A09

# Space debris observation technologies of JAXA R&D directorate

**Toshifumi Yanagisawa and Hirohisa Kurosaki (JAXA)**

JAXA R&D directorate is developing space debris observation technologies especially using optical sensors like CCD and CMOS which are developed in terms of their sizes, sensitivities, and cost-effectiveness, recently. By combining these sensors with the powerful image-processing technologies using FPGA and/or GPGPU, innovative debris survey system is possible. We developed the sophisticated image-processing technologies which uses numerous frames of optical sensors and detect very faint objects. A lot of un-cataloged GEO objects are detected and orbit-determined analyzing CCD data with the technologies. We are currently applying the technologies to the data of LEO observation which are taken with much faster sensor, CMOS. 100 times faster analysis technologies are required to deal with the CMOS data. Optical fence for LEO objects using a lot of CMOS sensors will be possible. These technologies will contribute to the future SSA activities in Japan. We also started to develop the technology for the motion and attitude estimation of ADR targets.

***Biography***

**Toshifumi Yanagisawa**

Toshifumi Yanagisawa received Ph.D. in Astrophysics from the Nagoya University in 2000. He has been working on the observation technologies and the image-processing for space debris and near-earth objects as an associate senior researcher of Japan Aerospace Exploration Agency (JAXA) for 18 years. He worked on space debris observation using optical sensors at the space debris program office of NASA from 2005 to 2007. He was the chairman of the working group 1 (space debris observation) of the Inter-Agency Space Debris Coordination Committee (IADC) from 2016 to 2018.

*8th Space Debris Workshop in Chofu*

# Space debris observation technologies of JAXA R&D directorate

Japan Aerospace Exploration Agency (JAXA)
Research and Development Directorate

T.Yanagisawa and H.Kurosaki

## Abstract

JAXA R&D directorate is developing space debris observation technologies especially using optical sensors like CCD and CMOS. By combining these sensors with the powerful image-processing technologies using FPGA and/or GPGPU, innovative debris survey system is possible. We developed the sophisticated image-processing technologies which uses numerous frames of optical sensors and detect very faint objects. A lot of un-cataloged GEO objects are detected and orbit-determined analyzing CCD data with the technologies. We are currently applying the technologies to the data of LEO observation which are taken with much faster sensor, CMOS. Optical fence for LEO objects using a lot of CMOS sensors will be possible. These technologies will contribute to the future SSA activities in Japan. We also started to develop the technology for the motion and attitude estimation of ADR targets.

