Morphological Transformations of Spiral Galaxies induced by Mergers

Cecilia Scannapieco* **and Patricia B. Tissera**

Instituto de Astronomía y Física del Espacio.

Casilla de Correos 67, Suc. 28 (1428) Ciudad de Buenos Aires, Argentina

* cecilia@iafe.uba.ar

The variation of the structural and astrophysical properties of spiral galaxies through the Hubble classification is generally interpreted in terms of an evolutionary sequence. However, the physical mechanisms that could drive this evolution are not fully understood. It has been suggested that mergers of galaxies would play a crucial role in their evolution, being capable of triggering transformations of morphology through the Hubble sequence.

We use numerical Smooth Particle Hydrodynamical simulations to study the effects of mergers on the structural properties of galaxy-like objects in hierarchical clustering scenarios. The simulations take into account the gravitational and hydrodynamical evolution of dark matter and baryons in a cosmological framework of a standard Cold Dark Matter Universe ($\Omega = 1$, $\Lambda = 0$). Gas particles are transformed into stars according to the Schmidt law:

$$\frac{d\rho_{\rm star}}{dt} = c\frac{\rho_{\rm gas}}{t_*} \tag{1}$$

where c is a star formation efficiency and t_* is a characteristic time of the star formation process. In this context, mergers are a natural result of the evolutionary history of galaxy-like objects (GLOs) through the hierarchical process.

We identified galaxy-like objects at their virial radius at redshift $z = 0$ and followed their evolution back in time. In this way we constructed the merger trees and star formation rate histories of the GLOs. We studied only those mergers that are directly linked to starbursts in the star formation history of each GLO. During a merger event, the progenitor object is chosen as the more massive baryonic clump within the merger tree, while the minor colliding clump is referred to as the satellite.

We analised comparatively the effects of *secular evolution* induced by tidal fields during the orbital decay phase of a merger event and those of the *actual fusion* of the baryonic cores of the merging objects. For this purpose, we projected the mass distributions of the GLOs onto the perpendicular plane to their total angular momentum and performed bulge-disc decompositions to these distributions, at redshift $z = 0$ and at different stages of the merger processes. We used an exponential law for the discs and the Sérsic law for bulges:

$$\Sigma_{\rm d} = \Sigma_{\rm d}^{\rm o}\exp(-(r/r_{\rm d})) \tag{2}$$

$$\Sigma_{\rm b} = \Sigma_{\rm b}^{\rm o}\exp(-(r/r_{\rm b})^{1/n}) \tag{3}$$

where $r_{\rm d}$ and $r_{\rm b}$ are the disc and bulge scalelengths, $\Sigma_{\rm d}^{\rm o}$ and $\Sigma_{\rm b}^{\rm o}$ the corresponding central mass surface densities and n the bulge shape parameter. We found that mergers trigger starbursts at the fusion of the two colliding baryonic cores. During some merger events, a previous starburst is detected during the orbital decay phase. These events will be called double starbursts (DSBs). If only one starburst is detected during a merger event, we will refer to as a single starburst (SSB) (see Tissera et al. 2002 for details).

Figure 1 shows the distribution of the bulge and disc scalelengths of the GLOs for different ranges of the bulge shape parameter, and different observational results. From this figure we can see that as we restrict the n value to more exponential profiles ($n \to 1$), the scalelength relation for both

