Analysis of the Halo Globular Cluster M30 and its Variable Stars

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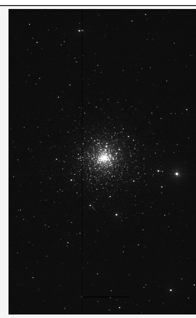
ABSTRACT

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 stars' mean colors 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 μ = 14.504 ± 0.127 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 II type globular cluster.

OBSERVATION

Images of M30 were gathered using the Swope telescope located at Cerro Las Campanas, Chile during an observing session in 2005. The entire data set consisted of 342 total images taken in the B, V, R and I Johnson standard filters. Short and long duration exposure images were gathered through each filter in order to provide well exposed images of both bright and faint stars, thus ensuring good photometry of all stars regardless of their luminosity.

Standard bias removal and flat fielding processing were performed by the observers while at the observatory. Some pixels that consistently displayed atypical behavior in all images were masked. Evidence of the masking can be seen in the sample image below.



A sample image taken from our data set. Image is a short exposure I filter image.

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 ISIS (Alard, 2000). This was done to provide preliminary information about the variability of all stars within our field and to aid in the identification of variable stars in our primary DAOPHOT II photometry. Differential photometry also often 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.

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.

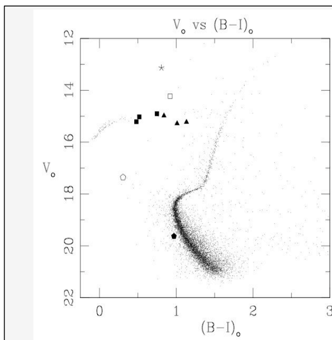
Documented variable stars and stars flagged as variable candidates in our photometry were calibrated individually using differential techniques. These calibrations were carried out after the whole-field calibration had been completed. The magnitude and color calibrations of each variable star candidate were calculated for each individual image separately based on six non-variable comparison stars chosen specifically to resemble the variable candidate's position on the HR diagram, photometry uncertainty and position on the CCD chip.

Calibration Statistics

Filter	Exposure Time	# Calibration Stars	$RMS_{magnitude}$	RMS_{color}
B	Short (70 sec)	103	0.0219	0.0158
B	Long (250 sec)	92	0.0197	0.0112
V	Short (20 sec)	104	0.0348	0.0298
V	Long (150 sec)	94	0.0294	0.0264
R	Short (10 sec)	10	0.0220	0.0192
R	Long (100 sec)	4	0.0256	0.0251
I	Short (10 sec)	74	0.0237	0.0228
I	Long (100 sec)	64	0.0230	0.0205

HR DIAGRAM

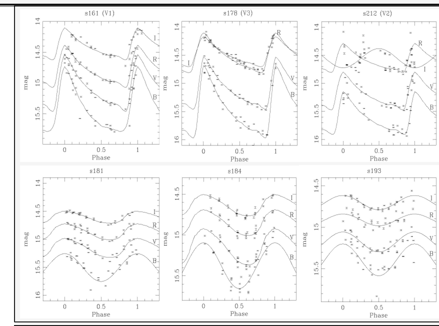
We prepared an HR diagram using our B, V and I data sets. We combined the 20 highest quality images from each of our short and long exposure subsets for each filter to create a single set for each filter that contained stars spanning from the red giant branch tip to about 3 magnitudes fainter than the main sequence turnoff. Stars with photometry errors larger than 0.03 magnitudes in V and within 200 pixels of the cluster center were excluded from this diagram. The HR diagram is shown below.



A reddening and extinction corrected HR diagram of M30 prepared from our data. Filled triangles denote RRab stars, filled squares RRc.

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).



RR Lyrae Stars

ID	Type	Period (d)	$(B-V)_{min}$	$(V-I)_{min}$	V_{mag}
s161	ab	0.7422	0.402	0.757	15.057
s178	ab	0.6536	0.445	0.643	15.175
s212	ab	0.6950	0.467	0.708	15.075
s181	c	0.3479	0.225	0.555	15.147
s184	c	0.4198	0.335	0.585	15.151
s193	c	0.4831	0.195	0.491	15.168

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 $(B-V)_{min}$ and Guldenschuh, Layden, Wan et al. (2005) for $(V-I)_{min}$ along with two documented values of Schlegel, 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 ± 0.037 this yielded a distance modulus of μ = 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.

Oosterhoff Classification

Cluster	<Pab> (d)	<Pc> (d)	[Fe/H]	n(c)/n(ab+c)
Oo I	0.55	0.32	-1.0 < [Fe/H] < -1.8	0.17
Oo II	0.64	0.37	-2.0 > [Fe/H]	0.44
M30	0.6969	0.4169	-2.02	0.50

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