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Shapes and Orientations of Galaxy Clusters

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Abstract

Galaxy clusters are large, gravitationally bound structures, primarily consisting of stars and dark matter. These two components form different shapes, which are oriented differently. Using data from IllustrisTNG, a publicly available set of hydrodynamical simulations, we calculate the 2D shapes from the inertia tensor of these clusters. Based on shapes measured from various methods, we find the misalignment between each shape. From these misalignments, we find that alignments between shapes measured based on individual particle positions tend to be much stronger than those measured with galaxy positions. We also find that shapes measured with these galaxy positions tend to be much more round as opposed to elliptical in shape.

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Introduction

Galaxy clusters are large gravitationally bound structures in our Universe consisting of hundreds or thousands of galaxies. Galaxy clusters are also made up of a large mass of dark matter that exists largely around the galaxies contained within, referred to as a halo (see fig 1.). The satellite galaxies are within subhalos.

This project is primarily focused on how the shapes and orientations of the stellar components compare to the shapes of their host halos. Using data from IllustrusTNG, a publicly available set of hydrodynamic simulations, we have written code to determine the 2D shapes and alignments of these two aspects of galaxy clusters. This project specifically uses TNG 300-1 in our calculations.

Method

This project focuses on calculating the shapes of galaxy clusters. This is done by using the x and y positions of each matter particle relative to the central point in the cluster to calculate an inertia tensor, which in this case is a 2x2 matrix created from these positions as shown in the equations below. From this tensor, we can get the size of the major (a) and minor (b) axes of the galaxy shape, along with the directional vector of its major axis.

$$I_{xx} = \sum_i x_i^2 \qquad I_{xy} = \sum_i x_i y_i \qquad I_{yy} = \sum_i y_i^2$$