## Optical Observational Facility of JAXA at Mt. Nyukasa

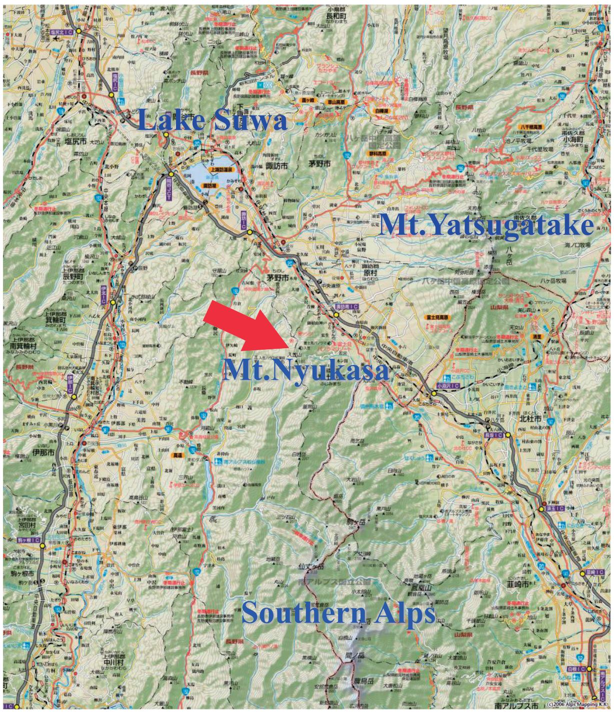
Location

Longitude: 138° 10′ 18″ E

Latitude: 35° 54′ 05″ N

Altitude: 1870m

MPC Code: 408 Nyukasa

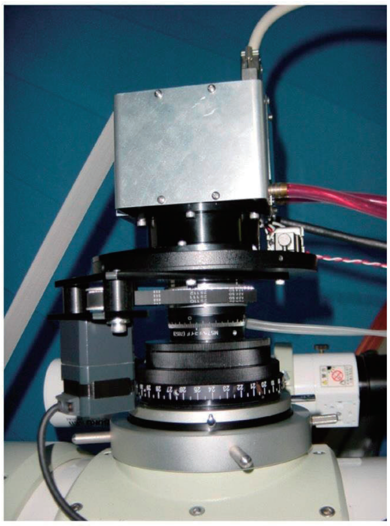



## Optical Observational Facility of JAXA at Mt. Nyukasa

Overview of the facility

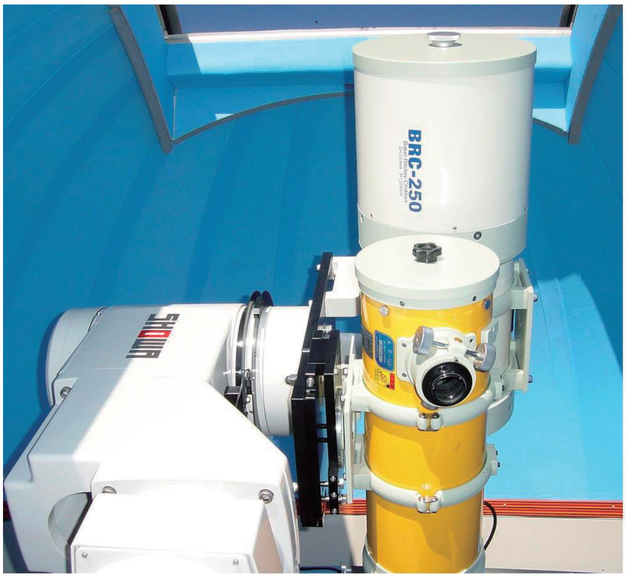
## Observational equipment: 35cm telescope and 2K2K CCD camera

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

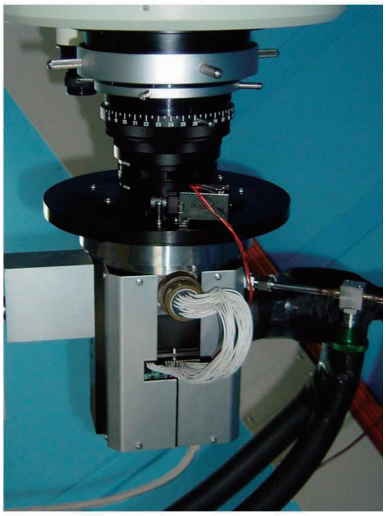


CCD camera: N.I.L. CCD42-40
chip: 2K2K back-illuminated (e2v)
cooling: peltier device(-30° )
FOV: 1.27×1.27°

## Observational equipment: 25cm telescope and 4K4K CCD camera




Telescope: Takahashi BRC-250
D: 250mm f : 1268mm (F/5.1)
Equatorial mount: Showa eccentric elbow-type 25EL

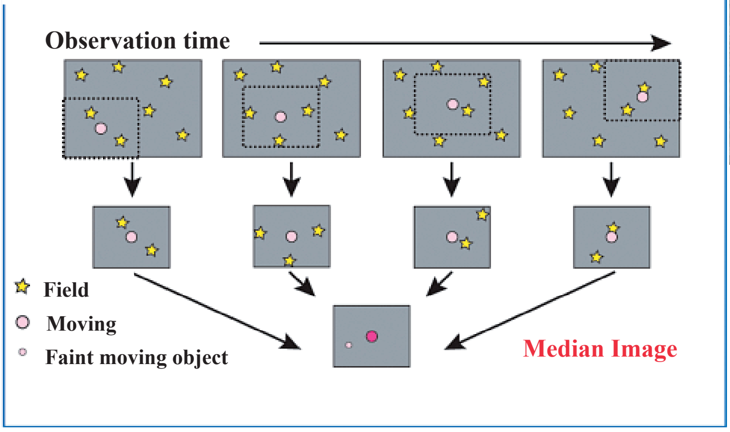


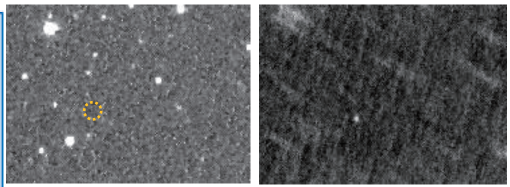
CCD camera: N.I.L. CCD44-82x2
chip: 2K4K back-illuminated (e2v) ×2
cooling: circling refrigrant(-100℃)
FOV: 2.78×2.78°

