NBODY/SPH simulations of individual galaxies

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ABSTRACT

We present preliminary results on galactic Dark Matter (DM), halo structure, and galaxy evolution. We show how during the first Gyr of the evolution of a $10^{10} M_\odot$ dwarf elliptica feed-back from stars (SNæ and stellar winds) leads to an extended constant density isothermal core with radius of 0.15 the virial radius R_{200}. We also present first results on galaxy merging as a possibile scenario to form ellipticals, studying in particular how the details of the merging evolution vary as a function of the mass ratio of the interacting galaxies.

1. Introduction

Numerical N-body and gasdynamical simulations have become a major tool to investigate how galaxies formed and evolved. Massively parallel computers, like Cray T3D or T3E supercomputers, have allowed to run high resolution simulations of large scale structure formation (VIRGO or GIF projects), leading to impressive results on the distribution of DM in different cosmological scenarios (Jenkins et al. 1997).

On galaxy scales, Navarro et al. (1996a) showed that galactic DM halos should follow a universal density profile. In other words, the violent, collisionless dynamical relaxation processes during the formation of DM halos lead to equilibrium profiles with similar shapes, independent of the halo mass, the initial density fluctuation spectrum, and the adopted cosmological model.

However, recent studies (Persic et al. 1996; Burkert & Silk 1997) have found evidence, in real galaxies, of significant departures from this universal profile both in the inner and in the outer galactic regions.

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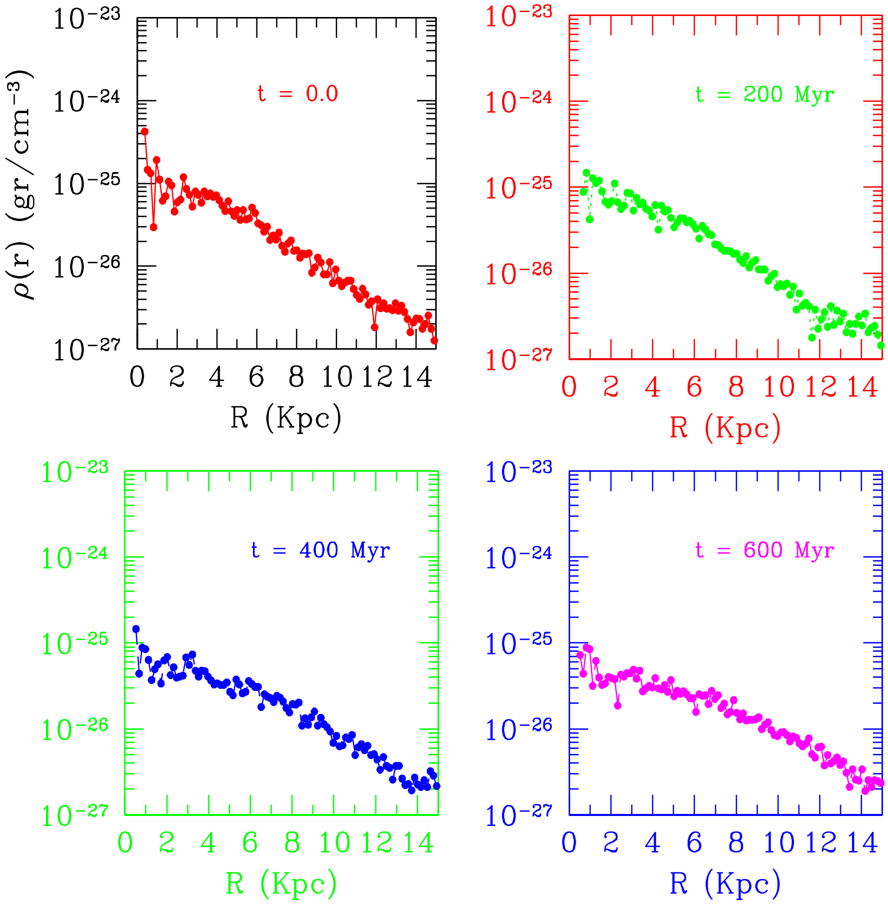

Figure 1: Time evolution of the DM density profile.

In particular, the presence of extended DM cores seems to be a firm result. The occurence and the development of cores with costant density is not yet completely understood. It has been suggested that the discrepancy between observations and Cold Dark Matter (CDM) predictions could be solved by assuming secular processes in the baryonic component which may also affect the innermost halo regions. An analytic approach used by Navarro et al. (1996b) has suggested that such processes might produce core only in low mass galaxies.

