Jet Propulsion Laboratory
California Institute of Technology

In-Space Assembled Telescope (iSAT) Study

Steering Committee Telecon 6

November 6, 13, 15, 2018

Nick Siegler
Chief Technologist, NASA Exoplanet Exploration Program
Jet Propulsion Laboratory, California Institute of Technology

Rudra Mukherjee
Robotics Technologist
Jet Propulsion Laboratory, California Institute of Technology

CL#18-6849

Today's Agenda

1. Study Status
2. Preliminary Approach to Activity 2 (Cost and Risk Assessments of iSAT)

Study Status

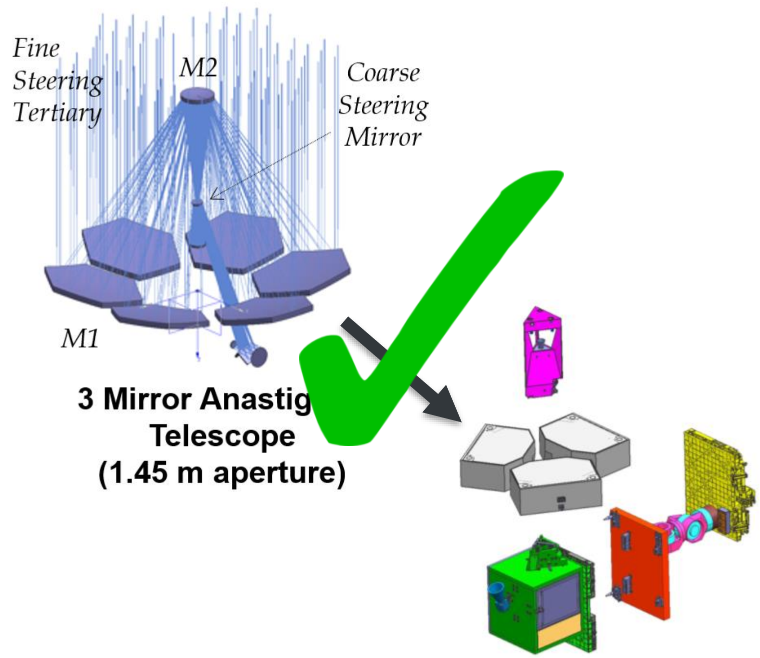
Study Activities

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

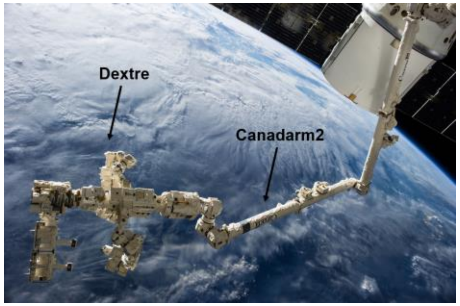
Activity 2: Estimate the costs and assess the risks of a reference iSAT

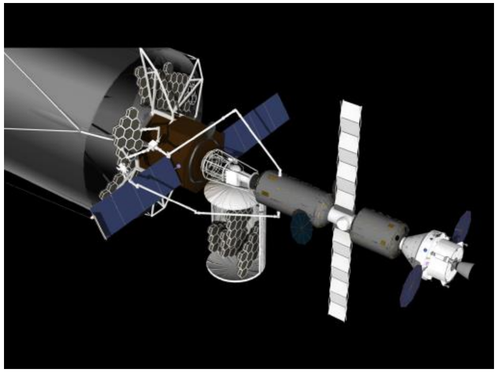
Activity 1b: Assembly and Infrastructure

