Passive Orbital Debris Removal Using Special Density Materials

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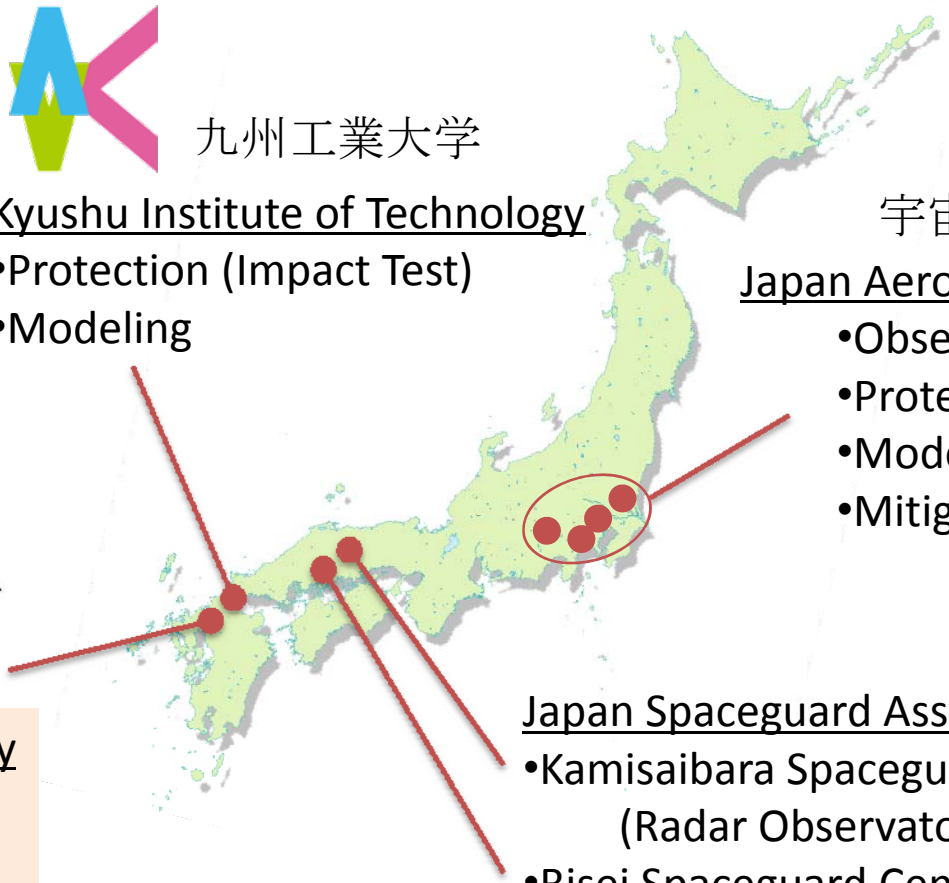
Contents

- Introduction of Japanese Activity
  - Activities in Japan
  - Activities in Kyushu University

- Orbital Debris Removal
  - Proposing Concepts and Effectiveness
  - Overview of Possible System and Removal Scenarios
  - Major Requirements
  - Summary

Activities in Japan



九州工業大学

Kyushu Institute of Technology
- Protection (Impact Test)
- Modeling

宇宙航空研究開発機構

Japan Aerospace Exploration Agency
- Observation
- Protection
- Modeling
- Mitigation

九州大学
KYUSHU UNIVERSITY

Kyushu University
- Modeling
- Observation
- Mitigation

Japan Spaceguard Association
- Kamisaibara Spaceguard Center (Radar Observatory)
- Bisei Spaceguard Center (Optical Observatory)

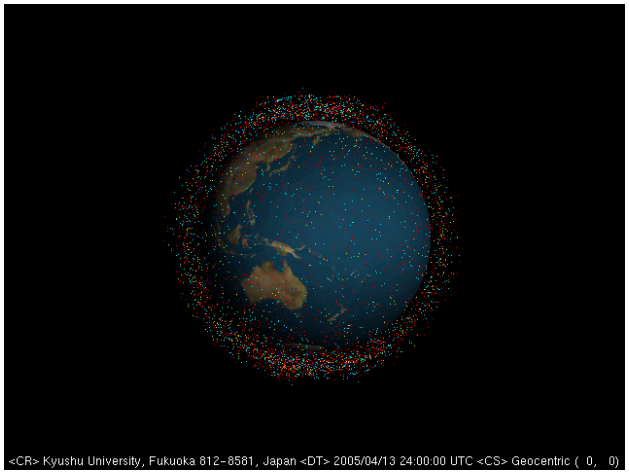
Activities in Kyushu University

九州大学
KYUSHU UNIVERSITY

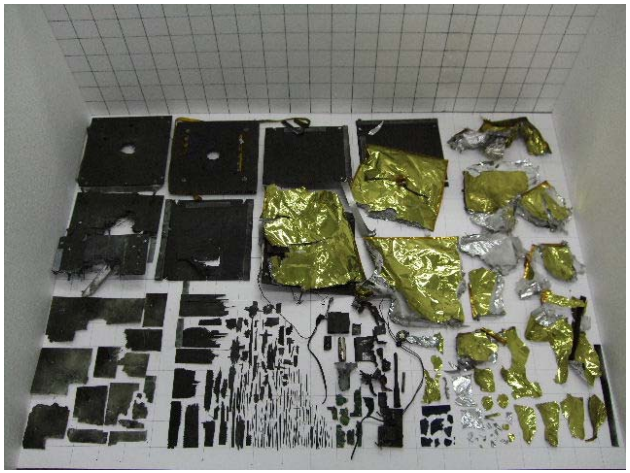
- Department of Aeronautics and Astronautics
  - Space Systems Dynamics Laboratory
    - Prof. Toshiya Hanada
    - Assistant Prof. Hiroshi Hirayama
    - 15 Students

    - Space Debris
    - Micro Satellite
    - Interplanetary Trajectory

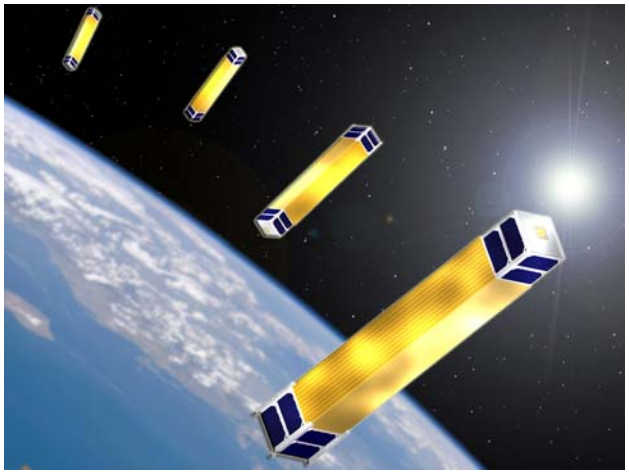
- Modeling: Evolution, Breakup, Collision Risk
- Observation: Optical, Radar, In-situ dust detector
- Mitigation: Electro-dynamic tether, Passive material



