Observation of Light Curves of Space Objects

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Abstract

Geostationary orbit and low earth orbit have many artificial satellites, and the accidents of these satellites affect every area such as weather forecasts and communications. In the optical observation, the periodical change of the brightness which is caused by the type and the shape of the satellite is seen.

In the case of LEO debris, since the movement is fast, it crosses the field of view in several seconds. We used an observation method to get the data of LEO debris. In case of the GEO debris, the rate of motion is slow in comparison with LEO debris. Fixed stars are observed by the same position on the image when the telescope is operated in sidereal tracking mode. Then, space objects are recorded on the image with streaks of light.

In this paper, the observation and the detection method of light curve of geostationary orbit debris are discussed. Observing the changes of the operative satellites with some time intervals may help to detect the abnormalities and accidents of them.

1. INTRODUCTION

Artificial satellites that have finished their missions and used rockets are called space debris. Most of them are not under any control. The space debris problem must be solved to perform future space development and maintain safety.

Many artificial satellites indispensable for human activities circle the earth. If one of these satellites malfunctions, many human activities are impacted. An artificial satellite is monitored to control its trajectory while it is in operation. However, we cannot easily monitor the external appearance of the main body of a satellite. We can track the position of debris by observation, but this does not provide adequate information about its status. Optical observations can identify a spinning satellite, a satellite with different reflecting surfaces or debris based on a periodic light intensity change. In addition, regularly observing light intensity change reveals changes in the pattern of the light intensity which is thought to be the result of an abnormality of an operational satellite. It can be inferred that this is the influence of an external factor etc. Observing light intensity change of debris reveals its state, permitting an estimation of its approximate shape.

2. SATELLITES OF THE GEOSTATIONARY ORBIT

A geostationary orbit is a circular orbit located in the sky about 36,000km above the equator, and its orbital period is 23 hours 56 minutes 4 seconds. Because this orbit is synchronized with the rotation of the earth, the satellite appears to stand still. Since artificial satellites in this orbit always appear in the same direction, they include many communications satellites, broadcasting satellites, meteorological satellites, etc. However, because a geostationary orbit is limited, it is important to mitigate the problem of debris by, for example, changing the orbit of a satellite after its operation is ended.

3. OBSERVATION

3.1. Nyukasayama Optical Observatory

An optical telescope has been installed at Nyukasayama Optical Observatory, Nagano Prefecture, primarily to develop GEO debris observation technology. It is in the northern area of the Southern Alps of Japan. The altitude of the site is 1,870 m. Figure 1 is a photo of the Nyukasayama Optical Observatory. This observatory will consist of two 3-meter domes for 35 cm and 25 cm telescopes with equatorial mounts, a 2K2K back-illuminated CCD camera cooled by peltier devices and a 4K4K mosaic CCD camera cooled by refrigerator. The image sensors used at this facility are back-illuminated high-speed readout CCD cameras. Figure 2 is a photograph of the 35 cm telescope and the 2K2K CCD camera. Tables 1 and 2 give overviews of the main characteristics of the 35 cm telescope and the 2K2K CCD camera, which is currently the main detector at this facility.

Fig. 1. Nyukasayama Optical Observatory

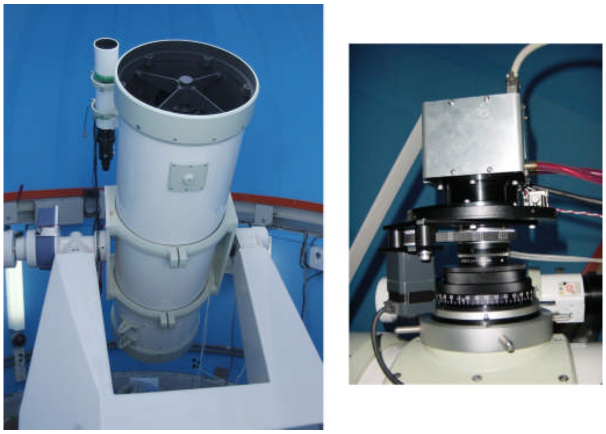


Fig. 2. 35cm Telescope and 2K2KCCD camera

Table 1. Characteristics of the 35 cm Telescope and Mount System

Telescope	ε -350 (Takahashi Co.)
Diameter	350 mm
Focal Length	1,248 mm(F/3.6)
Image circle	70 mm
Mount	SHOWA 25EF Equatorial Fork-Mount (Showa Co.)
Drive	Stepping Motor (85 deg/ 60 sec)

