JAXA's Space Debris Related Activities : Mitigation, R&D

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Innovative Technology Research Center
ARD/JAXA

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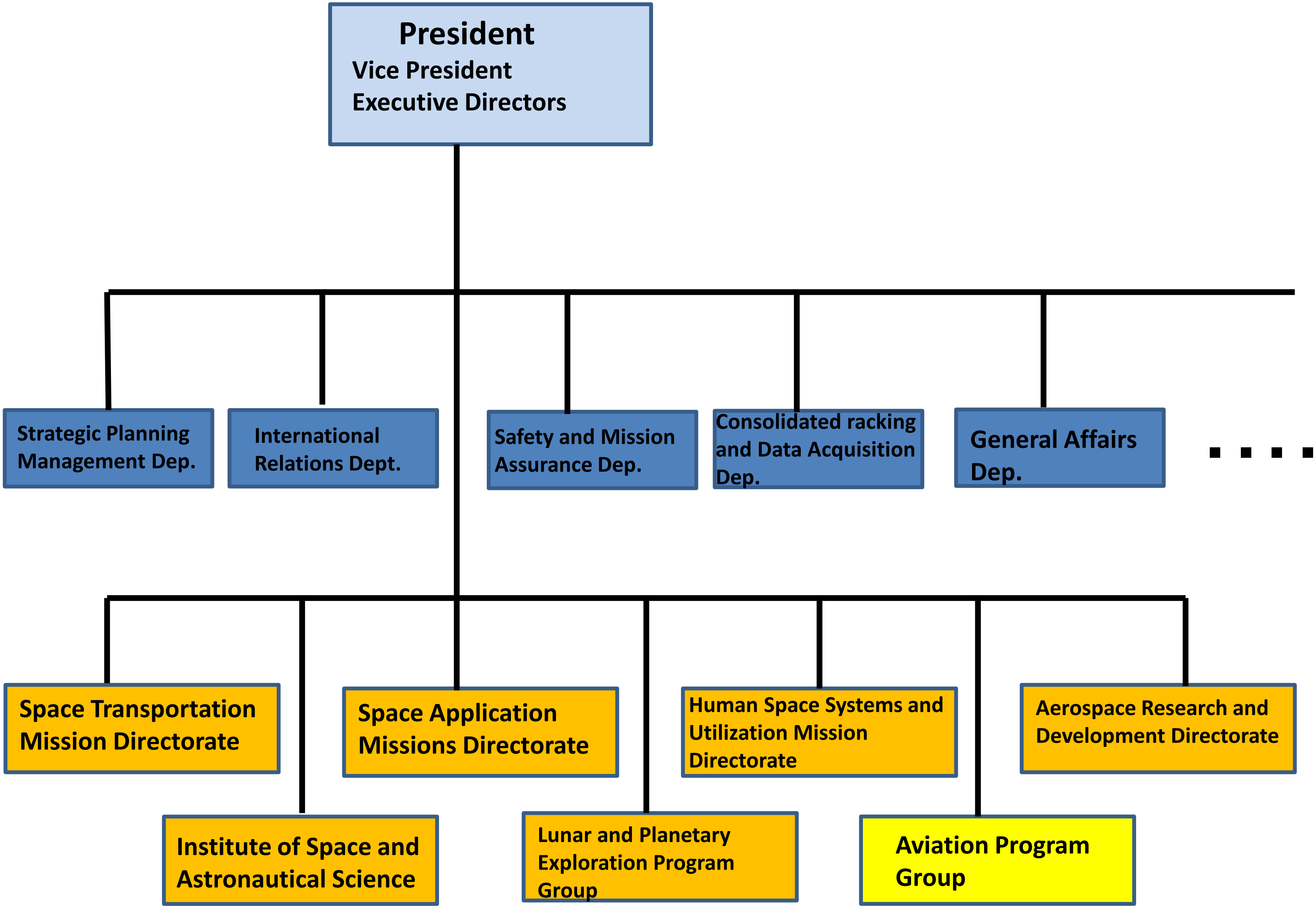
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Vice President
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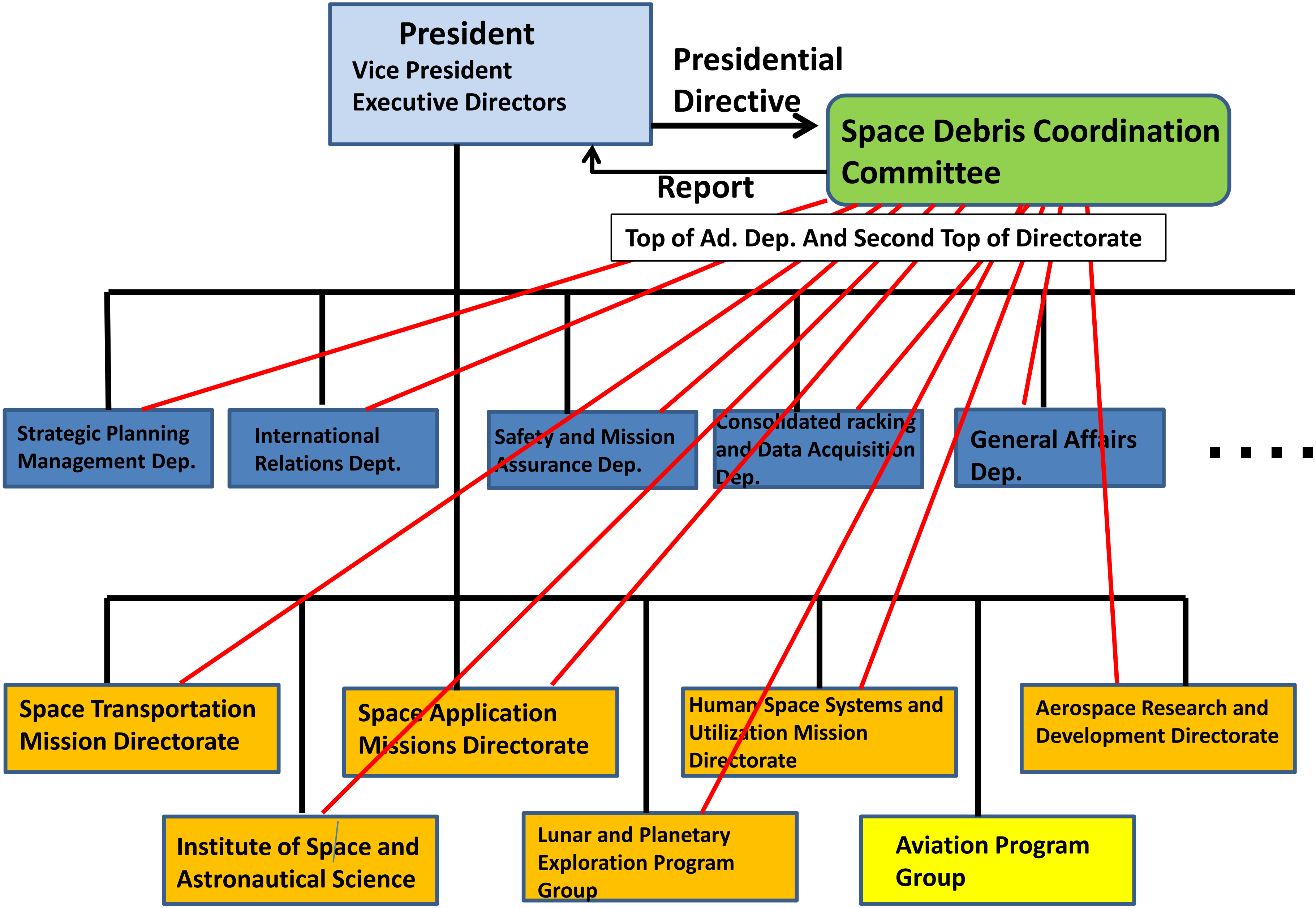
Space Transportation Mission Directorate
Space Application Missions Directorate
Human Space Systems and Utilization Mission Directorate
Aerospace Research and Development Directorate
Institute of Space and Astronautical Science
Lunar and Planetary Exploration Program Group
Aviation Program Group

1. Organizational Scheme of JAXA's Space Debris Related Activity(1)

- Space Debris Coordination Committee
  - Organized by President's directive(No.18-11) in 2006,
  - Composition: Second top level representatives of each directorate and directors of related administrative departments,
  - Mandates
    - Promotion and coordination of Space Debris related activities in JAXA,
    - Coordination with domestic and international debris related organizations, such as Government of Japan, IADC, UN and ISO,
    - Planning, Coordination, budget allocation and Evaluation of Space Debris related R & D activities in JAXA.


President
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1. Organizational Scheme of JAXA’s Space Debris Related Activity(2)

JAXA’s Document System on Space Debris

– **JAXA’s Strategic Plan on Space Debris(GEH-08002)**

The strategy described in this document is incorporated in the following documents at each administration level.

- **JAXA General Operation Plan(Short term operation plan)**
  - Directorate Operation Plan
    - R & D Control Document
- **JAXA’s Technology Road Map (Long term technological goals and plans)**
  - Mission assurance against Space Debris Technology RM
  - Debris Mitigation Technology RM
  - Ground Safety Assurance Technology RM

2. Debris Related R&D Activity in JAXA (1)

"JAXA's Strategic Plan on Space Debris(GEH-08002)"establishes four strategic goals and sets several specific R&D issues for each goal,

- **<u>Strategic Goal 1</u>**

Assure mission success by reasonable and practical countermeasures depending on importance of the mission.

- **<u>Strategic Goal 2</u>**

Suppress generation of new debris at some reasonable level with a good balance of cost and reliability to ensure sustainable space development and utilization activity.

- **<u>Strategic Goal 3</u>**

Assure the ground safety in reentry process of space systems.

- **<u>Strategic Goal 4</u>**

Develop cost-effective enabling technologies for ADR operation and to pursue implementation of a practical ADR system through the framework of international cooperation.

2. Debris Related R&D Activity in JAXA (2)

- **<u>Strategic Goal 1</u>**

Assure mission success by reasonable and practical countermeasures depending on importance of the mission

- **<u>Specific R&D issues</u>**
  - **Debris environment evolution model**
  - Collision avoidance
  - Ground based debris observation
  - On orbit debris observation
  - Space system protection
  - Micro Meteoroid and Debris Impact Detector

List of evolutional models available

- ASI/Space Debris Mitigation long-term analysis program (SDM)
- ESA/Debris Environment Long-Term Analysis Software (DELTA)
- ISRO/Long-term debris environment projection model(KSCPROP)
- JAXA-Kyushu Univ./LEO Long-Term Debris Environment Evolution Model (LEODEEM)
- NASA/LEO-to-GEO Environment Debris Model (LEGEND)
- UKSA-Univ. of Southampton/Debris Analysis and Monitoring Architecture the Geosynchronous Environment(DAMAGE)

Using LEODEEM, JAXA is actively contributing to international study activities, such as IADC and IAA.

