ON THE STRENGTH OF THE GALACTIC SHOCK WAVE AND THE DEGREE OF DEVELOPMENT OF SPIRAL STRUCTURE

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Abstract. The luminosity of a spiral arm is believed to originate primarily in the very young, newly forming stars; and the spiral arm itself to be a spiral wave which is capable of triggering the formation of the young stars selectively along the wave crest. A semi-empirical study of the density wave patterns predicted in the density wave models of twenty-five external galaxies has been made and one result of this study is presented here. It is found that those galaxies of the sample whose models predict the possibility of strong shock waves are also the galaxies which exhibit long, well-developed spiral arms; and those galaxies whose models predict weak shock waves are also the galaxies which exhibit less-developed spiral structure. This trend is seen through a correlation between $w_{\perp 0}$, the velocity component of basic rotation normal to a spiral arm, which is an important parameter in determining the shock strength on the one hand, and luminosity class, which is a measure of the degree of development of spiral structure on the other.

The spiral structure often observed in disk-shaped galaxies is commonly thought to be associated with wave phenomena. The luminosity of a spiral arm originates primarily in the very young, newly-forming stars, and the spiral arm is believed to be a spiral wave which is capable of triggering from the gas the formation of young stars selectively along the wave crest. The wave itself has been seen from two different viewpoints: first, as a density wave (Lindblad and Langebartel, 1953; Lindblad, 1963; Lin and Shu, 1964, 1966; Lin *et al.*, 1969; Lin, 1971; Roberts and Yuan, 1970) in which gravitational forces are dominant, with magnetic forces playing only a minor role; and second, as a hydromagnetic wave (Piddington 1967a, b; 1970; 1973a, b) in which magnetic fields are dominant.

Of these two, only the density wave model has been developed sufficiently to provide quantitative predictions regarding spiral structure. In this model, galactic shock waves form in the gaseous component of the galactic disk as a necessary consequence of the theory of waves for sufficiently large amplitudes (Shu *et al.*, 1973). As the nonlinear counterpart of the small-amplitude linear density wave, the galactic shock is visualized as a possible triggering mechanism for the gravitational collapse of gas clouds, leading to star formation along a spiral arm (Roberts 1969, 1972).

One might wonder how important such waves are in influencing the evolution

* Operated by Associated Universities, Inc., under contract with the National Science Foundation.

John R. Shakeshaft (ed.), The Formation and Dynamics of Galaxies. 439–441.

of a galaxy and in governing the generation and appearance of the spiral structure. Furthermore, one could question the entire basis of the wave interpretation and ask: are those galaxies in which strong shock waves are predicted also the galaxies which exhibit long, well-developed spiral arms?

In recent work (Roberts, Roberts and Shu, in preparation; also Shu *et al.*, 1971), a semi-empirical study has been made of the density wave patterns predicted for twenty-five galaxies. Included in this study are all galaxies with observed rotation curves, except the Magellanic Clouds, which satisfy the following two criteria:

(i) a luminosity classification has been assigned by van den Bergh (1960a, b),

(ii) the velocity data prescribing the rotation curve are complete over a significant fraction of the photometric radius of the galaxy.

