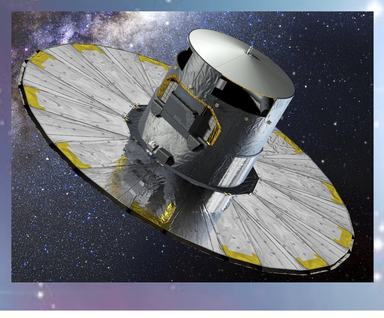
Mapping a star-forming region in 3D with Gaia astrometric data

Callum Murison | cm469@st-andrews.ac.uk

University of St Andrews

Gaia satellite

Launched in 2013 by ESA (the European Space Agency), it aims to collect high-precision **astrometry** (positions, motions and distances) for over a billion stars.



Why map star-forming regions?

Mapping allows us to identify star **clusters** and **associations** – groups of stars moving together. Because the stars within a cluster tend to have formed at the same time, they provide an ideal sample on which we can test astrophysical theories. It also helps for observations if have a well-constructed map of what we've seen so far.

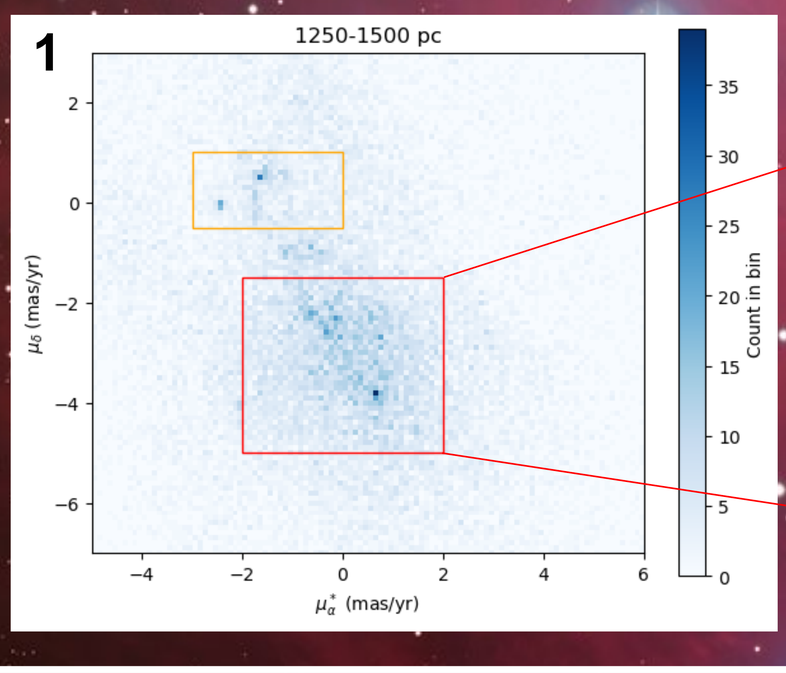
Data selection

- The region of interest, near the **Monoceros** constellation, has galactic coordinates l and b:
  - 196.5° < l < 206.5° *(longitude)*
  - -4.5° < b < 1.5° *(latitude)*
- Additional conditions were added to the query to select only higher-quality data
- Distances to the stars are around 400 – 1600 pc
  - 1 pc ≈ 31 million billion metres
- Smaller subsets of distance were used for analysis, such as for 1250-1500 pc below

Looking for clusters

- Clusters have stars which are **moving together**, **close in space**, and are the **same age**
- Stars moving together can be found by looking in 'proper motion space'
  - Essentially a plot of the observed motion of stars on the sky (see plots 1 and 2 below)
  - It shows how large an angle a star appears to move by in a given time period
- To find the stars which are moving together, the goal was to select the high-density regions in proper motion space, which are the darker blue regions in plot 1 below
- Some of these regions could be selected by eye
- For the less obvious high-density regions, which couldn't be seen by eye, a 2D **Gaussian Mixture Model** was developed to select them for further analysis
- The 3 most clustered regions were then plotted alongside the raw data (see plot 2 below)