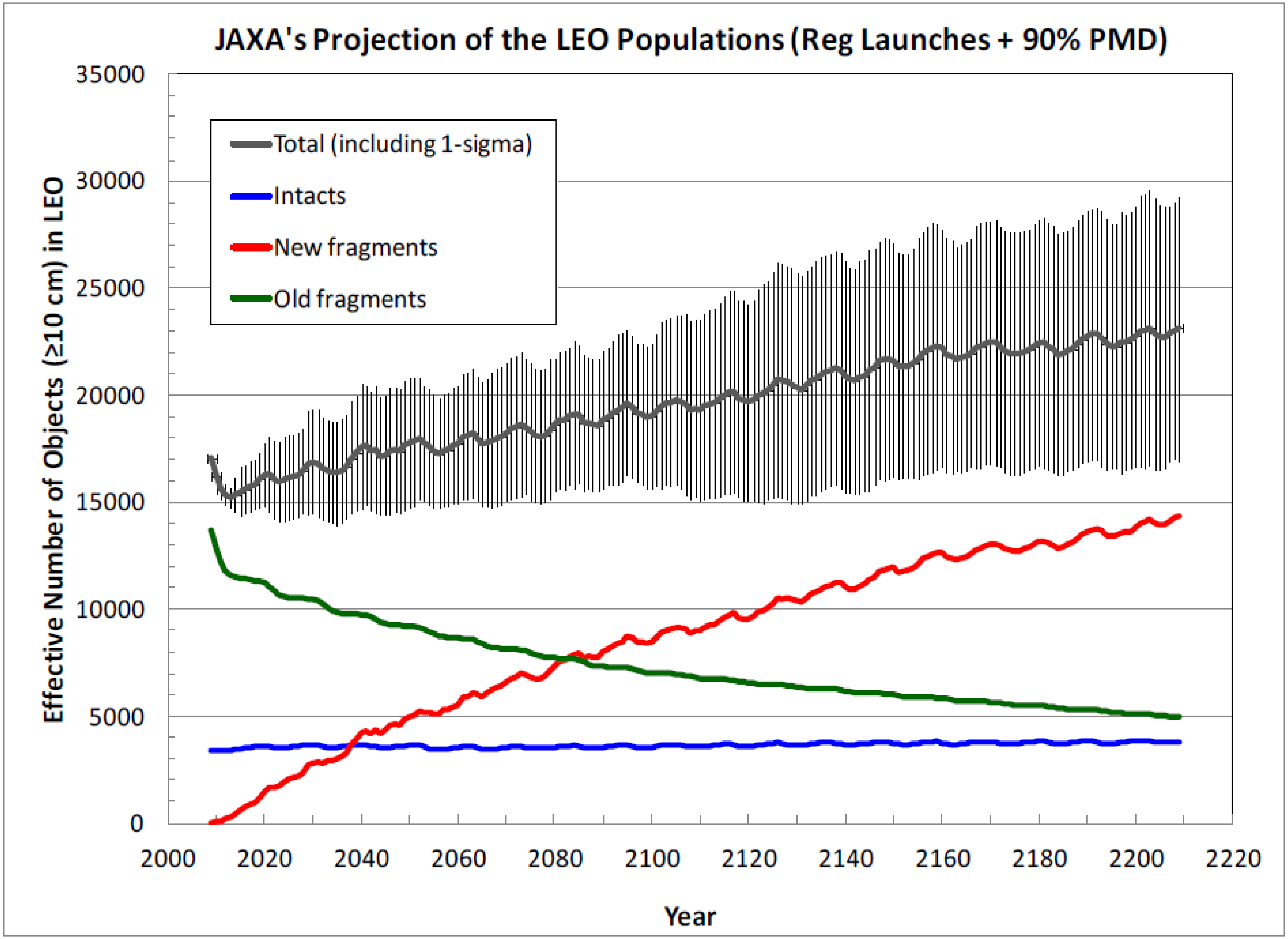


Figure 9. JAXA's projection of the future LEO population.

IADC AI27.1, 2013

2. Debris Related R&D Activity in JAXA (2)

- **Strategic Goal 1**

Assure mission success by reasonable and practical countermeasures corresponding to importance of the mission

- **Specific R&D issues**
  - Debris environment evolution model
  - Collision avoidance
  - **Ground based debris observation**
  - On orbit debris observation
  - Space system protection
  - Micro Meteoroid and Debris Impact Detector

Ground based debris observation

Japan, as well as other countries, is owing to the US observation capability (SSN) very much. JAXA's contribution in this field is limited but very unique.

- **R&D on Optical Observation technology using "Nyukasa" optical observational facility.**
  - **"Stacking method" for GEO observation,**
  - **Application of optical observation technology in LEO debris observation.**

- Cataloging Efforts
  - Observation and data logging using "Bisei" optical observatory and "Kamisaibara" radar observatory, basically based on TLE information.

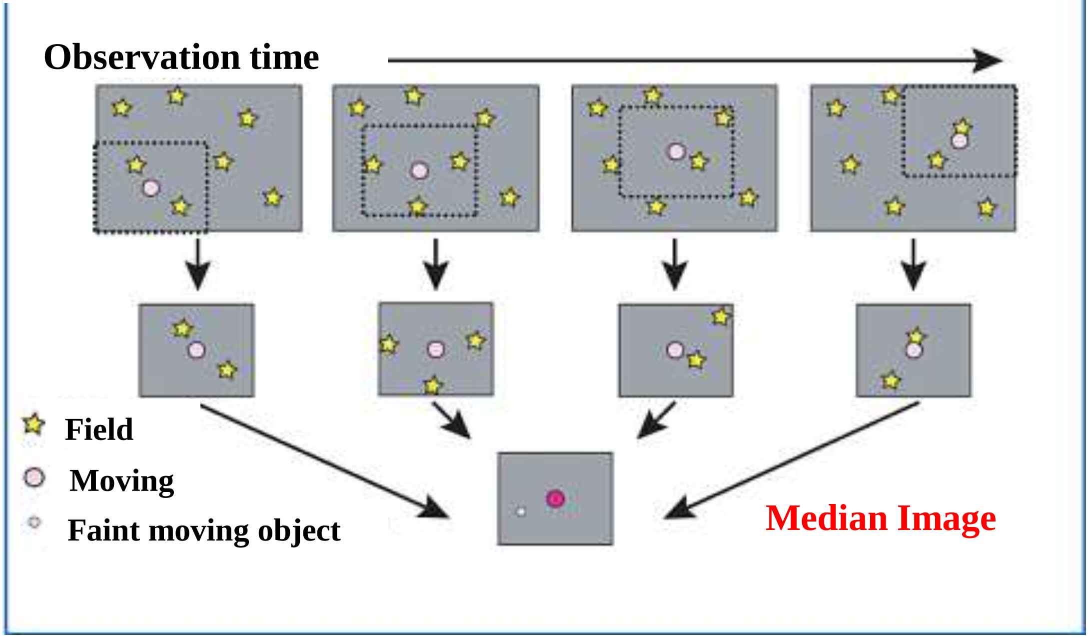
Optical Observational Facility of JAXA at Mt. Nyukasa

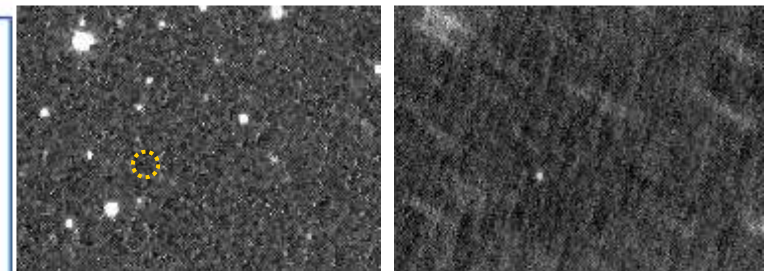
Overview of the facility

Data analysis process Ⅰ: Stacking method

The stacking method uses multiple CCD images to detect very faint objects that are undetectable on a single CCD image.

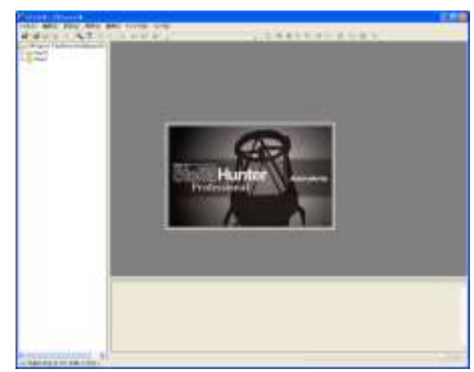
Concept of the stacking method





A faint object detect with the stacking method. One CCD image (left) and the stacked image (right).

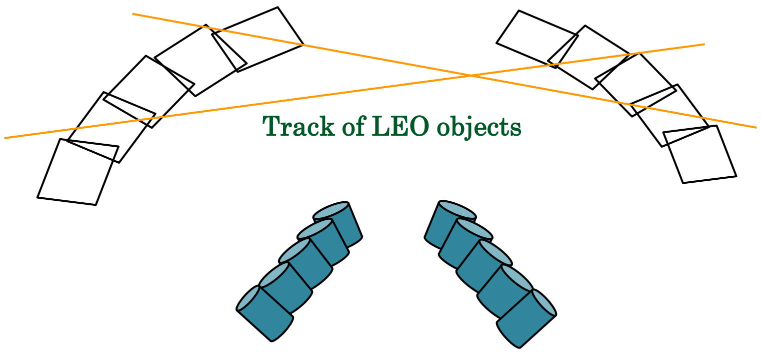
Sub-images are cropped from many CCD images to follow the presumed movement of moving objects. Faint objects are detectable by making the median image of these sub-images.

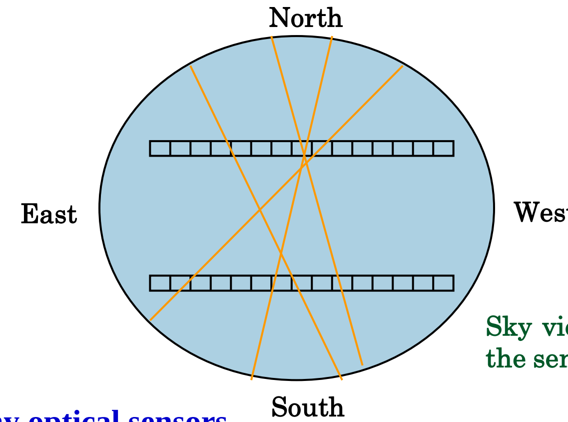


Stellar Hunter Professional: Commercial software for discovering asteroids and comets.

Many asteroids were discovered by the method.

