The impact of baryons on dark matter distribution in galaxies

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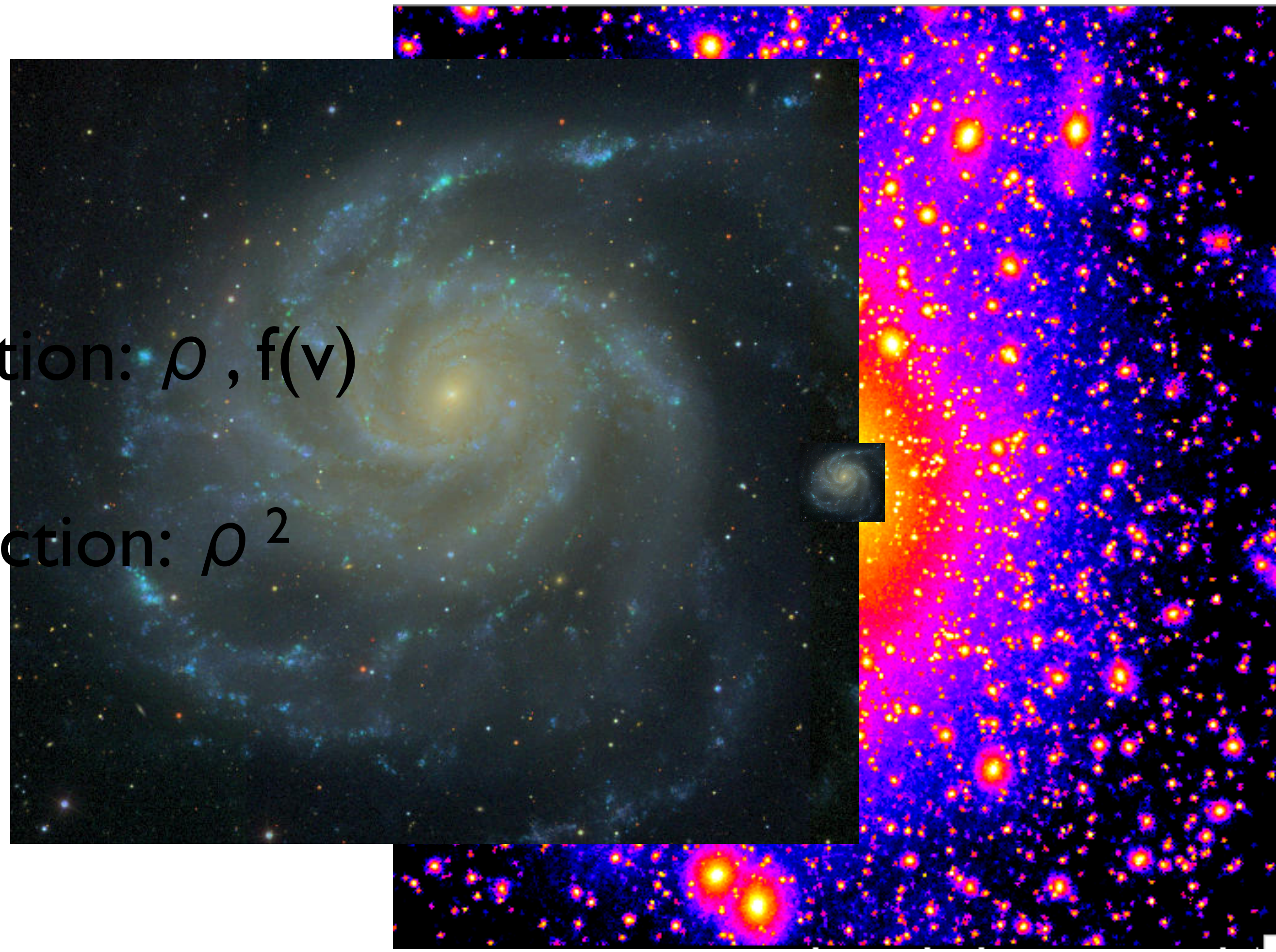
Trieste – April 14th 2015

MAX-PLANCK-GESELLSCHAFT

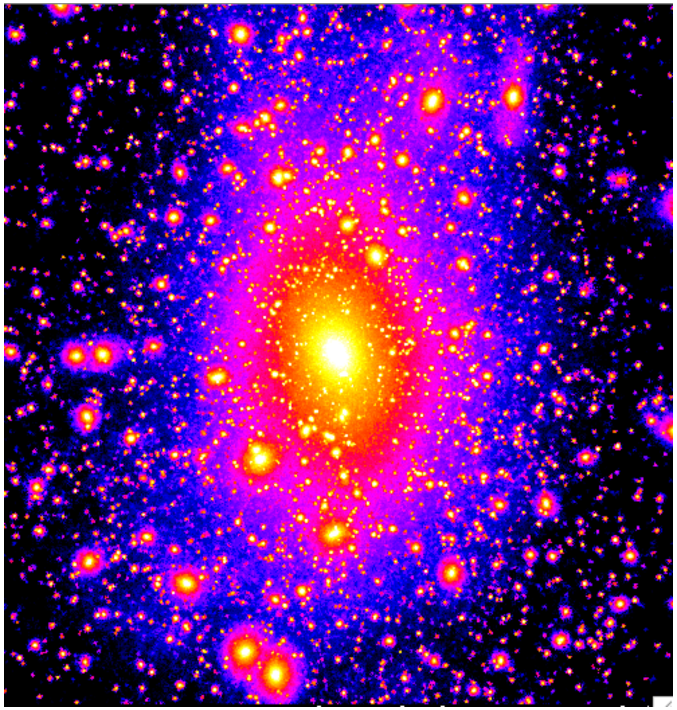
How is Dark Matter distributed around galaxies?

- Direct detection: ρ , f(v)

- Indirect detection: ρ^2

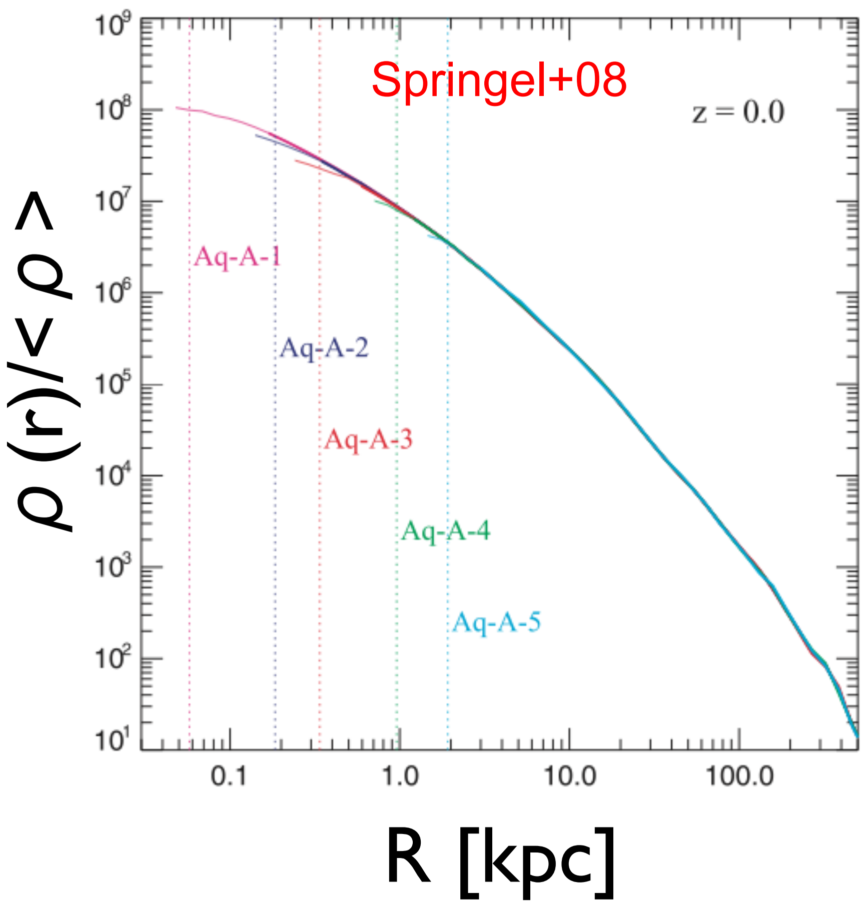


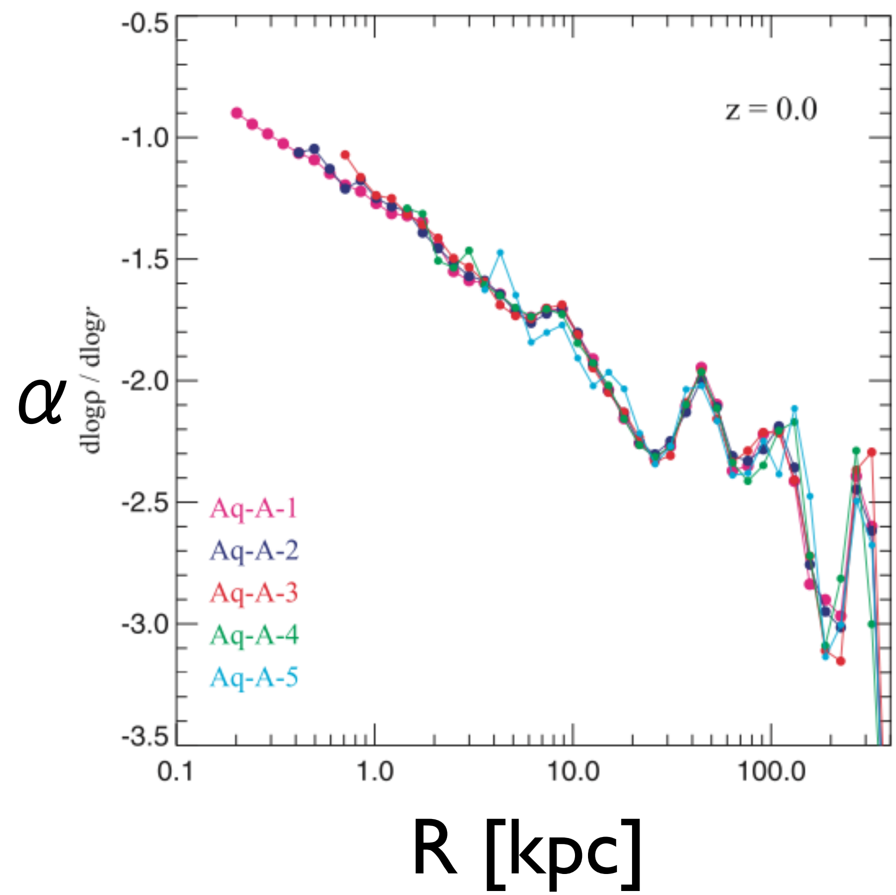
Results from pure gravity simulations



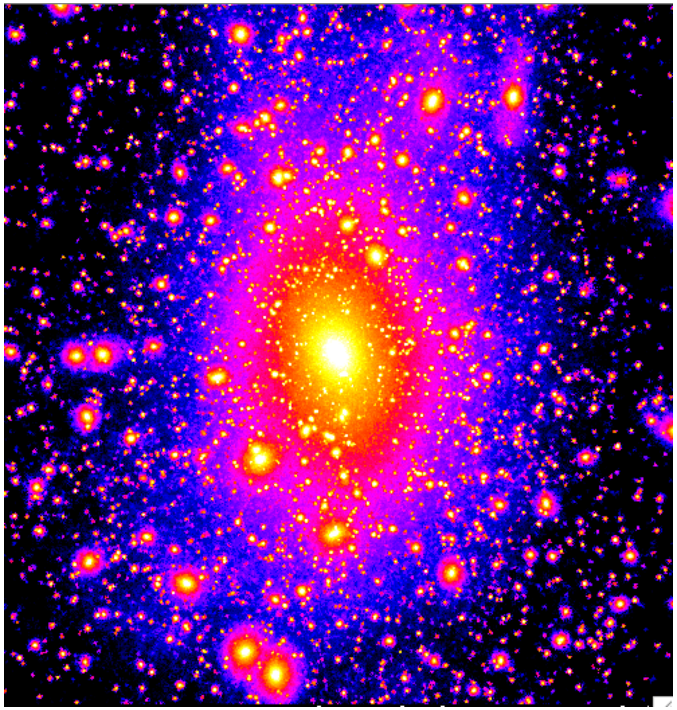
DM has a Universal Profile

DM universal profile





Results from pure gravity simulations



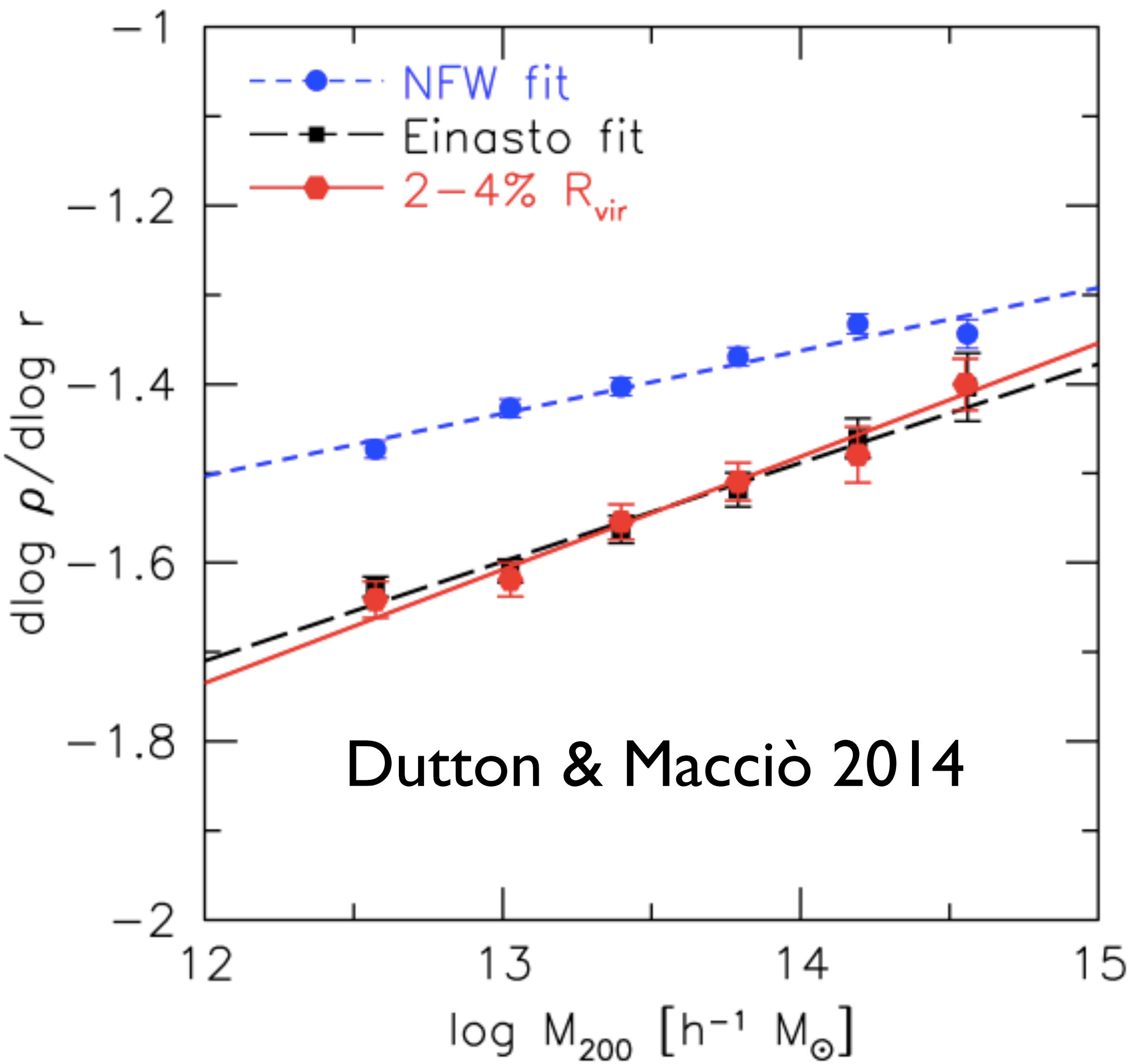
DM has a Universal Profile

$$\frac{\rho_{\rm NFW}(r)}{\rho_{-2}} = \frac{4}{(r/r_{-2})(1+r/r_{-2})^2}$$

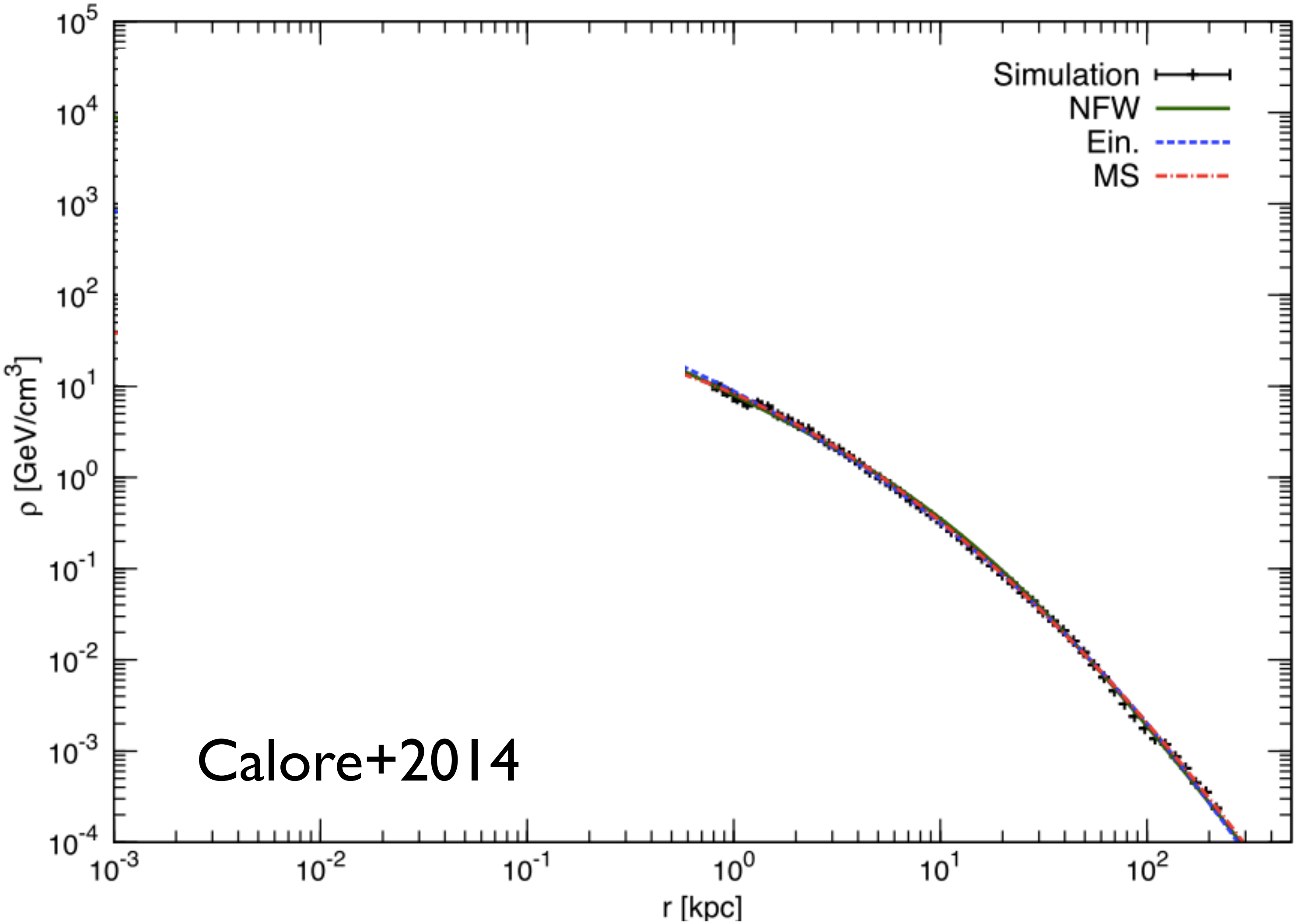
$$\frac{\rho_{\rm EIN}(r)}{\rho_{-2}} = \exp\left\{-\frac{2}{\alpha}\left[(r/r_{-2})^{\alpha}-1\right]\right\}$$

