TIC 158794976 Stellar Characterization

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1 Introduction

Eclipsing Binary (EB) systems are tremendously important for determining the stellar parameters. These systems consists two, or even more stars revolving around their Center Of Mass.This gives rise to the periodic eclipses which can give insights about the stellar parameters of the system, such as Mass, Temperature, Orbital period, Luminosity, its distance from Solar System, etc. Amongst the Detached (DBS),Semi Detached (SDBS) and Contact binary Systems(CBS), the DBS offer distinct primary and secondary eclipse patterns which enable us to predict the stellar parameters with great accuracy.

One such system is KIC 7023917 (GSC 03129- 01771, TYC 3129-1771-1, TIC 158794976, Gaia DR3 2102332172948222976). This object was studied by [1] and the parameters were found out with minimal error using standard sophisticated methods. We aim to recreate the results, but using various approximations as discussed below.

2 Data Acquisition

The Transiting Exoplanet Survey Satellite (TESS) data was used for finding the eclipse patterns. The LIGHTKURVE package [2] was used to extract Lightcurves (LC's) from the TESS data. The TESS sector having a properly recorded LC pattern was chosen for this purpose.

The Radial Velocity (RV) data was taken from [1], recorded using 2 meter Perek telescope. The Mass ratio and inclination values for the system were also referred from [1]. The Distance and Magnitude data was taken from the [3] for the purpose of comparison with obtained values.

3 Stellar Parameter Prediction

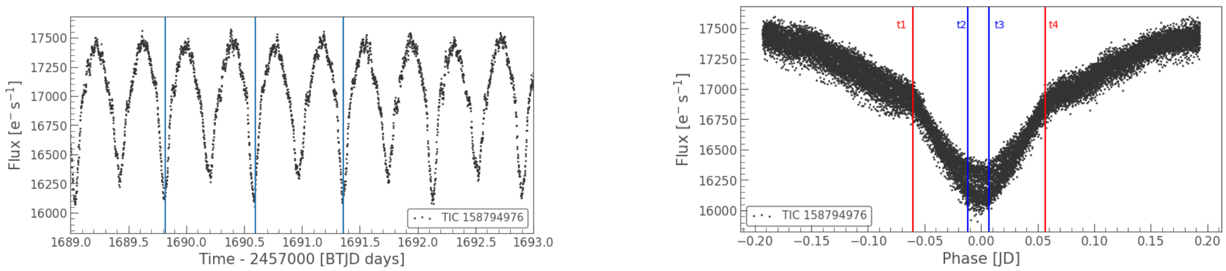
3.1 Orbital Period

Using the LC from the Sector 14, the primary and secondary eclipses were observed and the characteristics such as their depth and duration were used to predict the orbital period. The period of complete overlap of the two bodies was found to be 1264 seconds and that of partial overlap was 7783 seconds. The inbuilt Box Least Square function in [2] was used for this purpose. It predicted the most likely eclipse position in the LC and formed a phased light curve by wrapping this time series data around the corresponding period. The eclipse pattern and the partial and complete overlap durations are shown in figure 1

3.2 Semi-Major Axis of the system

The Semi-Major axis length was found using the relation:

$$a = \frac{K_1 P(q+1)}{2\pi q \sin i}$$



(a) The primary and secondary eclipse patterns

(b) Eclipse after Phase folding

Figure 1:

where i is the inclination of the system with respect to the observer on Earth and q is the Mass ratio of the light star to the heavy star. The calculated value was found to be $4.5106753 R_{\odot}$ as compared to the $4.189 R_{\odot}$ by [1]

3.3 Semi-Amplitude of RV

The RV measurements by [1] were used and RV curve was plotted. Instead of modelling the RV curve by J.B. Irwin model used in [1], a simple mean of the maximum and minimum amplitude data points was taken as an approximation. The Semi amplitude of RV curve was found to be 24.015 km/s , as compared to 22.28 ± 2.71 km/s calculated by [1] (See figure 2)

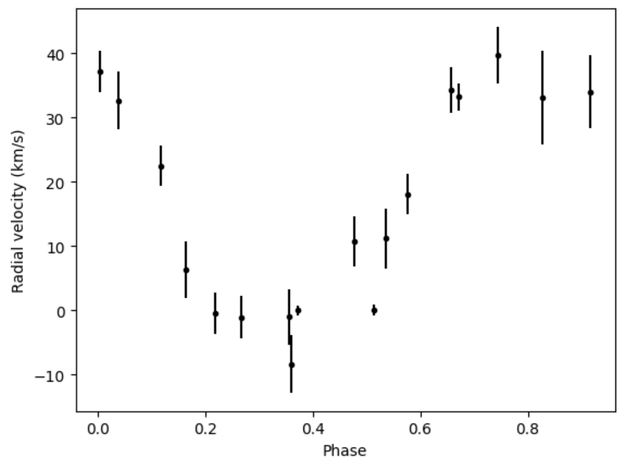


Figure 2: RV curve using the observations in [1]

3.4 Combined Mass

According to Kepler's third law, the relation between period of the orbit and the combined mass is:

$$P^2 = \frac{4\pi^2 a^3}{G(m_1 + m_2)}$$

Rearranging this equation, we get:

$$(m_1 + m_2) = \frac{4\pi^2 a^3}{GP^2}$$

The calculated value of the combined mass of the system was $2.07696832 M_\odot$ as compared to the value $2M_\odot$ predicted by [1]