Table 2. Characteristics of the 2K2K CCD Camera

CCD camera	e2v CCD42-40 Back-illuminated
Pixels	2048×2048
Pixel size	13.5 µm×13.5 µm
Area	27.6mm×27.6mm
FOV (with 35cm Tele.)	1.27 × 1.27 deg.
Readout time	10 sec (2 ch out)
Exposure time	1 – 7200 sec
A/D trans.	1MHz – 50kHz(Variable)
Cooling	Peltier + water cooling
Shutter	Copal DC-392 (Mechanical)
Power supply	DC12V, 2A
Dimensions	W140×H140×D100 mm
Mass	1.5 kg

3.1. Observation of the LEO debris

In the case of LEO debris, since the movement is fast, it crosses the field of view in several seconds. We used an observation method to get the data of LEO debris. This method observes a field of view in the sky calculated from the TLE of targeted Iridium 33 debris so that a track of the target is obtained. The exposure is begun right before the targeted debris passes through the field of view. We tried this method at March 11, 2009, and observed several pieces of debris.

American communications satellite "IRIDIUM 33" (during operation) and Russian military communications satellite "COSMOS 2251" (an operative end) collided at Siberia sky about 790km at 16:56 on February 10, 2009. Many space debris occurred by this accident. At the time of collision, the debris went around the orbit that optical observation was unable from Japan. Therefore we applied observation on March 11 when observation condition improved of the IRIDIUM33 debris. We observed it with an 35cm optical telescope and a high sensitive CCD camera. Furthermore, we calculated orbit and a rotational period of the debris.

It was observed for some debris, and nine space objects were able to be confirmed from image. The space object which was able to be observed identified it with object debris from coordinates, inclination of the streak of light in the time which passed by with orbital element. A light intensity change was seen from streak of light of the debris which was able to be observed. This means that debris rotates. Several image of the IRIDIUM33 debris is shown. International designator 97051C identified it with the main body of IRIDIUM 33, and the brightest ray of light was recorded among the debris which we were able to observe (see Fig 3). Strong reflection was seen in exposure. As for 97051BH, the change of periodic light intensity is shown conspicuously (see Fig 4). Figure 5 shows light curve of 97051BH. The object which could estimate brightness, a size, rotation period of observed debris calculated estimation value.

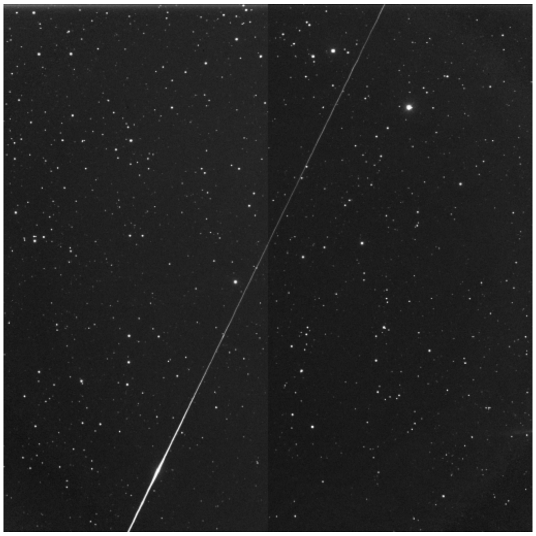


Fig. 3. An observation image of 97051C debris.