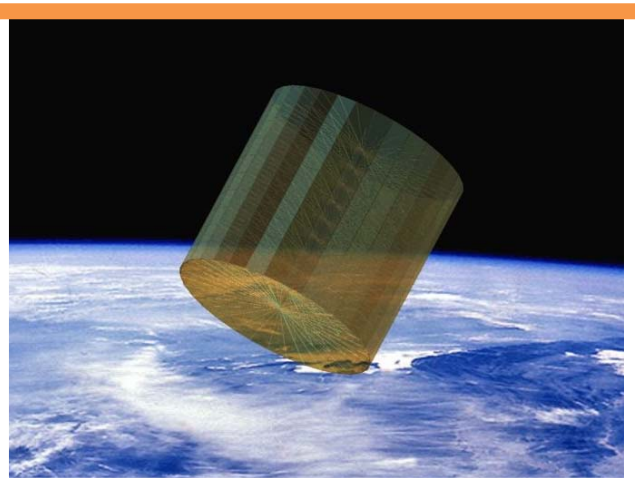
Evolutional and Engineering Model



Impact Fragmentation Modeling



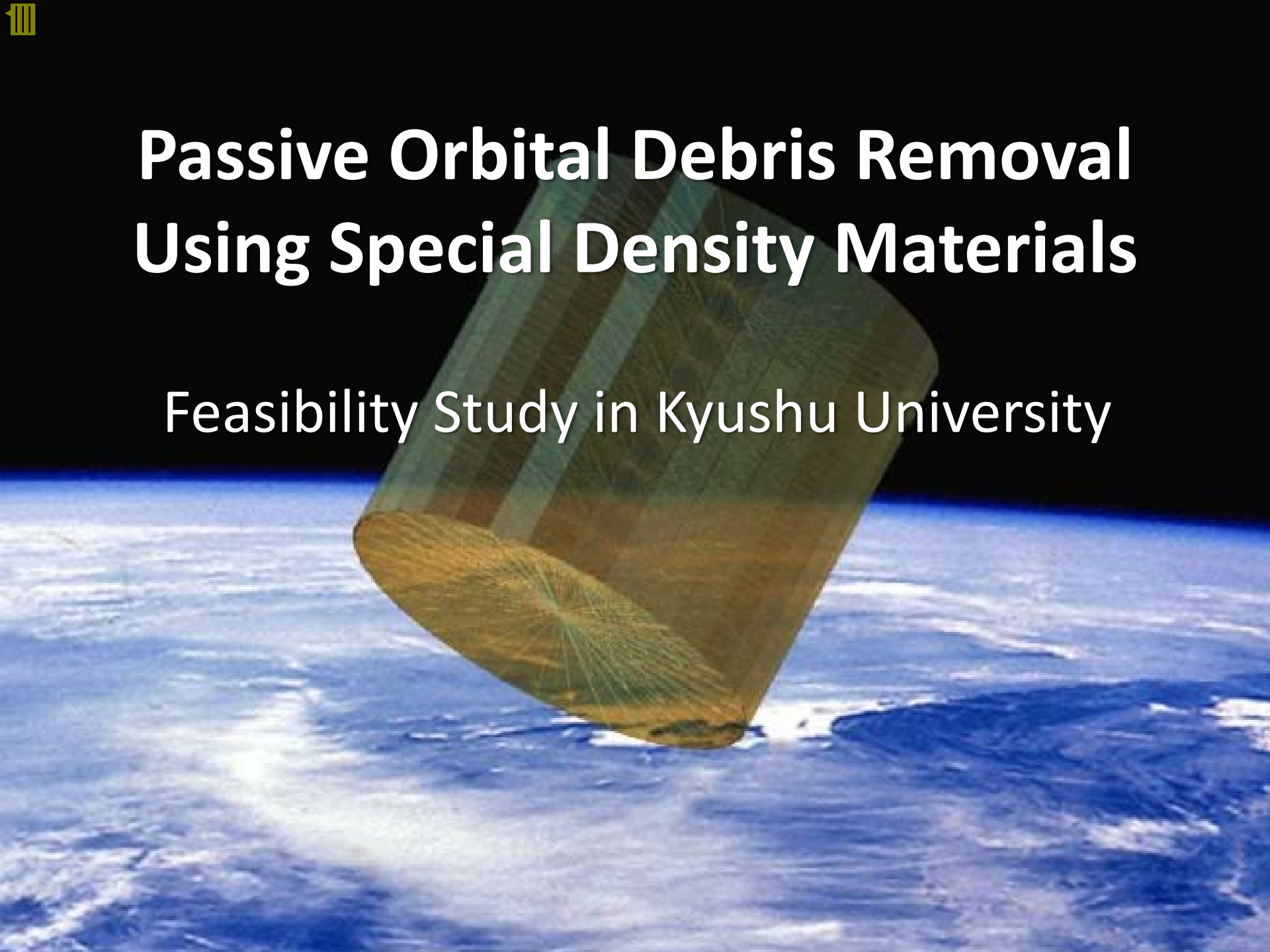
Designing In-situ Measuring Satellite



Passive Orbital Debris Removal (ODR)

Passive Orbital Debris Removal Using Special Density Materials

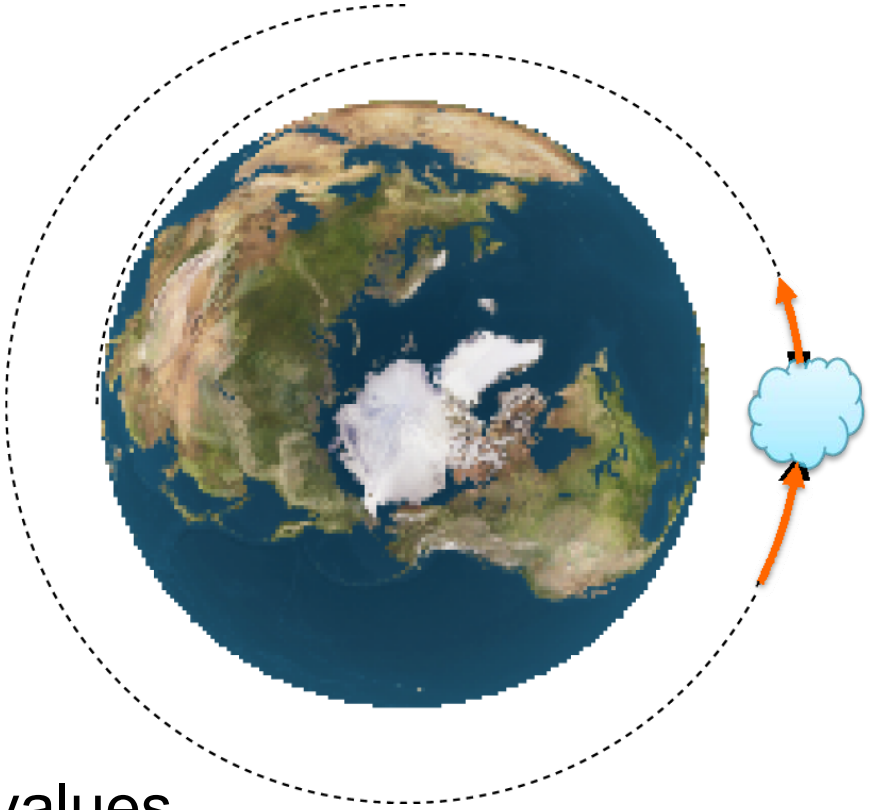
Feasibility Study in Kyushu University



PROPOSING CONCEPTS AND EFFECTIVENESS

Basic Idea

- Passive capturing without fragmentation is quite difficult
- Smaller deceleration to promote orbital decay is easier
- All we need is to build space with density larger than local atmospheric values
- Is it feasible in realistic size?



