Astroscale's ELSA-d Mission and ESA Support Mechanisms

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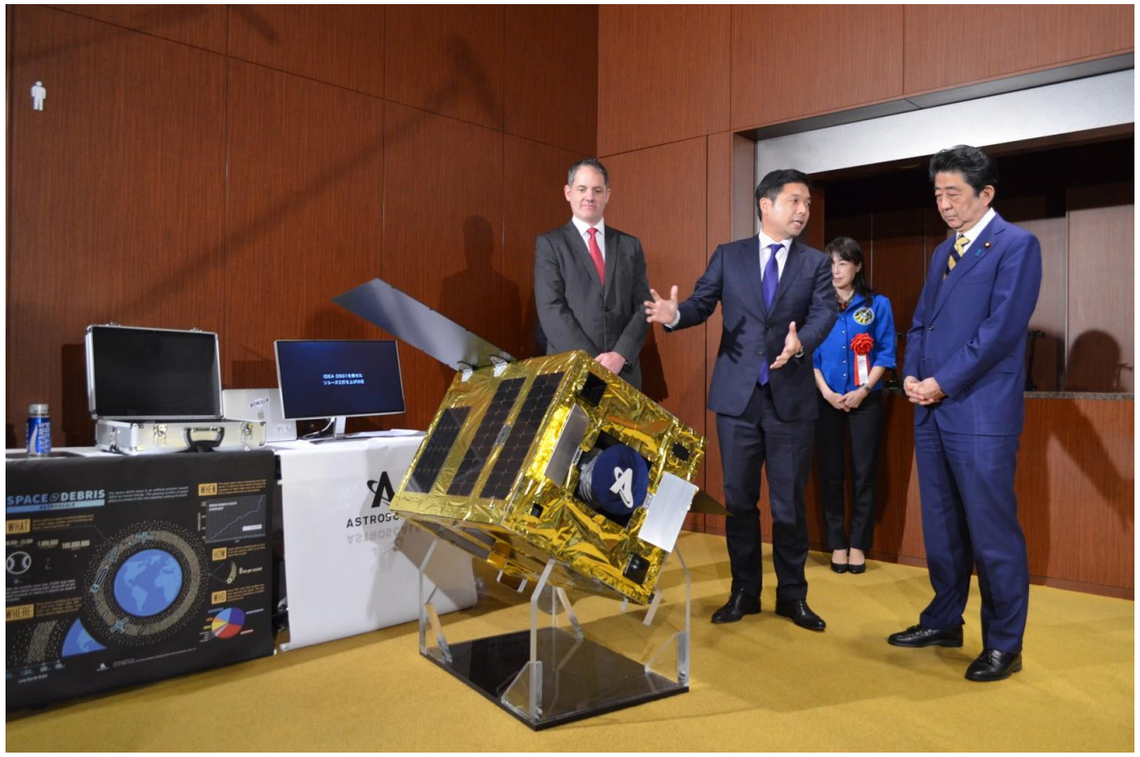
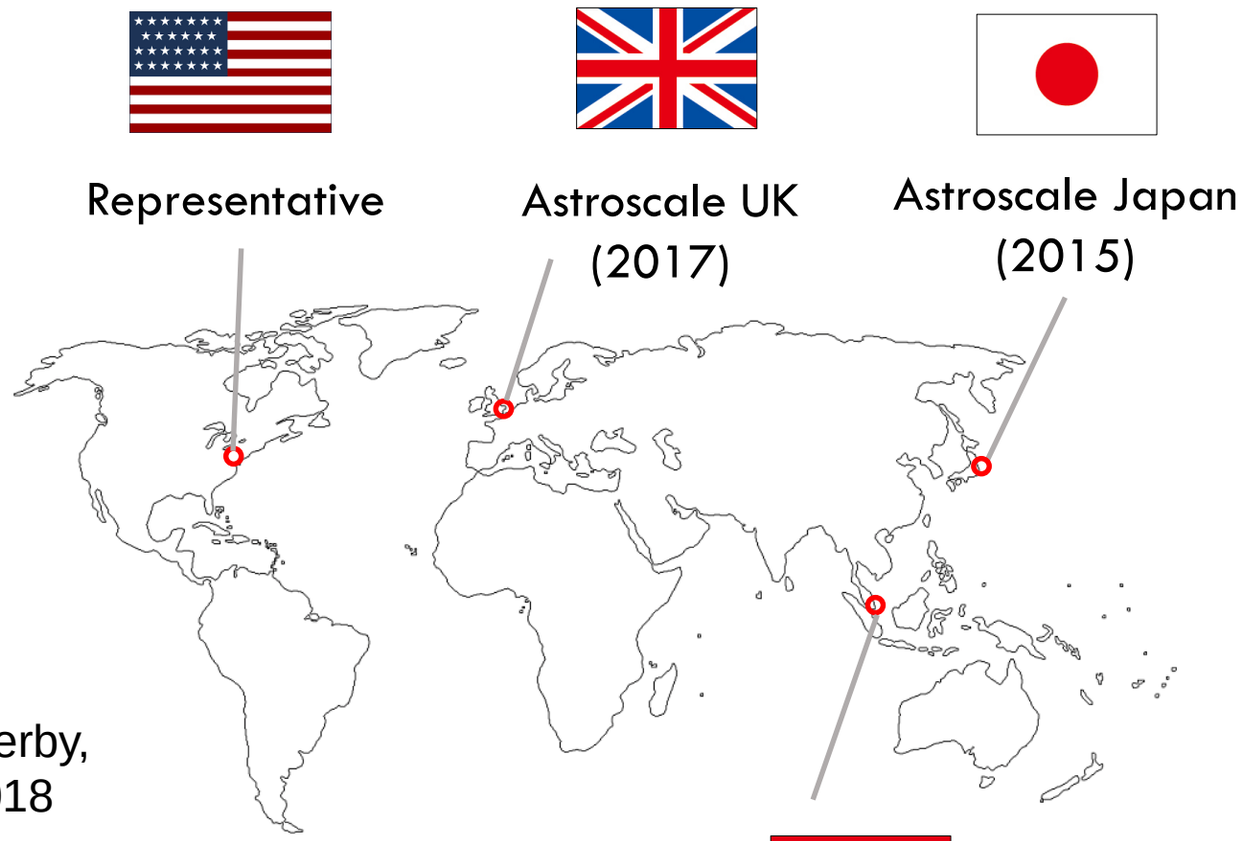
Astroscale: An International Company Solving a Global Problem



