B3

デブリ観測・防御技術の研究開発動向

Research and Development of Space Debris Observation and Protection Technologies

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デブリ問題解決のためのアプローチとしてデブリ観測及び防御技術があげられる。現在、低軌道デブリの観測能力は 10 ㎝であるのに対し宇宙機が防御できるサイズは数 mm といわれている。観測及び防御能力の向上によりこのギャップを埋めることはデブリ問題の解決に大きく貢献する。講演では世界でどのような観測、防御技術に関する研究開発が実施されているかを概観し、JAXA 未踏センター内で行われている最新の研究開発内容を紹介する。観測技術に関しては光学観測装置を利用した未カタログデブリの検出や軌道決定技術について、防御技術については 2 段軽ガスガンを利用した宇宙機構成物に対するデブリ衝突時の特性について説明する。

In order to cope with the space debris problem, improvements of observation and protection technologies must be considered. The main concern is that there is a gap between observable size (10cm) and protectable size (a few mm). Burying this gap by enhancing both observation and protection technologies will greatly contribute to solving the problem. I would like to outline what is currently going on the areas of space debris observation and protection in the world and introduce our activities in JAXA on these area.

Research and Development of Space Debris Observation and Protection Technologies

Japan Aerospace Exploration Agency (JAXA)

Innovative Technology Research Center

T. Yanagisawa, M. Higashide

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JAXA

Abstract

In order to cope with the space debris problem, improvements of observation and protection technologies must be considered. The main concern is that there is a gap between observable size (10cm) and protectable size (a few mm). Burying this gap by enhancing both observation and protection technologies will greatly contribute to solving the problem. This talk outlines what is currently going on the areas of space debris observation and protection in the world and introduce our activities in JAXA on these area.

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JAXA

U.S.A.

Improving Space Surveillance Network (SSN) to Space Fence System is underway. Space objects of about 10 times will be tracked. Joint Space Operations Center (JSpOC) is providing the conjunction assessment services to satellites' operators since 2009.

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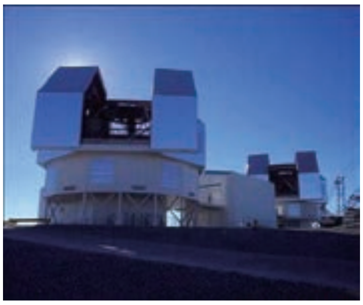
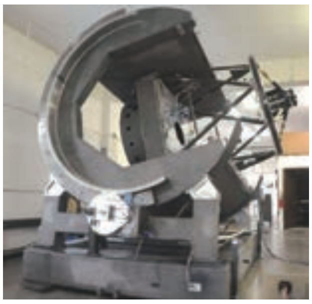
U.S.A.

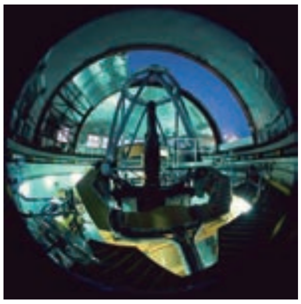
61cm MODEST Telescope at CTIO in Chile



6.5m Magellan Telescope at CTIO in Chile



Meter Class Autonomous Telescope in Ascension Island



3.8m UKIRT Telescope in Hawaii

NASA is collecting GEO debris data using 61cm MODEST telescope in Chile under the collaboration with Michigan University since 2001. From 2011, 6.5m Magellan Telescope which can carry out spectroscopy is being used.

Meter Class Autonomous Telescope is being constructed in Ascersion Island. The telescope will be able to observe GEO and LEO with photometry and spectroscopy mode. It will also contribute SSA.

3.8m UKIRT Telescope for IR photometry and spectroscopy is also available.

