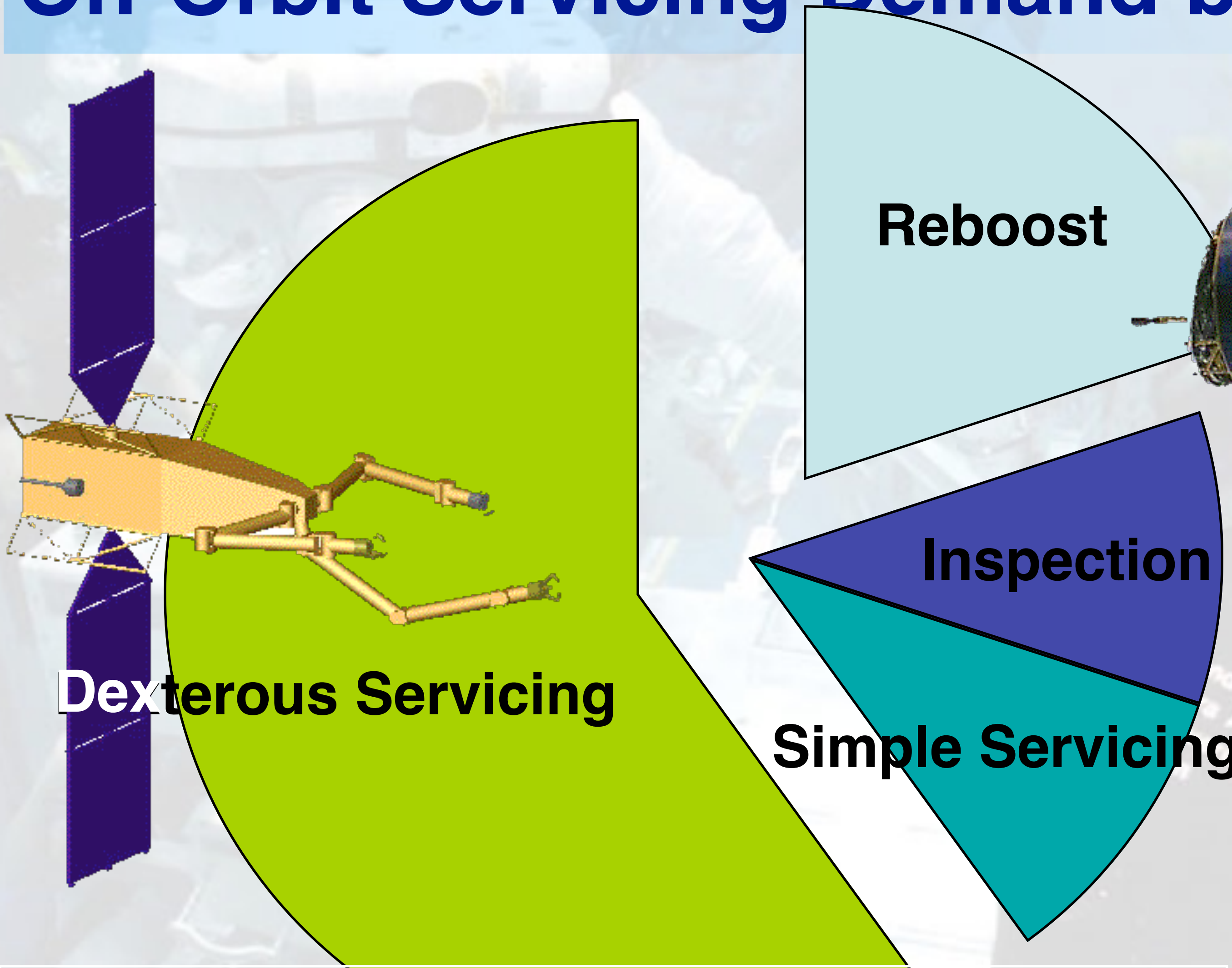
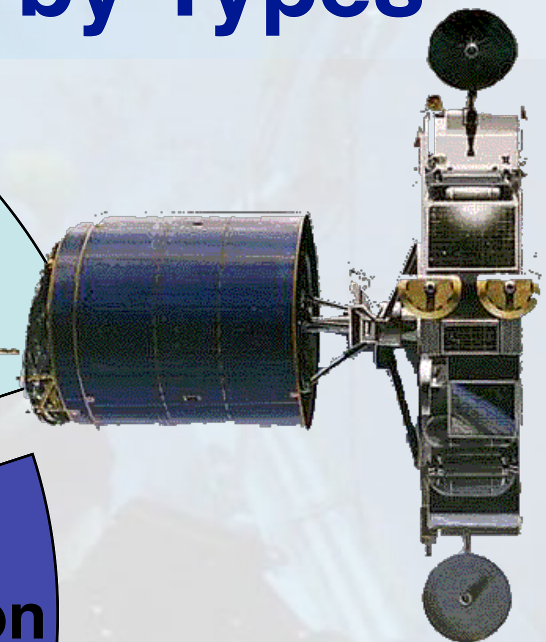
Robotic On-Orbit Satellite Servicing: One Size Does *Not* Fit All

Dr. David L. Akin

Dr. Craig R. Carignan

On-Orbit Servicing Demand by Types





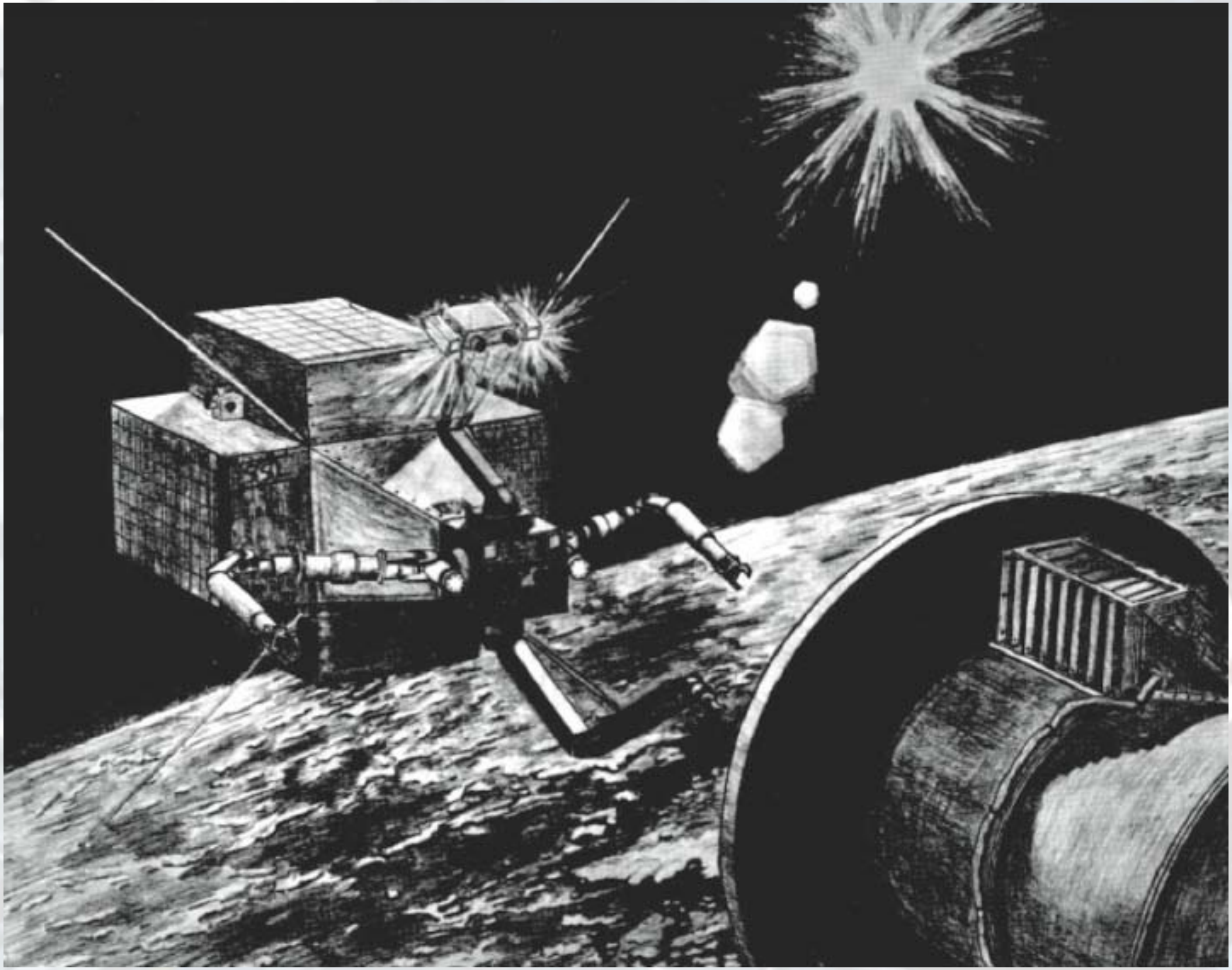
Total Servicing Market ~$3-5B/year

Commercial Satellite Servicing Concept

Robotic Servicing Economics

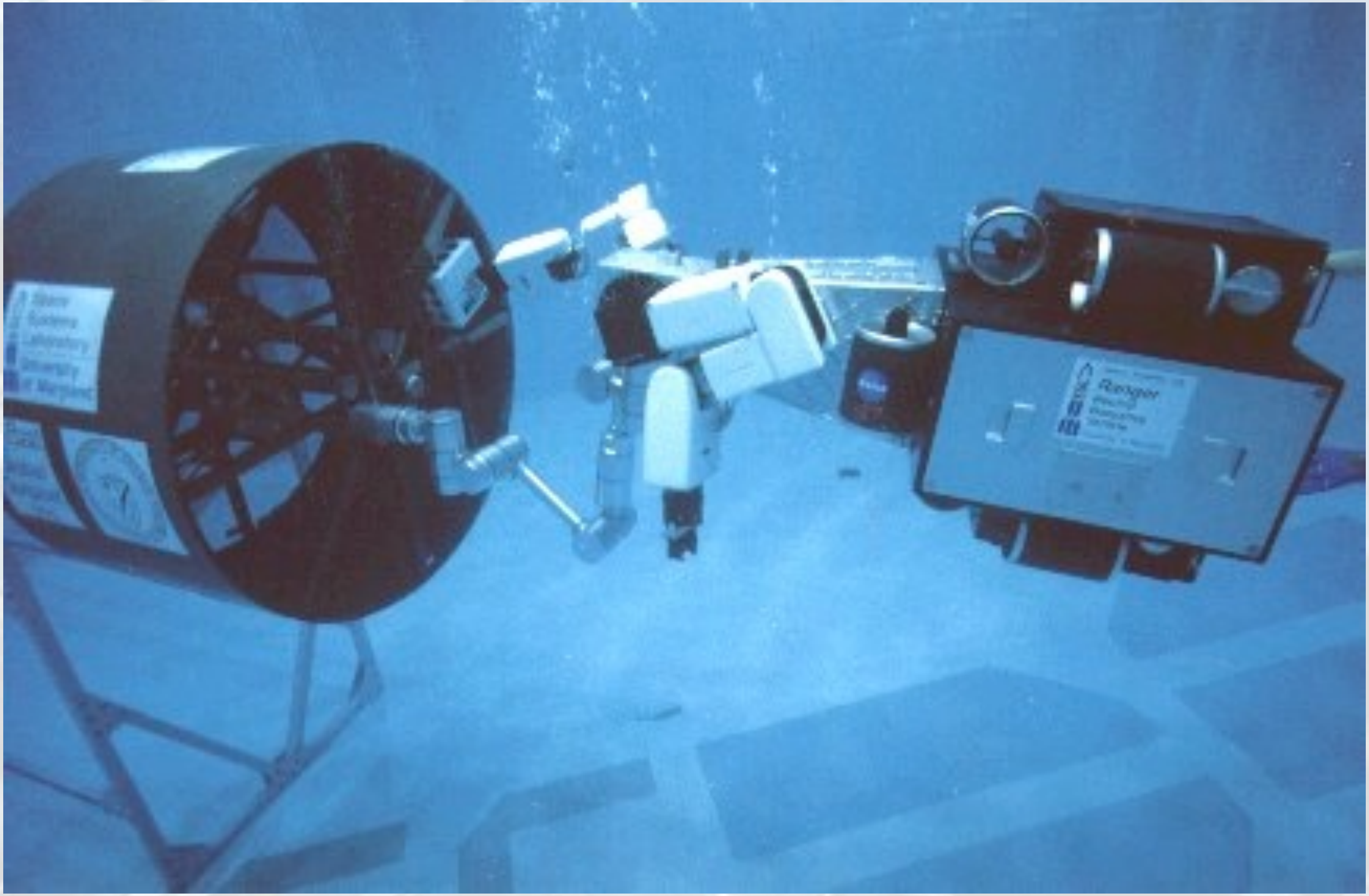
- Servicer mass ~ client satellite mass
  - Cost of servicer is comparable to client
  - Launch costs are comparable to client
  - Best solution: replace the satellite
- Closing the business case
  - Service a number of clients on each mission
  - Limits servicing to “low hanging fruit”, e.g., refueling or orbit modification
- Alternative approach
  - Smaller servicers to reduce costs
  - Close business case with dedicated servicing mission

