Building the Future: In-Space Assembled Telescopes Study

Overview and Status

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

Harley Thronson
Senior Scientist
NASA Goddard Space Flight Center

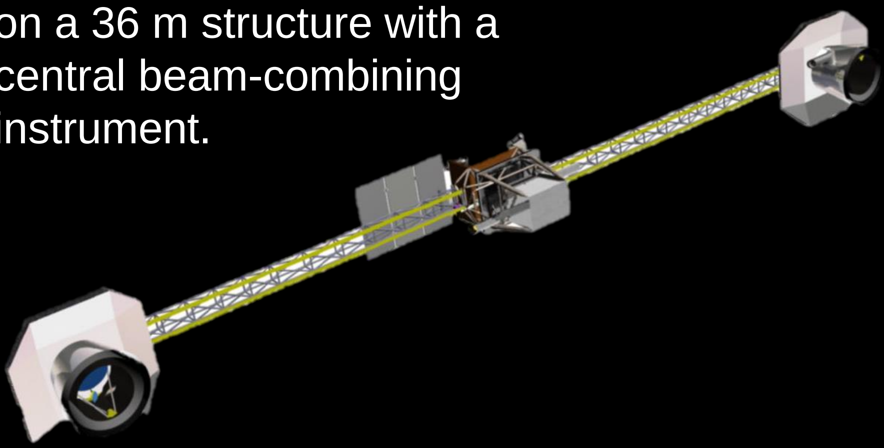
Rudra Mukherjee
Robotics Technologist
Jet Propulsion Laboratory / California Institute of Technology

COPAG IR Science Interest Group
June 4, 2019

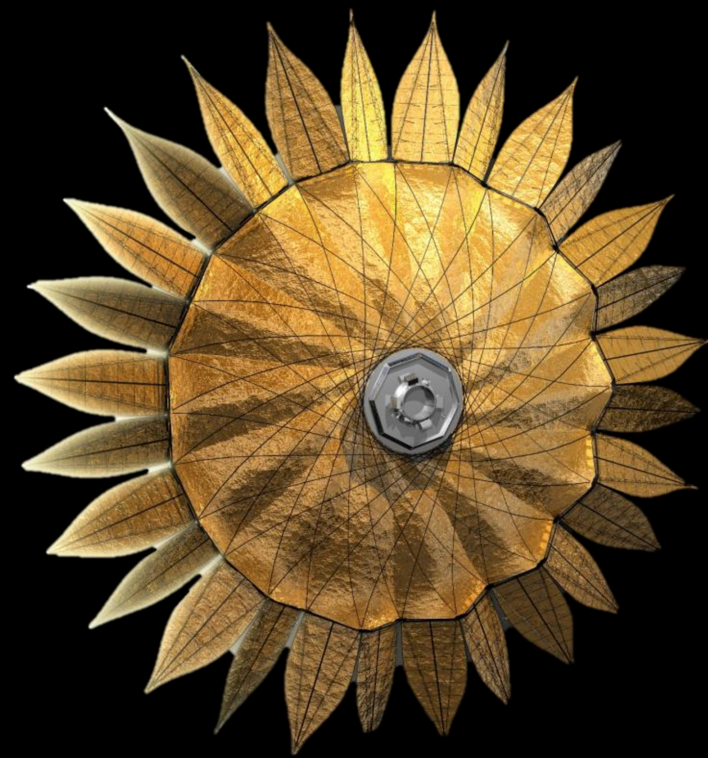
Other Spacecraft Assembly Possibilities

Interferometers

Two-1-m diameter cryo-cooled movable telescopes on a 36 m structure with a central beam-combining instrument.



SPIRIT, David Leisawitz (NASA GSFC)

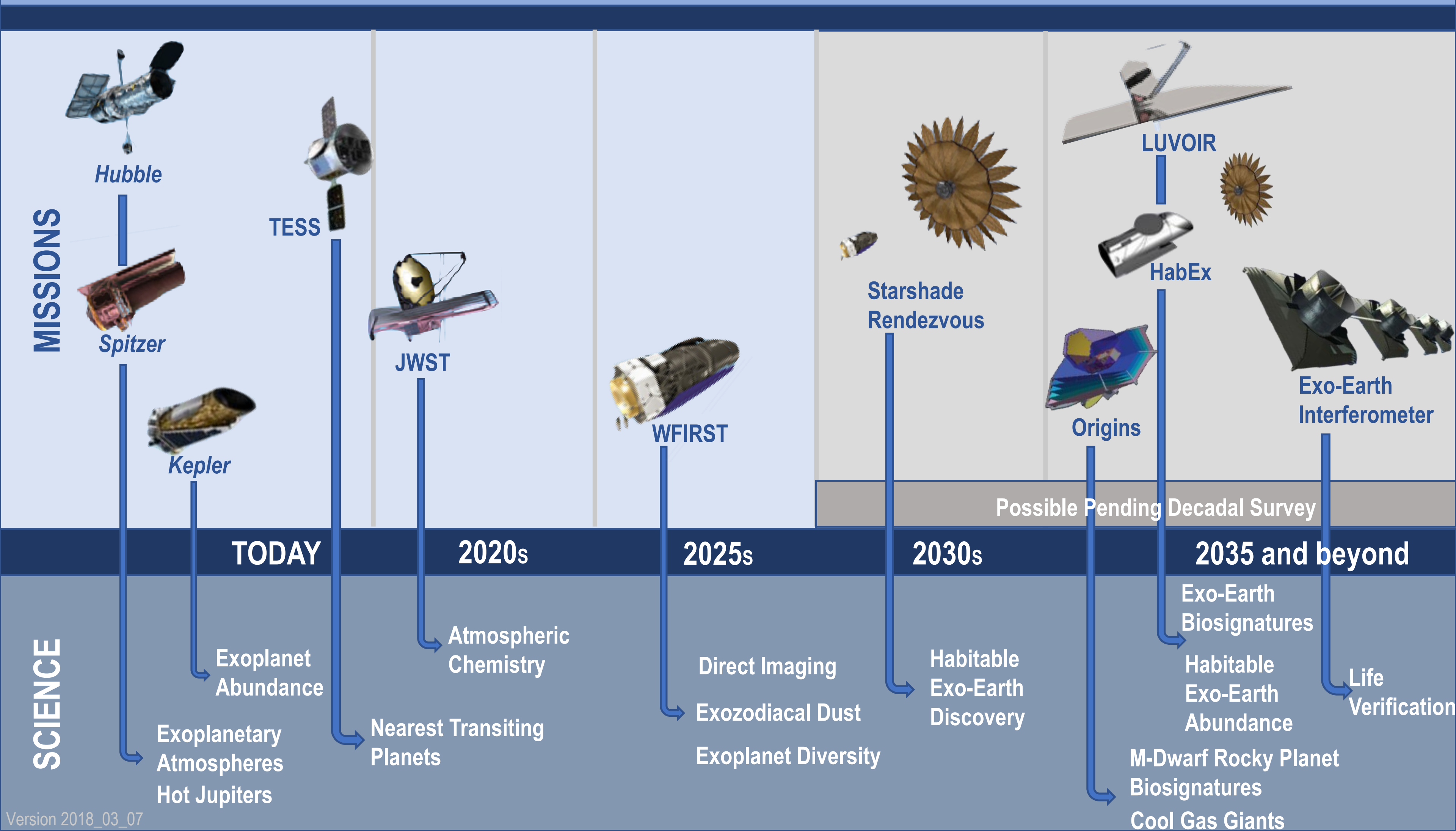


Starshades

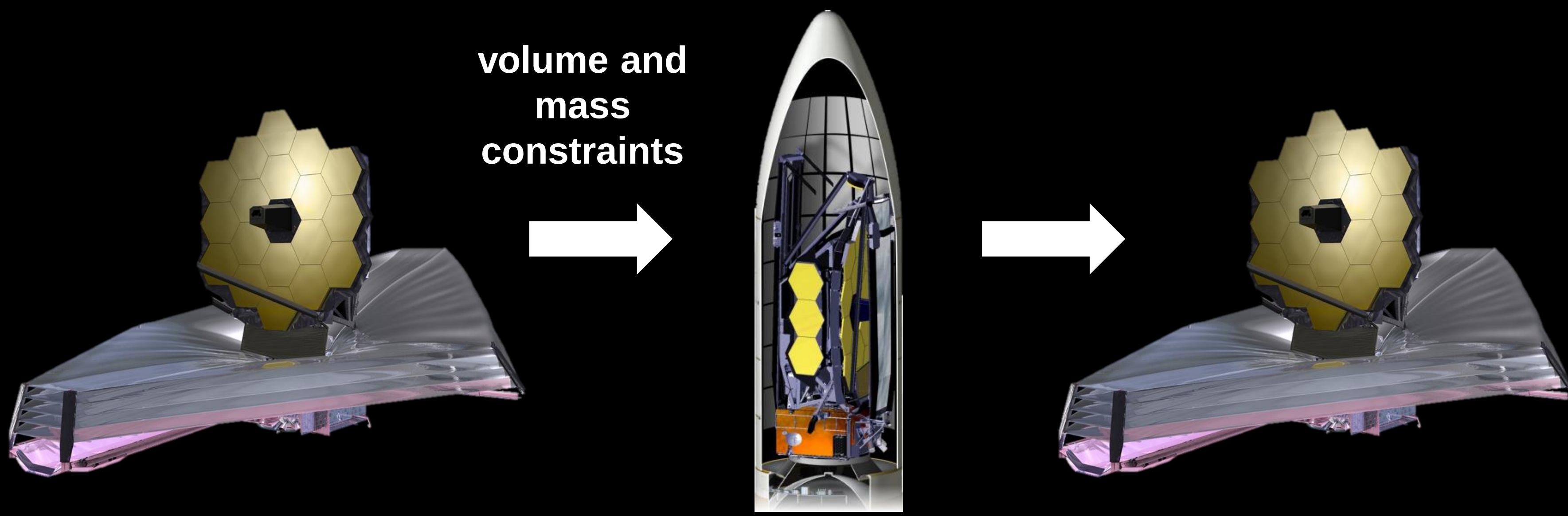
Starshade deployed to block light from central star, allowing orbiting exoplanet to be observed.

NASA/JPL-Caltech

Possible NASA Missions Roadmap to Advancing Exoplanet Science



Existing Large Observatory Paradigm: Constraints



- **Severe packaging and mass constraints have driven complexity on JWST**
  - Over 20 sequential deployment events, 40 deployable structures, 178 release mechanisms – all of which must work.
  - Numerous light-weighting iterations to meet LV mass constraints
  - Complex modeling development and validation efforts
- **No servicing capabilities**
  - No fault recovery if anomaly during commissioning or operations
  - No instrument upgrading to extend useable life (already ~ 10 yrs old at launch)

Study Objective and Deliverables

Dr. Paul Hertz
Director
Astrophysics Division
Science Mission Directorate
NASA Headquarters

- **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:**

  An Astro 2020 Decadal Survey whitepaper by July 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 current launch vehicle deployment techniques (*an enhancing capability*)

- **Decadal Survey Statement of Task:**
  - *Consider ongoing and planned activities and capabilities in other organizational units of NASA, including (but not limited to) in-space assembly and servicing and existing and planned research platforms in Earth orbit and cis-lunar space.*

NASA-Chartered iSAT Study

(iSAT = in-Space Assembled Telescope)

Study Assumptions

1. Reference telescope:
   - Non-cryogenic operating at UV/V/NIR assembled in space
   - Four sizes between 5 – 20 m
2. Driving requirements:
   - Structural stability required by coronagraphy of exo-planets
3. Operational destination:
   - Sun-Earth L2
4. Launch vehicles:
   - Use of 5 m-class LV fairings
5. Number of reference concepts to study:
   - *Only one*
   - *Not a down select, not a recommendation*

Process Approach

Four steps

- Step 1a: A systematic approach was used to select a reference telescope and its modularization strategy for apertures between 5-20 m.
- Step 1b: A systematic approach was used to select reference assembly orbit, assembly agent (astronaut vs robot), assembly platform, launch vehicles, and notional con-ops

A two-pronged costing (and risk) approach:

- ❖ Two separate teams initially blind to each other’s findings; then converged to check consistency to get verification.