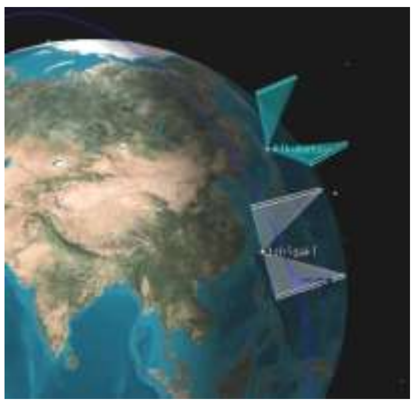
Large array of optical sensors for LEO debris observation

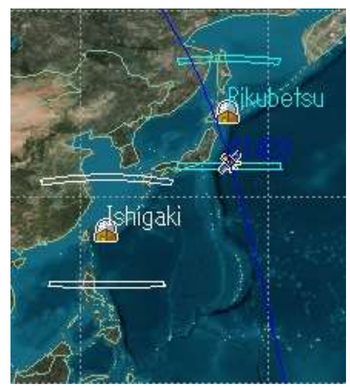




Sky view and FOV of the sensors

LEO observation system using many optical sensors





1st pass

2nd pass

Detection of identical object at sites

●**Many optical observation units are installed to cover large area since each unit has narrow FOV. In order to get long arc for accurate orbit determination, 2 narrow rectangular regions which separate about 80-degree are observed using 40 observation units.**

●**Observation of 2 consecutive passes enable us to do accurate orbit determination. For this reason, 2 longitudinally separated sites are considered.**

Test observation

Observation sites:

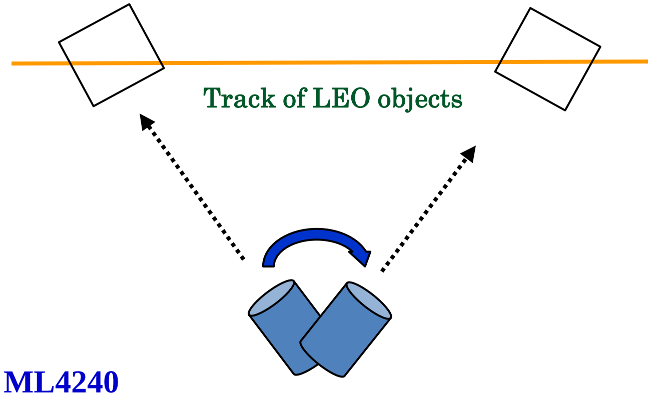
Ishigakijima Morita Observatory (Okinawa)

Rikubetsu Observatory (Hokkaido)

Observation equipments:

Canon 200mm F2 + FLI ML23042

Canon 300mm F2.8 + FLI ML4240



Observation date and time: Jul/27-28/2012 after dusk and before dawn

Targets: 4 TLE-objects (14521, 13589, 20720, 21574)

In order to mimic the observation using the optical array system described before, some TLE-objects were observed assuming one of the sensor of the system detects those objects with no TLE information. Each object was observed at 2 separate sky regions on each site. The first day's data was used for orbit determination and the second day's was for evaluation of the accuracy of the orbit determination.

2. Debris Related R&D Activity in JAXA (2)

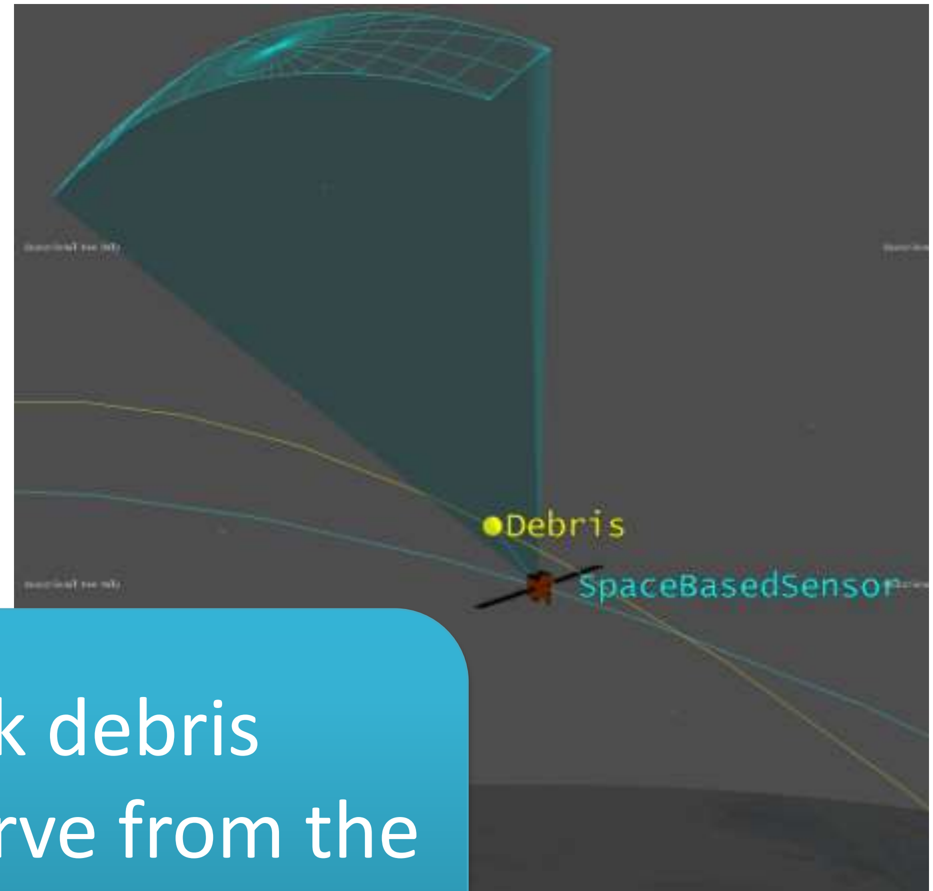
- **Strategic Goal 1**

Assure mission success by reasonable and practical countermeasures corresponding to importance of the mission

- **Specific R&D issues**
  - Debris environment evolution model
  - Collision avoidance
  - Ground based debris observation
  - **On orbit debris observation**
  - Space system protection
  - Micro Meteoroid and Debris Impact Detector

Space-Based Observation

- Why space-based ?
  - ✓ No atmospheric extinction
  - ✓ No visible time constraint
  - ✓ No geographical limit
  - ✓ Flexible operation scenario
  - ✓ Higher sensitivity



Enable to detect and track debris which is too faint to observe from the surface (i.e. smaller than 10 cm)

Catalog efficiency analyses

Simulation conditions

Satellite: sun-synchronous orbits in the vicinity of in the day-night trminator and the line of sight directed anti-solar. 600 km altitude.

Objects: 600 to 800 km altitude, eccentricity 0.002 choosing 967 objects

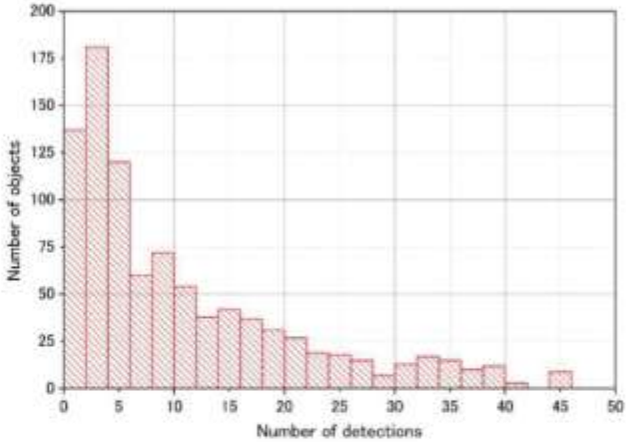
Period: 01/15/2013 ~ 01/25/2013

Optical sensor : 15.8 ° × 15.8 ° FOV

Exposure time 1sec

To count up newly detected objects in the CCD.

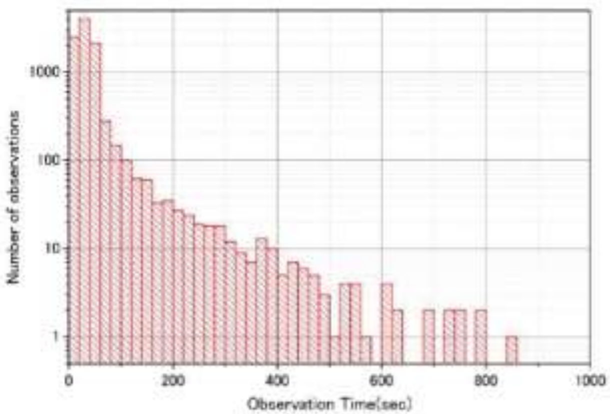
Result(1/2)



Number of detections of three days from 2013/01/15.
315 (32.6%)individual objects can be observed continuously for 3 days.

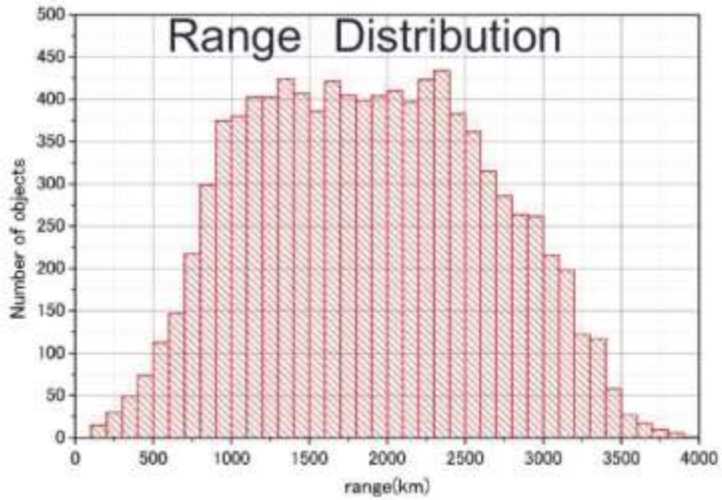
Detection objects in the number of in different times

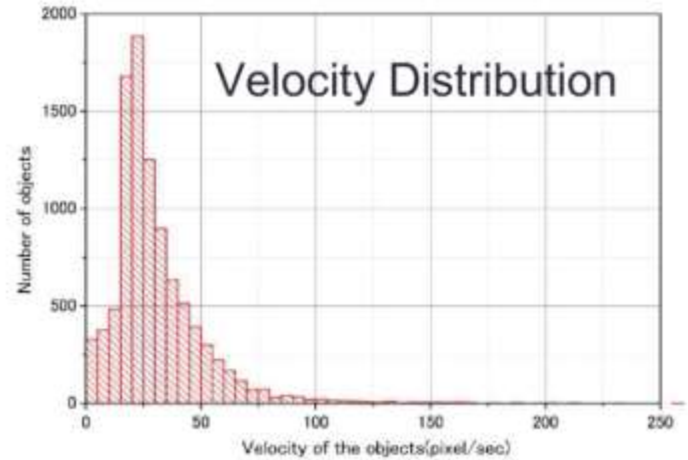
Detection time	Number of objects	Percentage
1day	585	60.5%
2days	792	81.9%
3days	855	88.4%
4days	883	91.3%
10days	937	96.9%

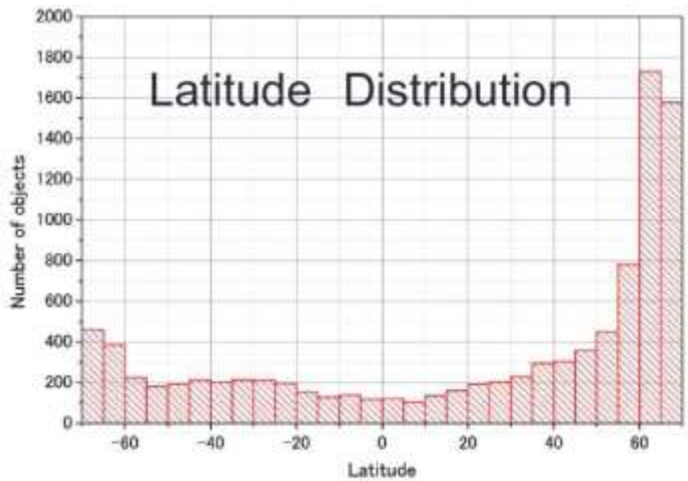


Observation time of object(3 days)

Result(2/2)


Range Distribution
Number of objects
range(km)
0
500
1000
1500
2000
2500
3000
3500
4000
50
100
150
200
250
300
350
400
450


Velocity Distribution
Number of objects
Velocity of the objects(pixel/sec)
0
50
100
150
200
250
500
1000
1500
2000

