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A SEARCH FOR NEW OPEN CLUSTERS HOSTING CEPHEIDS

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Abstract. We analyze yet-unknown genetic links between open star clusters (OSCs) and galactic Cepheids and report the results of the new search for Cepheids – probable OSC members. A sample of 25% of the stars from a new catalog by Berdnikov (published in Melnik et al. 2015) which lists 674 Cepheids with reliable parameters was investigated. Based on photometric and kinematic data, we selected 17 Cepheids that are likely to be related to star clusters, four of which being new OSCs discovered by us.

Key words: stars: variables: Cepheids – open clusters and associations: general

1. INTRODUCTION

The modern universal distance scale is based on the Period-Luminosity (PL) relation for classical Cepheids. Scientists use several techniques to determine its zero point: highly accurate trigonometric distances to Cepheids; luminosities estimated from pulsation radii of Cepheids (variations of the Baade–Becker–Wesselink technique, see Barnes and Evans 1976; Balona 1977; Rastorguev et al. 2013); photometric distances to young open star clusters whose members are Cepheids (Berdnikov et al. 1996; An et al. 2007). The latter method seems to produce better results because the cluster distances, their color excesses and ages can be evaluated more reliably using the technique of fitting clusters color-magnitude diagrams (CMDs) with theoretical isochrones.

According to the common point of view, the majority of stars are born in star groups – star associations and young open star clusters (OSCs). Consequently, we can expect many Cepheids, which are young stars, supergiants and giants, with ages below 300 Myr to be detected near such objects. A search for clusters and associations linked genetically to Cepheids is being conducted for the last five dozen years. Summing up contributions by many authors during this period, Turner & Burke (2002) published a list of 46 Cepheids – member candidates in 44 clusters or associations. However, to draw out the PL relation, the authors typically used not more than a dozen of probable Cepheid cluster members (Berdnikov et al. 1996; An et al. 2007). The main problem here is the proof of the Cepheid's membership

in a cluster. To do this reliably, one needs accurate estimations of various physical properties of both the Cepheid and the cluster, including, normally, the distance, age, metallicity, radial velocity, proper motions.

Thanks to the All Sky Automated Survey (ASAS) by Pojmanski (1997, 2002) and Pojmanski et al. (2005), a large number of new Galactic Cepheids have been discovered during the recent years. In addition, many authors conducted a search for unknown galactic clusters triggered by new large infrared surveys (Kronberger et al. 2006; Froebrich et al. 2007; Glushkova et al. 2010; Schmeja et al. 2014; etc.). These investigations resulted in a nearly two-fold increase in the number of known OSCs and Cepheids in our Galaxy.

Recently, new attempts have been undertaken to find Cepheids attributable to open star clusters. Anderson et al. (2013) cataloged all data on physical parameters of OSCs and Cepheids available in the literature: distances, color excesses, metallicities, ages, radial velocities, and proper motions. On their own, the authors measured the radial velocities of 103 Cepheids accurate to 10 $\mathrm{m\,s^{-1}}$ and derived the PL relation based on the data sample involving distances to 622 stars. Taking all data on 900 OSCs and 1021 Cepheids, Anderson et al. (2013) evaluated the probabilities of Cepheids membership in the clusters. Out of nearly 4000 Cepheid–OSC combinations, they proved a genetic relation between the variable star and the cluster in 23 cases, with five combinations being new.

Another massive search for cluster-related Cepheids was conducted by Chen et al. (2015). The authors used the data on the Cepheids available in the literature and calculated the physical properties of the clusters themselves, using JHK-photometry data from the 2MASS and UKIDSS surveys. Chen et al. (2015) reported eight new Cepheid–cluster pairs.

In this paper, we are making a new attempt to discover Cepheids coupling with clusters or associations. The cited authors typically checked such a genetic linkage of Cepheids to OSCs described in the literature, whereas we extended this program by searching JHK_s data in the 2MASS catalog for yet-unknown star clusters and verifying them by means of the technique developed by Koposov et al. (2008).

1. DATA

1.1. Cepheids

As the core catalog, we took the list of 674 Cepheids by Berdnikov (published in Melnik et al. 2015) containing the stars from the GCVS (General Catalog of Variable Stars, Samus et al. 2007–2013) and the Cepheids from the ASAS (Pojmanski et al. 1997, 2002; Pojmanski et al. 2005) survey, whose classification was confirmed during long-term multicolor photometric measurements (Berdnikov et al. 2009ab, 2011). For all stars on this list, homogeneous series of observational data are available; accurate values are determined for the periods and mean magnitudes in the $BVRI$ filters; E_{B-V} color excesses are derived using intrinsic colors (Dean et al. 1978) and used, with the involvement of the PL relation from Berdnikov et al. (1996), to calculate approximate distances to the Cepheids that are needed to compare the relative space positions of the Cepheids and OSCs. We borrowed JHK_s magnitudes of Cepheids from 2MASS (Skrutskie et al. 2006) and the literature (provided the mean values were available). To calculate the ages of

the Cepheids, we employed the formula

$$\log t = 8.49(\pm 0.03) - 0.77(\pm 0.025) \log P \quad (1)$$

derived by us using evolutionary tracks for optical data by Girardi et al. (2002) and the PL relation by Berdnikov et al. (1996). Proper motions of the Cepheids are taken from the HIPPARCOS (van Leeuwen 2007) and UCAC4 (Zacharias et al. 2013) catalogs; radial velocities and metallicities of the variable stars were collected in the literature.

