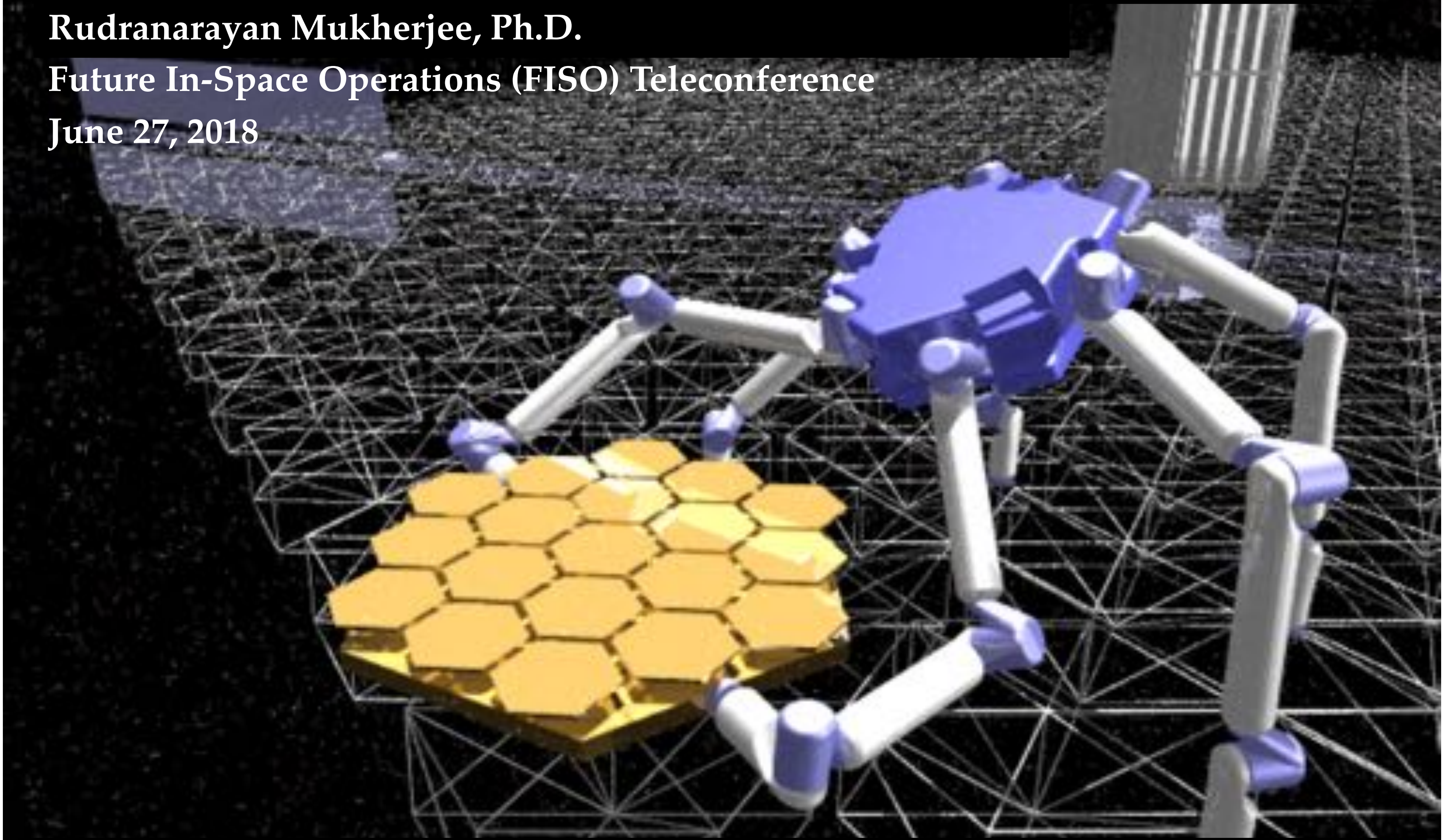
Robotic Assembly of Space Assets: Architectures and Technologies

Rudranarayan Mukherjee, Ph.D.

Future In-Space Operations (FISO) Teleconference

June 27, 2018

Jet Propulsion Laboratory
California Institute of Technology



Recent In Space Assembly Related Talks in FISO

Robotics for Improved Capability, Utilization, and Flexibility on a Cislunar Habitat
Daniel Rey (CSA) & Paul Fulford (MDA)
May 30, 2018

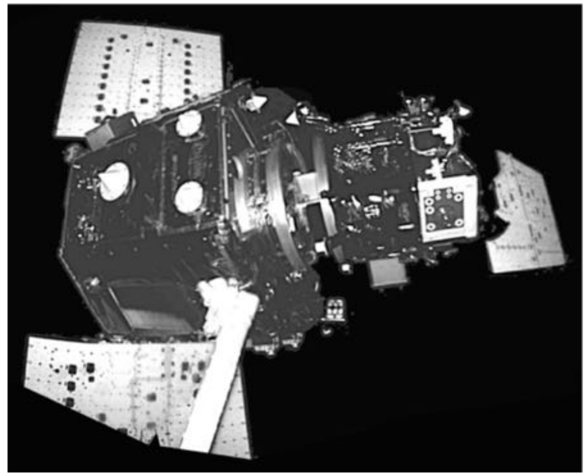
Future Applications for Robotics in Earth Orbit
Gordon Roesler , DARPA
May 2, 2018

Findings and Observations from the November 2017 NASA in-Space Servicing and Assembly Technical Interchange Meeting
Nicholas Siegler , NASA/JPL , Bradley Peterson , OSU & STScI & Harley Thronson , NASA GSFC
Feb 21, 2018

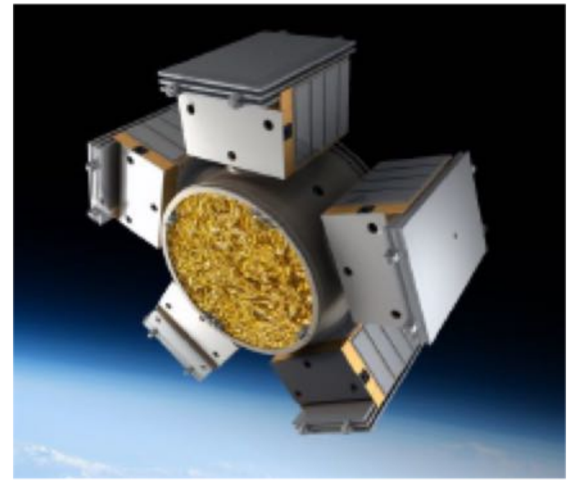
Autonomous In-Space Assembly 'Deja-vu': Leveraging Our Heritage to Enable the Future
Lynn Bowman , NASA LaRC
Sep 27, 2017

On-Orbit Manufacturing and Assembly of Spacecraft: Opportunities and Challenges
Iain D. Boyd & Bhavya Lal , IDA Science and Technology Policy Institute
Sep 6, 2017

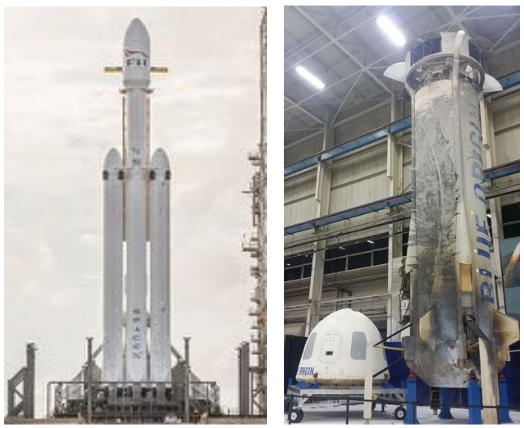
Instrument Assembly on the ISS



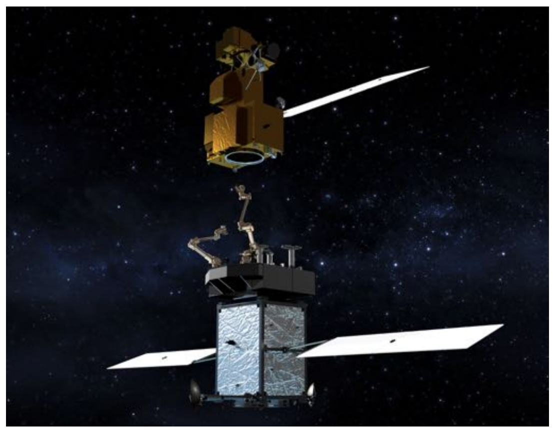
Rendezvous and Proximity Operations



Secondary Launch Vehicles

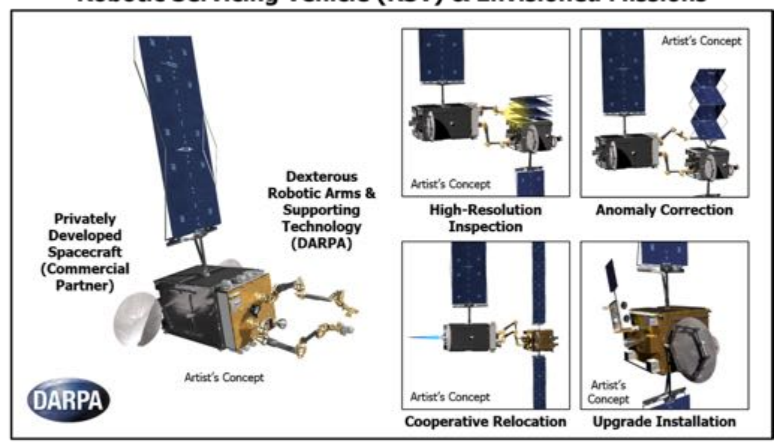


Commercial Low(er)
Cost Launch Vehicles

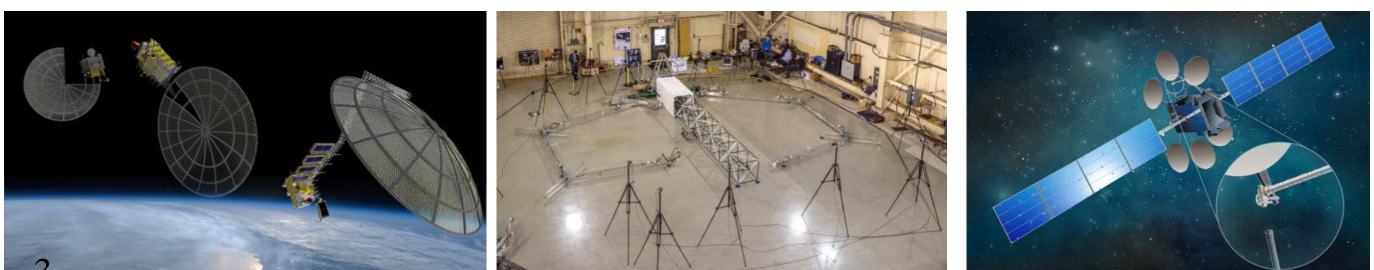


NASA Restore-L Mission

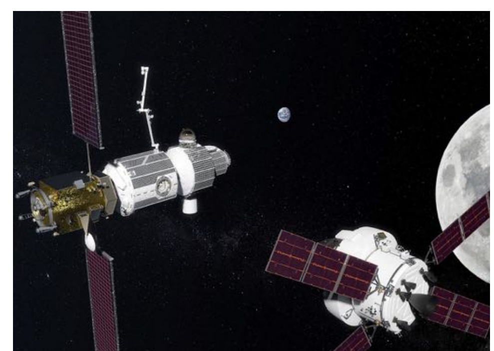
Robotic Servicing Vehicle (RSV) & Envisioned Missions



DARPA RSGS

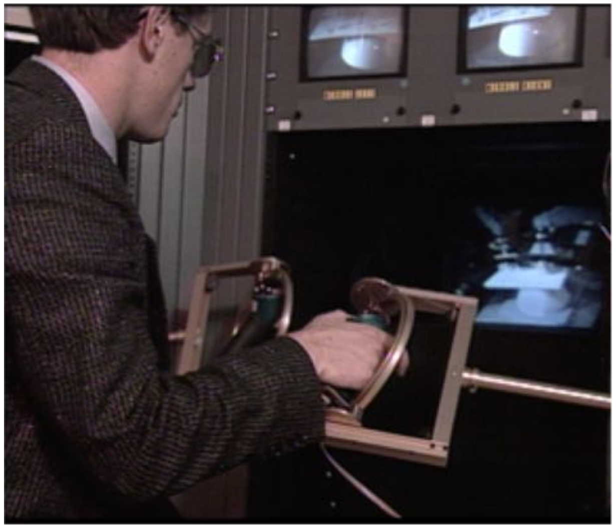


In-space Robotic Manufacturing and Assembly (IRMA)

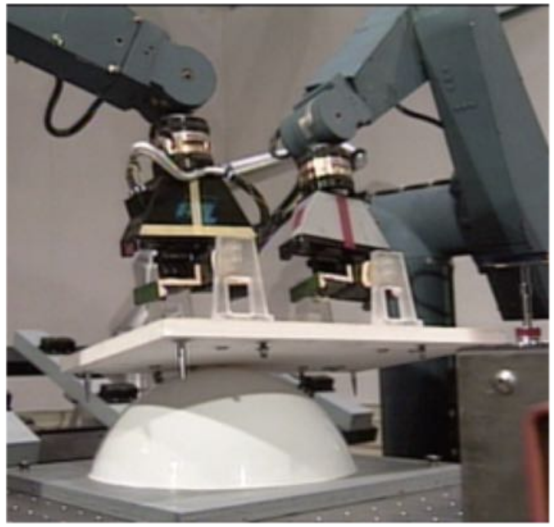


Lunar Orbital Platform-Gateway

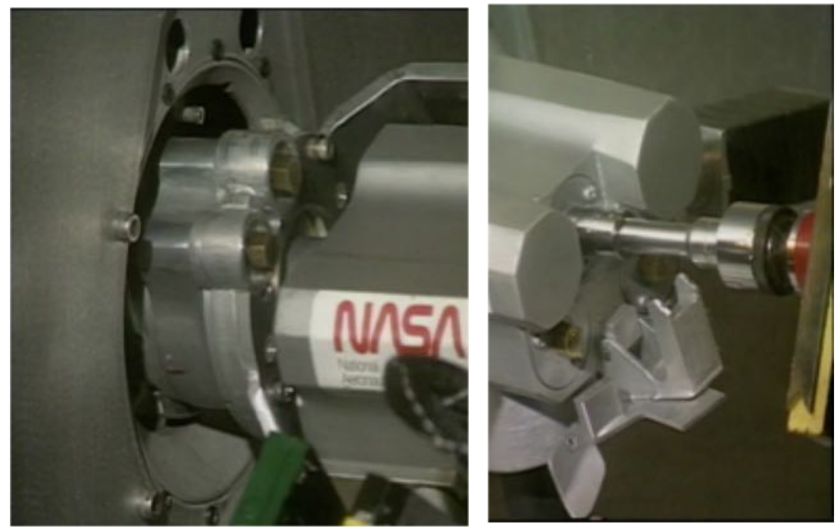
1990s - High Bandwidth Telerobotic Assembly at JPL



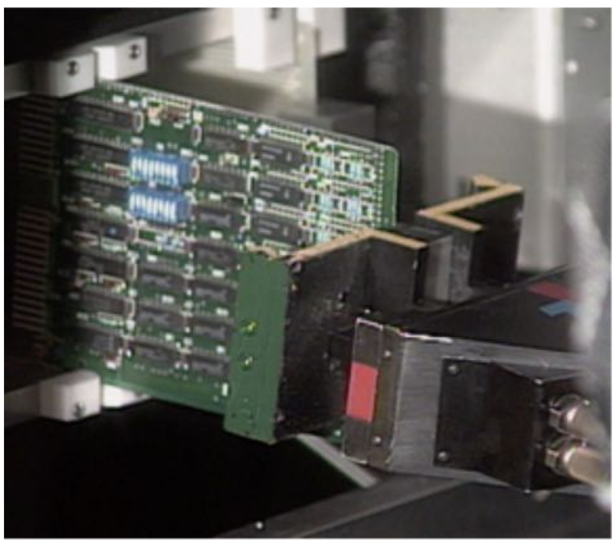
Telerobotic Human Interface



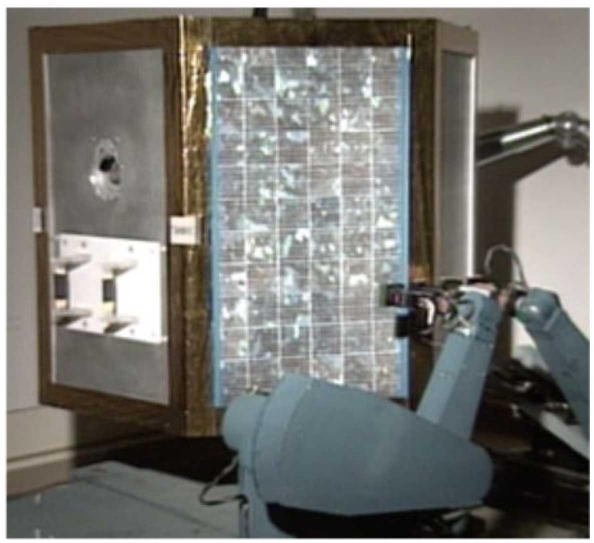
Contour Following



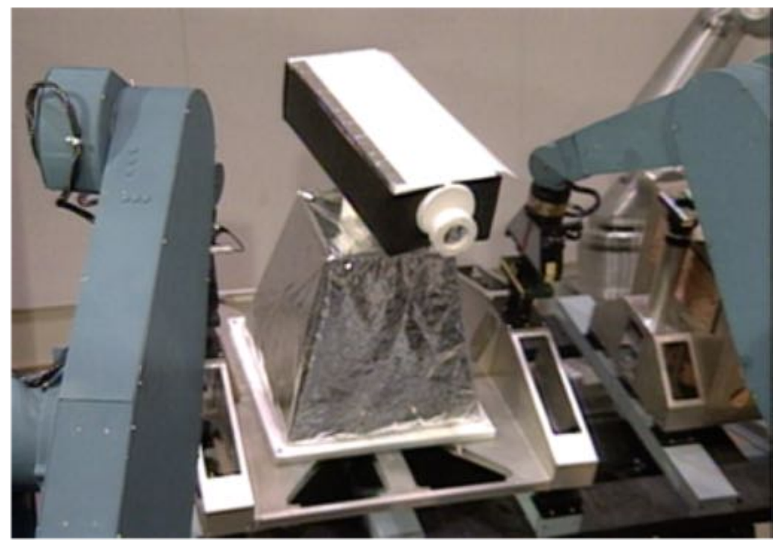
Fluid Coupler Assembly and Ratcheting



Card Insertion



Spinning Body Capture



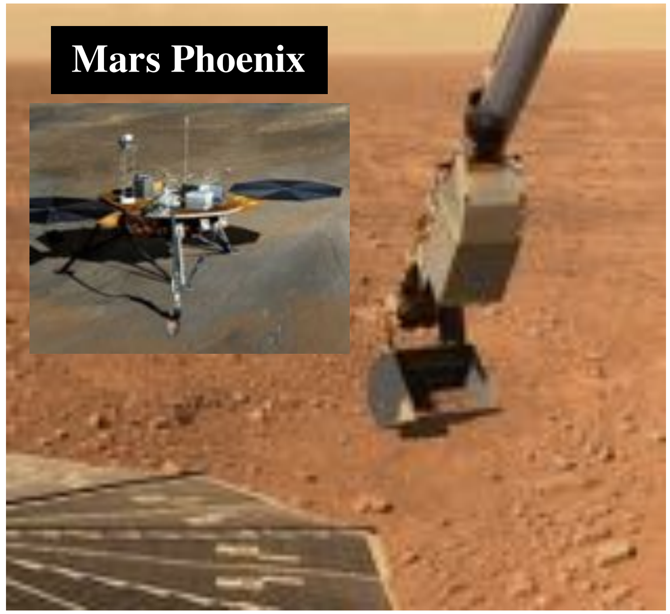
Dual Limbed Instrument Docking

Picture Credits: Dr. Paul Backes, JPL

Example Manipulation Behaviors in Mars Flight Applications

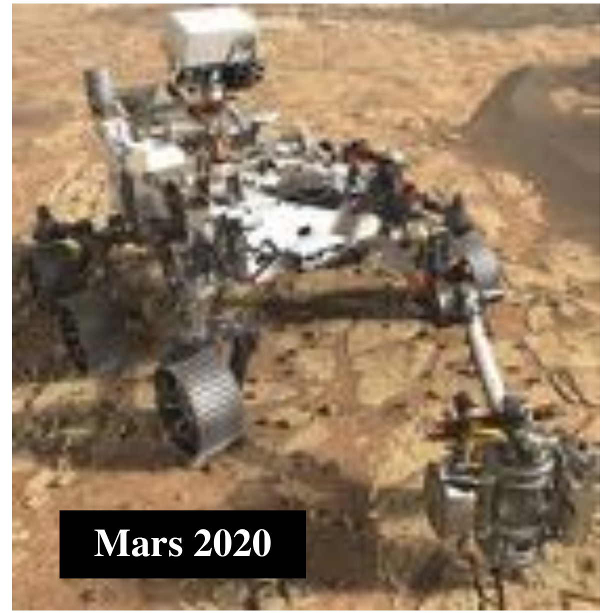
Single command approach and instrument placement

With 3D target selected on rock, rover autonomously approaches rock, deploys robotic arm, and deploys science instrument at target point on rock.



