A New Method to Determine Star Cluster Distances?

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Abstract

Determining cluster distances is essential to analyse their properties and distribution throughout the Galaxy. In particular it is desirable to have a reliable, purely photometric method for large samples of newly discovered (candidate) clusters (e.g. from 2MASS, UKIDSS-GPS, VISTA-VVV). This would allow us to estimate distances independent of isochrone fits and cluster properties (age and reddening). Here we present our attempt to 'calibrate' such a method, based on a set of about 100 star clusters with known distances. Our method relies on the photometric decontamination of cluster and field stars, based on the colour and position of a star relative to the cluster, to determine cluster membership probabilities. We then estimate the total number of foreground stars to the cluster (per unit area) based on the colours of low probability cluster members. These are then compared to predictions from the Besancon Galaxy Model by Robin et al. (2003) to estimate the cluster distance. This poster will show our preliminary results on the accuracy of such distance calculations. We will discuss which parameters of the photometric decontamination are required to achieve the best calibration, and if the accuracy depends on e.g. the age of the cluster or its position in the Galaxy.

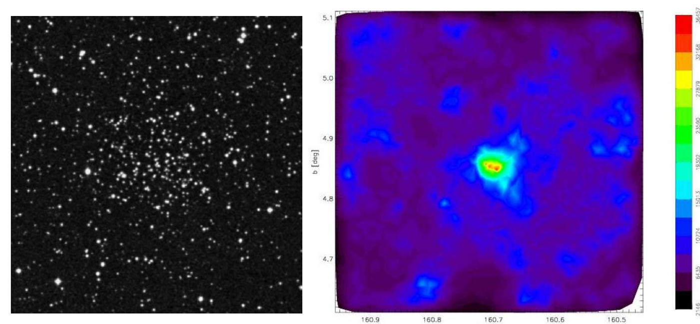

Figure 1: Shows FSR0705 (NGC 1798) as a 10x10 arcminutes DSS image (left) and a star density map (right).

Froebrich et al. (2007) identified 1788 cluster candidates using 2MASS star density maps, known as the FSR clusters. Our aim is to 'calibrate' a method of determining their distances from a homogeneous data set (i.e. only 2MASS data). Here we calibrate the method against 100 previously known 'old' (>100MYr) FSR star clusters, whose distances are available in the literature [Froebrich et al. 2010]. We aim to apply this method to the entire FSR sample and future cluster candidate lists.

Method

We applied the following methodology to calculate the star cluster distances:

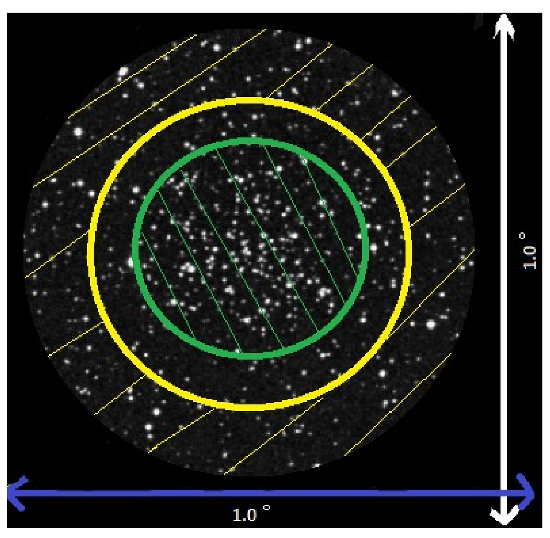

Figure 2: *DSS image of FSR0705 (NGC 1798). **Acl** is defined in green, **Acon** is defined in yellow.*

***Acl** is varied for the purpose of calibration, but always less than five times the cluster radius.*

Define Cluster and Control Field Areas

A radial star density profile fit was done to determine the cluster radius. As cluster area, **Acl**, we consider everything within a certain times the cluster radius. The control field area, **Acon**, is everything outside five times the cluster radius, but within 0.5 degrees.

$$r_{ccm} = \sqrt{\frac{1}{2}\left[J^i - J^j\right]^2 + \left[JK^i - JK^j\right]^2 + \left[JH^i - JH^j\right]^2}$$

$$P_{cl} = 1.0 - \frac{N^n_{ccm}}{\mathrm{n}}\frac{A_{cl}}{A_{con}}$$

***Equation 1a** (**Top**): Determines the colour-colour-magnitude (CCM) distance r_{ccm} between the star of interest (i) and every other star in **Acl**, using the NIR photometry from 2MASS. The n^{th} smallest distance for $i \neq j$ is selected and the number of stars N^n_{ccm} closer than r_{ccm} in the control field are counted.*

