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Investigation of the nearby open clusters with Gaia DR2 data

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Abstract. Gaia DR2 catalog provides a unique possibility to study the three-dimensional structure and the three-dimensional velocity field of the nearby open clusters. We can either select stars with a maximum membership probability and the most accurate values for the proper motions, parallaxes, and the radial velocities, or study these clusters statistically using overwhelmingly large areas of sky of tens by tens degrees. The second approach allows us to reveal the extensive outer parts of the clusters - a corona and the tidal tails and to study the luminosity and mass functions of these clusters. We present the first results of the investigation of several nearby open clusters, including Pleiades, Alpha Persei, Ruprecht 147.

Keywords. open clusters and associations: general, stars: kinematics, stars: luminosity function, mass function

1. Introduction

The most severe problem in the investigation of open star clusters is the field stars contamination. It is especially crucial for nearby open clusters which can span tens square degrees of the celestial sphere. A solution to this problem is well known. It is a selection of the probable cluster members by their joint motion in space, namely, by the proper motions and the radial velocities. The Gaia mission and the Gaia DR2 catalog (Gaia Collaboration *et al.* 2016, 2018) have made a revolution in this field presenting the proper motions and the trigonometric parallaxes for more than one billion stars. The Gaia data allow us to realize two different approaches. The first approach assumes the selection of stars with a maximum membership probability and the most accurate values for the proper motions, parallaxes, and the radial velocities. The second approach uses a sample of stars with a relatively mild restriction on parameters (it allows to reduce the sample volume) and the statistical methods for evaluation of the cluster stars distribution functions (Seleznev 2016b). This paper presents some results of a collaboration project of Ural Federal University and Padova University devoted to the study of the structure, stellar content, internal kinematics, and dynamics of open clusters with Gaia data and the data of the infrared surveys. These first results concern the open clusters Pleiades, Alpha Persei, and Ruprecht 147.

2. Ruprecht 147

Yeh *et al.* (2019) selected the probable cluster members; it allowed to find the tidal tails of this cluster. The sample compiled for a statistical investigation of the cluster contains 64564 stars with $G \leq 18$ mag in the field 40 by 40 degrees. Fig. 1a shows the density profile

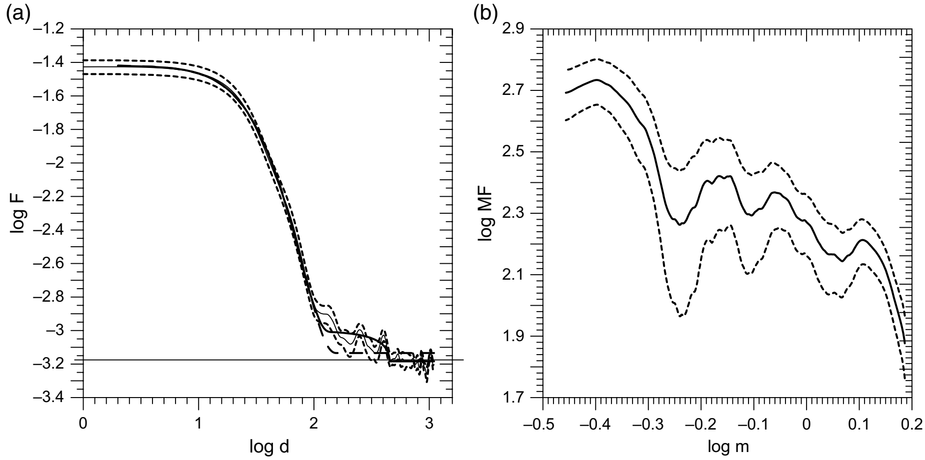

Figure 1. Ruprecht 147. (a) - The density profile (surface density F in $(arcmin)^{-2}$, projected distance d in $arcmin$). The thin solid curve shows the density values, the short-dashed lines show the 2σ confidence interval, the thick solid curve shows an approximation of the profile by the combined function (Seleznev 2016a), and the long-dashed curve shows an approximation by King profile. The solid straight line shows the mean-field density. (b) - The mass function (m in $M_{\odot}$, MF in $M_{\odot}^{-1}$). The dashed lines show the 2σ confidence interval.

plotted with the Seleznev (2016a) method. It gave the cluster radius of $R_c = 7.5 \pm 0.2$ deg (35 ± 1 pc) and the cluster core radius of $R_{core} = 100$ arcmin (we consider the cluster core boundary as a point, where the density gradient changes abruptly). The density profile reveals the presence of the extended cluster corona. Fig. 1a shows the result of an approximation of the density profile by the King function (King 1962) as a long-dashed curve and by the "combined" function (Seleznev 2016a) as a thick solid curve. It is well seen that these two approximations coincide in the cluster core, but the King profile can not reproduce the density distribution in the cluster corona. The "density waves" are well seen in the cluster corona.

