Structure of Open Clusters - the current status

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Abstract: We investigated the available Gaia catalogue data (DR3) of open clusters and studied cluster distances, sizes and membership distributions in the 3D space. We argue that within two kpcs, the inverse-parallax method gives results comparable to the Bayesian approach based on the exponentially decreasing volume density. We also looked at a measure of elongations of the studied clusters and found that the most distant cluster contains about half of its members within a spherical fit located at about 1000 pc. These results show that the 3D structure of an open cluster cannot be studied appropriately beyond about 500 pc when using standard transformations of parallaxes to distances. A star cluster elongates with time along its path and begins to lose members, primarily low-mass stars, forming two tidal tails along the cluster orbit. Our N-body simulations have revealed that for circular orbits, the length of the overdensities along the tidal tail from the cluster centre is solely dependent on the mass of the cluster and the strength of the tidal field. This length decreases monotonically with time. In the more general case of eccentric orbits, the orbital motion influences the length, leading to periodic compression and stretching of the tails, resulting in an oscillation with time.

Introduction

Galactic star clusters are the most important objects not only when it comes to describing the Milky Way and its structure, but also for studying the individual stellar members. Various star groups, such as variables and binaries, can be statistically studied in star clusters. This is based on the idea that the cluster reddening, age, distance, and metallicity can be assumed to be the same for each of the cluster members. These cluster parameters can be deduced by fitting proper isochrones, for example.

The Milky Way exerts tidal forces onto its gravitationally bound stellar sub-systems with the effect that these sub-systems continuously lose members. Once the members are no longer gravitationally bound, they might remain in co-moving tidal tails that lead and trail their home sub-system. The tidal tails of stellar clusters are an important piece of information on the clusters' kinematic evolution, the process of dissolution, and the impact of the Galactic gravitational field onto a sub-system. It is therefore believed that a significant amount of Galactic field stars are former star cluster members.

Interestingly enough, the analysis of structural parameters such as density profiles, ellipticities, and tidal radii is mainly done for Globular clusters.

3D - Structure

Due to the uncertainties in observed parallaxes, most of the clusters have needle-like shapes and are not even close to being spherical. We conclude that this affects the determination of distances not only when using inverted parallaxes but also when the Bayesian approach with decreasing volume density prior is applied. The use of the Galactic model in the prior seems to have little to no effect on the apparent elongation of clusters along the line of sight.

With the currently available data, the diameters of open clusters can be well studied up to about 2 kpc (using a statistical approach). The results of the overall distribution are in line with the current models showing that all clusters have diameters less than 20 pc with a peak value lying between 2 and 4 pc. However, this result depends critically on the method used to determine the cluster membership probabilities. Furthermore, we find that individual open clusters beyond 500 pc should not be considered for 3D studies with the most widely used parallax-to-distance transformation methods.

A comparison of the derived cluster distances with isochrone fitting methods shows that both approaches give statistically very similar. Looking at the comparison of the derived projected widths with the diameters, we find no evidence that would show an expected systematic increase of the cluster diameters with the increasing cluster ages.

