Jet Propulsion Laboratory
California Institute of Technology

In-Space Assembled Telescope (iSAT) Study

Activity 1b Study Members Kickoff Telecon

August 30 and
Sept 5, 2018

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NASA Jet Propulsion Laboratory, California Institute of Technology

CL#18-4829

Today's Agenda

1. **What: Objective and Deliverables**
2. **Why: Background and Motivation**
3. **Who: Participants and Roles**
4. **How: Process**
5. **When: Next Steps**

What: Objective and Deliverables

Study Objective and Deliverables

- **Study Objective:**
  - ***"When is it worth assembling space telescopes in space rather than building them on the Earth and deploying them autonomously from single launch vehicles?"***

- **Deliverables:**

  A whitepaper by June 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 iSA telescopes (iSAT).

Why: Background and Motivation

"All the News That's Fit to Print"

The New York Times

Late Edition

Today, patchy morning fog, partly sunny, warm, high 64. **Tonight,** mostly cloudy, mild, low 52. **Tomorrow,** clouds and sunshine, showers, high 66. Weather map is on Page B9.

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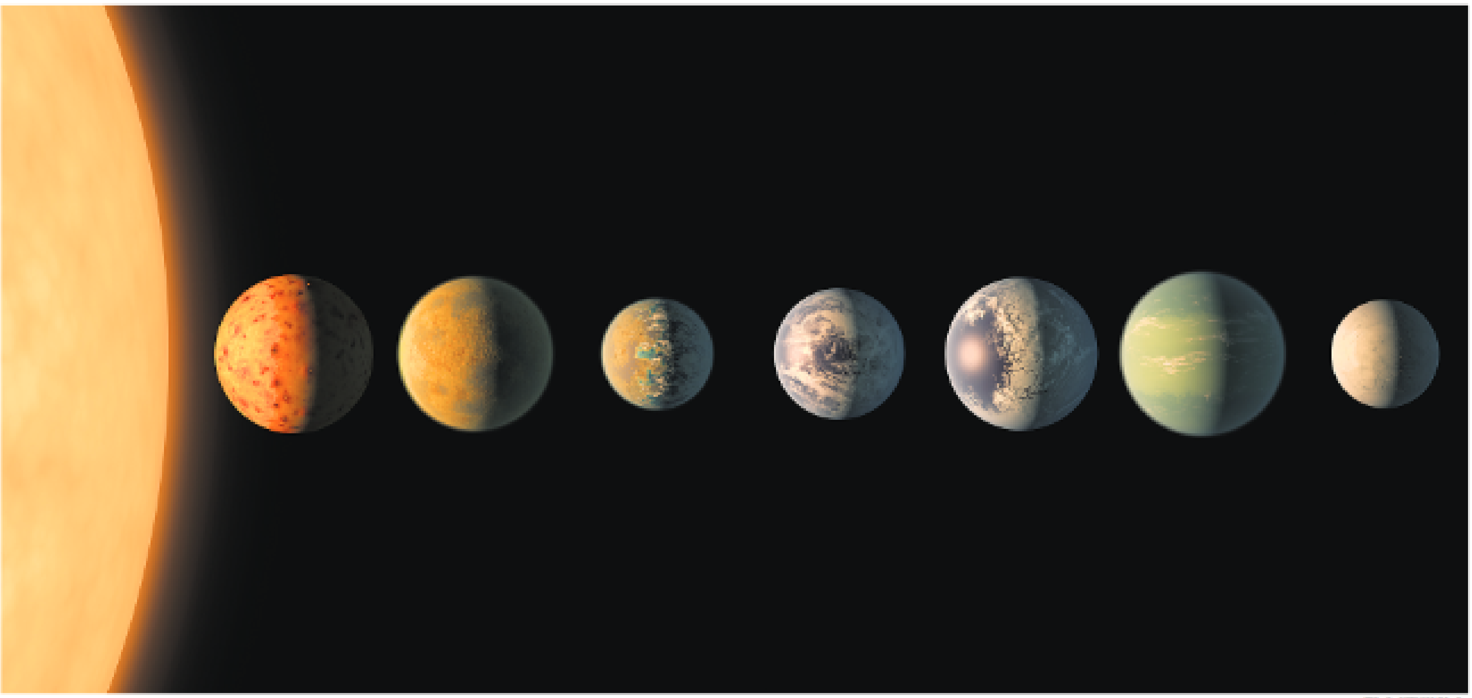
NEW YORK, THURSDAY, FEBRUARY 23, 2017

$2.50



JPL-CALTECH/NASA

A rendering of newly discovered Earth-size planets orbiting a dwarf star named Trappist-1 about 40 light-years from Earth. Some of them could have surface water.

Circling a Star Not Far Away, 7 Shots at Life

By KENNETH CHANG

Uber's Culture Of Gutsiness Under Review

By MIKE ISAAC

Migrants Hide, Fearing Capture on 'Any Corner'

By VIVIAN YEE

No going to church, no going to the store. No doctor's appointments for some, no school for others. No driving, period — not

IMMIGRATION A police department worries a crackdown will harm work to fight gangs. PAGE A11

MEXICO The secretary of state pays a visit at a time of rising

duras.

If deportation has always been a threat on paper for the 11 million people living in the country illegally, it rarely imperiled those who did not commit serious crimes. But with the Trump ad-

TRUMP RESCINDS OBAMA DIRECTIVE ON BATHROOM USE

ENTERING CULTURE WARS

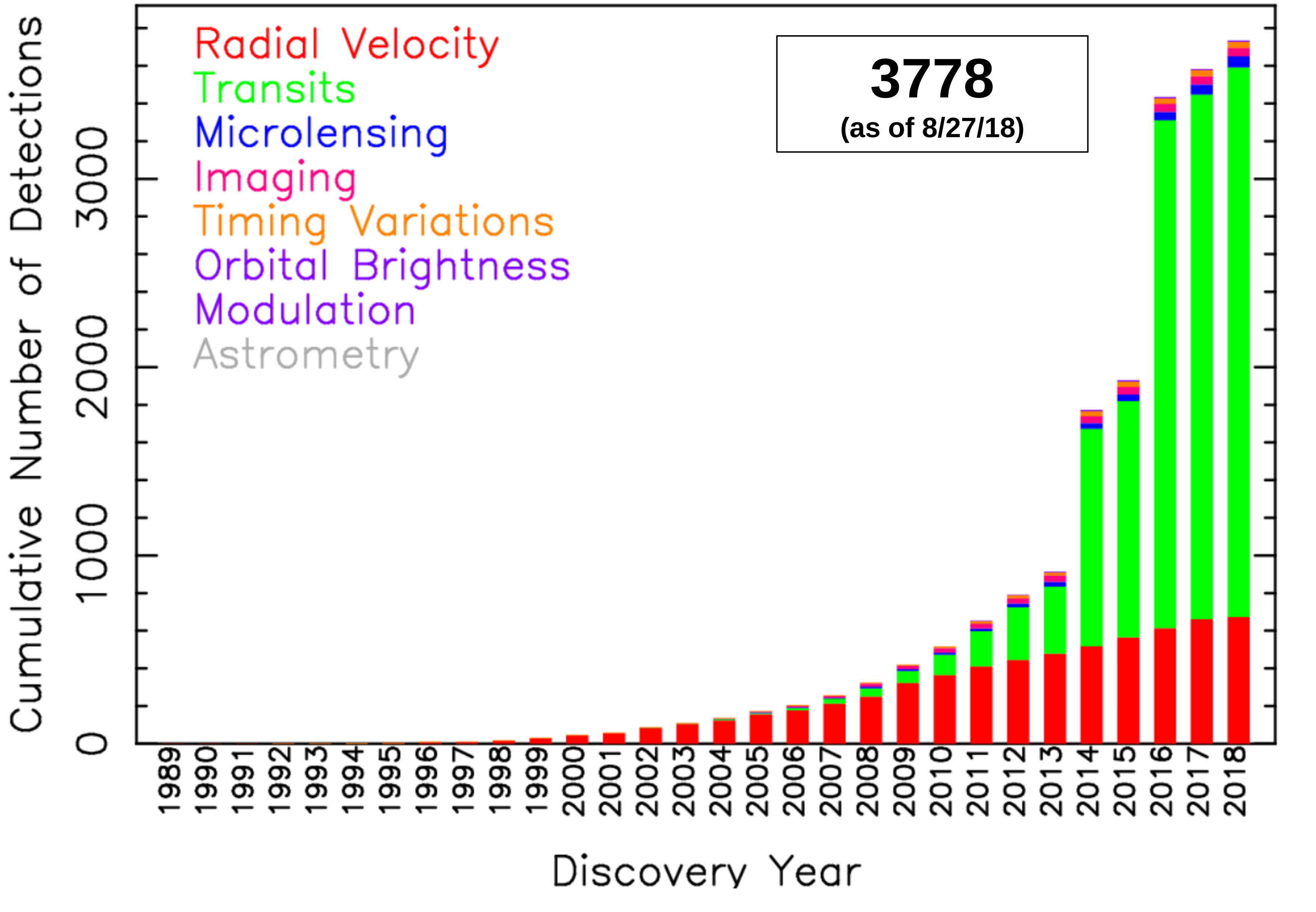
Question of Transgender Rights Splits DeVos and Sessions

This article is by Jeremy W. Peters, Jo Becker and Julie Hirschfeld Davis.

WASHINGTON — President Trump on Wednesday rescinded protections for transgender students that had allowed them to use bathrooms corresponding with their gender identity, overruling his own education secretary and placing his administration firmly in the middle of the culture wars that many Republicans have tried to leave behind.

In a joint letter, the top civil rights officials from the Justice Department and the Education Department rejected the Obama administration's position that nondiscrimination laws require schools to allow transgender students to use the bathrooms of their choice.

That directive, they said, was improperly and arbitrarily devised, "without due regard for the primary role of the states and lo-


Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness
Modulation
Astrometry
3778
(as of 8/27/18)
Cumulative Number of Detections
0
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2018
Discovery Year
exoplanetarchive.ipac.caltech.edu

