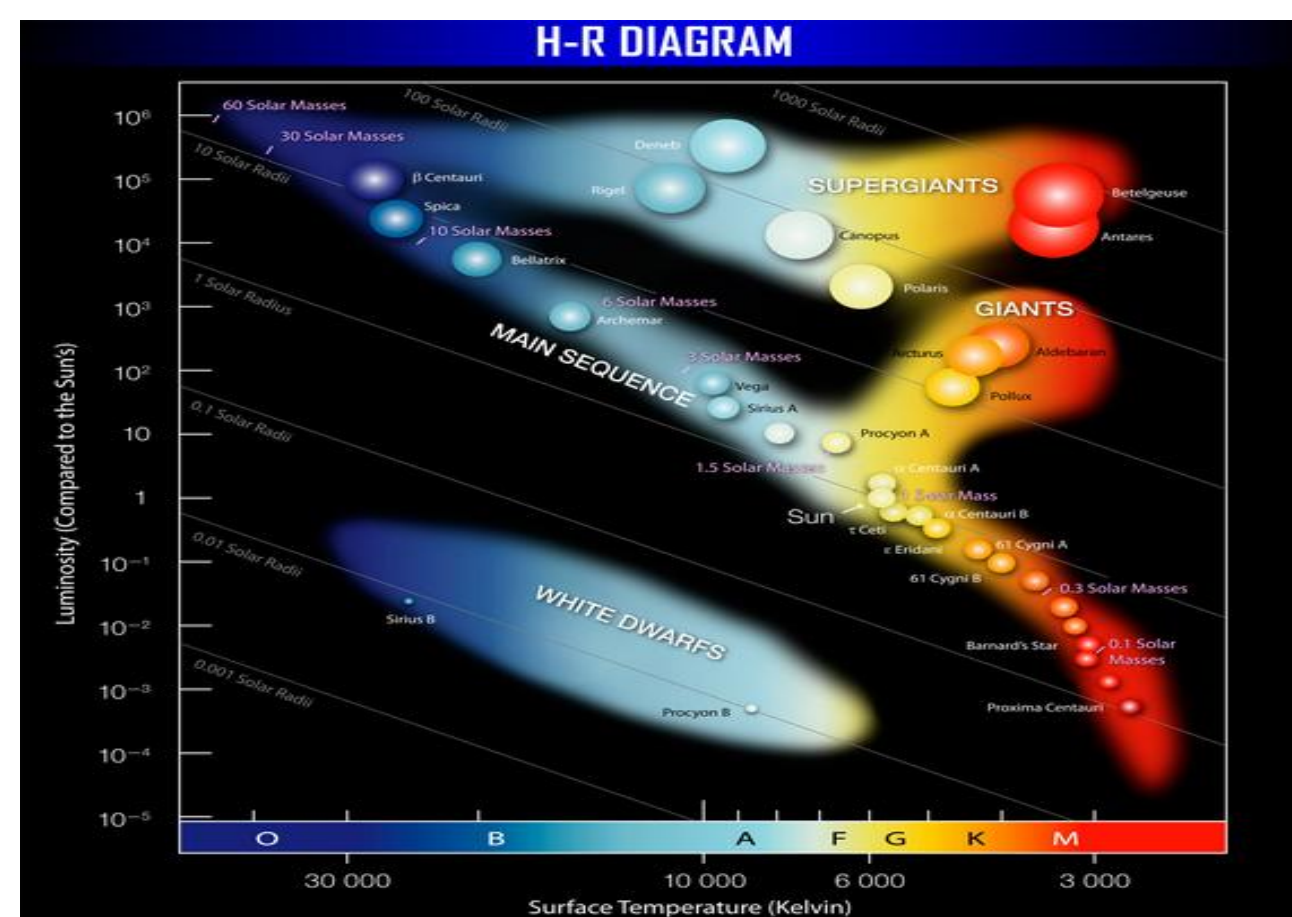


Distinguishing Multiple Stellar Populations of Star Clusters M56 and M13

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Introduction

Globular star clusters are groups of $\sim 10^5$ stars bound together gravitationally. One primary way globular clusters are studied is through HR diagrams, which plot each star's apparent brightness vs. color (a so-called color-magnitude diagram, or CMD), or luminosity vs. surface temperature. Stars begin on the main sequence, fusing hydrogen. Once all their hydrogen has been used up, they become red giants, and move to the red giant branch (RGB) on the HR diagram. As technology has evolved, and the diagrams have become more precise, a splitting of the red giant branch has been observed. One group of stars appear redder than the other. This is caused by differences in chemical abundances. Stars with high light element