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Using the Python Lightkurve Module to Analyse Light Curves for Beginners

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Abstract

A binary star is a star system that has been studied by astronomers around the world since the 17th century. From the beginning, binary star research used simple methods and tools. However, since the 20th century, computers and programming languages such as Python have been used to study binary stars and their light curves. The development of the Lightcurve Python module is very helpful for people and ordinary people to understand how to use the Lightcurve Analyser in an easy to understand language. There are many tutorials on how to use the Python light curve module on Youtube channels, which can be used for references such as Planet Hunters

Keywords: ***Binary Star System, Python Module, Lightkurve***

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A. Introduction

A light curve is a graph showing fluctuations in light as a function of time [1]. Fluctuations in the light curve are caused by an object blocking the light source (star) behind it. The object can be another star (a binary star) or a planet [2].

Light curve observations use the astronomical method of photometry, which measures the intensity of light over a range of the spectrum, such as visual, UV and other wavelengths. Photometric methods can be implemented and installed on several space missions, such as the Kepler satellite, COROT[3]and, most recently, the Transiting Exoplanet Survey Satellite (TESS) mission. TESS was launched in 2018 and its main mission is to detect planets outside the Solar System by observing light curves using the transit method.

A binary star is a system of two or more stars that are bound together by gravitational interactions so that the two stars orbit each other. In general, binary systems are divided into three types, which are visual (visually close but with a considerable separation distance, such as the star Sirius, which has an orbital period of 50 years), spectroscopic (there is a Doppler shift in the spectrum) and double eclipsing.

Python is a programming language widely used by researchers in many different fields. Python has several modules that can support astronomical research activities, such as spectrum processing with the *specutils* module or light curve processing with the *lightkurve*module[4].The *lightkurve* module can perform basic light curve analysis in a clear and detailed manner, so that even beginners can use it.

In this paper, the author will describe how to use the Python lightkurve module for basic light curve analysis. It is hoped that this paper can serve as a first reference for using the module to analyse the light curves of binary systems or stars with planetary systems outside the solar system.

B. Methods

The objects used are binary star systems that can be found in the Binary Star Database or in various databases such as SIMBAD[5]. The author uses the specific object of a Be double star system, which is a double star that has an emission profile in its spectrum. Some of these systems can be found in Kogure and Leung . In this journal we have chosen one of these objects, HD 174638, known as Beta Lyrae.

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C. Resultsand Discussion

Results

Before we can use this module, we must first install it in our Python directory using the command:

pip install lightkurve

This command will install the lightkurve module on our Python system so that we can use it.After the installation, we can search if our object has a light curve in *The Barbara A. Mikulski Archive for Space Telescopes* (MAST) database archive, which is a built-in function of the *lighkurve* module, using the command:

import lightkurve as lk;

lc=lk.search_lightcurve('HD 174638')

SearchResult containing 21 data products.

#	mission	year	author	exptime	target_name	distance
				s		arcsec
0	TESS Sector 14	2019	SPOC	120	28569279	0.0
1	TESS Sector 14	2019	TESS-SPOC	1800	28569279	0.0
2	TESS Sector 14	2019	QLP	1800	28569279	0.0
3	TESS Sector 14	2019	TASOC	120	28569279	0.0
4	TESS Sector 14	2019	TASOC	1800	28569279	0.0
5	TESS Sector 14	2019	TASOC	1800	28569279	0.0
6	TESS Sector 26	2020	SPOC	120	28569279	0.0
7	TESS Sector 26	2020	TESS-SPOC	1800	28569279	0.0
8	TESS Sector 26	2020	QLP	1800	28569279	0.0
9	TESS Sector 26	2020	TASOC	120	28569279	0.0
10	TESS Sector 26	2020	TASOC	1800	28569279	0.0
11	TESS Sector 26	2020	TASOC	1800	28569279	0.0
12	TESS Sector 40	2021	SPOC	120	28569279	0.0
13	TESS Sector 40	2021	TESS-SPOC	600	28569279	0.0
14	TESS Sector 40	2021	QLP	600	28569279	0.0
15	TESS Sector 53	2022	SPOC	120	28569279	0.0
16	TESS Sector 53	2022	TESS-SPOC	600	28569279	0.0
17	TESS Sector 53	2022	QLP	600	28569279	0.0
18	TESS Sector 54	2022	SPOC	120	28569279	0.0
19	TESS Sector 54	2022	TESS-SPOC	600	28569279	0.0
20	TESS Sector 54	2022	QLP	600	28569279	0.0

Figure1. Object Searching

The import command is a command to import the lighkurve module into our workspace as 'lk'. lc' is a new variable that we can create at any point. To view the search