Transit Exoplanet Survey Satellite

Launched April 18, 2018

Credit: NASA

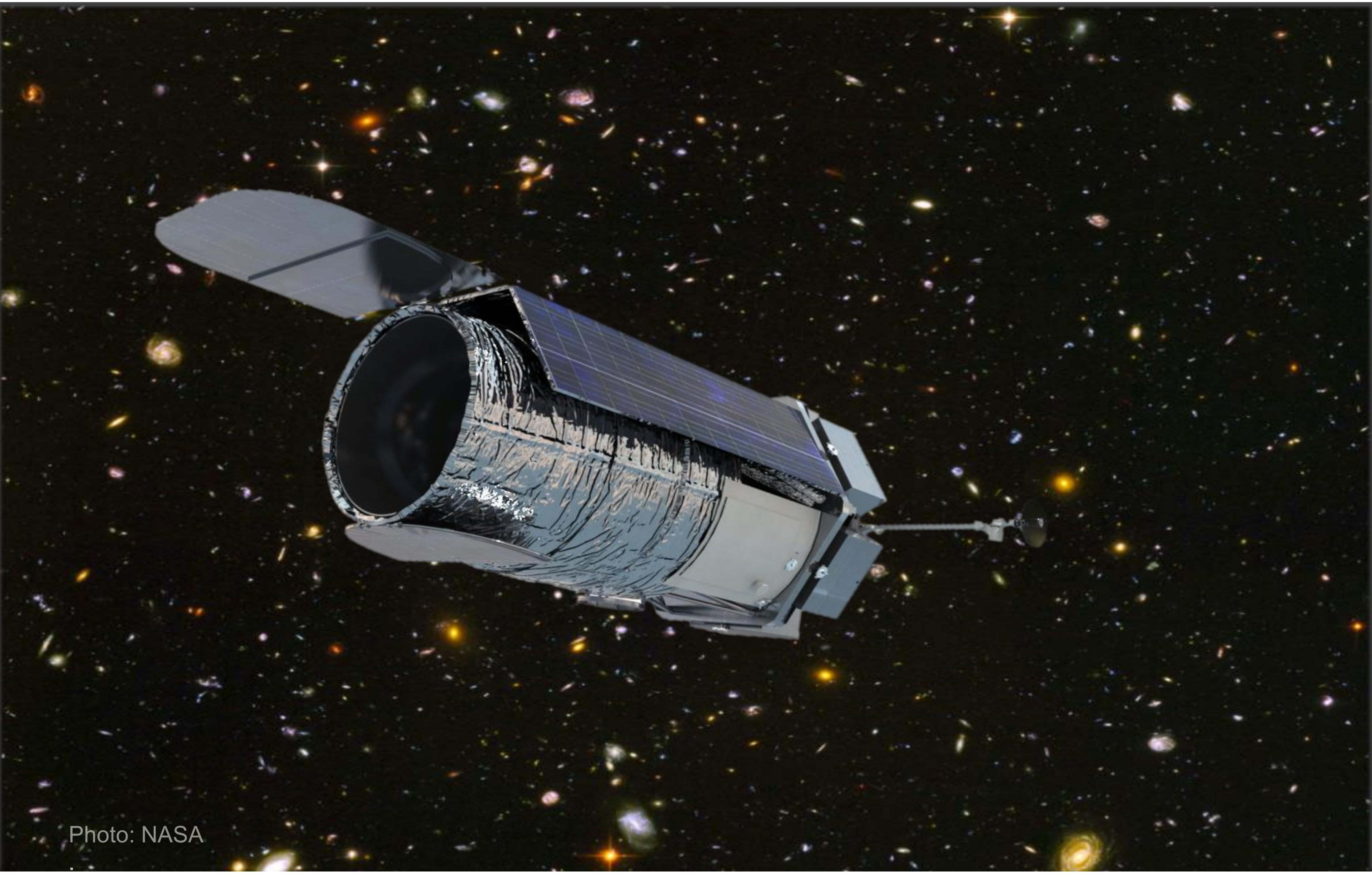
James Webb Space Telescope

Planned launch March 2021

Credit: Northrop Grumman

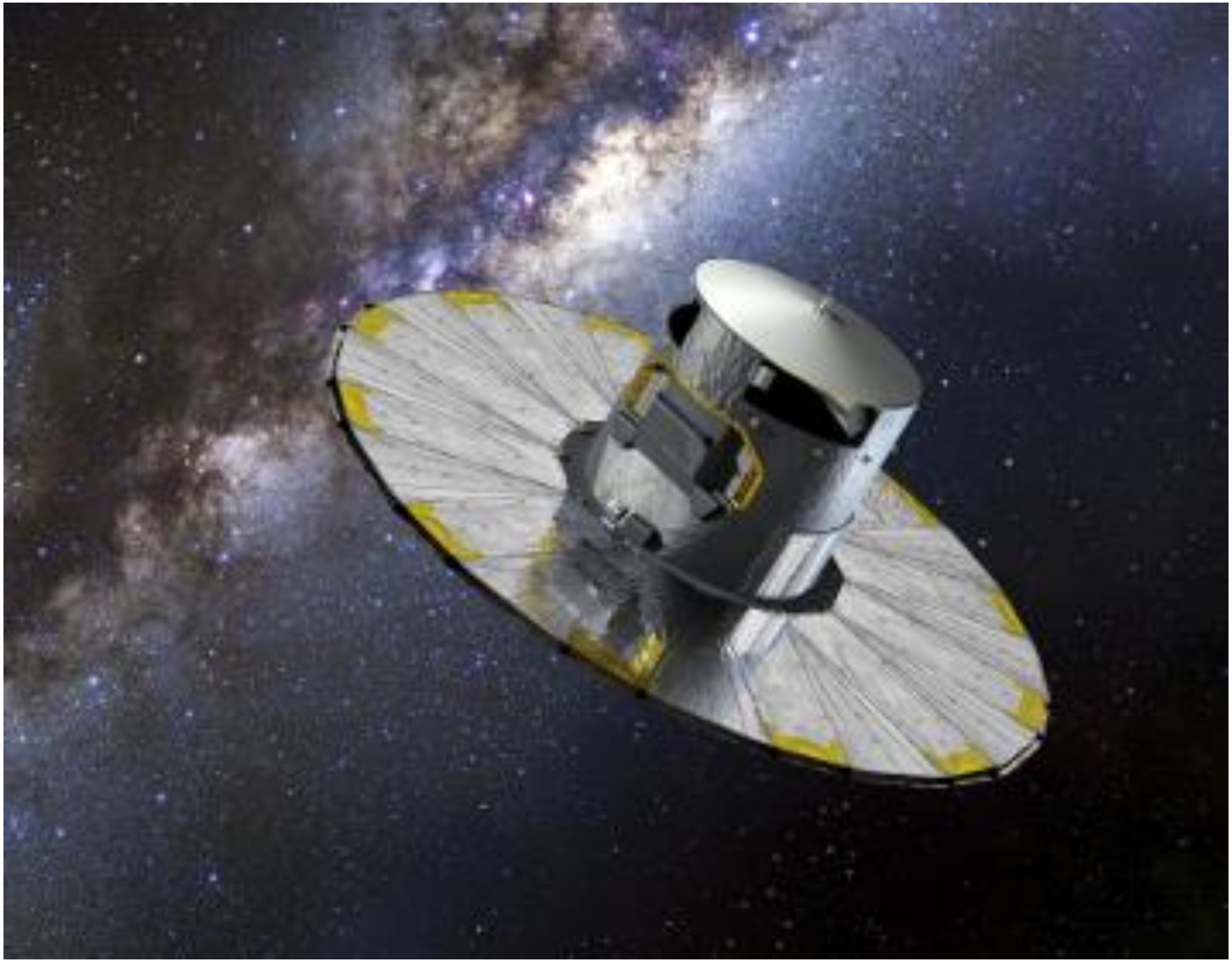
Wide Field InfraRed Survey Telescope (WFIRST)

Planned launch approximately mid-2020s



Gaia

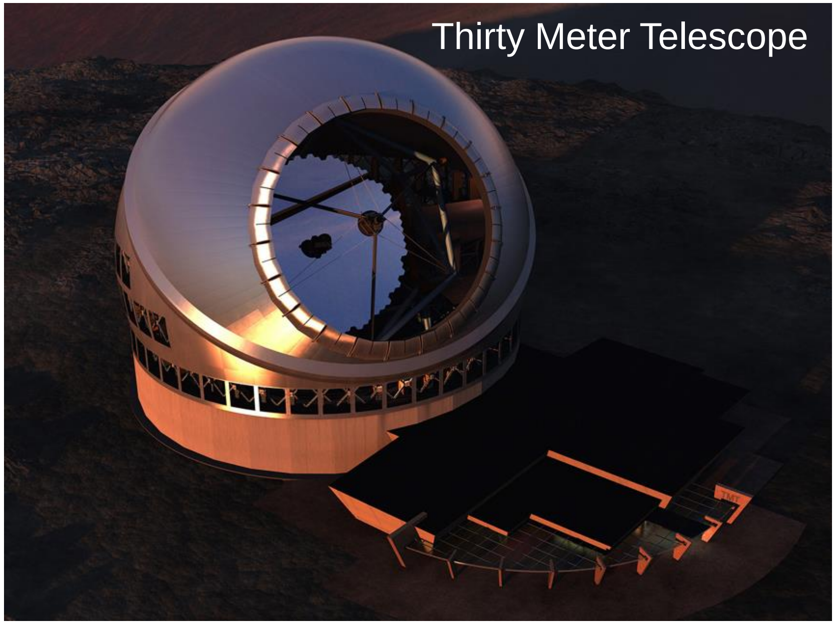
Astrometric Discovery of Exoplanets (Launched December 2013)

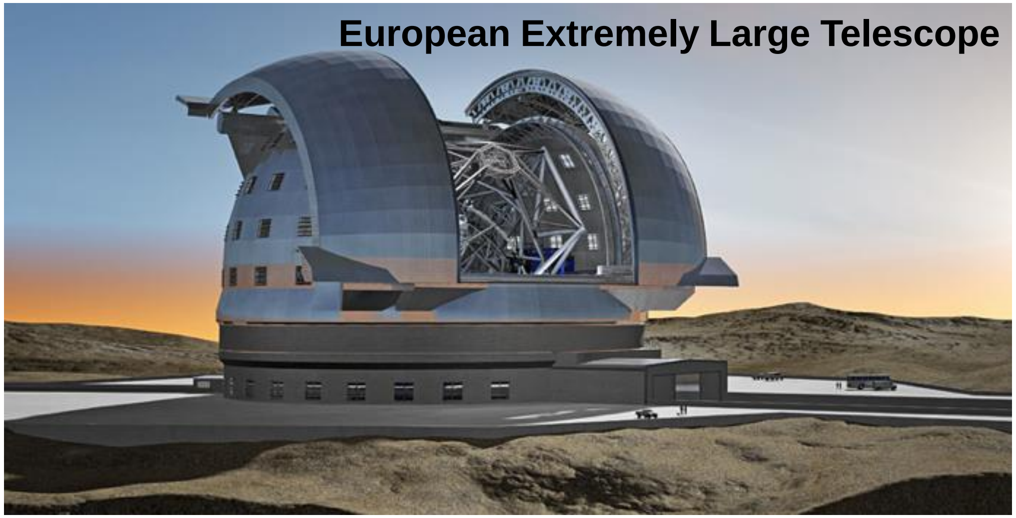


Credit: ESA

New Ground-Based Extremely Large Telescopes

24 – 40 meters in diameter, approximately 2020s





We now know that in our Galaxy…

Planets are common (> 1 per star)

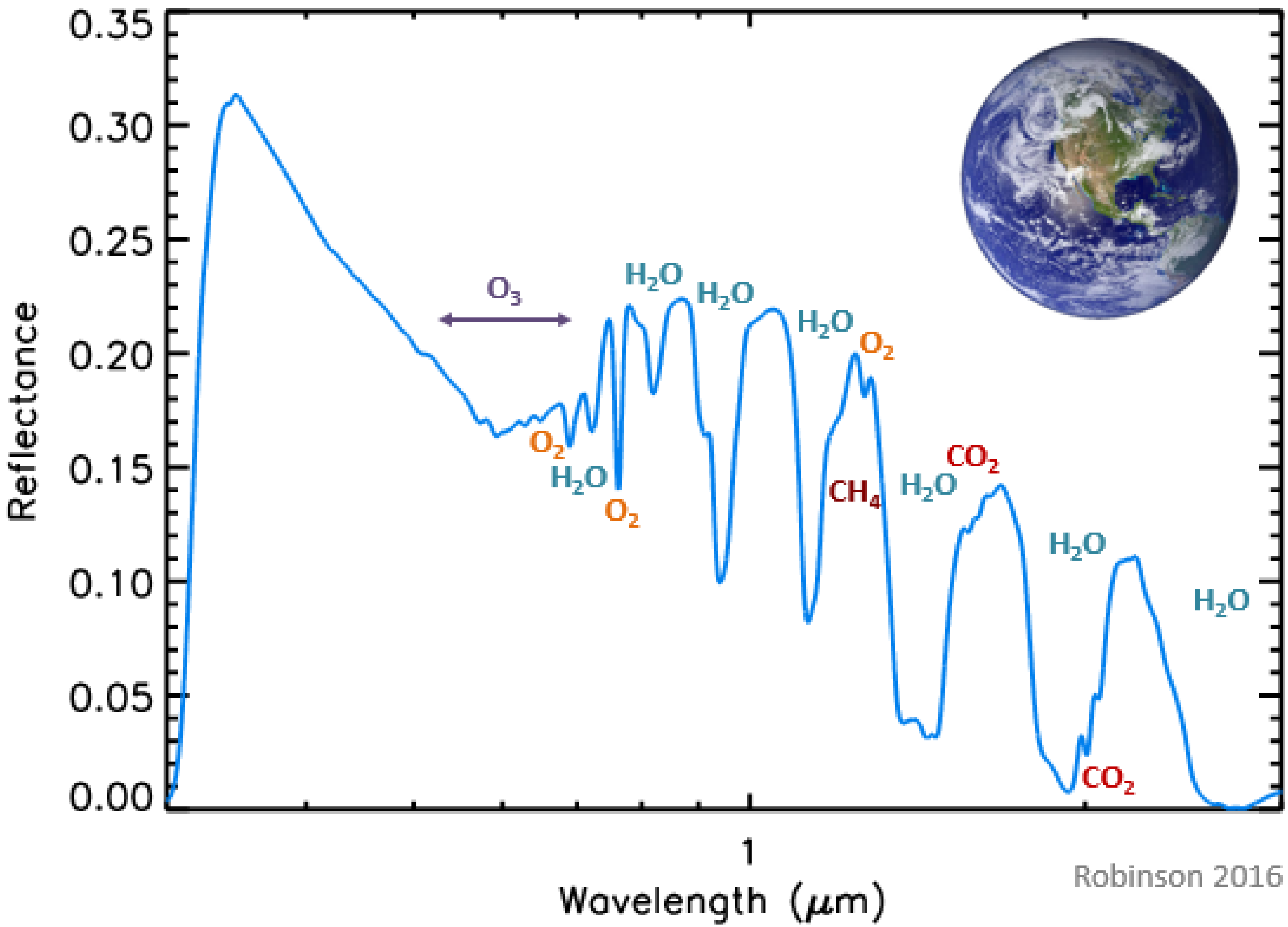
Planets with sizes 0.5-2 times Earth are the most common

Earth-size planets in the Habitable Zone are common

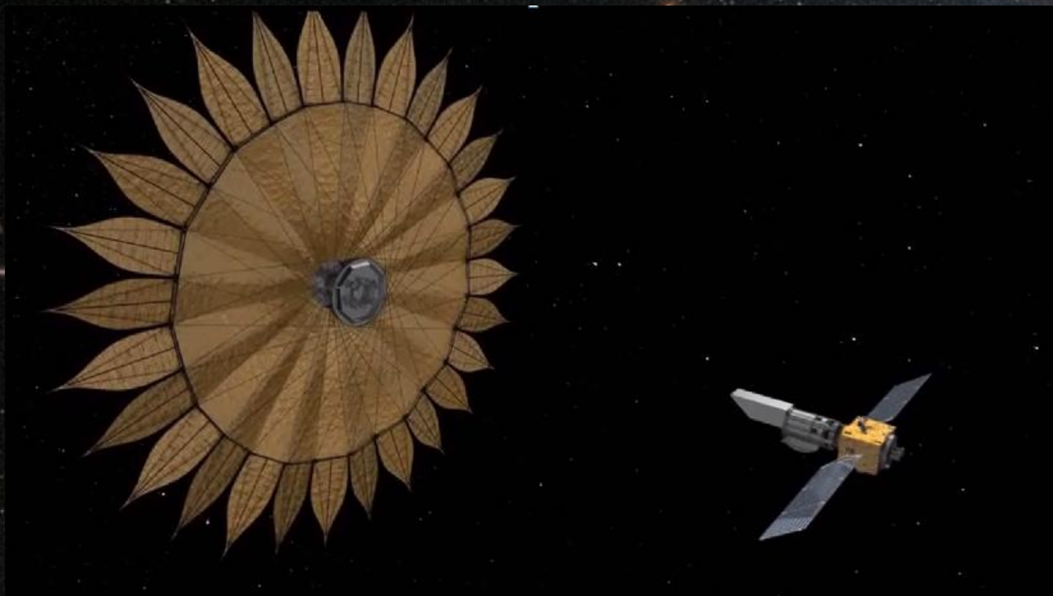
…we're ready for the search for life

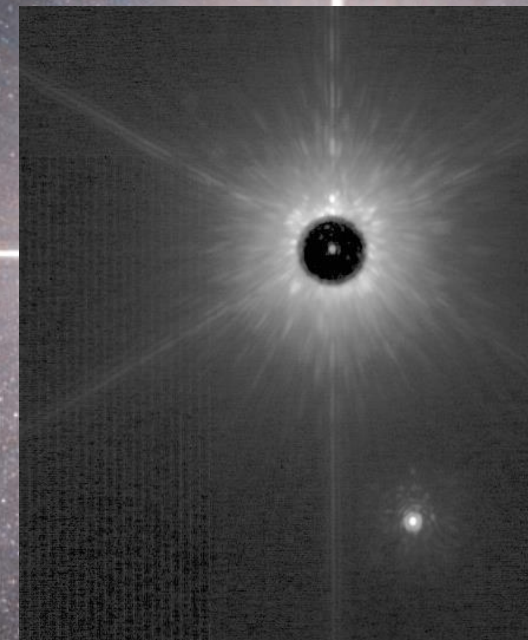
Potential Biosignature Gases

Spectral Lines

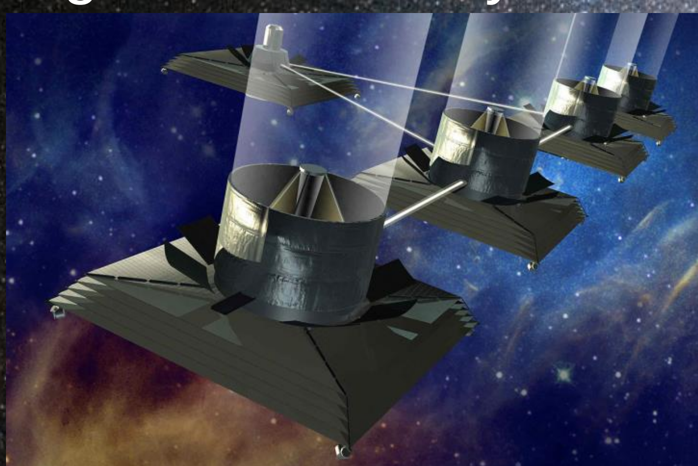


External Occulters (Starshades)

