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Project #3: "Studying the Galaxy with Globular Clusters"
Physics 228, Winter 2021

Introduction

Globular clusters are important to the study of stars and stellar evolution. Within globular clusters, stars typically have very similar compositions, making it possible to study the effects that mass has on how stars change over time. The theoretical evolutionary tracks of such clusters based on mass, time, and composition are known as isochrones, and these tools can serve as a comparison to actual data. In an effort to demonstrate the usefulness of an isochrone, I conducted an analysis on photometric data of a specific globular cluster, using trial-by-error methods to determine distance to the object. Then, using data on the positions of many globular clusters, I demonstrate how our understanding of the formation of these objects can help determine our place in the Milky Way Galaxy.

Analysis

The bulk of the work for this project was done with Microsoft Excel's graphing tools. For my first analysis I will be discussing a simple procedure for determining the distance to a globular cluster, known as main sequence fitting, with both the advantages and challenges of the technique. For my second analysis I will be demonstrating how surveys of globular clusters can give us an idea of the layout of our galaxy. For each analysis, I will first describe my procedure and data, and then give commentary on the outcomes.

Analysis 1 – Finding the distance to a globular cluster

Data/Procedure: The data for this project was provided to me in DAT file format. This analysis concerns reddening-corrected photometric data of a single globular cluster, containing information on each star's apparent magnitudes in the V and I filter. First, I calculated each stars color index (V-I) and plotted it against V magnitude (Figure 1). I adjusted the features of the plot until the trends were visually apparent. I then read in the data provided for the isochrone, which included each theoretical star's mass and absolute V and I magnitudes. In order to determine the distance to the observed cluster, I recalled that absolute magnitude plus distance modulus is apparent magnitude. Thus, I fitted the isochrone data to the observed main sequence by adding a constant value to every theoretical star's absolute V magnitude (representing a distance modulus). By trial-and-error I was able to determine a fairly accurate distance modulus which matched the isochrone to the observed cluster shape, that value being 13. The result is shown in Figure 2. With a distance modulus in hand, I proceeded to calculate an approximate distance to the globular cluster, which came out as 3981.1 parsecs.

Discussion: This process for determining the distance to a globular cluster is very simple. Because we know that the stars in a cluster will all be about the same age, we can reliably count on a model to represent any cluster accurately. Such a computational model can be generated by parameters such as chemical composition and age (found by observing the cluster), and theoretical absolute magnitudes can be determined. From here, the procedure of fitting can vary.

Possibly the quickest way is the guess-and-check method that I employed, but it poses the problem of inaccuracy from human error. I do not expect my answer to match perfectly with any of my classmates; it may be off by as much as a couple magnitudes based on what an astronomer constitutes as a good fit. Personally, I did my best to fit the isochrone to the main sequence of the observed data, but another student may have focused more on a fit to the Red-Giant Branch. Herein lies the problem: which fit is more accurate? During my fitting process, I struggled to settle on a specific placement of the curve, because the main sequence of the cluster is anything but a thin line. Without weighing important factors such as the specific characteristics of this cluster, the error in the gathered data, and the significance of each feature of the cluster's diagram, accuracy cannot be reliably determined.

Analysis 2 – Our Place in the Milky Way

Data/Procedure: This analysis concerns data of the galactic locations of a multitude of different clusters. First, I read in the data, consisting of cluster names, distance from Sun, and galactic coordinates. Galactic coordinates are defined by galactic longitude and latitude, measured from the galactic midplane which intersects the celestial sphere. Importantly, these coordinates are measured from our point of view, which is not the center of the galaxy. I then transformed the data into cartesian coordinates, where x points towards the Galactic center, y points in the direction of Galactic rotation, and z points perpendicular to the galactic plane, with the center of the galaxy serving as the origin. Then I created three graphs, an x-y, y-z, and x-z plane (Figures 3, 4, 5), where each cluster's location was plotted. Based on these graphs, I made an estimate of the coordinates of the center of the displayed points, the result being $x = 8.65$, $y = 0.02325$, and $z = -0.25$, measured in kiloparsecs.

