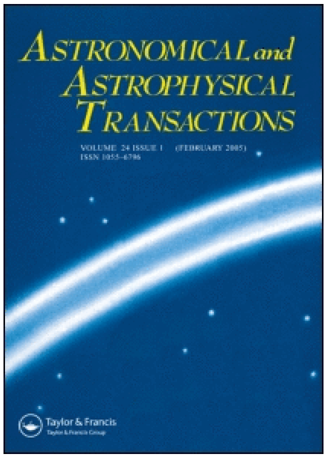


Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Components of the open cluster system of the Galaxy from kinematic analysis

I. I. Nikiforov [a]; E. E. Kazakevich [a]
[a] Sobolev Astronomical Institute of St Petersburg State University, Staryj Peterhof, St Petersburg, Russia

Online Publication Date: 01 April 2006
To cite this Article: Nikiforov, I. I. and Kazakevich, E. E. (2006) 'Components of the open cluster system of the Galaxy from kinematic analysis', Astronomical & Astrophysical Transactions, 25:2, 189 - 194
To link to this article: DOI: 10.1080/10556790600918505
URL: http://dx.doi.org/10.1080/10556790600918505

Astronomical and Astrophysical Transactions
Vol. 25, Nos. 2–3, April–June 2006, 189–194

Components of the open cluster system of the Galaxy from kinematic analysis

I. I. NIKIFOROV* and E. E. KAZAKEVICH

Sobolev Astronomical Institute of St Petersburg State University, Universitetskij Prospekt 28, Staryj Peterhof, St Petersburg 198504, Russia

(Received 3 July 2006)

The possibility of using open clusters as reference objects in kinematic analysis including the estimation of the distance to the Galactic centre is investigated. This analysis has produced distinctly different results for three components of the Galactic open cluster system: clusters of young, intermediate and old ages. We revealed that kinematic analysis of only young clusters ($\lg t < 8.1$), although based on new data, cannot provide even a statistically reliable estimation of R_0. Old remote clusters ($\lg t > 8.8$) can stabilize the solution but they seem to have a significantly underestimated distance scale (formal estimates of $R_0 \approx 6 \pm 0.7$ kpc).

Keywords: Galaxy; Open clusters; Kinematics; Structure; Galactic centre distance; Distance scale

1. Introduction

Open clusters (OCs) are traditionally used for kinematic analysis of the Galaxy (see, for example, [1–4]), and in particular for the estimation of the distance to the centre of rotation of Galactic subsystem, i.e. the distance R_0 to the Galactic centre (see, for example, [5–7]). However, in the majority of the mentioned studies, combined samples of objects (not only OCs) were used. Such samples are obviously more affected by systematic errors than are homogeneous samples [8]. Only in [5, 6] were homogeneous (i.e. only OCs) samples used, but these latter were very small ($N = 19$–34) owing to strong spatial constraints according to the methods applied. In these studies, either the statistical significance of the obtained results was not estimated [5] or it was considerably overestimated by applying the method of propagation of errors [6], which seems to be inappropriate in this case. In addition, in the last few years the statistics of OC data significantly increased and the OC distance scale was calibrated by comparison with Hipparcos parallaxes [9, 10] or by using statistical parallaxes [4]. All the above was the motivation for this study, the initial purpose of which was to approve separate use of (new) OC data in kinematic analysis, imposing no spatial restrictions on the data sample.

*Corresponding author. Email: nii@astro.spbu.ru

Astronomical and Astrophysical Transactions
ISSN 1055-6796 print/ISSN 1476-3540 online
http://www.tandf.co.uk/journals
DOI: 10.1080/10556790600918505

2. Data on open clusters

Two compiled data samples were used for kinematic analysis. One of these is the compilation of the second version of the homogeneous catalogue of the OC parameters by Loktin *et al.* [11] (according to Loktin [12], further data have been added) and the new catalogue (version 2.2) of optically visible OCs and candidates by Dias *et al.* [13]; this sample is denoted LD. In total, 212 OCs contained in both catalogues were identified as being the same. The heliocentric distances r were taken from [11, 12]; the Galactic coordinates l and b and the heliocentric radial velocities V_r were taken from [13].