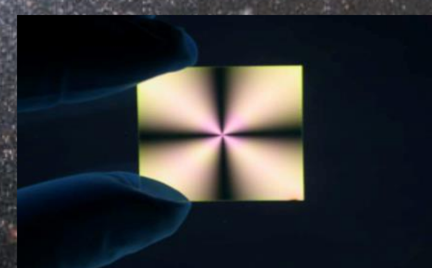


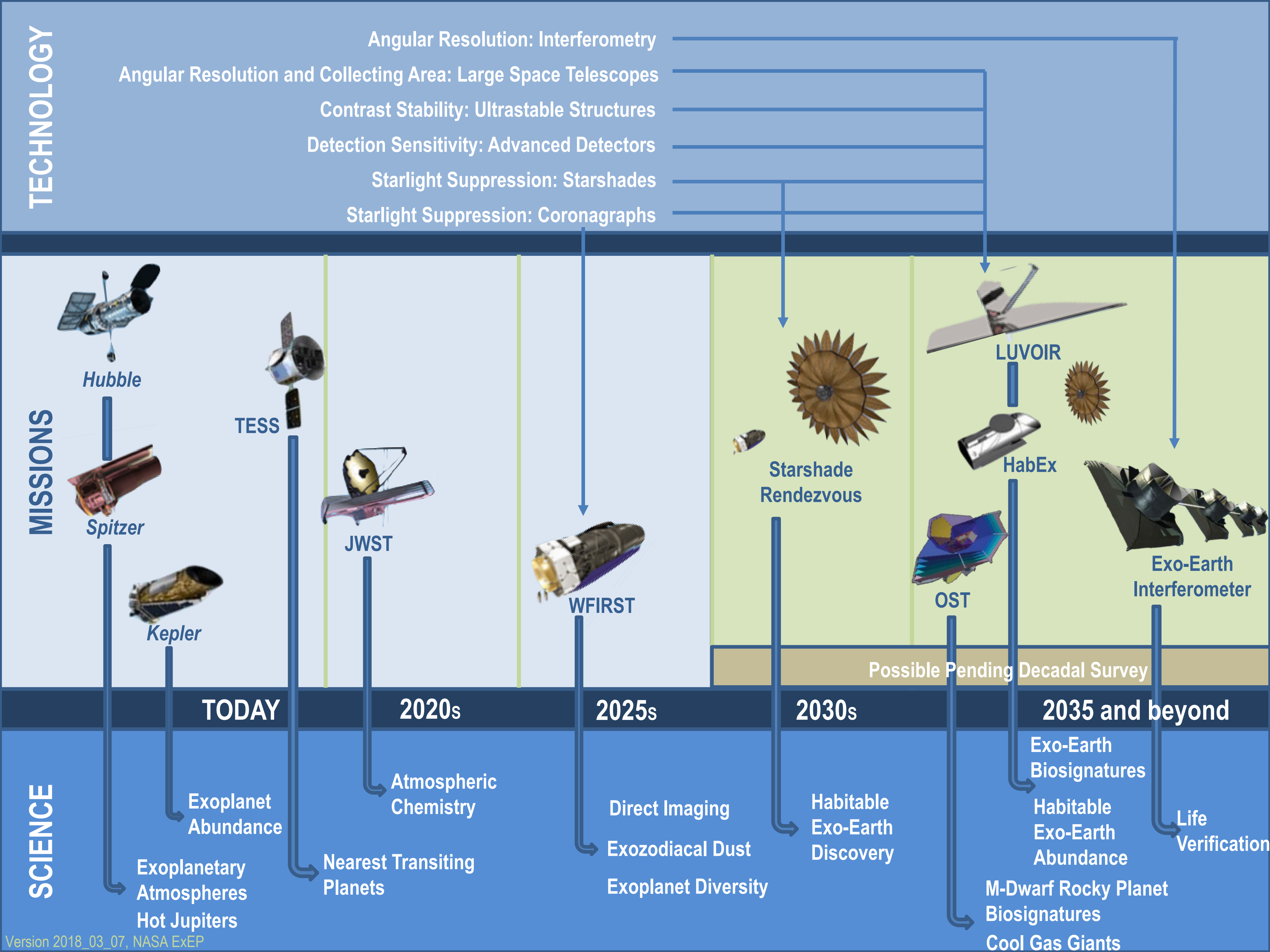


Nulling Interferometry



Internal Occulters (Coronagraphs)



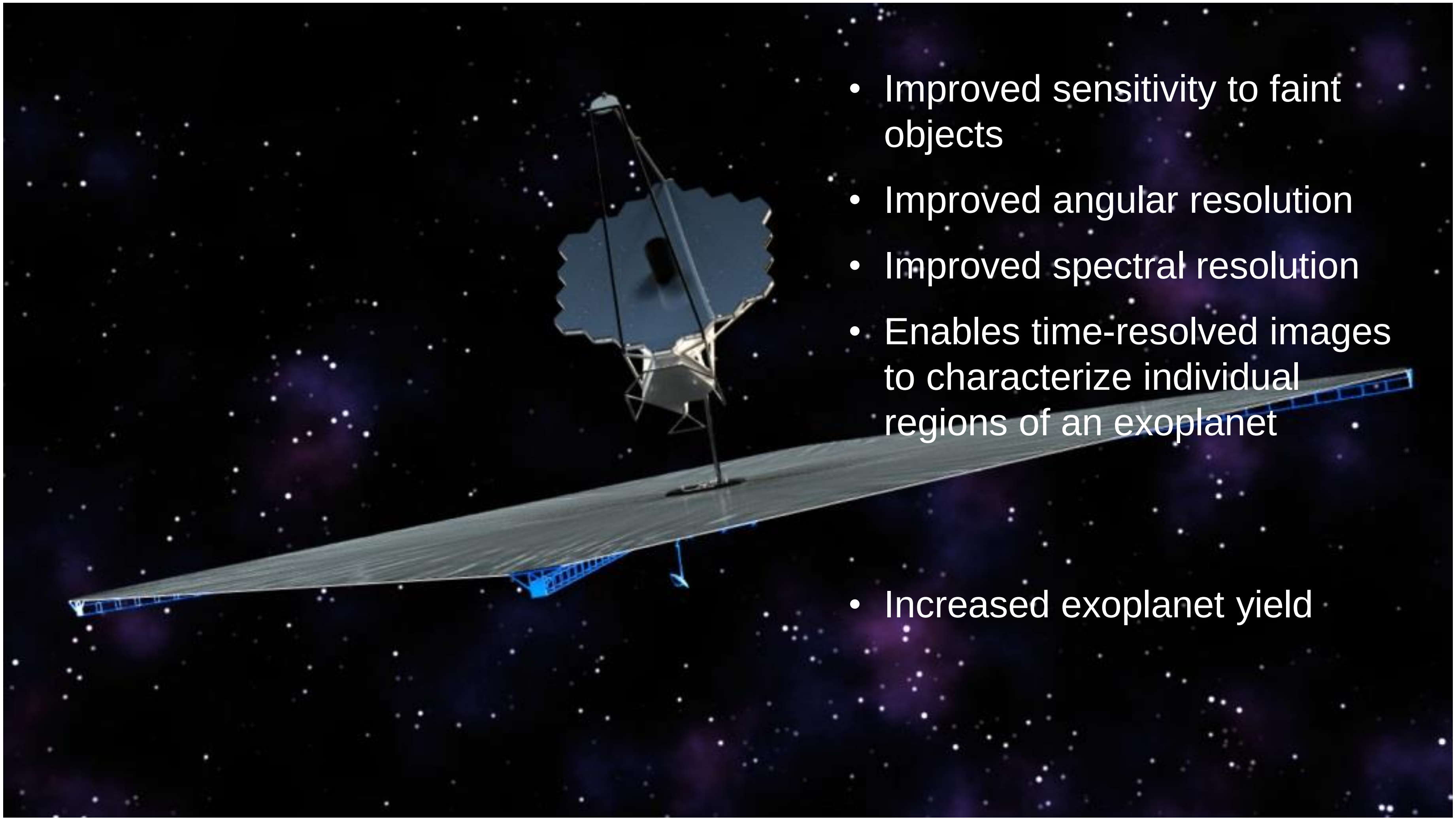


TECHNOLOGY
Angular Resolution: Interferometry
Angular Resolution and Collecting Area: Large Space Telescopes
Contrast Stability: Ultrastable Structures
Detection Sensitivity: Advanced Detectors
Starlight Suppression: Starshades
Starlight Suppression: Coronagraphs
MISSIONS
Hubble
Spitzer
Kepler
TESS
JWST
WFIRST
Starshade Rendezvous
LUVOIR
HabEx
OST
Exo-Earth Interferometer
Possible Pending Decadal Survey
TODAY
2020s
2025s
2030s
2035 and beyond
SCIENCE
Exoplanet Abundance
Exoplanetary Atmospheres
Hot Jupiters
Nearest Transiting Planets
Atmospheric Chemistry
Direct Imaging
Exozodiacal Dust
Exoplanet Diversity
Habitable Exo-Earth Discovery
Exo-Earth Biosignatures
Habitable Exo-Earth Abundance
M-Dwarf Rocky Planet Biosignatures
Cool Gas Giants
Life Verification
Version 2018_03_07, NASA ExEP

Challenges in the Not-So-Distant Future

- **Science will require increasingly larger telescopes for which no existing or planned launch vehicles can deploy autonomously**

In the Search for Life on Distant Planets
Bigger is Better



- Improved sensitivity to faint objects
- Improved angular resolution
- Improved spectral resolution
- Enables time-resolved images to characterize individual regions of an exoplanet
- Increased exoplanet yield

Illustration: ATLAST Study Team (NASA)

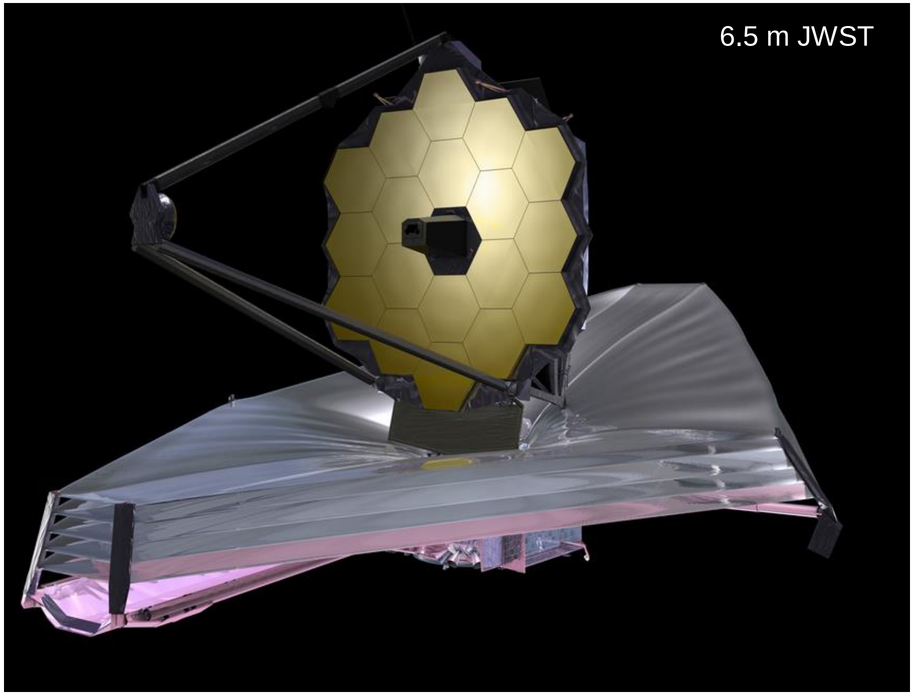
Challenges in the Not-So-Distant Future

- **Science will require increasingly larger telescopes for which no existing or planned launch vehicles can deploy autonomously**
  - SLS is not a guarantee
- **Expensive telescopes and spacecrafts will continue to have relatively short lifetimes (~10–20 yr) with no chance of upgrade**
  - JWST's lifetime is expect to be 5-10 yr
  - HST is entering its 29th year of operation and still providing exceptional science
  - Ground-based telescopes can have ~ 50 yr lifetimes
- **These large telescopes may occasionally need in-space repairs during their planned primary mission (as was the case with HST)**
  - JWST has no opportunity to be serviced for repairs or upgrades
- **Deployment designs are getting more complicated (i.e. costlier) and riskier**

Telescope Size Current Limitations

Deployment Complexity, Fairing Size, and Lift Capacity

Ariane 5 (4.6 m fairing)



Falcon Heavy (5.2 m fairing) – 9 m telescope
SLS Block I (8 m fairing) – 12 m telescope
SLS Block II (10 m fairing) – 15 m telescope
? – > 15 m telescope

- 40 deployable structures
- 178 release mechanisms (all of which must work for the deployment to be successful)

A Possible Vision for Large Space Telescopes

1) **Assembled in space**

2) **Serviced in space to extend their utility by:**
   - replacing the instrument payloads with newer more advanced ones
   - upgrading spacecraft subsystems as they wear and age
   - refueling to extend their lifetimes,
   - repairing when needed, and
   - incrementally enlarging the apertures over time

These potential benefits of iSSA of large future telescopes require study.

The Big Picture

1. ***We need a new approach that provides the capability to build larger telescopes for less money and with less risk.***

We are here →

2. ***We need to demonstrate that this new approach will deliver on cost and risk.***

3. ***We need to begin developing the capabilities and technologies to enable this new approach.***

Why Now?

- **Inform the 2020 Decadal Survey and SMD that space servicing, upgrade, and assembly offers:**
  - potential science enabling capabilities (large science telescopes, extended lifetimes)
  - cost reduction possibilities
  - risk reduction opportunities
  - synergies with other NASA directorates and within SMD, commercial, DoD

- **Technology development time**
  - The process of identifying, developing, and maturing the technologies to enable servicing, repair, and assembly will take time
  - We need to begin creating a technology roadmap and implementing early development efforts in the very near future, for example using ISS as a testbed prior to its termination

- **Opportunity to coordinate early**
  - Early involvement with industry and NASA Gateway teams offers opportunities to influence studies before designs are “frozen in”

In-Space Assembly and Servicing Workshop

70+ participants from government, industry, and academia

- 30 NASA Centers
- 29 Industry
- 7 NASA HQ
- 4 academia
- 4 STScI
- 1 DARPA

Planning team chair: Harley Thronson (NASA GSFC)
November 1-3, 2017
NASA GSFC

How does iSSA reduce cost and risk? (2 of 4)

Extracted from Nov TIM Summary Report
https://exoplanets.nasa.gov/exep/technology/in-space-assembly/

Potential cost savings offered through iSSA:

- **Eliminates engineering design work and testing required to (1) creatively fit large structures into existing fairings and (2) autonomously deploy**
  - JWST invested a significant effort into designing and testing the telescope's folded wing design; even more for the observatory deployment with 40 deployable structures and 178 release mechanisms (all of which must work for the deployment to be successful)
- **Reduces need for hardware redundancy**
- **Reduces system "ruggedization" to survive launch environment**
- **Reduces need for new and unique ground test facilities**
  - JWST required new ground facilities to be built
- **Reduces the need for a large standing army during I&T**
- **Leverages existing and less-costly medium-lift LVs**
- **New instruments can be swapped out over longer periods of time before new additional observatories are needed**

How does iSSA reduce cost and risk? (3 of 4)

Extracted from Nov TIM Summary Report
https://exoplanets.nasa.gov/exep/technology/in-space-assembly/

Potential new challenges may also INCREASE costs:

- **Would a full-scale, robotically-assembled telescope have to be demonstrated on the ground to mitigate concerns and risks? And then disassembled?**
- **New robotic capabilities will be required as part of iSA that would not be required in the autonomous deployment approach.**
- **New “standing army” post launch**
  - Potential additional cost for any astronauts in the loop
- **Sending multiple modules into space for assembly will require new containers and interfaces needing to undergo environmental testing.**
- **New Earth-based problems yet unknown in standardization and assembly, as well as new unknown problems created in space, will likely need to be solved.**

How does iSSA reduce cost and risk? (4 of 4)

Extracted from Nov TIM Summary Report
https://exoplanets.nasa.gov/exep/technology/in-space-assembly/

Risk reduction opportunities arising from iSSA

- **Reducing risk becomes increasingly more important as mission costs increase.**
- **Future larger observatories are likely to require more complex deployment schemes. iSSA can mitigate risk of failure by:**
  - Modularizing the design enabling repair and replacement of faulty sections
  - Designing servicing capabilities (robotic and/or human) into the architecture
  - Minimizing single-point failures
  - Enabling end-to-end testing (often not possible on ground)
- **iSA does not require next-generation launch vehicles**
  - Several future mission concepts under study rely on the SLS Block II
- **Launch failure need not be equivalent to mission failure**

Key Workshop Recommendations to NASA

✓ 1. **Commission a design study to understand how large-aperture telescopes could be assembled and serviced in space**
   - Initiate the study in time for initial results to be available to Gateway and robotics designers before end 2019.

