ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

NOVEMBER II **1998**, PAGE 25

Astron. Astrophys. Suppl. Ser. **133**, 25–28 (1998)

CCD photometry of distant open clusters

IV. Trumpler 5*

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Received April 21; accepted May 13, 1998

Abstract. We present BVI photometry for Trumpler 5, a rich open cluster located in the Galactic anticenter. The cluster age is slightly lower than the age of M 67. Its distance modulus $(m-M)_0$ and reddening $E(B-V)$ are estimated at 12.4 and 0.58, respectively. These values were obtained for the assumed solar metallicity of the cluster. Our data indicate that Tr 5 is one of the richest objects among the sample of known old open clusters. The total mass included only in upper-main sequence stars exceeds 3000 $m_\odot$. The angular diameter of the cluster is estimated at 11.6 arcmin, which corresponds to a linear size of about 20 pc for an estimated distance $d \approx 3.0$ kpc[1].

Key words: open clusters and associations: individual: Trumpler 5 — HR diagram

1. Introduction

This paper continues a series in which we present a photometry of rich, distant, open clusters (Kaluzny 1994, Paper I; Kaluzny & Rucinski 1995, Paper II; Kaluzny 1997, Paper III). The faint open cluster Trumpler 5 = Tr 5 (l = 203 deg, b = +1.1 deg) was discovered and cataloged by Trumpler (1930). So far it received a little attention from observers. Dow & Hawarden (1970) obtained the photographic photometry and presented the color magnitude diagram (CMD) for a few dozen stars from the cluster field. Their photometry did not reach the main sequence of the cluster. Photographic study by Kalinowski (1979) revealed that Tr 5 is a highly reddened and old object. Janes & Adler (1982) used Kalinowski's data to estimate $E(B-V) = 0.80$ and $(m-M)_V = 14.40$ for the reddening and apparent distance modulus of the cluster, respectively. Examination of POSS charts reveals that the cluster is projected on the sky against distant opaque clouds of interstellar gas.

2. Observations and data reduction

Observations of Tr 5 were collected during three observing runs at the Kitt Peak National Observatory. Table 1 gives the essential information about these runs. Preliminary processing of the data was done with the standard routines in the IRAF-CCDPROC package[2]. The instrumental photometry was extracted using DAOPHOT/ALLSTAR package (Stetson 1987, 1991). The constant point spread function (PSF) was adopted while reducing data from run #1. For runs #2 and #3 PSF varying linearly with coordinates was applied to extract instrumental photometry. A sufficient number of Landolt standards (Landolt 1983, 1992) was observed during each of the runs to establish reliable transformations from the instrumental to the standard $BVI_{\rm C}$ system.

Two overlapping sub-fields covering the central part of the cluster were observed during run #1. We obtained four exposures for each sub-field: 70 s and 300 s exposures in the V-band plus 70 s and 300 s exposures in the I-band.

Two overlapping sub-fields covering the central part of the cluster were observed during run #2. We obtained four exposures for each sub-field: 60 s and 300 s exposures in the V-band, 100 s and 700 s exposures in the B-band.

Two overlapping sub-fields were observed during run #3. Sub-field a was centered on the cluster center. Sub-field b was centered about 6 arcmin north of the center of

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[1] The data presented in Fig. 1 are available in electronic form at the CDS, via ftp 130.79.128.5.

[2] IRAF is distributed by the National Optical Astronomical Observatories, operated by AURA, Inc., under contract with the National Science Foundation.

Table 1. Summary of observations of Tr 5

Run	Date of Obs. UT	Telescope	Detector	Scale ″/pix	Field arcmin^2	Filters	Seeing ″
1	1990 Nov. 11	2.1-m	TEK1	0.30	2.6×2.6	VI	1.1–1.3
2	1991 Oct. 06	2.1-m	T1KA	0.30	5.1×5.1	BV	1.1–1.3
3	1991 Oct. 10,11	0.9-m	T1KA	0.68	11.6×11.6	BV	1.5–1.6

sub-field a. The following set of exposures was obtained for sub-field a: $B - 3 \times 900$ s, $B - 200$ s, $B - 180$ s, $V - 3 \times 600$, $V - 150$ s, $V - 120$ s. For sub-field b we obtained only long exposures: $B - 900$ s and $V - 600$ s.