- Step 2a: A qualitative approach based on experiences and lessons learned, including JWST, ISS, HST, Restore-L, Orbital Express, RSGS
- Step 2b: A quantitative approach based on a grass-roots costing exercise by SMEs from various subsystem followed by a Team-X session
  - Define assembly conops
  - Phase A-E schedules
  - Implementation plans, including testing, V&V, and integration
  - Resource needs and budget, MEL, PEL

Study Participants

Gov't Agencies
- NRL
- DARPA
- USAF
- NRO

Key Commercial Companies
- Lockheed
- Ball
- NGIS (O-ATK)
- NGAS
- SSL
- Harris
- several consultants

Study Involvement
- > 100 participants
- 6 NASA Centers
- 14 private companies
- 4 gov't agencies
- 5 universities

SMEs

Missions: JWST, HST, ISS, Restore-L, RSGS, NASA Tipping Point, APD STDTs, Gateway

Disciplines:
- RPO
- telescope optics
- robotics
- structures
- sunshade
- instruments
- I&T + V&V
- launch vehicles
- orbital dynamics

Name	Institution	Expertise
		Metrology
		Mirror Segments
		Pointing/Stability/Control
		Pointing/Stability/Control
		Telescope Architecture
		Telescope Architecture
		Systems Engineering
		Systems Eng/Structures
		Robotics
		Robotics
12. Gordon Roesler	DARPA	
		Telescope Structures
		Mechanical/I&T
		Technologist/Detectors
		Technologist
		Robotics Systems Engineering
		Astrophysicist
		Thermal
		Systems Engineering
		Optical Modeling/I&T
		Systems Engineering
		Thermal
35. Keith Havey	Harris	Telescopes
36. Lynn Allen	Harris	Optics
37. Ben Reed	NASA GSFC	Robotic Servicing
38. Scott Knight	Ball	Optics
46. Ken Ruta		
69. Max Fagin		
72. Rob Hoyt		
73. Scott Rohrbach	NASA GSFC	Scattered Light

Four Face-to-Face Meetings

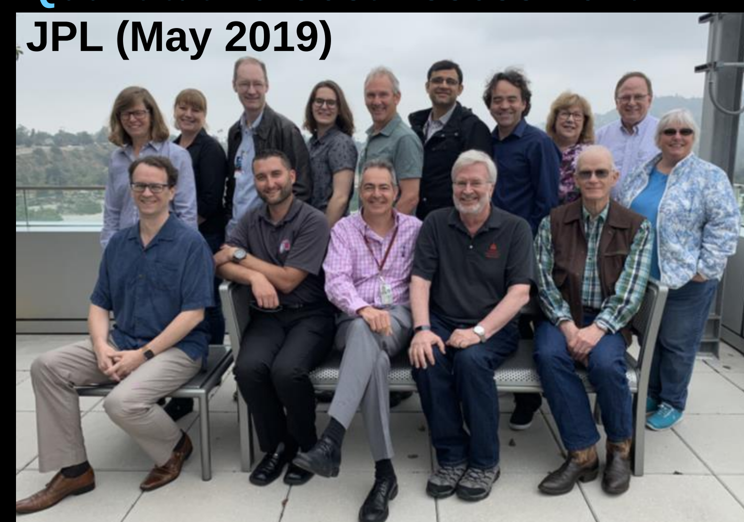
… and multiple weekly telecons

Telescopes: Caltech (June 2018)

Robotics, Orbits, LVs, Assembly Platforms: LaRC (Oct 2018)

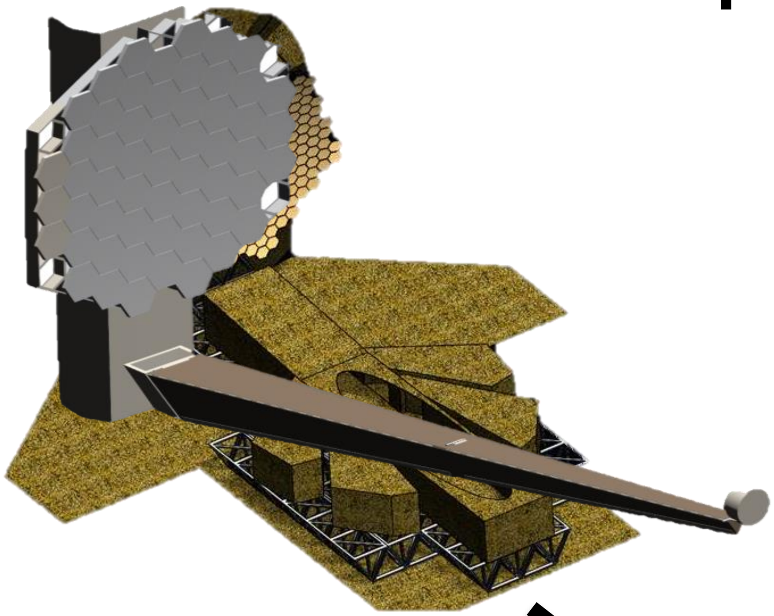
Qualitative Cost, Risk Assessments: JPL (Feb 2019)

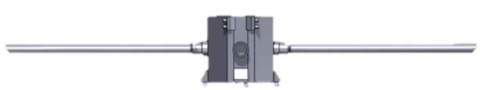
Quantitative Cost Assessment

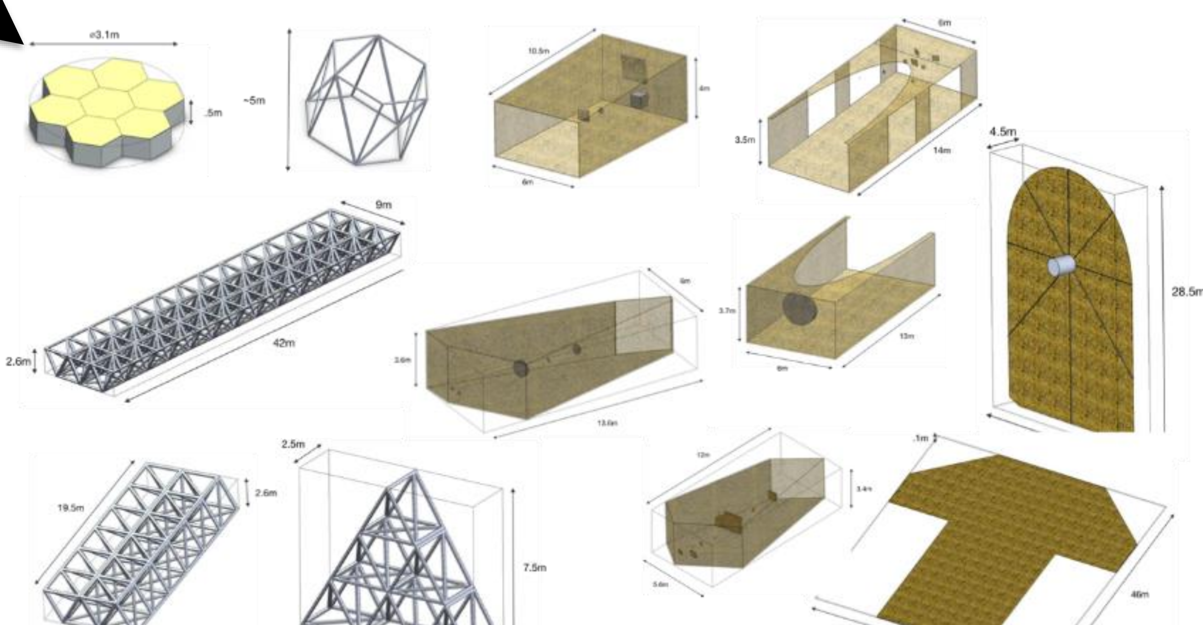


JPL (May 2019)

Modularization of a Space Telescope





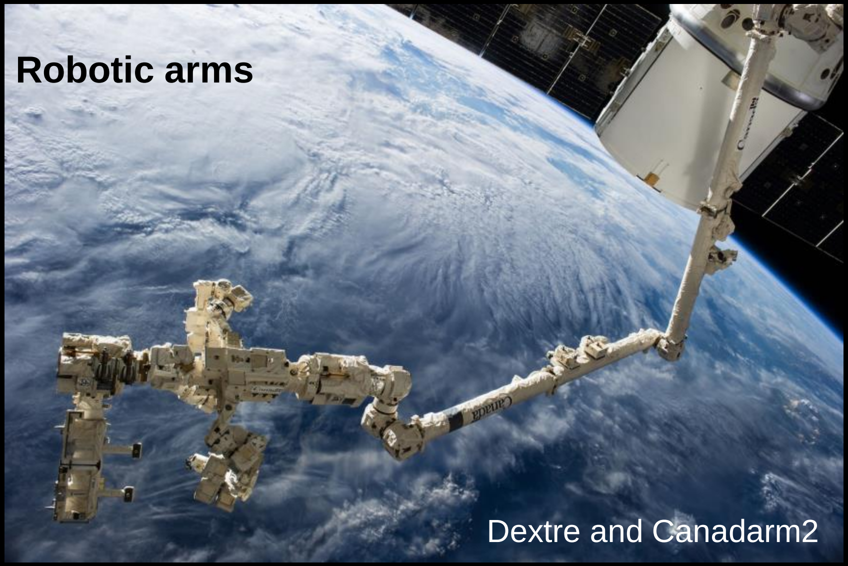


Picture Credit:
R. Mukherjee et. al., 2018

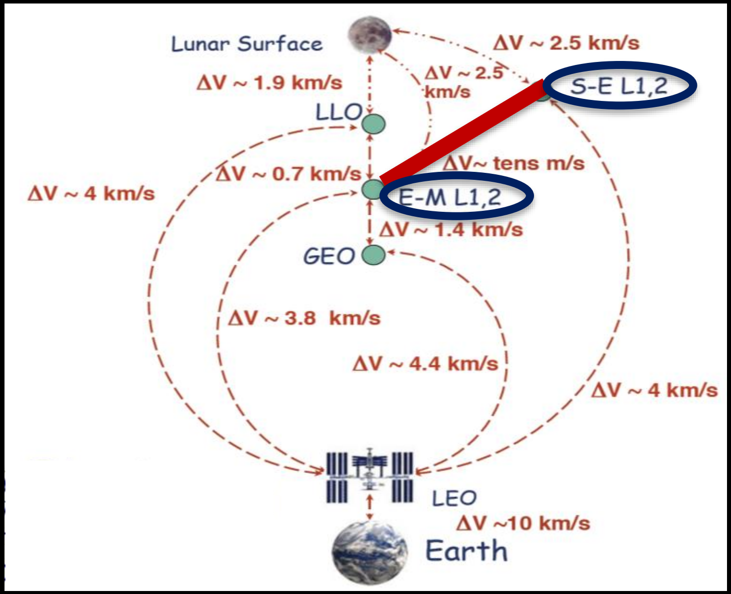
Reference Mission Concept

Very large option space

Assembly Agent



Assembly Orbit



Launch Vehicles

ULA's Delta IV Heavy

Photo: United Launch Alliance

ULA's Atlas V

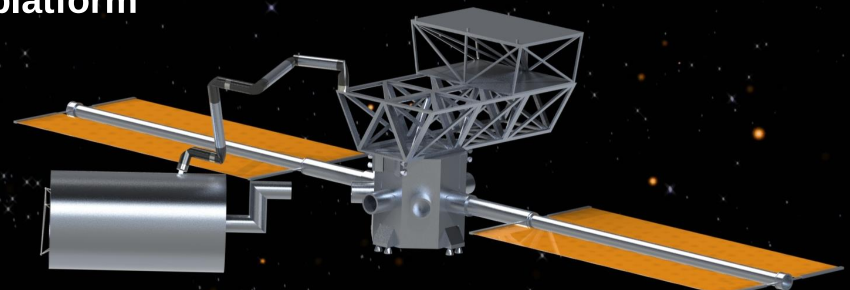
Photo: United Launch Alliance

SpaceX's Falcon Heavy

Photo: SpaceX

Telescope's spacecraft bus as the assembly platform

Assembly Platform



Delivery ConOps

Disposable Cargo Delivery Vehicle (CDV)