Assumptions

Debris	
Material	Aluminum
Density	2.77×10^3 kg/m^3
Diameter	< 10 cm
Area to Mass ratio of debris	0.054 m^2/kg
Drag Coefficient	2.2
Special Density Material	
Material	Aerogel
Density	20 kg/m^3
Orbit	
Initial Altitude	800 km
Final Altitude (perigee)	90 km

Deceleration model

$$D = \frac{1}{2}\rho V^2 S C_D$$

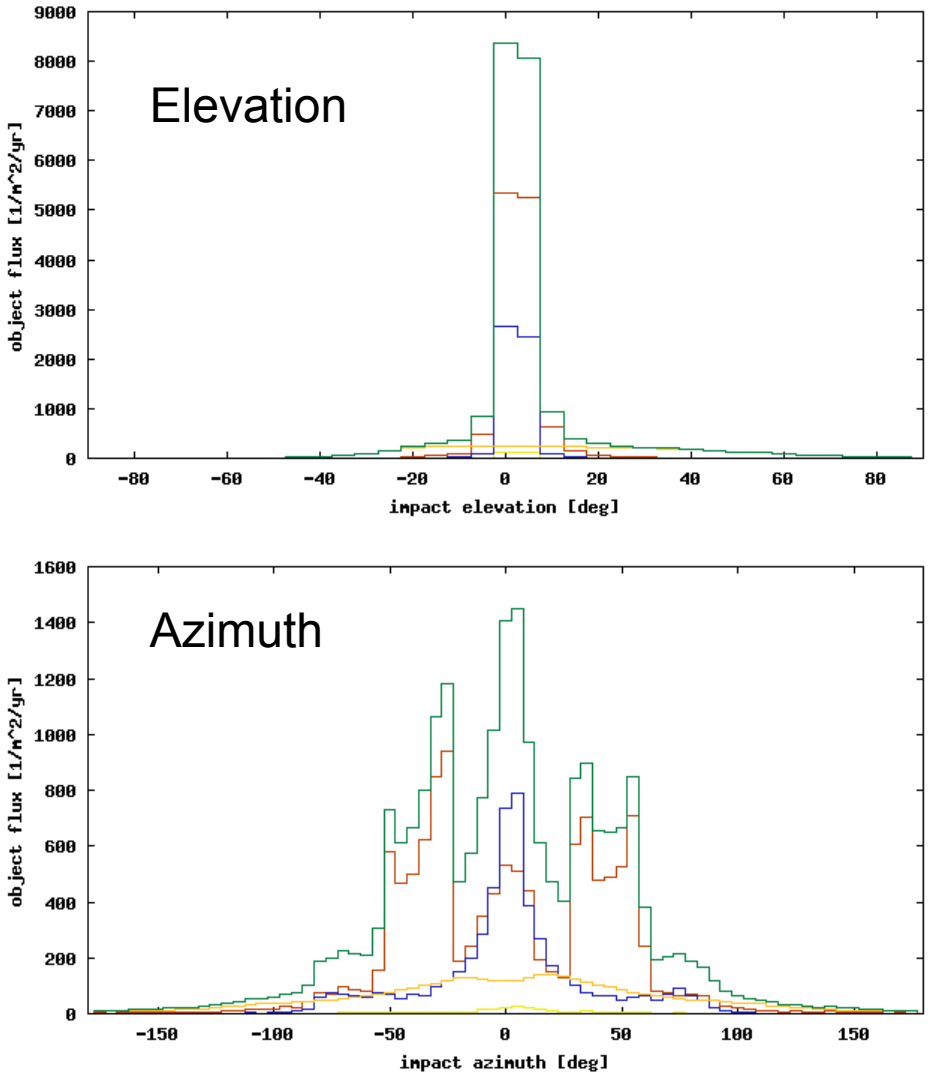
Required deceleration

200 m/sec

Incident Angles

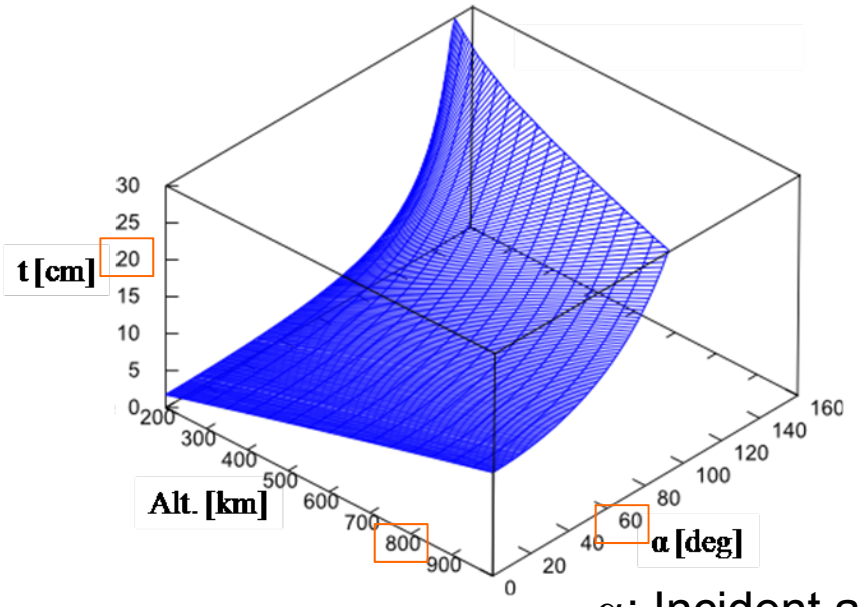
- Sun-synchronous orbit
  Altitude: 800 km

- Most debris come from horizontally, ram side
  - Incident elevation: 0 deg
  - Incident azimuth: −60~+60 deg

