MASARYKOVA UNIVERZITA
Přírodovědecká fakulta
Ústav teoretické fyziky a astrofyziky

Bakalářská práce

Brno 2025 Miroslav Almáši

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Studium takřka dotykové těsné dvojhvězdy

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Vedoucí práce: doc. RNDr. Miloslav Zejda, Ph.D. **Brno 2025**

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Abstrakt

V tejto bakalárskej práci sa venujem štúdiu takmer dotykovej tesnej dvojhviezde WZ Cep a jej periốde. Pomocou dát z TESS a novo získaných pozorovaní dát som nafitoval parametre svetelných kriviek. Tieto parametre boli získané z rôznych zdrojov. Následne pomocou získanej periódy som vytvoril O-C diagram časov miním. Mojou úlohou bolo pridať nové okamihy míním z TESS a napozorovaných dát. Následne porovnať priebeh zmeny periódy zo starších a novších dát.

Abstract

In this thesis I study near contact binary star WZ Cep and its period. With the help of TESS data and newly observed data I fitted parameters of light curves. These parameters are from different sources. Next, I constructed O-C diagram of times of minima. My task was to add new times of minima on O-C diagram. After that compare the period changes in old data and new data.

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Ředitel *ústavu* PřF MU Vám ve smyslu Studijního a zkušebního řádu MU určuje bakalářskou práci s názvem:

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Student by měl získat vlastní fotometrické pozorování vybrané takřka dotykové soustavy, provést jeho zpracování. S využitím dostupných dat z fotometrických přehlídek by dále měl určit aktuální hodnotu periody světelných změn a její případné změny v historii a spočítat základní model dvojhvězdy s využitím dostupných programů.

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HILDITCH, Ronald W. *An introduction to close binary stars*. Cambridge: Cambridge University Press, 2001, x, 381. ISBN 0521798000.

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Prohlášení

Prohlašuji, že jsem svoji bakalářskou práci vypracoval samostatně pod vedením vedoucího práce s využitím informačních zdrojů, které jsou v práci citovány.

Brno 13. květen 2025

. . . .

Miroslav Almáši

Contents

Introduction

When the human eye looked into the sky for the first time, we saw lights, lights whose importance we did not understand. As time went on, we found that these lights, now called stars, are practically the same as our Sun, which is making our world habitable. But lots of these stars were changing their brightness, which is not observable on the Sun, at least not to that extent. What is happening to these stars? Well, that is what started the whole branch of astronomy and astrophysics. Astrophysicists who were interested in this branch found that there is no easy, a few-word answer. They found that there is more then one way how a star can change its brightness. From those that change their brightness directly to those whose flow is affected by another object. From those that are changing periodically to those that are aperiodic. All of these stars change our view of the world. Variable stars are, in general, a very interesting topic. There are lots of types of them. Astrophysicists study these stars as they ”tell” us about the space around us, more than just a classic one-star system with a star, whose brightness does not change.

One type of these stars are called a binary stars. These are not easy-to-solve systems, but not too hard to be unsolvable. Therefore, these stars are ideal to start with, if we want to get into a world of variable stars.

Chapter 1

Binary stars

We define a binary star system as two stars bound by gravitational forces. These two stars orbit each other; to be more specific, they orbit around the center of their gravity on elliptical/circular orbits. As they are orbiting, a binary star can change its brightness when one of the stars happens to be somewhere between us (observers) and the other star.

Astrophysicists study these stars as many things can be calculated through these changes in brightness, for example, period, inclination, and relative sizes.

Fortunately, a significant number of the stars that we can observe are multi-component (two or more stars) systems. That makes the work of astrophysicists in some ways easier, as there are more systems to study and higher chances that they will find a system that is suitable for their research. But, on the other hand, it is more difficult because having too many things happening at the same time in one system can make it hard to ”solve”.

As the binary system has two components (two stars), the brighter is called the primary star, while the less bright is called the secondary. Also, as mentioned, even more than two stars can make a system.

When talking about these stars, there are a few terms used that need to be explained.

- **Light curve:** Curve of points that show us how bright a star is at some point in time. This brightness can be expressed by magnitudes, fluxes, or counts.
- **Period:** It is the time interval after which the phenomenon repeats itself. Or in the context of binaries can be explained as the time between two nearest primary minima or two nearest secondary minima.
- **Phase:** The number that represents which stage of the period the star is in. This number starts from zero and grows to 1, which means that the star went through a full period. Or it can be seen as a fraction of the period; 0.25 means the star is in the first quarter of its period.
- **O-C diagram:** A diagram of times of minima that shows us if our period is correct or can show us that the period changes. The name comes from the fact that the graph shows the observed times of minima minus our prediction or calculation of times of minima.

1.1 Types of binary stars

As we started finding more and more binary stars, we sorted them into categories. Now, we can categorize them by their light curves. But also by what types of stars which they are composed of, how far from each other they are, the stage of development of components, and so on.

But firstly, we have optical and physical binaries

- **Optical** ones are not real binaries but stars that happen to be near each other in our sky.
- **Physical** binaries are "true" binaries. They are composed of two stars bound by gravitational force, and everything mentioned in this work about binaries applies to them.

Then, the physical binaries can be divided into

- **Visual:** Components are far enough from each other that we can see both components; these binary stars are relatively close to Earth.
- **Spectroscopic:** We do not see any eclipses, but we can detect the Doppler shift in spectral lines due to orbital movement.
- **Astrometric:** These stars behave like classic lone stars, they don't change brightness. Except that their movement in the starry sky is somewhat unexpected. A weird circular motion in the night sky that has nothing to do with the movement of Earth. Almost looks like something is pulling the star. This movement was then associated with another non-visible component.
- **Eclipsing:** Two stars in the same system, and once in a while, one star will be between us and the other star, making an eclipse that changes luminosity.

Then, eclipsing binaries by luminosity/light curve:

- **Algol type:** We can see two eclipses on the graph of a light curve, but the secondary one is shallow. The light curve in moments when no eclipse is happening can, to some degree, be considered as linear, and then when the eclipse starts, the brightness starts dropping sharply.

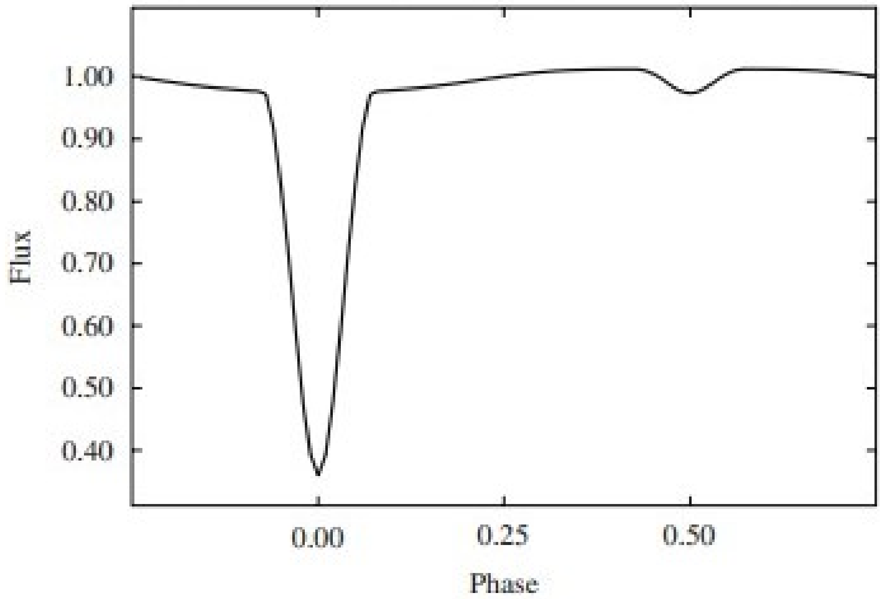

Figure 1.1: Phase curve of Algol type binary star (Kallrath and Milone, 2010)

- **β Lyrae type:** The secondary eclipse is noticeably deeper than in Algol type, but still not as deep as primary. The light curve is also smoother due to the change in brightness being more continuous than the Algol type.

