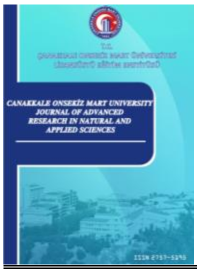
e-ISSN 2757-5195



Çanakkale Onsekiz Mart University

Journal of Advanced Research in Natural and Applied Sciences

Open Access

doi.org/10.28979/jarnas.1324188 2023, Vol. 9, Issue 4, Pages: 822-830 dergipark.org.tr/tr/pub/jarnas

Kepler Light Curve Modeling of KIC 9788457

Fahri Aliçavuş[1],*

[1]Çanakkale Onsekiz Mart University, Faculty of Science, Physics Department, Çanakkale, Türkiye
[1]Çanakkale Onsekiz Mart University, Astrophysics Research Center and Ulupınar Observatory, Çanakkale, Türkiye

Article History

Received: 07.07.2023

Accepted: 10.08.2023

Published: 20.12.2023

Research Article

Abstract − Eclipsing binary systems are significant objects for astrophysical studies since they offer more accurate fundamental stellar parameters (mass, radius). In particular, the determination of the astrophysical parameters of semi-detached binary stars is important in terms of examining the physical processes that occur as a result of interactions between components such as mass transfers and mass losses, since one of their components fills the Roche-lobe. Therefore, in this study, the first binary modeling of KIC 9788457 is presented to estimated the fundamental stellar parameters of the system. The photometric data of the system were taken from Kepler that provides high-quality data. When the light curve was checked it was found that the more luminous massive component has a significant light contribution into total. Therefore, using the spectral energy distribution and also color index (B-V) values effective temperature (T_{eff}) value was estimated for the primary component. Utilizing this T_{eff} value, the binary modeling of the system was carried out. As a result, fundamental physical parameters of KIC9788457 were obtained. The radius (R) and mass (M) values of the components are M_1=1.89 ± 0.05 M_{sun} and R_1= 2.03 ± 0.02 R_{sun} for the massive component and M_2=0.81 ± 0.02 M_{sun} and R_2= 1.74 ± 0.03 R_{sun} for the less massive component, respectively. Additionally, the distance of the system was determined to be 1407 ± 85 pc.

Keywords *− Eclipsing binary, fundamental parameter, photometric analysis*

1. Introduction

Binary stars are important objects, especially if they are an eclipsing binary star. They are invaluable objects for stellar astrophysics, as their fundamental stellar parameters (mass M, radius R) can be determined with high precision (Torres et. al., 2000; Southworth 2013). Fundamental parameters obtained from the analysis of observational data are essential for checking the accuracy of the evolutionary models and understanding the impact of binarity effects on stellar evolution. Many studies have been carried out in the literature on this subject (e.g. Kahraman Alicavus et al., 2022). Semi-detached binary systems, which are a subclass of the interacting binaries, are valuable for the analysis of the component's interaction in stellar evolution. Therefore, determination of the absolute parameters with the high precision data is essential for discerning the semi-detached binary systems. Hence, in this study, the first binary light curve examination of the Kepler field star, KIC 9788457, is presented by using high-quality Kepler data.

KIC 9788457 (2MASS J19524768+4631476, TIC 273870931, Gaia DR3 2085538610305376128, V=$12^m.89$) was first observed by Kepler. It was classified as an eclipsing binary system with an orbital period of 0.963345 day (Slawson et al., 2011). The binary modeling of the system has not been carried out in the literature yet. Conroy et al. (2014) first examined the Kepler data of the binary system to investigate its orbital-period variation. In their study, they obtained 2938 minima times and found that the system has a third component with a 1000 days orbital period. The Kepler minima times of the system were also analysed by Borkovits et al. (2016). In their study, they showed that the variation on the orbital period caused by a third component

[1] fahrialicavus@comu.edu.tr

*Corresponding author

which moves around the same centre of mass. Borkovits et al. (2016) also determined that the binary system has an eccentric orbit with a value e=0.46 (1) and it moves around the centre of mass with 1960 days orbital period. They estimated a minimum mass to be 0.07 $M_\odot$ for the possible third component.

