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JAXA における宇宙デブリ研究の概要

Overview of JAXA's research on Space Debris

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JAXA は、国際社会との連携を取りながら、デブリの脅威を無くすための研究開発に総合的に取り組んでいる。JAXA のデブリ研究内容は、以下の３項目に大別される。
１）　デブリの観測技術の向上による宇宙機運用の安全性確保
２）　デブリによる宇宙機への衝突影響を最小化するための防護技術の開発とシステムのロバスト化設計
３）　デブリ除去技術の研究開発と実現に向けた軌道上実証の検討
　本講演では、JAXA におけるこれら研究開発の目的と現状について概観する。

JAXA is working in a comprehensive manner to eliminate the threats of space debris through the R&D and the cooperation with the international community.
Studies on Space Debris in JAXA consist in three major R&D subjects as follows.
1) Observation technology to contribute to the safety of the spacecraft operations
2) Protection and robust design techniques to minimize the impact on spacecraft by space debris
3) Active space debris removal and in-orbit demonstration
Objectives and status of these studies are overviewed in this presentation.

Biography

Ryoichi IMAI
Vice　President
Director General, Research and Development Directorate

Mr.Ryouichi Imai was appointed to Vice President of JAXA in 2015. He is in charge of Research and Development Directorate and is also Center Director of Tsukuba Space Center of JAXA.
He received Bs.degree in Physics and Ms.degree in Electrical Engineering from Kyoto University and joined National Space Development Agency of Japan (NASDA) in 1981.

He has been mostly involved in the research and development of Engineering Test Satellites through his carrier in NASDA and JAXA. He was also served to the development of the government satellites as a project manager.

In conjunction with his carrier in NASDA and JAXA, he was a visiting scholar in University of California in 1989 to make research in space robotics and was a senior researcher in National Communications Research Laboratory to make research in high speed satellite communications system in 1996-1998.


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research on Space Debris
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Ryoichi IMAI, JAXA
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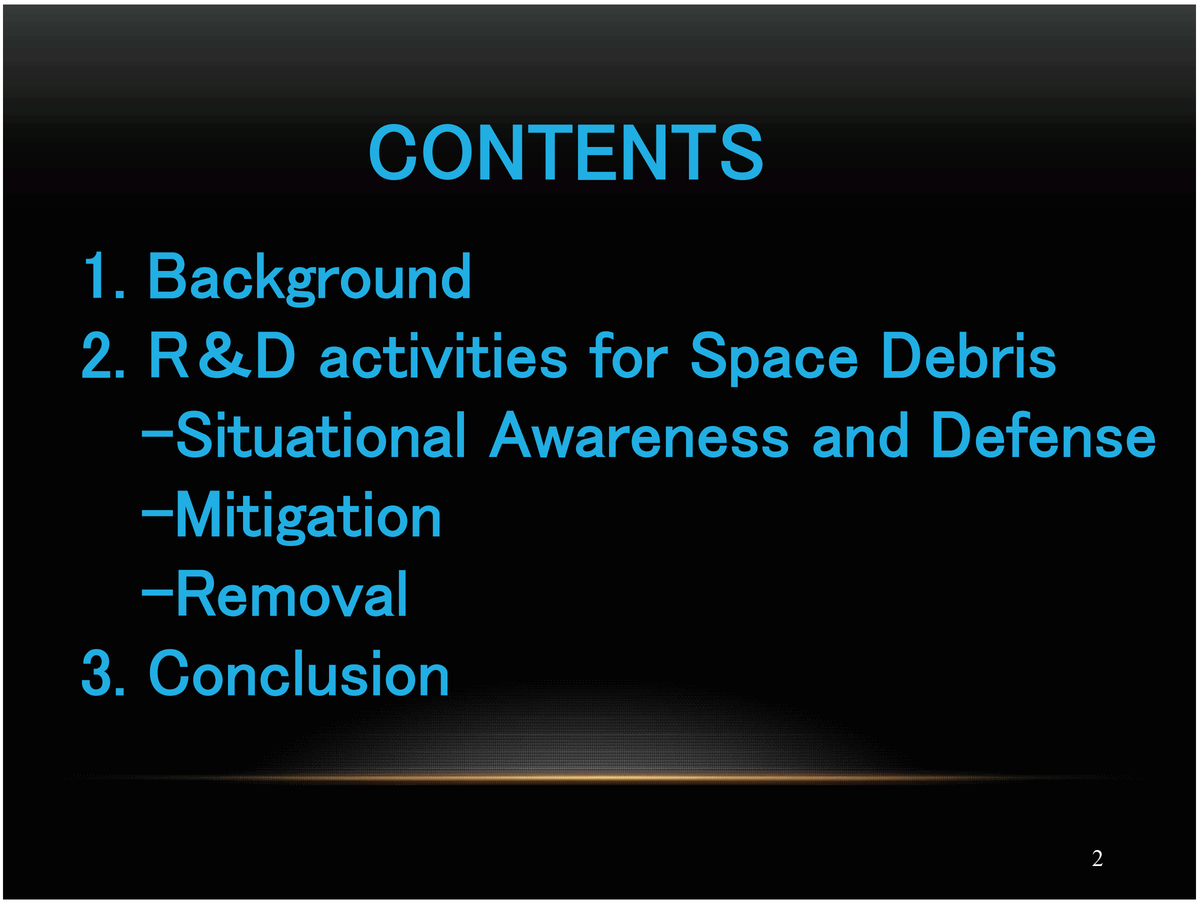
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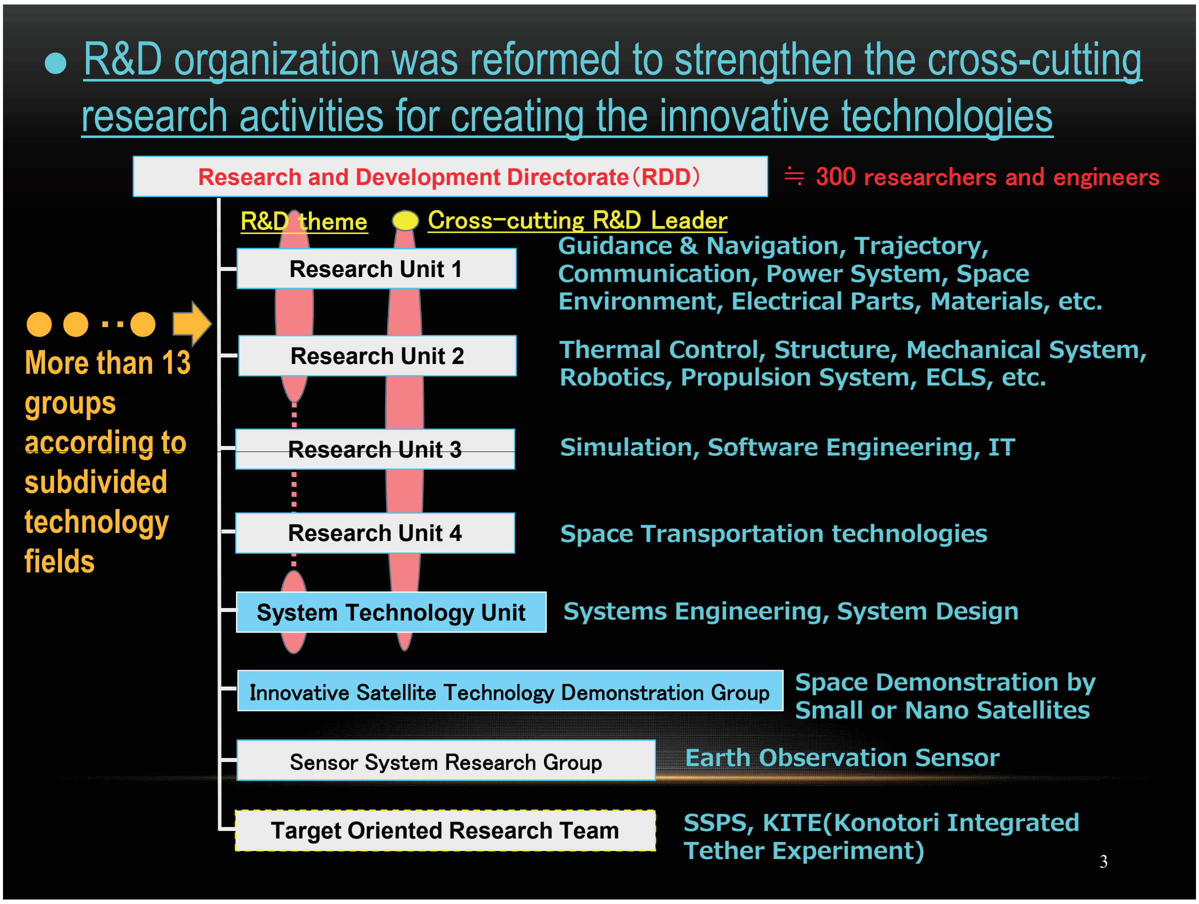

