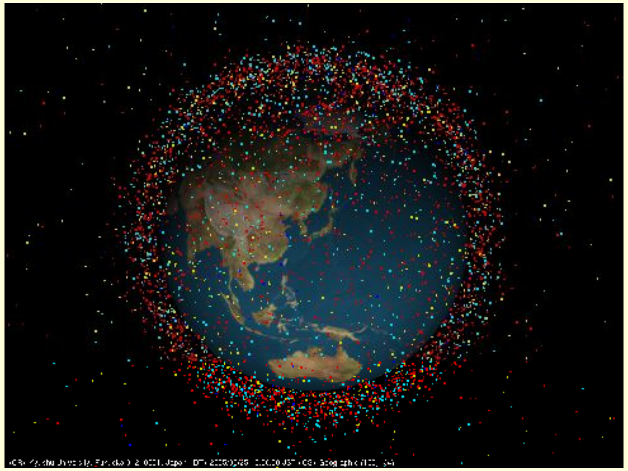
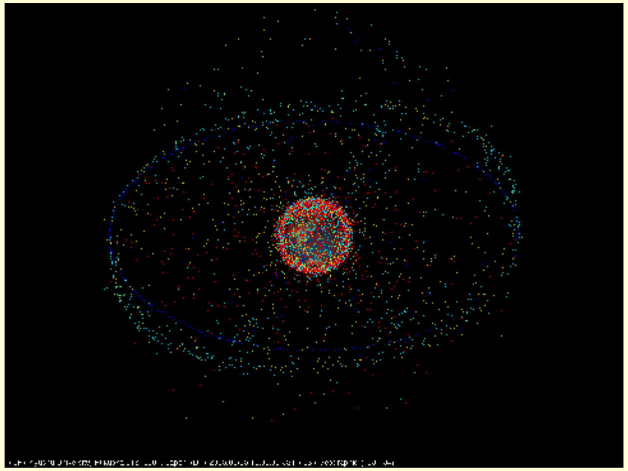
Research Topics for Asia-Pacific Regional Collaboration in the Area of Orbital Debris Issues

Toshiya HANADA
Kyushu University, Fukuoka, Japan
Yukihito KITAZAWA
IHI Corporation, Tokyo, Japan
Toshifumi YANAGISAWA and Haruhisa MATSUMOTO
Japan Aerospace Exploration Agency (JAXA), Tokyo, Japan

General Stats on Orbiting Objects

- Natural debris
  - Asteroids, comets, etc.
    - Some pass through the near-Earth space
    - Usually smaller than man-made and harder to observe because they are darker
- Artificial debris (called orbital debris)
  - Sputnik 1 launched on 4 October 1957
  - > 4,500 space missions flown since Sputnik 1
  - 39,017 objects created since Sputnik 1
    - 16,900 still on orbit
      - Only 800 or less functional spacecraft
      - Remaining objects are orbital debris

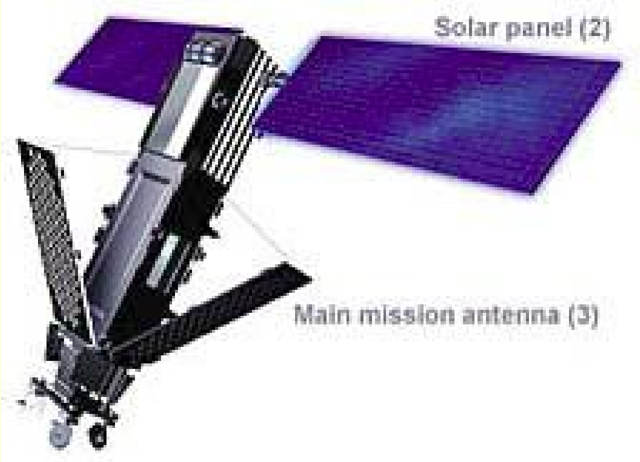




What Is Orbital Debris?

- All space objects non-functional and human made
  - Fragmentation debris (59%)
    - breakups of satellites
      - unused fuel, dead batteries, etc.
    - productions of deterioration
      - paint flakes, thermal blankets, etc.
  - Rocket bodies (12%)
  - Mission-related debris (7%)
    - refuse from human missions
    - objects released from spacecraft
    - deployment and operation
  - Non-functional spacecraft (16%)

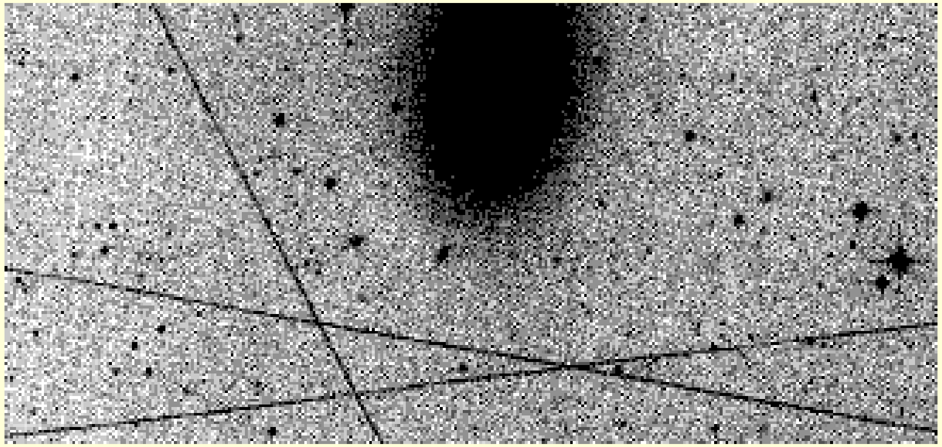
Klinkrad (2011)