abundances appear redder and less luminous due to their increased opacity. In order for these stars to have different chemical compositions, they must have formed at different times. One reason to create these HR diagrams is to detect this. Our group dedicated this summer to finding the best procedure to create these CMDs, and to analyze them in order to find this spitting on the red giant branch.



Example of an HR diagram. Notice the main sequence and the giant branch (International Year of Astronomy - The Hertzsprung-Russell Diagram¹).

Objectives

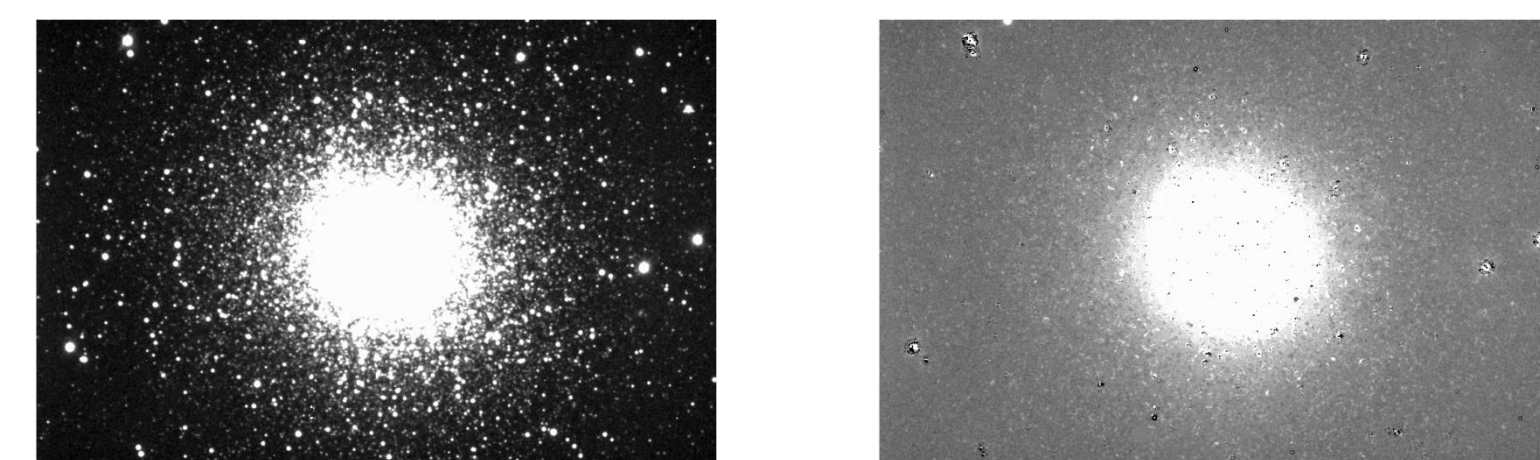
- Perfect procedure to find correct magnitudes of stars in our two cluster, M13 and M56.
- Make accurate color magnitude diagram for star clusters M56 and M13, with low uncertainty.
- Analyze these CMDs and look for evidence that indicates multiple generations of stars that cannot be explained away by photometric error.

