TETHERS ROBOTICS

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TETHERS UNLIMITED

TUI OSAM Technologies

Hardware:

KRAKEN Robotic Arm

- Modular Joints
- Active Compliance
- Embedded Controller

MANTIS

- Robotic EXPRESS Rack locker for ISS
- Payload Automation
- 6DoF Microgravity Controls Testbed

AXON Connector Family

- ARTIE Tool Changer
- Dactylus Soft Capture End Effector
- Structure Connectors

Software and Controls:

Cylon

- Control of Multiple Robotic Arms
- GNC/ADCS Integration

MOSAIC

- OSAM Dynamics Simulation
- Multi-Agent/Formation Controls
- Large Structure Distributed Attitude Control

AstroPorter

- Dynamic Mass Properties Estimator
- Multi-Agent Cargo Handling Solution
- Evaluating on Astrobee Testbed

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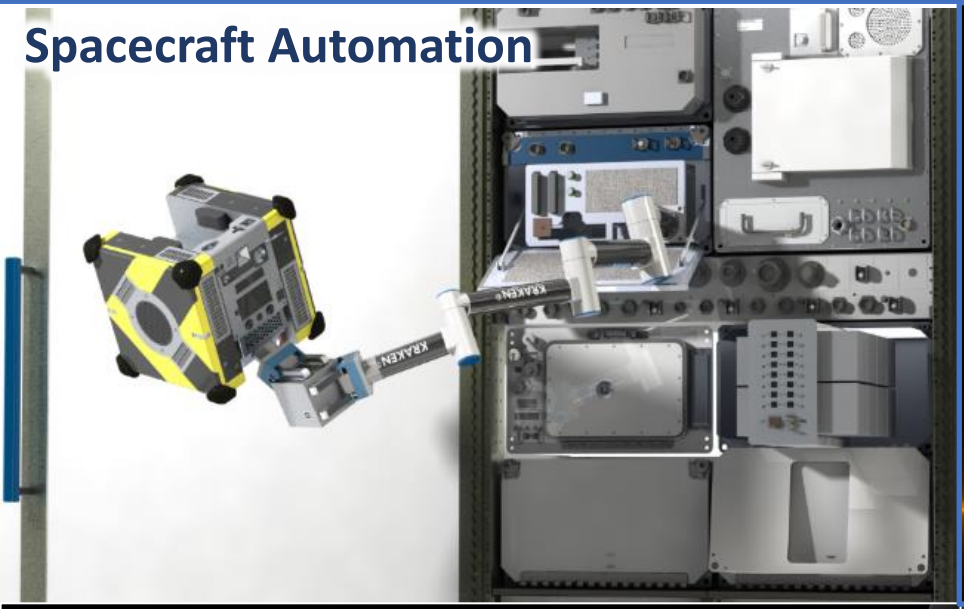
TUI Robotics Applications



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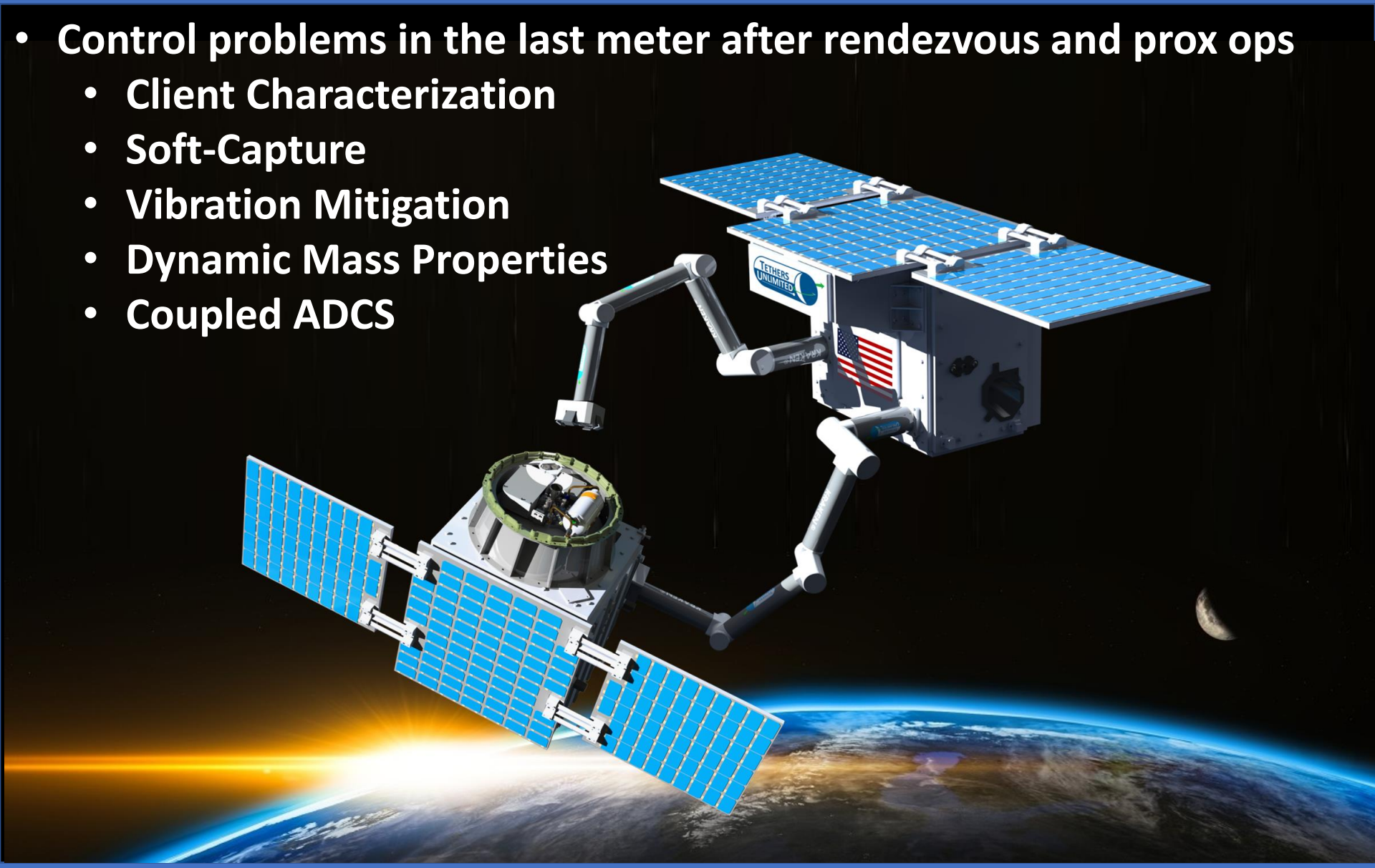
OSAM - The Longest Meter