The out-of-eclipse light variations of the KIC 9788457 were also examined by Gaulme and Guzik (2019). In this study, they found that the system exhibits Delta Scuti type pulsations. The pulsation properties and available third component in the system make it very remarkable to be investigated. Therefore, obtaining the fundamental stellar parameters of the system with a detailed analysis is important. Hence, a high-quality Kepler light curve analysis of KIC 9788457 is presented in the current study.

The paper is organized as follows. In Sect. 2, the observational data and the analysis of spectral energy distribution are introduced. The light curve analysis is presented in Sect. 3. Calculation of the fundamental stellar parameters and conclusions are given in Sect. 4 and Sect. 5, respectively.

2. Observational data and Spectral energy distribution

The increasing number of space observations has improved the accuracy of the photometric data and helped us to determine even small amplitude variations. Especially thanks to the Kepler (Borucki et al., 2010) and Transiting Exoplanet Survey Satellite (TESS, Ricker et al. 2010) data, we are now able to reach the high-quality light curves of stellar systems including the eclipsing binaries. Kepler provides two cadences of data: short cadence (SC) and long cadence (LC). KIC 9788457 has LC Kepler data which were observed from quarter 1 to 17 expect for two quarters of 7 and 15. In this study, the quar-ter 1 and 2 data of the star were used, and these data were taken from the Barbara A. Mikulski Archive for Telescopes (MAST) database. The observational data first were converted to the magnitude, and it was phased by using the values of $P=0^{d}.963345$ and T_0=2454965.186856 (Slawson et al., 2011). The observational data were normalized for further analysis.

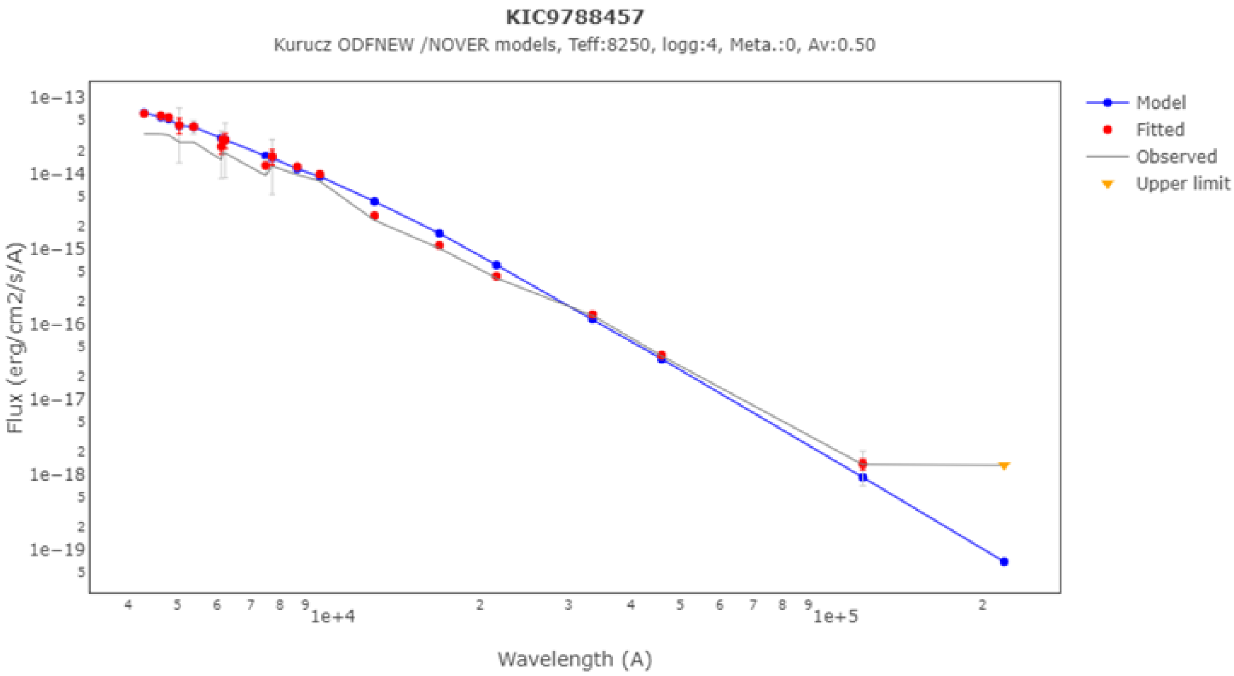


Figure 1. The spectral energy distribution for KIC 9788457.