In this contribution we present a fully Nbody simulation of the formation of a dwarf elliptical galaxy to investigate whether baryonic feedback can actually be the cause of the cores developments.

Tothis aim we use our own TreeSPH code (for details see Carraro et al 1997 and Lia et al 1998).

2. DM haloes of Ellipticals

Bertola et al (1993), using the gaseous component's rotation curve of the gas for a sample of giant ellipticals, showed that the halos surrounding elliptical galaxies have characteristics similar to those of the spiral halos. In particular the DM density profile in the inner region of the galaxies is similarly much flatter than the baryons'

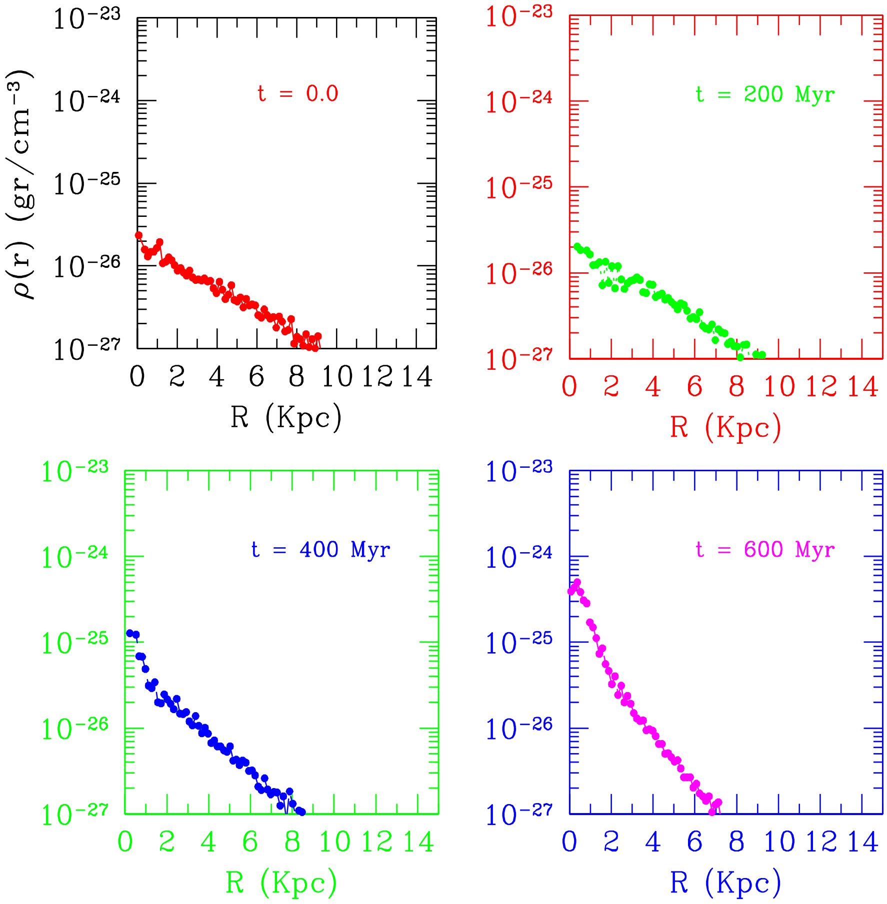

Figure 2: Time evolution of the baryons density profile.

profile, the two profiles intersecting at roughly the effective radius.

In order to study the formation of the core we have considered a sperically symmetric virialized ”primordial galaxy of ”$10^{10} M_\odot$ with a baryon fraction of 5%. The system is described by 8000 particle, half in form of baryons and half in form of DM. Virialization is obtained by distributing dark particles according to a $1/r$ density profile, with velocity components suitable to produce the velocity dispersion necessary to support and stabilize the system. Gas is set on the top of dark particles with the same velocity components. At this point cooling switches on, and the gas falls in towards the center forming stars. The time evolutions of the DM profile and of the baryon profile are shown in Figs. 1 and 2, respectively; the situation at the end of the run is presented in Fig. 3 (DM: open circles; baryons: filled circles).

Looking at Figs 1-3 we clearly recognize that the DM density profile gets flatter developing a core radius of about 2.0 kpc: this is similar to the effective radius as obtained by fitting the stars' distribution to a Hernquist profile. The baryons, on the contrary, become more centrally concentrated, producing a steeper profile.

