Space Debris Optical Observation System in JAXA/IAT

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Abstract

For the development of the optical observation technologies for space debris, Institute of Aerospace Technology(IAT) of JAXA has prepared two small optical observation facilities of LEO and GEO debris detections. LEO debris tracking facility is located at HQ of JAXA, Tokyo, with a 35cm telescope onboard the 3-axis tracking mount system, GEO debris observation facility is located at Nyukasa-yama mountain in Nagano Prefecture. A 35cm Newtonian optical telescope with 2K2K CCD camera and a 25cm BRC optical telescope with 4K4K CCD camera are supported on each equatorial mount system. The latter facility is under construction and will be operated within this autumn. The altitude of this site is 1,870m and the optical environment will be adequate for detecting faint objects. One of the most important study item in our R&D is to develop an automatic small size GEO debris detection software. In usual case, a long exposure time is necessary to detect a faint object by accumulating weak light energy during the time. On the contrary, short exposure observation is necessary for GEO debris detection to avoid the influence of the fixed star streaks image. We have proposed a stacking method for detecting a noise-level faint GEO debris by accumulating the signals of a number of images, for example, a hundred frames. By applying the stacking method for asteroid survey observation, 21^{st} magnitude asteroid can be detected by using this small telescope. This paper introduces the JAXA's facilities for LEO and GEO space debris observation and describes some developing technologies and evaluated results.

1. Introduction

About fifty years have passed since the first launch of the artificial satellite in the earth orbit. During the time, several thousand rockets and satellites have launched and the total mass will be estimated several thousand tons. These expensive rockets and satellites turn out debris when they finish their missions. Many of the debris still move around the earth, which brings increased anxiety of collision with the satellites in service or the International Space Station (ISS) under construction. The consideration of debris problem requires the accurate information of present state of the contamination of real space environment.

Some Space Surveillance Networks with optical telescopes and radar sensors have been developed in the world. GEODSS in the military programs, for example, has three observation sites with 1 meter telescopes for satellites and GEO debris observations. In the research programs, variety of aperture telescopes(from 20 cm to 1 meter class) have been used in each organization for space debris observation and technology developments.

JAXA/IAT has been developing the optical observation technologies and evaluating the data obtained at the JAXA's observation facilities. For the improvement of the observation technologies, especially to detect small GEO debris (about 10-20cm size), a new JAXA's optical observation facility includes two 3-meter domes, in which 35cm and 25cm optical telescopes are set up, was constructed at Nyukasayama-mountain area. For the LEO debris observation, LEO satellite tracking facility is operational at the headquarter of JAXA in Tokyo (Chofu-city). These two facilities with small aperture optical telescopes are the main tools for the R&D on space debris observation in JAXA/IAT.

2. LEO Debris Tracking Facility

For the LEO debris and large space structures observation, JAXA has operated X-Y mount high speed tracking facility at Chofu(location:Lat.35.40'42",Long.139.33'24", Altitude:60m) since 1999. Fig.1 shows the 0.35m SC(Schmidt Cassegrain) telescope with 3,910 mm focal length onboard the X-Y mount system in the sliding roof[1].

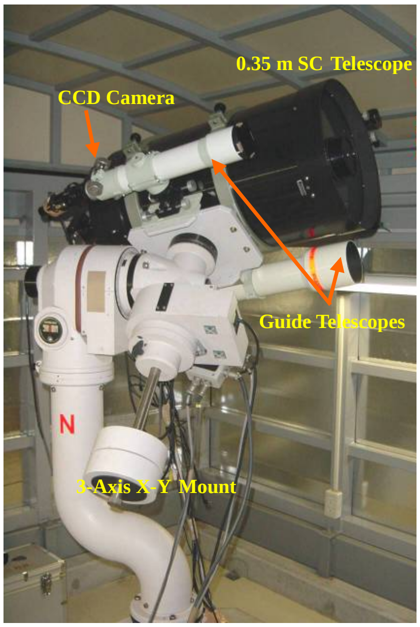


Fig.1 LEO debris Tracking Facility

Table 1 Characteristics of LED Debris Tracking Facility

Items	Characteristics
System	
Telescope	Schmidt Cassegrain
Diameter	350 mm
Focal Length	3910 mm(F/11) 2400mm with reducer(F/7)
Mount	3 axes(Az, Tr, El) controlled X-Y mount
Tracking	3 deg./sec. maximum
Camera	
CCD device	Sony ICX085AL
Pixels size	1280×1024/6.7μm×6.7μm
Area	8.6mm×6.9mm
A/D Conv.	12bit/18MHz
Frame rate	10 frames/sec
Cooling	Perche
Exposure time	0.0001 – 1800sec
Interface	PCI board(128MB memory)
Power supply	DC12V, 2A
Camera mount	C-mount
Dimension	W80×H90×D95mm
Mass	600gr

