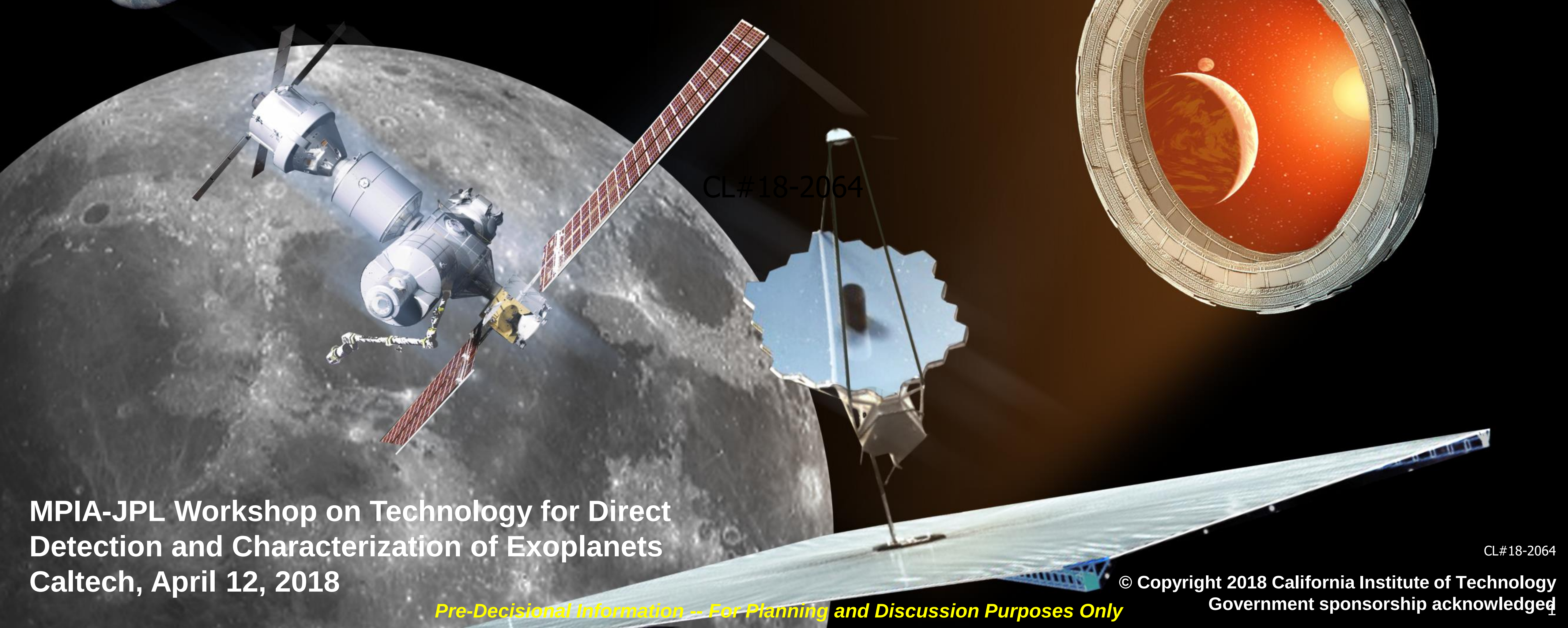
Jet Propulsion Laboratory
California Institute of Technology

Building the Future:
in-Space Servicing & Assembly of Large Aperture Space Telescopes

Nick Siegler (NASA Exoplanet Exploration Program, Jet Propulsion Laboratory, California Institute of Technology)

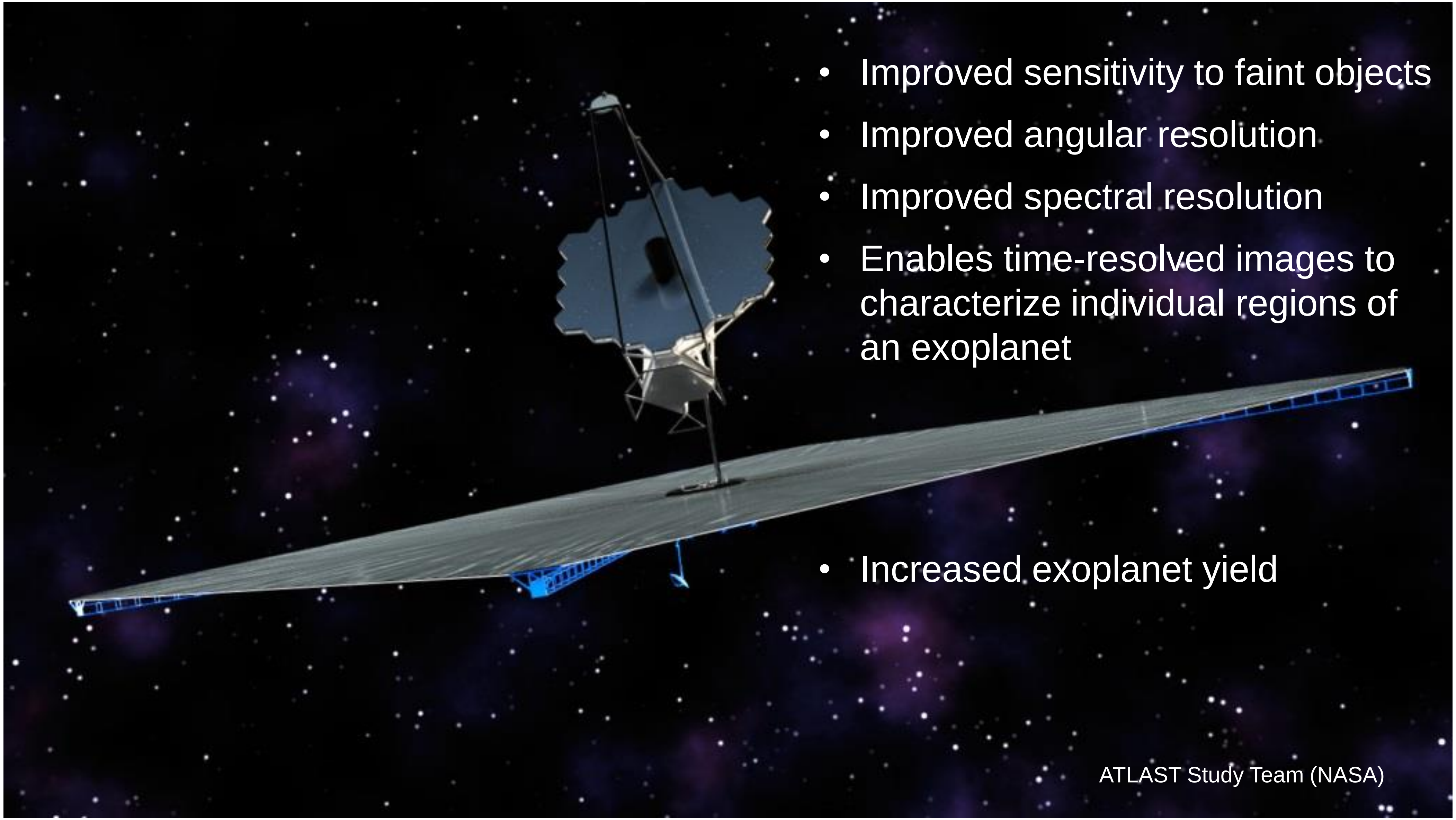


CL#18-2064

MPIA-JPL Workshop on Technology for Direct Detection and Characterization of Exoplanets
Caltech, April 12, 2018

CL#18-2064

In the Search for Life on Distant Planets Bigger is Better

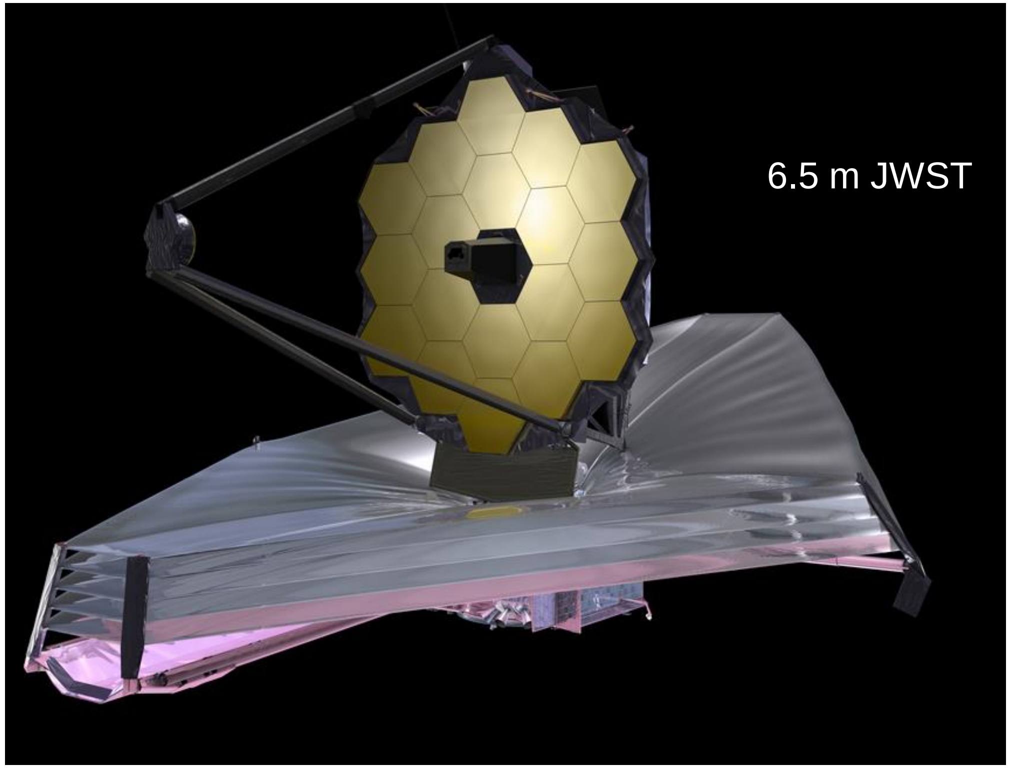


- Improved sensitivity to faint objects
- Improved angular resolution
- Improved spectral resolution
- Enables time-resolved images to characterize individual regions of an exoplanet
- Increased exoplanet yield

ATLAST Study Team (NASA)

Telescope Size Currently Limited by Deployment Complexity, Fairing Size, and Lift Capacity

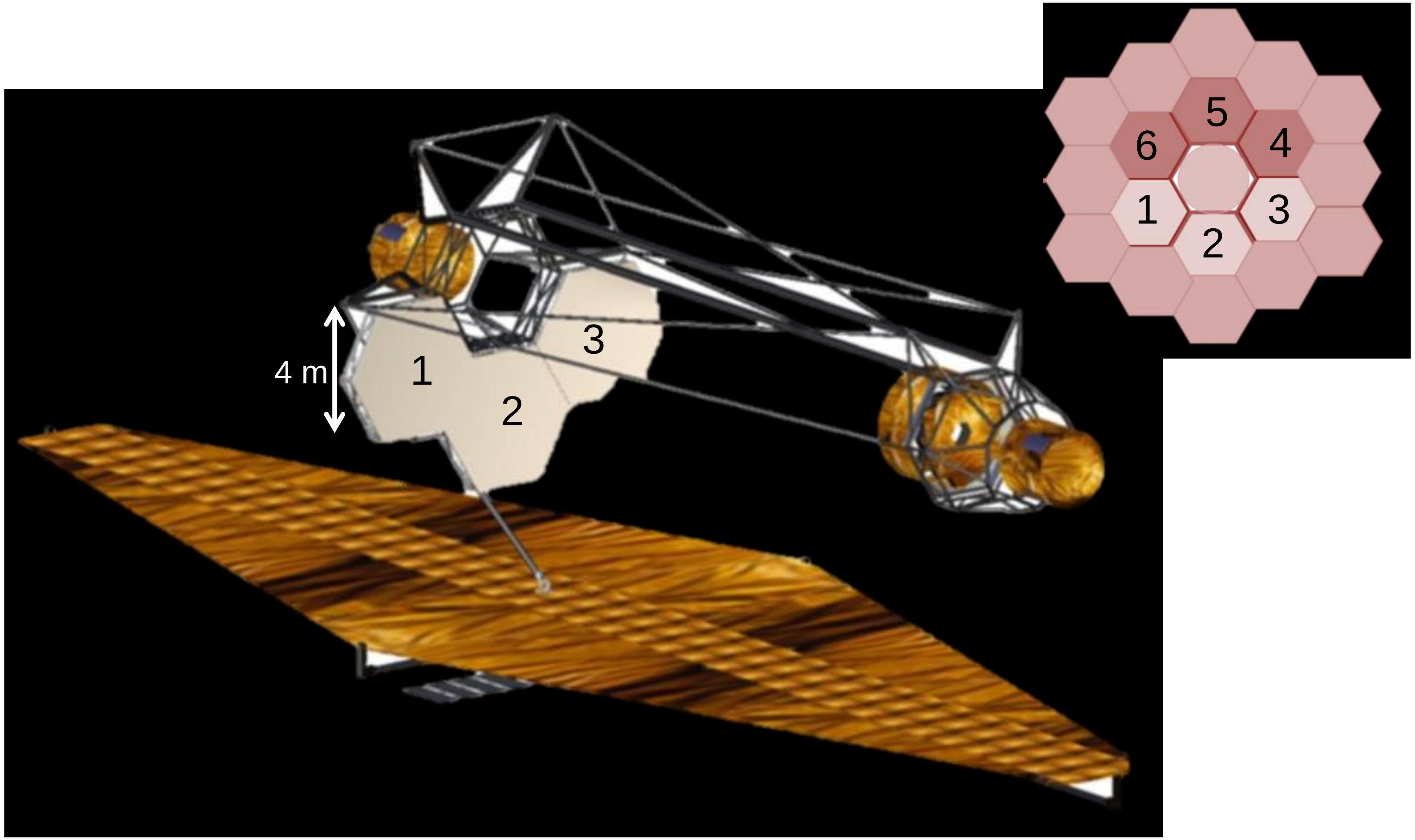
Ariane 5 (4.6 m fairing)



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

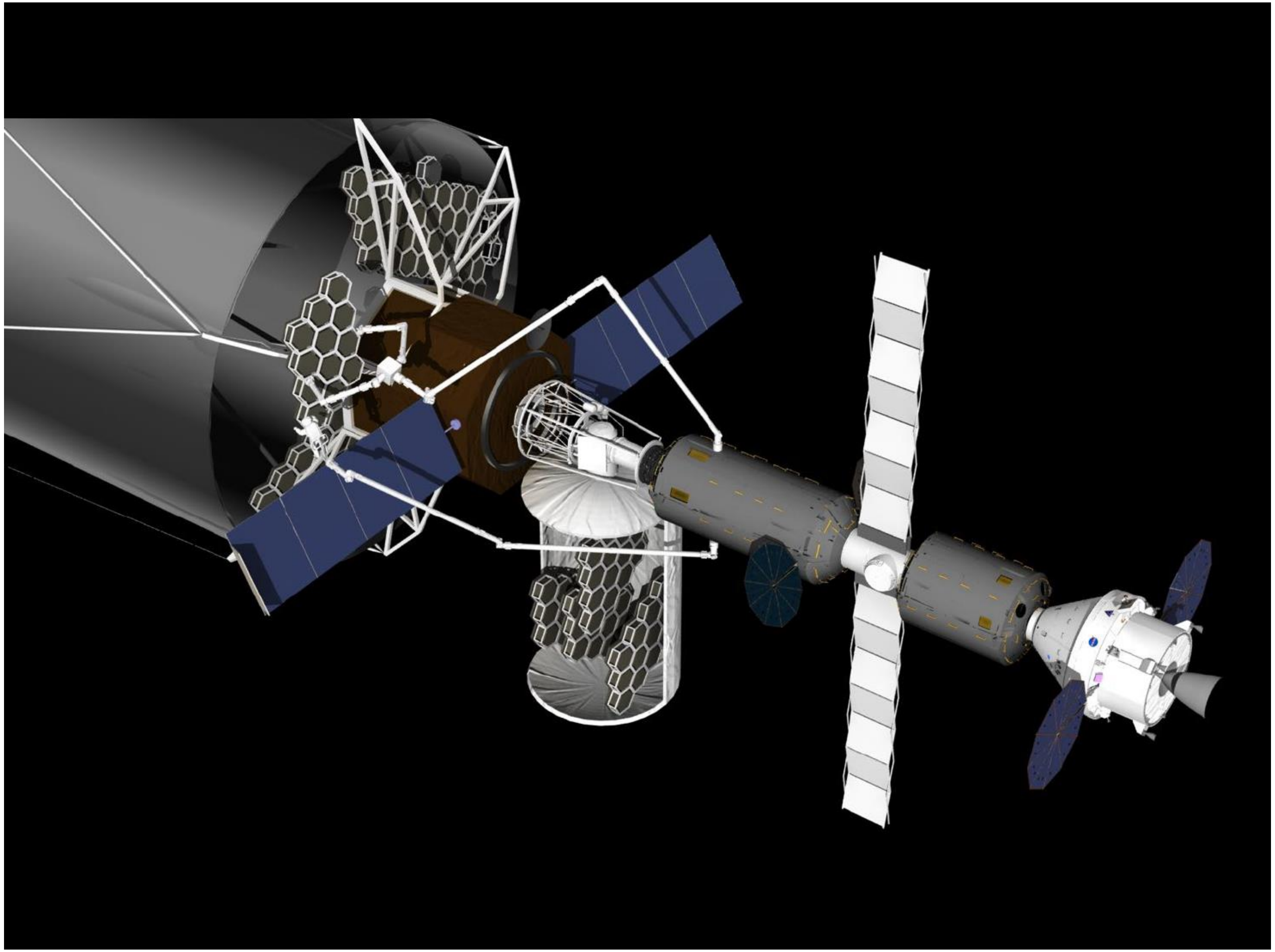
In-Space Assembly (iSA)

The Evolvable Space Telescope (NGAS)



Polidan et al. 2016

Lunar Orbital Platform - Gateway



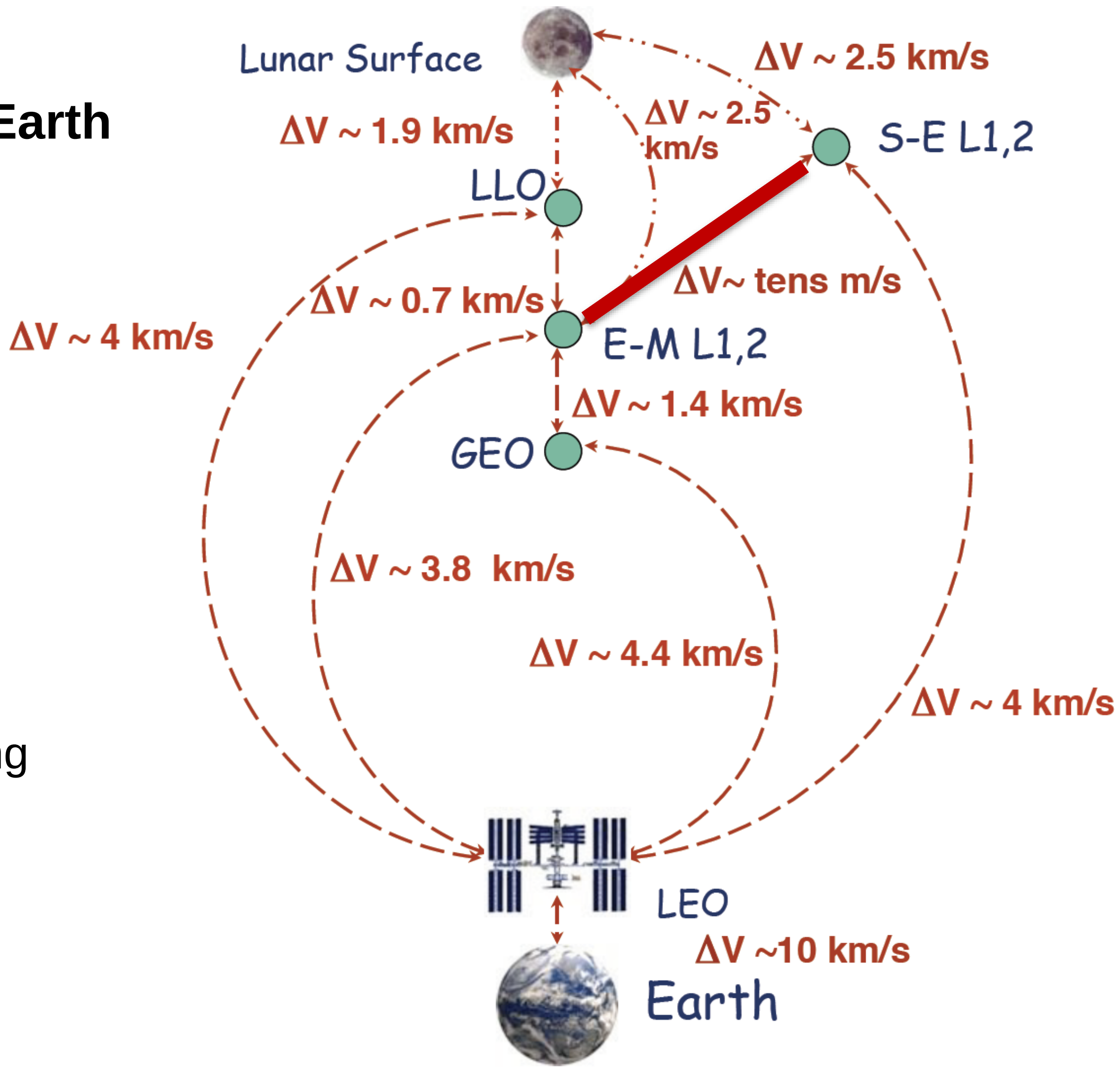
NASA

Benefits of Gateway Platform and Orbit

- **Cis-lunar orbit is ideally accessible to Sun-Earth L2**
  - Δv ~ 10's of m/s
  - Low propulsion needs to go back and forth (EML1 <---> SEL2) for servicing

