Origins: From the Protosun to the First Steps of Life
Proceedings IAU Symposium No. 345, 2018
B. G. Elmegreen, L. Viktor Tóth & M. Güdel, eds.

doi:10.1017/S1743921318008335

Kinematics of OB-associations in the 3-kpc solar neighborhood

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Abstract. We use *Gaia* (DR1, DR2) stellar proper motions to study the kinematics of OB-associations. The average one-dimensional velocity dispersion inside 18 OB-associations with more than 10 Gaia DR1 stars is $\sigma_v = 3.9$ km s^{-1}. The median virial and stellar masses of OB-associations are equal to 7×10^5 and 9×10^3 solar masses, respectively. The median star-formation efficiency is $\epsilon = 2.1\%$. We have found the expansion in several OB-associations. Models of the Galaxy with a two-component outer ring R_1R_2 can reproduce the average residual velocities of OB-associations in the Perseus, Sagittarius and Local System complexes.

Keywords. Galaxy: kinematics and dynamics, open clusters and associations: general.

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1. Introduction

The distribution of the velocities of young stars in a wide solar neighborhood can tell us a lot about the structure and evolution of the Galaxy. There are several lists of OB-associations in the Galaxy, but the catalog by Blaha & Humphreys (1989) can be considered as the most universal. OB-associations are loose groups of OB stars. The sky-plane sizes of OB-associations from the catalog by Blaha & Humphreys (1989) are very different, but 90% of them are less then 200 pc. The main advantage of OB-associations over open clusters in kinematical studies is that OB-associations contain more stars with known line-of-sight velocities and proper motions, so their average velocities are more reliable.

Star formation proceeds with different intensity in different regions of the Galactic disk. Efremov & Sitnik (1988) identified several regions in the Galaxy containing a lot of molecular and neutral gas as well as young open clusters and OB-associations. These regions were named stellar-gas complexes. Figure 1a shows the distribution of young open clusters (Dias *et al.* 2002) and rich OB-associations (Blaha & Humphreys 1989) in the Galactic plane. We can see that young clusters and OB-associations concentrate to the stellar-gas complexes located in the Sagittarius, Carina, Cygnus, Local System and Perseus regions (e.g., Melnik *et al.* 2016).

2. Results and Conclusions

First let us consider the internal motions inside OB-associations. We used *Gaia* Data Release 1 (DR1) to determine the velocity dispersions inside 18 OB-asssociations with