Autonomous digging: Digging while modifying digging behavior based on sensed hardness of Martian soil.

Terrain model generation using tool placement on grid locations



Autonomous drilling in rocks, force-controlled docking of coring bit with rover.

Drilling into rocks with force controlled feed rate using coring tool at end of robotic arm.

Docking coring tool bit at bit station on rover with force control for bit exchange.

Manipulation for Mars Flight Applications

- On-board autonomy for Mars lander and rover manipulation
- Commands: commands map to autonomous behaviors implemented in on-board flight software.
- Sequences: uplinked sequence of commands to execute, with capability for simultaneous execution of multiple sequences
- On-board behaviors: single state, multi-state, and hierarchical state machines to implement behaviors to change state of robot or environment.
- Anomalies: continuous monitors to ensure robot stays away from dangerous states, or detect and accommodate.

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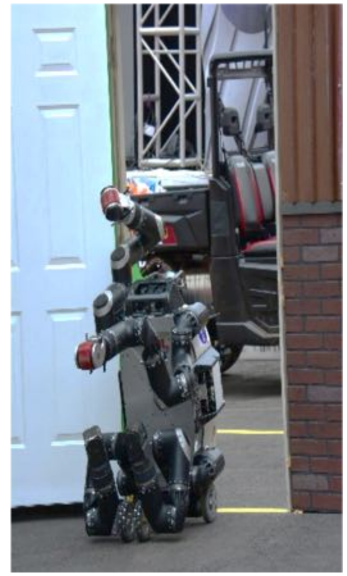
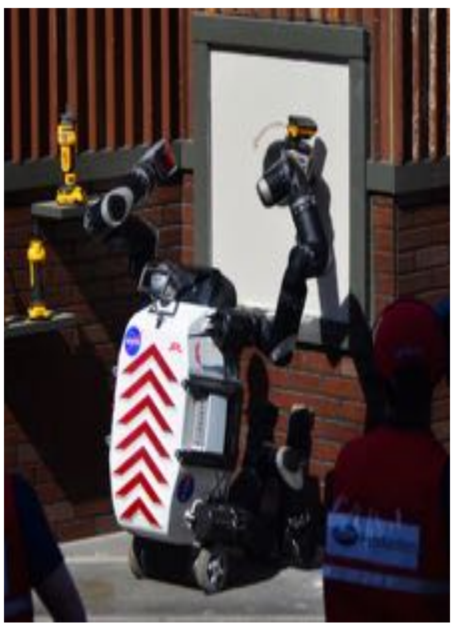
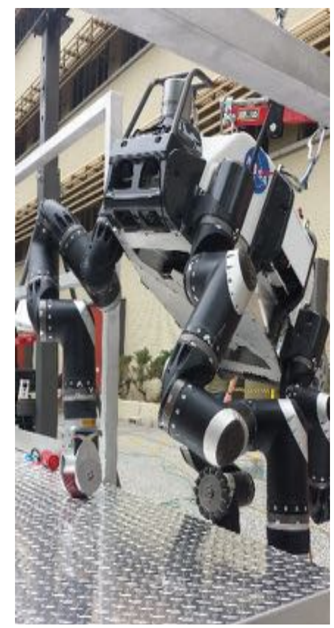
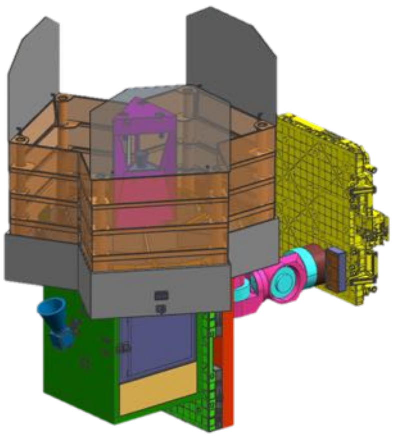
DARPA Robotic Challenge (DRC 2013-15)



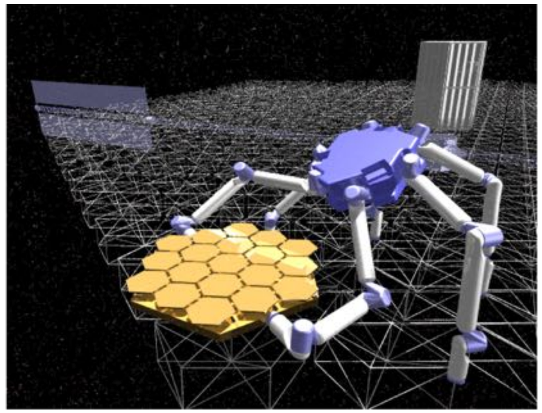




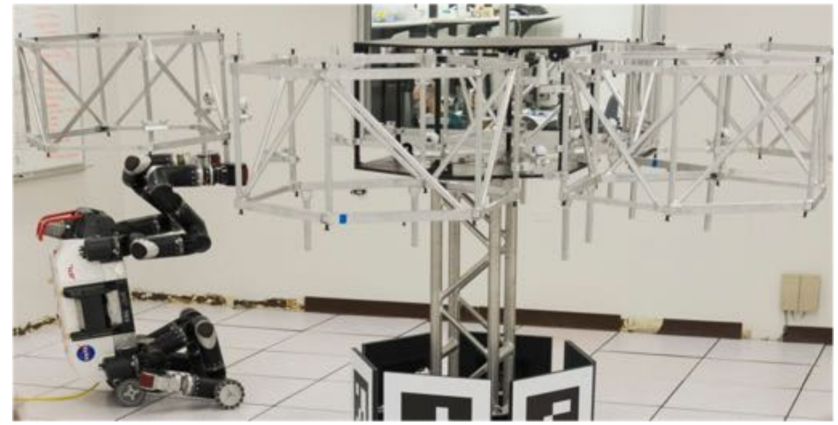
Recent Robotic Assembly Efforts at JPL



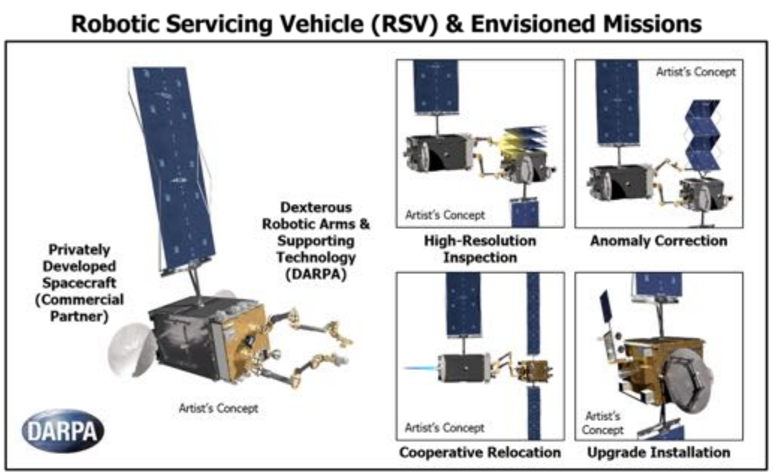
Optical Testbed and Integration on ISS eXperiment (OpTIIX)



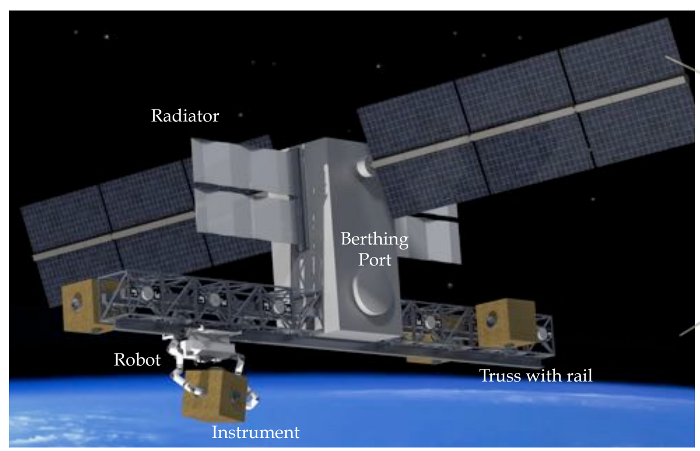
Large Telescope Assembly Architecture with Caltech



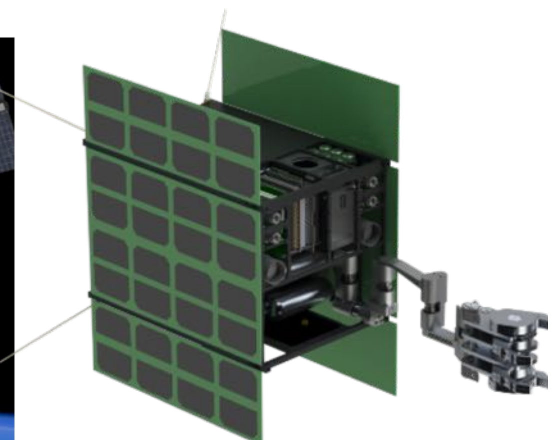
DARPA In-Lab Truss Assembly Demonstration



DARPA RSGS Technical Evaluation and Risk Analyses



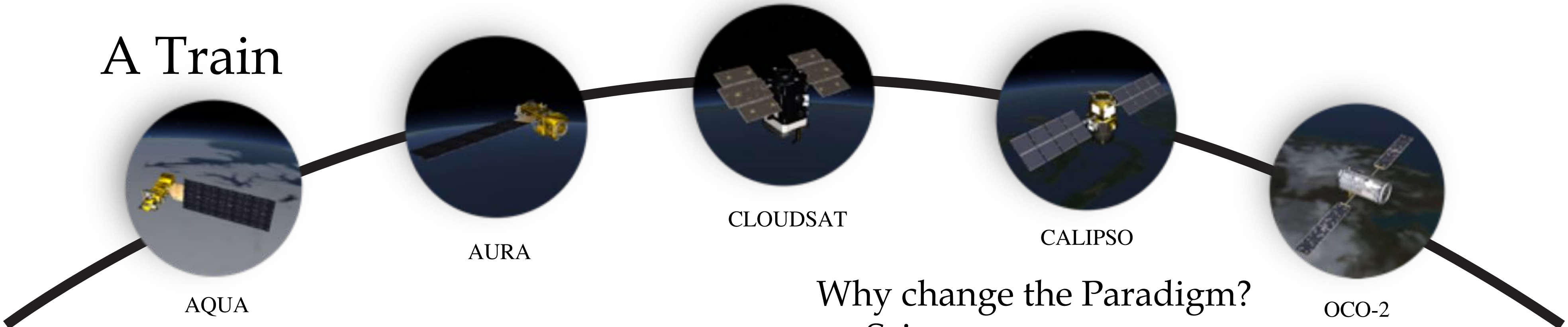
Persistent Robotic Observation Platform
aka Science Station
Collaboration with Space System Loral



DARPA Robotic Arms on Cube/SmallSats

Persistent Robotic Observation Platform (Science Station)

A Train



Why change the Paradigm?

- Science
- Technical Feasibility
- Cost

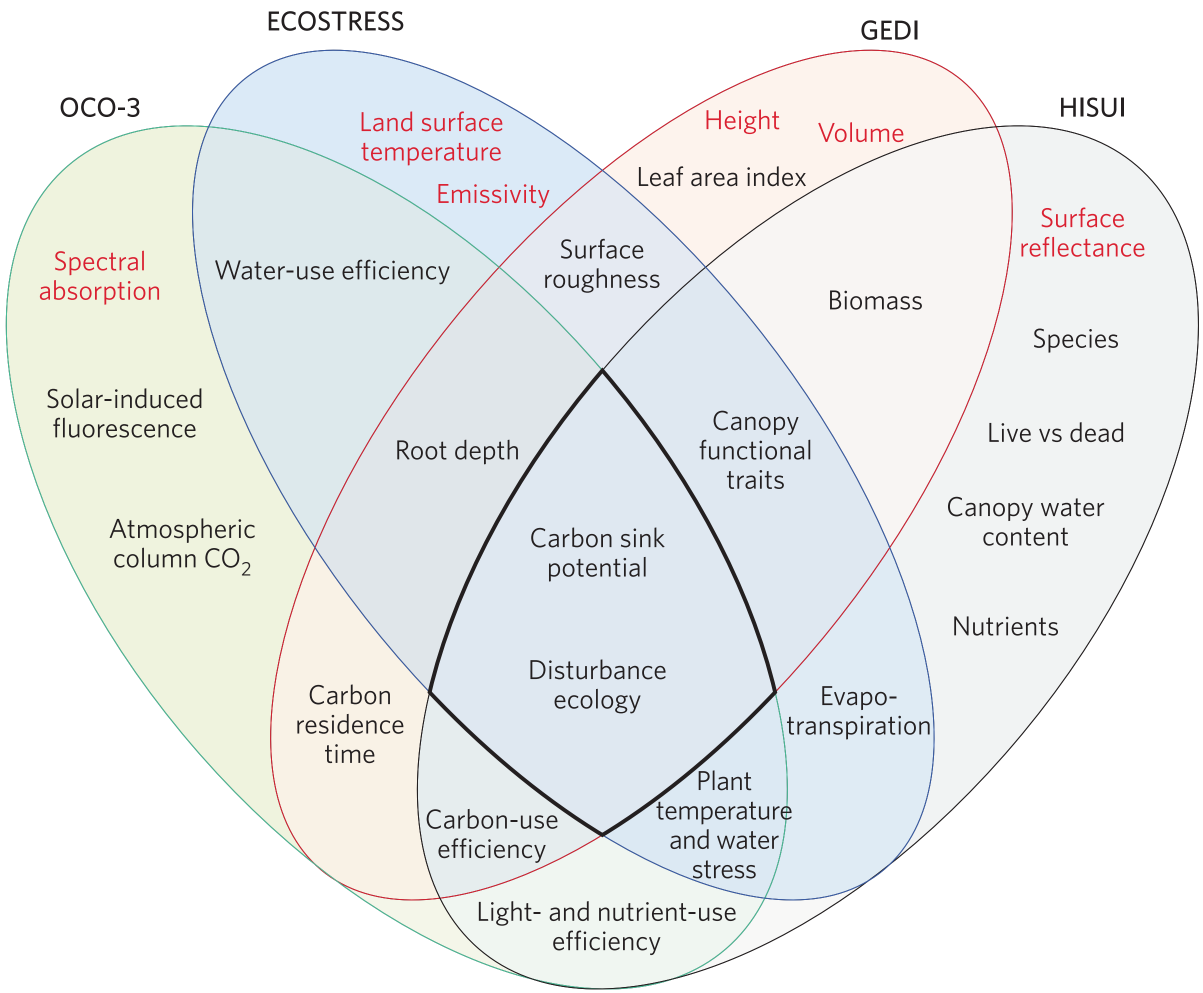
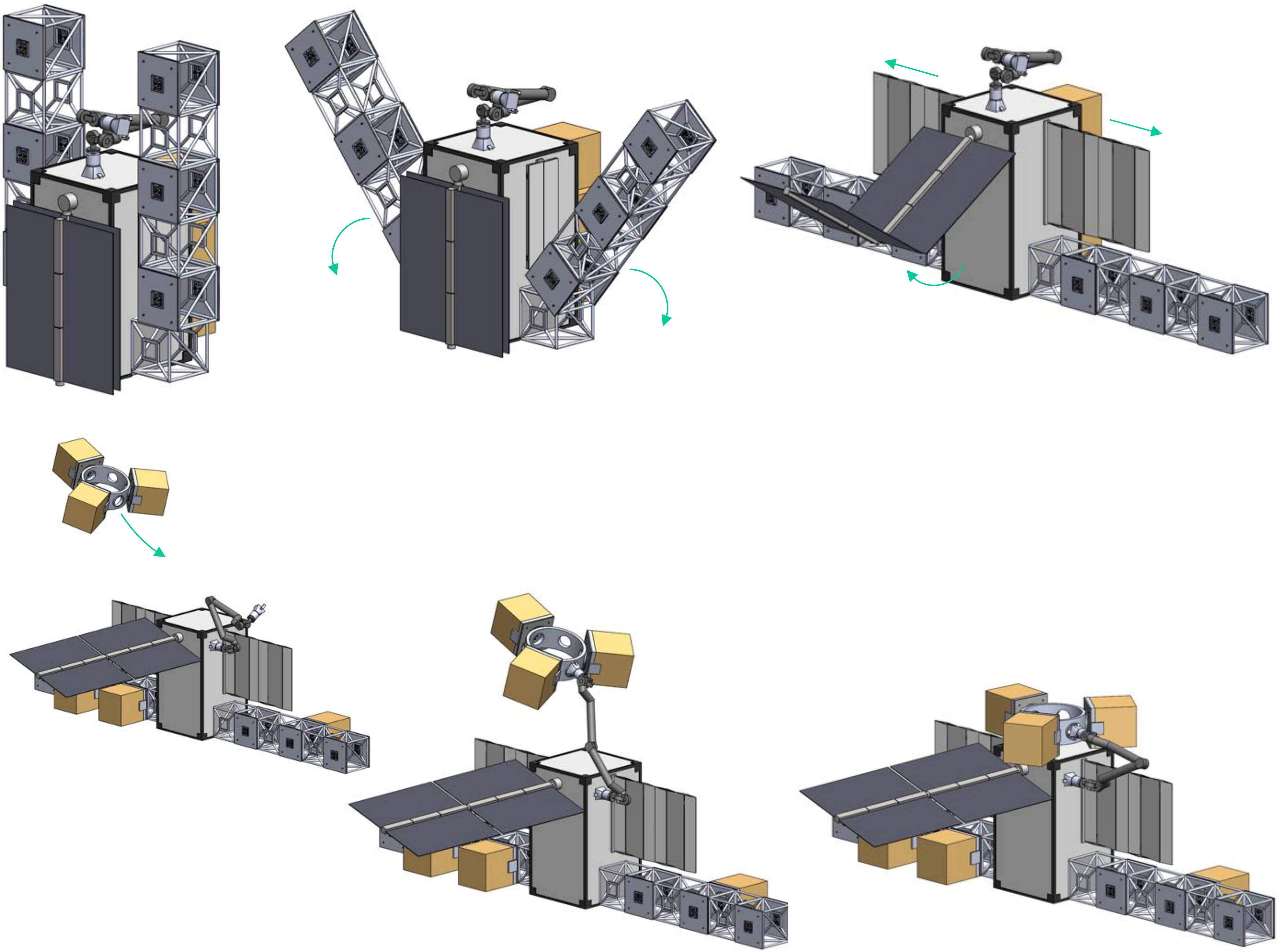
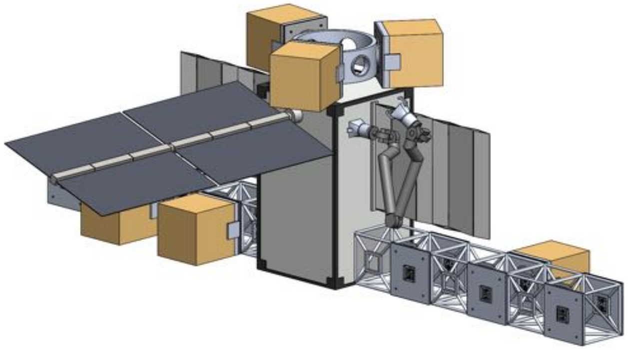
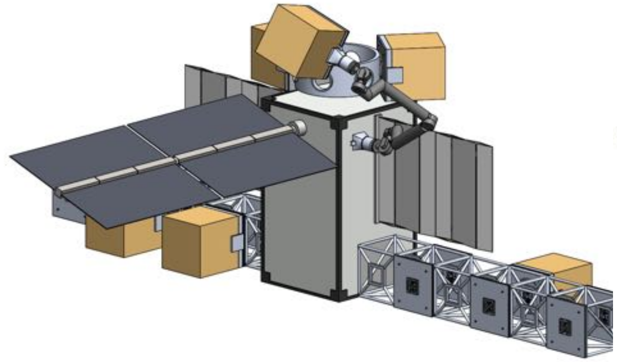
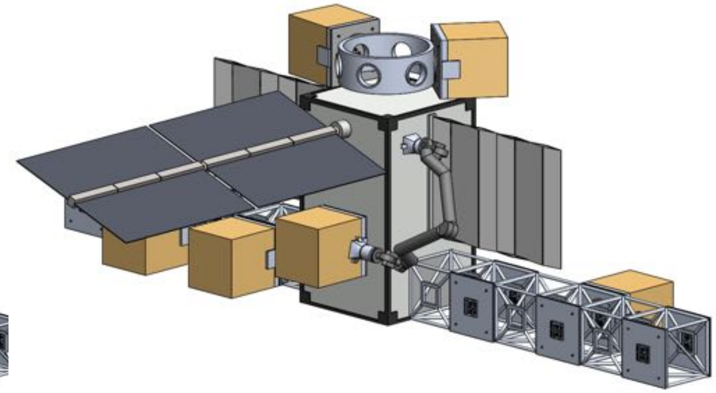
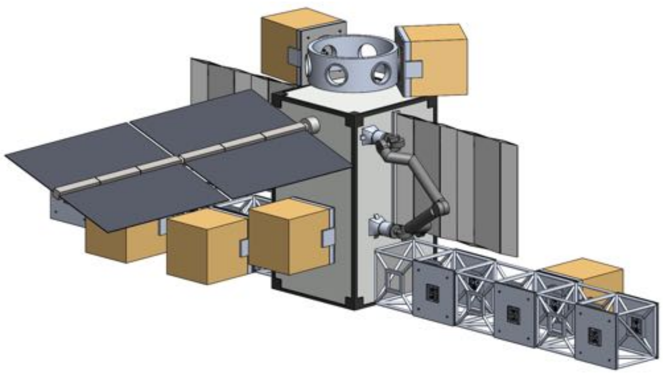
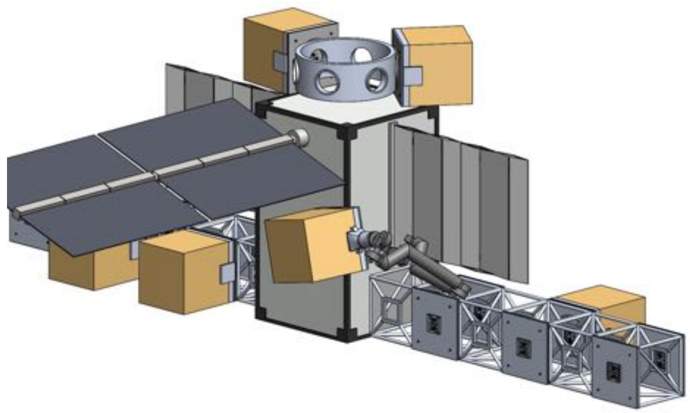
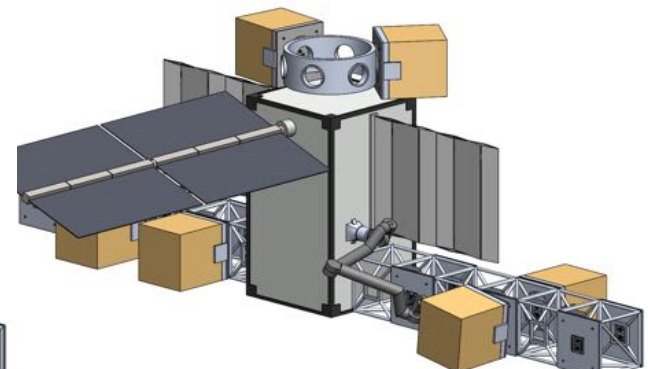
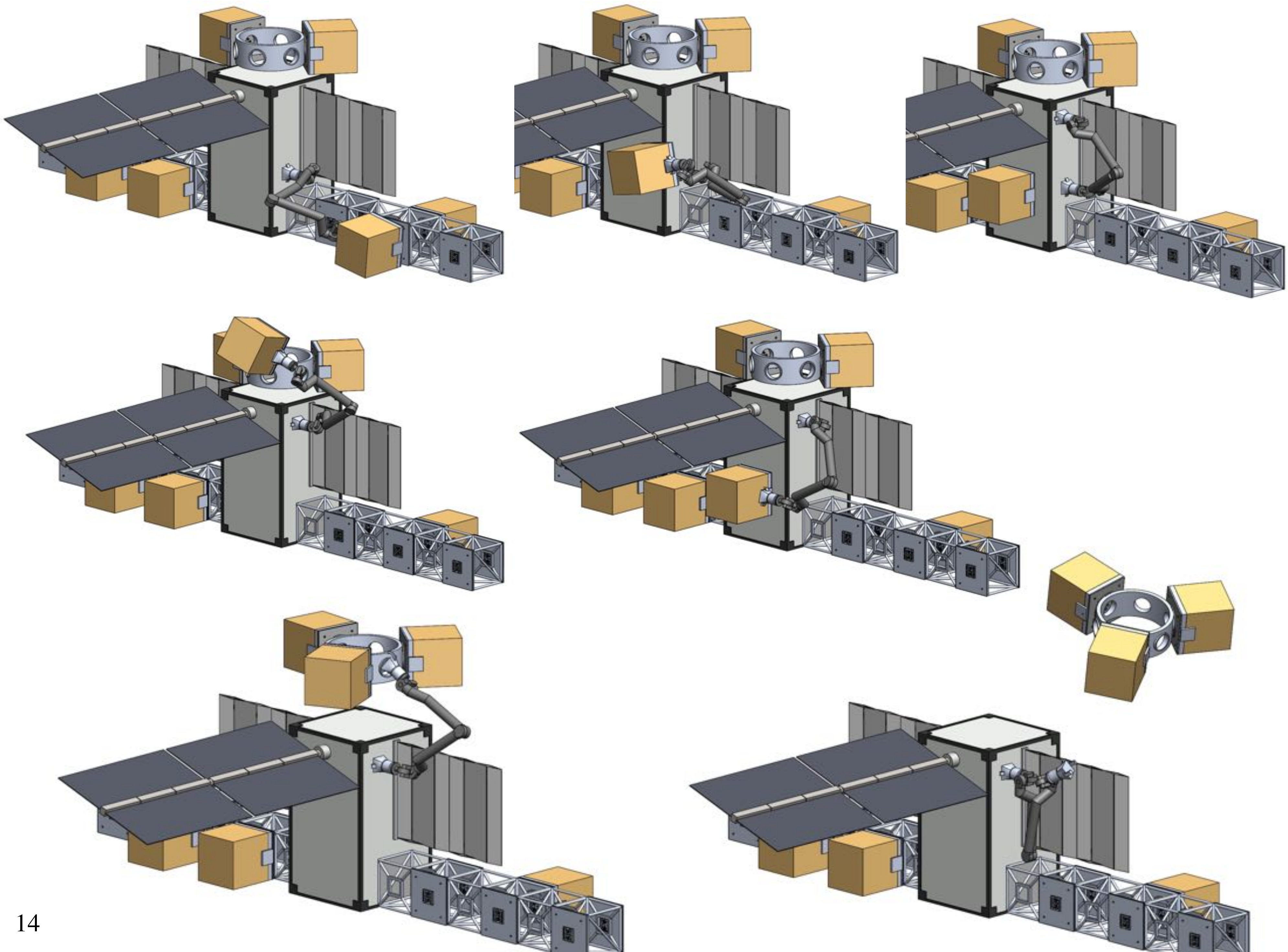
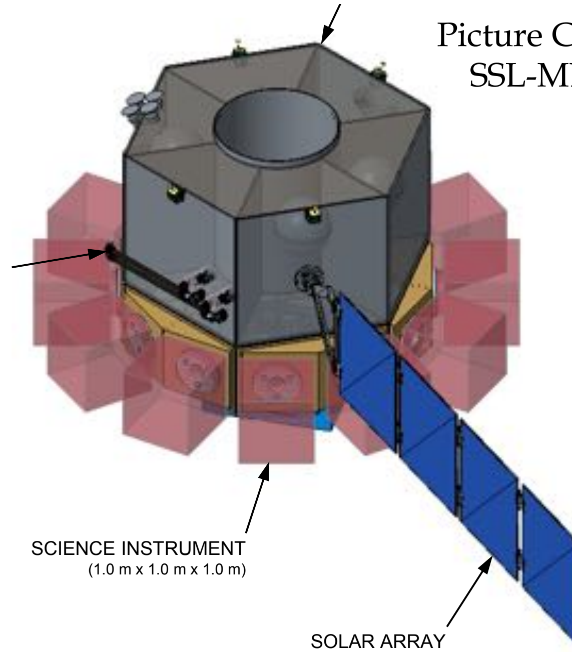


