# Symbiotic stars in Galactic open clusters

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**Abstract.** The age determination of symbiotic stars is essential to put further constraints on models explaining these binary systems. In the Galactic field, this is especially problematic because of several limitations due to reddening estimations, for example. We searched for symbiotic stars as members of Galactic open clusters for which the age and overall metallicity can be determined in a statistical sense. The most recent lists of well-established and candidate symbiotic stars and open clusters were matched, and we found seven good candidates from which the well-established symbiotic star CQ Dra seems to be a true member of the old open cluster HSC 1224. The colour-magnitude diagrams for the other candidates raise some doubts about membership.
**Key words:** symbiotic binaries – open clusters – stellar associations

## Introduction

Symbiotic stars are a particular type of interacting binaries. They generally consist of three components: (i) a hot star, typically a white dwarf or neutron star with an accretion disk, (ii) a cool star, either a red giant or a star on the asymptotic giant branch (AGB), and (iii) a nebula consisting of ionized material that has been lost by the cool component (Munari, 2019). The nebulae surrounding these objects are detected via various emission lines.

Symbiotic stars represent a crucial stage in the binary evolution of low and intermediate-mass stars. Among other objects, they are candidate progenitors of supernovae of type Ia (SNe Ia; Mikołajewska, 2013). Recently, Laversveiler et al. (2025) argued that the contribution of the single-degenerate channel of SNe Ia from symbiotic progenitors is estimated to be on the order of 1% for our galaxy. Additionally, symbiotic stars are important sources of soft and hard X-rays (Luna et al., 2013; Muerset et al., 1997).

These objects provide insights for studying the loss of matter, acceleration mechanisms of stellar winds, and accretion of stellar winds in late-type giants (Saladino et al., 2019). They also allow the analysis of mass transfer, the characteristics of accretion-disk boundary layers, and astrophysical jets (Schmid et al., 2017).

Symbiotic stars are classified into two main categories based on their near-infrared data (Webster and Allen, 1975): (i) those with a near-IR colour temperature of a K, M, or G-type giant (3000 to 4000 K; stellar or S-type), and (ii) those with a near-IR colour temperature of around 700 to 1000 K, indicating a circumstellar envelope surrounding a more evolved AGB star. Later on, further subgroups were defined or suggested by Akras et al. (2019); Allen (1982); Nussbaumer and Vogel (1987).

However, a lot of questions remain unanswered, probably because the number of confirmed Galactic symbiotic stars is about nearly 300, with about 750

**Table 1.** Galactic symbiotic stars taken from the latest version of the catalogue by Merc et al. (2019) as possible members of star clusters. The columns “Name” and “Class” are taken from the aforementioned list.

| *Gaia* DR3_ID | Name | Class | $\alpha$ (2000) | $\delta$ (2000) | Cluster |
|---|---|---|---|---|---|
| 464643791317333248 | LW Cas | Suspected | 44.33995 | +60.68879 | SAI 24 |
| 1683014206596170240 | CQ Dra | Confirmed | 187.52767 | +69.20088 | HSC 1224 |
| 5980480722594527872 | [MMU2013] 355.12+03.82 | Likely | 259.63451 | −30.92904 | CWNU 170 |
| 4058686267291546880 | Gaia DR3 4058686267291546880 | Suspected | 261.93828 | −29.86994 | HSC 2962 |
| 4066469336476655232 | PPA J1808-2355 | Suspected | 272.07708 | −23.92852 | Collinder 367 |
| 4155838500543591168 | VPHASDR2J183044.6-100757.4 | Suspected | 277.68563 | −10.13259 | HSC 225 |
| 2027037101299276928 | SSTGLMC G062.9176+00.0981 | Suspected | 297.50614 | +26.46056 | HSC 509 |

additional being most likely or suspected ones[3]. A lot of efforts were put into identifying unambiguous common characteristics, using photometry and spectroscopy over the entire electromagnetic spectrum (Akras, 2023; Akras et al., 2019; Lucy et al., 2024; Merc et al., 2021; Munari et al., 2021). Because of the typical binary separations of a few to tens of AU, they observed orbital periods on the order of hundreds of days to a few years (Gromadzki et al., 2013).

The age and lifespan of symbiotic stars mainly depend on the mass of the cool component. A star with $8\,M_\odot$ on the main sequence evolves in about 35 Myr to the red giant phase. It stays there for just a very short time. If we exclude the possibility that blue giants and supergiants may also form a corresponding binary system, about 35 Myr (depending on the metallicity and rotation) seems the lower limit for the age of symbiotic stars.