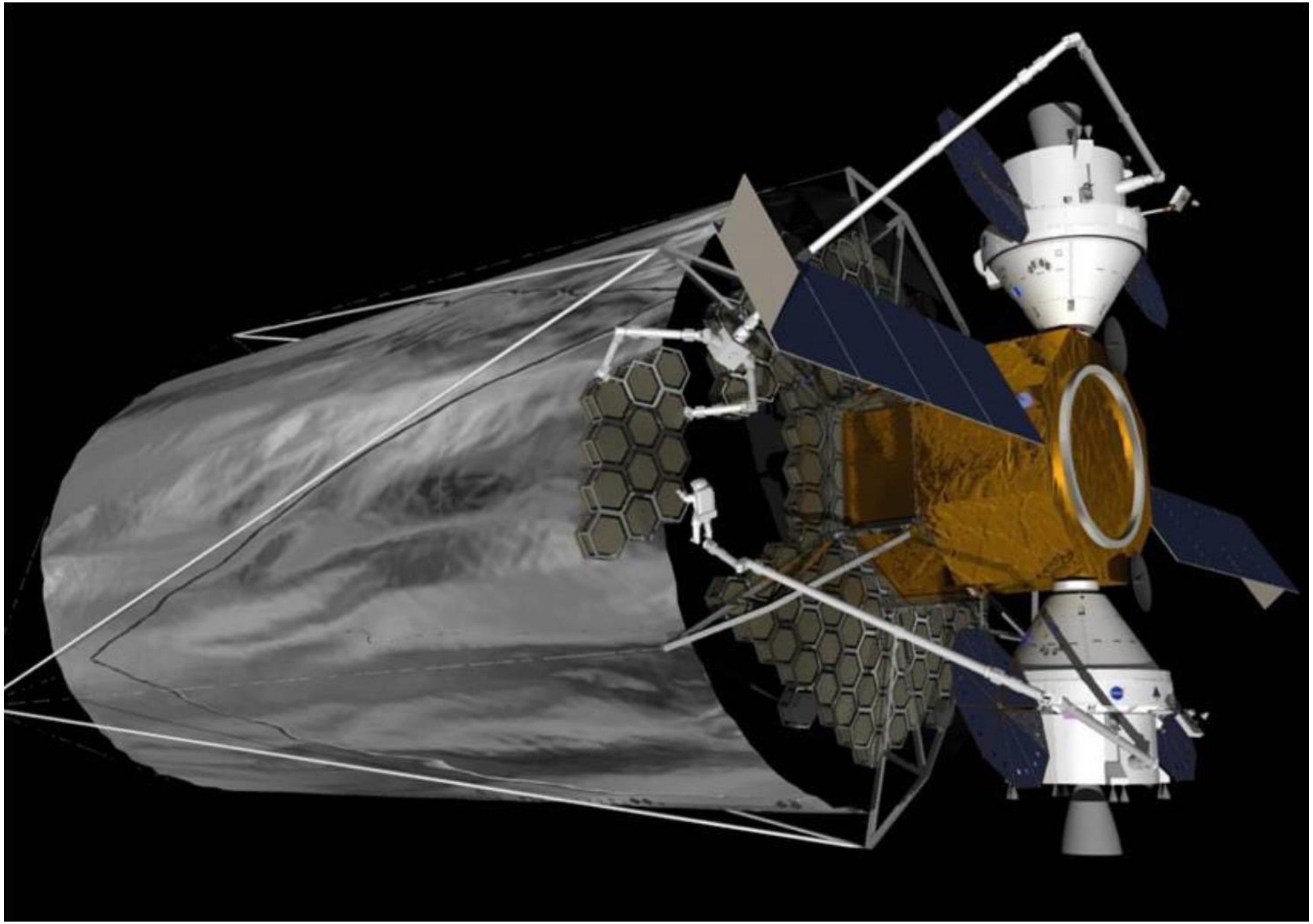
- **Expected to offer both astronaut and tele-robotics capabilities**

- **Expected to be equipped with important infrastructure**
  - High-data rate communication, versatile imaging systems, robotic arms, astronaut support



NASA's Decade Planning Team (2000)

Using the Spacecraft Bus as the Assembly Platform

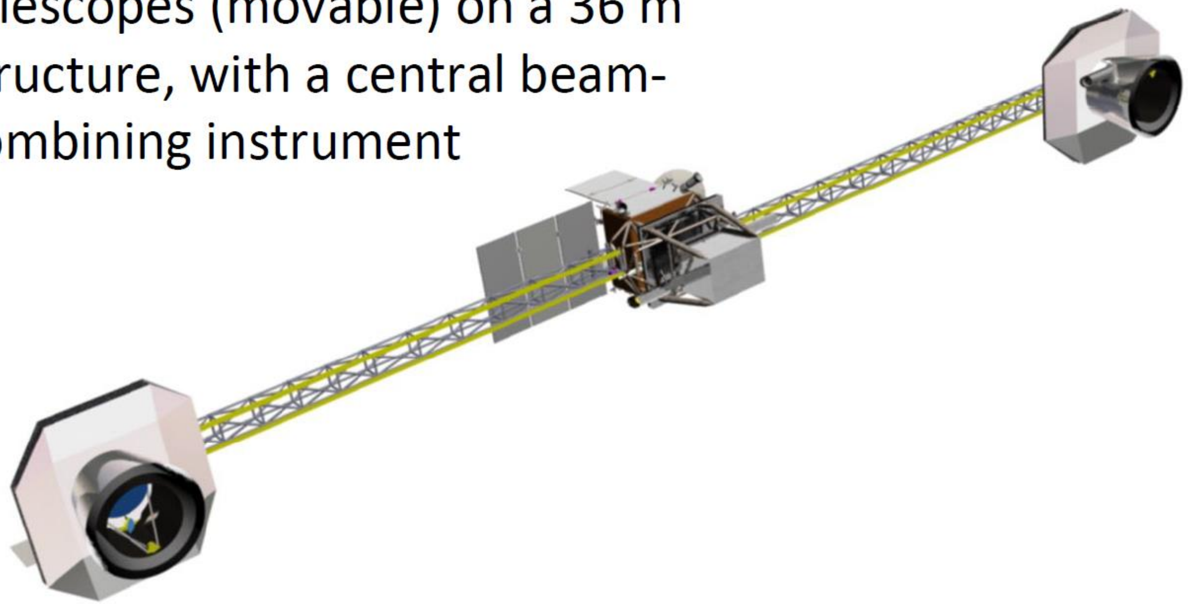


NASA

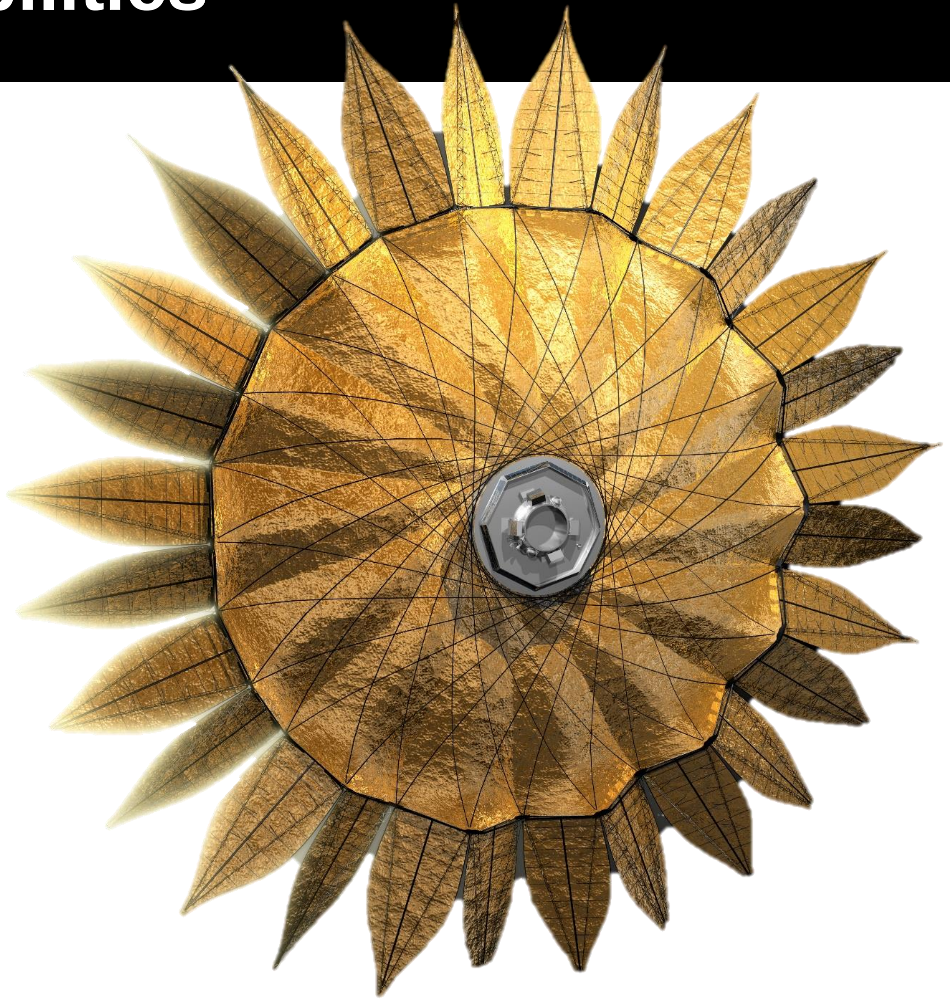
Other Spacecraft Assembly Possibilities

Interferometers

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



SPIRIT, David Leisawitz (NASA GSFC)

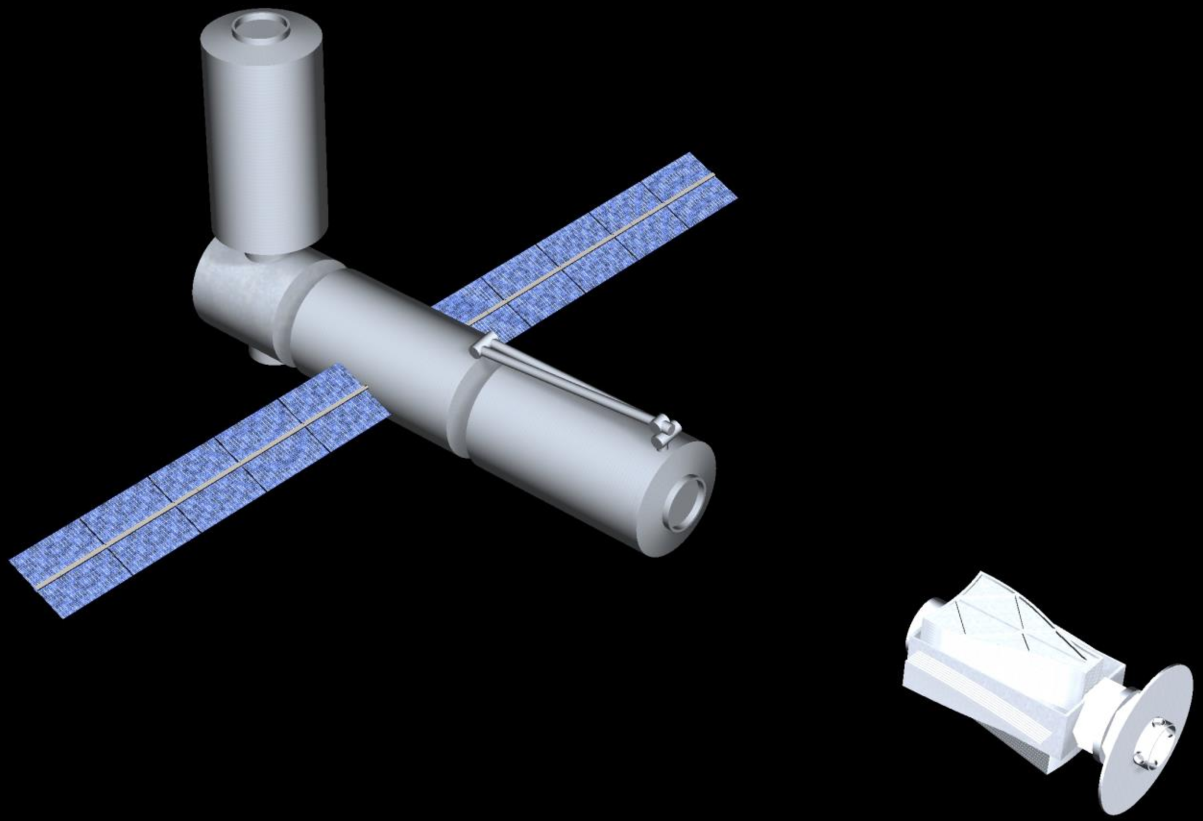


Starshades

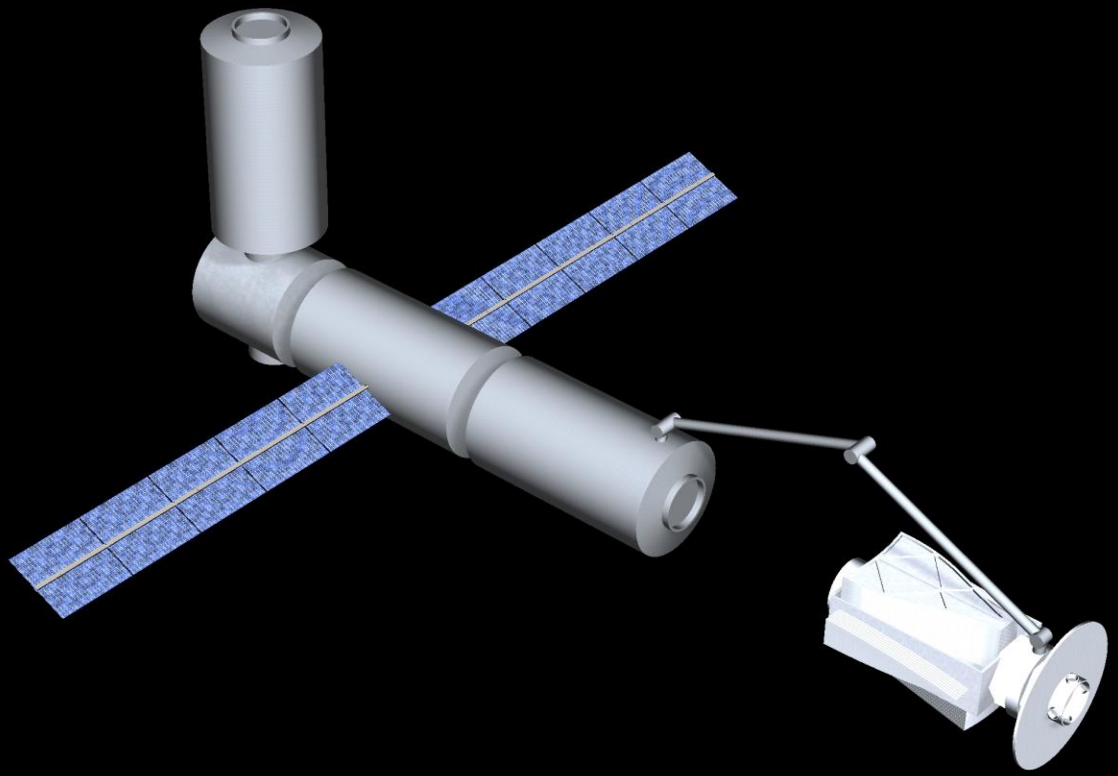
Starshade deployed to block light from central star, allowing orbiting exoplanet to be observed.