In order to investigate the origin of the core , we have plotted in Fig. 4 the trend of the halo concentration, defined as ρ_1/ρ_4, which is a measure of the core development, against the SFR at four epochs along the run. There is a clear relation, suggesting that the dynamical feedback of star formation on the halo may be responsible for

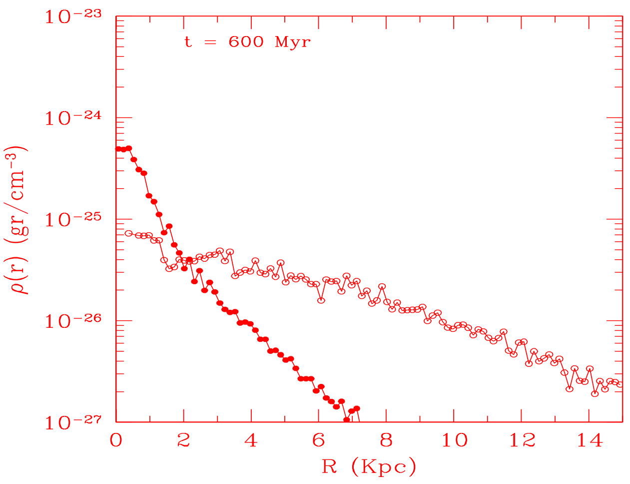

Figure 3: Baryons (filled circles) and DM (empty circles) density profiles at the ned of the simulation.

the formation and development of the core . Work is in progress to see whether this scenario is appropriate also for more massive galaxies.

3. Galaxy Merging

Many theoretical studies and numerical simulations have supported the hypothesis that the merging of two disk galaxies could be the dynamical process leading to the formation of an elliptical galaxy. On the observational side, this hypothesys is supported by the presence, in many ellipticals, of several photometric or kinematical peculiarities, like boxy or disky departures of the isophotes from an elliptical shape, counterrotating cores, the presence of shells, etc.

In the simulations described here, each galaxy is obtained from the adiabatic collapse of a rotating gas plus sphere whith initial r^{-1} density profile. Each galaxy consists of 1824 particles, equally distribuited between gas and DM. We let the system evolve until virial equilibrium is reached. Then we set the two galaxies along a specified orbit one around the other.

As noted by Toomre & Toomre (1972), the most interacting galaxies probably have highly eccentric orbits and are coming together for the first time only now; so $0 \ll e \leq 1$. On the other hand, a pair of galaxies in an extended distribution of dark matter, could be accelerated to a nearly hyperbolic encounter ($e \geq 1$). So a good compromise between these two possibilities is to consider a parabolic orbit ($e = 1$).

We assign the initial orbit in terms of the masses of the two galaxies, of the eccentricity

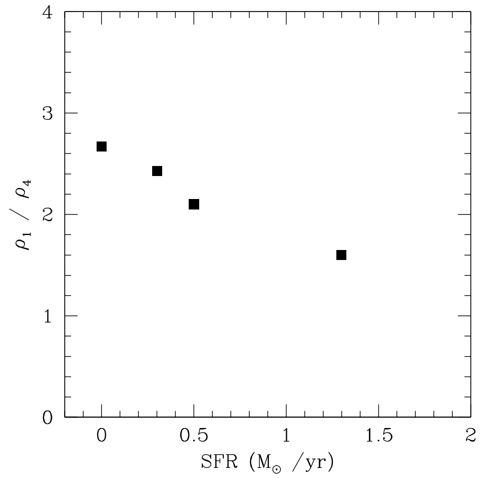

Figure 4: Core development as a function of the Star Formation rate.

Table 1: Parameters for the merging simulations.

Model	M_1	M_2	ϕ	ϵ	p
A	0.5	0.5	$-\pi/2$	1.5	1.0
B	0.9	0.1	$-11/20\pi$	1.0	2.0

e, the aperture p and the initial anomaly ϕ. Then we calculate the initial velocities and initial positions of the particles in the center of mass frame. The parameters of the two encounters (in code units) are summarized in Table 1.

