POSSIBLE PATTERN SPEEDS OF A DENSITY WAVE IN OUR GALAXY

Preben J. Grosbøl

Copenhagen University Observatory
Copenhagen, Denmark

I. INTRODUCTION

Since the density wave theory was introduced by Lin and Shu (1964) to explain the spiral structure considerable effort has been made to detect this kind of wave in our galaxy and to determine its parameters. Observations of the distribution and velocity field of gas and young objects show the present shape and location of the spiral pattern in our galaxy but tell little about its angular velocity. It was proposed by Strömgren (1967) to estimate this important parameter by calculating the places of formation of moderately young stars for which accurate space velocities and ages are known. This was done assuming that the majority of stars is formed in spiral arms so that the stellar birthplaces would outline the position of the spiral pattern at different epochs. Later, Yuan (1969) and Wielen (1973) calculated stellar birthplaces in the spiral potential given by Lin et al. (1969). These investigations showed no disagreement with the assumed density wave, however, the number of stars was too small to verify the assumed pattern speed.

II. MODELS AND RESULTS

In the present work 216 B0 - A0 stars with ages less than 300 mill. years and within 200 pc from the sun are used to determine the possible values of the pattern speed. Their space velocities and ages are given by Grosbøl (1977) where the ages were derived from the isochrones of Hejlesen (1975) with the chemical composition $(X,Z) = (0.7,0.03)$.

The orbits were calculated in the axisymmetric field given by Contopoulos and Strömgren (1965) with a two-armed spiral potential superimposed:

$$-a \tan i \; \varpi_0^2 \Omega_0^2 / 2 \; \cos\left[2(\Omega_p t - \theta) + \frac{2}{\tan i} \ln\left(\frac{\varpi}{\varpi_0}\right) + 2\theta_1\right] \qquad (1)$$

where ϖ is the distance from the galactic center and θ is the position angle in an inertial frame so that the sun has $\theta = 0$ at the time $t = 0$. The values of the solar distance ϖ_0 and angular velocity Ω_0 were defined by the axisymmetric model. The four parameter of the spiral field were: the ratio a of the maximum radial spiral force over the axisymmetric force at ϖ_0, the pitch angle i of the spiral pattern, the pattern speed Ω_p and the position angle θ_1 of the Sagittarius arm at ϖ_0 for $t = 0$.

A net of models with parameters in the intervals: $-14° \leq i \leq -5°$, 11 km s^{-1} $kpc^{-1} \leq \Omega_p \leq 36$ km s^{-1} kpc^{-1} and $-165° \leq \theta_1 \leq -15°$ was computed for $a = 0.04$. This field strength is just large enough to affect the orbits but too weak to force the stars into the spiral arms. In each model the assumed basic solar motion was corrected for perturbations from the spiral potential. In these calculations only stars older than 60 mill. years were used because the younger stars are unaffected of the spiral perturbation. Further, they are likely to be formed in local condensations (e.g. the Orion spur or the Gould belt) no being part of the main spiral structure. To limit the computation time only orbits of the 93 stars having the most accurate ages were calculated for the whole net of models.

Each star was assigned a weight w_i being inverse proportional to the total uncertainty on the position angle $\Delta\varphi$ of its birthplace

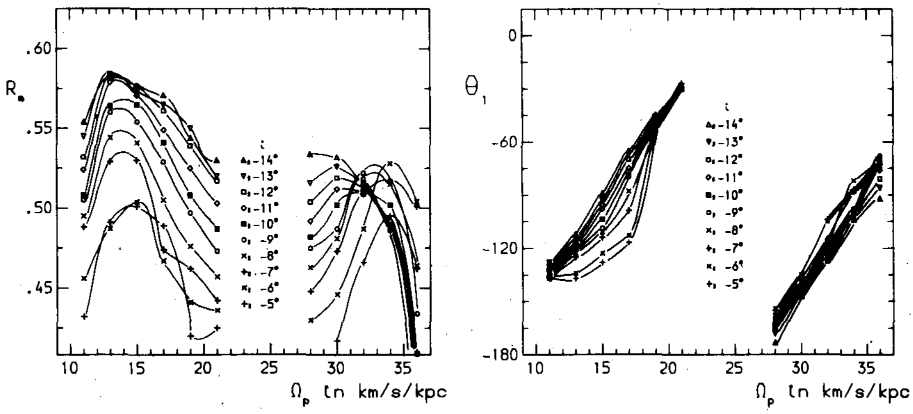

Figure 1

Fig. 1. The values of R_* and θ_1 for which R_* has maximum as a function of θ_1 for fixed i and Ω_p.

