Organizational and Operational Requirements for Space Debris Remediation

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Yukihito Kitazawa
(IHI Corporation, JAPAN)

From Mitigation to Remediation

Mitigation

Mitigation aims at reducing the generation of space debris through combined measures associated with the design, manufacture, operation, and disposal phases of a mission.

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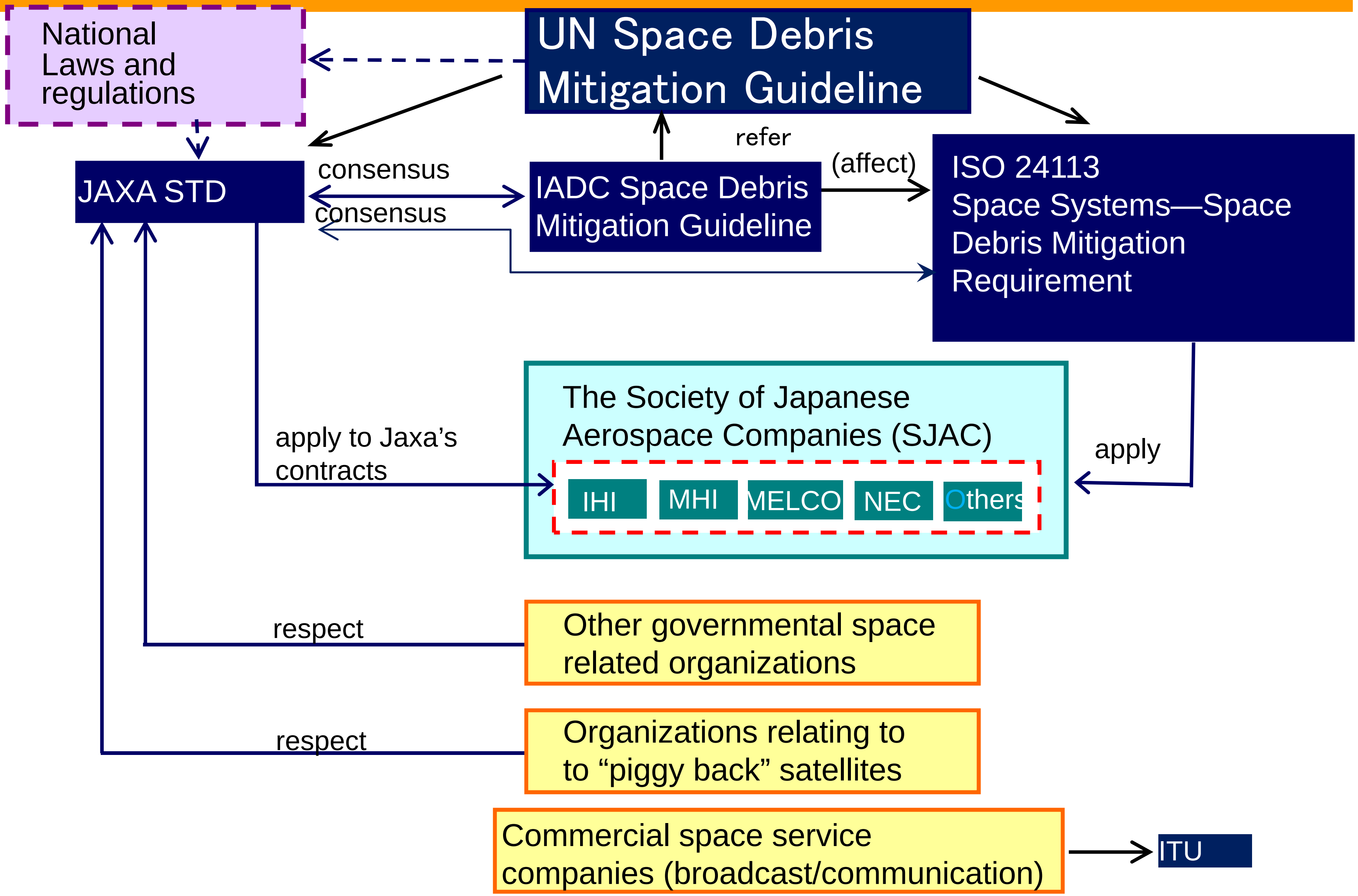
Remediation

Remediation aims at managing the amount of existing space debris through debris removal

Cf. Overview of debris **mitigation** framework in JAPAN



Cf. Comarison of recommendations/requirements in debris mitigation standards (based on Akira Kato (JAXA,2011)