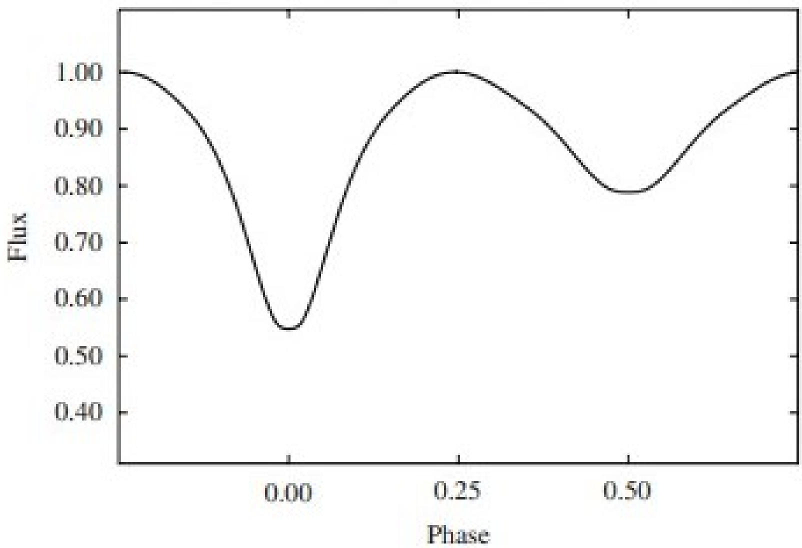

Figure 1.2: Phase curve of β Lyrae type binary star (Kallrath and Milone, 2010)

- **W UMa type:** Change in brightness in secondary eclipse is nearly as big as in primary eclipse.

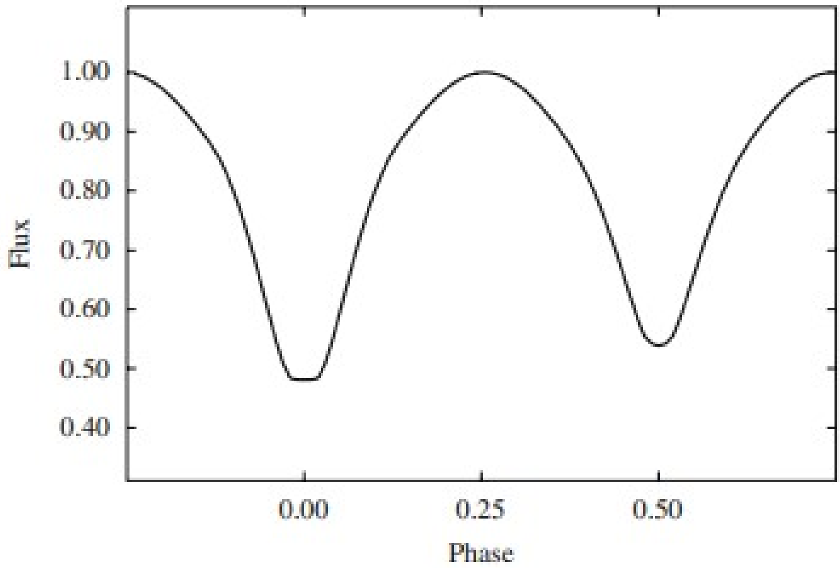

Figure 1.3: Phase curve of W UMa type binary star (Kallrath and Milone, 2010)

Of course, there are more ways how to sort binaries, but the ones mentioned above are more general and most used.

Chapter 2

Roche model

It is a physical model that describes the behavior and shapes of objects in a gravitational field. It stands on equipotential surfaces, which are surfaces where each point has the same potential. These surfaces would be spherical if stars were non-rotating objects and alone, enveloping the whole star. But in case we have two stars in a binary system (rotating, orbiting), things become more complicated. Equipotential surfaces near the surface of both stars are practically spherical due to gravity having the biggest effect on potential here. But those further away, where gravity weakens, and where the contribution of rotational speeds and orbital speeds of stars becomes more visible, the equipotential surfaces start changing their shape. The further away from the surface of a star, the more this shape deviates from a sphere, creating an ellipse. But we have two stars that are close enough to each other, close enough for these surfaces to envelop not only one star, but both of them. There is an equipotential surface where everything inside this surface is gravitationally bound. This ”lobe”, as it is called by its shape, is called the Roche lobe. Named after French astronomer Éduardo Roche.

Also, stars can be categorized by how much they fill their Roche lobe (Wilson, 2001)

- **Detached:** Two separated stars, neither of them filling its Roche lobe.

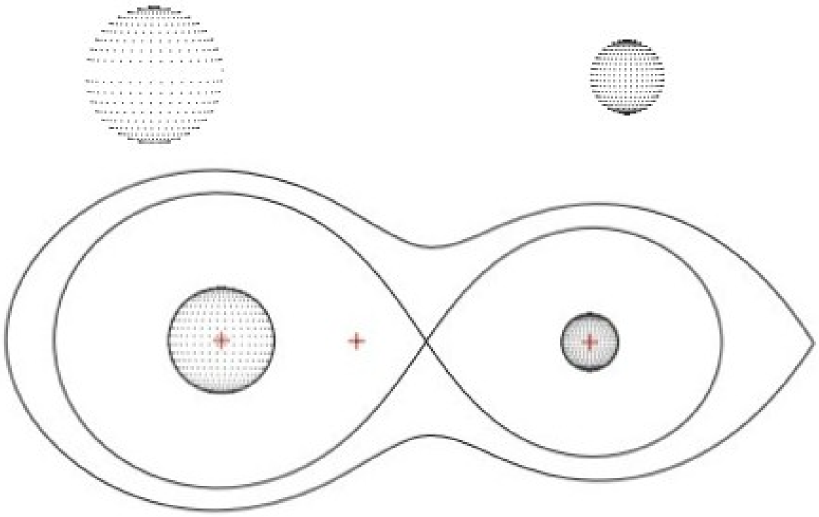

Figure 2.1: Detached binary (Kallrath and Milone, 2010)

- **Semi-detached:** Still two separated stars, but one is filling its Roche lobe.

