The Role of Gravitational Shock Heating in Isolated Ellipticals from Cosmological Simulations

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Any questions, comments or suggestions are very welcome. Please ask me! Or write me at: jose.onnorbe@uam.es

1. Introduction

Galaxy formation scenarios generally predict that galaxies are embedded into halos of hot diffuse gas, extending well beyond the distribution of stars. These halos are thought to consist of gravitationally trapped gas with a temperature of millions of Kelvin. It is important to remark the difficulty of studying the structure of hot gas halos around elliptical galaxies because it requires that they are as isolated as possible and this type of galaxies (specially the most luminous) are usually in dense environments.

The new generation of X-ray instruments (Chandra, XMM) confirms and extends previous findings in ellipticals [1]:

- Ellipticals, as clusters, are not baryonically closed. Why? Where are missing baryons?
- Observations link hot gas halo properties with intrinsic host galaxy. Origin of shock heating? Gravitation and/or feedback: AGN, Supernovas

2. Method: Cosmological Simulations

We used **DEVA** code [2]:

- Gravity: AP3M-like method + Hydrodynamics: SPH technique
- Star Formation: turbulent sequential star formation framework [3]. Empirical Kennicutt-Schmidt law [4]. Two runs with different parameters: **A** and **B**
- I.C.: Concordance cosmological model [5]
- Simulations runs, robustness of results:
  - Box size: 10, 20, 80 Mpc
  - Resolution: spatial 1.15, 0.55 kpc; mass $\sim 10^8+10^7$, 10^7+10^6
  - Cosmological model parameters (within ΛCDM model).
  - Star Formation parameters

Abstract & Some Definitions

Using a sample of elliptical-like objects (ELOs) obtained from self-consistent hydrodynamical simulations, we have studied the role of gravitational shock-heating in the stellar, gas and dark matter structural and kinematical properties from the galaxy scale up to the halo scale. We have found a systematic decrease of baryonic fraction with increasing ELO mass at all these scales. We have follow the ELO sample up to higher redshifts to study the origin of this effect that can have an important role in explaining the tilt of the Fundamental Plane and the lack of baryons observed at halo scales.

Isolated galaxies: In this work we considered isolated galaxies those that do not have companions with mass > $5\times10^9\ M_\odot$ up to their virial radius.

Cosmological simulations: We used DEVA code to follow the primordial perturbations up to nowadays by solving gravity and hydrodynamic evolution equations.

Shock heating: the nonisentropic heating of a fluid when a shock wave passes through it.

3. Elliptical Galaxies in the simulations

Elliptical-like-objects (ELOs): identified as those objects having a dynamically relaxed stellar spherical component with no disks.

ELO samples built at different redshifts: z=0, z=0.5, z=1, z=1.5

ELOs show a good agreement with observational data (Figs. 1 & 2):

Fundamental Plane

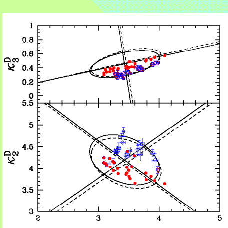

Fig. 1. Dynamical Fundamental Plane in kappa^D system [6]. Edge-on projection (top panel) and nearly face-on projection (bottom panel) of the dynamical FP of ELOs in the kappa^D variables (red filled symbols: A-Z0 sample; blue open symbols: B-Z0 sample). Concentration ellipses (with their major and minor axes) stand for the SDSS early-type galaxy sample from [7] in the z band (solid line) and the r band (dashed line). Error bars account for projection effects.

Stellar age population

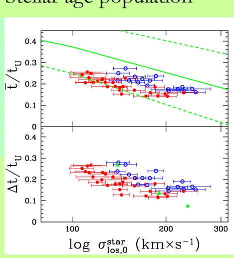

Fig. 2. Stellar properties. Upper panel: Mean age of the stellar population of our simulated ellipticals. Lower panel: The width of the stellar population age distribution from our ELO samples. In both panels, red filled circles stand for the A-Z0 sample and blue open circles for the B-Z0 sample. Error bars account for projection effects. Full green line (upper panel) and green triangles stand for observational data obtained by [8].

6. Conclusions

- ELOs are not baryonically closed at r_{vir}. They also show a clear trend with the mass: more massive ELOs have less baryonic content inside virial radius than less massive ones.
- Missing baryons inside r_{vir} appear as a hot gas corona outside virial radius. In our simulations ELOs seems to close at ~4-6 times the virial radius.
- The hot gas halos of ELOs in our simulations are the result of a continuous mass assembly process in the ΛCDM model. They are totally linked with shocks generated in accretion and merging processes.
- Gravitational shocking as a possible origin of the trends of hot gas halos properties with the host galaxy properties. Important role in explaining the tilt of the Fundamental Plane.

5. Where are the missing baryons?

- Baryonic fraction profiles present a typical pattern for all ELOs (Fig. 5):
  - high value at the center
  - decrease to a minimum
  - increase up to a maximum
  - decrease to cosmic value
- Missing baryons inside r_{vir} appear as a hot gas corona outside virial radius (Fig. 6).

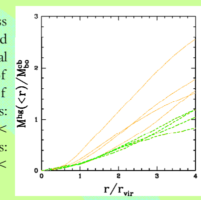

Fig. 6. The hot gas mass profiles normalized to the cold baryon content for typical ELOs. $M^{hg}(<r)$ is the mass of hot gas within a sphere of radius r. Orange point lines: ELOs with $1.5\times10^{12} < M_{vir} < 5\times10^{12}\ M_\odot$; green dashed lines: ELOs with $M_{vir} < 1.5\times10^{12} M_\odot$.

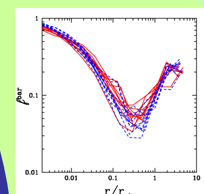

Fig. 5. Baryon fraction profiles in the same range of virial mass. $1.5\times10^{12}\ M_\odot < M_{vir} < 5\times10^{12}\ M_\odot$.

$$f^{bar}(r) = \frac{\rho^{bar}(r)}{\rho^{tot}(r)}$$

4. Baryonic content inside r_{vir}

- ELOs are not baryonically closed (Fig. 3)
- More massive ELOs show lower total baryon fraction inside their virial radii (Fig. 3)
- More massive ELOs are more effective in heating gas by shocks. ELOs are more effective as mass increases.
- Therefore less massive objects would have more baryons available to transform them to starts at the galaxy scale

⟹ Origin of the tilt of the FP (Fig 4) [9,10]

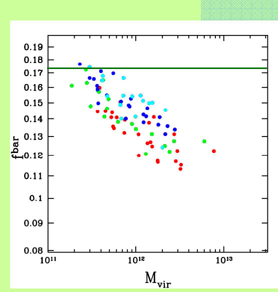

Fig. 3. Baryon fraction (baryon matter inside the virial radius over the total virial mass) at different redshifts for the Λ ELO samples. Green line stand for the cosmological value.

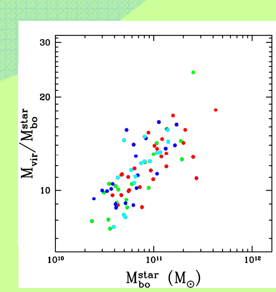

Fig. 4. The virial mass over the stellar mass of the central ELO as a function of the ELO stellar mass scale at different redshifts for the Λ ELO samples.

• z=0.0 • z=0.5 • z=1.0 • z=1.5

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