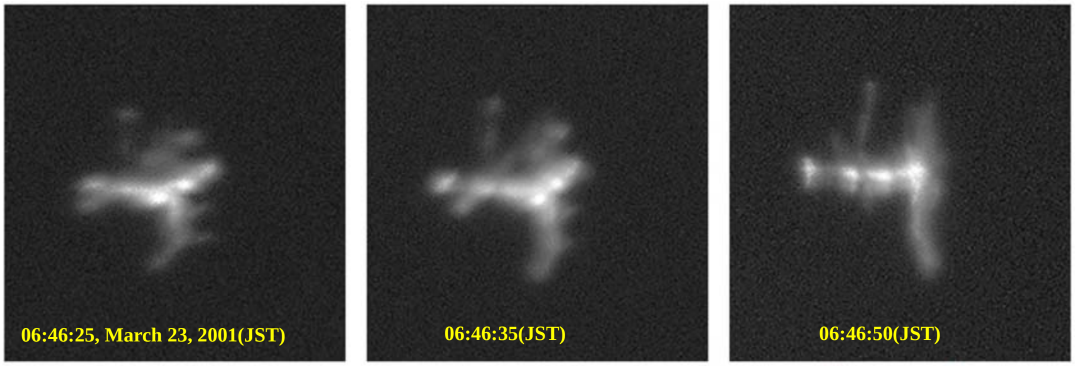
The purposes of this facility are:

(1) Tracking and orbit/attitude determination of large debris and large manned structure as ISS.

(2) Co-operating of some facilities located at other observation sites for tracking the same object to determine the orbital parameters quickly and also monitoring large debris before re-entry such as MIR Space Station(re-entered on March 23, 2001(JST) at the south Pacific region) and rocket bodies.

(3) Tumbling motion of LEO debris will be estimated by tracking and monitoring the light variations. The tumbling information is necessary for capturing the debris to retrieve or repair in the future.

For the item(1), the Russian Mir Space Station, which was re-entered on March 23, 2001(JST) at the South Pacific ocean, was captured about 6 hours before the re-entry by this facility. Fig.2 shows the images of the Mir Station passing above Tokyo. The TLE orbital data was installed in the controller of the facility and the X-Y mount tracked the Mir Station with some manual adjustments for precise tracking by monitoring the guide telescope. The images of the ISS were taken since 2000. Fig.3 shows the image of the ISS dated on July 2001 and Fig.4 shows the ISS docked with space shuttle STS-114. Japanese astronaut Soichi.Noguchi joined this mission. The image was taken on 5:43:47, August 5, 2005(JST). The focal length and the exposure time were 2,450 mm and 10 msec, respectively.



Facility:JAXA LEO Debris Tracking System
Telescope:0.35 meter SC, f=3910 mm
CCD Camera:1K1K
Exposure Time:15 msec

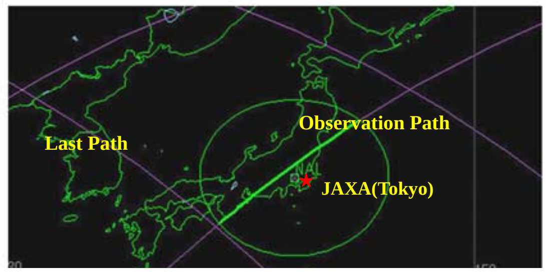


Fig.2 Images of Mir Space Station taken by JAXA LEO Debris Tracking Facility Before Re-Entry