1. Background

● Basic Plan on Space Policy ：

- Promoting the international activities to draw up the ICOC(International Code of Conduct for Outer Space Activities)
- Improving the capability of SSA
- Addressing the R&D on debris removing technologies

● JAXA's contribution and R&D activities ：

- Proposing the technical guidelines for debris mitigation through the activities on IADC(Inter-Agency Space Debris Coordination Committee).
- Taking advantages of Japan's strengths and promoting the research and development on the space debris mitigation technologies such as observation, protection and safety removal.

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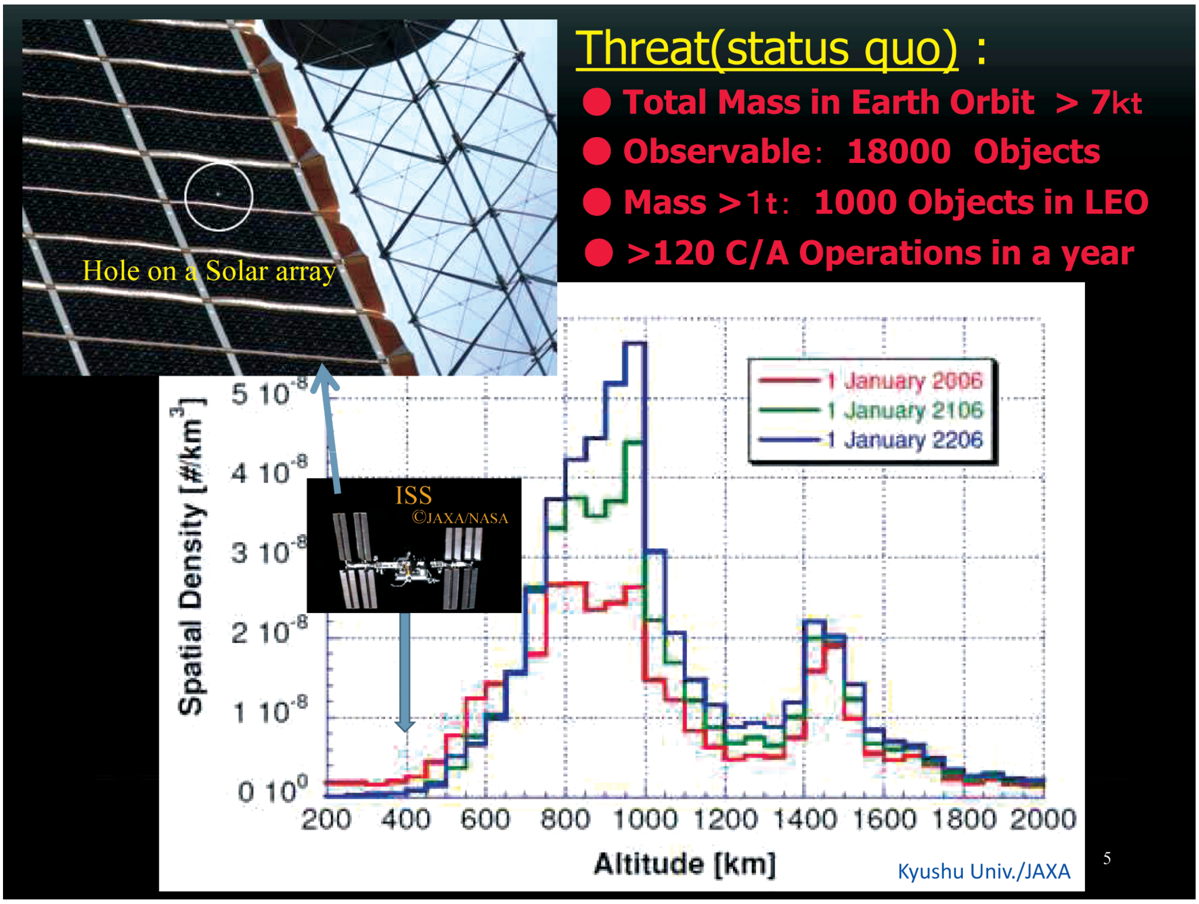
Threat(status quo) :
Total Mass in Earth Orbit > 7kt
Observable: 18000 Objects
Mass >1t: 1000 Objects in LEO
>120 C/A Operations in a year
Hole on a Solar array
ISS
©JAXA/NASA
Spatial Density [#/km³]
5 10⁻⁸
4 10⁻⁸
3 10⁻⁸
2 10⁻⁸
1 10⁻⁸
0 10⁰
1 January 2006
1 January 2106
1 January 2206
200 400 600 800 1000 1200 1400 1600 1800 2000
