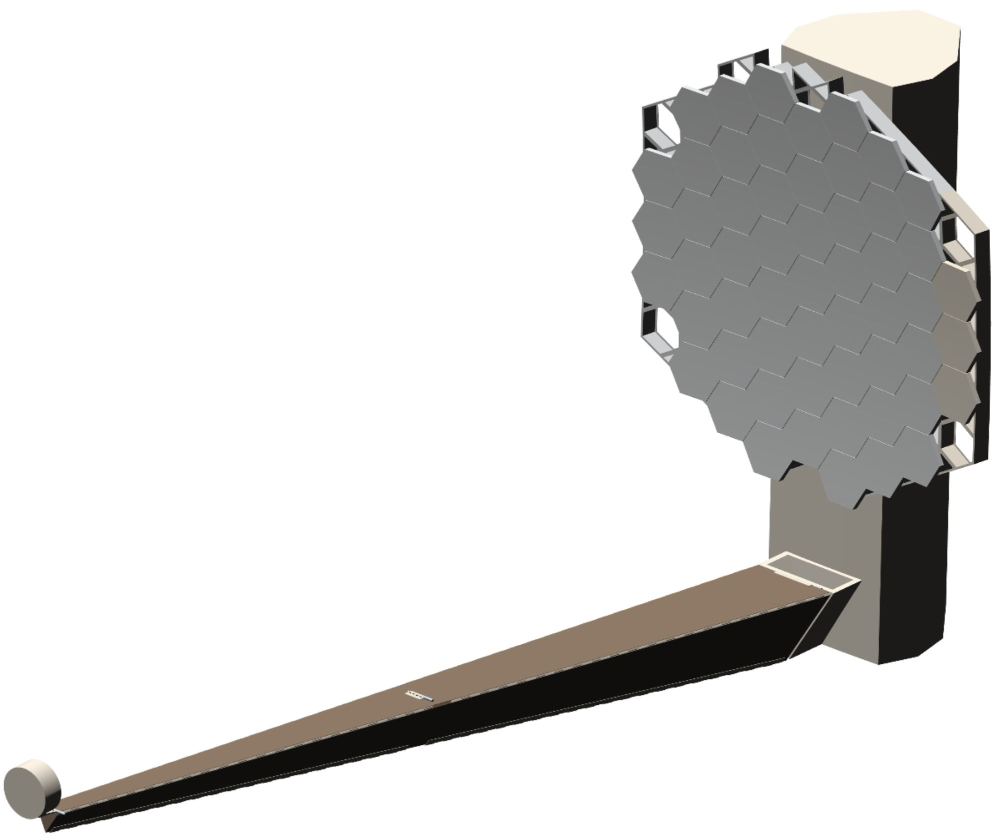


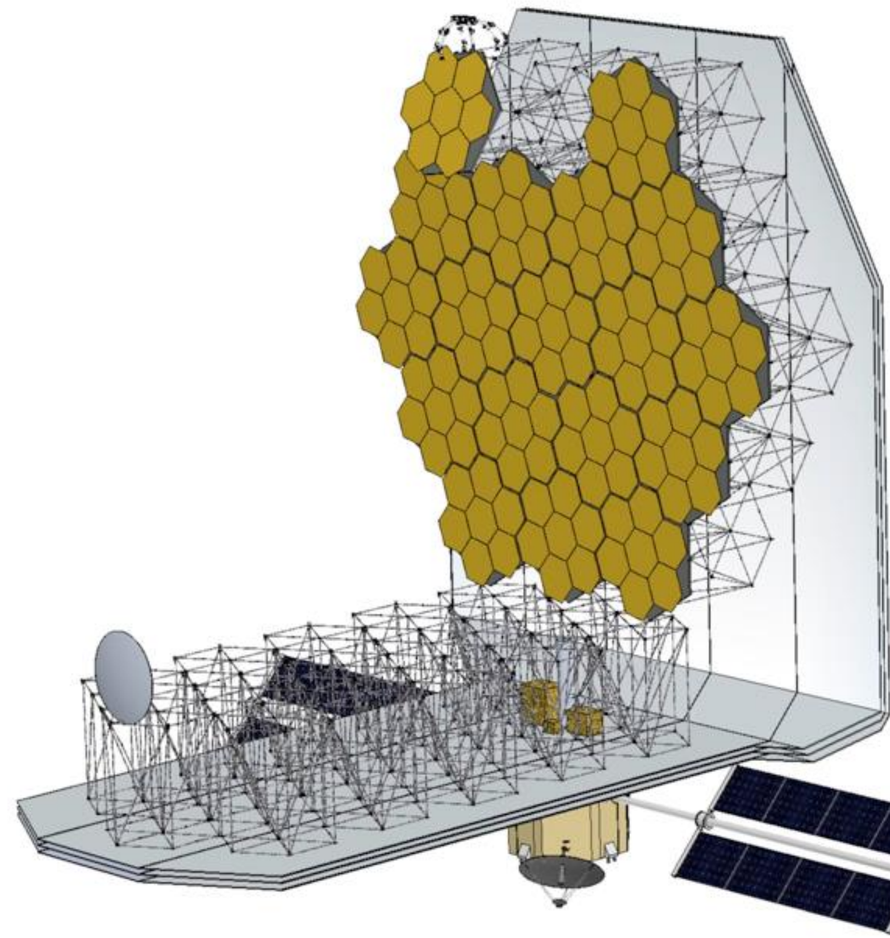
LUVOIR B architecture scaled to 20 m, f/2.5, off-axis