# Image-processing technology : Stacking method

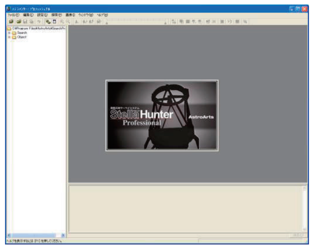
The stacking method uses multiple images to detect very faint objects that are undetectable on a single image.

## Concept of the stacking method



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



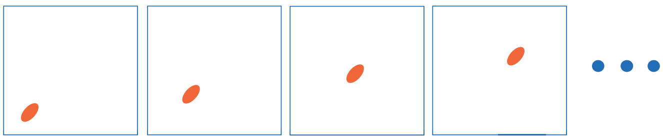
Stellar Hunter Professional: Commercial software for discovering asteroids and comets.

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

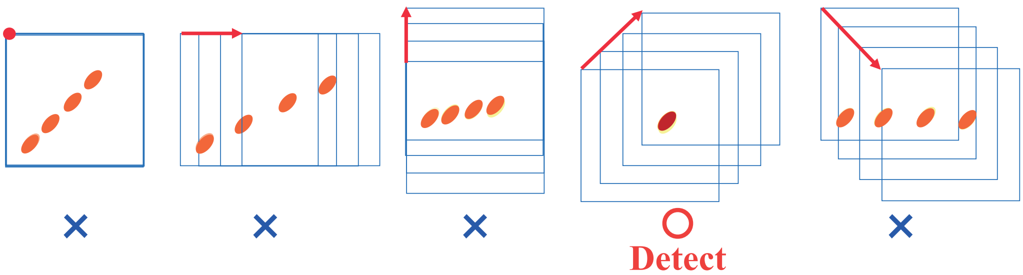
**Many asteroids were discovered by the method.**

# Image-processing technology : Stacking method

The weak point of the method is taking time to analyze the data in case of detecting unseen object whose movement is not known, because various movements of the object have to be presumed.



**Many CCD image are taken with telescope-fixed mode.**




**Images are stacked in many ways, as various shift values are presumed. Once a object is detected, its movement is also determined.**

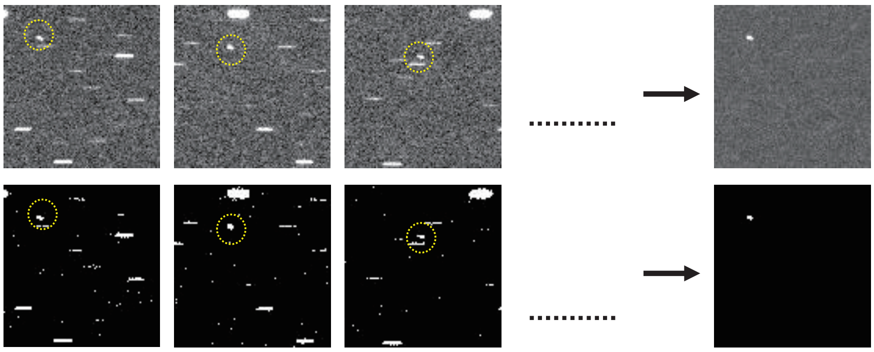
**Analysis time for 65536 processes of 32 1024×1024-pixel frames which are intended to detect objects moving within 256×256 pixels is about 280 hours using 1 normal PC.**

