B4

デブリ除去技術の概要と動向

Overview of studies on active debris removal

○河本聡美、大川恭志、壹岐賢太郎、青山順一、奥村哲平、片山保宏(JAXA)
○S. Kawamoto, Y. Ohkawa, K. Iki, J. Aoyama, T. Okumura, Y. Katayama (JAXA)

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とデブリ推移モデルにより予測されている。そのため、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る。本発表では、デブリ除去の必要性、除去対象、必要な技術、非技術的課題、世界の動向等、デブリ除去技術に関する概要を報告する。

The amount of space debris has been increasing, and some evolutionary models predict that it would increase because of mutual collisions between existing objects. In such a case, debris mitigation measures will be inadequate and an active debris removal (ADR) will be needed to preserve the space environment. In order to realize ADR, a removal satellite that will rendezvous with non-cooperative debris object and attach propulsion system for de-orbiting, and recently many studies have been conducted for realizing ADR all over the world. This presentation introduces overview of ADR, such as the necessity of ADR, targets for removal, required technologies, non-technological issues to be solved, and so on.

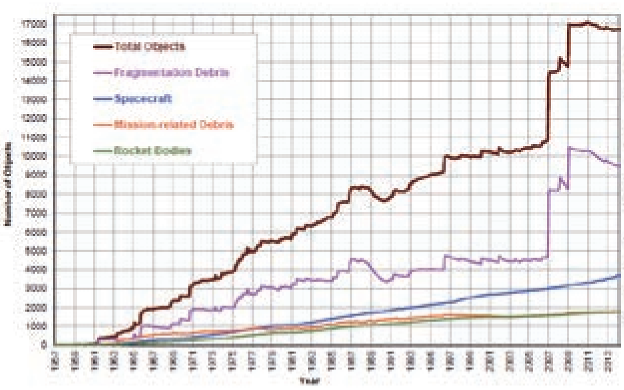
6th Space Debris Workshop
2014/12/17

Overview of Studies on Active Space Debris Removal

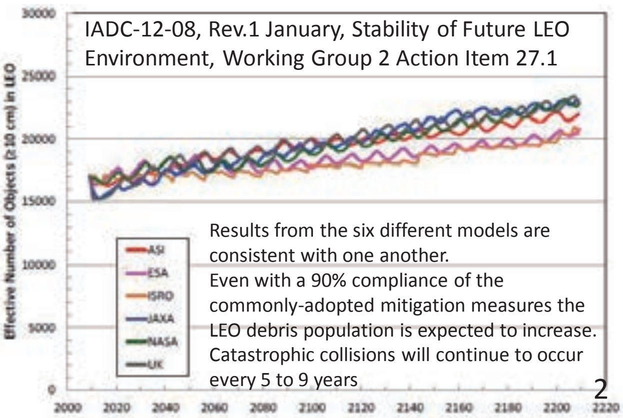
S. Kawamoto, Y. Ohkawa, K. Iki, T. Okumura,
J. Aoyama, Y. Katayama(JAXA/ARD)

Introduction : Necessity of Active Debris Removal (ADR)

- The amount of space debris has been increasing
  - Accidental collisions have been actually occurred
  - Debris countermeasures such as collision avoidance maneuvers (CAM) and debris protection design are indispensable
- Debris evolutionary models predict the amount of debris will continue to increase due to mutual collisions
- Active debris removal is necessary to reduce
  - Burden of CAM and debris protection design
  - Risks of unavoidable debris collisions



NASA The Orbital Debris Quarterly News 18-1 (2014, Jan)

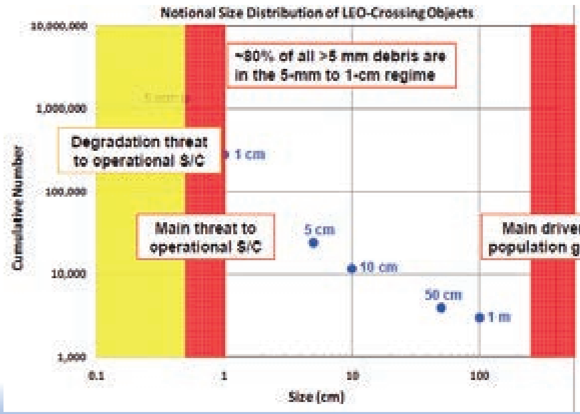


IADC-12-08, Rev.1 January, Stability of Future LEO Environment, Working Group 2 Action Item 27.1