NASA/JPL-Caltech

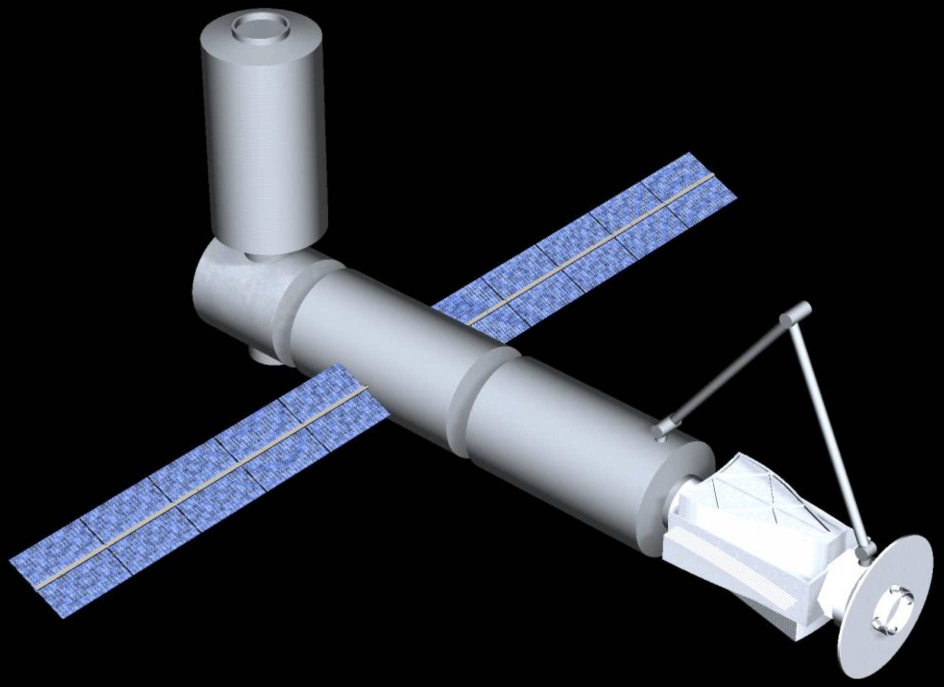
Spacecraft approaching the DSG



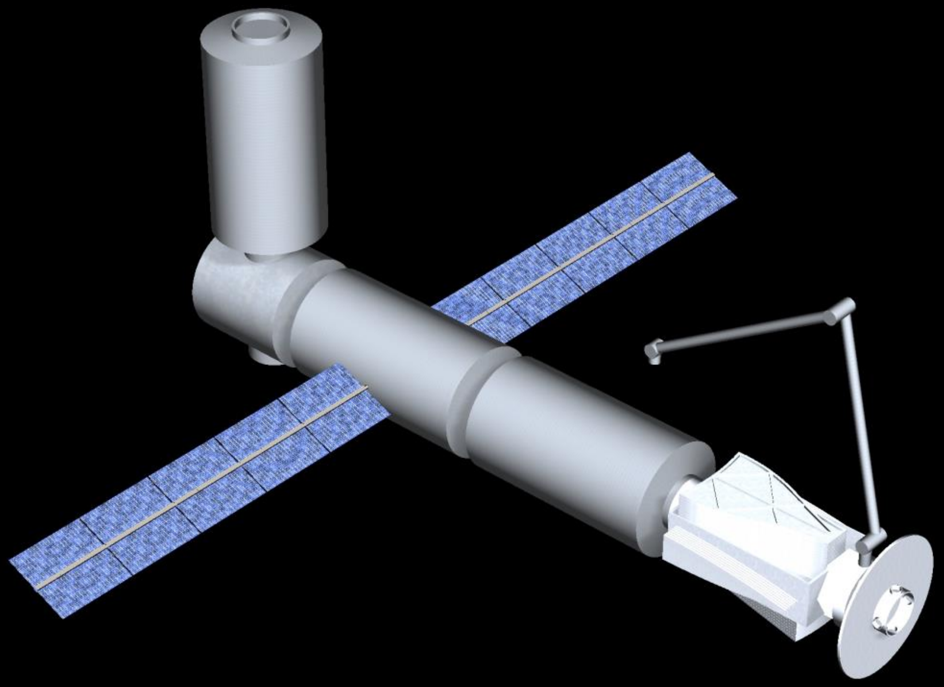
Grapple



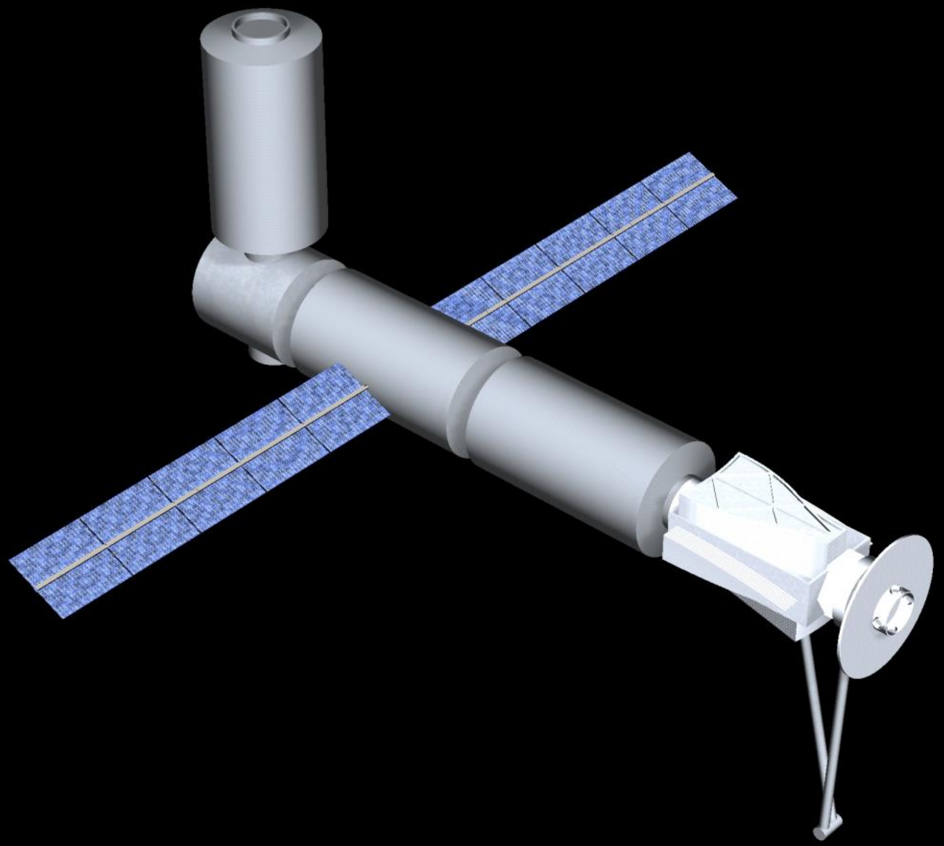
Berthed



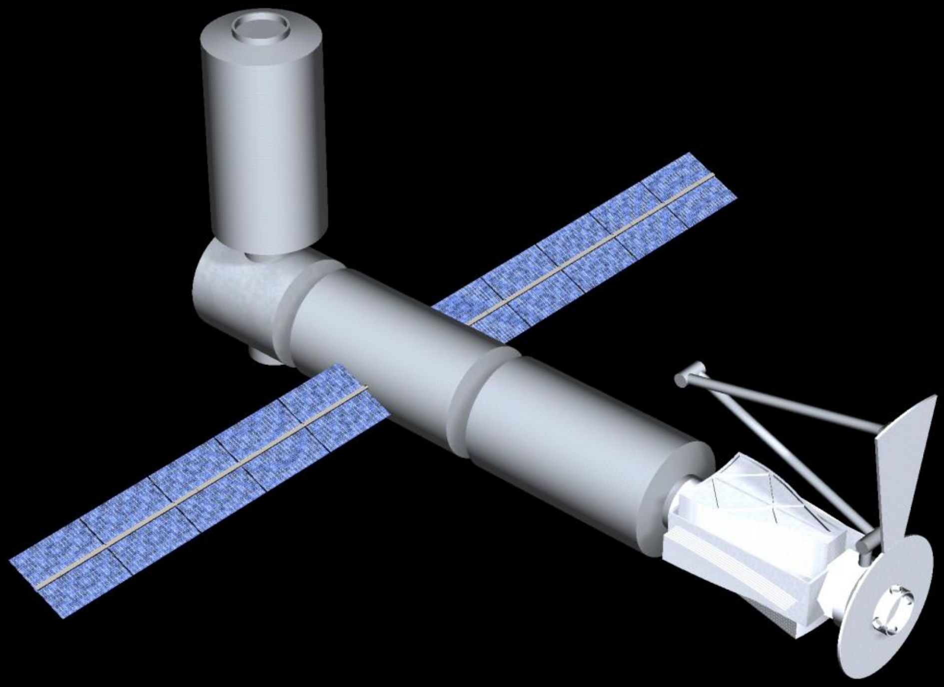
Arm Walk Off to Starshade Spacecraft



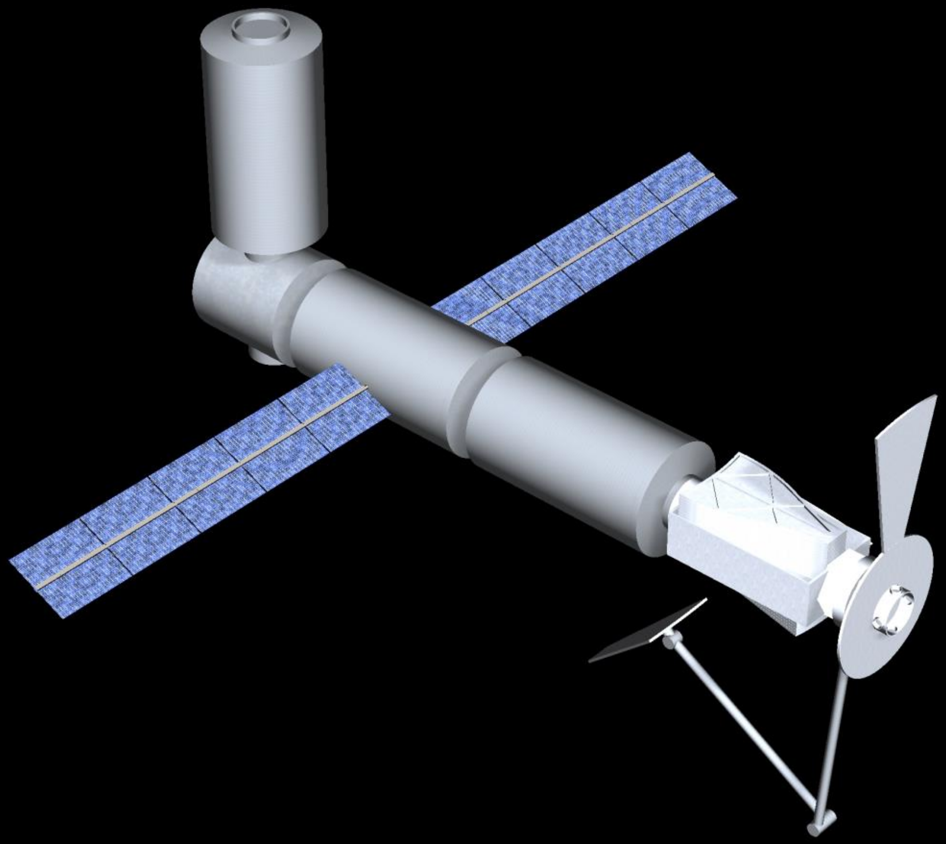
Grab Panel



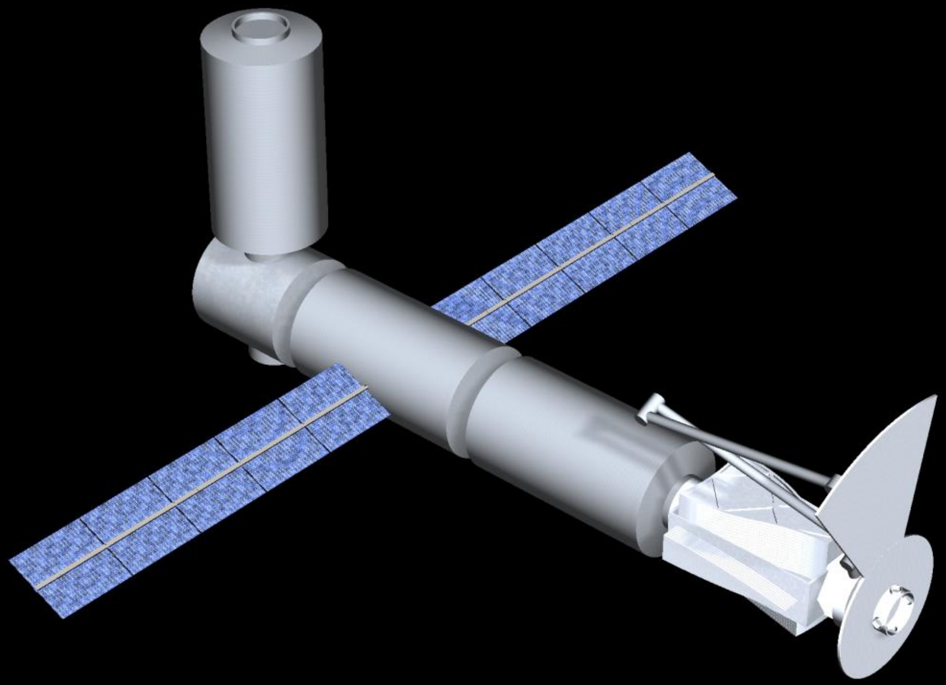
Place First Panel



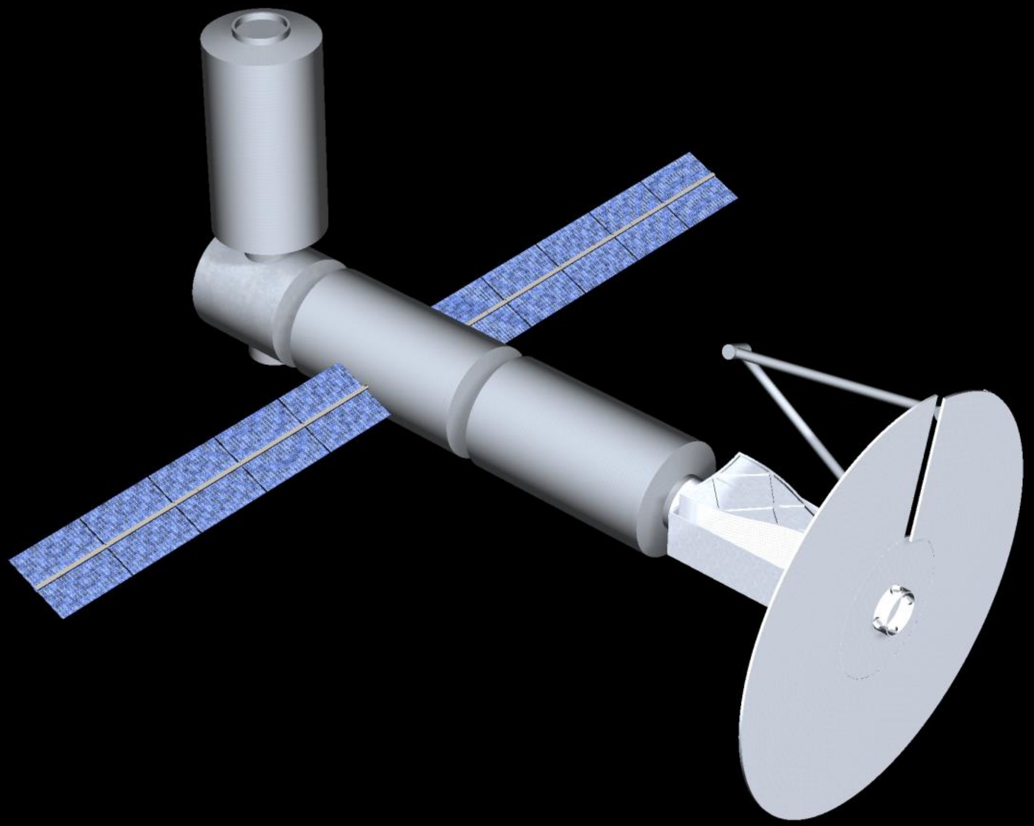
Second Panel



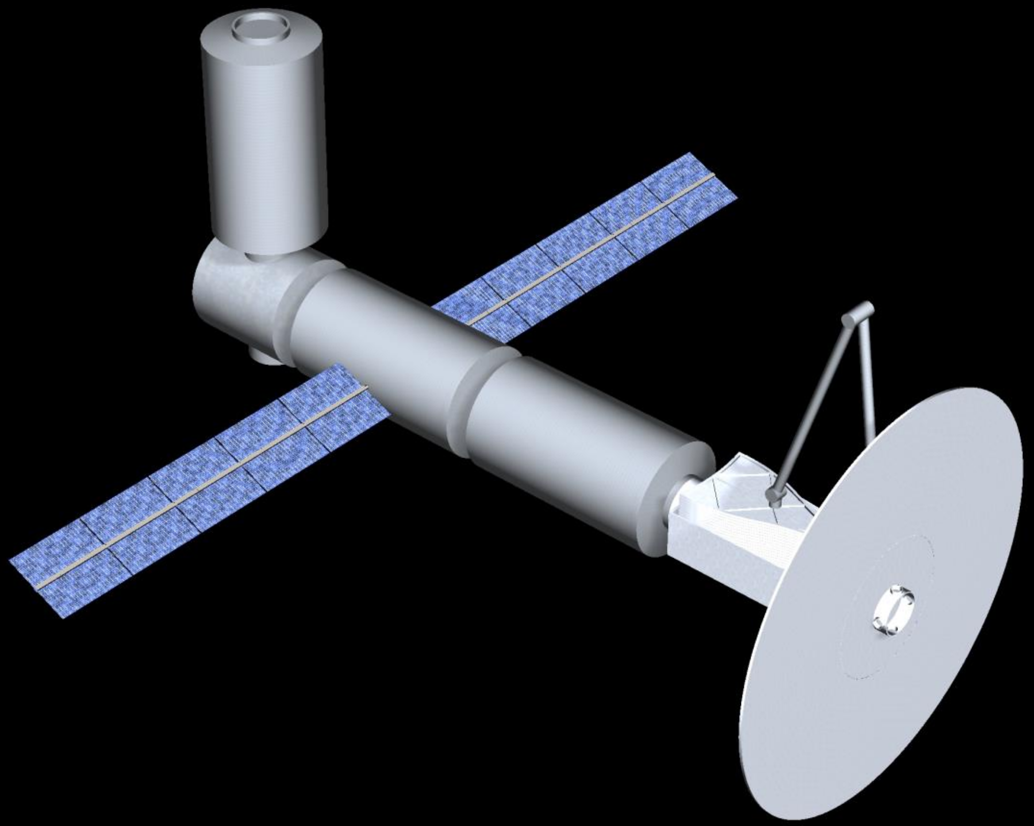
Place Second Panel



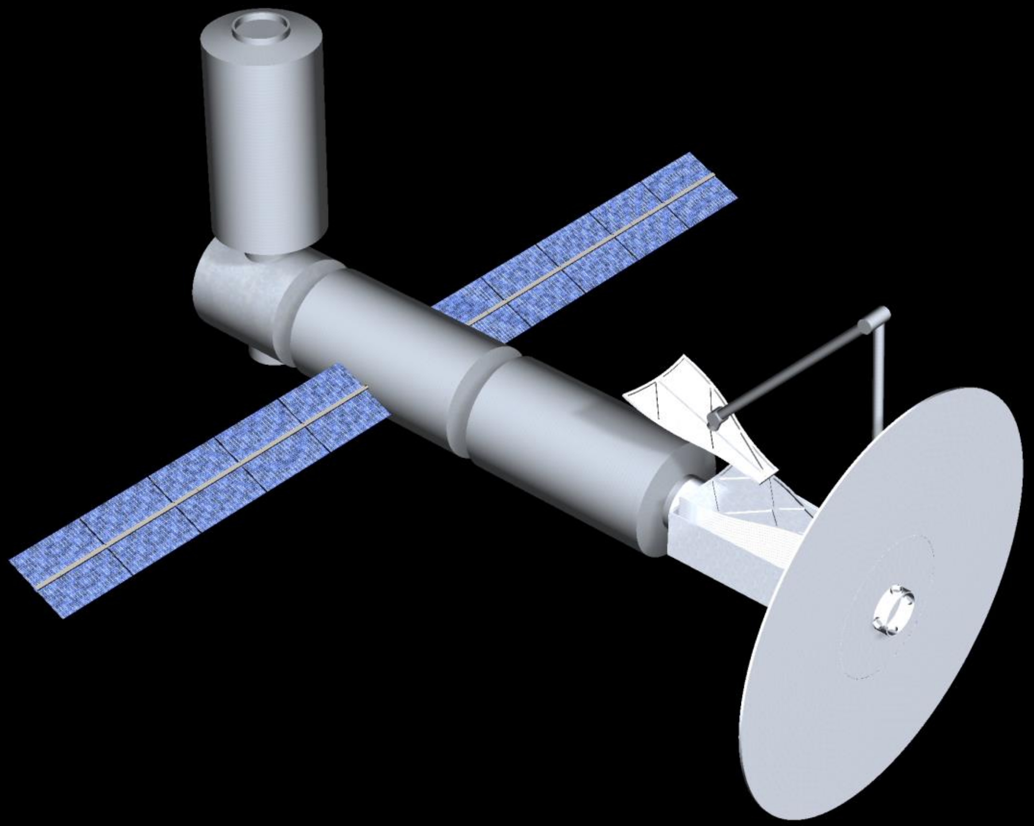
Complete Inner Ring



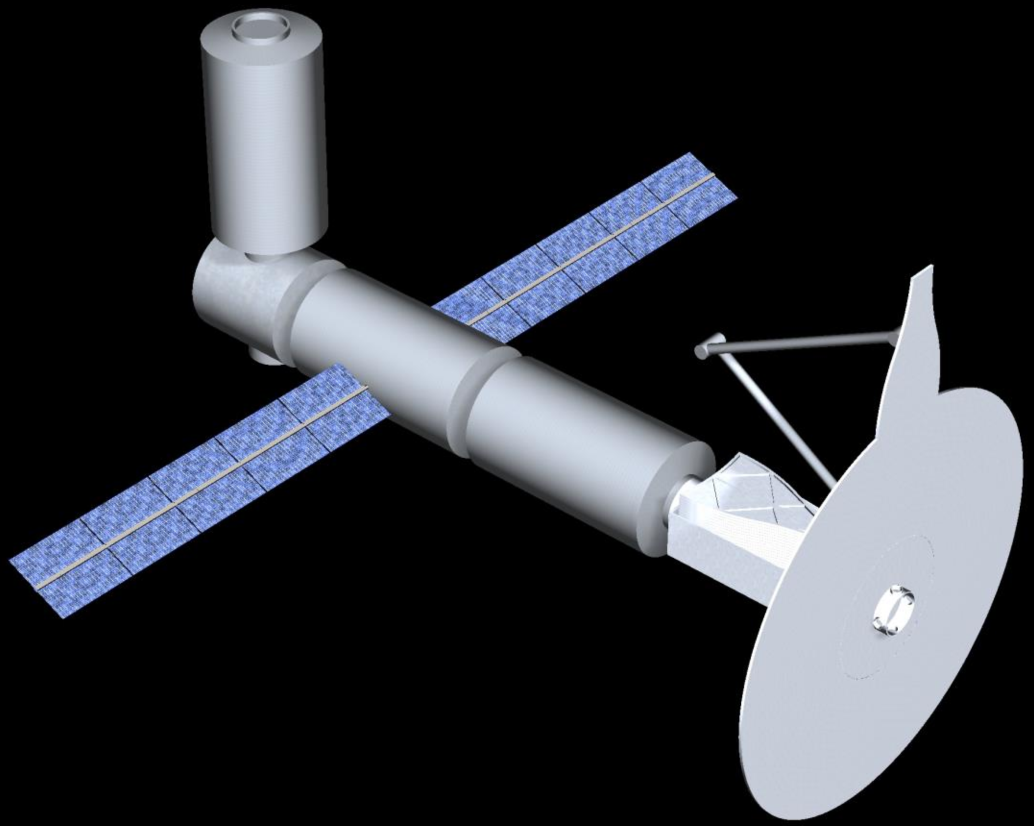
Begin Second Ring