Results

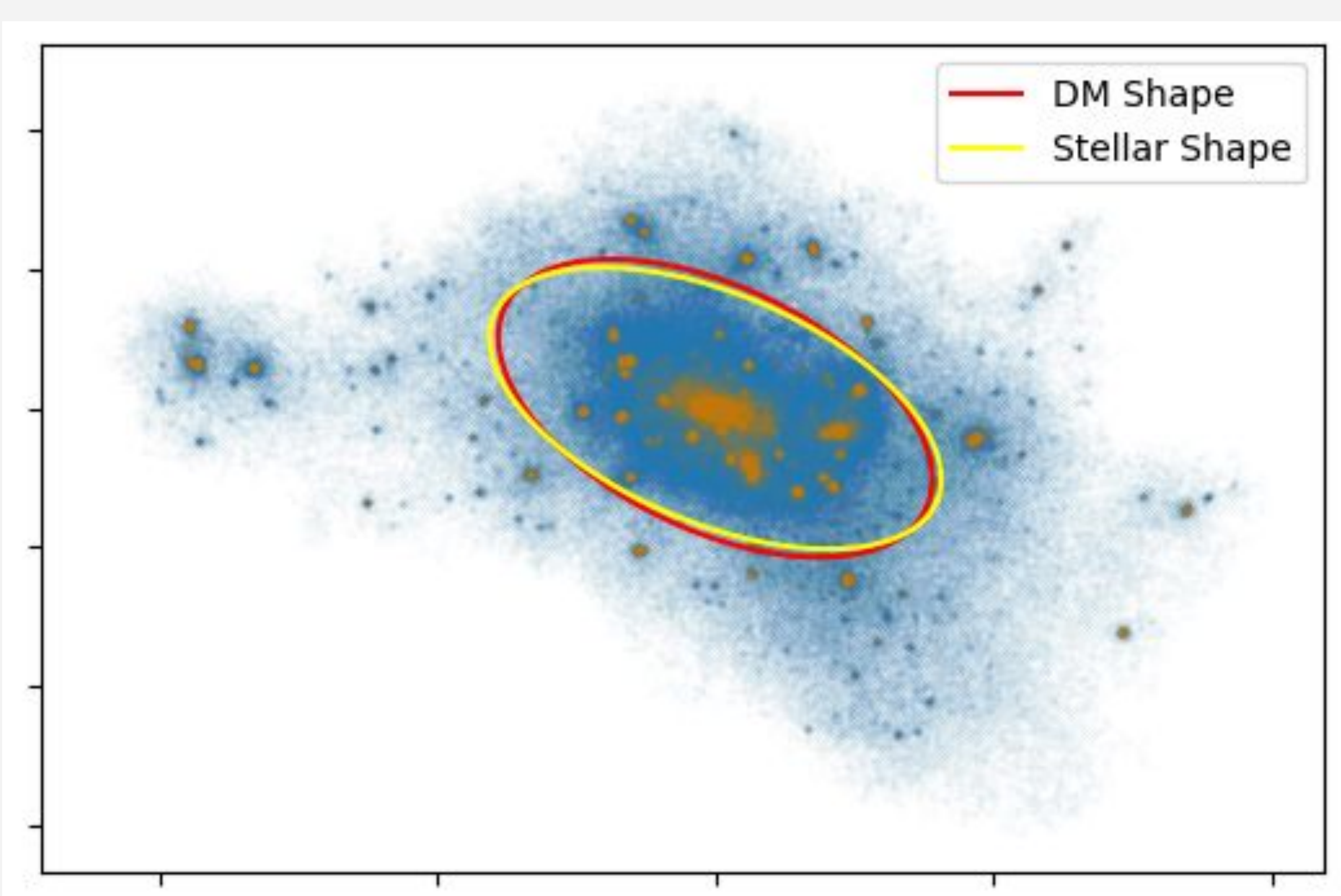

Figure 1 shows the distribution of stellar and dark matter within a galaxy cluster, with the blue points representing dark matter and the orange representing stellar matter. The two ellipses show the 2D shapes of each type of matter, and outlines the area in which the density of matter is 200 times the critical density of the universe, or R200. As we can see, the shapes are fairly similar, but not exactly the same, and they aren't quite lined up on the same axis. This helps indicate the differences in shape focused on in this project.

Results

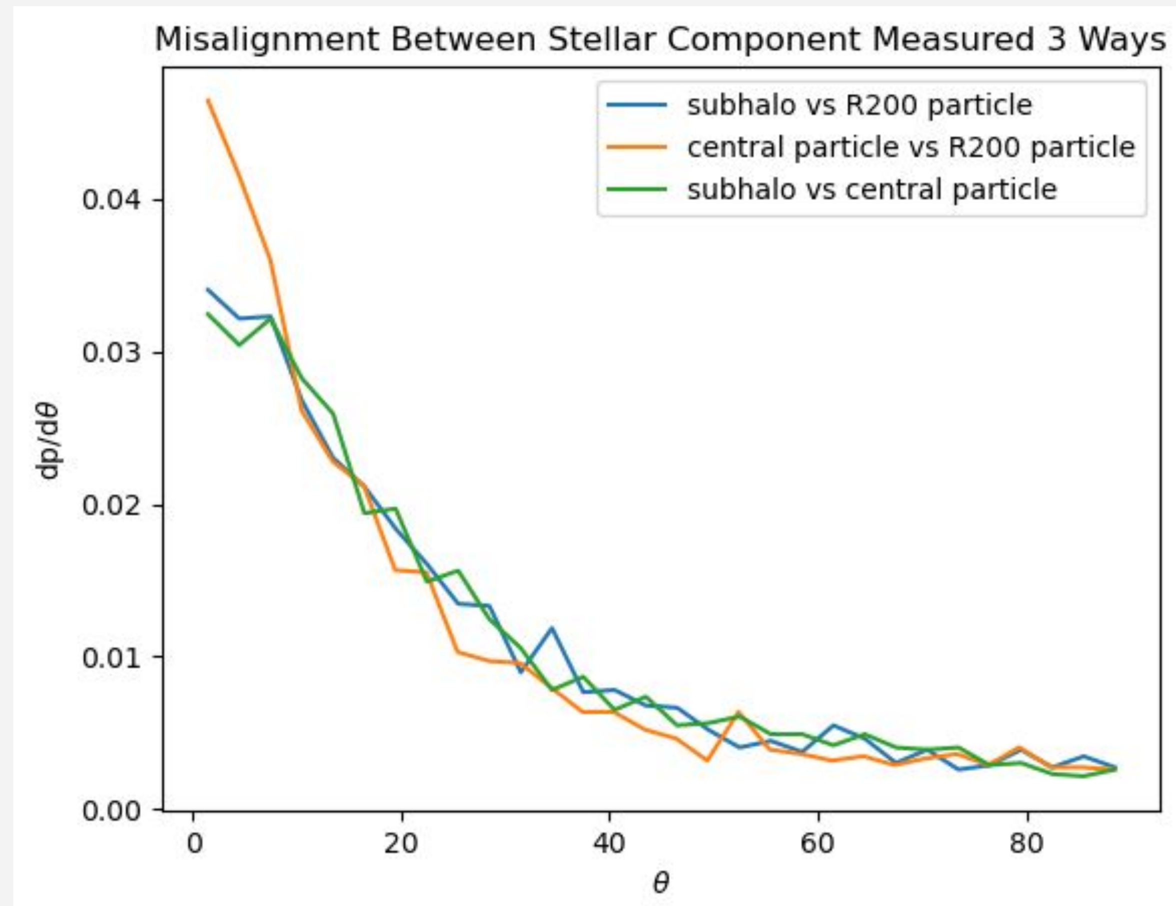

Figure 2 compares the alignments of cluster shapes measured using the galaxies within R200, using all of the particles within R200 and using all the particles in the central most galaxy. As we can see, the particles of the central galaxy and the particles within R200 show the strongest alignment, while the two that compare with the shape from subhalos tends towards a weaker alignment. This makes sense because the central galaxy and R200 particles contain many of the same particles and many more particles. The galaxies have a much smaller number and their positions have a larger effect on the overall shape.

