

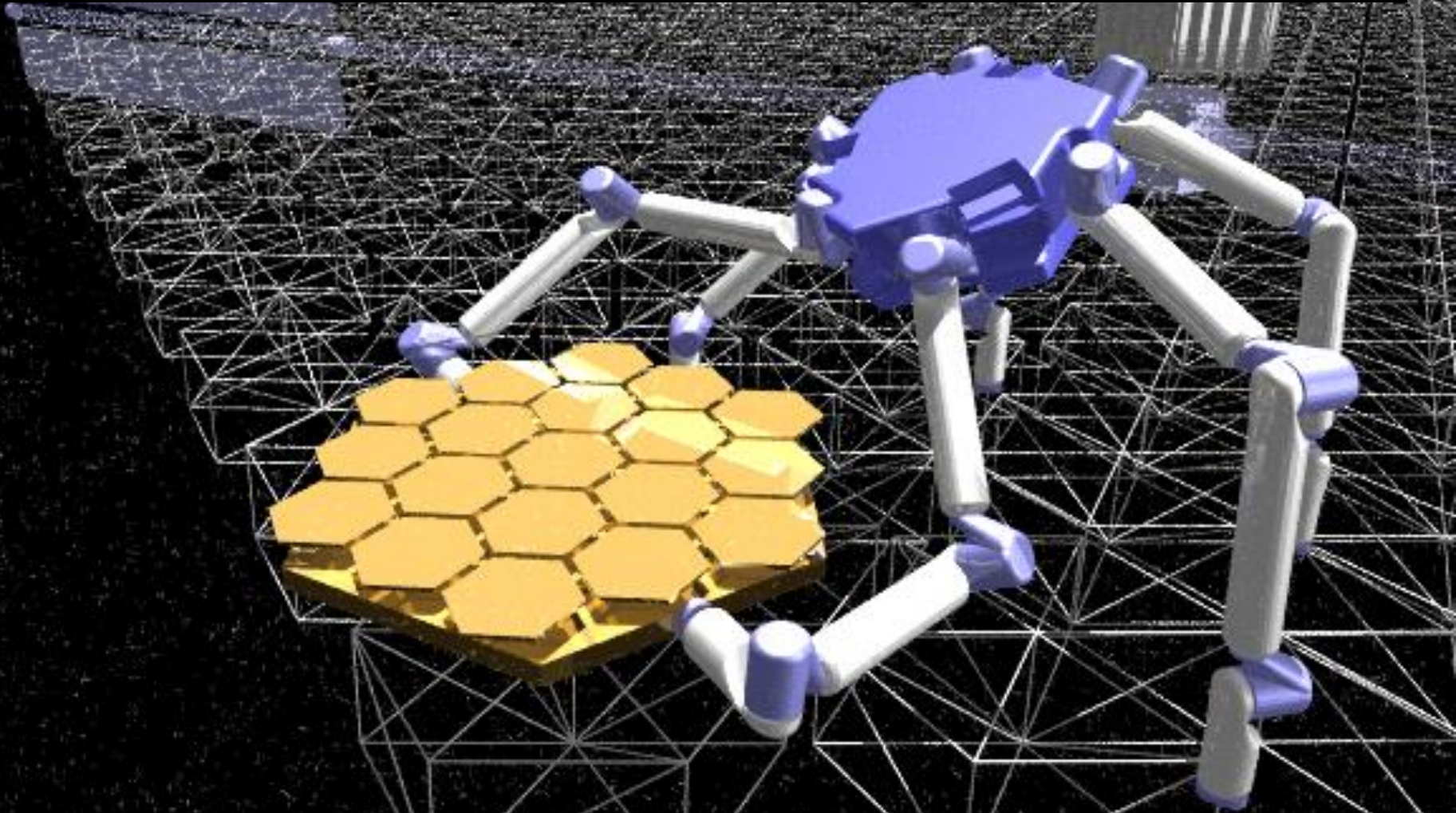


Jet Propulsion Laboratory
California Institute of Technology

In-space Assembly of Large Telescopes for Exoplanet Direct Imaging

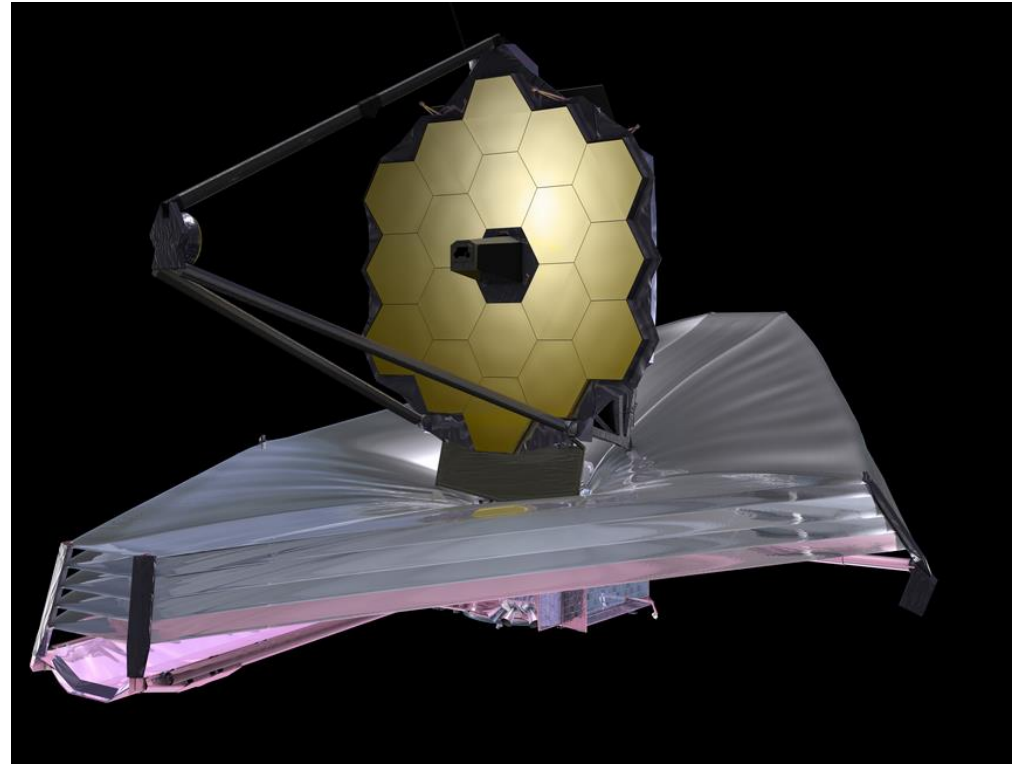
Nick Siegler, Chief Technologist, NASA Exoplanet Exploration Program (JPL/Caltech)

Rudranarayan Mukherjee, Robotics Technologist (JPL/Caltech)



