Galaxy formation on small scales
+
Effects of feedback on galaxies discussion

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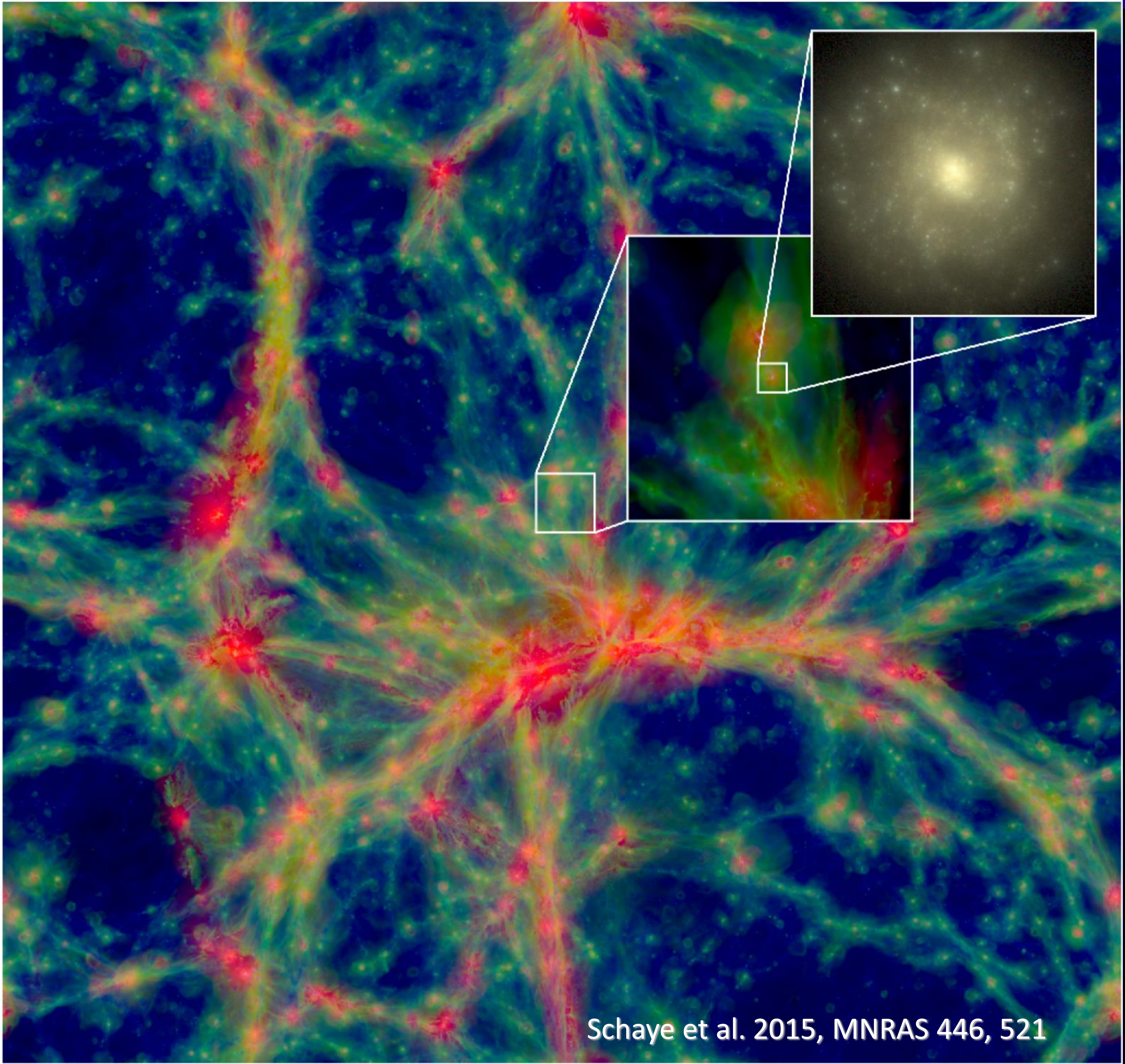
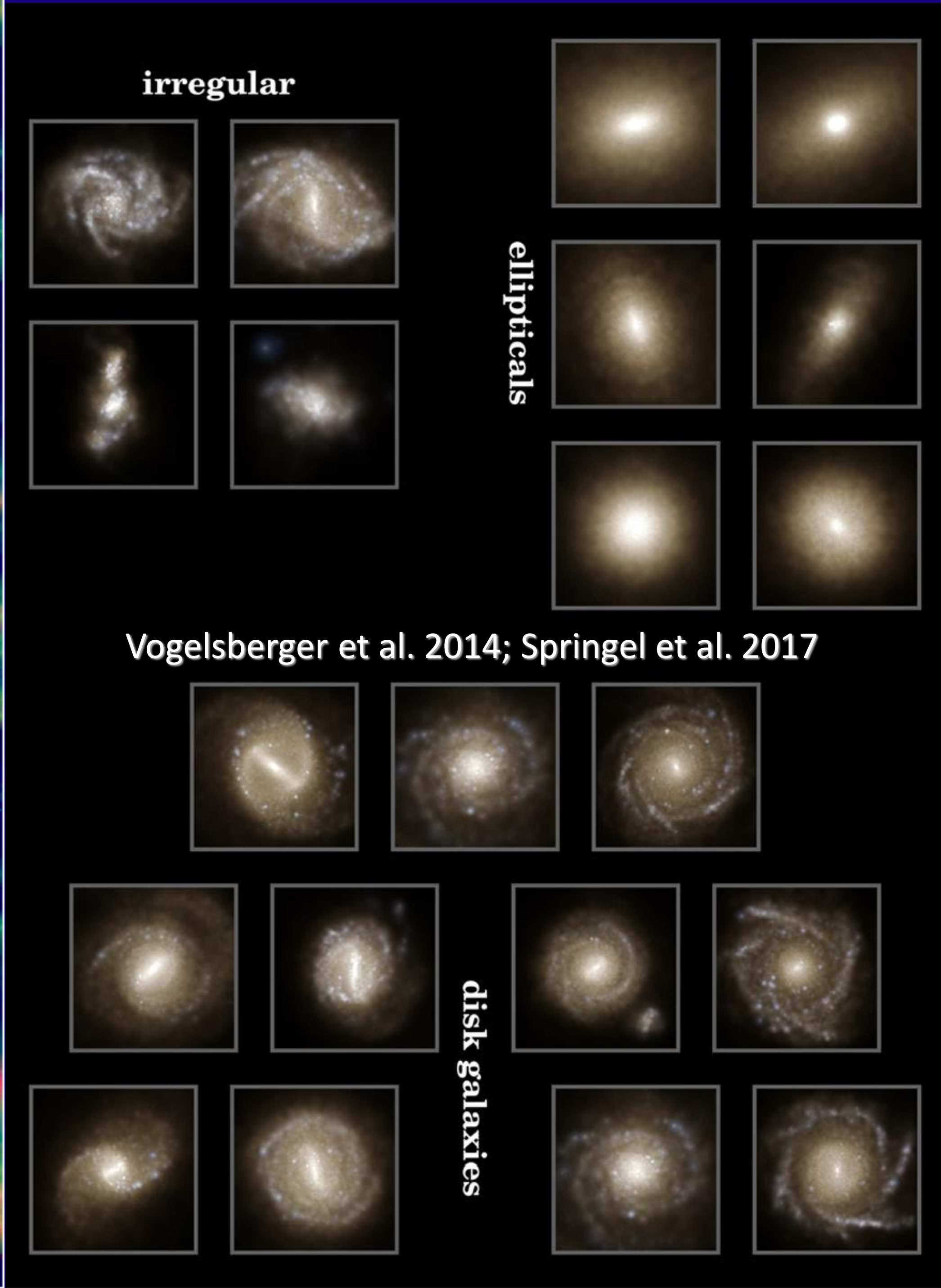
What is “small scales”?