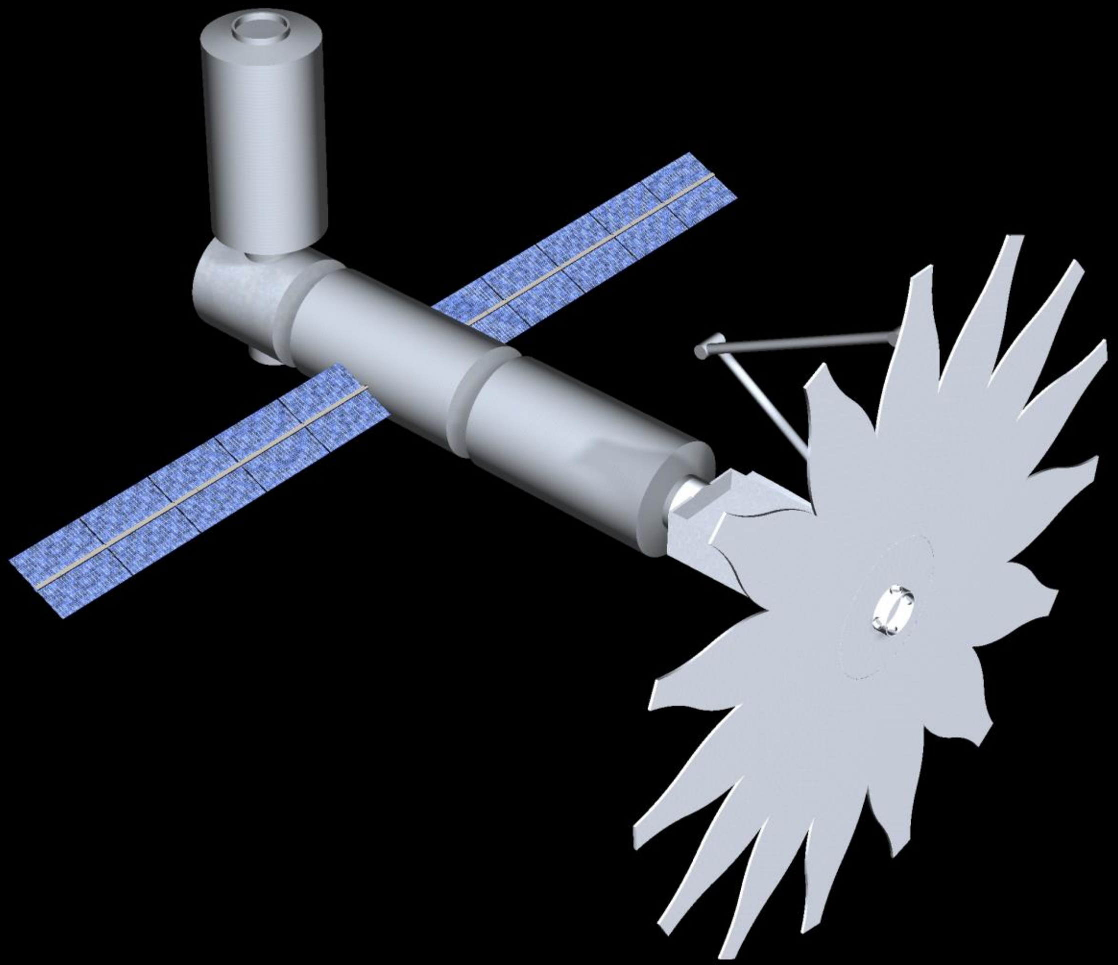
Move Second Ring Pedal



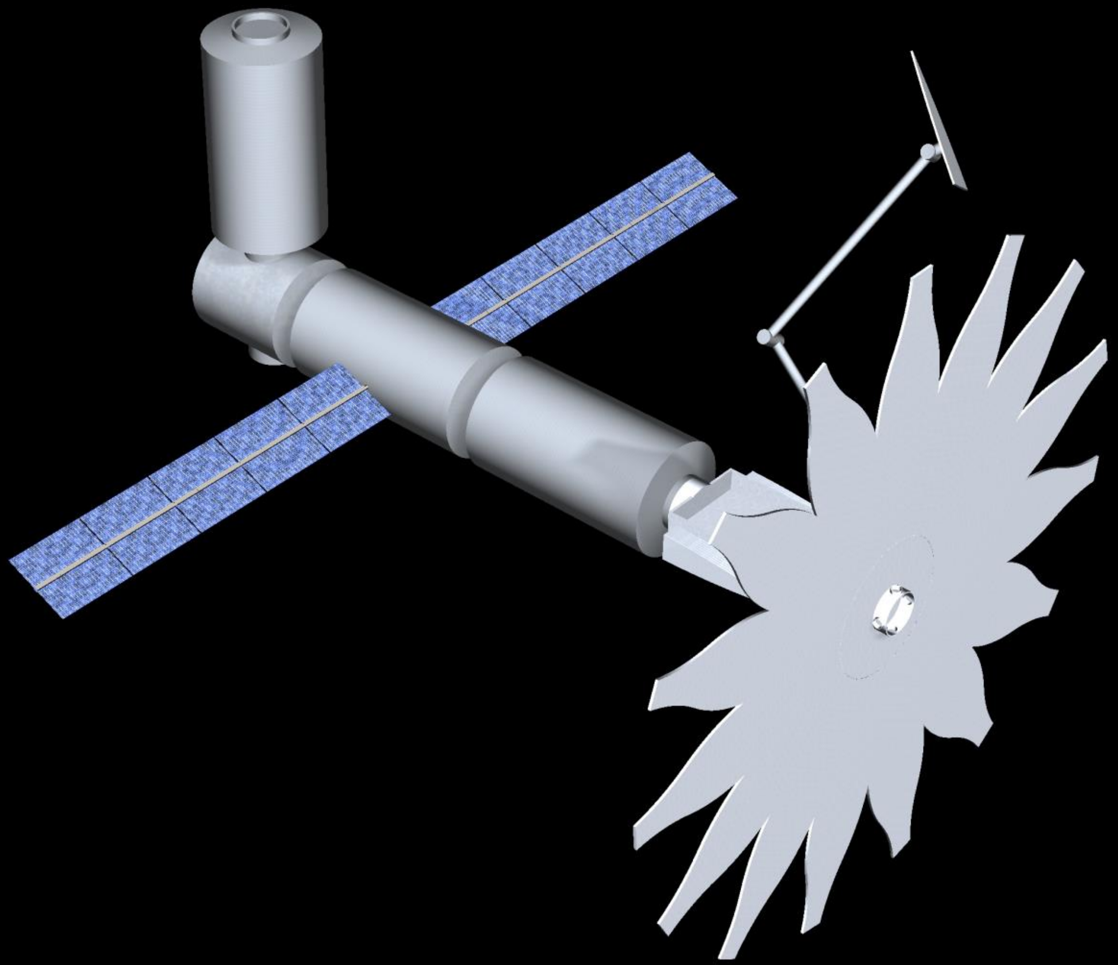
Place Pedal



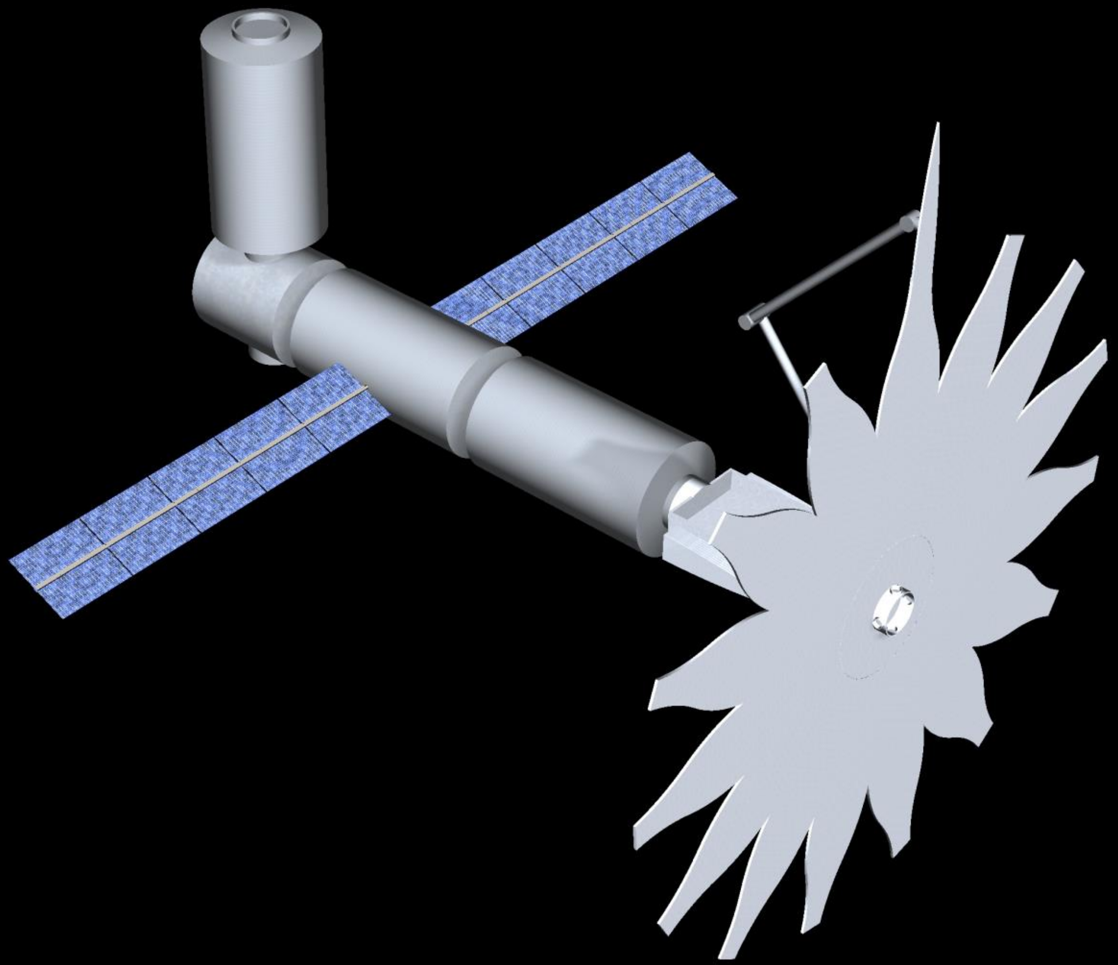
Pedals Complete



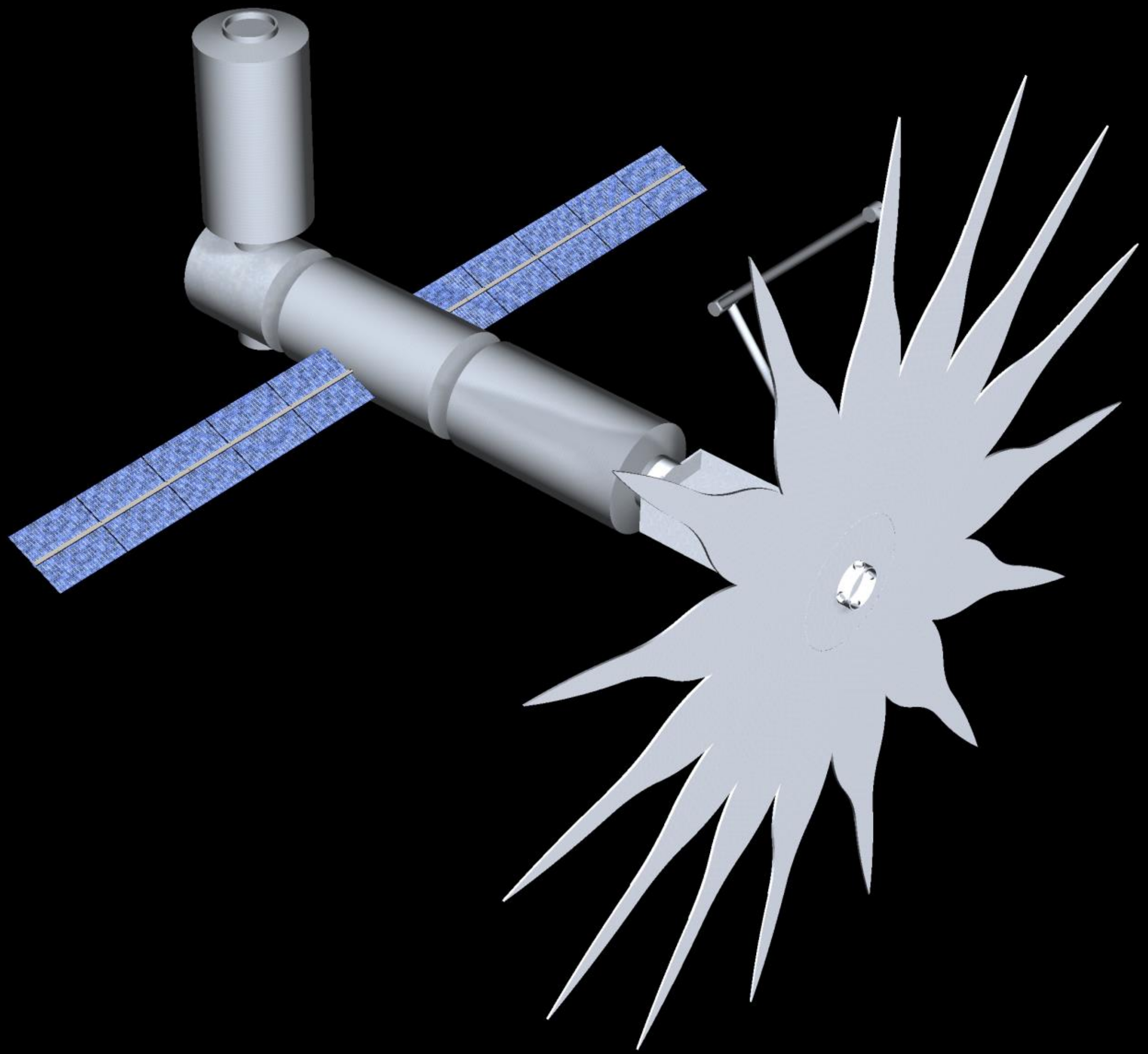
Third Ring Tip Move



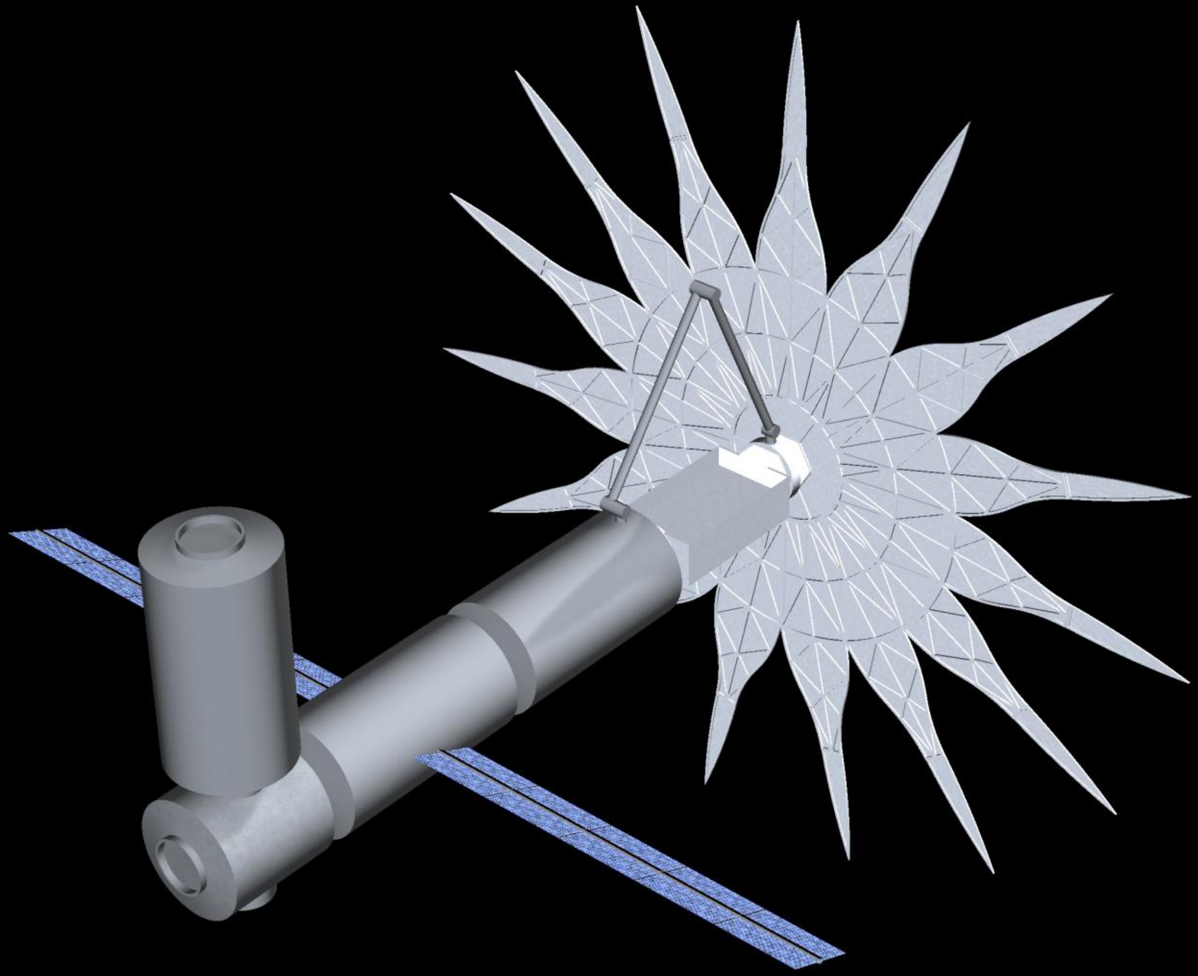
Tip Place



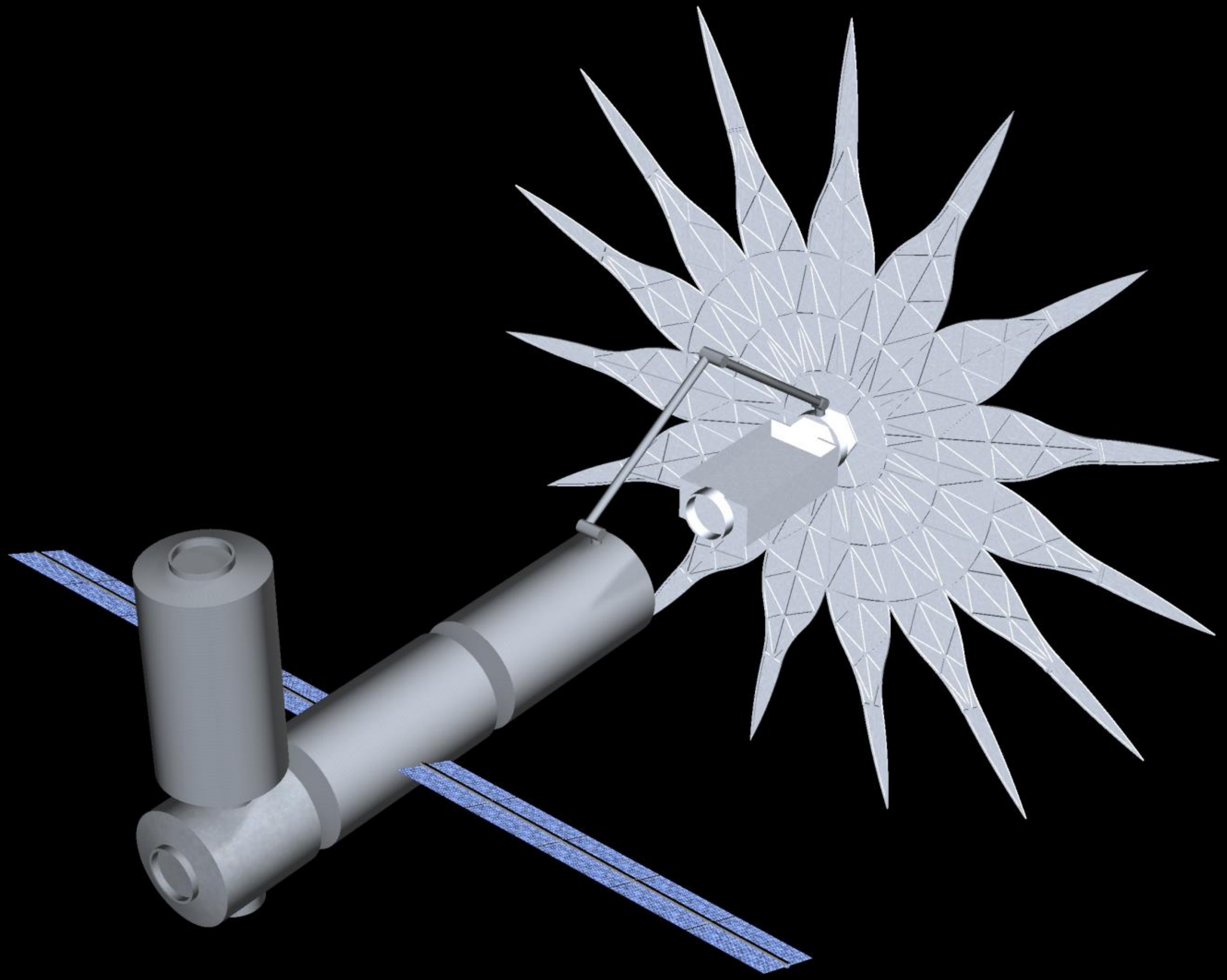
Tips Complete



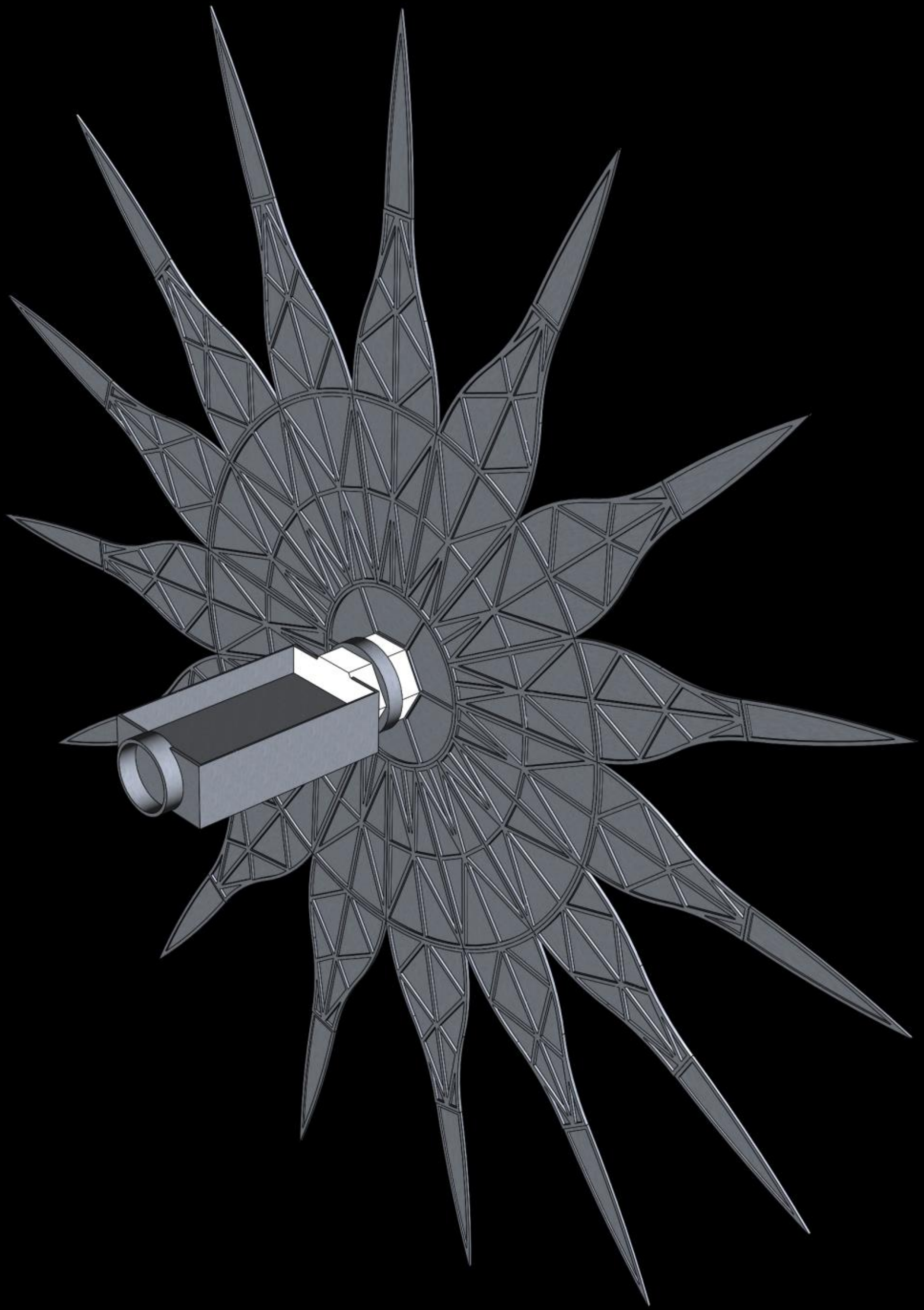
Stow Robotic Arm



Unberth

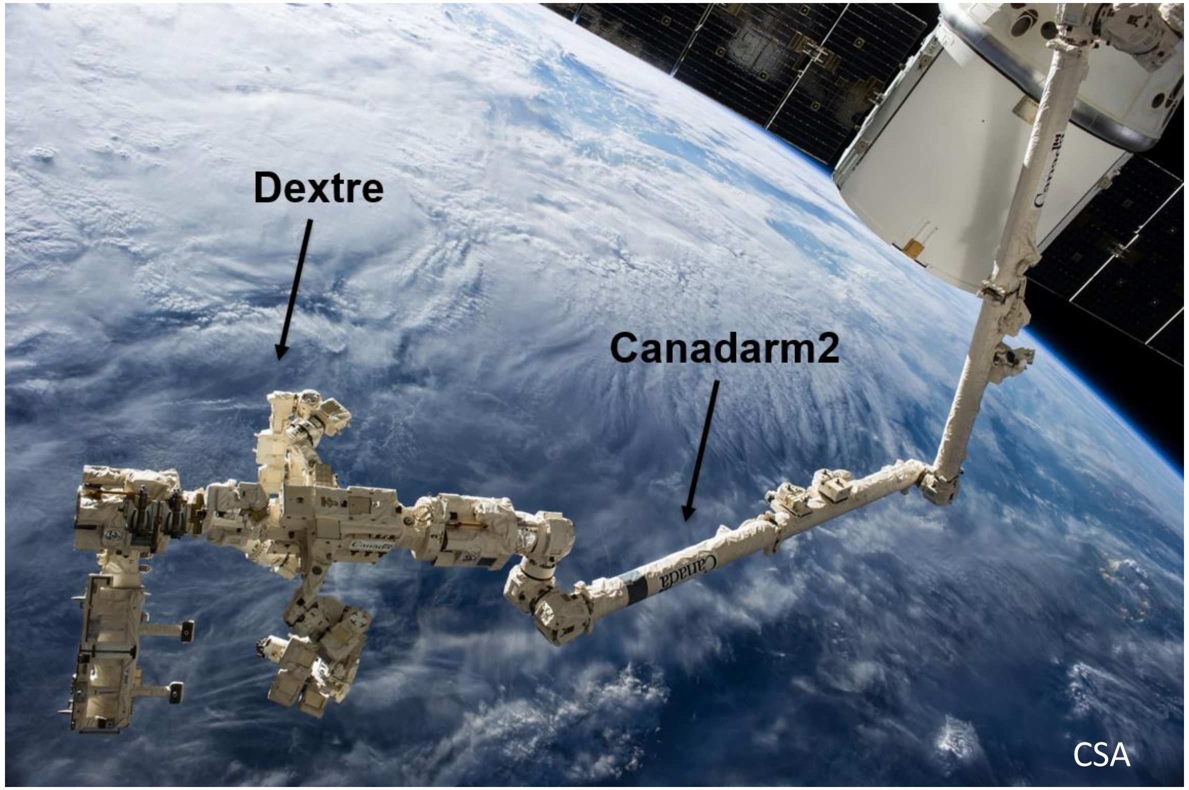


Deployed



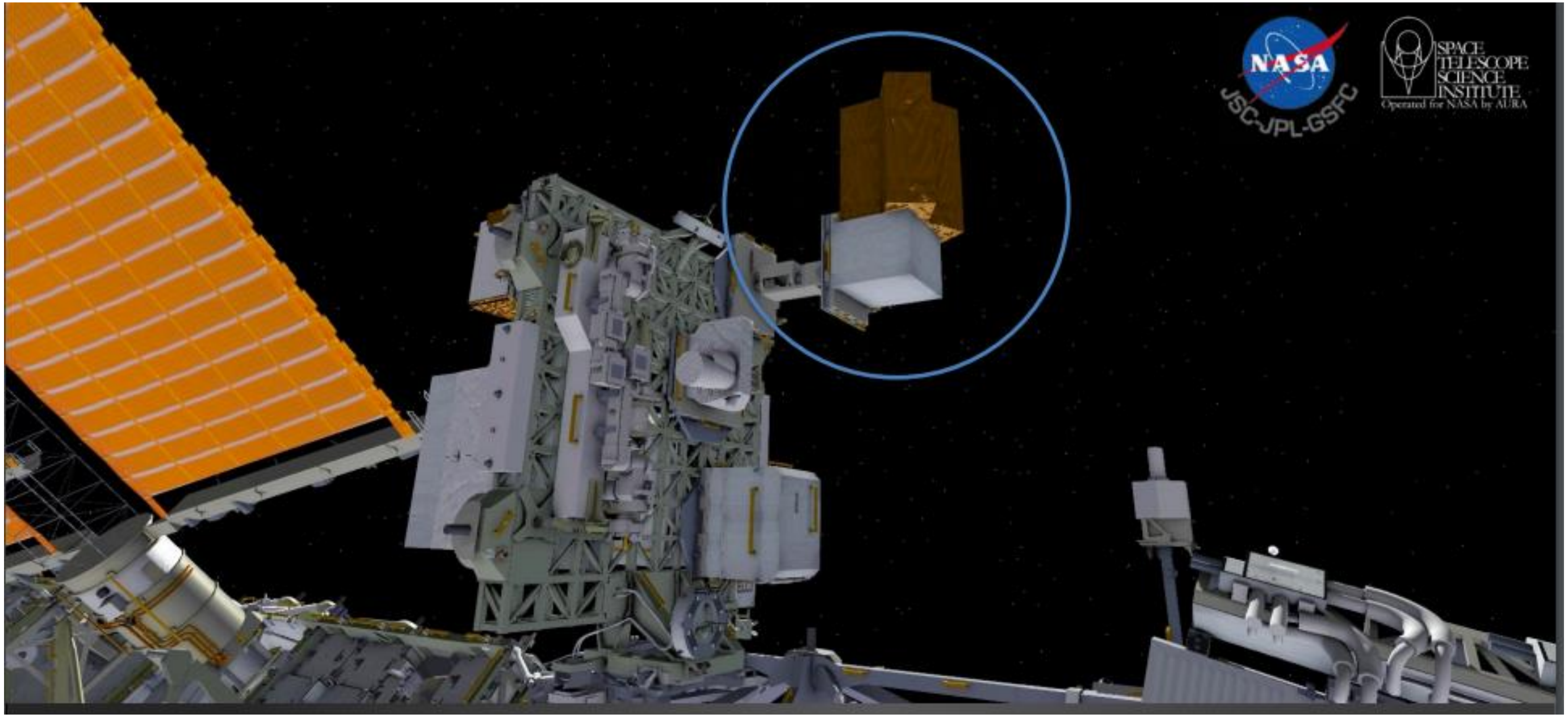
Status of Work in this Field: in-Space Assembly

ISS is the best example of large-scale assembly in space.



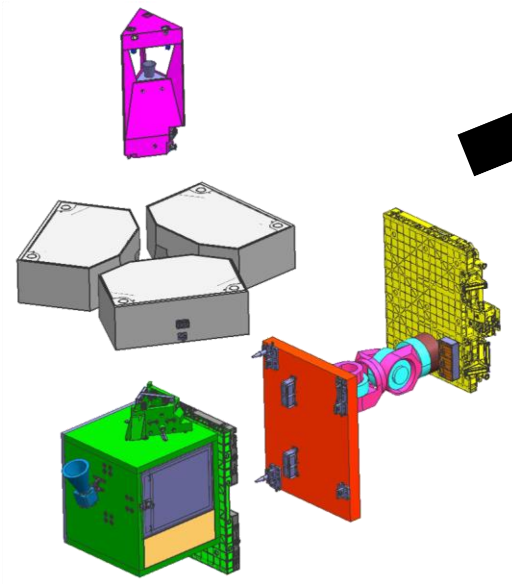