Founder and CEO, Nobu Okada, and COO, Chris Blackerby, meeting Japanese Prime Minister Shinzo Abe, March 2018



Astroscale Singapore (HQ)
(2013)

Founded:	May 4, 2013
Team:	~55
Capital:	$53M during three funding rounds, supported by angel investors, VCs, public-private fund, and private companies.
Mission:	Secure long-term spaceflight safety for future generations
Services:	End of Life (includes large constellations) Active debris removal

Key Business Markets – I

Services	End of Life (EOL) “Don’t add any more debris”	Active Debris Removal (ADR) “Remove debris that is already there”
Potential Customers	Constellations, Private Satellite Operators	Governments, International framework
Target Objects	- Satellites that have failed in orbit or reached end of operational lifetime - 50~500kg	- Environmentally critical objects - 500kg+ - Existing debris
Rationale	- Business continuity and maximize revenue - Adhere to best practices and public demands	- Demonstrate commitment to orbital sustainability - Assure spaceflight safety for all operators
	Global Responsibility	
Model	Semi-cooperative approach and capture	Non-cooperative approach and capture
Astroscale provides	Chaser Mission licensing Customized insurance Ground segment & operations Universal DP Retro-reflector	Chaser Mission licensing Customized insurance Ground segment & operations

Key Business Markets – II

By 2021 there will be an estimated $2.7B(*) market for debris monitoring and removal

EOL

Problem	**Active satellites in orbit (2018): ~1,200 (25% commercial)** **Active satellites in orbit (2028 est): ~10,000 (90% commercial)** **Approximately 5-10% could fail: ~500-1,000 new pieces of debris in 2020s**
Solution	**Attach deorbit mechanism to satellites before launch for future retrieval** **Remove 50-100 satellites per year**
Customer	**Satellite operators; Public Private Partnerships**

