ON THE LOCAL STANDARD OF REST

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I. Introduction

Under the influence of a spiral gravitational field, there should be differences among the mean motions of different types of objects with different dispersion velocities in a spiral galaxy. The old stars with high dispersion velocity should have essentially no mean motion normal to the galactic rotation. On the other hand, young objects and interstellar gas may be moving relative to the old stars at a velocity of a few kilometer per second in both the radial (galacto-centric), and circular directions, depending on the spiral model adopted. Such a velocity is usually referred as the systematic motion or the streaming motion. In this paper, we shall show that the conventionally adopted local standard of rest is indeed co-moving with the young objects of the solar vicinity (also see Lin and Yuan 1974). Therefore, it has a net systematic motion with respect to the circular motion of an equilibrium galactic model, defined by the old stars.

Using the spiral pattern consistently adopted by Lin, Yuan and Shu (1969), the radial component of this motion is found to be about 7 km/sec toward the anticenter direction and the tangential component is about 5 km/sec in the direction of rotation. The outward motion of the adopted local standard of rest can be shown in excellent agreement with the observations. In particular, it resolves the long-standing problem of the differences between the northern and southern rotation curves as indicated in HI observations (Kerr 1964). The tangential component, however, is not well supported by the observations. It may suggest that the local arm, the Orion spur, is associated with a mass density which is comparable with a typical spiral arm, and therefore disturbs the systematic motion near the sun.

The observations are summarized in section 2. The results on the systematic motion based on the density-wave theory are presented in section 3. We compare and discuss the results and observations in the concluding section.

II. Observations.

The local standard of rest is determined by measuring the solar motion with respect to the local stars and interstellar gas. Since no differentiation was expected between the old stars and the young objects in their mean motions at the time the determinations were made. The adopted local standard of rest relies heavily on the data of young stars, because of their superior observational quality. In fact, B0 stars are given a weight of 6 compared to 0.3 for dM5 stars (Delhaye 1965). Thus the adopted local standard of rest practically coincides with the mean motion of the B0 stars in solar vicinity (See Table 1).

Table 1 summarizes the solar motions determined wih respect to different types of objects in the solar vicinity. The notation (U,V,W) denotes the three velocity components in the anti-center, rotational and vertical directions respectively. The table is by no means complete. However, it gives a fair representation of the existing observations.

Table 1: Solar Motion

	U km/sec	V km/sec	W km/sec	Ref km/sec
Standard	-10.4	14.8	7.3	1
Peculiar	- 9.0	12.0	7.0	1
B0	- 9.6	14.5	6.7	1
O-B5	- 9.8	17.0	7.5	2
dK0	-10.8	14.9	7.4	1
dK5	- 9.5	22.4	5.8	1
dM0	- 6.1	14.6	6.9	1
dM5	- 9.8	19.3	8.6	1
H_2CO	-10.1	18.2	10.2	2
CO:Dark Cloud	-11.1	19.9	11 6	2
High latitude HI	-11.9	15.7	7.7	3
Molecular Clouds	- 6.0	-	-	4

1 Delhaye (1965)
2. Frogel and Stothers(1977)
3. Mast and Goldstein (1970)
4. Blitz (1982)

It is clear from table 1 that the U component of the solar motion changes very little among different types of objects, from very young to moderately old, or to be more precise, from those with low velocity dispersion to those with high velocity dispersion. The V component does display some significant change. But, the situation is complicated by the effect of the asymmetric drift. Extrapolating the data of the stars of higher velocity dispersion, Delhaye (1965) arrived at a conclusion that the true value V after the correction of the asymmetric drift lies between 10 km/sec to 13 km/sec. He adopted the value 12 km/sec, which is reflected in the peculiar solar motion listed in Table 1. If this value is indeed correct, the young objects such as the B0 stars, HI gas, etc are moving at a velocity lower than the mean motion of the old stars in the rotational direction (2.5 km/sec for B0, 3.7 for HI gas, etc.).