Altitude [km]
Kyushu Univ./JAXA
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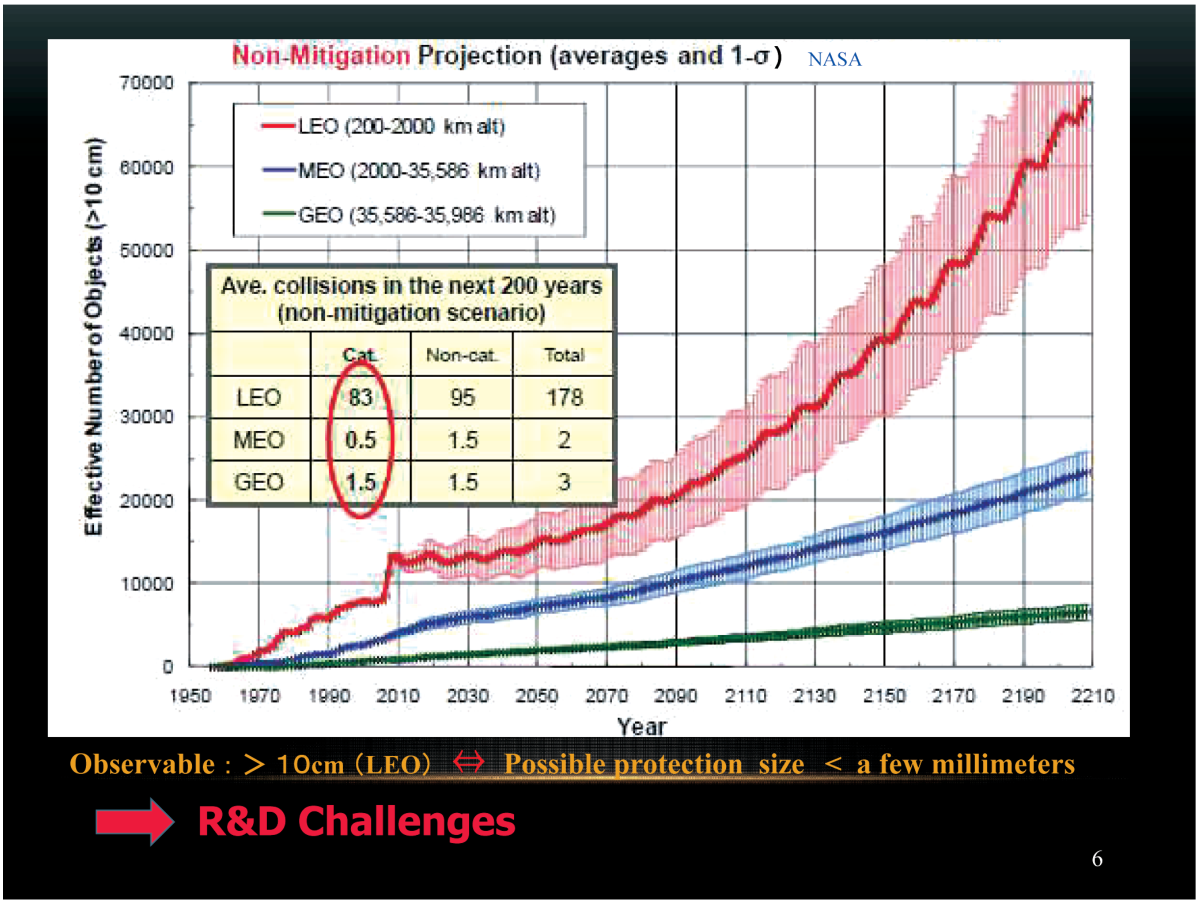
Non-Mitigation Projection (averages and 1-σ)
NASA
LEO (200-2000 km alt)
MEO (2000-35,586 km alt)
GEO (35,586-35,986 km alt)
Ave. collisions in the next 200 years
(non-mitigation scenario)
Cat. / Non-cat. / Total
LEO 83 95 178
MEO 0.5 1.5 2
GEO 1.5 1.5 3
Effective Number of Objects (>10 cm)
70000 60000 50000 40000 30000 20000 10000 0
1950 1970 1990 2010 2030 2050 2070 2090 2110 2130 2150 2170 2190 2210
Year
Observable : > 10cm (LEO) ⇔ Possible protection size < a few millimeters
R&D Challenges
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2. R&D activities for Space Debris :

- **Situational Awareness and Defense**
  - ⇒ Ground Observation and In-Orbit Observation
  - ⇒ Maneuver Planning
  - ⇒ Modeling
  - ⇒ Protection
- **Mitigation**
  - ⇒ Safe re-entry(Post mission disposal and ground safety)
- **Removal**
  - ⇒ Cost-effective removal scenario
  - ⇒ Technologies
  - ⇒ EDT Experiment using HTV-6 (2016)

