Dark Matter 2021: from the smallest to the largest scales

Dark-matter-deficient galaxies in the hydrodynamical simulation IllustrisTNG

Elisa Tau & Claudia Scóccola

Outline

1. Context and motivation
2. Methodology
3. Characterization of the sample
4. Results:
    a. Analysis of the DMDGs population
    b. Comparison between IllustrisTNG100 and IllustrisTNG50
    c. Formation history and evolution of the DMDGs
5. Summary and conclusions

Context and motivation

In the standard cosmological model, ΛCDM, dark matter is the dominant mass budget of the Universe. Even low-mass galaxies are expected to be dark-matter-dominated, at least within their central regions.

However, recent observations suggest that some low-mass galaxies may have very low dark matter fractions[1,2]. These galaxies would be dark-matter-deficient, and this makes them a very interesting object of study.

There are some studies in the literature that address this problem using hydrodynamical simulations (EAGLE[3], ILLUSTRIS[3], NewHorizon[4]). In this talk, we present the results of our study using IllustrisTNG simulations, to analyze the population of dark matter deficient galaxies.

[1] Oh S.H. et al., 2015, AJ, 149, 180.
[2] Guo, Q. et al., 2019, Nature Astronomy, 4, 246.
[3] Jing, Y. et al., 2019, MNRAS 488, 3, 3298.
[4] Jackson, R., et al. 2021, MNRAS 502, 2, 1785.

Methodology: IllustrisTNG

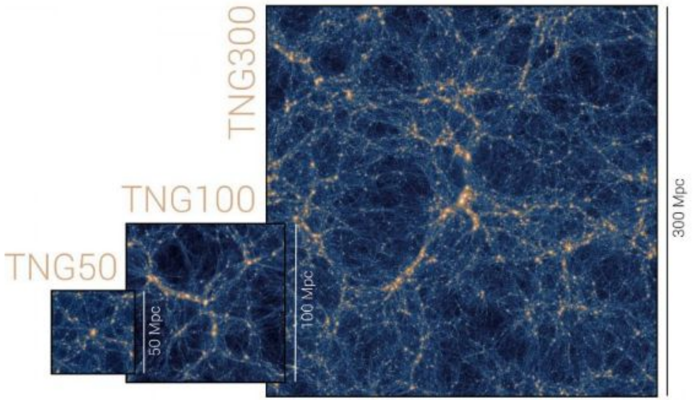
The IllustrisTNG project is a suite of state-of-the-art cosmological galaxy formation simulations. It consists of hydrodynamical simulations in which the evolution of different components (dark matter, gas, stellar mass, black holes) is studied. The set of simulations are of high resolution in mass, for all of the particle types.

Three physical simulation box sizes are employed: cubic volumes of roughly 50, 100, and 300Mpc side length. In this project, the TNG100 data at redshifts z = 0, 0.1, 0.4, 1 and 2 were used to study dark matter deficient galaxies. Afterwards, we studied this population at z = 0 using the TNG50 due to its better resolution.

The dark matter fraction is measured as $f_{DM} = M_{DM}/M_{tot}$. Dark matter deficient galaxies (DMDGs) are defined as those with a dark matter fraction below 50%.

$f_{DM}(tot)$

$f_{DM}(2R_h)$



Characterization of the sample

TNG100

Halos

- z = 0: 6,291,349 halos
- z = 0.1: 6,396,059 halos
- z = 0.4: 6,529,597 halos
- z = 1: 6,736,881 halos
- z = 2: 6,864,573 halos

Found using the FoF algorithm

Subhalos

- z = 0: 4,371,211 subhalos
- z = 0.1: 4,449,889 subhalos
- z = 0.4: 4,685,322 subhalos
- z = 1: 5,127,294 subhalos
- z = 2: 5,621,338 subhalos

Found using the SUBFIND algorithm

TNG50

- **Halos:** 10,247,012 at z = 0
- **Subhalos:** 5,688,113 at z = 0

For the analysis of the $f_{DM}(2R_h)$ we only considered those subhalos with a defined R_h.

Results: analysis of the DMDGs population

Using TNG100, we have found that a small percentage of galaxies have a dark matter fraction below 0.5 at each studied redshift, either when considering only the mass within the central region of the subhalo or its total amount.

