NSSC 2021

Data Analytics

Identification and Analysis of Transiting Exoplanet Signals

Overview

The fact that our earth is the only life-sustaining orb and the solar system is the only planetary system in this vast universe seemed skeptical to many. Philosophers hypothesized centuries ago that our solar system was not unique, and with the discovery of the first extrasolar planet orbiting a pulsar, time proved that they were right. Ever since then, exoplanet exploration has entered into a science-rich area of characterization, in which detailed information about individual planets can be inferred from observation beyond mere detection.

Though there are various methods to confirm the existence of alien worlds, the most widely used and effective one to date is Transit Photometry, a technique that looks for the periodic dip in the light curve of a star to trace out transiting worlds. Not only does this method help in detecting planets, but it also helps in estimating the planetary parameters when combined with the radial velocity method. With the launch of Kepler, TESS, and other space telescopes that hunt for transiting exoplanets, we are in possession of thousands of light curves, which can be visualized and analyzed using various computer programming algorithms to dig out fascinating worlds.
National Students Space Challenge 2021 is providing you an opportunity to blend your programming and data skills with astronomy to delve into photometric data and work out some intriguing questions in the world of possibilities in exoplanets.

Instructions

- This is the problem statement for the event Data Analytics.
- The problem statement consists of 4 questions related to transit photometry of exoplanets and each of them needs to be attended sequentially.
- The weightage of each question is stated along with it.
- The definitions for the underlined terms in the problem statements can be found in the attached document Dictionary
- For more information about transit photometry and asteroseismology, candidates can refer to the following documents : Transit Photometry Asteroseismology
- Participants are free to choose any programming language, environment, method, and library. [However, it is preferable to use Google Colab, Jupyter Notebook, etc. as the programming environment]
- For submission, each team needs to **create a report in the form of a single PDF**. The report should detail the approach as well as solutions. All the plots and the outputs need to be shown in the report along with proper explanations and descriptions, the final answers should be highlighted.
- All the code snippets should also be attached to the report. The snippets should be well commented on and should convey a clear idea of their working.

Problem Statement

(20 marks) (4+4+4+8)

1. Plotting and Analysis of noisy transit signals:

In order to analyze a transit signal, it's important to convert the optical data obtained from a telescope into a light curve(a graphical data which is the variation of flux with time) so as to find out if there is a dip in brightness. Since a telescope observes a part of the sky at a time, it is obvious that the observed light curve of a particular star contains many undesired signals(like nearby stars' flux, dark current, readout noise, etc) called noise, which reduces the probability of finding accurate transit signals. So, to correctly trace out the transit signal it is necessary to convert the optical data into a light curve and modify it. Various advanced libraries, available in programming languages like Python aid scientists and astronomers to do these tasks.

In this module, you are asked to plot, modify and analyze the light curve of Kepler-17, a G-type star with one identified exoplanet named Kepler-17 b. TESS Input Catalog(TIC) ID, and Kepler Input Catalog(KIC) ID, of Kepler-17, is given below:

TIC ID: TIC 273874849

KIC ID: KIC 10619192

(4 marks)

(a) Search and download all the light curve data of the star Kepler-17. For downloading the light curve you can follow the method shown in the link or you can use any other site. You are free to use ‘lightkurve’ or any other python library

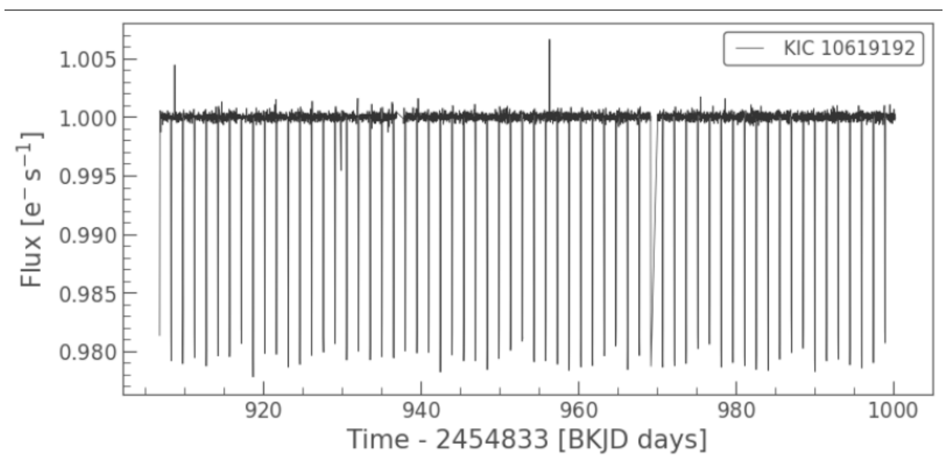
(4 marks)

(b) Obtain the best-suited light curve and plot it. While plotting, it should be kept in mind that Kepler data are recorded in different quarters at different cadences. The participants are expected to try out data from different cadence and quarters to find the best possible result.

