Milky Way- and M31-like galaxies with TNG50: disk survival through mergers and disk flaring

Diego Sotillo Ramos
Annalisa Pillepich
and the IllustrisTNG team
Max-Planck-Institut für Astronomie, Heidelberg

Ken Freeman @ 80
Perth, 21.9.2022

Main take-home messages

According to TNG50:

- MW/M31-like galaxies can undergo recent major mergers and still have a relatively thin stellar disk (scale height as low as ~100-200 pc)

- MW/M31-like galaxies exhibit a very diverse phenomenology of flaring, encompassing all previous numerical findings

MW/M31-like galaxies in TNG50: selection criteria

The galaxy must match, at z=0, the following three conditions:

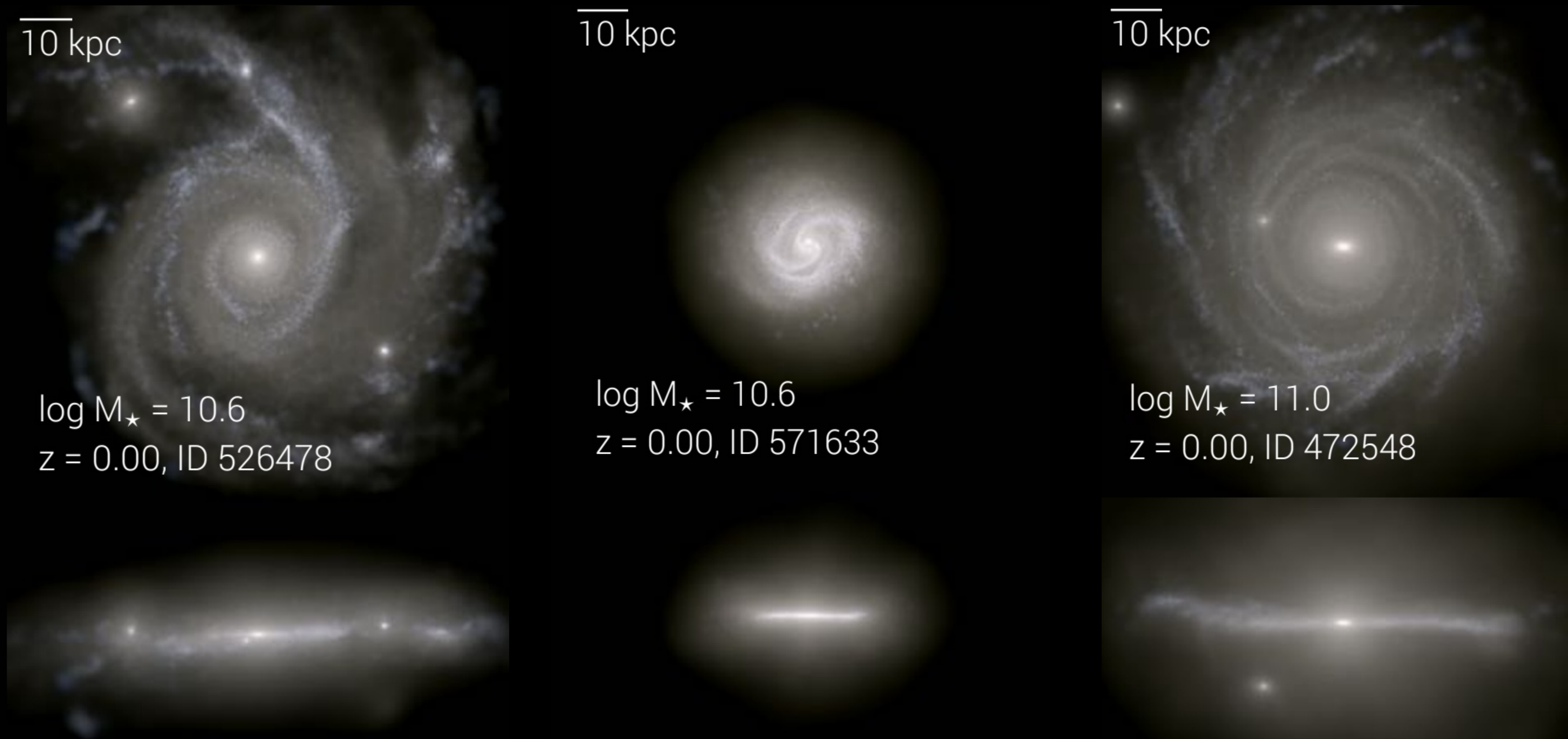
- **Stellar mass**: $\log_{10}(M_{star}/M_{sun})$ (<30kpc) within [10.5, 11.2].
- **Diskyness**: either shape constrain (a) or by visual inspection (b):
  a) Minor to major axis ratio ... < 0.45
  b) Visually disky = AP visu... l images, face-on and edge-on.

more details: talk by Annalisa Pillepich

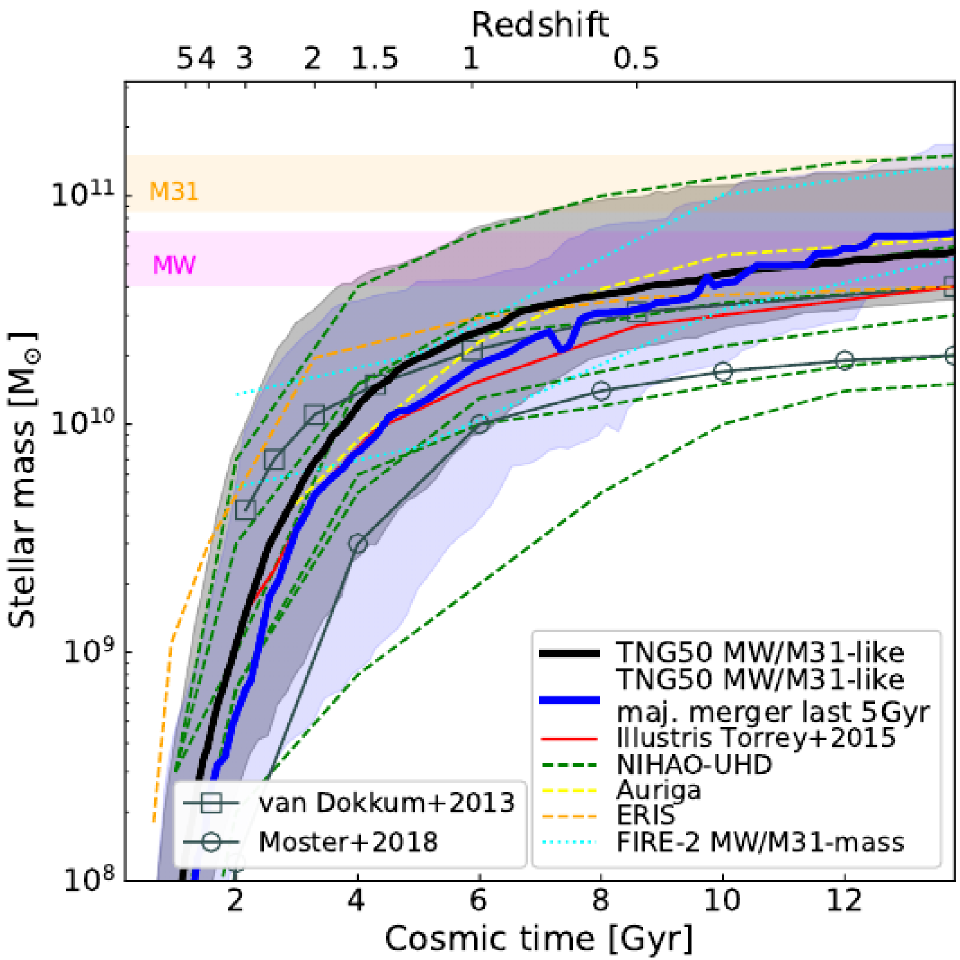
- **Isolation**: no galaxy with $\log_{10}(M_{star}/M_{sun})$ ... 0.5 within 500 kpc distance and $M_{200c,Host} < 10^{13}$ M_{sun}

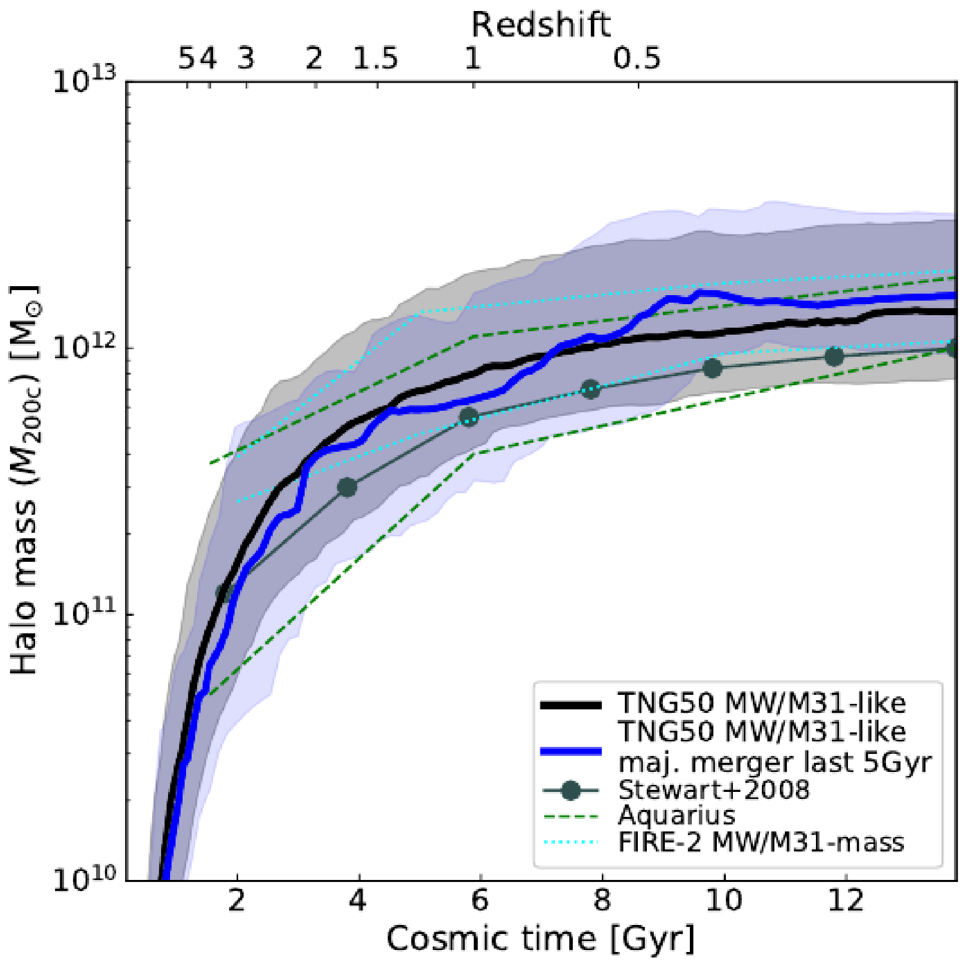
→ 198 MW/M31 analogs in TNG50

Examples of MW/M31 analogs in TNG50



Who are the progenitors of MW and M31?





Sotillo-Ramos, Pillepich et al. 2022

Outline

- How can MW/M31-like galaxies survive recent major mergers?

Sotillo-Ramos, Pillepich et al. 2022

- Do all MW/M31-like galaxies show flaring of the stellar disk?

