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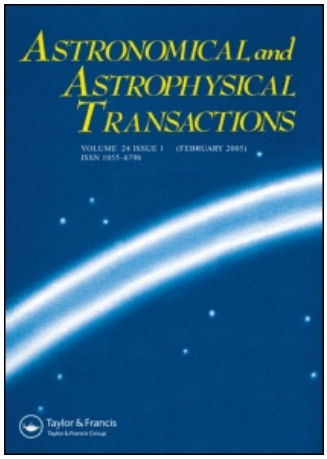

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PERIODIC PATTERN IN THE RESIDUAL VELOCITY FIELD OF OB-ASSOCIATIONS

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An analysis of the space velocity field of the OB-associations within 3 kpc of the Sun revealed a periodic pattern in the residual radial velocity field along the galactic radius-vector with a typical scale length of $\lambda = 2.0 \pm 0.2$ and a mean amplitude of $f_R = 7 \pm 1$ km s^{-1}. The fact that the radial residual velocities of almost all OB-associations in rich star-gas complexes are directed toward the Galactic center proves that the region considered is inside the corotation circle. The azimuthal velocity field of OB-associations exhibits a well-defined periodicity in the region $l < 180°$ and no periodicity in the region $l > 180°$. The galactocentric distances of the Cygnus and Perseus arms as inferred from separate analyses of radial and azimuthal residual velocity fields agree with each other within the errors.

KEY WORDS Kinematics, OB-associations, spiral structure

1 INTRODUCTION

The gist of our approach is to determine the wavelength λ of periodic velocity variations along the Galactic radius-vector. Parameter λ is, to a first approximation, equal to the interarm distance. We abandoned the idea of directly determining the spiral-arm pitch angle because it would require knowledge of the stellar kinematics over a wide neighborhood comparable in size with the Galactocentric distance of the Sun. Note that it is the interarm distance and not the spiral-arm pitch angle that we infer directly from an analysis of stellar kinematics. When applied to the Cepheid space velocity field, this method yielded a wavelength of $\lambda = 1.9 \pm 0.2$ kpc (Mel'nik *et al.*, 1999). To estimate the pitch angle, we must also know the number of arms. For the two-armed spiral pattern a λ of about 2 kpc corresponds to a mean spiral pitch angle of $i = 5°$.

We used the following catalogs and calibrations to analyze the space velocity field of OB-associations: the catalog of stars in OB-associations by Blaha and Humphreys (1989); the solar Galactocentric distance $R_0 = 7.1 \pm 0.5$ kpc, as inferred from Cepheid kinematics in terms of the short distance scale (Dambis *et*

Table. Parameters of the periodic pattern and those of the circular rotation law.

u_0^* *km* s^{-1}	v_0 *km* s^{-1}	Ω_0' *km* s^{-1} *kpc*$^{-2}$	Ω_0'' *km* s^{-1} *kpc*$^{-3}$	Ω_0 *km* s^{-1} *kpc*$^{-1}$	λ kpc	f_R *km* s^{-1}	f_θ *km* s^{-1}	φ_R *deg.*	φ_θ *deg.*	σ_0 *km* s^{-1}
−7.5	11.2	−5.0	1.5	30.2	2.0	6.6	1.8	38	−33	6.6
±0.9	±1.3	±0.2	±0.2	±0.8	±0.2	±1.4	±1.4	±12	±48	

al., 1995; Glushkova *et al.*, 1998); the short distance scale for OB associations, $r = 0.8 r_{\rm BH}$, which agrees with the short distance scale for Cepheids (Sitnik and Mel'nik, 1996); 70 line-of-sight and 62 tangential velocities of OB-associations derived from individual-star data adopted from the line-of-sight velocity (Barbier-Brossat and Figon, 2000) and HIPPARCOS (1997) catalogs, respectively.

2 APPROACH TO THE SOLUTION AND GENERAL RESULTS

We fit radial V_R and azimuthal V_θ components of residual velocities to the following periodic functions of galactocentric distance R:

$$V_R = f_R \sin\left(\frac{2\pi R_0}{\lambda} \ln\left(\frac{R}{R_0}\right) + \varphi_R\right), \quad (1)$$

$$V_\theta = f_\theta \sin\left(\frac{2\pi R_0}{\lambda} \ln\left(\frac{R}{R_0}\right) + \varphi_\theta\right), \quad (2)$$

where f_R and f_θ are the amplitudes and angles φ_R and φ_θ determine the phases of oscillations at a solar galactocentric distance.

In the approach used by Mishurov *et al.* (1997) to investigate noncircular motions of young stars the phases of radial and azimuthal oscillations are assumed to be shifted by $\pi/2$ relative to each other. Dropping this requirement allowed considerable azimuthal oscillations to be found in the $l < 180°$ region.

