QUASI-STATIONARY SPIRAL STRUCTURE IN GALAXIES

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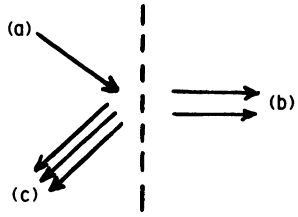
The hypothesis of *quasi-stationary spiral structure* in galaxies was explicitly formulated in the early 1960's in papers of Bertil Lindblad and of Lin and Shu. It asserts that the grand design observed in spiral galaxies may be described by the superposition (and interaction) of a *small* number of spiral *modes*. (See Lin and Bertin, 1981 for a fairly extensive review of the theory.) We wish to re-affirm the correctness of this hypothesis in the present contribution. Early numerical experiments by P.O. Lindblad and by Miller, Prendergast and Quirk demonstrated that spiral structures occur naturally in certain models of stellar systems, although it was difficult to control the morphological types of galaxies simulated. We are now able to simulate galaxies of various morphological types in a controllable manner. Numerical fluid-dynamical codes developed by Pannatoni (1979) and improved by Haass (1982) have been used to calculate normal modes of various spiral types (Haass, Bertin, and Lin 1982) in the morphological classification of Hubble, Sandage, and de Vaucoulers. Furthermore, the processes that govern the maintenance and the excitation of these modes simulating both normal spirals and barred spirals, can be understood by using analytical theories which are closely related to the local dispersion relationship, as Bertin will describe in his paper at this conference. Understanding these mechanisms enables us to choose the parameters and the distribution functions in our models more properly in order to exhibit the desired characteristics in the computed modes. Such an approach also has important implications on observational studies. Much of the previous work on comparison between theory and observations in normal spirals used only the short trailing waves. A mode must consist of at least two waves propagating in opposite directions. It has been found that, at least in normal spiral modes, the long wave branch provides essentially only a *modulation* of the amplitude along the short wave branch, which accurately describes the phase. Previous calculations are thereby justified. [These points were not adequately covered in the previous paper reviewing theory of spiral modes.]

I wish now to turn to the discussion of another point of great

E. Athanassoula (ed.), Internal Kinematics and Dynamics of Galaxies, 117–118.

significance to observers. The powerful "swing" amplification process suggests that the spiral structure might be rapidly varying, on the time scale of an epicyclic period and *not* quasi-stationary. Actually, this perception of swing amplification only holds for wave *packets*. In the context of steady wave *trains* or *modes*, it can be shown that an exactly equivalent amplification mechanism can be described in terms of a process of wave amplification via stimulation of emission of radiation (WASER, see figure). The same analytical and numerical calculations are involved; only the physical interpretation of the symbols are different. Indeed, the amplification factor at the corotation circle of a mode has been systematically calculated and published by Drury (1980) for two standard rotation curves. We have now further clarified the comparison of the two approaches by deriving a second order differential equation for the Fourier transform of the perturbation of the gravitational potential, with a time-*independent* wave number ξ as the independent variable. The parameter ξ then takes the place of the time-*dependent* wave number in the swing formalism. Otherwise, the equations to be solved are identical in form to Eq. (35a) [homogeneous part] and Eq. (35b) in the 1978 paper by Goldreich and Tremaine and to Eqs. (18) and (20) in the 1981 paper of Toomre. The numerical calculations required are also the same. The WASER is, however, more *appropriate* for the description of modes or steady wave trains. Indeed, Goldreich and Tremaine (1978) already demonstrated the equivalence of the swing process with the WASER processes in the special case studied earlier by Mark, who incorporated the amplification mechanism into the asymptotic theory of normal modes (WASER I). Now the equivalence is demonstrated for all spiral modes. Incorporation of the WASER process into the theory of bar modes (WASER II) will now be explained by Bertin.

Figure 1. *WASERS OF TYPES I AND II:* As the incident wave is refracted, there is also stimulated an emission of radiation. This strengthens the returned wave, thereby providing amplification in the feedback cycle.



Type I: (a) long trailing wave
(b) short trailing wave
(c) short trailing wave

Type II: (a) (short) leading wave
(b) (short) trailing wave
(c) (short) trailing wave

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