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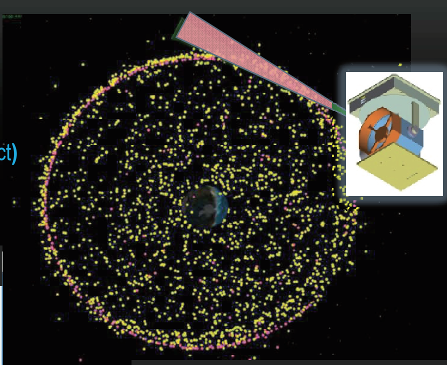
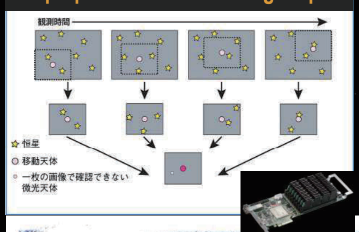
Observation
From Ground

- Optical (Discovery of un-cataloged object)
- Radar



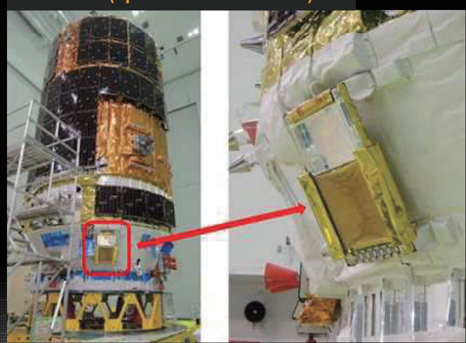
Superposition of a faint bright spot

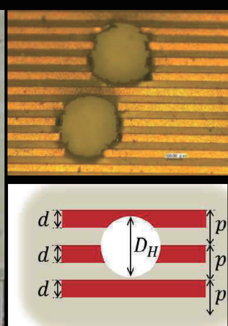


Observation
In Orbit

- Onboard Camera (GEO, >1cm)
- Impact sensor (LEO, >0.1mm)

HTV-5 (space debris monitor)





⇒Goal: Seamless Mapping

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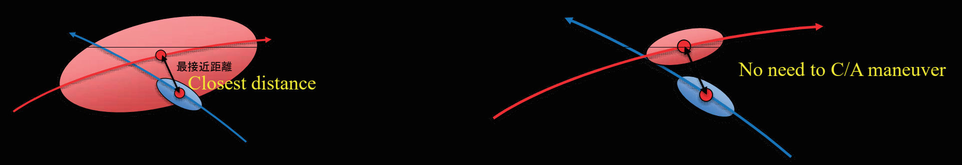
● Maneuver Planning

Because of the low determination accuracy of debris orbit, there is a high uncertainty to estimate the collision risk.

Increasing number of space debris makes higher the operation load of collision avoidance.

- Current Criteria : Radial distance of 200m and total miss distance of 1000m



⇒ Improving the orbit determination and prediction of space debris

・Embark the development of new observatory (Radar & Optical)

・Modeling the determination error with the operation history data

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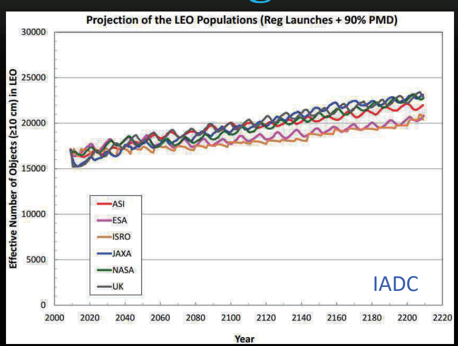
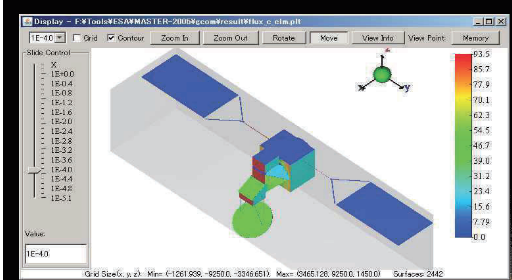
● Modeling



Transition Prediction of Debris environment



Collision probability and effects estimation

JAXA develops debris related models and tools

・To predict the future changes in the number of debris : "debris evolutionary model" (developed in collaboration with Kyushu University)

・To assess the probability of damage caused by debris collision: "debris collision damage analysis tool"

・To assess the compliance with debris mitigation standards: "debris mitigation standard support tools"

⇒Reflected in the design rules for spacecraft as well as in the regulatory rules for debris prevention

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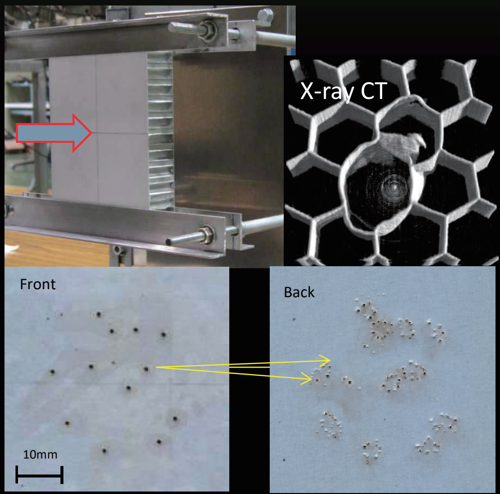
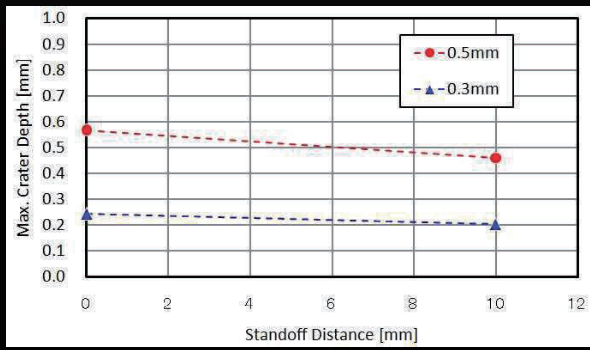
● Protection





At the 10mm away point from the outer skin, the energy of impact will be reduced by 15-20%