Redshift	# of considered subhalos	# of DMDGs	# of considered subhalos ($2R_h$)	# of DMDGs ($2R_h$)
z = 0	4,371,211	1,410	203,284	2,402
z = 0.1	4,449,889	1,435	211,282	2,431
z = 0.4	4,685,322	1,516	235,400	2,808
z = 1	5,127,294	1,416	286,505	3,185
z = 2	5,621,338	872	368,354	2,532

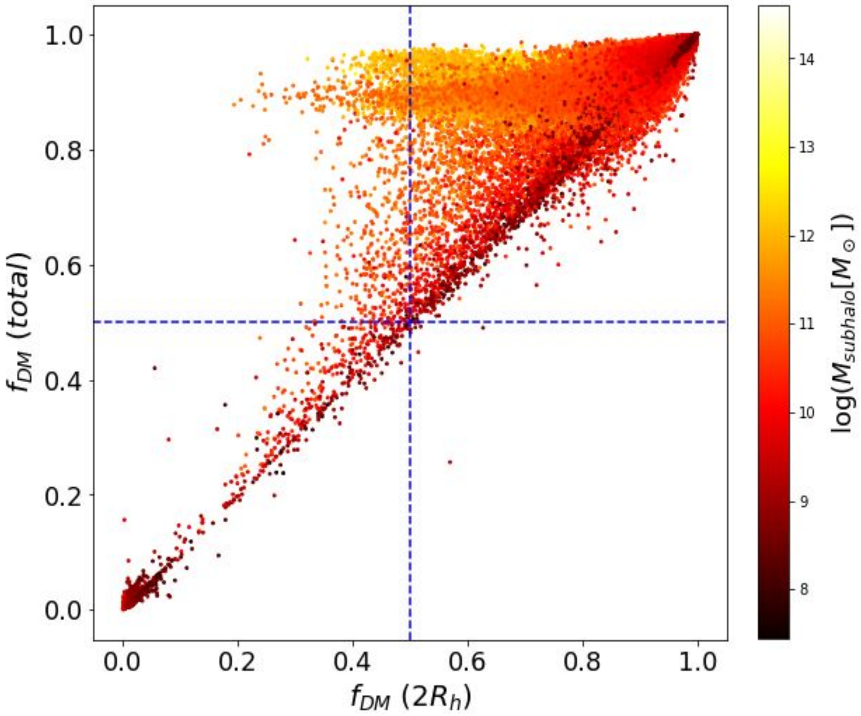
We also found a few percentage of DMDGs at z = 0 using TNG50, either when considering only the mass within the central region of the subhalo or its total amount.

Redshift	# of considered subhalos	# of DMDGs	# of considered subhalos ($2R_h$)	# of DMDGs ($2R_h$)
z = 0	5,688,113	912	98,714	1,171

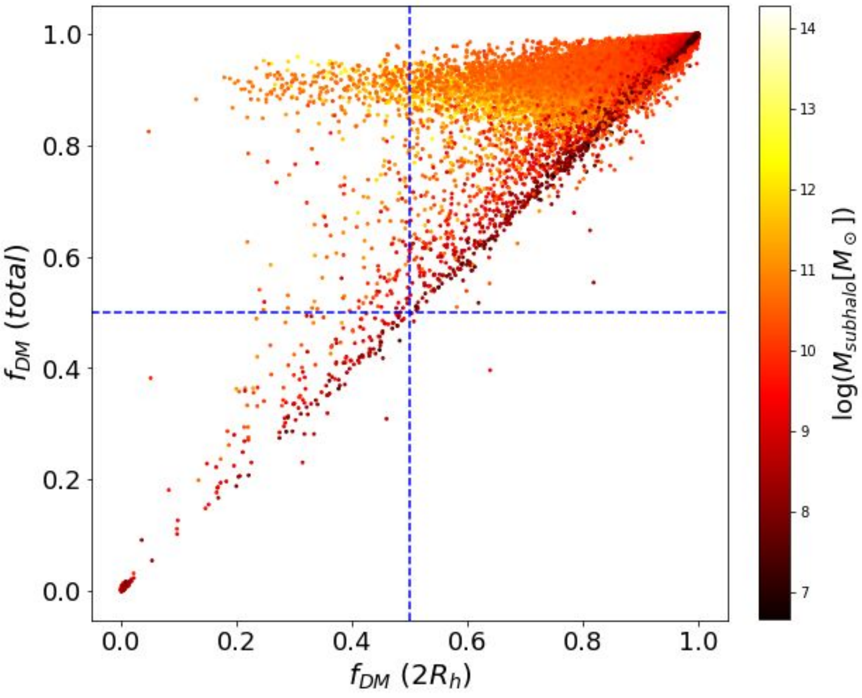
Results: comparison between TNG100 and TNG50

