B2

# JAXAにおけるデブリ除去の研究状況

## Current status of studies on active debris removal at JAXA

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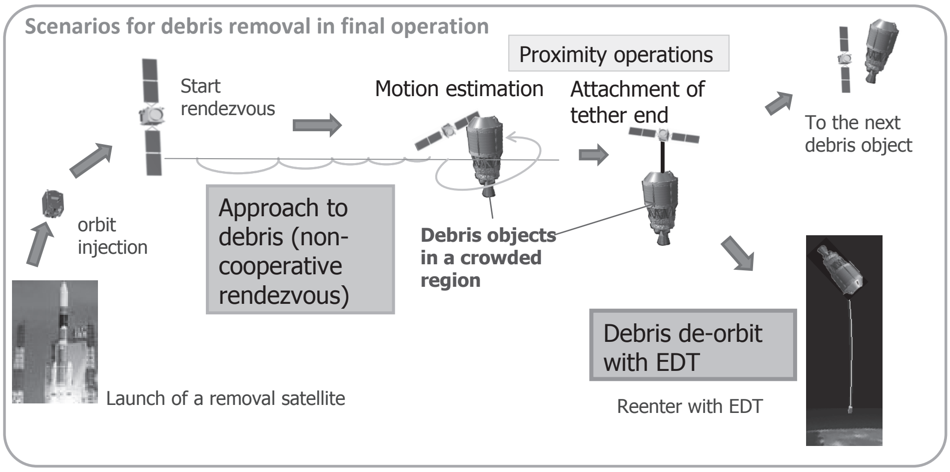
スペースデブリは近年急増しており、混雑軌道では今すでに軌道上にあるデブリ同士の衝突により数が増加していく自己増殖が開始していると考えられている。その場合、これから打ち上げる宇宙機のデブリ発生低減対策だけでは不十分で、衝突確率の高い大型デブリ（使用済み衛星やロケット上段）を能動的に除去する必要があり、世界でもデブリ除去の実現に向け検討が進められつつある。デブリ除去のためには非協力対象であるデブリに接近、推進系を取り付けて軌道を変換する必要があり難易度が高いが、JAXA では安価なコストで実現できるデブリ除去技術の開発を目指して研究を実施している。本発表では、JAXA 研究開発本部未踏技術研究センターで行われているデブリ除去の研究について報告する。

The amount of space debris has been increasing, and many evolutionary models predict that it would increase even if new satellite launches were stopped because of mutual collisions between existing objects. In such a case, debris mitigation measures such as explosion prevention and end-of-mission de-orbit will be inadequate and an active debris removal will be needed to preserve the space environment. The Japan Aerospace Exploration Agency (JAXA) has been studying a cost-effective active debris removal system. This presentation introduces the current status of studies on active debris removal at JAXA.



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***5th Space Debris Workshop, 2013***

## Introduction

- JAXA has been studying cost-effective removal of large intact objects in crowded regions for many years
- Contents
  - Target of removal
  - Removal scenario and required technologies
  - Current status of each technology
  - Roadmap for developing debris removal system

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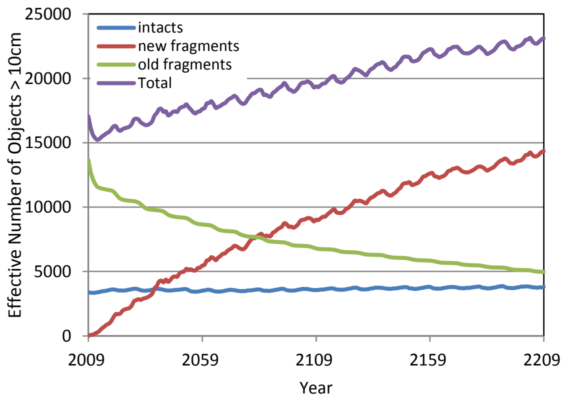
## Introduction : Necessity of Active Debris removal (ADR)