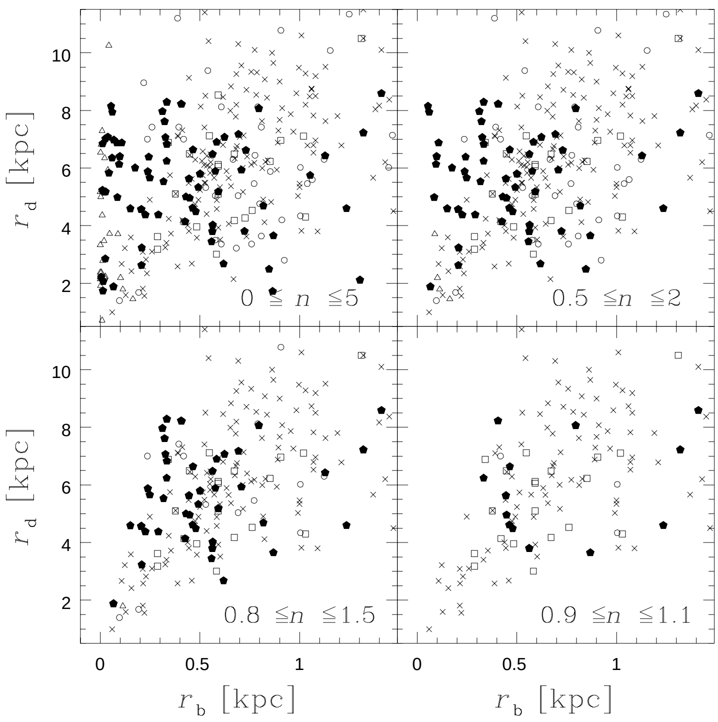

Figure 1: Disc scalelength ($r_{\rm d}$) as a function of bulge scalelength ($r_{\rm b}$) for simulated objects at $z = 0$ and progenitors (filled blue pentagons), for which bulges are described by $0 \leq n \leq 5$ (a), $0.5 \leq n \leq 2$ (b), $0.8 \leq n \leq 1.5$ (c) and $0.9 \leq n \leq 1.1$ (d). Observational data from Courteau, de Jong & Broeils (1996, red crosses), Moriondo, Giovanelli & Haynes (1999, open black squares), Khosroshahi, Wadadekar & Kembhavi (2000, open blue triangles) and MacArthur, Courteau & Holtzman (2003, open green circles) for the same shape parameter intervals are also shown.

observations and simulations gets better defined. We also note that the $r_{\rm b}$ versus $r_{\rm d}$ distribution for GLOs and galaxies with bulges with $n > 1.5$ shows no trend at all. It is encouraging that the observed and simulated disc structures show scalelength distributions with similar patterns, for both $n \approx 1$ or $n \neq 1$ bulge profiles. In the case of exponential bulges ($0.9 \leq n \leq 1.1$), the correlation is well defined with $< r_{\rm b}/r_{\rm d} >= 0.14 \pm 0.05$ and $< r_{\rm b}/r_{\rm d} >= 0.13 \pm 0.06$ for observations and simulations, respectively. Table 1 summarizes the mean values of $r_{\rm b}/r_{\rm d}$ for different ranges of n.

Figure 2 shows the variations in the shape parameter of the baryonic mass profiles of the GLOs as a function of the fraction of stars already formed in the progenitor when the mergers start, for the orbital decay phase (a) and the fusion of the baryonic cores (b), for single and double starbursts. We can see from this figure that secular evolution tends to decrease the bulge shape parameters to more exponential profiles ($n \approx 1$), while fusions tend to increase the shape parameters. The more important variations are detected in objects that experience double starbursts, which are more unstable objects and lack a well-formed stellar bulge (Tissera et al. 2002).

The luminosity bulge-to-disc ratio B/D has been traditionally used as an indicator of morphology (Andredakis & Sanders 1994): observations show that B/D correlates with n (e.g., Graham & de Block 2001). We found that the relation between B/D and n is disordered by secular evolution and,

Table 1: Mean values of the ratio between bulge and disc scalelengths for simulations (SIM) and observations (OBS) for different cases. (Observational results correspond to a combined sample including the results from Moriondo, Giovanelli & Haynes 1999; Khosroshahi, Wadadekar & Kembhavi 2000 and MacArthur, Courteau & Holtzman 2003). The bootstrap errors are shown in brackets.

	$< r_{\rm b}/r_{\rm d} >_{\rm SIM}$	$< r_{\rm b}/r_{\rm d} >_{\rm OBS}$
$n < 0.9$	0.24 ± 0.20 (0.05)	0.16 ± 0.07 (0.01)
$0.9 \leq n \leq 1.1$	0.13 ± 0.06 (0.02)	0.14 ± 0.05 (0.02)
$n > 1.1$	0.05 ± 0.05 (0.01)	0.03 ± 0.04 (0.01)

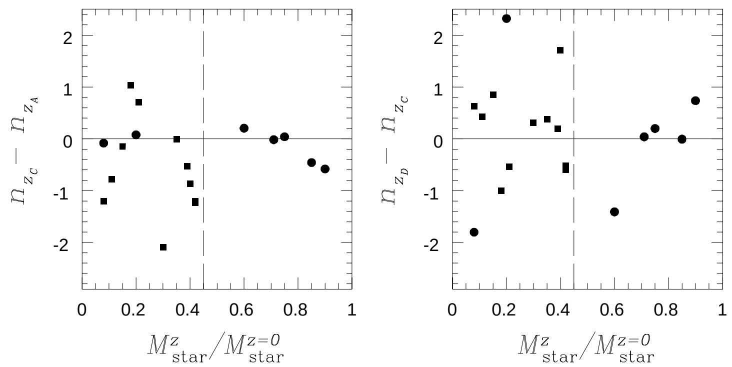

Figure 2: Variations in the shape parameter of the progenitors during the orbital decay phase (a) and during the fusion of the baryonic clumps (b) in single (filled red circles) and double (filled blue squares) SBs, as a function of the fraction of stars already formed in the progenitors, $M^{\rm z}_{\rm star}/M^{\rm z=0}_{\rm star}$ when the mergers start.

on the contrary, the fusion tends to produce correlated changes between these two parameters.

Our results suggest that the combined action of secular evolution and fusions could play a significant role in the determination of the observed properties of galaxies. According to our models, their effects could depend on the particular evolutionary history of the galactic objects (see Scannapieco & Tissera 2003 for details).

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