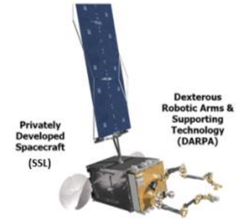
Activity 1a: Modularization and Testing

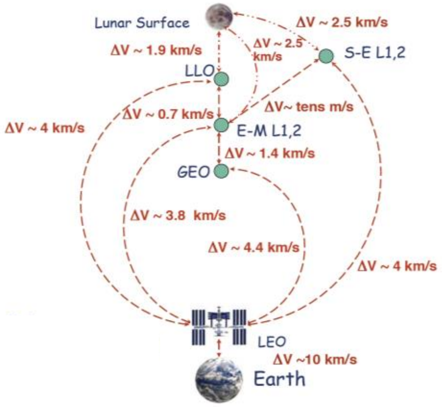


6 launch modules for assembly

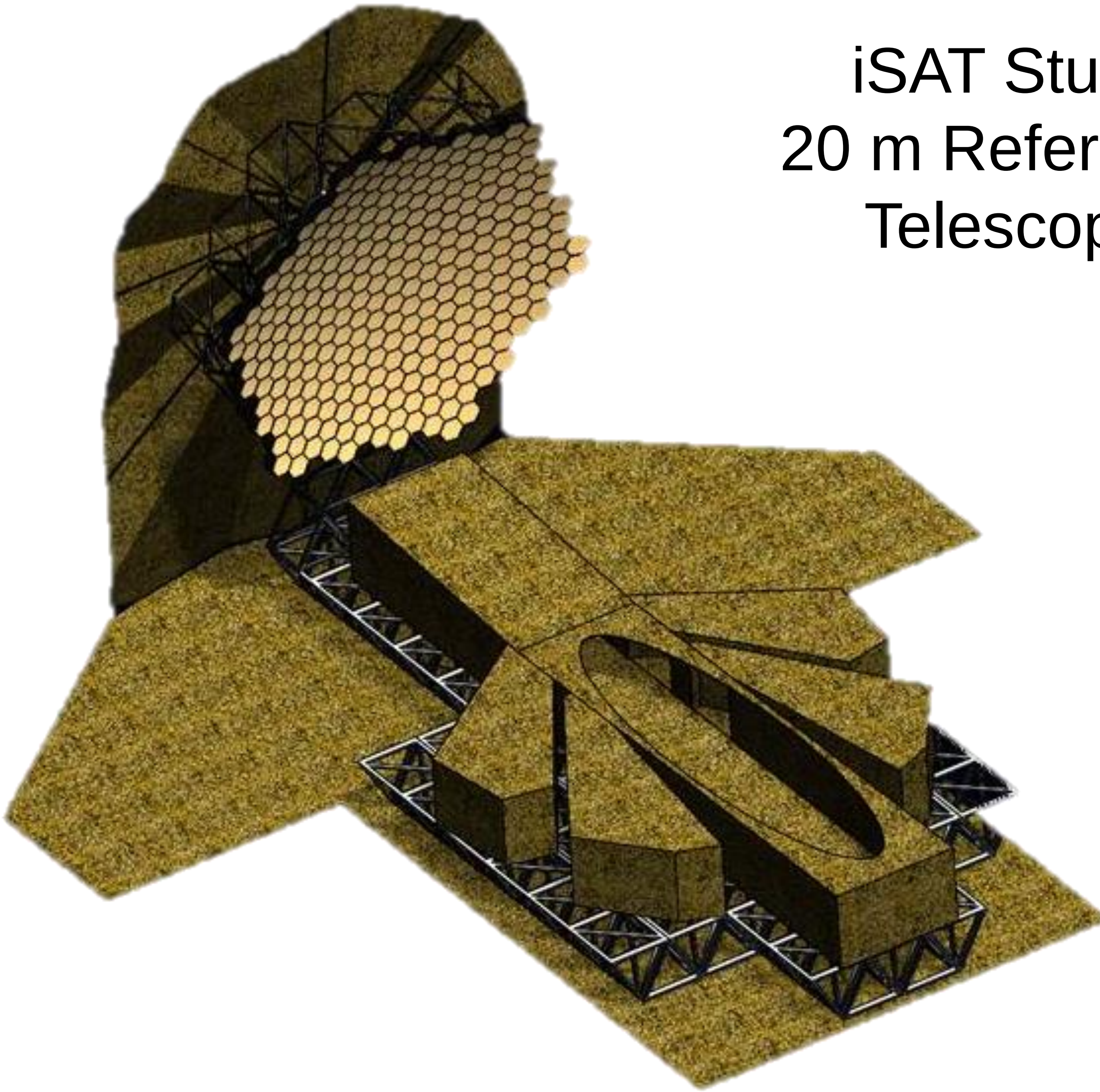




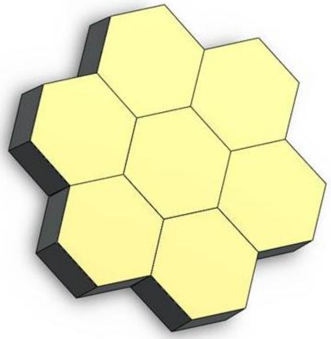




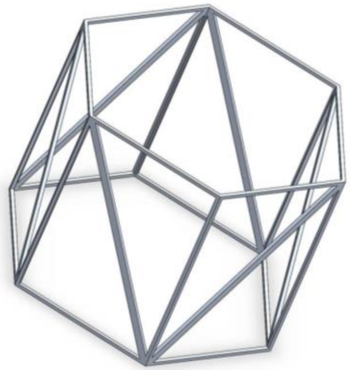
iSAT Study
20 m Reference
Telescope



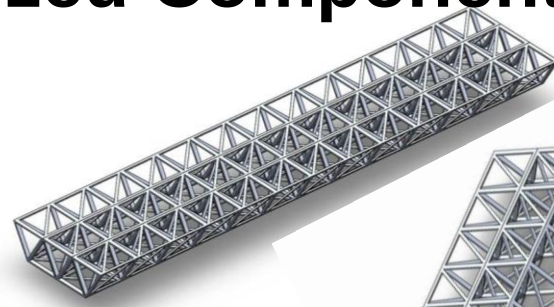
The Notional Modularized Components



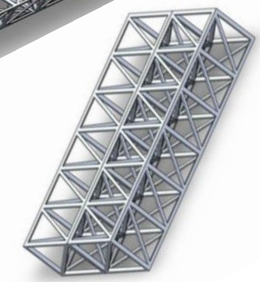
Primary Mirror Rafts
24 units



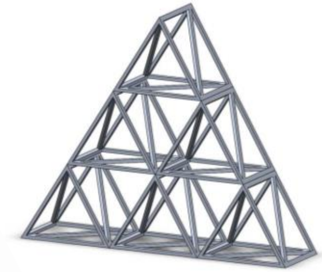
Deployable Truss Modules
24 units



Metering Truss (PM-SM)
5 units

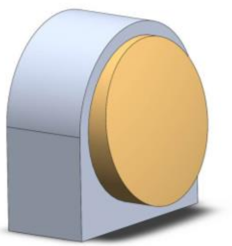


Instrument Support Truss
10 units

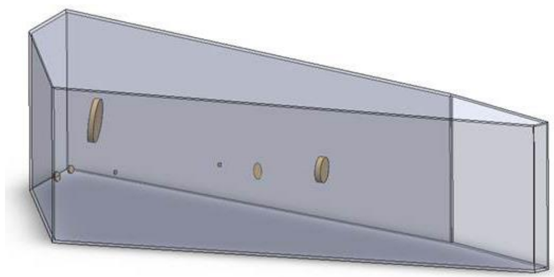


Transition Structure
1 unit

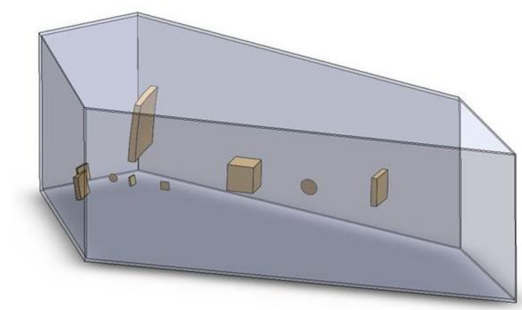
Bottom Sunshade
1 unit



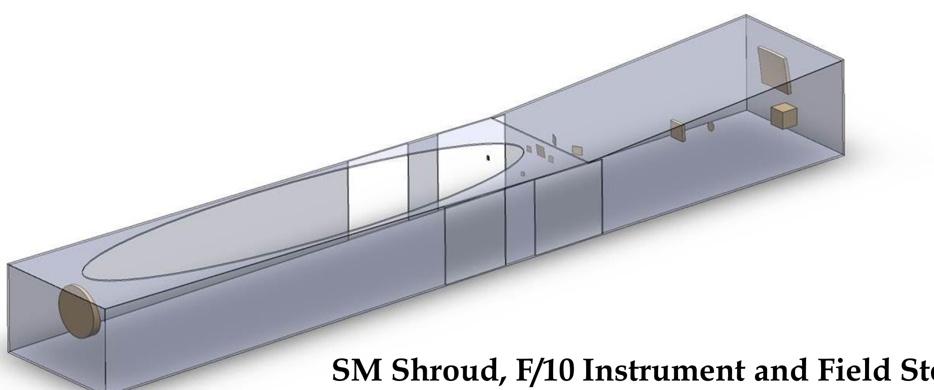
Secondary Mirror
1 unit



F/30 Instrument Module
2 units



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



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

Back Sunshade
1 unit

NASA Langley Research Center
Integrated Engineering Services Building
Face-to-Face Meeting (Oct 2-4)

