A photometric study of the young open cluster NGC 1220∗,**

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Abstract. We present $UBV$ CCD observations obtained in the field of the northern open cluster NGC 1220, for which little information is available. We provide also $BV$ CCD photometry of a field 5′ northward of NGC 1220 to take into account field star contamination. We argue that NGC 1220 is a young compact open cluster, for which we estimate a core radius in the range 1.5–2.0 arcmin. We identify 26 likely candidate members with spectral type earlier than A5, down to $V_0 = 15.00$ mag on the basis of the position in the two-colour Diagram and in the Colour Magnitude Diagrams (CMDs). By analyzing the distribution of these stars in the colour-colour and CMDs, we find that NGC 1220 has a reddening $E(B-V) = 0.70 \pm 0.15$ mag, is placed 1800 ± 200 pc distant from the Sun, and has an age of about 60 Myrs. The cluster turns out to be located about 120 pc above the Galactic plane, relatively high with respect to its age.

Key words. open clusters and associations: individual: NGC 1220 – open clusters and associations: general

1. Introduction

NGC 1220 (Collinder 37, OCL 380) is an open cluster in Perseus for which not much information is available. Its near anticenter projection ($l = 143.03^\circ$, $b = -3.96^\circ$; J2000 $\alpha = 3^h11^m40^s$, $\delta = 53^\circ20'45''$), small angular size (3′) and its contrasted appearance with respect to the field, as inspected on DSS (Digitized Sky Survey) images, make it an interesting target. To our knowledge, this cluster remained unstudied insofar, but for the very preliminary investigation by Phelps et al. (1994), who presented $BVI$ instrumental CMDs. Since they were looking for old open cluster candidates, their analysis was limited to the remark that this cluster has to be young, since no clear giant branch and clump were detected. Therefore, these authors do not report any estimates of the cluster fundamental parameters. In the present study we provide the first calibrated $UBV$ CCD photometry of NGC 1220, aiming at determining its basic parameters, such as reddening, distance and age, which are fundamental to understand the disk sub-system which the cluster belongs to.

The plan of this paper is as follows.

In Sect. 2 we present the observations and data reduction and in Sect. 3 we derive an estimate of the cluster diameter. In Sect. 4 we describe the CMDs, whilst in Sect. 5 we derive cluster reddening, and isolate candidate members. Section 6 is dedicated to derive NGC 1220 distance and age. Finally, in Sect. 7 we draw some conclusions and suggest further lines of research.

2. Observations and data reduction

Observations were carried out with the CCD SIT #1 camera at the Observatorio Astronómico Nacional (OAN) de S. Pedro Martir, B.C., Mexico, in the photometric nights of September 16–17, 2001. This CCD samples a $4'/6 \times 4'/6$ field in a $1K \times 1K$ thinned CCD. The typical seeing was around 1.7 arcsec.

The details of the observations are listed in Tables 1 and 2, where the observed fields are reported together with the exposure times, the typical seeing and the airmass from the night of September 16 and 17, respectively. The covered region is shown in Fig. 1, where a DSS1 map is presented for NGC 1220.

The data have been reduced by using the MIDAS and DAOPHOT packages. The calibration equations obtained by observing Landolt (1992) SA 92, SA 95, PG 0220+015, PG 2331+055 and PG 0231+051, PG 2336+004 and
PG 1633+099 fields along both nights for a total of 58 independent measurements, are:

\[
\begin{align*}
\alpha &= U + 19.56 \pm 0.015 + (0.04 \pm 0.02)(U - B) + 0.42X \\
b &= B + 21.23 \pm 0.015 - (0.08 \pm 0.017)(B - V) + 0.22X \\
v &= V + 21.90 \pm 0.015 + (0.015 \pm 0.010)(B - V) + 0.14X
\end{align*}
\]

where UBV are standard magnitudes, ubv are the instrumental ones, and X is the airmass. The zero points are for 1 s exposure time. The standard stars in these fields provide a very good colour coverage from \(-0.33 \leq (B - V) \leq 1.44\). Only one standard star has been excluded because of its large deviation from the average value (SA 95–106). For the extinction coefficients, we assumed the typical values of the site of 0.42, 0.22 and 0.14 for U, B and V passbands, respectively, available from the OAN web site\(^2\). The photometric errors are presented in Fig. 2 for \(V\), \((B - V)\) and \((U - B)\). The zero point errors of the final photometry should include also the transfer from the DAOPHOT convolved magnitudes to the wide aperture ones (6.7 arcsecs radius) needed to avoid any PSF and seeing variation effect. This transfer accounts for an additional \(\pm 0.02\) mag uncertainty on all colours.

