Determination of Galactic Model Parameters and Space Densities of Cataclysmic Variables from Gaia DR3 Data

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ABSTRACT

The spatial distribution, Galactic model parameters and luminosity function of cataclysmic variables (CVs) are established using trigonometric parallaxes of Gaia DR3 re-estimated by Bailer-Jones et al. (2021). The data sample of 1,849 CVs in this study is claimed to be reliable as the distances are based on trigonometric parallaxes and the Gaia DR3 photometric completeness limits were taken into account when the sample was created. Space densities and scale heights were calculated by fitting the exp and sech² functions to the density profiles of CVs. The scale heights calculated for CVs increases towards shorter orbital periods. The space densities obtained in the study are in very good agreement with those observationally obtained by Pala et al. (2020) and those predicted by the simulations of Belloni et al. (2020), who used the reduced magnetic braking model of Li, Wu & Wickramasinghe (1994). The comparisons of the luminosity function of white dwarfs with the luminosity function of all CVs in this study show that 500 times the luminosity function of CVs fits very well to the luminosity function of white dwarfs.

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References: Original article

INTRODUCTION

Cataclysmic variables (CVs) are a class of double star systems consisting of a white dwarf primary and a secondary star, typically a late-type main sequence star. The secondary star fills the Roche lobe and transfers material to the white dwarf through an accretion disc, leading to a variety of observable events such as novae, dwarf novae, and nova-like variables with irregular changes in brightness due to the thermal instability of the accretion disk (Warner, 1995, Hellier, 2001,). CVs are a major focus of interest in the field of stellar astrophysics because of their complex evolutionary pathways, their variability, and the information they provide about binary star evolution and accretion processes.

METHODS AND MATERIALS

Systems classified as cataclysmic variables (CVs) in the literature were compiled from the catalogs. The equatorial coordinates (α, δ)J2000 and Galactic coordinates (l, b) of the systems were obtained from SIMBAD. The Gaia magnitudes (G, GBP, GRP) and trigonometric parallaxes (ω) of the CVs were taken from the Gaia Data Release 3 catalog (Gaia DR3, Gaia Collaboration 2022). The orbital periods (Porb) and the detailed parameters of the systems were obtained from the detailed studies in the literature. Systems with unknown or negative trigonometric parallaxes were excluded from the statistics, resulting in a catalog of 4,993 CVs.

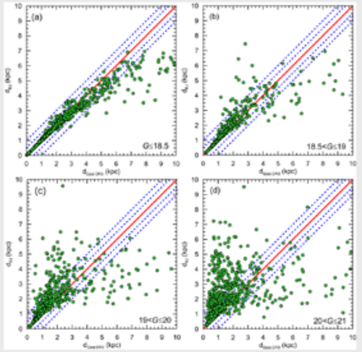


Figure 1. Comparison of CV distances obtained from Gaia DR3 and Bailer-Jones et al. (2021) (dBJ). Different G apparent magnitude intervals are shown in panels (a), (b), (c) and (d). The red line represents the one-to-one line and blue dashed lines 500 and 1000 pc distances from the red line.

RESULTS

As seen in Figure 1, it has been determined that the CVs in the G ≤ 18 magnitude range exhibit a more consistent distance distribution compared to the CVs in the other three fainter brightness ranges. Therefore, to work with a more sensitive CV sample in this study, the limiting apparent magnitude was set to G = 18, and 1,849 CVs were obtained.

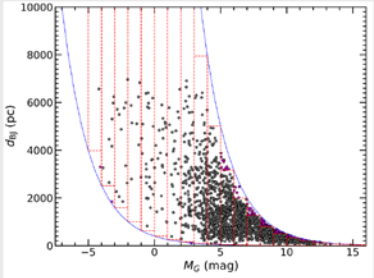
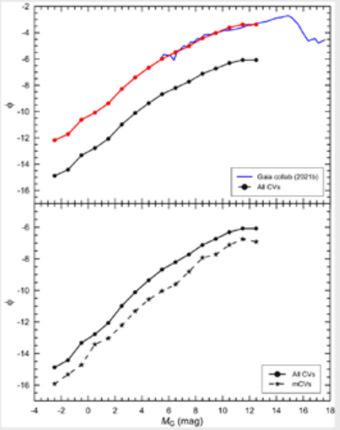


Figure 2. The absolute magnitudes MG of CVs in the preliminary sample against their distances dBJ obtained from Bailer-Jones et al. (2021). Red dashed lines show distances estimated from the bright (G = 9 mag) and faint (G = 18:5 mag) limiting apparent magnitudes for absolute magnitude intervals of 1 mag. Blue solid lines correspond to the bright and faint apparent magnitude limits.



RESULTS

Galactic model parameters

In the calculation of the Galactic model parameters for CVs, z-histograms generated for the distance intervals perpendicular to the Galactic plane were used. Although the Galactic model parameters in this study were obtained with an exponential (exp) function, Bilir et al. (2006a) demonstrated that the density profiles of late-type stars produced more consistent results with a hyperbolic secant (sech²) function.