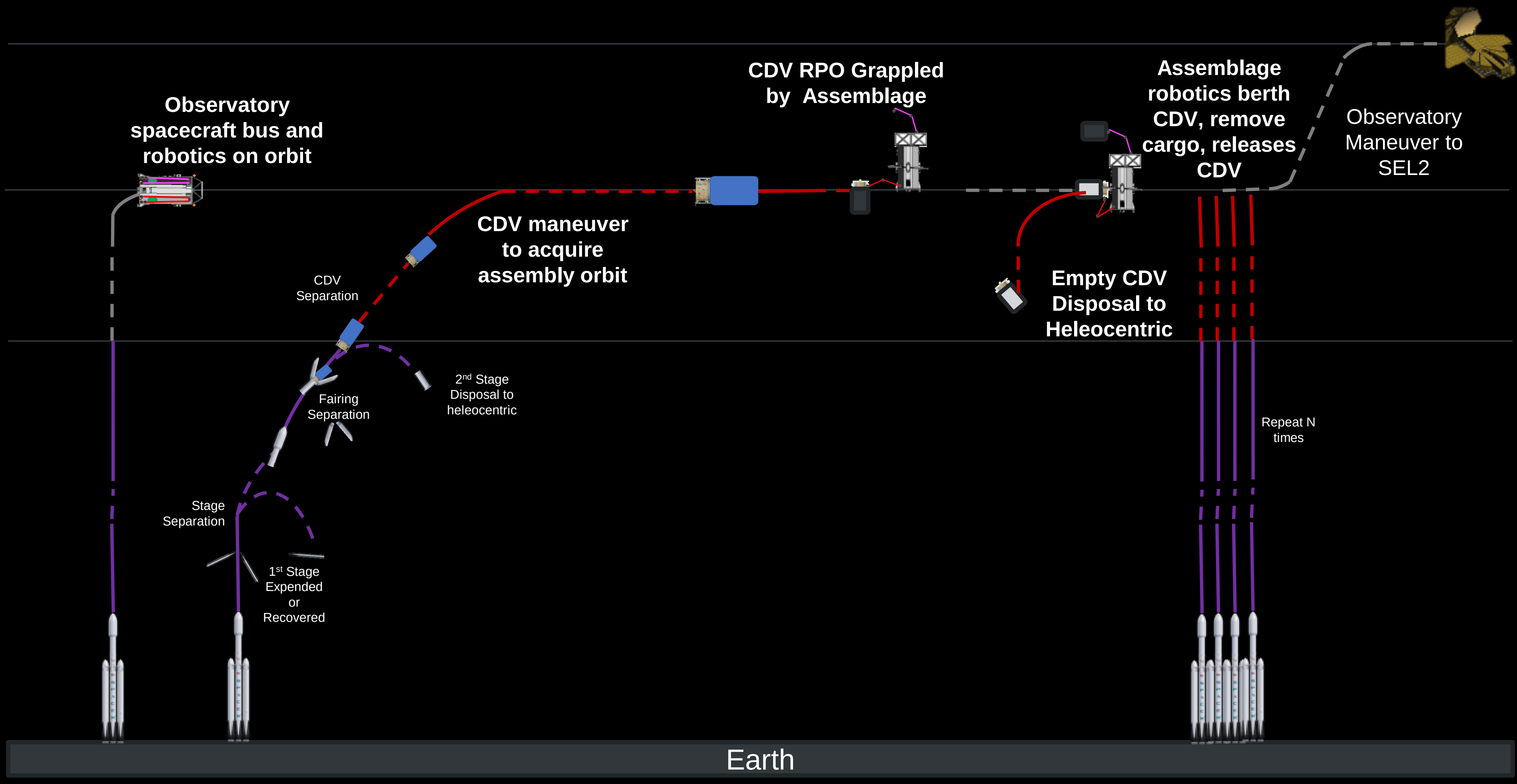
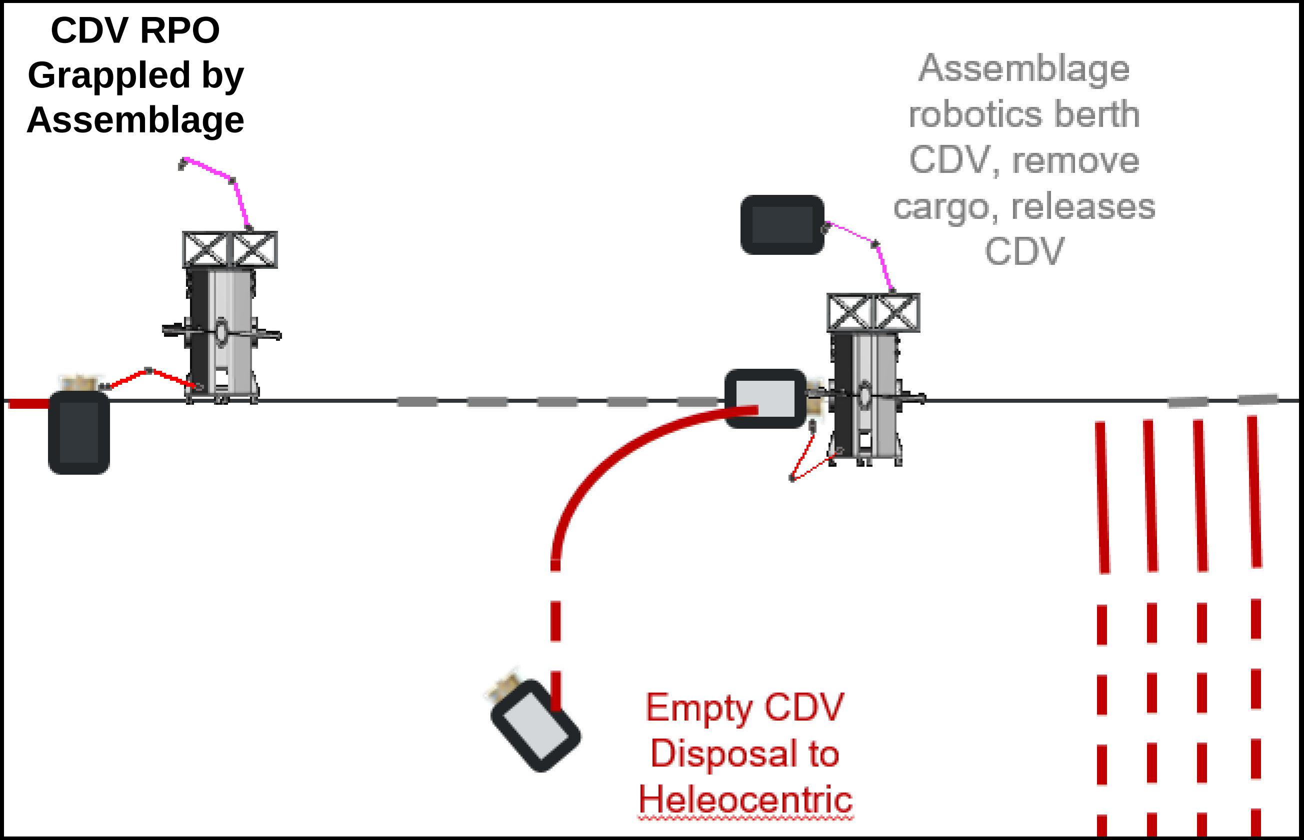


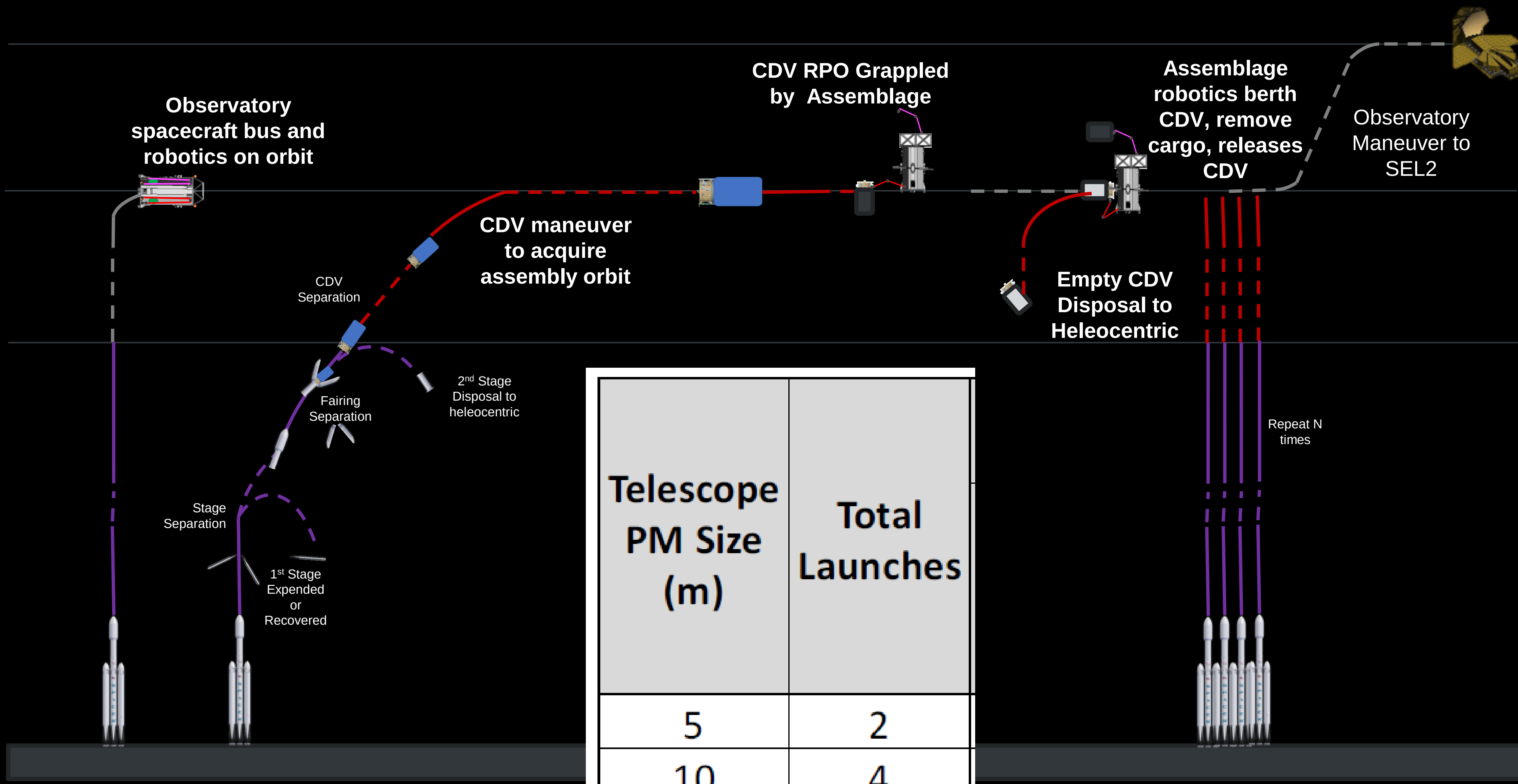
Illustration: Bo Naasz (NASA GSFC)