Ref. Higashide, et al., Trans. JSASS Aerospace Tech. Japan, 2012

Collision Test to the honeycomb sandwich panel

・Object of 1mm ϕ with the velocity of 10km/sec

・AL-Skin Honeycomb Panel : t_{skin}=0.25mm, h_{core}=25.4mm

⇒ Reflected in the design guidelines and the damage evaluation

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● Mitigation

- Compliance with 25 years rule and Controlled reentry
- Data acquisition of the re-entry stage .
- Utilization of the advanced carbon-fiber composite materials
  - Fuel tank is melted during re-entry

⇒ To secure ground safety

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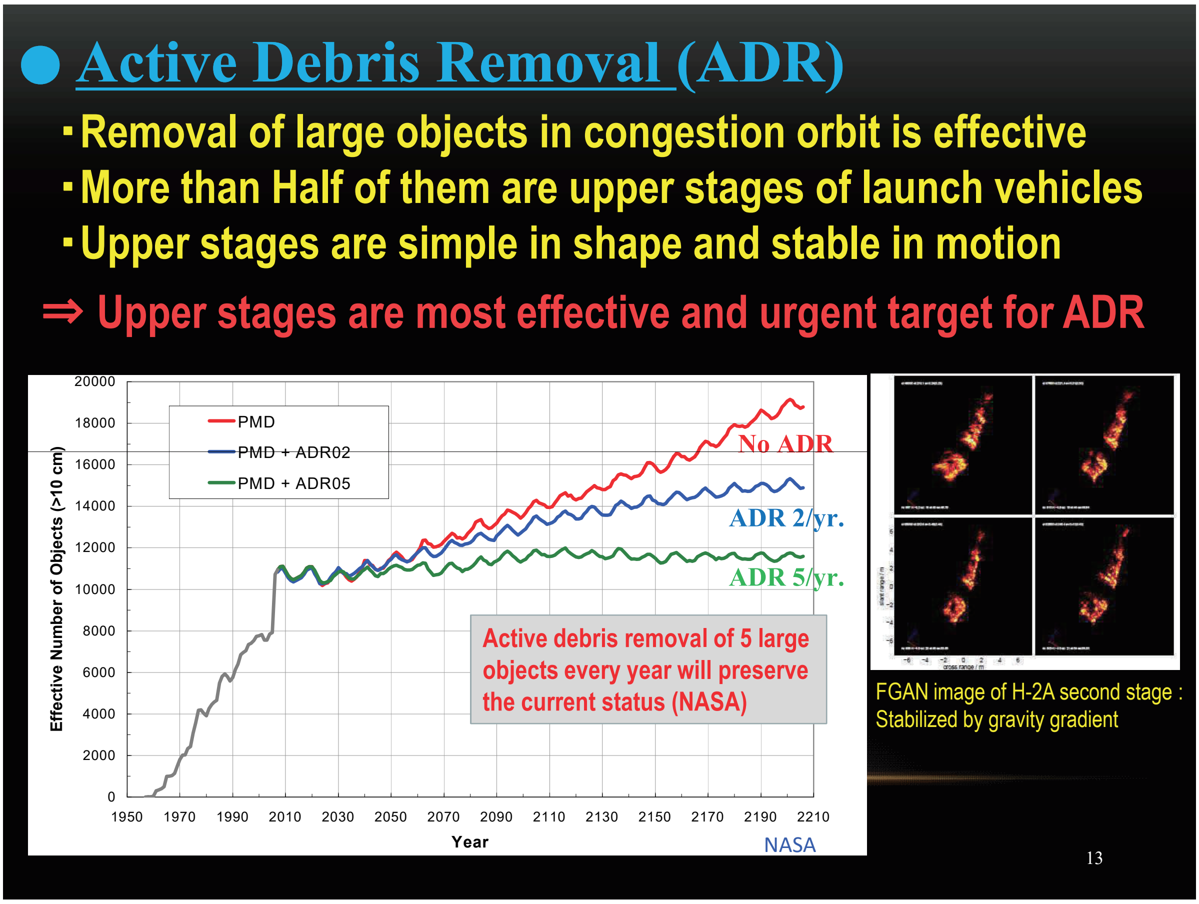
● Active Debris Removal (ADR)
・Removal of large objects in congestion orbit is effective
・More than Half of them are upper stages of launch vehicles
・Upper stages are simple in shape and stable in motion
⇒ Upper stages are most effective and urgent target for ADR
Effective Number of Objects (>10 cm)
Year
PMD
PMD + ADR02