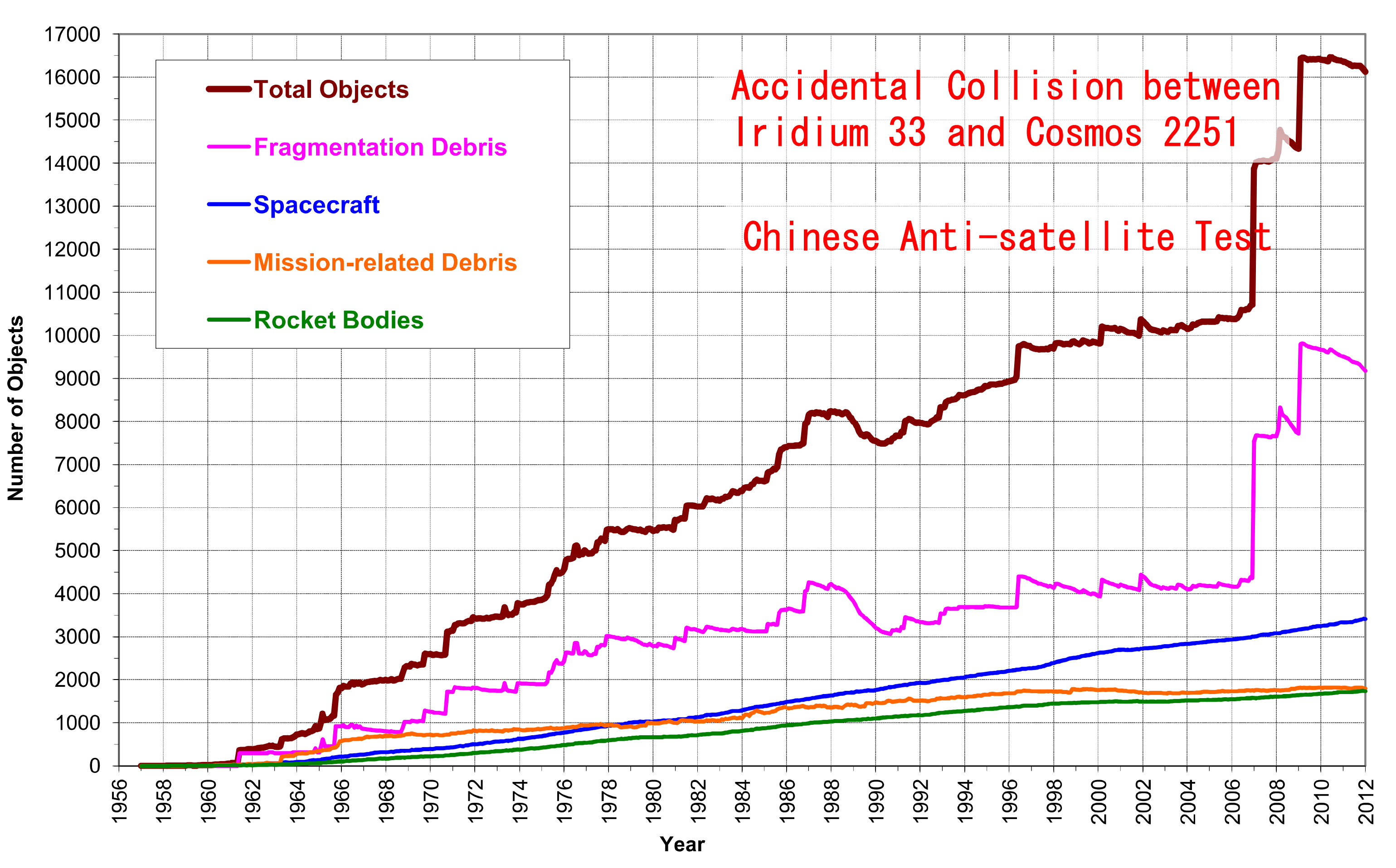
Example of Fragmentation Experiment

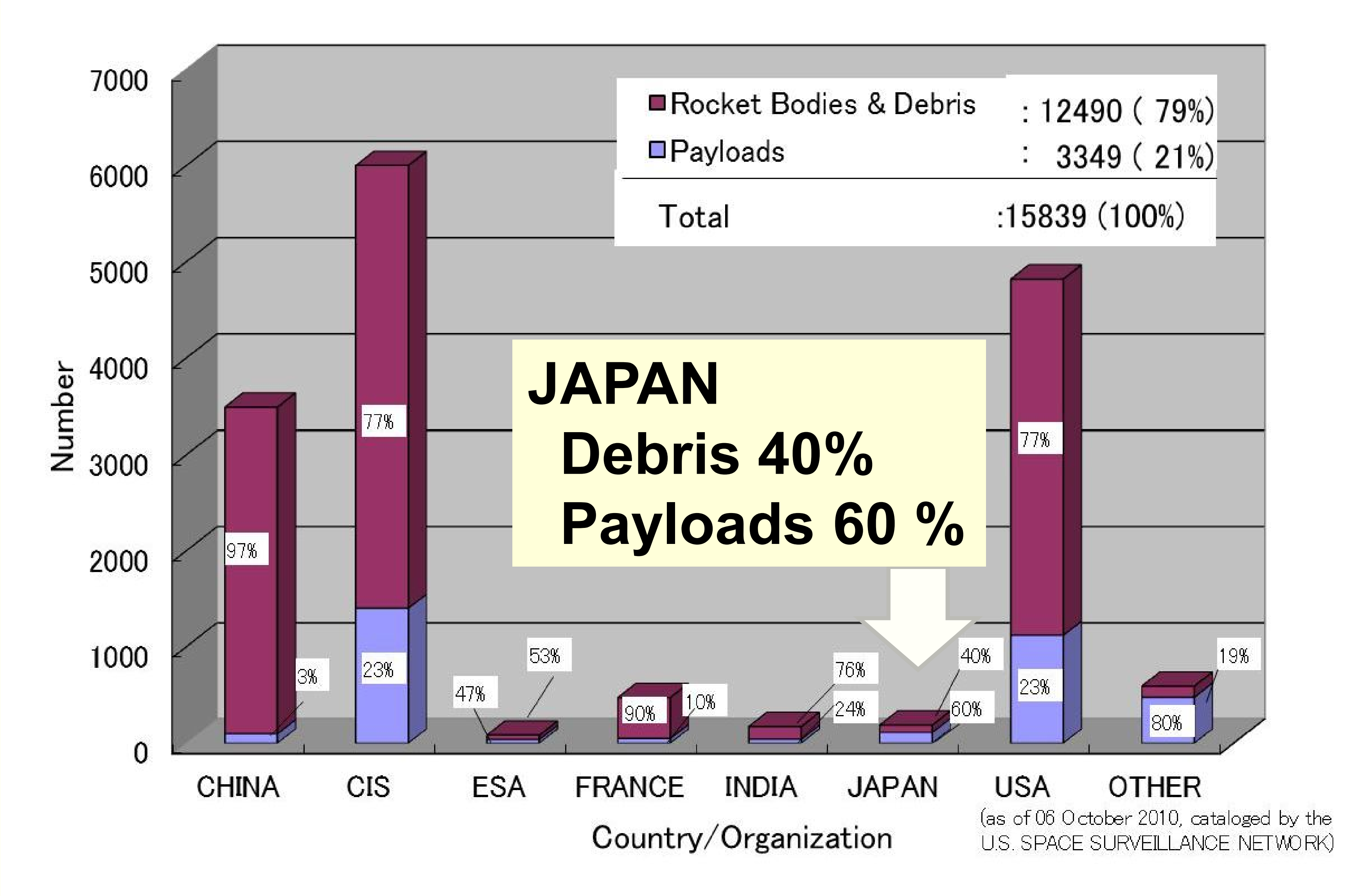
How Do We Find the Debris? (1)

- Radar and Optical Measurements (for objects > 0.2 cm)
  - Stare at the sky using a telescope and look at what flies through the field of view
  - Objects that are bright or big can be observed from the ground
    - Objects > 10 cm are followed (tracked), so that spacecraft can maneuver away from those objects
    - Objects between 0.2 and 10 cm are observable but not tracked (too small to predict orbit accurately)



Monthly Number of Objects in Earth Orbit

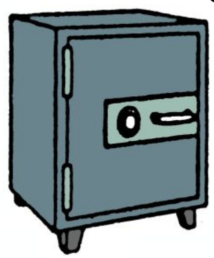



Rocket Bodies & Debris : 12490 (79%)
Payloads : 3349 (21%)
Total :15839 (100%)
JAPAN
Debris 40%
Payloads 60 %
Number
7000
6000
5000
4000
3000
2000
1000
0
97%
3%
77%
23%
47%
53%
90%
10%
76%
24%
40%
60%
77%
23%
19%
80%
CHINA
CIS
ESA
FRANCE
INDIA
JAPAN
USA
OTHER
Country/Organization
(as of 06 October 2010, cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

How Do We Find the Debris? (2)

- Returned Spacecraft Measurements (for objects < 0.1 cm)
  - Shuttle, MIR, International Space Station (ISS), Hubble Space Telescope (HST), European Retrievable Carrier (EURECA), Space Flyer Unit (SFU)
  - Long Duration Exposure Facility (LDEF, picture at right)
    - Launched on 6 April 1984, to measure the material reaction to space environment (included orbital debris)
    - Retrieved on 12 January 1990
    - Gathered data on small-sized debris (< 0.1 cm)