When the light curve of the system was examined, it was seen that the primary component has a significantly high luminosity contribution in total (~93%). Therefore, the spectral energy distribution analysis of the system will give us a good estimation of the effective temperature (T_{eff}) for the primary component. Hence, the liter-ature magnitudes in different colours were gathered. When the literature magnitudes of KIC 9788457 were searched for, we found that the system has APASS B-V, Sloan SDSS g-r, Pan-STARSS g,r,i,z, y, 2MASS J-H-Ks and also WISE W1, W2,W3 and W4 colors in the literature. The used fluxes in the spectral energy distribution are given in Table 1. To eliminate the interstellar extinction effect, the extinction coefficient value of the star was calculated by using the Schlafly et al. (2011) and the Gaia DR3 distance (Gaia Collaboration et al., 2021) and the value was obtained to be $A_v=0^m.516$ (For detail please see Eker et al. 2020). The spectral energy distribution analysis was performed in the Vosa database (Bayo et al., 2008) by using the Kurucz models (Kurucz, 1993) and assuming the surface gravity (log g) and metallicity values (M/H) as 4 and 0. In conclusion, the T_{eff} of the primary system was determined to be 8250 ± 280 K. The theoretical spectral energy distribution fit to the observational data is illustrated in Fig. 1.

Table 1
The list of the used fluxes in the generation of spectral energy distribution of KIC 9788457.

Filter	λ_{med}	Observed Flux	Observed ΔFlux	Dereddened Flux	Dereddened ΔFlux	Model Flux
APASS.B	4297.17	3.35E-14	8.64E-16	6.20E-14	1.60E-15	6.34E-14
SDSS.g	4640.42	3.34E-14	4.61E-16	5.84E-14	8.06E-16	5.58E-14
PS1.g	4810.88	3.22E-14	1.02E-16	5.53E-14	1.75E-16	5.27E-14
GAIA.Gbp	5050	2.61E-14	5.94E-15	4.36E-14	9.95E-15	4.30E-14
APASS.V	5394.29	2.61E-14	1.75E-15	4.17E-14	2.80E-15	4.14E-14
SDSS.r	6122.33	1.51E-14	3.14E-15	2.27E-14	4.70E-15	2.94E-14
PS1.r	6156.33	1.89E-14	6.53E-16	2.82E-14	9.76E-16	2.91E-14
GAIA.G	6230	1.86E-14	4.23E-15	2.77E-14	6.31E-15	2.79E-14
PS1.i	7503.66	9.37E-15	6.65E-16	1.27E-14	9.03E-16	1.70E-14
GAIA.Grp	7730	1.24E-14	2.83E-15	1.67E-14	3.81E-15	1.60E-14
PS1.z	8668.53	9.61E-15	1.94E-16	1.23E-14	2.48E-16	1.15E-14
PS1.y	9613.4	7.88E-15	1.53E-16	9.72E-15	1.89E-16	9.07E-15
2MASS.J	12350	2.39E-15	4.40E-17	2.75E-15	5.06E-17	4.25E-15
2MASS.H	16620	1.01E-15	1.96E-17	1.11E-15	2.14E-17	1.61E-15
2MASS.Ks	21590	4.08E-16	7.89E-18	4.32E-16	8.36E-18	6.09E-16
WISE.W1	33526	1.30E-16	2.87E-18	1.34E-16	2.97E-18	1.17E-16
WISE.W2	46028	3.77E-17	7.28E-19	3.85E-17	7.45E-19	3.44E-17
WISE.W3	115608	1.37E-18	2.22E-19	1.39E-18	2.25E-19	9.29E-19
WISE.W4	220883	1.34E-18	3.05E-19	1.35E-18	3.08E-19	7.04E-20

