Bulge formation in MW- and M31-like galaxies :

Origin of low and high-Sérsic bulges and the connection to bulge formation pathways

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Motivation

$$I(r) = I_{\rm e} \exp\left\{ -b_n\left[(r/r_{\rm eff})^{1/n} - 1\right]\right\} + I_0 \exp\left[-(r/R_{\rm scale})\right]$$

Motivation

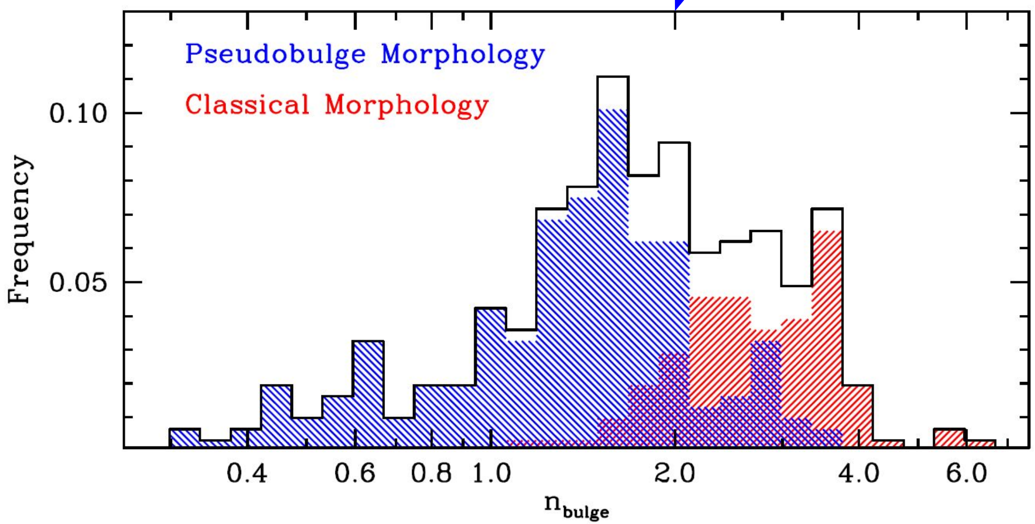
$$I(r) = I_e \exp\left\{-b_n\left[(r/r_{\rm eff})^{1/n} - 1\right]\right\} + I_0 \exp\left[-(r/R_{\rm scale})\right]$$

Bulge (I_e, r_{eff}, n)

Disc (I_0, R_{scale})

Motivation

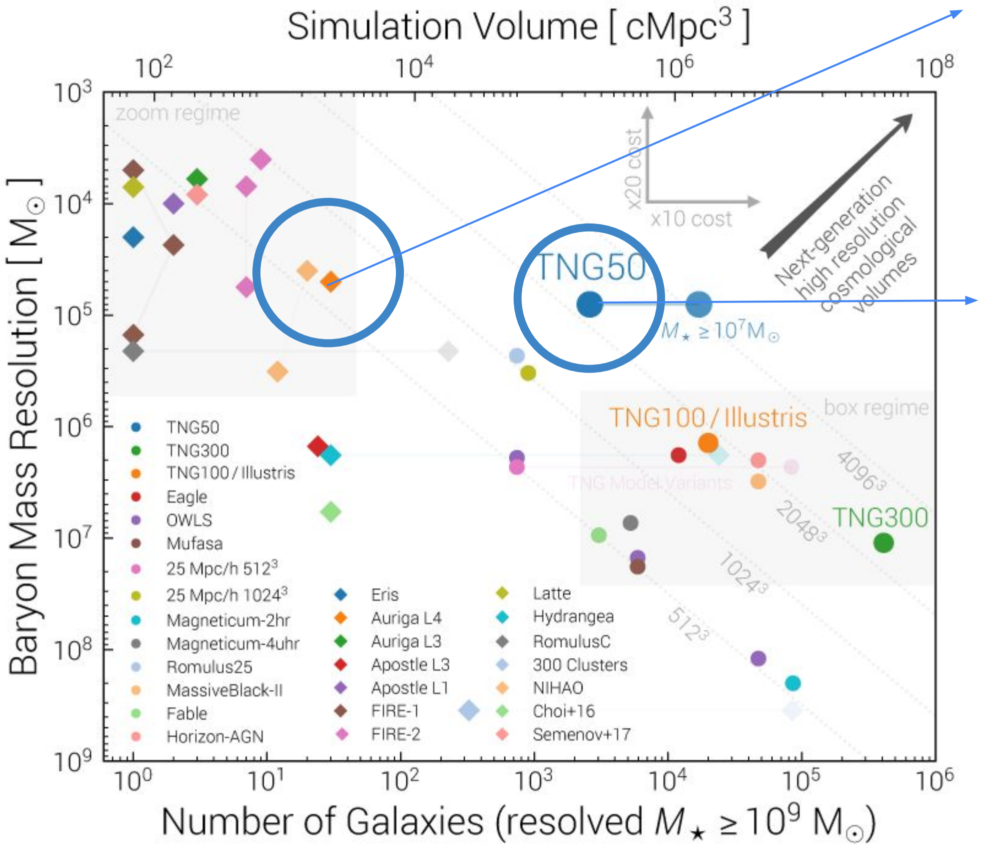
$$I(r) = I_e \exp\left\{ -b_n\left[(r/r_{\mathrm{eff}})^{1/n} - 1\right]\right\} + I_0 \exp\left[-(r/R_{\mathrm{scale}})\right]$$



Fisher & Drory (2016)

- 308 nearby disc galaxies with high resolution images (HST) and bulge-disc decompositions.
- 87% of classical bulges have n > 2 and 86% of pseudo-bulges have n < 2.