But no precision assembly activities currently planned.

Optical Testbed & Integration on ISS eXperiment (OpTIIX)

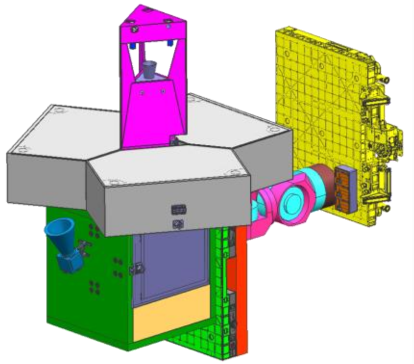


- Intended to demonstrate assembly, alignment, calibration, and operation of future space observatories
- Robotically assembled and operated

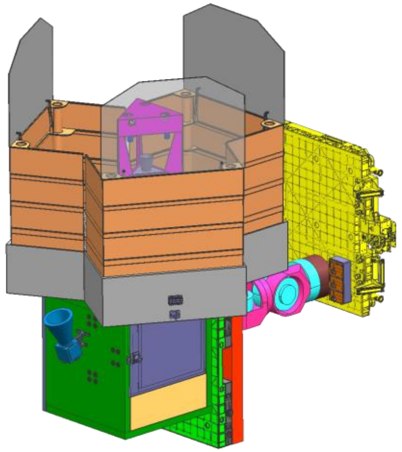
Optical Testbed & Integration on ISS eXperiment (OpTIIX)



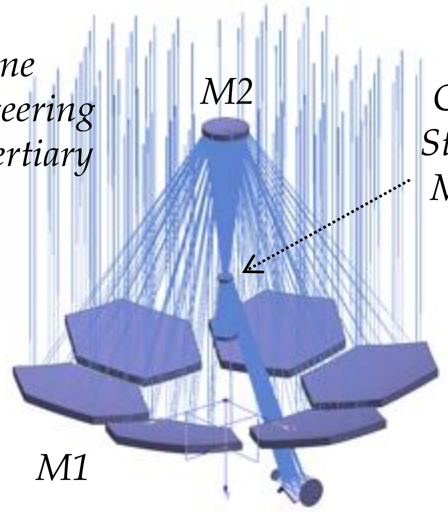
6 launch modules for assembly



Assembled modules

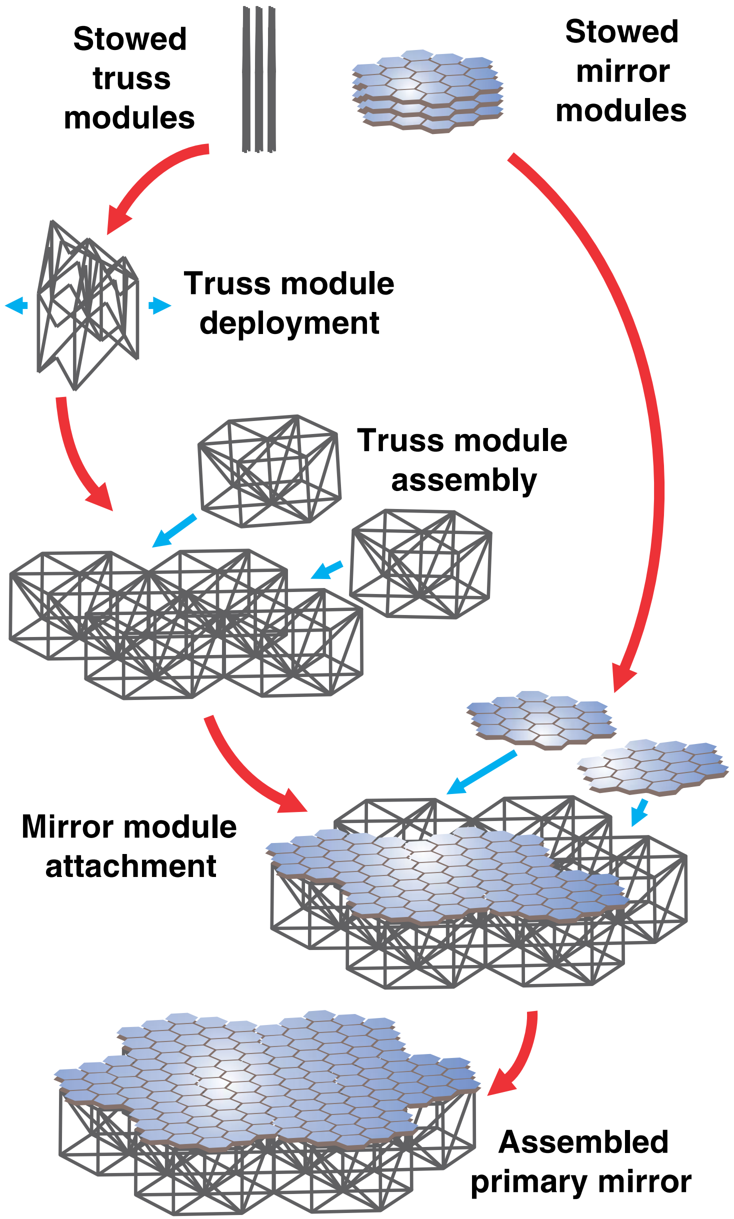


Full deployment of sunshades



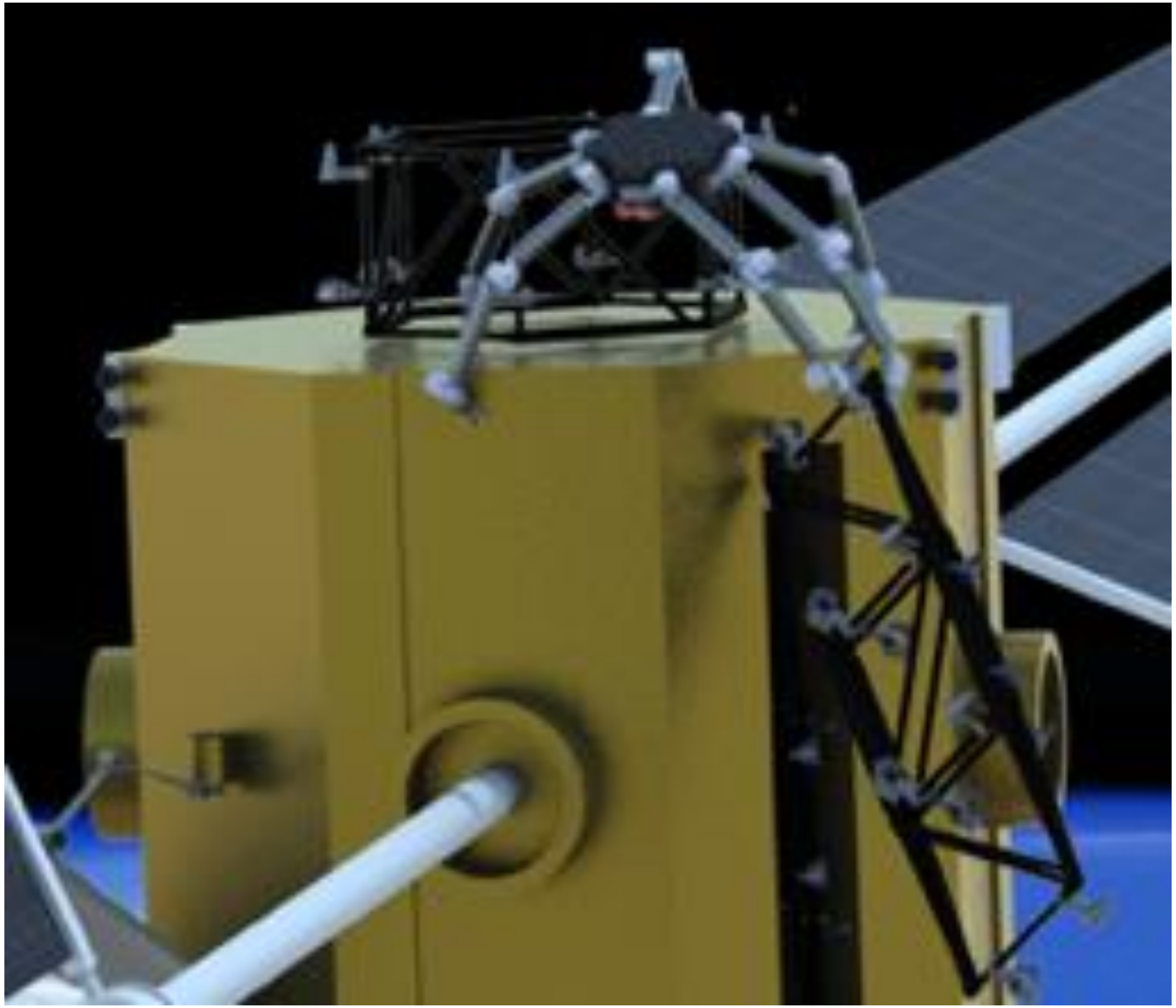
3 Mirror Anastigmat Telescope (1.45m aperture)

