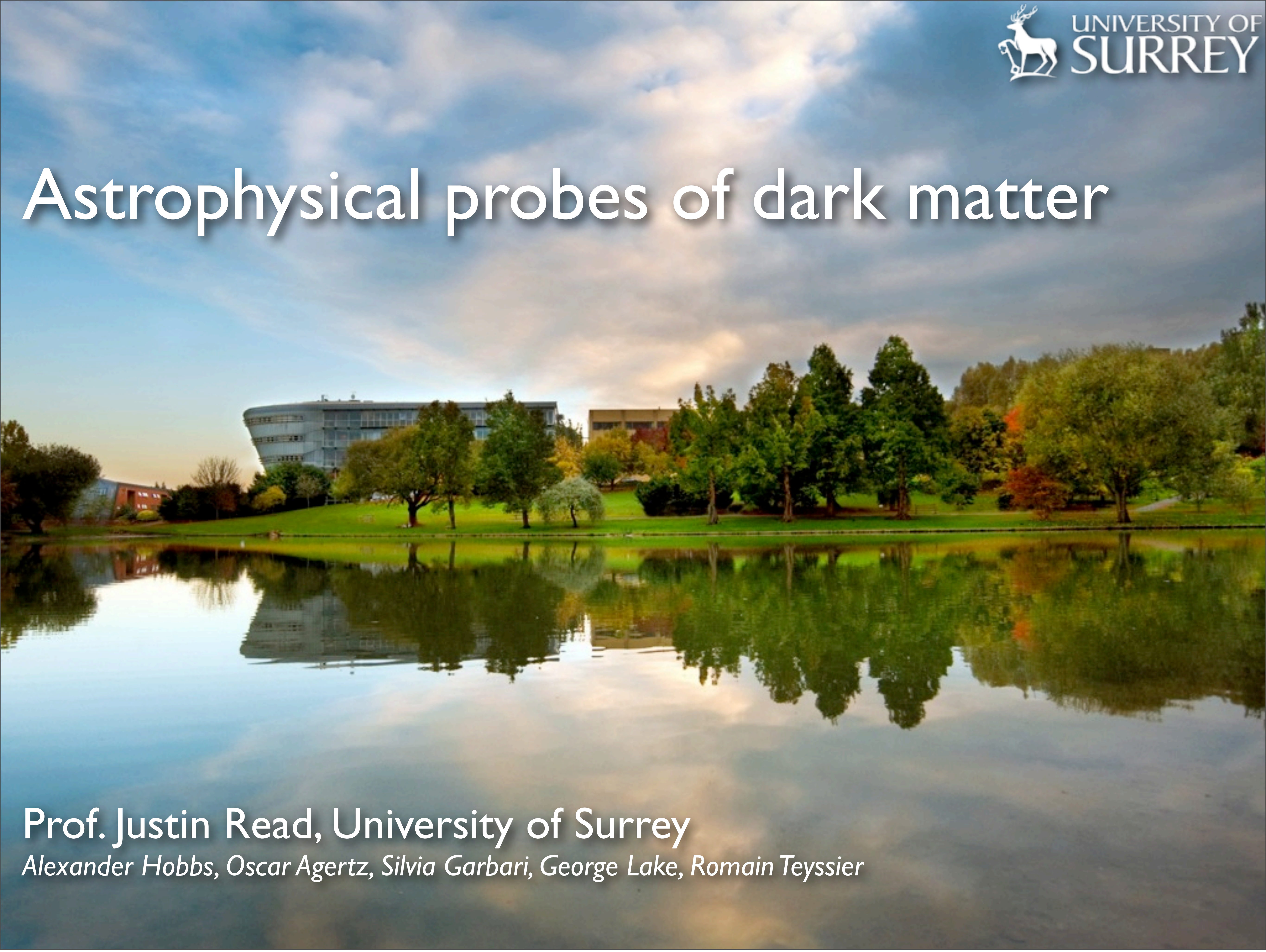
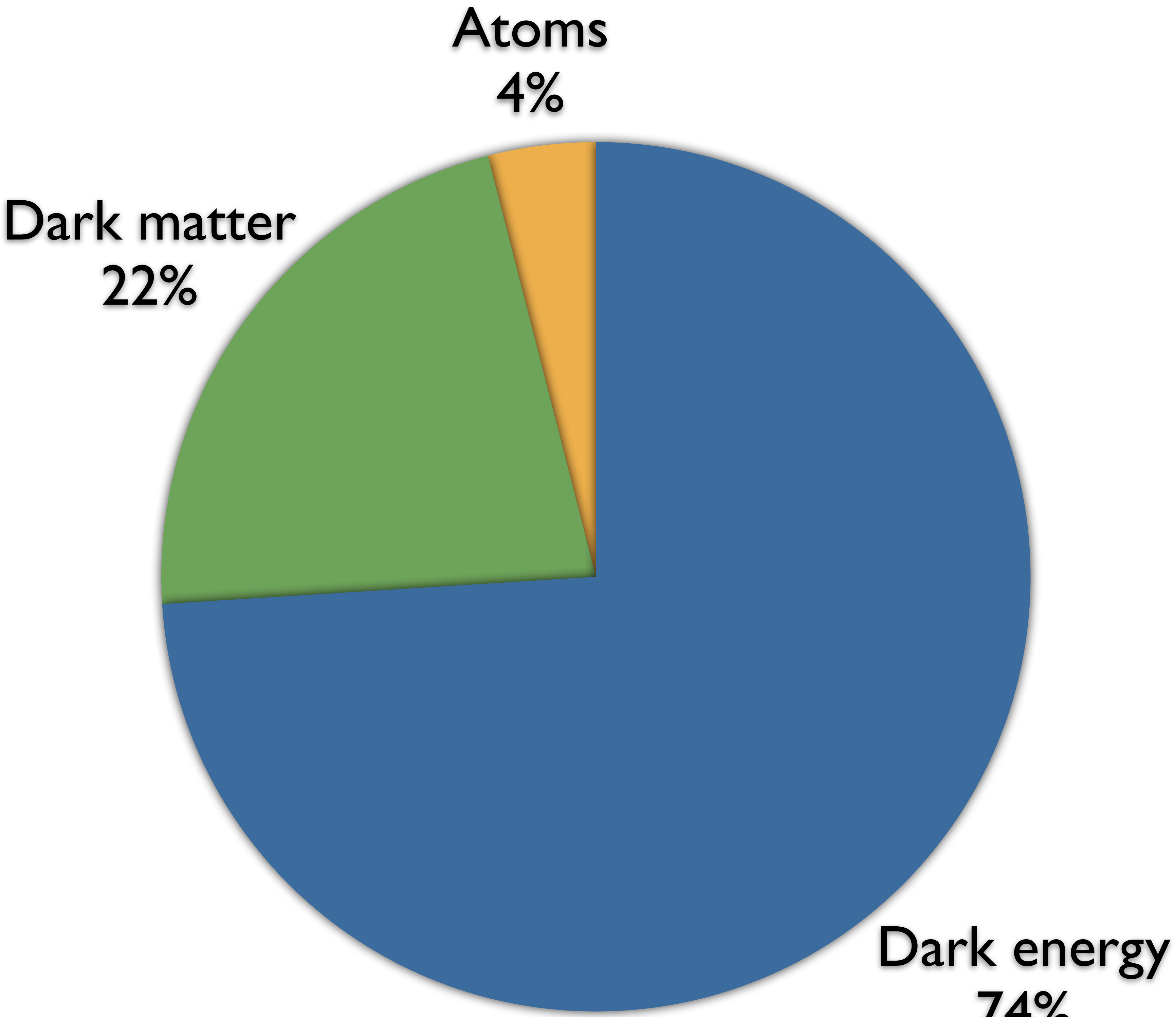


Astrophysical probes of dark matter

Prof. Justin Read, University of Surrey

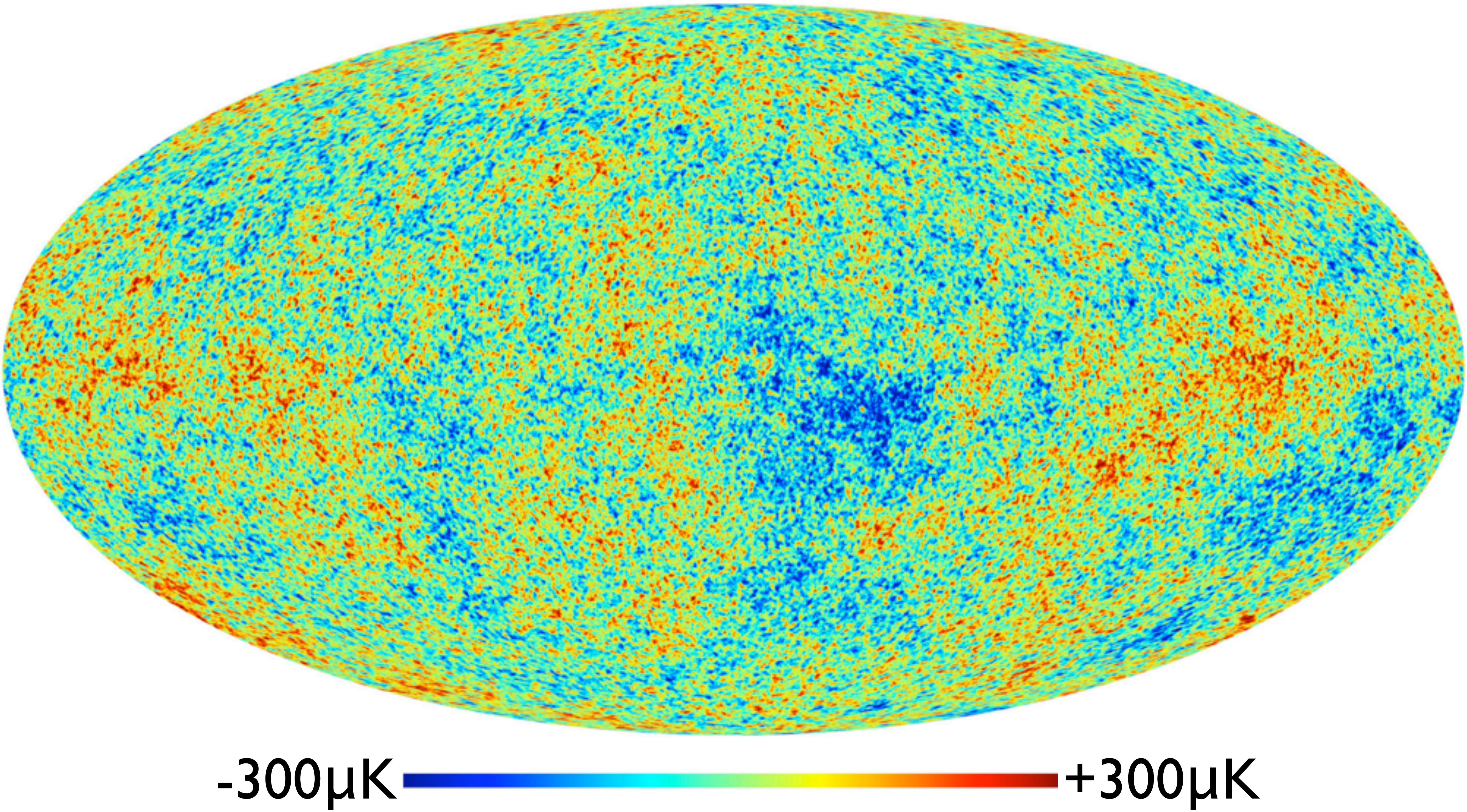
Alexander Hobbs, Oscar Agertz, Silvia Garbari, George Lake, Romain Teyssier

Background | The standard cosmological model LCDM



Planck collaboration 2013

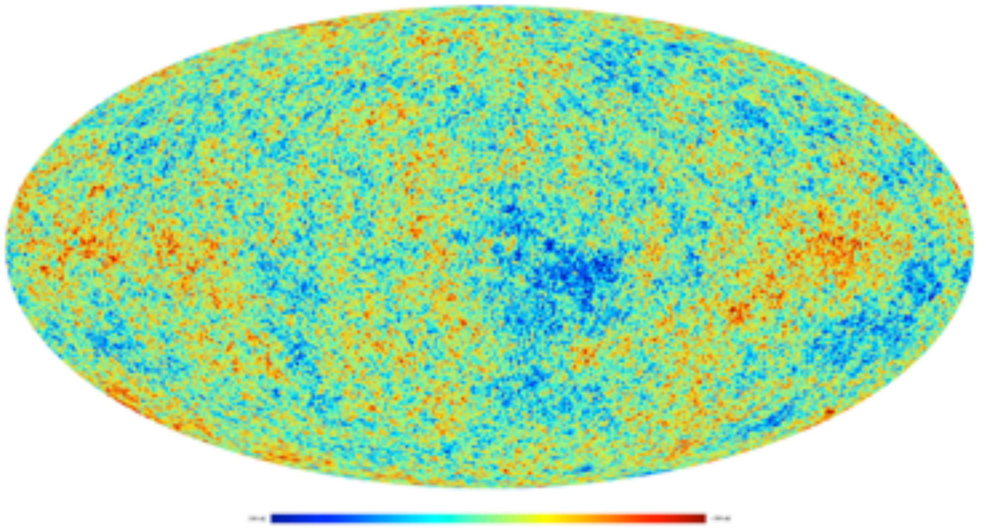
Background | The standard cosmological model LCDM


-300μK
+300μK

Planck collaboration 2013

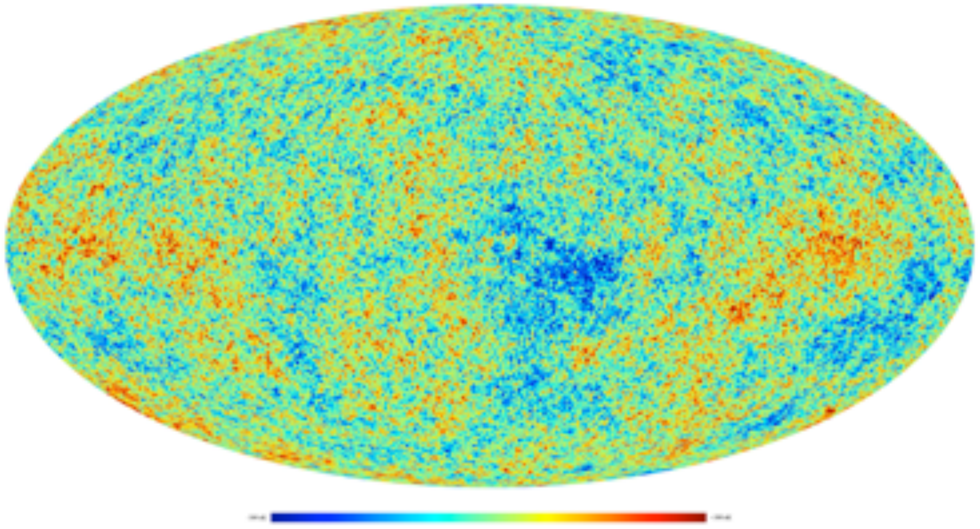
Background | Probing dark matter through gravity

CMB



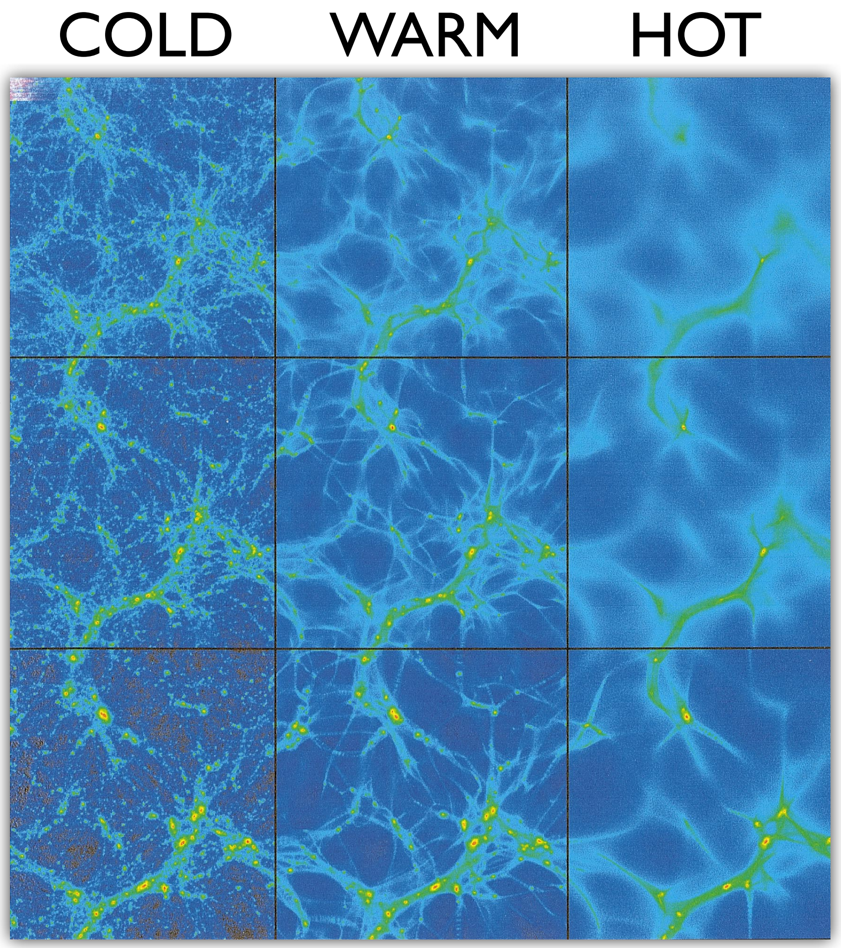
Background | Probing dark matter through gravity

CMB



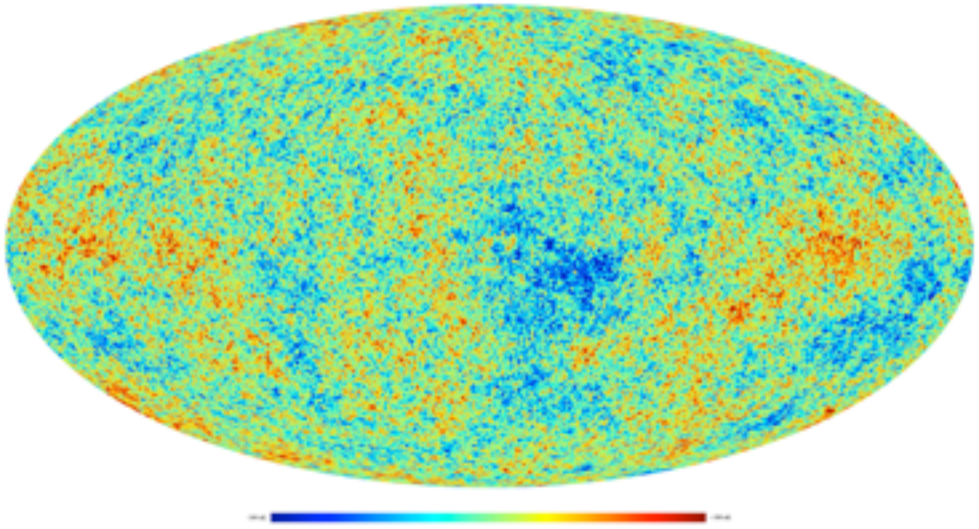
N-body

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



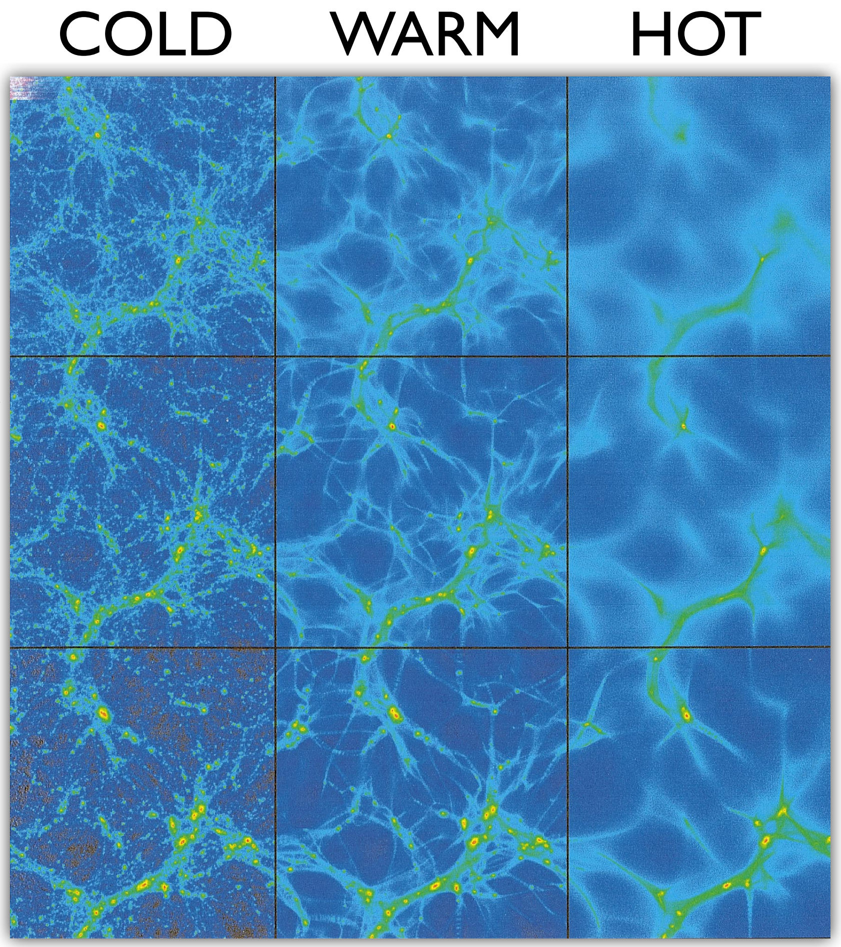
Background | Probing dark matter through gravity

CMB



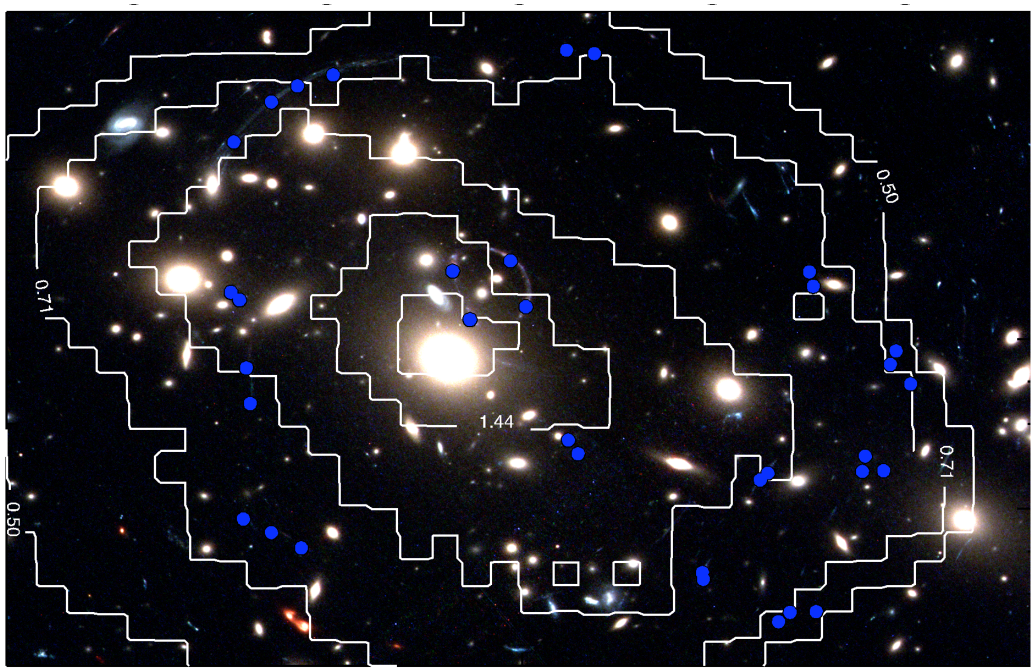
N-body

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


COLD
WARM
HOT

Observation

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


0.50
0.71
1.44
0.71
0.50

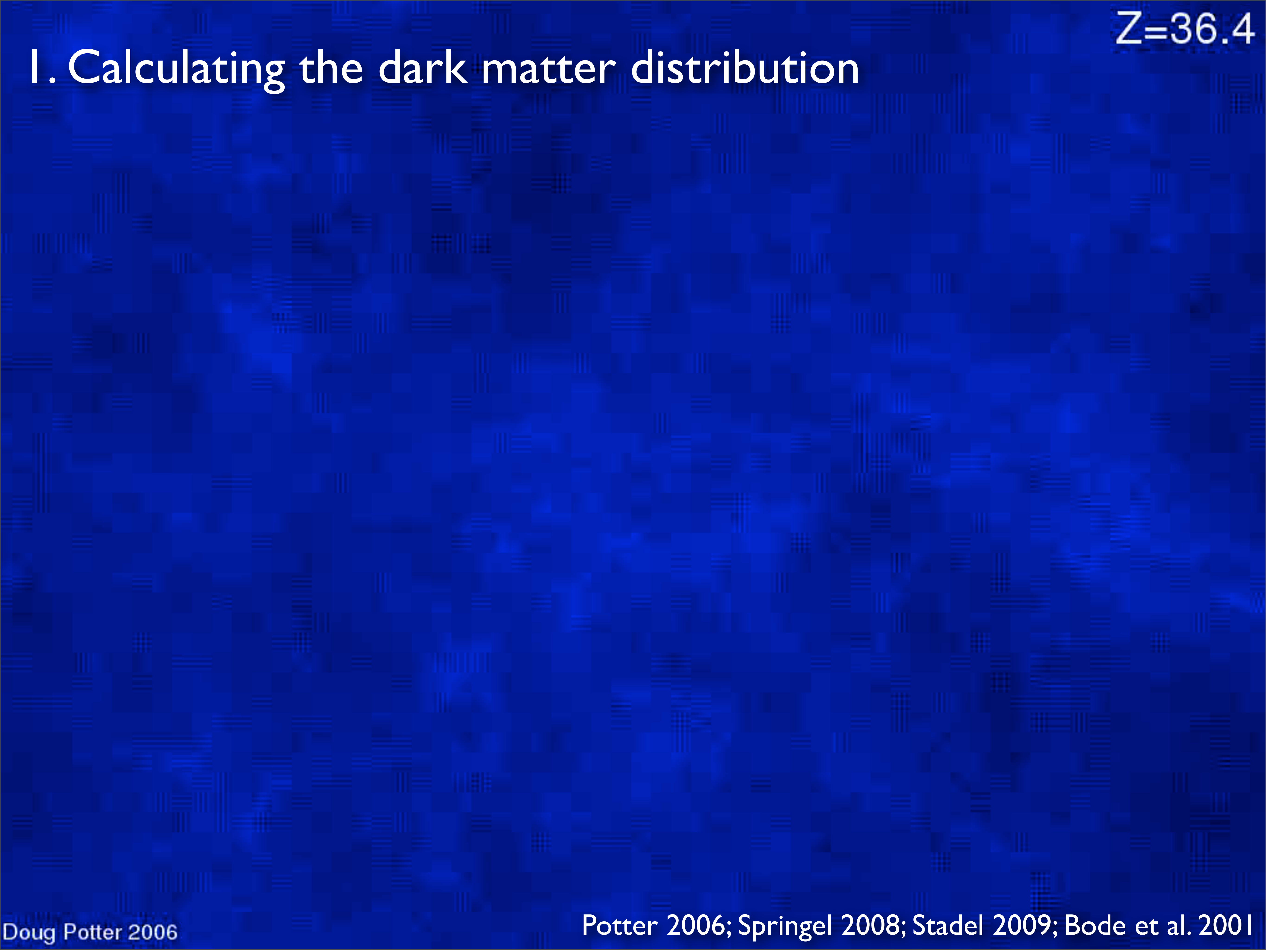
Gravity

['Dark Matter Only' (DMO) simulations]

