Estimation of Distance and Age of a Globular Cluster

PH 556 - Project Write-up

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1 Motivation

"Astronomy is a science in which you are not able to touch anything you study"

- Allan Sandage, American Astronomer.

For any astronomical object in the universe, we want to know its distance from us and its age. Once these basics are known, we can go into deeper analysis of the object.

Thus, our motivation for this project is to demonstrate the calculations of the age and distance of a Globular Cluster.

2 Introduction

2.1 What are Globular Clusters?

Globular Clusters are a spherical collection of stars. They orbit around the core of the galaxy together. The stars within a Globular Cluster are very tightly bound by gravity. This is responsible for their spherical shapes and high concentration of the stars at the centre of the Globular Cluster. [1]

There are about 157 Globular Clusters in the Milky Way Galaxy itself. [2] Larger galaxies can contain many more Globular Clusters. For example, Andromeda has as many as 500 Globular Clusters and M87 has atleast 13,000 Globular Clusters. [3]

2.2 What other types of clusters exist?

An Open Cluster is a group of stars that have been formed from the same molecular cloud. Hence, these stars have similar chemical composition, similar ages and similar distances.

2.3 How are Globular Clusters different to Open Clusters?

Globular Clusters are normally found in the halo regions of the galaxy. Open Clusters, on the other hand, are found in the disk of the galaxy. Globular clusters are older than Open Clusters. In general, Globular Clusters are denser than Open Clusters. [1]

2.4 What are Variable Stars?

A star whose brightness as seen from Earth that is its apparent magnitude fluctuates with time is classed as a variable star. These variations can be caused by a change in it's emitted radiation or something blocking the light coming from the object. Thus, these are classified into Intrinsic Variables and Extrinsic Variables. [4]

Most stars have at least some variation in luminosity. For example, Sun's luminosity varies by 0.1 % over an 11 year cycle. [4]

The classification of Variable Stars is as follows -

1. Intrinsic Variable Stars
   (a) Pulsating Variables - Stars whose radius contracts and expands
   (b) Eruptive Variables - Stars which experience eruptions like flares or mass ejections
   (c) Cataclysmic or Explosive Variables - Novae and Supernovae
2. Extrinsic Variable Stars
   (a) Eclipsing Binaries - Doubles stars which eclipse each other as seen from Earth
   (b) Rotating Variables - Examples - Ellipsoidal Stars due to high rotation speeds, Stars with extreme sunspots that affect their Apparent Magnitude.

In particular, Cepheids and RR Lyrae from Pulsating Variables are of particular importance to us as they follow a set period - luminosity relationship.

A Cepheid Variable star pulsates radially. It varies periodically in terms of both, the radius and the temperature. [5] Similarly, RR Lyrae Variables are also periodic variable stars. These are commonly found in Globular Clusters. They are often used as references to measure galactic distances. This class of stars is named after the prototype and brightest one, RR Lyrae. [6]

3 Astrophysics

3.1 Hertzsprung–Russell Diagram

The Hertzsprung–Russell Diagram is a scatter plot of stars showing the relationship between the their absolute magnitudes, and hence, their luminosities versus their stellar classifications or effective temperatures. As the stars of the same Globular Cluster are at the same distance, we can have a Colour-Magnitude Diagram.

On the basis of the CM Diagram, or an HR Diagram, the age of the Globular Cluster can be estimated using isochrones. This is based on the turning point of the Diagram. [7]–[10]. We can also see the stellar evolution of the stars in the cluster.

3.2 Variables - Cepheids & RR Lyrae

Cepheids and RR Lyrae show a period - luminosity relation. For Classical Cepheids, we have the following relation -

$$M_v = -2.43(\log_{10} P - 1) - 4.05$$

where, P is the time period measured in Days, and M_v is its mean Absolute Magnitude. [6]

For RR Lyrae, we have similar relations in different bands. Using 3 bands, we should be able t arrive at a good estimate of P and Z. [11].

As Apparent Magnitude is already known to us from the observations, this allows us to estimate distances in the universe. This techniques is especially useful when the distances are so large that standard parallax methods no longer work.

4 Study Goals

We want to take observations of the Globular Cluster with an additional focus on the Variable Stars in the Globular Cluster, to estimate the age and the distance of the Globular Cluster.

For this, we need the apparent visual magnitude of observed stars from the g', r', i' over a period of time, depending upon the period of the variable stars.

Using this information, the aim is to make an HR Diagram, and then, on the basis of the turning point, and comparison with standard charts for stellar evolution, estimate the age of the cluster.

The next item is to calculate the period of the variables, using peak-to-peak distance after folding. Using the period, the luminosities can be calculated, and hence, the absolute magnitudes can be calculated. Now, as the apparent magnitudes are already known, the distances can be calculated.

Finally, the distance and the age values are to be compared to those in the literature. In the case one or the other information is indeterminable, we plan to use the values in the literature to proceed with the further calculations.

