Why do we model galaxies?

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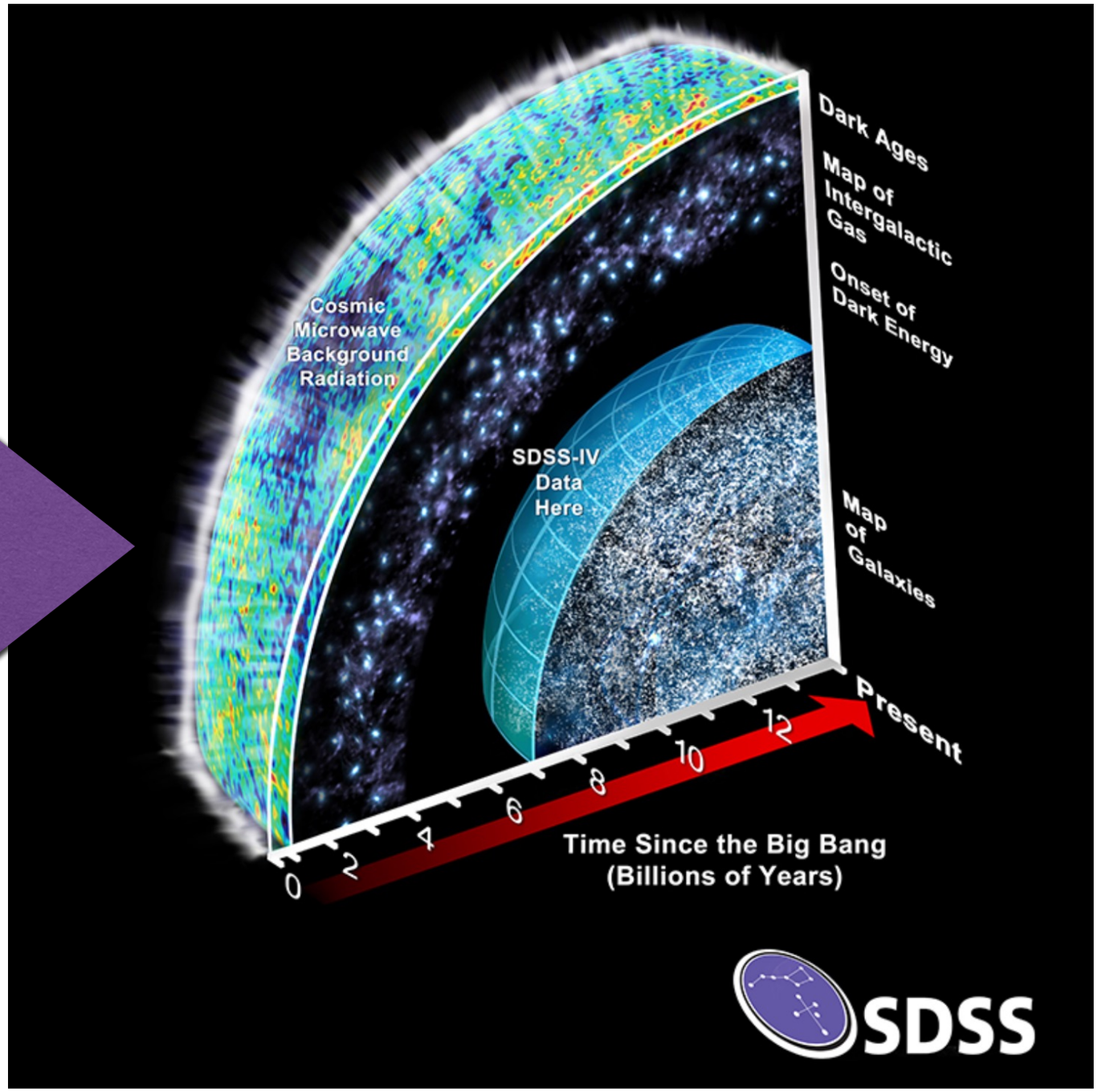
ICG Portsmouth

From the CosmicUniverse App

- What is a galaxy?
- Why do we want to make a model galaxy?

- From galaxy scales (tens of kpc) to the local group size (Mpc) to the size of the observable Universe (tens of Gpc):



However, subpc processes affect properties at galactic scales

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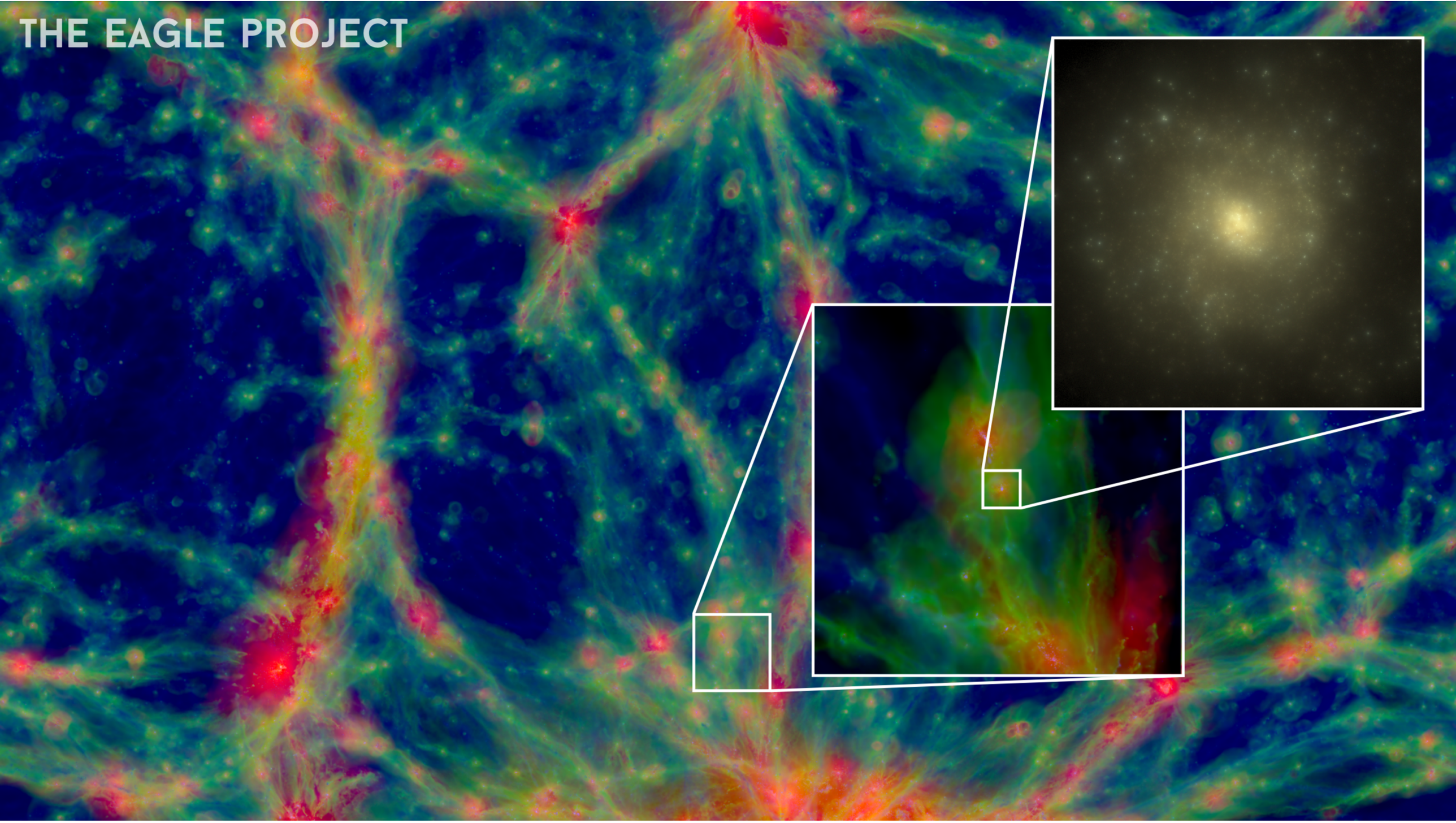
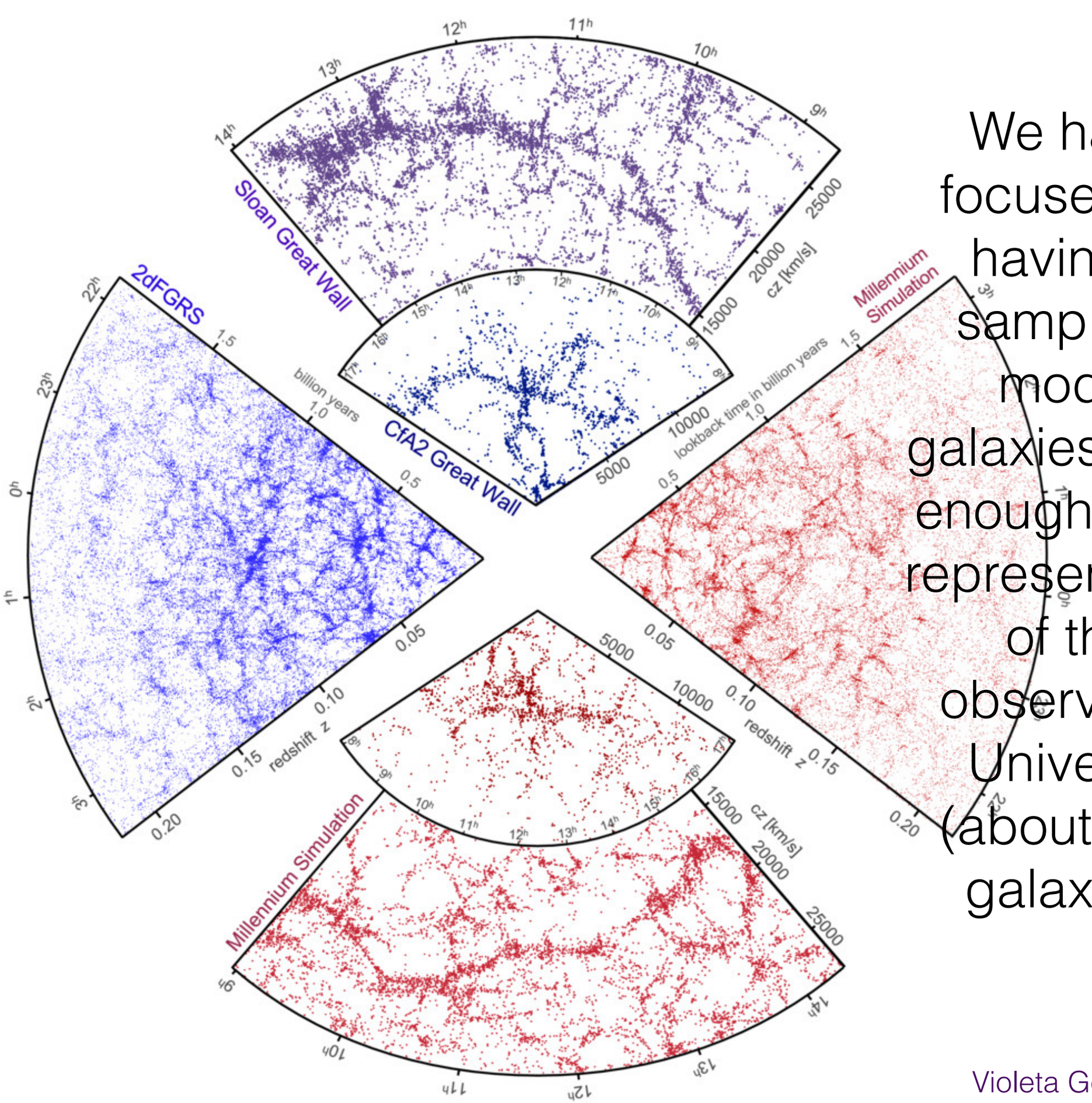
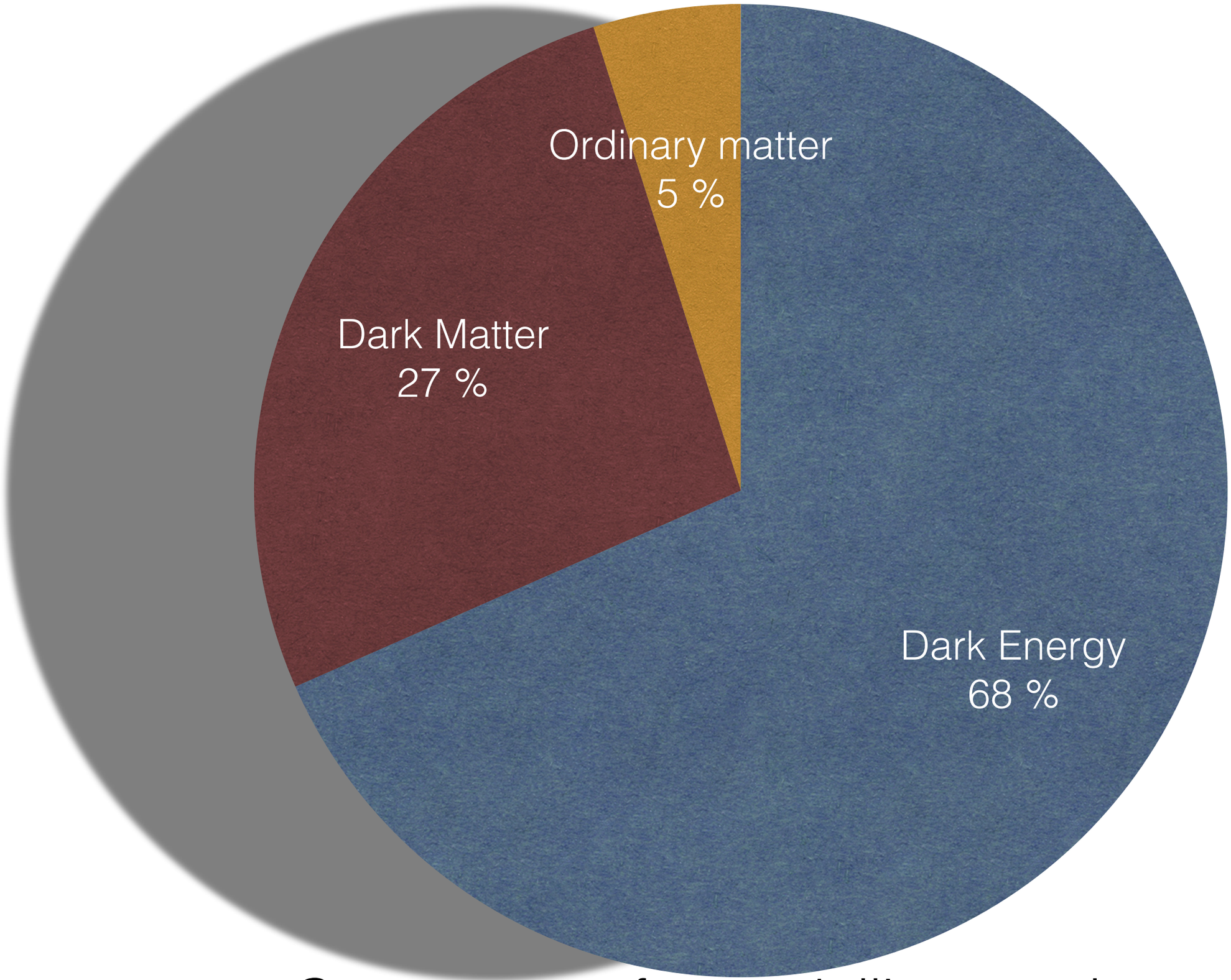


As resources are finite, the level of detail needed at different scales depends on the problem we want to address.