- **Control problems in the last meter after rendezvous and prox ops**
  - **Client Characterization**
  - **Soft-Capture**
  - **Vibration Mitigation**
  - **Dynamic Mass Properties**
  - **Coupled ADCS**



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KRAKEN® Robotic Arm

Force-controlled manipulator developed for NRL and NASA's Robonaut Team to enable:

- On-Orbit Servicing, Assembly and Manufacture (OSAM)
- Automation for volume/mass constrained missions
- Safe Co-working with Astronauts

Features:

- Series Elastic Actuators
- Modularly Configurable Joints
- Force Control & Active Compliance
- On-board Embedded Controller

Baseline KRAKEN Configuration:

- 7 DoF
- 1m Reach
- Mass: 7.1kg
- Payload Capacity: 500g in 1G

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Modular Joint Design

Specifications

- 10Nm, 30Nm, 60Nm, 120Nm Joint Sizes
- 50mNm, 250mNm, 500mNm, 1Nm accuracy
- ± 345° rotation range
- Back-drivable @ 1Nm
- EtherCAT motor driver for kHz set-point control frequency

Series Elastic Actuators

- Planar disk spring between drive & link output
- Co-located (direct) deflection sensing
- Sized to driver current sense resolution & motor stall torque

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KRAKEN Mass

The mass of the KRAKEN arm varies with joint configuration and radiation environment

Configuration	Mass in kg (LEO)	Mass in kg (GEO)
F/T, L,L,M,M,S,S,S	7.06	9.18
F/T, XL,XL,L,L,M,M,M	10.23	13.30
F/T, All Small	4.97	6.46
F/T, All Medium	7.01	9.11
F/T, All Large	10.28	13.36
F/T, All X-Large	15.13	19.67

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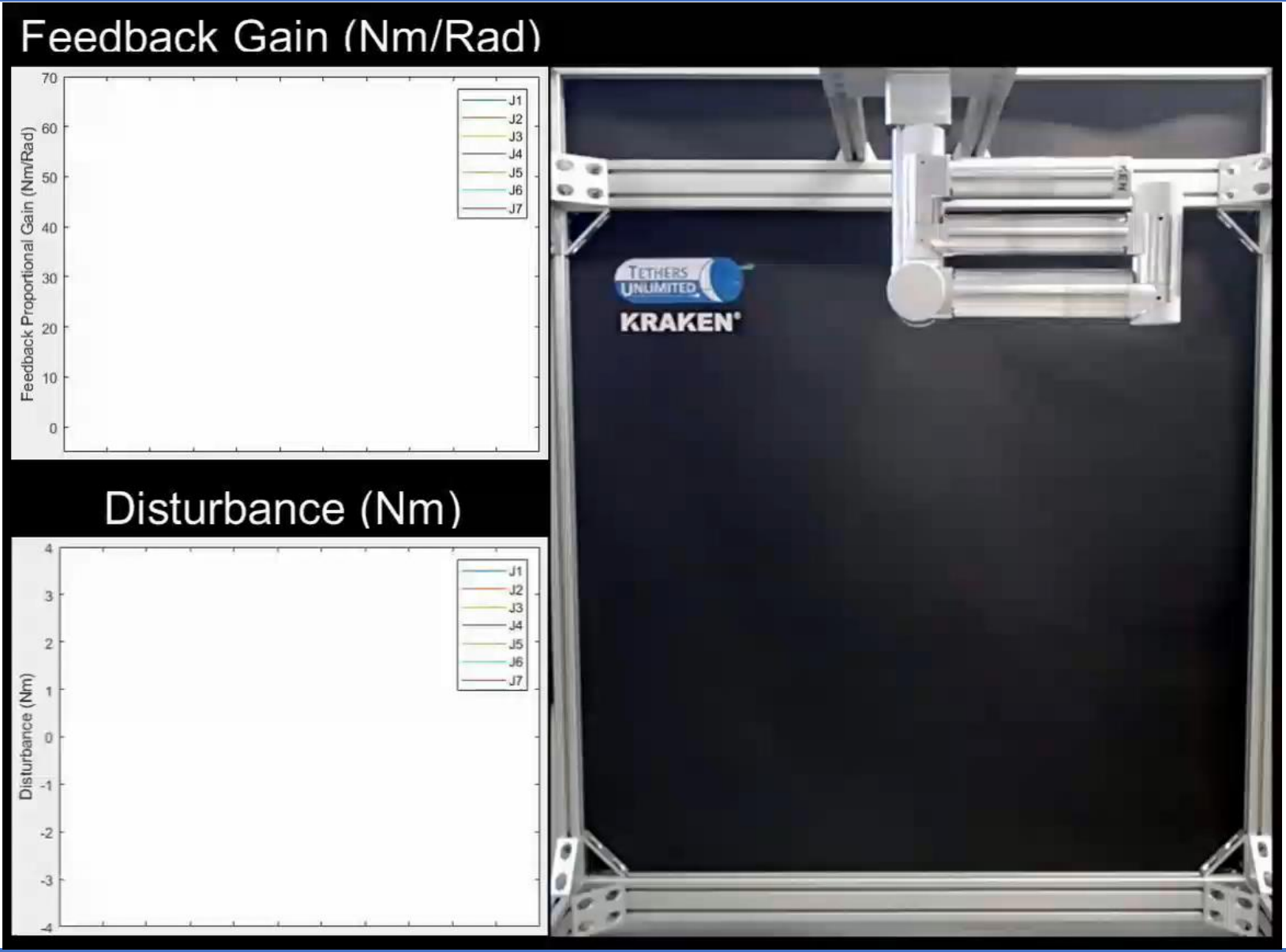
Active Compliance Demo