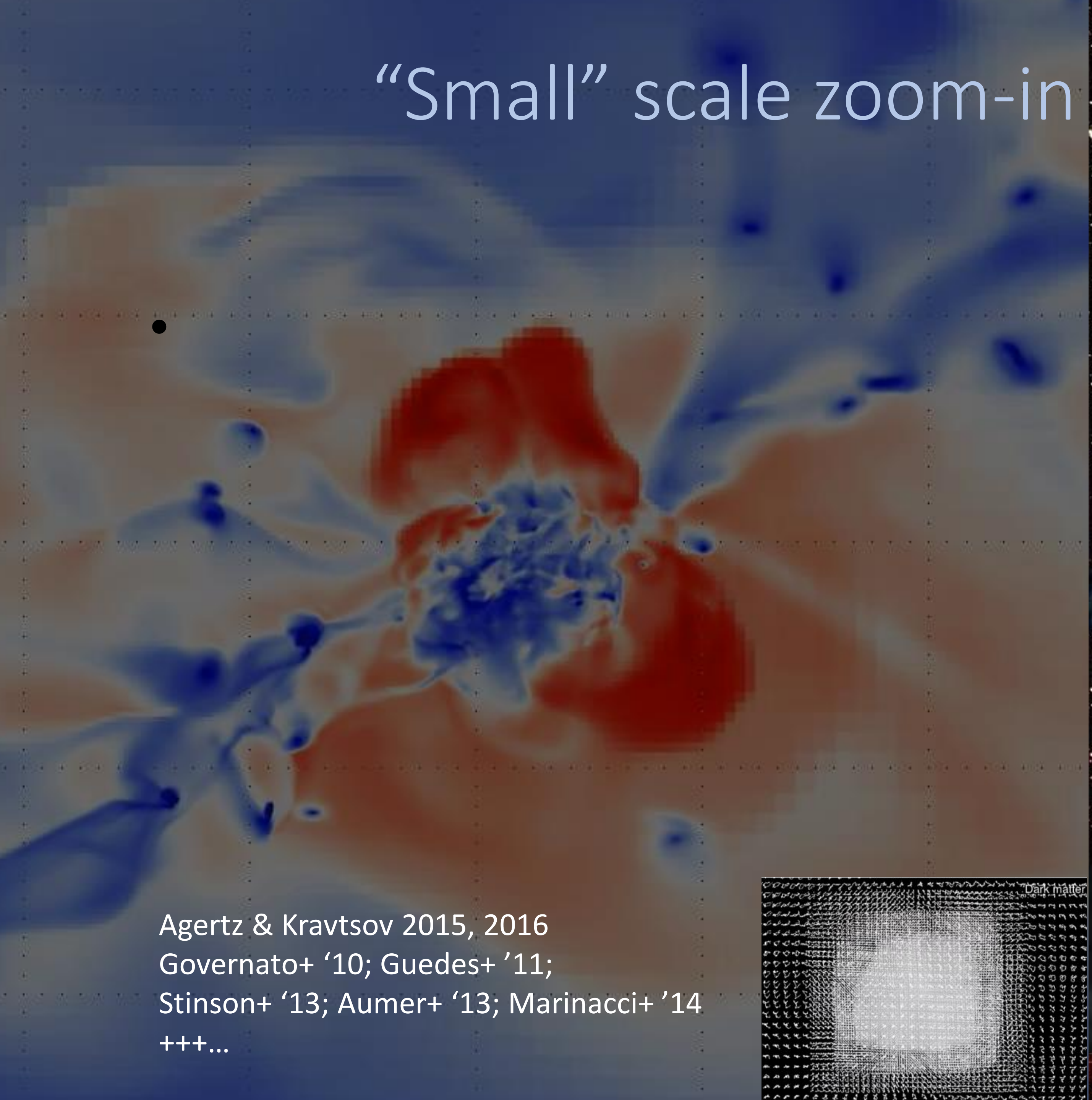
In modern highest-resolution simulations the small-scale is this...