PMD + ADR05
No ADR
ADR 2/yr.
ADR 5/yr.
Active debris removal of 5 large objects every year will preserve the current status (NASA)
NASA
FGAN image of H-2A second stage : Stabilized by gravity gradient
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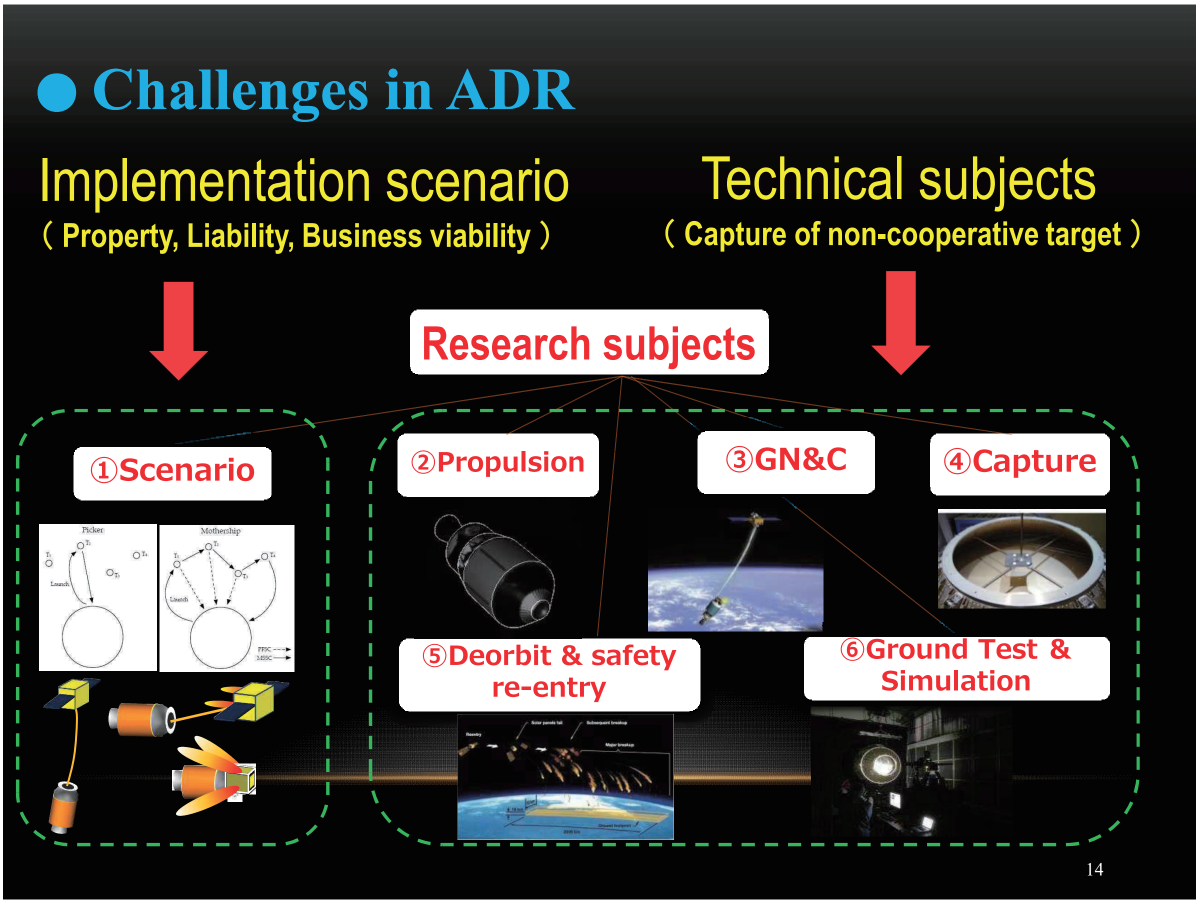
● Challenges in ADR
Implementation scenario
(Property, Liability, Business viability)
Technical subjects
(Capture of non-cooperative target)
Research subjects
①Scenario
②Propulsion
③GN&C
④Capture
⑤Deorbit & safety re-entry
⑥Ground Test & Simulation
Picker
Mothership
Launch
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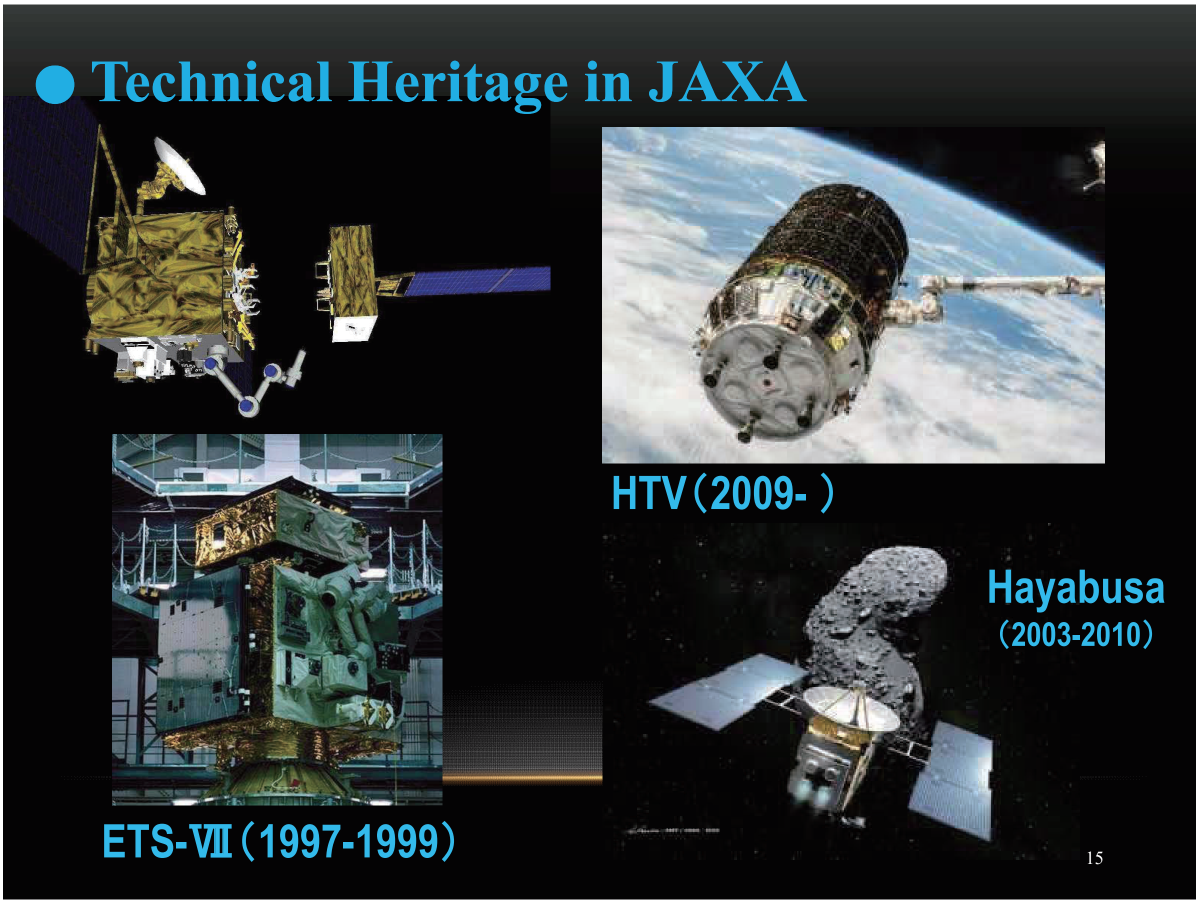
Technical Heritage in JAXA
HTV（2009- ）
Hayabusa
（2003-2010）
ETS-Ⅶ（1997-1999）
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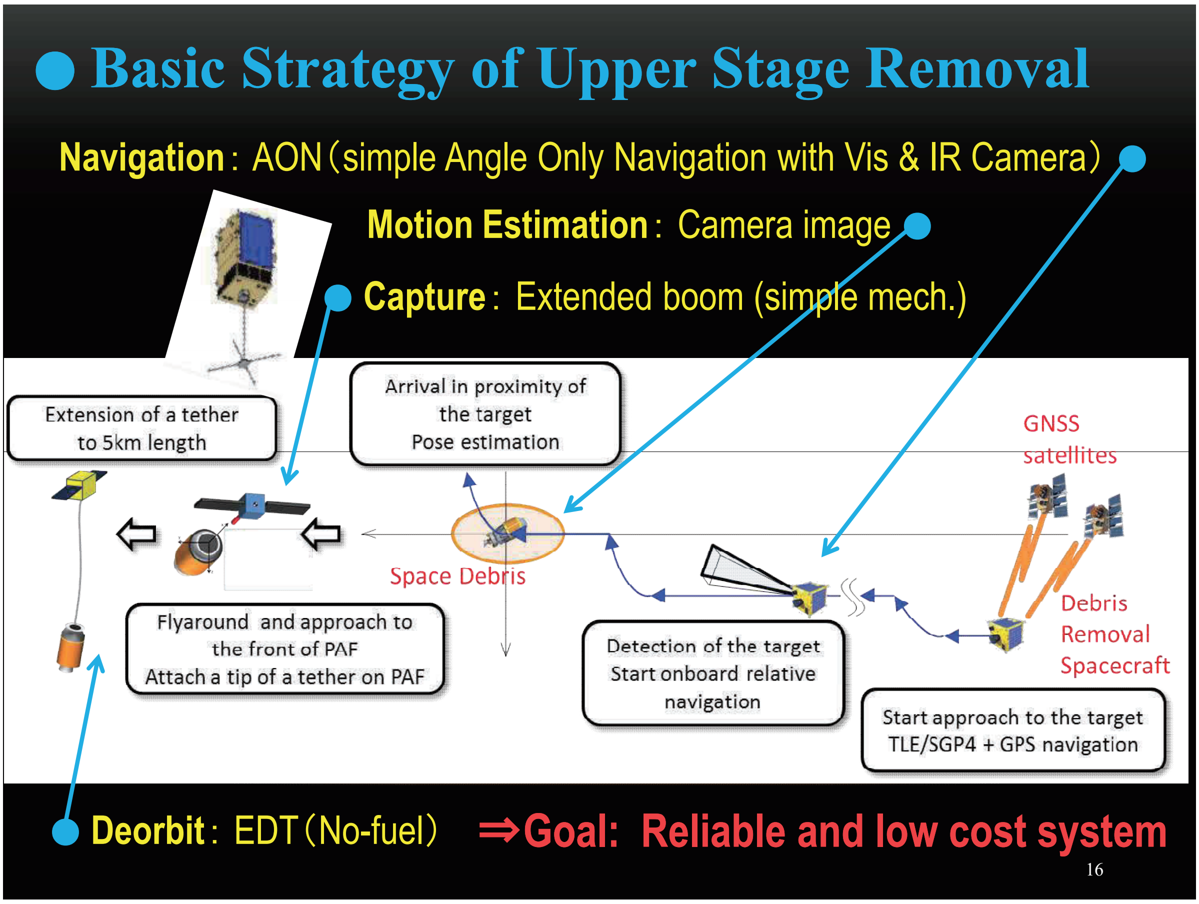
Basic Strategy of Upper Stage Removal
Navigation：AON（simple Angle Only Navigation with Vis & IR Camera）
Motion Estimation：Camera image
Capture：Extended boom (simple mech.)
