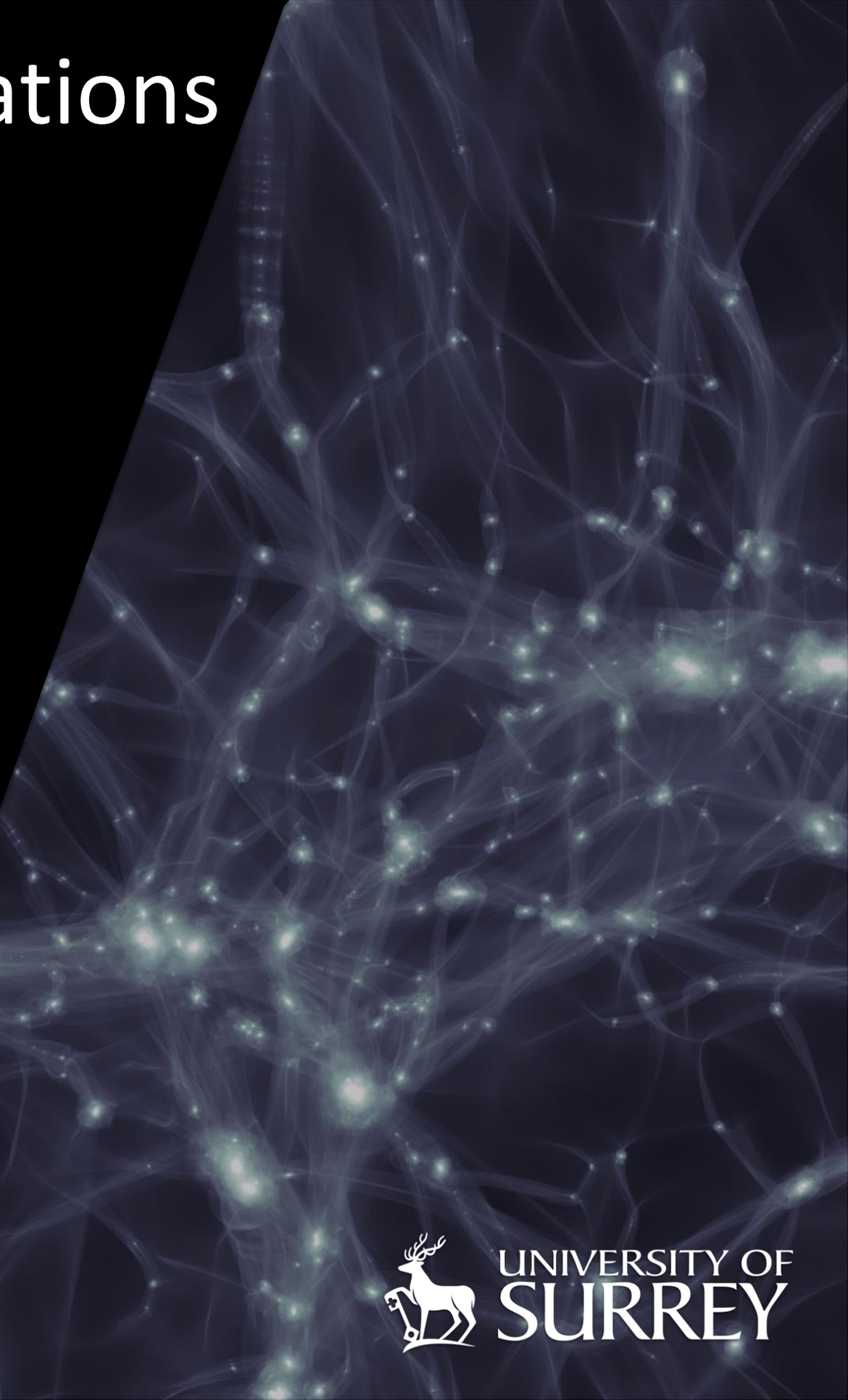
Galaxy formation simulations

for probing the nature of dark matter



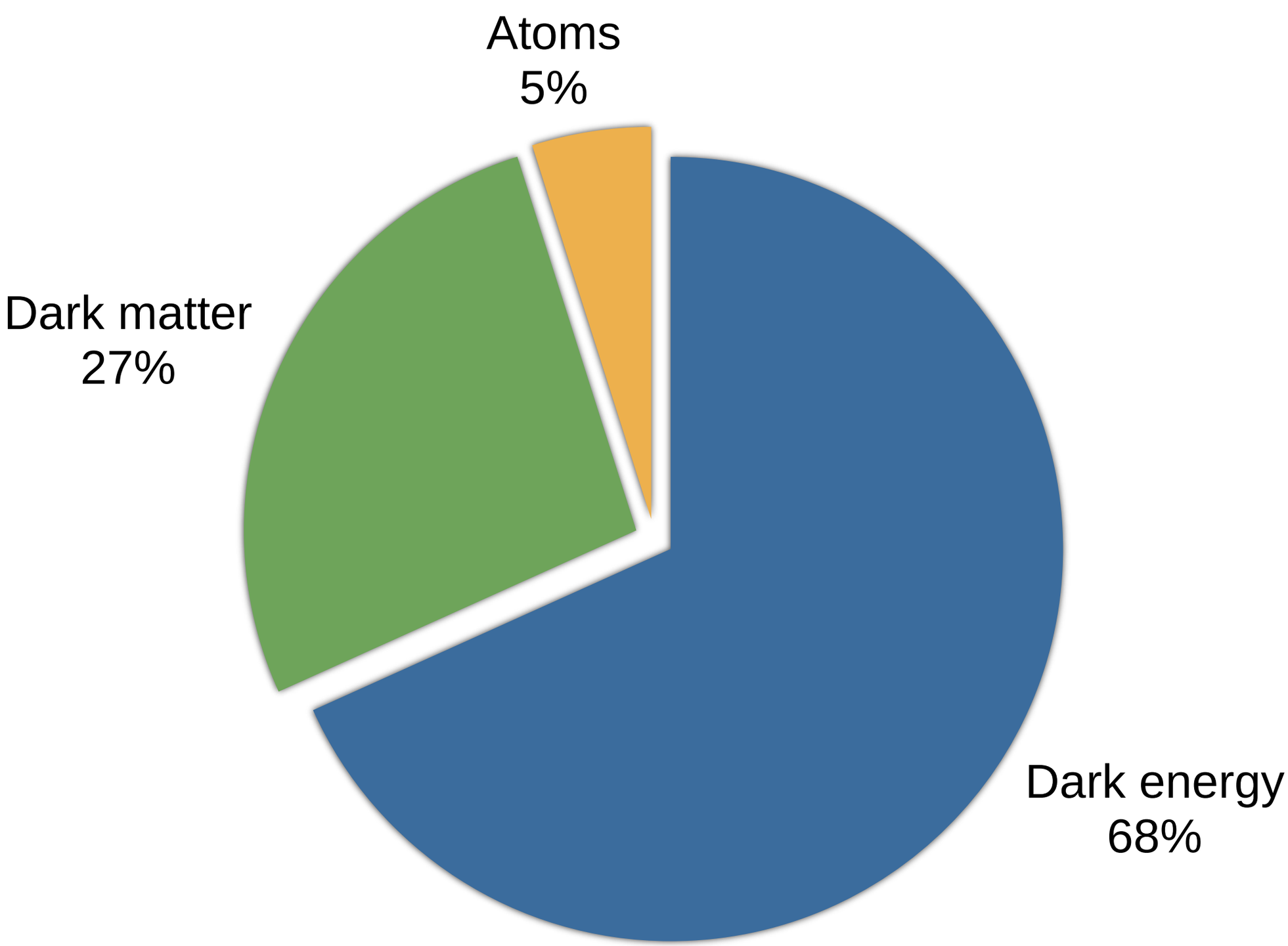
Prof. Justin I. Read

Matthew Walker, Pascal Steger, Oscar Agertz, Michelle Collins, Denis Erkal, Giuliano Iorio, Filippo Fraternali, Alexandra Gregory, Matthew Orkney, Andrew Pontzen, Martin Rey, Stacy Kim, Ethan Taylor, Alex Goater