***Equation 1b** (**Bottom**): The cluster membership P_{cl} for star i is calculated. The number n is varied between 10 and 30.*

Calculate Cluster Membership Probabilities

For each star in **Acl** we calculate the cluster membership probability based on its NIR colours using the method of Bonatto & Bica (2007) and Froebrich et al. (2010). See ***Equations 1a*** and ***1b***.

$$\rho_{fg} = \frac{\sum^{\text{Blue Stars}} (1.0 - P_{cl})}{A_{cl}}$$

Equation 2: *Determination of the foreground star density.*

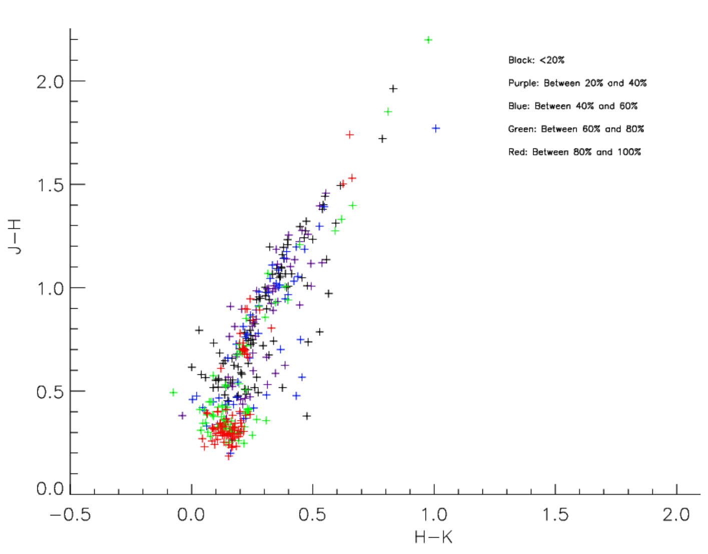

Figure 3: *Colour-colour diagram for FSR0141. The colours of the symbols indicate cluster membership probabilities.*

Identify Foreground Stars

The median H-K colour, $\mathbf{HK_{med}}$, of the top 15%-45% high probability cluster members is calculated. All stars with a H-K value less than $\mathbf{HK_{med}}$ are considered blue. The number of foreground stars per sq/deg, $\boldsymbol{\rho_{fg}}$, is calculated by summing up field star probabilities of all blue stars (***Equation 2***).

Use Foreground Star Density to Determine Cluster Distance

We use the Besancon Galaxy Model (Robin et al. 2003) and the photometric limits of our 2MASS data to model the density of foreground stars along the line of sight to the cluster. Determining at what distance the model predicts the same foreground star density as our $\boldsymbol{\rho_{fg}}$ estimate gives a model distance to the cluster. We expect systematic off-sets to the real cluster distance. Hence, the method needs to be calibrated using clusters of known distances.

Calibration

Calibration and Results

Calibration

We plot our model based distance vs literature distance for each calibration cluster. There is no obvious 1:1 correlation and a significant scatter of the data points (***Figure 4***).

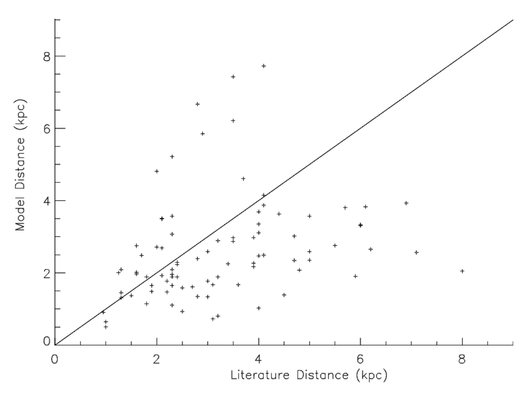

Figure 4: *Plot of our determined model distance vs literature distance for the 100 calibration clusters. The solid line represents a 1:1 correlation.*

As a measure of the scatter of our method we calculate the ratio 'R_{log} = log(literature distance / model distance)'. A histogram of the initial R_{log} values (see e.g. ***Figure 6*** for the final version of this after calibration) shows a Gaussian like distribution with a width indicating a mean scatter of **S=2.00**, i.e. a factor of two in the accuracy.