1. Calculating the dark matter distribution

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

1. Calculating the dark matter distribution


Z=36.4
Doug Potter 2006

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

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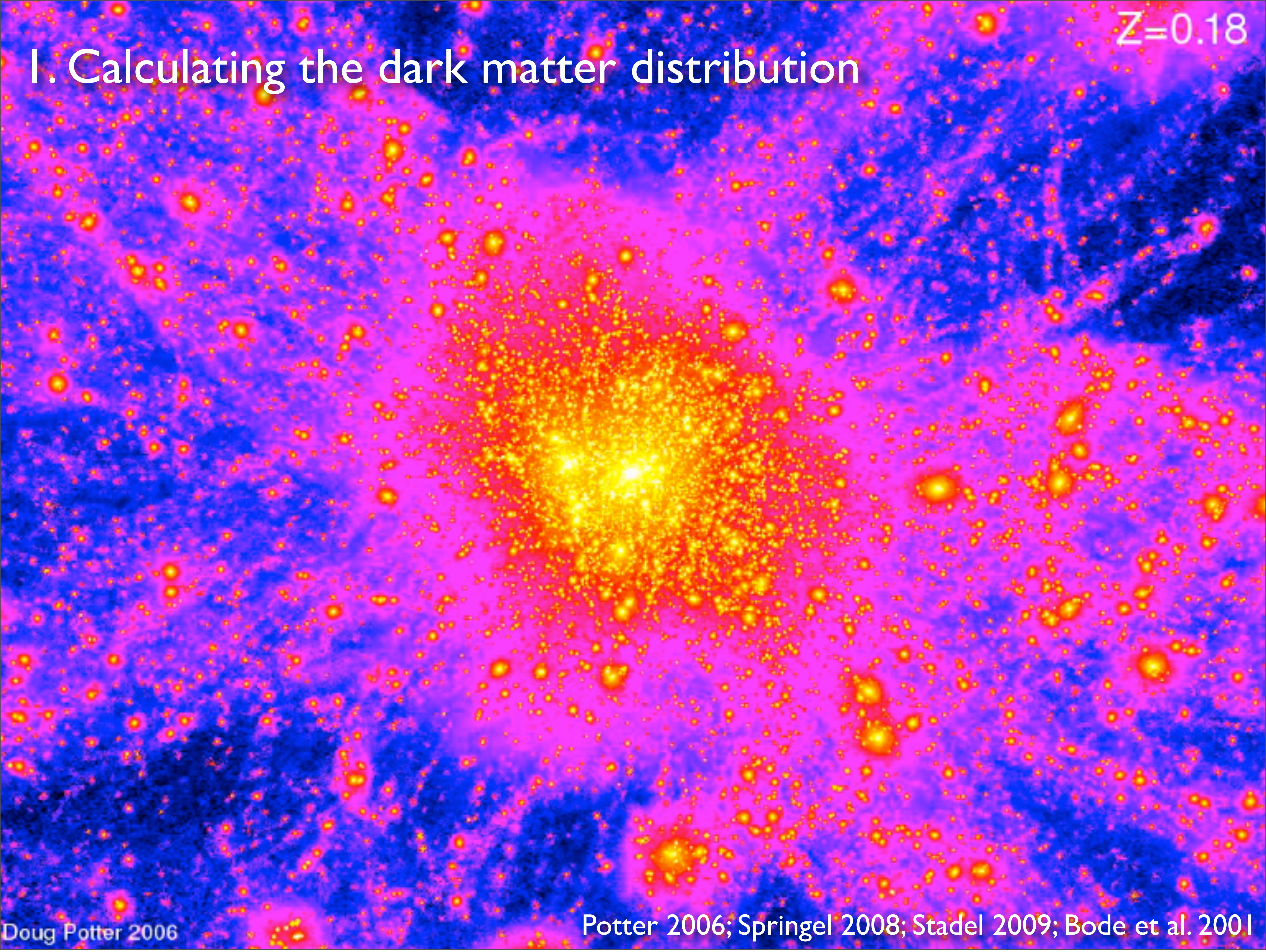
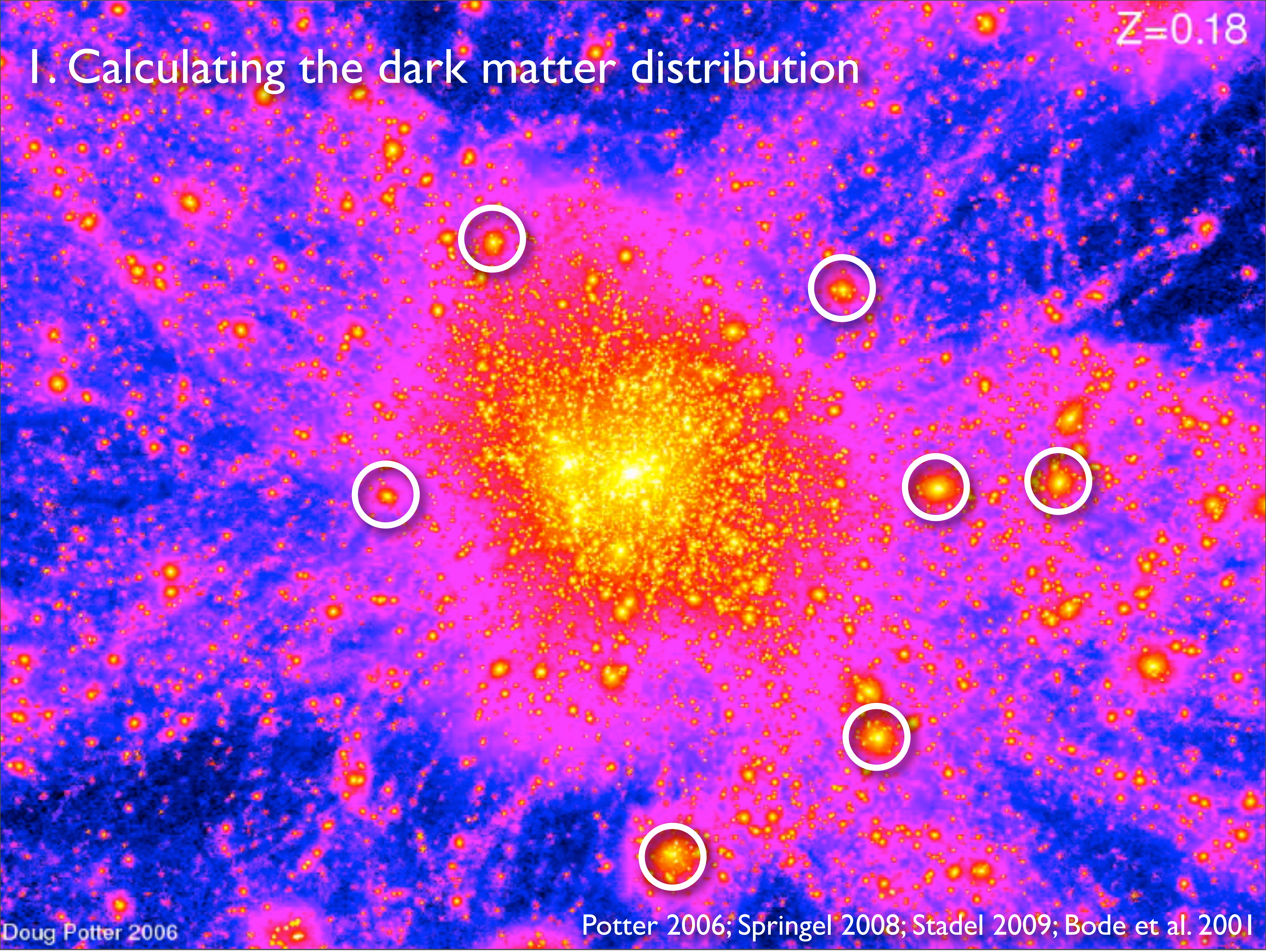

Z=0.18
Doug Potter 2006

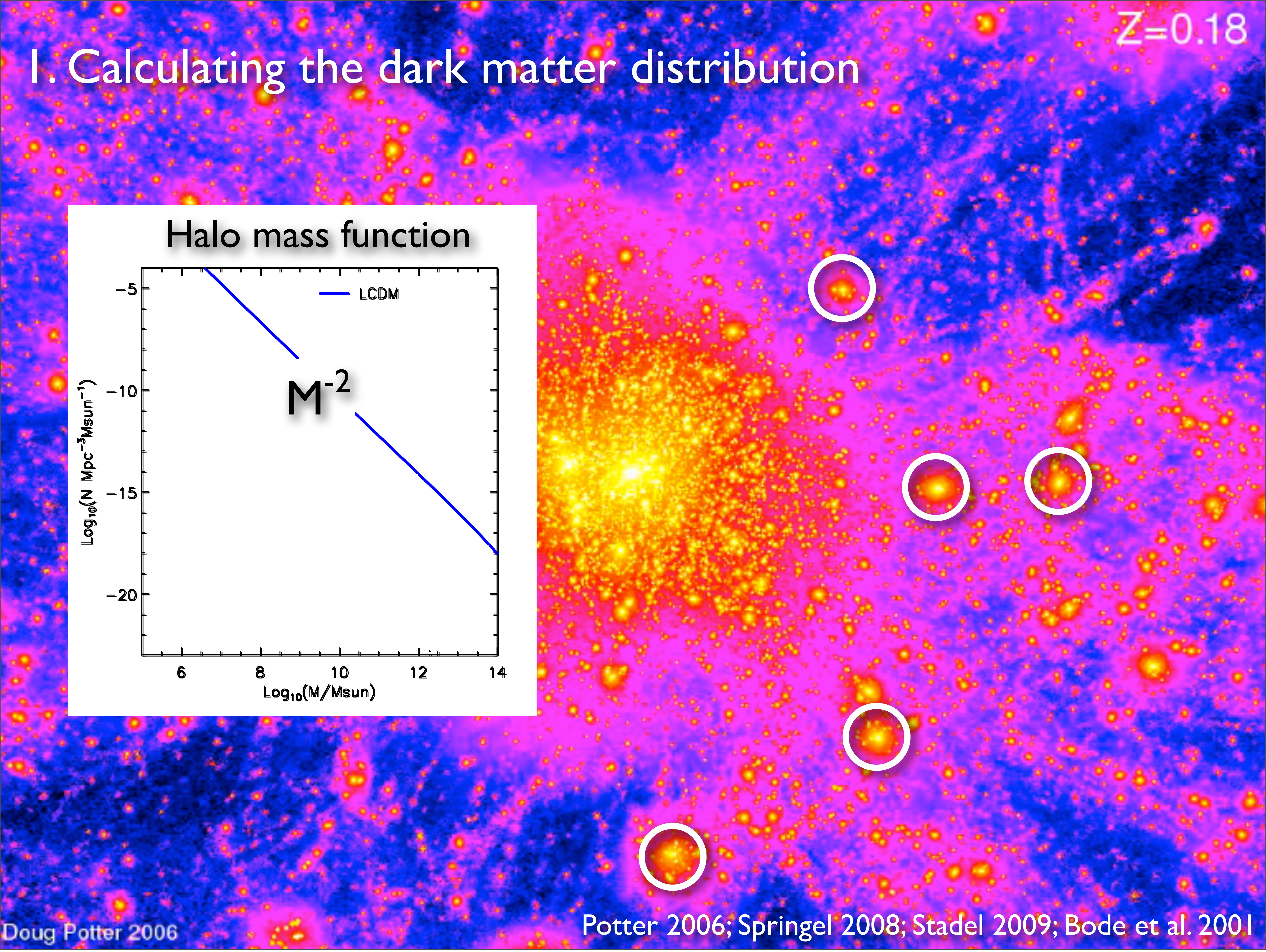
Potter 2006; Springel 2008; Stadel 2009; Bode et al. 2001

1. Calculating the dark matter distribution


Z=0.18
Doug Potter 2006

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

1. Calculating the dark matter distribution



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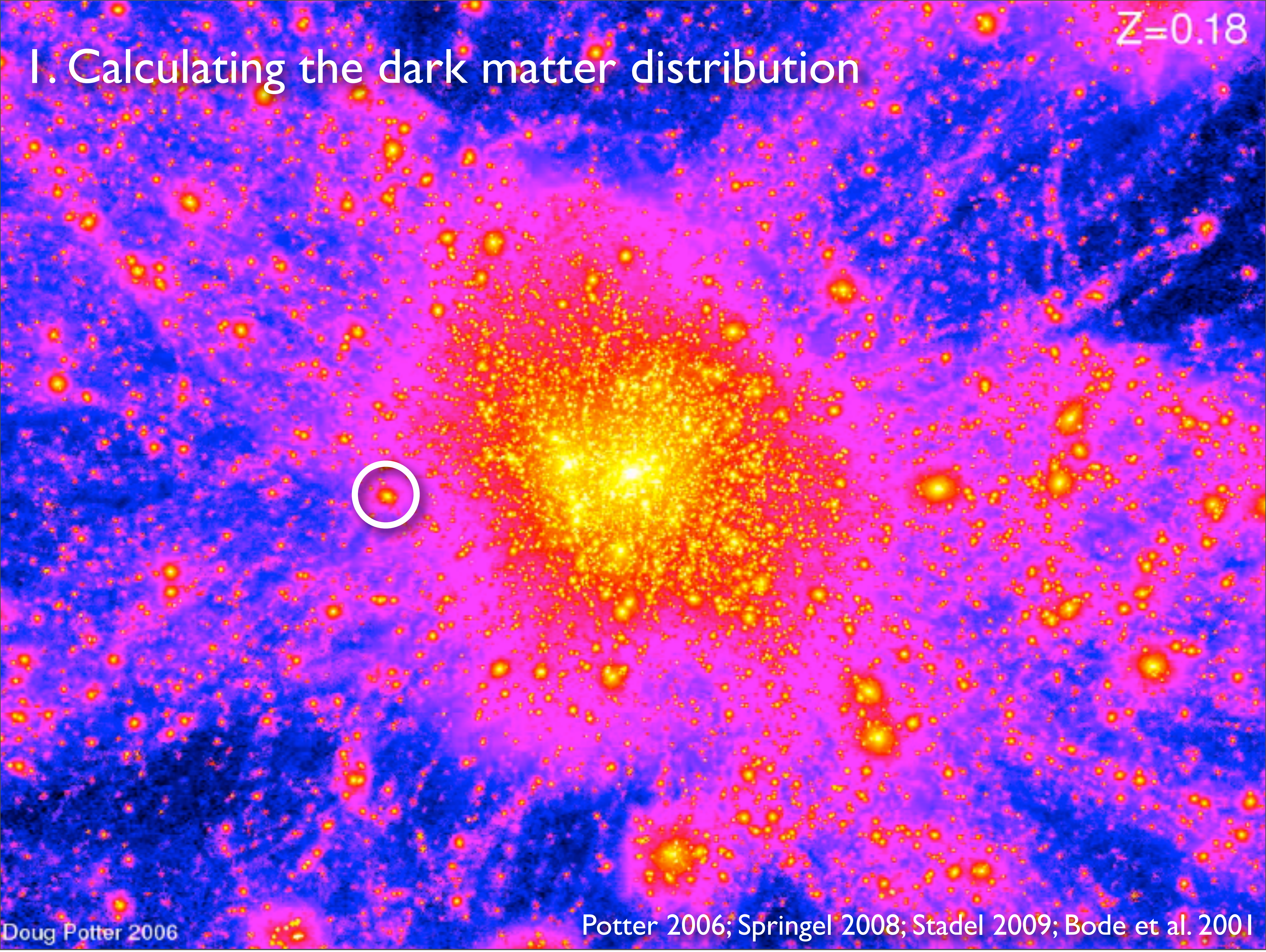
1. Calculating the dark matter distribution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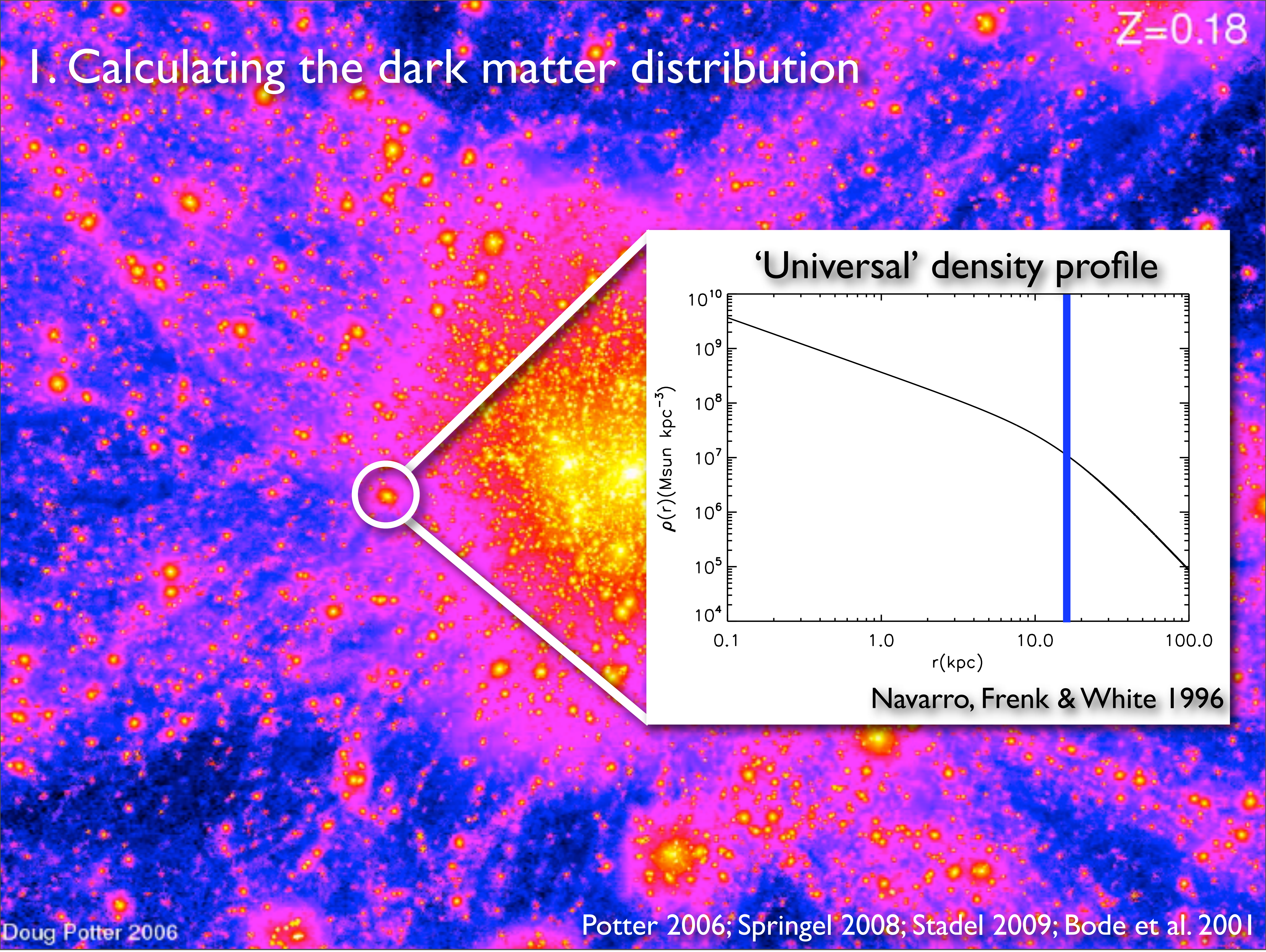
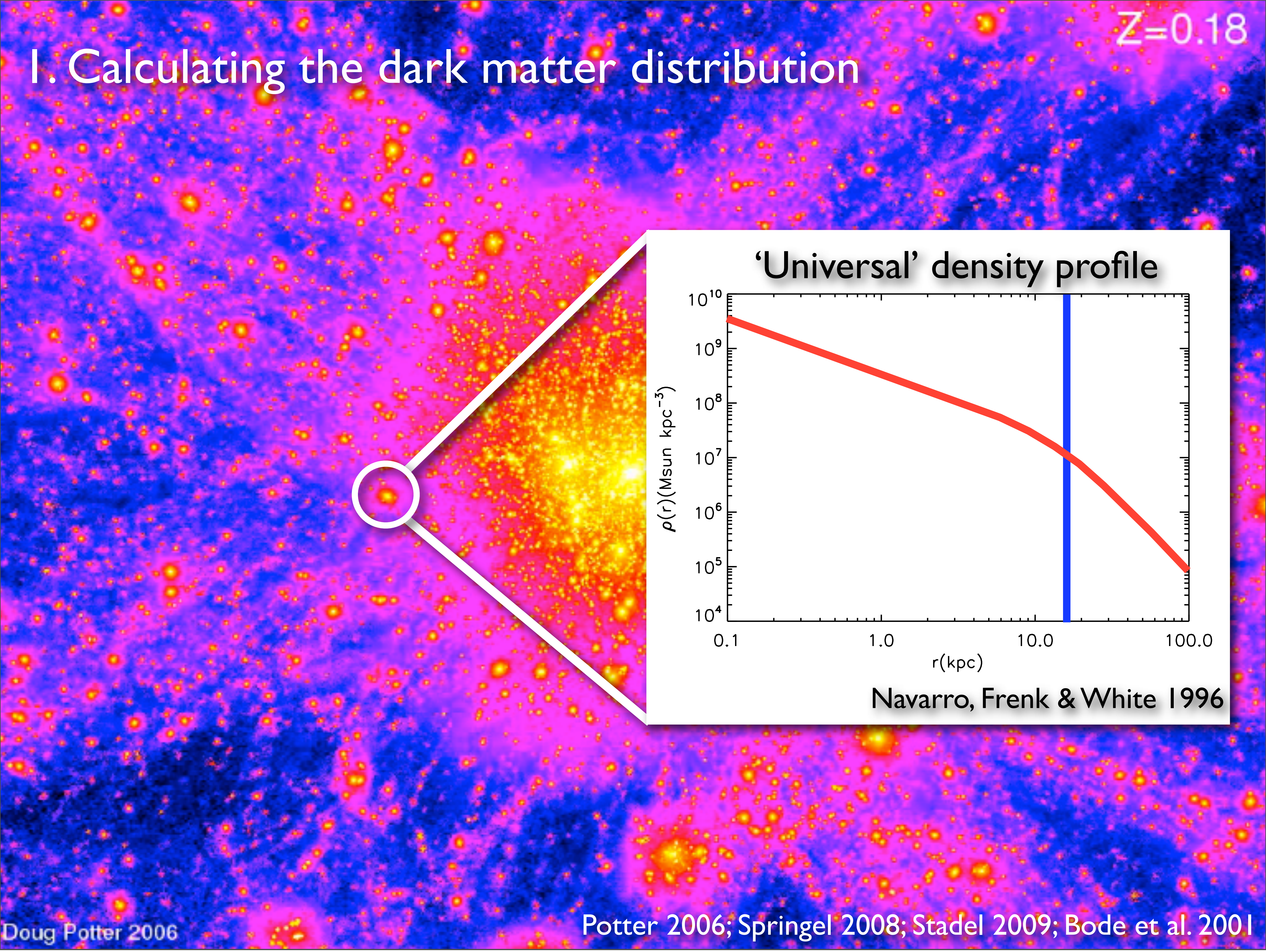


'Universal' density profile

Navarro, Frenk & White 1996

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

1. Calculating the dark matter distribution



Navarro, Frenk & White 1996

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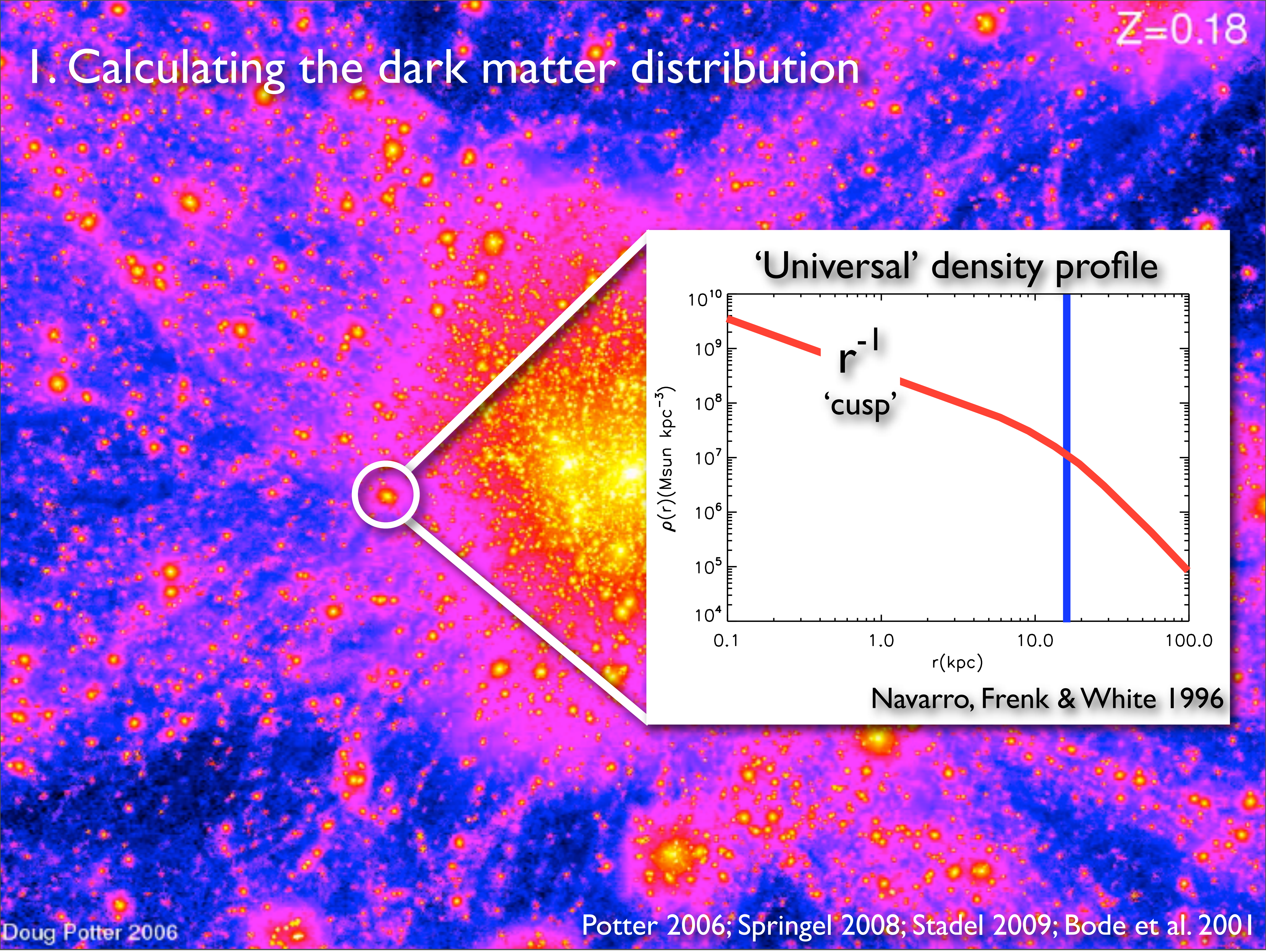
1. Calculating the dark matter distribution



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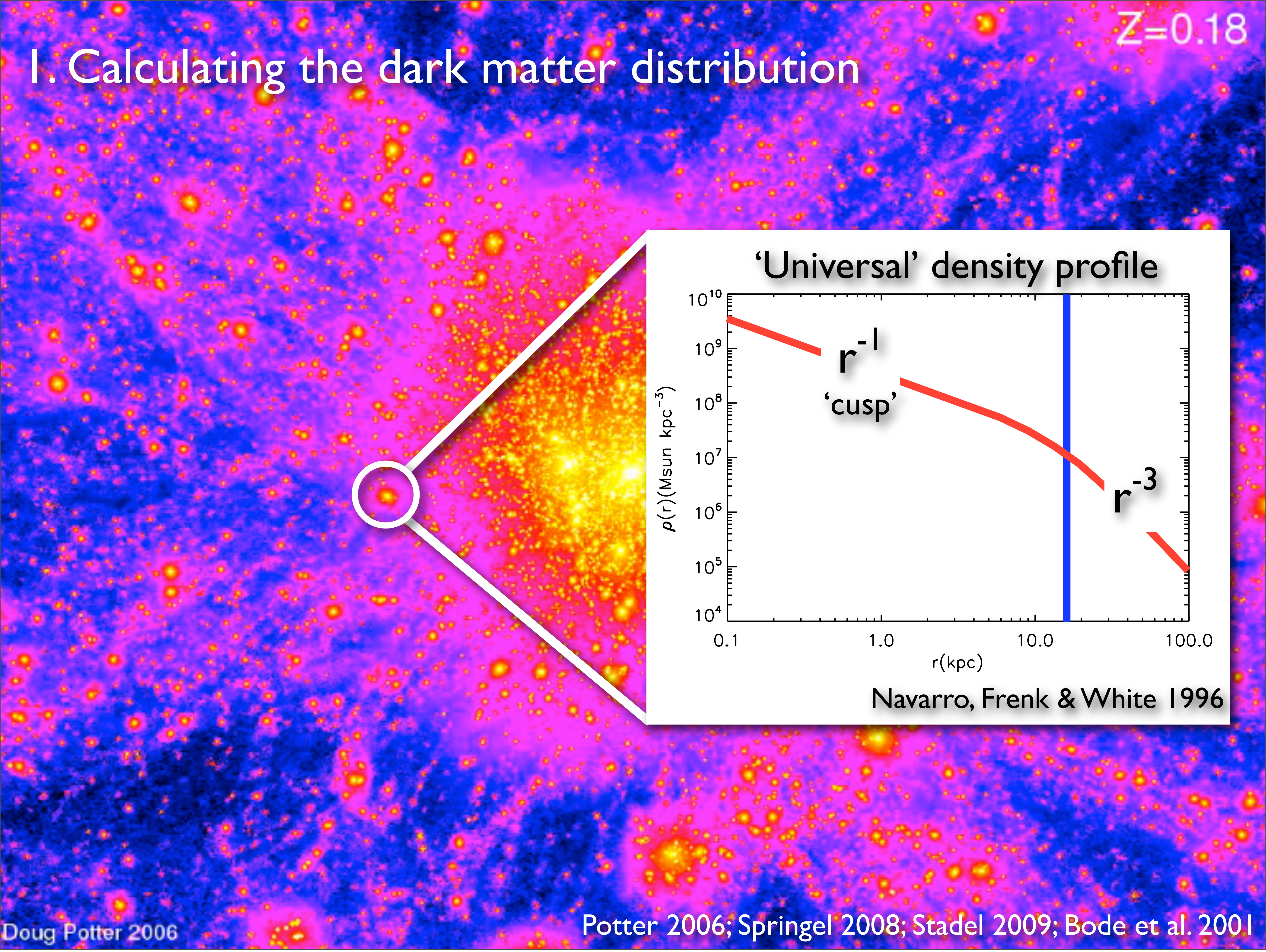
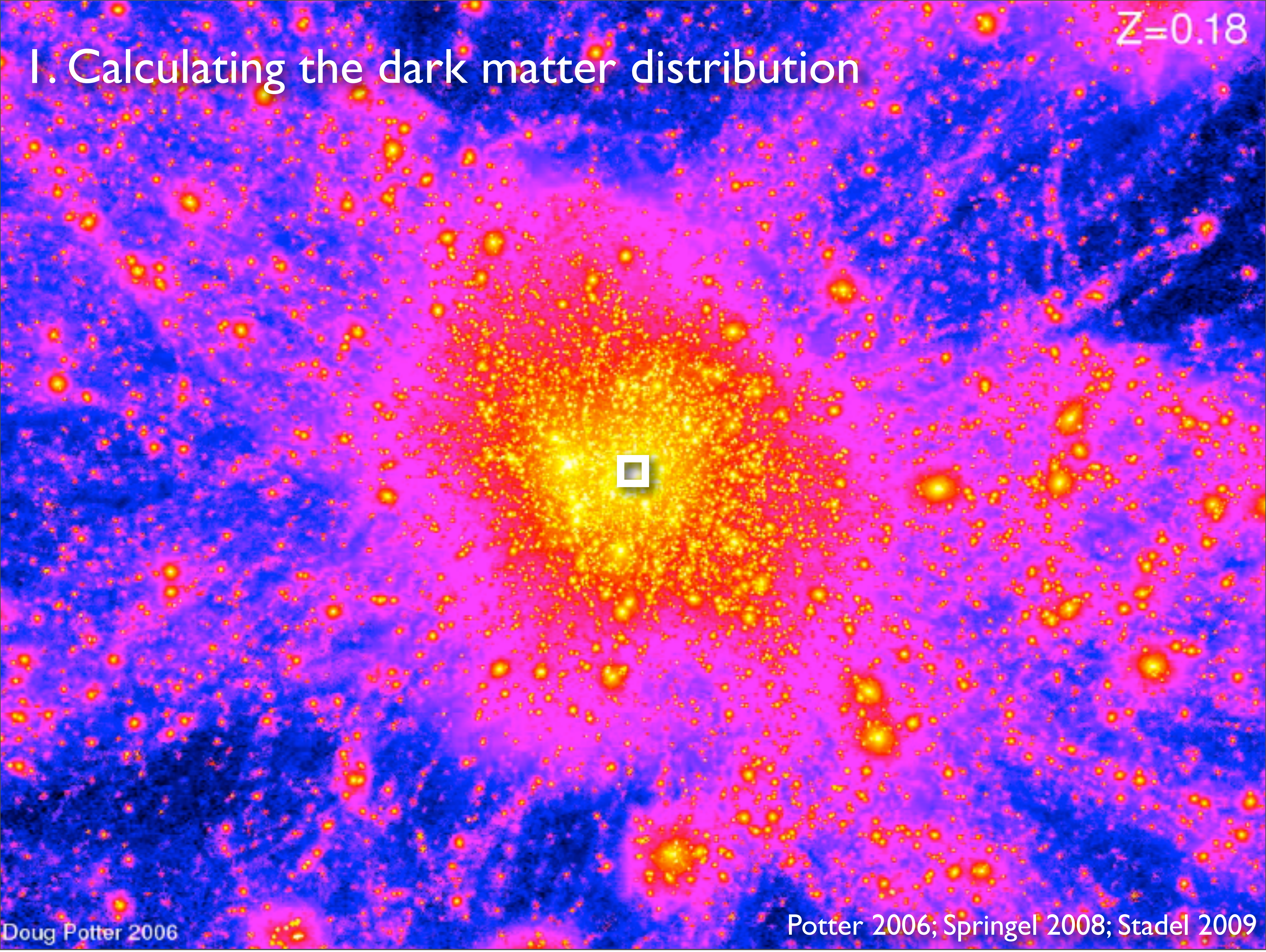


