The Preliminary Results from Long-term Sparse Photometric Data

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ABSTRACT

From June 2017, the long-term photometry of a low orbit satellite is performed continuously with an optical network which consists of several small aperture optical telescopes, and the corresponding data is obtained. However, the precise photometry is seriously affected for a few reasons, e.g. the extremely short optical visibility time limits the span of the light curve and makes it difficult to extract the apparent rotation period, the low altitude and high apparent brightness limit the exposure time for single image and make it hard to measure the flux and find background stars to perform astronomical calibration. Under the circumstances, most methods to derive the apparent rotation period maybe invalid. Here we try to use several methods to derive apparent rotation period from the light curve, including fitting the sinusoidal function, phase dispersion minimization periodogram, epoch folding and so on. And then these results are compared to each other. By analyzing the derived apparent rotation periods of the light curves at different time from June 2017 to March 2018, some preliminary conclusions are drawn.

Keywords: sparse data, photometry, apparent rotation period, light curve

1. INTRODUCTION

A light curve can provide the information about the rotation properties and reveals the physical status of space objects. Even a tri-axial ellipsoidal model including rotational axis direction, rotation period, and precession can be derived using only light curve [1, 2]. The apparent rotation period of space debris is very important. It is often extracted from the light curve. Hence a light curve database is very crucial in space situation awareness and the research of space object rotation [3]. For GEO or HEO, the space object can be observed in a rather long time. However, for LEO or a decaying satellite, the optical visibility time is very short. This is challenging in extracting the apparent rotation period from the light curve with short duration.

Tiangong-1 is China's first prototype space station, and it was announced to officially end service from March 2016. From June 2017, the long-term photometry of Tiangong-1 is performed continuously with an optical network which consists of several small aperture optical telescopes, and the corresponding data is obtained. However, the precise photometry is seriously affected for a few reasons. First, the extremely short optical visibility time limits the span of the light curve (generally no more than one apparent rotation period). Second, the low altitude and high apparent brightness limit the exposure time for single image and make it hard to measure the flux and find background stars to perform astronomical calibration. Third, the exposure time of the data derived in a single tracklet is not always the same. Therefore, the data is short, fragmented and not standard magnitude. It is very difficult to extract the apparent rotation period from such data. Therefore, most methods to derive the rotation curve period maybe not suitable.

In the paper, due to the reason that the data are so flawed that the apparent rotation period cannot be derived directly and easily. The data must be preprocessed before using it. Firstly, the data should be sorted by the exposure time. Because it is hard to find background stars to perform astronomical calibration, only relative magnitude can be derived. The magnitude zero points of different exposure times are different and unknown, so it is necessary for us to pick the data with the same exposure time together in a tracklet. Secondly, distance correction is made to every data. Thirdly, it is necessary to make data merging. there are often several sorted segmental data at or close to the same observation time from different telescopes. The duration of one segment is too short to be used. Hence in order to make use of the data, it is necessary to merge these segments which are close to each other in observation time. A function is used to fit the fragmented data using the least squares regression. After these corrections, the light curve seems to be consecutive. And then, the apparent rotation period is extracted from the merged light curve using several different methods. Finally, atmospheric extinction correction is made to some data, and the apparent rotation period is also extracted from the corrected data. Some conclusions are made by comparing these results.

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2. DATA PREPROCESSING

From June 2017 to March 2018, Tiangong was observed continually. However, its latitude decreased from 338 km to 254 km in about 9 months as shown in Fig. 1. This limited the optical visibility time. Although there is observation data in about 59 days from June 2017 to March 2018, the duration of most data is too short to be used. Hence, only 8 sets of data which have longer time spans than others are picked, they are shown in Fig. 2 and Fig. 3.

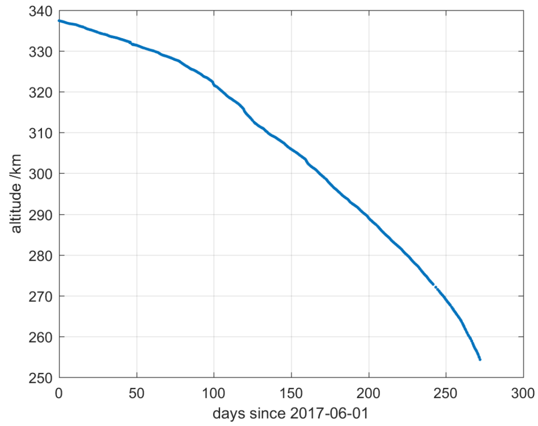

Fig. 1. The altitude of the space object from June 2017 to March 2018 (NORAD ID: 37820, COSPAR ID: 11053A).

In Fig. 2 and Fig. 3, the different colors in a subfigure mean that the data is obtained from different telescopes in the same station or the data is corresponding to different exposure times from the same telescope. Hence, it can be concluded that the data is of the following characteristics:

(1) Irregular, there is no similarity for them;
(2) Short duration for each segment;
(3) Fragmented, as shown in Fig. 3 (18-01-19), there are 6 short segments from 2 telescopes;
(4) Discontinuous, as shown in Fig 2 (17-08-15) and Fig 3 (18-01-19);
(5) Not the standard magnitude.

For each of the above characteristics, it can be a difficult challenge for extracting the apparent rotation period from a light curve. Therefore, the data in one day should be merged first, or it is very hard to process such data.