1



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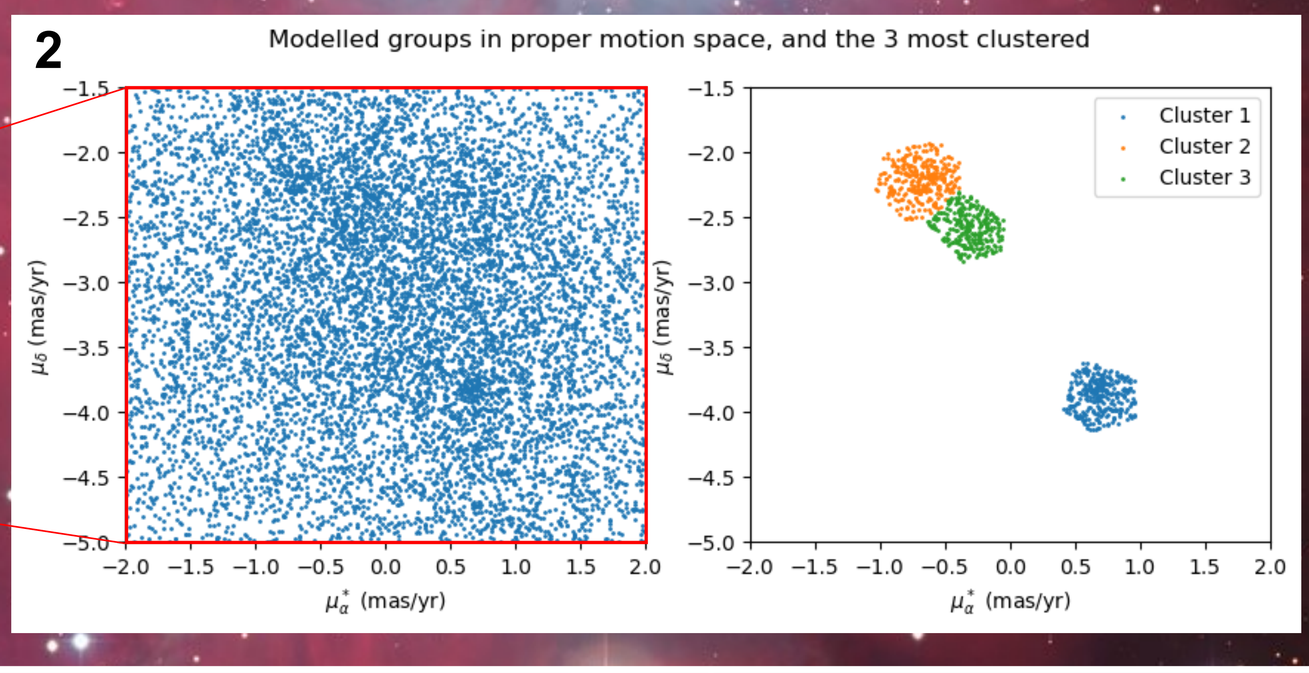
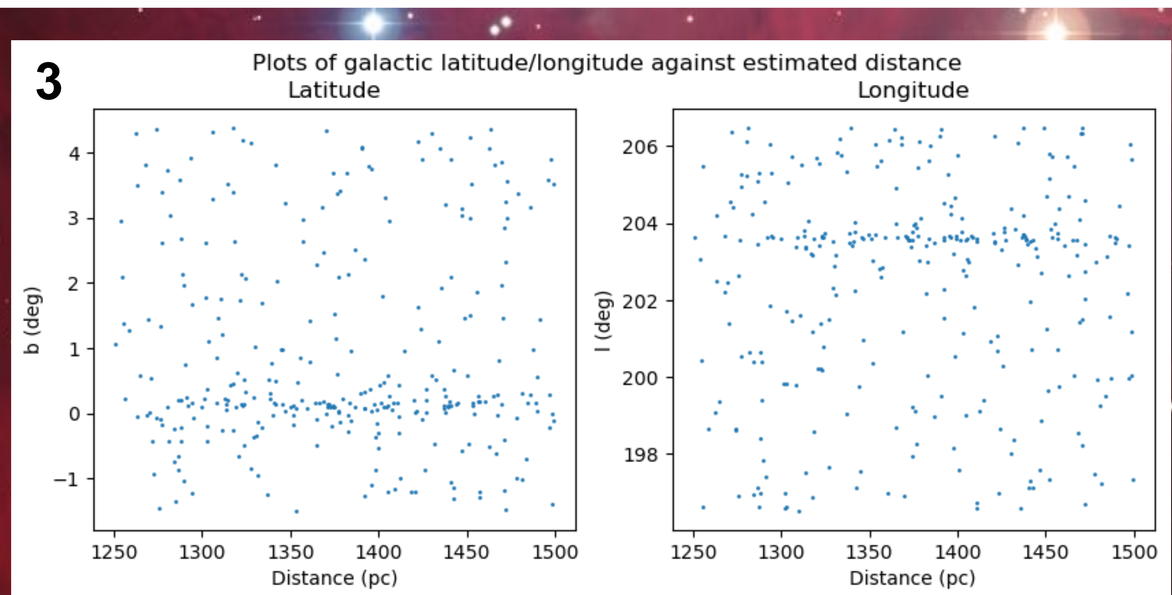