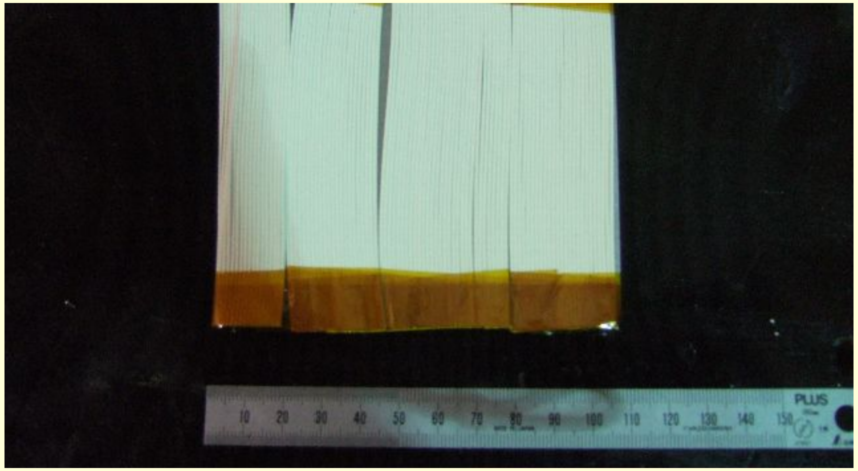
Effect Induced by Space Debris Impact

- < .01 cm ＝ Surface Erosion
- < .1 cm ＝ Possibly Serious Damage
- < .3 cm at 10km/sec (32,630 feet/sec) ＝  Bowling Ball att 60 mph （88 feet/sec）
- 1 cm Aluminum Sphere at 10 km/sec ＝  400 lb. Safe At 60 mph （88 feet/sec）

©NASA

Example and Result of Impact

- JAXA Space Debris Protection Design Manual (JERG-2-144-HB001) reveals:
  - Example of impact of a 300 um diameter solid sphere on a wire harness at a speed of 4 km/s
  - Orbital debris, even < 1 mm, may cause a fatal damage on a spacecraft
  - Information on debris > 200 um should be incorporated in design

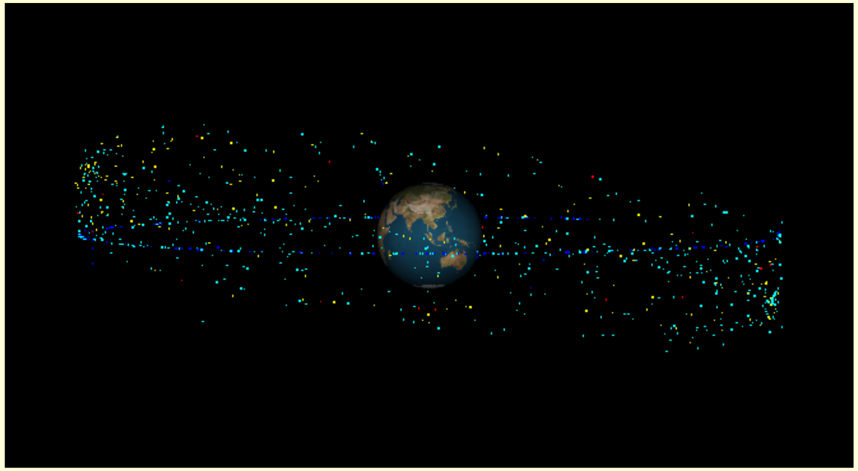


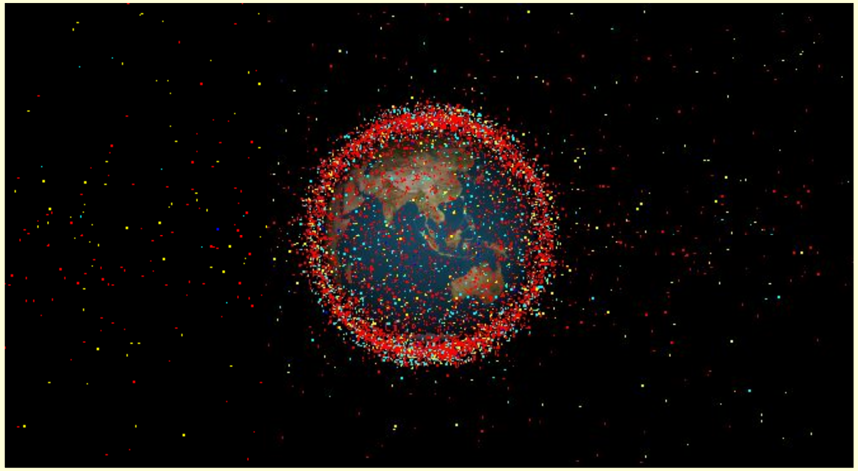
Space Debris Related Concerns

- Protection
  - JAXA Space Debris Protection Design Manual (JERG-2-144-HB001)
- Mitigation
  - UN Space Debris Mitigation Guidelines (Resolution of 22/December 2007)
  - Space Debris Mitigation Requirements (ISO 24113:2011) and related Standards
  - JAXA Space Debris Mitigation Standard (JAXA-JMR-003B)
- Remediation (by Orbital Debris Removal)
  - Research and Development on Active Debris Removal is underway in Japan
- Measurements

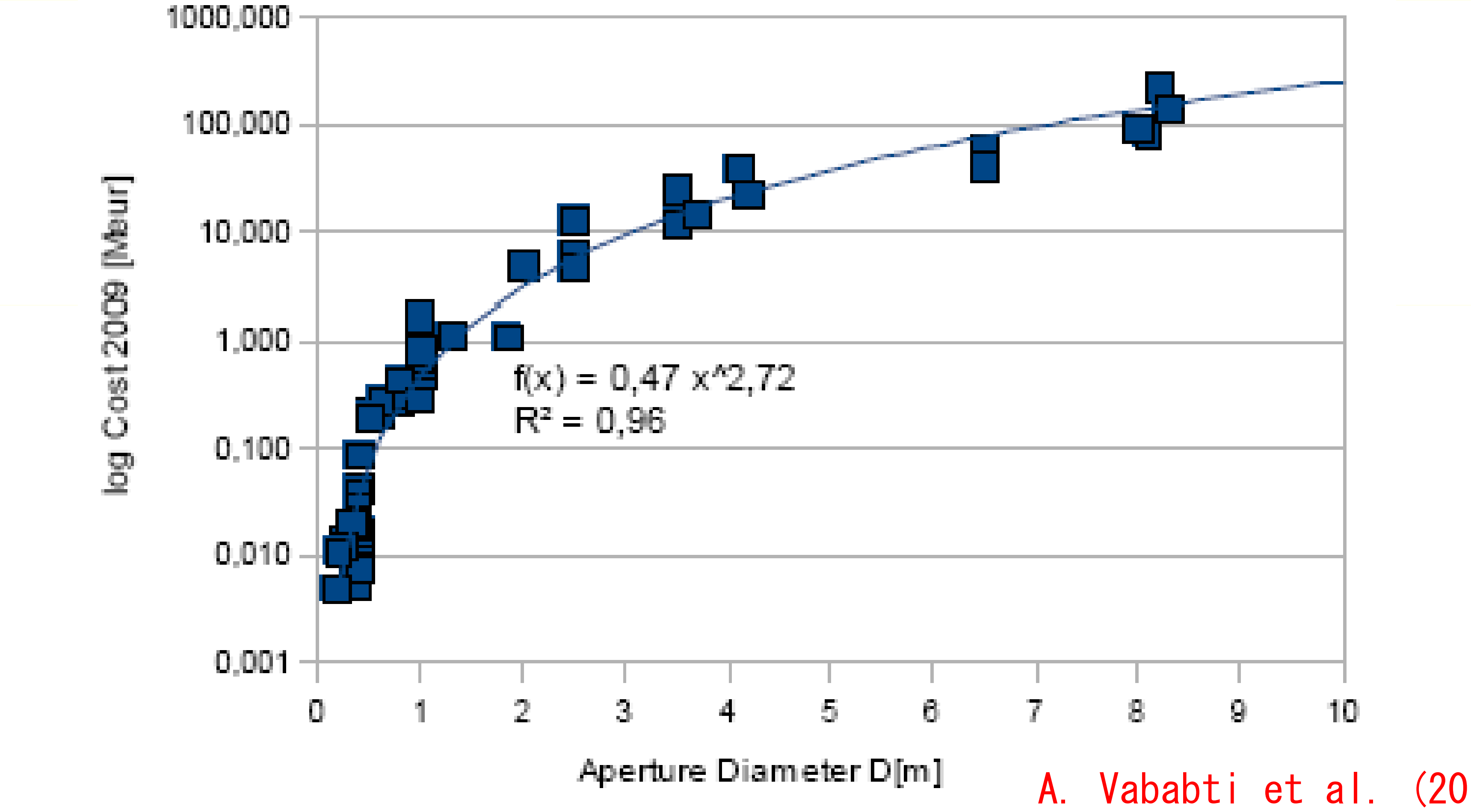
Research Topics for Asia-Pacific Regional Collaboration