The subhalos that are DMDGs($2R_h$) and DMDGs(tot) have low masses in both TNG100 and TNG50.

TNG100

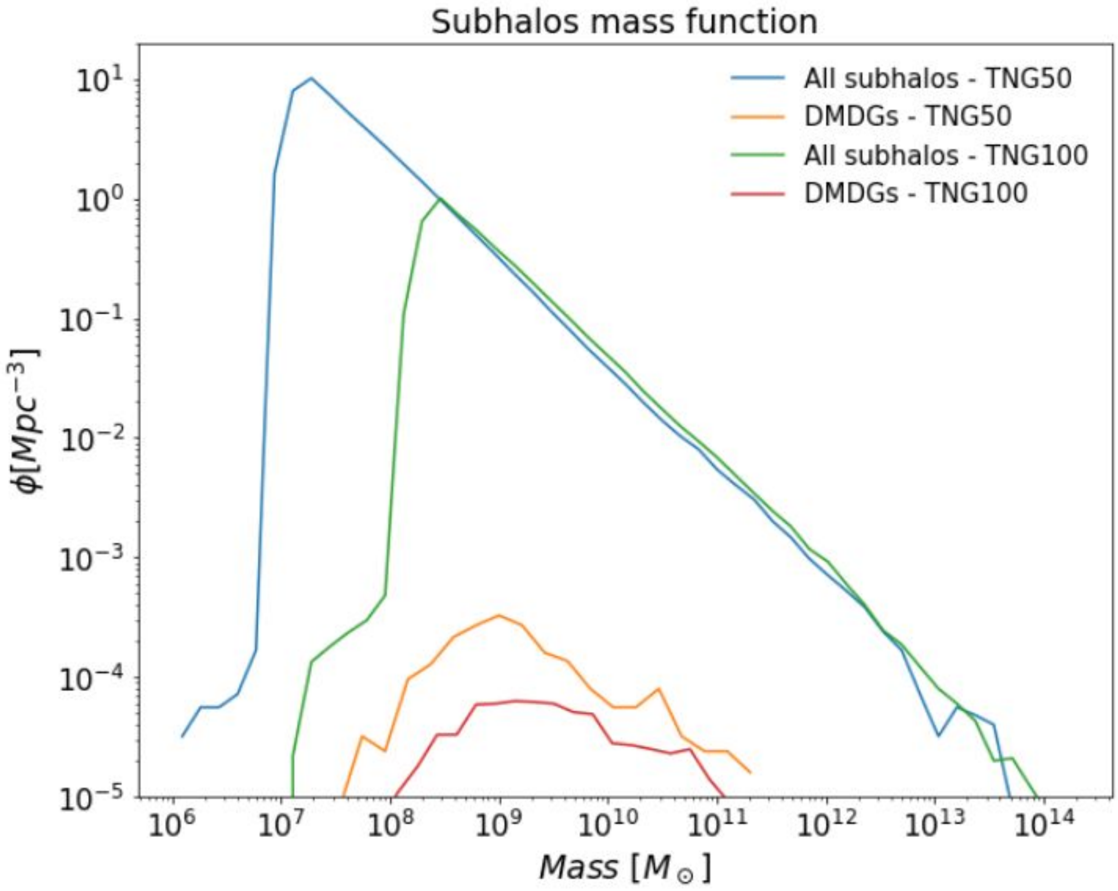


TNG50



z = 0

We then studied the subhalo mass function at z = 0 for TNG100 and TNG50, as well as the DMDGs mass function for both simulation boxes.
More low-mass subhalos are present in TNG50 due to its better resolution.