The three data sets described above were calibrated independently of one another. The zero points of the V photometry derived during runs #1, #2 and #3 are in a good agreement with each other. The observed systematic differences do not exceed 0.02 mag. Also the zero point of the $B - V$ photometry based on the data from run #2 agrees to 0.02 mag with the zero point of photometry based on run #3. The $V/V - I$ and $V/B - V$ color-magnitude diagrams (CMD) based on the observations collected during runs 1-3 are shown in Fig. 1.

3. Age, reddening and distance

The presented data are not sufficient on their own for an accurate determination of basic properties of Tr 5. The main obstacle is a lack of an independent information on the cluster's reddening and metallicity. Our photometry confirms an earlier finding, based on the Kalinowski's (1975) photometry, that Tr 5 is an old open cluster (Janes & Adler 1982; Phelps et al. 1994). The cluster CMD shows a clearly marked red giant branch with a populous red giant clump. Also an observed color of the cluster turnoff can be determined with confidence from our data. We note that despite a low galactic latitude of Tr 5, its area is poorly populated by the background stars. The presented CMD's are contaminated mostly by the foreground objects. Apparently, the light of most of disk stars located behind the cluster is screened by a molecular cloud against which Tr 5 is projected[3].

Ages of old and intermediate-age open clusters can be estimated with a good accuracy using morphological parameters ΔV, $\Delta(B-V)$ and/or $\Delta(V-I)$ (e.g. Castellani et al. 1992). The parameter ΔV is defined as a difference in magnitudes between a red giant clump and the brightest point of a given cluster's turnoff. The second age diagnostic is a difference in color, $\Delta(B-V)$ or $\Delta(V-I)$, between the cluster's turnoff and the red giant branch at the level of the clump. Unfortunately, the exact determination of the brightest V magnitude at the turnoff is impossible in case of Tr 5. Apparently, binary stars and/or field objects make that task difficult. We may only state that $\Delta V > 1.5$. Parameters $\Delta(B-V)$ and $\Delta(V-I)$ can be determined with confidence from the data presented in Fig. 1. We obtained $\Delta(B-V) = 1.63 - 1.03 = 0.60$ and $\Delta(V-I) = 1.83 - 1.27 = 0.56$. These numbers can be compared with values of the respective parameters for M 67. From photometry obtained for that cluster by Montgomery et al. (1993) one gets $\Delta(B-V) = 0.56$ and $\Delta(V-I) = 0.50$. Hence, it turns that Tr 5 is slightly younger that M 67. Adopting the age 4.8 Gyr for M 67 (Carraro & Chiosi 1994) and using calibrations implied by the theoretical isochrones of Bertelli et al. (1994) we can estimate the age of Tr 5 at about 4.1 Gyr.

To estimate the reddening of Tr 5 let us assume for a moment that metallicity of the cluster is the same as metallicity of M 67. In that case the difference of cluster ages implies that the red giant branch of Tr 5 should be bluer by ≈ 0.03 mag than the red giant branch of M 67. The same differences are expected for both colors, $B-V$ and $V-I$, based on isochrones published by Bertelli et al. (1994). The observed differences of colors measured at the level of the red giant clump are $\delta(B-V) = 0.50$ and $\delta(V-I) = 0.67$. Hence, the differential reddening of Tr 5 relatively to M 67 can be estimated at $\Delta E(B-V) = 0.50 + 0.03 = 0.53$ and $\Delta E(V-I) = 0.67 + 0.03 = 0.70$. Adopting $E(B-V) = 0.05$ and $E(V-I) = 0.065$ for M 67 (Montgomery et al. 1993) we obtain $E(B-V) = 0.58$ and $E(V-I) = 0.765$ for Tr 5. We note that the obtained estimates of the $E(B-V)$ and $E(V-I)$ are consistent with each other as they fulfill the standard relation $E(V-I) = 1.28 \times E(B-V)$ (e.g. Dean et al. 1978).