Sotillo-Ramos and Donnari, Pillepich, et al. in prep.

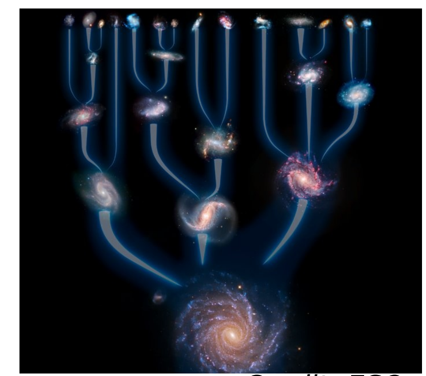
The merger histories of MW/M31-like galaxies in TNG50

Introduction: Disk galaxies and mergers

- Disk galaxies are common
  - 2/3 of MW-mass galaxies are disky

- Galaxies grow through mergers

  (but not only, of course)



Credit: ESO

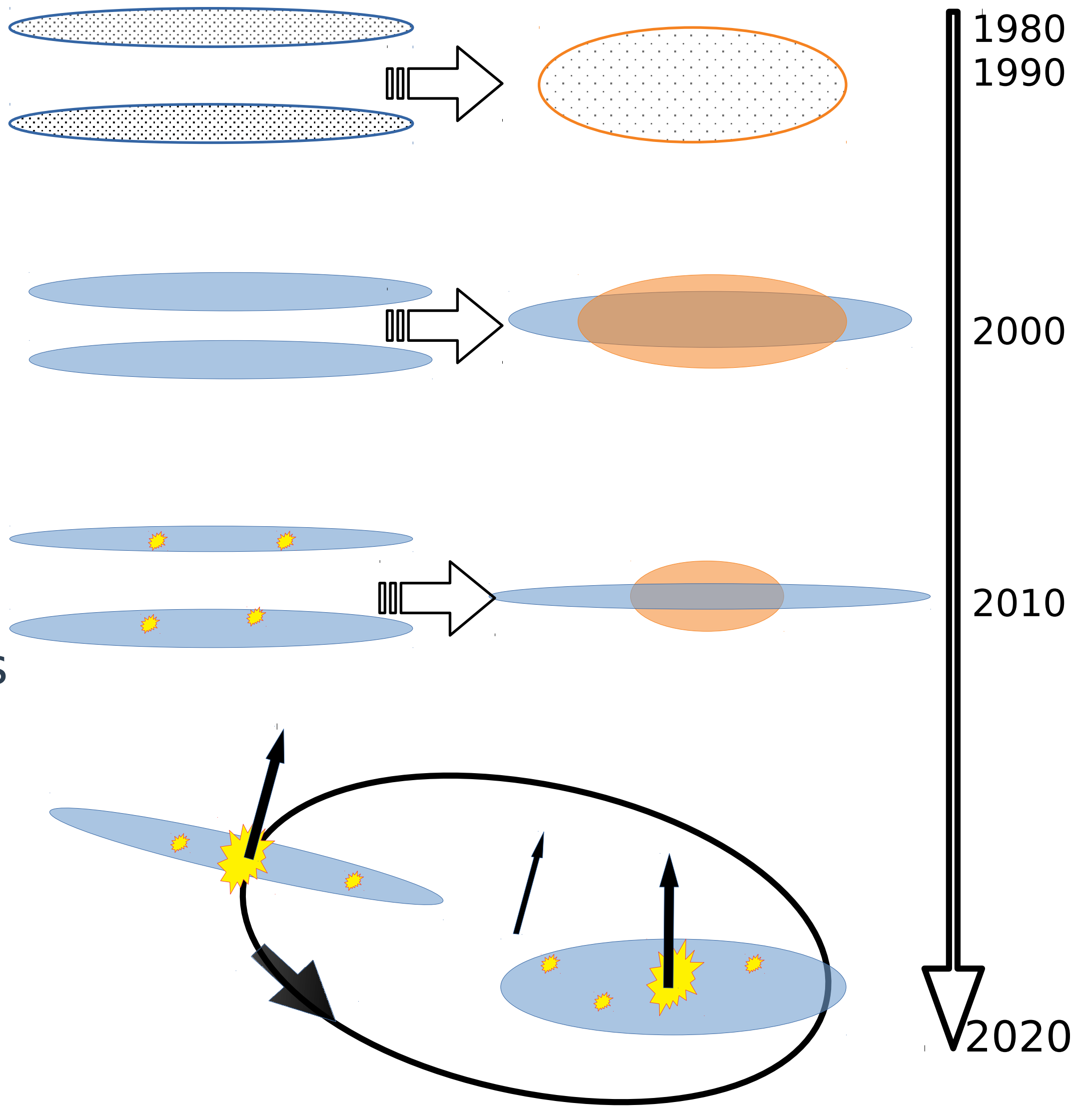
- Mergers are ubiquitous

- Mergers induce morphological changes

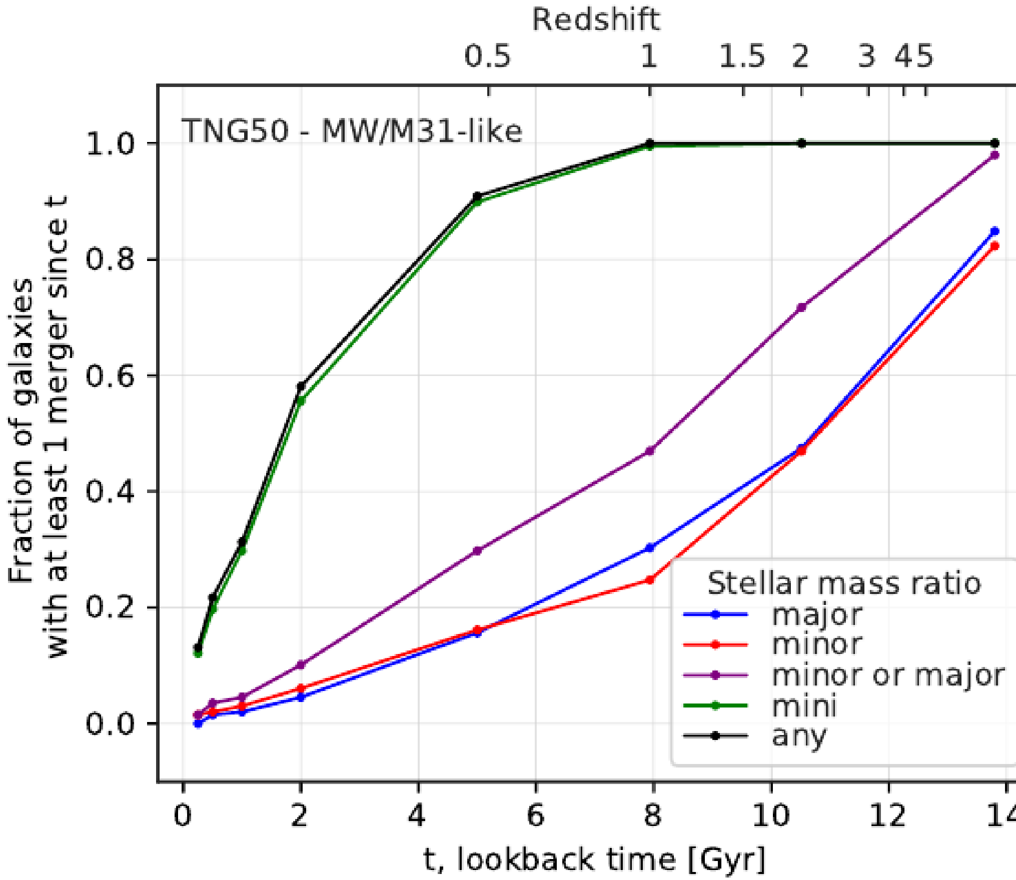
Disk galaxies & mergers (models+simulations)

- Disk galaxies can form spheroids through mergers (n-body collisionless)
- Adding gas: disk galaxies (but disks too thick and bulges too massive)
- Increasing resolution, stellar feedback and improved star formation recipes: realistic thin disks
- Other relevant processes: AGN feedback, orbital configuration, spin of the progenitors, etc.

→ Many merger parameters to explore



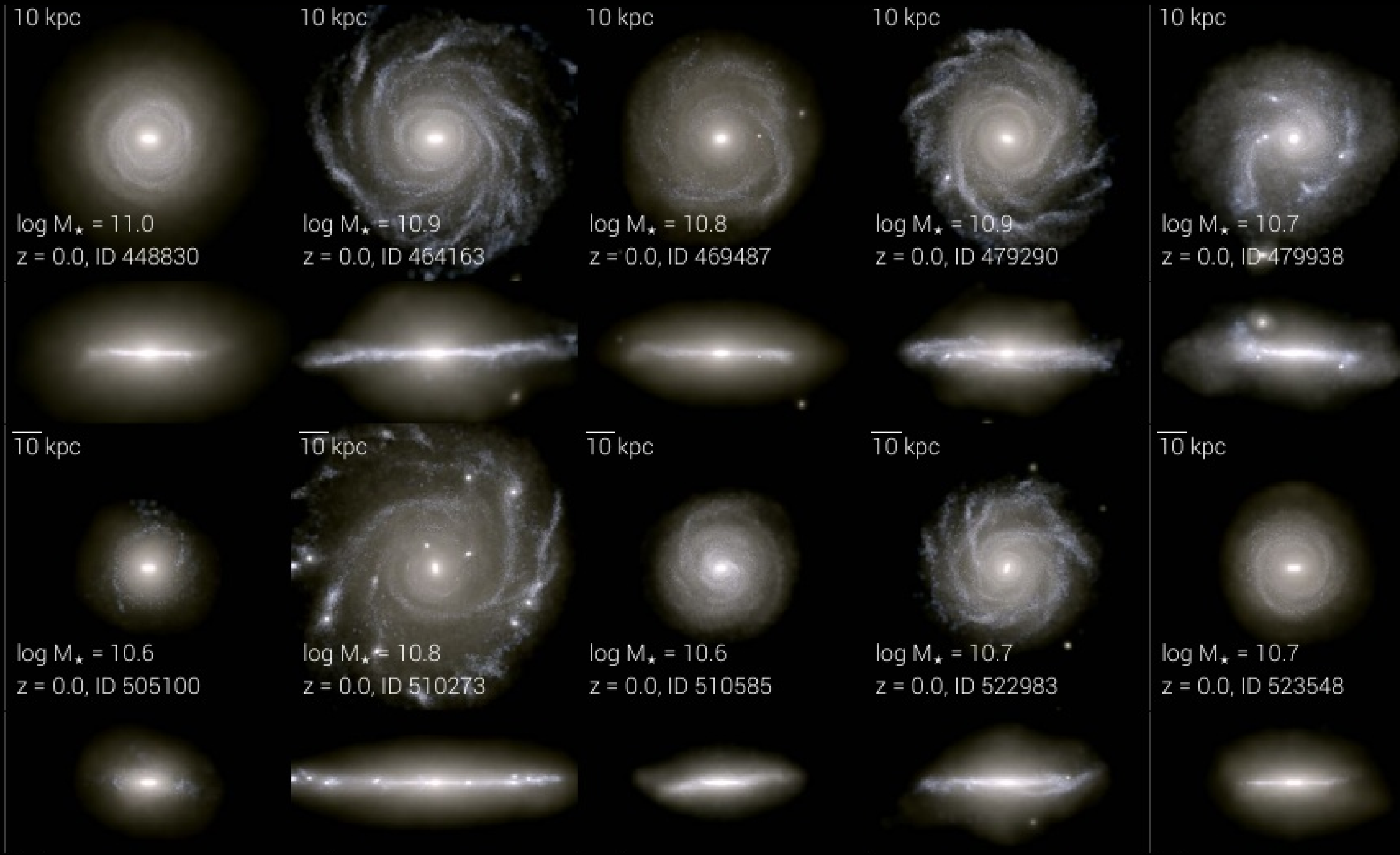
Merger histories of TNG50 MW/M31 analogs are very diverse