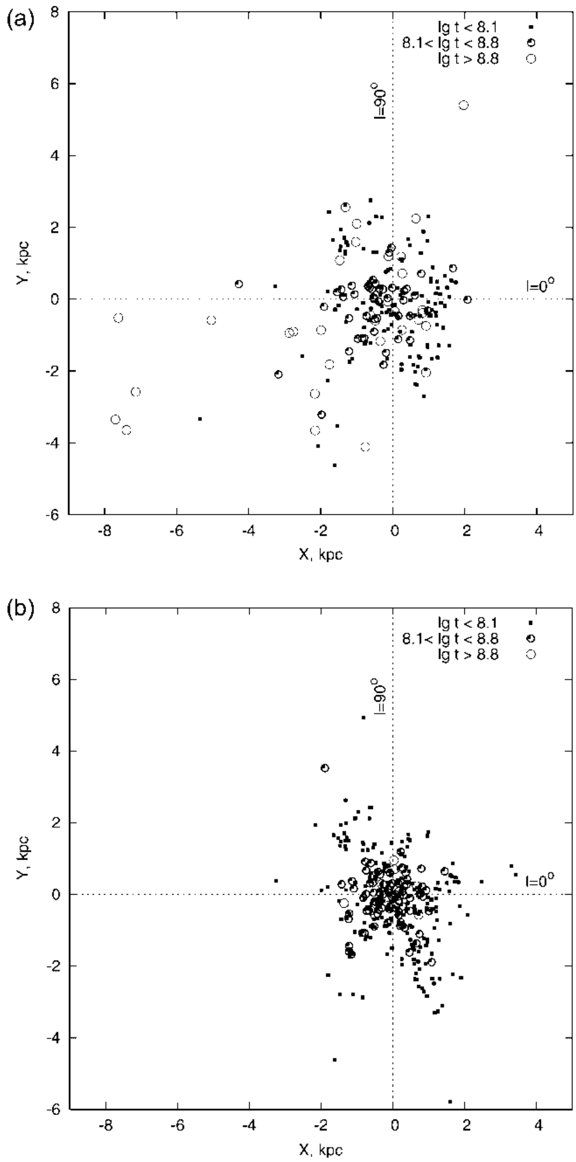


Figure 1. Distributions of OCs with known distances and radial velocities in the Galactic plane, according to (a) the LD catalogues and (b) the COCD. The X axis is towards $(l, b) = (0°, 0°)$, and the Y axis is towards $(l, b) = (90°, 0°)$. The Sun is at $(X, Y) = (0, 0)$ kpc.

The second data sample COCD consists of 322 OCs from the catalogue of OC data and its extension 1 published by Piskunov *et al.* [14] with known radial velocities. This sample is referred to as homogeneous in regard to the astrometric and photometric data, the kinematic and photometric criteria of OC member selection and the technique for determination of the cluster parameters.

The distributions of OCs in the Galactic plane are shown in figure 1.

3. Method

We adopted a simple (axisymmetric) model for the radial velocity V_r. Assuming the polynomial approximation for the linear velocity of rotation, $\theta(R) = \sum_{i=0}^{n} \theta_i (\Delta R)^i$, where $\Delta R \equiv R - R_0$, we obtain the following expression for model of V_r:

$$V_{\rm mod}(l,b,r) = \left(-2A\ \Delta R + \sum_{i=2}^{n} \theta_i (\Delta R)^i\right) \frac{R_0}{R} \sin l \cos b - u_0 \cos l \cos b - v_0 \sin l \cos b - w_0 \sin l. \tag{1}$$

Here $R = R(l,b,r; R_0)$ is the distance from an object to the Galactic axis; u_0, v_0 and w_0 are the components of the peculiar velocity of the Sun relative to the OC subsystem in the directions $(l,b) = (0°, 0°)$, $(l,b) = (90°, 0°)$ and $b = 90°$; A is the Oort constant; θ_i are the polynomial coefficients. Here w_0 is taken to be equal to 8 km s^{-1} [6].

