A study of Cepheids in open clusters in the Gaia eDR3 era

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Based on the results published by Medina et al. (2021)

Motivation

Cepheids in open clusters (OCs) present several specific interests, e.g., the calibration of the Cepheid period-luminosity and period-age relation (PAR), or for chemical abundance studies of Cepheids.

However, only a small number of bona fide cluster Cepheids is currently known. This could be because they are inherently rarely associated, or due to observational biases.

We performed a census of Galactic cluster-Cepheids with state-of-the-art catalogs taking advantage of the Gaia unprecedented data quality. In addition, we determined the age of OCs to study their (dis)agreement with the theoretical PAR.

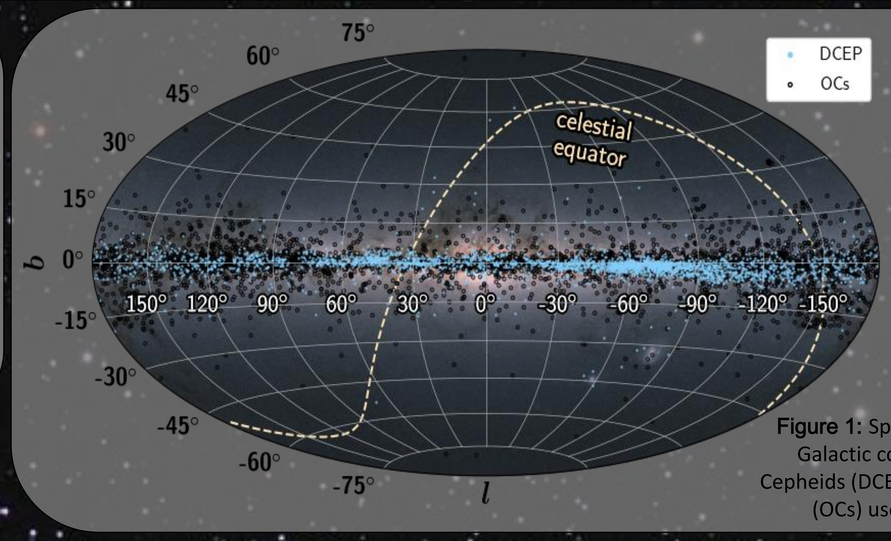

Figure 1: Spatial distribution in Galactic coordinates of the Cepheids (DCEP) and open clusters (OCs) used in this work.

Membership determination

In order to look for cluster-Cepheid pairs (combos), we focused on astrometric and kinematic information mainly from Gaia DR2 and eDR3 (parallaxes, and proper motions). Radial velocity information was also used, when available (e.g., from [7] and [14]).

The dataset used is a compilation of cluster (e.g. [6], [8], [11]) and Cepheid catalogs [e.g. OGLE, Gaia DR2, GCVS, VVV], consisting of a total of 4,140 clusters, and 2,921 Cepheids (**Fig. 1**).

After an initial on-sky crossmatching, over 40,000 potential pairs were considered.

We follow the Bayesian approach of [1].This method allow us to quantify the membership probability P(A|B) of each pair assuming:

$$P(A|B) \sim P(A) \times P(B|A)$$

where the prior P(A) is computed based on the on-sky separation of the cluster-Cepheid pair and falls off exponentially for Cepheids outside their cluster's core, and P(B|A) is the likelihood resulting from determining the Mahalanobis distance of the pair when considering the astrometry and kinematics of the pair.

Cluster Cepheid census

From the cluster-Cepheid pairs with higher P(A|B), 163 have membership probabilities higher than 1%, 67 higher than 10%, and only 44 over 25%.

We are able to confirm several cluster-Cepheid associations as bona fide, such as *NGC 6067* and *V0340 Nor* (**Fig. 2**), *Berkeley 55* and *ASASSN-V J211659*, and *Lynga 6* and *TW Nor*.

Based on the data used for this work, we are not able to recover a group of cluster-Cepheid pairs from the literature (e.g. *Collinder 394* and *BB Sgr*, *Berkeley 58* and *CG Cas*, *Ruprecht 175* and *X Cyg*).

We also report several clusters potentially hosting more than one Cepheid.