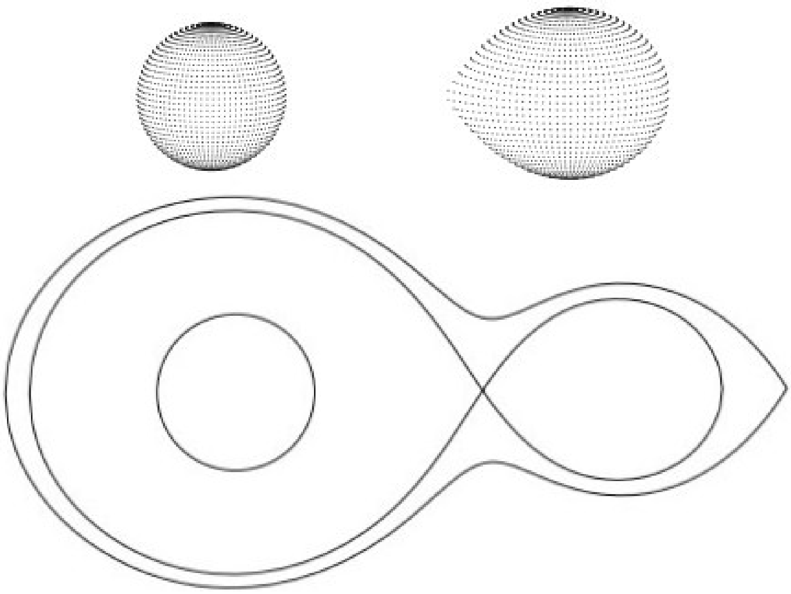

Figure 2.2: Semi-detached binary (Kallrath and Milone, 2010)

- **Contact:** Both components are filling their Roche lobes.

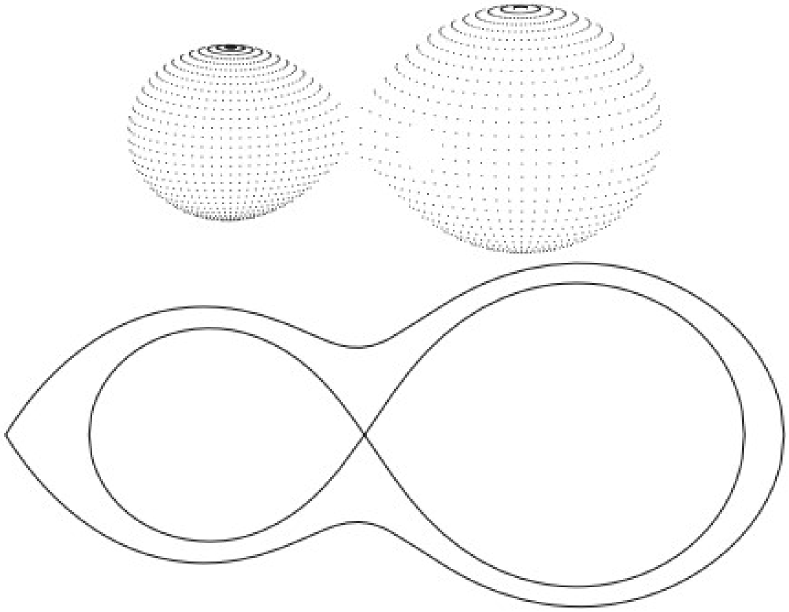

Figure 2.3: Contact binary (Kallrath and Milone, 2010)

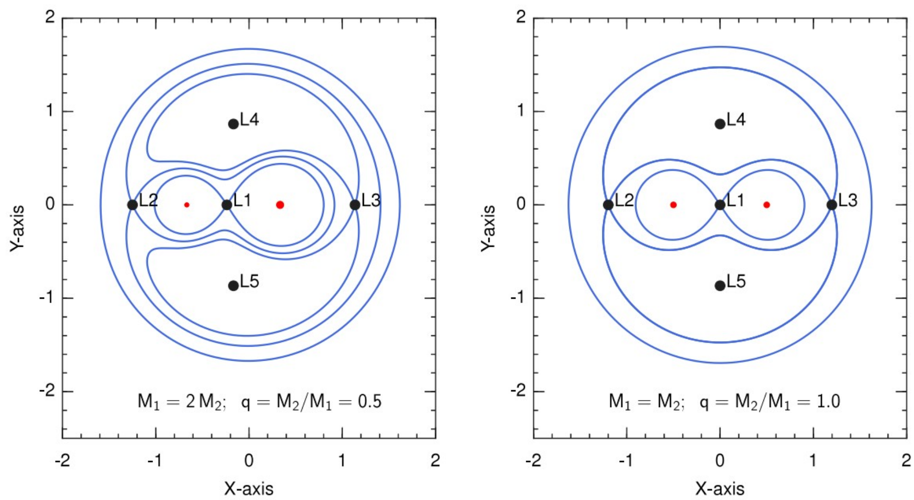

Figure 2.4: In this picture from Chen et al. (2024), we can see two objects with their equipotential layers

Chapter 3

Near contact binaries (NCBs)

In Shaw (1990), these binaries were defined as close binaries with both stars filling or nearly filling their Roche lobes. There is no large-scale energy transfer between components as they display strong tidal interaction and EB-type variations. Primary stars are usually A or F spectral type, and secondaries are G or K.

These stars were suspected to be missing part in the evolution between detached systems and W UMa type as NCBs looks like A-type W UMa type binaries in that the primary star is bigger and hotter compared to its companion.

Other speculations say that these stars are temporarily detached as they ”take a break” and they will return to contact.

NCBs and W UMa types share some similarities, but they are also different. Mainly, NCBs are not in contact, so that components can have big differences in temperatures and different evolution stages, and NCBs does not have enhanced ultraviolet emission.

3.1 Types of NCBs

As defined in Zhu and Qian (2011):

- **D:** Both components are nearly filling their Roche lobes but are still detached. These systems are in the beginning state of mass transfer.
- **SD1:** The Primary component is filling its Roche lobe with secondary detached. So-called reverse Algol systems. Mass transfer determines their evolution. Also, the orbital period decreases.
- **SD2:** Secondary component is filling its Roche lobe with primary detached Algol-like systems. They have symmetric light curves.
- **C:** Both components fill their Roche lobes and have a large temperature difference. They can be called poor-thermal contact binaries.

Chapter 4

Observations

4.1 Processing of data

If we want to study a star, we can make observations, or we can acquire it from catalogs or archives. With the first option we get raw data, frames from a telescope. We need to work with these frames to get useful information about our object out of them, but that will be explained in the next subsections of this chapter.

The second option, acquiring data from archives, can be more comfortable. And basically makes most of this chapter irrelevant as somebody has already done that, and you will be provided with files containing information you searched for. But still, it is good to know what is behind these files and what process they have been through. The disadvantage of these easy-to-access data is that there may be a mistake, or there may be little information necessary for your study or project that is not listed here.

4.1.1 Instrumental corrections

In this subsection, I would like to talk about processing. After we acquire the data, it is necessary to process it. Firstly, we must make ”corrections” on our frames.

Dark current is caused by randomly generated electrons in pixels. This can be negated (to some extent) by cooling your CCD chip. But in general, it is easy to make corrections. You will need to prevent any light from going into your telescope and then take frames with the same exposure time and with the same temperature of the chip as when science frames were made. Then you need to make a ”master dark” frame from your dark frames. That is by averaging counts on dark frames or add up all dark frames and then dividing the counts on each pixel by a number of dark frames. If you had multiple exposure times, you would need a master dark frame for each exposure time (combine with multiple temperatures). And every telescope needs its own master dark frame, too.