Exoplanet Science Strategy Recommendation

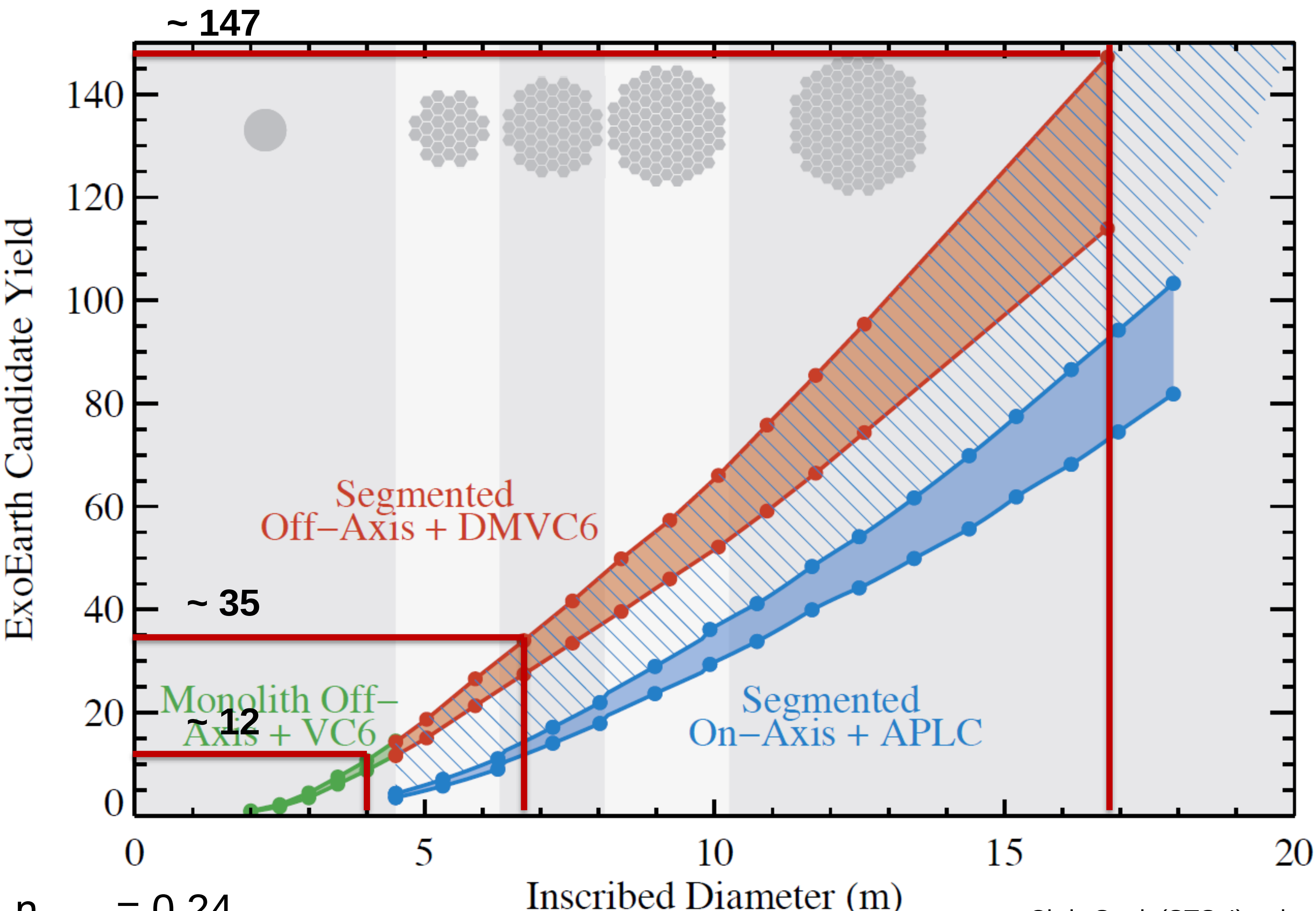
Released September 5, 2018 by the National Academies

Recommendation #1:

NASA should lead a large strategic direct imaging mission capable of measuring the reflected-light spectra of temperate terrestrial planets orbiting Sun-like stars.

