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GAIA DR3 2059297390930630400: AN ECCENTRIC BINARY WITH CONSIDERABLE APSIDAL MOTION

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Abstract: Apsidal motion in binary stars refers to the gradual precession of the elliptical orbits of two stars around their common center of mass. This phenomenon occurs due to gravitational interactions, which cause the orientation of the orbit to shift over time. We present the indication of apsidal rotation in the eclipsing binary system Gaia DR3 2059297390930630400 (ZTF J195804.88+343708.1) by using the photometric data from the Zwicky Transient Facility (ZTF) and Transiting Exoplanet Survey Satellite (TESS). We used Peranso to derive the orbital period from ZTF and times of minima from the TESS data.

1 Introduction

Gaia DR3 2059297390930630400 is an eccentric binary system positioned at RA 19 58 04.88 DEC +34 37 08.026 (J2000). The object has an effective temperature of 7514.8 K according to Gaia DR3 and can therefore be classified as spectral type A/F, which applies to both components of the binary system, as the minima are of comparable depth. In this paper, we present the evidences to show the indication of apsidal motion in this system by obtaining the Times of Minima (ToM). ToM refers to the specific moment/time when the brightness of an eclipsing binary star system is at its lowest. This search is based on Chen et al. (2020), in which we identified the object of interest during a systematic search for eclipsing binaries with asymmetrically located secondary minima.

Similar work with a greater understanding of three southern close eccentric eclipsing binaries has been conducted by Wolf et al. (2024) on GM Nor, V397 Pup, and PT Vel.

2 Data and analysis

We collected photometric data from ZTF (Bellm et al., 2019), obtaining magnitudes in the zg, zi, and zr filters, as well as data from sectors 14, 41, 54, 55, 74, and 75 from the TESS satellite (Ricker et al., 2015). TESS (Transiting Exoplanet Survey Satellite) is mainly dedicated to searching for exoplanets using the transit method, while Zwicky Transient Facility (ZTF) is a ground-based observatory that monitors variable celestial objects. Our analysis was primarily done with Peranso - Light Curve and Period Analysis

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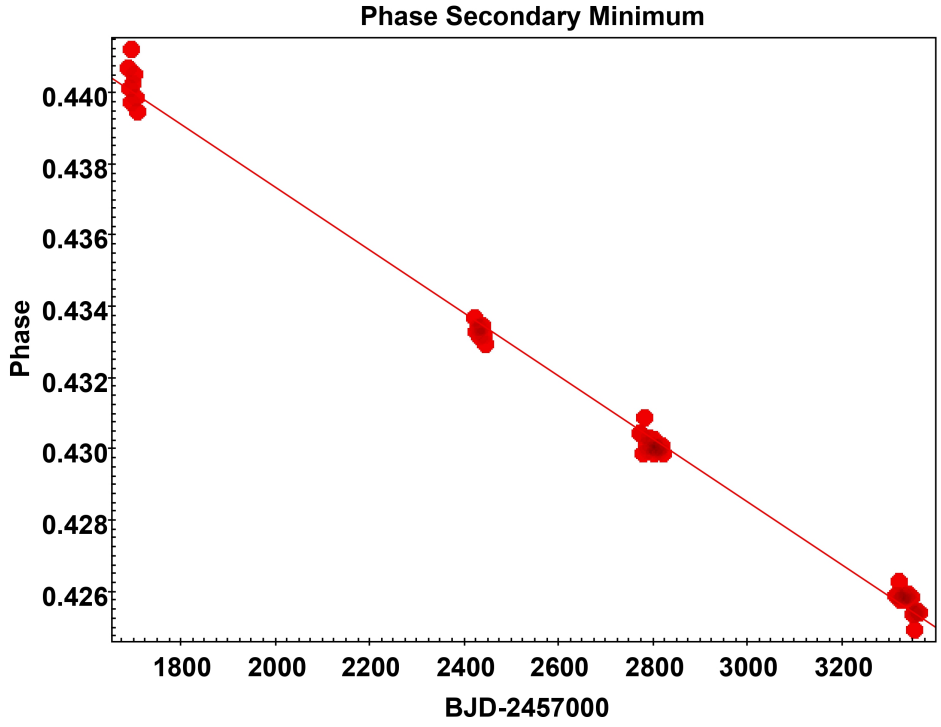

Figure 1: Phase as a function of Secondary Times of Minima

Software (Paunzen & Vanmunster, 2016), including period analysis and analysis of Times of Minima. First, we obtained the system's orbital period as 3.137204 days from the ZTF data, which is in line with the period found in Chen et al. (2020). To refine the period and calculate the ephemeris, we extracted the Times of Minima from each sector of the TESS data, presented in Table 1. Furthermore, the Times of Minima can serve to determine the apsidal motion rate of an eclipsing binary system (Giménez & Bastero, 1995).

Using the method of least squares, the following ephemeris for the primary minima were derived from the Times of Minima:

$$BJD_{minI} = (2458684.7210 \pm 0.0003) + (3.1372013 \pm 8) * E \tag{1}$$

where E is the epoch/cycle number.

