

Dark matter deficient galaxies in hydrodynamical simulations

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Resumen / Las galaxias deficientes en materia oscura perdieron sus halos de materia oscura debido a interacciones durante su evolución; en particular, durante su historia de fusión. La existencia de este tipo de galaxias es un tema controversial en la literatura, tanto desde el punto de vista observacional como teórico. En este trabajo, estudiamos la población de galaxias deficientes en materia oscura en las simulaciones hidrodinámicas IllustrisTNG, las cuales siguen la evolución de las partículas de materia oscura y de materia bariónica. Analizamos la distribución de estas galaxias dentro de sus respectivos halos anfitriones, así como también cómo cambia esta distribución con el corrimiento al rojo. El objetivo de este trabajo es obtener información acerca de cómo se forman estas galaxias y cómo evolucionan sus poblaciones.

Abstract / Dark matter deficient galaxies have lost their dark matter halos due to interactions during their evolution; in particular, during their fusion history. The existence of these galaxies is a debated subject, both from the observational and theoretical points of view. In this work, we study the population of dark matter deficient galaxies in the hydrodynamical simulation IllustrisTNG, which follows the evolution of dark matter and baryonic matter. We analyse the distribution of these galaxies within the host halo, and how this distribution changes with redshift. The aim of this study is to gather information about how these galaxies are formed, and how their population evolves.

Keywords / galaxies: dwarf — galaxies: evolution — galaxies: formation — dark matter

1. Introduction

In the ΛCDM model, dark matter is the dominant mass component of the universe, and structure formation takes place through gravitational collapse of dark matter halos. Galaxies form within them, with a mechanism that involves many different baryonic processes. In this standard model, it is expected that halos are dominated by dark matter, specially low mass halos. Indeed, low-mass galaxies are expected to be dark-matter-dominated even within their central regions.

Interestingly, recent observations suggest that some of these low-mass galaxies may have very low dark matter fractions. For example, Guo et al. (2020) report 19 dwarf galaxies that could consist mainly of baryons up to radii well beyond their optical-light half-radii ($r_e \approx 1$ kpc). Previously, two dwarf galaxies with low dark matter content were reported, NGC1052-DF2 (van Dokkum et al., 2018) and NGC1052-DF4 (van Dokkum et al., 2019), in group environments. However, Montes et al. (2020) presented observational evidences that favour the scenario in which dark matter has been stripped out of the dwarf galaxy NGC1052-DF4 due to tidal interactions with its neighbouring galaxy NGC1035.

While the observational evidence for the existence of these dark matter deficient galaxies (DMDGs) is not completely established, some works have been carried out from the point of view of simulations, to try to clarify if their existence is pausible within the standard model, and which could be their possible formation channels. Jing et al. (2019) explore the population and origins of DMDGs in two hydrodynamical simulations, the EAGLE (Schaye et al., 2015; Crain et al., 2015) and Illustris (Genel et al., 2014; Vogelsberger et al., 2014) projects. They focus on satellite galaxies with masses in the range $10^9 - 10^{10}$ M$_\odot$ in groups with $M_{200} > 10^{13}$ M$_\odot$. Shin et al. (2020) use high resolution simulations to explore the possibility that DMDGs could be produced when two gas-rich, dwarf galaxies collide with a high relative velocity. In this scenario, as a result of the collision, the dark matter would separate from the warm disk gas which subsequently would be compressed by shock and tidal interaction to form stars. However, these authors did not find evidence that these types of collisions actually produced DMDGs in the TNG100-1 run of the IllustrisTNG project (Nelson et al., 2019).

In this work, we present some preliminary results of our study using IllustrisTNG simulations, to analyze the population of DMDGs at different epochs. Our aim is to study this population at different redshifts, as a function of the mass of the host galaxy, in order to find hints of which could be the mechanism by which those satellite galaxies lose most of their dark matter halo.