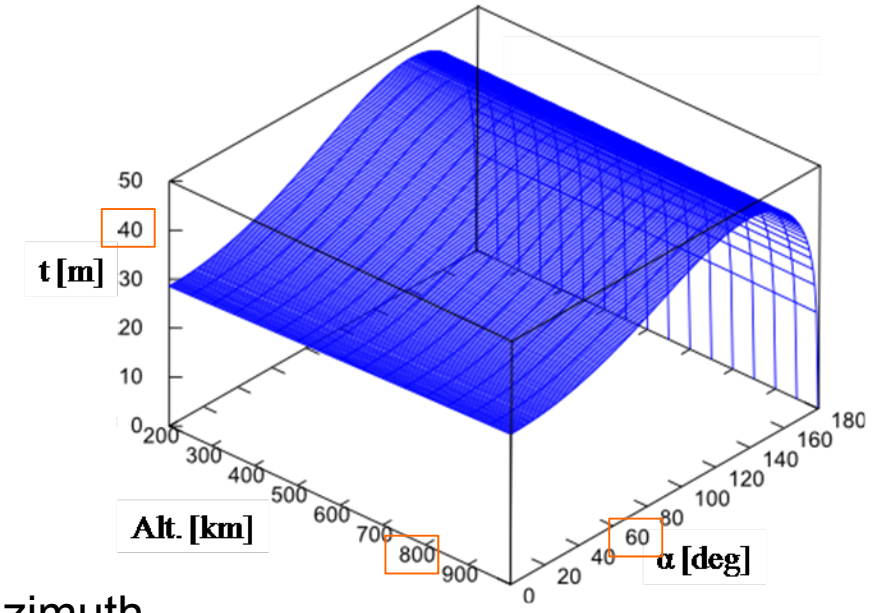


Required Thickness

to promote orbital decay
~ 20 cm



to capture in material
~ 40 m



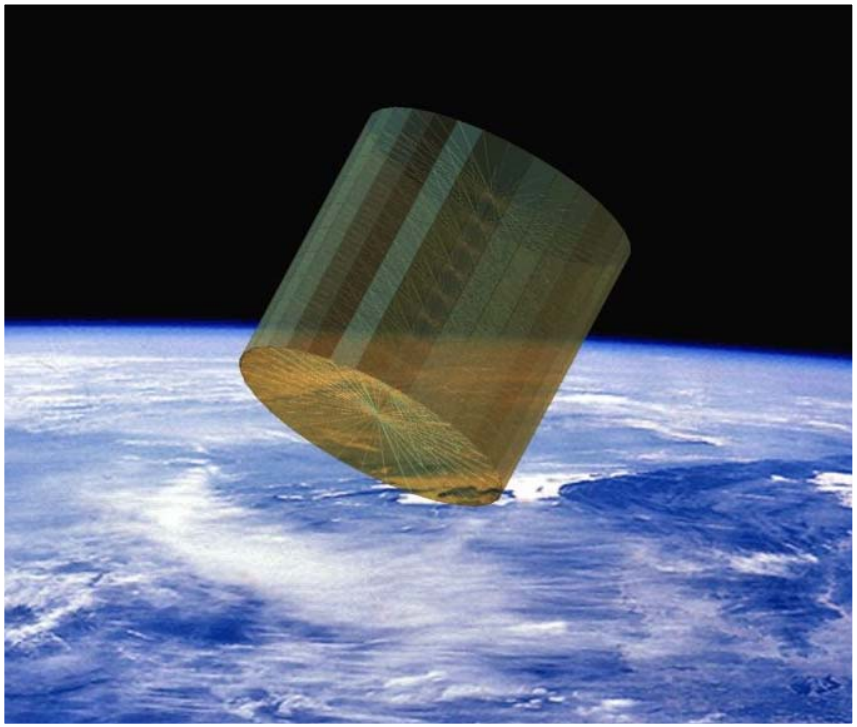
α: Incident azimuth

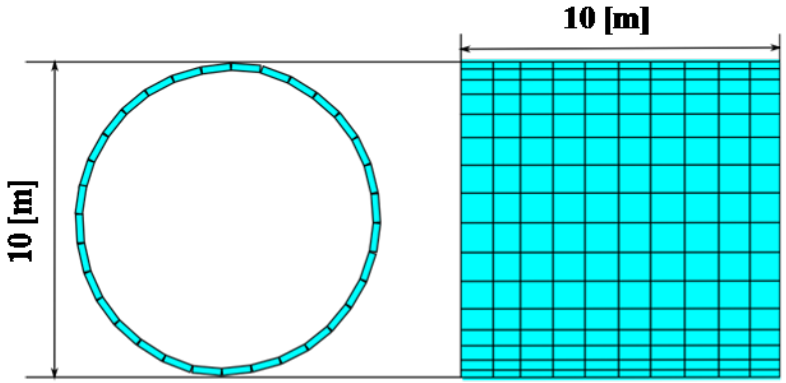
These are results for debris 10 cm in diameter
Required thickness is proportional to the diameter

OVERVIEW OF POSSIBLE SYSTEM AND REMOVAL SCENARIOS

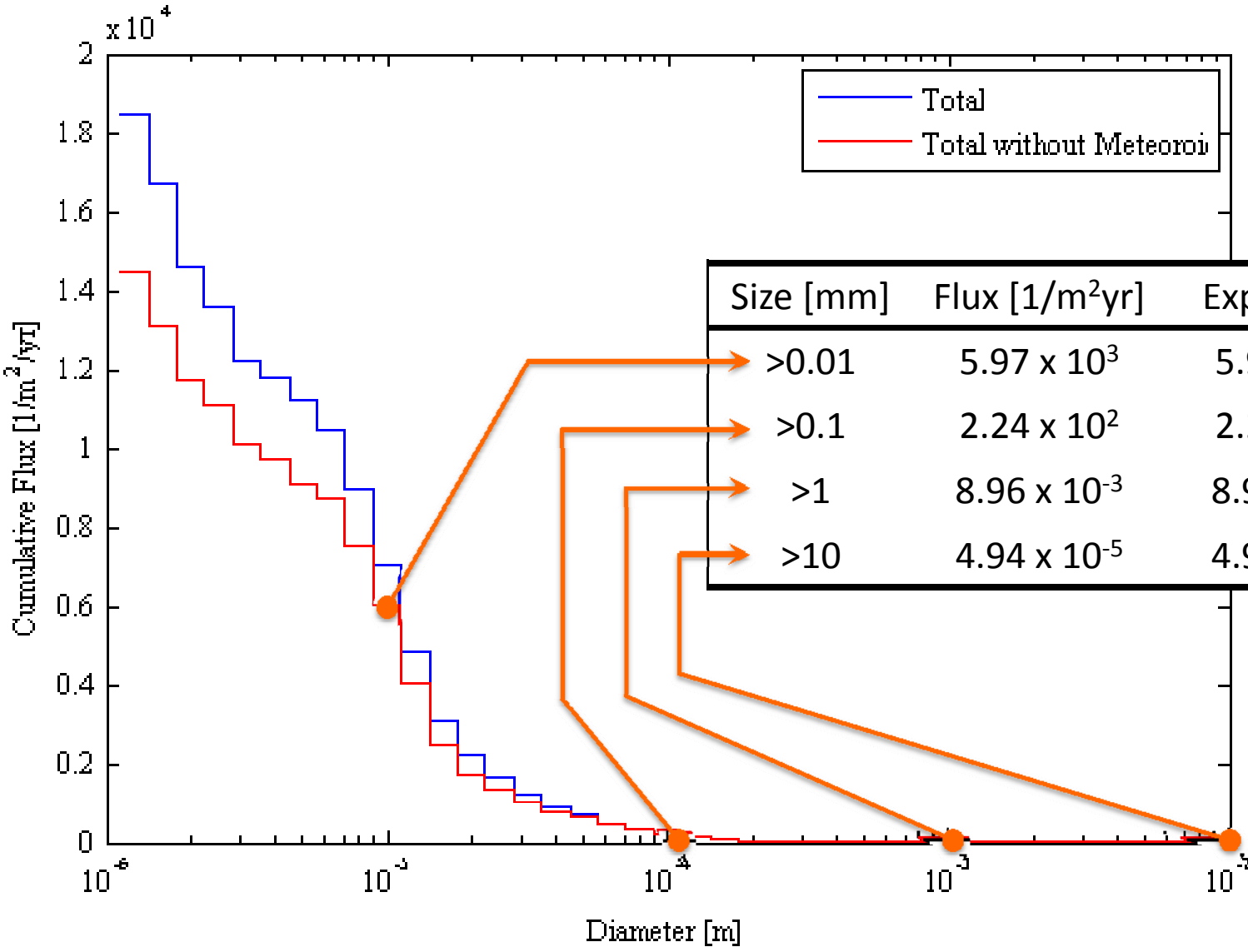
Overview of Possible System

Mission Equipment	
Aerogel Panels (1 m ×1 m × 320)	
Dust Detector	
Shape	
Cylindrical Tube	
Diameter	10 m
Height	10 m
Aerogel Thickness	0.1 m
Mass	
Aerogel	640 kg
Bus System	360 kg
Orbit Configuration	
Type	Sun-Synchronous
Altitude	800 km
Inclination	98.6 deg



