Contrib. Astron. Obs. Skalnaté Pleso **55/3**, 425 – 430, (2025)
https://doi.org/10.31577/caosp.2025.55.3.425

Physical stellar properties of red giant ellipsoidal binaries in Gaia DR3

C. Navarrete[1], **A. Recio-Blanco**[1], **P. de Laverny**[1] and **A. Escorza**[2,3]

[1] *Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Bd de l'Observatoire, CS 34229, 06304, Nice Cedex 4, France (E-mail: camila.navarrete@oca.eu)*

[2] *Instituto de Astrofísica de Canarias, C. Vía Láctea, s/n, 38205 La Laguna, Santa Cruz de Tenerife, Spain*

[3] *Universidad de La Laguna, Dpto. Astrofísica, Av. Astrofísico Francisco Sánchez, 38206 La Laguna, Santa Cruz de Tenerife, Spain.*

Received: November 1, 2024; Accepted: February 5, 2025

Abstract. Ellipsoidal red giant binaries are a particular class of binary stars where the primary gets tidally deformed by the interaction with the companion. They are the prelude stage before binary interactions, and the study of their population properties is therefore of great relevance to understanding the effects of tidal circularization and the binary evolution of these systems. Combining various *Gaia* data sets, including astrometry, photometry and spectroscopy, as well as variability information, we derived the physical parameters of more than 300 ellipsoidal red giant binary candidates. An estimate for the mass of the secondary star was also recovered. This unprecedentedly large sample allows us to compare its physical properties (mass, luminosity, radius), orbital parameters (mass-ration, filling factor, eccentricity) and chemical information (metallicity, [α/Fe] abundances), to better understand this stage in binary evolution.

Key words: binaries: general – binaries: spectroscopic – binaries: close

1. Introduction

The *Gaia* mission has produced a revolution in the fields of Galactic and stellar astronomy, providing an unprecedentedly large sample of stars having precise astrometry, photometry and spectroscopy. In particular, the third data release (DR3; Gaia Collaboration et al., 2023c) presented for the first time the analysis of binary stars in the non-single star catalogue (see Gaia Collaboration et al., 2023a). More than 800 000 binary systems with orbital solutions are included, among which more than 180 000 are spectroscopic binaries. This is the largest sample of single-line spectroscopic binaries collected so far (see the review of El-Badry, 2024, for a detailed comparison of the *Gaia* binary star sample and previous compilations in the literature), offering a unique dataset to study binary stars in a holistic approach, having homogeneous and high-quality *Gaia* data available for all the sources.

Ellipsoidal binaries are systems in which the primary star gets tidally deformed, adopting an ellipsoidal shape. This geometric deformation produces that, during one orbital period, the photometric light curve shows two maxima and two minima. Hence, the photometric period results in being half of the orbital period. The study of the population of ellipsoidal variables can therefore provide useful constraints to (i) the expected tidal effects in binary systems (Nie et al., 2017); and (ii) population studies of asymmetric planetary nebulae, as they are considered their immediate precursors (see e.g., Jones & Boffin, 2017). Having *Gaia* data, both photometric and spectroscopic, provides us with the opportunity to characterize this population in terms of its physical parameters (luminosities, mass and radii) and, thereby, better understand the effects of tidal circularization and binary evolution.

2. Ellipsoidal red giant binaries in Gaia FPR

The Gaia Focused Product Release (FPR; Gaia Collaboration et al., 2023b) produced an additional catalogue of variability information, both in terms of photometric G, $G_{\rm BP}$, $\rm G_{RP}$ magnitudes and spectroscopic, radial velocity (RV) time series, for thousands of long-period, >40 days, variable stars. Among this sample, pulsating variable stars such as Mira and semi-regular variables are included, as well as long-secondary period variables and a subpopulation of non-pulsating sources, mainly composed of ellipsoidal variables. Based on their variability amplitudes, non-pulsating variables in this sample can be isolated as

