Proper Motion Study of the Orion Nebula Cluster

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1 Introduction

Motivated by a recent investigation of binary properties in the Orion Nebula Cluster (ONC), in which, among other models, a rapidly expanding ONC is studied (Kroupa et al. 1998), we re-investigate the kinematical state of the cluster.
Earlier investigations claimed to have found evidence for expansion (Strand 1958) as well as for an overall contraction (Fallon, Gerola & Sofia 1977) of the ONC. Both results have been questioned later on by other authors.
More recent proper motion studies of the ONC focused primarily on the selection of new member candidates, determining relative proper motions of the stars which are in general more accurate than absolute proper motions, but make it impossible to detect any systematic motions like expansion, contraction or rotation of the cluster stars.
Here we use absolute proper motions taken from various catalogues (Hipparcos [ESA 1997], PPM [Röser & Bastian 1988, Bastian & Röser 1993, Röser et al. 1994], ACT [Urban et al. 1997] and STARNET [Röser 1996]) for several dozens of stars probably belonging to the ONC to investigate any possible systematic motions.

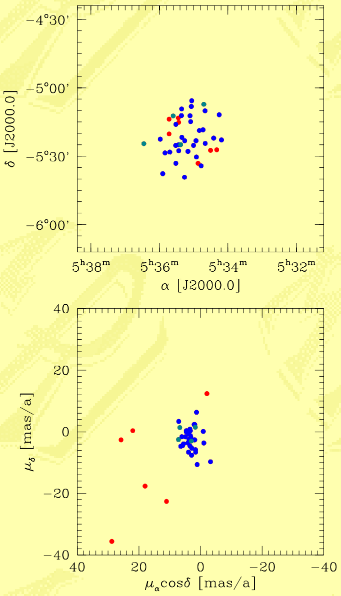
2 Member Selection

a) The sample

As a first step all stars in the catalogues mentioned in the introduction within a radius of $0\overset{\circ}{.}3$ (or 2.5 pc at a distance of 470 pc) around the adopted cluster centre θ^1 Ori ($\alpha_{2000} = 5^{\rm h}\,35^{\rm m}\,10\overset{\rm s}{.}00$, $\delta_{2000} = -5^\circ\,23'\,29\overset{\prime\prime}{.}3$), which covers the region of the ONC with the Trapezium cluster in its core, were cross-identified.
For stars which were present in more than one of the catalogues the most accurate proper motion was adopted, unless in the following case: if the proper motions in different catalogues were discordant, priority was given to ACT and STARNET since such large discrepancies are often due to orbital motions of double stars (Wielen 1997), so that their effect could be minimized by using larger epoch data. Altogether we could identify 41 stars in the region of the ONC in proper motion catalogues.

b) Kinematical Member Selection

As a second step we performed a kinematical membership selection. This is rather easy in the Orion region, as one expects no stars at distances greater than the Orion clouds at about 470 pc in the sample because of the high extinction. Foreground stars however could easily be identified because of their large proper motion. Thus 7 stars were rejected, leaving us with 34 probable ONC members (Fig. 1). We did not use any membership probabilities based on relative proper motions, since this already could introduce a kinematical bias in the case where systematic motions are present across the cluster which were not accounted for in the calculation of the membership probabilities.



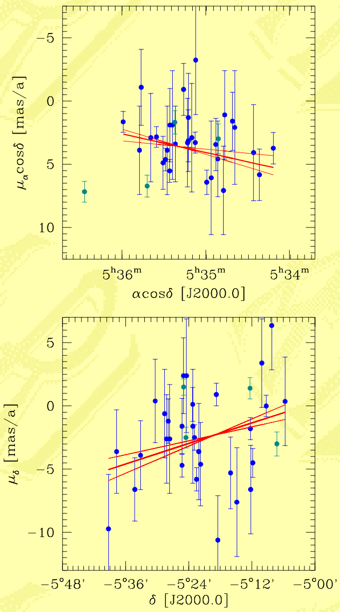
↑ **Fig. 1:** All 41 stars which we could identify in a region with radius $0\overset{\circ}{.}3$ around the Trapezium cluster in our proper motion catalogues. The 7 stars shown in red were rejected as ONC members because of their large proper motions. 4 stars not used for the fit (see Fig. 2) are shown in green.