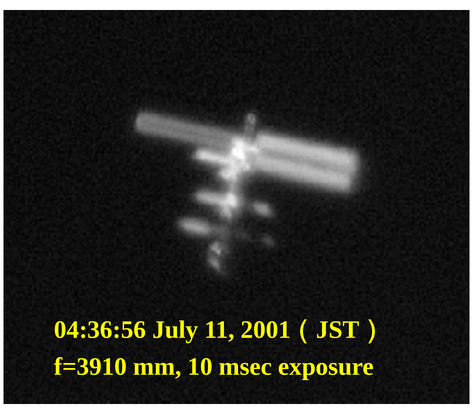


Fig.3 ISS image(1)

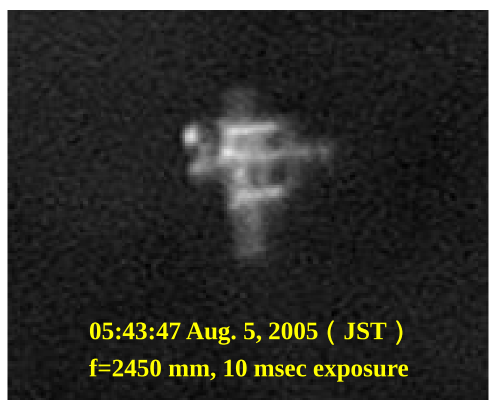


Fig.4 ISS image(2)

For the item(2), cooperating observations are necessary in order to track the re-entry debris. The high-speed tracking telescopes were located at Rikubetsu(Hokkaido), Toyama, Bisei (Okayama) and Chofu(Tokyo) as shown in Fig.5. The phased-array radar system at Kamisaibara Space Guard Center(KSGC) in Okayama Prefecture is now operational and will be joined to this optical tracking network. By using these facilities, near re-entering LEO debris will be tracked continuously and monitored their behaviors. The apertures of the telescopes of Rikubetsu and Toyama astronomical observatories are 1 meter with Az/El mount system. 0.5m telescope of the BSGC has a wide field-of-view(3 deg.) with 1000 mm focal length. 0.35m telescope of JAXA is designed as a portable system and can be divided into three parts, but nominally it is located at Chofu, Tokyo. The radar system at Kamisaibara is a research facility and has the capability of 1 meter resolution from 600 km distance. A continuous observation experiment for LEO debris passing through Japan from south to north is planed in the near future.