## Development of the new algorithm

**Calculating median is complicated and time-consuming process as compared with calculating average.**

**Simple calculation process like average that contains the advatage of median is required.**

**Binarization solves the problem!!**

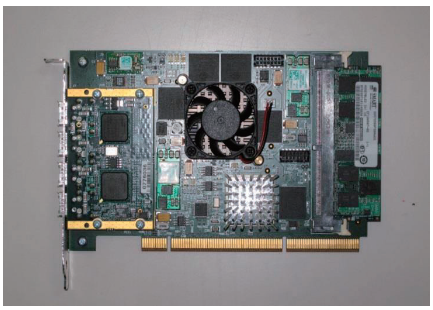


**Deference between the original algorithm of the stacking method (upper) and the new algorithm using binarized images.**

**Analysis time is reduced to one 60th.**

## Development of the new algorithm

**The new algorithm is installed to the FPGA board for further speed-up.**



FPGA board H101-PCIXM manufactured by Nallatech.

**FPGA board system manufactured by iDAQs.**

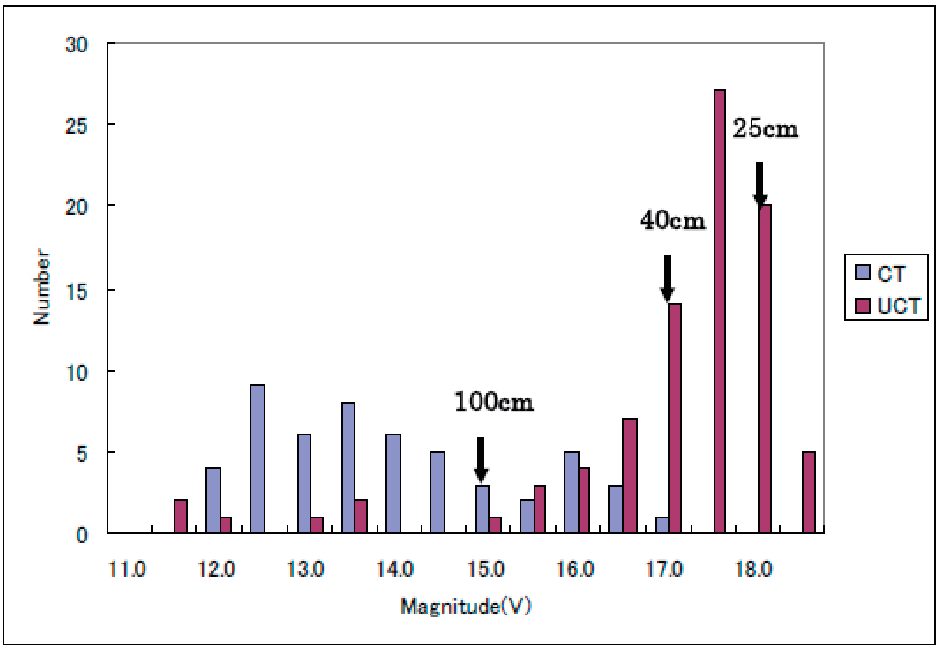
**Analysis time is reduced one 20th more. (Total is one 1200th.)**

**280 hours → 14 minutes**

**This is a very powerful tool to detect small size objects in GEO and LEO.**

## Observation Result

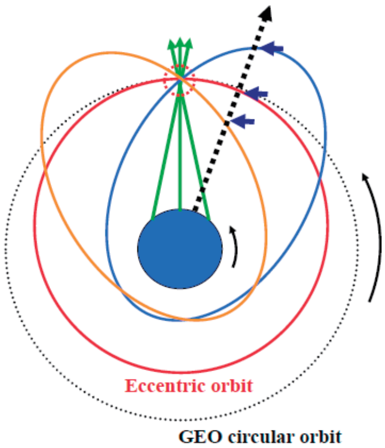
**The result of GEO survey using 35cm telescope**




**Magnitude distribution of detected objects**

## Observation Result

**Effective orbital determination method was developed.**




**2 nights' observation for one inertia region**

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**Pairing of each night's object using simple orbital elements.**