Potter 2006; Springel 2008; Stadel 2009; Bode et al. 2001

1. Calculating the dark matter distribution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Doug Potter 2006

Potter 2006; Springel 2008; Stadel 2009

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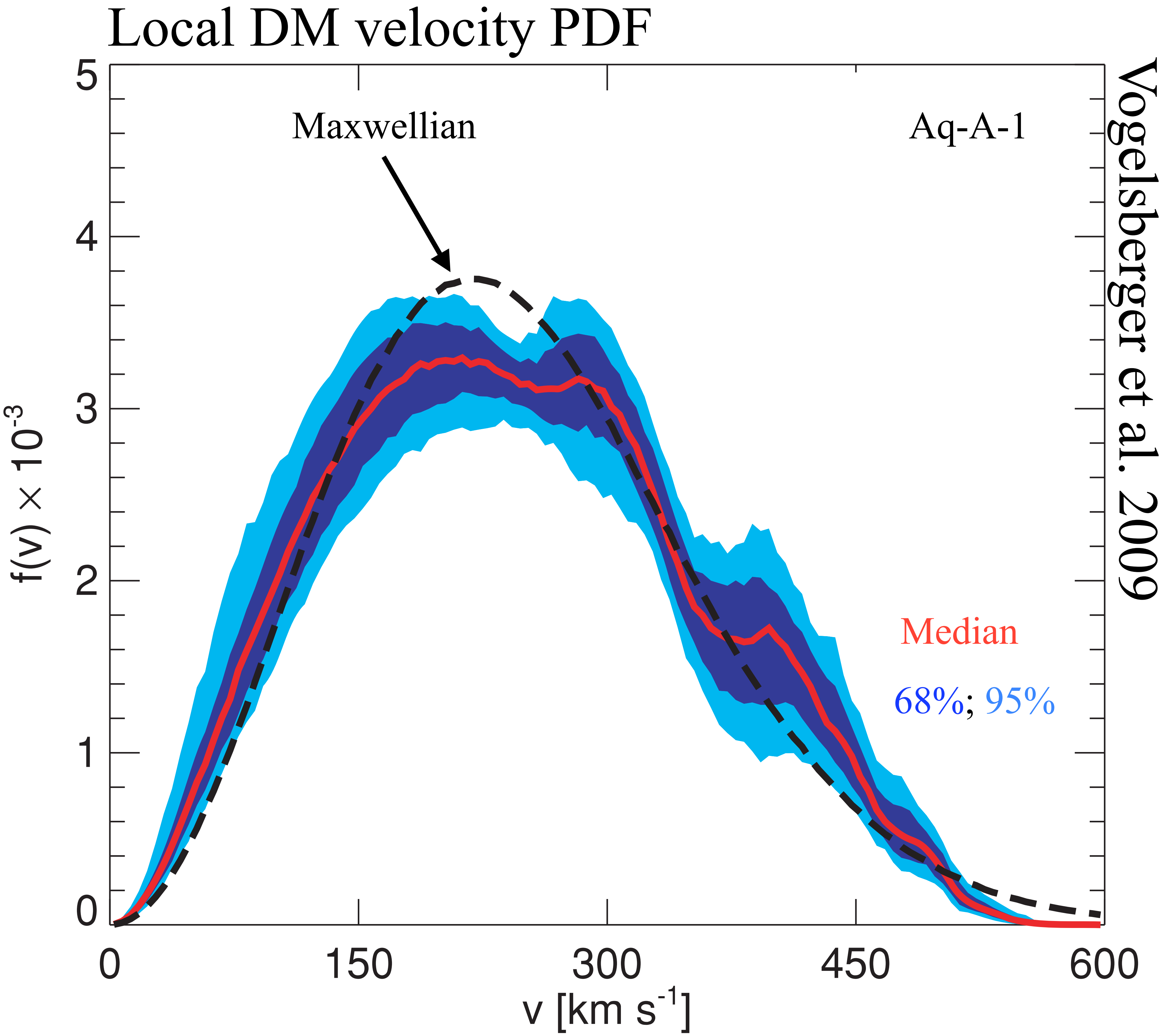
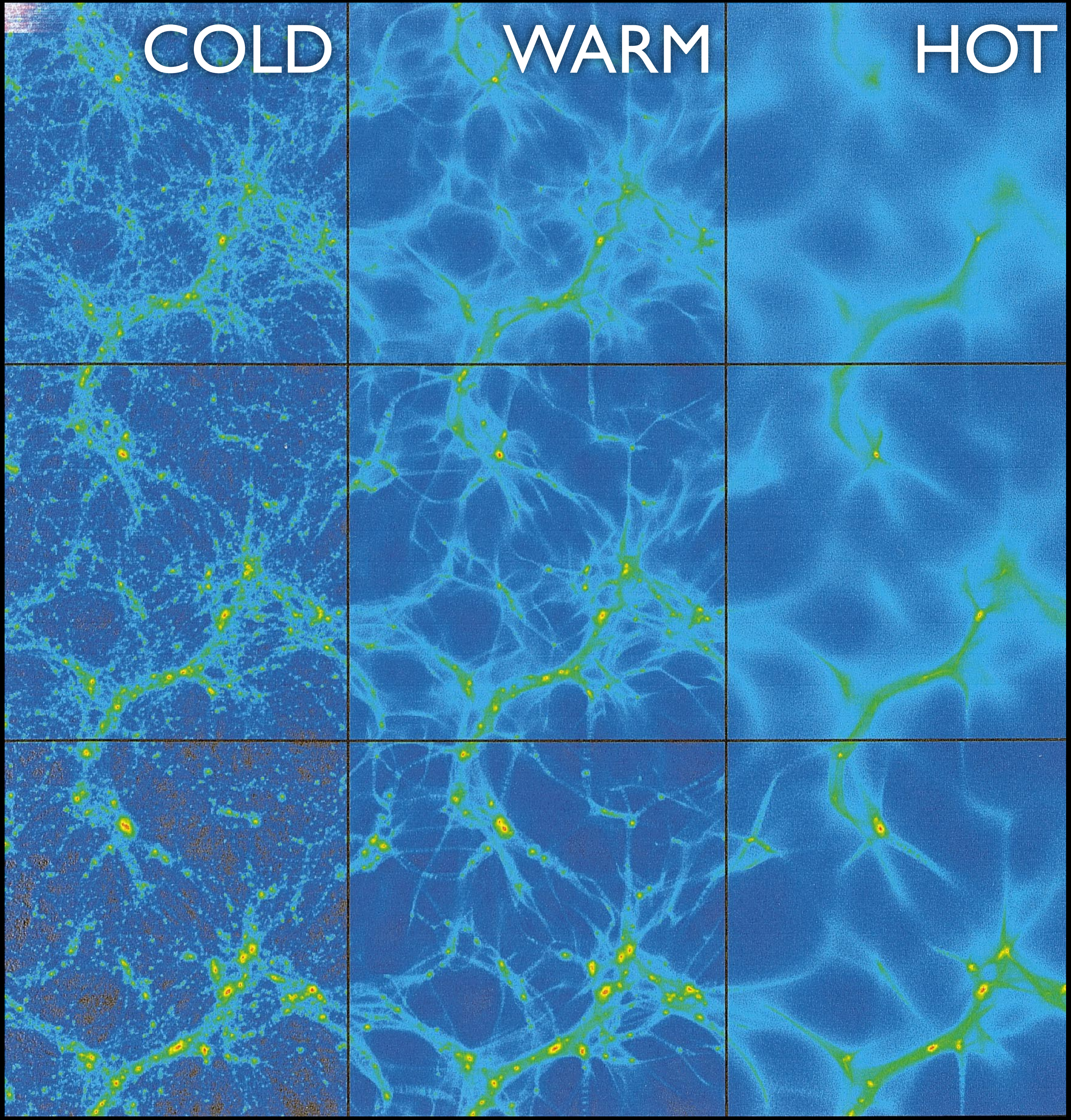
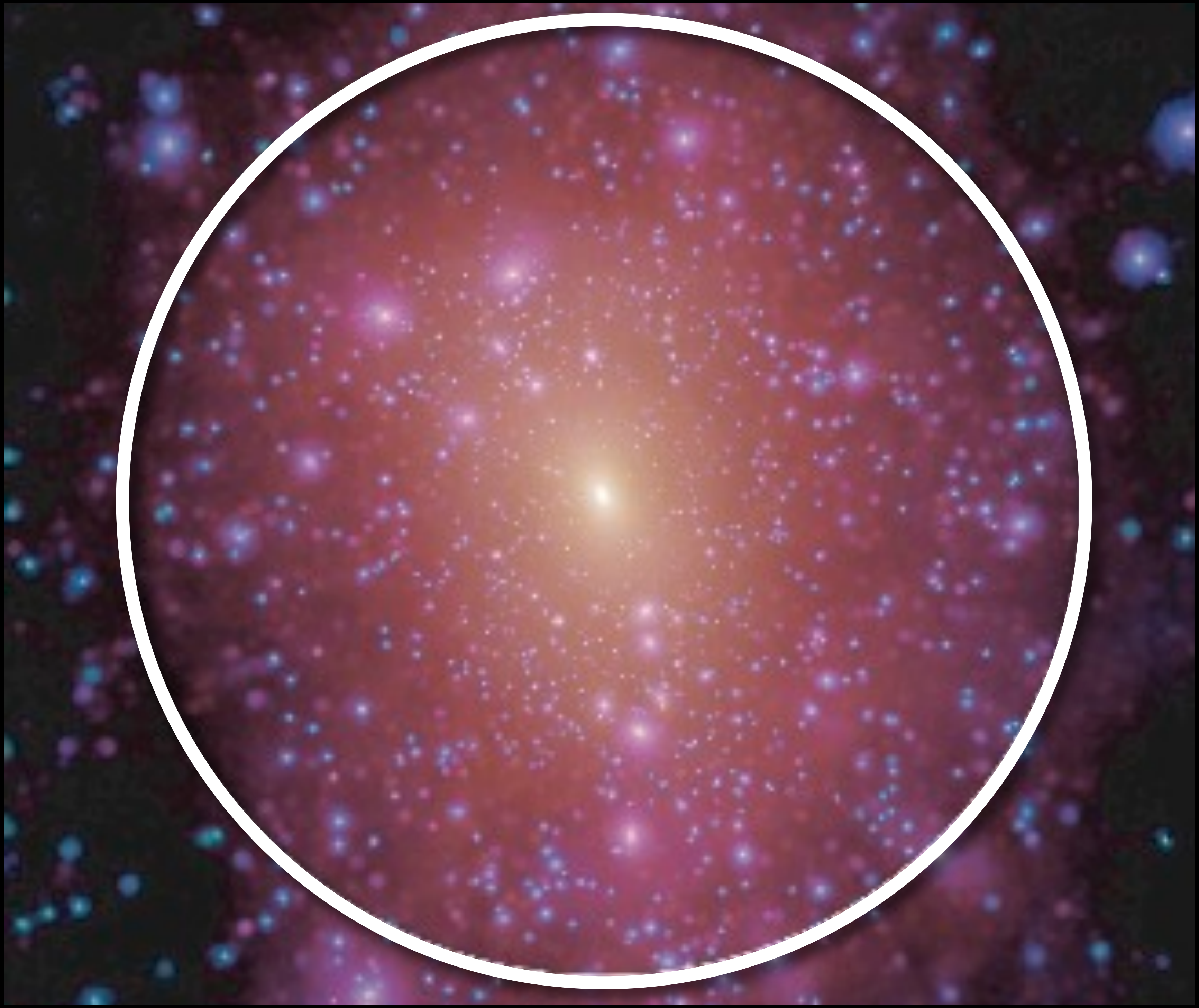


1. Calculating the dark matter distribution


COLD
WARM
HOT

Bode et al. 2001

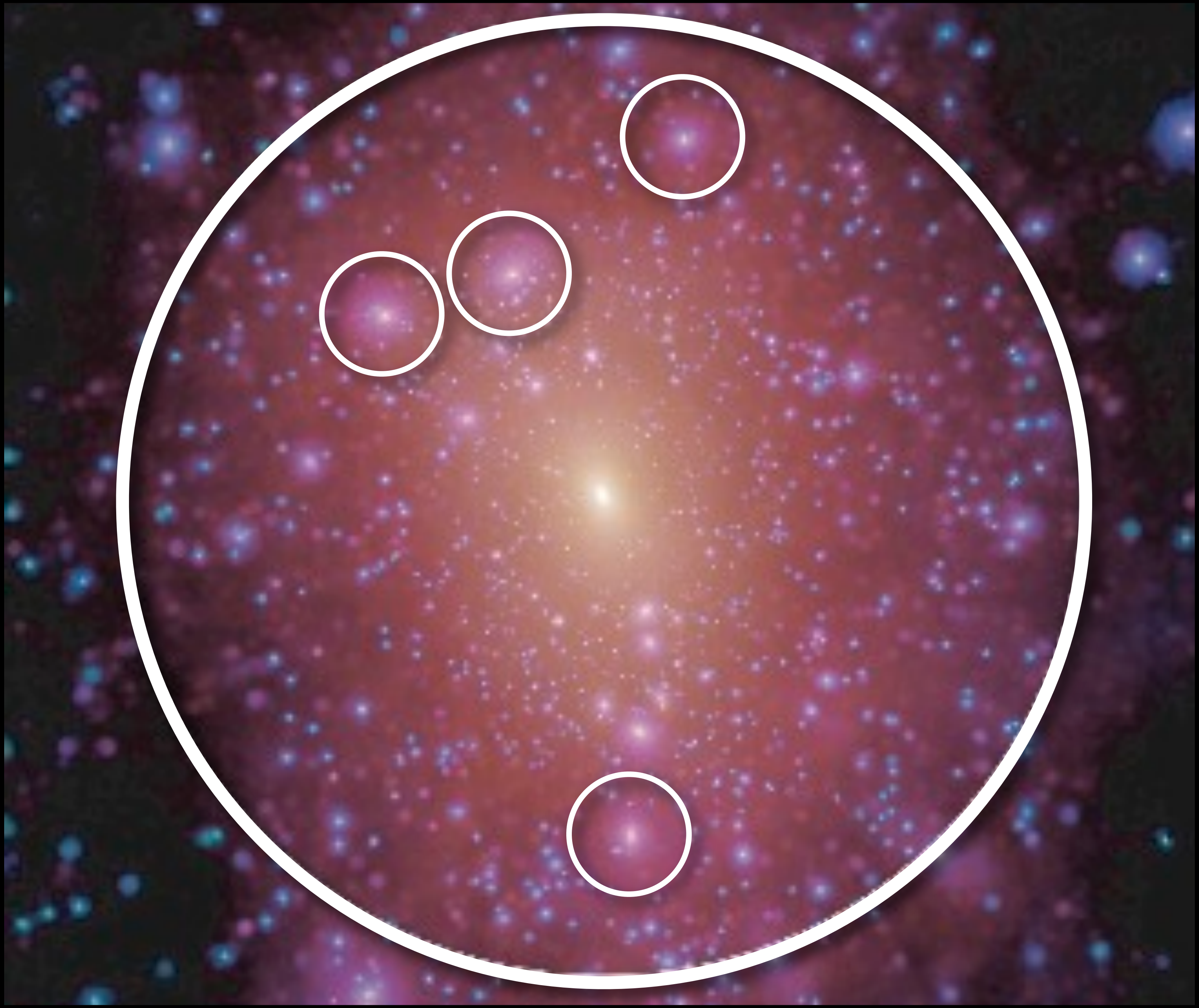
1. Calculating the dark matter distribution



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

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

1. Calculating the dark matter distribution



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

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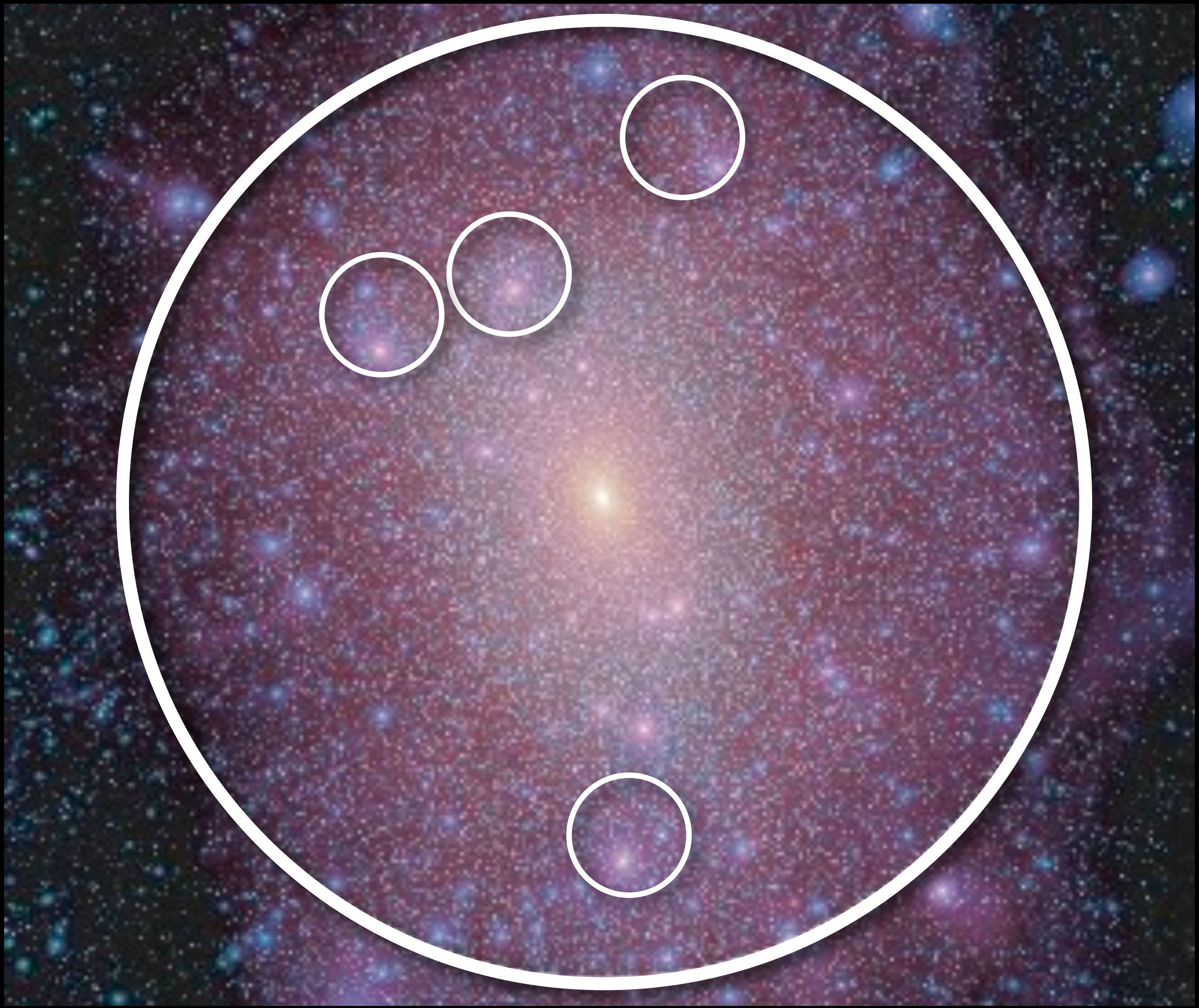

$N_{\mathrm{hr}} = 4,252,607,000$

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

1. Calculating the DM dist. | The trouble with WDM

GADGET | Maccio et al. 2012

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GADGET | Maccio et al. 2012

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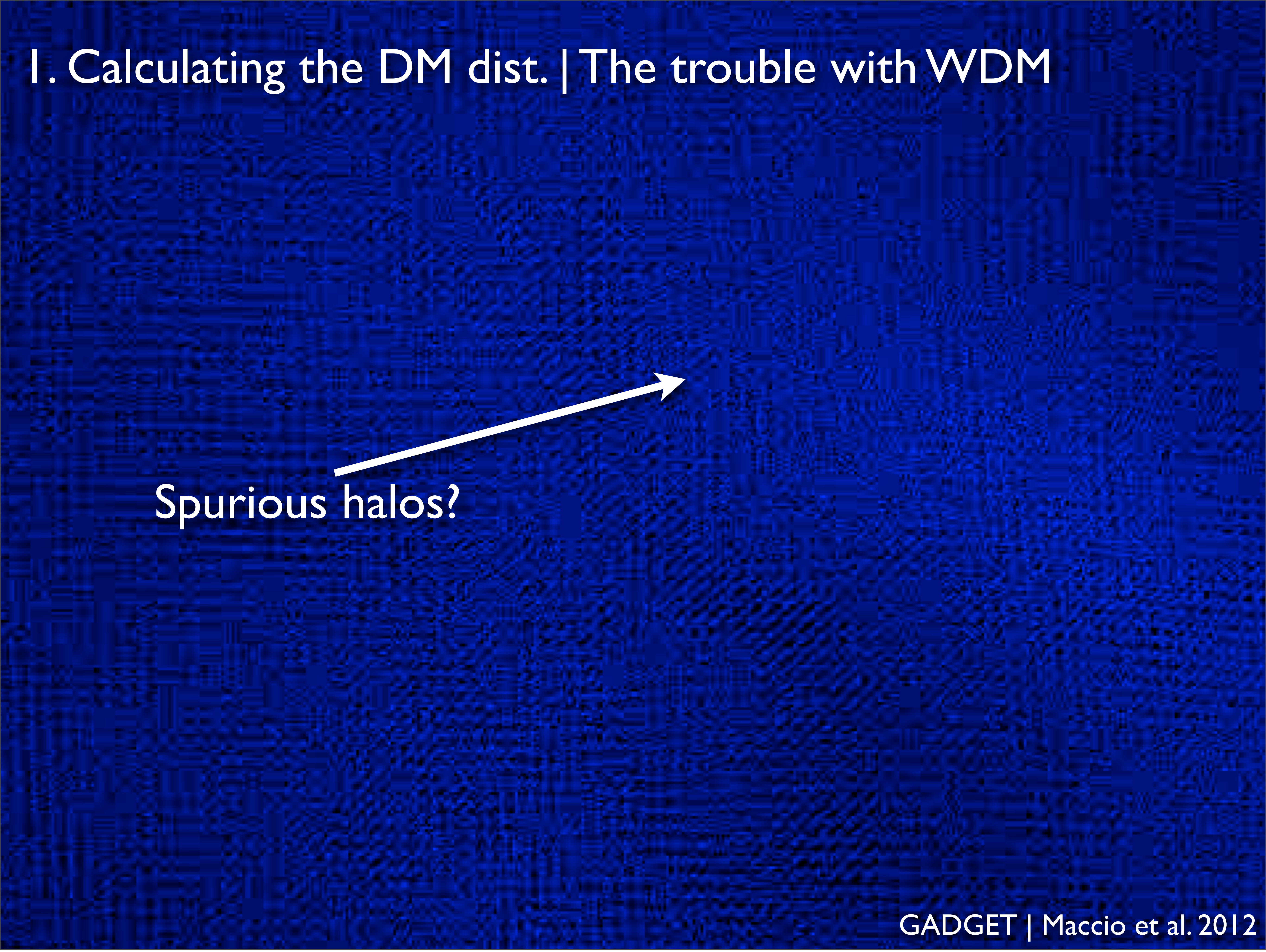
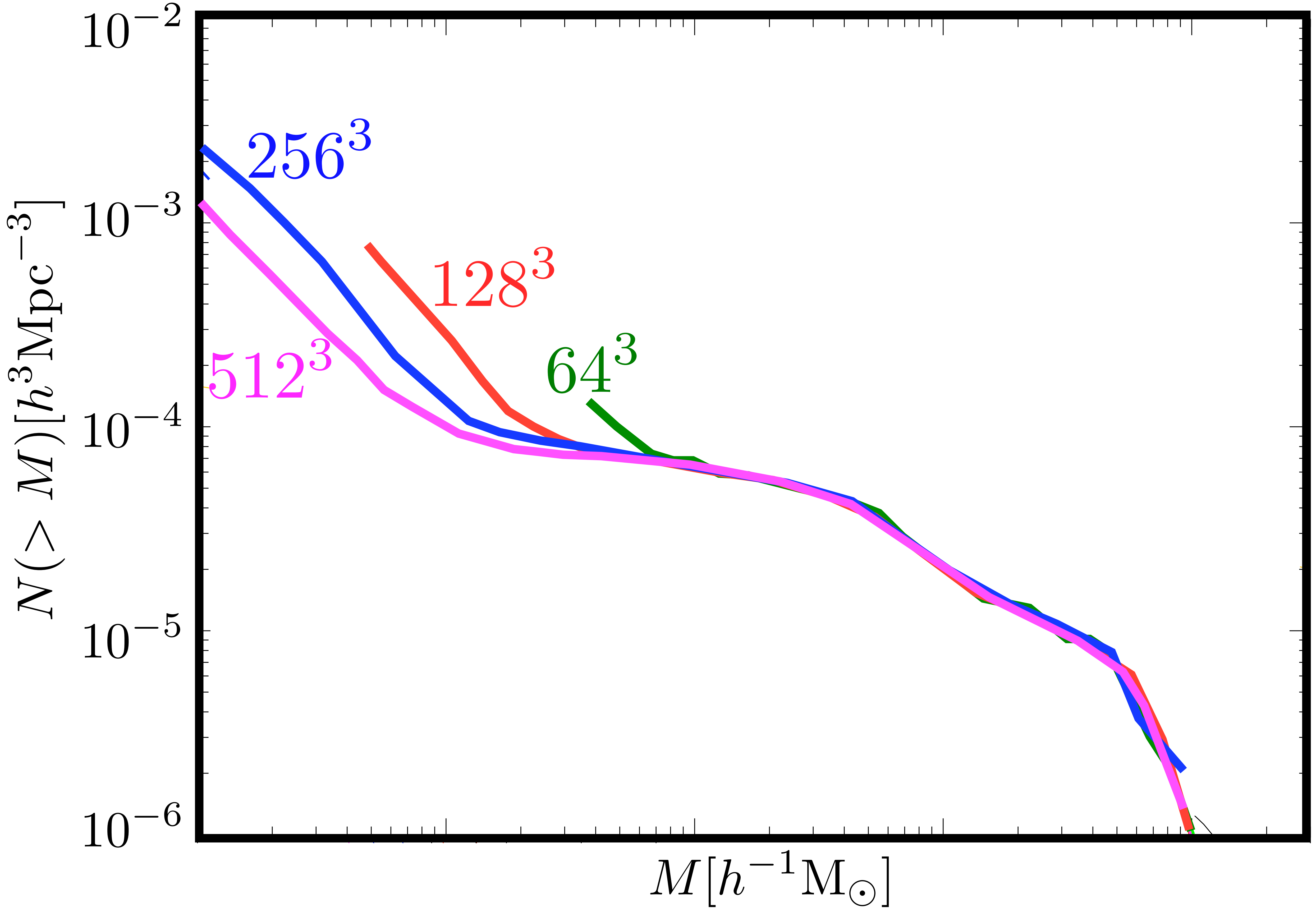

Spurious halos?

GADGET | Maccio et al. 2012

1. Calculating the DM dist. | The trouble with WDM



GADGET | Wang & White 2007

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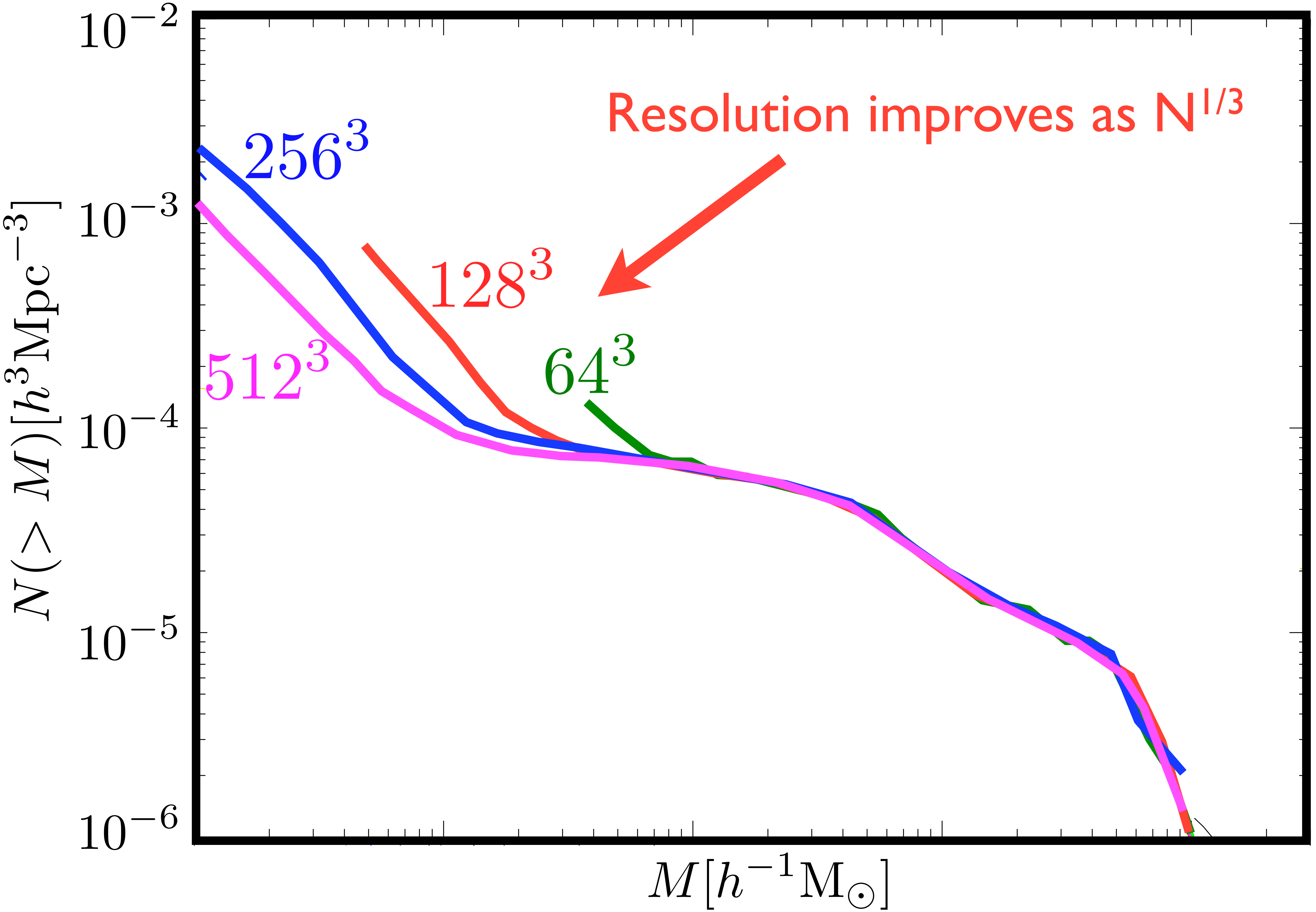
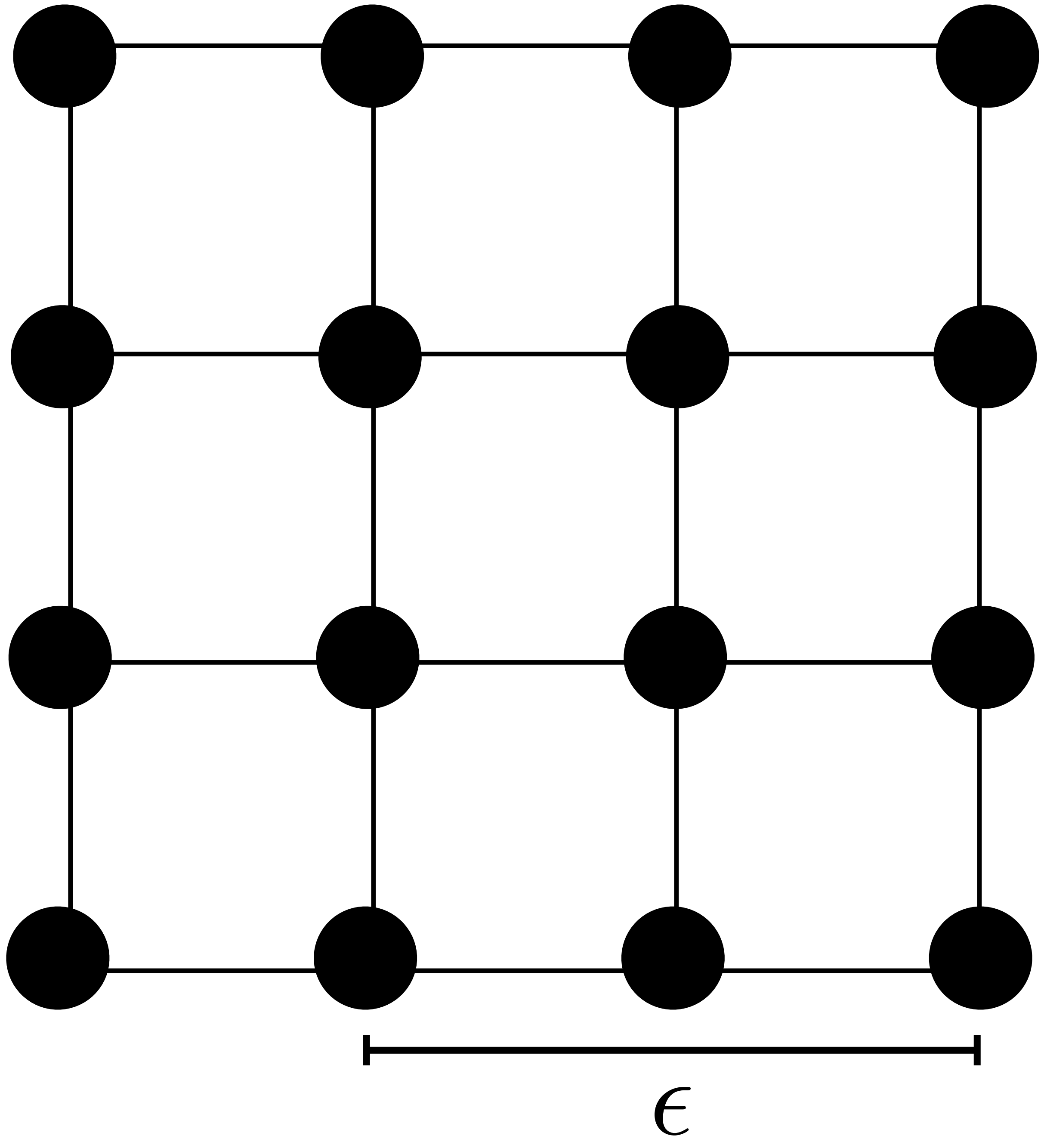


