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PRESENTACIÓN MURAL

Optical and infrared photometric study of four galactic open clusters

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Abstract. We present CCD UBVI$_{KC}$ photometry for the open clusters (OCs) NGC 2311, Trumpler 6, NGC 2432 and BH 54. The resulting colour-magnitude and colour-colour diagrams as well as their radial density profiles show that these are small ($\leq 4'$) OCs highly contaminated by field stars. We have derived their angular radii, reddenings, heliocentric distances and ages. Using 2MASS data, we confirmed the consistency between the 2MASS photometry scale and ours an also our photometric membership assessment of the cluster stars. A detailed version of this work can be seen in MNRAS, 408, 1147 (2010).

Resumen. Presentamos fotometría CCD UBVI$_{KC}$ para los cúmulos abiertos (CAs) NGC 2311, Trumpler 6, NGC 2432 y BH 54. Tanto los **diagrams** color-magnitud y color-color como los perfiles de densidad **radial** demuestran que estos objetos son pequeños ($\leq 4'$) y están altamente contaminados por estrellas del campo. Hemos derivado sus radios angulares, enrojecimientos, distancias heliocéntricas y edades. Usando datos del catálogo 2MASS, confirmamos que los resultados de la **fotometría** 2MASS son consistentes no sólo con la escala óptica sino también con el reconocimiento fotométrico de los probables miembros de cada cúmulo. Una versión detallada del trabajo puede verse en MNRAS, 408, 1147 (2010).

1. Photometric diagrams analysis

We obtained images of NGC 2311, Trumpler 6, NGC 2432 and BH 54 with the UBVI$_{KC}$ filters and the Cerro Tololo Inter-American Observatory (Chile) 0.9 m telescope. The field stars were filtered by applying a statistical method described in a previous study (Piatti et al. 2009). The coordinates of the geometrical clusters' centers were determined by fitting Gaussian distributions to the stars counts in the x and y directions. The stars projected along these two directions were counted within intervals of 50 pixels wide. In order to determine the clusters' radial density profiles we used the expression: $(n_{r+25}$ - $n_{r-25})/[(m_{r+25}$ - $m_{r-25})\mathrm{x}50^2]$,where n_j and m_j represent the number of stars and boxes included in a circle of radius j, respectively. From the resulting radial density profiles, angular radii of 4.0′, 2.7′, 3.3′ and 1.7′ were derived for NGC 2311, Trumpler 6, NGC 2432 and BH 54, respectively.

Using the colour-magnitude diagrams (CMDs) and colour-colour diagrams (CCDs) cleaned from field star contamination and the previously determined angular radii, we applied the criteria defined by Clariá and Lapasset (1986, CL86) to evaluate the membership status of the measured stars. To identify what stars fulfill these criteria, we superimposed the Zero-Age Main Sequence (ZAMS) of Lejeune and Schaerer (2001, LS01) to the observed $(U-B,\ B-V)$ diagram by adopting a colour excess $E(B-V) = E_o$, which corresponds to the bluest envelope of the observed sequence. If we adopt $E(V-I)/E(B-V) = 1.25$ (Dean et al. 1978), this value implies $E(U-B)/E(V-I) = 0.58$. Thus, by sliding the ZAMS according to this reddening line in the $(U-B,V-I)$ diagram, we discarded as cluster members all stars that fall beyond 0.10 mag from the ZAMS (first criterion of CL86). Next, using all the stars that complied with this first requirement, we kept as probable members those stars whose locations correspond to the same evolutionary stage in the three CMDs (second criterion of CL86). We then superimposed the ZAMS to the three CMDs and adopted the above $E(B-V)$ value using the apparent distance modulus V-M_V which best fits the ZAMS to the unevolved star sequence. Finally, by carefully inspecting the three CMDs and the two CCDs, we could distinguish the possible cluster members. We repeated this procedure for different $E(B-V)$ values increasing them in steps of 0.05 mag each time. We recall that no star sequence survives for $E(B-V)$ values different from those corresponding to the cluster MSs. In Fig. 1 we only show the CMDs and CCDs of the NGC 2311 stars located within its circular radius (dots). In the same figure, we also overplotted the previously obtained cleaned diagrams (open circles), as well as the probable cluster members according to the above photometric criteria (filled circles). Similar diagrams were built for the remaining three OCs. The ZAMSs, appropriately shifted by the cluster colour excesses and distance moduli, were also superimposed. When comparing the cleaned and fiducial cluster CMDs and CCDs observed, the differences in stellar composition became evident. Although the fiducial features of the OCs looked clearer, some unavoidable field interlopers could also be present.

2. Astrophysical parameters and 2MASS photometry

We used the derived reddenings, the apparent distance moduli and the most frequently used values for the $A_V/E(B-V)$ ratio (Straizys 1992, = 3.2) to obtain the cluster true distance moduli V_o-M_V, the heliocentric distances (d) and the linear radii (r). By using the cluster Galactic coordinates and the calculated heliocentric distances, we derived the clusters' (X,Y,Z) coordinates and their Galactocentric distances, assuming the Sun's distance from the centre of the Galaxy to be 8.5 kpc. To determine cluster ages, theoretical isochrones of Lejeune and Schaerer (2001, LS01) of solar metal content were fitted to the three CMDs. The resulting cluster parameter values are presented in Table 1.

Although the four clusters have been studied here only in the optical spectral range, the availability of the 2MASS photometric catalogue (Skrutskie et al.

