Density wave triggered star formation in grand design spirals

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In normal spiral galaxies the arms are the main sites for star formation. This is the cause of their optical contrast compared with the rest of the disc. The spiral structure can be observed as a higher concentration of HII regions, neutral gas (both atomic and molecular via CO), dust and stars than in the interarm disc. It seems generally accepted that, at least in grand design spirals, there are density waves in the discs. However, several questions are not clear yet and still under discussion. An important question could be termed the *triggering dilemma* (by analogy with the "winding dilemma" raised in the forties): Is the enhanced star formation in the spiral arms triggered by the passage of a system of density waves or is it simply due to the presence of a higher column density of gas there?

In the present work, we use triggering in the same sense as the moderate to strong triggering defined by Elmegreen (1992), that is to say that star formation in the arms occurs at a rate faster than that in the interarm zone, relative to the available placental gas.

Our group has designed several tests to elucidate whether or not star formation is triggered in the arms with respect to the interam region and here we summarize one of them, that of the ratio of the star formation efficiency in the arms divided by that of the interarm zone at the same galactocentric distance which we may call the *relative massive star formation efficiency*, where the efficiency is defined using the ratio of the mass of stars (evaluated via the Hα flux) to the mass of neutral gas, atomic plus molecular (which must be measured with the adequate angular resolution). If the relative efficiency is of order unity, the star formation is proportional to the mass of gas, if some kind of induced star formation is present, the relative efficiency should be considerably larger than unity.

The relative star formation efficiency has been evaluated in great detail, up to now, in five spirals: NGC 628, NGC 3992 and M 33 (Cepa & Beckman 1990a), NGC 4321 (Cepa & Beckman 1990b) and M 51 (Knapen *et al* 1992). NGC 628, NGC 3992, NGC 4321 and M 51 are grand design spirals and M 33 is flocculent (Elmegreen 1987). The grand design spirals studied show relative efficiencies much larger than unity (of order 10–20) where all the arms of a given galaxy show a geometrically congruent pattern of peaks and dips (Figs. 1 and 2). The dips can be identified with resonances, the most conspicuous being the corotation radius (where the pattern speed and the velocity of the material of the disc are the same, and for this reason no triggering of star formation is to be expected). The region where the relative efficiencies are larger than unity is confined by the inner Lindblad resonance and the outer Lindblad resonance, the dominion of existence of a single mode of a density wave. These characteristics are in good agreement with the model of star formation triggering induced by a density wave, and would be difficult to account for by any of the alternative models which have been proposed to explain the presence of arms.

This situation of peaks and dips with relative efficiencies much larger than unity and coherent for all the arms is not present in the flocculent galaxy studied (M 33, as shown in Fig. 3) indicating that the star formation is not induced here by a resonant system, but could be a result of a self–propagating scenario (Seiden & Gerola 1982).

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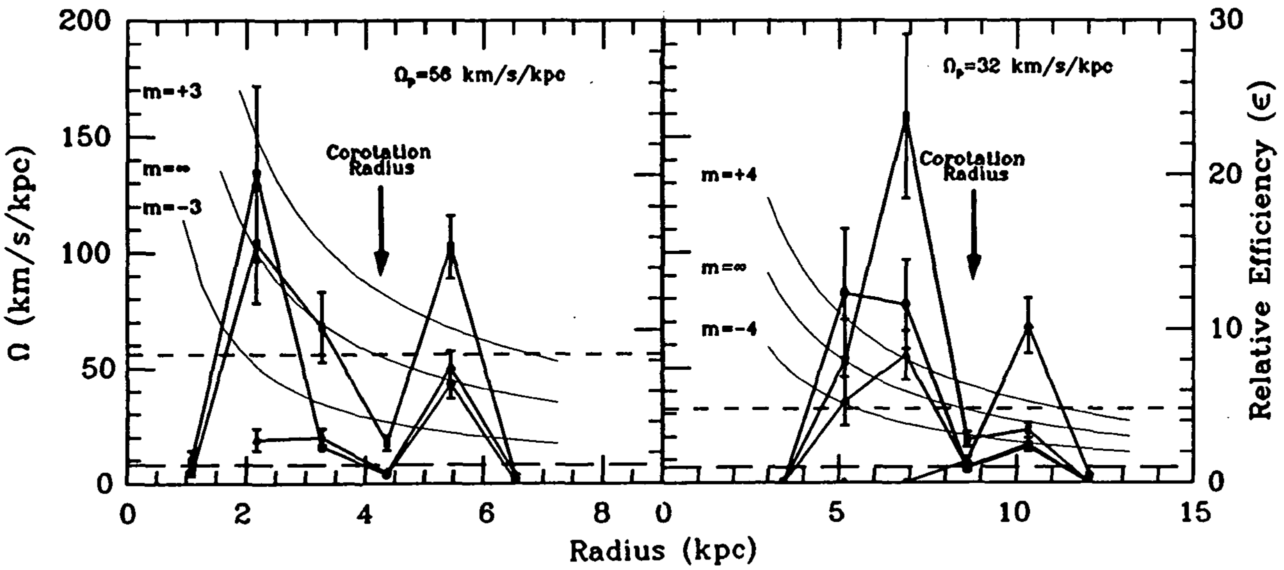