1. Geostationary region
   - Optical measurements of possible fragments from orbital anomalies using a network of telescopes in the Asia-Pacific region
2. Low Earth orbit region
   - In-situ and near real-time measurements of micro-debris using a network of micro-satellites





Telescope Cost vs. Aperture Diameter

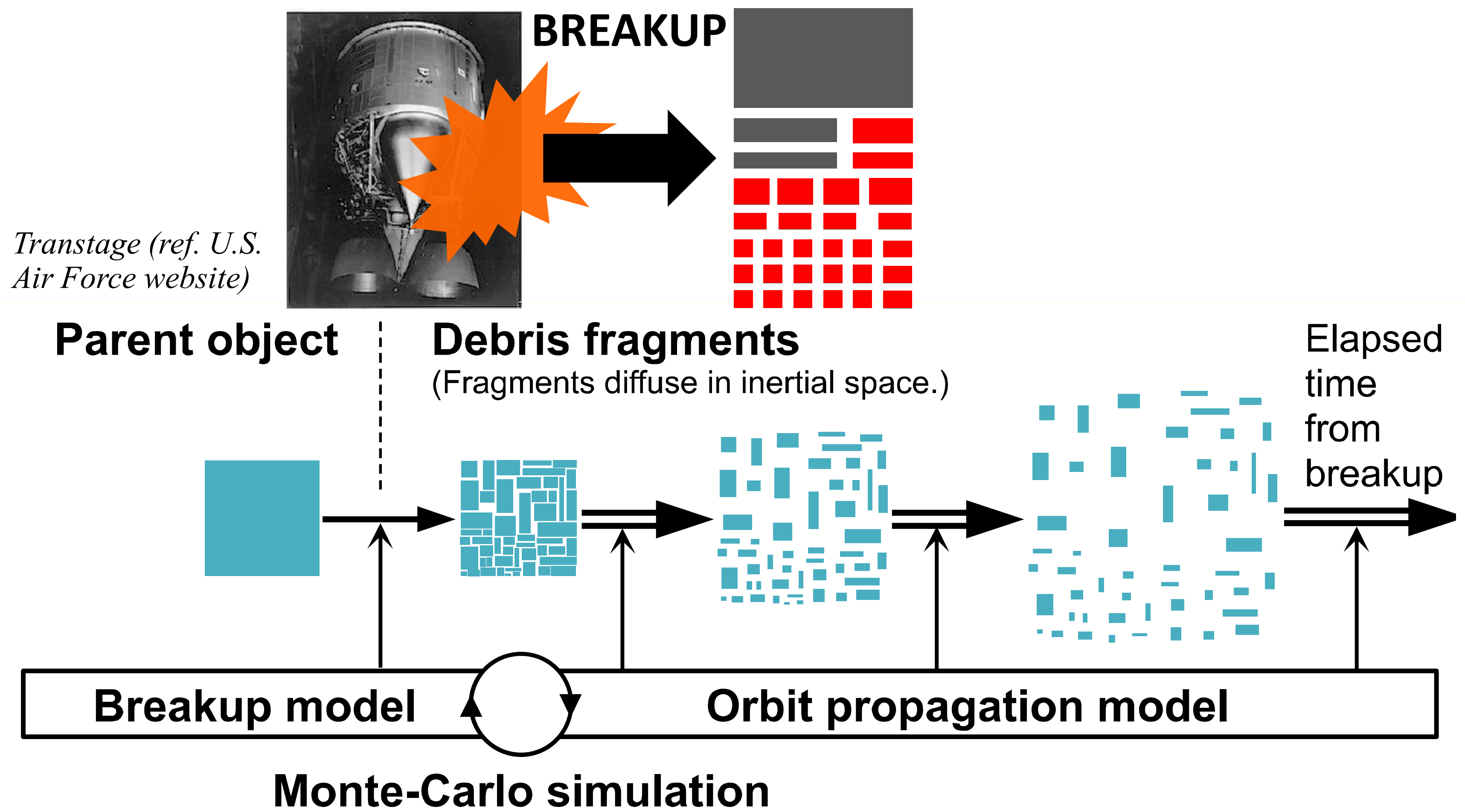


A. Vababti et al. (2010)

Issues to Be Solved and Solutions

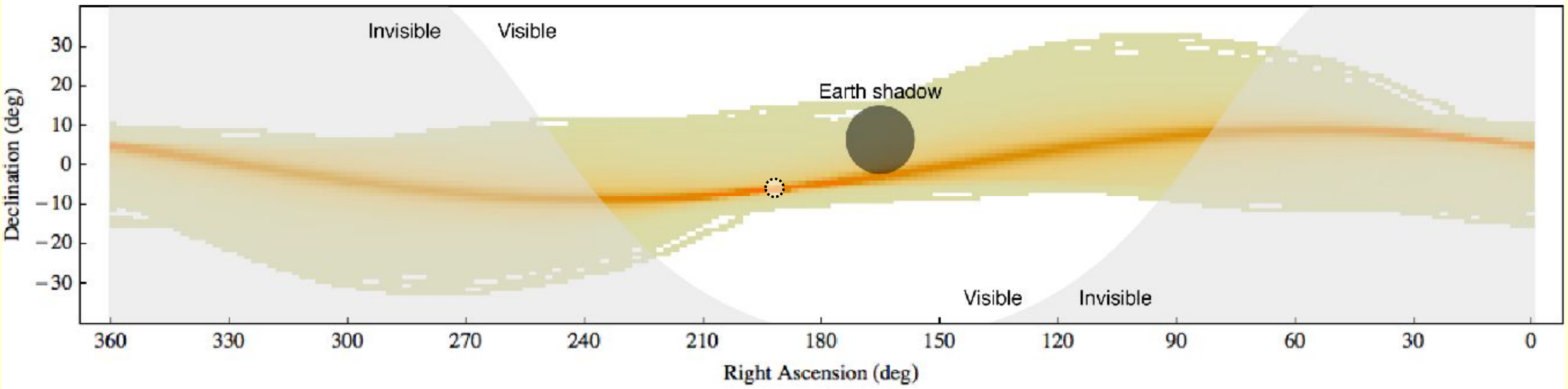
- Issues to be solved:
  - Cost of larger aperture telescope
  - Uncertainty in population
  - Uncertainty in motion
  - Difficulty in detection of low-luminosity objects
- Solutions:
  - Orbital debris modeling techniques enable population prediction and motion prediction
  - Population prediction enables effective observation planning
  - Combination of JAXA stacking method with motion prediction enables sub-meter-sized aperture telescopes to detect fainter objects by stacking successive images that have been shifted according to the predicted motion of the target object