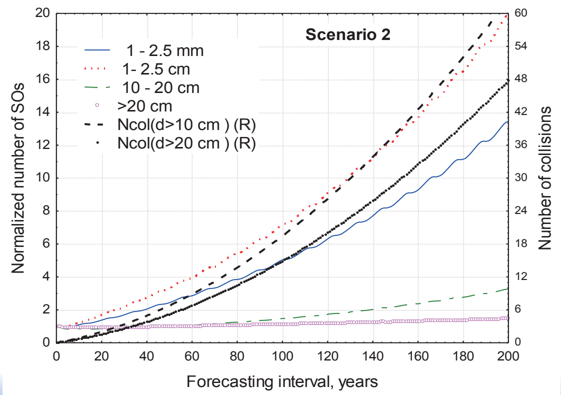
Results from the six different models are consistent with one another.
Even with a 90% compliance of the commonly-adopted mitigation measures the LEO debris population is expected to increase.
Catastrophic collisions will continue to occur every 5 to 9 years

Targets of ADR: Size

- Burdens and risks of debris arise from small size debris
  - Burden of Collision Avoidance Maneuvers by fragments cataloged debris (~10 cm)
  - Burden of debris protection design by debris < 1mm
  - Risks of unavoidable debris collisions by debris a few mm < debris < some cm
- Removal of such small size objects is difficult
  - A huge amount of smaller debris exists, and these are spread over a vast area of space
  - A catastrophic collision between two pieces of large debris may generate numerous new small size objects at once
- We can remove large intact objects in crowded regions since they are a potential source of numerous smaller debris that pose direct risks



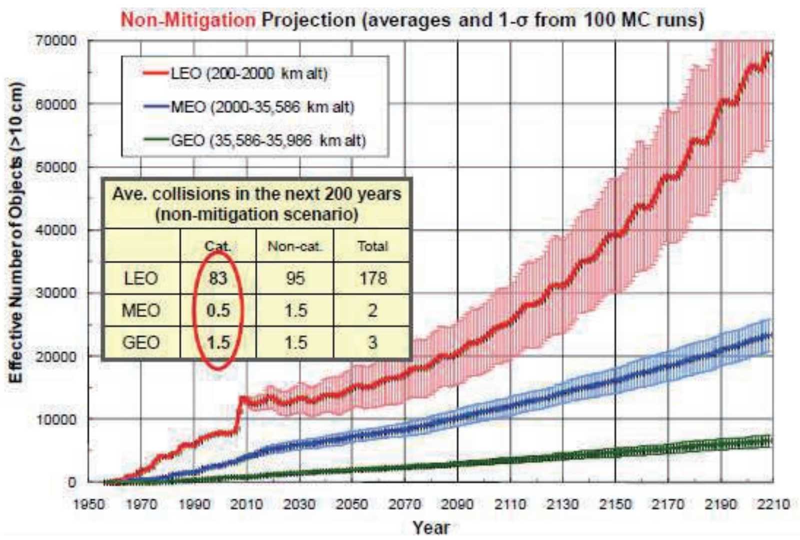
J.-C. Liou, NASA



A. Nazarenko, IAC-11.A6.4.2, 2011

Targets of ADR: Orbit

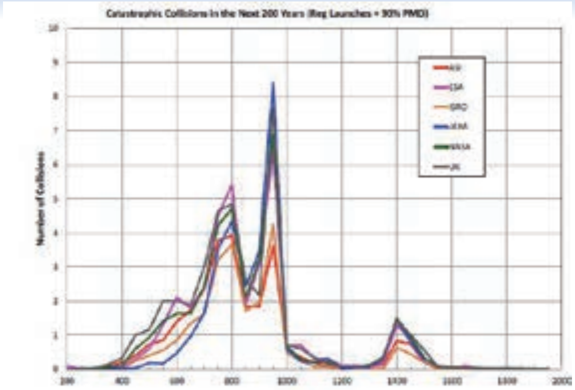
- Non-linear increase predicted in LEO > GEO、MEO
  - Nearly all the economic activity in GEO
  - Specific debris objects that interrupt operation can be the targets of ADR in GEO