(4 marks)

(c) Modify the above-plotted graph by normalizing it. Plot the modified graph and show it. (You need to take all the outliers and NAN-values)

The final lightcurve might look something like this:



(8 marks)

(d) After plotting, estimate the following information about the light curve:

I. Mean of the flux

II. The standard deviation of the flux

III. Combined Differential Photometric Precision (CDPP)(refer to the dictionary to understand what is CDPP)

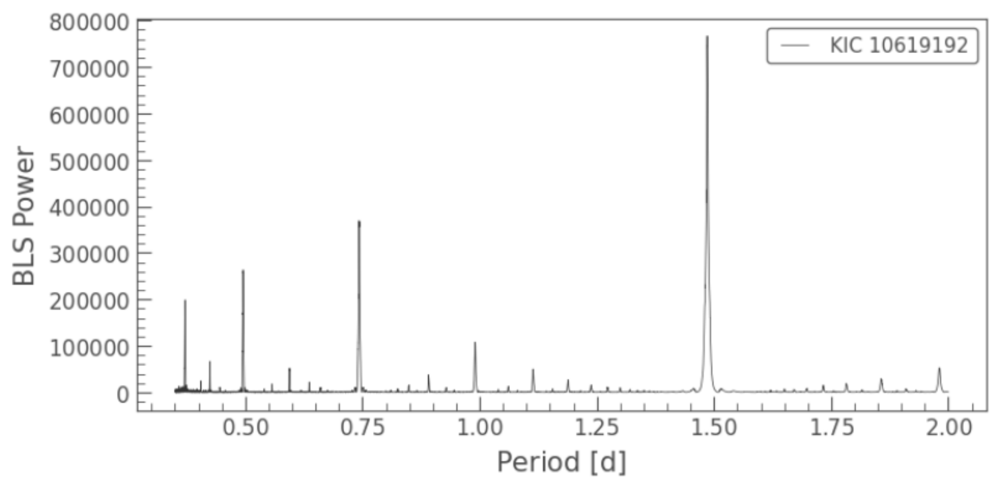
2. Transit Signal Detection and Analysis: 35 marks (6+7+10+10+2)

Due to background noise and feeble dip in brightness produced by a planet, detecting a transit signal from the normalized light curve is still difficult. So to trace out the transit signal, the normalized plot needs to be modified in such a way that the dip in brightness becomes more visible and the noise gets reduced. <u>Box Least Square periodogram</u> along with various functions like <u>folding</u>, <u>binning</u>, etc can be used for this task.

(6 marks)

(a) Plot and show the Box Least Square (BLS) periodogram of the modified light curve obtained in question 1(c).

The periodogram might look something like this.



(7 marks)

(b) Using this BLS periodogram, find the following parameters:

(i) Transit duration

(ii) The time period of revolution

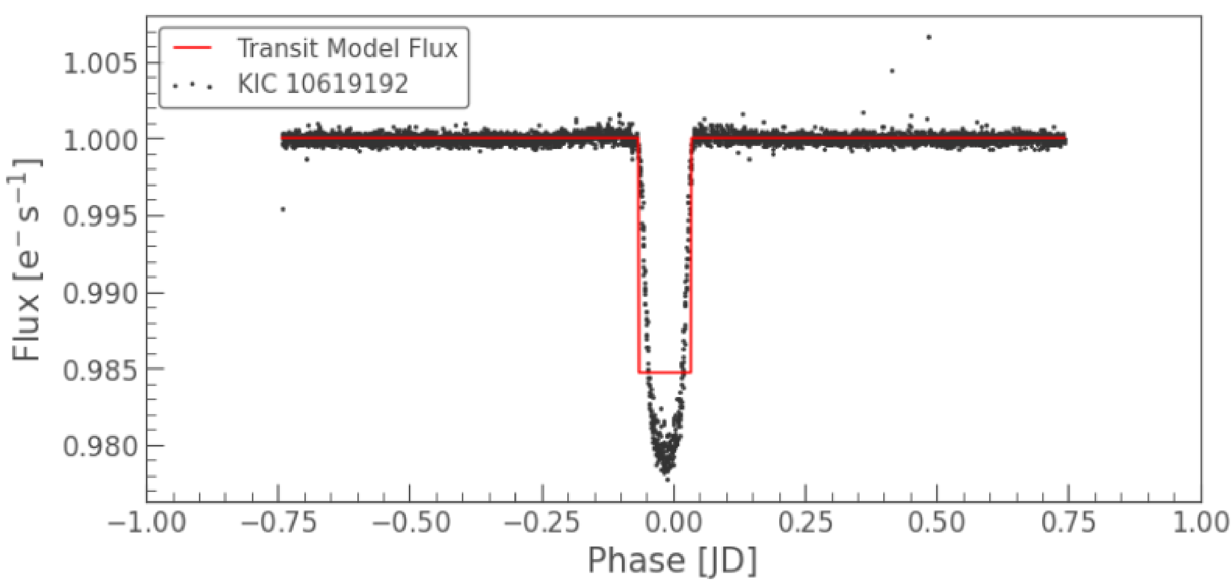
(10 marks)