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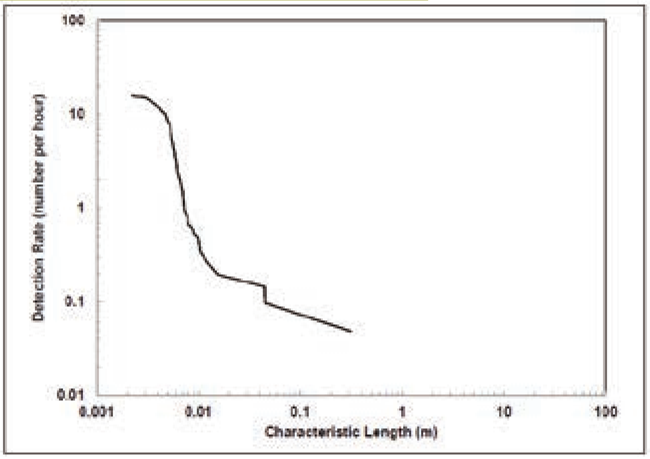
U.S.A.

Haystack radar in Lexington



Size distribution of all objects detected by Haystack in 2008 campaign

NASA is monitoring LEO environment using Haystack radar and Haystack Auxiliary (HAX) radar in Lexington. Although they can't determine orbits of detected objects, it can detect LEO objects of a few mm in size.

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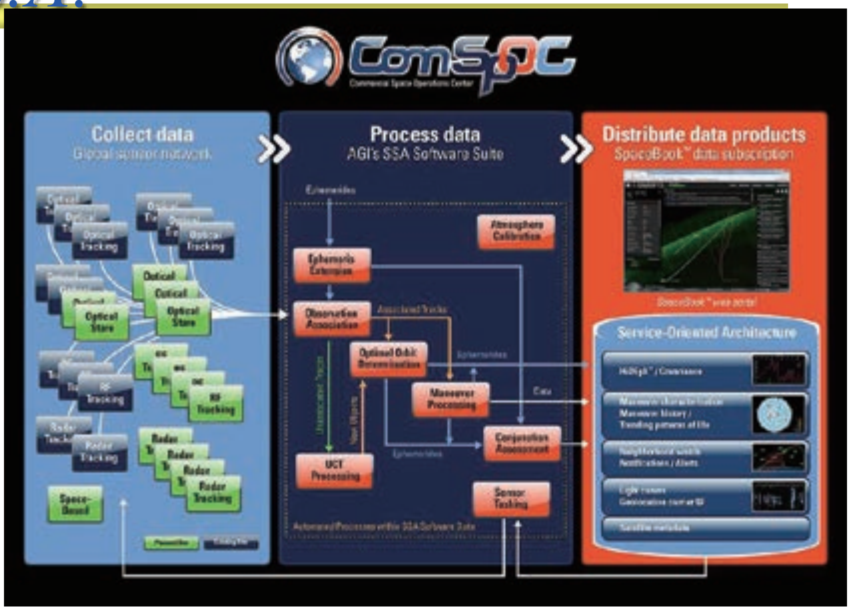
U.S.A.



AGI established Commercial Space Operation Center (ComSpOC). By using world wide optical and radar sensors, ComSpOC provide satellites with variety of SSA services including conjunction analysis. Up to 100x reduction in uncertainty dramatically reduces the number of false alarms and warnings.

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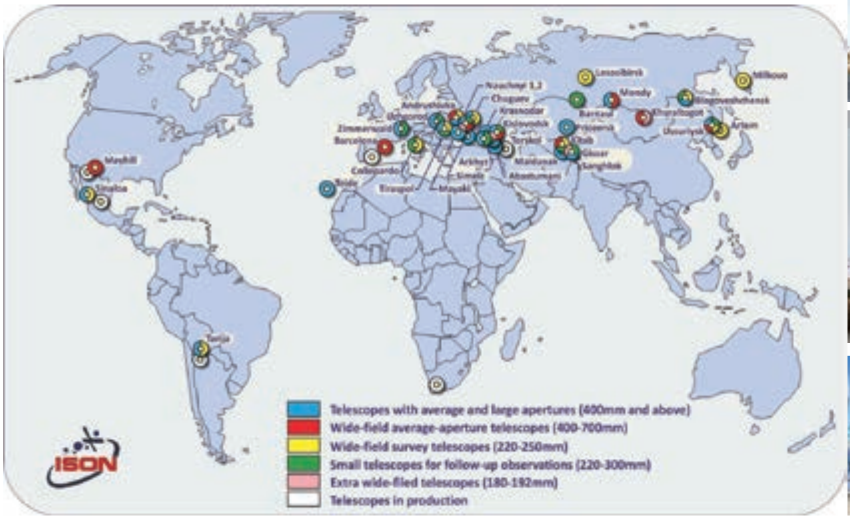
Russia



International Scientific Optical Network (ISON) started in 2005 has been adding new telescopes every year. Currently, 80 telescopes in 15 countries are joined. The main objective is GEO monitoring, but LEO observations are also planned. Most of the telescopes are ranging from 20cm to 40cm.

