The emergence of the morphology-radius relation through analysis of TNG-Clusters
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Abstract

We report preliminary results of the TNG-Cluster simulation used to investigate the morphology-radius relation (MRR) over a redshift range of z=0.0 to z=2.0. The MRR describes the correlation of galaxy morphology to the radius from the center of a galaxy cluster. We examie the extent the MRR is present in the TNG-Cluster simulation, compared to the results from the Horizon Run 5 (HR5) simulation. A total of 2533 cluster galaxies from TNG-Cluster, and 4395 from HR5, and their progenitors are used to analyze this. Galaxy morphology is analyzed using Asymmetry parameter, Sérsic index and specific star formation rate (sSFR), and evaluated with respect to cluster-centric distance d/R200.

Keywords: Cosmology Large Scale Evolution Simulation: TNG - galaxy clusters: galaxy, morphology, Star Formation Rate

Introduction

The range of galaxy morphology in the observable Universe is presented graphically in the Hubble sequence. Hereby, early-type galaxies (ETGs) and late-type galaxies (LTGs). ETGs are characterized by elliptical or lenticular shape, higher mass, redder color, and lower star formation rates. LTGs on the contrary, have spiral or irregular shapes, lower mass, bluer color, and higher star formation rates. Since then, many more properties relating to galaxy morphology have been found. The most important of these is arguably the discoveries by Alan Dressler [2], whose morphology density relation describes the overabundance of early-type galaxies in the dense regions of galaxy clusters, and the overabundance of late-type galaxies in their sparse regions. For a virialized cluster, the morphology-radius relation follows from the morphology-density relation, as the local galaxy number density is inversely correlated with clustercentric radius. Further observational investigations have shown these relations to be in place since about z~1

Research Method

Data. Clusters were selected from TNG-Cluster's primary zoom targets within the range of 1.0×1014 M⊙ ≤ Mtot ≤ 4.0×1014 M⊙ at z=0.0. The amount Mtot includes all mass belonging to a cluster's Friends-of-friends (FoF) groups. 51 clusters were found to fall within this range. Within these clusters, galaxies were selected with a stellar mass cut of M*≥5.0×109 M⊙, which amounted to 2586 galaxies. Subsequently, the progenitors of these galaxies were found with the help of the merger trees, which connected them by the SubLink algorithm.

Morphology Analyses. To analyze galaxies' morphology, several parameters were calculated. First of all, the irregularity of the galaxies' stellar particles were calculated by the asymmetry parameter [6]. This is calculated by an algorithm that constructs a three-dimensional grid over the stellar particles of a galaxy, and calculates the differences in smoothed stellar density between cells on opposite sides of the galactic center. The grid consisted of 20×20×20 cells, which spanned out to an orthogonal radial distance of 2 times the root-mean-square distance of the stellar particles from the galactic center. At all cells' centers which were beyond a radius of 0.8 pkpc, the following equation was evaluated: $A = \sum |\rho_{*,i} - \rho_{*,j}| \; i \; 2 \sum \rho_{*,i}$ (Equ. 1) .
The Sérsic index is an exponent in the equation for the Sérsic profile for radial light intensity distribution [Sersic, 1963]. Given in (2), $I(R)$ gives the light intensity as a function of galactocentric radius R, $I0$ is the light intensity at R = 0, k is a scaling parameter, and n is the Sérsic index. It is around 4 for elliptical galaxies and 1 for disk galaxies, with a threshold of 1.5 often being used. $I(R) = I0 \exp[-kR1\, n/]$ (Equ. 2).

Distances. The galaxies' distances from cluster centers were normalized by the clusters' R200 values at their final snapshot, zf. This was done to keep the normalization factor constant. For TNG-Cluster, zf=0.0, and for HR5, zf=0.625. Cluster progenitors were found at all snapshots by finding the progenitors of the clusters' BCGs. Subsequently, for all combinations of galaxies and clusters, values of d/R200 were calculated, whereby d is the distance between the galaxy's and cluster's centers, and for each galaxy, the minimum value of d/R200 was used to plot the morphological parameters against. For TNG-Cluster, because each cluster was the primary zoom target in its own simulation box, the distance d came down to the galaxy's clustercentric distance.

