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Discovering exoplanets in Pleiades with transiting exoplanet survey satellite

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Abstract. No transiting exoplanets have previously been found in the Pleiades. The Pleiades is a relatively young star cluster near us, which makes it valuable for investigation. This study aims to determine the existence of exoplanets in Pleiades using the transit method. Specifically, it sought to determine if the listed 83 stars have exoplanets by inspecting on light-curves from data of Transiting Exoplanet Survey Satellite (TESS). The TESS mission, with a better resolution and observed sky area than the previous Kepler mission, aimed to find more exoplanets around stars. To test the hypothesis that exoplanets do exist in the 83 stars of the Pleiades, we downloaded their light-curves using Jupyter notebook and the Lightkurve package, then checked using BLS method and fitting if there were transits. The results showed no clear sign of transiting planets in those stars. These results suggest that the 83 stars checked likely don't have a transiting exoplanet, but 83 stars cannot represent the whole Pleiades star cluster. Other methods should be used in analysis to gain more accurate results and more stars should be checked to investigate whether or not transiting exoplanets exist in the Pleiades star cluster.

Keywords: exoplanet, TESS, transiting method.

1. Introduction

Our group found that nobody has done similar researches that to find transit in Pleiades, so we decided to have a try to find an earth like transit in Pleiades as it is so close to us. The TESS (Transiting Exoplanet Survey Satellite) mission has been conducted to find many small planets around the nearest stars in the sky which were recorded by using transit method to find exoplanets and has mission area 400 times larger than Kepler [1]. It records the nearest brightest main sequence stars hosting transiting exoplanets. The research mainly focuses on some stars in the Pleiades. Pleiades is a young cluster about 444 light years and in the range of TESS observation. These 83 stars are selected and a table is made to find out whether those stars have transits or not by processing the data from TESS mission.

In astronomy, a transit is a phenomenon when a celestial body move across the surface of a larger body and thus the flux of star will change with the portion where it covers. It has been a long-time people use this method to find planets. In section 2, we are going to further talk about the method we use. Because the stars in Pleiades are all very young, the stars in it are moving in a not very regular period compared with other older clusters [2]. In the end we summarized some difficult points which are hard to solve because of the limit of the time and program we wrote and some reminders in case someone in the future would like to use the same sets of data to have some researches in section 5 and 6.

In the end, a table can be found shows the data we have for the 83 planets including some known but useful data [3].

2. Methods

2.1. Tools used

For better data analysis, Python 3 was used as our main tool to process star flux data from TESS. This research made use of Lightkurve, a Python package for Kepler and TESS data analysis [4]. In our project, the Lightkurve module was designated to download data of the brightness of a star over time and plot a diagram for further investigation.

2.2. Main Procedure

Due to the reason that Pleiades is a young cluster and most of stars from it have not been named yet, the first problem we met was how to filter the candidate stars to access their flux data. Through the VizieR web interface, a table of positions of 502 stars in Pleiades region was acquired and the Two Micron All-Sky Survey codes of stars in Pleiades were obtained, which could be used to search in the Lightkurve module [5]. Our group selected 80 stars from the candidate list and used the Searchlightcurve function to obtain a data table which lists the light curve files that lie within a region of sky centered around the position of target and within a cone of a given radius [6,7]. For each of the star, 3 missions from TESS were conducted and the sector 42 was chosen for all of stars. The light curves were plotted using Matplotlib's scatter method. The table 1 below shows an example table of light curve.

Table 1. k value of each star in Pleiades.

No.	k value	uncertainty
23-	8.94375845e-06	4.06172912e-01
24-	0.03154948	0.0139419
25-	0.00751532	inf
26-	0.09856064	inf
27-	2.81331926e-05	3.14858153e-01
28-	0.08001018	1.45708762e+01
29-	0.03375335	0.0024886
30-	0.01137006	1.18295331e-02
31-	0.06658005	6.39453682e+01
32-	6.69536262e-06	7.57517161e-01
33-	0.03721988	inf
34-	0.03764043	1.36126527e+00
35-	0.01486415	4.04206650e-01
36-	0.03629728	0.02042692
37-	0.00664221	2.57473388e-02
38-	0.013368	inf
39-	0.04009453	0.21848686
40-	1.43053625e-04	7.15506507e-02
41-	0.00977423	3.55277204e-01
42-	2.31617989e-05	1.35415645e-01
43	0.01960216	6.04389488e-03
44	0.02127566	1.11712070e-02

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Table 1. (continued).