Einasto vs. NFW

$\boxed{\alpha}$

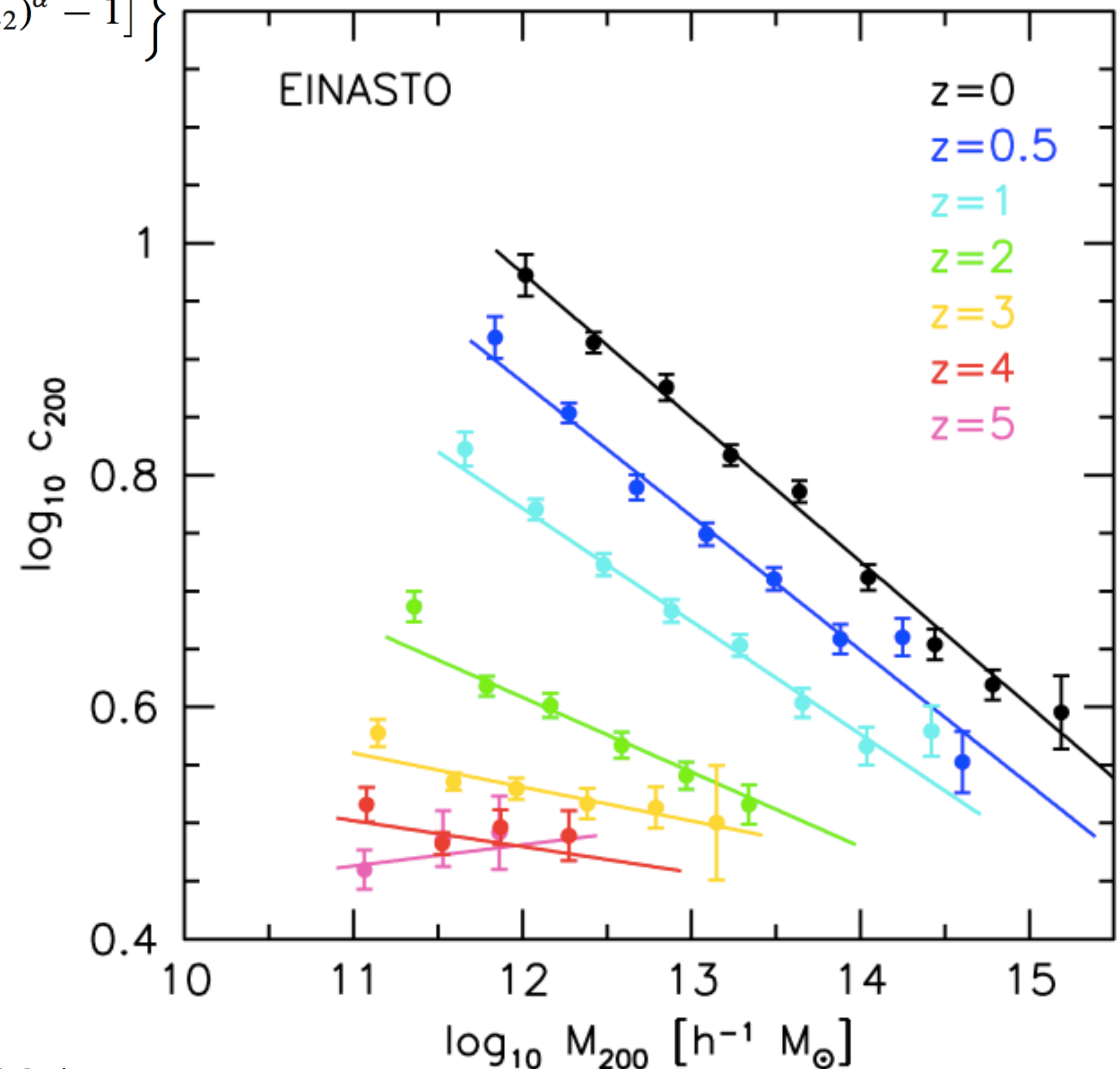


Why should you care?



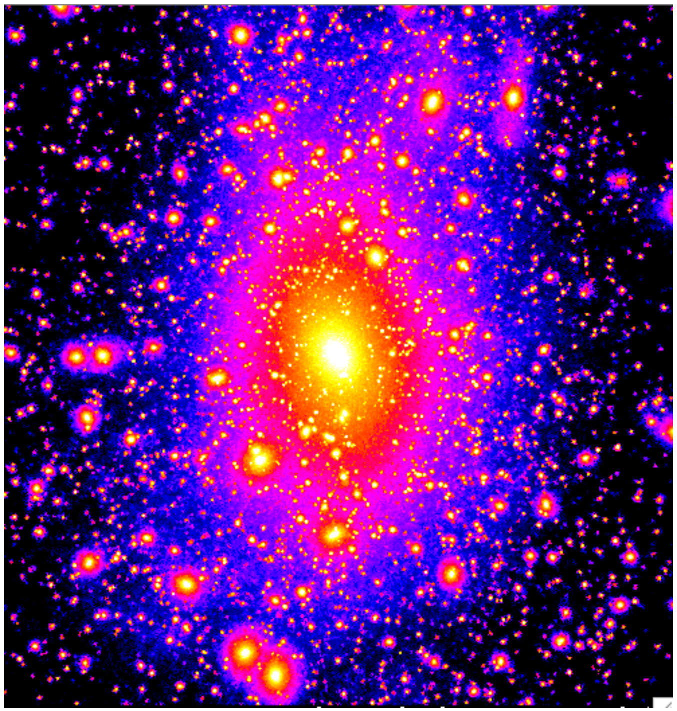
$$\frac{\rho_{\rm EIN}(r)}{\rho_{-2}} = \exp\left\{-\frac{2}{\alpha}\left[(r/r_{-2})^{\alpha} - 1\right]\right\}$$

$$c_{200} = \frac{R_{200}}{r_{-2}}$$

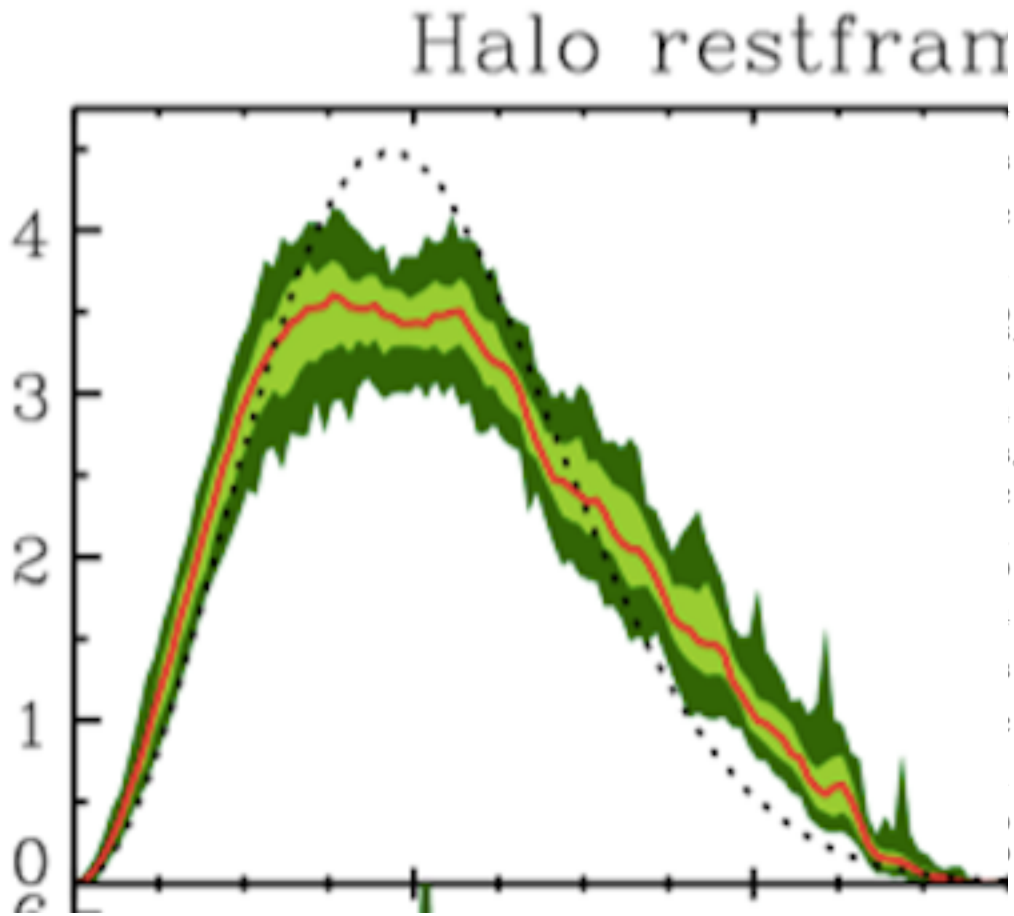


Dutton & Macciò 2014

Results from pure gravity simulations



DM has a Universal Profile

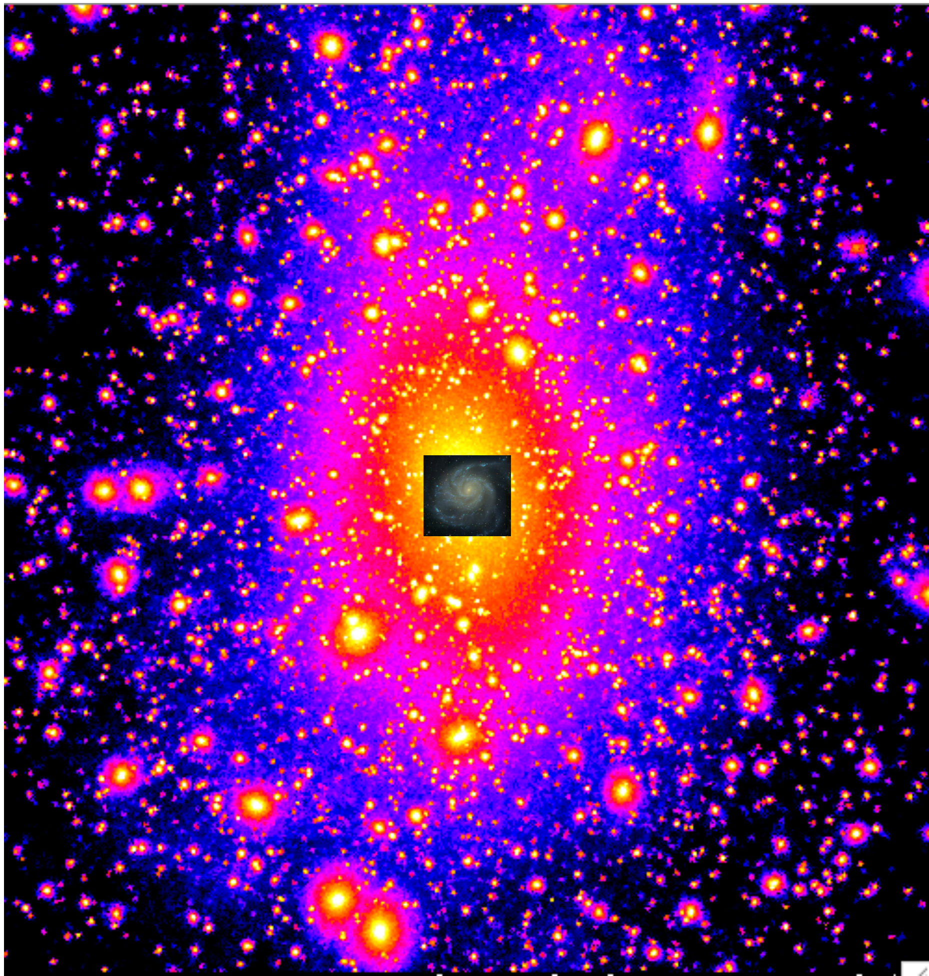


DM velocity distribution is Maxwellian, with a possible excess at high vel. (Kuhlen+10)

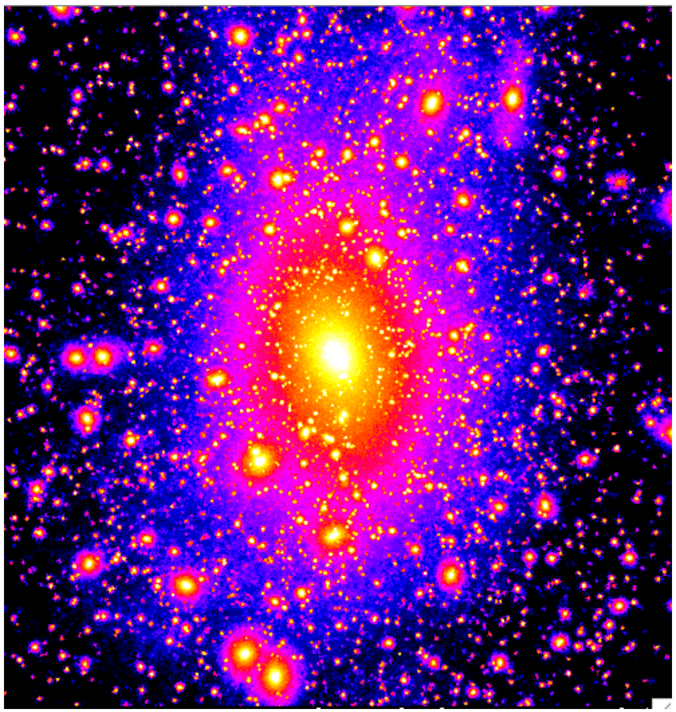
Is this the end of the story?

We were lying to you!!!

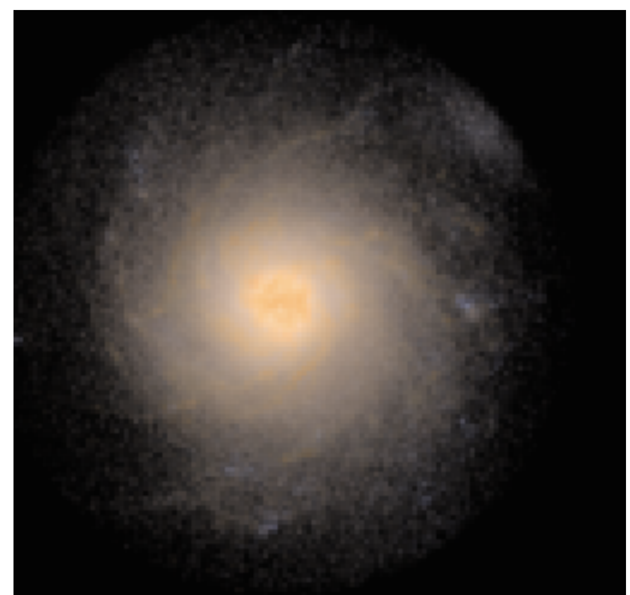
At solar radius more than 50% of the mass is in stars!



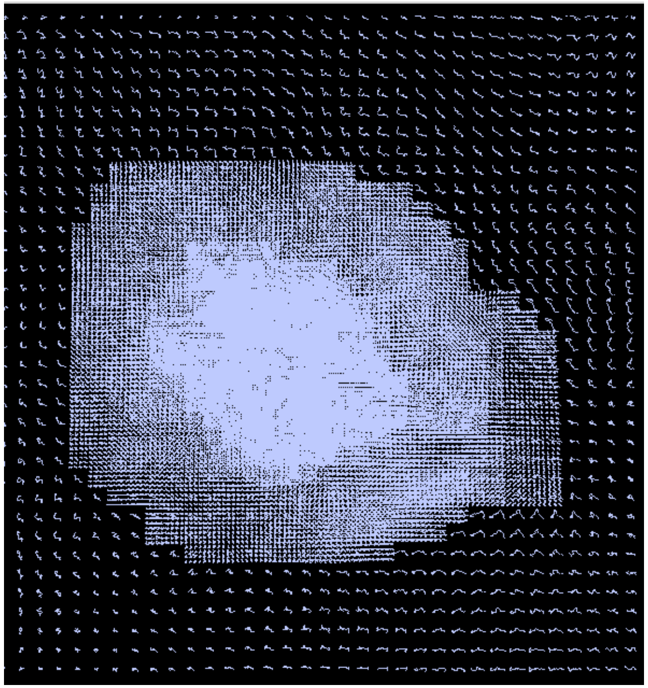
Dark Matter distribution around galaxies



DM distribution from pure gravity simulations

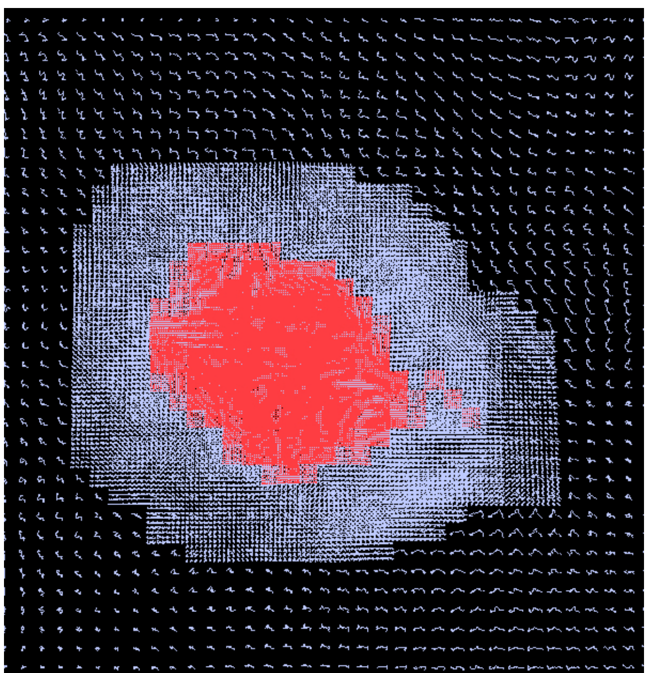


DM distribution with galaxy formation



Pure Gravity (Nbody)

$$\nabla^2\Phi = 4\pi G a^2 \rho$$



Hydro-dynamical simulations

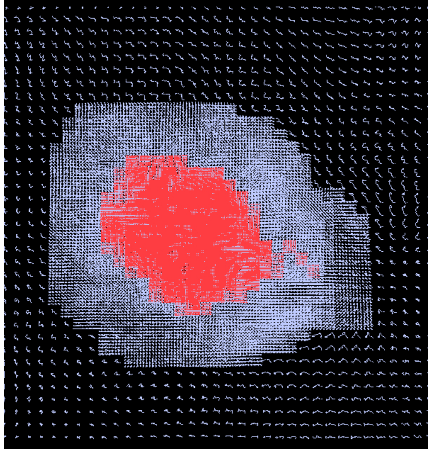
$$\nabla^2\Phi = 4\pi G a^2 \rho$$

$$\frac{\partial}{\partial t}(\rho u) + \frac{1}{a}\nabla(\rho u) = -(\rho u + P)\left(\frac{1}{a}\nabla\cdot v + 3\frac{\dot{a}}{a}\right)$$

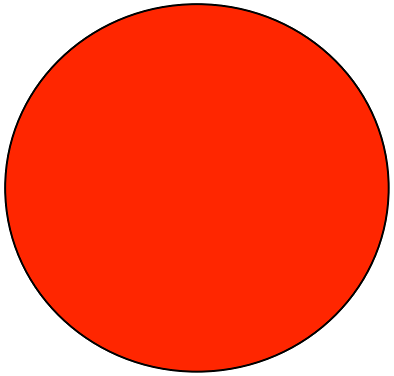
$$\boxed{\frac{du}{dt} = -\frac{P}{\rho}\nabla\cdot v - \frac{\Lambda(u,\rho)}{\rho}}$$

$$\frac{\partial\rho}{\partial t} + \frac{3a}{a}\rho + \frac{1}{a}\nabla\cdot(\rho v) = 0$$

