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

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Abstract. Self-gravitational extragalactic systems are structures of different scales, from galaxies to galaxy clusters, whose formation and evolution are governed by gravitational interactions. This work aims to study and analyze quantitatively different aspects and phenomena associated with the galaxy-cluster interaction, with special attention to features in the cluster dark matter density profile, such as the splashback radius.For this, we simulated spherical collapse and orbit of galaxies in a cluster with `Gadget2` and `NEMO/gyrfalcON`. 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. Each process (the primordial collapse and the matter accretion) contribute to the splashback feature. So, what information can we get from this signature? Expanding the analysis can bring us new insights into the galaxy-cluster interaction and its impact on the density profile.

Resumo. Sistemas extragalácticos autogravitacionais envolve estruturas de diferentes escalas, desde galáxias a aglomerados de galáxias, cuja formação e evolução são regidas por interações gravitacionais. Este trabalho tem como objetivo estudar e analisar quantitativamente diferentes aspectos e fenômenos associados à interação galáxia-aglomerado, com atenção especial às assinaturas presentes no perfil de densidade de matéria escura do aglomerado, como o raio de *splashback*. Para isso, simulamos colapso esférico e órbitas de galáxias em um aglomerado com `Gadget2` e `NEMO/gyrfalcON`. Com isso, obtemos que o raio do *splashback* em função de R_{200m} depende da força de colapso (em termos da razão virial), enquanto a inclinação mínima do perfil de densidade pode nos fornecer informações sobre a massa do halo. Cada processo (o colapso primordial e o acréscimo de matéria) contribui para a assinatura de *splashback*. Então, quais informações podemos obter disto? Expandir a análise pode nos trazer novos *insights* sobre a interação galáxia-aglomerado e seu impacto no perfil de densidade.

Keywords. Galaxies: clusters: general – Galaxies: evolution – Methods: numerical

1. Introduction

Features in the outer regions of the cluster density profile can be signatures of its formation and evolution. Despite what is expected from dark matter collapse models, the density profile slope become extremely steep over a narrow range of radius in the outer regions (i.e. $0.1 < r/R_{\mathtt{vir}} < 9$) of dark matter halos in simulations Diemer & Kravtsov (2014). Through a systematic study of simulated halos with `GADGET2` (Springel 2005), they found that the slope of the density profile reach the smallest value near to the R_{200m} (i.e. radius where the average matter density of the halo is 200 times the matter density of the universe), and increasing again when increasing the radius.

These features are produced by a caustic, related with the material that reaches its first passage through the apocenter (Diemer & Kravtsov 2014; Adhikari et al. 2014; Shi 2016,?). For this, the radius defined by the region with the lowest slope in the density profile became known as *splashback radius* (R_{sp}), and can separate between the material already collapsed and the infalling material (Diemer 2021; O'Neil et al. 2022).

Due this dependence, some works suggest the use of splashback radius as the best option to define the physical limits of a halo than the commonly used choices , such as R_{200} (i.e. radius where the average density of the halo is 200 times the critical density of the universe) (e.g. More et al. 2015) which can hide traces of evolution in the outer regions, especially for high redshift (e.g. Cuest et al. 2008; Diemer et al. 2013). Rather than using the halo physical properties, these definitions are made by fixing the halo average density (O'Neil et al. 2022). This can lead to non-physical growth because even if a halo has no matter accretion, M_{200} (i.e. mass in a sphere with radius R_{200m}) can increase due to change in critical density of the universe and consequently change in R_{200} (e.g. More et al. 2015).

In the context of the dark matter halos, galaxy clusters are the largest and dynamically younger structures (Kauffmann et al. 1999; Dehnen et al. 1985). They are formed and evolve by accretion of dark matter, gas, galaxies and galaxies groups. Current studies detected the splashback radius of galaxy clusters (e.g. Bianconi et al. 2021) and related this to the matter accretion history of these structures. Understanding the relation between the galaxies cluster evolution and the splashback radius, with all different estimations, can provide us information about the formation and evolution of cluster that we observe. Also, this is essential to have a better comprehension about the structures formation in our universe.

In this work, we study the galaxy accretion by a cluster, with attention to the splashback radius. We aims to get clues about how different conditions in the initial conditions of this interaction can affect the splashback radius defines by the dark matter density profile. For this, we use `GADGET4` (Springel et al. 2021) to simulated galaxies falling in a cluster. This allows to perform a systematic and controlled study of different conditions in the cluster-galaxy relation. With this approach we can discern the features that only one galaxy can imprint in the dark matter halo and how this may influence our interpretation of the formation and accretion halo history.

2. Methodology

We used the `NEMO` package Tauben (1995) to simulate a spherical collapse, representing a galaxy cluster, and the code for cosmo-

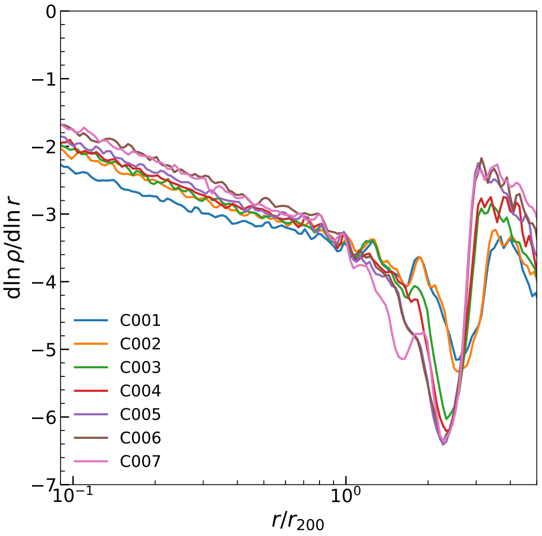

Figure 1. Density profile slope as function of the radius. Velocity dispersion profile. All cases have the same galaxy and initial conditions, with different clusters. C001 is the smallest ($M = 8.9 \times 10^{14} \mathrm{M}_{\odot}$) and C007 is the largest ($M = 34.4 \times 10^{14} \mathrm{M}_{\odot}$). The initial conditions of the galaxy are $(x, y, z) = (351, R_{200}, 0)$ kpc and $(v_x, v_y, v_z) = (0, -724, 0)$ km/s.