		Measures	UN Guidelines	IADC Guidelines	ISO 24113	JAXA Standard
Mission Related Objects		Operational Debris	Addressed in Rec-1	Addressed in 5.1	Required	Required
		Slag from solid motor			Required	Required
		Pyrotechnics			Combustion Products < 1 mm	Combustion Products < 1 mm
		secondary ejector				
On-orbital Break-ups		Intentional Destruction	Addressed in Rec-4	Addressed in 5.2.3	Required	Required
		Accident during Operation	Addressed in Rec-2	Addressed in 5.2.2 (Monitoring)	Probability of BU < 10^{-3}	Probability of BU < 10^{-3}
		Post Mission Break-up (Passivation, etc.)	Addressed in Rec-5	Addressed in 5.2.1	Required	Required
Collision		with Large Objects	Addressed in Rec-3 (CAM, COLA)	Addressed in 5.6		Required（CAM, COLA）
		with Small Objects		Addressed in 5.6		Required
Post Mission Disposal	GEO	Addressed in Rec-7	Reorbit at EOL	235 km+ (1,000･Cr･A/m) e < 0.003	235 km+ (1,000･Cr･A/m) e < 0.003 Success Probability > 0.9 100 years' guarantee	235 km+ (1,000･Cr･A/m) e < 0.003 Success Probability >0.9 100 years' guarantee
			GEO Lower Limit	-200 km		-200 km
			Protected Inclination	-15< latitude <15 deg.	-15< latitude <15 deg.	-15< latitude <15 deg.
	LEO (MEO)	Addressed in Rec-6	Reduction of Orbital Lifetime	Addressed in 5.4 (Recommend 25 years)	EOL Lifetime < 25years Success Probability >0.9	EOL Lifetime < 25years Success Probability >0.9
			Transfer to Graveyard		Required 100 years' guarantee	Required
			On-orbital Retrieval	Addressed in 5.4		Required
		Addressed in Rec-6	Ground Casualty	Addressed in 5.4	Required	Ec < 10^{-4}

Discussion issues

1. Who should undertake space debris remediation?
2. What is needed to reduce the risk of mishaps, misperceptions, and mistrust?
3. What are specific transparency and confidence building measures, norms of behaviour, and best practices for debris remediation?
4. How do you handle the economics and funding?

1. Who should undertake space debris remediation?

The best practice of organizations for debris mitigation is reaching its limit, and debris removal needs to be considered.

- As a general principle, the beneficiary (producer of the debris) should bear responsibility for disposing of it.
- However, under current circumstances, clean up of the orbital environment is a technologically challenging issue, and entails large costs.
- GPS, weather satellites, Earth observation satellites and other spacecraft already form social infrastructures, which give great benefits to the world, not only to the "space countries."

Through international cooperation, it is necessary for those participating in space development to pay their fair share

2. What is needed to reduce the risk of mishaps, misperceptions, and mistrust?

What is meant by "reduce the risk"?

For debris mitigation

(Increasing the reliability of spacecraft design and manufacture)

- Implementation of space debris mitigation guidelines/requirements (e.g. ISO 24113)

For avoiding accidental collision

- Performance of collision avoidance maneuvers

The above efforts certainly reduce risk. However, the corrosion risk mainly caused by **fragments**.