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results, we simply create a command:

lc =lk.search_lightcurve('HD 174638')

Figure 1 shows a description of the TESS mission data and its sector, year, author (mission name), exposure time (in seconds), object name and distance (in arc seconds). Sectors are the parts of the sky around the ecliptic that TESS observes, with a sector area of 24° x 96°. For example, if we only need 1 sector (e.g. sector 54) and the author name is TESS-SPOC, the command would be

lc=lk.search_lightcurve('HD 174638', sector=54, author='TESS-SPOC')

The search result shows only 1 table. To download and plot the data, we can use the command:

BetaLyr=lc.download()

BetaLyr.plot()

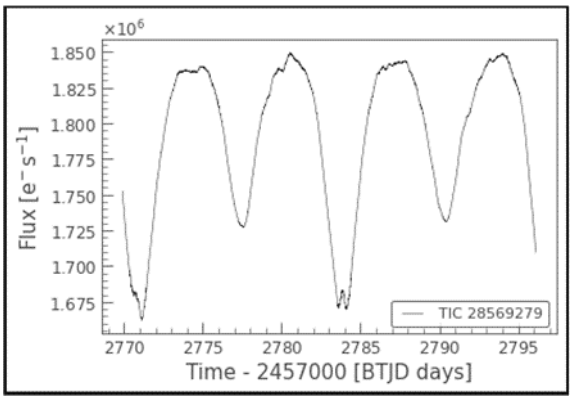

Figure 2. Beta Lyra light curve in sector 54 in 2022

Figure 2 shows a light curve with flux in electrons/second and time in days. To make the flux values easier to understand, we can normalise the values and plot them using the command:

BetaLyr=lc.download().normalize()

BetaLyr.plot()

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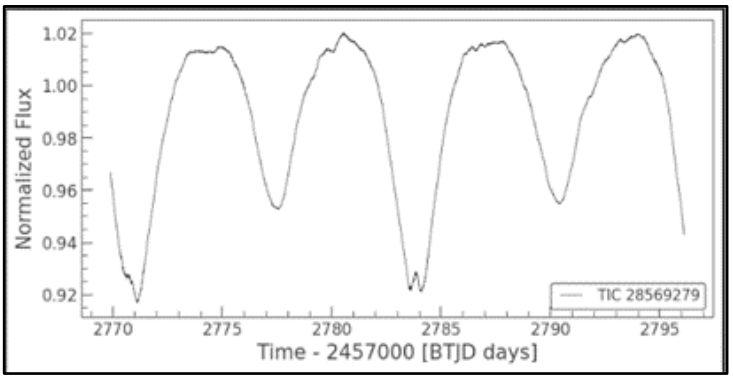

Figure 3. Normalisation of Beta Lyra Light Curve

Once we have our preferred light curve, we can proceed to find the period of the system, which is the period of evolution of the components relative to each other. Figure 3 shows normalisation of Beta Lyra Light Curve.Manually, we can determine the period by using the time difference between the brighter component and the fainter component (the smallest flux value), but this method is very time-consuming if our object has a non-uniform period due to various reasons, such as the deformation of the stellar surface (the shape of the star is not perfectly spherical) or the presence of a 'hidden' light source called the third component.

Therefore, to determine the period, we create a periodogram using the concept of Fourier transform. This concept simply transforms a function of intensity over time F(t) into power over frequency. This transformation makes it easy to understand how much a star oscillates (for a binary system this can be called its evolutionary period).The commands used to create periodograms and plots are:

```
perio=BetaLyr.to_periodogram(maximum_frequency=6)
perio.plot()
```

In the perio command we limit the processed frequency to 6 1/day so that we can clearly see where the maximum frequency is. The maximum frequency is the frequency at which the amplitude (power) is greatest. As can be seen in Figure 4, the maximum frequency is 0.1526 1/d or 6.5538 days. The maximum frequency can also be said to be half the oscillation (evolution of a binary), so we can know that the evolution period of the Beta Lyr

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system is 13.1076 days.