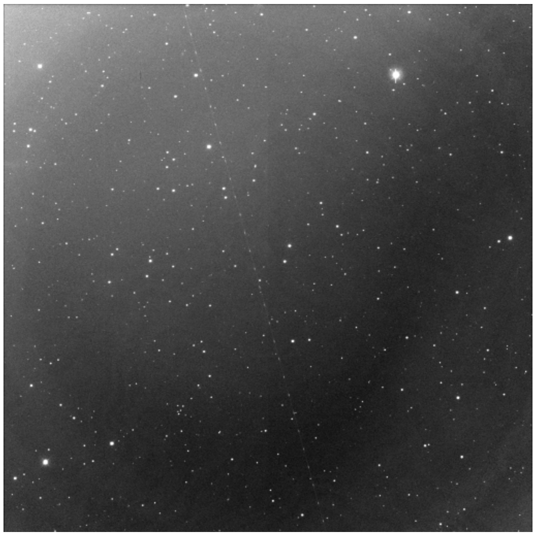


Fig. 4. An observation image of 97051BH.

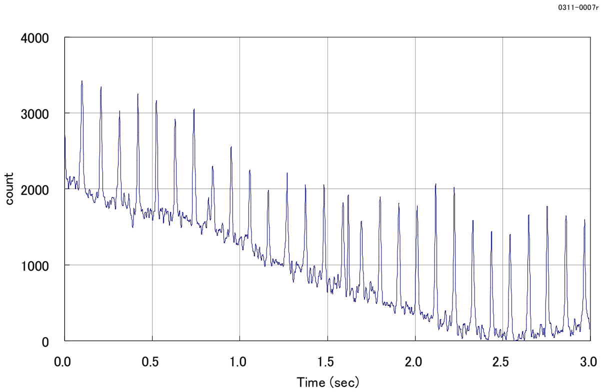


Fig. 5. Light curve of 97051BH.

3.2. Observation of the geostationary orbit

We observed the upside of the geosynchronous belt with a 35cm telescope in the beginning of March, 2008 and ending April, 2009. Because many space objects crossed the field of view of the image, we used it for analysis. Figure 6 shows one frame of an image taken by a telescope performing sidereal tracking. Fixed stars are observed at the same position on an image when a telescope is operated in sidereal tracking mode. And in this case, space objects are recorded on the image as streaks of light. And in particular, when a telescope is observing an equatorial belt, satellites pass the field of view in rapid succession.

Fig. 6. An observation image of the geostationary orbit belt

4. ANALYTICAL METHOD

4.1. CONFIRMATION SUCH AS THE GEOSTATIONARY ORBIT DEBRIS

At the present stage, there is no method of automatically detecting space objects in an observation image. Therefore, the images were checked by a visual inspection. Furthermore, coordinates of space objects were read.

4.2. PREPROCESSING OF THE OBSERVATION IMAGES

At first, dark images with the same exposure time are subtracted from the images acquired by observation. Furthermore, it is divided by a flat image according to uniform light source. Next it is aligned by a reference star. Because of incorrect installation of the telescope, if long-time sidereal tracking is performed, the processed image is out of the observation field of the image. Because this harms the following mask processing, a reference star is chosen, and the position of the same fixed star must be corrected in all images. There are always fixed stars at the same position in the image when we operate a telescope with a fixed star. The fixed star is not necessary for this analysis. Images of the fixed star in the same position are provided when we take the all the medians of dozens of parts of an image which were taken in the same field. When the mask pattern image is prepared from this image with one threshold value, and it is overlapped with one frame of the original image, a masked image with the fixed star deleted is created (see Fig.7 and Fig.8). An image with only streaks of light of geostationary orbit space objects clearly seen is created by this process. When a fixed star overlaps with a moving object, the fixed star is deleted by a mask image, and this part of the streak of light of the object is deleted. Therefore, we disregard this data.