Orbital Debris Modeling Techniques
- Debris Generation and Orbit Propagation -



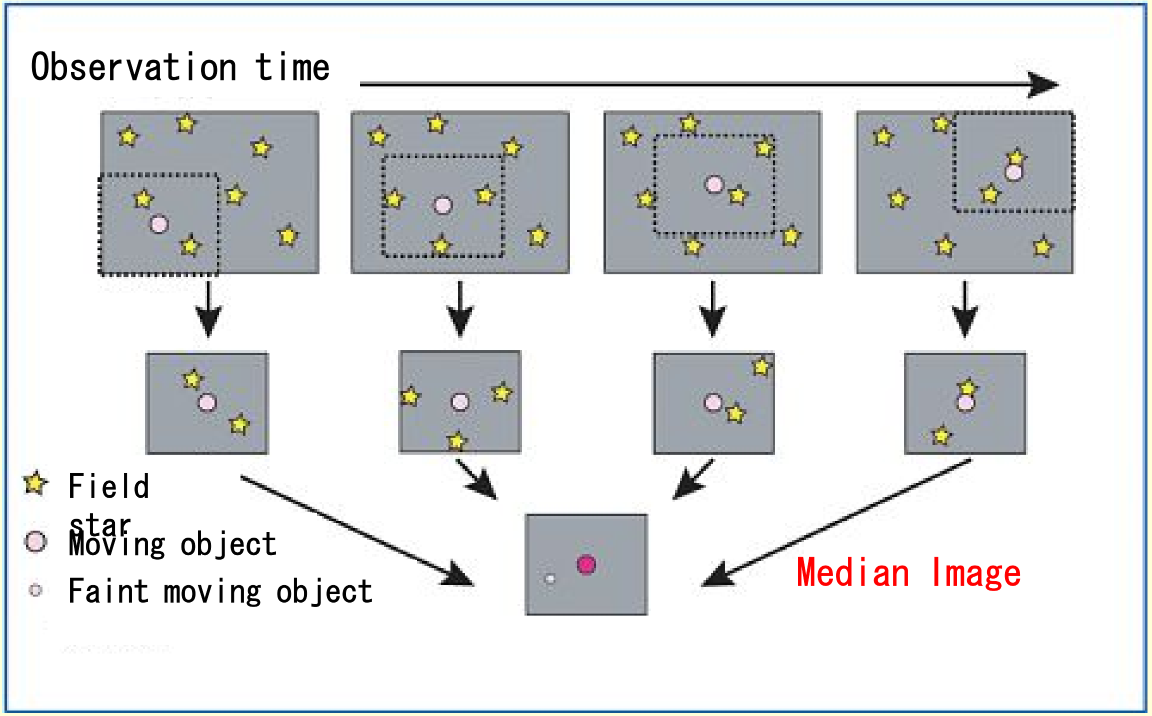
Effective Observation Planning

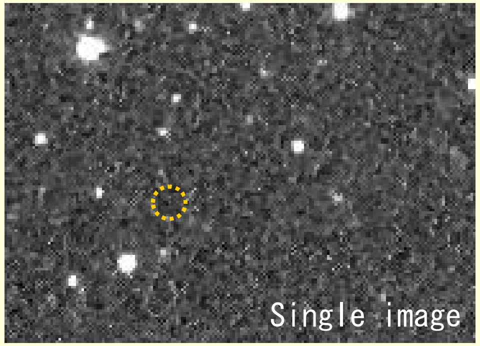
- Use population prediction
- Mask invisible region from a given site
- Overlay Earth shadow at the nominal geostationary altitude
- Specify the point where most fragments will be detected
- Set duration to keep looking at the point

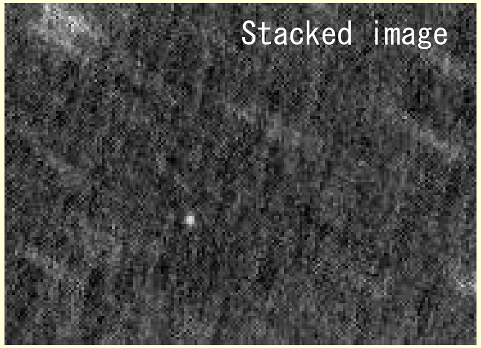


JAXA Stacking Method

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





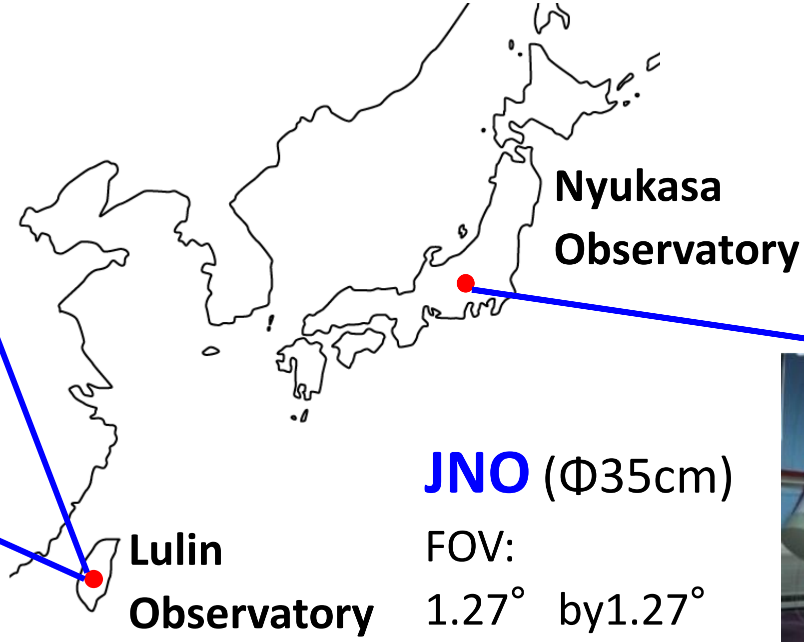


Sub-images are cropped from many CCD images to follow the presumed movement of moving objects. Faint objects are detectable by making the median image of these sub-images.