Flatfield correction is made by making short exposure frames of an evenly illuminated surface. By these frames, we eliminate the uneven sensitivity of pixels on the CCD chip. But vignetting (brightness decrease towards the edges of the CCD chip) or even dust can affect pixel sensitivity. These flatfield frames need their own correction by their own dark frames. After they are corrected/ subtracted by dark frames, you can make a master flat frame. Same as with the master dark frame, the average or median of these frames can be used.

The whole correction should look like this

$$I_{\text{corrected}} = \frac{I_{\text{raw}} - MD}{MF},$$

where I_{raw} is raw image, MD is master dark frame, MF is master flat-field image, $I_{\text{corrected}}$ is corrected frame.

4.1.2 Atmosphere interference

Then it is time to identify our object (our variable star) in frames with a comparison star and a check star. These should be the same or near spectral type as our variable star, be in the same region on a frame (not like variable being in the middle and comparison in the edge), and have constant brightness. These stars we choose because we need to compare them with our variable star, because of the atmosphere, any star will change its brightness when the observation condition worsens, even if conditions would be great it still would change in brightness as the variable star would be changing its position on the sky (the nearer to horizon star is the thicker atmosphere its light need to go through). But these stars are chosen, even if we use a space telescope, it helps with the calibration and precision of the data. This way, you can say that if our variable star changes its brightness and our comparison does not, that means that it is not caused by the atmosphere. They must be the same spectral type, which means that they have the same temperature, and they should have the same distribution of energy in the spectrum.

4.1.3 Light curve and phase curve

After we found a suitable comparison star, we can get a light curve. The light curve is a curve that shows how a star changes its brightness over time. Just by looking at a complete light curve (at least a period or a few), can tell us something about our object. If we have enough data, we can make a phase curve. Assuming a periodic increase and decrease in brightness, we can make the phase function. That we can make by knowing a period from

$$\frac{t_{\text{observed}}}{P} = x = E + f,$$

where t_{observed} is time of observation,P is period, x is number that we divide into its whole part E (epoch) and decimal part f (phase). Epoch is a number that means how many periods have passed from our ”T-zero”; more frequent is M_0. This point represents a selected time of primary minima.

After we have the phase curve, we can say if our period is correct. That is when all data is concentrated on one ”path”, the way in which data is distributed along our ”curve” is determined by the precision of our data.

Chapter 5

WZ Cep

Our object is WZ Cep. It also has other names such as TIC 317470793, NSVS 182245, 2MASS J23222421+7254566, and many others. It is a binary star located in the Cepheus constellation on coordinates J2000 RA $23^{h}\,22^{m}\,24{,}19^{s}$ DEC $+72°\,54'$ 56,8s". Its spectral type is F5, which means that it's hotter than the Sun and its brightness varies between 12.45 and 13.01 magnitudes (in V filter).

Figure 5.1: Cepheus constellation with marked WZ Cep. From Stellarium online https://stellarium-web.org/

One of the reasons why this star system was picked is because of its change on the O-C diagram. The period of WZ Cep increased until the 1960s, then began to decline in a ”wavy motion” and then more or less stabilized in 2005 and has been declining without undulations since then. There is some theory that W UMa-like stars have phases when the stars are in contact and then when they are not, and perhaps cycle through these phases. Or this is just a transition phase when the star system comes from semi-detached to a contact state.

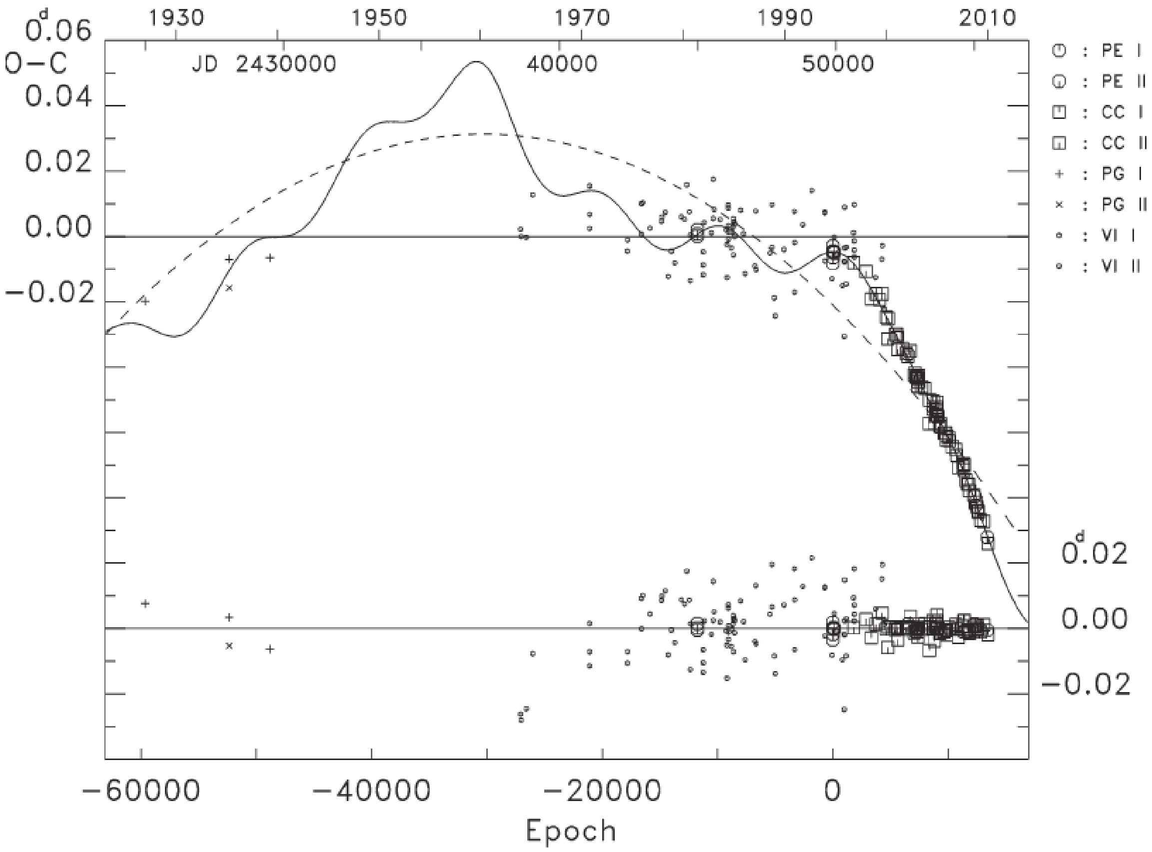

Figure 5.2: Diagram is from Jeong and Kim (2011)

Chapter 6

Data

6.1 Astronomical diary

The places of our observations were Observatory and Planetarium Brno (Kraví hora, 49°12′16.56″ N, 16°35′1.68″ E) and Observatory and Planetarium Ždánice (49°3′56.67″ N, 17°2′16.25″ E), both in the Czech Republic It is most suitable to have as much data as possible. I made a ”little observation campaign”, because more people means more possible observations.

