**Introduction**

#welcome audience and introduce ourselves

1

The aim of this project was to study the properties of an open star cluster in the milky way galaxy.

Firstly, what is an open cluster? An open cluster is a grouping of up to a few thousand recently-formed stars. They form from the same gas cloud and so the cluster members were all born in the same location and have very similar ages and chemical compositions. As a result, differences in luminosity are due only to differences in mass.

Because of this, properties such as distance, age and metallicity of the stars can be more easily determined compared to lone stars, making them very useful as probes for studying stellar evolution.

###possibly discuss open cluster formation

2

In the project we determined the age and distance to the open cluster NGC869, otherwise named h-persei – a member of a double cluster in the constellation perseus.

Additionally, the radial distribution function and initial mass function for h persei was determined.

These properties tell us how number density and mass are distributed in the cluster.

3

In this presentaion, we will discuss how we gathered data on h-persei, as well as the data reduction procedure to ensure the data was accurate and reliable so that valid conclusions could be made. Then how the aims were achieved from the data, along with the associated results. Finally we will address potential errors and problems we had to overcome along the way, followed by a reflection of the project.

**LITERATURE DATA**

1

A method called main sequence fitting was used to determine the properties of the cluster. This involves using HR diagrams which are plots showing the colour of stars against their brightness where colour is defined as the difference in brightness between two bands for a star. In these diagrams most stars fall along a band known as the main sequence so properties of the h-persei cluster can be determined by comparing its main sequence to the main sequence of a cluster with previously determined properties.

2

The previously studied cluster that we choose to compare our own data with was Pleiades, which is among the nearest and most visible star clusters from the Earth. Pleiades is a young cluster dominated by luminous, blue stars and so is comparable to our cluster target.

3

The Pleiades data was obtained from an astrophysics catalogue and the magnitudes were in the B, V, U filters but these were different from the filters used in the observation. As such the Pleiades data had to be transformed to the g’, r’, u’ filters using the transformations in the karaali et al 2005 paper.

4

From the Pleiades data a colour-colour plot was created which was needed to determine the degree of interstellar reddening. these colour - colour plots are useful as all main sequence stars lie along a common line and so the colours of h persei, which would be altered by interstellar reddening, can be directly compared to the literature plot from pleiades.

To make the colour-colour plot as accurate as possible, outliers were removed from the Pleiades data and then a polynomial was fitted.

**Observation night**

1

In preparation for the observation night, two standard stars which would be used to calibrate the magnitude readings were selected. They were selected such that they would have optimal elevations on the night. Additionally h – persei had been selected as the target cluster as it was bright enough, and had a good position in the sky.

2

During the night, each of the two standard stars had images taken at two different elevations in the sky. To increase the reliability of the data, multiple exposures were taken, which were then stacked.

3

In regards to taking images of the cluster, multiple exposures were taken for each of the pointings in each of the filters, with the aim of again increasing the signal to noise ratio. Specifically, 5 pointings were taken: a central frame in gru filters, and 4 outer quadrant pointings in the gr filters.

\*image of pointings on top of cluster\*

Throughout the observations, exposure times were varied according to saturation of the photon detector. Additionally, as the u filter is dimmer, this filter required a longer exposure time to aide in increasing the signal to noise ratio.

**Data reduction**

**1**

The images from the observation are taken using charge-coupled devices called CCDs which are a grid of pixels that generate electrons when incoming photons are observed. The electrons are then used to build up an image. The raw observation images can carry a number of different instrumental signatures which must be corrected in a process known as Data Reduction before they can be used for scientific analysis.

This process is carried out using IRAF, a program used to analyse and reduce astronomical data. The first instrumental signature to be corrected for is unwanted signal due to electronics in the detector and thermally generated electrons called the dark current. The other important instrumental signature to take into account is the fact that the sensitivity of the pixels in the ccd are not all the same. These are corrected using a dark frame and a flat fielding frame respectively, which were both collected on the observation night.