The simulations

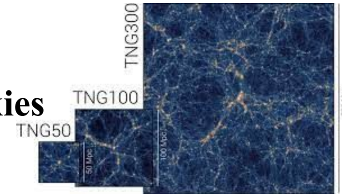


Auriga 4 : Gargiulo I.D. et al. (2019, **G19**)

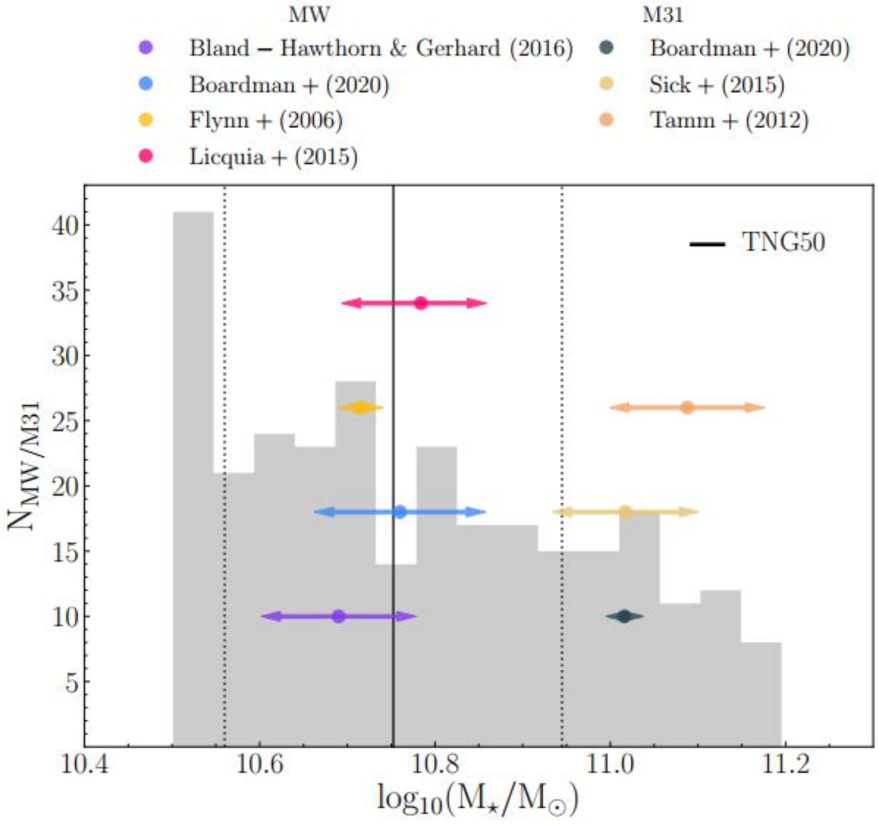
- re-simulated → more isolated DM haloes
- **30 MW-mass galaxies** at that moment
- mass resolution : ~ 4 x 10^4 $M_\odot$

IllustrisTNG50-1: Gargiulo I.D. et al. (2022, **G22**)

- cosmological volume (50 cMpc)
- sample of **287 MW/M31-like galaxies**
- mass resolution : ~ 8 x 10^4 $M_\odot$



Simulated galaxies : Sample selection in TNG50

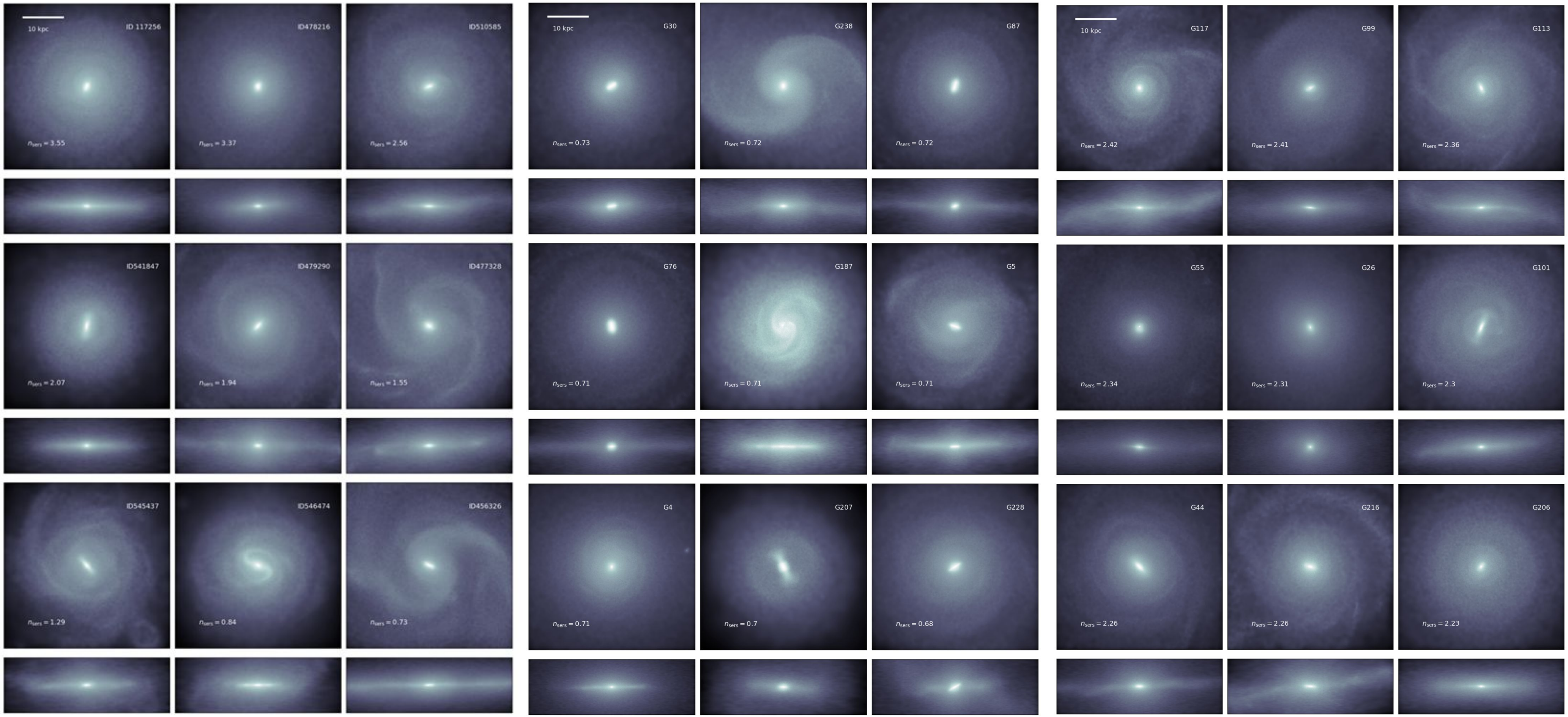


Selection criteria:

(based on Pillepich+2022, in prep, Engler+2021)

