Are simulated disk galaxies robust to collisional relaxation?

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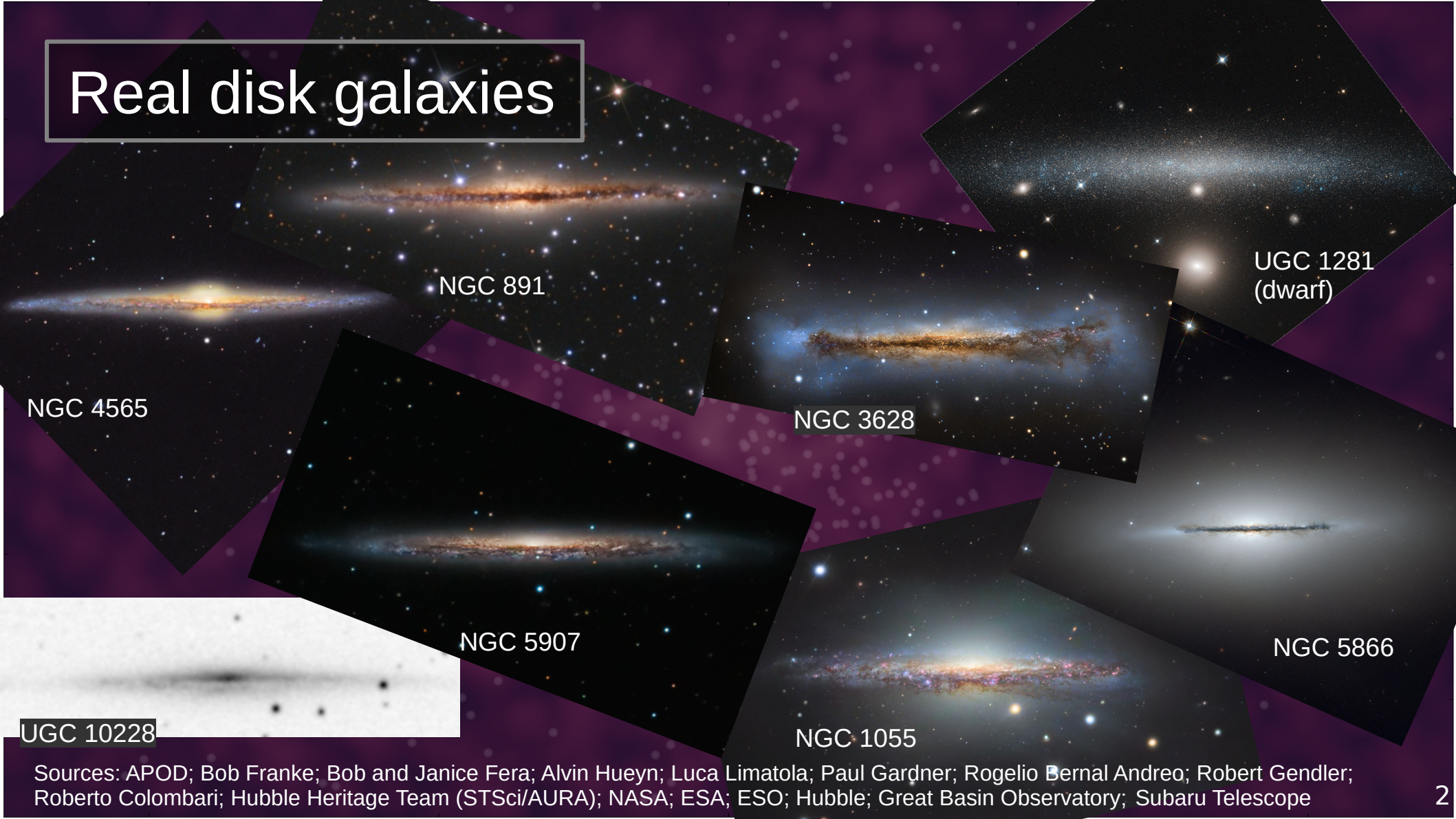
Real disk galaxies



Sources: APOD; Bob Franke; Bob and Janice Fera; Alvin Hueyn; Luca Limatola; Paul Gardner; Rogelio Bernal Andreo; Robert Gendler; Roberto Colombari; Hubble Heritage Team (STSci/AURA); NASA; ESA; ESO; Hubble; Great Basin Observatory; Subaru Telescope

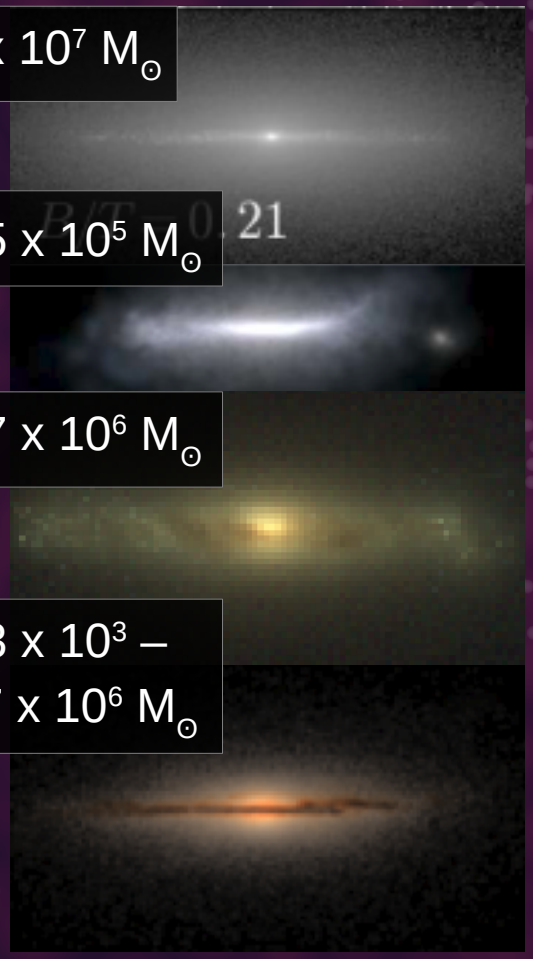
Simulated disk galaxies

M_{DM} = 8 x 10^7 $M_\odot$

M_{DM} = 4.5 x 10^5 $M_\odot$

M_{DM} = 9.7 x 10^6 $M_\odot$

M_{DM} = 3.3 x 10^3 – 1.7 x 10^6 $M_\odot$



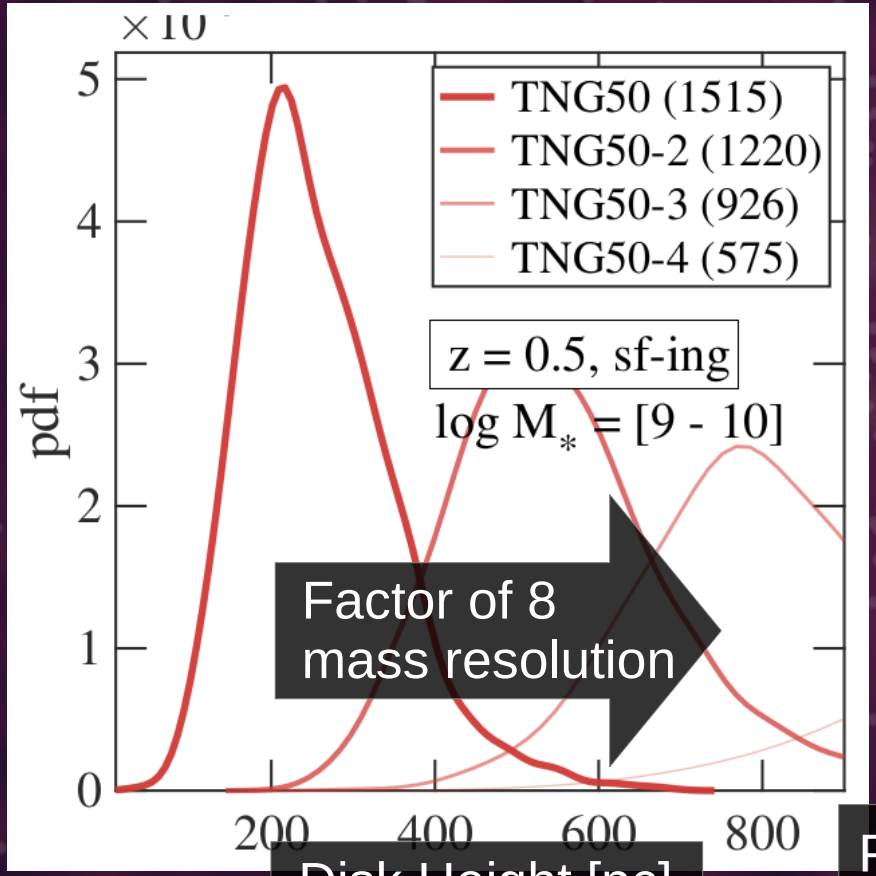
NewHorizon: Park et al. 2021

TNG50 (z=2): Pillepich et al. 2019

EAGLE: Shaye et al. 2015

NIHAO: Wang et al. 2015

Convergence at cosmological resolutions



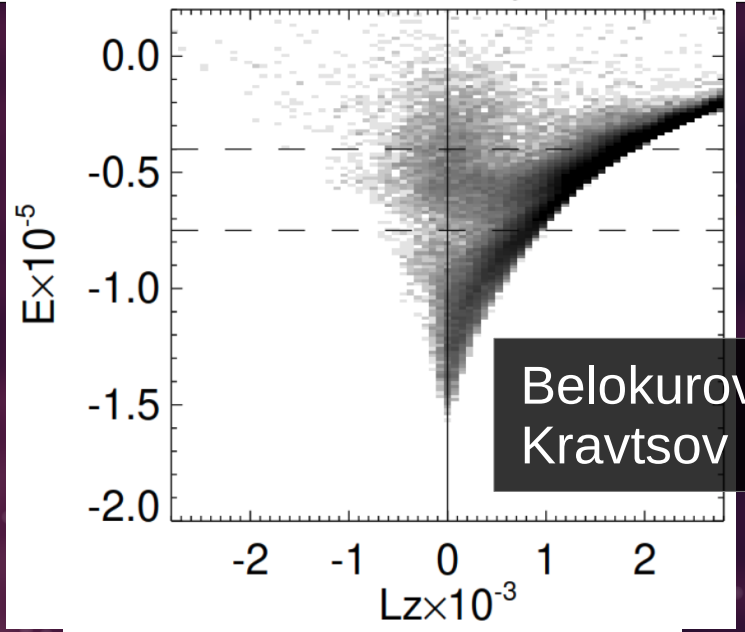
	m_{DM} [$M_\odot$/h]
TNG50	3.1×10^5
TNG50-2	2.5×10^6
TNG50-3	3.7×10^7
TNG50-4	2.9×10^8

Pillepich et al. 2019

Which stars are disk stars?