**3. Star counts and cluster size**

NGC 1220 appears as a compact cluster of about 20 stars (see Fig. 1). According to Lyngå (1987), NGC 1220 has a diameter of 2 arcmin, so our study covers the entire cluster region. To infer an estimate of the radius, we derive the surface stellar density by performing star counts in concentric rings around the center of the covered area, and then dividing by their respective surface areas. The final density profile and the corresponding Poisson error bars are depicted in Fig. 3. The dashed line in this plot represents the star counts in the accompanying field, where we estimated 6.3 stars/arcmin\(^2\). The cluster clearly dominates over the field up to about 2 arcmin, then it completely merges with the Galactic disk field star component. Therefore, we estimate a cluster radius of about 1.5–2.0 arcmin, somewhat larger than the value reported by Lyngå (1987).

\(^2\) http://bufadora.astrosen.unam.mx
4. Colour-Magnitude diagram

The CMD for all the stars measured in the direction of NGC 1220 is shown in Fig. 4. In the left panel we plot all the stars in the $V$ vs. $(B-V)$ plane, where in the middle panel we plot in the same plane stars from the accompanying field observed 5° northward of NGC 1220. Finally, in the left panel we present the CMD in the plane $V$ vs. $(U-B)$. These CMDs are easy to interpret. On the left panel, the cluster Main Sequence (MS) extends almost vertically from $V \approx 13$ up to $V \approx 21$, although it starts widening at $V \approx 19$. This is clearly related to the field star component, which is heavy in the direction of NGC 1220, a cluster located quite low in the Galactic plane. In fact (see the middle panel) the contribution of field stars is quite heavy in the magnitude interval $18 \leq V \leq 21$ mag, and some stars on the red side of the MS most probably belong to the field. The appearance of this CMD suggests that we are facing a young cluster. The three very red stars in the left panel might be the signature of a possible evolved population in NGC 1220. We claim that this is very difficult. First of all, the faintest star of the triplet has a nice counterpart in the middle panel, which

\begin{table}[h]
\centering
\begin{tabular}{lcc}
\hline
Field & Filter & Time integration (s) & Seeing ("") & Airmass \\
\hline
SA 95 & $U$ & 120 & 1.7 & 1.21 \\
& $B$ & 45 & 1.8 & 1.20 \\
& $V$ & 30, 30 & 1.6 & 1.22 \\
NGC 1220 & $U$ & 120 & 1.8 & 1.16 \\
& $B$ & 120,1800 & 1.9 & 1.13 \\
& $V$ & 30, 900 & 1.6 & 1.14 \\
PG 1633+099 & $U$ & 90 & 1.9 & 1.38 \\
& $B$ & 40 & 1.8 & 1.37 \\
& $V$ & 20 & 1.7 & 1.39 \\
PG 0231+051 & $U$ & 90 & 1.6 & 1.11 \\
& $B$ & 30, 30 & 1.7 & 1.12 \\
& $V$ & 20, 20, 20 & 1.7 & 1.12 \\
PG 0220+015 & $U$ & 90 & 1.6 & 1.12 \\
& $B$ & 30 & 1.7 & 1.12 \\
& $V$ & 20, 20 & 1.8 & 1.12 \\
\hline
\end{tabular}
\caption{Journal of observations of NGC 1220, the accompanying field, and standard star fields (September 16, 2001).}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{lcc}
\hline
Field & Filter & Time integration (s) & Seeing ("") & Airmass \\
\hline
SA 92 & $U$ & 90 & 1.7 & 1.16 \\
& $B$ & 30 & 1.8 & 1.16 \\
& $V$ & 20, 20 & 1.6 & 1.16 \\
NGC 1220 & $U$ & 1200 & 1.6 & 1.13 \\
PG 2336+004 & $U$ & 90 & 1.9 & 1.20 \\
& $B$ & 30 & 1.8 & 1.21 \\
& $V$ & 20, 20 & 1.7 & 1.21 \\
PG 0231+051 & $U$ & 90 & 1.6 & 1.13 \\
& $B$ & 30, 30 & 1.7 & 1.13 \\
& $V$ & 20, 20 & 1.8 & 1.14 \\
Field & $B$ & 1200 & 1.6 & 1.09 \\
& $V$ & 20, 600 & 1.6 & 1.10 \\
PG 2331+055 & $U$ & 90 & 1.6 & 1.11 \\
& $B$ & 30, 30 & 1.7 & 1.11 \\
& $V$ & 20, 20 & 1.8 & 1.14 \\
\hline
\end{tabular}
\caption{Journal of observations of NGC 1220, the accompanying field, and standard star fields (September 17, 2001).}
\end{table}
implies that it is much probably a field star. Moreover, in the case of young clusters, the $V$ vs. $(U-B)$ CMD is better suited to separate members from non members. The right panel of Fig. 4 indeed shows quite a tight MS, and some stars rightward, well detached from the MS, which presumably are all field stars.

