LIGHT CURVE PROPERTIES OF HIGH EARTH OBITAL ROCKET BODIES OBSERVED AT WEIHAI OBSERVATORY OF SHANDONG UNIVERSITY

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ABSTRACT

On-orbit spacecraft security is severely threatened by space debris, which may cause collisions, resulting in failures of space missions. Space debris surveillance and observation research are crucial to space activities. Most of the space debris surveillance work is operated by ground-based observations, in which optical telescopes play important roles, especially for the high earth orbital space debris surveillance. Motion properties investigation of space debris is crucial for space debris research. Brightness variation is common for space debris. Brightness variability of space debris may show some characters of the motions, shapes, materials, etc. Some light curves may show periodicities which may be related to their rotation properties. Compared with other types of debris, rocket bodies are easier to observe for their larger effective areas and simpler shapes. In April and May 2016, nineteen high earth orbital rocket bodies were observed in four nights using the one-meter telescope at Weihai Observatory of Shandong University. Light curves were derived and the periodicities of light curves were analyzed using two methods. Results show that brightness varies for each light curve, and periodicity is detected for almost all of them.

Keywords: Periodicity analysis; Space debris surveillance; Optical observations.

1. INTRODUCTION

With the development of space exploitation, research on space debris has been more and more important to on-orbit objects. In recent years, the removal of space debris has been a hot topic for space debris being a great threat to on-orbit objects, and knowing the motion properties of space debris is necessary to the removal. Thus, space debris surveillance and observation research are crucial to human space activities. Both ground-based and space-based observations are carried for space debris surveillance, and most of the space debris surveillance work is operated by ground-based observations. The ground-based observations can be divided into two types, radars and optical telescopes. Radar equipment can run continuously, and they are crucial to low earth orbit(LEO) space debris surveillance. However, the echo signal intensities are inversely correlated to the fourth power of distance R between the observer and space debris, which leads to low-efficiency for high earth orbit(HEO) ones. Optical telescopes observe the reflected sunlight by space debris, and the signal intensity decreases with R^{-2}. Although they can only work in the night and are easily affected by weather, they play important roles in space debris surveillance, especially for the HEO ones.

Motion properties investigation of space debris is crucial for space debris research. Brightness variation is common for space debris, and they may show some characters of the motions, shapes, materials, etc. Some light curves may show periodicities which may be related to their rotation properties[1]. Compared with other types of debris, rocket bodies are easier to observe for their larger effective areas and simpler shapes.

In this paper, we observed nineteen rocked bodies using the one-meter telescope at Weihai Observatory of Shandong University [2]. The telescope was installed in 2007 and the software was upgraded in 2012 for HEO space debris observation. The telescope has a nice performance in astrometric calibration[3].

This paper is arranged as follows. Section 2 refers to observations and Section 3 gives analysis methods for periodicity. Results and discussions are presented in Section 4.

2. OBSERVATIONS

In April and May, 2016, we observed space debris using the one-meter telescope of Shandong University, Weihai Observatory. For a better time resolution and a higher signal to noise ratio, space debris were observed with the clear filter, which has a higher transmissivity than any other filters. We observed nineteen rocket bodies, and the observation log were listed in Table 1. A light curve example is shown is Figure 1.

Proc. 7th European Conference on Space Debris, Darmstadt, Germany, 18–21 April 2017, published by the ESA Space Debris Office
Ed. T. Flohrer & F. Schmitz, (http://spacedebris2017.sdo.esoc.esa.int, June 2017)

Table 1. The observation log of rocket bodies

Date(mm-dd)	NORAD ID
0404	16528, 34780, 37235, 39482
0407	38353
0408	12850, 13882, 16870, 20474, 20559, 23756, 25339, 26393, 26486, 38353
0504	11570, 11684, 11862, 15963, 13899

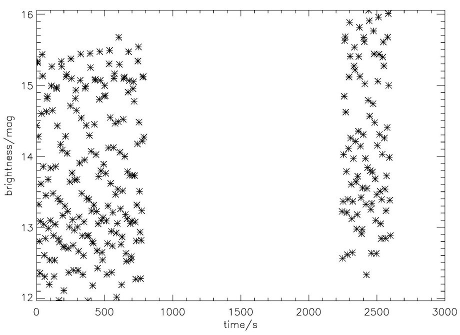


Figure 1. Light curve of rocket body 16528. The time refers to the time since the first image observed, and the magnitude refers to the instrument magnitude.