In the adopted coordinate system, the orbital plane coincides with the XY plane and the origin is in the center of mass of the two galaxies. The galaxies move about each other in a counterclockwise direction and the encounters are direct.
In encounter A (Fig. 5) the two galaxies have the same mass (M1=M2=0.5, in code units), The two galaxies approach for the first time at $t = 1.5$ but then go far apart, departing from the initial keplerian orbit. After the first approach, the *gas* of each galaxy exhibits the effects of tidal stripping in the form of moderate tails opposit to the sense of motion. Around $t = 4.5$ the two galaxies approach for the second time,

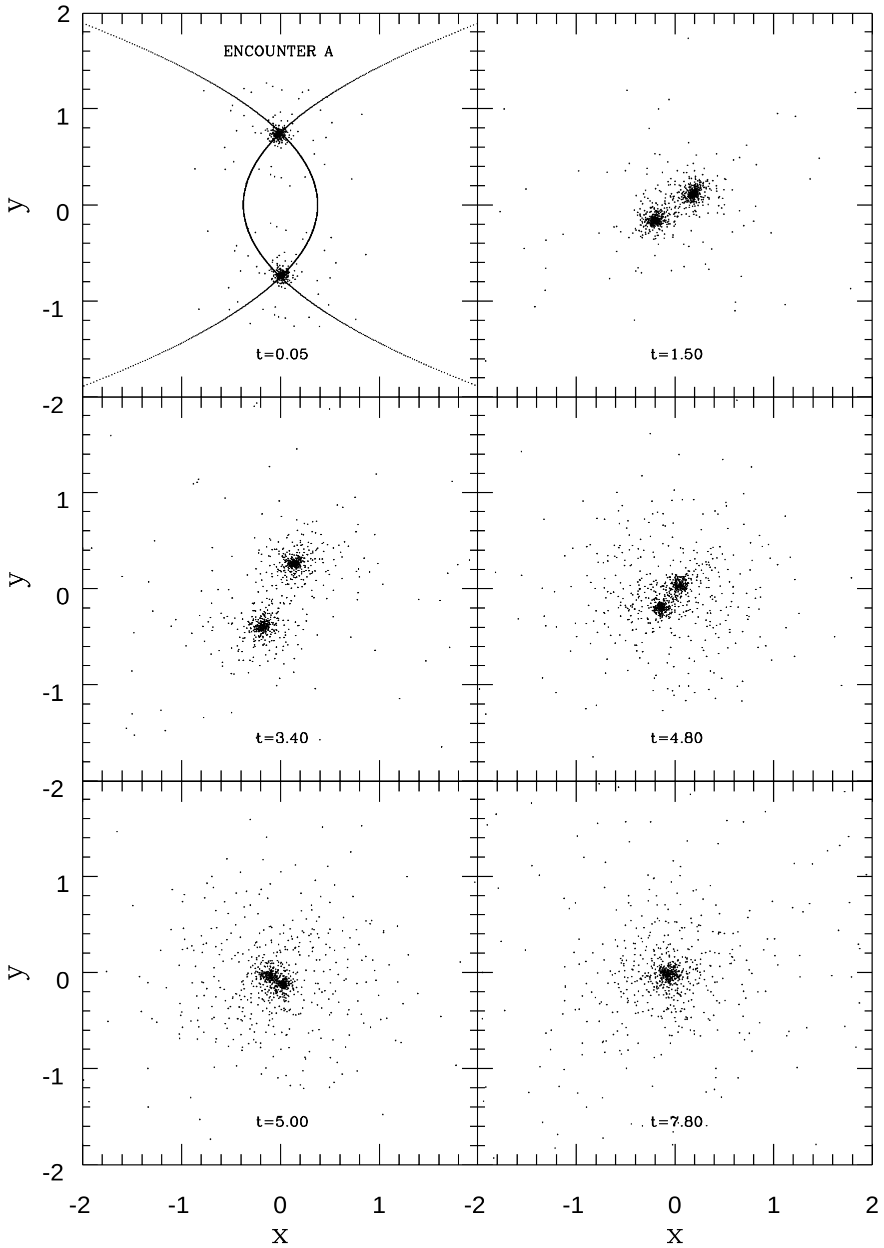

Figure 5: Merging evolution for the case A.