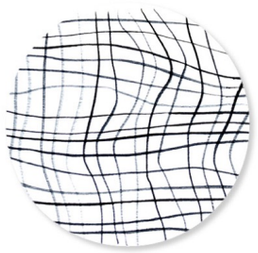
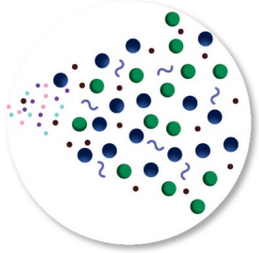
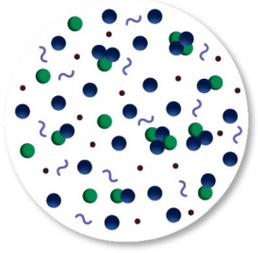
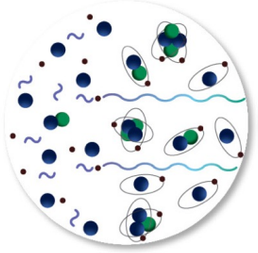
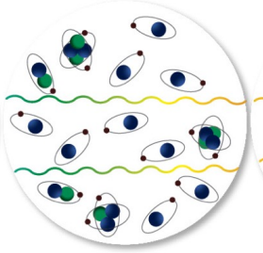
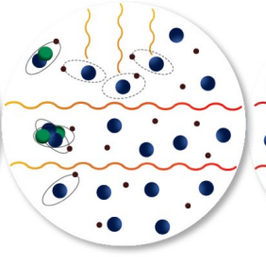
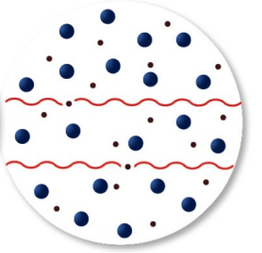
We have focused on having a sample of model galaxies large enough to be representative of the observable Universe (about 10^{10} galaxies)

How do we proceed:
Ingredients, processes, quality check



Components for modelling a galaxy

→ COSMIC HISTORY

10^{-32} seconds	1 second	100 seconds	380 000 years	300–500 million years	Billions of years	13.8 billion years
Beginning of the Universe	**Inflation** Accelerated expansion of the Universe	**Formation of light and matter**	**Light and matter are coupled** Dark matter evolves independently: it starts clumping and forming a web of structures	**Light and matter separate** • Protons and electrons form atoms • Light starts travelling freely: it will become the Cosmic Microwave Background (CMB)	**Dark ages** Atoms start feeling the gravity of the cosmic web of dark matter	**First stars** The first stars and galaxies form in the densest knots of the cosmic web	**Galaxy evolution**	**The present Universe**
								
• Tiny fluctuations: the seeds of future structures *• Gravitational waves?*	*Frequent collisions between normal matter and light*	*As the Universe expands, particles collide less frequently*	*Last scattering of light off electrons* ***→ Polarisation***	*The Universe is dark as stars and galaxies are yet to form*	*Light from first stars and galaxies breaks atoms apart and "reionises" the Universe*	*Light can interact again with electrons* ***→ Polarisation***		

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Gravity is the main driver for the growth of structures.

The star formation in galaxies can be regulated by

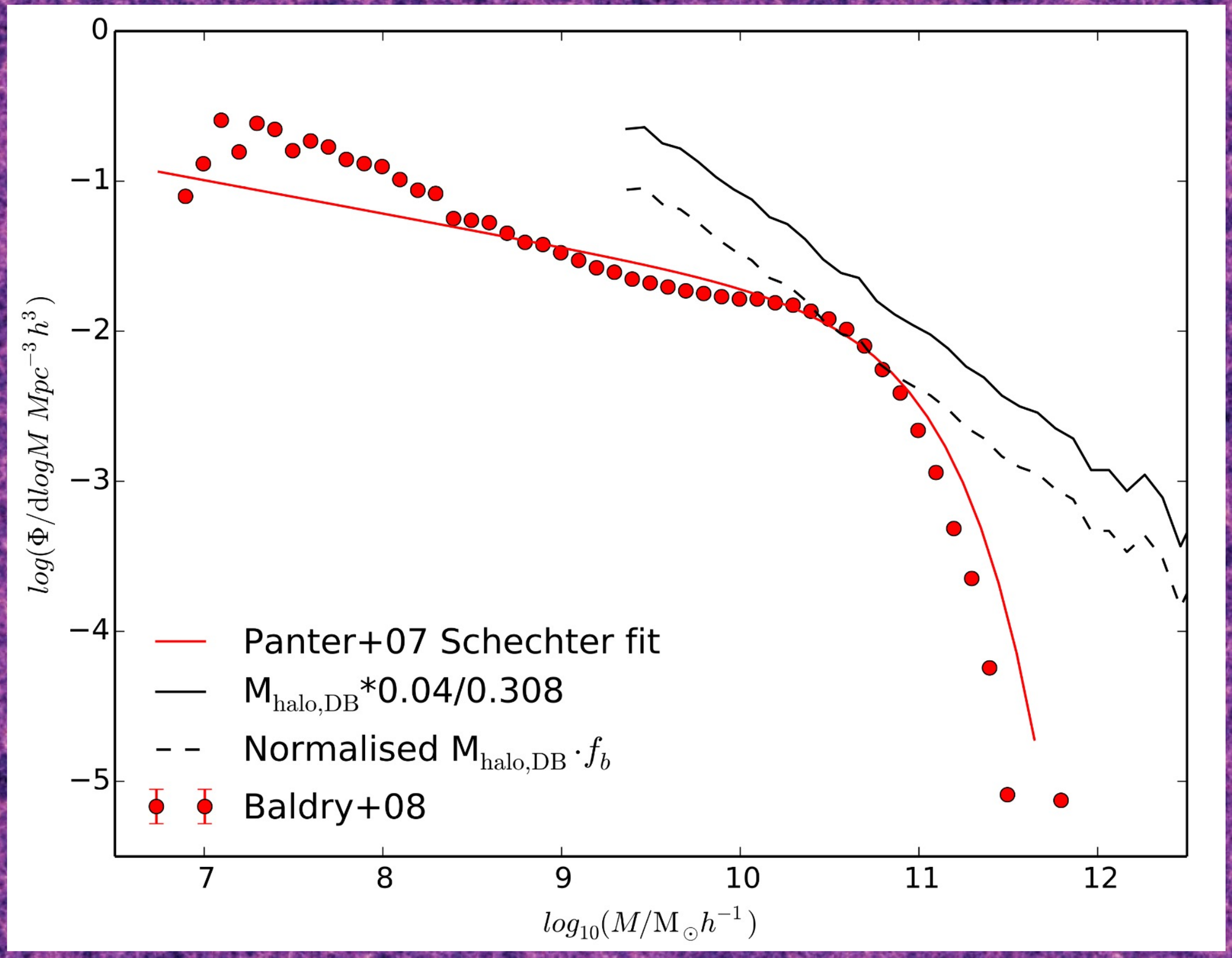
Internal processes
or nature or stellar mass

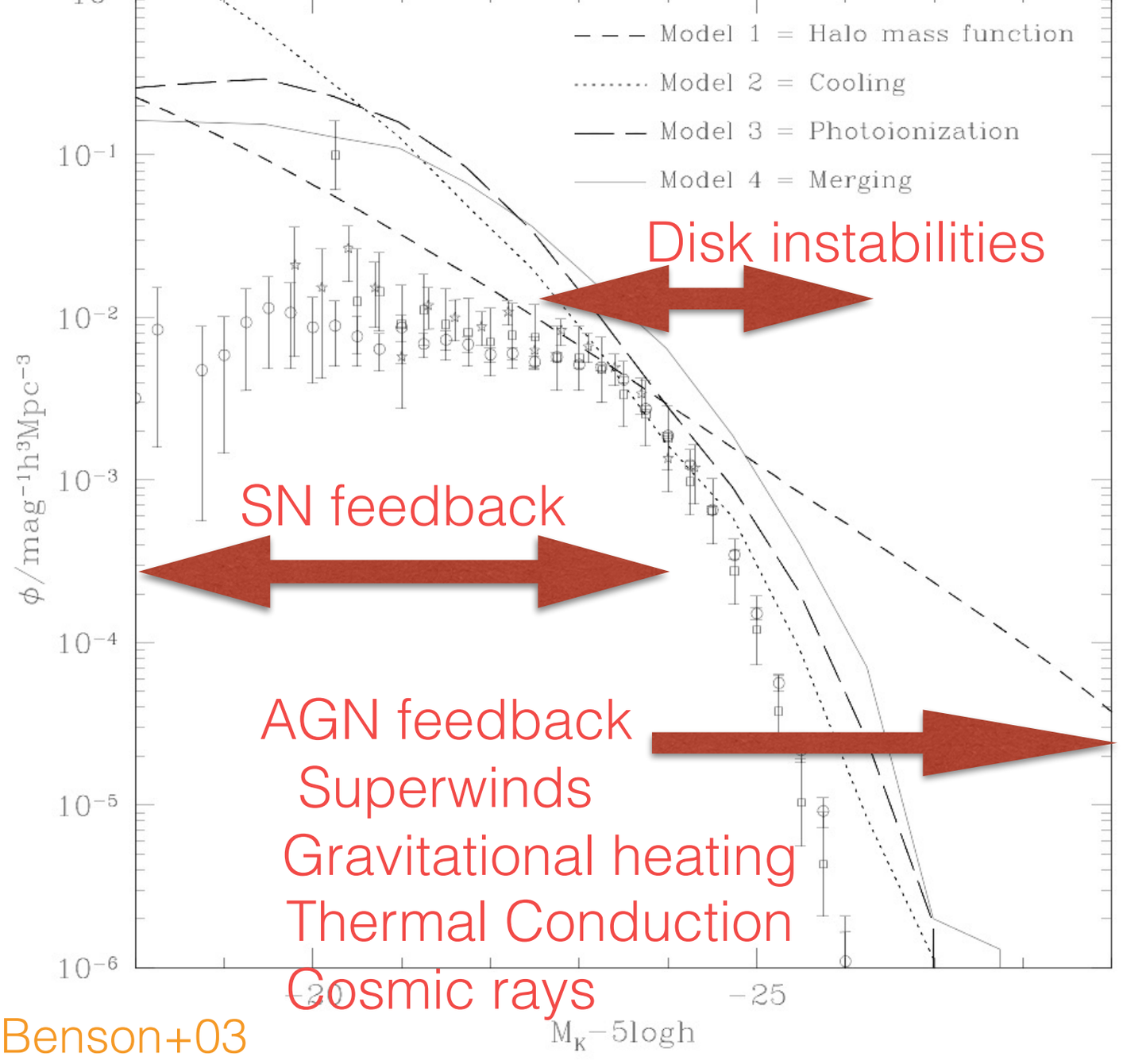

NGC 4414

External processes
or nurture or environment


HST Frontier Fields

which ones dominate depend on being
central/satellites, z, etc.