As described, symbiotic stars’ evolutionary status is essential to constrain the corresponding evolutionary models. It is well known that the age determination of Galactic field stars is not straightforward. For cool type stars, it can be done via isochrone fitting (Valle et al., 2021), gyro-kinematic techniques (See et al., 2024) or asteroseismology (Fritzewski et al., 2024), to mention a few. Because symbiotic stars are rather ”exotic“ binaries with unusual reddening values and energy distributions, most previously mentioned methods will result in large errors.

A way out of this dilemma is the search for symbiotic stars among members of star clusters. Because all members of a star cluster are assumed to be born from one molecular cloud, they exhibit the same age (and metallicity; Dias et al., 2021). Up to now, no symbiotic star has ever been confirmed in a Galactic globular cluster. Belloni et al. (2020) analysed the possible astrophysical reasons and found that most progenitors of these systems are destroyed through dynamical interactions in dense globular clusters before effectively becoming symbiotic stars. However, they should still be present in less dense clusters, but their overall rareness explains the absence.

With the availability of the *Gaia* data set, it becomes more and more important to discriminate between star clusters (remnants) and moving groups. The situation becomes complicated when trying to prove if an aggregate was formed from one molecular cloud and if the members are gravitationally bound (Faherty et al., 2018; Kushniruk et al., 2020).

[3] https://sirrah.troja.mff.cuni.cz/˜merc/nodsv/

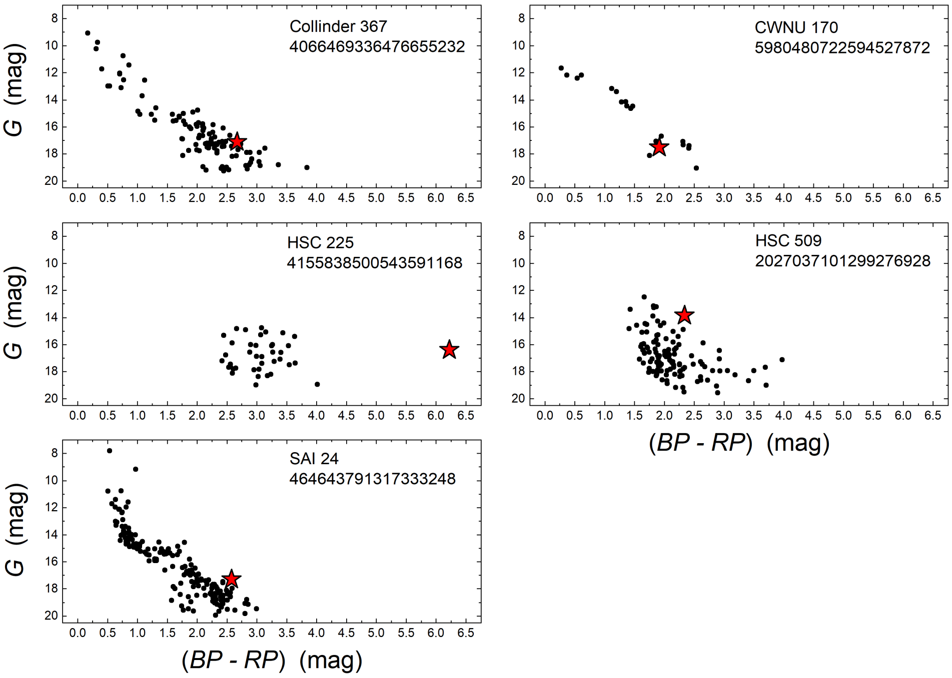


**Fig. 1.** The CMDs of the open clusters Collinder 367, CWNU 170, HSC 225, HSC 509, and SAI 24 together with the corresponding symbiotic candidate.

In this paper, we concentrate on symbiotic stars that are possible members of Galactic open clusters. Because of the *Gaia* satellite mission (Gaia Collaboration et al., 2016), the analysis of open clusters made enormous progress (Cantat-Gaudin, 2022). Based on the *Gaia* DR3 (Gaia Collaboration et al., 2023b), several independent studies analysed the members and cluster parameters of a significant number of aggregates (e.g. Alfonso et al., 2024; Hunt and Reffert, 2023). We compared lists of symbiotic stars and open clusters to find possible members.