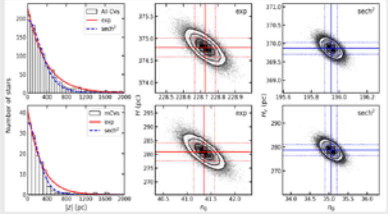


Figure 3. The z-histograms for CVs. The upper panel shows the z-histogram for All CVs in the sample and the lower panel magnetic systems (mCVs). The blue dashed line represents the sech2 function and the red solid line the exponential function. The 2-D posterior probability distributions of the model parameters sampled by MCMC are demonstrated to the right of the z-histograms.

Group	N	Function	n_0	H(pc)
All CVs	1587	exp	229±1	375±2
		sech^2	196±1	370±1
mCVs	124	exp	41±1	281±3
		sech^2	35±1	279±3

Table 1. The Galactic model parameters for All CVs and mCVs in the sample. Model functions are given in the third column. Here, exp denotes for exponential function and sech² for secans hiperbolicus square function. N is the number of systems in the object group, n_0 is the number of stars in the Solar neighbourhood, H the scale height for the model function.

Space Density

Space density is an important parameter for population synthesis studies based on theoretical evolutionary models of a selected object type. The space density of a group of stars is derived by dividing the number of stars in consecutive distances from the Sun to the corresponding partial spherical volumes: D=N/ΔVi,i+1. (Bilir et al. 2006a,b,c).

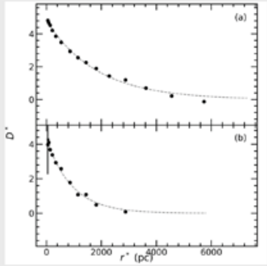


Figure 4. The logarithmic density functions of All CVs (panel a) and mCVs (panel b) in the sample. Dashed lines represent exponential ts applied to the data.

Group	N	D^*	D_0 ($\times10^{-6}$ pc^{-3})
All CVs	1587	4.83±0.07	$6.8^{+1.3}_{-1.1}$
mCVs	124	4.33±0.09	$2.1^{+0.5}_{-0.4}$

Table 2. The logarithmic and local space densities of CVs. Symbols for subgroups are as in Table 1. N denotes the number of stars in the subgroup, D_0 is the local space density and D* logarithmic space density.

Luminosity Function

The luminosity function is dened as the space density of objects in a certain absolute magnitude interval (Karaali et al. 2004; Ak et al. 2007). In this study, the logarithmic luminosity function (ϕ) was calculated for all CVs and mCVs were also computed.

Figure 5. Logarithmic luminosity functions of CVs. Lower panel shows luminosity functions for All CVs and mCVs. Upper panel demonstrates the logarithmic luminosity function for All CVs in the sample. Red line represent the 500 times the luminosity function of All CVs and the blue line logarithmic luminosity function of white dwarfs taken from Gaia Collaboration (2021b).

Distribution of cataclysmic variables in our Galaxy and their position in the HR diagram in the Gaia era

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Abstract

In this study, the distances of stellar systems classified as cataclysmic variables in the literature were determined by using the trigonometric parallaxes compiled from the Gaia DR3 catalog. The spatial distributions of cataclysmic variables in the heliocentric Galactic coordinate system are obtained and their positions in the Hertzsprung-Russell (HR) diagram constructed from Gaia colors are discussed. The height scales for the cataclysmic variables whose perpendicular distances from the Galactic plane were calculated were obtained from the sensitive astrometric data of Gaia DR3..

Introduction

Cataclysmic variables (CVs) are binary star systems consisting of a white dwarf as the primary component and a low-mass main-sequence star that fills its Roche lobe. Matter is transferred from the secondary to the primary through a gas stream and an accretion disk. In magnetic CVs, the strong magnetic field of the white dwarf prevents the formation of an accretion disk, and the matter accretes onto the white dwarf through accretion columns and channels.

A review of the literature on CVs highlights their significance in various fields, such as disk formation and evolution, binary star formation and evolution, compact objects, strong and moderate (106-108 G) magnetic fields, thermal and non-thermal radiation, mass transfer, solar-type magnetic cycles, and more. These systems also allow astrophysical research across nearly the entire electromagnetic spectrum, from X-rays to radio waves. While these characteristics make CVs scientifically valuable, the presence of numerous astrophysical processes simultaneously also complicates observational and theoretical studies.

In this study, systems classified as CVs in the literature were analyzed using photometric and astrometric data from the Gaia DR3 catalog. The three-dimensional distribution of these systems in the vicinity of the Sun and their positions on the Hertzsprung-Russell (HR) diagram were examined.