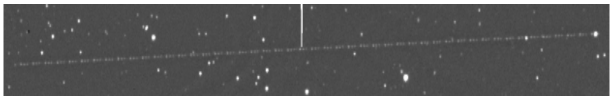


Fig. 7. Image of the streak of light part of debris

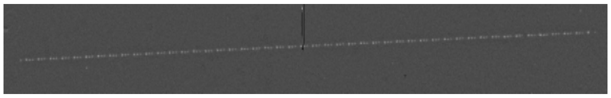


Fig. 8. Image of deletion of a fixed star by mask processing

4.3. EXTRACTION OF THE RAY OF LIGHT OF THE DEBRIS

From the preprocessed mask image, we read the coordinates of either the start and the end positions of the streaks of light of the geostationary orbit debris. We used the astronomical image analysis tool IRAF (Image Reduction and Analysis Facility) and viewed a streak of light as a straight line to take out the count value (brightness). Noises were coordinated by taking the average for several pixels.

4.4. CHECKS ON IDENTIFICATION SUCH AS THE DEBRIS

The identification of satellites and the debris which are the objects which appeared in the image was done using an orbital element (TLE) at the time of the observation. The orbital simulation was done using the astronomy calculation software, TheSky 6. In this way, space objects seen during the observation date and time in the observation field can be identified.

5. LIGHT INTENSITY CHANGE

5.1 FIRST OBSERVATION

The first observation time was about 2:00 a.m. on March 2, 2008. The central coordinates are right-ascension 12h20m08s, and declination +2º20'50". It is one exposure frame from among dozens of sheets of images taken over a period of 180 seconds. The observation field is a little to the north side of a geostationary orbit belt. Streaks of light such as space objects with an orbital inclination were frequently recorded.

Cases where the intensity of light changes periodically are presented and analyzed.

5.1.1 JCSAT 2 90001B

JCSAT 2 is Japanese commercial satellite launched on January 1, 1990, and operated until July 5, 2002. This satellite is a cylinder type spin satellite with a diameter of 3.7m, and height of 10m. At the time of orbit injection, it weighed 1364kg. Figure 9 shows a graph prepared by extracting the streak of light (JCSAT2) from an image in figure 8 printed in a foregoing paragraph. This graph reveals that the brightness of the streak of light varies. This graph shows the brightness of a streak of light changing radically. The periodic time shows great change at about 3.7 seconds. Furthermore, the period of this change was calculated accurately by a fast Fourier transform. The result is shown in figure 10. According to this, about 0.27Hz, 0.54Hz, 0.80Hz, 1.07Hz are detected.

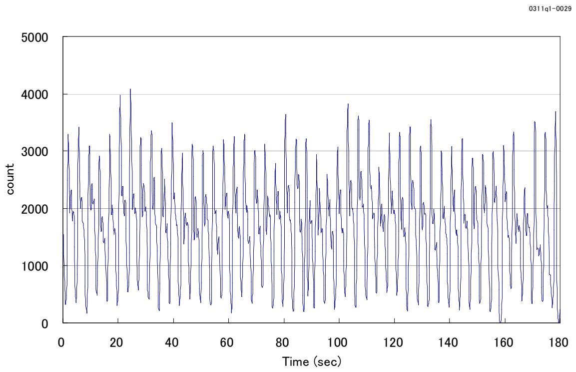


Fig. 9. Light curve of JCSAT 2

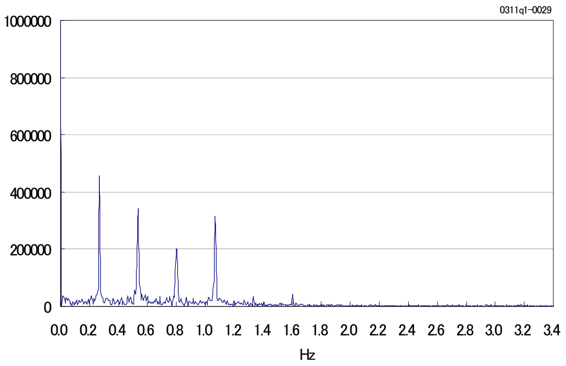


Fig. 10. Fourier transform of light curve of JCSAT 2

5.1.2 ASIASAT 1 90030A

ASIASAT 1 is Hong Kong communication broadcasting satellite. It was launched from China on April 7, 1990, was located in the 105.5 east longitudes, and its operation has already ended. This satellite is a cylindrical spin satellite with diameter of 2.16m, and overall height 6.6m. A graph of the light intensity change of ASIASAT 1 is shown in figure 11. Figure 12 shows the result of the Fourier analysis of this graph. This analysis result confirmed 0.56Hz, 0.62Hz, and 1.1Hz.