2. **Initiate an iSA coordination group between the three Mission Directorates and perhaps with international space agencies as well.**

✓ 3. **Provide input to the 2020 Decadal Survey about iSA as a potential implementation approach for future large apertures.**

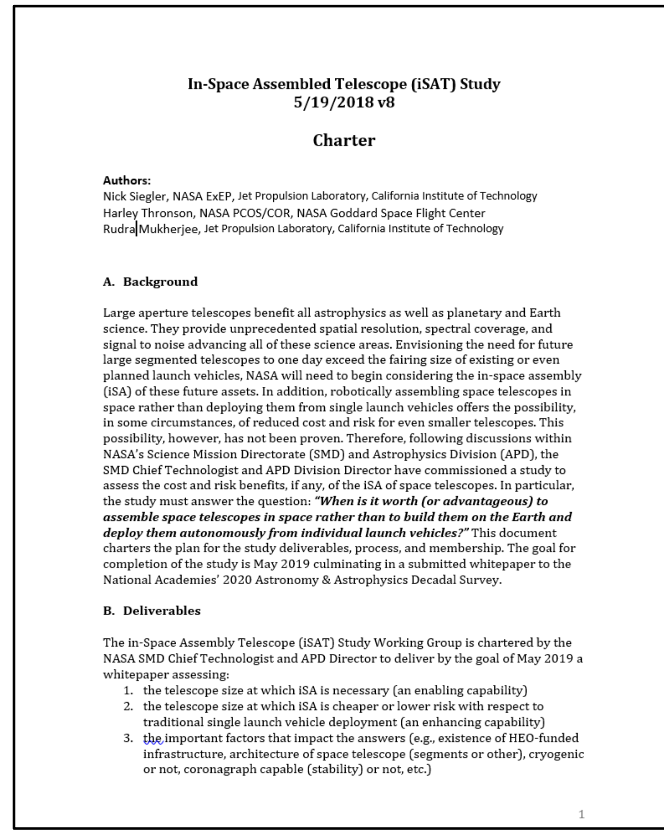
In-Space Assembled Telescope Study Funded

Sponsors: Astrophysics Division and Science Mission Directorate

"When is it worth assembling space telescopes in space rather than building them on the Earth and deploying them autonomously from individual launch vehicles?"

Final deliverable:

A whitepaper to the 2020 Decadal Survey committee



In-Space Assembled Telescope (iSAT) Study
5/19/2018 v8

Charter

Authors:
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Harley Thronson, NASA PCOS/COR, NASA Goddard Space Flight Center
Rudra Mukherjee, Jet Propulsion Laboratory, California Institute of Technology

A. Background

Large aperture telescopes benefit all astrophysics as well as planetary and Earth science. They provide unprecedented spatial resolution, spectral coverage, and signal to noise advancing all of these science areas. Envisioning the need for future large segmented telescopes to one day exceed the fairing size of existing or even planned launch vehicles, NASA will need to begin considering the in-space assembly (iSA) of these future assets. In addition, robotically assembling space telescopes in space rather than deploying them from single launch vehicles offers the possibility, in some circumstances, of reduced cost and risk for even smaller telescopes. This possibility, however, has not been proven. Therefore, following discussions within NASA's Science Mission Directorate (SMD) and Astrophysics Division (APD), the SMD Chief Technologist and APD Division Director have commissioned a study to assess the cost and risk benefits, if any, of the iSA of space telescopes. In particular, the study must answer the question: ***"When is it worth (or advantageous) to assemble space telescopes in space rather than to build them on the Earth and deploy them autonomously from individual launch vehicles?"*** This document charters the plan for the study deliverables, process, and membership. The goal for completion of the study is May 2019 culminating in a submitted whitepaper to the National Academies' 2020 Astronomy & Astrophysics Decadal Survey.

B. Deliverables

The in-Space Assembly Telescope (iSAT) Study Working Group is chartered by the NASA SMD Chief Technologist and APD Director to deliver by the goal of May 2019 a whitepaper 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 single 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.)

1

How: Process

Activity 3
Deliver Final Whitepaper

Write and deliver the Final Whitepaper (around May/June)

a) Submit to APD Director who submits to 2020 Decadal Survey

Activities 2a and 2b
Detailed Engineering Design and Costed

Activity 2a: Advance the engineering fidelity of the concept(s) 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.

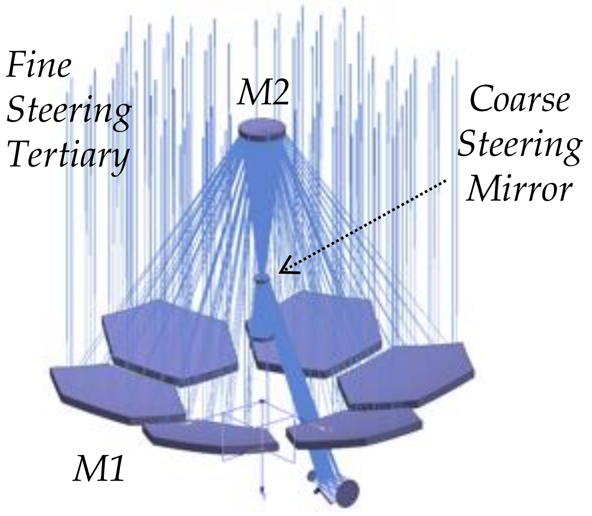
Activity 2b: Estimate, through an independent body, the cost of designing, architecting, assembling, and testing the reference space telescope?

a) Input design from Activity 2a
b) Identify risks
c) Parameterize the cost to smaller apertures

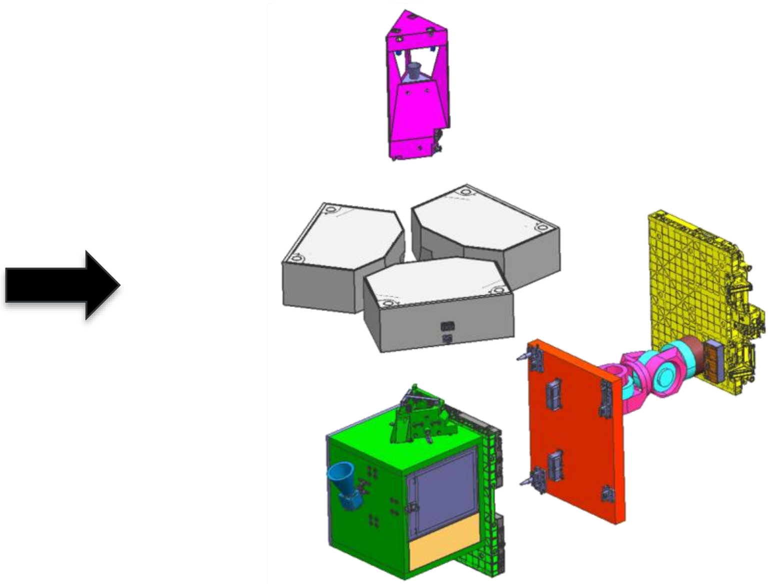
Activity 1a
Concept Design and Architecture for the iSAT

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)

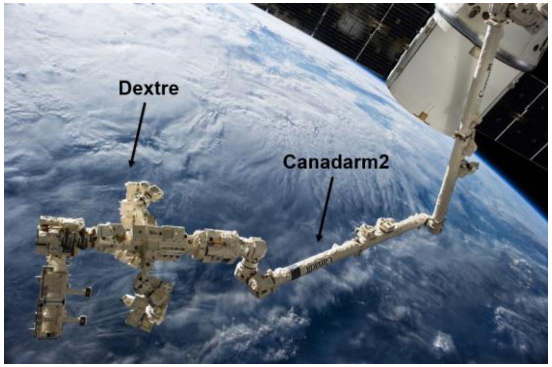


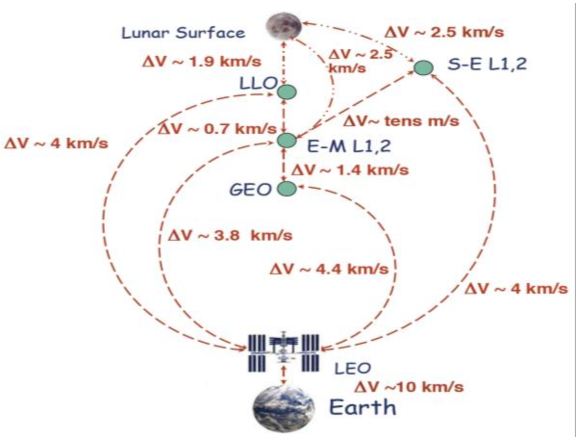
6 launch modules for assembly

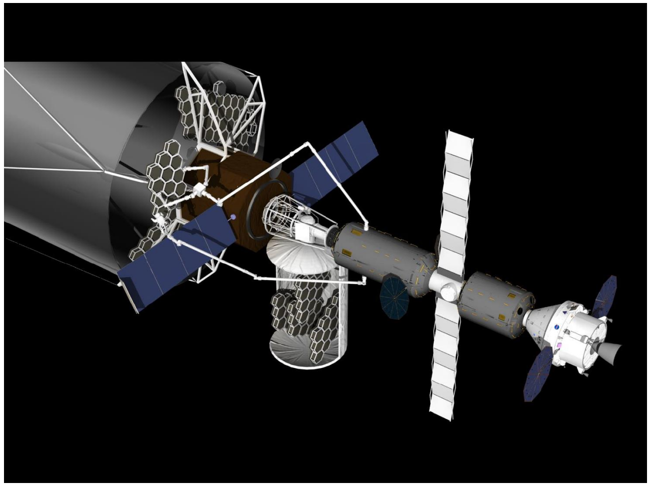
Activity 1b:

Concept for Assembly and Infrastructure for the iSAT

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







Activity 1a
Telescope Modularization

Telescope Modularization Workshop

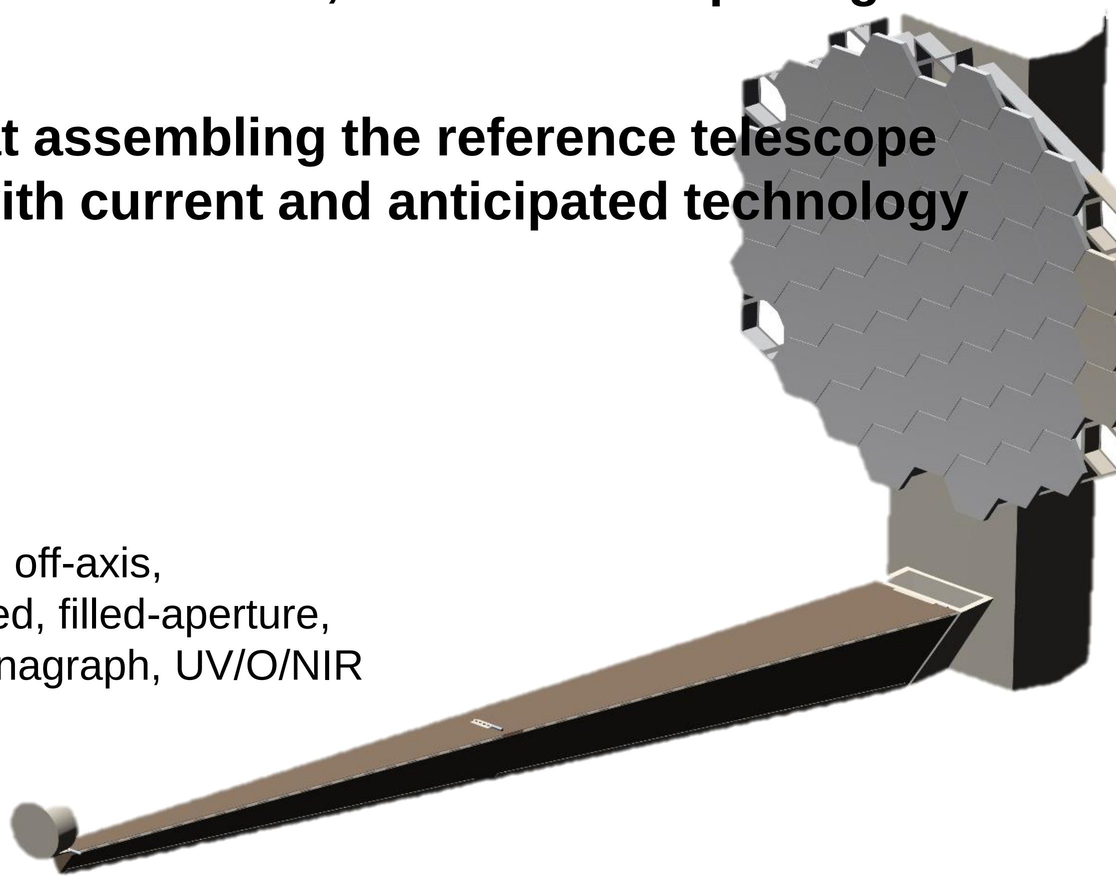
Caltech, June 5-7

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

Telescope Modularization In-Process Results

Activity 1a

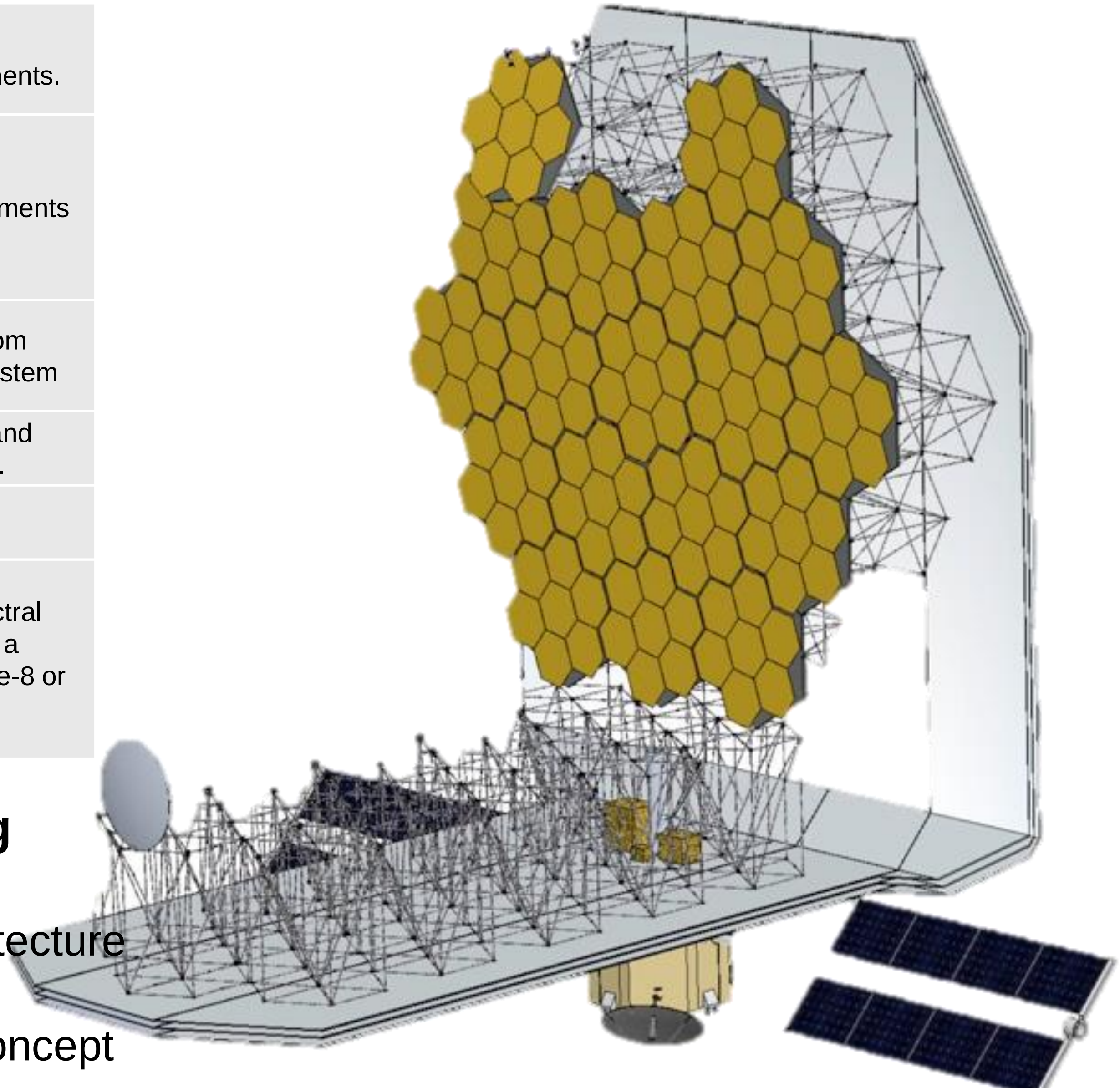
- **A 20 m off-axis f/2 telescope would serve as a good reference for the Study**
- **<u>No</u> major show stoppers were found; no better compelling alternatives.**
- **The consensus was that assembling the reference telescope in space was feasible with current and anticipated technology and processes.**



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

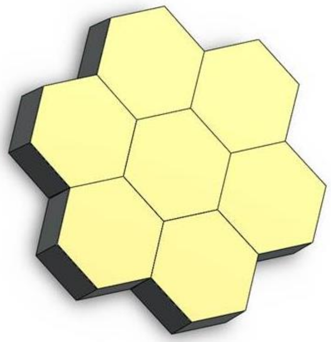
Telescope Modularization In-Process Results

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.

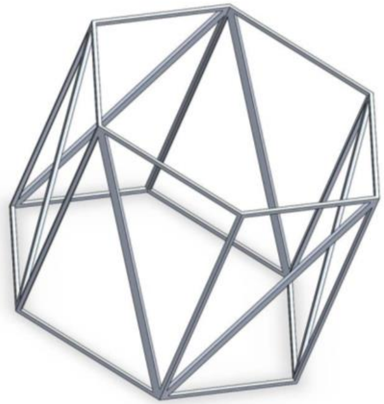


Three analyses requiring additional work

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

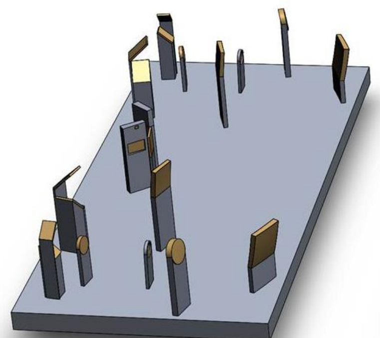


Primary Mirror Rafts
24 units

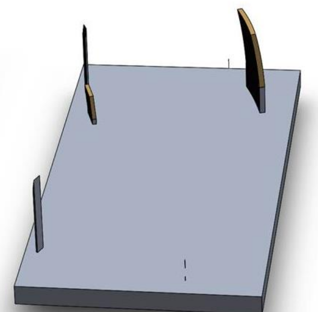


Deployable Truss Modules (BSF)
24 units

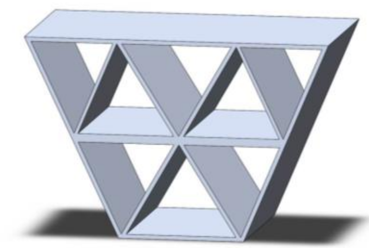
BSF Sunshade
1 unit



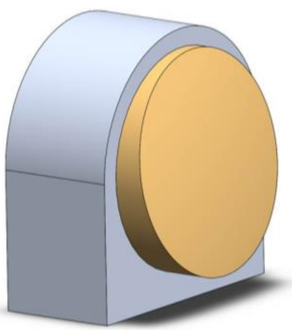
Ancillary Optics Bay 1
1 unit



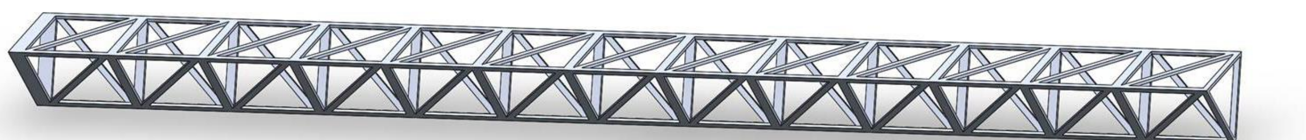
Ancillary Optics Bay 2
1 unit



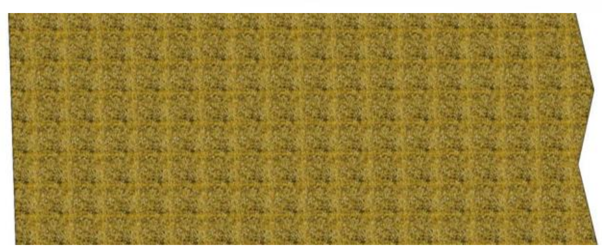
Transition Structure
1 unit



Secondary Mirror
1 unit



Metering Truss (PM-SM)
1 unit



Metering Truss Sunshade
1 unit

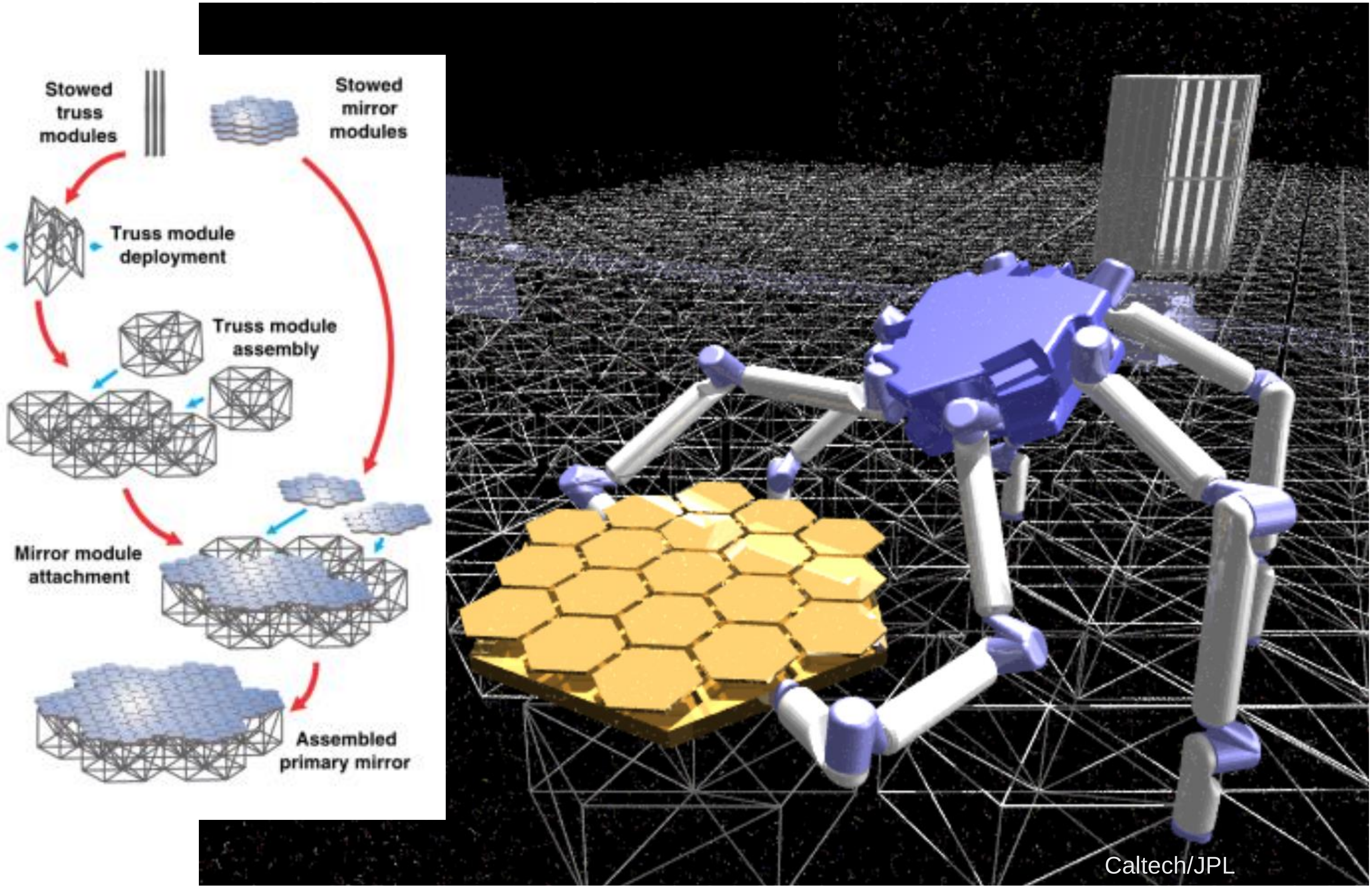
Activity 1b
(starts now!)

A taste of what is to come…

Robot Candidates

Multi-Limbed Robot

Caltech/JPL; Lee et al. (2016)