3. Light curve analysis

To determine the precise fundamental parameters (M, R) of KIC 9788457, Kepler light curve analysis was performed. The normalized and phased Kepler light curve of the KIC 9788457 was analysed. In the light curve analysis, it is very critical to fix the T_{eff} value of the primary component by a good estimation. Armstrong et al. (2014) estimated the T_{eff} values of the primary and secondary binary components as T_{eff1}=10107 ± 1313 K and T_{eff2}=6148 ± 1454 K respectively. Unfortunately, their T_{eff} estimations have large error bars. Another T_{eff} estimation for the system is given as 7939 K by the investigation of the Kepler data (Prša et. al. 2011; Slawson et. al. 2011; Kirk et. al. 2016). When these T_{eff} values were taken into account, the T_{eff} value calculated in the current study by a spectral energy distribution was found between the previous T_{eff} estimations. Another T_{eff} estimation of the system could be done by using the B-V. In the T_{eff} calculation with B-V, the E(B-V) value was used by estimating from the calculated A_v. The $(B-V)_0$ value was calculated to be $0^m.164 \pm 0.023$ by using the APASS B ($13^m.22$) and V ($12^m.89$) colours. The T_{eff} values from this analysis will give us a good evaluation for the primary components T_{eff} when the less flux contribution of the secondary component was considered. By using the $(B-V)_0$ value and the colour-T_{eff} relations given by Eker et al. (2020), the T_{eff} value for the primary component was obtained to be 8032 ± 150K. This value was used in the binary light curve analysis as it has lower uncertainty value. The bolometric albedos and the gravity darkening values of the binary components were fixed during the analysis.

The bolometric albedos were taken as 1 and 0.5 for the radiative and convective atmospheres, respectively (Rucinski, 1969). The gravity darkening values were also fixed as 1 (Von zeipel, 1924) for the primary and 0.32 (Lucy, 1967) for the secondary components. The eccentricity (e) value was taken as 0 during the analysis as this value is expected for Algol type binary systems. The synchronize rotation was assumed as well ($F_{1,2=}1$). The T_{eff} of the secondary component, the mass ratio (q), orbital inclination (i), phase shift, third light (l_3), the relative luminosities and also dimensionless surface potentials ($\Omega_{1,2}$) of the components were searched for. The light curve analysis was carried out with the Wilson-Devinney (W-D) code (Wilson & Devinney, 1971) simulated with Monte-Carlo (MC) (Zola et al., 2010). In the analysis, no differences between the solutions with third body consideration or without were found. The minimum χ^2 value was found for the semi-detached configuration mode, mode5. As a result, it was determined that the secondary component fills its Roche lobe, the primary component fills 83% of its first Roche lobe. Also, considering the minimum third body mass found by Borkovits et al. (2016), a significant light contribution could not be obtained as expected. The final parameters of the light curve analysis are given in Table 2. The resulting theoretical fit to the observations and the Roche lobes of the components are demonstrated in Fig. 2.

Table 2
Photometric solution parameters and their errors for KIC 9788457 system. *fixed parameters.

Parameters	Value	Error
T_{eff_1}(K)	8032*	150
T_{eff_2}(K)	4598	180
i (deg)	83.029	0.095
Ω_1	3.296	0.010
Ω_2	2.745	0.029
q (=M_2/M_1)	0.429	0.001
Phase shift	0.0005	0.0002
$L_1/(L_1+L_2)$	0.923	0.008
$L_2/(L_1+L_2)$	0.077	0.008
l_3	0.00	-
Filling factor(%)	83	-
Filling factor(%)	100	-
r_1 (mean)	0.3558	0.0001
r_2 (mean)	0.3051	0.0001

