The effect of galaxy orbits on the outer regions of clusters: connections with the splashback radius

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Abstract: The outer regions of dark matter halos does not behave as expected: the density profile slope reaches a minimum and increases again (Diemer and Kravtsov 2014). The radius where this occurs is the splashback radius (More, Diemer, and Kravtsov 2015), and is related to the halo formation and evolution (Adhikari, Dalal, and Chamberlain 2014). To study this relation we simulated spherical collapse and orbit of galaxies in a cluster. We get that the splashback radius as a function of R_{200m} depends on the force of collapse (in terms of the virial ratio), while the minimum slope of the density profile can give us information about the halo mass. Recent splashback radius detection show us that studies like this will be increasingly important as a way to better understand the information we can get from the splashback features about halo formation and evolution.

Key-words: Extragalactic, Dynamical Evolution, Structures Formation, Numerical Simulations.

Introduction

Features in the outer regions of the cluster density profile (e.g. Fig 1) can be signatures of its formation and evolution (Diemer; Kravtsov, 2014). Adhikari, Dalal and Chamberlain (2014) showed that this signature is associated with the material that reaches its first pass through the apocenter. For this reason, the radius defined by the region of the lowest slope in the density

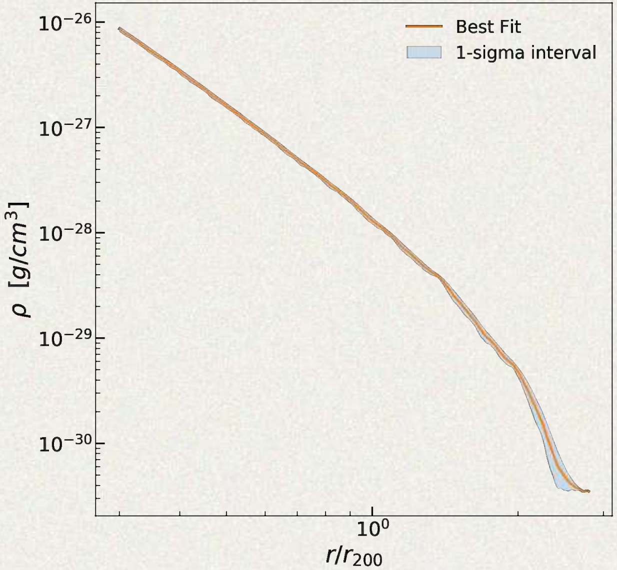


Figure 1: Density profile for the simulated cluster after the galaxy infall.

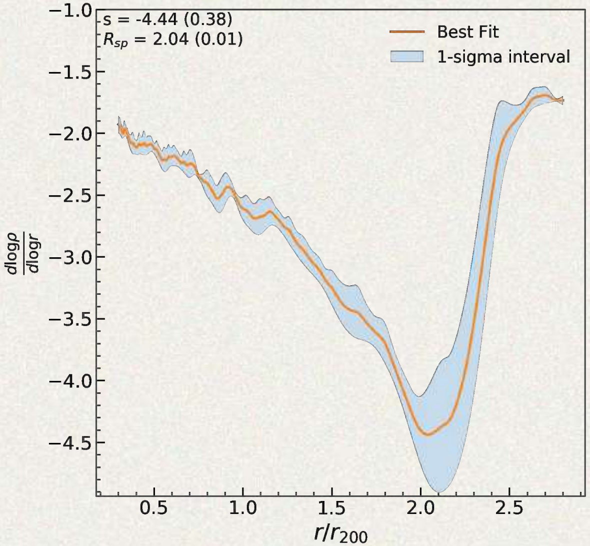


Figure 2: Density profile slope as function of the radius. R_{sp} is the splashback radius, i.e. the radius where we have the minimum slope s.

profile (e.g. Fig 2) is known as **splashback radius**, which may be the best option to define the physical limits of a halo, as suggested by More, Diemer and Kravtsov (2015). This project aims to study the specific effect of galaxy orbits on the outer region of a cluster. Thus, the result can be compared with theoretical studies about the splashback radius.

Materials and Methods

We used the NEMO package (Teuben 1995) to simulate a spherical collapse, representing a galaxy cluster, and the code for cosmological simulations Gadget-2 (Springel 2005) to simulate galaxy orbits in clusters (Figs. 3, 4 and 5). We performed N-body simulations with different parameters for each case. For the analysis, a script was developed that computes the cluster density profile and determines the splashback radius (Figs. 1 and 2).

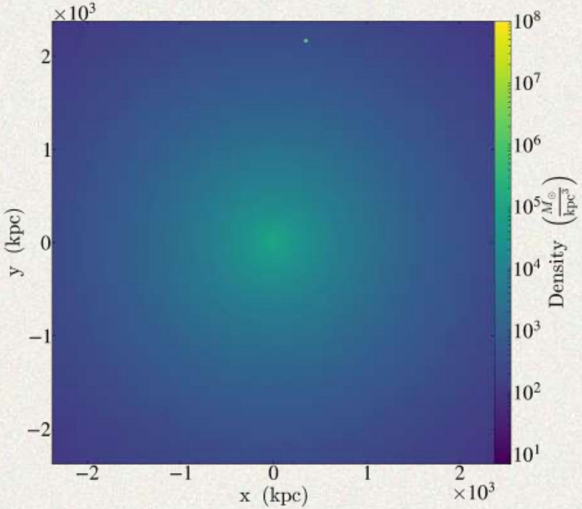


Figure 3: Projected surface density of the galaxy (the small structure in x = 270 kpc and y = 2000) in a cluster with M_{cl} = 8.9 x 10^{14} $M_\odot$ and R_{200} = 2164 kpc.

