

Trumpler 20 – an old and rich open cluster^{★†‡}

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ABSTRACT

We show that the open cluster Trumpler 20, contrary to the earlier findings, is actually an old Galactic open cluster. New CCD photometry and high-resolution spectroscopy are used to derive the main parameters of this cluster. At $[\text{Fe}/\text{H}] = -0.11$ for a single red giant star, the metallicity is slightly subsolar. The best fit to the colour–magnitude diagrams is achieved using a 1.3-Gyr isochrone with convective overshoot. The cluster appears to have a significant reddening at $E(B - V) = 0.46$ (for B0 spectral type), although for red giants this high reddening yields the colour temperature exceeding the spectroscopic T_{eff} by about 200 K. Trumpler 20 is a very rich open cluster, containing at least 700 members brighter than $M_V = +4$. It may extend over the field of view available in our study at $20 \times 20 \text{ arcmin}^2$.

Key words: stars: abundances – open clusters and associations: individual: Trumpler 20.

1 INTRODUCTION

The number of old open clusters (age $\gtrsim 1 \text{ Gyr}$) is ~ 60 (Friel 1995) or only ~ 4 per cent of the all known clusters in the Milky Way (Dias et al. 2004). Because of this small number of such clusters and the fact that many of them are poorly populated, any addition to this body of old clusters is highly desirable. Here, we report a serendipitous discovery of an old open cluster among the known registered clusters in the WEBDA.¹ It seems to be enlightening and worthy to reflect on what initially led us to this object. In 2008 March, we had an observing run at the 2.2-m MPG/European Southern Observatory (ESO) telescope with the FEROS spectrograph (Kaufer et al. 1999). For the morning hours, there were no regular targets available and, hence, we started to look for some old open cluster with

$12^{\text{h}} < \text{RA} < 16^{\text{h}}$. There are seven such clusters in the WEBDA but none of them appeared to be well suited for our instrumental setup or offering a compelling science. A search for other potential targets led us to a large photometric survey of 55 young open clusters in the southern sky by McSwain & Gies (2005). The primary goal of their survey was to examine the age and evolutionary dependence of the Be star phenomenon. Examining the provided colour–magnitude diagrams (CMDs), our attention was caught by the CMD of Trumpler 20 (Tr 20). It was obvious that for this cluster the authors had missed out a characteristic signature of all old open cluster – i.e. the red clump, prominently displayed in its CMD at $y = 14.5$ and $b - y = 0.9$ (McSwain & Gies 2005, fig. 59). These authors opted for a young 160-Myr cluster, instead. The apparent lack of reliable parameters for Tr 20 prompted the present study.

In the discovery paper (Trumpler 1930), Tr 20 (=C1236-603) is described as a ‘rich cluster of regular outline composed exclusively of very faint stars nearly evenly scattered’ and classified as a type III 2r cluster. Using the calibrations between the estimated linear diameter and the apparent angular diameter, for this cluster with an angular diameter of 10 arcmin Trumpler reports a distance equal to 2240 pc. A few decades later, Hogg (1965) estimated the total number of cluster members from starcounts to be at ~ 200 down to $m_{\text{pg}} \sim 17$. The Strömberg by photometry given in McSwain & Gies (2005) has a limited potential in deriving a photometric distance of Tr 20 because it covers as little as $\sim 1.5 \text{ mag}$ of its main sequence. One helpful hint from the paper by McSwain & Gies (2005) is the noted relatively high reddening in this area of the sky at

[★]Based on observations collected at La Silla Observatory, ESO (Chile), with the FEROS spectrograph at the MPG/ESO 2.2-m telescope [program ID 080.D-2002(A)].

[†]Table 1 is available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/MNRAS/>.

[‡]This is Paper 35 of the WIYN Open Cluster Study (WOCS).

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¹ <http://www.univie.ac.at/webda/>

Table 1. Sample of *BVI* photometry in Tr 20. Please see the Supporting Information section for details of the full table.

ID	α_{J2000}	δ_{J2000}	V	$B - V$	$V - I$	ϵ_V	ϵ_{B-V}	ϵ_{V-I}	n_{BV}	n_{VI}
1	189.670 25	−60.801 23	12.746	0.686	1.030	0.010	0.014	0.014	2	2
2	190.040 24	−60.800 76	16.684	1.117	1.638	0.010	0.031	0.019	1	2
3	189.966 85	−60.798 39	16.405	0.804	1.058	0.013	0.028	0.019	2	2
4	190.085 71	−60.798 29	17.084	99.999	2.112	0.017	0.000	0.022	0	2
5	190.122 92	−60.795 95	15.238	0.738	1.042	0.011	0.018	0.016	2	2

$E(B - V) \sim 0.35$. For the open clusters located within 2° from Tr 20, the WEBDA data base offers additional reddening estimates, reaching up to $E(B - V) = 0.4$.