Fig. 1b shows the present-day mass function (MF) of Ruprecht 147 plotted following Seleznev *et al.* (2017). Integration of the MF gave the cluster star number of 280 ± 67 and the cluster mass of 234 ± 52 $M_{\odot}$. The comparison of the MF for the cluster core and the cluster corona showed significant mass segregation (Yeh *et al.* 2019).

3. Pleiades

The initial sample selected for a statistical investigation of the cluster contains 47195 stars in the field 60 by 60 degrees. The density profile plotted as previously (see above) gave the cluster radius $R_c = 10.9 \pm 0.3$ deg (26 ± 1 pc) and the cluster core radius of $R_{core} = 157$ arcmin. This sample was used to plot the luminosity function and the mass function with the same method as above. Fig. 2 shows the MF of Pleiades. The long-dashed curve there is for the cluster core. It is well seen that the core is relatively less populated by the low-mass stars than the cluster as a whole. Integration of the MF gave the cluster star number of 1540 ± 120 and the cluster mass of 855 ± 104 $M_{\odot}$.

The probable cluster members were selected from the initial sample by their parallaxes and proper motions inside the circle with a radius 10.9 deg and by the color-magnitude diagram. In this way, we selected 1391 probable member stars with $G \leq 18$ mag. The probability of these stars membership was estimated to be 86.9 percent (Danilov & Seleznev 2019).

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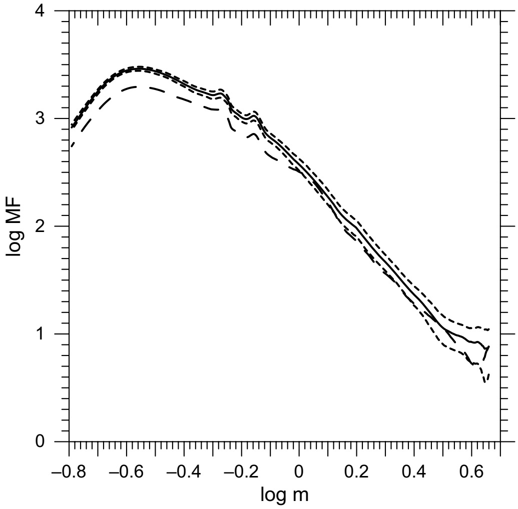

Figure 2. The mass function of the Pleiades cluster (a solid line). The short-dashed lines show the 2σ confidence interval; the long-dashed curve shows the mass function of the cluster core.

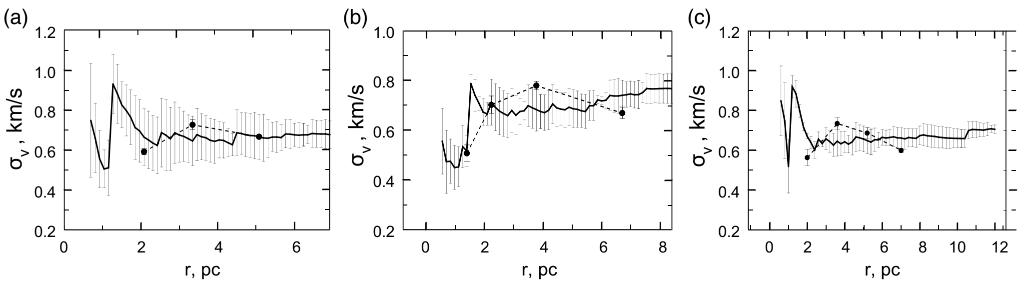

Figure 3. The mean-square velocities of the Pleiades stars inside a sphere with the radius r and the center coinciding with the cluster center. (a) – Stars of sample II ($G < 15$ mag); (b) – stars of sample I ($G < 16$ mag); (c) – stars of sample III ($G < 17$ mag).

Three subsamples were selected from this sample, taking into account the error of the stellar velocity in the tangent plane. These subsamples were used to estimate the cluster rotation and investigate the velocity field of the cluster (Danilov & Seleznev 2019).

Fig. 3 shows the mean square velocities for three subsamples inside a sphere with the radius r from the cluster center and comparison with the condition of the Jeans instability (the dashed lines). It is seen that this condition takes place at some distance interval from the cluster center. Fig. 4 shows the radial and tangential velocity components in the tangent plane for three subsamples. The oscillations of the velocity components indicate the non-stationarity of the cluster (Danilov & Seleznev 2019).