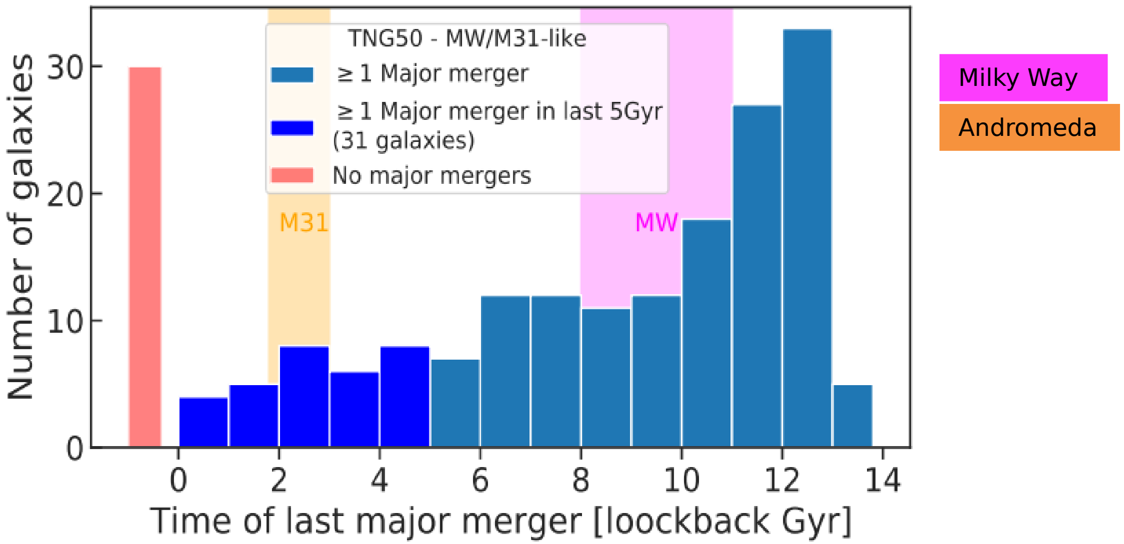
Sotillo-Ramos, Pillepich et al. 2022

- 95/198 (~47%) undergo major mergers since z=2
- 31/198 (~16 %!) undergo major mergers in the last 5 Gyr

Some MW/M31 analogs with recent major mergers

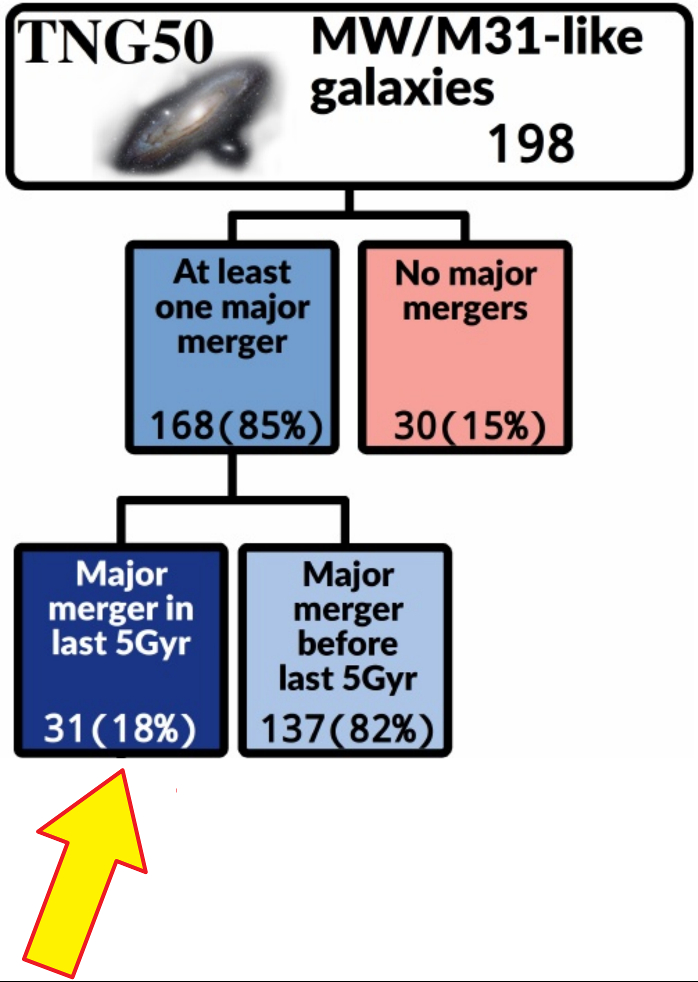


Last major mergers of MW/M31-like galaxies

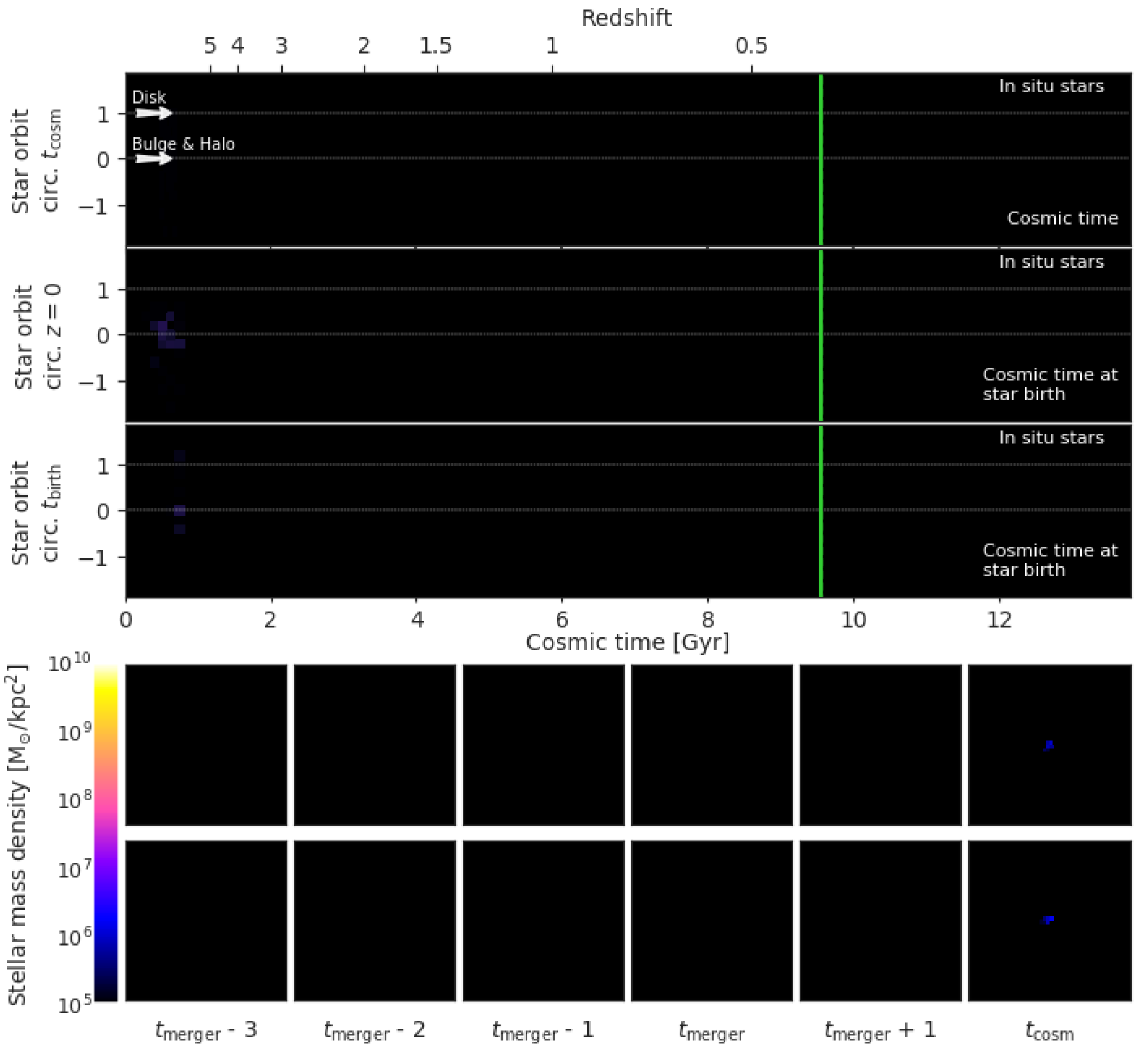


Sotillo-Ramos, Pillepich et al. 2022

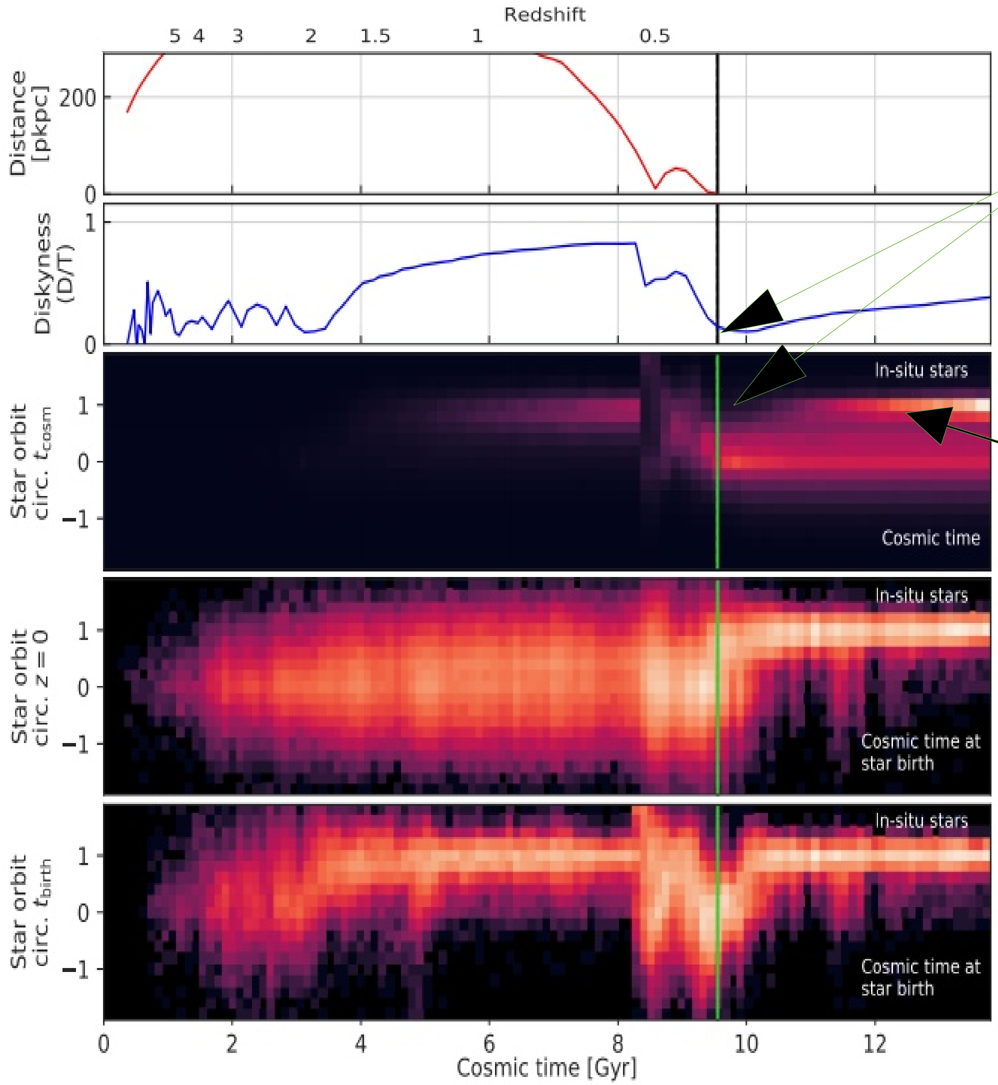
- Recent major mergers in different moments of the last 5 Gyr
- Galaxies compatibles with MW and M31 scenarios