UNIVERSITY OF SURREY

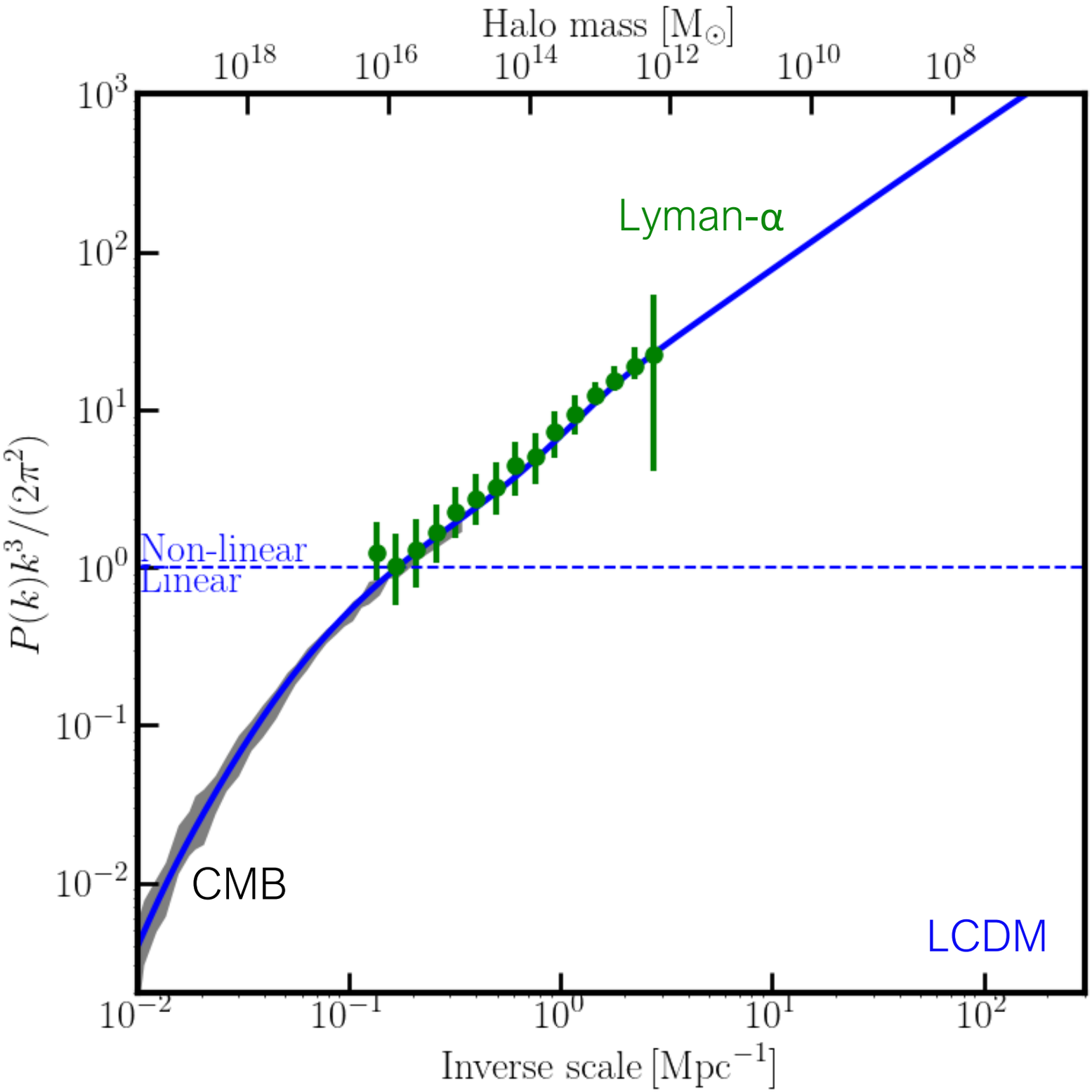
The Standard Cosmological Model

The standard cosmological model



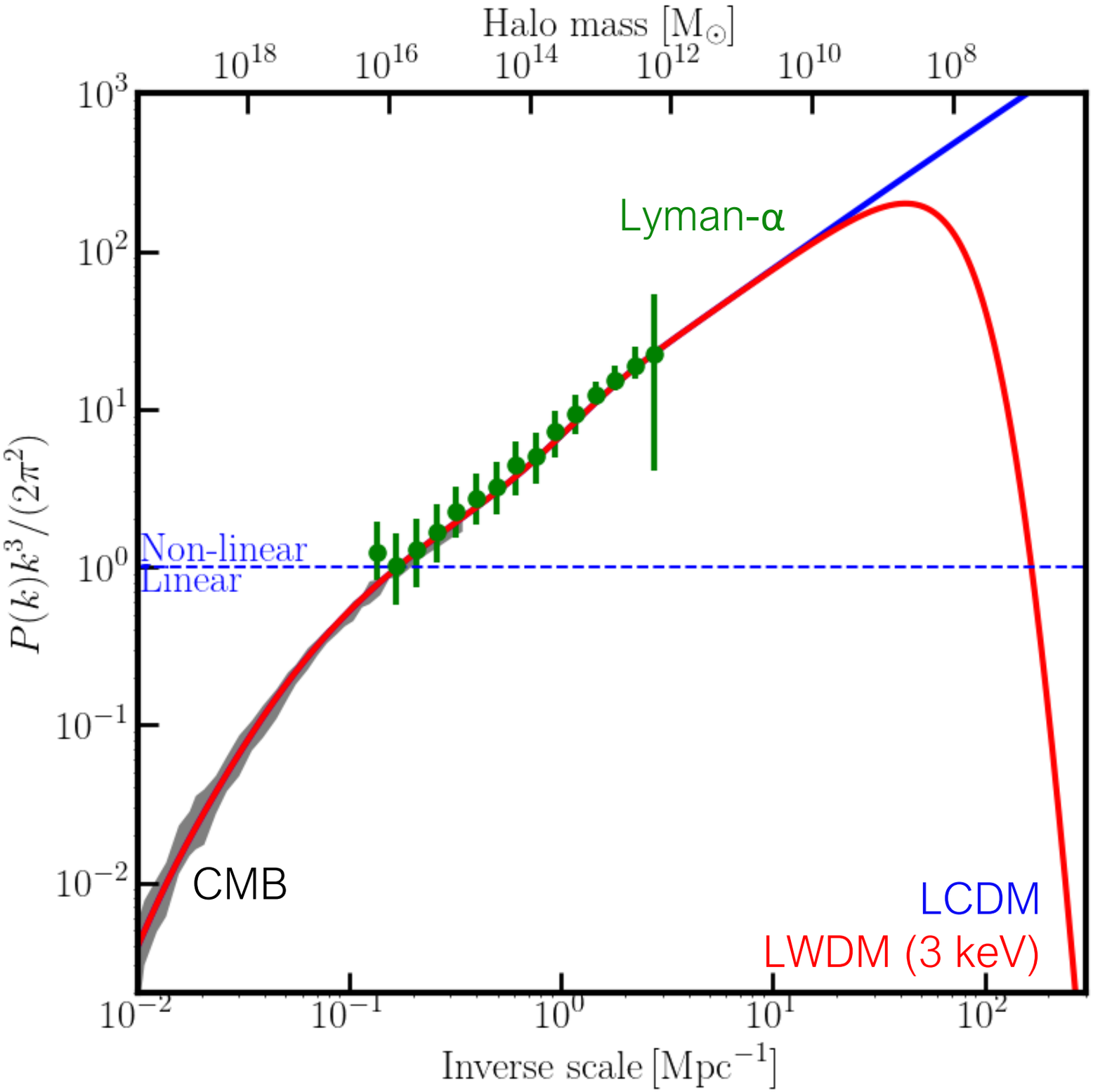
Planck Collaboration 2015

Probing DM with the matter power spectrum



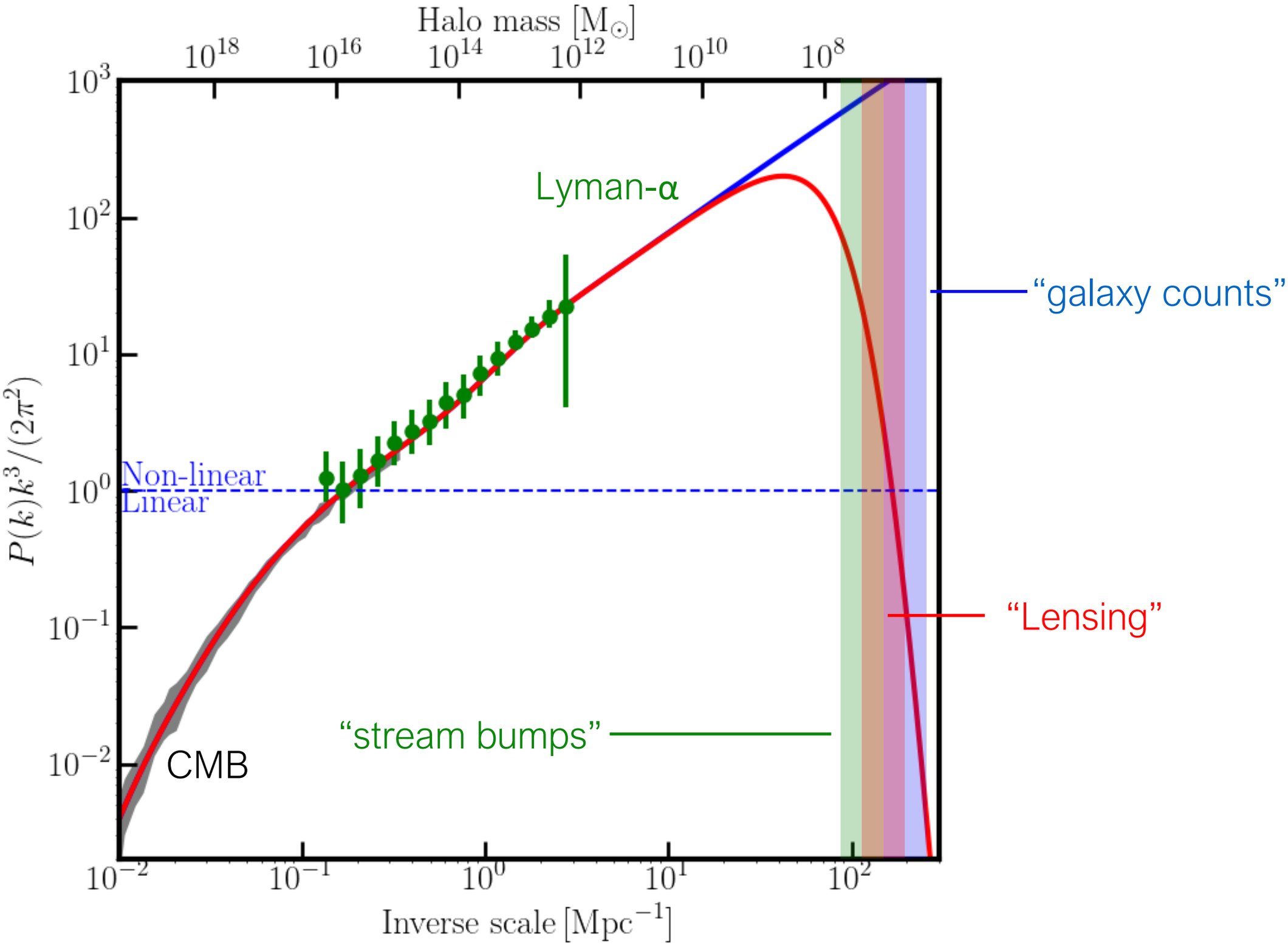
Planck Collaboration 2015; Zaroubi et al. 2006

Probing DM with the matter power spectrum