Another important piece of observations to be included in ourdiscussion is the well known result of the difference between the northern and southern rotation curves determined from the HI data (Kerr 1964). This result should be given higher weight than those of the solar motion, in the sense that it deals with the local motion relative to the Galaxy as a whole, while the solar motion observations are confined only to the immediate neighborhood of the Sun. If the adopted local standard of rest has an outward motion u_ϖ, the difference between the northern and southern observatins can be expressed as

$$|v_{ls}|_{north} - |v_{ls}|_{south} = 2u_\varpi \cos l$$

where v_{ls} is the line-of-sight velocity of HI with respect to the adopted local standard of rest at the tangent points and l stands for +l for the northern data or -l for the southern data. Comparing the HI observational data with this formula, Kerr (1964) suggested a general expansion of 7 km/sec near the sun. It might be noted that the tangential component of the net motion of the adopted local standard of rest has no contribution at all here.

III. Systematic Motion in the Solar Vicinity.

In response to the spiral gravitational field, the stars and the gas would deviate from the pure circular motion of an equilibrium model. The amount of deviation will depend on the spiral pattern, the strength of the spiral gravitational field, the velocity dispersion and finally the location relative to the spiral arms. Using the spiral model that we have consistently adopted since 1969, we calculate the systematic motions of the stars and the gas along the

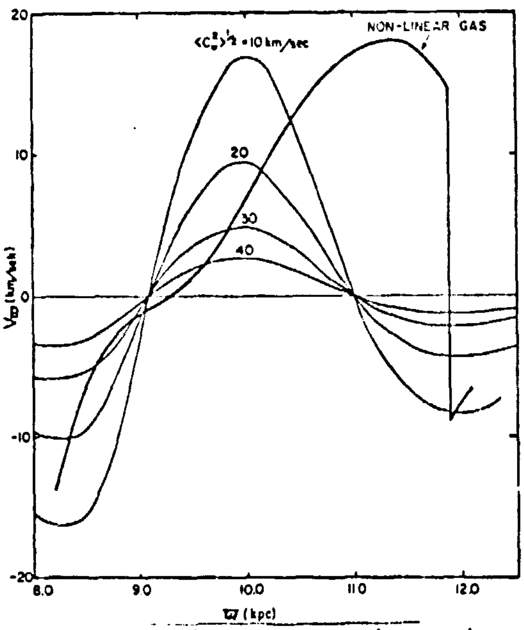

Figure 1 Radial Systematic Motions of the Stars and Gas

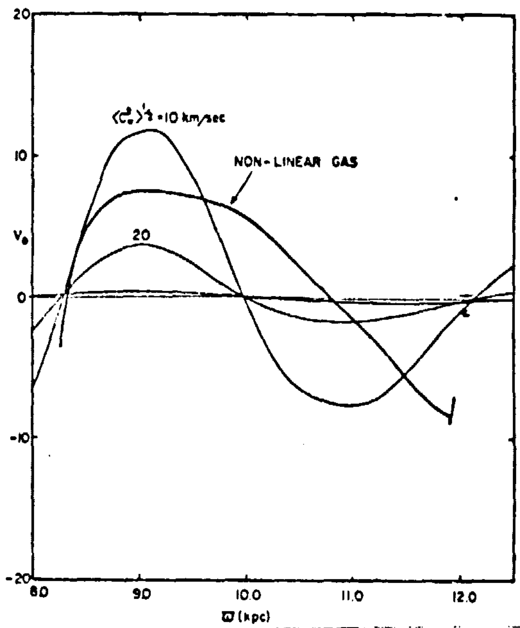

Figure 2. Tangential Systematic Motions of the stars and the gas

line connecting the galactic center and the sun from 8 kpc to 12 kpc. The results of the calculations are plotted in Figures 1 and 2. The response in stars is calculated by the linear density-wave while the response in the gas, by the non-linear theory. One of the underlying assumptions of these calculations is that the stars and the gas are in a quasi-stationary state. This is certainly true for the moderately old stars, or stars with higher dispersion velocities as well as the gas. But, it is not true for the very young stars whose have just been formed out of gas clouds, and their initial conditions at birth probably still play a dominant role in their present motions. Figures 1 and 2, therefore are applicable to the gas in general and to the stars of dispersion velocity at least higher than 20 km/sec.