UMd SmallSat Servicing Concept (1990)

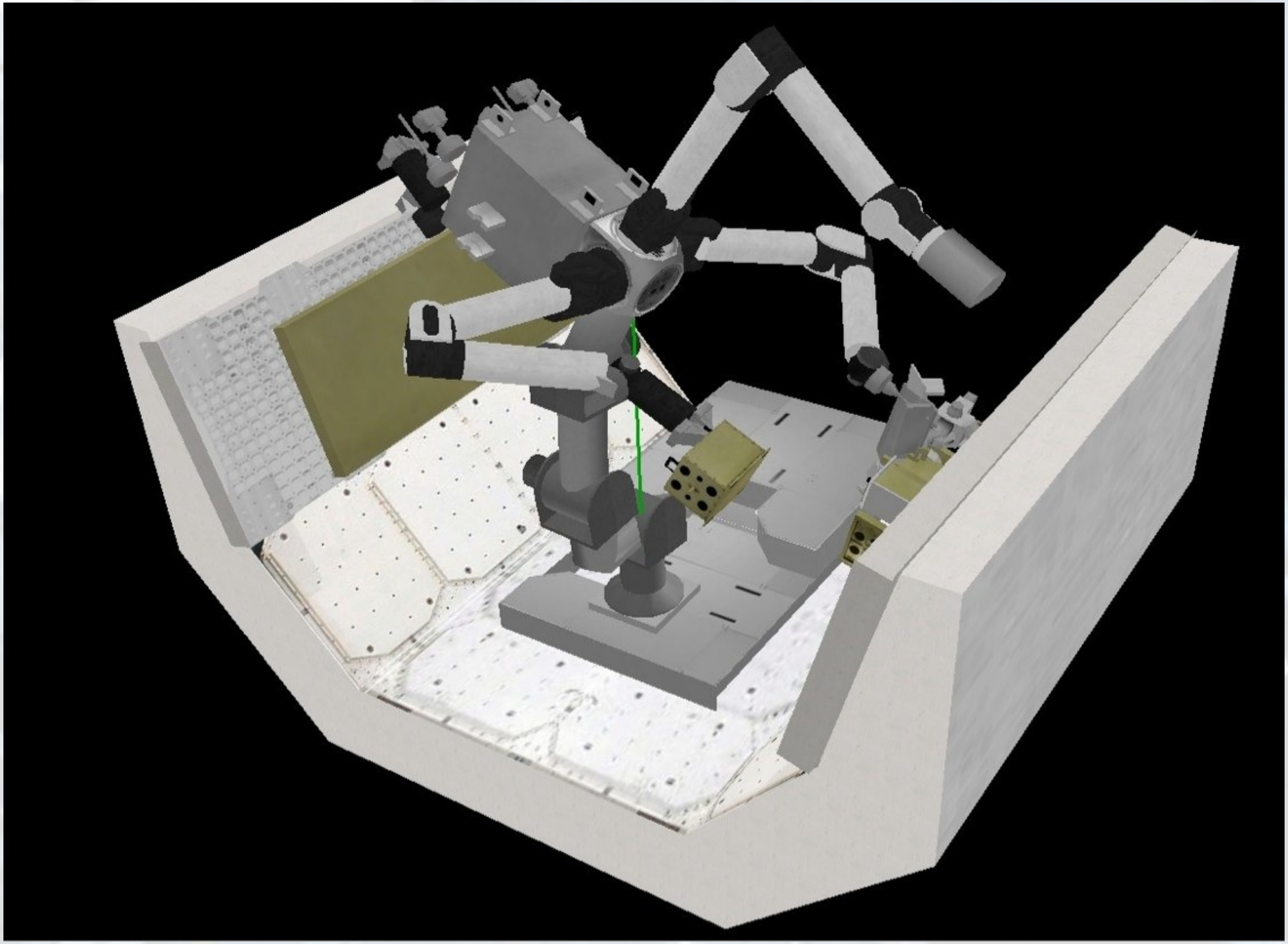


Ranger Telerobotic Flight Experiment

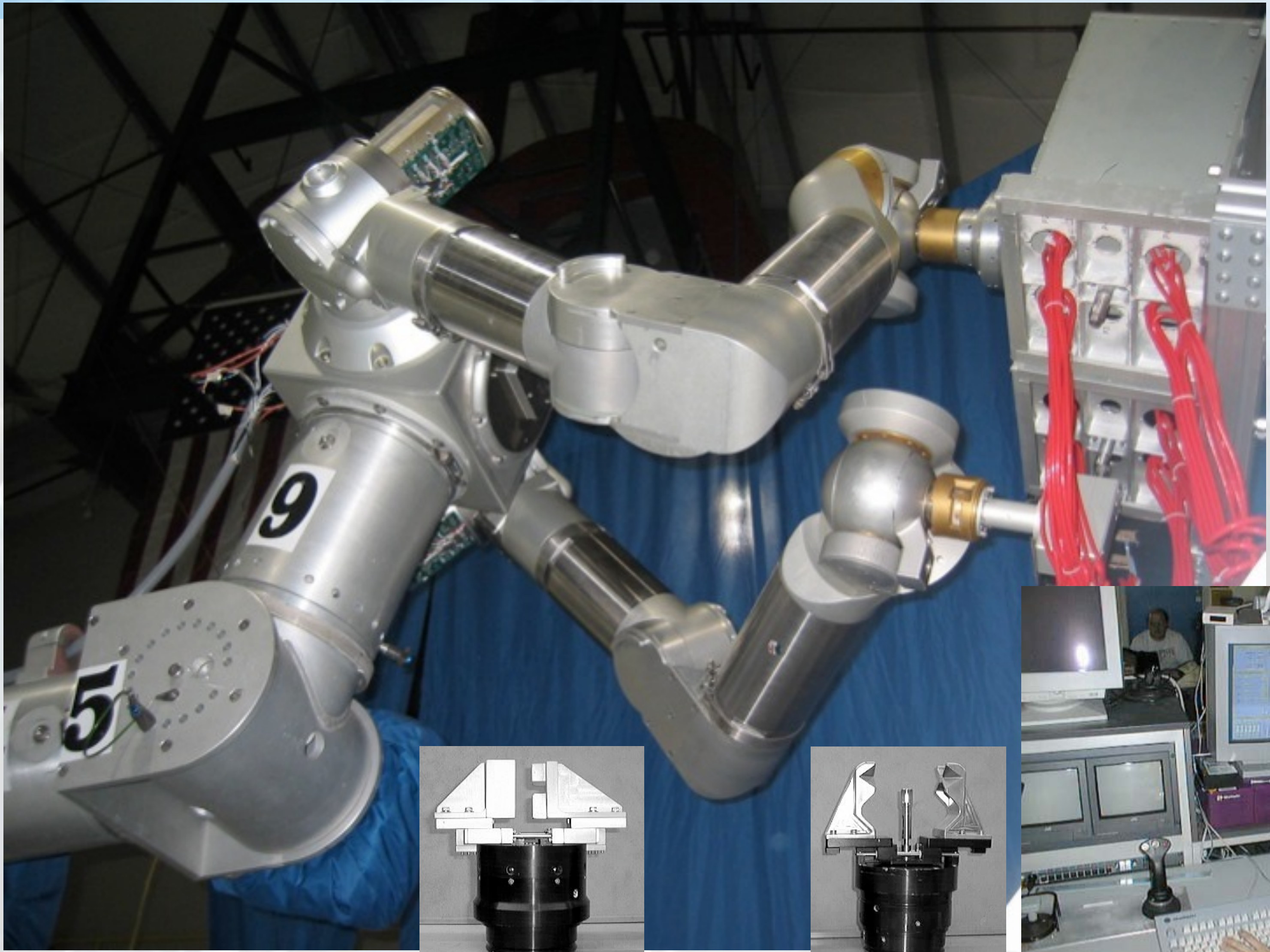
Ranger Neutral Buoyancy Vehicle I

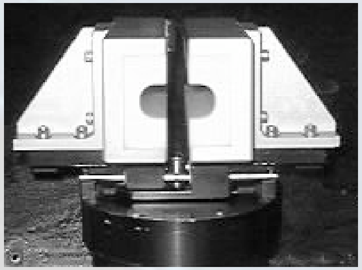


Ranger Telerobotic Shuttle Experiment

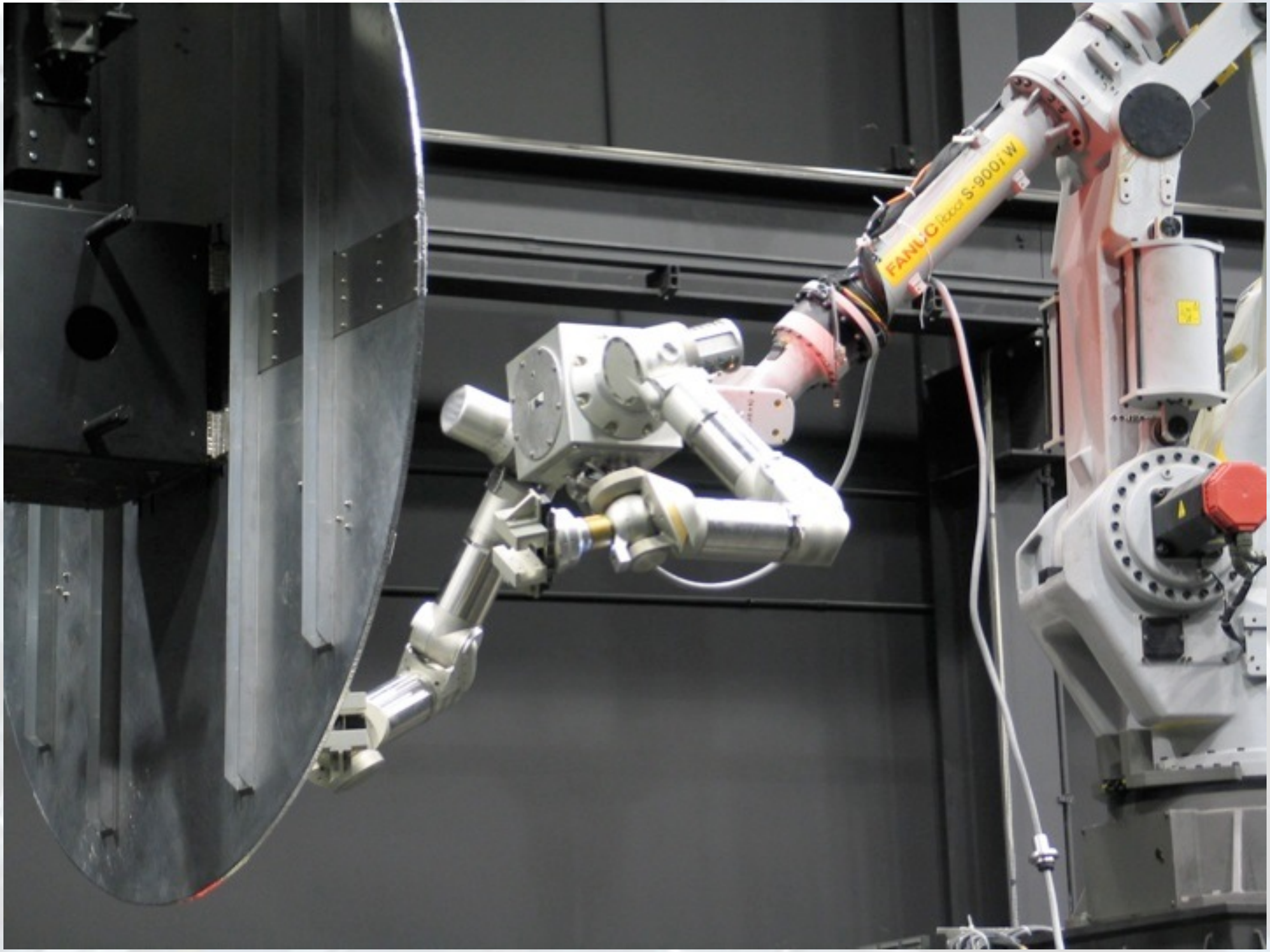


Ranger Spacecraft Servicing System

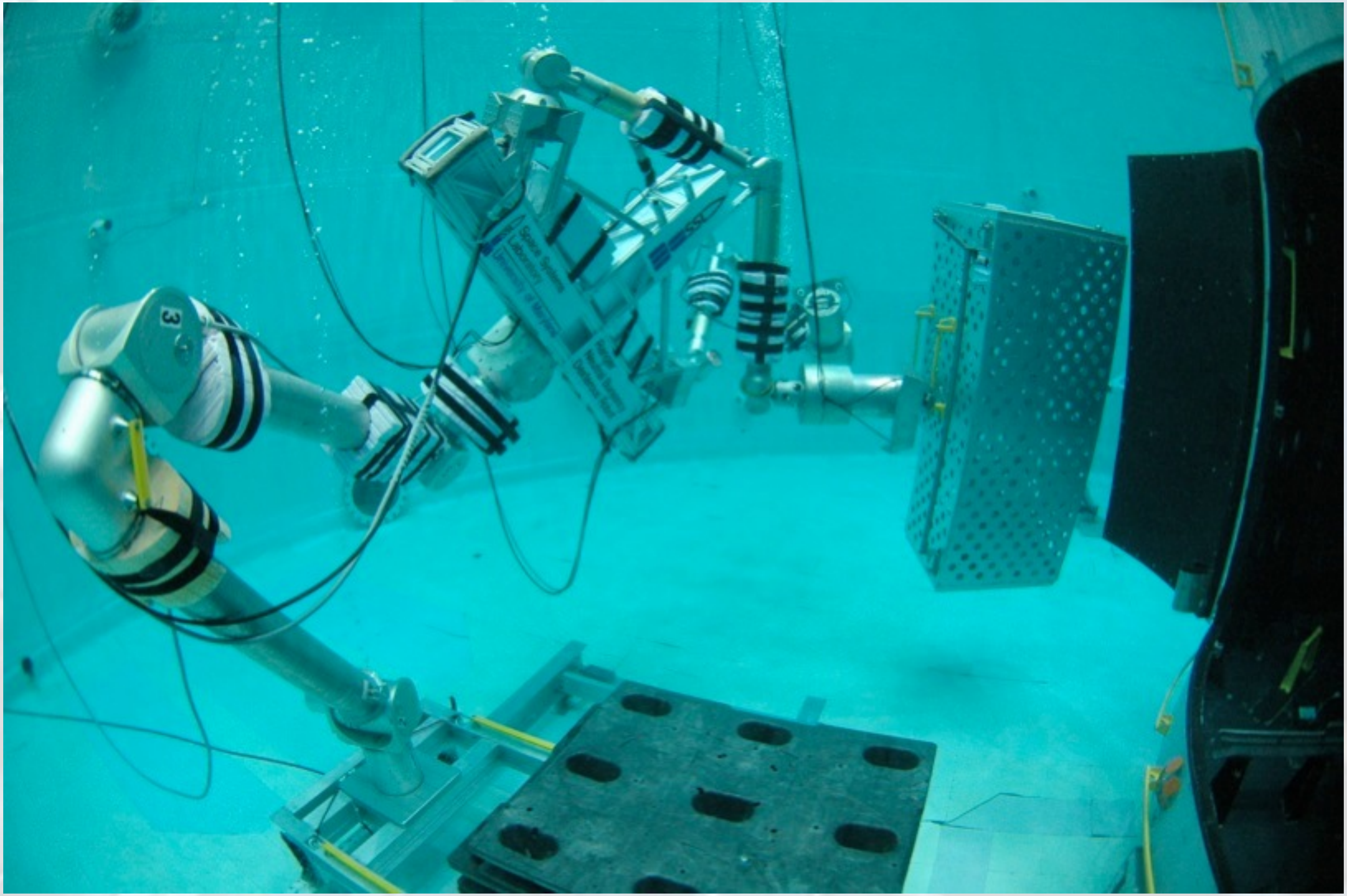




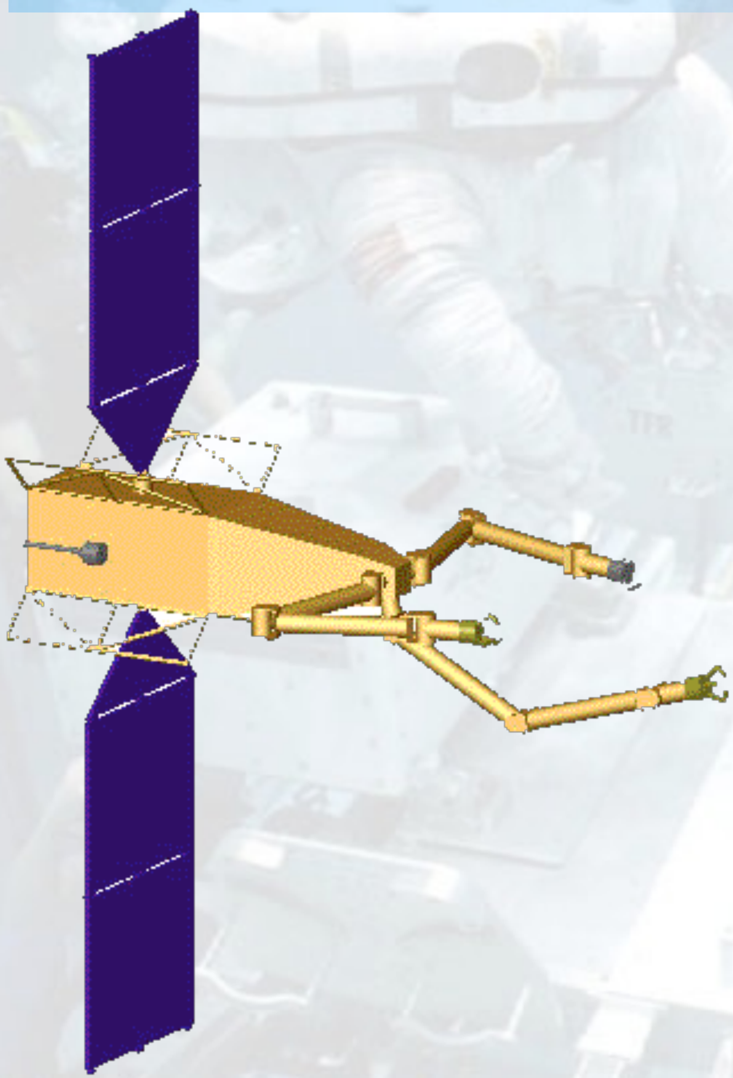
Ranger Arms for SUMO Grappling



Ranger Performing HST AI Changeout



MODSS Dexterous Servicer Concept

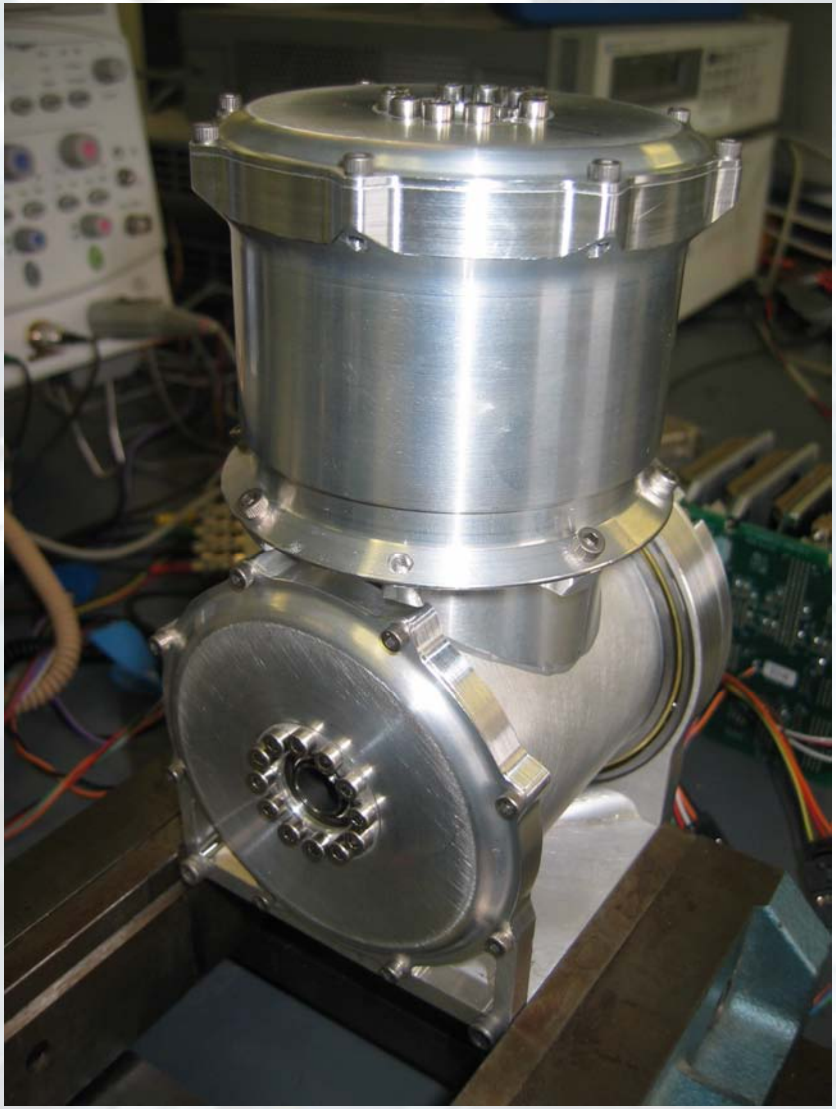


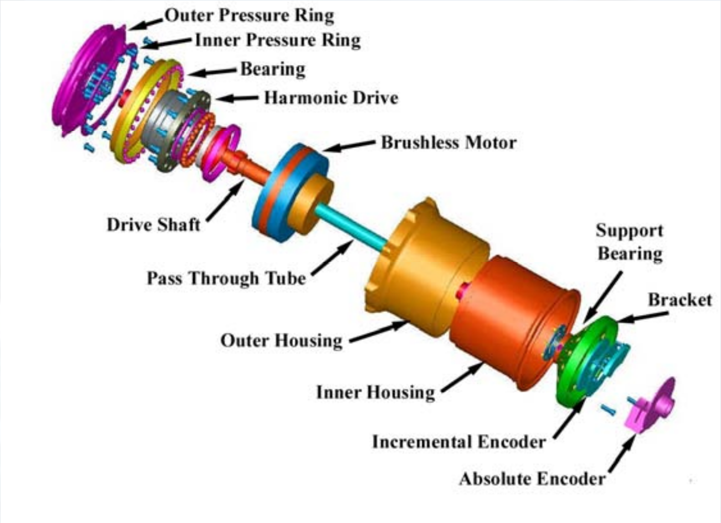