Methods

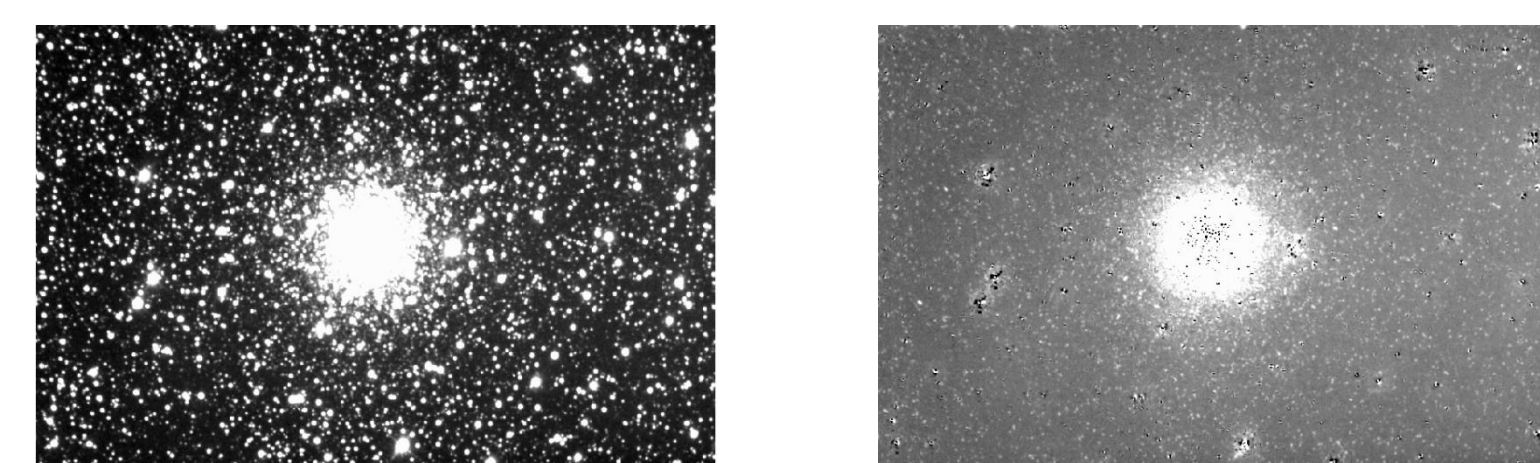
The software package DAOPHOT measures star brightness by identifying stars via the shape of their light profiles and subtracting them from the image in an iterative way. This is necessary since it is a crowded field, and many stars are obscured by others. In order to create an accurate CMD, we must first create these subtracted images using DAOPHOT. The following is our method of creating them:

- 1) Using DAOPHOT, choose ~ 100 isolated stars in the images to define a point spread function (psf).
 - Stars are supposed to be point objects in images, but due to optical properties their light spreads out. A psf is a measure of this spread.
- 2) Once the psf is finalized, perform photometry on all stars DAOPHOT was able to find.
- 3) Subtract these stars from the original image.
- 4) Run through DAOPHOT again, finding new stars from the subtracted image, and perform photometry on this new list of stars.
- 5) Append this new list to the one created in step 2.
- 6) Subtract, from the original image, all of the stars in this combined list.
- 7) Repeat steps 4-6, making a master list of all stars DAOPHOT was able to find during every iteration, until all light from images is subtracted.

Creating a well-defined psf is the most important step in our method. If our psf is not accurate, then we will not be subtracting the right amount of light from each star, and our magnitudes will be wrong.



Images of M13 in the V filter before (left) and after (right) subtraction



Images of M56 in the V filter before (left) and after (right) subtraction

After we were happy with our subtracted images, we ran two programs, DAOMATCH and DAOMASTER, to match up the stars in both filters. This allows us to have the V and I magnitudes for each star matched up to easily create a CMD (Figure 1).

Results

After we were confident with our magnitude measurements, we made our CMDs.