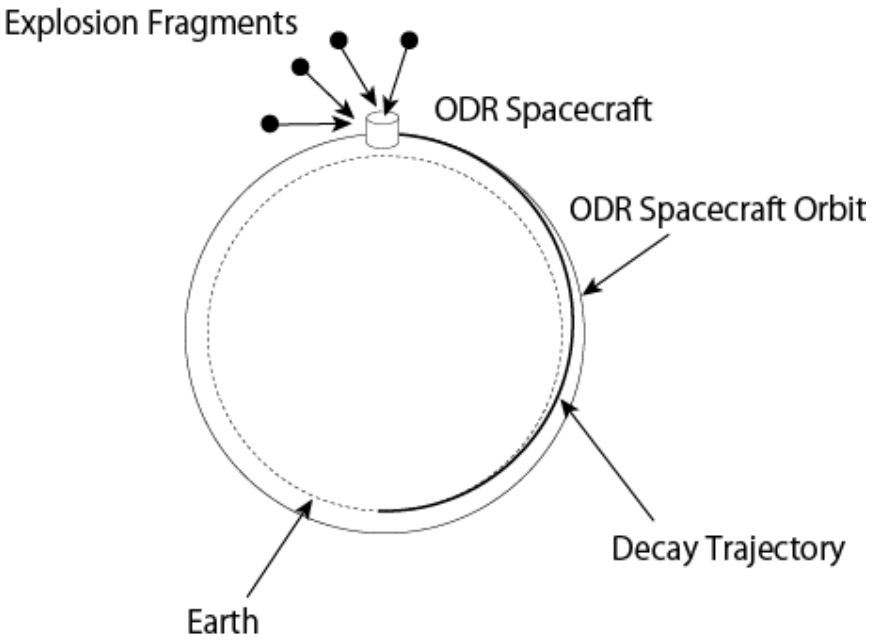


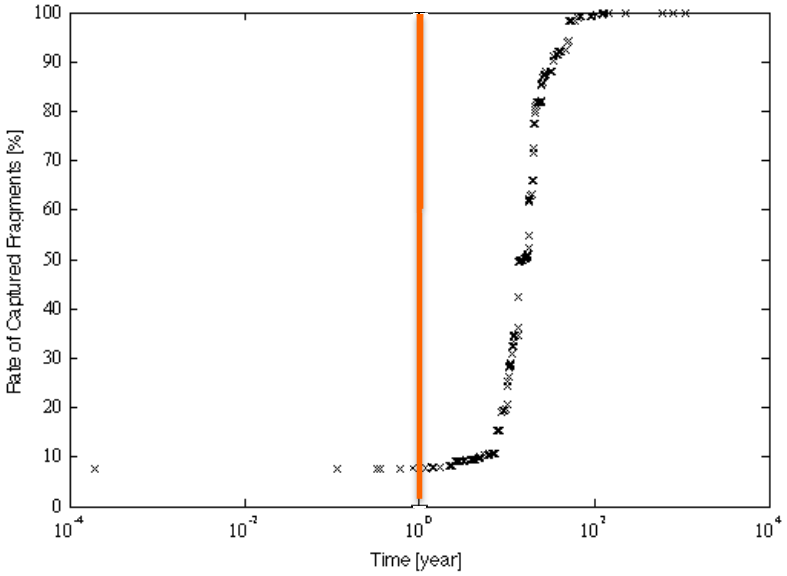
Background Debris



Size [mm]	Flux [1/m^{2}yr]	Expecting #
>0.01	5.97 x 10^{3}	5.97 x 10^{5}
>0.1	2.24 x 10^{2}	2.24 x 10^{4}
>1	8.96 x 10^{-3}	8.96 x 10^{-1}
>10	4.94 x 10^{-5}	4.94 x 10^{-3}