Identified Workshop Analyses

Three analyses requiring advancement:

- Primary mirror truss architecture
- Stray light analysis
- Sunshade architectural concept





Where are We Now?

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					

Problem Statement (Activity 1a): Prioritize concepts of modularized designs and architectures for a 20 m in-space assembled telescope.				
ID		COMMENTS	Reference Option A	Reference Option B
	OPTION DESCRIPTORS			
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		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 ground.)	
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 insulation. Could consider wireless power/comm but could also use proven mechanical connectors (mated upon segment installation).	
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		Robotically-assembled, human-supervised	
D11	Number of new technologies	Best to complete during Assembly 1b		
D12	Type of LV needed	Look out for unique launchers		
D13	Number of LVs to complete system assembly		3 launches for the PM (mass limited?), 1 launch for instruments, 1 for trusses, 1 for bus	
D14	Serviceability	What modules can and can't be serviced?	Not all modules will be required to be serviced. Certainly instrument modules. Anything with consummables including fuel batteries. Servacibiliy should occur at simple interfaces. Modules should be refurbished/replaced at the assembly platform.	
D15	Need for new industry facilities	vacuum chambers, test facilities, etc	Not all modules will be required to be serviced. Certainly instrument modules. Anything with consummables including fuel batteries. Servacibiliy should occur at simple interfaces. Modules should be refurbished/replaced at the assembly platform.	

Musts

Under review

ID			COMMENTS		Reference Option A	Refere
	Modular design option MUST…		**COMMENTS**			
	Technical					
M1	Enable necessary adjustability and correctability of key optical components.				Will require modeling with MUFs with integrated modeling	
M3	Permit module servicing (repair, replacement, refueling) of all instruments and key spacecraft elements.				Things that have high failure rate, things that can go obsolete, things that get consumed/degrade. Not all modules will be servicable but all consummables, instruments, key spacecraft hardware, mirror segments.	
M4	Not enable a failure within a module to propagate through to the system				Expected in the design; need to think through replacement instrument process	
M5	Fit into the selected LV		Sanity check		Sanity check for mass, volume, separate instruments into different launches	
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	