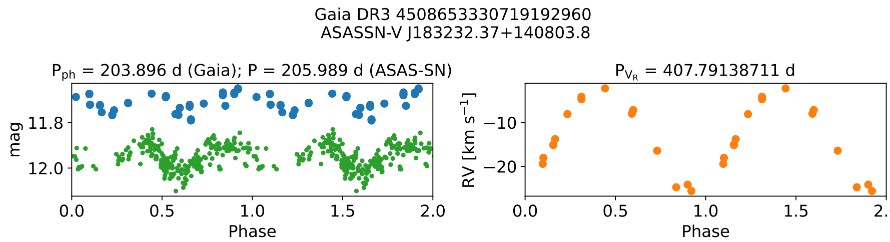

Figure 1. Photometric light curve (left panel) and RV time series (right panel) for one of the ellipsoidal candidates in our sample. The V-band light curve, in green, comes from the ASAS-SN, while the G-band (blue points, left panel) and RV (orange points, right panel) time series are from Gaia. The periods derived in each survey are shown in the title of each panel.

$$A_G < 0.3\,\text{mag} \quad \text{and} \quad \frac{A_G}{\text{mag}} < 2.5 \cdot 10^{-3} \cdot \left(\frac{A_{V_R}}{\text{km}\,\text{s}^{-1}}\right)^2 . \tag{1}$$

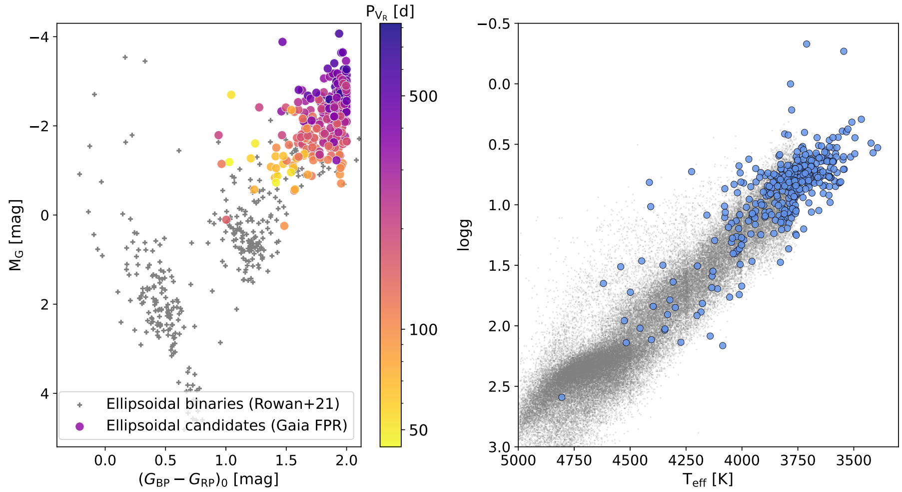

Figure 2. Left panel: Color-Magnitude diagram for the ellipsoidal candidates and those detected based on the photometric ASAS-SN by Rowan et al. (2021) (shown as grey crosses). The ellipsoidal binary candidates in *Gaia* are colored based on the orbital period, P_{V_R}. Right panel: Kiel diagram for the spectroscopic effective temperature and surface gravity of the ellipsoidal red giant binary sample. The grey points in the background are a comparison sample of stars having accurate atmospheric parameters from *Gaia* DR3.

This selection boundary separates pulsating, high-amplitude variables from those having relatively small G-amplitudes ($A_G \lesssim 0.2$ mag) and large RV variations ($A_{V_R} \gtrsim 5$ km s^{-1}, see Section 3 in Gaia Collaboration et al. 2023b). Figure 1 shows the G-band light curves and the RV time series of one of the ellipsoidal variables in the *Gaia* FPR. The V-band light curve from the All-Sky Automated Survey for Supernovae (ASAS-SN; Jayasinghe et al., 2018), where the source is classified as a semi-regular variable, is included as green dots. The photometric periods based on *Gaia* and ASAS-SN are compatible and correspond to half the RV (orbital) period. This example shows the advantage of *Gaia* data: despite having a smaller number of epochs, the cadence is enough to recover the variability while the epoch spectroscopy is complementary to the photometry to identify this kind of binaries.