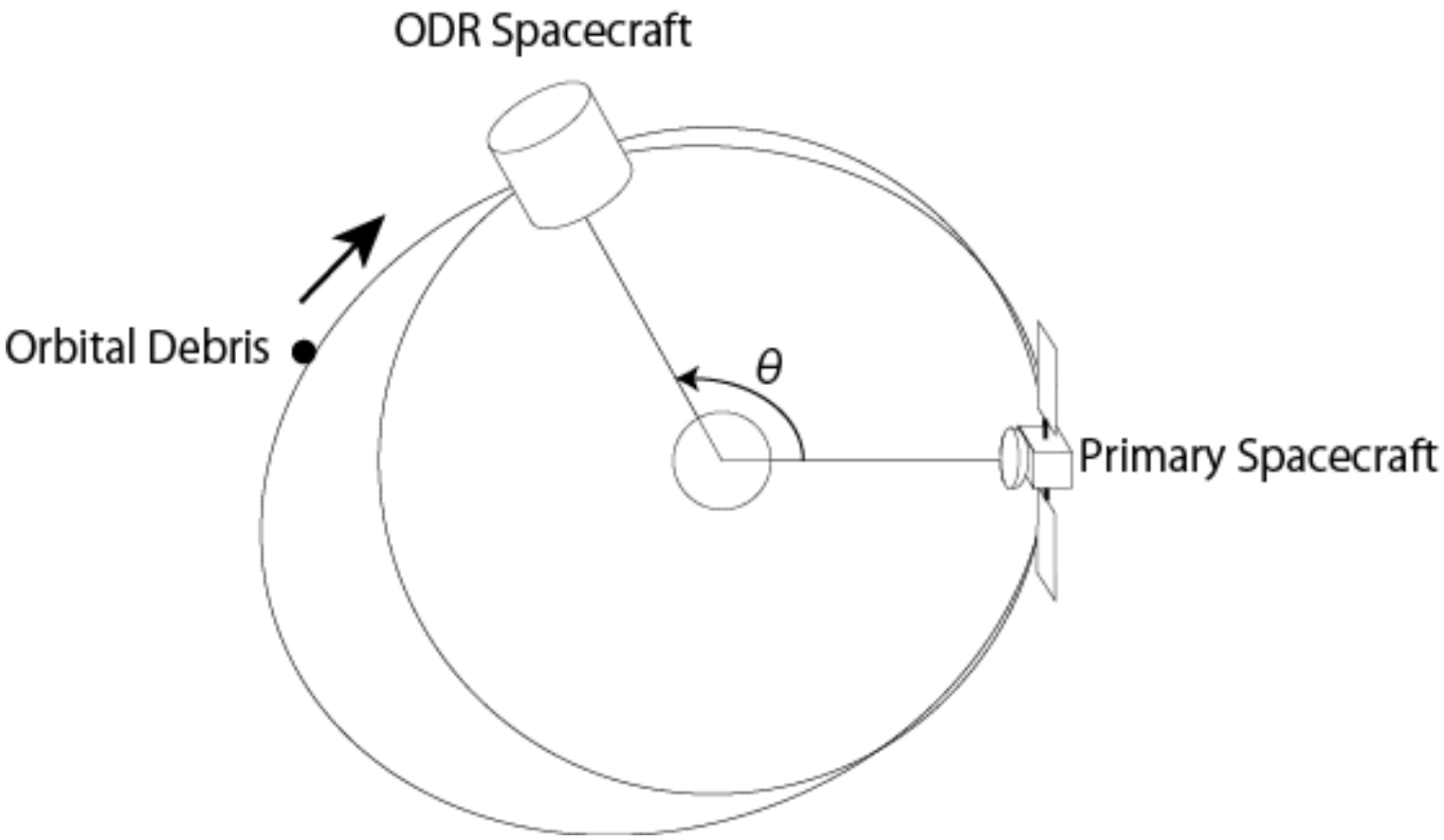
Explosion Fragments



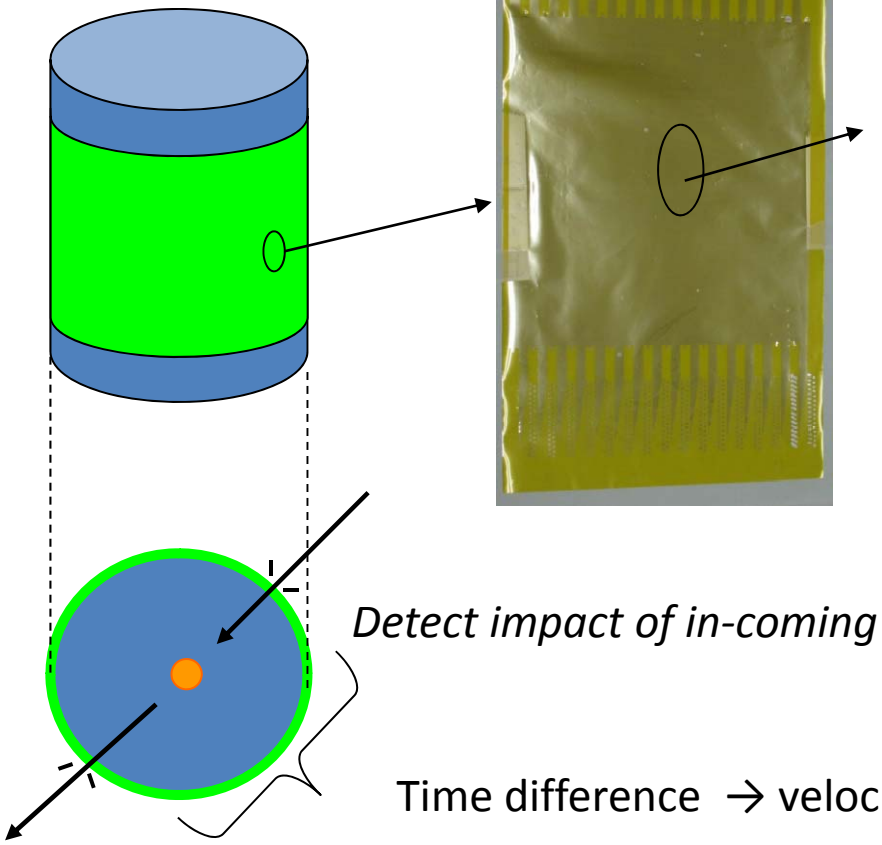


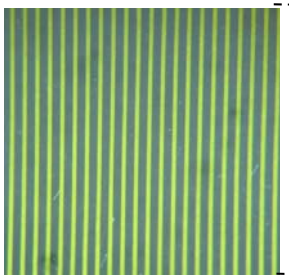
Type	Rocket
Mass	3,000 kg
Fragments #	377,796

Escort Spacecraft

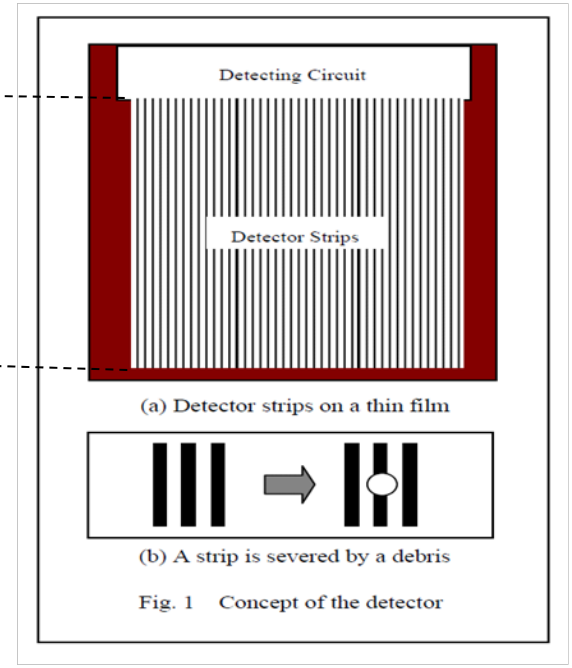


How to Confirm Effectiveness





Width of a conductive strip:70um



Multitude conductive lines on thin polyimide film for detecting debris perforation and measure the size.

Detect impact of in-coming debris

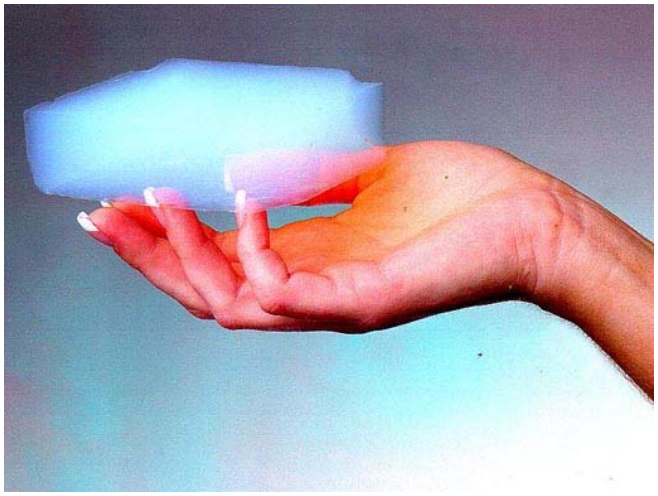
Time difference → velocity

Detect out-going

MAJOR REQUIREMENTS

Special Density Materials (Example)

Aerogel



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Pore Foam

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Requirements for Materials

Space-proven materials with density slightly higher than the atmospheric density, not fragmented during mission