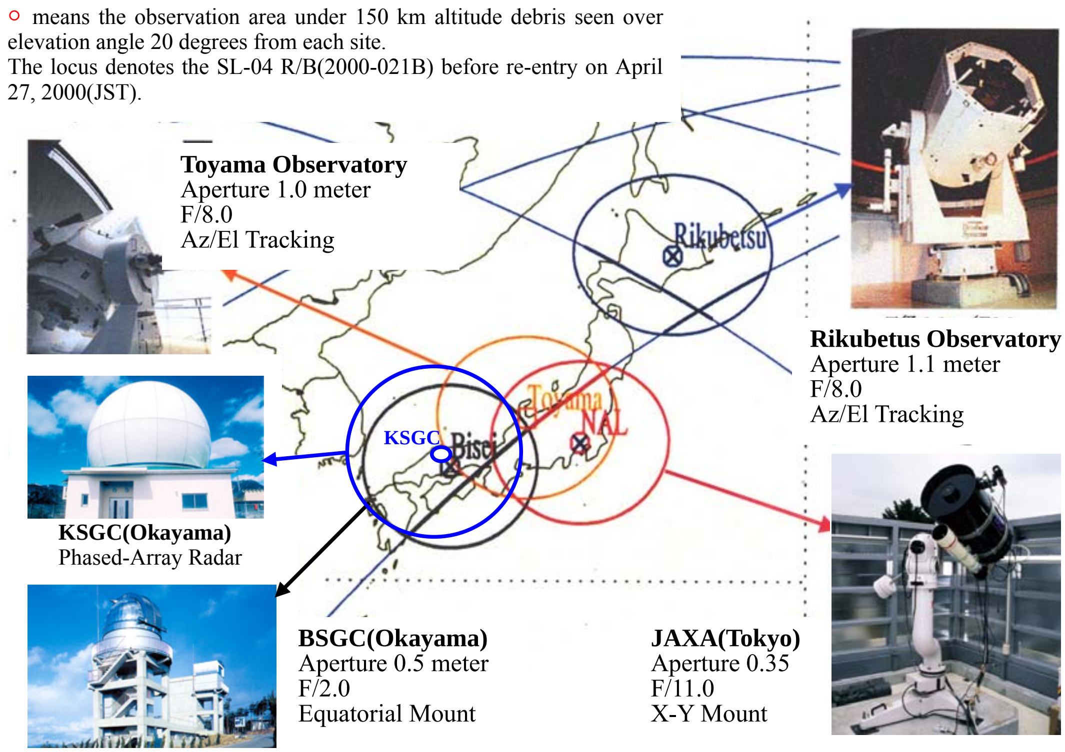


Fig.5　LEO Debris Optical and Radar Tracking Facilities in Japan

For the item(3), light curve observations and evaluations of rotational LEO large debris have been studied[2],[3]. Fig. 6 shows paths of cosmos2082 rocket body(international number is 1990-046B), owned by USSR. Its apogee, perigee and inclination are 855km, 834km and 70 degrees, respectively. The bold green lines shows the visible paths from our facility. The right side path (a) is observed at from 19:03:51 to 19:09:27 on January 6, 2004(UT), just after the sun rise and left side path (b) is observed at from 20:45:47 to 20:52:08(UT), respectively. The light curve data of them are shown in Fig.7(a) and (b). X and Y-axis show the observation time and the brightness of the target in analog-to-digital unit (ADU), respectively. From the figure, the object repeats the increase and the decrease of

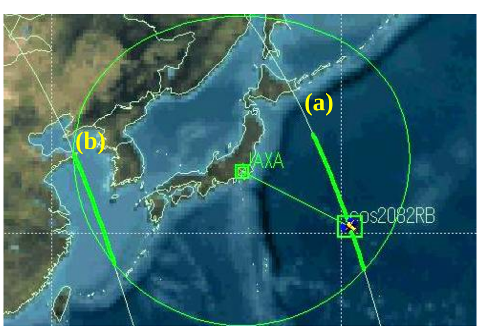


Fig.6 Two paths of cosmos 2082 rocket body on January 6, 2004.

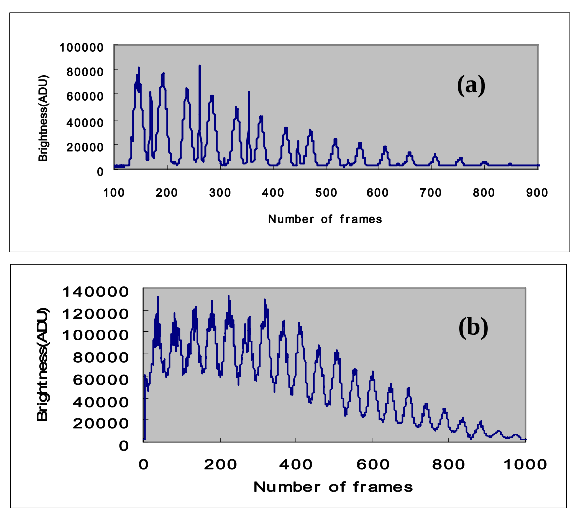


Fig.7　(a) and (b) show the light curves of the right and left side path of Fig. 6, respectively.

its brightness. This means that the object is rotating and has an elongated shape. Numbers of observations or multi-site observations reveal more detailed information. We are going to get such light curve data periodically, investigate the characteristic of the motion and the shape of LEO debris and contribute to get a preliminary attitude information for the future debris retrieval system.

3. GEO Debris Observation Facility

For the accurate GEO debris modeling, the improvement of the GEO debris optical observation system is necessary. Larger than 1m-size GEO debris have been already determined their orbits and faint objects about 10–20cm-size are under surveying in the world. 1m telescope has the capability of detecting 20cm-size debris. For the determination of their orbits, many optical observation systems are required and co-operating campaign observations are necessary. Recently, high area-to-mass ratio debris has been focused on the observation[4] and continuous observation are necessary for their orbit determination. JAXA/IAT's optical facilities are too small to detect such faint object directly, on the contrary, by using image processing techniques, 20 cm-size GEO debris will be expected to detect by 35 cm small aperture telescope.

Fig.8 shows the JAXA/IAT's new optical observation facility constructed this summer. The site is located at the northern area of the Japanese South Alps and the altitude is about 2,000 meters, which has a good optical condition. 35 cm telescope in the 3m dome is operational and 25cm telescope will be operational within this year.

Table 1 shows the main characteristics of the facility and some instruments.