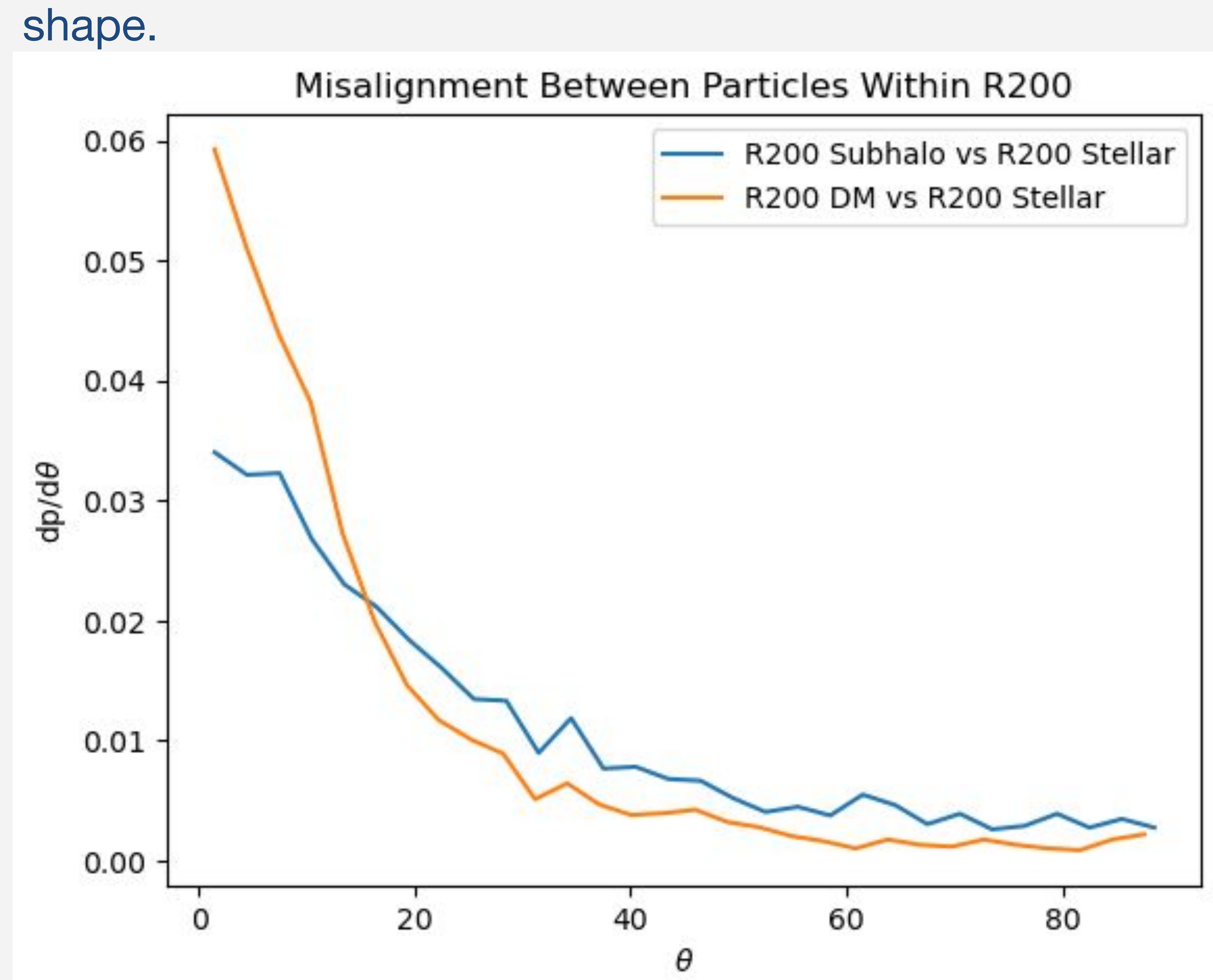

Figure 3 compares the alignments of cluster shapes, all measured within R200, specifically of all stellar particles, all dark matter particles and subhalos. We use R200 because the central and R200 shapes (see fig.2) are very similar, and this provides a constant to compare other shapes. Here, we can see that the dark matter particles compared to stellar particles has a very strong alignment, while the alignment between subhalos and stellar particles is less strong. This makes sense due to the reasons outlined in figure 2, along with the fact that the dark matter and stellar particles are gravitationally bound and will likely find a similar orientation.