For stars with low dispersion velocities, their mean motion should be determined by the method of star migration calculations (Yuan and Grosbol 1982). Unfortunately, due to our choice of the spiral model, the very young stars, say O-B5, whose ages are within 60 x 10^6 years (Stothers 1980) would not have enough time to migrate to the solar vicinity after their birth in the Sagittarius Arm and the Perseus Arm. The sun is situated between these two major arms in our model (See Figure 3). Those young stars near the sun are likely formed by mechanisms other the shock-driven star formation proposed by Roberts (1969) or simply delayed in formation after the galactic shock by some reasons. Being so young, they probably still move with the same velocity of the nearby gas clouds out of which they were formed. Therefore, the present purpose, we shall use the results of the non-linear gas motion for the young stars as a rule. In order to get some feeling about the star migration calculations, the mean velocity for B5 stars, with age ranges 55-70 x 10^6 (Stothers 1980) is v_ϖ = 10 km/sec and v_θ = 0 km/sec, although the number density for those stars formed in the Sagittarius Arm and the Perseus Arm and having migrated to the solar vicinity is too small to be considered seriously. The theoretical results are summarized in Table 2 in which (u_ϖ, u_θ) is the systematic motion for the gas and (v_ϖ, v_θ), for the stars.

Table 2 Systematic Motions at the position of the Sun (in km/sec).

Non-linear gas	u_ϖ = 6.5	u_θ = 5.0
Stars with $\langle c_\varpi^2 \rangle^{1/2}$ =20 km/sec	v_ϖ = 9.5	v_θ = 0
Stars with " 30 "	v_ϖ = 5.0	v_θ = 0
Stars with " 40 "	v_ϖ = 3.0	v_θ = 0
Star Migration for B5 stars	v_ϖ =10.0	v_θ = 0

IV. Discussion

We first examine the radial motion of the stars and the gas in the solar vicinity. Let us recall that the adopted local standard of rest is practically comoving with the B0 stars, and there seems no significant difference among various types of object in their radial velocity components. Furthermore, as suggested by the difference of the northern and southern rotation curves, the adopted local standard of rest seems to have a net motion of 7 km/sec in the anti-center direction. The theoretical results for the radial systematic motion listed in Table 2 are in perfect agreement with these obvservations. The young objects, such as B0 stars as well as the HI gas are indeed expected to have a systematic motion towards the anti-center direction with a magnitude equal to about 7 km/sec. For the moderately old stars whose dispersion velocites are around 30 km/sec, the outgoing motion is only slightly reduced to 5 km/sec. Only when the velocity dispersion reaches 40 km/sc or more, does the motion of the star drop below 3 km/sec. The observational data for the disk stars with velocity dispersion greater than 40 km/sec are scarce. With u_{π} = 6.5 km/sec the northern and the southern rotation curves based on the 1965 Schmidt model are shown in Figure 4.

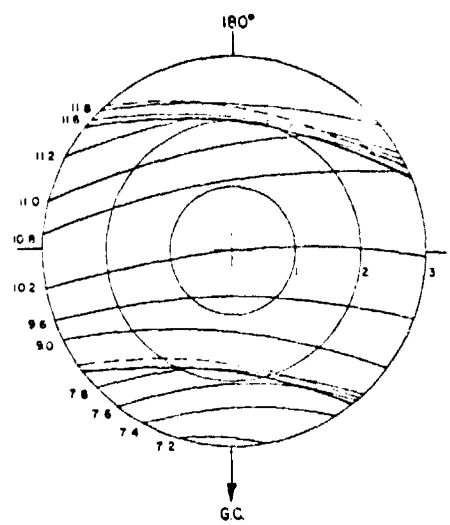

Figure 3. The adopted spiral pattern and the gas streamlines in the neighborhood the sun. The darklines are the potential minima and the thick lines are the location of the shocks.

