M15 Hertzprung Russell Analysis

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Abstract

In this lab, we image the globular cluster M15 (NGC 7078) using a CCD camera attached to the James R. Houck 25-inch Telescope with three different Johnson-Cousins-Glass filter bands (B, V, and R). We also image the standard star SA 115 427 in the same three bands to calibrate the photometric data. Using these data, I create three calibrated Hertzprung Russell diagrams (V vs B-V, R vs V-R, and R vs B-R). These diagrams are used to determine the age, metallicity, and distance of the cluster by comparison with theoretical isochrone models from Leo Girardi's Padova Database. The age is found to be ~12 Gya while the distance is ~12.6 kPc.

Introduction

The purpose of this lab is to produce several HR diagrams of the more distinguishable stars in the globular cluster M15 and, from these diagrams coupled with theoretical isochrone models, determine the age, distance, and metallicity of the cluster. Globular clusters make good candidates for luminosity, or apparent magnitude, versus temperature, or a quantity proportional to temperature, study because all the stars that comprise the cluster lie at an equal distance from the sun. Because all the stars lie at the same distance, their apparent magnitudes are all shifted by an equal amount. By calculating the offset of the apparent magnitudes from the bolometric magnitudes, one can determine the distance to the cluster.

A simple way of determining the magnitude offset is to use an isochrone model, which is a model that can be evolved in time. I plot several different models with varying metallicities and ages to fit the main-sequence turnoff point and horizontal branch. The models are also shifted vertically (with respect to the apparent magnitude) to provide the magnitude difference or distance modulus. From this, the distance can be easily calculated.

Procedures

Observations were made on the night of September 19, 2014 on the Houck 25-inch Telescope at the HBO using the previously studied thermoelectrically cooled Andor CCD camera. The following exposures were taken:

Exposure Number	Object	Univsersal Time	Air Mass	Exposure (sec)	Filter (JC glass)
6	M15	2:58 AM	1.16	60	R
7	M15	3:01 AM	1.16	180	V
8	M15	3:06 AM	1.16	300	B
9	SA 115 427	3:33 AM	1.41	10	R
10	SA 115 427	3:37 AM	1.41	15	V
11	SA 115 427	3:38 AM	1.40	20	B
12	BIAS	-	-	-	-

13	FLAT	-	-	6	B
14	FLAT	-	-	15	V
15	FLAT	-	-	5	R
16	BIAS	-	-	-	-

SA 115 427 was used as a photometric standard star. These exposures were all read into a floating point array in IDL. Exposures 6 through 11, which where images of M15 and the standard star, were bias corrected using bias frame 12. The flats were bias corrected using bias frame 16. There was a minute difference in the two bias levels, which was most likely due to bias drift. The flats were scaled to unity and were used to flat field the respective images of the cluster and standard star.

Using tools in IDL, namely the "find" function, stellar positions, in pixels, were determined for the V frame. All stars within a radius of 85 pixels to the globular cluster's center, which was determined to be (1011,231), were discarded to prevent later errors in magnitude measurements caused by overcrowding. This left approximately 700 stars for study.

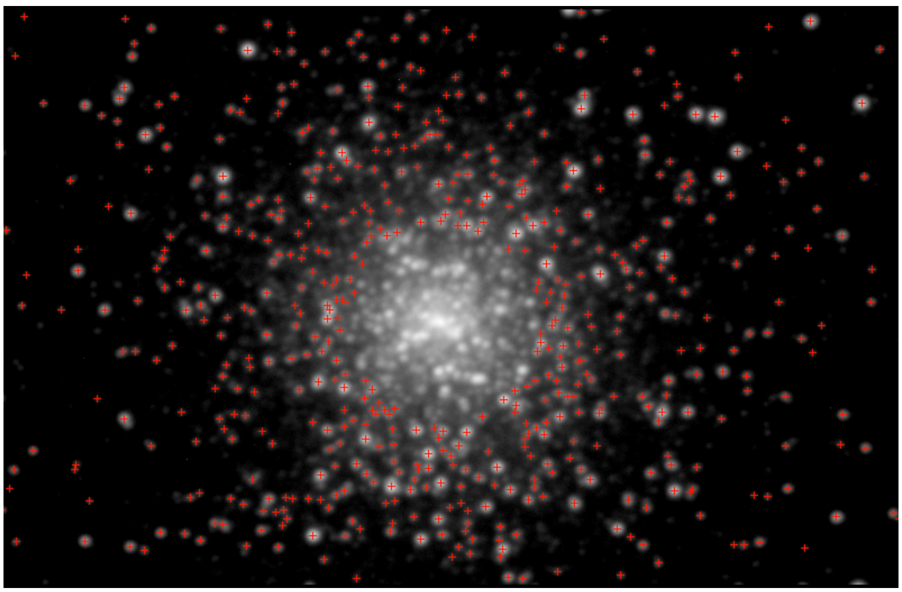

Figure 1

Figure 1 presents a plot of the found positions, which excludes stars near the cluster's center, superposed on the V frame of M15 (exposure number 7). The same positions were used on the B and R frames, which were adjusted in both x and y to line up with the positions found in the V image.

The "aper" function was used with the previously described position vectors to determine an uncorrected magnitude and magnitude error measurement for each star in all three object frames (exposures 6, 7, and 8). An aperture of 5 pixels, an inner sky radius of 15, and an outer sky radius of 20 were used to limit error associated with overcrowding.

Calibration

Because such a small aperture radius was used to determine the magnitudes, a single isolated star, specifically the one located at (279,295), was used to generate an aperture correction to the magnitude. The magnitude was determined both with a large aperture (13 pixels) to allow for convergence and with the standard 5 pixel aperture. The difference was used to determine the correction. This same process was repeated in the B and R M15 frames.