Further analysis

1. Analysing the **positions** of these candidates by eye (plot 3).
2. 'Cleaning up' the data by performing a **2D bivariate Gaussian fit**
3. Analysing the **ages** of these candidates. This was achieved by plotting a colour-magnitude (CM) diagram – a plot of brightness against colour – and then performing analysis known as 'isochrone fitting' (plot 4).

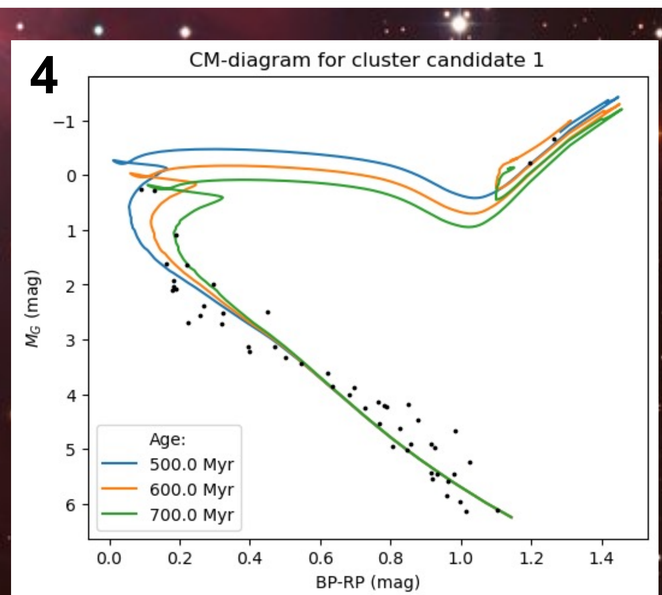
Graphs to the right are for 'Cluster 1' described in the summary below.

3



Positions: looking for patterns such as the above. Distinctive 'lines' at particular galactic latitudes/longitudes can indicate a cluster.

4



Ages: stars of the same age lie roughly along the same coloured line (isochrone).

Summary

This work culminated in the discovery of two likely clusters.

Cluster 1:
- 51 stars, at a distance of ~1390 pc
- Cluster age of ~600 Myr
- Centred at (l, b) = (203.6°, 0.11°)

Cluster 2:
- 27 stars, at a distance of ~1420 pc
- Cluster age of ~10-20 Myr
- Centred at (l, b) = (205.9°, -0.45°)

Discussion

Cluster 1 is an old cluster at 600 million years old, whereas Cluster 2 would be considered a young cluster. Other clusters in the Monoceros region have ages roughly in agreement with Cluster 2, meaning that the age of Cluster 1 is a big surprise – more work is required to try to find out why it is so different. Further analysis showed neither cluster to be expanding, which is another unusual feature of Cluster 1 – we would expect random motions of stars to increase over time, leading to expansion in older clusters.

The hope is that a 5D Gaussian Mixture Model may be refined in future to automate the process further.

My work opens the door to further studies – both to analyse my results in more detail, and continue the search for other clusters in this region.

Acknowledgements

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References

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2. *"Statistics, Data Mining and Machine Learning in Astronomy", Ivesic et al*
3. *MIST isochrones in Python, https://isochrones.readthedocs.io/en/latest/index.html*
4. *ESO and ESA photo archives*