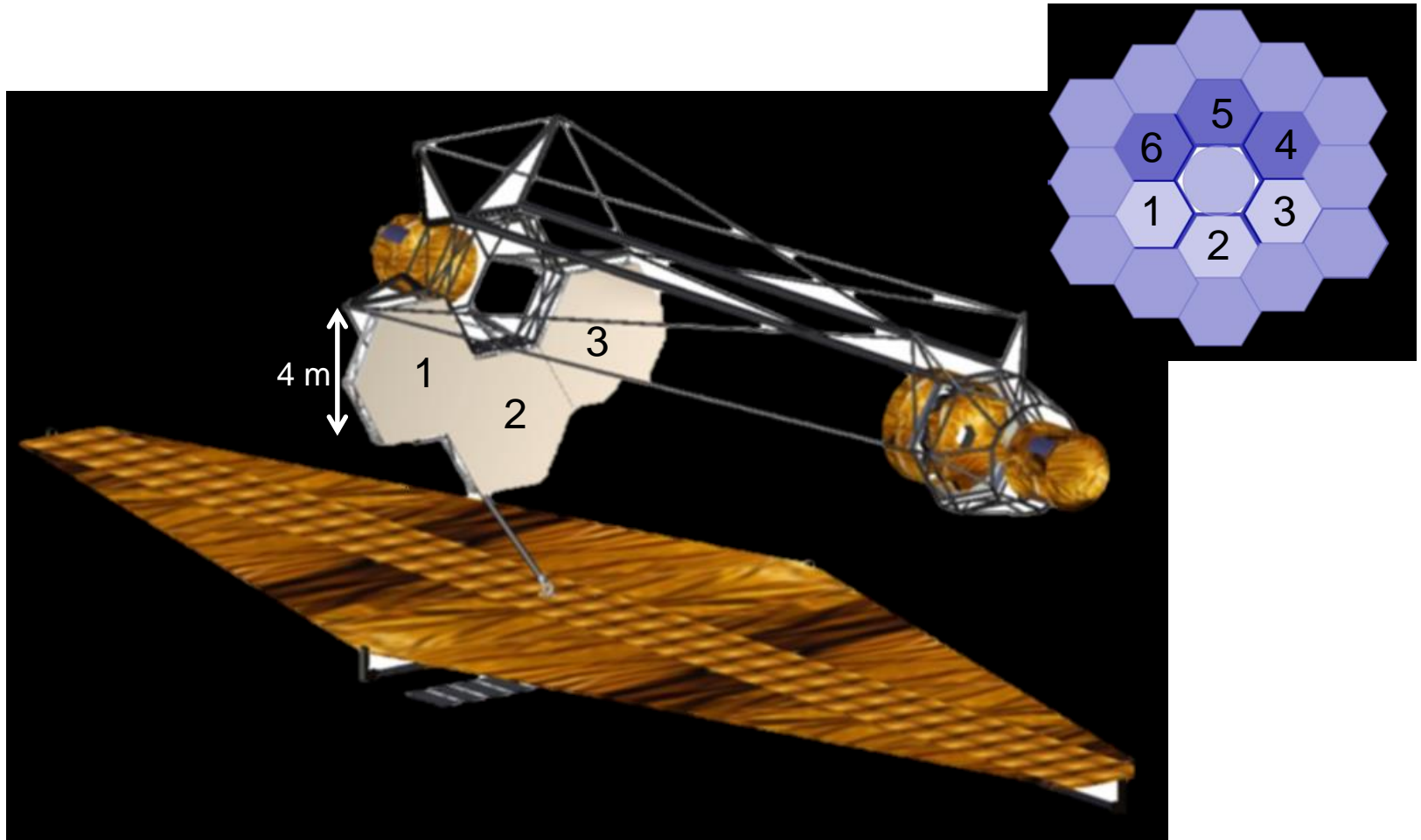
Aperture size limited by launch vehicle

Future science needs will require increasingly large telescopes



In-Space Large Aperture Telescope Assembly

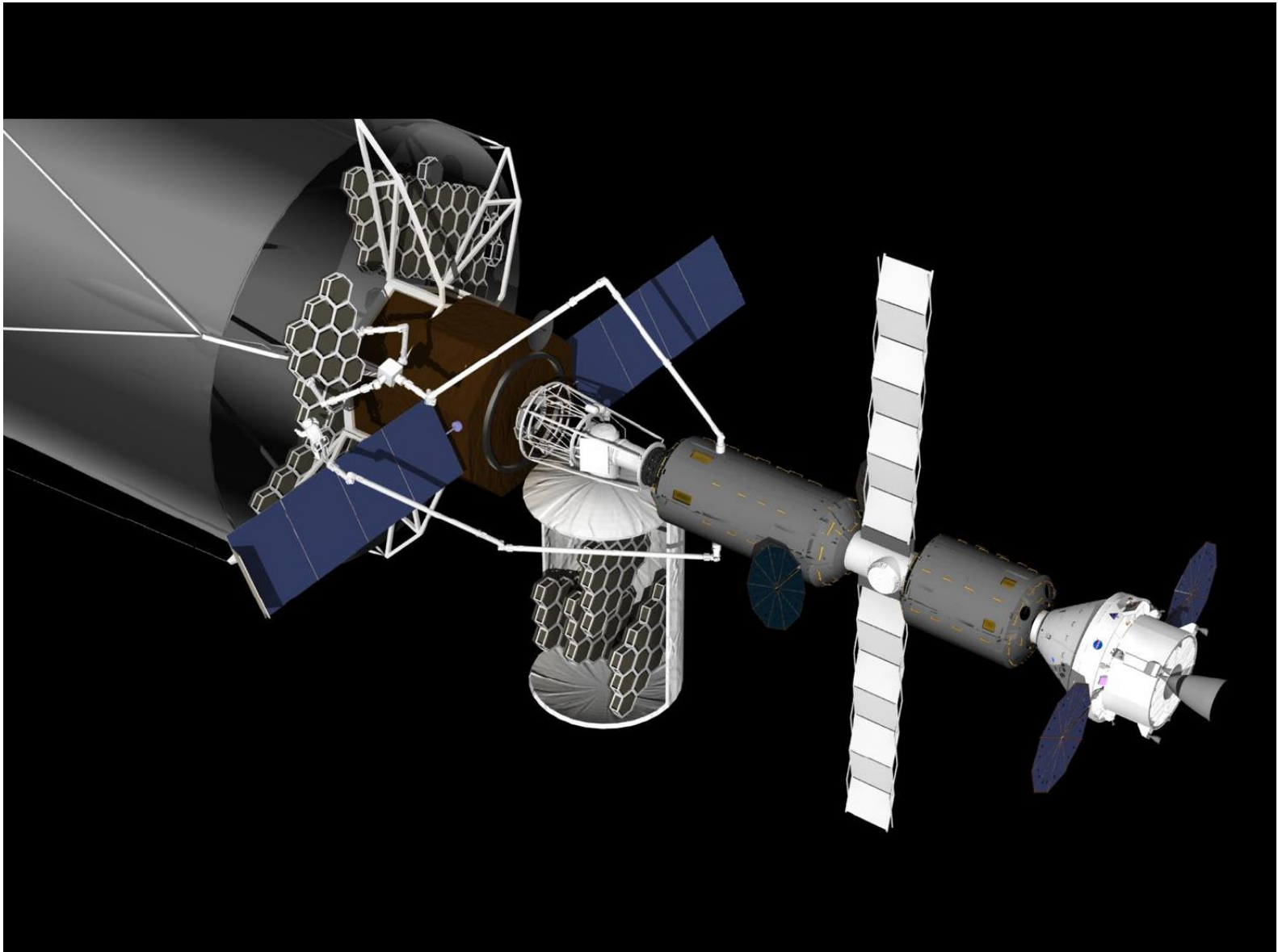
Evolvable Space Telescope (NGAS)



Polidan et al. 2016

In-Space Large Aperture Telescope Assembly

Using the Deep Space Gateway (cis-Lunar orbit) to assemble



In-Space Large Aperture Telescope Upgrade

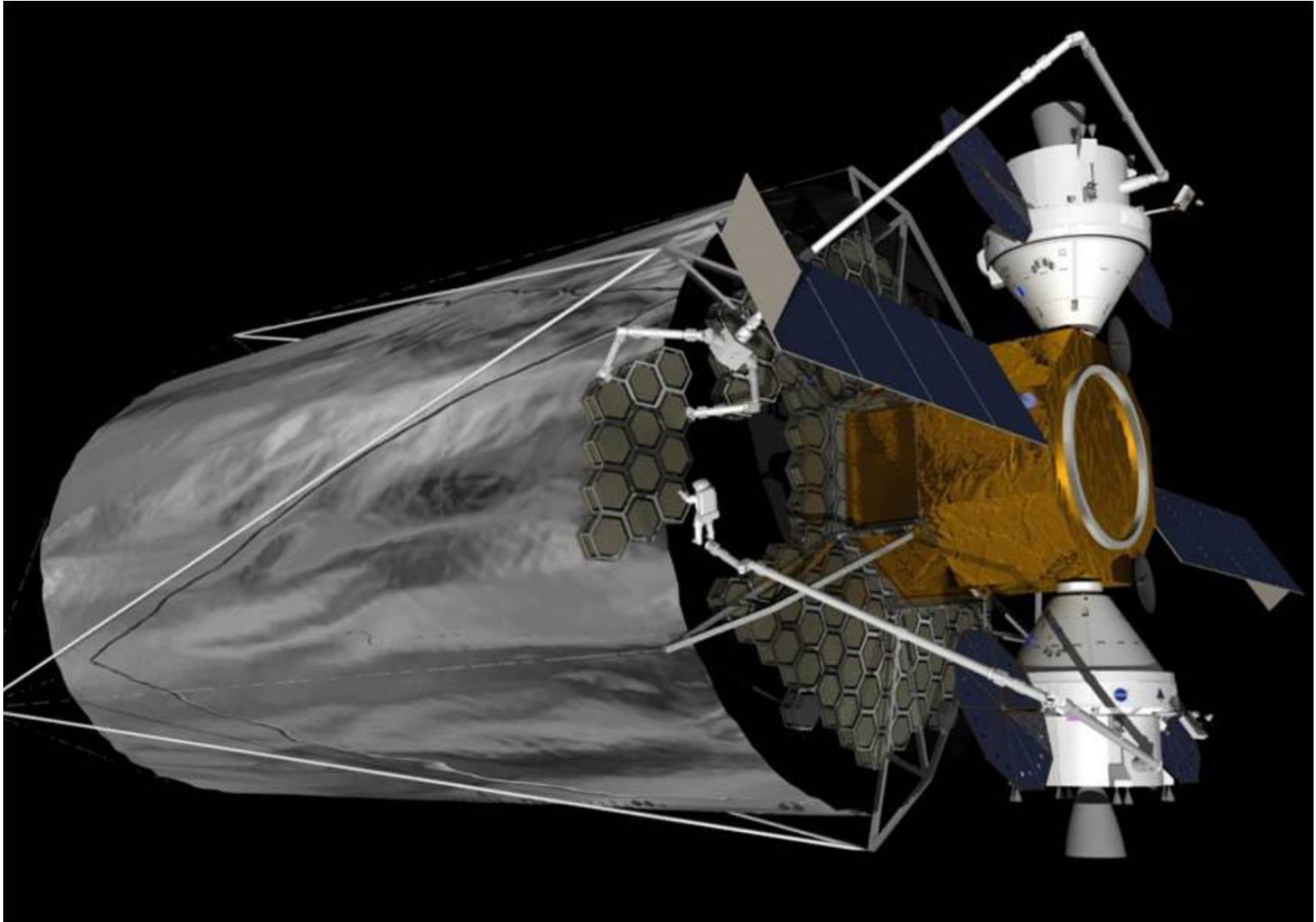
Telescope returns from ESL2 for servicing at EML1