Figure 1 | Spatial and temporal synergy of observations and their applications. A pretzel diagram of observations (red text) from each instrument (coloured shapes) and the synergistic physical parameters that can be derived (black text) when observations are taken at synchronous and complementary spatial and temporal resolutions.

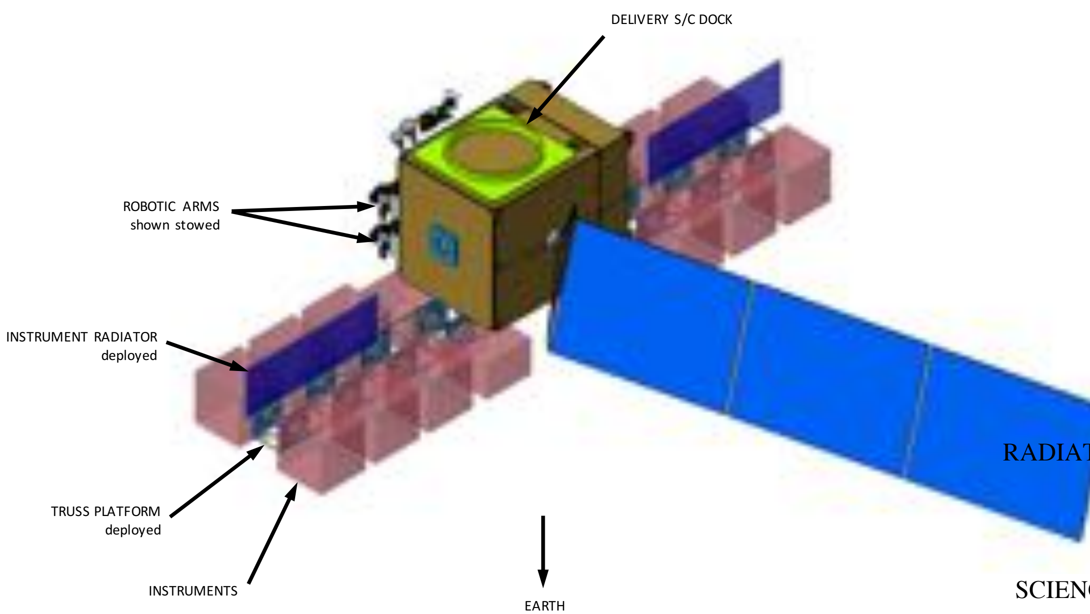


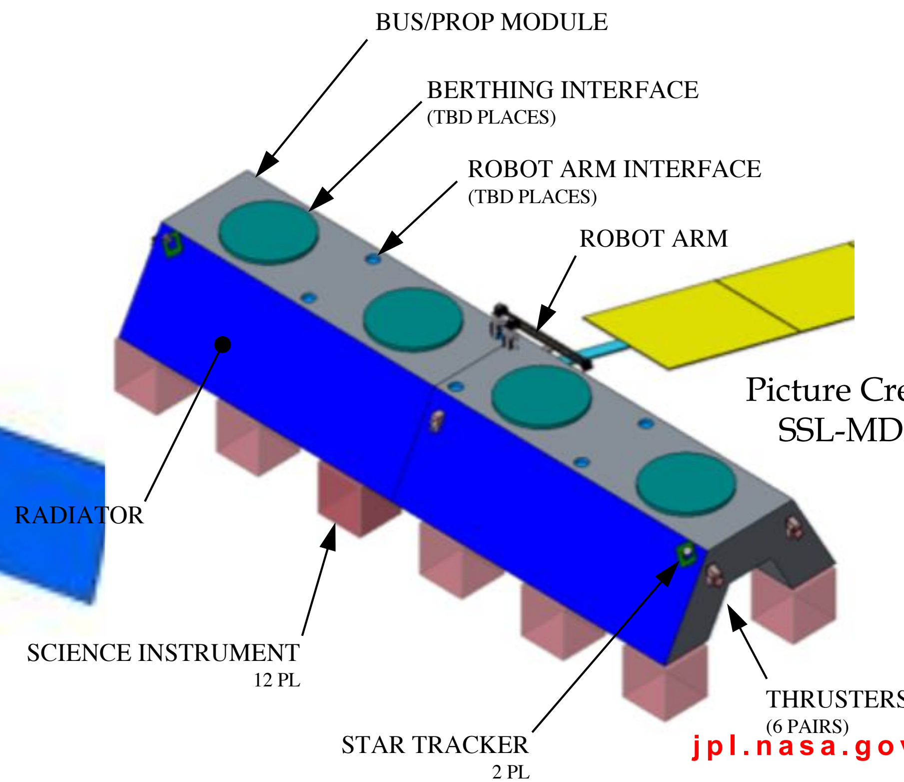




Picture Credit:
SSL-MDA

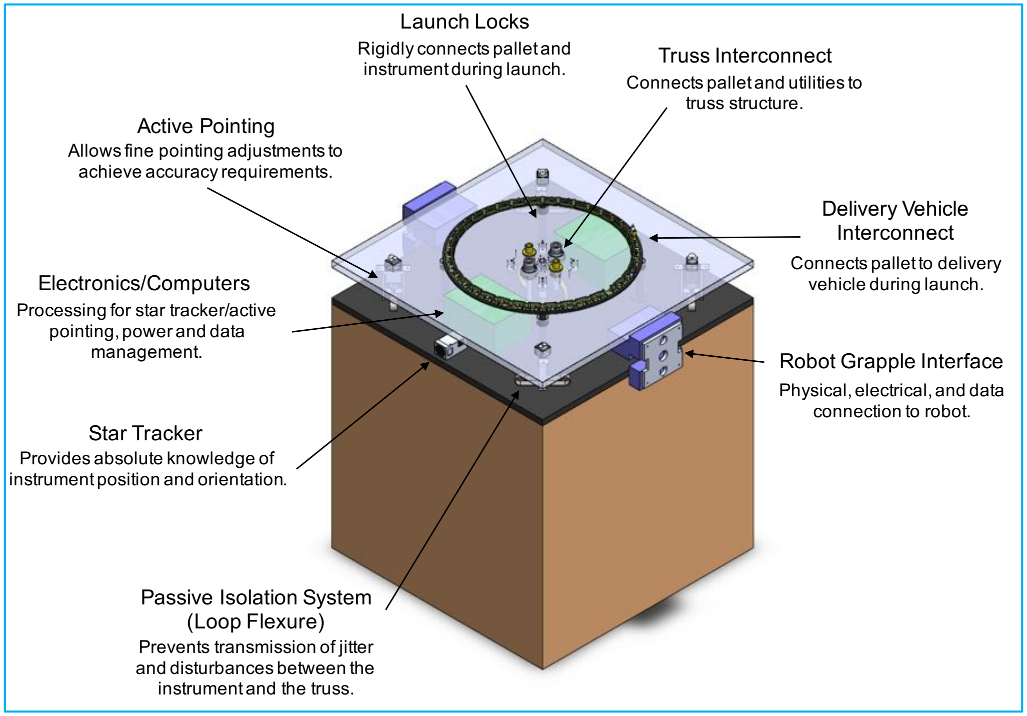


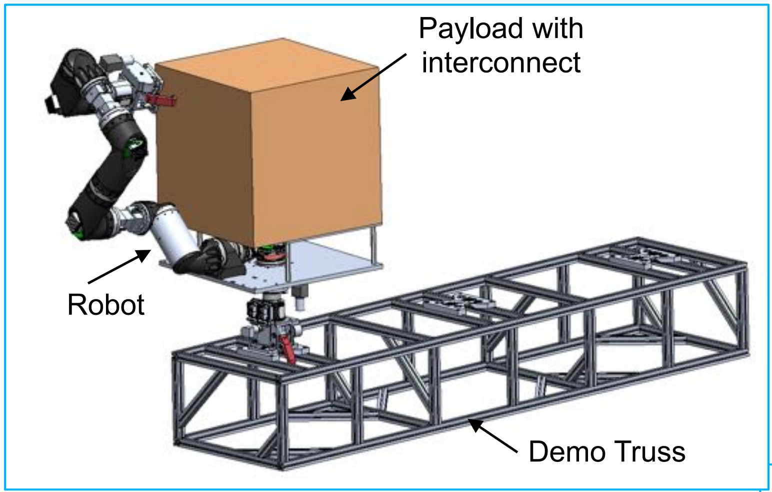
Picture Credit: SSL-MDA

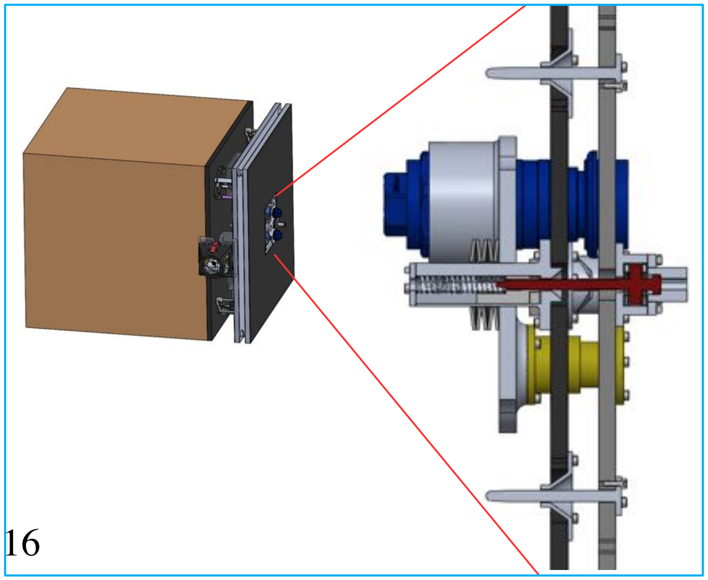


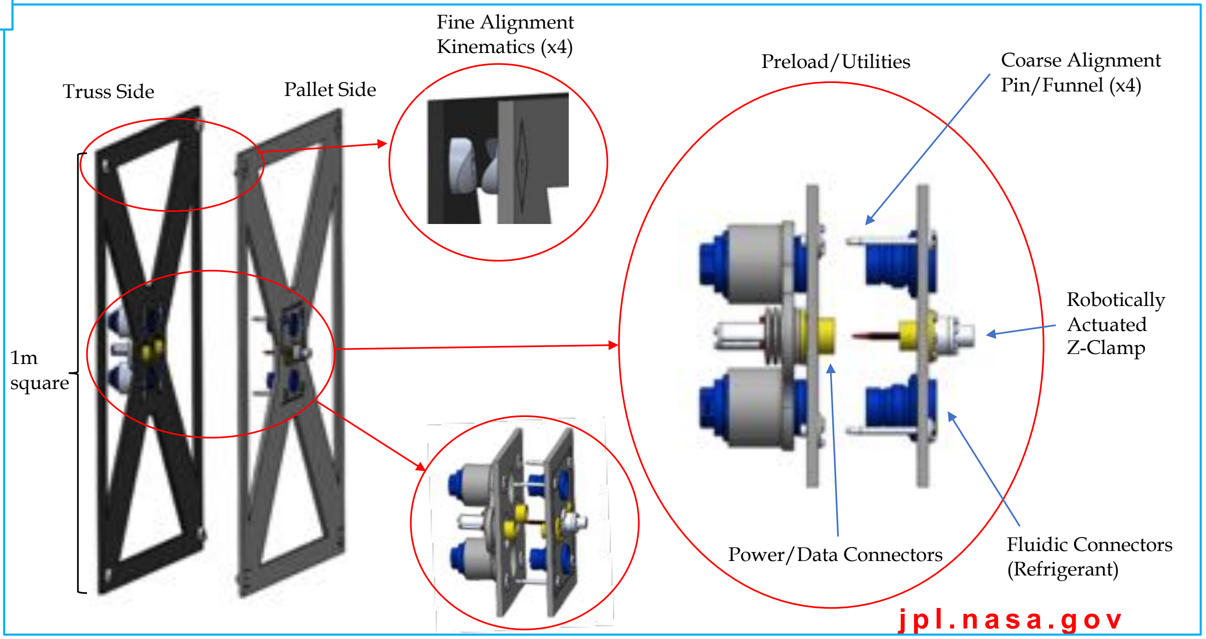
Picture Credit:
SSL-MDA

SMLS	**FTS**
Calipso	**Cloudsat**
Radiometer	**IR Sounder**
MSPI	**Radiation**
VSWIR Spectrometer	**TIR Imager**
Ocean and Coast Imager	**FAR IR Spectrometer**