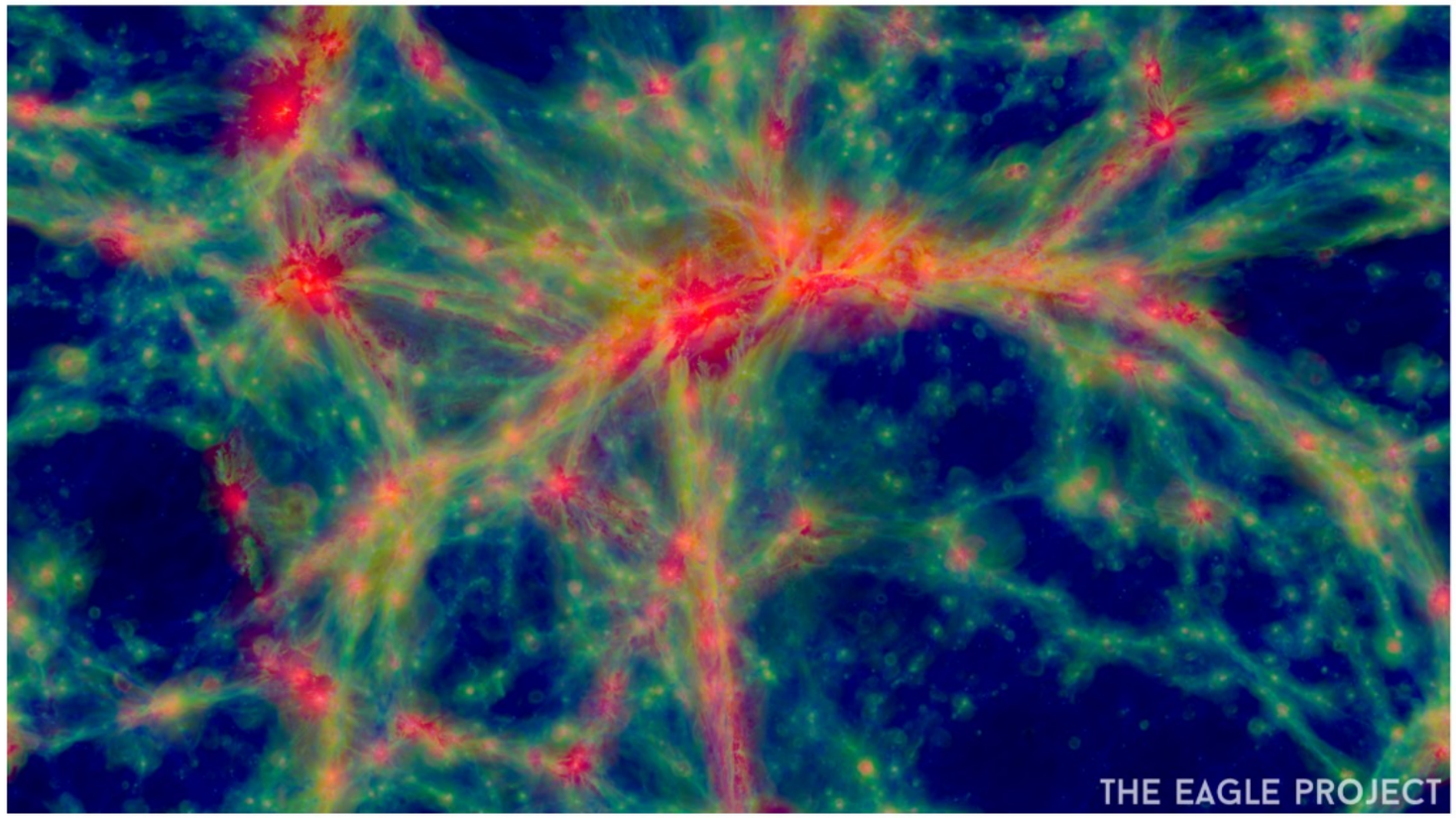

0
−1
−2
−3
−4
−5
7
8
9
10
11
12
$log(\Phi/\mathrm{d}logM\ Mpc^{-3}\,h^3)$
$log_{10}(M/\mathrm{M}_\odot h^{-1})$
Panter+07 Schechter fit
$\mathrm{M}_{\mathrm{halo,DB}}$*0.04/0.308
Normalised $\mathrm{M}_{\mathrm{halo,DB}} \cdot f_b$
Baldry+08



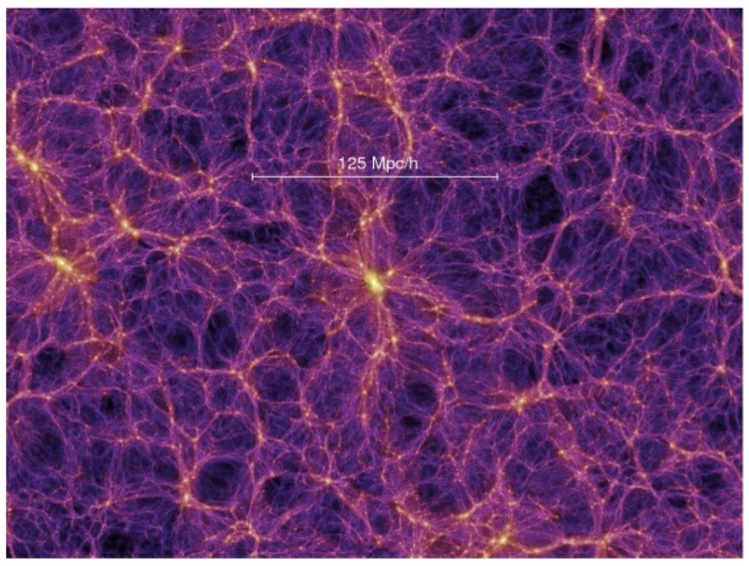
Benson+03

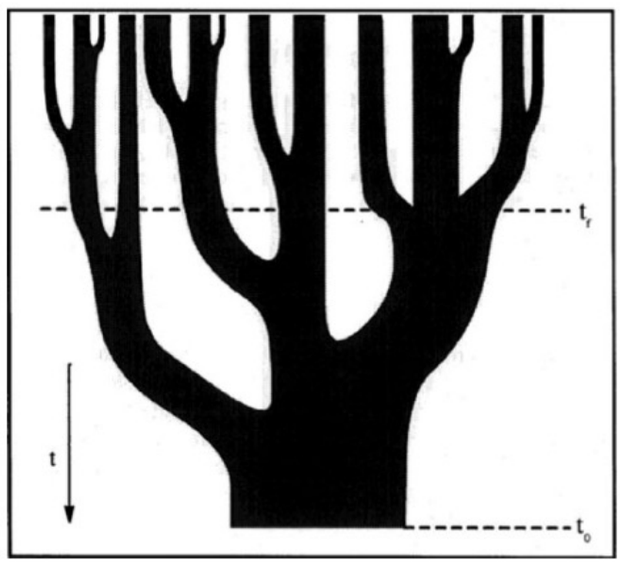
FIG. 1.—*K*-band luminosity function of galaxies. The points show the observational determinations of Cole et al. (2001; *circles*), Kochanek et al. (2001; *squares*), and Huang et al. (2003; $z < 0.1$, *stars*). Lines show model results. Model 1 (*dashed line*) shows the result of converting the dark matter halo mass function into a galaxy luminosity function by assuming a fixed mass-to-light ratio chosen to match the knee of the luminosity function. Model 2 (*dotted line*) shows the result from GALFORM when no feedback, photoionization suppression, galaxy merging, or conduction is included. Models 3 and 4 (*long-dashed and solid lines, respectively*) show the effects of adding photoionization and then galaxy merging.

a) In parallel: hydrodynamical simulations

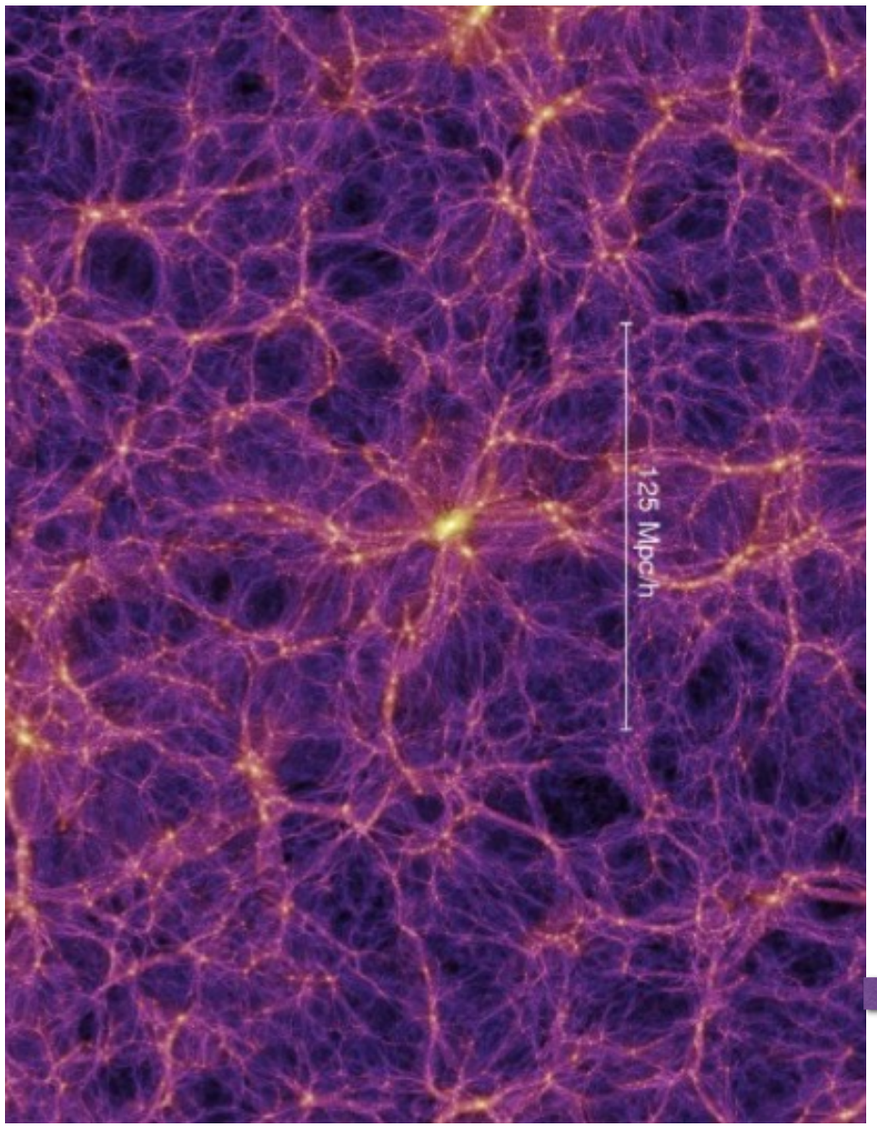


b) In series: SAMs, EMs, SHAMs, HOD modelling

1. 

2. 

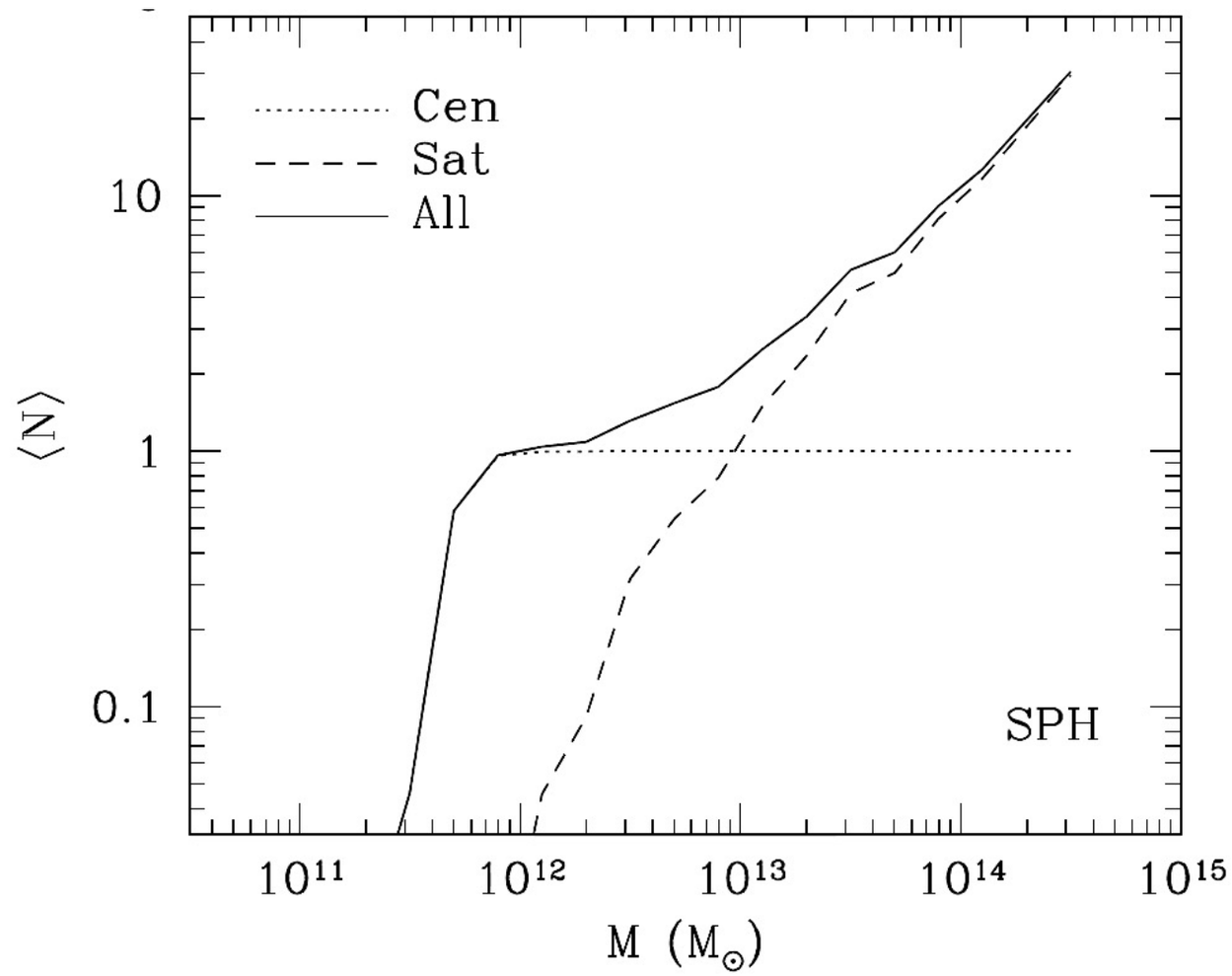
3. 