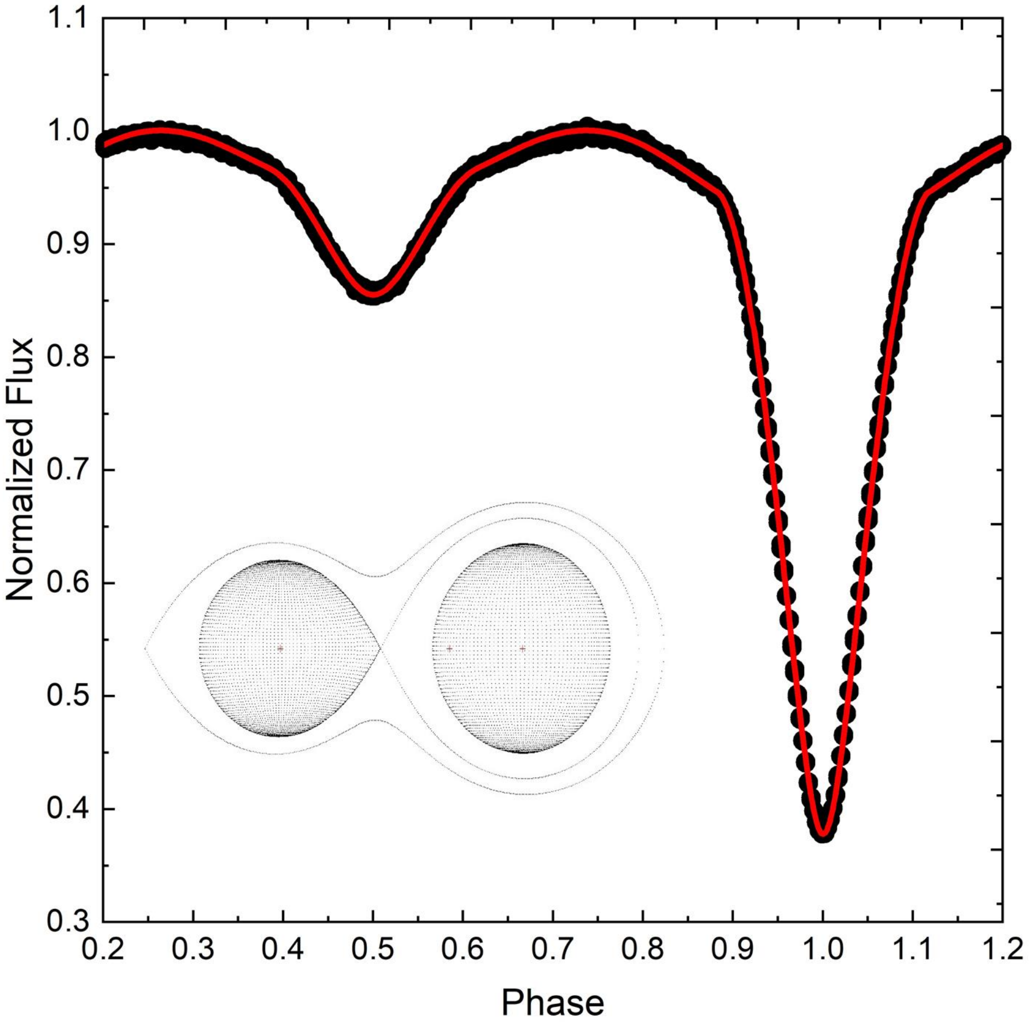


Figure 2. The best fitting theoretical binary modeling of KIC 9788457 and Roche configuration.

4. Fundamental stellar parameters

The fundamental stellar parameters of KIC 9788457 were calculated by using the results of the light curve analysis given in Table 2. This method is commonly used for the binary system not having spectroscopic data (Zola et al., 2010). In the calculations, first M of the primary component was estimated as M_1=1.89 ± 0.05 M_{sun} by considering it as a main-sequence star and also using the T_{eff} – Spectral type and M relation given by Eker et al. (2020). Then the M value of the secondary component was calculated taking into account the M_1 and q values. The semi-major axes (a) was also calculated from the Kepler third law. The R of the component stars was determined by utilizing the fractional radii obtained in the light curve analysis and a value. The luminosities (L) and the bolometric magnitudes (M_{bol}) of the components were calculated with the help of solar T_{eff} = 5772 K, M_{bol} = $4^m.74$ values and bolometric corrections given by Eker et al. (2020). The log g values were also determined by using the R and M of the components. The distance of the system was estimated using the E(B-V), absolute magnitude (M_v) values and also flux ratios of the components. For calculation of the distance (d) following parameters were used; E(B-V) = $0^m.16$, BC_1 = $0^m.02$, m_{v1} = $12^m.98$, M_{V1} = $1^m.74$ and as a result, d was found to be 1407 ± 85 pc. All calculated astrophysical parameters of KIC 9788457 were given in Table 3. The uncertainties of the parameters given in Table 3 were estimated taking into account the errors revealed by the MC method as a result of the light curve analysis and the observational errors from some basic parameter assumptions. In addition, with the help of the calculated fundamental parameters, the age of KIC9788457 is around 650 million years when the position of the primary component in the H-R diagram is examined considering the single star evolution (MIST models (Dotter 2016; Choi et. al. 2016; Paxton et. al. 2011; Paxton et. al. 2013; Paxton et. al. 2015; Paxton et. al. 2018) were used and assuming the Asplund et al. 2009 solar abundance as Z= 0.0142). However, binary star evolution models that take into account mass transfer and loss mechanisms and orbital evolution are very important in order to determine the age of such semi-detached systems more accurately. For such evolution models to give accurate results, spectral data of the components are needed.