Table 6.1: List of observations

Observer	**Date**	**Place**	**Telescope**	**Filter**
A	18.3.2024	Brno	Newton 600/2780 + G4-16000	*B,V,R*
P	19.3.2024	Brno	Newton 600/2780 + G4-16000	*B,V,R*
V	2.4.2024	Brno	Newton 600/2780 + G4-16000	*B*
Z	6.4.2024	Ždánice	AZ 800/5480 + G4-16000	*B,V,R*
Z	7.4.2024	Ždánice	AZ 800/5480 + G4-16000	*B,V,R*
A	12.4.2024	Ždánice4	AZ 800/5480 + G4-16000	*R,I*

Note: A – author, V – Jakub Vyskočil, P – Sabina Pačková, Z – Miloslav Zejda

6.2 Observatories

6.2.1 Brno

In Brno, there is a place called Kraví hora, a small hill on top of which is a little park, and in the park is the observatory. There is an available telescope, Newton 600/2780, and *B, V, R, I* filters. Suitable for my work were *B, V, R,* as in Brno are not the greatest observational conditions. There are some limitations with the telescope. It has a small window where it can not be observed (to the north).

6.2.2 Ždánice

In Ždánice, there is a telescope ASA AZ800 f6.85 and *B, V, R, I* filters, just as in Brno. But as it is not near the city, there are better conditions. There is a limitation near Zenit (a point in the sky directly above our position).

6.3 Processing of data

For the processing of data, I used SILICUPS (v3.2.4), SIPS4 (Version 4.0.3), and PHOEBE 1.0 (Prša and Zwitter, 2005). SILICUPS and SIPS4 are from Moravian Instruments (2023).

6.3.1 SIPS4

SIPS4 is a program that is used for processing frames from observations. You give it your frames (master dark, master flatfield...) and it will do it automatically. Of course, you need to define that, where is your master dark frame and master flat, but after you do it, you only tell it where your frames are, and it will go through them. After that, you can choose your check and comparison star, and it will show you the light curve. You can save the data and use it elsewhere.

6.3.2 Adjustments to data

In this subsection, I would like to talk about additional changes to the data I did before using PHOEBE.

Data that where not observed by people who participated in the campaign were acquired from (Space Telescope Science Institute, 2025). I was searching for data from the telescope TESS. Data downloaded (TESS-SPOC) from there are in FITS format. To open these files, I used FV (FITS Viewer). I was searching for data related to time, magnitude/flux, and error of magnitude/flux. I found time was in BJD (barycentric julian date); actually, it was BJD subtracted by 2457000, and the flux data with its error. I then adjusted so that I added to the time in the data by those 2457000. Fluxes were converted to magnitude by formula.

$$m = -2.5 \cdot \log(F) + C,$$

where m is magnitude, F is flux, C is a constant that is related to a system used; in the case of TESS, it is 20.44.

6.3.3 PHOEBE

It is a program that is used to fit data that represents the light curve of the system being studied. It can use a few combinations of binaries. These combinations restrict some parameters that you can change, there are certain relations between some parameters in some models. It is there just because you can fit data in many ways, and not all are physically correct, and we are interested in those physically correct.

PHOEBE can also be used to fit radial velocity curves, to find masses of stars in a system, as there is a relation between masses and velocities of components.

$$\frac{m_1}{m_2} = \frac{v_2}{v_1},$$

where m represents mass and v is velocity.

I mentioned some parameters that PHOEBE can use to fit light curves. These parameters are affecting the shape of the light curve each differently, like the inclination angle affects the shape of the minima, and can even make it flat. The luminosities are affecting the depth of minima and the height of maxima.

The process of fitting is a bit complicated as parameters change. Just because the program says that luminosities of stars on the first fit are some numbers, these numbers can and most probably will change as you fit other parameters. So it's a process going back and forth as you try to find a combination of parameters that fits the best. Firstly, I loaded the data and looked at the ranges of magnitudes that the data were in. Then subtracted the value primary minima from the data and set the offset of magnitudes so that when stars are not eclipsing is 0. After that, I added all parameters that I found about WZ Cep, like the mass ratio of components and their temperatures. After I set the combination of stars to Overcontact but not in thermal contact, I started fitting luminosities and subsequently the surface potential. Then I looked at the inclination angle, because of the flat secondary minima, it must be near 90°, the calculation changes it to around 88°. Then I started fitting two parameters at once, even with parameters that I found on the web. But still watching them so that they do not change drastically. After a couple of iterations with parameters in pairs, I tried to fit all parameters except limb darkening (this parameter must be fitted last). If it looked promising, I saved it and fitted limb darkening; if not, I did not save that and iterated it some more until it looked good. By looking good, I mean the light curve was fitting the data, and the parameters that I used for the star were not changed drastically.

PHOEBE provides a correlation matrix, a convenient thing, which provides information on how fitted parameters affect each other. The closer the numbers (correlation coefficients) in the matrix are to zero, the better, as it means a weak or no relation between parameters. Numbers closer to 1 or -1 show dependency of the parameters.

6.3.4 SILICUPS

The program is able to fit the minima of the light curve and then compare it to a period in the O-C diagram.

To use it, you create a file that the program refers to as a field. Then you add an object, which is your star. After that, you upload your light curves. The function of the program I used was fit minima. This function determines the timings of minima. Each of these minima can then be seen in the ETV diagram, which is basically an O-C diagram.

Chapter 7

Results

7.1 Light curve

In Figure 7.1, we can see all the data from TESS, and we can see that there is ”little splitting” near the primary minima. This tells us there might be a problem with a period. The thickness of data on Figure 7.1 can be caused by imperfect calibration. The data that caused this are from sectors 17 and 18, there is a big time jump between the data from these two sectors and others.

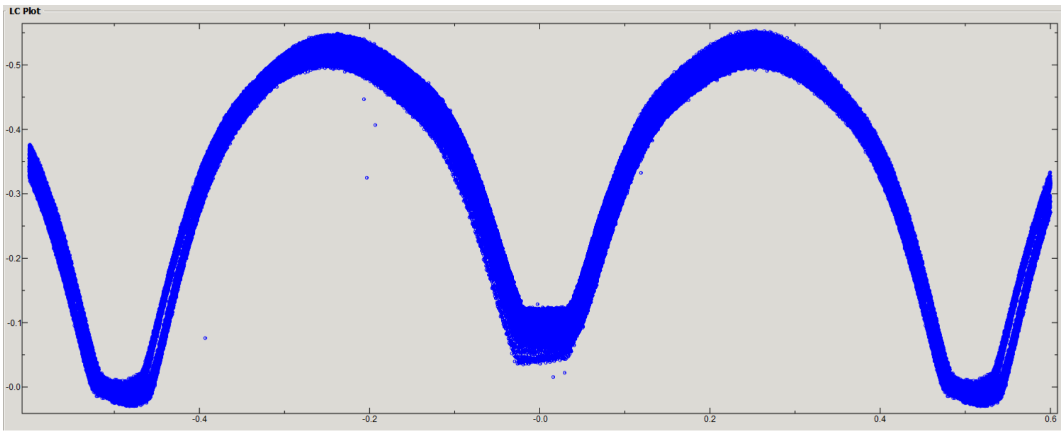

Figure 7.1: Phase curve WZ Cep all sectors (17, 18, 52, 58, 59, 78, 79) from TESS

Also, we can see secondary minimum is thick, and this is the reason why I had problems fitting each sector separately. It is not always possible to set parameters so that the light curve would fit that secondary minimum. Other parts of the curve are concentrated around the supposed light curve, which means parameters did not change much (from sector to sector), but with a minimum lower than other sectors, it needs a different set of parameters so that it would fit the curve whole. .If there was a problem in my fit, it was this minimum or the fact that this curve is not symmetric, but it is not visible in Figure 7.1.