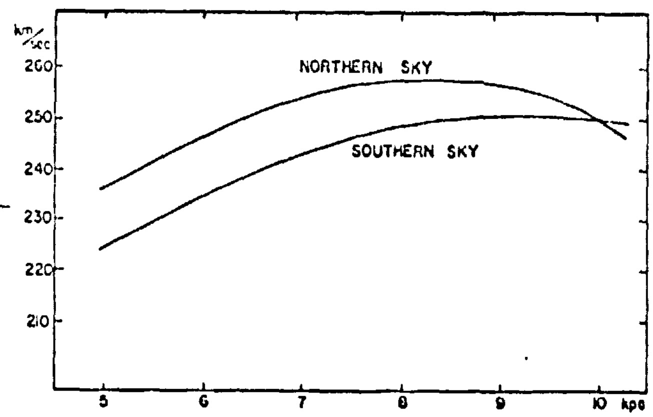

Figure 4. The northern and the southern rotation curves based on the 1965 Schmidt model and an outgoing motion of 6.5 km/sec for the local standard of rest.

The situation for the tangential component, however, is far from ideal. First, there is the asymmetric drift. After its effect carefully removed, the young objects would still move slightly faster than the old stars in the rotational direction. The trend is difficult to reverse even though we would like to press harder for more correction. The result therefore is at variance with the observation, in which the young stars and the gas lag behind the old stars by about 3 km/sec.

A possible explanation of this discrepancy may lie on the fact of the presence of the local arm. In our view, the local arm is not a major arm of the basic two-arm pattern, but an inter-arm spur (Lin, Yuan and Shu 1969). The spur is comoving with the local material and it may be associated with a certain mass concentration. Using the linear analysis of the gas response, we may be able to give a order-of-magnitude estimate of the mass density required for the systematic motiin of the gas to reverse its direction . The formula is given as follows:

$$\sigma_1/\sigma_0 : \hat{u}_{\varpi}/\varpi\Omega : \hat{u}_\theta/\varpi\Omega = (-k\varpi) : (1-\Omega_p/\Omega) : \kappa^2/2\Omega^2$$

where σ_1/σ_0 is the ratio of the perturbed surface density to the mean density of the gas, $(\hat{u}_\varpi, \hat{u}_\theta)$ are the amplitudes of the velocity components, k is the radial wave number, Ω is the local angular speed, Ω_p the pattern speed, κ is the epicyclic frequency, and is the galacto-centric distance. Since the interarm spur is a material arm, $\Omega_p = \Omega$. Thus, no radial velocity component is caused by its presence, which is an excellent feature of this approach. If we take the wavelength for the Orion spur to be 2.5 kpc, or k = 2.13 kpc^{-1} and $\hat{u}_\theta$=8 km/sec we obtain a ratio σ_1/σ_0 equal to 0.8. This is somewhat greater than the mass density of a spiral arm. A concentration like this in a spiral galaxy is not uncommon. We can also check this by placing a point mass 300 pc away in the anti-center direction of the sun. The mass required for u_θ = -8 km/sec is of the order of $10^7 M_O$.

In conclusion, we believe that the conventionally adopted local standard of rest is comoving with the young objects which has a net outward motion of about 7 km/sec and a net motion of 5 km/sec in the direction of the galactic rotation. This outward motion of the young object is due to the presence of the spiral density waves. The fact that the tangential motion is not observed implies that the local arm may have a mass density like those in the regular spiral arm.

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References

Blitz, L.: 1982, private communication
Delhaye, J. : 1965, in Galactic Structure, Stars and Stellar Systems Vol V, ed. Blaauw, A. and Schmidt, M., Univ. of Chicago Press, Chicago, pp. 61-84.
Frogel, J.A. and Stothers, R.: 1977, A.J., 82, 890.
Kerr, F.J.: 1964, I A.U. - U.R.S.I. Symp. 20, 81
Lin, C.C. and Yuan, C.: 1975, B.A.A.S., 7, 344
Lin, C.C., Yuan, C. and Roberts, W.W.: 1978, A. A., 69, 181.
Lin, C.C., Yuan, C. and Shu, F.H.: 1969, Ap.J., 155, 721.
Roberts, W.W.: 1969, Ap.J., 158, 123
Stothers, R.: 1980, private communication
Yuan, C. and Grosbol, P.: 1981, Ap.J., 243, 432.