The access to high-resolution spectroscopy at the 2.2-m MPG/ESO gave us an opportunity to measure radial velocities for a few possible Tr 20 members and even attempt to measure its metallicity $[\text{Fe}/\text{H}]$. Another fortunate concurrence involved an access to photometric observations at the 1-m telescope of the Cerro Tololo Inter-American Observatory (CTIO). These two facilities allowed us to collect the necessary data and were instrumental in obtaining fundamental properties of Tr 20.

2 CCD *BVI* PHOTOMETRY

In 2008 March 20–22, new photometric CCD observations of Tr 20 were obtained at the CTIO 1-m telescope, operated by the Small and Moderate Aperture Research Telescope System (SMARTS) consortium. The instrumental setup includes the Y4K Cam consisting of an STA 4064 \times 4064 CCD with 15- μm pixels mounted in the LN₂ dewar. The pixel scale is 0.289 arcsec pixel^{−1}, allowing to cover a field of view (FOV) of 20×20 arcmin².

Our nightly observations in the Johnson–Cousins *BVI*_C filters consisted of 10 domeflats in each filter, imaging of three Landolt (1992) standards (PG1323, PG1633 and Mark A) and imaging the cluster itself using its nominal centre from WEBDA. We recognize that the colour range of our Landolt standards is relatively narrow, ranging from -0.24 to $+1.13$ in $B - V$ (only one star at $B - V = 1.49$). This may affect the accuracy of colour terms in transformations to the standard system, especially for red stars. Exposure times for Tr 20 ranged from 10 to 600 s, depending on a filter, so that in each filter there was a short and a longer exposure. This arrangement was kept in each of these three nights. One potential drawback of our observations is a relatively high airmass (1.49–1.74) at which the cluster was observed. It degraded the seeing down to ~ 1.7 arcsec.

Although the Y4K Cam is a single-chip CCD imager, it has four sections (quadrants) operated by independent amplifiers. Therefore, each section has its own bias level and gain. For initial reductions (triming, bias, flat-field and illumination corrections), we used the IRAF scripts prepared by P. Massey² specifically for this camera. We note that all raw CCD images contain a number of ‘dust ghosts’ which, unfortunately, cannot be completely eliminated. In most severe cases, the residual ghosts can be of the order of a few per cent of the background level.

We used the IRAF routines DAOPHOT and PHOT to perform the aperture photometry on our CCD images. To generate the lists of instrumental magnitudes, an in-house IRAF script was applied to all images. The aperture correction was derived from instrumental magnitudes through 8- and 12-pixel apertures. Our magnitudes are derived using

an 8-pixel aperture. Conventional calibration equations (Sarajedini et al. 1999, equations 2, 3 and 7 but without the universal time terms) were used to derive photometry in the standard *BVI*_C. In this notation, our mean colour terms for B , V , I _C filters are $+0.132$, -0.043 and -0.013 , respectively. The standard error of the calibration fits ranged from 0.008 to 0.023 mag, depending on the filter.

The catalogue of CCD photometry is constructed by combining all calibrated magnitudes in each of the three filters. A photometric measurement is not included if its formal error exceeds 0.08 mag, effectively enforcing a cut at $V \sim 18.5$ mag. In order to qualify for an entry in the catalogue, a star must have at least three detections in V filter. The mean magnitudes are calculated by weighted individual measurements by the formal photometric errors.

The astrometric calibration of pixel coordinates was performed using the UCAC2 stars (Zacharias et al. 2004) as a reference frame. The coordinate transformation required a plate model with the linear and quadratic terms, including the two main cubic distortion terms. At the epoch of 2008.22, the average standard error of a solution is ~ 75 mas. The catalogue (complete Table 1 is available in electronic form only) contains identifier, J2000 equatorial coordinates, *BVI* photometry and its formal errors for 7166 stars. Last two columns indicate the number of image pairs available for each of the *BV* and *VI* indices.

The only external source of CCD photometry in a bandpass reasonably close to the Johnson V is that of McSwain & Gies (2005). The differences between our V magnitudes and Strömgren y can be approximated by a linear relationship $V - y = 0.008 - 0.035(B - V)$, showing the residual scatter (standard error) of 0.022 mag. The slope in this relationship has an opposite sign, if compared to a similar transformation between the Johnson and Strömgren visual magnitudes for unreddened stars: $V - y = +0.038(B - V)$ (Cousins & Caldwell 1985). Such a sign flip is clearly related to the effect of a considerable reddening of stars in the area of Tr 20. Similarly, for the colour differences, we obtained the following linear regression: $(B - V) - (b - y) = -0.092 + 0.373(B - V)$ with a standard error of 0.030. A direct transformation from Strömgren $(b - y)$ to $(B - V)$ yields $(B - V) = -0.085 + 1.497(b - y)$ and a standard error of 0.057 mag. This transformation cannot directly be compared to the published relationships because an important term which includes the Strömgren index m_1 is missing. Overall, our *BV* photometry appears to be on the standard *UBV* system.