## Target Selection

We took all established, likely, and suspected Galactic symbiotic stars from the recent version of the catalogue by Merc et al. (2019). We have not included the misclassified objects listed in this database. The matching was done via *Gaia* IDs of objects from this list. All objects were cross-matched with the cluster member list and membership probabilities by Hunt and Reffert (2023). This catalogue contains the parameters (age, reddening, and distance) of 7167 star clusters including moving groups. They used the widely applied Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN) algorithm (McInnes et al., 2017). It is well known that this method bears

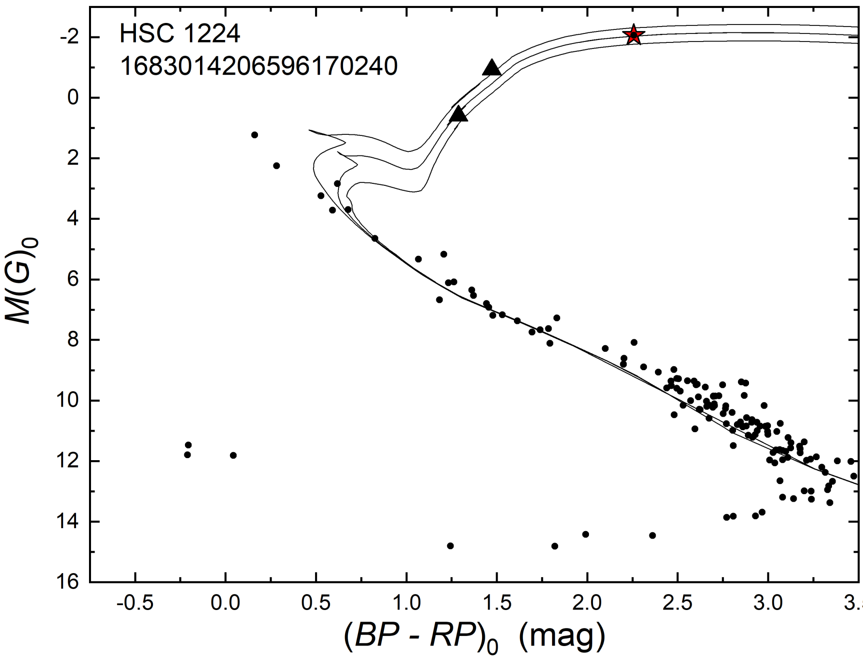


**Fig. 2.** The only confirmed symbiotic star of our sample, *Gaia* DR3 1683014206596170240 and its host open cluster HSC 1244. The triangles denote HD 40325 and HD 73131, two newly discovered members which support the derived age. The isochrones are from Bressan et al. (2012) with $\log t$ values of 9.2, 9.4, and 9.6, respectively.

some limitations and flaws, mainly when it is used as a numerical black box. Therefore, we utilised the positional, mean proper motion, and mean parallax information of the aggregates from Hunt and Reffert (2023) and all stars from the *Gaia* DR3 (Gaia Collaboration et al., 2023b). The matching limits of Prišegen et al. (2021) were employed and additional members of open clusters were identified. This ensures the best possible list of members using different approaches. We found seven symbiotic star candidates as possible members (Table 1).

## Results

We must stress that it is still challenging to determine cluster parameters, although we already get a reasonable estimate of the distances from the *Gaia* dataset (Dias et al., 2021; Netopil et al., 2015).

*LW Cas* and *SSTGLMC G062.9176+00.0981:* Here, we see turn-off points. Cavallo et al. (2024); Hunt and Reffert (2023) list ages less than 10 Myr for both open clusters. Whereas SSTGLMC G062.9176+00.0981 seems to be a blue star, LW Cas is red. However, these stars can only be red