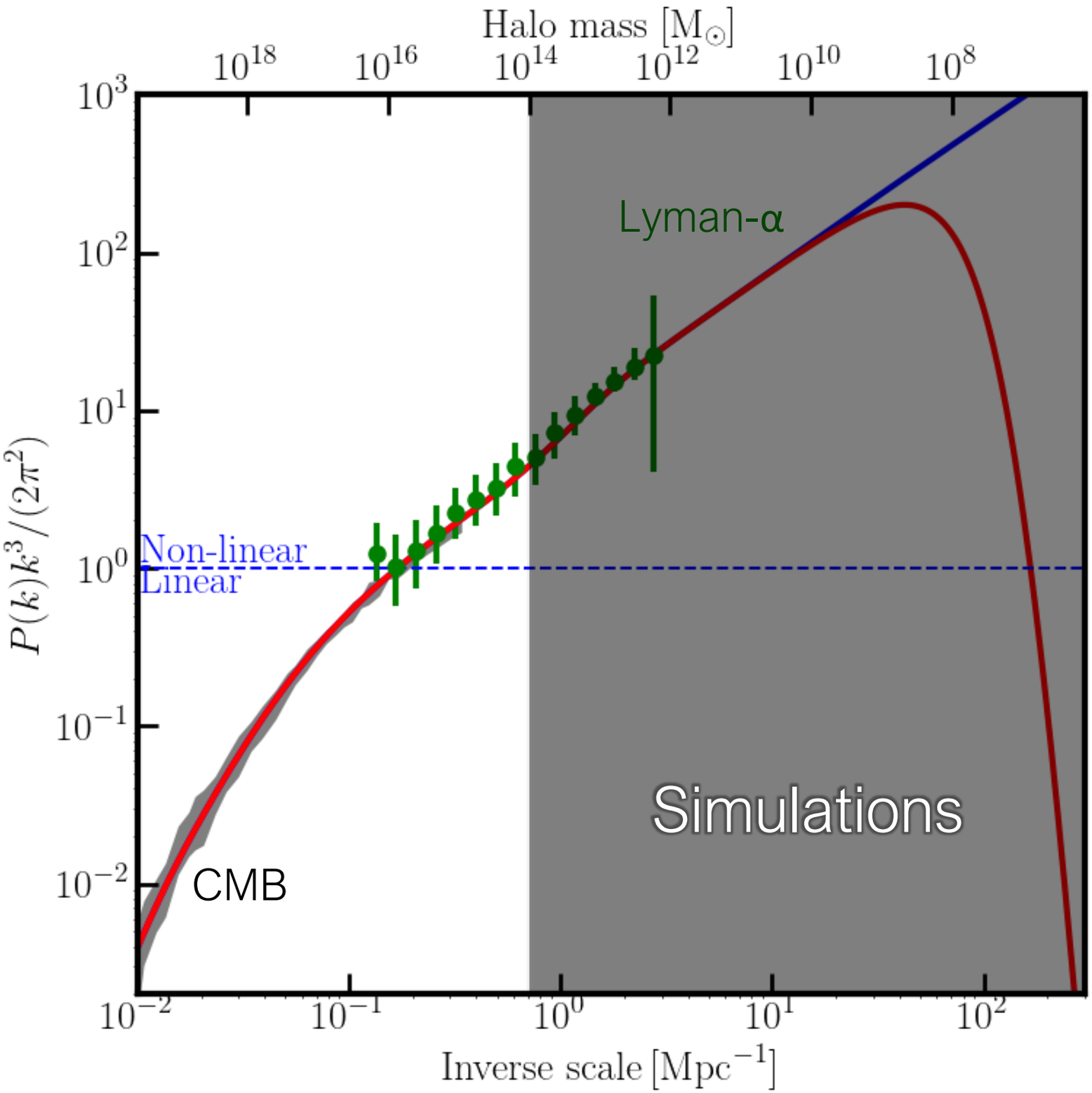
Zaroubi et al. 2006; Movie credit: Andrew Pontzen

Probing DM with the matter power spectrum



Banik et al. 2019; Hsueh et al. 2019; Gilman et al. 2020; Newton et al. 2020; Nadler et al. 2020

Probing DM with the matter power spectrum



Banik et al. 2019; Hsueh et al. 2019; Gilman et al. 2020; Newton et al. 2020; Nadler et al. 2020