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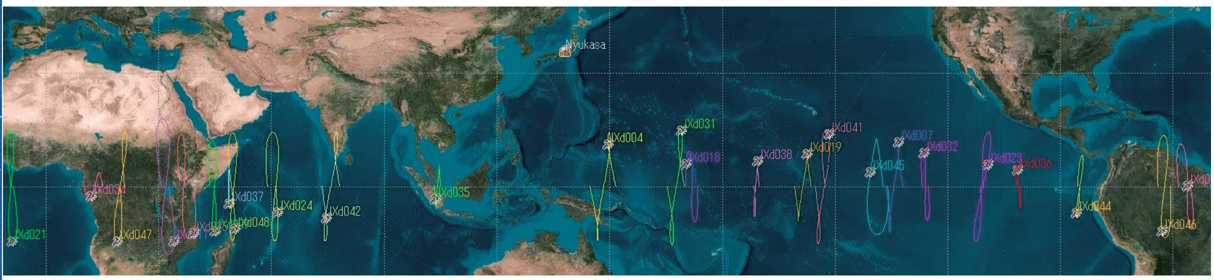
**3rd night observation of different direction for eccentricity and argument of perigee**



## The large CMOS sensor

**CMOS sensor:** Canon 35mm FHD

**Number of pixel:** 2000 × 1128

**Pixel size:** 19μm × 19μm

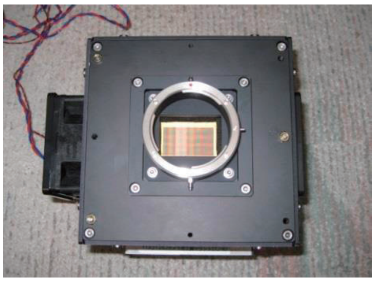
**Effective area:** 38.0mm × 21.4mm

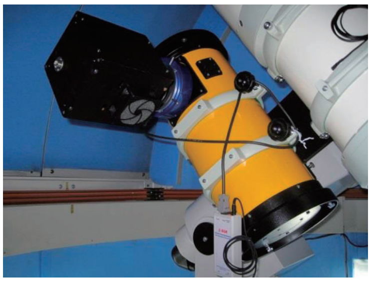
**FOV :** 4.4 × 2.5-degree with Takahashi ε180ED

**Modified for LEO observation by Canon (GPS time stamp, and interval observation)**

**Advantage of the CMOS sensor:**

**high speed, low noise, high sensitivity, large area, low cost**

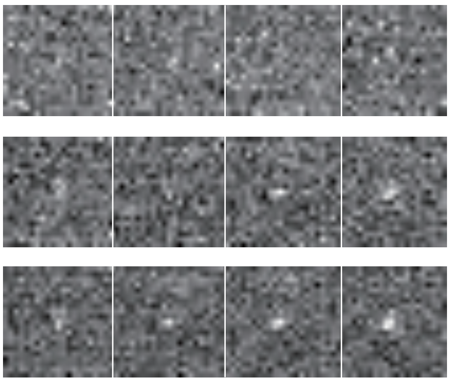




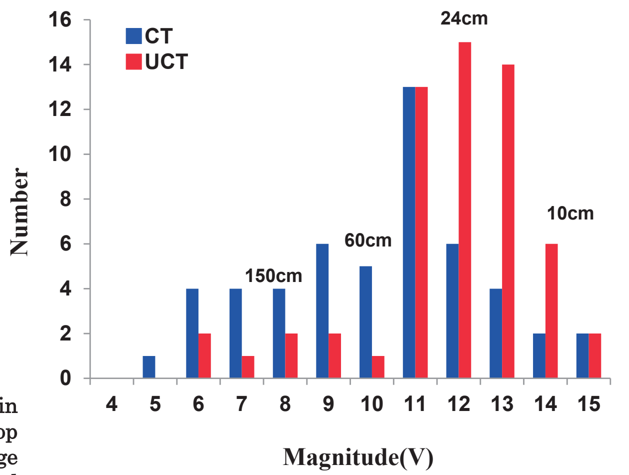


## LEO survey using CMOS sensor

109 LEO objects were detected. 58 of them (53%) were un-cataloged.



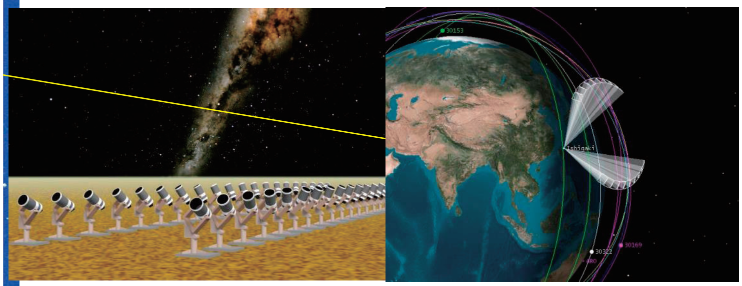
The faintest object (about 7cm in diameter) detected in this study. Top figure shows the original image around the detected object. The second and the third images are the stacked images using 4 and 8 frames, respectively. The bottom image is the final stacked image .