3 SPECTROSCOPY WITH FEROS

The spectroscopic observations of Tr 20 at the MPG/ESO 2.2-m telescope in La Silla, Chile, using the two-fibre FEROS echelle spectrograph (Kaufer et al. 1999), were collected exactly on the same dates as our photometry. The high resolution of this spectrograph ($R \sim 50\,000$) and its wide wavelength range (360–920 nm) make this instrument very useful in the chemical abundance studies, allowing us to select unblended weak iron lines. The observations

² <http://www.lowell.edu/users/massey/obins/y4kcamred.html>

Table 2. Heliocentric radial velocities in Tr 20.

ID	MG	V	$B - V$	$\langle RV \rangle \text{ km s}^{-1}$
3309	794	13.787	1.524	-40.85
3317	791	14.590	1.306	-39.43
3730	685	14.579	1.278	-42.20
3764	675	13.625	1.521	-40.86
4645	454	13.680	1.501	-44.44
4684	442	14.492	1.279	-40.76
1441		15.605	1.074	
2156	1055	15.876	1.201	
3606	715	15.844	1.155	
3847	654	15.777	1.155	
4498		15.741	1.222	
6117	132	15.674	1.116	
6241	116	15.855	1.191	

were obtained in the Object-Sky mode in which one fibre collects the light from target and the other fibre from the sky background.

We used McSwain & Gies (2005) photometry to select a handful of spectroscopic targets for Tr 20. These included three bright stars from the tip of the red giant branch (RGB) and three fainter stars from the red clump (Table 2). While these stars are still bright enough for radial velocity determination with the FEROS setup, a high enough signal-to-noise ratio (S/N) required for abundance analysis is problematic for a ~ 13.5 -mag star. Hence, for a chosen chemical abundance star 3764 = MG 675, we obtained four separate exposures spread over all three nights and totalling three hours.

3.1 Radial velocities

The reductions of all spectra were performed using the standard FEROS pipeline, which yields a one-dimensional rebinned spectrum sampled at 0.03-Å steps. The radial velocities have been derived using the cross-correlation techniques and a K0 III spectral type digital mask as the template (Queloz 1995; Baranne et al. 1996). A moderate S/N of our spectra at 30–50 yields the radial velocity photon noise errors of the order of 25 m s^{-1} . The final uncertainty of radial velocity is limited by the overnight spectrograph drift due to the changes in the index of air refractivity and atmospheric pressure. A couple of standard stars were used to account for this drift, described in detail by Platais et al. (2007). The formal precision of this correction is about 20 m s^{-1} . Thus, the estimated accuracy of our radial velocity determination is $\sim 30 \text{ m s}^{-1}$ per single observation. The repeat observations of 3764 = MG 675 indicate the standard error of its radial velocity to be at the level of 25 m s^{-1} . The cluster’s mean heliocentric radial velocity is estimated to be -40.8 km s^{-1} , excluding from the sample star 4645. The mean heliocentric radial velocities are given in Table 2. First column is our star number and the second, marked as MG, the star number from McSwain & Gies (2005). Remaining columns are self-explaining. Only two stars (3764 and 4645) are observed more than once. The last seven stars are tentative photometric subgiant branch stars in Tr 20 for which we do not have radial velocities. It is a high priority to establish their cluster membership via radial velocities because these stars are crucial in anchoring the isochrone fit (see Section 4).

3.2 [Fe/H] determination

Limited by the requirement to reach an adequate S/N, we focused just on star 3764 = MG 675. Its radial velocity appears to be stable

and is very close to the mean velocity of Tr 20, thus minimizing the chance that the star might be a binary. We consider it a typical representative of the entire cluster. The final spectrum is combined from four individual exposures that total 10 778 s of the open shutter time. The data were extracted using a standard pipeline routine, and the final spectrum has a S/N of ~ 65 per resolution element near 6100 Å .

The parameter determination of 3764 = MG 675 was based on the analysis of Fulbright, McWilliam & Rich (2006). We have adopted the list of iron lines from Fulbright et al. (2006). The lines in this list were selected to be those least affected by blending for use in the study of metal-rich bulge giants, where the differential analysis was done relative to Arcturus. In Fulbright et al. (2006), the zero-point of the differential metallicity scale was set by another differential analysis between the Sun and Arcturus. They adopted a solar iron abundance of $\log \epsilon(\text{Fe}) = 7.45$. The lines were measured manually using the IRAF *splot* package. We do not use lines stronger than $\sim 120 \text{ mÅ}$.