Resolution improves as $N^{1/3}$

GADGET | Wang & White 2007

Tuesday, May 13, 2014

1. Calculating the DM dist. | The trouble with WDM



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

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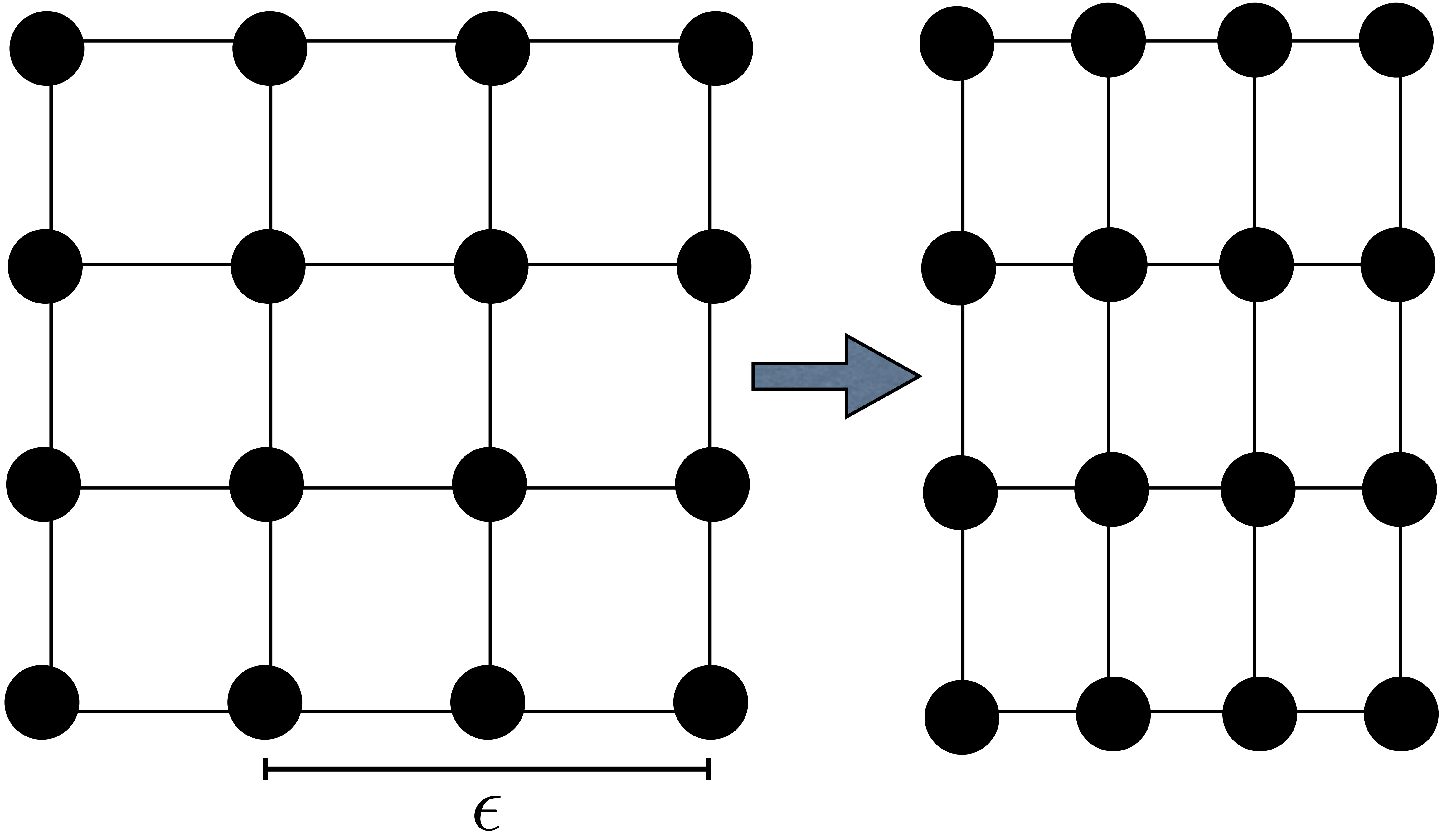

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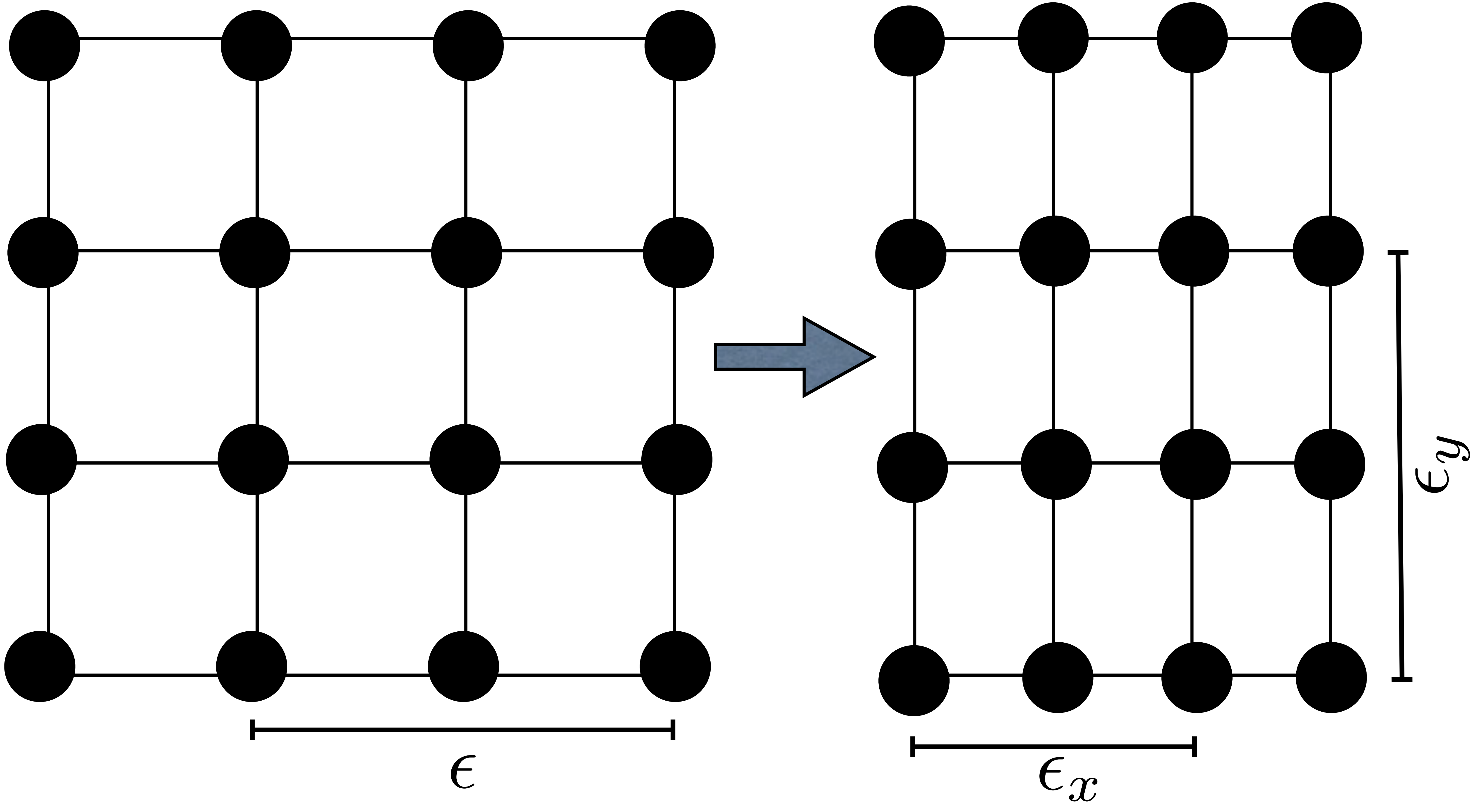
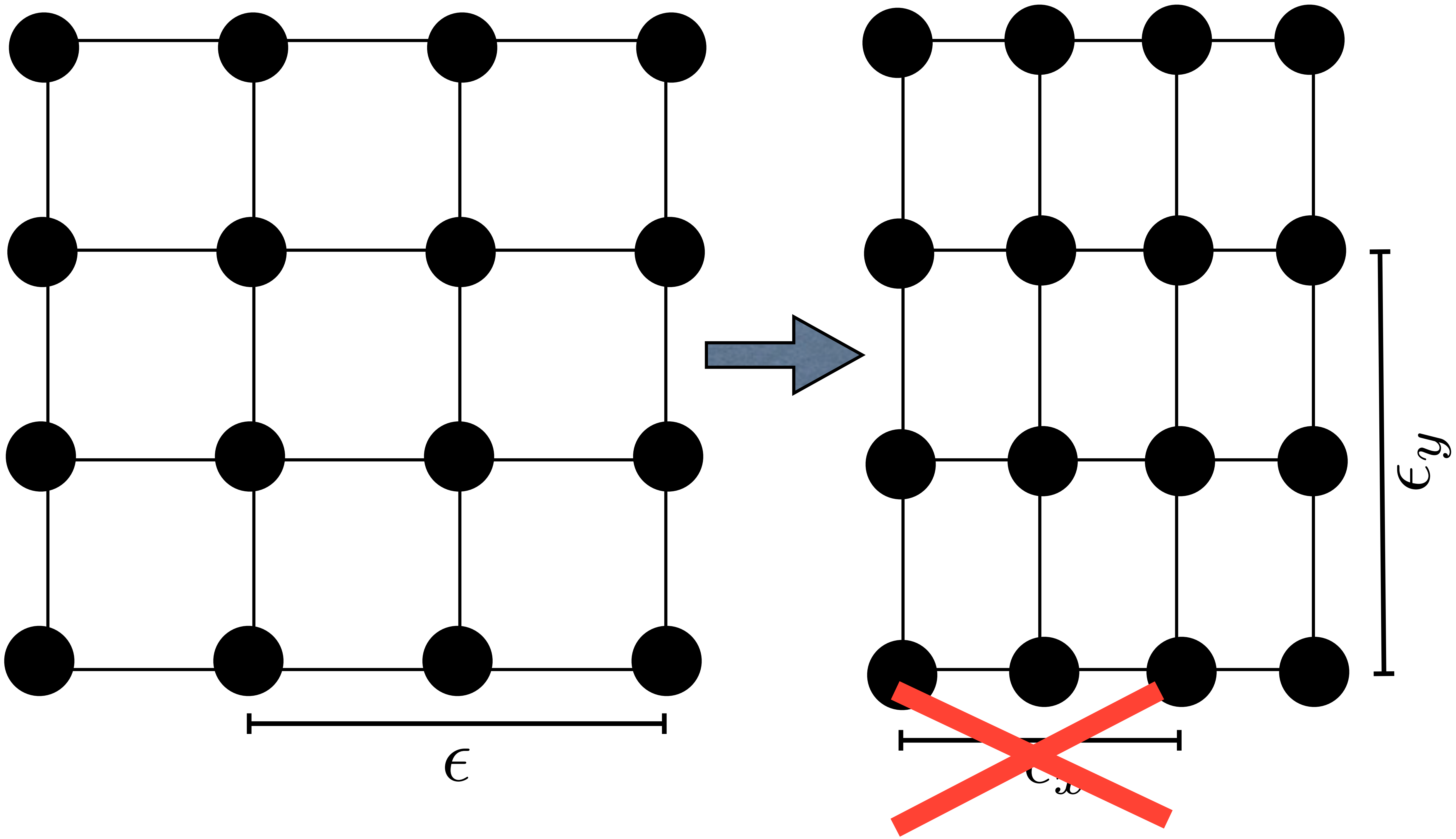


ϵ
ϵ_x
ϵ_y

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

1. Calculating the DM dist. | The trouble with WDM


ϵ
ϵ_x
ϵ_y

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

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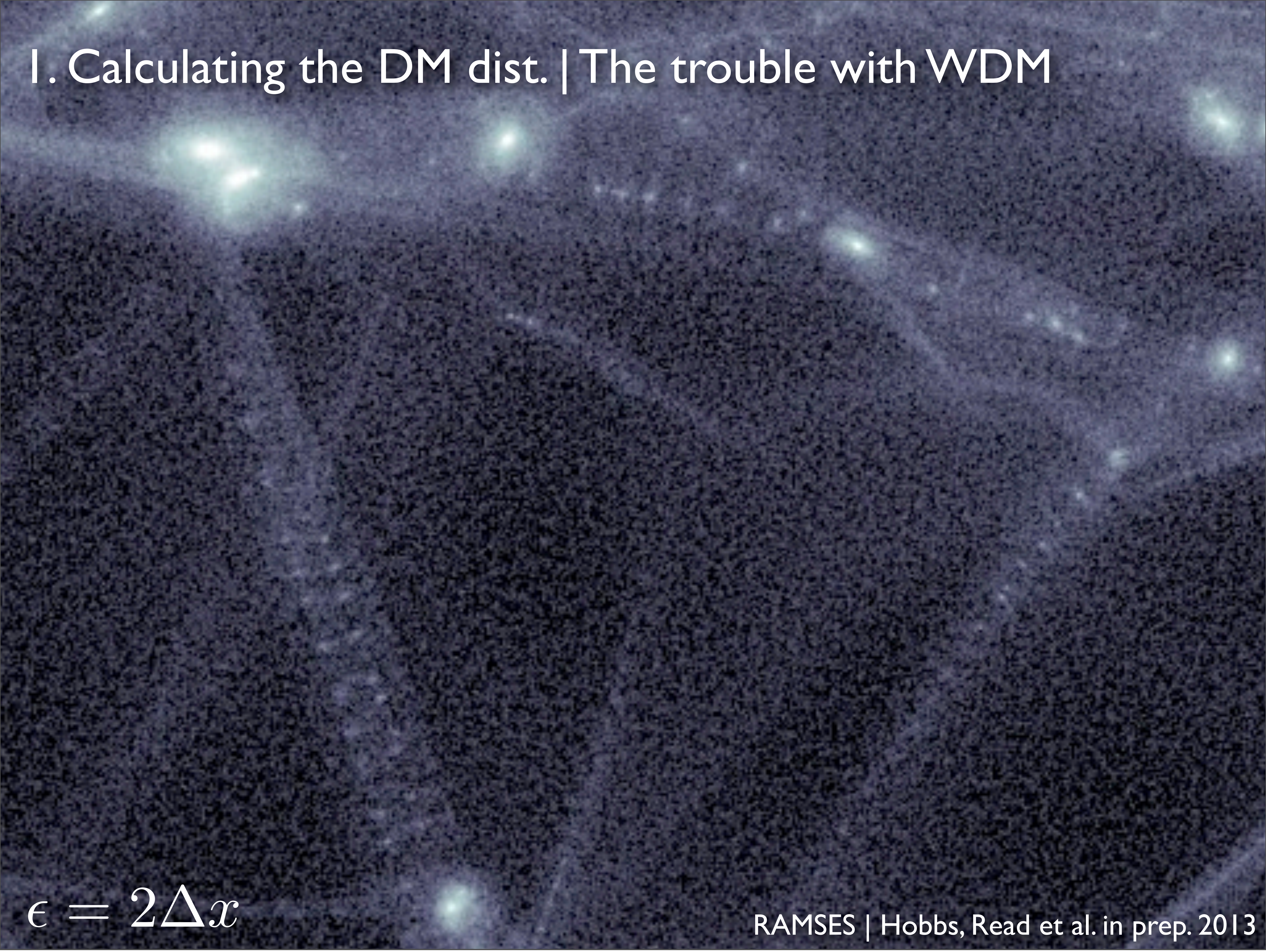
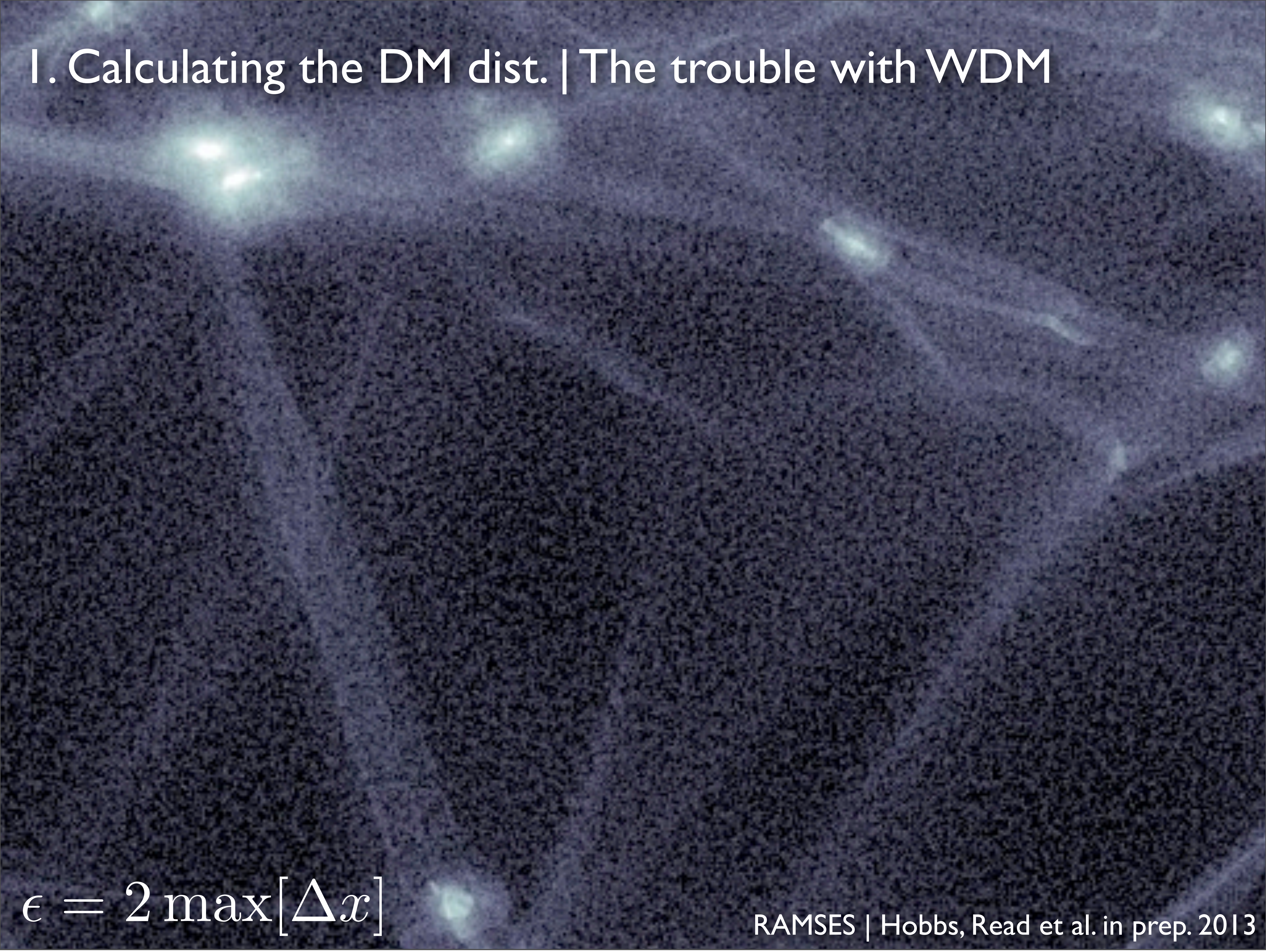


$\epsilon = 2\Delta x$

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

1. Calculating the DM dist. | The trouble with WDM



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

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

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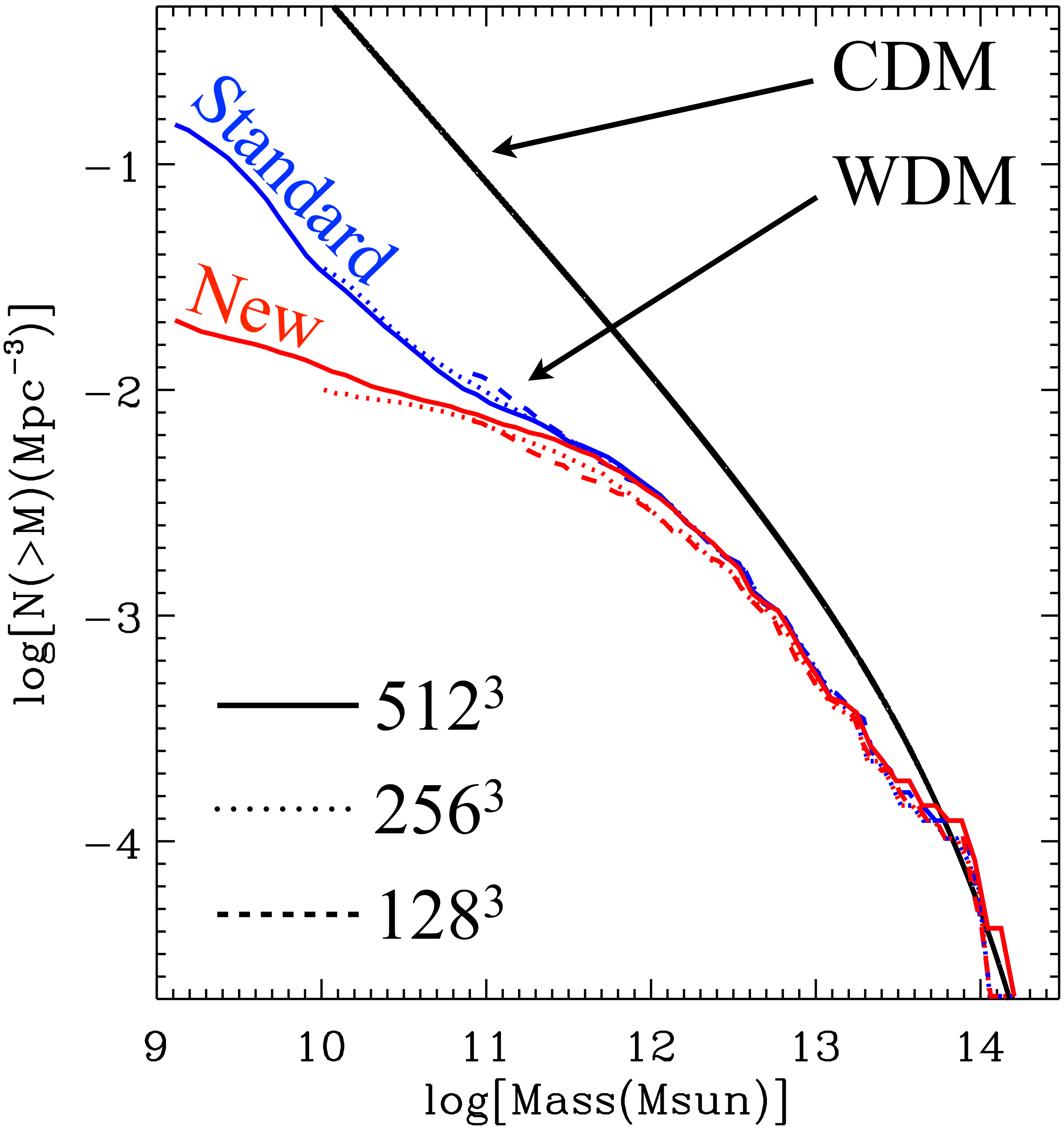
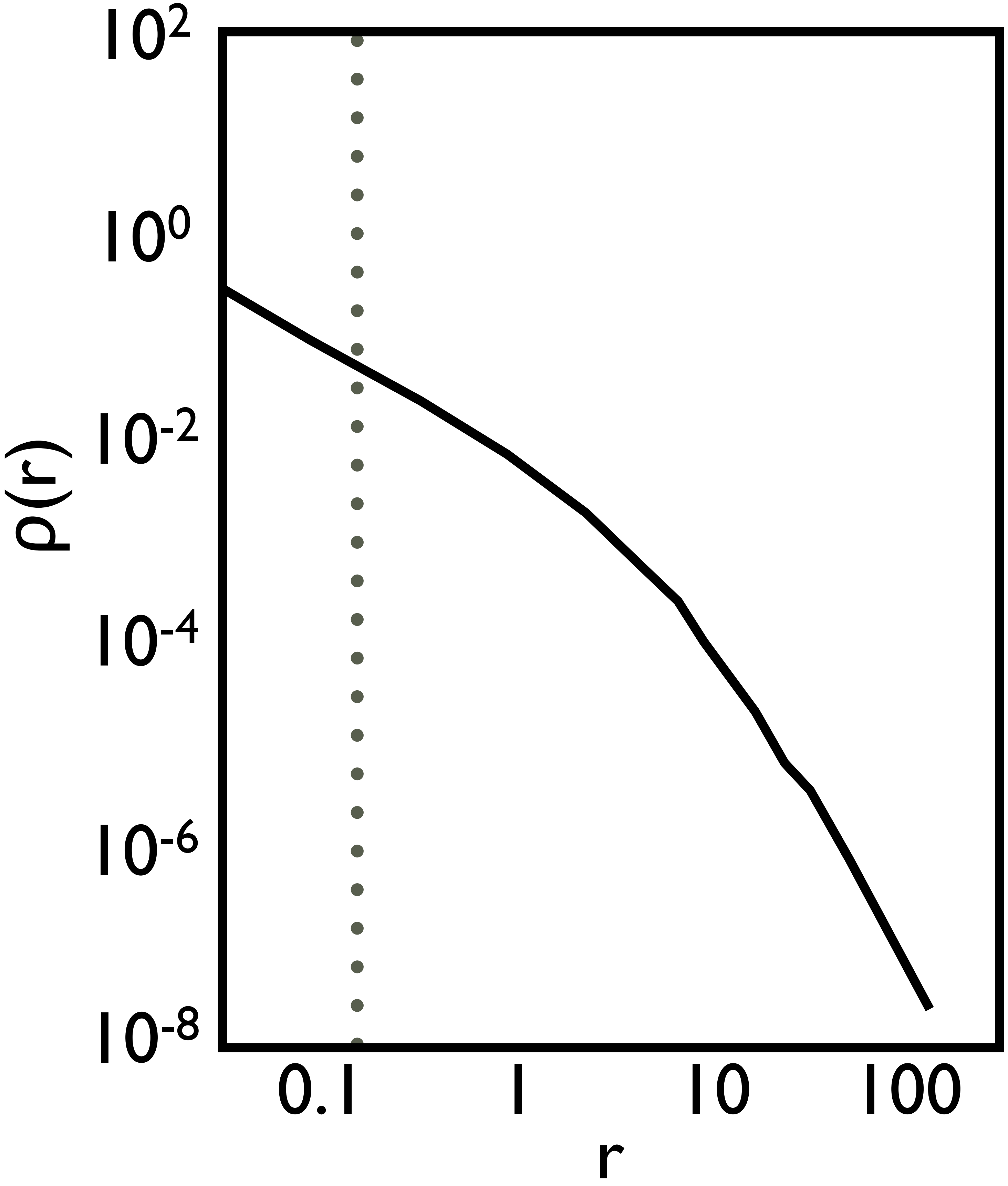
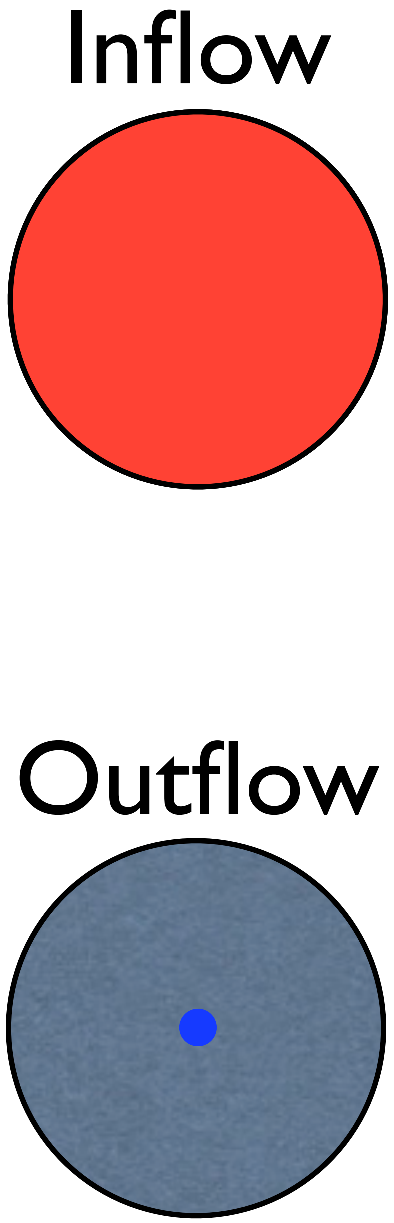