All disk stars must be on reasonably circular orbits.

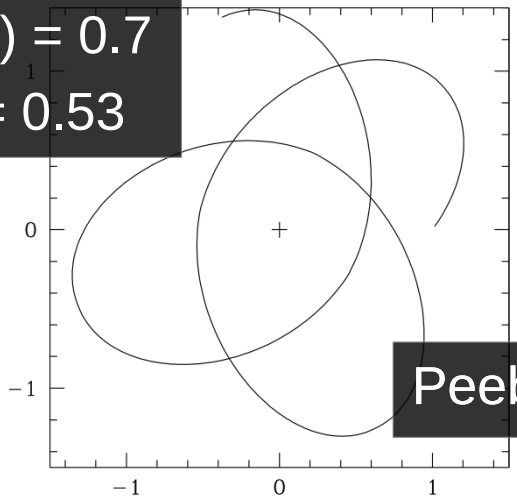
- A good way to quantify this is with ellipticity, $j_z/j_c(E)$.
- e.g. disks $j_z/j_c(E) \geq 0.7$
- Incompatible with observations (Peebles 2020)
- Galaxy disks should mostly be supported by rotation: $\sigma > v$



Belokurov & Kravtsov 2022

$j_z/j_c(E) = 0.7$

$\sigma_r/v_c = 0.53$



Peebles 2020

Disks are particularly susceptible to heating

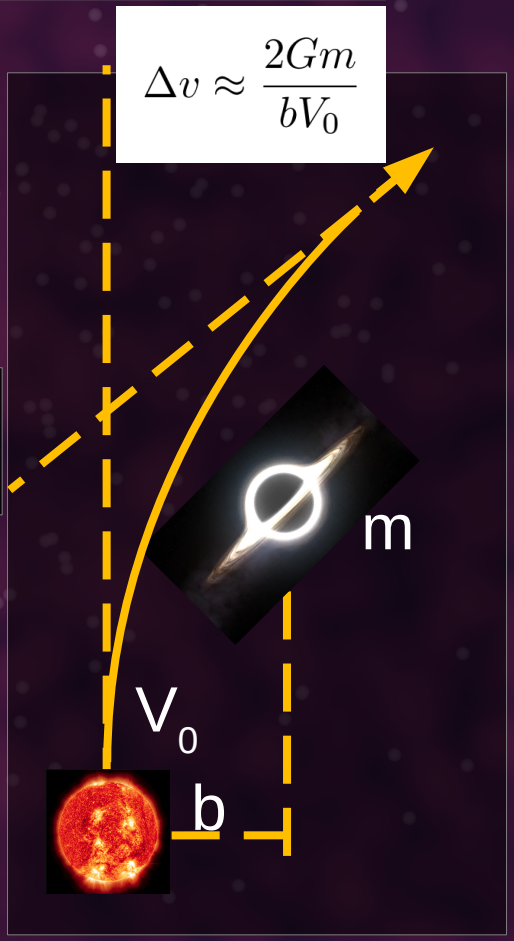
Cumulative random kicks:

$$\frac{1}{4}\langle\sum(\Delta v)^2\rangle \approx \Delta\sigma_\star^2 = \sqrt{2}\pi \ln\Lambda\, f(...)\frac{G^2\,\rho_{\rm DM}\,m_{\rm DM}}{\sigma_{\rm DM}}\Delta t$$

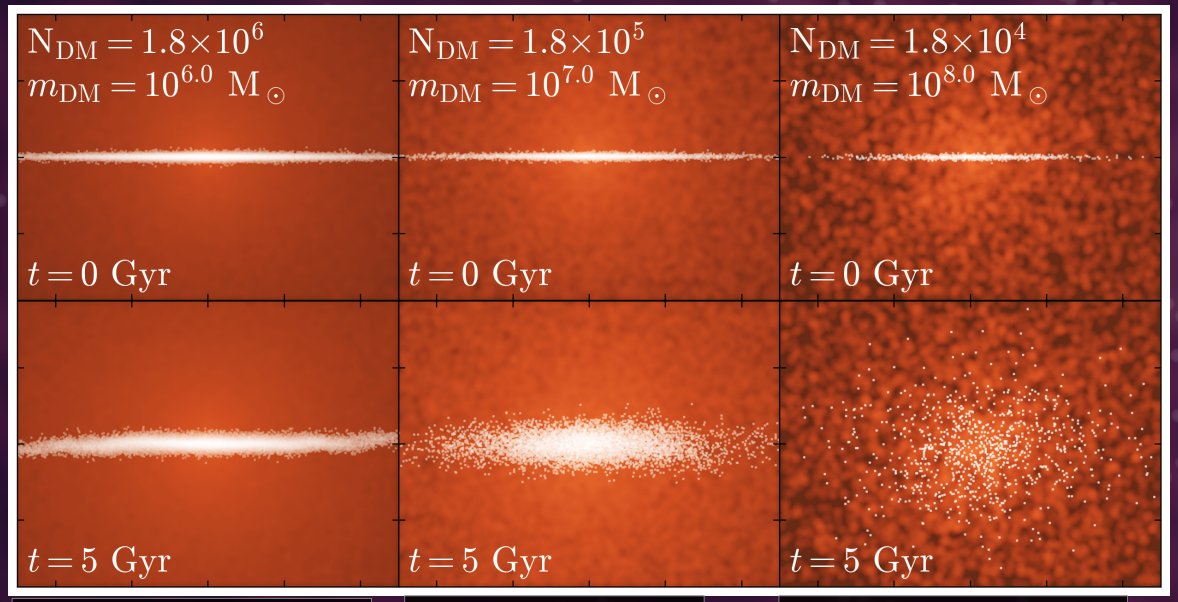
Lacey & Ostriker 1985

MW halo (1 Gyr, r=R_d):