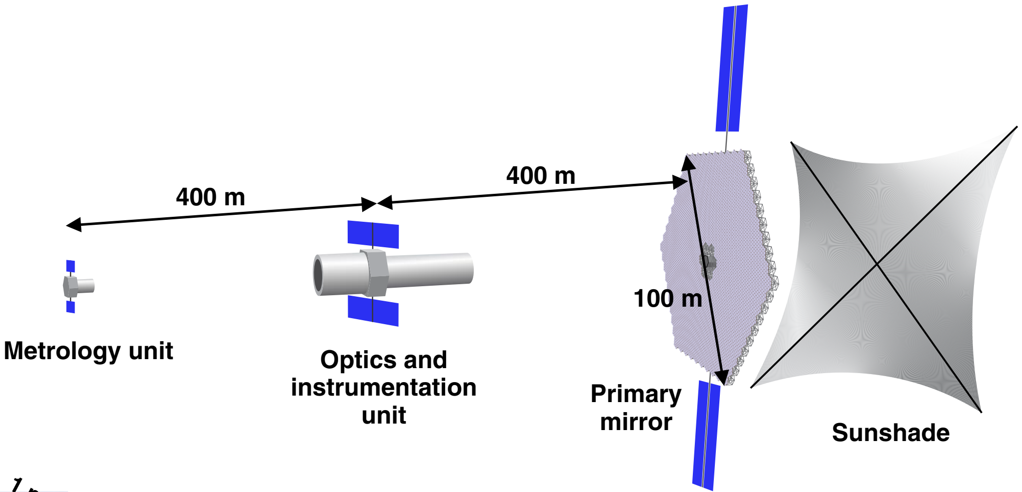


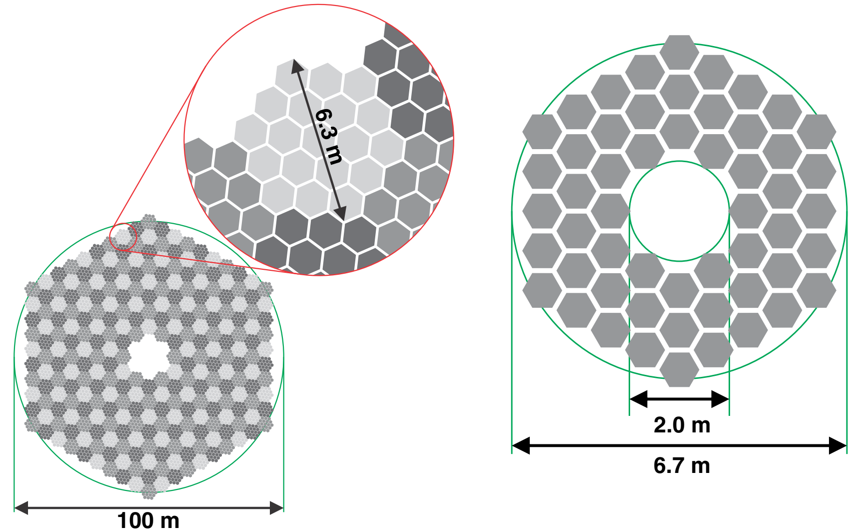


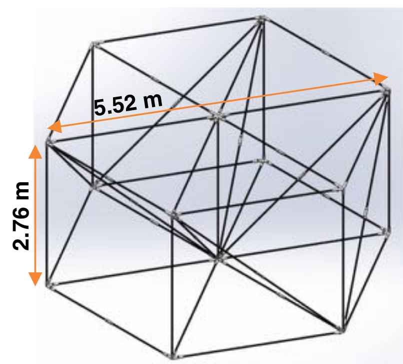


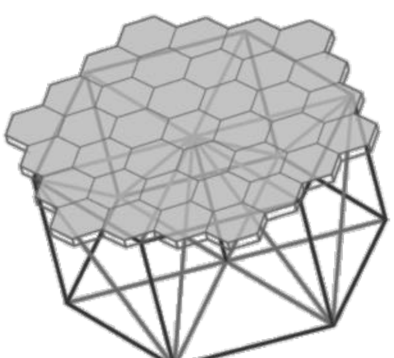


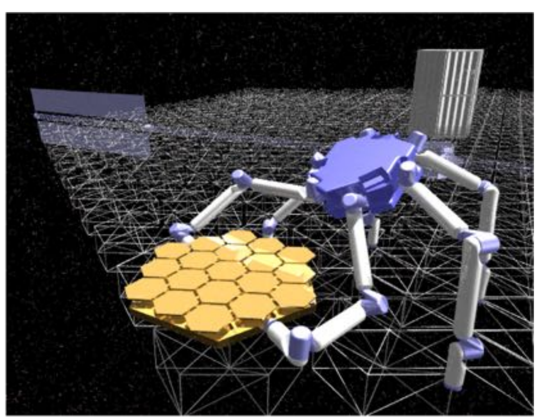
The 100m Robotically Assembled Telescope

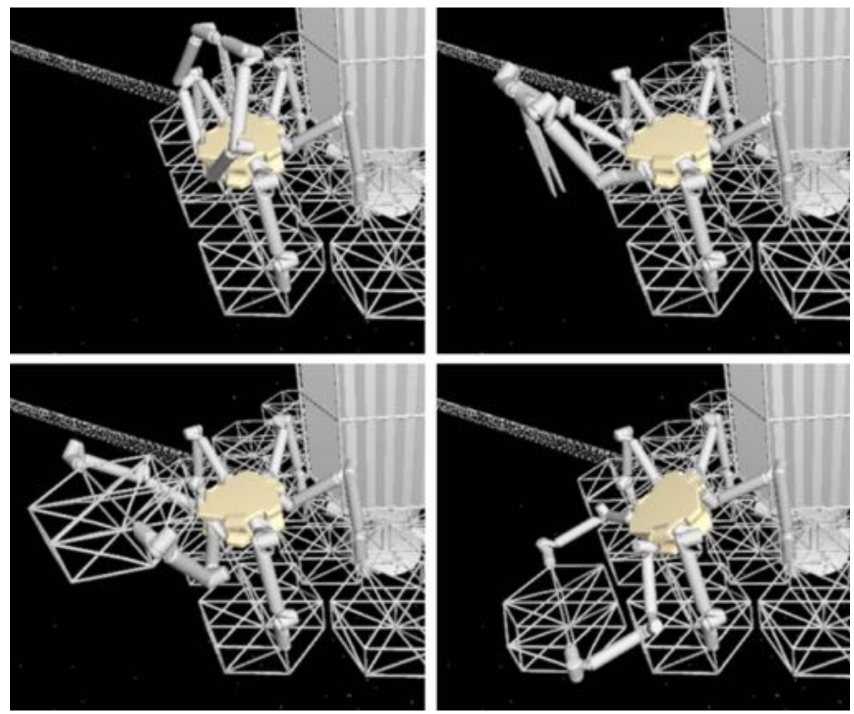












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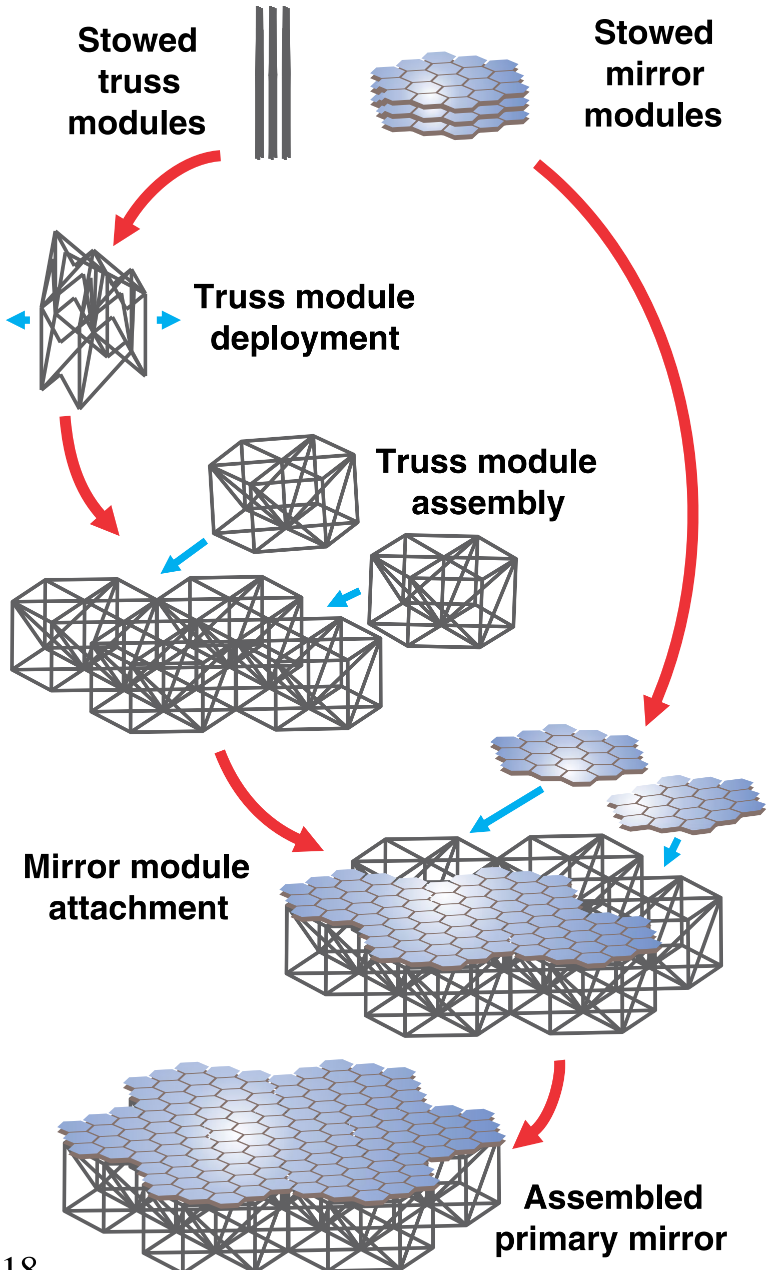
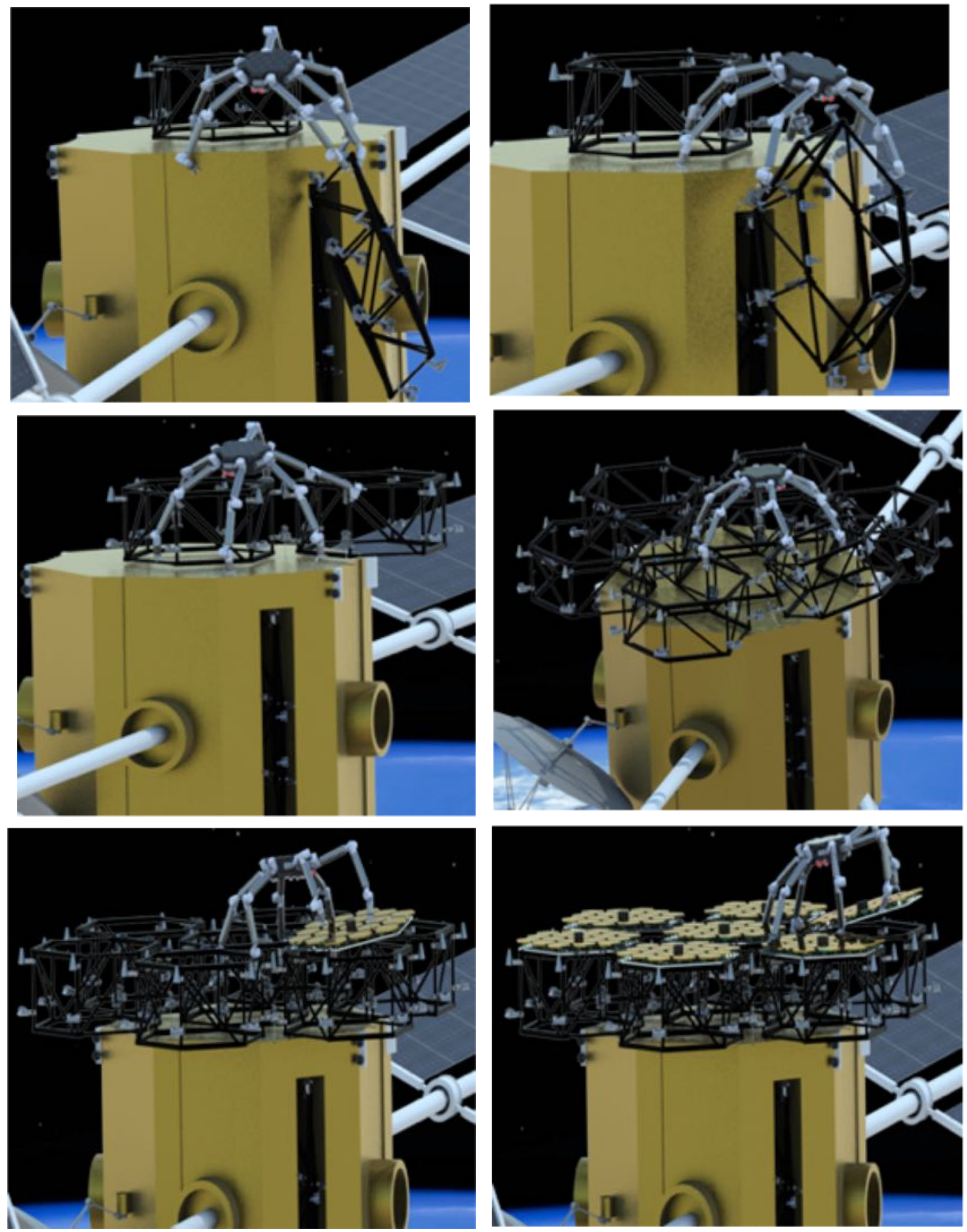
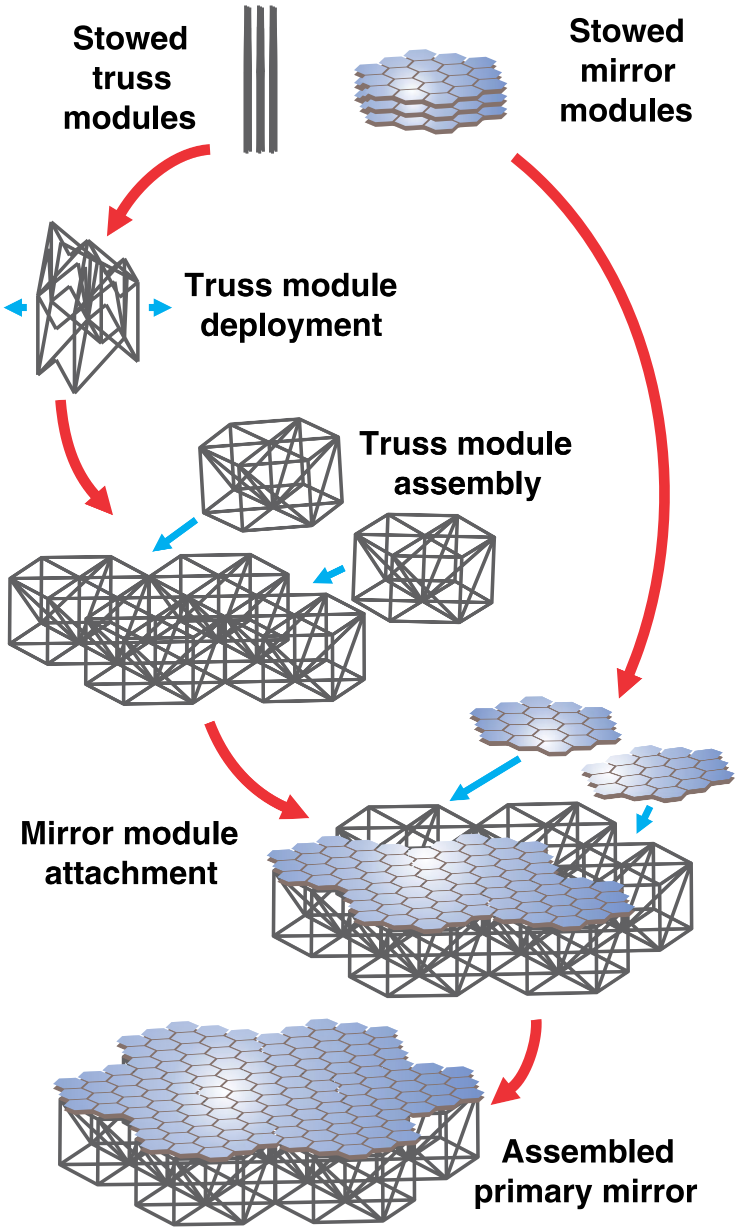
"Architecture for in- space robotic assembly of a modular space telescope," J. Astron. Telesc. Instrum. Syst. 2(4), 041207 (2016), doi: 10.1117/1.JATIS.2.4.041207

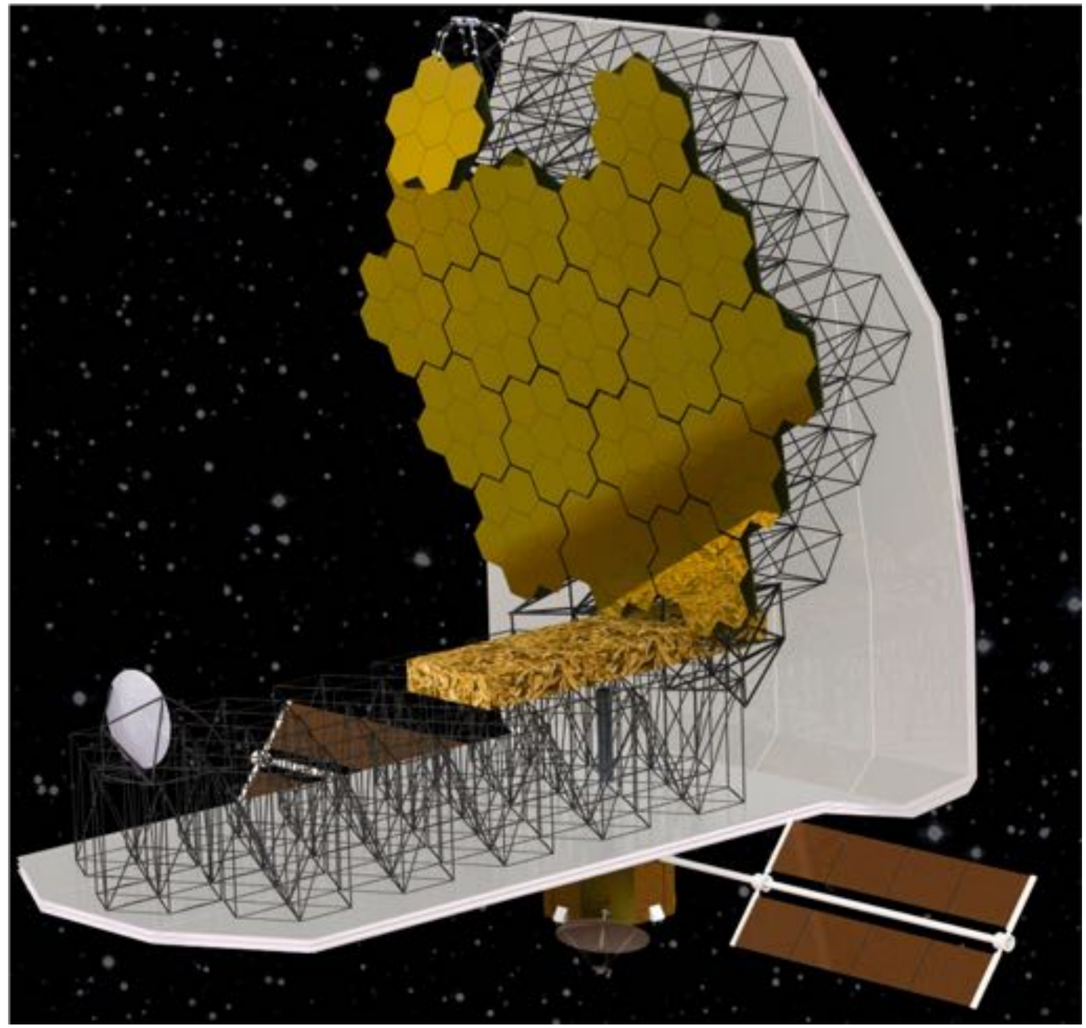
In Space Telescope Assembly Robotics

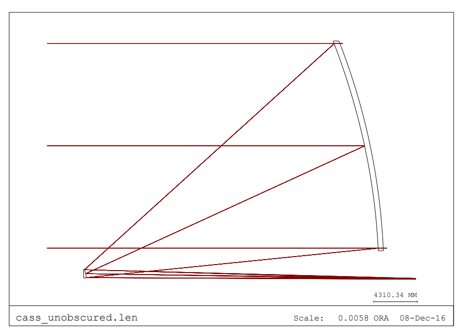




In Space Telescope Assembly Robotics







Unobscured Ritchey-Chretien

FOV 24.5x24.5 arc-sec.

