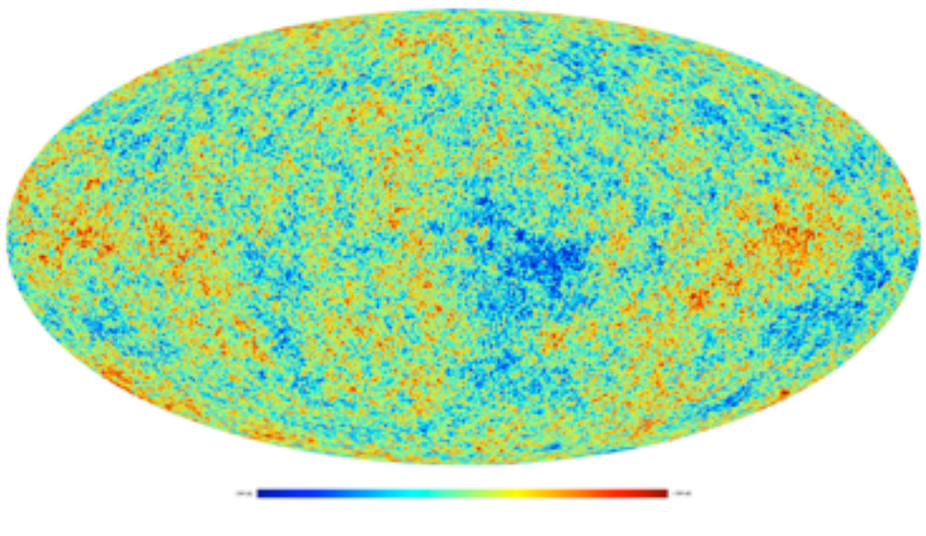
Astrophysical probes of dark matter

Prof. Justin Read, University of Surrey
Alexander Hobbs, Oscar Agertz, Silvia Garbari, George Lake, Romain Teyssier

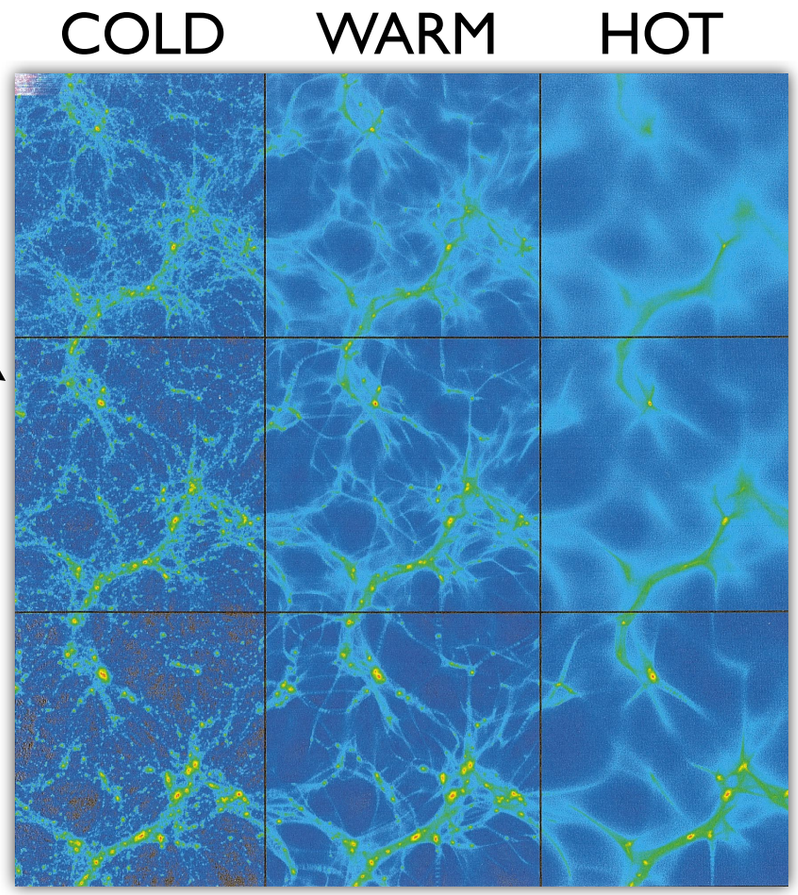
Background | Probing dark matter through gravity

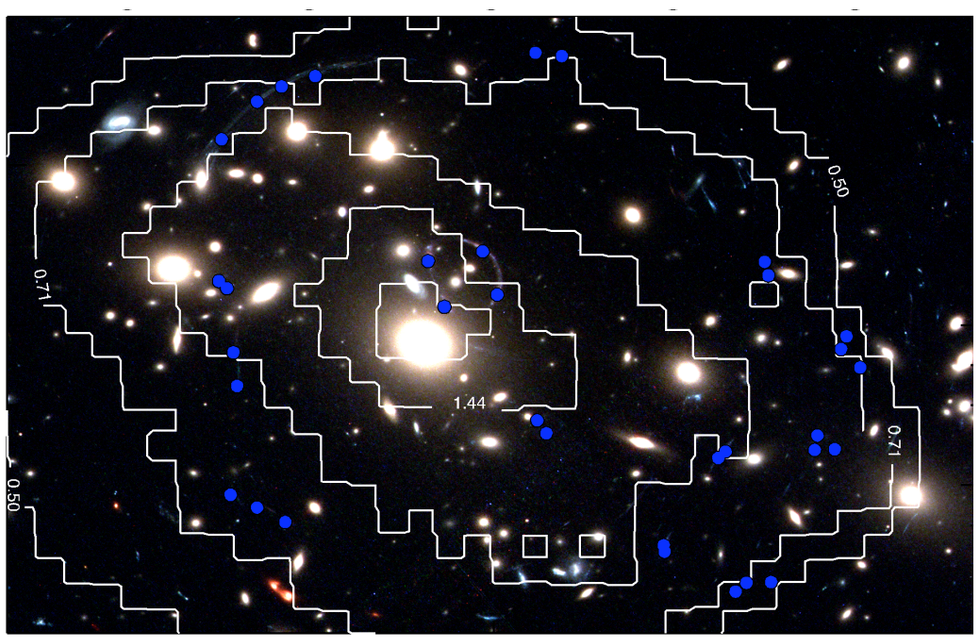
CMB



N-body

[Assume something about dark matter, cosmology, and galaxy formation]





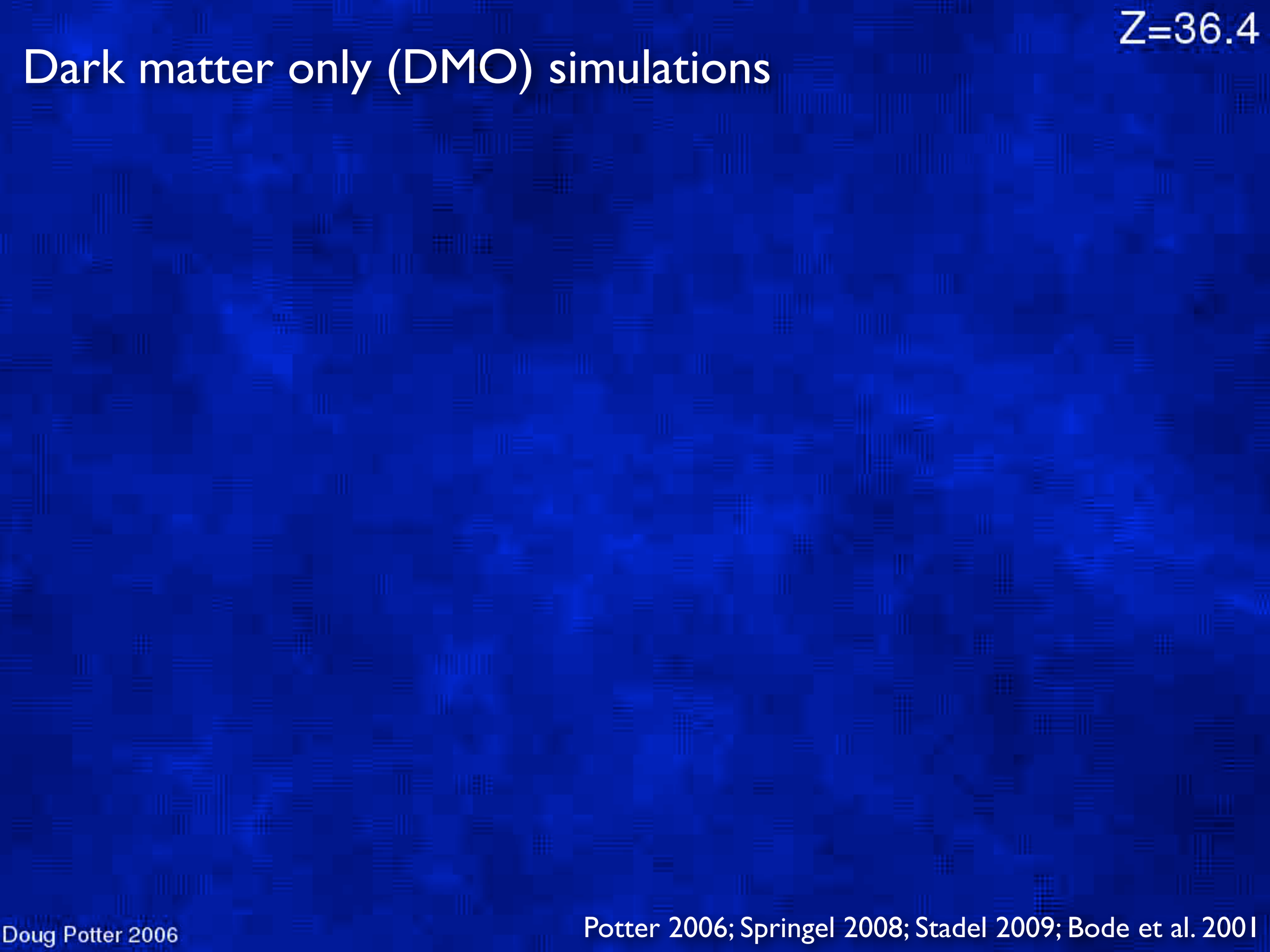
Observation

[e.g. rotation curves; lensing; galaxy counts etc.]

Gravity

['Dark Matter Only' (DMO) simulations]