The initial sample of ellipsoidal binaries is therefore composed of variable sources satisfying the condition in Eq. 1, as well as having compatible periods for the G, G_{BP} and G_{RP} photometric time series. Moreover, we restricted the sample to those sources having low parallax uncertainty ($\epsilon_{\varpi}/\varpi < 0.15$). From this sample, those having available atmospheric parameters (T_{eff}, $\log g$, [M/H]) from Gaia spectra (either from the Gaia Radial Velocity Spectrometer, RVS, or the BP/RP spectra, see Recio-Blanco et al., 2023; Andrae et al., 2023, respectively). We recovered more than 400 systems having atmospheric parameters, as well as photo-geometric distance estimates based on Gaia early DR3 parallaxes and photometry derived by Bailer-Jones et al. (2021). This unprecedented dataset, in terms both of the number of sources as well as the homogenous photometric and variability observations, allows us to derive luminosities, radii and masses of this population. Figure 2 shows the Color-Magnitude diagram (left panel) and Kiel diagram (right panel) for the ellipsoidal variable sample. For reference, the CMD includes the sample of ellipsoidal variables from the ASAS-SN in Rowan et al. (2021), while the Kiel diagram includes a sample of *Gaia* sources having precise atmospheric parameters from the *GSP-Spec* module (see Recio-Blanco et al., 2023). The extinction of the sources was obtained based on the observed (G_{BP} - G_{RP}) color and the expected intrinsic color for the effective temperature, using the color-T_{eff} relations for *Gaia* DR3 bandpasses[1]. Our sample of ellipsoidal binaries is located at the same position as the giant ellipsoidal variables from Rowan et al. (2021), as expected given the minimum orbital period considered in *Gaia* FPR being 35 days. In the Kiel diagram, our sample is consistent with cool K and M giants.

3. Physical parameters

Combining the *Gaia* measurements for the distance, spectroscopic T_{eff} and the apparent mean G magnitude with the derived extinction, the bolometric magnitude and luminosity of the primary star were derived. The radii and masses were derived by combining the luminosity and the spectroscopic atmospheric parameters (T_{eff}, $\log g$, see de Laverny et al. 2025, in preparation). The masses and radii obtained through these measurements were compared to the values obtained using asteroseismology observations for single stars in *Gaia* (Recio-Blanco et al., 2024), and red giant binaries from Beck et al. (2024). We found an excellent agreement in the measured radii, while the masses have a good agreement with a median bias difference in the spectroscopic estimates of 0.1 $M_\odot$, with a dispersion of 0.8 $M_\odot$.

Figure 3 shows the spectroscopic mass for the primary star derived in this work versus the minimum mass for the secondary component, obtained by solving the mass function of the system at a maximum inclination (i.e, $\sin i = 1$). The equivalent measurements for red giant ellipsoidal binaries in the Large Magellanic Cloud (LMC) from Nie et al. (2017) are shown as pink points. The distribution of masses in our sample is consistent with low and intermediate-mass primary stars, from $\simeq 0.45$ up to 5 $M_\odot$, slightly less massive than the distribution of ellipsoidals in the LMC. The masses of the secondaries are predominantly below 1.0 $M_\odot$, indicating low-mass companions (a main sequence or a compact object).

[1]https://github.com/casaluca/colte

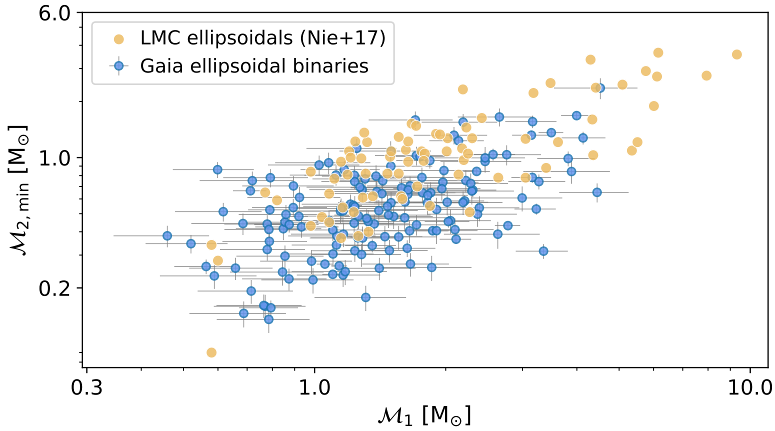

Figure 3. Mass of the primary star, $\mathcal{M}_1$ and minimum mass for the secondary star, $\mathcal{M}_{2,\mathrm{min}}$ for our sample of Galactic ellipsoidal red giant binary candidates, and the primary and secondary masses of ellipsoidal red giant binaries in the LMC, derived based on the modeling of the photometric and RV time series in Nie et al. (2017).

