B08

低軌道デブリ光学観測システム
Optical Observation System for LEO Objects

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JAXA では豪州に遠隔観測施設を整備し、低軌道デブリを観測するための研究開発を実施している。小型望遠鏡に大型 CMOS センサを設置、センサから得られる大量の画像データを独自の手法で解析することにより 10 cm程度の多数の未カタログ物体をほぼリアルタイムで検出することが可能である。本講演では最新の研究状況及び検討している将来の低軌道デブリ監視システムについて紹介する。

The remote observation site for LEO debris was establish at Siding The optical remote observation system using small telescopes and large CMOS sensors was established in Australia. By analyzing a lot of data from the CMOS sensors with the image-processing technologies developed at JAXA, number of un-cataloged LEO objects are detectable. The system will contribute to the space situation awareness in the future.

The quadruple telescope for LEO objects observation. It consists of 4 18cm-telescopes and 4 large CMOS sensors.

9th Space Debris Workshop Feb 25th 2021

Optical observation system for LEO objects

Japan Aerospace Exploration Agency(JAXA)
Research and Development Directorate

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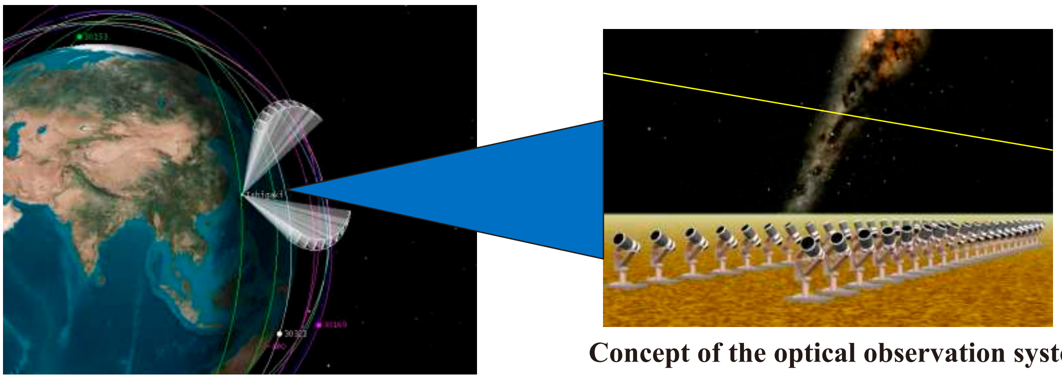
Abstract

We are considering optical observation system for LEO objects. Although the lighting condition and the bad weather limit the observable time, the system will be constructed with extremely low cost. In addition, optical sensors like CMOS become large, highly sensitive and less noisy. Combining these sensors with high-speed data analysis using FPGA and/or GPGPU enable us to establish the system which will complement the current space surveillance network and contribute to the SSA in the future.



Concept of the optical observation system

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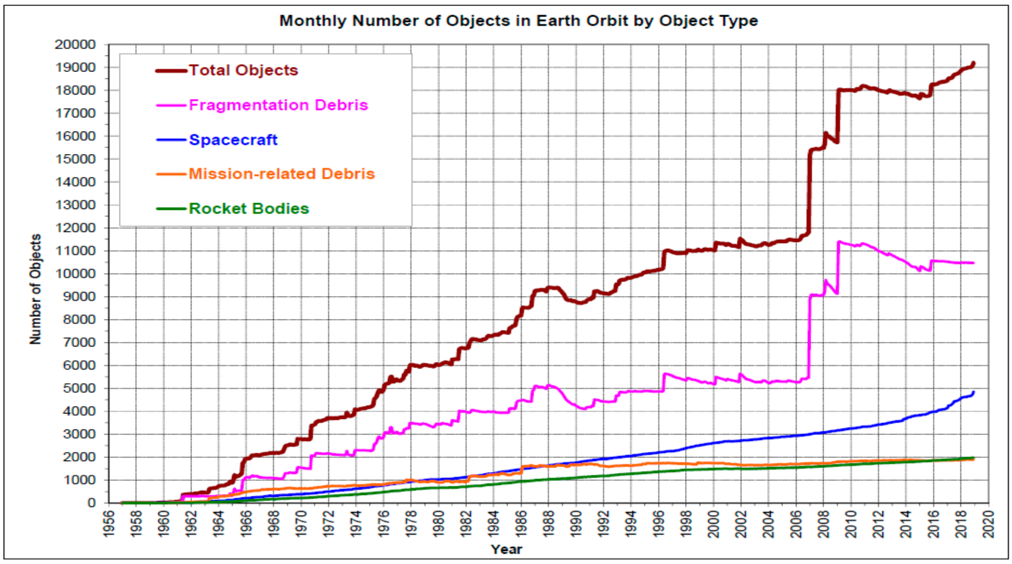
Background