Delivery Via Disposable Cargo Delivery Vehicle



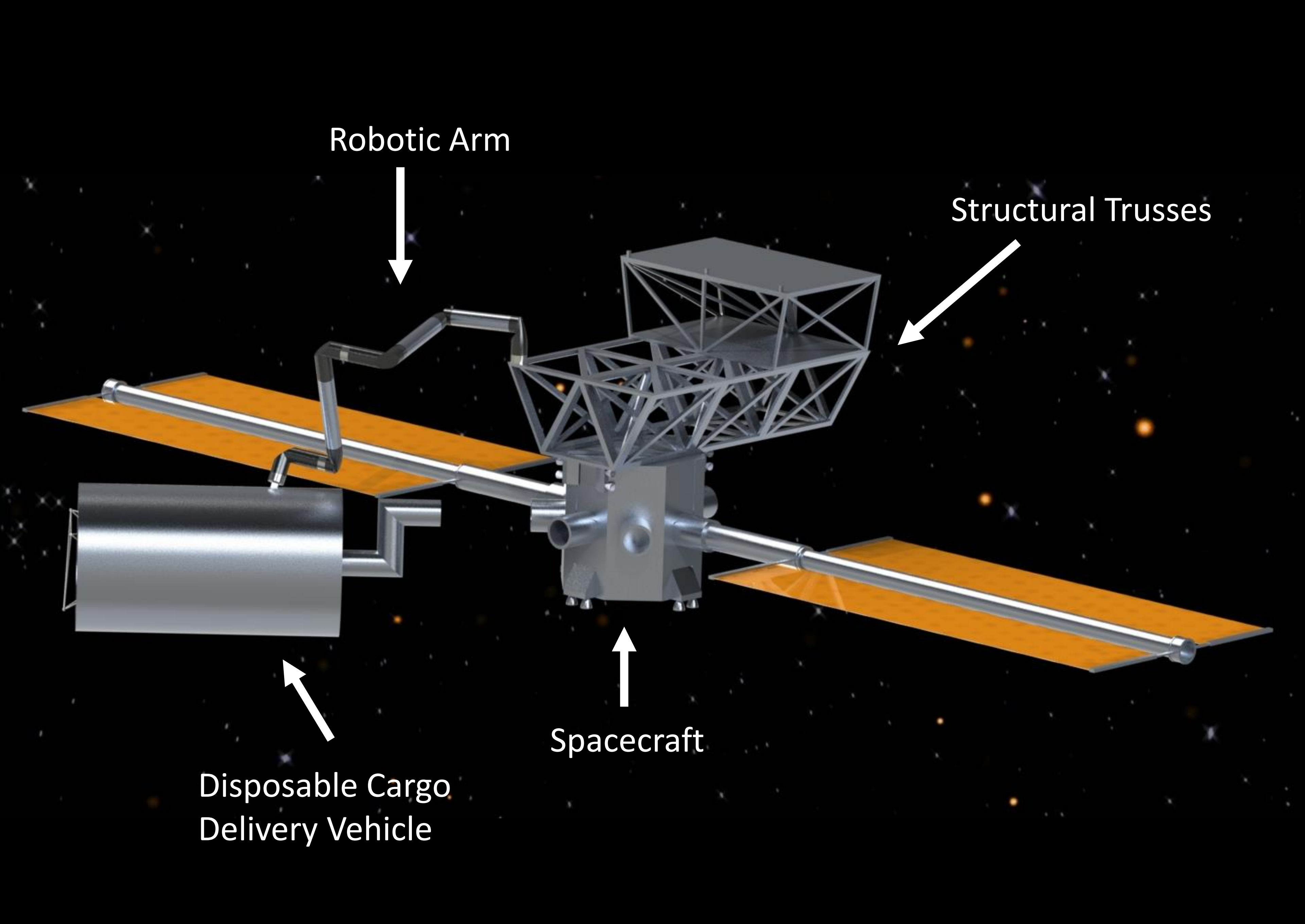
Delivery ConOps

Disposable Cargo Delivery Vehicle (CDV)

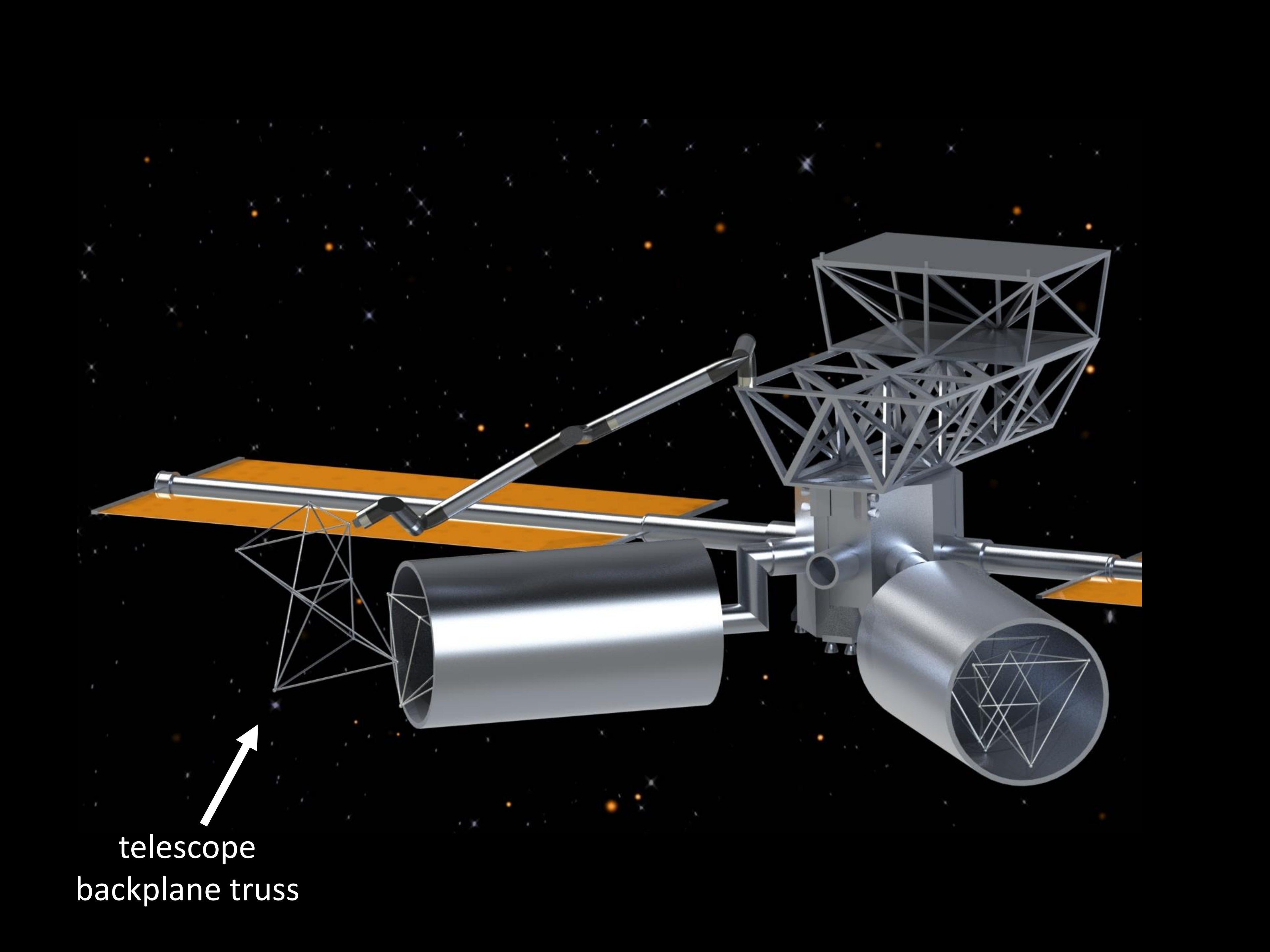


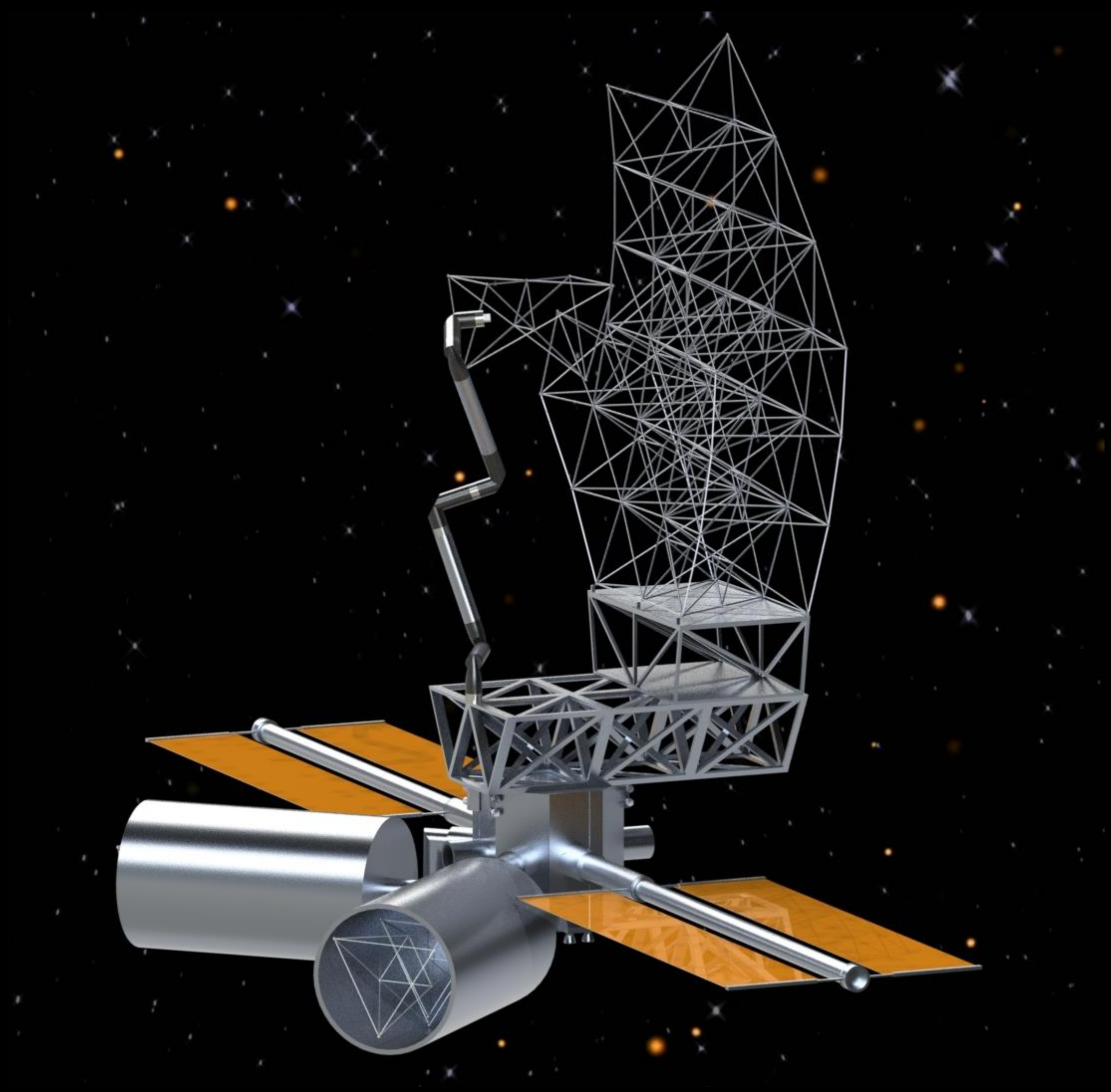
Telescope PM Size (m)	Total Launches
5	2
10	4
15	7
20	12

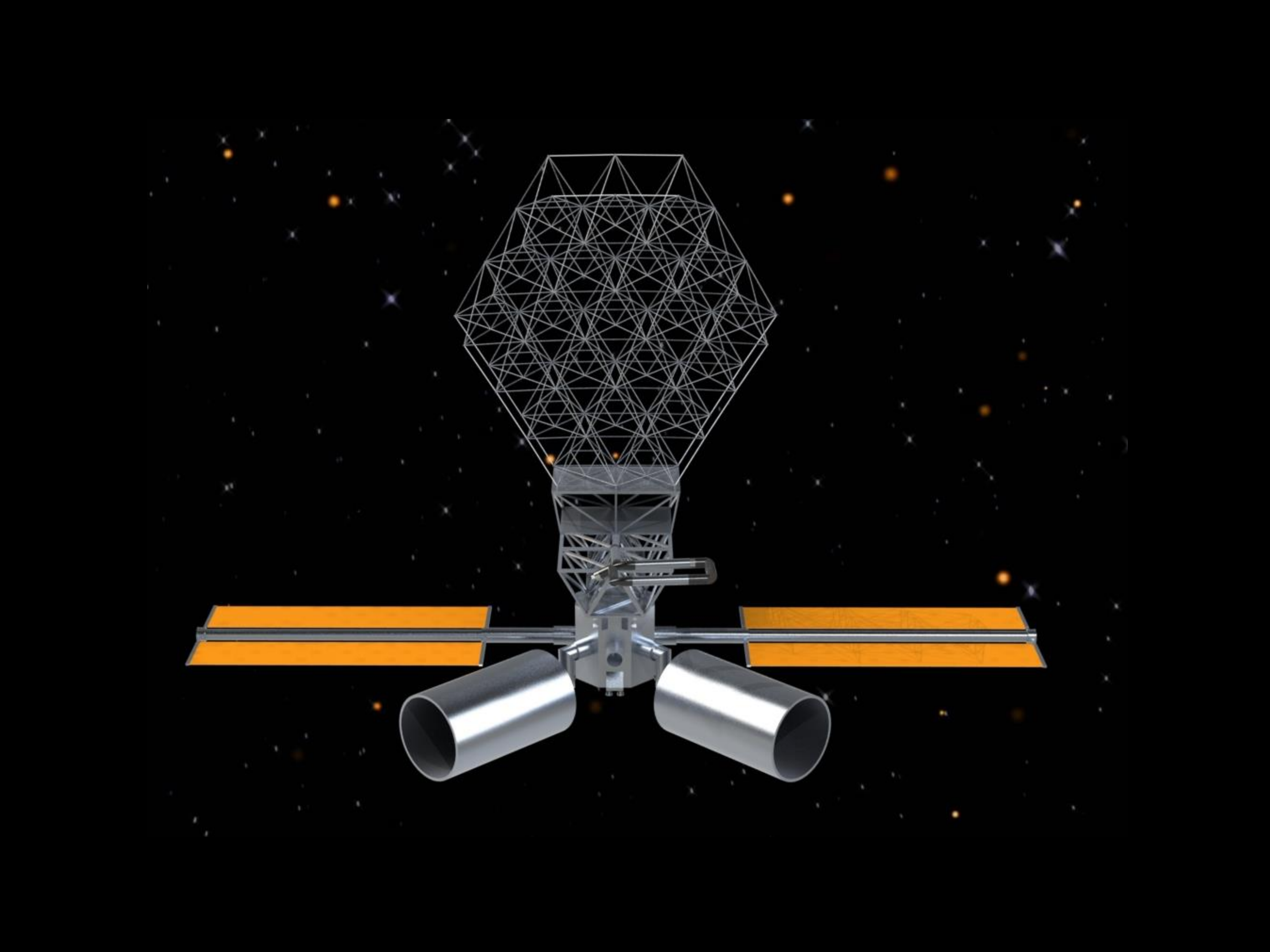
Illustration: Bo Naasz (NASA GSFC)