- 100 kg-class operational servicer
- Maneuvering spacecraft bus using “green” propellants
- Dual dexterous manipulators with interchangeable end effectors and grappling arm
- Capable of performing at EVA equivalence
- Ideal for operationally responsive dedicated servicing missions

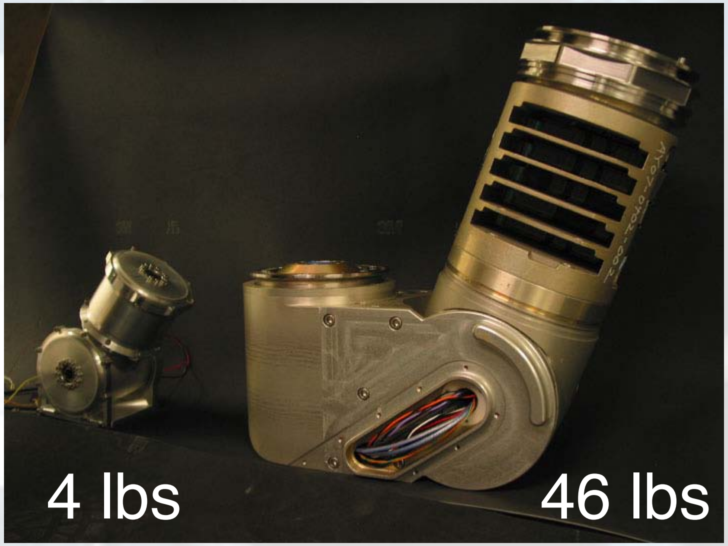
Critical Issues in SmallSat Servicing

- Robotics
  - Grappling
  - Gross manipulation
  - Dexterous manipulation
- Dynamics and control
  - Coupled dynamics
  - Stabilization with robotic motion perturbations
- Operations
  - Low-bandwidth command and control
  - Automation
  - Time delay mitigation