All of the current galaxy formation simulations can be thought of as "small-scale", but they differ in how far down in resolution they push and how ISM and feedback is treated numerically


Schaye et al. 2015, MNRAS 446, 521


irregular
ellipticals
Vogelsberger et al. 2014; Springel et al. 2017
disk galaxies

“Small” scale zoom-in simulations



Agertz & Kravtsov 2015, 2016
Governato+ ‘10; Guedes+ ’11;
Stinson+ ‘13; Aumer+ ‘13; Marinacci+ ’14
+++…

Hopkins et al. 2013, 2017
http://fire.northwestern.edu/about-fire/

What does pushing to higher resolution give us?

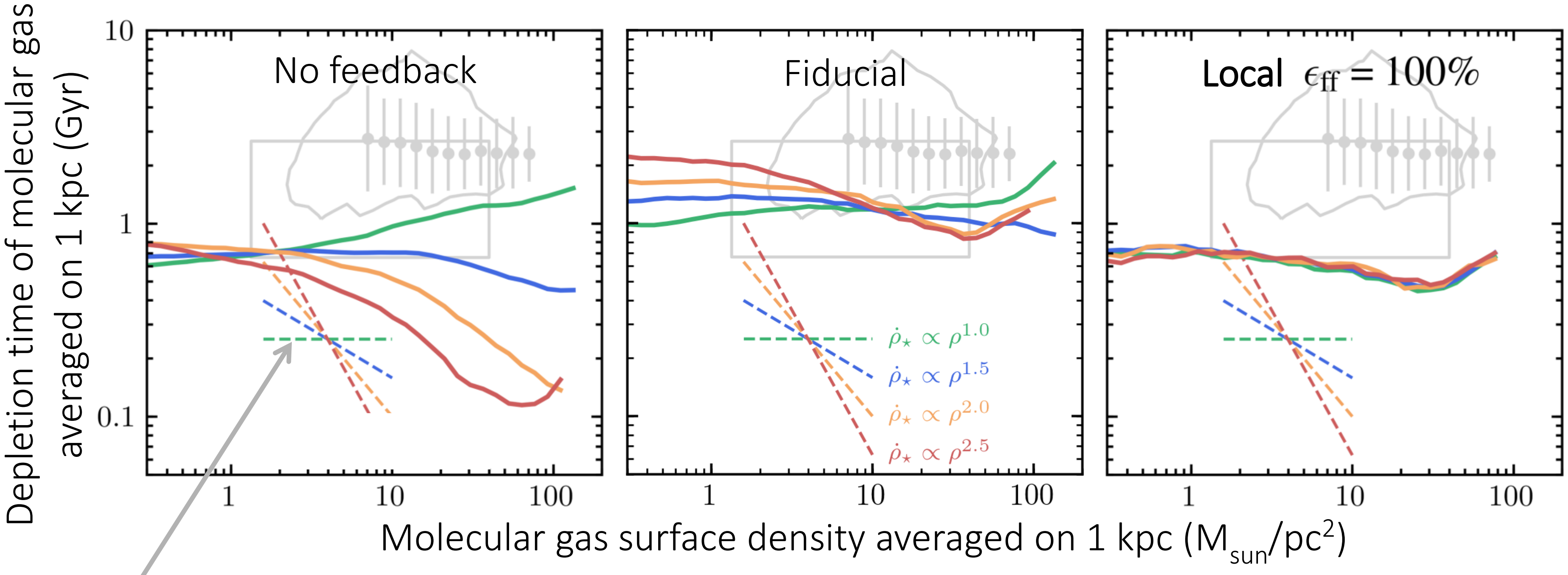
self-regulation of the slope of molecular KS relation

when feedback is efficient the KS slope on large scales is insensitive
to the density slope of local star formation prescription on small scales

$$\dot{\rho}_\star = \epsilon_{\rm ff} \frac{\rho_0}{t_{\rm ff,0}} \left(\frac{\rho}{\rho_0}\right)^\beta$$

cf. Vadim Semenov's talk on Monday
Semenov, Kravtsov & Gnedin 2018b, in preparation