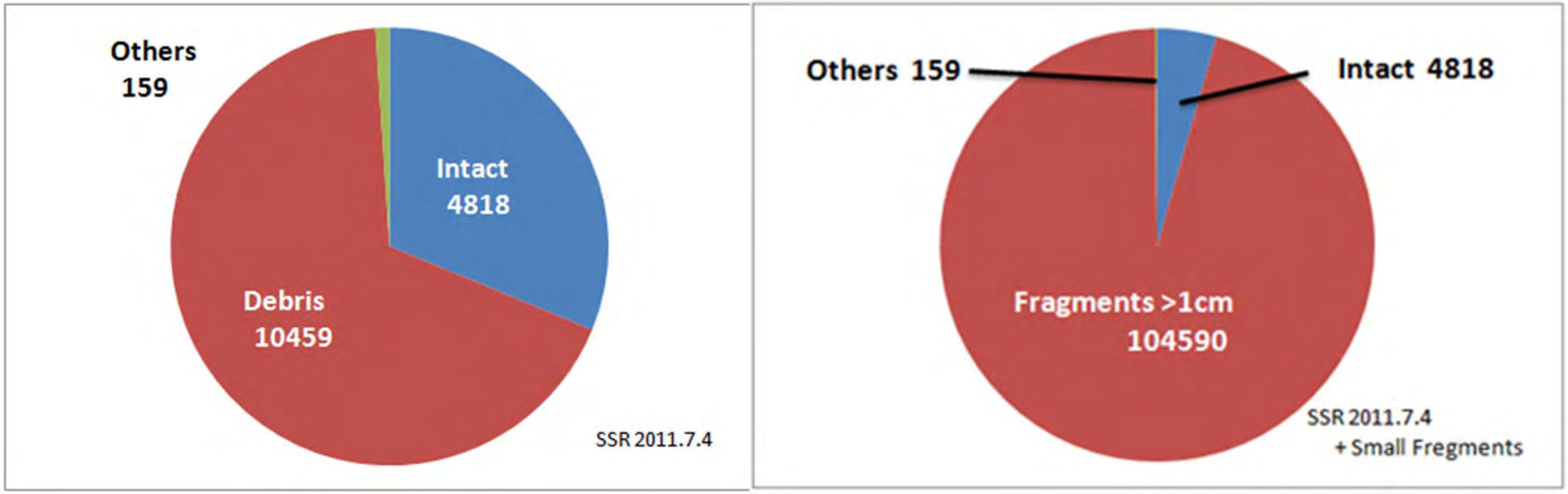


Fig. 1-a Orbital Objects (2011. 07.04) Fig. 1-b Objects larger than 1 cm
(Yasaka,2011)

The hazards to the environment caused by spacecraft (includes rocket bodies) should be quantitatively evaluated.
(eq. Spacecraft /Rocket bodies are the potential source of fragments)

Proposal of evaluation index of hazardousness of object

We should observe objects capable of colliding with and damaging other objects

However, the debris creation capability (i.e. collision hazardousness) of orbiting objects is not quantitatively evaluated.

--- E.g. Which is more hazardous, many small satellites or one large one?

A quantitative indicator of an orbiting object's influence on the orbital environment is required

This indicator is important for evaluating "Remediation."

Proposal of evaluation index of hazardousness of object

An example of hazardousness index of object

"Debris Index " by Yasaka (2009, 2011)

$$I_{DEB} = \alpha M \cdot A \cdot F(h) \cdot T_{orb}, \quad (A \cdot F(h) \cdot T_{orb} \leqq 1)$$

Where,

αM: **Number of fragments created by mass M of object (ex. spacecraft, rocket body, etc.)**

A: **Cross sectional area of the object**

$F(h)$: **M&D flux at altitude *h***

T_{orb}: **Orbital life of the object**

Numerical example of debris index (Yasaka, 2009, 2011)

If one Collision Avoidance (CA) maneuver is performed.

$$I_{DEB} = \alpha M \cdot A \cdot F(h) \cdot \varepsilon_{AVOI} \cdot T_{orb}$$

If multiple CA maneuvers are performed.

$$I_{DEB} = \alpha M \cdot A \Sigma_i F(hi) \cdot \varepsilon_{AVOI,i} \cdot T_{orb,i}$$

Satellite Type	α 1/kg	Altitude km	Flux 1/year/m²	Orbital Life year	Mass kg	Area m²	Debris Index	
							w/o CA	CA
Typical SSO Sat	30	800	10^{-4}	25	800	4	269	27
Typical GEO Sat	3	36000	10^{-6}	10	2000	10	0.6	0.1
Object in SSO	30	800	10^{-4}	100	2000	10	6000	N/A
Small Sat	30	800	10^{-4}	25	50	0.25	0.9	N/A
Cube Sat	30	800	10^{-4}	25	1	0.01	0.001	N/A

Fragments/Flux considered >1cm

W/O CA: No CA maneuvers

CA:10 CA maneuvers

Tentative assumptions

$\alpha = 30(\text{LEO}), 3(\text{GOE})$ $\varepsilon_{AVOI} = 0.1$

$F(800) = 10^{-4}(1\text{year/m}^2)$ $F(36000) = 10^{-6}(1\text{year/m}^2)$

An example of another proposal for quantitative index of hazardousness of object

<u>By Hanada (2011)</u>

- Time when the cumulative probability of collision

 and

- Expected number of fragments during the time exceeds 0.001

Many uncertainties still remain regarding evaluation of the indicator

- Fragmentation model of object
- Reliability of collision avoidance
- Debris flux