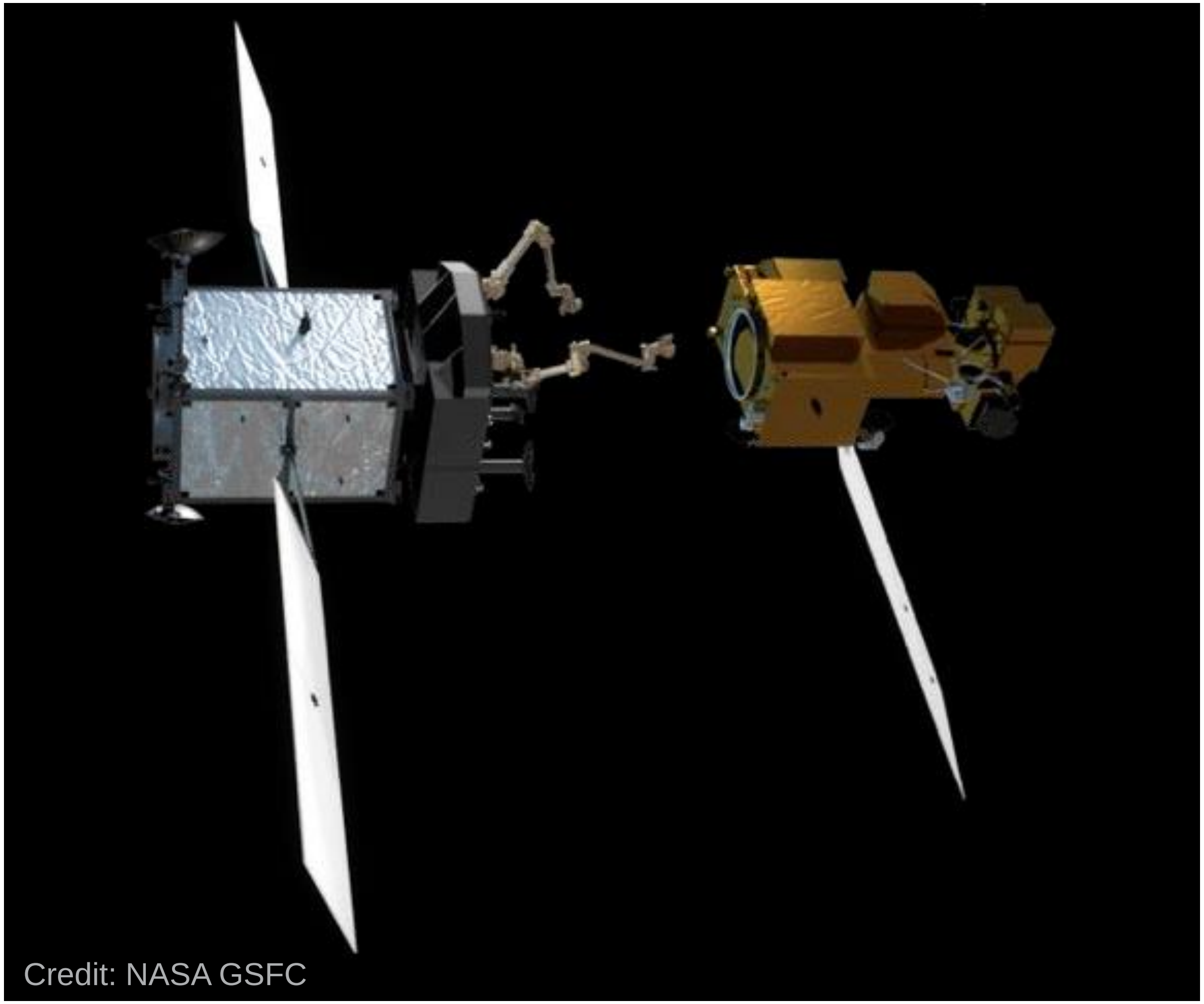


Free-Flying Robots

NASA's Restore-L

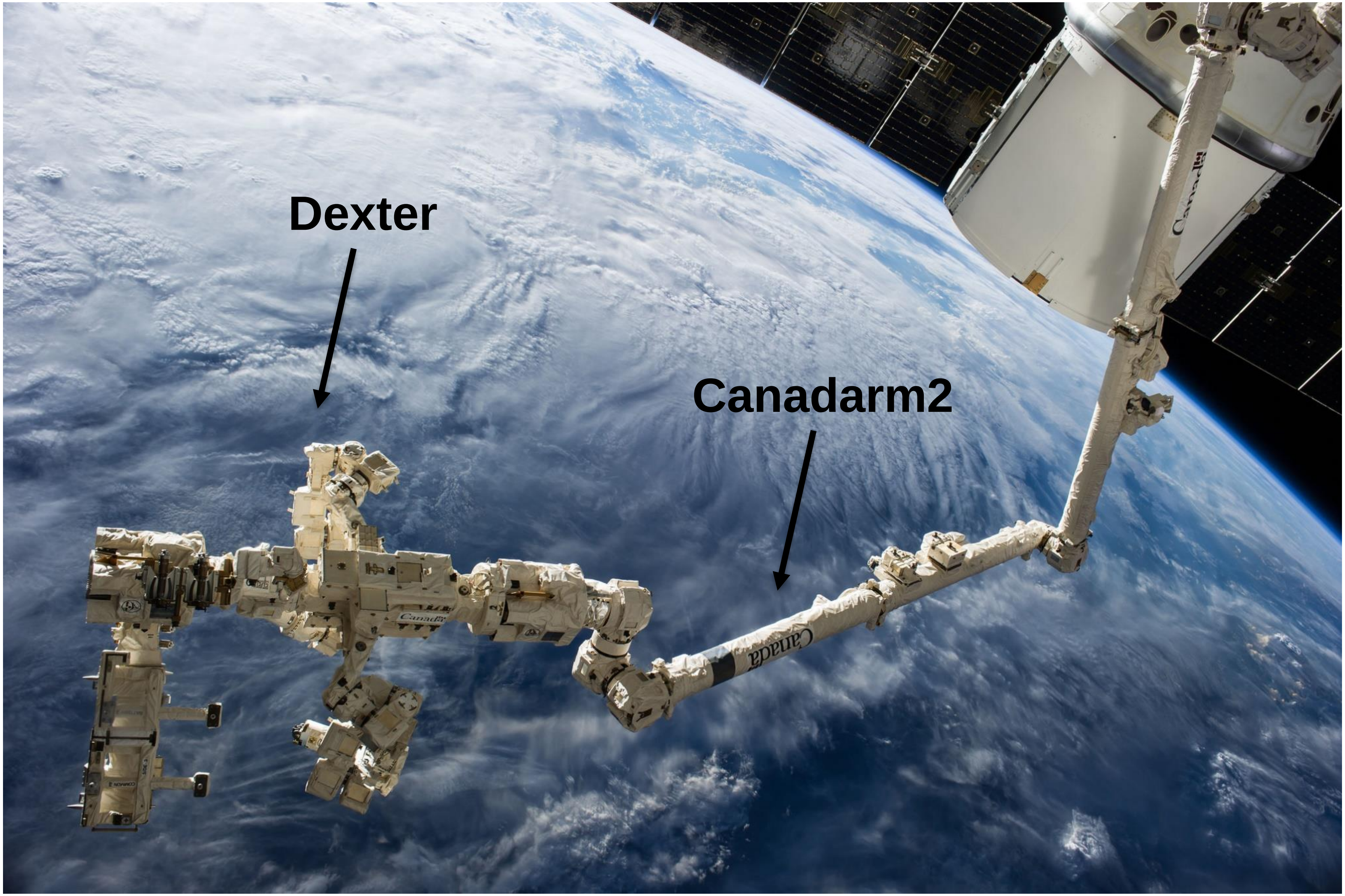
DARPA/SSL's Robotic Servicing of Geosynchronous Satellites

Orbital ATK's Mission Extension Vehicle



Robotic Arm

ISS’s DEXTER and Canadarm2



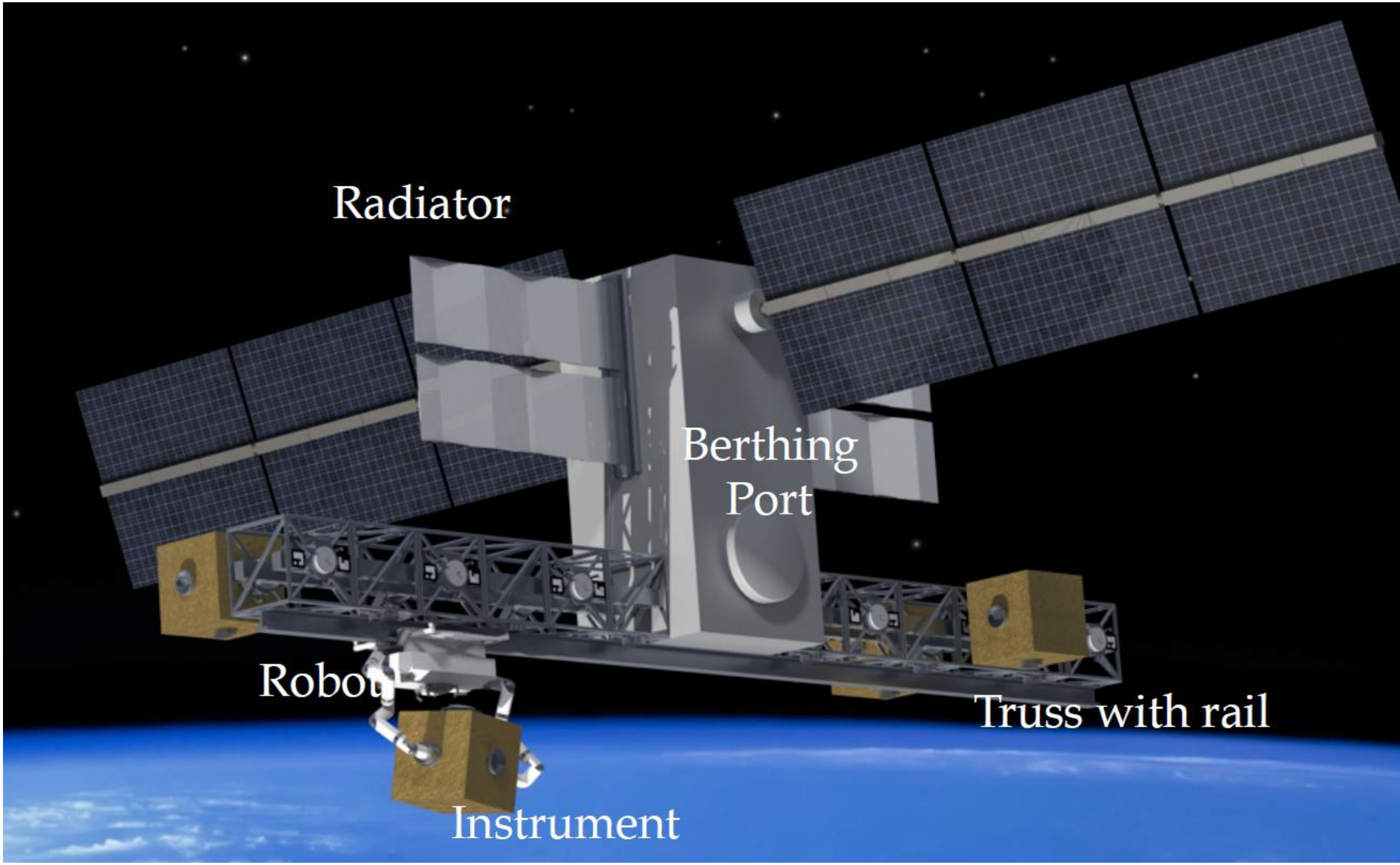
Assembly Platform Candidates

International Space Station

LEO

Earth Sciences Space Station

Sun Synchronous Orbit



Lunar Orbiting Platform - Gateway

cis-Lunar orbit

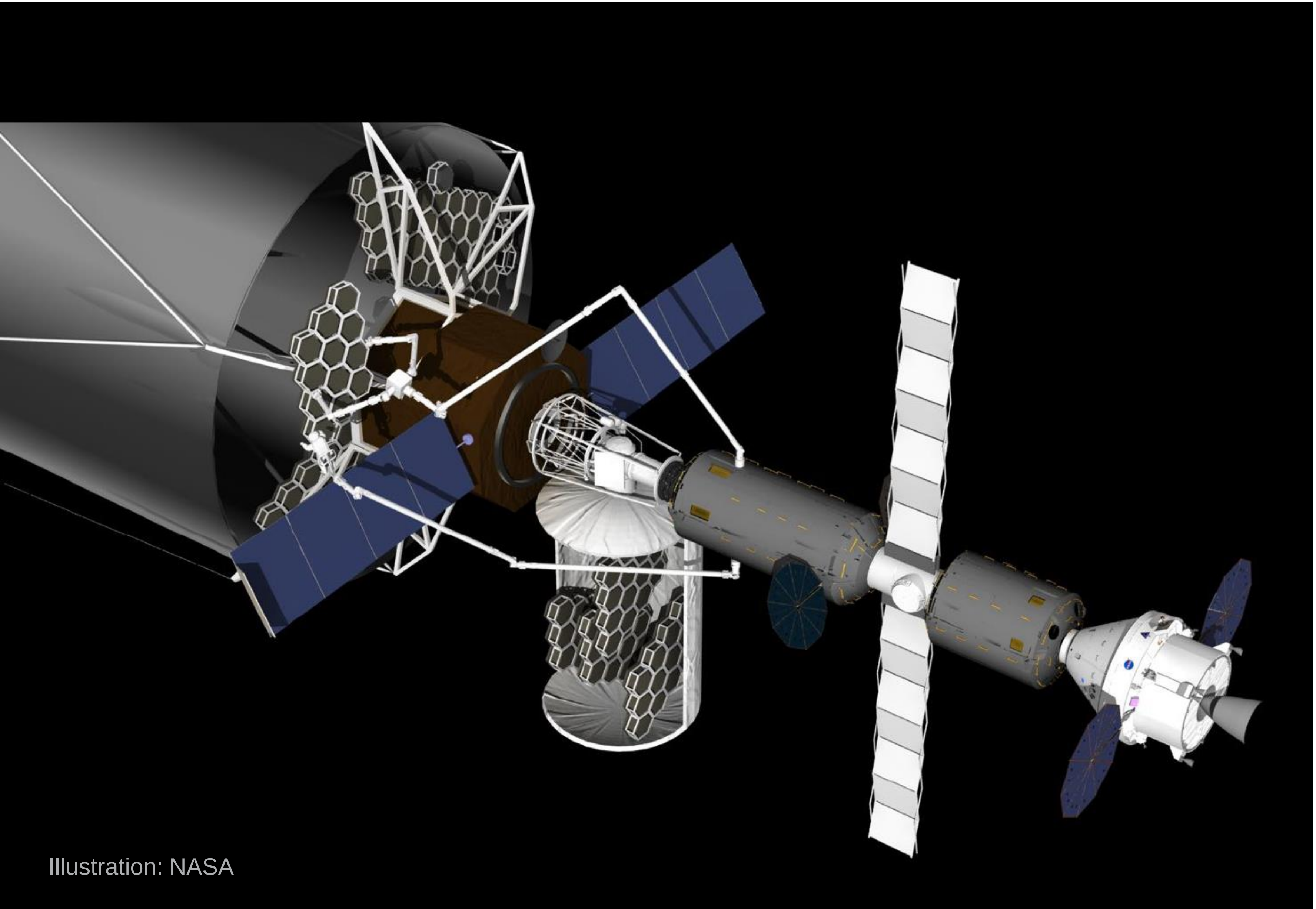
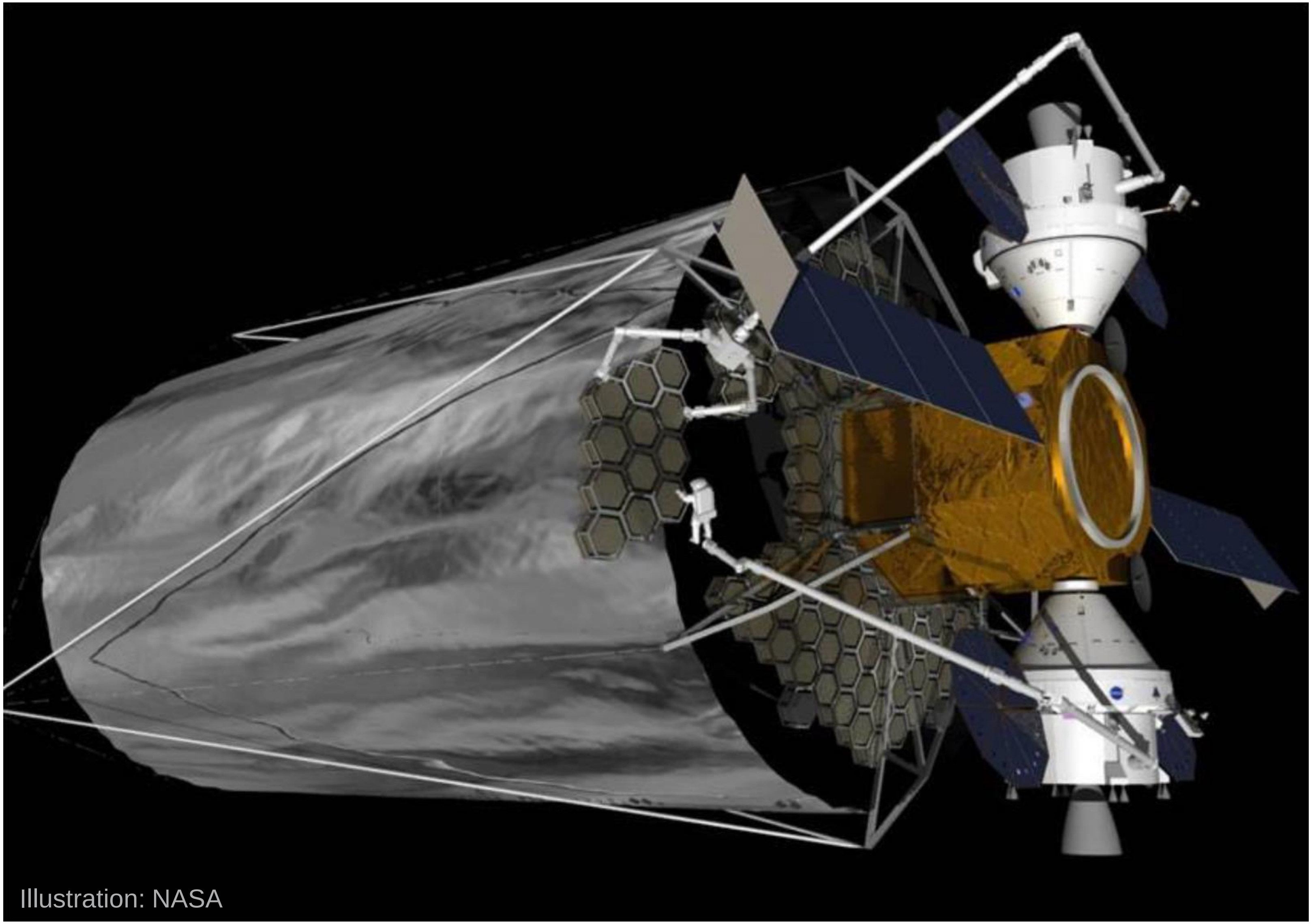