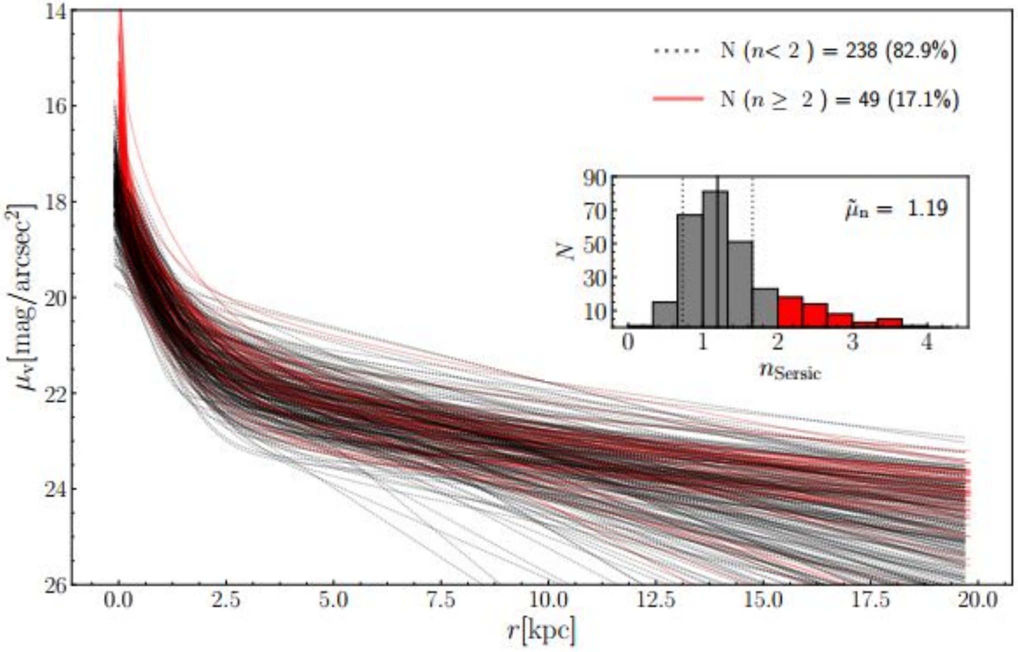
- Stellar mass in the range $[10^{10.5} - 10^{11.2}]\ M_\odot$
- Disc galaxies : ratio s = c/a < 0.45 , minor-to-major axis of the stellar moment of inertia tensor.

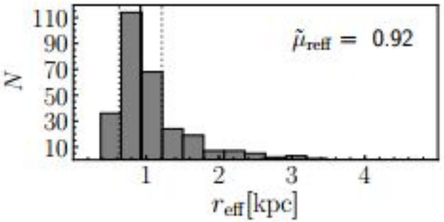
TNG50-1 MW/M31-like galaxies

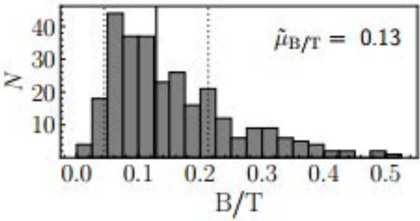


2-Component - 1D decompositions

$$I(r) = I_e \exp\left\{ -b_n \left[(r/r_{\rm eff})^{1/n} - 1 \right] \right\} + I_0 \exp\left[-(r/R_{\rm scale}) \right]$$







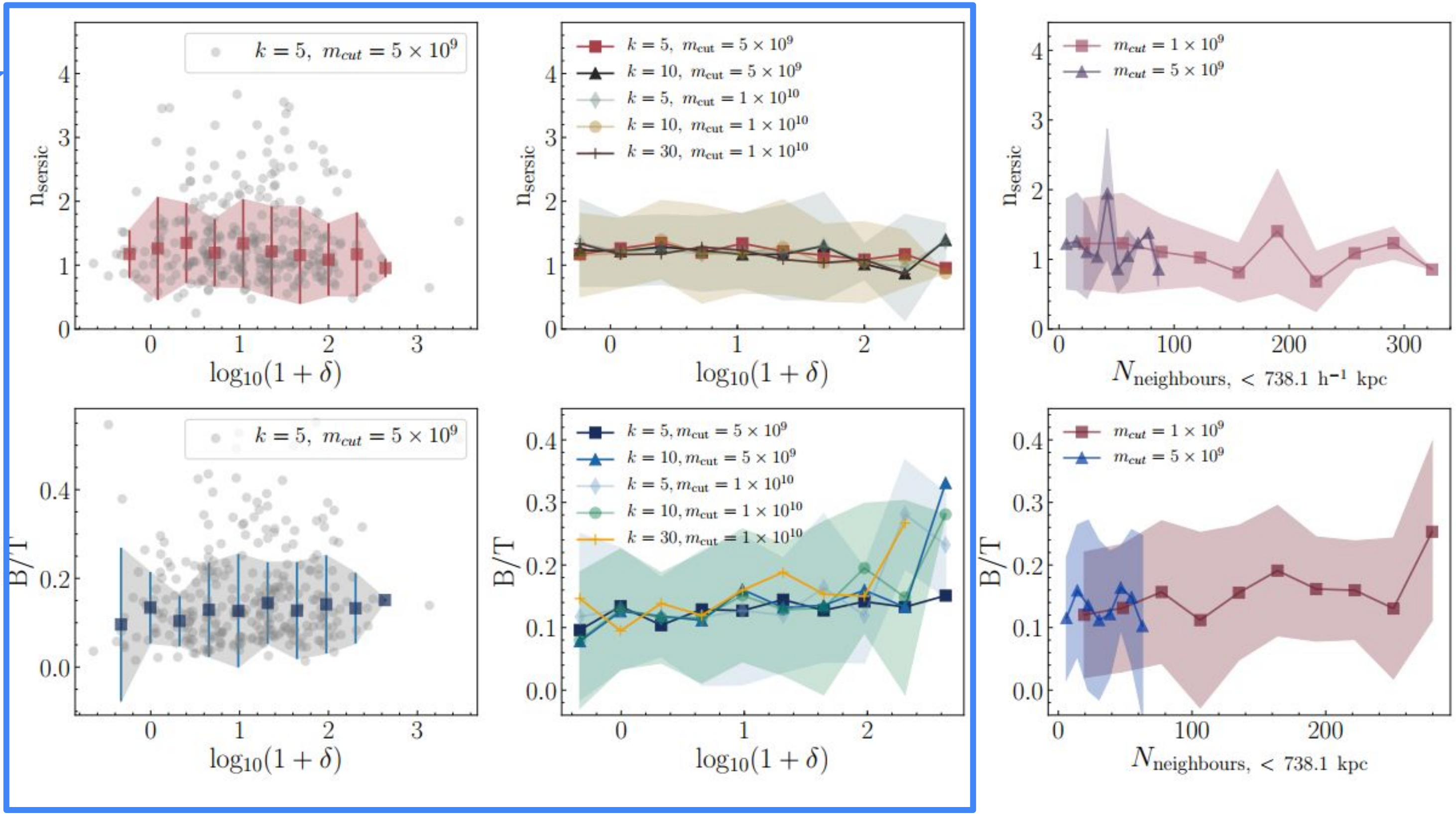
17.1 % of high Sérsic index photometric bulges

Does bulge type depend on environment?

