Differential Photometry of M39

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(Dated: 28 September 2017)

We used differential photometry to determine magnitudes of four objects in M39 using two foreground stars as references. We could only process three of the objects of interest due to poor image data for the other objects. The magnitudes were as follows: BD+47 3447, V=10.189(19), B=10.394(56), HD 205085 V=7.9696(75) B=8.0264(16), and BD+47 3453, V=9.540(10), B=9.669(24). The reference stars we used were BD+47 3454, V=8.917, B=9.028 and HD 205073, V=7.845, B=7.870. Our magnitudes agree with other papers on M39 and our precision is around one-hundredth of a magnitude. We noted our brighter stars have less error, generally.

I. INTRODUCTION

This lab seeks to determine the V and B magnitudes of four objects in M39, an open galactic cluster. M39 contains around 30 stars of various brightness and is about 9° from Deneb (α Cyg).

To determine the magnitudes of our objects, we used differential photometry. This process uses the simplicity of having two objects taken in the same image, through the same filter, through the same optical path, and exposed for the same amount of time to determine

$$m_{tar} = m_{ref} + m_{diff} \tag{1}$$

The way an imaging program does this is by determining the instrumental magnitudes and then comparing them to the reference magnitudes.

$$m_{inst} = -2.5 \log_{10}(S - B) \tag{2}$$

where S is the sum of all the pixel values in a given aperture and B is the sum of all the pixel values of some background section, usually an annulus. The way AstroImageJ calculates these sums is dependent on more complex equations that parameterize the electron gain of the CCD and can do more image processing prior to integrating the pixel values. These extra parameters allow for determining the error of the instrumental magnitude.

After the instrumental magnitude of a reference star is found, we can determine the magnitude correction value by combining Equation 1 and Equation 2.

$$m_{corr} = m_{ref} - m_{inst} \tag{3}$$

and finally we can find the magnitude of any target star with

$$m_{tar} = m_{inst} + m_{corr} \tag{4}$$

We used a weigthed average and standard deviation to report our numbers, with weight equal to the inverse error squared.

$$\bar{x}_w = \frac{\sum_i x_i/\sigma_i^2}{\sum_i 1/\sigma_i^2} \tag{5}$$

$$\sigma_w = \sqrt{\frac{1}{n-1}\sum (x_i - \bar{x}_w)^2} \tag{6}$$

II. DATA ACQUISITION AND SETUP

Observations were made on at the Zaffarano Hall observation deck in Ames, Iowa (−93.647 34°, 42.029 96°, 342 m). The night was mostly clear and the ambient temperature was around 12 °C. The moon was full that night which caused higher than usual lunar presence. Observations were made using a Meade 8" reflector telescope with an SBIG ST-402ME CCD camera with internal V, B, and I filters.

Setting up the telescope was the same as previous observations made with the 8" Meade telescope at Zaffarano Hall. An obstacle we faced with alignment and slewing was the misalignment of our sight by a significant amount. To combat this, we shined a laser through the eyepiece to roughly show the target of the main mirror.

We took 15 frames of data at 13 s at two locations in the sky. Of those 15, 5 were with photometric V, 5 were with photometric B, and 5 were dark frames. The first target contained two M39 objects (BD+47 3452 and HD 205172), however this data was deleted by accident and was not used for analysis. The second target contained objects BD+47 3447, HD 205085, BD+47 3453, and BD+47 3458, all of which are recorded in Table III. Of these images, another issue we encountered was centering the images as the telescope shifted according to its tracking movements. Because of this, a few of the images do not contain a clear view of BD+47 3458.

III. DATA ANALYSIS

Our data analysis involved preparing our science images and performing differential photometry on them. To prepare our images we created a median dark frame in AstroImageJ for our only exposure time, 13 s. We then subtracted this frame from each science image to filter out systematic noise from our CCD. These images were then grouped into two stacks, one for each photometric filter.

We used AstroImageJ to process each stack using multi-aperture photometry. Our reported electronic gain was 1.49 e/ADU. AstroImageJ processes the stack of images in a way that allows for quick aperture placement. An aperture can be placed on each star of interest in an

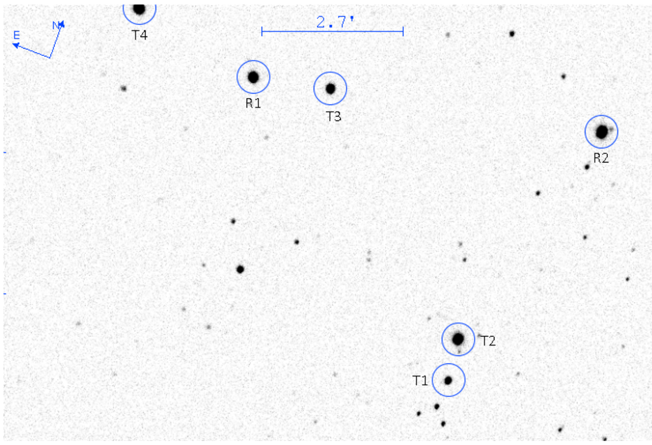

FIG. 1. Map showing the celestial direction, target stars, and reference stars. The names of the objects above are in Table II.

image and AstroImageJ allows placing target stars and reference stars, where the reference stars have predetermined magnitudes.