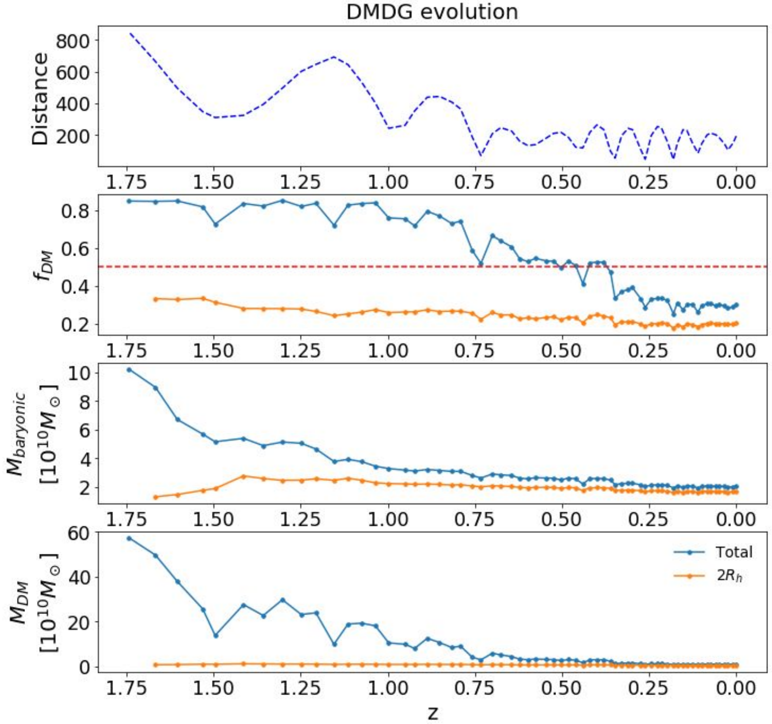


We only selected the DMDGs that have a cosmological origin.

Results: DMDGs evolution history

TNG100

ID = 92 at z = 0



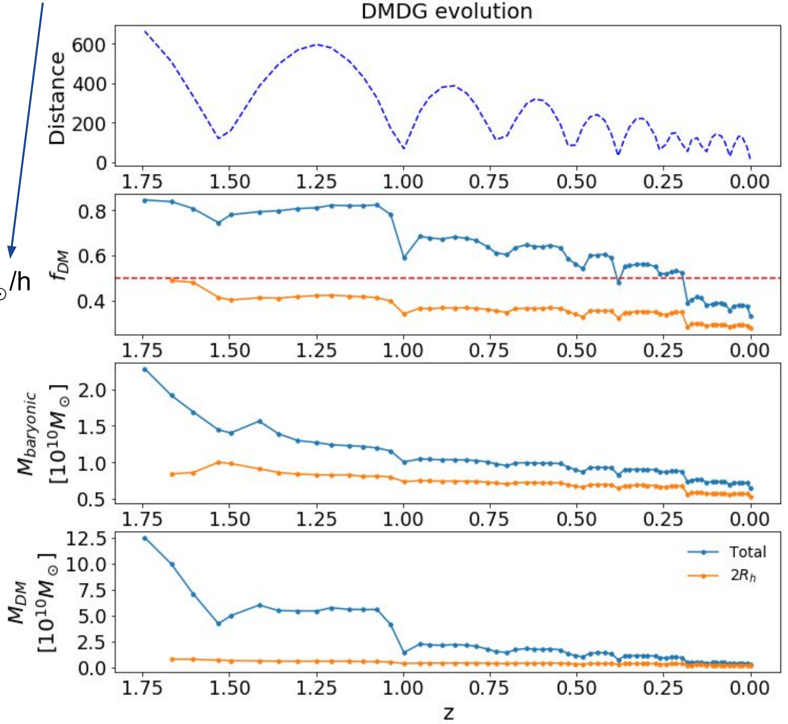
M_{tot} at z_{acc}: 67.7 × 10^{10} $M_\odot$/h
M_{tot} at z = 0: 2.96 × 10^{10} $M_\odot$/h