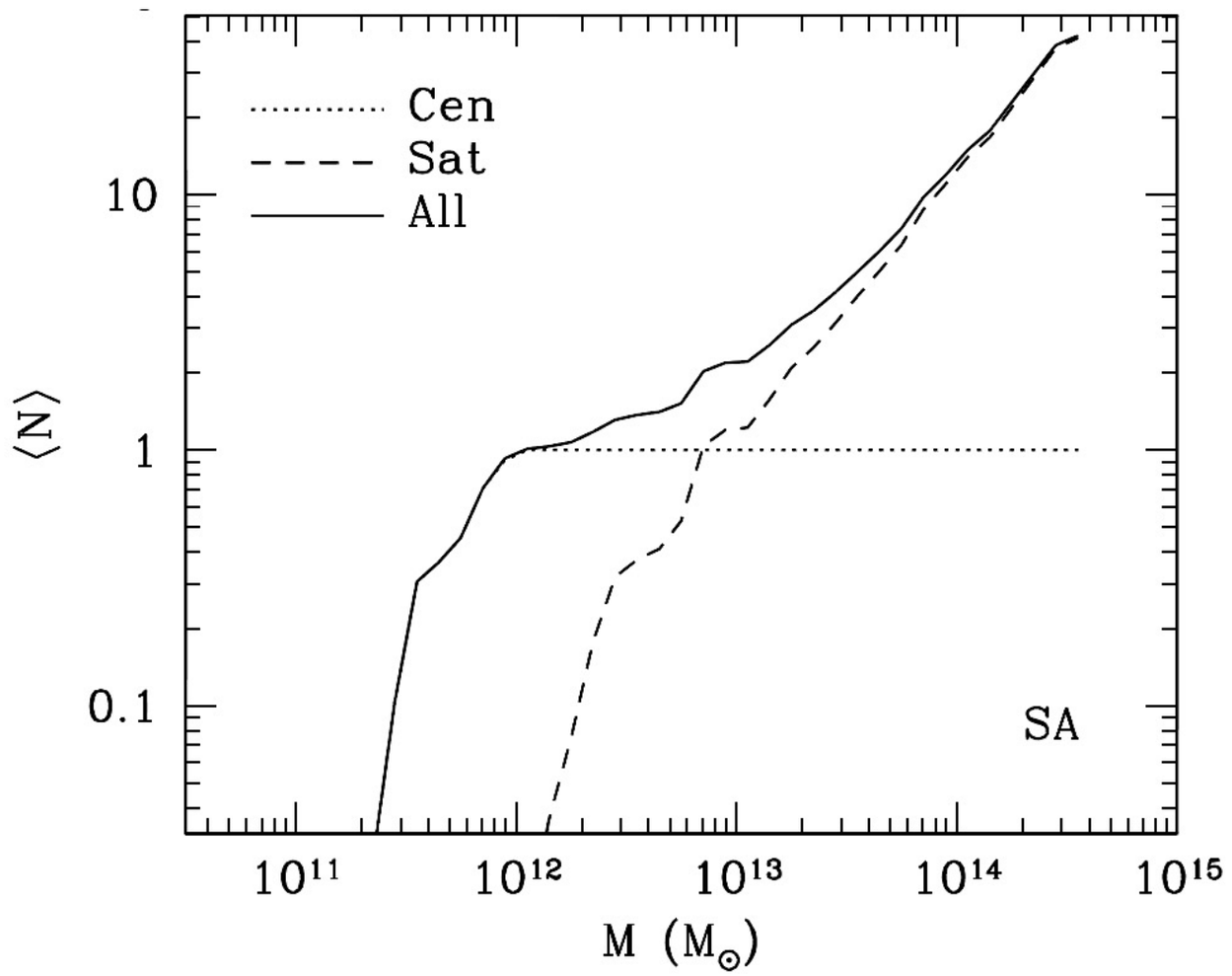


Empirical models, (sub) halo abundance matching, halo occupation distribution models

Great for very large scales but contain limited information about the physics shaping the properties of galaxies

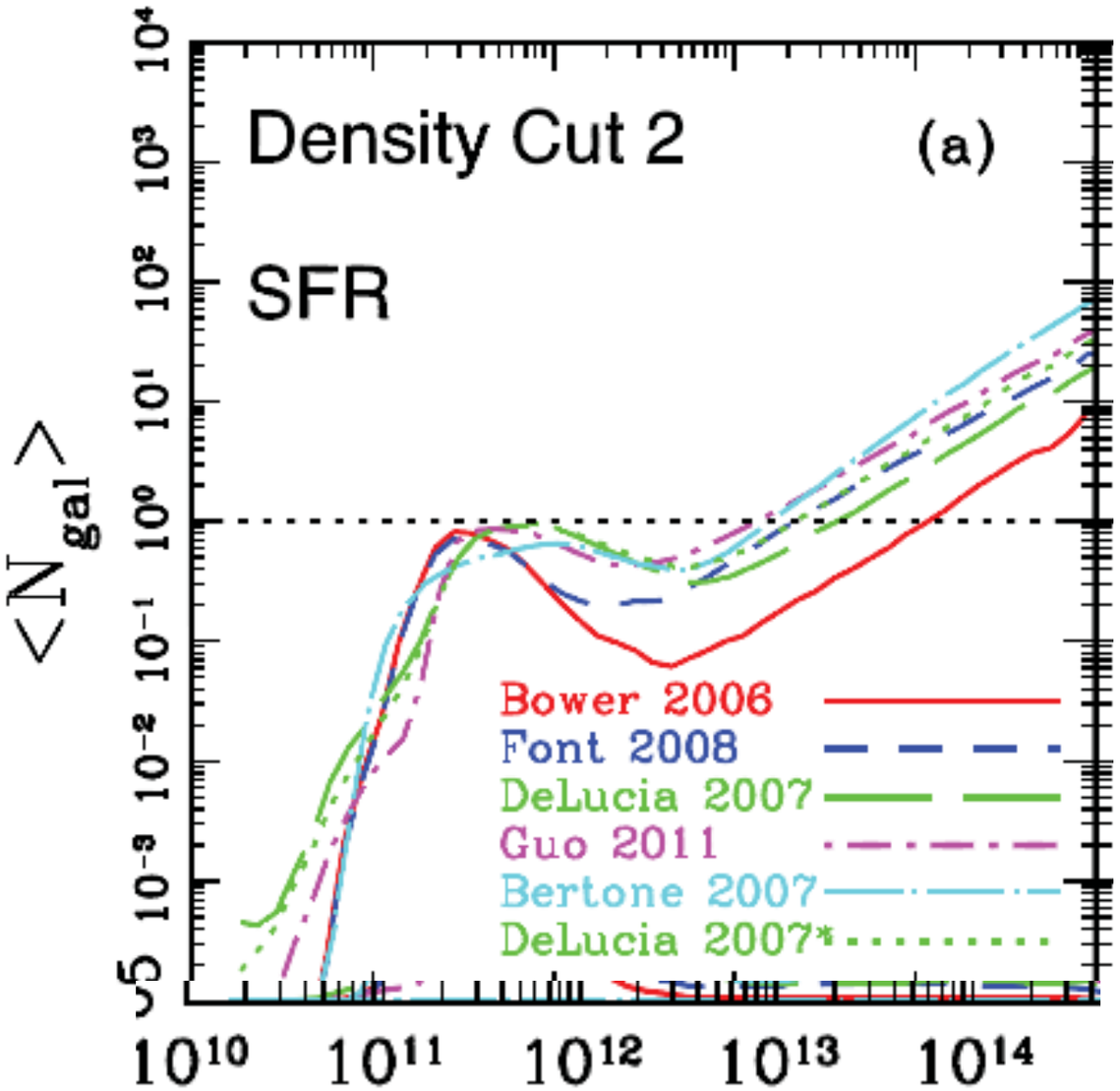
The HOD for a mass-selected sample of galaxies

