Formation of stellar inner discs and rings in spiral galaxies through minor mergers

M. C. Eliche-Moral[1], A. C. González-García[2,3], M. Balcells[4,2,3], J. A. L. Aguerri[2,3], J. Gallego[1], J. Zamorano[1], & M. Prieto[2,3]

[1]Universidad Complutense de Madrid, [2]Instituto de Astrofísica de Canarias, [3]Universidad de La Laguna, [4]Isaac Newton Group of Telescopes

INTRODUCTION

Observations have shown that stellar inner discs and rings are frequent structures in the centres of spiral galaxies (found in ~1/3 of them). Traditionally associated to bars, recent studies show that these inner components (ICs) do not reside preferably in barred galaxies, contrary to expectations ([1-4]). Their formation in many spiral galaxies may then differ from that described by the traditional bar-origin scenario. In contrast, the role of minor mergers in producing these ICs, while often invoked, is still poorly understood.

AIM

We investigate the capability of minor mergers to trigger the formation of inner discs and inner rings in spiral galaxies through collisionless N-body simulations. This study is presented in Eliche-Moral et al. (2011, A&A, in press, [5]).

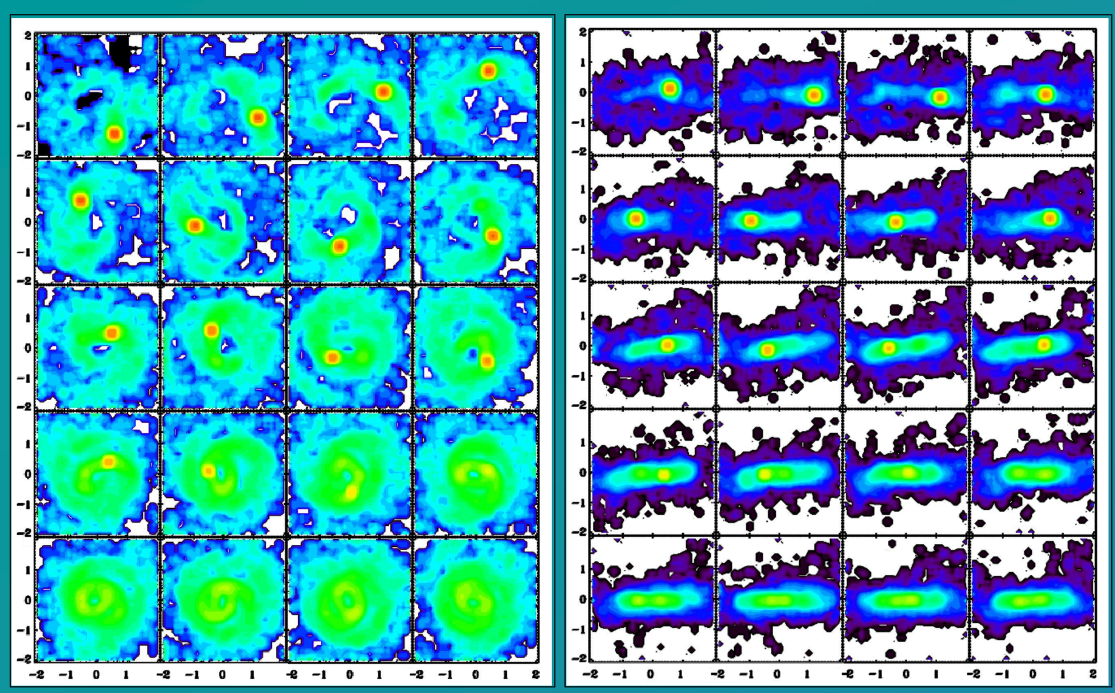
THE N-BODY MODELS

We run a battery of minor merger simulations with the GADGET code in which both primary and satellite galaxies are modelled as disc-bulge-halo galaxies with realistic density ratios (see [5-6]). Different orbits (long and small pericenter orbits, direct and retrograde orbits) and mass ratios (1:6, 1:9, 1:18) are considered, as well as two different models for the primary galaxy (with B/D=0.5 and 0.08).

Satellites are scaled replicas of the primary galaxy model with the large bulge in all the experiments (B/D=0.5). A physically-motivated size-mass scaling was used to ensure that the primary-to-satellite density ratios are realistic, forcing both galaxies to obey the Tully-Fisher relation (see [6]).