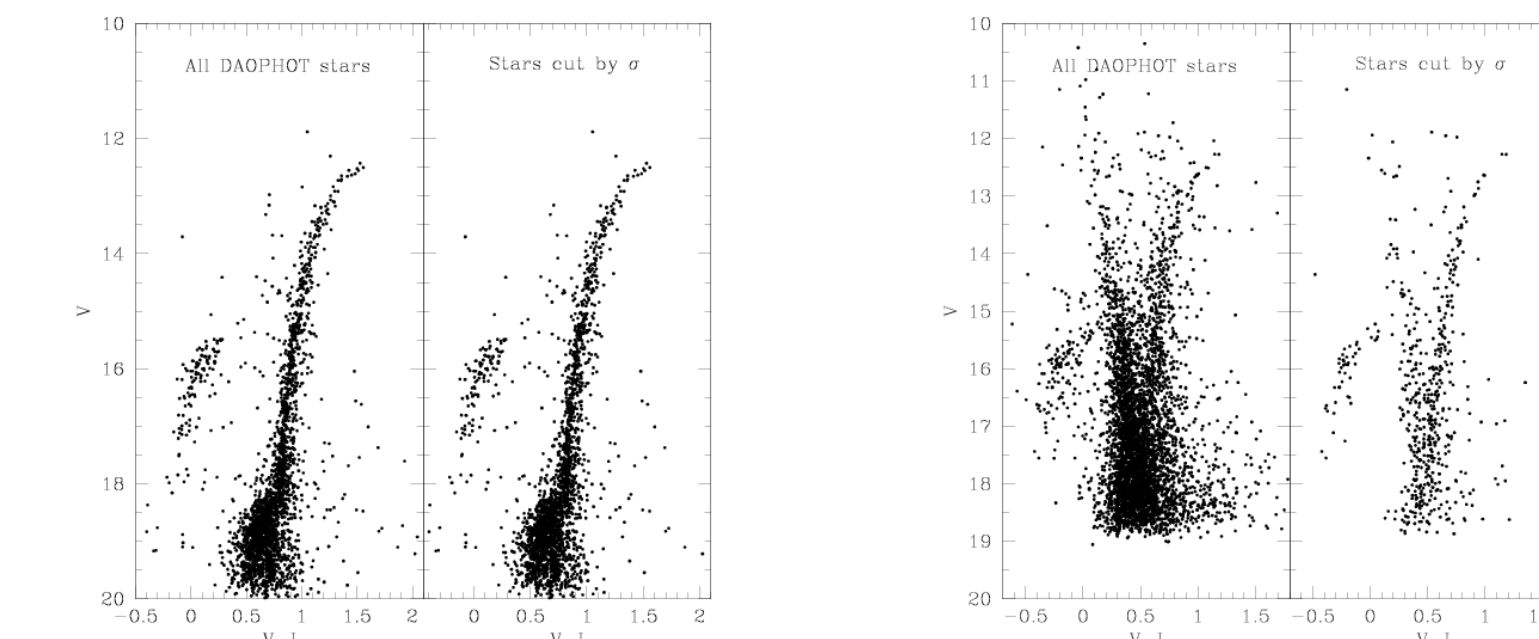


Figure 1. V-I CMD of M13 (Left) and M56 (right). Left panel in each contains all stars found by DAOPHOT. Right panel in each contains only stars with reasonable uncertainty (σ).

Another interesting aspect about globular clusters is that stars with high abundances in light elements tend to be more centrally located within a cluster. To investigate this, we created a mean-ridge line (MRL) on the RGB, and split up those stars into two groups, blue and red.