Hobbs, Read et al. in prep. 2013

Baryons

1. Calculating the DM dist. | The importance of baryons

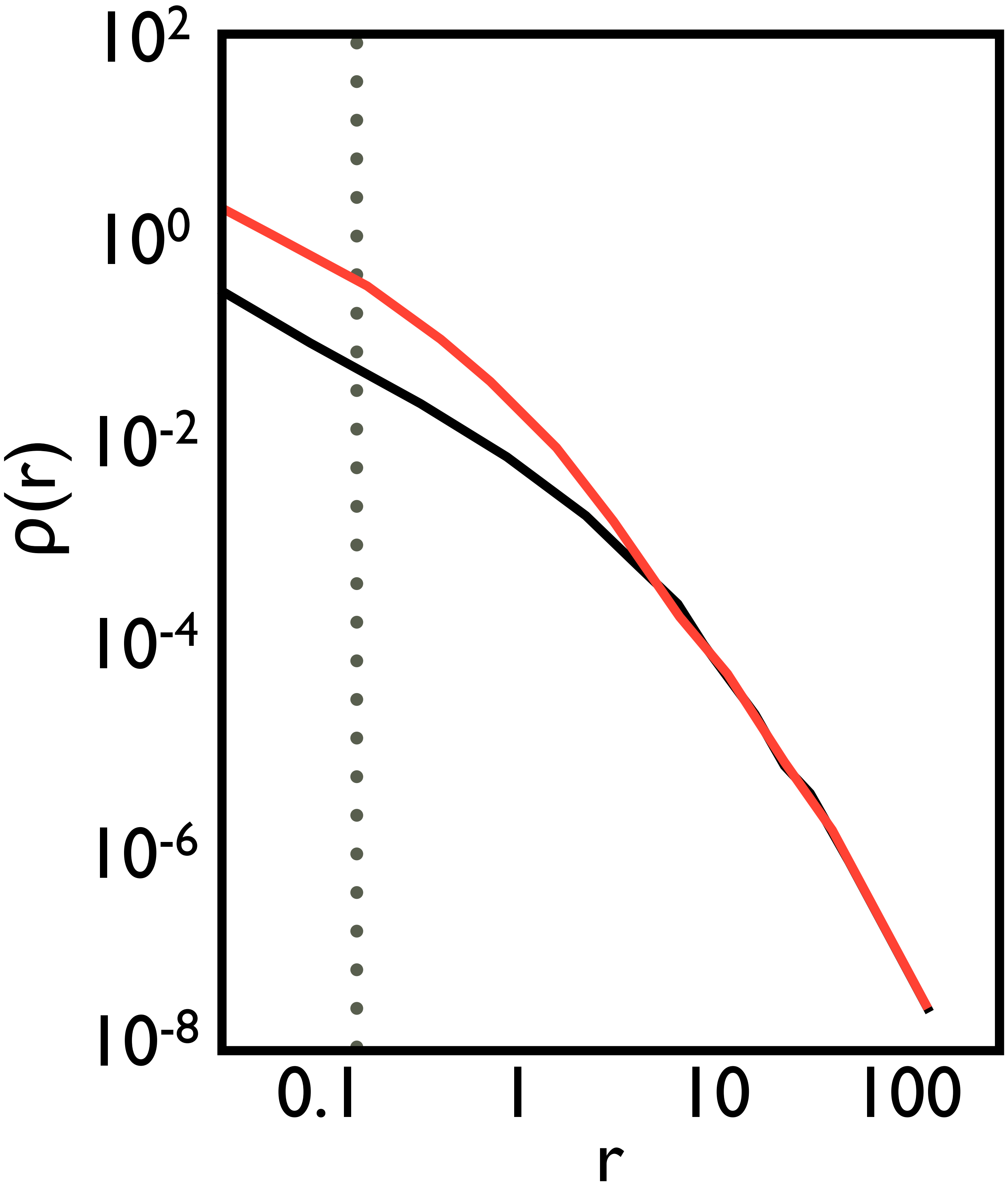




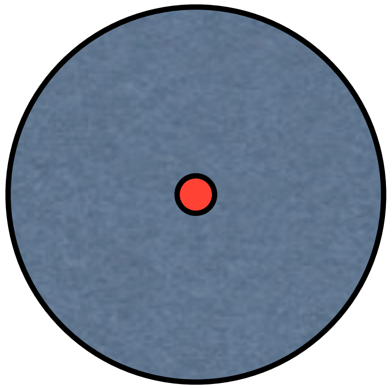
Inflow
Outflow

Read & Gilmore 2005; Navarro et al. 1996

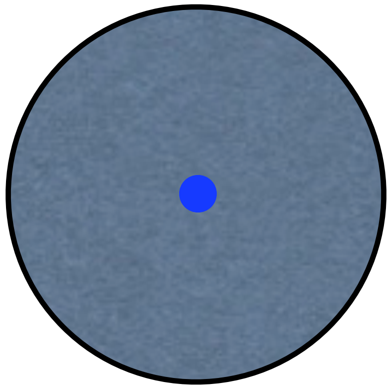
1. Calculating the DM dist. | The importance of baryons



Inflow



Outflow



Read & Gilmore 2005; Navarro et al. 1996

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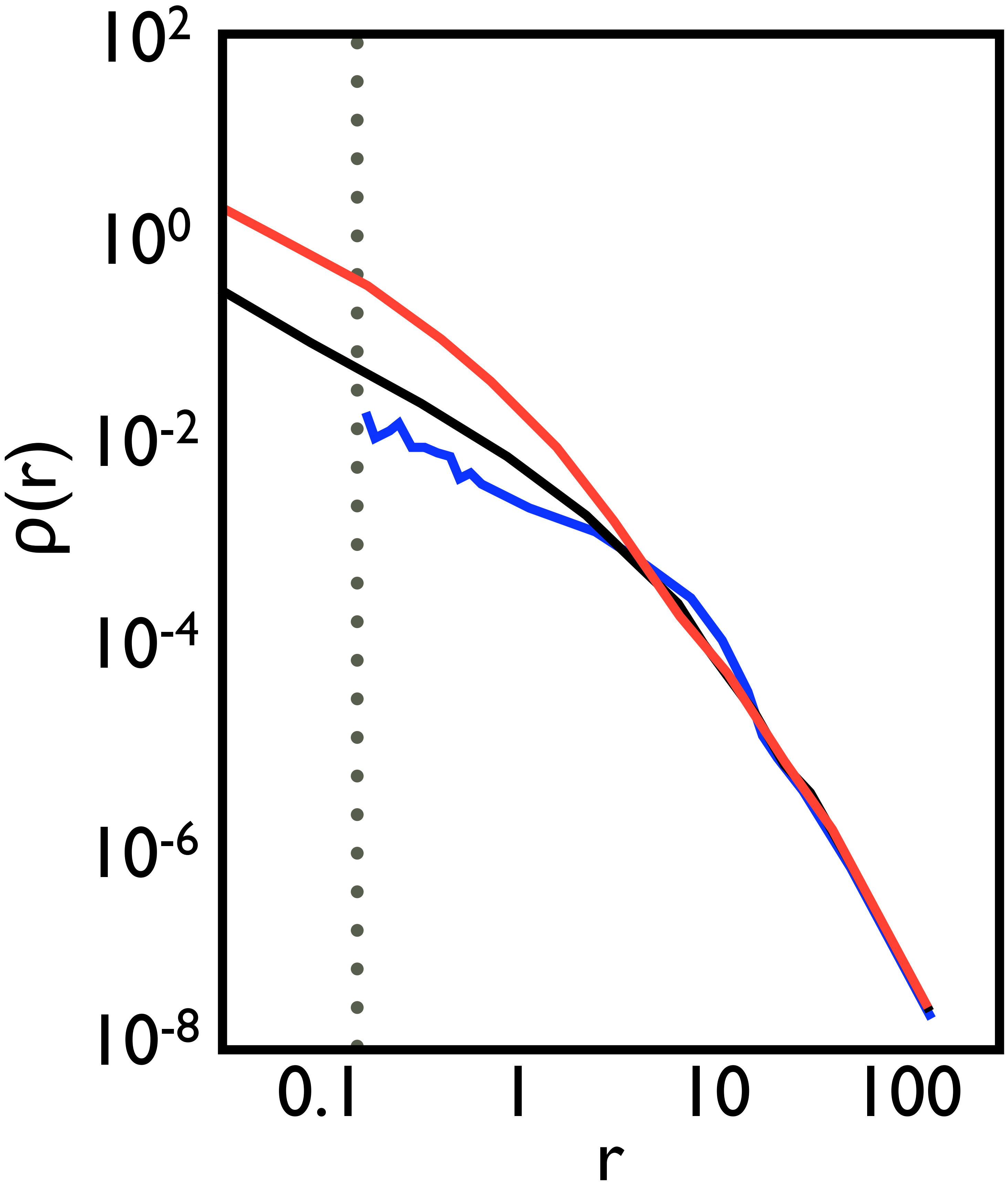

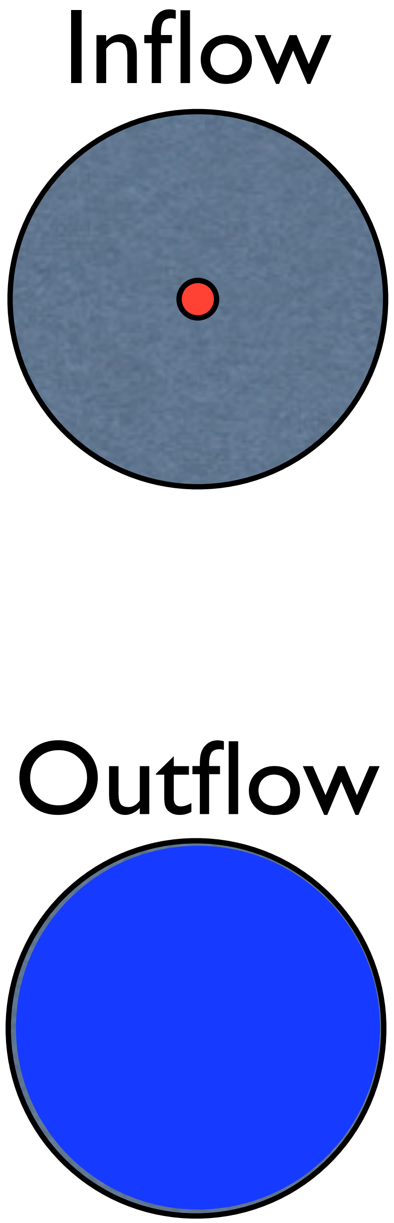

Inflow
Outflow

Read & Gilmore 2005; Navarro et al. 1996

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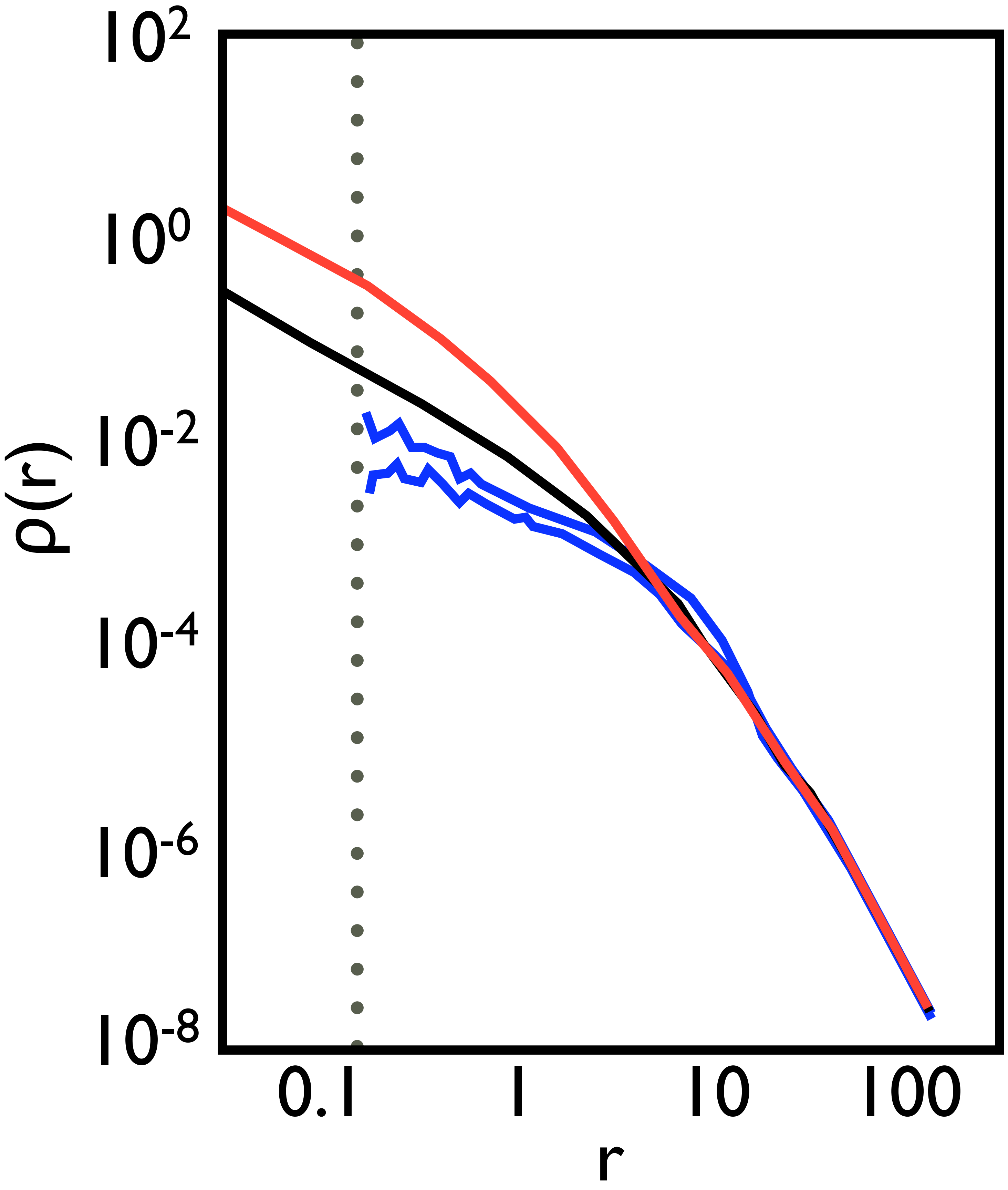
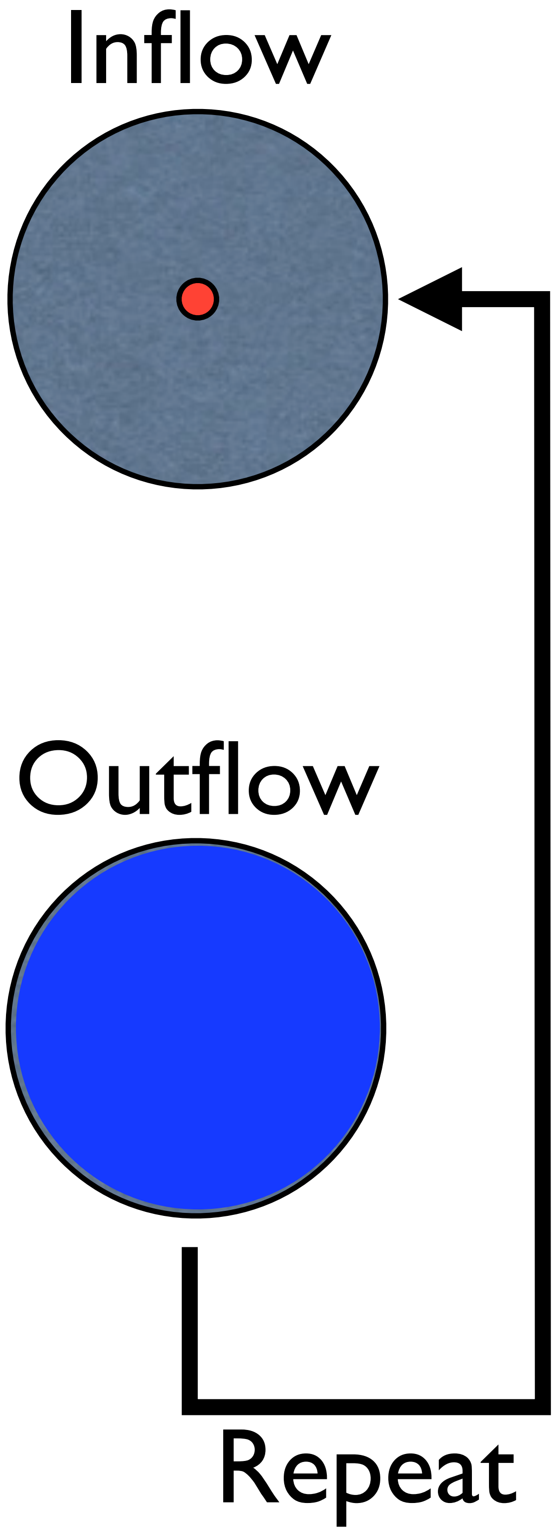
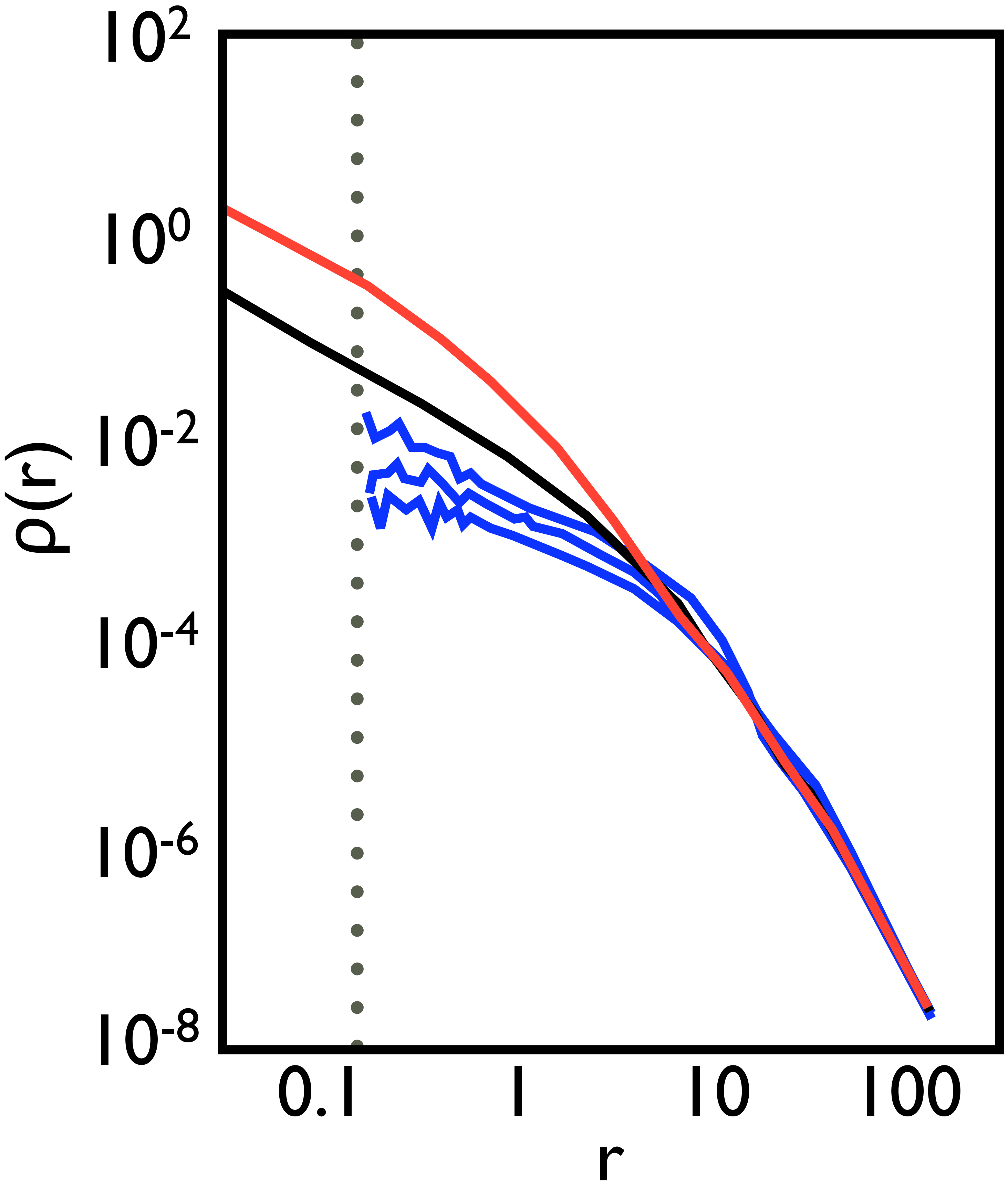


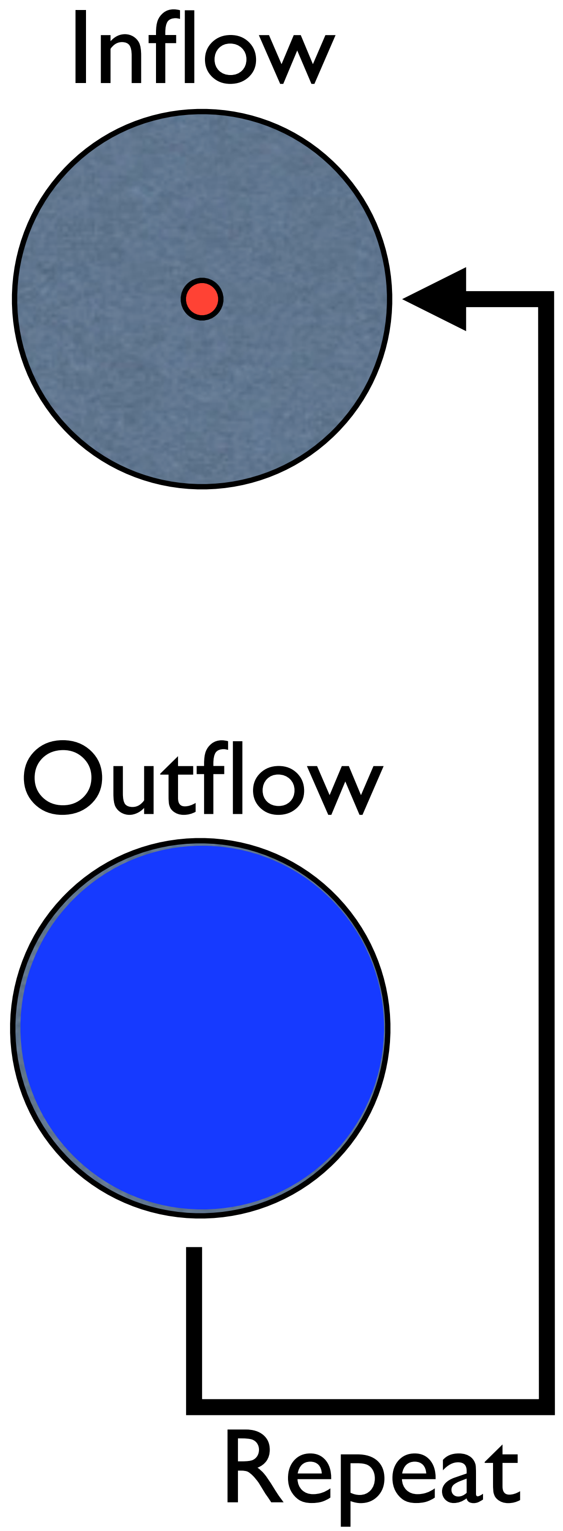


Inflow
Outflow
Repeat

Read & Gilmore 2005; Navarro et al. 1996

1. Calculating the DM dist. | The importance of baryons




Inflow
Outflow
Repeat

Read & Gilmore 2005; Navarro et al. 1996

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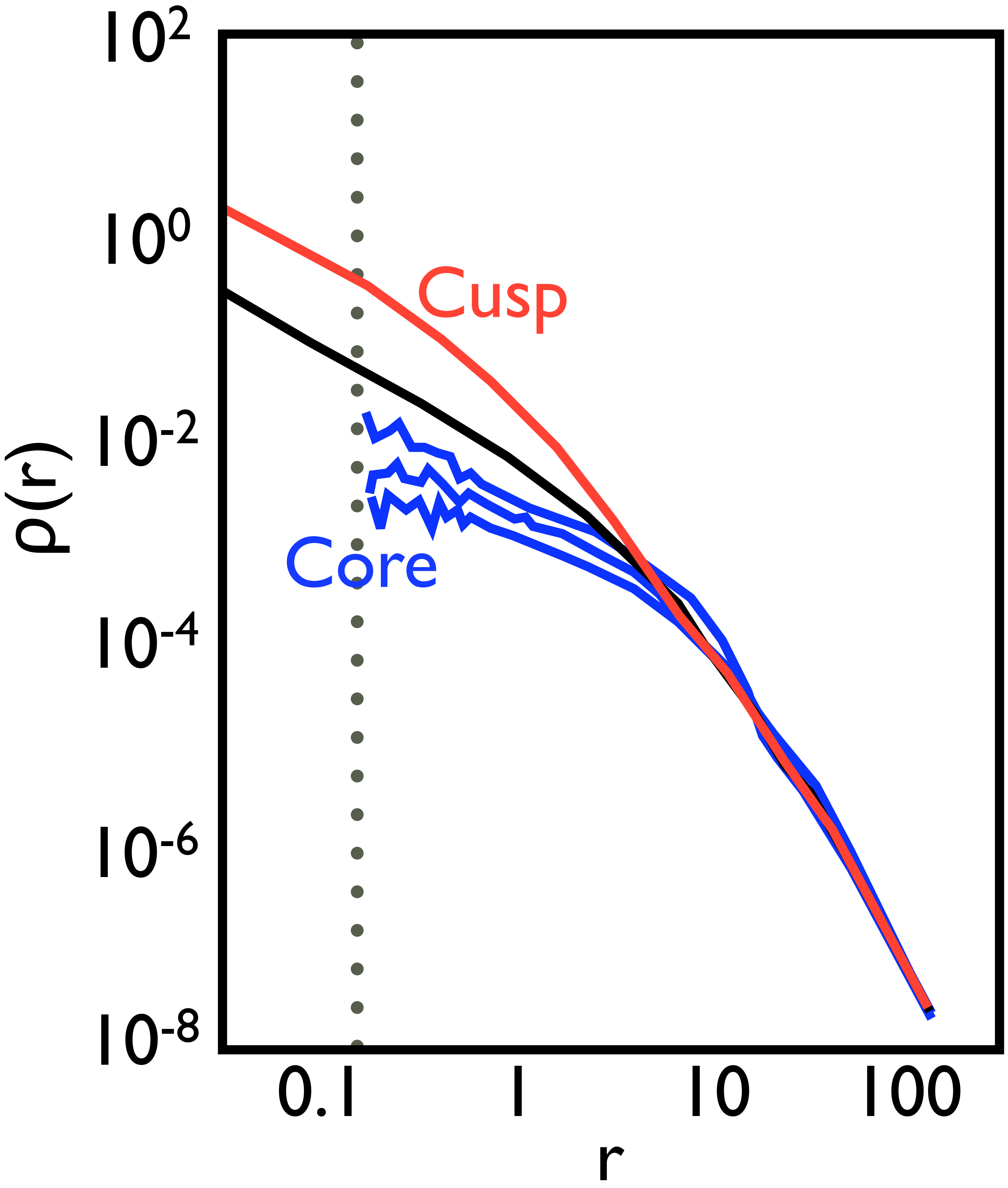

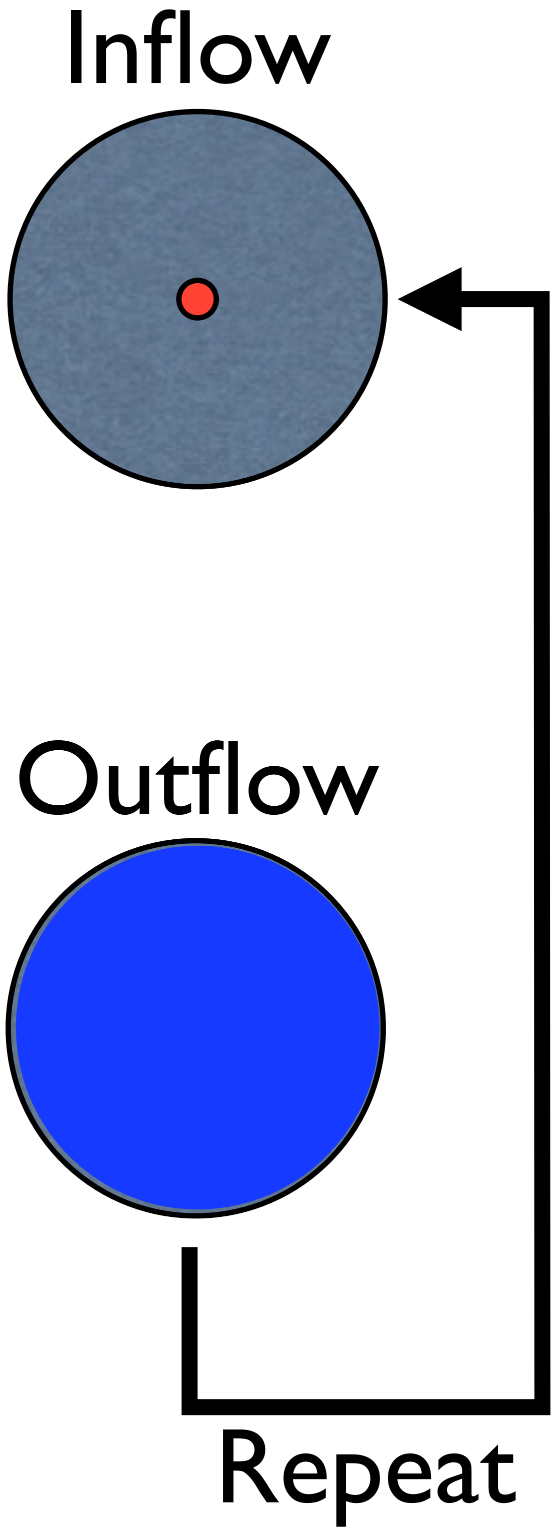

Inflow
Outflow
Repeat

Read & Gilmore 2005; Navarro et al. 1996

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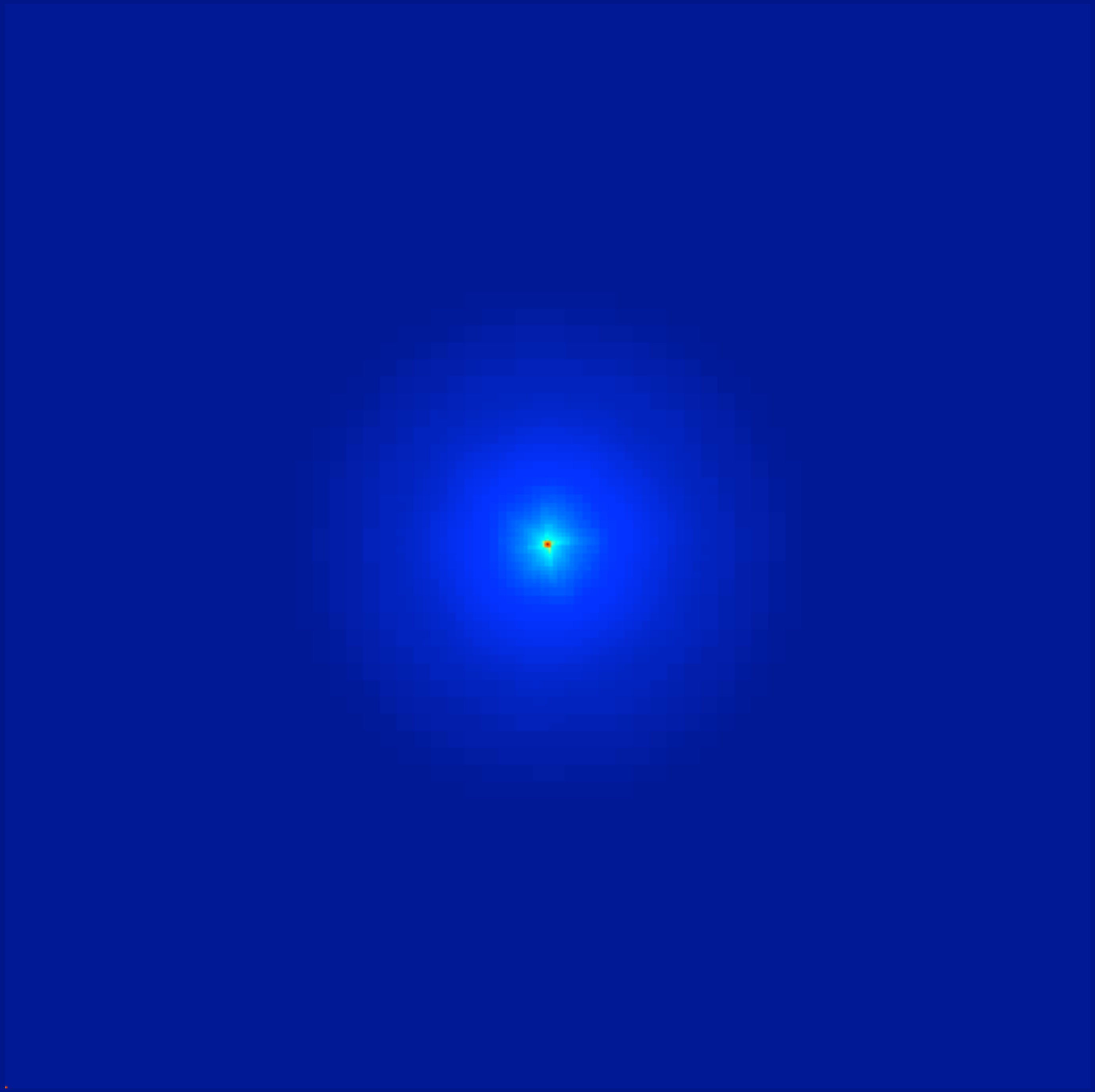