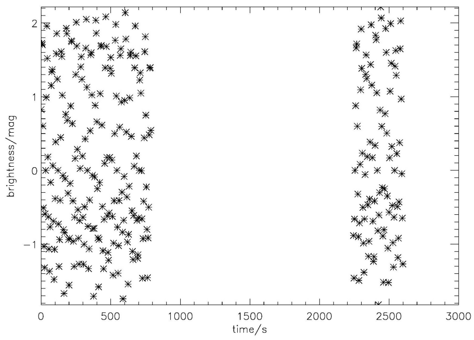


Figure 2. Relative magnitude of rocket body 16528 with linear trend eliminated.

3. PERIOD ANALYSIS

Each light curve show a short-term vibration and a long-term trend variation. We simplify the long-term one as a linear trend, and we did a linear fit using the IDL linfit procedure. After that, we eliminate the linear tread and get relative magnitudes, and an example is shown in Figure 2. After that, periodicity is analyzed for each light curve using Jurkevich method and Lomb-Scargle periodogram method.

3.1. Jurkevich method

The Jurkevich method was first proposed to analyze periodicity by Jurkevich in 1971 [4]. It is based on expected mean square deviation, and it is a powerful tool to detect periods of random and unevenly sampled observations. This method is described as follows.
For a data set $\{x_i\}$ of size N, with overall mean value $\bar{x}$ and overall sum of squared deviations V^2. For a trial period, the data are folded and divided into m groups according to their phases and the corresponding statistical parameters of the $j-$th group are given by

$$\begin{aligned} \bar{x_j} &= \frac{1}{m_j} \Sigma_{i=1}^{m_j} x_i \\ V_j^2 &= \Sigma_{i=1}^{m_j} (x_i^2 - \bar{x_j}^2) \end{aligned} \tag{1}$$

where m_j is the number of observations in the $j-$th group. The sum of the squared deviations of m groups is then derived by

$$V_m^2 = \Sigma_{i=1}^{m} V_j{}^2 \tag{2}$$

If the trial period equals to a real one, V_m^2 reaches its minimum. Normalized V_m^2 result for the light curve of 16528 is shown in Figure 3. In our analysis, we set 8 as the value of m. Period of 35.30s and its multiples are found, which indicate that 35.30s is a probable period for the brightness variation. For clarity, Jurkevich results for other objects are not shown.

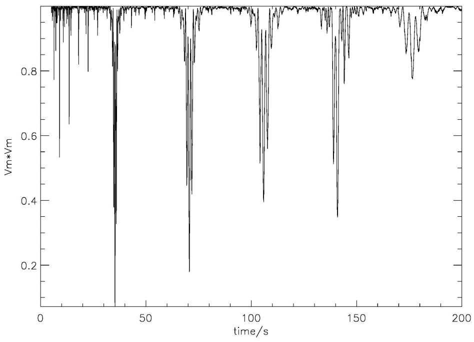


Figure 3. Periodicity analysis of light curve of 16528 using Jurkevich method.

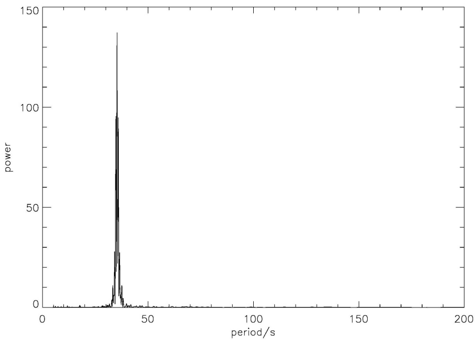


Figure 4. Periodicity analysis of light curve of 16528 using Lomb-Scargle method.