- EAGLE resolution: Δσ ~ 30 km/s
- TNG50 resolution: Δσ ~ 6 km/s



N-body experiments



High resolution

Intermediate resolution

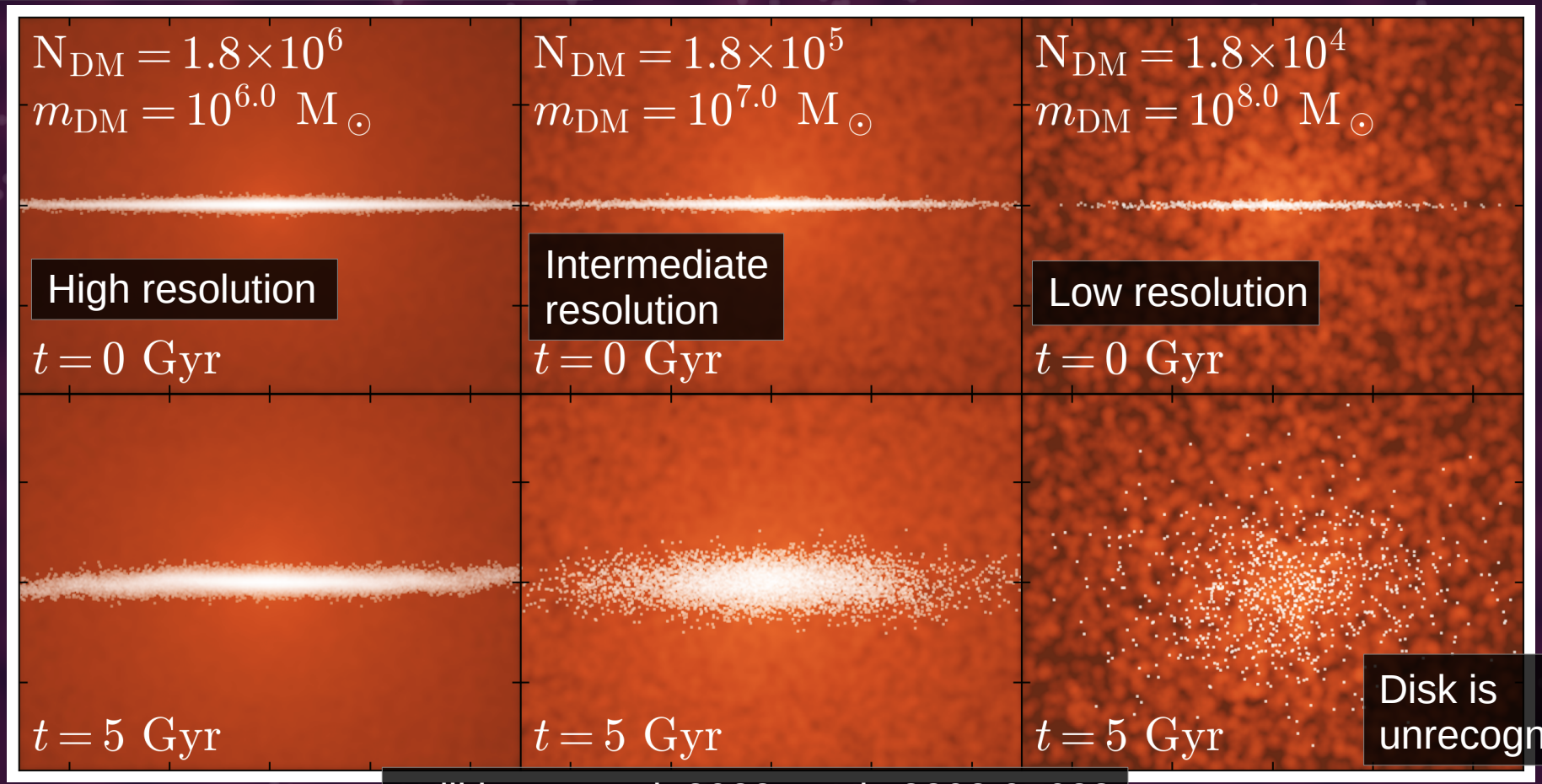
Low resolution

Suite of 43 N-body simulations

- Numbers of particles (2×10^4 to 2×10^6)
- Particle mass ratios (1, 5, 25)
- Concentrations
- Initial disk heights
- Halo masses
- Live / static halo