The equation

$$V_r = V_{\rm mod}(l,b,r) \tag{2}$$

was constructed for each OC with known l, b, r and V_r. A set of equations (2) has been solved by the least-squares technique with a given n for the unknown parameters R_0, A, θ_i $(i = 2, \ldots, n)$, u_0 and v_0. The formal errors of all parameters were derived as projections of the multidimensional confidence region on the corresponding axes of parameters [8, 15, 16]. For optimization of the smoothness of rotation model we applied the technique described in [8, 15]. Objects with large residuals were excluded iteratively according to the algorithm with a flexible boundary depending on the sample volume [8].

4. Results and discussion

The results for the LD and COCD data samples are shown in table 1. Here lg t is the logarithm of the OC age, N is the number of stars (in the case of exclusion of OCs with large residuals there are two values separated by a solidus (/)), σ_0 is the velocity dispersion; all errors are at the 1σ level. Two OCs from the COCD were excluded after the first test calculations because of enormous residuals in V_r: ASCC 63 (7.5σ) and NGC 2527 (6.0σ). (It should be noted that the COCD contains many OCs with large residuals, which seem to be caused by erroneous V_r from observations of only one star.) For most of our OC subsamples the optimal model order n is equal to 1. This result is not unexpected since OCs with necessary data are, in general, within 2 kpc of the Sun.

Usually kinematic analysis is carried out on only OCs of *young age* (see, for example, [6, 7]). This is reasonable for increasing homogeneity of data and for decreasing velocity dispersion.

Table 1. Results of kinematic analysis for the LD catalogues [11–13] and the COCD [14].

Sample	N	n	R_0 (kpc)	A (km s^{-1} kpc^{-1})	v_0 (km s^{-1})	u_0 (km s^{-1})	σ_0 (km s^{-1})
LD							
$\lg t < 8.1$	133/130	1	$8.09^{+3.35}_{-1.74}$	18.86 ± 1.02	14.3 ± 1.7	11.5 ± 1.7	13.0
All	212/210	1	$6.10^{+0.62}_{-0.61}$	18.38 ± 0.93	12.0 ± 1.5	11.5 ± 1.7	15.0
$\lg t < 8.9$, $R < 12$	188/187	1	$6.37^{+0.69}_{-0.70}$	18.23 ± 0.99	10.7 ± 1.6	11.5 ± 1.6	14.6
$\lg t < 8.8$, $R < 12$	177/176	1	$6.93^{+2.38}_{-1.37}$	17.71 ± 1.06	11.3 ± 1.7	11.3 ± 1.6	14.4
$8.1 < \lg t < 8.8$, $R < 12$	45	1	$3.6^{+\infty}_{-1}$	12.5 ± 3.0	5.1 ± 4.0	12.4 ± 3.0	14.9
$\lg t > 8.8$, $R < 12$	29	1	$6.01^{+0.93}_{-1.09}$	20.4 ± 3.3	9.2 ± 6.2	15.9 ± 6.7	20.1
COCD							
$\lg t < 8.1$	232/227	3	$12.4^{+9.7}_{-3.9}$	16.72 ± 1.09	13.5 ± 1.4	7.2 ± 1.2	11.6
All	320/309	3	$10.4^{+6.1}_{-2.9}$	15.62 ± 1.07	12.0 ± 1.3	9.6 ± 1.1	12.3
$8.1 < \lg t < 8.8$	74/67	1	$6.8^{+\infty}_{-3.5}$	10.9 ± 3.3	10.2 ± 2.2	15.7 ± 2.1	11.7
$\lg t > 8.8$	13	1	$8.2^{+\infty}_{-8.2}$	31.7 ± 12.9	5.1 ± 8.9	5.2 ± 9.6	19.5

