



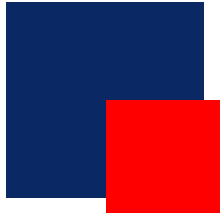
INNOVATION IN SPACE AND DEFENCE

Evolution of On-Orbit Robotics Operations and Technology for Commercial Servicing

Clean Space Industrial Days – 24 October 2018

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Maxar Technologies

- Vertically integrated new space company with products across the value chain for every moment before and after launch.
- Global leader in satellite communications, earth observation, *space robotics*, *on-orbit servicing*, data analytics, ground networks, propulsion systems, cybersecurity and the protection / monitoring of space assets.
- Provider of innovative cost-effective space solutions that generate customer value by integrating leading-edge capabilities.
- ~ \$3 billion revenue / 6,500 employees / international customer base



MDA – Canada's Space Company



Space Radar Solutions

- Satellite-based radar missions and systems
- Radar analytics, services and imagery
- Mission and infrastructure operations



Earth Observation Systems

- Multi-mission Earth observation ground systems
- Mission planning through reception, processing and analytics
- Enterprise geospatial systems



Robotics, Sensors and Automation

- *Robotic manipulators, interfaces and tools*
- *Rovers, sensors and mechanisms*
- *Space exploration, on-orbit servicing and space debris removal*
- *Medical, nuclear and industrial automation*



Satellite Antennas, Electronics and Payloads

- Engineering, manufacturing and testing of satellite antennas, electronics and payloads
- Space-based communications, radar, exploration and science
- High-volume production for large satellite constellations



Defence Systems

- System integration and complex system delivery and operations
- C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance)
- Engineering, production, in-service support partner



MDA™

40+ Years Heritage in On-Orbit Servicing



- 90 Space Shuttle missions with robotic operations
- 18+ years of ISS robotic assembly, operations and maintenance

Space Shuttle and International Space Station experience provides foundation for the design and execution of future remotely operated Servicing Solutions



Canadarm2 robotic free flyer capture and berthing of SpaceX Dragon





On-Orbit Servicing Market Trends

	Today + Tomorrow	Tomorrow
Users	Institutional Programs (e.g. Mobile Satellite Servicing)	Commercial Customers (TBD)
Safety	Robotics meet extremely stringent requirements for human spaceflight	Robotics “do not harm” either chaser or client spacecraft
Flexibility	Multiple missions / multiple applications / multiple robotic tools	
Affordability	Custom robotics solutions funded by national space agencies	Standard robotics solutions that close the business case
Mass / Volume / Power	Fewer constraints	More constraints

