NEW N-BODY EXPERIMENTS ON THE SPIRAL STRUCTURE OF GALAXIES

K.O. Thielheim and H. Wolff
University of Kiel, F.R.G.

N-body experiments with stellar disks like those performed by Hohl (1971) and Sellwood (1981) show regular, global, two-armed spiral structures associated with bar formation. The question is whether the spiral is caused by the bar, and if this is true, how the generating mechanism works.

To answer this question we have performed three types of experiments (Thielheim and Wolff 1984), in which the motion of some 10 000 stars in a model disk galaxy under the influence of their mutual gravitational interaction is followed by means of a two-dimensional N-body code. This code differs from others mainly in that the gravitational field of the stars is calculated by expanding their distribution into a biorthogonal system of surface mass density and potential functions, the so-called Hankel-Laguerre functions (Clutton-Brock 1972). These functions are particularly suited to the problem and thus only few are needed to approximate the large-scale mass distribution.

In a first series of experiments we have studied the evolution of unstable disks. These experiments show that spiral structure develops during the formation of a central bar. This process is accompanied by a mass redistribution away from corotation and by radial transfer of angular momentum that leads to the "heating" of the disk.

In a second series of experiments we study the response to oval distortions. Evolved disks are symmetrized azimuthally to produce stable axisymmetric disks. These stable disks are perturbed by an imposed oval distortion. These response experiments show that spiral patterns very similar to those in unperturbed, self-gravitating disks can be generated by bar forcing.

To study the influence of self-gravity, a third series of experiments is performed. The response experiments are repeated with disks of non-interacting stars, i.e., without self-gravity. The response patterns are virtually identical. Hence, the self-gravity of the disk is not required for the response mechanism.

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The results of our experiments are summarized schematically in Figure 1. N-body models with halo masses not exceeding approximately half of the total galactic mass show global instabilities that lead to the formation of bars that extend to the corotation radius. The growth of the bar amplitude during the bar instability destroys the symmetry of the stellar equations of motion and produces a quasi-stationary spiral-shaped response outside of the corotation radius. This mechanism does not require the self-gravity of the stars that participate in the spiral wave. The gravitational field of the spiral, however, exerts a torque on the bar and thus transports angular momentum from the bar region in outward direction to the region of the outer Lindblad resonance, around which the spiral is located. The extraction of angular momentum from the stellar orbits in the bar region leads to an increasing eccentricity of these orbits and thus to a reinforcement of the bar, which therefore continues to grow. This step closes the positive-feedback cycle.

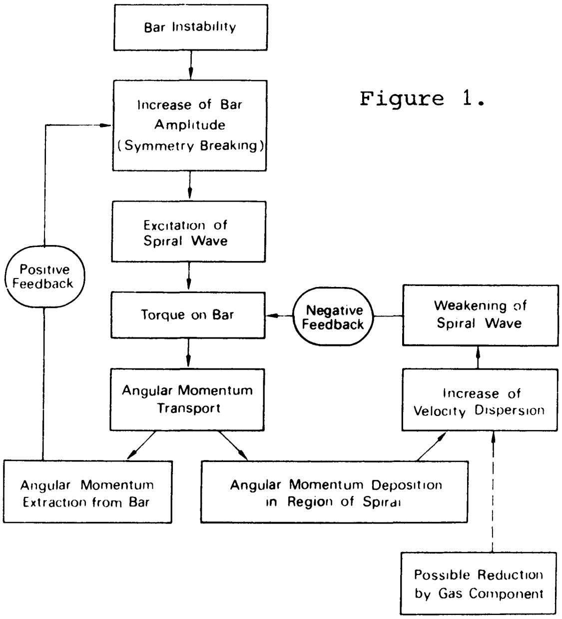

Figure 1.

On the other hand, the angular momentum drained from the bar is deposited around the outer Lindblad resonance and is also increasing the orbital deviations from circular motion which are partially transformed into random motion. Thus the velocity dispersion of the stars in this region is increased and the amplitude of the spiral wave is decreased. Consequently, the torque exerted on the bar is reduced. This step closes the negative-feedback cycle. Since the deposition of angular momentum near the outer Lindblad resonance is a cumulative effect, the negative-feedback cycle eventually dominates and the spiral structure vanishes, leaving the bar rotating without further change. This saturation can be avoided or at least slowed down by interaction with the interstellar gas through star formation which is "cooling" the disk.

REFERENCES

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