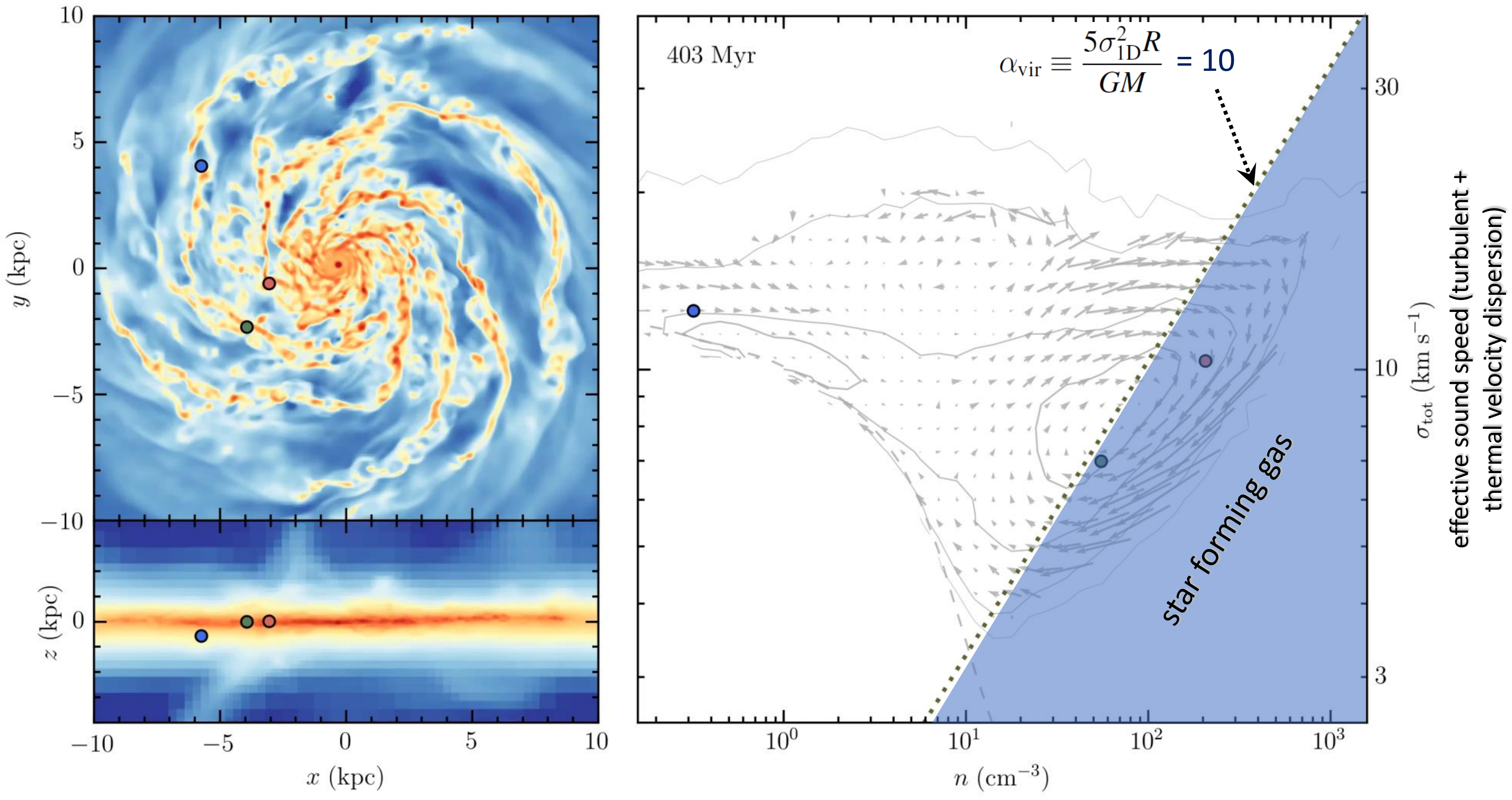
Feedback becomes more important



Slope of $\rho/\dot{\rho}_\star$ adopted on 40 pc scale

evolution of three representative ISM gas tracers

- tracers cycle between non-star forming and star forming regions on ~10-50 Myr time scales
- stellar feedback disrupts star forming regions and limits time in star forming stage
- tracers spend a significant fraction of time in non-star forming, diffuse gas



Emergence

"is the arising of novel and coherent structures, patterns and properties during the process of self-organization *in complex systems."*

Jeffrey Goldstein, 1999, Emergence 1, 49-72

ability of simulations to model emergence phenomena is related to their predictive power