Covers 8K x 8K x 12 micron FPA

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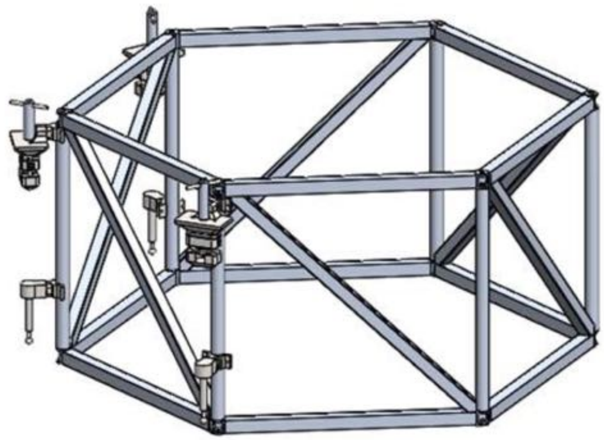
DARPA In Lab Telescope Truss Assembly Robotics

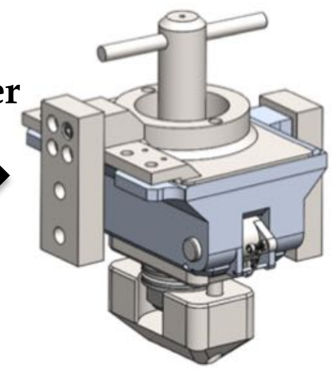
Assemble a 3m truss in a “closed kinematic loop” configuration to 1 cm flatness from Deployable Truss Modules (DTMs) using autonomous robotics

Stowed DTMs

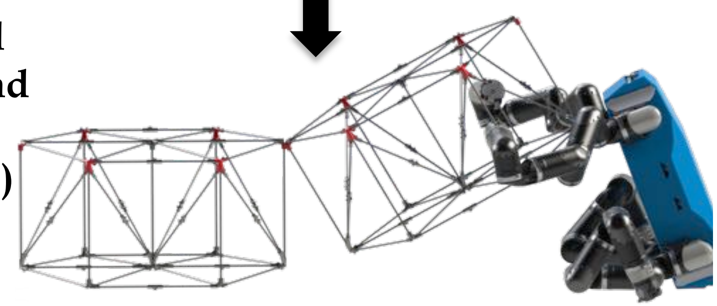
Robotically Deploy



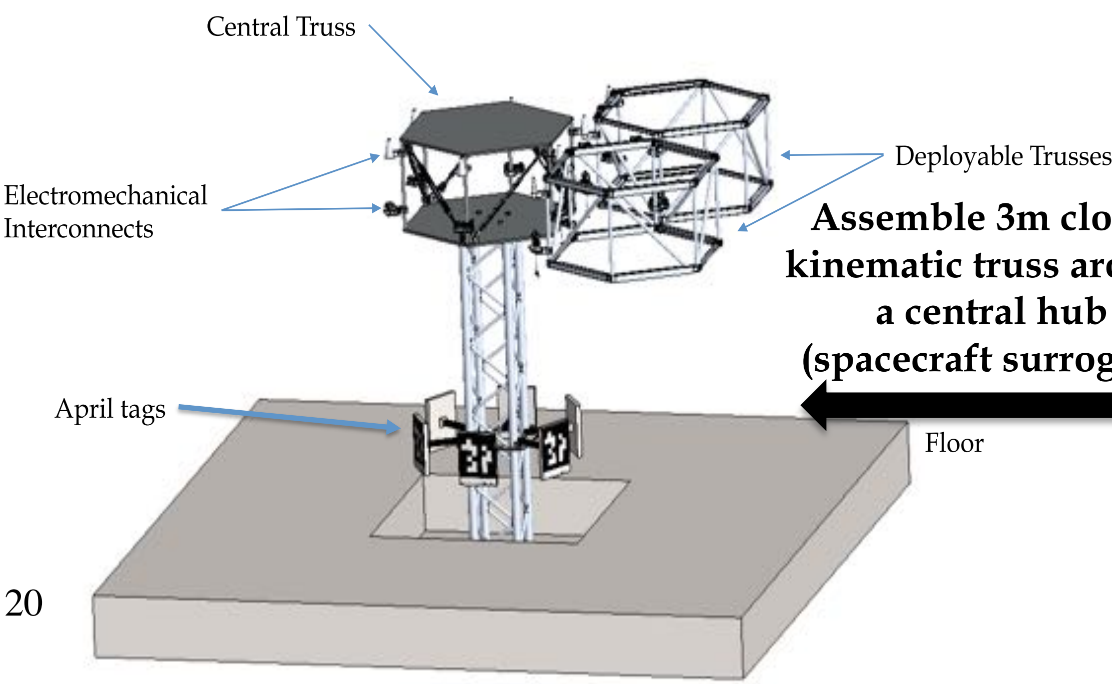
Use adjustable structural and power interconnects



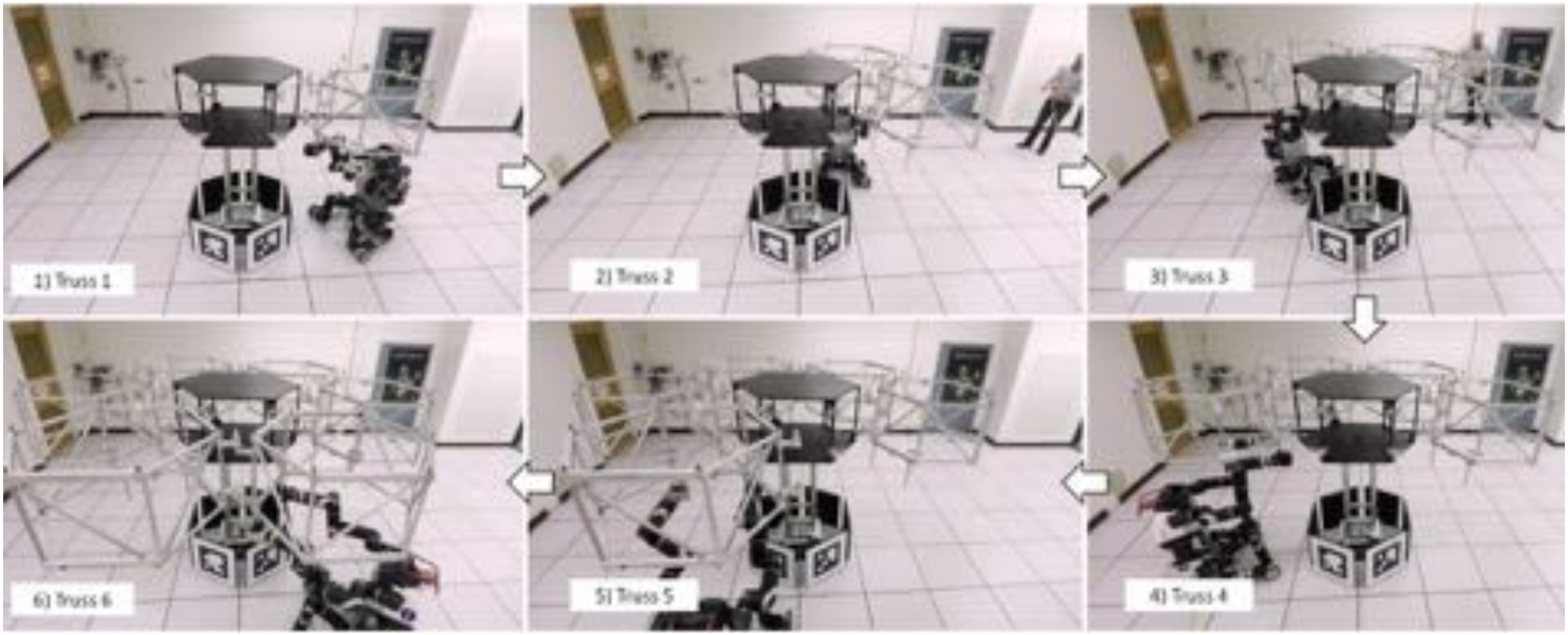
Autonomous mobile manipulation for precision repeated robotic assembly



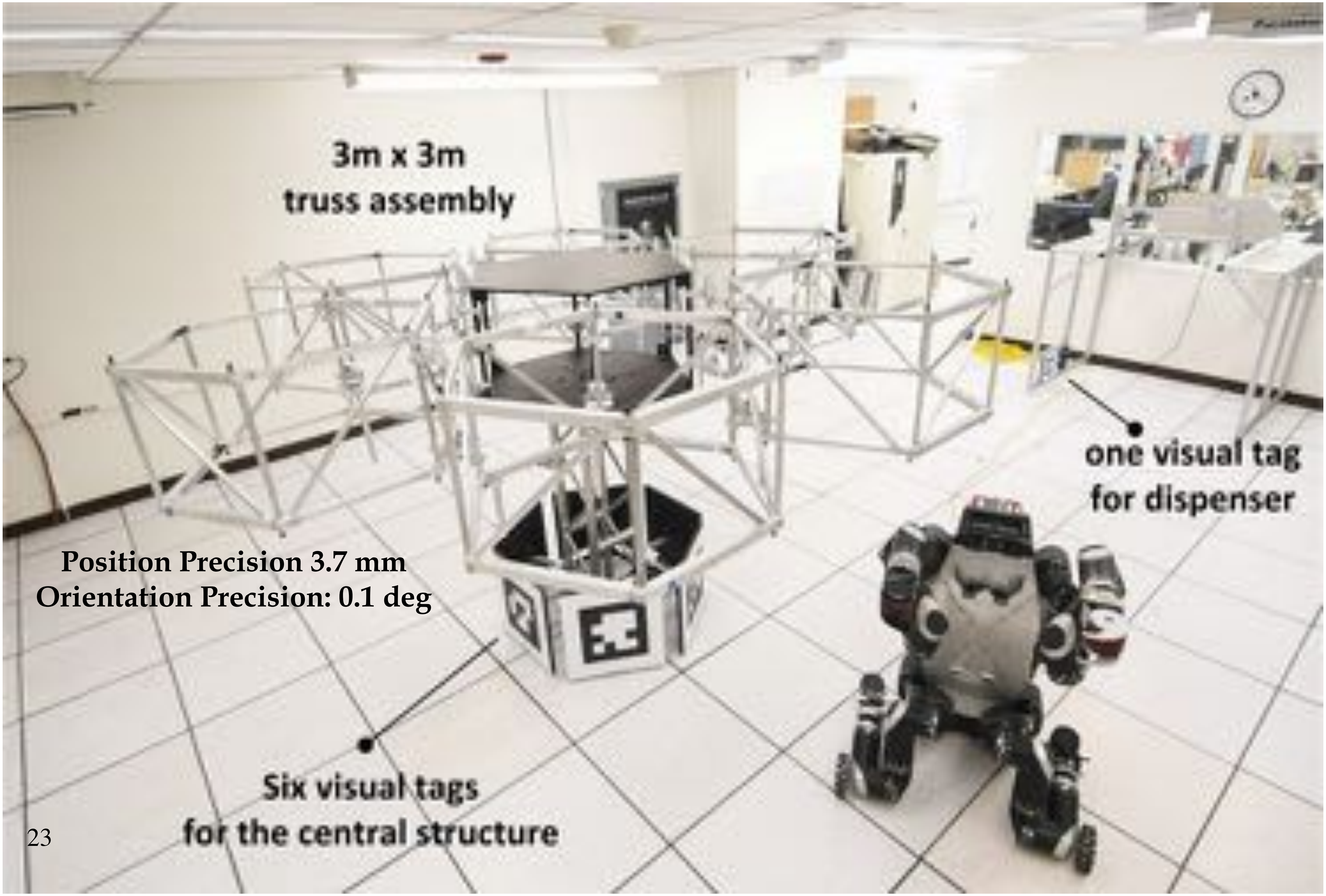
Assemble 3m closed kinematic truss around a central hub (spacecraft surrogate)




1) Start
2) Back up
3) Grab
4) Pop latch
latch
5) Deploy
6) Insert


1) Truss 1
2) Truss 2
3) Truss 3
4) Truss 4
5) Truss 5
6) Truss 6

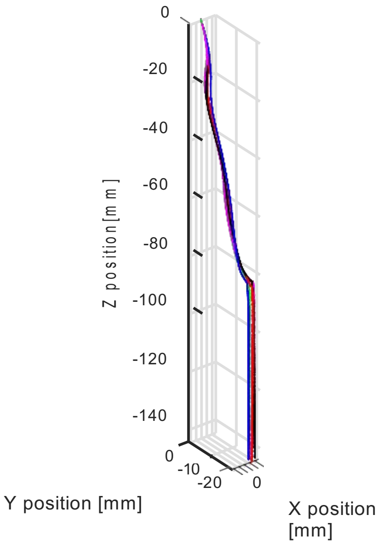
26 min, End-to-End Autonomous 3m Ring Truss Assembly

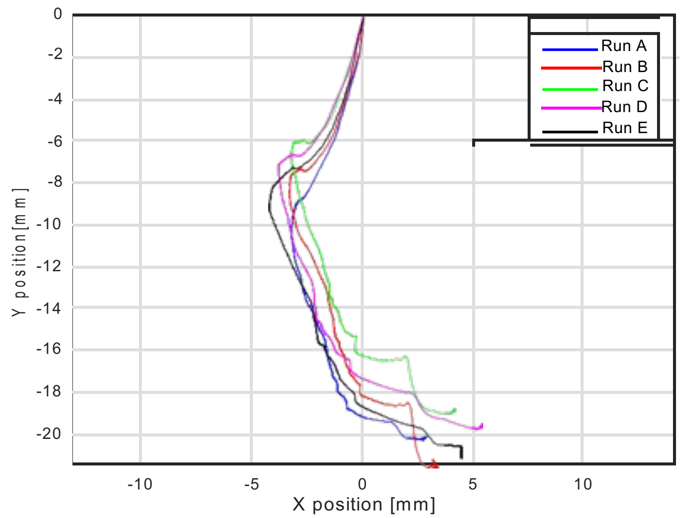


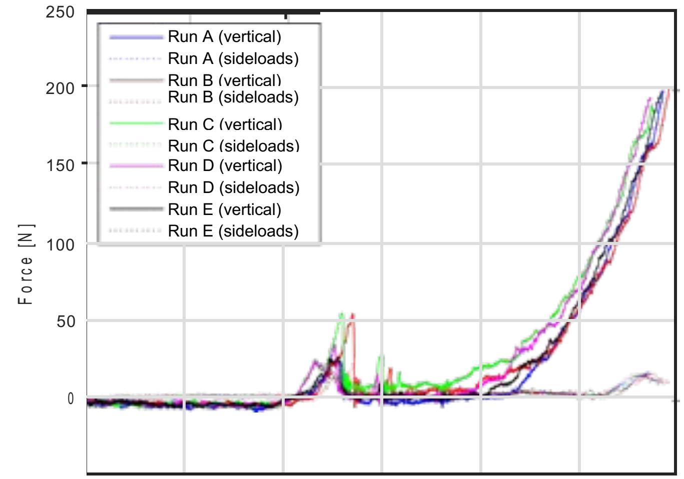
Position Precision 3.7 mm
Orientation Precision: 0.1 deg

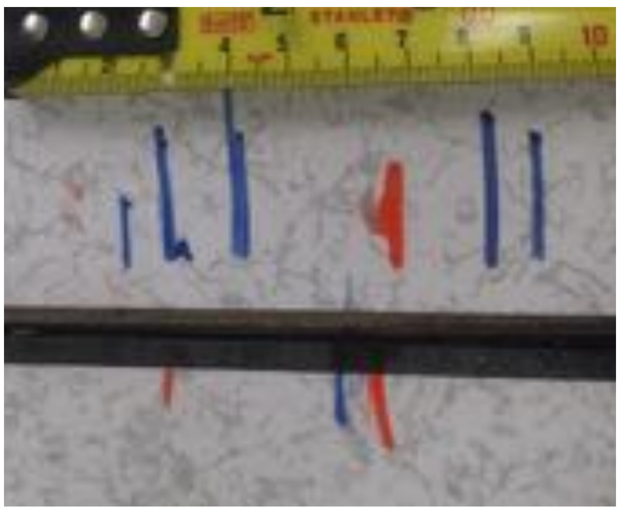
https://exoplanets.nasa.gov/internal_resources/837/

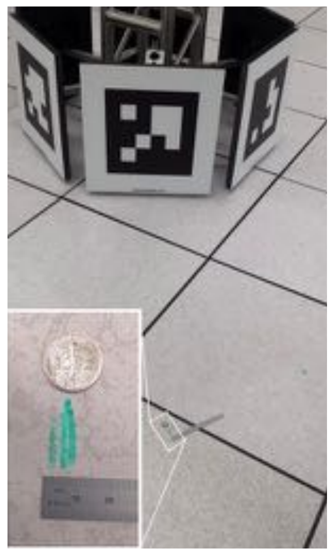
Demonstration video link

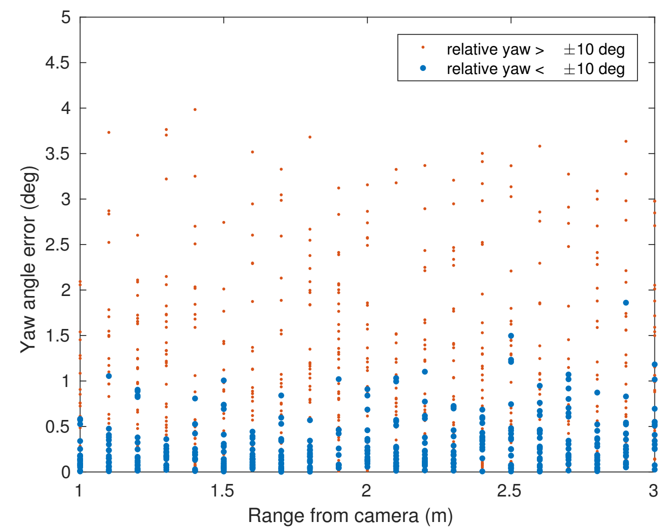


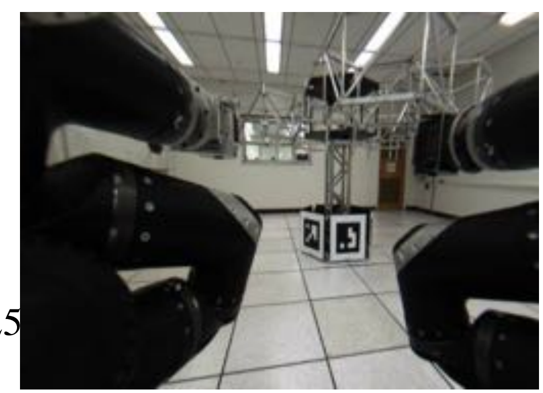


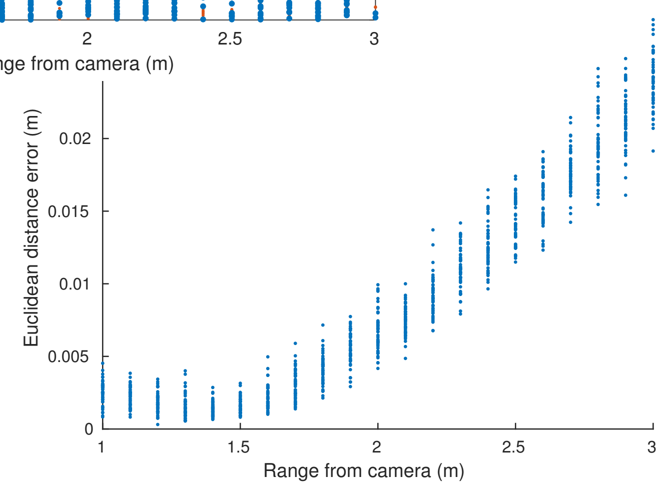






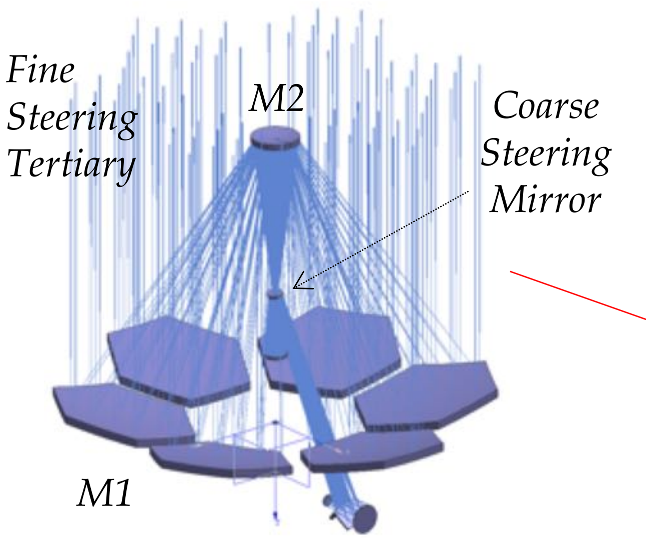




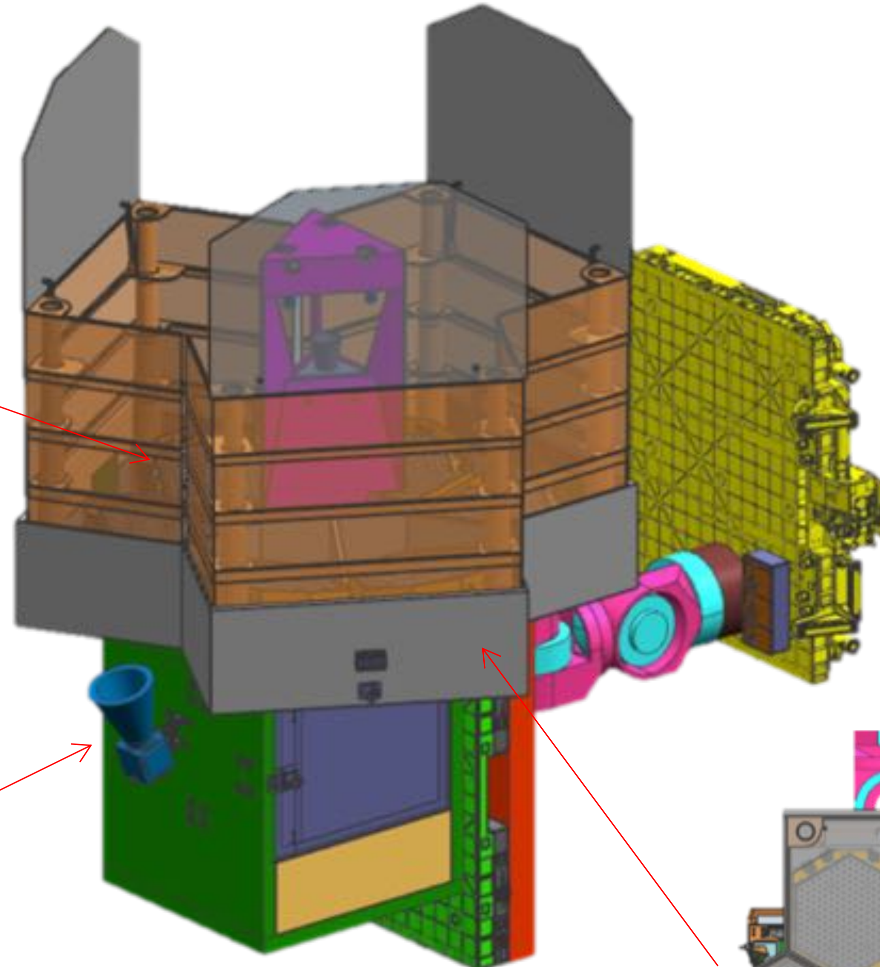


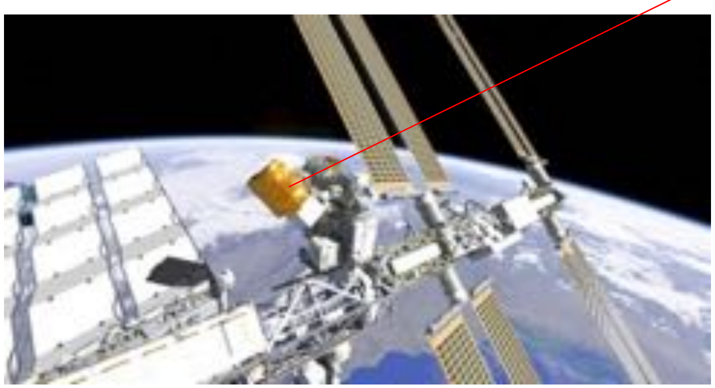
Position Accuracy 21.5mm
Position Precision 3.7 mm
Orientation Accuracy: 1.07deg
Orientation Precision: 0.1 deg