ADR

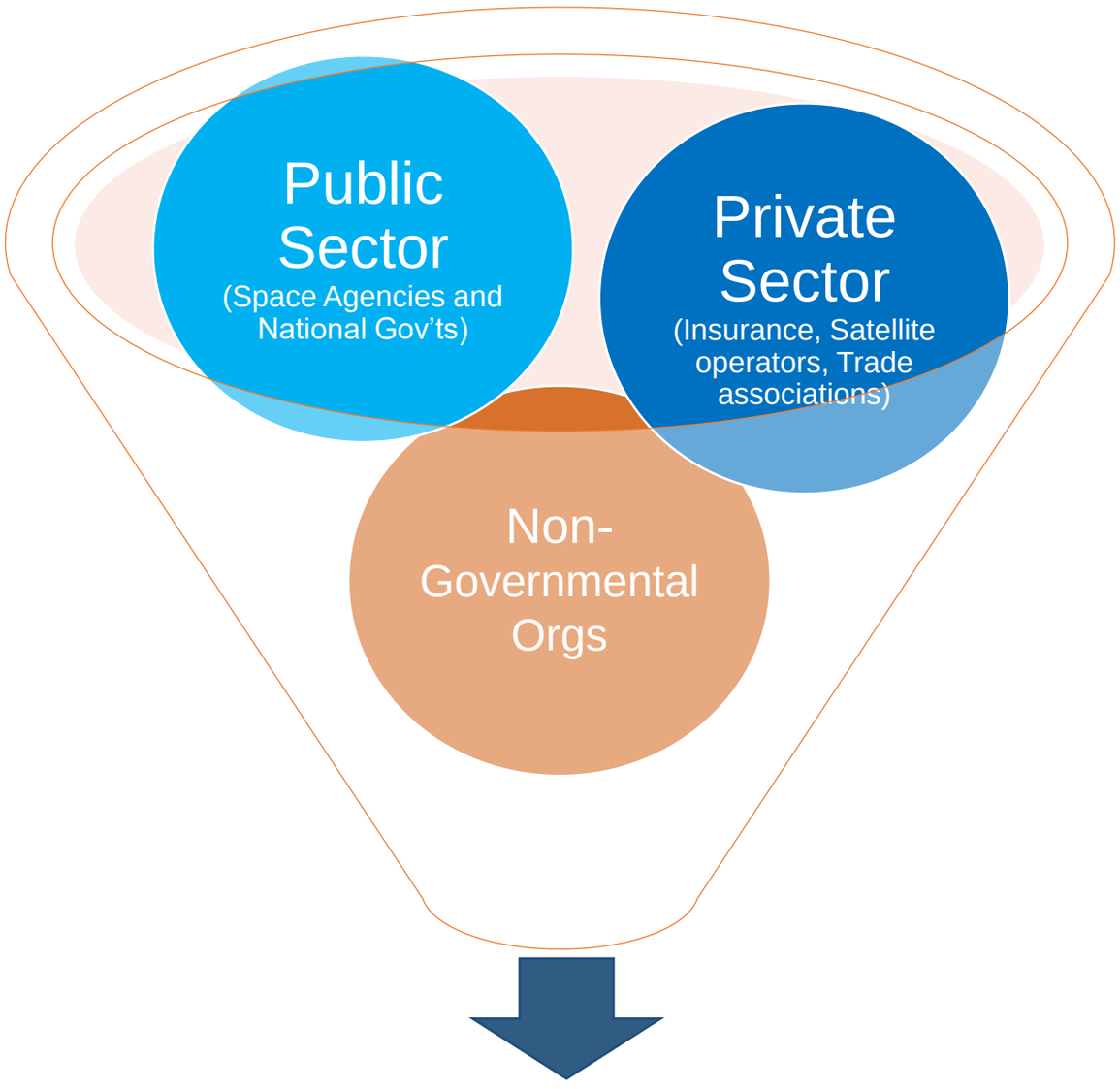
Problem	**Over 200 critical objects (3-9 tons) in orbit that could destroy operating satellites**
Solution	**Remove multiple pieces of debris annually beginning in early 2020s; 2025-2045: Removal of ~120 environmentally critical objects significantly reduces collision risk**
Customer	**National governments; Innovative prizes**

*: Technavio.com: "GLOBAL SPACE DEBRIS MONITORING AND REMOVAL MARKET 2017-2021"

Business Activities – Regulation, Insurance, Licensing

Active discussions with multiple parties to develop doctrine, standards and regulation, critical to the economic exploration of space.