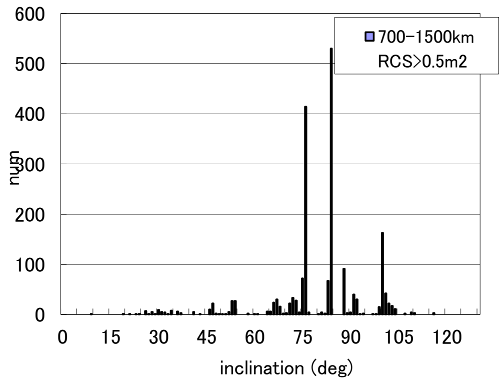
- Evolutionary models predict the amount of debris will continue to increase due to mutual collisions
- Active debris removal is necessary to reduce
  - Burden of Collision Avoidance Maneuvers (CAM)
  - Burden of debris protection design
  - Risks of unavoidable debris collisions
- To realize a practical debris removal
  - Technological feasibility
  - Reasonable cost
  - International cooperation

  will be needed

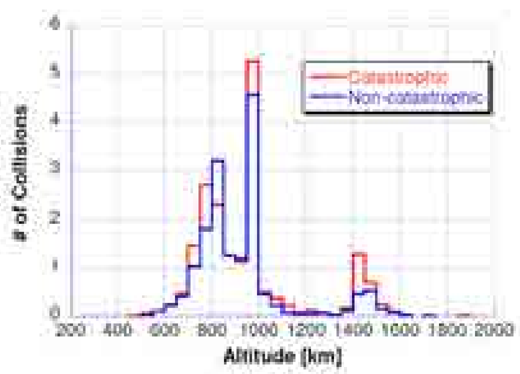



## Targets of removal

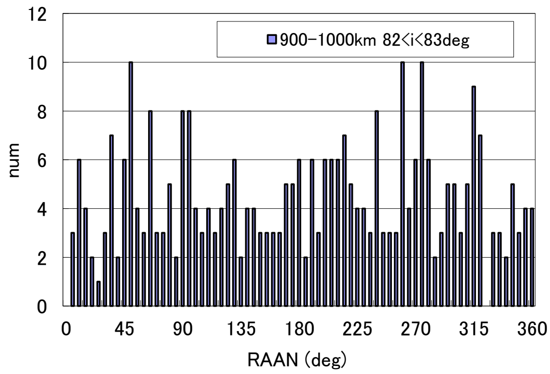
- Removal of large intact objects from crowded regions such as
  - SSO (98-100deg)
  - 900-1000km, 82-83deg
- Because they are the potential source of numerous small debris that pose direct risks and burdens
  - Removal of small debris is not efficient
- Numerous debris objects in the narrow orbital plane




The number of objects in altitude of 700-1500 km with RCS > 0.5 m2 in each 1 deg inc. bin



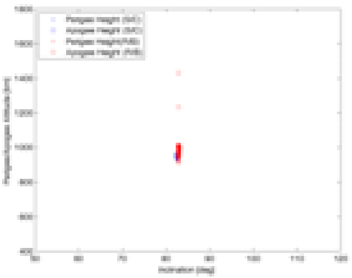

Number of collisions at each altitude predicted by LEODEEM, debris evolutionary model developed by Kyushu Univ. and JAXA




The number of objects in alt. of 900-1000 km and inc. 82-83 degree with RCS > 0.5 $m^2$ in each 5 deg RAAN bin.

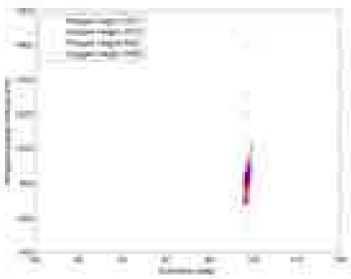
# Which debris should be removed?

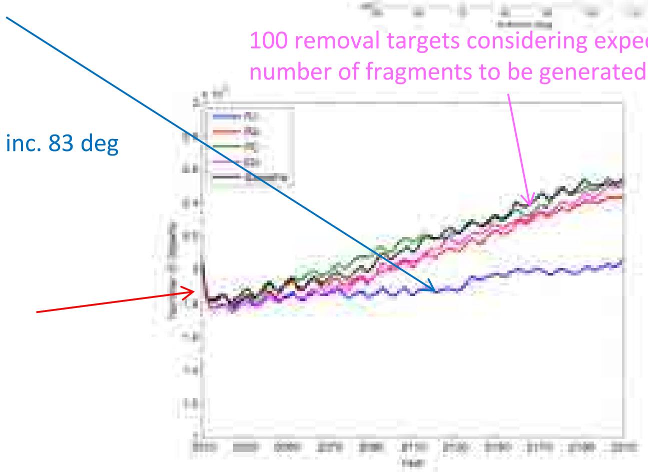
- The effect of removal was studied using debris evolutionary model developed by Kyushu Univ. and JAXA
- We must consider the effect of removal, technological aspects, legal aspects, etc