5. Two-colour diagram and members selection

We derive cluster membership by grouping stars according to their mean reddening. Individual reddening values have been computed by means of the usual reddening free parameter $Q$:

$$Q = (U-B) - 0.72 	imes (B-V),$$

and the distribution of the stars in the two colour Diagram, following the procedure outlined in detail in Carraro (2002a,b), where the young open clusters Trumpler 15 and NGC 133 have been studied, respectively. This method is a powerful one to isolate early spectral type (from $O$ to $A5$) stars having common reddening, which are most probably likely cluster members (see, for a reference, the study of Trumpler 14 by Vazquez et al. 1996). Moreover the reddening based members selection nicely compares with – for instance – proper motion based members selection (see Rudworth et al. 1993; Patat & Carraro 2001 for some clusters in the Carina region).

Our results are shown in Fig. 5, where we plot all the stars having $UBV$ photometry in the two-colour Diagram. The solid line is an empirical ZAMS from Schmidt-Kaler (1982). In this figure, we have plotted with filled symbols all the stars having a mean reddening $E(B-V) = 0.70 \pm 0.15$ mag (31 stars in total) previously determined, which obviously crowds close to a ZAMS shifted by $(m-M)_V = 13.5 \pm 0.2$ mag, whereas the dotted line is the same ZAMS, but 0.70 mag brighter, drawn to mimic the location of the unresolved binary stars.

Finally, more information can be derived by considering the distribution of the stars in the reddening corrected CMD (see Fig. 6). In this figure we have plotted all the likely early spectral type members. To guide the eye, two ZAMS have been drawn. The solid one, which fits the distribution of the bulk of member stars, has been shifted by $(m-M)_V = 11.3 \pm 0.2$ (see also next section). The dotted one has been placed to mimic the location of presumed unresolved binary stars. One can readily see that most of member stars fall close to the ZAMS location. There are actually some exceptions (stars #1, #3, #9, #14, and #67), which are clearly off (too red or too blue) the MS. We are not going to consider these stars as NGC 1220 likely members.

In conclusion, we would like to argue that the population of stars having $E(B-V) = 0.70 \pm 0.15$ mag (26 stars)
Table 3. Photometry of likely member stars in the field of NGC 1220. In the last column, *p.n.m.* means probable non member.