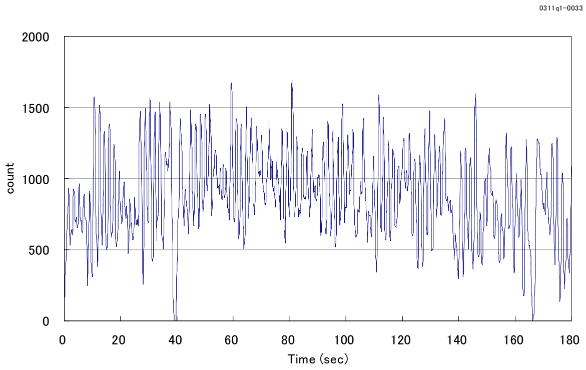


Fig. 11. Light curve of ASIASAT 1

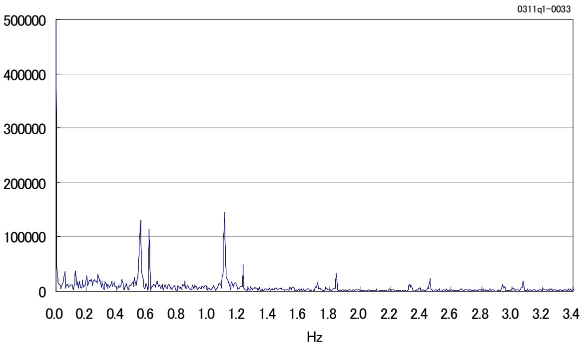


Fig. 12. Fourier transform of light curve of ASIASAT 1

5.2 SECOND OBSERVATION

The second observation time was on April 29, 2009. The central coordinates are right-ascension 13h56m16s, and declination -5º23'48". It is one exposure frame from among dozens of sheets of images taken over a period of 60 seconds. The observation field is a little to the north side of a geostationary orbit belt. Streaks of light such as space objects with space objects were frequently recorded. We were able to confirm 98 space objects from image of 324 frame of April 29.

5.2.1 SL-12 R/B (2) 89098D

It is debris observed at 2009.4.29 about 17:40 (UT). This SL-12 R/B (2) debris is the second stage of the Proton rocket when Russia launched Raduga-24 on December 15, 1989. Figure 13 is image of the streak of light part of SL-12 R/B (2). The light curve that was able to be extracted from this image is shown in figure 14. That a light intensity change is taking place periodically is known well. The thing which did Fourier analysis of this result next is shown in figure 15.

Fig. 13. Image of the streak of light part of SL-12 R/B (2)

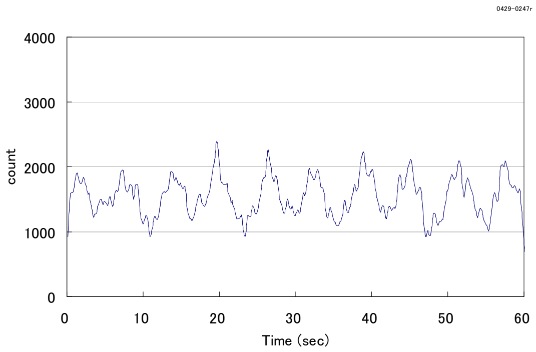


Fig. 14. Light curve of SL-12 R/B (2)