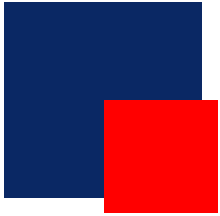




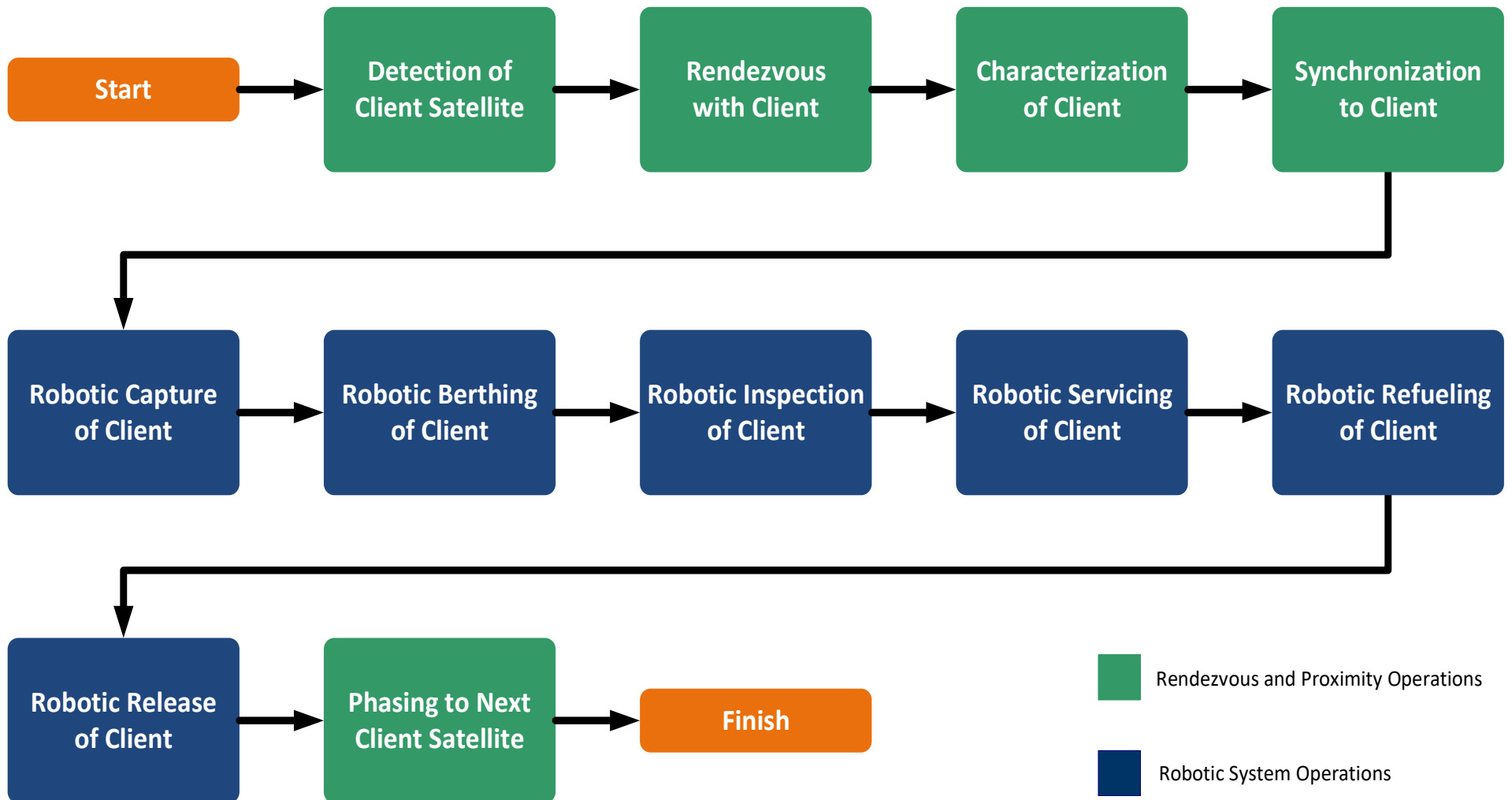
On-Orbit Servicing Market Trends

	Today + Tomorrow	Tomorrow
Clients	Cooperative (TRL 9)	Uncooperative (TRL 4)
Interfaces	Prepared (robotically compatible) (e.g. grapple fixtures, vision targets, etc.) (robot-payload ICD)	Unprepared (no interfaces, no targets, no alignments, reflective surfaces, etc.)
Operations	Tele-Operations	Autonomy (cost, safety, latency, off-nominal conditions, etc.)
Use Cases	Inspection, Anomaly Resolution, ORU Extraction / Insertion (Payload Upgrades) and Capture & Berthing	On-Orbit Assembly and Refueling