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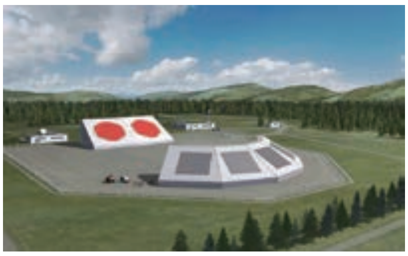
JAXA

Europe



Future SSA radar system

1m telescope in Tenerife

TIRA radar

ESA started SSA program which will be funded 0.8 billion dollars in 10 years from 2009.

ESA is conducting GEO, GTO, MEO surveys using the 1m telescope in Tenerife. LEO environment is continuously monitored by TIRA radar . The data obtained both sites are reported in IADC every year.

Envisat rotation was investigated using radar and optical data. Rotation rate was jumped up to 3.5 degrees/s in 2013 from 0.4 degree/s in 2012.

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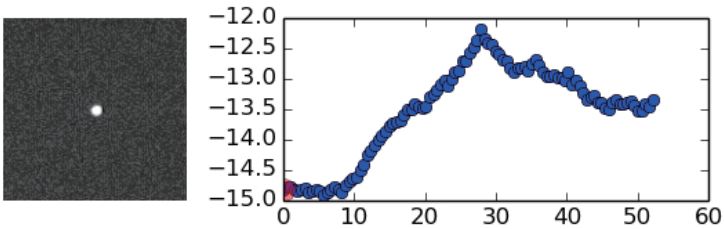
China



Light curve observation by CNSA

Laser ranging of space debris

A lot of light curve observations were carried out to investigate rocket bodies' attitude in LEO region. Laser ranging toward space debris are being conducted using high power laser to get accurate orbital information.

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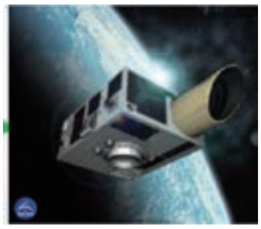
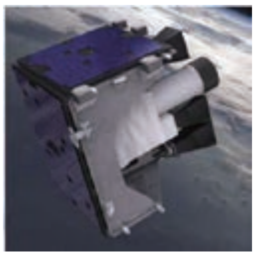
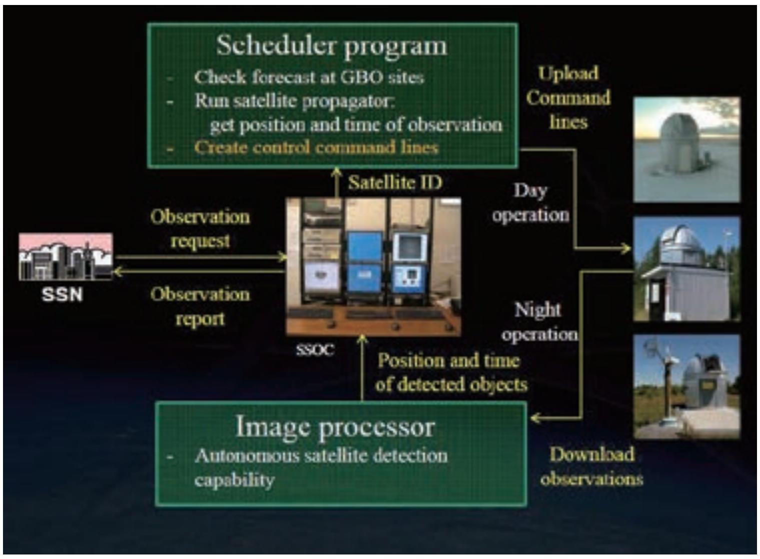
Canada



NEOSSat



SAPPHIRE



Two small satellites, NEOSSat for NEO observation and SAPPHIRE for GEO debris observation, were successfully launched. Ground-based optical automated observatories were constructed using 4 40cm-telescopes.