(c) Verify the transit by phase folding the modified light curve in question 1(c) at the transit time. Also, plot the phase folded light curve and show it.

(10 marks)

(d) Make a model curve of the transit by plotting a best-fit curve through the folded data points. Plot the model curve and phase folded curve in a single plot.

The final plot should look like the following:



(2 marks)

(e) From the created model, estimate the relative flux dip (ΔF/F) where F is the base flux of the star and ΔF is the change in flux during transit.

3. Estimation of Stellar Parameters using Asteroseismology: Stellar properties, in particular, stellar mass and stellar radius are essential for measuring the properties of exoplanets. One of the interesting and transparent ways to obtain the stellar properties for stars exhibiting solar-like oscillation is by a method called asteroseismology, which uses the frequency spectra of the star to estimate its parameters. [Note: You can find more information about asteroseismology and the terms mentioned in the question here: Asteroseismology]

(30 marks) (2+2+5+7+8+4+2)

(a) Search, download and plot short cadence light curves for quarters 2,5,6,7 of the star 'Kepler-21'(KIC ID- KIC 3662418 and TIC ID- TIC 121214185). [Note: you can use any of the methods mentioned in question 1(a) to obtain the lightcurve data for the given star]. (2 marks)

(b) Since all light curves are of different offsets, stitch, normalize and remove the long-term trends from the curve. Plot this normalized light curve and show it. (2 marks)

(c) Plot the periodogram (i.e. convert the light curve into frequency domain) and show it. [Note: keep the view type as log so that larger data can fit into the plot] (5 marks)

(d) Identify the region of Power excess power on the periodogram and plot the zoomed-in version of the periodogram around the frequency of power excess and smoothen the periodogram. Show the final plot of the zoomed-in version of the periodogram. (7 marks)

(e) The distribution of the frequencies in the periodogram follows a Gaussian distribution. Draw the best fit Gaussian curve enveloping the periodogram. Show the periodogram along with the Gaussian envelope.

(8 marks)

(f) From the Given periodogram find the numax and deltamax. (4 marks)

(g) Now using this information about numax and deltamax figure out the following information about the star. (2 marks)

I. The radius of the star.

II. The Mass of the star.

All the relevant information for figuring out the radius and mass is given in the Asteroseismology document.

4. Estimation of Planet Parameters from Transit Data:

The most important step after finding out a new world is to estimate its physical parameters. Only with the help of this, further analysis and study of the planet can be possible. Exoplanets discovered by or followed up with radial velocity measurements, which also transit their parent star, hold a special place in research, as for such planets we will have their masses measured (or estimated) and, along with their radius, yield a mean density value allowing further characterization of them.

(15 marks) (4+5+6)

(a) Estimate the radius of the planet Kepler-17 b, if the radius of Kepler-17 is 1.01 solar radius. (4 marks)

[All the necessary information is already calculated by you in parts 1 and 2, and all the necessary theory is present in the transit document provided.]

(b) Assuming that the orbit is circular, estimate the radius of the planet's orbit if the stellar mass is 1.04 solar mass.

(5 marks)

(c) Find out the mass of the planet if stellar velocity is 0.228 km/s(Apply angular momentum conservation). Hence determine the density of the planet. Under what category of exoplanets will it come? (6 marks)

SUBMISSION RULES:

Submit your final document via the google form https://forms.gle/DtPNWQ9DbnouosSM8 ,it should contain plots and a short explanation of each plot and the method used to obtain it. Also, add commented code snippets in your document.

JUDGING CRITERIA:

Participants will be awarded based on the accuracy of the plots and the explanation of their method and code snippets. Full score will be awarded if the results and the thought process are right. A partial score will be awarded for the correct approach in case the results are wrong.