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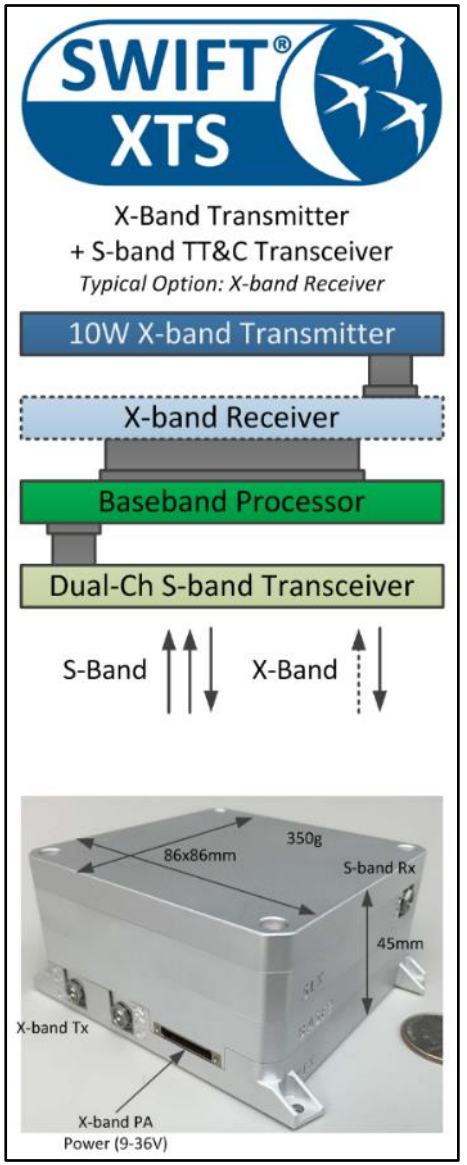
Embedded Controller

- **Goal**
  - Support high-performance force control for lunar & deep-space missions
- **Flight Controller Requirements**
  - Flight qualified for GEO
  - EtherCAT Master
  - Close 1kHz control loop
  - Execute feedforward model in real-time
- **SWIFT Software-Defined Radio**
  - Baseband processing module*
  - 7 radios operational in LEO
- **Mass: 100g → 1kg depending upon environment**



*All KRAKEN prototypes run on SWIFT baseband-equivalent prototypes

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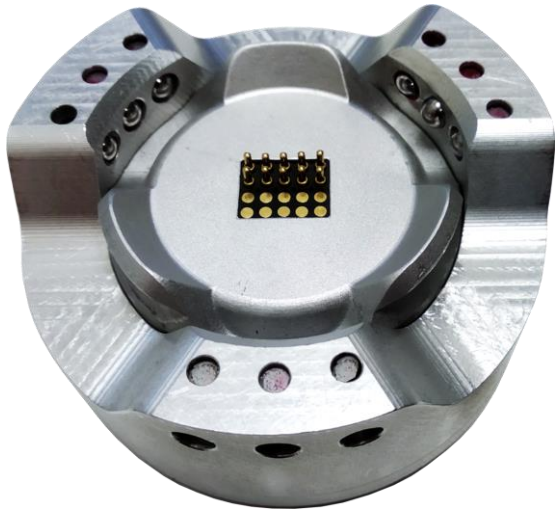
ARTIE Compact Tool Changer

- **AXON Connector:**
  Androgynous Robotic Tool-change Interface (ARTIE)
  - Compact hot-swap capability for docking ports & end-effectors
  - Wireless power/data interface
    - First-contact ESD protection for on-orbit servicing
  - Power protection safe-to-connect functionality
  - Wide alignment tolerances for autonomous applications
  - Mass ~ 500g