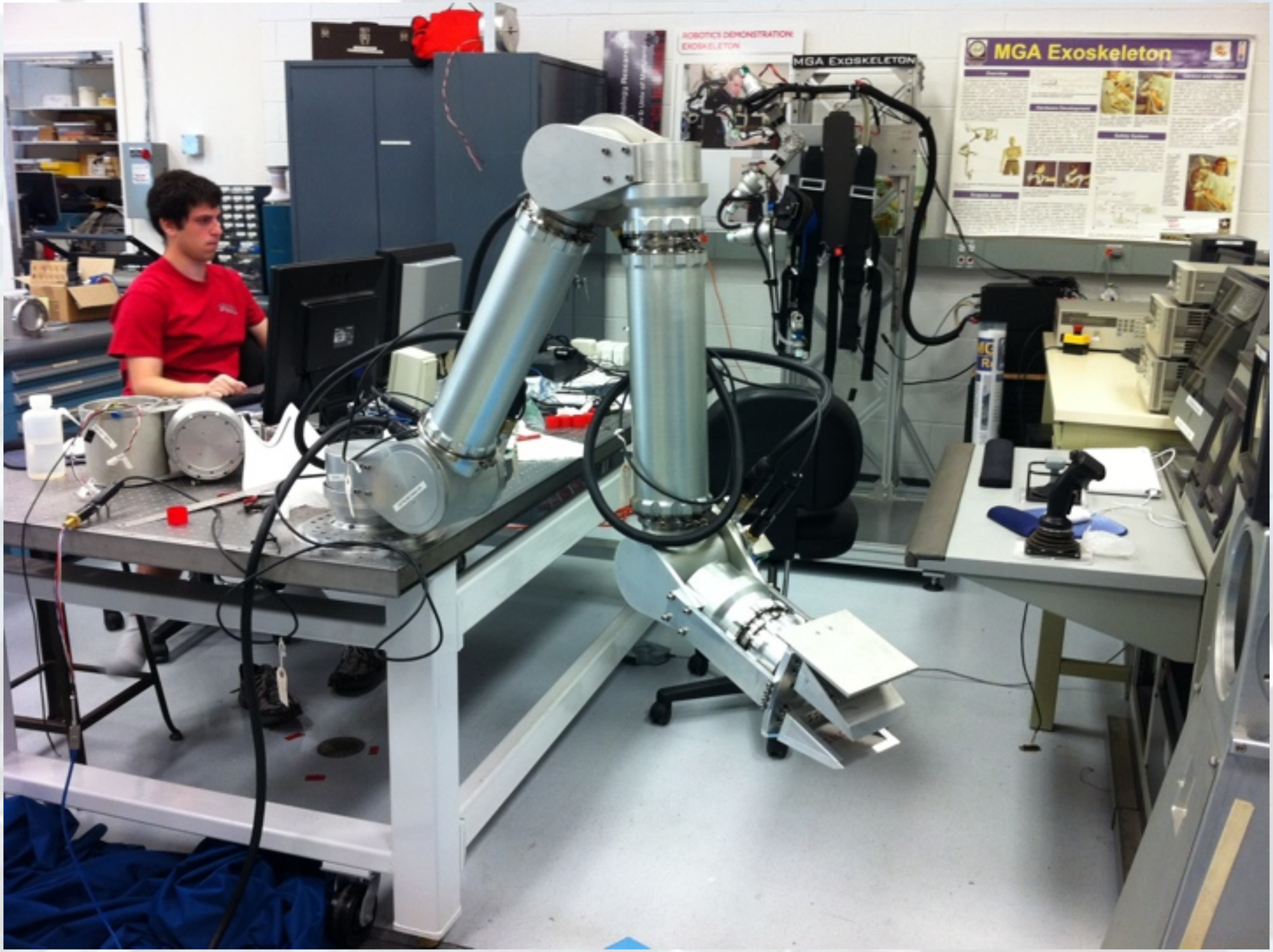
MORPHbot Actuator Technology



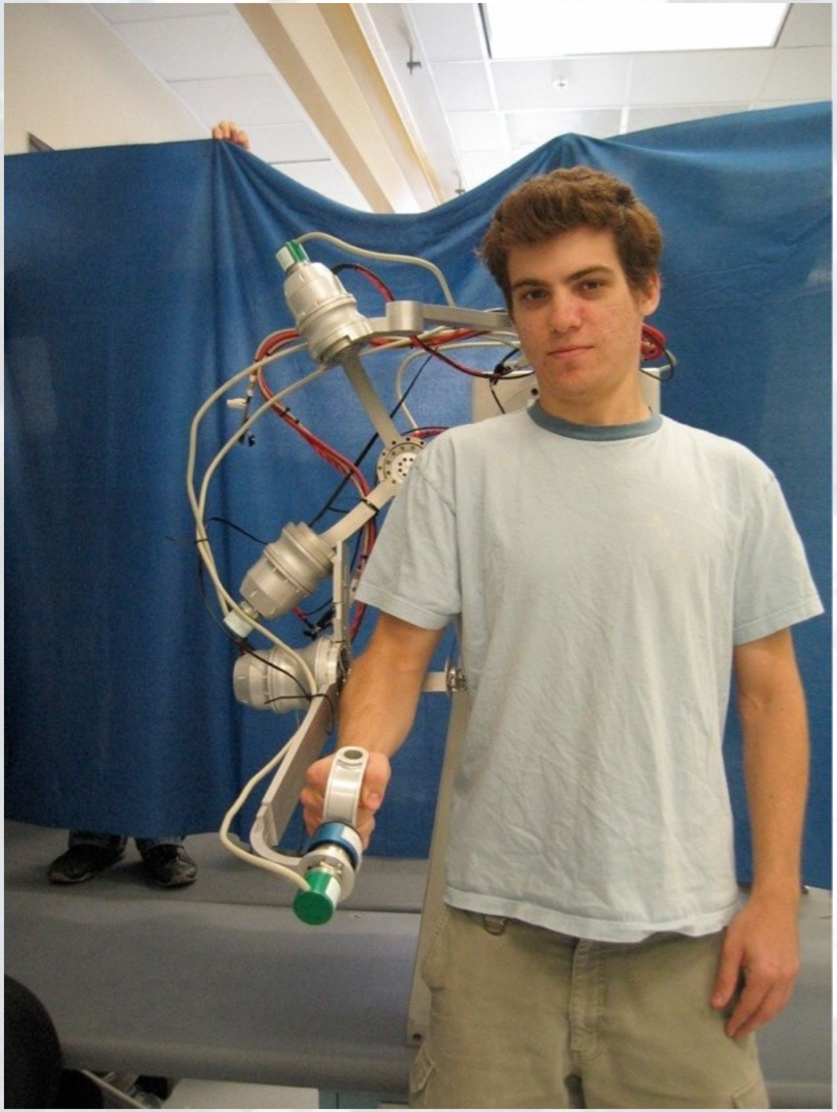




SAMURAI Deep Submergence Arm



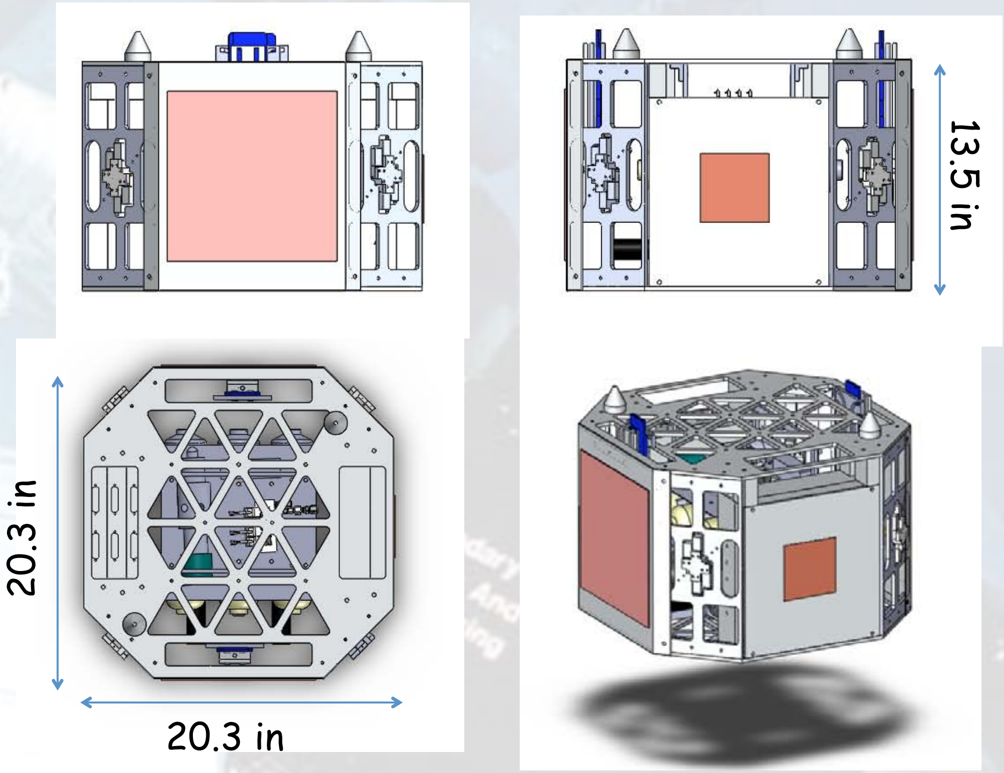
Exoskeleton for Shoulder Rehabilitation



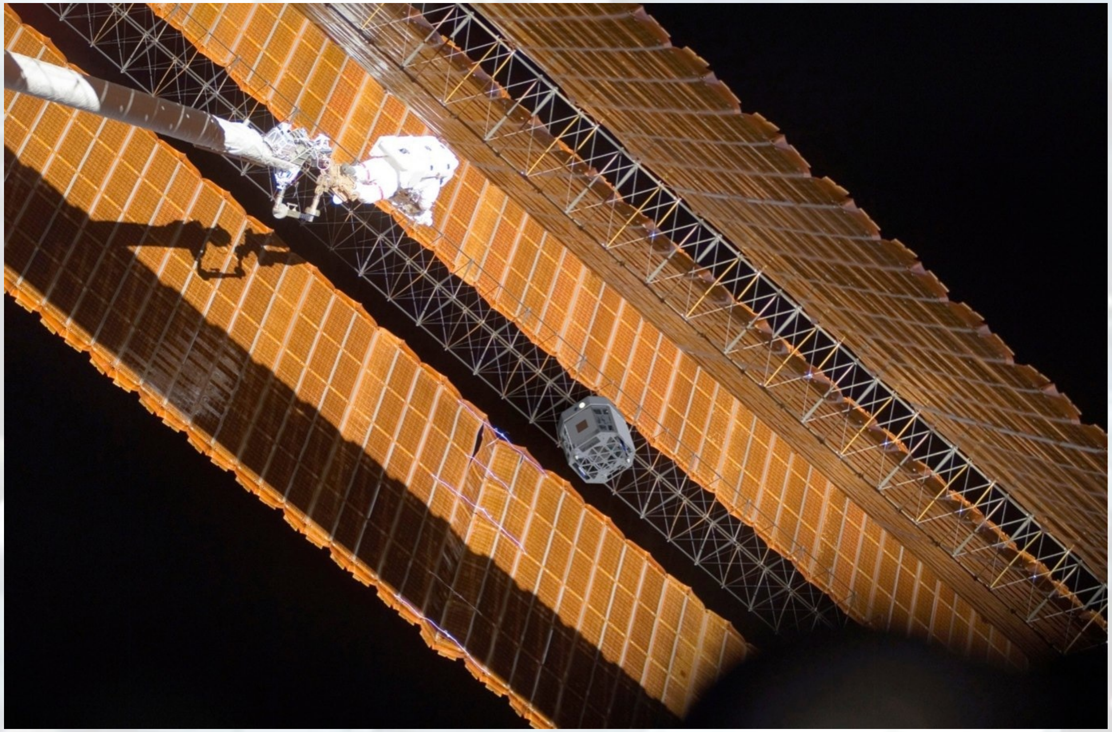
- 5 DOF, capable of lifting itself and subject's arm in Earth gravity
- Full range and speed of motion equivalence to human
- Designed for rehabilitation of severe shoulder trauma
- Safety-critical redundant control architecture to protect patients

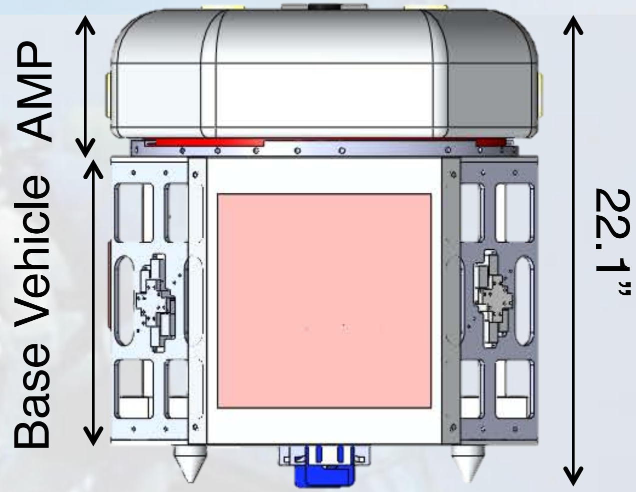
Exo-SPHERES Overview

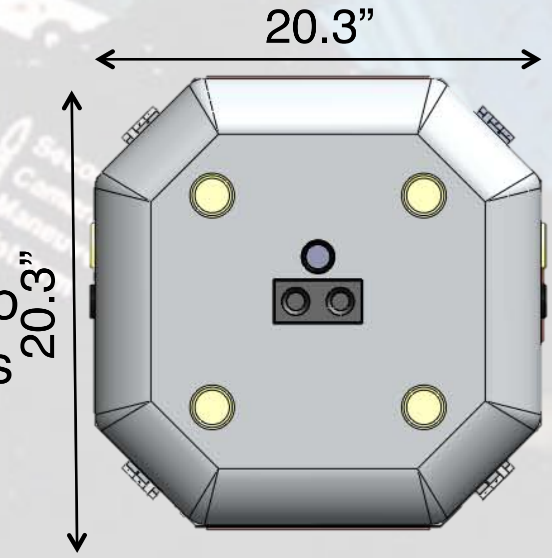
- Goal was to create a vehicle capable of routine operational use at ISS
- Interchangeable modules fore & aft for mission specific payloads
- Teleoperated from ISS using COTS networking protocols