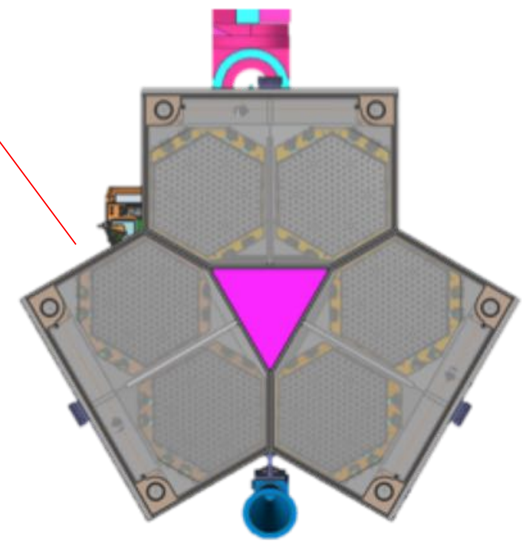
Optical Testbed and Integration on ISS eXperiment (OpTIIX)



3 Mirror Anastigmat Telescope
(1.45m aperture)

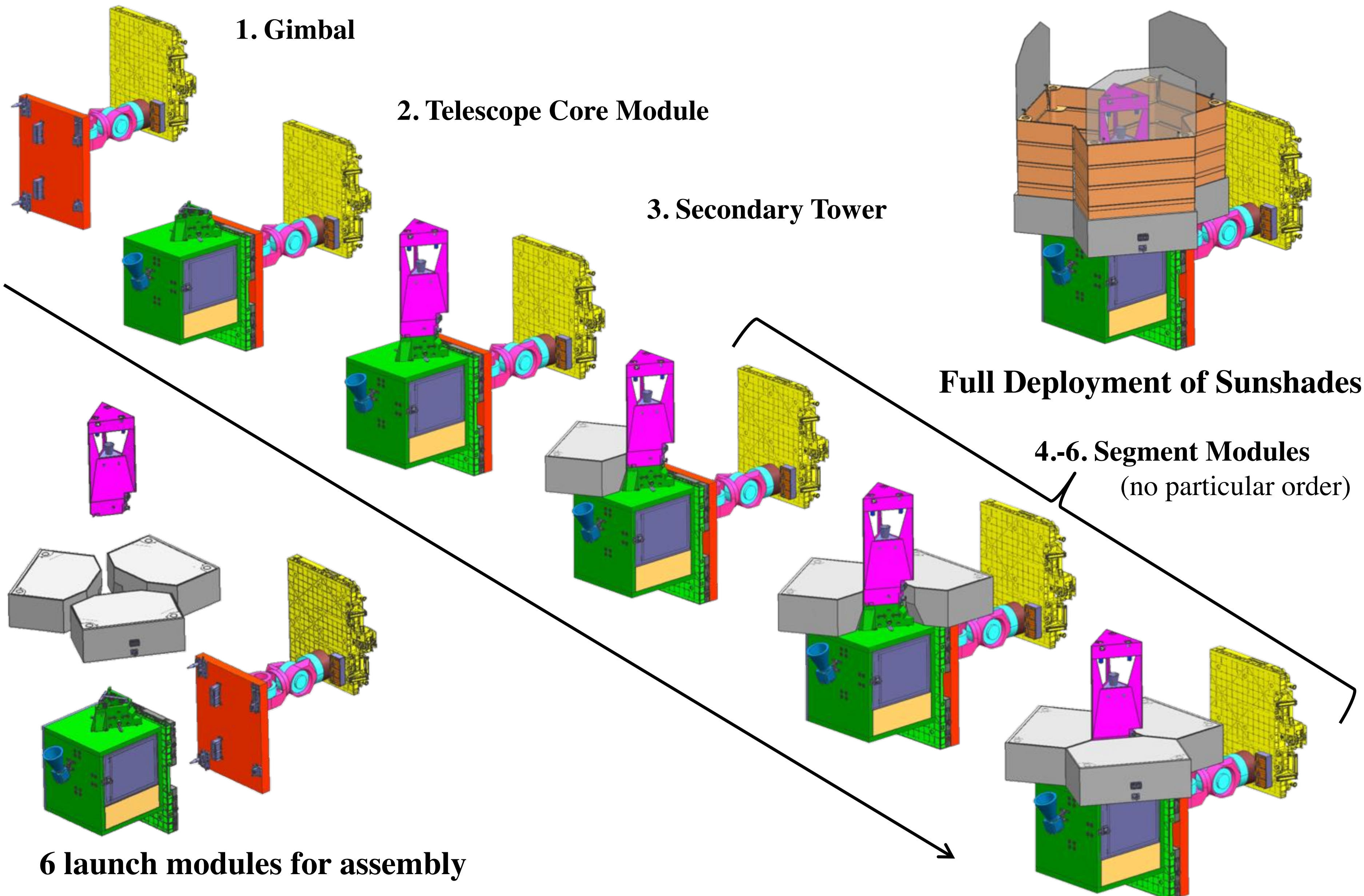




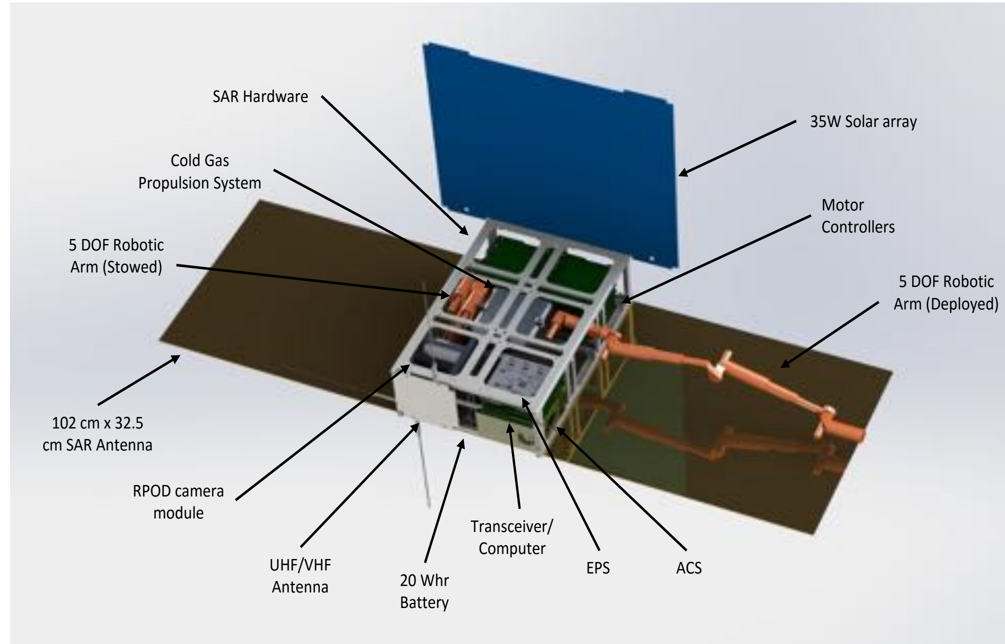


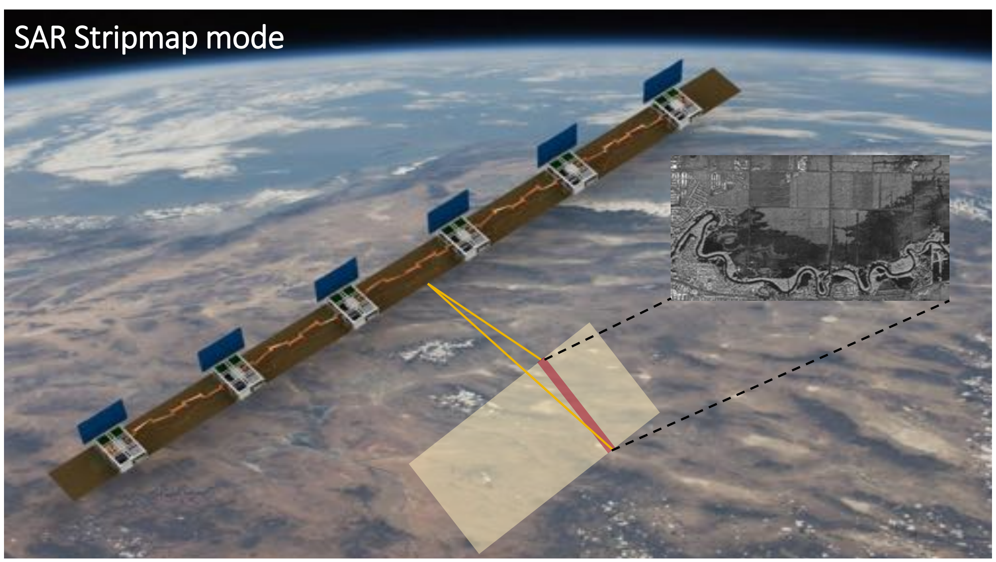
Robotically assembled and operated at
Express Logistics Carrier (ELC3)

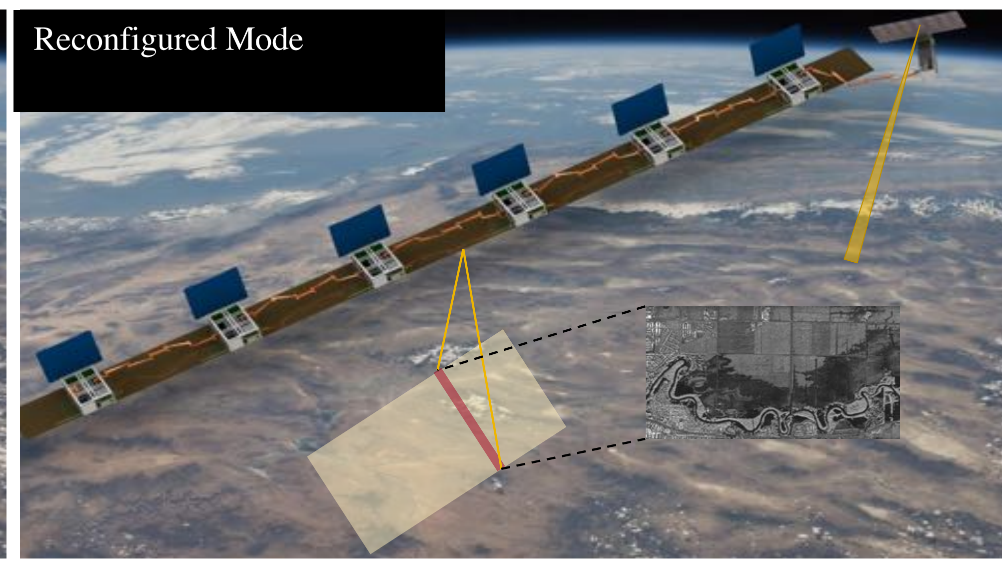
OpTIIX Assembly Sequence



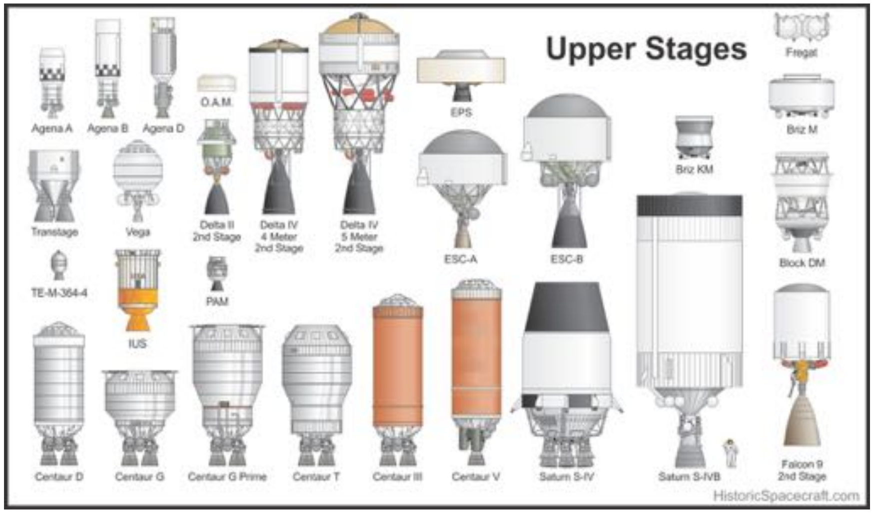
Cluster Formation Using CubeSats with Robotic Arms

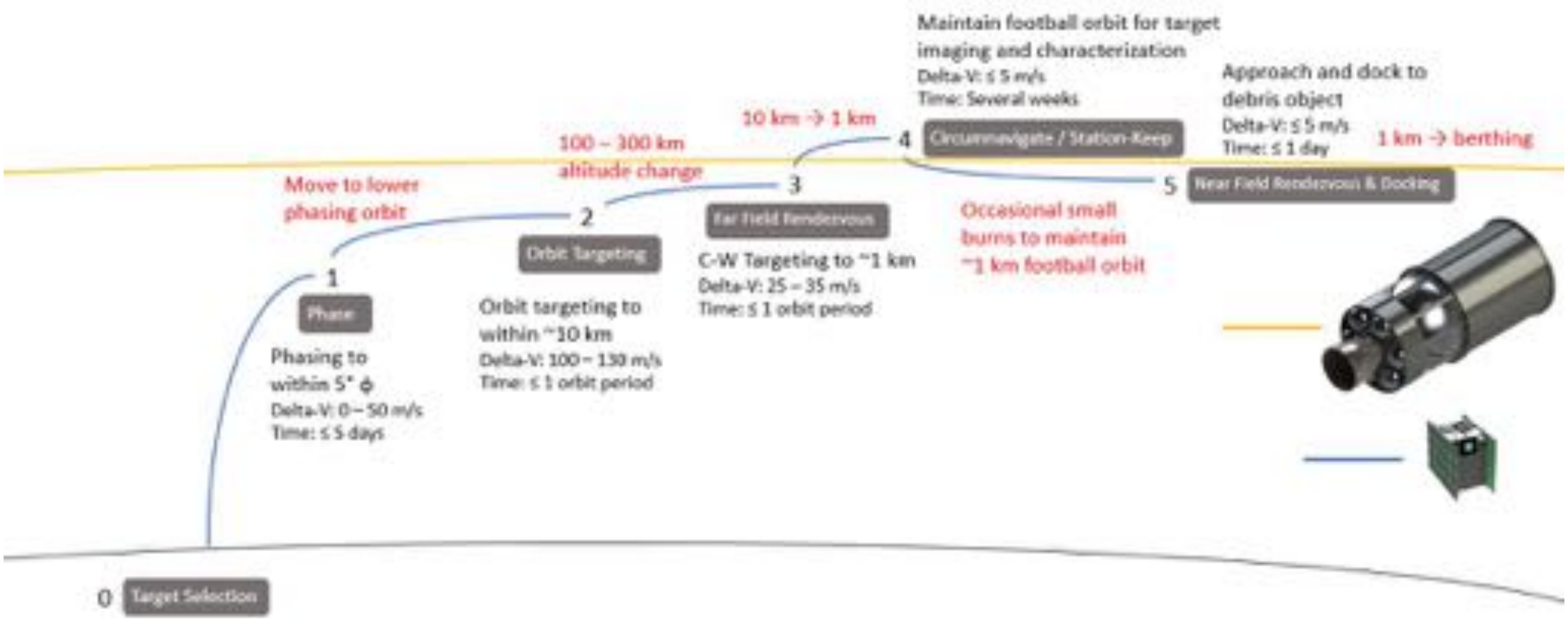






Orbital Debris Mitigation with Robotic Arms on CubeSats





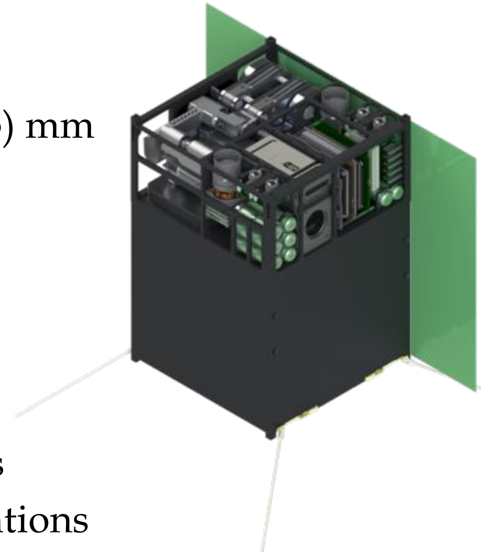
6U Spacecraft

Requirements

- Size: (100 x 226.3 x 340.5) mm
- Mass: 12.0 kg

Functionality

- Accessible launch
- Tracking capabilities
- Rendezvous capabilities
- Limited trajectory alterations