3.5 Temperature Ratio

The Stellar Temperature is usually found by the spectroscopic analysis, by analyzing the chemical composition of the surface, etc. But here we approximate the Star as an ideal blackbody and check whether the results come out to be in agreement with the actual spectroscopic values. By Stefan's law, the power radiated by the star is proportional to the fourth power of its temperature. So for a binary system consisting of two stars A and B:

$$B_{\text{Total}} = 4\pi R_A^2 \sigma T_A^4 + 4\pi R_B^2 \sigma T_B^4$$

As the smaller star gets completely shadowed as viewed from our line of sight:

$$B_{\text{Secondary}} = 4\pi R_A^2 \sigma T_A^4$$

When the smaller star is in front of the bigger star:

$$B_{\text{Primary}} = 4\pi (R_A^2 - R_B^2) \sigma T_A^4 + 4\pi R_B^2 \sigma T_B^4$$

Therefore,

$$B_{\text{Total}} - B_{\text{Primary}} = 4\pi R_B^2 \sigma T_A^4$$

$$B_{\text{Total}} - B_{\text{Secondary}} = 4\pi R_B^2 \sigma T_B^4$$

So,

$$\frac{B_{\text{Total}} - B_{\text{Primary}}}{B_{\text{Total}} - B_{\text{Secondary}}} = \frac{T_A^4}{T_B^4}$$

This Left hand side ratio is nothing but the ratio of depths of primary and secondary eclipses that we found earlier.

3.6 Luminosity

Using the blackbody approximation again, Total Luminosity of the system is nothing but the energy emitted by it and will be given as:

$$L = 4\pi R_A^2 \sigma T_A^4 + 4\pi R_B^2 \sigma T_B^4$$

3.7 Absolute Magnitude

Absolute magnitude can be helpful for the determination of distance. According to the relation:

$$m_2 - m_1 = -2.5 \log_{10} \left(\frac{L_1}{L_2} \right)$$

where

$$m_1, m_2 = \text{Apparent magnitudes of the two objects}$$

$$L_1, L_2 = \text{Luminosities of the two objects}$$

The Right Hand Side ratio can determined from the previous step and the absolute magnitude for Sun is taken to be 4.83, which enables us to find the absolute magnitude of the system.

3.8 Distance

We can determine distance of the system from sun using the relation:

$$m - M = 5\log_{10} d - 5$$

where

$$m = \text{Apparent magnitude of the object}$$

$$M = \text{Absolute magnitude of the object}$$

$$d = \text{distance of the object}$$

The distance found using this method comes out to be 442.1062 parsec, whereas the [3] distance is 432.46 parsec.

4 Discussion and Conclusion

The values of stellar parameters without the use of approximations as in [1] certainly differ from those using the approximations. The error margins developed from the approximations are listed in the table below:

Stellar Parameter	Values as per [1]	Values as per this project	% Error
Semi-Major Axis ($R_\odot$)	4.189	4.5106753	7.68
Semi-Amplitude Velocity(Km/s)	22.28	24.015	7.787
Combined Mass ($M_\odot$)	2	2.0769	3.845
Temperature Ratio	1.16378	1.035	11.06566
Luminosity ($L_\odot$)	14.4	14.8536	3.15
Distance (Parsec)	432.46	442.106217	2.230545

Table 1: Errors in parameter calculation of this project

It is therefore observed that the Temperature estimation, which was done using the approximation of considering Stars to be ideal Blackbodies, results in 11 % error. This shows why the initial predictions in Astronomy using the same approximations were not as accurate as the Temperatures determined by spectroscopic methods.

Even though the distance error is the minimum amongst the rest, the difference is still 10 Parsecs, nearly 32 lightyears. This might be caused because of the absorption of incoming light from the binary system being absorbed by dust clouds, resulting in false Absolute and Apparent magnitudes, in turn affecting the distance measurements. These fluctuations might have been considered in the Spectroscopic model used in [1], but not in this project.

Therefore, this project recreated the entire analysis of TIC 158794976 Eclipsing Binary carried out by [1], except the Pulsation study. We found that Physical approximations can be used to predict near-accurate values of Stellar Parameters, within the maximum error of 11 % and minimum 2.2 %. We also found that the Temperature predictions using Stefan's law are not very accurate for the system and it is mandatory to use more sophisticated methods such as Spectroscopic models used in modern astronomy.

References

[1] P. Gajdoš, Š. Parimucha, M. Skarka, M. Kamenec, J. Lipták, and R. Karjalainen, "Analysis of KIC 7023917: Spotted Low-mass Ratio Eclipsing Binary with δ Scuti Pulsations," , vol. 168, p. 171, Oct. 2024.

[2] Lightkurve Collaboration, J. V. d. M. Cardoso, C. Hedges, M. Gully-Santiago, N. Saunders, A. M. Cody, T. Barclay, O. Hall, S. Sagear, E. Turtelboom, J. Zhang, A. Tzanidakis, K. Mighell, J. Coughlin, K. Bell, Z. Berta-Thompson, P. Williams, J. Dotson, and G. Barentsen, "Lightkurve: Kepler and TESS time series analysis in Python." Astrophysics Source Code Library, record ascl:1812.013, Dec. 2018.

[3] A. Vallenari, A. G. Brown, T. Prusti, J. H. De Bruijne, F. Arenou, C. Babusiaux, M. Biermann, O. L. Creevey, C. Ducourant, D. W. Evans, *et al.*, "Gaia data release 3-summary of the content and survey properties," *Astronomy & Astrophysics*, vol. 674, p. A1, 2023.