Table 3
Absolute parameters of KIC 9788457.

Parameter	Values	Error
a (R_{sun})	5.72	0.24
M_1 (M_{sun})	1.89	0.05
M_2 (M_{sun})	0.81	0.02
R_1 (R_{sun})	2.03	0.02
R_2 (R_{sun})	1.74	0.03
$\log g_1$	4.10	0.02
$\log g_2$	3.86	0.02
L_1 (L_{sun})	15.51	1.25
L_2 (L_{sun})	1.22	0.18
M_{bol1} (mag)	1.76	0.09
M_{bol2} (mag)	4.52	0.16
d (pc)	1407	85

5. Conclusion

In this study, the fist binary modelling of KIC 9788457 is presented by using the Kepler data. According to the light curve it was estimated that the luminous massive component in the system has significant light contribution. Therefore, the T_{eff} parameter for the primary component was determined by using the photometric colours with the spectral energy distribution. In addition, T_{eff} value of the primary component was estimated with B-V colour. Since the uncertainness of B-V colour T_{eff} is lower, that value was used in the binary modeling. The binary modeling was carried out with the WD program and the binarity parameters were determined. Using the resulting parameters from the binary modelling, some fundamental stellar parameters were estimated. The M parameters for the primary and secondary components were found to be 1.89 ± 0.05 M_{sun} and 0.81 ± 0.02 M_{sun}, respectively. The R parameters were also estimated as 2.03 ± 0.02 R_{sun} and 1.74 ± 0.03 R_{sun} for the primary and secondary systems. According to filling factors the secondary components fills its Roche lobe. The distance of the system was calculated as well and found to be 1407 ± 85 pc. When the Gaia distance (1568 pc) was compared with the distance found in this study, there is around 150 pc differences between two distances. This difference may be due to observational measurement errors and inability to calculate interstellar absorption accurately. When the astrophysical parameters found in this study were examined, it is seen that the primary component is in the instability region where delta Scuti type oscillation is dominant, as stated by Gaulme and Guzik (2019). The results obtained because of sensitive satellite observations of such binary systems with pulsating components are very important in terms of contributing to the studies on the pulsating components. In addition to these, it is very important to make spectral observations of the system in order to control the findings in this study and to conduct evolutionary status studies in detail. In addition, long-term spectral observations are needed to check the existence of a third body.

Acknowledgement

I would like to thank the reviewers for their constructive and improving comments.

Author Contributions

Fahri Aliçavuş: All analysis presented in the paper.

Conflicts of Interest

The authors declare no conflict of interest.

References

Armstrong, D. J., Gómez Maqueo Chew, Y., Faedi, F., & Pollacco, D. (2014). A catalogue of tempera-tures for Kepler eclipsing binary stars. Monthly Notices of the Royal Astronomical Society, 437(4), 3473-3481. Retrieved from: https://academic.oup.com/mnras/article/437/4/3473/1006401

Asplund, M., Grevesse, N., Sauval, A. J., & Scott, P. (2009). The chemical composition of the Sun. Annual review of astronomy and astrophysics, *47*, 481-522. Retrieved from: https://www.annualreviews.org/doi/full/10.1146/annurev.astro.46.060407.145222

Bayo, A., Rodrigo, C., y Navascués, D. B., Solano, E., Gutiérrez, R., Morales-Calderón, M., & Allard, F. (2008). VOSA: virtual observatory SED analyzer-An application to the Collinder 69 open cluster. Astronomy & Astrophysics, 492(1), 277-287. Retrieved from: https://www.aanda.org/articles/aa/abs/2008/46/aa10395-08/aa10395-08.html

Borkovits, T., Hajdu, T., Sztakovics, J., Rappaport, S., Levine, A., Bíró, I. B., & Klagyivik, P. (2016). A comprehensive study of the Kepler triples via eclipse timing. Monthly Notices of the Royal Astronomical Society, 455(4), 4136-4165. Retrieved from: https://academic.oup.com/mnras/article/455/4/4136/1264839