Dark frames are images taken with the ccd shutter closed. There were multiple dark frames taken for each exposure time used during the observation night. These were then subtracted from the corresponding observation images.

Flat field frames are images of a uniform light source, that will reveal the variations in pixel sensitivities. On the observation night the light source used was the twilight sky. Then in the data reduction process, after the dark frame subtraction, the observation images are divided by the flat field frames to correct for the differing pixel sensitivities.

After all the raw images are corrected for instrumental signatures, the exposures for each pointing in a given filter should be stacked to increase signal to noise ratio. During the subsequent exposures in a given filter, the star position would have moved due to the relative motion of the earth, and so the exposures need to be aligned, using the iraf imalign function, before combining the images. Although the telescope has a tracking system, it is not perfect and so this aligning procedure must still be carried out.

The aligned exposures for a pointing in a given filter were then stacked using the iraf imcombine function, to create a set of final images which could be used for scientific purposes.

**Atmospheric Extinction**

1

Atmospheric extinction is when light is scattered and absorbed by the atmosphere, which therefore must be corrected for when using a ground based telescope. The amount of atmospheric extinction is dependant on wavelength and the airmass, which is a measure of the amount of atmosphere the light has travelled through.

\*diagram showing airmass\*

To do this, standard stars are used, what is a standard star? They are stars with known brightness, and so by comparing how bright they appear with how bright they should be, we can work out the zero point magnitude. The zero point magnitude is used for correcting for atmospheric extinction and calibrating the instrument measurement. The two standard stars were observed twice during the night, so that data was taken at different airmasses.

2

The zero point magnitude required for calibration of the cluster data was calculated by first working out the zero points from the two standard stars each measured at two airmasses. These values were then plotted in a zero point magnitude against airmass plot.

3

Then by using the airmass at which each cluster image was observed, the correct zero point could be read off from the graph and used to calibrate the cluster star magnitudes values.

**Source extractor / catalogue / topcat**

extracting the data from the images

1

After the fully reduced images are produced, the data from the images must be extracted. The software used for this is Source Extractor, which builds catalogues of stars from images. It does this by detecting a star as a grouping of pixels that are a certain threshold above the background signal level. It can then output a catalogue containing various properties, such as magnitude, magnitude error and position for each object. This was carried out for each of images

~insert image of gaia image containing source extractor apertures~

2

~image of example catalogue produced~

3

~image of bad source extractor selection / side by side with good example~

The important parameters to tweak in source extractor were signal threshold – which filters out dim background objects, the number of connected pixels – which filters out hot pixels and deblending – which identifies stars close together.

4

Catalogues of every image were made using Source Extractor and joined together using TOPCAT into a number of final catalogues used in different tasks. For example a catalogue containing data in the g r u filters was created for use in colour – colour plots.

However, this catalogue was limited in the number of stars due to the u filter being dimmer and detecting less stars. Therefore, a separate catalogue was created for making the HR diagram, which only used the g & r images, which had greater star detection.

**Interstellar Redenning**

**1**

The h-persei cluster stars had to be corrected for interstellar reddening which is when dust particles absorb or scatter light from stars. This affects blue wavelengths of light more than red wavelengths causing stars to appear redder than they actually are.

2

The task of correcting for interstellar reddening is done using a colour-colour diagram where the h-persei data is compared with the literature plot. Once the h-persei data has been corrected for reddening, it will lie on the main sequence line. The current shift between the main sequence line and the h persei data points is described by a reddening vector.

3

The model of the reddening vector used was given by the Cardelli et al paper and can be thought of as containing two components - the magnitude of the shift and the direction. The direction of the shift, C, was calculated directly using the equations from the cardelli model which depends on wavelength, whereas the magnitude of the shift, Av, was calculated using a chi squared best fit method.cu

When calculating the reddening vector it was important to only use stars which were likely to be part of the cluster so non cluster stars were eliminated. Stars on the redder end of the spectrum and stars which were far from the centre of the cluster were more likely to be non cluster stars so they were removed from the

data. Additionally we used only the brightest stars because they involve fewer errors.