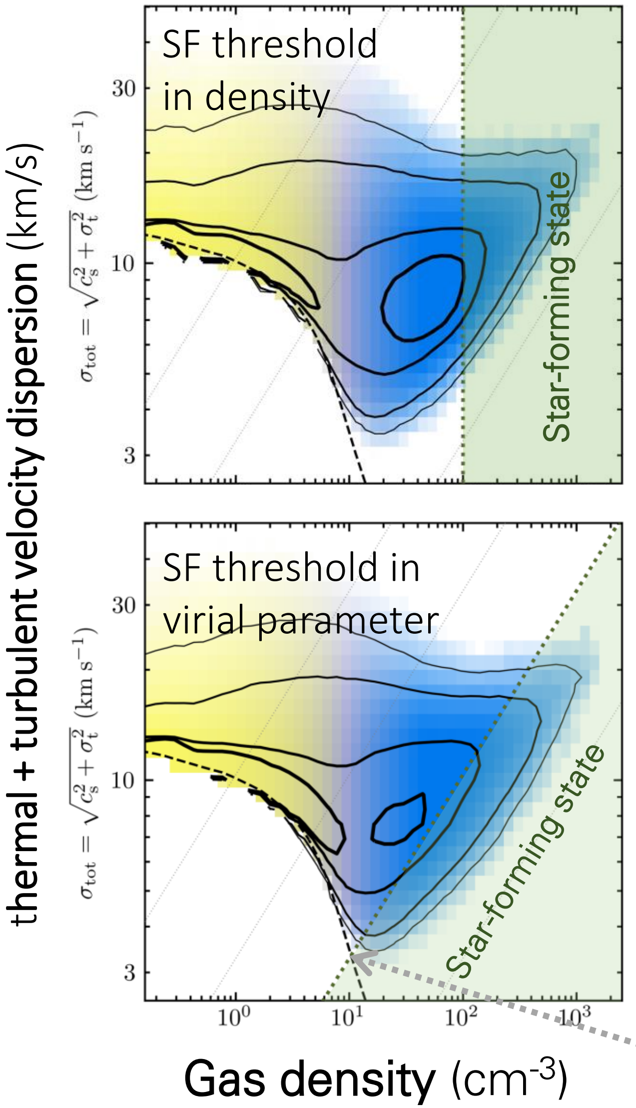
We generally want predictive power, but there are many questions…

- What is the optimal resolution for modelling galaxy formation in cosmological context?
- Which scales/process should be modelled and which should be “subgridded”?
- We want a numerical “effective theory” of ISM; processes that separate well in scale from the processes followed in simulations are ripe for subgrid modelling (e.g., star formation)

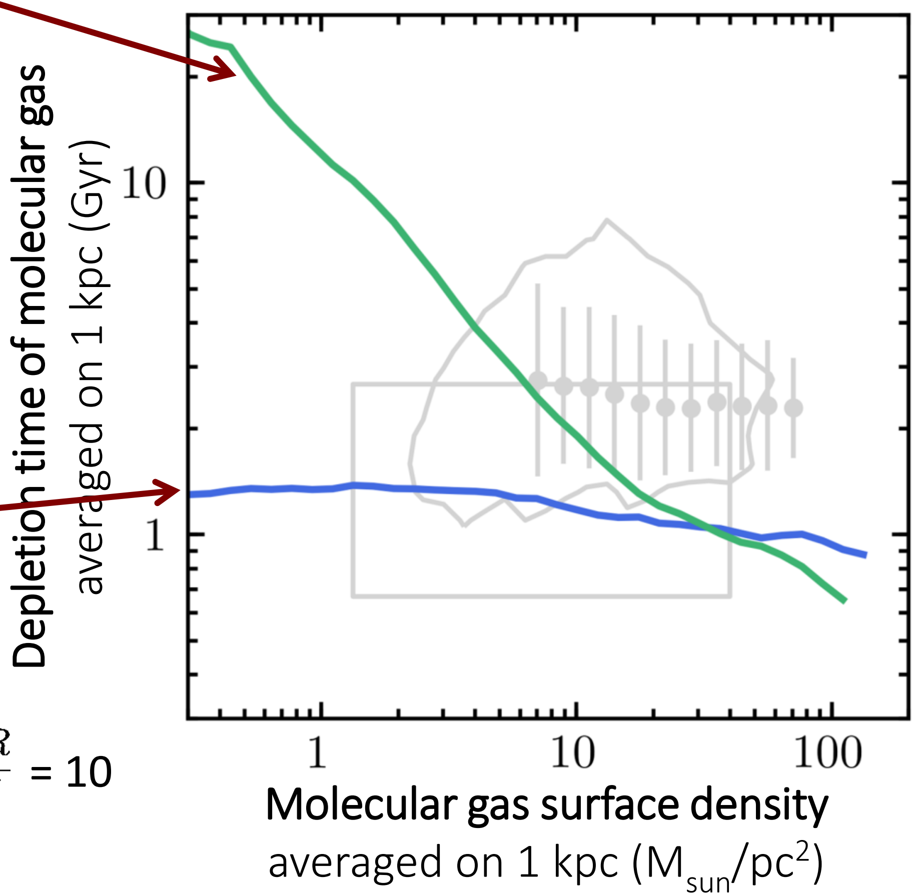
What does pushing to higher resolution give us?