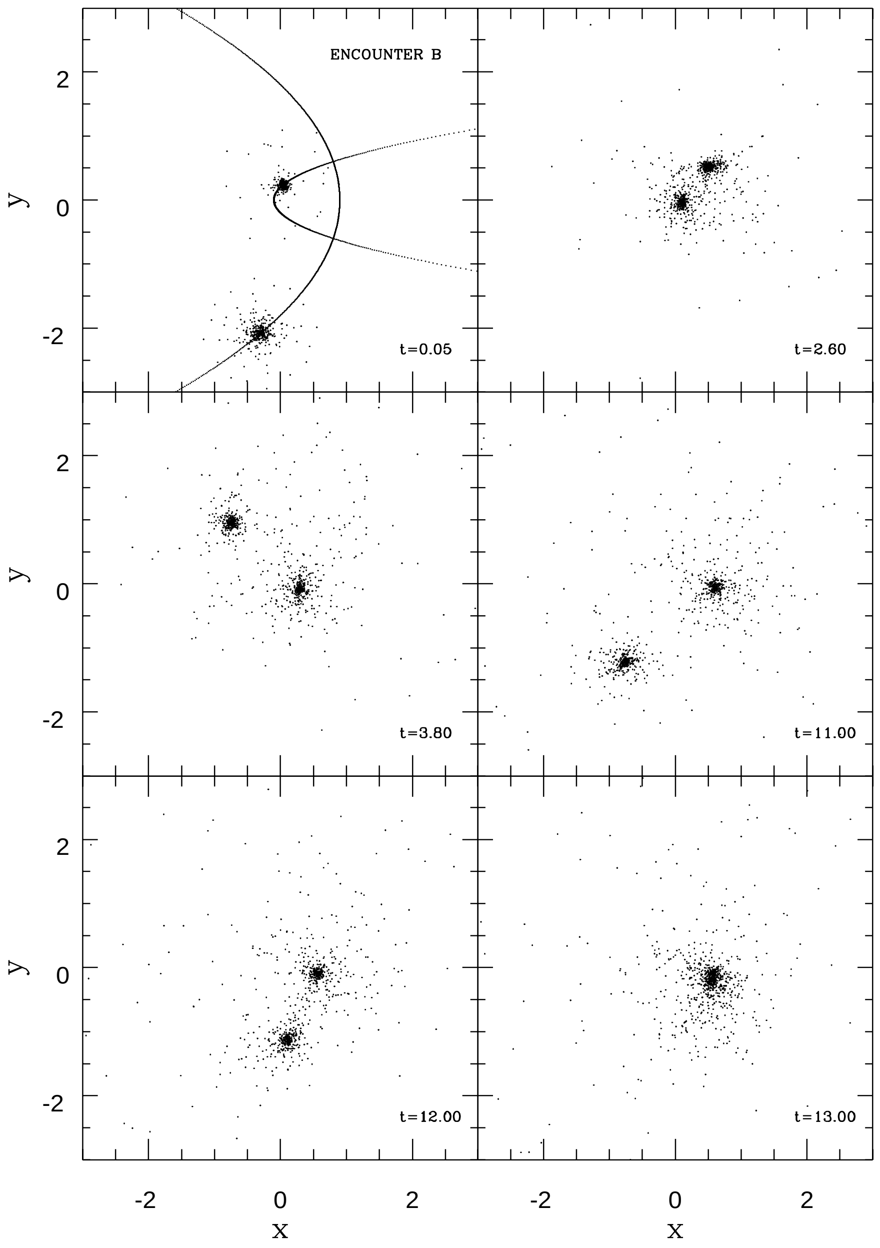

Figure 6: Merging evolution for the case B.

starting a slow merging that eventually leaves a round-shaped remnant at around $t = 7.8$

Encounter B (Fig. 6) is slower than encounter A. Galaxy 1 (mass 0.9) remains quite stationary, while galaxy 2, with a lower mass, orbits around galaxy 1. There is a close encounter around $t = 2.6$, then the two galaxies go far apart. After the first encounter, galaxy 2 continues its motion around galaxy 1 until it merges at around $t = 13.0$. It is interesting to notice that the gas of galaxy 2 is more spread out during the encounter B than during the encounter A.

4. Conclusions

This paper is a report on two ongoing projects in Galaxy Formation. Within the context of the monolithic collapse scenario we have proposed a possible explanation for the formation of a DM core in a dwarf elliptical, emphasising the role of secular processes related to stellar feedback. In the context of the merging scenario for the formation of ellipticals, we have presented preliminary results on the merging of two spiral-like galaxies for two cases with different mass ratios.

5. Acknowledgements

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