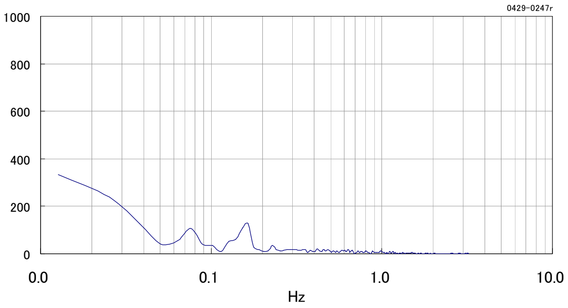


Fig. 15. Fourier transform of light curve of SL-12 R/B (2)

5.2.2 Unknown 1

It was observed at 2009.4.29 about 13:55, but there was not the applicable object from orbital element. Figure 16 is image of the streak of light part of Unknown 1. This space object can confirm a high-speed light intensity change. The light curve that was able to be extracted from this image is shown in figure 17. Figure 18 is FFT of light curve.

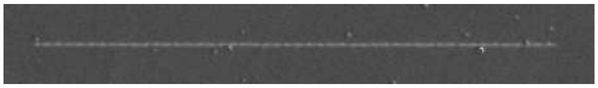


Fig. 16. Image of the streak of light part of Unknown 1

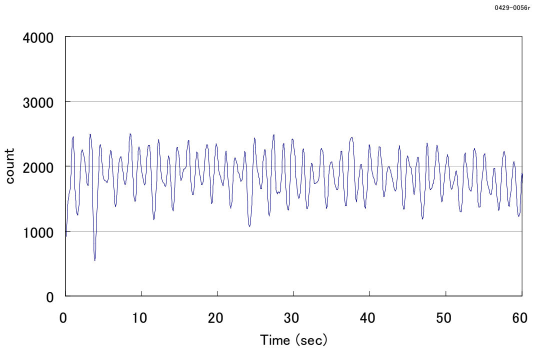


Fig. 17. Light curve of Unknown 1

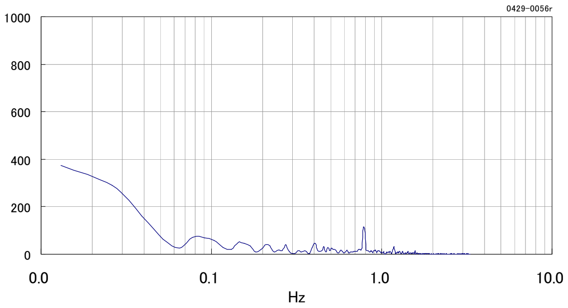


Fig. 18. Fourier transform of light curve of Unknown 1

5.2.3 Unknown 2

It was observed at 2009.4.29 about 15:47, but there was not the object which this was applicable to from orbital element. Figure 19 is image of the streak of light part of Unknown 2. From this image, a light intensity change is seen slowly (see Fig.20). Figure 21 is Fourier transform of light curve.

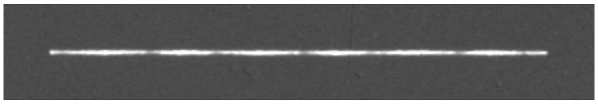
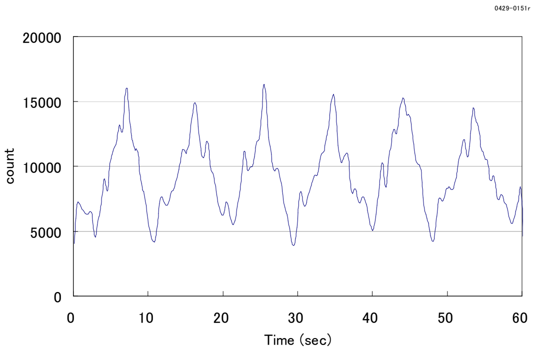


