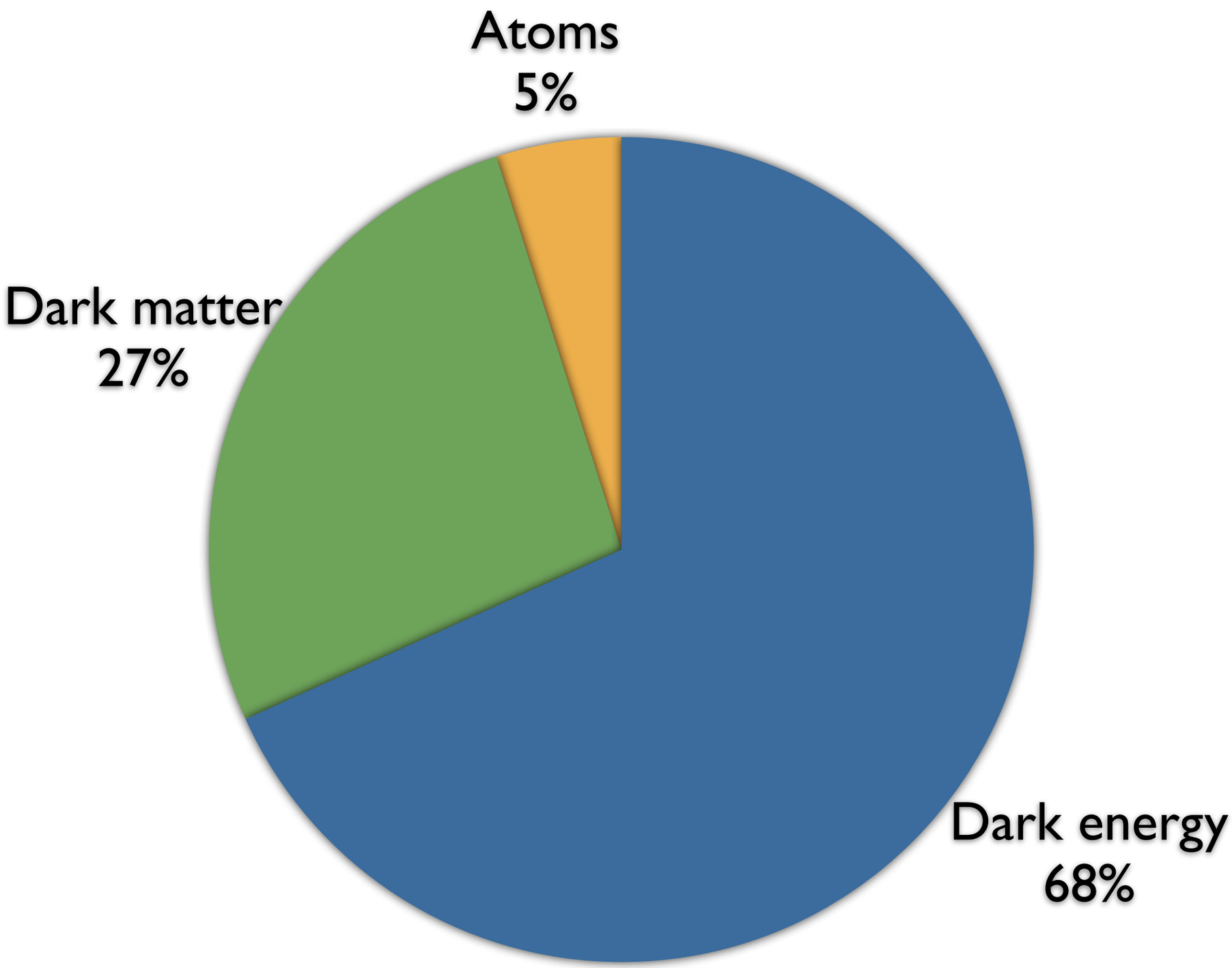
Towards predictive structure formation simulations with baryons