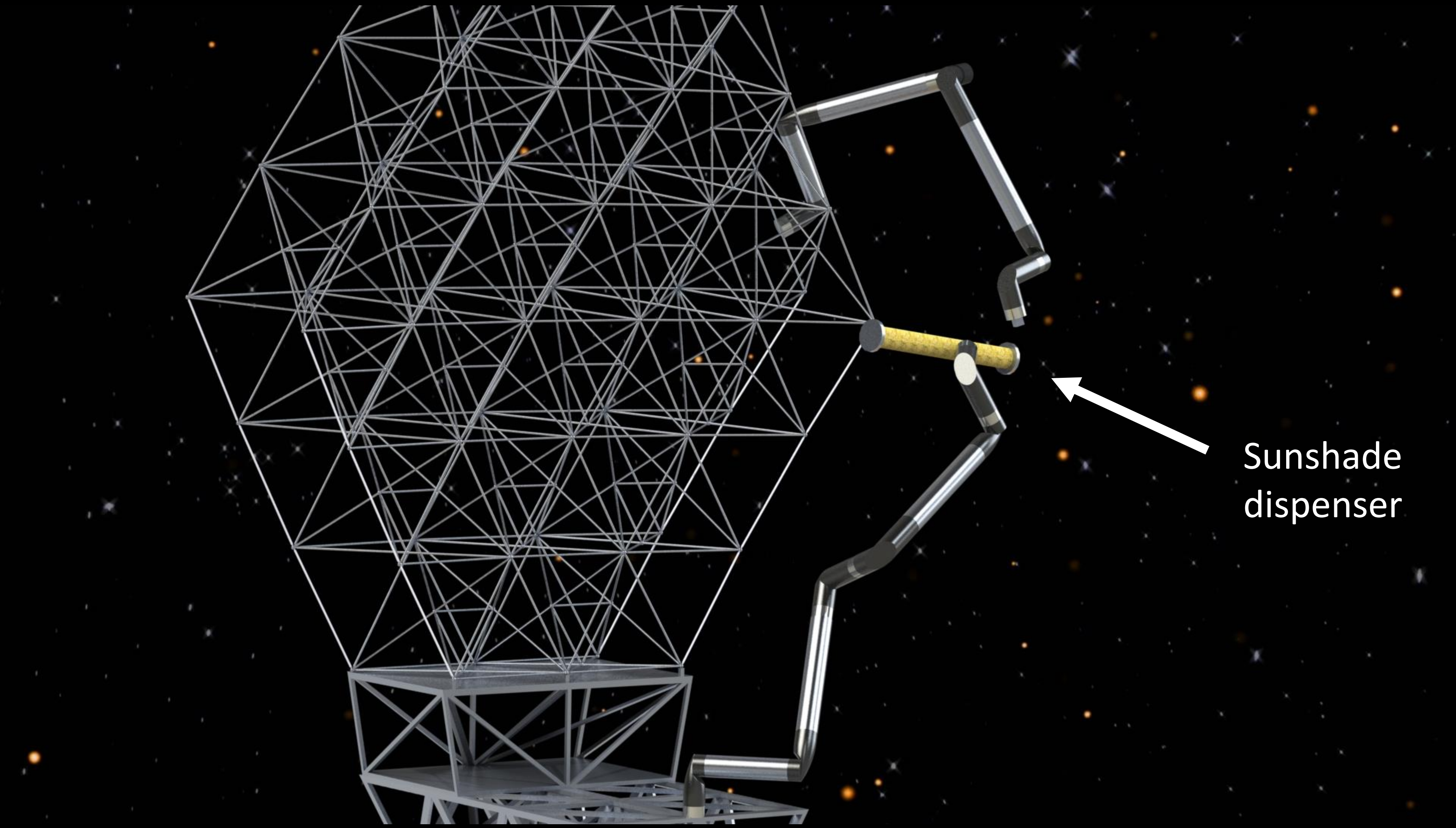


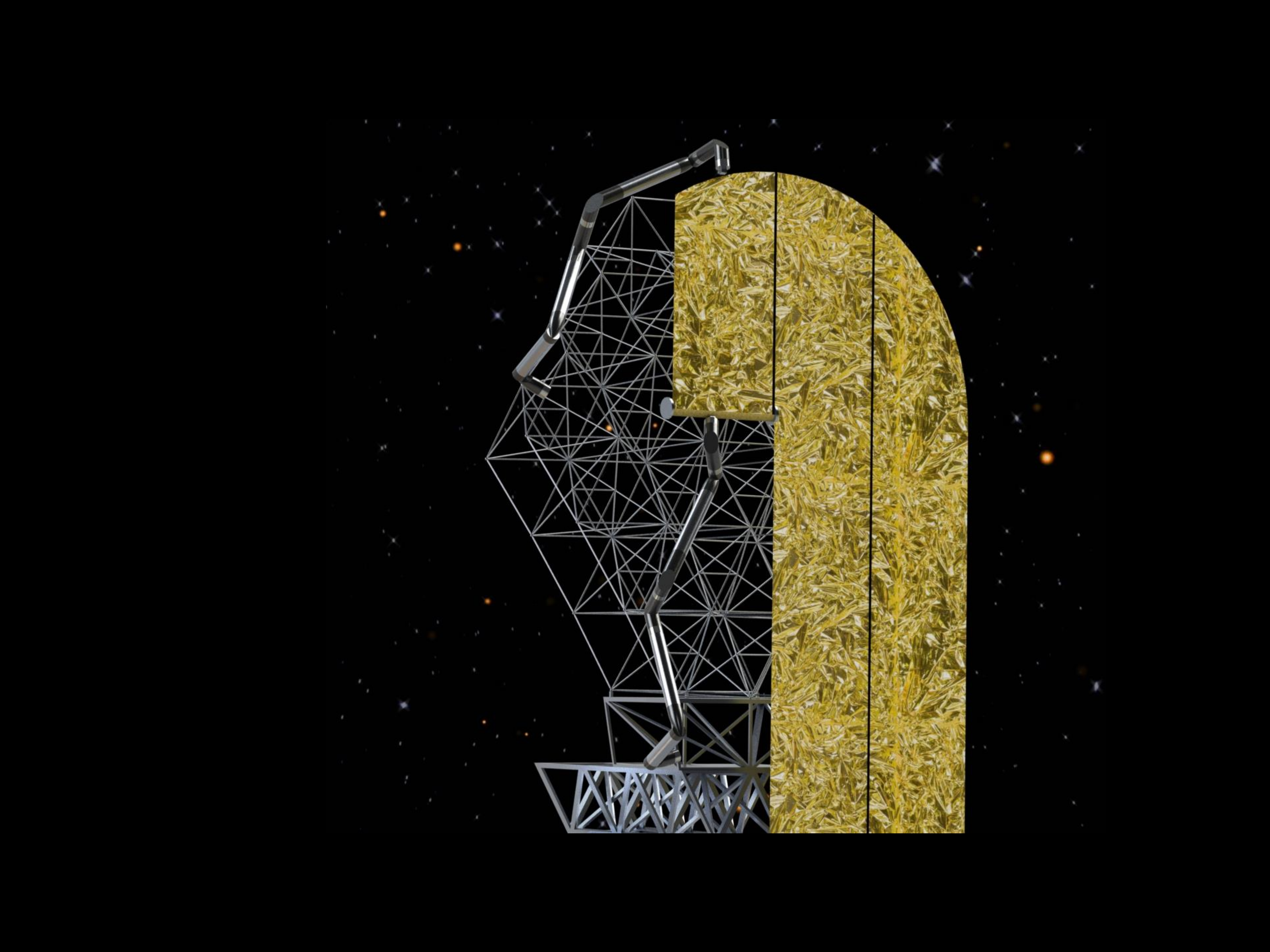
All illustrations by R. Mukherjee and D. Mick (NASA/JPL/Caltech)