Pure dark matter simulations

Pure dark matter simulations

Springel et al. 2008

Pure dark matter simulations

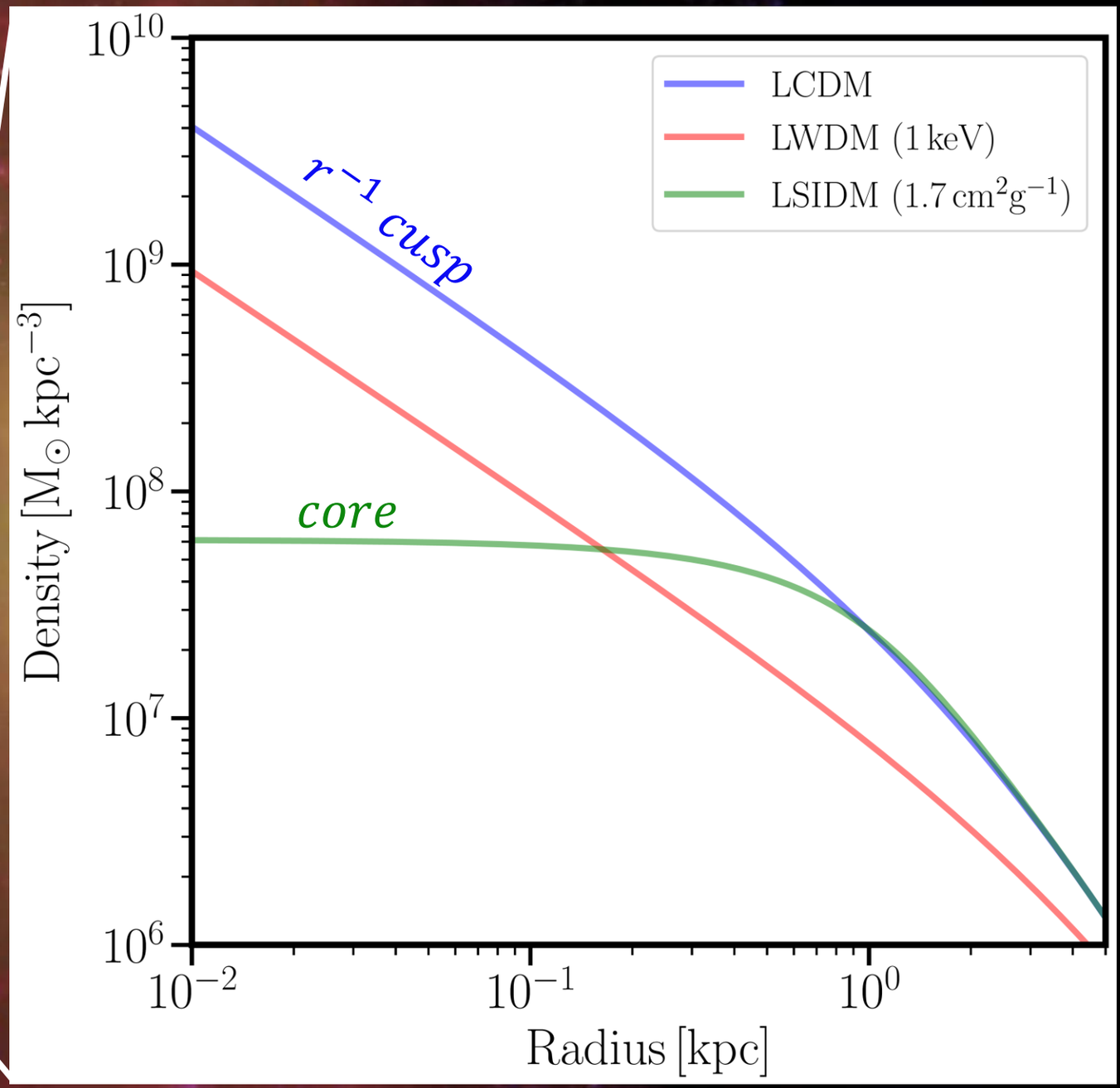
LCDM

Navarro et al. 1996; Schneider et al. 2012; Lovell et al. 2014

Pure dark matter simulations

UNIVERSITY OF SURREY

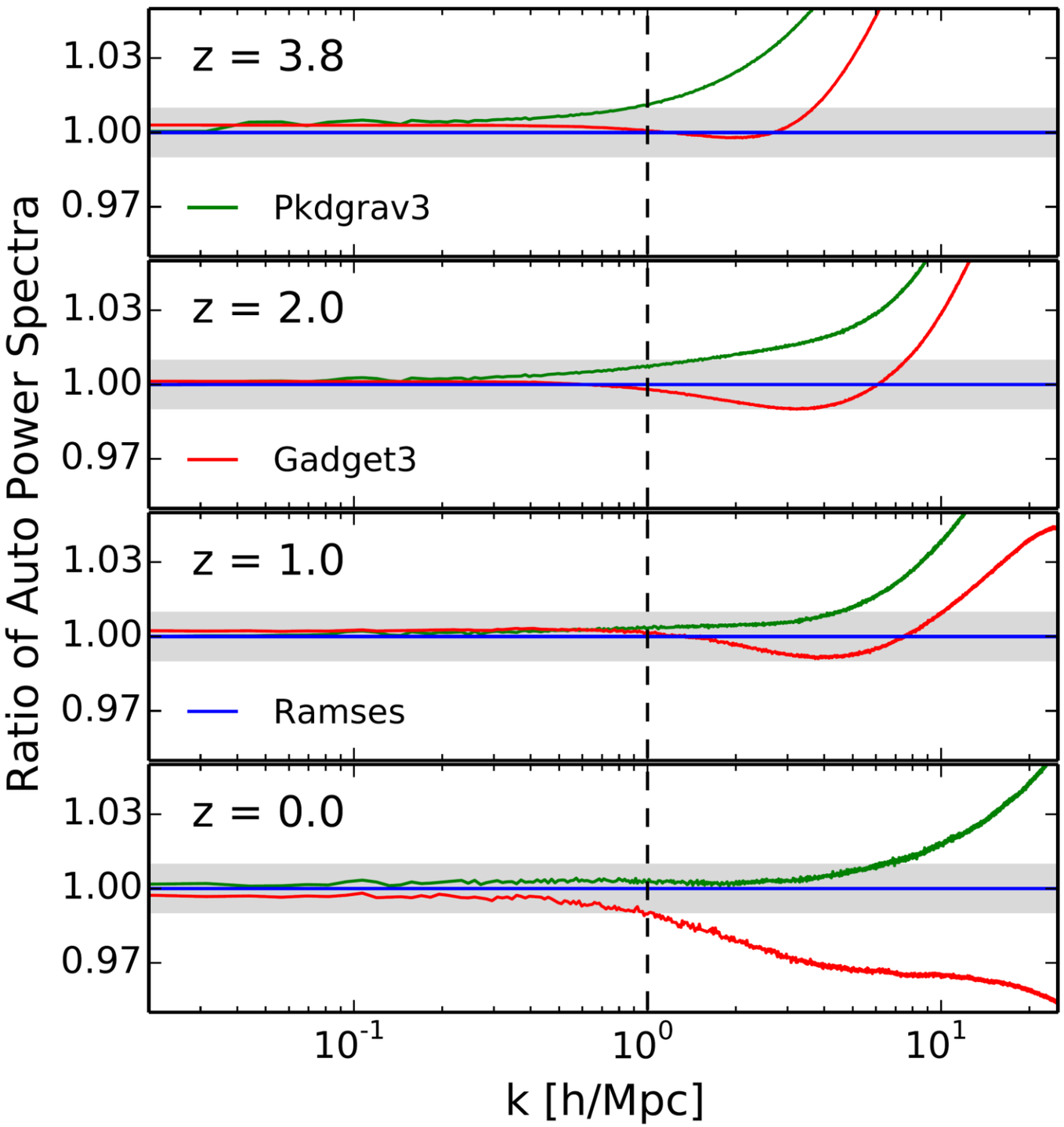
LWDM (1.5 keV)



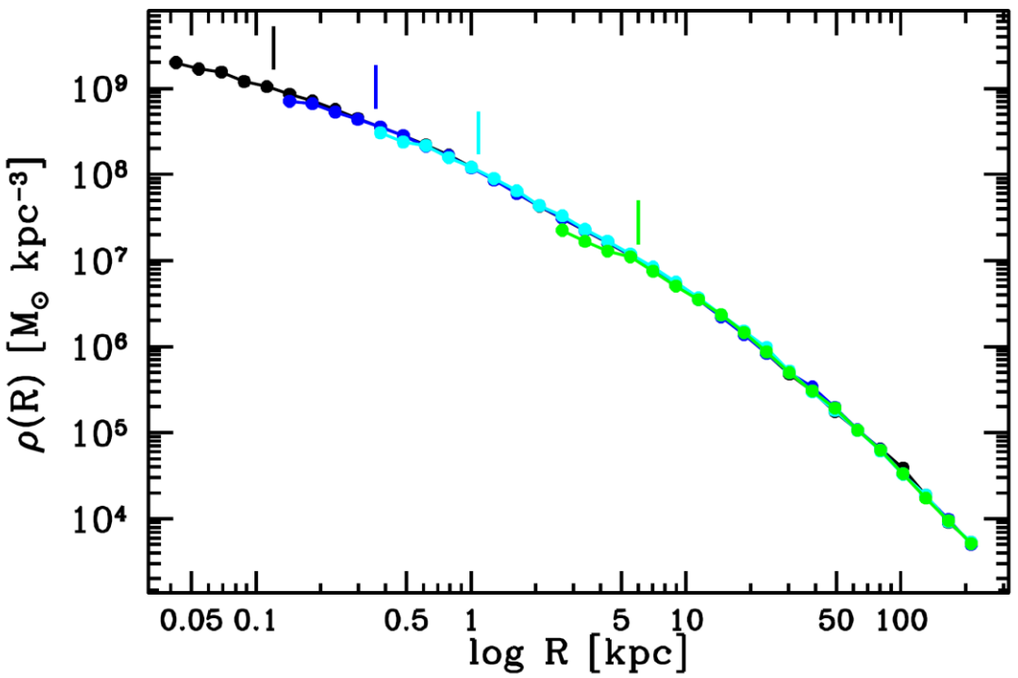
Navarro et al. 1996; Schneider et al. 2012; Lovell et al. 2014

Simulation convergence

Power spectrum



DM halo structure



Schneider et al. 2016; Stadel et al. 2009

Adding Baryons

[galaxy formation]

Why baryons matter

UNIVERSITY OF SURREY

APOSTLE | Sawala et al. 2015; Fattahi et al. 2016

Why baryons matter

Which dark matter halos light up in stars?

Can dark matter be rearranged during galaxy formation?