Dark matter only (DMO) simulations

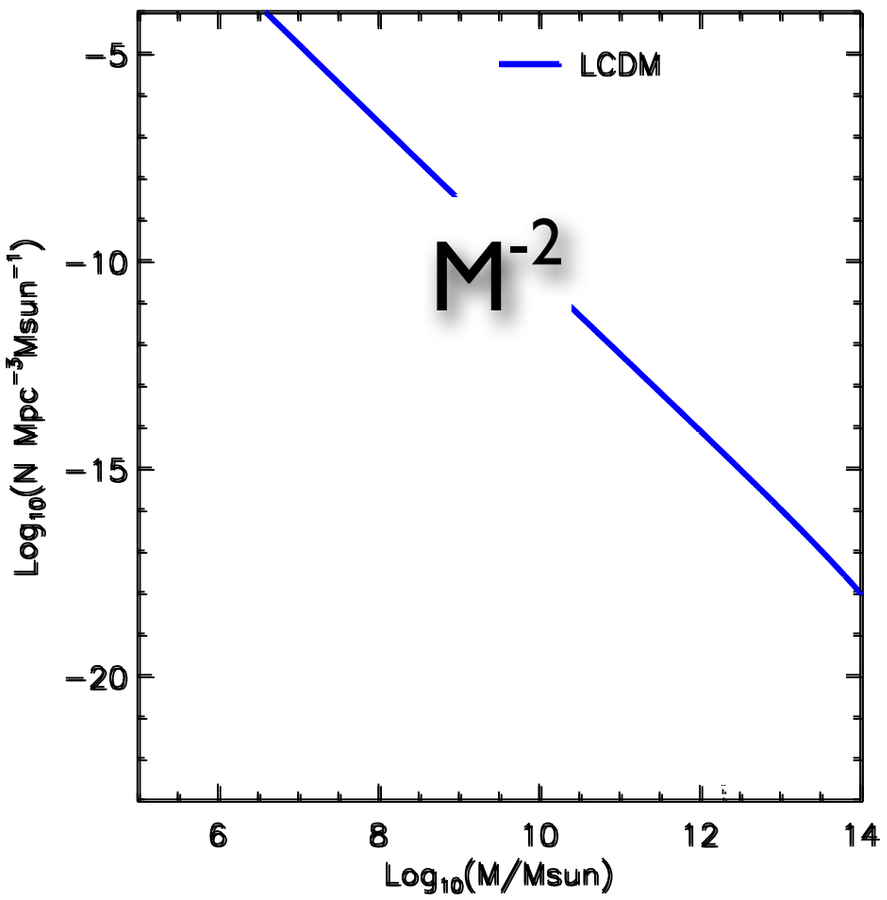


Potter 2006; Springel 2008; Stadel 2009; Bode et al. 2001

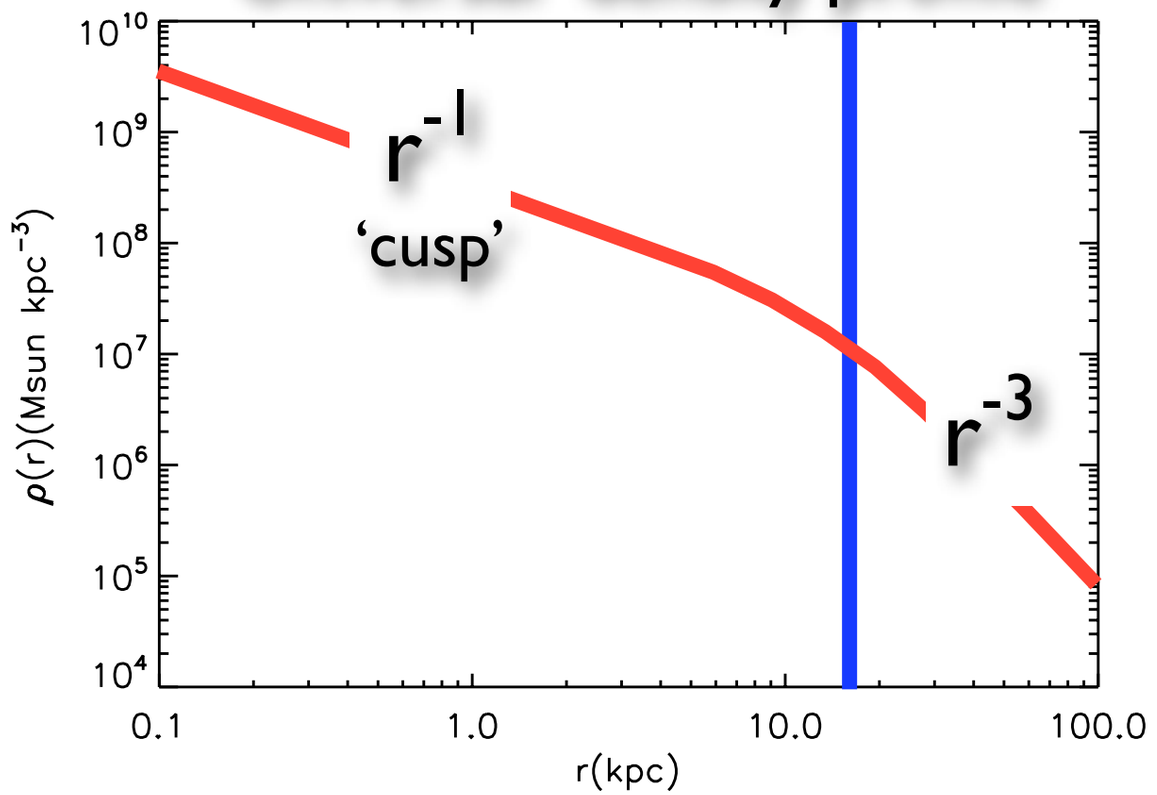
Dark matter only (DMO) simulations

Z=0.18

Halo mass function



'Universal' density profile

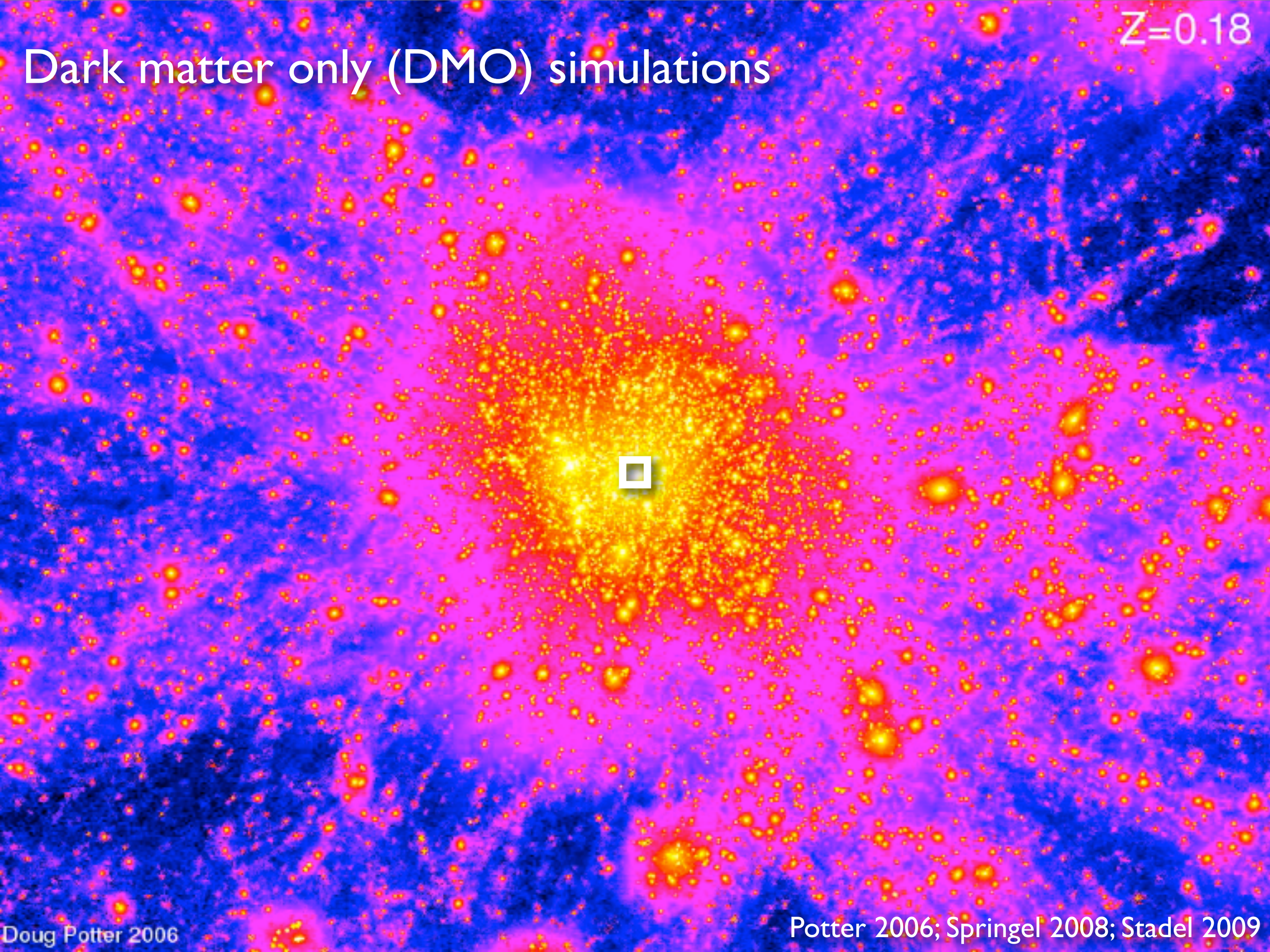


Navarro, Frenk & White 1996

Doug Potter 2006

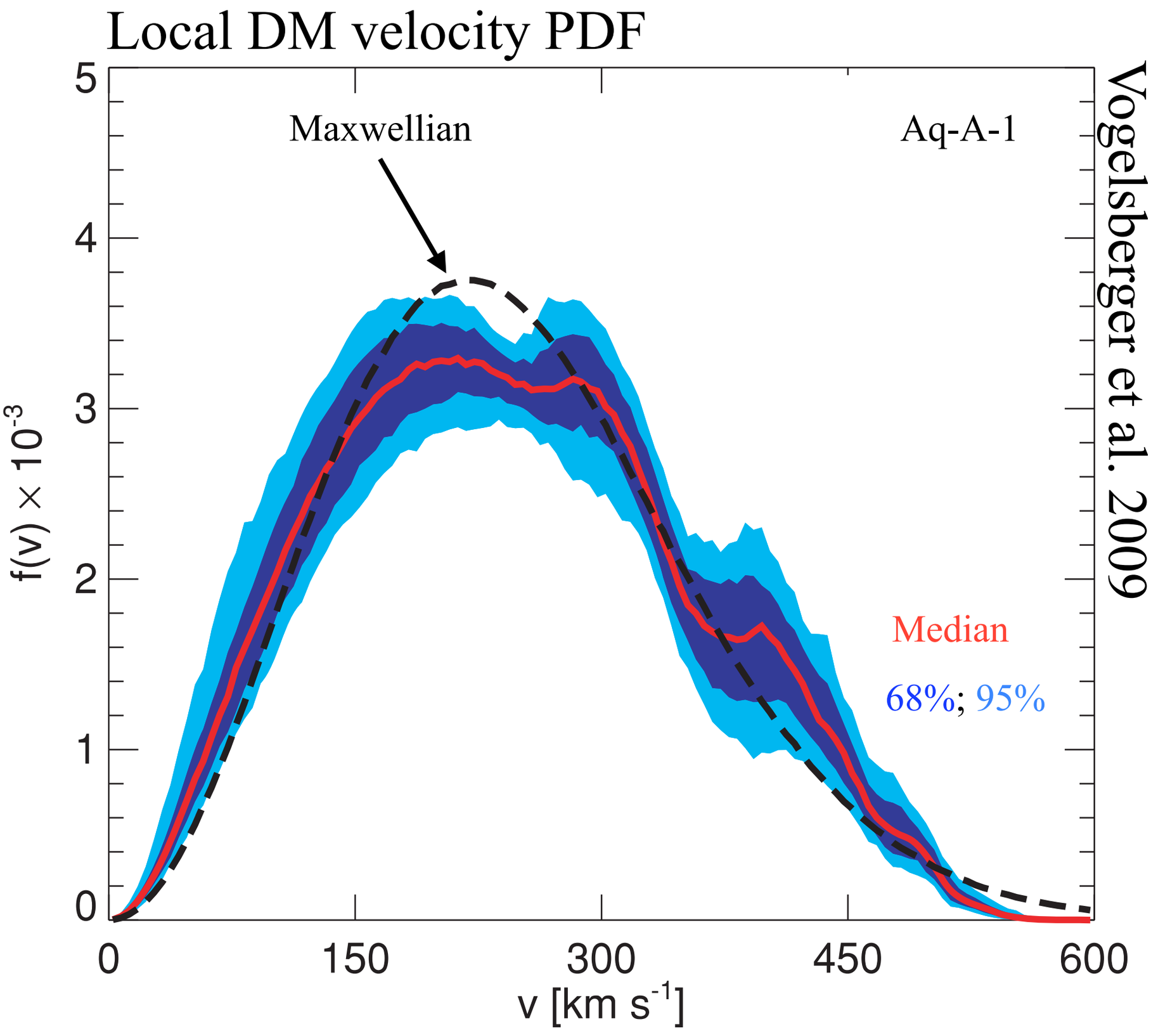
Potter 2006; Springel 2008; Stadel 2009; Bode et al. 2001