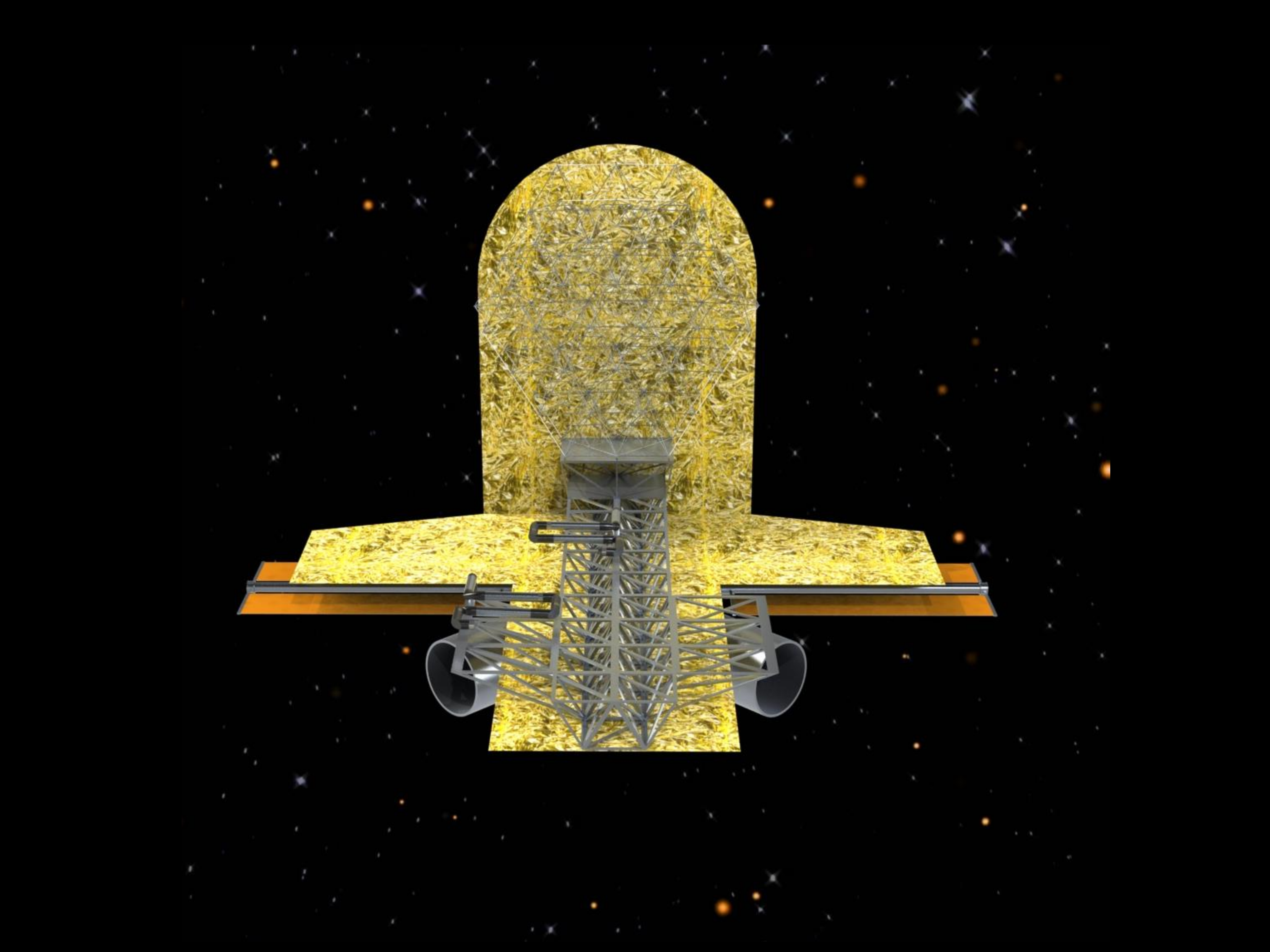

telescope
backplane truss

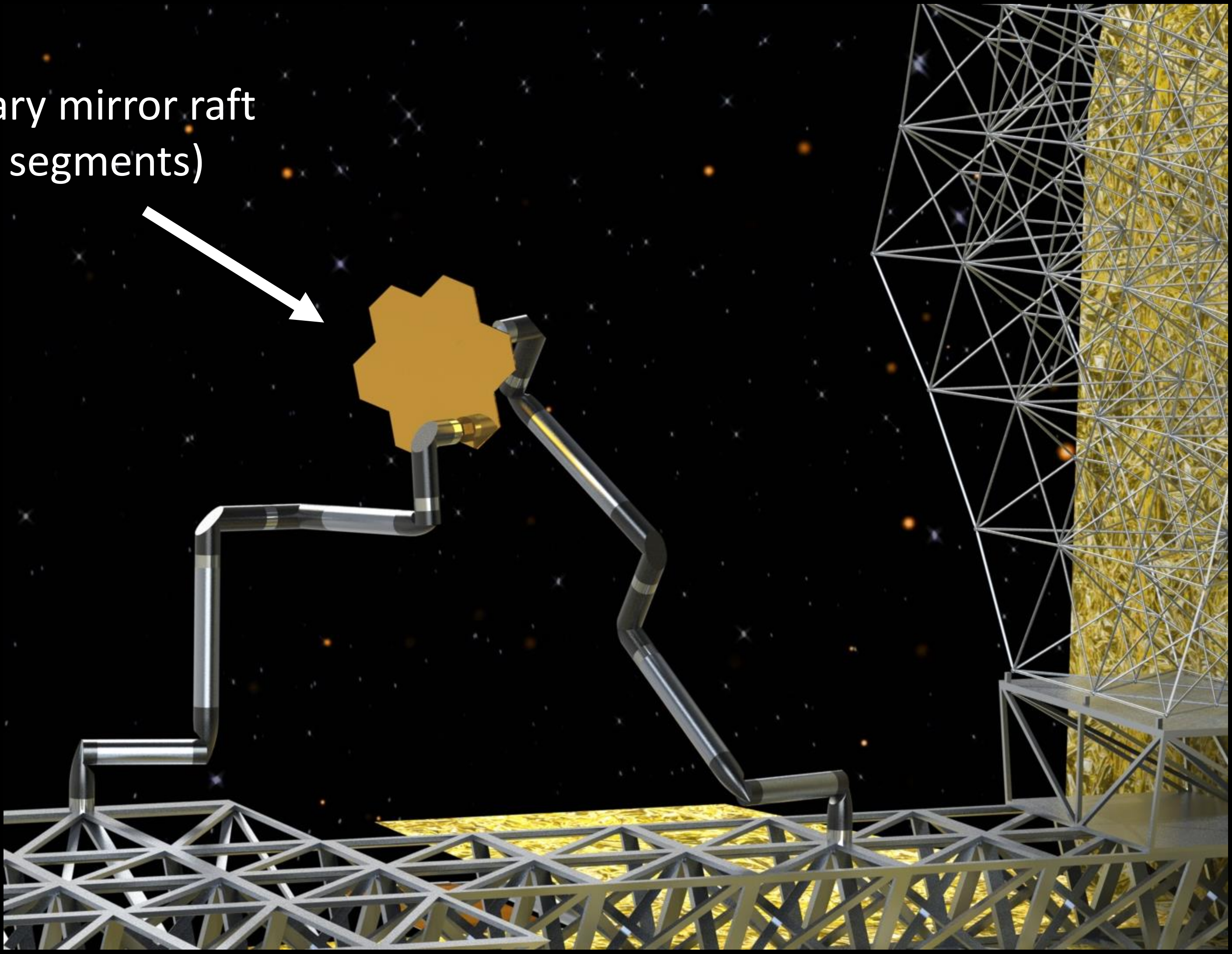


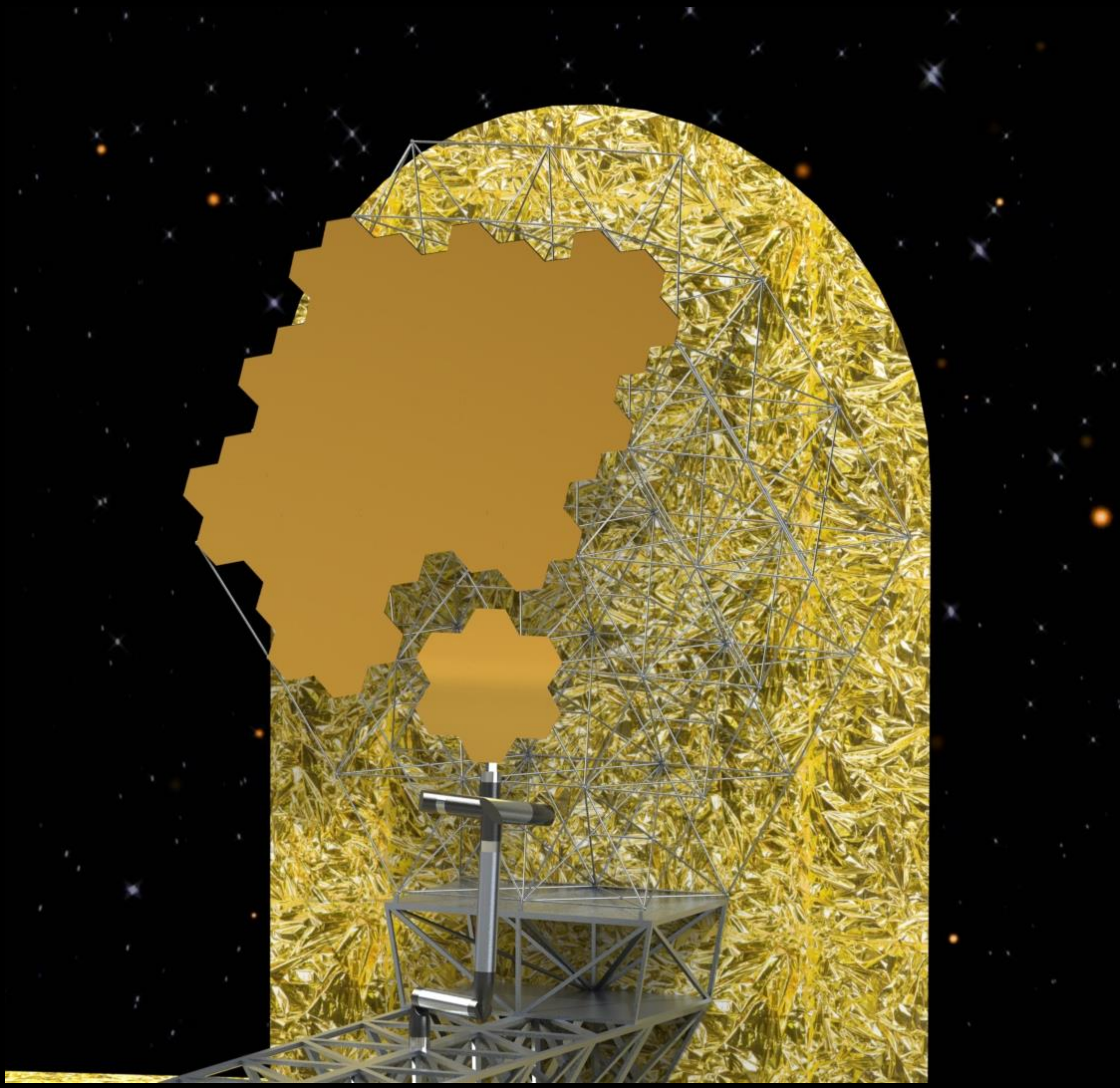


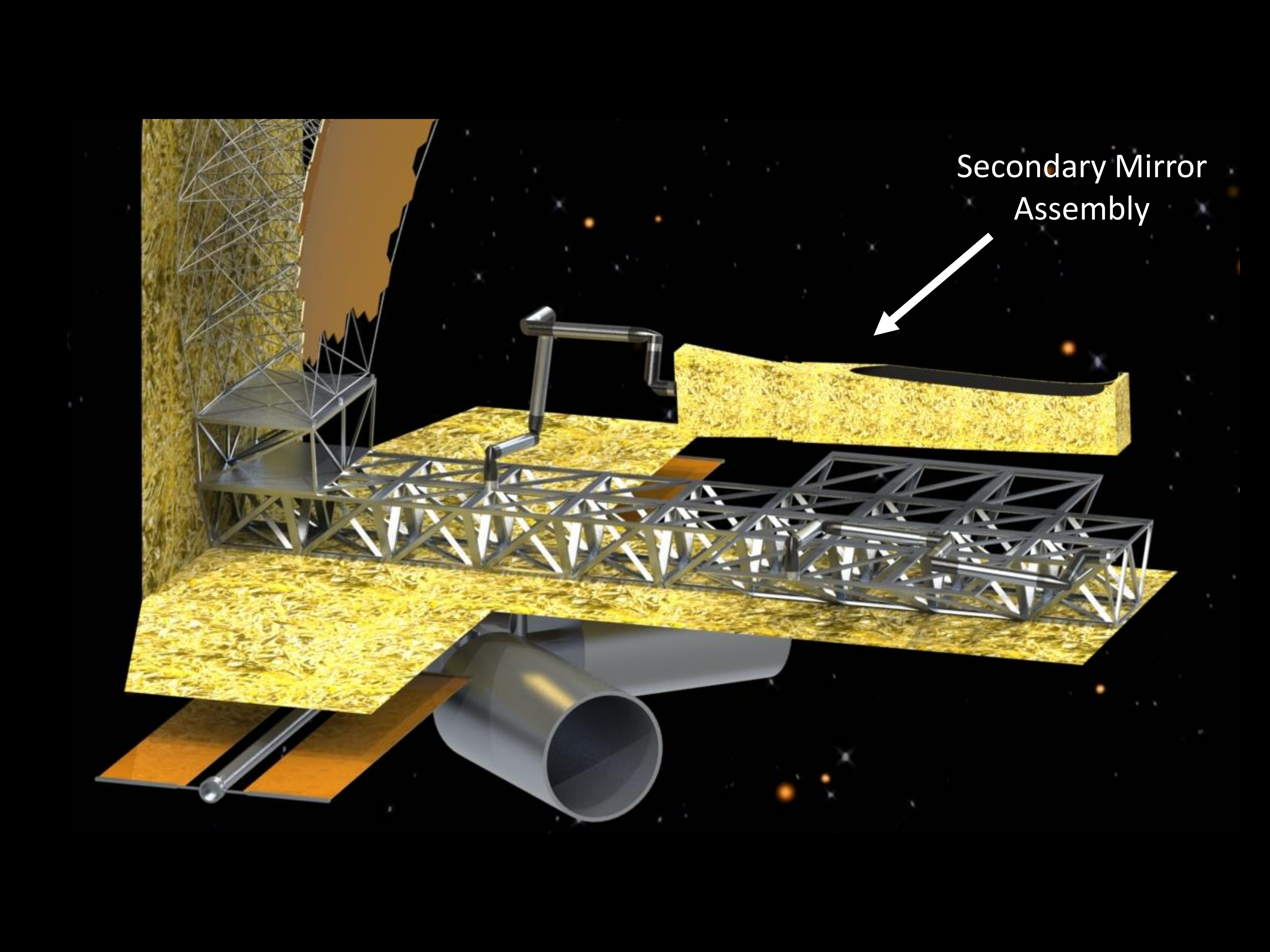

Sunshade
dispenser

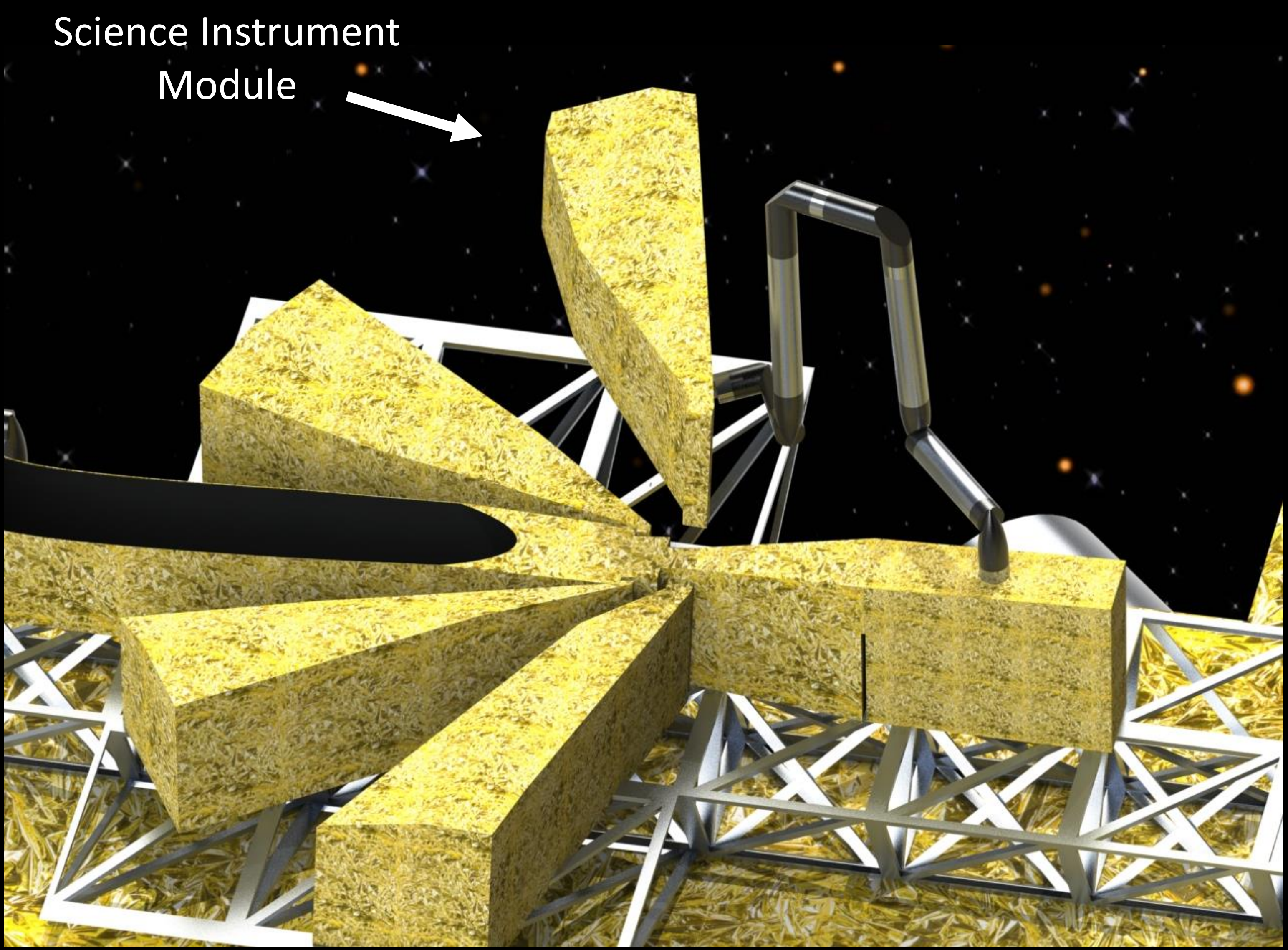


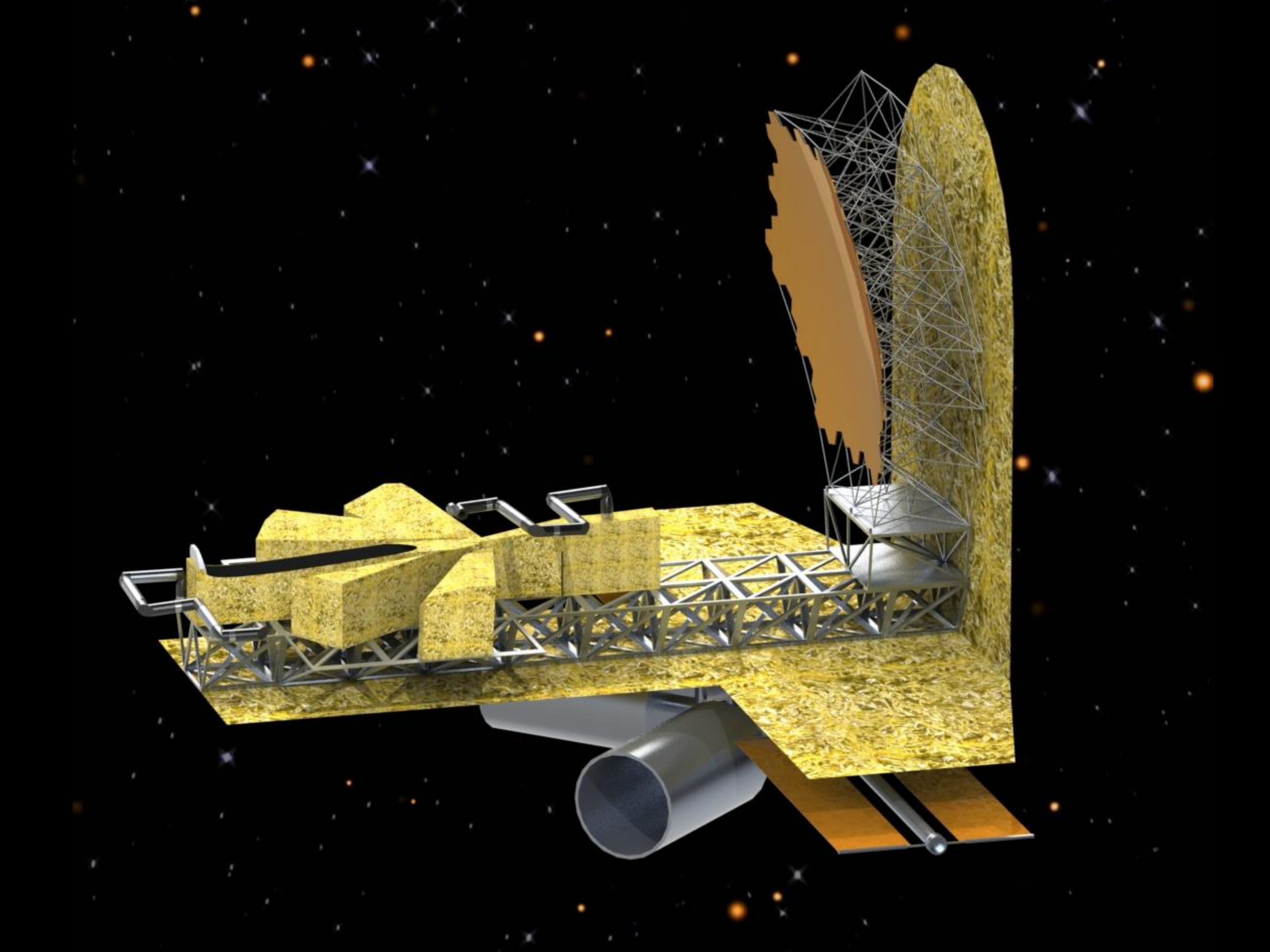



Primary mirror raft
(7 segments)




Secondary Mirror
Assembly


Science Instrument
Module



Key Interim Results

iSAT Leverages Many TRL 9 Capabilities

NASA, DARPA, industry, and international partners

Past Capability Advances

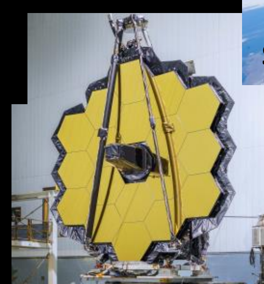
HST Servicing – Inspects, Repairs, Upgrades, Optical Alignment

ISS Assembly – Modularity, Multiple LV's, Robotic Arms

Orbital Express
Autonomous Rendezvous and Soft Capture, Removal/installation of ORUs, Fluid Transfer

Ongoing Capability Improvements

ISS Servicing and Assembly – Robotic Repairs, Autonomous Docking, Instrument Assembly



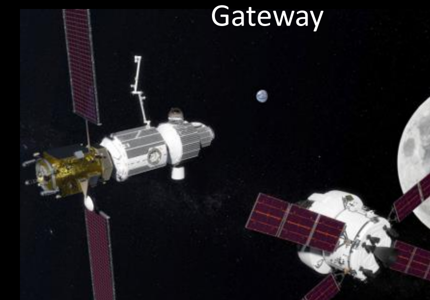
JWST:
Segmented Optics
WFS&C Phasing

Supervised Autonomy Robotics

