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Is the Hogg 12-NGC 3590 pair a new open cluster binary system?

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Abstract. Based on CCD UBVI$_{KC}$ images obtained at Cerro Tololo Inter-American Observatory (CTIO, Chile) and on morphological criteria, as well as on the stellar density in the region, we confirm that Hogg 12 is a genuine open cluster (OC) separated in the sky from NGC 3590 by scarcely 3.6 pc. The colour-magnitude diagrams of Hogg 12, cleaned from field star contamination, reveal that this is a solar metal content cluster, affected by $E(B-V) = 0.40 \pm 0.05$, located at a heliocentric distance $d = 2.0 \pm 0.5$ kpc, and of an age similar to that of NGC 3590. Evidence that these two objects form an OC binary system is presented. A detailed version of this work can be seen in PASP, 122, 516 (2010).

Resumen. Usando imágenes CCD UBVI$_{KC}$ obtenidas en el Observatorio Inter-Americano de Cerro Tololo (CTIO, Chile) y en base a criterios fotométricos y a la densidad estelar en la región, confirmamos que Hogg 12 es un cúmulo abierto (CA) genuino separado en el cielo de NGC 3590 por apenas 3.6 pc. El diagrama color-magnitud de Hogg 12, corregido por la contaminación que producen las estrellas del campo, revela que el mismo es un cúmulo de metalicidad solar, afectado por $E(B-V) = 0.40 \pm 0.05$, ubicado a una distancia heliocéntrica $d = 2.0 \pm 0.5$ kpc y con una edad similar a la de NGC 3590. Presentamos evidencia de que estos dos objetos forman un sistema doble de CAs. Una versión detallada del trabajo puede verse en PASP, 122, 516 (2010).

1. Photometric data analysis

The presence of an apparent concentration of stars in the sky does not necessarily imply that such concentration is a real physical cluster. Confirmation is indeed possible only in the case of globular clusters or very concentrated OCs. In this context, Hogg 12 is indeed an arguable case. In this study we attempt to clarify the nature of Hogg 12 (ESO 129 SC11) by using CCD UBVI$_{KC}$ photometry down to $V = 22$ obtained with the CTIO (Chile) 0.9 m telescope. The proximity of the well-known OC NGC 3590 in the same field allowed us to use it as a control cluster, not only to check the quality of our photometry but also to compare their stellar densities and their fiducial cluster features. We applied the

statistical method described by Piatti et al. (2010) to filter the field stars from both the colour-magnitude diagrams (CMDs) and the colour-colour diagrams (CCDs). We thus found that our photometry does not permit us to distinguish cluster stars from field stars for $V > 16$. We determined the coordinates associated with the geometrical centers of NGC 3590 and Hogg 12 by fitting Gaussian distributions to the stellar density profiles projected onto the directions for the x and y axes. The resulting coordinates for the clusters turned out to be (x_c,y_c) = (820 ± 30,1210 ± 30) pixels and (1670 ± 30,1000 ± 50) pixels, equivalent to $\alpha_{2000} = 11^h\ 12^m\ 23.5^s$, δ_{2000} = -60^0 46' 52" and $\alpha_{2000} = 11^h\ 12^m\ 46^s$, δ_{2000} = -60^o 48' 15" for Hogg 12 and NGC 3590, respectively. To determine the morphology of the clusters more precisely, we considered the possibility of their being elliptically shaped. Using the N2GAUSSFIT program in the STSDAS/IRAF package, we derived x and y coordinate centers in excellent agreement with those derived before, being the ellipticity 0.5 in both cases. The semimajor axes of the ellipses turned out to be 1.8' and 1.0' for NGC 3590 and Hogg 12, respectively. Finally, we applied the method of Pavani & Bica (2007) to measure how different the stellar densities encompassed by the adopted ellipses are with respect to the field star density. Pavani & Bica (2007) defined the R^2 statistics, which compares the distribution of field fluctuations and density contrast in the CMD of the clusters to those in the star field. We built 70 different CMDs for boxes of 250x250 pixels distributed throughout the field, as well as the CMDs for NGC 3590 and Hogg 12. Then, we built the histograms of the R^2 distributions and performed a Gaussian fit. We found that the R^2 values for both OCs exceed by more than 10σ the mean values derived for the field. Since NGC 3590 is a well-known real OC, this result implies that Hogg 12 also constitutes a genuine physical system, in contrast with the assumption of Moffat & Vogt (1975) who considered that it is a random fluctuation of the field star density.

2. Is the Hogg 12-NGC 3590 pair a new open cluster binary system?

Fig. 1 shows the filtered CMDs and CCDs for stars distributed within the adopted ellipse for NGC 3590. Despite the presence of some unavoidable interlopers, most of the stars appear to trace the cluster fiducial main sequence (MS). We adopted the $E(B-V)$ colour excess and apparent distance modulus from Clariá (1976) and overplotted the Zero-Age Main Sequence (ZAMS) of Lejeune & Schaerer (2001) to the (V,$B-V$), (V,$U-B$), and ($U-B$,$B-V$) diagrams. We also fitted the (V,$V-I$) and ($U-B$,$V-I$) diagrams by using $E(V-I)$ = 0.60. The ZAMS that best matches the cluster features is the one of solar metal content. Besides, the isochrone of log t = 7.20 ± 0.20 (t = 30 Myr) and solar metal content turned out to be the one which most accurately reproduces the cluster features in the three CMDs (Fig. 1). The age derived is in excellent agreement with the value estimated by Clariá (1976).