APOSTLE | Sawala et al. 2015; Fattahi et al. 2016

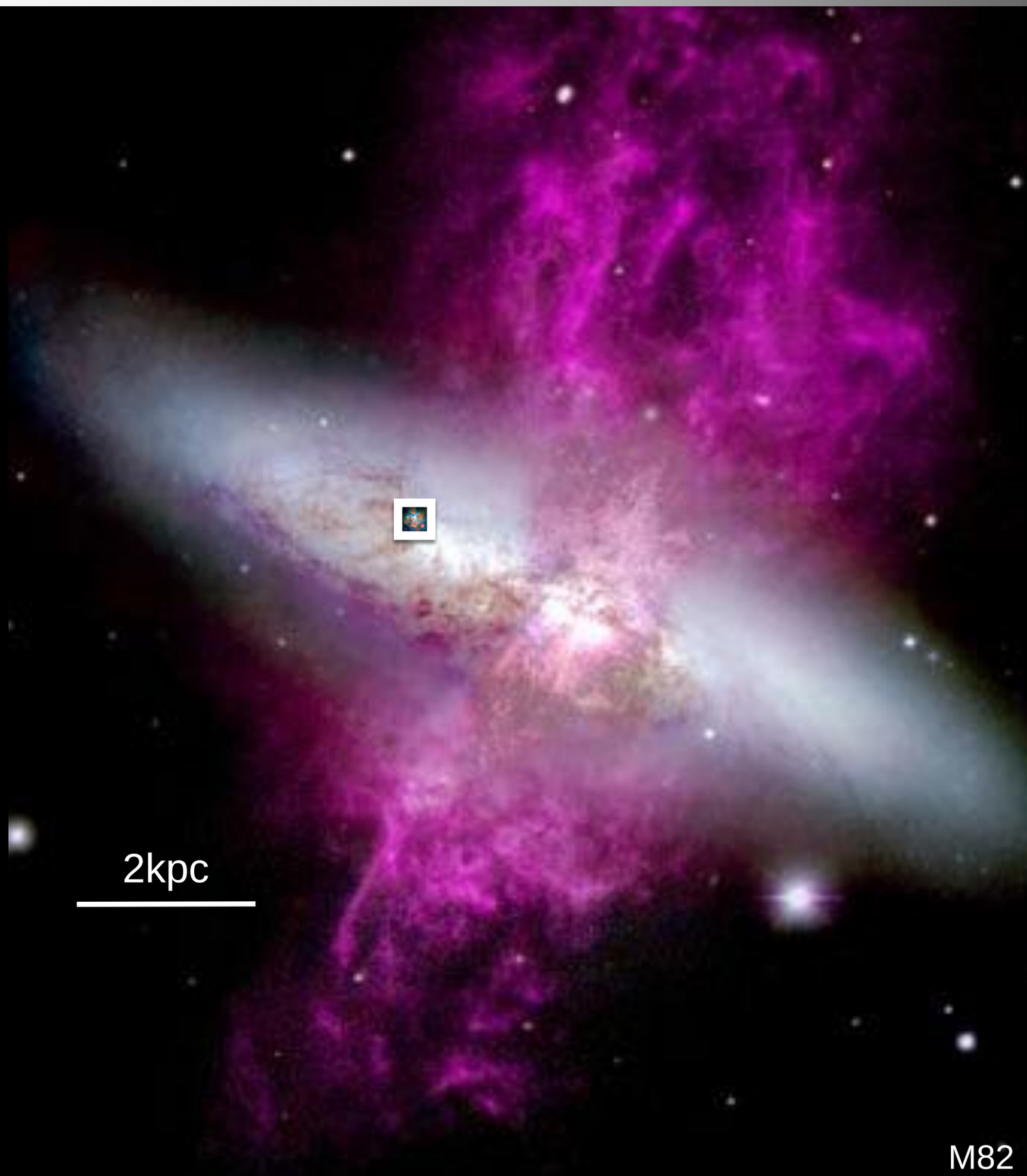
The challenge of adding baryons

Illustris TNG-100 | Pillepich et al. 2017

The challenge of adding baryons

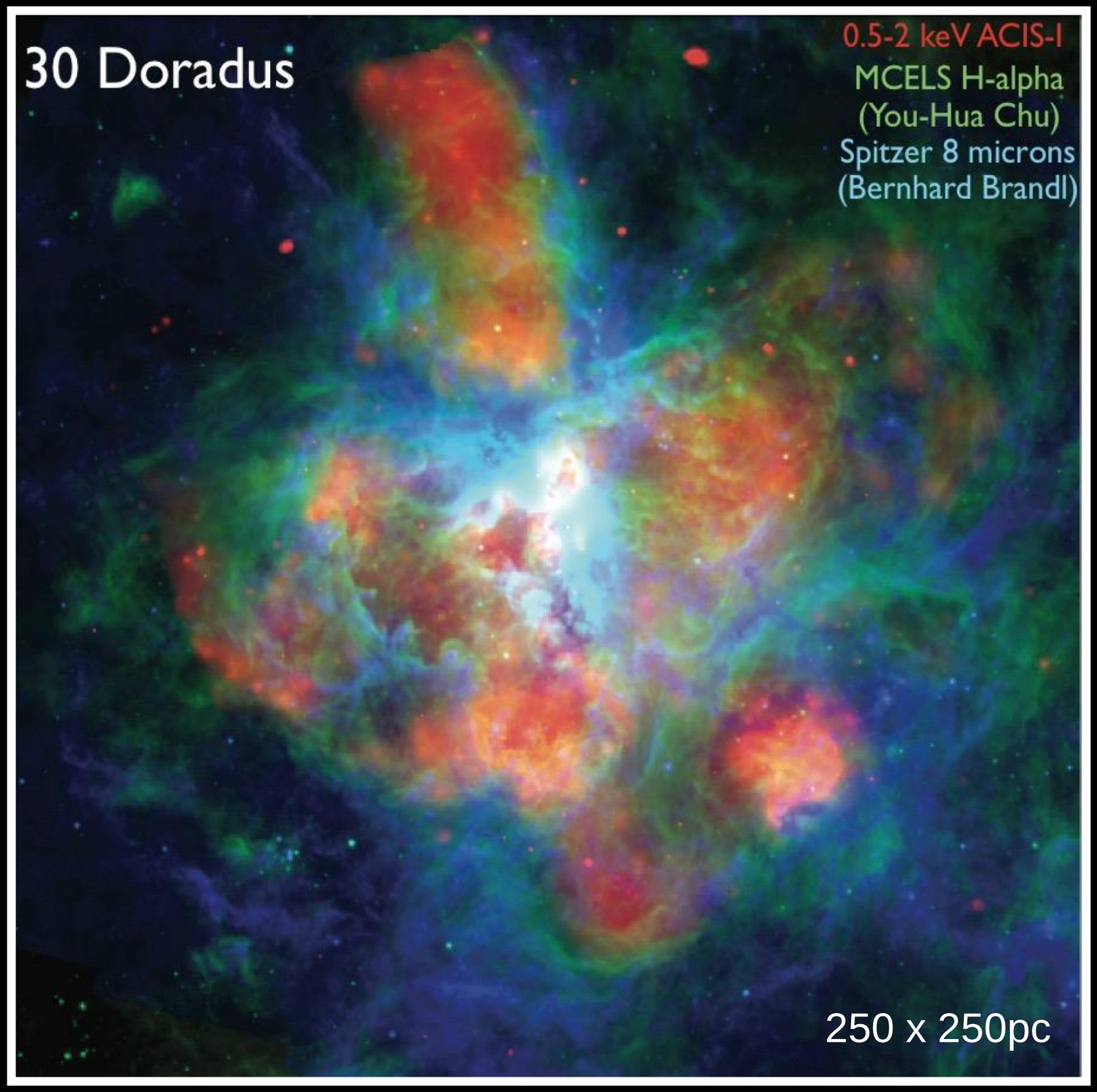
M82 | Westmoquette et al. 2009

The challenge of adding baryons



M82 | Westmoquette et al. 2009

The challenge of adding baryons



