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# Measuring Age, Distance, and E(B-V) of NGC2323 using Photometry and $\chi^2$ Techniques

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## ABSTRACT

We present an analysis of the open star cluster NGC 2323 (M50) using a combination of astrometric data from the Gaia mission and photometric observations from the Mount Laguna Observatory (MLO) 1.0m telescope. B and V band images were processed to correct for bias and flat-field effects, and photometric calibration was performed using reference magnitudes from the APASS catalog. Cross-matching with Gaia sources enabled us to identify likely cluster members based on distance and proper motion, while ensuring photometric integrity by selecting isolated stars. Using the resulting calibrated dataset, we constructed a color–magnitude diagram (CMD) and compared it to theoretical stellar isochrones through $\chi^2$ minimization. Our best-fit results yield an age of $\log_{10}(\text{age}) = 7.9$ (approximately 79 million years) and a color excess $E(B-V) = 0.404$. This study demonstrates how combining ground-based photometry with space-based astrometry and model fitting techniques can be used to derive precise cluster properties.

*Keywords:* Open star clusters (1160), Color–magnitude diagrams (278), Stellar photometry (1620), Photometric calibration (1227), Stellar distances (1603), Reddening (1376), Astrometry (80), Proper motions (1297), Parallax (1184), Isochrone fitting (2076)

## 1. INTRODUCTION

Understanding the physical properties of star clusters provides us important insights into the evolution of stars and the structure of the Milky Way. Having accurate measurements of a star cluster's distance, age, and color excess are fundamental to this goal. However, obtaining these measurements is more nontrivial. Observations are often contaminated by field stars, and measured stellar brightness and color are affected by both distance and extinction. An important tool for interpreting stellar populations is the Hertzsprung-Russell(HR) diagram. This relates a star's temperature (intrinsic color) to its luminosity ( Gaia Collaboration et al. 2018). In this paper, we will use the color-magnitude diagram (CMD) as the basis of our analysis. The color-magnitude diagram is a variation of the Hertzsprung-Russel diagram, but what the CMD does differently is it uses the ratio of the intensity of the star in two spectral bands ( IPAC/Caltech 2025). By overlaying theoretical stellar isochrones we can compare our data to models of stellar evolution. The cluster we will analyze for this report is going to be NGC 2323 or also known as M50. To find the best-fit parameters for NGC 2323, we will perform $\chi^2$ minimization by comparing the corrected observed stars to stellar isochrones at a range of ages and extinction values. This process allows us to extract the cluster's age, distance, and color excess $E(B-V)$ values of NGC 2323. In the coming sections of this paper we will describe the data calibration, cluster identification, CMD construction, and $\chi^2$ fitting process.

## 2. DATA

For this report we will use data from the Gaia mission and the Mount Laguna Observatory 1.0m telescope. The Gaia Mission provides precise astrometry (parallax and proper motion), which enables distance measurements and identification of cluster members. Meanwhile, the data from the Mount Laguna Observatory provided us B and V band images provide photometric measurements that we calibrate using standard stars from the APASS catalog (N. M. Law et al. 2009). After identifying isolated cluster members, we correct their observed magnitudes for the extinction and distance values, and construct a CMD.

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# 3. ANALYSIS

## 3.1. *Processing B and V Band Images*

For the first step we must process the B and V band images of NGC 2323 taken from the MLO 1.0m telescope. This focuses on removing the bias and flat-field issues that can contaminate our measurements. This step is crucial as these images are going to be our observed photometry providing us B and V magnitudes. In order to achieve this we must identify the bias in the images and know there are two types of bias we can account for. $B_f$ represents the floating bias that varies over time, meaning it varies from frame to frame. $B_s$ represents the static bias which is constant over time but varies from pixel to pixel.