2. Methodology

The IllustrisTNG project is a suite of state-of-the-art cosmological galaxy formation simulations. It consists

Redshift	$M_{\rm host}$ [M$_\odot$]	# Satellites	# DMDGs
$z = 0$	3.89×10^{14}	17 184	39
$z = 0.4$	1.85×10^{14}	7 718	32
$z = 1$	1.09×10^{14}	4 948	26
$z = 2$	3.05×10^{13}	1 501	8

Table 1: Population of DMDGs in the most massive halos at different redshifts. The columns inform the redshift z, the mass of the most massive halo, the number of satellites halos, and how many of them are DMDGs.

of hydrodynamical simulations in which the evolution of different components (dark matter, gas, stellar mass, black holes) is studied. The set of simulations are of high resolution in mass, for all of the particle types. Three physical simulation box sizes are available: cubic volumes of roughly 50, 100, and 300 Mpc side length. In this project, we use the TNG100 data at redshifts $z = 0, 0.4, 1, 2$, to study dark matter deficient galaxies. The selected simulation box has $(106.5\ \rm Mpc)^3$ comoving volume that contains 1820^3 dark matter particles and 1820^3 gas cells. The mass of the baryon and dark matter particles are 1.4×10^6 M$_\odot$ and 7.5×10^6 M$_\odot$, respectively.

To analyse the dark matter fraction within the central regions of subhalos, we select the dark matter mass $M_{\rm dm}$, and the total mass $M_{\rm tot}$ contained within twice the half-light radius ($2R_h$) for each subhalo. We focus on the population of satellite galaxies of the most massive halo of the simulation. We also compute their halo-centric distances (i.e. the distance to their host halo). We repeat this analysis in each of the snapshots corresponding to the studied redshifts. We measure the dark matter fraction as $f_{\rm dm} = M_{\rm dm}/M_{\rm tot}$, and define DMDGs as galaxies characterized by $f_{\rm dm} < 0.5$.

3. Results

At each redshift, we select the satellite galaxies of the most massive host halo, and compute their dark matter fraction. In Table 1, we provide details about the DMDG population amongst the satellites of the most massive halos at different redshifts (which are not necessarily the same halo at each analysed redshift). While dark matter dominates the total mass budget of the majority of the satellite galaxies within $2R_h$, we have found that a few percent of galaxies have a dark matter fraction below 50%. This percentage of dark matter deficient galaxies over the total amount of satellite galaxies is higher at higher redshifts: we found that at $z = 2$ there is a percentage of 0.53%, while at $z = 0$ it decreases to 0.23%.

We plot the dark matter fraction $f_{\rm dm}$ as a function of the halo-centric distance, r/R_{200}, for each subhalo at the different redshifts in which the DMDGs were studied. The results for redshift $z = 0, 0.4, 1,$ and 2, are shown in Figures 1, 2, 3, and 4, respectively. We color-coded the total mass of the subhalo, in order to easily identify any relationship between the dark matter fraction and the mass of the satellite. Furthermore, we can investigate from these plots the position of the DMDGs in their host halo. We see that at higher redshifts, there are

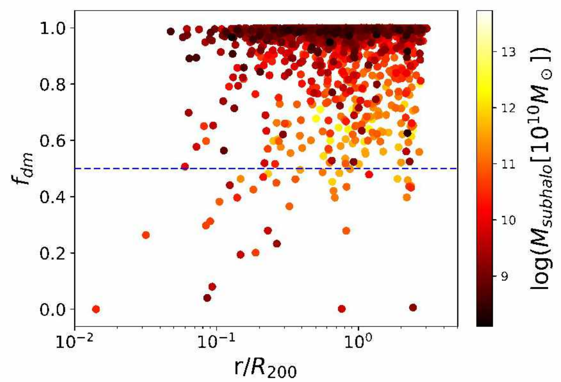

Figure 1: Dark matter fraction $f_{\rm dm}$ as a function of halo-centric distance at $z = 0$, for the subhalos of the most massive host.

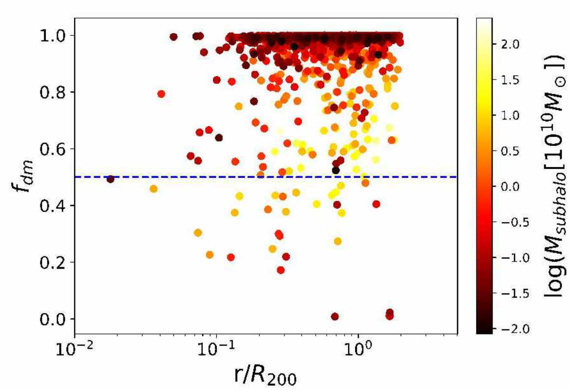

Figure 2: Dark matter fraction $f_{\rm dm}$ as a function of halo-centric distance at $z = 0.4$, for the subhalos of the most massive host.

more massive DMDGs with respect to what is observed at lower redshifts. This might indicate that the satellite loses part of their dark matter halo well in advance, and continues to lose mass as it evolves. This investigation is a work in progress.