45	0.09608608	inf
46	0.09608608	inf
47	none	
48	-3.64268168e-06	2.89796632e-02
49	-9.82993609e-06	3.15714735e-01
50	4.93416482e-06	8.11568139e-01
51	0.01097463	2.34794527e-02
52	0.04016899	9.49936383e+00
53	-1.38635370e-05	1.47207744e-01
54	0.04434365	2.06421032e+01
55-	0.04035016	1.94857317e+01
56-	8.78967663e-05	1.67392820e-01
57-	0.12491735	2.19934037e+00
58-	-0.00803954	inf
59-	0.07440186	3.34168352e+01
60-	0.20470037	inf
61-	0.01400613	3.04281918e-03
62-	0.05563235	1.88066612e+00

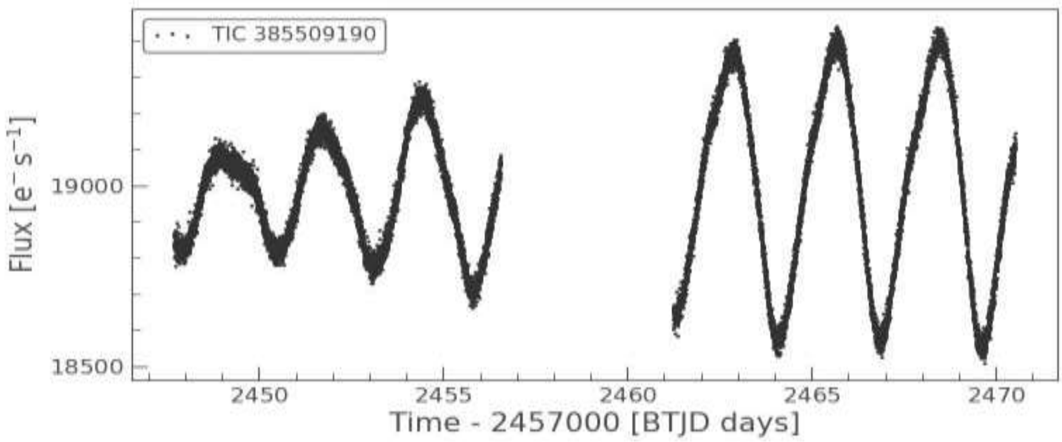

Figure 1. Flux versus time of 2MASS J03445639+2425574.

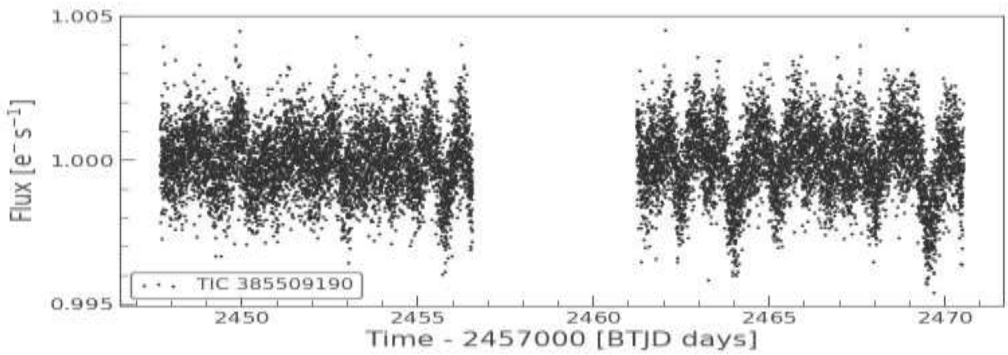

Figure 2. The flattened flux versus time of 2MASS J03445639+2425574.