Robotic Assembly of a Telescope: Modular Deployable Structure



Lee et al. 2016 (Caltech/JPL)

In Space Telescope Assembly Robotics: Multi-Limbed Robot



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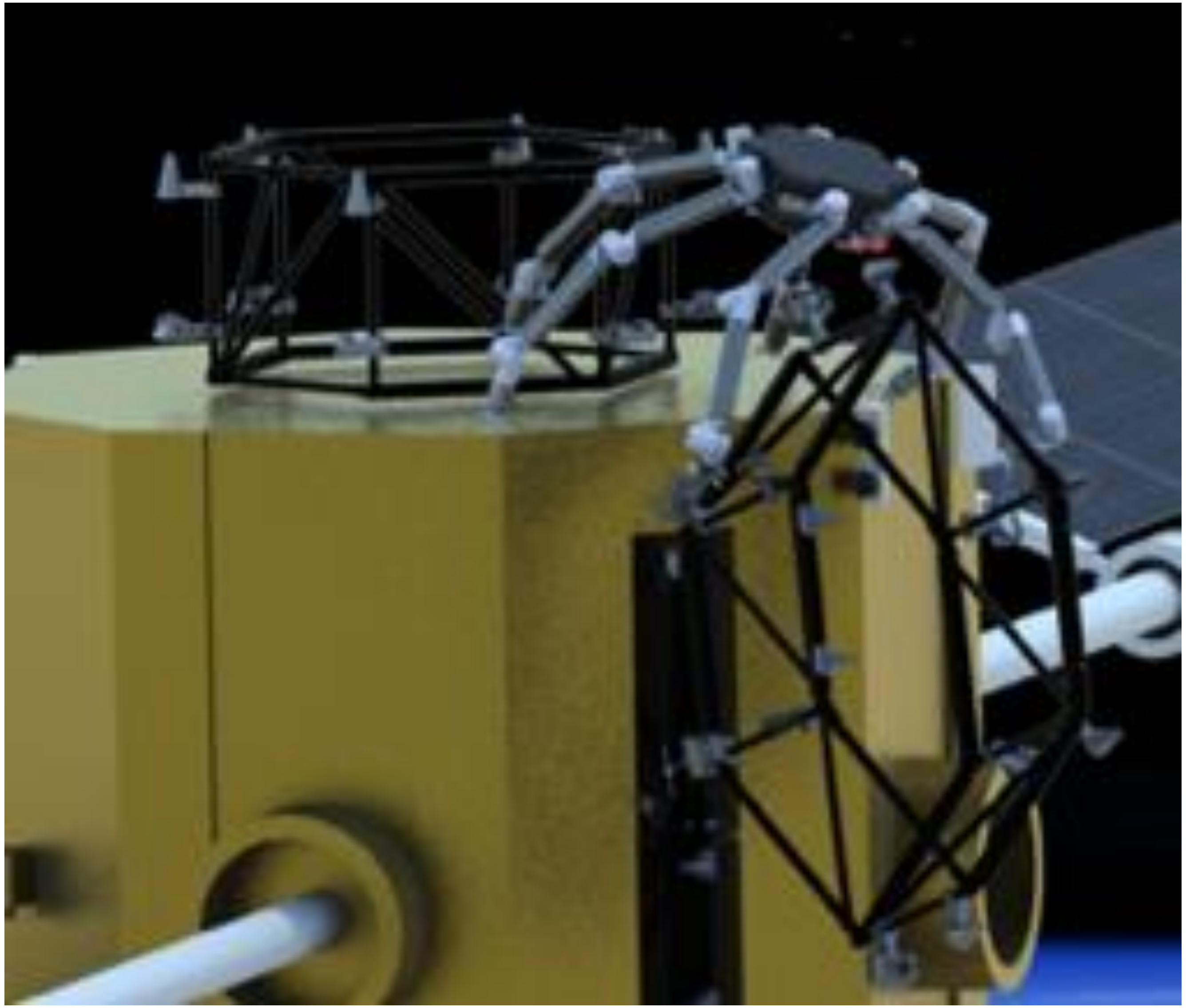

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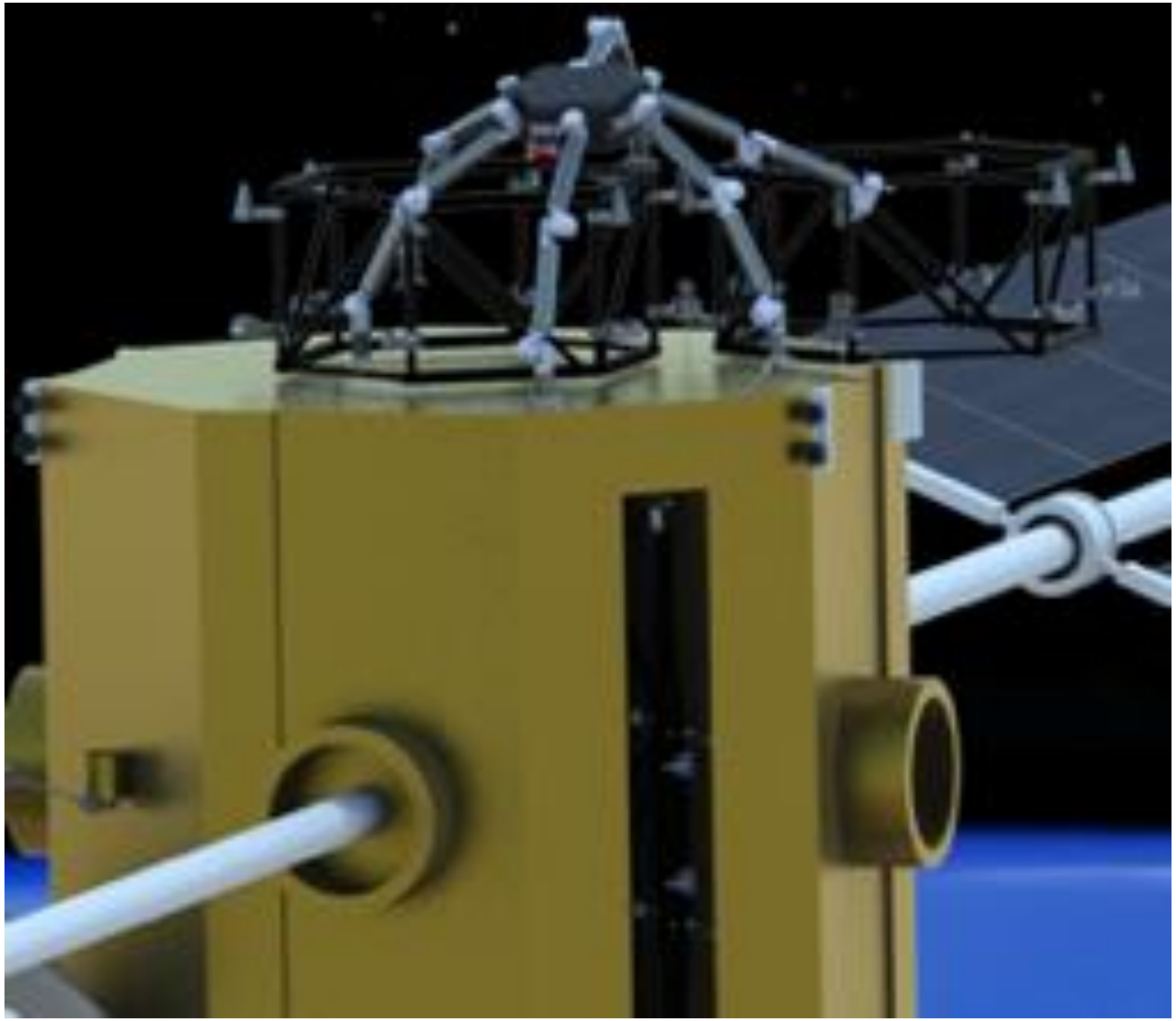

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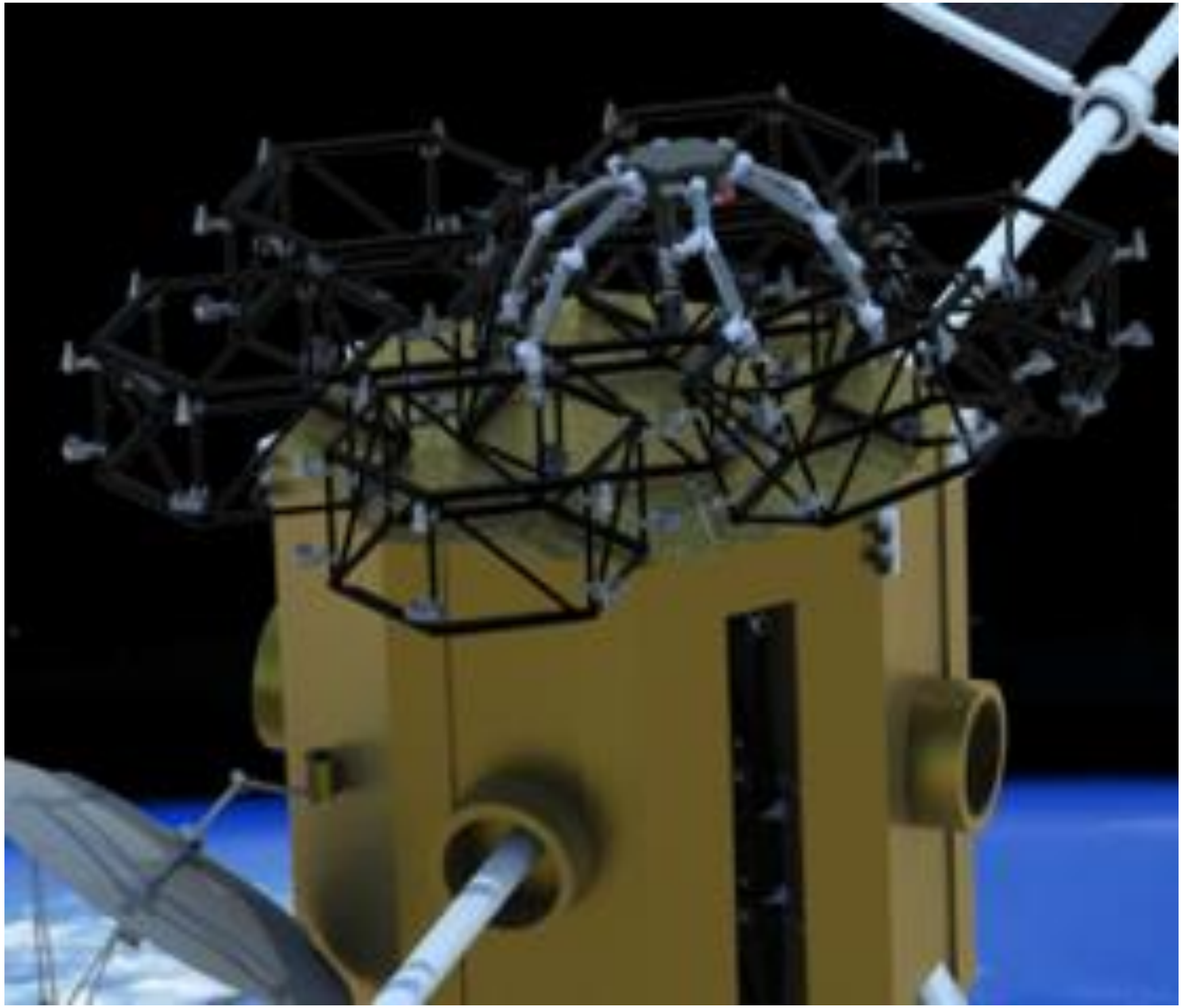

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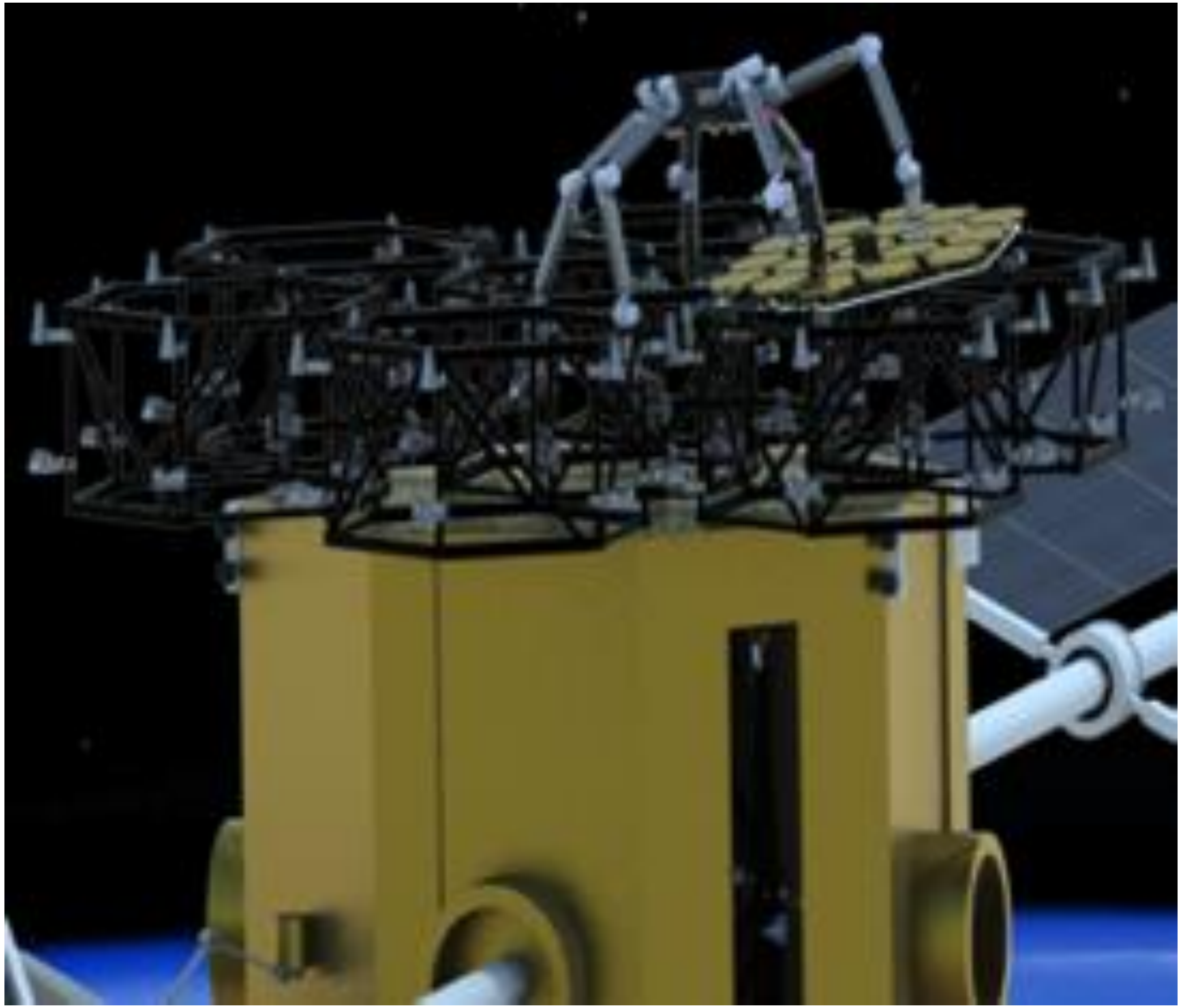