Courtesy: Future In-Space Operations (FISO) working group (2007)

In-Space Large Aperture Telescope Assembly

Free-fliers (e.g. Orion) and assembly module docked to spacecraft bus



DARPA Orbital Express (2007)



- Multiple autonomous berthing and docking maneuvers

In-space firsts:

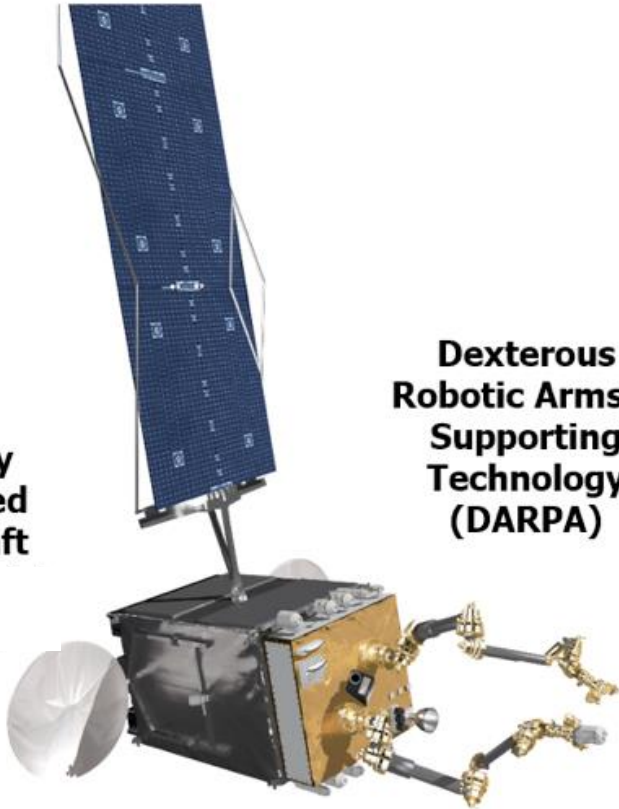
- Transfer of fuel
- Transfer of a battery through the use of 3-m long robotic arm

DARPA/Boeing/MDA/Ball Aerospace

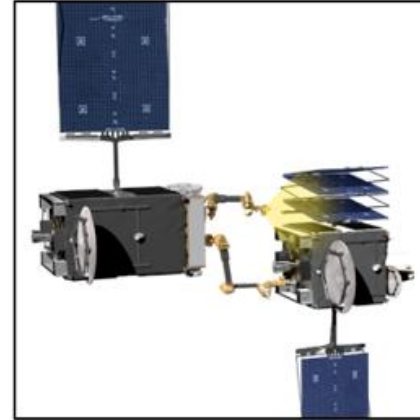
Robotic Servicing Missions

DARPA Robotic Servicing of Geosynchronous Satellites (RSGS)

Privately
Developed
Spacecraft
(SSL)



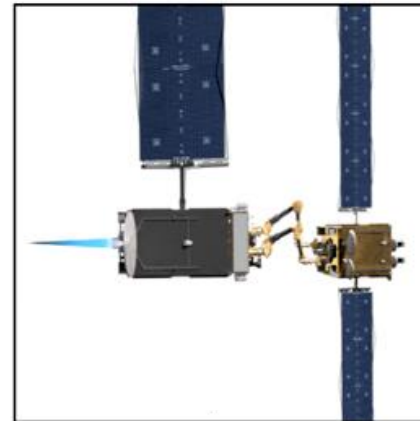
Dexterous
Robotic Arms &
Supporting
Technology
(DARPA)



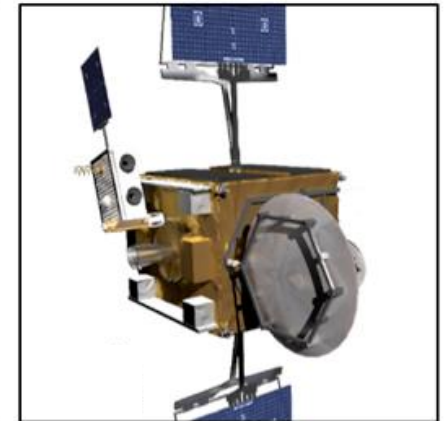
High-Resolution
Inspection



Anomaly Correction



Cooperative Relocation

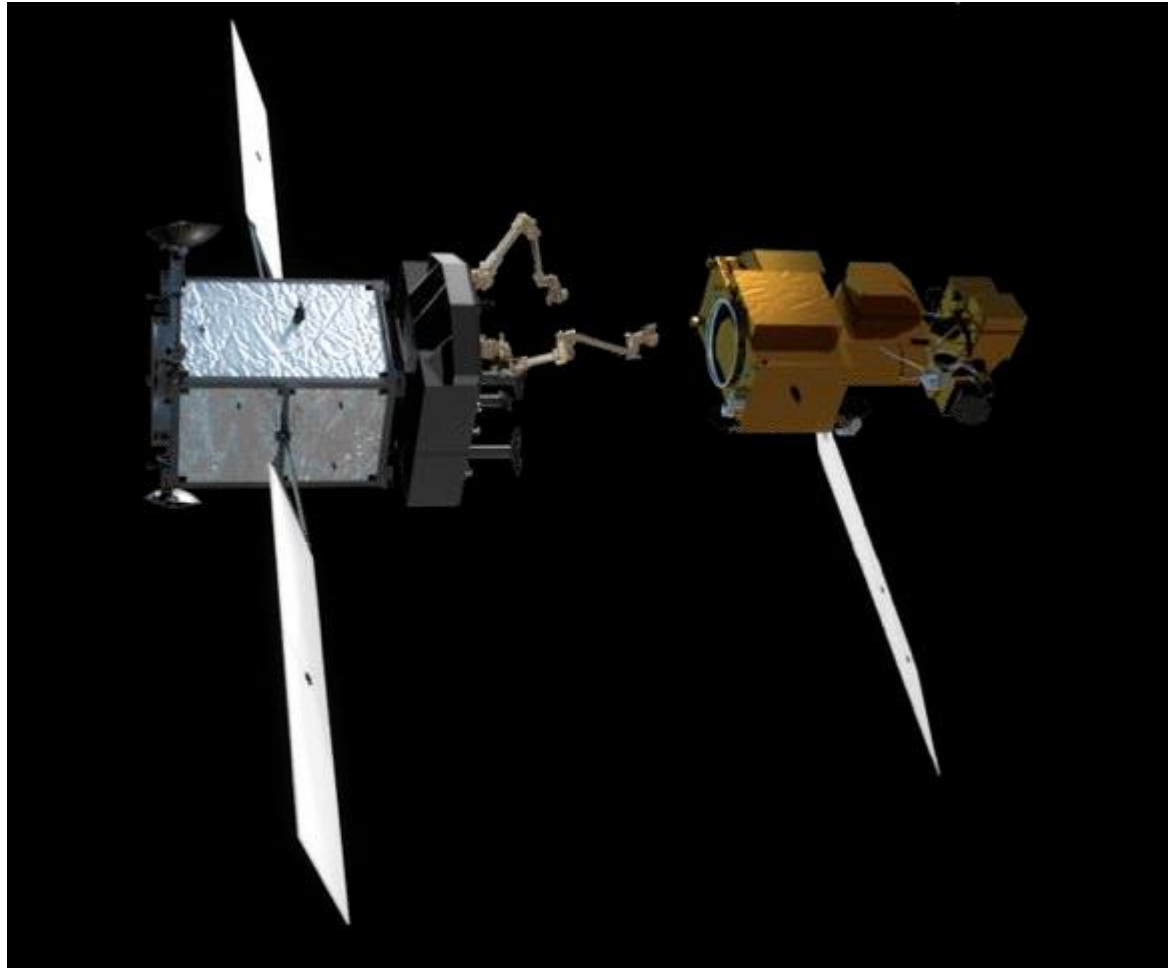


Upgrade Installation

Robotic Servicing Missions

Restore-L (NASA GSFC)

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



NASA GSFC

Beam Assembly Teleoperator (1983)

Neutral buoyancy robot (Space Systems Laboratory)