As we can see, such flux curve in figure 1 is in a sinusoidal form. The reason for causing such phenomenon may due to the spots on the surface of the star and rotation of the star. To minimise the interference of the fluctuation and optimise the identification of the curve, a method named Savitzky-Golay filtering was applied to each curve to remove the low frequency trend [8]. In this function, the window length and the polyorder parameters were adjusted for each set of data to obtain the best result. The optimised figure of the example star is presented below in figure 2.

For those flux curves like pattern in figure 2 with notable change of pattern, a Box Least Squares (BLS) periodogram is further created. The light curve was converted to a periodogram that represents a power spectrum, with values of frequency on the x-axis (in any frequency units) and values of power on the y-axis (in units of flux2 / [frequency units]) [9]. This tells us some usual fluctuations existed, if there was a notable peak in the spectrum.

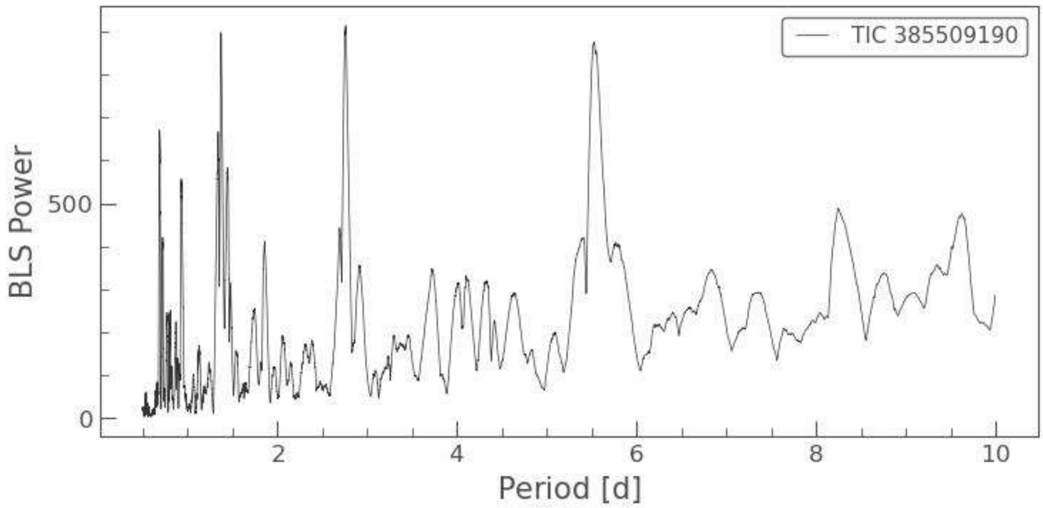

Figure 3. The BLS power versus time of 2MASS J03445639+2425574.

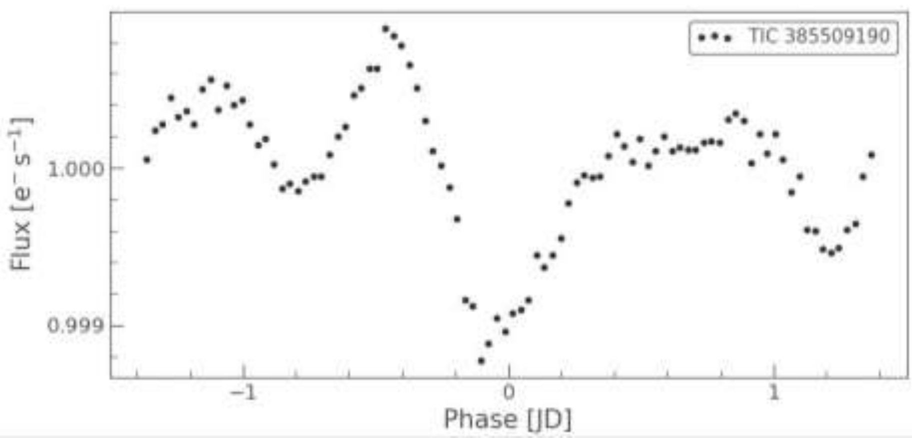

Figure 4. The folded flux versus time of 2MASS J03445639+2425574.