Based on this ephemeris, we calculated the phase difference of each of the minimas of all TESS sectors using,

$$\phi = \frac{T - T_0}{P_{orb}} \tag{2}$$

where P_{orb} is the orbital period of the system.

Our primary analysis included plotting all phase values against the Minima Times of the Secondary eclipse as seen in Figure 1.

We have also made a O−C plot using obtained times of minima shown in Figure 2. The plot was built using the ephemeris above.

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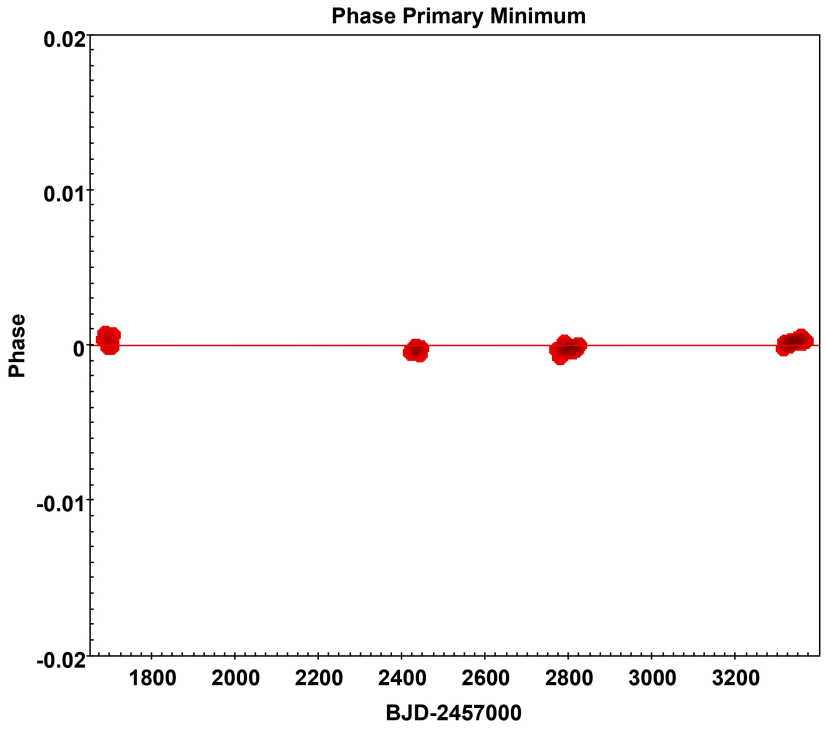

Figure 2: Ephemeris of all primary minima

Figure 3 shows the folded light curve of TESS Sector 14 and Sector 75, showing the variation between the first and the last sector of observations, adding to the evidence of apsidal motion.

3 Conclusion

In conclusion, we observe that a trend is being followed concerning the phase of the secondary eclipse against the secondary minima times. This shows an indication of apsidal rotation in the system. However, we have only observed a small part of the apsidal cycle in the period between BJD 2458684 and BJD 2460366 (1682 days). This aligns with the long periods (about 80, 335, and 160 years) found for the three objects studied in Wolf et al. (2024). Additional observations are required for a better and more complete understanding of the system's behavior.

Acknowledgments:

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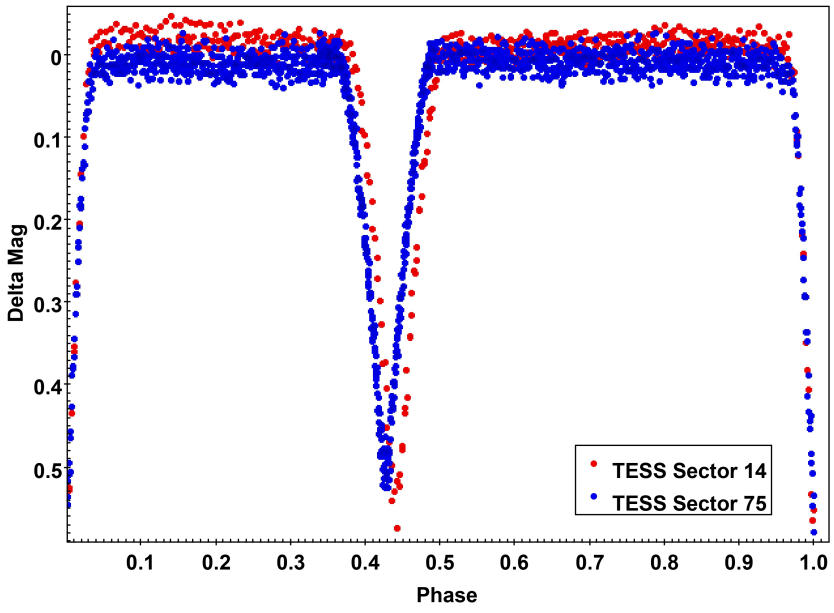