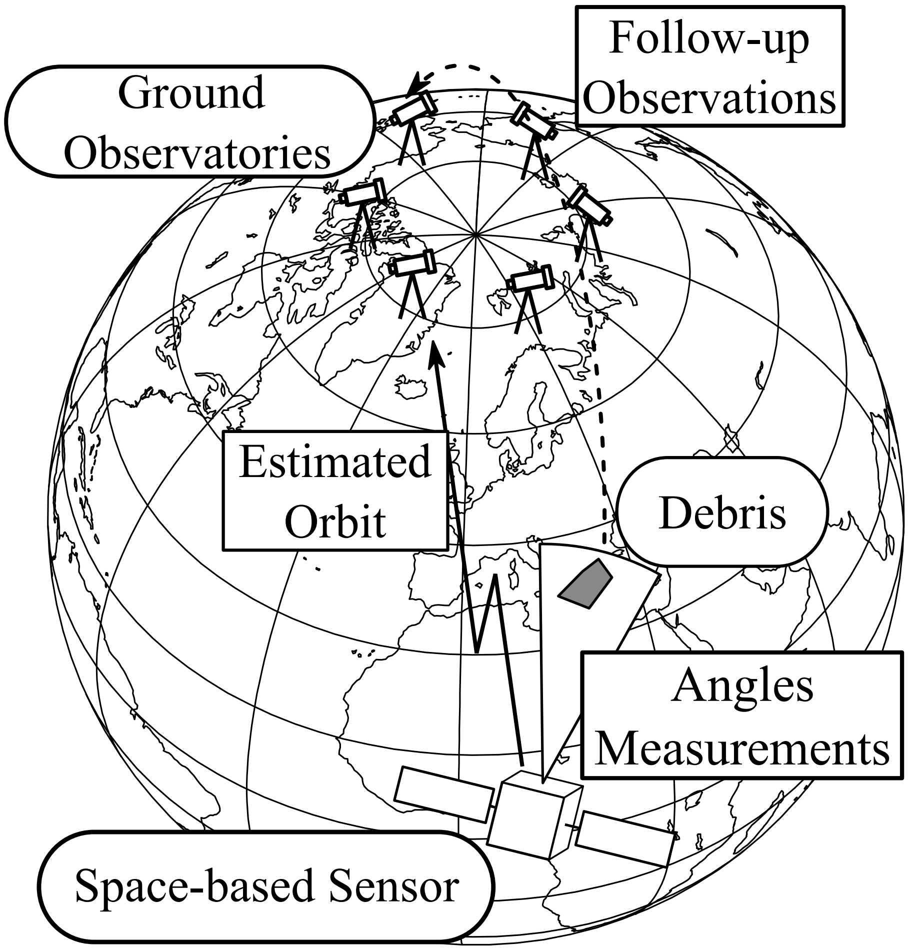

Latitude Distribution
Number of objects
Latitude
-60
-40
-20
0
20
40
60
200
400
600
800
1000
1200
1400
1600
1800
2000

Space-Based Observation : Current Issue

- **A space-based sensor is not a silver bullet**
  - ✓ **Good for detect (high sensitivity)**
  - ✓ **Bad for tracking (low obs. frequency)**

A sensitive and frequent observation system is required to achieve the final goal

- **One of the solutions is a collaborative observation system illustrated in right figure**



2. Debris Related R&D Activity in JAXA (2)

- **Strategic Goal 1**

Assure mission success by reasonable and practical countermeasures corresponding to importance of the mission

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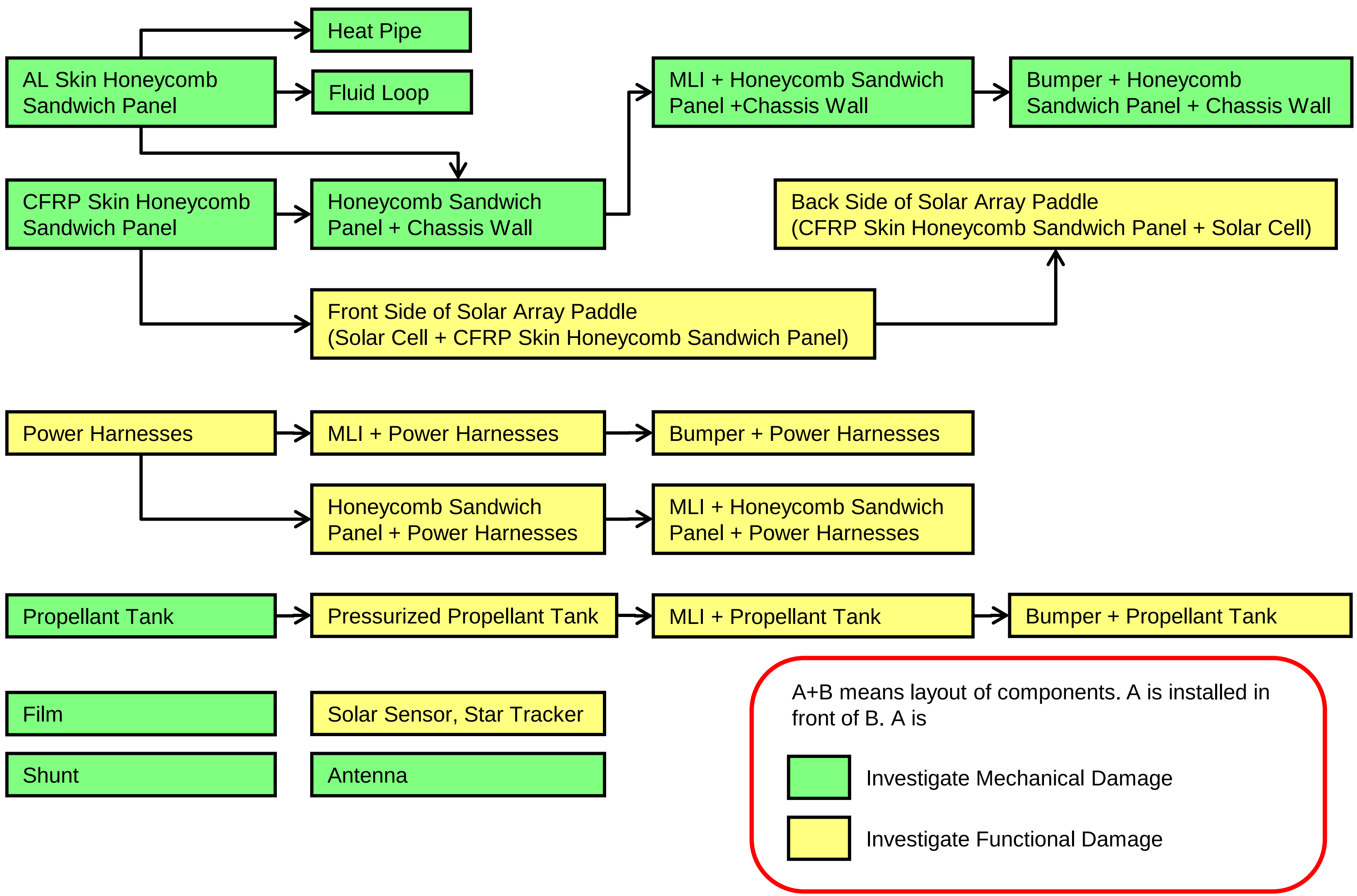
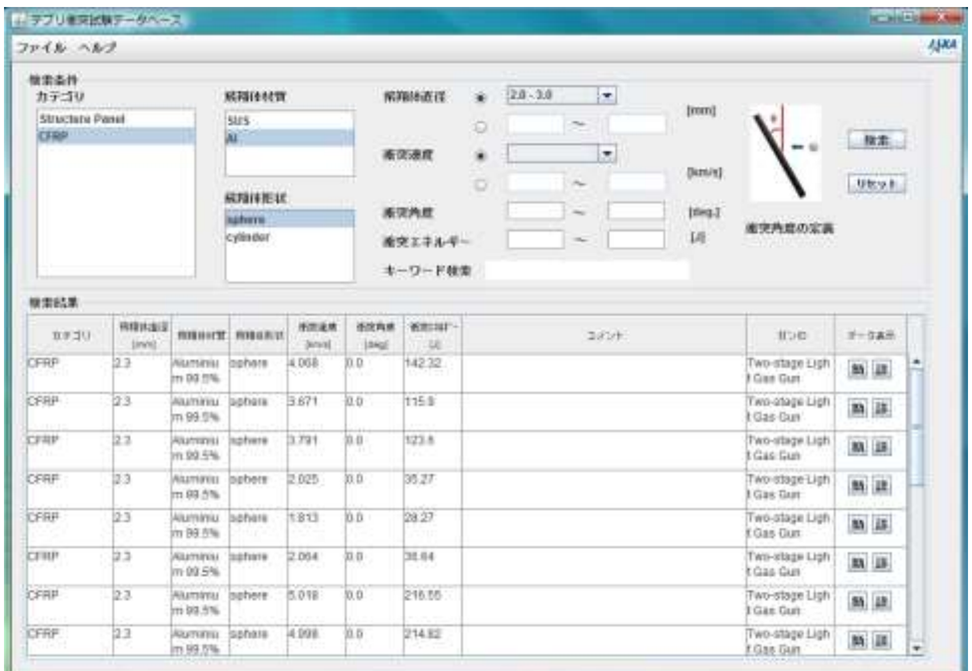
Spacecraft Components Required Debris Impact Data



Database

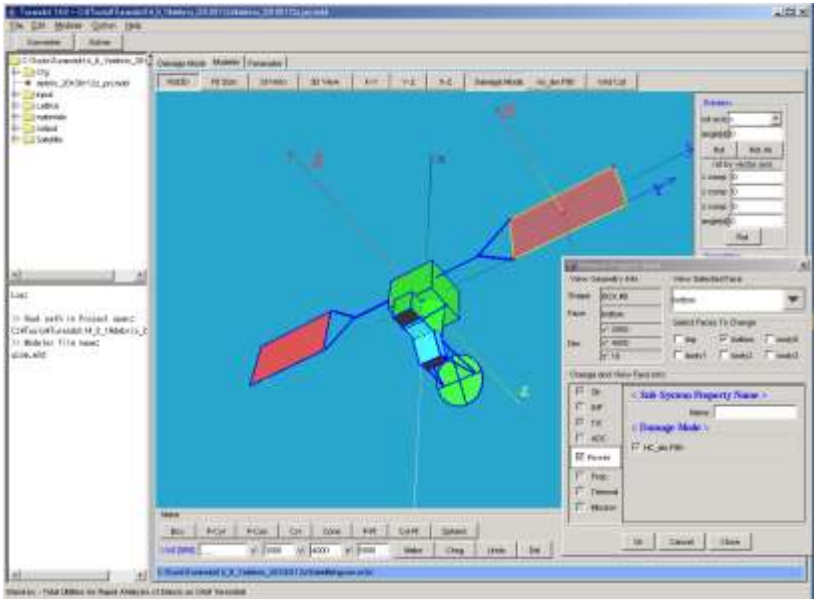
- **Database for hypervelocity impact experiment and hydrocode simulation results**
- **Interoperability with other organization’s database should be pursued through international framework such as IADC.**