Result & Discussion

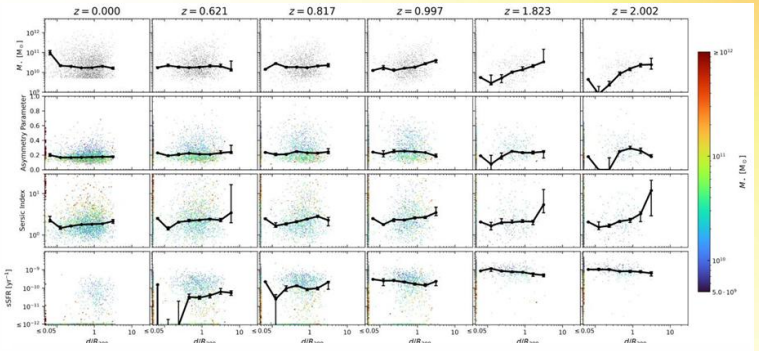

Figure 1: Stellar mass, asymmetry parameter, Sérsic index and specific star formation rate sSFR for cluster galaxies and progenitors across 6 redshifts of TNG-Cluster. Each point displays a galaxy, whereby in the bottom 3 rows, the point's size and colour are proportional to its stellar mass (shown by the colour bar on the right). The black line shows the median value in bins (calculated from all values, including 0 values), and the error bars include 68% of the values from the mean. In each subplot, for the left-most bin, the values at d/R_{200}=0 were included in the median calculation.

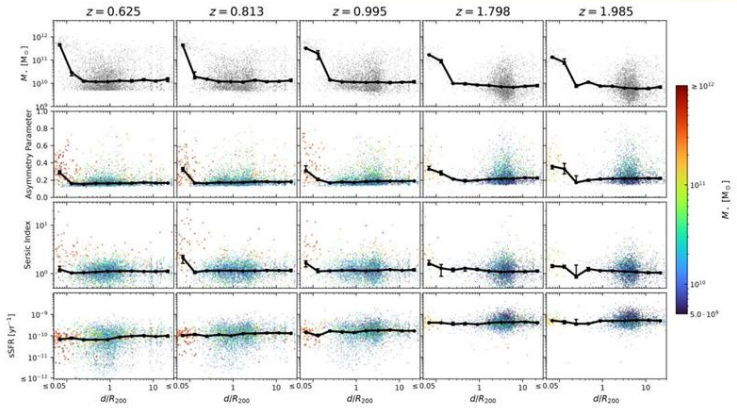

Figure 2: Stellar mass, asymmetry parameter, Sérsic index and specific star formation rate sSFR for cluster galaxies and progenitors across 5 redshifts of HR5. Each point displays a galaxy, whereby in the bottom 3 rows, the point's size and colour are proportional to its stellar mass (shown by the colour bar on the right). The black line shows the median value in bins (calculated from all values, including 0 values), and the error bars include 68% of the values from the mean. In each subplot, for the left-most bin, the values at d/R_{200}=0 were included in the median calculation.

At z<1, the central galaxies' sSFR starts dropping, and the correlations become positive. This could be interpreted as the accurate modelling of the reversal of the SFR-density relation, which is a more widely understood phenomenon [8]. Also, the lower sSFR in the core can be seen as an indicator of the accurate modelling of the overabundance of ellipticals in cluster cores.

Conclusion

The findings are that some aspects of the MRR, such as higher M∗ and higher Sérsic index values in the cores, are present in TNG-Cluster, albeit to a weak extent. The MRR seems to emerge after about z~0.6. Other observations made on TNG-Cluster include that the sSFR values over the entire range of galaxies has dropped significantly by z=0, implying a possible overactivity in the simulation's quenching mechanisms. HR5 also shows the trends of high M∗ and higher Sérsic indices for central galaxies. In addition, it shows lower sSFR values for central galaxies. In HR5, the central galaxies spread out to a higher clustercentric distance, and have lower M∗ values. This implies TNG-Cluster's brightest cluster galaxies (BCGs)are accreting mass at a higher rate.

Main References

Dressler, A. (1980); Elbaz, D. et al (2007: Hong, S. etal (2024); Park, C. et al (2022); Pillepich, A.et al (2018); Sersic, J. L. (1963); Smith, J. P. et al (2005); https://www.tng-project.org/cluster/

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