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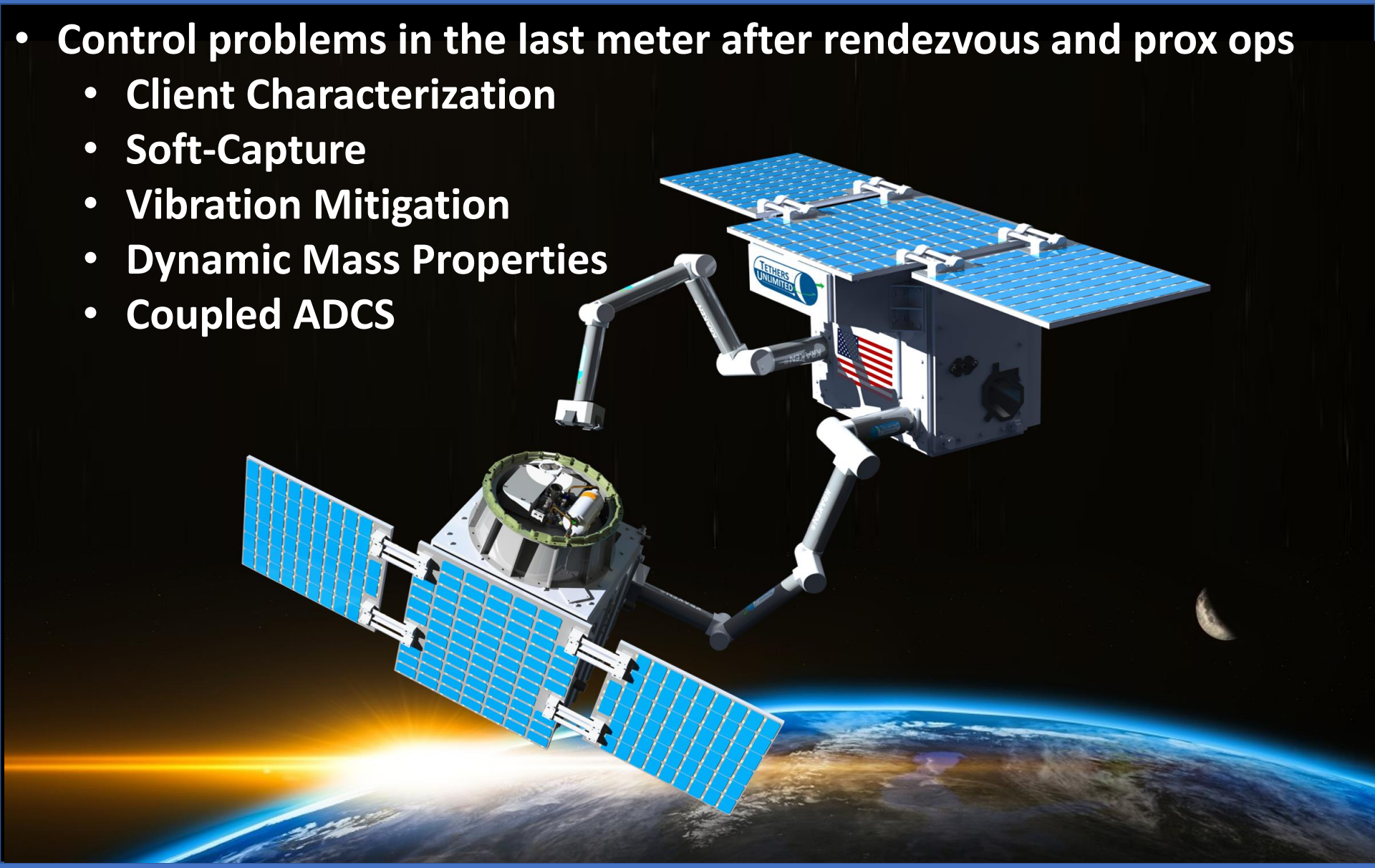

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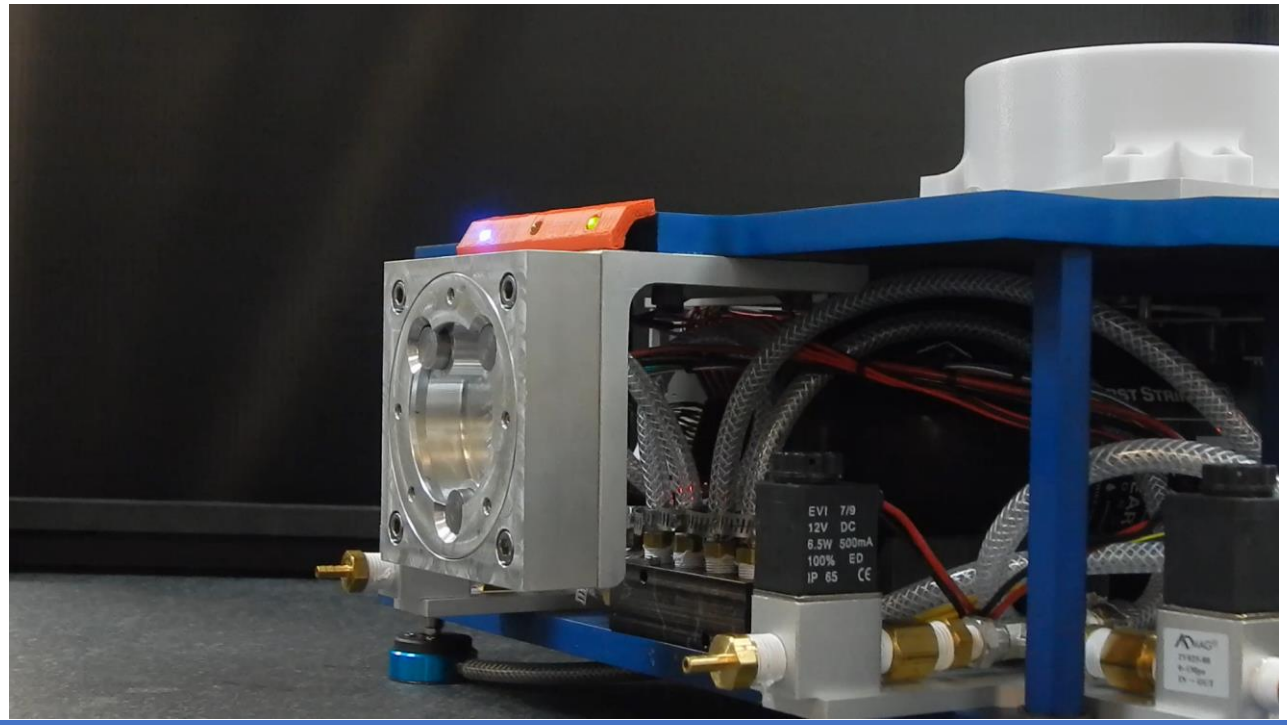
Dactylus