$$C = \frac{(B_f + B_s + \epsilon N_\gamma)}{g} \tag{1}$$

Eq 1 represents the output value of the analog to digital converter taken from the CCD from MLO. $B_s$ and $B_f$ are the bias added in the numerator, but $N_\gamma$ represents the incident photons captured by the CCD. We want to eliminate the bias and just be left with $N_\gamma$ in the numerator as this will get us the image of NGC 2323. To get the static bias ($B_s$) accounted for in each image, we take 25 zero second exposure shots with the shutter closed. We do this because when a picture is taken with the shutter closed, the CCD still processes non-zero data from the pixels. To combine them into a master bias image, we would combine each frame together and then get the average of the frame. The averaged non-zero data from these images would be our static bias that we can remove from each image. Figure 1 is the master bias frame that we will use to process the image of NGC 2323. Now that the $B_s$ is taken into account, we

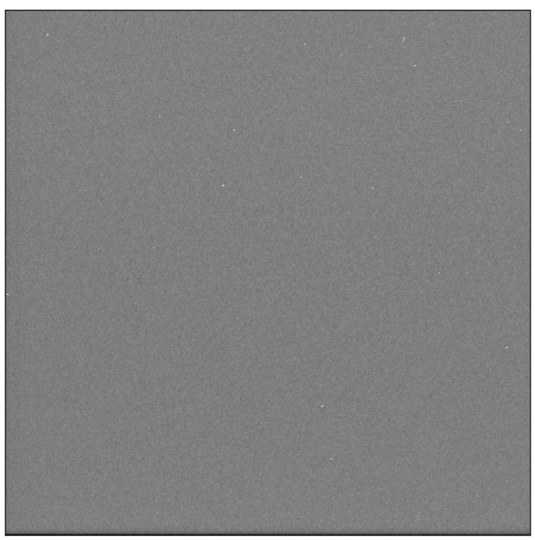


**Figure 1.** The output image for the Master Bias frame. Notice how there are still white dots scattered throughout the image even though we had the shutter closed.

can move to identifying $B_f$ which is the floating bias. The floating bias is responsible for the pixel-pixel variations in our images. To account for this, we will take an exposure image of a uniform light source in each band, in this case the B and V bands. The creation of a master flat image is similar to making a master bias image, but we need to subtract the master bias to the data. Once that is done we take the flat corrected values and divide each image with the median of the corrected flat. This will result in us getting a master flat image in each band. Figure 3 and Figure 2 are our master flats. Now that we have the master bias image and master flat images we can now process our images. One thing to note about the images used for this report, is not only were they taken in the B and V bands but also at varying exposure times. The varying exposure times were at 5, 20, and 80 seconds. So once we process the images we

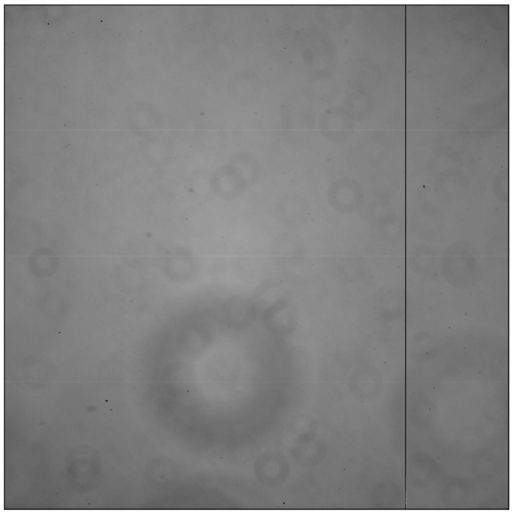


**Figure 2.** Processed flat image in the V band, notice the donut like rings spread throughout the image. This is what the flat field images help calibrates for

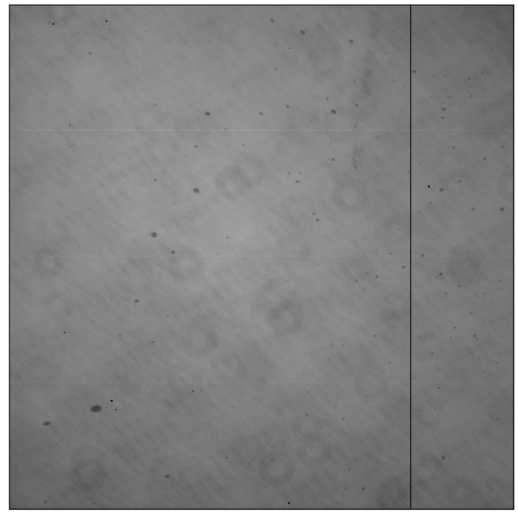


**Figure 3.** Processed flat image in the B band. Notice how the images are different in each band. This shows how each band captures entirely different bias from band to band.