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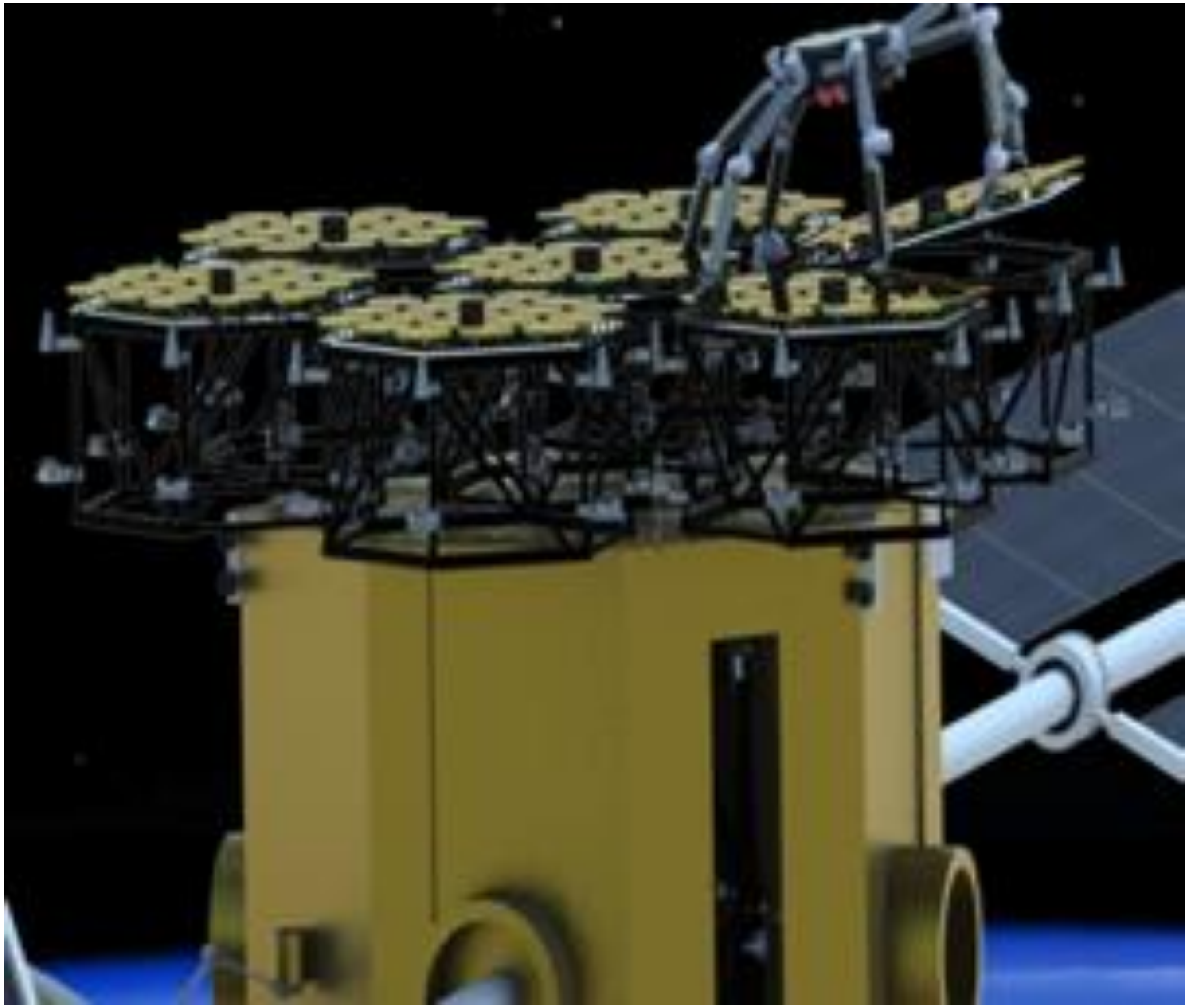
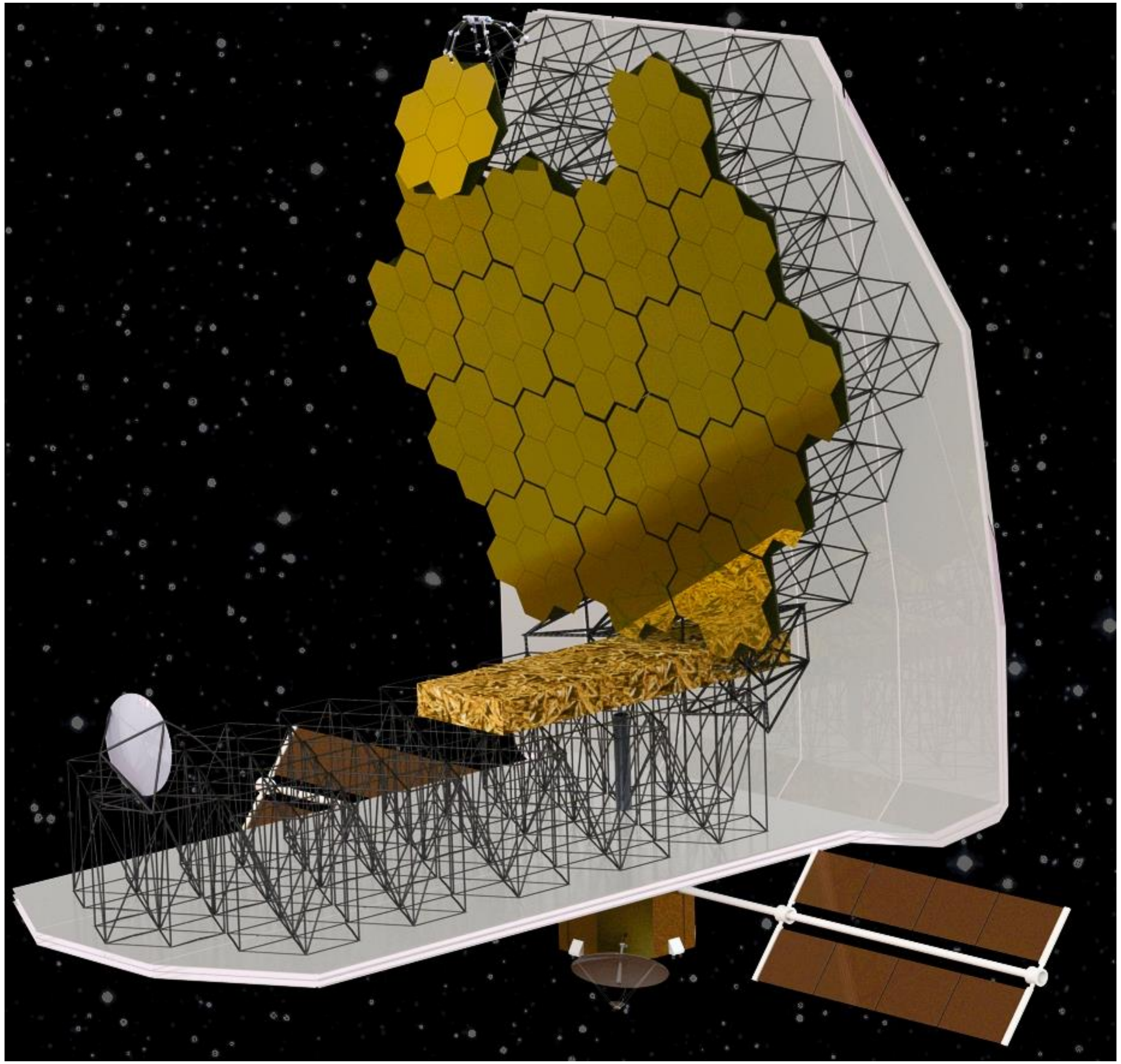


Lee et al. 2016 (Caltech/JPL)

In Space Telescope Assembly Robotics

Unobscured Ritchey-Chretien

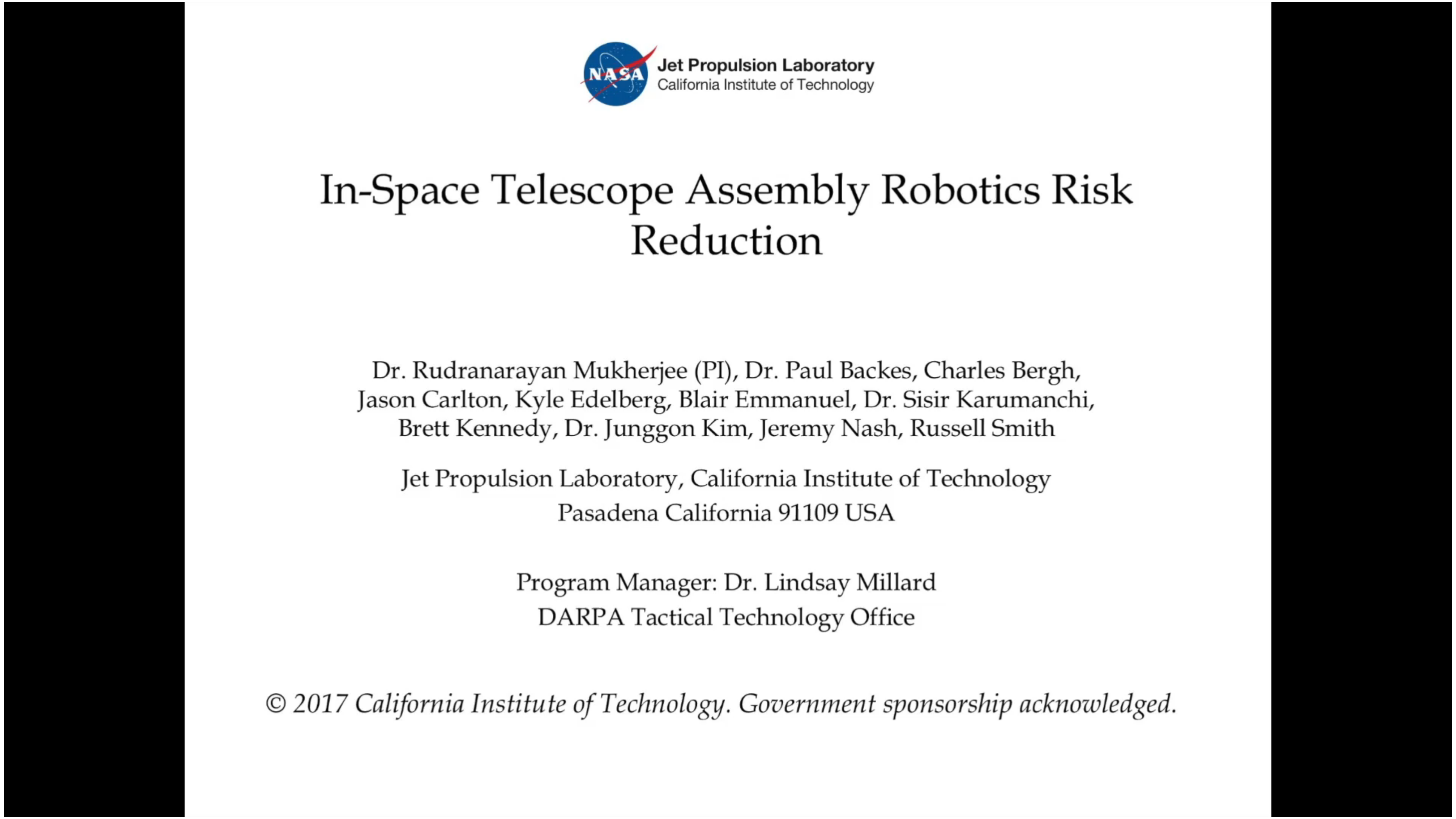


Lee et al. 2016 (Caltech/JPL)

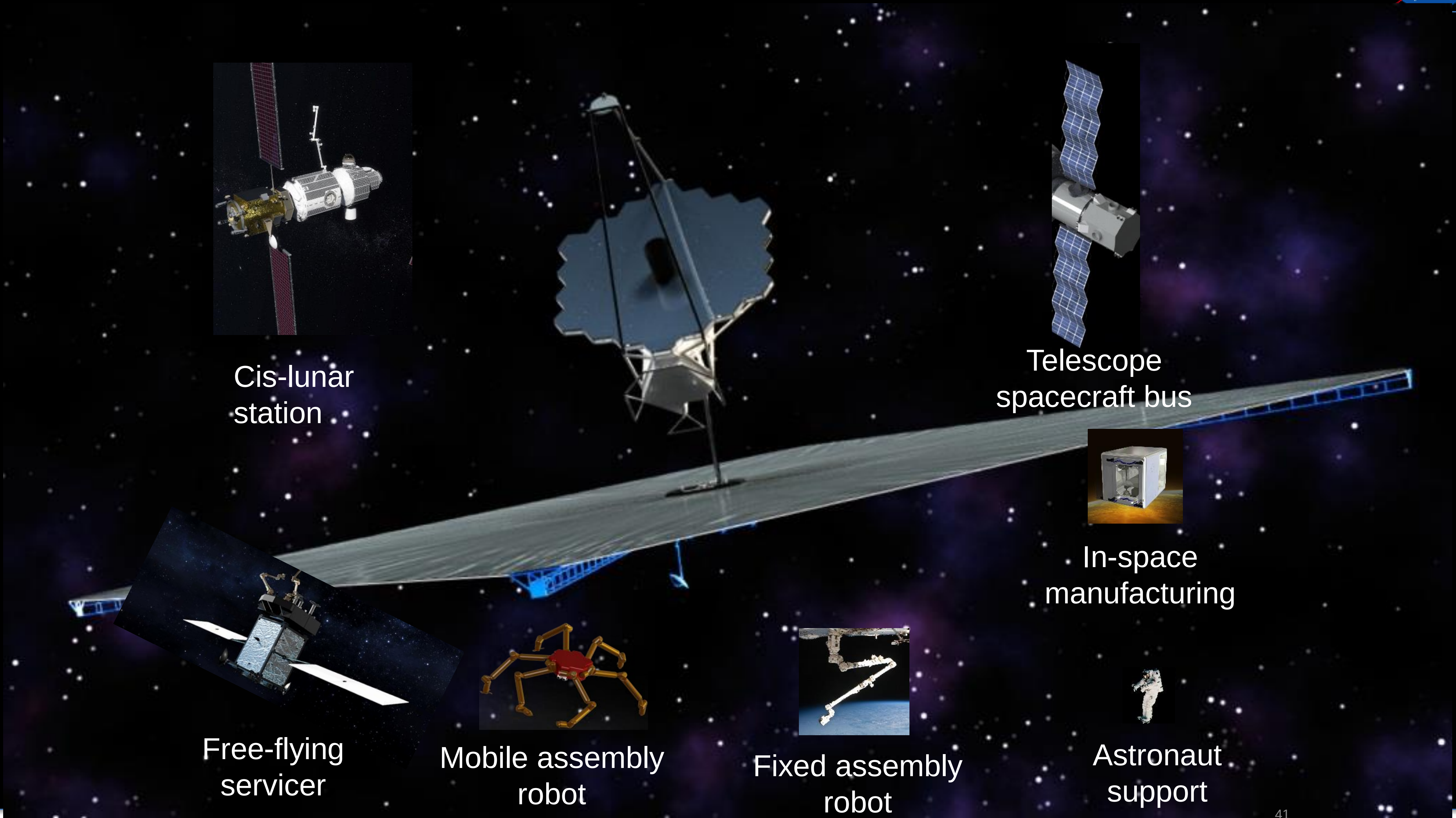
In-Lab Telescope Truss Assembly Robotics

DARPA-funded JPL 3 m telescope assembly demo

See video at https://exoplanets.nasa.gov/exep/technology/in-space-assembly/



Large Solution Space for In-Space Assembly



In-Space Servicing (iSS)

Benefits of iSS

- **iSS <u>extends</u> the lifetime of observatories.**
  - Potentially enabling a Great Observatories paradigm (persistent assets)
  - Spacecraft could be refueled, subsystems could be replaced or upgraded
  - Mirrors could be recoated and decontaminated
  - Starshade membrane and edges could be repaired after micrometeoroid damage

- **iSS <u>enhances</u> our capability to more rapidly respond to new science questions through the replacement and upgrade of payload instruments**
  - “HST is a better observatory today than when it first launched”
  - Instrument technology is ~ 10-15 yr old by launch (technology lag)

How will future large observatories be serviced? (1 of 2)

- **As Sun-Earth L2 is the likely operational destination for many science missions, servicing could be performed in situ or in an orbit in the lunar vicinity.**
  - Earth-Sun L2 ←→ cis-lunar has a delta-v of 10’s of m/s
  - LEO, GEO are other options but have large delta-v and are outside of their operational environment

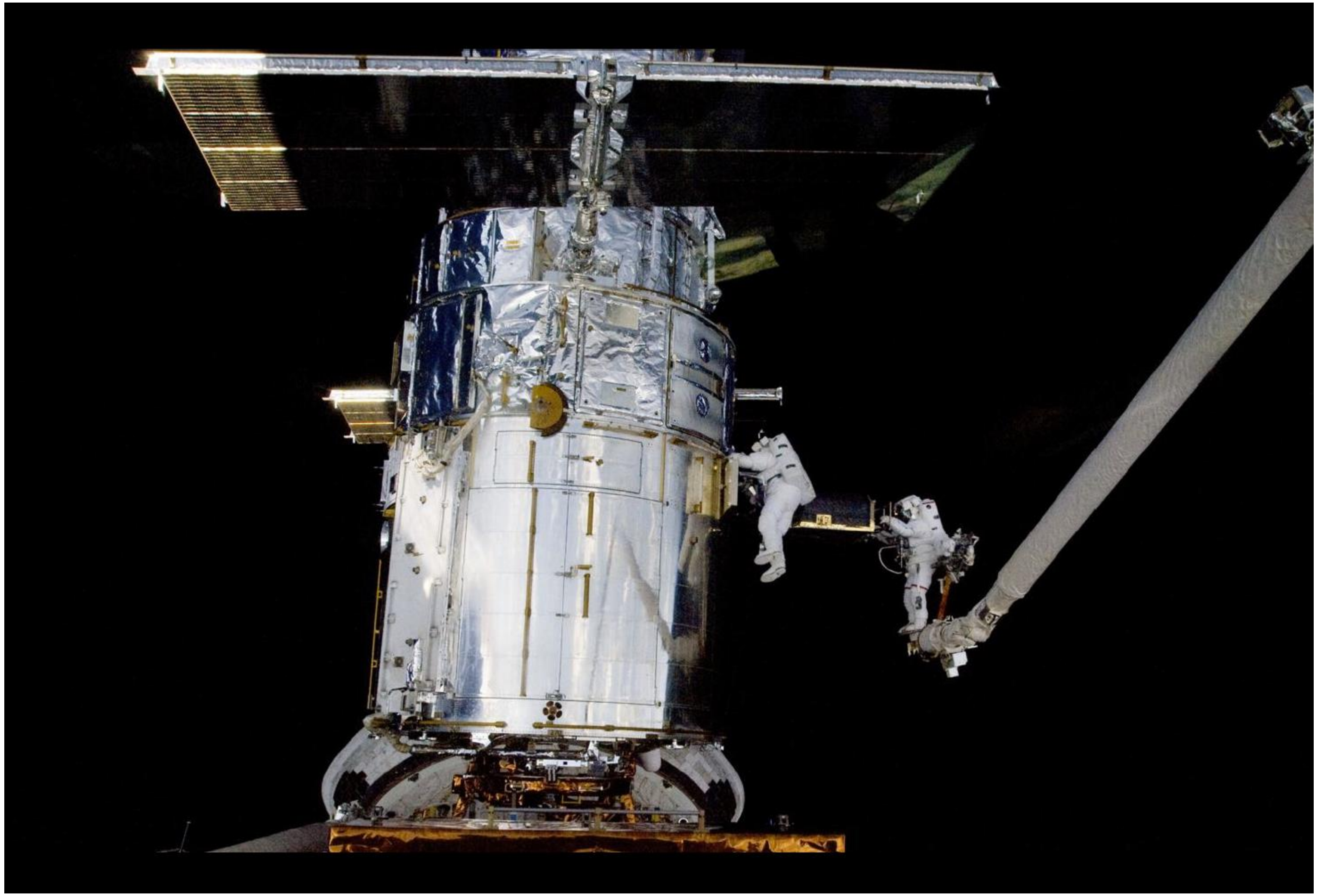
- **Servicing observatories at Sun-Earth L2 may be preferred if operations are relatively simple.**
  - Simplicity – cooperative architecture aided by high levels of modularity
    - Re-fueling, swapping out instrument payloads, replacing solar arrays and batteries
  - Servicing can be conduced by a free flyer (e.g. DARPA RSGS, Restore-L)
  - Due to relatively long latencies operations would be semi-autonomous

How will future large observatories be serviced? (2 of 2)

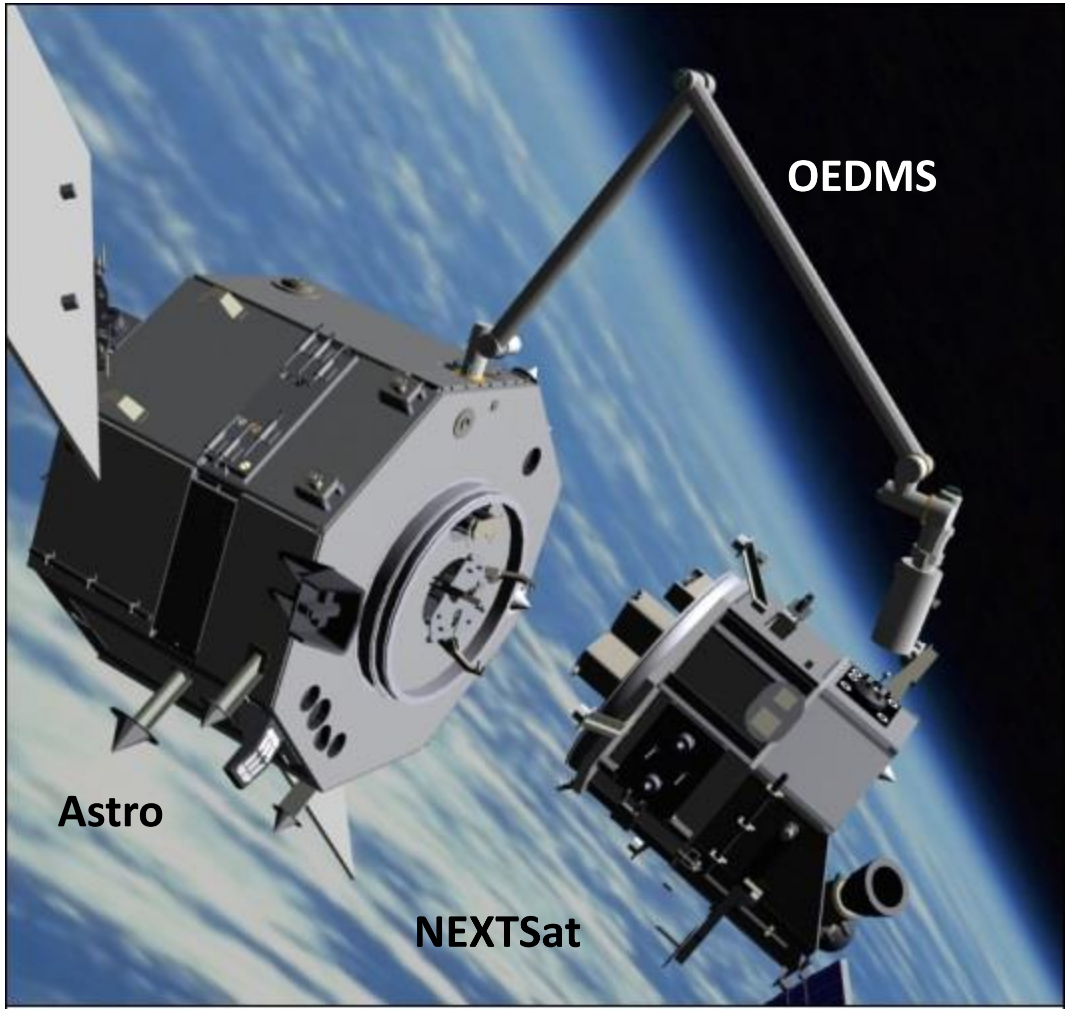
- **If servicing operations are relatively <u>complex</u>, then the mission can transfer from Sun-Earth L2 and be serviced at an accessible orbit in the lunar vicinity (e.g. Earth-Moon L1).**
  - Human and robotic support may be both important
  - Can leverage existence of an in-space assembly infrastructure (e.g. DSG)