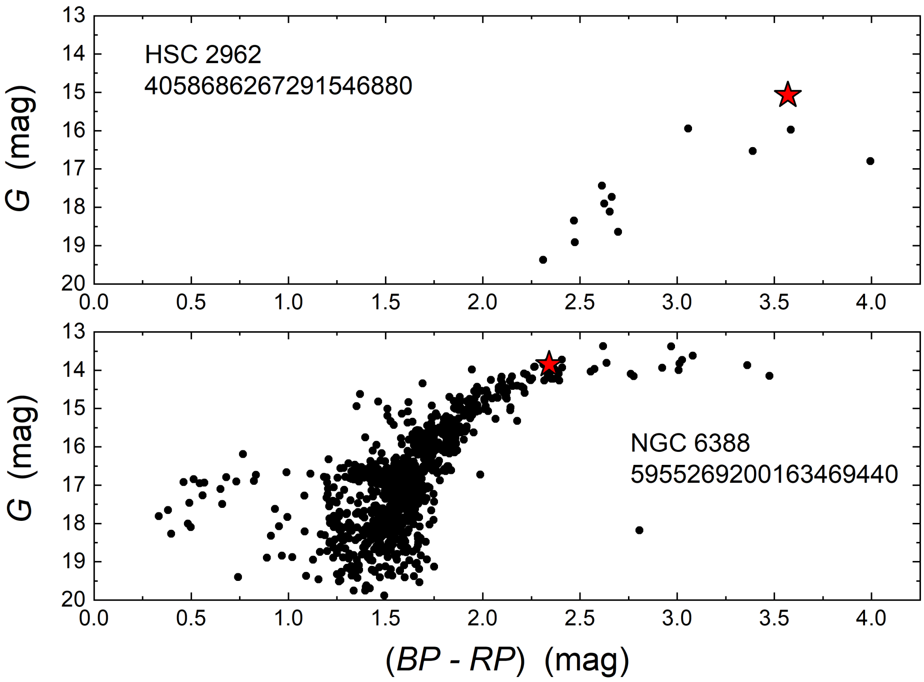


**Fig. 3.** *Upper*: *Gaia* DR3 4058686267291546880 located in the cluster HSC 2962, classified as an open cluster in Hunt and Reffert (2023). *Lower*: The globular cluster NGC 6388 with the candidate symbiotic star *Gaia* DR3 5955269200163469440 as a comparison. See text for a more detailed discussion.

giants if they have a significant selective reddening in the visual because their colours correspond to late-type objects. Another explanation for this unusual position for symbiotic stars would simply be misclassifications by previous studies. Especially LW Cas would become a Young Stellar Object (YSO) rather than a symbiotic star. Additionally, this star was classified as A0 III by Cohen (1980) and given the possibility of being an FU Ori star by Wenzel and Fuhrmann (1983), further making the classification as a symbiotic star debatable.

*CQ Dra:* This is our sample's only confirmed symbiotic star, first suspected by Eggleton et al. (1989) and confirmed via X-ray spectroscopy by Wheatley et al. (2003). The possible host cluster, HSC 1224 is very close to the Sun (145 pc) and listed with an age estimation of $7.74 < \log t < 8.38$ in Hunt and Reffert (2023). As described in Sect. 1, we searched for new members of the host clusters and found two (HD 40325 and HD 73131) for HSC 1224. We used the reddening $E(BP - RP) = 0.072$ mag derived from CMDs using synthetic $U$ magnitudes from BP/RP spectra (Gaia Collaboration et al., 2023a) and the corresponding distance to get the CMD shown in Fig. 2. The newly found members are on the red giant branch, which matches their spectral classification of early K-type luminosity class III stars (McDonald et al., 2012). CQ Dra is located at the giant branch with a $\log t$ of 9.4, respectively. Note that the presence of three White Dwarfs within this open cluster also points towards an older age. The turn-off point is difficult to determine. It seems that there two Blue Stragglers are present, which is also not unusual for an old open cluster (Jadhav and Subramaniam, 2021).

*[MMU2013] 355.12+03.82:* This star was first reported as a candidate symbiotic star by Miszalski et al. (2013). Based on their analysis, it shows emission in H I and maybe He I as well as absorption features of TiO and Na I D. The host open clusters do not show any turn-off point and must be considered young. The Symbiotic candidate is located close to the main sequence. Only selective absorption can place it in the giant region of the CMDs. This can, of course, lead to the conclusion that the star was misclassified previously and could be a YSO.