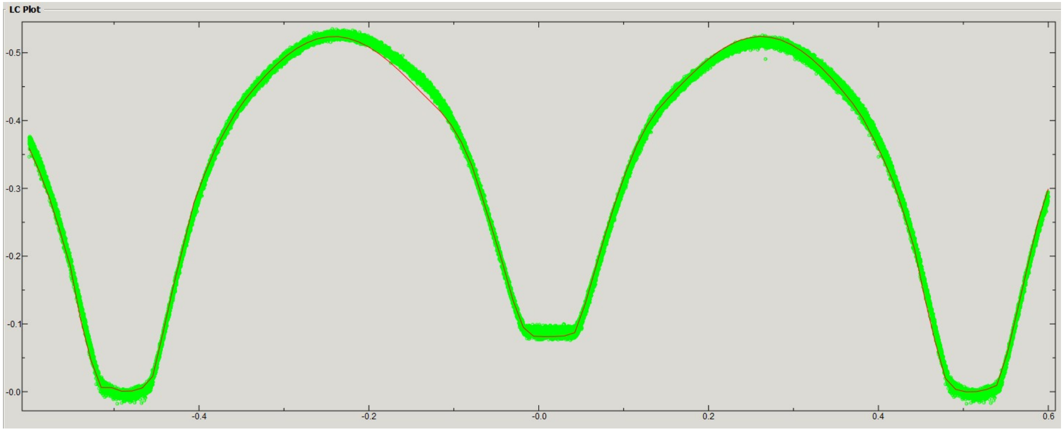

Figure 7.2: Phase curve TESS Sector 17

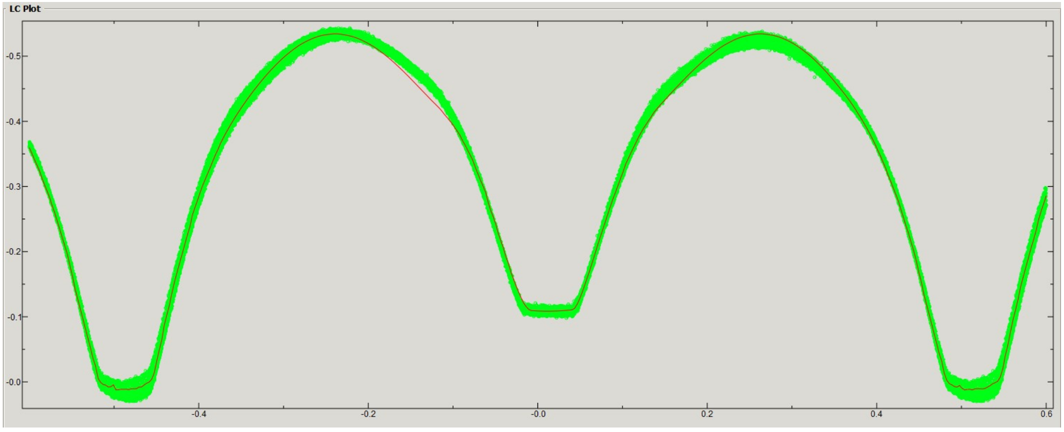

Figure 7.3: Phase curve TESS Sector 18

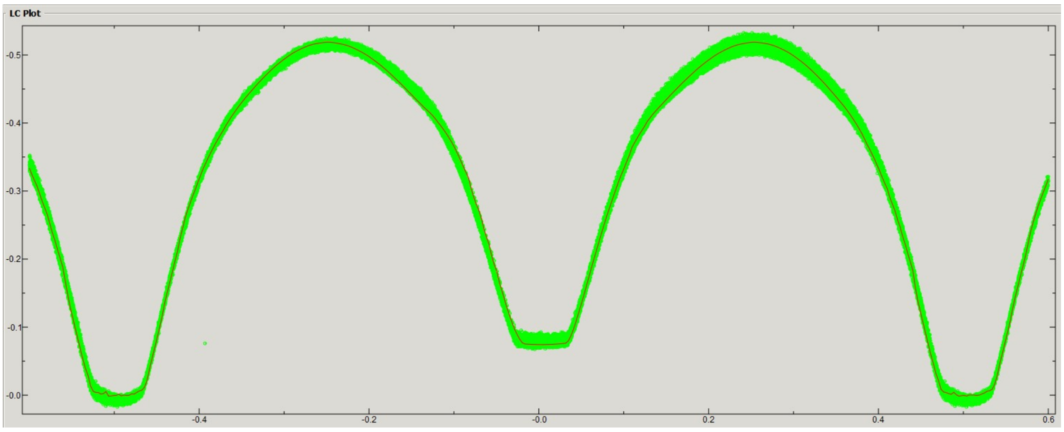

Figure 7.4: Phase curve TESS Sector 52

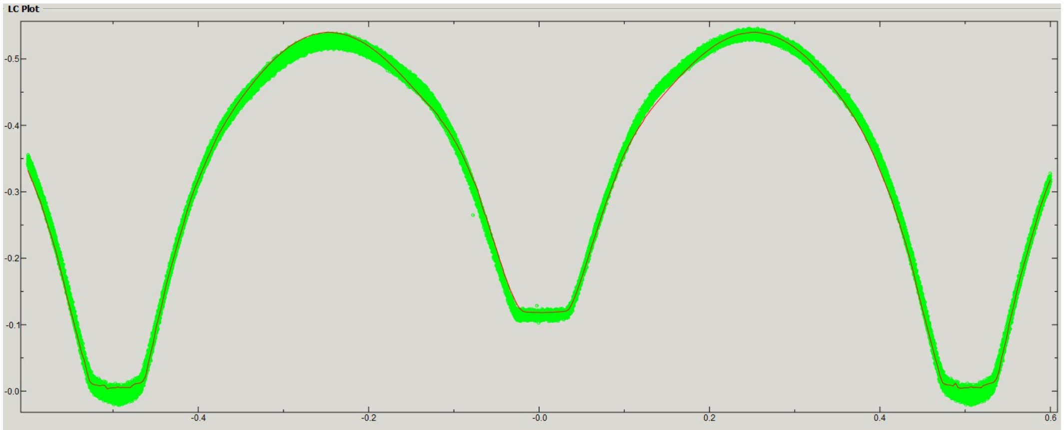

Figure 7.5: Phase curve TESS Sector 58

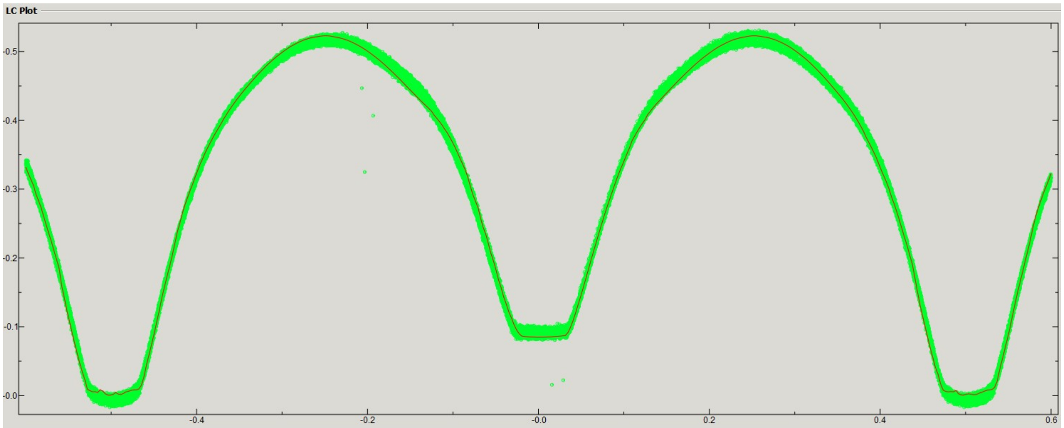

Figure 7.6: Phase curve TESS Sector 59

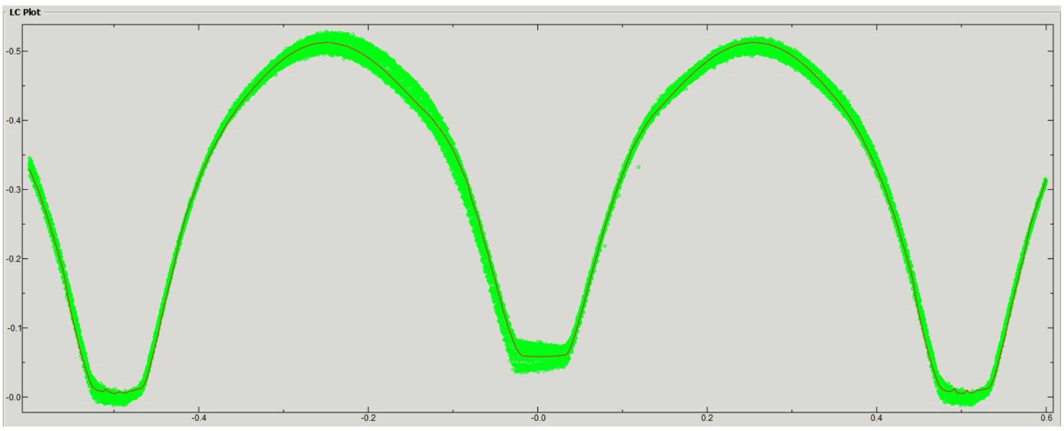

Figure 7.7: Phase curve TESS Sector 78

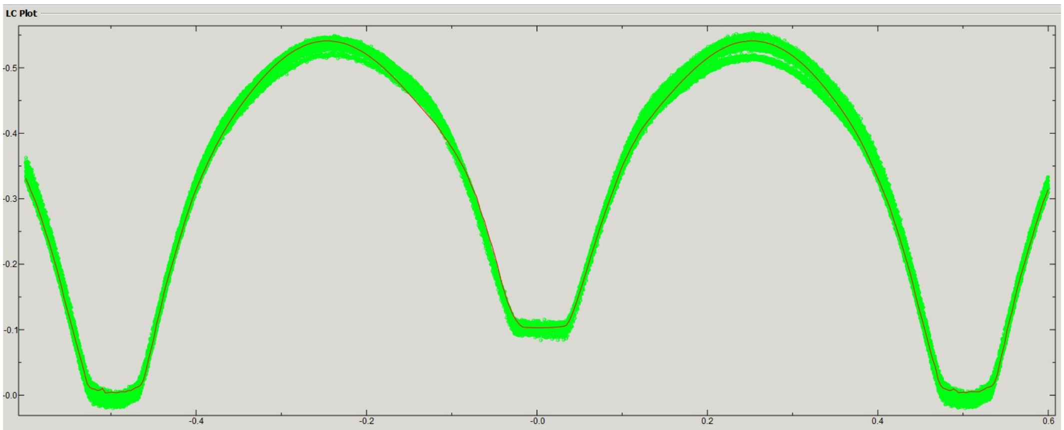

Figure 7.8: Phase curve TESS Sector 79

From Figure 7.2 to 7.8 are data from TESS, which were fitted in PHOEBE. I used the combination of an Overcontact binary not in thermal contact. This combination was used because using unconstrained binary can create some non-realistic scenarios. The combination of Overcontact binary not in thermal contact was used because it looked promising, as stars have nearly 500 K temperature difference.

When we look at each sector individually, we can notice that the data are not symmetrical like in Figure 7.2 and Figure 7.3, where there is part of the fit that is visibly off the data, but not on the other side. This can mean that there is some sort of spot on