Discussion: Globular clusters typically form near the center of their galaxy. With this in mind, we are able to roughly determine our position in the galaxy based on the coordinates we measure for the position of the center of the globular cluster systems, which should be at or near the center of the galaxy. Our position should simply be in the opposite direction we measured, thus $x = -8.65$, $y = -0.02325$, and $z = 0.25$, measured in kiloparsecs. We can then determine our actual distance from the center of the galaxy by using Pythagoras' theorem, giving us a value of $R = 8.653$ kiloparsecs. Notice that this is essentially the same value as our x distance from the center. What does this mean? Besides not being the center of the galaxy, our solar system resides within the galactic disc (where most of the galaxy's mass is). According to our z position, we lie about 800 light years above the plane of the galaxy, which is within the thickness of the disc at 1000 light years. The y value is less interesting, simply ensuring that we are certainly within the radius of our galaxy when combined with the x value. This data supports the common knowledge in astronomy that we are outside of the center of our spiral galaxy on one of the arms. Do note, though, that this position calculated is once again based on "eyeing" the plotted data, so will vary from astronomer to astronomer.

Conclusion

In this project, I was able to experiment with and evaluate the effectiveness of the main sequence fitting technique to determining globular cluster distance. It was determined that a trial-by-error method for calculating distance modulus with a given isochrone is quick and easy, but inconsistent from astronomer to astronomer. If detailed studies are to be done on a certain cluster, it would definitely be best to use statistical methods to calculate a best fit, rather than the human eye. Then, using a large survey of globular cluster locations and knowledge of formation trends, I was able to roughly find our position in the Milky Way Galaxy. I was reassured that we are not at the center of the galaxy, and learned that we are within the disc, and not the halo. Concluding, I learned primarily about how globular clusters fit into our models for stellar evolution. Both of these analyses were excellent ways of demonstrating how we can both study globular clusters themselves, and then use them to study other astronomical areas of interest.

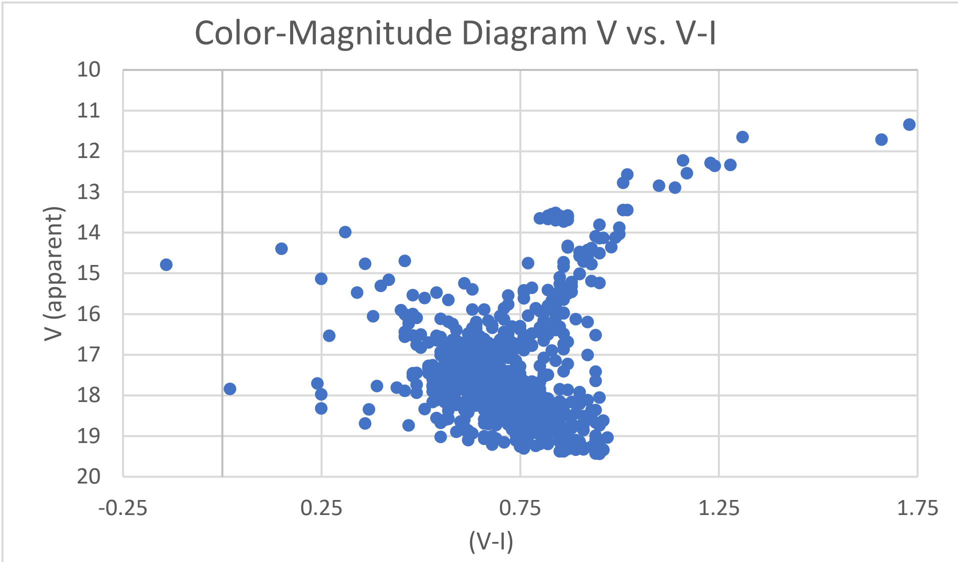

Figure 1: Plotted color index (V-I) and apparent magnitude V for given globular cluster.

