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# TRIGGERED STAR FORMATION IN SPIRAL ARMS

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## RESUMEN

Presentamos el estado actual de nuestra investigación, referente al desencadenamiento de formación estelar por choques galácticos a gran escala asociados a ondas de densidad espirales. Alrededor de una tercera parte de las galaxias de nuestra muestra parecen no ser adecuadas para esta clase de estudio, porque presentan un efecto, probablemente de opacidad, que no está bien entendido. Los objetos restantes parecen mostrar formación estelar inducida por ondas de densidad en los brazos. La comparación con modelos de síntesis de población estelar y las posiciones de las resonancias orbitales para estas galaxias (derivadas a partir de las velocidades angulares del patrón espiral), corroboran esta hipótesis.

## ABSTRACT

We present the status of our research, relative to the triggering of star formation by large-scale galactic shocks associated with spiral density waves. Around a third of the galaxies in our sample do not seem suitable for this kind of study, because they present an effect, probably due to opacity, that is not well understood. The remaining objects seem to favor the idea of density wave triggering of star formation in the arms. The comparison with stellar population synthesis models, and the orbital resonance positions for these galaxies (derived by means of spiral pattern angular speeds) corroborate this hypothesis.


*Key Words:* galaxies: spiral — stars: formation

## 1. GENERAL

After the density wave theory was established, the idea that spiral density waves were able to trigger star formation in the spiral arms of disk galaxies was proposed (Roberts 1969). Although this scenario may take place in real galaxies, the role and importance of this process is still an open question. González & Graham (1996) developed a method sensitive to the light of red and blue supergiants, using the reddening-free photometric index

$$Q(rJgi) = (r - J) - \frac{E(r - J)}{E(g - i)}(g - i)\,. \tag{1}$$

Using this index, they were able to detect spiral density wave triggering of star formation in M99. Stellar population synthesis models (e.g. Bruzual & Charlot 2003) predict that the behavior of $Q$ for a burst of star formation is well defined and can be observed for near face-on galaxies. This behavior is manifested in real galaxies as an azimuthal color gradient across spiral arms.

A sample of 31 galaxies with deep photometry was obtained during 1994–1996, in the optical filters $g, r, i$, and the infrared passbands $J, K$. A preliminary analysis (Martínez-García et al. 2007) of the data shows that azimuthal age gradients can be detected in other disk galaxies besides M99. A more careful inspection of the behavior of the $Q$ index for the disks of this sample shows that in around a third of them the two halves of the disk present different mean values of $Q$. We believe that this effect may be due to the position of the dust lanes and stars with respect to the observer. More research needs to be done to understand the origin of this effect. So, in order to proceed with the original project, the galaxies with this *"Q opacity effect"* have been excluded. These galaxies were NGC 864, NGC 1703, NGC 3001, NGC 3059, NGC 3513, NGC 3338, NGC 4254, NGC 4593, NGC 4603, NGC 7083, and NGC 7217. The remaining galaxies were divided in two groups (see Table 1). The first one includes non barred galaxies types A and AB (de Vaucouleurs 1959), and the second B type barred galaxies. Preliminary results for the first group of galaxies indicate that some of them present azimuthal color gradients due to spiral density wave triggering of star formation. The candidate zones were compared with stellar population synthesis models (Bruzual & Charlot 2003). The relative positions of dust lanes (traced by the color $g - J$), the density waves (indicated by the $K$-band data), and the age gradients (inferred from $Q$) seem

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TABLE 1

GALAXY SAMPLE

| | Name | Type |
|---|---|---|
| Group 1 | | |
| | NGC 578 | SAB(rs)c |
| | NGC 918 | SAB(rs)c |
| | NGC 7125 | SAB(rs)c |
| | NGC 1421 | SAB(rs)bc |
| | NGC 3162 | SAB(rs)bc |
| | NGC 5371 | SAB(rs)bc |
| | NGC 6951 | SAB(rs)bc |
| | NGC 7753 | SAB(rs)bc |
| | NGC 1417 | SAB(rs)b |
| | NGC 718 | SAB(s)a |
| | NGC 3938 | SA(s)c |
| | NGC 7126 | SA(rs)c |
| | NGC 4939 | SA(s)bc |
| Group 2 | | |
| | NGC 7479 | SB(s)c |
| | NGC 6907 | SB(s)bc |
| | NGC 5383 | SB(rs)b |
| | NGC 7496 | SB(s)b |
| | NGC 266 | SB(rs)ab |
| | NGC 986 | SB(rs)ab |
| | NGC 4314 | SB(rs)a |

to be in accordance with theory.

By a simple approximation,

$$\Omega_p \cong \frac{1}{R}\left(\frac{v_{\rm app}}{\cos(I.A.)} - v_{\rm rel}\right) \quad (2)$$

(where $R$ is the mean radius of the zone of study, $v_{\rm app}$ is the apparent velocity of rotation, $I.A.$ is the inclination angle, and $v_{\rm rel}$ is obtained from the fit of the model to the data) the pattern speed of the spiral wave can be obtained. The pattern speeds acquired this way must be consistent with the positions of major resonances (e.g., corotation, the outer and inner Lindblad resonances – OLR & ILR), if we are indeed observing an azimuthal age gradient as expected from theoretical considerations. The preliminary results for NGC 7125 show that the age gradient found in one of the arms of this galaxy yields a pattern speed $\Omega_p \sim 20$ km s$^{-1}$ kpc$^{-1}$. With this value, the spiral pattern starts at the ILR and extends all the way to the OLR. Ongoing work is taking place to obtain global statistics for the A, AB & B galaxies in our sample. The color gradients will be compared with the latest stellar population synthesis models of Bruzual & Charlot (2003).

So far, the age gradients found is some of the galaxies of our sample confirm that such gradients are mainly observed in sites devoid of bright HII regions, as already observed by González & Graham (1996). HII regions may mask the gradients. The observed gradients indicate that spiral density wave triggering of star formation takes place for real galaxies and plays an important role for the cycling of the ISM in disk galaxies.

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