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Can we link galaxy assembly times to the assembly times of their host halos?: A perspective from Mutual Information II

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Building upon our previous analysis, which explored the connection between the assembly histories of galaxies and their host dark matter haloes using galaxies with stellar masses in the range $10^9 \leq M_\star[h^{-1}M_\odot] \leq 10^{11.5}$ from \textit{the Next Generation Illustris} simulations (IllustrisTNG), our study employed the Mutual Information (MI) statistic to quantify the degree of dependence between the galaxy assembly time (z_G) and various halo and galaxy properties. We found that the MI between z_G and the halo assembly time (z_H) is moderate for galaxies with $M_\star$
$lesssim 10^{10.25}h^{-1}M_\odot$, decreasing towards higher stellar masses. In the present work, we extend this framework to include the galaxy formation efficiency ($F_\star$) and a set of cluster observables: the magnitude gap, satellite richness, and the projected distances to the second and fourth most massive (or luminous) satellites. For galaxy properties, we find a strong correlation between $F_\star$ and z_H in low-mass central galaxies, suggesting a co-evolutionary link between stellar growth and halo assembly. In contrast, cluster observables show weaker overall correlations with halo formation time, although satellite richness systematically increases with stellar mass. This trend implies that richness becomes a more effective tracer of formation history in massive haloes, where satellite accretion dominates their late-time growth.

Author: CAMARGO CAMARGO, Yeimy Dallana (Universidad Nacional de Colombia)

Co-author: CASAS MIRANDA, Rigoberto Angel (Universidad Nacional de Colombia)

Presenter: CAMARGO CAMARGO, Yeimy Dallana (Universidad Nacional de Colombia)