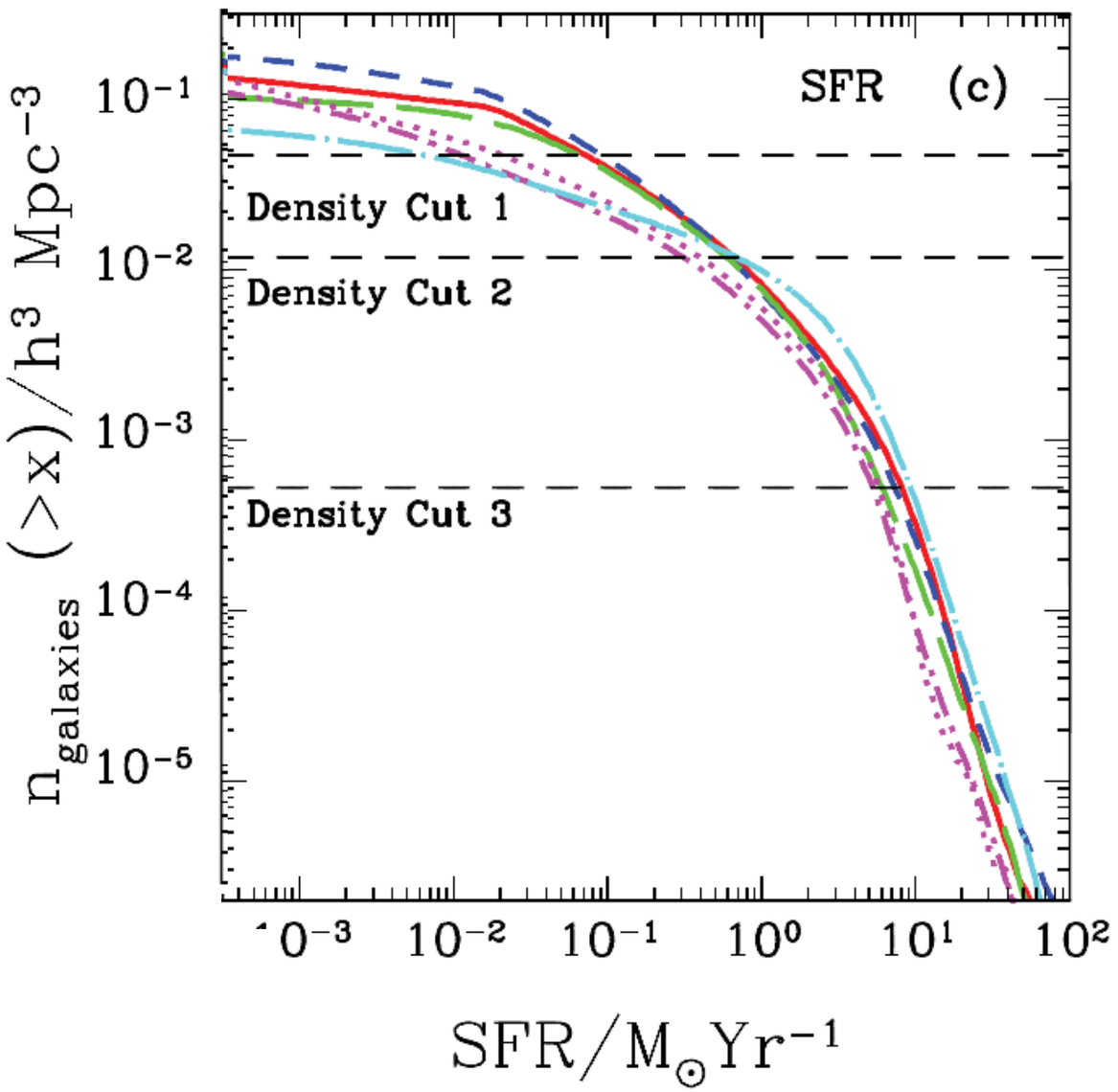




Zheng 2005

The HOD for a SFR-selected sample of galaxies

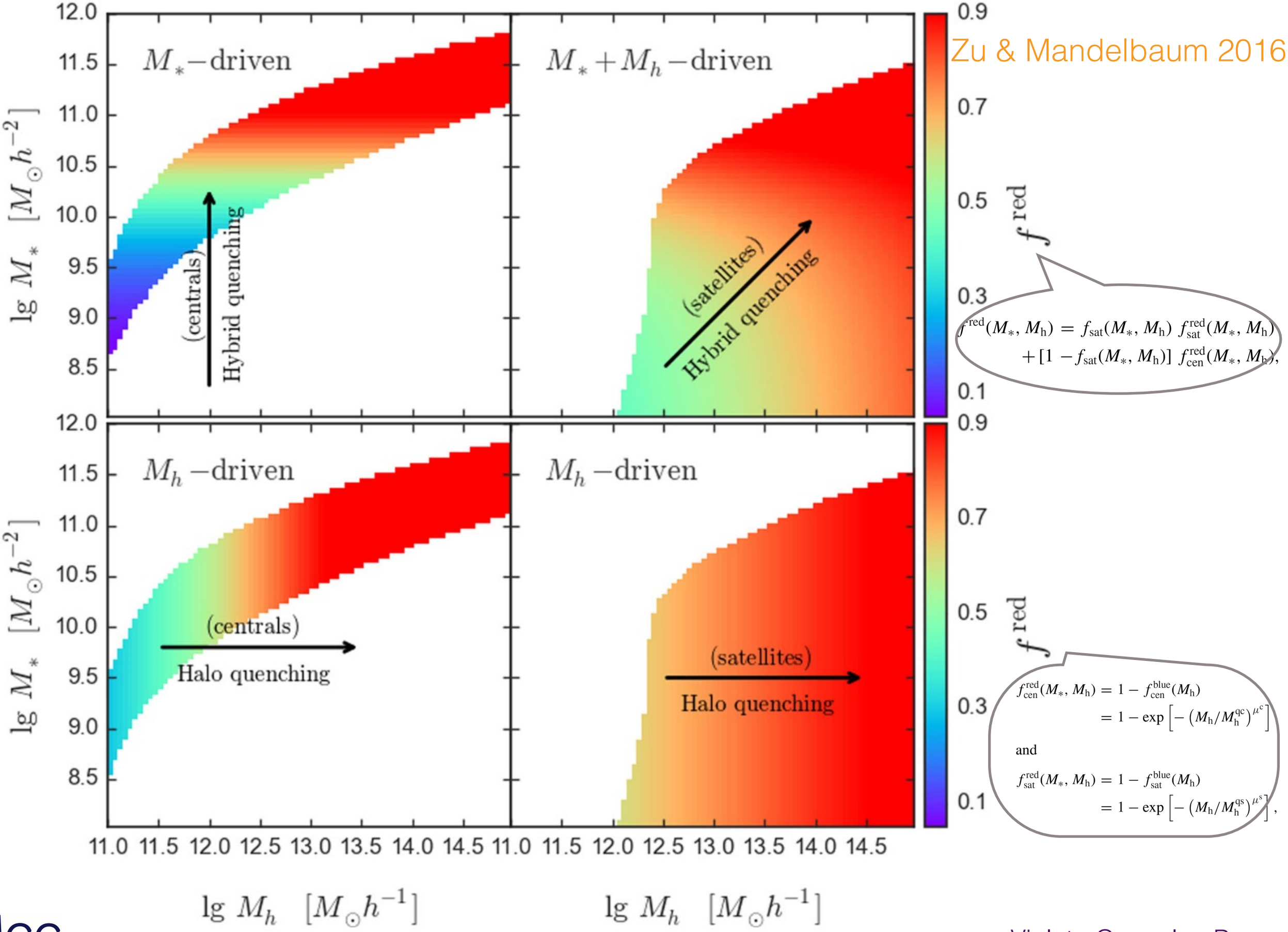




$M_{halo}/\ h^{-1}\ M_{\odot}$

Contreras 2013

Zu & Mandelbaum 2016



$$f^{\rm red}(M_*, M_{\rm h}) = f_{\rm sat}(M_*, M_{\rm h})\, f^{\rm red}_{\rm sat}(M_*, M_{\rm h}) + [1 - f_{\rm sat}(M_*, M_{\rm h})]\, f^{\rm red}_{\rm cen}(M_*, M_{\rm h}),$$

$$f^{\rm red}_{\rm cen}(M_*, M_{\rm h}) = 1 - f^{\rm blue}_{\rm cen}(M_{\rm h}) = 1 - \exp\left[-\left(M_{\rm h}/M^{\rm qc}_{\rm h}\right)^{\mu^{\rm c}}\right]$$

and

$$f^{\rm red}_{\rm sat}(M_*, M_{\rm h}) = 1 - f^{\rm blue}_{\rm sat}(M_{\rm h}) = 1 - \exp\left[-\left(M_{\rm h}/M^{\rm qs}_{\rm h}\right)^{\mu^{\rm s}}\right],$$

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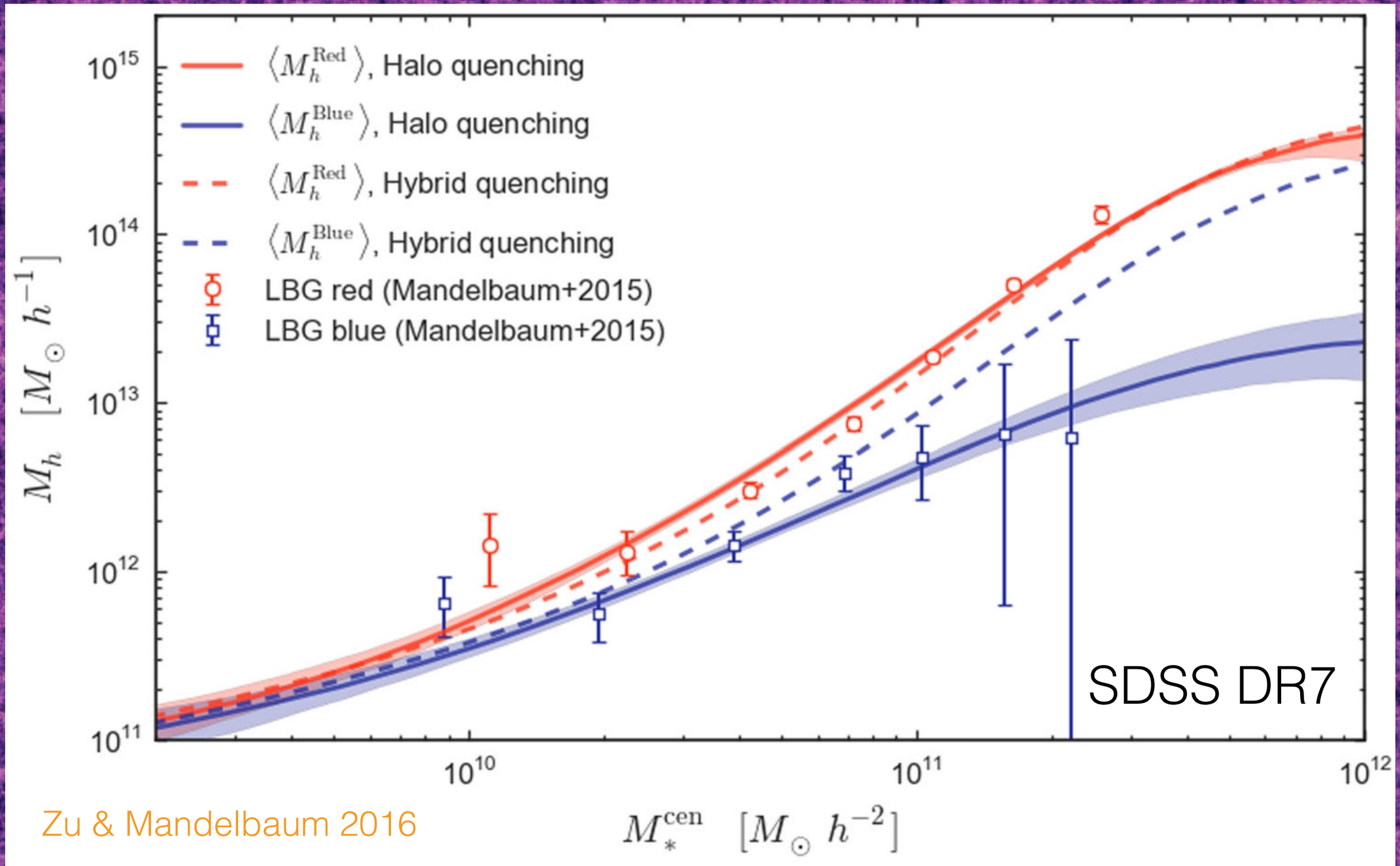


Zu & Mandelbaum 2016

Semi-analytical model

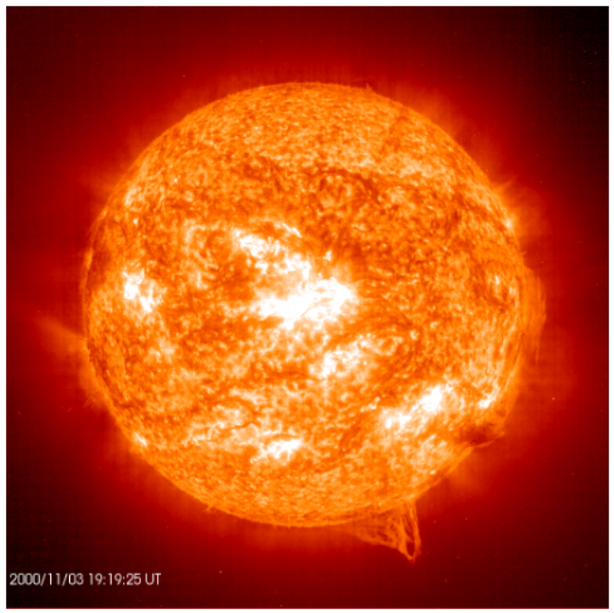
Gas bounded to a gravitation potential

Dark Halo

No

Efficient cooling?

Yes



Disc

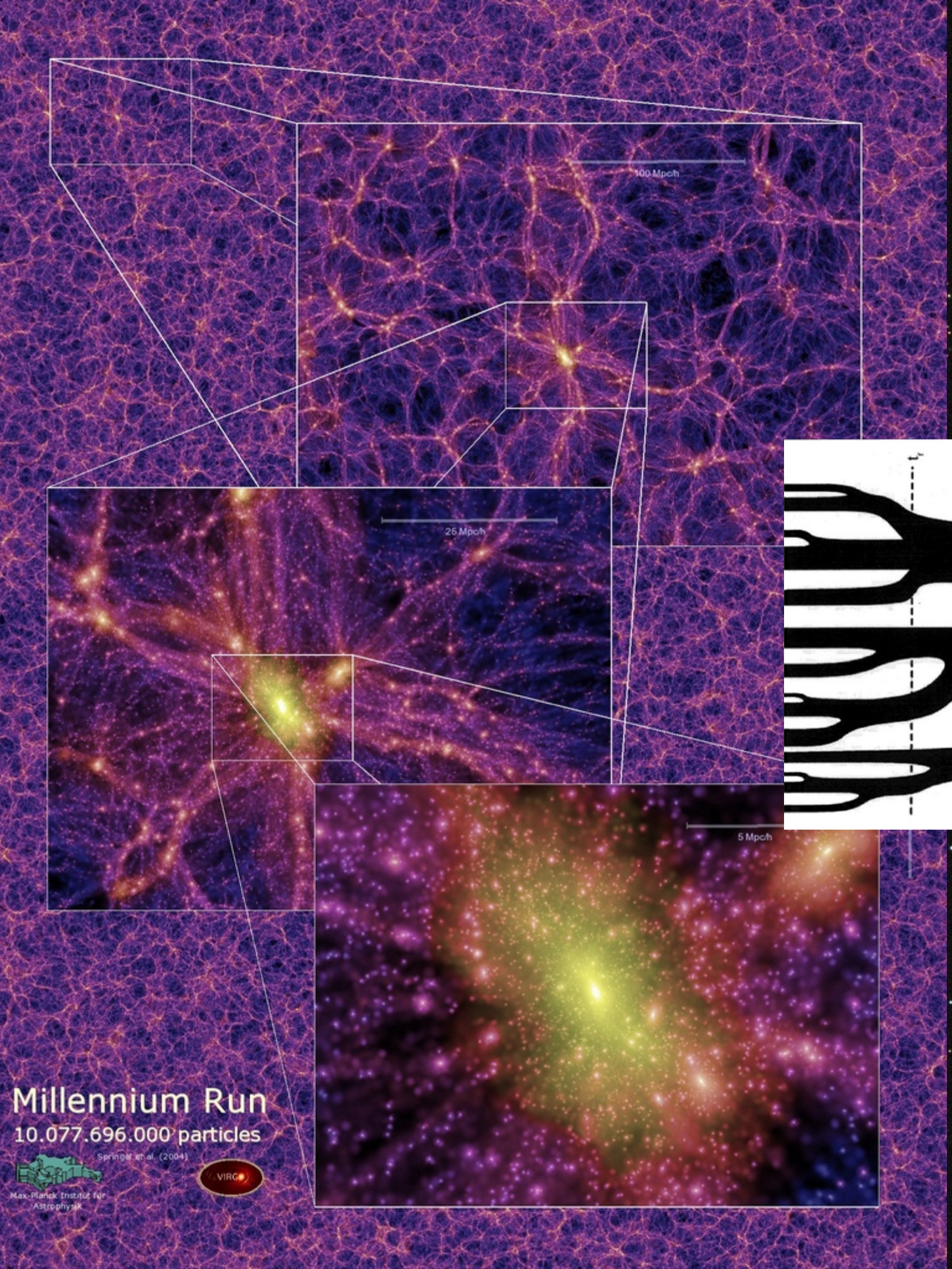
Yes

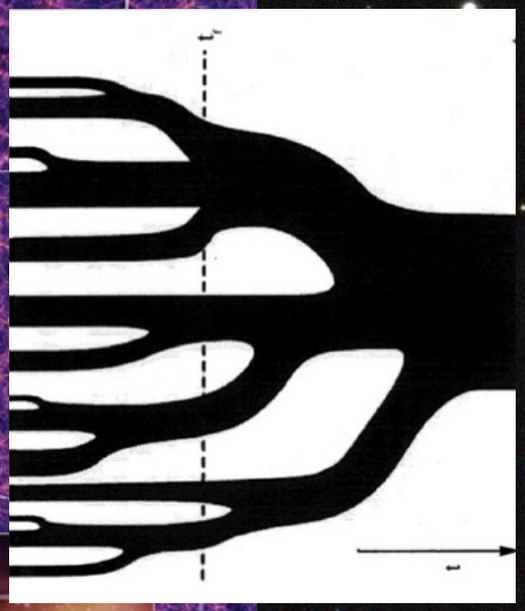
Large j?

Merger? Disc in-stability?