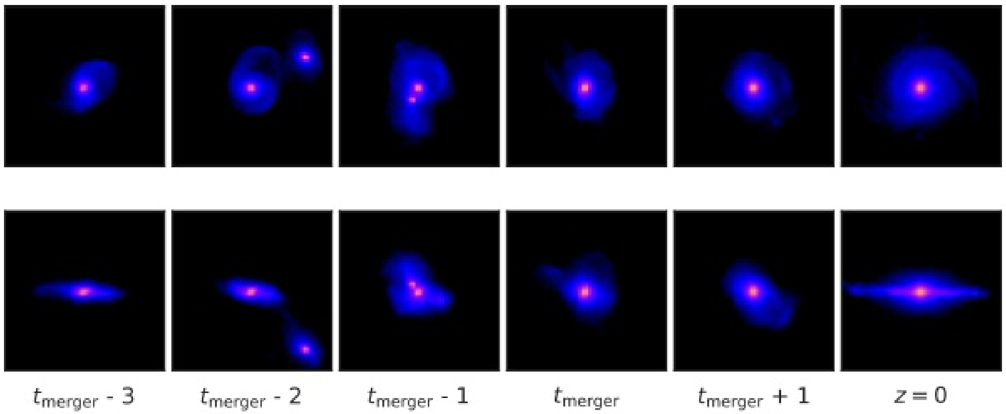
Merger scenarios: destroyed+reformed disks



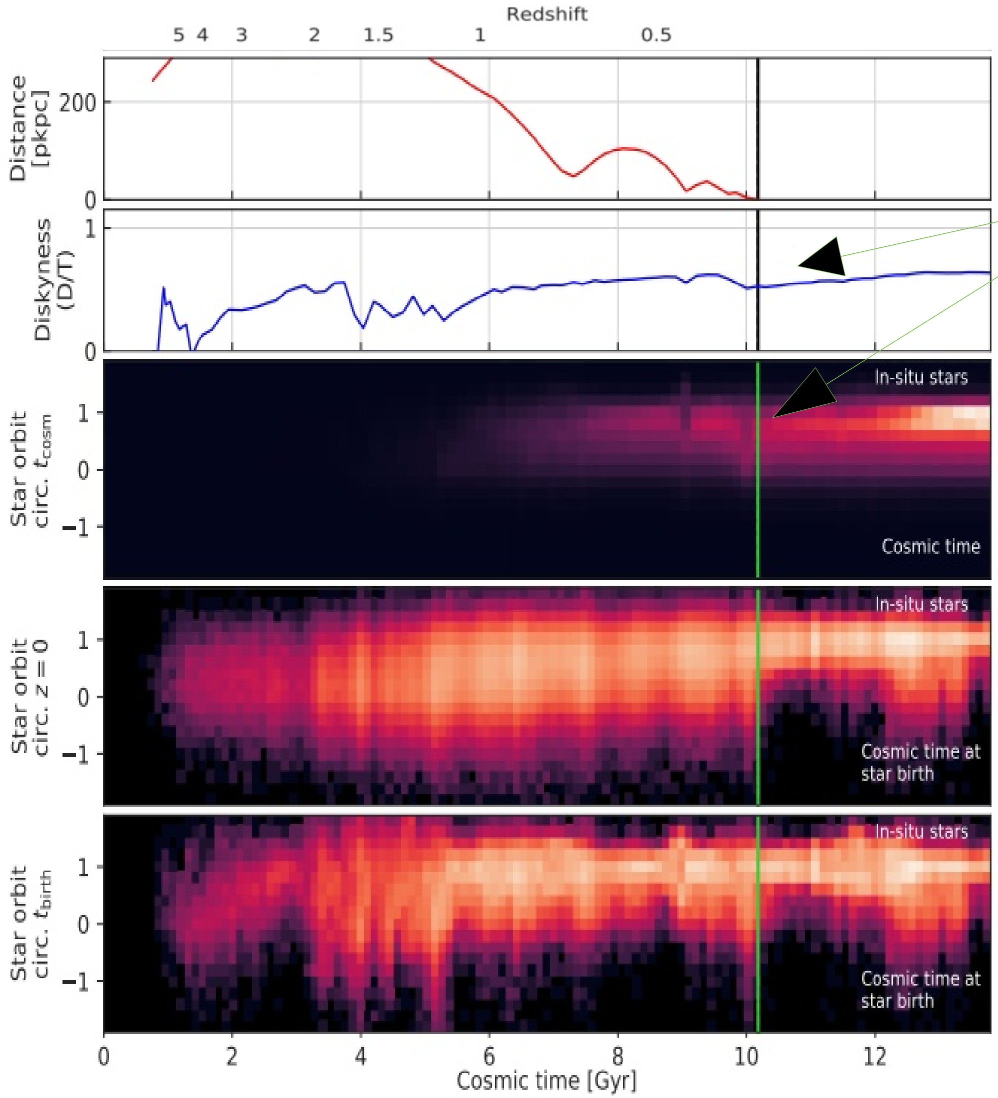
Merger scenario 1: destroyed+reformed disks



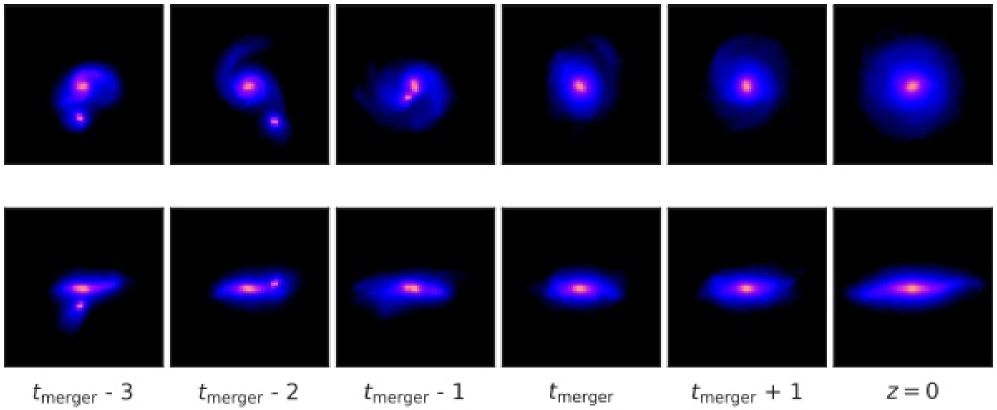
- 2/3 galaxies with a major merger in the last 5 Gyr
- Significant drop in the diskyness during the merger event (starting sometimes with the last pericentric passage)
- After the merger and until z=0, a new stellar disk forms



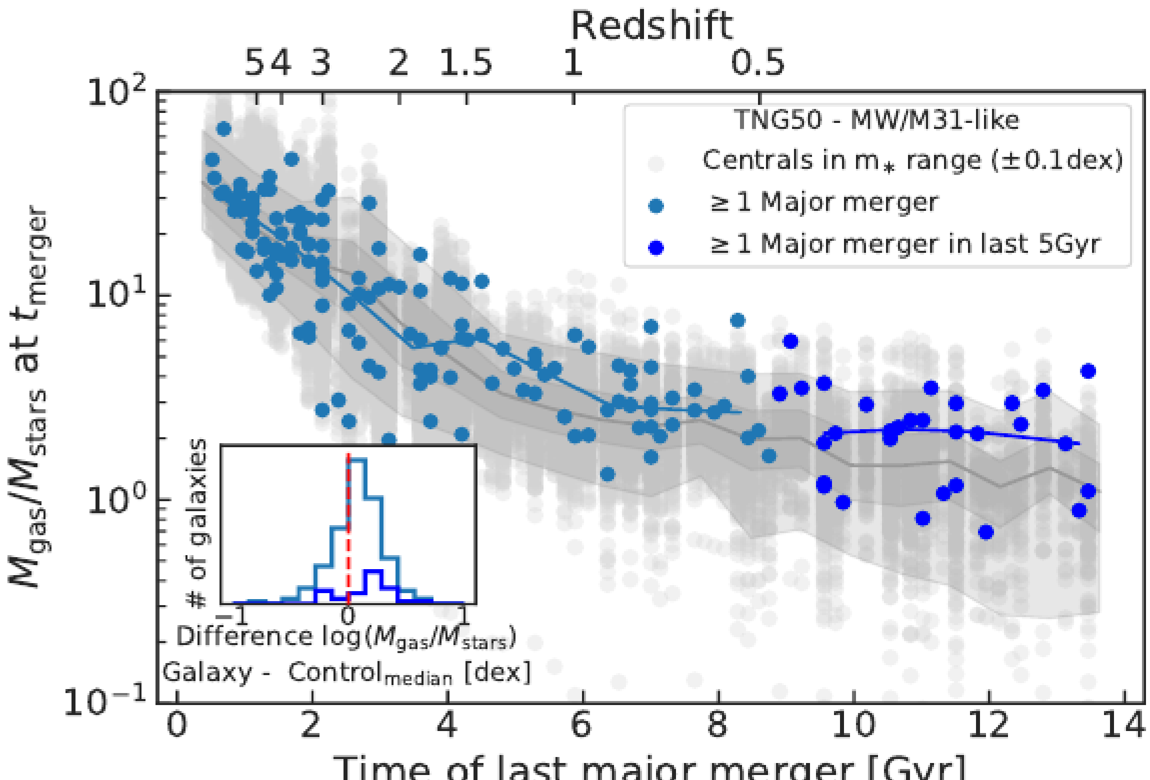
Merger scenario 2: non-destroyed disks



- 1/3 galaxies with a major merger in the last 5 Gyr
- Similar fraction of diskyness before and after the merger. Only minimal drop