Differentiating between different choices for what gas is star forming (e.g., star formation threshold):

- Density-based threshold leads to a nonlinear molecular Kennicutt-Schmidt relation, while a_{vir}-based threshold produces linear molecular KSR



$\alpha_{vir} = \frac{5}{3}\frac{\sigma_{tot}^2 R}{GM}$ = 10

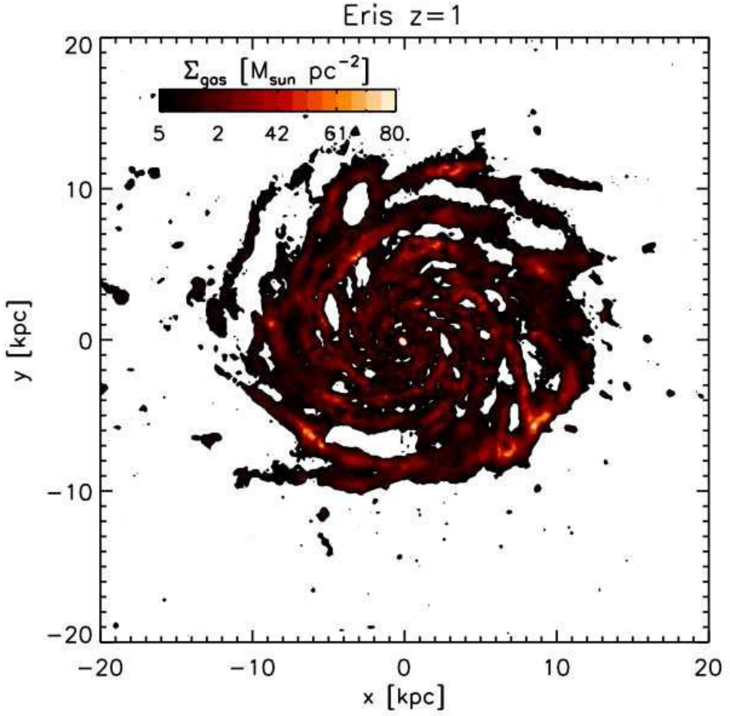


Feedback effects are highly sensitive to whether stars are forming throughout ISM or in high-density regions

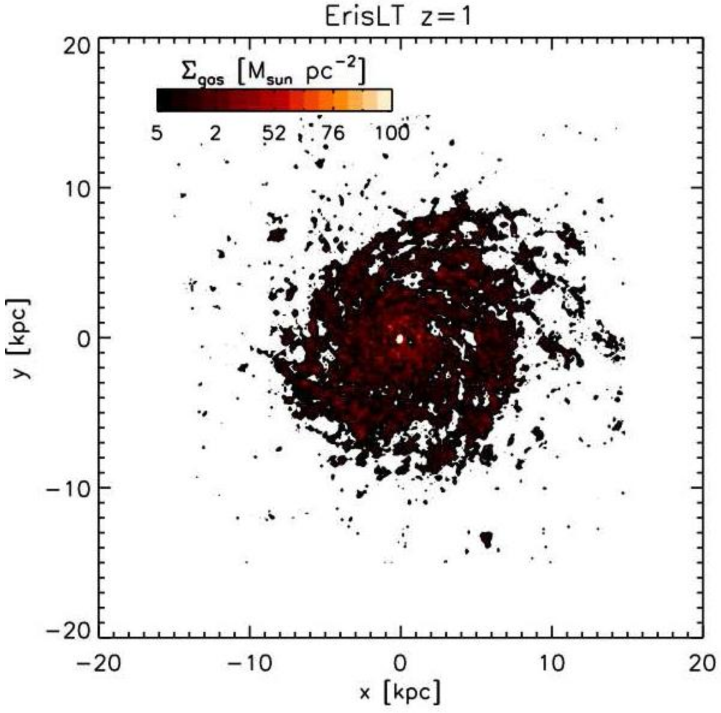
Governato et al 2010; Guedes et al. 2011

cold gas distribution in two simulations from identical initial conditions

this simulation forms stars at densities $n>5\ cm^{-3}$ -> realistic gas disk



this simulation forms stars at densities $n>0.1\ cm^{-3}$ -> small disk, little gas



What does pushing to higher resolution give us?