Extension of a tether
to 5km length
Arrival in proximity of
the target
Pose estimation
GNSS
satellites
Space Debris
Flyaround and approach to
the front of PAF
Attach a tip of a tether on PAF
Detection of the target
Start onboard relative
navigation
Debris
Removal
Spacecraft
Start approach to the target
TLE/SGP4 + GPS navigation
Deorbit：EDT（No-fuel）
⇒Goal: Reliable and low cost system
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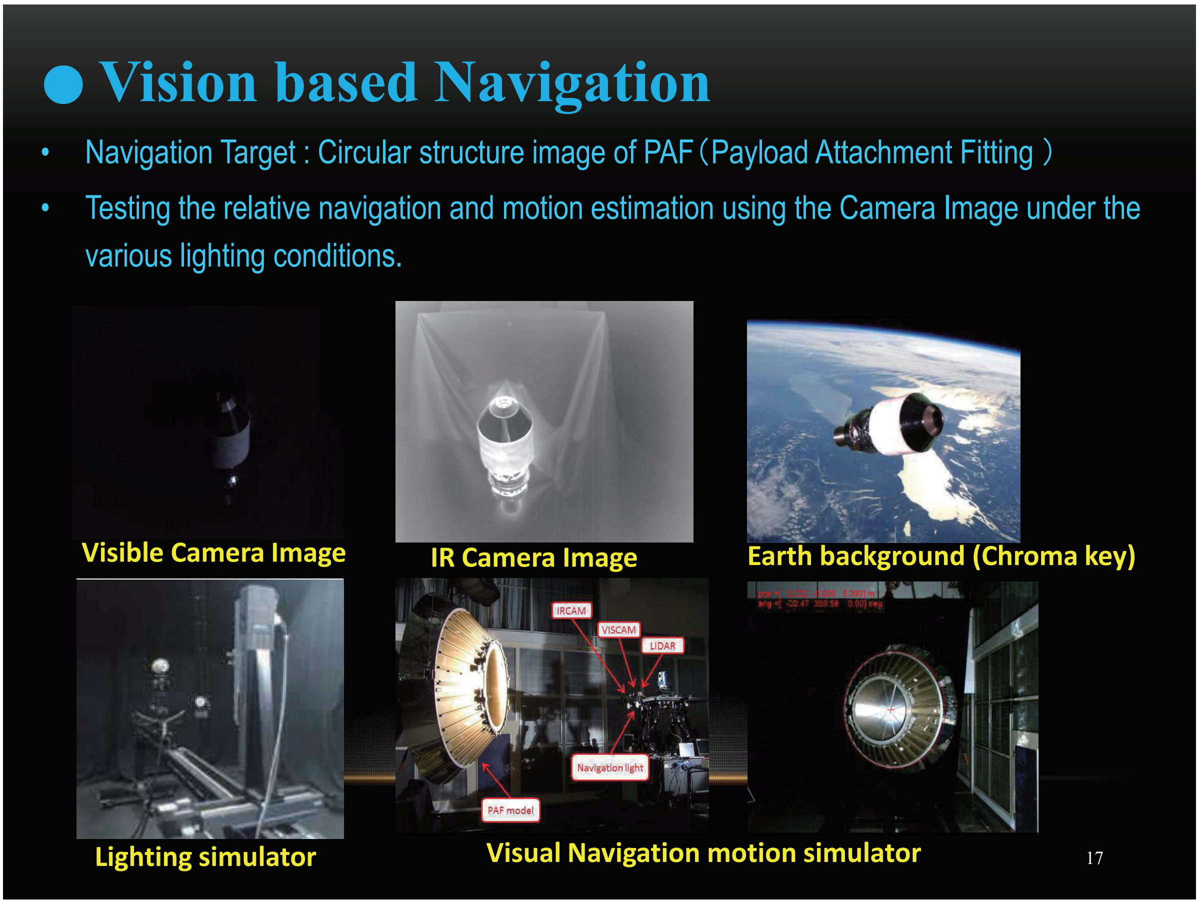
● Vision based Navigation
• Navigation Target : Circular structure image of PAF（Payload Attachment Fitting ）
• Testing the relative navigation and motion estimation using the Camera Image under the various lighting conditions.
Visible Camera Image
IR Camera Image
Earth background (Chroma key)
IRCAM
VISCAM
LIDAR
Navigation light
PAF model
Lighting simulator
Visual Navigation motion simulator
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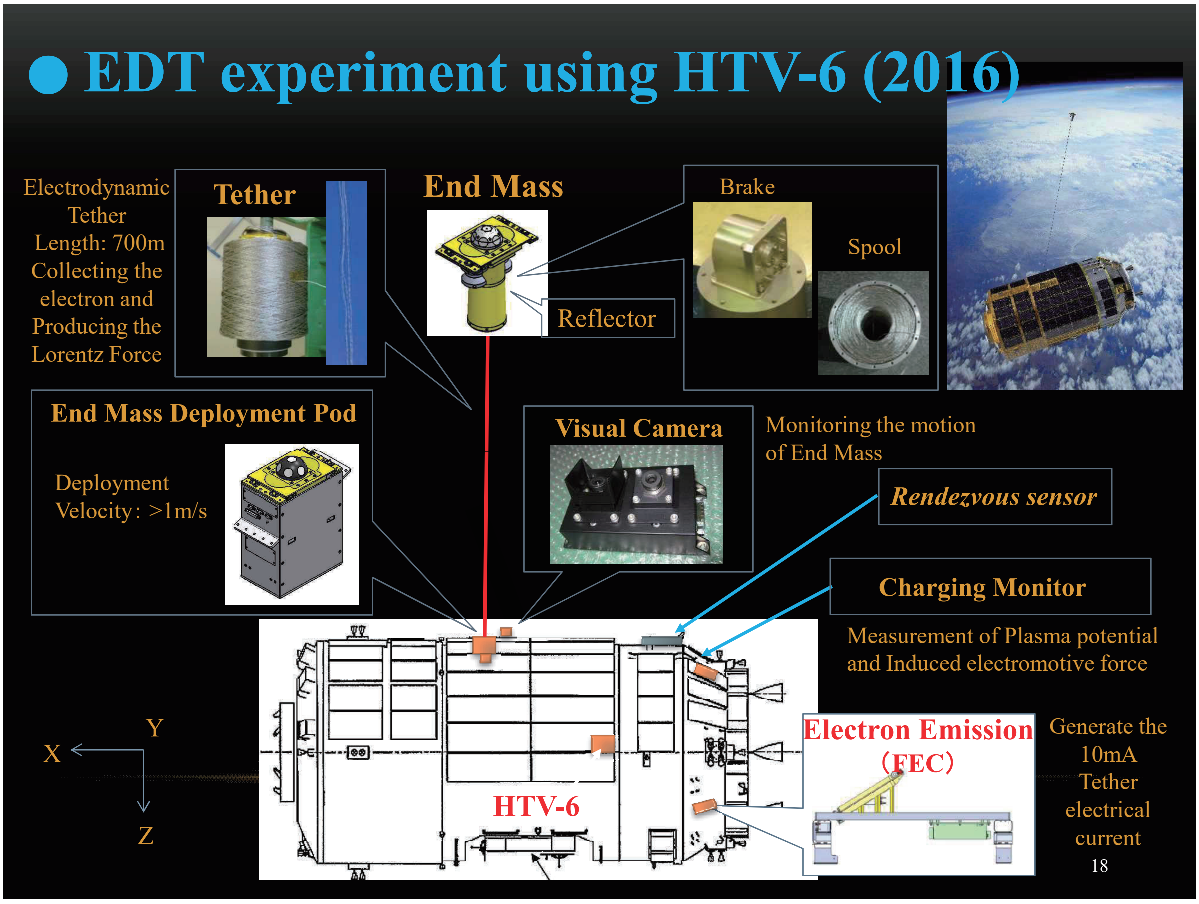
● EDT experiment using HTV-6 (2016)
Electrodynamic Tether
Length: 700m
Collecting the electron and Producing the Lorentz Force
Tether
End Mass
Brake
Spool
Reflector
End Mass Deployment Pod
Deployment Velocity: >1m/s
Visual Camera
Monitoring the motion of End Mass
Rendezvous sensor
Charging Monitor
Measurement of Plasma potential and Induced electromotive force
Electron Emission (FEC)
Generate the 10mA Tether electrical current
HTV-6
X
Y
Z
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3. Conclusion :

- JAXA is promoting the comprehensive approach to Space Debris Mitigation
- The primary goal of JAXA is to secure the safety of the space activities.
- In particular, JAXA focuses on the R&D of the practical technologies for removing the large space debris in the congestion orbit.
- Cooperation with international partners and private companies is important for feasible and sustainable activities.

Thank you for your attention

ご清聴ありがとうございました

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