- Space environment is deteriorated with space debris especially in LEO region recently.
- Dead zone problem. (a few mm to 10cm)
- Inaccuracy of TLE

Observation ability of space objects must be reinforced.

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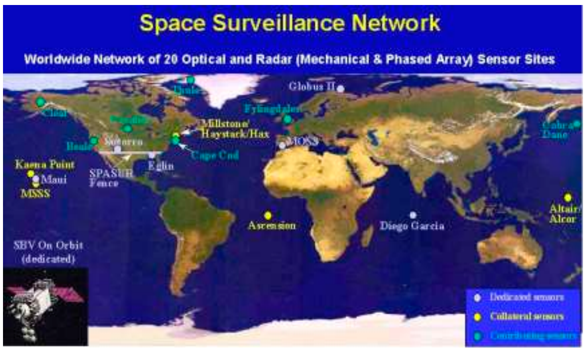
Background



ISON network of Russia

Observation methods of LEO objects

①Radar observation: SSN of USA. 24-hour and 365-day observation is possible. Enormous cost is needed to construct and maintain.

②Optical observation: ISON network of Russia. Observable time is limited by lighting condition of the sun and weather. Very cost effective.

- Optical Sensors(CCD, CMOS) are improving
- PC performances are improving
- Position accuracy of optical sensor is much better than radar

Cost-effective ground-based optical observation system of LEO objects which is used for SSA will be possible.

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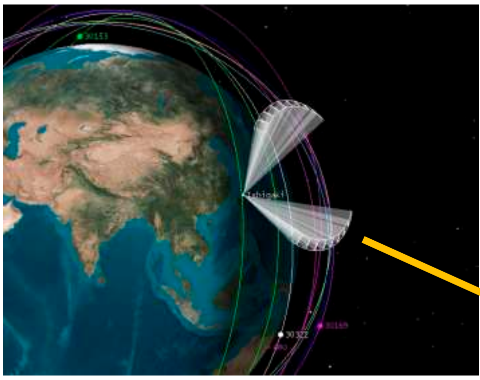
LEO survey system using the optical fence

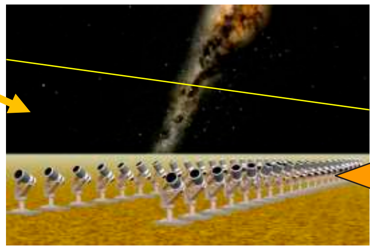


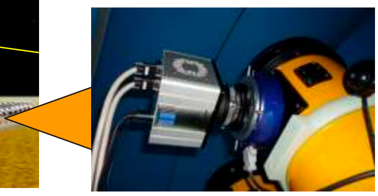
Optical fence for LEO survey

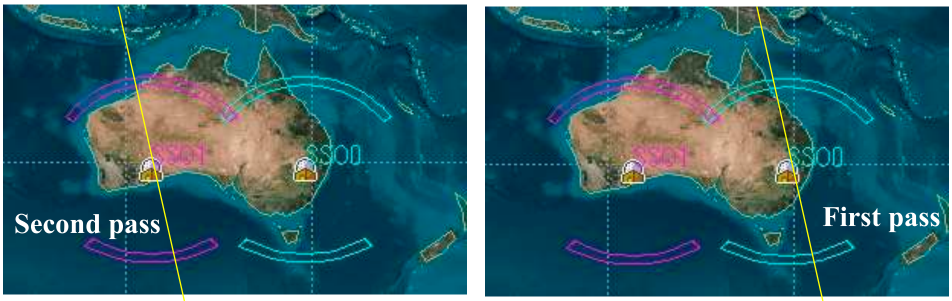
About 40 optical sensors are installed to one site.