Fig. 19. Image of the streak of light part of Unknown 2



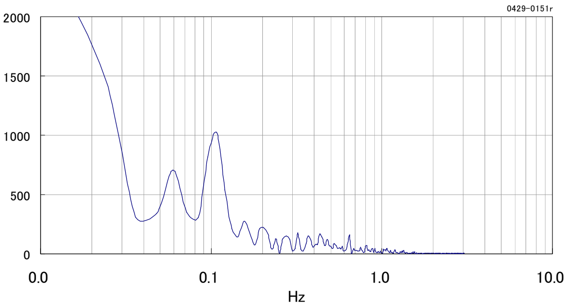


Fig. 20. Light curve of Unknown 2

Fig. 21. Fourier transform of light curve of Unknown 2

5.2.4 Unknown 3

It was observed at 2009.4.29 about 17:12, but there was not the object which this was applicable to from orbital element. Figure 22 is image of the streak of light part of Unknown 3. It can be hardly decided from image, but a small light intensity change is seen when a light curve is extracted (see Fig.23). Figure 24 is FFT of light curve.

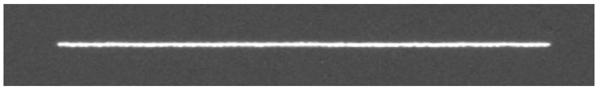
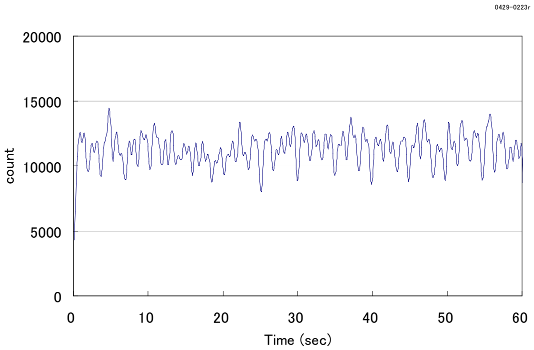


Fig. 22. Image of the streak of light part of Unknown 3



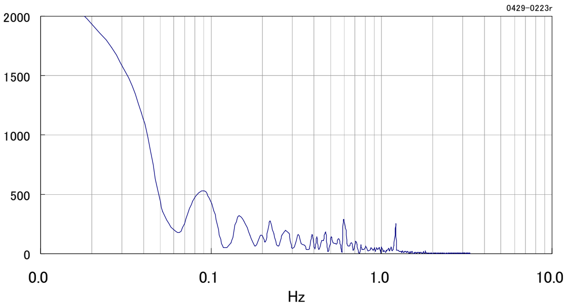


Fig. 23. Light curve of Unknown 3

Fig. 24. Fourier transform of light curve of Unknown 3

6. CONSIDERATIONS

A light intensity change was seen from most of the space object which passed an observation field by fixed star tracking by this observation method. The exposure time was shortened in this observation, and the sky went up was restrained. This analysis found changes of intensity of light in about 30% of the space objects passing through the observation field. However, noise components of the image often caused problems, preventing reading of changes. If exposure time is shortened at the time of observation, restraining the rise of the sky, it will be possible to obtain a little better data. In addition, a better result will be obtainable by improving the technique used to pick out streaks of light from the images.

7. SUMMARY

Fixed stars are observed in the same position on images when a telescope is operated in sidereal tracking mode. And artificial satellites and debris are recorded on the image as streaks of light. When a telescope is observing an equatorial belt in particular, satellites pass the field of view in rapid succession. This research calculated the rotation periods of some satellites and some pieces of space debris in the geostationary orbit detected in the observational images. In the future, we wish to improve the observation method and analytical technique as we accumulate information concerning the intensity of light change of satellites or debris in the geostationary orbit belt.

We now know that periodical observations will provide information of use in detecting malfunctions and other abnormalities in operative satellites.

8. REFERENCES

1. H. Kurosaki, et al., *Space Debris Observation, Detection and Evaluation*, Journal of Space Technology and Science, vol.24, no.2, (2009).
2. H. Kurosaki, et al., *Development of Detection Technology for Space Debris in Nyukasayama Optical Observatory*, JSASS, 51st Space Sciences and Technology Conference, 2F16 (2007). (in Japanese)
3. H. Kurosaki, et al., *Observation of light curve of GEO debris etc*., JSASS, 52nd Space Sciences and Technology Conference, 2H13 (2008). (in Japanese)