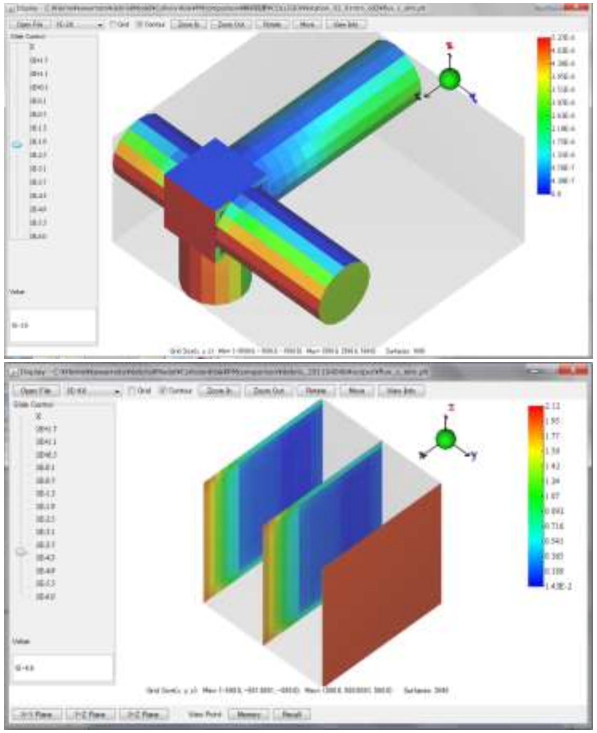
Simple view (in Japanese) and Detail view (in English) are implemented

Collision risk analysis tool "TURANDOT"

- **Debris impact probability on each surface of a space system can be analyzed using the system configuration model and debris environment engineering models, such as MASTER and ORDM.**



TURANDOT



Benchmark test models (IADC)

2. Debris Related R&D Activity in JAXA (2)

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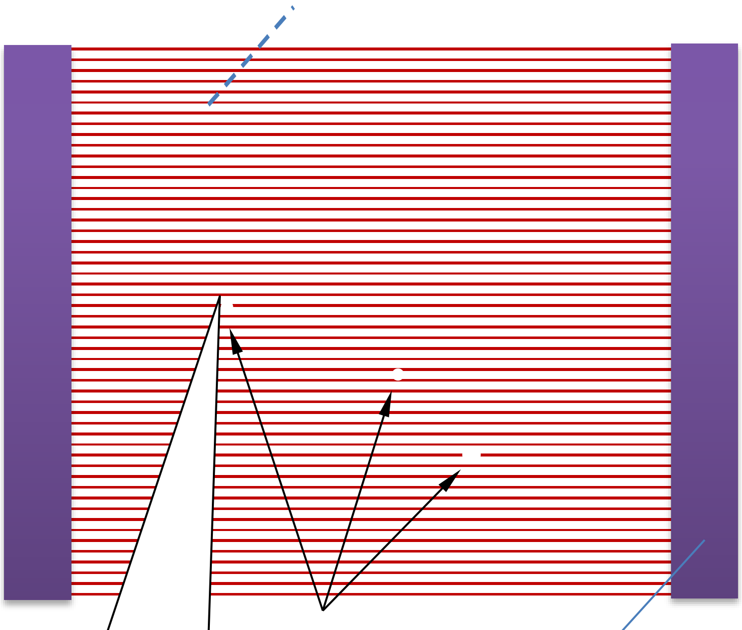
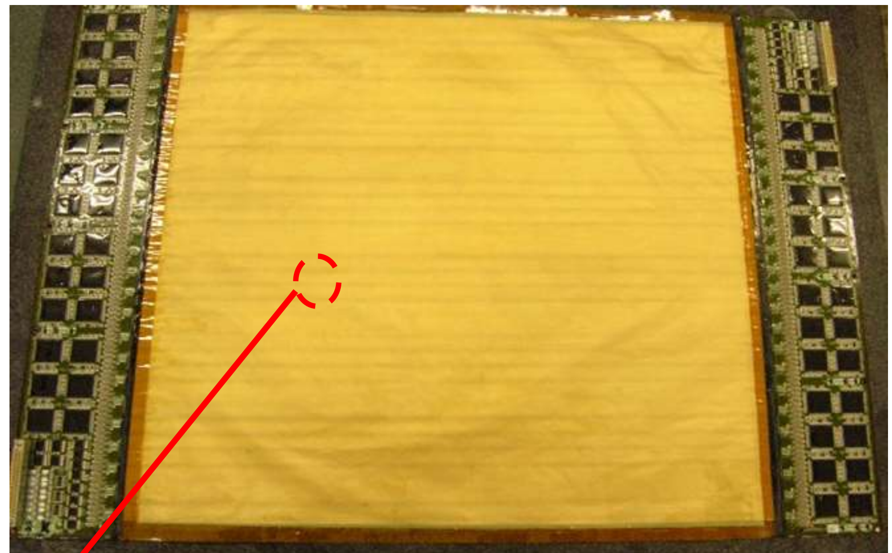
Sensor Concept and EM (Engineering Model)

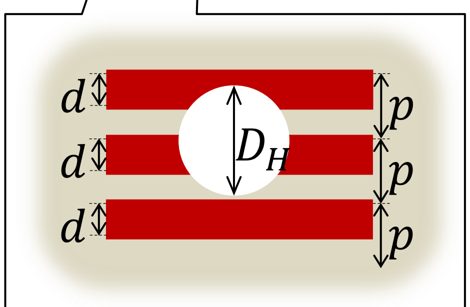
Sensor surface: Multitude of thin conductive strips are formed with fine pitch on a thin polyimide film



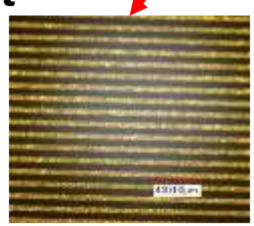


Sensor area：35 cm (W) x 30 cm(L)/ 1 unit

Sensor Circuit
Detection of severing

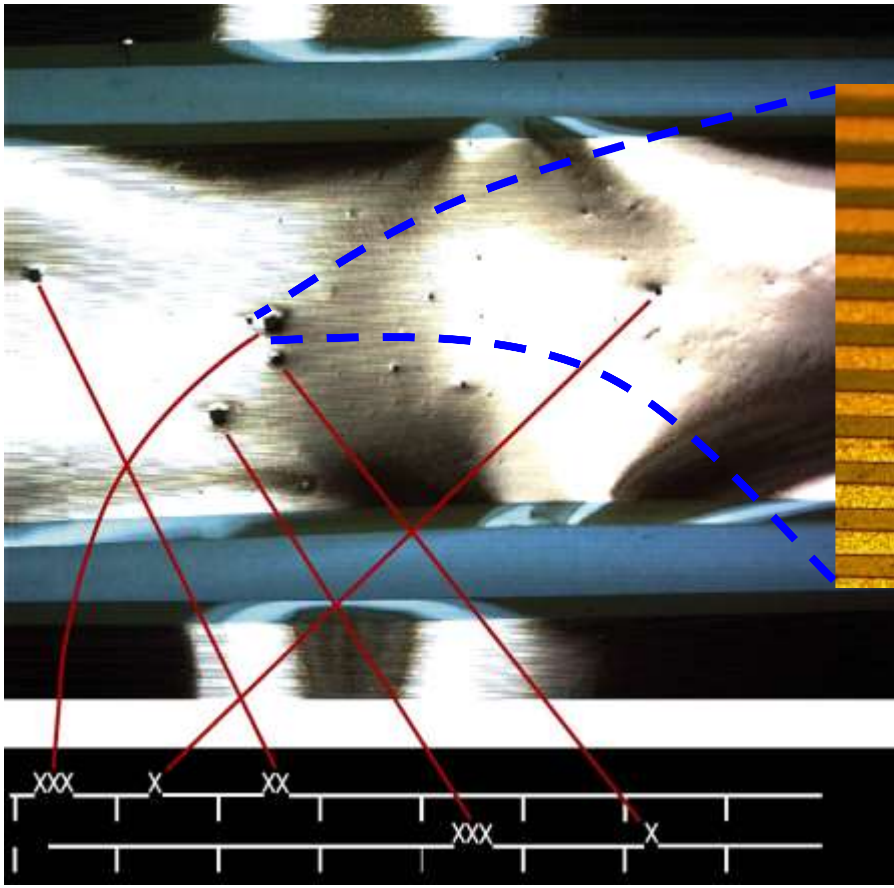


(Sakurai, 2008)

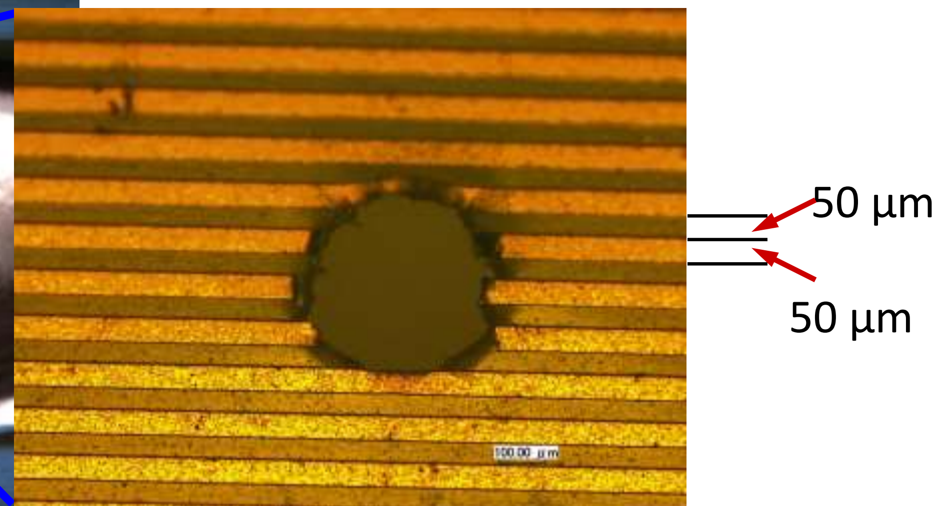


- Width of strip:(d) 50 μm
- Pitch(p) 100 μm
- Thickness: 25 μm

One large FCP board as a sensor and making the connections
- No mechanical connections.
- Reduce the number of parts