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

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







2 observation sites in Australia for two consecutive pass observations

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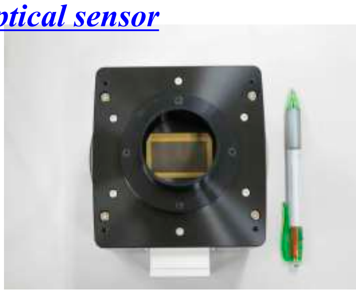
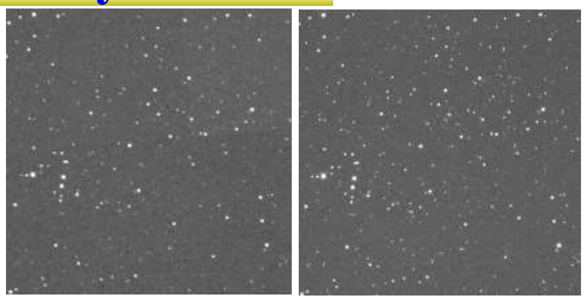
Component of the system

Optical sensor

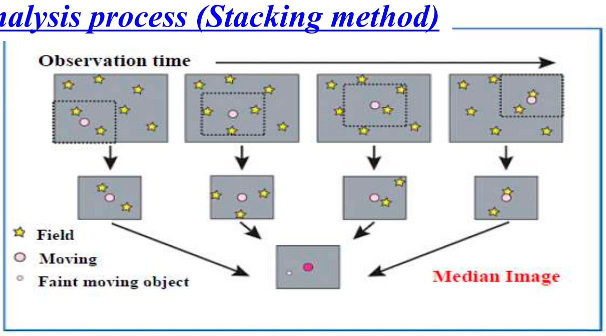


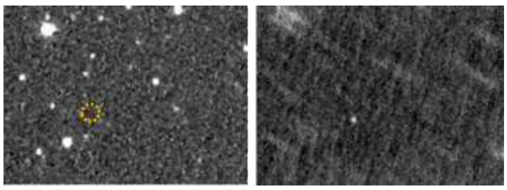
Large CMOS camera developed for LEO objects. The readout speed is 60 times faster that CCD.



Difference between CCD frame(left) and CMOS frame(right) under the same condition

Analysis process (Stacking method)





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

●Optical sensor: small telescope＋large CMOS camera

●Analysis process: Multi-core PC + FPGA based image-processing technique

Real time detection of LEO objects of 10cm

FPGA developed for the method

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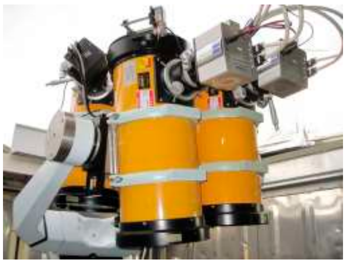
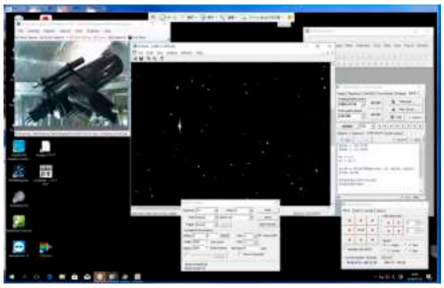
Observational environment

Remote observation site in Australia





Remote observation site was developed at Siding Spring Observatory in Australia. Four sets of the 18cm telescope and the large CMOS camera were installed.

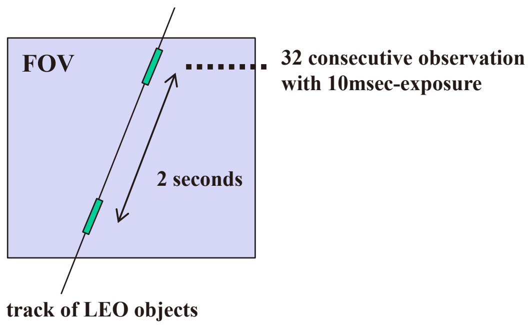
Test scene in Japan

The FPGA machine and the multi-core PC for the analysis

LEO survey using CMOS sensor

To investigate the usefulness of the CMOS sensor, LEO survey observations were carried out using two sets of 18cm telescope and the CMOS sensors.
To avoid the overflow of the memory, interval observation was carried out. Data was analyzed with the FPGA-based stacking method offline.