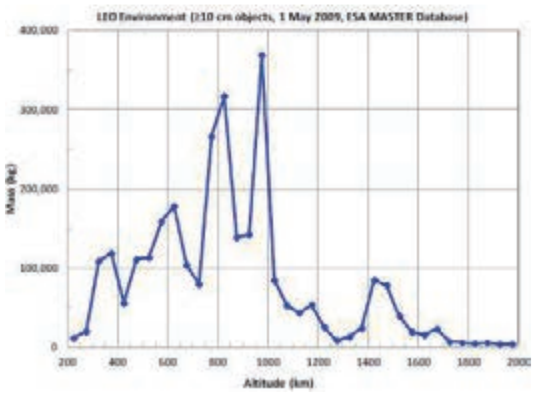


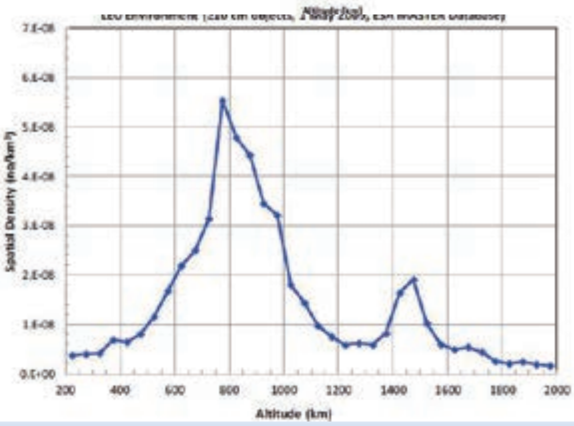
The Top 10 Questions for Active Debris Removal, J.-C. Liou (NASA), European Workshop on Active Debris Removal, 22 June 2010, CNES HQ, Paris, France

Targets of ADR: Orbit

- Collisions are predicted to occur in crowded regions such as 950-1000km, 700-800km altitude





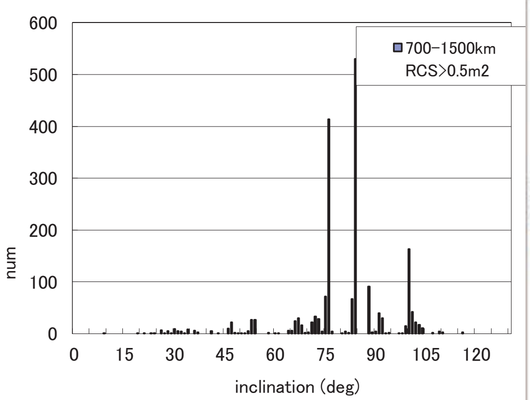


Stability of the Future LEO Environment IADC-12-08, Rev. 1 , 2013

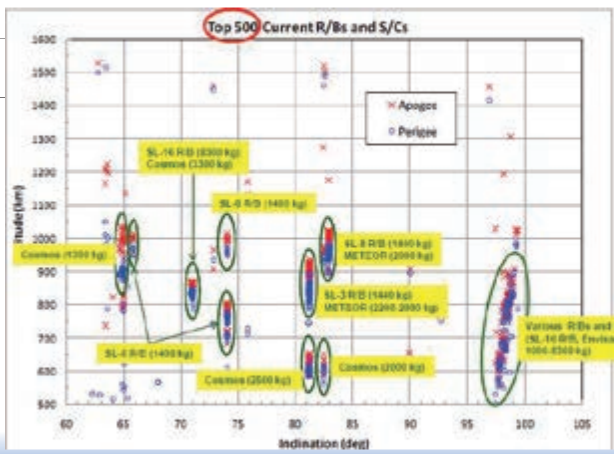
5

Targets of ADR: Orbit

- Sharp peaks exist such as 83 deg, 74 deg, 98-100deg inclination
- Mass x Pc (collision probability)
  – Evaluation using debris evolutionary model will be required considering realistic restrictions and long term effect



