A study of the Colour Magnitude diagrams of M35 and M38 Open Clusters versus M15 Globular Cluster

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Objective

- Select 3 cluster targets from given sets of clusters. We chose M15, M35 and M38
- Schedule queue based observations on PIRATE to image the chosen clusters
- Use AstroimageJ to perform double aperture photometry on the produced FITS images.
- Update python scripts to read photometry data, convert to B_{mag} ; V_{mag} and B-V data then create CMD plots of V_{mag} versus B-V data.
- Determine features of CMD and calculate distance estimates based on magnitude of A_0 star.
- Determine relative ages of the open clusters by locating the main sequence turn-off for M35 and M38.

Imaging

- Select 3 cluster targets from given sets of clusters. We chose M15, M35 and M38
- Schedule queue based observations on PIRATE to image the chosen clusters
- Identify reference stars in magnitude range 9 to 11 in Vizier/Aladin for each cluster and mark in AstroimageJ along with 400-500 other appropriate stars for each cluster, (double image photometry).
- Different strategies were used to capture data, selection of only known stars, random stars, hybrid mix of known and random stars. (the hybrid approach worked best)
- All selections were conducted as accurate as possible under high magnification

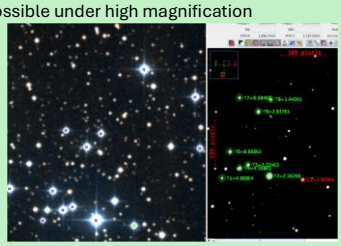


Figure 1: Image from Aladin next to AstroimageJ, readings were carefully made at high magnification carefully hopping from asterism to asterism interspaced with occasional 'relatively' bright stars up to approx numbers of 200 to 400 in total (Open University, 2024, Astronomy;PIRATE)

Python

- AstroimageJ data files were processed using python pandas and various chart plotting packages.
- The core python application was based on customised OU provided Photometry.ipynb and CreatingColourMagnitudeDiagrams.ipynb files, (Open University, 2024, Notebooks for PIRATE)
- The plotting package Plotly was used to produce CMD's
- Python beziers were added to highlight the main sequence and turn-offs
- Python was used to calculate minimum, mean and maximum distances
- Python was used to calculate Absolute magnitudes from calculated distances

```
REF_B_MAG = 9.906                    # <<<< Enter the apparent B magnitude of the reference star
REF_V_MAG = 9.76
Excess=0.25
# Check for negative values
mask = (ClusterData['B'] >= 0) & (ClusterData['V'] >= 0)
# Filter the DataFrame to only include rows where both values are non-negative
ClusterData = ClusterData[mask].copy()

ClusterData['Bmag'] =  -2.5*np.log10(ClusterData['B'])  + REF_B_MAG  #Flux ratio of Ref/Target star
ClusterData['Vmag'] =  -2.5*np.log10(ClusterData['V'] ) + REF_V_MAG  #Flux ratio of Ref/Target star
ClusterData['B-V'] = ClusterData['Bmag'] - ClusterData['Vmag'] - Excess
```

Figure 2: Calculation of B_{mag} ; V_{mag} ,(B-V) in python. Also showing correction for colour excess

M15 Globular Cluster CMD

A Globular Cluster in Pegasus, at a distance of 10.944 ± 0.131kpc. It contains approximately 100,000 stars. A CMD of M15 shows a noticeable giant branch, asymptotic branch, horizontal branch and potential blue straggler.

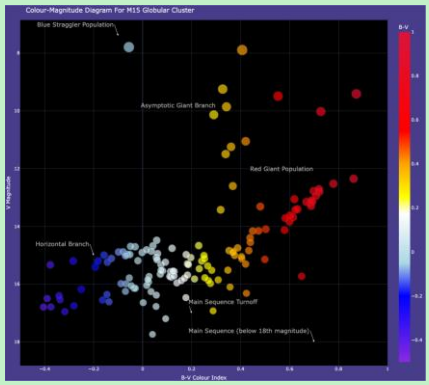


Figure 3: CMD for M15 Globular. Visible stars have 'turned-off' the main sequence and the limiting magnitude at 120 s renders most of the main sequence too faint. Since the cluster is in the galactic halo gas and dust in line of sight are minimum hence extinction, E(B-V) at 0.1 is low