After placing the apertures for one image in the stack we move forward in the stack and by choosing the same initial aperture AstroImageJ will place the remaining apertures automatically. The reference magnitudes are shown in Table I. After each aperture has been placed on each image in the stack and the reference star magnitudes have been set, AstroImageJ will do the photometry and creates a measurement table with the results. The full results are shown in section B. The skymap for the target and reference stars is shown in Figure 1.

TABLE I. Reference Stars

Object	Name	V Mag	B Mag
R1	BD+47 3454	8.917	9.028
R2	HD 205073	7.845	7.870

IV. RESULTS

The table of the results from AstroImageJ are in section B and the results calculated using Equation 5 and Equation 6 are in Table II. We do not report a magnitude for BD+47 3458 because of issues with the photometry. The star had drifted out of frame for some of the images and therefore the instrumental magnitude was not correct. Also, the star moved due to telescope drift and the amount of the star cut off was inconsistent which caused a large variance in the pixel value counts.

TABLE II. Photometry Results

Object	Name	V Mag	B Mag
T1	BD+47 3447	10.189(19)	10.394(56)
T2	HD 205085	7.9696(75)	8.0264(16)
T3	BD+47 3453	9.540(10)	9.669(24)
T4	BD+47 3458	NA	NA

V. CONCLUSIONS

Although we encountered issues with framing the images and accidentally deleting half of our data, we are satisfied with the results of the differential photometry. A quick comparison to the magnitudes reported by other papers shows that we are mostly accurate and our process was effective given our equipment. The precision of our photometry as also reasonable. We are happy to see that we can generally be precise to the hundredth of a magnitude. We also noted that the brighter the object the less error we had.

ACKNOWLEDGMENTS

Thank you to Dr. Charles Kerton and Brandon Marshall for their guidance and assistance in this work.

Appendix A: Observation Log

TABLE III. Observed 06 September 2017 by Miles Lucas and John Brandon

Time	File	N Frames	Object	Filter	Exposure	Camera Temp.	Notes
21:39	M39_2_V_13s_	5	M39 Objects T1, T2, T3, and T4; stars R1 and R2	V	13 s	5.33 °C	
21:41	M39_2_V_13s_dark_	5	M39 Objects T1, T2, T3, and T4; stars R1 and R2	V	13 s	5.33 °C	Dark frames
21:43	M39_2_B_13s_	5	M39 Objects T1, T2, T3, and T4; stars R1 and R2	B	13 s	5.33 °C	

Appendix B: Photometry Results

TABLE IV. Full results from AstroImageJ multi-aperture differential photometry for the photometric V images

Slice	T1 Mag	T1 Err	T2 Mag	T2 Err	T3 Mag	T3 Err	T4 Mag	T4 Err	R1 Mag	R1 Err	R2 Mag	R2 Err
1	10.18609	0.176984	7.960098	0.037337	9.537899	0.10435	8.716391	0.055953	8.917	0.061367	7.845	0.025834
2	10.193105	0.187644	7.973817	0.04062	9.537579	0.111398	8.786726	0.06126	8.917	0.0653	7.845	0.02774
3	10.195668	0.191079	7.968483	0.041178	9.529998	0.112293	9.008232	0.071347	8.917	0.066747	7.845	0.028051
4	10.220418	0.200807	7.963982	0.042037	9.557328	0.116375	9.249187	0.086958	8.917	0.06898	7.845	0.028695
5	10.169891	0.14342	7.978648	0.03339	9.537594	0.086798	10.330707	0.155808	8.917	0.051375	7.845	0.022805

TABLE V. Full results from AstroImageJ multi-aperture differential photometry for the photometric B images

Slice	T1 Mag	T1 Err	T2 Mag	T2 Err	T3 Mag	T3 Err	R1 Mag	R1 Err	R2 Mag	R2 Err
1	10.374302	0.058418	8.028253	0.019926	9.661362	0.038906	9.028	0.025439	7.87	0.014405
2	10.398856	0.072556	8.024075	0.023852	9.66782	0.047418	9.028	0.030662	7.87	0.017282
3	10.467363	0.175167	8.026245	0.033794	9.702747	0.094185	9.028	0.053192	7.87	0.023198
4	10.423689	0.190297	8.026522	0.036299	9.665717	0.103558	9.028	0.058534	7.87	0.024633
5	10.470166	0.211676	8.025427	0.038635	9.701385	0.114719	9.028	0.062982	7.87	0.02621