Here in the figure 3, the window length represents the length of the filter window and the polyorder is the order of the polynomial used to fit the samples. Some peaks are worthy noting around period 0.5d, 2.6d and 5.5d. These peaks are the potential periods with which the transits might occur. Therefore, we use BLS function to pick out the period, the transit time and duration at max power. By inserting the calculated period and transit time, we could return these results to a light curve object folded on a period

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and epoch, to observe if a more obvious trough in the curve exists. The Figure 4 below shows the returned object within the original curve.

2.3. The Target Pixel File Approach

Target Pixel Files can be considered as stacks of images, with one image for each timestamp of the data captured by the telescope. Each timestamp is referred to as a 'cadence'. These images are 'stamps' of the complete observation to make them easier to manipulate. For those curves with prominent peaks or troughs, this method can be used to visually justify the existence of transit [10]. A special discovery will be mentioned below using such method.

3. Discussion

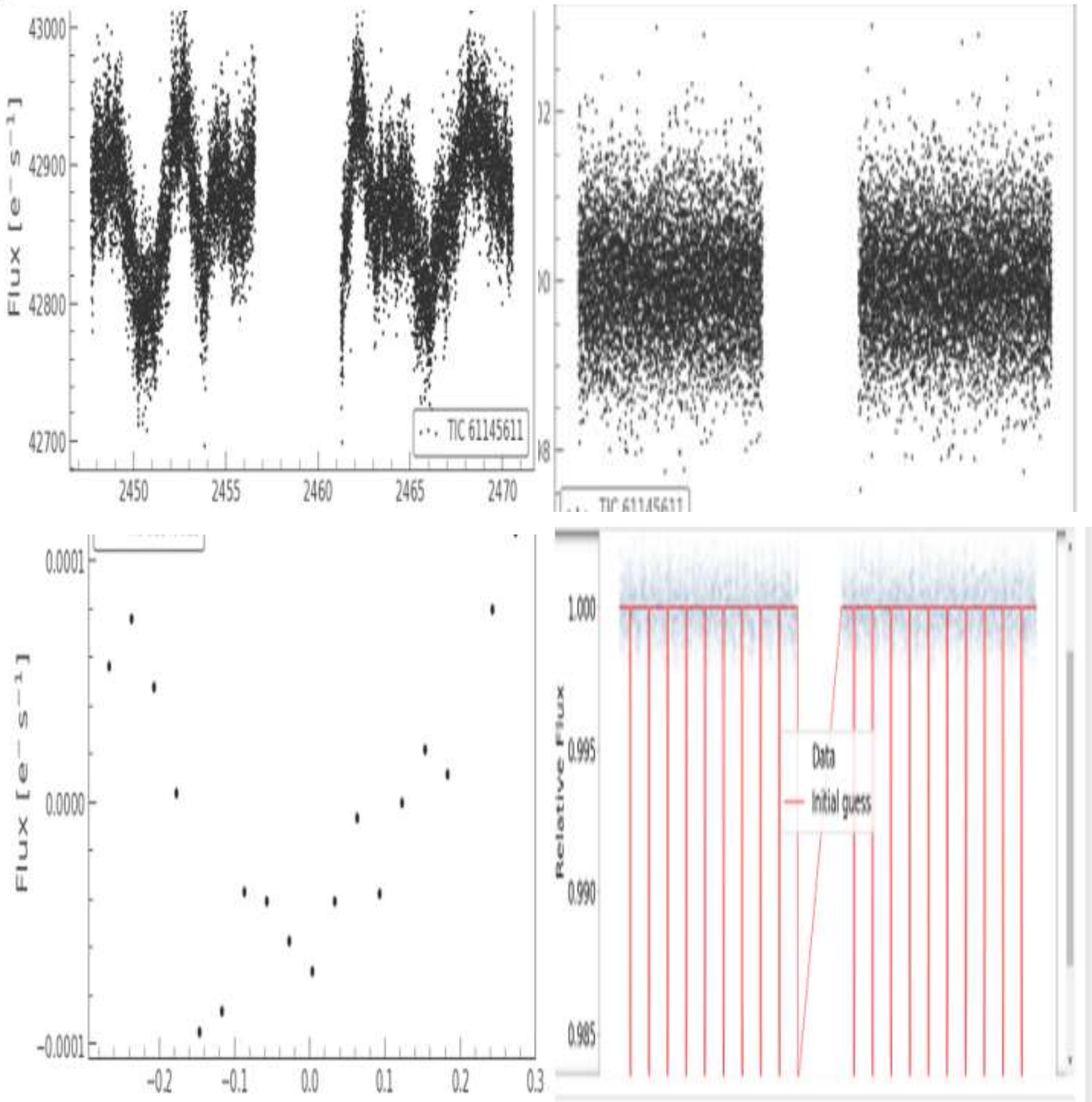

Figure 5. The flux versus time of 2MASS J03463839+2255112.

Unfortunately, clear images of planets in the data were not found. Therefore, we divided the planets into three categories based on the image shapes and calculated their best stellar radius ratio (planet radius)/(star radius) and analyzed them based on the results to prove that there are indeed no planets among them or some of the most likely conditions if there were planets. A randomly selected example will be analysed and elaborated on from each category, while the rest of the data results will be presented in the appendix. The first one is shaped like the image of sin or cos function. In the example 37, the curve becomes infinite in uncertainty after calculating the radius ratio, and also anomalies appear on top of the fitted image. Therefore, it is obvious that this is a failure case - it is almost impossible to have a transit.