100 removal targets considering expected number of fragments to be generated in 25 years

100 removal targets in alt. of 900-1000 km and inc. 83 deg





100 removal targets in SSO, 0.5ton<mass<4ton

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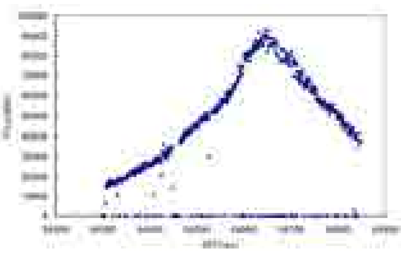
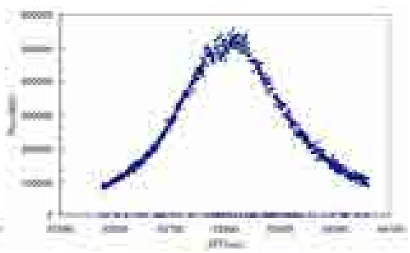
# Rocket stages

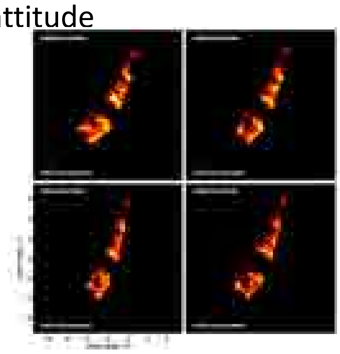
- Rocket stages can be removal targets
  - Their design details are less confidential than satellites. ← non-technological
  - There is less variation in the shapes compared with satellites
  - Rocket stages are cylindrical and the reflections of light, lasers or other signals can be more easily predicted than satellites.
  - Unlike some satellites they do not possess appendages such as solar paddles that pose a collision risk in proximity operations.
  - Their axisymmetric shape means that their attitude motions are likely to be simple with no complicated tumbling.
  - Some studies indicate that any rotational motions will almost have been stopped due to interaction between their metal bodies and the geomagnetic field → there are some R/Bs with stable attitude

← technological





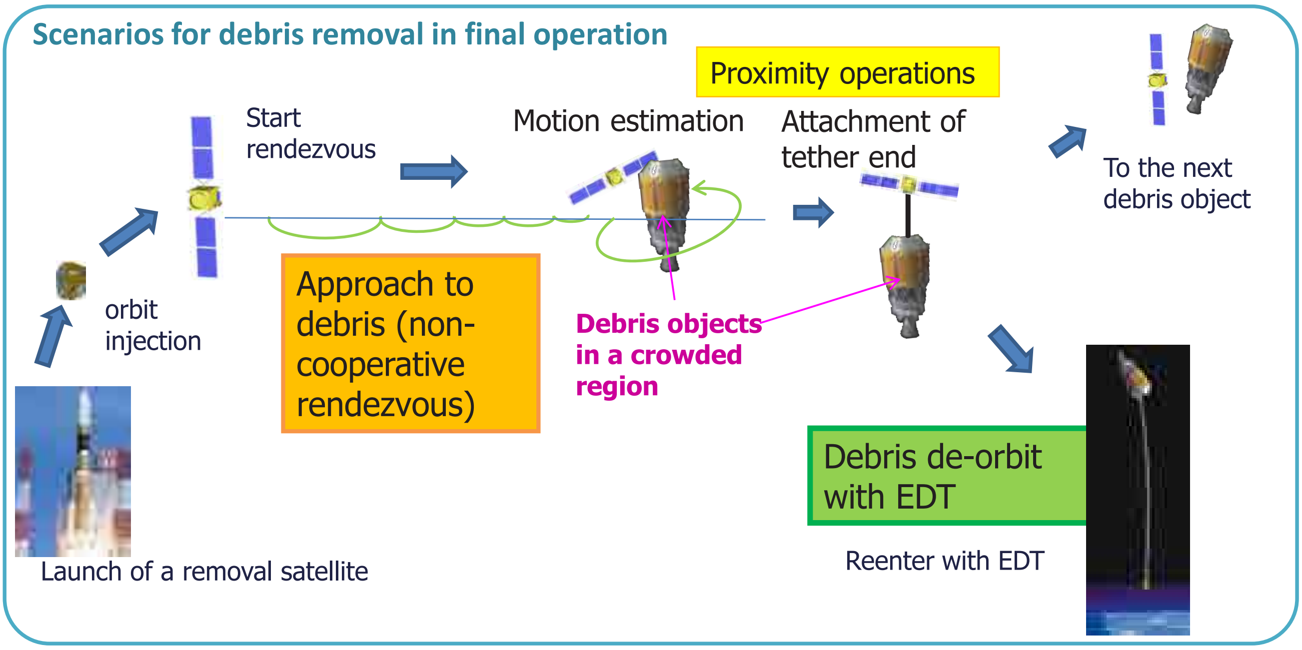
Light curve of SL-8 rocket upper stage.
There exists no tumbling objects.