Star formation and feedback in a nut shell

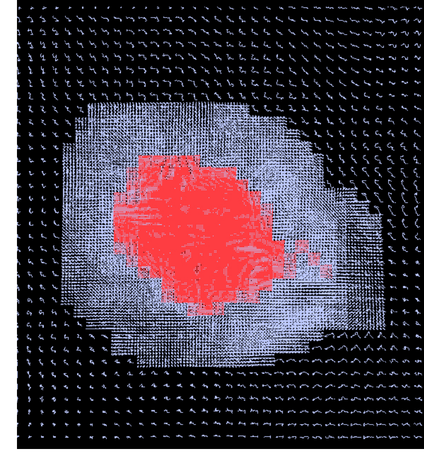


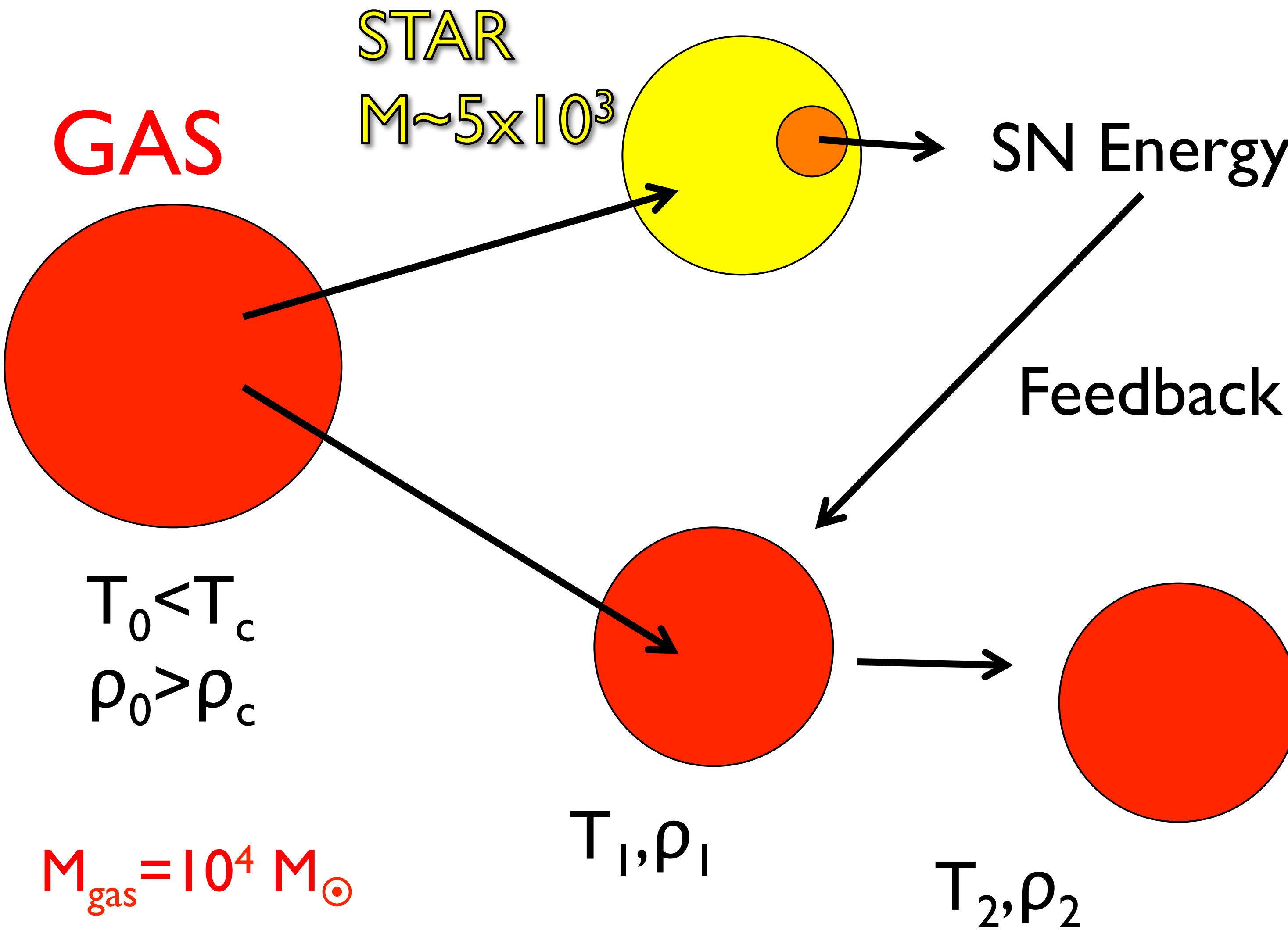
GAS



$M_{gas}=10^4\ M_\odot$

Star formation and feedback in a nut shell

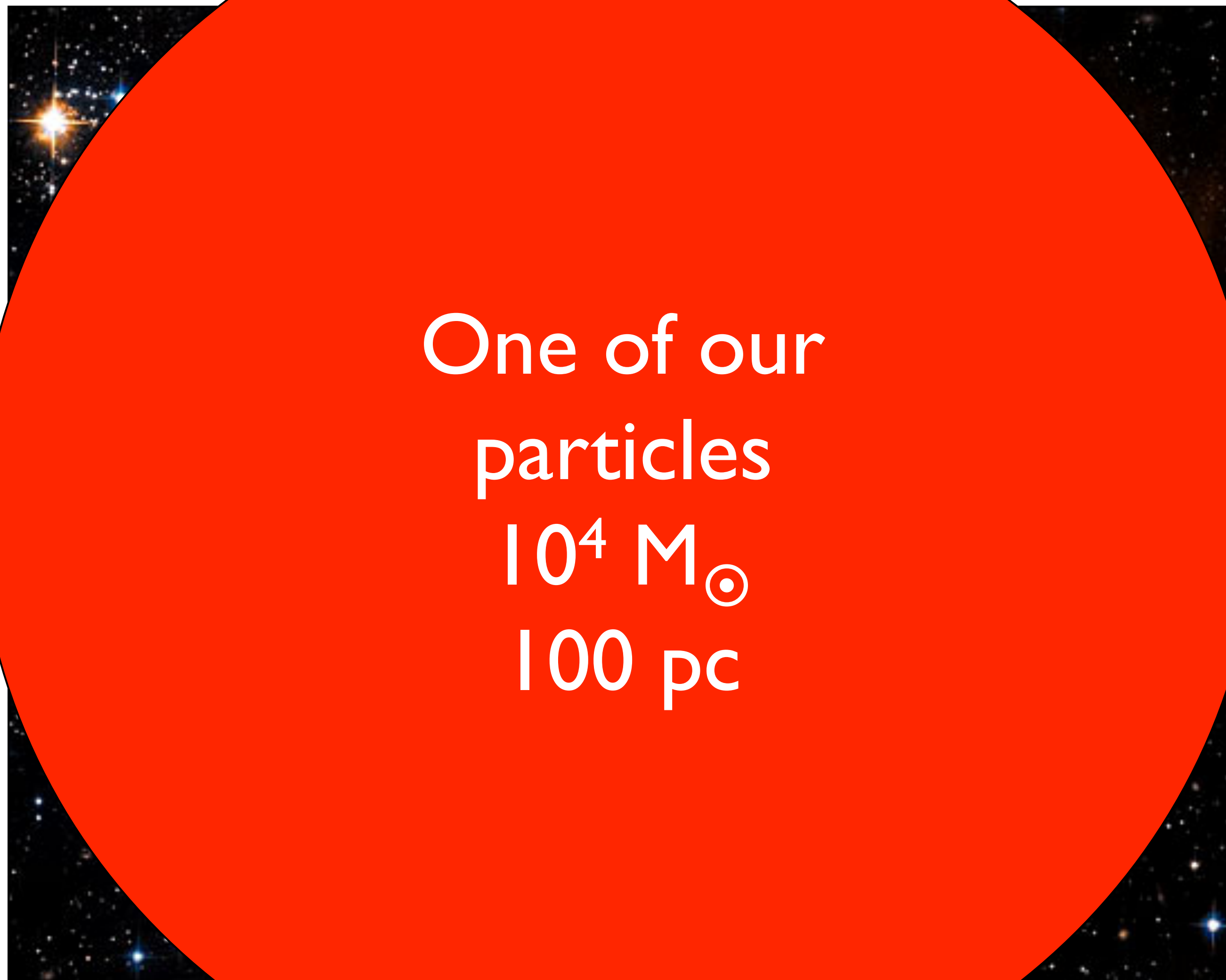




We cannot simulate galaxy formation from first principles!

Subgrid Physics

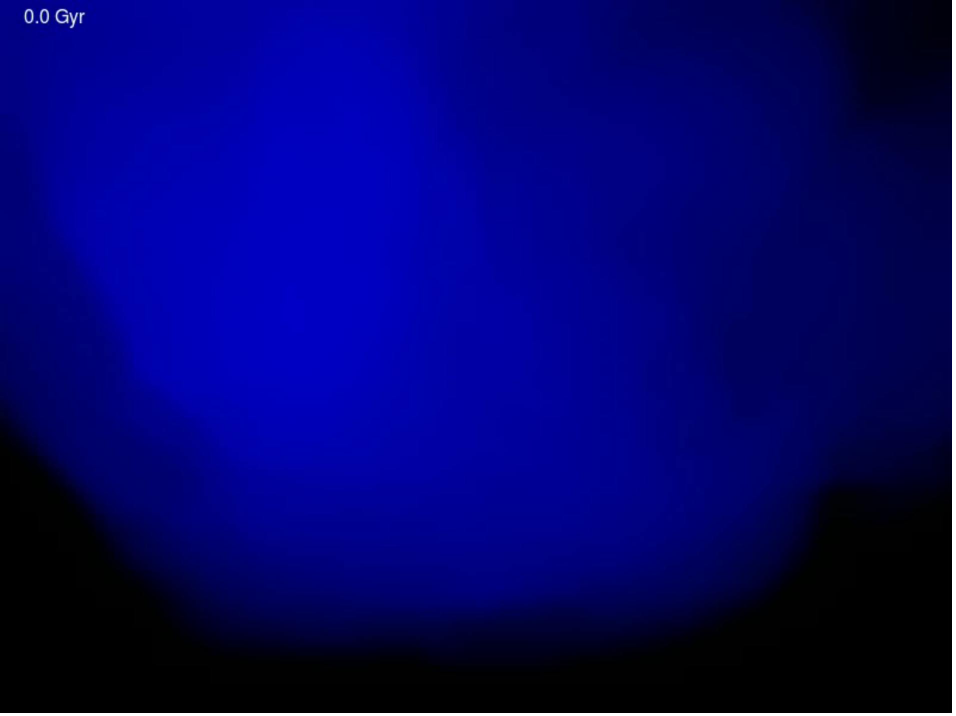
~100 pc

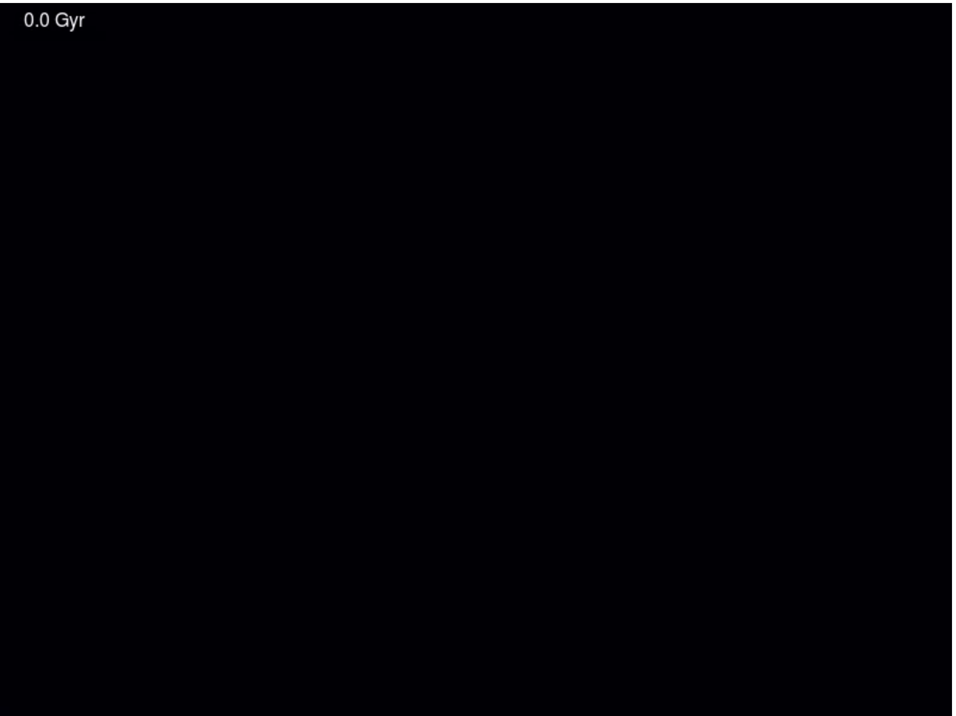


One of our particles

10^4 $M_\odot$

100 pc





DAGAL

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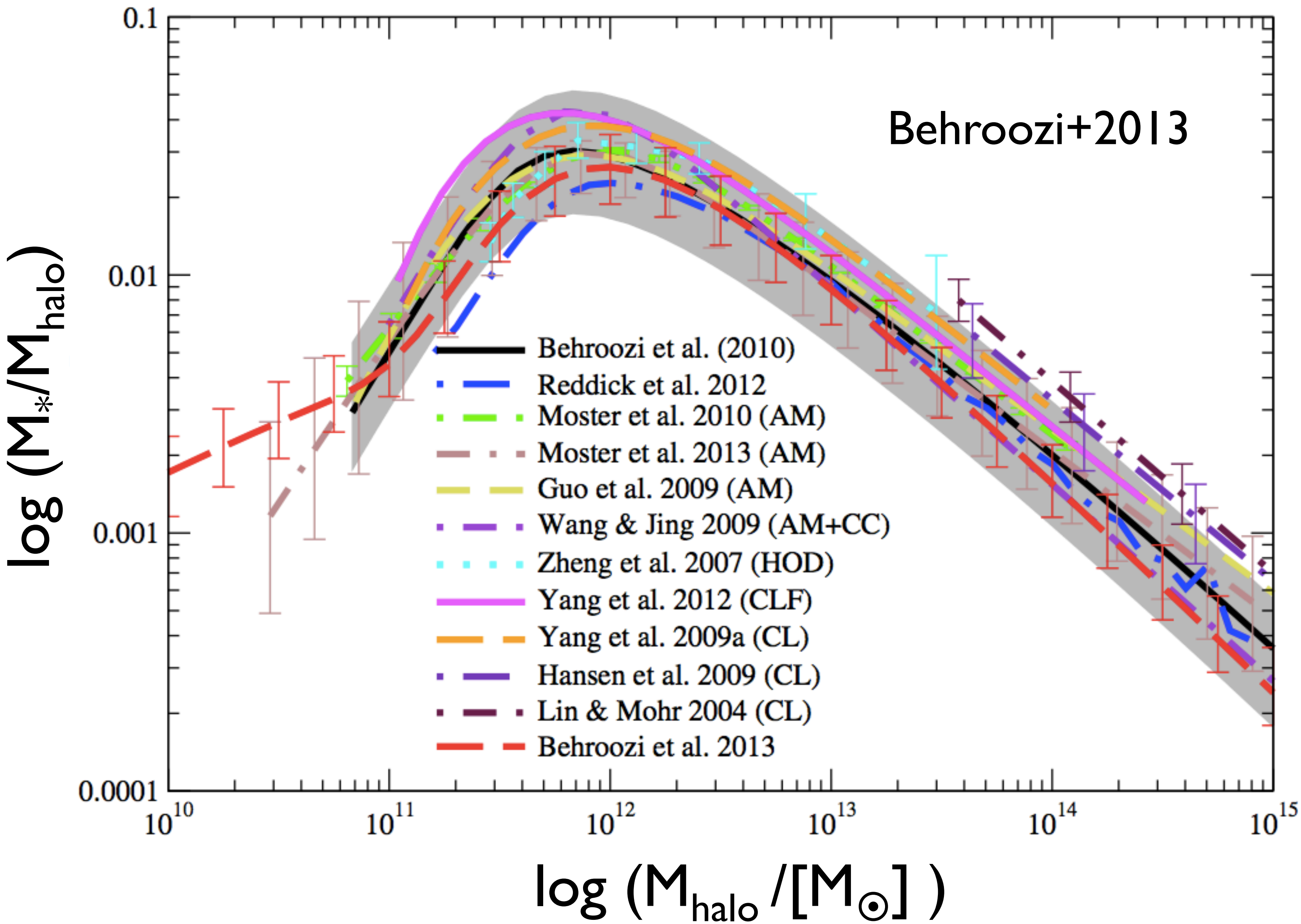
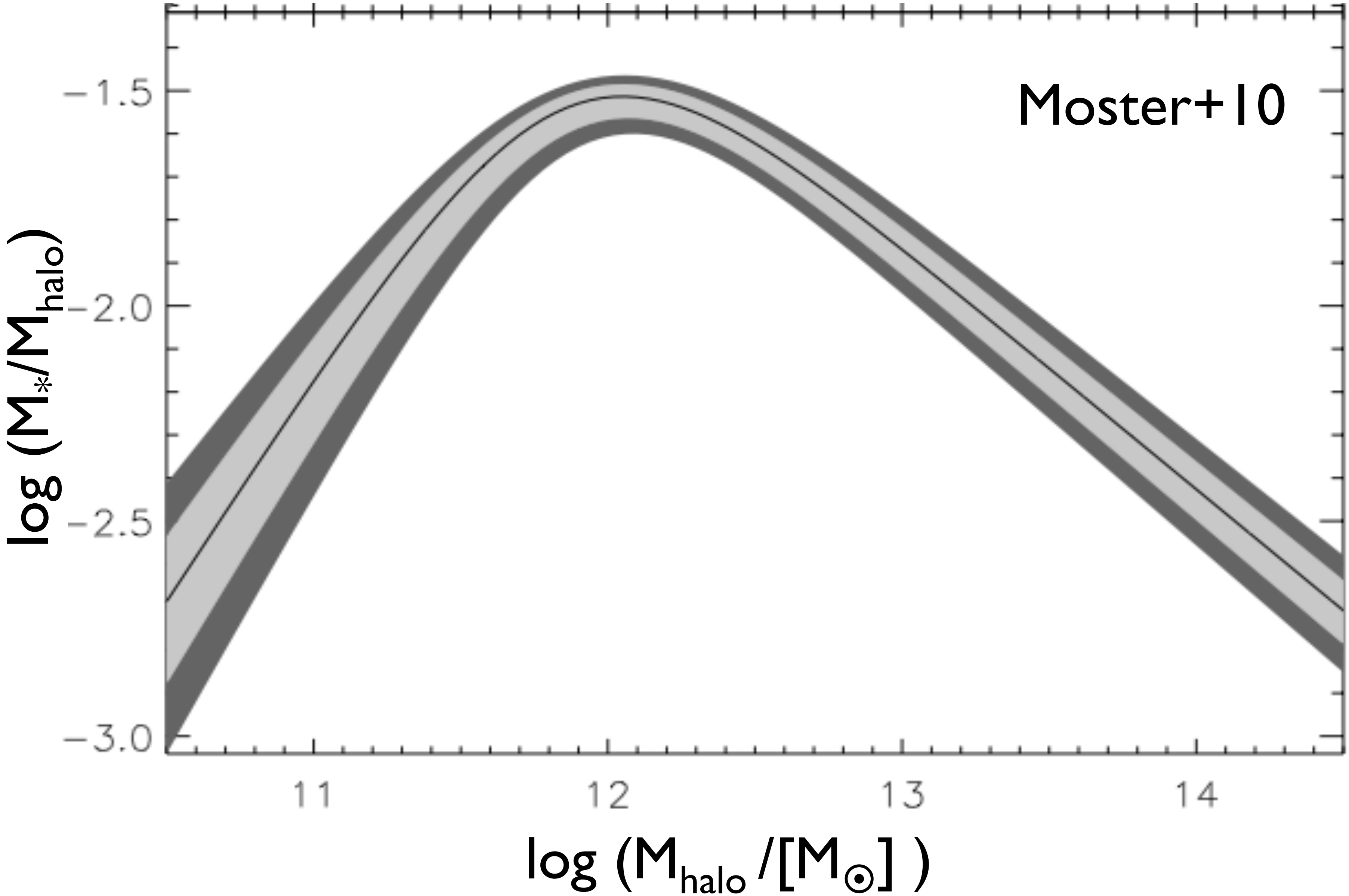
SFB 881

Are simulated galaxies realistic?