3.2. Lomb-Scargle periodogram method

The Lomb-Scargle periodogram is a powerful method which can also be applied to the periodicity analysis of random and unevenly sampled observations [5],[6]. This method is described as follows.
For a time series $X(t_k)(k = 0, 1, 2, ..., N_0)$, the periodogram is defined as

$$P_x(\omega) = \frac{1}{2}\{\frac{[\Sigma_i X(t_i)cos\omega(t_i-\tau)]^2}{\Sigma_i cos^2\omega(t_i-\tau)} + \frac{[\Sigma_i X(t_i)sin\omega(t_i-\tau)]^2}{\Sigma_i sin^2\omega(t_i-\tau)}\} \quad (3)$$

where ω is the angular frequency, τ is defined by the formula

$$\tau = \frac{1}{2\omega}tan^{-1}[\frac{\Sigma_i sin2\omega t_i}{\Sigma_i cos2\omega t_i}] \quad (4)$$

Figure 4 shows an example of Lomb-Scargle periodgram, and period of 35.30s is obvious with a prominent peak in the periodgram. The result is in accordance with result derived by Jurkevich method. For clarity, Lomb-Scargle periodgram results for other objects are not shown.

Table 2. Period analysis results

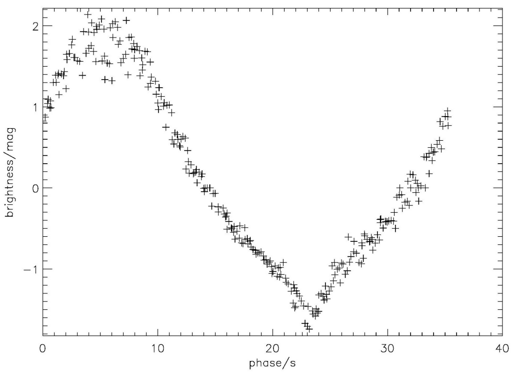
NORAD ID	Period(s)	NORAD ID	Period(s)
16528	35.30	34780	329.50
37235	12.15	39482	158.25
38353	18.25	12850	54.00
13882	11.10	16870	13.40
20474	196.55	20559	123.10
23756	5.51	25339	23.70
26393	6.73	26486	10.44
11570	28.71	11684	4.14
11862	7.76	15963	4.72
13899	Not Determined		

4. RESULT AND DISCUSSION

After period analysis with the methods mentioned above, we derived that eighteen out of nineteen rocket bodies behave periodicity in their light curves. Light curves are plotted in Figures 5, 6 and 7, in which time is folded according to their phases. For the one with NORAD ID 38353, observed in 7th and 8th, April, we derived the same period 18.25s, which shows that algorithm used for periodicity determination is robust. From the results derived, we find that eighteen out of nineteen rocket bodies show periodic variations. However, the one with NORAD ID 13899 is hard to determinate its periodicity. Its light curve is plotted in Figure 8, and the left and the right panel show light curves without and with linear elimination, respectively. From the light curve, we find that its variation is in 0.1 magnitude after linear elimination, which means the object did not show obvious periodicity during our observation. However, we can not give a conclusion relying on current data. The brightness decreases for about 1.0 magnitude in less 1250 seconds for the observation, which may imply rotation of the rocket body. To know this object better, further observations are needed.
In this paper, we observed nineteen rocket bodies using the one-meter telescope at Weihai Observatory of Shandong University. Results show that 18 out of 19 show periodicity, which should be caused by their rotation, and the left one is not certain for the short observation time. Based on the results we derived, we can made a conclusion that almost all the rocket bodies show periodic variation.

ACKNOWLEDGMENTS

This work is supported by the Young Scholars Program of Shandong University, Weihai. We acknowledge with thanks the observation assistant of Weihai Observatory



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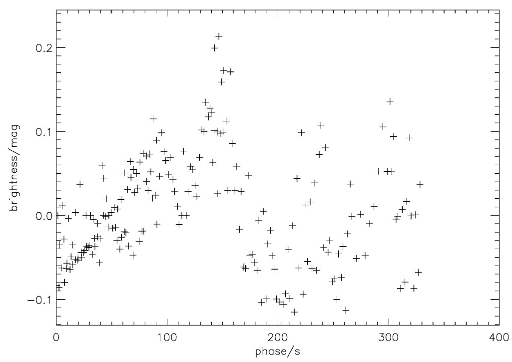

