Few-Body Problem: Theory and Computer Simulations
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Does the Local Galactic Standard of Rest Oscillate?

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Abstract. The classical assumption that the local Galactic standard of rest moves in a circular orbit in an axisymmetric Galaxy is examined. Contemporary values for the scale of the Galaxy $R_\odot$, its local circular speed $V_\odot$, and the total local density $\rho_\odot$, allow the construction of a Galaxy model with multiple local resonances. The periodic action of an internal bar or other non-axisymmtric, central distortion in this model can cause periodic oscillation of the local standard of rest, as well as other dynamical effects.

1. Introduction

The development of the theory of axisymmetric, collision-free stellar systems in equilibrium has a distinguished history extending over a century. The theoretical and observational work of Liouville, Boltzmann, Jeans, Vlasov, Fokker-Planck (if collisions are important), Lindblad, Oort and others underpin the theory. For the Galaxy, a basic assumption of the theory is that the local standard of rest (LSR) revolves in a *uniform circular orbit* at a speed $V_\odot$ in the plane of the Galaxy, at a distance $R_\odot$ from the centre. Local stellar motions are calculated with respect to the adopted LSR, and the attendant statistical analyses build the theory in relation to the LSR. As a result, each local star, such as the Sun, has a "peculiar" motion with respect to the LSR. For the Sun, this motion is about 16.5 km/sec towards $l = 53°$ Galactic longitude, $b = 25°$ Galactic latitude. To compute an individual star's Galactic orbit, one needs a Galactic mass model. For this purpose, values are assumed for $R_\odot$, $V_\odot$ and $\rho_\odot$ and the rotation curve of the Galaxy $V(R)$. The latter curve is usually taken to be fairly flat in the contemporary literature. For example, for a flat rotation curve, it follows at once that the Galactic mass must increase linearly with galactocentric distance R. Additional observations determine the vertical mass distribution, at least near the Sun. For this kind of potential, numerical orbit integration is necessary to obtain a star's Galactic orbit; for the Sun, the resulting trajectory resembles somewhat that of Mars, with a pseudo-eccentricity of about 0.1. A full discussion of the theory can be found in Binney & Tremaine (1987).

1.1. Problems with the Theory

Problems arise with the axisymmetric theory in several ways: (a) There exists the well-known north-south asymmetry in the 21-cm neutral hydrogen rotation curve data, for $R < R_\odot$. This asymmetry can be seen in, *eg* Mihalas & Binney

(1981), Fig. 8-14. Kerr (1963) first proposed a possible solution to the asymmetry: the LSR moves radially outward with a speed of about 10 km/sec. This proposal has not received general acceptance as it presumes significant, net radial outflow of material in the Galaxy, thus vitiating the assumption of overall Galactic steady-state equilibrium. Other possible explanations can be found in Mihalas & Binney *ibid*, none of which seem very convincing. (b) The real Galaxy is not axisymmetric. This arises from a number of reasons: (i) The Galaxy has clear spiral structure. This is not usually considered a major problem because spiral structure is, at most, a gravitational perturbation of a few percent. (ii) The Galaxy exhibits an antisymmetric warp in both gas and stars in its outer parts. (iii) There probably exists a bar in the central part of the Galaxy. Considerable contemporary research supports the existence of such a bar, *eg* the recent observational study of (Benjamin *et al*, 2005). (iv) A non-axisymmetric bulge or distortion may also exist in the central part of the Galaxy.

2. Periodic perturbations in a Galactic model with local resonances

One possible Galaxy model with a triple local resonance was used in the recent review of Kapteyn's star (Kotoneva *et al*, 2005). The identical, simple triple resonance in that model is also used here: [Galactic year at $R_\odot$:local epicycle period] = [3:2] and [local epicycle period:vertical period] = [2:1]. To show that there is still much flexibility in this kind of resonance modeling, in the present model we adopt $R_\odot = 7.6$ kpc, $V_\odot = 200$ km/sec and $\rho_\odot = 0.109 M_\odot/\text{pc}^3$. Note that the last value is now exactly as listed in Holmberg & Flynn (2000), and not as in Kotoneva *ibid.* These changes have required an adjustment only to the mass of the disk/halo of the model. The rotation curve still rises at 3.5 km/sec/kpc at $R_\odot$, with the Oort constants being $(A, B) = (11.4, -14.9)$ km/sec/kpc. In addition, the angular rate of the bar used in Kotoneva *et al, ibid* has been doubled, *ie* to the same rate as the adopted circular angular rate $\Omega_\odot$. One can next proceed to an approximate, purely empirical and non self-consistent, numerical simulation of particles in this system so as to gain insight into which way their orbits will *begin* to evolve.

3. Results

To see which way the LSR starts to move, test orbits were integrated, starting at $R_\odot$ with velocity $V_\odot$, *ie* a circular orbit in the plane of the Galaxy with the bar perturbation turned on. If this initial, additive perturbation is as little as 0.1 km/sec in the starting R-velocity, then one observes an immediate oscillation in that direction of period $\approx 1.56 \times 10^7$ yr. Of course, if the bar or asymmetric distortion is tilted, one would expect an analogous oscillation in the vertical z-motion. In fact, the coupling of the resulting $R - z$ motion is quite strong and probably cannot be modeled in such a simple way. Although *exact* resonances have been used here, near-resonances can be expected to have a similar effect, but have a longer timescale.

4. Conclusions

It has been argued to a primitive first approximation, that the action of a periodic, non-axisymmetric perturbation in the Galactic interior can induce immediate, periodic oscillation of all the stellar material near $R_\odot$in the presence of suitable (near) resonances. This is, in effect, a modification of Kerr's (1963) proposal of radial outflow at $R_\odot$into a periodic phenomenon, thus requiring no net outflow of material. If such (near) resonances do exist, together with a suitable periodic driver such as a bar, this result may require a revision (at the perturbation level) of classical Galactic dynamics, and *eg* theories of spiral structure, etc. For very eccentric orbits, such as for Kapteyn's star, these kinds of multiple resonances can cause chaotic behaviour if not near ergodicity. Further study is planned for less eccentric Galactic stellar orbits. Of course a fully self-consistent simulation to confirm these results will require a Galactic n-body procedure; our results indicate that the additional effort would be fully warranted.

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References

Benjamin, R.A. *et al* 2005. Astrophys. J. 630, L149B

Binney, J. & Tremaine, S., 1987. *Galactic Dynamics, Princeton Univ. Press.*

Holmberg, J., & Flynn, C., 2000. MNRAS 313, 209

Kerr, F.J., 1963. MNRAS 123, 327

Kotoneva, E., Innanen, K., Dawson, P.C., Wood, P.R., & De Robertis, M.M., 2005. A&A 438, 957

Mihalas, D. & Binney, J., 1981. *Galactic Astronomy, 2nd ed, Freeman*