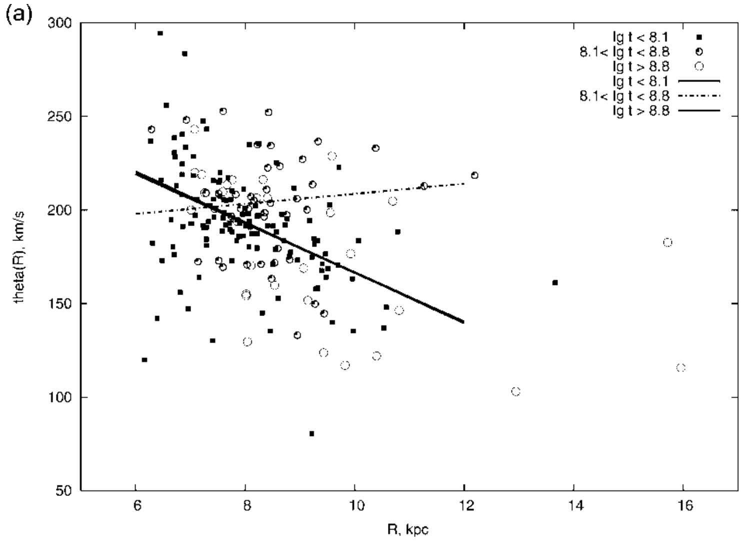
However, our R_0 estimation from young OCs unexpectedly turned out to be ambiguous, even in the statistical sense (see table 1). This ambiguousness is not caused by any kinematic anomalies or systematic errors in the observational data. Numerical simulations verified this enormous uncertainty for the R_0 estimate, regardless of the assumption of the axisymmetric rotation of the OC subsystem and lack of random errors in the distances r, if young clusters are distributed in such a small vicinity of the Sun as in our samples. Thus, it allows us to conclude the following: *without remote objects the OC kinematics cannot provide serious constraints on the value of* R_0. The close agreement between the R_0 values from LD and previous studies (see, for example, [5, 6]) can be explained by the similarity of the contents of the OC samples, and the obtained 'realistic' point estimate of $R_0 \approx 8$ kpc should be considered only as a happy accident. The fact that the addition of new OCs to the COCD leads to a dramatic shift in R_0 value (see table 1) supports our last conclusion.

The inclusion of LD clusters of *old age* (which are, in general, rather remote objects in LD) in the sample drastically increases the statistical accuracy of the R_0 estimate (up to 10%) with an abrupt switch at lg $t \approx 8.8$–8.9 (table 1). For OCs of *intermediate age* the solution is actually absent, although they are not so few in the LD catalogues. However, the value of $R_0 \approx 6 \pm (0.6$–$0.7)$ kpc from LD samples with old OCs, which are relatively accurate statistically, are obviously underestimated; the current 'best value' for R_0 is 7.9 ± 0.2 kpc [17]. The cause of this result seems to be *an underestimation of the distance scale for old OCs*.

R_0 estimates from COCD samples turned out to be even more uncertain as an essential number of their OCs is very close to the Sun. That is why results from the COCD cannot clarify the problems arising in this study, although they do not contradict the conclusions drawn above.

The rotation curves from OC data for $R_0 = 7.9$ kpc and the angle rotation velocity at the Sun, $\omega_0 = 26.4$ km s^{-1} kpc^{-1} [18], are shown in figure 2.

The OCs of *intermediate age* have obviously anomalous kinematics (table 1). This anomaly occurs also at fixed R_0 (figure 2). The distance scale for additional OCs of *old age* included in the COCD seems to be even more underestimated, since their addition results in an extremely large value for the Oort constant A (table 1 and figure 2).