Teyssier, Pontzen, Dubois & Read, MNRAS 2013

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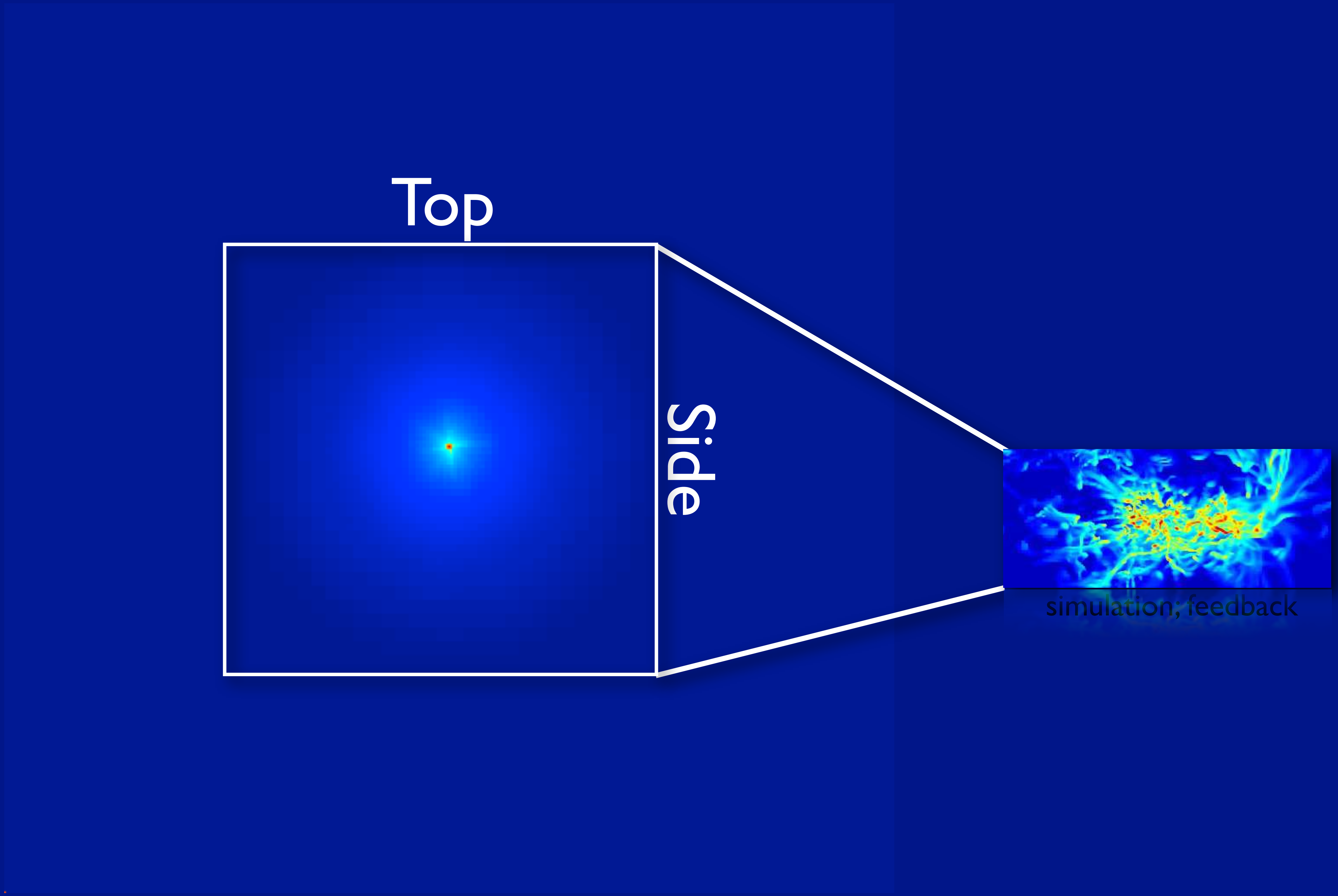
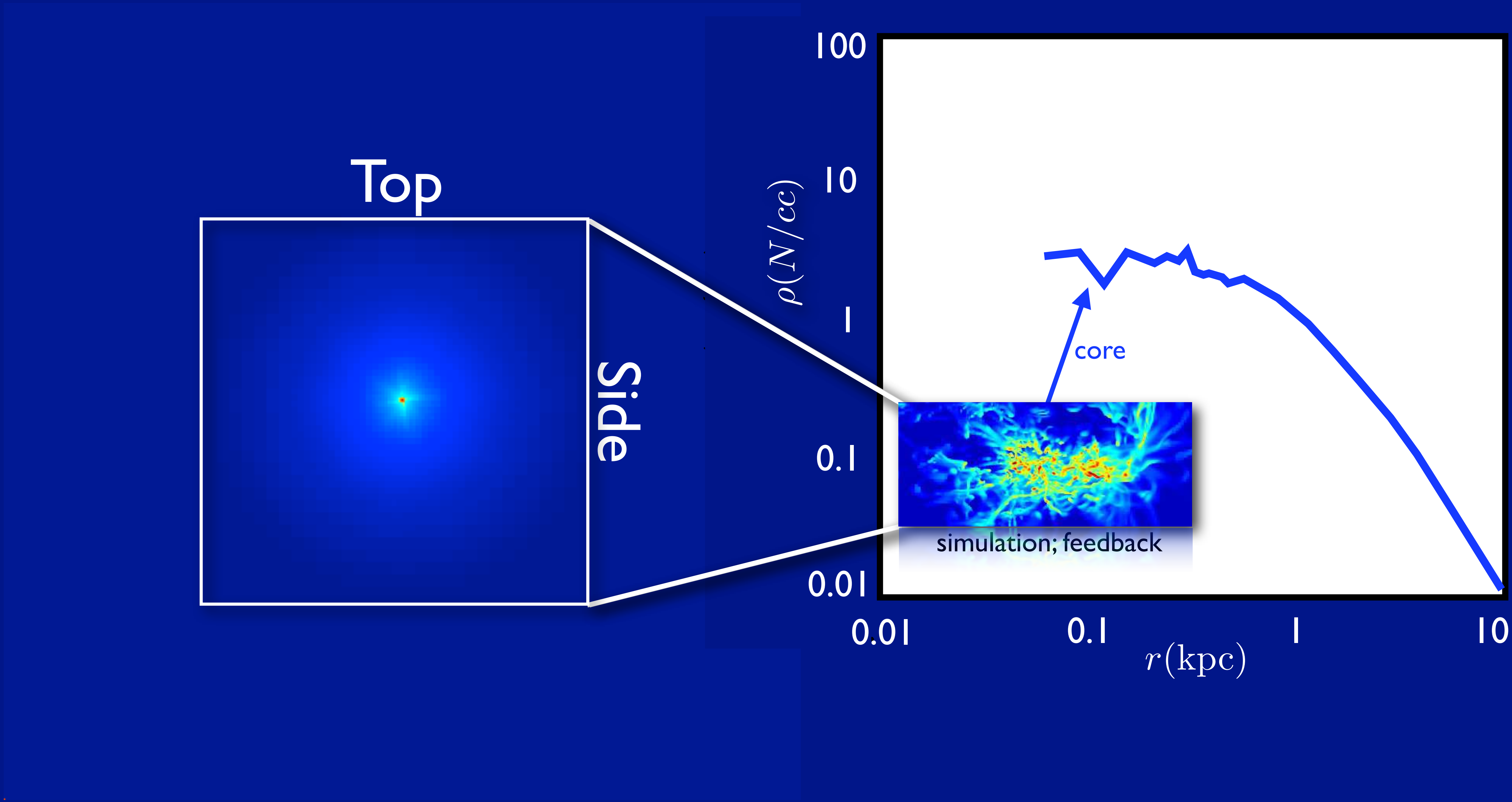

Top
Side
simulation; feedback

Teyssier, Pontzen, Dubois & Read, MNRAS 2013

1. Calculating the DM dist. | The importance of baryons



Teyssier, Pontzen, Dubois & Read, MNRAS 2013

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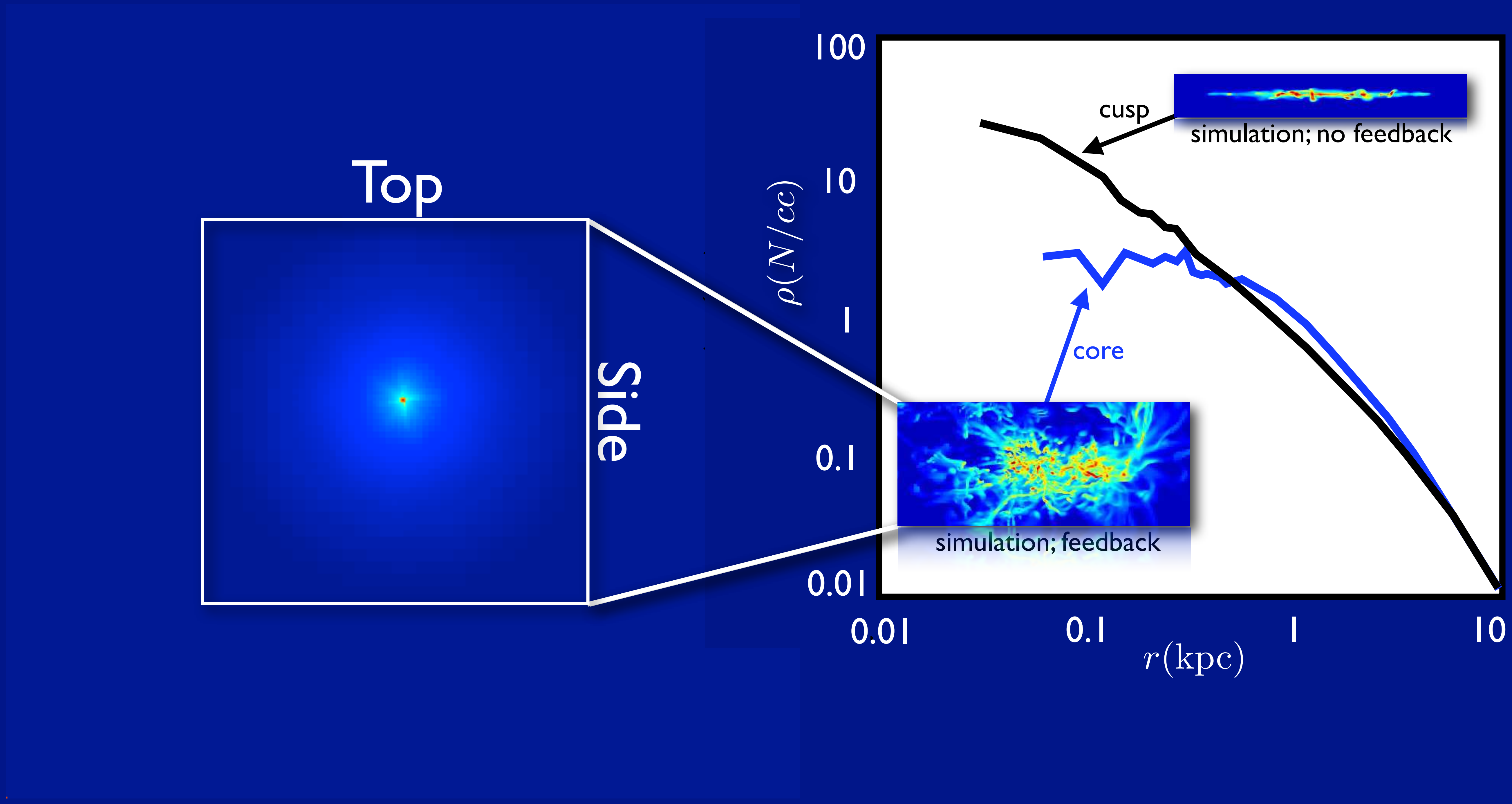

Teyssier, Pontzen, Dubois & Read, MNRAS 2013

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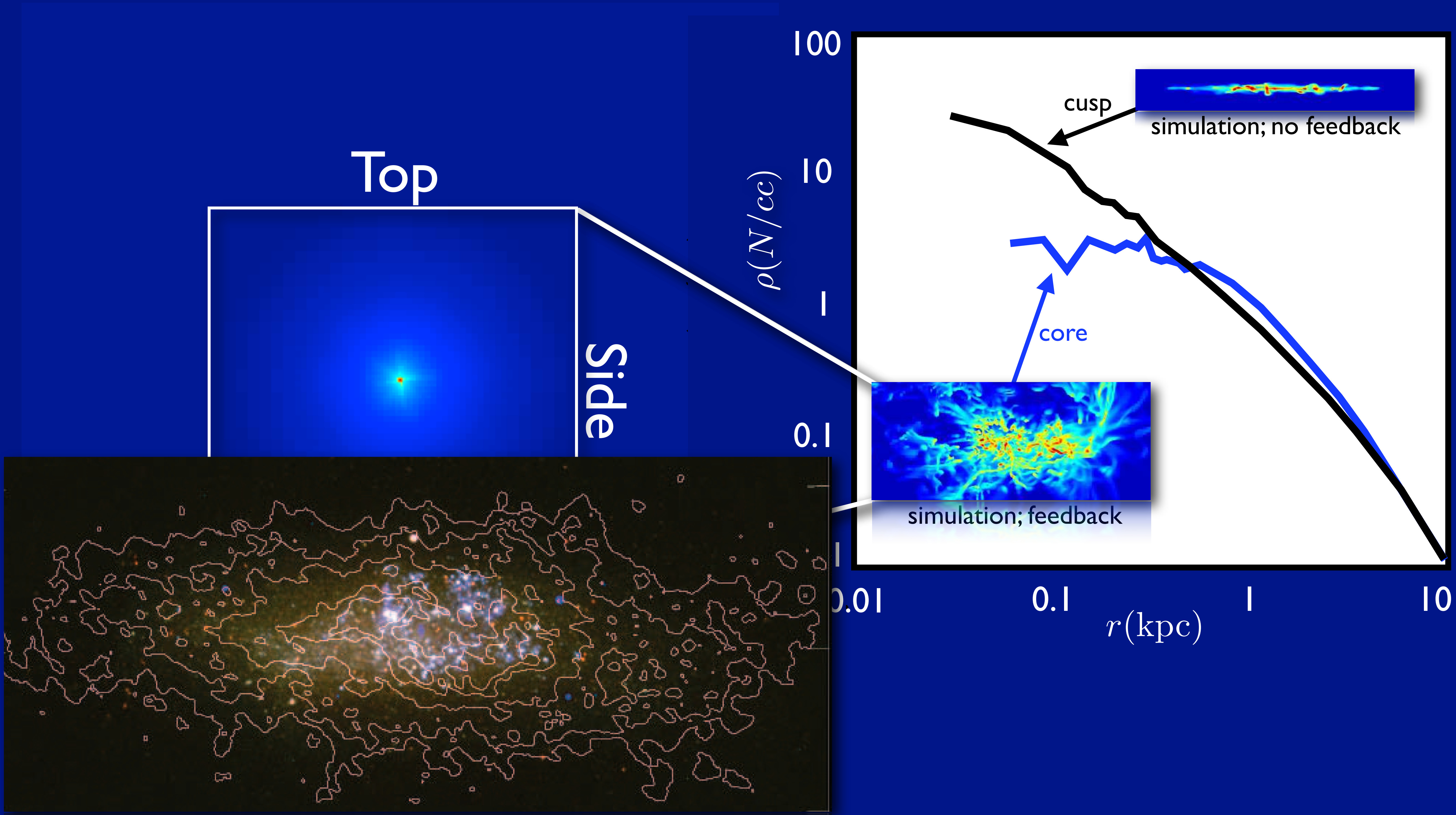


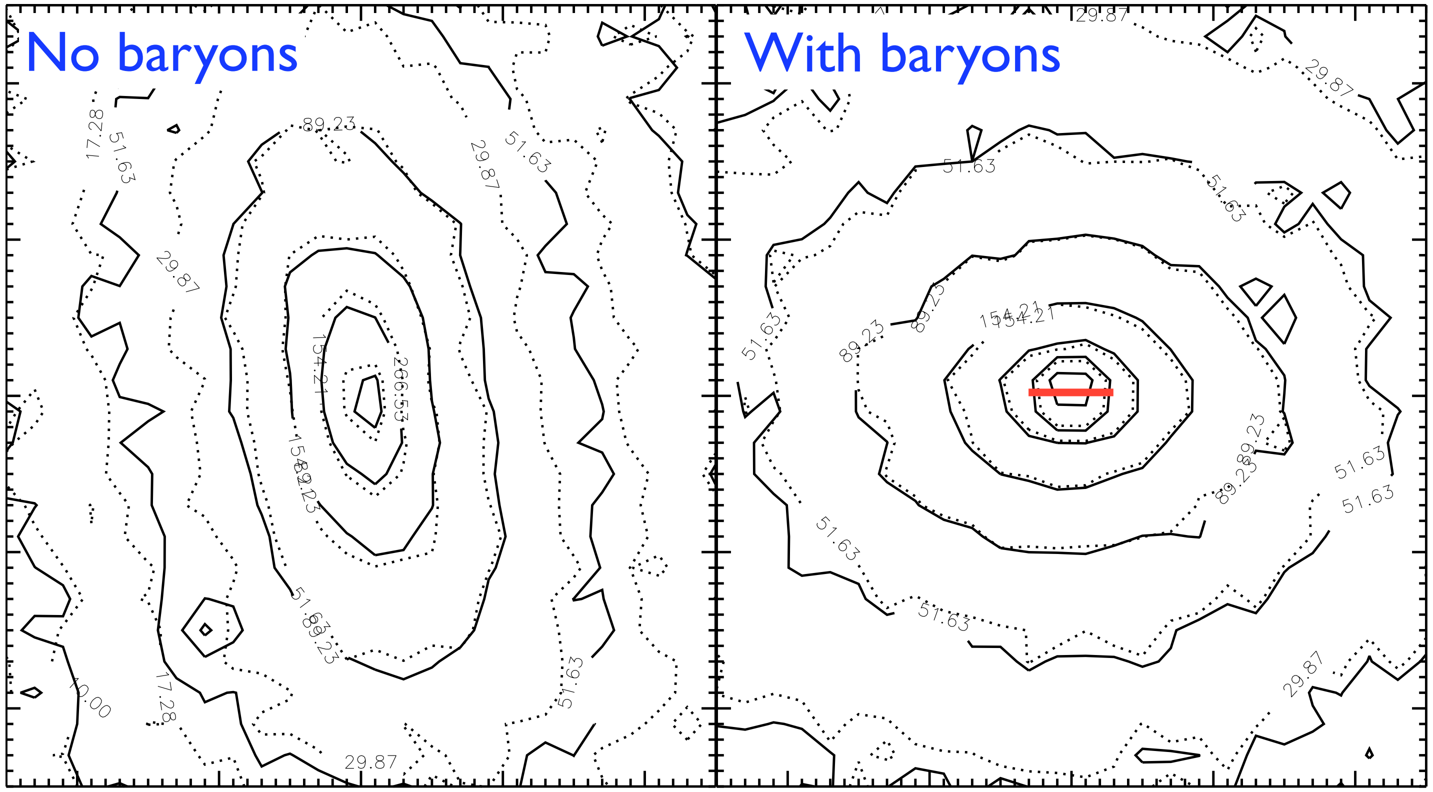
‘WLM’ dwarf galaxy

Teyssier, Pontzen, Dubois & Read, MNRAS 2013

1. Calculating the DM dist. | The importance of baryons

1. Calculating the DM dist. | The importance of baryons

Shape change

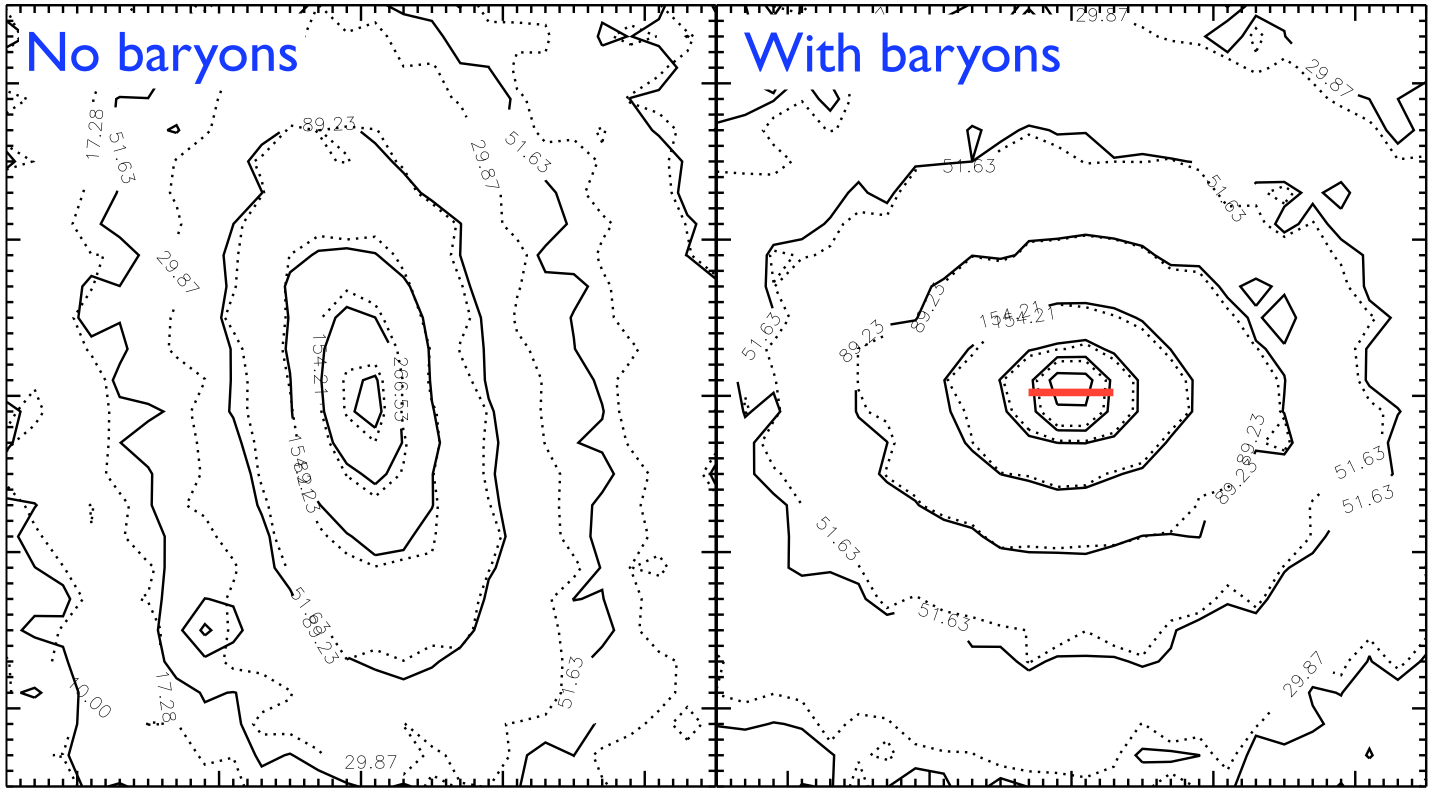

No baryons

With baryons

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

1. Calculating the DM dist. | The importance of baryons

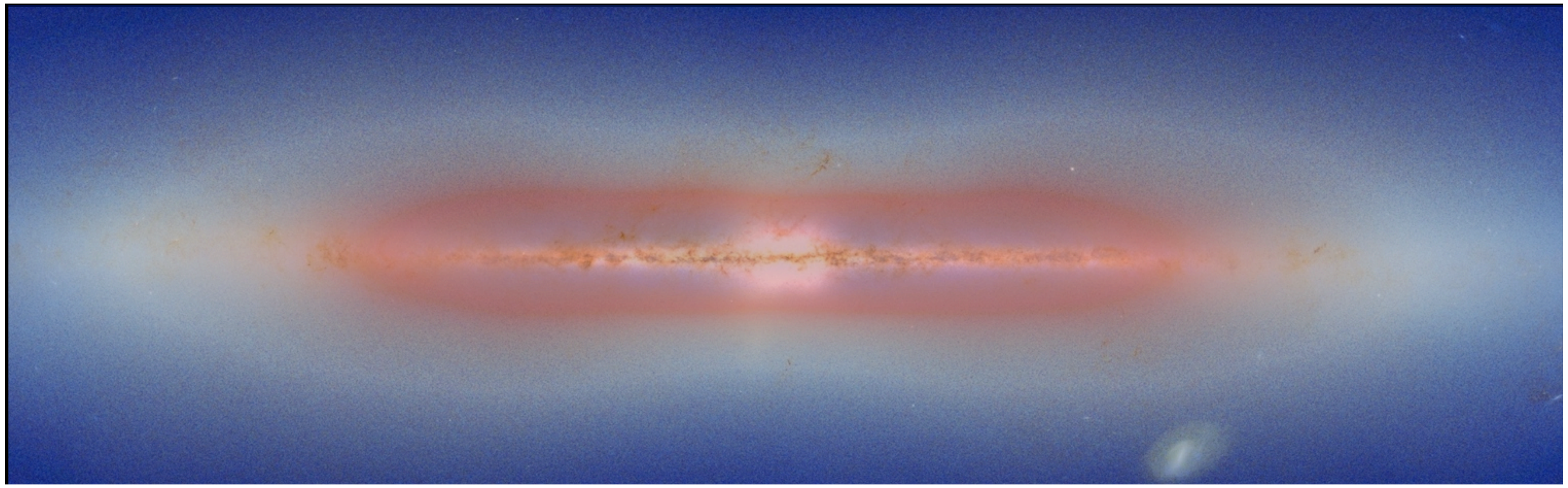
Shape change


No baryons

With baryons

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

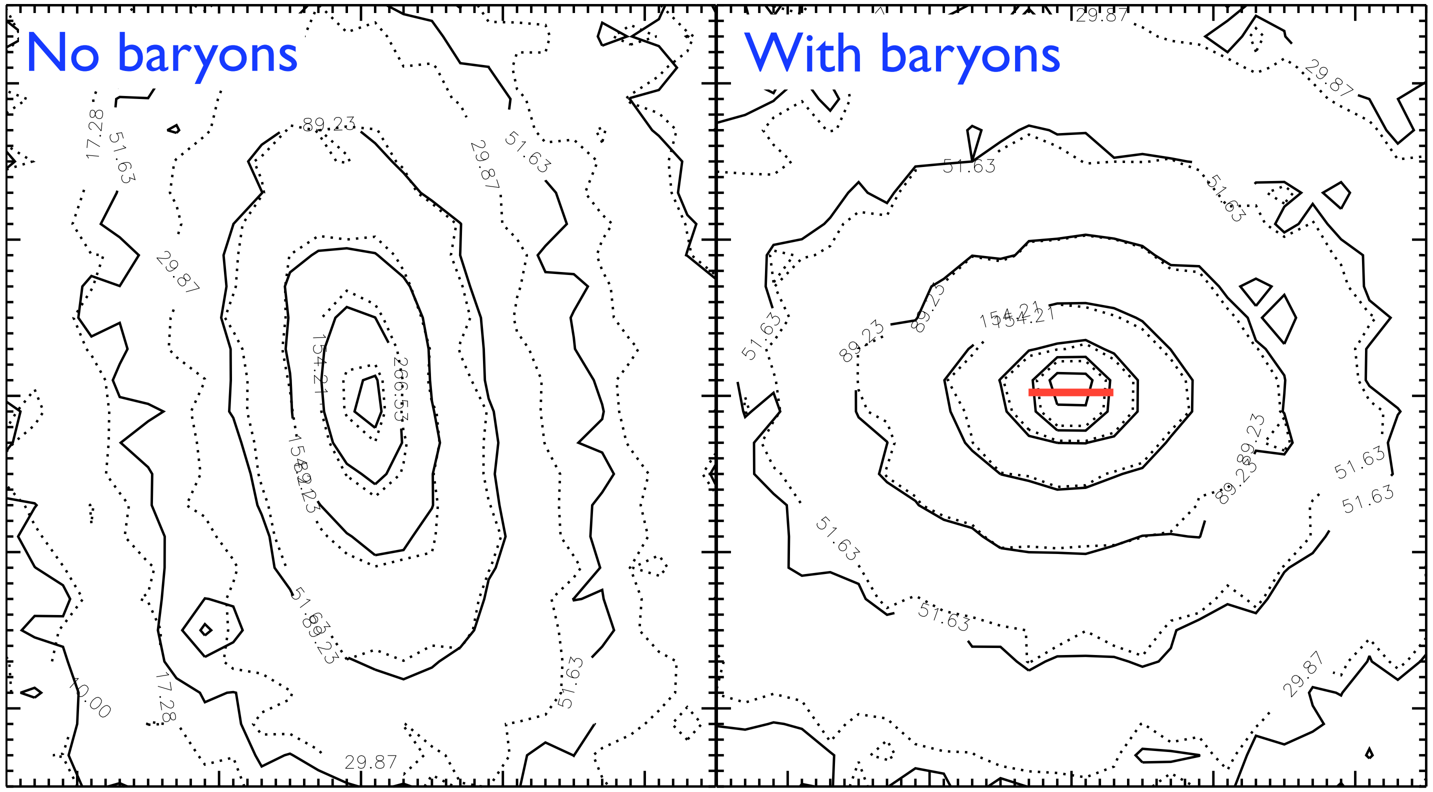
Dark discs



Lake 1989; Read et al. 2008/9

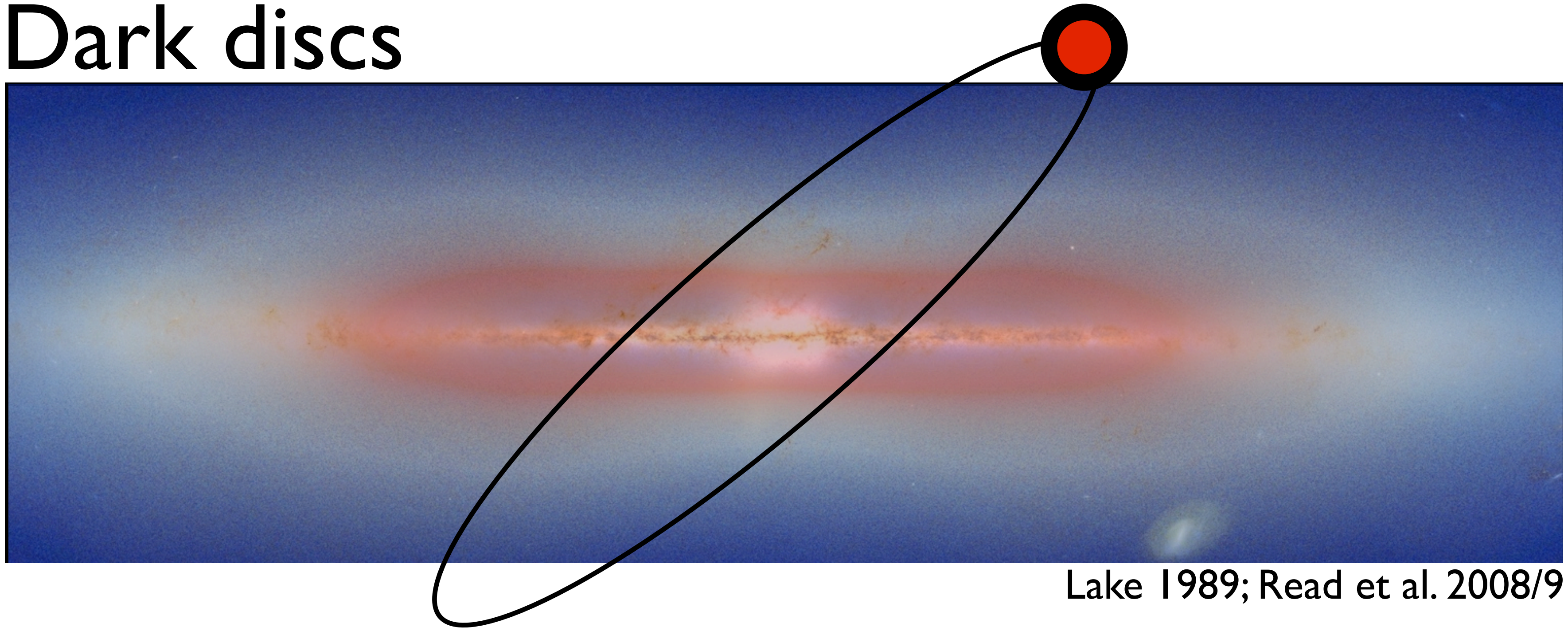
1. Calculating the DM dist. | The importance of baryons