Illustration: NASA

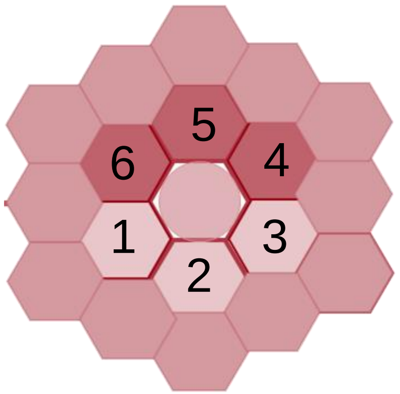
Bring Your Own Assembly Platform

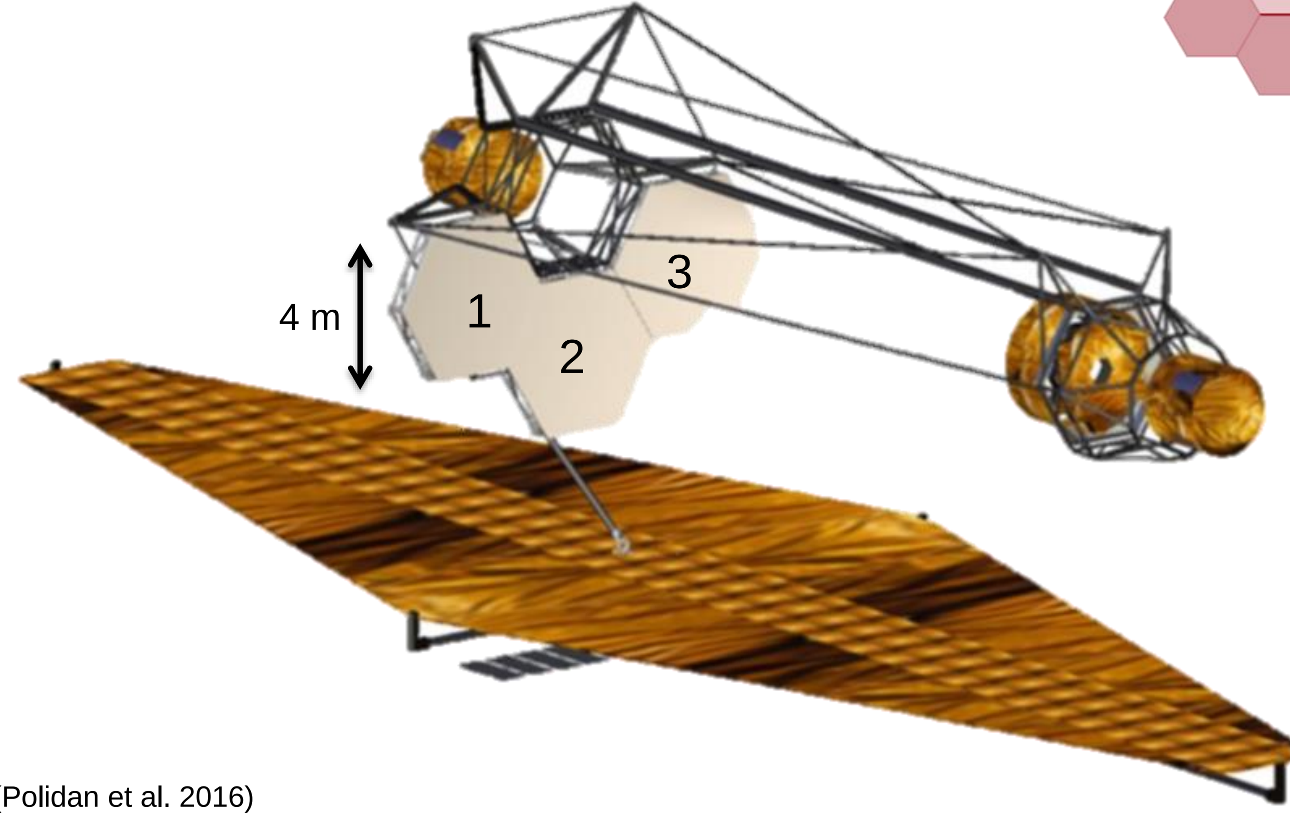
Free-fliers with specialized robotic arms docked to spacecraft bus



Evolvable Space Telescope

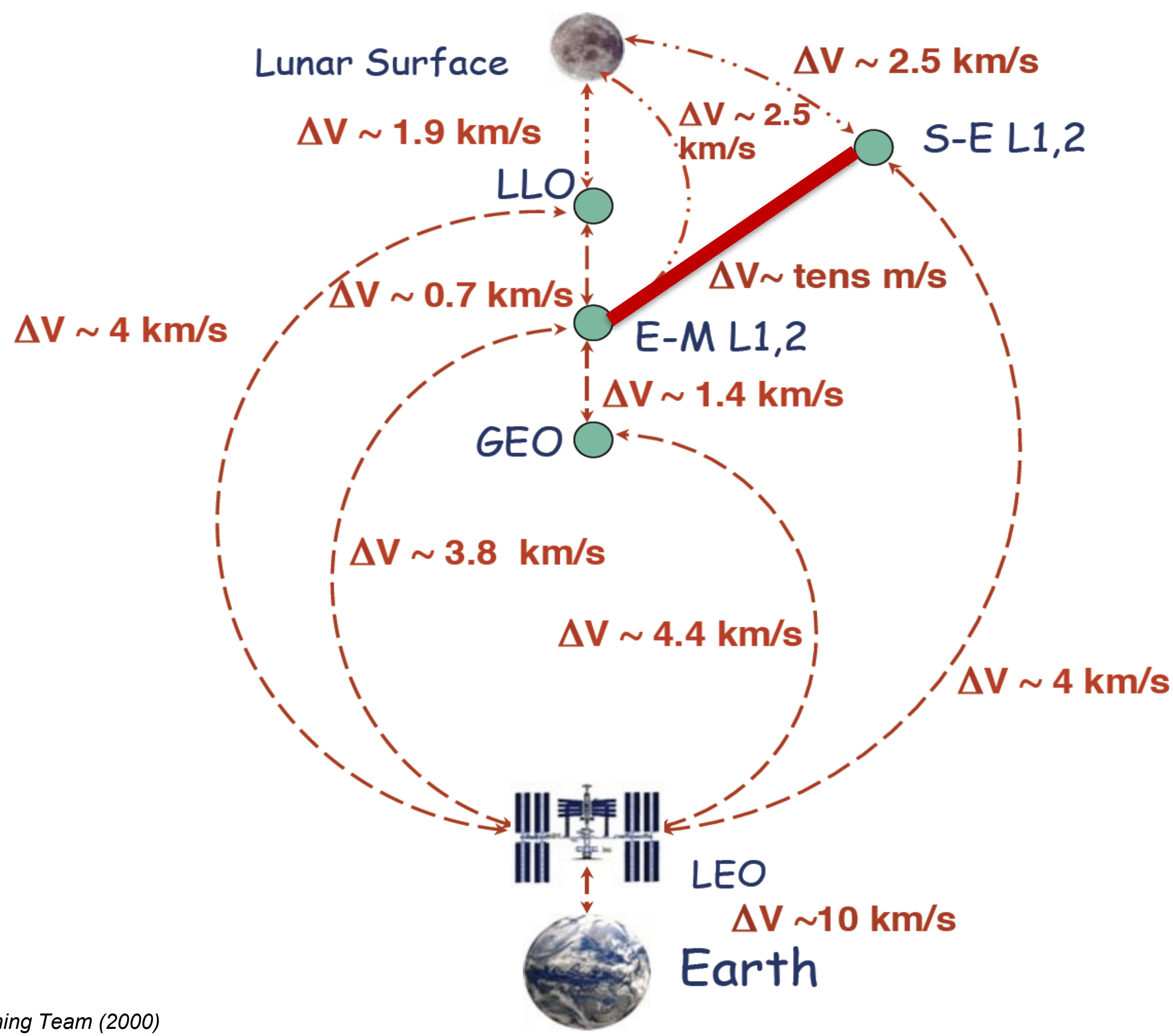
Northrop Grumman





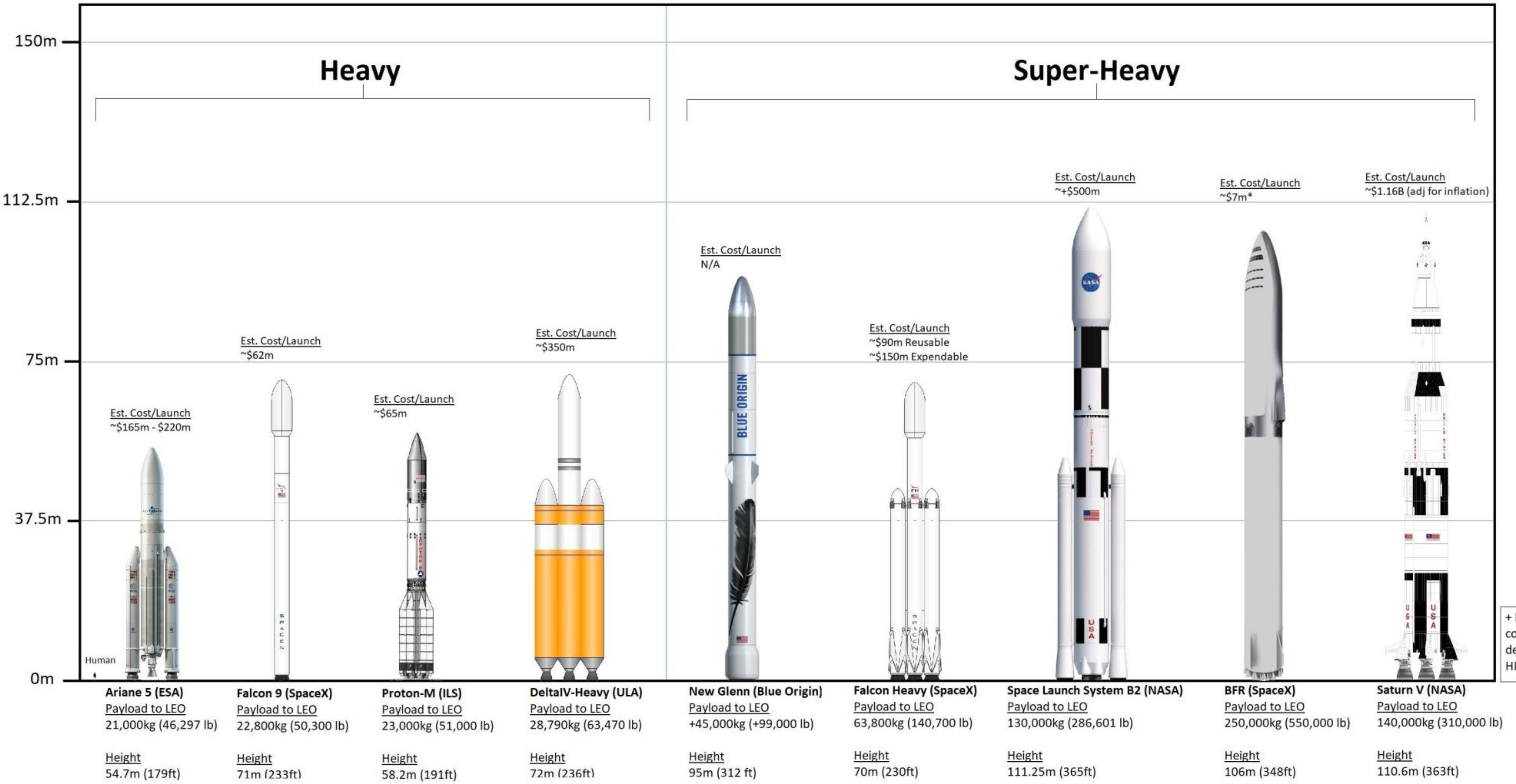
(Polidan et al. 2016)

Orbit Candidates



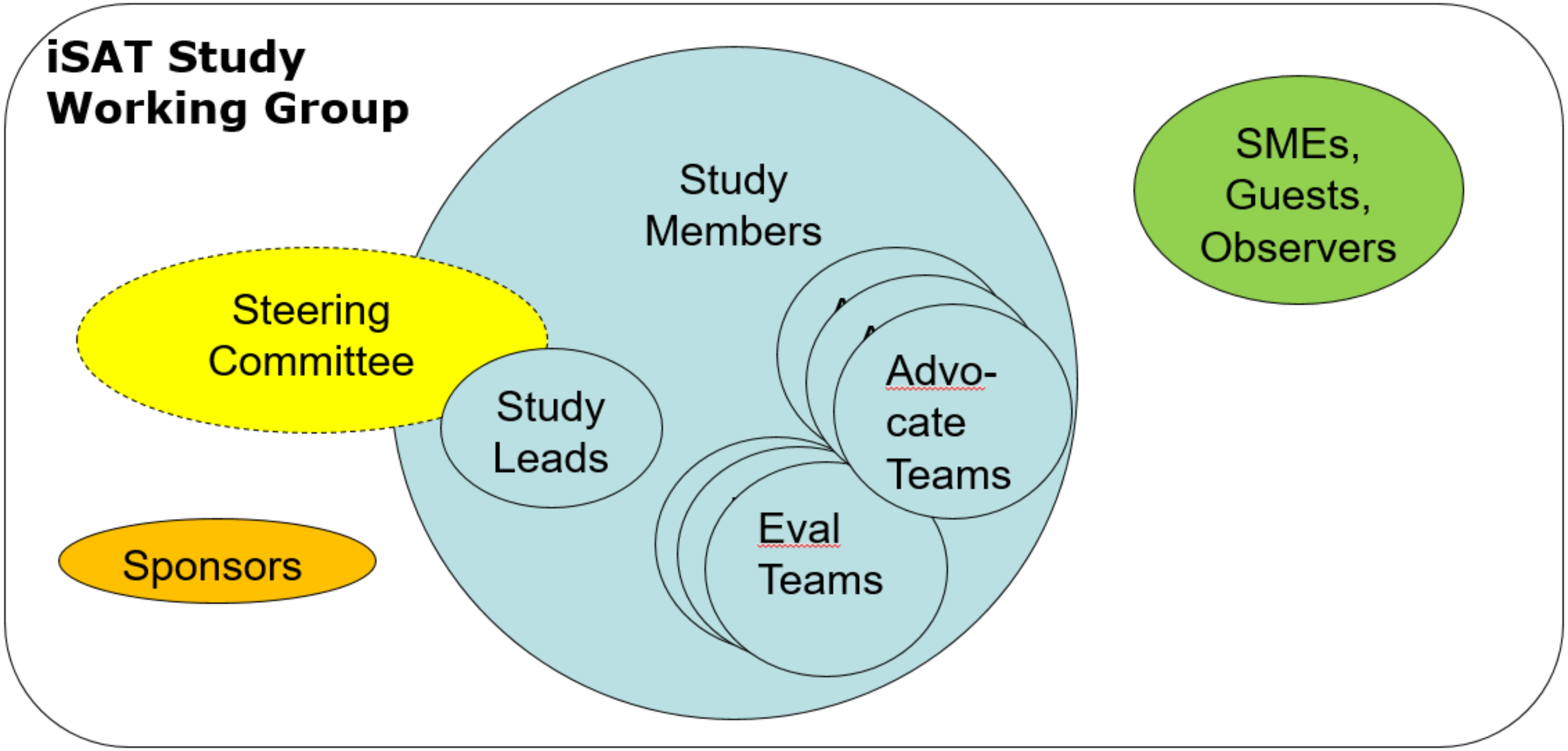
NASA's Decade Planning Team (2000)