Collaborative Observations in Asia

LOT (Φ1m)
FOV: 26.4’by13.2’
CCD: 4k2k

TAOS (Φ50cm)
FOV:
1.74° by1.78°
CCD: 2k2k

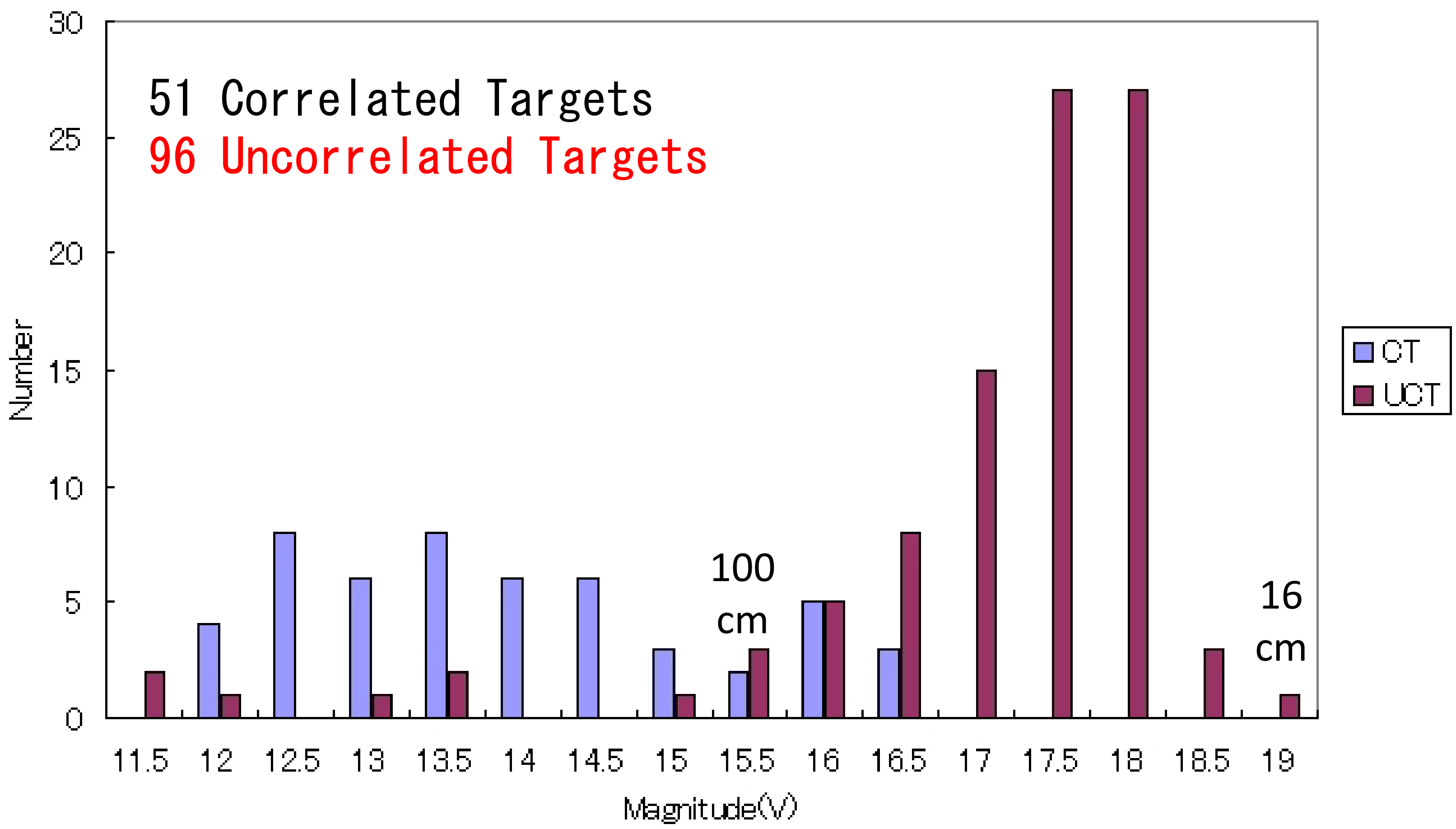


JNO (Φ35cm)
FOV:
1.27° by1.27°
CCD: 2k2k

Search target	1968-081E (Titan IIIC Transtage) fragments
Observation period	20 – 22 Oct. 2011 (3 nights)
Observation mode	Search Survey (6 hours / night)

➡ 40 uncataloged objects are detected and associated with 1968-081E fragments

Outcome of the Collaborative Observations
- TAOS 50 cm Diameter Aperture Telescope -

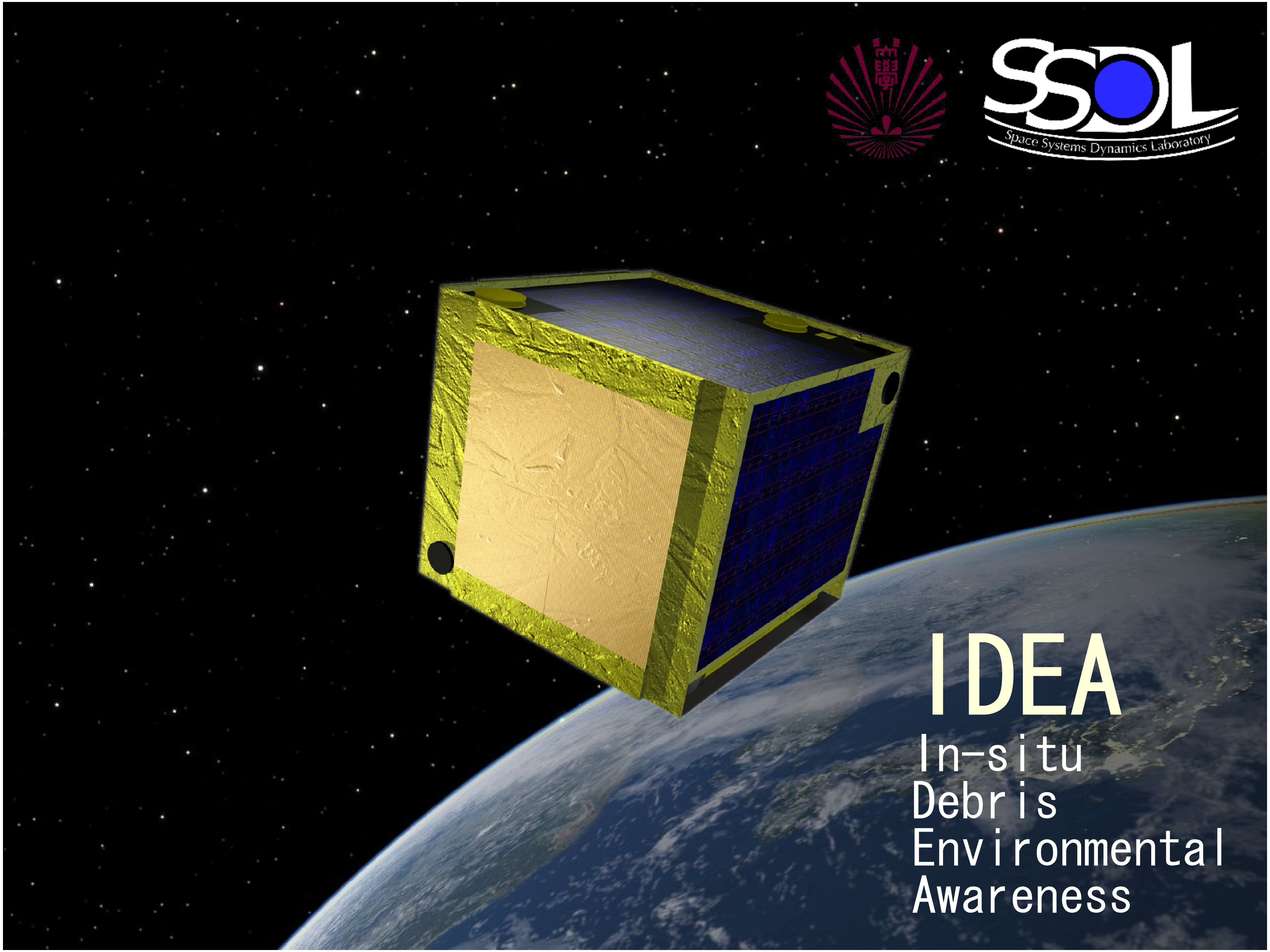


Future Scope

- All-in-one observation system at IHI Corporation
  - Small aperture telescope
  - Observation planning
  - Online robotic control
  - Image processing and identification
  - Orbit estimation
- Research Topics
  - Effectiveness of Asia-Pacific regional network
  - Practical astronomy and space engineering

Why In-situ and Real-time Measurements?

- Current environment has not been defined well because
  - Measurements of micro-debris are
    - Nearly impossible from the ground
    - Quite limited in terms of orbital regimes
    - Not continuously available
  - Latest information on micro-debris is
    - Not enough regarding recent major breakups such as
      - Chinese anti-satellite test using Fengyun-1C on 11 Jan. 2007
      - US Iridium 33 and Russian Cosmos 2251 accidental collision on 9 Feb. 2009
- Information should be dynamically updated based on measurements in the actual environment


SSDL
Space Systems Dynamics Laboratory
IDEA
In-situ
Debris
Environmental
Awareness

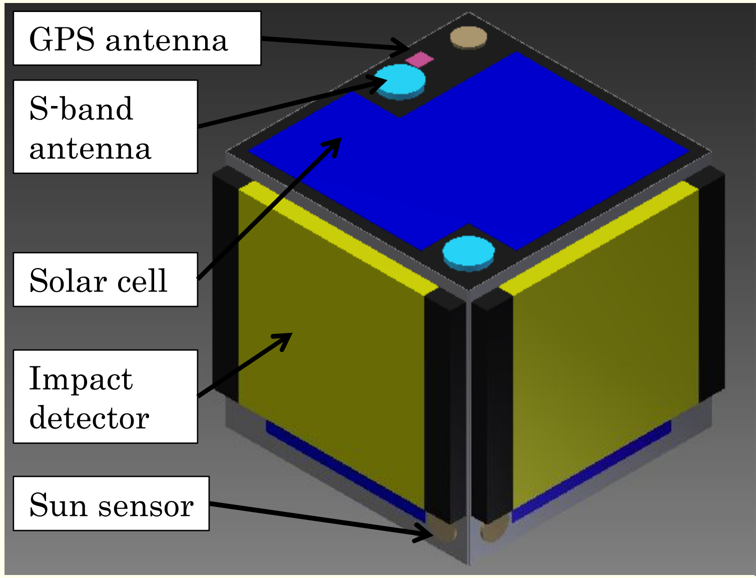
IDEA the project for In-situ Debris Environmental Awareness