<table>
<thead>
<tr>
<th>ID</th>
<th>X(pixel)</th>
<th>Y(pixel)</th>
<th>V</th>
<th>(B − V)</th>
<th>(U − B)</th>
<th>Q</th>
<th>E(B − V)</th>
<th>Sp.Type</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>967.330</td>
<td>15.690</td>
<td>14.848</td>
<td>0.575</td>
<td>0.462</td>
<td>0.048</td>
<td>0.568</td>
<td>A1</td>
<td>p.n.m.</td>
</tr>
<tr>
<td>3</td>
<td>228.090</td>
<td>285.270</td>
<td>14.480</td>
<td>0.709</td>
<td>0.526</td>
<td>0.016</td>
<td>0.713</td>
<td>B9</td>
<td>p.n.m.</td>
</tr>
<tr>
<td>4</td>
<td>567.300</td>
<td>397.170</td>
<td>13.539</td>
<td>0.502</td>
<td>−0.107</td>
<td>−0.468</td>
<td>0.669</td>
<td>B7</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>475.760</td>
<td>433.540</td>
<td>14.387</td>
<td>0.664</td>
<td>0.163</td>
<td>−0.315</td>
<td>0.779</td>
<td>B6</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>520.020</td>
<td>483.510</td>
<td>13.923</td>
<td>0.579</td>
<td>−0.049</td>
<td>−0.466</td>
<td>0.745</td>
<td>A4</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>492.600</td>
<td>9.870</td>
<td>17.667</td>
<td>0.727</td>
<td>0.578</td>
<td>0.055</td>
<td>0.718</td>
<td>A2</td>
<td>p.n.m.</td>
</tr>
<tr>
<td>13</td>
<td>688.280</td>
<td>235.520</td>
<td>15.743</td>
<td>0.656</td>
<td>0.198</td>
<td>−0.189</td>
<td>0.610</td>
<td>B8</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>851.920</td>
<td>237.320</td>
<td>15.247</td>
<td>0.537</td>
<td>−0.189</td>
<td>0.610</td>
<td>0.750</td>
<td>A3</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>536.950</td>
<td>276.220</td>
<td>15.442</td>
<td>0.537</td>
<td>−0.237</td>
<td>0.626</td>
<td>B7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>570.490</td>
<td>419.710</td>
<td>15.627</td>
<td>0.623</td>
<td>0.319</td>
<td>−0.130</td>
<td>0.676</td>
<td>B9</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>550.960</td>
<td>473.700</td>
<td>15.491</td>
<td>0.637</td>
<td>0.305</td>
<td>−0.159</td>
<td>0.698</td>
<td>B9</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>690.850</td>
<td>503.320</td>
<td>13.219</td>
<td>0.507</td>
<td>−0.138</td>
<td>−0.503</td>
<td>0.686</td>
<td>B5</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>520.440</td>
<td>538.900</td>
<td>15.966</td>
<td>0.737</td>
<td>0.519</td>
<td>−0.012</td>
<td>0.750</td>
<td>B9</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>373.510</td>
<td>541.340</td>
<td>16.054</td>
<td>0.694</td>
<td>0.393</td>
<td>−0.107</td>
<td>0.739</td>
<td>B9</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>716.750</td>
<td>577.490</td>
<td>16.697</td>
<td>0.759</td>
<td>0.534</td>
<td>−0.012</td>
<td>0.772</td>
<td>A0</td>
<td></td>
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<tr>
<td>48</td>
<td>126.610</td>
<td>791.540</td>
<td>14.783</td>
<td>0.608</td>
<td>−0.017</td>
<td>−0.455</td>
<td>0.770</td>
<td>B5</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>246.520</td>
<td>214.460</td>
<td>16.085</td>
<td>0.655</td>
<td>0.370</td>
<td>−0.102</td>
<td>0.698</td>
<td>B9</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>494.780</td>
<td>423.660</td>
<td>15.987</td>
<td>0.749</td>
<td>0.457</td>
<td>−0.082</td>
<td>0.786</td>
<td>B9</td>
<td></td>
</tr>
<tr>
<td>66</td>
<td>422.610</td>
<td>460.180</td>
<td>14.023</td>
<td>0.627</td>
<td>−0.024</td>
<td>−0.475</td>
<td>0.796</td>
<td>B5</td>
<td>p.n.m.</td>
</tr>
<tr>
<td>67</td>
<td>440.650</td>
<td>525.220</td>
<td>14.875</td>
<td>0.627</td>
<td>0.086</td>
<td>−0.365</td>
<td>0.759</td>
<td>B5</td>
<td></td>
</tr>
<tr>
<td>68</td>
<td>556.110</td>
<td>530.450</td>
<td>14.997</td>
<td>0.636</td>
<td>0.183</td>
<td>−0.275</td>
<td>0.738</td>
<td>B6</td>
<td></td>
</tr>
<tr>
<td>69</td>
<td>605.160</td>
<td>540.530</td>
<td>16.387</td>
<td>0.700</td>
<td>0.475</td>
<td>−0.029</td>
<td>0.719</td>
<td>A0</td>
<td></td>
</tr>
<tr>
<td>78</td>
<td>537.330</td>
<td>350.389</td>
<td>17.033</td>
<td>0.846</td>
<td>0.674</td>
<td>0.065</td>
<td>0.833</td>
<td>A3</td>
<td></td>
</tr>
<tr>
<td>79</td>
<td>528.560</td>
<td>378.300</td>
<td>15.982</td>
<td>0.732</td>
<td>0.512</td>
<td>−0.015</td>
<td>0.746</td>
<td>B9</td>
<td></td>
</tr>
</tbody>
</table>

identifies the brightest members of the open cluster NGC 1220. Later spectral type stars are more difficult to be detected, due to the degeneracy described above. The final photometry of the likely candidate members of NGC 1220 is listed in Table 3, together with individual reddenings and photometric spectral types. The latter have been obtained by deriving intrinsic colours from observed colours and reddenings. We use Johnson (1966) intrinsic colours to infer approximate spectral types. The typical uncertainty in the spectral type is ±2, due to both photometric errors and the difficulty to estimate the luminosity classes.