30 Doradus star forming region in Large Magellanic Cloud | Townsley et al. 2006

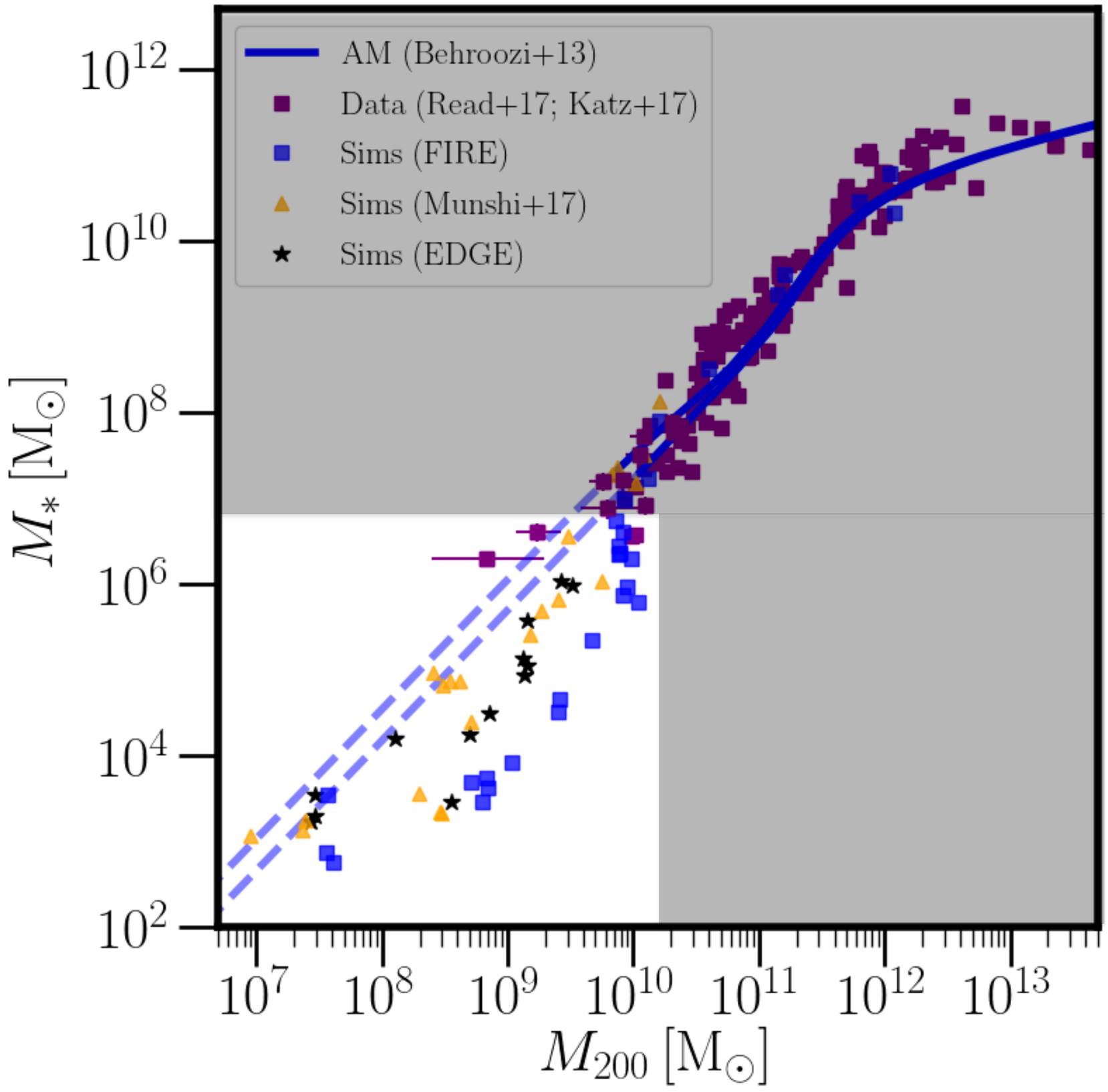
Cosmological “Zoom” Simulations

Cosmological “zoom” simulations

z=23.9

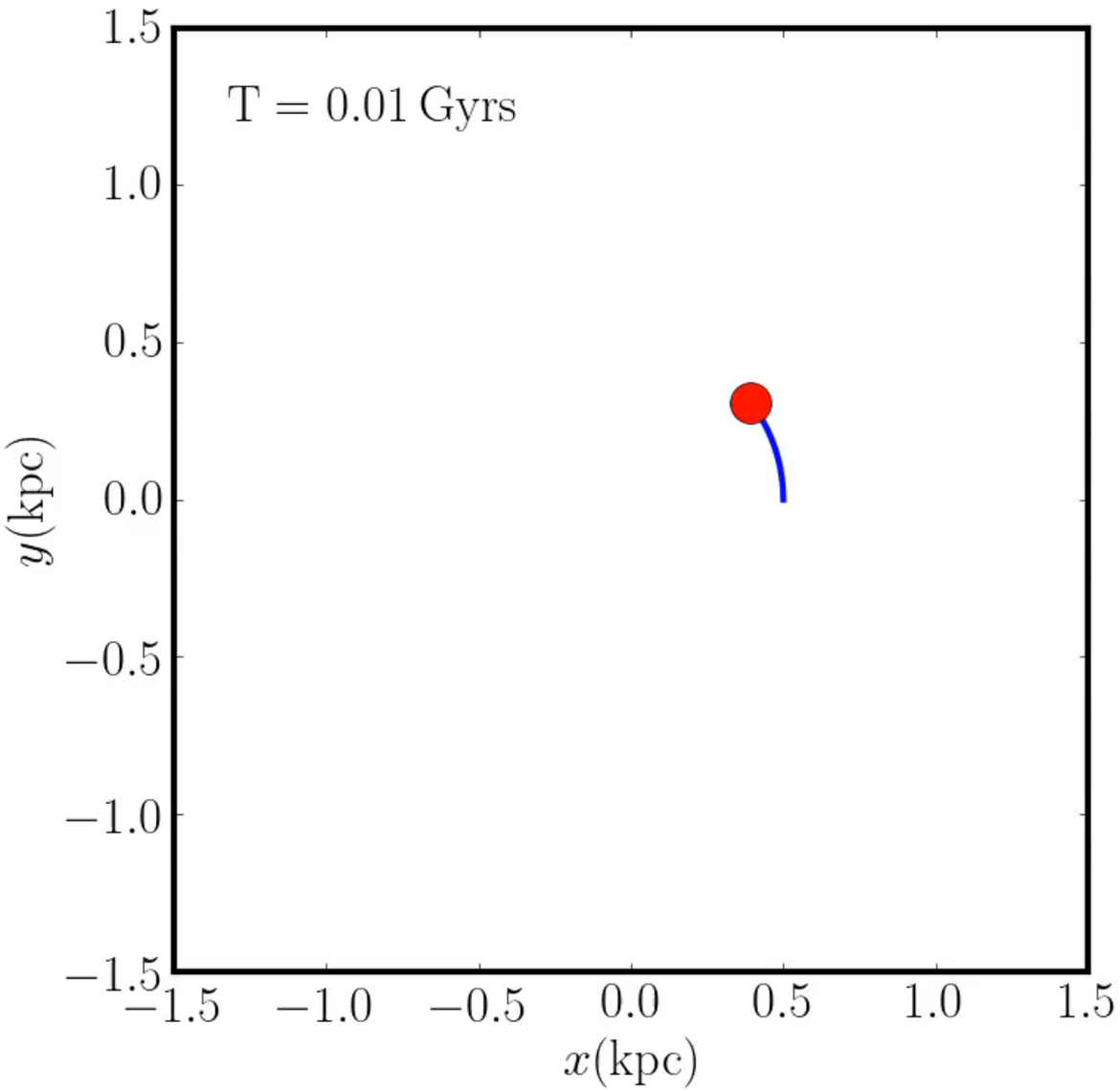
Vintergatan | Agertz et al. 2020

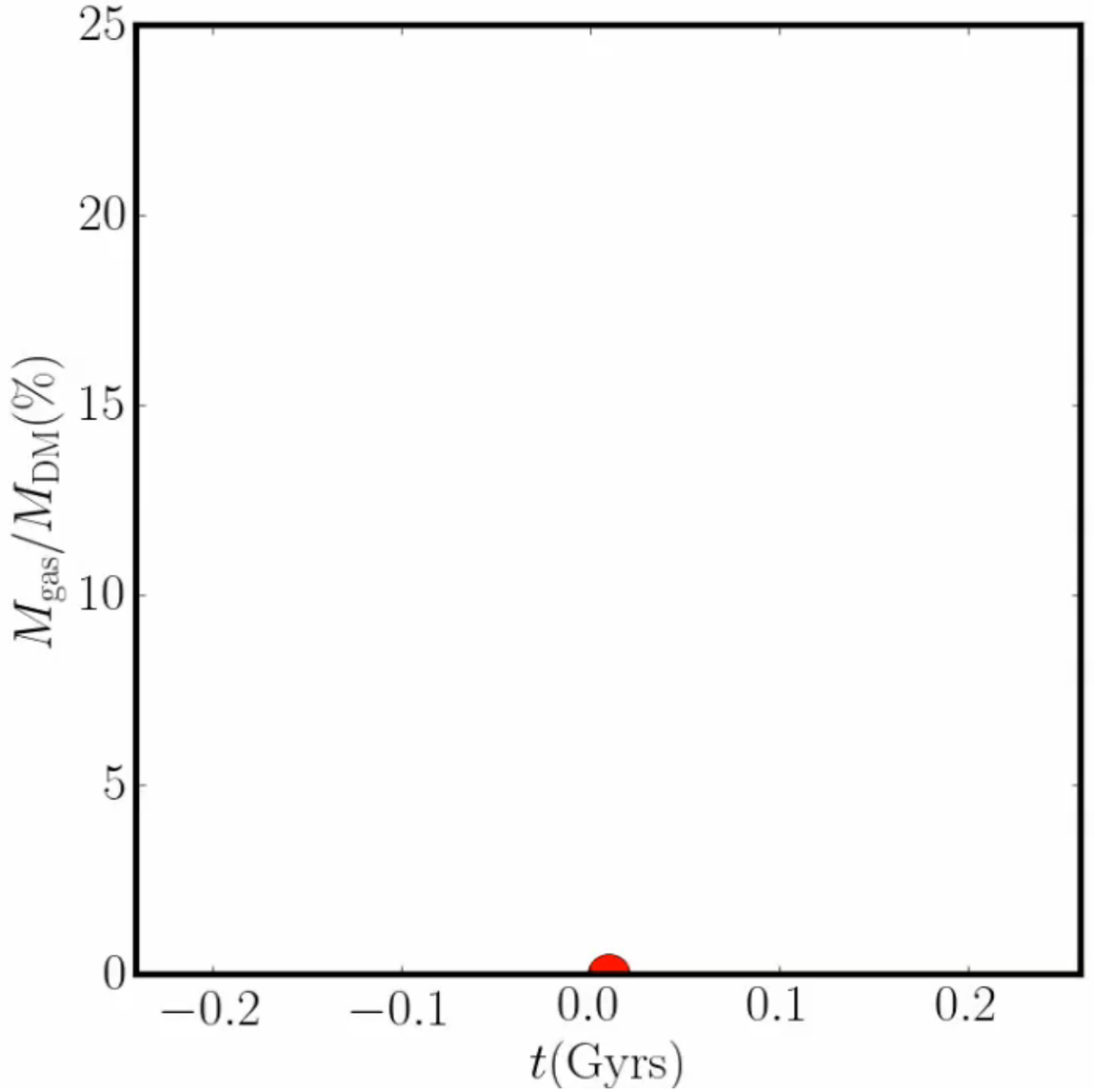
Which halos light up in stars?