Fig.8 JAXA Nyukasayama-mountain GEO Debris Optical Observation Facility:(a)Front Overview, (b)Back View of the Two Domes and (c)35-cm Telescope

Table 1 Main Characteristics of the Facility

Coordinates
Longitude : 138°10'18", Latitude : 35°54'05", Altitude : 1,870m.
Telescopes
(1) Takahashi ε-350, φ355mm, f=1,248mm, F/3.6, Image Circleφ70mm
(2) Takahashi BRC-250M, φ250mm, f=1,268mm, F/5.1, Image Circleφ100mm
Mount types
(1) Showa Kikai Equatorial Folk-Mount
(2) Takahashi EM-500 Temma2(BRC-250MQT2)
Domes
Nisshin dome, φ3m, 2 sets
Cameras
(1) NIL 1Kx1K back illuminated CCD, 13μmx13μm, Mechanical and Electric Shutters
(2) NIL 2Kx2K back illum. CCD, 13.5μmx13.5μm, Mechanical Shutter, FOV:1.3°x1.3° for ε-350
(3) NIL 2Kx4Kx2 back illum. Mosaic CCD, 15μmx15μm, Mechanical Shutter
FOV:2.4°x2.4° for BRC-250M

The main telescope of the facility is a 35cm Newtonian type reflector. This telescope is commercial-based product with low cost and relatively wide field-of-view(FOV). The limiting magnitude of 10 seconds exposure time is about 17.5, which will be equivalent to about 0.5m-size GEO debris. For detecting more faint object of 20cm-size GEO debris, the stacking method was proposed, which will be possible to improve the detecting magnitude up to 19^{th} magnitude for this 35cm telescope. The stacking method for debris observation is under development and the asteroid detection software using this stacking method was sold as commercial-based product.

Three types of CCD cameras are prepared as sensor system. They are two 1Kx1K CCD cameras with electronic and mechanical shutter, 2Kx2K CCD camera with mechanical shutter and 4Kx4K mosaic CCD camera composed of two 2Kx4K CCD chips with mechanical shutter. The 4Kx4K camera is under development. The pixel size is different each other. The larger pixel size is better from the viewpoint of the sensitivity, but has a demerit of spatial resolution. The pixel resolution of the CCD camera and telescope system used in this facility is about 2 arc seconds, which is equivalent to the seeing size of the atmosphere. Fig.9 shows CCD cameras expressed in the table 1.

(a) 1Kx1K CCD Camera (b) 2Kx2K CCD Camera (c) 4Kx4K CCD Camera

Fig.9 CCD Cameras used at JAXA Optical Observation Facility

4. GEO Debris Detection Method

GEO debris automatic detection software using the stacking method is under development[5],[6],[7][8]. The purpose of this software is to improve the detectable limiting magnitude by stacking many images. The process of the software is shown in Fig.10. The preliminary detection of GEO debris or operational