The standard star was used in conjunction with published magnitudes from the Landolt Standards catalog to determine a magnitude correction associated with the instrument and perhaps some atmospheric obscuration. The correction was determined separately in all three bands.

A magnitude correction that takes into account the different exposure times was also determined from the equation: $m_{exp\ correction} = 2.6*\log_{10}(exp_{obj} / exp_{std})$, where exp_{obj} is the length of the object exposure in seconds and exp_{std} is the length of the standard exposure in seconds. This correction was determined separately for all three bands.

A final correction was made to account for foreground galactic extinction. These corrections were found from NED and used results from Schlafy and Finkbeiner. These extinction corrections were applied independently to all three bands.

Theoretical isochrone models from Girardi, Bertelli, et al. were plotted on the corrected HR diagrams. From these plots it is possible to determine the difference between the measured, corrected magnitude and the bolometric magnitude and therefore the distance modulus. One can also approximate the age and metallicity using these isochrone models.

Results and Discussion

Corrected HR Diagrams Without Error

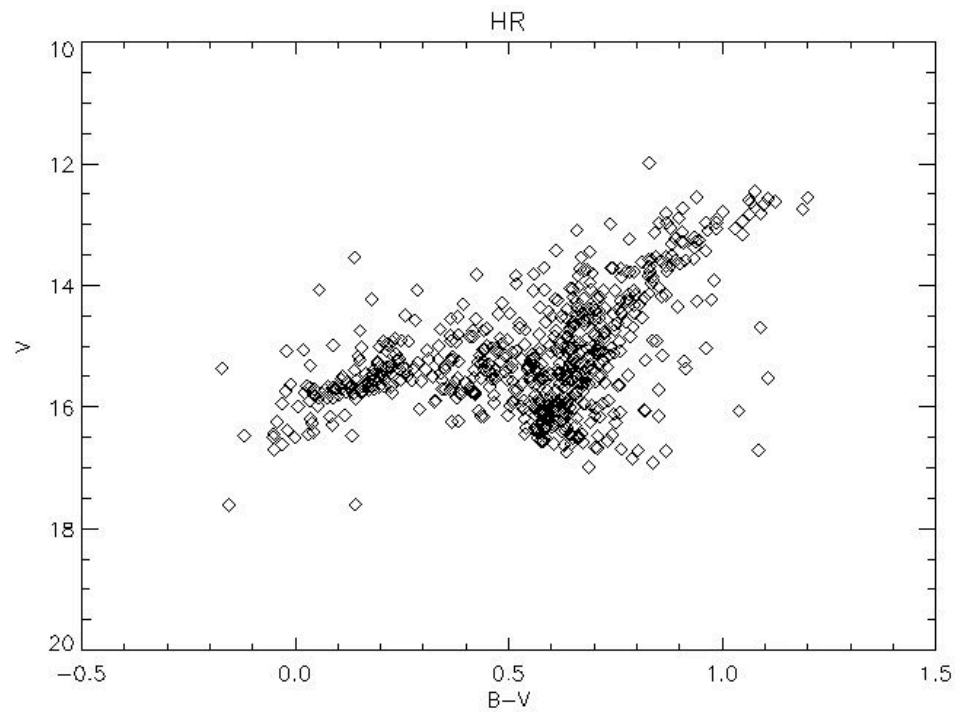

Figure 2

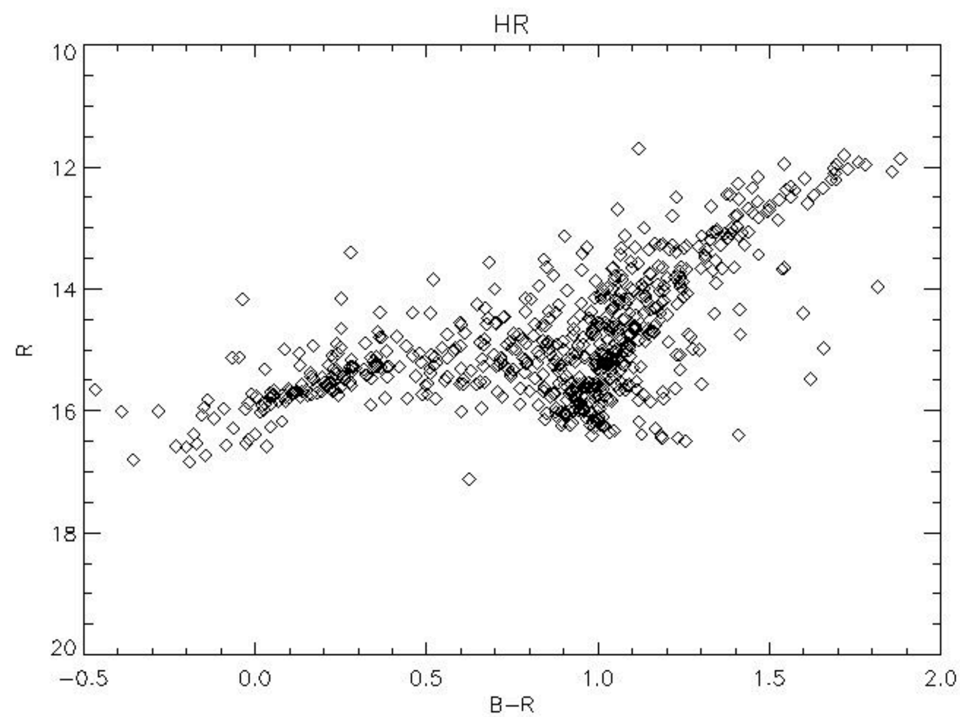

Figure 3

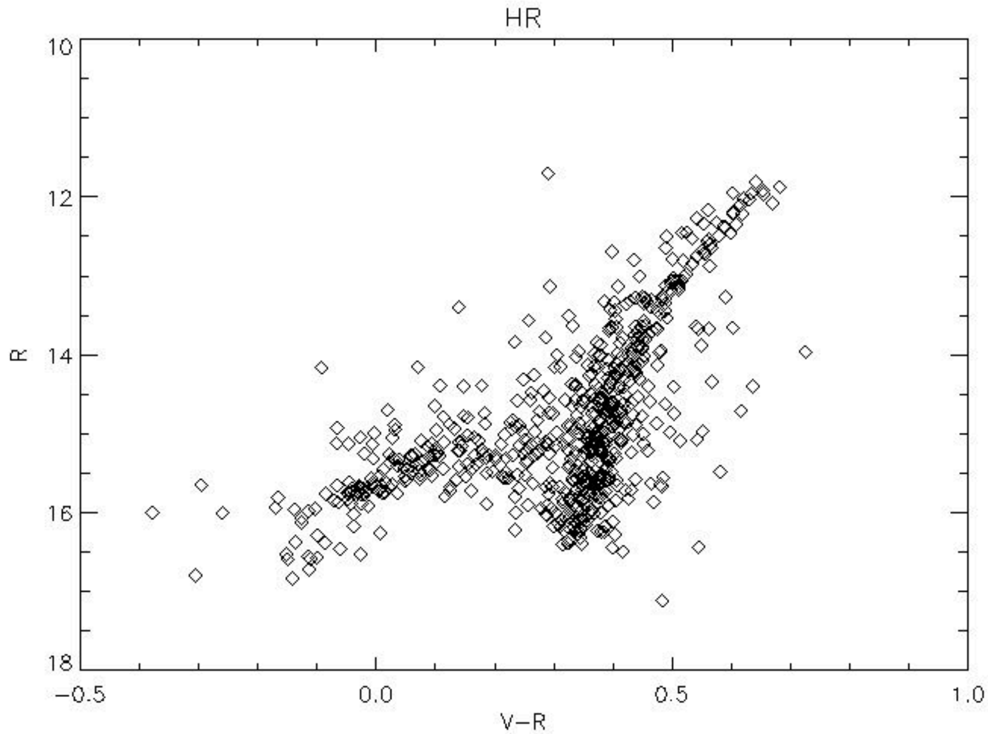

Figure 4

Corrected HR Diagrams with Error Bars

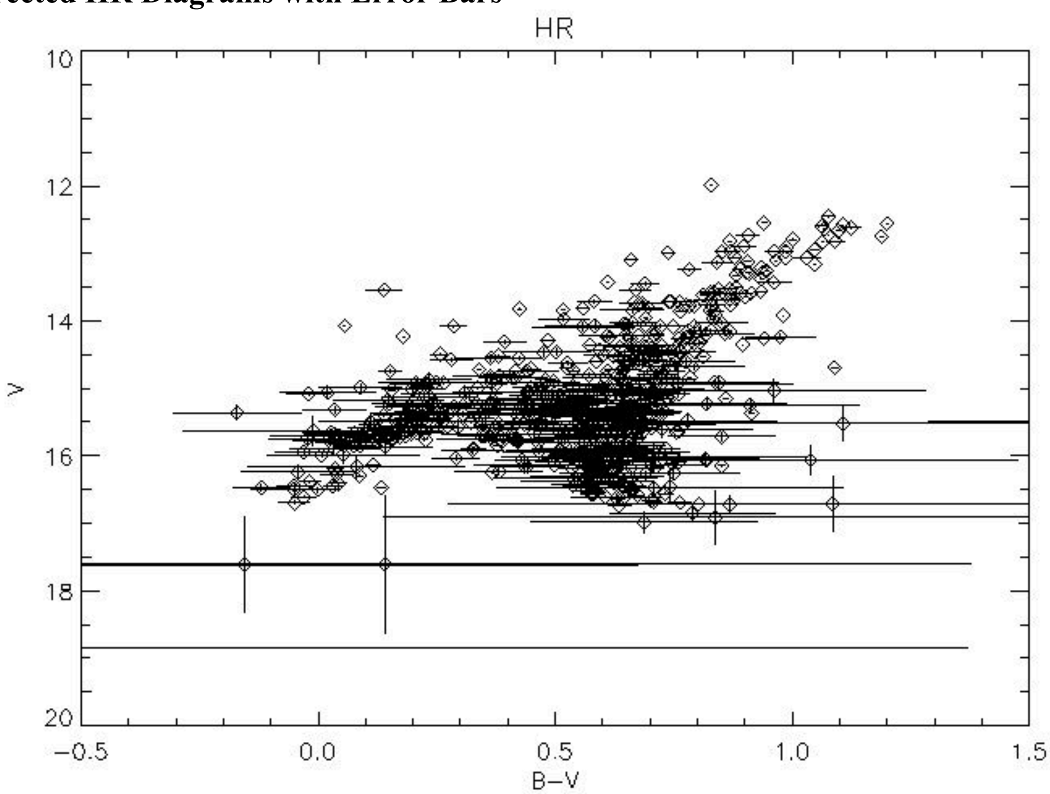

Figure 5

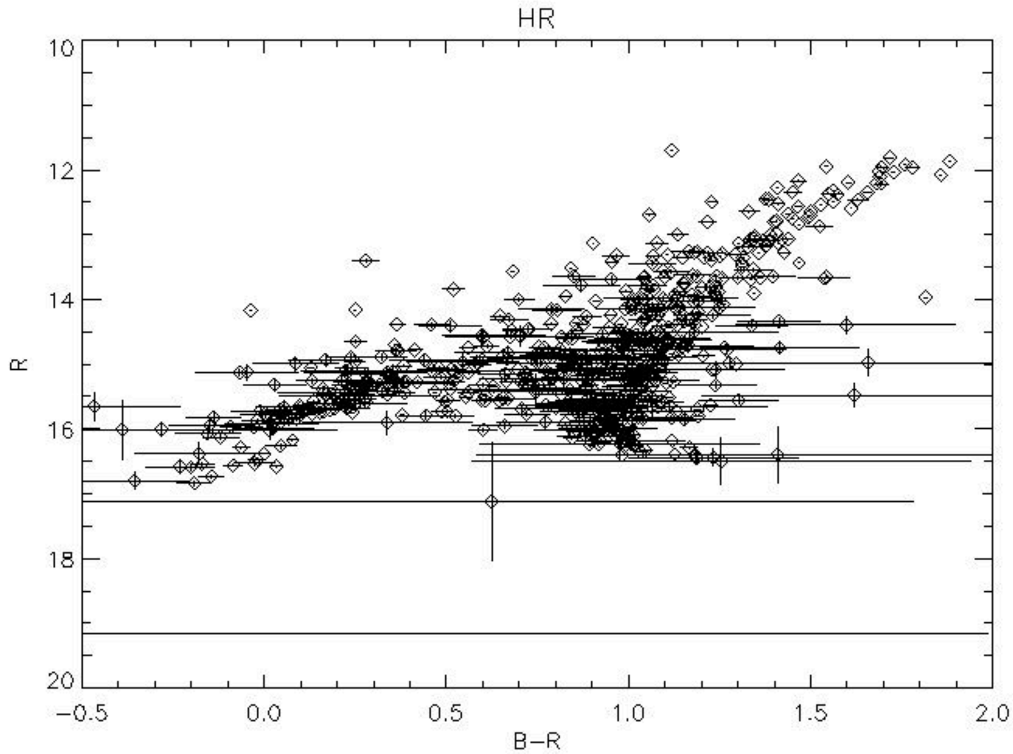

Figure 6

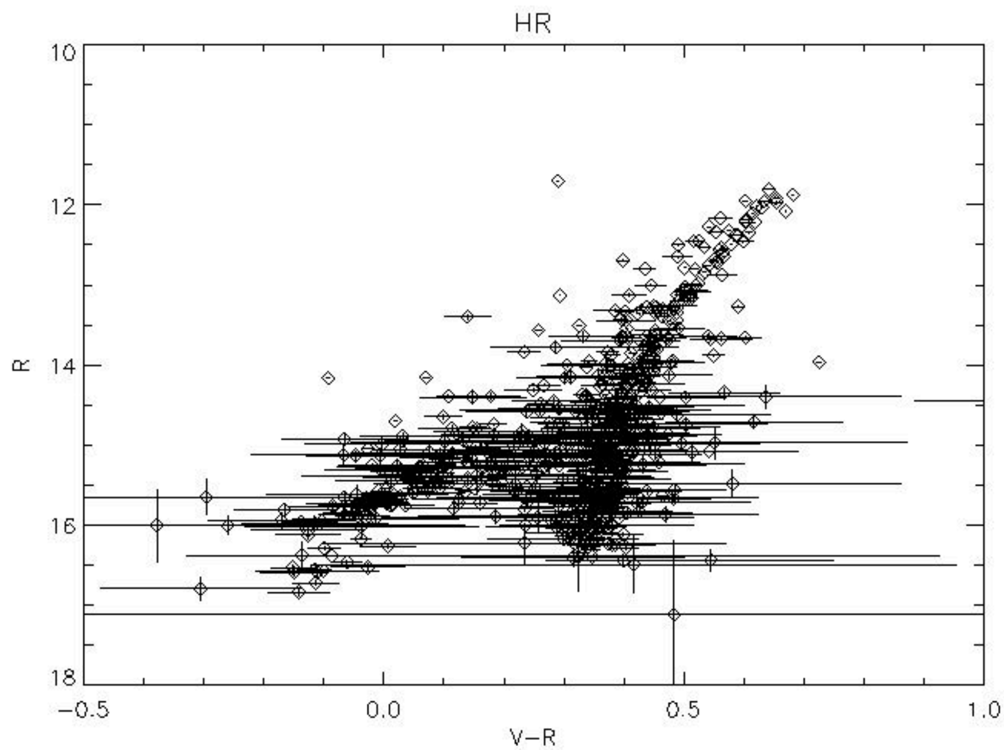

Figure 7

It’s clear that stars with an apparent magnitude greater than ~17 were not detected. This also explains the increasing error (visible in figures 5 through 7) for larger magnitude stars. Because the stars are so dim it’s not really possible to get a precise measurement of magnitude.

Because of this limitation, the main sequence isn’t really visible. Still, the giant branch extends down almost to the turnoff point, and there’s a distinctive horizontal branch. This allows for a study of age and metallicty using the previously described isochrone models.

Distance Modulus

When fitting the isochrone models, I found that the magnitude offset was consistently ~15.5. This can be used to calculate distance. $d = 10^{(15.5/5 +1)}$ = <u>12,589 pc.</u>

This is slightly larger than the published value of 10.4 kpc from Harris’s 1996 globular cluster catalog.