1.2. Clusters and associations

For both OSCs and OB associations, we used the 2MASS catalog as the source of photometric data (JHK_s) and the UCAC4 catalog as the source of data on proper motions. The list of OB associations is supplied by Melnik & Efremov (1995). The coordinates of cluster centers, radial velocities, and metallicities of known OSCs were taken from the catalogs by Dias et al. (2002) and Kharchenko et al. (2013) and the papers by Schmeja et al. (2014) and Scholz et al. (2015). Besides, we undertook a search for new clusters in the vicinity of the Cepheids, first, among the density peaks detected earlier by us when processing the 2MASS data, yet not analyzed in our papers (Koposov et al. 2008; Glushkova et al. 2010), and also among star concentrations visually detectable on optical maps from the DSS.

2. RELATIONSHIP BETWEEN OPEN STAR CLUSTERS AND CEPHEIDS

2.1. Methodology

As a first step, we searched known clusters and density peaks (see Subsection 1.2) for potential candidate Cepheid–cluster pairs within a circle of 60 arcmin radius around every Cepheid. At 800 pc from the Sun, the radius of 60 arcmin corresponds to 14 pc, that is, our search was conducted in wider areas as compared to the theoretical tidal radius in the solar region for cluster masses of 300–400 $M_\odot$.

Then, for each cluster and/or density peak found at the first step and suspected in "genetic coupling" with Cepheids, we built the J vs. J–H diagram along with the corresponding Cepheid and the instability strip. As the mean line of the instability strip, we employed the PL relation by Berdnikov et al. (1996), its red- and blue-color boundaries being drawn at the distance of $\Delta(J-H) = \pm 0.1$ mag from the mean line, which corresponds to the width of the instability strip for the LMC Cepheids (Sandage & Tammann 2006).

To further process the selected objects, we fitted the CMD of the cluster with a corresponding isochrone by Bonatto et al. (2004) using the technique developed by the authors and described elsewhere (Koposov et al. 2008). To judge whether a Cepheid belongs to a cluster, we checked the star against the complex criterion of its simultaneous hits on both the instability strip and the cluster isochrones allowing for possible differences in the ages and absorption in the directions toward the Cepheid and the cluster.

A lack of high-quality data on proper motions in the UCAC4 catalog, together with improper star accounting as members of the clusters, makes it impossible to accurately determine mean proper motions of cluster candidates. Therefore, as the mean proper motion of the cluster, we used the mean value of the proper motions