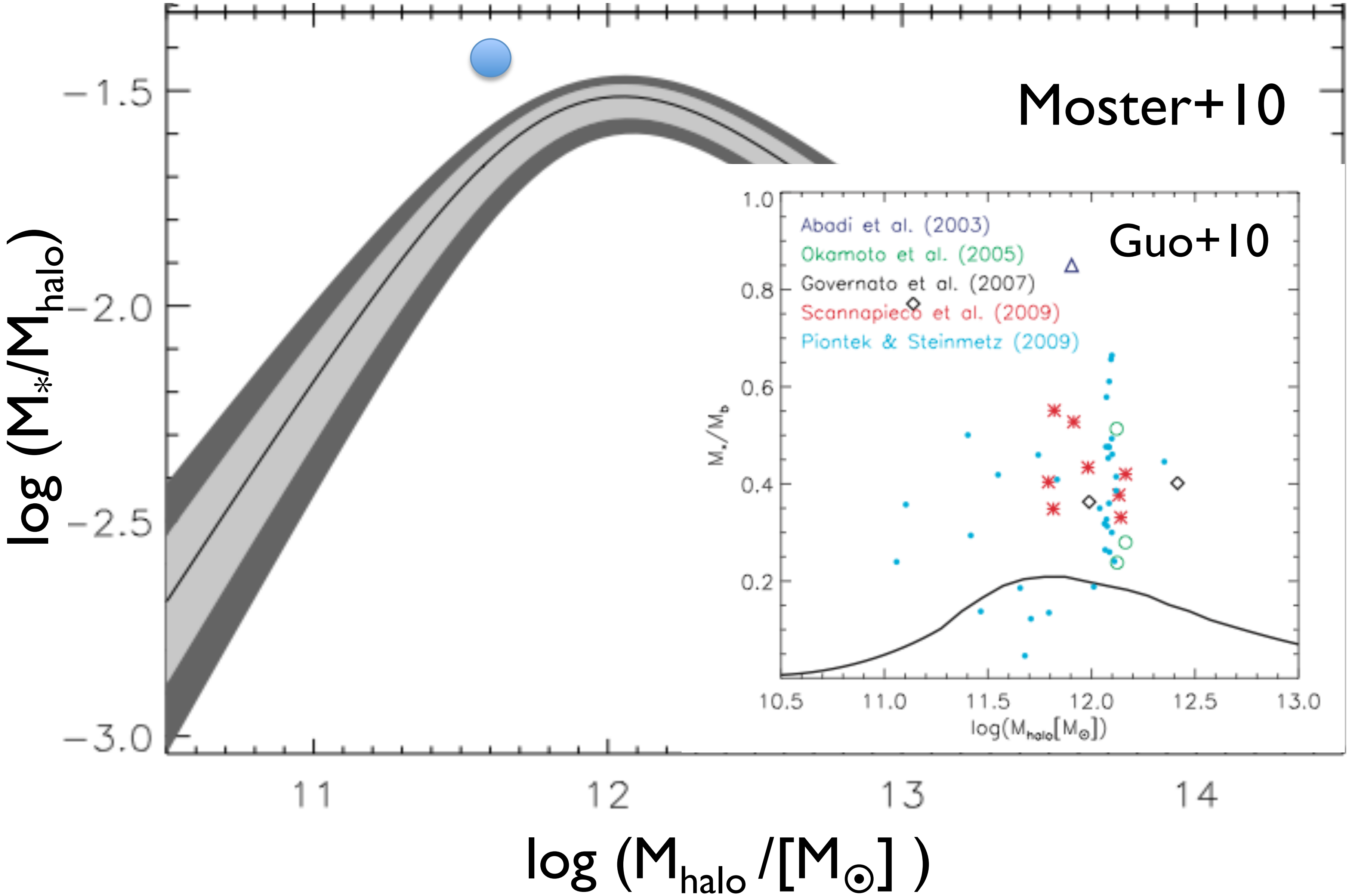
Halo mass – stellar mass relation



Halo mass – stellar mass relation



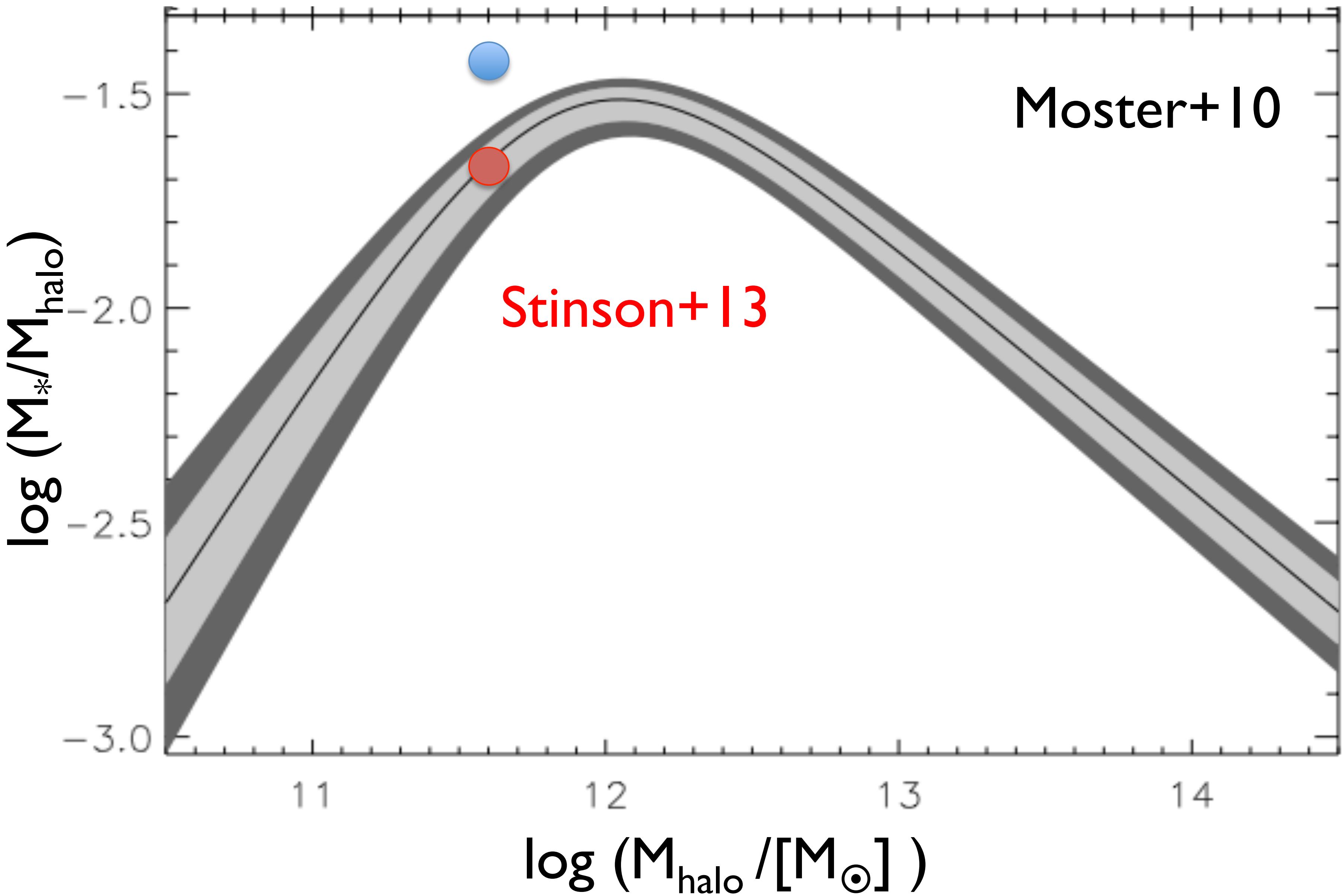
Halo mass – stellar mass relation



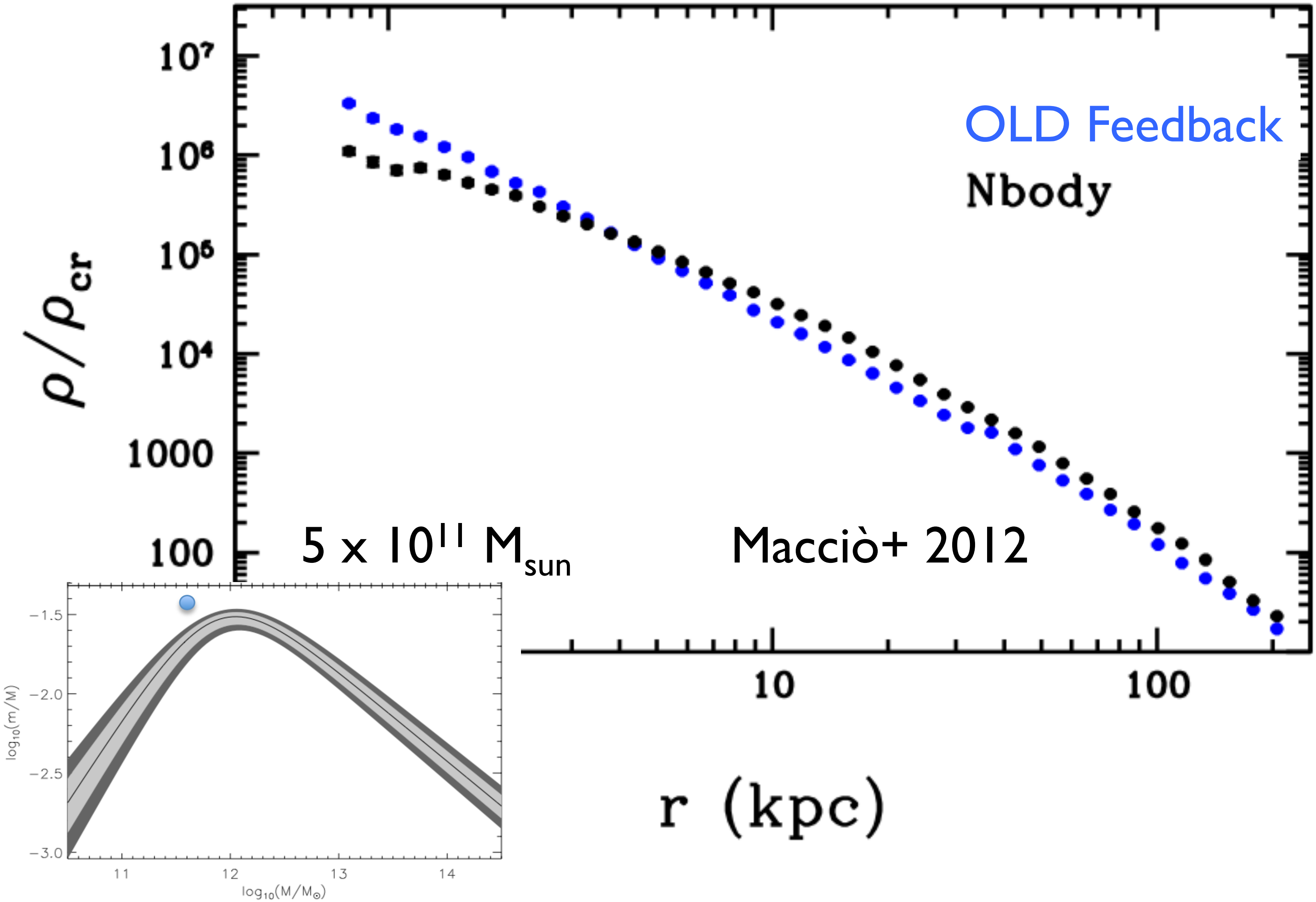
Gasoline 2

- Smoothed Particle Hydrodynamics (SPH) (Wadsley+06)
- New low temperature and Metal Cooling (Shen+ 2010)
- UV heating (Haardt & Madau 1996, 2011)
- Metal Diffusion (Wadsley+ 2010)
- Star Formation and SN feedback (Stinson+ 2006)
- *Chabrier IMF & Stellar feedback (Stinson, Brook, AM 2013)*
- *New SPH implementation (Keller+14, Stinson+2015)*