Metallicity

The following HR diagrams present a plot of three isochrone models (represented by the + symbols) superposed on the same data (now in points). In all figures (8 through 10) the top model corresponds to a metallicity of Z=0.0001, the middle to Z=0.001, and the bottom to Z=0.004. Several other metallicities were studied, but these three fit best. A constant age of $1.23*10^{10}$ years was used throughout.

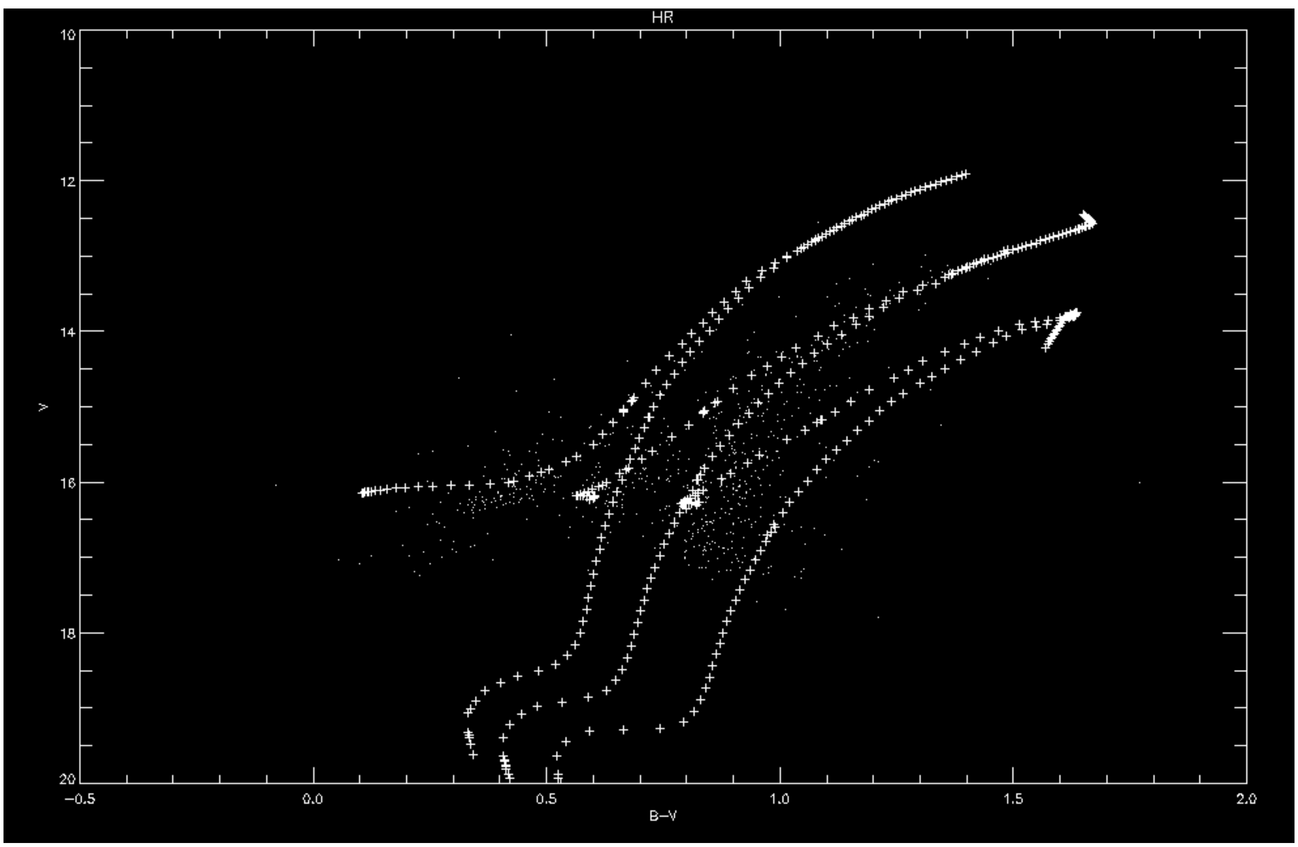

Figure 8

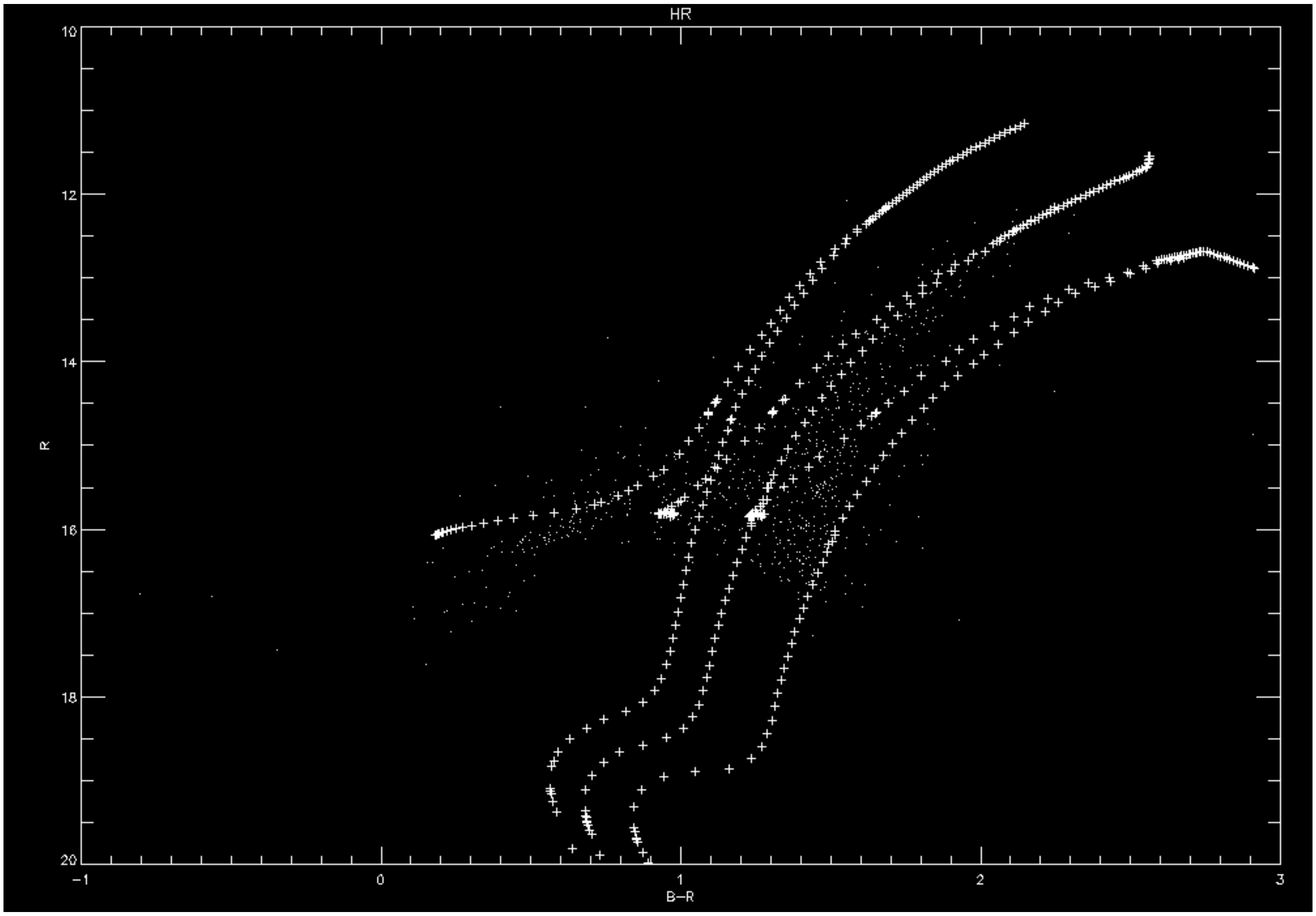

Figure 9

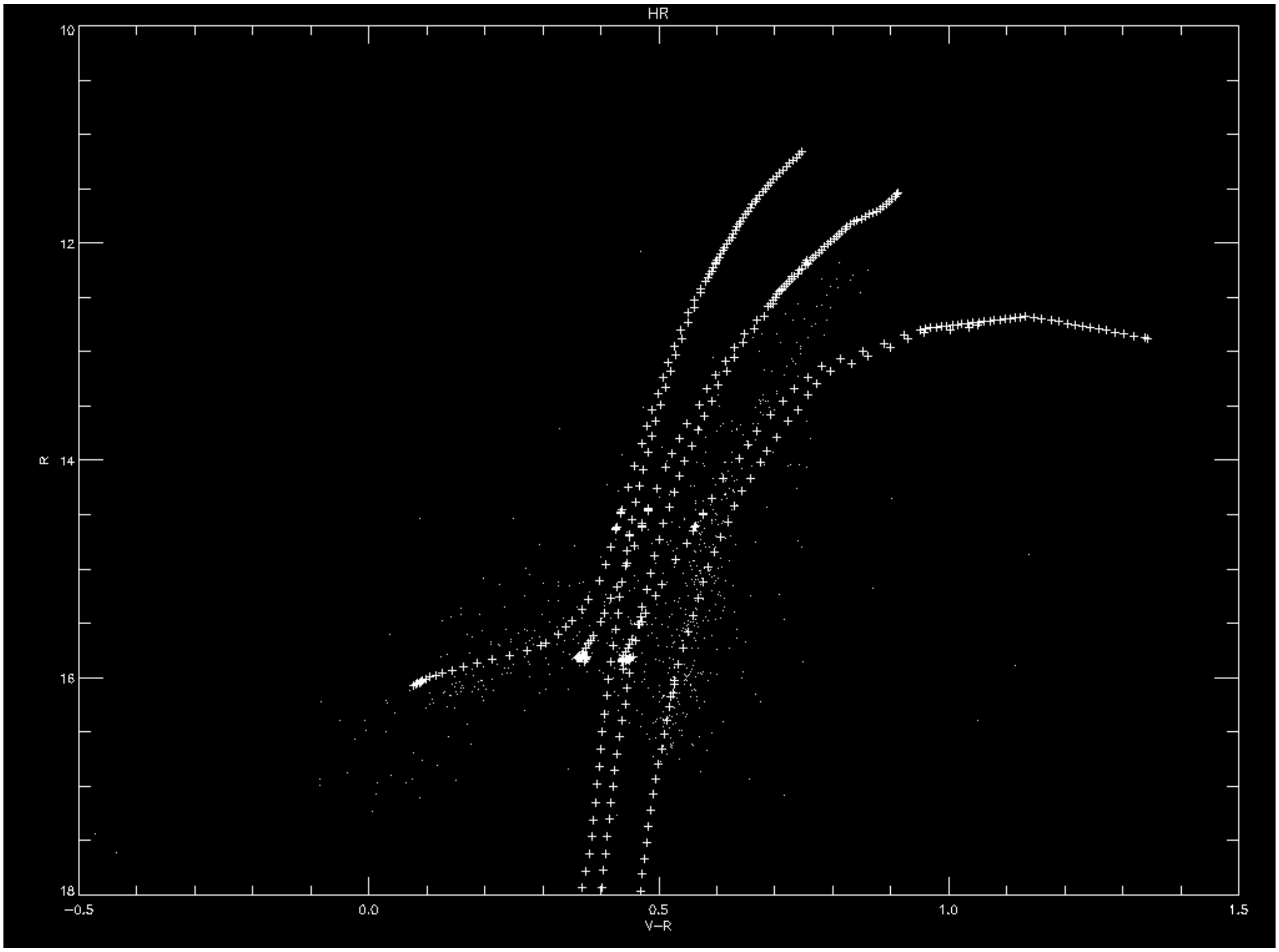

Figure 10

Overall, I determined that the middle model corresponding to a metallicity of Z=0.001 fit best. The published value is -2.37 dex or ~0.004.