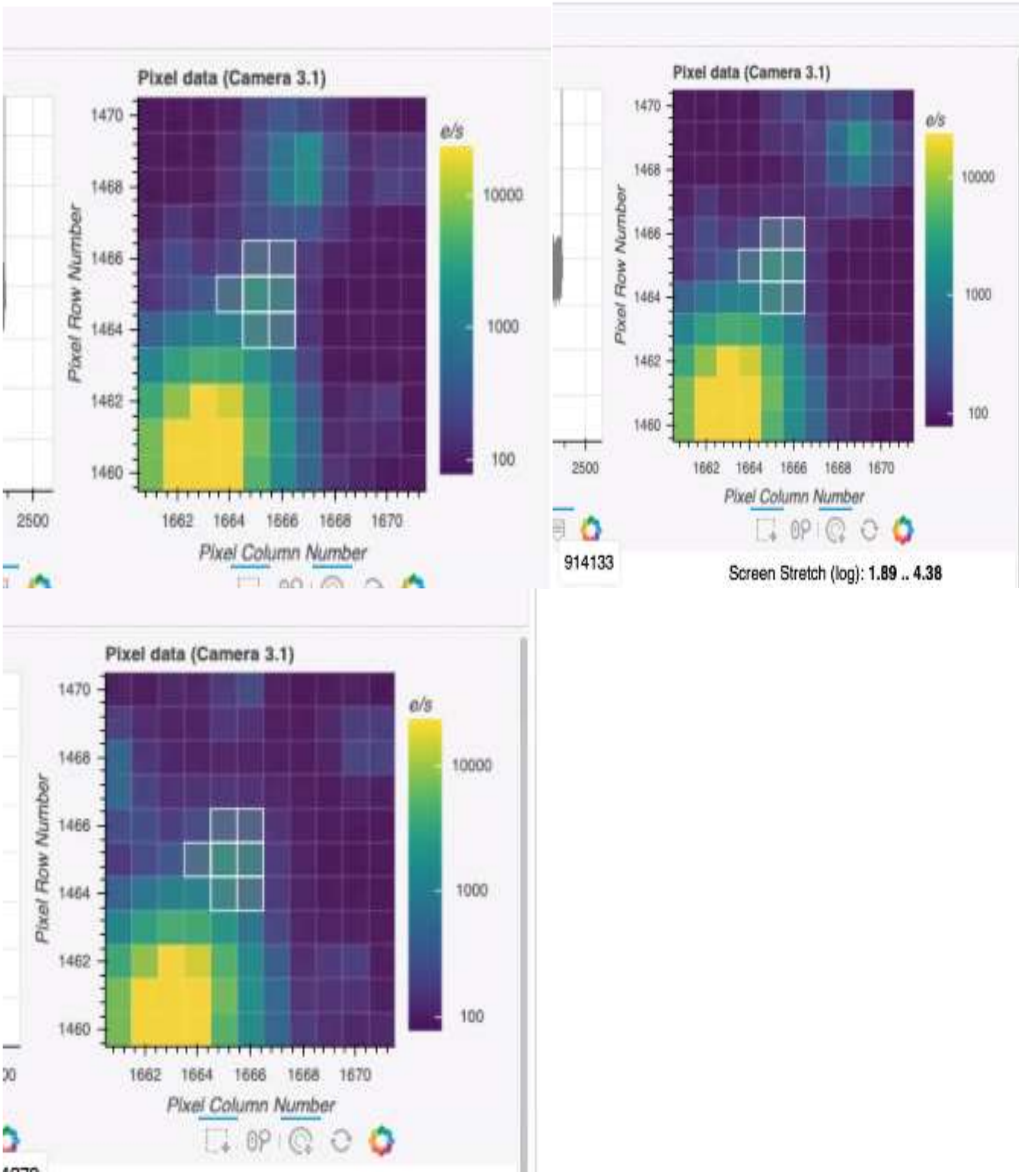

Figure 6. The target pixel file of the asteroid.

The second kind is shown on the figure 5 with flare. There are many reasons for the occurrence of flares, which may be measurement errors, or the brightness fluctuation and relative motion of stars. Next is a special example. To more clearly identify what it is, we used the search target pixel file to see it more specifically. After observation in figure 6, it can be seen that something interesting occurs-when

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the image of the time of the dip is shown. The figures showed an object moving from right to left across the image, which is an asteroid or maybe a satellite.

So, it caused the light curve of the star to be contaminated by the light from this object, which means that the light curve for this particular set of times is not credible. As a result, we cannot use this group of data for further research. The third type of image is images with no pattern. This time we choose 76 in the figure 7 - this is a nice example-its ratio plus uncertainty crosses zero and the fitted image is a better fit.