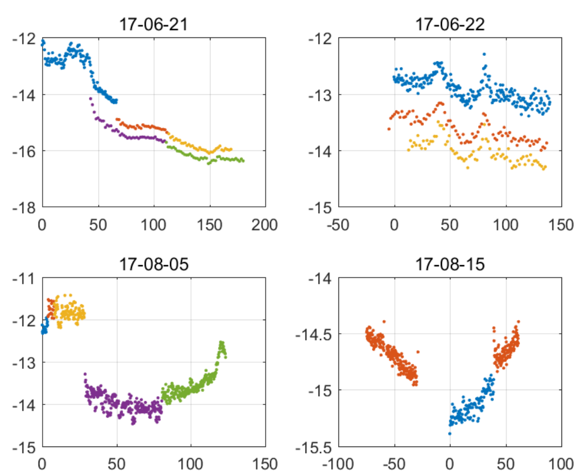

Fig. 2. The relative magnitude in 17-06-21, 17-06-22, 17-08-05 and 17-08-15.
The horizontal axis is the duration (s), and the vertical axis is the relative magnitude.

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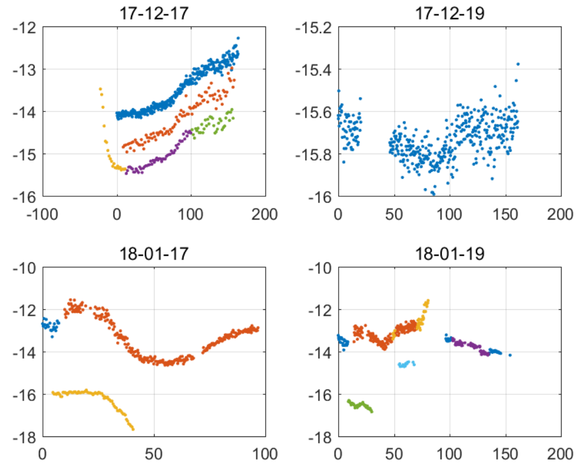

Fig. 3. The relative magnitude in 17-12-17, 17-12-19, 18-01-17 and 18-01-19.
The horizontal axis is the duration (s), and the vertical axis is the relative magnitude.

To merge the data, a function consisted with a constant and a sinusoidal function is proposed to fit the data, it is of the following form,

$$f(t_i) = c_k + A\sin(\omega t_i + \phi),\ k = 1,2,\cdots,K, i = 1,2,\cdots,n, \tag{1}$$

where K is the number of the segments in a subfigure, n is the total number of the magnitude points, so the number of parameters need to be refined is K+3, that is, $c_k, \omega, and\ \phi$.

Except the subfigure (17-12-19) which has only one segment, each of the other subfigures in Fig. 2 and Fig. 3 should be processed using the above function and the least squares regression to merge the fragmented data. After performing the data merging. The merged results are presented in Fig. 4 and Fig. 5. it is obvious that the data are continuous by refining the constant terms those represent the difference of magnitude zero points. The sinusoidal term is to ensure the continuity between different segments in the whole light curve. We note that there is a leap labeled in the black circle in Fig. 4 (17-06-21). It indicates that this model may not be perfect in merging the data in the paper. Of course, the emerging effect is determined by the appropriate model which depends on the properties of the data. Hence experience plays a very important role in the process. In the paper, except the subfigure (17-12-19), the data merging method works well for all the other data. The process extends the duration of the light curve, so it is possible to extract the apparent rotation period more precisely. It will be presented in the next section.

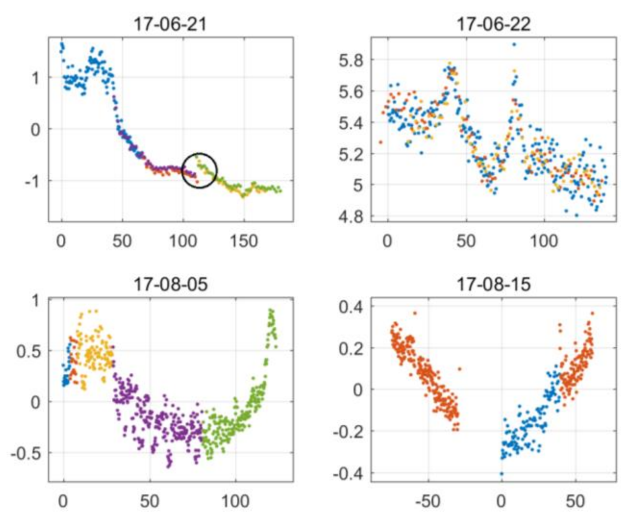

Fig. 4. The merged relative magnitude in 17-06-21, 17-06-22, 17-08-05 and 17-08-15.
The horizontal axis is the duration (s), and the vertical axis is the relative magnitude.