Commercial LEO – Infrastructure Buildup, Support Services

Future Capability

Advanced Servicing – Autonomy, Telerobotics, Refueling, Servicing



Key Aspects of the iSA Paradigm

1) Modularized flight elements: encapsulation of complexity, standardized interfaces, more readily assembled/serviceable, tailor to LV fairing size

2) Multiple launches: leverages existing commercial medium-lift capabilities for lower cost, more flexibility, greater margins

3) Commercial cargo delivery vehicles (or a space tug) to deliver modules to the assembly site; leverages ISS experience

4) Supervised autonomous robotic arms: ISS-qualified arms; ensures executed commands are correct before launching subsequent steps

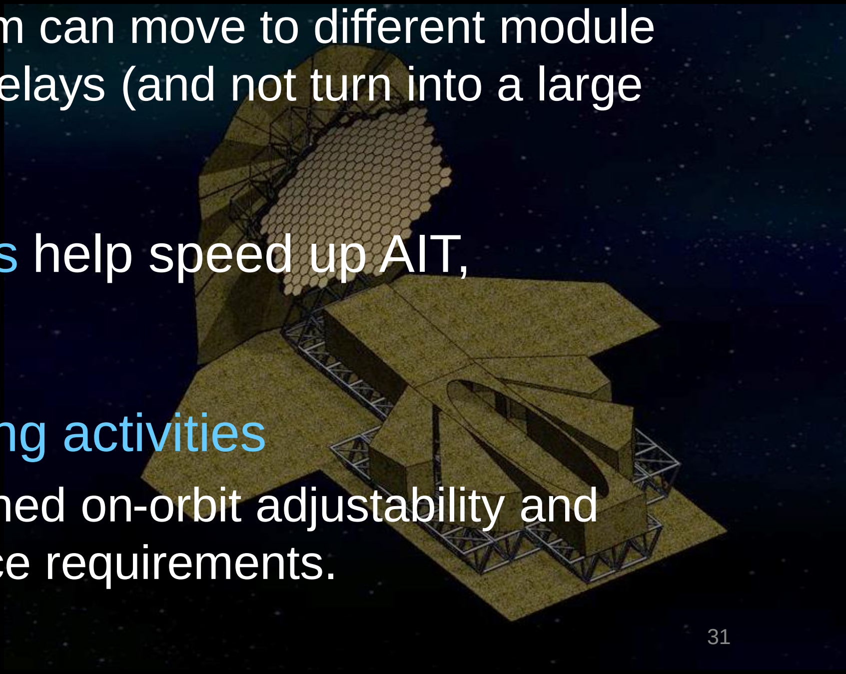
5) V&V: Combination of “smart” module diagnostics, onboard metrology, model validation; subsequent modules do not launch until V&V complete

6) Servicing: Follows same paradigm – no explicit servicer needed

Key Cost Benefits Enabled by iSA (1 of 2)