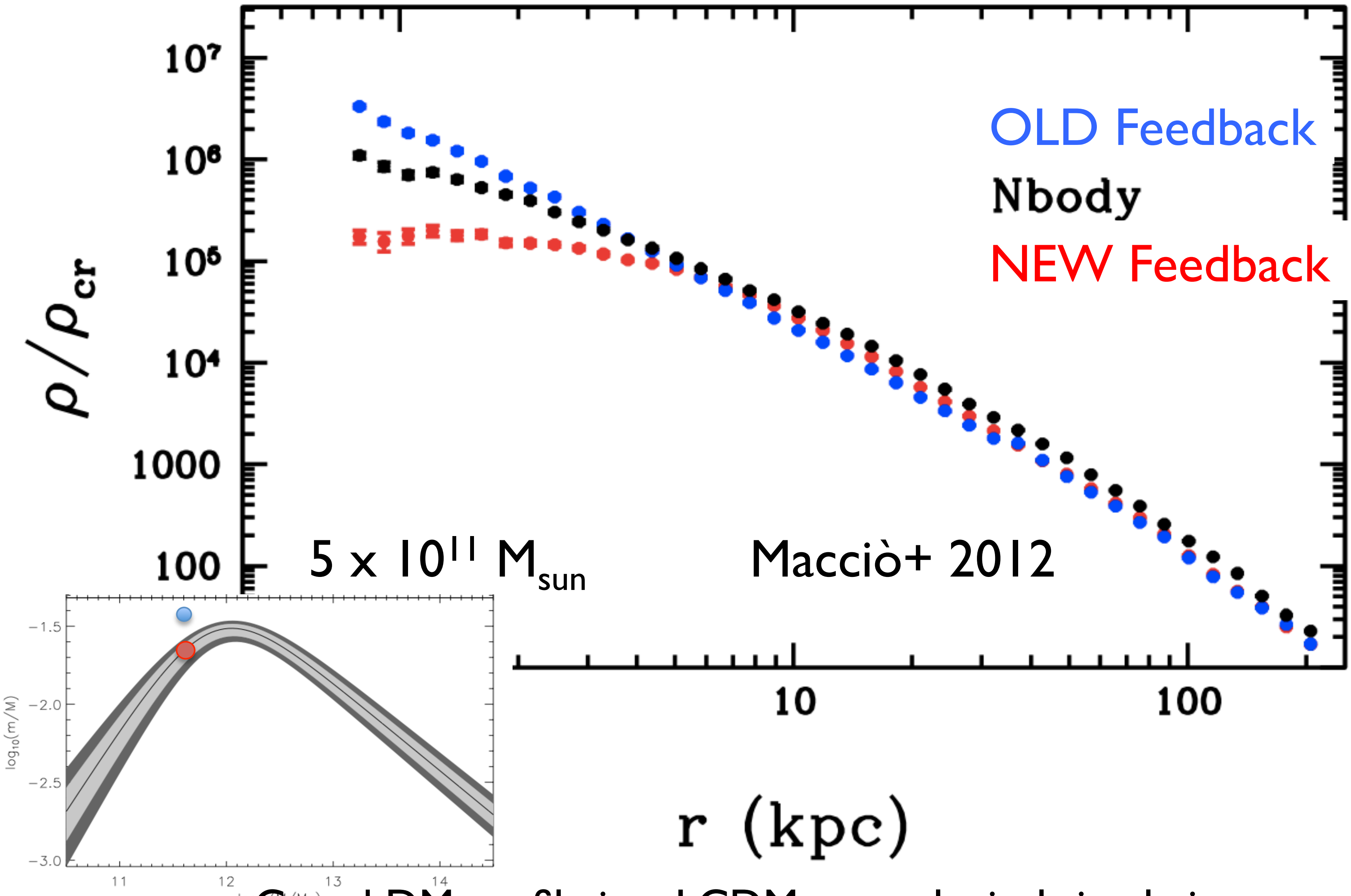
Halo mass – stellar mass relation



DM distribution

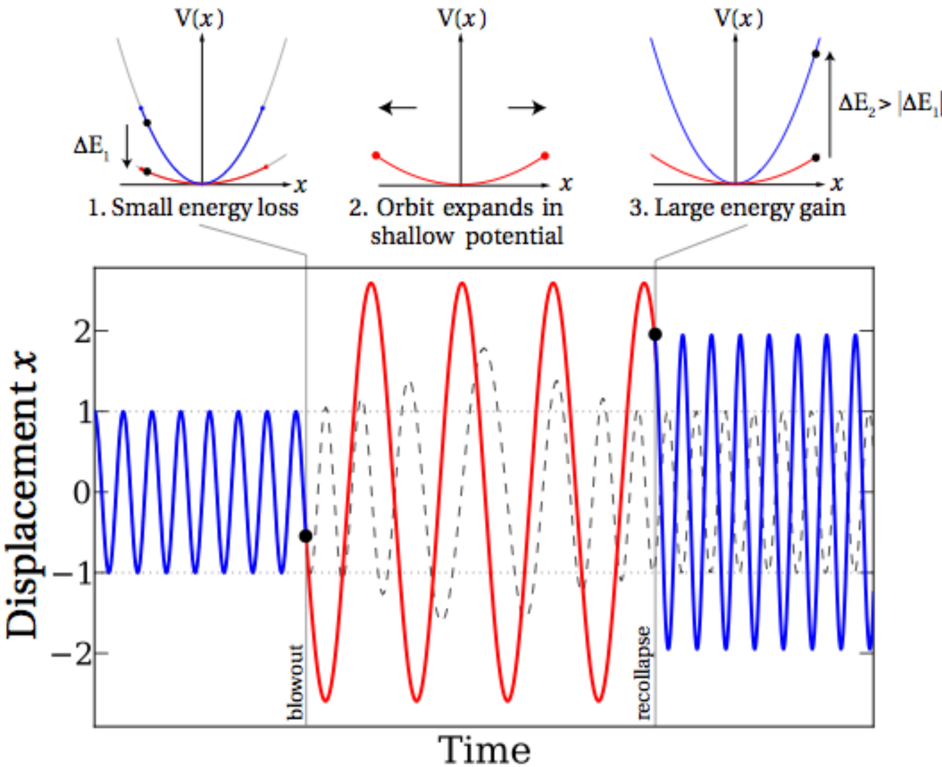


DM distribution



Cored DM profile in a LCDM cosmological simulation

Erasing the Cusp

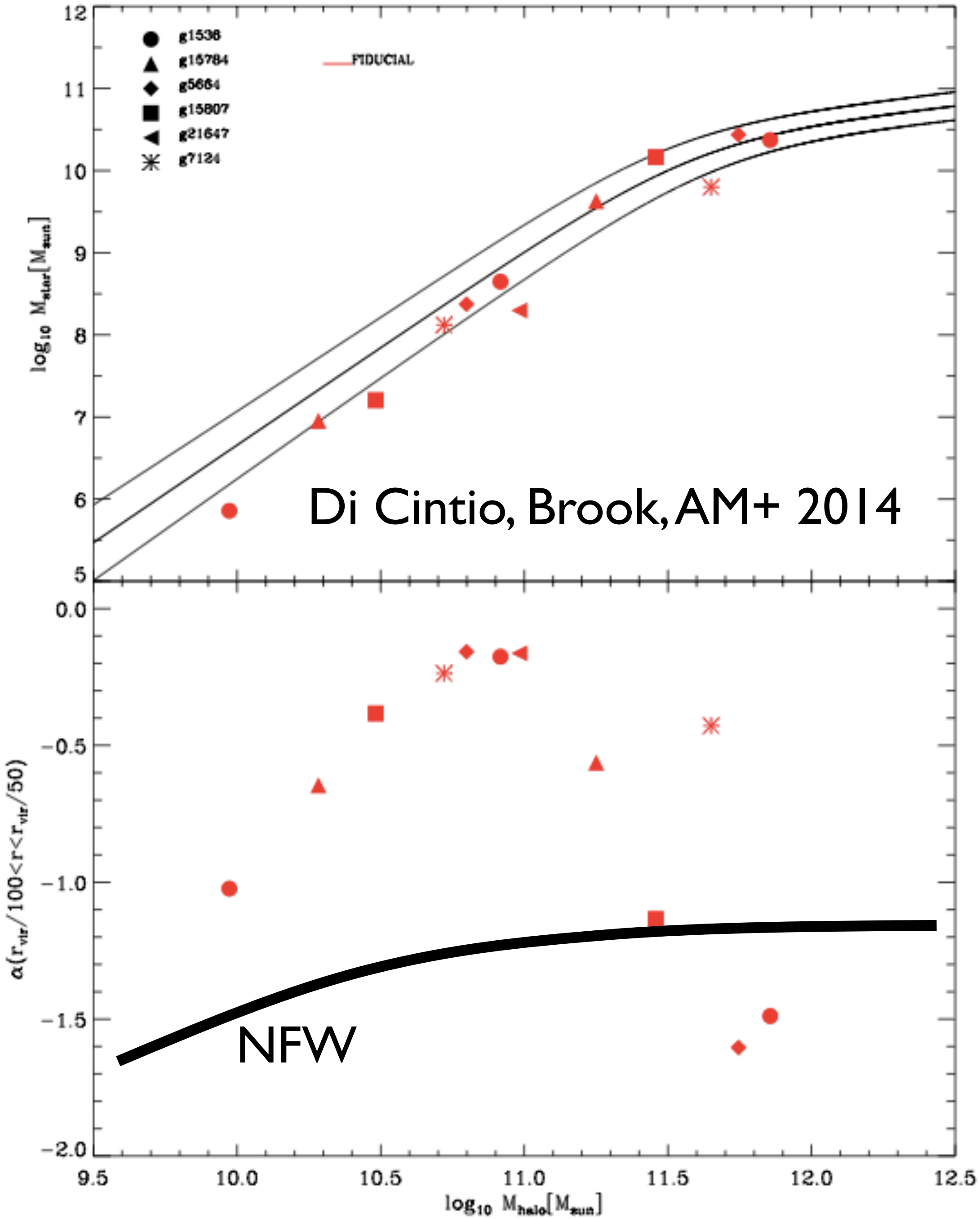


Pontzen & Governato 2011

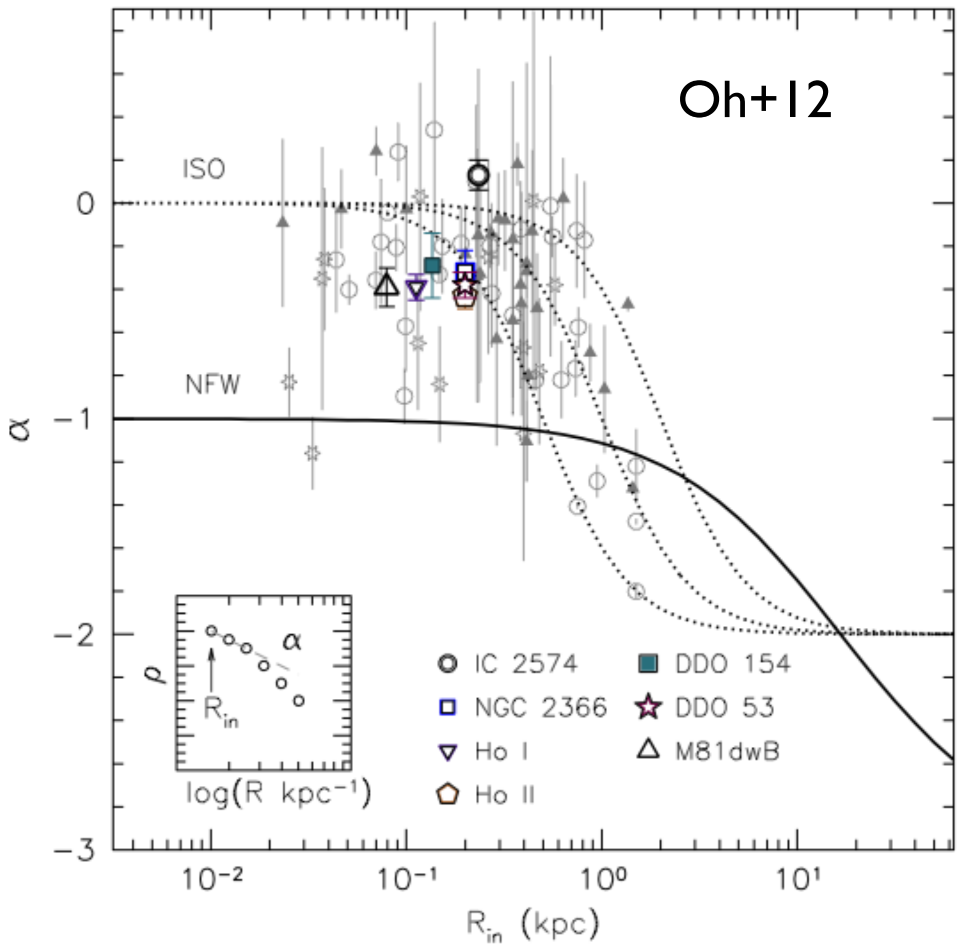
Galaxy formation simulation AM+12

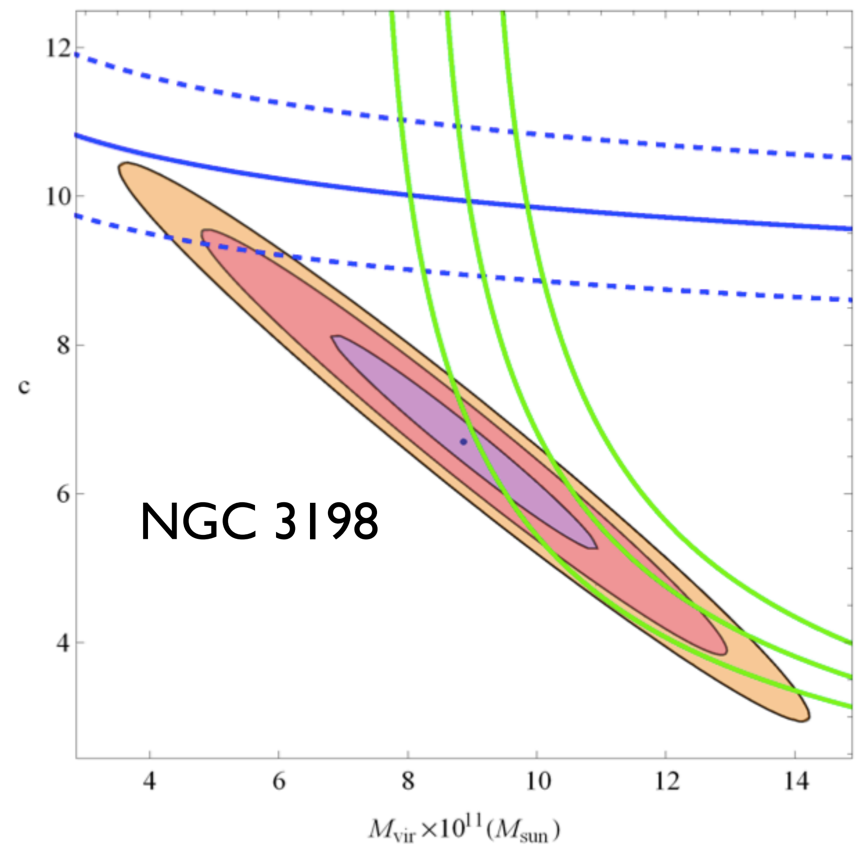
NON adiabatic expansion

MaGICC


g1536
g15784
g5664
g15807
g21647
g7124
FIDUCIAL
Di Cintio, Brook, AM+ 2014
NFW
$\log_{10} M_{star}[M_{sun}]$
$\alpha(r_{vir}/100<r<r_{vir}/50)$
$\log_{10} M_{halo}[M_{sun}]$

Cored profiles needed by observations





Karukes, Salucci, Gentile 2015

A statistical sample of galaxies

The NIHAO project

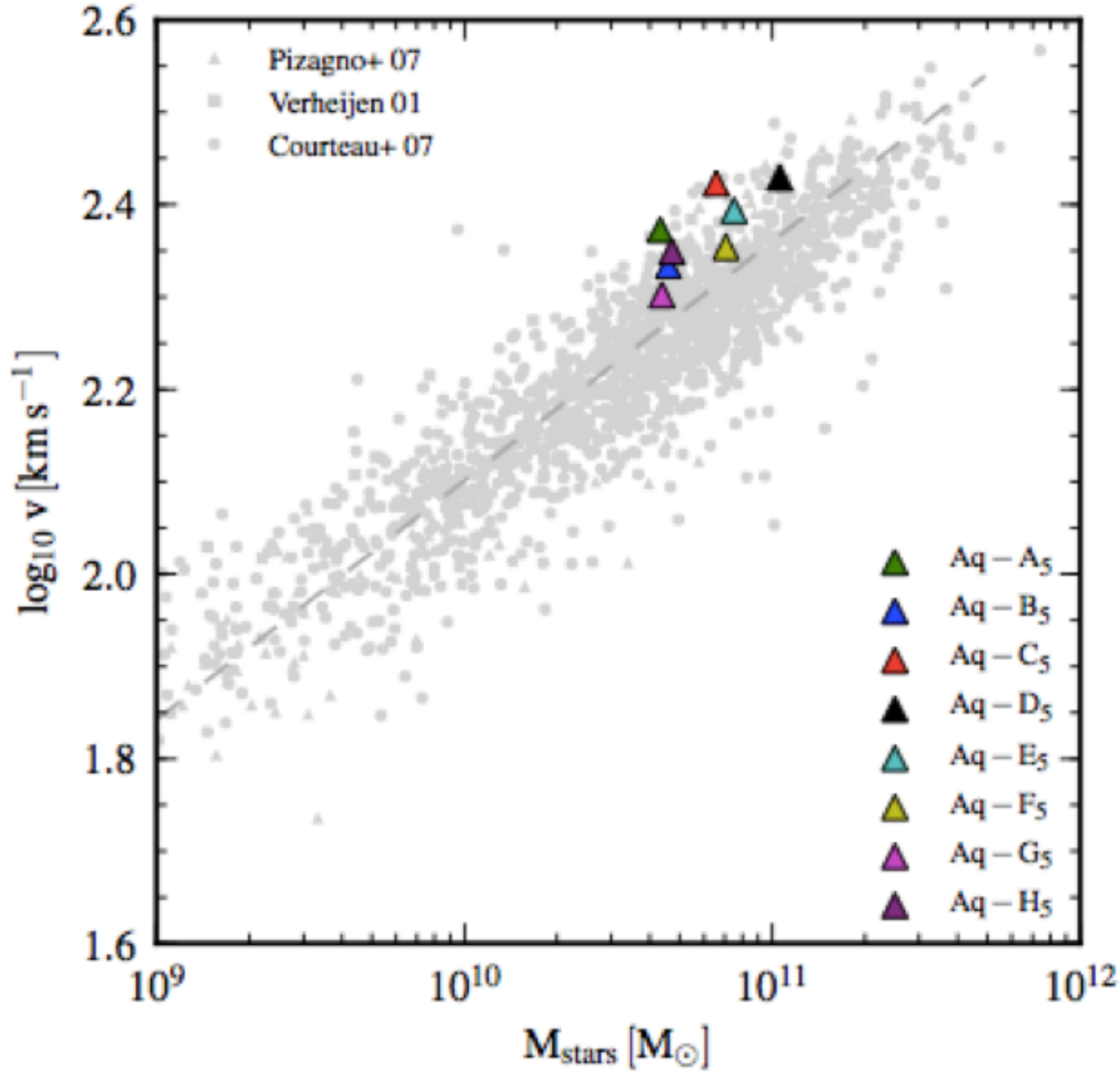
Numerical
Investigation (of)
Hundred
Astrophysical
Objects

你好

MPIA Heidelberg – Purple Mountain Observatory Nanjing

A statistical sample

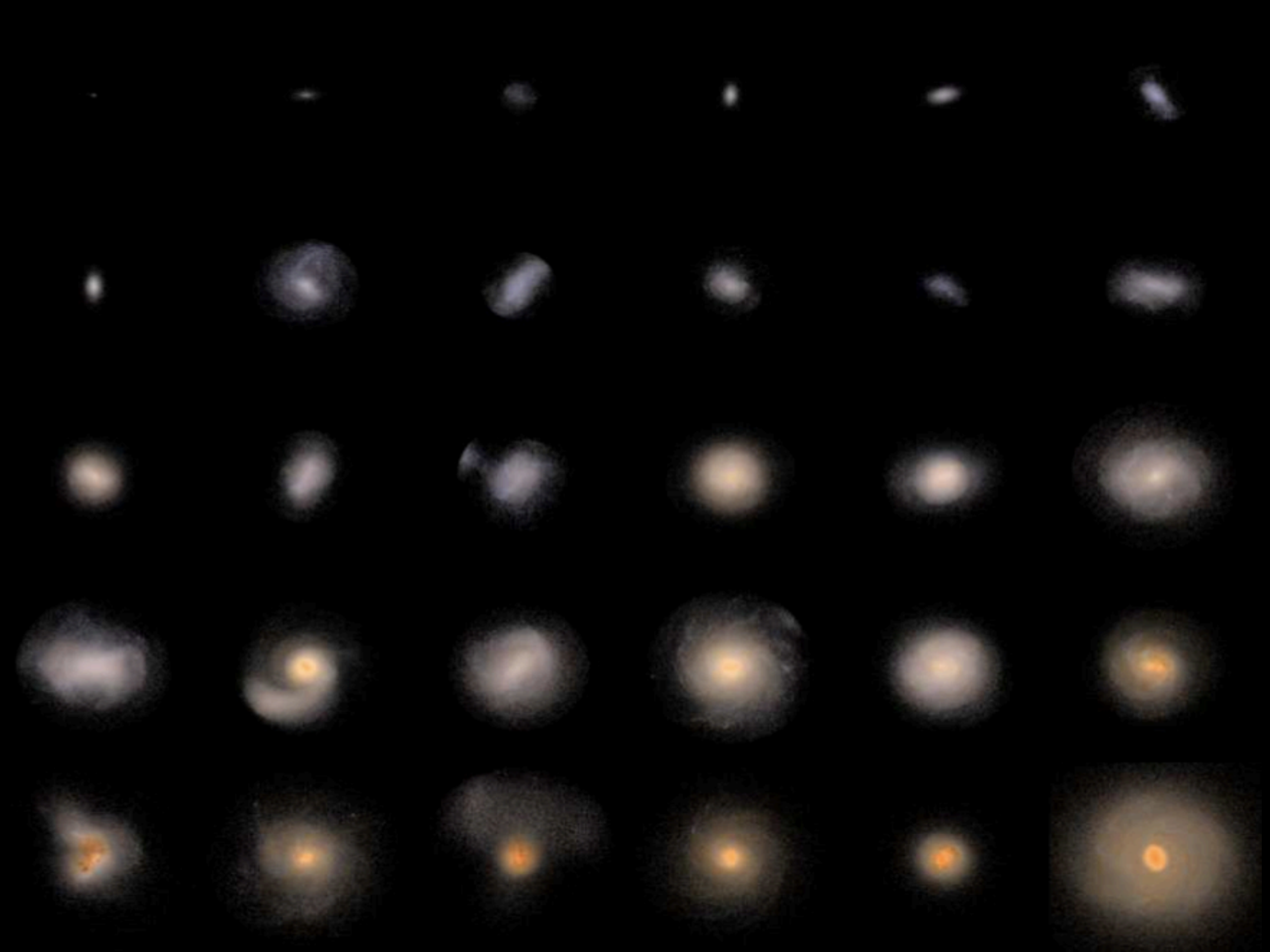
Numerical
Investigation
***H**undred*
Astrophysical
Objects



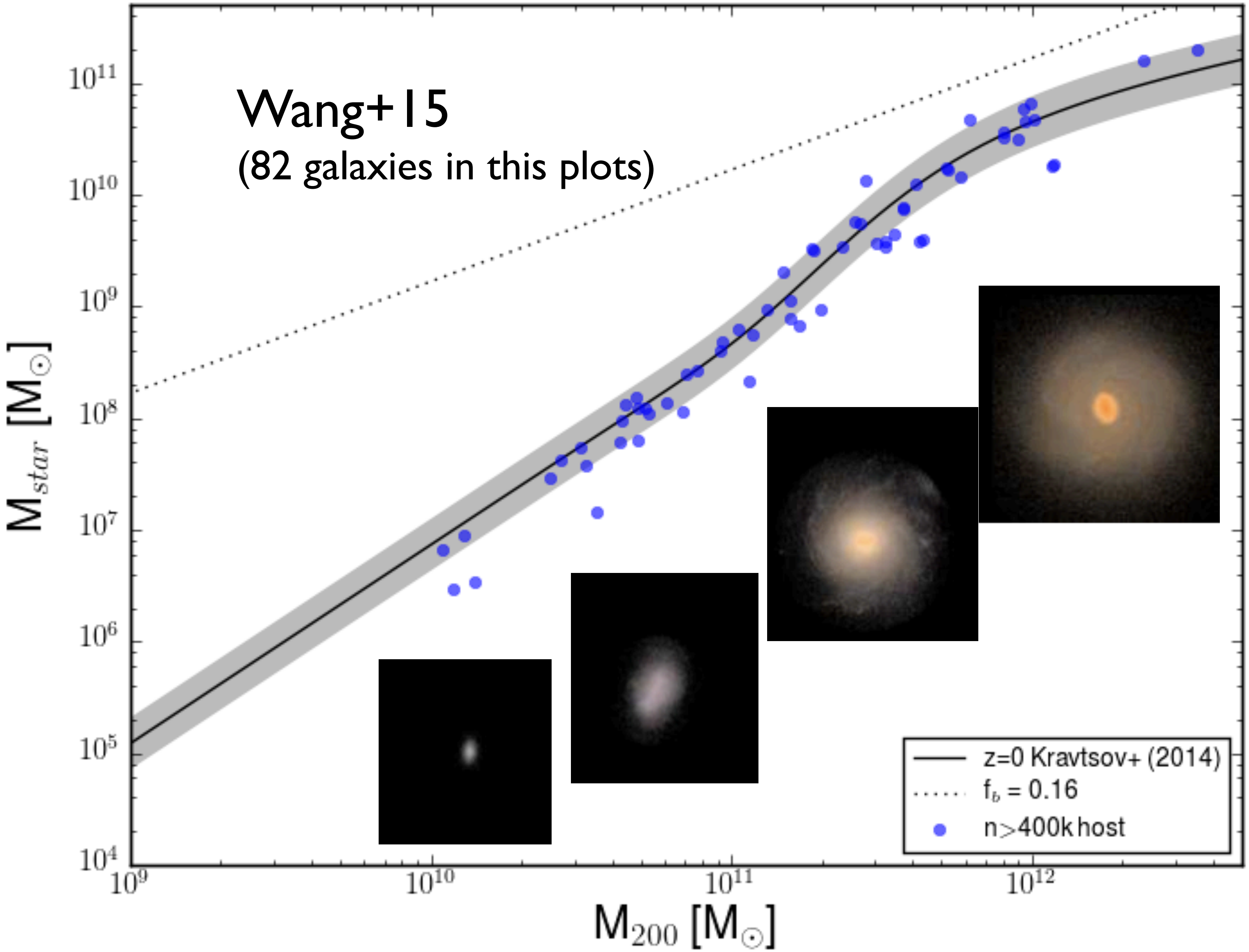
NIHAO in numbers

- Gasoline 2.0 (with SPH fix)
- Planck Cosmology
- ***100 high resolution (zoomed) galaxies***
- **10^6** particles in each halo
- 5×10^9 – 5×10^{12} $M_\odot$ halo mass range
- **100 times better than ILLUSTRIS**
- **50 times better than EAGLE**
- **86 galaxies done** – 14 running

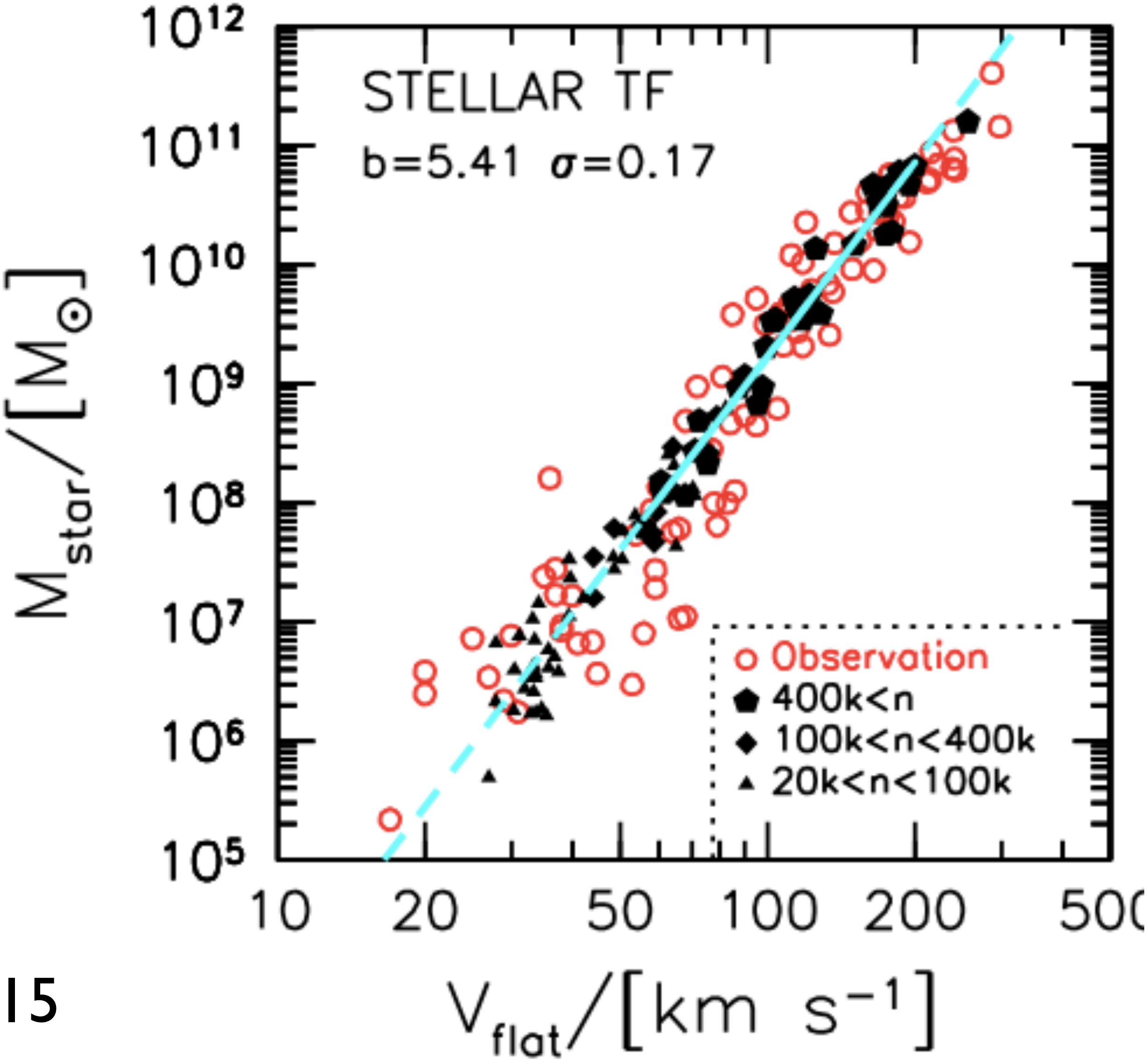
Wang, Dutton, Stinson, Macciò et al. 2015
arXiv:1503.04818