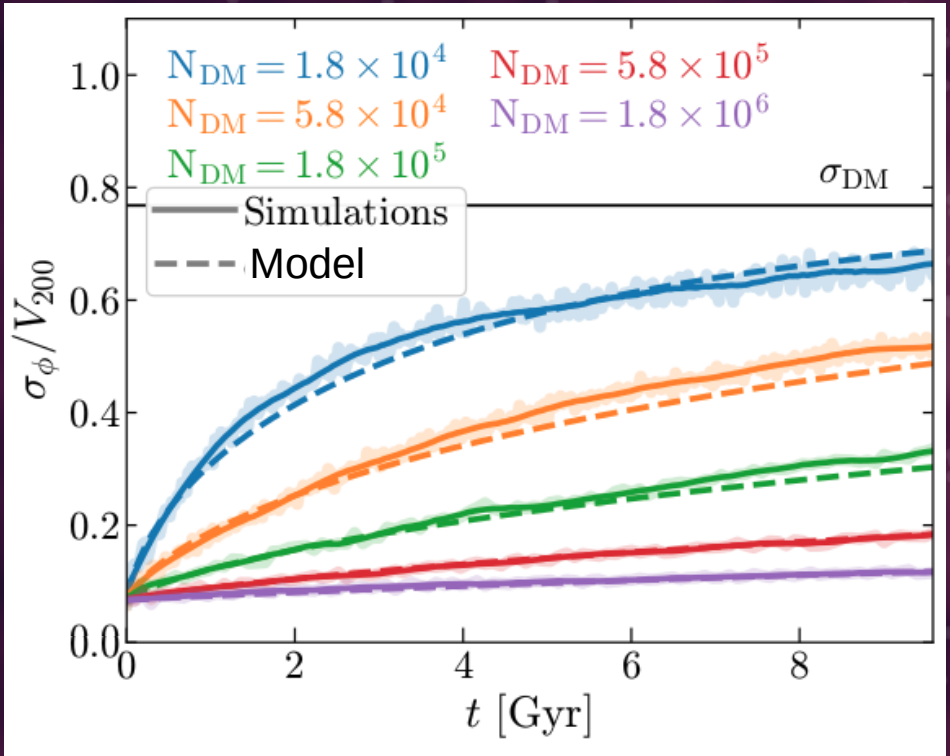
First used in Ludlow et al. 2021

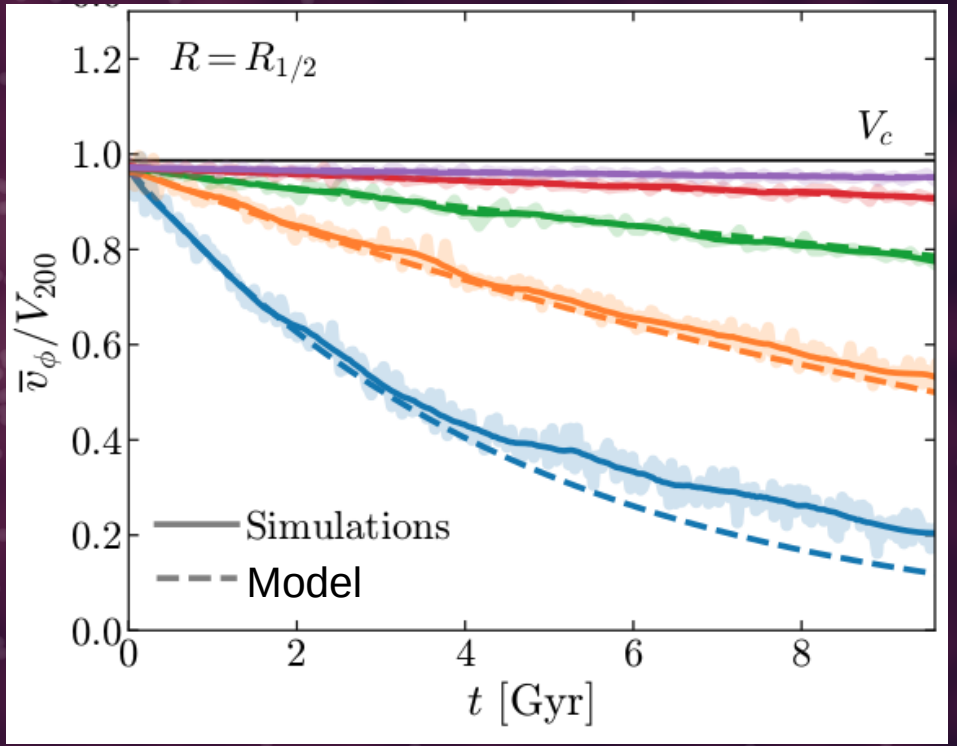
Visual morphology



Wilkinson et al. 2022, arXiv:2208.07623

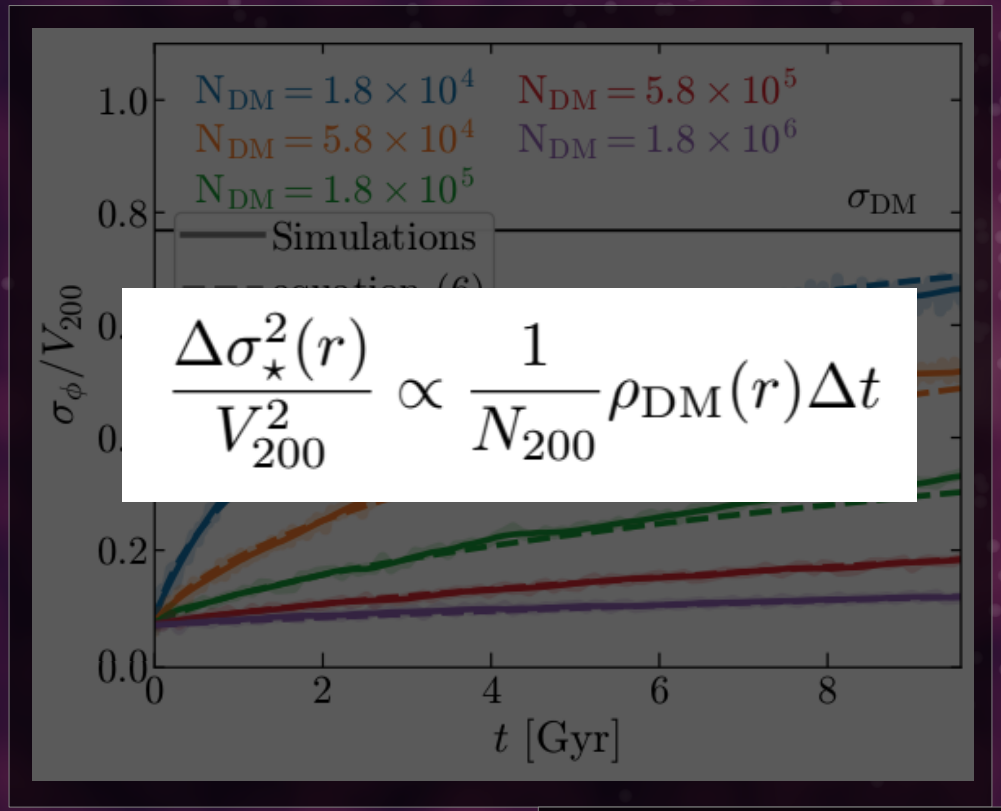
Velocity evolution

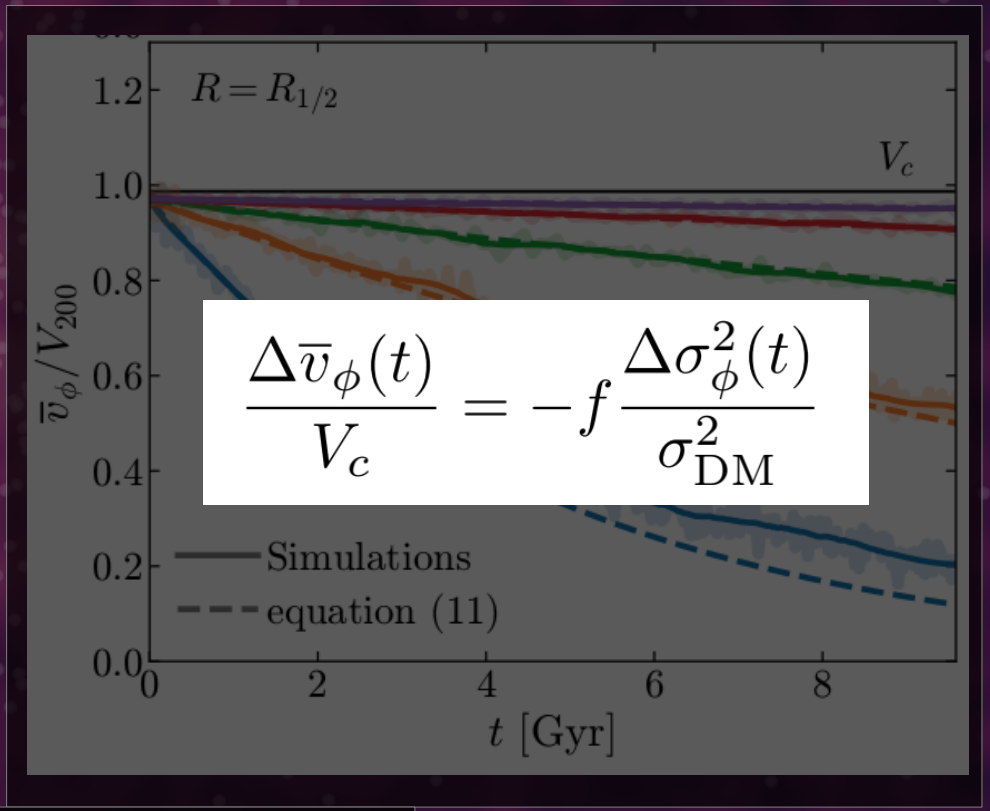




Wilkinson et al. 2022, arXiv:2208.07623

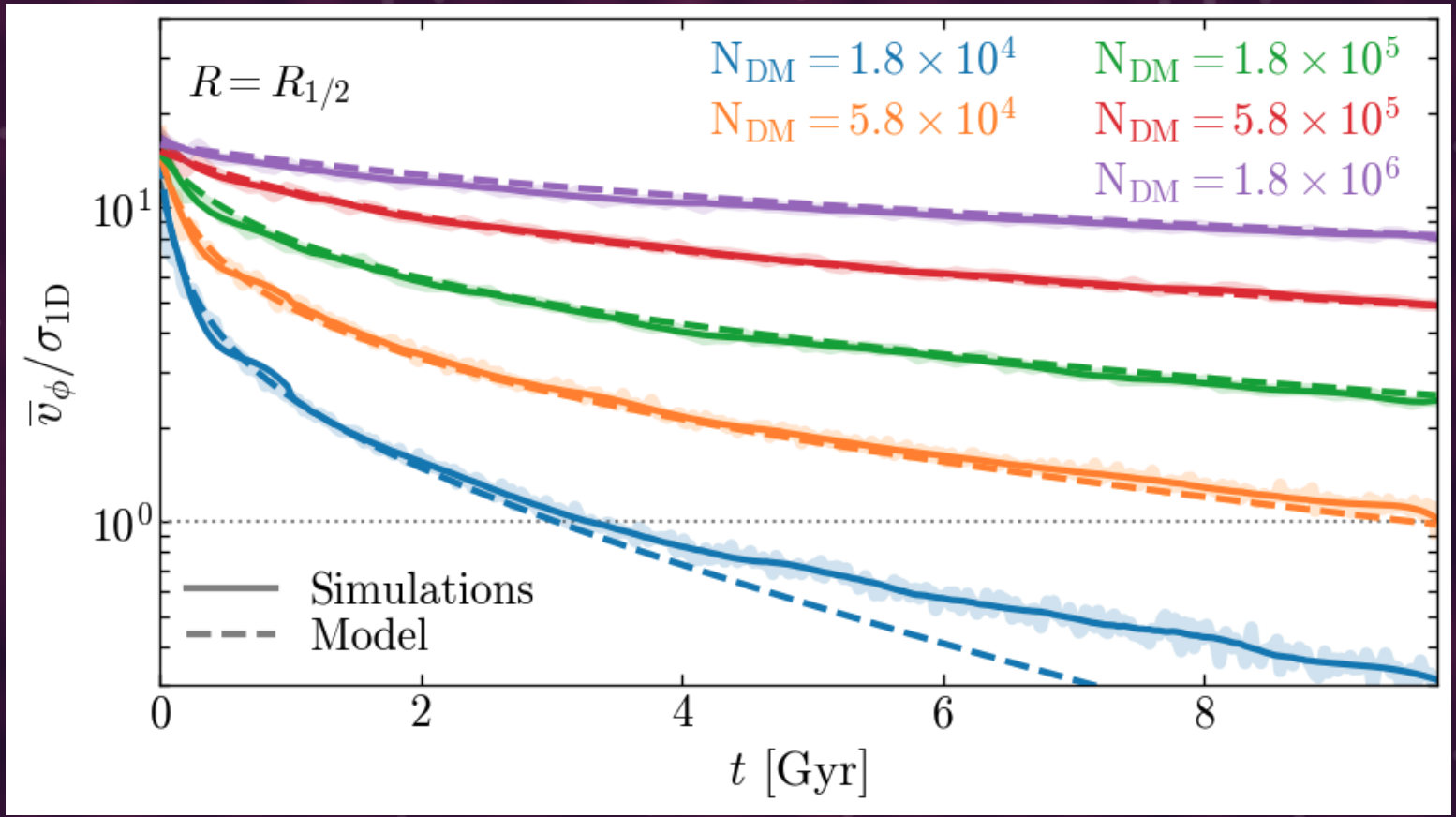
An effective model





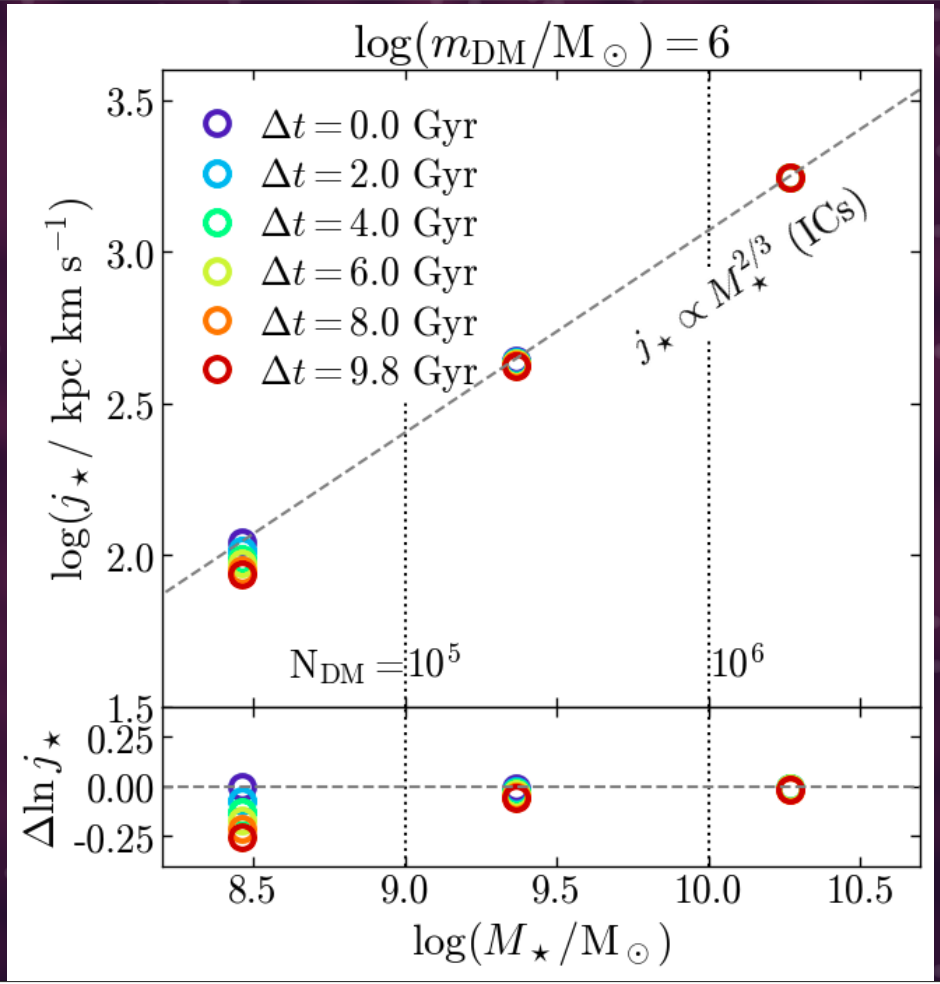
Ludlow et al. 2021,
Wilkinson et al. 2022, arXiv:2208.07623