Exo-Earth Model Predictions

As a function of telescope aperture size; coronagraph architecture



$\eta_{Earth} = 0.24$

Chris Stark (STScI), priv comm

iSAT Study Members Meeting

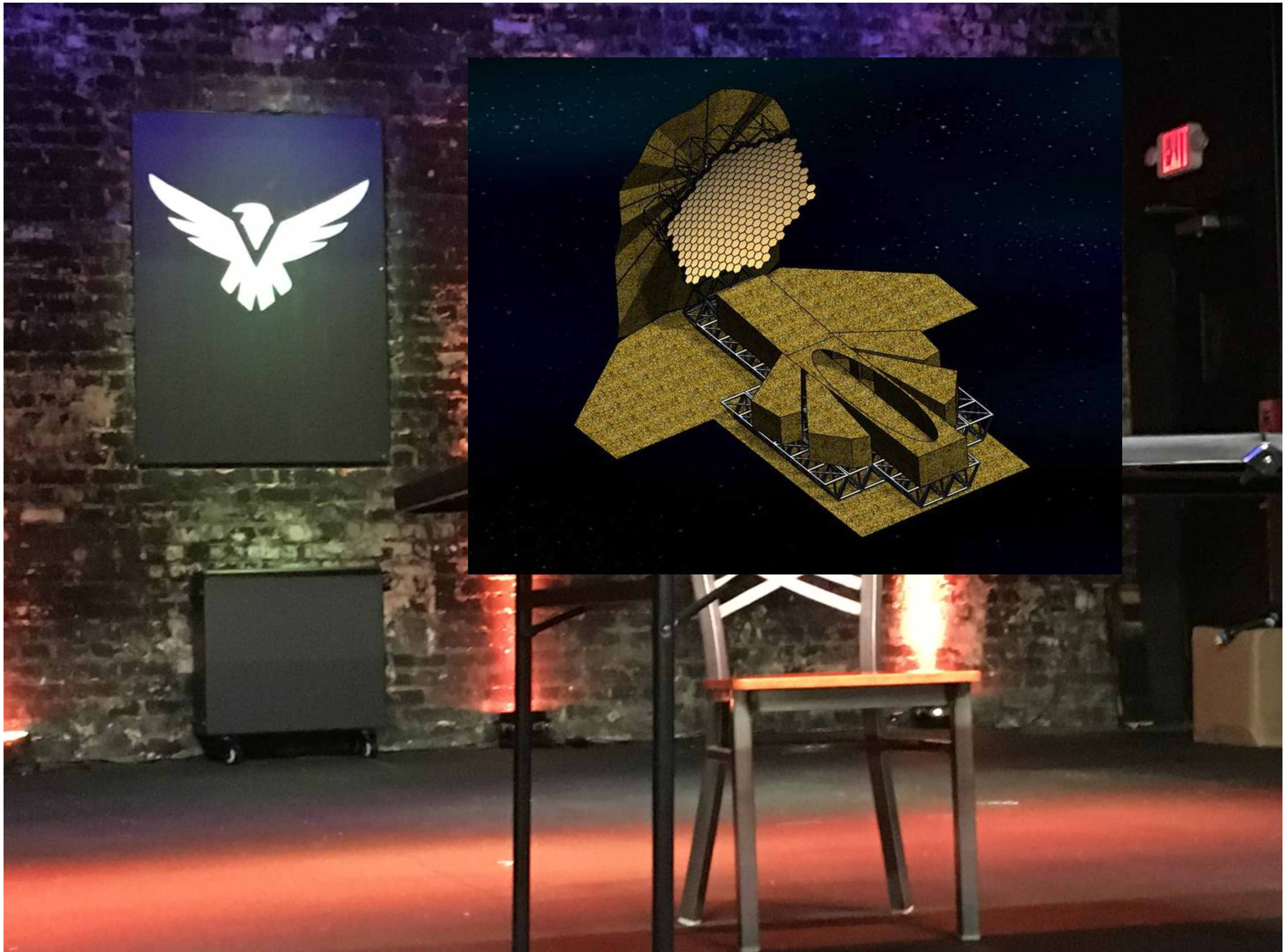
NASA LARC October 2-4

Breakout Teams

Team A	Team B	Team C
John Grunsfeld	**David Miller**	**Gordon Roesler**
Keith Havey	Bob Hellekson	
Howard MacEwen	David Redding	Kevin Patton
Paul Backes	Glen Henshaw	Erik Komendera
	John Lymer	Michael Fuller
Al Tadros		Kenneth Ruta
Diana Calero	Roger Lepsch	Keenan Albee
Kim Aaron	Allison Barto	Sharon Jefferies
Douglas McGuffey		
William Doggett	John Dorsey	Jason Herman
Robert Briggs	Kevin DiMarzio	Rob Hyot
Alex Ignatiev	Nate Shupe	Bradley Peterson
David Folta	Bo Naasz	Kimberly Mehalick
		Michael Elsperman
Keith Belvin		Samantha Glassner
Blair Emanuel	Ryan Ernandis	Evan Linck
	Beeth Keer	Josh Vander Hook
Alison Nordt	Michael Renner	
Lynn Bowman	**Ron Polidan**	**Eric Mamajek**

iSAT Study Members Meeting

Thunderbird



General Principles

- Keep it simple
- Infrastructure costs must be small compared to telescope cost (no habitats for instance)
- Minimize time to construct
- Minimize cost
- Maximize dual use (if reduces cost or time)
- Use existing infrastructure
- Deploy if it makes sense (some sunshields?)
- Work that can be done on the ground should be done on the ground (example: shimming of segments in raft)

Observations from the LaRC Meeting

Narrowing of Parameter Space

- **Assembly orbit preferences for cis-lunar and SE-L2**
  - No LEO, GEO, HEO
  - No one selected on the Gateway (however, would consider at the vicinity of the Gateway as a contingency if it existed)
  - Partial or complete assembly at cis-lunar for 3 of the 6 concepts
- **Servicing/upgrading orbit preferences at SE-L2**
  - Servicing: repair, refuel, orbit adjustment
  - No one scared off by 10 sec round-trip latency
  - Trade to assess bringing telescope to cis-lunar for servicing/upgrading
- **Assembly agents preference for robotic arms**
  - No free fliers, no multi-limbed robots, no astronauts
- **Emergence of the Space Tug**
  - Tug enables simple upper-stage cargo vehicles and cleaner propulsion
  - Discussions also included tender, depots, and a building way
  - One concept tugs modules from LEO

Summary of the Mission Concepts

Problem Statement (Activity 1b): Prioritize assembly and infrastructure concepts for a 20 m modularized in-space assembled telescope.							
ID	OPTION DESCRIPTORS	Concept Team A Grunsfeld Cis-lunar Direct via Tug	Concept Team B1 Miller SE-L2 Direct	Concept Team C1 Roesler Cis-lunar Direct via Depot	Concept Team B2 Miller SE-L2 Direct via Depot	Concept Team B3 Miller SE-L2 via LEO	Concept Team C2 Roesler Cis-lunar Way via Depot
D1	Describe the Concept architecture.	**Assembled at cis-lunar**, modules are launched to cis-lunar, transferred to a space tug, and delivered to the assembly location; assembled by 2 walking robotic arms on the telescope S/C bus, telescope with 2 instruments conducts first light at cis-lunar, propels to SE-L2, subsequent instruments installed and serviced at SE-L2. Can take advantage of Gateway infrastructure for contingency if available.	**Assembled directly at SE-L2**, modules are launched directly to assembly location at SE-L2. Off-nominal repairs at SE-L2 (would consider Gateway if available). Staging is on-board telescope. Includes long-reach robotic arms + smaller onboard dexterous robots, possibly needed to add additional structure/scaffolding for those arms.	**Assembled at cis-lunar**, modules are launched to cis-lunar and delivered to a "depot" via a space tug. Some pre-assembly can occur at the depot before transporting to cis-lunar telescope assembly location via a tender. Final assembled telescope is propelled to SE-L2. Teaming of multiple heterogeneous robots. *Tender= multi-limbed free flying robot for short range transportation and manipulation	**Same as B1**, but here modules are staged off-board at SE-L2 at a depot and tendered to the assembly location.	**Same as B1**, but here modules are launched into LEO and tugged to SE-L2.	**Same as C1**, but here the assembly platform is a building way that detaches before telescope propels to SE-L2.

Recommendation moving forward is to combine the 6 concepts to 2 – one for cis-Lunar orbit as the assembly location and the other SE-L2.