Dark matter only (DMO) simulations

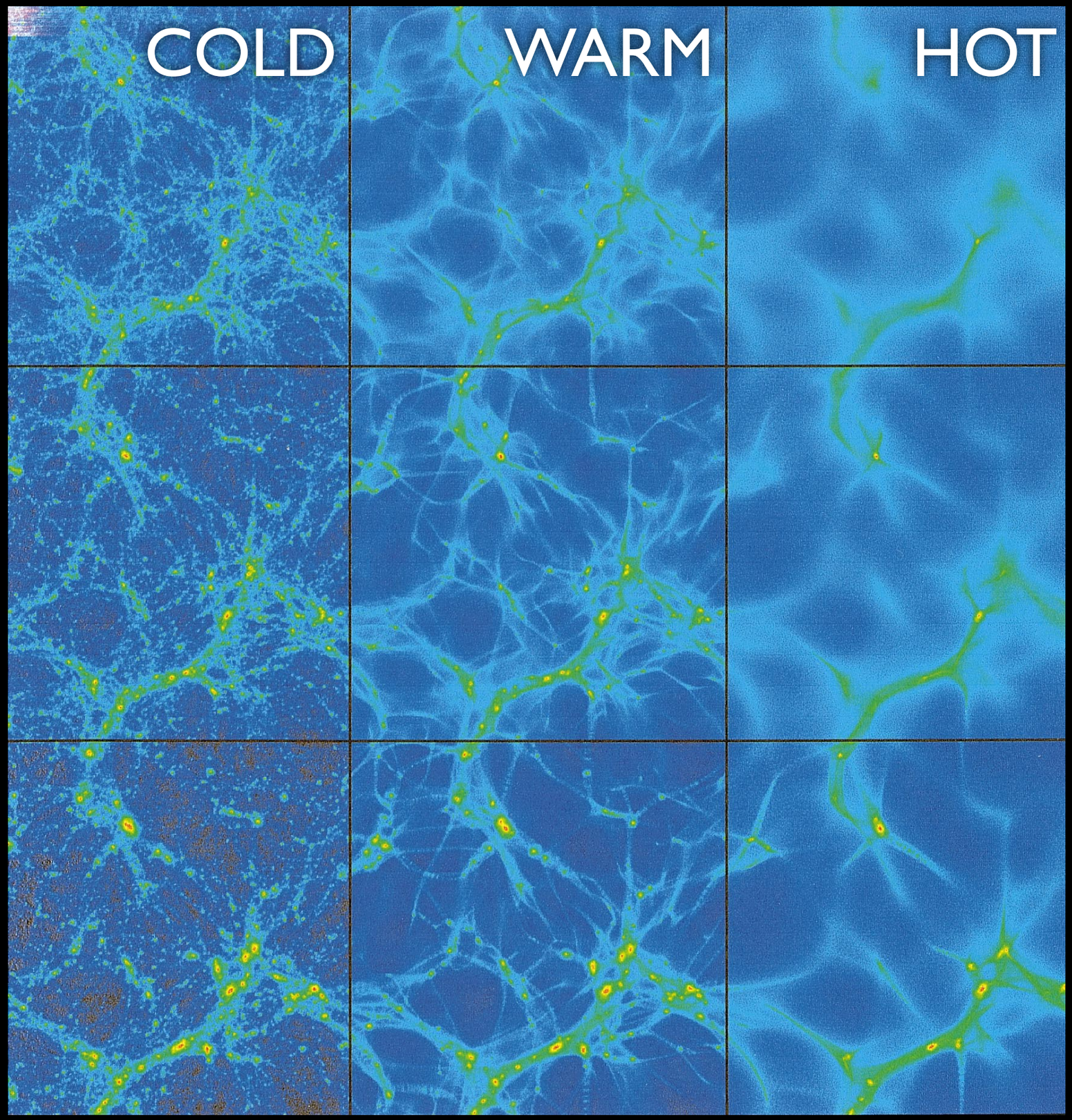


Potter 2006; Springel 2008; Stadel 2009

Dark matter only (DMO) simulations

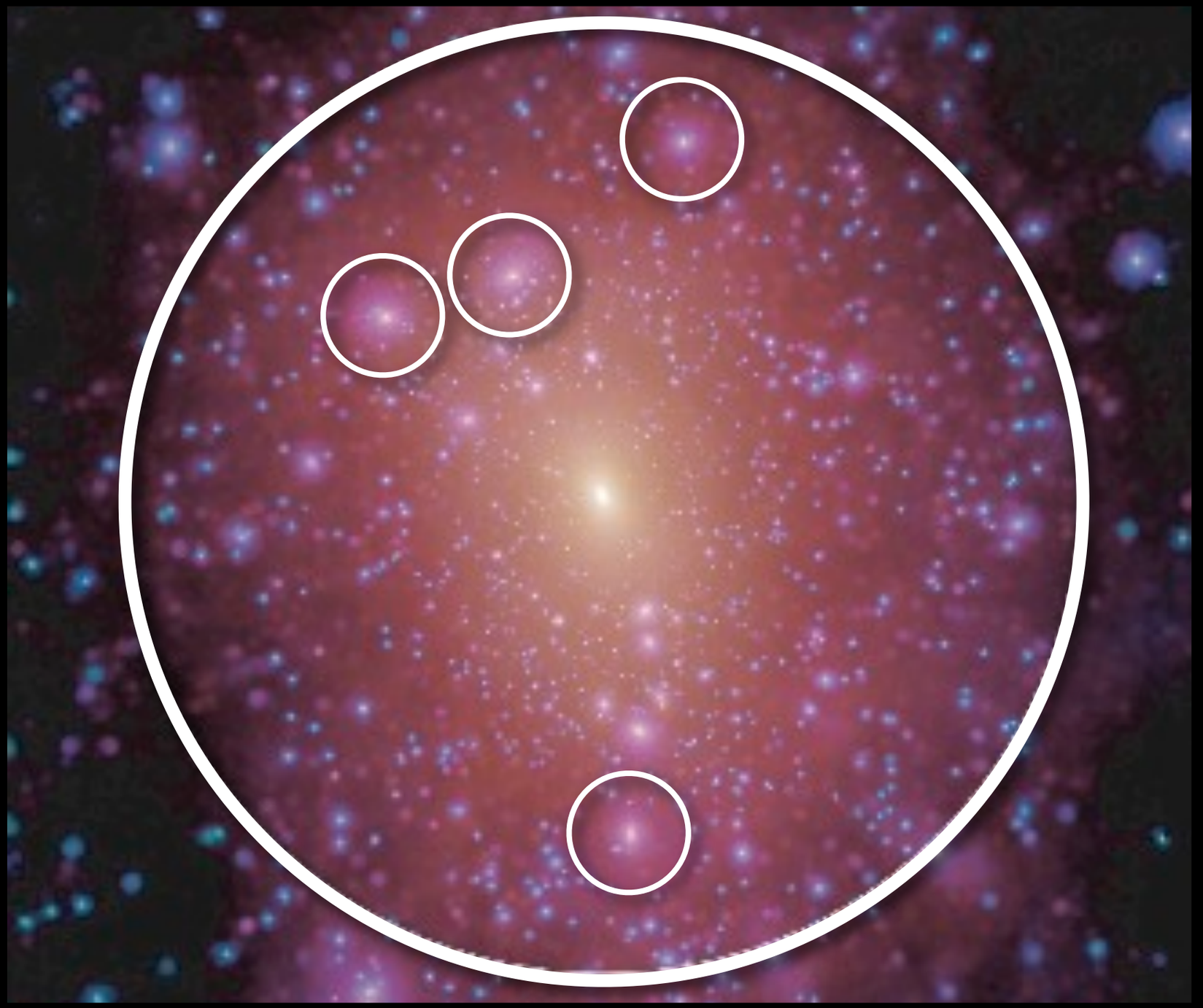


Dark matter only (DMO) simulations



Bode et al. 2001

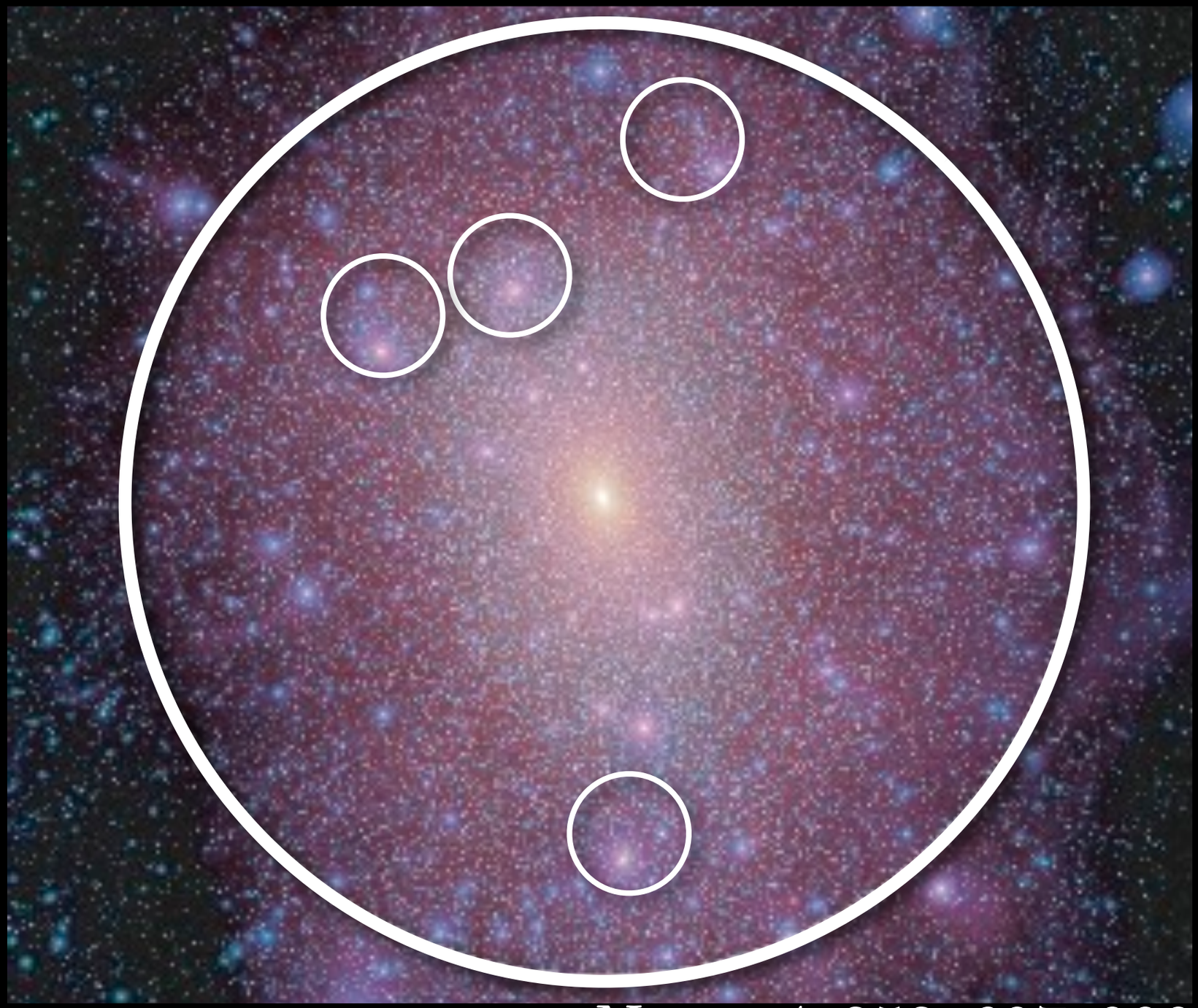
Dark matter only (DMO) simulations



$N_{\rm hr} = 18,535,972$

GHALO; Stadel et al. 2009 | Aquarius; Springel et al. 2008

Dark matter only (DMO) simulations



$N_{\rm hr} = 4,252,607,000$

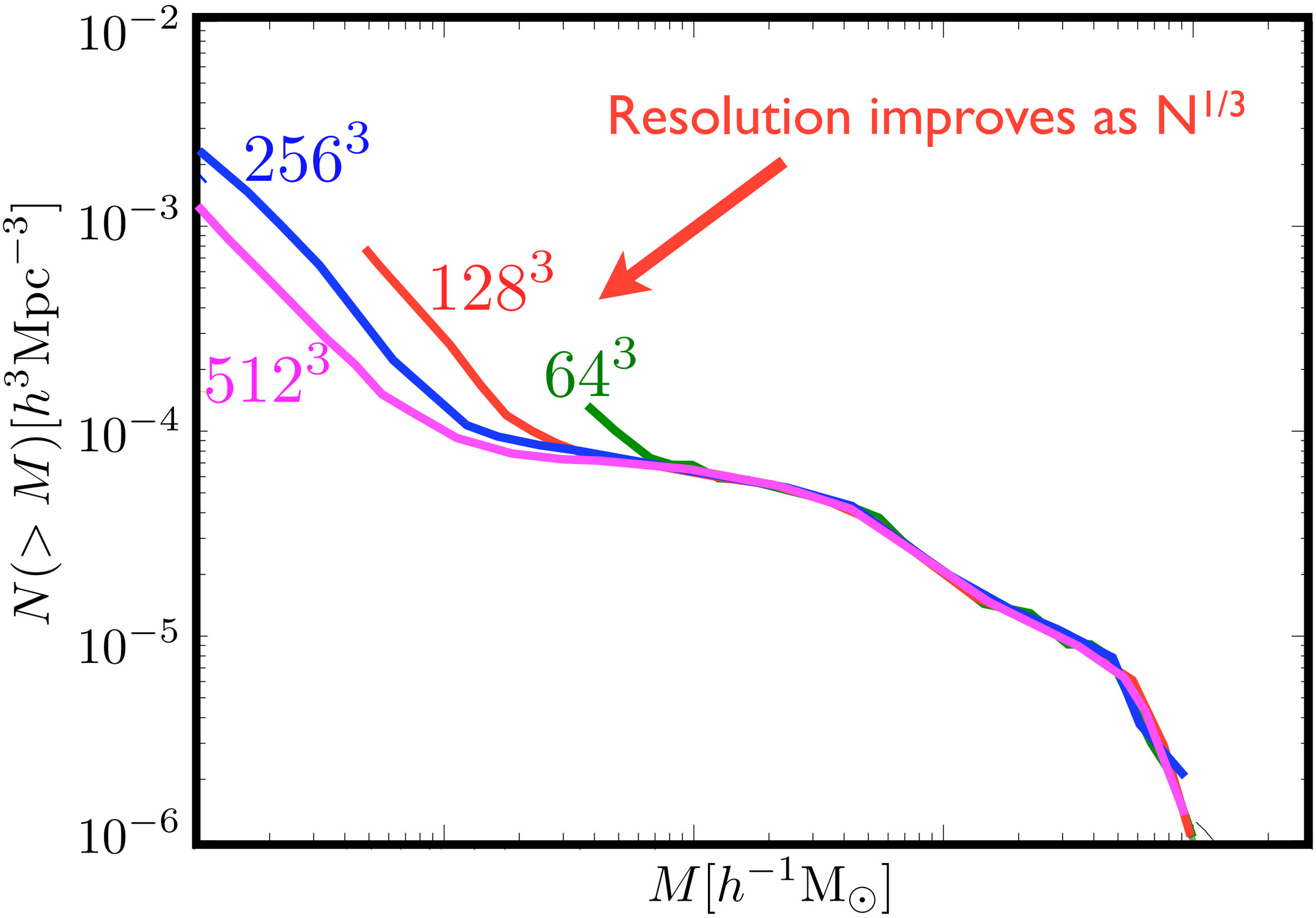
GHALO; Stadel et al. 2009 | Aquarius; Springel et al. 2008

Dark matter only (DMO) simulations | Warm Dark Matter

Spurious halos?

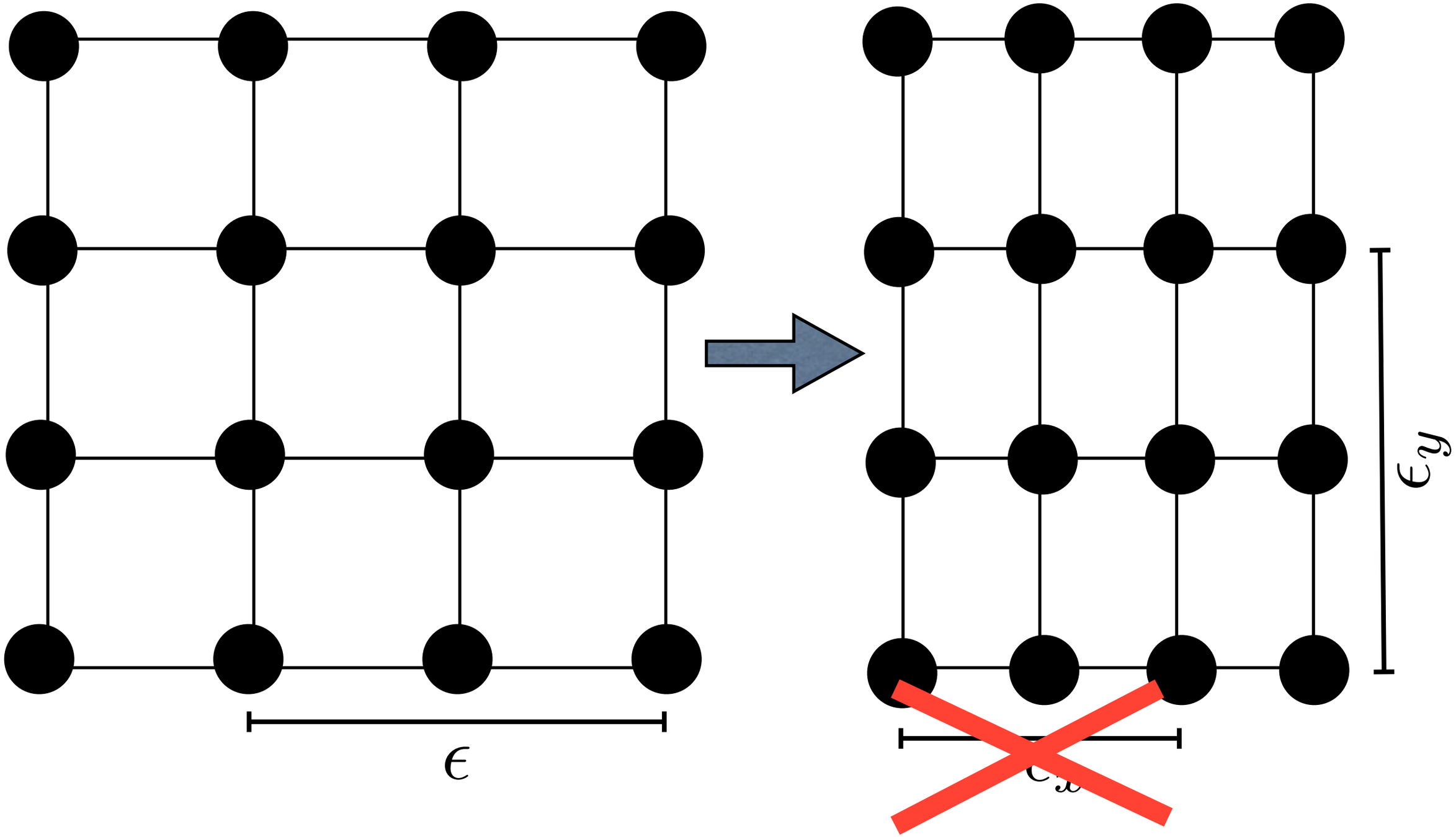
GADGET | Maccio et al. 2012

Dark matter only (DMO) simulations | Warm Dark Matter



GADGET | Wang & White 2007

Dark matter only (DMO) simulations | Warm Dark Matter



Hobbs, Read et al. in prep. 2013 and see Hahn et al. 2013

Dark matter only (DMO) simulations | Warm Dark Matter

$\epsilon = 2\Delta x$

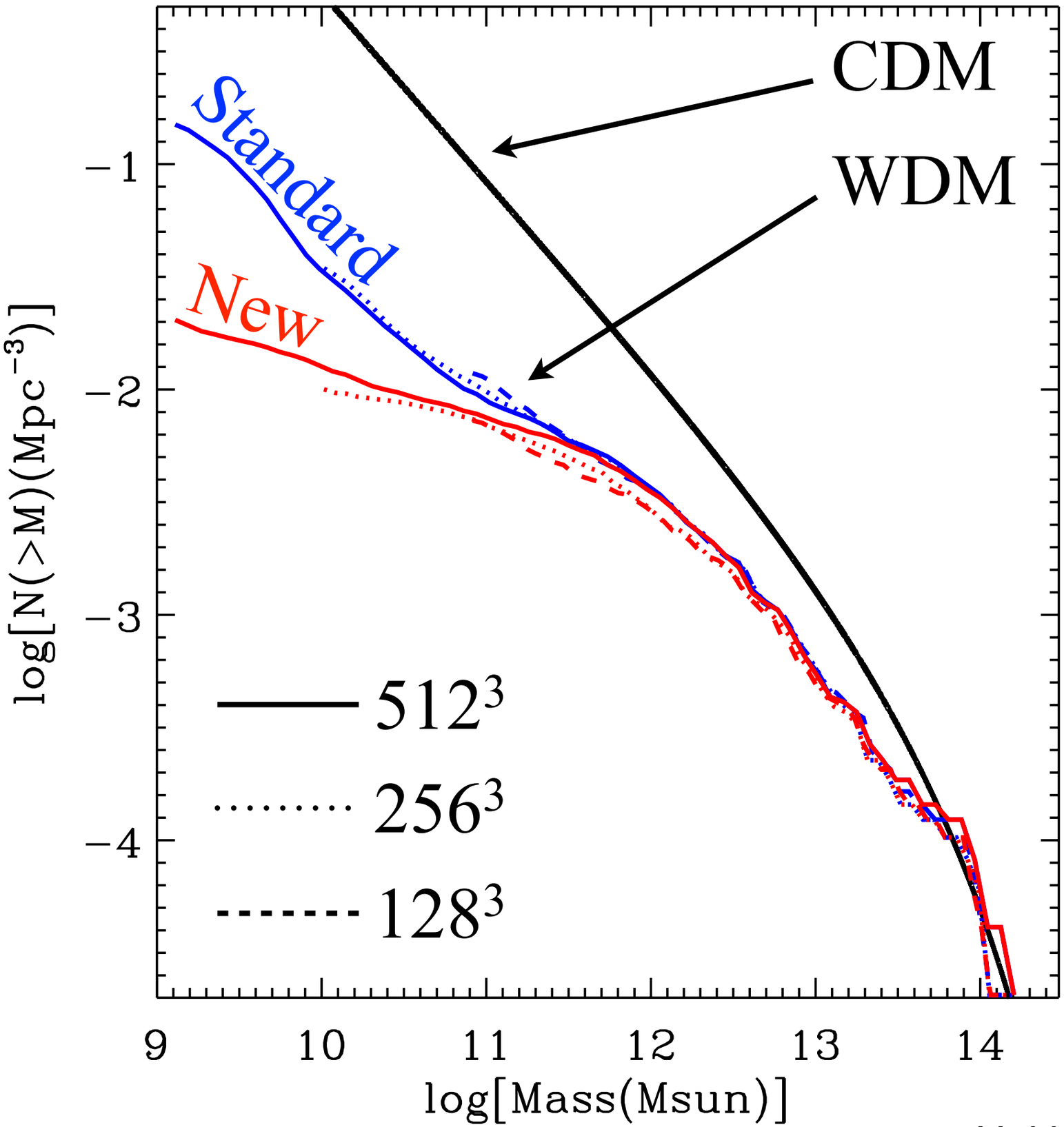
RAMSES | Hobbs, Read et al. in prep. 2013

Dark matter only (DMO) simulations | Warm Dark Matter

$$\epsilon = 2\max[\Delta x]$$

RAMSES | Hobbs, Read et al. in prep. 2013

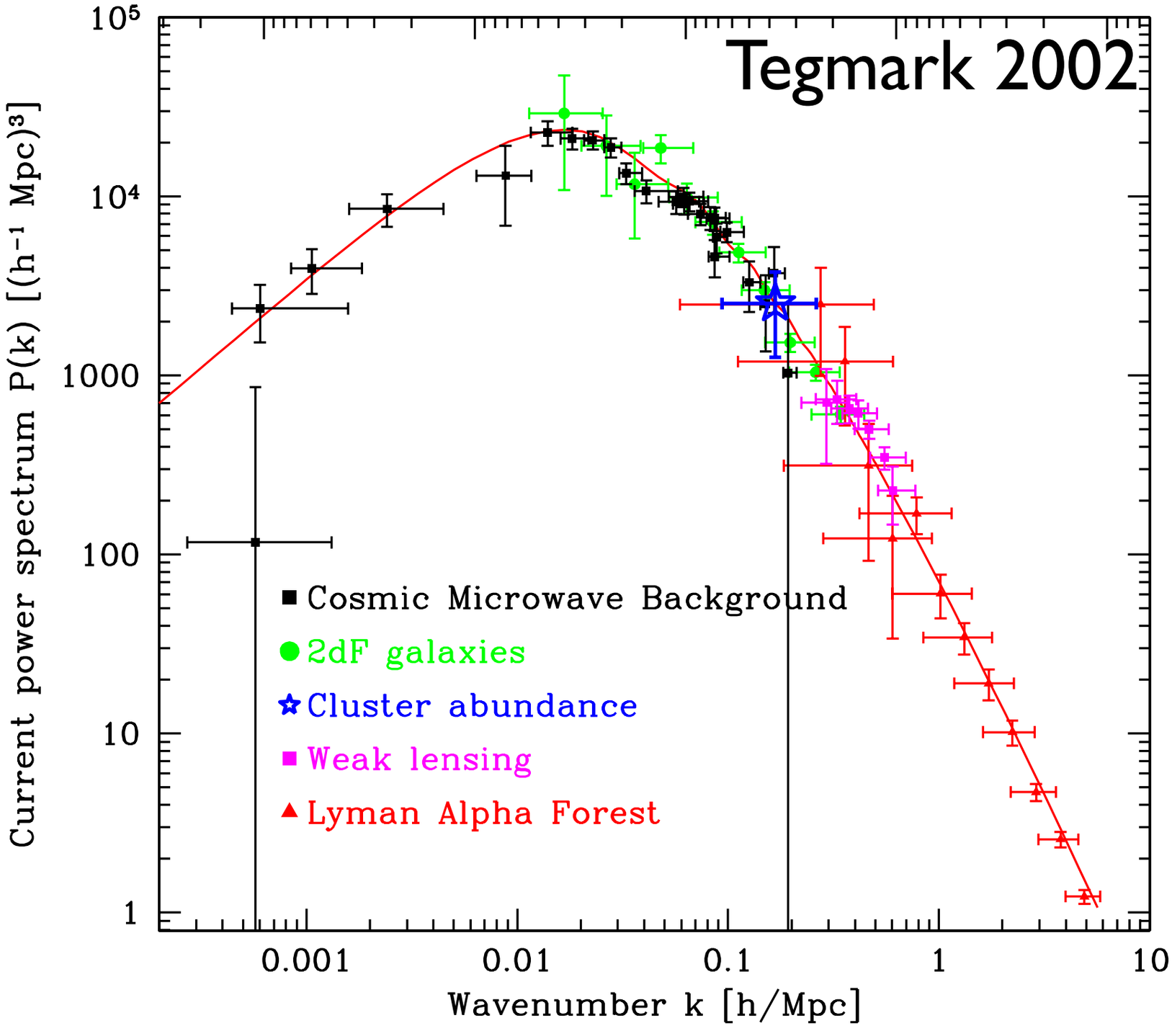
Dark matter only (DMO) simulations | Warm Dark Matter