A detailed analysis of the morphology, structure, and kinematics of the ICs resulting from the minor merger is performed. We use simulation units in the figures below. The primary galaxy with a large bulge matches the Milky Way when the units of length, velocity, and mass are R = 4.5 kpc, v = 220 km/s, and $M=5.1\times10^{10}$ Msun. In this case, the corresponding time unit is 20.5 Myr.

RESULTS



All the simulated minor mergers develop flattenned and extended ICs made out of disrupted satellite material in the centre of the final remnants (see Fig. 1).

Figure 1: Disruption of the satellite in one of the models. Time rises from left-to-right and from top-to-bottom.

The formed ICs present radial surface density profiles that can be described by one or two (nested) exponential profiles (see Fig. 2).

In half of cases, the innermost components are thin enough to be considered inner discs ([7]). The outer ICs resemble thick flared discs, surrounding the main disc of the final remnant. All ICs are aligned to better than 5º with the main disc of the remnant.

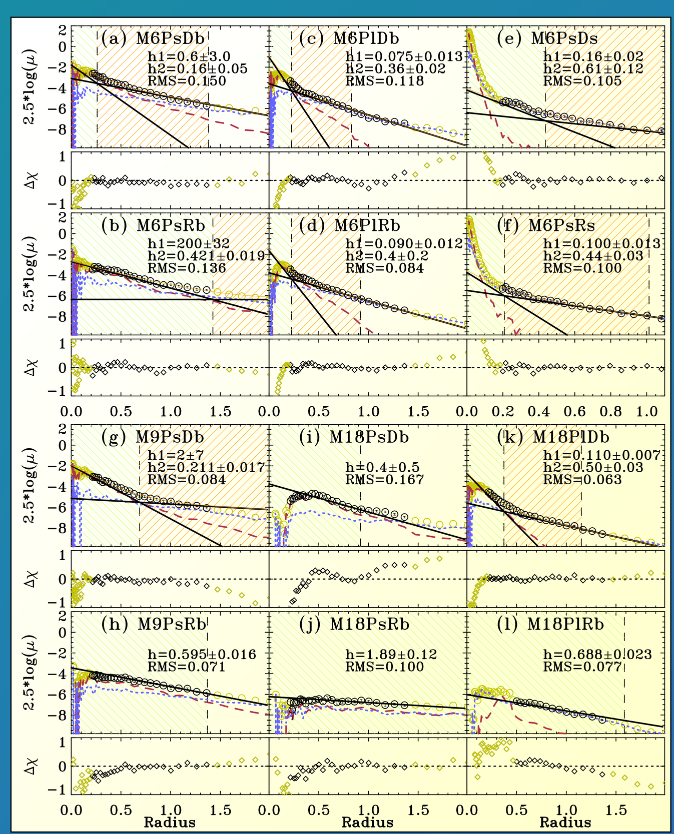
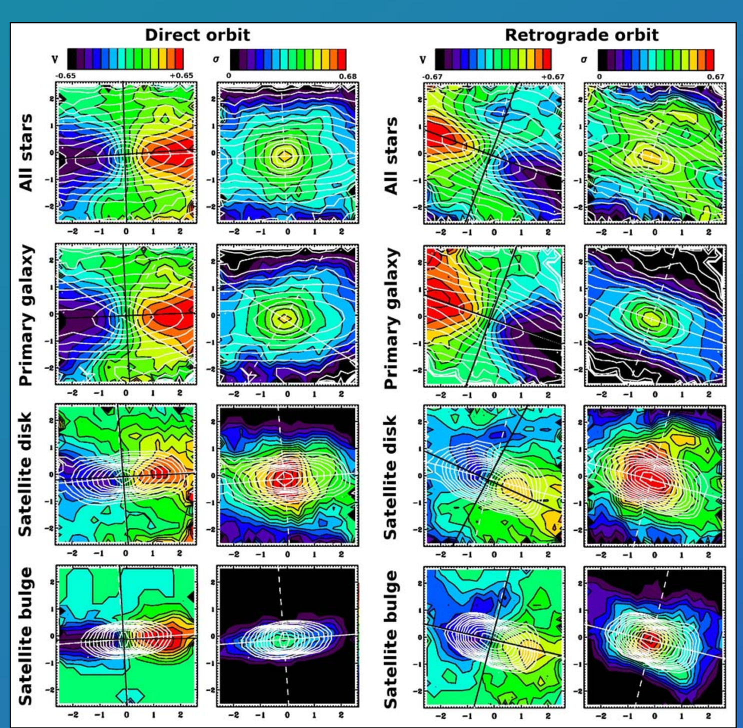


Figure 2: Radial surface brightness profiles of stellar satellite material in the final remnants of all the models (*circles*). Depending on the case, one or two exponential discs are required to fit these radial density profiles (*black solid lines*).