Borucki, W. J., Koch, D., Basri, G., Batalha, N., Brown, T., Caldwell, D., ... & Prsa, A. (2010). Kepler planet-detection mission: introduction and first results. Science, 327(5968), 977-980. Retrieved from: https://www.science.org/doi/10.1126/science.1185402

Choi, J., Dotter, A., Conroy, C., Cantiello, M., Paxton, B., & Johnson, B. D. (2016). Mesa isochrones and stellar tracks (MIST). I. Solar-scaled models. The Astrophysical Journal, *823*(2), 102. Retrieved from: https://iopscience.iop.org/article/10.3847/0004-637X/823/2/102/meta

Conroy, K. E., Prša, A., Stassun, K. G., Orosz, J. A., Fabrycky, D. C., & Welsh, W. F. (2014). Kepler eclipsing binary stars. IV. Precise eclipse times for close binaries and identification of candidate three-body systems. The Astronomical Journal, 147(2), 45. Retrieved from: https://iopscience.iop.org/article/10.1088/0004-6256/147/2/45

Dotter, A. (2016). MESA Isochrones and Stellar Tracks (MIST) 0: methods for the construction of stellar isochrones. The Astrophysical Journal Supplement Series, *222*(1), 8. Retrieved from: https://iopscience.iop.org/article/10.3847/0067-0049/222/1/8/meta

Eker, Z., Soydugan, F., Bilir, S., Bakış, V., Aliçavuş., Özer, S., ... & Köse, Y. (2020). Empirical bolo-metric correction coefficients for nearby main-sequence stars in the Gaia era. Monthly Notices of the Royal Astronomical Society, 496(3), 3887-3905. Retrieved from: https://academic.oup.com/mnras/article/496/3/3887/5869829

Gaia-Collaboration, Klioner, S. A., Mignard, F., Lindegren, L., Bastian, U., McMillan, P. J., ... & Hodgkin, S. T. (2021). Gaia Early Data Release 3: Acceleration of the Solar System from Gaia astrometry. Retrieved from: https://www.aanda.org/articles/aa/full_html/2021/05/aa39734-20/aa39734-20.html

Gaulme, P., & Guzik, J. A. (2019). Systematic search for stellar pulsators in the eclipsing binaries ob-served by Kepler. Astronomy & Astrophysics, 630, A106. Retrieved from: https://www.aanda.org/articles/aa/full_html/2019/10/aa35821-19/aa35821-19.html

Kahraman Aliçavuş, F., Handler, G., Aliçavuş, F., De Cat, P., Bedding, T. R., Lampens, P., ... & Leone, F. (2022). Mass transfer and tidally tilted pulsation in the Algol-type system TZ Dra. Monthly Notices of the Royal Astronomical Society, 510(1), 1413-1424. Retrieved from: https://academic.oup.com/mnras/article-abstract/510/1/1413/6449399?redirectedFrom=fulltext

Kirk, B., Conroy, K., Prša, A., Abdul-Masih, M., Kochoska, A., MatijeviČ, G., ... & Borucki, W. (2016). Kepler eclipsing binary stars. VII. The catalog of eclipsing binaries found in the entire Kepler data set. The Astronomical Journal, 151(3), 68. Retrieved from: https://iopscience.iop.org/article/10.3847/0004-6256/151/3/68

Kurucz, R. L. (1993). ATLAS9 Stellar Atmosphere Programs and 2 km/s grid. Kurucz CD-Rom. Re-trieved from: https://ui.adsabs.harvard.edu/abs/1993KurCD..13.....K

Lucy, L. B. (1967). Gravity-darkening for stars with convective envelopes. Zeitschrift fur Astrophysik, 65, 89. Retrieved from: https://articles.adsabs.harvard.edu/pdf/1967ZA.....65...89L

Paxton, B., Bildsten, L., Dotter, A., Herwig, F., Lesaffre, P., & Timmes, F. (2011). Modules for experiments in stellar astrophysics (MESA). The Astrophysical Journal Supplement Series, *192*(1), 3. Retrieved from: https://iopscience.iop.org/article/10.1088/0067-0049/192/1/3/meta