The temperature can be calculated using the V-R or R-I Magnitudes. [12] Thus, once we have the luminosities, the mean radius of the Variable Stars can be estimated assuming the stars to be black bodies.

5 Feasibility

We looked into multiple Globular Clusters - Palomar 13, Terzan 5, NGC 4147. All 3 contain either Cepheids or RR Lyrae, and hence, can be used for the purpose of this project. There are multiple RR Lyrae Variables in NGC 4147 [13] and Terzan 5 [14]. The apparent magnitudes are 13.47, 12.8, 10.74 respectively. However, the first 2 are not very visible from the night sky. The third, though lower in magnitude has excellent visibility as well as moon distance, as can be seen in 1. Terzan 5 is also borderline feasible.

The coordinates for NGC 4147 are - 12 10 06.149 +18 32 31.78 and for Terzan 5 are - 17 48 05.00 -24 46 48.0 (ICRS). (Courtesy Simbad)

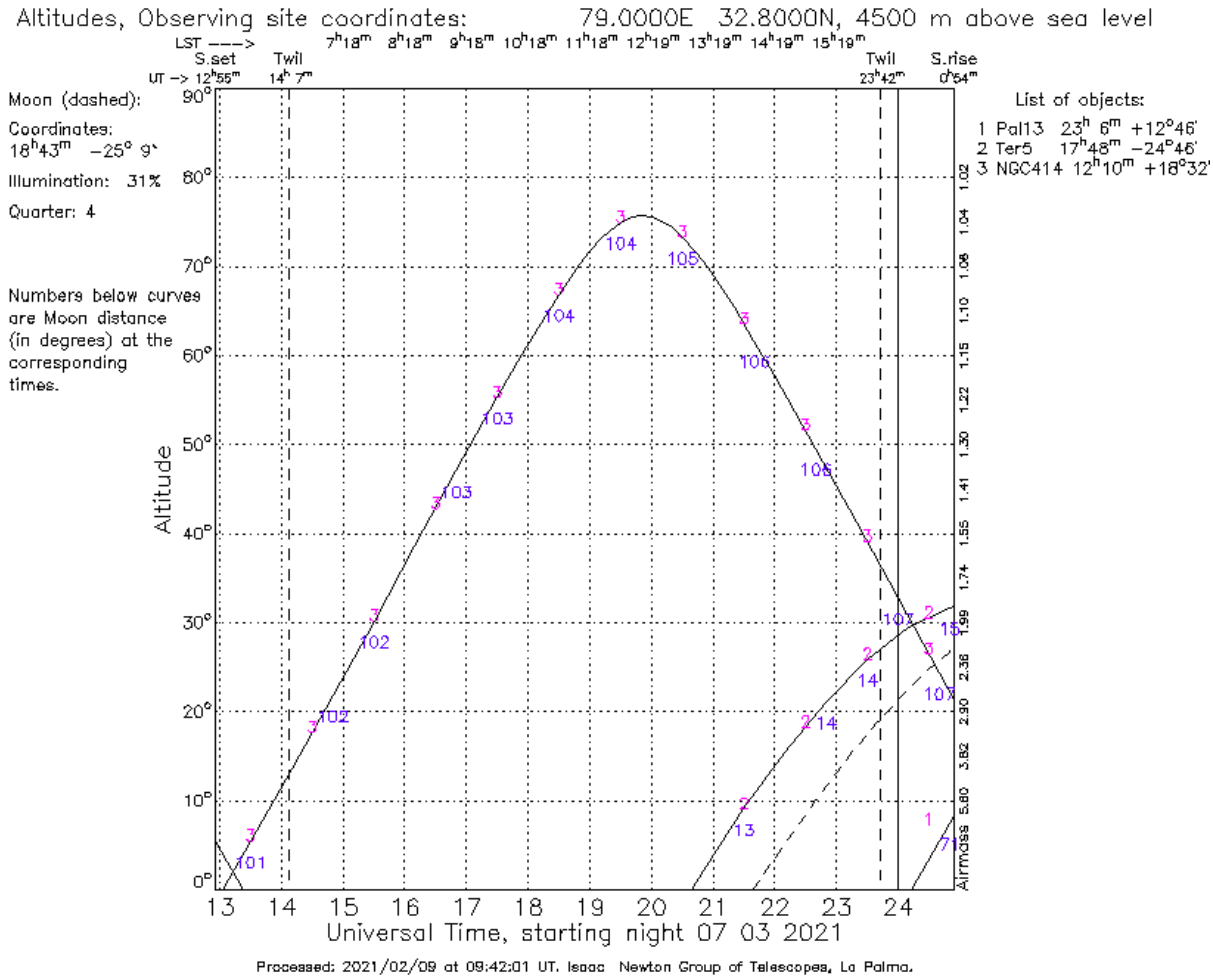

Figure 1: Visibility on 7th March, 2021, courtesy http://catserver.ing.iac.es/staralt/

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