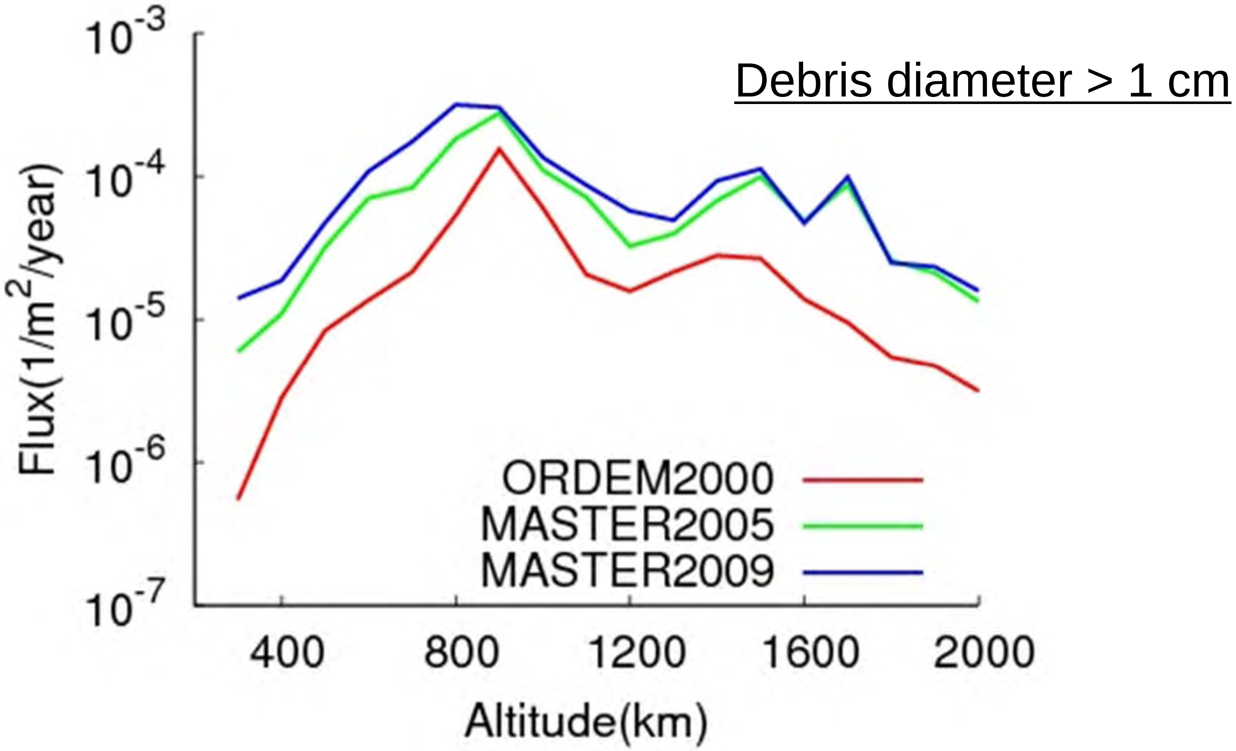
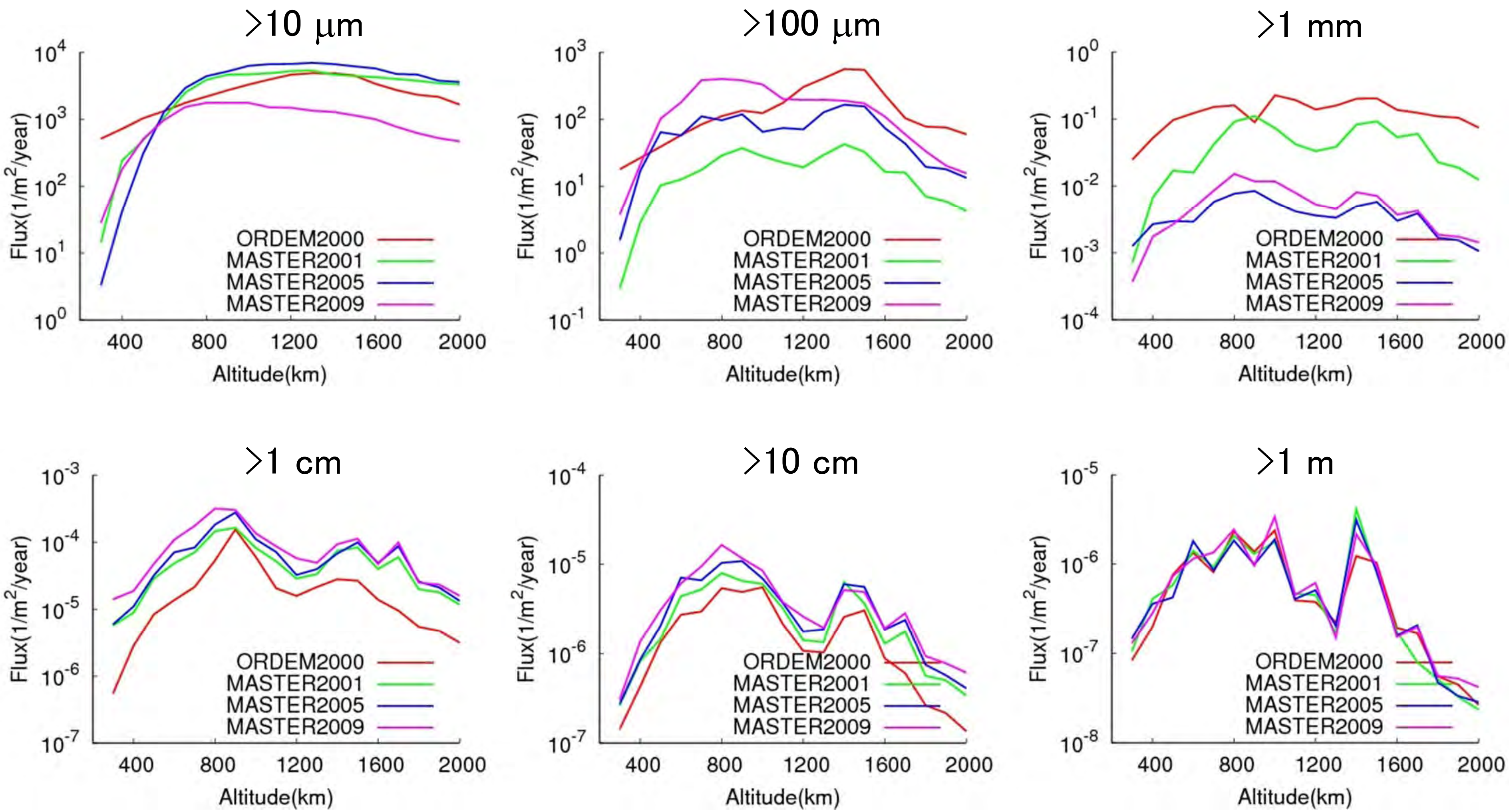