will have in total 6 images, 3 in the B band and 3 in the V band. The way we will process these images is represented in Equation 2.

$$P = \frac{D - B_s}{f} \tag{2}$$

Using this equation will result in us getting our desired processed image. $D$ represents the data at the various exposure times. $B_s$ represents the static bias, and we divide the difference between $D$ and $B_s$ over $f$ which is the master flat image. Figure 5 and Figure 4 are processed images in the B and V band which were both taken with a 20 second exposure time. Now that we have our processed images we can use these images to find our observed magnitudes in later steps using photometry.

### 3.2. *Querying the Gaia archive*

Next, we use the Gaia archive to query astronomical data about NGC 2323. To do this, we do an ADQL query from the Gaia archive for its: Right Ascension (RA), Declination (Dec), Parallax, Proper Motion RA, Proper Motion Dec, and their accompanying error values. We also want to create this search to only include the $G_{BP}$ (Gaia Blue Photometric Band) less than 19 and a parallax 5 times greater than the uncertainty. Once the query is finished we were left with a list of 824 light sources.

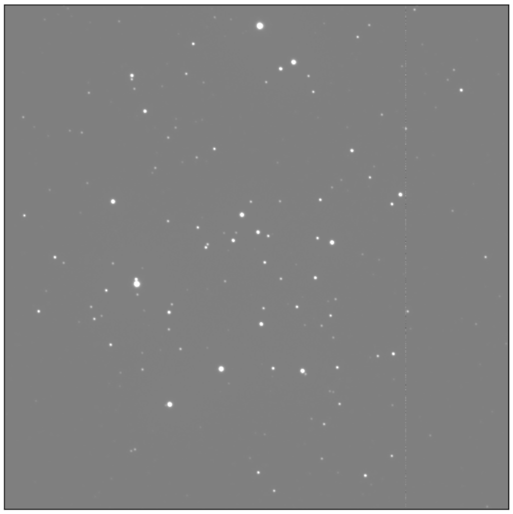


**Figure 4.** Processed image in the V-Band under a 20 second exposure.

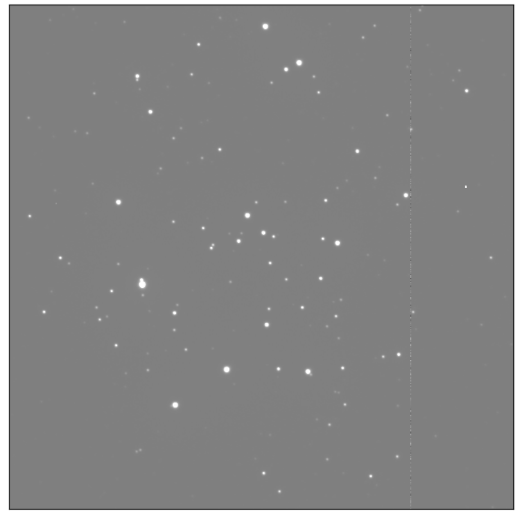


**Figure 5.** Processed image in the B-Band under a 20 second exposure.

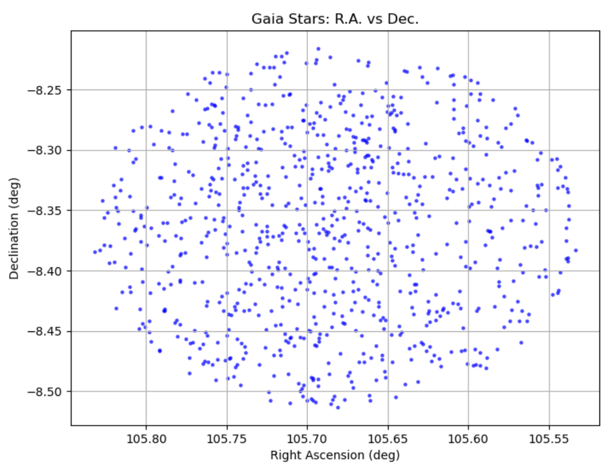



**Figure 6.** RA and Dec plotted from the archived stars of the Gaia query. See how this is a large cluster of stars in the image