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

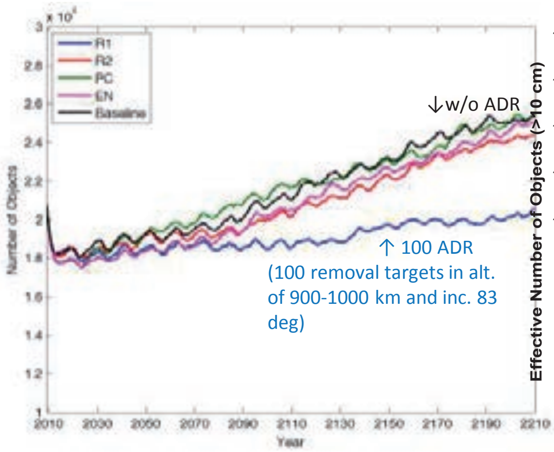


J.-C. Liou, NASA 2010

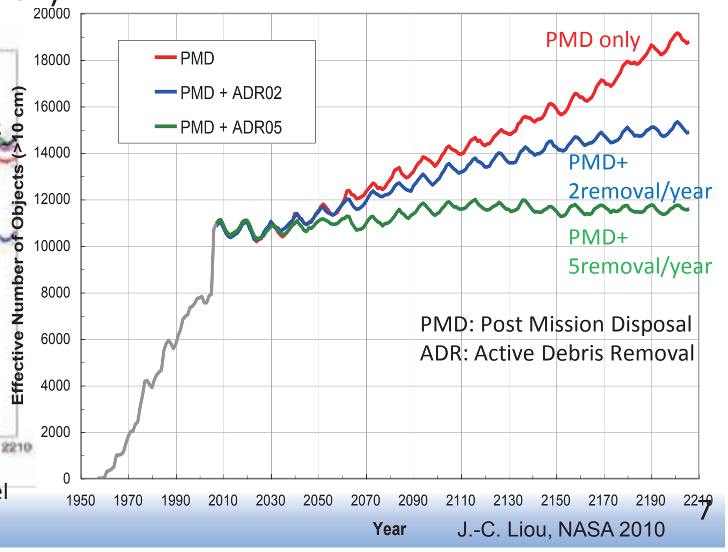
6

Effect of active debris removal

- Active Debris Removal of currently existing 100-150 debris objects or 5-10 debris objects/year is required in order to stabilize LEO environment
  - No need for removal of all 20000+ catalogued debris
  - Continuous removal will be needed because 90% compliance of PMD is assumed (10% fail)



Effect of removal using debris evolutionary model
Kyushu Univ./JAXA

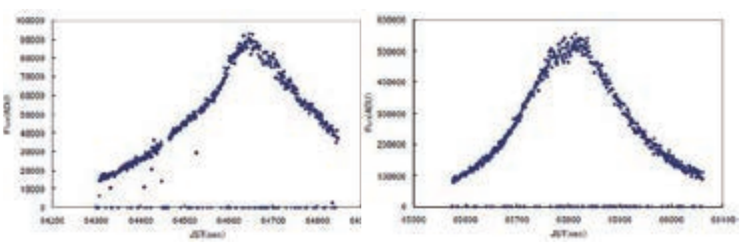


J.-C. Liou, NASA 2010

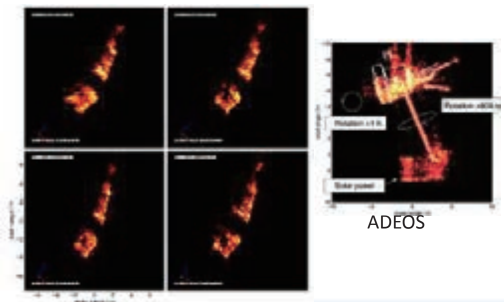
7

Targets of ADR: Type

- Removal of rocket upper stages may be both technologically and non-technologically less challenging compared with satellites debris
  - There is less variation in the shapes compared with 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
  - There exist some rocket bodies with almost stable attitude
  - Their design details are less confidential than satellites



