

# 100 years of Hubble’s Bulges: How do bulges grow in modern high-resolution Magneto-Hydrodynamical Cosmological simulations? An insight from IllustrisTNG.

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A century after Hubble’s morphological classification of galaxies, the advent of the James Webb Space Telescope is offering an unprecedented view of galaxy structure back to within the first billion years of cosmic history [3], bringing renewed urgency to a longstanding question: how do galactic bulges form and grow? Two mechanisms have long been identified; mergers between galaxies and internal disc instabilities, yet disentangling their respective contributions remains a central challenge of extragalactic astrophysics [1, 2, 4].

Here we present a statistical study of bulge formation using the IllustrisTNG50 simulation [5], which uniquely combines a cosmologically representative volume with sufficient resolution to resolve the vertical structure of galaxies. We track the evolution of morphological indicators including the stellar bulge-to-total mass ratio,  $B/T$ , and the mean stellar surface density within the central kiloparsec  $\Sigma_1$ , as a function of stellar mass  $M_*$ , and examine how these diagnostics differ between galaxies that have undergone recent mergers and those that have not. We investigate whether merger-built and disc-instability-built bulges occupy distinct regions of the  $B/T - M_*$  and  $\Sigma_1 - M_*$  parameter space, with the prospect of providing observational discriminators applicable to high-redshift galaxies where image quality is limited.

We further explore the conditions under which discs become gravitationally unstable, and quantify the role of gas inflows driven by both mergers and instabilities in fuelling central star formation and supermassive black hole growth [1, 2]. Our results are discussed in the context of whether star formation enhancement saturates at high redshift, with implications for the gas infall rates that drive bulge growth in the early Universe.

## References

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