Figure 6 shows our light sources plotted from the our ADQL search. One thing to note about this is that not every star here is part of the cluster. This is plotted in the RA and Dec, so this is what we see here on Earth, but some of these stars could be further out or closer to us and not part of the cluster. This is why we collect the proper motion data from the stars in the Gaia query. This allows us to see what stars are physically part of the cluster by seeing how similar they move together. What we need to do now is create a list that we can populate later with data from the stars regarding its name, distance, id, ra, dec, proper motion values, and magnitudes in the V and B band along with the accompanying errors with these values.

### 3.3. *Querying APASS Catalog for Magnitudes*

Next we want to query the APASS catalog via VizieR to retrieve the B and V magnitudes of the stars in our field. Although we have the magnitudes from the MLO images and the Gaia archive, we need to calibrate the magnitudes by finding the zero points. Using data from the APASS catalog, we match the stars with the nearest Gaia stars by their coordinates, we only keep the stars that have a max separation distance of 1 arc second within each other.

### 3.4. *Measuring B and V band brightness*

Now we can perform aperture photometry on the calibrated images taken from MLO. To do this, we have to measure the flux in a 1-FWHM radius aperture at each Gaia source. Since we have 3 images in each band with varying exposure times, we can use the shorter exposure times to record the magnitudes of brighter objects and the longer times can be used to measure the fainter magnitudes. To record the magnitudes we can use Equation 3 where $F$ represents the flux of the star and $Zp$ is the zeropoint taken from the earlier step. Once we figure out the B and V magnitudes we want to save it to a data array to use in the next steps.

$$m = -2.5log_{10}(F) + Zp \tag{3}$$

Now that we have the B and V magnitudes from each star in a data set we can use this as our observational data set. This allows us to construct a color-magnitude diagram with our data. Figure 7 shows the CMD plot and from it we can see that it follows a slight curve from the center moving to the bottom right. With this, we can determine the age of the stars in this cluster by comparing it with theoretical isochrones using $\chi^2$ fitting.

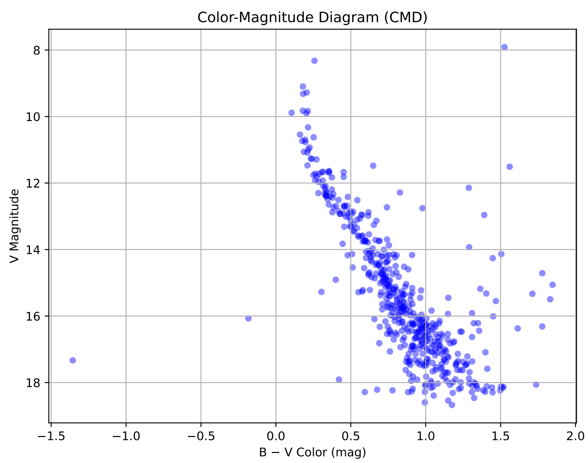


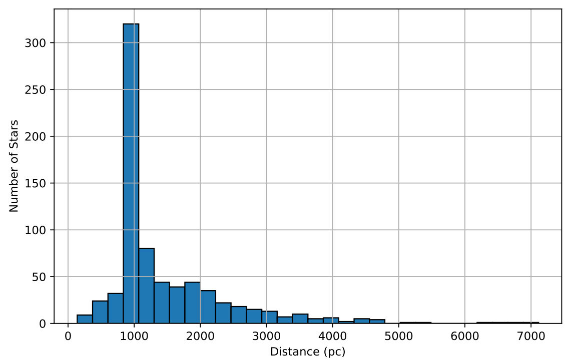

**Figure 7.** CMD plot taken from Dr. Quimby's data set on NGC 2323. His data set performed the same steps detailed in this paper for constructing the data.