In both cases, there are a series of trades that must be addressed such as (1) pros/cons for using a tug to transfer modules from upper-stage launch vehicle to the assembly area rather than going direct (2) benefits of depots, (3) benefits of tugging LEO-delivered supply capsules to the assembly locations

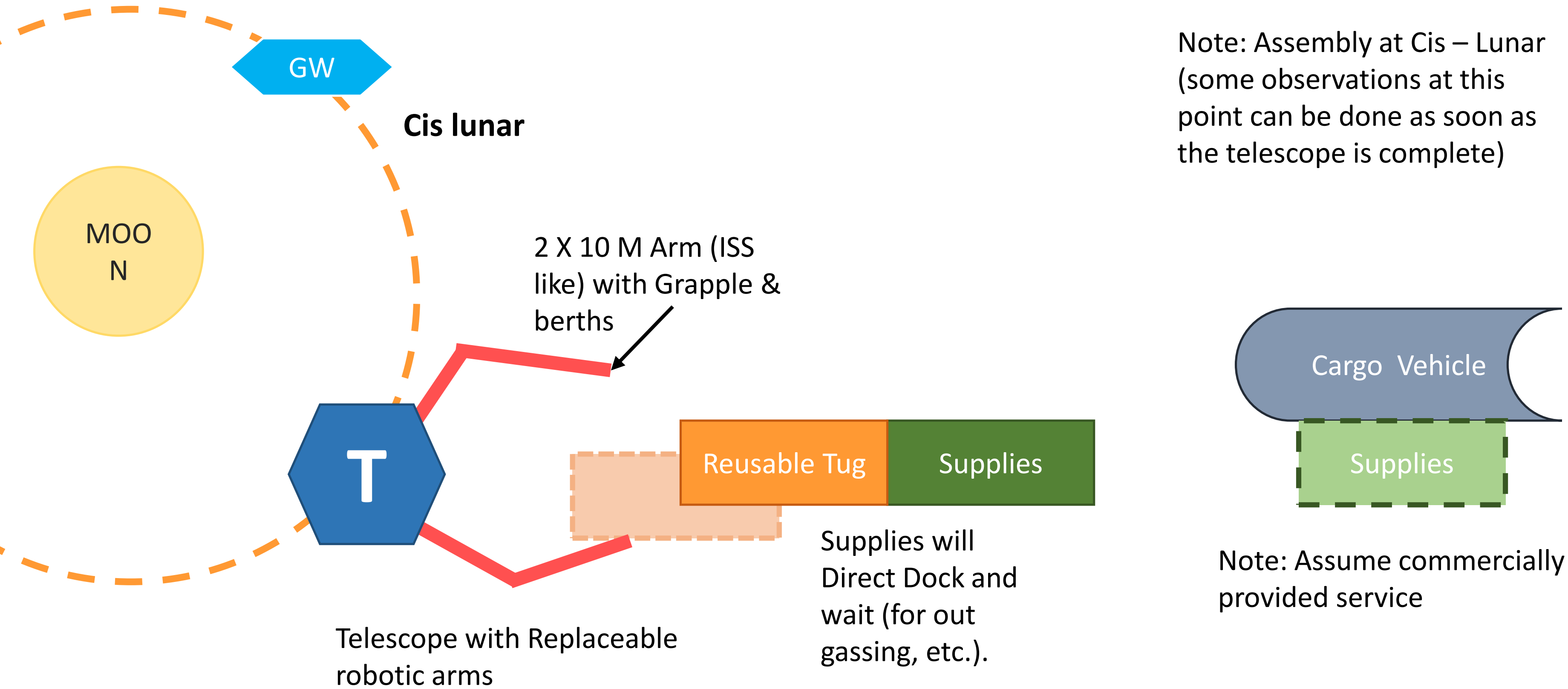
The Two Mission Concepts Under Study

1. **A Hybrid Cis-Lunar to SE-L2**
   - Earth-Moon L2 for initial assembly through first light, with a partially-filled PM, SM, and at least 1 imaging instrument
     - Assemble structure, other infrastructure, and minimum optical train
     - Thorough checkout in cis-lunar orbit, where transport and com times are shorter
     - Continue assembly, verifying each subsequent module as assembled
   - Transfer to final orbit (SE-L2), continuing checkout (and early science?)
     - Complete assembly and V&V in final orbit as modules become available
     - Service, replenish and replace in final orbit
   - Operate at SE-L2
   - Option to return to EM-L2 or cis-lunar orbit for repair

2. **Straight to SE-L2**
   - Who needs an intermediate point?

Assembling at cis-Lunar Mission Concepts

Teams Grunsfeld and Roesler



Proposed Description of Activity 2:

Cost Estimate and Risk Assessment

Phase 2 Plan (1/2)

Objective: Develop an understanding of the value proposition of iSA for large telescopes.

Challenge: iSA mission is not well understood and a definitive cost and risk posture is difficult to postulate in the absence of a clear lifecycle plan, schedule, and a bounded technical approach.

Opportunity: A well qualified team of experts across a diverse set of technical and programmatic fields are involved in this study. The team is self motivated and we have the benefitted from some excellent technical inputs.

Must do: Answer the sponsor question: When is iSA favorable compared to current paradigm?

Activity 1: Consensus on optical design, on the overall architecture and module concept definitions, orbits and robotic systems, some clarity on mission concept, fairing size among others. Provides a good launching point for a more focused Activity 2

Phase 2 Plan (2/2)

Two pronged approach:

Anectodal Assessment

1. A subjective study quantifying the connections between different aspects of an iSA mission to glean the expert opinion based expected impact of iSA, provide qualitative measures for understanding cost and risk postures; also identify technology readiness

Detailed Assessment

2. A more focused product lifecycle plan for parameterized telescopes (5-20 m) that follows the paradigm of a step 1 New Frontiers proposal concept plan with granularity at major subsystems, bounded with clear statement of assumption and projected uncertainties

Constraint: Must finish in time to inform the Decadal Survey

The Subjective Effort

Not so subjective

Expected Steps:

- Create a list of all important parameters that define an iSA mission versus current approach
- Capture interactions/dependencies between these parameters
- Show qualitatively how these parameters alone impact cost and risk
- Then show the impact of these parameters collectively via their interactions
- Discern **nuggets** that provide positive and negatives of iSA as a paradigm vs current approach. Support **nuggets** with clearly understandable rationale
- Must close, do not leave things hanging – i.e. cover the full iSA spectrum
- Identify areas where analyses may be needed – do not do analyses
- Identify technology enablers and risks

Deliverable:

- An initial presentation capturing the parameters and their relations (+4 weeks)
- A plan of action demonstrating feasibility (+8 weeks)
- A report summarizing the findings, and the cost and risk posture of iSA mission vs current paradigm (+16 weeks)

The Detailed Study

Expected Steps:

- Create a project WBS and identify major subsystems
- Create separate small teams from the WG for each subsystem and WBS element (as appropriate)
- Each team studies Phase A-E. Generates, with bounds/uncertainties:
  - ❑ a schedule,
  - ❑ implementation plan, including testing, V&V and integration
  - ❑ resource and budget,
  - ❑ technology heritage, technology development plan
  - ❑ MEL, PEL
- An overarching systems team shadows and integrates each study team
- An overarching formal costing team shadows and integrates each team

Notional Studies:

- Structure, joining means and metrology
- Sunshade
- Spacecraft
- Robotics
- Reflector Rafts, Secondary Mirror, and metrology
- Launches and RVC
- System Engineering

Next Steps

Next Steps

- **Complete Activity 1b**
  - Planning for end-Nov
  - Identify key analyses needing to be worked out

- **Begin Activity 2: Assess Cost and Risk Impacts of iSA Paradigm**

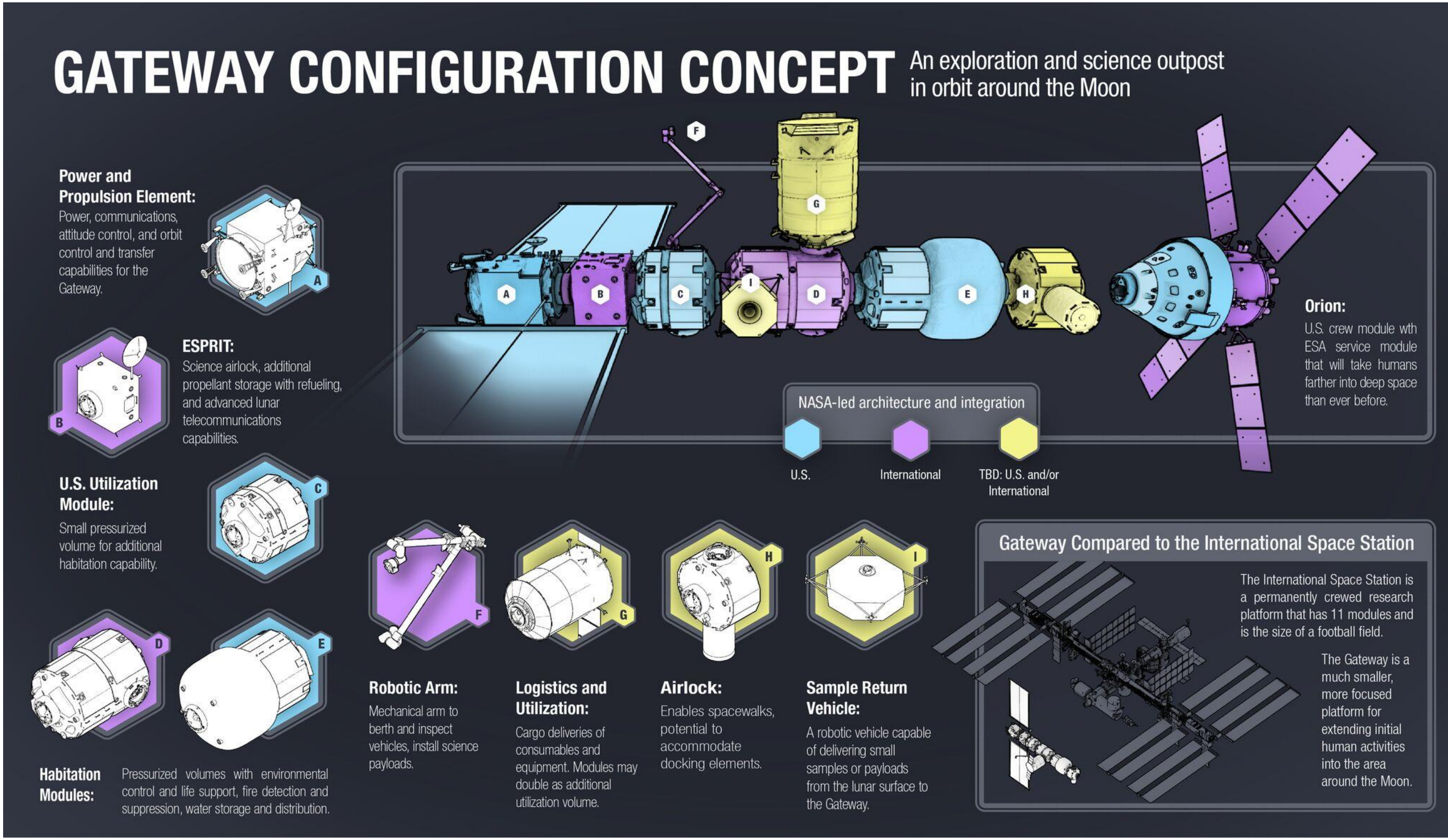
  1) Identify cost and risk deltas with respect to the current paradigm
  2) Small study teams to look at
     - PM segment rafts, robotics, systems engineering, integration and test, V&V, structural trusses, RPO/GNC, laser metrology, spacecraft bus, sunshade,
  3) Costing exercise - combination of grass roots plus heritage
     - Some subsystems will have heritage and some will require new costing
  4) Parameterize to smaller apertures to understand scaling laws

Additional Slides

Trades & Analyses

Do now, later or just document answer?

- **The role of astronauts in iSA**
- **Mass and volume estimates to calculate number of LVs as a function of aperture size**
- Are there mass or volume limitations for a robotic arm?
- **Cost/risk trade between a tug and direct send to SE-L2**
- **Advantages of cis-lunar vs SE-L2 in absence of Gateway**
  - Can we justify cis-lunar without Gateway?
- Why not GEO assembly and transit to SE-L2
- Cost profile across the Project Life Cycle
- **Orbital analyses: delta v and transit times**
- **Benefits of the Gateway as a physical location for assembly or in-vicinity**
- **Staging on-board the telescope or off-board the telescope?**
  - Possible off-board options such as a building way, tug, or depot
- Access to PM rafts - robotic translation capabilities along perimeter, backside of the PM trusses, long-reach arm?
  - A building way parked in cis-lunar may be a good option (a way could be an example of gov't-funded infrastructure)
- Deferred Trades
  - Connections: Joint welds or latches or other
- **Can robotic arms travel with the telescope and not impact WFE rqmts?**