Kinematic Morphology



Wilkinson et al. 2022, arXiv:2208.07623

Scaling relations are not recovered correctly

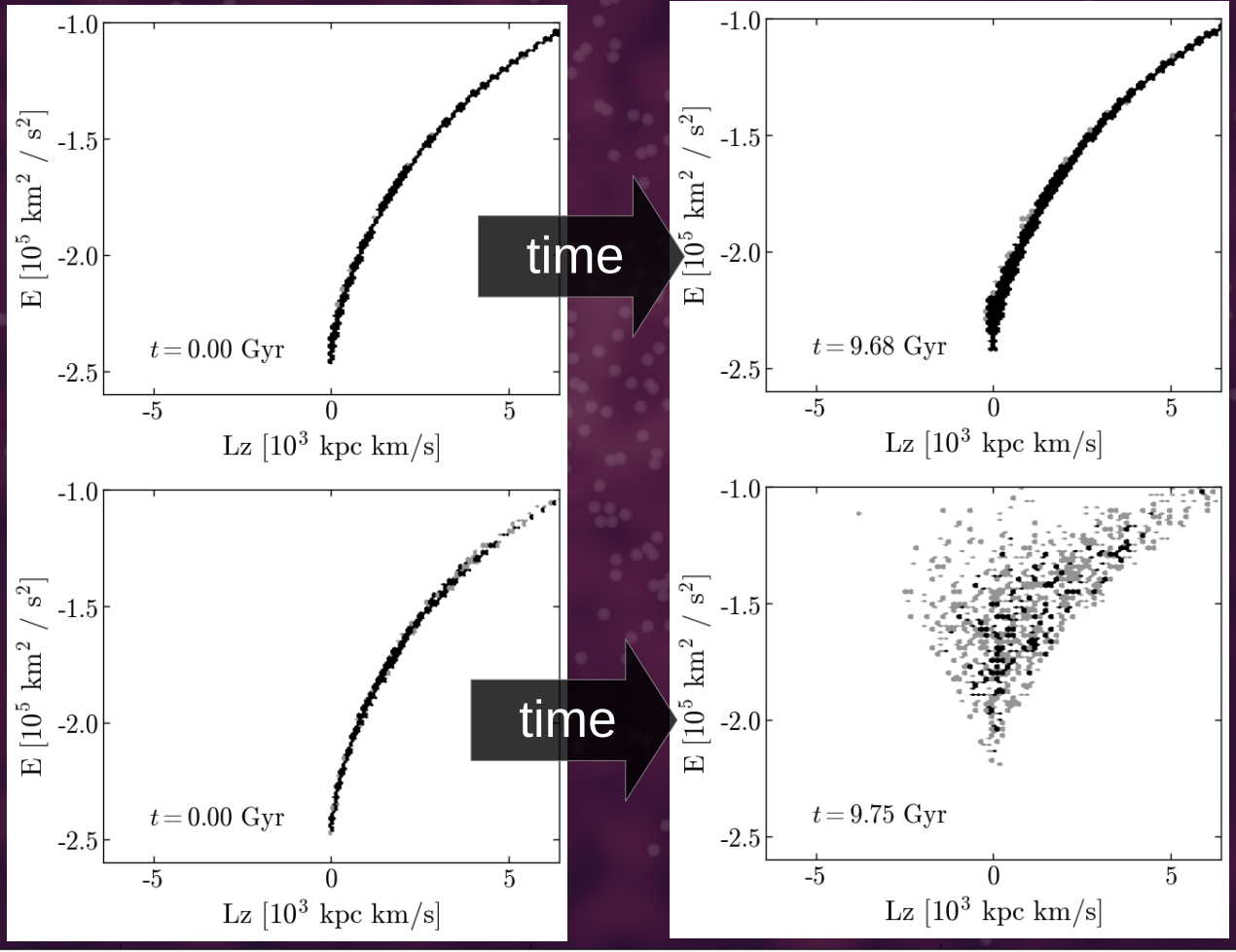


Wilkinson et al. 2022, arXiv:2208.07623

Collisionful (non-collsionless) dynamics

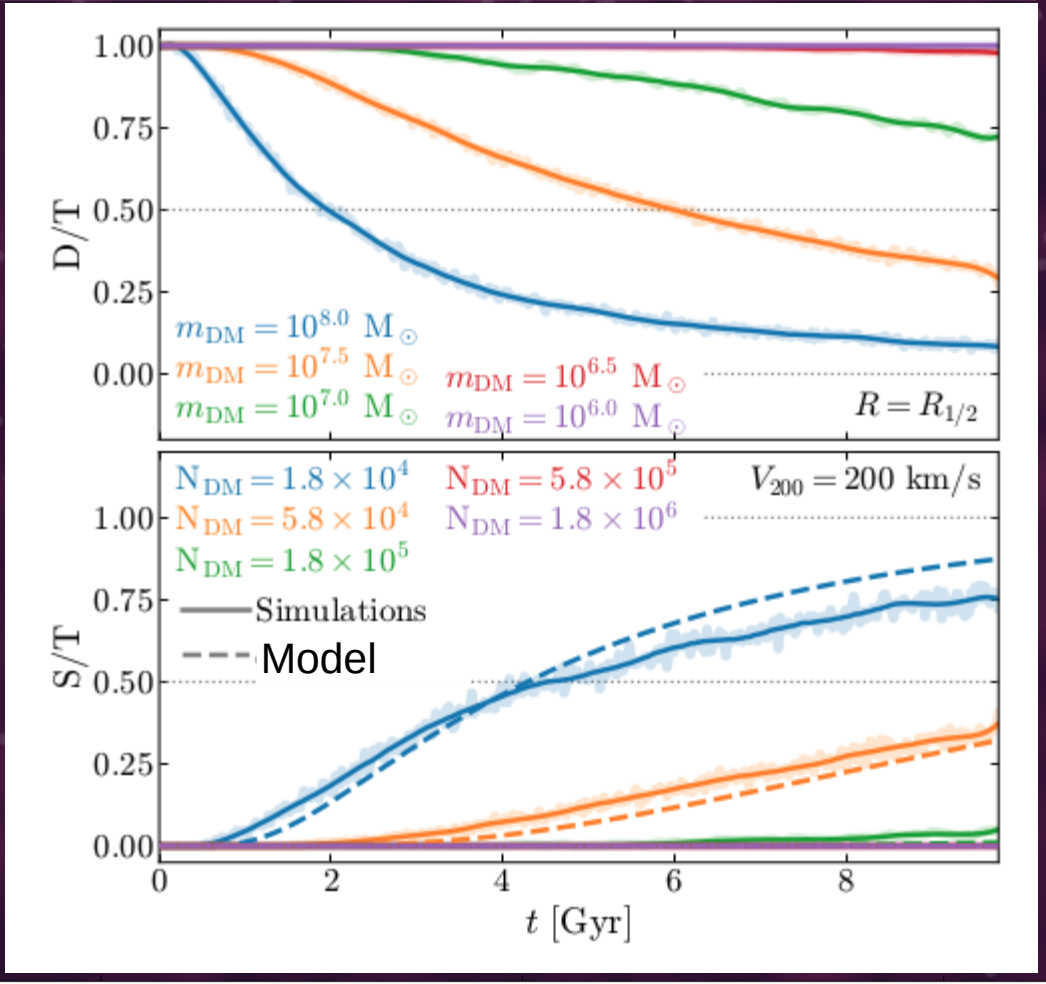
High resolution
N_{DM} = 1.8 x 10^6

Low resolution
N_{DM} = 1.8 x 10^4

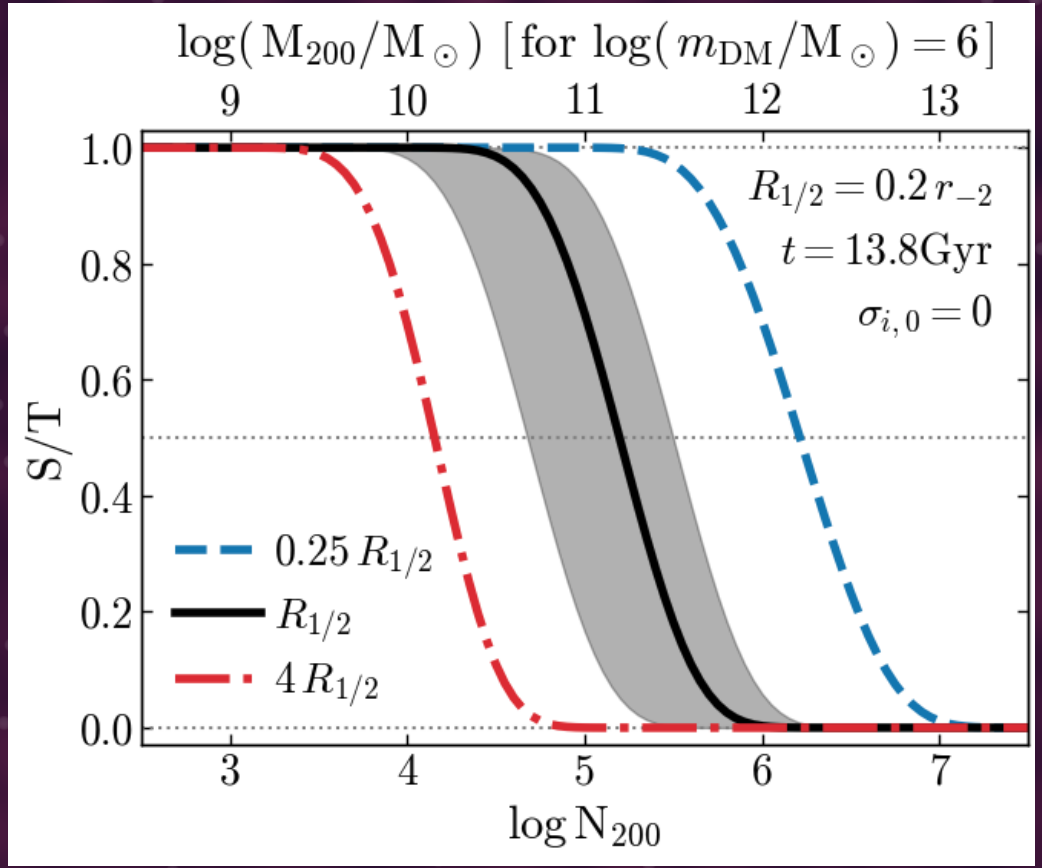


Scattering causes spurious evolution

Heating mimics cosmological phenomena

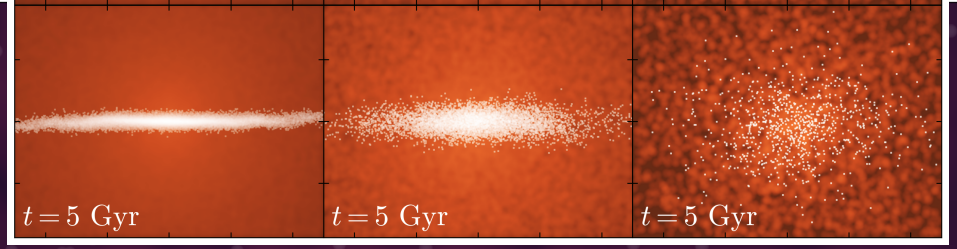


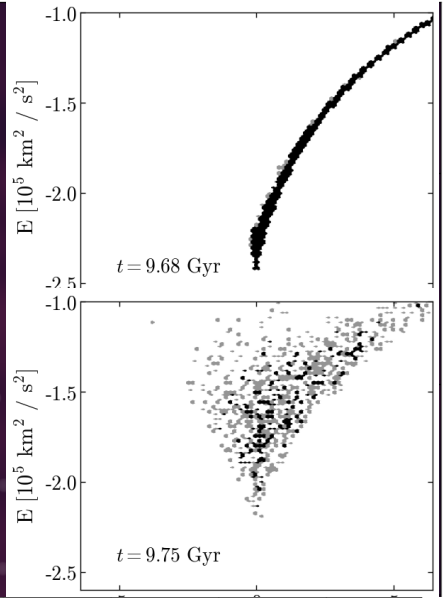
Predicted spheroid growth



Wilkinson et al. 2022, arXiv:2208.07623

Conclusion





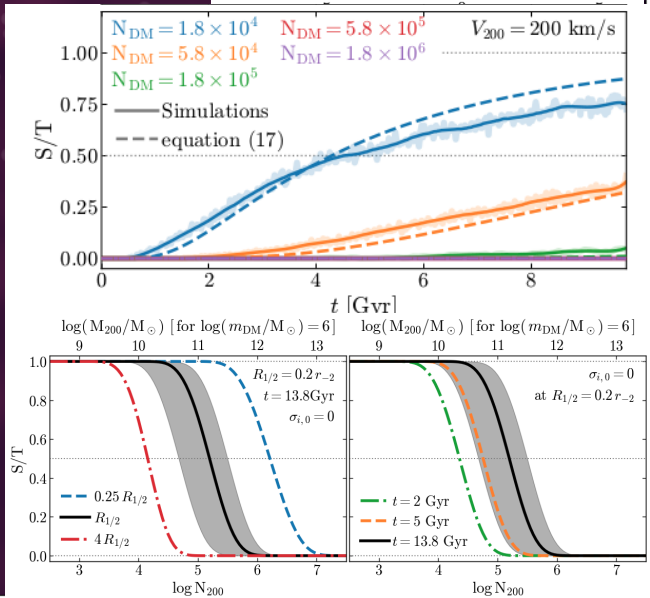