Dark Matter Heating

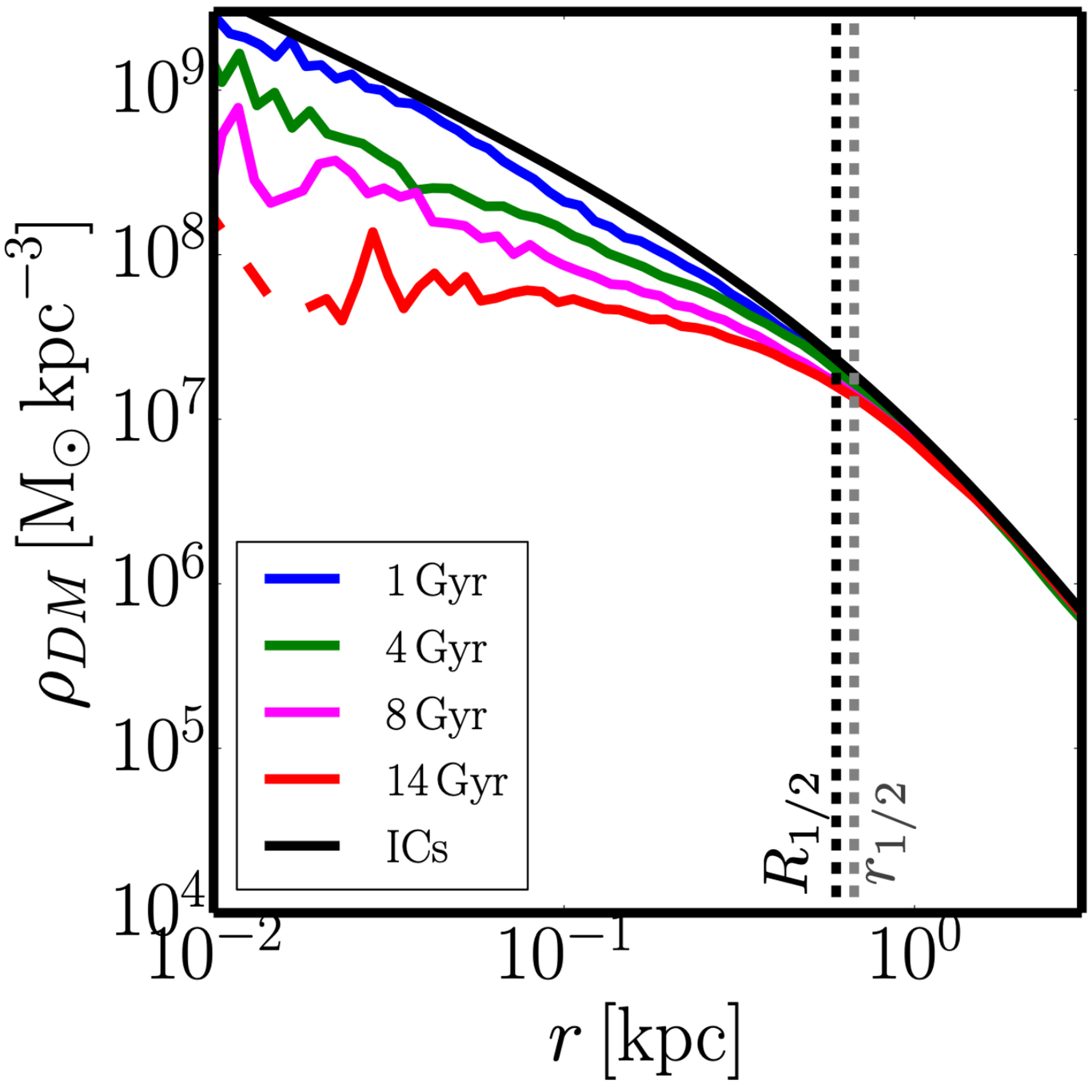
Dark matter heating





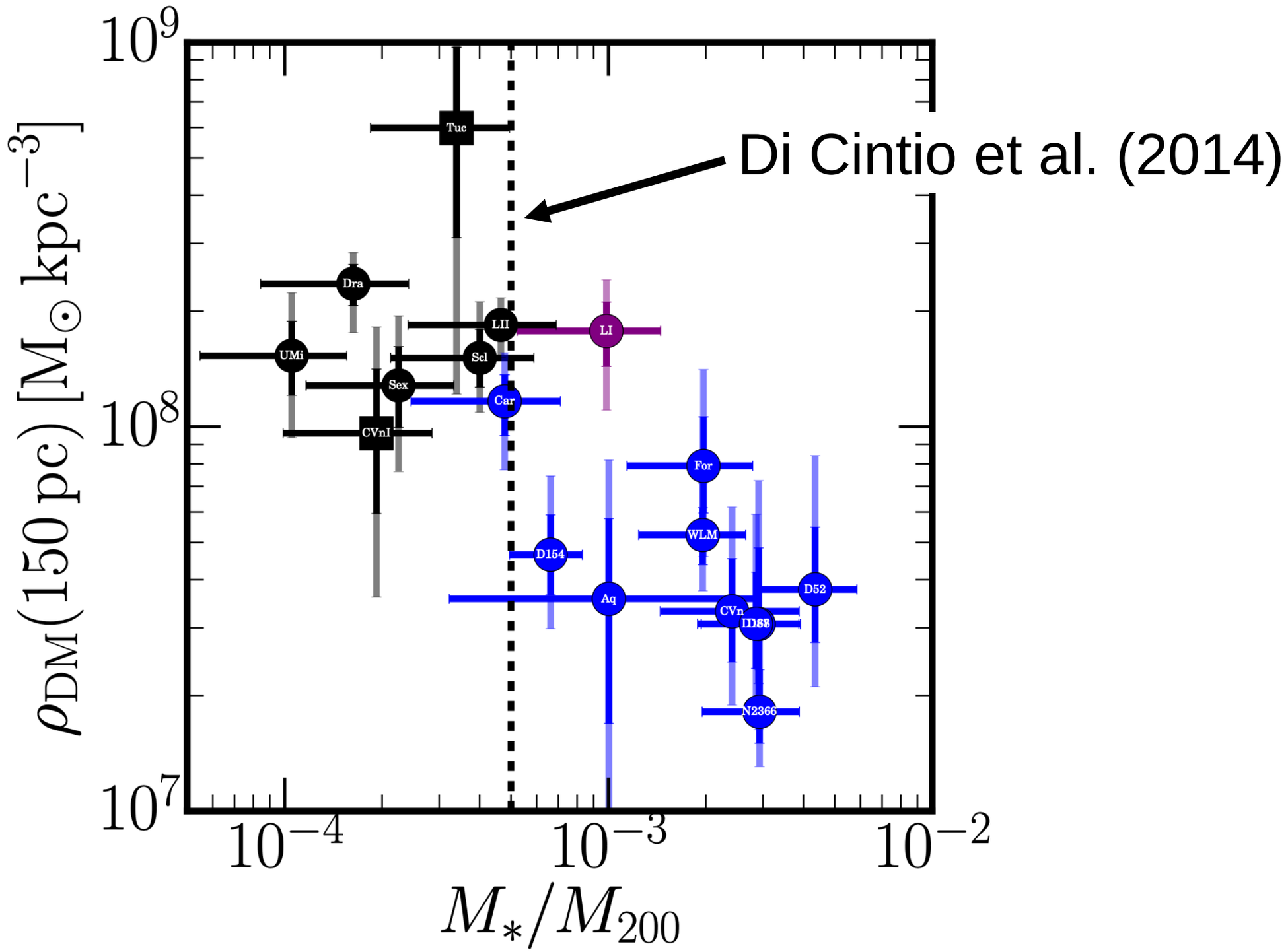
e.g. Navarro et al. 1996; Read & Gilmore 2005; Pontzen & Governato 2012; Read et al. 2016