Accumulated a large database comparing human and robot performance in space

Demonstrated the ability of robots to assist astronauts during EVA excursions

ACCESS and EASE (1985)

Astronaut demo of large-structure piece-parts assembly



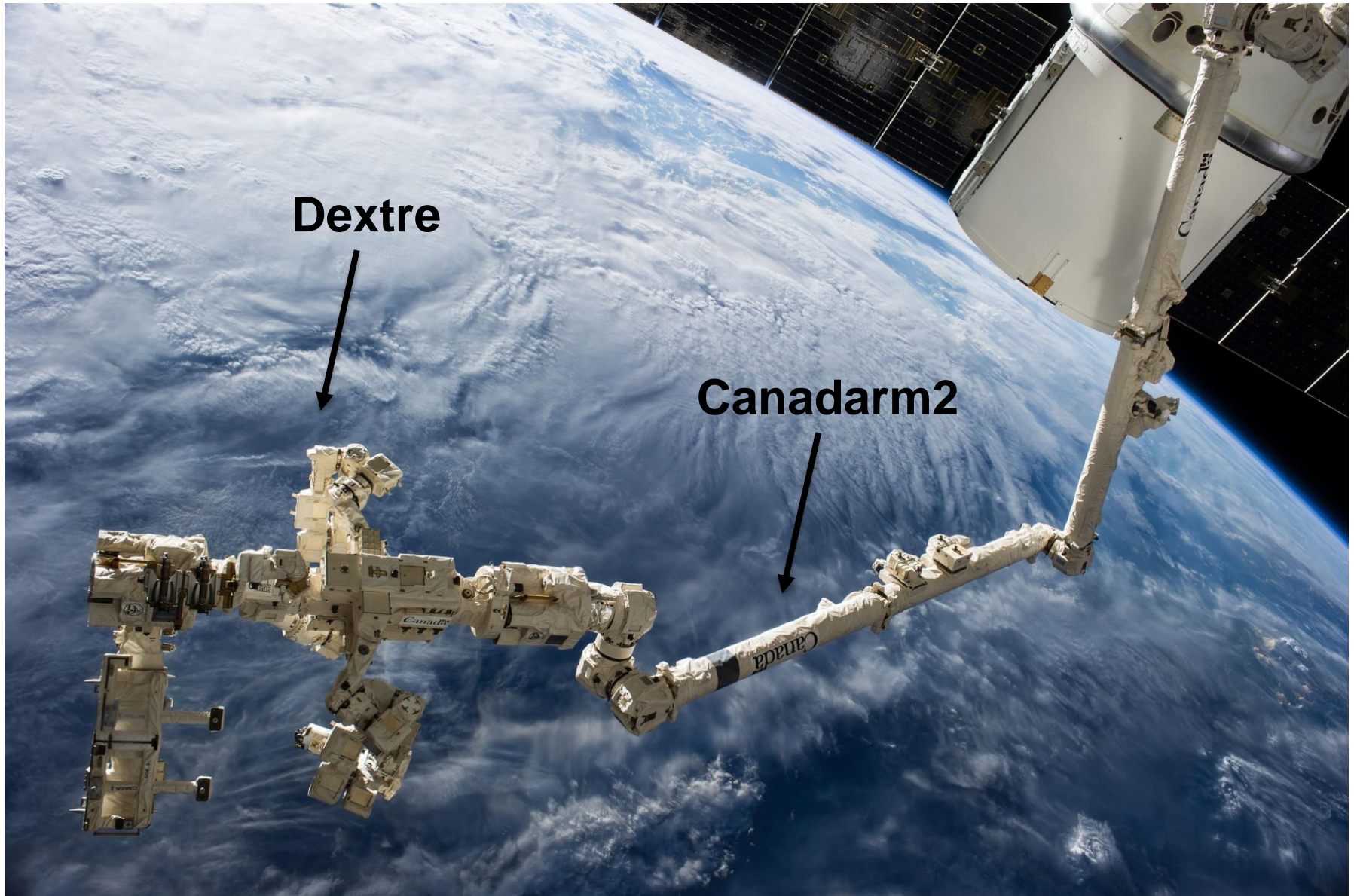
ACCESS (NASA LRC)



EASE (NASA MSFC and SSL)

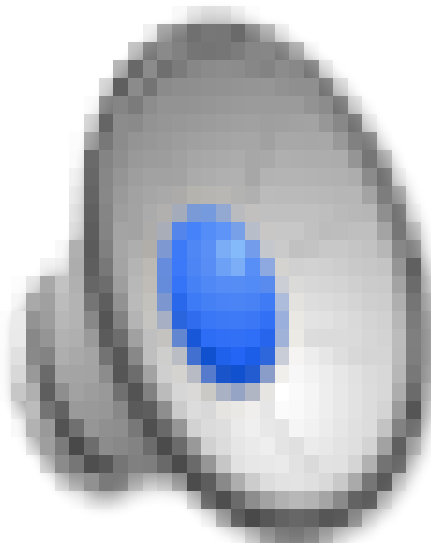
ISS Robotic Systems

Canadarm (2001), Dextre (2008)



ISS Robotic Systems

Canadarm



Optical Testbed & Integration on ISS eXperiment

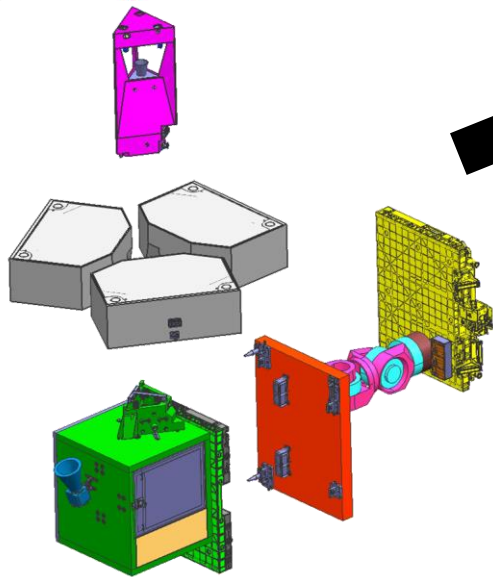
In-space assembly demo of a segmented space telescope (2012)



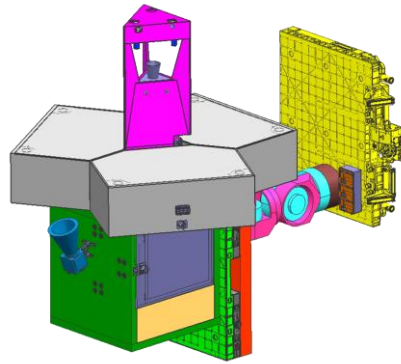
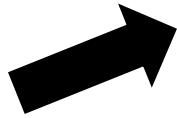
- Intended to demonstrate assembly, alignment, calibration, and operation of future space observatories
- Robotically assembled and operated

Optical Testbed & Integration on ISS eXperiment

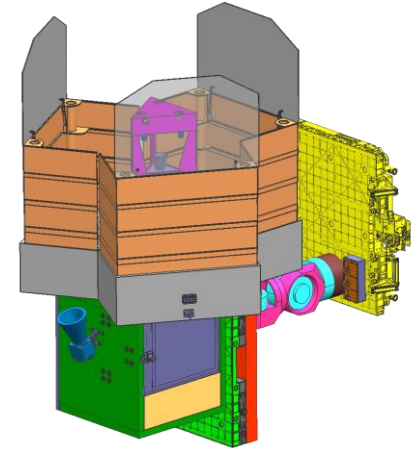
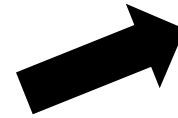
Robotically assembled and operated