Hobbs, Read et al. in prep. 2013

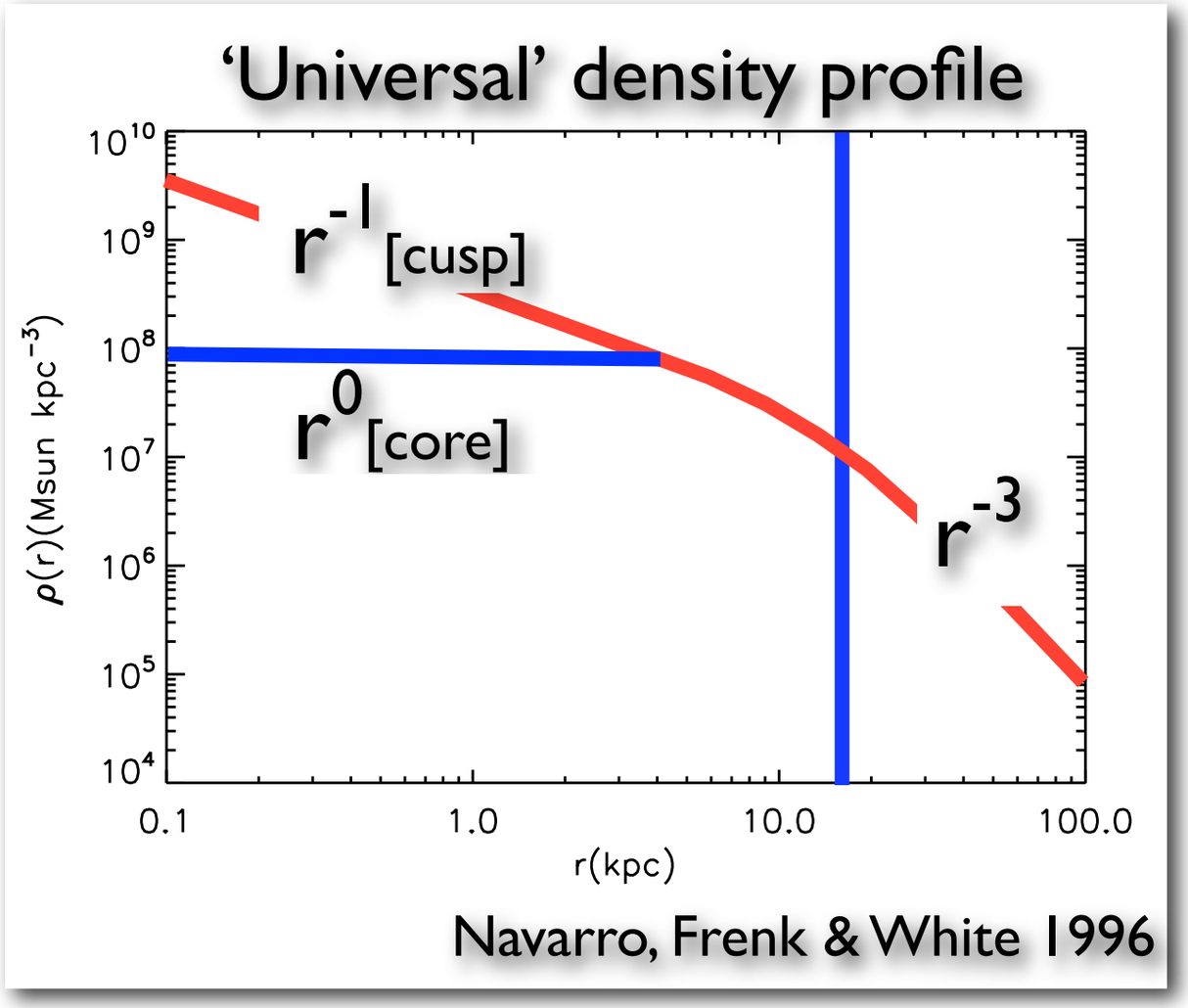
DMO simulations | The "Small Scale Crisis"

LCDM [DMO] ➠ Excellent match to large scale structure



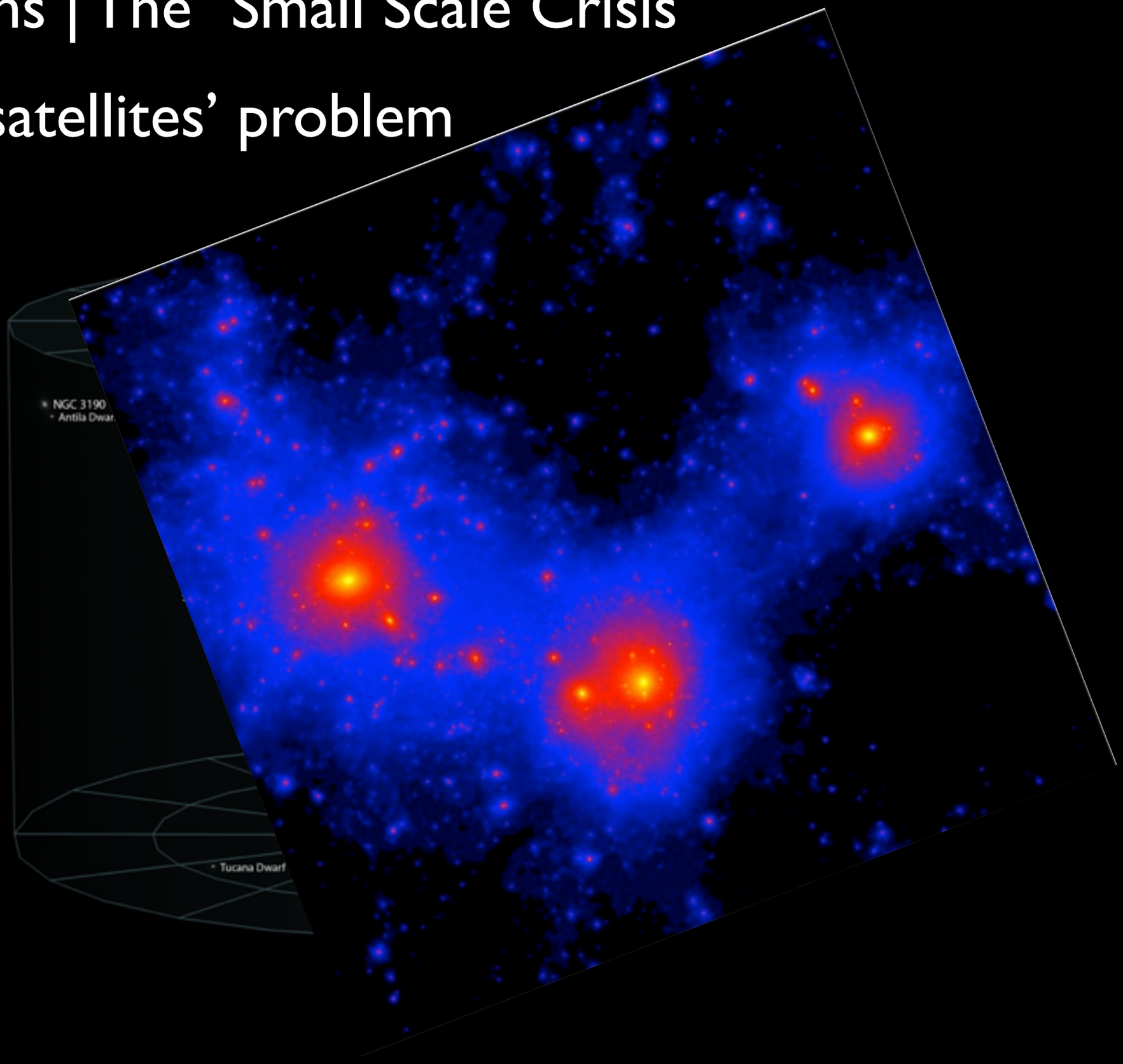
DMO simulations | The "Small Scale Crisis"

a) The 'cusp-core' problem



DMO simulations | The "Small Scale Crisis"