Concept of the interval observation



Observation time: 90minutes after the dusk on Dec 9th 2019.
Observation site: The remote observation site at Siding Spring Observatory
Observation equipment: Takahashi 18cm telescope, and Bitran CMOS sensor
Data acquisition: 32 consecutive frames with 10msec exposure (2-second interval)
Data analysis: FPGA-based stacking method

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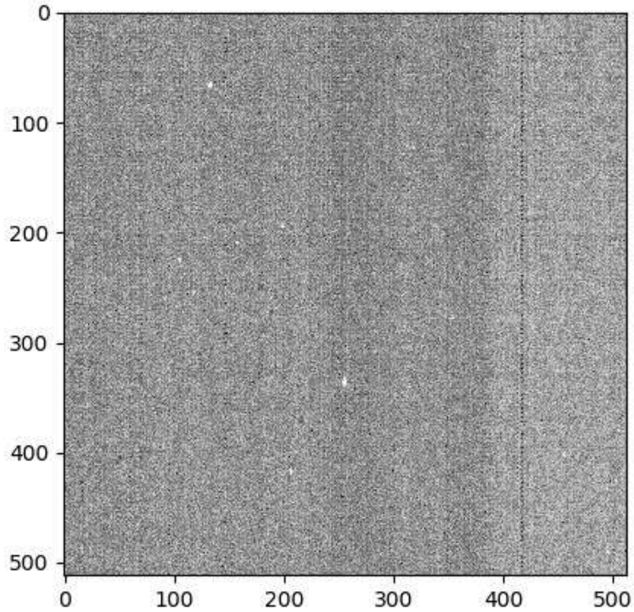
LEO survey using CMOS sensor



A LEO object detected in the survey. 6.1-magnitude. 500 × 500 pixels around the object. Played with 10-time speed.

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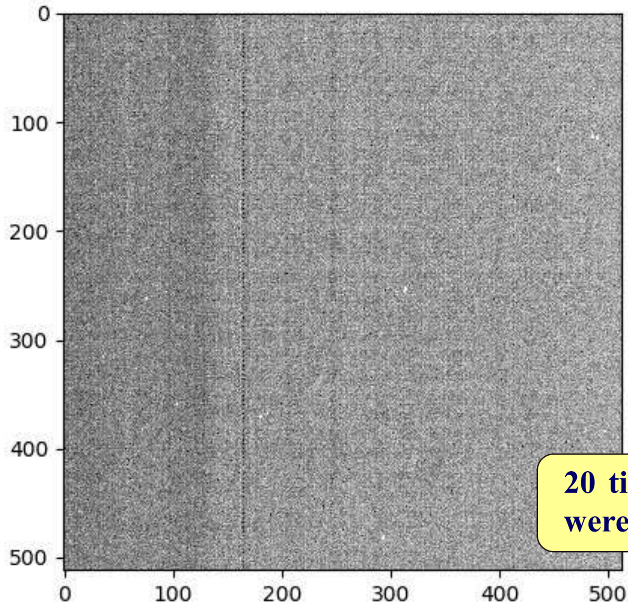
LEO survey using CMOS sensor



20 times fainter objects were detectable.

A LEO object detected in the survey. 9.7-magnitude. 500 × 500 pixels around the object. Played with 10-time speed.

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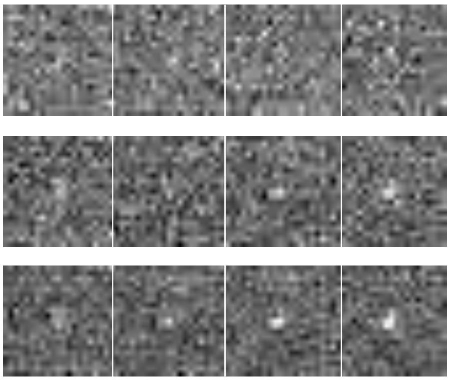
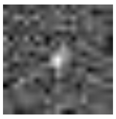
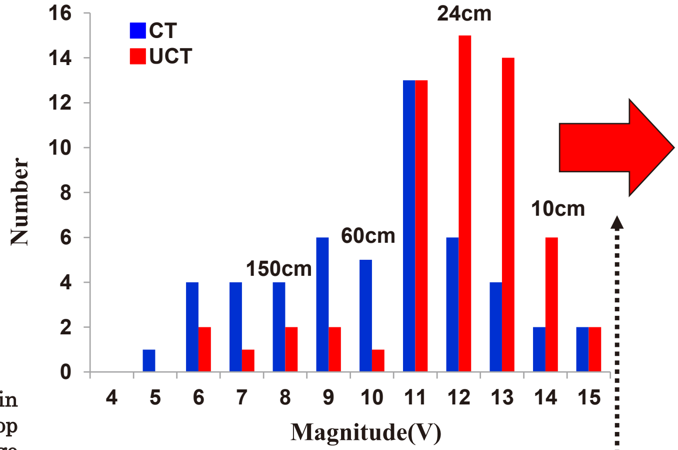
LEO survey using CMOS sensor

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 .