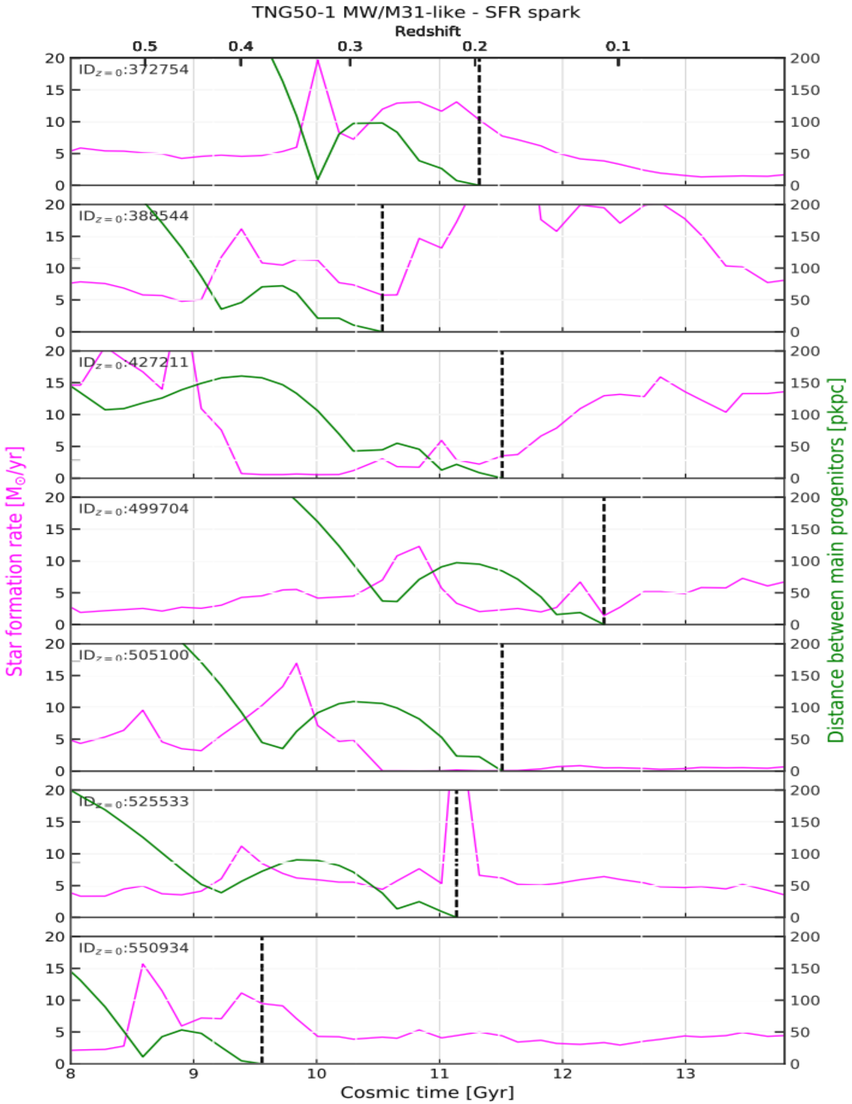
Gas availability allows star formation



Sotillo-Ramos, Pillepich et al. 2022

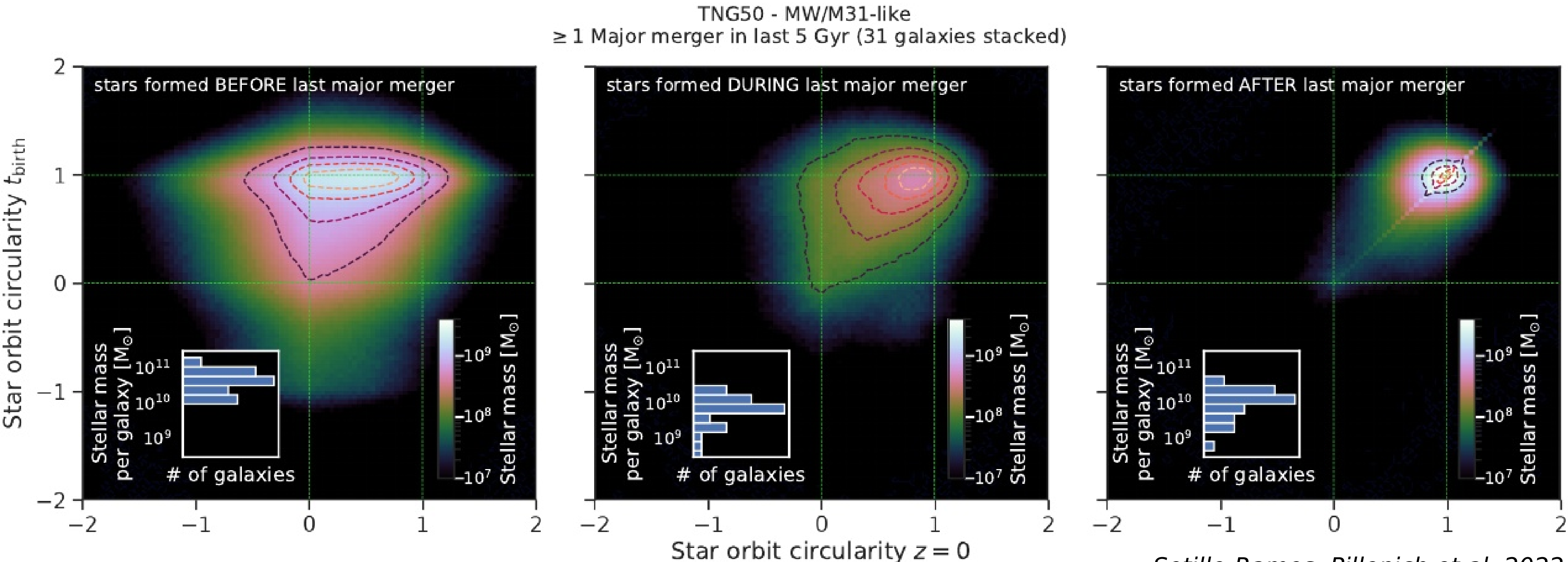
- MW/M31 analogs with recent major mergers are, on average, richer in gas content than central galaxies in a similar (+/- 0.1 dex) stellar mass range

SF bursts are triggered by pericentric passages



- Last pericentric passages can trigger star formation in a bursty manner
  - Observed in 10/31 galaxies
  - Only possible through TNG50 high particle resolution: not in original Illustris or TNG100
  - Implications for MW and Magellanic Clouds

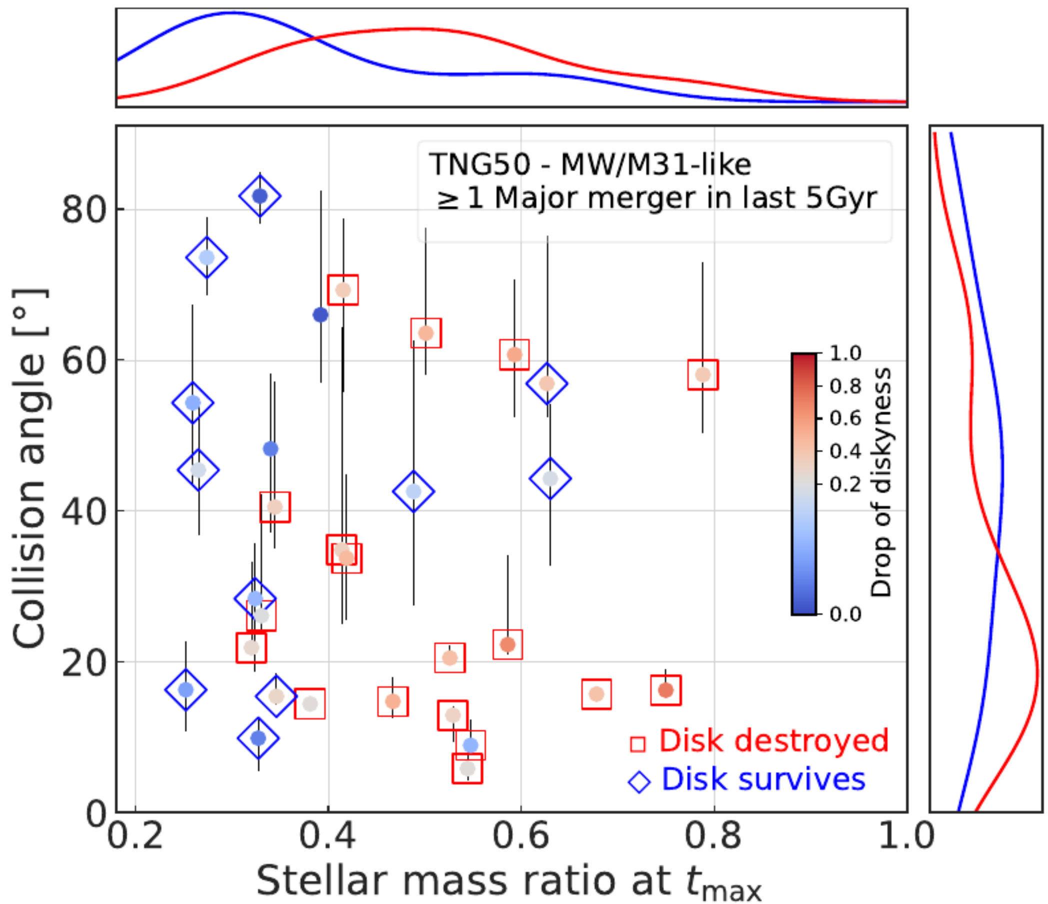
SF during and after the last major merger



Sotillo-Ramos, Pillepich et al. 2022

- Most stars born before, during and after the LMM formed in circular orbits (Ɛ ≈ 1)
  - At z=0 orbits have been heated (0 ≲ Ɛ ≲ 1) for stars born before and during the LMM
  - At z=0 orbits remain circular (Ɛ ≈ 1) for stars born afther the LMM