M_{tot} at z_{acc}: 14.8 × 10^{10} $M_\odot$/h
M_{tot} at z = 0: 0.97 × 10^{10} $M_\odot$/h

z_{acc} = 1.74

ID = 63901 at z = 0

TNG50

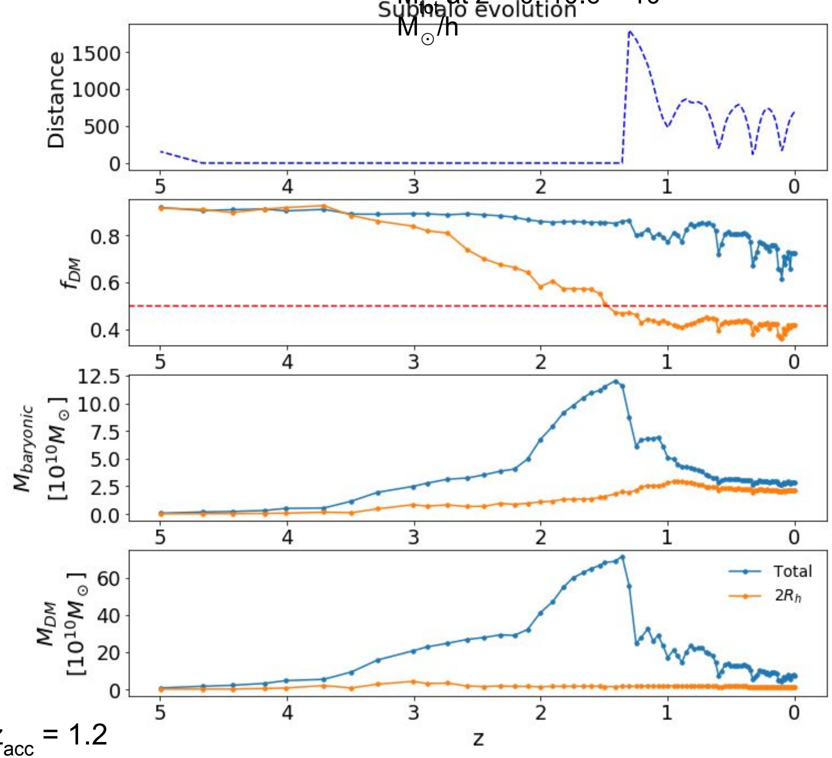


Dark-matter-deficient subhalo only within its central region

TNG100

ID = 53 at z = 0

M_{tot} at z_{acc}: 34.71 × 10^{10} $M_\odot$/h
M_{tot} at z = 0: 10.6 × 10^{10} $M_\odot$/h

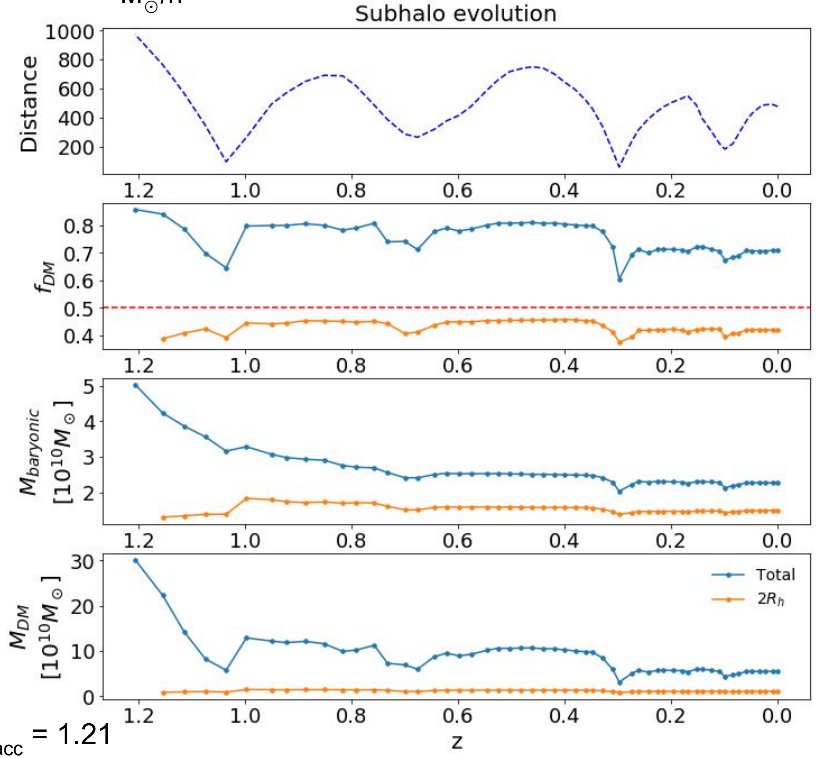


z_{acc} = 1.2

TNG50

ID = 15 at z = 0

M_{tot} at z_{acc}: 35.2 × 10^{10} $M_\odot$/h
M_{tot} at z = 0: 7.77 × 10^{10} $M_\odot$/h