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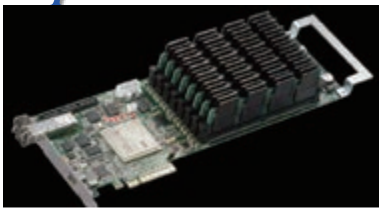
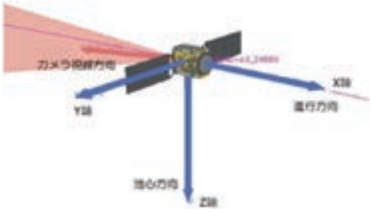
Japan



FPGA board developed for image-processing

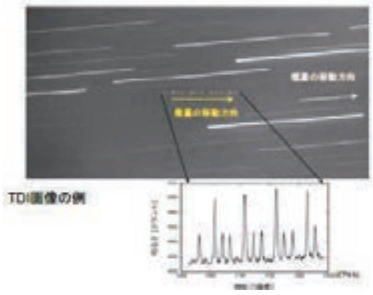
CMOS sensor for detection of LEO objects



Space based optical sensors for GEO debris

Phased array radar of Kamisaibara space guard center

Optical telescopes of Bisei space guard center



Light curve data taken with 1m telescope at Bisei space guard center

FPGA board for image-processing and CMOS sensor for detection of LEO were developed. Space based optical sensors for GEO debris are being considered. GEO and LEO are being monitored with both a phased array and optical telescopes in Japan.

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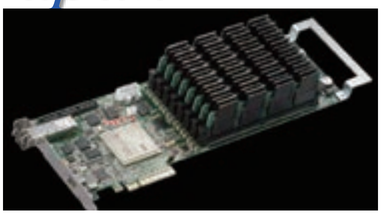
Japan



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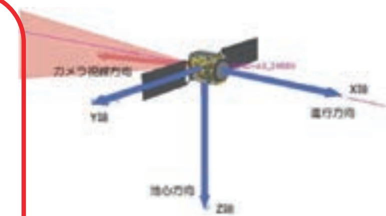

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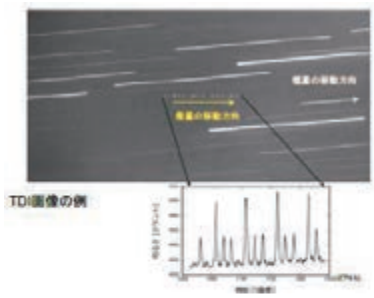

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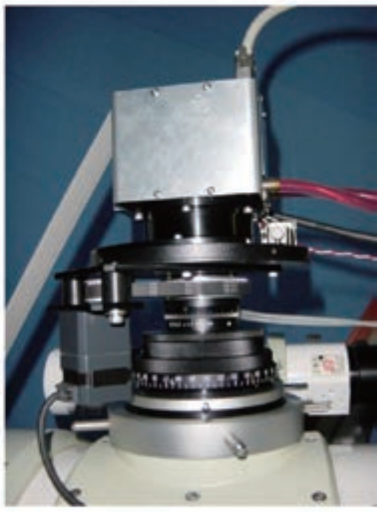
Optical Observational Facility of JAXA at Mt. Nyukasa

Overview of the facility

Observational equipment: 35cm telescope and 2K2K CCD camera

Telescope: Takahashi ε-350
D: 355mm f:1248mm (F/3.6)
Equatorial mount: Showa fork-type 25EF