Examples of pairs of interest, including new combos are: *Gaia 5* and *V0423 CMa, Kronberger 84* and *ASASSN-V J213533.70, FSR 0172* and *Dauban V16*, *UBC 130* and *SV Vul, LP 1937* and *DF Cas,* and *UBC 290* and *X Cru* (**Fig. 3**).

Age determination

To age-date the clusters, we limit ourselves to cluster membership established in previous studies (e.g. [5]). Photometry in the G, GBP, GRP, and near-infrared bands (J, H, and K) was used.

We adopted two approaches: a χ^2-based one developed on our own, and one using the AURIGA neural network [12].

For the χ^2 method, we used the PARSEC stellar evolution models [4]. Because rotationally induced instabilities affect the evolution of stars, we also adopted MIST evolutionary tracks that consider rotation [15,9]. We used cluster distances, E(B-V), metallicities, and ages from the literature as initial conditions for the fitting routine.

The precision of the age determinations was of the order of 0.2 dex, even when the examined clusters contain post main-sequence stars (**Fig. 2**).

Conclusions

After investigating over 40,000 combos, we found 67 with association probabilities > 10%.

We confirm 19 cluster Cepheids previously considered bona-fide, and question the established membership of other 6 associations.

We identified 138 cluster Cepheid candidates of potential interest, mainly in recently discovered open clusters. However, only a subset are considered good candidates.

The number of Cepheids currently hosted by OCs remain low (< 5%), albeit the significant increase in the number of clusters in the recent years. The low fraction of Cepheids in OC could be an indication of the rapid dissoultion of young clusters, or that they are born elsewhere.

We advocate for dedicated follow-up studies for combo confirmations.

We conclude that current (young) cluster age determinations do not reach the accuracy required to serve as a check of the Cepheids PAR (**Fig. 4**). We argue that this occurrs due to the lack of clearly defined MSTO and evolved stars in young open clusters (especially the less massive ones).

References

[1] Anderson R. I., Eyer L., Mowlavi N., 2013. MNRAS, 434, 2238.
[2] Anderson R. I., et al., 2016, A&A, 591, A8
[3] Bono G., et al., 2005, ApJ, 621, 966
[4] Bressan, A. et al., 2012. MNRAS, 427, 127
[5] Cantat-Gaudin T., et al., 2018. A&A, 618, A93
[6] Cantat-Gaudin T., et al., 2020, A&A, 640, A1
[7] Carrera R., et al., 2019, A&A, 623, A80
[8] Castro-Ginard A., et al., 2020, A&A, 635, A45
[9] Choi J., et al., 2016, ApJ, 823, 102
[10] De Somma G., et al., 2020, MNRAS, 496, 5039
[11] Hunt E. L. & Reffert S., 2021, A&A, 646, A104
[12] Kounkel M., Covey K., Stassun K. G., 2020, AJ, 160, 279
[13] Medina G. E., Lemasle B., Grebel E. K., 2021, MNRAS, 505, 1342
[14] Mel'nik A. M., et al., 2015, AN, 336, 70
[15] Paxton B., et al., 2011, ApJS, 192, 3

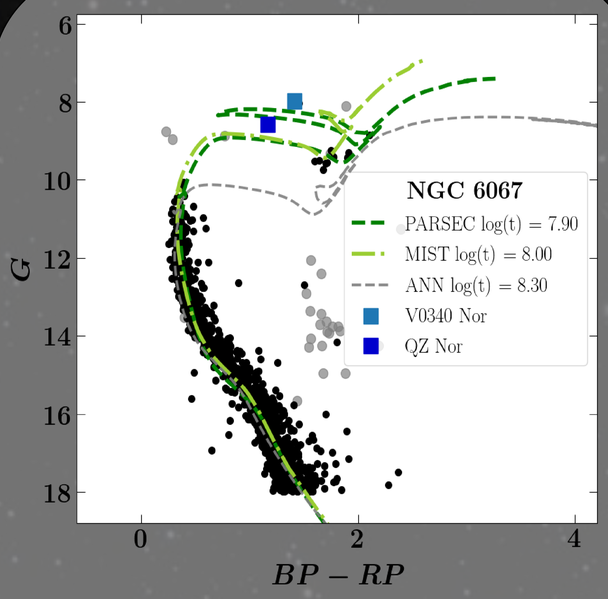

Figure 2: Color-magnitude diagram of one of the few Galactic clusters believed to host more than one Cepheid, showing presumed and likely cluster members (grey and black, respectively). The best-fit isochrones from different models and techniques are overplotted in green and grey.