Simulating realistic galaxies

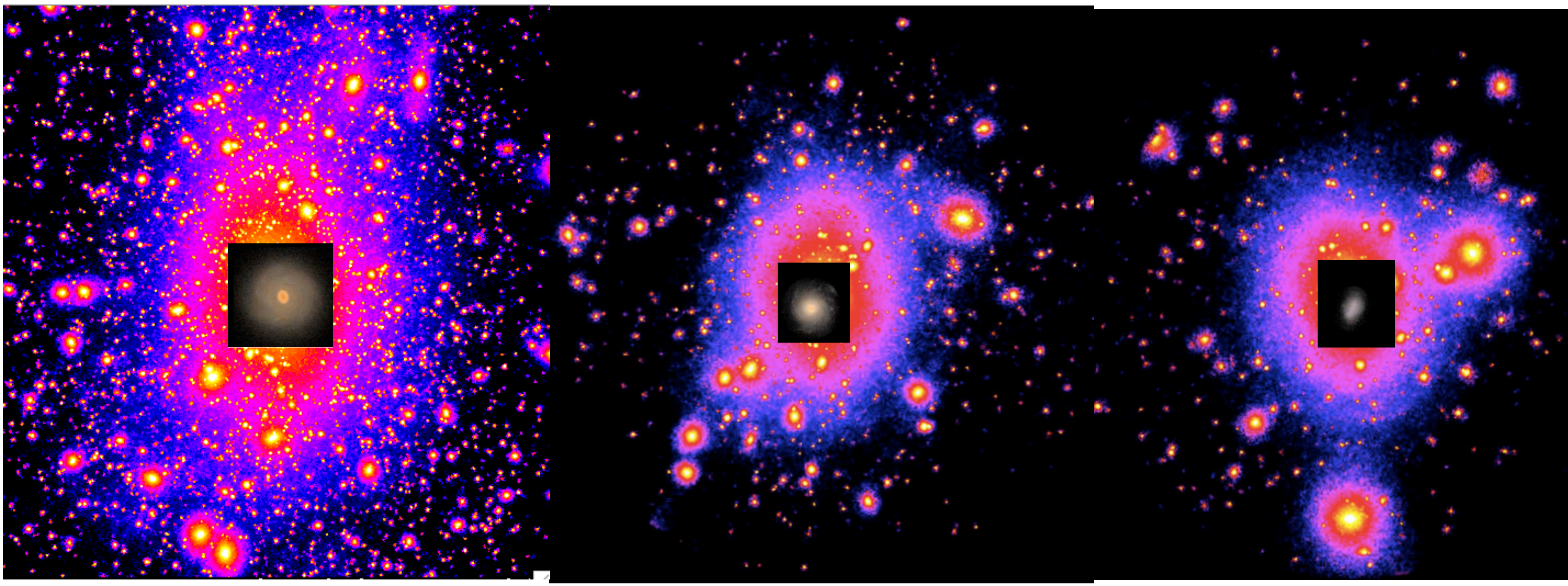


Simulating realistic galaxies



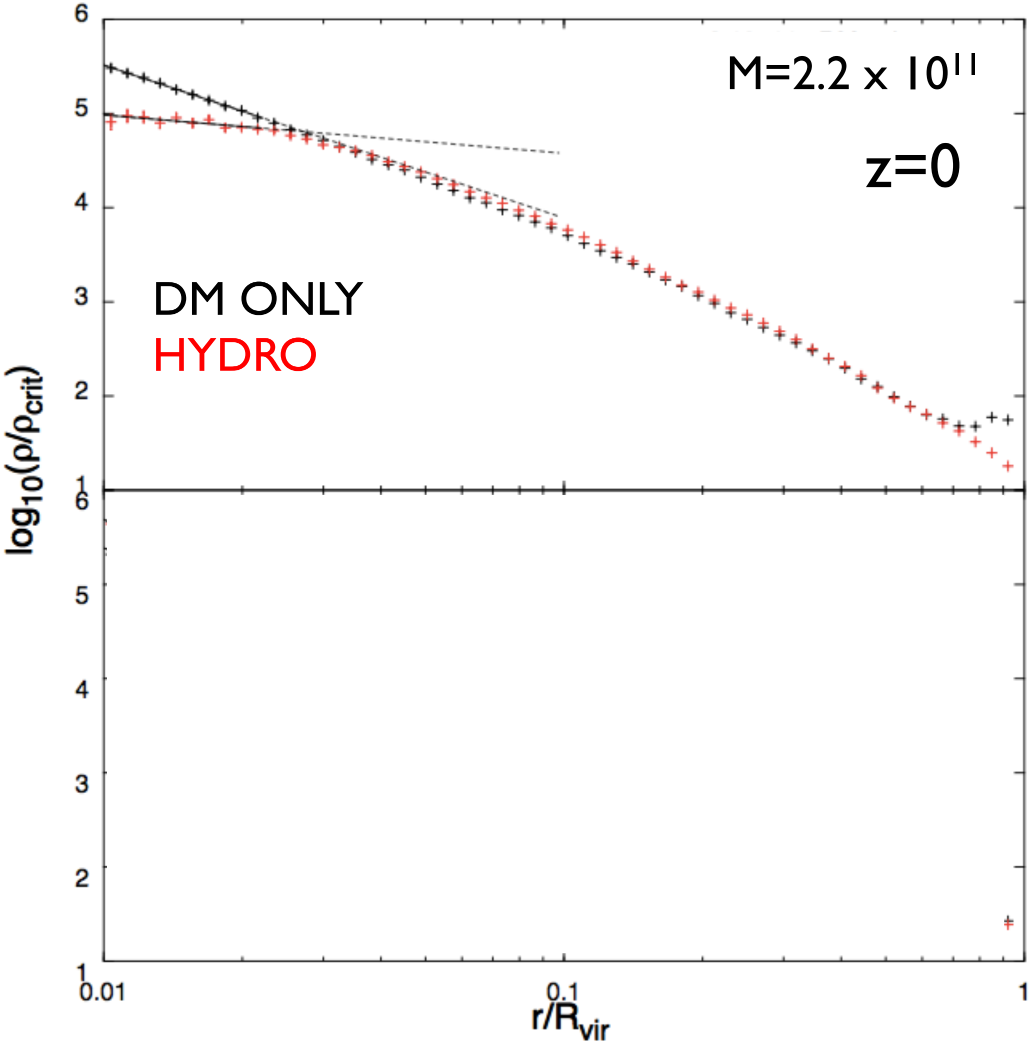
Wang+2015

DM with galaxy formation



Not too scale!!!

DM reaction to galaxy formation

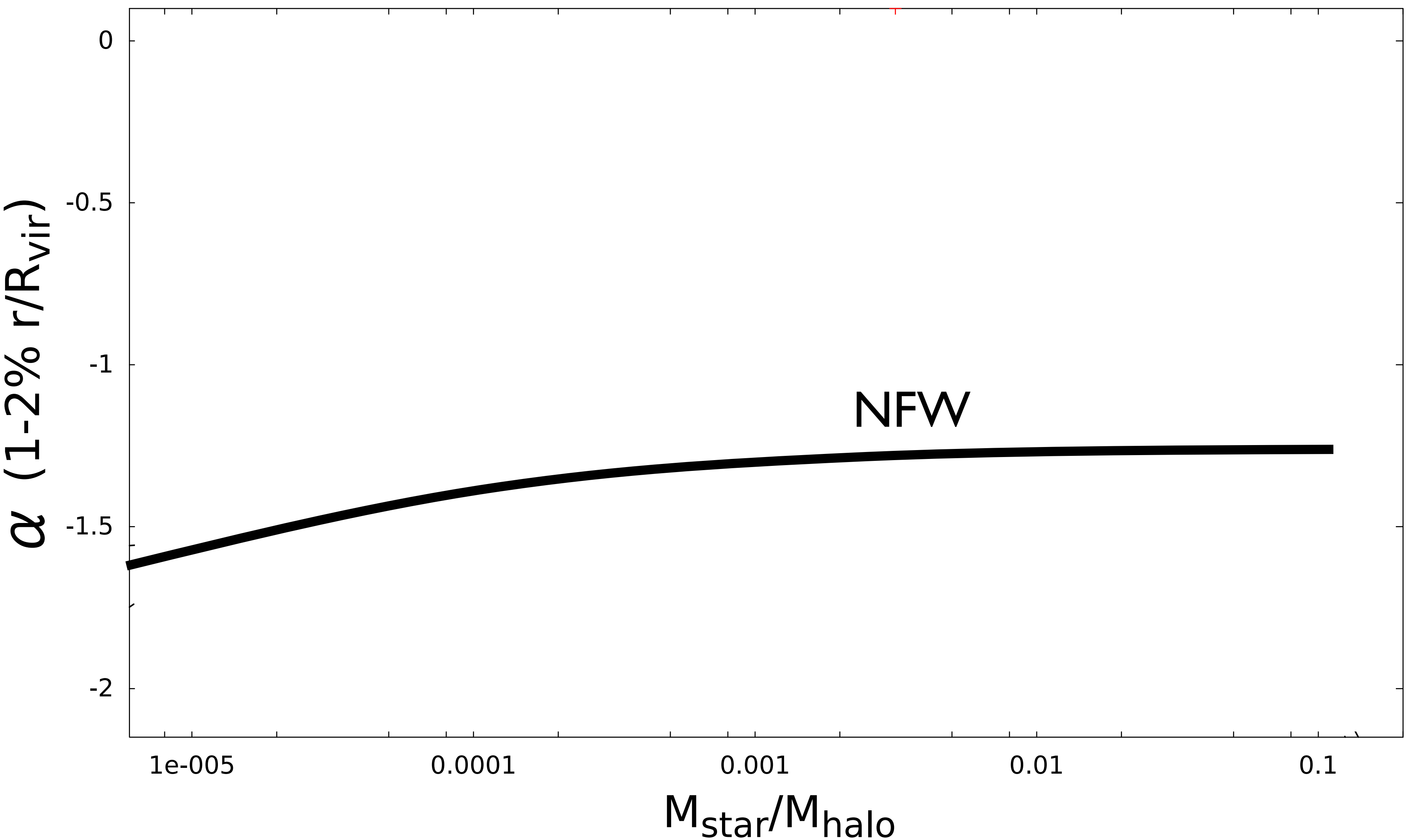


Halo Expansion

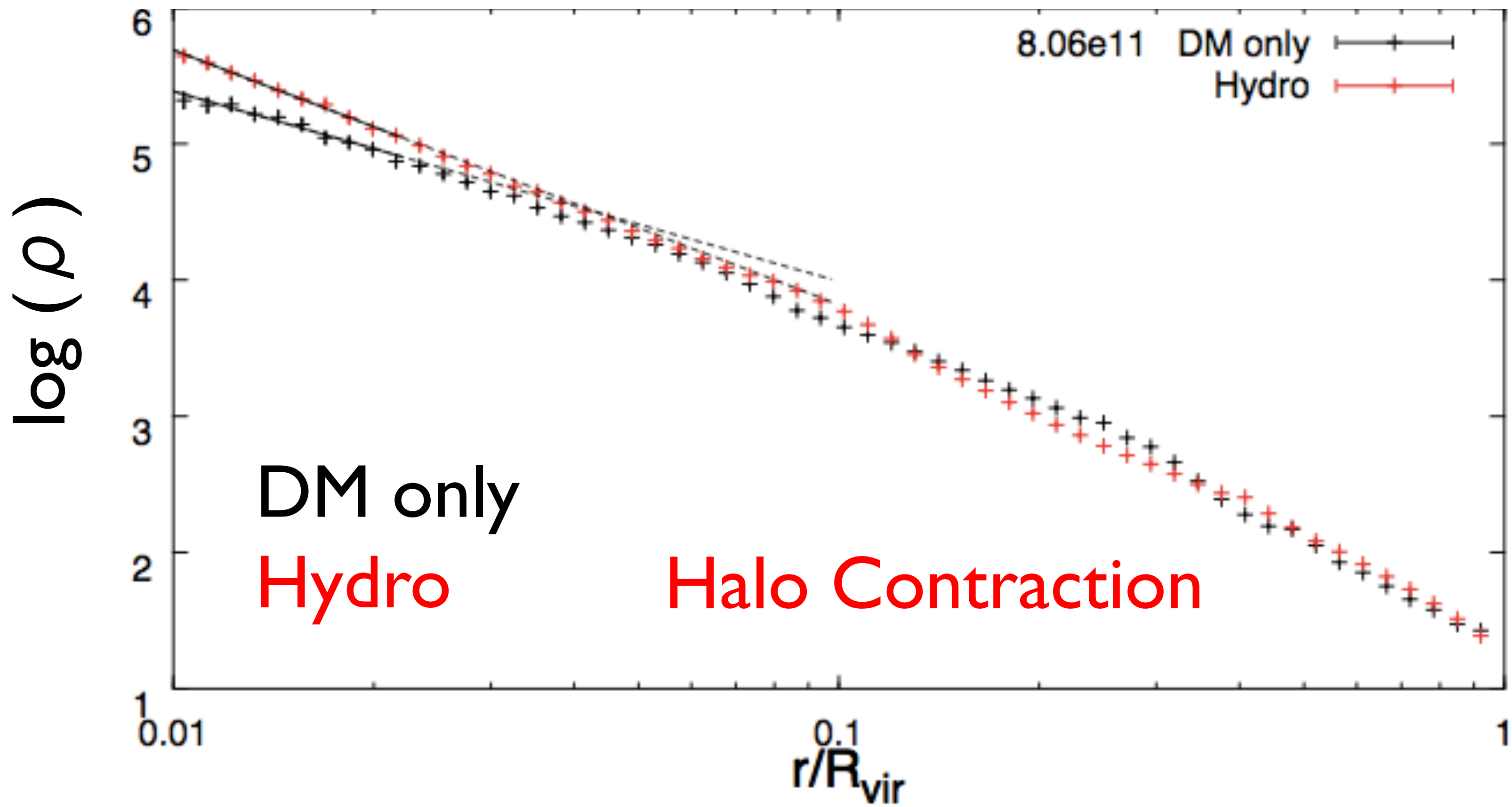
Halo Contraction

Tollet, Macciò+ 2015 in prep.