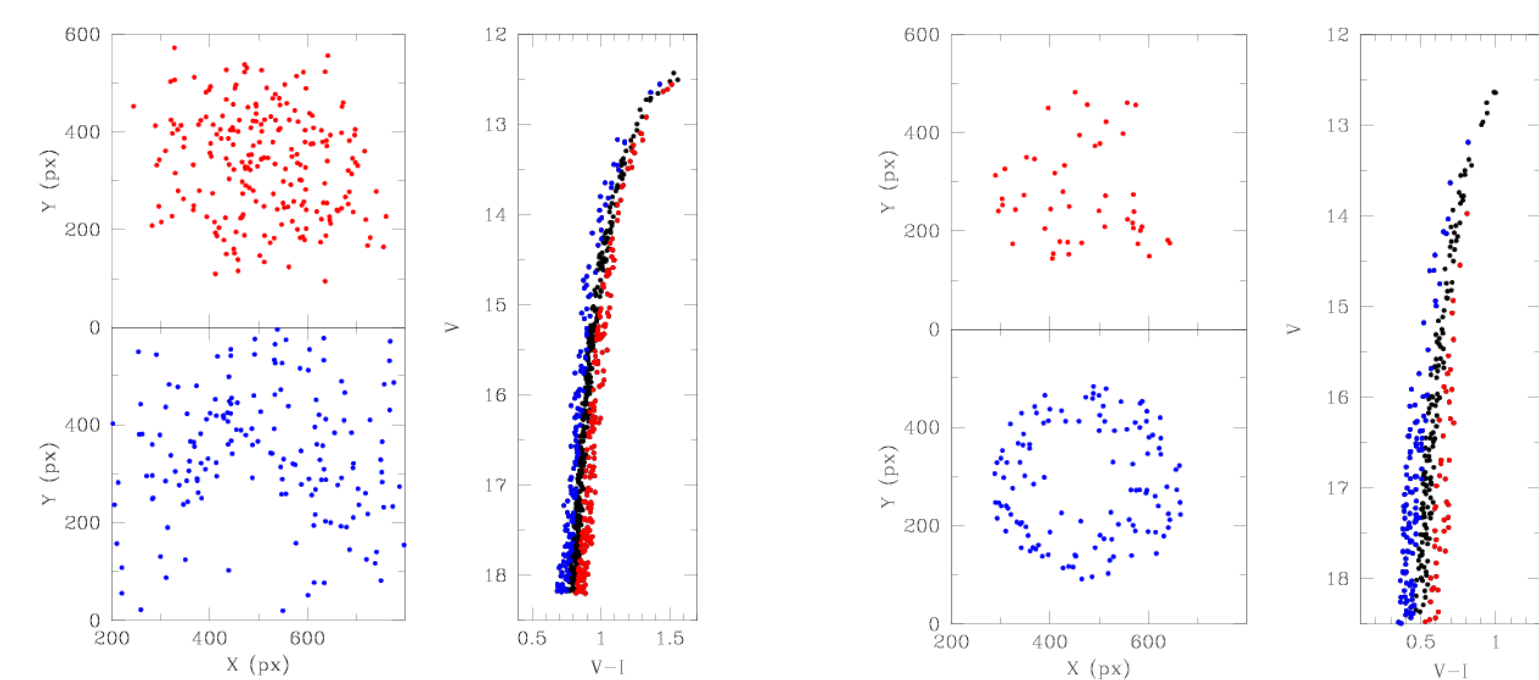


Figure 2. Upper-left panel shows the locations of the stars that fall to the right of the MRL. Lower-left panel shows the locations of the stars who fall on the left side of the MRL. Right panel shows these stars on the RGB (Black points indicate those stars that, accounting for uncertainty, could fall to either side of the MRL).

Notice how the red stars in each cluster seem to be more concentrated, while the blue stars appear to be more widely distributed.

To show this even further, we can plot the cumulative fraction of red and blue stars in the two clusters as a function of their distance from the center.