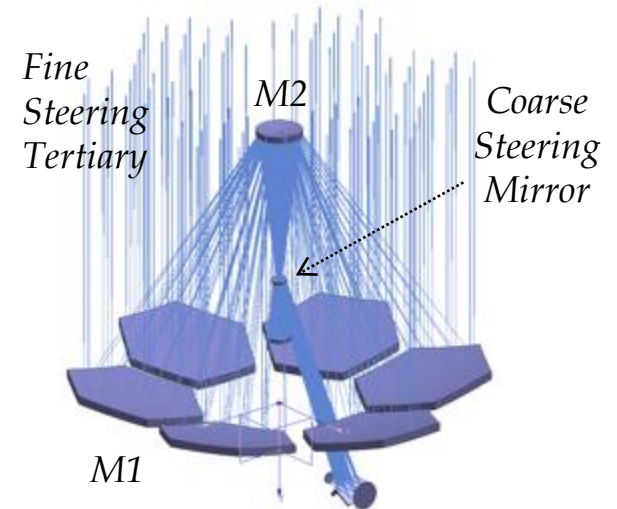
**6 launch modules
for assembly**



**Assembled
modules**



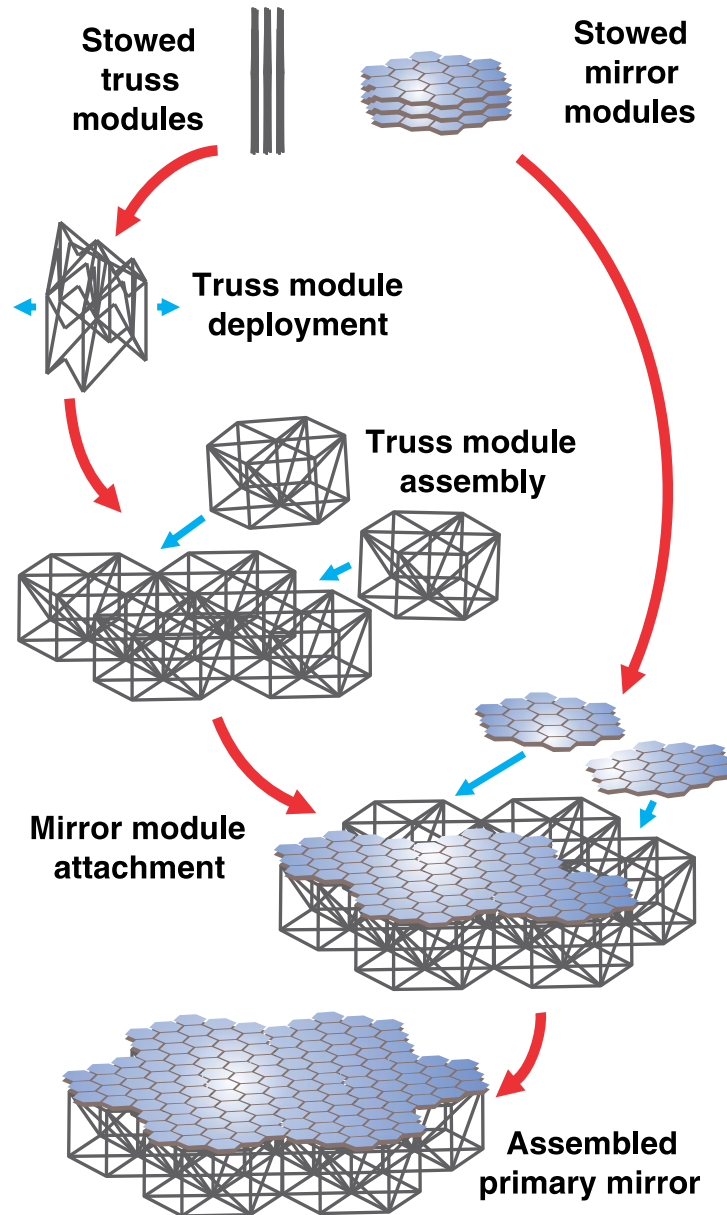
**Full deployment of
sunshades**



*3 Mirror Anastigmat Telescope
(1.45m aperture)*

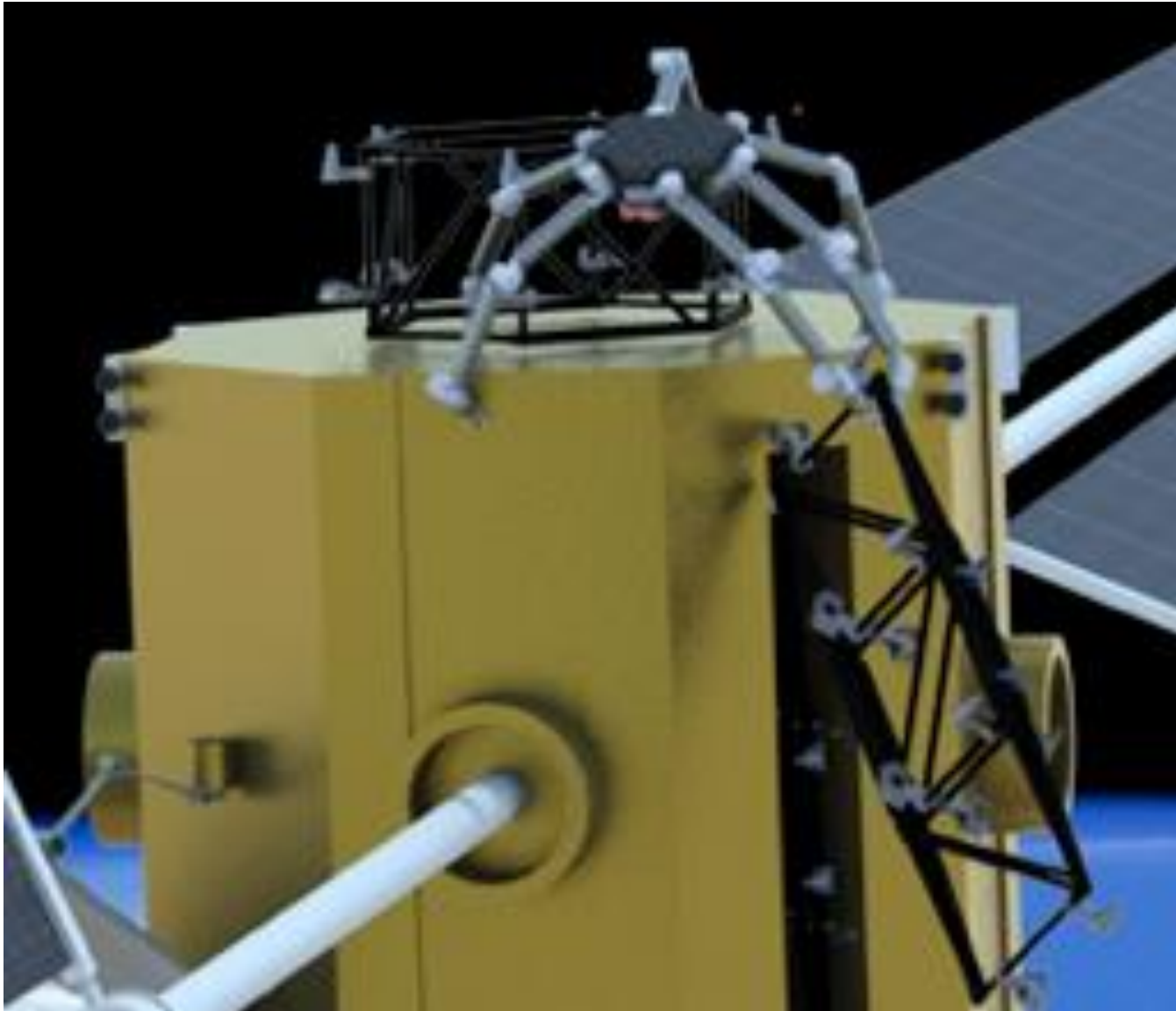
Robotic Assembly of a Telescope

Modular deployable structure



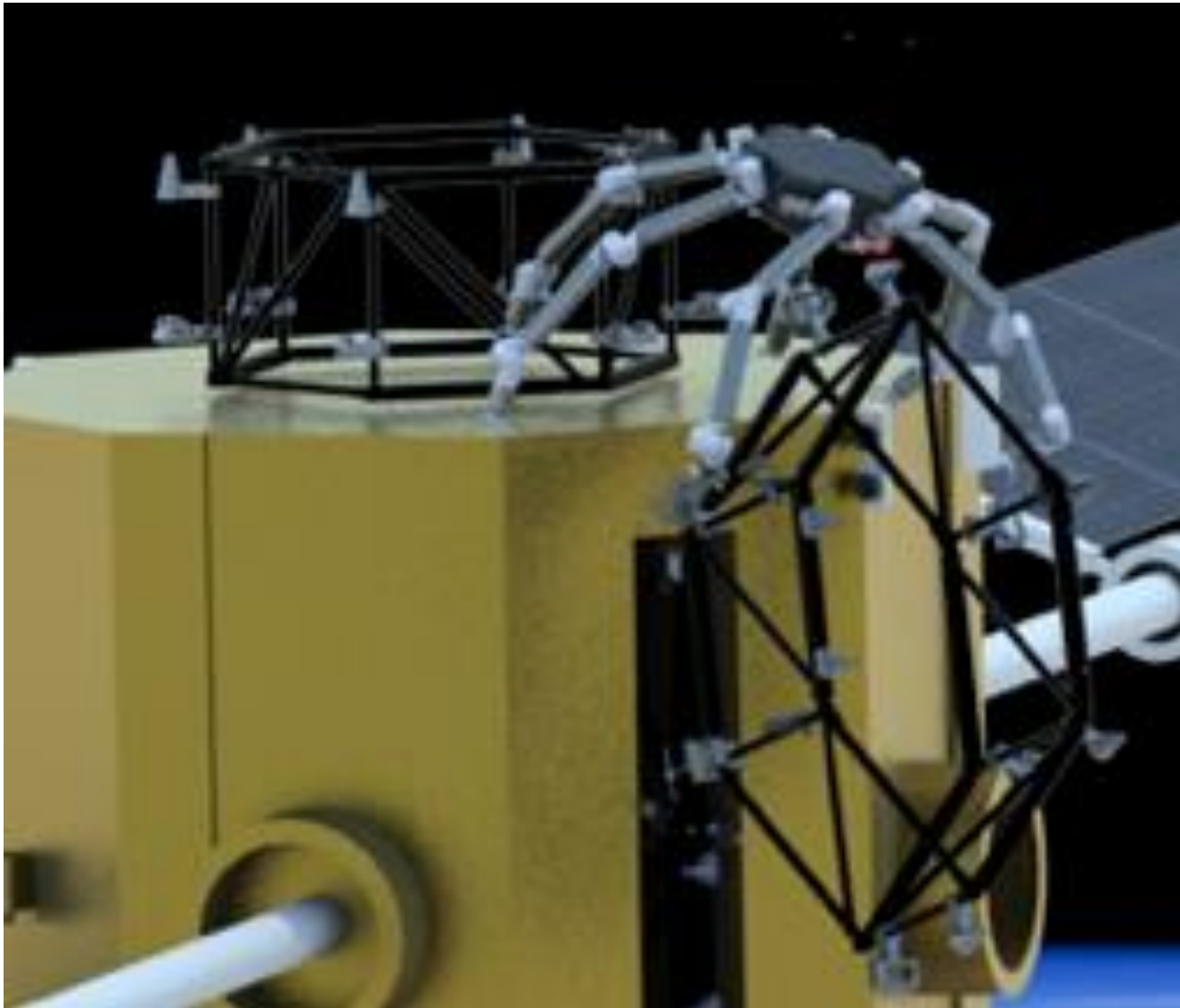
In Space Telescope Assembly Robotics

Multi-limbed robot



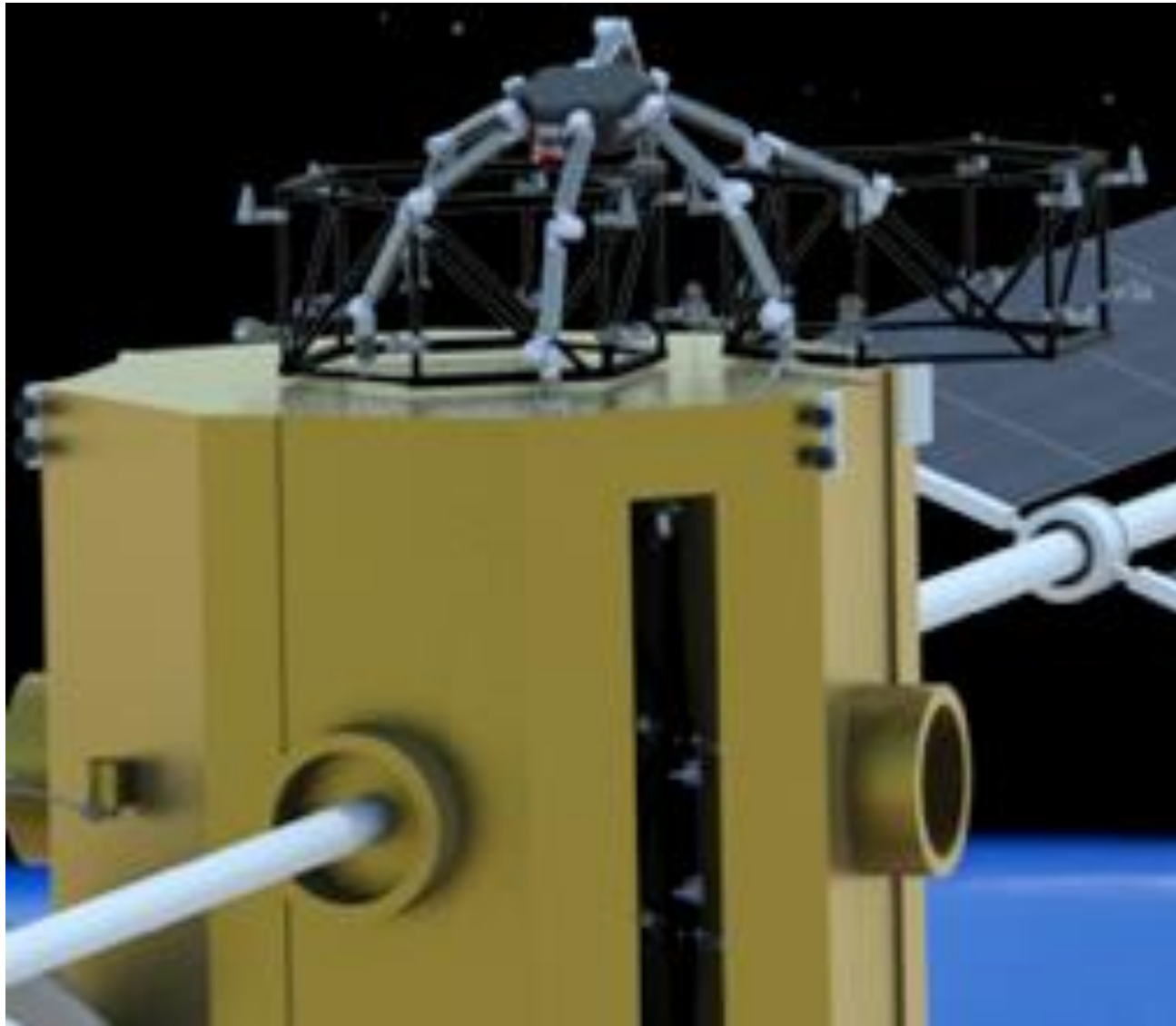
In Space Telescope Assembly Robotics

Multi-limbed robot



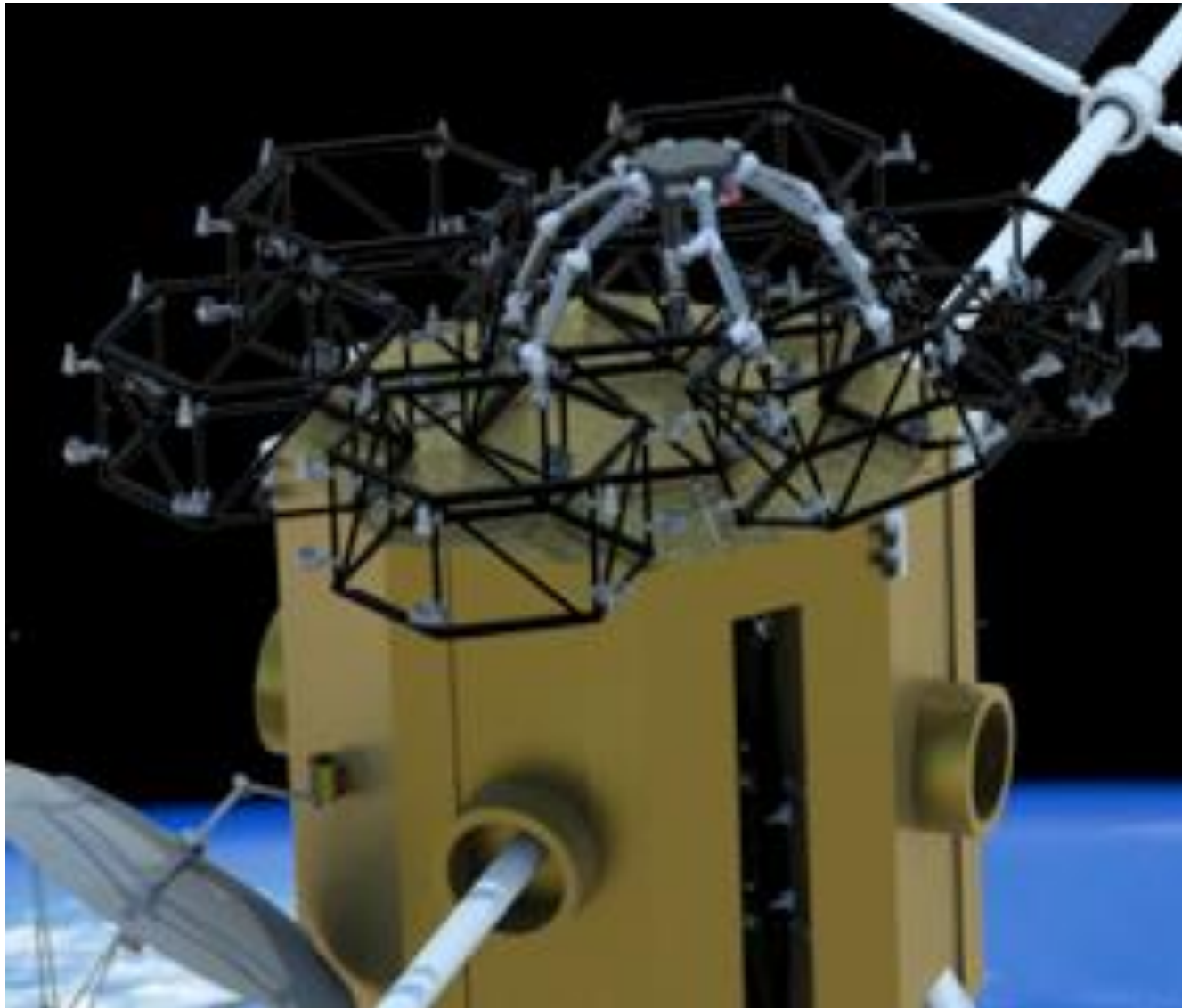
In Space Telescope Assembly Robotics

Multi-limbed robot