Operations Flow for On-Orbit Servicing



Satellite Servicing Mission Sequence

1. Launch

NGSC Testbed Demonstration
e.Deorbit Capture Simulations

2. Orbit Maneuvering

Routine spacecraft operations

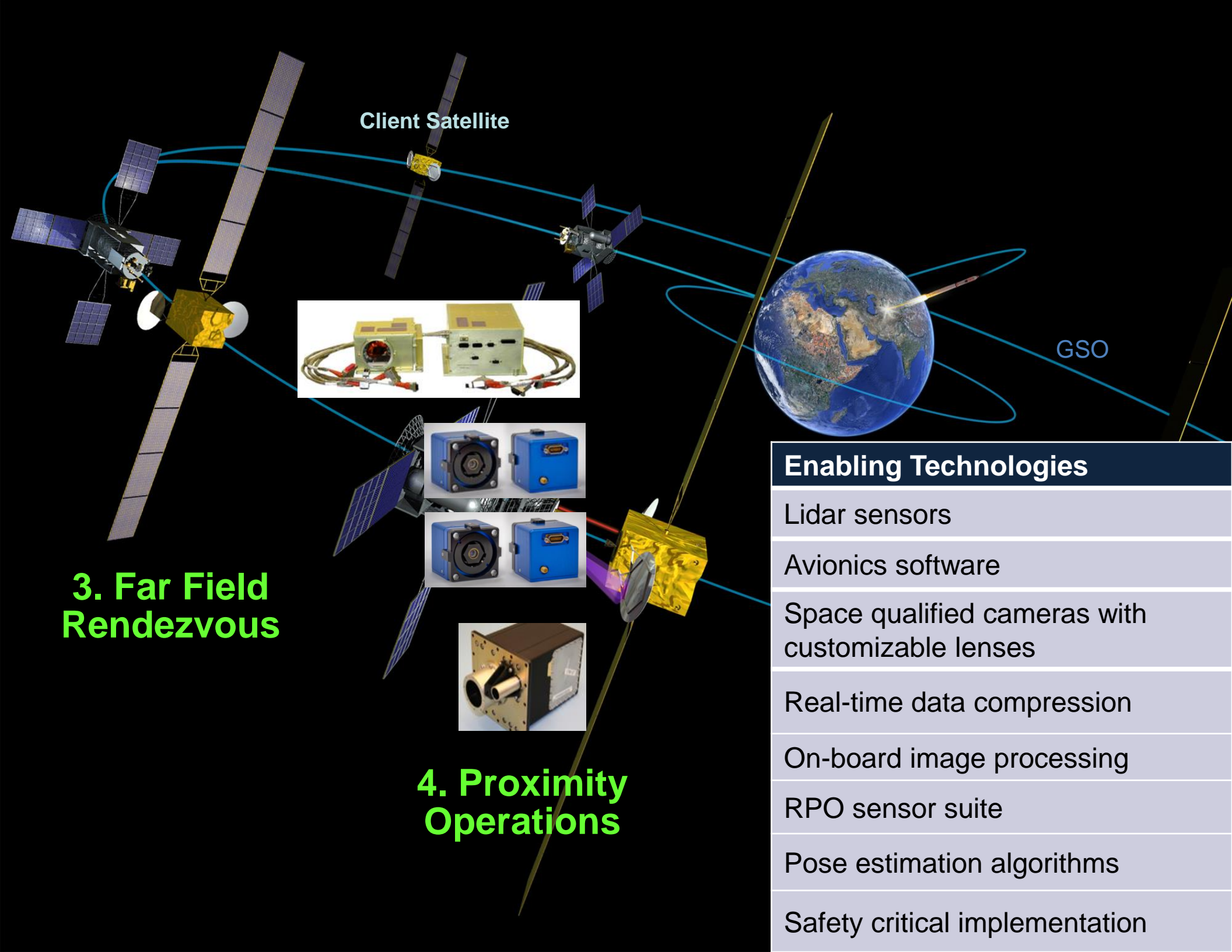
Client Satellite

4. Proximity Operations

DARPA Orbital Express and
visiting vehicle capture operations
on ISS using tele-operated and
autonomous systems

3. Far Field Rendezvous

US Air Force XSS-11
mission used MDA provided
rendezvous sensor and
navigation data