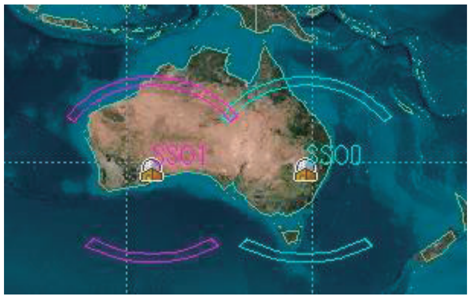

CMOS with FPGA-based stacking method is very effective to detect LEO objects

**Much faster analysis is needed for CMOS data. New fund from Acquisition, Technology and Logistics Agency of Japan will be used to develop such technologies**

# Application to SSA



Optical LEO survey system



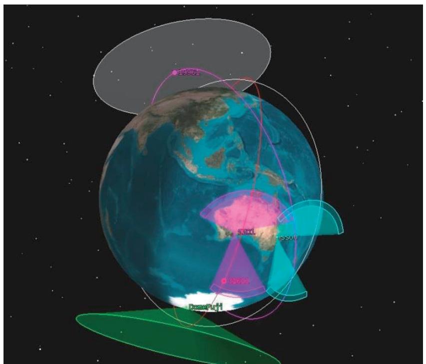
2 observation sites in Australia for two consecutive pass observations

**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.**

**About 60% of LEO objects which are cataloged by SSN will be detected and orbit-determined in four months.**

**Two tracking sites which are placed to both polar regions are needed to maintain orbital elements of those objects.**



**Concept of the tracking observation**

**Very cost effective**

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# Application to NEO

NEO (Near Earth Object) problem is one of the most serious concerns to be solved for the human being

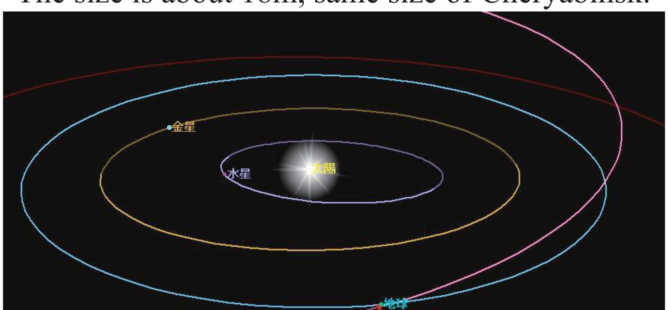
We discovered 7 NEOs applying our technologies.

<u>About 2018EZ2</u>

2018EZ2 approached 0.0014AU to the Earth (half distance to the moon).

This NEO can't be detected by other US big surveys (Pan-Starrs, CSS and so on).

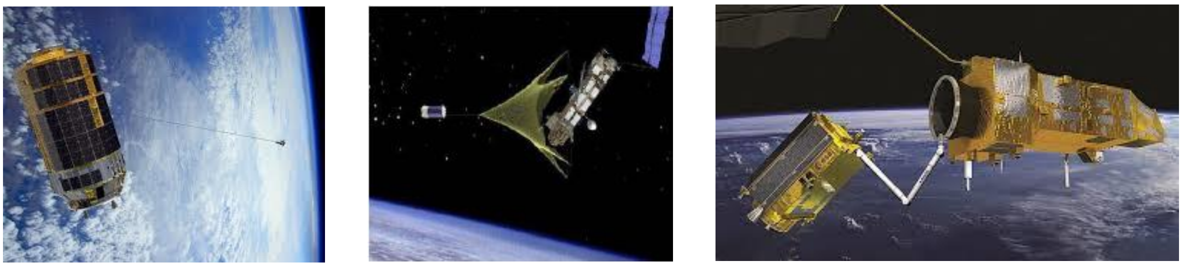
The size is about 18m, same size of Cheryabinsk.