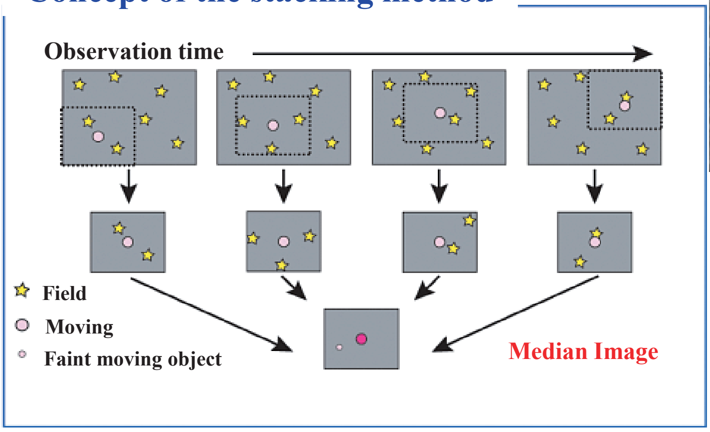


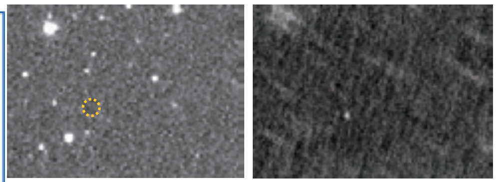
CCD camera: N.I.L. CCD42-40
chip: 2K2K back-illuminated (e2v)
cooling: peltier device(-30°)
FOV: 1.27×1.27°

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.

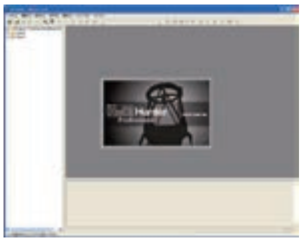
Concept of the stacking method





An asteroid 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.

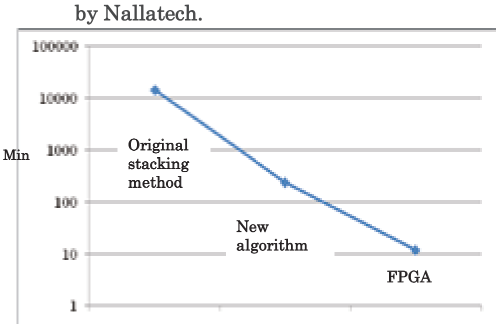
Many asteroids were discovered by the method.

Development of the new algorithm

The algorithm is installed to the FPGA board for reducing analysis time.

FPGA board H101-PCIXM manufactured by Nallatech.

FPGA board system manufactured by iDAQs.



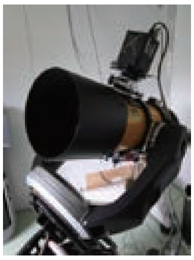
Change of analysis time

Analysis time is reduced one 1200th.

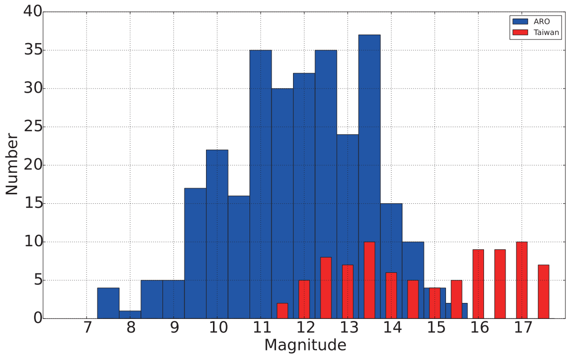
280 hours → 14 minutes

Remote observation in Australia

Remote observations using small telescope at Australia are being carried out. Weather condition there is much better than Japan.



Australian Remote Observatory (Queensland , Oakey)



Brightness distribution of detected GEO objects using 50cm telescope in Taiwan(red) and 18cm telescope in Australia(blue).