GATEWAY CONFIGURATION CONCEPT
An exploration and science outpost in orbit around the Moon
Power and Propulsion Element:
Power, communications, attitude control, and orbit control and transfer capabilities for the Gateway.
ESPRIT:
Science airlock, additional propellant storage with refueling, and advanced lunar telecommunications capabilities.
U.S. Utilization Module:
Small pressurized volume for additional habitation capability.
Habitation Modules:
Pressurized volumes with environmental control and life support, fire detection and suppression, water storage and distribution.
Robotic Arm:
Mechanical arm to berth and inspect vehicles, install science payloads.
Logistics and Utilization:
Cargo deliveries of consumables and equipment. Modules may double as additional utilization volume.
Airlock:
Enables spacewalks, potential to accommodate docking elements.
Sample Return Vehicle:
A robotic vehicle capable of delivering small samples or payloads from the lunar surface to the Gateway.
Orion:
U.S. crew module with ESA service module that will take humans farther into deep space than ever before.
NASA-led architecture and integration
U.S.
International
TBD: U.S. and/or International
Gateway Compared to the International Space Station
The International Space Station is a permanently crewed research platform that has 11 modules and is the size of a football field.
The Gateway is a much smaller, more focused platform for extending initial human activities into the area around the Moon.
A
B
C
D
E
F
G
H
I

iSAT and the Gateway

Very preliminary findings

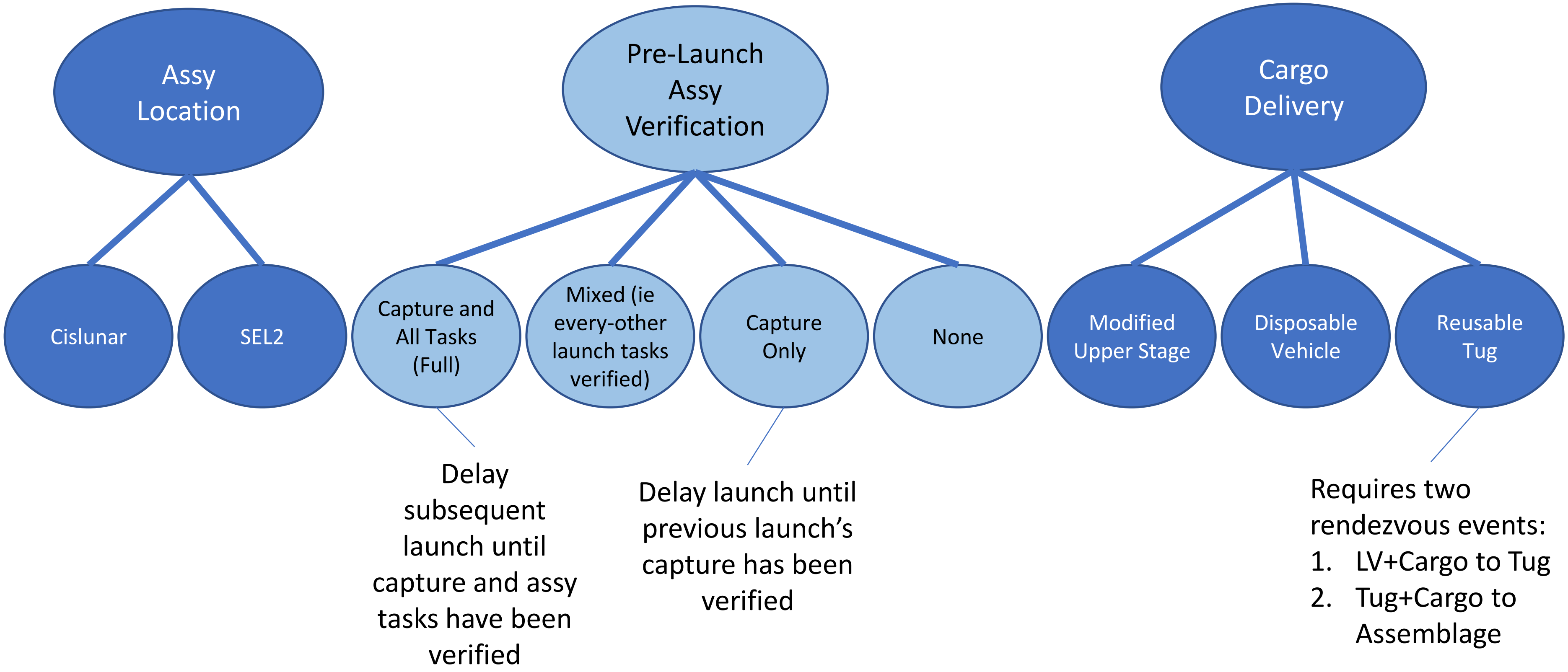
- **None of the three iSAT Breakout Teams selected a Gateway as a baseline architecture.**
- **Various concerns/limitations for 10-20 m telescope assembly:**
  - Stack control (propulsion and pointing) as the telescope is assembled and grows (CG offset, solar pressure)
  - Contamination
  - Gateway-driven requirements (driven by astronaut environment) → more expensive
  - Risk of realization (political creature?)
- **Unclear if more feasible for smaller aperture telescopes**
- **However, possible benefits as a contingency platform for the telescope to return to for servicing and instrument upgrade**

iSAT and the Gateway

Possible benefits

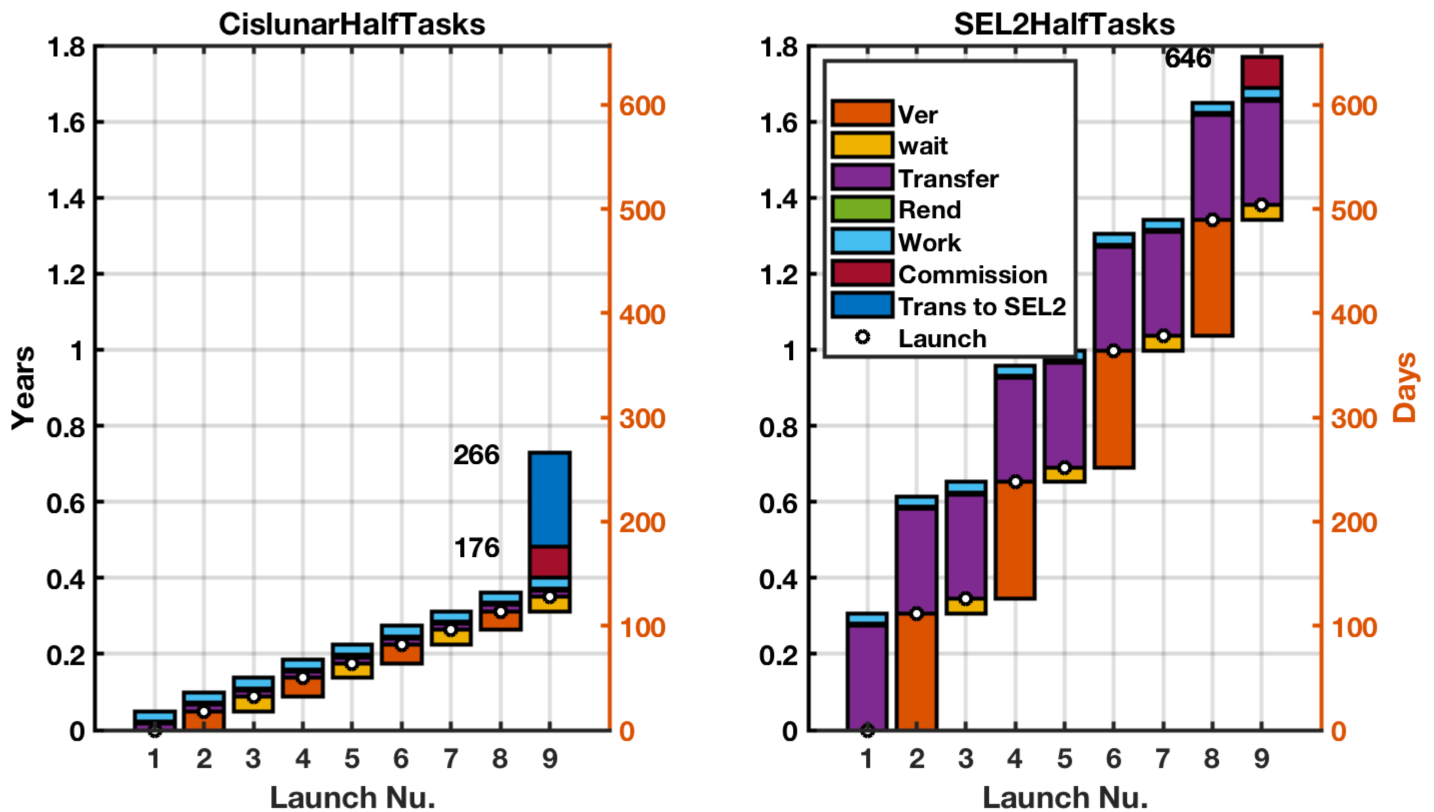
- **Support for assembly**
  - Docking ports for cargo vessels, tugs, tenders
  - Sub-assembly integration
  - Robotics and imaging systems on Gateway can support unpacking and inspection of deliveries, assembly, and V&V of parts and assemblies.
  - Comm can provide relay for telescope assembly
  - Up to 4 kW power for utilization
  - Astronaut involvement (EVA for trouble-shooting, tele-operations)
- **Ride-sharing**
- **Venue for technology demonstrations**
  - Including autonomous operations with longer latency times
  - Communication
- **Venue for pre-cursor science and technology missions toward eventual flagship telescope**