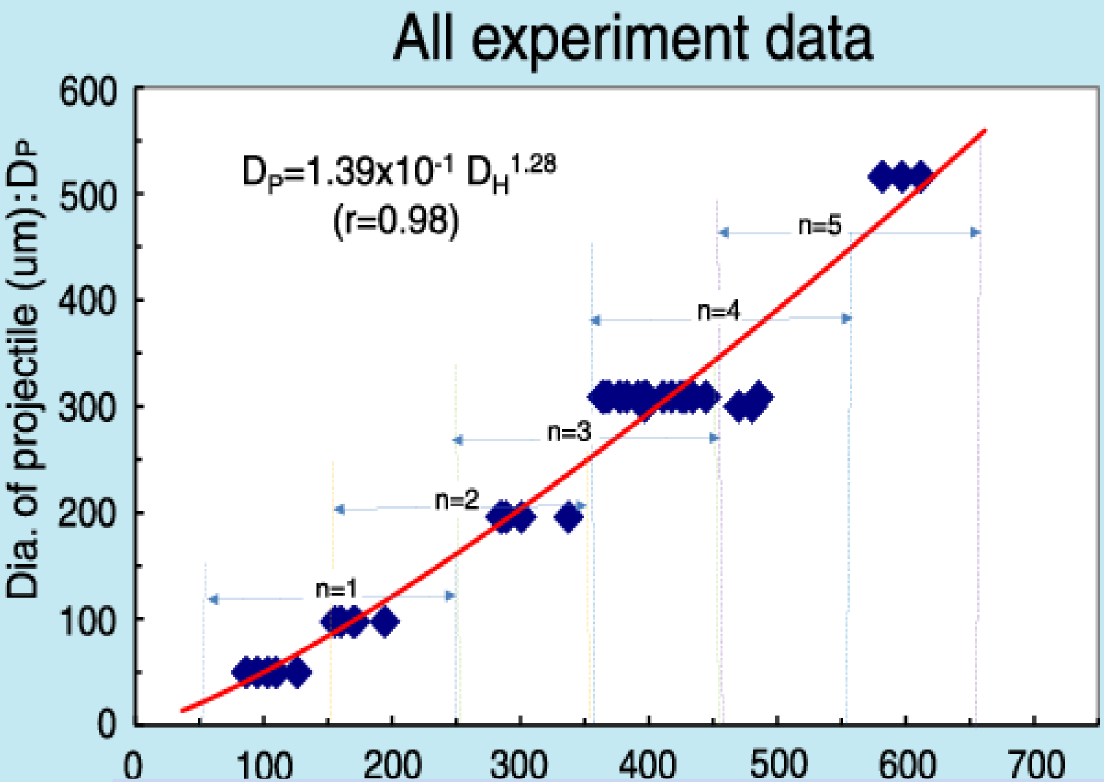
Signals of perforation holes



Example perforation hole on sensor surface

Projectile: SUS 309 µm
Impact velocity: 4.65 km/s

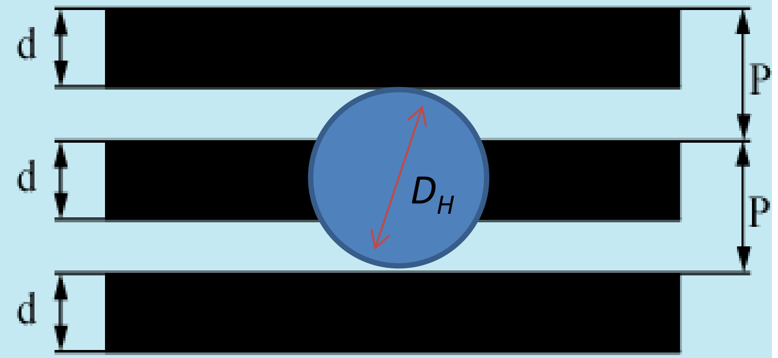
<u>Example correspondence between signal and perforation hole</u>



Dia. of perforation hole (µm): D_H

Dia. of perforation hole vs. Dia. of projectile

(n: number of severed conductive strips)

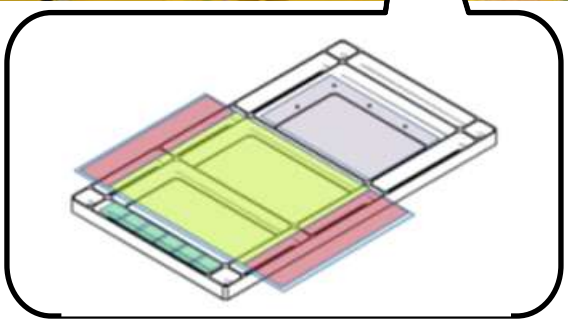


$$D_{H(Maximum)} = np + d + p$$
$$D_{H(Minimum)} = np + d - p$$

D_H: dia. of perforation hole
n: number of severed strips
d: width of conductive strips
p: pitch of conductive strips

Flight experiment on HTV

- HTV (H-II Transfer Vehicle) called "KOUNOTORI"
  - JAXA's unmanned cargo transfer spacecraft which delivers supplies to the International Space Station (ISS).
- KASPER (KOUNOTORI Advanced Space Environment Research Equipment)
  - Space Debris Monitor + Charging Monitor
  - On the propulsion module of HTV-5 launched in 2014
  - Mission duration: 1-2 months
- To demonstrate the sensor's functional capability in space environment.
  - Housing and controller of the debris sensor are developed.



2. Debris Related R&D Activity in JAXA (3)

- <u>**Strategic Goal 2**</u>

Suppress generation of new debris at some reasonable level with a good balance of cost and reliability to ensure sustainable space development and utilization activity

- <u>**Specific R&D Issues**</u>
  - **Maintain and update JAXA's Debris Mitigation Standard**
  - Contribution to ISO standardization activity
  - Active participation in IADC
  - Enhance understanding in the industrial sector
  - Issue debris related specification of JAXA
  - Related R&D

Debris Mitigation Standard Support Tools "DEMIST Ver. 0.6"

- **Easily check compatibility of mission and system design with JAXA's debris mitigation standard (JMR003) at early stage of a project .**

2. Debris Related R&D Activity in JAXA (3)

- **Strategic Goal 2**

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  - Enhance understanding in the industrial sector
  - Issue debris related specification of JAXA
  - **Related R&D**

Metal-free composite solid propellant

- Metal fuel (Al) in composite solid propellant generates Al/Alumina slug (Space Debris).
- Isp of Metal free solid propellant is insufficiency for solid propulsion system.
- GAP polymer is one of the candidate for the energetic propellant binder to enhance Isp.
- Isp loss of the new composition (metal free-GAP/AP) is within 8 %.

Conventional

Oxidizer	Fuel	
AP	Al	HTPB

Al/Alumina Slug Exhaust⇒Debris

New composition

Oxidizer	Fuel
AP	GAP-Polymer

Debris Free Exhaust

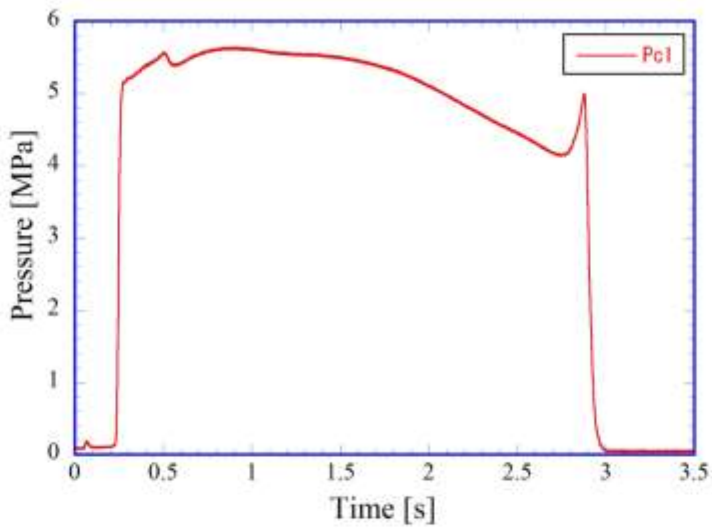


Fig.1 Pressure Profile

Fig.2 Static Firing test

※
AP: Ammonium perchlorate
HTPB: Hydroxy-terminated polybutadiene
GAP: Glycidyl-Azide polymer

2. Debris Related R&D Activity in JAXA (4)

- **<u>Strategic Goal 3</u>**

Assure the ground safety in reentry operation of space systems

- **<u>Specific R&D Issues</u>**
  - Improvement of the assessment tool (ORSAT-J) for ground safety through reentry operation
  - Observation of reentering risk objects
  - **R&D for reduction of risk on ground**

Reentry Melting Promotion Type Propellant tank

In order to reduce the casualty risk on ground, JAXA is developing the easy melting propellant tank for satellite below, made of CFRP with aluminum liner.

Table 1 Tank specifications

Parameters	Requirements
MEOP	2.76MPa
proof pressure	3.45MPa
burst pressure	4.14MPa
temperature range	5～60°C
total volume	$0.35m^3$
propellant	hydrazine (N_2H_4)
other fluid	He, H_2O, IPA, N_2
external leakage	$\leq 1.013\times10^{-7}$ Pa m^3/s @MEOP,He
pressurization cycle	MEOP:>20, Burst:>5
expulsion Efficiency	≥99.5%
mass	≤20.0kg
on orbit life	≥5years(target:≥15years)

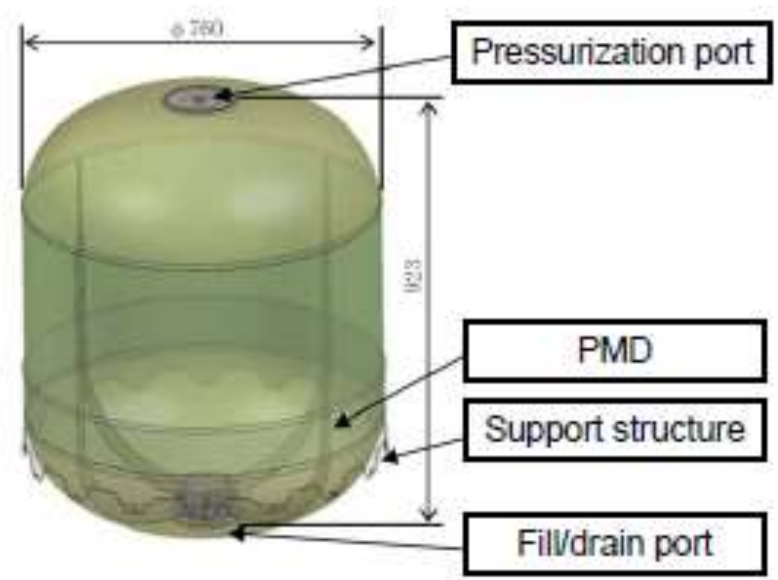


Fig. 1 Configuration

2. Debris Related R&D Activity in JAXA (5)

- **<u>Strategic Goal 4</u>**

Develop enabling cost-effective technologies for ADR operation and to pursue actual implementation of a practical ADR system through the framework of international cooperation.

- **<u>Specific R&D Issues</u>**
  - **ADR(Details will be given in another lecture on ADR)**

3. JAXA's Space Debris Mitigation Activity (1)

- Document system on Debris Mitigation
  - **Debris Mitigation Standard (JMR003B)**
  - Space Debris Mitigation Support Document (CAA-110029)
  - Space Debris Protection Manual (JERG-2-144HB001)
  - Rocket Design and Operation Manual (under discussion)
  - Spacecraft Design and Operation Manual (CAA-111003)

3. JAXA's Space Debris Mitigation Activity (2)

Space Debris Mitigation Standard (JMR-003B)

■ **Principles**

(1) Preventing the on-orbit break-up of the space systems

(2) Transferring a spacecraft that has completed its mission in GEO into higher orbit

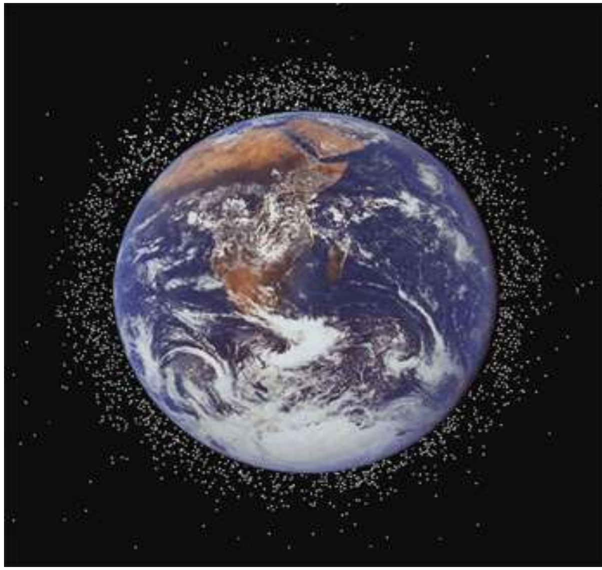
(3) Reducing the stay time of the orbital stage in the GTO

(4) Minimizing the number of objects released in orbit during operation

(5) Reducing the stay time of the space systems in LEO. (≤ 25 years)

(6) Minimize the casualty risk on the ground during reentry disposal of space systems

(7) Avoidance of the on-orbit collision



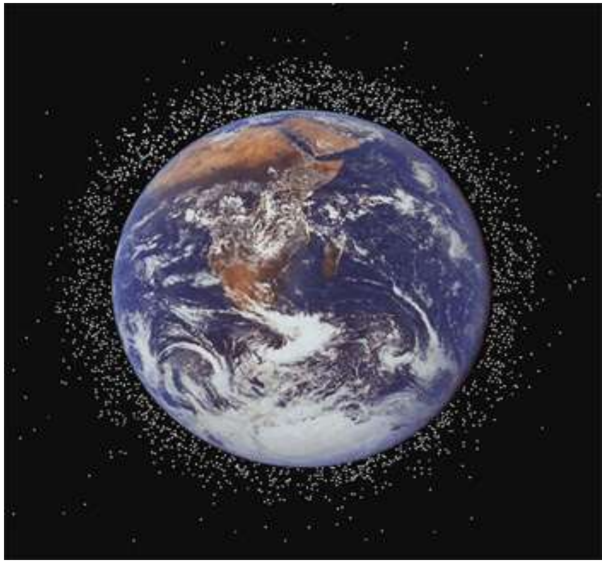
■ Space Debris Mitigation Management

(1) Project and contractors shall assign a responsible organization or individual that has responsibilities to study, plan, implement and review the effective measures to ensure space debris mitigation management.