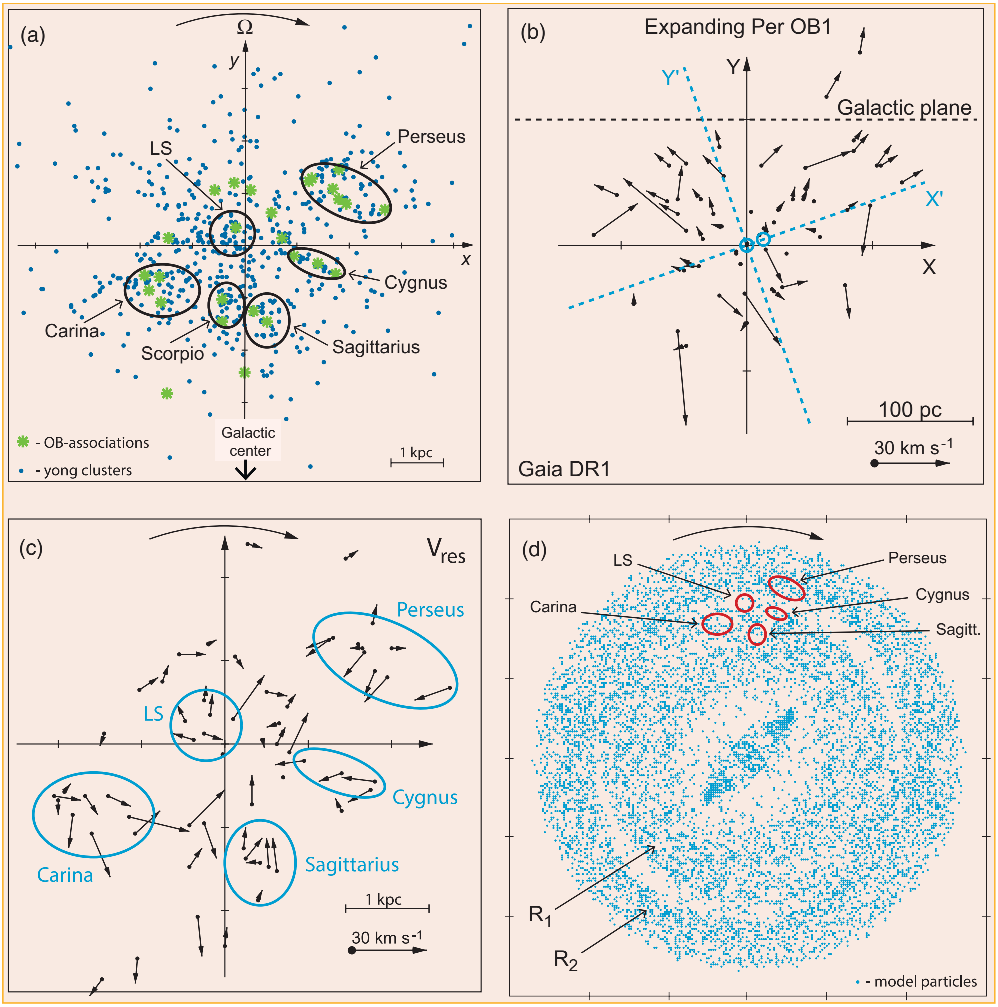

Figure 1. (a) Distribution of young open clusters (black circles, colored blue in electronic edition) and rich OB-associations (gray asterisks, colored green in electronic edition) in the Galactic plane. The Galactic center is at the bottom, the x-axis is directed in the sense of Galactic rotation. The Sun is at the origin. The ellipses indicate the positions of stellar-gas complexes. (b) Distribution of relative velocities in the Per OB1 association. The two gray circles (colored blue in electronic edition) indicate the position of the double cluster h and χ Persei. (c) Distribution of residual velocities of OB-associations in the Galactic plane. (d) Distribution of model particles (black dots, colored blue in electronic edition) and the positions of stellar-gas complexes (black ellipses, colored red in electronic edition) in the Galactic plane.

more than 10 *Gaia* DR1 stars (Gaia Collaboration *et al.* 2016a,b; Michalik, Lindegren & Hobbs 2015). The average one-dimensional velocity dispersion appears to be $\sigma_v = 3.9$ km s^{-1}. Note that *Gaia* DR2 (Brown *et al.* 2018; Lindegren *et al.* 2018) gives a bit larger value of $\sigma_v = 4.8$ km s^{-1} . This small increase in σ_v can be attributed to the contribution of binary systems. However, both estimates of σ_v are considerably smaller than the standard deviation of the velocities of OB-associations from the rotation curve, which is equal to 7.4 km s^{-1}. This fact suggests that OB-associations identified by Blaha & Humphreys (1989) mainly include stars born from the same molecular cloud (see Melnik & Dambis 2017, 2018 for more details).

Giant molecular clouds (GMC) are supposed to be close to their virial equilibrium (Larson 1981; Krumholz, Matzner & McKee 2006) and therefore the velocity dispersions of stars in OB-associations must correspond to the masses of their parent GMC. We can use simple formulae of stellar dynamics to estimate the virial masses of OB-associations:

$$M_{vir} = \frac{5a\sigma_v^2}{G}, \tag{2.1}$$

where a is supposed to be the radius containing 68% of the association member stars. The median value of virial masses of OB-associations with more then 10 *Gaia* DR1 stars appears to be 7×10^5 $M_\odot$, which is consistent with the masses of giant molecular clouds 10^5-10^6 $M_\odot$ obtained by Sanders, Scoville & Solomon (1985).