Several Related Trades



Credit: Bo Naasz (NASA GSFC)

Comparing Cislunar and SEL2 Assy (with half tasks verified)

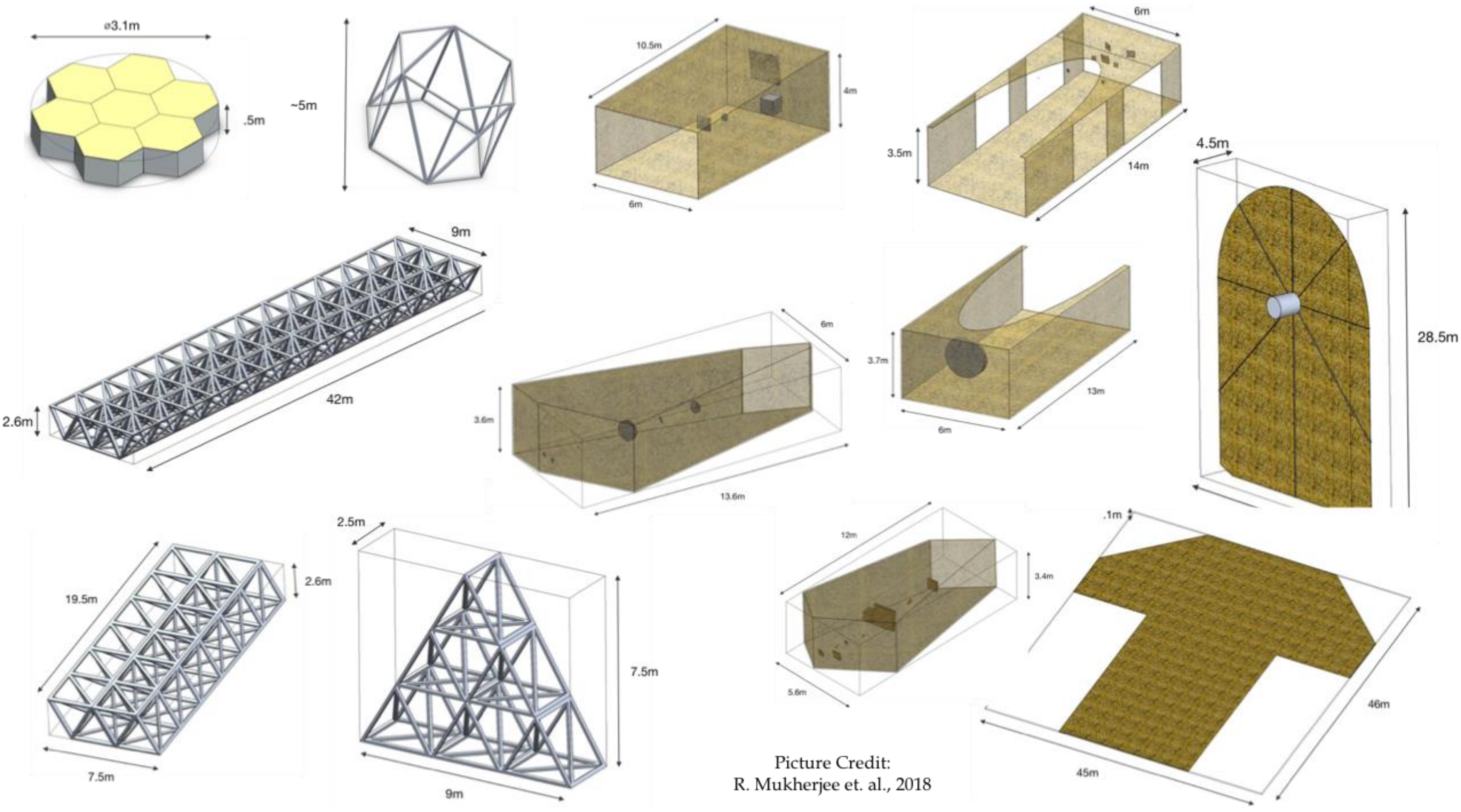



```
launchcount = 9;
rendtime = 2;  % days to add for each rendezvous event
worktime = 10; % Days of work to assemble each launch cargo set
mintimebetweenlaunches = 14; % days
cislunartransfer = 6; %days from launch site to cislunar
SEL2transfer = 100; %days from launch site to SEL2
```

Cislunar assembly complete in 25% of SEL2 assembly time

Credit: Bo Naasz (NASA GSFC)

The Notional Modularized Components



Picture Credit:
R. Mukherjee et. al., 2018

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