Di Cintio et al. 2014, Chan et al. 2015, Tollet et al. 2016

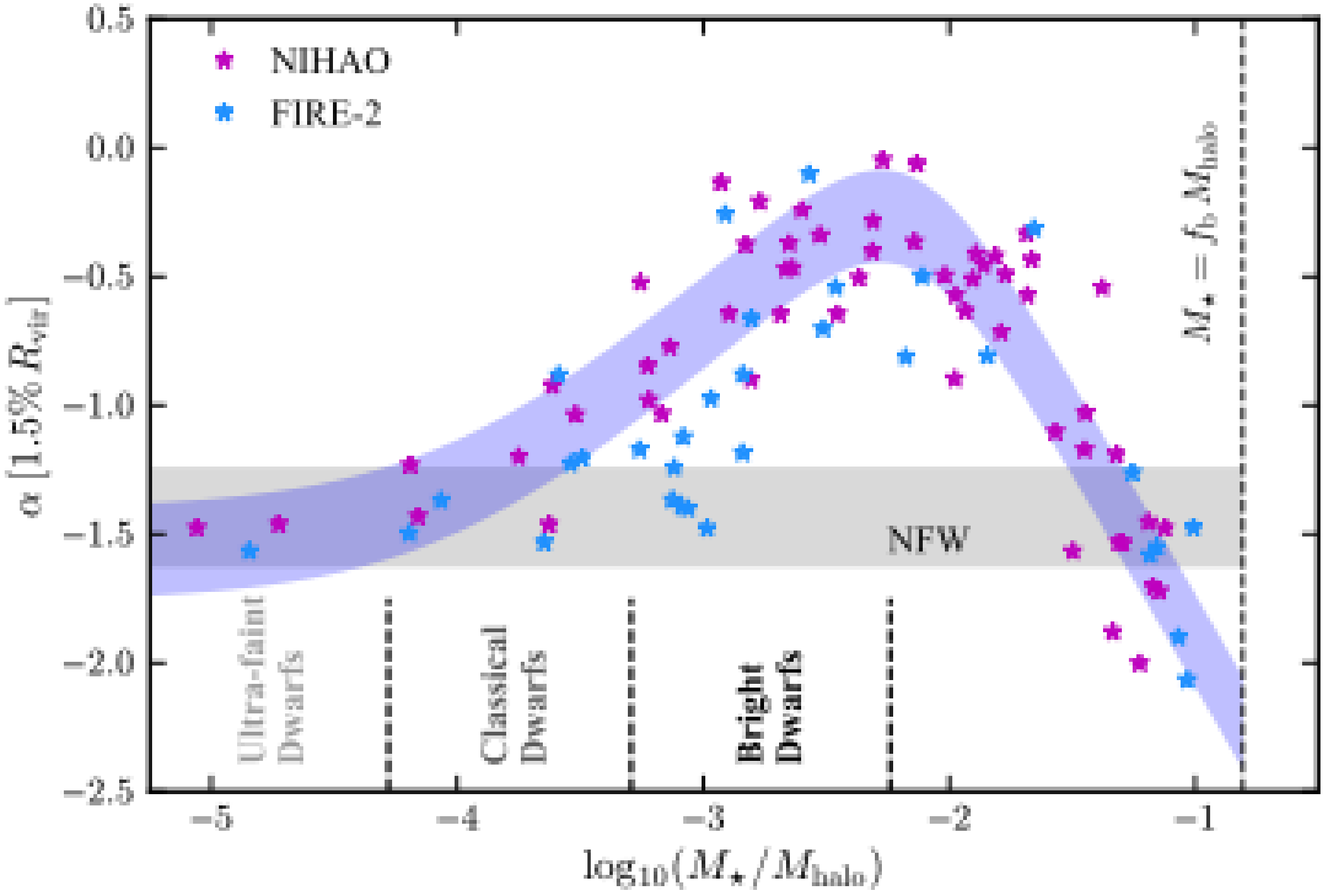
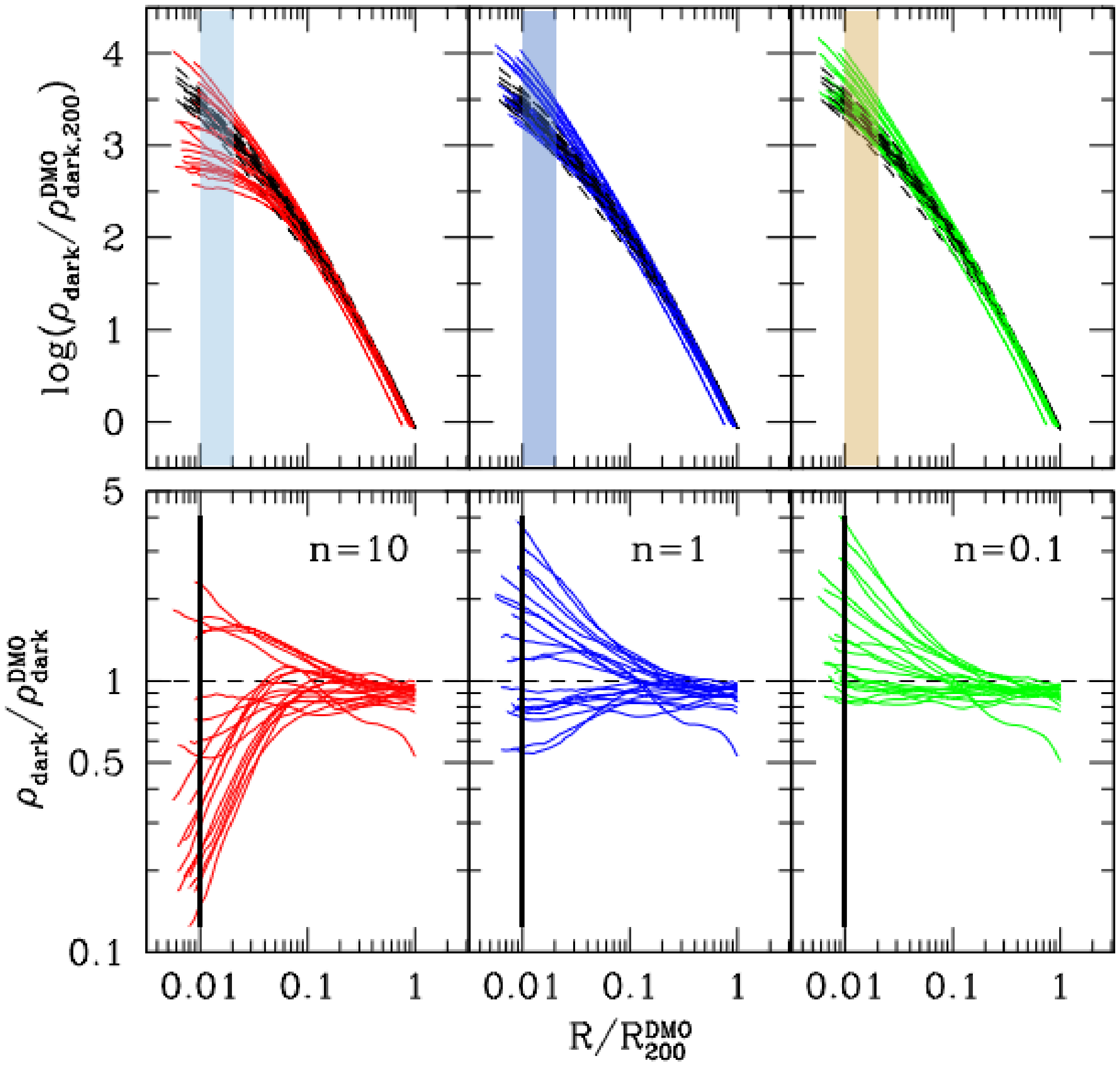