Client Satellite

GSO

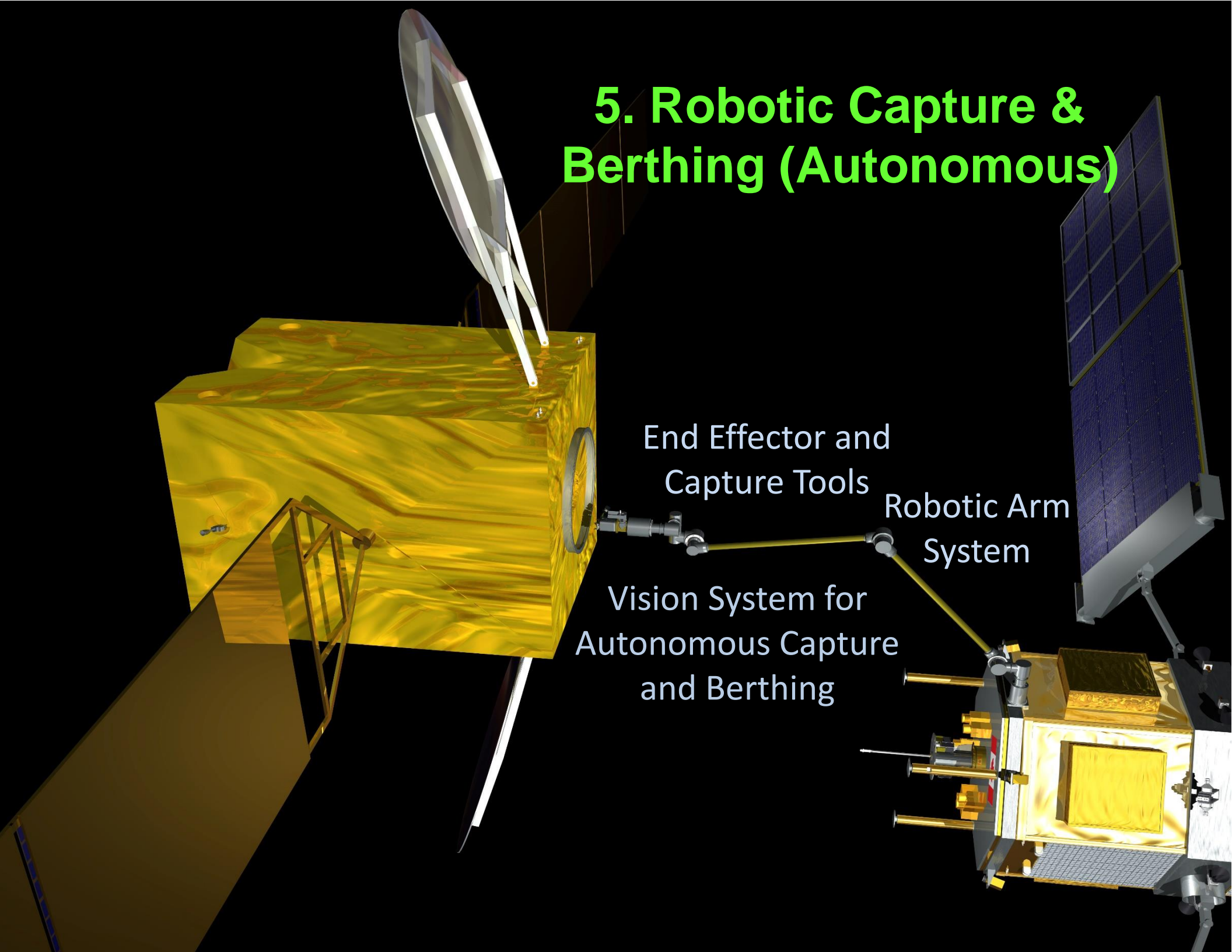
3. Far Field Rendezvous

4. Proximity Operations

Enabling Technologies

- Lidar sensors
- Avionics software
- Space qualified cameras with customizable lenses
- Real-time data compression
- On-board image processing
- RPO sensor suite
- Pose estimation algorithms
- Safety critical implementation