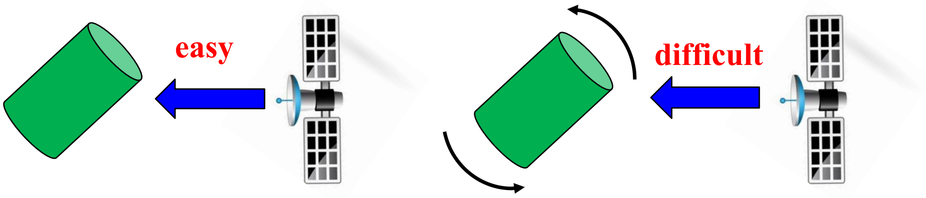



Orbit of 2018EZ2

**Remote observation site in Australia**

## Observation technologies for ADR






**A lot of ADR methods are being proposed in the world. If the targets are rotating fast, it is very difficult to access them. Therefore, understanding the motion and the attitude of the targets is one of the most important issues to design and establish ADR system.**

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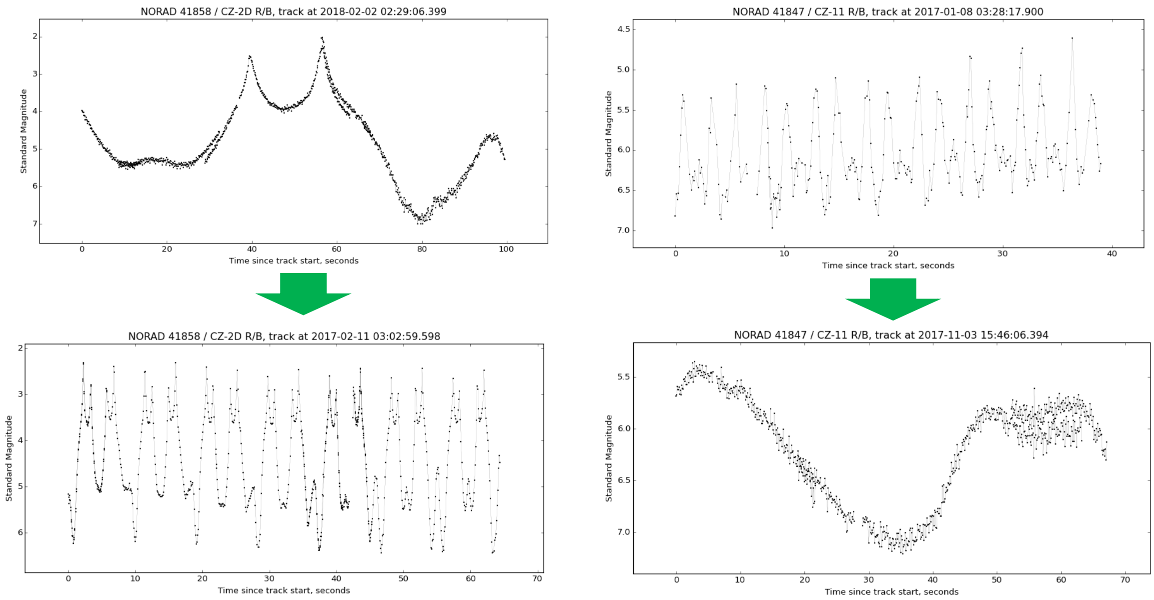
## Observation technologies for ADR




**Sudden light curve changes were confirmed at IADC light curve campaign observation. From event ratio, 30-50% of LEO objects may rotate someday.**