the stars. This can be supported by Djurasevic et al. (1998), where they report that the best fit of the WZ Cep light curve is achieved by adding spots on the primary star. They also mentioned that WZ Cep is in slight overcontact. And there is a newer study to support it even more (Zhu and Qian, 2009).

From Jeong and Kim (2011) we can also find masses of component stars as primary having $1.33 \pm 0.08\,\mathrm{M}_\odot$ and secondary $0.43 \pm 0.03\,\mathrm{M}_\odot$. Which can also help us in fitting. Parameters like temperature can be found on the site of Vilanova University (`https://tessebs.villanova.edu/0317470793`) The temperature of the primary star is 6400 K, and the secondary is 5950 K.

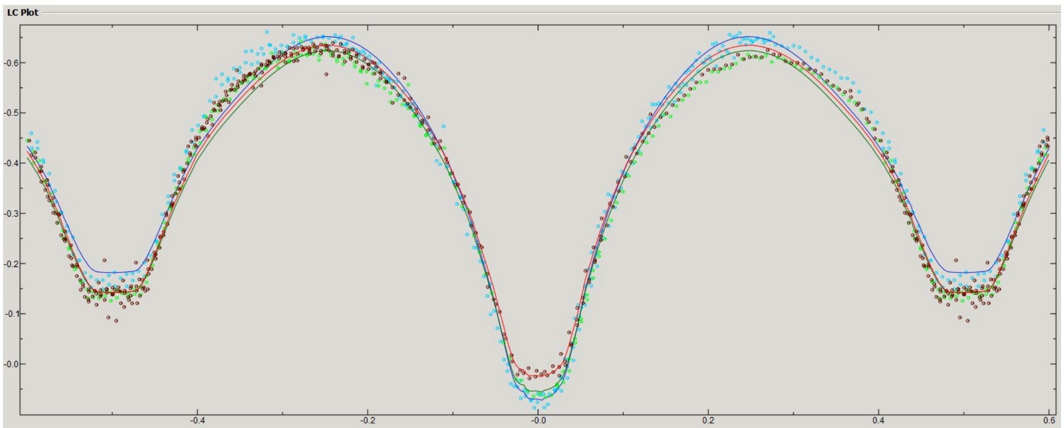

Figure 7.9: Phase curve of observed data filters *B* (blue), *V* (green), *R* (black)

In Figure 7.9, we can see observed data in filters *B, V, R*. There, we can see that the fit is not perfect and there are places (mainly near maxima) where our fitted parameters do not fit well, but that is a problem even in the data from TESS. The secondary minima are visibly flat, which can be seen on TESS data as well. Parameters used to fit this observed curve are in the Table 7.1 and 7.2

