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Spiral triggering of star formation in normal galaxies

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Abstract. We present results for 13 spiral galaxies from a sample of 31, where we have used the method developed by González & Graham 1996, to search for and analyze azimuthal color gradients across spiral arms (see figure 1 in Martínez-García *et al.* 2009). A total of 23 regions were analyzed in the spiral disks. Ten of the galaxies present regions that match theoretical predictions.

Keywords. galaxies: kinematics and dynamics – galaxies: photometry – galaxies: stellar content – galaxies: spiral – galaxies: structure

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1. Observations and analysis

1.1. *Observations*

The galaxies analyzed are almost face-on. The observations were carried out during 1992-1995, at Cerro Tololo Inter-American Observatory (0.9-m and 1.5-m telescopes), Kitt Peak National Observatory (1.3-m telescope), and Lick Observatory (1.0-m). The galaxies were observed at g ($\lambda = 5000$ Å), r ($\lambda = 6800$ Å), i ($\lambda = 7800$ Å), J, and K_s. The mean exposure time was 30 minutes at each wavelength; the data were properly reduced and calibrated.

1.2. *Analysis*

The galaxies were deprojected to a face-on view. Next, the spiral arms were unwrapped (see, Iye *et al.* 1982), by plotting them in a $\ln R$ vs. θ map (R is the radius measured from the center of the galaxy). The arms were then straightened, by adding a ($\ln R$-dependent) phase shift to each one of the columns, while keeping the $\ln R$ coordinate fixed. We then proceeded to create, with the straightened images of each galaxy, the reddening-free parameter $Q(rJgi)$, defined as:

$$Q(rJgi) = (r - J) - \frac{E(r - J)}{E(g - i)}(g - i). \tag{1.1}$$

where $E(r - J)$ and $E(g - i)$ are color excesses. High values of this parameter trace blue and red supergiants (i.e., star formation), whereas low values indicate an old stellar population, as shown in González & Graham (1996).

Finally we searched for possible azimuthal color gradients in the Q image with straightened arms. To improve the signal-to-noise ratio of potential gradients, columns in the region of interest were averaged.

2. Comparison with stellar population synthesis models, the link to spiral dynamics

In order to determine the pattern speed of the spiral wave, we compared the observed Q profiles with the stellar population synthesis models of Charlot & Bruzual (2007).

If one assumes that stars form in the site of the shock, and that they age as they move away from this birthsite, then distance from the dust lane (at constant radius) parameterizes stellar age. In fact, stretching the model Q to fit the data fixes the ratio between the distance, d, and the age of the stellar population, t_{age}. If, in addition, the rotational velocity is known, it is possible to find the angular velocity of the spiral pattern, Ω_p, as follows:

$$\Omega_p \cong \frac{1}{R}\left(v_{\rm rot}(R) - \frac{d}{t_{\rm age}}\right). \tag{2.1}$$

Here, R is the mean radius where the gradient has been detected, measured from the center of the galaxy; $v_{rot}(R)$ is the rotational velocity of the disk at such radius (taken from the literature); d is distance from the shock, and t_{age} is the stellar age derived from fitting the population synthesis model to the observations.

With the pattern speed, we obtained the location of major resonances: the Outer Lindblad Resonance (OLR), corotation, and the 4/1 resonance. The results of this analysis are summarized in Fig. 4 of Martínez-García *et al.* (2009) (hereafter MG09). Early spiral theory has shown that density waves must propagate between the ILR and the OLR (Lin 1970, Mark 1976, Toomre 1981), or corotation if spirals do not grow. Another approach involving stellar orbits predicts that strong spirals (i.e, Hubble types Sb or Sc) should extend to the 4/1 resonance (Contopoulos & Grosbøl 1986). According to the results of MG09, the data do not seem to support the theory of Contopoulos & Grosbøl (see, also, Elmegreen *et al.* 1992; Zhang & Buta 2007).

3. Conclusions

The results of this research indicate that azimuthal color gradients may indeed be frequent, and relatively easily detected with the right technique, at least in some regions of the spiral arms. The effects of dust, and of stellar densities, circular velocities, and metallicities on the color gradients seem to have a negligible effect, according to MG09. Ongoing work refers to non-circular motions product of spiral shocks, and to the analysis of the remaining galaxies (barred included).

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