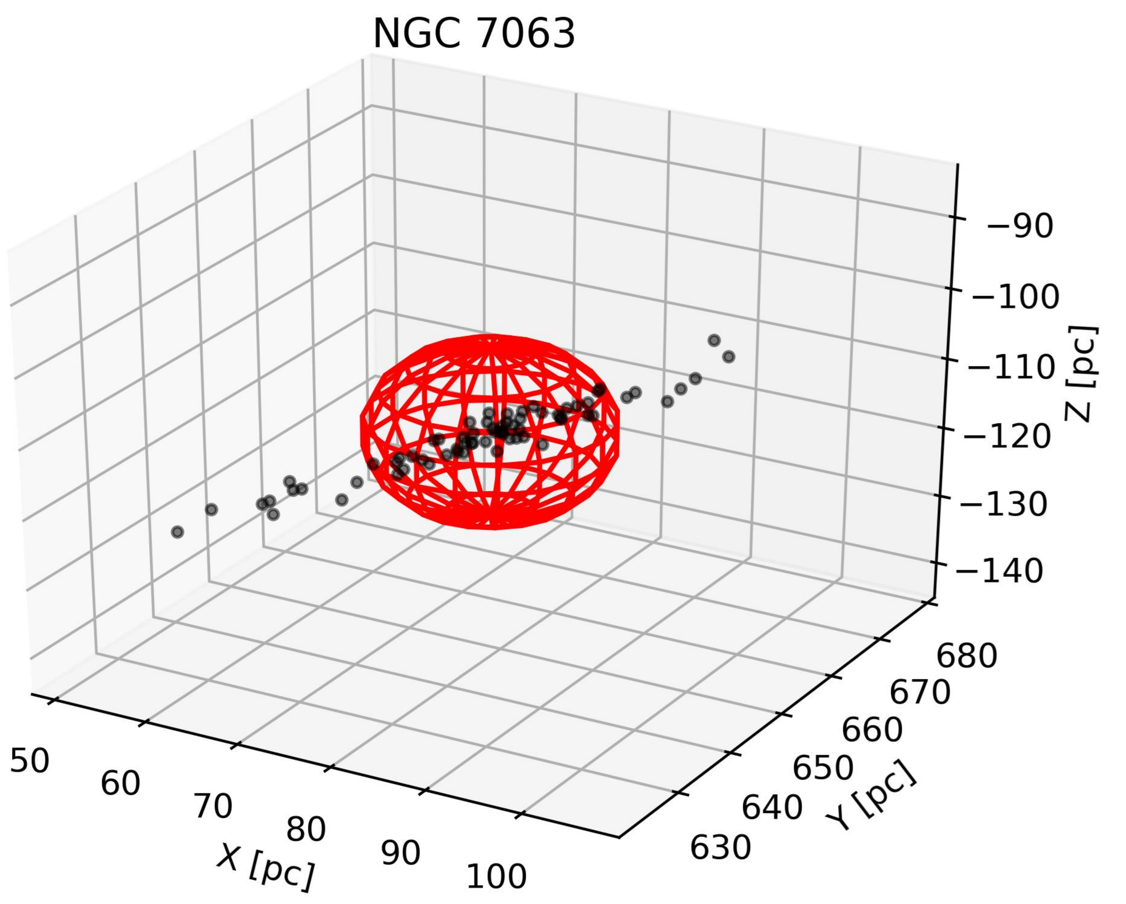

Figure 1: The 3D structure of NGC 7063 at 665(2) pc. The elongation is the result of uncertainties in the observed parallaxes. Included is a sphere with a radius of 12 pc centered at the star cluster