The resulting ICs are strongly supported by rotation (see Fig. 3), except in the models with small primary bulges. Weak transitory oval distortions appear in the remnant centre in many cases, but none of them develops a noticeable bar.

Figure 3: Line-of-sight rotation velocity and velocity dispersion maps of the stellar material coming from different original components in the final remnants of the models with mass ratio 1:9 (direct and retrograde cases). The colour levels used in all maps are the same in each case.

Minor mergers can produce highly aligned, dynamically cold, thin ICs out of disrupted satellite material, without either dissipation or the development of noticeable bars.

A wide morphological zoo of ICs are obtained, including inner discs, rings, pseudo-rings, nested discs, spiral arms, and combinations of them (see Fig. 4).

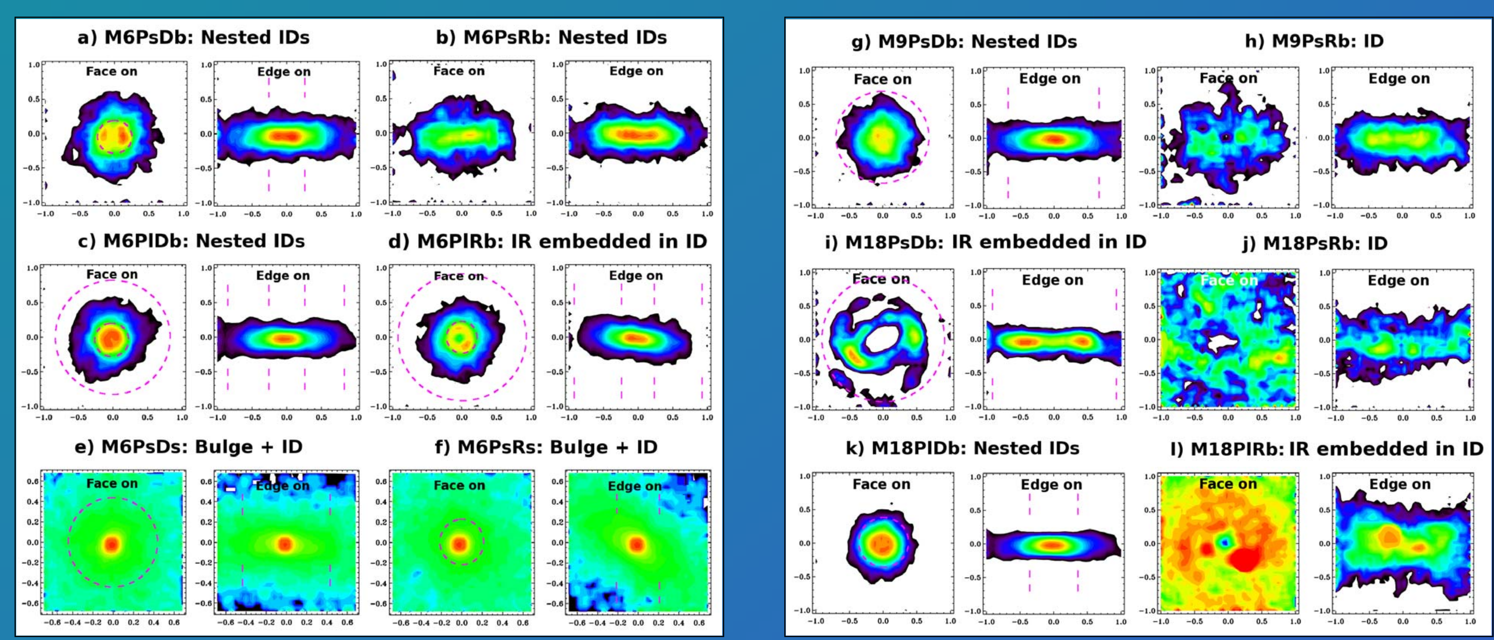


Figure 4: Morphology of the ICs formed in the final remnants of all experiments.

The ICs produce photometric and kinematical features similar to those observed in real galaxies ([3-4, 8-9]).

These include changes of trends of the ellipticity and position angle (PA) profiles, disturbed and stretched iso-velocity contours in the centre, S-shaped kinematic twists, h4 peaks, and dumbbell-like structures in σ maps generated by counter-rotating inner discs (see Fig. 5).

