Pitch Angle of Galactic Spiral Arms

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In a differentially rotating disk, a leading density pattern rotates to a trailing one due to the shear. If Toomre's Q value is larger than unity but not too much, the amplitude of the pattern can be enhanced during the rotation. This mechanism is called swing amplification [1]. If a perturber such as the corotating overdense region exists, trailing patterns form. In N-body simulations, since a disk consists of a finite number of stars, small density noise always exists. Thus, even if there is not a perturber, the small leading wave always exists, and the trailing wave can grow spontaneously due to the swing amplification mechanism. The spirals generated by the swing amplification are not stationary but transient and recurrent, which appear and disappear continuously. This transient and recurrent picture is supported by N-body simulations for multi-arm spirals [2].

One of the key parameters that characterize spiral arms in disk galaxies is a pitch angle that measures the inclination of a spiral arm to the direction of galactic rotation. The pitch angle differs from galaxy to galaxy, which suggests that the rotation law of galactic disks determines it [3]. In order to investigate the relation between the pitch angle of spiral arms and the shear rate of galactic differential rotation, using local N-body simulations and linear analyses, we study the pitch angle of the spiral arms with various parameter sets [4].

We performed local N-body simulations of pure stellar disks based on the epicycle approximation. We do not consider an entire disk but a small rotating patch by employing a local shearing box. This treatment reduces the number of necessary particles in a simulation significantly, and enables us to perform high resolution simulations. The typical density snapshot and the autocorrelation function are shown in Figure 1. The x-axis is directed radially outward, the y-axis is parallel to the direction of rotation. Spiral or wake structures are formed due to gravitational instability and they are trailing.

We quantitatively evaluated the pitch angle using the autocorrelation function with various parameters. The result is summarized in Figure 2. We found the clear trend that the pitch angle θ decreases with the shear rate Γ.

Using the formulation of the collisionless Boltzmann equation, we performed linear analyses of the swing amplification and found that the pitch angle of the most amplified wave for $Q \gtrsim 1.5$ is given as

$$\tan\theta = \frac{2}{7}\frac{\sqrt{4-2\Gamma}}{\Gamma} \quad (1)$$

As shown in Figure 2, the pitch angle formula agrees well with the results of the numerical simulations. These results suggest that the spiral arms in this simulation are formed by the swing amplification from the leading wavelet in the density fluctuation.

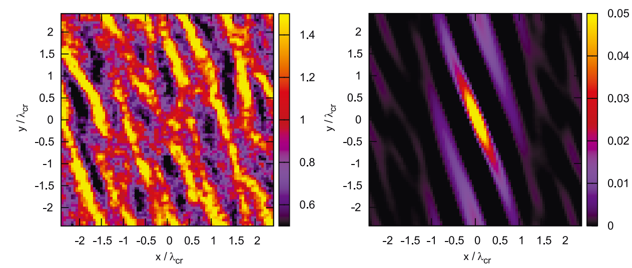

Figure 1: Surface density snapshot (left) and the autocorrelation function for the shear rate $\Gamma = 1.0$.

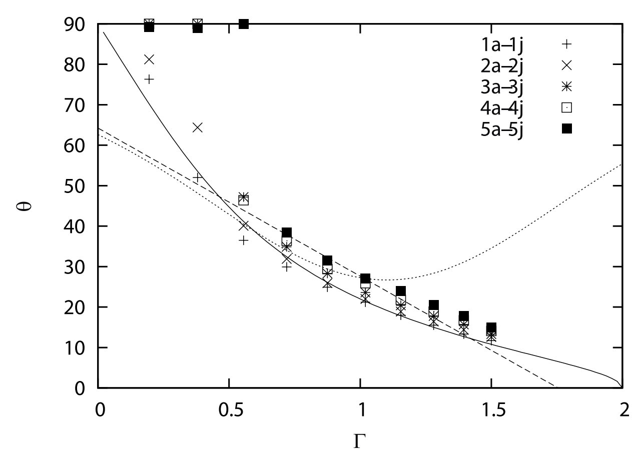

Figure 2: The pitch angle of the spiral arms in N-body simulations as a function of Γ. The solid curve denotes the pitch angle formula given by Equation (1).

References

[1] Julian, W. H., Toomre, A.: 1966, *ApJ*, **146**, 810.
[2] Fujii, M. S., et al.: 2011, *ApJ*, **730**, 109.
[3] Seigar, M. S., et al.: 2006, *ApJ*, **645**, 1012.
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