Aim to detect smaller objects with improvements of observation method and analysis process

A large amount of data taken by the CMOS camera became to be analyzed using the multi-core PC and the FPGA machine in almost real time basis.

The technology may contribute to SSA in the future

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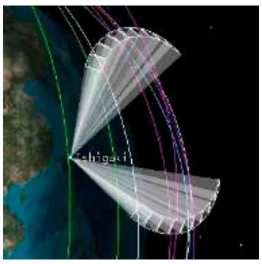
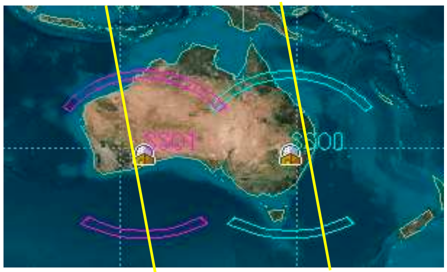
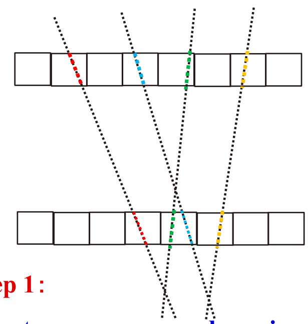
Orbit Determination

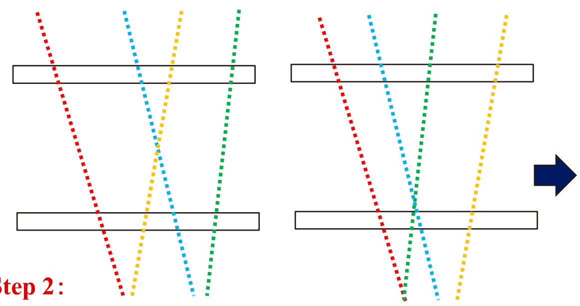






Step 1 :

One-to-one correspondence in one site data



Step 2 :

One to one correspondence in two site data

Precise orbit determination

One-to-one correspondence for each object is needed for precise orbit determination. Four sets from two sites observation data must be collected.

Circular orbit is calculated using the data taken with each sensor. One-to-one correspondences are possible for almost all the objects comparing the circular orbital elements.

Orbit Determination

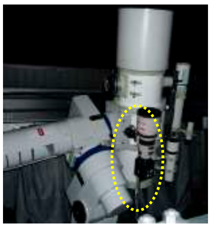
Observation sites:

Ishigakijima Morita Observatory (Okinawa)

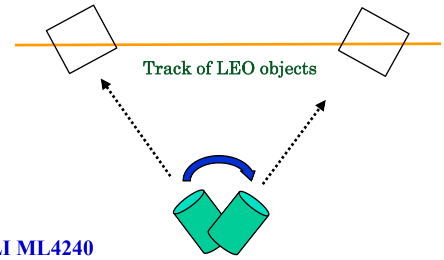
Rikubetsu Observatory (Hokkaido)

Observation equipments:

Canon 200mm F2 + FLI ML23042



Canon 300mm F2.8 + FLI ML4240

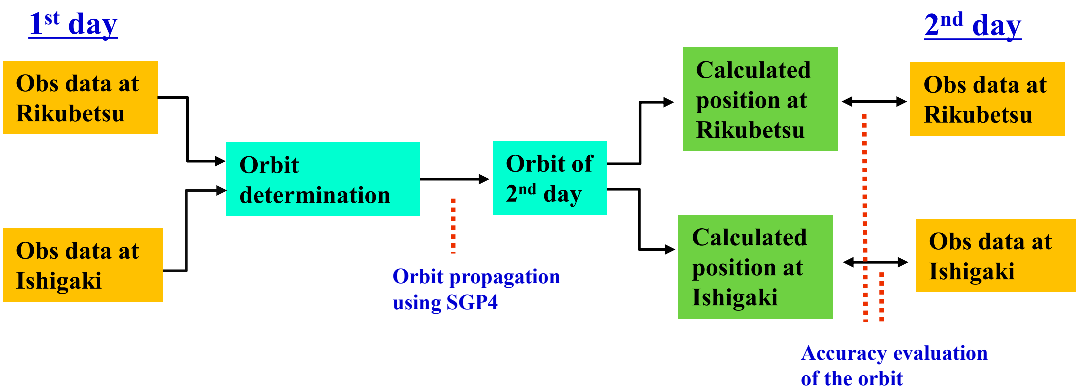


Observation date and time: Jul/27-28 after dusk and before dawn

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

In order to mimic the observation using the optical fence system described before, some cataloged objects were observed from 2 longitudinally separate sites, assuming one of the sensor of the system detects those objects with no orbital 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 one was for evaluation of the accuracy of the orbit determination.

Orbit Determination



Result of the accuracy evaluation

SSC number of objects	14521	13589	20720	21574
Rikubetsu dRA(arcsec)	181.19	34.99	19.62	199.27
Rikubetsu dDec(arcsec)	186.08	33.06	11.08	246.91
Ishigaki dRA(arcsec)	96.23	10.84	N/A	195.52
Ishigaki dDec(arcsec)	339.20	14.22	N/A	491.74

The result shows the orbit determinations are accurate enough to track objects next day in spite of quite limited observation data. In the case of the objects of 13589 and 20720, the differences are less than 0.01-degree. These facts indicate the proposed optical observation system is quite useful for orbit determination of un-cataloged LEO objects.

Detection ability of the system

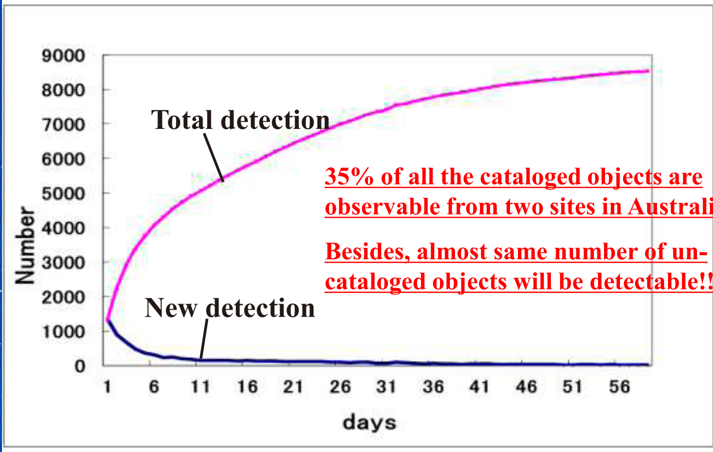
Number of detected and orbit-determined objects was estimated using STK. Objects of 10cm and larger are assumed to be detected with the system.

Sites: Siding Springs Observatory in Australia and one imaginary observatory located at western side to the Siding Spring Observatory by 25-degree.

Devices: 40 sets of the 18cm telescope and the CMOS sensor for each site.

Targets : Cataloged objects

period: Four months from Jan 1st of 2020



About 9100 objects (35% of all the objects) were detected and orbit-determined after 4 mouths observation using the system.

Weather conditions were not considered.

As shown in the next slide, orbital planes of the objects are rotating around the globe.

↓

The sites for follow-up observation are needed

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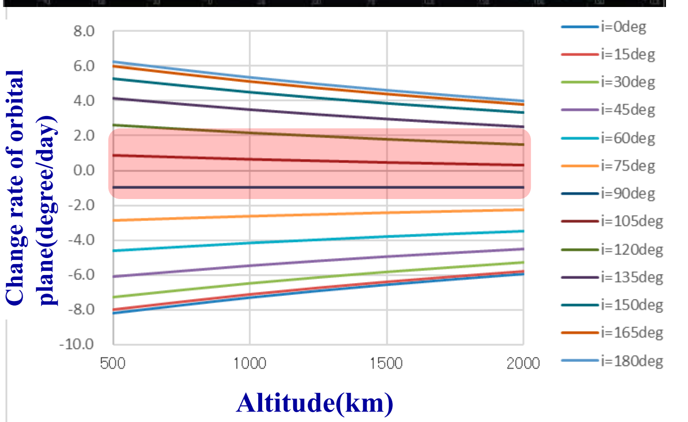
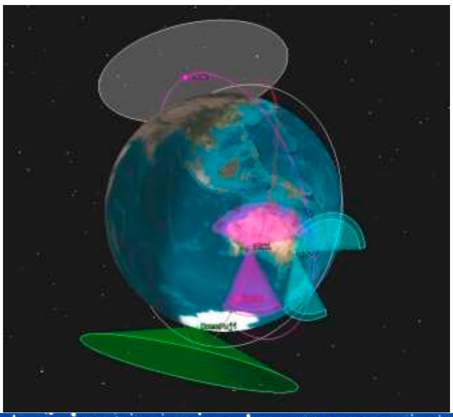
Observation Ability