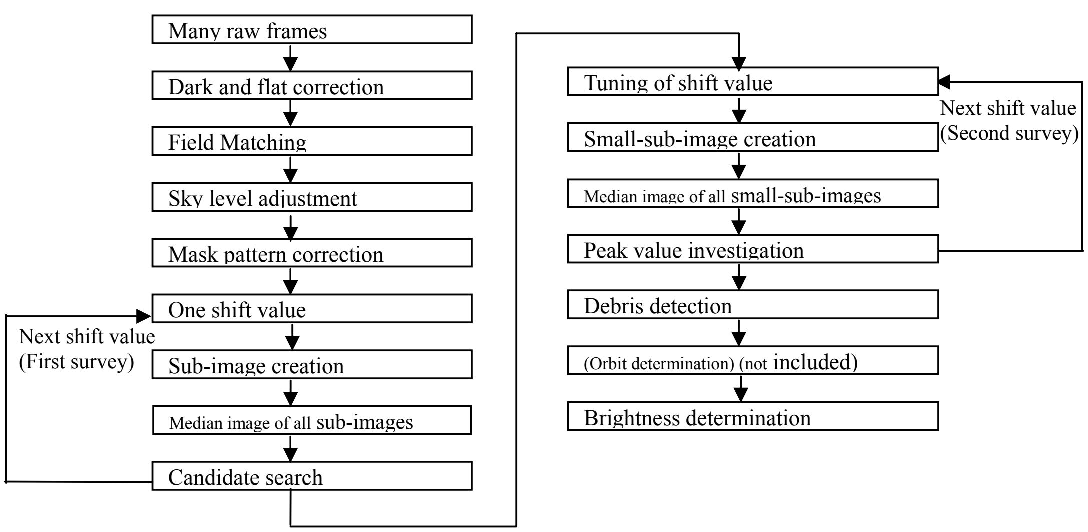


Fig.10 Automatic Debris Detection Software Flow Chart

satellites(space objects) are shown in Fig.11 and 12. Fig.11 shows the lists of candidates of space objects as a result of the secondary survey process after checking the stacked image and blinking its behavior. 9 candidates are listed up and the 9th one is an unknown object, which was recognized as a noise. The 6th candidate, for example, is recognized as BSAT-1B. These space objects are represented in the star chart mapping as shown in Fig.12.

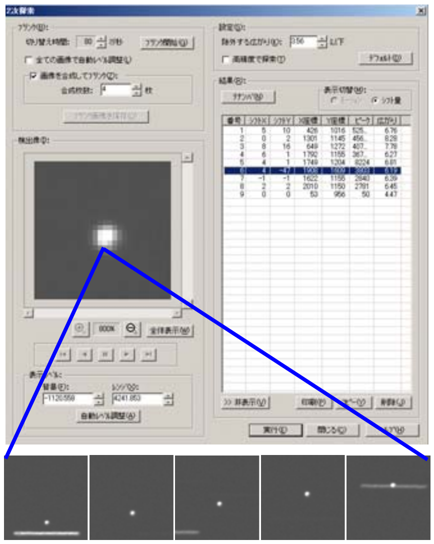


Fig.11 Secondary Survey Results and Stacked/Blinking Images

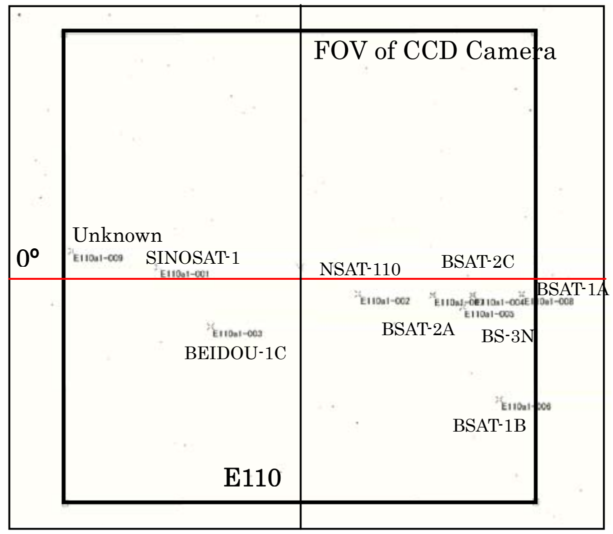


Fig.12 Space Objects Mapping on the Star Chart at Longitude 110 East

At the moment, small size GEO debris is not yet observed. Preliminary survey observation will start from this autumn and will be expected to detect 20cm-size debris. The stacking method applied for asteroid detection software proved that the accumulation of images with respect to the movement improved the S/N and possible to detect more than 2 magnitude darker objects than the single image processing. In case of asteroid detection software, about 22nd magnitude asteroid was detected by using 40 images with 3 minutes exposure time and the capability is comparable with 1 meter aperture telescope.

5. Conclusions

Space debris optical observation facilities constructed and operated by JAXA/IAT were introduced. Under the limitations of budget, small aperture optical telescopes are used for R&D on space debris technologies. For LEO debris observation, a 0.35m Schmidt Cassegrain Telescope onboard a X-Y mount tracking facility at Chofu, Tokyo has been prepared. The attitude motion of large LEO debris can be estimated by observing directly its shape and/or light curve characteristics. For GEO debris observation, a 0.35m Newtonian telescope onboard an equatorial mount system has been used at Nyukasayama, Nagano prefecture. A smaller 0.25m telescope will be available from this winter. By using these two telescopes, survey and tracking observation of GEO region are planed. At the same time, debris detection software development has been continued. As a next step for GEO/GTO debris observations, the construction of a 1m-class optical telescope is under discussion.

6. References

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