Data

Ritter & Kolb (2003) compiled a catalog of cataclysmic variables (CVs), low-mass X-ray pairs and related objects from the literature, including their equatorial coordinates (α, δ), apparent magnitudes (V), orbital parameters (P) and other characteristics. In our study, a total of 1709 CVs were obtained from recent papers and the proper motion ($\mu_\alpha\cos\delta$, μ_δ) components, trigonometric parallaxes (ϖ) and G, G_{BP} and G_{RP} magnitudes for these systems were obtained from the Gaia DR3 catalog.

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Results

Photometric data are affected by the interstellar medium. To correct for extinction and reddening in the photometric data, the color excess along the line of sight to the stars (from their Galactic coordinates (l, b) and trigonometric parallaxes (ϖ)) was obtained from the dust maps of Schlafly and Finkbeiner (2011), providing $E_\infty(B-V)$, $\langle E_\infty(B-V)\rangle$, and $E_d(B-V)$. For the color excess between the Sun and the stars, the Bahcall and Soneria (1980) formula,

$$E_d(B-V) = E_\infty(B-V)\,[1 - \exp(-|d\times\sin b| / H)],$$

was used. The extinction coefficients

$$A_{G_{BP}} = 1.002\times3.1\times E_d(B-V),$$
$$A_{G_{RP}} = 0.589\times3.1\times E_d(B-V),$$
$$A_{G0} = 0.789\times3.1\times E_d(B-V)$$

were calculated following Wang and Chen (2019), allowing the de-reddened colors G0, (GB)0, and (GR)0 to be determined.

The data set we obtained is divided into subgroups as shown in Table 1. The spatial distributions of the subdivided CVs are shown in Figure 1 and Figure 2 shows the distribution according to their absolute brightness and true color.

Table 1. Median distances of CVs by type.

Group	N	d' (pc)	X' (pc)	Y' (pc)	Z' (pc)
mCVs	132	578	-54	-4	19
non-mCVs	1577	1003	92	93	-13
All CV	1709	956	74	76	-11

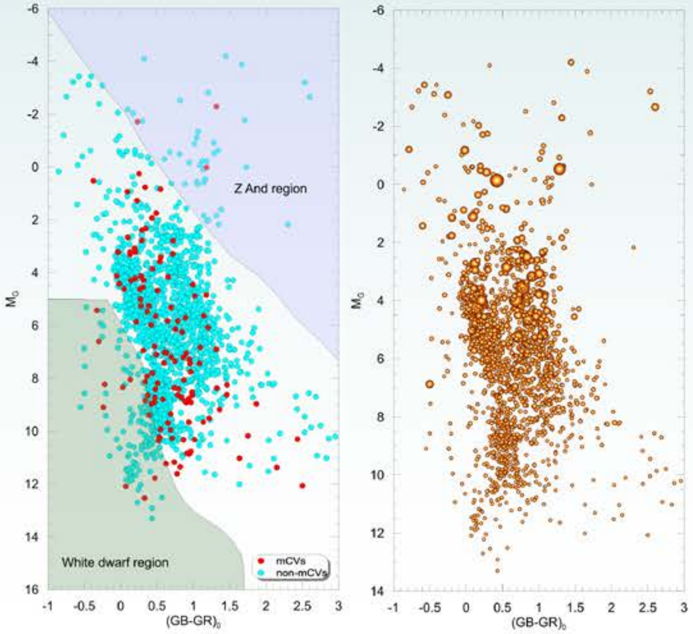

Figure 2. Distribution of known KDs in the HR diagram of Gaia DR3 data.

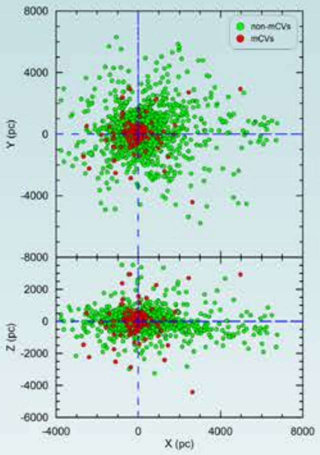

Figure 1. The spatial distribution of CVs with respect tothe Sun. X, Y and Z are Sun-centered rectangular Galacticcoordinates

Discussion and Conclusion

The spatial distribution of the CVs used in this study reveals a concentration towards the galactic center. Taking into account the absolute luminosity of the CVs and the σ_ϖ/ϖ value derived from the true colors, they exhibit the distribution illustrated in Figure 2 (right panel).In considering the HR diagram obtained for the CVs, if we focus on how to classify them based on components, Fusillo et al. (2019) established a boundary separating white dwarfs from main-sequence stars. When we apply this boundary to our dataset, we observe a dominance of white dwarfs among the CVs within this region. Additionally, a study by the Gaia collaboration (2019) explored the color-luminosity diagrams of variable stars, demonstrating the distribution of subtypes such as Z Andromedae (Z Andes), U Geminorum (U Gem), and cataclysmic variables (CVs). Upon digitizing the Z Andes region within the giant arm and comparing it with our study, it is evident that giant components dominate this area (Figure 2, left panel). For the objects situated between the two lines, the dominance of main-sequence components can be inferred.