To make sure that the results are independent of the adopted circular rotation model, we found parameters of the periodic pattern jointly with those of circular rotation law (Ω_0, Ω_0', Ω_0'') and the components of solar velocity (u_0^*, v_0) relative to the OB-association centroid (see the table). The wavelength is equal to $\lambda = 2.0 \pm 0.2$ kpc, and the amplitudes of radial and azimuthal velocity perturbations are $f_R = 6.6 \pm 1.4$ km s^{-1} and $f_\theta = 1.8 \pm 1.4$ km s^{-1}, respectively. Numerical simulations showed the periodic pattern found in the radial velocity field to be statistically significant at a confidence level of $P = 99\%$ (i.e. not due to random fluctuations of stellar velocities and distances), but the periodic pattern in the azimuthal velocity field may also ($1 - P = 25\%$) be a result of random fluctuations.

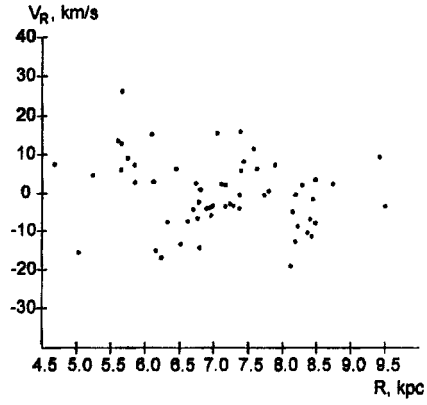

Figure 1 Residual radial velocities V_R of OB-associations plotted as a function of Galactocentric distance R.

Figure 1 shows residual radial velocities V_R of OB-associations plotted as a function of Galactocentric distance R. We determined the residual velocities as the differences between heliocentric velocities and circular rotation velocities computed with parameters u_0^*, v_0, Ω_0, Ω_0', Ω_0'' adopted from the table. It is evident from Figure 1 that there are two minima. One of them is related to the OB-associations of the Perseus-Cassiopeia region ($R = 8.4$ kpc), and the other to the associations of the Carina–Centaurus ($R = 6.5$ kpc) and Cygnus ($R = 6.9$ kpc) regions. Figure 2 shows the residual velocity field of the OB-associations with known space velocities projected on the galactic plane. Also shown are circular arcs corresponding to the maximum mean radial residual velocity V_R in the direction of the Galactic center.

The gravitational potential perturbation propagating in a rotating disk with a supersonic speed produces a shock front which affects the kinematics of gas and young stars born in this gas (Roberts, 1969). Inside the corotation, the shock front must coincide with the maximum radial velocity of streaming motions V_R directed toward the galactic center and maximum azimuthal velocity V_θ in the direction opposite that of galactic rotation. Let us assume that the Sun is inside the corotation. It then follows, in view of the small value of the pitch angle, that the arcs shown in Figure 2 should coincide with the inner arm edges and must be located near the minima of gravitational potential. Note that star-gas complexes (Efremov and Sitnik, 1988) in the Carina–Centaurus (l = 286–315°), Perseus–Cassiopeia (l = 104–135°), and Cygnus (l = 73–78°) regions through which the arms pass, are the richest in the number of OB-stars (the contours of these regions are shown in Figure 1).

If the region considered were outside the corotation the arms would be shifted by $\lambda/2$ relative to the lines drawn in Figure 2, implying that the richest star-gas complexes are located in the interarm space, which is inconsistent with the modern theory of star formation (Elmegreen and Elmegreen, 1983).

An analysis of the velocity field of OB-associations in the two regions $l < 180°$ and $l > 180°$ revealed some specific features of the periodic pattern. The objects

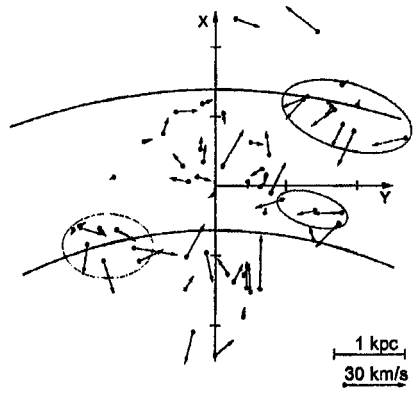

Figure 2 The space residual velocity field of the OB-association projected on the galactic plane. The X-axis is directed outward from the Galactic center, and the Y-axis is in the direction of galactic rotation. The Sun is at the origin. Circular arcs correspond to the maximum mean radial residual velocity in the direction toward the Galactic center. The richest star-gas complexes are outlined.

in the region $l < 180°$ show two minima in the Galactocentric radial dependence of both radial and azimuthal residual velocities. The positions of these minima determine the kinematical positions of the Cygnus and Perseus arms, where the mean amplitudes of radial and azimuthal velocity perturbations are equal to about $f_R \approx f_\theta \approx 6$ km s^{-1}. The positions of the Cygnus and Perseus arms as inferred from separate analyses of radial and azimuthal residual velocity fields agree with each other within the errors. This agreement is difficult to explain without invoking the shock effects that arise during supersonic density-wave propagation through a gaseous medium. The azimuthal velocity field of OB-associations shows no periodicity in the $l > 180°$ region. Note that the azimuthal residual velocity field of Cepheids also shows a well defined periodic pattern in the region $l > 180°$ and no periodicity in the region $l < 180°$.

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