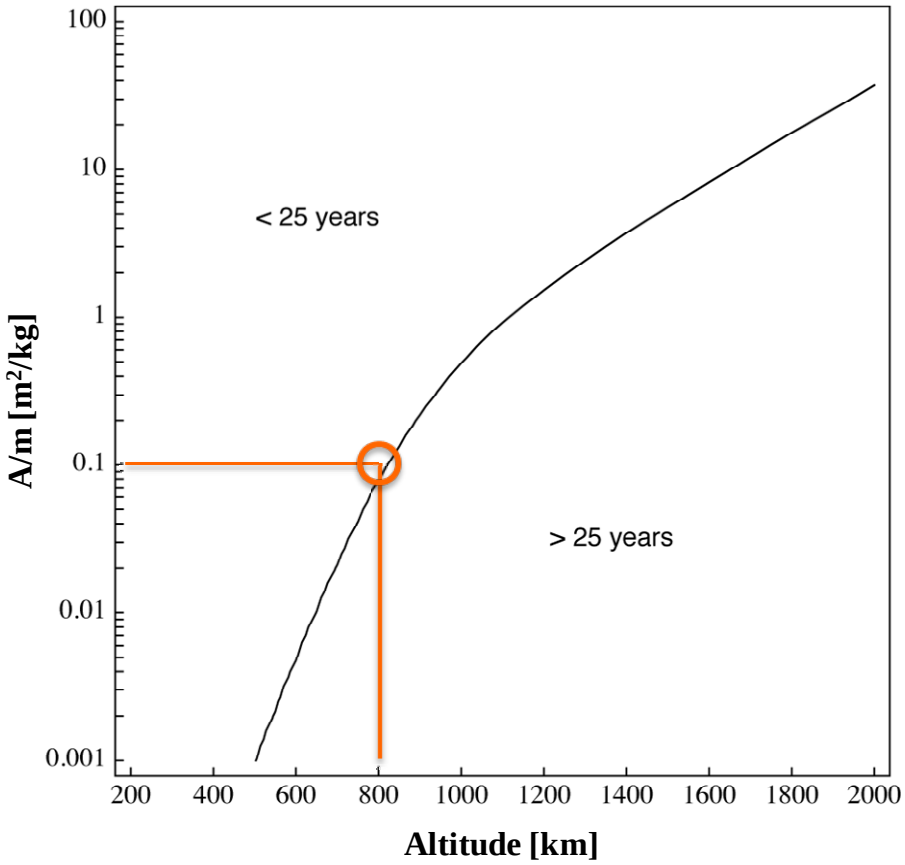
Material	Density (kg/m^3)	Flight-proven	Stability /Handling	Mass (Support structure)	Cost	Overall Score
Aerogel (Silica-aerogel)	1-100	Dust sample return missions (ex. MPAC, STARDUST)	Fragile	Heavy	High	Poor
Pore-foam (Polyimide foam)	1-100	Dust sample return missions (ex. MPAC, US shuttle experiments)	Stable	Light	Low	Good
Foil stack	10-100	Passive dust measurement (ex. LDEF)	Stable	Medium	Low	Fair
Gus can	10-100	Meteoroid impact sensors (ex. Pioneer 10,11)	Stable	Heavy	High	Poor

Good	Fair	Poor

Requirement for 25 Years Rule

- ODR satellite itself must follow IADC's mitigation guideline
  - ➢ decay within 25 years after its mission

- A/m = 0.1 m^2/kg
  - ➢ 10 m × 10 m
  - ➢ 1000 kg

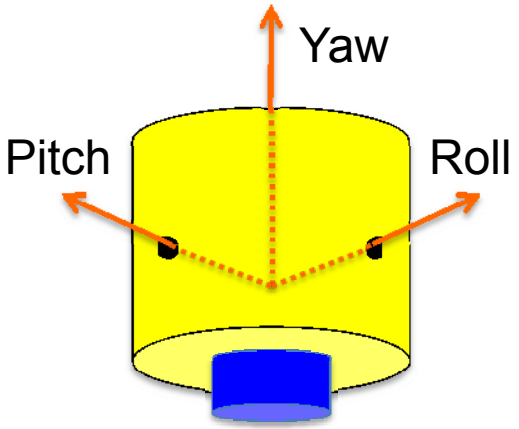


Requirement for Attitude Stabilization

- Stable in gravity gradient

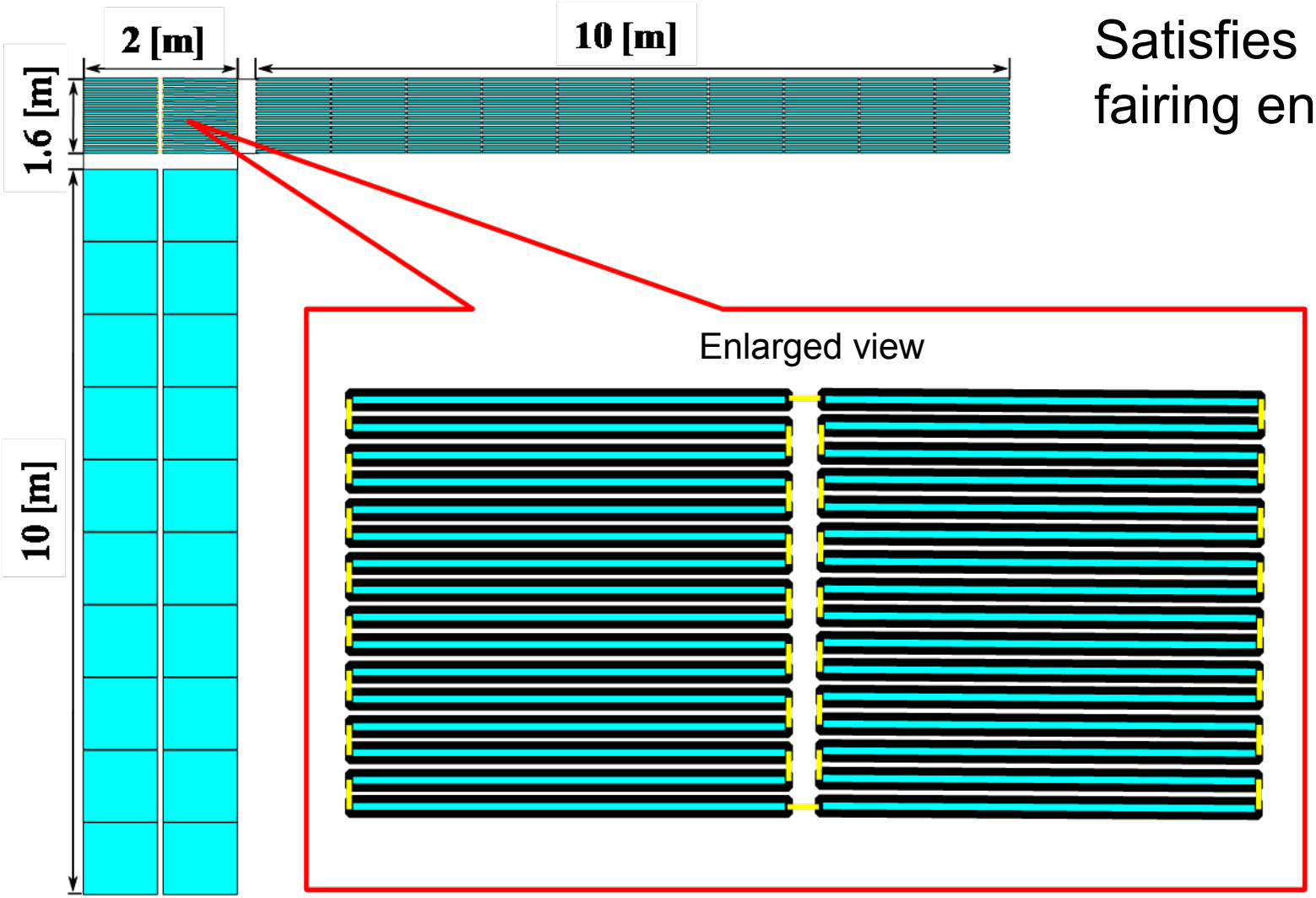
  $I_{yaw} < I_{roll}, I_{pitch}$

  - I_{yaw} = 15798 kg m^2
  - $I_{roll} = I_{pitch}$ = 19590 kg m^2



- Critical angular rate to exceed stability
  - 0.045 deg/sec in roll
  - 0.052 deg/sec in pitch
- They can be excited only when debris larger than 2 cm impacts on top of the ODR satellite