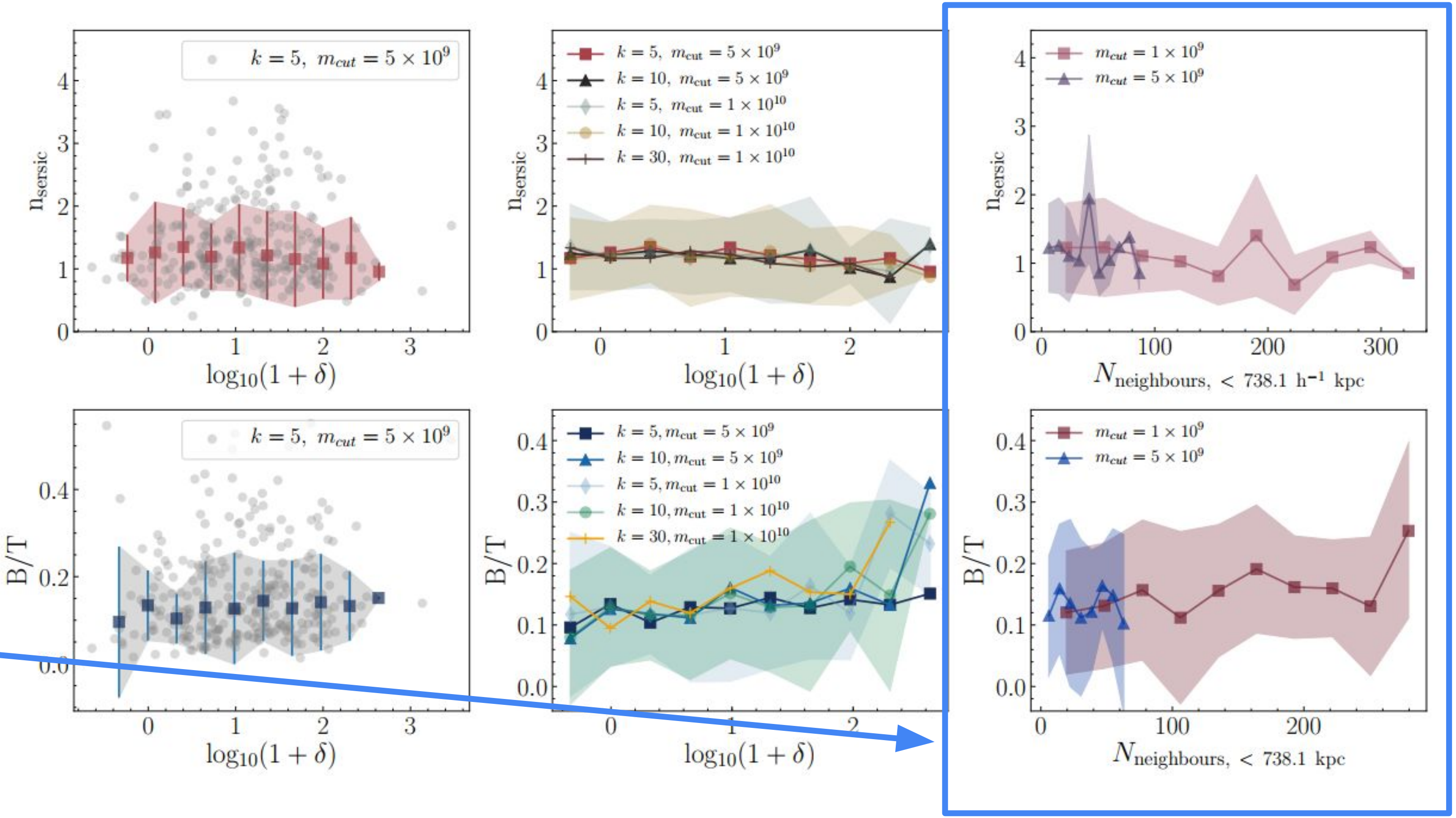
$$1 + \delta = \frac{P}{P_{\mathrm{median}}},$$

$$P(\mathbf{r}_i) = \frac{3k}{4\pi \sum_{j=1}^{k} d_{ij}^3}.$$

(e.g. Darvish +2014)



Does bulge type depend on environment?



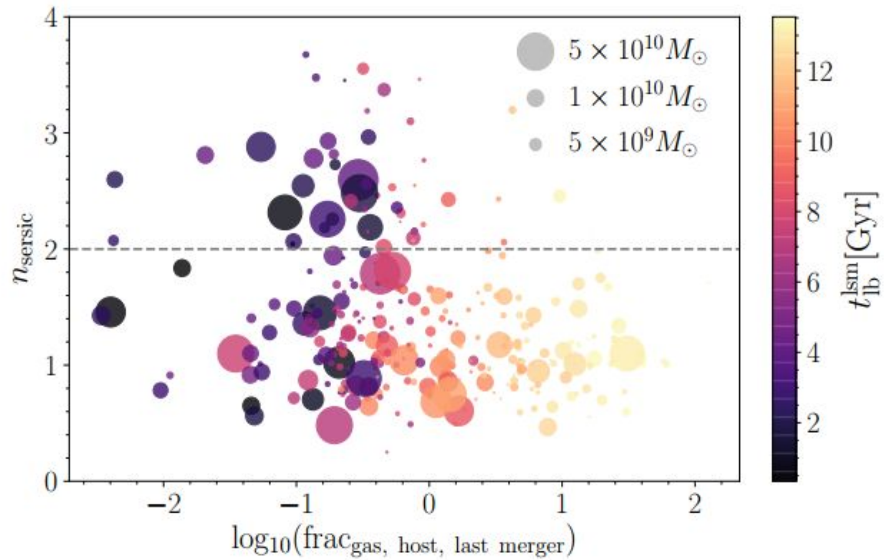
Number of neighbours inside a 500/h = 738.1 kpc sphere