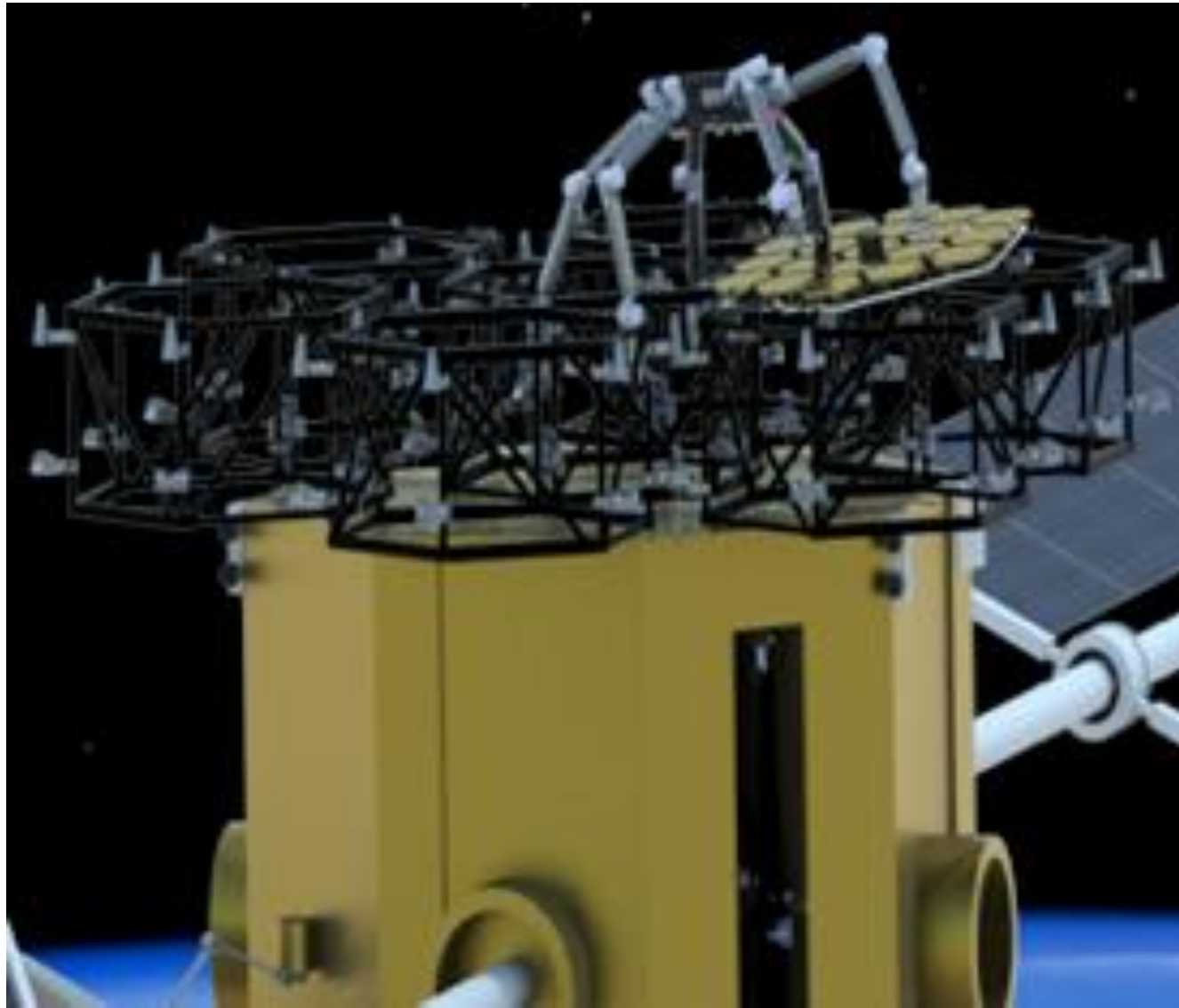
In Space Telescope Assembly Robotics

Multi-limbed robot



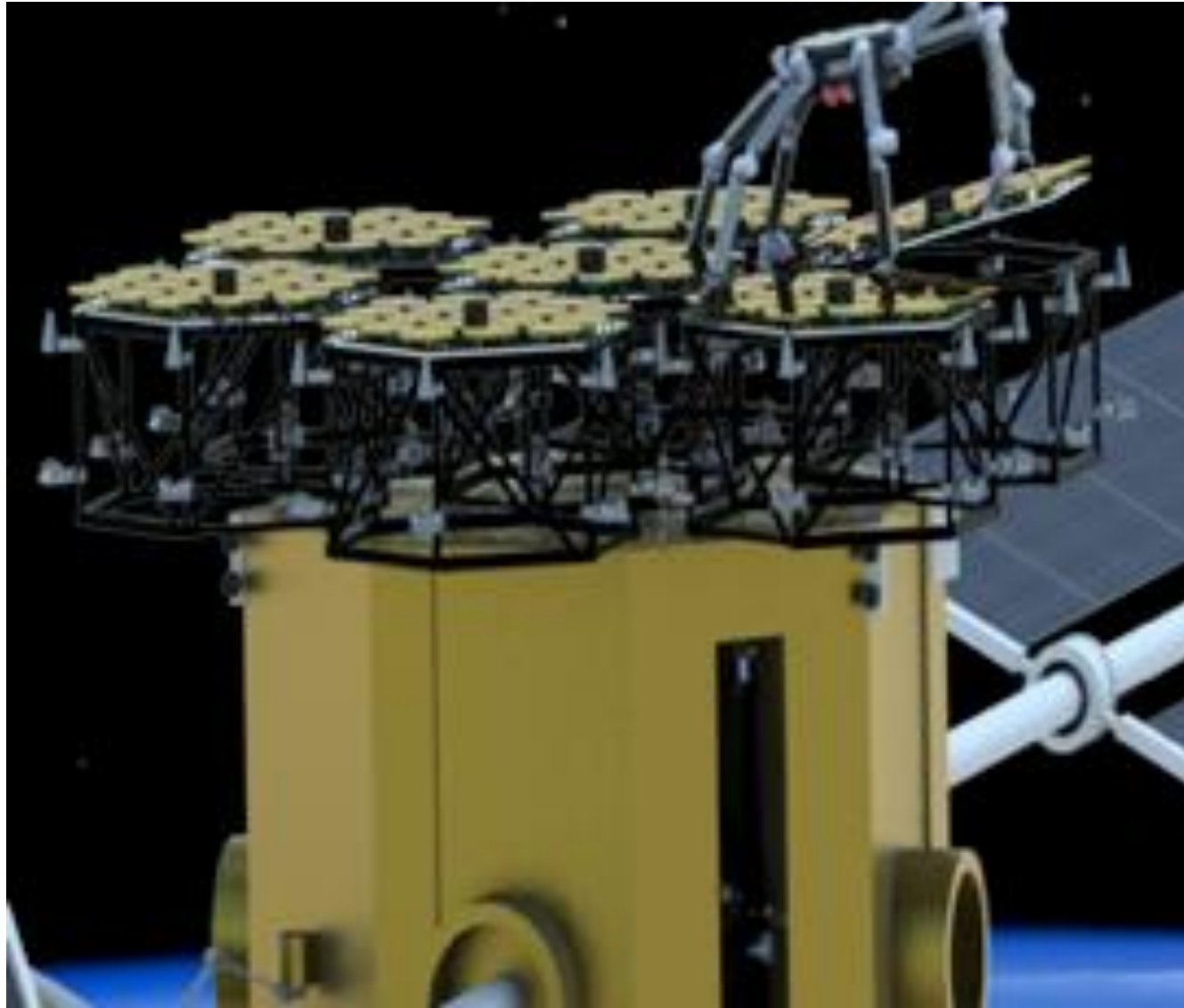
In Space Telescope Assembly Robotics

Multi-limbed robot



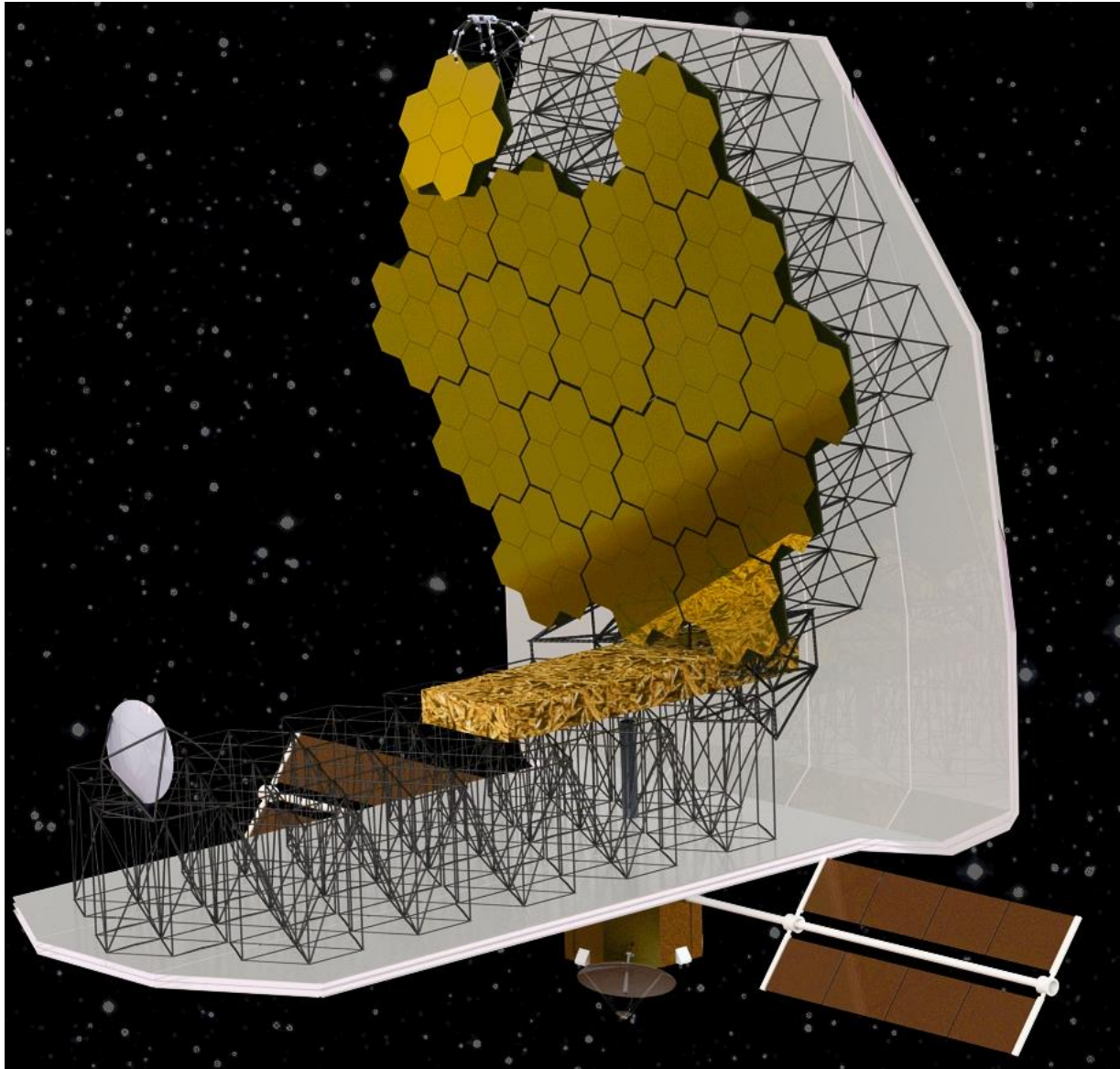
In Space Telescope Assembly Robotics

Multi-limbed robot



In Space Telescope Assembly Robotics

Unobscured Ritchey-Chretien



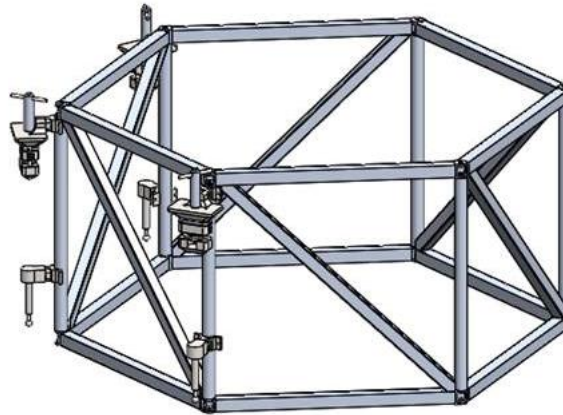
In-Lab Telescope Truss Assembly Robotics

DARPA-funded JPL 3-m telescope assembly demo

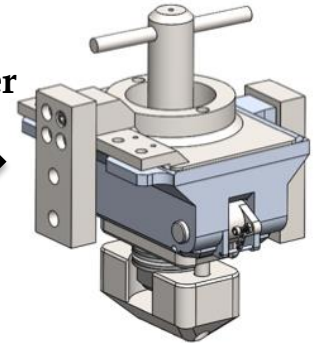
Stowed DTMs



Robotically Deploy



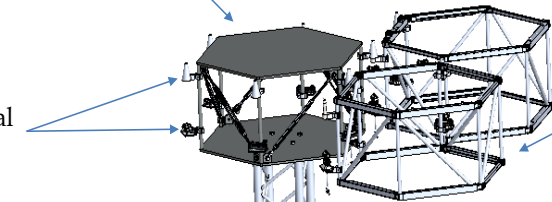
Use adjustable structural and power interconnects