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

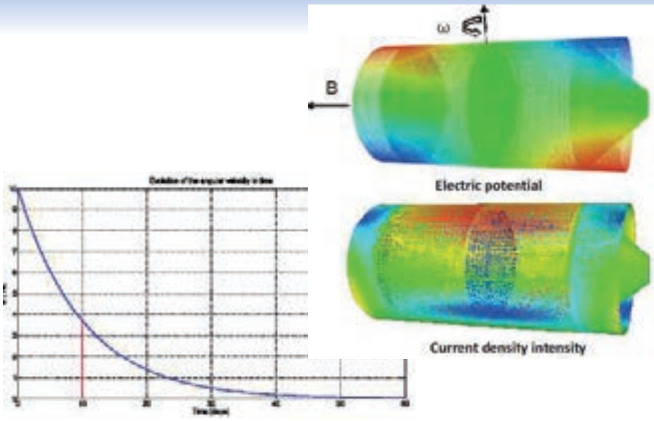


H-IIA rocket body observed by FHR
(2006.10) TIRA RADAR

8

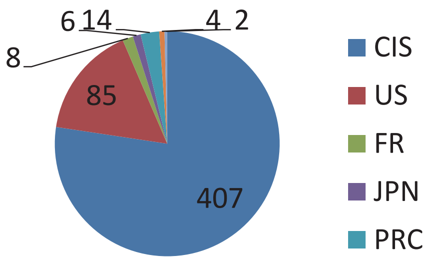
Targets of ADR: Type

- Need survey to understand the attitude motion of objects
  - Damping by eddy current interaction



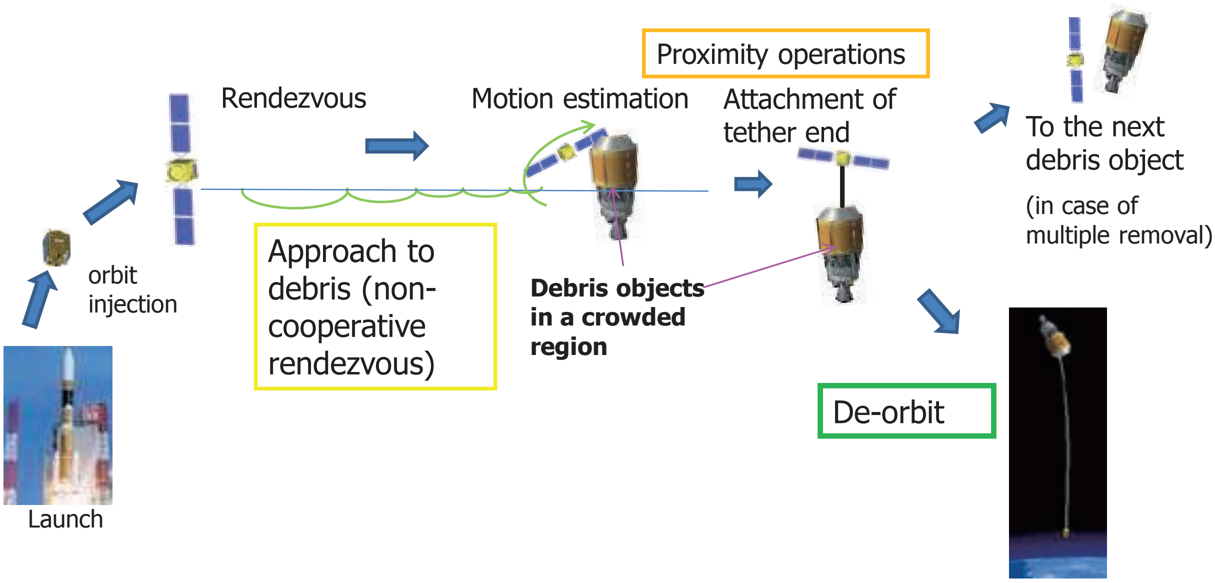
N. Praly, Study on the eddy current damping of spin dynamics of space debris