Table 7.1: Results of fitting (parameters) 1

Sector/filter	**T P/S (K)**	**inclination(°)**	**Mass ratio**	**luminosity(primary)**
17	6500/6020	87.92	0.34	9.48
18	6690/5940	87.96	0.34	9.66
52	6460/6010	87.94	0.34	9.33
58	6370/5700	88.10	0.34	9.74
59	6510/6000	88.26	0.34	9.43
78	6340/6030	87.83	0.33	9.20
79	6440/5830	87.89	0.33	9.61
B	6440/5830	88.22	0.37	9.87
V	6440/5830	88.22	0.37	9.35
R	6440/5830	88.22	0.37	9.28

0.37 *Note: T P/S - temperature primary secondary, every parameter except temperature has an error of 0.01 and temperature has an error of 10*

Table 7.2: Results of fitting (parameters) 2

Sector/ filter	**PSHIFT**	**PSSP**	**limb darkening(X1/X2)**
17	-0.49	2.51	0.53/0.51
18	-0.49	2.49	0.56/0.49
52	-0.50	2.52	0.50/0.49
58	-0.50	2.47	0.49/0.48
59	-0.50	2.51	0.51/0.51
78	-0.50	2.49	0.53/0.51
79	-0.50	2.46	0.51/0.46
B	0	2.51	0.69/0.80/0.17/0.14
V	0	2.51	0.63/0.70/0.20/0.19
R	0	2.51	0.61/0.65/0.22/0.21

Note: PSHIFT - phase shift, PSSP - primary star surface potential, limb darkening in observed data is in form X1/X2/Y1/Y2, every parameter has an error of 0.01

In Tables 7.1 and 7.2, we can see parameters of fits that are the results of fitting in PHOEBE. Certain consistency can be seen as the value of the parameter is within some range. In table 7.2, I used phase to move the light curve to fit well because I did not set a selected time of primary minima.

7.2 O-C diagram

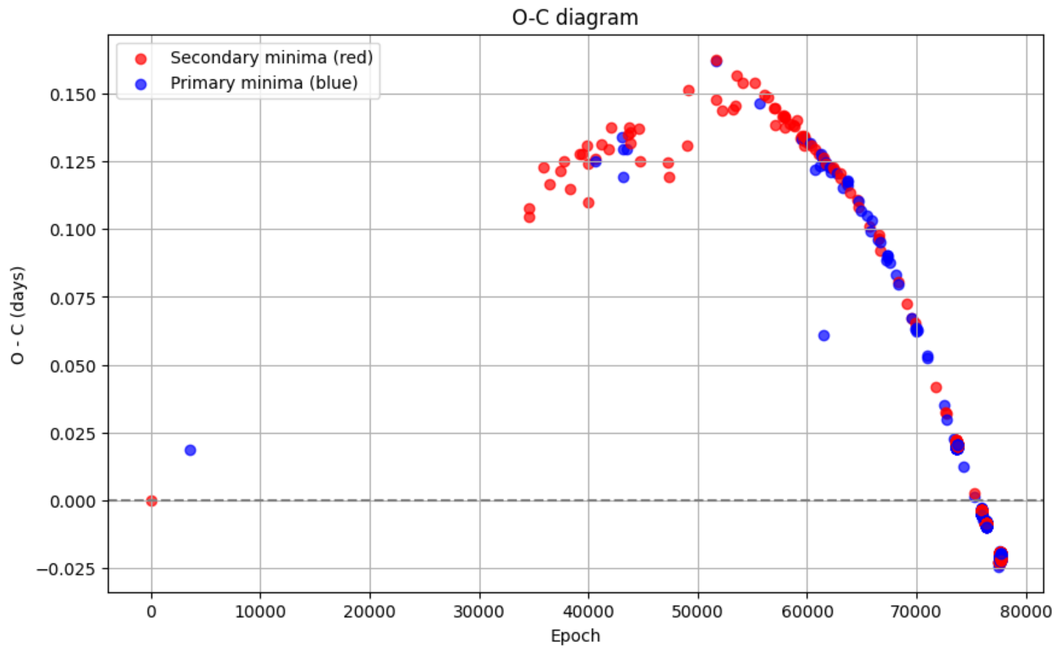

Figure 7.10: O-C diagram the data from TESS, observed and data from VarAstro (Variable Star and Exoplanet Section, n.d.),

In Figure 7.10 we can see the O-C diagram of all data from TESS, observed data, and data from VarAstro of primary and secondary minima. In this diagram, the period used was 0.417444 *days* and the T_0 for the primary minima was 2428040.765 (JD) and for the secondary minima was 2428040.556 (JD). It can be seen that the TESS data and the data that were observed (epoch 75000 and more, that is, the interval where there are mainly data from TESS) are positioned well on the path of the data from VarAstro.

Also if we compare Figure 7.10 with Figure 5.2 there are some differences in data, mainly if we compare in Figure 7.10 epochs from 0 to 50000 and in 5.2 epochs from -60000 to 0 there might be different M_0 that was chosen, that would caused that. But other data from these points are concentrated on a line, like in 5.2. Therefore, I would conclude that data from TESS and our observed ones sit well on a model of 5.2 that is a model of Zhu and Qian (2009).

Conclusion and Future Insights

In Figures 7.10 and 5.2, we see that some changes in period are happening continuously. From the first observed data, the period was rising and after peaking, suddenly started dropping. But why is this happening? Well, there may be more ways to explain it.

First, we could conclude that there can be some mass transfer/loss that slows down those stars, which would solve the rising part of the period. And after some time, this transfer might have stopped, and the system is trying to adapt to the changes that happened. Or the flow of mass did not stop, but the increasing weight of the star receiving the mass started negatively affecting the period, and therefore slowing it down. This is just a speculation, NCBs should not have big mass transfers according to Shaw (1990). But there might be some exceptions.

The second speculation is that stars are not changing masses due to mass transfer; perhaps they do not change their masses. Well, loss in speed means there is some energy loss, but not by mass transfer. That energy must go somewhere. Or maybe not? What if this energy did not go elsewhere but just changed form? If the period started to change and slowed down, it might be because they are changing their distance. If two objects are bound together via gravitational force (in general, there are other ways) and orbiting each other, and they are getting further away from each other, they need to slow down so that the momentum of the system is conserved. That would explain how binary stars can change their period without loss of energy.

Or this change can be described by a combination of these two speculations. Like, stars firstly speed up because they were getting closer until they got close enough that some mass transfer started. Then this mass transfer translated enough energy to a star on the receiving end (secondary), so it started to get further away.

These are the ways in which a binary star can change its period, they are even mentioned in Jeong and Kim (2011) There is an explanation in Zhu and Qian (2011). Based on their research, they suggest a case of a mass transfer. When the primary stars evolve, so that it is filling their Roche lobe. Therefore, a mass transfer stars from the primary to the secondary star, decreasing its period. The secondary star will expand to fill its critical Roche lobe. At that time, components would be in contact with a temperature difference. Then, if the period increases, the configuration would change into a semi-detached or even detached system. If the period decreases, the system will evolve from that state with poor thermal contact to the overcontact with true thermal contact.

In the future, it would be interesting to see how an O-C diagram of this star evolves, whether the period will only decrease, or if it will one day stop and stabilize.

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