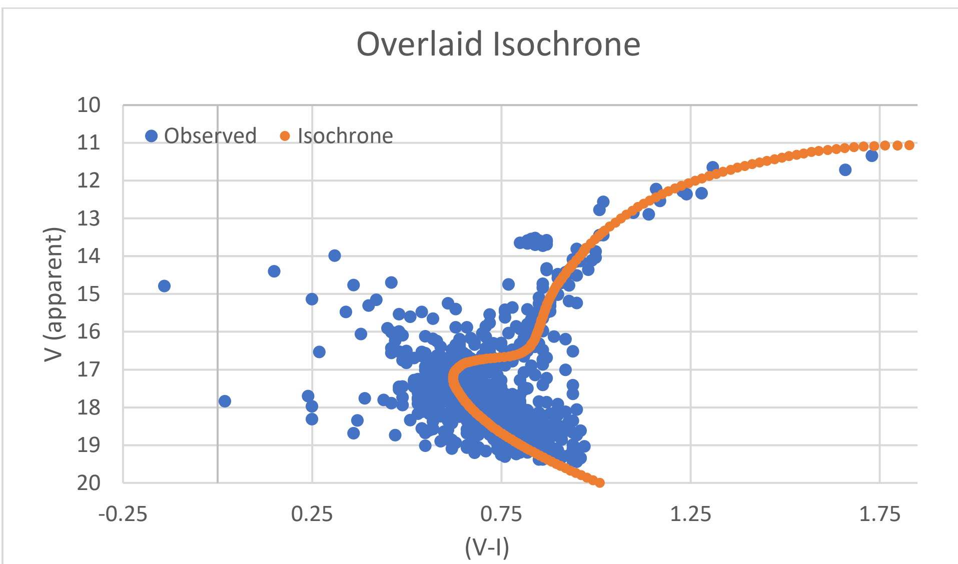

Figure 2: Observed cluster with fitted isochrone overlaid

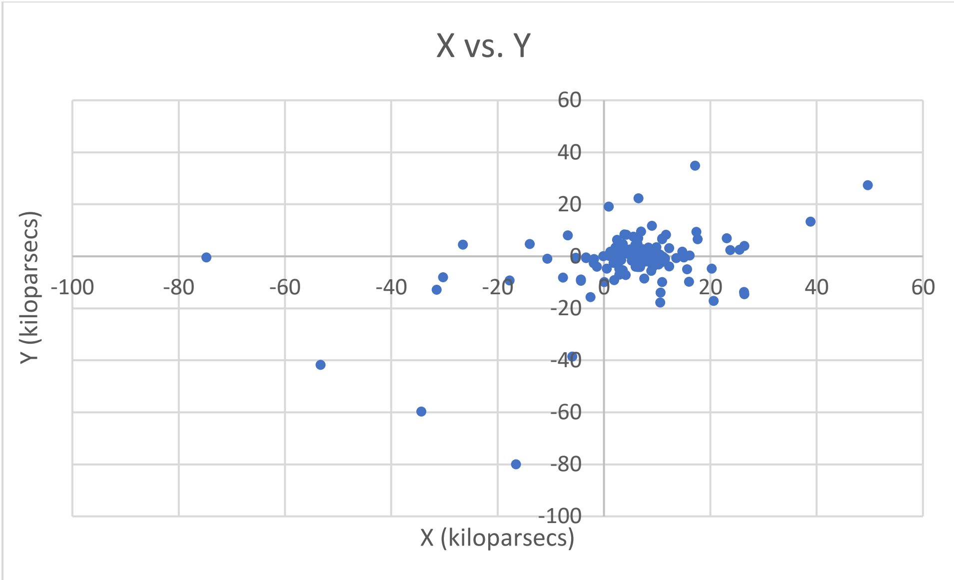

Figure 3: X-Y plane for globular cluster positions