H-IIA rocket body observed by FHR (2006.10)
TIRA RADAR

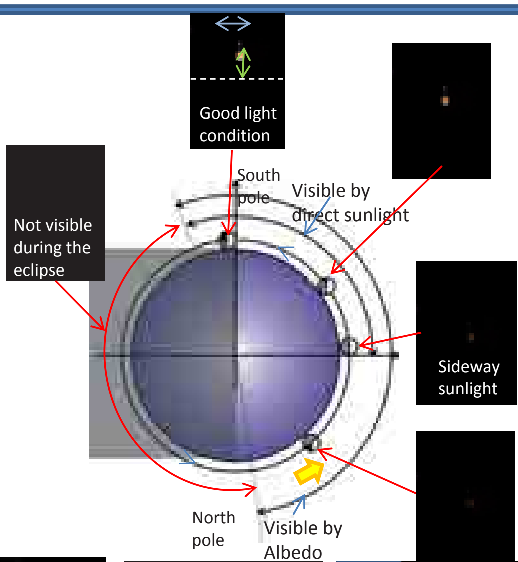
# Scenarios for debris removal

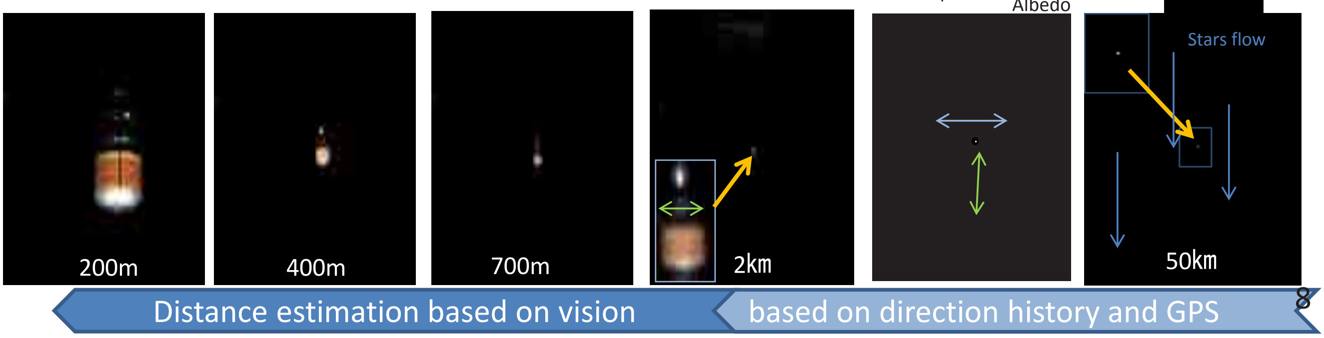
- Technologies to realize ADR have been studied and key technologies to be demonstrated identified




# Non-cooperative rendezvous

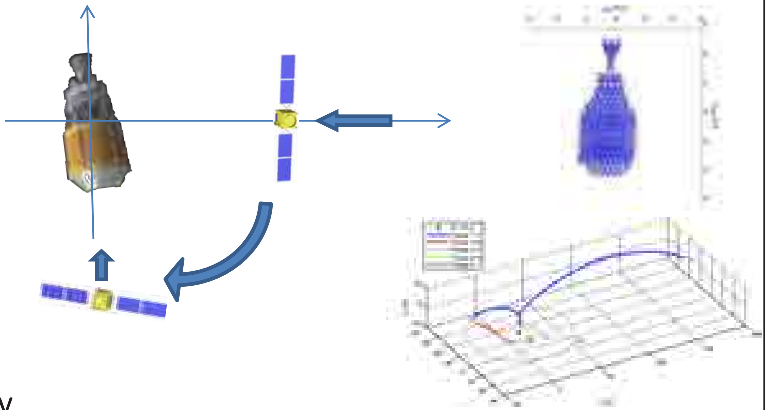
- Estimation of relative distance and attitude motion of debris that has no markers nor reflectors is difficult
- Orbital motion effects much compared with rendesvous with asteroids such as optical environment changes so
- Status:
  - Non-cooperative rendezvous using simple, low cost sensors such as GPS receiver, optical cameras have been studied
  - Cameras have been evaluated using "optical simulator"

