ON THE 3-KPC ARM: WAVES EXCITED AT THE RESONANCE BY AN OVAL DISTORTION IN THE CENTRAL REGION

Chi Yuan
NASA Ames Research Center, Moffet Field, CA 94035 U.S.A.
On leave from the City University of the City College of New York

A relatively minor oval distortion in the central region of the Galaxy, turning at a representative angular pattern speed, can excite outgoing waves at the outer Lindblad resonance of that pattern speed. Associated with the density crest of these waves is fast-expanding gas flow. The physical basis of this phenomenon can be understood through a linear analysis. However, to explain the observed expanding velocity in the "3-kpc arm", the non-linear theory must be used. In our calculations an oval distortion turning at 118 km s^{-1} kpc^{-1} with a perturbation of 10% of the mean gravitational field at the outer Lindblad resonance (located at 3 kpc in the present case) can generate an outgoing velocity of 53 km s^{-1} at the first density crest of the wave (located at 3.6 kpc).

The mechanism which is responsible for the expanding motion can be understood as resonance excitation through a linear analysis. Within the short-wave approximation of the linear theory, the amplitude of the wave, say, for the radial velocity, is governed by a second-order inhomogeneous ordinary differential equation. This equation has a turning point at the outer Lindblad resonance such that its solution decays algebraically towards the center and has a wave-like behaviour outside the resonance. Together with the phase term, the solution is represented by two tightly-wound trailing spiral waves in the rotating frame of the oval distortion. The density and the radial velocity are in phase with each other, so the density crest is always associated with the maximum outmoving velocity. The amplitude of the wave for the density in the absence of viscous damping remains fairly constant as it propagates, although the forcing term decreases like a quadruple moment from the center. This suggests that the fast-turning oval distortion pumps its energy and angular momentum into the disk system mainly by means of exciting waves at the resonance regions, and that this excess of energy and angular momentum is carried away by the gas medium in the form of compression waves.

An assessment of the importance of viscous effects for these waves can be made by calculating a kinematic viscosity associated with a mean-free-path for cloud-cloud collisions, ℓ, and the random speed of HI

H. van Woerden et al. (eds.), The Milky Way Galaxy, 545–546.

https://doi.org/10.1017/S007418090024312X Published online by Cambridge University Press

clouds, a. A viscosity of 1 kpc km s^{-1} obtains for ℓ = 0.1 kpc and a = 10 km s^{-1}. The e-folding distance for this viscosity is about 1 kpc. Thus one expects that the energy dissipation and angular-momentum deposition will occur within a short distance beyond resonance and will therefore not interfere with the outer spiral waves.

The resonance-excitation mechanism described above is so effective that an oval field of merely 1% of the mean gravitational field at the resonance would produce a disturbance which well exceeds the limit of the linear theory. We must therefore use the non-linear theory in order to explain the "3-kpc arm" phenomenon. Since we are only interested in a narrow region in the neighbourhood of the resonance, a transformation may be introduced to reduce a two-dimensional steady problem to a one-dimensional unsteady but periodic problem. Some accuracy is lost in this transformation, but the general non-linear nature is preserved. The non-linear solution has the same wave character as the linear solution. With a 10% oval field, the first density crest reaches a peak of 4.6 (from an unperturbed density equal to 1) and the corresponding radial velocity is 53 km s^{-1}. The mesh size in the numerical calculation is taken such that the numerical viscosity involved is comparable to the kinematic viscosity estimated above. The results are depicted in the figures 1 and 2.

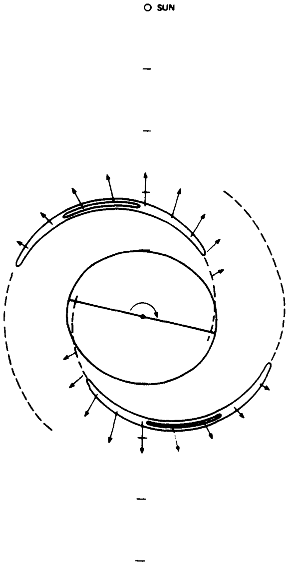

Figure 1. Density Contour of the 3-kpc arm. Arrows indicate radial expansion velocity.

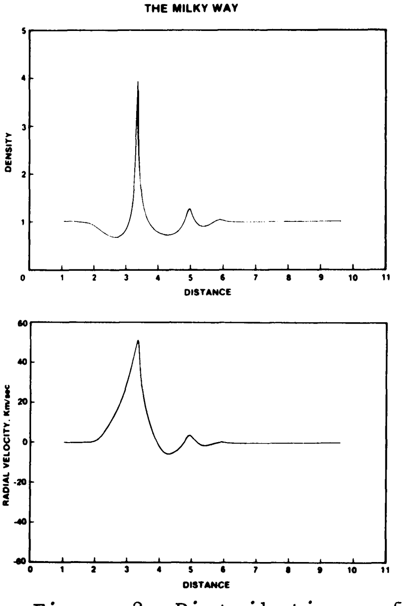

Figure 2. Distributions of density (above) and radial velocity (below) in the ray towards the Sun.