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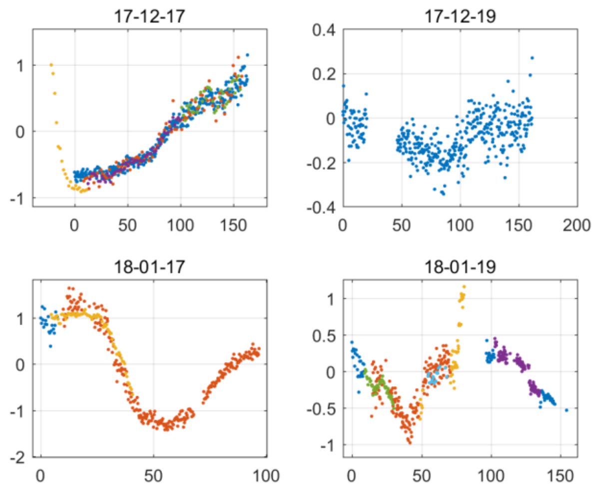

Fig. 5. The merged relative magnitude in 17-12-17, 17-12-19, 18-01-17 and 18-01-19.
The horizontal axis is the duration (s), and the vertical axis is the relative magnitude.

3. Apparent Rotation Period

The data merging is made to all the data in former section. The data seems to be regular and continuous. Besides, the effective time span is longer which makes the data useful. In this section, six kinds of methods are used to extract the apparent rotation periods from these light curves [4, 5]. It should be noted that all the data is irregularly sampled.

(1) The model is sine function and the least absolute deviation regression is used;
(2) Calculating an Epoch Folding [6] or analysis of Variance periodogram [7];
(3) Calculating a Phase Dispersion Minimization periodogram [8];
(4) The model is periodic spline function with four B-splines per cycle;
(5) The model is Fourier series of second degree;
(6) The model is Fourier series of third degree.

Each of the above methods calculates a periodogram by fitting the corresponding periodic function to the light curve in the paper. Except (1) which uses the least absolute deviation regression, the others use the least squares regression.

When performing these methods, the trial periods from 1 to 1000 seconds with a step of 1 second are adopted. In the obtained periodograms shown from Fig 6 to Fig. 13, only part of periods [30, 1000] are displayed in the figures. The horizontal axis is the corresponding frequency.

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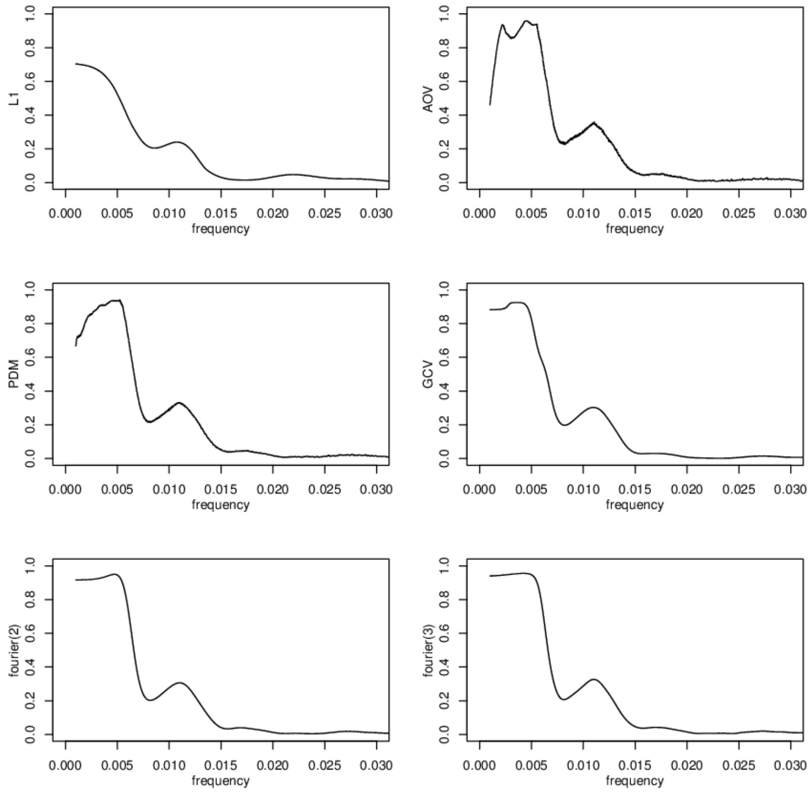

Fig. 6. The periodograms of the light curve in 17-06-21.