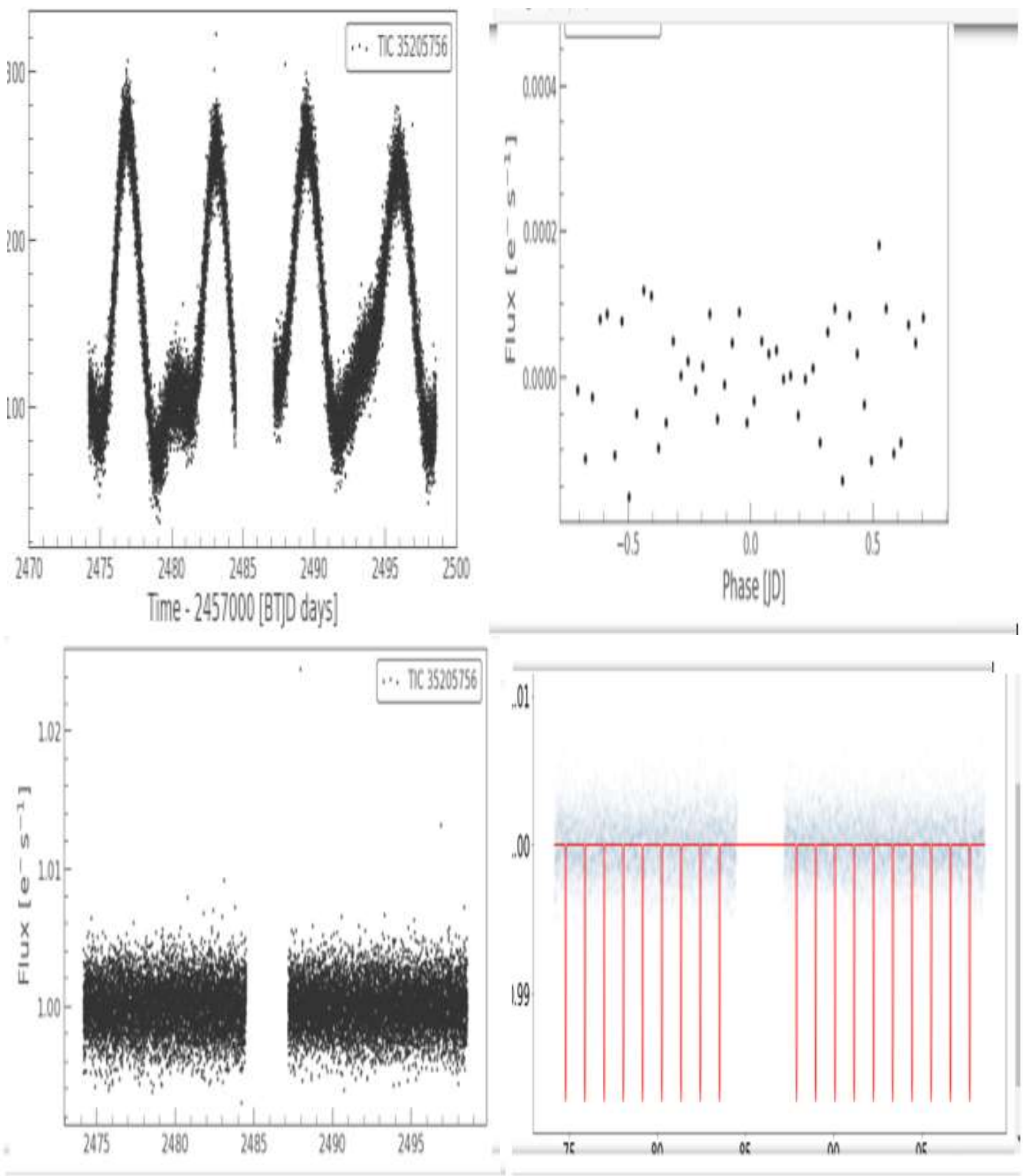

Figure 7. The flux versus time of 2MASS J03505508+2411508.

4. Conclusion

The question aimed to answer in this research is: if there are any exoplanets in the Pleiades by using the transit method. The main tool used for drawing graphs is Jupyter notebook and the data for the 83 stars are from Lightkurve package collected by TESS mission. After being roughly analyzed, no sign of transiting planet is founded by eye. During the short time research, our group split the candidate stars into four groups each checked by one member separately. Unfortunately, there is no enough time to check each other's section. As the stars in Pleiades are considerably young, they tend to move and change in a fast speed and their flux fluctuate in a short period. Thus, the BLS method is hard to apply to such kind of stars' graph as the potential transits may be erased by flattening. It is highly possible that with further process and more advanced python program to deal with the stars with tricky and weird flux graph. Overall, our group only tried to fit few candidates due to the time limit. For further research, it is suggested that other methods be used to analyse. For example, Fourier transform could be used to solve the problem of high-fluctuating stars that couldn't be flattened or analysed successfully using the BLS method. Most of the high-fluctuating stars have a sine-shaped light curve, so the Fourier transform could be very useful in analysing these stars. It is also suggested for more stars to be checked. Although this study aimed to find transits in the Pleiades, we checked only 83 stars. The Pleiades star cluster include thousands of stars, so there is still a high probability to find transits in other stars of the Pleiades. This study did not find any sign of transiting planets in the 83 stars checked of the Pleiades. However, there is one unusual case of a sudden substantial drop in flux (2MASS J03495035+2342202, sector 1). Under closer investigation, it is found to be an asteroid passing through the sky area the observed star is at, disturbing TESS's observation and the data it collected.

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Xinyue Huang, Yuhan Yan, Shuangyu Yang, and Meng Yuan contributed equally to this work and should be considered co-first authors.

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