Fig. Flux against altitude at inclination 100 degrees

Example of uncertainty of debris flux model (Inclination 100 degrees)



(Kanemitsu *et al. ,2011*)

3 .What are the specific transparency and confidence building measures, norms of behaviour, and best practices for debris remediation?

Basic requirements for best practices

- International standardization (consensus) of a quantitative indicator of "hazardousness"
- Confirmation of implementation of ISO 24113 (Space Debris Mitigation Requirement) and other related standards
- Information sharing/evaluation of debris environment
- Decision making on orbital debris removal

  (cf. Conjunction analysis; Collision probability x Mass of object)
- Negotiation with state of registry of object (proprietor of object)

For transparency, confidence building measures, and norms of behaviour

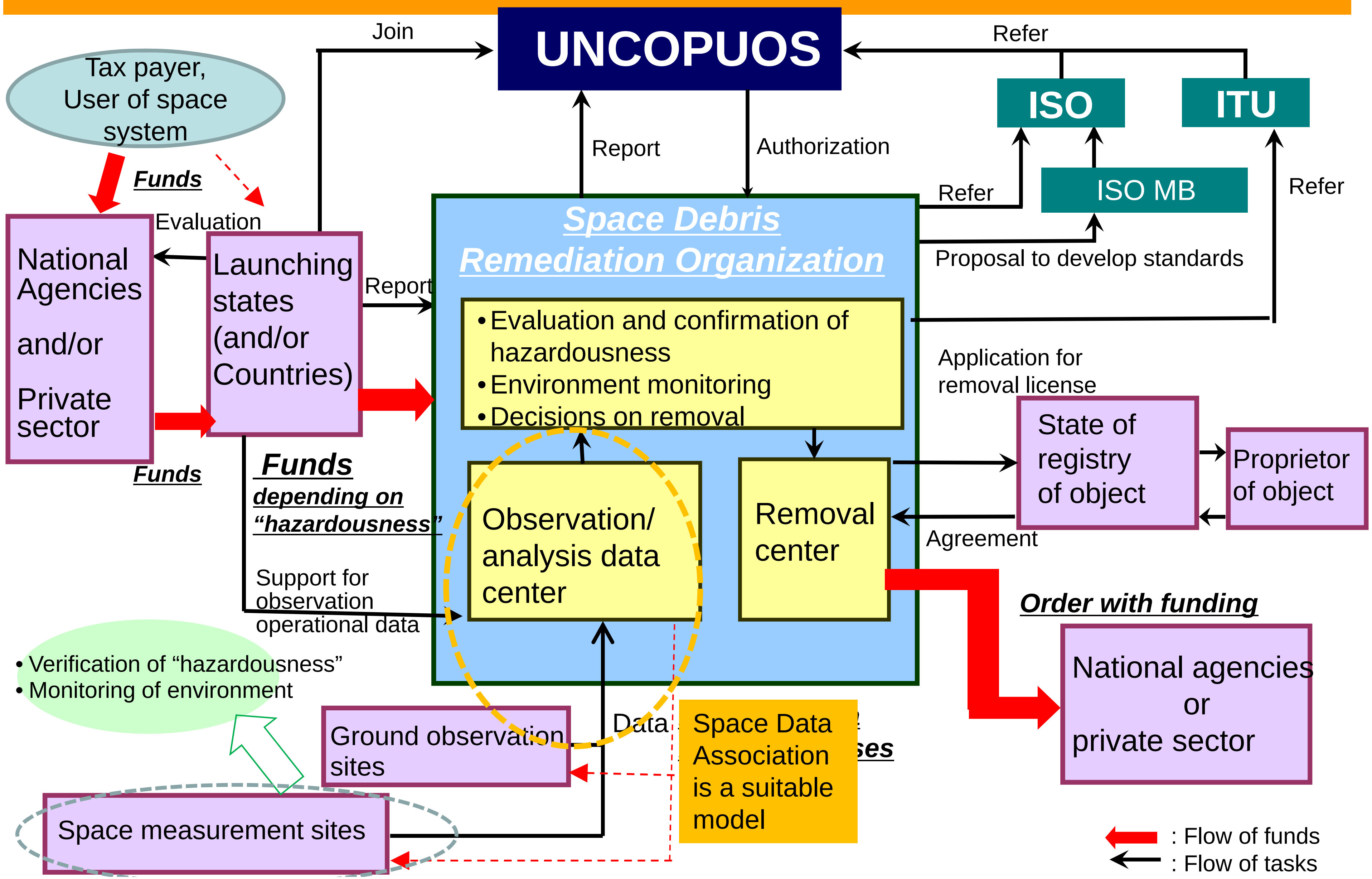
- Need to be assessed by independent international organization(s)
- The organization must have the ability to verify practices