- **AXON Connector**
  Low-profile Soft Capture End Effector
  - Fully passive client-side fixture
  - Rigid, un-powered mechanical mate within 0.5 seconds after trigger set
  - Optional wireless power & data interface
    - First-contact ESD protection for on-orbit servicing
  - Power protection safe-to-connect functionality



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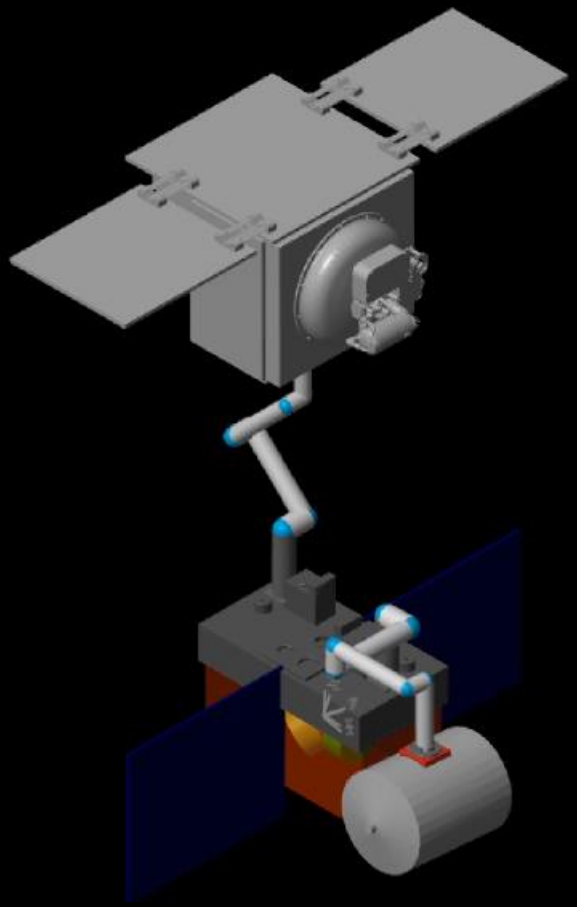
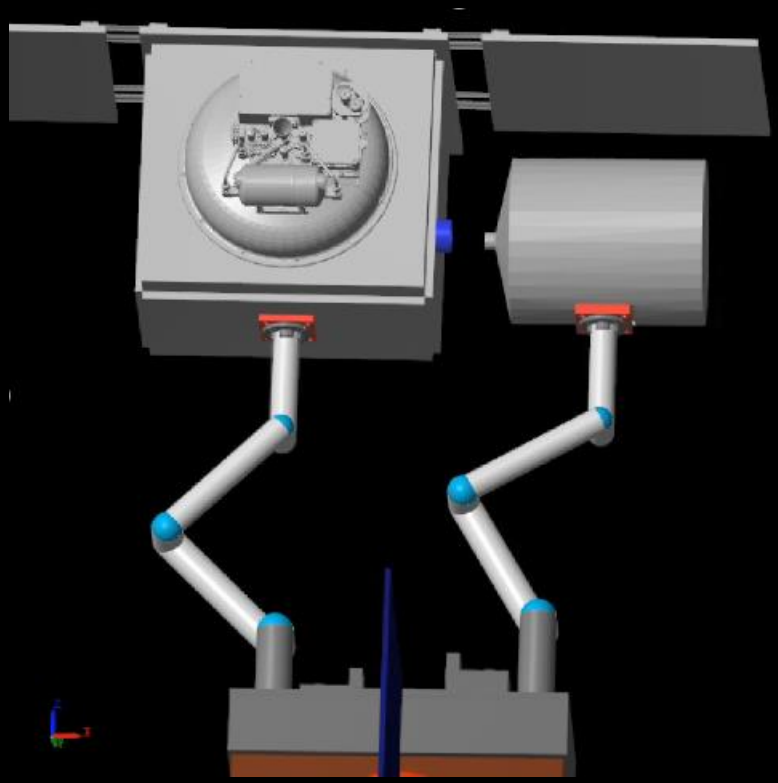
CYLON Multi-Arm Controls





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MOSAIC Simulation

Development Environment for TUI's Distributed ACVMS system:

- **Spacecraft configurations for the platform architecture**
  - Sensor and actuator models
  - Dynamics (mass characteristics and configuration)
  - Network types (eg physical/wireless network)
  - Physical structure configuration
- **Control software**
  - Local spacecraft attitude and translational control
  - Formation control/inter-agent control
  - Force minimization control for rigid formations
- **Satellite state estimation**
  - State estimation techniques for satellite attitude and position
  - Sensor fusion techniques dependent on sensor configuration

MOSAIC is a Simulink-based environment for developing and testing satellite assembly, servicing, and formation flight control methods

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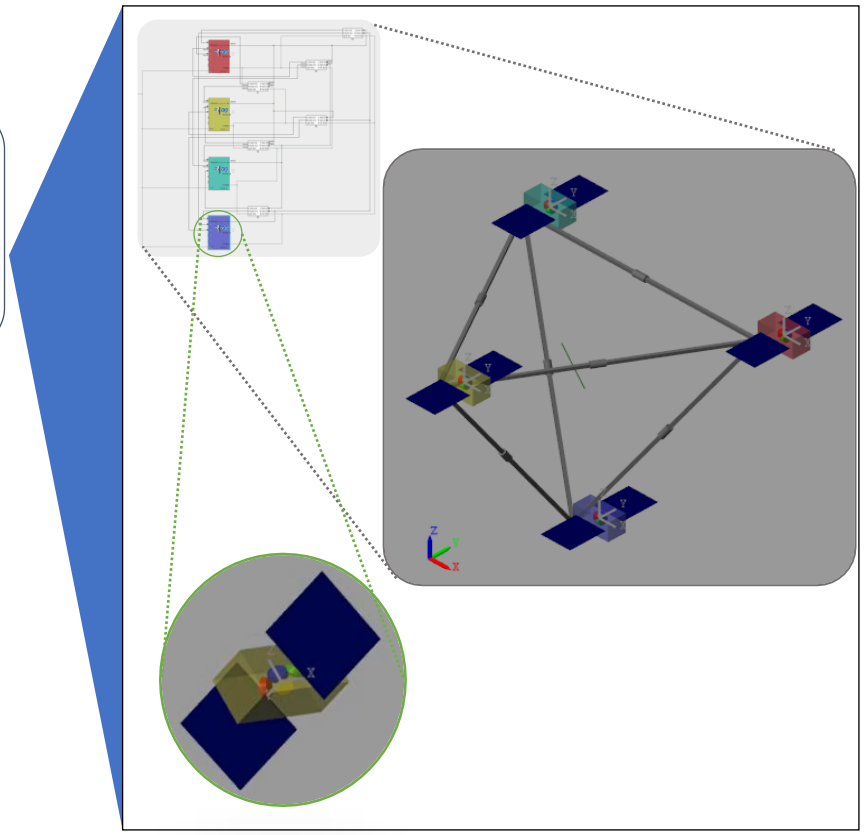
MOSAIC Simulation

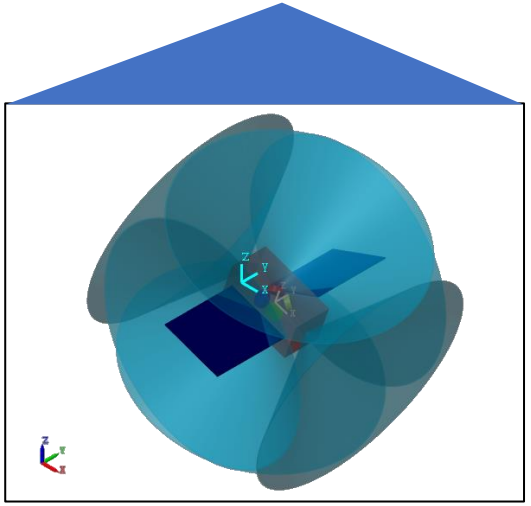
Multi-Objective Simulation for Aerospace Inter-agent Control (MOSAIC)

– **MOSAIC is a configurable orbital simulation environment for development and testing of multi-body dynamics control methods.**

- Satellite network control
- Local satellite control



- Satellite state estimation
- Satellite instrumentation



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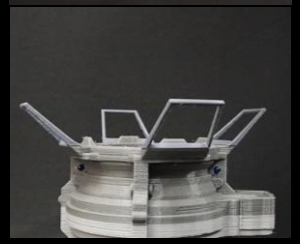
AXON™ Payload/Module Connectors