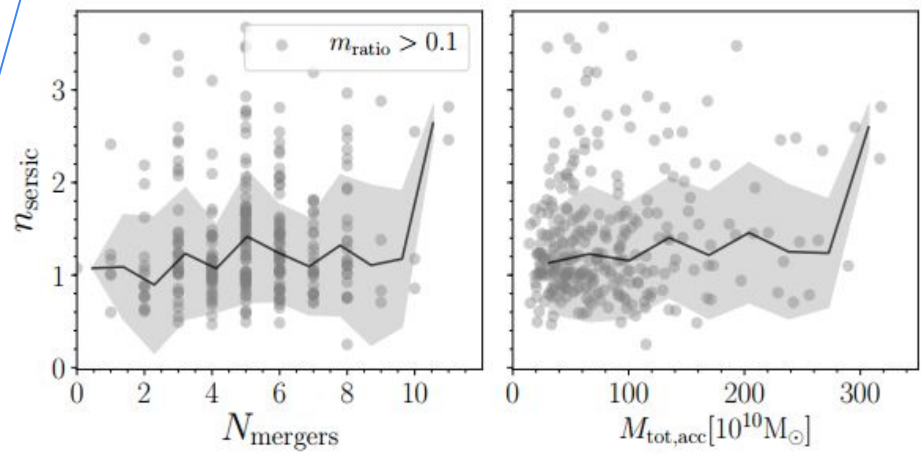
(e.g., Moustakas+2009)

Effect of Mergers - Number, total mass, and gas fractions

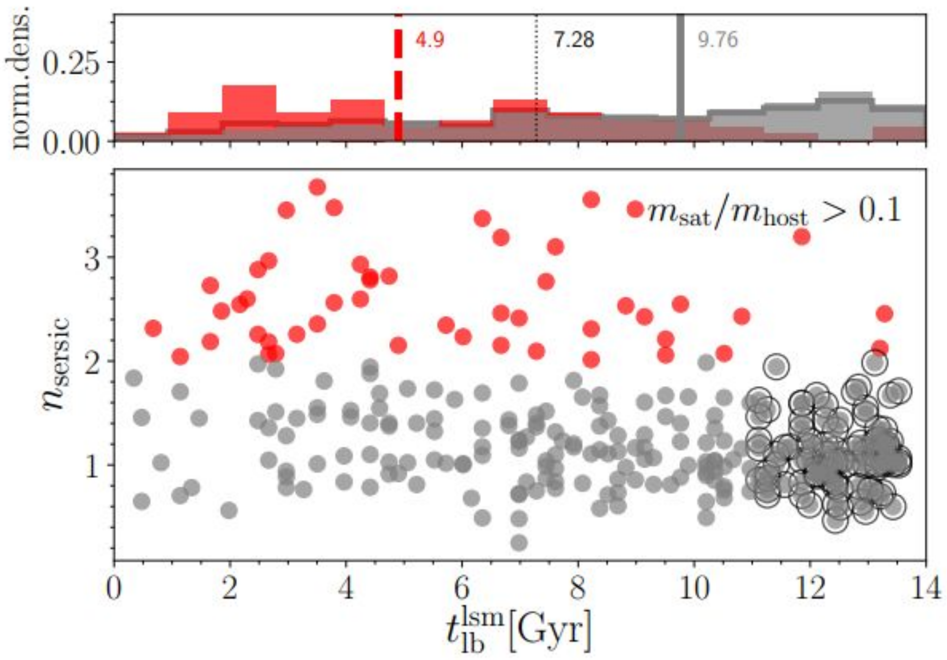
***Def.*:** A Significant merger has a merger ratio $m_{sat}/m_{host} > 0.1$, where m_{sat} and m_{host} are the *total* mass of the satellite and the host galaxy.

Lookback time of the last significant merger





Effect of Mergers - Timing

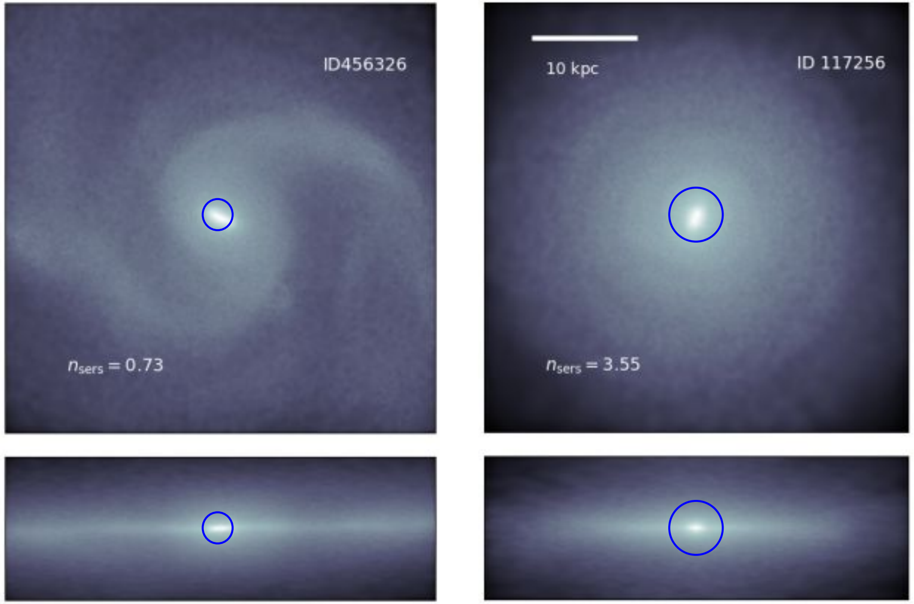


- Galaxies with high Sérsic index bulges have a later last significant merger on average, wrt galaxies with low Sérsic index bulges.

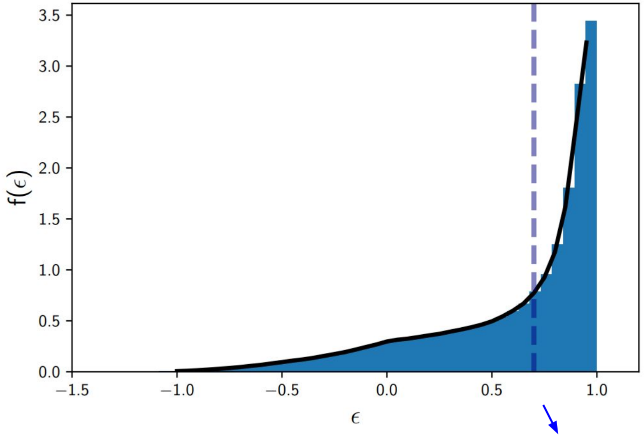
- However there is a significant amount of galaxies with low-Sérsic bulges that experienced a late significan merger

The kinematic bulge

Radial cut ✚ **Circularity parameter cut ,** Abadi (2003)