The system can detect the targets under the condition of lighting for targets and umbra for the sites. Change rate of orbital plane contributes to detect all the targets. The objects of the small change rate are difficult to re-observe after the first observable period. Follow-up site for polar region can observe these targets.





Follow-up observation

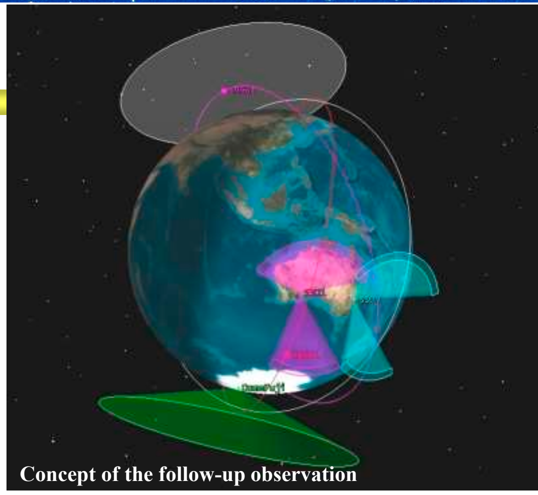
Observabilities of 7 typical objects from the sites near both polar regions are investigated using STK.

Sites : Dome Fuji of the South Pole and Svalbard islands near the North Pole

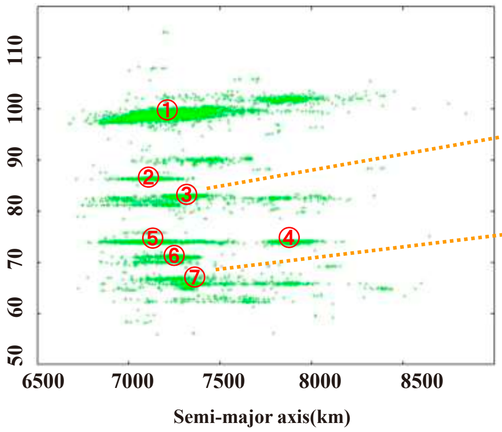
Devices : 8 sets of the 18cm telescope and the CMOS sensor for each site.

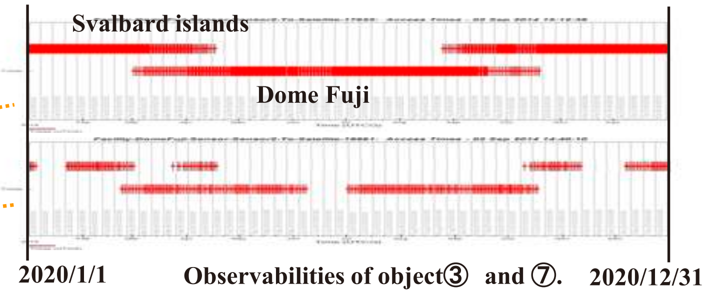
Targets : 7 typical objects detected by the system.

Period : One year from Jan 1st of 2020



Concept of the follow-up observation





Observabilities of object③ and ⑦.

Objects ① to ④ are observable from the South Pole and/or the North Pole. Objects ⑤ to ⑦ have un-observable period from both sites.

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Summary

We are considering optical observation system for LEO objects. Although the lighting condition and the bad weather limit the observable time, the system will be constructed with extremely low cost. In addition, optical sensors like CMOS become large, highly sensitive and less noisy. Combining these sensors with high-speed data analysis using FPGA and/or GPGPU enable us to establish the system which will complement the current space surveillance network and contribute to the SSA in the future. We confirmed that LEO objects of around 10 to 20cm were detectable using the basic observation and analysis unit established in Australia.

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Acknowledgement

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