Spurious heating does occur in simulated disk galaxies. This is a consequence of physics introduced by their reduced resolution.

We model heating with the properties of the DM halo.

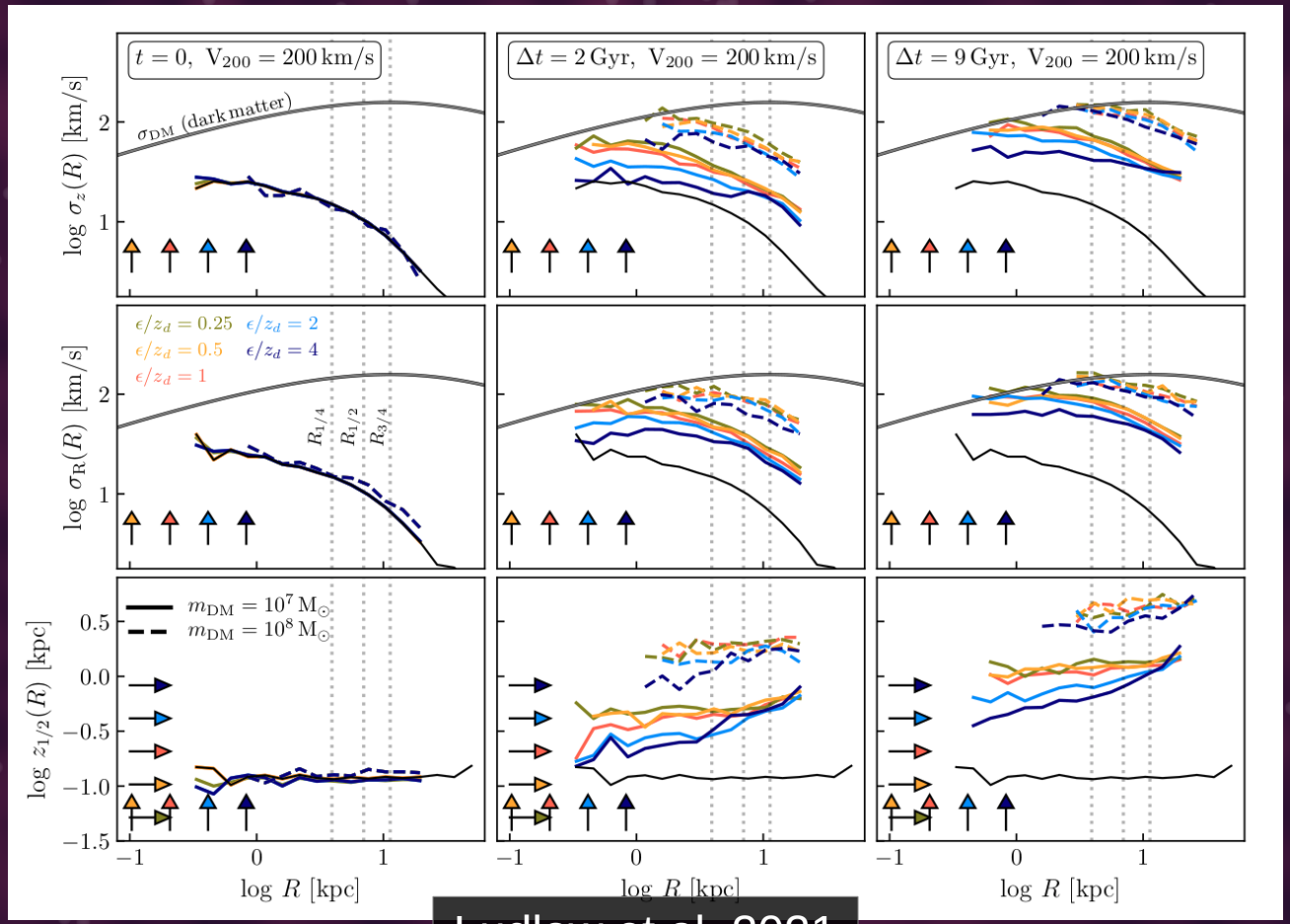
Below the mass range that corresponds to $N_{DM}=10^6$, simulated morphologies are contaminated by numerical heating. Smaller radii require even higher resolution.

Our models contain no astrophysical sources of heating, but also no star formation.

With this work, we have a better understanding of where our simulations are reliable.

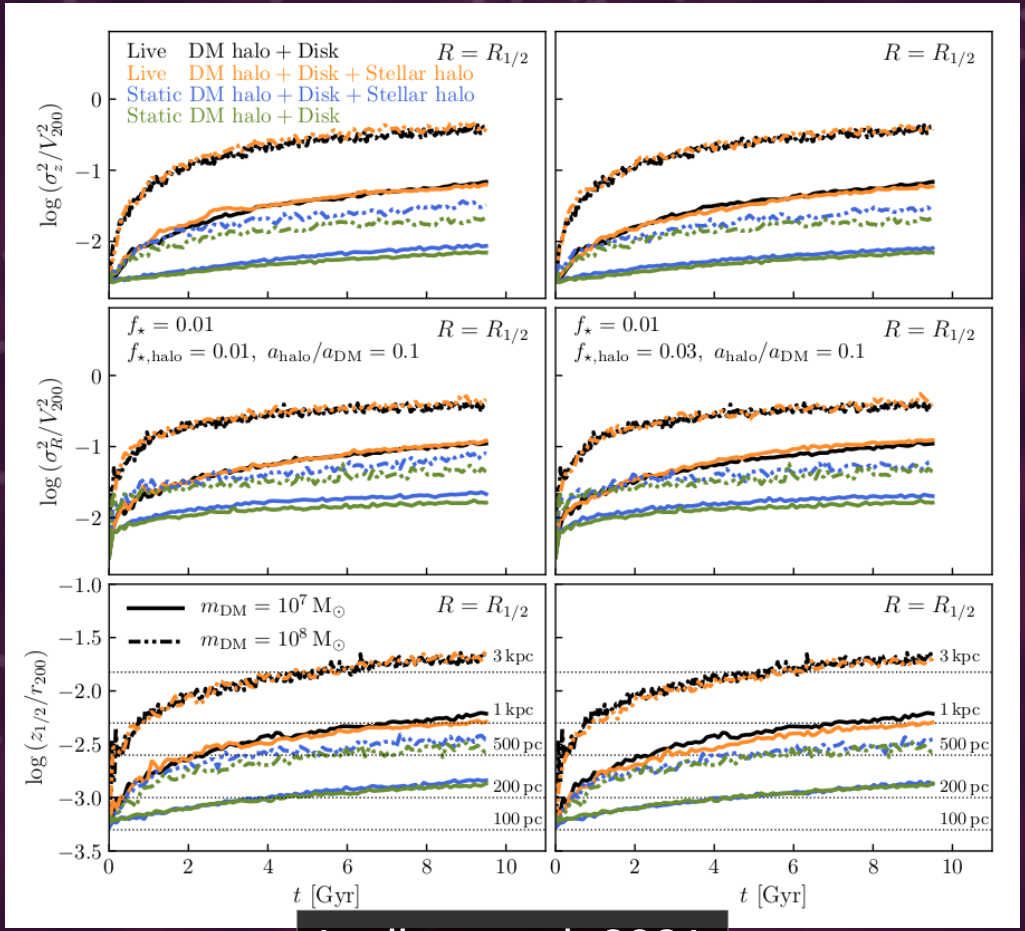


Bonus slide: Gravitational softening (experimental)