5. Robotic Capture & Berthing (Autonomous)



End Effector and
Capture Tools

Robotic Arm
System

Vision System for
Autonomous Capture
and Berthing

5a. Vision System

- Natural feature detection and tracking
- 6 DOF relative pose estimation
- Real-time feedback (20Hz or higher) to the robotic arm



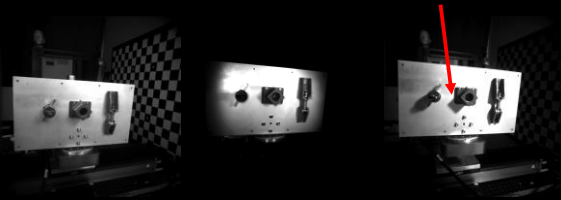
External Berthing Camera System



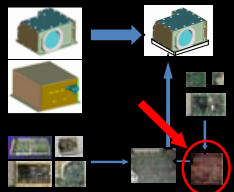
Space Qualified Smart Programmable Camera



Object Recognition and Pose Estimation (ORPE)



Hubble Robotic Servicing ORPE Vision System



Next Generation Lidar Avionics

Enabling Technologies

Cameras with space heritage

Smart sensors

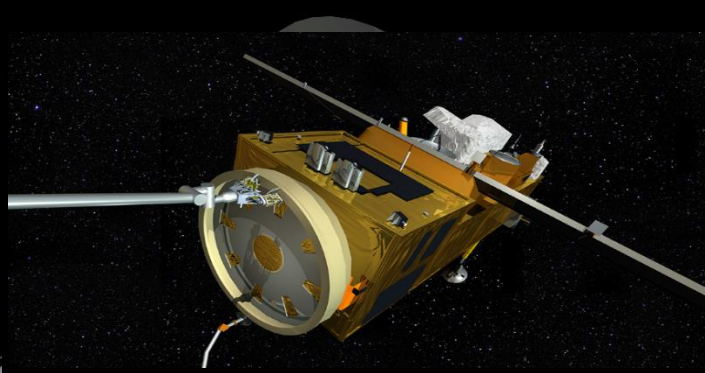
Image processing units (integrated, low power)

Targets and berthing cue systems

Safety critical algorithms



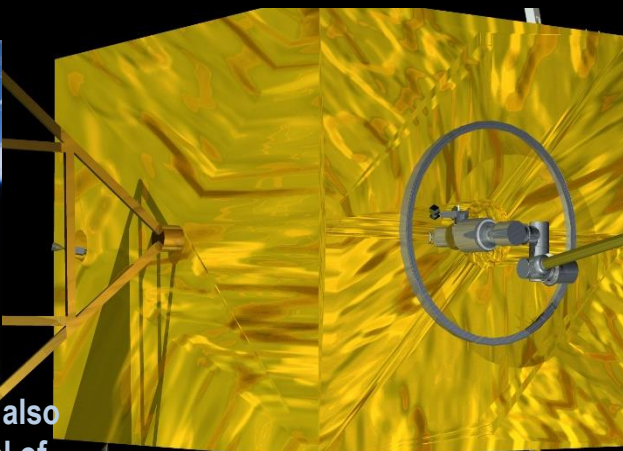
Tele-Operated by an On-Board Astronaut



Full Autonomous Operation, Failure detection and abort modes. Unprepared interface, uncooperative/tumbling client



Tele-Operated by an Astronaut, Now also Ground Controlled. Increasing Level of Automated Response. Captures still Human in the Loop



Full Autonomous Operation, Failure detection and abort modes. Still a Prepared Interface (Grapple Fixture / Target)



5b. Robotic Arm System

- Dexterous manipulator with low friction joints with force feedback
- Full or variable autonomy
- High bandwidth response with precise tracking

