SBO Telescope Time Proposal
Measuring Age and Distance of Milky Way Clusters
ASTR 3510

Introduction

Open clusters are - as the name suggests - clusters of stars within galaxies that contain hundreds to thousands of stars that were all formed from one molecular cloud (Kolena). The stars in open clusters are young, more 'spread out,' and far less numerous compared to their counterparts in globular clusters (Kolena). Every star in these clusters formed from the collapse of the same molecular cloud and have very homogeneous features such as: all being formed at the same time (in cosmic terms) and thus having the same ages, and staying rather close over time, (due to them being gravitationally bound) which will mean that every star has the same distance from away from Earth (Main Sequence Fitting). These features make the clusters extremely useful for determining and constraining distances and ages in our galaxy, as we can fairly easily use this information to get these variables via the knowledge of an Hertzsprung-Russell diagram as discussed below.

Set Up

To find the age of the cluster, we will make a plot of each star's V magnitudes versus their (B-V) magnitudes. The plotted population of stars in the cluster will be used to create a color-magnitude diagram, an analog of a Hertzsprung-Russell diagram. This plot will show, graphically, at what point the stars start to 'turn off of' or leave the main sequence (the main sequence being a recognizable pattern in a color-magnitude diagram that represents stars in the hydrogen-burning phase) (Palma). The spectral type of the stars that are at the point of main sequence 'turnoff' will indicate the age of the cluster due to the fact that those particular stars are just starting to enter their helium-burning phase (Pamla). Based on previous studies of stellar evolution, we will be able to use a method called isochrone fitting to find the time that must elapse for certain stars to leave the main sequence and therefore find the age of the cluster (Palma). The concept of isochrone fitting is to fit theoretical functions to the main sequence in color-magnitude diagrams for clusters of varying evolutionary stages. The isochrone line of best fit for our cluster will show the proper age.

To find the distance to the cluster, we use a technique known as main-sequence fitting that compares the brightness of our cluster to one of known distance. If we plot the cluster of known distance on our color-magnitude diagram, we will see that its main sequence traces a line some distance from our cluster's main sequence; this distance will be the distance modulus (M-m). We can then use the equation

$$M - m = 5log_{10}\left(\frac{d}{10pc}\right)$$

to find the distance d to the cluster (Main Sequence Fitting).

Observations

We will observe the cluster IC 348 (RA 03:44:34, DEC +32:09:48) and use M34 (RA 02:42:06, DEC +42:46:00) as our reference cluster for main sequence fitting. We will be observing in early November; this is about 6 weeks after September 21st, so LST will be 3h at midnight. To avoid a high airmass, we want to observe our objects when they are less that 3h away from the meridian. Therefore, we will observe between the hours of 10pm and 2am. We estimate that one night of observing will be sufficient to collect our data.

We will observe the clusters in the V and B filters so that we may make a B-V color index plot. We will be using in-field standard stars for each cluster in lieu of the actual magnitude of the cluster itself to estimate times needed to observe. These stars will be used because we do not have the actual magnitude of the clusters (due to their light being spread out unevenly). Therefore, the actual magnitude will be integrated from all sources within the cluster - data we will not have pre-observation. We will also use these standard stars as references to find magnitudes of other stars within the clusters with unknown magnitude values. Below, we outline the exposure times that we will need:

From previous observations in the V band - specifically observations of the asteroid Ceres - we know that a 7.5 magnitude object gives ≈14,000 ADU in 20s, or $\frac{700ADU}{s}$, in the V filter. Our standard star for open cluster IC 348 has a V magnitude of 8.68; this gives a $\Delta Magnitude = 1.18 \Rightarrow \approx 3x$ fainter. Therefore, we know that our cluster will yield about $\frac{233ADU}{s}$, so we need to observe for 85 seconds to get an ADU of 20,000 (just under saturation but should ensure that all stars are bright enough). Using the photometry equations given in class, we find that the cluster will yield about $\frac{135ADU}{s}$ in the B filter, so we will want to observe for 148 seconds to get 20,000 ADU.

All of these times are indicative of an object of a larger magnitude (the standard star which will be less bright) than the actual cluster, so qualitatively we know that in order to not saturate our cluster (specifically, the brightest stars in the cluster) we will need to observe for a shorter period of time. We estimate that each time will be roughly cut by half in order to ensure no over saturation. Thus for IC 348 we have new estimated exposure times of 43 seconds for V band and 74 seconds for the B band.

Our comparison cluster, M34, has a visual magnitude of 5.5 compared to IC348's 7.3, so it is about 5x as bright. Therefore, we expect to observe to 5x less time to get 20,000 ADU. We will therefore observe M34 in the V band for 9 seconds. As we do not have previous B-band observation to compare to, we cannot have an exact exposure time estimate for the B-filter. However, we know that exposures in the B filter saturate less quickly than those in the V filter because blue light is scattered more easily by the atmosphere. Therefore, we expect our exposure time to be longer than that for the V filter. We will start with an estimate of approximately twice as long (following the pattern from IC348), but will find the exposure time by experiment on the night of observation.

For each object, we will take three exposures of the appropriate exposure time for each band. We will combine these images to mitigate any cosmic rays that may have interfered.

Results

Our observations will yield measurements on the brightness of each star in the clusters in the B and V magnitudes.

Because the in-field standard stars have magnitudes that are brighter than 12, we can consider photon noise for a quick estimate of the noise. Using imexamine on an average star in our data, we find a total flux that we can use to find the photon noise

$$PhotonNoise = \sqrt{\frac{325,000ADU}{1.33\frac{e-}{ADU}}} = 494ADU$$

So we get an estimate of our SNR to be

$$\frac{S}{N} = \frac{325,000ADU}{4694ADU} = 657$$

in the V filter. Using the same method, we find our SNR to be 524 for the B filter.

Our results will allow us to create a B-V vs V color index plot for the two clusters, which will allow us to determine the age and distance of IC 348 as described above. With our value for the SNR, we will be able to find an uncertainty on the magnitudes of the cluster stars to be

$$\sigma_m = 1.086\frac{1}{SNR}$$

We use the star magnitudes to plot them accurately on the color index plot , from which we find the age of the cluster using the best isochrone fit and the distance to the cluster using the distance modulus with M34. Therefore, the uncertainty in the magnitude will propagate into both our age and distance measurements.

Implications

The implications of this research will be very important in not only the understanding of distances and ages of this particular cluster using H-R diagram fitting, but also to constraining these variables for more important objects such as our Galaxy and even our observable universe. Although dated historically in our modern scientific world, observing these data for ourselves is an important process in learning to use these methods more extensively. Understanding the distance to this cluster will give us lower bound on the scale of the Milky Way Galaxy, because we are aware that this cluster is within the plane of the Milky Way (Kolena). Understanding the age of this cluster will also give us insight to a lower bound on the age of the Milky way, and thus also on the observable universe. Both age and distance could have been even better constrained if we were using globular clusters as we know that these lie farther away in the halo, as well as being significantly older than stars within open clusters (Kolena). However, the first constraints we can give using these methods are very important in confirming past research.

Open clusters, because they contain new stars, are the types of clusters that are found within the spiral arms of galaxies, where compression of interstellar gas triggers star formation. Therefore, a collection of distances to many open clusters in our galaxy could provide the means to map out the spiral arms and get a better sense of the Milky way structure. This project would be a useful addition to a larger project with that intent.

References

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4. Palma, Christopher. ”Measuring the Age of a Star Cluster.” E-Education Institute. Pennsylvania State University, n.d. Web. 30 Oct. 2016.