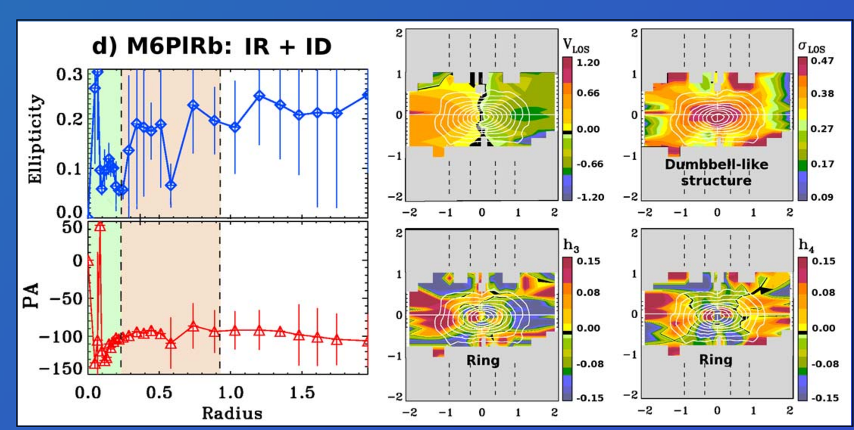
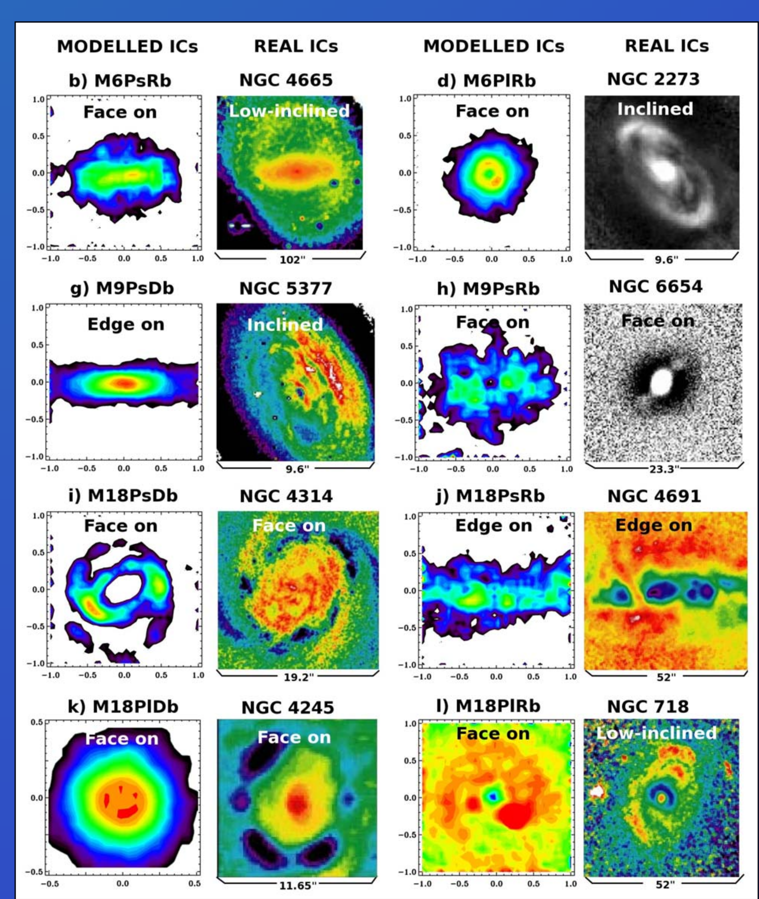


Figure 5: Ellipticity and PA isophotal profiles and 2D-maps of the kinemetric moments (V, σ, h_3, h_4) of the line-of-sight velocity distribution of all the stars in one remnant.



The simulated minor mergers produce ICs with morphologies and sizes similar to those observed in real galaxies (with radii ranging from ~360 pc to 2.5 kpc, see Fig. 6).

Figure 6: Comparison of the morphology of some ICs formed in our minor merger experiments to real observational examples ([8]).

The ICs in our mergers are formed through the coupling of three physical processes: the orbital circularization during the satellite decay, its disruption, and the disc resonances induced by the merger ([10]).

CONCLUSIONS

These models prove that minor mergers are an efficient mechanism for forming rotationally-supported stellar ICs in spiral galaxies, without requiring either strong dissipation or the development of noticeable bars.

Minor mergers can then account for the existence of pure-stellar old ICs in unbarred galaxies. The role of minor mergers in the formation of ICs must have been much more complex than just bar triggering.

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