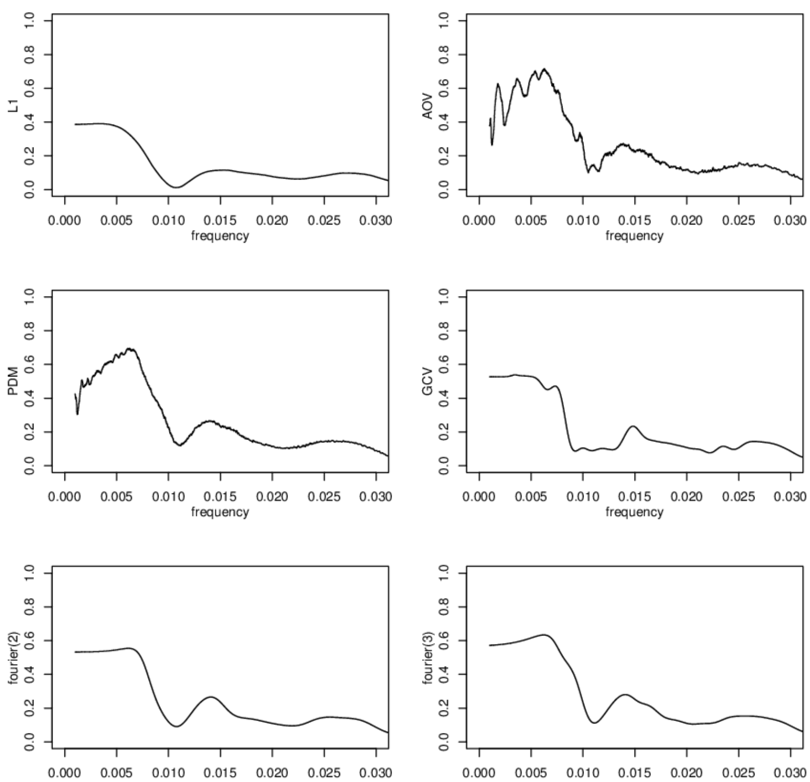

Fig. 7. The periodograms of the light curve in 17-06-22.

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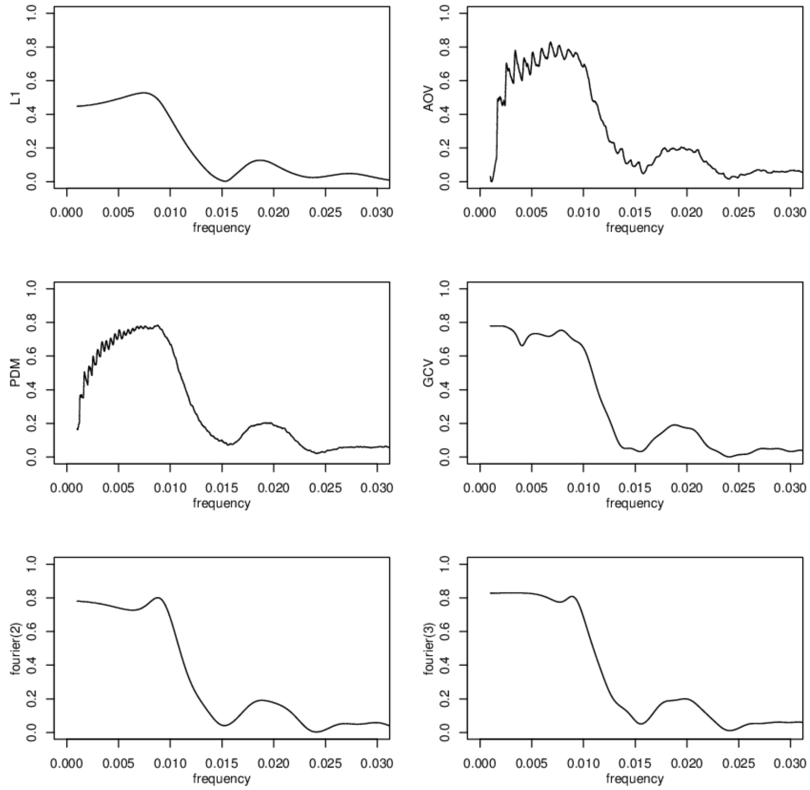

Fig. 8. The periodograms of the light curve in 17-08-05.

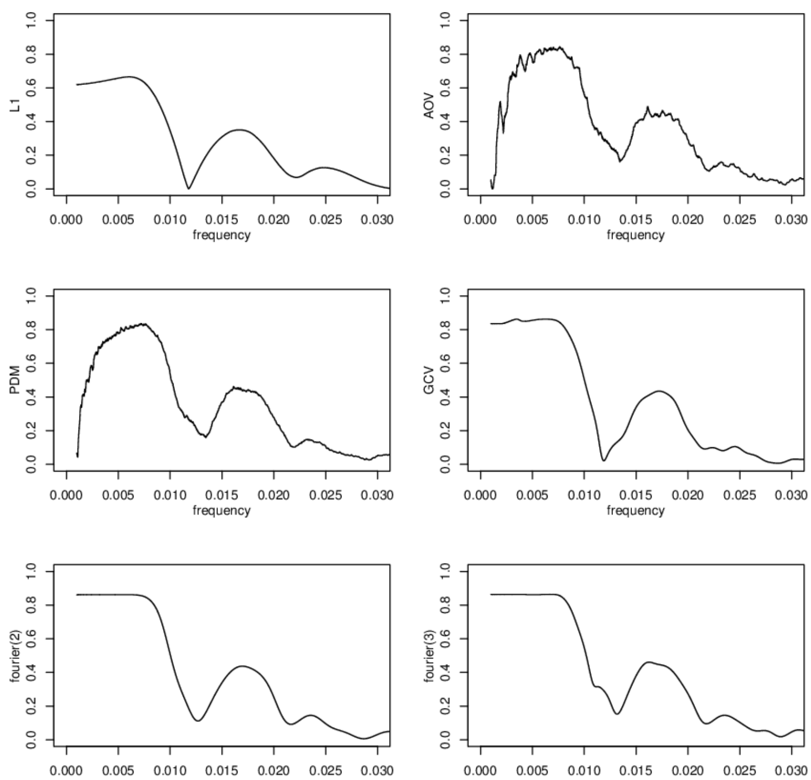

Fig. 9. The periodograms of the light curve in 17-08-15.