Autonomous mobile manipulation for precision repeated robotic assembly



Central Truss

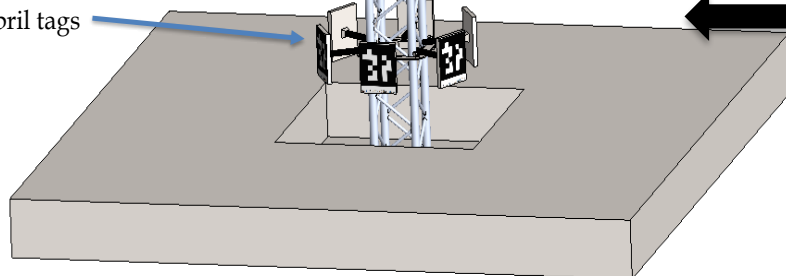


Deployable Trusses

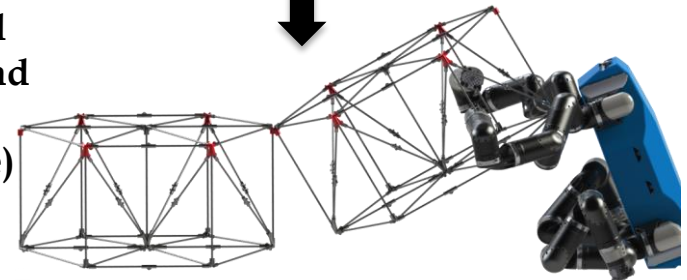
Electromechanical Interconnects

Assemble 3m closed kinematic truss around a central hub (spacecraft surrogate)

April tags



Floor



In-Lab Telescope Truss Assembly Robotics

DARPA-funded JPL 3 m telescope assembly demo



In-Space Telescope Assembly Robotics Risk Reduction

Dr. Rudranarayan Mukherjee (PI), Dr. Paul Backes, Charles Bergh,
Jason Carlton, Kyle Edelberg, Blair Emmanuel, Dr. Sisir Karumanchi,
Brett Kennedy, Dr. Junggon Kim, Jeremy Nash, Russell Smith