- Aims a prompt and clear understanding of micro-debris environment
- Deploys a group of micro satellites, those conduct in-situ and real-time measurements of micro-debris
- Realizes a high temporal-spatial resolution
- Defines and dynamically updates micro-debris environment
- Identifies environmental change due to a breakup
- Estimates impacts on the future micro-debris environment

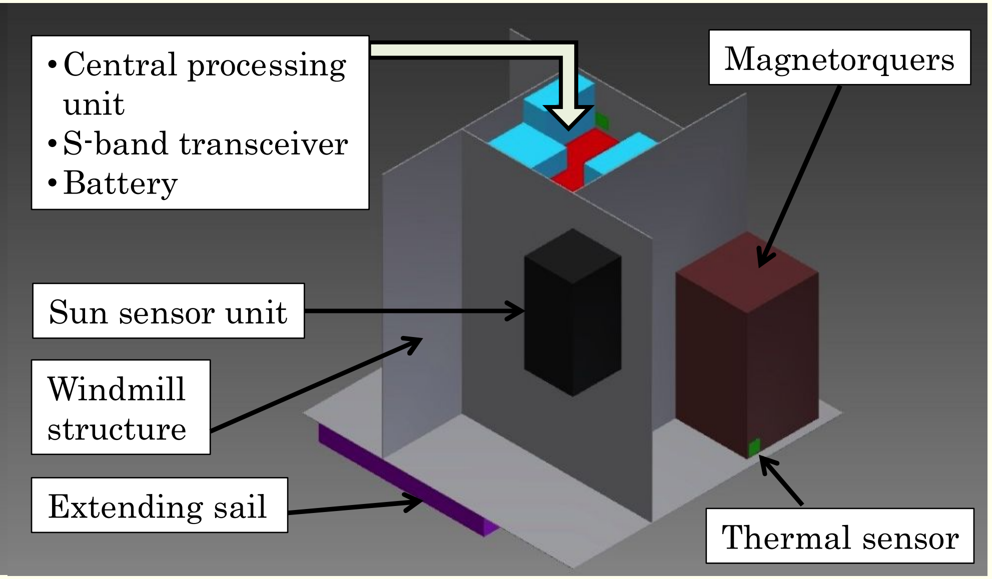
Research and Development at Kyushu University

- Development of IDEA satellite
  - Practical Education for Space Engineering
  - Collaboration with JAXA
    - JAXA is developing of a micro-debris sensor
  - Collaboration with small enterprises
- Research on dynamical environment model
  - Definition and dynamical update of micro-debris environment
  - Identification of environmental change due to a breakup
  - Precise assessment of impact risk on spacecraft