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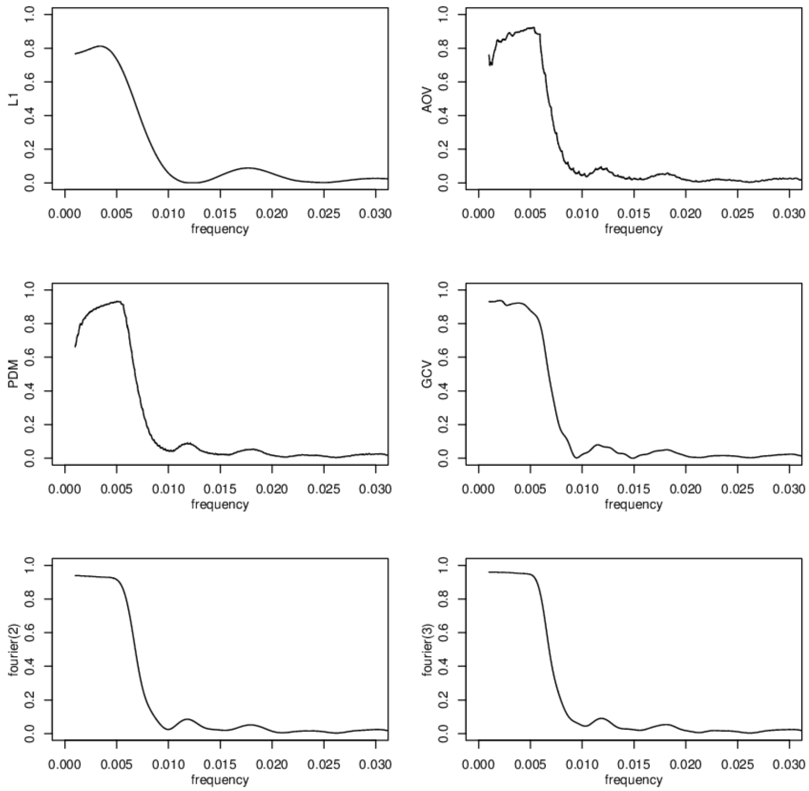

Fig. 10. The periodograms of the light curve in 17-12-17.

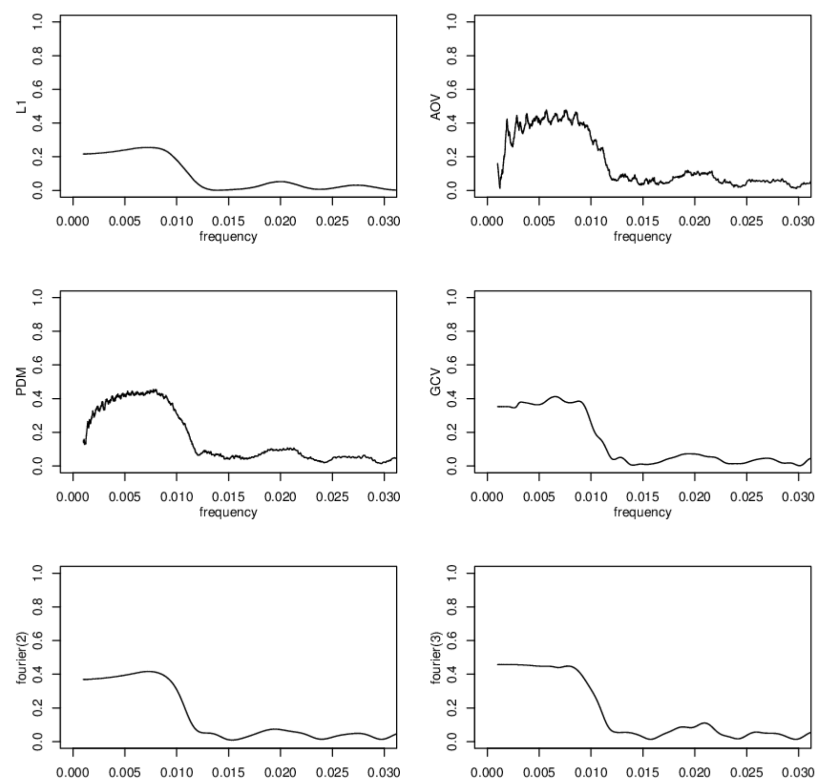

Fig. 11. The periodograms of the light curve in 17-12-19.

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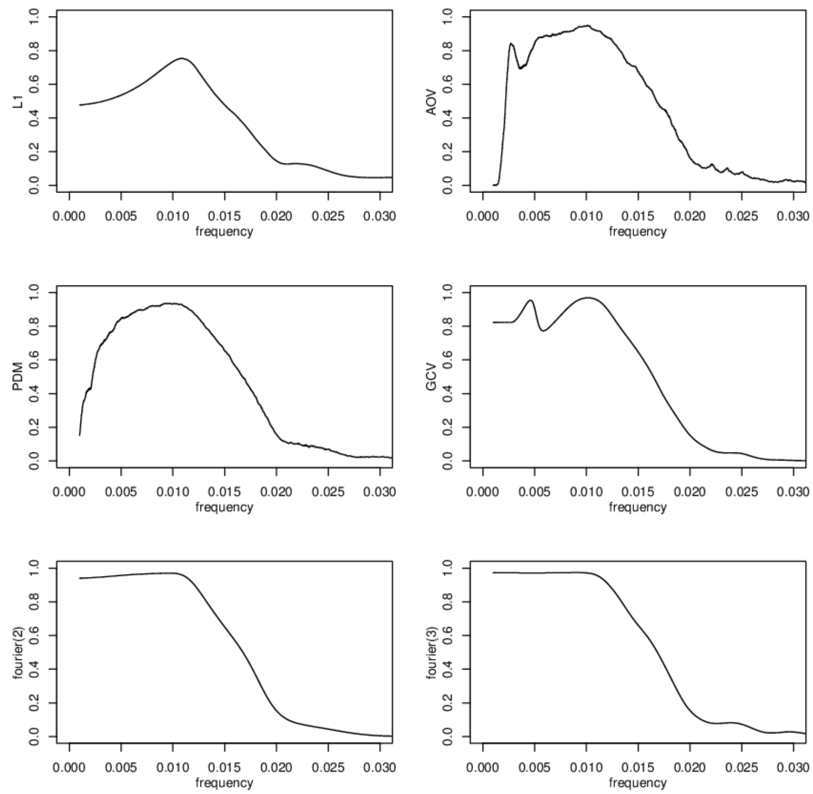