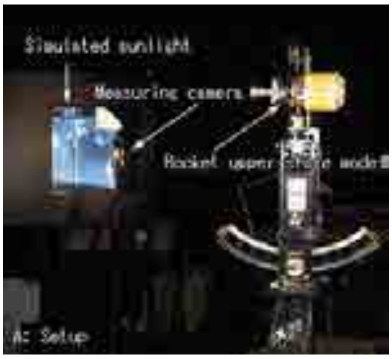


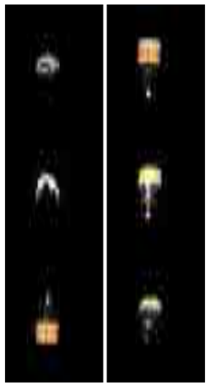
## Proximity operations (1)

- Attitude of debris is unknown as their attitude is no longer controlled
- Status:
  - Final approach using have been studied using
    - Image processing using stereo vision
    - Model matching to identify its attitude/position and motion
  - Numerical simulations and on-ground experiments using a model of H-IIA rocket upper stage and optical simulator have been performed






Optical simulator



Rocket upper stage model images taken using optical simulator

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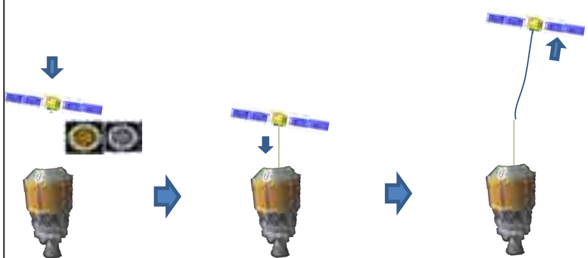
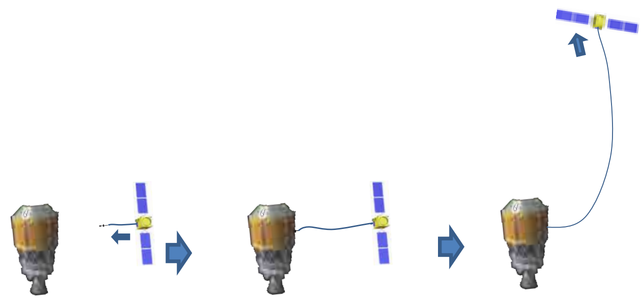
## Proximity operations (2)

- Attachment of propulsion is required to give dV > 100 m/s to debris with > some tons
  - Control of C.G. when removal satellite pushes debris, or stable pulling is required
- Status:
- Attachment of the tether end without need for precise position control
  - Attachment to the payload attachment fitting of the rocket upper stage using an extensible boom mechanism
  - Harpoon
  - Extensible robot arms
- Preliminary studies including numerical simulations have been performed and challenges to be studied were identified



Attachment to the PAF using an extensible boom mechanism. Image processing of PAF structure to estimate relative position and attitude is studied



Attachment using a harpoon. Impact analysis showed that fragment will not be generated when harpoon penetrates the propellant tank of R/B

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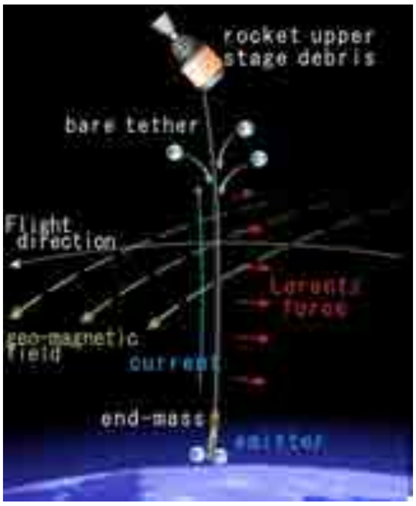
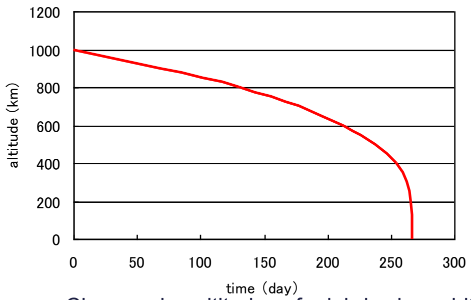
# Deorbit (Efficient Orbital Transfer)

