Analysis of the Halo Globular Cluster M30 and its Variable Stars

Michael T. Smitka, Austin Peay State University
Andrew C. Layden, Bowling Green State University

ABSTRACT
Photometry of the metal-poor globular cluster M30 is presented in B, V, R and I. A color-magnitude diagram created from this photometry indicates that accurate magnitude measurements were obtained for stars from the tip of the red giant branch down to approximately 3 magnitudes fainter than the main sequence turnoff. Time-series photometry is presented for six RR Lyrae type variable stars, three of which are newly discovered. Four variable stars of other types, three of them newly discovered, were also detected. A metallicity value of [Fe/H] = −2.02 was adopted for this study. Using the RR Lyrae trend in color at minimum light, a reddening of E(B−V) = 0.053 ± 0.010 was found for this cluster as well as an extinction value of A_v = 0.165 ± 0.031. A distance modulus of (BB−V) = 7.958 ± 0.147 kpc and the corresponding distance of 7.958 ± 0.147 kpc was also computed using the RR Lyrae stars’ mean magnitudes. The discovery of three RRc variables allowed us to definitively classify M30 as an Oosterhoff type II globular cluster.

CALIBRATION
The calibration of our photometry of all stars in our M30 field to the standard system was performed for each of the 8 image subsets independently. Three sets of field standard stars were used in this process: those of Stetson (2000), Alcaino et al. (1987) and a third set that was created at Bowling Green State University specifically for this study. Calibration calculations were carried out using linear fitting techniques in two phases: a magnitude-dependent calibration first and a color-dependent one second. Statistics of the calibration calculations for each image subset can be found in the table below.

<table>
<thead>
<tr>
<th>Filter</th>
<th>Exposure Time</th>
<th># Calibration Stars</th>
<th>RMS_\text{m}_{\text{template}}</th>
<th>RMS_\text{m}_{\text{star}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Short (50 sec)</td>
<td>101</td>
<td>0.0219</td>
<td>0.0158</td>
</tr>
<tr>
<td>B</td>
<td>Long (250 sec)</td>
<td>92</td>
<td>0.0197</td>
<td>0.0112</td>
</tr>
<tr>
<td>V</td>
<td>Short (20 sec)</td>
<td>104</td>
<td>0.0348</td>
<td>0.0298</td>
</tr>
<tr>
<td>V</td>
<td>Long (150 sec)</td>
<td>94</td>
<td>0.0294</td>
<td>0.0264</td>
</tr>
<tr>
<td>R</td>
<td>Short (10 sec)</td>
<td>10</td>
<td>0.0220</td>
<td>0.0192</td>
</tr>
<tr>
<td>R</td>
<td>Long (100 sec)</td>
<td>4</td>
<td>0.0256</td>
<td>0.0251</td>
</tr>
<tr>
<td>I</td>
<td>Short (10 sec)</td>
<td>74</td>
<td>0.0277</td>
<td>0.0228</td>
</tr>
<tr>
<td>I</td>
<td>Long (100 sec)</td>
<td>64</td>
<td>0.0230</td>
<td>0.0205</td>
</tr>
</tbody>
</table>

We prepared an HR diagram using our B, V and I data sets. We combined the 20 highest quality images from each of our short and long exposure subsets for each filter to create a single set for each filter that contained stars spanning from the red giant branch tip to about 3 magnitudes fainter than the main sequence turnoff. Stars with photometry errors larger than 0.05 magnitudes in V and within 200 pixels of the cluster center were excluded from this diagram. The HR diagram is shown below.

PHOTOMETRY
Photometry was performed using the DAOPHOT II, ALLSTAR (Stetson, 1987), ALLFRAME (Stetson, 1994), and DAOMASTER software packages. We chose to employ this program suite because it was designed specifically for crowded field photometry and enabled us to resolve individual stars in the dense core of the cluster. For the photometry computations the data set was broken up into 8 subsets, each of which was computed independently. Each subset was composed of images of one filter with a common exposure time. The average number of images per subset was 43.

We also performed differential photometry of the 8 subsets of images using SIS (Alard, 2000). We had to do this work to determine the photometric accuracy of the variable stars within our field and to aid in the identification of variable stars in our primary DAOPHOT II photometry. Differential photometry also enables variable stars to be detected and have their periods measured in dense fields where their profiles are blended with neighboring non-variable stars and are otherwise difficult or impossible to detect.

VARIABLE STARS
10 stars were found to be variable in this study, six of them RR Lyrae type. Of these 6 RR Lyrae, 3 were previously documented RRab stars (Rosino, 1949) and 3 are RRc type stars newly discovered by this study. Periods were calculated and light curves were created for these stars using the template fitting methods of Layden et al. (1999) and Layden (1998).

CONCLUSIONS
A metallicity of [Fe/H] = −2.02 was adopted from the literature for this study. Using the RRab stars’ colors at minimum light we were able to calculate the interstellar reddening and extinction of the starlight. Reddening values were calculated using the methods of Blanco (1992) for (B−V)_\text{abs} and Gehrels, Layden, Wan et al. (2005) for (V−I)_\text{abs} along with two documented values of Schlögel, Finkbeiner & Davis (1998) and Harris (1996). An average of the four values yielded a reddening of E(B−V) = 0.053 ± 0.010 and the corresponding extinction of A_v = 0.165 ± 0.031. A theoretical absolute magnitude of M_v(RR) = 0.46 ± 0.121 was calculated for the RR Lyrae stars using the method of Chaboyer (1998). When combined with our visual magnitude average of m_v(RR) = 14.964 ± 0.057 this yielded a distance modulus of \( \mu_v = 14.504 ± 0.127 \), or d = 7,958 ± 0.147 kpc. The discovery of 3 RRc variables additionally served to definitively classify M30 as an Oosterhoff II type cluster based on trends observed in RR Lyrae period, metallicity and the proportion of RRc stars to all RR Lyrae present (Smith, 1995). Prior to our findings the classification of M30 was ambiguous because no RRc stars had been observed.

BIBLIOGRAPHY
[15] Alonso, A., Arribas, S. and Igl...