(2) Project should develop a feasible Debris Mitigation Plan after tailoring the requirements of this standard in coordination with the Safety and Mission Assurance Department.

(3) The plan may be incorporated into the System Safety Program Plan. The plan should be offered to the System Safety Review Board for review.

(4) Contractors should also prepare a Space Debris Mitigation Management Plan which complies with the Debris Mitigation Plan presented by JAXA. The plan should be submitted to JAXA for its approval.



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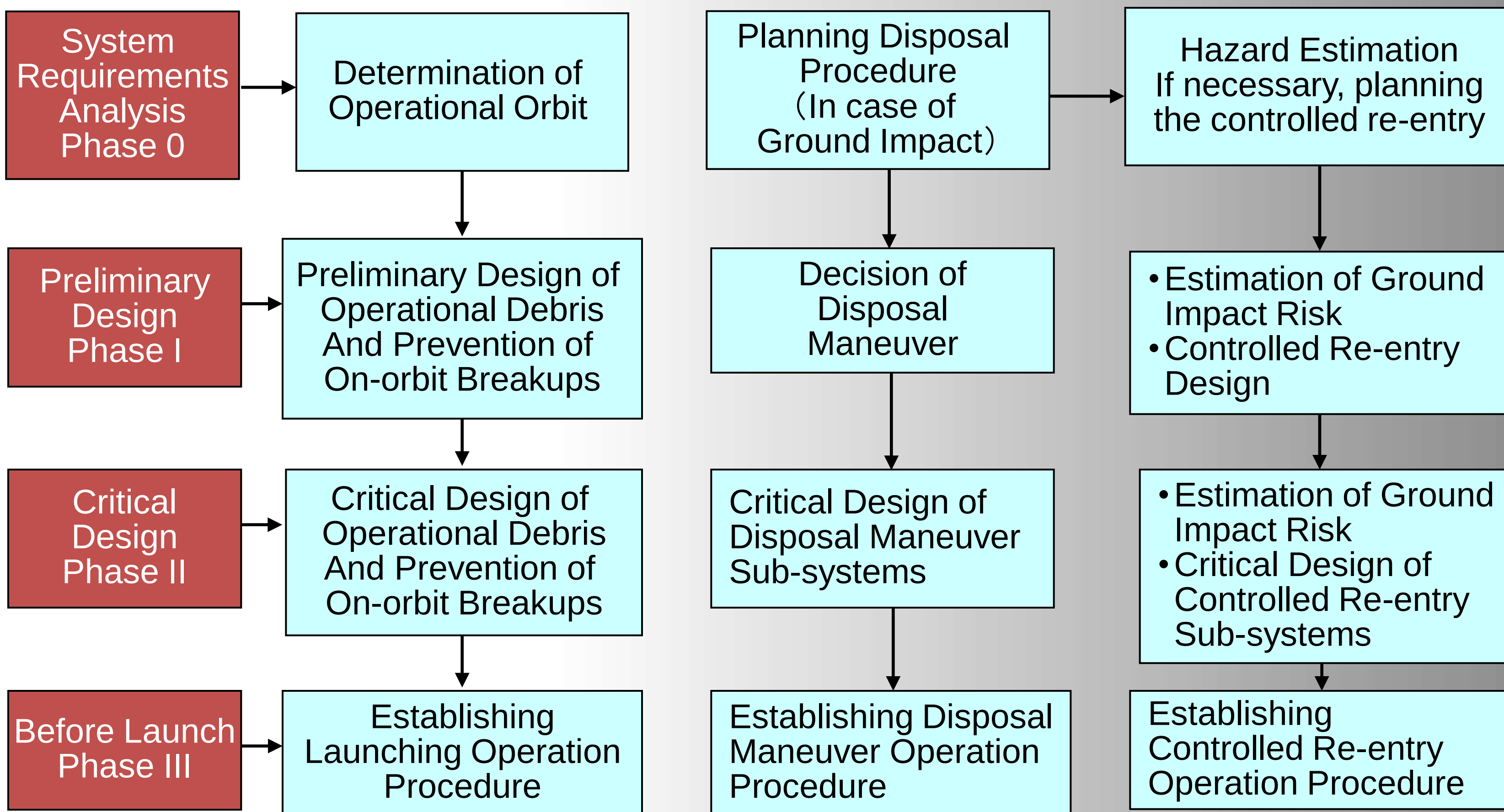
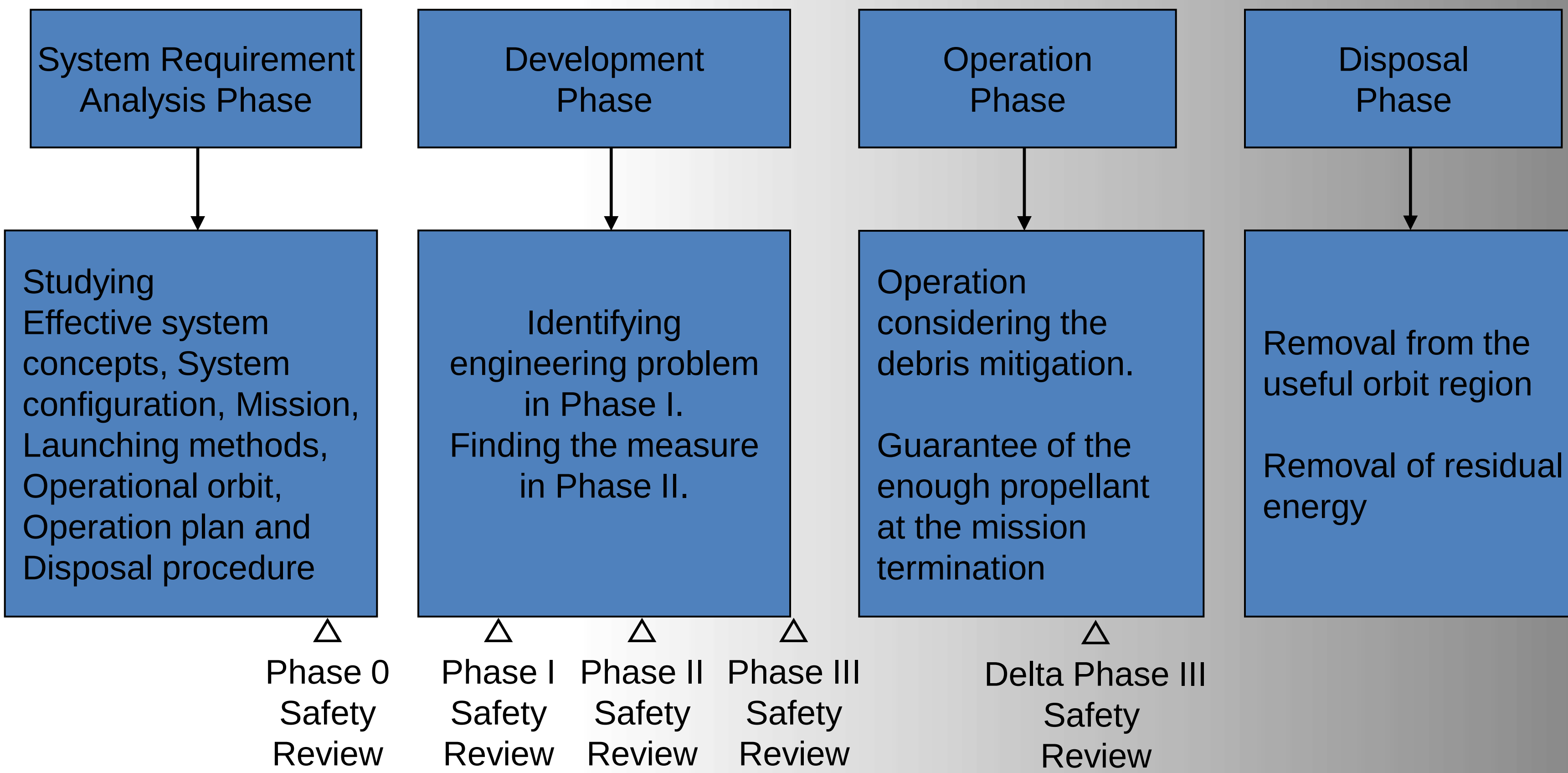
■ Engineering Study in Each Phase