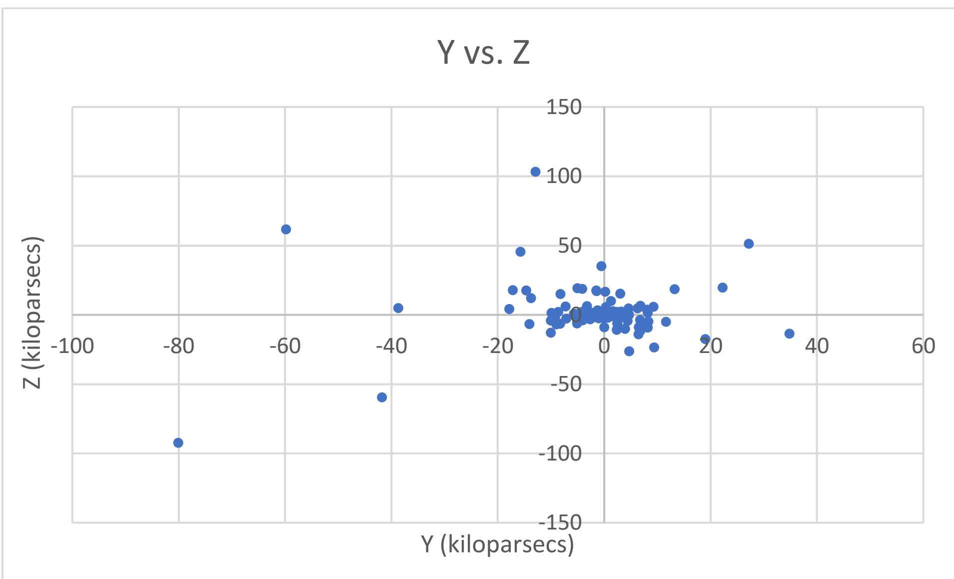

Figure 4: Y-Z plane for globular cluster locations

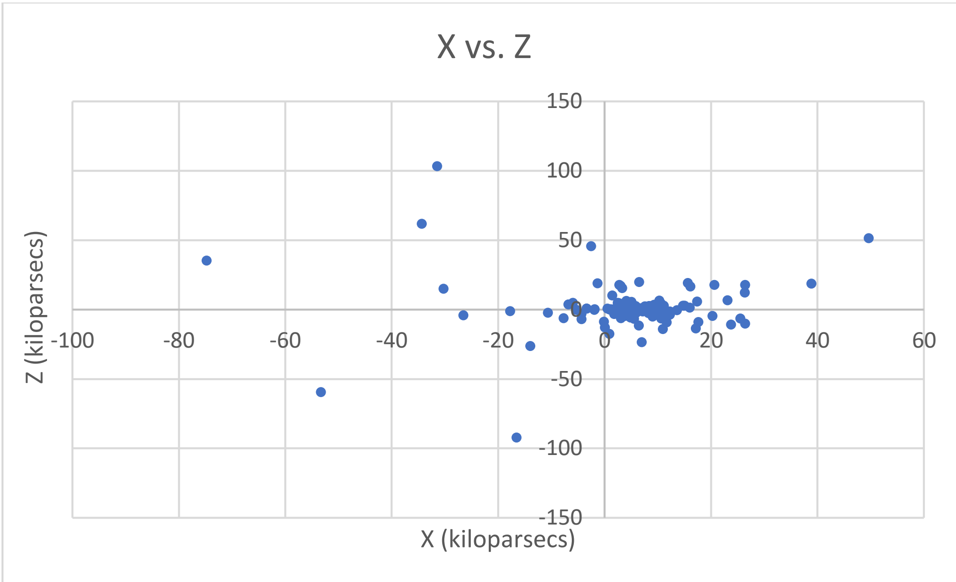

Figure 5: X-Z plane for globular cluster locations