The effective temperature (T_{eff}), surface gravity and microturbulent velocity (v_t) of 3764 = MG 675 were set by the excitation temperature method as described in Fulbright et al. (2006). If we adopt a mass of $1.5 M_{\odot}$ and $M_V = -0.2$, we determine $T_{\text{eff}} = 4321 \pm 59 \text{ K}$, $\log g = 1.82$ and $v_t = 1.80 \pm 0.08 \text{ km s}^{-1}$. For the 107 Fe I lines analysed, we find a mean abundance of $\log \epsilon(\text{Fe}) = 7.34 \pm 0.13$, and for the five Fe II lines we find 7.48 ± 0.09 . Therefore, we adopt $[\text{Fe}/\text{H}] = -0.11 \pm 0.13$ for the entire Tr 20. The difference in the iron abundances as determined by the neutral and ionized lines would be lessened if the mass of the star were slightly lower or the adopted absolute magnitude were slightly brighter.

McSwain & Gies (2005) give $(b - y) = 1.046$ for 3764 = MG 675. If we adopt $E(B - V) = 0.46$ (see Section 4.1) and $E(b - y) = 0.745E(B - V)$, we find $(b - y)_0 = 0.703$. The colour- T_{eff} relations for giant stars by Ramírez & Meléndez (2005) yield a photometric T_{eff} of 4500 K for this star at $[\text{Fe}/\text{H}] = -0.11$ dex. Our spectroscopic T_{eff} is 180 K cooler, which corresponds to the star being ~ 0.06 mag bluer in $(b - y)_0$, possibly overcorrected for the reddening.

4 COLOUR-MAGNITUDE DIAGRAM AND ISOCHRONE FIT

As the result of this study, new CMDs in BV and VI can be constructed for analysis (see Table 1). Although the nominal depth of deep V frames is $V \sim 20.5$, the considerably shallower B and I frames limit our CMDs to $V \sim 18$ –18.5. We do not reproduce here the observational CMDs. Instead, our goal is to obtain reddening-free CMDs which then can be fitted with the theoretical isochrones. Such CMDs have been constructed only for stars located inside the circle with a radius of 8 arcmin, centred on to the cluster. Owing to the lack of kinematic membership, the chosen size of field appears to be a reasonable compromise between a desire to include the majority of cluster members and minimizing the impact of field star contamination.

4.1 Interstellar reddening and age

For evolved F-G spectral class main-sequence stars, the determination of reddening is not trivial. This point is well illustrated by critical analysis of all published $E(B - V)$ values for M67 (Taylor 2007), ranging from -0.01 to $+0.14$! Our analysis of reddening is further complicated by the fact that we do not have a clean sample of cluster stars. Despite the possible shortcomings, we have chosen the isochrone fit as a tool to estimate the reddening of Tr 20

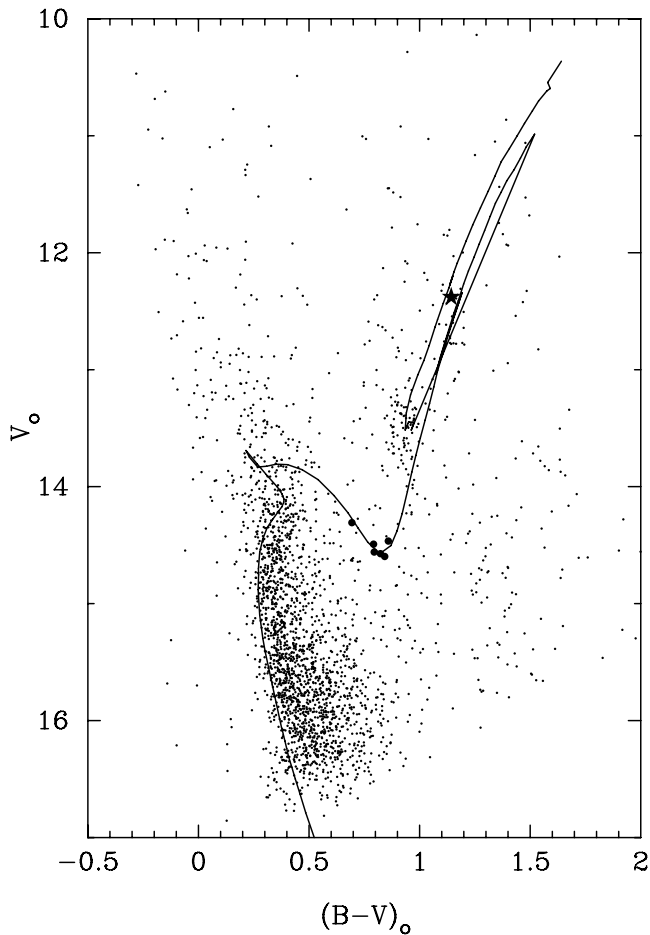


Figure 1. A fit of 1.3-Gyr isochrone to the BV CMD of Tr 20. The bold points indicate the tentative subgiant branch stars (see Table 2). Star 3764 is marked by the asterisk. The two main cluster parameters – reddening and distance modulus – applied to the observational CMD and the fit itself are listed in Table 3. Note that here and in Fig. 2 we plot only those stars which have complete BVI photometry. There are 2452 such stars.