### 3.5. *Identifying Cluster Members and Isolated Stars*

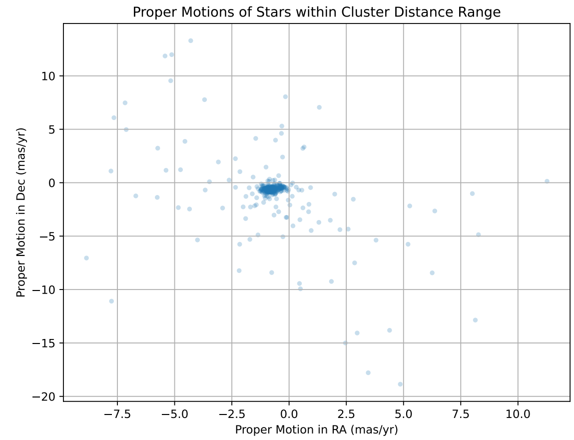
Now that we have a data set of NGC 2323 we can plot a histogram of the distance from each star in the data set. We need to do this to see what the distribution is like for the distance of the stars. Notice in Figure 8a that much of the stars are located within 800 and 1300 parsecs. We can set these distances as our min and max to filter out more stars that are not within NGC 2323. Next we can plot the proper motions of the stars within our min and max distances to see how these stars move together. Figure 8b shows a concentration of stars at ±1.5 mas/yr within the origin. We can set the min values for the proper motion of the RA and Dec to be -1.5 mas/yr and the max to be 1.5 mas/yr. Doing this helps us filter out more stars that are not within our desired clusters.

### 3.6. *Determining best Age and E(B-V) through $\chi^2$ Minimization*

Now that we have our cluster data we can model determine the age and E(B-V) values through $\chi^2$ minimization. First, we must create the models to predict our values. To do this, we used data that simulated populations of stars at various ages. Figure 9 shows the simulated populations plotted. With this model we can compare the B-V colors and the V-Band magnitudes from the stars in the cluster.




(a) Histogram of the distances from the NGC2323_phot.pkl database. See how much of the stars are mainly distributed in a specific distance. This is one way we are going to identify the stars in the cluster.




(b) Proper motion of the stars within the 800 to 1300 parsecs. Notice there is a clump of stars concentrated on a small point. This is another way we can determine the stars in the cluster.

**Figure 8.** Cluster member identification using distance and proper motion.

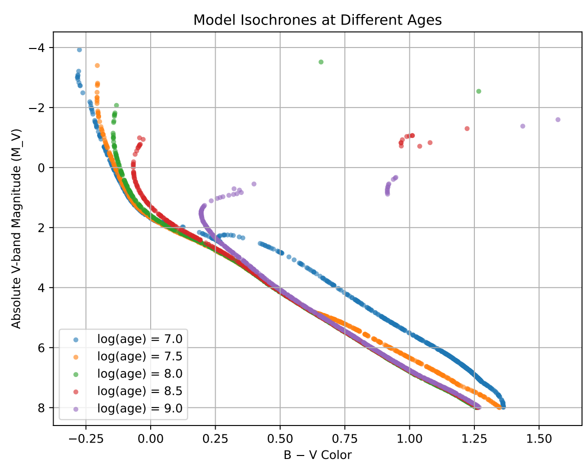



**Figure 9.** Plotted graph of the model Isochrones at varying ages. This is the model we will use to compare and fit our data in.