No

Bulge


100 Mpc/h
25 Mpc/h
5 Mpc/h
Millennium Run
10.077.696.000 particles
Springel et al. (2004)
VIRGO
Max-Planck Institut für Astrophysik

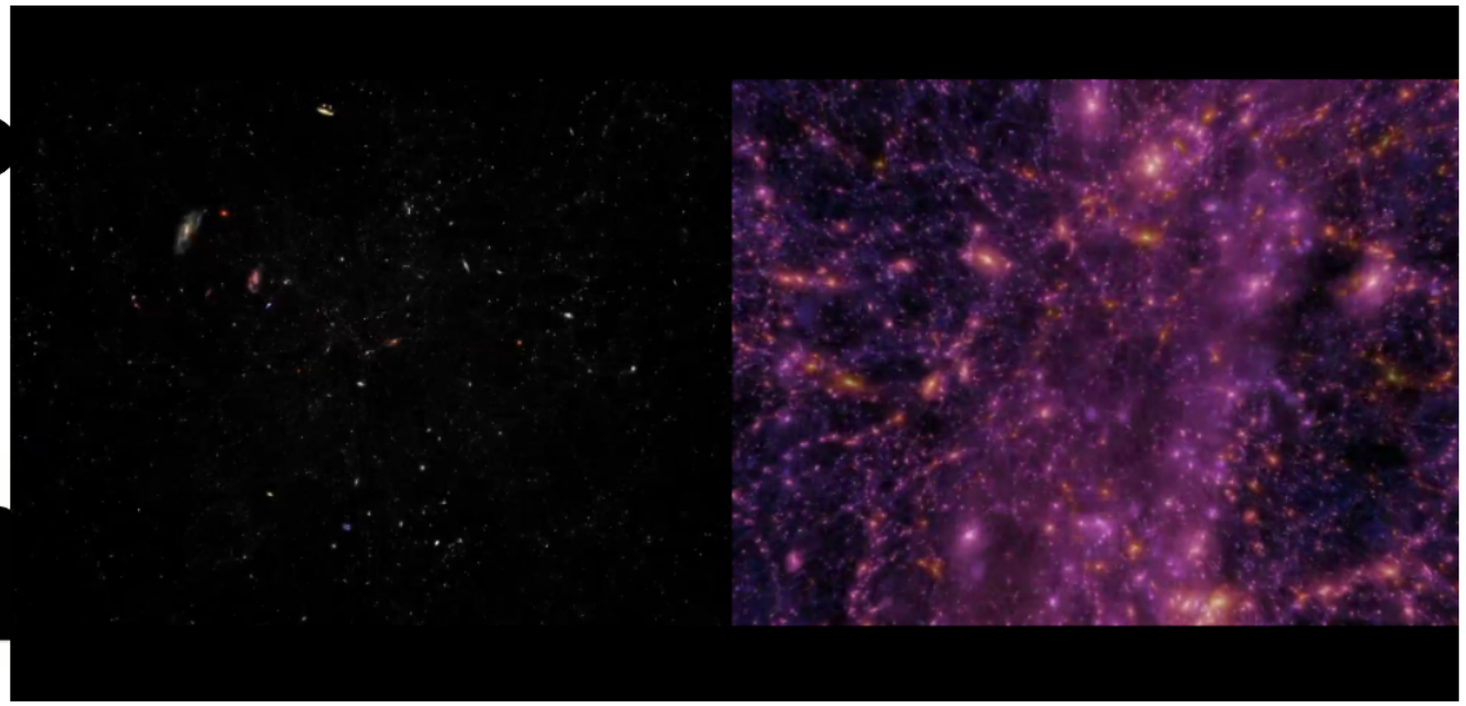


Galform

The semi-analytical approach

ΛCDM Cosmology

DM Merger trees



Galform

update free parameters

NO

Observable galaxy properties

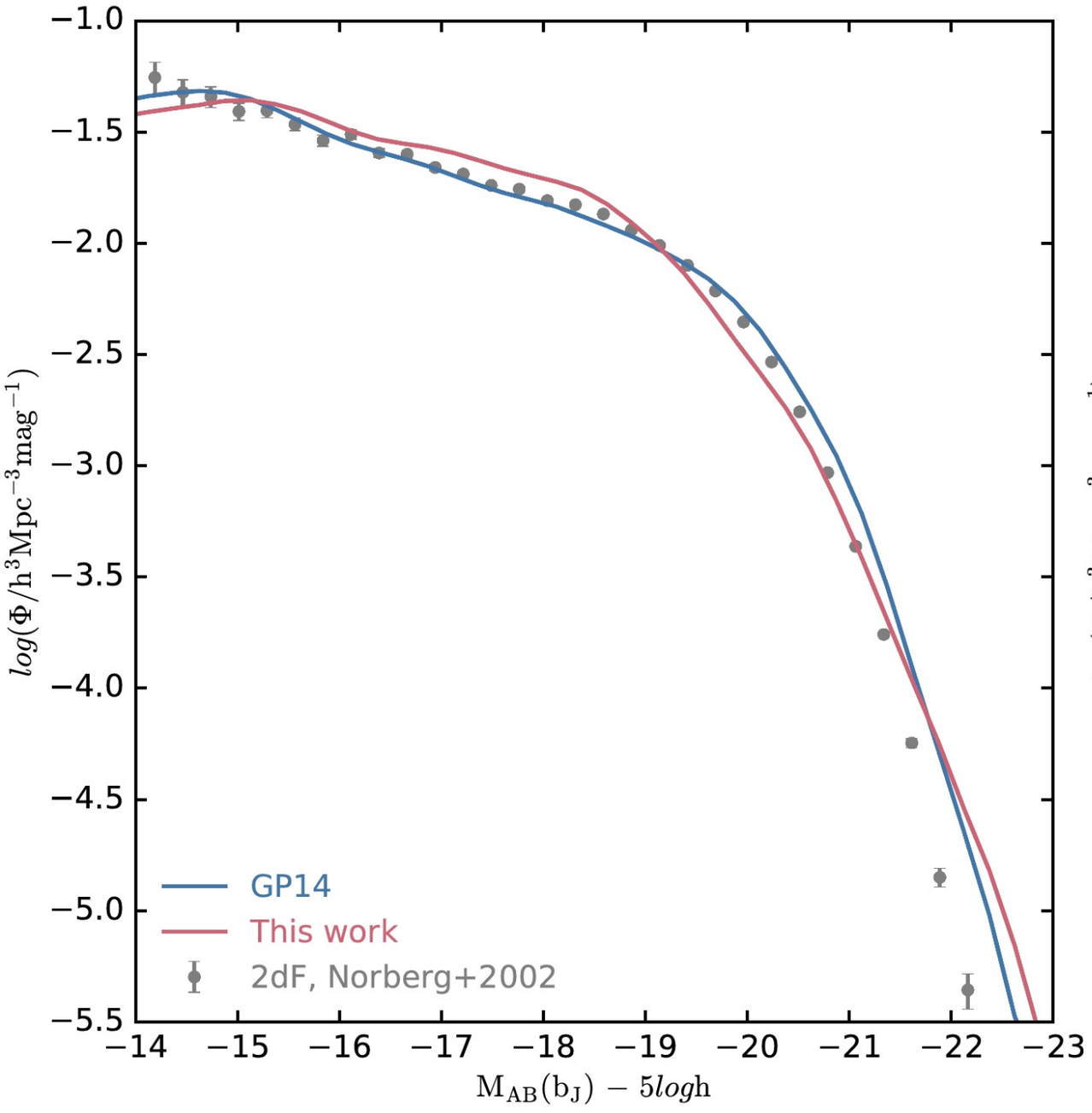
Test

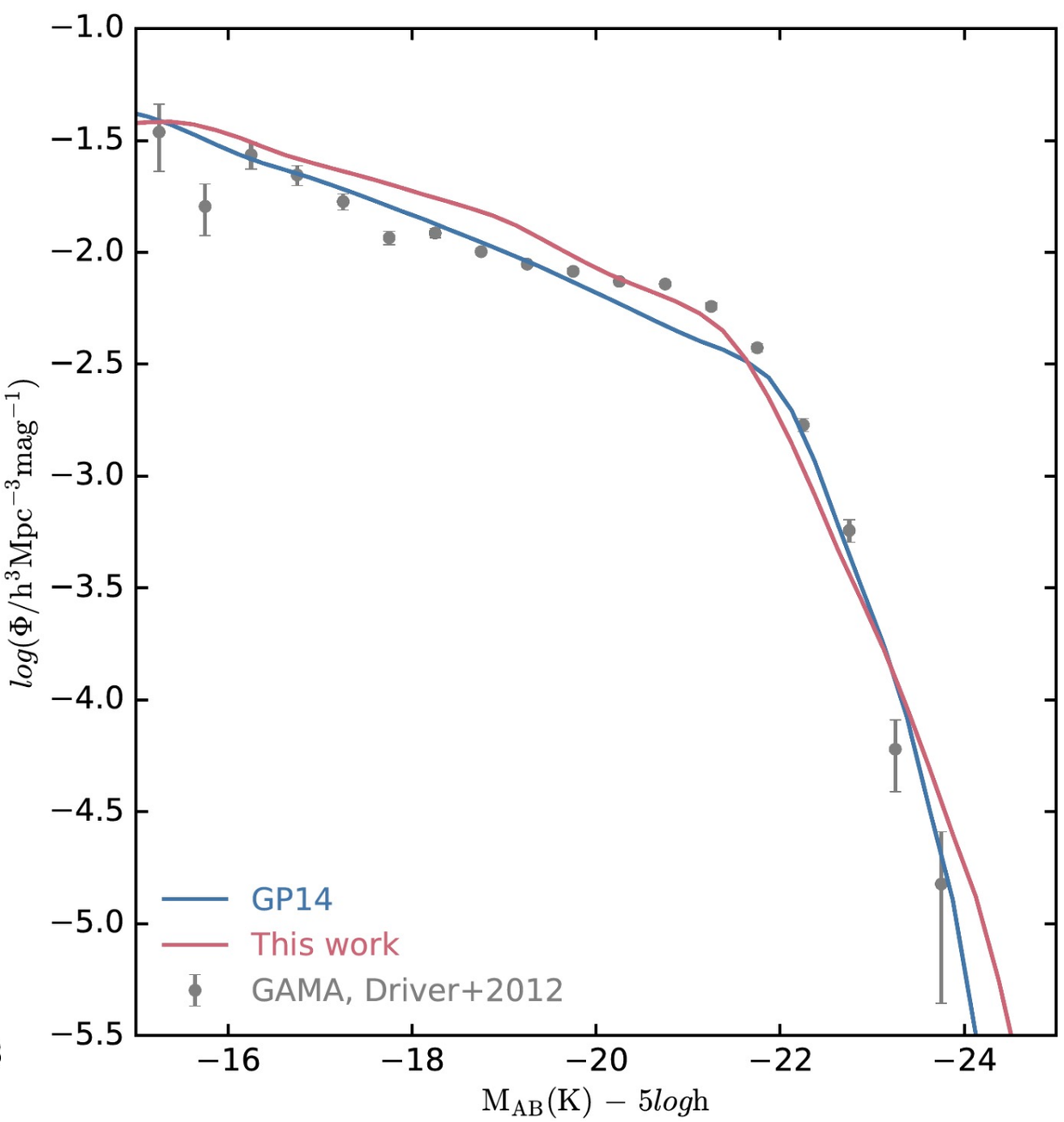
Fit obs. at z=0?

