ON THE MAINTENANCE OF SPIRAL STRUCTURE

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A concentrated nuclear bulge with about 30% of the galaxy mass is sufficient (Lin, 1975; Berman and Mark, 1978) to eliminate strong bar-forming instabilities which dominate the dynamics of the stellar disk. Weak bar-like or oval distortions might remain depending on the model. In such systems self-excited discrete modes give rise to global spiral patterns which are maintained in the presence of differential rotation and dissipation (cf. especially the spiral patterns in Bertin et al., 1977, 1978). These spiral modes are standing waves that are physically analyzable (Mark, 1977) into a superposition of two travelling waves propagating in opposite directions back and forth between galactic central regions and corotation (a resonator). Only a few discrete pattern frequencies are allowed. An interpretation is that the central regions and corotation radius must be sufficiently far apart so that a Bohr-Sommerfeld type of phase-integral condition is satisfied for the wave system of each mode. The temporal growth of these modes is mostly due to an effect of Wave Amplification by Stimulated Emission (of Rotating Spirals, abbrev. WASERS, cf. Mark 1976) which occurs in the vicinity of corotation. In some galaxies one mode might be predominent while other galaxies could exhibit more complicated spiral structure because several modes are present. Weak bar-like or oval distortions hardly interfere with the structure of these modes. But they might nevertheless contribute partially towards strengthening the growth of one mode relative to another, as well as affecting the kinematics of the gaseous component.

Berman, R.H. and Mark, J.W-K.: 1978, manuscript in preparation.
Bertin, G., Lau, Y.Y., Lin, C.C., Mark, J.W-K. and Sugiyama, L.: 1977, Proc. Natl. Acad. Sci. USA, 74, 4726.
Bertin, G. and Mark, J.W-K.: 1978, Astron. Astrophys. 64, 389.
Lin, C.C.: 1975, in Structure and Evolution of Galaxies, ed. G. Setti, p. 119.
Mark, J.W-K.: 1976, Astrophys. J., 205, 363.
Mark, J.W-K.: 1977, Astrophys. J., 212, 645.

W. B. Burton (ed.), The Large-Scale Characteristics of the Galaxy, 151–153.

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DISCUSSION

Miller: Your computer simulations look a good deal like the pictures Hohl showed at Besancon (I.A.U. Symposium 69) as an example of a long-lived bar. Your axis ratios look nearly the same as his. Yet you claim this simulation did not show a bar. Could you explain this difference of interpretation?

Mark: When we have a strong bar in the stellar disk, as in the cases run with no spheroidal matter, then our bar really is a thin bar or an open spiral object, and not to be confused with the bar-shaped shock waves of some gas-dynamical calculations. But in the simulation with a 30% bulge, we actually have an open spiral which terminates before reaching the galactic center. If you wish, you may talk of the inner open spiral or part of a bar or oval distortion, but this "bar" does not continue through the center.

Sanders: How do you model the bulge component?

Mark: In order to limit the spheroidal component to a bulge, and not allow spillage into a halo, we have taken a bulge density which decays as R^{-5} rather than the slower decay of observed spheroidal components. Eighty percent of the "bulge" mass lies within 4 or 5 kpc of the galactic center. Note that we have removed disk matter from the central parts of the Kuzmin disk and replaced it by spheroidal matter.

Toomre: In view of the all-trailing nature of your feedback cycle, what assurance can you offer that your relatively slowly growing modes will not be swamped or otherwise overwhelmed by some more general and much more rapidly growing global instabilities possibly admitted by the same model galaxies?

Lin: First, the transient growth rates, obtained for shearing models by you and Julian and by Lynden-Bell and Goldreich, are indeed very impressive; but they are not necessarily indicative of the growth rates for modes. This remark is based on the 1907 result of Orr for infinite flow with uniform shear. It exhibits rapid transient growth of periodic disturbances, but all investigators agree that the flow has no unstable modes. Besides these transient effects, I am not aware of any extraordinarily large growth rates for the kind of mass distribution described. Of course there may be other additional excitation mechanisms, such as that due to a stationary halo, as discussed by Mark and by Marochnik. But our primary aim is to discuss a mechanism of maintenance with a calculated pattern speed. The growth rate is only approximately obtained in our calculations.

Contopoulos: May I address a question to Dr. Toomre? Dr. Lin and his associates have found solutions that give unstable modes: Did you find any different solution that is more strongly unstable.

Toomre: Yes, too often! Of course, in challenging Lin and Mark just now, I was thinking mostly of the severely unstable spiral modes found by Kalnajs, Erickson, and Bardeen starting almost a decade ago, plus the various N-body experiments of Miller, Hohl, and others. Yet I do caution also from some recent personal experience: During the past several years, Tom Zang and I have been studying numerically the global modes of a class of stellar disks with flat rotation curves--and, incidentally, also with artificial inside "holes" or immobile central regions very similar to those favored by Lau, Lin, and Mark. What worries both of us is that these disks again exhibit strongly growing two-armed modes whenever we carve out those holes sharply enough, and even if we also lock as much as half of the remaining disk density into a rigid halo. Worse still, just as in the earlier global-mode work or the N-body experiments, some of these instabilities persist if the local stability parameter, Q, is assigned values as large as 1.5 or 2.0. Mind you, I am not suggesting that such rapid instabilities could still be present in any of the real galaxies. More likely, they are just nuisances to be avoided, or at least to be reduced greatly in severity. But I do suggest that theorists proposing any gentler and more desirable spiral modes should nowadays be asked to guarantee that those nuisances have in fact been avoided.

Lin: Let me re-emphasize that we only claim that our solutions apply to galaxies with the type of mass distribution described.

Mark: In fact we obtained comparable spiral structures and growth rates for models of the type which was studied by Zang; in some cases, there may be differences of factors of two in the growth rate.

Lin and Mark: The models involving large growth rates and large values of Q are not of interest to us. Neither are these resultant modes expected to occur with mass distributions of the type we consider; nor are they expected to lead to quasi-stationary spiral structure. For example, the N-body experiments mentioned by Dr. Toomre all have hot stellar disks because their structure is dominated by a strong bar. After all, is it not the original point of Ostriker and Peebles that these N-body experiments do not give a realistic simulation of normal spiral galaxies? We now know that the difference between these earlier N-body experiments and our results is due to the presence of a sufficiently massive spheroidal component. For the latter galaxy models, we have now shown that there are relatively slower growing modes which may be expected to lead to quasi-stationary spiral structures; we do not find any evidence for strongly growing modes.