Distance estimates to five open clusters based on 2MASS data of red clump giants

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Abstract. Red clump (RC) giants are excellent standard candles in the Milky Way and the
Large Magellanic Cloud. The near-infrared $K$-band intrinsic luminosity of RC giants exhibits
only a small variance and a weak dependence on chemical composition and age. In addition, RCs
are often easily recognizable in the color–magnitude diagrams of open clusters, which renders
them extremely useful distance indicators for some intermediate-age or old open clusters. Here
we determine the distance moduli of five Galactic open clusters covering a range of metallicities
and ages, based on RC giants in the cluster regions using 2MASS photometric data. We compare
our result with those from main-sequence fitting and also briefly discuss the advantages and
disadvantages of RC-based cluster distance determination.

Keywords. open clusters and associations: individual (NGC 6791, NGC 2420, NGC 2682, NGC
2158, NGC 7789), distance scale

1. Cluster sample and red clump selection

The red clump (RC) is made up of core-helium-burning giant stars, just like a normal
horizontal branch. RC stars occupy a very compact locus in the Hertzsprung–Russell
diagram. Thus, its identification and its basis for accurate distance determination have
been proven, and the RC turns out to be an excellent tool for large-scale Galactic struc-
ture and kinematic studies (see, e.g., Paczyński et al. 1999; Alves 2000; Van Helshoecht
et al. 2007; Groenewegen 2008; and references therein).

In particular, the small variance of the RC's intrinsic $K$-band luminosity and the
weak dependence on chemical composition and age make it an extremely useful distance
indicator (Van Helshoecht 2007). In addition, the RC also has the advantage that it is
easily recognizable in the color–magnitude diagrams (CMDs) of most open clusters.

We plan to undertake a systematic search of RC stars in Galactic open clusters based
on 2MASS/Point Source Catalog data. As a preliminary performance test, we selected
five open clusters covering a wide range in metallicity and age as a test sample. Table
1 lists the basic parameters of the five star clusters (Dias et al. 2002), including their
central positions in both equatorial and Galactic coordinates, their average reddening
values, distances to the sun, ages, and metallicities.

We used 2MASS infrared photometry (Cutri et al. 2003) to extract sample RC stars in
the fields of the five Galactic open clusters. Radii from 3.75 to 12 arcmin were adopted
for the different clusters, based on the values in Dias' catalog (Dias 2002). The $K_s$ versus
$(J−K_s)$ CMD was plotted for each cluster field, and median RC magnitudes were derived.

As an example, Fig. 1 shows the CMD of NGC 6791 for radii $r < 5′$ (top left) and the
$K_s$-band luminosity function in the same region (top right). In addition, we present the
Table 1. Basic information about our sample of five open clusters

<table>
<thead>
<tr>
<th>Cluster</th>
<th>R.A. (J2000.0)</th>
<th>Dec. (J2000.0)</th>
<th>l</th>
<th>b</th>
<th>E(B − V)</th>
<th>Distance</th>
<th>Age</th>
<th>[Fe/H]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(hh:mm:ss)</td>
<td>(dd:mm:ss)</td>
<td>(deg)</td>
<td>(deg)</td>
<td>(mag)</td>
<td>(pc)</td>
<td>(Gyr)</td>
<td>(dex)</td>
</tr>
<tr>
<td>NGC 6791</td>
<td>19 20 53</td>
<td>+37 46 18</td>
<td>69.96</td>
<td>10.90</td>
<td>0.12</td>
<td>5853</td>
<td>4.4</td>
<td>0.15</td>
</tr>
<tr>
<td>NGC 2420</td>
<td>07 38 23</td>
<td>+21 34 24</td>
<td>198.11</td>
<td>19.63</td>
<td>0.04</td>
<td>2480</td>
<td>1.1</td>
<td>−0.26</td>
</tr>
<tr>
<td>NGC 2682</td>
<td>08 51 18</td>
<td>+11 48 00</td>
<td>215.70</td>
<td>31.92</td>
<td>0.06</td>
<td>908</td>
<td>2.6</td>
<td>0.0</td>
</tr>
<tr>
<td>NGC 2158</td>
<td>06 07 25</td>
<td>+24 05 48</td>
<td>186.63</td>
<td>1.78</td>
<td>0.36</td>
<td>5071</td>
<td>1.9</td>
<td>−0.25</td>
</tr>
<tr>
<td>NGC 7789</td>
<td>23 57 24</td>
<td>+56 42 30</td>
<td>115.51</td>
<td>−5.38</td>
<td>0.28</td>
<td>1795</td>
<td>1.7</td>
<td>−0.08</td>
</tr>
</tbody>
</table>