Ludlow et al. 2021

Bonus slide: Static halo



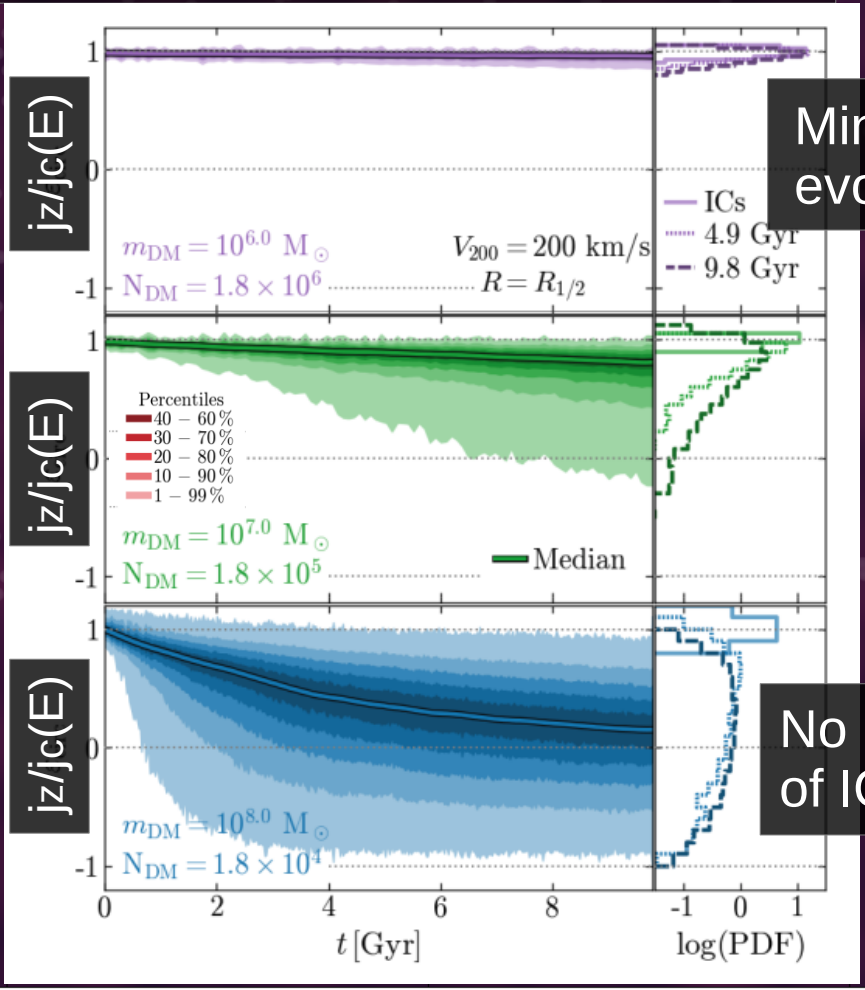
Ludlow et al. 2021

Angular momentum randomisation

High resolution

Intermediate resolution

Low resolution



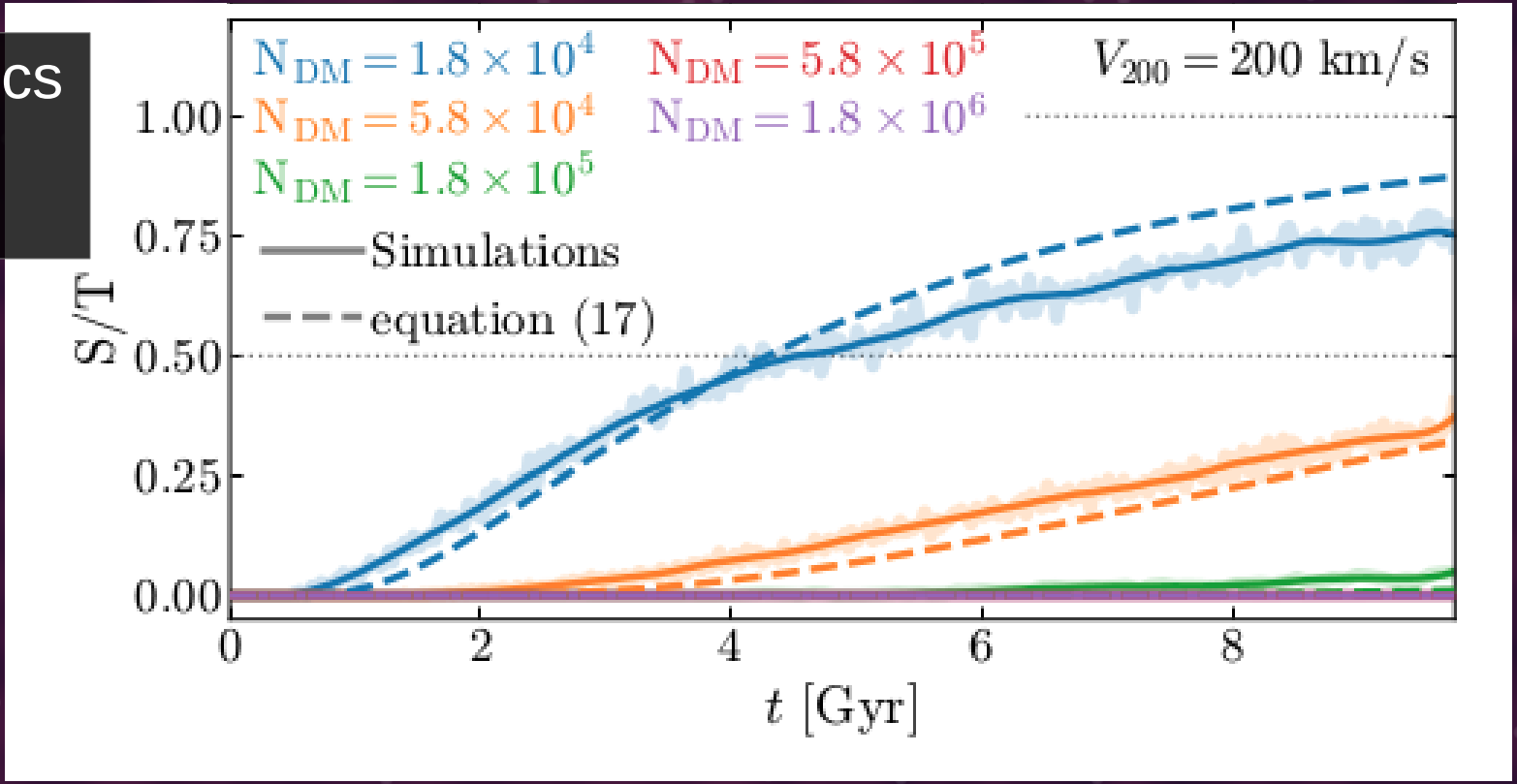
Minimal evolution

Wilkinson et al. 2022, arXiv:2208.07623

No memory of ICs

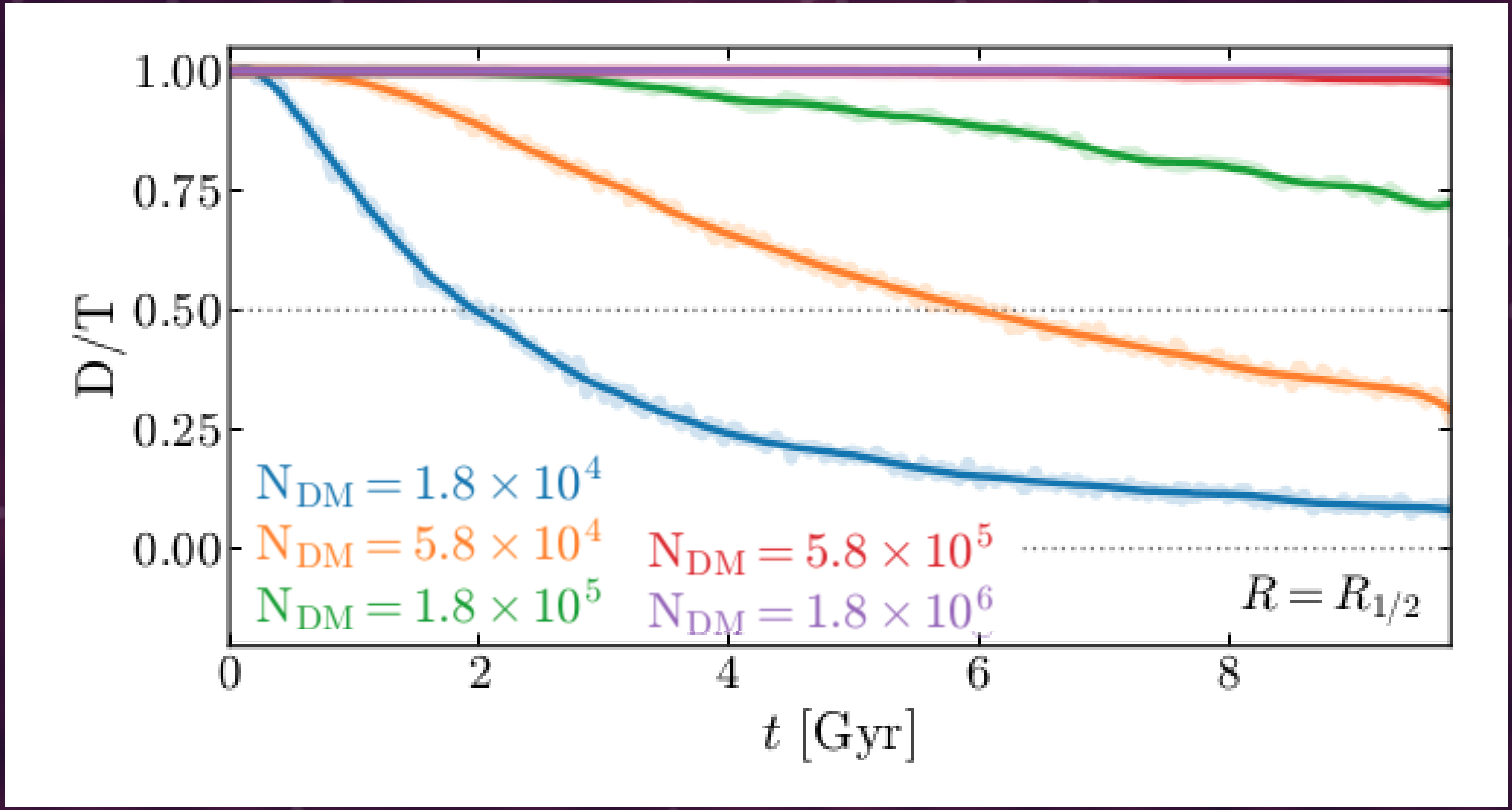
Scattering causes spurious spheroid growth