Disk survivavility depends on collision angle and stellar mass ratio

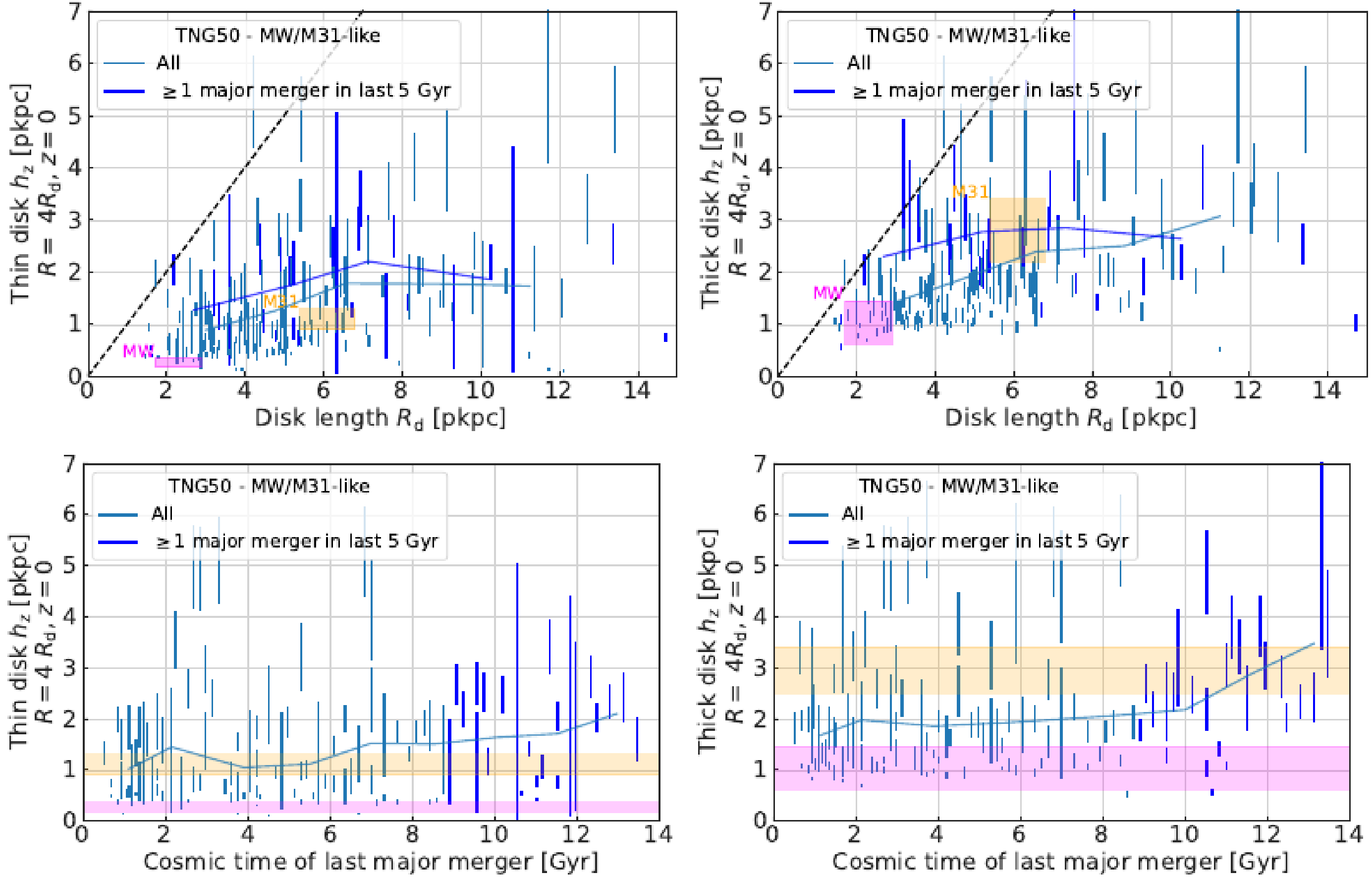


Sotillo-Ramos, Pillepich et al. 2022

For the MW/M31 analogs with recent major mergers:

- More likely that the disk survives if the accreted galaxy is less massive
- Head-on collisions destroy stellar disks more frequently

Galaxies with recent LMM are “thicker” (at z=0)



$$\rho(z) = \rho_{\rm thin}\, \mathrm{sech}\left(\frac{z}{h_{\rm thin}}\right) + \rho_{\rm thick}\, \mathrm{sech}\left(\frac{z}{h_{\rm thick}}\right)$$

$$\rho(z) = \rho_{\rm thin}\, \mathrm{sech}^2\left(\frac{z}{2h_{\rm thin}}\right) + \rho_{\rm thick}\, \mathrm{sech}^2\left(\frac{z}{2h_{\rm thick}}\right)$$

Sotillo-Ramos, Pillepich et al. 2022

But… there are still some of them with a thin disk as thin as the MW disk (~100-200)

Disk flaring with TNG50

(plots from: *Sotillo-Ramos and Donnari, Pillepich et al.*, in prep.)

What is flaring?

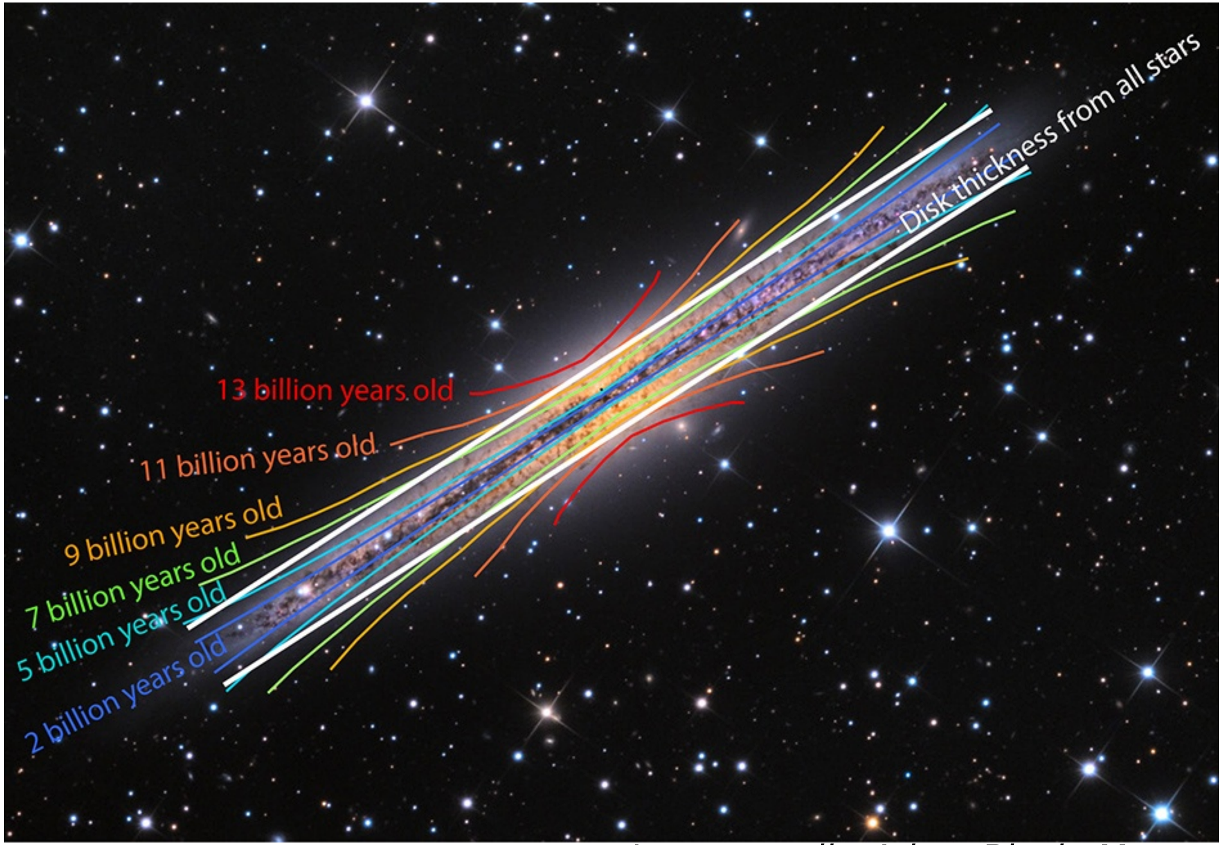


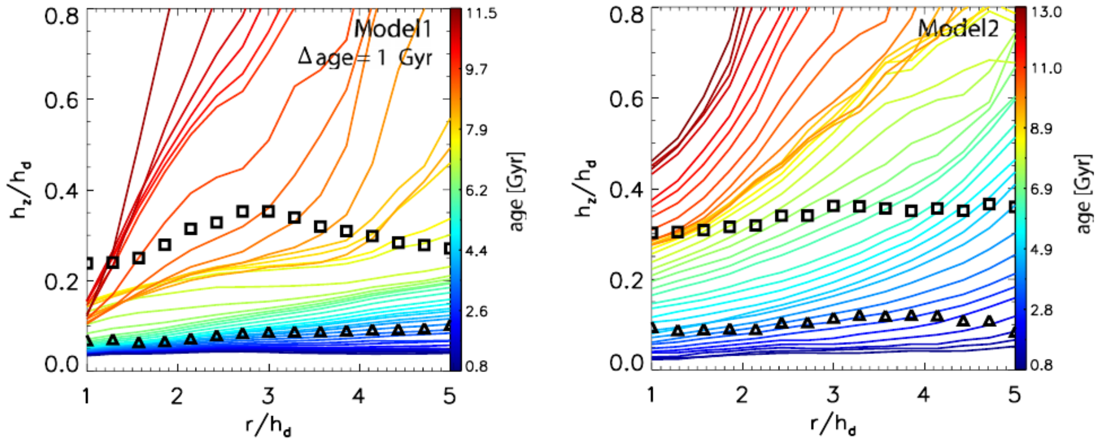
Image credit: Adam Block, Mt. Lemmon SkyCenter, University of Arizona / Ivan Minchev, AIP

Flaring: increase of stellar disk height with increasing radius

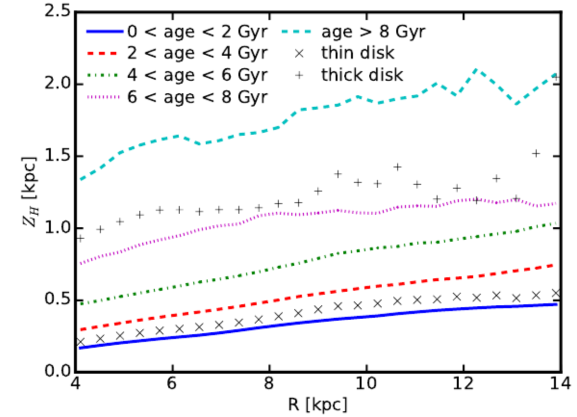
What causes the flaring?

- Secular evolution, e.g. radial migration?
- External interactions, e.g. satellite accretion or fly-bys?

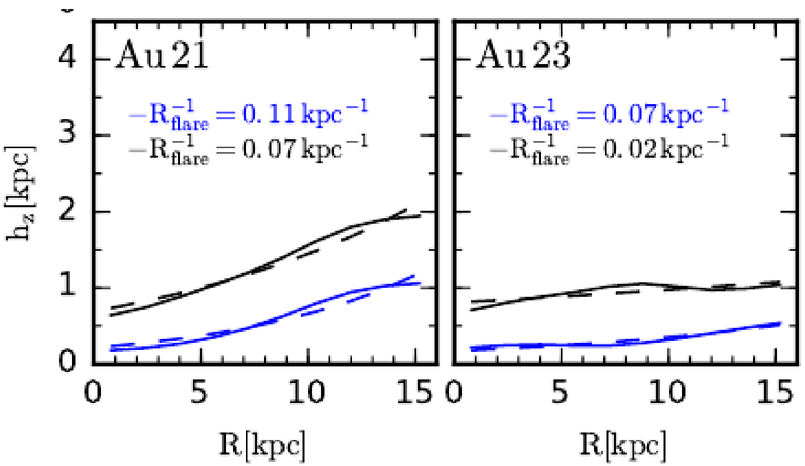
Flaring: previous simulations



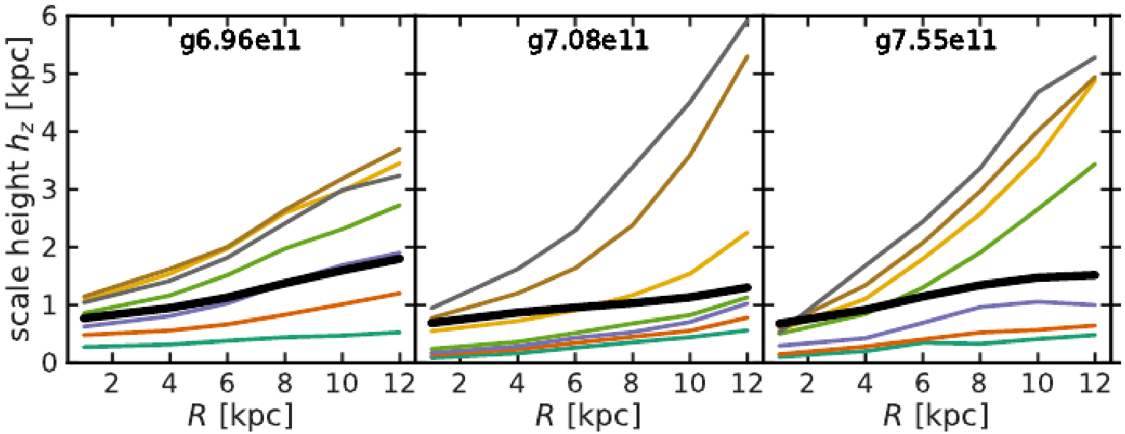
Minchev+2015



Ma+2017 (LATTE)