2006) becomes a very valuable tool for different reasons. On the one hand, if a properly shifted isochrone satisfactorily matches the (V, $B-V$) CMD and the 2MASS (J,$J-H$) CMD for a cluster, this means that both independent photometric scales are consistent. On the other hand, a successful isochrone matching in the near-infrared region using stars adopted as cluster members from the $UBVI$ analysis reinforces our belief that the cluster members have been correctly identified. Thus, we extracted near-infrared J, H, and K_s 2MASS photometry for all the probable photometric members in the four studied OCs and built the corresponding (J,$J-H$) and (J,$J-K_s$) CMDs. Using the ages, apparent distance moduli and reddenings derived for the cluster sample, we superimposed the theoretical isochrones by LS01 on to the cluster (J,$J-H$) and (J,$J-K_s$) CMDs, once they were shifted by the corresponding J-M_J, $E(J-H)$ and $E(J-K_s)$ values. We converted $E(B-V)$ to $E(J-H)$ and $E(J-K_s)$ and V-M_V to J-M_J using the relations $A_J/A_V = 0.276$, $A_H/A_V = 0.176$, $A_{K_s}/A_V = 0.118$, $A_J = 2.76E(J-H)$ and $E(J-H) = 0.33E(B-V)$ (Dutra et al. 2002). The results of this task are illustrated in Fig. 2, which confirms the consistency between the 2MASS photometric and our $UBVI_{KC}$ scale as well as our previous photometric membership assessment of the cluster stars.

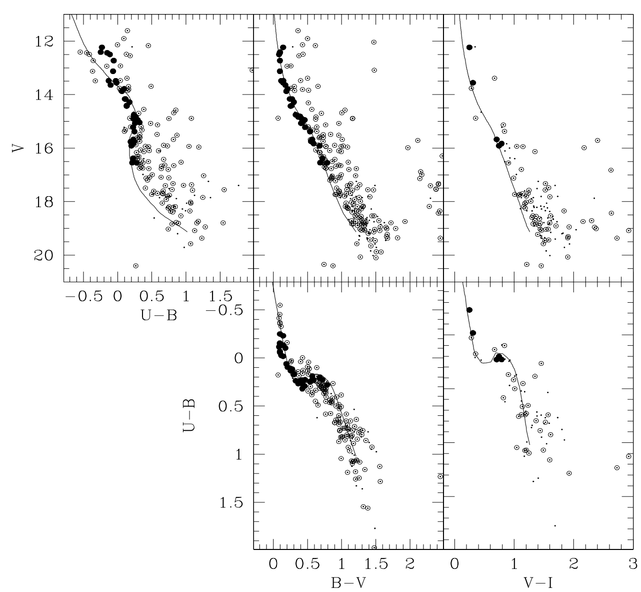

Figure 1. Extracted (V,$U-B$), (V,$B-V$), and (V,$V-I$) diagrams and ($U-B$,$B-V$) and ($B-V$,$V-I$) diagrams for NGC 2311. Dots, open circles, and filled circles represent the observed, cleaned, and cluster diagrams, respectively. The ZAMS for luminosity class V stars is overplotted.

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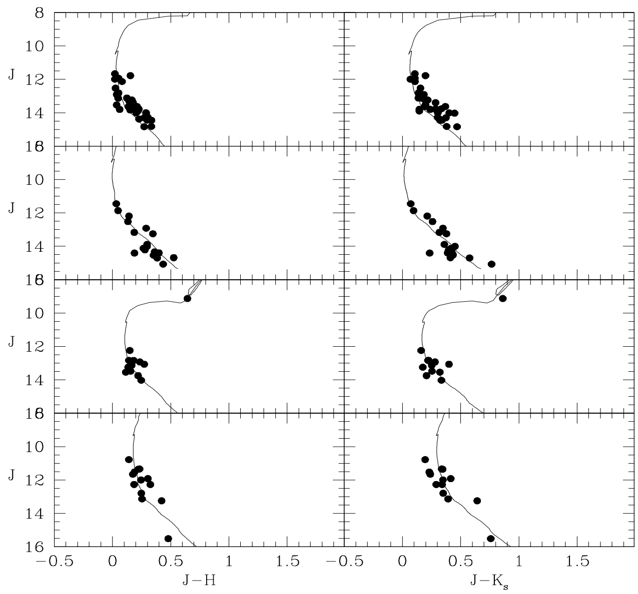

Figure 2. From top to bottom: 2MASS (J,$J-H$) and (J,$J-K_s$) diagrams for the probable members of NGC 2311, Trumpler 6, NGC 2432 and BH 54. The adopted isochrone from LS01, computed taking into account overshooting, is overplotted in solid lines.

Table 1. Possible solutions for the cluster fundamental parameters

	NGC 2311	Trumpler 6	NGC 2432	BH 54
$E(B-V)$ (mag)	0.25 ± 0.05	0.15 ± 0.05	0.35 ± 0.05	0.75 ± 0.05
$E(V-I)$ (mag)	0.30 ± 0.05	0.20 ± 0.05	0.45 ± 0.05	0.95 ± 0.05
$V-M_V$ (mag)	12.50 ± 0.25	10.75 ± 0.25	12.25 ± 0.25	13.00 ± 0.25
V_o-M_V (mag)	11.70 ± 0.40	10.27 ± 0.40	11.13 ± 0.40	10.60 ± 0.40
d (kpc)	2.20 ± 0.40	1.10 ± 0.20	1.70 ± 0.30	1.30 ± 0.25
r (pc)	2.5 ± 0.5	0.8 ± 0.1	1.6 ± 0.3	0.6 ± 0.1
X (kpc)	10.239	9.076	9.463	8.625
Y (kpc)	-1.347	-0.934	-1.400	-1.294
Z (kpc)	-0.026	-0.070	0.053	-0.006
R_{GC}	10.327	9.124	9.566	8.721
Age (Myr)	100 ± 50	100 ± 50	250 ± 60	60 ± 50

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