figure from Bullock & Boylan-Kolchin 2017, ARAA review

Enclosed Dark Matter Density Profiles

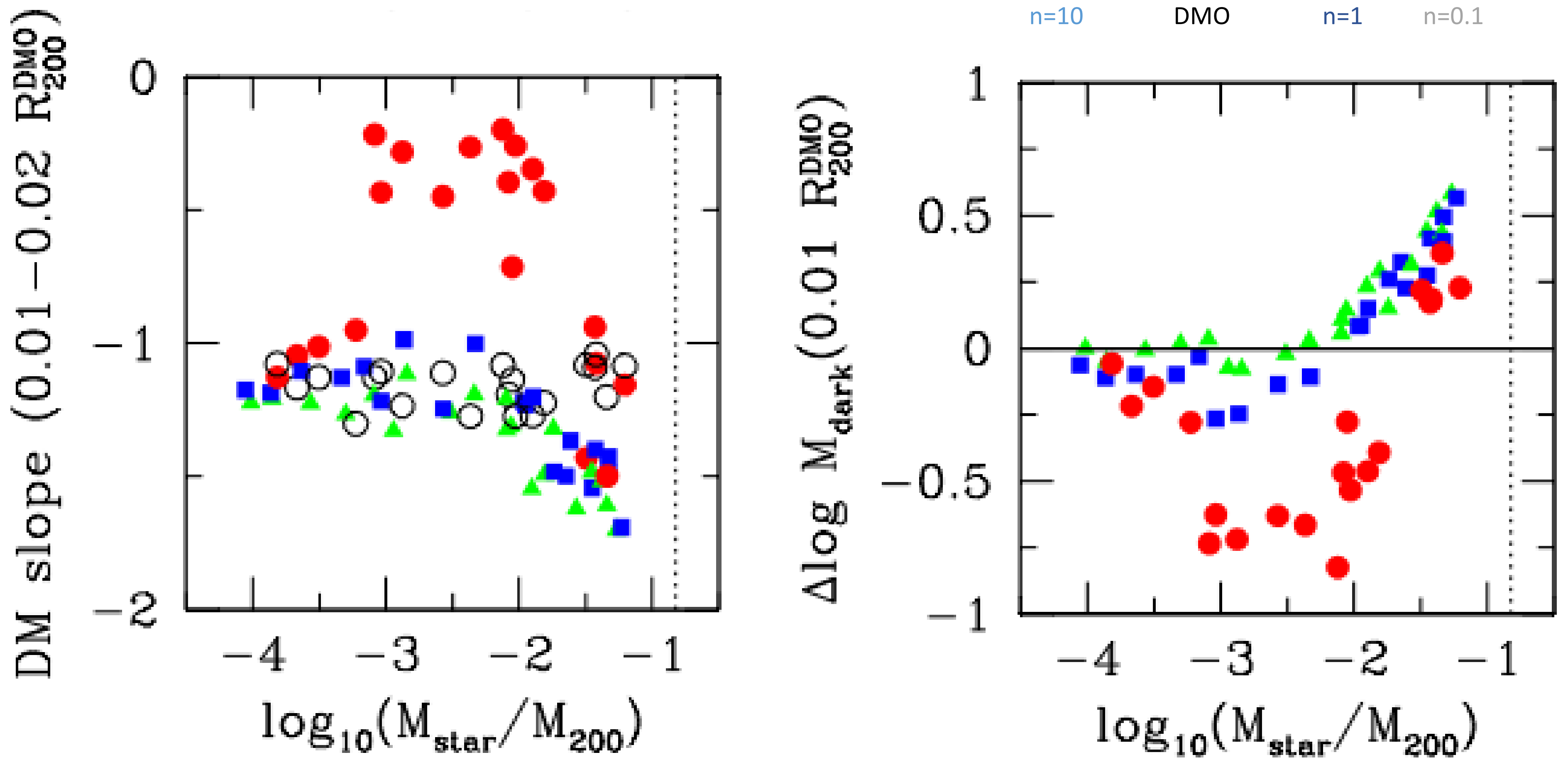


measure
slope between
1 and 2% of R200

measure
mass ratio at
1% of R200

NIHAO XIX - Dutton et al. 2018 (*cf Aaron Dutton's talk on Friday*)

Halo Response



NIHAO XIX - Dutton et al. 2018