Inspection Exo-SPHERES Overview

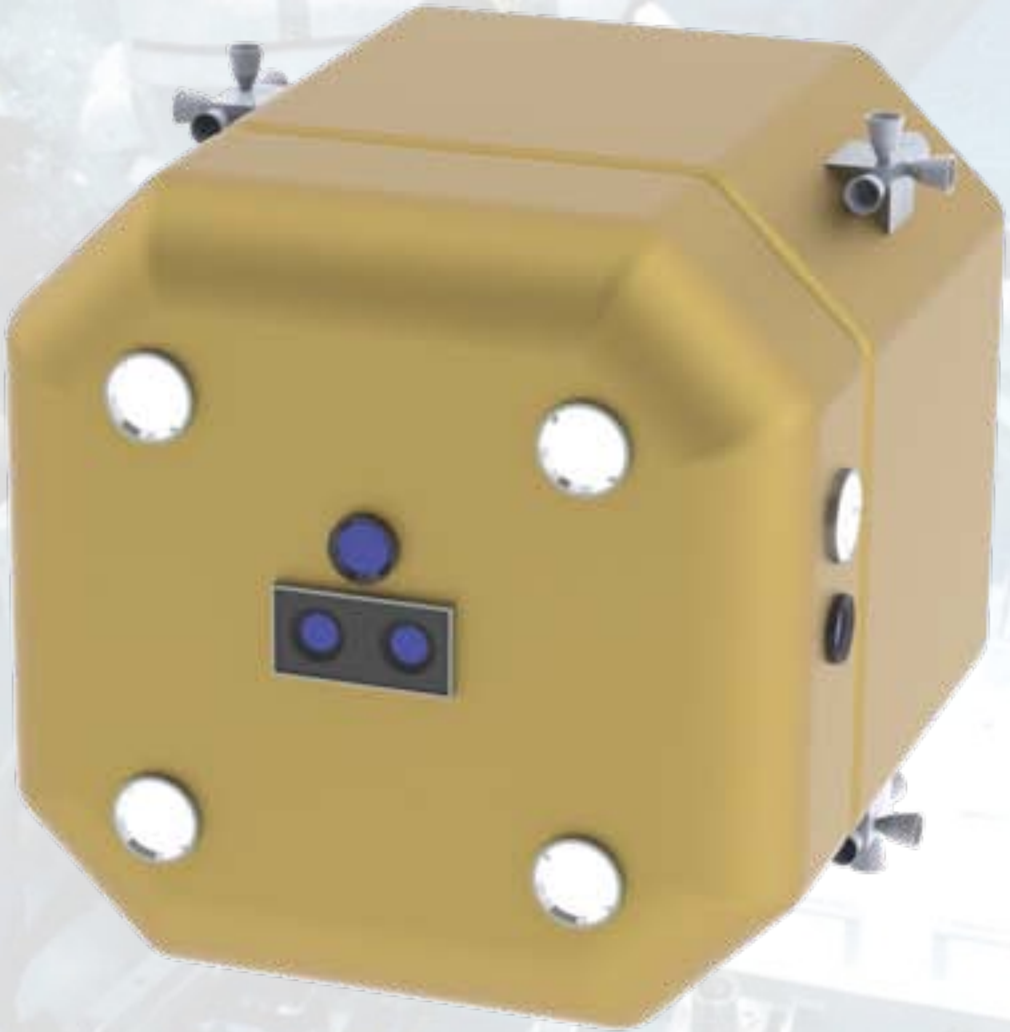






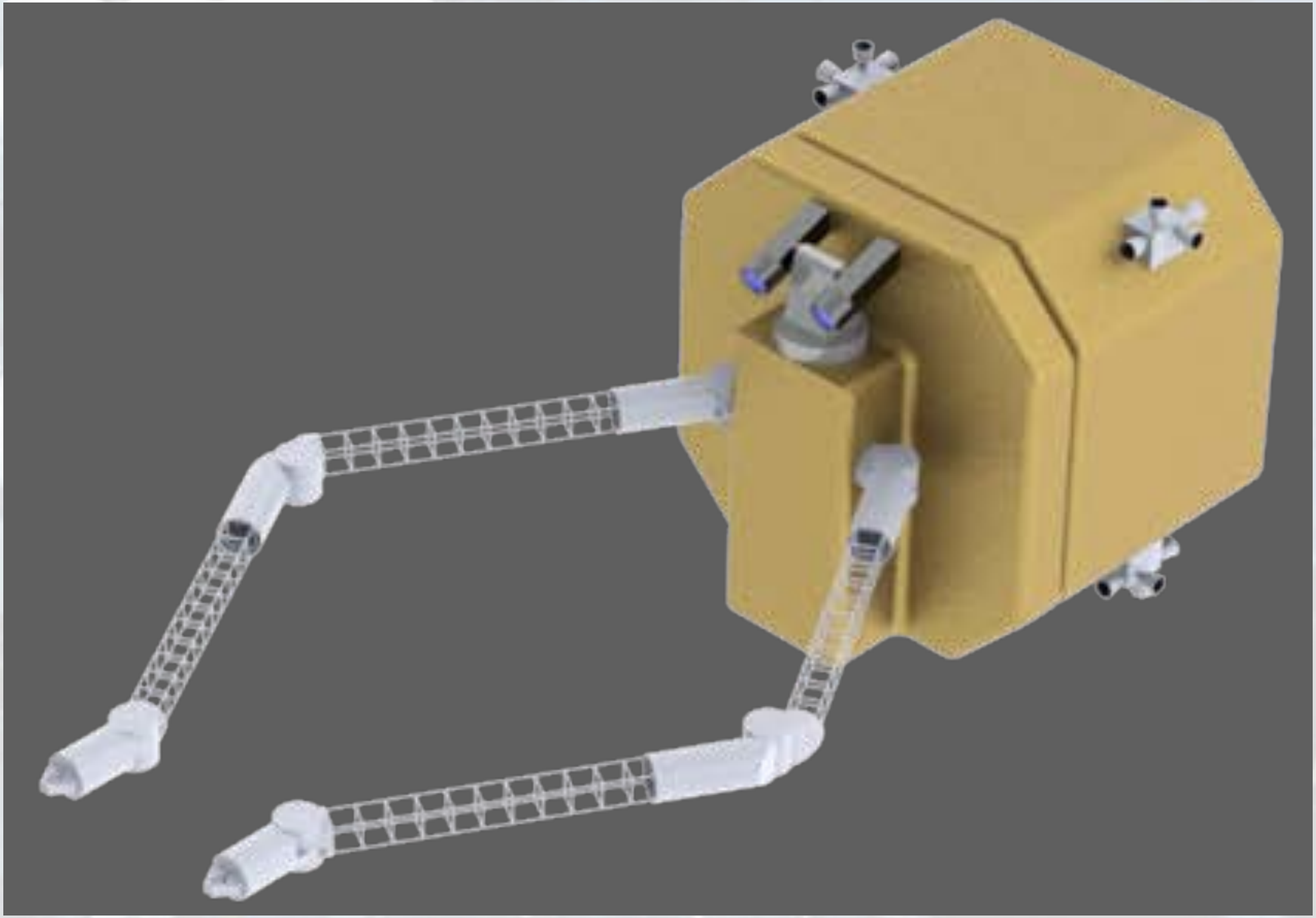
Advanced Mission Packages (AMPs) are attached to the base vehicle, allowing for more science missions and easy upgrades.
Example: Inspection AMP which contains lights and cameras in order to do visual inspections.

Exo-SPHERES with Inspection AMP



- 50 kg freeflyer for ISS external ops
- Advanced Mission Packages (AMPs) for sortie-specific payloads
- CO2 cold gas propulsion with autonomous docking and replenishment
- Developed under DARPA and NASA funding

Exo-SPHERES with Servicing AMP

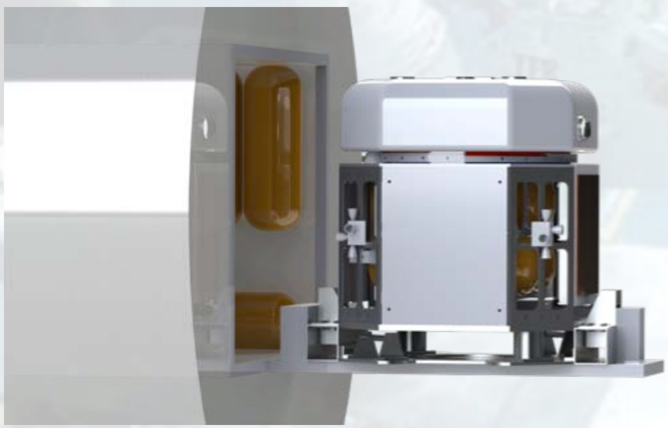


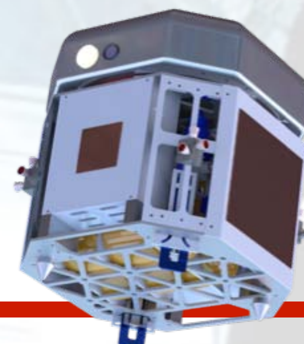
Sortie Timeline (Base Mission)

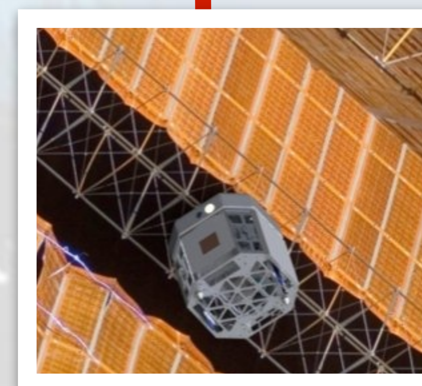
Phase 1:
Attach AMP
- Inside ISS

Phase 2:
Start Up
- C&DH start up
- Run systems checks

Phase 3:
Deploy from Kibo





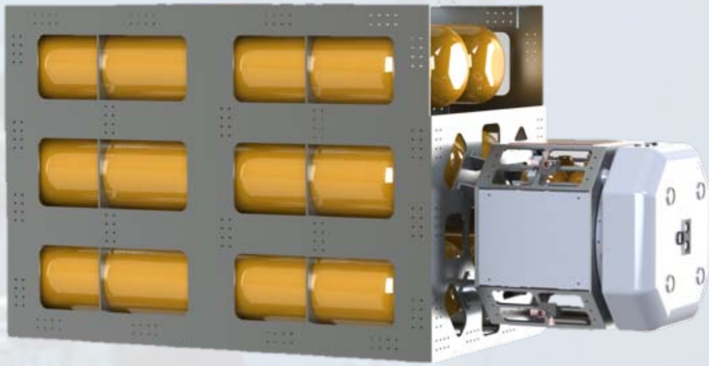


Phase 4:
Tele-operation
- Example: inspection mission
- Up to 8 hour duration

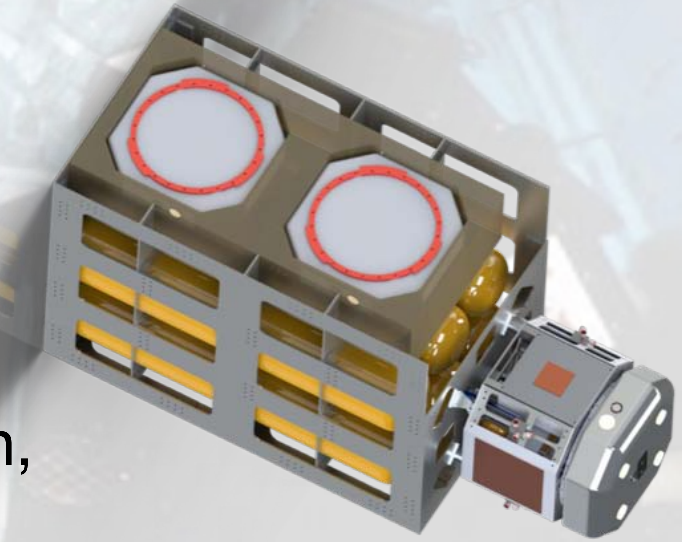
Phase 5:
Return to Kibo airlock
- Autonomously dock
- Repressurization

Growth Option: Exposed Facility Interface

- Operational issues discovered with Kibo airlock
  - No user-available power or data
  - Airlock envelope is very restrictive in volume
  - Consumables loss with every depress/repress cycle
- Alt recharge/resupply plan
  - Second docking site on Exposed Facility, draws power from station, resupply from attached tanks.
  - Allows external AMP exchange