4. How do you handle the economics and funding?

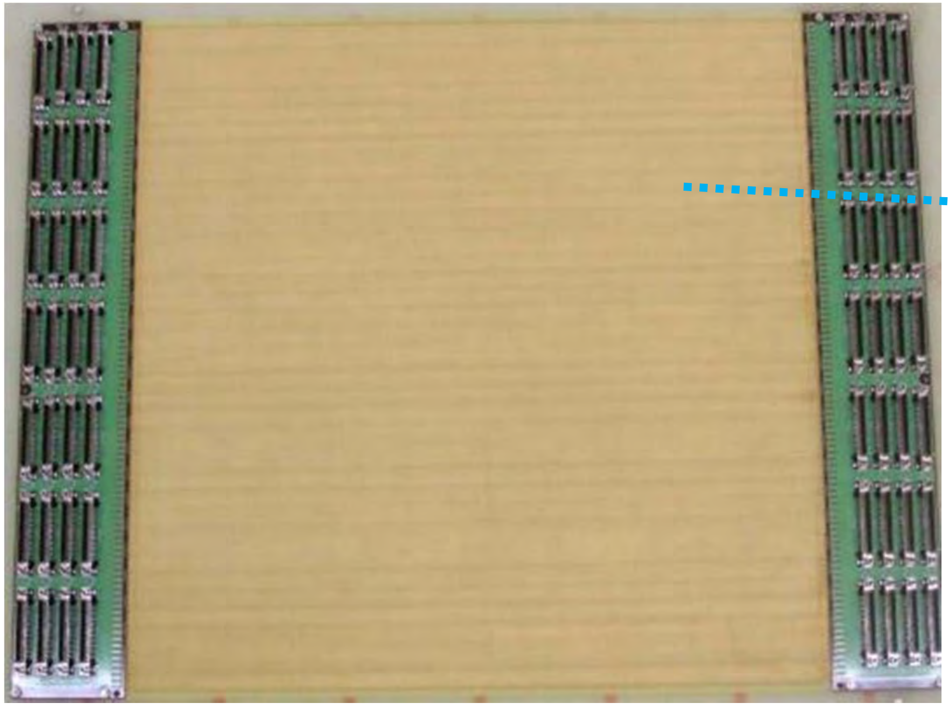
- Evaluate hazardousness index (debris index) and degree of implementation of ISO24113 on each launch.
- Based on evaluation results, launching states (or countries) supply funding to the international organization

  (Flexible charge rate dependent on evaluation results)
- Launching states can judge internal charges.
- "Emission trading" is also acceptable, similar to CO_2 problem
- Since the charge is based on the hazardousness index and ISO, it does not prevent small satellite missions by developing countries.
- If a national agency or private company gets a contract for orbital debris removal from the organization, funds can be recovered.

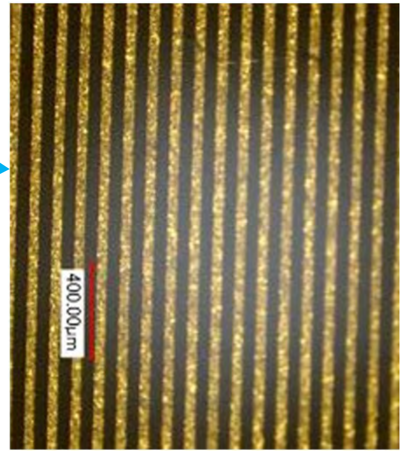
Functions of Space Debris Remediation Organization



Debris monitoring sensor BBM



Sensor area ：
35 cm (W)
x 30 cm(L)
~ 1 m^2 / 1 unit



Width of strip: 50μm
(Approx.)

Pitch: 100 μm
(Approx.)