Spherical region, r < $2 \times r_{\mathrm{eff}}$

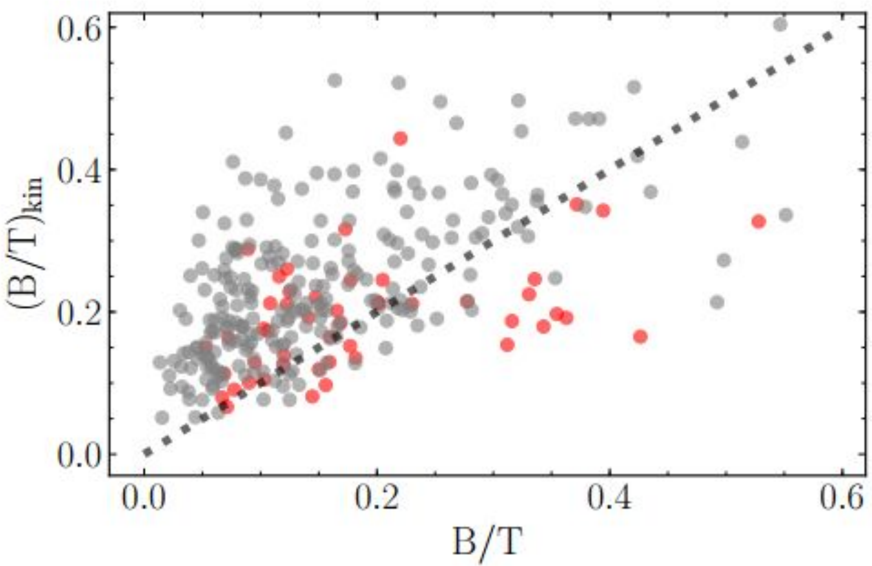


$$\epsilon = J_z / J(E)$$

ϵ_{thresh} = 0.7

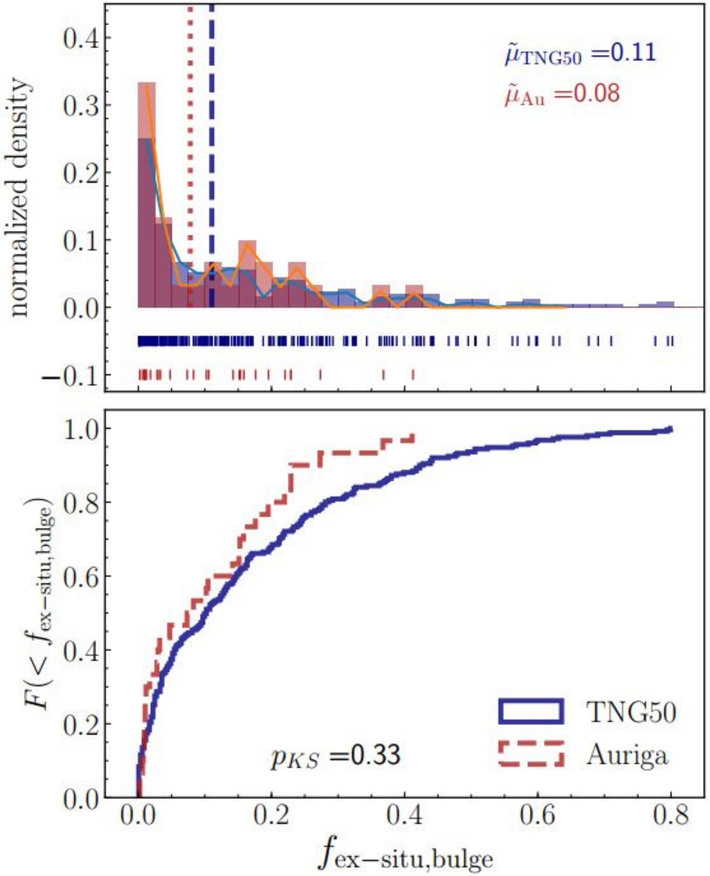
The kinematic bulge

Bear in mind that the kinematic and photometric bulges are different

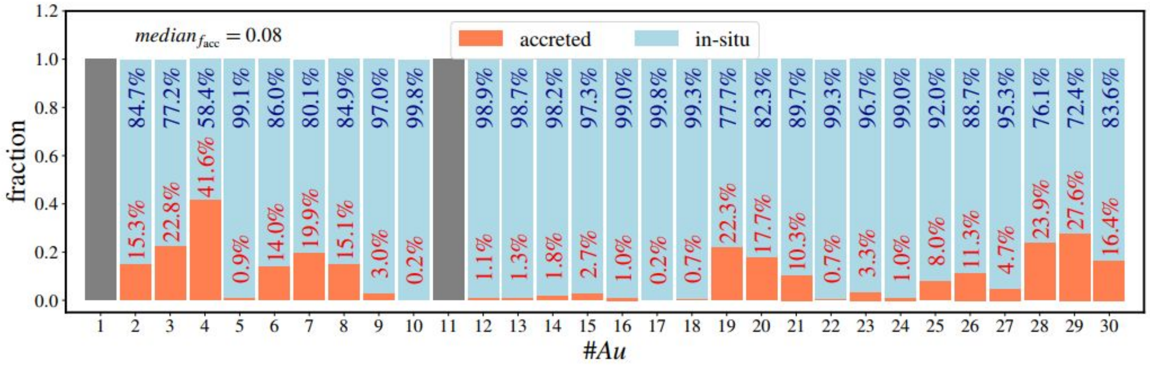


In-situ/Ex-situ component in the kinematic bulge

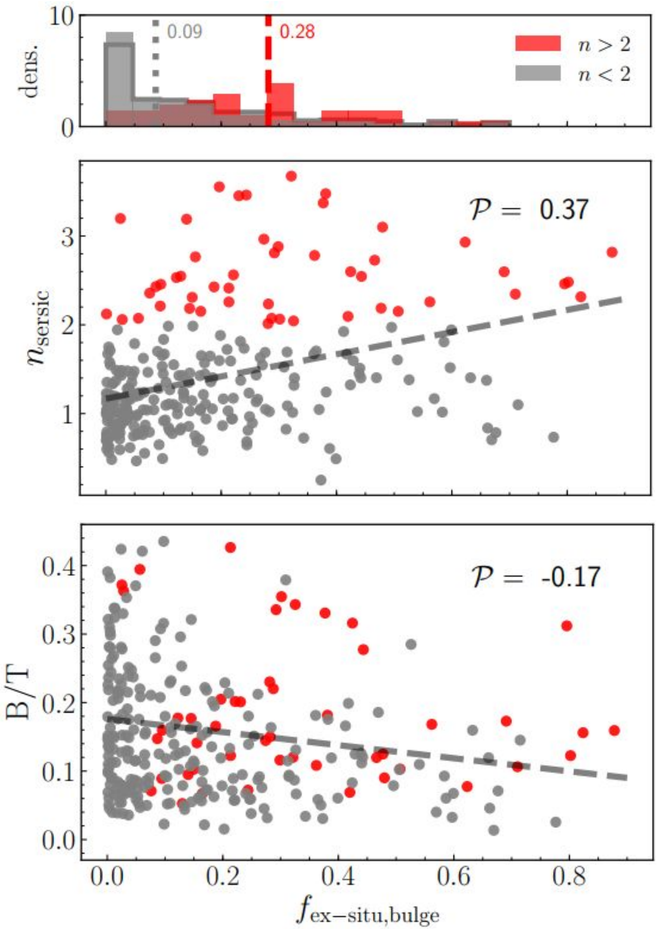
Auriga and TNG50 comparison

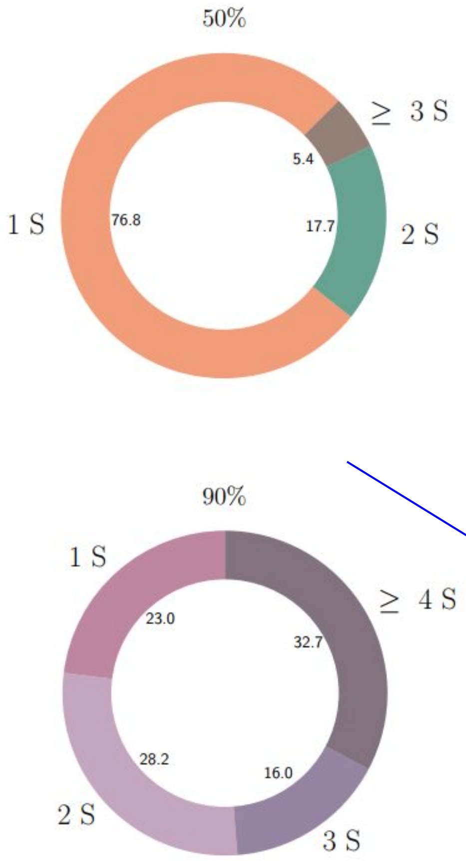