- **Private sector** – Pressure will increase on satellite operators to prepare satellites for retrieval prior to launch.
  - ➢ Astroscale is in preliminary discussions with UK insurance providers.
- **Governments** – Growing trend to pay for removal of critical objects
  - ➢ Astroscale is in early discussions with the UKSA to ensure a licensable chaser design.
- **Public** – Increasing public awareness adds to pressure on operators and governments to take action.



ELSA-d – An Overview

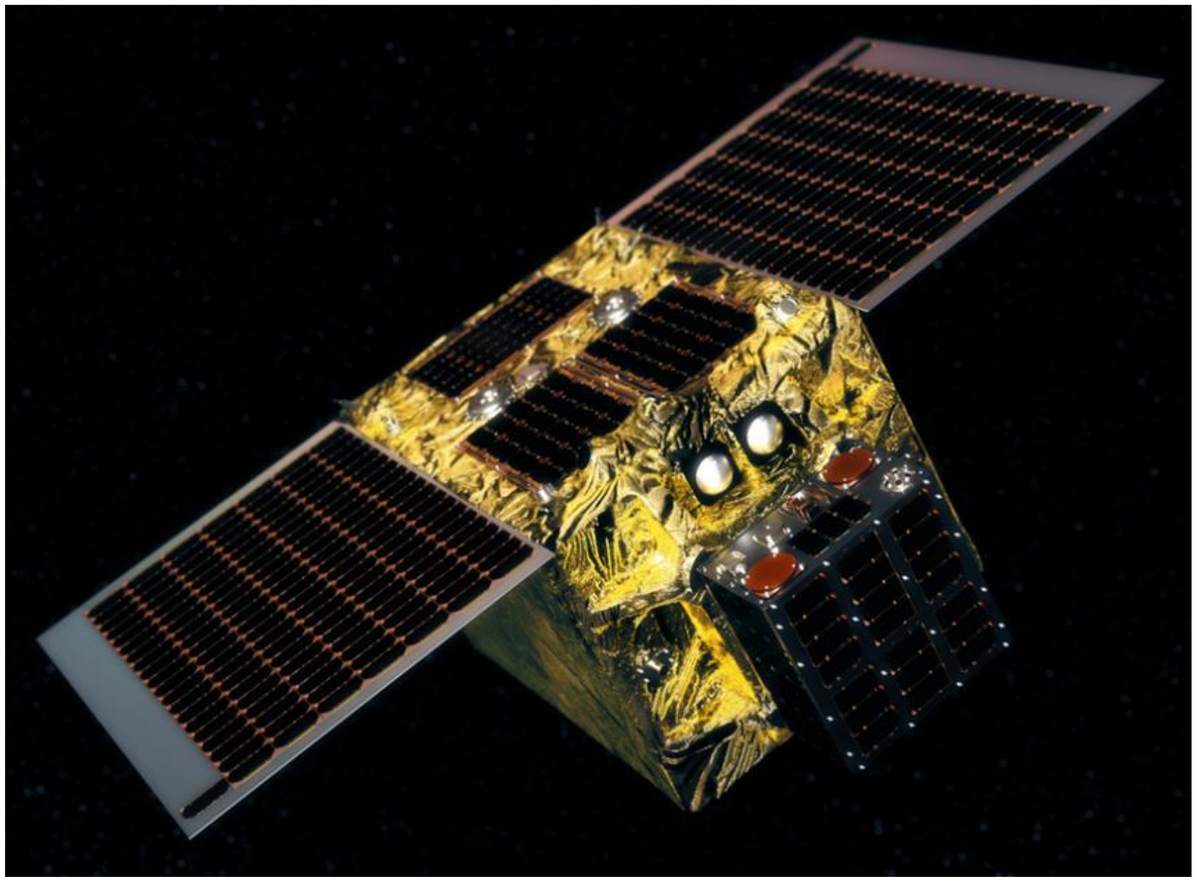
Key Mission Details

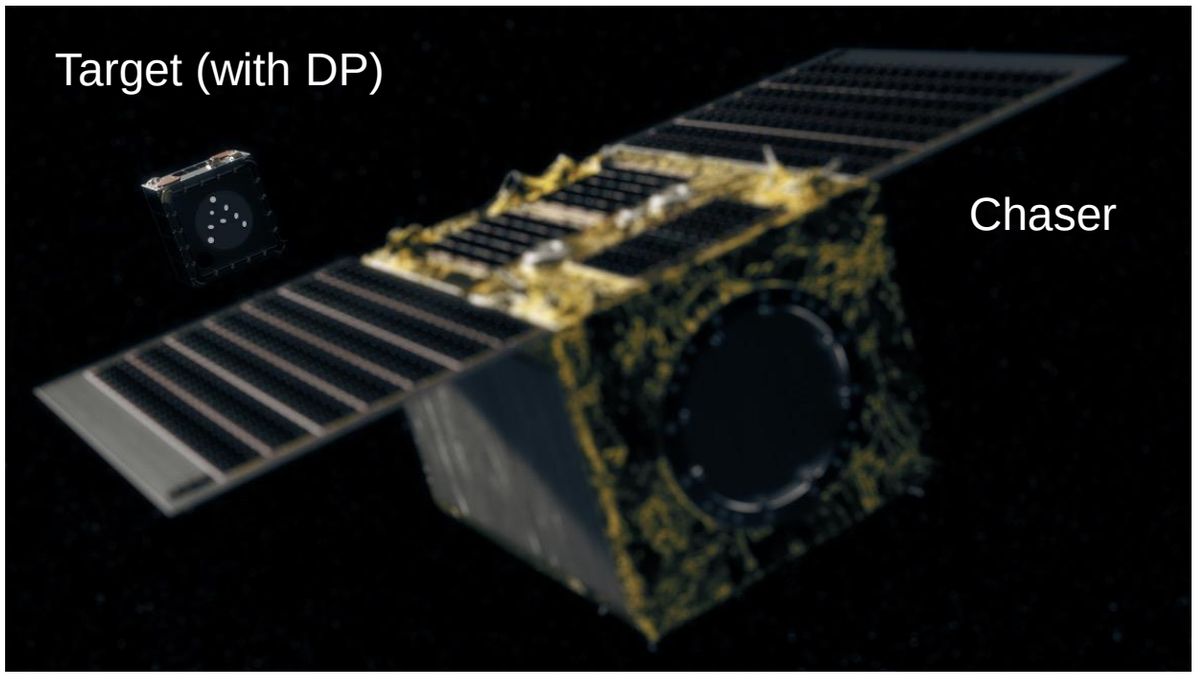
- Chaser: 160 kg
- Target: 20 kg with docking plate (DP)

- Presently in final design stages with AIT to commence Q1 2019.
  - Range of hardware and software prototypes available with testing underway.

- Launch targeting Q1 2020
  - Signed with Glavkosmos/GK Launch Services, Soyuz 2
  - SSO (500-600 km), LTAN 10.30-11.00.

- Full phases of operations that would be necessary for a full EOL service, including target search, inspection, capture, re-orbit and de-orbit.





ELSA-d – Mission Video and CONOPS

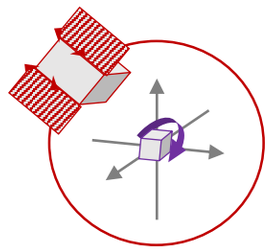
ELSA-d – Key Technologies – I

End-to-end rendezvous solution including far and short-range approach

- Two GNC processors (GNC command, data handling)
- Usual complement of attitude sensing e.g. star trackers, attitude control e.g. RWs and position sensing e.g. GPS
- Specialist rendezvous: ranging system, night navigation cameras (wide and short angle), day cameras, range finders, illumination device

Advanced operational capabilities

- Search for targets and approach with absolute to relative navigation hand-over.
- Fly-around inspections of target with operator assessment.