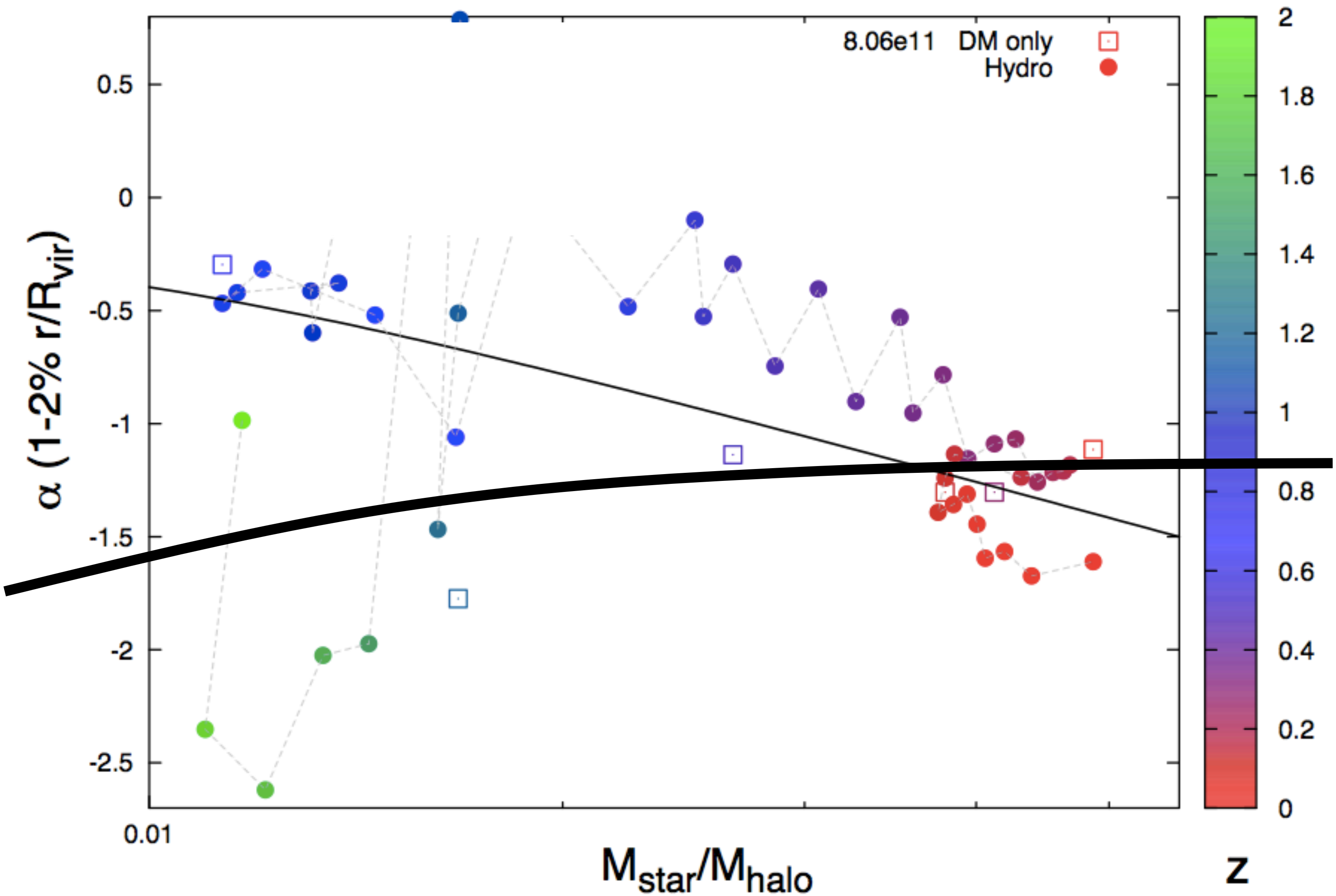
The DM distribution



The DM distribution *evolution*

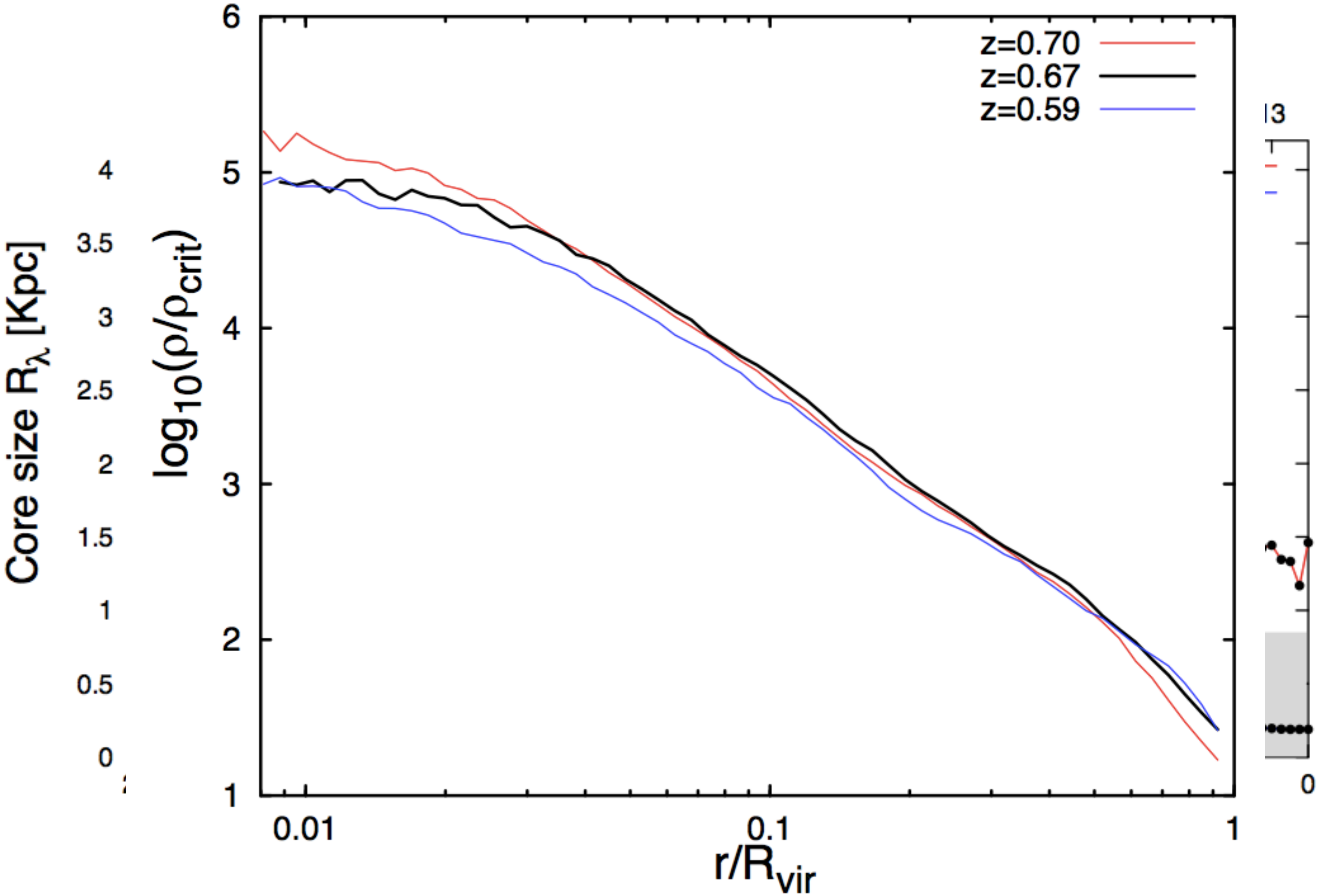


The DM distribution *evolution*

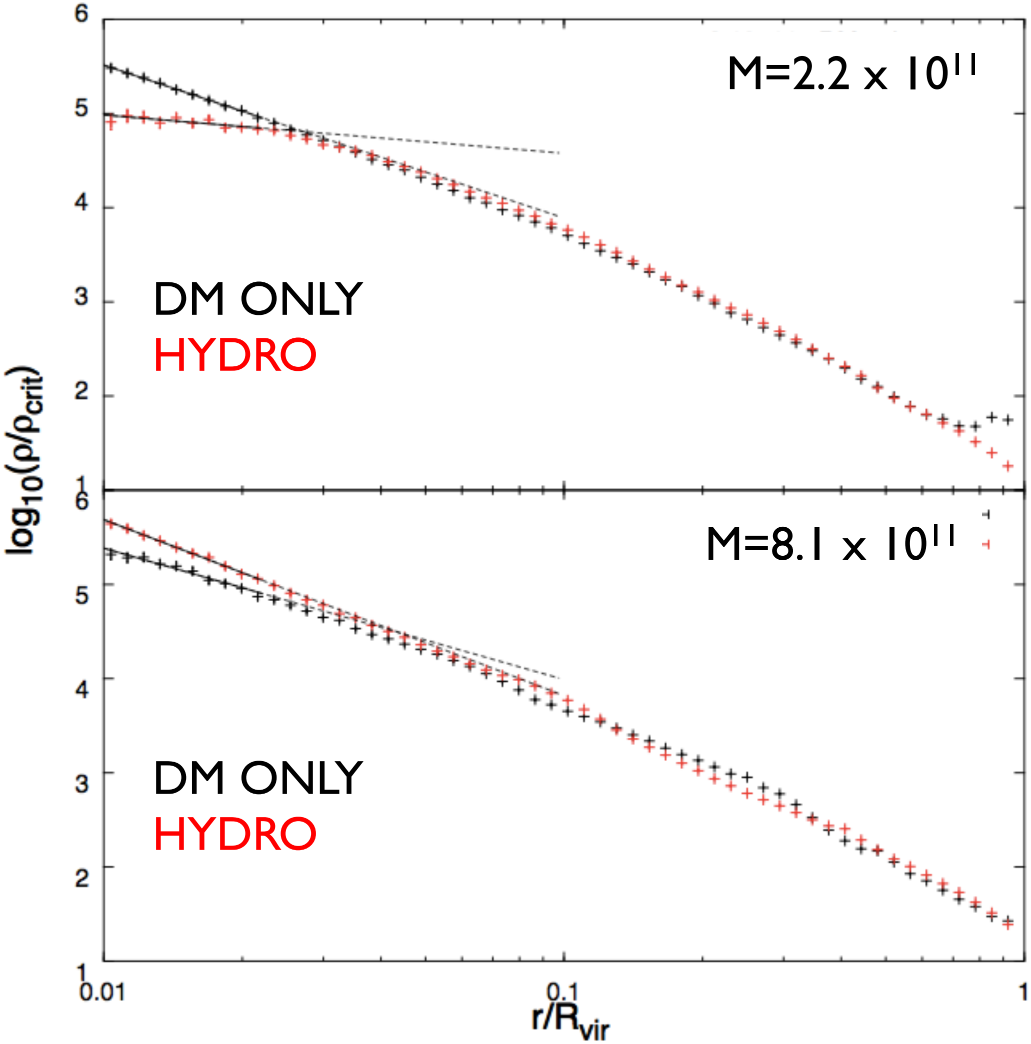


Core creation and core destruction

Core creation and core destruction



Why are cored destructed?

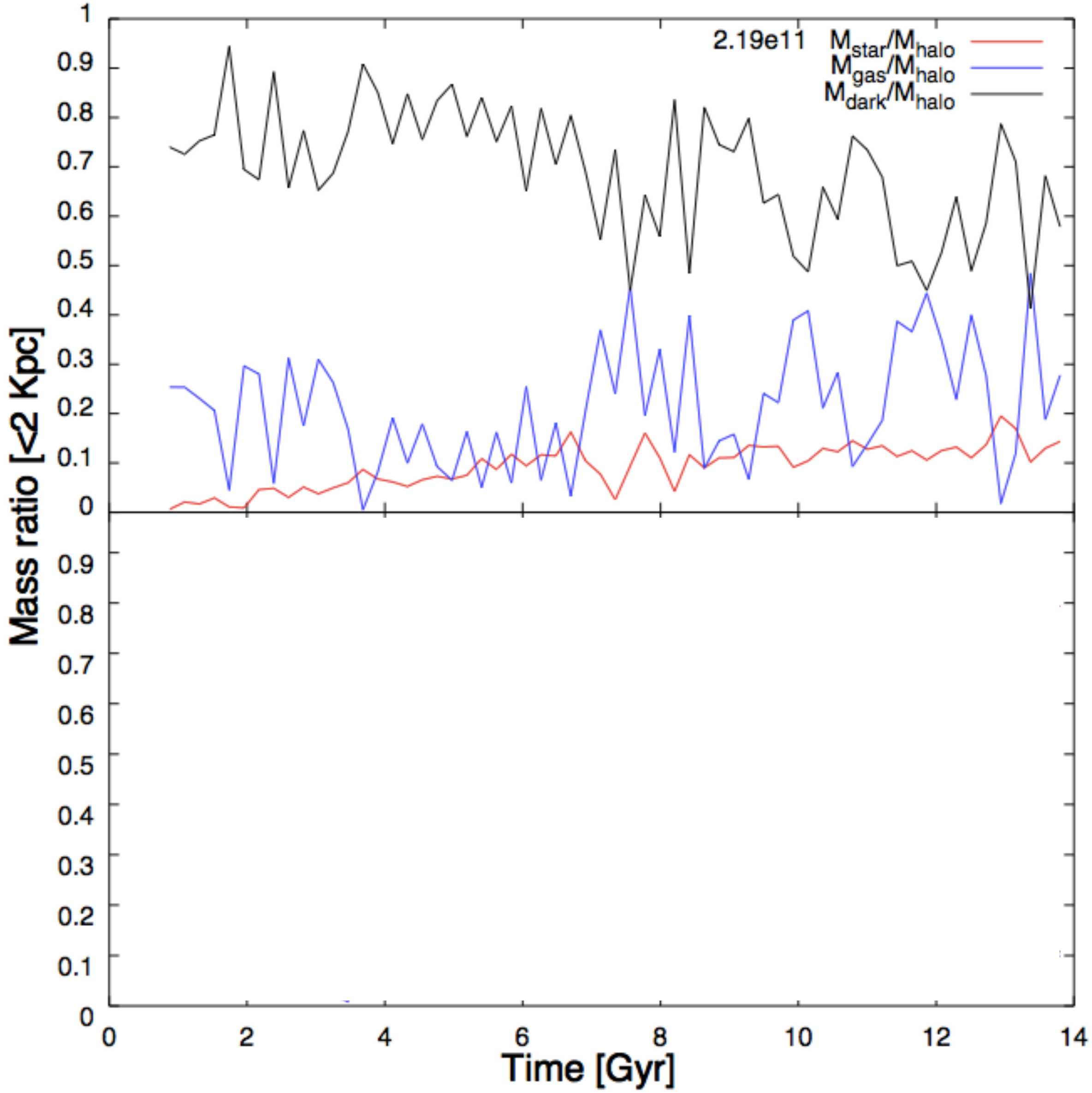


Halo Expansion

Halo Contraction

Tollet, Macciò+ 2015

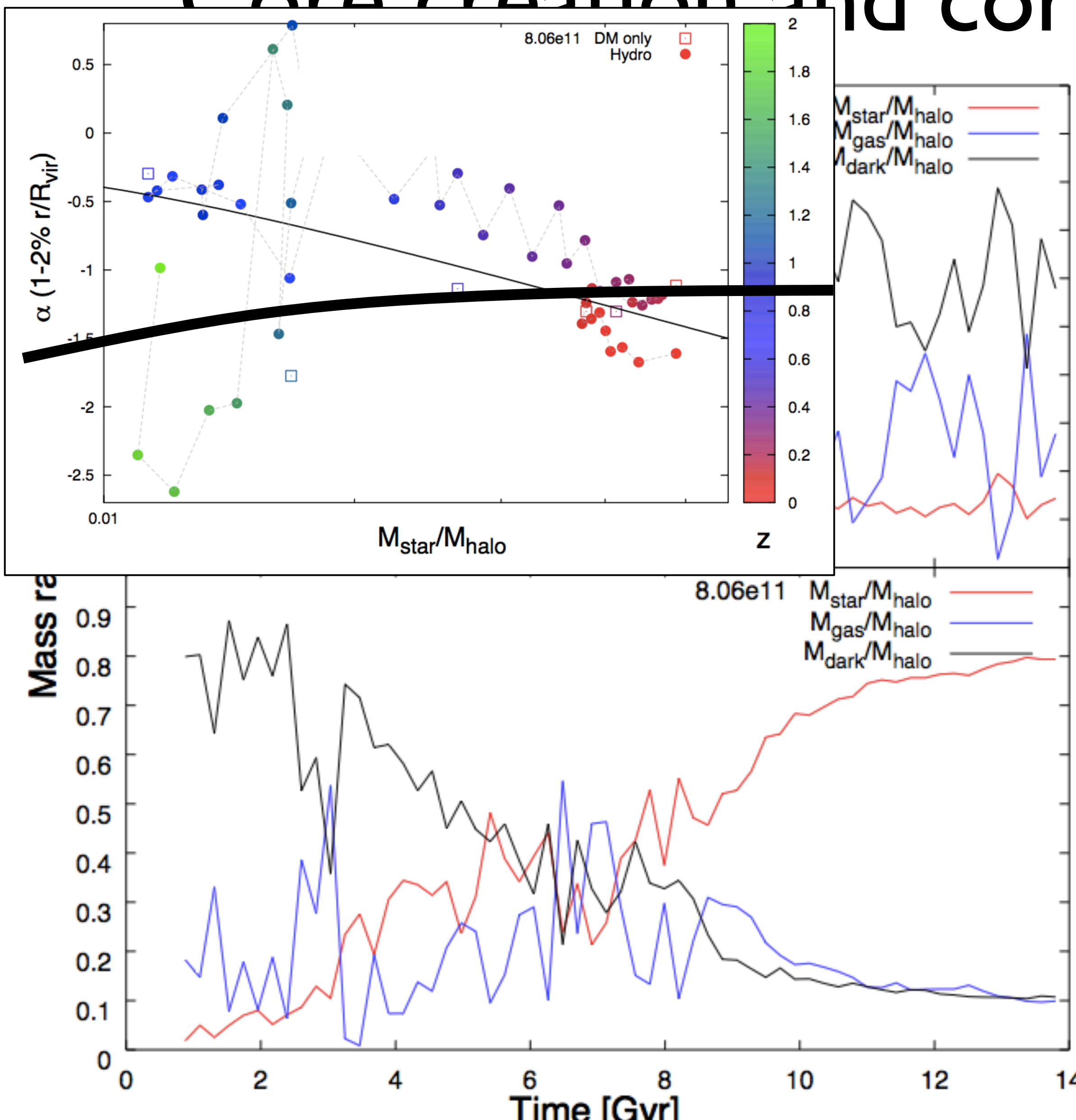
Core creation and core destruction



Halo Expansion

Halo Contraction

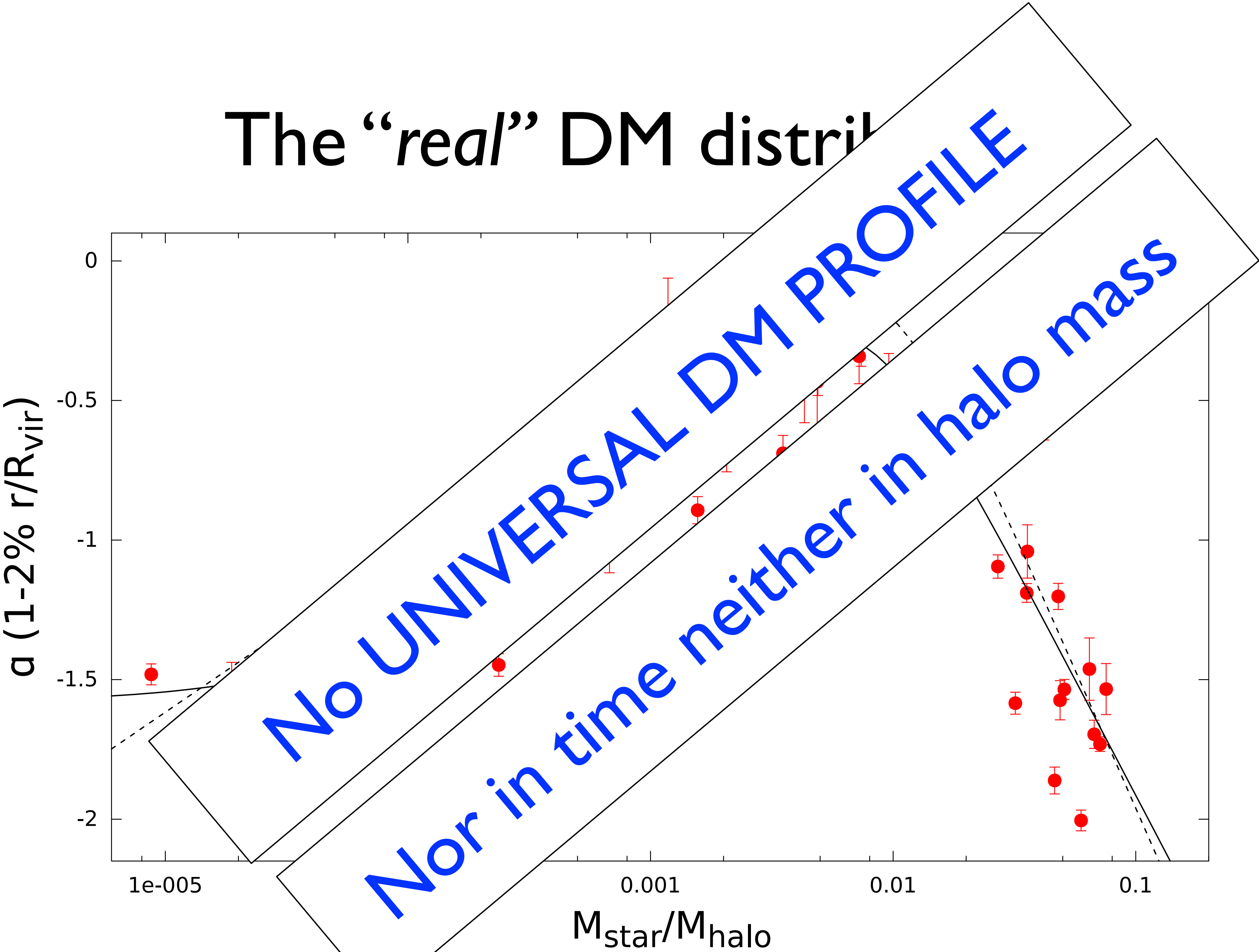
Core creation and core destruction



Halo Expansion

Halo Contraction

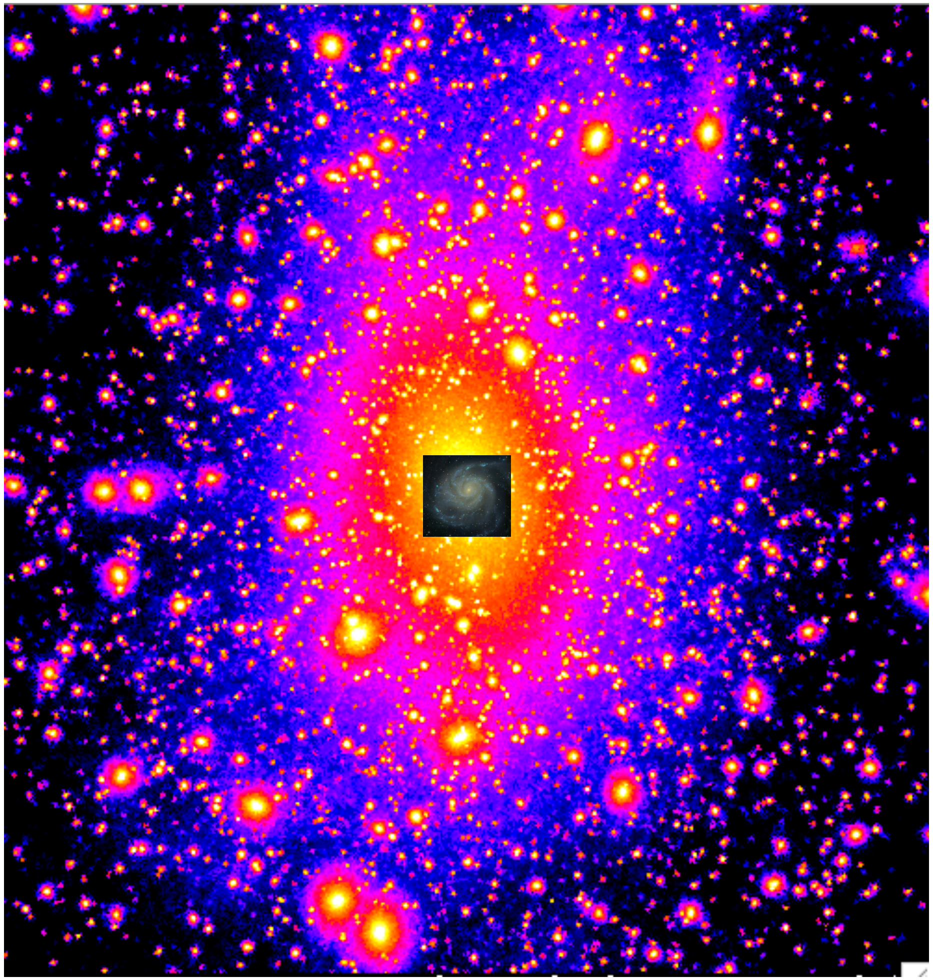
The “*real*” DM distrib



Dark Matter velocity distribution

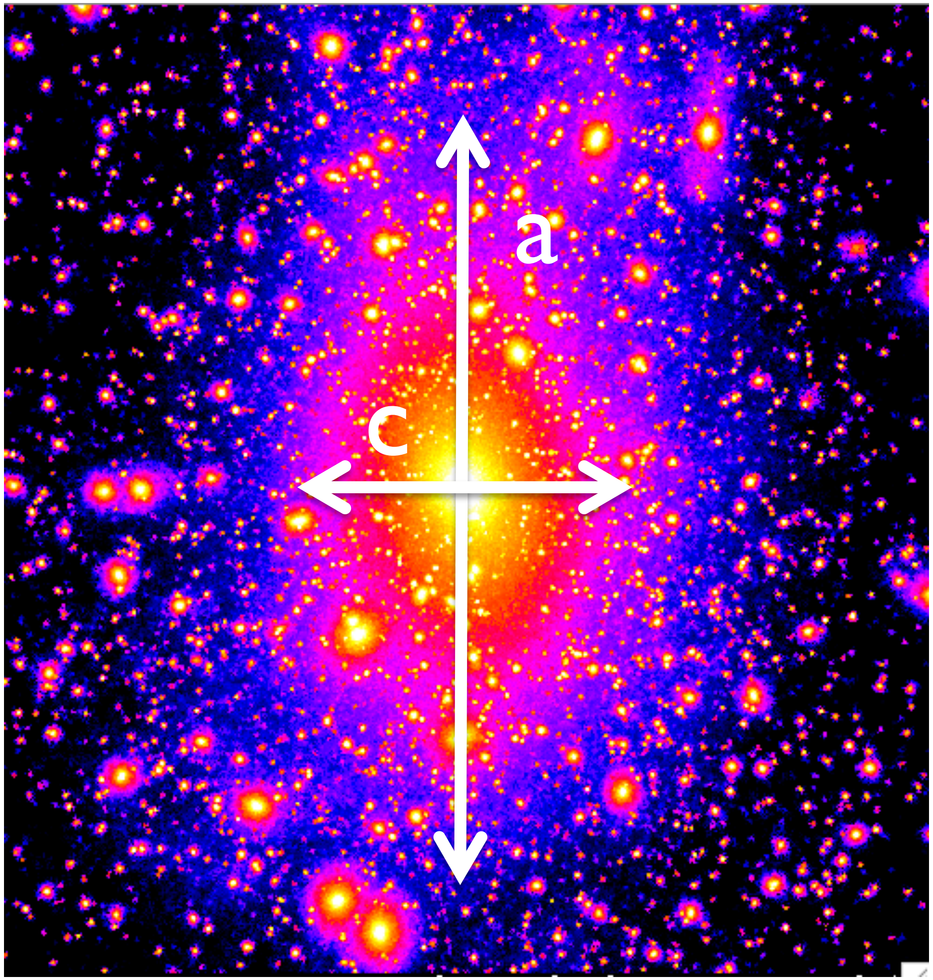
- Direct detection: ρ , f(v)