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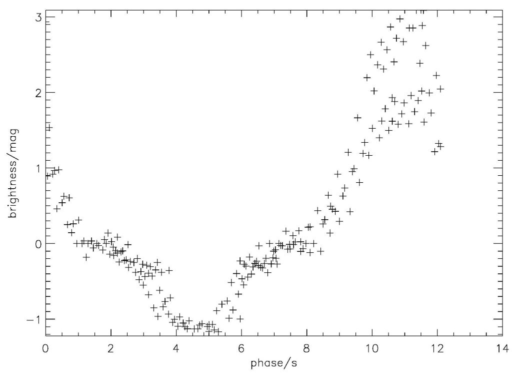

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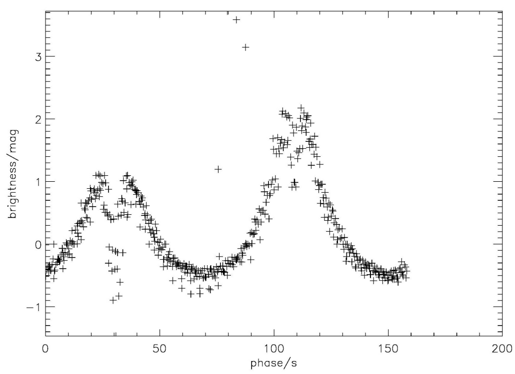

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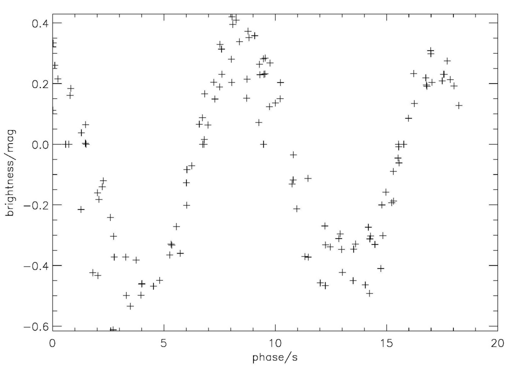

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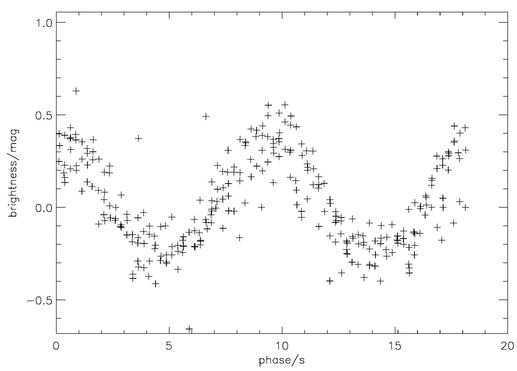

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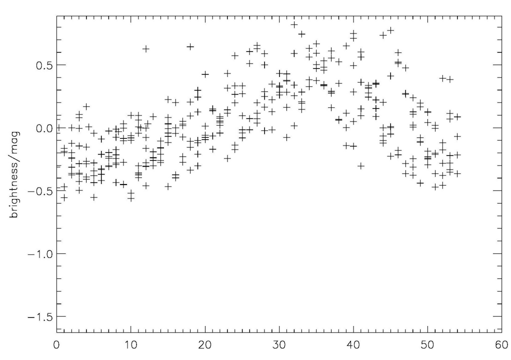