External Base with CO2 Tanks

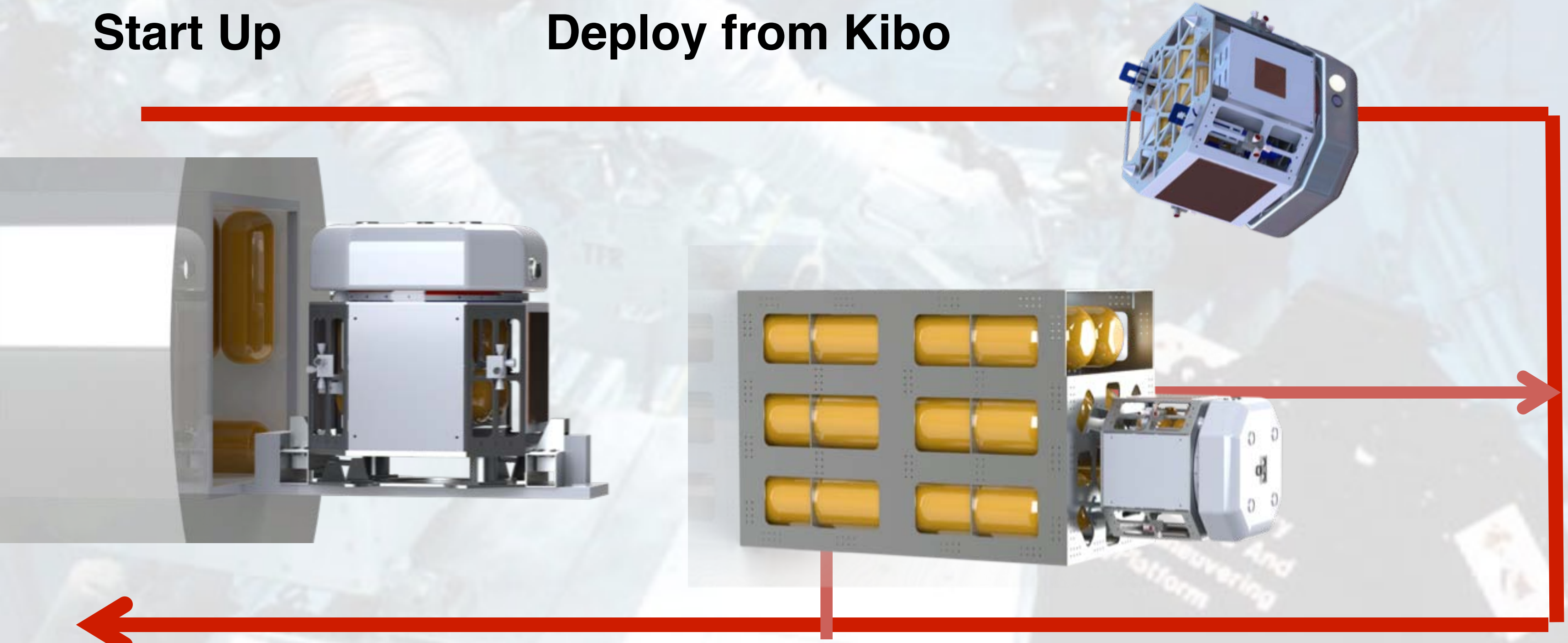


External Base with CO2 Tanks and replacement AMPs

Sortie Timeline (External Basing)

Phase 1:
Start Up

Phase 2:
Deploy from Kibo

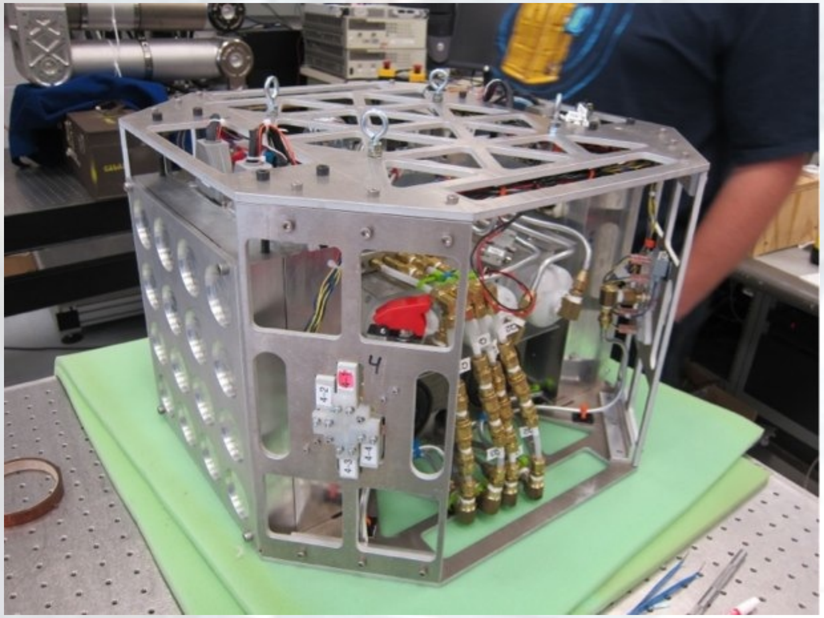


Phase 3:
Tele-operation

Phase 4:
Resupply / Recharge at base
- Change AMPs
- Perform repeated sorties

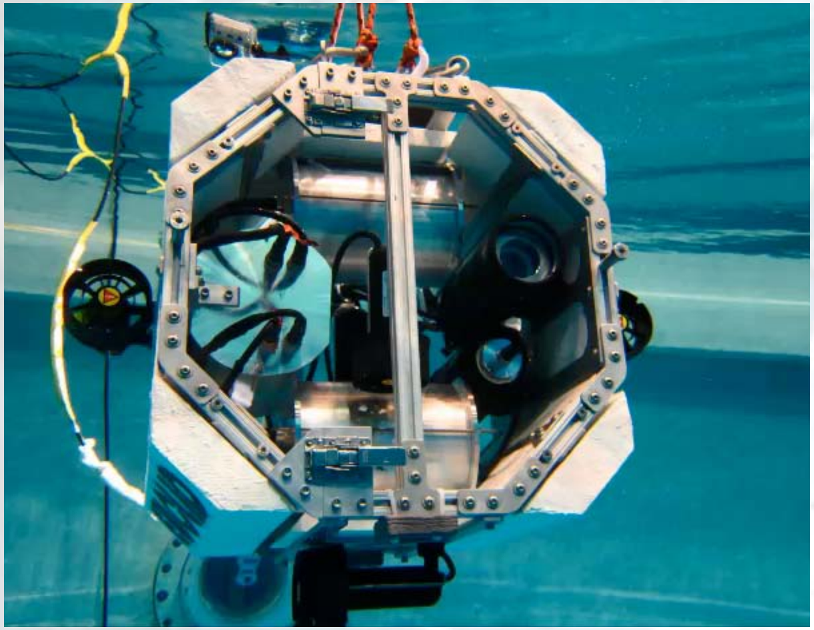
Phase 5: Return to Kibo
for major service/ reconfiguration

Exo-SPHERES Protoflight Vehicle



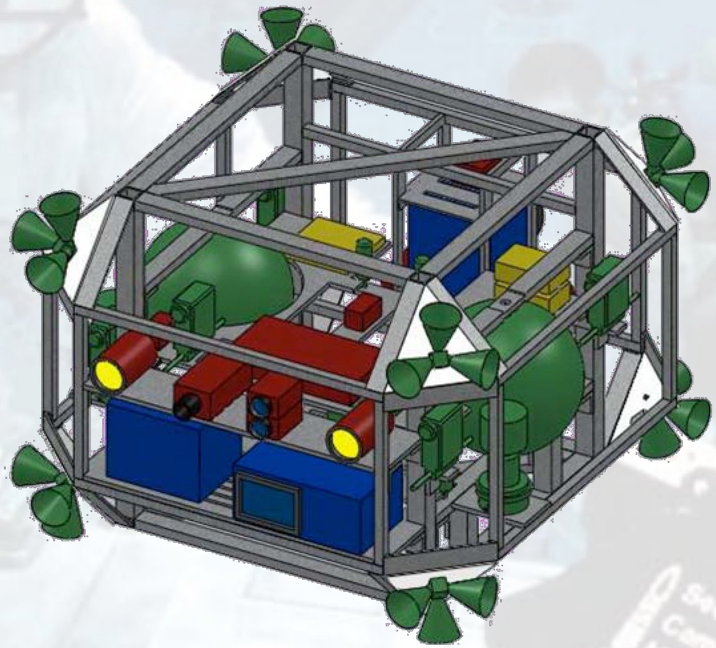
- Exo-SPHERES flight prototype
- Maximum commonality with flight vehicle configuration, electronics, software
- Used for thermal vacuum testing; air-bearing table operation
- Being adapted for parabolic flight testing

EUCLID Neutral Buoyancy Test Vehicle



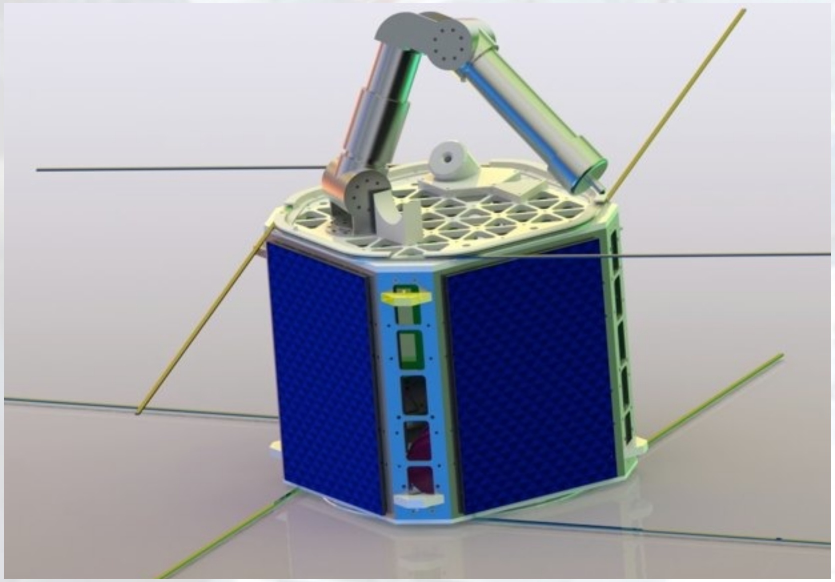
- Neutral buoyancy version of Exo-SPHERES
- Maximum commonality with flight vehicle configuration, electronics, software
- Allows end-to-end simulation of flight operations in 6 DOF
- Motion capture cameras provide state vector, used to mitigate water drag effects

NEO Mission ExoSPHERES Design



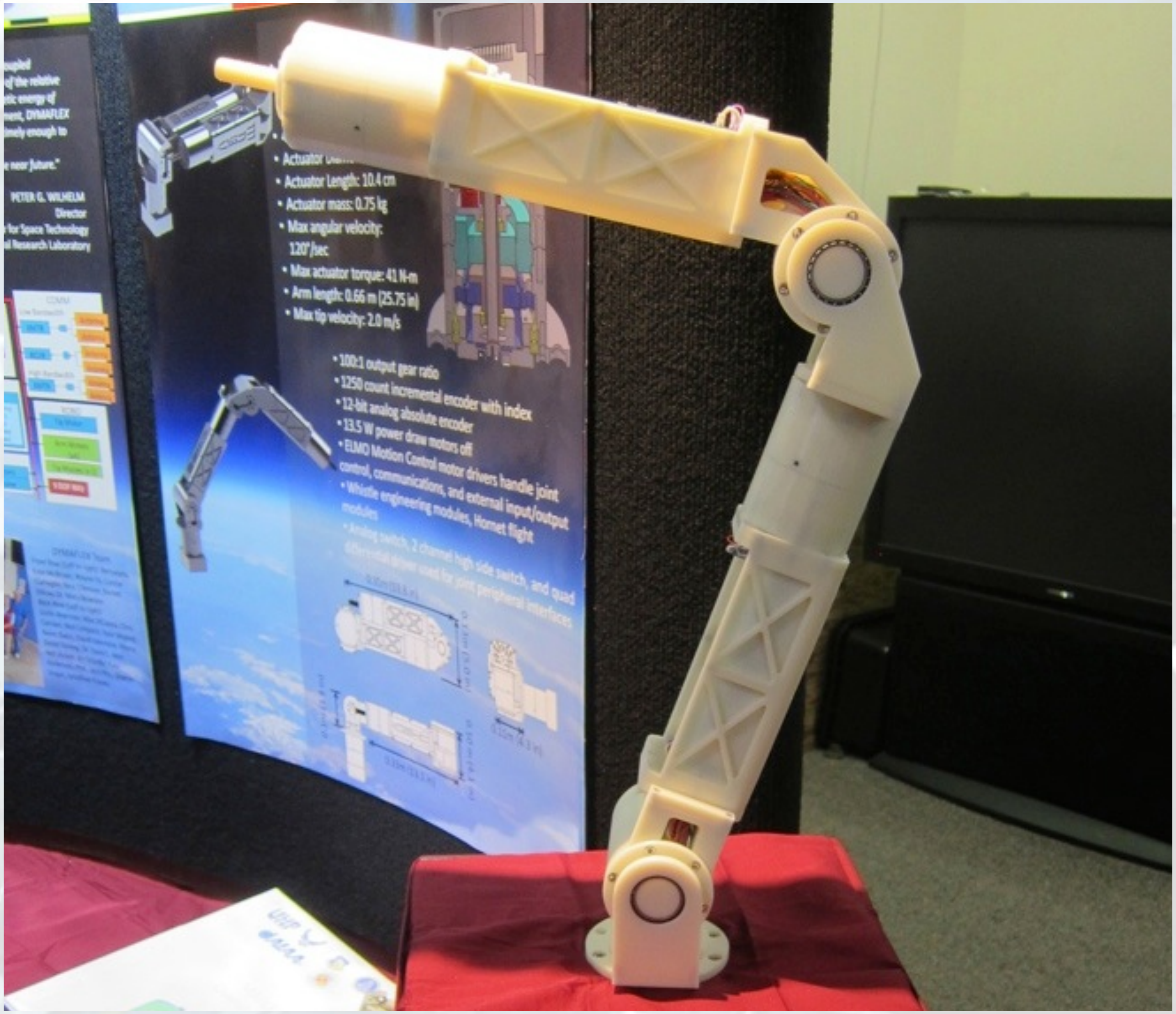
Robotic vehicle for close-proximity navigation, surveying, and scientific investigation around asteroids or comets