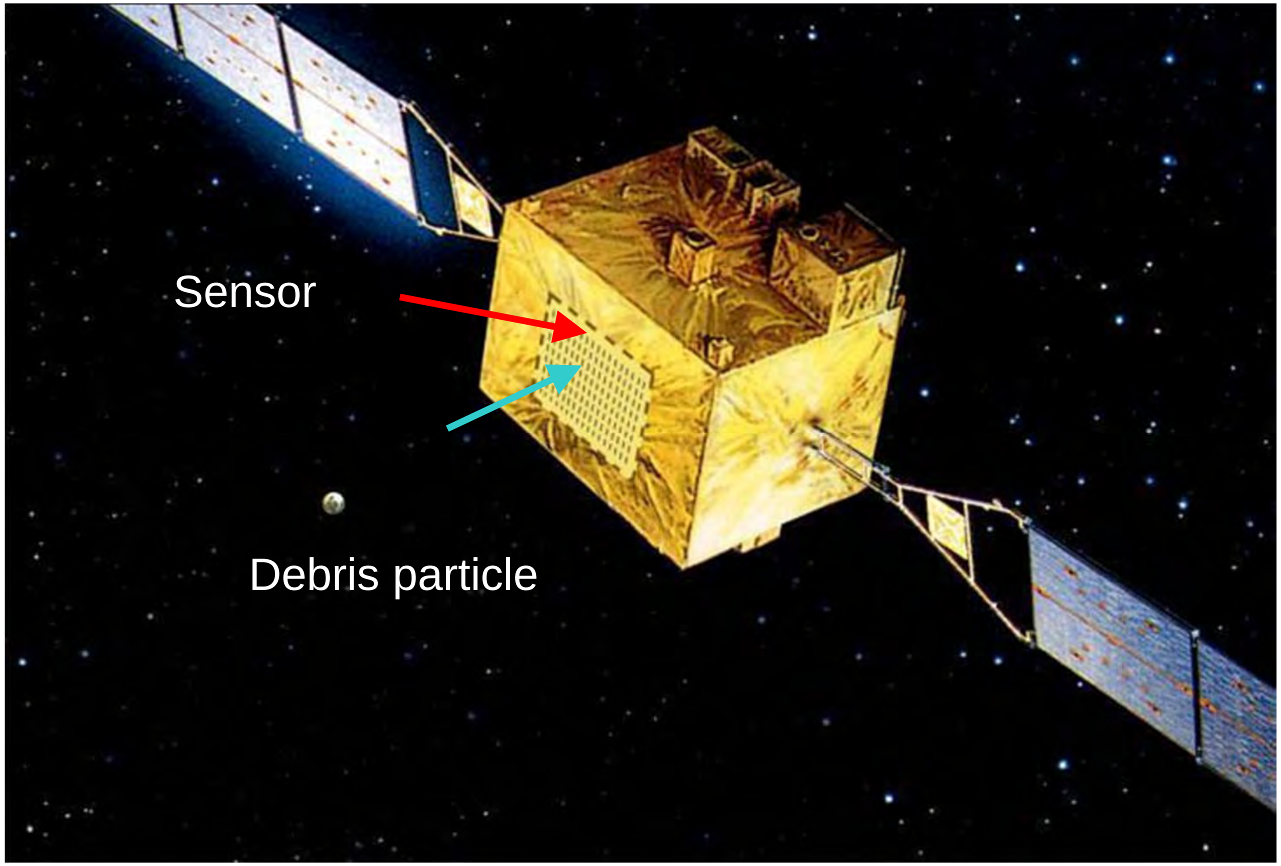
One large, "flexible printed circuit board(FCP)" as a sensor and making the connections

- No mechanical connections.   - Reduce the number of parts

(kitazawa eta al, 2011)

An example application on satellite

1) Environment estimation
2) Real time monitoring to estimate debris impact damage on a satellite.