Fig. 12. The periodograms of the light curve in 18-01-17.

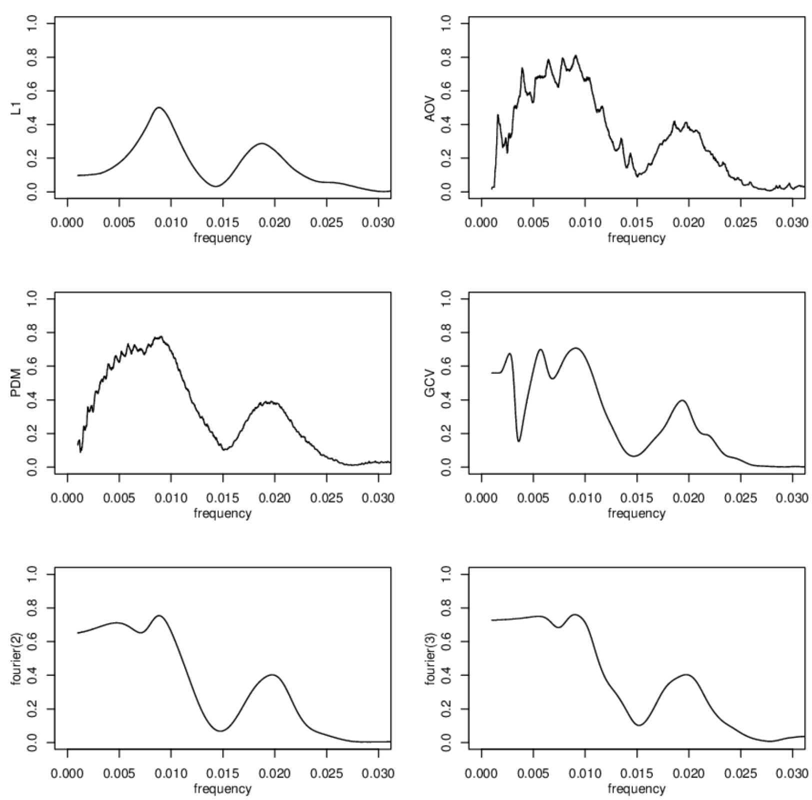

Fig. 13. The periodograms of the light curve in 18-01-19.

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As shown in the Fig. 6-13, the results derived from different methods are not always the same, some methods even failed to present the results clearly which are labeled '\' in the table 1. The stations (Sa-b) in table 1 indicate the source of the data, "a" represents the station and "b" represents the telescope.

From the results in the figures and table, the following preliminary conclusions are drawn:
(1) There is no absolute advantage for any one of these methods which can always works;
(2) There are slight differences between difference methods due to different models used;
(3) The light curve of 18-01-17 in Fig. 5 shows clear periodicity. However, four of the six methods did not present the result well, and obviously the reason is that the duration is too short;
(4) Although the durations of the data in 17-12-17 and 17-12-19 are long enough, the periodicity of them are not so clear. There is only weak periodicity shown in Fig. 10-11 for all the methods.
(5) It is found that the results between "L1" method and other methods in 17-12-17 differ too much. It is inferred that the periodicity of the data is too weak or some of the models are not suitable for processing this type of data. Maybe both two reasons work.

Table 1. The apparent rotation periods extracted by different methods.

DATE	L1	AOV	PDM	GCV	Fourier2	Fourier3	DUR /s	STATIONS
17-06-21	93.1	90.4	90.8	91.2	90.8	90.8	180.2	S1-1, S1-2, S1-3
17-06-22	\	72.0	71.8	67.4	71.0	71.0	144.3	S1-1, S1-2, S1-3
17-08-05	53.6	51.5	50.9	53.2	53.1	50.6	123.3	S2
17-08-15	59.9	61.9	61.9	58.0	58.9	61.5	136.2	S2
17-12-17	56.5	84.4	84.4	86.9	84.6	84.3	185.6	S1-1, S1-2, S1-3
17-12-19	49.8	51.8	48.4	51.6	51.4	47.8	161.5	S3-1
18-01-17	92.3	\	\	94.8	\	\	96.7	S3-1, S3-2
18-01-19	53.4	53.7	50.9	51.7	50.7	50.7	154.4	S3-1, S3-2

In the above process, the atmospheric extinction correction is not made to the data. In order to verify the effect of atmospheric extinction correction, the data in 17-06-21 and 17-12-17 which have longer durations is tested. Besides, due to the failures of the four methods in extracting the period, the atmospheric extinction correction is also made to the data in 18-01-17. The light curves after atmospheric extinction correction are presented in Fig. 14. Obviously, they are more horizontal than before.