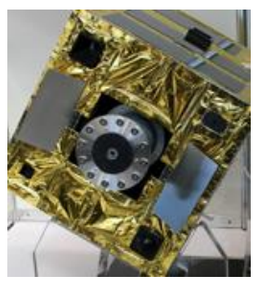


Docking plate to enable semi-cooperative removal

- Designed with constellation customers in mind.

At-night magnetic capture of non-tumbling and tumbling targets

- Capture system is designed to extend and retract and allow multiple captures and releases.



ELSA-d – Key Technologies – II

Flight software targeting roughly ECSS Level-3 autonomy

- Event-based autonomous operations
- Execution of on-board operations control procedures

Re-orbit, de-orbit and passivation capabilities

- Green propulsion system with high ISP and compatibility to small launch vehicles

Mission designed with safety evacuations and passively safe trajectories in mind

- Collision avoidance (passive and active abort)
- Movement to evacuation point
- Protected safety ellipse
- Manual experiment abort
- Protected critical functions (including de-orbit)
- Safety critical computing: FDIR and safety tasks
- Architectural redundancy
- High-fidelity ground-based simulation

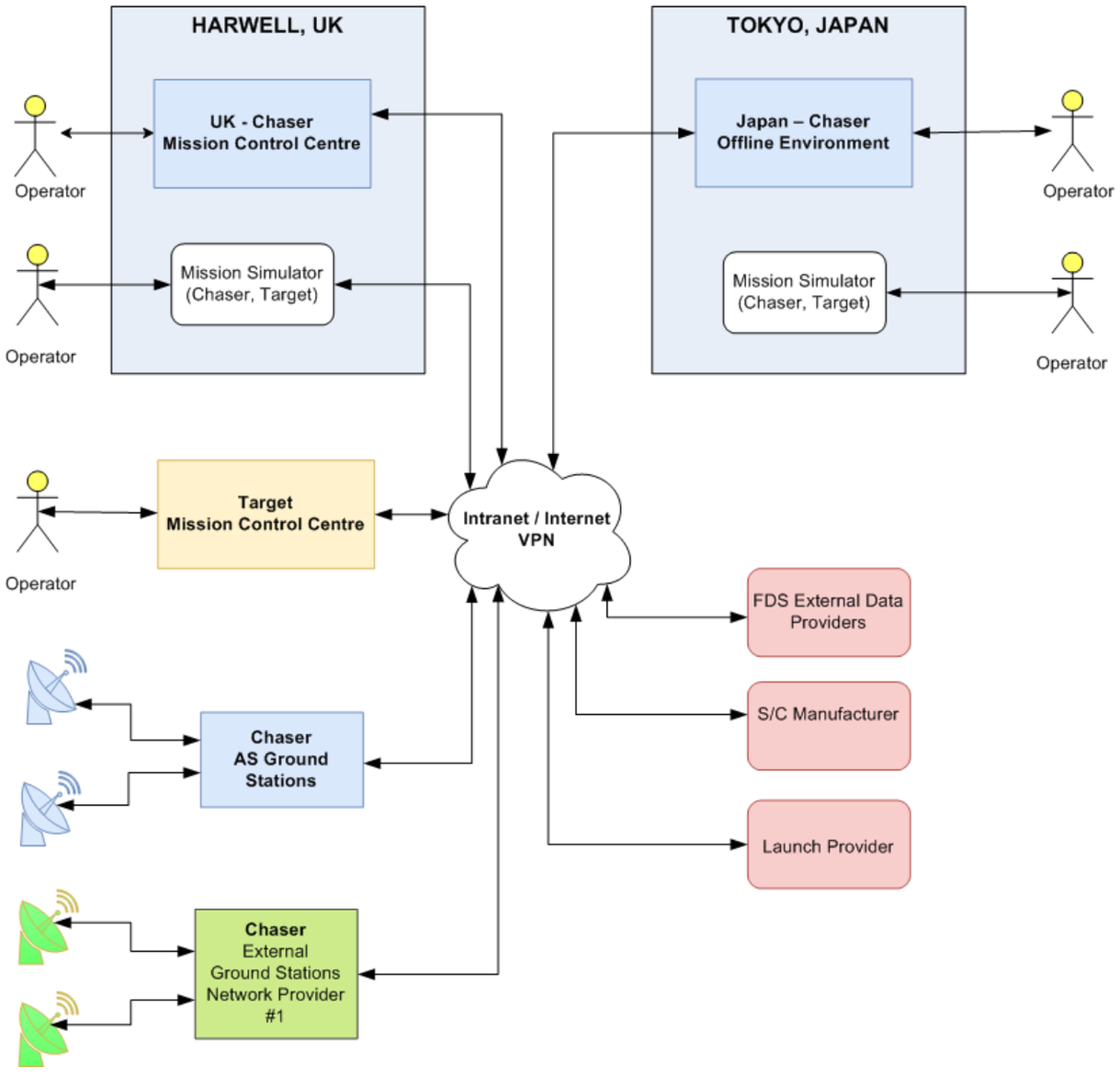
Ground segment designed specifically for in-orbit servicing (separate slide)