Paxton, B., Cantiello, M., Arras, P., Bildsten, L., Brown, E. F., Dotter, A., ... & Townsend, R. (2013). Modules for experiments in stellar astrophysics (MESA): planets, oscillations, rotation, and massive stars. The Astrophysical Journal Supplement Series, 208(1), 4. Retrieved from: https://iopscience.iop.org/article/10.1088/0067-0049/208/1/4/meta

Paxton, B., Marchant, P., Schwab, J., Bauer, E. B., Bildsten, L., Cantiello, M., ... & Timmes, F. X. (2015). Modules for experiments in stellar astrophysics (MESA): binaries, pulsations, and explosions. The Astrophysical Journal Supplement Series, 220(1), 15. Retrieved from: https://iopscience.iop.org/article/10.1088/0067-0049/220/1/15/meta

Paxton, B., Schwab, J., Bauer, E. B., Bildsten, L., Blinnikov, S., Duffell, P., ... & Timmes, F. X. (2018). Modules for Experiments in Stellar Astrophysics (): Convective Boundaries, Element Diffusion, and Massive Star Explosions. The Astrophysical Journal Supplement Series, 234(2), 34. Retrieved from: https://iopscience.iop.org/article/10.3847/1538-4365/aaa5a8/meta

Prša, A., Batalha, N., Slawson, R. W., Doyle, L. R., Welsh, W. F., Orosz, J. A., ... & Borucki, W. (2011). Kepler eclipsing binary stars. I. Catalog and principal characterization of 1879 eclipsing binaries in the first data release. The Astronomical Journal, 141(3), 83. Retrieved from: https://iopscience.iop.org/article/10.1088/0004-6256/141/3/83

Ricker, G. R., Latham, D. W., Vanderspek, R. K., Ennico, K. A., Bakos, G., Brown, T. M., ... & Worden, S. P. (2010, January). Transiting exoplanet survey satellite (tess). In American Astronomical Society Meeting Abstracts# 215 (Vol. 215, pp. 450-06). Retrieved from: https://ui.adsabs.harvard.edu/abs/2010AAS...21545006R/abstract

Rucinski, S. M. (1969). The proximity effects in close binary systems. II. The bolometric reflection effect for stars with deep convective envelopes. Acta Astronomica, 19, 245. Retrieved from: https://articles.adsabs.harvard.edu/pdf/1969AcA....19..245R

Schlafly, E. F., & Finkbeiner, D. P. (2011). Measuring reddening with Sloan Digital Sky Survey stellar spectra and recalibrating SFD. The Astrophysical Journal, 737(2), 103. Retrieved from: https://iopscience.iop.org/article/10.1088/0004-637X/737/2/103

Slawson, R. W., Prša, A., Welsh, W. F., Orosz, J. A., Rucker, M., Batalha, N., ... & Koch, D. (2011). Kepler eclipsing binary stars. II. 2165 eclipsing binaries in the second data release. The Astronomical Journal, 142(5), 160. Retrieved from: https://iopscience.iop.org/article/10.1088/0004-6256/142/5/160

Southworth, J. (2013). The solar-type eclipsing binary system LL Aquarii. Astronomy & Astrophysics, 557, A119. Retrieved from: https://www.aanda.org/articles/aa/full_html/2013/09/aa22195-13/aa22195-13.html

Torres, G., Lacy, C. H. S., Claret, A., & Sabby, J. A. (2000). Absolute dimensions of the unevolved B-type eclipsing binary GG Orionis. The Astronomical Journal, 120(6), 3226. Retrieved from: https://iopscience.iop.org/article/10.1086/316855

Von Zeipel, H. (1924). The radiative equilibrium of a rotating system of gaseous masses. Monthly No-tices of the Royal Astronomical Society, 84, 665-683. Retrieved from: https://academic.oup.com/mnras/article/84/9/665/951714

Wilson, R. E., & Devinney, E. J. (1971). Realization of accurate close-binary light curves: application to MR Cygni. The Astrophysical Journal, 166, 605. Retrieved from: https://articles.adsabs.harvard.edu/pdf/1971ApJ...166..605W

Zola, S., Gazeas, K., Kreiner, J. M., Ogloza, W., Siwak, M., Koziel-Wierzbowska, D., & Winiarski, M. (2010). Physical parameters of components in close binary systems–VII. Monthly Notices of the Royal Astronomical Society, 408(1), 464-474. Retrieved from: https://academic.oup.com/mnras/article/408/1/464/1058765