4. Alpha Persei

The analogous investigation is performed now for Alpha Persei open cluster. The density profile plotted with the initial sample in the 30 by 30 degrees field gives the cluster radius value of $R_c = 11.2 \pm 0.2$ deg (35 ± 1 pc). Fig. 5 shows the fascinating structure of the cluster outskirts with the visible tidal tails and some additional structures.

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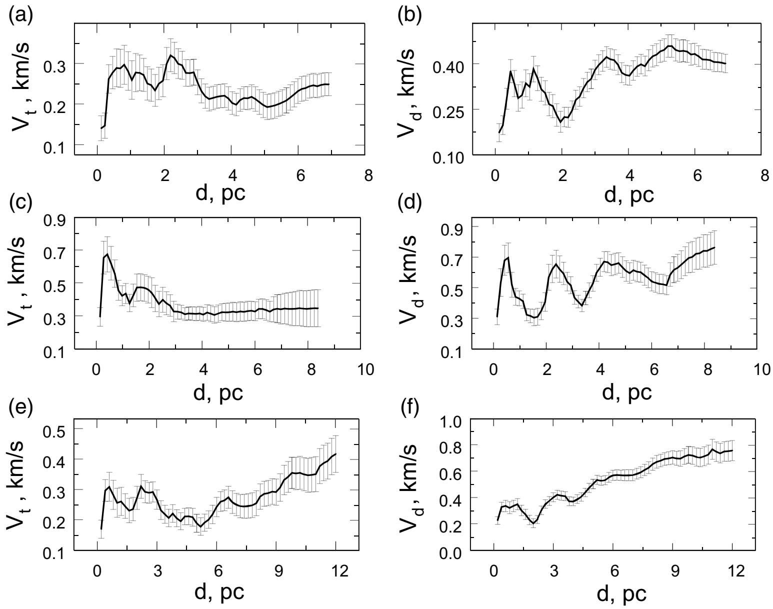

Figure 4. The dependencies of the radial and tangential velocity components of the Pleiades stars on the projected distance from the cluster center. (a),(b) – Stars of sample II ($G < 15$ mag); (c), (d) – stars of sample I ($G < 16$ mag); (e), (f) – stars of sample III ($G < 17$ mag).

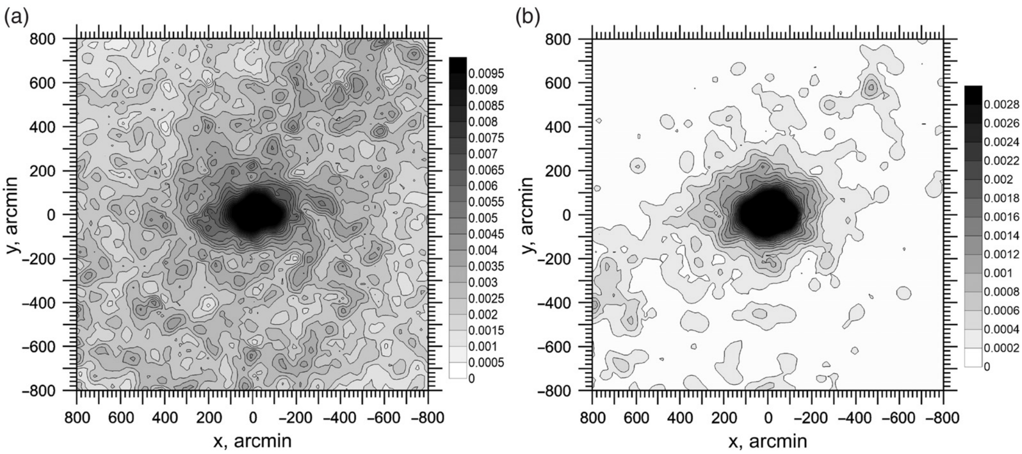

Figure 5. The projected density map of the Alpha Persei cluster. (a) - Initial sample, (b) - the probable cluster members.

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References

Danilov, V. M. & Seleznev, A. F. 2019, *Astrophys.Bull.* submitted
Gaia Collaboration, T. Prusti, J. H. J. de Bruijne, *et al.* 2016, *A&A*, 595, A1
Gaia Collaboration, A. G. A. Brown, A. Vallenari, *et al.* 2018, *A&A*, 616, A1
King, I. R. 1962, *AJ*, 67, 471
Seleznev, A. F. 2016a, *MNRAS*, 456, 3757
Seleznev, A. F. 2016b, *Baltic Astron.*, 25, 267
Seleznev, A. F., Carraro, G., Capuzzo-Dolcetta, R., *et al.* 2017, *MNRAS*, 467, 2517
Yeh, F. C., Carraro, G., Montalto, M., & Seleznev, A. F. 2019, *AJ*, 157, 115