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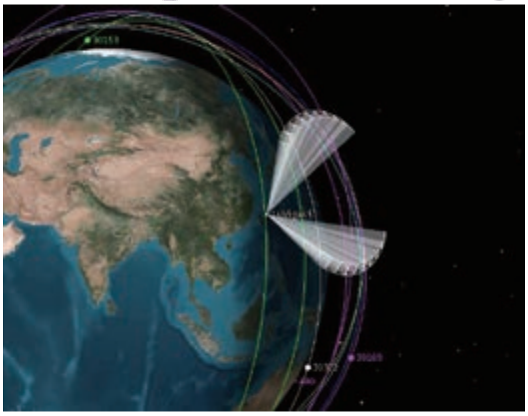
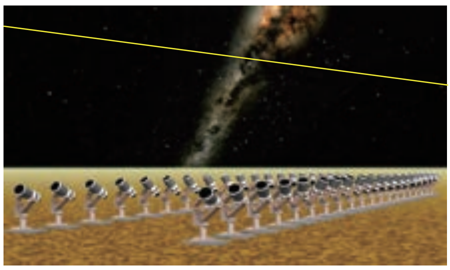
Optical Fence System for LEO objects

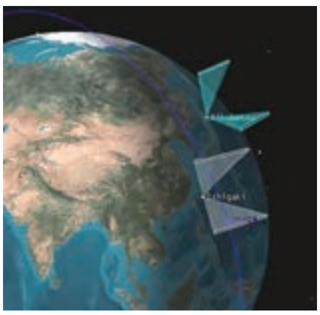


About 40 optical sensors are installed to one site.

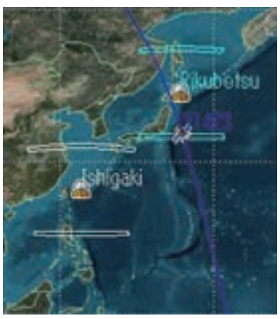
2 regions of the sky are monitored to get long arc.

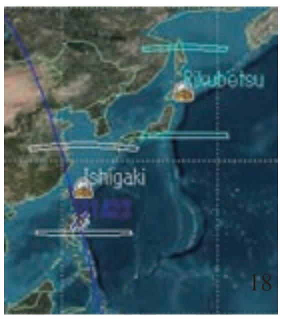
2 consecutive passes should be observed for accurate orbital determination. For this reason, 2 longitudinally separated sites are considered.





Detection of identical object at 2 sites





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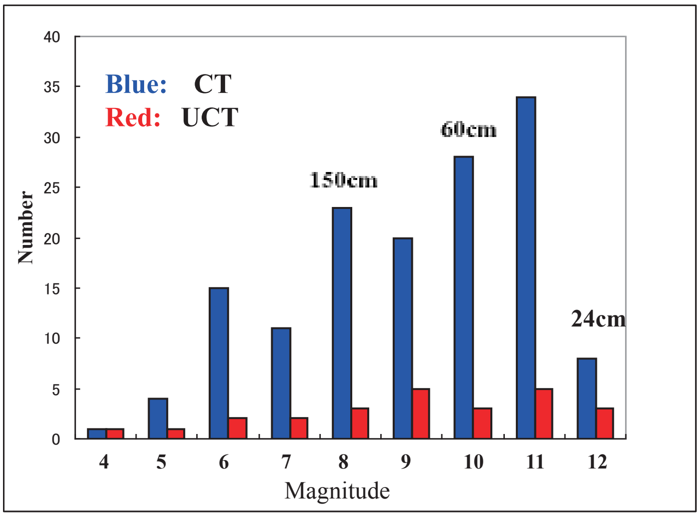
Detection abilities



Diffuse reflection with 90-degree phase angle and albedo 0.1

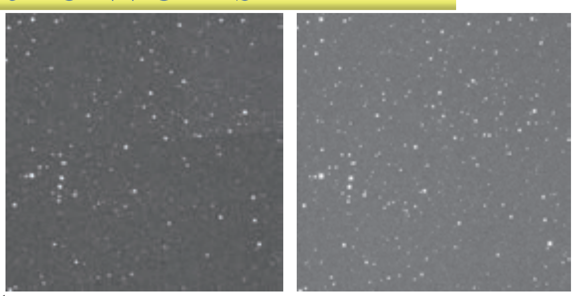
Result of 16 days' survey

About 30cm LEO objects are detectable

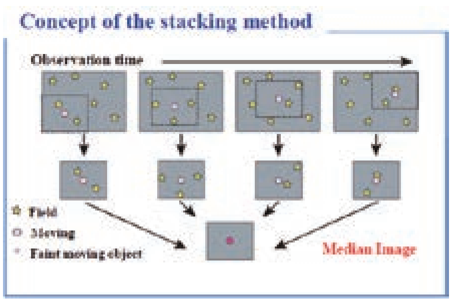
About 15% of detected objects are un-cataloged