Age

The following three figures (11 through 13) are a plot of three different ages with a constant metallicity of Z=0.001. In all cases, the top plot corresponds to an age of $\sim 1.2*10^8$ years, the middle to $\sim 1.2*10^9$, and the bottom to $\sim 1.2*^{10}$.

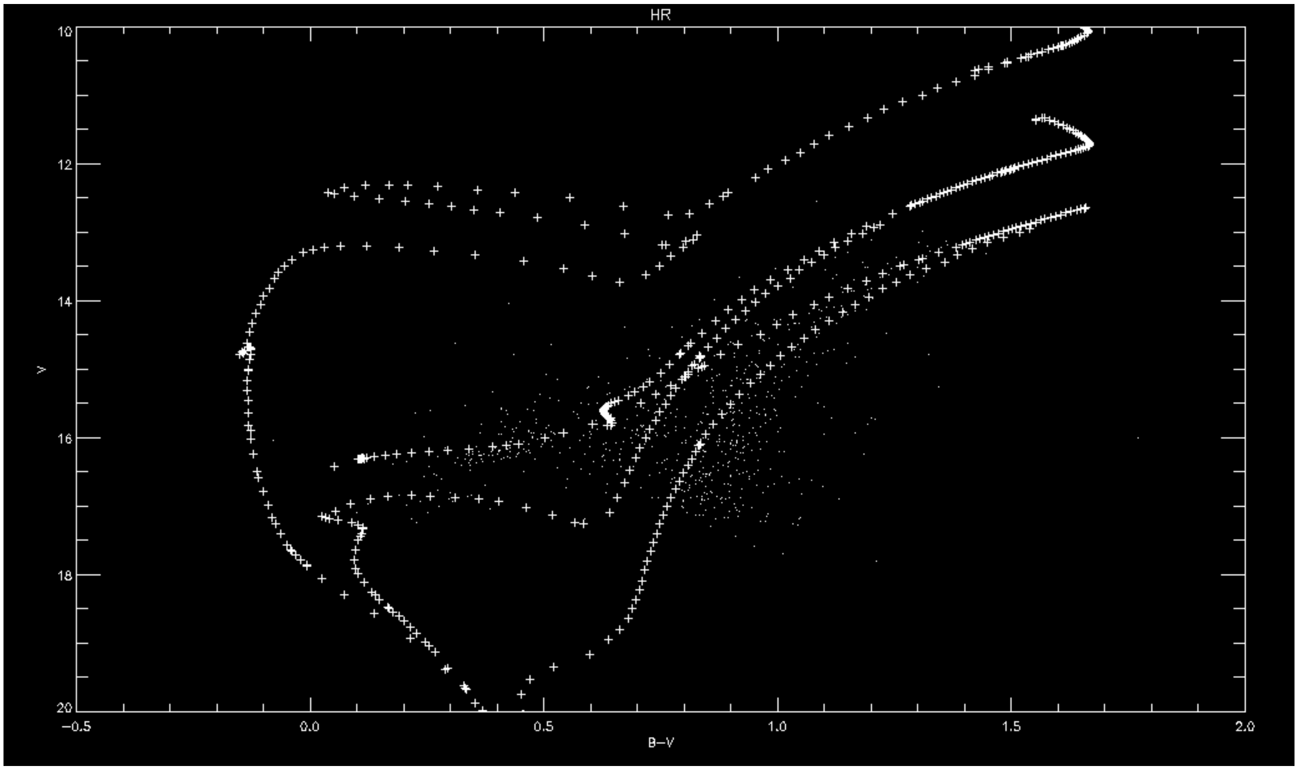

Figure 11

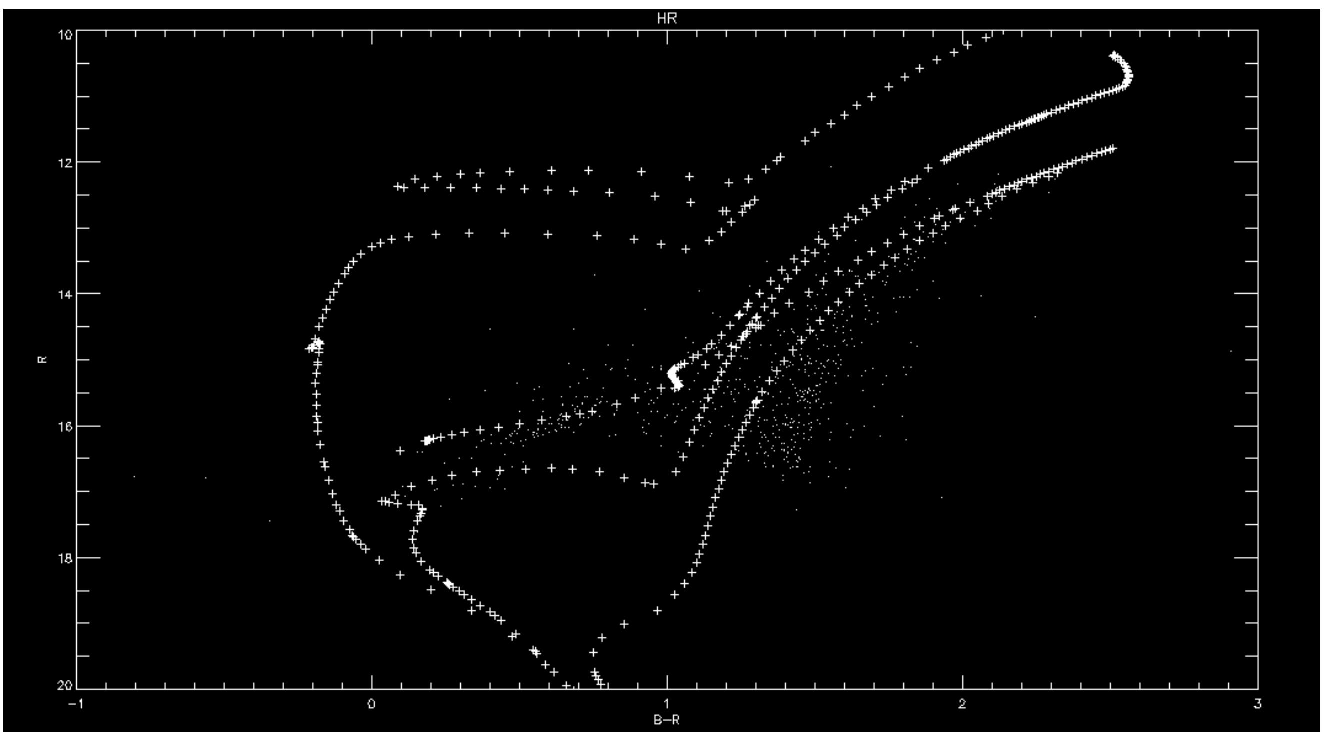

Figure 12

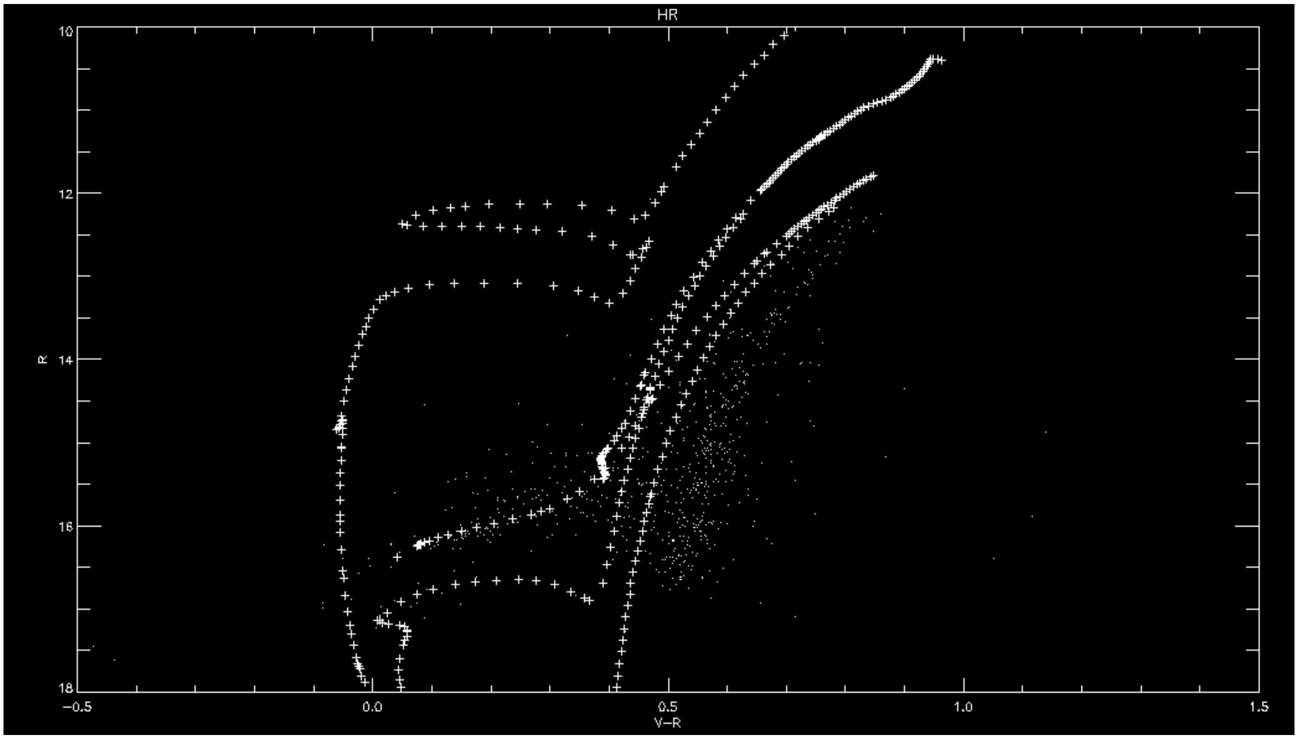

Figure 13

The plots corresponding to an age of $1.26*10^{10}$ years were found to fit best. This is close to other published approximations which all hover around 12 Gya.

Conclusion

The results suggest that M15 is an old globular cluster that formed only about a billion years after the big bang. Because it is so old, it is dominated by population II stars. This also explains why it has a relatively low metallicity.

The inaccuracy of the metallicity determination may be due to the basic observational limitations. If the experiment were repeated with greater sensitivity under better conditions and analyzed with more sophisticated tools, it is likely that the metallicity would be found to be higher.

References

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