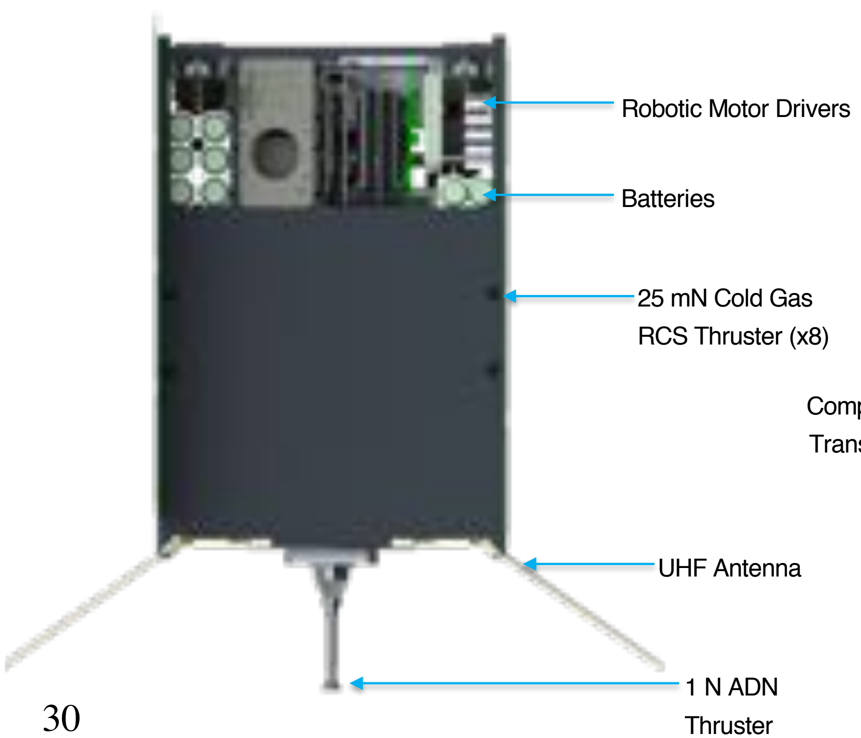
12U Spacecraft

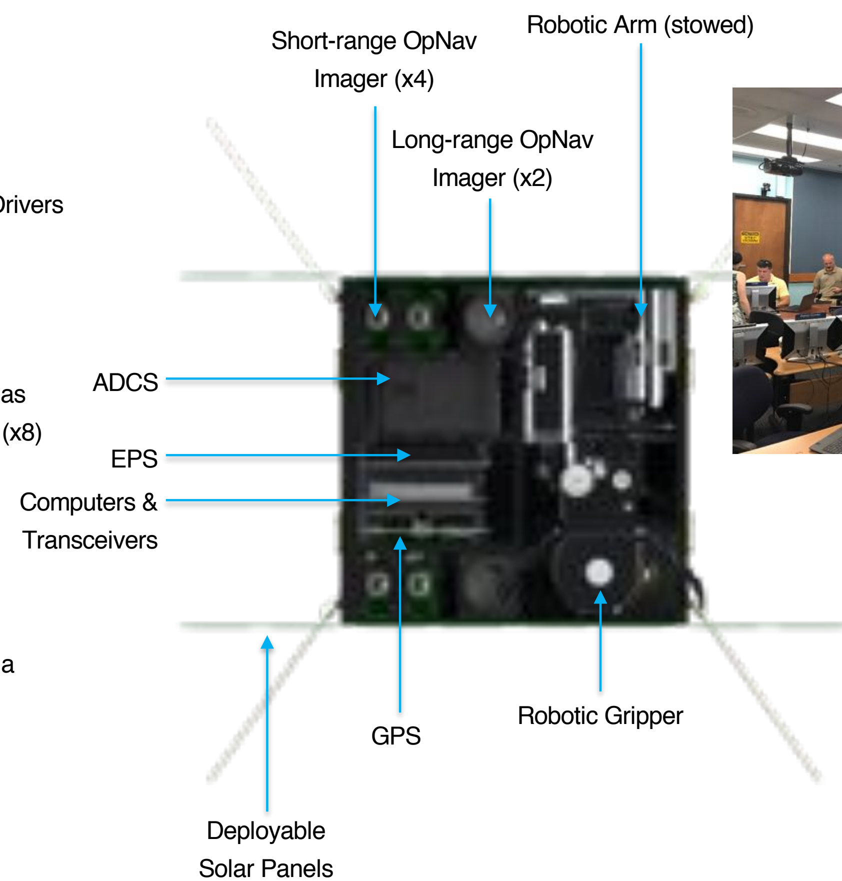
Requirements

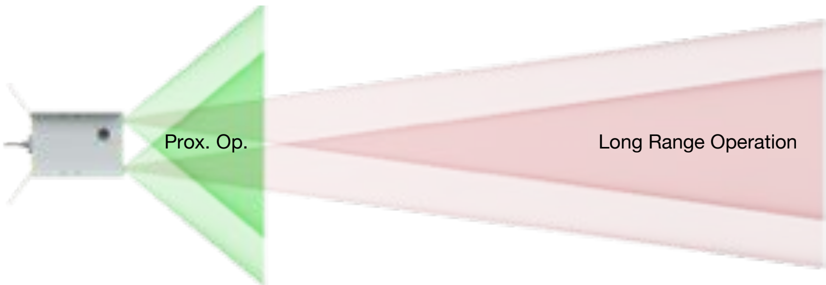
- Size: (226.3 x 226.3 x 340.5) mm
- Mass: 24.0 kg

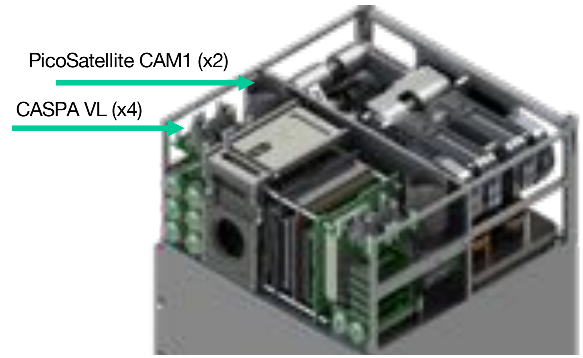
Functionality

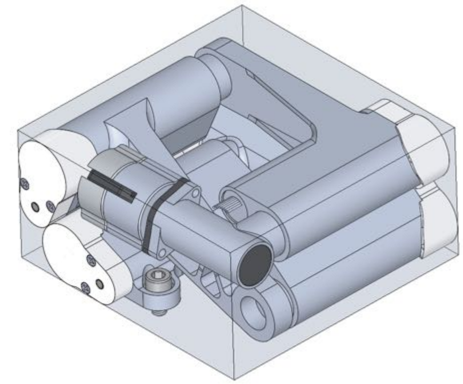
- 12U P-POD less mature
- Tracking capabilities
- Rendezvous capabilities
- Trajectory alterations

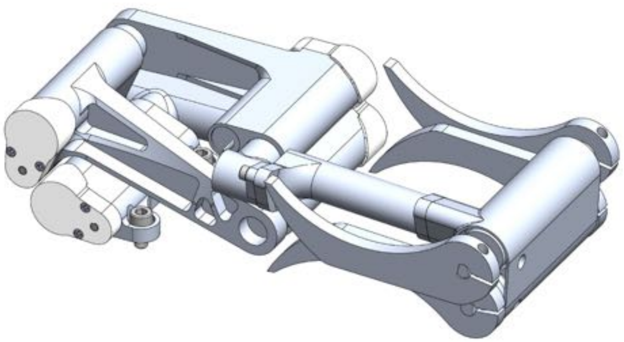


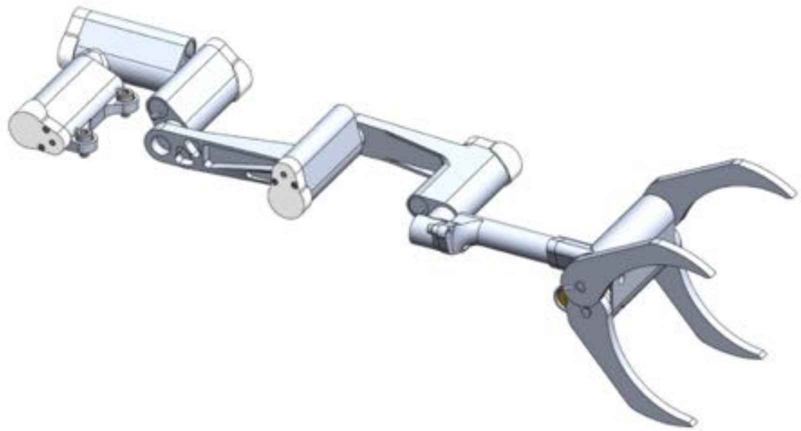


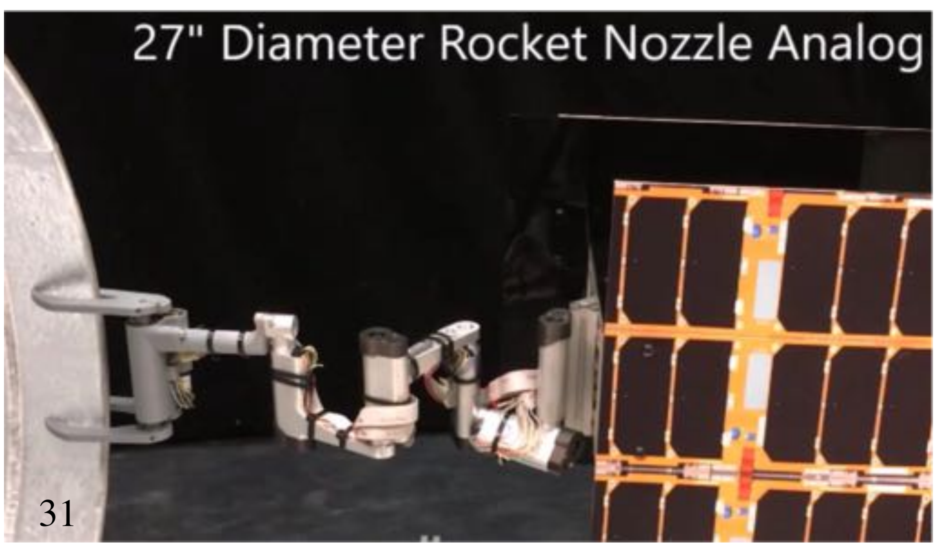

Prox. Op.
Long Range Operation

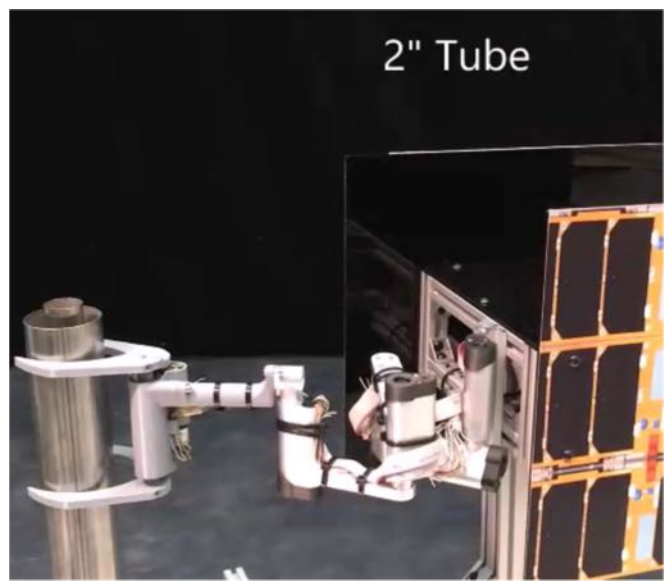

PicoSatellite CAM1 (x2)
CASPA VL (x4)

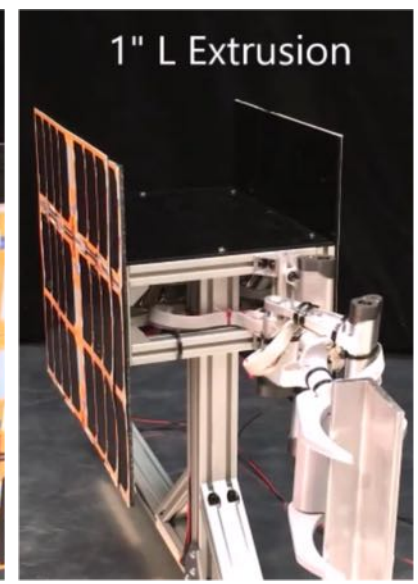




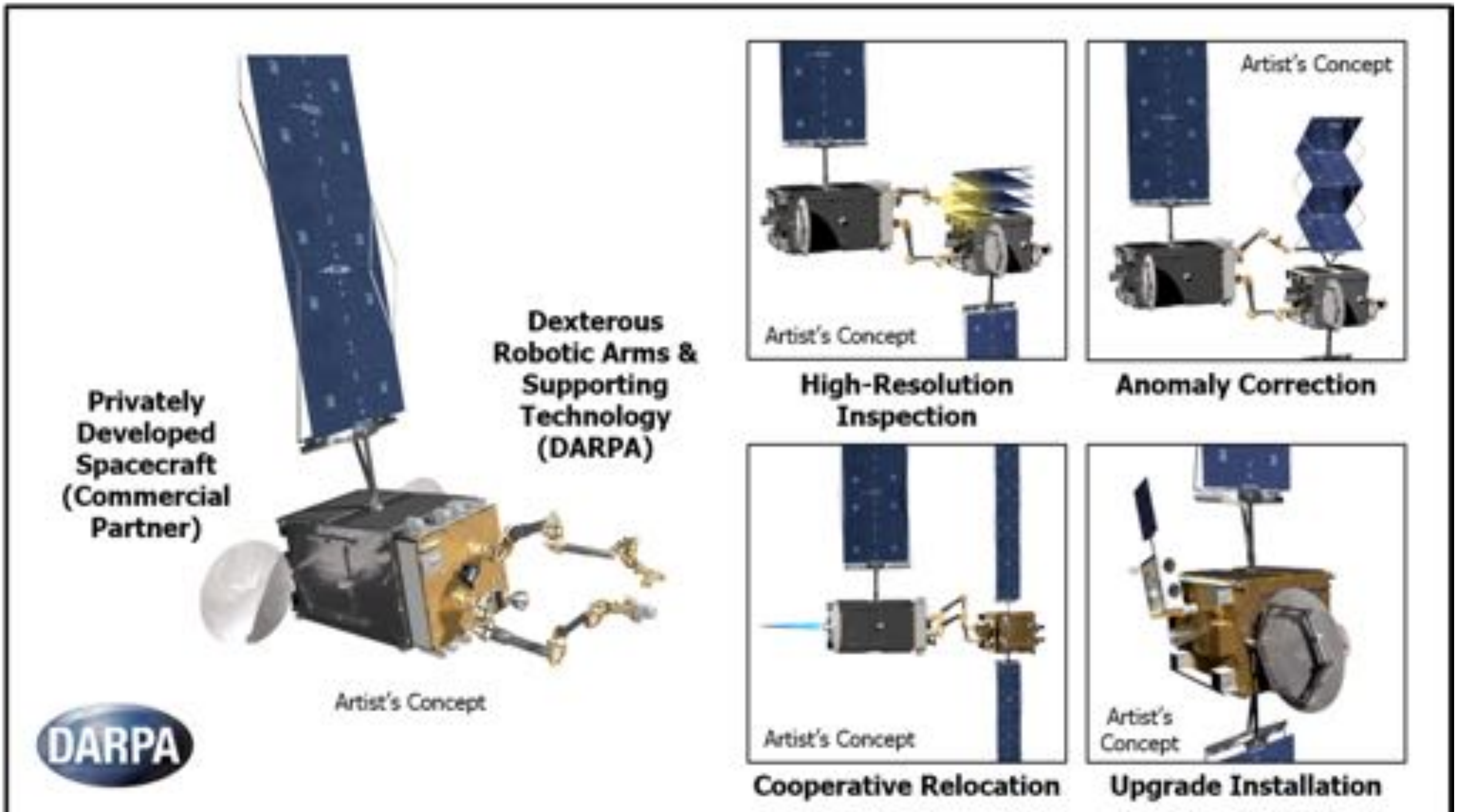



27" Diameter Rocket Nozzle Analog

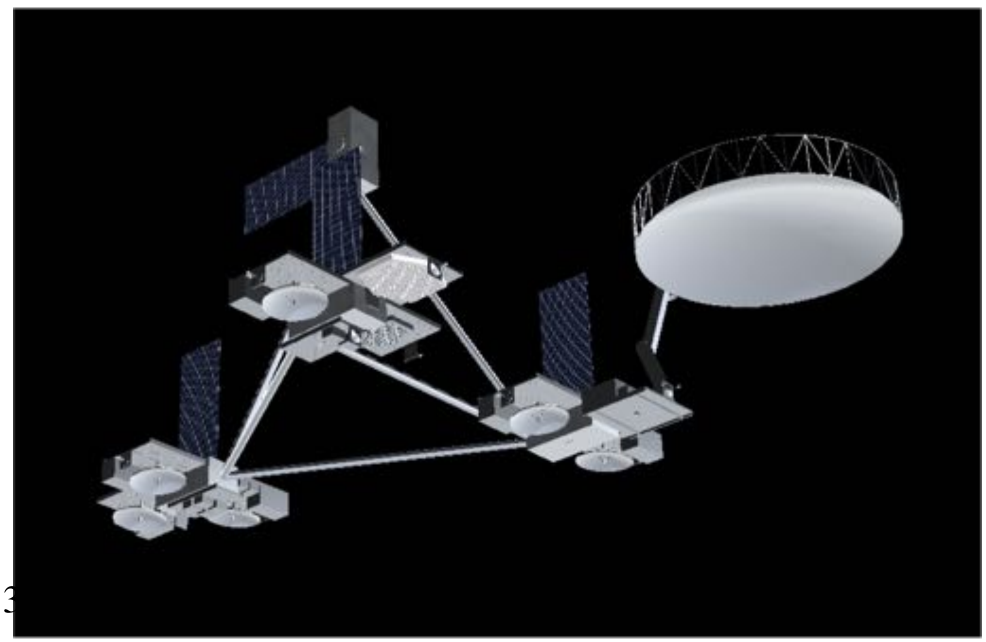

2" Tube


1" L Extrusion

Robotic Servicing Vehicle (RSV) & Envisioned Missions

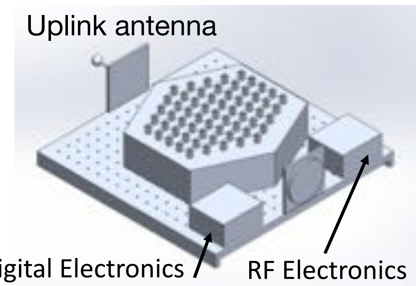


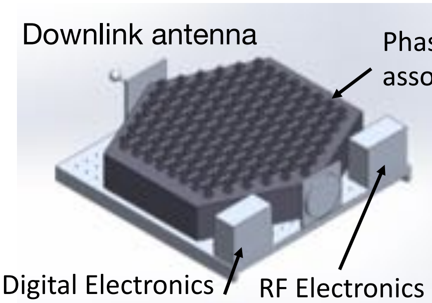
Robotically Assembled and Refurbishable Communication Payload

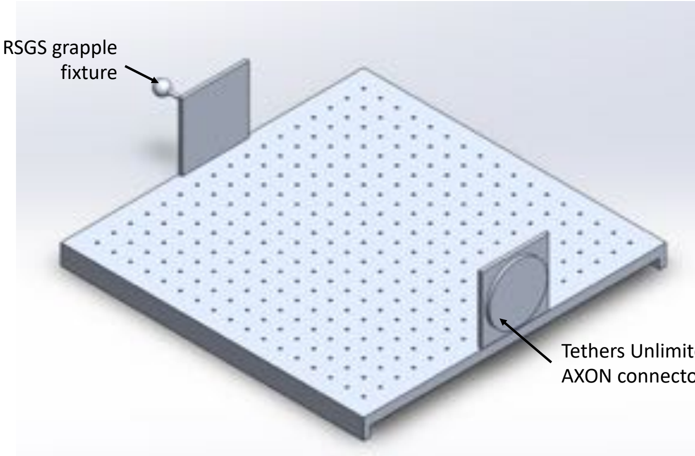


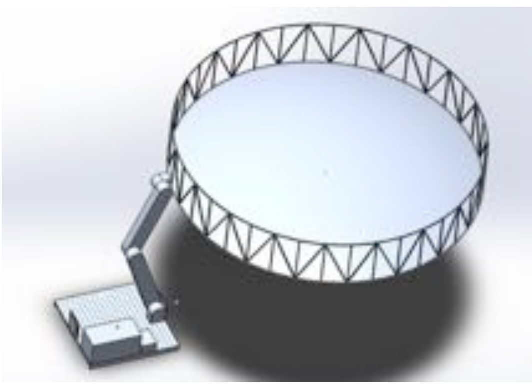
DARPA Payload Orbital Delivery (POD) System

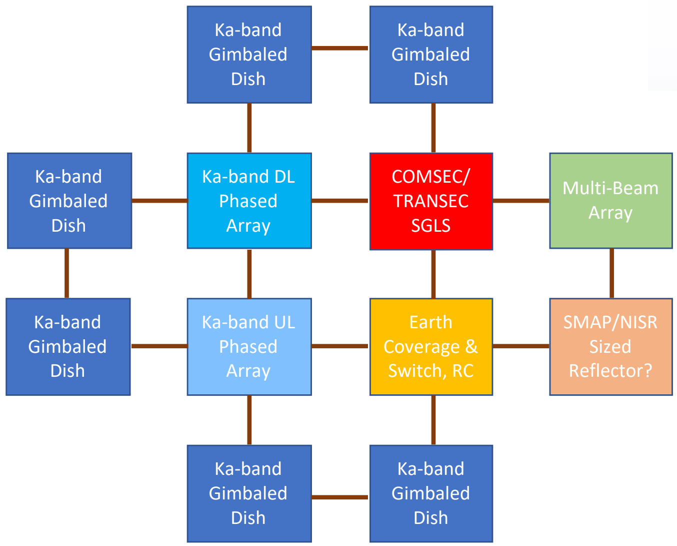
Modular Communication Units for Robotically Assembled Payload