DYnamic MAnipulation FLight EXperiment

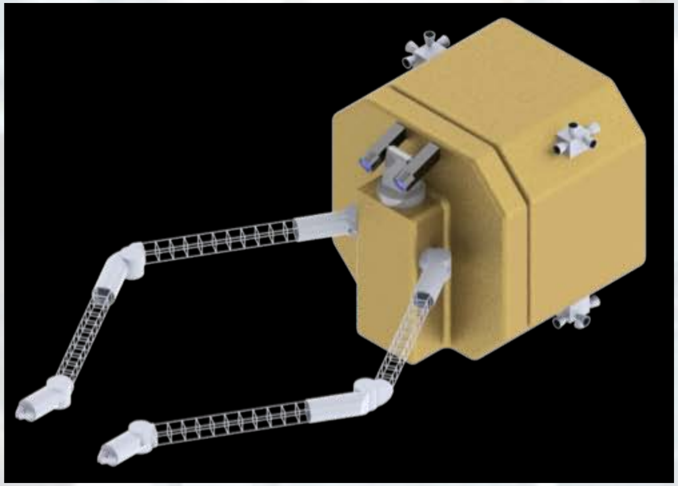


- Flight experiment to develop and qualify flight control algorithms for free-flying vehicles with significant manipulator disturbances
- 4 DOF manipulator with interchangeable tip masses to alter inertias
- Autonomous operations with periodic downlink to single ground station
- AFOSR UNP-7 program

DYMAFLEX Manipulator Prototype

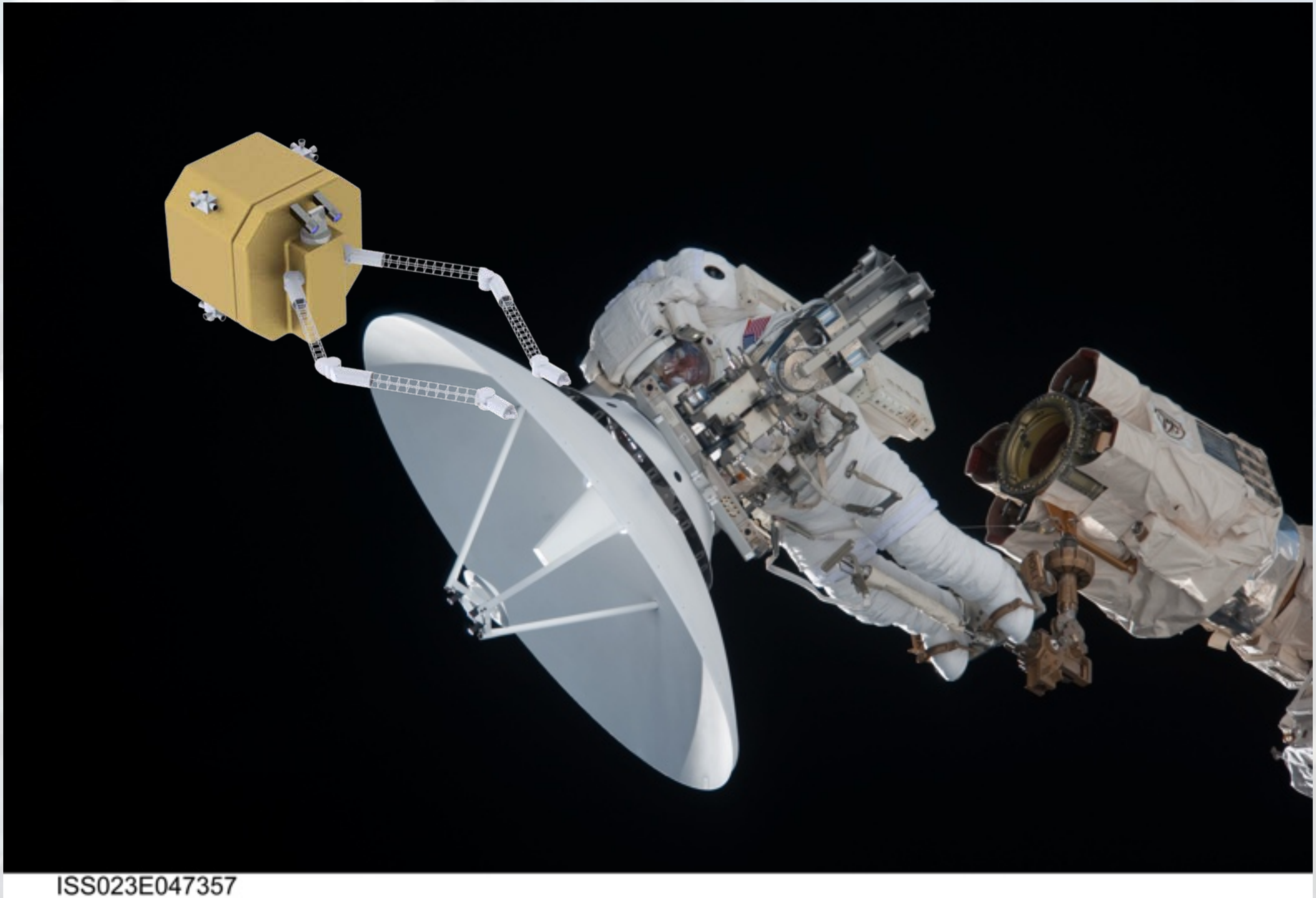


Exo-SPHERES for Dexterous Ops

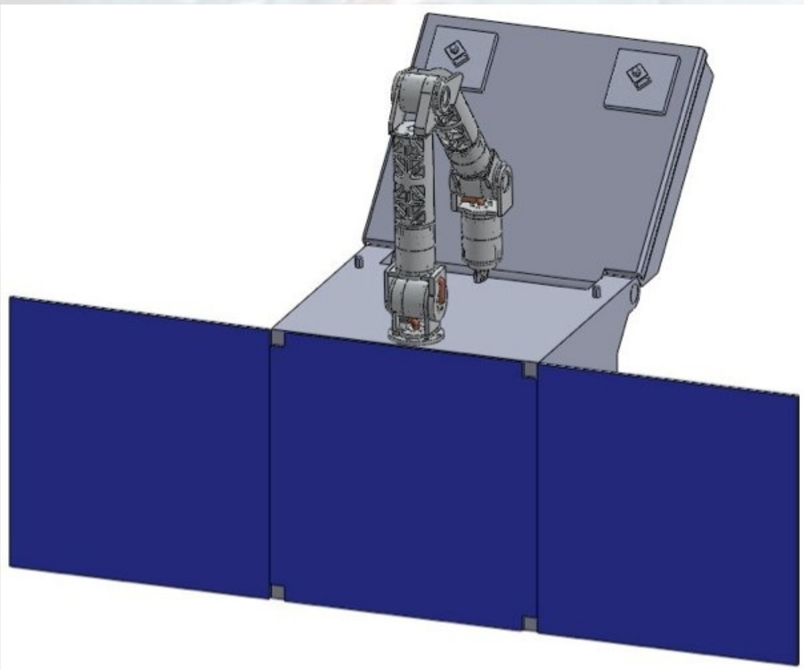


- AMP with dual dexterous manipulators, vision system
- Capable of anchor and instrument placement, sample collection, maintenance tasks
- DYMAFLEX manipulator characteristics
  - 80 cm long
  - 7 DOF with interchangeable end effectors
  - 5 kg per arm

Exo-SPHERES Assisting EVA Servicing

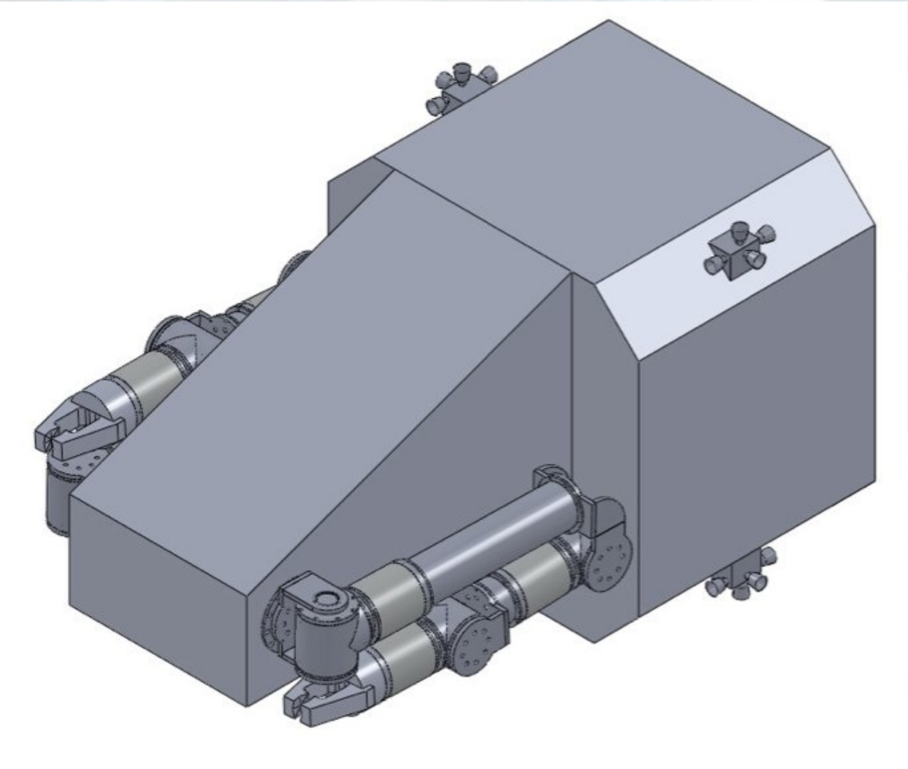


DOSS Servicing Flight Demo Concept



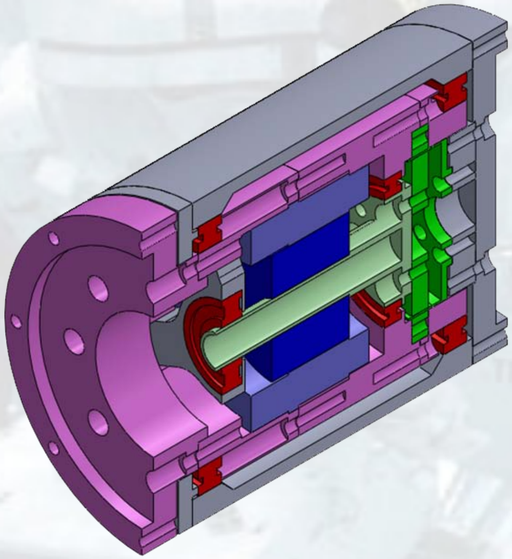
- Dexterous Orbital Servicing by Smallsat
- Flight demonstration of servicing tasks
- Self-contained task board
- Autonomous and teleoperated task performance
- Proposed for AFOSR UNP-8

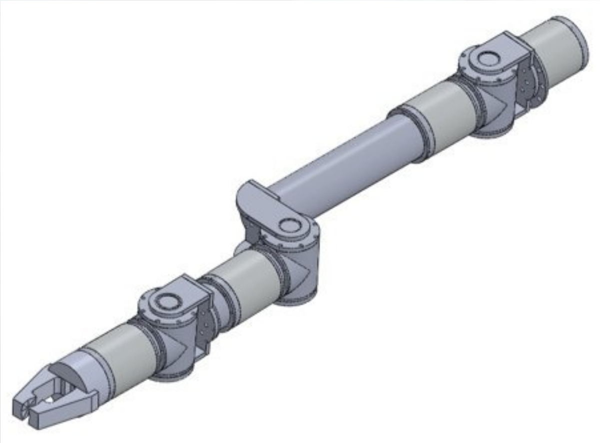
SCAMP End-to-End Servicing Demo



- Smallsat Concept for Advanced Manipulation and Proxops
- Secondary launch on ESPA ring or Dragon
- Self-deploys two cubesats for rendezvous and docking targets
- Performs servicing tasks on surface-mounted task board
- NASA Edison proposal