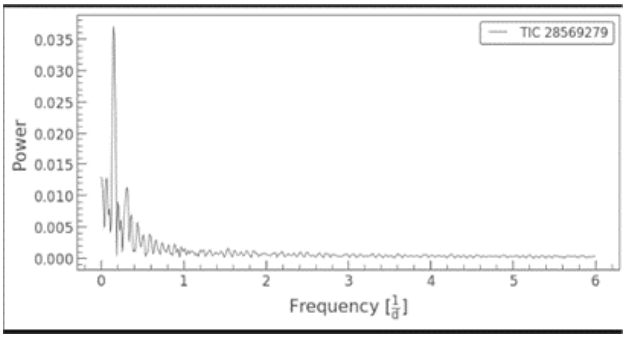

Figure 4. Periodogram Beta Lyra

Next, we can plot the orbital phase. In simple terms, this process 'overwrites' the flux at each point in time, and the result of the overwriting is determined as the mean value as the new flux value (y-axis). The x-axis of the orbital phase graph has values between 0 and 1, where 0 and 1 represent the phase of the primary eclipse (brighter components are obscured by fainter components) and 0.5 represents the phase of the secondary eclipse. The 0 -1 phase represents the length of one orbital period.

Disscussion

In the *lightkurve* module, the 'fold' command is used to create the orbital phase curve. This command consists of several important data entries, such as:

1. period: time period of the system
2. epoch_time: A reference time that indicates when phase 0 begins. It can be obtained from a reference or from data
3. normalize_phase: It normalises the finite phase to the form 0 and 1. The *True* means that this is possible in Python

The commands that can be input in the Python module are

fold=BetaLyr.fold(period=2*perio.period_at_max_power, epoch_time=2784).scatter()

‘.scatter()’, pada akhir python m

The .scatter() in the Python command above is to display the graph in the form of a ‘.’.

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The command perio.period_at_max_power is the strongest power value in the periodogram. epoch_time is taken at the time of the primary eclipse. The result of the folding is shown in Figure 5.

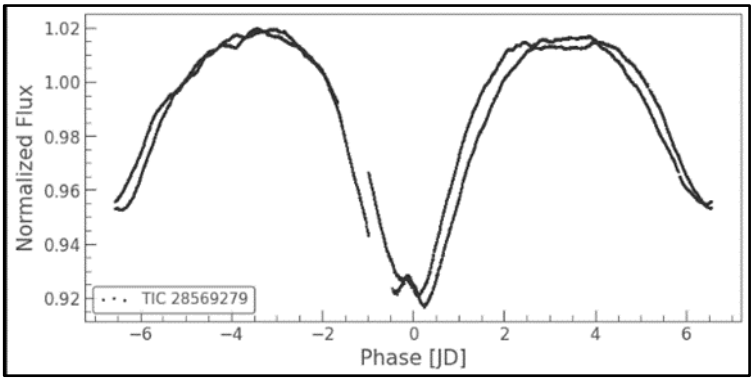

Figure 5. Orbit phase

Figure 5 shows the orbital phase of Beta Lyr in Julian Date (JD). Julian Date is a solar-based calendar that began during the reign of Emperor Julius, starting around 46 BC[6], yang mana antara -6 dan 6 setara dengan 1 periode. where -6 to 6 equals 1 period. As for the fold command, we can add by normalising so that the graph becomes:

```
fold=BetaLyr.fold(period=2*perio.period_at_max_power, epoch_time=2784,
normalize_phase=True).scatter()
```

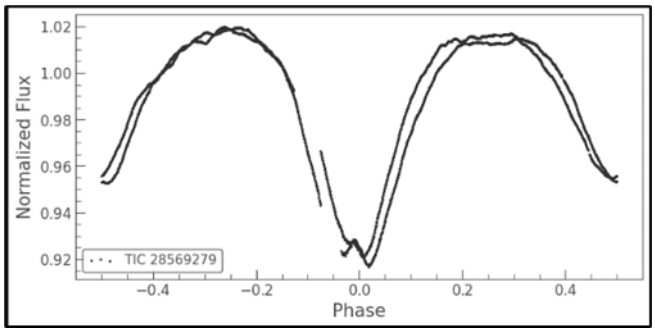

Figure 6. Normalised Orbit Phase Result

Figure 6 shows the normalised orbit phase result. To save the values of the above data in .csv or .xlsx format, the fold command must remove normalised_phase and .scatter. The commands are:

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```
fold=BetaLyr.fold(period=2*perio.period_at_max_power,
epoch_time=2784).to_excel('BetLy.xlsx')
```

The purpose is to allow the data to be further processed, for example using data processing applications (e.g. Excel), Matlab or other analysis programs.

D. Conclusion

The Python *lightkurve* module makes it easy to analyse light curves. Lighkurve has several commands that can help to analyse light curves, such as 'fold', 'periodogram' and 'seismology'. The 'seismology' command is used for pulsar-like or sun-like objects (similar mass, spectral class).

The use of the light curve module can be combined with other programs to maximise light curve research. Understanding the use of the Lightcurve module and the mechanics of lightcurves can also be aided by tutorials available on the internet, such as Planet Hunters.

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