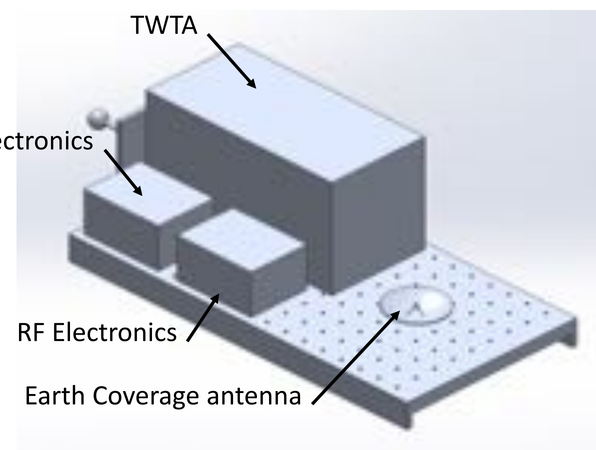


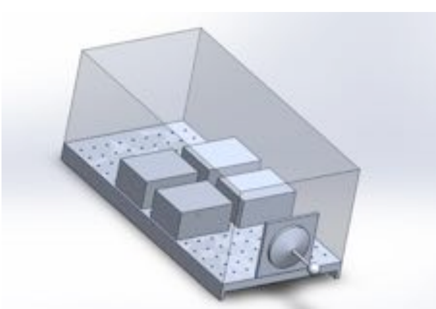


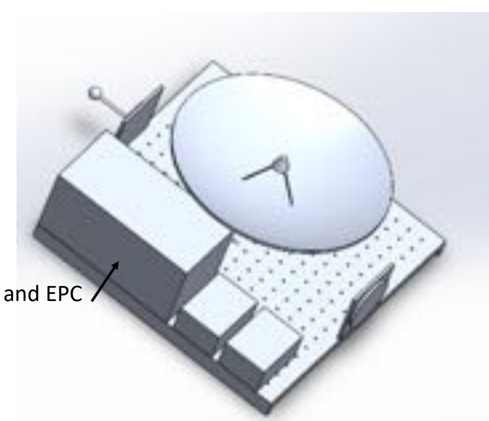




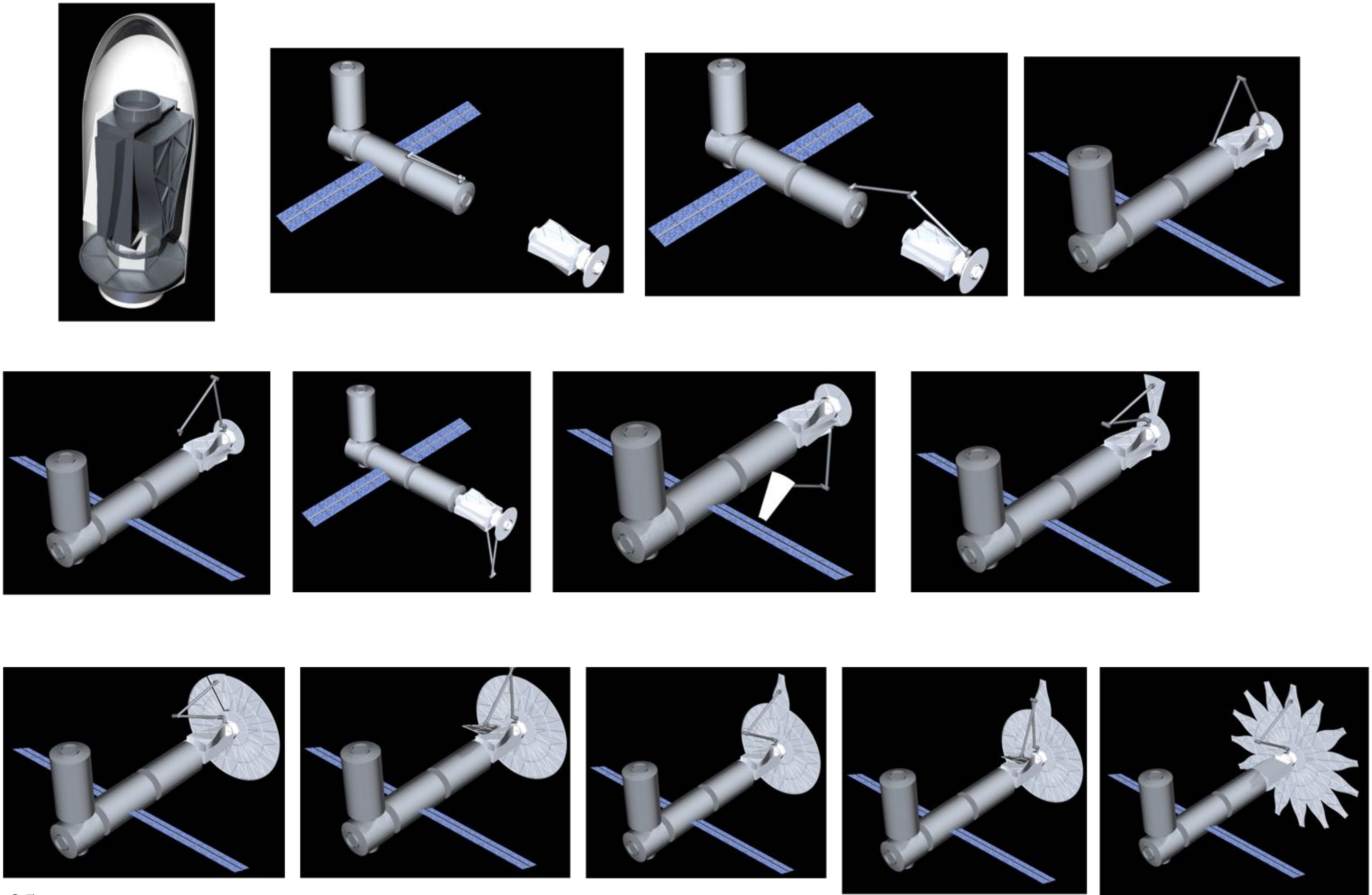


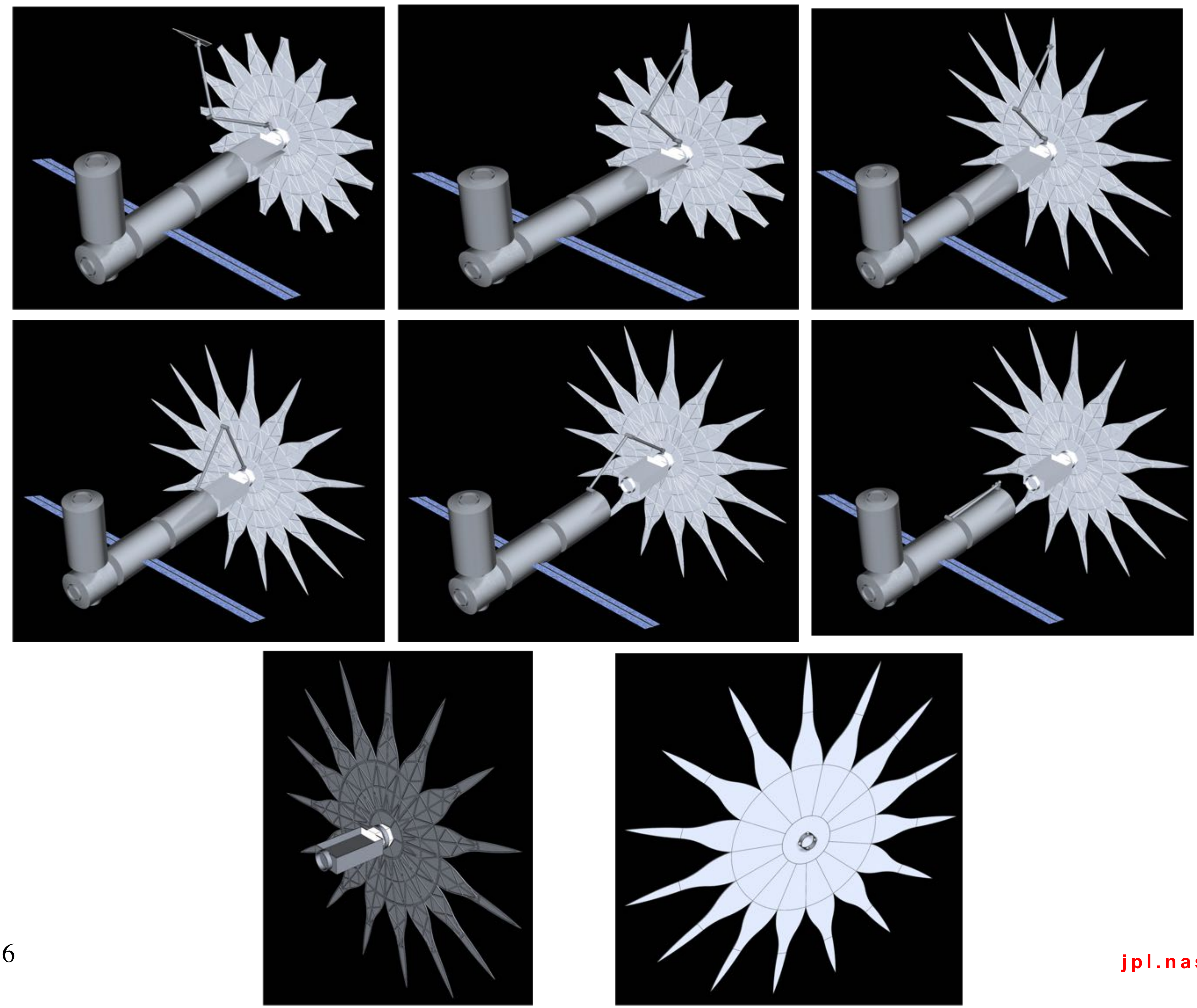


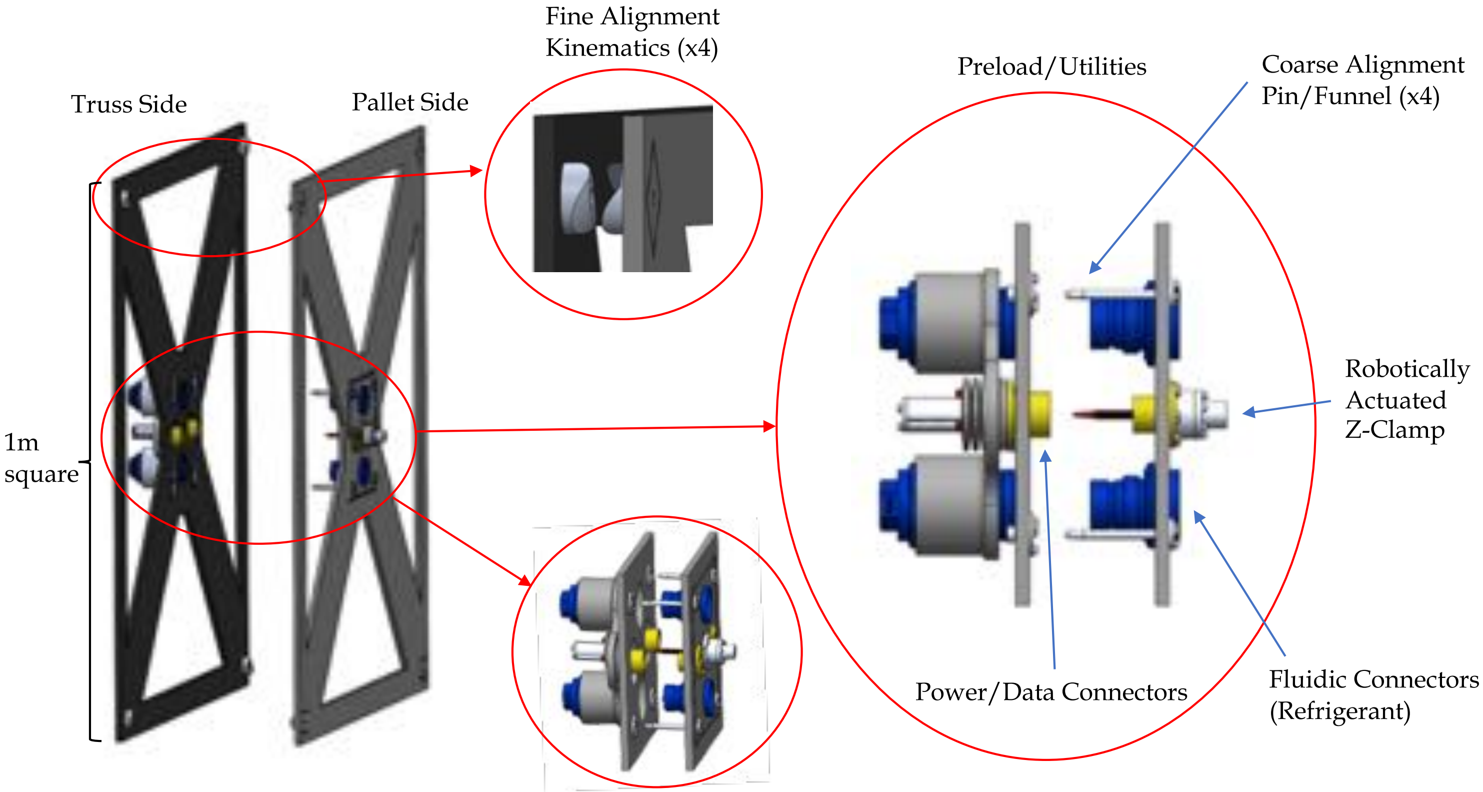


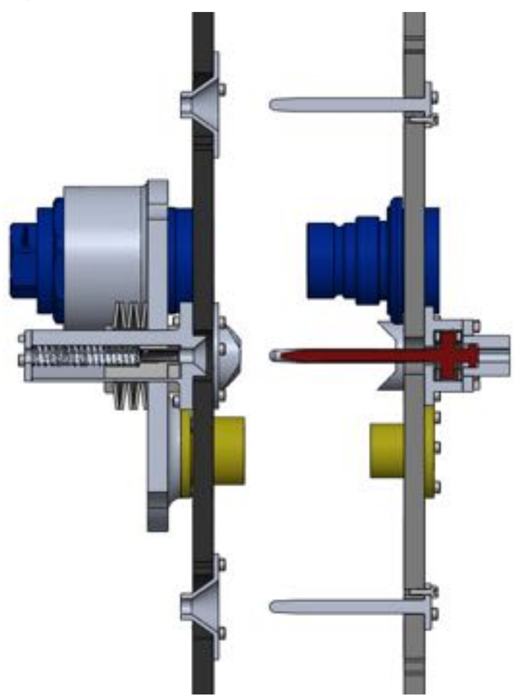


Robotically Assembled 30m Starshade



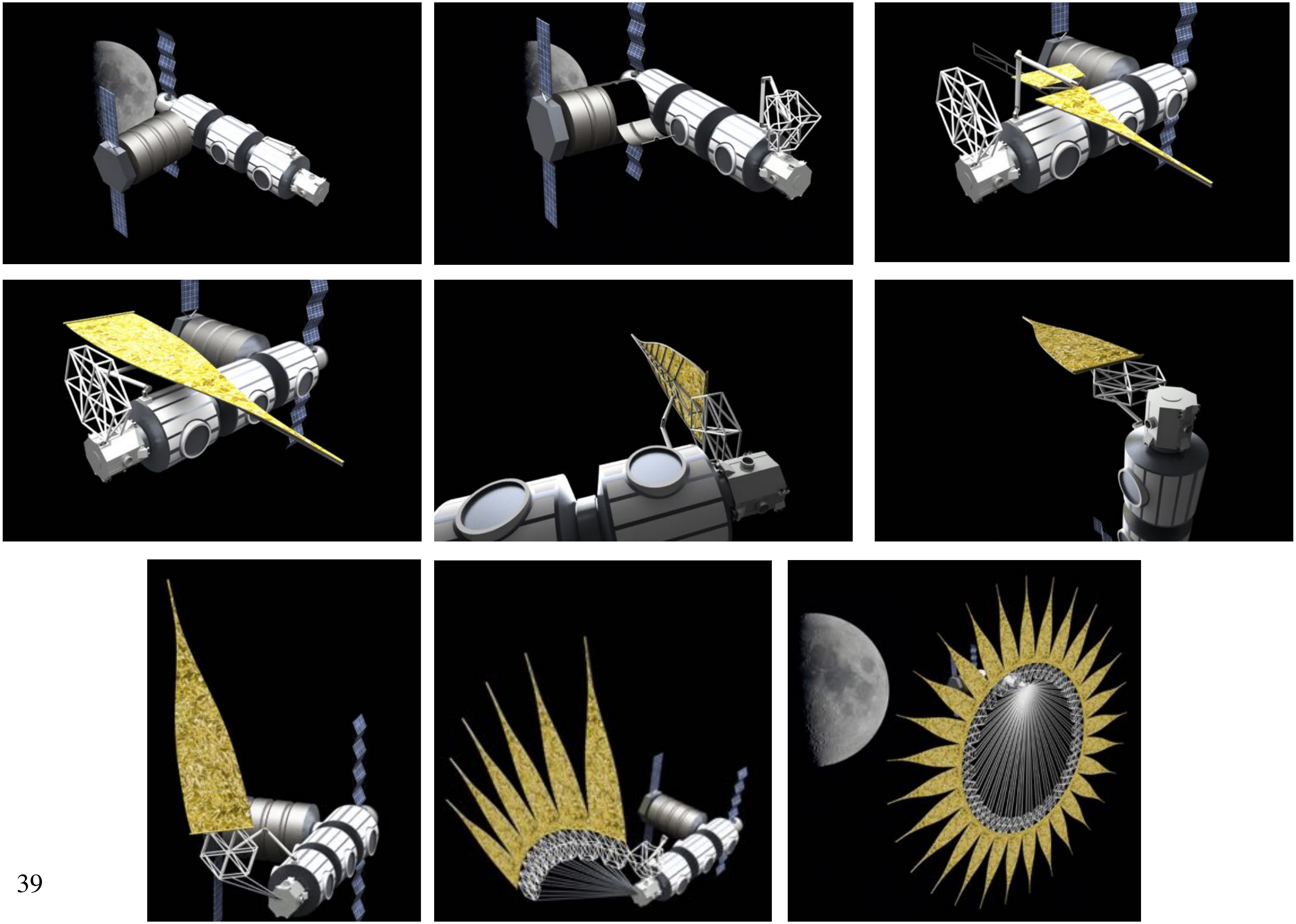



Fine Alignment
Kinematics (x4)
Truss Side
Pallet Side
Preload/Utilities
Coarse Alignment
Pin/Funnel (x4)
1m
square
Robotically
Actuated
Z-Clamp
Power/Data Connectors
Fluidic Connectors
(Refrigerant)

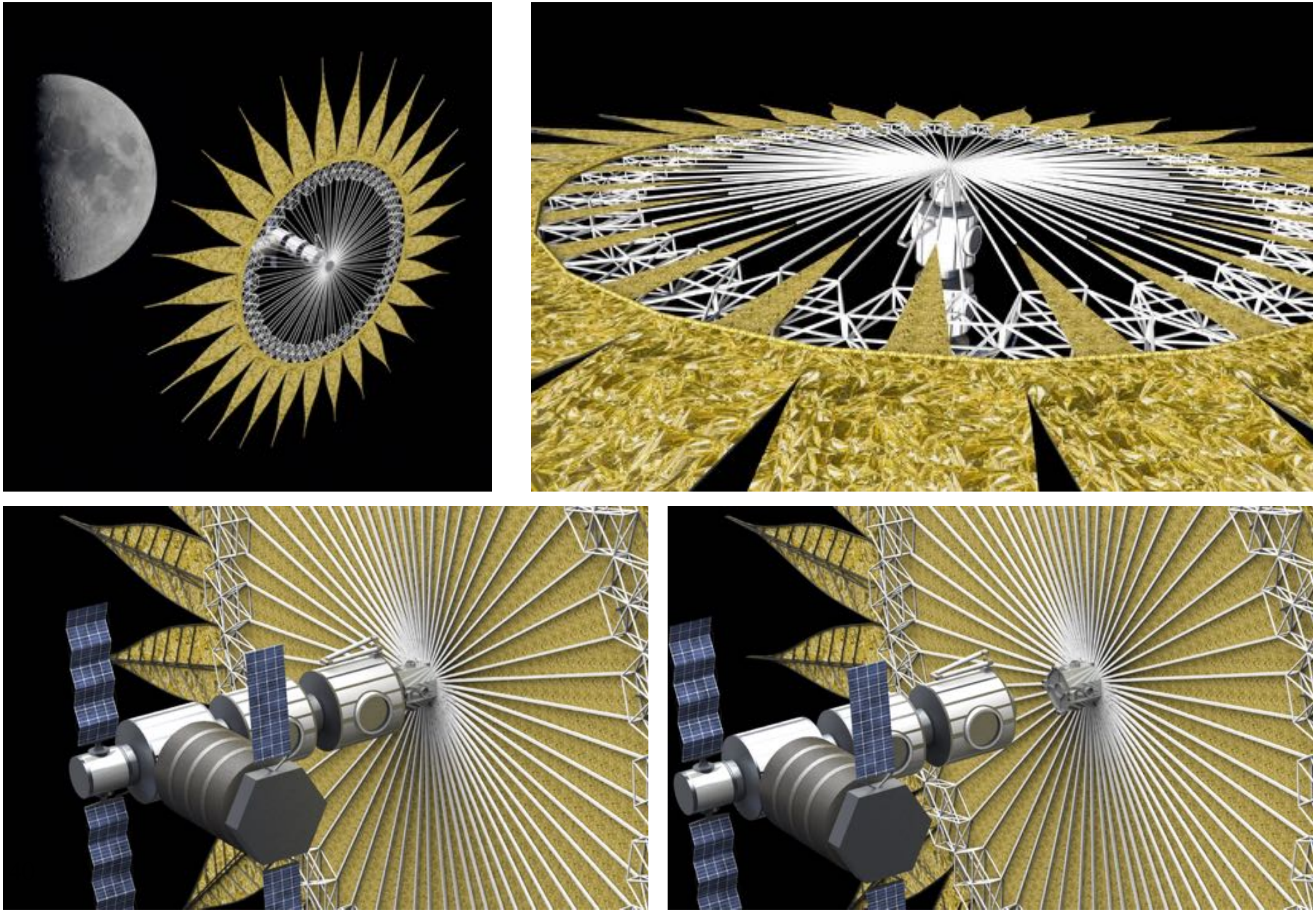


Robotically Assembled 150m Starshade

Robotically Assembled 150m Starshade



Robotically Assembled 150m Starshade



Jet Propulsion Laboratory
California Institute of Technology

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