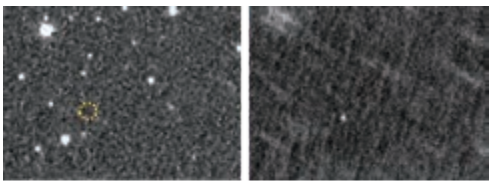
Future Works

CMOS sensor for LEO observation. Readout time is 60 times faster than that of CCD



Comparison between a CCD frame(left) and CMOS frame(right) in same condition





An asteroid detect with the stacking method. One CCD image (left) and the stacked image (right).

- Improve equipment: CMOS sensor will be used for the LEO survey observation
- Improve analysis method: Linear Motion Detection Algorithm → Stacking method

Aim to detect about 10cm LEO objects

U.S.A.

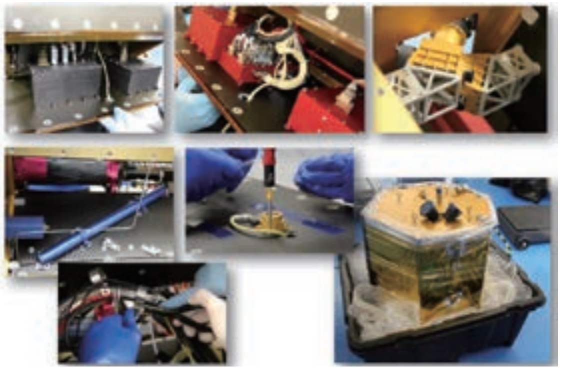
Ref. Rivero, M., et al., Proc. 65th IAC, 2014.

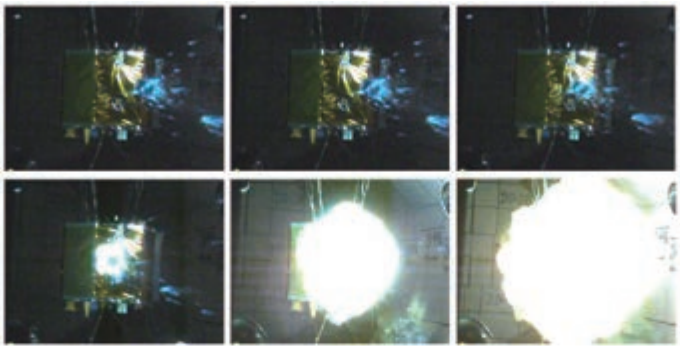
DebrisSat Project

NASA collaborates with University of Florida, The Aerospace Corp., and US Air Force

Design and fabricate a 60-cm/50-kg class satellite, including MLI and solar panels, to be representative of modern payloads in LEO

Perform hypervelocity impact test with sufficient kinetic energy to completely breakup DebriSat





Fragments were collected with foam panels

The collected fragments are characterized the physical properties

Analyze the data to improve NASA satellite breakup models

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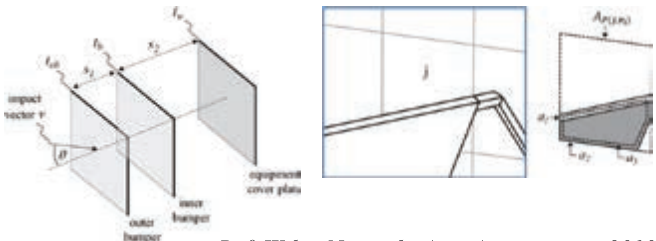
Europe

Risk Assessment of Satellite Internal Structure

Fraunhofer EMI conducted as a part of EU FP7 project P²ROTECT

Estimate satellite internal structure damage by using a triple-wall ballistic limit equation

Investigate damage of electronics boxes from impact experiments



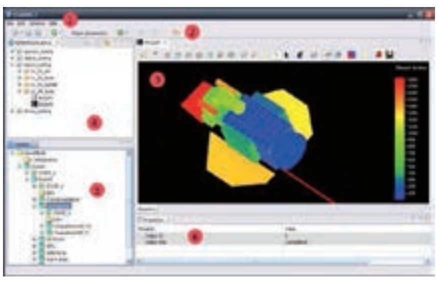
Ref. Welty, N., et al., Acta Astronautica, 2013.