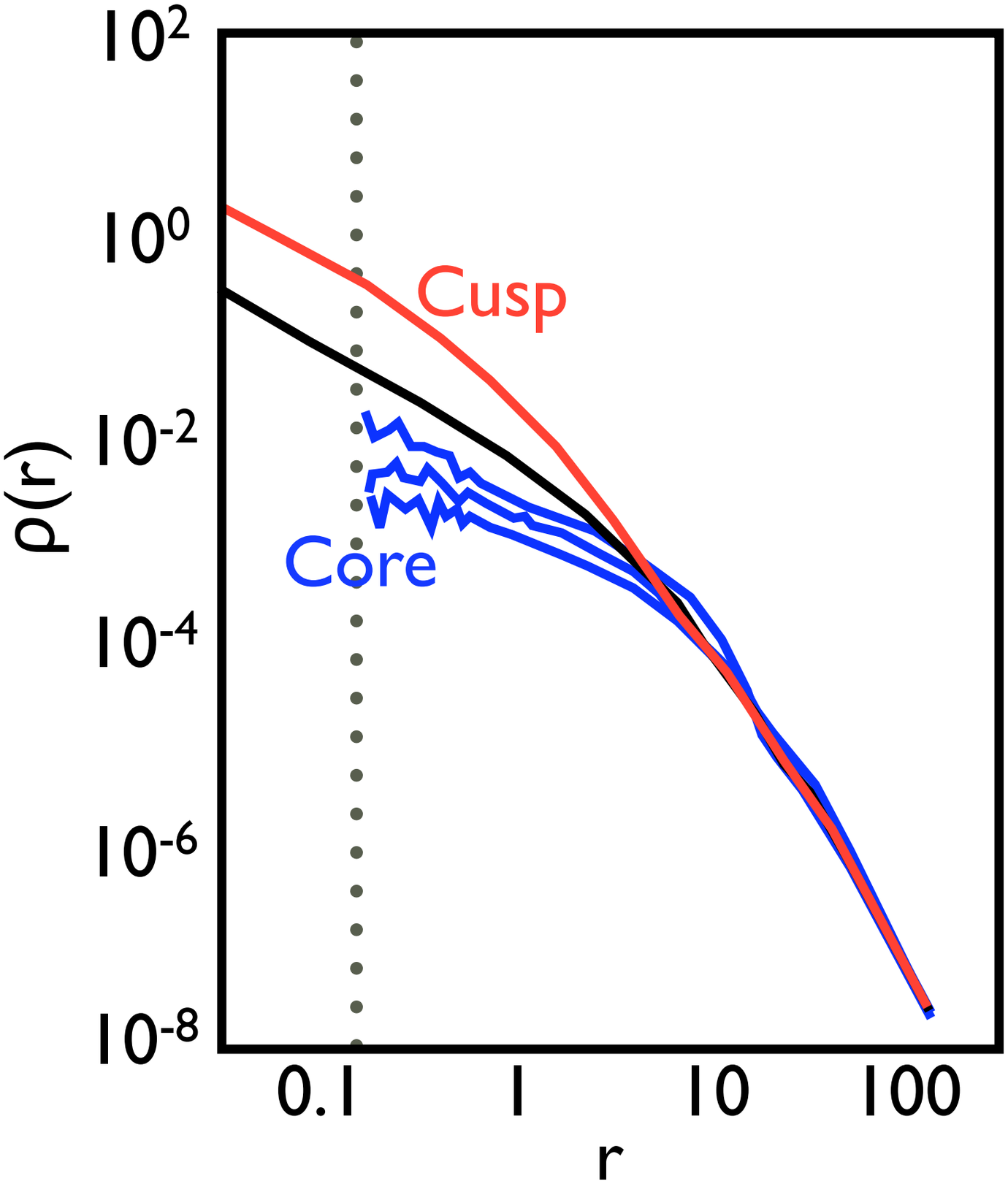
b) The 'missing satellites' problem

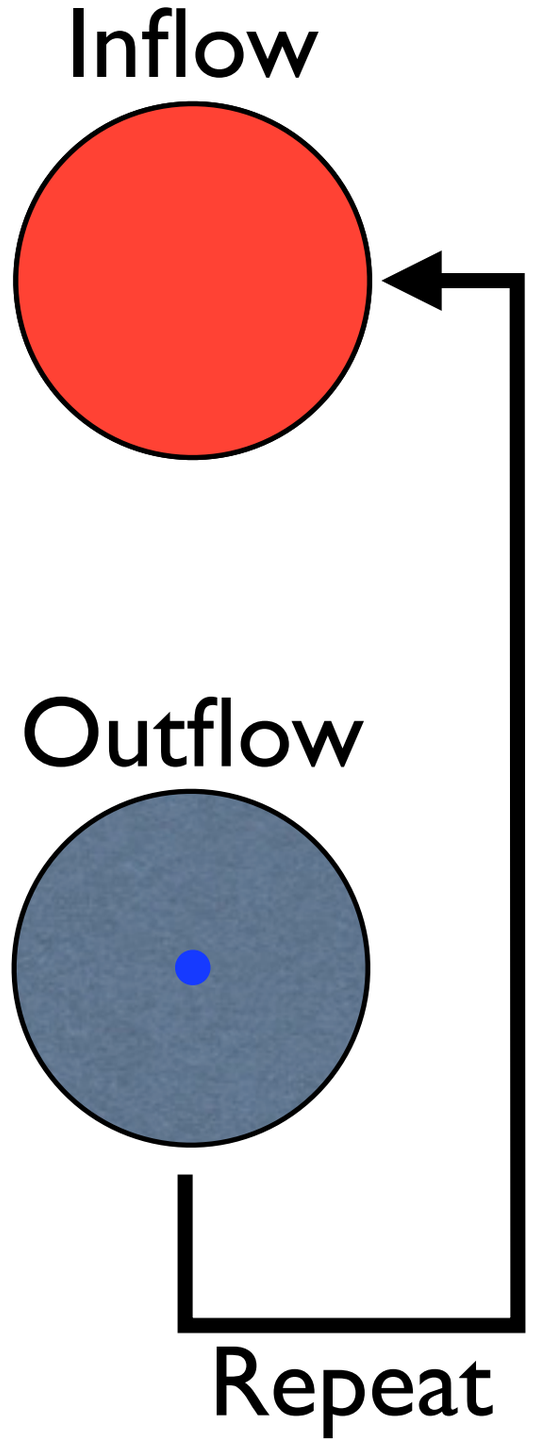


http://www.clues-project.org

Baryons

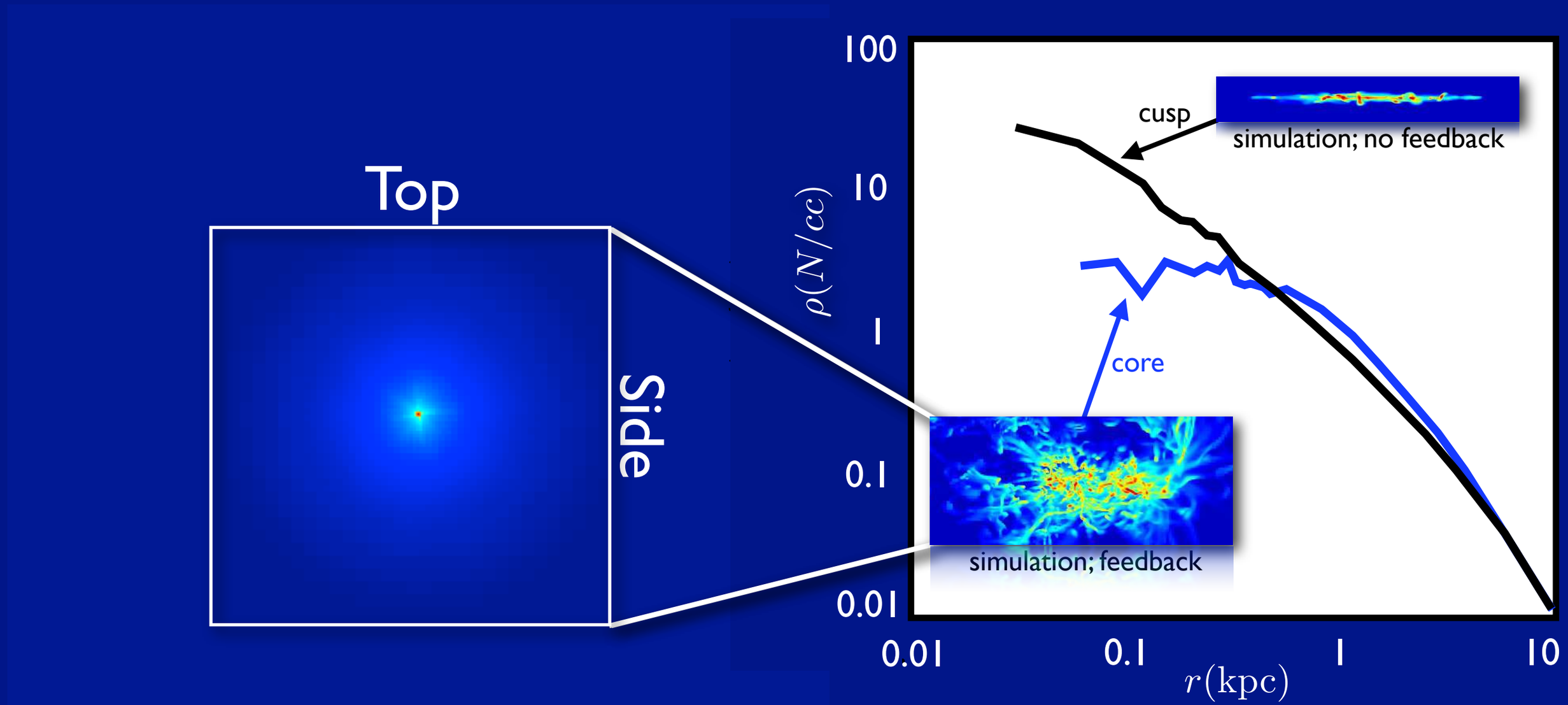
Including baryons (stars and gas)





Read & Gilmore 2005; Navarro et al. 1996

Including baryons (stars and gas)



Teyssier, Pontzen, Dubois & Read, MNRAS 2013

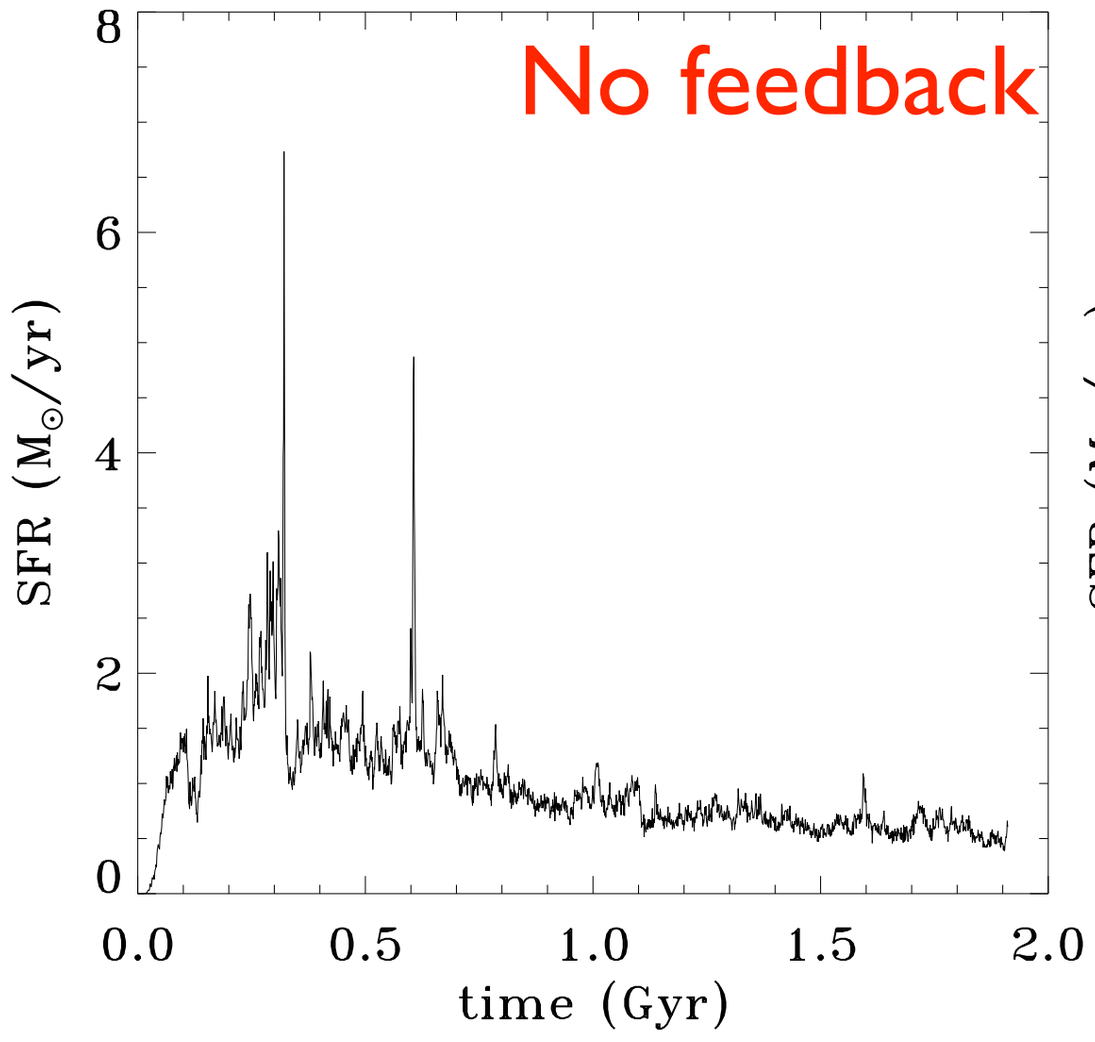
Including baryons | The “Small Scale Crisis” ...

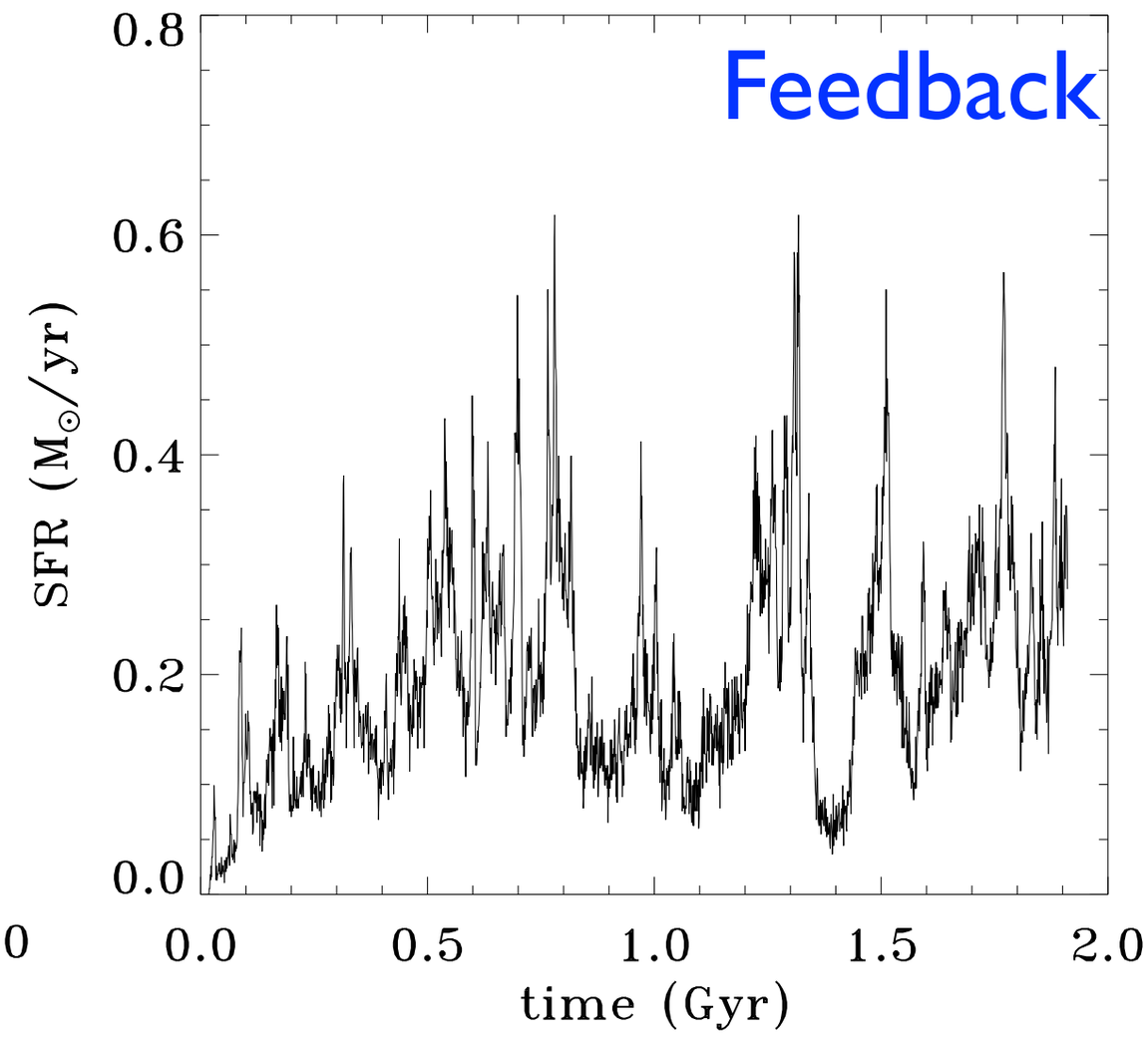
T13 ➠ 2 key observational predictions:

Including baryons | The "Small Scale Crisis" ...

T13 ➠ 2 key observational predictions:

i) Star formation should be bursty

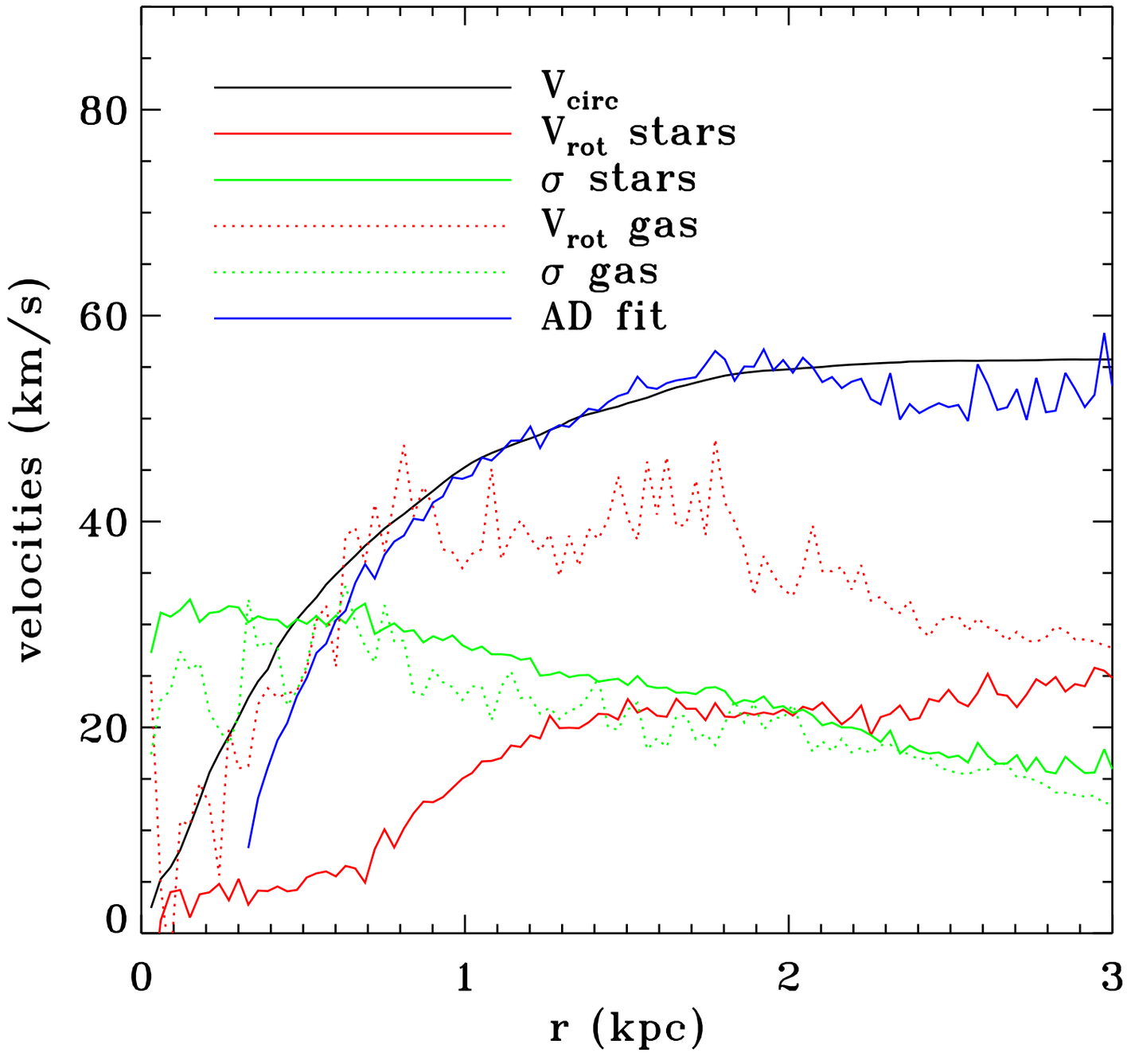




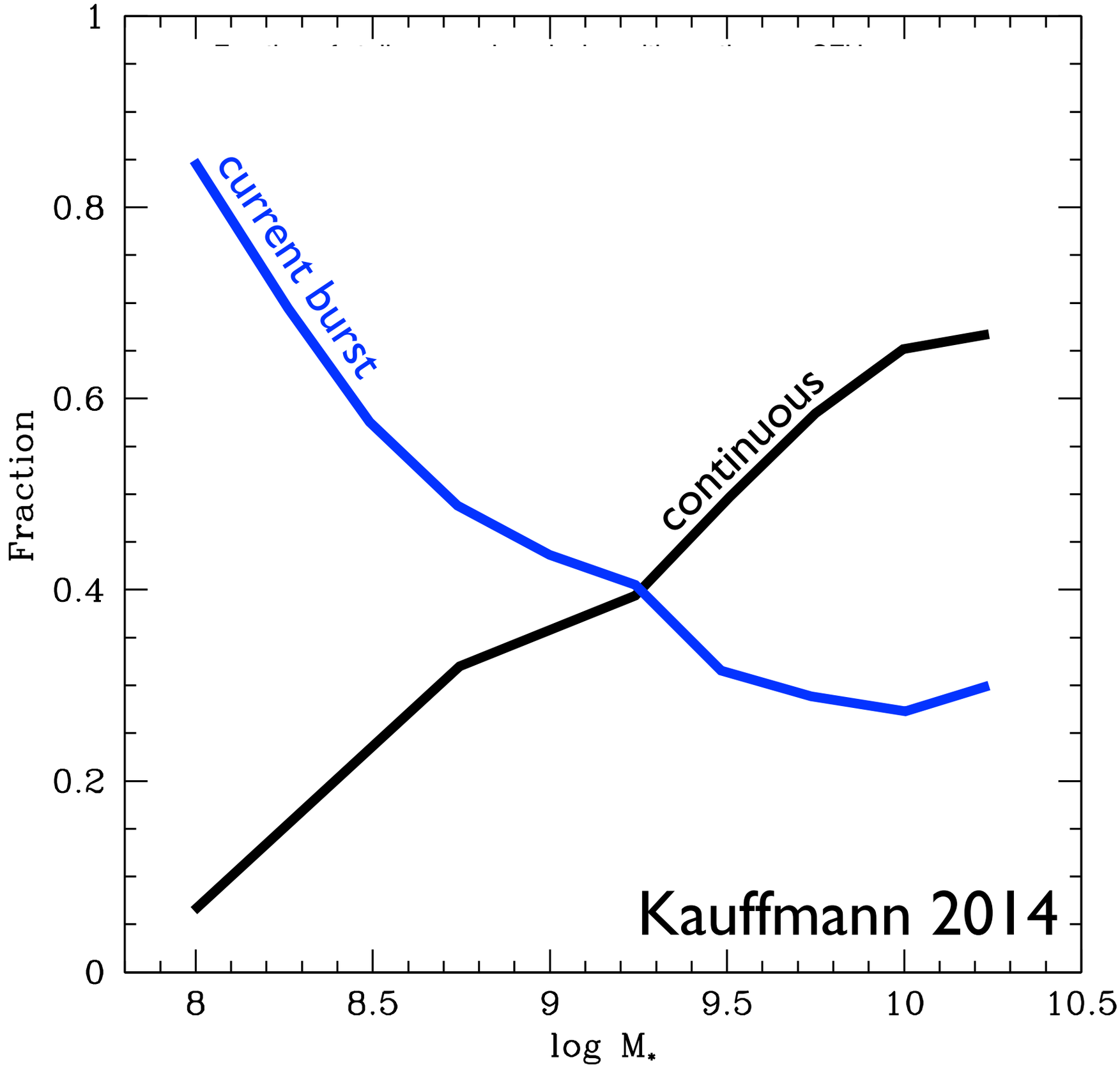
Including baryons | The "Small Scale Crisis" ...