To do this we first must identify the distance modulus represented by Eq 4. The distance modulus bridges the gap between what we see and what we want to know, by accounting for how brightness fades with distance.

$$\mu = 5log_{10}(D) - 5 \tag{4}$$

Next we want to identify $M_V$ and $M_B$ which is the extinction corrected absolute magnitudes. This can be represented by Eq 5 and Eq 6.

$$M_v = V - \mu - A_V \tag{5}$$

$$M_B = B - \mu - A_B \tag{6}$$

We also want to identify the intrinsic color as the observed magnitude also depends on this value. This helps us by telling us the star's true color unaffected by dust as well as its true temperature. E(B-V) represents the color excess that is caused by interstellar reddening. Correcting for this, we are given the intrinsic color of the star, which prepares the data to be compared with the model.

$$(B-V)_0 = M_B - M_V \tag{7}$$

With these variables determined, we can now run a $\chi^2$ in order to find the best fit cluster age and E(B-V) values. The best-fit age and reddening are defined as the pair of values that produce the lowest total $\chi^2$. These are the model parameters for which the isochrone best matches the overall distribution of stars in the CMD. The lower the $\chi^2$, the better the agreement between observed data and model prediction, given the uncertainties. By completing this step, we directly address the main scientific goal of the paper which was measuring the cluster's age and color excess E(B-V). Figure 10 shows our best fit line and see how well the data matches the model. From this model we were able to determine the age of the cluster to be 7.9. This is in $log_{10}(age)$ so this would actually mean an age of $10^{7.9}$ years or 79 million years old). It also tells us that color excess best fit value is 0.404.

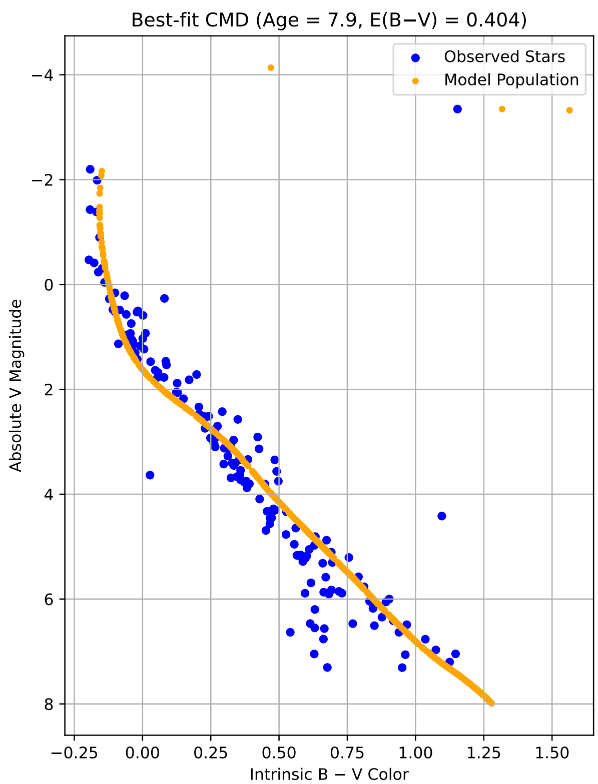



**Figure 10.** Our observed data $\chi^2$ fitted to our model.

## 4. CONCLUSION

For this report, we combined astrometric data from the Gaia mission with photometric observations from the Mount Laguna Observatory (MLO) 1.0-meter telescope to determine the physical properties of the open cluster NGC 2323. Through careful image processing, photometric calibration using the APASS catalog, and cross-matching with Gaia sources, we constructed a clean and calibrated dataset of B and V magnitudes. We then identified likely cluster members based on consistent distances and proper motions, and further filtered for isolated stars to ensure reliable photometry. Using this refined dataset, we constructed a color–magnitude diagram (CMD) and performed $\chi^2$ minimization against theoretical stellar isochrones to determine the best-fit cluster parameters. Our results indicate that NGC 2323 has an age of $\log_{10}(\text{age}) = 7.9$, corresponding to approximately 79 million years, and a color excess $E(B-V) = 0.404$. These values provide insight into the cluster's evolutionary stage and the amount of interstellar dust along the line of sight.

This paper demonstrated how combining Gaia data with ground-based observations from the MLO and stellar models can yield precise measurements of fundamental cluster properties using robust, statistically driven techniques.

## APPENDIX

## REFERENCES

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