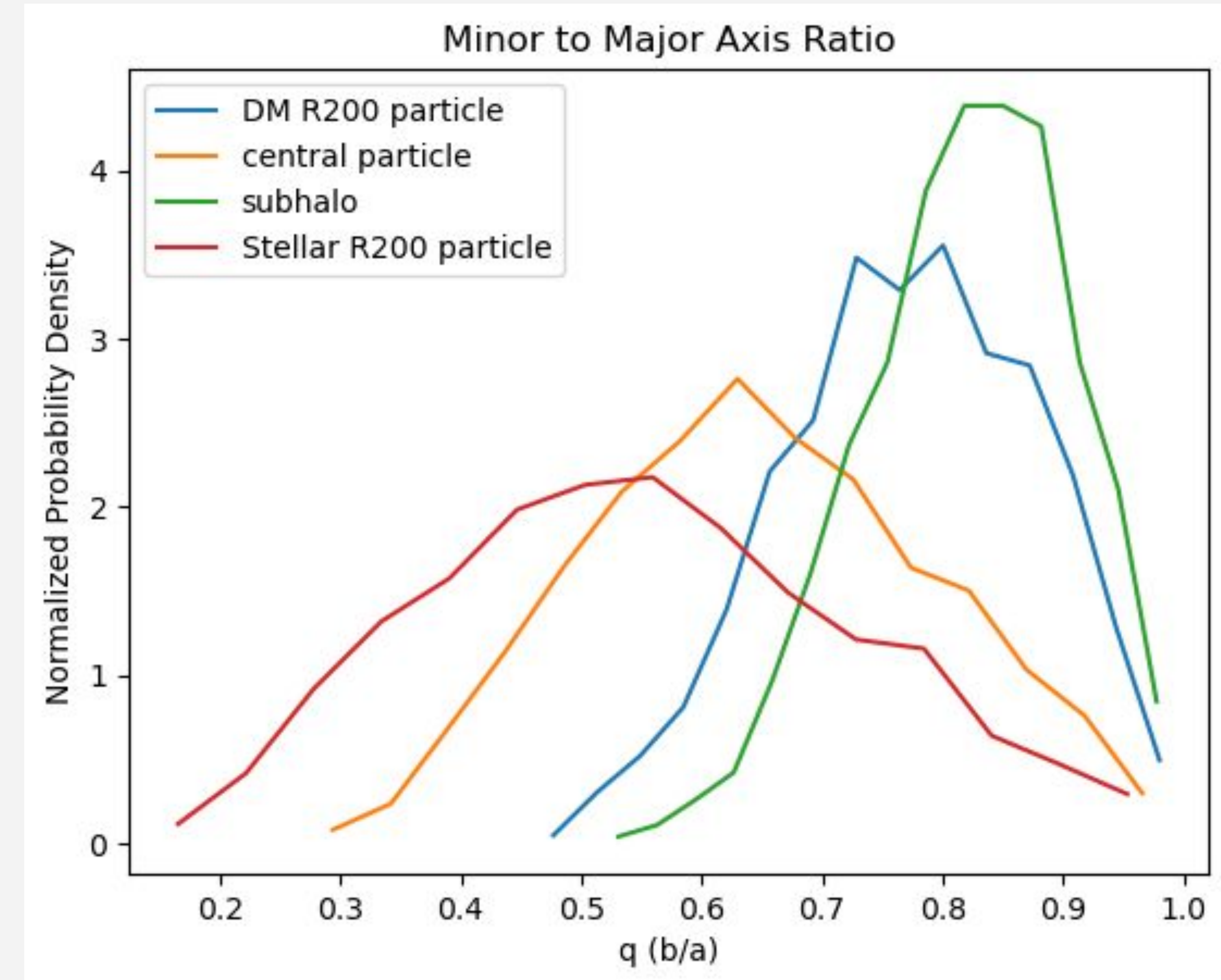

Figure 4 relates the shapes of the galaxy clusters using the same methods outlined in figure 2 and figure 3, by taking the axis ratio between the major and minor axes. In this figure, there is a higher tendency towards a more circular shape for the when calculated with subhalos and dark matter within R200, while the central galaxy and stellar shape within R200 show a tendency towards a more elongated shape. It makes sense that the central galaxy and stellar matter within R200 would have a similar shape, as they contain many of the same particles and showed strong alignments in figure 2. It makes sense that dark matter is more circular in shape, as it tends to be more spread out than stellar.

Conclusion

The method used to calculate the shape of a galaxy cluster can have an effect on the calculated shape and orientation. Shapes computed from subhalos had a higher tendency to produce different results than those calculated from particles, which showed a strong relationship. Subhalos and dark matter also show a tendency towards a rounder cluster shape.

References

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