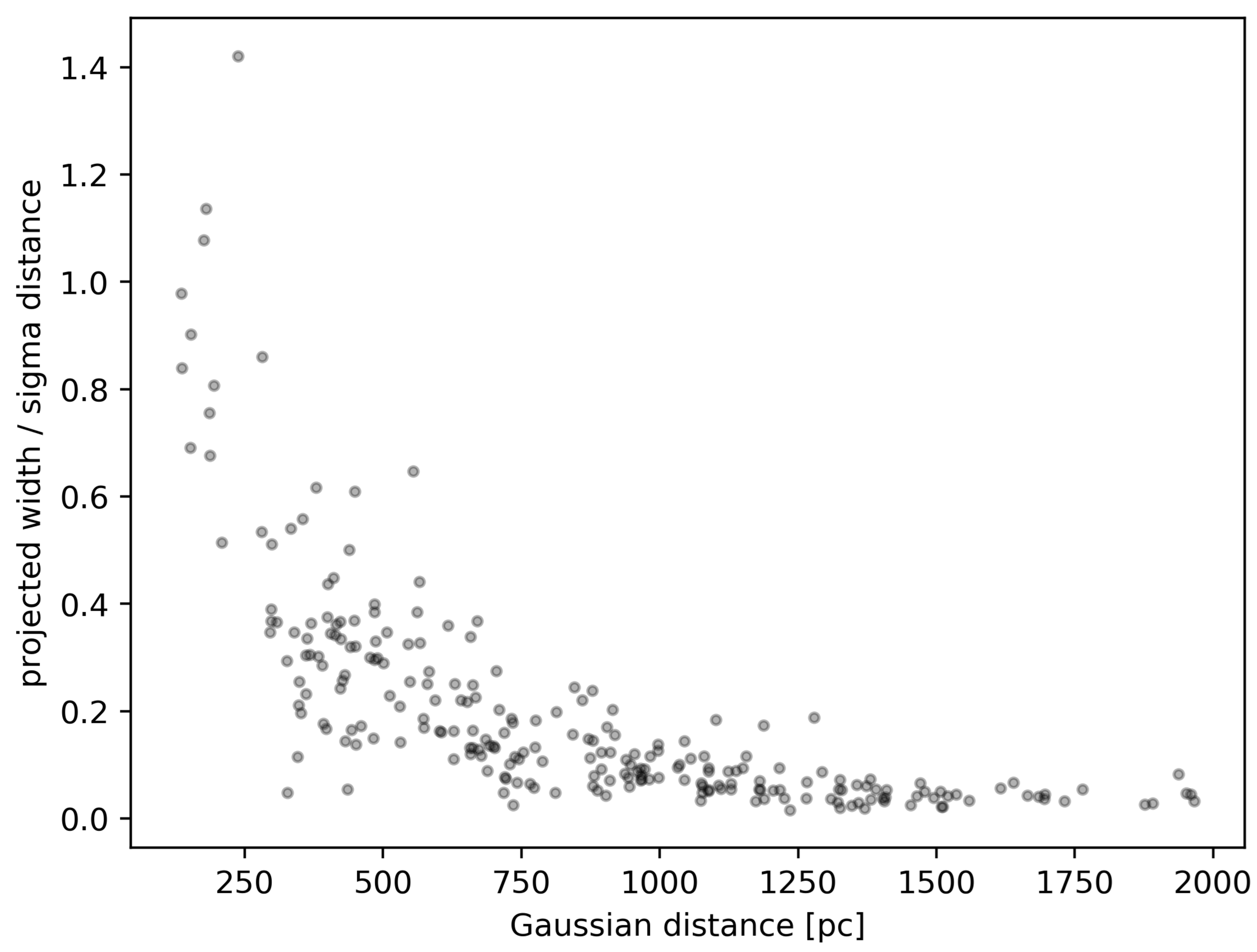

Figure 2.: The plot of a measure of ellipticity of clusters against the distance of the clusters.

Ellipticities

To further analyse the limitations of the data for studying clusters we may need to find a measure of the ellipticity of clusters. For this, we have chosen to take the ratio of projected widths and distance sigma parameters. In Fig. 2 we see how this measure behaves as a function of the distance. We have used a strict sample (with the best-known cluster parameters) to get the best possible results. It can be seen that the clusters from our sample significantly differ from spherical symmetry already at 500 pc.

Tidal tails

A rather well-known effect are tidal tails of star clusters. It is expected that star clusters should have a finite lifetime resulting from the dynamical evaporation process. Especially for old open clusters, the total mass at birth is difficult to establish because of the member loss over several hundreds of millions of years. However, estimating this parameter is important for putting constraints on the star-forming rate in the Milky Way. Tidal tails were investigated for the close open clusters such as Gamma Velorum, Hyades, and Praesepe, for example. The search for such tidal tails is not straightforward because according to models they could reach up to a length of about 800 pc, as in the case of the Hyades.

To find these tails, one has to use a method calculating the space velocities to a convergent point. However, because measured radial velocities are missing for the vast majority of stars, most works rely on criteria solely based on tangential velocities. We searched for tidal tails in all star clusters closer than 2 kpc.

We have to emphasize that the needle-like structures seen in Fig. 1 are not due to tidal tails but due to the uncertainties in observed parallaxes of the individual members of star clusters.

As the last step, we simply simulated several clusters at a random distance to predict the expected tidal tails. We have chosen to simulate 500 clusters (containing between 100 and 300 members) at distances between 100 pc and 2000 pc. The cluster radii were chosen to be 5 pc.

Our simulations match the results from the literature putting a tight constraint on the definition of moving groups and true star clusters beside the commonly used criterion about gravitationally forces.

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This work was supported by the grant GAČR 23-07605S.