ELSA-d – Ground Segment

- Astroscale awarded a £4M grant from the UK Government to help establish a **National In-Orbit Servicing Satellite Control Centre** at the Satellite Applications Catapult in Harwell, Oxford.
- Development partially contracted to: Catapult, RHEA, GMV, SCISYS.

- Ground segment is one of the most important considerations in future EOL/ADR missions.
  - Aligning ground stations to link pass segments allows longer periods of continuous operation.
  - Allows for operator oversight into mission with manual safety aborts.
  - Core capabilities based on licensed ESOC tools (used on all ESA missions).

- Capabilities:
  - Mission Control System (MCS)
  - Flight Dynamics System (FDS)
  - Image Processing System (IPS)
  - Mission Planning System (MPS)
  - Automation System (MOIS)
  - Ground Station Control System
  - High Fidelity Simulator



ESA Support Mechanisms

- Astroscale has a **strategic agreement with ESA**. Both parties have confirmed their mutual strategic interest in pursuing collaboration on the ELSA-d mission by exchanging data and expertise related to mission operations, the environmental monitoring of debris and active debris removal.

Support Mechanism ESA could provide…	**ELSA-d**	**Future Missions**
Engineering consultancy for image processing-based attitude determination algorithms. Drawn from the expertise gained with the Rosetta mission. Cross-validation of some of the blocks of the attitude determination chain with in-house tools.	✓	✓
Support and advice on its flight-proven ground control software product, primarily through the review of mission documentation and advice on system validation & testing.	✓	✓
Review of design related to rendezvous, GNC and operations.	✓	✓
Tracking services to monitor the chaser and target during operations. Laser-based tracking, interface with JSpOC. Access to attitude estimation from ground capabilities.	✓	✓
Ongoing mission analysis functions including performing re-entry casualty risk assessment and examination of debris for CAMs.	✓	✓
A shared role in support during **operations**. Based on preliminary discussions with ESA, ESA is driving towards a stronger collaboration on operations in ELSA-d and future missions.	TBD	✓
ESA could support with supporting developing using their ESA **CDF**.	-	✓
Use of facilities. Includes test facilities at ESTEC and ground control facilities from ESOC.	-	✓
An **ESA cachet** or future missions that would demonstrate to other funding entities as a mark of quality that the concept had been assessed by ESA.	-	✓

Conclusions – Next Steps – I

From an EOL perspective:

- Astroscale is engaging large constellation providers to perform an IOD mission.
  - An IOD mission will solidify a partnership and enable technology to be matured.
  - Main driver is minimising cost to Astroscale and cost to the customer.

From an ADR perspective:

- ESA is in the preliminary stages of considering whether there could be services for the removal of ESA-owned assets.
- Astroscale is working with the Japanese Government and Space Agency (JAXA).
  - Astroscale has already completed initial mission design studies with JAXA.
  - Two missions are currently being considered by JAXA in the 2019 to 2025 timeframe to remove JAXA-owned assets.

Conclusions – Next Steps – II

Growth of Company

- Astroscale Japan is expanded into two buildings in Tokyo and has ~45 employees.
- Astroscale UK has 12 employees, growing to 15 by end of year and 25 by end of 2019.

Ground Segment Facility, Harwell

July 2018, Opening of new Totsuka Ground Station, Yokohama

Astroscale

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