Dark matter heating



Read et al. 2016

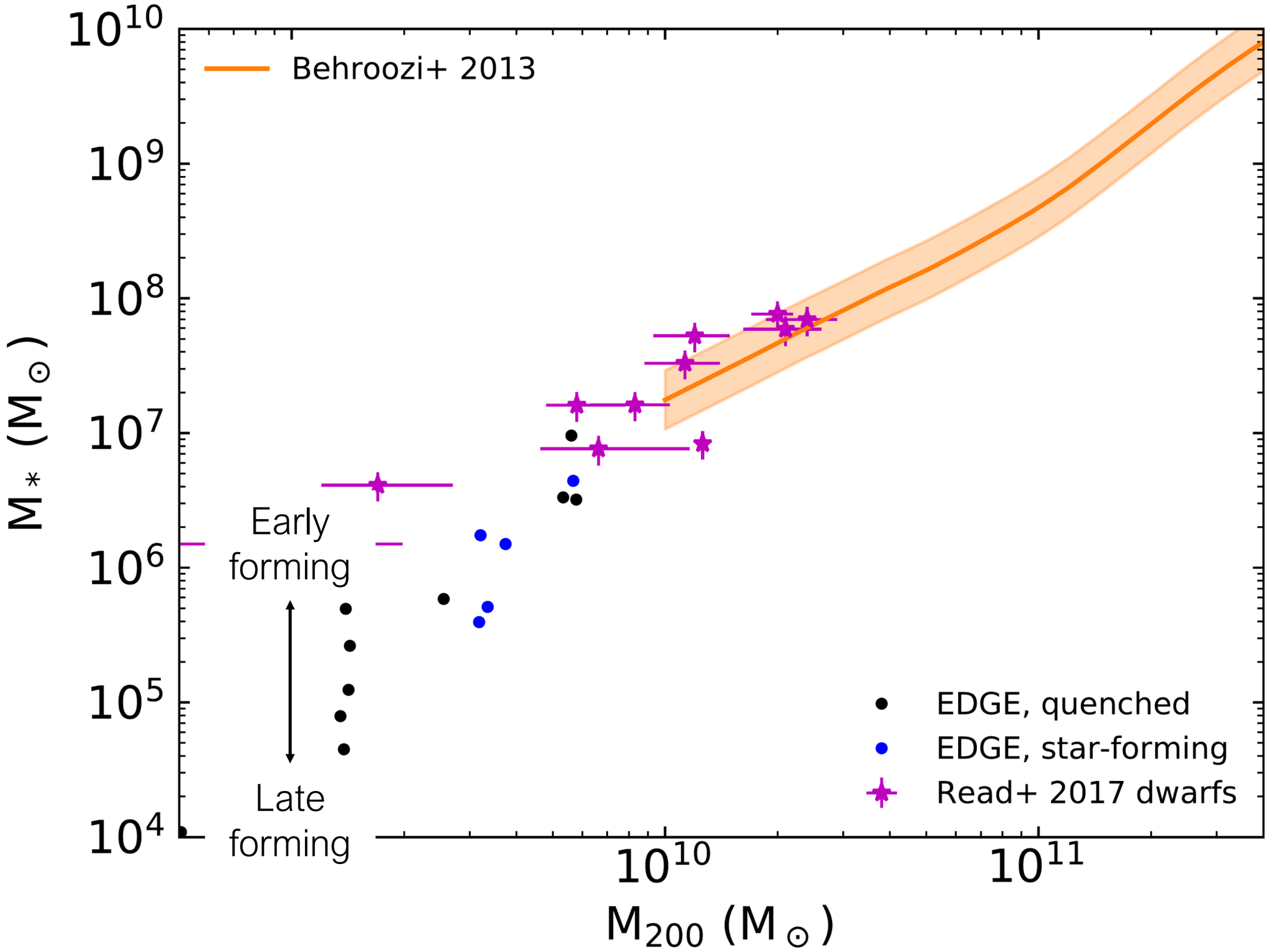
Does dark matter heating actually occur?



Read et al. 2019

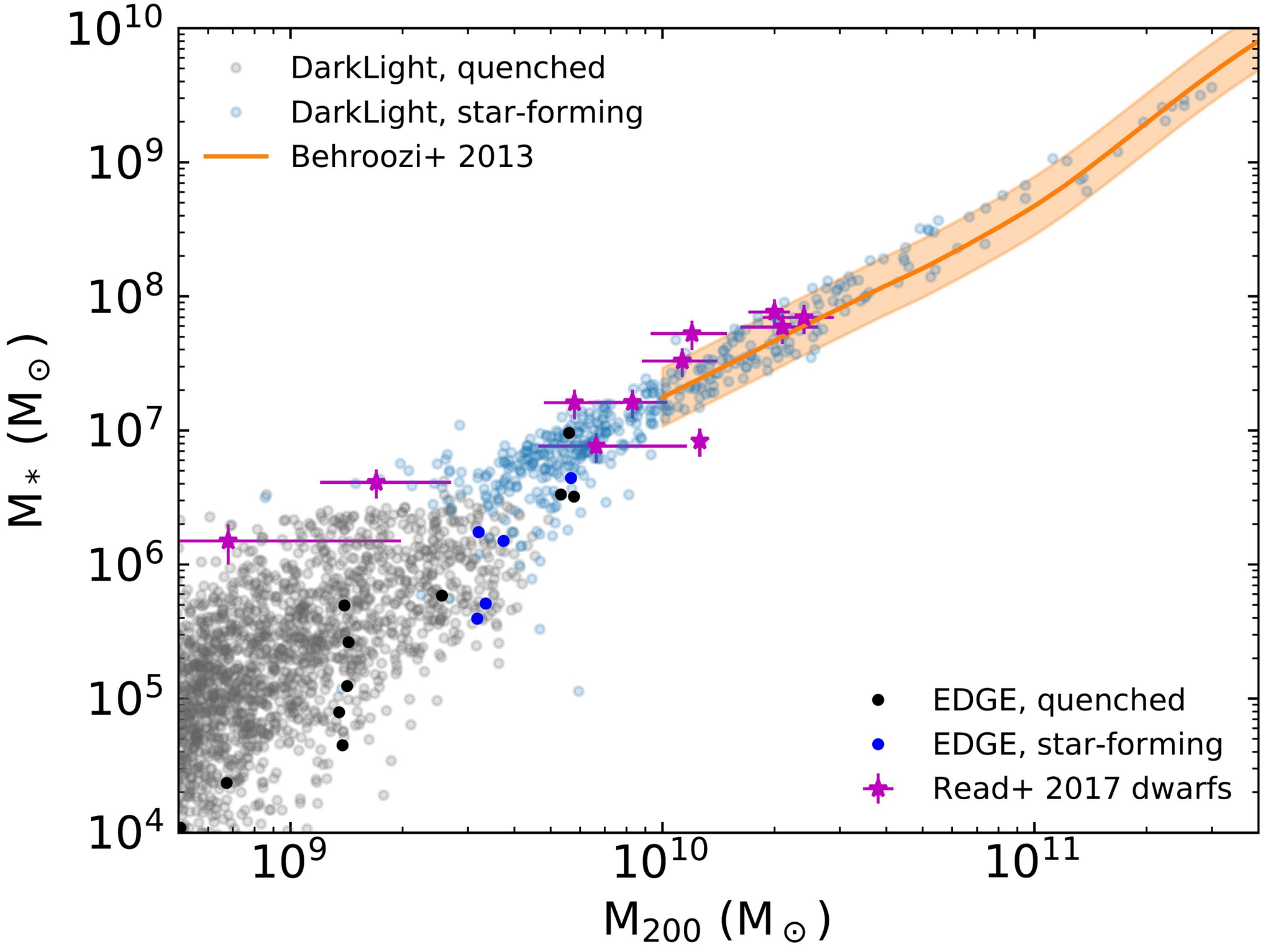
The future

The future



Kim et al. 2021, in prep.

The future



Kim et al. 2021, in prep.

Conclusions

Conclusions

- Pure dark matter cosmological simulations are well understood and produce converged results at ~3% accuracy in non-linear regime.

- Including “baryons” is hard due to the enormous dynamic range in space and time. Nonetheless, most simulations have now converged on the observed stellar mass-to-halo mass relation above a halo mass of ~10^{10} solar masses.

- At lower masses (where models are most sensitive to the nature of dark matter), there remain significant differences between groups on the stellar mass-to-halo mass relation and other predicted galaxy properties.

- There is mounting observational evidence that on these small scales dark matter has its inner density lowered by repeated gas flows (“dark matter heating”).

- New techniques can “learn” from a small number of high fidelity simulations. Applying these to large volumes will yield robust predictions at the smallest scales.

Justin I. Read