- Necessity of controlled reentry
  - Discussions within IADC
  - Some objects with low survival rate will be more appropriate for removal



SL_8	275
SL_14	55
SL__3	32
SL__16	20
DELTA_1_R/B	17

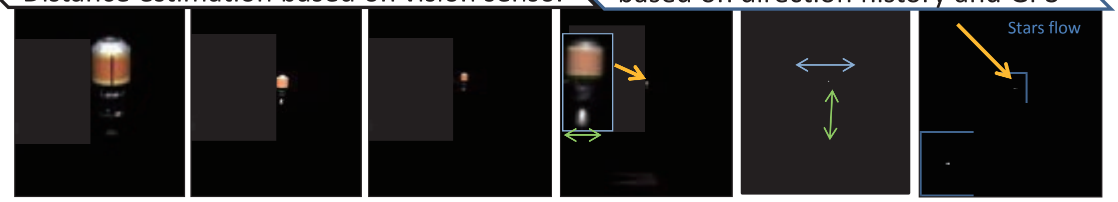
Operation Scenario for Active Debris Removal



Non-cooperative rendezvous

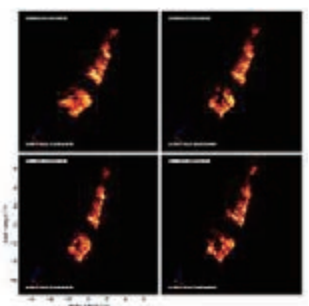
- Need to rendezvous with a non-cooperative target without colliding with it
- Predicted position accuracy based on ground observation: several kilometers
- Relative distance and attitude motion of debris without markers nor reflectors are needed
  - Radar without reflector is costly
- Optical environment changes drastically
  - Optical cameras observe target as a point in far range
  - No image obtained in eclipse
  - Optical environment is difficult to test on ground

Distance estimation based on vision sensor | based on direction history and GPS

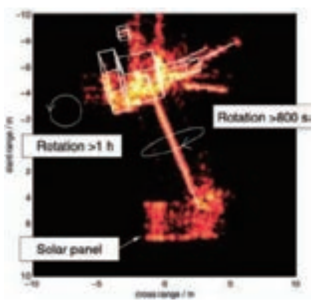


Proximity operations

- Need to capture and/or give thrust to a non-cooperative target
  - Attitude of debris is unknown as their attitude is no longer controlled
  - No handle nor grapple fixture
  - Angular momentum needs to be reduced before or after capturing if a target is tumbling
  - Short visibility time. Teleoperation is costly.
  - On-orbit environment such as no-gravity, large-scale are difficult to test on ground
- Attachment of propulsion is required to give dV > 100 m/s to debris with > some tons
  - e.g. 3000kg, 100m/s -> 1000N, 300sec
  - Firm fixation is required for some propulsion system



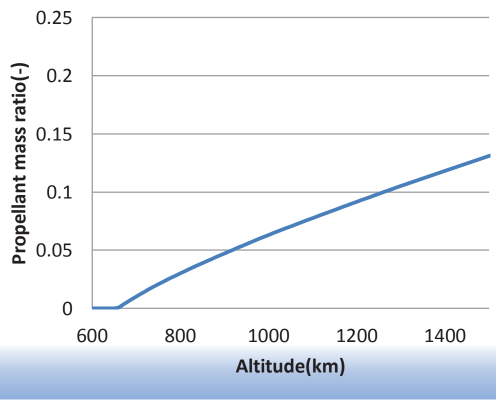
H-IIA rocket body observed by FHR (2006.10) TIRA RADAR