Thronson and JF&A 2007

Hubble Space Telescope's Five Servicing Missions



DARPA Orbital Express (2007)



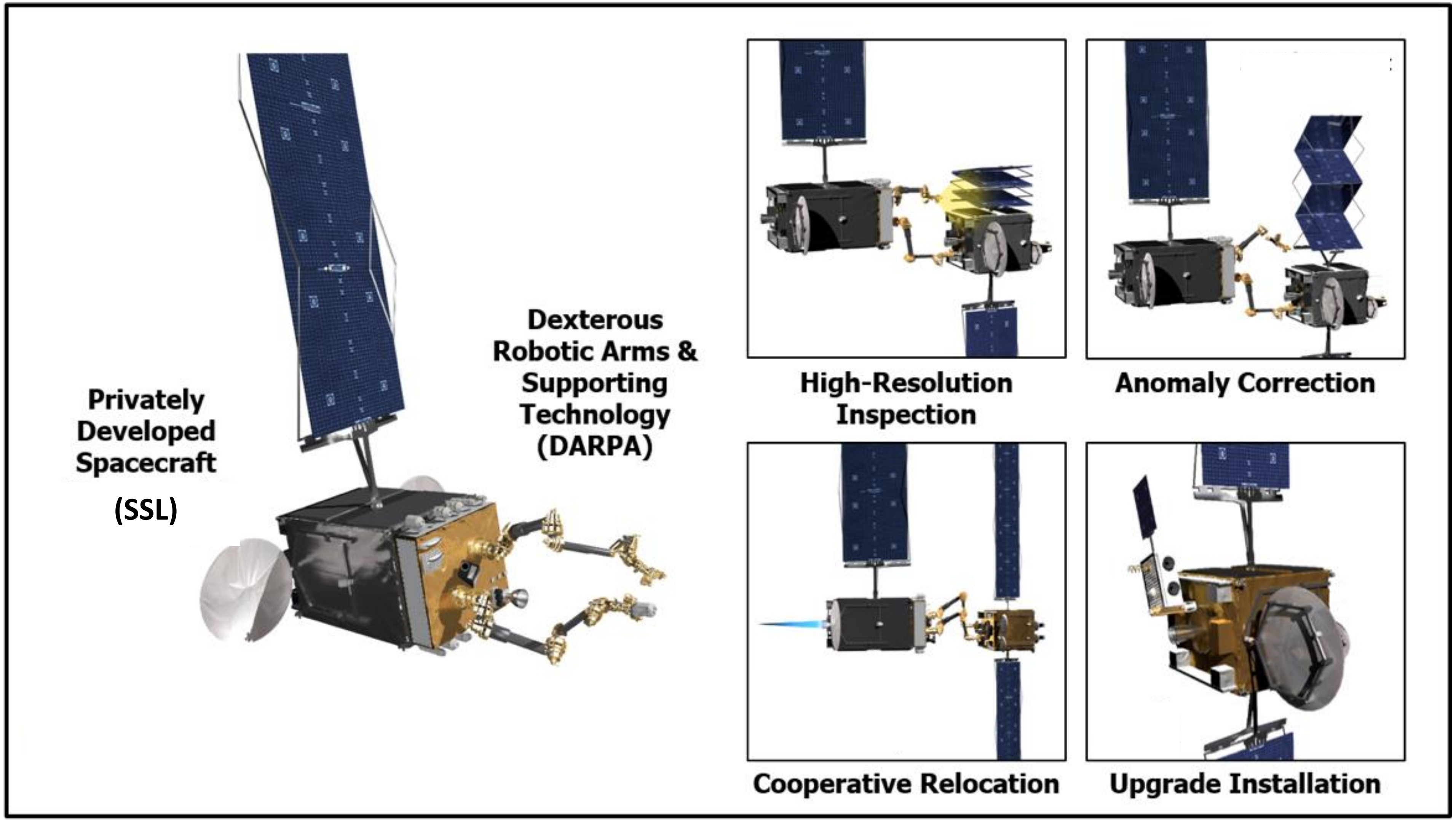
- Multiple autonomous berthing and docking maneuvers

<u>In-space firsts:</u>

- Transfer of fuel
- Transfer of a battery through the use of 3-m long robotic arm

DARPA/Boeing/MDA/Ball Aerospace

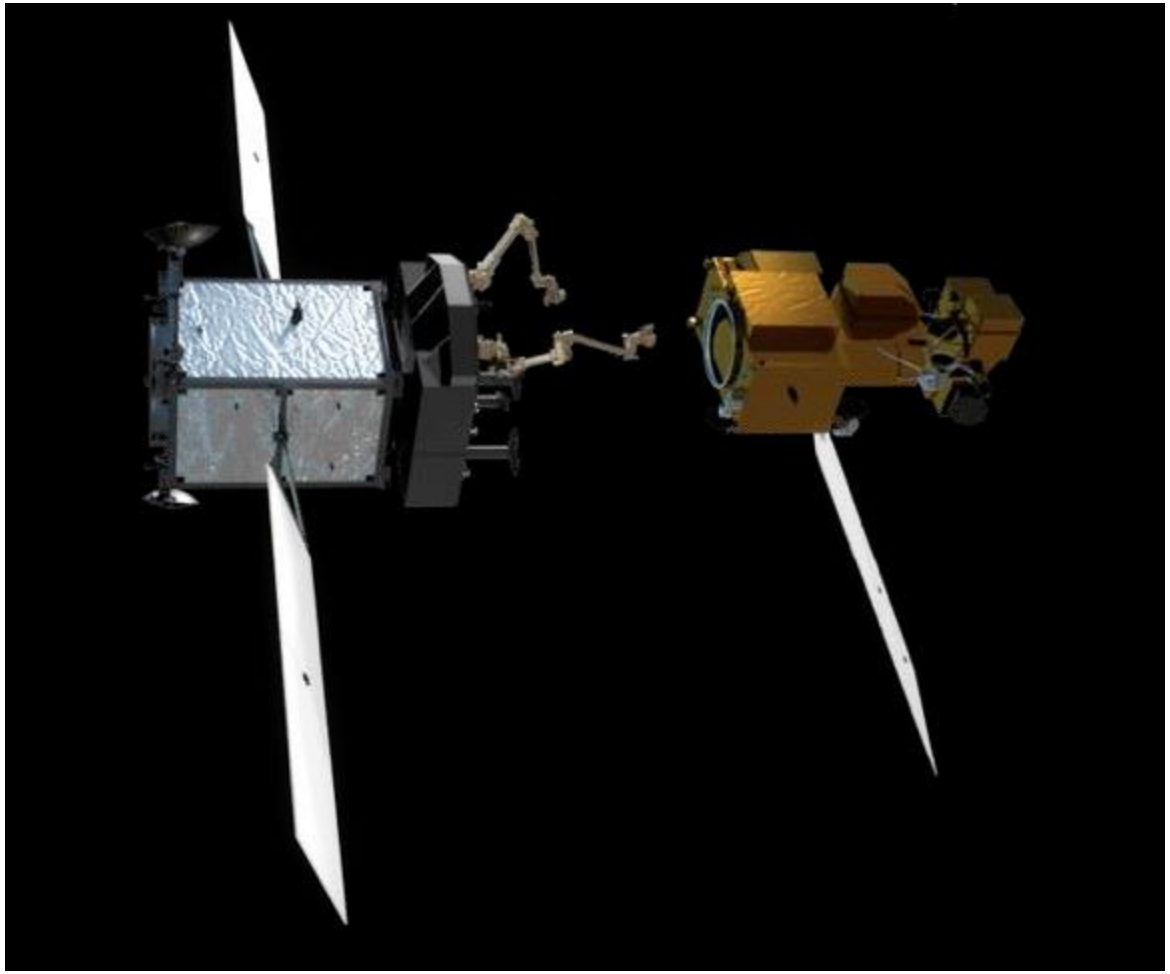
DARPA Robotic Servicing of Geosynchronous Satellites (RSGS)



DARPA

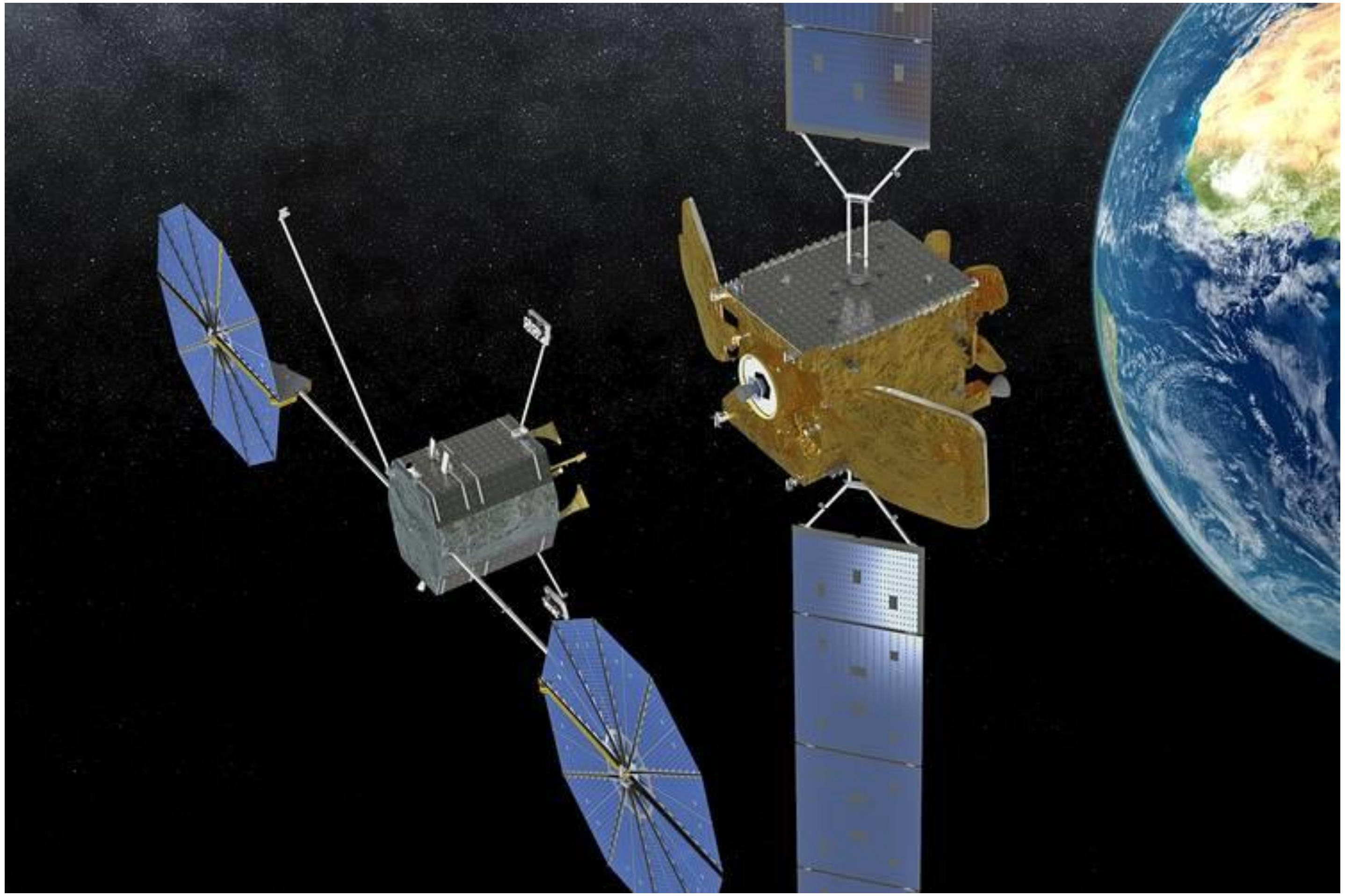
Restore-L (NASA GSFC)

- **Refueling an existing satellite (Landsat 7)**
- **Future capability demonstrations:**
  - ➢ Observatory repair
  - ➢ Instrument replacement
  - ➢ On-orbit assembly and manufacturing



NASA GSFC

Orbital ATK - Mission Extension Vehicle



Orbital ATK

iSSA Workshop at NASA Goddard

November 2017

(iSSA = in-Space Servicing & Assembly)

How does iSSA reduce cost and risk? (1 of 3)

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 > 100 single point failures
- **Moves architecture away from "every new telescope is a new point design"**
  - Greater commonality with previous system reducing development costs
- **Reduces "ruggedization" to survive launch environment**
- **Reduces need for new and unique ground test facilities**
- **Reduces need for hardware redundancy**
- **Leverages existing and less-costly medium-lift launch vehicles**
- **New instruments can be swapped out without additional observatories**
- **Leverages investments in human space flight facilities**

How does iSSA reduce cost and risk? (2 of 3)

<u>Potential new challenges may also INCREASE costs</u>

- **Would a full-scale, robotically-assembled telescope have to be demonstrated on the ground to mitigate concerns and risks? And then disassembled?**
- **Potential additional cost for any astronauts in the loop**
- **New robotic capabilities will be required as part of iSSA that would not be required in the autonomous deployment approach.**
- **Sending multiple modules into space will require new containers and interfaces each having 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? (3 of 3)

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:**
  - Designing servicing capabilities (robotic and/or human) into the architecture
  - Modularizing the design enabling repair and replacement of faulty sections
  - Minimizing single-point failures
- **iSA does not require next-generation launch vehicles**
  - Several future mission concepts under study rely on the SLS Block II (a potential programmatic uncertainty)
- **Launch failure need not be equivalent to mission failure**

Workshop Findings (1 of 2)

1. **The cost model for large telescopes is unlikely to change unless there is a paradigm shift.**

2. **There is a revolution underway in the SOA of terrestrial robotics**
   – DARPA RSGS and NASA Restore-L are embodiments of this for space demonstrations and have legacy from the 15+ years of Mars and ISS robotics

3. **DARPA RSGS is a game changer**

4. **The ISS is potentially an ideal testing platform for many iSA technology development activities, although is planned to be decommissioned mid-next decade**

5. **The 2010 Decadal made no mention of iSSA**
   – Is this merely an implementation issue? Or is the impact to science a critical issue?

Workshop Findings (2 of 2)

6. **The "serviceability" of future telescopes is ambiguous as there are no currently available servicers**
   – Consideration ought to be given on how to leverage existing servicer work (RSGS, Restore-L) including the opportunities enabled by a DSG

7. **Industry has very strong interest in iSSA and can play an important role**

8. **Large future space observatory concepts depend on availability of SLS Block II**
   – Some STDTs are relying on it

9. **A completed NASA Gateway infrastructure potentially offers a unique facility in which SMD may be able to leverage the iSSA of future large telescopes.**

NEW: iSA Telescope Assembly Study

- Study funded by NASA's Astrophysics Division to answer the question:

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

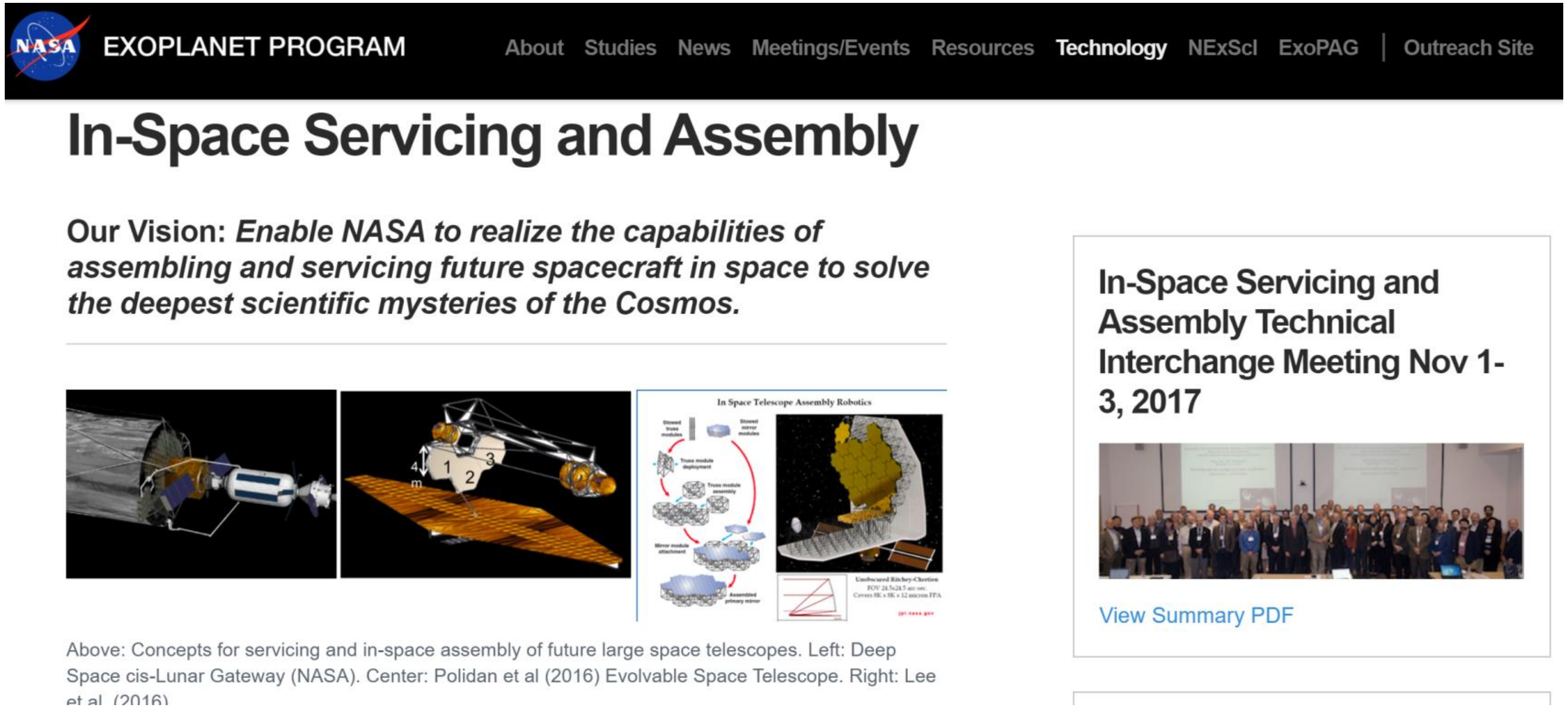
- Deliverable is a Whitepaper to the 2020 Decadal Survey

- Trade Study begins at a Workshop at JPL (June 5-7) to design and architect a large-aperture telescope that can be assembled in space (invitation only).

- Followed by another Workshop to identify the assembly approach, platform, orbit, and launch vehicles.

- Independent cost assessment

iSSA Website



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

Acknowledgment

Jet Propulsion Laboratory
California Institute of Technology

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