Once we checked that the filtering procedures of both CMDs and CCDs as well as the isochrone fitting method reproduced the fundamental parameter values of NGC 3590 derived by Clariá (1976), we applied the same methods to Hogg 12. Surprisingly, most of the stars in the ($U-B$,$B-V$) diagram can be matched by a solar metal content ZAMS reddened by $E(B-V) = 0.40 \pm 0.05$. On the other hand, the ZAMS reddened by $E(V-I) = 0.50 \pm 0.05$,

corresponding to an apparent distance modulus $m - M = 12.75 \pm 0.25$ matches reasonably well the star distribution in the $(U - B,V - I)$ diagram as well as in the three CMDs. If we applied the criteria defined by Clariá and Lapasset (1986) to evaluate cluster membership in Hogg 12, we would find that most of them would be probable cluster members. Note that according to these criteria, a few probable members could be discarded simply because they fall out of the MS in some of the three CMDs, which would possibly be due to an incorrect colour value. With the aim of comparing the ages of Hogg 12 and NGC 3590, we overplotted their extracted intrinsic CMDs (Fig. 2). As can be seen, the clusters seem to be nearly the same age. We used the derived reddening and apparent distance modulus values and $A_V/E(B - V) = 3.2$ (Straizys 1992) to obtain for Hogg 12 a heliocentric distance $d = 2.0 \pm 0.5$ kpc and a Galactocentric distance $R_{GC} = 8.0$ kpc, assuming the Sun's distance from the center of the Galaxy to be 8.5 kpc. If we accept that the major axes of the corresponding ellipses represent the dimensions of each cluster, the resulting angular radii are 1.00' and 1.78', equivalent to linear radii of 0.6 pc and 1.2 pc for Hogg 12 and NGC 3590, respectively. Given the fact that many young OCs have radii of $\sim$ 5 pc or even longer (Janes & Phelps 1994), both Hogg 12 and NGC 3590 appear to be very small OCs. They present an angular separation in the sky of 5.8', which is equivalent to 3.85 pc or 3.37 pc, depending on which cluster's heliocentric distance is used. Therefore, both OCs are separated in the sky by 3.6 ± 0.2 pc, which makes them one of the closest pairs of OCs carefully studied up to the present (de la Fuente Marcos & de la Fuente Marcos 2009). In fact, de la Fuente Marcos & de la Fuente Marcos (2009) compiled 27 candidate binary clusters from the catalogue of Dias et al. (2002) and found that only the pair Bica 1 and Bica 2 has a spatial separation (S) of 3 pc, whereas the remaining binary clusters have S values between 7 and 30 pc. The spatial separation of the two almost coeval OCs compared to their large heliocentric distance, suggests that these two objects were formed together. Although de la Fuente Marcos & de la Fuente Marcos (2009) did not include Hogg 12 and NGC 3590 in their study, both clusters match very well the relationship obtained by these authors between age difference of OC pairs as a function of their age and of their physical separation. In addition, since de la Fuente Marcos & de la Fuente Marcos (2009) concluded that the OC binary fraction in the Galaxy is at least 10%, one should expect to find $\sim$ 150 new Galactic OC physical pairs.

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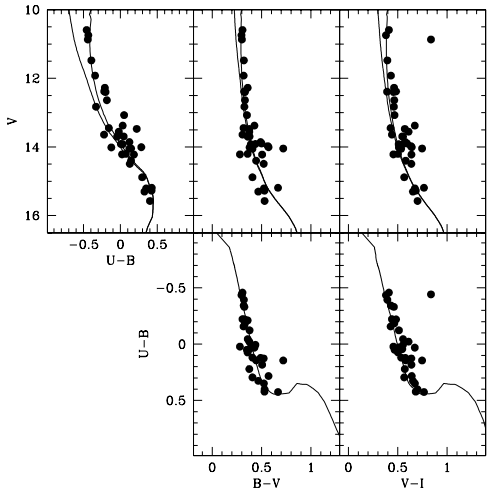

Figure 1. Cleaned extracted $(V,U-B)$, $(V,B-V)$, and $(V,V-I)$ diagrams (*top*), and $(U-B,B-V)$ and $(U-B,V-I)$ diagrams (*bottom*) for NGC 3590. The ZAMS and the isochrone of log $t = 7.5$ are overplotted.

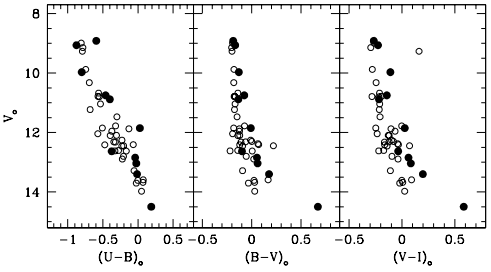

Figure 2. Intrinsic $(V,U-B)$, $(V,B-V)$, and $(V,V-I)$ diagrams for the probable members of Hogg 12 (*filled circles*), superimposed on those of NGC 3590 (*open circles*).

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