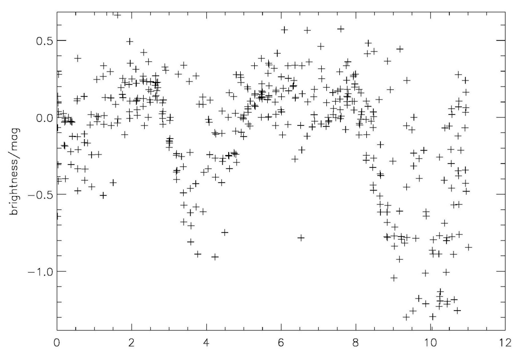

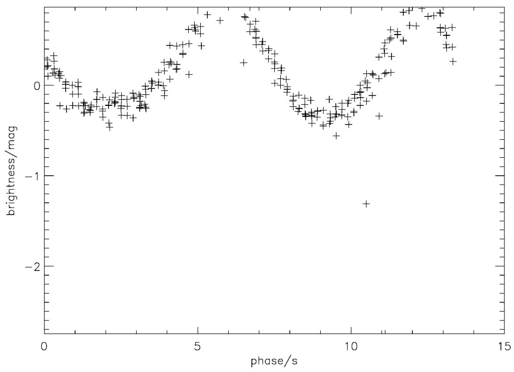

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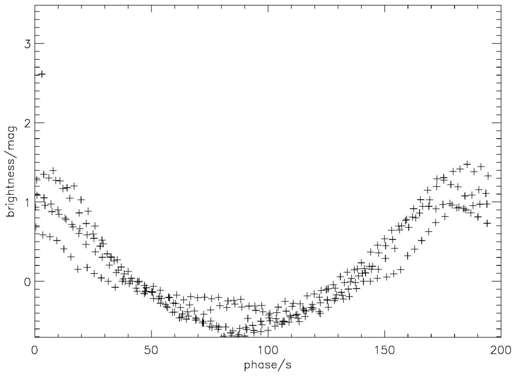

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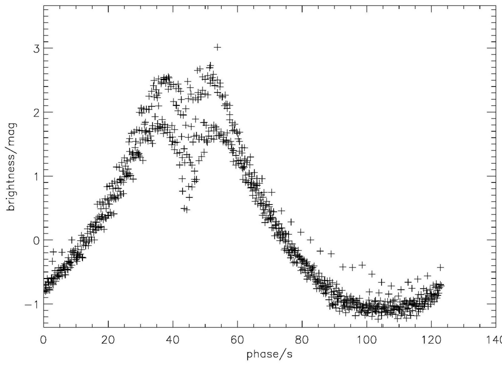

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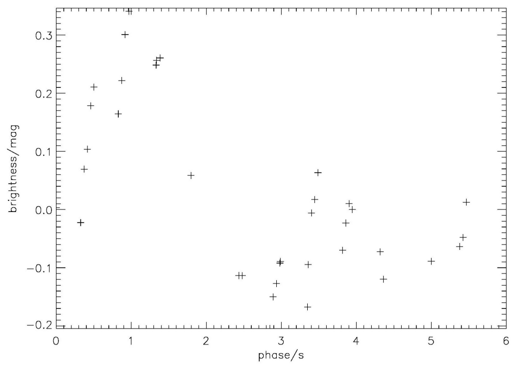

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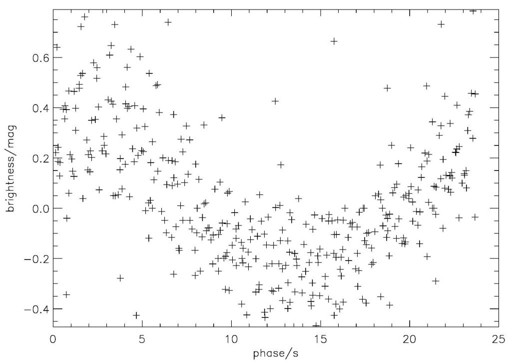

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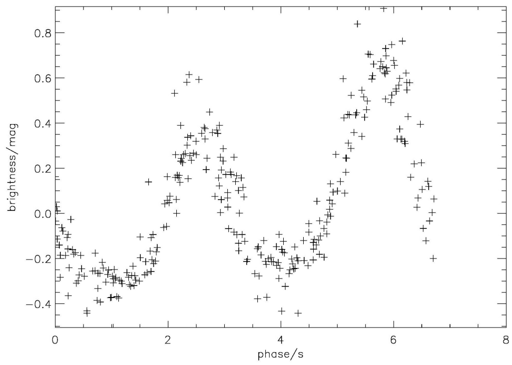

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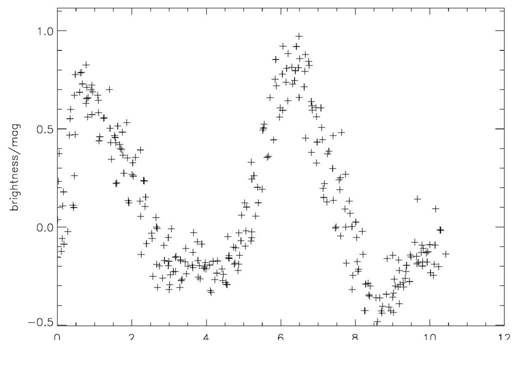