along with its age and distance modulus. Because the metallicity of Tr 20 seems to be reasonably well determined, we chose the Marigo et al. (2008) interactive web interface³ to generate isochrones to our specifications. A number of isochrones with convective overshoot of $D_{\text{mix}} = 0.25H_p$ (Girardi et al. 2000) were built between the ages from 1 through 2 Gyr at steps of 0.1 Gyr, $Z = 0.015$, and for zero interstellar extinction. These isochrones were used to visually find the best match to various features, simultaneously in both BV and VI CMDs. These features included the shape of the upper main sequence and the location of red clump and tentative subgiant branch stars (marked by the bold dots in Figs 1 and 2 and listed in Table 2). The optimal fit was achieved with a 1.3-Gyr isochrone. We note that in a simultaneous adjustment of reddening, age and distance, the age is the most sensitive parameter followed by the reddening. An imperfect knowledge of metallicity $[\text{Fe}/\text{H}]$ can also affect the reddening estimate and the colour match for RGB stars, although this plays a minor role in our study.

To deredden the observational CMDs, we used a range of possible $E(B - V)$ values at steps of 0.01 mag. As shown by

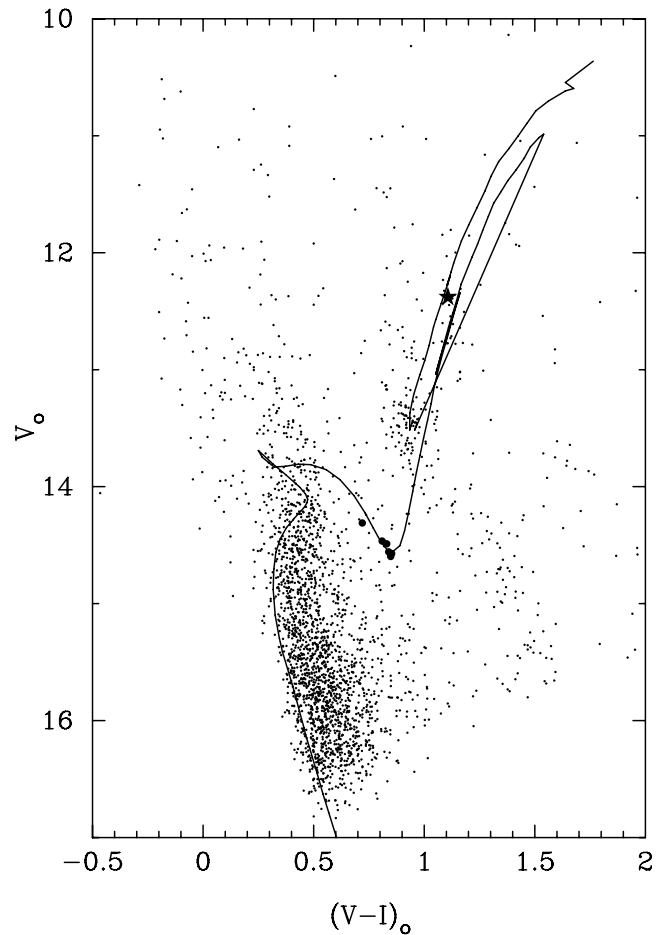


Figure 2. A fit of 1.3-Gyr isochrone to the VI CMD of Tr 20. The bold points indicate the tentative subgiant branch stars. The reddening adjusted to $V - I$ colour index and distance modulus are the same as in Fig. 1.

Fernie (1963), the reddening is a function of spectral type: $\eta = E_{B-V}(SpT)/E_{B-V}(B0)$, where $\eta = 0.97 - 0.09(B - V)_0$. Likewise, $E(V - I)/E(B - V) = 1.24[1 + 0.06(B - V)_0 + 0.014E(B - V)]$ as derived by Dean, Warren & Cousins (1978). Our estimate of reddening for Tr 20, extrapolated to a B0 spectral type, is $E(B - V) = 0.46$. From the placement of isochrones in Figs 1 and 2 using this reddening estimate, it may appear that a bit higher reddening would be more appropriate to better match the main sequence. This is not possible to achieve without ruining a fit of all the post-main-sequence features. An independent check of reddening is provided by star 3764 = MG 675. Its spectroscopic effective temperature can be converted into the reddening-free colours using a calibration of normal colours for giants from Bessell (1979). The corresponding normal colours for 3764 = MG 675 are: $(B - V)_0 = 1.20$ and $(V - I)_0 = 1.21$. Then, the observed reddening for this star is $E(B - V) = 0.32$ and $E(V - I) = 0.43$ while the isochrone fit indicates $E(B - V) = 0.38$ and $E(V - I) = 0.54$, i.e. we may have overcorrected the colours of this star by ~ 20 per cent. Unable to resolve this controversy (see also Section 3.2), we adopt $E(B - V) = 0.46$ as a compromise value of reddening for Tr 20. With this reddening and $A_v/E(B - V) = 3.1$, the true distance modulus of Tr 20 is $V_0 - M_v = 12.60$ or $d = 3.3$ kpc.