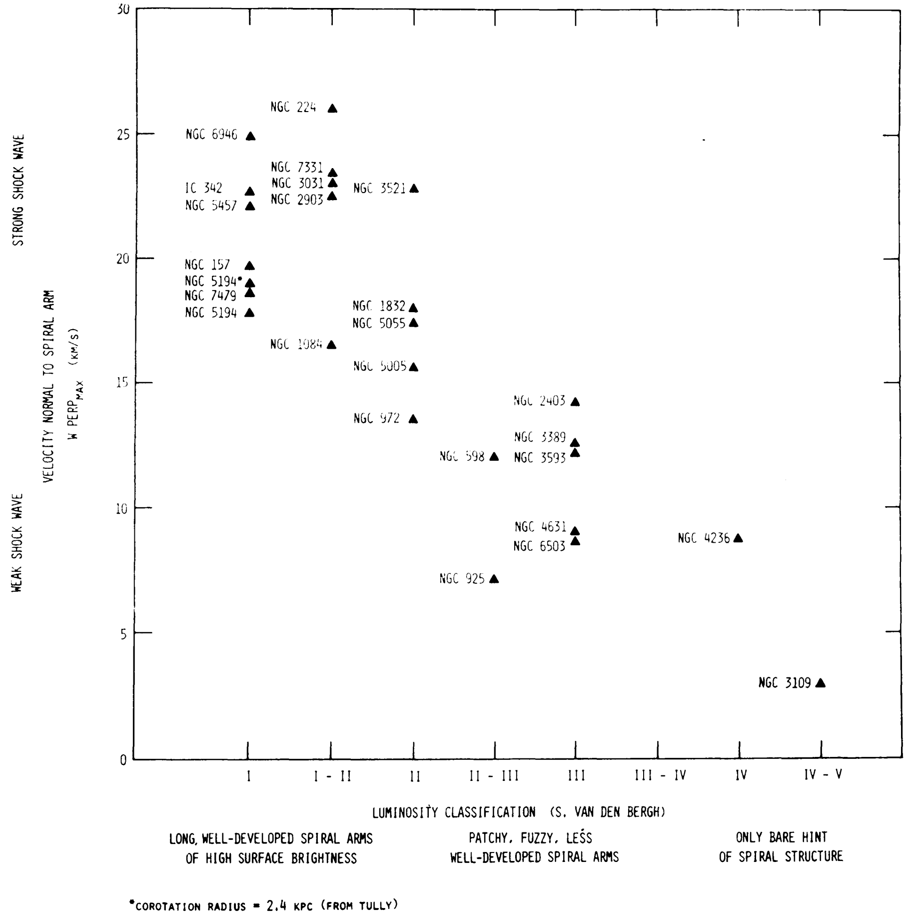

Fig. 1. A trend for a sample of twenty-five galaxies indicative of a correlation between $w_{\perp 0}$ – the velocity component of basic rotation normal to a spiral arm – and shock strength on the one hand, and luminosity classification and degree of development of spiral arms on the other. Those galaxies in which strong shock waves are predicted are found to exhibit long, well-developed spiral arms; and those galaxies in which weak shock waves are predicted are found to exhibit less-developed spiral structure.

By means of a standardized least squares fit to the rotation velocity data, an overall mass model for each galaxy is constructed, consisting of a mass model (Toomre, 1963) to cover the disk, together with one or two spheroidal mass models to cover the nuclear bulge, where necessary. On the assumption that the co-rotation radius is that of the easily visible disk and the outermost H II region, the density wave pattern for each galaxy is determined.

Figure 1 illustrates one result of this investigation. Plotted on the vertical axis is the maximum value reached by $w_{\perp 0}$, the velocity component of basic rotation normal to a spiral arm. The strength of the shock varies roughly as the square of $w_{\perp 0}$, and therefore the galactic shock is expected to be very strong in those galaxies with high values of $w_{\perp 0}$ and very weak in those with low values of $w_{\perp 0}$. Plotted on the horizontal axis is the luminosity classification by van den Bergh. Galaxies with long, well-developed arms of relatively high surface brightness are classified in category I; those with short, patchy, less-developed arms in categories II and III; and those with only a hint of spiral structure in categories IV and V.

Apparent in Figure 1 is a trend indicative of a possible correlation between $w_{\perp 0}$ and shock strength on the one hand, and degree of development of spiral structure on the other. Those galaxies whose models predict the possibility of strong shocks are found to be the galaxies which exhibit long, well-developed spiral arms; and those whose models predict weak shocks are found to be the galaxies which exhibit less-developed spiral structure.

The strengths of the compression regions along the spiral arms of eleven of these galaxies have been determined by van der Kruit (1973) from studies with the Westerbork Synthesis Radio Telescope, and his subsample shows a trend in general agreement with that for the larger sample of twenty-five galaxies in Figure 1 here.

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