We tracked down the DMDGs found at $z = 0$ to see if they matched the ones found at $z = 0.4, 1$ and 2. We found that some of them can be found at $z = 0.4$ and some others, besides being present at $z = 0.4$, can also be found at $z = 1$, but none of them are present at $z = 2$.

Fig. 5 shows the distribution of DMDGs as a function of their total mass, for redshifts $z = 0, 1,$ and 2, considering the complete subhalo sample, and not only the most massive halo. We notice that the mass of the DMDGs increases with increasing redshift.

The bimodality observed in each panel of Fig. 5 can be explained by our criterion to select DMDGs within $2R_h$. Indeed, for the most massive subhalos, a compact galaxy is formed in the central region, hence the $2R_h$ decreases and the dark matter contained within this region is lower. We detect this as a DMDG in the central region, although the subhalo is not dark matter defi-

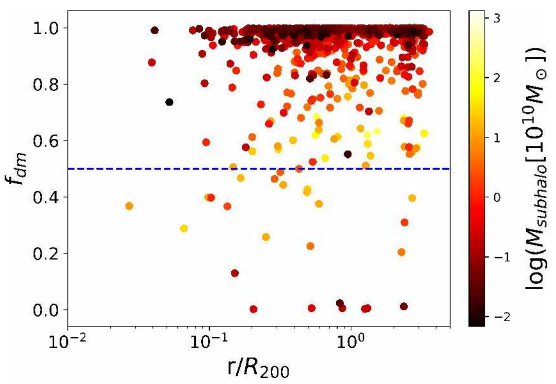

Figure 3: Dark matter fraction $f_{\rm dm}$ as a function of halo-centric distance at $z = 1$, for the subhalos of the most massive host.

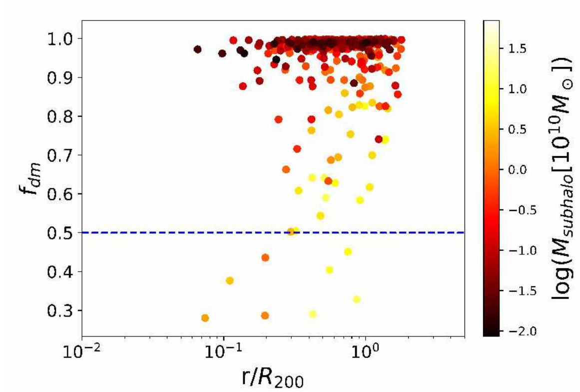

Figure 4: Dark matter fraction $f_{\rm dm}$ as a function of halo-centric distance at $z = 2$, for the subhalos of the most massive host.

cient when all the mass is taken into account. On the other hand, low mass subhalos remain to be dark matter deficient when considering the total mass. This will be explored in more detail in a future paper.

4. Conclusions and future goals

We found that DMDGs are allowed in current galaxy formation models, as can be seen in state-of-the-art hydrodynamical cosmological simulations. In the future, we plan to track down the dark matter deficient galaxies found at $z = 0$ in order to study their evolution and mass-loss history. We will also study the environment in which the DMDGs appear, to see if there is a dependence of the abundance of deficient dark matter subhalos on the properties of the environment. We will repeat the analysis shown in this work for different mass ranges of the host halo, at various redshifts, to study if there is a dependence of the population of dark matter deficient galaxies with the mass of the host.

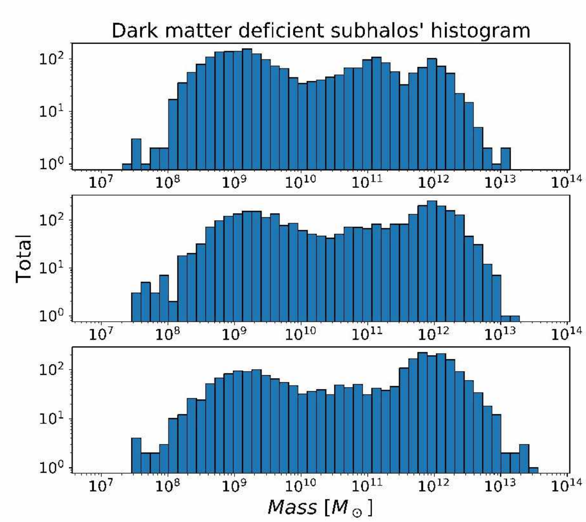

Figure 5: Distribution of the total number of DMDGs as a function of their mass, at $z = 0$ (*top panel*), $z = 1$ (*middle panel*) and $z = 2$ (*bottom panel*).

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