The red clump stars provide another check on our estimate of reddening and distance modulus. As pointed out by Paczyński & Stanek (1998) and Stanek & Garnavich (1998), the average absolute

³ <http://stev.oapd.inaf.it/cmd>

Table 3. Main Parameters of Tr 20.

Parameter	Value
Cluster centre (J2000.0)	$\alpha = 12^{\text{h}}39^{\text{m}}52^{\text{s}} \delta = -60^{\circ}38'$
Galactic coordinates	$\ell = 301^{\circ}5' b = +2^{\circ}2'$
Reddening $E(B - V)$	0.46 ± 0.1 (for B0)
Metallicity $[\text{Fe}/\text{H}]$	-0.11 ± 0.13
Distance modulus $V_0 - M_v$	12.60 ± 0.2
Distance (pc)	3300 ± 300
Angular diameter	~ 16 arcmin
Linear diameter (pc)	15
Cluster members ($M_V < +4$)	~ 700
Radial velocity (km s^{-1})	-40.8
Age (Gyr)	1.3

magnitude of the nearby red clump stars in Cousin's I bandpass ($M_I = -0.23$) is very stable and nearly independent of their $V - I$ colour. We estimate that our mean magnitude and colour of the red clump stars in Tr 20 are $V_0 = 13.50$ and $(V - I)_0 = 0.92$, respectively (see Fig. 2). Our distance modulus should be increased by ~ 0.2 mag to match the known mean absolute magnitude of the field red clump stars. A similar effect can be reached just by increasing our best value of $E(B - V)$ by 0.06 mag. These numbers are good indicators of inherent uncertainties in the distance modulus and reddening (see Table 3). We note that the stars in the red clump of Tr 20 require additional radial velocity measurements to identify binary stars which can easily bias the mean properties of its stars.

We conjecture three possible reasons why our reddening correction, especially that for the red giants, might be somewhat problematic (i) Our photometry of red giants is not exactly on the BVI_C system. Because the observed Landolt standards are virtually reddening-free (as opposed to the reddened cluster stars), their usage in the transformation equations can bias our calibrated colours. (ii) The dereddening formulae given by Fernie (1963) may not be as accurate as needed. These formulae should be checked on all old open clusters with considerable reddening, e.g. $E(B - V) \gtrsim 0.3$. (iii) Finally, the T_{eff} -to-colour transformation of theoretical isochrones for red giants itself can be biased. As pointed out by Pietrinferni et al. (2004), in different transformations the colours of RGB stars may differ by up to 0.2 mag. Which of these possible reasons is relevant to our study is not possible to disentangle from our data alone.

5 CLUSTER PARAMETERS AND CLOSE ANALOGUES OF TR 20

What we now know about Tr 20 is summarized in Table 3. We intentionally omitted an estimate of absolute proper motion using the UCAC2 catalogue (Zacharias et al. 2004). The formal errors of UCAC2 proper motions for stars fainter than $V \sim 14$ are reaching 6 mas yr^{-1} , which is grossly inadequate in obtaining a reliable absolute proper motion of Tr 20. The lack of kinematic cluster membership is the main reason for not attempting to assign any formal error to the age estimate.

Two rich open clusters NGC 2660 and NGC 2477 – close analogues of Tr 20 – were selected from the WEBDA to illustrate the sensitivity of cluster parameters upon the isochrone fit. The available CCD BV photometry from Sandrelli et al. (1999) for NGC 2660 and from Kassis et al. (1997) for NGC 2477 was de-reddened in the same fashion as for Tr 20. To fit the de-reddened CMDs (Figs 3 and 4), we used a solar-metallicity 1.3-Gyr isochrone with convective