Ref. Putzar, R.., et al., Proc. 56th IAC, 2005.

ESABASE2

MMOD impact risk assessment tool developed by ESA

Analyze impact risk against a satellite 3D model



Ref. ESABASE2 HP

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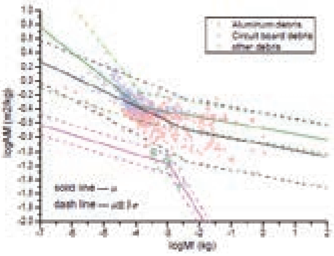
China

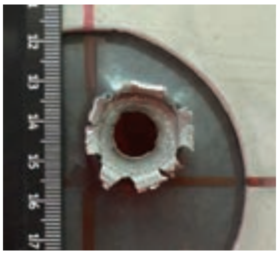
Ref. Liu, S., et al., Proc. 65th IAC, 2014.

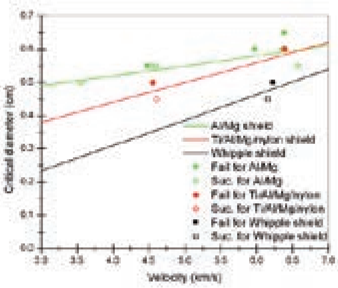
Spacecraft Breakup Model

Research by Hypervelocity Aerodynamics Institute of China Aerodynamics Research & Development Center

Develop the breakup model based on impact experiment results of dummy spacecrafts made of aluminum plates, filled with some simulated electronics boxes with a circuit board as the actual payload







Density-grade Bumper Shield

Research by China Academy of Space Technology

Develop new bumper made of density-grade material, Ti/Al/Mg/nylon and Al/Mg

Ref. Gong, Z., et al., Proc. 6th European Conference on Space Debris , 2013.

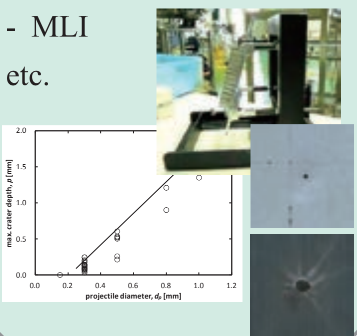
Japan

Protect spacecraft from space debris impacts

Investigate debris impact vulnerability of spacecraft components

- Honeycomb sandwich structures
- Wire harnesses
- MLI

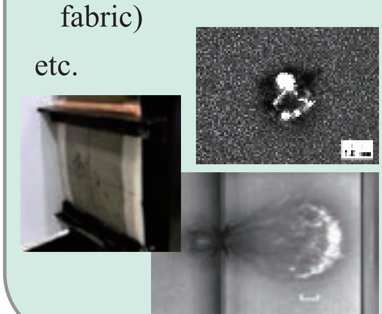
etc.



Propose debris bumper shields

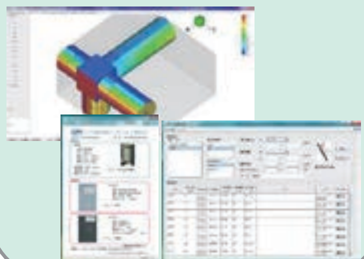
- Light weight bumpers (CFRP, Porous metal)
- Flexible bumpers (High-strength fiber fabric)

etc.



Develop tools to help space debris protective design

- Impact risk assessment tool (TURANDOT)
- Impact experiment & numerical simulation database



Conclusion

The trend of research and developments on space debris observation and protection in the world was outlined. JAXA’s activities on this field were also introduced. Strengthening observation and protection abilities against space debris is fundamental to solve the problem. We would like to bury the gap between observation and protection limit and contribute to solving the problem under the collaboration of other nations.

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