Wants

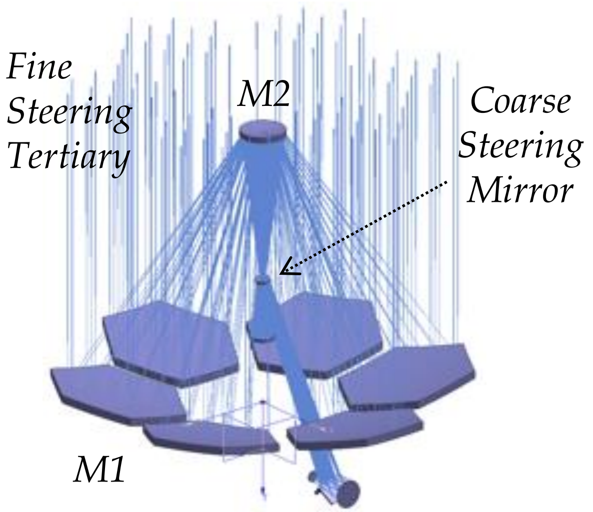
Under review

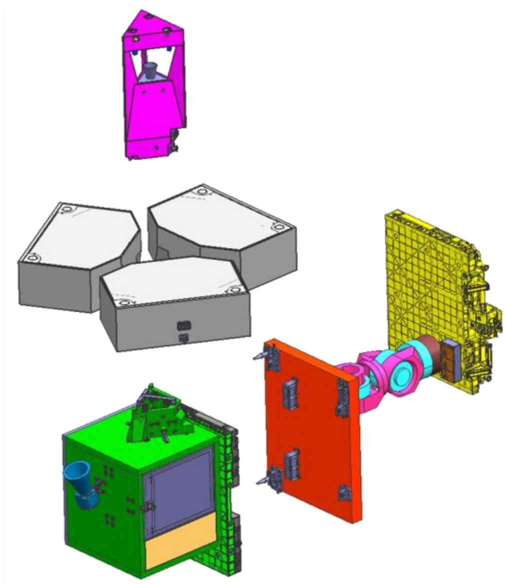
	WANTS	COMMENTS	
	Technical		
W1	**Few technologies exceeding the SOA**	The more mature the concept the better, the fewer "Miracles" the better; the larger the number of low TR subsystems the worse, reach TRL 5 at earliest possible date	
W2	**Clear and simple architectures and interfaces.**	This speaks 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 failure is not a mission failure,	Remove? Emailed Kim and Alison (email bounced)
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 serviceable modules for repairing or replacing.**	Architectural flexibility - the more access the better but perhaps not all modules need accessing; just the critical ones.	
	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.	

When do we know we're done with Activity 1a?

(Concept Design and Architecture for the iSAT)

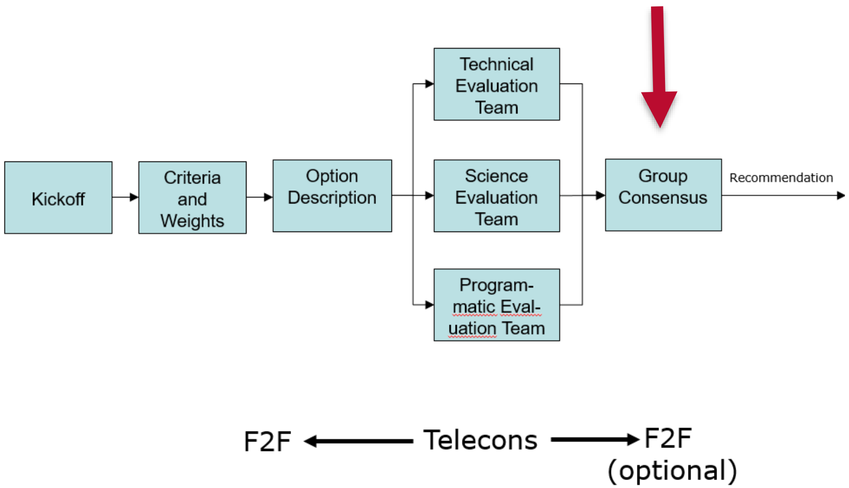
1. **Select a reference <u>design and architecture</u> concept for a 20 m, filled aperture, non-cryogenic space telescope to be assembled and tested in space.**
    - Musts and Wants completed; Risks captured
    - Is there a second concept to bring up?
2. **Advance the three analyses**
3. **Modularization diagram**



