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3D Shapes of Galaxy Cluster in TNG Simulations

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Abstract

Galaxy clusters are the largest structure in the universe, and their observed gravitational lensing signal can be used to study the formation of structure in the Universe. The 3D shape of galaxy clusters impacts the gravitational lensing signal generated by the cluster. However, the 3D shape has primarily been studied in dark matter-only simulations--without taking into account the impact of the gas. IllustrisTNG is a public project containing 18 hydrodynamic simulations of large sections of the universe. We have written code to determine the 3D shape of the clusters contained in the simulations. This work compares how the shape is affected both by the resolution of the simulations and the gas in hydrodynamic simulations. We find that gas tends to make clusters more spherical, while higher resolution tends to make clusters more elliptical. This project will help us understand how gas impacts the 3D shape of galaxy clusters. Moving forward this data will be compared with other simulations in literature.

3D Shapes of Galaxy Clusters in TNG Simulations

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INTRODUCTION

Galaxy clusters are the largest gravitationally bound structures in our universe. They consist of hundreds to thousands of galaxies, but their mass is dominated by dark matter (~80%) and gas (~18%). In simulations, we can measure the 3D shape of a cluster by using the mass particles within the cluster. The 3D shape of galaxy clusters impacts the gravitational lensing signal we observe. However, the 3D shape has primarily been studied in dark matter-only simulations without taking into account the impact of gas. This project will help us understand how gas impacts the 3D shape of galaxy clusters.

IllustrisTNG is a public data set containing 18 hydrodynamic simulations of large volumes of the universe. We have written code to determine the 3D shape of the clusters in these simulations. This work uses the largest simulation box size--TNG300--and compares how the shape is affected by the resolution of the simulations and the gas in hydrodynamic simulations.

PROCESS

We plot the dark matter particles depicting the location and mass distribution of the galaxy cluster (Fig. 1). The circle shown was used in a filter array to determine and plot which dark matter particles are located in the cluster (Fig. 2).

The shape is then calculated using the moment of inertia, which uses the center of the cluster and the x, y, z positions of the dark matter particles. The eigenvalues of the moment of inertia returns the three axes as a (shortest axis), b , and c (largest axis).

We repeat this process for each galaxy cluster with a mass greater than 10^{14} for different resolutions (TNG300-3 and TNG300-1), and for gas and dark-matter only (TNG300-3 and TNG300-3-Dark.

SETTINGS

Dark matter only vs. Gas

Each simulation has been run at 3 different levels of resolution and includes a hydrodynamic (gas) and dark matter only runs. The hydrodynamic runs--also known as “baryonic physics” runs take into consideration the gas particles and are more realistic. The dark matter runs simulate a universe that is only constructed with dark matter particles, ignoring the effect baryons have on the shape of galaxy clusters.

Resolution

IllustrisTNG offers 3 levels of resolution. A level-1 resolution simulation(TNG300-1) contains the highest resolution. The higher the resolution the greater the number of gas and dark matter particles.

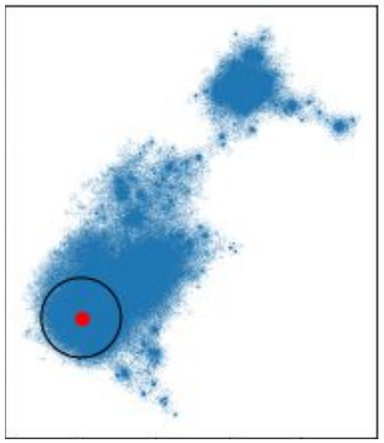


Fig 1. Location and radius of the largest galaxy cluster in the snapshot on x-y plane. The blue points represent dark matter particles and the red point is the center of the cluster.

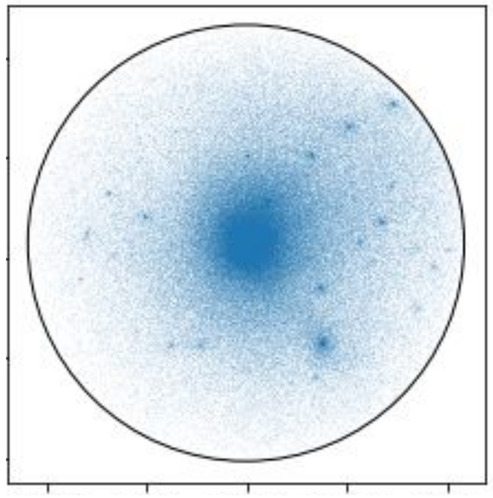


Fig. 2 Dark matter particles in the radius of galaxy cluster halo on x-y plane.

