NUMERICAL EXPERIMENTS ON THE RESPONSE MECHANISM OF BARRED SPIRALS

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As a generating mechanism of spiral structure, we have recently studied the driving of density waves in the stellar component of disk galaxies by growing barlike perturbations or oval distortions. Numerical experiments (Thielheim and Wolff 1981, 1982) as well as analytical calculations using the first-order epicyclic approximation (Thielheim 1981; Thielheim and Wolff 1982) have been performed, demonstrating that this mechanism is capable of producing two-armed trailing spiral density waves in disks of noninteracting stars. These regular, global spiral structures are similar to those found in N-body experiments on self-consistent stellar disks that show bar instabilities which are weak enough to allow spiral patterns to persist (e.g., Hohl 1978; Berman and Mark 1979; Sellwood 1981). On account of this similarity, we take the view that the spiral structure observed in N-body experiments is primarily not an effect of the self-gravity of the stellar disk but a response phenomenon, caused by the formation of a weak central bar and its subsequent growth due to angular momentum extraction by interaction with the spiral as described by Lynden-Bell and Kalnajs (1972).

In the contributions mentioned above, we had to defer the proof of the secondary role of self-gravity since, to determine its influence on the spiral structure, it is necessary to compare the response of a disk of noninteracting stars to an oval distortion with the response of a self-consistent disk to the same time-dependent perturbation. We here report results of N-body experiments that have been performed to allow such a comparison. A method using biorthogonal pairs of potential and surface density functions described by Clutton-Brock (1972) is used to calculate the force field of the self-consistent stellar disk. Adopting this method, less than 10,000 stars are sufficient for the present two-dimensional disk galaxy simulations. To advance the particle coordinates and velocities, the usual time-centered leapfrog scheme proposed by Buneman (1967) is employed. The disk stars are given an initial velocity dispersion and are imbedded in a rigid bulge/halo potential. After constructing a stable axisymmetric configuration, an external oval distortion is slowly imposed and the resulting response is studied.

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Inside corotation the response of the self-consistent disk is found to be barlike and in phase with the perturbation. Open two-armed trailing spiral density waves that emerge from the ends of the bar are observable for many rotation periods, although they dissolve as the perturbation asymptotically approaches its final strength.

Comparison runs equivalent to our previous response calculations are performed by excluding the self-gravity of the stellar disk. The response patterns of the disks with and without self-gravity are virtually identical in shape, particularly regarding the location of the spiral arms with respect to the principal resonances and their total azimuthal extension, though the spiral arms appear to be slightly narrower in the self-consistent disk. Differences are encountered in the amplitude of the bar and spiral response. Moreover, the self-consistent spirals are found to dissolve earlier. Both effects find an explanation in the fact that the amplitude of the self-consistent bar response does not strictly follow the time development of the imposed perturbation but increases faster in the beginning and slightly decreases at a late stage.

We come to the conclusion that the regular, global spiral patterns observed in N-body calculations are produced by a response mechanism invoked by the formation and subsequent growth of weak central bars. For this mechanism the self-gravity of the disk stars that participate in the spiral wave is not essential. Analysing the numerical experiments of Miller, Prendergast, and Quirk (1970), Quirk (1971) came to contradicting conclusions, however, he tried to drive spirals by nonevolving bars. Symmetry considerations (Thielheim 1980; Thielheim and Wolff 1981) point out the impossibility of exciting spirals in disks of noninteracting stars by nonevolving oval perturbations and this effect may also account for Quirk's results. N-body calculations performed by Sellwood (1981), which show regular spiral patterns associated with intermittent bar growth, support this interpretation.

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