3 Proper Motion Analysis

In order to investigate the kinematical state of the ONC we plotted the proper motions versus the positions for right ascension and declination separately (Fig. 2). Such diagrams can reveal an overall expansion (positive gradients) or contraction (negative gradients) of a group of stars. Interestingly, the stars of the ONC seem to contract in the direction of right ascension, whereas they seem to expand in the direction of declination! The scatter around the straight lines in Fig. 2 is quite high, but taking the errors of the proper motions into account (the median is 3 mas/a), the above interpretation seems justified: a χ^2-fit proved that the gradients are indeed significant. The contraction rate in right ascension is $-5.9(+3.2/-2.1)$ mas/a/°, the expansion rate in declination 8.1 ± 2.6 mas/a/° (1 mas/a/° corresponds to about 0.27 km/s/pc at a distance of 470 pc). For the fit we used the same set of 30 stars for both coordinates; 4 stars were rejected because their contributions to χ^2 were too high (shown in green in the figures).

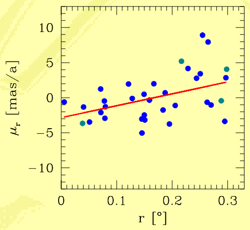
The corresponding values for χ^2 are 31.9 in right ascension, just as expected for 30 stars, and 69.7 in declination, which is about twice as high as expected. In principle one could reduce the value of χ^2 by rejecting some more stars, but then the statistics would get worse (in fact rejecting 3 more stars did not change the expansion or contraction rates significantly, but resulted in a value of $\chi^2 = 39.9$ in declination). However another explanation for the rather high χ^2 is more likely: a comparison of proper motions in ACT and TRC (Høg et al. 1998), which are based on the same observations and different reduction schemes, revealed that the errors of the proper motions in ACT might have been underestimated. Most of the stars which were rejected are ACT stars with error estimates around 1 mas/a, whereas errors in TRC, where a possible systematic error of 1.6 mas/a has been taken into account in addition to the individual random errors, are often 2 or 3 times larger (we did not use the TRC in this study because there are more stars present in ACT than in TRC in the ONC region).

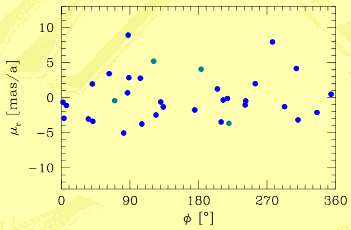
We also plotted the radial velocity component of each star relative to the mean proper motion of the ONC stars in our study ($\mu_\alpha \cos\delta = 3.1$ mas/a, $\mu_\delta = -2.5$ mas/a) versus radius and position angle, respectively (Fig. 3 and Fig. 4). Figure 3 indicates that stars in the core of the ONC generally move towards the centre, whereas stars in the outer parts of the cluster move away from the centre. Inspection of Fig. 4 however shows that the observed velocity field is consistent with the above interpretation of contraction along the direction of right ascension ($\Phi = 0^\circ - 180^\circ$) and expansion in the direction of declination ($\Phi = 90^\circ - 270^\circ$), since the data could easily be fitted by a double sine wave as an envelope just as expected in this scenario.



↑ **Fig. 2:** Proper motion versus position diagrams for the 34 probable ONC member stars. The straight lines represent χ^2-fits to the data and their 1σ confidence limits, respectively. The 4 stars shown in green were not considered in the fit.

→ **Fig. 3:** The radial proper motion component μ_r (i.e. the component of the proper motion which points radially away from the centre, calculated with respect to the mean proper motion of all ONC member stars) versus the projected cluster radius. Stars in the outer parts of the cluster have larger radial motions than the stars in the core region of the ONC.





← **Fig. 4:** The radial proper motion component μ_r versus the position angle Φ of a star with respect to the cluster centre. There are two maxima visible which correspond to the directions of increasing ($\Phi = 90^\circ$) and decreasing declination ($\Phi = 270^\circ$), respectively. The envelope function can be fitted by a double sine wave.

4 Conclusions

We showed that it is possible to interpret the observed velocity field of 30 probable ONC member stars as a contraction along the direction of right ascension and an expansion along the direction of declination. Indeed ellipses have been fitted to the observed density distribution of the ONC by Hillenbrand & Hartmann (1998) with the major axis pointing in the direction of declination, which could be a consequence of such a velocity field.

Walker (1983) already noted that some of the stars move towards the centre and some move away from it, but he considered their positions as random with respect to the cluster centre. If this scenario of contracting stars in one direction and expanding stars in the other direction could be confirmed with a higher number of more accurate proper motions, this would be an important finding for the understanding of the formation and the dynamical evolution of young star clusters.

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