Enabling Technologies

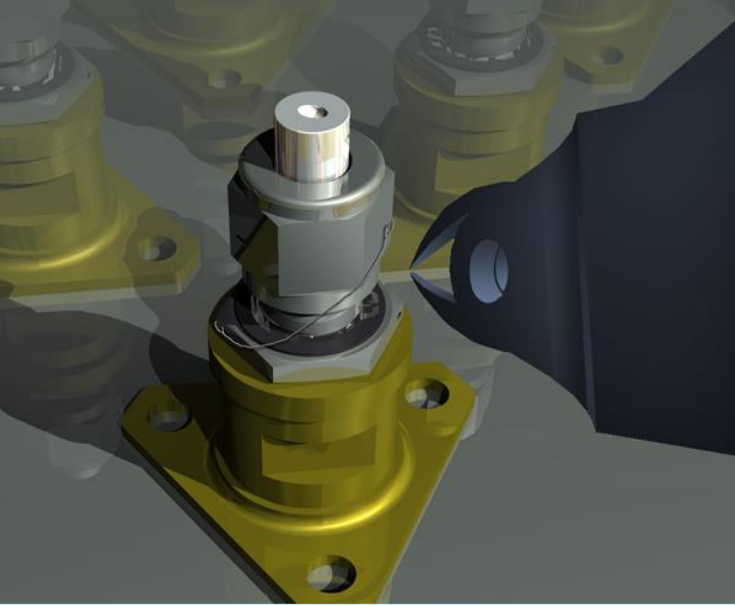
Robotic manipulator

Electromechanical joints with embedded sensors and actuators

Actuator control electronics

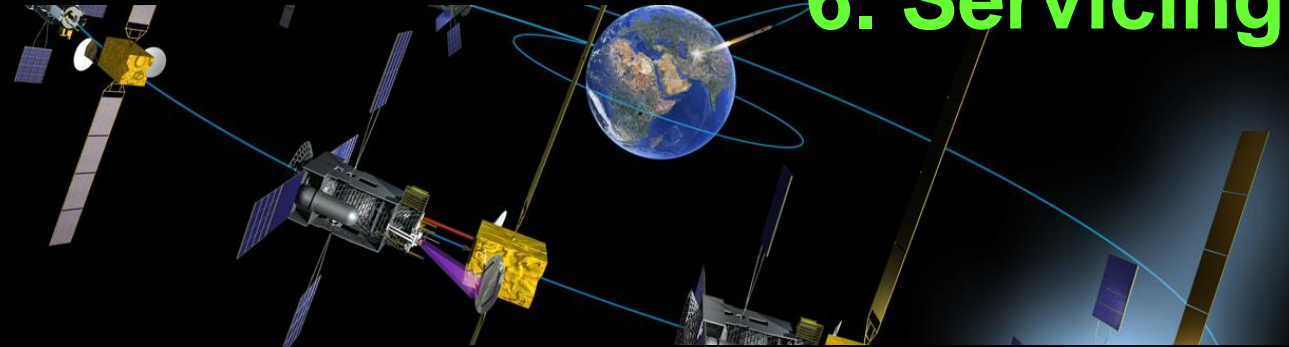
Human Machine Interface (HMI)

Ground Support Equipment (GSE)