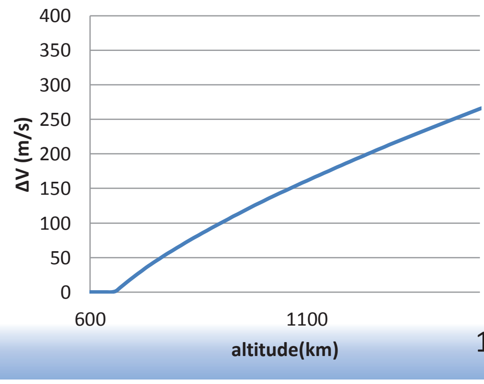


ADEOS

De-orbiting

- ΔV ~100m/s ~ 300m/s (depending on altitude, necessity of controlled reentry) required
- thrust vector control may be needed
  - Control of C.G. when removal satellite pushes debris, or stable pulling is required
- Multiple removal is preferred to reduce cost
- Heavy removal satellite becomes dangerous debris if it fails





13

Non-technological issues of ADR

- Legal and policy issues
  - Ownership
  - Liability for damage caused by debris
  - No obligation of removal when it is launched
    - Will be changed when ADR becomes technologically feasible ?
- International frameworks
  - Transparency and Confidence Building
  - Which debris should be removed?
- Affordable cost
  - Who pays?
    - Alternative spacecraft is cheaper in the short term
  - Business model

14

Worldwide Movement

- Conference/Workshop
  - 2009.12 NASA/DARPA　International Conference on Orbital Debris Removal
  - 2010.4 Russia ISTC（International Science & Technology Center）
  - 2010.6　CNES/ESA、European Workshop on Active Debris Removal
    - 2012.6 2nd WS, 2014.6 3rd
  - 2010.10 China/ISU/SWF、Beijing Orbital Debris Mitigation Workshop
    - 2011.10, 2012.11 Beijing Space Sustainability Conference
  - 2011.11 Mcgill Institute of Air and Space Law　International Interdisciplinary Congress on Space Debris Remediation
  - 2012.10 SWF European Conference on On-Orbit Satellite Servicing and Active Debris Removal: Exploring Commercial, Legal, and Policy Implications
  - 2013.2 SWF Singapore Conference on On-Orbit Satellite Servicing and Active Debris Removal
- IAA
  - initiated a comprehensive survey of techniques in 2006
  - published cosmic study on Space Debris Environment Remediation in 2013
- IADC
  - Discussion on Remediation Mission Guidelines

15

Worldwide Movement

	状況	実証計画	備考
ESA	CleanSpaceイニシアチブ（ADR€15-20M)の中で3年以内のデブリ除去ミッション設計を計画	2020年頃の実証を想定	出典: http://www.esa.int/Our_Activities/Space_Engineering/Clean_Space
EU	FP7でRemoveDEBRIS(Surrey大他、€13M）、BETs（導電性テザー、€1.8M)他多数の資金	RemoveDEBRISは2016年打上予定	出典: http://ec.europa.eu/enterprise/policies/space/research/fp7-projects/#h2-5 他
ロシア	2012年9月、ベルリンエアショーにてデブリ除去システム開発の計画を発表し国際協力を呼びかけ 2014年8月静止軌道の大型デブリ除去iquidator報道	2020年代のデブリ除去機の打ち上げを想定	出典: http://en.rian.ru/russia/20120912/175923000.html http://rt.com/news/182060-space-scavenger-geostationary-orbit/
DLR	ロボット技術実証衛星DEOS開発のため2012年9月Astriumに€15Mの契約	2018年頃打上予定	出典: http://www.dlr.de/dlr/presse/en/desktopdefault.aspx/tabid-10172/213_read-5173/
CNES	ATV技術を活かしたミッションとしてデブリ除去をセレクト。Astrium社とTAS社に各35万€の研究業務発注	2020年頃のシステム実証を想定	出典: Current status of CNES studies related to Active Debris Removal, ADR Workshop, June 2012
カナダ	2011年10月デブリ除去のシステム検討に2社を選定	実証計画不明	出典: http://www.asc-csa.gc.ca/eng/media/news_releases/2011/1027.asp
スイス	キューブサットによるCleanSpace Oneを提案 S3による打上と15Mスイスフラン獲得	2016-17頃の実証を計画	出典: http://space.epfl.ch/page-61745-en.html
NASA	2011年12月よりデブリ除去の検討Phase II。有望技術の絞り込みおよびロードマップを策定。2011年EDTを用いたデブリ除去システム”EDDE”の地上試験に$1.9M資金提供	実証計画不明	出典: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120011693_2012011338.pdf http://www.spacesafetymagazine.com/2012/03/13/electrodynamic-debris-eliminator-receives-funding/

