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Photometric study of close binary stars in the M35, M67, and M71 Galactic clusters

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Abstract. We obtained new multicolour photometry of close binary stars in the young open cluster M35, the solar-age open cluster M67, and the globular cluster M71. New observations have been carried out at the TÜBİTAK National Observatory (TUG) by using the 100 cm (T100) telescope. We present observational results for eclipsing binary systems in the selected Galactic clusters. New accurate light curves for 2MASS J19532554 + 1851175, 2MASS J19533427 + 1844047, 2MASS J06092044 + 2415155, and AH Cnc were obtained. We analysed the light curves and derived some of the orbital parameters of the systems.
Key words: stars: binaries: close – clusters: open – clusters: globular

1. Introduction

Stellar clusters are very important tools for studying stellar formation and evolution, as well as the formation, structure, and dynamical evolution of the Galaxy. There are more than three thousand open clusters and about a hundred and fifty globular clusters in the Milky Way. Globular clusters are important in determining the lower limit of the age of the Universe. Open clusters are made up of relatively young stars, while globular clusters are composed of very old and metal-poor stars. Typical globular and open clusters contain stars with very different masses and with different properties in the HR diagram. The binary systems in the star clusters, especially at the turn off point of the main sequence, provide great opportunities for studying the evolution of both the clusters and the binary systems. Therefore star clusters are ideal laboratories for testing and calibrating stellar evolution theories. For details, see Meynet et al. (1993), Harris (1996), Elmegreen & Efremov (1997), Chantereau et al.(2015), Chantereau et al.(2016), Hurley et al. (2005),Prantzos & Charbonnel (2006), Decressin et al. (2007), Yakut et al. (2009), Bilir et al. (2012), Yakut et al. (2015).

Galactic globular clusters are compact and old systems which contain more than 1 million stars. So, there is a very high probability of collision of the stars with each other. Globular clusters host a lot of binary stars. Studying binaries in a cluster has some advantages. For instance, all binaries are at equal distances from us, have (almost) same chemical composition and (almost) same

age. Nevertheless, the masses of the stars differ from one to another. By using stellar parameters of binary system, we can test the theoretical evolutionary models and elucidate some poorly understood astrophysical phenomena such as mass loss, mass transfer, physical parameter variations during the evolution, angular momentum problem, etc.

The distance to the M71 globular cluster is about 4 kpc and it is fairly metal-rich, low-density globular cluster in the Galaxy (Grundahl et al. 2002). M71 is an important laboratory for studying the formation of exotic objects such as blue strugglers, cataclysmic variables, low-mass X-ray binaries and millisecond pulsars (Ferraro et al. 1997; Pooley et al. 2003; Heinke et al. 2005). NGC 6791 is the oldest open cluster in the Galaxy with an age of 7.7×10^9 years (Yakut et al., 2015). Be 17 and NGC 188 are also among the oldest galactic clusters (Phelps 1997; Meibom et al., 2009). NGC 2168 (M35), classified by Trumpler in 1930, is a rich open cluster of almost 180 Myr old and its distance is about 900 pc. The open cluster M67 (NGC 2682) is located at a distance of 840 pc. This cluster has many different types of binary stars. The cluster is also important because of its solar age and solar-like chemical composition (Yakut et al., 2009). The chemical abundance and age of the cluster is very close to those of the Sun, which is important for testing stellar evolution models. M67 includes many blue stragglers that are bluer and brighter than the stars at the turn-off point of the cluster. Moreover, the cluster contains close and interacting binary stars like AH Cnc, ES Cnc, and EV Cnc.

2. New observations

We have obtained high precision new multi-colour observations of close binary systems in the open cluster M35, M67, and in the globular cluster M71. New observations were obtained using the 100 cm telescope at the TÜBİTAK National Observatory (TUG). M71 was observed during 15 nights in the V and R filters. M35 is scattered over an area of the sky almost the size of the full moon. Therefore, we observed it by dividing the CCD field into four regions. New CCD observations of M35 and M67 in the V, and R filters were obtained on 12 and 4 nights, respectively.