Jet Propulsion Laboratory, California Institute of Technology
Pasadena California 91109 USA

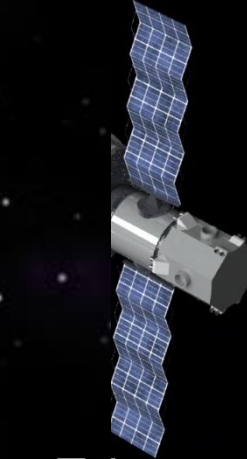
Program Manager: Dr. Lindsay Millard
DARPA Tactical Technology Office

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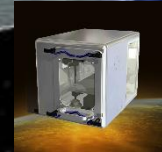
Large Solution Space for In-Space Assembly



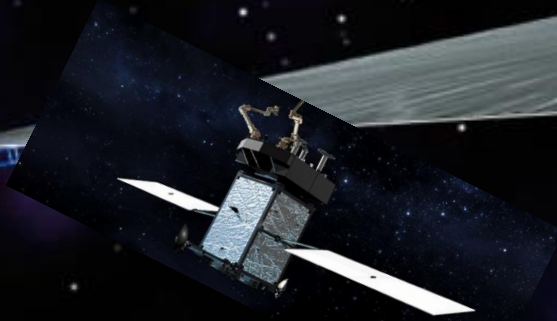
Cis-lunar station



Telescope spacecraft bus



In-space manufacturing



Free-flying servicer



Mobile assembly robot

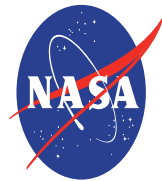


Fixed assembly robot



Astronaut support

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