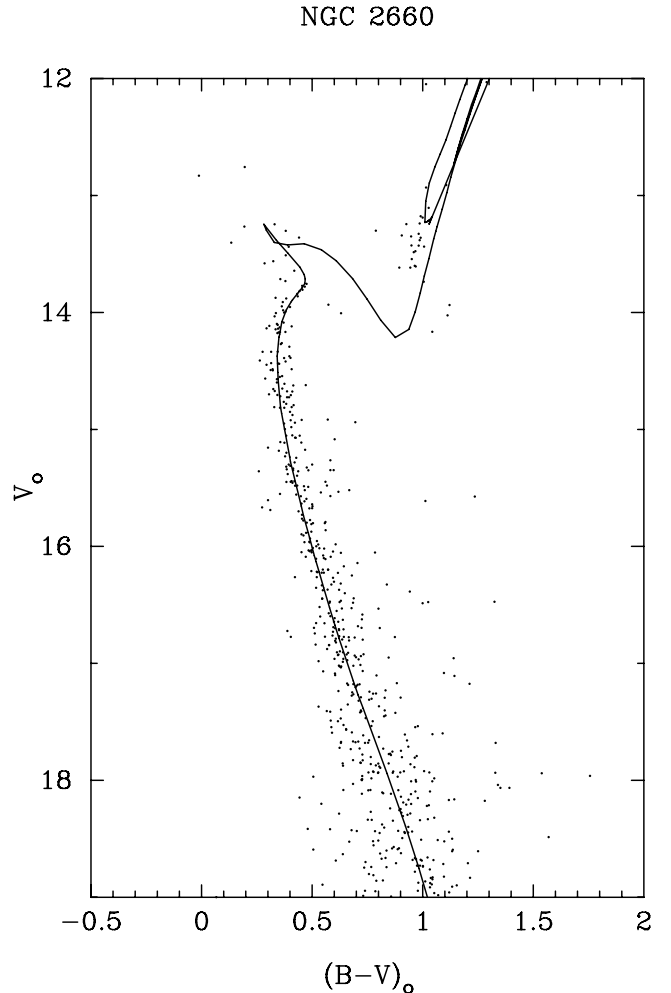


Figure 3. A fit of 1.3-Gyr isochrone to the BV CMD of NGC 2660. Its true age should be close to 1.3 Gyr despite a relatively poor match to the red giant clump. The isochrone fit suggests the reddening $E(B - V) = 0.34$ and $V_0 - M_V = 12.15$.

overshoot from Marigo et al. (2008). According to the analysis of high-resolution spectroscopy, both clusters have essentially a solar metallicity (Bragaglia et al. 2008). The placement of the red giant clump relative to the 1.3-Gyr isochrone indicates that the age of NGC 2660 is close to 1.3 Gyr but the age of NGC 2477 is definitely lower than 1.3 Gyr, in agreement with conclusions from the original studies. However, we note a need for a lower reddening in both clusters, provided the metallicity is correct. For a 1.3-Gyr isochrone near the turn-off of main sequence, an increase of $[\text{Fe}/\text{H}]$ by 0.1 dex is equivalent to the decrease of $E(B - V)$ by ~ 0.035 mag. Therefore, in deriving the cluster parameters from an isochrone fit, a prior accurate and consistent metallicity determination is crucial to this method.

The spatial distribution of stars over the FOV can serve to estimate the angular extent of Tr 20 and the cumulative number of cluster members brighter than the limiting magnitude of our study. Fig. 5 shows the density of stars as a function of radial distance (radius r) from the cluster centre. To construct this distribution, we used only the stars with reliable BV photometry. It is evident that the cluster has an angular diameter of at least 16 arcmin, which at the nominal distance of Tr 20 translates into 15 pc of linear diameter. Assuming that the density of field stars down to our limiting magnitude is about