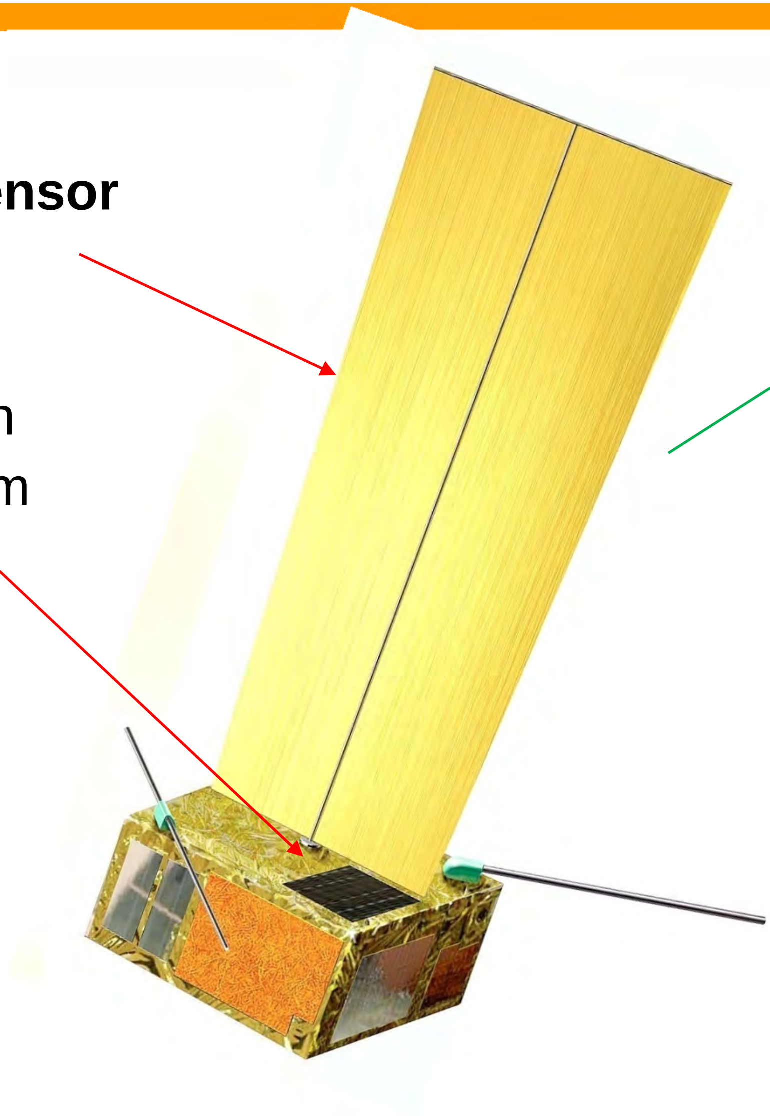


(kitazawa *et al.,* 2011)

An example of application for a small satellite

Debris Sensor

Separation
Mechanism
Flange



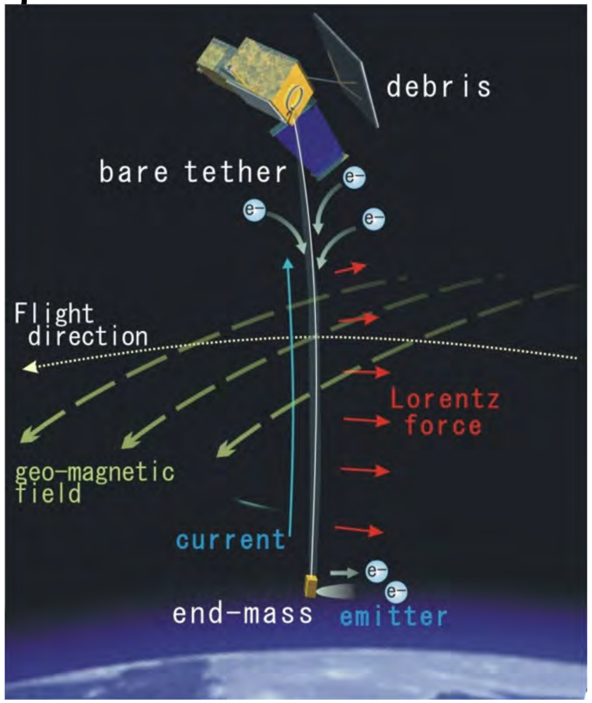
Real time dust measurement network using small satellites

http://www.i-qps.net/i-qps/

Efficient Orbital Transfer: EDT (Kawaamoto *et al*.,2009)

- Large amount of fuel will be required for de-orbit prohibiting removal by small satellite and multiple removal by one satellite
- Electrodynamic tether (EDT) is promising
  - No need for propellant or high electrical power
  - Its thrust is so small and attaching operation will be less challenging

Methods	merits	demerits
Chemical thruster	- established technology	- low Isp - difficult to fix to debris object
Ion thruster	- high Isp	- high electrical power
Solid rocket motor	- established technology - compact	- generate numerous slag/dust debris - difficult to fix to debris object
Air bag	- simple - no electrical power	- huge size required for heavy debris - debris impact risk
EDT	- high Isp - easy to attach to debris object	- debris impact risk (sustainable by net tether)



Discussion Issues

- Cash flow estimation / cost balance

  (Quantitative evaluation costs and funds)
- Assurance of sustainable activity of the organization
- Initial investment for R&D
- How do you deal with evaluation of existing debris?
- How can all this be done with due deference to national security, intellectual property, and proprietary information?

Summary

- We considered the kind of organization—and its functions—that would be suitable for debris remediation.
- Major organizational and operational requirements for the organization
  - Quantitative evaluation and confirmation of hazardousness
  - Environment change monitoring
  - Decision making on orbital debris removal