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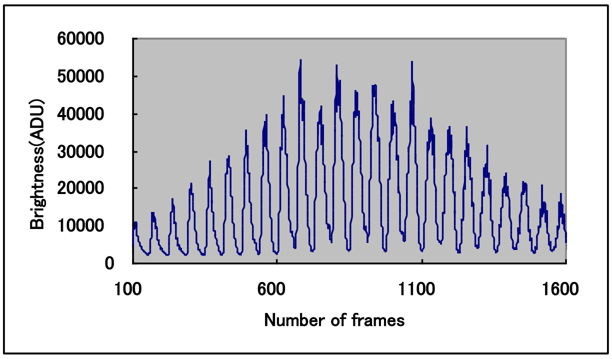
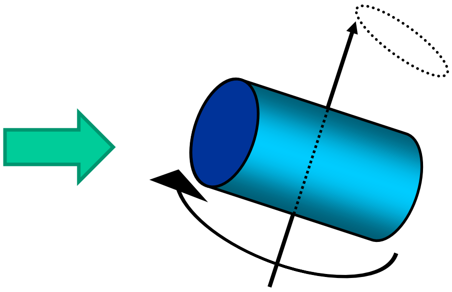
# Observation technologies for ADR

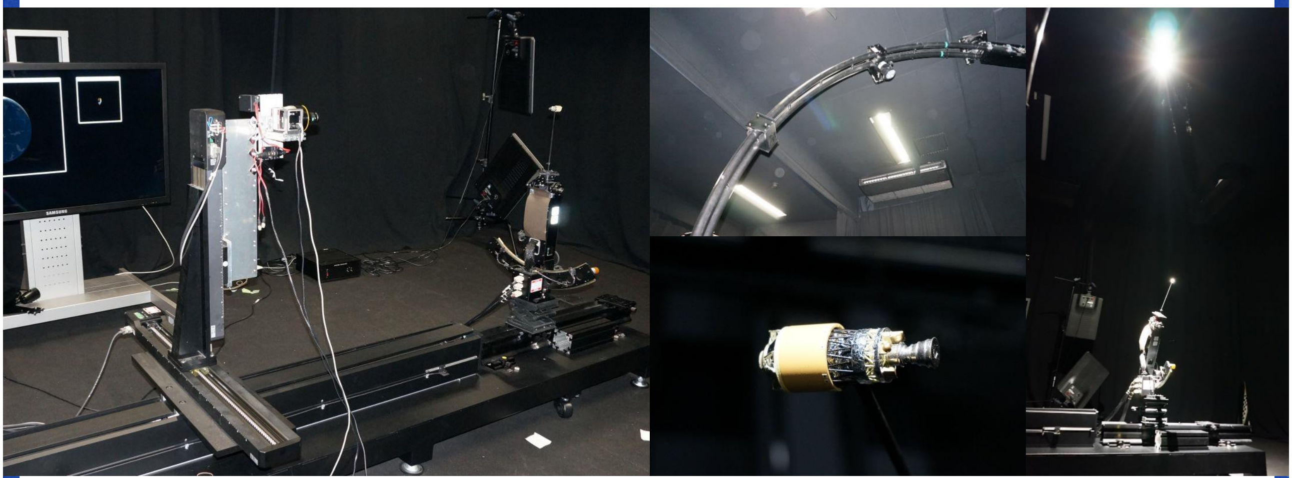


Technologies for understanding the motion of the target from the lightcurve is needed.
Optical simulator in JAXA was modified for artificial lightcurve.



# Observation technologies for ADR

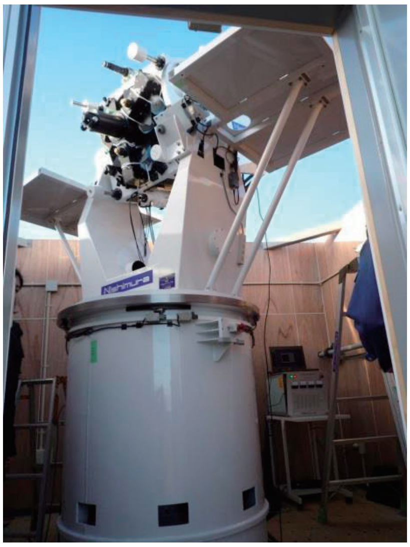


CCD used for actual light curve observation was installed.
Scale model of the target can simulate the motion in orbit.
Lighting condition is also simulated.

## Observation technologies for ADR

Image taken at Toyama Observatory


Image taken by AMOS



**We are also developing direct imaging technologies using the 60cm telescope at Mt. Nyukasa. Optimum adaptive optics are being considered.**

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## Summary

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