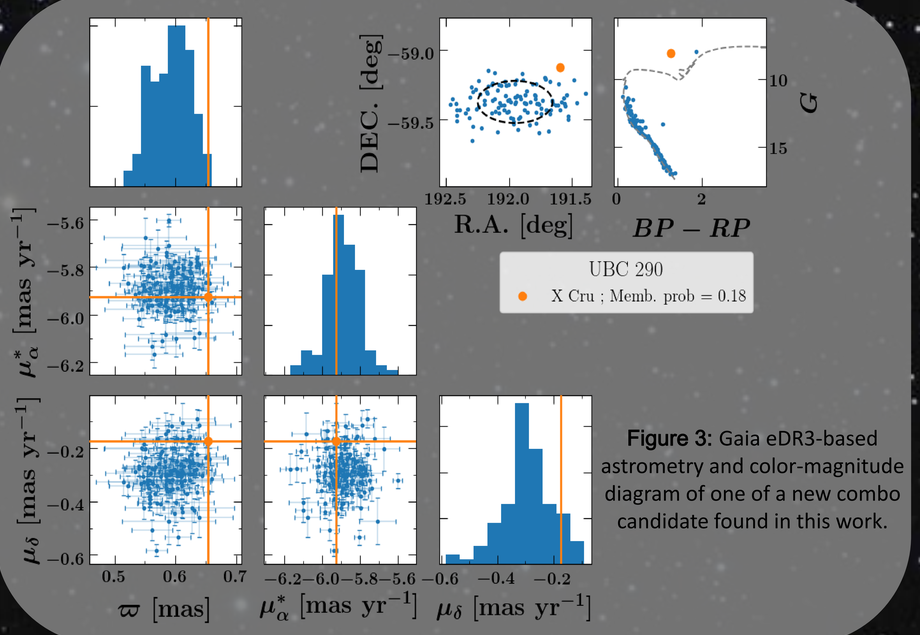

Figure 3: Gaia eDR3-based astrometry and color-magnitude diagram of one of a new combo candidate found in this work.

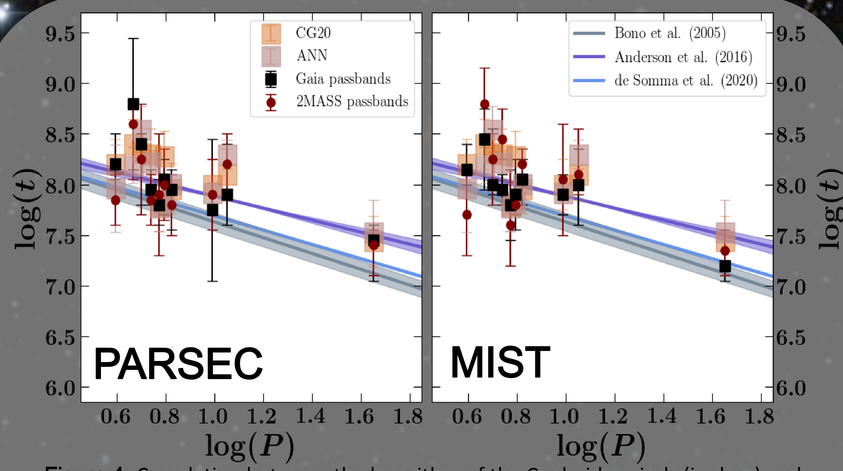

Figure 4: Correlation between the logarithm of the Cepheid periods (in days) and the cluster logarithmic ages (in years). Different symbols represent cluster ages obtained from Gaia and 2MASS photometry (this work), from the use of the ANN (this work), and those taken from the literature [6]. The theoretical PAR for fundamental-mode Cepheids derived by [3], in gray, [2], in blue, and [10] in light blue, for Z = 0.010, 0.014, and 0.020, respectively.