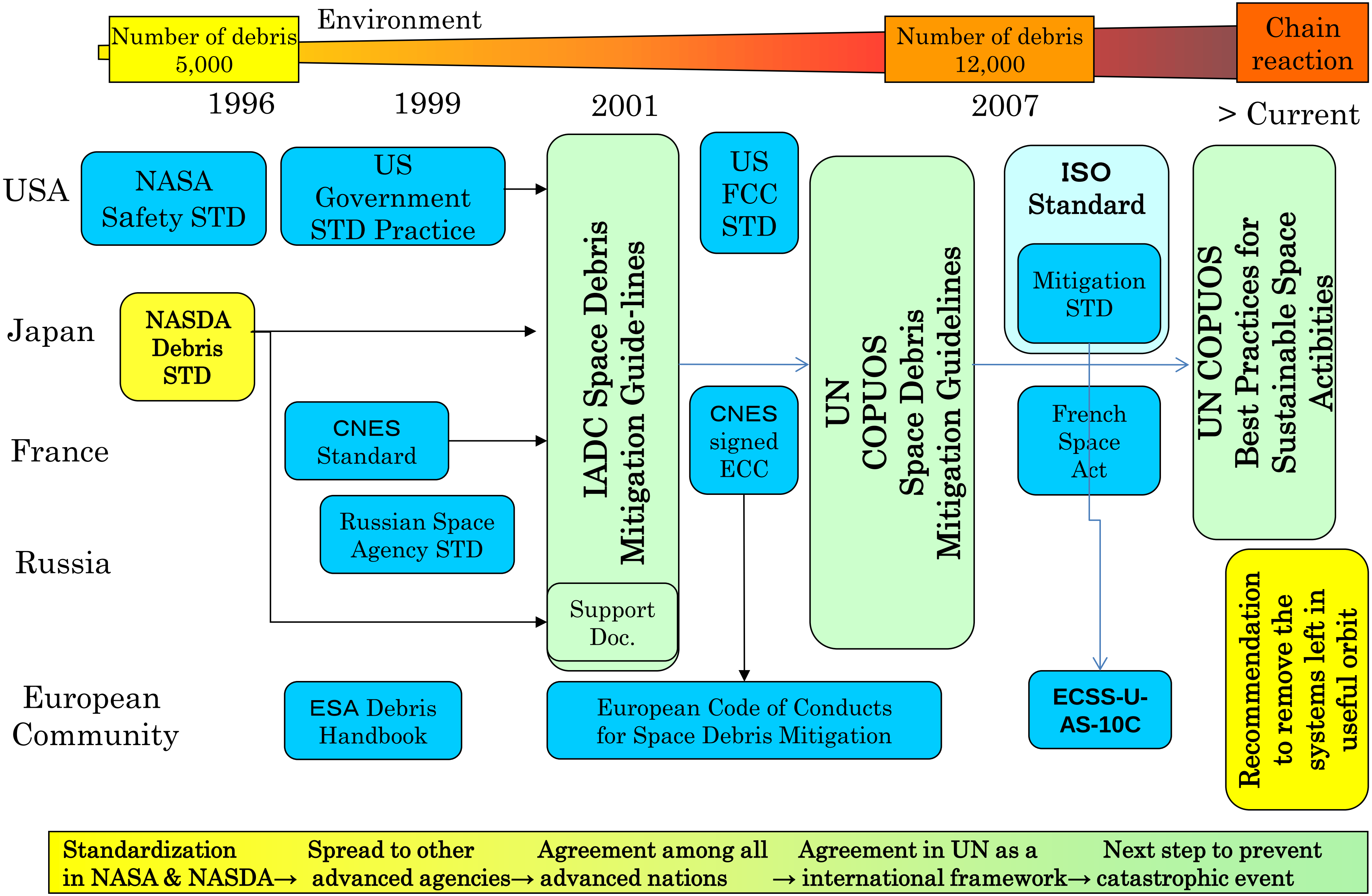


System Safety Review Board

■ System Safety Review Board in Each Phase



4. Comparison with Other Major Standards (1)



4. Comparison with Other Major Standards (2)

Major Debris Mitigation Standards in the world

a) ESA Space Debris Mitigation for Agency Projects, Director General's Office (2008)
b) ECSS-U-AS-10C, Space Sustainability: Adoption Notice of ISO 24113 Space Systems – Space Debris Mitigation Requirements (2012)
c) JAXA-JMR-003B, Space Debris Mitigation Standard (2011)
d) NPR 8715.6, NASA Procedural Requirements for Limiting Orbital Debris (2009)
e) NASA-STD-8719.14, Process for Limiting Orbital Debris (2011)
f) Space Debris Mitigation Guidelines of the COPUOS (2007)
g) IADC-02-01: IADC Space Debris Mitigation Guidelines (2007),
h) ISO-24113 Space systems — Space debris mitigation requirements (2011)
i) European Code of Conduct for Space Debris Mitigation (2004)

Table-1: Recommendations and Requirements in Major World Debris Mitigation Standards (Part 1 of 2)

	Measures	ESA Space Debris Mitigation for Agency Projects [a]	Space Sustainability (ECSS-U-AS-10C) [b]	JAXA (JMR-003B) [c]	NASA (NPR 8715.6 [d] and NPR 8719.14 [e])
Mission Related Objects	Operational Debris	Required	Required May not exceed: one for single payload launch, and two for multiple payloads	Required	(1) LEO: >1mm (decay within 25 years, and total < 100 object-years) (2) GEO: > 5cm (decay -500km within 25 years)
	Slag from Solid Motor	Slag < 1mm	Required (Slag < 1mm for GEO)	Required	--
	Pyrotechnics	Particles < 1mm	Combustion products < 1 mm	Combustion products < 1 mm	--
	Secondary Ejector	--	--	--	--
On-orbital Breakups	Avoidance of Intentional Destruction	Required	Required	Required	(1) <100 object-years (for > 10 cm) (2) Fragments > 1mm shall be limited 1 year (3) Fragments > 1mm, collision with Operating S/C shall be limited < 10^{-6}
	Accident During Operation	--	--	Required (Monitoring)	Probability of BU < 10^{-3}
	Postmission Breakup (Passivation, etc.)	Required (to be conducted < 2 months)	Probability of BU < 10^{-3}	Required	Required
Collision	With Large Objects	Risk Assessment	--	Required (CAM, COLA）	< 0.001 (with > 10 cm)
	With Small Objects	--	--	Required	Disposal Success > 0.01

		Measures	ESA Space Debris Mitigation for Agency Projects [a]	Space Sustainability (ECSS-U-AS-10C) [b]	JAXA (JMR-003B) [c]	NASA (NPR 8715.6 [d] and NPR 8719.14 [e])
Post mission Disposal	GEO	Reorbit at EOL	235 km+ (1,000・Cr・A/m) e < 0.005	235 km+ (1,000・Cr・A/m) Success Probability > 0.9 100 years' guarantee	235 km+ (1,000・Cr・A/m) Success Probability >0.9	235 km + (1,000・Cr・A/m) e < 0.003 Success Probability > 0.9 100 years' guarantee
		GEO Lower Limit	--	< -500 km (within 25 years)	< -500 km (within 25 years)	GEO - 500 km
		Protected Inclination	-15 < Inclination < 15 deg	-15< Inclination <15 deg.	-15< Inclination <15 deg.	-15< Inclination <15 deg
	LEO (MEO)	Reduction of Orbital Lifetime	EOL Lifetime < 25years	EOL Lifetime < 25years Success Probability >0.9	EOL Lifetime < 25years Success Probability > 0.9	Total Period < 30 years EOL Lifetime < 25years Success Probability > 0.9
		Transfer to Graveyard	Required (Excluding Galileo orbit)	Required	Required	2,000 km 〜 (GEO-500 km) (exclude 19,100 - 20,200 km)
		On-orbital Retrieval	--	--	Required	Retrieve within 10 years
		Ground Casualty	$Ec < 10^{-4}$	Required	$Ec < 10^{-4}$	$Ec < 10^{-4}$, (Count impact energy > 15 J)
Others		Tether	--	--	Required	Required

Table 1 (*Continued*): Recommendations and Requirements in Major World Debris Mitigation Standards (Part 2 of 2)

	Measures	UN Guidelines [f]	IADC Guidelines [g]	ISO (DIS-24113) [h]	European Code of Conduct for Space Debris Mitigation [i]	U.S. Gov. Standard Mitigation Practices
Mission Related Objects	Operational Debris	Addressed in Rec-1	Addressed in 5.1	Required	Required not exceed, one for single payload launch, and two for multiple payloads	> 5 mm (decay within 25 years)
	Slag from Solid Motor	--	--	Required	Slag < 0.01mm (Changed to 1mm)	--
	Pyrotechnics	--	--	Combustion Products < 1 mm	Objects < 0.01mm	--
	Secondary Ejector	--	--	--	Required (SD-DE-07)	--
On-orbital Breakups	Intentional Destruction	Addressed in Rec-4	Addressed in 5.2.3	Required	Required (SD-DE-04)	--
	Accident During Operation	Addressed in Rec-2	Addressed in 5.2.2 (Monitoring)	Probability of BU < 10^{-3}	Probability of BU < 10^{-4} (SD-DE-05)	Required
	Postmission Breakup (Passivation, etc.)	Addressed in Rec-5	Addressed in 5.2.1	Probability of BU < 10^{-3}	Required Inner Press. < 50% of critical Press. Dispose within 1 year Success Probability > 0.9	Required
Collision	With Large Objects	Addressed in Rec-3 (CAM, COLA)	Addressed in 5.6	--	Required	--
	With Small Objects	--	Addressed in 5.6	--	(Recommended by other document)	--

		Measures	UN Guidelines [f]	IADC Guidelines [g]	ISO (DIS-24113) [h]	European Code of Conduct for Space Debris Mitigation [i]	U.S. Gov. Standard Mitigation Practices
Post-mission Disposal	GEO	Reorbit at EOL	Addressed in Rec-7	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) Success Probability >0.9	>36,100 km (> 300km + GEO)
		GEO Lower Limit	--	-200 km	--	-200 km	--
		Protected Inclination	--	-15< latitude <15 deg.	-15< latitude <15 deg.	-15< latitude <15 deg.	--
	LEO (MEO)	Reduction of Orbital Lifetime	Addressed in Rec-6	Addressed in 5.4 (Recommend 25 years)	EOL Lifetime < 25years Success Probability >0.9 100 years' guarantee	EOL Lifetime < 25years Success Probability >0.9	EOL Lifetime < 25 years
		Transfer to Graveyard	--	--	Required	Required	2,000 - 19,700 km 20,700-35,300 km
		On-orbital Retrieval	--	Addressed in 5.4	--	--	Retrieve within 10 years
		Ground Casualty	Addressed in Rec-6	Addressed in 5.4	Required	$Ec < 10^{-4}$ (Excluding France)	$Ec < 10^{-4}$
Others		Tether	--	--	--	--	--

Table-1 global debris mitigation rules and JAXA standard

		Measures	ISO Standards (or Technical Reports)	JAXA (JMR-003B)	IADC Guidelines [g]
Limiting Debris Generation	*Released Objects*	General idea to refrain from releasing objects	**ISO-24113 / § 6.1.1**	Required	§ 5.1
		Slag from Solid Motor	**ISO-24113 / § 6.1.2.2, § 6.1.2.3**	Required	--
		Combustion Products from Pyrotechnics	**ISO-24113 / § 6.1.2.1** (Combustion Products < 1 mm)	Combustion products < 1 mm	--
	On-orbital Breakups	Intentional Destruction	**ISO-24113 / § 6.2.1**	Required	§ 5.2.3
		Accident During Operation	**ISO-24113 / § 6.2.2** (Probability < 10^{-3})	Required (Monitoring) (Probability < 10^{-3})	§ 5.2.2 (Monitoring)
		Post mission Breakup (Passivation, etc.)	**ISO-24113 / § 6.2.2.3 (Detailed in ISO-16127)** (Probability < 10^{-3})	Required	§ 5.2.1
Disposal at End of Operation	***GEO***	Reorbit at EOL	**ISO-24113 / § 6.3.2 (Detailed in ISO-26872)** § 6.3.2.2: 235 km+ (1,000・Cr・A/m), e < 0.003 § 6.3.1: Success Probability > 0.9	235 km+ (1,000・Cr・A/m) e < 0.003 Success Probability >0.9	§ 5.3.1 235 km+ (1,000・Cr・A/m), e < 0.003
	LEO (MEO)	Reduction of Orbital Lifetime	**ISO-24113 / § 6.3.3 (Detailed in ISO-16164)** § 6.3.3.1: EOL Lifetime < 25years § 6.3.1: Success Probability >0.9	EOL Lifetime < 25years Success Probability > 0.9	§ 5.3.2 (Recommend 25 years)
		Transfer to Graveyard	**ISO-24113 / § 6.3.3.2 (f)** (guarantee 100 years' non-interference)	Required	Mentioned in recommendation-6
		Other manners	**ISO-24113 / § 6.3.3.2 (a) ~ (e)**	--	§ 5.3.2
Re-entry		Ground Casualty	**ISO-24113 / § 6.3.4 (Detailed in ISO-27875)**	Ec < 10^{-4}	§ 5.3.2
Collision Avoidance with Large Debris			**ISO-16158**	Required (CAM, COLA)	§ 5.4
Protection from Impact of Tiny Debris			**ISO-16126**	Required	§ 5.4