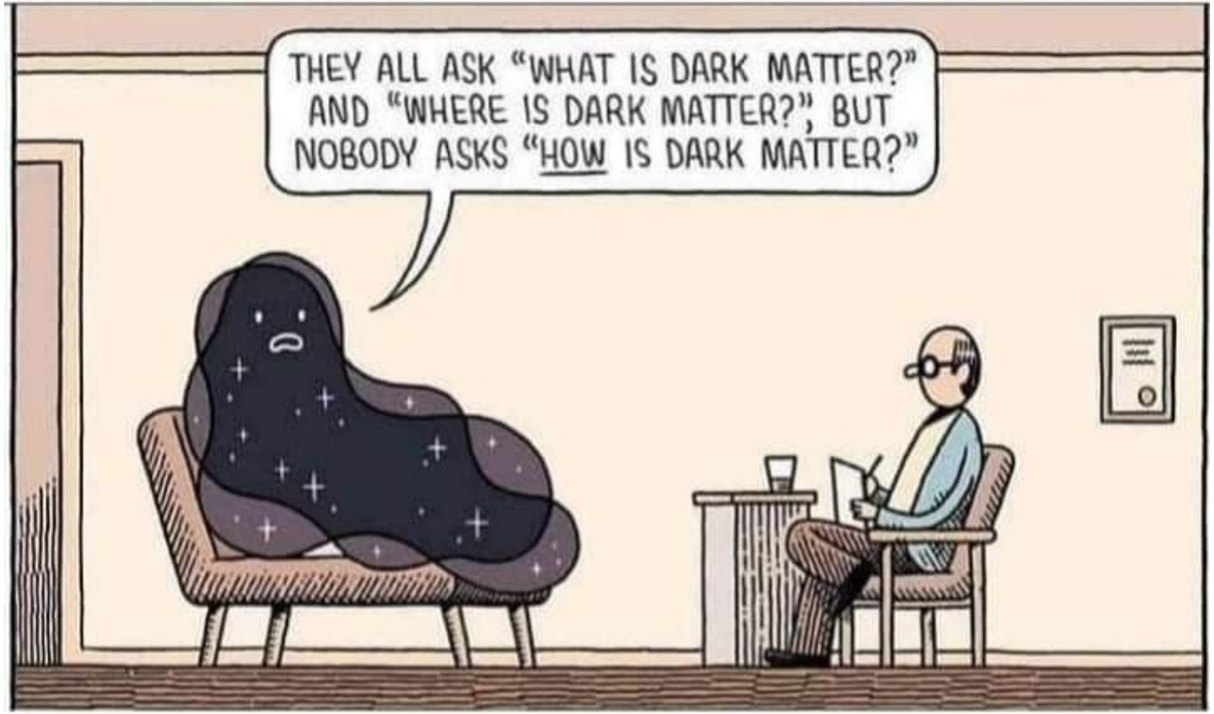


z_{acc} = 1.21

Summary and conclusions

- We have found that DMDGs are allowed in current galaxy formation models, as can be seen in state-of-the-art hydrodynamical cosmological simulations.
- The population of subhalos that are dark-matter-deficient when considering both their total mass and their mass within its central region have low masses in both TNG100 and TNG50.
- The f_{DM} decreases mostly when the distance between the subhalo and its host reaches its minimum along its orbit. Therefore, a tidal stripping scenario is well suited to explain the subhalo's loss of dark matter and, in consequence, its lack of it.
- The subhalos that present a dark matter deficiency only within their central regions do not necessarily lose their dark matter but instead have it placed in more extended areas. Moreover, the number of these subhalos is much higher than the number of actual DMDGs.

Thank you!


THEY ALL ASK "WHAT IS DARK MATTER?" AND "WHERE IS DARK MATTER?", BUT NOBODY ASKS "HOW IS DARK MATTER?"