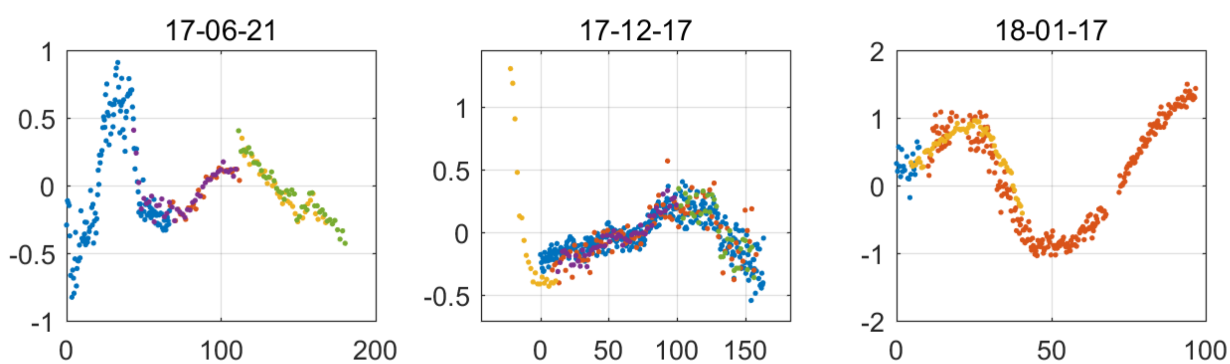

Fig. 14. The relative magnitude in 17-06-21, 17-12-17 and 18-01-17 after atmospheric extinction correction. The horizontal axis is the duration (s), and the vertical axis is the relative magnitude.

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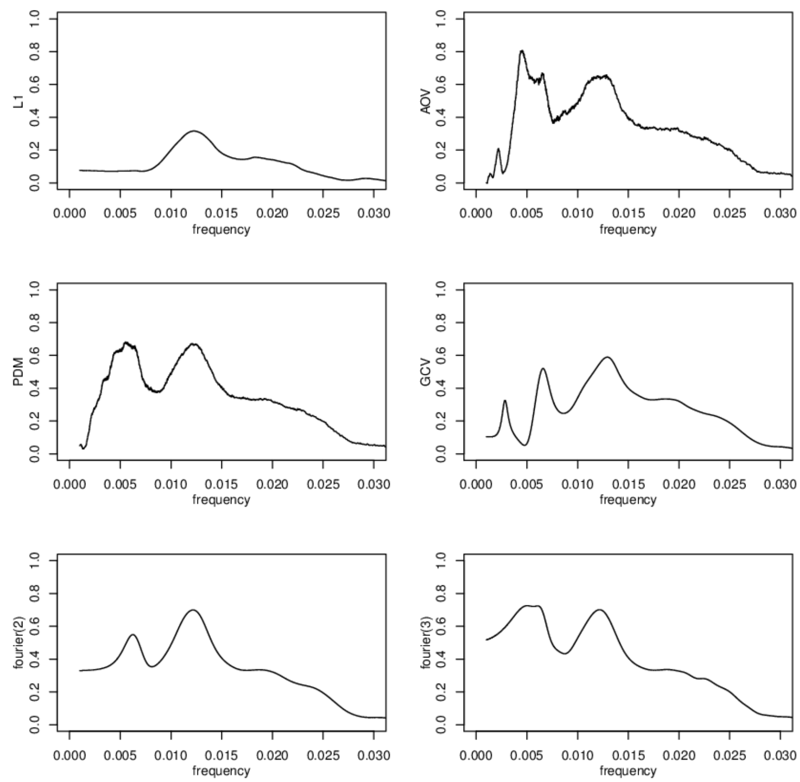

Fig. 15. The periodograms of the light curve after atmospheric extinction correction in 17-06-21.