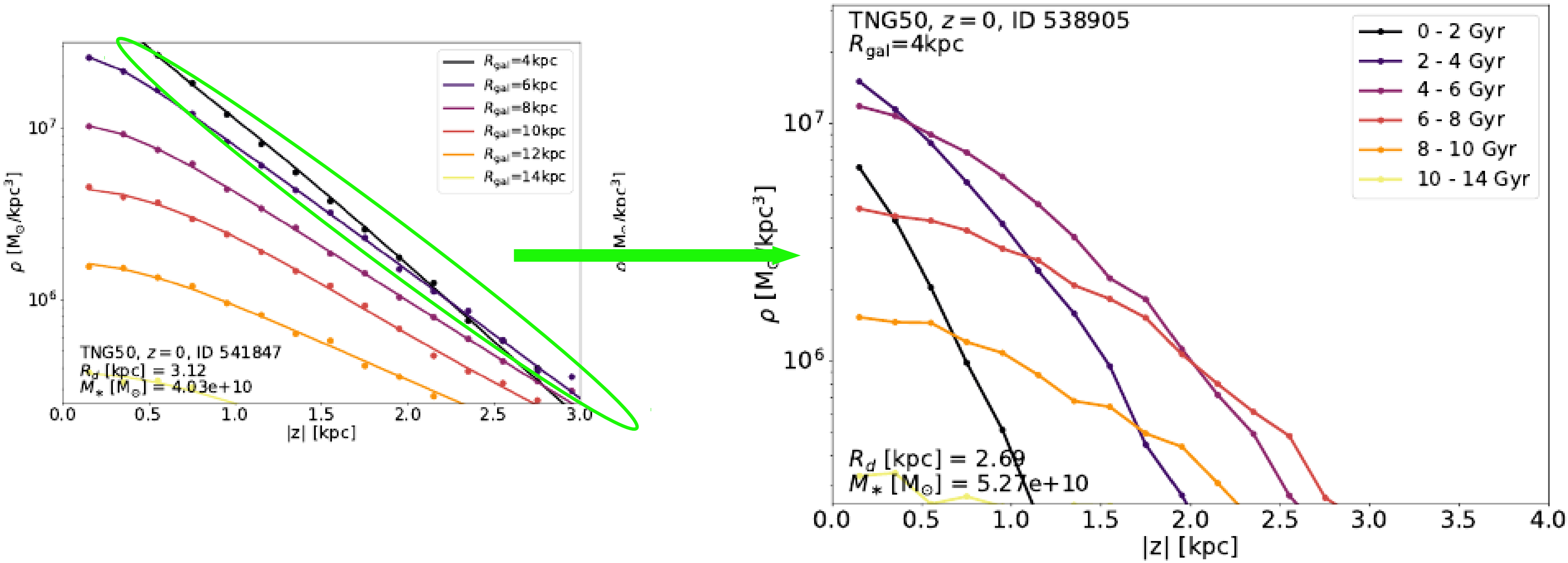


Grand+2017 (Auriga)



Buck+2019 (NIHAO-UHD)

Vertical profiles for monoage stellar populations

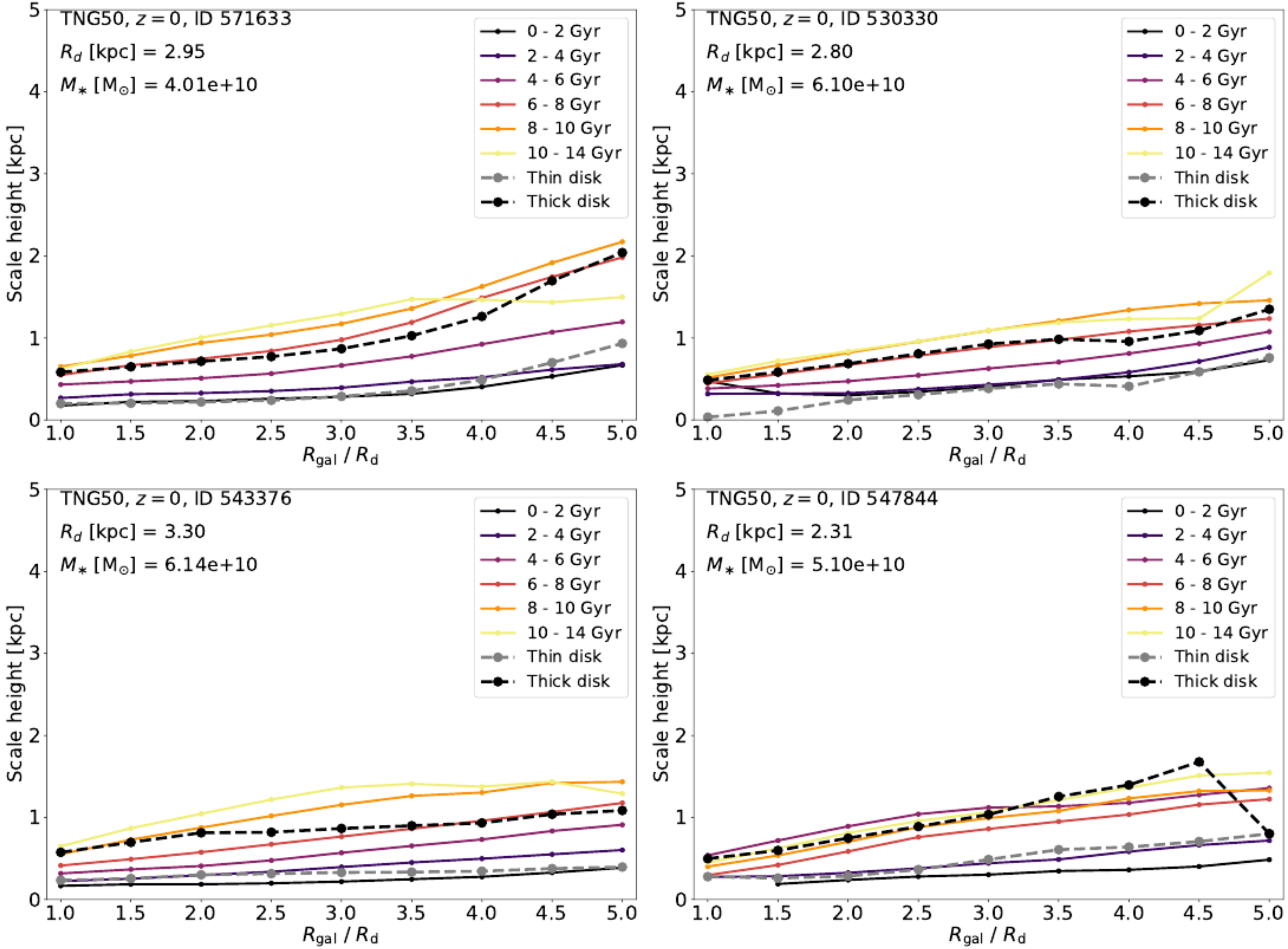


- Mono-age populations: $\rho(z) = \rho_0 \, \mathrm{sech}^2(z/h_z)$

Diversity in disk flaring

exponential

young stars flare more



linear

old stars flare more

How to quantify this diversity of flaring?

- A nonparametric approach

For each monoage population

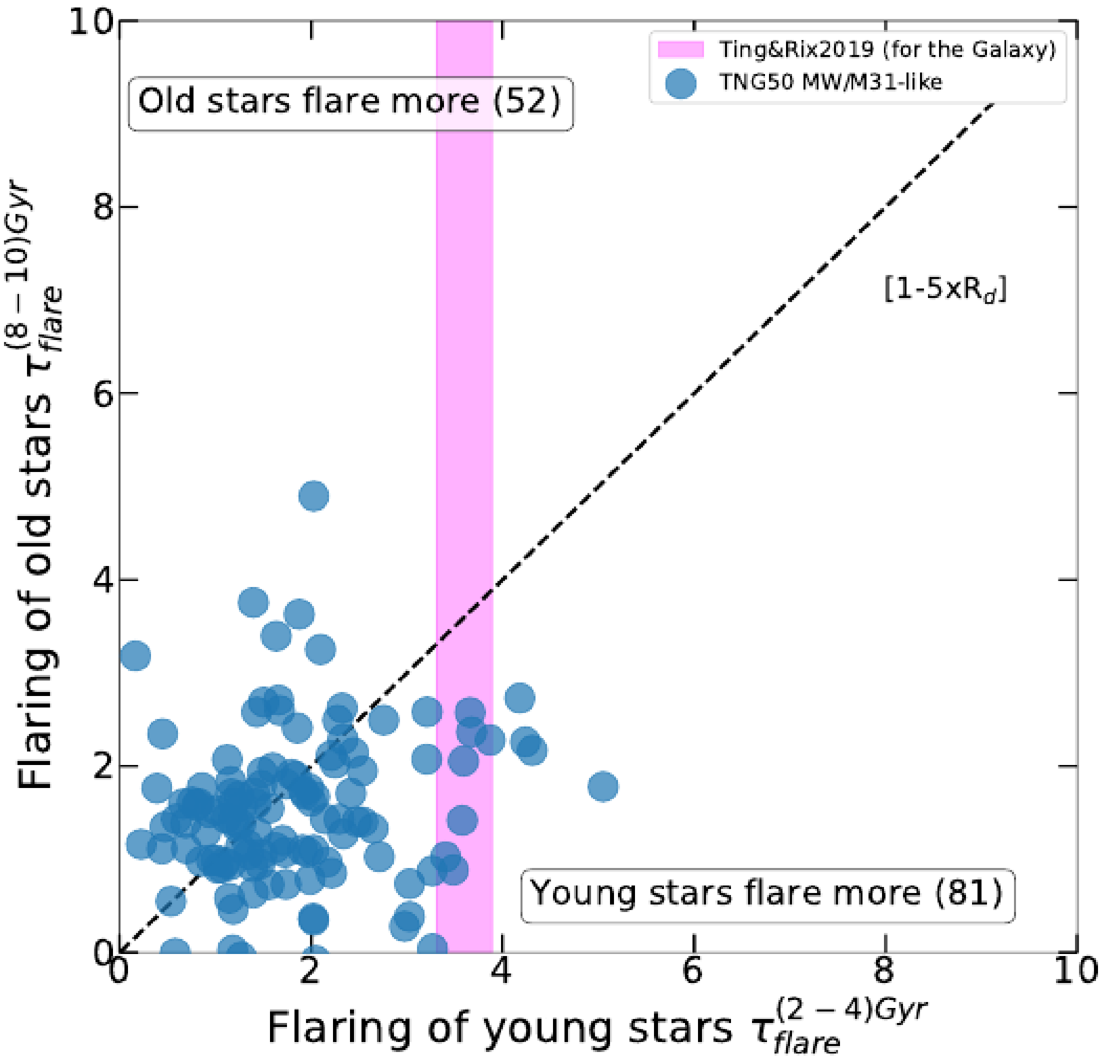
outer disk h_z

inner disk h_z

$$\tau_{\mathrm{flare}} = \frac{h_{z,5\times R_d} - h_{z,1\times R_d}}{h_{z,1\times R_d}}$$