The relation between magnitude and the corresponding uncertainties in the J band (bottom left) and the Ks band (bottom right). The rectangle superimposed on the CMD covers a color range of 0.7 ≤ (J − Ks) ≤ 0.8 mag and a magnitude range of 0.4 mag, i.e., 11.3 ≤ Ks ≤ 11.7 mag. A total of 19 RC stars fall in the region of interest and a median apparent Ks magnitude of 11.52 ± 0.07 was obtained.

We adopt $M_{Ks} = −1.54 ± 0.04$ mag, based on Groenewegen’s (2008) calibration using revised Hipparcos parallaxes. Thus, we derived the distance modulus of NGC 6791 as $(m − M)_{Ks}^0 = m_{Ks} − M_{Ks} − 0.11 × 0.31 × E(B − V) = 13.02 ± 0.08$ mag. Here we adopt a reddening of $E(B − V) = 0.117$ mag (from the WEBDA database: http://www.univie.ac.at/webda/).

2. Results and Discussion

Based on 2MASS infrared photometry, we derived the distance moduli of our five test open clusters using the RC’s Ks-band magnitude as a ‘standard candle.’

Table 2. Distance estimates for the five open clusters based on their RCs compared with results from main-sequence fitting (MSF).

<table>
<thead>
<tr>
<th>Cluster</th>
<th>RCs $(m − M)_0$</th>
<th>MSF $(m − M)_0$</th>
<th>MSF ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 6791</td>
<td>13.02 ± 0.08</td>
<td>13.11</td>
<td>Chaboyer et al. (1999)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13.0</td>
<td>King et al. (2005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13.07 ± 0.05</td>
<td>Carraro et al. (2006)</td>
</tr>
<tr>
<td>NGC 2420</td>
<td>11.76 ± 0.12</td>
<td>11.4 ± 0.2</td>
<td>McClure et al. (1974)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.80</td>
<td>Anthony-Twarog et al. (1990)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.9 ± 0.1</td>
<td>Lee et al. (1999)</td>
</tr>
<tr>
<td>NGC 2682</td>
<td>9.49 ± 0.09</td>
<td>9.38</td>
<td>Boyle et al. (1998)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.58</td>
<td>VandenBerg et al. (2007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.70 ± 0.05</td>
<td>Sarajedini et al. (2009)</td>
</tr>
<tr>
<td>NGC 2158</td>
<td>12.91 ± 0.09</td>
<td>12.70</td>
<td>Christian et al. (1985)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.8</td>
<td>Carraro et al. (2002)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.98</td>
<td>Bedin et al. (2010)</td>
</tr>
<tr>
<td>NGC 7789</td>
<td>11.44 ± 0.18</td>
<td>11.25</td>
<td>Vallenari et al. (2000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.56 ± 0.12</td>
<td>Bartasiute et al. (2004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.27 ± 0.04</td>
<td>Wu et al. (2007)</td>
</tr>
</tbody>
</table>

In Table 2 we compare our distance modulus results based on the RC magnitudes with those derived from main-sequence-fitting (MSF). The comparison shows that our results agree well with most MSF results. However, using the RC’s intrinsic K-band luminosity as
a distance indicator has the advantage of a weaker dependence on chemical composition and age (for wide ranges), and also of being less affected by reddening. In particular, the RC’s infrared-calibrated nature as a standard candle may play an important role in cluster distance determination. Among our five sample clusters, NGC 6791, NGC 2158, and NGC 7789 all have around 20 RC stars detected in their CMD, while the other two clusters have only approximately 10 RC stars each. The RC’s number density in the cluster CMD would be one of the main limitations to the accuracy of the resulting distance modulus.

Acknowledgements

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References