logical simulations `Gadget-2` Springel (2005) and `Gadget-4` Springel et al. (2021) to simulate galaxy orbits in clusters. We performed N-body/hydrodynamical simulations with different parameters for each case. In this way, it was possible to verify the dependence of the splashback feature with the conditions of the interaction. For the analysis, a script was developed that computes the cluster density profile and determines the splashback radius (Fig. 1). We also compute the velocity dispersion profile and study the caustic feature.

3. Results and Conclusions

The analyzes allowed us to get relations between the interactions parameters and the splashback radius features. The strength of the collapse (in terms of the virial ratio) is related to the relative position of the splashback radius, while the density profile slope value at R_{sp} is related to the halo mass (Figs. 2 and 2).

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 have recently started running new simulations with different parameters with focus on: the cluster mass, the impact parameter and the galaxy initial velocity. Expanding the analysis can bring 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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References

Adhikari S., Dalal N., Chamberlain R. T., 2014, J. Cosmology Astropart. Phys., 2014, 019

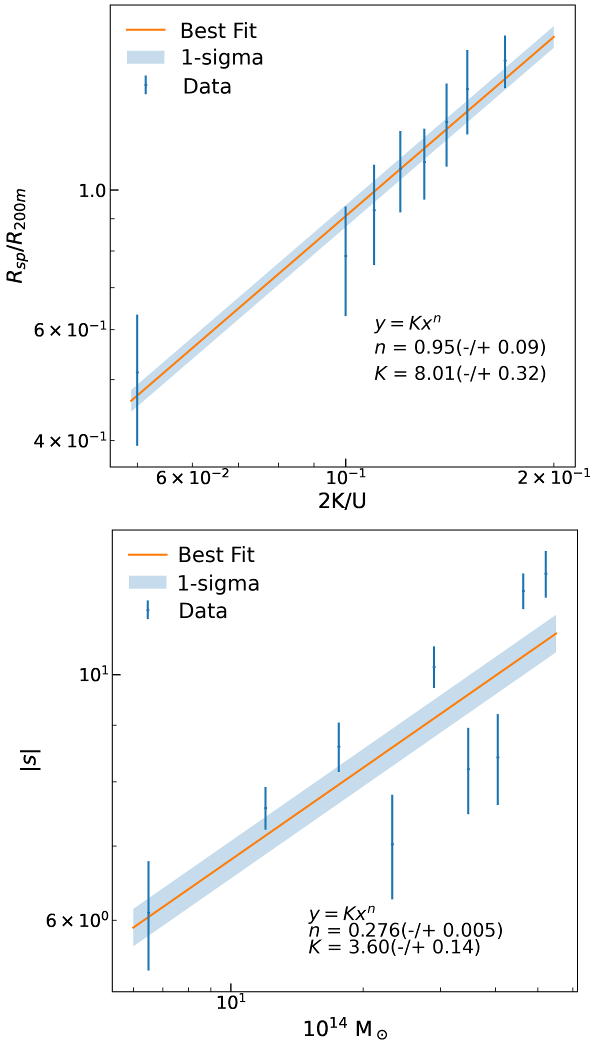

Figure 2. `First`: Splashback radius as a function of $2K/U$ for spherical collapse with an initial radius of $R = 2.0$ in `NEMO` units. `Second`: Absolute value of the slowest density slope $|s|$ as a function of cluster mass. In each case, the points are the simulation data, with its uncertainty; the orange line is the fit with the shaded region indicating a range of 1σ.

Bianconi M., Buscicchio R., Smith G. P., et al., 1984, Nature, 311, 517
Cuesta A. J., Prada F., Klypin A., et al., 2008, MNRAS, 389, 385
Dacunha T., Belyakov M., Adhikari S., et al., 2022, MNRAS, 512, 4378
Davis M., Efstathiou G., Frenk C. S., et al., 1985, ApJ, 292, 371
Dehnen W., 1993, MNRAS, 265, 250
Diemer B., 2020, ApJ, 903, 87
Diemer B., 2021, ApJ, 909, 112
Diemer B., Kravtsov A. V., 2014, ApJ, 789, 1
Diemer B., More S., Kravtsov A. V., 2013, ApJ, 766, 25
Kauffmann G., Colberg J. M., Diaferio A., et al., 1999, MNRAS, 303, 188
Lithwick Y., Dalal N., 2011, ApJ, 734, 100
More S., Diemer B., Kravtsov A. V., 2015, ApJ, 810, 36
O'Neil S., Barnes D. J., Vogelsberger M., Diemer B., 2021, MNRAS, 504, 4649
O'Neil S., Borrow J., Vogelsberger M.,et al., 2022, MNRAS, 513, 835
Shi X., 2016a, MNRAS, 459, 3711
Shi X., 2016b, MNRAS, 461, 1804
Springel V., 2005, MNRAS, 364, 1105
Springel V., Pakmor R., Zier O., et al., 2021, MNRAS, 506, 2871
Teuben, P. In: Shaw, R. A.; Payne, H. E.; Hayes, J. J. E. (Ed.). Astronomical Data Analysis Software and Systems IV. [S.l.: s.n.], 1995. Astr. Soc. of the Pacific Conference Series