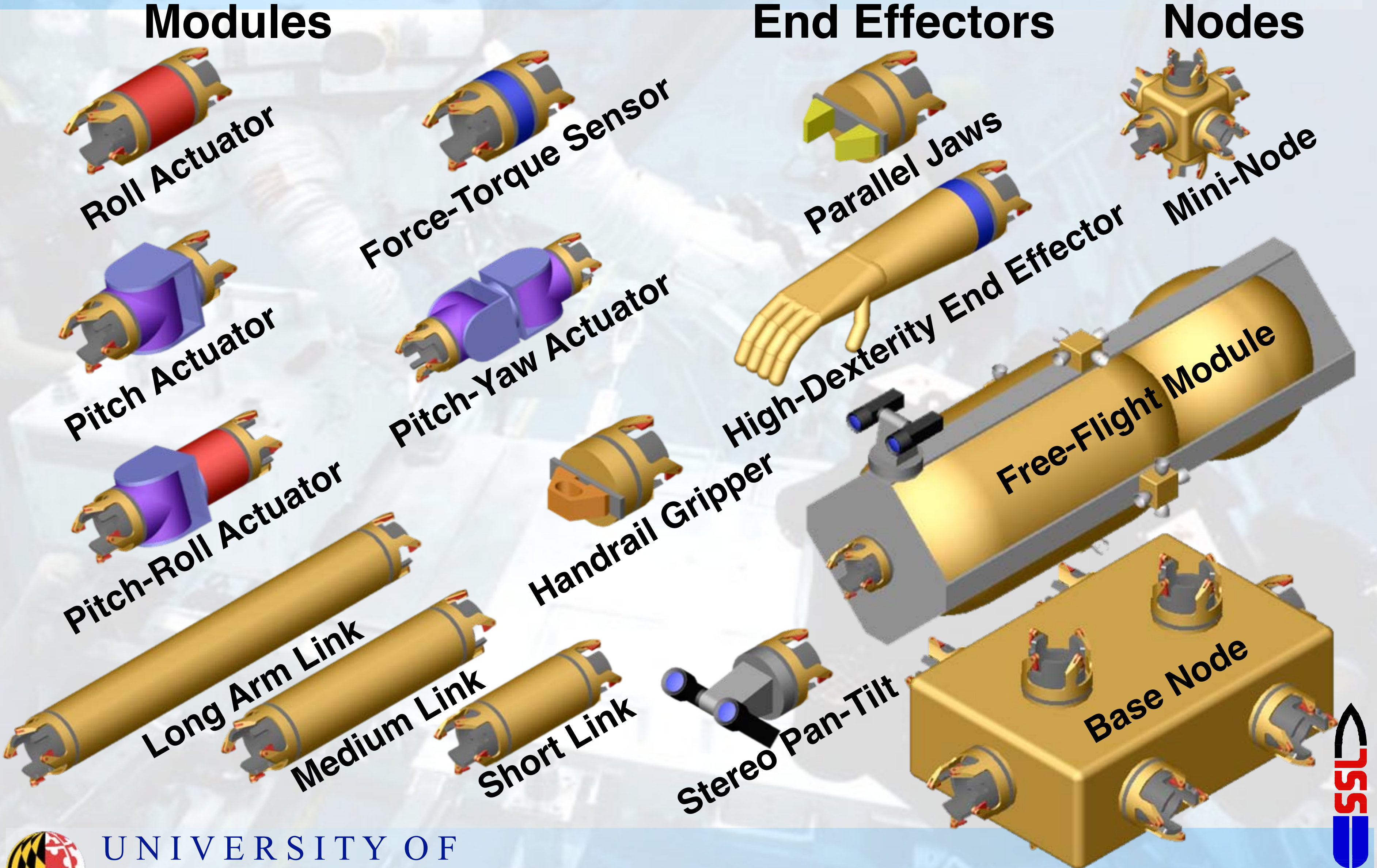
Proteus Dexterous Servicing Manipulator





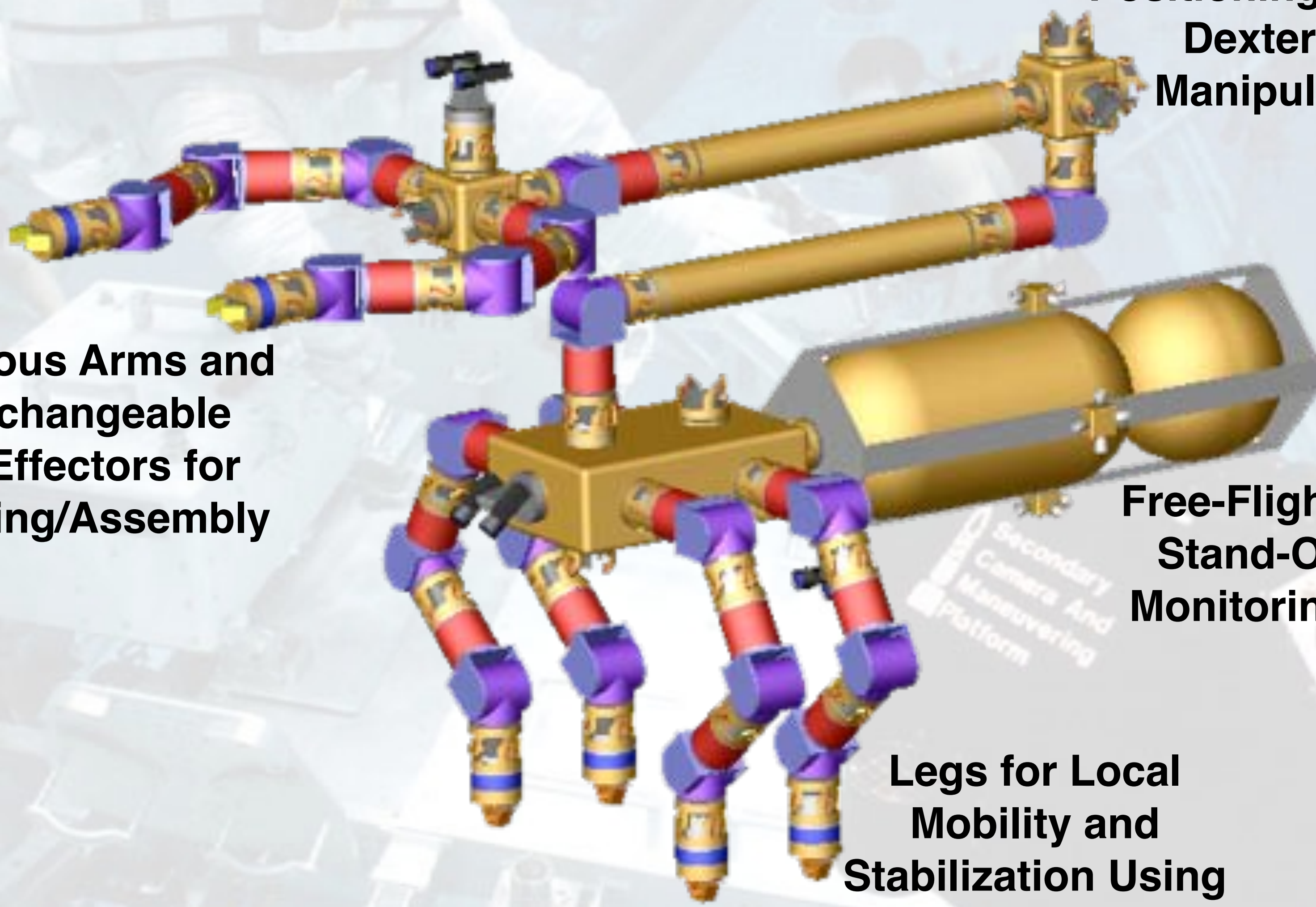
- Evolution of DYMAFLEX manipulator
- Human-scale manipulator
  - 6 cm diameter
  - 1 meter long
- Total mass 8 kg
- Interchangeable end effectors
- 80 N tip force (worst pose)
- >30 cm/sec max tip speed
- Nominal power 75 W

A Sample *Proteus* Toolbox



A Potential *Proteus* Configuration

Positioning Arm for Dexterous Manipulators



Dexterous Arms and Interchangeable End Effectors for Servicing/Assembly

Free-Flight Module/ Stand-Off Video Monitoring Source

Legs for Local Mobility and Stabilization Using EVA Hand Rails

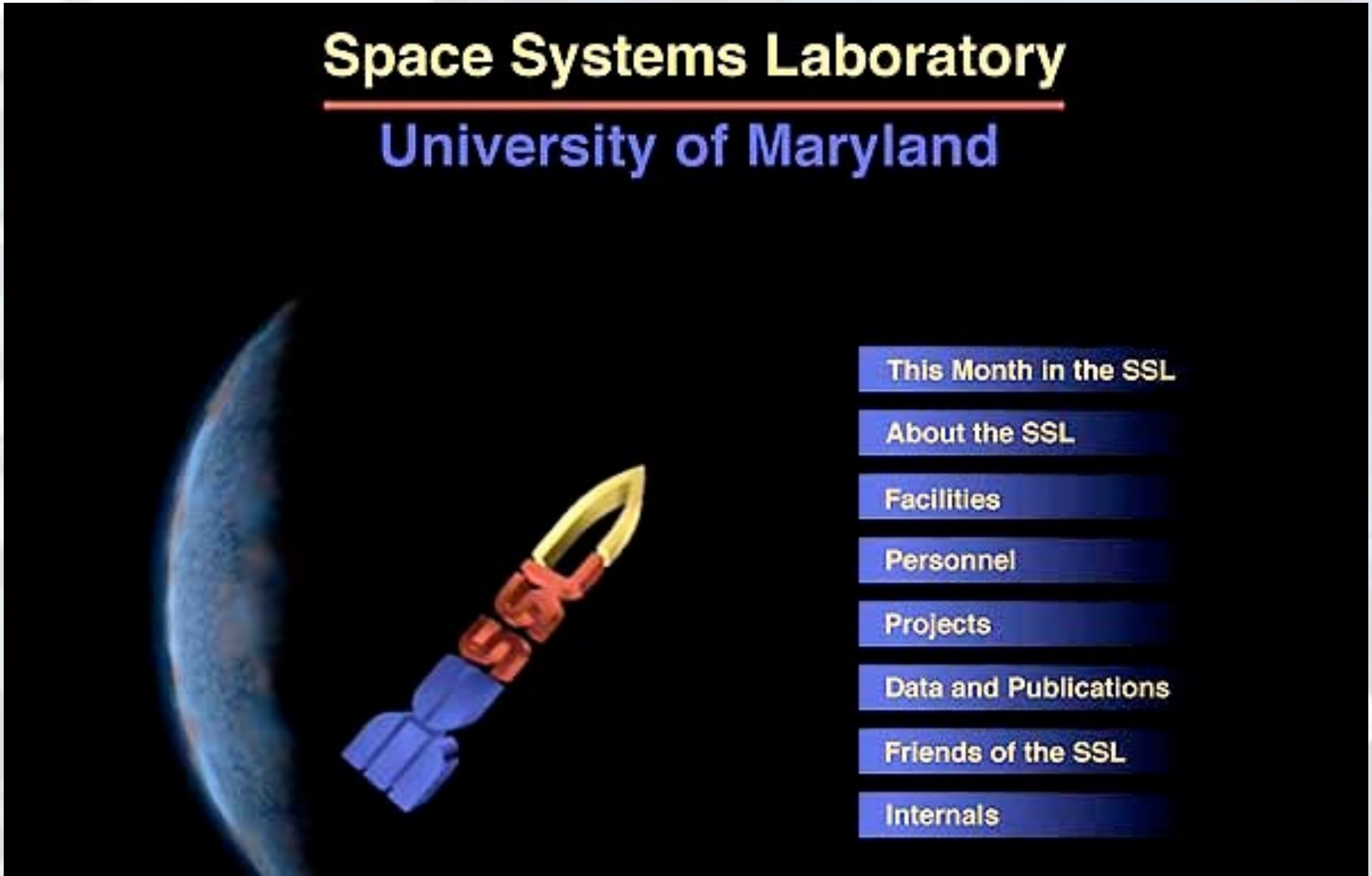
Closing Thoughts

- The problem with space robotics is that it has developed its own mythology through the years
  - “If I say my program needs a robot, I’ll have to pay for it”
  - “There’s no way a robot can do what an astronaut can”
  - “To develop and fly a space robot, you have to have already developed and flown a space robot”
- Highly capable (EVA-equivalent) space robots can be made compatible with ESPA secondary launch
- Small robots are lower in cost, and enable a business case to be made for single-target, expendable servicing missions

More Closing Thoughts

- Highlander myth: “There can be only one.”
  - Robots are not generalists; there are niches for a rich ecosystem of space robots
  - Not every task is optimally performed by a humanoid
  - Only one robot → feature creep → cost growth → longer planned lifetime → higher reliability → cost growth...
- If humans will always be the most expensive element in space, use robots to make them as capable as possible
- The robotics field is vastly bigger than NASA, or even the U.S. players → opportunity *and* peril

For More Information



http://www.ssl.umd.edu

dakin@ssl.umd.edu