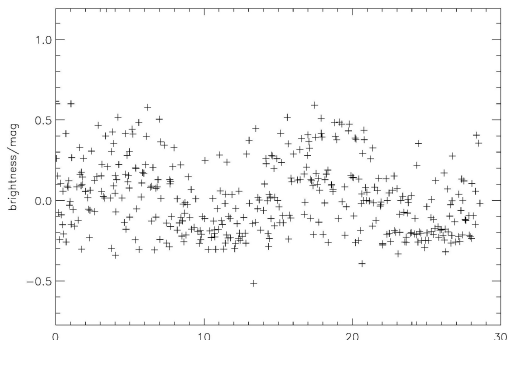

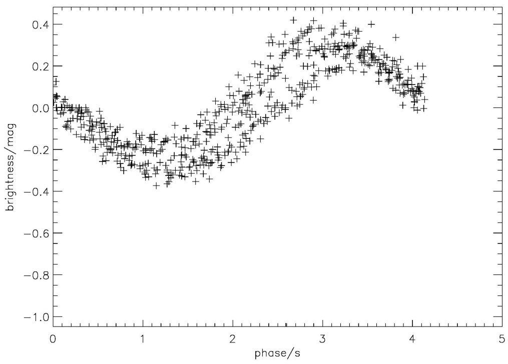

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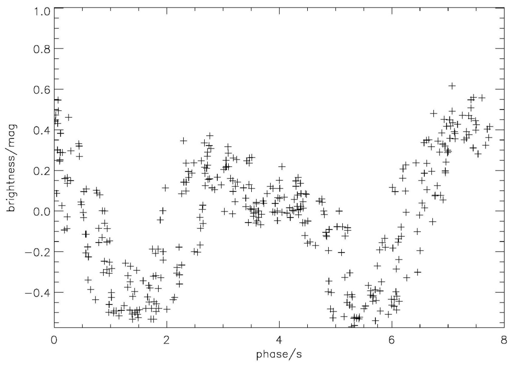

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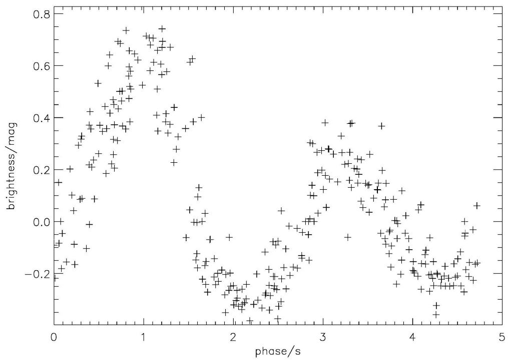

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Figure 7. Continuation of Figure 5.

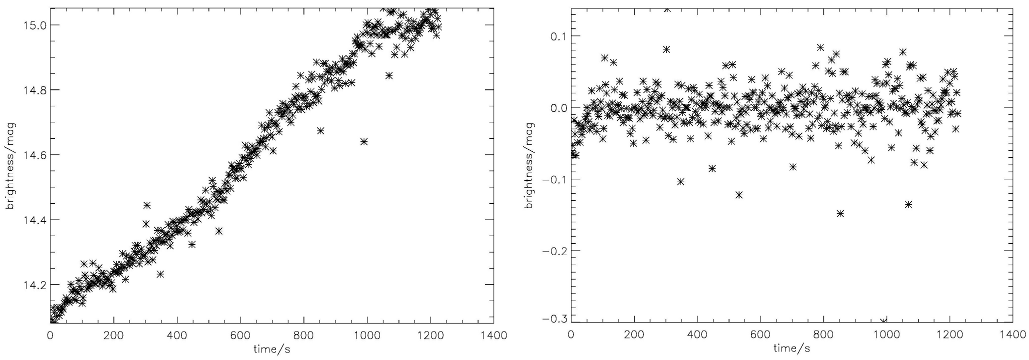

Figure 8. Light curves of 13899. The left and the right panel shows light curves without and with linear elimination, respectively.

for their hard working.

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