Launch Vehicle Candidates


150m
112.5m
75m
37.5m
0m
Heavy
Super-Heavy
Human
Est. Cost/Launch
~$165m - $220m
Ariane 5 (ESA)
Payload to LEO
21,000kg (46,297 lb)
Height
54.7m (179ft)
Est. Cost/Launch
~$62m
Falcon 9 (SpaceX)
Payload to LEO
22,800kg (50,300 lb)
Height
71m (233ft)
Est. Cost/Launch
~$65m
Proton-M (ILS)
Payload to LEO
23,000kg (51,000 lb)
Height
58.2m (191ft)
Est. Cost/Launch
~$350m
DeltaIV-Heavy (ULA)
Payload to LEO
28,790kg (63,470 lb)
Height
72m (236ft)
Est. Cost/Launch
N/A
BLUE ORIGIN
New Glenn (Blue Origin)
Payload to LEO
+45,000kg (+99,000 lb)
Height
95m (312 ft)
Est. Cost/Launch
~$90m Reusable
~$150m Expendable
Falcon Heavy (SpaceX)
Payload to LEO
63,800kg (140,700 lb)
Height
70m (230ft)
Est. Cost/Launch
~+$500m
Space Launch System B2 (NASA)
Payload to LEO
130,000kg (286,601 lb)
Height
111.25m (365ft)
Est. Cost/Launch
~$7m*
BFR (SpaceX)
Payload to LEO
250,000kg (550,000 lb)
Height
106m (348ft)
Est. Cost/Launch
~$1.16B (adj for inflation)
Saturn V (NASA)
Payload to LEO
140,000kg (310,000 lb)
Height
110.6m (363ft)

Who: Participants and Stakeholders

The iSAT Study Working Group



Our Sponsors

Dr. Paul Hertz
Director
Astrophysics Division
NASA Headquarters

Mike Seablom
Chief Technologist
Science Mission Directorate
NASA Headquarters

Steering Committee and Study Leads

Steering Committee

1.	Dave Redding	NASA JPL	Study Member (mirrors, WFSC)
2.	Joe Pitman	consultant	Study Member (opto-mech structures)
3.	Scott Knight	Ball	Study Member (optical design)
4.	Bill Doggett	NASA LaRC	Study Member (telescope structures)
5.	Matt Greenhouse	NASA GSFC	Study Member (astrophysicist)
6.	Ben Reed	NASA GSFC	
7.	Gordon Roesler	DARPA (ret)	Study Member (telescopes)
8.	John Grunsfeld	NASA (ret)	
9.	Keith Belvin	NASA STMD	
10.	Brad Peterson	STScI/OSU	Study Member (astrophysicist)
11.	Florence Tan	NASA SMD	
12.	Ray Bell	Lockheed	Study Member (telescope systems)
13.	Nasser Barghouty	NASA APD	
14.	Dave Miller	MIT	Study Member (robotics)
15.	Keith Warfield	NASA ExEP	Study Member (SME)

Study Leads

Nick Siegler (co-)	NASA ExEP/JPL	
Harley Thronson (co-)	NASA PCOS/COR Programs/GSFC	
Rudra Mukherjee (co-)	NASA JPL	Study Member (robotics)

Confirmed Participants for Activity 1b

(* means invited but no response)

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)

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

Launch Systems/AI&T
- Diana Calero (KSC)
- Roger Lepsch (LaRC)

Autonomous Systems
- Julia Badger (JSC) *
- Ron Diftler (JSC) *
- Eric Komendera (VA Tech)

Rendezvous & Proximity Operations
- Bo Naasz (GSFC)
- Scott Cryan (JSC) *

GNC
- Ed Swenker (JPL) *
- Bo Naasz (GSFC)

Manufacturing
- Kevin DiMarzio (MIS)
- Bobby Briggs (LMC)
- Rob Hoyt (Tethers)

Gateway
- Sharon Jeffries (LaRC)

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) *
- David Akin (Univ of Maryland) *
- Michael Fuller (Orbital)
- Adam Yingling (NRL)
- Bo Naasz (GSFC)
- Hsiao Smith (GSFC)
- Dave Miller (MIT)

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

SMEs/Observers
- Keith Warfield (JPL)
- Lynn Bowman (LaRC)
- Erica Rodgers (STMD)
- John Grunsfeld (NASA retired)
- Phil Williams (LaRC)
- Alison Nordt (LMC)
- Howard MacEwen (consultant)

Sunshade
- Jon Arenberg (NG)

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

Controls
- Larry Dewell (LMC)
- Oscar Salazar (JPL) *

Thermal
- Carlton Peters (GSFC)

Role of the Study Members

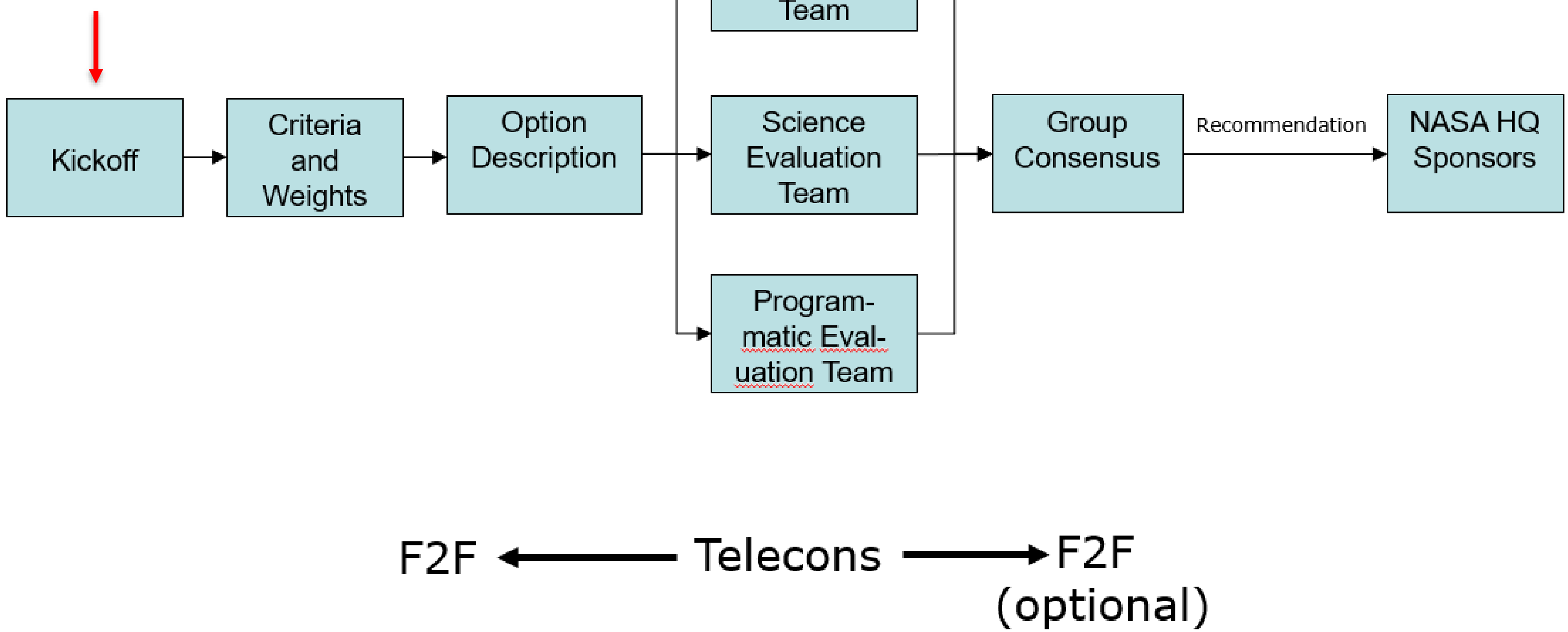
1. **The heart of the Study – the folks whose recommendations will lead to a new paradigm (or not)…**
2. **Will generate selection criteria**
3. **Will generate concepts of assembly and infrastructure (a.k.a. options)**
4. **Will provide the Study with evaluation teams**
5. **Will reach consensus on the criteria assessment for each concept**
6. **Weekly telecons / one face-to-face meeting**

Consensus

Drawn from NASA Policy

- **Consensus decisions**
  - May produce more durable decisions than those by votes or decree.
  - However, convergence time can be a factor.
- **We adopt a Constrained Consensus method defined as:**
  Strive for consensus in the reasonable time available, else, the leaders make a decision. Dissent (if any) is captured and the groups moves on with full support of the decision.
- **Follow 7120.5E, Ch 3.4, "Process for Handling Dissenting Opinion"**
  - Three options:
    (1) Agree,
    (2) Disagree but fully support the decision,
    (3) Disagree and raise a dissenting opinion
  - Treat (1) and (2) as consensus for iSAT Study Working Group
  - Dissents (3) if any will be documented and delivered to the Study Leads and to the Sponsors

How will iSAT Study Members Produce a Recommendation?



Features of Kepner-Tregoe Decision Process

Systematic Decision Making

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									

Process Overview

- Agree on **Evaluation Criteria** and **Weights**
- Document **Options** and **Description**
- **Evaluate** Options vs Criteria
- Reach **Consensus** on Evaluation
- Document **Risks, Opportunities**
- **Recommendation** accounting for Risks, Opportunities

Credit: Gary Blackwood (NASA JPL)

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

Evaluation			Weights	SPC	PIAACMC	HLC	VVC	VNC-DA	VNC - PO	Notes
Wants	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		Identify "Best" and others are: -Wash -Small Difference -Significant Difference -Very Large Difference
	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%							

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

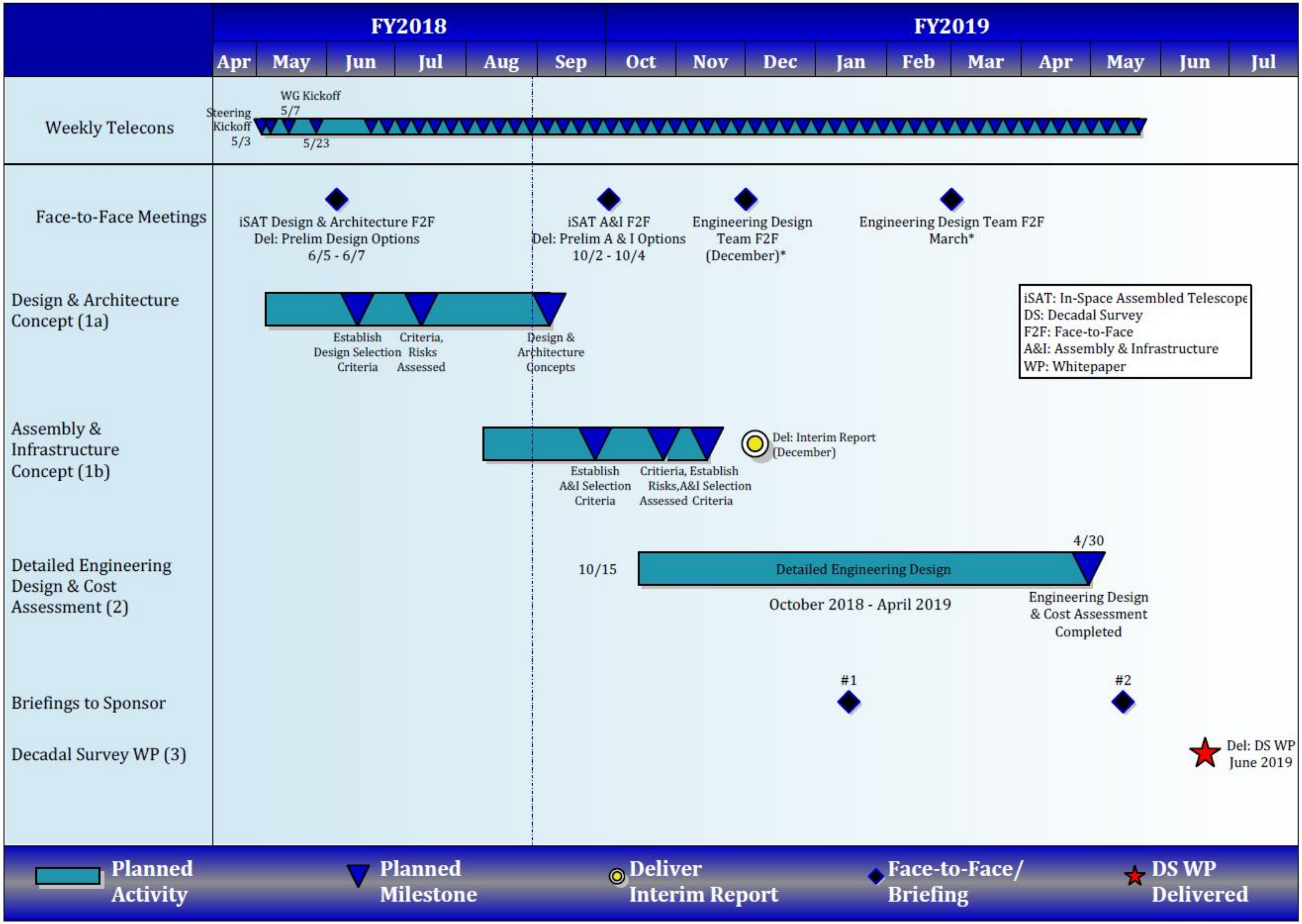
When: Next Steps

Next Steps

- **Subsequent Telecons with the entire Working Group**
  - Weekly cadence
  - Advance work on Selection Criteria

- **Second Face-to-Face Workshop for the Study Members**
  - Oct 2-4 at NASA LaRC (Hampton, VA)
  - Focus is on Activity 1b: Assembly and Infrastructure
  - Draft Agenda completed
  - Breakout sessions focused on concept options

Top-Level Schedule



*tentative date

Jet Propulsion Laboratory
California Institute of Technology