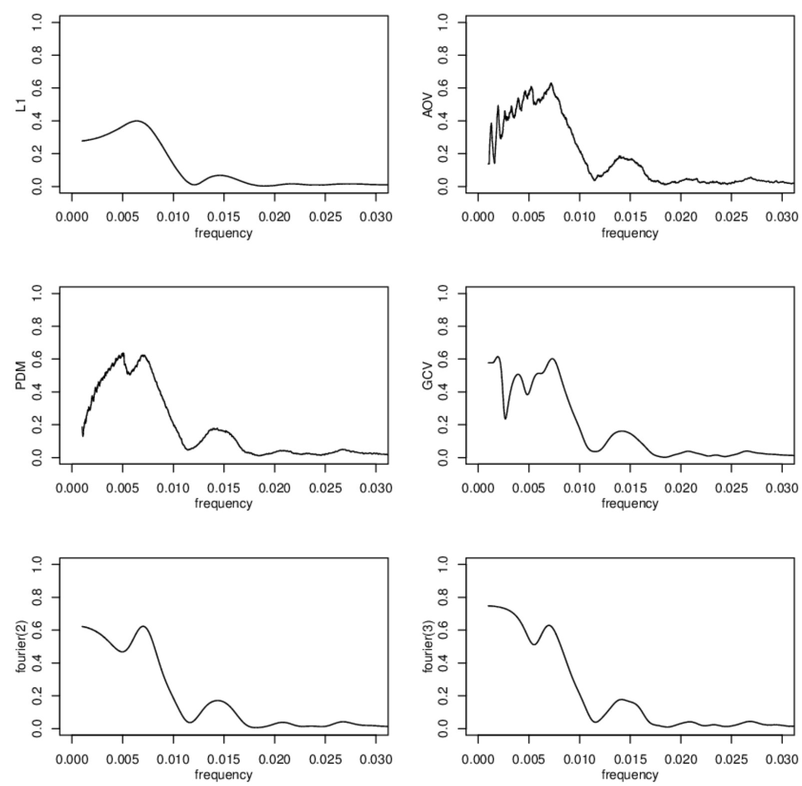

Fig. 16. The periodograms of the light curve after atmospheric extinction correction in 17-12-17.

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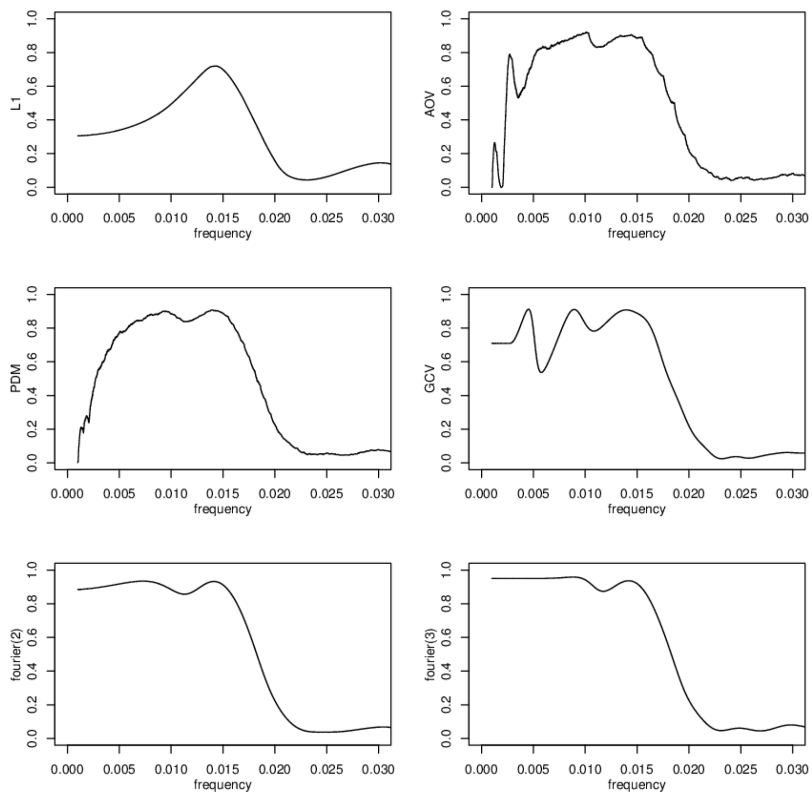

Fig. 17. The periodograms of the light curve after atmospheric extinction correction in 18-01-17.

Table 2. The apparent rotation periods extracted by different methods after atmospheric extinction correction.

DATE	L1	AOV	PDM	GCV	Fourier2	Fourier3	DUR /s	STATIONS
17-06-21	74.8	74.8	74.8	74.8	74.8	74.8	180.2	S1-1, S1-2, S1-3
17-12-17	68.4	71.6	69.7	70.5	69.5	70.7	185.6	S1-1, S1-2, S1-3
18-01-17	69.9	69.1	71.7	71.7	70.8	70.5	96.7	S3-1, S3-2

By comparing the results before and after atmospheric extinction correction, it is found that the derived apparent rotation periods are all smaller than before, and the periods in the three examples are close to each other. The periodograms are more explicit than before. It should be noticed that the huge difference between the results from the first method and the other methods disappears for the second example (17-12-17). It verifies previous inferring in part. Therefore, the results are more convincing and maybe reliable than the results before atmospheric extinction correction.

4. CONCLUSIONS

The decaying satellite Tiangong was observed frequently and the observation data in about 59 days was obtained from June 2017 to March 2018. However, the limited optical visibility time made most of the data useless in performing extracting apparent rotation period. Besides, the data was fragmented and not the standard magnitude. Hence, data merging was proposed to repair the data. In the paper, eight sets of data which have relative long durations than others were used.

After data emerging, six kinds of methods which use different periodic functions and regression techniques are adopted to extract the apparent rotation periods. However, the results depend on the duration of the data. Although data emerging extends the duration of the data effectively, the apparent rotation periods of some data are still hard to extract. Then atmospheric extinction correction is made to three sets of data. The periodograms show that the periods derived from the six kinds of methods are very close and smaller than before. More importantly, the periodicity is more explicit than before. This makes the latter results more reliable.

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In conclusion, after a series of processes, the data has longer duration and can be used in extracting the apparent rotation period. Six kinds of methods are tried, the periods between 50 seconds and 75 seconds are extracted from the light curves.

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