- Large amount of fuel required for de-orbit prohibiting removal by small satellite and multiple removal by one satellite
- Electrodynamic tether (EDT) is promising for LEO removal
  - No need for propellant or high electrical power
  - Its thrust is so small and attaching operation will be less challenging
- Status: Numerical simulations have been conducted and some key components are developed and tested



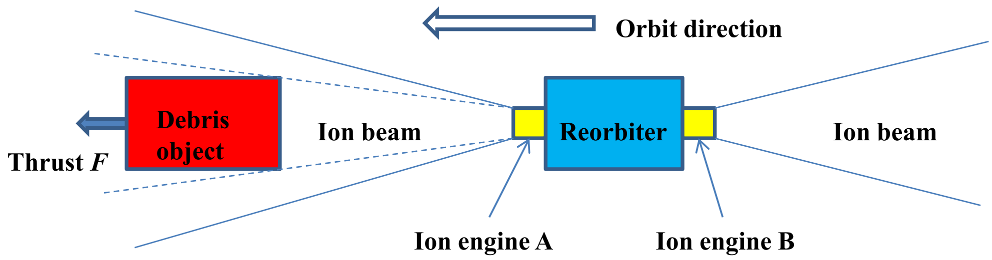



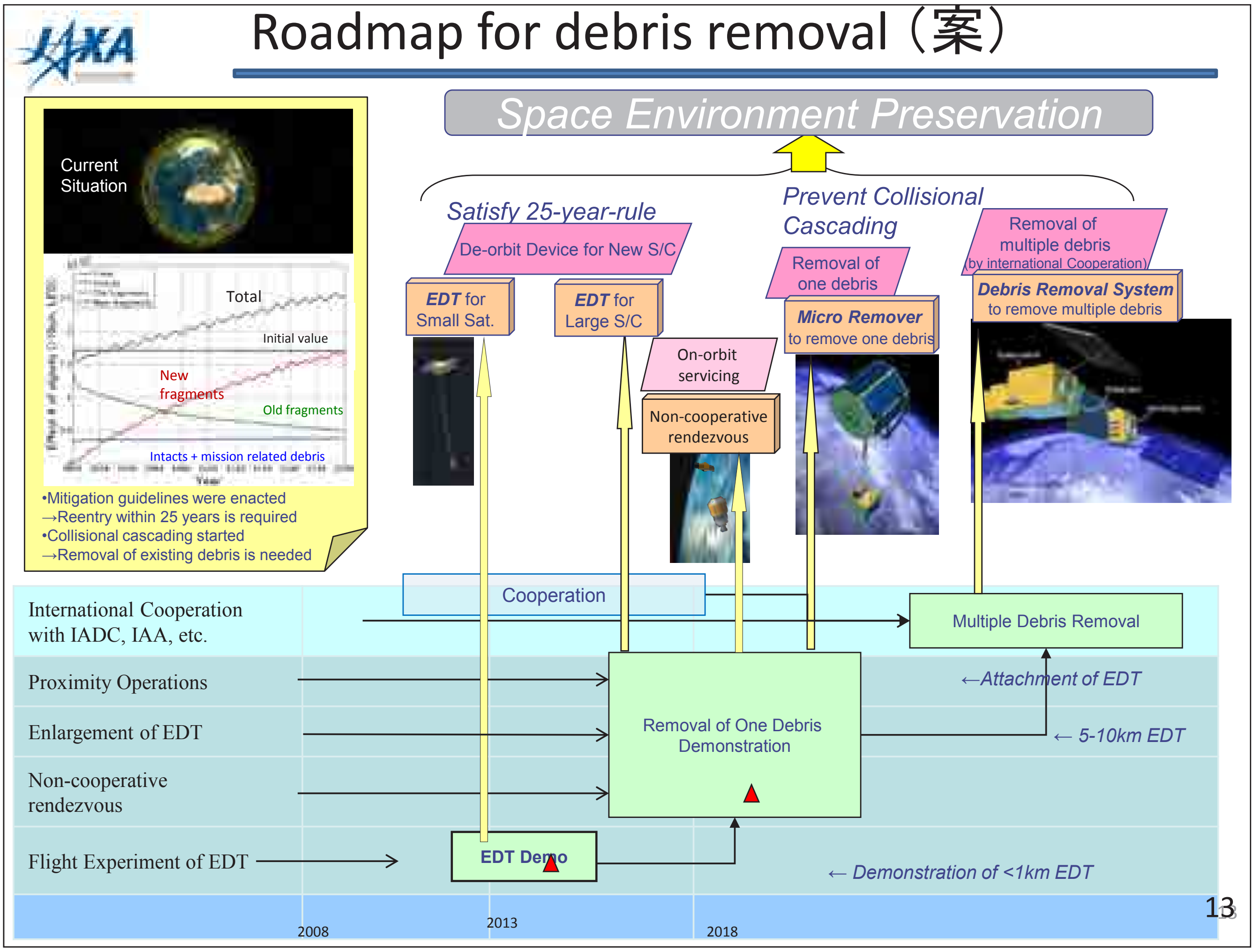

Change in altitude of debris in orbit altitude 1000 km, inclination 83 deg (1400kg) with EDT of 10 km.



# GEO Debris Reorbiter using Ion Beam Irradiation

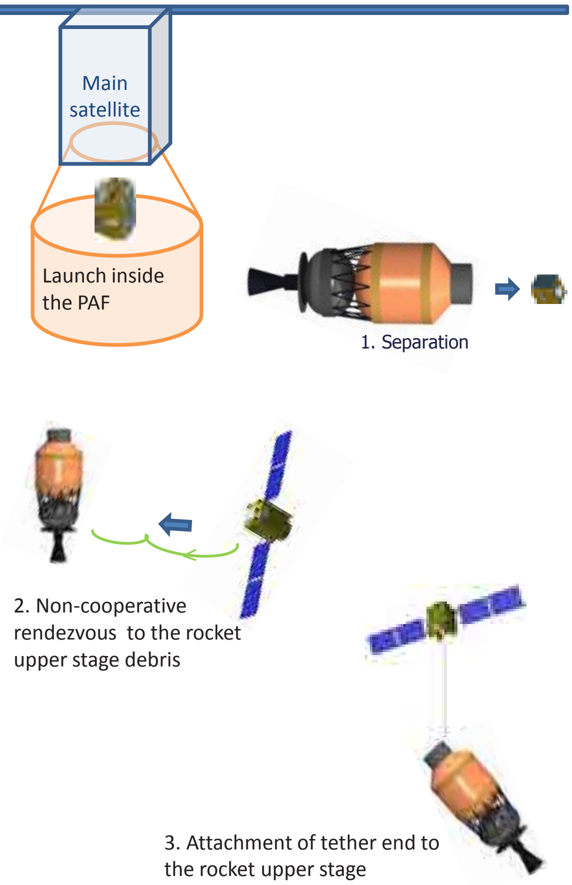
- GEO remediation is also necessary because no air drag to clean up debris is expected in the precious GEO
- Ion Beam Irradiation to put large debris to grave yard orbit
  - Non-contacting with non-cooperative debris
- Status
  - A preliminary system study has been conducted. Numerical simulations and some experiments in progress.






# System Demonstration (Removal of One Debris)

- Studies to remove a H-IIA rocket upper stage with almost stable attitude motion are ongoing
  - Non-cooperative rendezvous
  - Motion/attitude estimation
  - (Not required : Angular momentum reduction)
  - Attachment of tether end
  - Deorbit with EDT
- Removal satellite
  - Small satellite using an existing small satellite bus
  - Launched inside a payload attachment fitting of the main satellite as a secondary payload
  - deorbit with debris object as an endmass of the EDT



# Conclusions

- JAXA's studies for cost-effective active debris removal
  - Targets of removal are 100-150 large debris in some crowded regions such as SSO, 900–1000 km alt. and 83 deg inc.
  - Rocket bodies with stable attitude
- Technologies for realizing ADR
  - Non-cooperative Rendezvous
  - Proximity operations (motion estimation and attachment of tether end)
  - De-orbit by EDT for LEO and ion beam irradiation for GEO
  - Cost effective small satellite for debris removal
- Roadmap towards realizing the debris removal system was shown