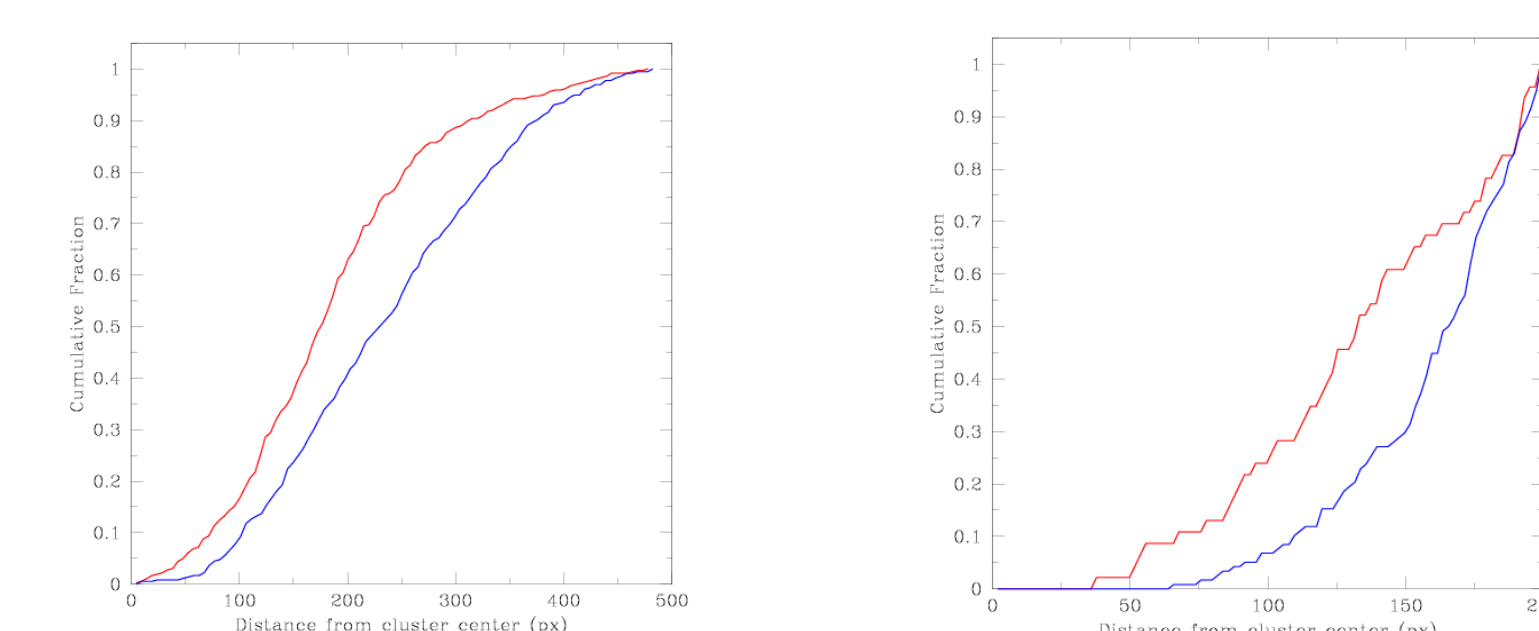
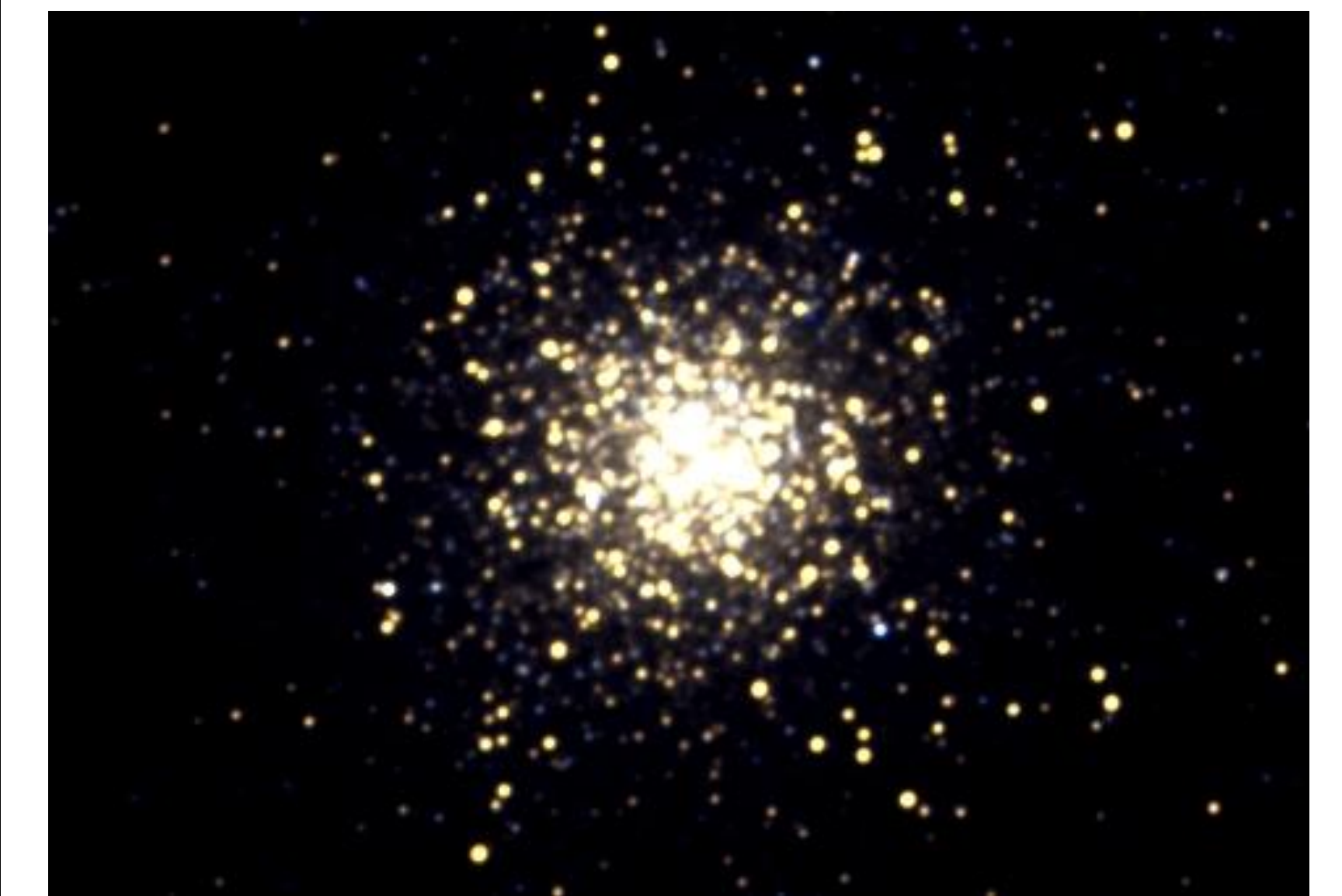


Figure 3. Cumulative radial distributions of M13 (left) and M56 (right). Notice how the number of red stars (red line) increases faster than the number blue stars (blue line) as you move out from the center of each cluster.

In both cases, the distributions of the two populations are different in a statistically meaningful way.



Color image of M13 taken with Calvin College's telescope in Rehoboth, NM.

Conclusion

This summer, we advanced a great deal through our research. We created a procedure that performs accurate photometry on stars in our clusters, and were able to make CMDs that we are confident in because of it. While focusing on the RGB, we found that stars more centrally located within the clusters do appear to be redder (and therefore may possibly be enriched second generation stars). Further study has the potential to shed light on the origin and history of individual clusters, as the field gradually moves away from a single model of cluster formation and evolution.

Future Work

Creating a V-I CMD is a good start, but in order to clearly find evidence of two populations of stars we must incorporate ultraviolet data. This is because the light being blocked by these light elements is strong in this range. After doing this, we will need to make a U vs. U-B CMD. Further analysis of photometric uncertainties is also needed in order to establish our confidence level in these results.

References

¹International Year of Astronomy - The Hertzsprung-Russell Diagram". *The Museum of Flights*. Web. 19 August 2015.