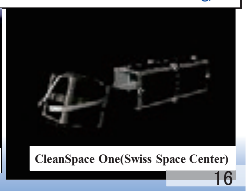

EDDE (STARInc.)


FASTSAT (NASA)


ROGER（ESA）


DEOS(DLR)


CNES

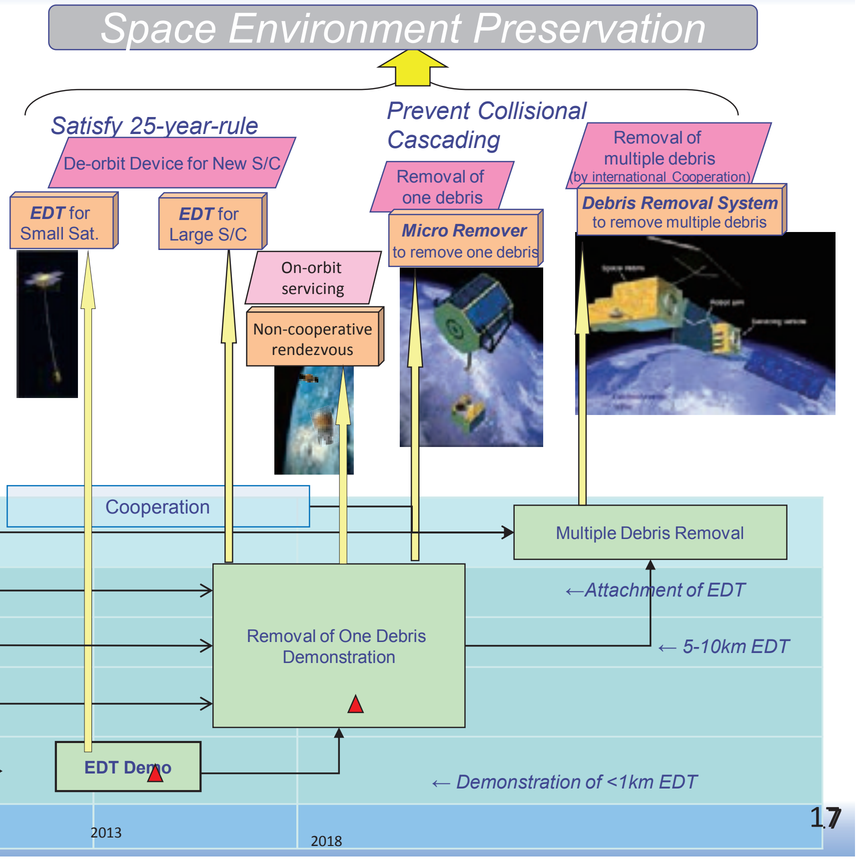

CleanSpace One(Swiss Space Center)

16

Roadmap for debris removal –JAXA's case

Steps for Realizing ADR

①Key technology demonstration (target : 2016)
②System demonstration (target : 2020)
③Practical ADR (target: mid–2020s)



Conclusion

- Overview of ADR were introduced
  - Necessity
  - Targets of removal
  - Challenges of ADR
    - Technological challenges
    - Non-technological issues
  - Worldwide Movement
  - Roadmap for debris removal –JAXA's case