Tr 5 is located in the galactic anticenter and its galactocentric distance is significantly larger than that of M 67. Hence, it is likely that metallicity of Tr 5 is lower than metallicity of M 67. Lower metallicity would in turn imply a bluer color of the red giant branch for a fixed age of the cluster. Therefore $E(B-V) = 0.58$ and $E(V-I) = 0.765$ should be considered just lower limits on the reddening of Tr 5.

As it was shown by Paczyński & Stanek (1998) the average I-band luminosity of the red clump giants does not depend on their intrinsic color in the range $0.8 < (V-I)_0 < 1.4$. Based on the Hipparcos distances they derived

[3] It has been kindly pointed out by Dr. K. Janes, the referee, that paucity of the backgroung stars in the observed field may bias the apparent location of the cluster main sequence. Using the observed density profile of the cluster (see Sect. 4) one may conclude that, in fact CMD based on the data from runs #1 and #2 are strongly dominated by the cluster members.

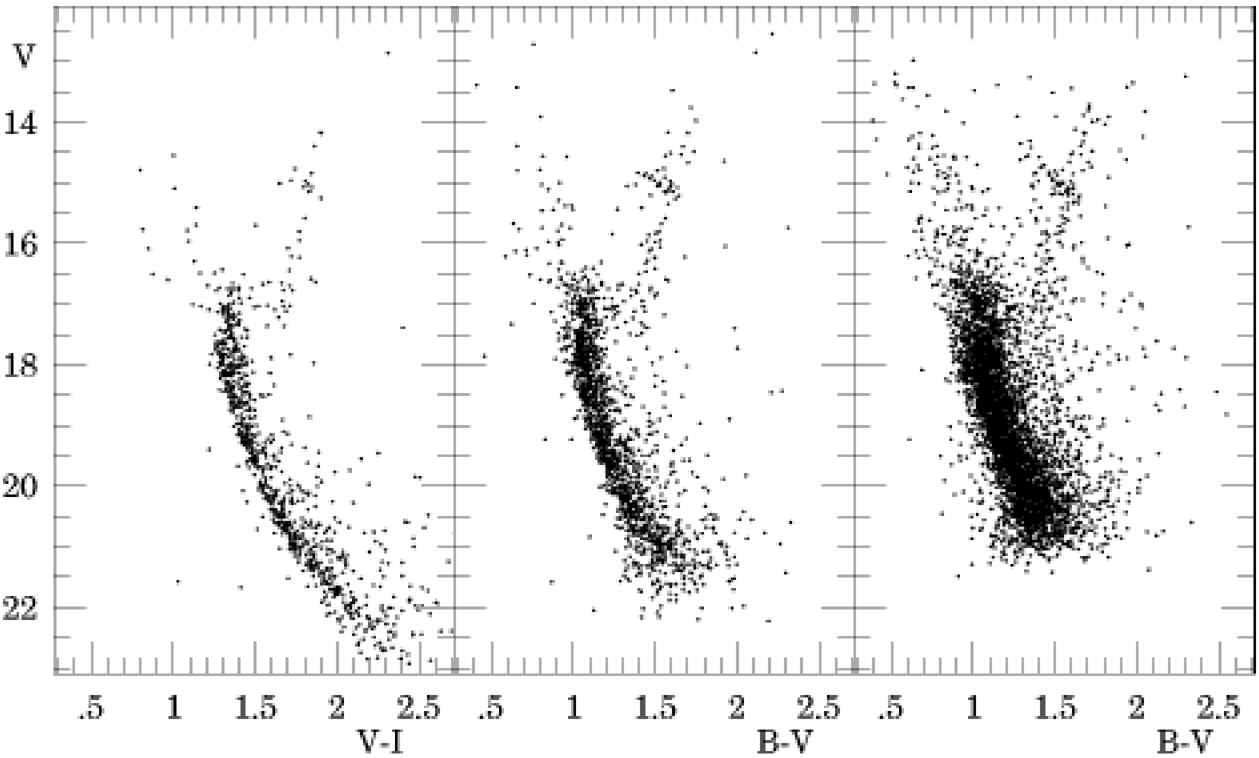

Fig. 1. Color magnitude diagrams for stars from the region of Tr 5 based on photometry obtained during runs #1 (left), #2 (center) and #3 (right)