T13 ➠ 2 key observational predictions:

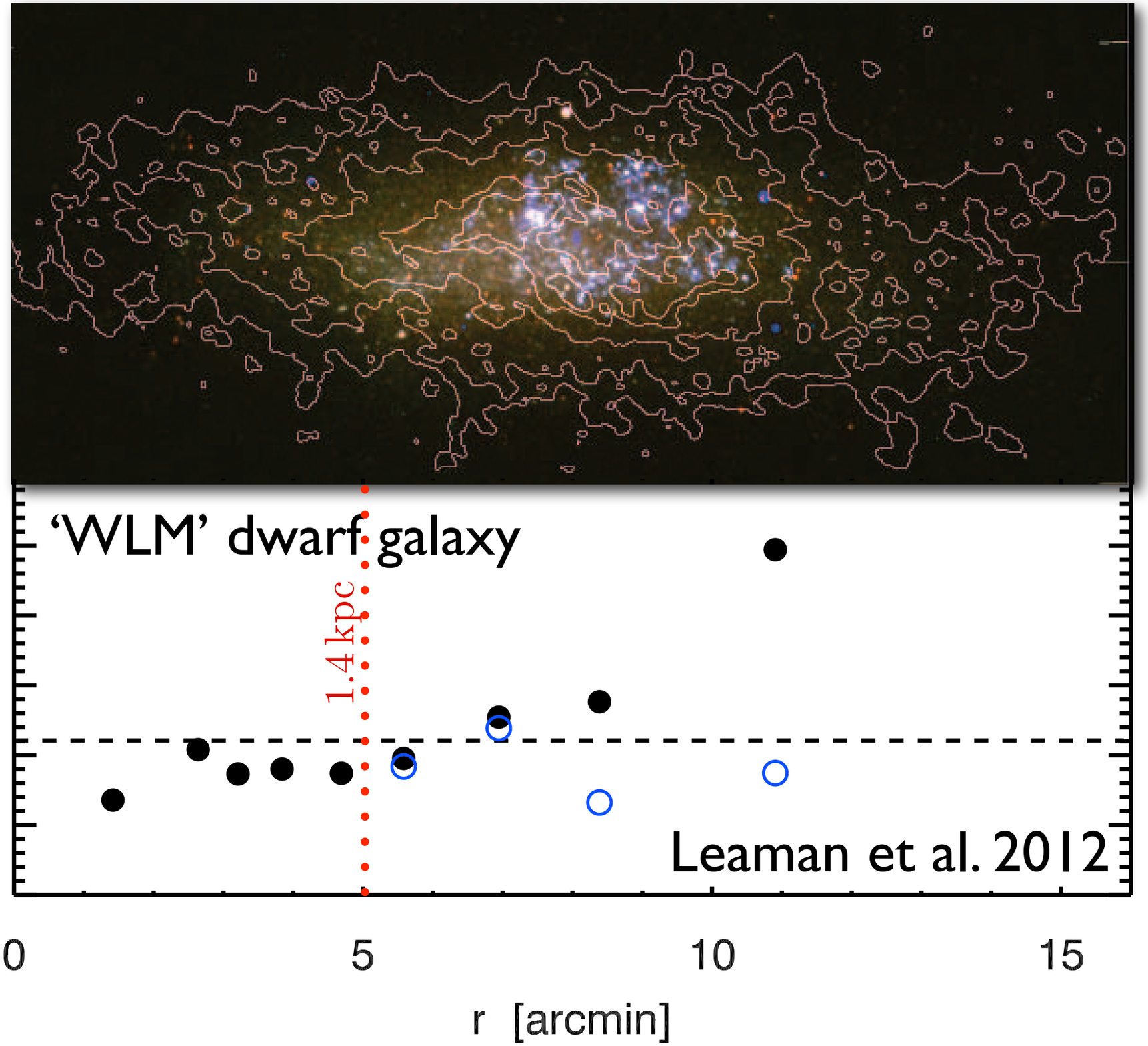
ii) Stars should be heated too



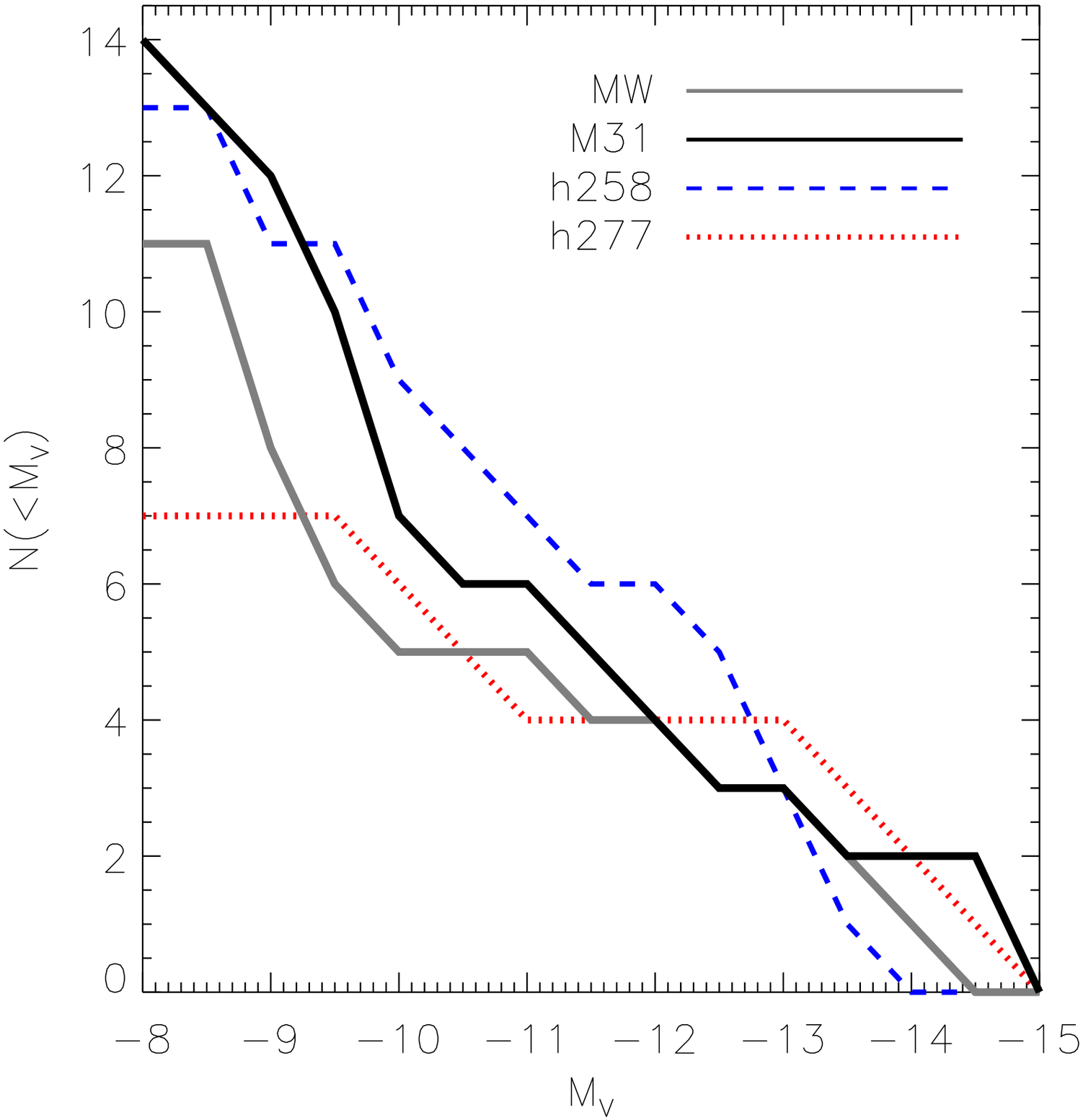
Including baryons | The "Small Scale Crisis" ...



Including baryons | The “Small Scale Crisis” ...



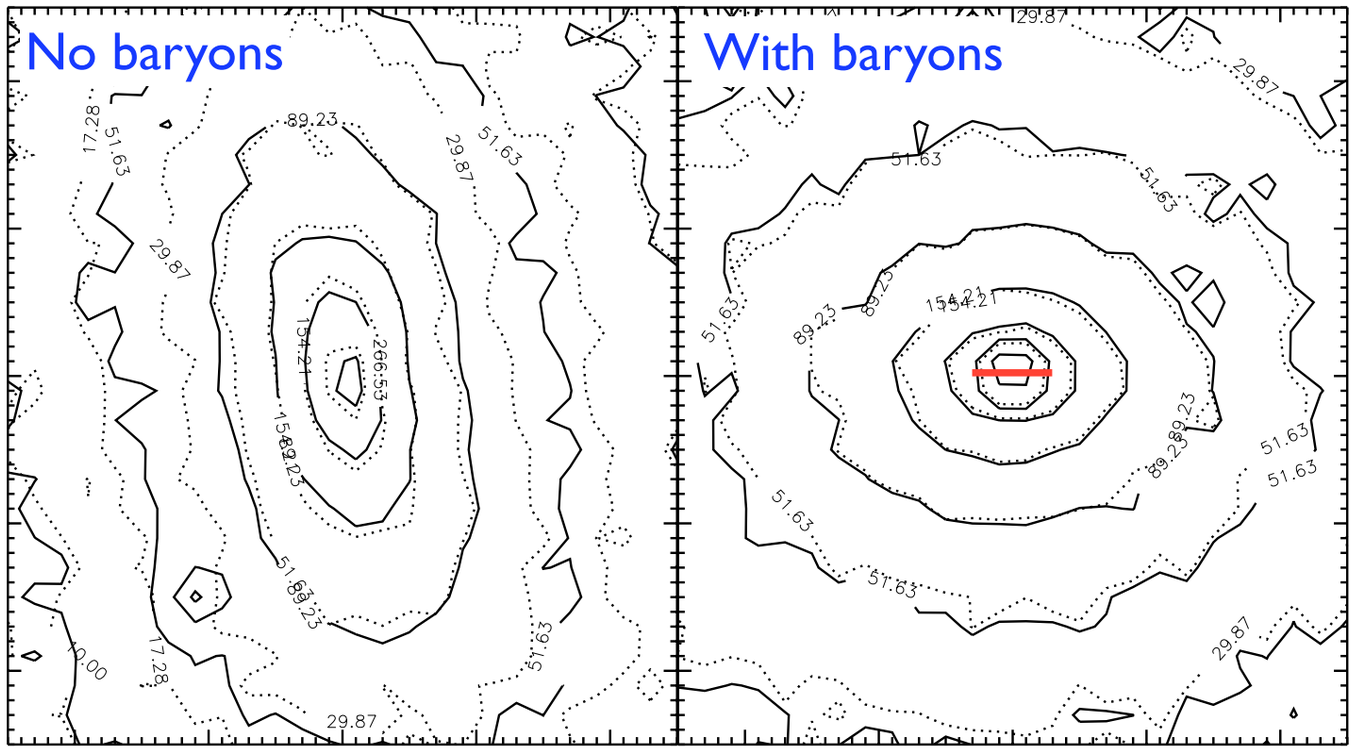
Including baryons | The "Small Scale Crisis" ...