Figure 1.– Relative arm/interarm star formation efficiencies (scale on the right) for each arm of NGC 628 (left diagram) and NGC 3992 (right diagram) indicated by the continuous thick line. The continuous thin line shows the curves $\Omega + \kappa/m$ where Ω is the rotation curve, κ the epicyclic frequency and m the number of spiral arms (or mode). The corresponding scale is that on the left. The estimated values for the pattern speeds (Ω_p) are at the top of the diagrams and indicated by a dashed line. The intersections between the curves $\Omega + \kappa/m$ and Ω_p show the inner Lindblad resonance, the corotation radius and the outer Lindblad resonance, from lower to larger values of the radius. At resonances and corotation the efficiencies go down to unity peaking between them at values as high as 25, with the same qualitative behaviour with galactocentric radius in all arms of a given galaxy.

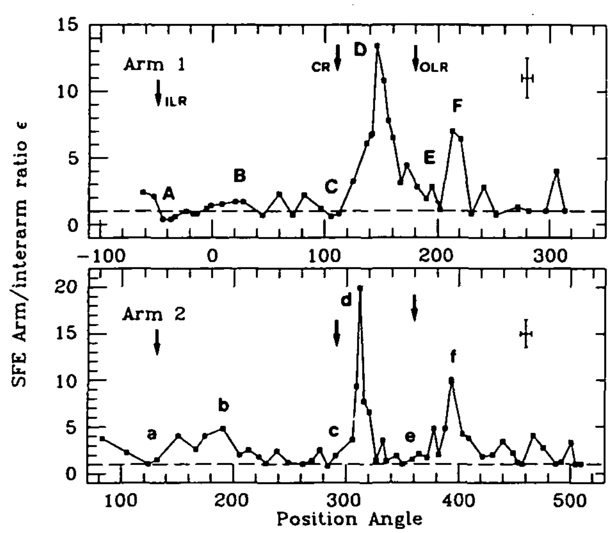

Figure 2.– Relative arm/interarm star formation efficiency for each arm of M 51 as a function of the position angle along the arms. Again, the same qualitative behaviour can be seen in both arms with relative efficiencies as high as 20 between the resonances identified by Elmegreen, Elmegreen and Seiden (1989) using broad band photometry.

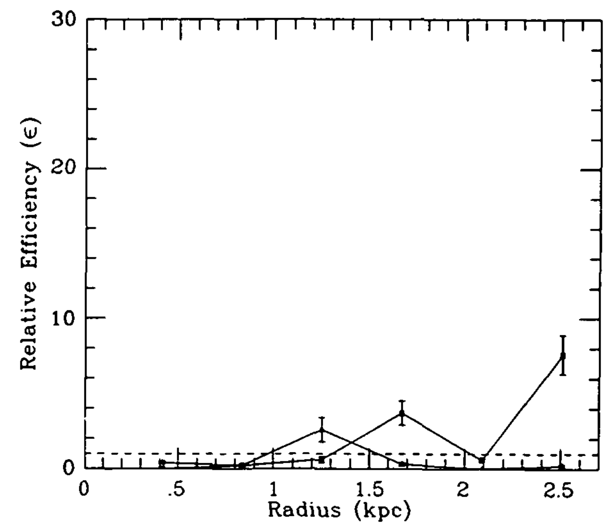

Figure 3.– Relative arm/interarm star formation efficiency for each arm of M 33 as a function of the radius. In this flocculent galaxy, the relative efficiencies are much lower than in the grand design spirals (Figs. 1 and 2), not rising to values above 4, except in the outermost point of one of the arms, which corresponds to NGC 604, a large and conspicuous HII region.