- Indirect detection: ρ^2

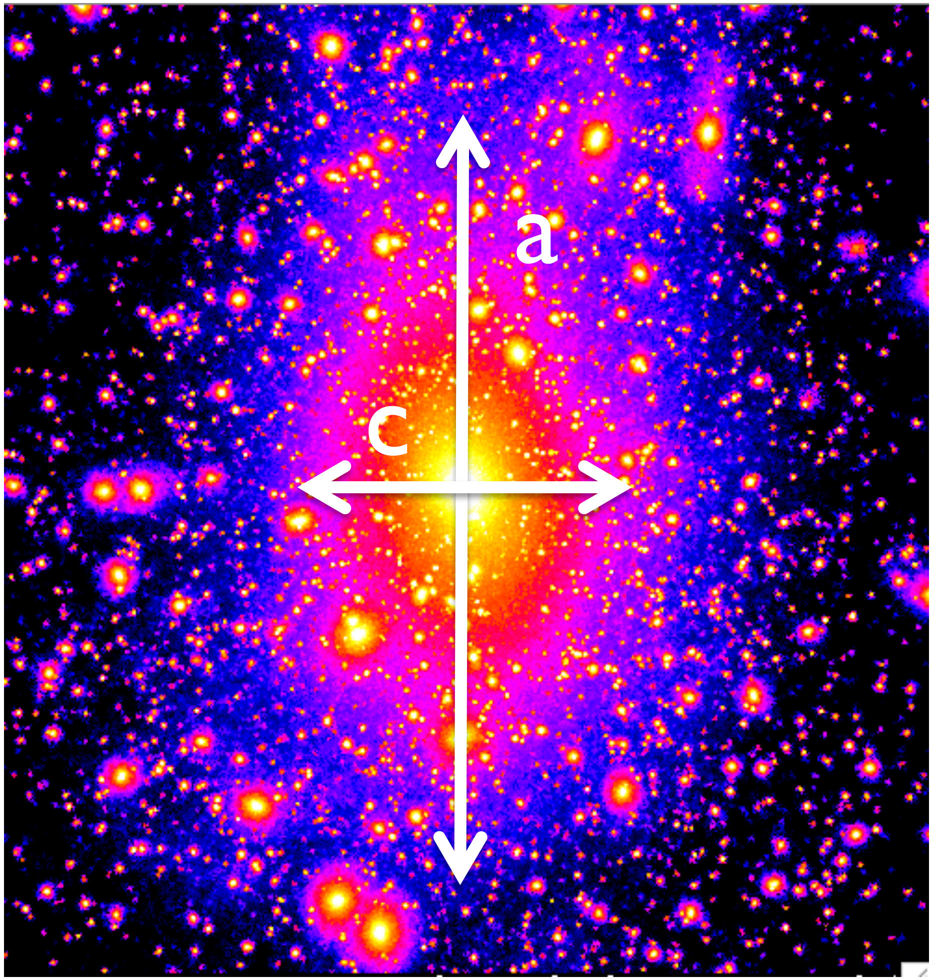


Butsky, Macciò+2015,
arXiv 1503.04814

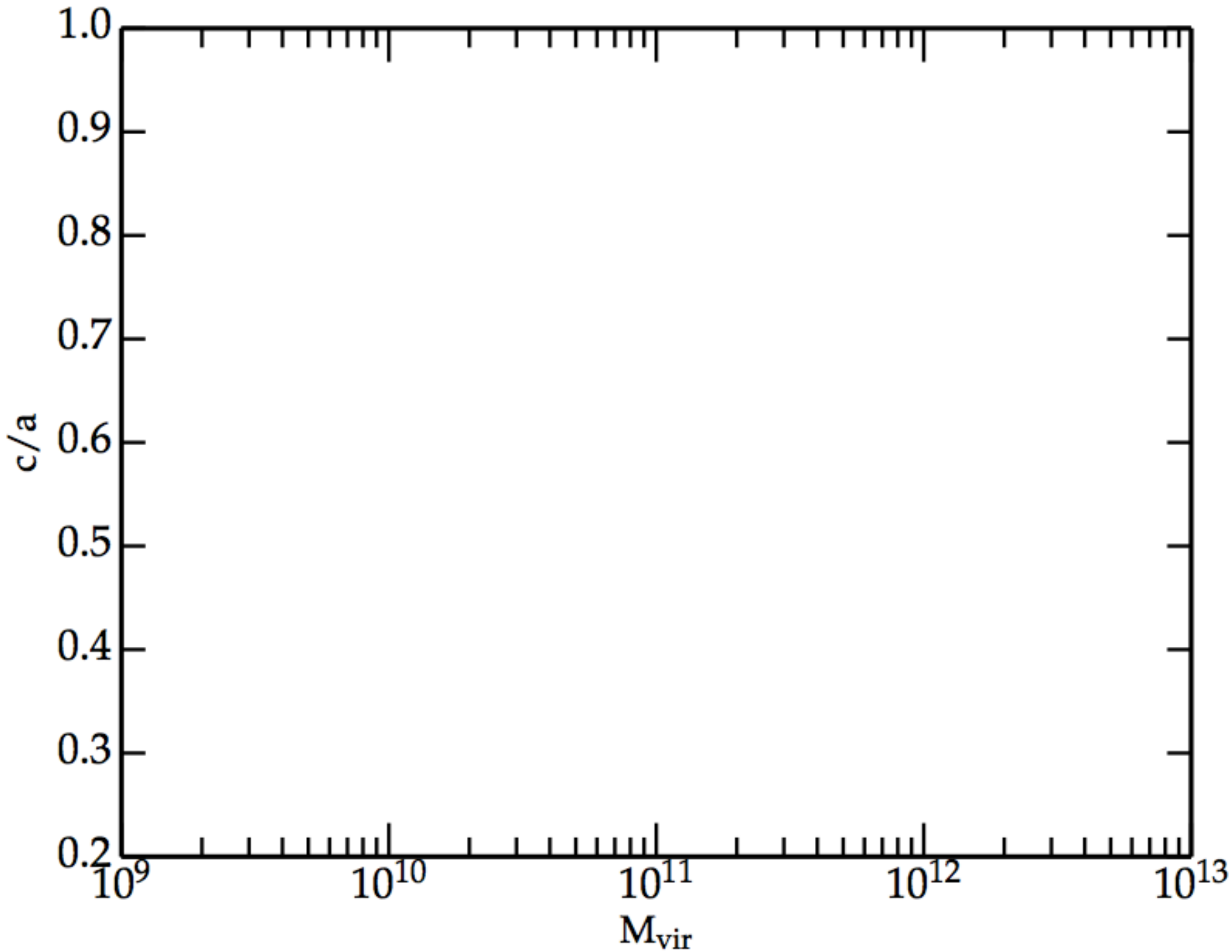
DM halo shape and f(v)



DM halo shape and f(v)

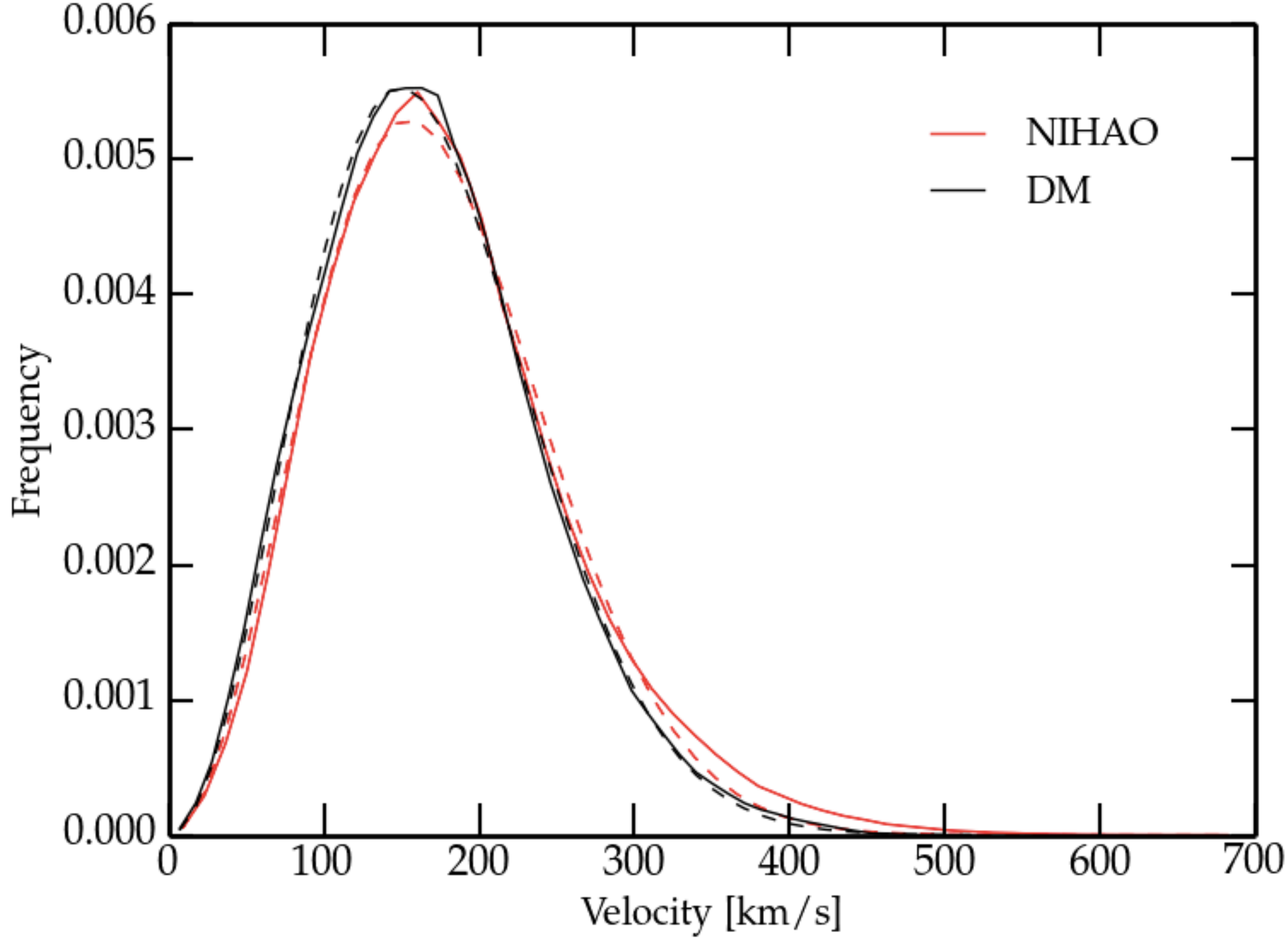


DM halo shape and f(v)

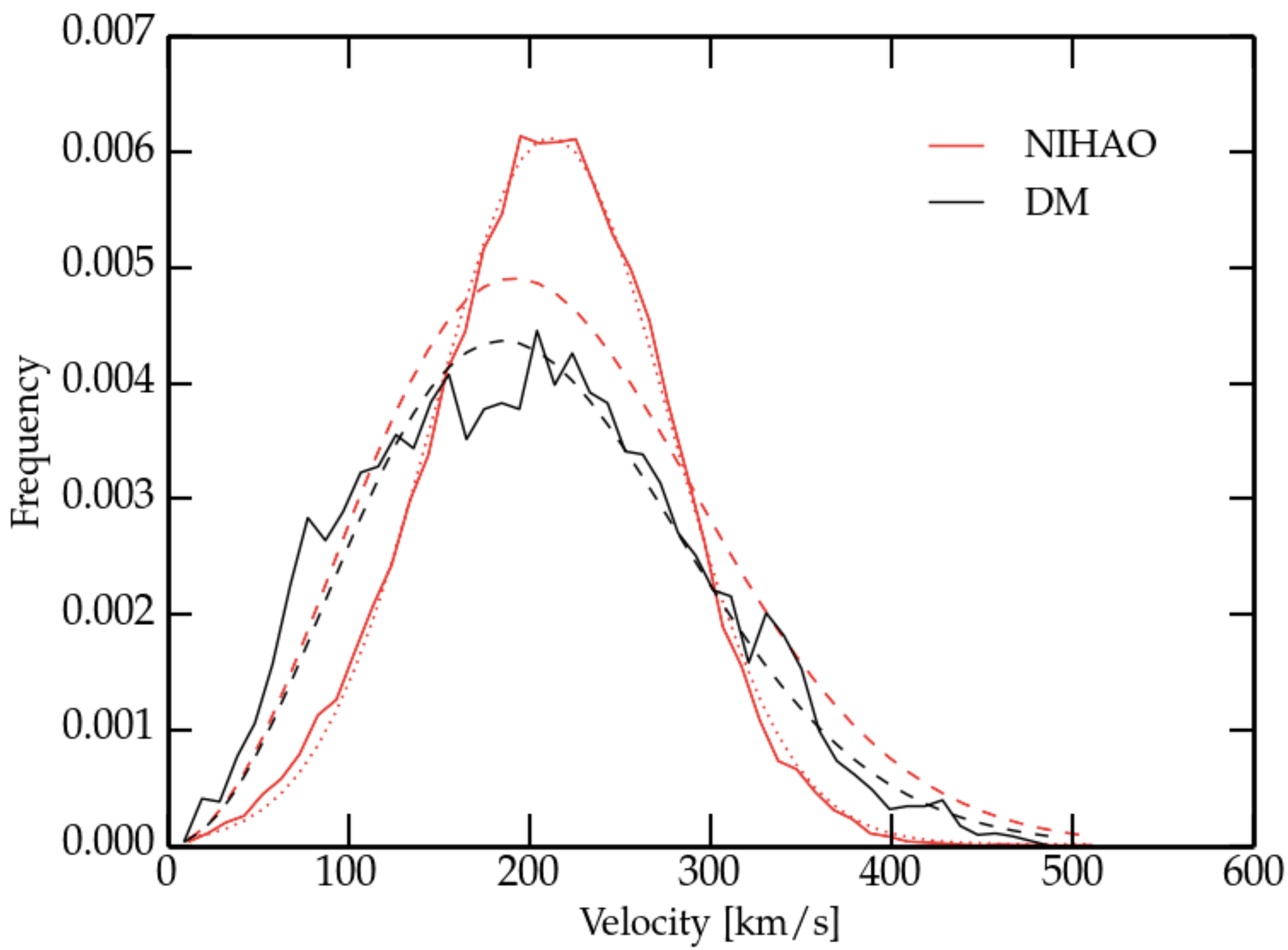


Butsky, Macciò+2015

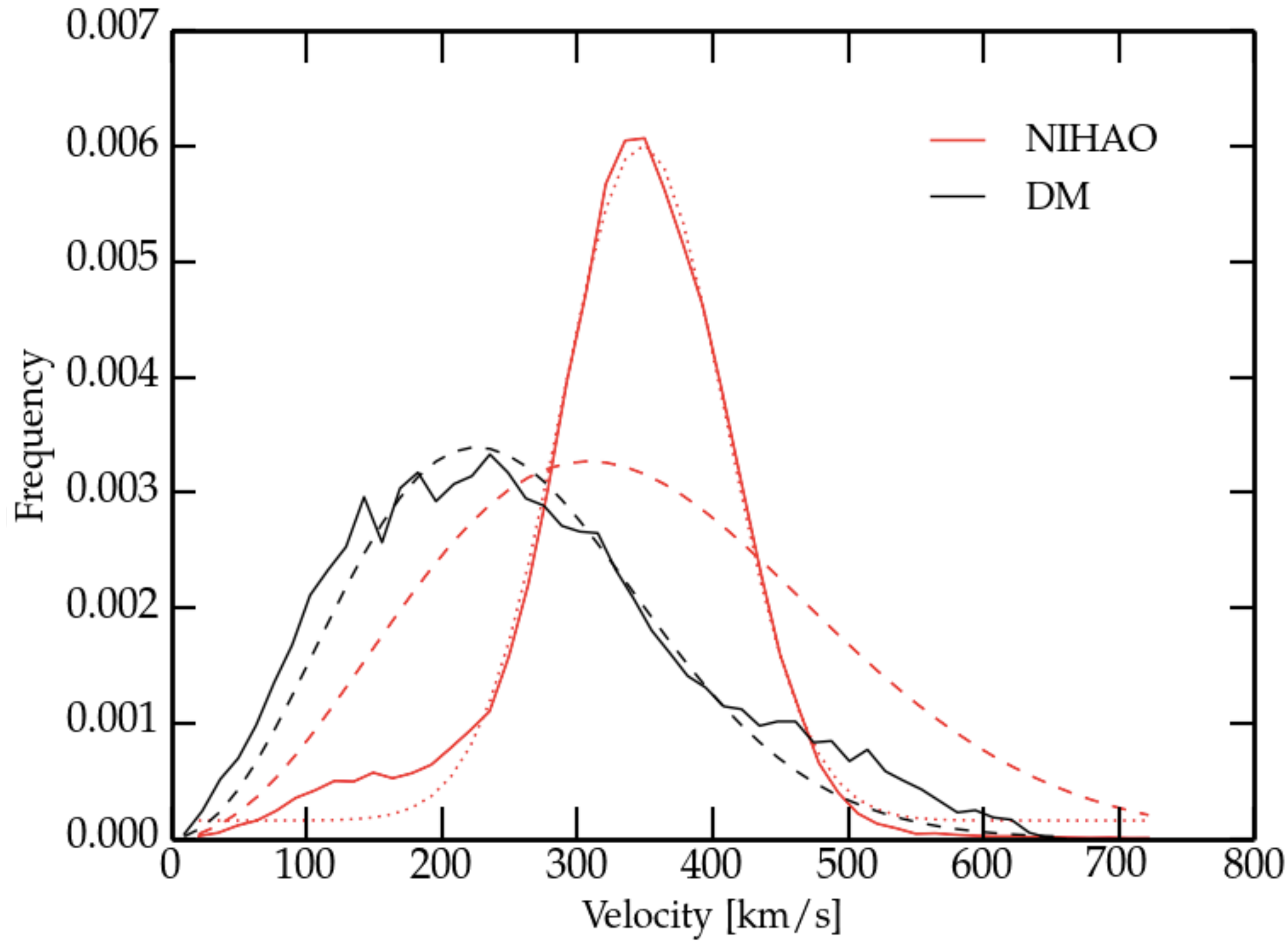
Global velocity distribution



Solar neighbors velocity distribution



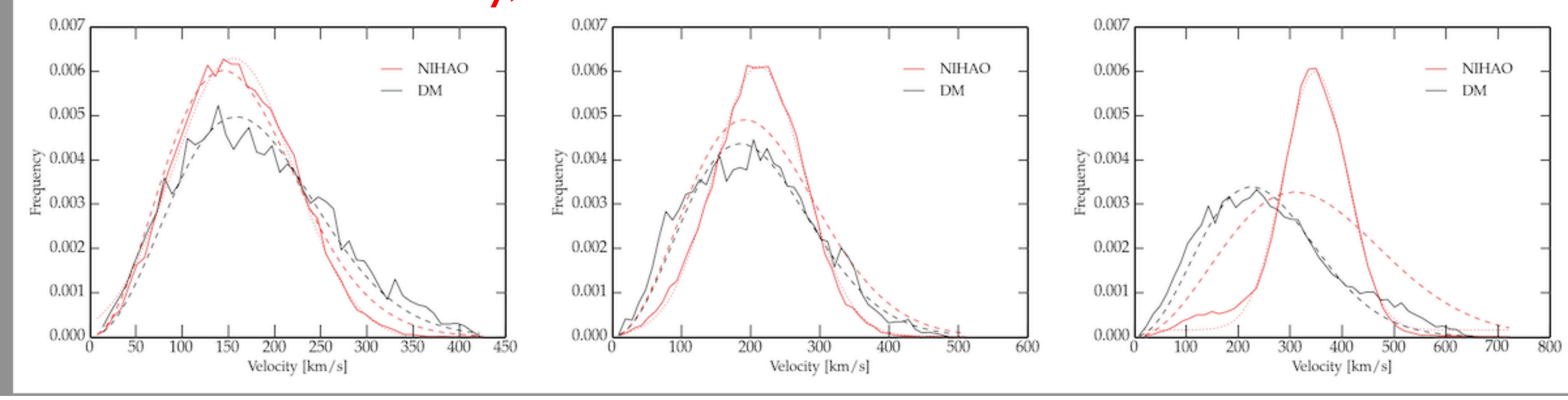
Solar neighbors velocity distribution



DM halo shape and f(v)

- DM Haloes are rounder when galaxy formation is taken into account
- Reshuffling of DM particles orbits (especially in the center)
- Gaussian velocity distribution (central limit theorem)

Butsky, Macciò+2015 arXiv:1503.04814



Conclusions

DM distribution in galaxies is strongly affected by baryons

NO universal profiles: cores and cusps are created and destroyed depending on stellar-to-halo mass and star formation history

DM velocity distribution is Gaussian and not Maxwellian

Take home message

Any comparisons of theoretical predictions with observational data can no longer rely on pure collisionless simulations, but must include the effects of visible matter.

Thank you