$M_\mathrm{I} = -0.26$ for a sample of red clump giants from the solar vicinity. The clump of Tr 5 is observed at $I \approx 13.2$ which implies $(m-M)_\mathrm{I} \approx 13.46$. For $E(V-I) = 0.765$ we have $A_\mathrm{I} = 1.03$ which leads to $(m-M)_0 \approx 12.4$ for Tr 5. In that case the heliocentric distance of the cluster would be about 3.0 kpc. A higher value of the cluster reddening (see the previous paragraph) would lead to a distance lower than 3.0 kpc.

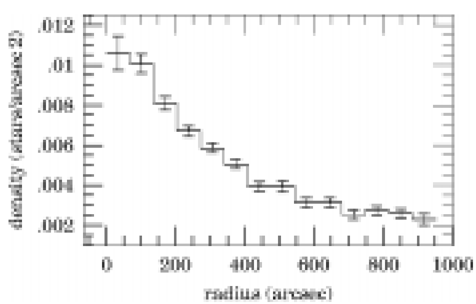

Fig. 2. Star density as a function of radial distance from the center of Tr 5 for objects with $16.5 < V < 20.5$

4. Radial extension

To study the radial extension and richness of Tr 5 we used the data obtained with the 0.9-m telescope. That set of photometry becomes significantly incomplete for $V > 20.5$. On the other hand, the upper main-sequence of the cluster terminates at $V \approx 16.5$. We limited therefore our attention to stars with $16.5 < V < 21.0$ while studying the radial extend of Tr 5. The average stellar density was calculated in successive, 68 arcsec (100 pixels) wide annuli around the cluster center. Figure 2 shows the stellar surface density as a function of distance from the cluster center. The density profile flattens at radius $r \approx 700$ arcsec. Adopting $r = 700$ arcsec for the cluster radius we derived $0.25\ 10^{-2}$ for the surface density of the field stars. Adopting the above listed parameters we may estimate from our data, that about 3030 stars with $16.5 < V < 20.5$ populate the upper main-sequence of the cluster. This estimate is in fact just a conservative lower limit. First of all we made no correction for the incompleteness of the photometry. Moreover, open clusters often possess extended coronas harboring a significant fraction of their member stars. Considering the number of upper-main sequence stars possessed by Tr 5 we may conclude that it is one of the richest objects in the sample of known old open clusters. Its mass contained only in the upper-main sequence stars exceeds 3000 $m_\odot$. This can be compared with M 67 for which the estimated total mass does not exceed 1000 $m_\odot$ (Montgomery et al. 1993). The linear diameter of the cluster can be estimated at 20 pc for the adopted heliocentric distance of 3.0 kpc. This places Tr 5 among the most extended objects in the sample of known old open clusters.

5. Discussion and conclusions

Photometric data presented above show that Tr 5 is a rich old open cluster. The cluster age is slightly lower than the age of M 67. By assuming solar metallicity of the cluster we estimated its unreddened distance moduli and reddening at $(m-M)_0 = 12.4$ and $E(B-V) = 0.58$, respectively. The cluster is located in the galactic anticenter and therefore its metallicity is likely to be lower than the solar value. In that case its unreddened distance modulus would be lower than 12.4 and reddening $E(B-V)$ would be higher than 0.58. Independent spectroscopic determination of metallicity of the cluster is needed to allow a more precise estimate of its parameters. Tr 5 is a relatively rich object in comparison with other known old open clusters. Our data imply 3000 $m_\odot$ as a conservative lower limit on the cluster mass.

Appendix A

Tables containing photometry presented in this paper are published by Astronomy and Astrophysics at the Centre de Données de Strasbourg. See the Editorial in A&A 1993, Vol. 280, page E1.

Acknowledgements. This work was supported by the Polish Committee of Scientific Research through grant 2P03D011.12 and by NSF grant AST 95-28096 to Dr. Bohdan Paczyński.

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