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DIVERSITY OF GALACTIC DISCS AT HIGH REDSHIFT IN COSMOLOGICAL SIMULATIONS

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Abstract. Galactic morphology is fundamental to understanding how galaxies form, interact with their environments and evolve across cosmic time. Recent observations show a surprisingly large population of disc-like galaxies up to $z = 8$, challenging formation models, while simulations only confirm such structures to $z \sim 5$ with their characteristics at earlier times not yet fully understood.To investigate this, we use the high-resolution cosmological simulation Obelisk to study galaxy morphology at $z = 6$. Surface density profile fitting separates disc and spheroidal components, with bulge-to-total (B/T) and disc-to-total (D/T) ratios tracing formation history. We further perform a kinematic analysis to identify rotationally supported discs, using the rotation-to-dispersion ratio V/σ as a measure of dynamical support, where higher values indicate disc-like structures.

Keywords: morphology, kinematics, galaxy formation and evolution, cosmological simulations

1 Introduction

Galaxies exhibit diverse shapes and structures, which can be correlated with distinct physical properties and evolutionary pathways. In 1926, Hubble broadly classified galaxies into elliptical, spiral and lenticulars. Beyond this, galaxies are complex systems often composed of several distinct components, such as a star-forming disc, a central spheroidal bulge, a bar, and other substructures.Discs are thought to form after the primordial collapse that creates the spheroidal bulge and halo, possibly through the cooling of hot gas contained within the halo of the newly formed galaxy. Decomposition of galaxies into disc and bulge component lays a foundation for categorizing galaxies in the Hubble sequence. High-redshift surveys with HST, ALMA, and AO-fed IFUs show that many $z > 1$ star-forming galaxies are rotationally supported, with large, clumpy, thick discs common by $z \sim 2$ (Nelson et al. 2013; Wisnioski et al. 2019). By $z \sim 5 - 7$, ALMA and JWST reveal turbulent, rotating gas reservoirs with elongated or clumpy morphologies (Smit et al. 2018). Cosmological simulations produce rotationally supported dynamically cold discs in star-forming massive galaxies at $z > 4$ (Kohandel et al. 2024). This study aims to identify the morphological diversity of disc-like structures in galaxies at $z = 6$.

2 Data and methodology

We use data from the high resolution ($\Delta x = 35pc$) cosmological radiation-hydrodynamics simulation Obelisk (Trebitsch et al. 2021), a subvolume and a resimulation of the Horizon-AGN simulation at a much higher resolution down to $z \simeq 3.5$ (Dubois et al. 2016). We focus on galaxies with stellar masses $M_* > 10^7\, M_\odot$.

Stars are projected onto a plane perpendicular to angular momentum and linearly binned into annuli between 35pc and $1.5R_{95}$, where R_{95} is the radius enclosing 95% of the stellar mass. The surface density profile is then fitted with a combination of a Sersic profile for the bulge and an exponential profile for the disc:

$$\Sigma(R) = \Sigma(R_e)_{bulge} \exp\left[-\beta_n \left\{ \left(\frac{R}{R_e}\right)^{1/n} - 1 \right\} \right] + \Sigma_{0,disc} \exp\left(\frac{-R}{R_d}\right) \tag{2.1}$$

The mass fractions of the disc and bulge are then obtained by integrating the respective profiles, where the disc-to-total ratio $\mathrm{D/T} = M_{disc}/M_*$. The rotational support of the galaxy is quantified using the rotation(v_θ) to dispersion(σ) ratio as a function of R using the same binning as above. The dispersion is the root-mean-square of the velocity components in the radial, azimuthal and vertical directions.

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3 Results and discussion

The morphological profiling of galaxies using a combined Sersic and exponential fit reveals a wide range of structures at $z = 6$. Figure 1 shows the fitting of the most massive galaxy in the simulation along with its rotation-to-dispersion (V/σ) profile.

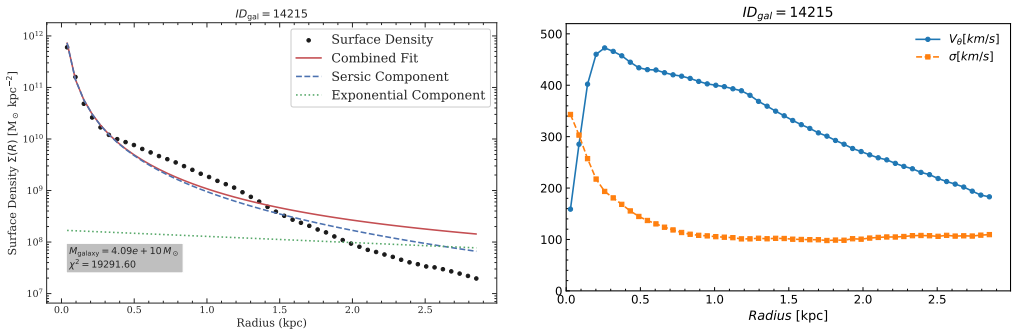

Fig. 1. Surface density profile (*left*) and rotation curve and dispersion profile (*right*) of the most massive galaxy at $z = 6$.

This fitting yields the best-fit parameters which are the Sérsic central density ($\Sigma_{0,bulge}$), exponential central density ($\Sigma_{0,disc}$), Sérsic scale length (R_{sersic}), exponential scale length (R_{exp}), and the Sérsic index (n). The D/T distribution of all galaxies with $M_* > 10^7\,M_\odot$ is shown in the left panel of Fig. 2. We find that 50% of galaxies have $D/T > 0.4$, and that more massive systems show more compact centers with smaller Sérsic scale lengths, while about $\sim 75\%$ of galaxies have exponential scale lengths below 1 kpc (Fig. 2).

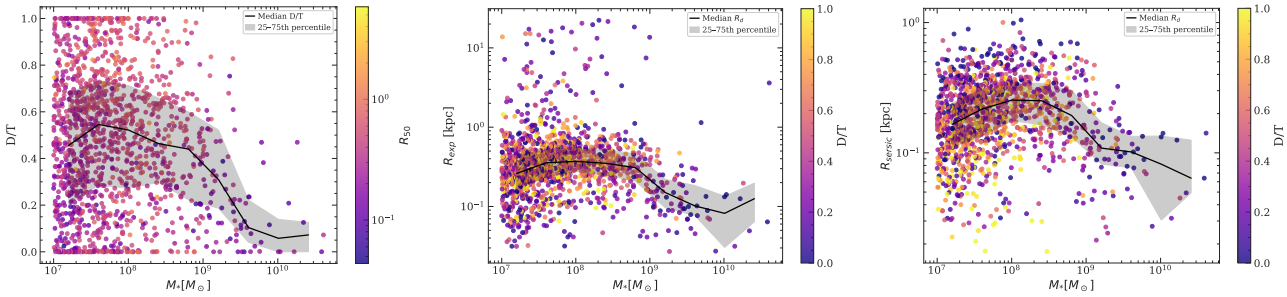

Fig. 2. *Left*: D/T ratio of all galaxies with $M_* > 10^7\,M_\odot$. *Middle*: Exponential scale length as a function of stellar mass. *Right*: Sérsic scale length as a function of stellar mass.

4 Conclusions

Our findings reveal a diverse range of morphologies, with half of the galaxies exhibiting a $D/T \sim 5$.We also compute the rotation to dispersion ratio at different radii to analyse the rotational support. We see from the scale length analysis that massive galaxies show a more compact central region, with most systems showing a disc smaller than 1kpc. A more detailed kinematic decomposition of these galaxies will give further information about the properties of these discs.

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