Auriga, **G19**



Ex-situ component in the kinematic bulge





Number of satellites needed to account for 50% and 90% of the ex-situ component in kin. bulges.

Influence of bars: bar strength and demography

Fourier mode analysis

$$a_n(R_j) = \sum_{i=1}^{N_R} m_i \cos(n\theta_i),$$

and

$$b_n(R_j) = \sum_{i=1}^{N_R} m_i \sin(n\theta_i),$$

$$B_n(R_j,t) = \sqrt{a_n(R_j,t)^2 + b_n(R_j,t)^2}.$$

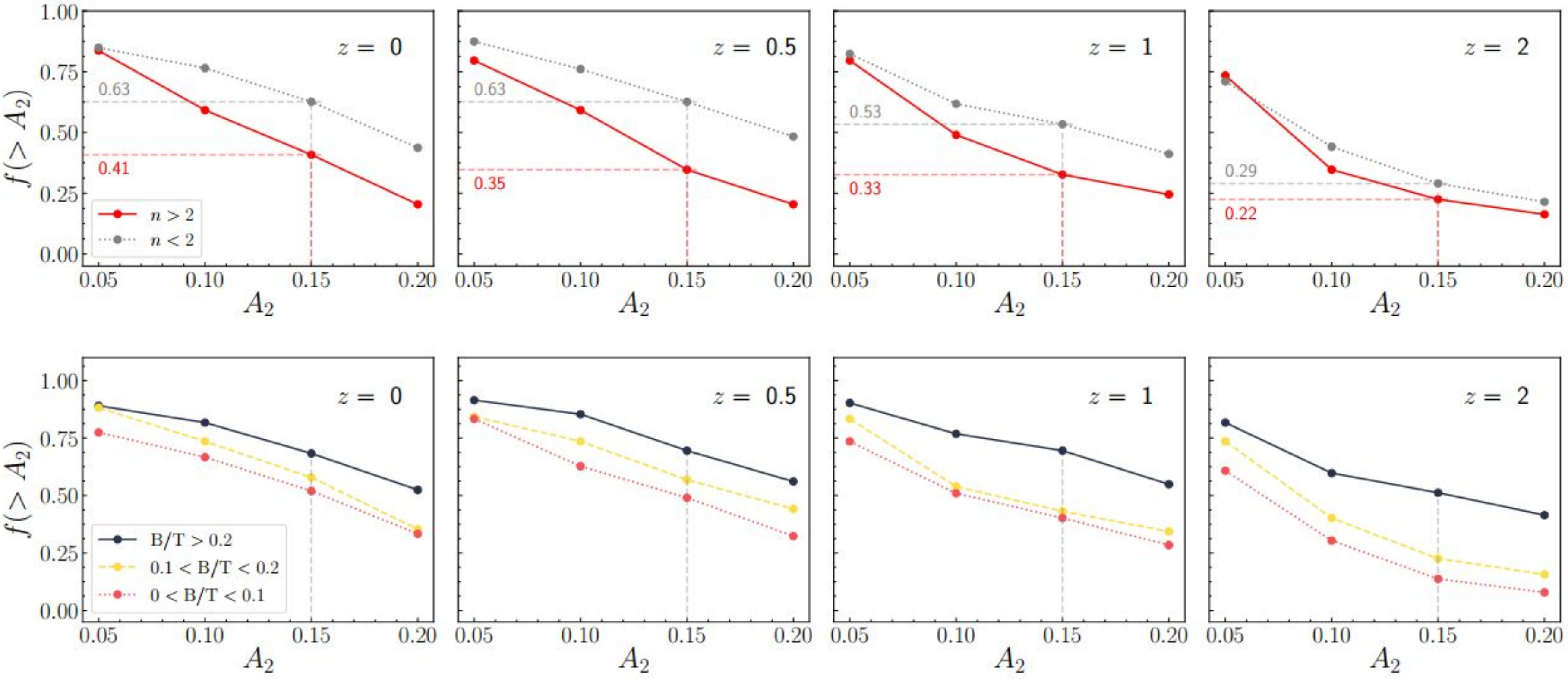
$$\theta_2' = \frac{1}{2}\mathrm{atan2}(b_2, a_2).$$