Figure 3: Folded light curve of TESS Sector 14 and Sector 75

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Appendix

	Primary Minima				Secondary Minma			
TESS Sector	**BJD-2457000**	**Error**	**Epoch**	**Phase calculated**	**BJD-2457000**	**Error**	**Epoch**	**Phase calculated**
14	1684.72205	0.008955	0	0.00015619	1686.104145	0.002353	0	0.440706119
	1687.860528	0.00647	1	0.000562284	1689.239541	0.002012	1	0.44012981
	1690.997558	0.00589	2	0.000506821	1692.380216	0.009221	2	0.441236101
	1694.132379	0.007167	3	-0.000252773	1695.512774	0.001678	3	0.439755273
	1700.407485	0.006495	5	-3.03E-05	1698.651643	0.003251	4	0.440286
	1703.543973	0.006032	6	-0.00025851	1701.789672	0.001795	5	0.440548884
	1706.683418	0.001746	7	0.000455976	1704.924695	0.002301	6	0.439853768
					1708.060793	0.002476	7	0.439501225
41	2421.961886	0.000258	235	-0.000833226	2420.187933	0.000713	234	0.433710081
	2425.09955	0.000529	236	-0.000686599	2423.323863	0.001101	235	0.433303987
	2428.23671	0.000957	237	-0.000700624	2426.461412	0.001526	236	0.433413957
	2431.374487	0.000658	238	-0.000517977	2429.597889	0.000909	237	0.433182222
	2434.5119	0.000832	239	-0.000451357	2435.873147	0.000968	239	0.433453164
	2437.648387	0.000627	240	-0.000679905	2439.010385	0.00075	240	0.433464002
	2440.784659	0.000682	241	-0.000976985	2442.146817	0.00074	241	0.433217923
	2443.923139	0.000662	242	-0.000570253	2445.283161	0.000818	242	0.432943793
54	2770.191701	0.000692	346	-0.000778719	2771.544525	0.0012	346	0.430440928
	2773.328621	0.000817	347	-0.000869245	2774.681573	0.000956	347	0.430391202
	2776.464812	0.000757	348	-0.001192144	2777.817242	0.000785	348	0.429901913
	2779.603982	0.00066	349	-0.000565472	2780.957548	0.001133	349	0.430890691
	2785.878484	0.000706	351	-0.000535509	2784.092285	0.001105	350	0.430104322
	2789.016329	0.000637	352	-0.000331187	2787.229025	0.000811	351	0.42995642
	2792.152997	0.000687	353	-0.000502039	2790.367352	0.001258	352	0.430314382
	2795.289205	0.000384	354	-0.00081952	2793.503919	0.001336	353	0.430111335
55	2798.426437	0.000304	355	-0.000810594	2799.777646	0.000559	355	0.429894263
	2801.563687	0.000675	356	-0.000795932	2802.91602	0.000561	356	0.430267206
	2804.701528	0.000722	357	-0.000592885	2806.052621	0.000625	357	0.430074997
	2807.838788	0.000731	358	-0.000575034	2809.18959	0.000645	358	0.430000089
	2810.975182	0.000894	359	-0.000833226	2812.326544	0.000645	359	0.429920401
	2814.11317	0.000623	360	-0.000583322	2815.464138	0.000494	360	0.430044715
	2817.249849	0.000677	361	-0.000750668	2818.601567	0.000661	361	0.430116435
	2820.387809	0.000746	362	-0.00050969	2821.738099	0.000795	362	0.429902231
	2823.524966	0.000604	363	-0.000524671				
74	3312.927955	0.000697	519	-0.000790832	3314.266595	0.000544	519	0.425907592
	3316.066	0.000443	520	-0.000522758	3317.403804	0.000585	520	0.425909185
	3319.203591	0.000645	521	-0.0003994	3320.542196	0.000579	521	0.426287867
	3322.340243	0.00047	522	-0.000575353	3323.677732	0.000608	522	0.425756183
	3325.477562	0.000399	523	-0.000538696	3326.815145	0.000482	523	0.425822803
	3328.614354	0.000473	524	-0.000670023	3329.95254	0.000618	524	0.425883685
	3331.752429	0.000601	525	-0.000392388	3336.227015	0.000799	526	0.425905042
	3334.889475	0.000386	526	-0.000442751	3339.364322	0.000649	527	0.425937873
	3338.026746	0.000473	527	-0.000421394				
75	3341.163935	0.00048	528	-0.000426176	3342.500892	0.000469	528	0.425735783
	3344.301543	0.000385	529	-0.000297399	3345.6385	0.000353	529	0.42586456
	3347.438551	0.000286	530	-0.000359875	3348.774195	0.000457	530	0.425383558
	3350.575634	0.000285	531	-0.000398444	3351.911383	0.000438	531	0.425378458
	3356.850955	0.000397	533	-0.00010742	3355.04719	0.000855	532	0.424933157
	3359.986946	0.000266	534	-0.000494071	3358.185888	0.000562	533	0.425409377
	3363.124876	0.000331	535	-0.000262654	3361.323201	0.000398	534	0.425444122
	3366.261824	0.000441	536	-0.000344256	3364.460389	0.000454	535	0.425439022

Table 1: Times of Minima of all TESS Sectors