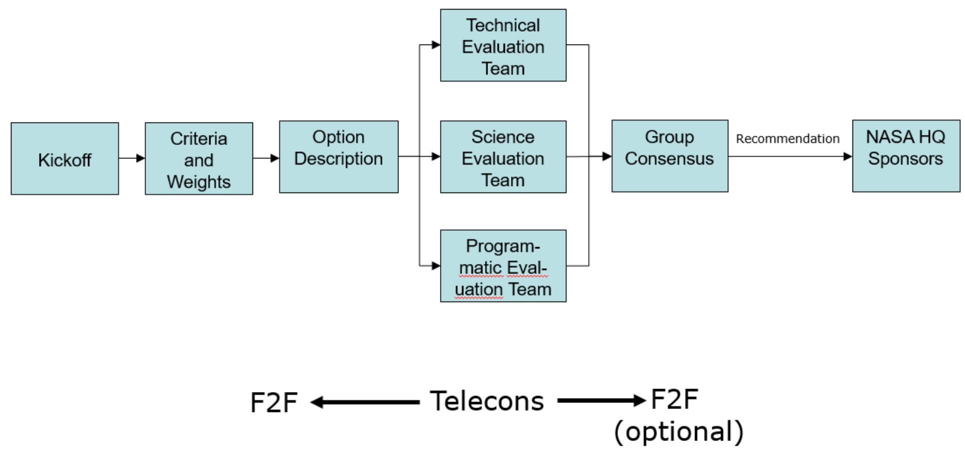


iSAT Study Process

(Activity 1a – Telescope Modularization)

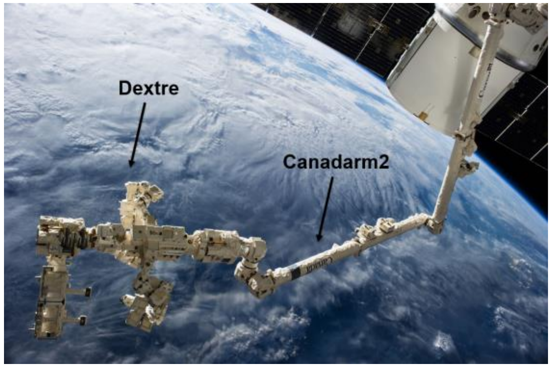


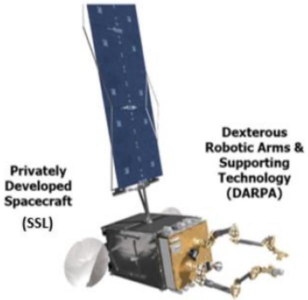
(Activity 1b – Telescope Assembly and Testing)

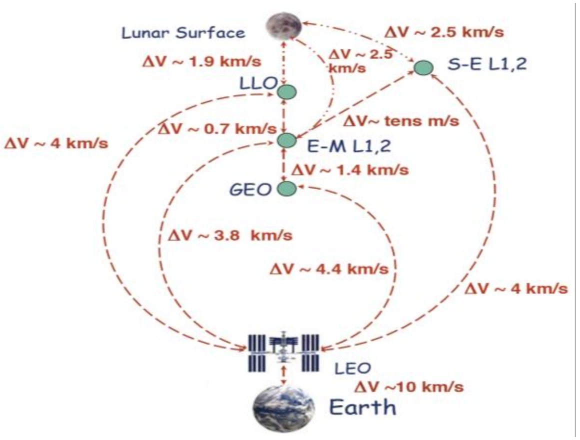


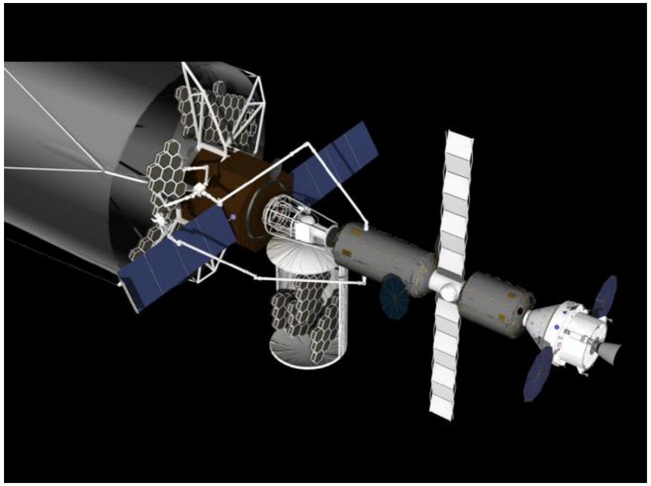
Activity 1b:
Concept for Assembling and Testing the ISAT

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









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

Next Steps

- **Complete Selection Criteria**
  - Through upcoming telecons and emails
  - 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/Wants/Risks
- **Start Activity 1b (Module Assembly, Testing, etc)**
  - Membership (and Steering Committee) will morph towards more assembly/robotics focused
  - Need names
- **Start planning Activity 2 (concept definition - cost and risk benefits)**

Advance Selection Criteria Concurrence

(switch to Excel)

Additional Slides

Activities 2a and 2b

(Not Yet Funded)

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

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