Shape change



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

Dark discs



Lake 1989; Read et al. 2008/9

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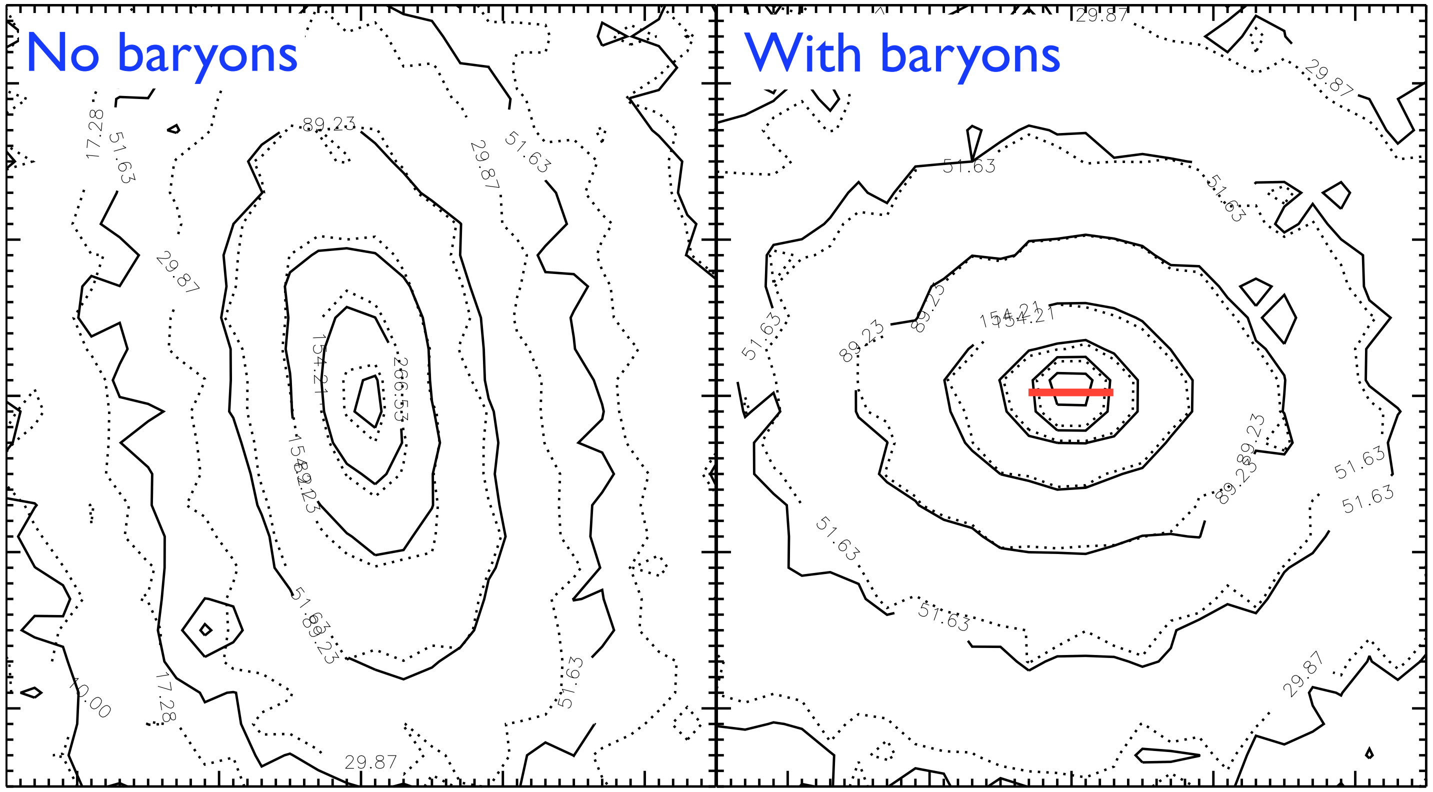
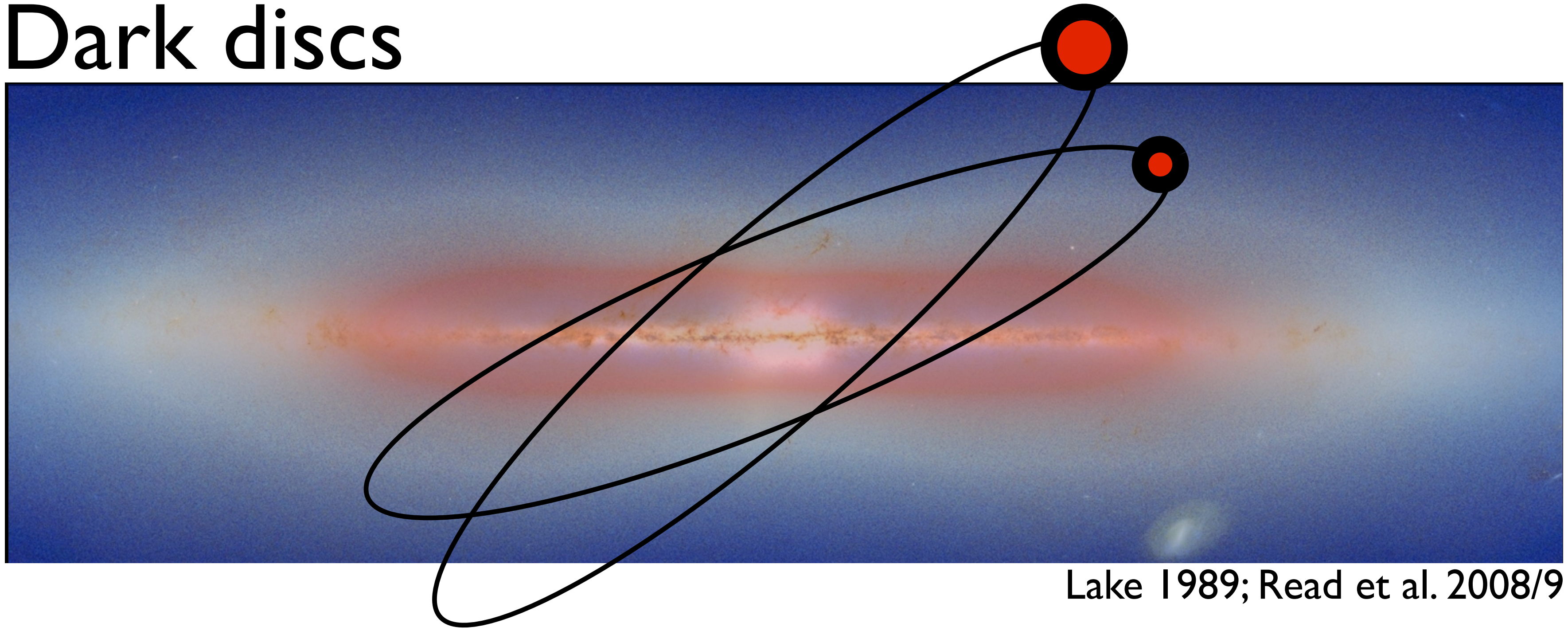
Shape change



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

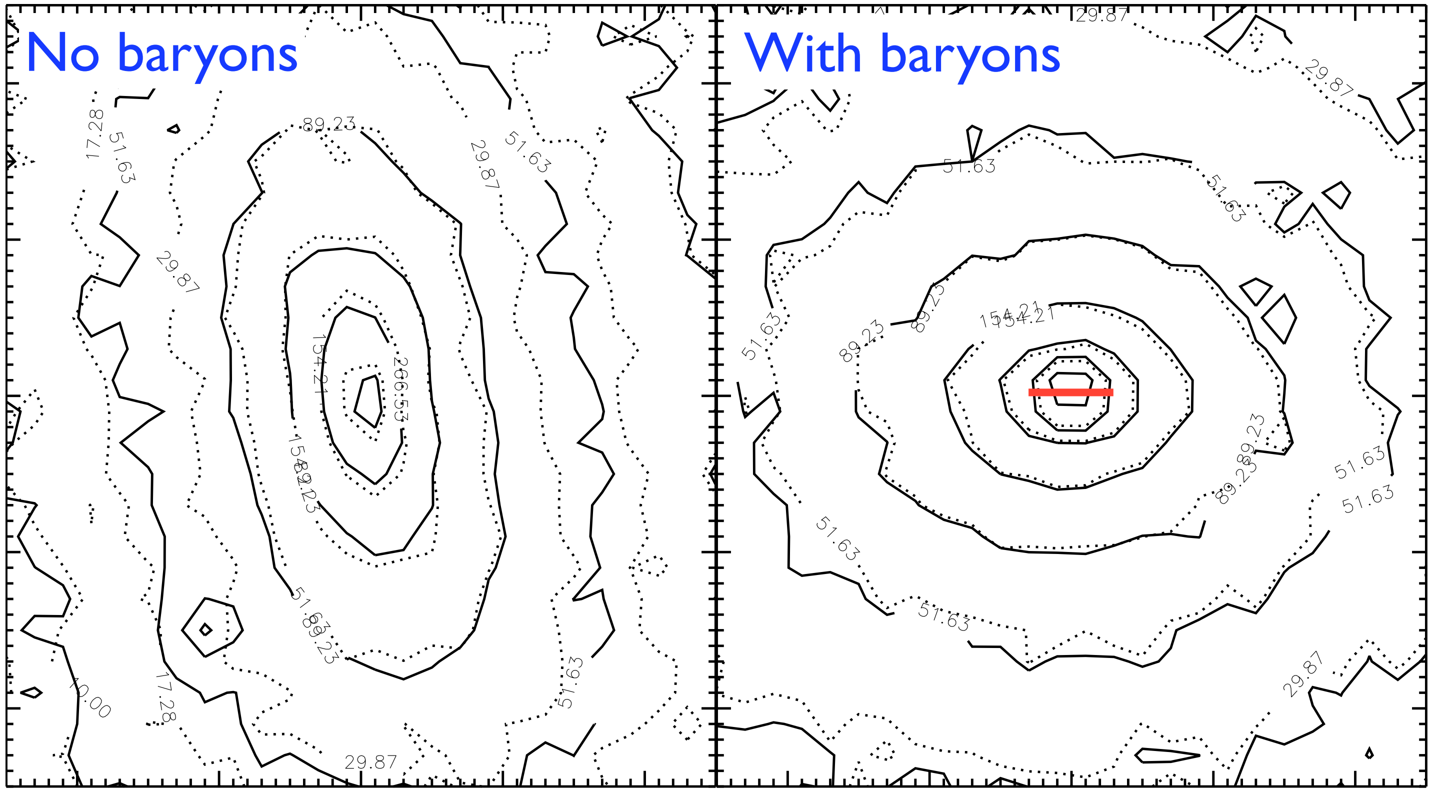
Dark discs



Lake 1989; Read et al. 2008/9

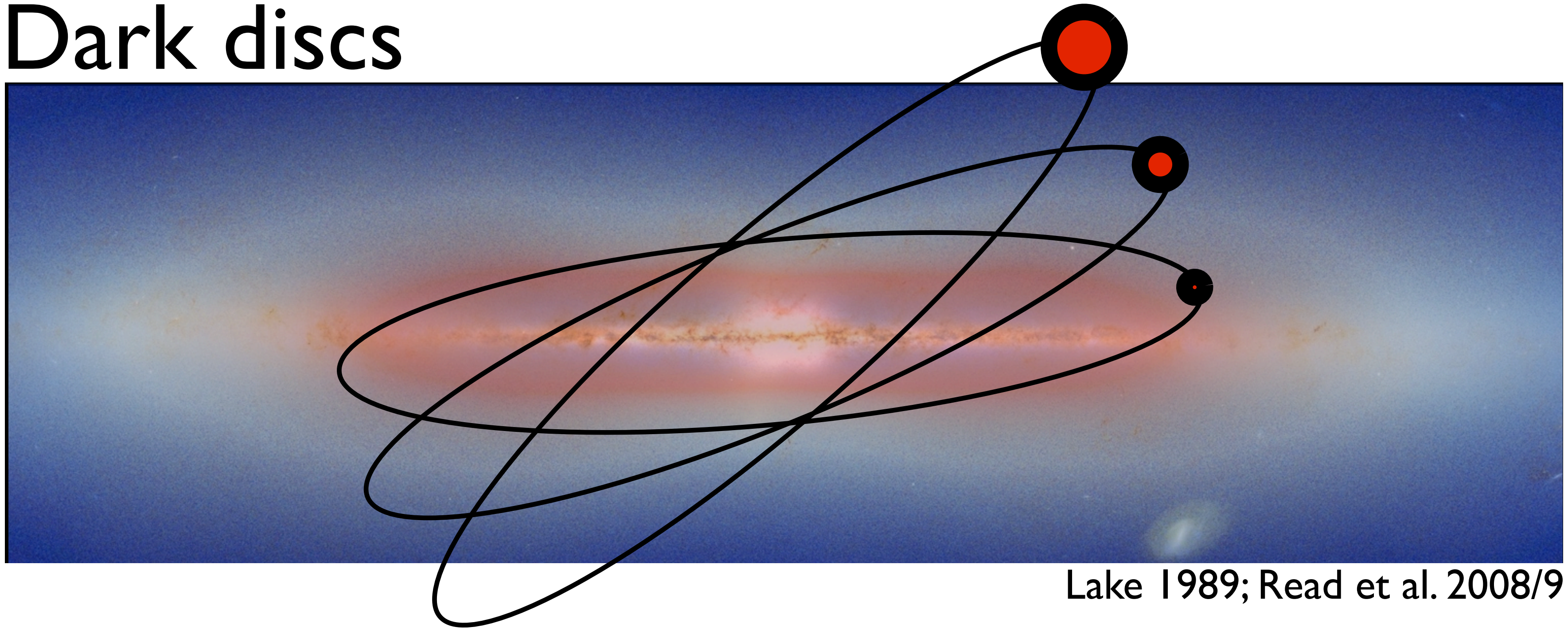
1. Calculating the DM dist. | The importance of baryons

Shape change



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

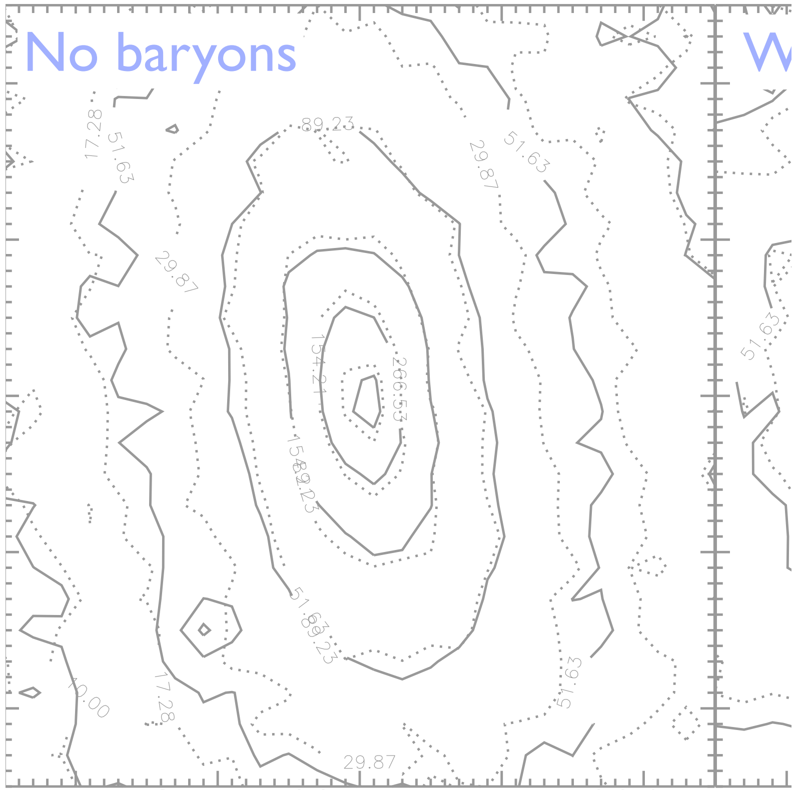
Dark discs



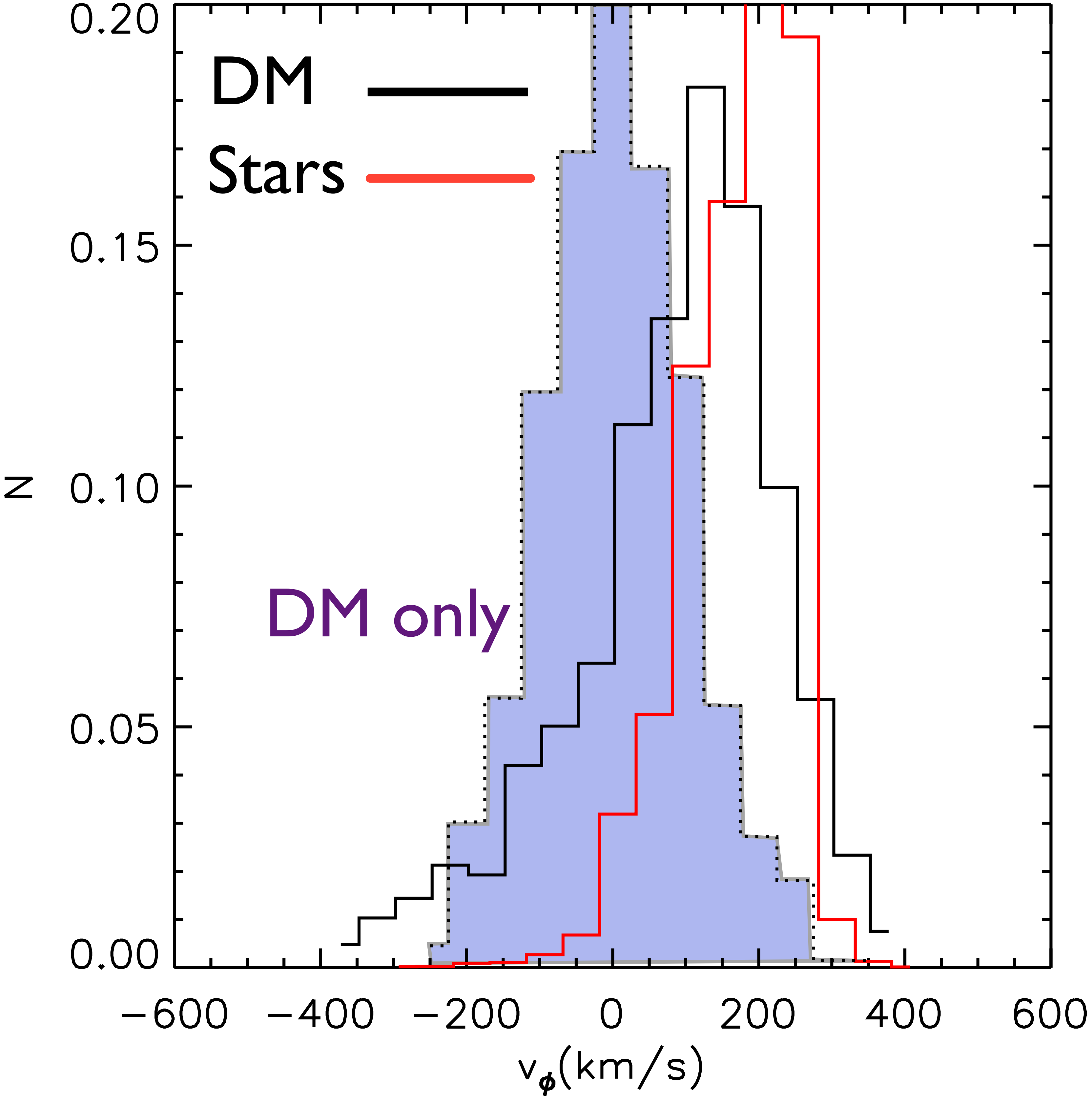
Lake 1989; Read et al. 2008/9

1. Calculating the DM dist. | The importance of baryons

Shape change



Katz & Gunn 1991; Dubinski 1994; Debat



2008/9

Ab Initio

[Towards *predictive* simulations with baryons]

1. Calculating the DM dist. | Towards predictive simulations

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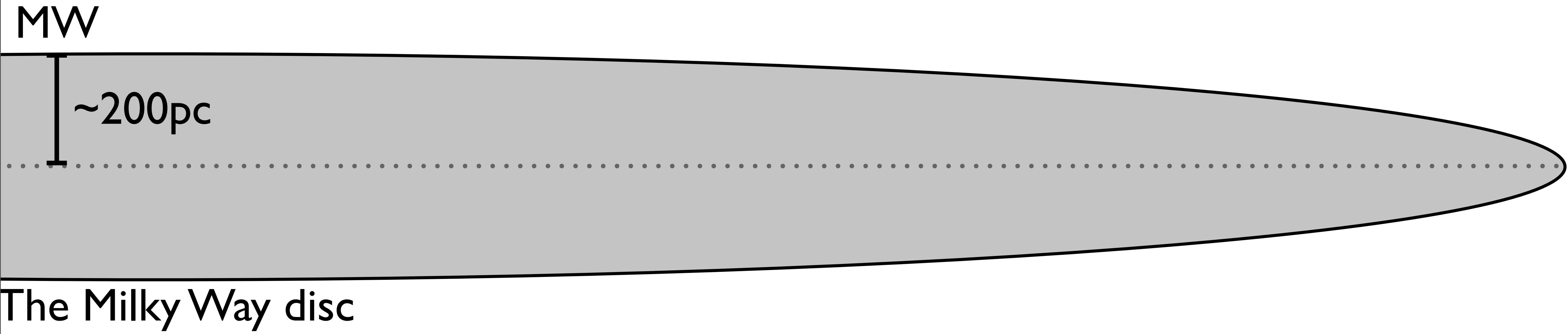
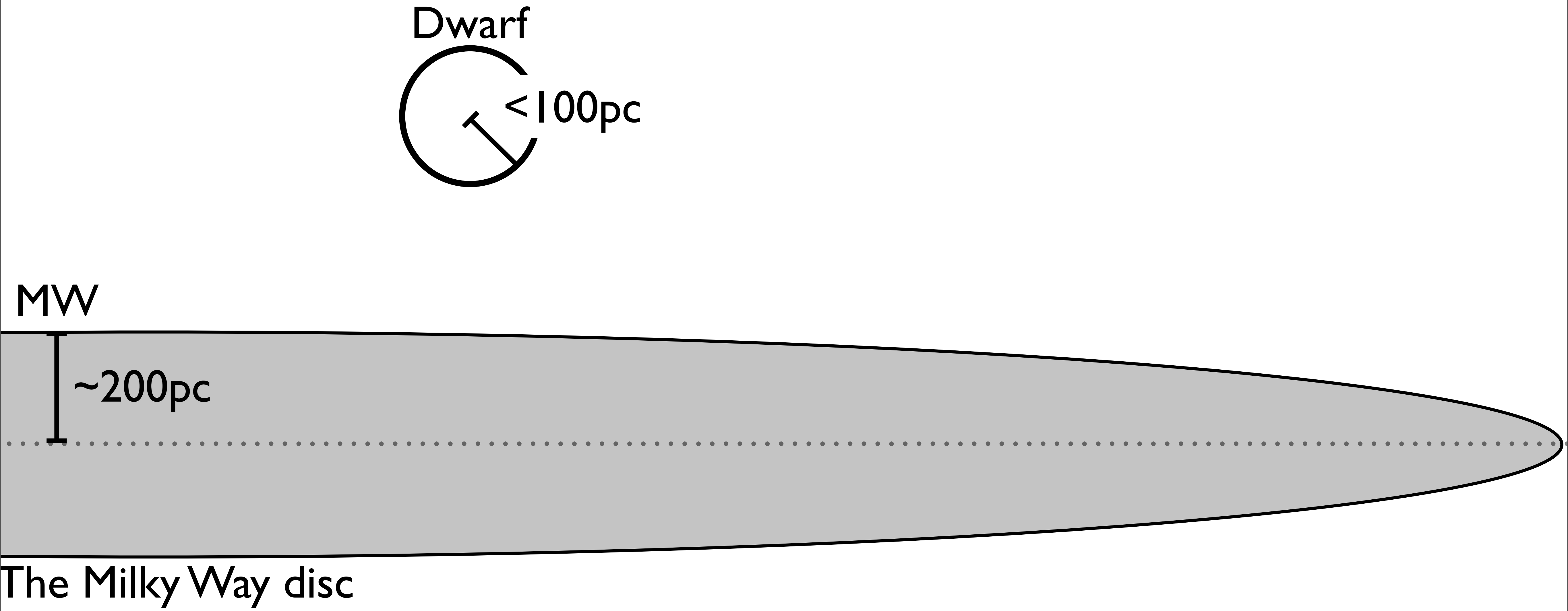
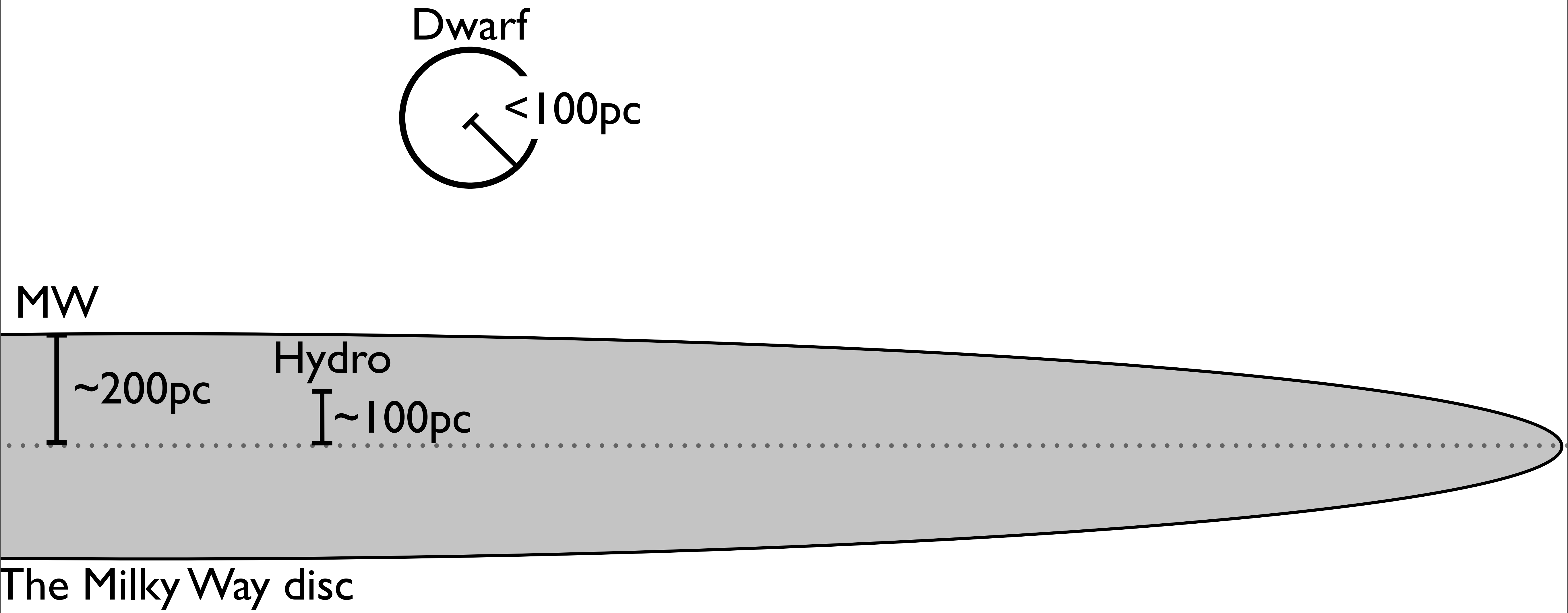

MW
~200pc
The Milky Way disc

1. Calculating the DM dist. | Towards predictive simulations


Dwarf
<100pc
MW
~200pc
The Milky Way disc

1. Calculating the DM dist. | Towards predictive simulations



Dwarf

<100pc

MW

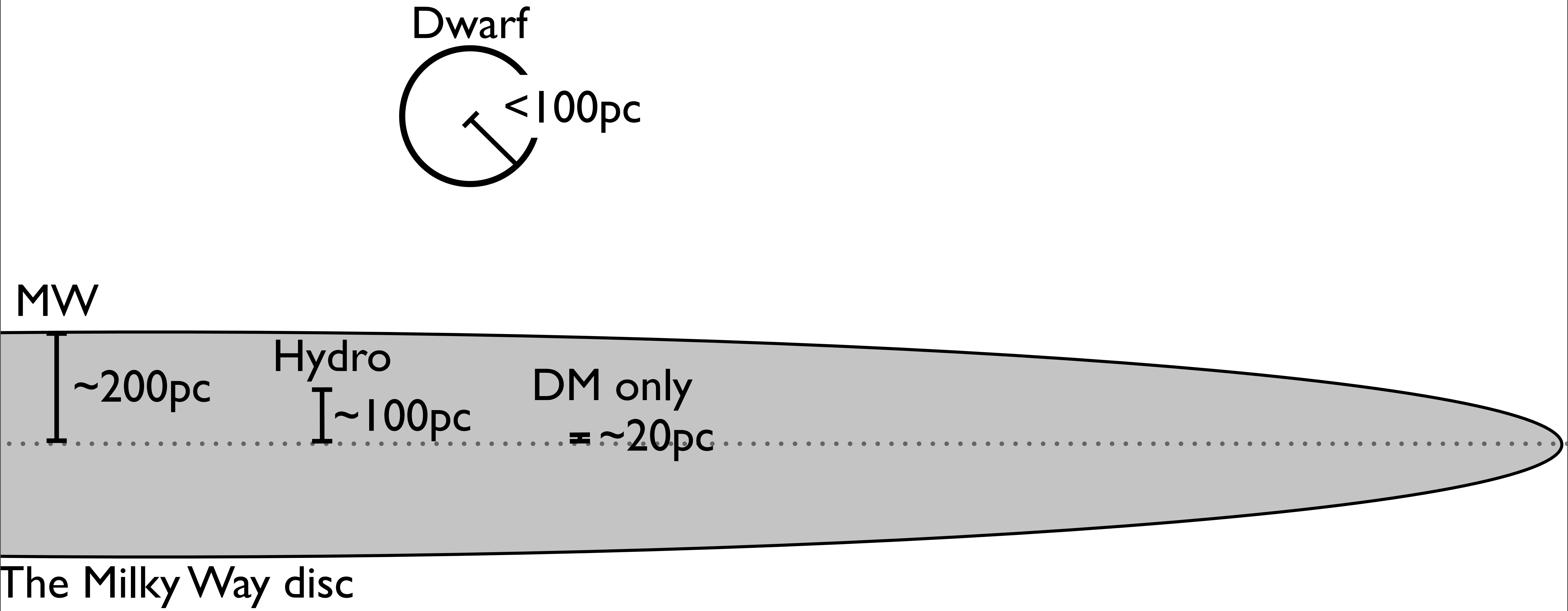
~200pc

Hydro

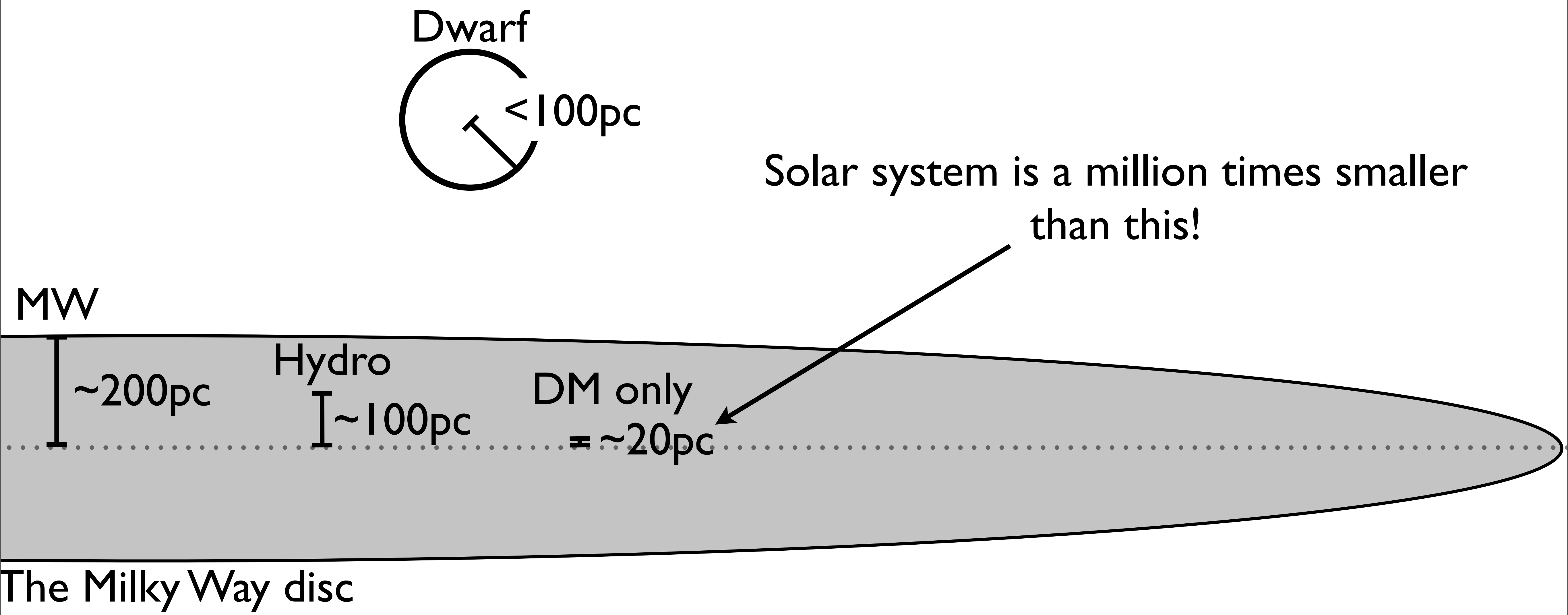
~100pc

The Milky Way disc

1. Calculating the DM dist. | Towards predictive simulations


Dwarf
<100pc
MW
~200pc
Hydro
~100pc
DM only
~20pc
The Milky Way disc

1. Calculating the DM dist. | Towards predictive simulations



Dwarf

<100pc

Solar system is a million times smaller than this!