M35 Open Cluster CMD

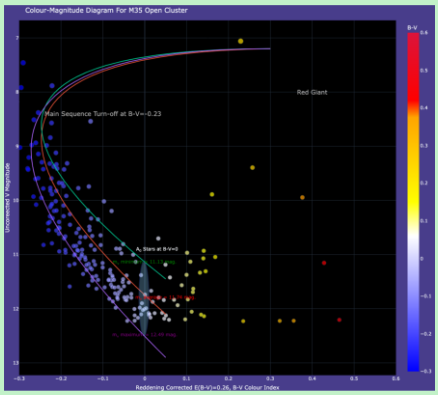


Figure 4: CMD corrected for scattering by shifting B-V to the left by E(B-V), A_0 stars will be found at B-V=0. A mean value of the range was taken to determine error in m_v , beziers show approximate main sequence and turn-off to giant branch

M35 Open Cluster CMD

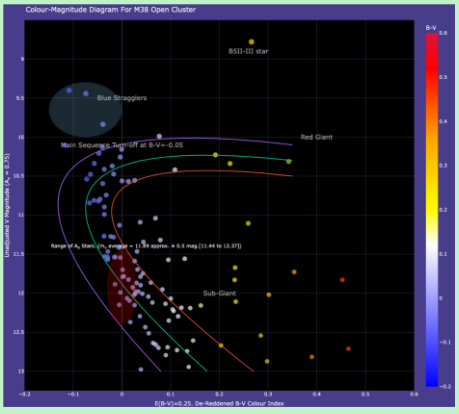


Figure 5: CMD corrected for scattering by shifting B-V to the left by E(B-V), A_0 stars will be found at B-V=0. A mean value of the range was taken to determine error in m_v , beziers show approximate main sequence and turn-off to giant branch

Measuring Distance

Interstellar dust in the line of sight causes a reddening of light due to scattering shifting the measured B-V to the right, the amount can be estimated by the empirical function E(B-V) (colour excess, e.g. 0.25) In addition gas and dust causes absorption and scattering thus reducing apparent magnitude of a star. This amount, Av (extinction) is approximately 3E(B-V). We can use the definition of an A_0 star having absolute magnitude of 0. (Green, Jones and J Simon Clark, 2015);(Open University, 2024, Astronomy:PIRATE).

$$\left(\frac{d}{parsec}\right) = 10^{\frac{m_v - M_v + 5 - A}{5}}$$

m_v = apparent magnitude : M_v =Absolute magnitude

Distance result

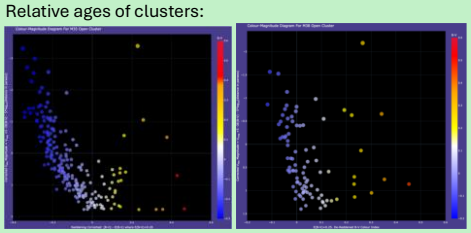
The distances were calculated in python using the above equation using mean values with error range of ± 0.5 magnitude based on the width of the main sequence at the 'turn-off'. For M15 dimmer stars under high magnification close to the core were used to approximate the low magnitude turn-off range.

	Minimum Distance	Mean Distance	Maximum Distance	Accepted Distance
M15	10.00kpc	12.59 kpc	15.85 kpc	10.94 kpc
M35	851 pc	1127 pc	1592 pc	912 pc
M38	995	1219	1549	1.066 kpc

Table: Summary of calculated distances to M15, M35 and M38 with associated error ranges. All clusters are within the margin for error.

Estimating age

Figure 6: Side by side representation of M35 and M38 CMD corrected for B-V reddening and absorption/scattering on magnitude, values are absolute magnitudes.
Relative ages of clusters:



- M15 - Oldest, many stars have progressed to the giant branch
- M35. - Heaviest stars are starting to migrate to giant branch at V_{ABS} =-2.0 to -3.0 mag
- M38 - Heaviest stars have migrated to giant branch at V_{ABS} = -0.5 to -1.0 mag

Conclusion

- Python was used to create CMD's for each cluster which were analysed to identify the main sequence turn-offs of each cluster.
- The approximate distances with potential error were calculated for each B-V and V_{mag} adjusted open cluster CMD's using the distance modulus equation.
- The relative ages of the open clusters were determined by locating the main sequence turn-off for M35 and M38.

References:
Green, S.F., Jones, M.H. and J Simon Clark (2015) An introduction to the sun and stars. Cambridge, United Kingdom: Cambridge University Press ; Milton Keynes, United Kingdom. Open University 'Astronomy:PIRATE'. SXPS288: Remote experiments in physics and space. Available at: https://learn2.open.ac.uk/mod/oucontent/view.php?id=2356725&printable=1 (Accessed: October 2024).Open University 'Notebooks for PIRATE'. SXPS288: Remote experiments in physics and space. Available at: https://learn2.open.ac.uk/mod/folder/view.php?id=2356708 (Accessed: October 2024).