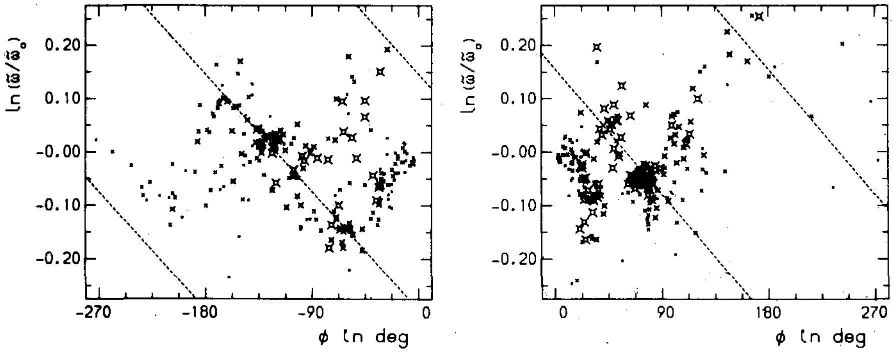

Figure 2

Fig. 2. Birthplaces of stars in a frame rotating with the imposed spiral field (a, i, Ω_p, θ_1) = (0.05,-8°,14 km s^{-1} kpc^{-1} ,-120°)(left) and (0.05,-9°,32 km s^{-1} kpc^{-1} ,-120°)(right). The dashed lines represent the spiral potential minima. The size of the points inticates the weight of the stars.

relative to the nearest spiral potential minima in a coordinate system fixed to the spiral pattern. Thus, the weight of a star depends on the spiral parameters e.g. models with a larger value of $|\Omega_p - \Omega_0|$ will have smaller weights. For every model the ratio R_a:

$$R_a = \frac{\sum w_i \exp\left(-\frac{1}{2}\left(\frac{\Delta\phi_i}{0.3}\right)^2\right)}{\sum w_i} \tag{2}$$

was calculated to indicate the agreement between the birthplaces and the spiral arms. Since most of the stars seem to come from a single arm R_a was only derived for the most populated arm.

The ratio R_a of the different models should be compared with that obtained from a random sample. A number of such samples were computed giving R_a- values in the range 0.40 to 0.49 depending on the spiral parameters. It should be noted that R_a for models with open spirals generally is larger partly due to the definition of the weights and the field strength. Calculations of the birthplaces in the pure axisymmetric potential gave a R_a not significant different from that of a random model.

To find the best models the maximum of R_a as a function of θ_1 was determined for all the (i, Ω_p) net points. The values of R_a and θ_1 in the maxima are given in figure 1. The peaks around Ω_p = 14 and 32 km s^{-1} kpc^{-1} are both significantly larger than the values expected for random samples. It can be seen that both have $\theta_1 \simeq -120°$ which correspond to a range of $-6°$ to $-8°$ in pitch angle if the Sagittarius arm is located approximately 8 kpc from the galactic center in the direction of the sun.

The best models near these two values of Ω_p were found by calculating smaller and finer nets in which also the field strength was varied from 0.04 to 0.07. The largest values of R_a were obtained for the spiral parameters $(a, i, \Omega_p, \theta_1) = (0.05, -8°, 14 \text{ km s}^{-1} \text{ kpc}^{-1}, -120°)$ and $(0.05, -9°, 32 \text{ km s}^{-1} \text{ kpc}^{-1}, -120°)$. The birthplaces of the two models are given in figure 2.

The method used to determine the possible parameters of density wave in our galaxy is expected to give a good estimate of Ω_p and θ_1 for which the errors are of the order of 2 km s^{-1} kpc^{-1} and 20°, respectively. The field strength a and the pitch angle i may, however, be more strongly affected by systematic errors e.g. in the basic solar motion.

III. CONCLUSION

Within the range of spiral parameters covered in this investigation only models with a pattern speed $\Omega_p \simeq 14$ km s^{-1} kpc^{-1} or $\simeq 32$ km s^{-1} kpc^{-1} show a significant enhancement of birthplaces in the spiral arms. The best models indicate that of the order of 20% of the stars were formed outside the arms. It has been assumed that the stars mostly form near the spiral potential minima this may, however, not always be the case for very open spirals.

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