5.1. Distance and age

In Fig. 7 we plot the reddening corrected CMDs for the likely member stars above determined. In both diagrams we have overimposed the empirical Schmidt-Kaler (1982) ZAMS, shifted by \((m − M)_V = 11.3 \pm 0.3\) mag, which provides a nice fit of the stars distribution. This implies that NGC 1220 is located 1800 ± 200 pc away from the Sun, where the uncertainty mirrors the difficulty of the fit due to the almost vertical structure of the MS.

From the location of the stars in the \((B − V)\) vs. \((U − B)\) plane, we infer that the stars spectral types range from B5 to A5 by deriving the absolute colours from the ZAMS at the same.
Fig. 8. CMDs of all the stars in the region of NGC 1220. The solid line is a solar metallicity 60 Myr isochrone from Girardi et al. (2000), whereas the dashed one is a 250 Myr isochrone.

position of the stars (see also Table 3 and previous section). If the stars having B5 spectral type are still along the MS, we derive an age around 50 Myrs for NGC 1220 (Girardi et al. 2000).

We checked this age estimate by fitting CMDs of NGC 1220 with theoretical isochrones from Padova models (Girardi et al. 2000). The result is presented in Fig. 8. In the left panel we plot the NGC 1220 stars in the plane V vs. (B−V), and overimposed two solar metallicity isochrones. The solid line is for the age of 60 Myr, the dashed one for the age of 250 Myr. This latter has been drawn with the intention to try to fit the three very red stars previously mentioned. The same isochrones have been overlaid to NGC 1220 stars in the V vs. (U−B) diagram (right panel). The overall fit is very good in both diagrams. However, by closely inspecting only the left panel, one could not definitely rule out the larger age for NGC 1220, since the dashed isochrone (250 Myr) nicely fits the bulk of the stars but for only the two bright stars above the TO, which nevertheless might be accounted for by invoking their possible binary nature.

In this respect the CMD in the right panel (V vs. (U−B)) helps a lot in solving the mystery. In fact in this colour combination the colour separation of the bluest stars is much wider. It results very clearly that only the 60 Myr isochrone provides a good fit to the MS stars, thus ensuring us that all the stars redwards the MS are simply field stars. Therefore we conclude that NGC 1220 is a young open cluster, about 60 Myr old.

The Galactocentric coordinates are $X = -9.43$ ($X < 0$ means our side of the Galaxy), $Y = 1.08$ and $Z = -0.12$ kpc, considering the distance to the Galactic center to be $R = 8$ kpc (Reid 1993). The cluster is thus outside the solar circle, in the Perseus arm (Taylor & Cordes 1993). However, we notice that NGC 1220 is fairly high above the Galactic plane with respect to his age. In fact, it takes at least $10^7$ yr for a young cluster with a typical velocity of 10 km s$^{-1}$ to move about 100 pc.

Combining together the estimated age, distance and position in the Galaxy, we conclude that NGC 1220 is a genuine Galactic this disk star cluster, presently located relatively high above the Galactic plane, but presumably formed within the thin disk.

6. Conclusions

In this paper we have presented new CCD $UBV$ photometry for the stars in the field of NGC 1220, and provide the first estimates of its fundamental parameters.

Our findings can be summarized as follows:

- NGC 1220 is a compact 20–25 stars group, with a radius of 1.5–2.0 arcmin, which turns into 0.79–1.05 pc at the distance of the cluster;
- we identified 26 likely members with spectral type earlier than A5 on the basis of the reddening and the position in the reddening corrected CMDs;
- the cluster turns out to be located about 1800 pc away from the Sun in the Perseus spiral arm;
- we estimate a reddening $E(B−V) = 0.70 \pm 0.15$;
- the probable age is around 60 Myrs;
- NGC 1220 is presently located 120 pc above the Galactic plane, relatively high with respect to its age. With the available data it is not possible to conclude whether the cluster formed at some distance above the galactic plane, or formed well within the thin disk and then moved away. This latter hypothesis would imply a non negligible vertical motion of the cluster.

We would finally like to note that more precise estimates of the cluster age can be derived by obtaining spectroscopic classification of the brightest stars. Moreover a proper motion
study would permit to better distinguish NGC 1220 physical members.

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