Requirement for Stowing and Deployment



Satisfies H-IIA fairing envelop

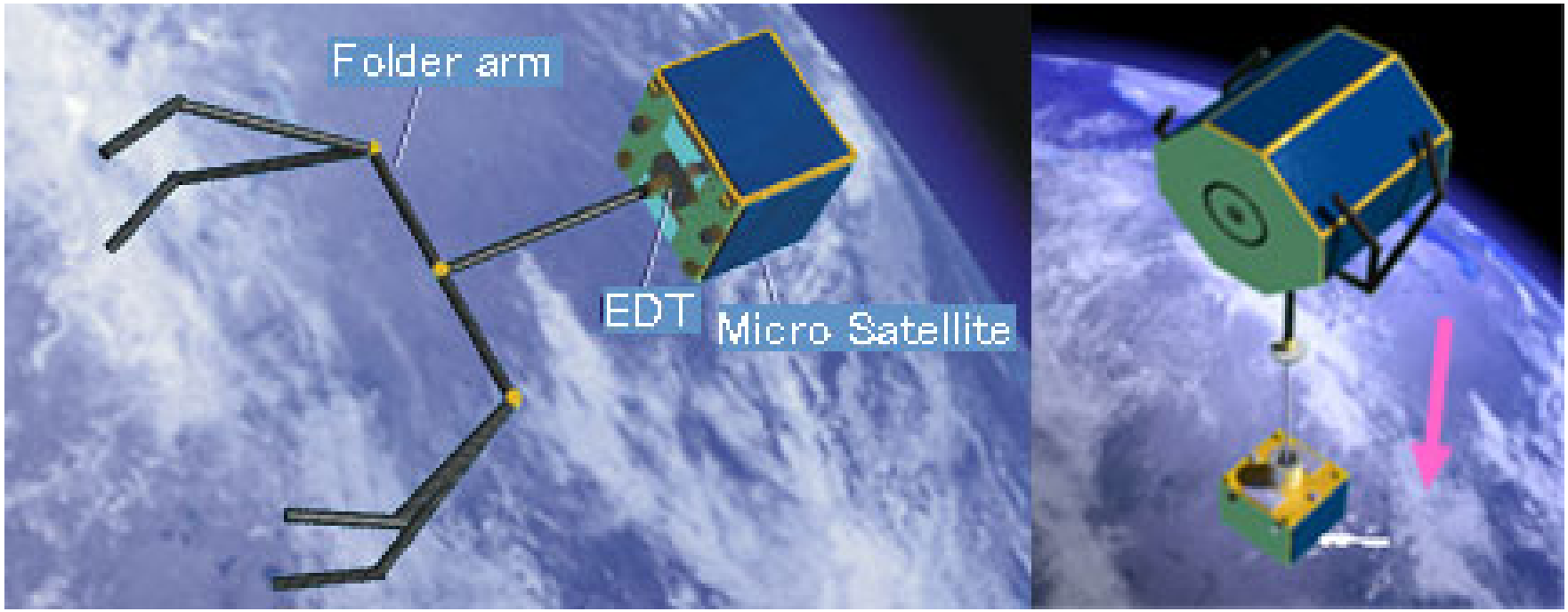
Summary

- Feasibility and requirements
- Effectiveness
- Option for in-situ observation

- Future work
  - Further analysis of effectiveness
  - Experiment to confirm the deceleration model
  - Designing the deployment mechanism

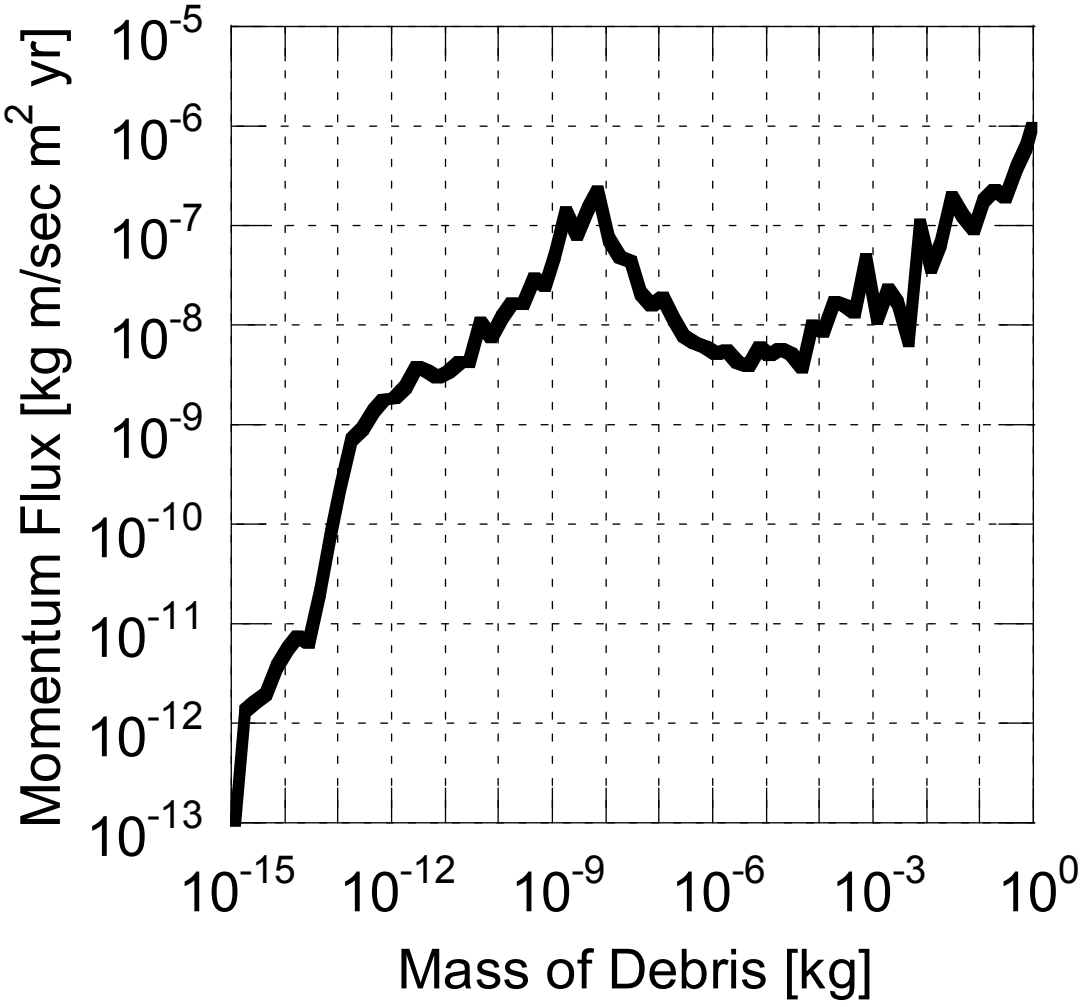
BACKUP SLIDES

JAXA's Conceptual ODR with EDT



JAXA's Optical Observatory on Mt. Nyukasa

For Orbital Debris and NEO


Momentum Flux [kg m/sec m^2 yr]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-15}
10^{-12}
10^{-9}
10^{-6}
10^{-3}
10^{0}
Mass of Debris [kg]

- Angular velocity excited by impact on tip
  - Largest target size 10cm
    → 5 deg/sec, (once in 1000 years)
  - Most effective size 0.1mm
    → 5×10^{-9} deg/sec, (once in 30 minutes)