Specifically through modularization and capability of using multiple LVs

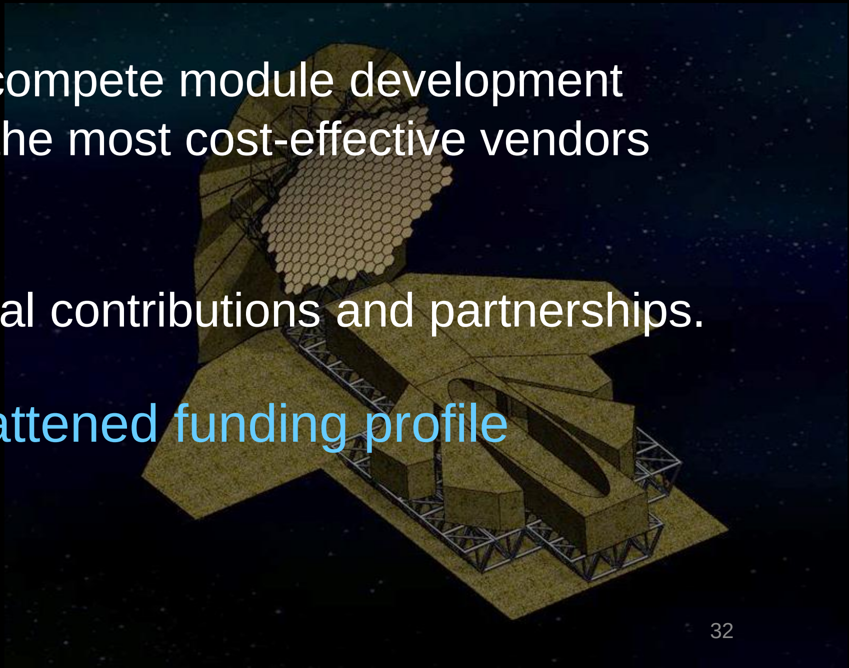
- Relaxes mass and volume constraints
  - Reduces engineering design complexity and time (i.e. cost).
  - Eliminates complex folding designs, reduces mass iterations, less need for complex modeling
- More flexible scheduling
  - More work conducted in parallel
  - Critical path is broadened so AIT team can move to different module deliveries when there are schedule delays (and not turn into a large marching army).
- Modules with standardized interfaces help speed up AIT, especially during anomaly resolution.
- Eliminates costly systems-level testing activities
  - Enabled by greater degrees of designed on-orbit adjustability and correctability to meet system tolerance requirements.



Key Cost Benefits Enabled by iSA (2 of 2)

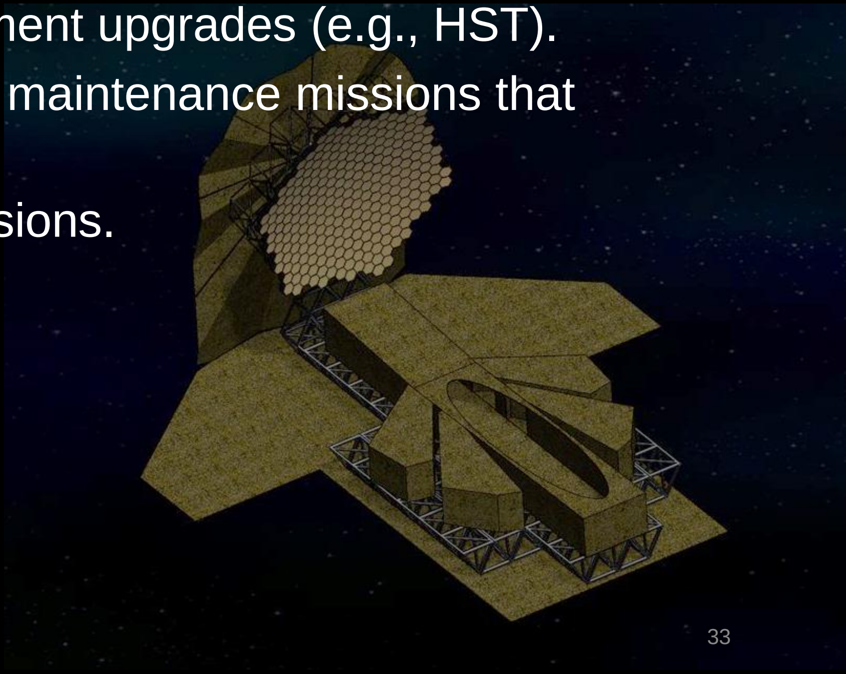
Specifically through modularization and capability of using multiple LVs

- Diminishes cost and schedule impacts from late-stage hardware re-design changes and iterations.
- Reduces need for ruggedizing the system and its interfaces to survive launch.
- Less need for new and larger ground test facilities.
- Spread the wealth: Can distribute and compete module development work across NASA and industrial base to the most cost-effective vendors and facilities.
- Share the wealth: Enhances international contributions and partnerships.
- More readily enables prescribed or flattened funding profile programs.



Key Science Benefits Enabled by iSA

- No "Tyranny of the fairing"
  - Telescope diameters and configurations that achieve science goals not possible with apertures constrained by single launches.
  - Instruments may be more capable as they are independently launched and less constrained by mass and volume.
- Telescopes can evolve and last decades
  - Continuous stream of planned instrument upgrades (e.g., HST).
  - Can plan for refueling and preventive maintenance missions that extend useable lifetime.
  - Can authorize unexpected repair missions.
- No explicit servicer needed
  - Cost and science benefits

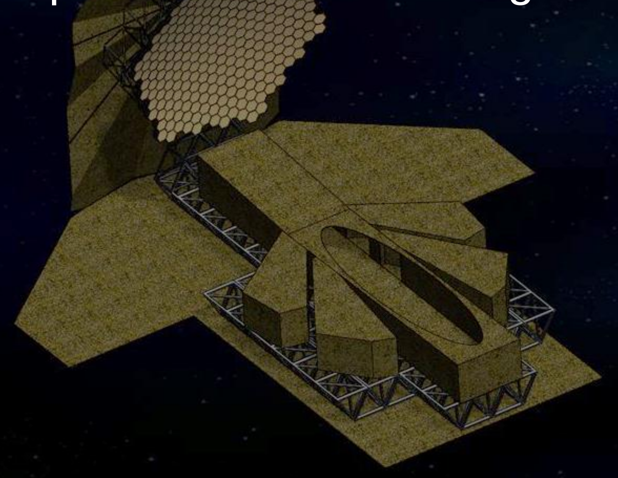


Key Risk Benefits Enabled by iSA

- Eliminates complex autonomous self-deployments.
- Mitigates the risks associated with a single LV or deployment anomaly.
  - Faulty modules can be replaced during commissioning
  - Or, with servicing, during operations.
  - *Launch failure need not be mission failure.*
- Modularization enables faults and anomalies to be more readily contained and not propagated.
- Multiple LV vendors reduces programmatic risk of depending on a specific vendor in case of over-subscription or anomaly.

iSAT will also have Challenges/Drawbacks

– **iSAT operations not required in single LV deployment approach:**
  - Phases A and B likely longer durations
  - Space AI&T is a new engineering development
  - Robotic arms autonomy software development
  - Robotic arm testbeds demonstrating assembly and sequences
  - In-space rendezvous and capture operations
  - iSA contamination issues
  - Fewer anomaly resolution options while in space and more expensive
  - Ground Data Systems will have to be altered to include robotic assembly
  - Multi-decade lifetime may require additional component dev and testing



(Interim) Key Study Findings

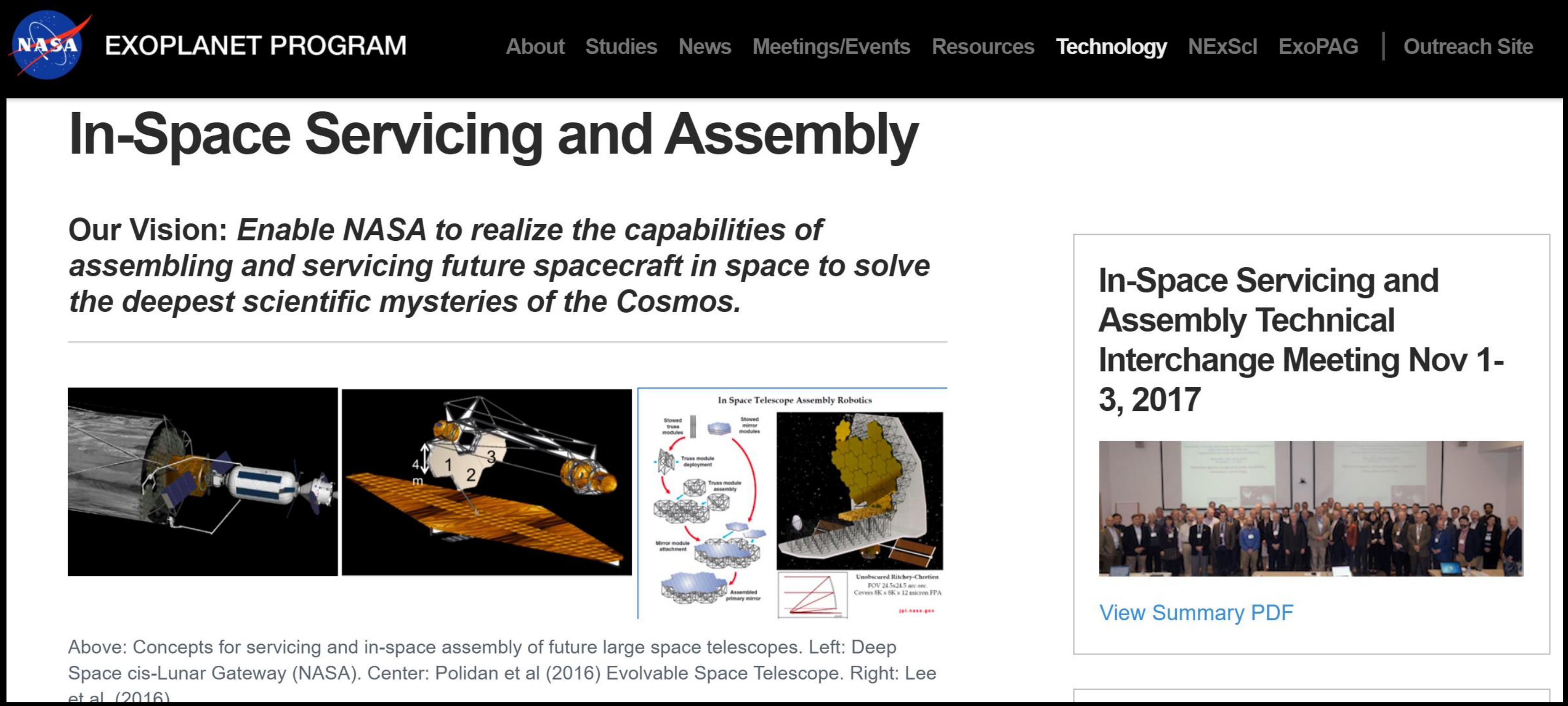
- Likely Key Finding 1: *No technical showstoppers for iSAT have been found.*
  - Further engineering dev required in several areas; some tech gaps.
- Likely Key Finding 2: Current telescope cost models are inadequate
  - *Mass can be your friend.*
- Likely Key Finding 3: iSAT offers a natural solution to the servicing dilemma.
- Likely Key Finding 4: iSAT offers the possibility of leveling annual funding levels if deemed a priority.
- Likely Key Finding 5: iSATs can be achieved without astronauts and external platforms such as the Gateway or the ISS
- Likely Key Finding 6: *iSA is clearly enabling for telescope sizes that don't fit (even when folded) in fairings of existing or near future launch vehicles.*
- Likely Key Finding 7: *iSA is anticipated to be enhancing for sizes even when a deployed telescope from a single fairing is possible.* At what size?
  - Qualitative study: ~ 8-10 m
  - Quantitative study: Costing results still being reviewed

(Interim) Key Study Recommendation

Likely Recommendation: If the 2020 Astro Decadal Survey recommends a space telescope greater than 4-5 m in aperture the Study recommends:

1. NASA conduct a point design study sufficiently detailed to enable a detailed trade study between the different implementation approaches.
2. If iSA is found to be advantageous then implement an engineering and technology program to advance key technologies to TRL 5 before a mission start.

iSAT Website



https://exoplanets.nasa.gov/exep/technology/in-space-assembly/iSAT_study/