Bar face angle

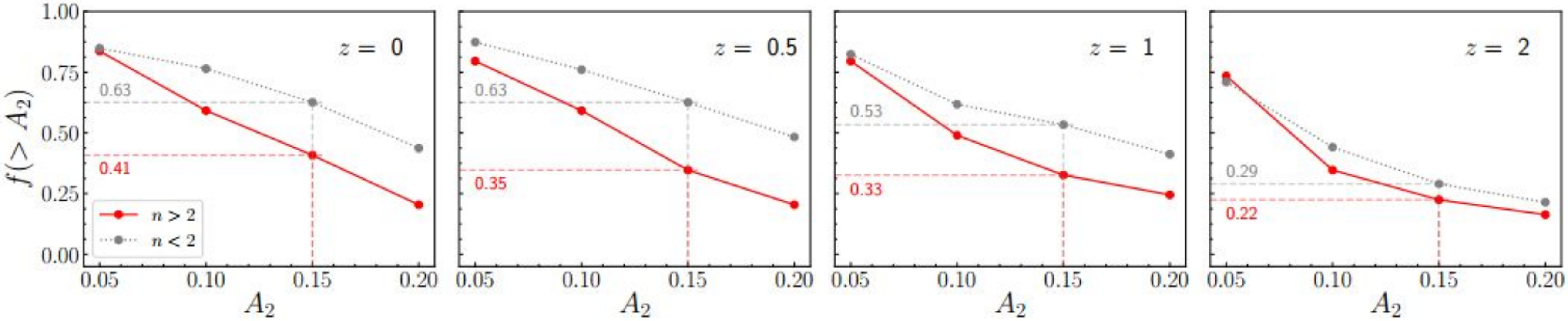
$$A_2(t) = \frac{\sum_j B_2(R_j,t)}{\sum_j B_0(R_j,t)}.$$

Bar Strength: Mass weighted mean of the amplitude of the m=2 Fourier mode within the bar region

Influence of bars: bar evolution



Influence of bars: bar evolution



Two-fold causality

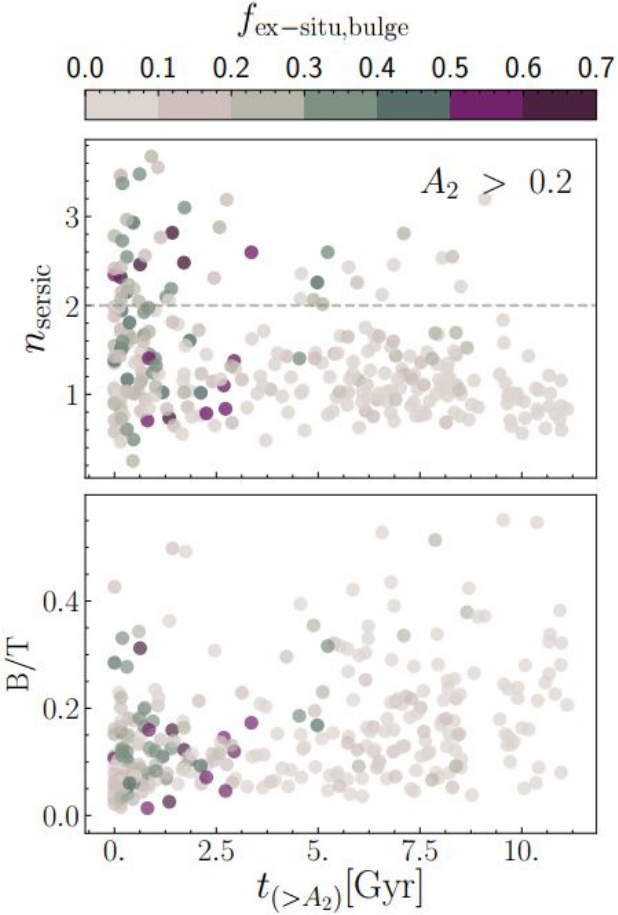
Bars contribute to form low-Sérsic index bulges

- Many known mechanisms (See e.g. Gadotti (2020), Bittner (2020) TIMER survey , → bars lead to the formation of inner discs)

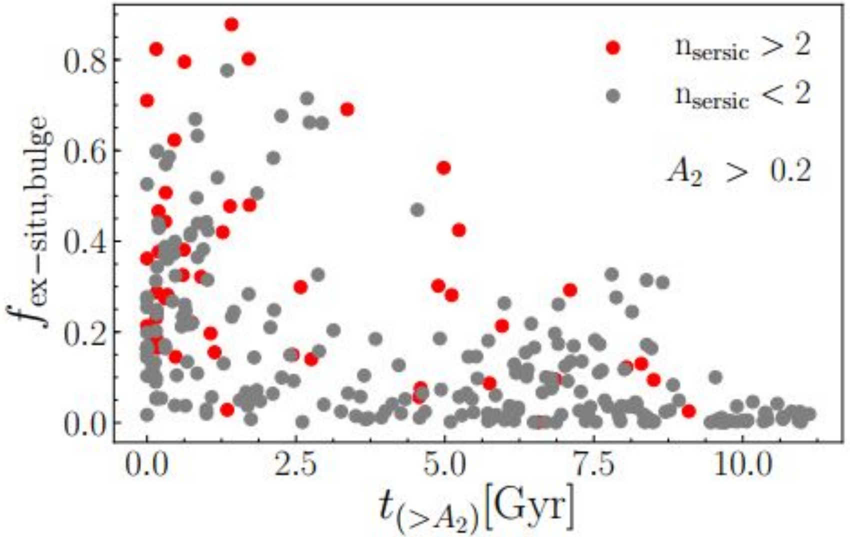
Concentrated bulges prevent the formation of bars

- stops the feedback in the "Swing amplifier and feedback loop" process . See e.g Kataria & Das (2018), Saha & Elmegreen(2018) for recent numerical experiments.

Influence of bars: integrated effect of bars



$$t_{(>A_{\mathrm{thresh}})} = \frac{1}{2} \sum_{i_{>A_{\mathrm{thresh}}}} \left([t_{\mathrm{lb}}(S_{i-1}) - t_{\mathrm{lb}}(S_{i+1})] \right)$$



What does this tell us about the formation and/or evolution of galactic bulges?

Concentrated photometric bulges, (with high Sérsic index in a 2-component 1-dimensional SB decomposition) have, more commonly, ***a later significant merger*** than low-Sérsic bulges.

Stellar particles in kinematically selected bulges of MW/M31-like galaxies form predominantly ***in-situ***

A single merger explain the majority of ex-situ stars in the central regions of most MW/M31-like galaxies. A few of them is enough to explain the total ex-situ component. Galaxies with ***high fractions of ex-situ stars*** in their kinematically selected bulges have <u>more commonly</u> ***high Sérsic bulges.***

Bars, when present, play a significant role in adding mass to the central regions of all bulges and contribute to form ***low-Sérsic index photometric bulges.***

The photometric bulge type of a galaxy ***does not*** depend on the environment where the galaxy resides.

General opinion: There is a huge diversity of bulges in MW/M31-like galaxies. The connection between photometric bulge type and their formation pathways is not straightforward. Fitting all of them in only two categories, from a theoretical point of view, is increasingly difficult.