Zolotov et al. 2012; and see Read et al. 2006; Penarrubia et al. 2010

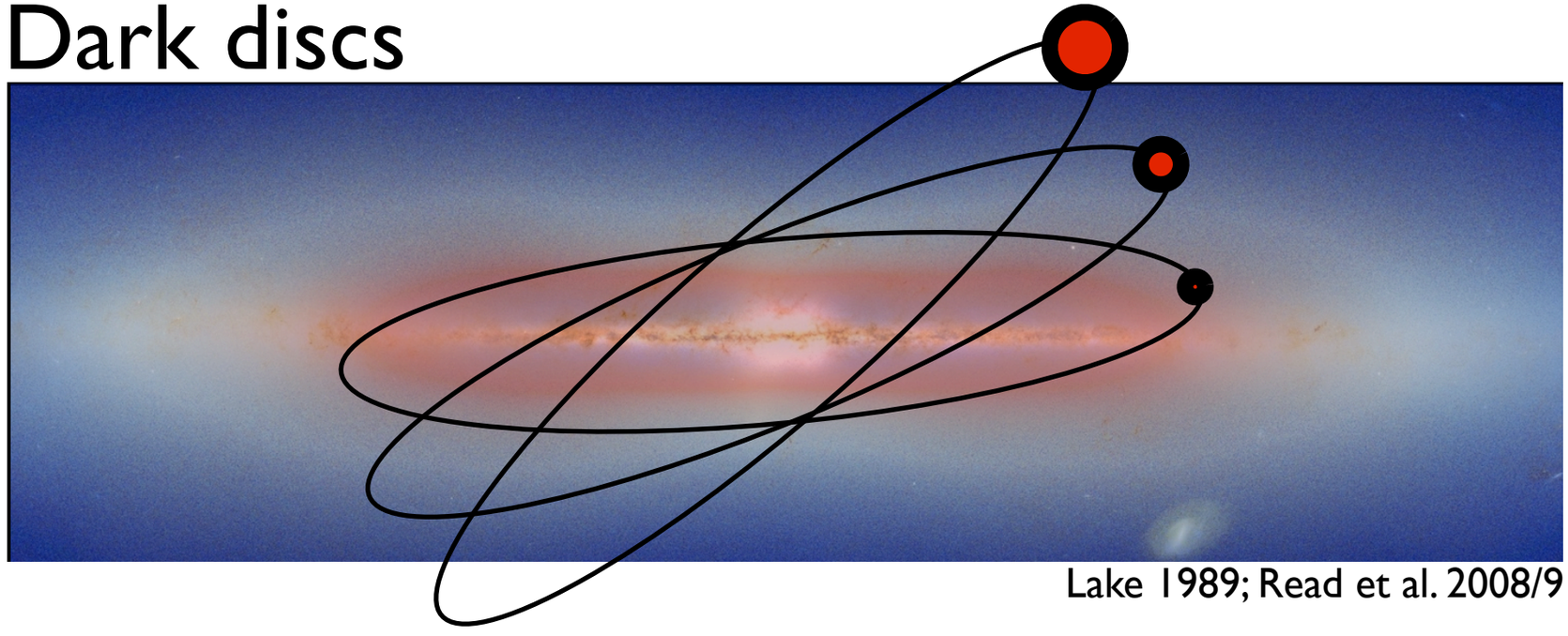
Including baryons | Other changes

Shape change



Katz & Gunn 1991; Dubinski 1994; Debattista et al. 2008; Read et al. 2009

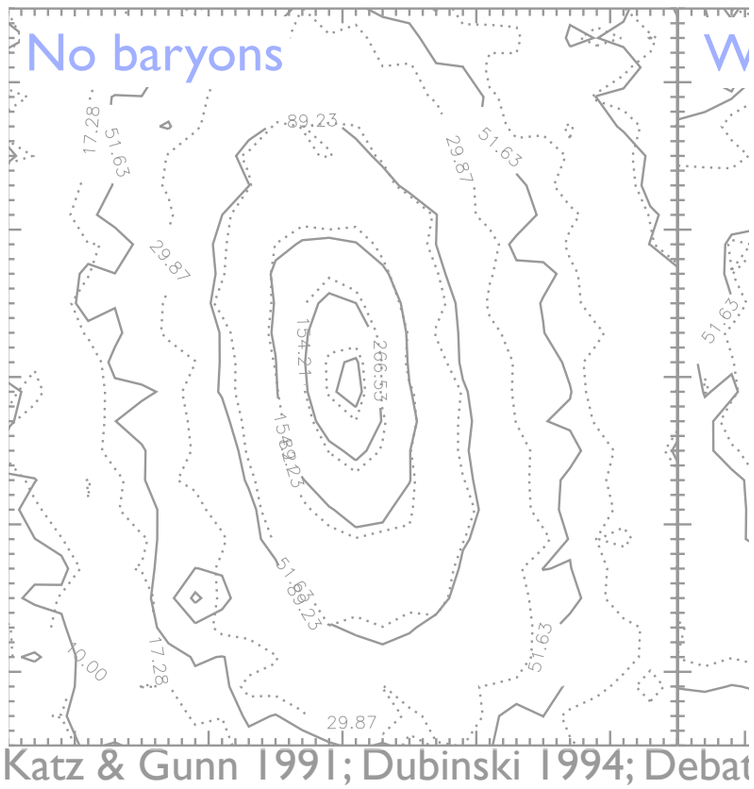
Dark discs



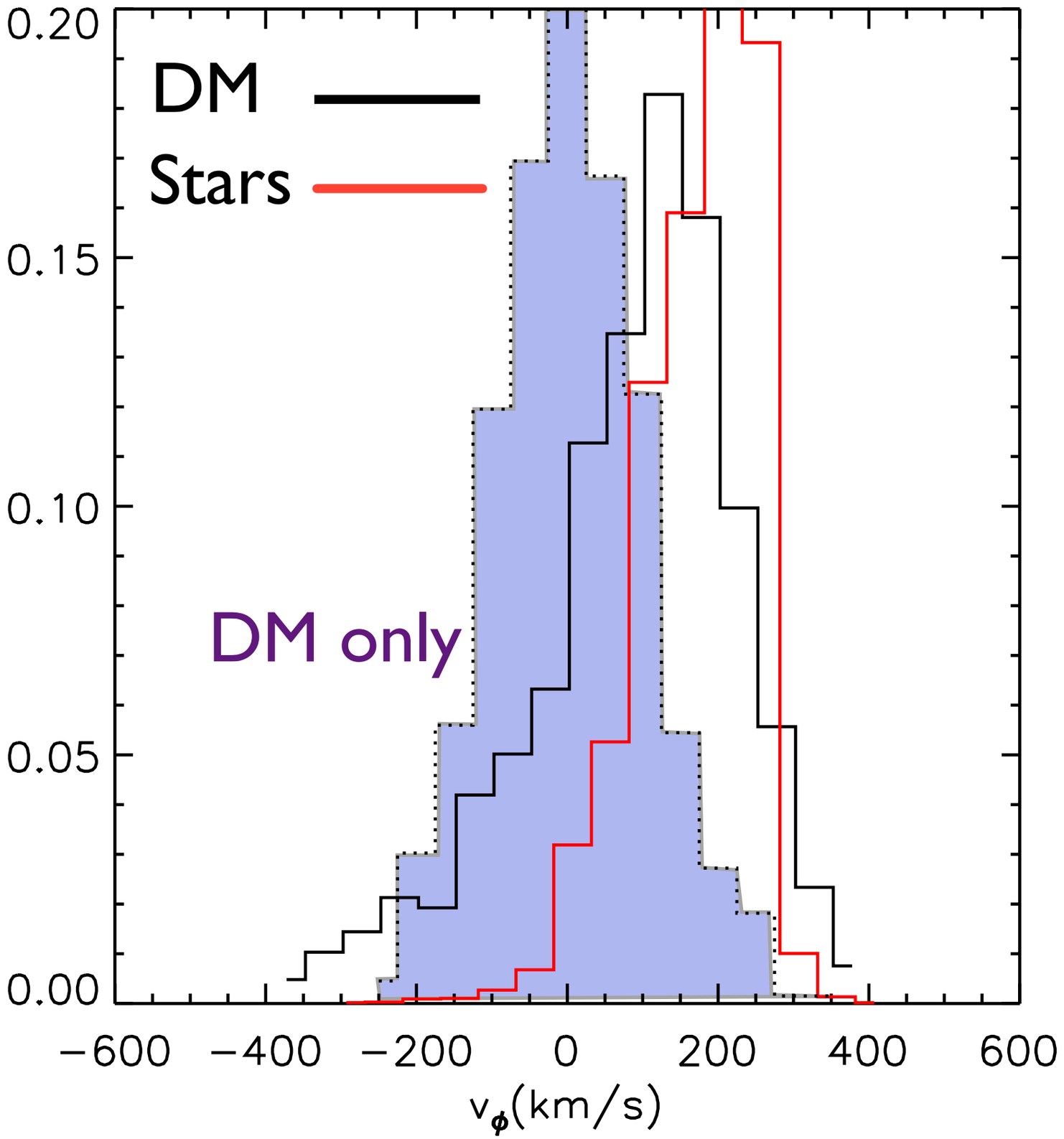
Lake 1989; Read et al. 2008/9

Including baryons | Other changes

Shape change



Katz & Gunn 1991; Dubinski 1994; Debat

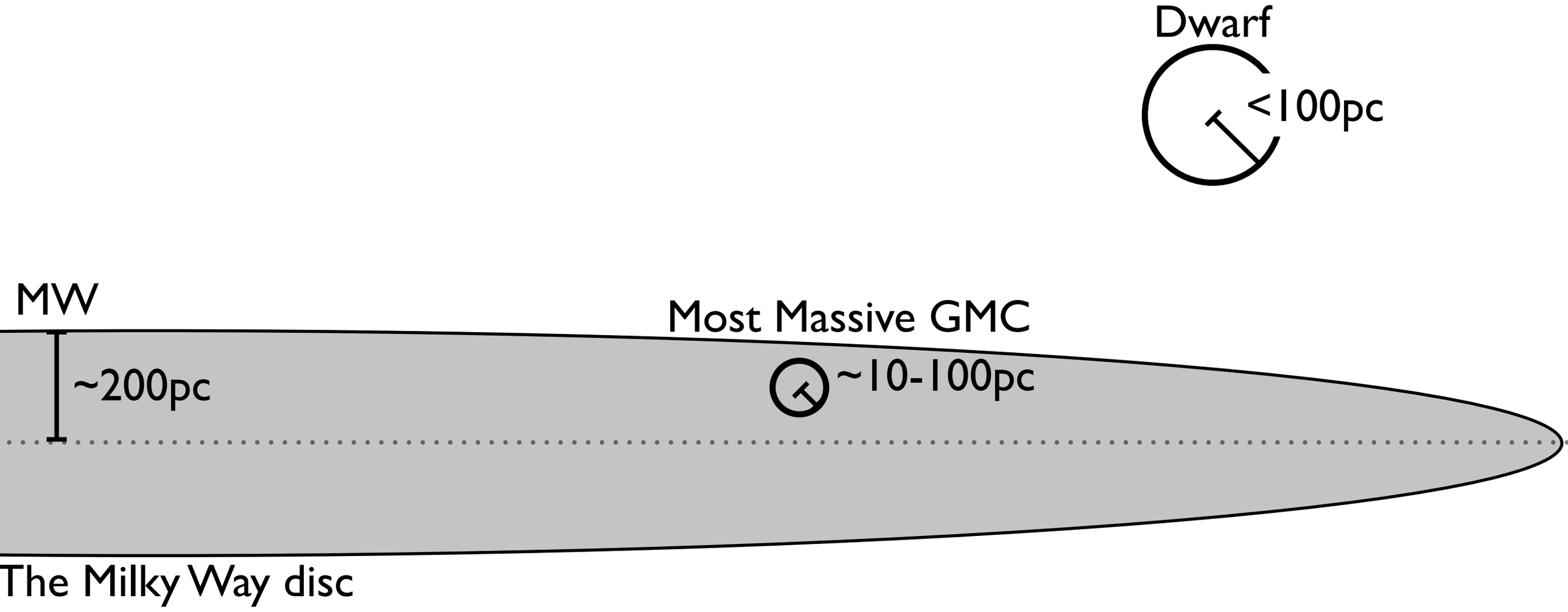


2008/9

Ab Initio

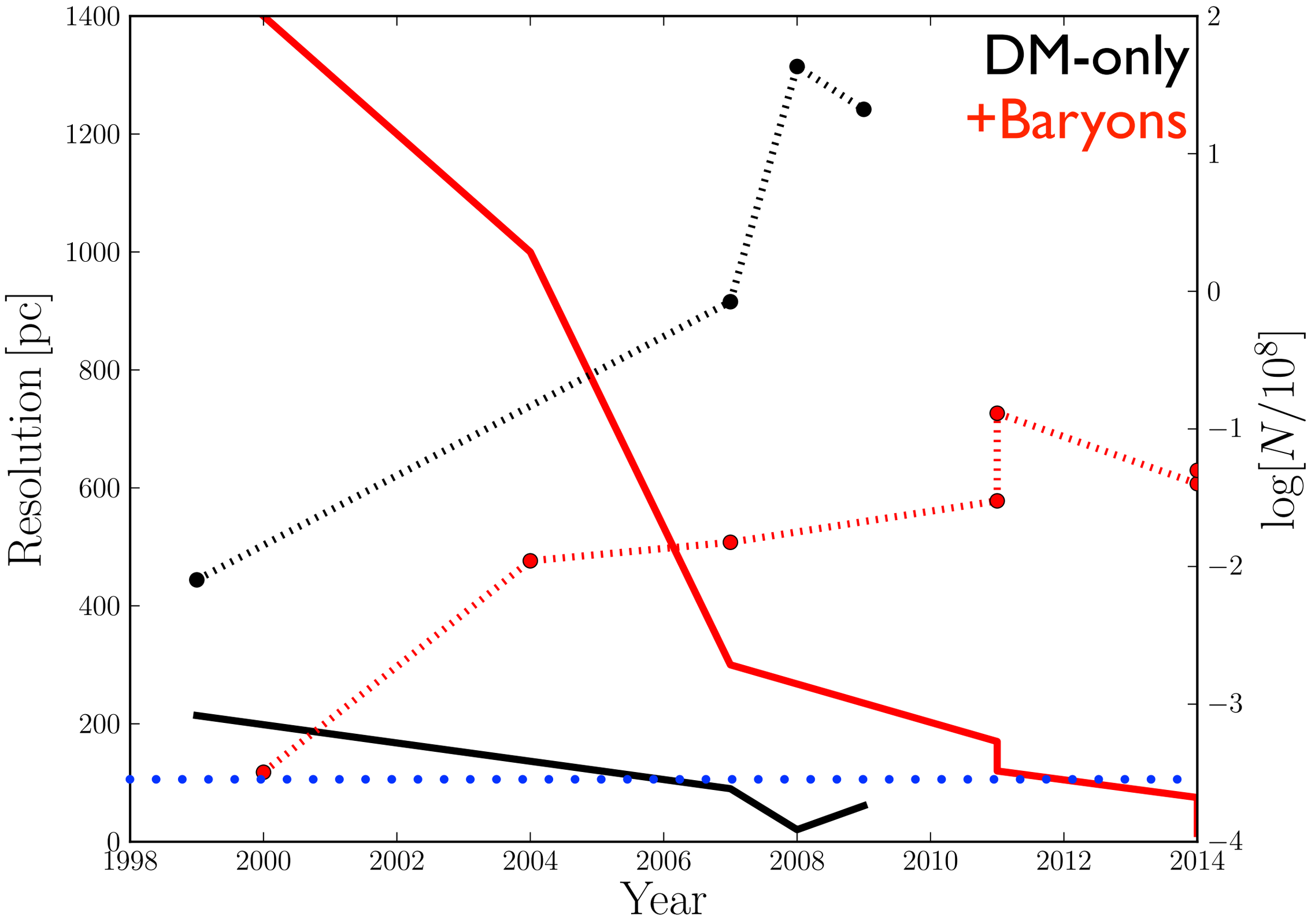
[Towards *predictive* simulations with baryons]

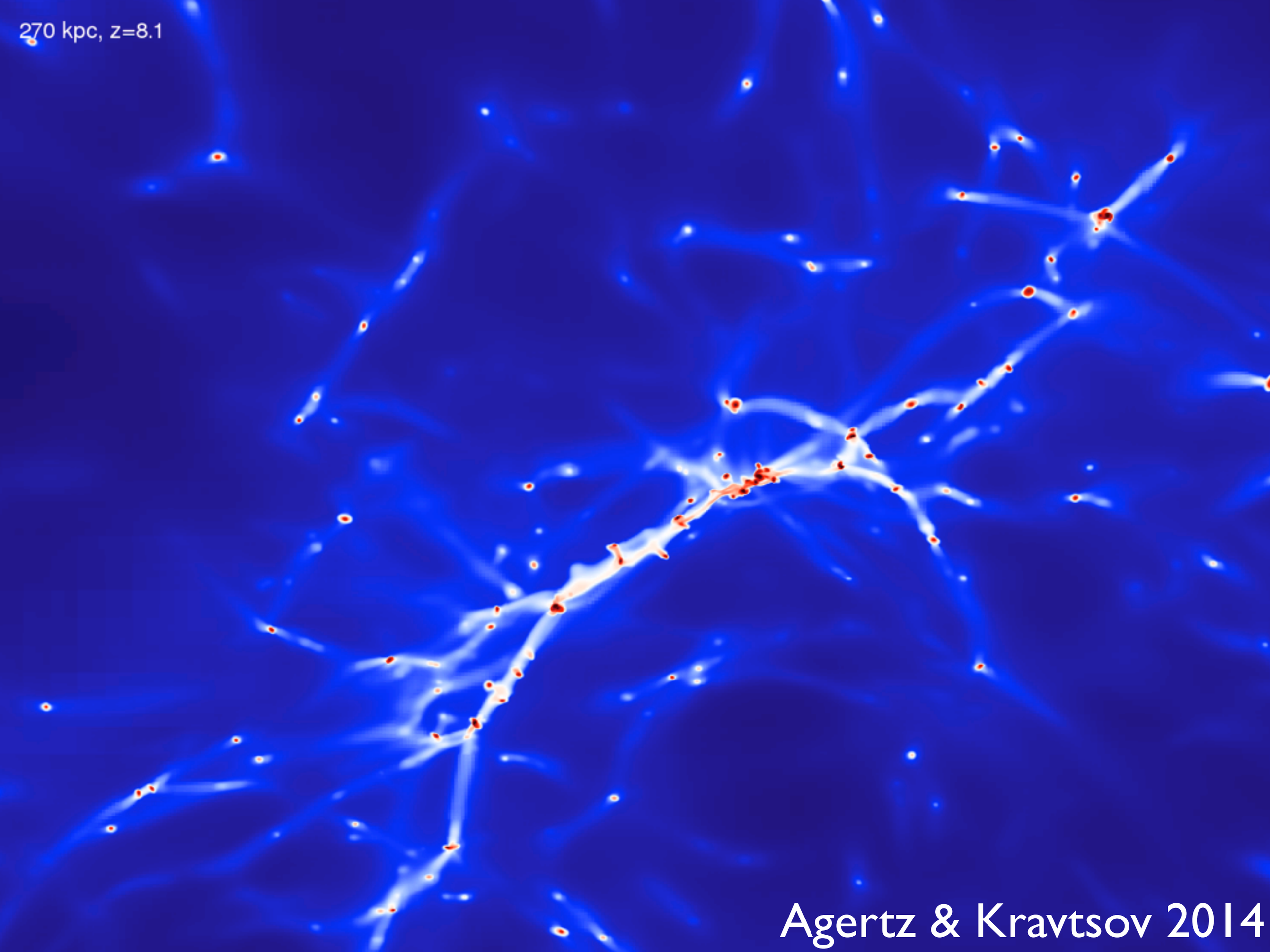
Towards *predictive* simulations with baryons