Schematic Design of IDEA Satellite



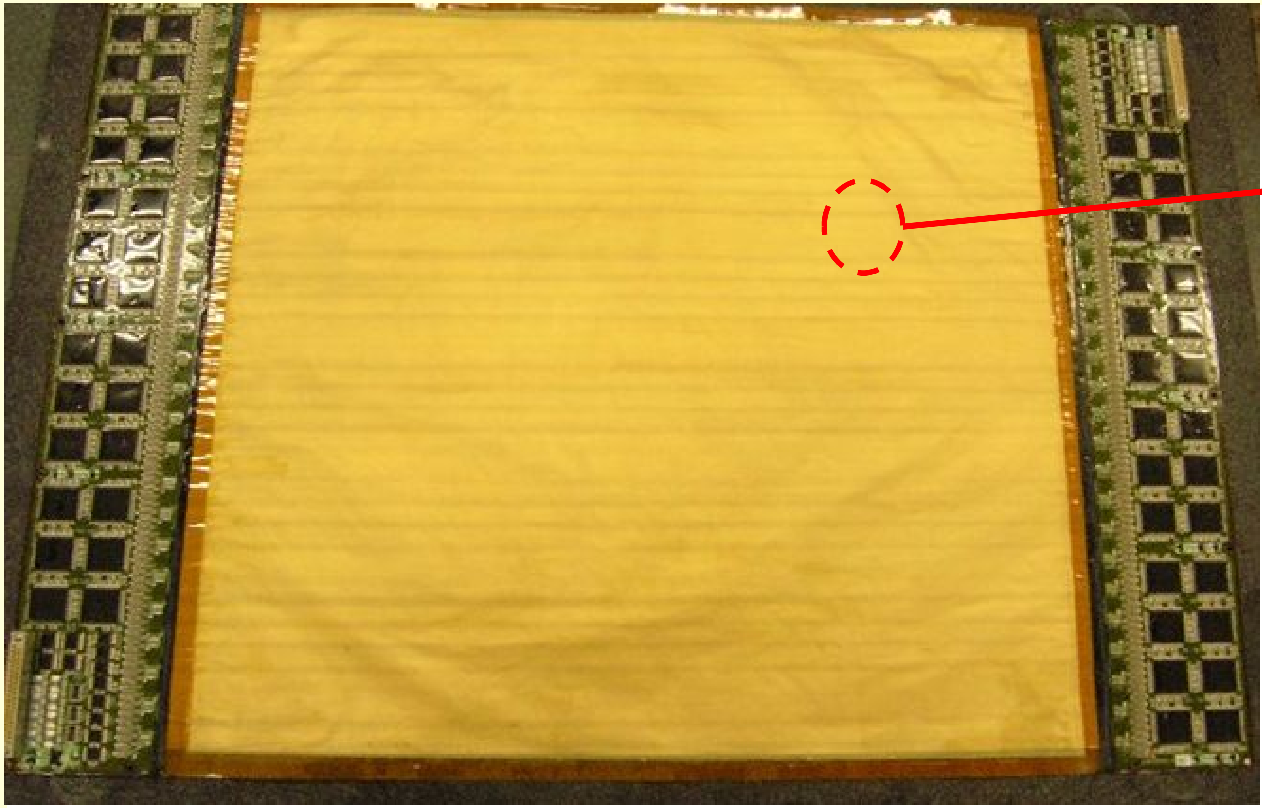
External View

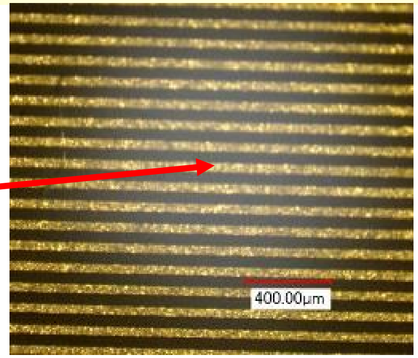


Inner Layout

Dimension	**50 cm by 50 cm by 50 cm**
Mass	**25 kg**
Power	**31.5 W**

Micro-debris Sensor Developed at JAXA



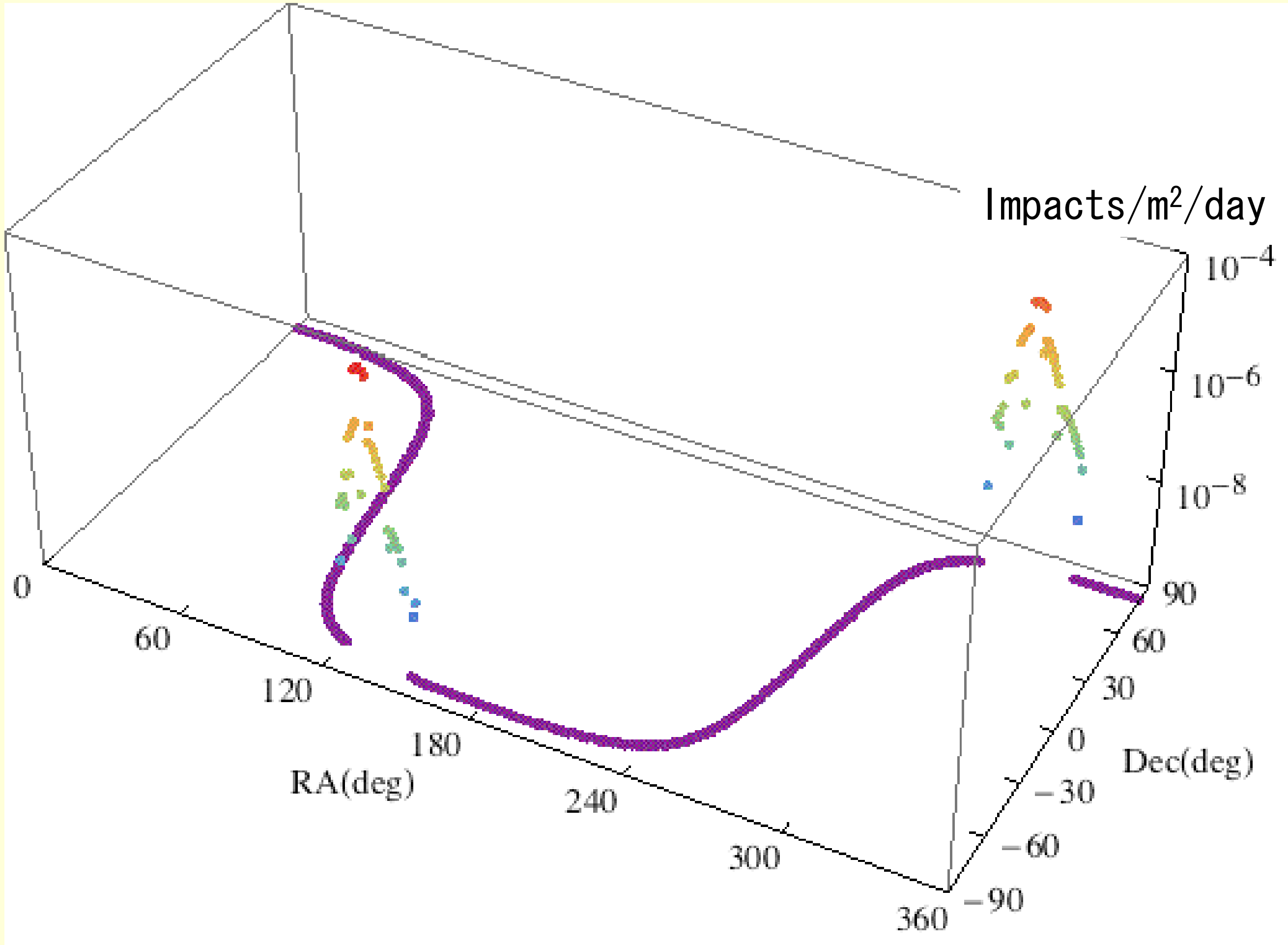


Strip width ~ 50 µm
Pitch ~ 100 µm
Thickness ~ 25 µm

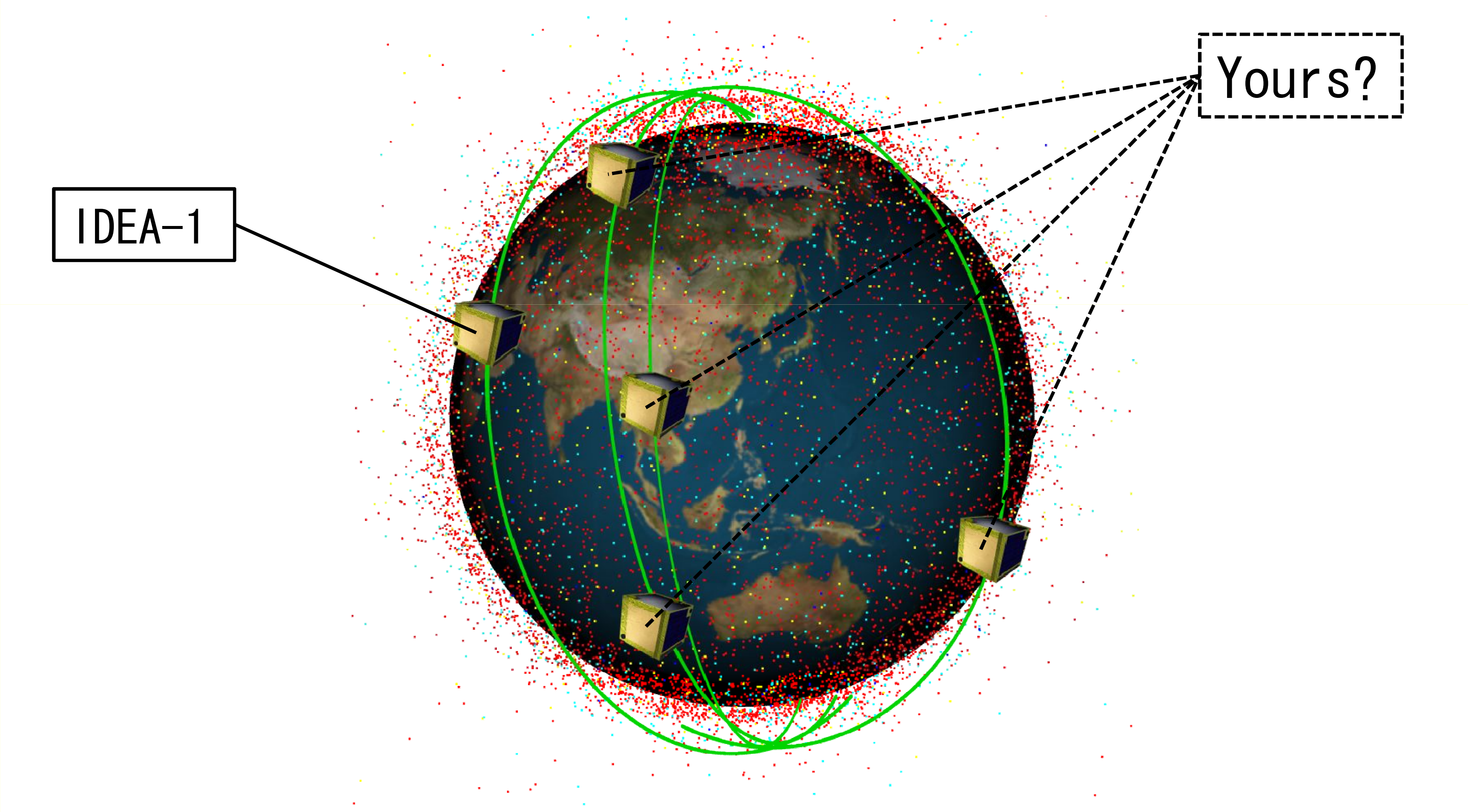
Sensor area： 35 cm (W) by 30 cm(L) ~ 1000 cm^2 per unit

Expected Outcome of IDEA Project

- Environmental Change on a Spacecraft -



Future Vision of Collaboration Through IDEA



Summary

- Any space-faring countries have to take into account space debris issues
- Measurements are essential to Protection design; Mitigation; Remediation; Spacecraft Operations
- Telescopes in Asia-Pacific region have a potential to contribute in terms of detectability and coverage
- Fukuoka/Kyushu is the gateway to Asia-Pacific region
- You are welcome to join:
  - Optical measurements of objects in the geostationary region using smaller aperture telescopes
  - Deployment of micro satellites for in-situ and near real-time measurements of micro-debris