We then plot the R_{log} value against cluster properties (such as Galactic Longitude, Latitude, $\mathbf{HK_{med}}$, etc.) to find correlations that can be systematically corrected for to improve the scatter.

In ***Figure 5*** we show that the value of R_{log} systematically changes with the Galactic Longitude. We fit this trend by a polynomial function and correct our model distances accordingly. Afterwards, the scatter of the corrected R_{log} values indicates a significant improvement to **S=1.60**, i.e. a 60% scatter.

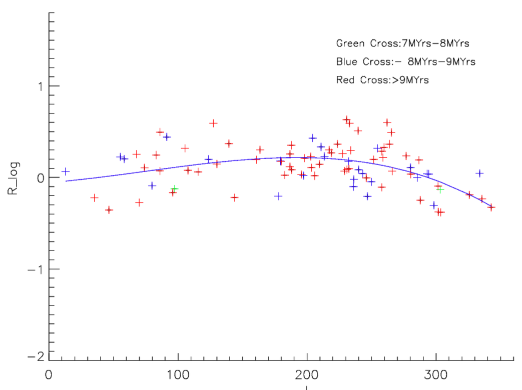

Figure 5: *Plot of R_{log} vs Galactic Longitude for the calibration clusters (different colours indicate different cluster ages). The solid line indicates the trend of R_{log} with Galactic Longitude fit by a polynomial and corrected for during the calibration.*

We further investigated varying the values of 'n' used for the determination of cluster membership probabilities (see ***Equation 1b***) between 10 and 30 and found the best results (lowest values for **S**) for 15<n<25. We also vary the size of the cluster area during this step from one to three cluster radii, with the best results for twice the cluster radius.

Crowding of the stellar images is a prominent observational effect in star clusters. The high density of stars in the cluster leads to an under estimate of the field star density. In other words, the field star density of the control field compared to the density of field stars in cluster area (the sum of all non-membership probabilities) should be equal. If we correct for this, the accuracy improves further to **S=1.50**.

Finally, the Besancon model does not naturally account for large scale foreground extinction along the line of sight to the cluster as well as crowding (which can be high in the Galactic Plane and not just in the dense central part of the cluster as discussed above). Thus, if the Besancon model predicts more stars per unit area than we detect in the control field, the implication is that there is a foreground cloud to the cluster with significant extinction and/or significant crowding in the field. This can be corrected for as well. After doing so, the scatter reaches **S=1.40**, i.e. a 40% accuracy of the distances (see ***Figure 6***).

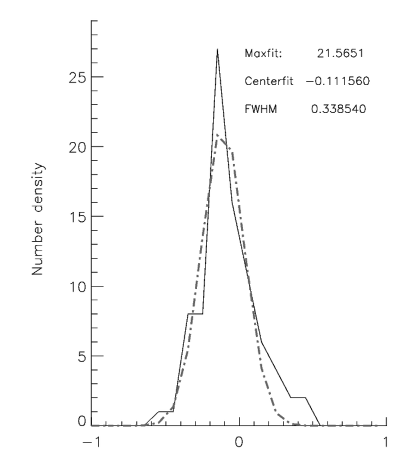

Figure 6: *Histogram of the distribution of R_{log} values after the calibration (solid line). The dashed line represents a Gaussian fit to the distribution. The width indicates a typical scatter **S of 40%**.*

Results

- **Our method works in principle, in particular after the calibration procedure (outlined above).**
- **We don't yet fully understand the detailed behaviour of the calibration procedure when varying some of the parameters.**
- **So far we can only achieve a 40% accuracy for the distance determination. When this method is applied to dark clouds (an ideal scenario as all background stars are extincted), Ioannidis & Froebrich (2012, in preparation) found an accuracy of 25%. Thus, realistically we cannot expect to achieve a smaller scatter than this.**
- **Our calibration is performed on 100 'old' (>100MYr) star clusters. Results for younger clusters should show significant improvement, since they are associated with dark clouds.**

Future Work

We will continue to investigate improvements to our calibration technique. In particular we will apply the technique to samples of clusters with different ages.

The calculation of cluster membership probabilities will be expanded to use the star's position in the cluster as well as the use of different colours (such as obtained from Glimpse IRAC).

We anticipate that using the H-4.5μm colour as separator of foreground and background stars instead of H-K will significantly improve results.

References

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This poster can be viewed online at: **http://astro.kent.ac.uk/~df/vortrag/nam2012/clusters.pdf**