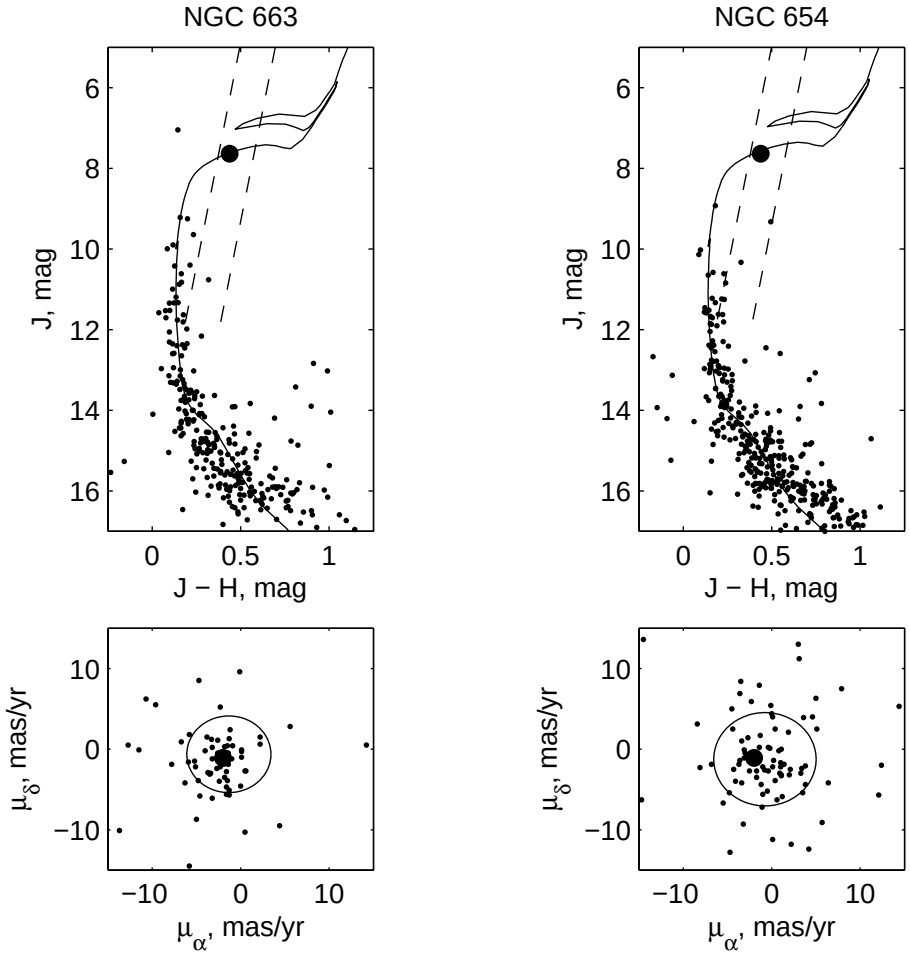

Fig. 1. The color–magnitude diagrams and proper motion distributions in the 5-arcmin fields of the clusters NGC 663 and NGC 654. The large solid dot is the Cepheid BY Cas. The NGC 663 CMD is fitted using the isochrone with $\log t = 7.9$, $E_{J-H} = 0.19$ mag, $J - M_J = 12.06$ mag; the NGC 654 CMD, using the isochrone with $\log t = 7.9$, $E_{J-H} = 0.19$ mag, $J - M_J = 12.00$ mag.

of all stars in the UCAC4 catalog in the field of the cluster with a diameter of 5 arcmin. As an additional kinematical criterion of the Cepheids membership in the cluster, we used the agreement between the Cepheid's proper motion and the mean proper motion of stars in the field within the mean proper motion error of cluster stars.

In the cases when the authors knew the radial velocities and metallicities from the literature, their agreement for the Cepheid and the cluster served as another criterion confirming the Cepheid membership in the cluster.

Fig. 1 illustrates the positions of the Cepheid BY Cas in the color–magnitude diagrams and the proper motion diagrams of the clusters NGC 663 and NGC 654: this Cepheid shows connections with three OSCs (see Table 1). The diagrams are

Table 1. The list of Cepheids probably related to the clusters.

Cepheid	Cluster/association
V493 Aql	NGC 6735
RW Cam	Tombaugh 5
UX Car	IC 2581
XZ Car	Ruprecht 93
CY Car	Collinder 236
ER Car	Stock 13
FF Car	OSC 161.01462 − 58.48389
GZ Car	OSC 155.12613 − 59.68861
BY Cas	NGC 663, NGC 654, NGC 659, Cas B8
VY Cyg	FSR 253
BZ Cyg, V514 Cyg	OSC 311.90482 + 45.07656
V386 Cyg	OSC 318.45887 + 41.91009
V532 Cyg	Basel 14
V Lac, X Lac	FSR 384
ASAS J101016-5811.2	BH 90

drawn for all stars within the circle centered at the cluster centers, with a diameter of 5 arcmin. The solid curves in the top panels correspond to the isochrones computed with overshooting taken into account; the dotted lines stand for the instability strip. In the bottom panels, the proper motion diagrams are shown, with the Cepheid plotted as a solid dot; the radius of the circle drawn around the cluster centroid corresponds to the mean error of individual stellar proper motions; it was used additionally for Cepheids' selection as cluster members.

3. RESULTS

At the current stage of our investigation, we studied 230 of the 674 Cepheids. Among them, we discovered 17 new cluster member candidates, four clusters being earlier unknown OSCs, and the FSR 253 cluster, although being known, but not included in the catalog by Dias et al. (2002). Additionally, we found four new open clusters (0.56625 +61.88928, 158.81921 –60.69119, 162.63768 –58.71387, 163.32586 -59.69245) near the Cepheids, but the connection between the Cepheids and the clusters is not confirmed. Table 1 lists the Cepheids and the clusters probably related to them. In two cases, one OSC relates to two Cepheids. The star BY Cas has parameters similar not only to the nearest cluster NGC 663 but also to the clusters NGC 654 and NGC 659 and the association Cas 8, all located in the vicinity of the star.

Note that Chen et al. (2015) considered the pair XZ Car and ASCC 64 but set its status "uncertain", whereas we believe that the Cepheid XZ Car can probably be coupled with the cluster Ruprecht 93.

4. CONCLUSIONS

We completed a preliminary search for young open star clusters and associations, known as well as unknown in the literature, within the circles of a radius of 60 arcmin around each of 230 Cepheids on the list by Berdnikov (Melnik et al. 2015). To confirm the membership of the Cepheids in OSCs, we applied empiri-

cal criteria based on physical properties both of the Cepheids and clusters, their relative positions and kinematic parameters. 17 Cepheids were identified as probable candidate OSC members; four clusters were discovered using data from the 2MASS survey. It will subsequently be possible to use these Cepheids to improve the period–luminosity relation and to reveal statistical regularities in the mutual distribution of young open star clusters and Cepheids.

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