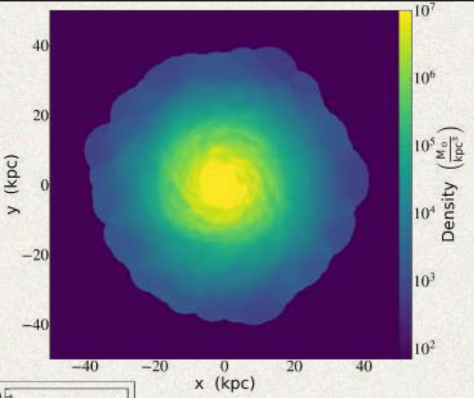


Figure 4: Projected surface density of the galaxy with M_g = 1.6 x 10^{11} $M_\odot$ before infalling in the cluster.

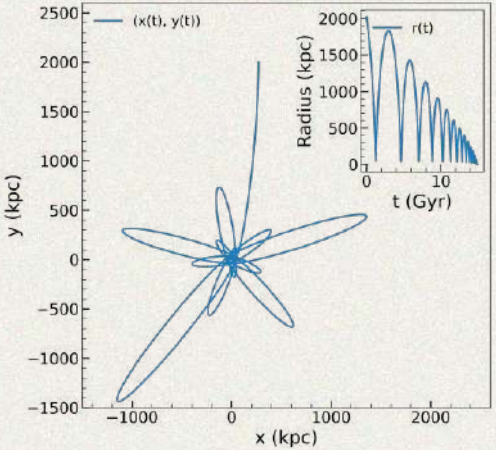


Figure 5: Semi-analytical model of a Galaxy (Fig. 4) orbit in a cluster (Fig. 3) with initial condition (x, y, z) = (270, 2000, 0) kpc and (v_x, v_y, v_z) = (0, -726, 0) km/s. The subplot is the radius as function of time.

Results

The analysis of the splashback radius through spherical collapse allowed us to identify the relation between its position in terms of R_{200m} as a function of the virial ratio (Fig. 6). With the simulated galaxy orbits in clusters we noticed a strong drop in slope that relates to the cluster mass and the effect of the galaxy-cluster interaction (Fig. 7).

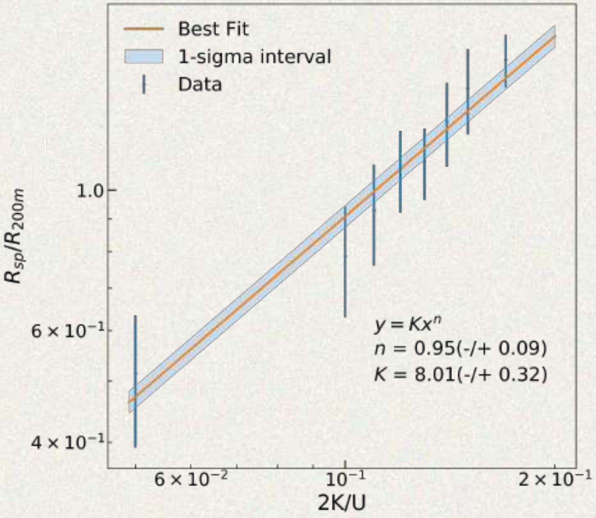
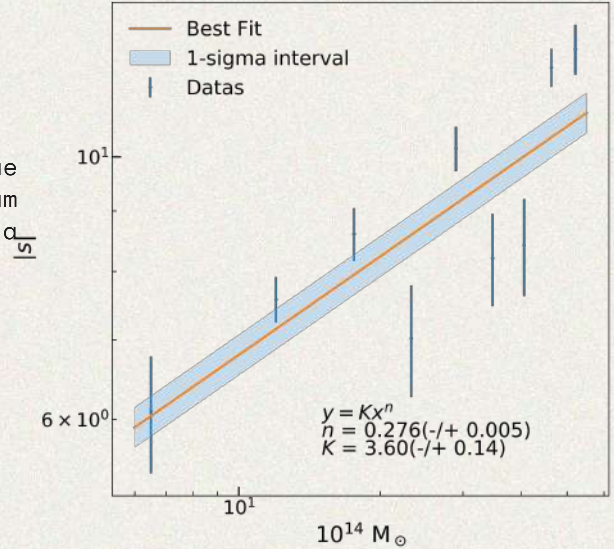


Figure 6: Splashback radius in terms of R_{200m} as a function of the virial ratio, i.e. ratio between twice the kinetic energy and the potential energy.

Figure 7: Absolute value of the minimum slope |s| as a function of the cluster mass.



Since the cluster is generated with a Hernquist profile (Hernquist 1990), the splashback feature is only due this interaction. This demonstrates that analyzing the splashback radius is important to have a better insight about the informations we can get with its feature.

Conclusions

How does each process (the primordial collapse and the matter accretion) contribute to what we observe today in the outer region of a cluster? Simulations with more galaxies and even considering cluster merger with groups or another clusters can give us more clues about what we can expect due to the accretion of matter and about how the splashback radius depends specifically on each cluster interactions. For this, we are recently doing new simulations with different parameters and initial conditions. Expanding the analysis can bring us new insights into the galaxy-cluster interaction and its impact on the density profile, with a focus on the splashback radius. This study is important in the light of new works related to this topic, including splashback radius detection (e.g. Bianconi et al. 2021) and analysis of this feature in different components of the cluster (e.g. Dacunha et al. 2021).

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