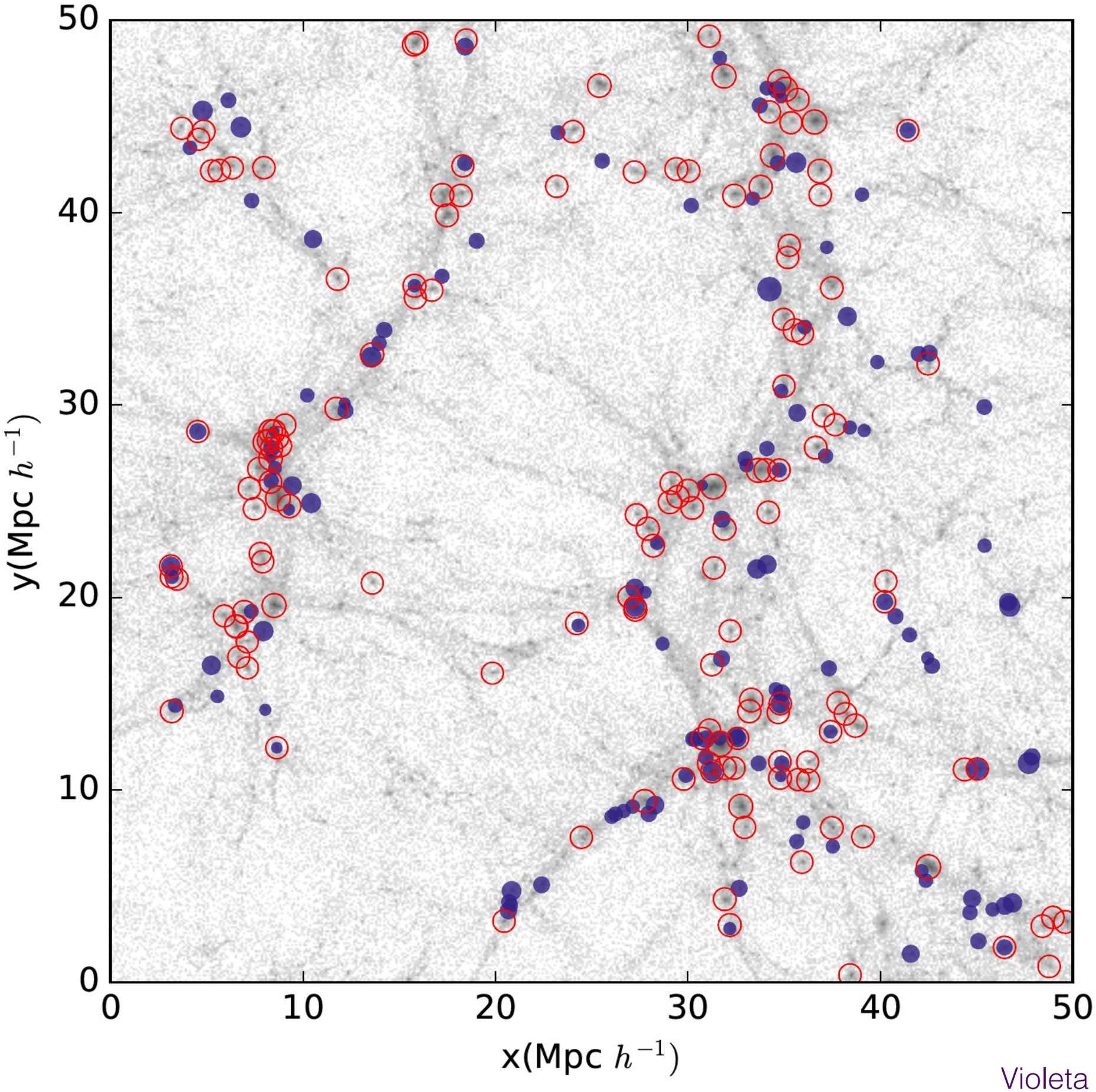
YES

Stable model

The GALFORM flavour used for this work: calibration







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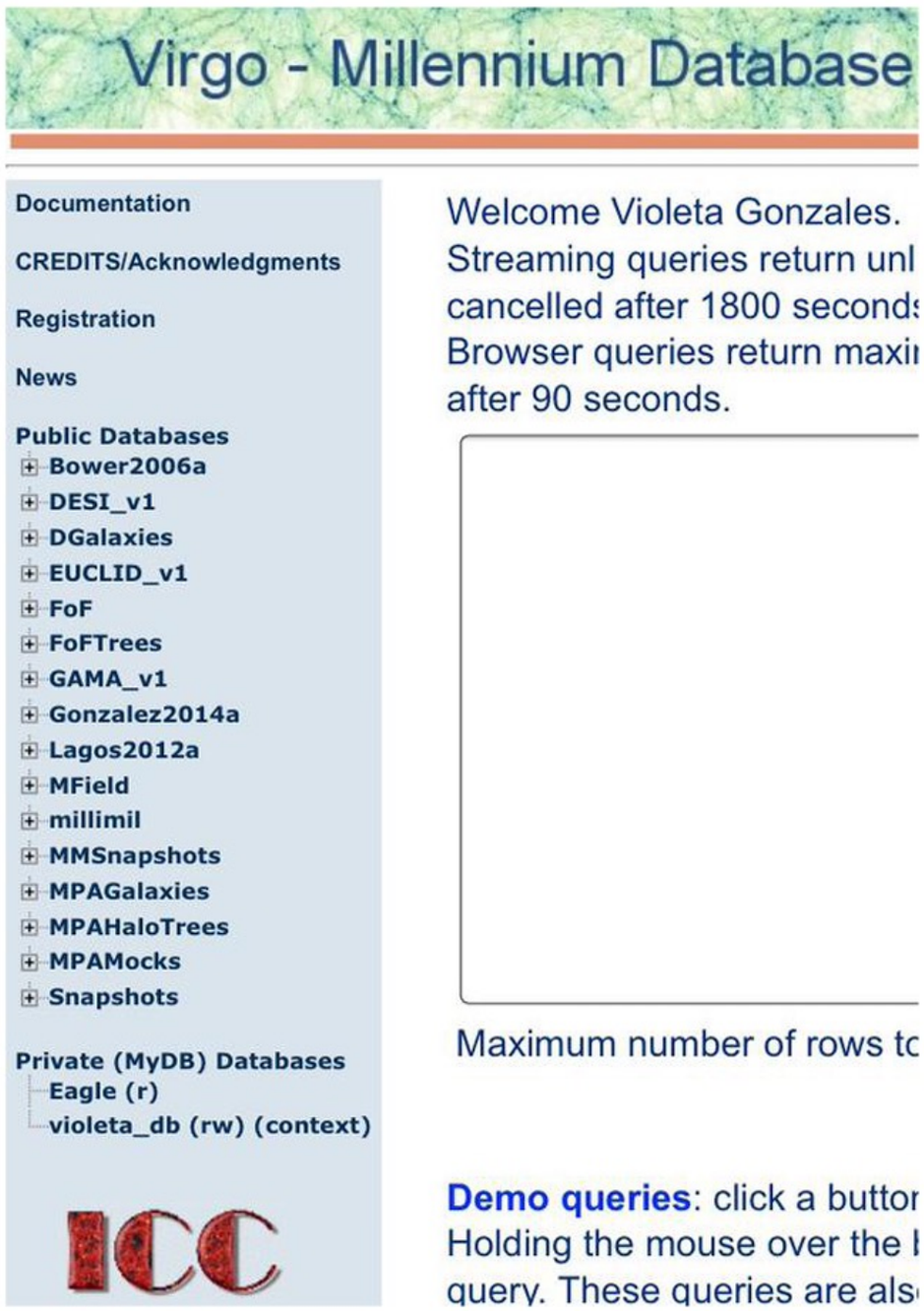
Semi-analytical models and outputs are publicly available



- http://www.virgo.dur.ac.uk/
- https://tao.asvo.org.au/tao/
- https://github.com/darrencroton/sage
- http://galacticusblog.blogspot.com.au/
- http://galformod.mpa-garching.mpg.de/public/LGalaxies/
- Coming soon: Multidark galaxies

Hyrodynamical models

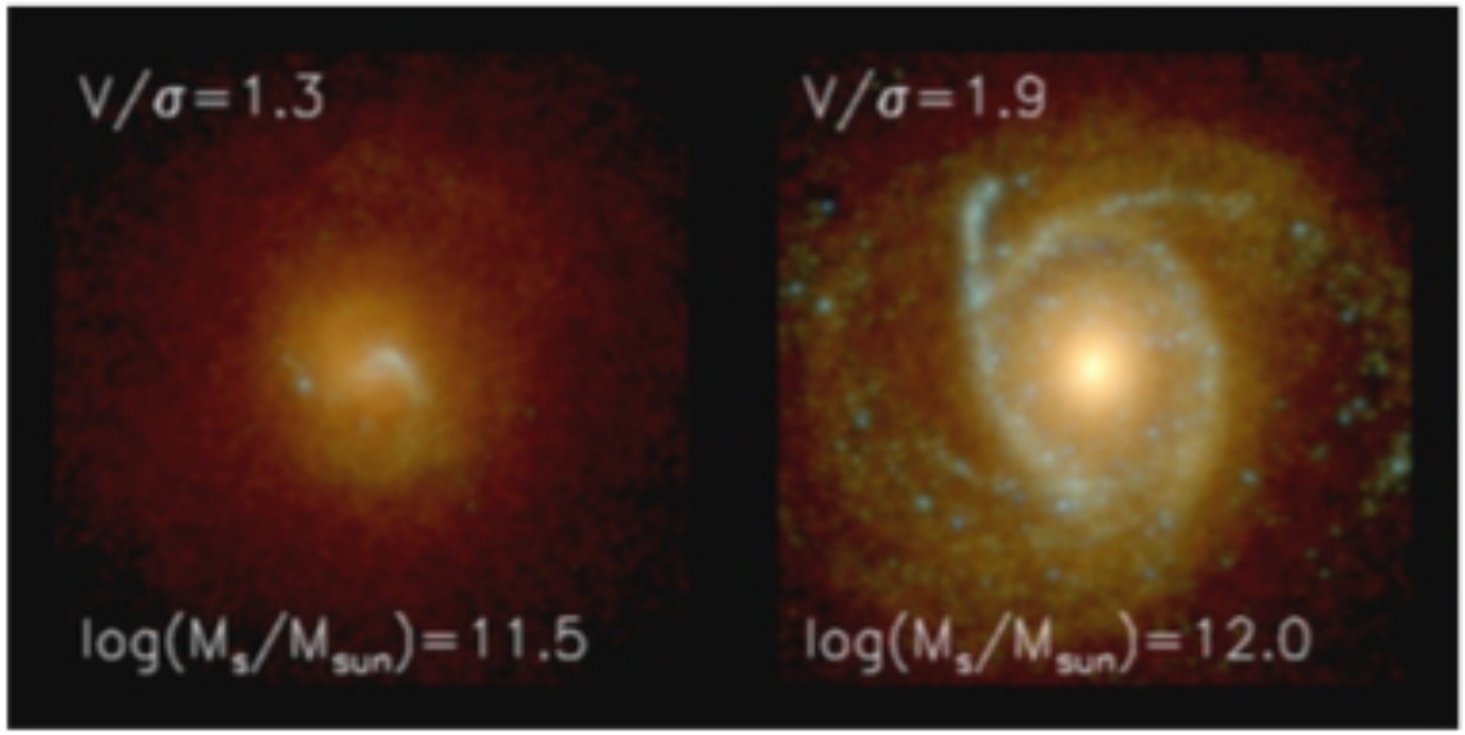
Gas

Dark
Matter

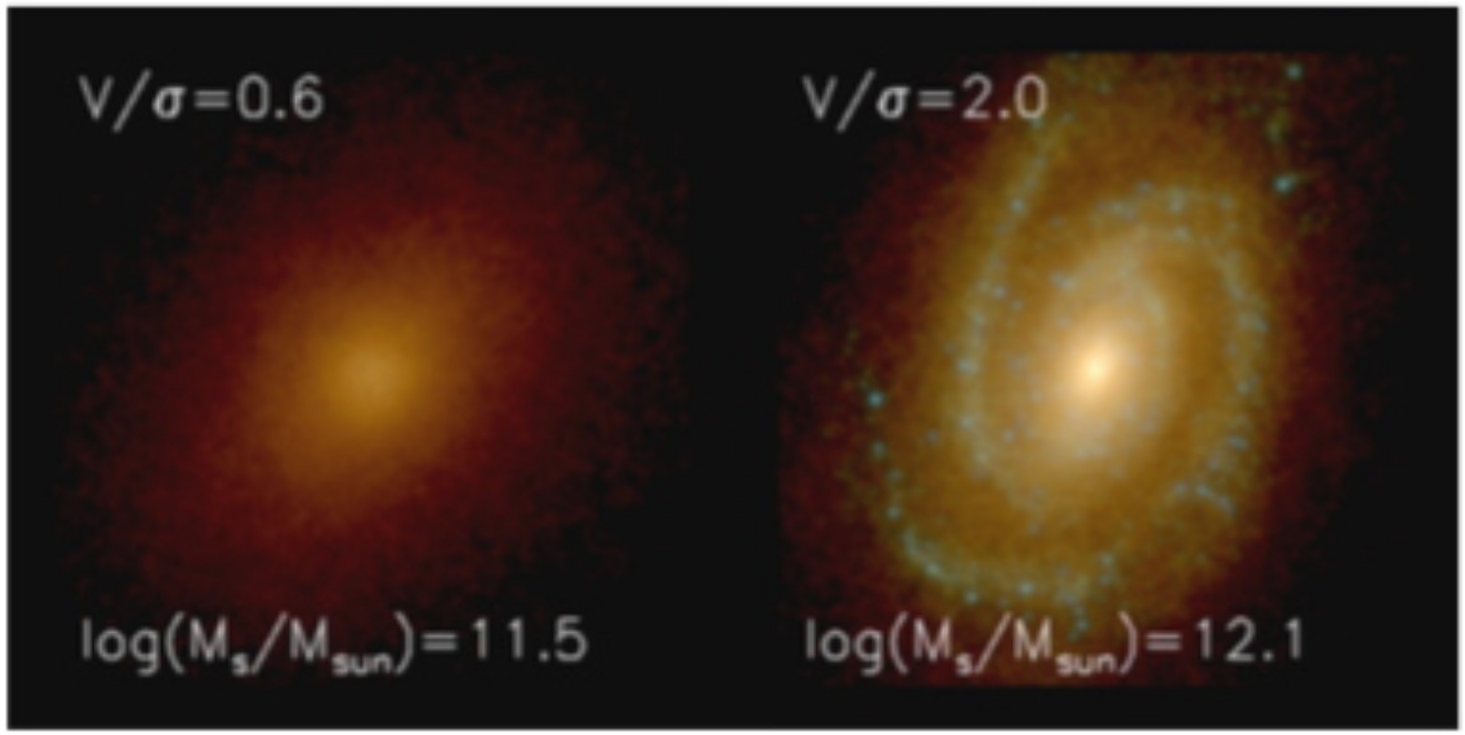
Hydrodinamical simulations: The Eagle project