6c Lockwire Removal

Demonstrated in robotic test bed



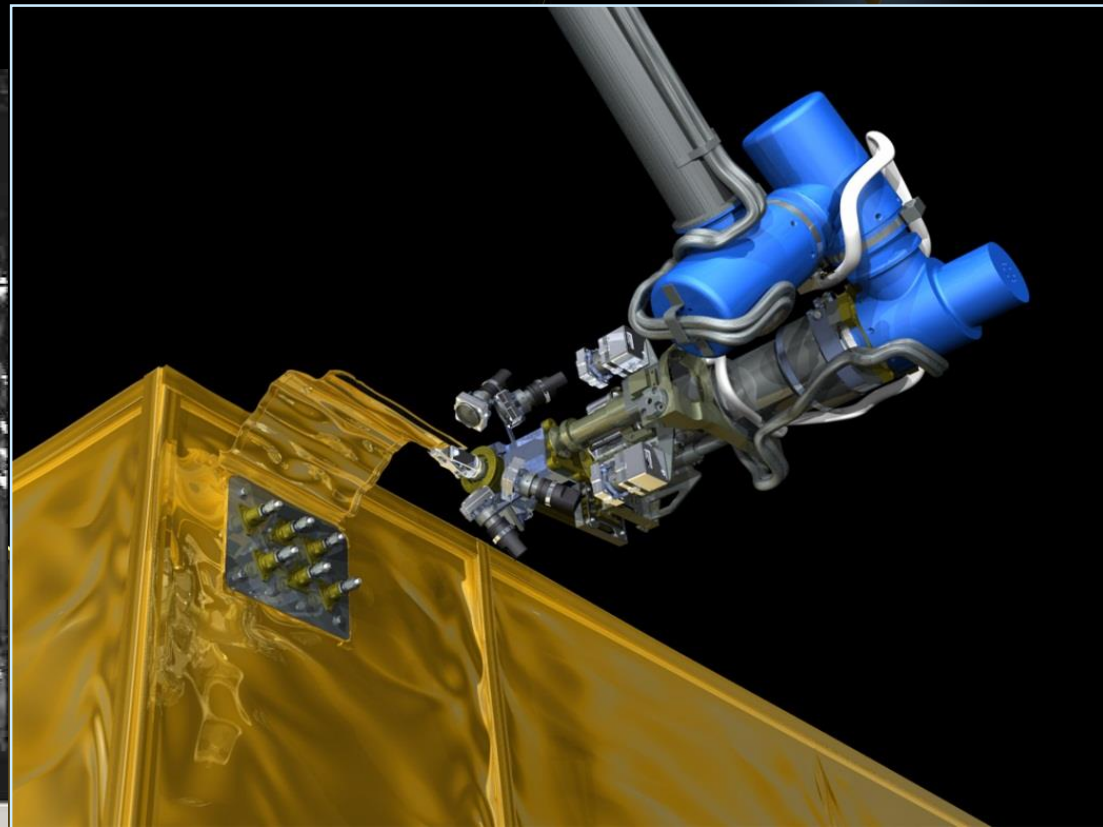
6. Servicing

6b Thermal Blanket Removal

Demonstrated at Hubble Space Telescope lab at Goddard Space Flight Centre

6a Client Inspection / Worksite Preparation

Routine robotic operations on ISS, Space Shuttle and Orbital Express





6e Refueling

Demonstrated on NGSC
Laboratory Prototype



6. Servicing



6d ORU Extraction / Insertion

Demonstrated on ISS
Orbital Express and Hubble Demonstration

Enabling Technologies

End effector with tool changer, torque driver, power / data interfaces & fluid interconnects

Tool caddy

Special purpose tools (e.g. refueling)

Multi-purpose tools for mass optimization

Avionics software (arm and joint control)

Control systems for unprepared interfaces

Real-time vision system to enable autonomy

Force / moment control sensors



On-Orbit Servicing Heritage

- MDA is the global space robotics leader with 40+ years heritage. It not only provides technology and solutions but also operates and maintains robotic systems in space (e.g. MDA operates the SPDM on the MSS every day).
- In addition to designing, building, operating and maintaining the robotics systems on the International Space Station, MDA has worked with ESA and all of the European LSIs on the e.Deorbit program for the past six years.
- MDA's extensive technical and operational heritage developed on institutional programs is a solid foundation for unlocking the potential of the commercial on-orbit servicing market.

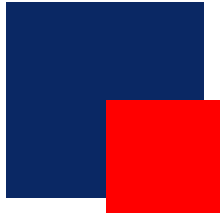




Summary

- The on-orbit servicing market is expanding from institutional programs to commercial customers.
- Many of the critical technology building blocks for the nascent commercial on-orbit servicing market exist.
- MDA would be pleased to discuss your requirements for space robotics solutions to address opportunities in the on-orbit servicing (and debris removal) market.
- Thank you for listening.





Questions?



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