4

To find the value of Av a chi squared test was used which gives a measure of how well observation data fits to a theoretical distribution. The chi squared test was carried out on the data with a range of different Av values, and so a plot of chi squared value against Av could be produced. The best fit occurs when the chi squared is minimised, which enables an true Av value to be derived.

With the Av value now known, the extinction magnitudes in each of the filters can now be calculated and the observation data can be de-reddened.

**Distance to star cluster / Age of star cluster**

\*hr diagram showing distance shift\*

After the cluster data has been corrected for reddening the distance and age can be found. Firstly, the hr diagram is compared with the pleiades hr diagram.

As all main sequence stars lie along a common lie on these plots, the only differences should be due to the differences in distance between h persei and pleiades. To calculate an accurate value for the magnitude shift, cluster data was split into bins with the average g magnitude in each bin being computed. Then the shift in g, known as the distance modulus, between the cluster data and the Pleiades line was calculated for each bin. This distance was then plotted in a graph and the average shift was found.

\*equation for distance modulus\* \*distance modulus graph\*

As seen from the distance modulus graph the error bars are quite large due to the large spread of points within each bin. This spread can be due to a number of reasons, from experimental errors, to overlapping binary stars.

The average distance modulus was found to be 6.21 +- 0.026 with the error being the standard error of the mean, using equation then distance found was to be 2.3 +-0.14 kpc with the error being calculated with standard propogation of errors.

Lit value is 2.3 kpc

In determining the age for the cluster we used the fact that the lifetime of a star is closely related to its luminosity, or in other words the absolute magnitude, with the largest most luminious stars having shorter lifetimes.

At the end of the stars lifetime in the cluster , they move off the main sequence into the final stage of their evolution. The age of the cluster can be calculated as the lifetime of the most luminious star that is a member of the cluster as any stars more lumininous will already have died. This approximation is valid due to fact that the majority of a stars lifetime is spent on the main sequence with the last stage being very rapid.

So by converting the apparent magnitude of the most luminious cluster star from the hr diagram into an absolute magnitude, and then converting this into an age using ‘’ the age can be estimated.

The value obtained was approximately 11Myr, lit value is quoted as being most probably 13Myr.

**Radial Distribution**

The radial distribution function shows how the number density of stars change with distance from the centre of the cluster. This was useful to understand the structure and layout of the cluster.

This was found by counting the number of stars in each bin and dividing by the volume.

It would be expected that the number density of stars near the centre of the cluster would be high then this would decrease rapidly with radius and tends towards a constant value at large distances due to non cluster stars. This behaviour can be clearly seen in our results for h-persei as the number density peaks close to the centre of the cluster then decreases and tends towards a constant value around 0.5 degrees. This result for angular size agrees with the literature value for h-persei.

**Initial mass function**

The evolution of stars and their properties is closely related to their masses so it was useful to document the distribution of masses. This was done by using an initial mass function which shows the number of stars formed for various masses. Also the IMF is relatively constant from one group of stars to another which makes it a useful tool for analysing stars.

\*Insert diagram of polynomial fit\*

To find the mass of the stars in the cluster the apparent magnitudes were converted into absolute magnitudes. Then values from previously documented stars were used to plot a polynomial line of best fit for absolute magnitude against mass. The values of absolute magnitude for the stars in the h-persei cluster could then placed on this polynomial fit to find the masses of the stars. The stars were then binned into a histogram according to their masses to create the IMF.

The IMF is described by a power law so it would be expected that the cluster IMF would follow this same model.

#The IMF is described by a power law so it would be expected that the fit would follow a m-a #curve where a is a constant. It can be seen that the IMF would follow a power law.

\*insert power law diagram\*

\*\*\*\*\* How quadrant images were used\*\*\*\*\*