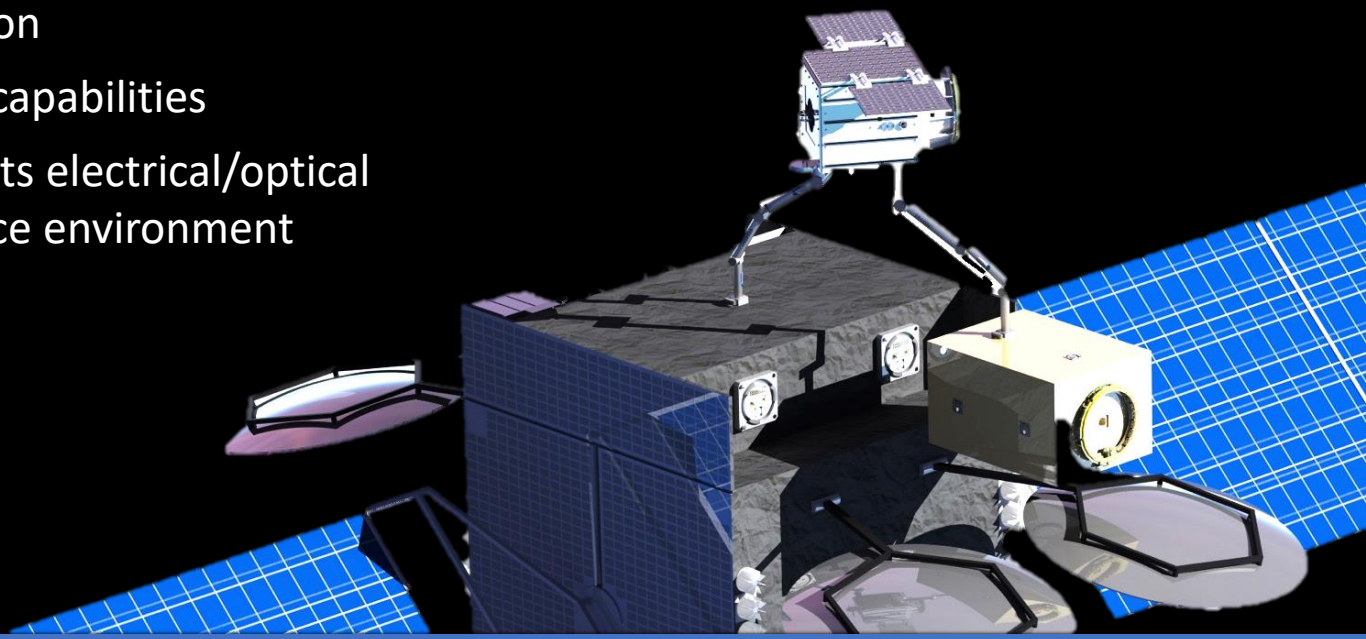
Electromechanical connector for:

- Integration of payloads onto hosted payload platforms, either pre-launch or on-orbit
- On-orbit assembly of modular space systems



Features:

- Androgynous – either side can secure or separate the connection
- Safe-to-mate sensing capabilities
- Actuated cover protects electrical/optical connections from space environment



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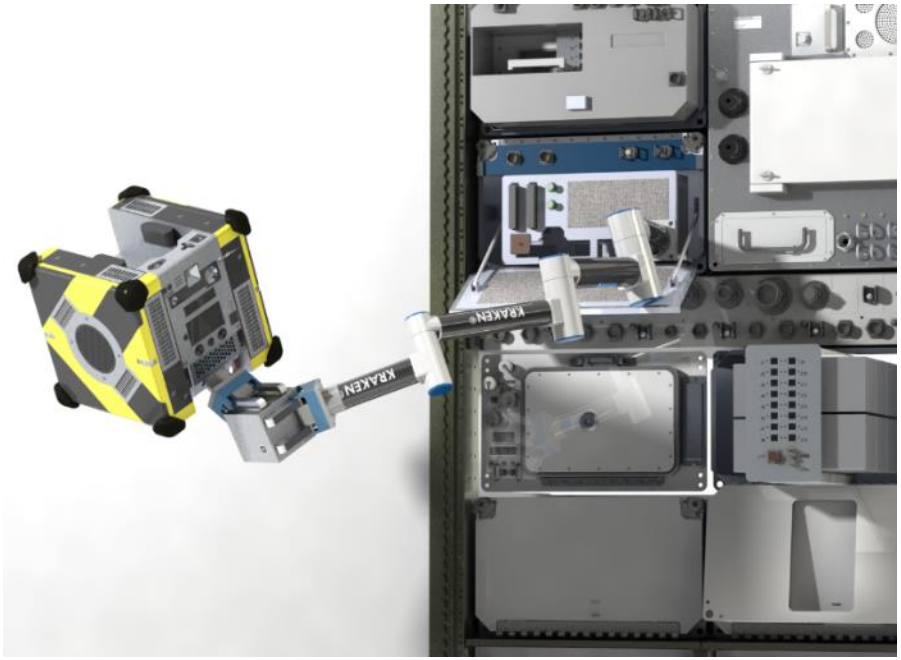
AstroPorter

- **Multi-agent cargo transfer**
  - Fill software/controls gaps for payload transport
- **Develop on-line mass property estimator**
  - Automatically update Astrobee mass properties without needing foreknowledge of cargo



Conceptual render of an Astrobee bringing a Nanolabs (by Nanoracks) payload to MANTIS for installation(left), and tugging a double locker (right).