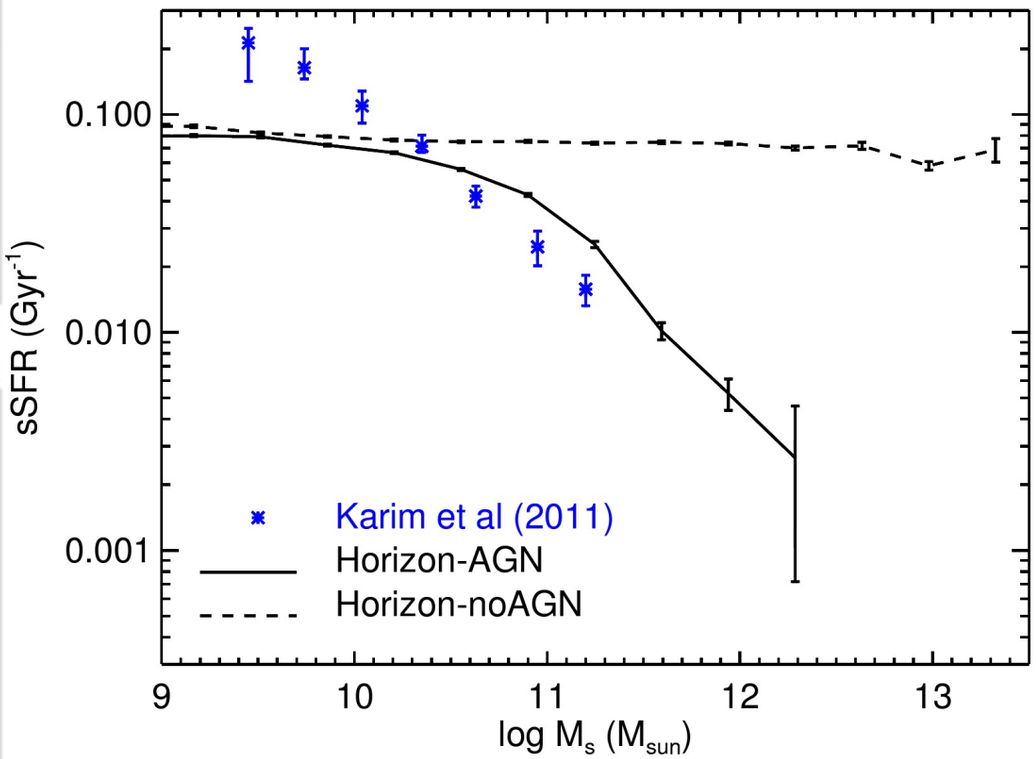
Stars

Cold
gas



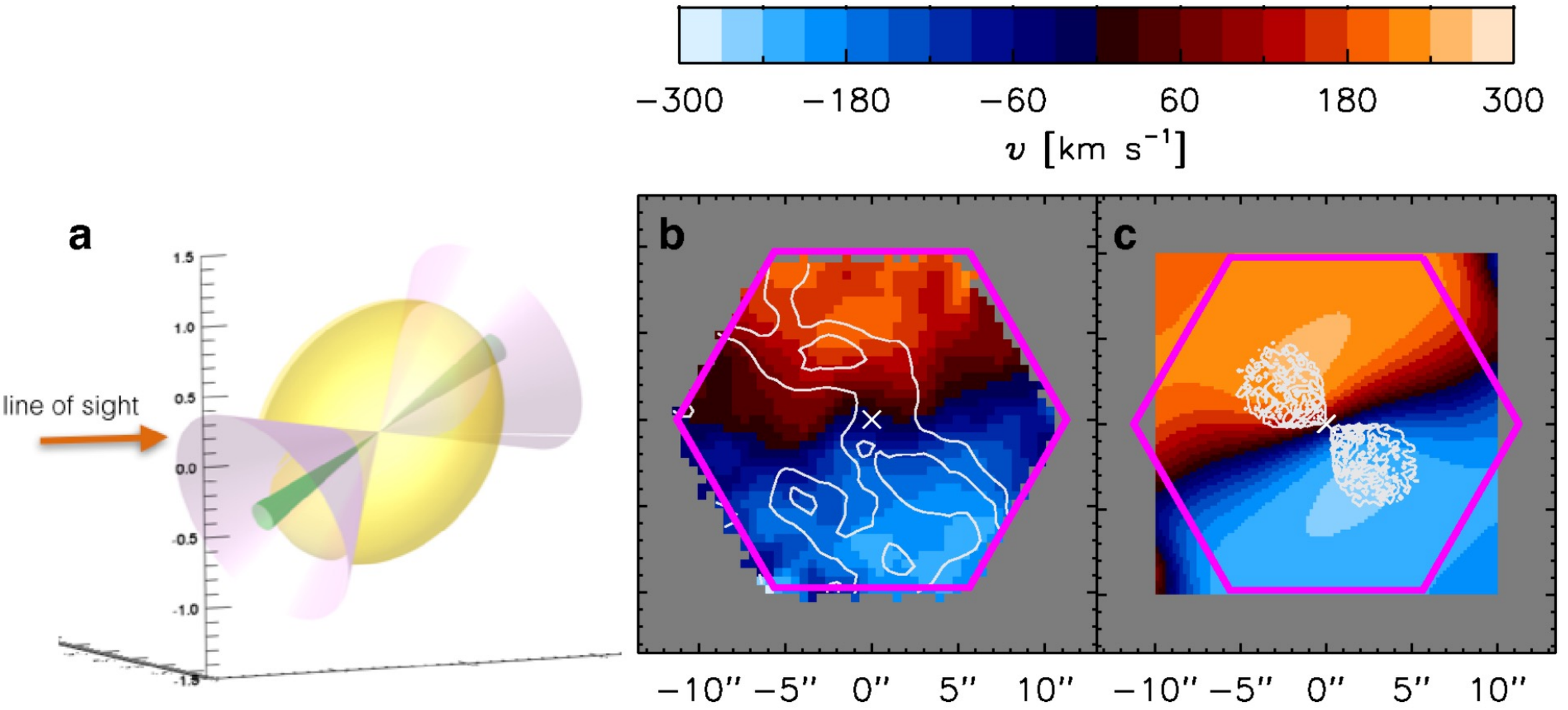
No AGN feedback



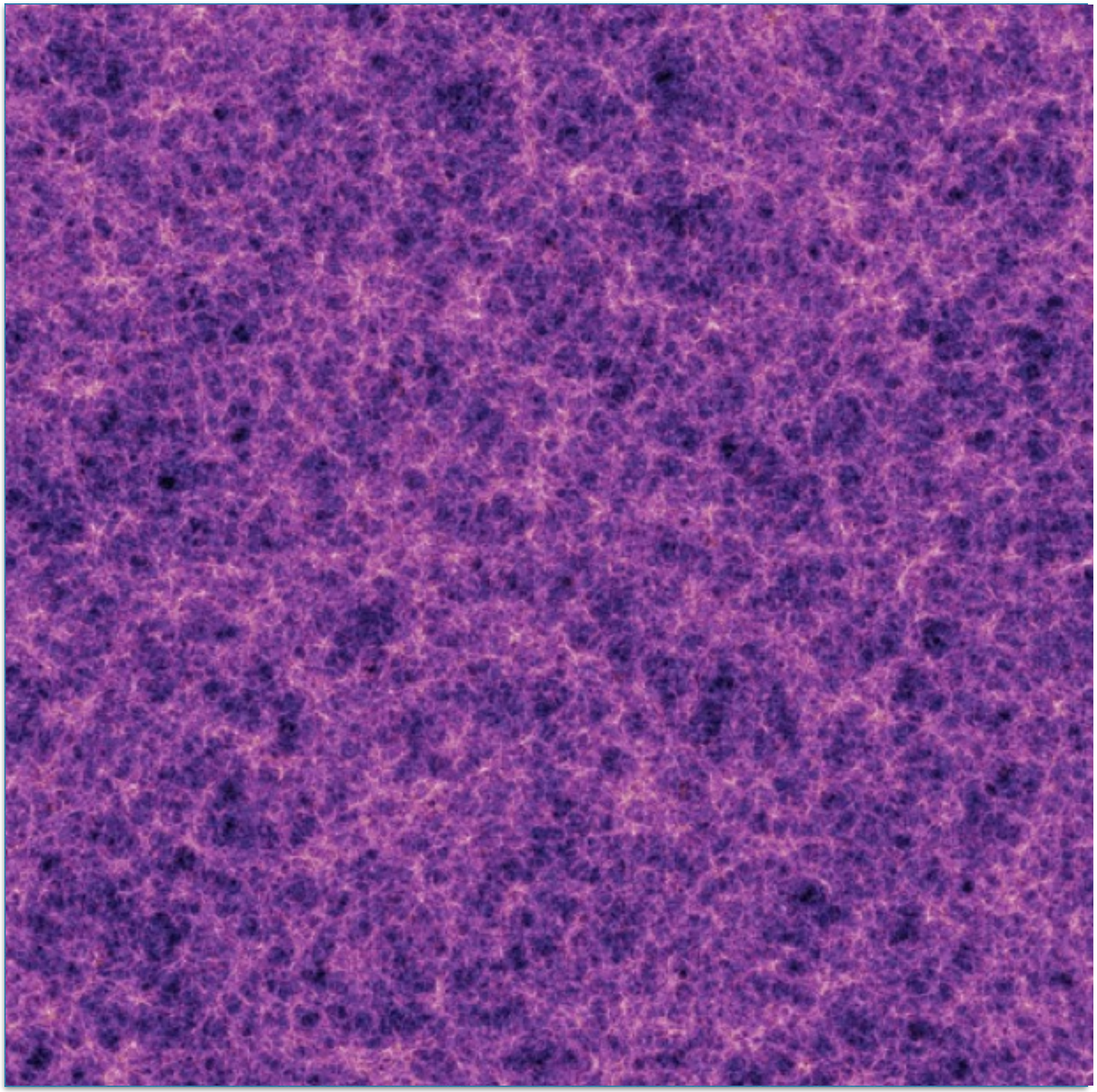


Dubois+16, Horizon-AGN simulations

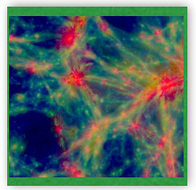
Which type of AGN feedback?



Cheung+16, MANGA observations

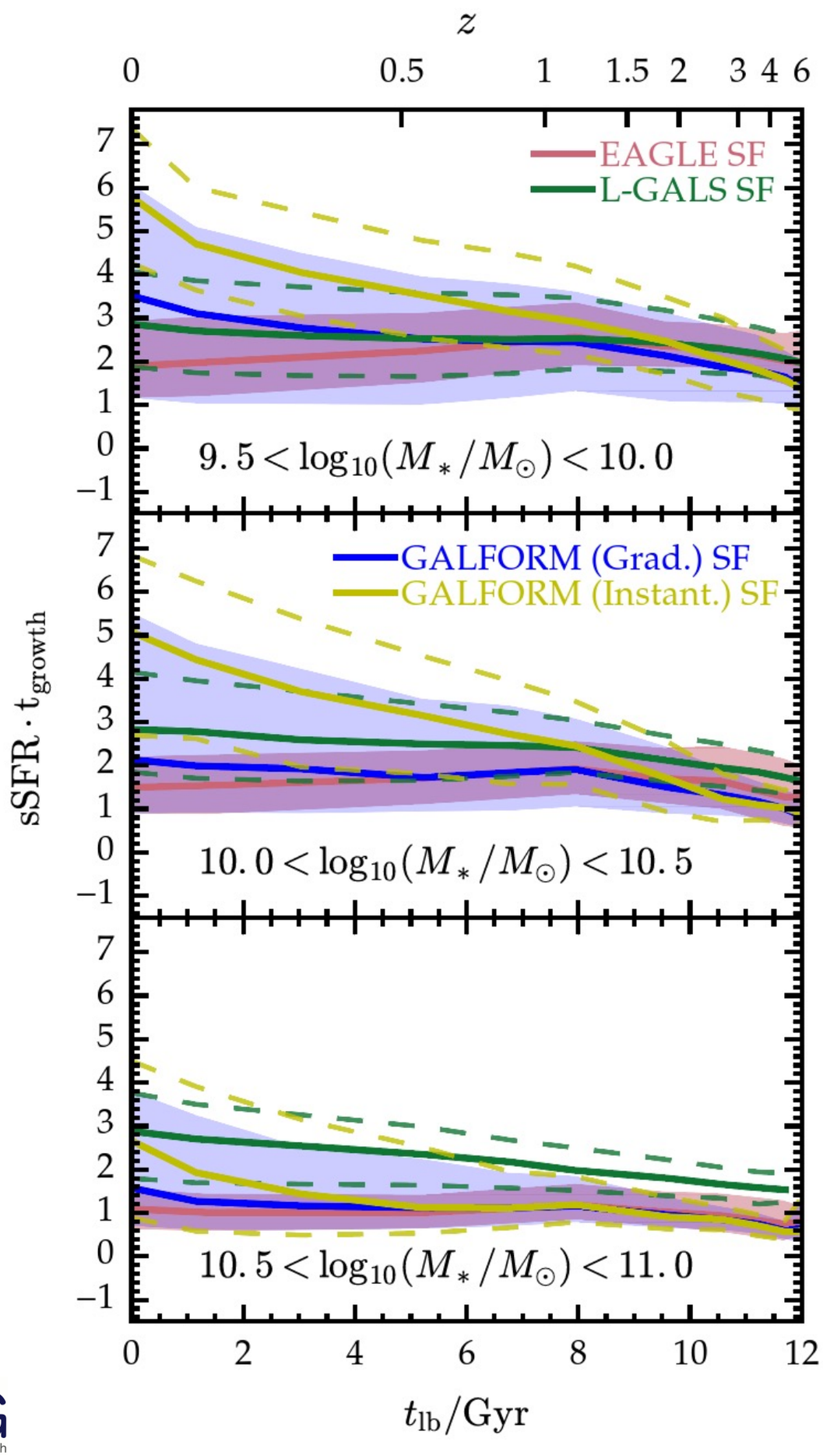


Millennium type simulation



The Eagle simulation

The final Eagle run took 4.5 10^6 CPU h + 40 10^6 CPU h for callibration



$$t^{-1}_{\mathrm{growth}}(\mathrm{Gyr}^{-1}) = \frac{\mathrm{d}M/\mathrm{d}t}{M(z)}$$

$$M(z) = M_0(1+z)^{\alpha}e^{\beta z}$$

Guo, VGP+16