Data reductions were performed by subtracting the bias and dark frames and dividing by the flat frame. We studied each night separately following the time correction and performed differential photometry similar to our earlier study (İçli et al., 2013). In the data reduction we used IRAF/DAOPHOT and AstroImageJ (Collins et al., 2017). For the contact binary AH Cnc we used *Kepler* satellite observations. The raw data show some fluctuations due to common instrumental effects (Jenkins et al., 2010). We eliminate these systematic variations by applying cotrending and detrending processes, as we did in our earlier *Kepler* studies (Çokluk, et al., 2019; Yakut et al., 2015). Fig. 1 shows the light variation of the selected systems in the galactic clusters M35 (2MASS

J06092044+2415155), M67 (AH Cnc), and M71 (2MASS J19533427+1844047, 2MASS J19532554+1851175).

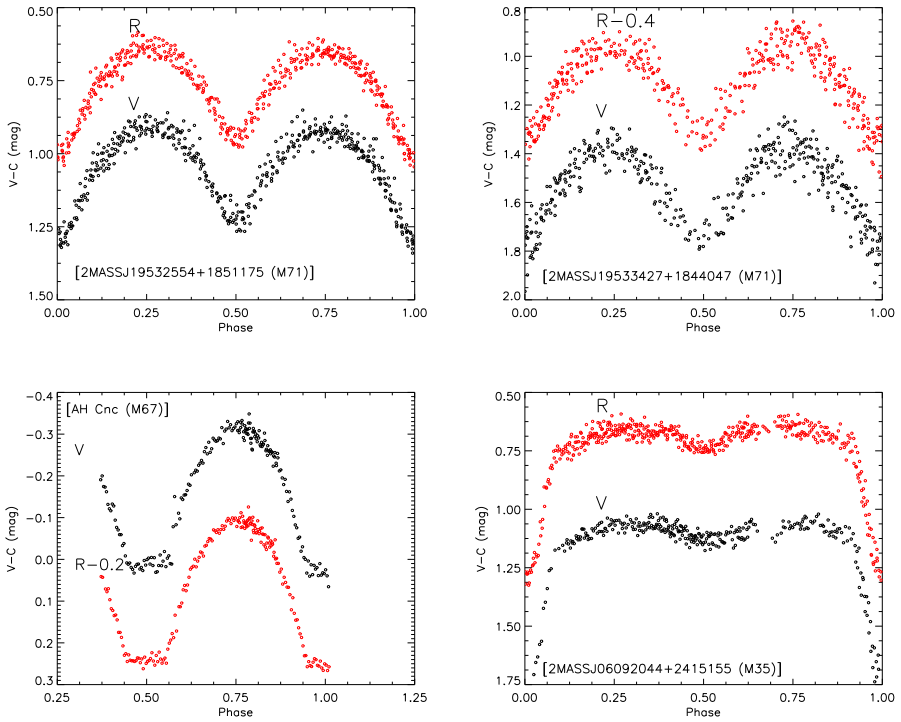

Figure 1. V, R and Kepler (K_p) light curves of some close binaries in the Galactic clusters M71, M67, and M35.

3. Results

In this study, accurate multicolor light variations of some eclipsing binary systems in several galactic open and globular clusters were obtained. Using new observations, synthetic light curves were modelled with Phoebe (Prša & Zwitter, 2005; Wilson & Devinney, 1971; Wilson, 1979). During the light curves analysis, the limb darkening coefficients (from van Hamme, 1993), albedos (from Rucinski, 1969) and the values of the gravity-darkening coefficients (from Lucy 1967) were taken as fixed parameters. Preliminary analysis resulted in the determination of the orbital inclination (i), the mass ratio (q), and the fractional radii of

Table 1. Light curve solution parameters and formal 1σ errors for 2MASS J06092044+2415155, AH Cnc, 2MASS J19533427+1844047, and 2MASS J19532554+1851175.

	J06092044	AH Cnc	J19533427	J19532554
i (deg)	69.1 ± 0.7	87.9 ± 0.2	71.8 ± 0.2	71.2 ± 0.4
q (M_2/M_1)	0.71 ± 0.01	0.147 ± 0.004	0.13 ± 0.01	0.22 ± 0.01
r_1 (R_1/a)	0.3022 ± 0.0013	0.5660 ± 0.0005	0.567 ± 0.015	0.333 ± 0.008
r_2 (R_2/a)	0.3482 ± 0.0013	0.2483 ± 0.0008	0.232 ± 0.047	0.424 ± 0.007

the primary (r_1) and secondary (r_2) components for the selected binaries listed in Table 1.

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