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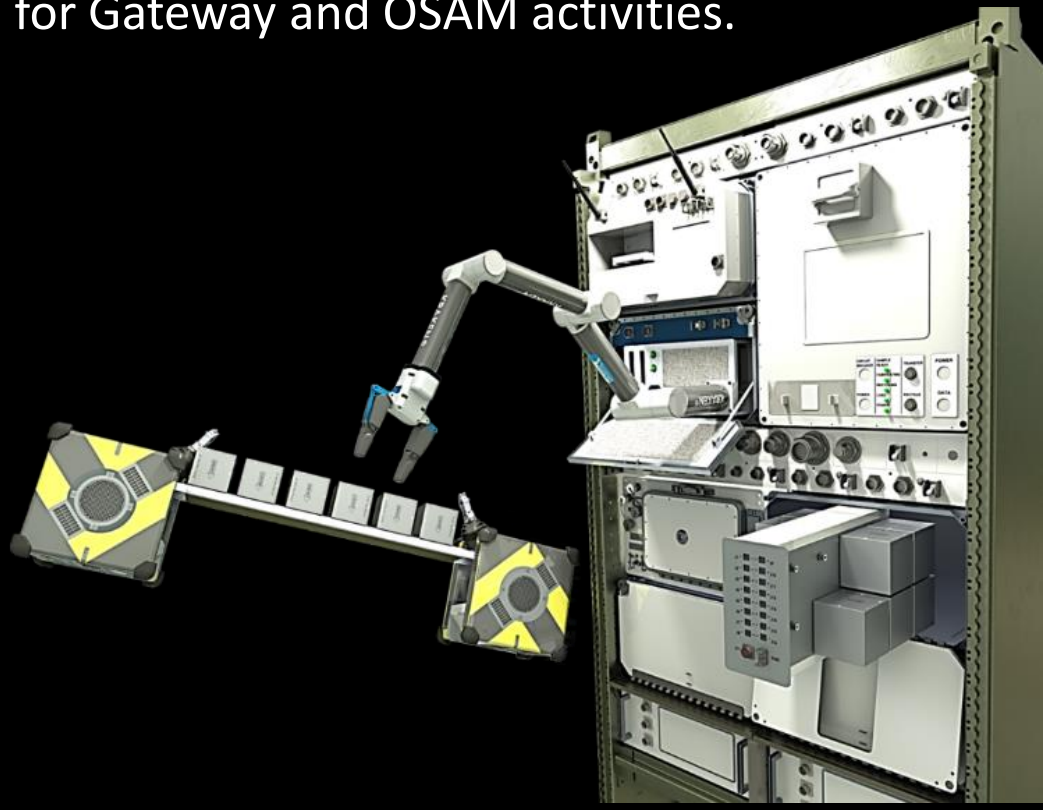
MANTIS

The MANTIS ISS payload utilizes TUI's *KRAKEN* Robotic Arm and hot swappable end-effectors for semi-autonomous telerobotics on the ISS – saving crew time and demonstrating crucial capabilities for Gateway and OSAM activities.



Development Timeline

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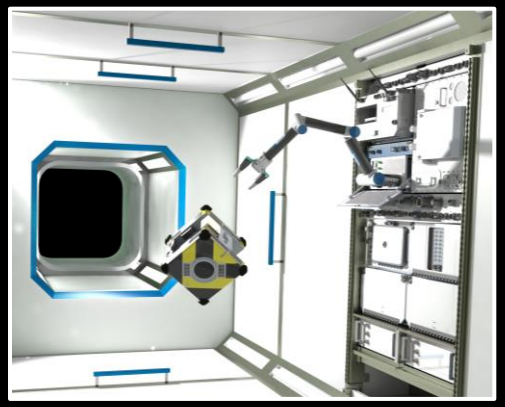
MANTIS Directives



Develop and test crucial capabilities for applications in OSAM, Gateway, the Moon, Mars, and beyond

- Increase scientific productivity of ISS by enabling researchers on the ground to operate ISS experiments
- Increase commercial productivity of the ISS by enabling automated in-space fabrication processes and on-demand sample return
- Inspire the next generation of scientists, engineers and leaders through hands-on STEM outreach and education

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MANTIS – Designed for Astronaut Safety

Where Ground-Breaking Science, Service and Safety Meet

FabLab Demonstration Video:

KRAKEN Robotic Arm
Servicing ISS ExpressRack Payloads

FabLab Demonstration Video:

KRAKEN Robotic Arm
Impedence Control for Crew Safety

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Tethers Unlimited, Inc. (TUI)

~ 25 Years of Innovation in Space ~

SWIFT Radios

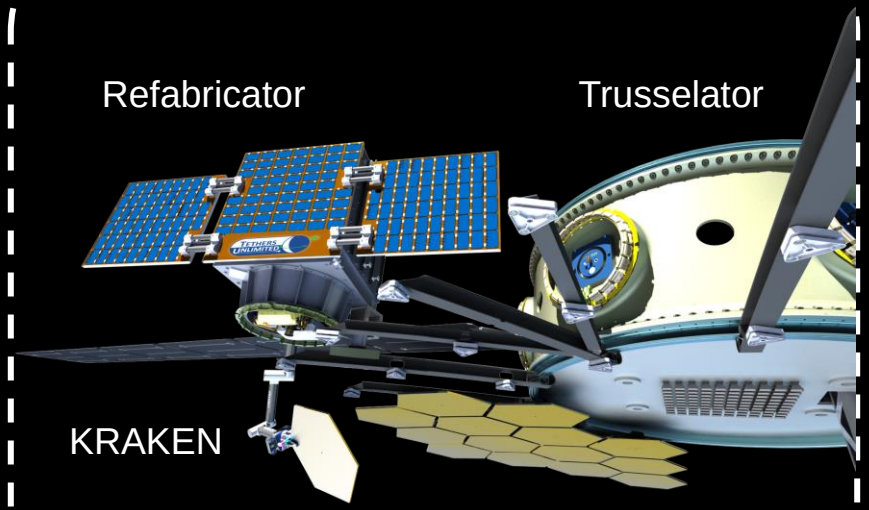
HYDROS Thrusters

COBRA Gimbals

High-Performance SmallSat Components

Refabricator

Trusselator



KRAKEN

Dactylus

Hex-Caster

In-Space Robotic Servicing, Manufacturing & Assembly

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