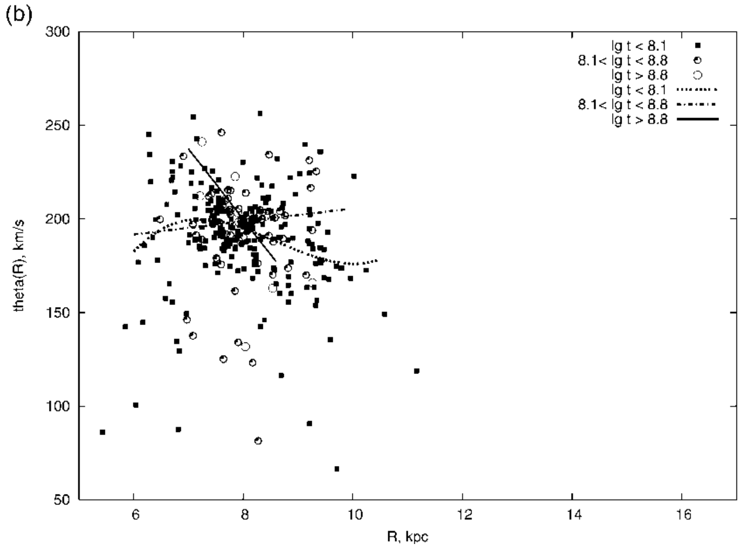


Figure 2. The rotation curves for the OCs from (a) the LD catalogues and (b) the COCD.

Acknowledgements

We acknowledge the Russian Foundation for Basic Research grants 04-02-17447 and the Leading Scientific School grant NSh-4929.2006.2.

References

[1] W.S. Dias and J.R.D. Lépine, Astrophys. J. **629** 825 (2005).
[2] J. Hron, Astron. Astrophys. **176** 34 (1987).
[3] A.V. Loktin and G.V. Beshenov, Astron. Zh. **80** 8 (2003).
[4] M.V. Zabolotskikh, A.S. Rastorguev and A.K. Dambis, Pis'ma Astron. Zh. **28** 516 (2002).
[5] K.A. Barkhatova, T.P. Gerasimenko, M.E. Blum, Byul. Abastumansk. Astrophys. Observ. **59** 169 (1985).
[6] T.P. Gerasimenko, Astron. Zh. **81** 124 (2004).
[7] E.V. Glushkova, A.K. Dambis, A.M. Mel'nik *et al.*, Astron. Astrophys. **329** 514 (1998).

[8] I.I. Nikiforov, Spatial-kinematic and dynamic modelling of the Galaxy. PhD thesis, St. Petersburg State University (2003) (in Russian). Available online at: www.astro.spbu.ru/astro/publications/disser/NikiforovII/ (accessed 2003).
[9] A.V. Loktin and G.V. Beshenov, Pis'ma Astron. Zh. **27** 450 (2001).
[10] A.V. Loktin and G.V. Beshenov, Astron. Zh. **78** 819 (2001).
[11] A.V. Loktin, T.P. Gerasimenko and L.K. Malysheva, Astron. Astrophys. Trans. **20** 607 (2001).
[12] A.V. Loktin, private communication (2005).
[13] W.S. Dias, B.S. Alessi, A. Moitinho *et al.*, Astron. Astrophys. **389** 871 (2002).
[14] A.E. Piskunov, N.V. Kharchenko, S. Röser *et al.*, Astron. Astrophys. **445** 545 (2006).
[15] I.I. Nikiforov, Astrofizika **42** 399 (1999).
[16] W.H. Press, B.P. Flannery, S.A. Teukolsky *et al.*, *Numerical Recipes in Pascal: The Art of Scientific Computing* (Cambridge University Press, Cambridge, 1989), p. 759.
[17] I.I. Nikiforov, in *Order and Chaos in Stellar and Planetary Systems*, Astronomical Society of the Pacific Conference Series, Vol. 316, edited by G.G. Byrd, K.V. Kholshevnikov, A.A. Mylläri *et al.* (Astronomical Society of the Pacific, San Francisco, California, 2004), p. 199.
[18] F.J. Kerr and D. Lynden-Bell, Mon. Not. R. Astron. Soc. **221** 1023 (1986).