Heating mimics cosmological phenomena



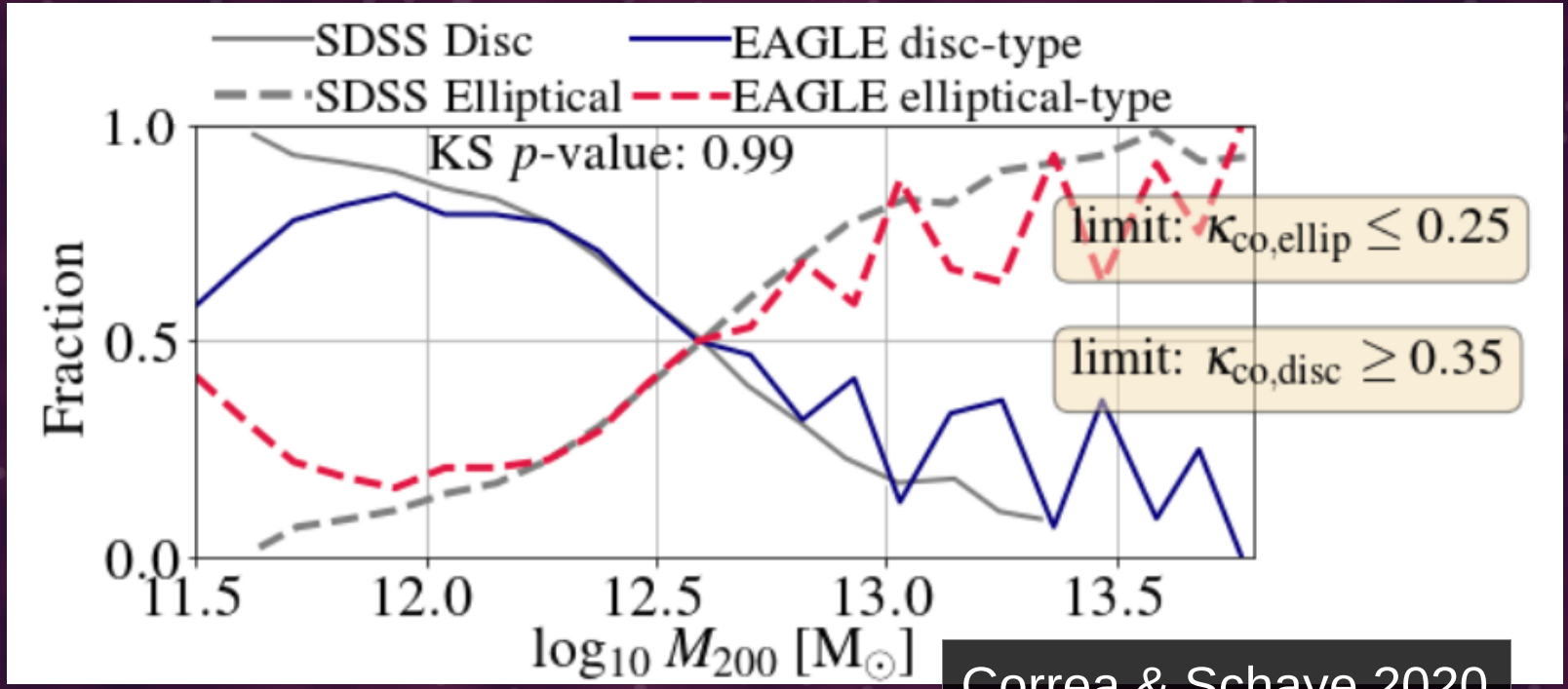
Wilkinson et al. 2022, arXiv:2208.07623

Disk fraction



Wilkinson et al. submitted

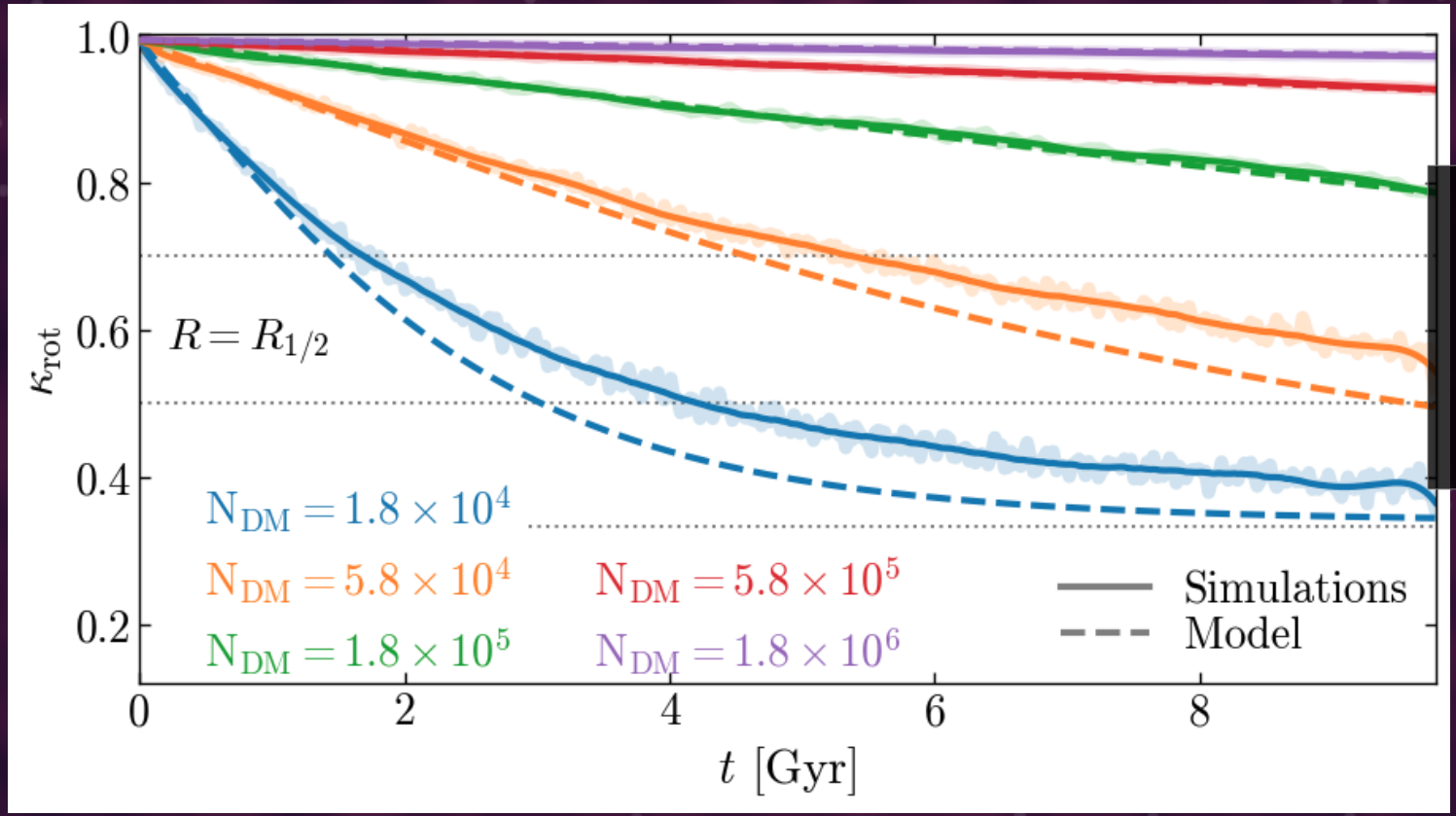
Simulated disk galaxy population?



Correa & Schaye 2020

κ_{co} = fraction of kinetic energy in co-rotation

Rotational energy



Heating causes galaxy evolve away from disk like kinematics

$$\kappa_{\rm rot} \approx \frac{\overline{v}_\phi^2 + \sigma_\phi^2}{\overline{v}_\phi^2 + \sigma_{\rm total}^2}$$

Wilkinson et al. 2022, arXiv:2208.07623