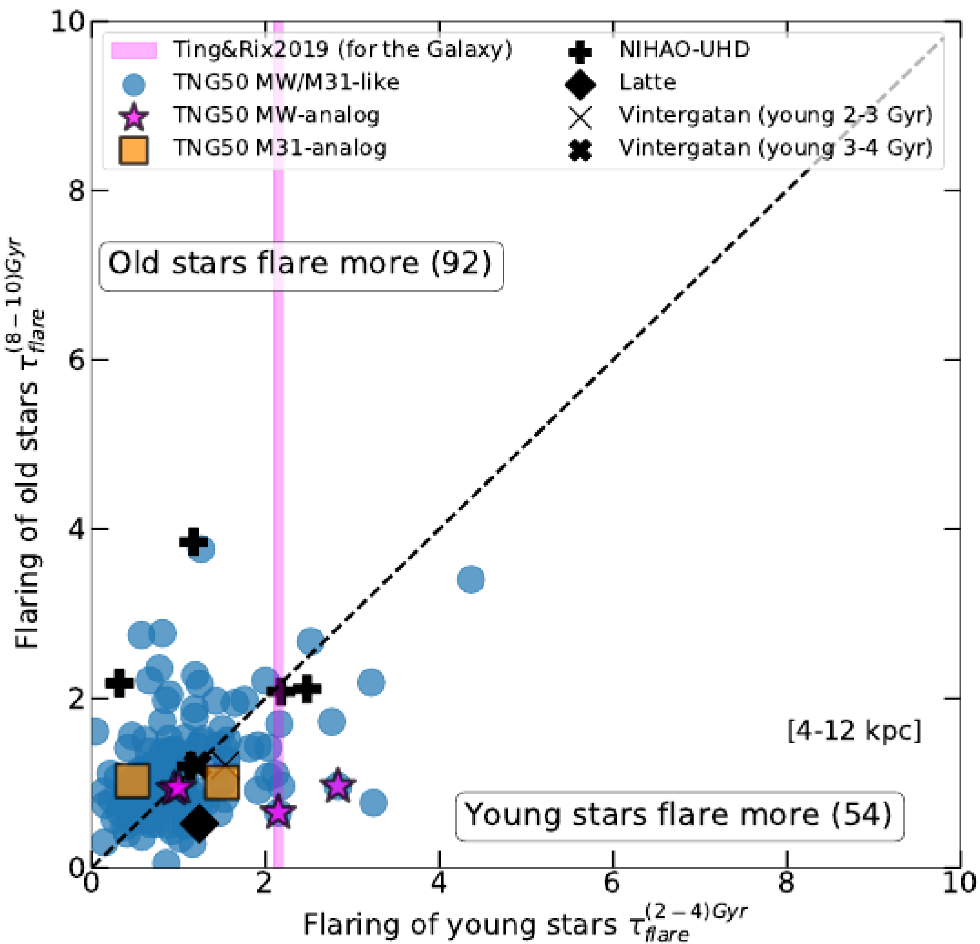
Compare the relative enhancement of disk height at two radii

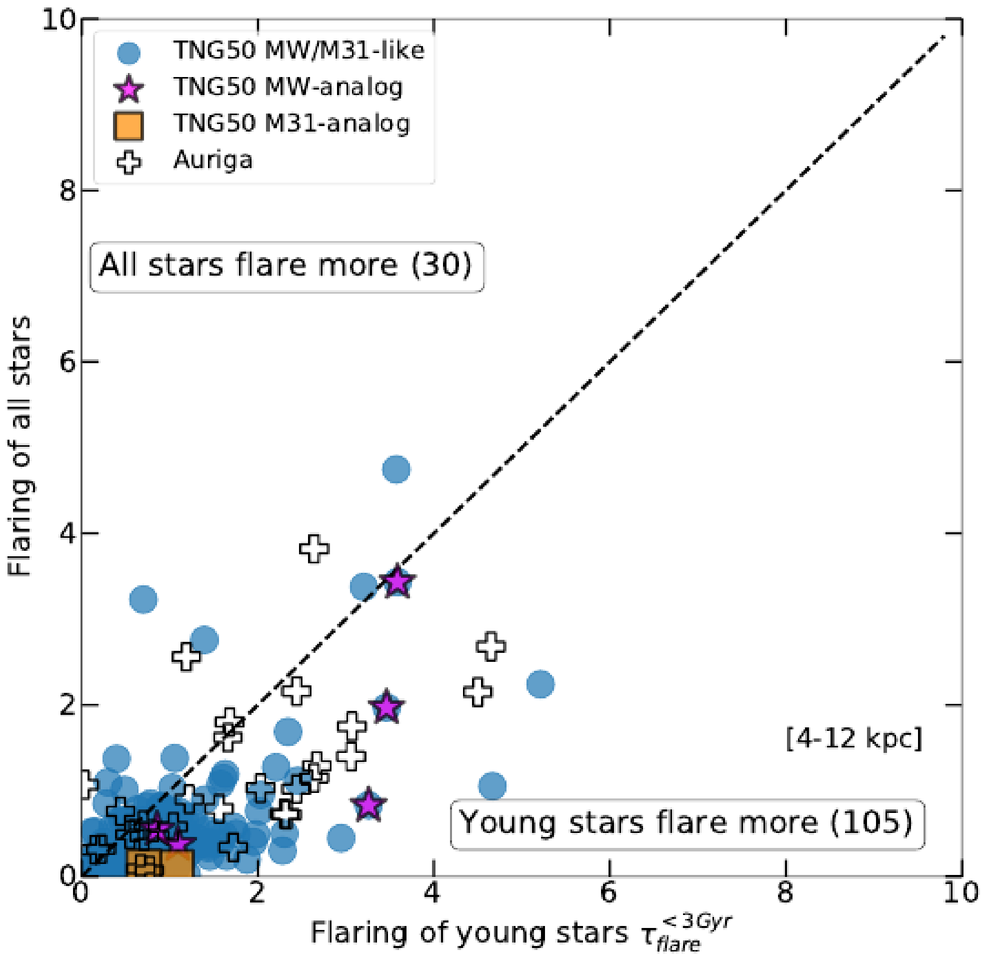
Flaring in TNG50: old vs young stars



Great diversity of flaring

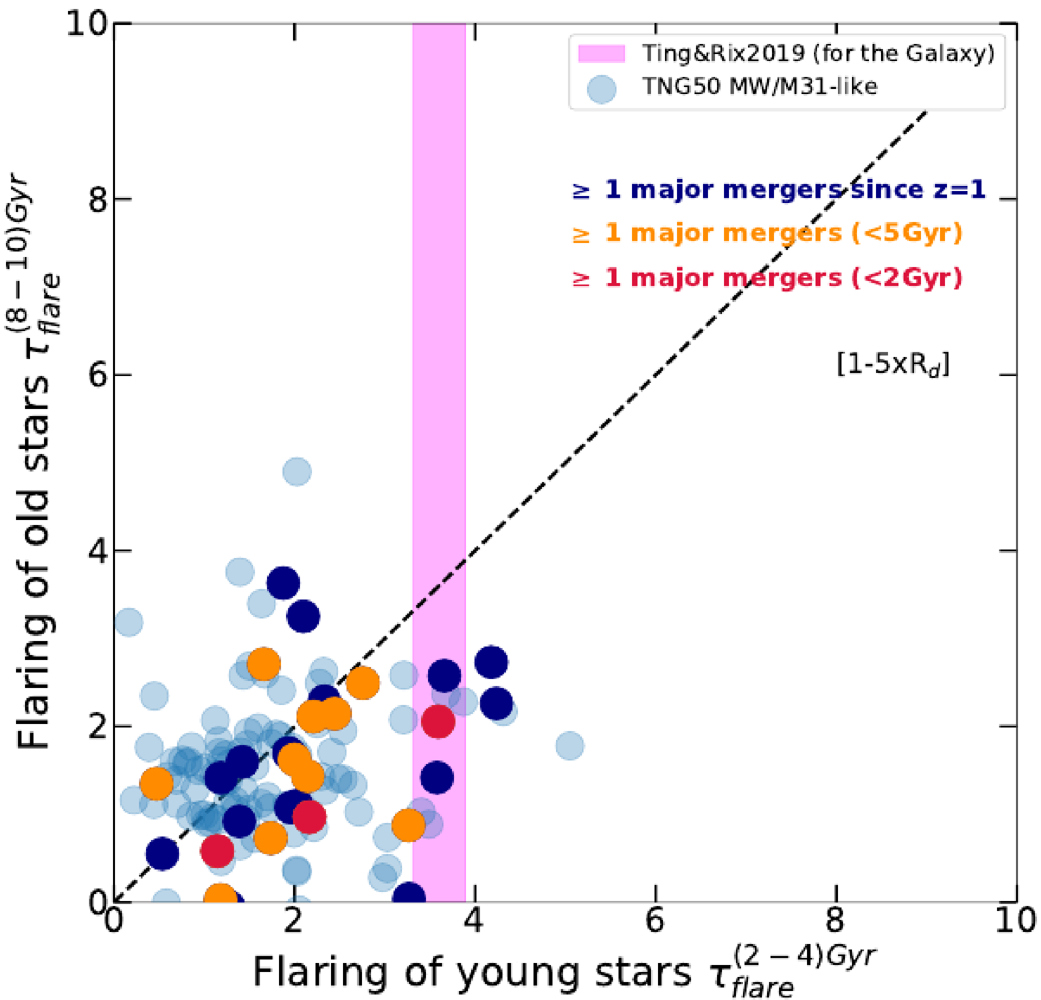
TNG50 covers all previous flaring flavours





… thanks to a large sample!

Do mergers enhance flaring?

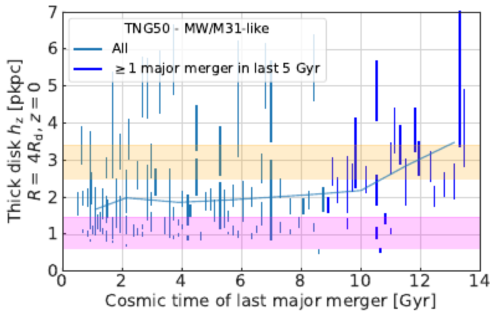


Summary and conclusions

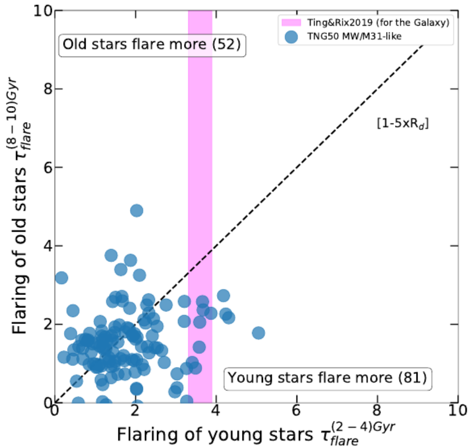
Main take-home messages

According to TNG50:

- MW/M31-like galaxies can undergo recent major mergers and still have a relatively thin stellar disk (scale height as low as ~100-200 pc)



- MW/M31-like galaxies exhibit a great diversity phenomenology of flaring, encompassing all previous numerical findings



→ The diversity present in a large enough sample is the key!