MW

~200pc

Hydro

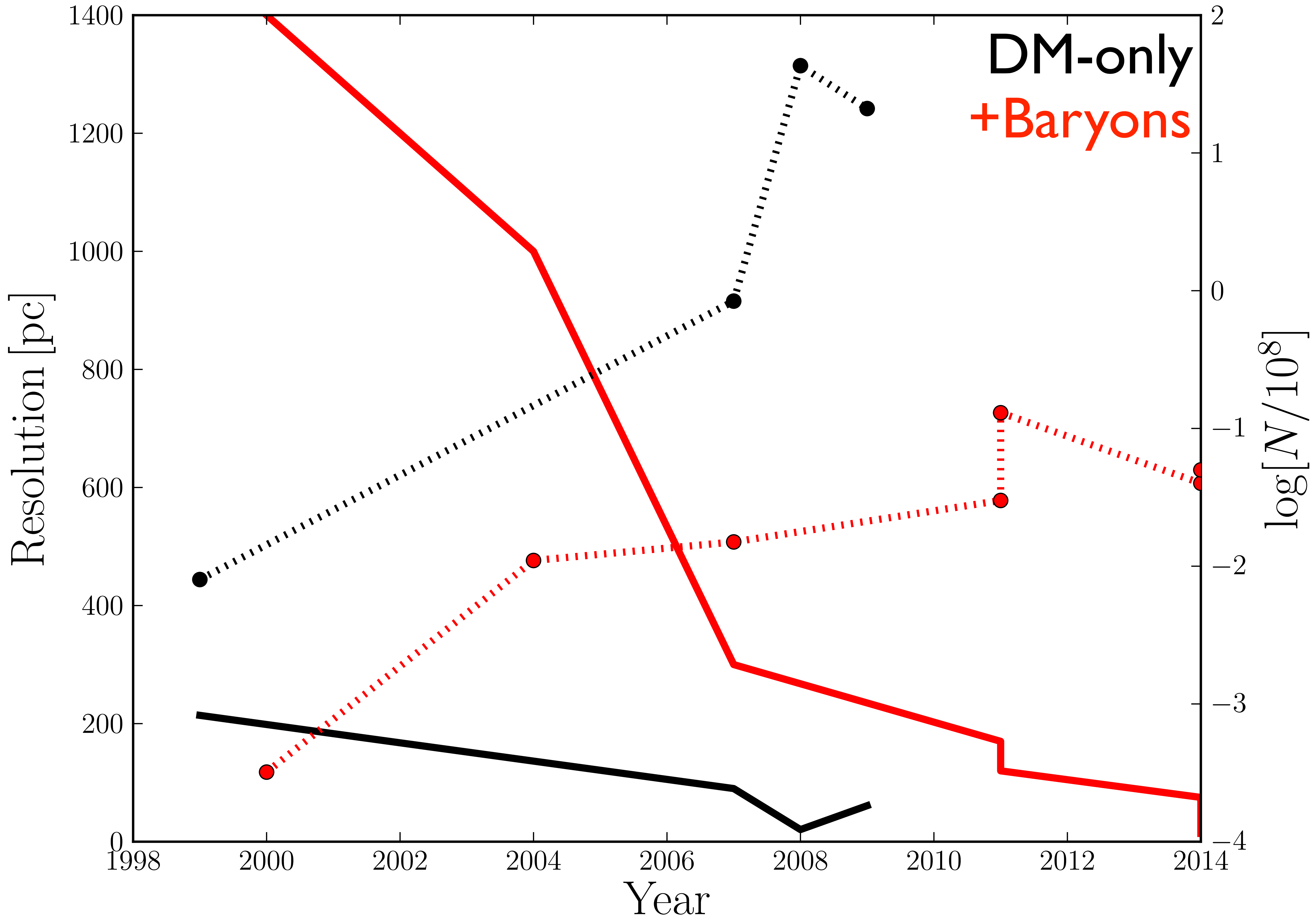
~100pc

DM only

~20pc

The Milky Way disc

1. Calculating the DM dist. | Towards predictive simulations



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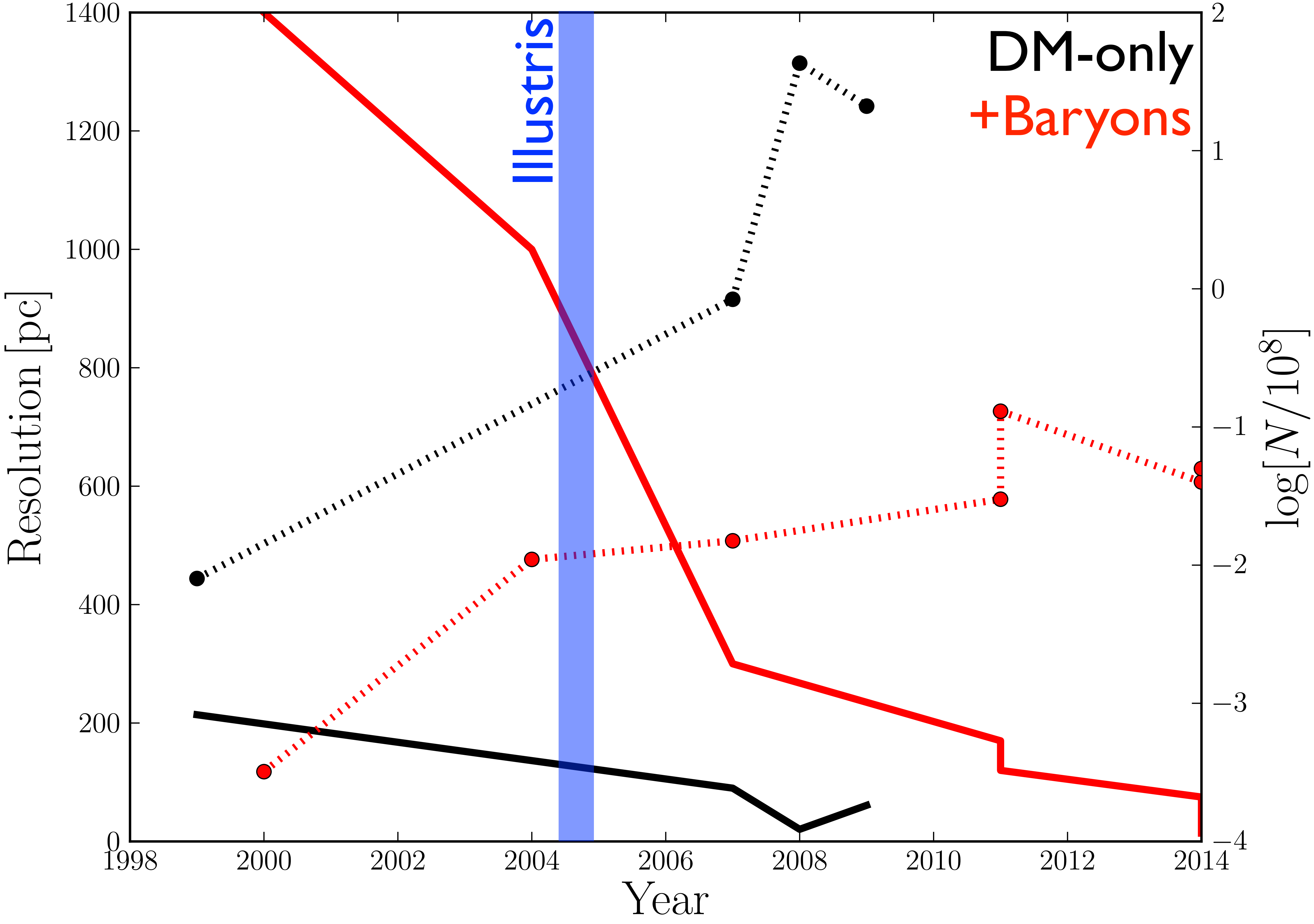

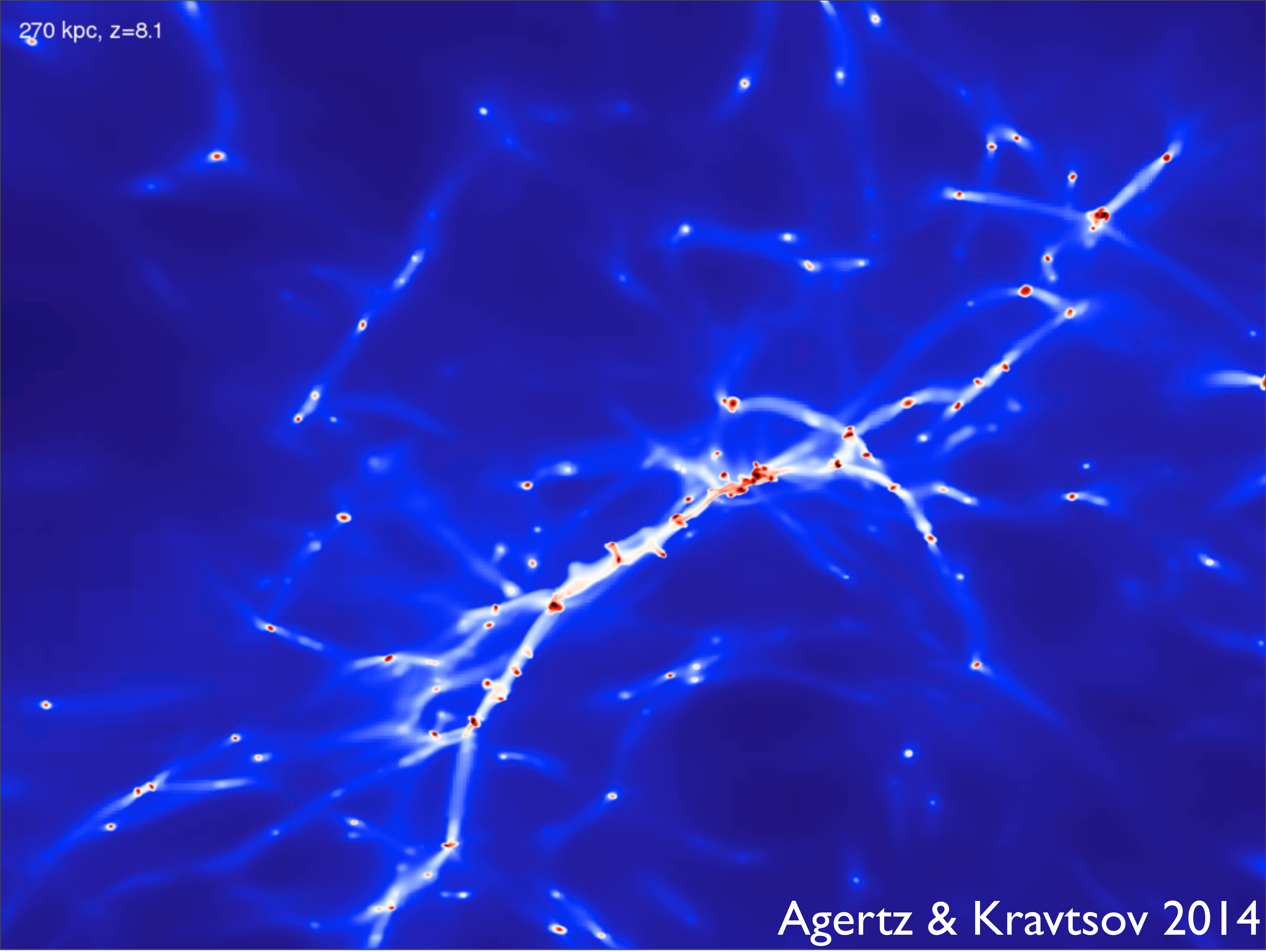

Agertz & Kravtsov 2014

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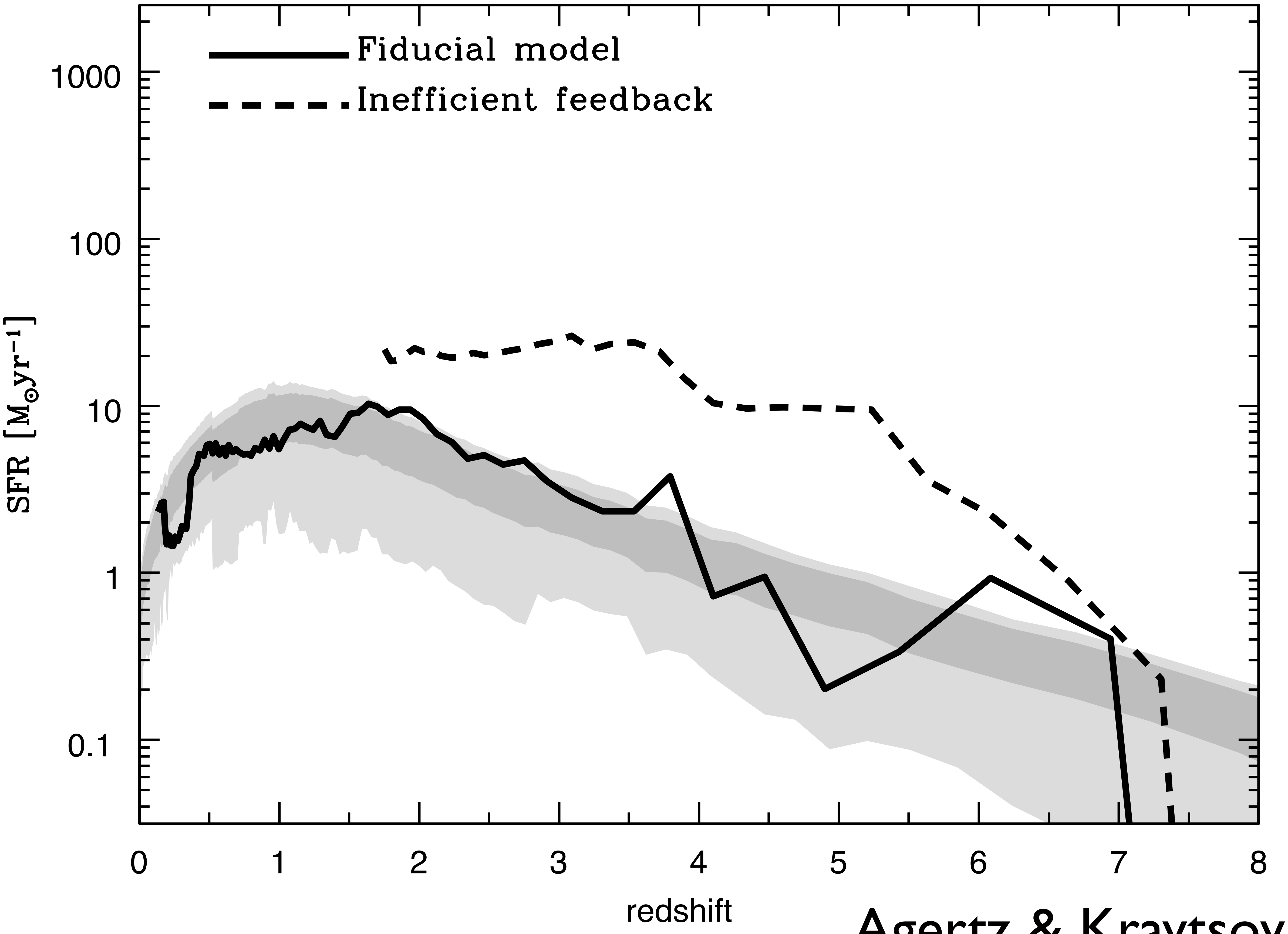

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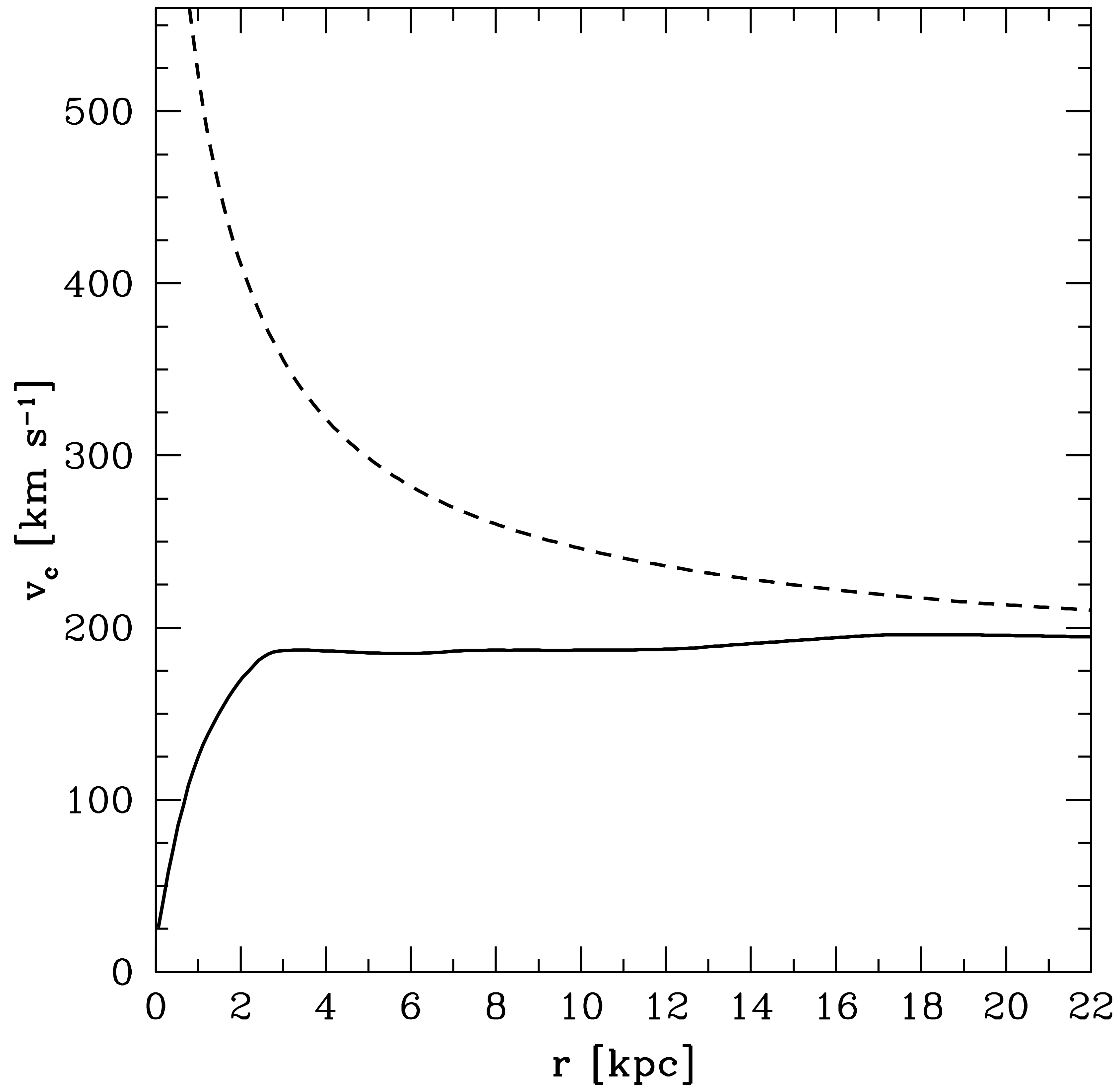

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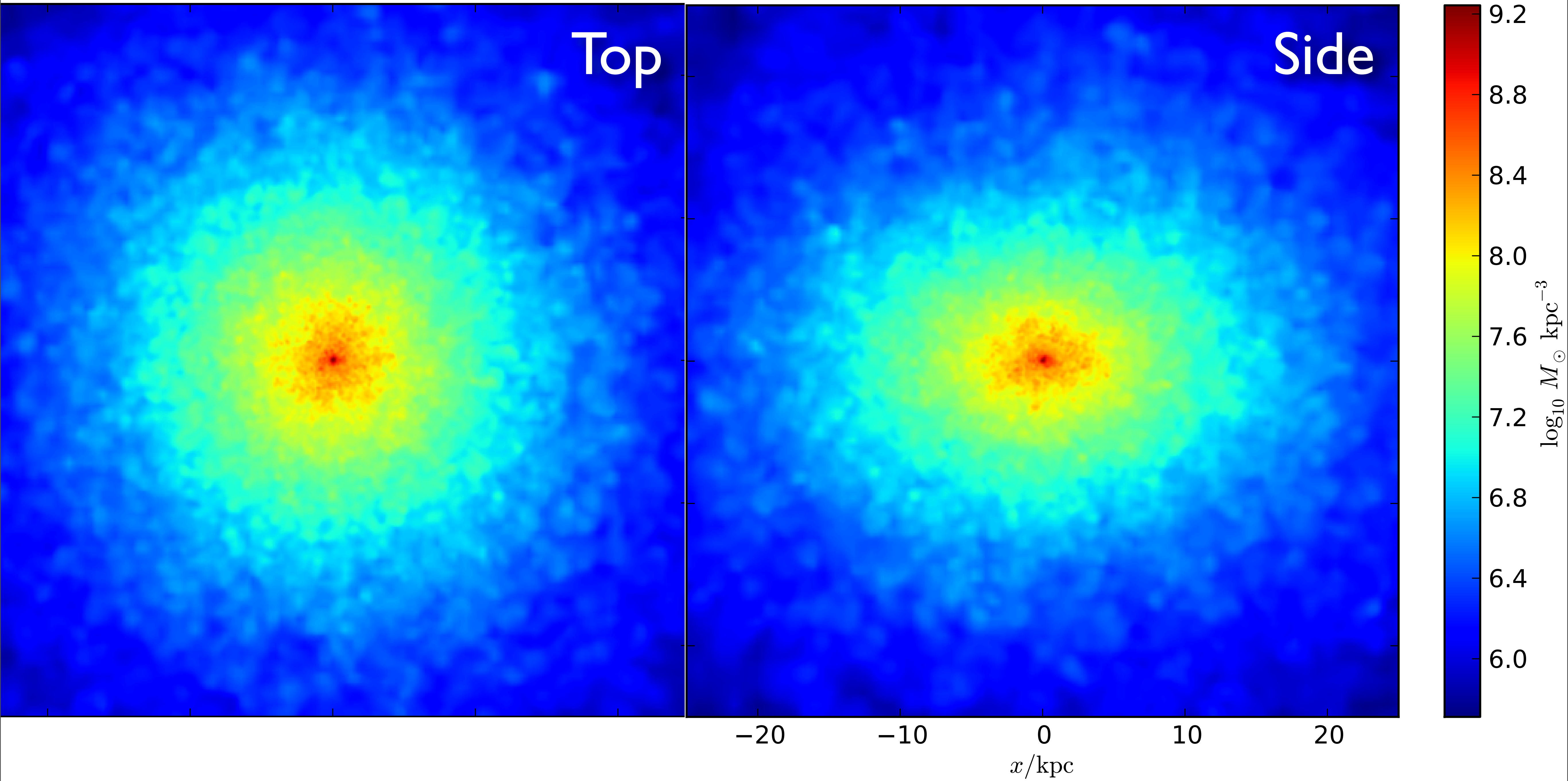

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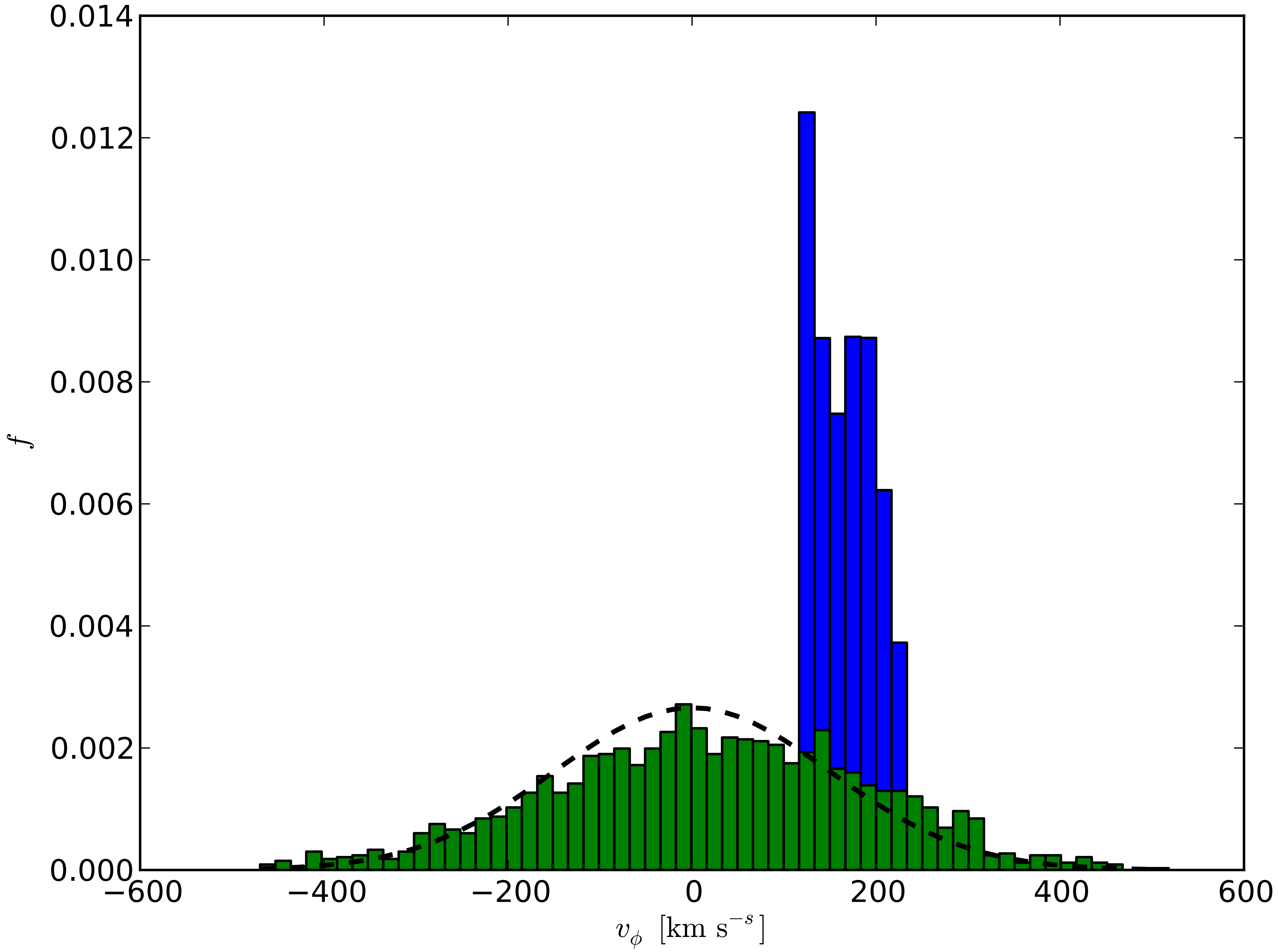

Agertz & Kravtsov 2014

Conclusions

- Cold Dark Matter "DM-only" simulations are well converged across different codes. WDM simulations are more problematic, but solutions are on the way ... watch this space!
- Including models for baryons in the Universe can, in principle, 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".
- WDM is becoming increasingly constrained. Latest Ly-alpha measurements ➟ M_{WDM} >3.3keV/c^2 [thermal]
- The observed distribution of DM agrees with "DM-only" simulations only on the very largest scales.