*Gaia DR3 4058686267291546880:* This star was reported as a possible symbiotic star in Rimoldini et al. (2023) by means of machine learning methods. It is located in HSC 2962, which is listed as an intermediate age (around 350 Myr) open cluster with an extreme reddening of six magnitudes in the visual and a distance of about 5 kpc (Hunt and Reffert, 2023). A comparison with the CMD of the globular cluster NGC 6388 and the location of *Gaia* DR3 5955269200163469440 (Rimoldini et al., 2023) shows conspicuous similarities (Fig. 3). Hunt and Reffert (2023) included NGC 6388 in their compilation and list an extremely high visual absorption of 3.3 mag and an age estimation between 25 Myr and 380 Myr. However, it is known that it has an age of at least 11 Gyr and a reddening of only one magnitude at most (Carretta and Bragaglia, 2022). Also for HSC 2962, the reddening values from different other sources (Amôres et al., 2021) result in half the value given in Hunt and Reffert (2023). Taking realistic reddening, age and distance values, we conclude that *Gaia* DR3 4058686267291546880 is on the red giant branch of the incorrectly classified globular cluster HSC 2962. However, due to the relative faintness and low number of the members reported by Hunt and Reffert (2023), this cluster is difficult to characterise in detail and thus may not exist. This idea is strengthened by the relatively low astrometric signal-to-noise ratio in Hunt and Reffert (2023) who assign a value of $\sim 3.36$ to this quantitiy, while mentioning that all clusters with astrometric S/N below 5 are to be taken cautiously.

*PPA J1808-2355*: The star is listed as a candidate symbiotic star in the Hong Kong/AAO/Strasbourg H$\alpha$ planetary nebula database (HASH, Parker et al., 2016). It shows emission in the Balmer lines and also [NII]. It is also one of the stars that seem to be more on the (pre-)main sequence rather than on the giant branch. This again would only be possible due to either misclassification, extreme extinction or poor membership to the cluster. Further detailed analysis is needed.

*VPHASDR2J183044.6-100757.4:* This is quite a particular case as seen in Fig. 1. The host open cluster can hardly be recognised by its CMD. It is a cloud of stars spreading over 1.5 mag in colour and 2.5 mag in apparent magnitude. This is reflected by very different cluster parameters in the literature (Cavallo et al., 2024; Hunt and Reffert, 2023). VPHASDR2J183044.6-100757.4 is three magnitudes redder than the other stars, which would place it in the red giant region. The cluster is located in the Galactic disc (Galactic latitude of $-0.0696°$) with a significant reddening. Therefore, getting more precise photometric data of fainter stars seems to be difficult, but it is necessary to analyse this open cluster in more detail. The star was identified as a symbiotic candidate by Akras et al. (2019) making use of machine learning methods based on infrared colours, specifically from 2MASS and WISE.

### Check for YSO contamination

A few of our candidates seem too close to the main sequence of their host clusters, making it difficult to decide from that alone if they are symbiotic stars (Fig. 1). The stars in question were checked for their spectral energy distributions (SED) in order to discern them from young stellar objects (YSO). We checked the Virtual Observatory SED Analyzer (VOSA; Bayo et al., 2008) for their characteristics in the infrared. Two out of three stars, LW Cas and PPA J1808-2355, show infrared excess, making it more likely for them to be YSOs rather than symbiotic binaries. In the case of [MMU2013] 355.12+03.82, VOSA could not detect any IR excess.

## Conclusions and Outlook

We presented a search for symbiotic stars and candidates that are members of Galactic open clusters. Matching the newest lists resulted in seven good candidates. A closer look at the cluster parameters and CMDs revealed the shortcomings of the black-box algorithm in this research field. Specifically, there are problems with membership analysis using HDBSCAN which can be overconfident in detecting clusters, resulting in a number of false positives (Hunt and Reffert, 2023). Also, each machine learning method used in the literature comes with their own disadvantage in terms of how the data are processed and analysed. Additionally, we found that two symbiotic star candidates from the catalogue of Merc et al. (2019) seem to be YSOs according to their SEDs. Our results show that symbiotic stars indeed be found in open clusters, this allows us to put more constraints on the age of these objects, given proper astrometry and cluster membership analysis. We see that especially for CQ Dra where we get to an age of $\log t \approx 9.4$.

We want to stress that proper motion and parallax measurements for extended objects and binaries might pose a problem within the *Gaia* data sets. Initially, each object is treated as a single star. If the solution is unsatisfactory, several corrections caused by binarity were applied (Halbwachs et al., 2023). This includes acceleration and orbital models for unresolved binaries with either components that do not vary photometrically or one component that is always much brighter than the other. However, such corrections are always limited. Merc and Boffin (2025) mention an effect of the orbital period on the parallax measurements, making the parallax unreliable for shorter periods. Another problem might be the parallax measurements of intrinsically extended objects, such as symbiotic stars with nebulae. A similar situation is found for Planetary Nebulae for which González-Santamaría et al. (2021) discussed possible shortcomings. Therefore, several symbiotic stars as members of open clusters could be undetected. The upcoming fourth data release of the *Gaia* consortium might resolve this issue.

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