The Milky Way disc

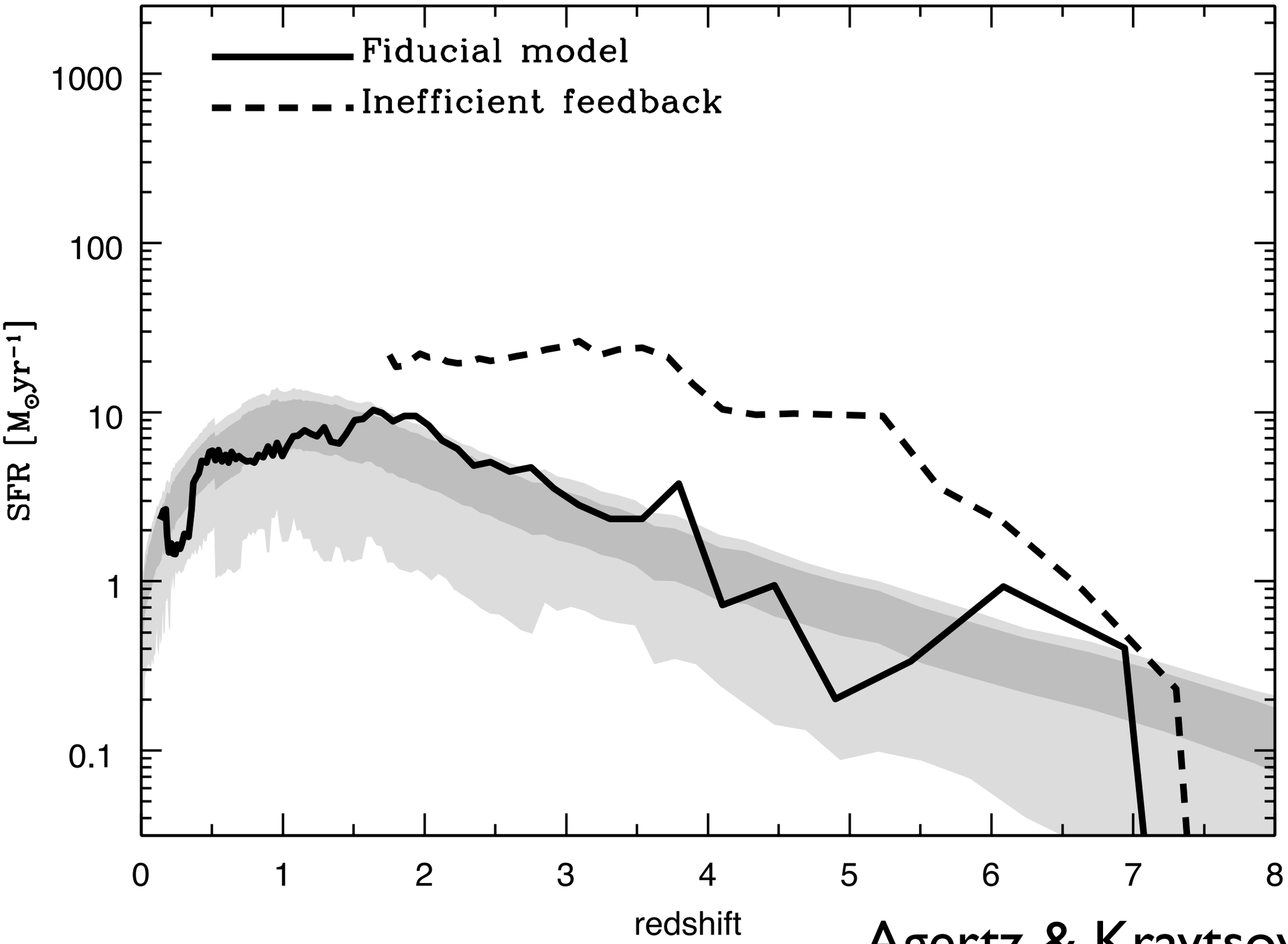
Towards *predictive* simulations with baryons





Agertz & Kravtsov 2014

Towards *predictive* simulations with baryons



Agertz & Kravtsov 2014

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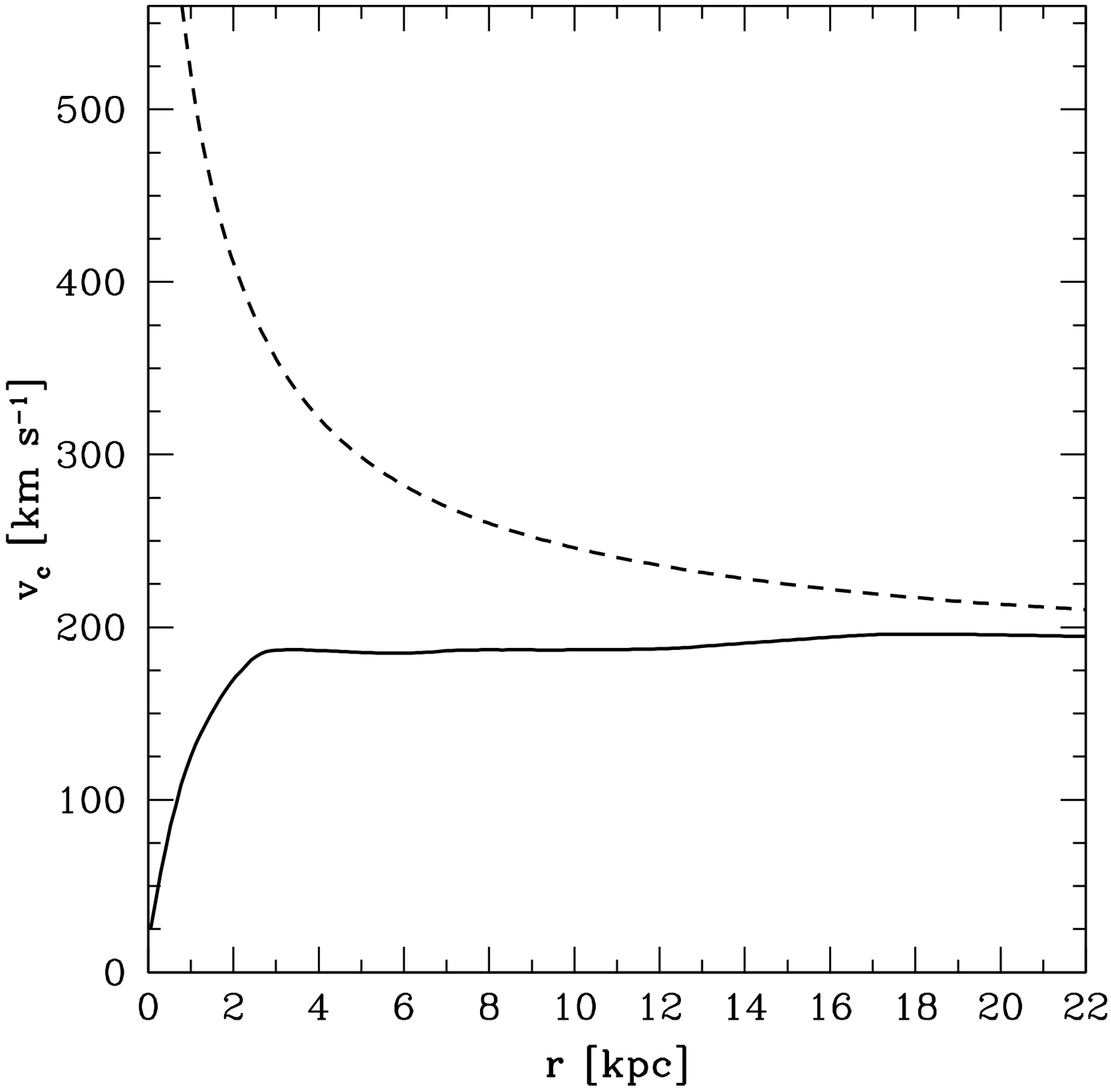

Agertz & Kravtsov 2014

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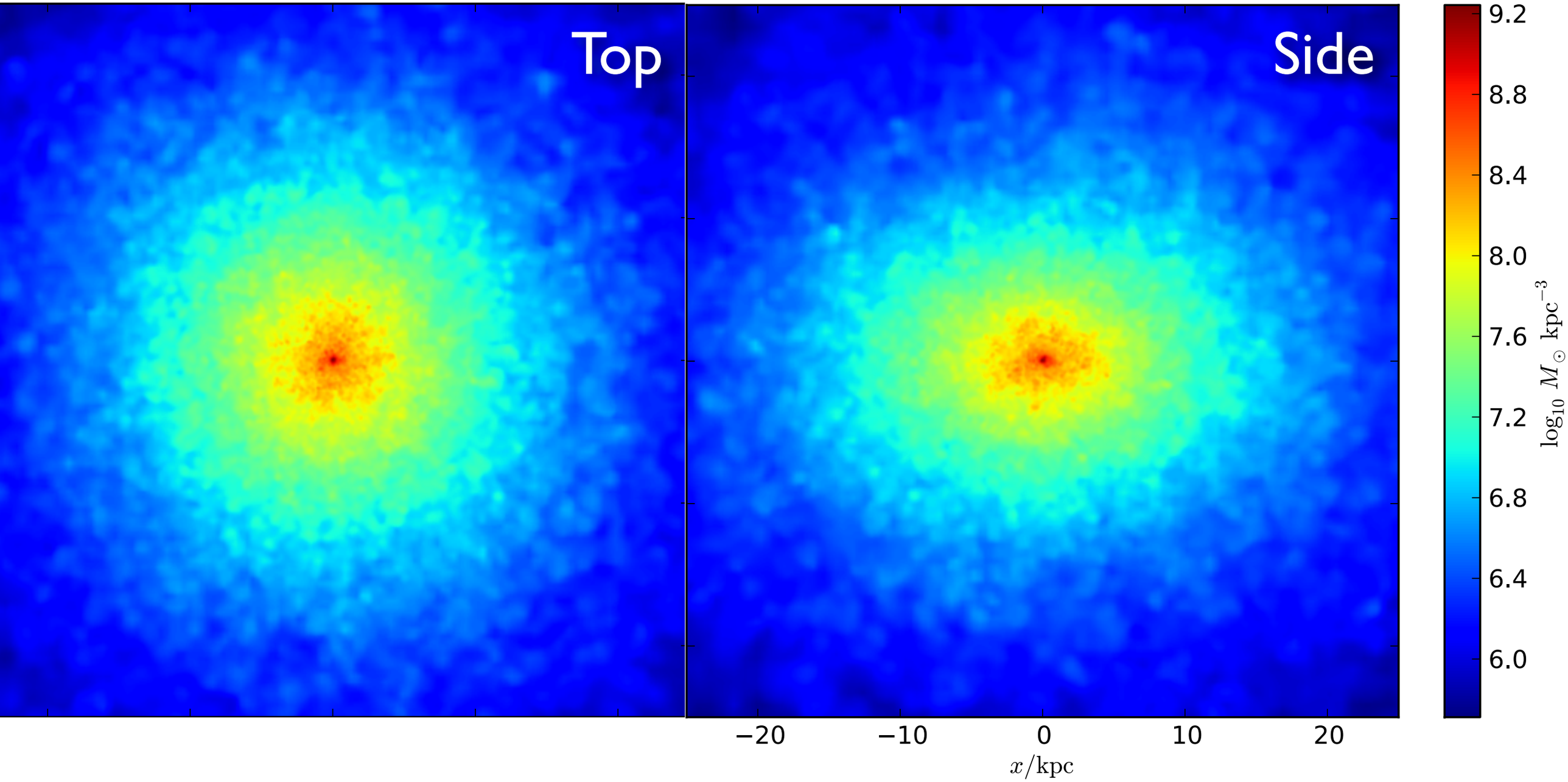
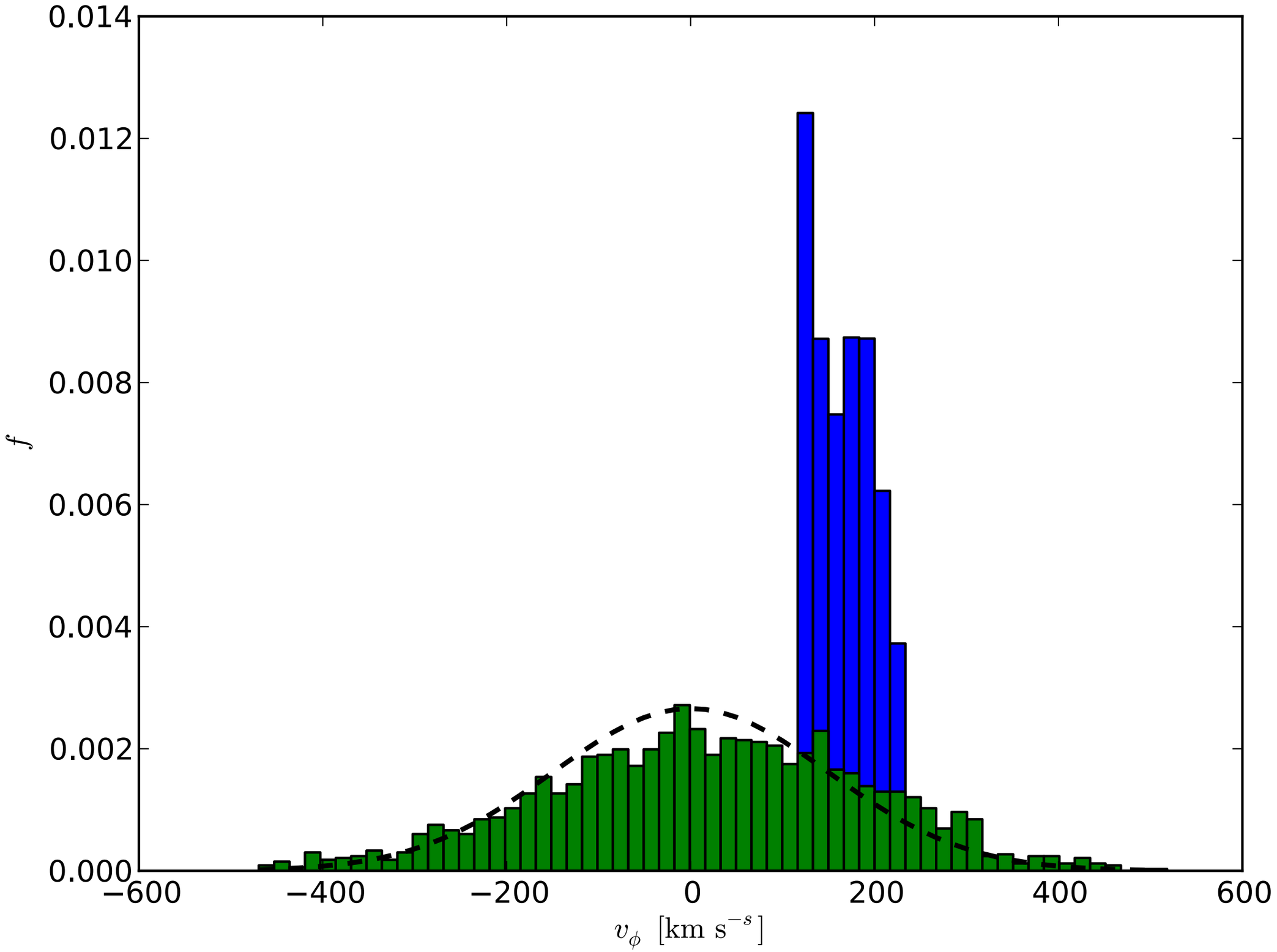


Agertz & Kravtsov 2014

Towards *predictive* simulations with baryons



Agertz & Kravtsov 2014

Conclusions

- Cold Dark Matter "DM-only" simulations are well converged across different codes ➟ excellent match to large scale structure

- WDM simulations are more problematic, but solutions are on the way ... watch this space!

- Including models for baryons in the Universe can significantly alter the results from structure formation simulations:
  - Triaxial "halos" ➟ Oblate/round halos.
  - Cuspy dark matter profiles ➟ Cored dark matter profiles.
  - Cored halos are more easily tidally disrupted ➟ Fewer satellites.
  - An existing stellar disc ➟ An accreted "dark disc".

- Simulations are rapidly improving and have passed a critical resolution threshold ➟ expect more predictive simulations including baryons soon!