To estimate the stellar masses of OB-associations we use the multi-component power law of initial mass function (IMF) ($dN \sim M^\alpha dM$) by Kroupa (2002) and the assumption that the catalog by Blaha & Humphreys (1989) includes all stars with $M > 20$ $M_\odot$. The median value of stellar masses of OB-associations is 9×10^3 $M_\odot$.

The average efficiency of star formation in a parent GMC is the ratio of the stellar to virial masses of an OB-association. Its median value is 2.1%, which is consistent with other estimates (Myers *et al.* 1986, Evans *et al.* 2009, Garcia *et al.* 2014).

We found the expansion of four OB-associations – Per OB1, Car OB1, Sco OB1 and Ori OB1 – from an analysis of *Gaia* proper motions of their member stars. The expansion of the Per OB1 and Car OB1 associations first was found in the distribution of *Gaia* DR1 proper motions and was then confirmed by *Gaia* DR2 data. The expansion of the Sco OB1 and Ori OB1 associations was obtained with *Gaia* DR2 proper motions only (Melnik & Dambis 2017, 2018).

Figure 1b shows the distribution of relative velocities in the Per OB1 association. The relative velocities are calculated with respect to the center of the OB-association. Also shown is the position of the double cluster h and χ Persei residing practically at the center of the association. We can see that the fastest expansion happens in the direction Y′, which is nearly perpendicular to the main plain of the double cluster. The expansion velocity is 4.7 ± 1.3 km s^{-1}. The mass loss in a gas cloud due to thermal pressure of HII regions can create an expanding group of stars. If mass is ejected from the system within a time comparable to the crossing time, then the system becomes unbound after 50% mass loss (Hills 1980). However, more accurate treatment of relaxation processes shows that the system can form an expanding OB-association with a bound cluster in the center (Kroupa, Aarseth & Hurley 2001). The kinetic and potential energies depend differently on mass, so the mass-loss destroys the virial equilibrium. The gravity of the remaining gas just cannot keep the group inside the original volume.

Now let us consider motions of OB-associations as single entities. Figure 1c shows the distribution of residual velocities of OB-associations in the Galactic plane. The residual velocities are determined as the differences between the observed heliocentric velocities and the velocities due to the galactic differential rotation and the solar motion toward the apex ($V_{res} = V_{obs} - V_{rot} - V_{ap}$). The residual velocities characterize non-circular motions in the Galactic disc. The projections of the residual velocity on the radial and azimuthal directions are designated by V_R and V_T, respectively. We can see that the residual velocities in some complexes have a preferred direction. In the Perseus complex the majority of OB-associations have the radial component V_R of the residual velocity directed toward the Galactic center, while in the Sagittarius region and in the Local System most of objects move away from the Galactic center. This kinematical feature can be reproduced in a model with a two-component outer ring R_1R_2.

Models with analytical Ferrers bars form the outer rings R_1 and R_2 after ~ 1 Gyr from the start of simulations. Figure 1d shows the distribution of model particles and the positions of stellar-gas complexes in the Galactic plane. The outer rings form due to the resonance between the epicyclic motion and the orbital motion with respect to the bar. The outer rings lie near the Outer Lindblad Resonance (OLR) of the bar. Of the two outer rings, R_1 is located a bit closer to the Galactic center than the ring R_2. We can see that the Perseus complex is related to the ring R_2 while other complexes belong to the ring R_1. Models with the outer rings R_1R_2 can reproduce the residual velocities of OB-associations in the Perseus, Sagittarius and LS stellar-gas complexes (Melnik & Rautiainen 2009, 2011; Rautiainen & Melnik 2010, Melnik 2019).

Acknowledgements

This work has made use of data from the European Space Agency (ESA) mission *Gaia* (https://www.cosmos.esa.int/gaia), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

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Discussion

ALFARO: Did you determine the vertex deviations for these stars? In my opinion this vertex deviation is a more accurate test for comparing with the models.

MELNIK: The vertex deviation approach is relevant for a sample of objects located in a small solar vicinity while residual velocities can tell us a lot about kinematics in a wide solar neighborhood (3 kpc).