RESULTS

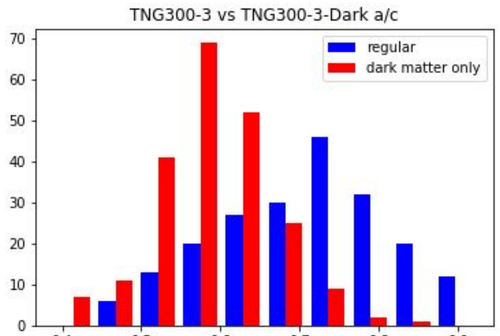


Fig. 3 Comparison of TNG300-3 and TNG300-3-Dark with component a/c for each cluster above 10^{14}.

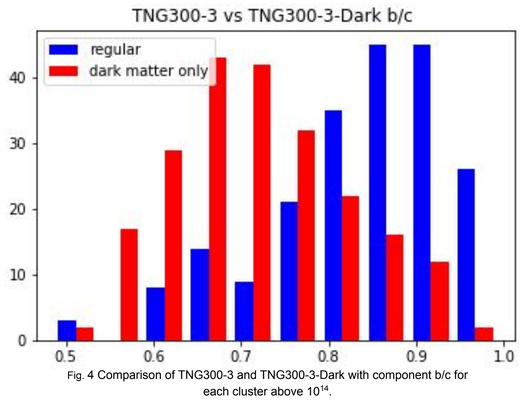


Fig. 4 Comparison of TNG300-3 and TNG300-3-Dark with component b/c for each cluster above 10^{14}.

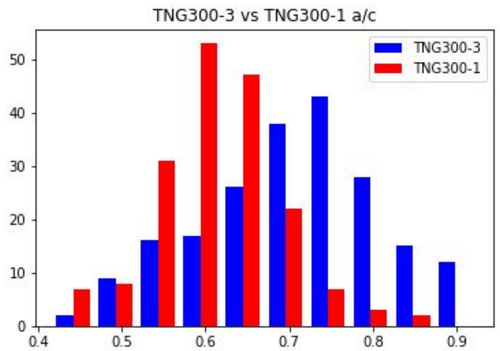


Fig. 5 Comparison of TNG300-3 and TNG300-1 with component a/c for each cluster above 10^{14}.

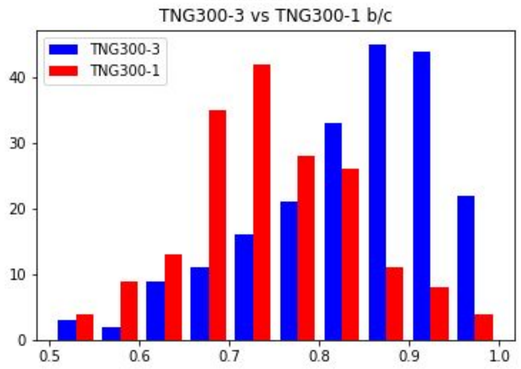
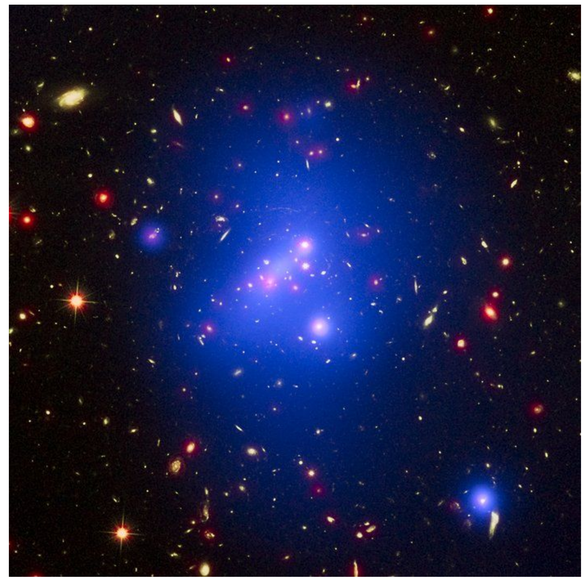


Fig. 6 Comparison of TNG300-3 and TNG300-1 with component b/c for each cluster above 10^{14}.



Multiwavelength image of galaxy cluster IDCS 1426. X-rays from the NASA Chandra X-ray Observatory in blue, visible light from the NASA/ESA Hubble Space Telescope in green, and infrared light from the NASA Spitzer Space Telescope in red.

RESULTS

The histograms as seen in Fig. 3 and Fig. 4 compares the shape of the galaxy clusters for the same simulation but with a regular run containing gas and a dark matter only run. The graphs show that the runs with galaxy clusters containing gas particles are more spherical than the dark matter only runs. The pressure from the gas particles is what causes the round shape in the cluster.

When comparing different resolutions, we see that he clusters are more elliptical in simulations with higher resolution. Since the higher resolution is more precise it will be more accurate to observation.

SUMMARY/FUTURE WORK

The shape of galaxy clusters are greatly influenced by the presence of gas particles as demonstrated by the histograms. Future simulations would benefit from taking into consideration hydrodynamic runs as well as higher resolutions when determining cluster shapes.

The future plan is to compare these results with other simulations in literature. In addition the 3D shape will also be connected to the gravitational lensing signal we observe from galaxy clusters.