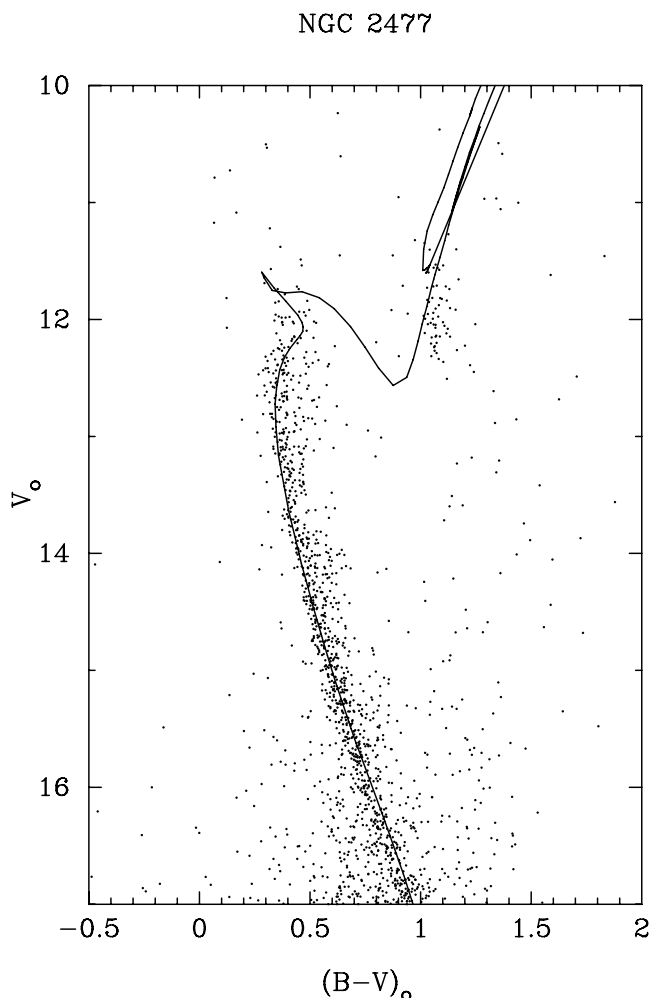


Figure 4. A fit of 1.3-Gyr isochrone to the BV CMD of NGC 2477. The location of the red-giant clump with respect to this isochrone clearly favours a younger age. The isochrone fit suggests the reddening $E(B - V) = 0.16$ and $V_0 - M_V = 10.50$.

9 stars per arcmin², the cumulative number of cluster members down to $M_V = +4$ is ~ 700 . Even this conservative estimate is indicative of a very rich open cluster.

6 CONCLUSIONS

Tr 20 has several features which make it attractive for the future studies. There is no doubt that Tr 20 is a ~ 1.3 -Gyr old open cluster. In its age group Tr 20 appears to be the richest Galactic open clusters. Our isochrone fit by no means can be considered final. It also carries a burden of correlations between the distance, age, metallicity and reddening. Among the parameters derived in this study, the reddening estimate is clearly the least satisfactory. We provide potential clues possibly biasing our reddening estimate, which should help in planning the future photometric observations. The upper part of CMD requires a rigorous cleanup by the means of radial velocities to better delineate the upper main sequence, subgiant, and giant branches. Although we are confident that the metallicity of Tr 20 is slightly subsolar, it is desirable to obtain high-resolution spectra for the clump stars and redo the analysis and try to eliminate the apparent discrepancy between the photometric and spectroscopic T_{eff} . It is not clear what causes a considerable width of the main sequence,

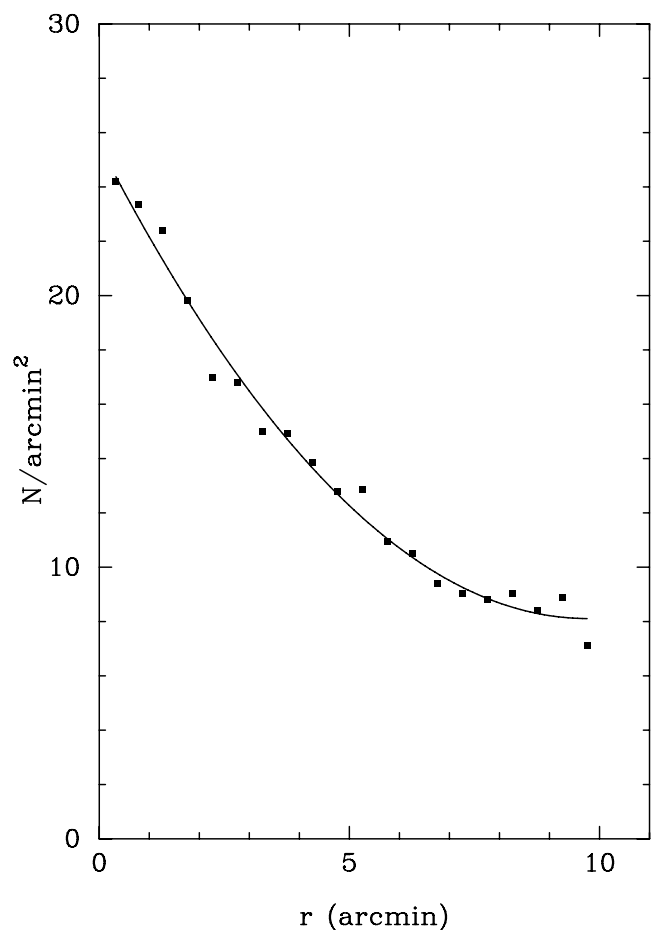


Figure 5. Radial distribution of stars in Tr 20. The spatial density of stars is plotted as a function of radius. The solid line representing a quadratic fit to the points is just for guidance. It is estimated that the angular diameter of Tr 20 is at least 16 arcmin.

reaching ~ 0.3 mag. Is it differential reddening, large population of binaries or a combination of both? The observed spread of the red clump star colours indicates that differential reddening in Tr 20 may not exceed ~ 0.1 mag in $B - V$. There is a hint of the blue straggler population which photometrically is impossible to disentangle from numerous field stars. We hope that the future studies will enable the refining of the cluster parameters and possibly open up new venues of research of this rich open cluster.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table 1. Sample of *BVI* photometry in Tr 20.

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