4. Conclusions

Previous measurements for this kind of stars were done based on the modelling of the photometric light curve, particularly for ellipsoidal binaries in which the primary star is a main-sequence (see e.g., Rowan et al., 2021), or using both photometry and spectroscopy for a limited sample, such as the 81 ellipsoidal red giant binaries in the LMC analyzed in Nie et al. (2017). Our sample is composed of more than 300 ellipsoidal red giant binaries, which allows us to analyse the physical and orbital (eccentricities, mass of the companion, tidal circularization) properties of this population for the first time in the Milky Way. The detailed analysis of this population, as well as a subsample of rotational variables, is published Navarrete et al. (2025).

Acknowledgements. This work has made use of data from the European Space Agency (ESA) mission Gaia (https://www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium (DPAC). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement.

References

Andrae, R., Rix, H.-W., & Chandra, V., Robust Data-driven Metallicities for 175 Million Stars from Gaia XP Spectra. 2023, *Astrophysical Journal, Supplement*, **267**, 8, DOI:10.3847/1538-4365/acd53e

Bailer-Jones, C. A. L., Rybizki, J., Fouesneau, M., Demleitner, M., & Andrae, R., Estimating Distances from Parallaxes. V. Geometric and Photogeometric Distances to 1.47 Billion Stars in Gaia Early Data Release 3. 2021, *Astronomical Journal*, **161**, 147, DOI:10.3847/1538-3881/abd806

Beck, P. G., Grossmann, D. H., Steinwender, L., et al., Constraining stellar and orbital co-evolution through ensemble seismology of solar-like oscillators in binary systems. A census of oscillating red giants and dwarf stars in Gaia DR3 binaries. 2024, *Astronomy and Astrophysics*, **682**, A7, DOI:10.1051/0004-6361/202346810

El-Badry, K., Gaia's binary star renaissance. 2024, *arXiv e-prints*, arXiv:2403.12146, DOI:10.48550/arXiv.2403.12146

Gaia Collaboration, Arenou, F., Babusiaux, C., et al., Gaia Data Release 3. Stellar multiplicity, a teaser for the hidden treasure. 2023a, *Astronomy and Astrophysics*, **674**, A34, DOI:10.1051/0004-6361/202243782

Gaia Collaboration, Gaia Collaboration, Trabucchi, M., et al., Gaia Focused Product Release: Radial velocity time series of long-period variables. 2023b, *arXiv e-prints*, arXiv:2310.06051, DOI:10.48550/arXiv.2310.06051

Gaia Collaboration, Vallenari, A., Brown, A. G. A., et al., Gaia Data Release 3. Summary of the content and survey properties. 2023c, *Astronomy and Astrophysics*, **674**, A1, DOI:10.1051/0004-6361/202243940

Jayasinghe, T., Kochanek, C. S., Stanek, K. Z., et al., The ASAS-SN catalogue of variable stars I: The Serendipitous Survey. 2018, *Monthly Notices of the RAS*, **477**, 3145, DOI:10.1093/mnras/sty838

Jones, D. & Boffin, H. M. J., Binary stars as the key to understanding planetary nebulae. 2017, *Nature Astronomy*, **1**, 0117, DOI:10.1038/s41550-017-0117

Navarrete, C., Recio-Blanco, A., de Laverny, P., & Escorza, A., A comprehensive Gaia view of ellipsoidal and rotational red giant binaries. 2025, *Astronomy and Astrophysics*, **696**, A82, DOI:10.1051/0004-6361/202453394

Nie, J. D., Wood, P. R., & Nicholls, C. P., The Orbital Nature of 81 Ellipsoidal Red Giant Binaries in the Large Magellanic Cloud. 2017, *Astrophysical Journal*, **835**, 209, DOI:10.3847/1538-4357/835/2/209

Recio-Blanco, A., de Laverny, P., Palicio, P. A., et al., Double red giant branch and red clump features of Galactic disc stellar populations with Gaia GSP-Spec. 2024, *Astronomy and Astrophysics*, **692**, A235, DOI:10.1051/0004-6361/202449443

Recio-Blanco, A., de Laverny, P., Palicio, P. A., et al., Gaia Data Release 3. Analysis of RVS spectra using the General Stellar Parametriser from spectroscopy. 2023, *Astronomy and Astrophysics*, **674**, A29, DOI:10.1051/0004-6361/202243750

Rowan, D. M., Stanek, K. Z., Jayasinghe, T., et al., High tide: a systematic search for ellipsoidal variables in ASAS-SN. 2021, *Monthly Notices of the RAS*, **507**, 104, DOI:10.1093/mnras/stab2126