Prof. Justin Read | University of Surrey

Motivation

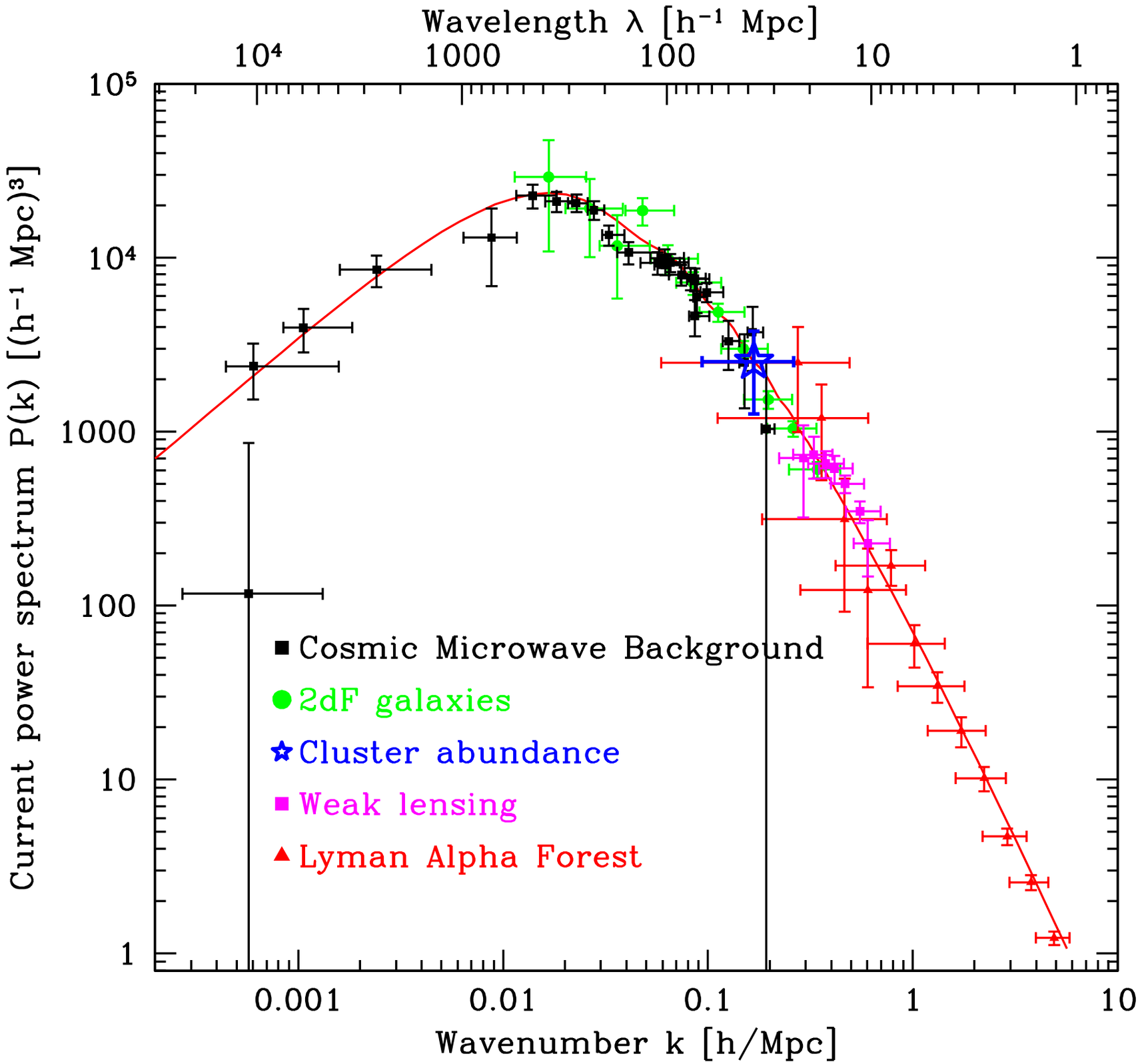
[Why worry about baryons?]

Background | The standard cosmological model LCDM



Planck collaboration 2013

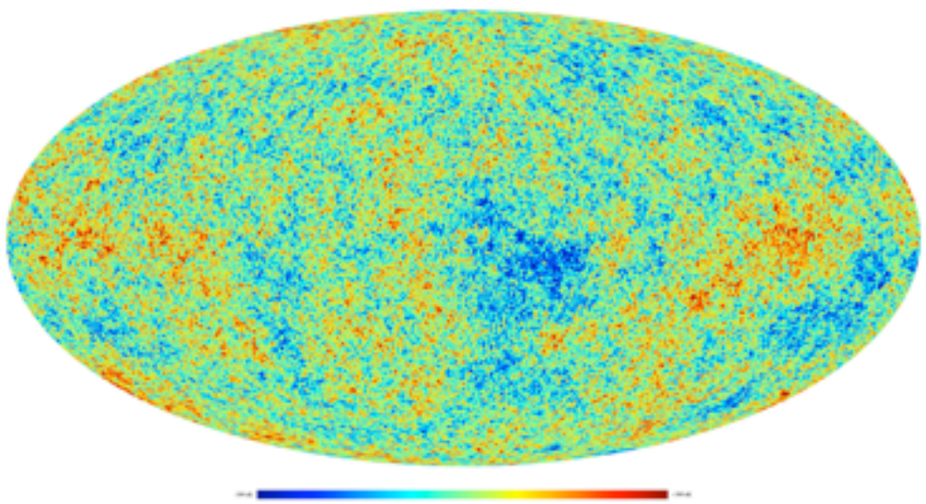
Background | The standard cosmological model LCDM



Tegmark & Zaldarriaga 2002

Background | Near-field Cosmology

CMB



Background | Near-field Cosmology

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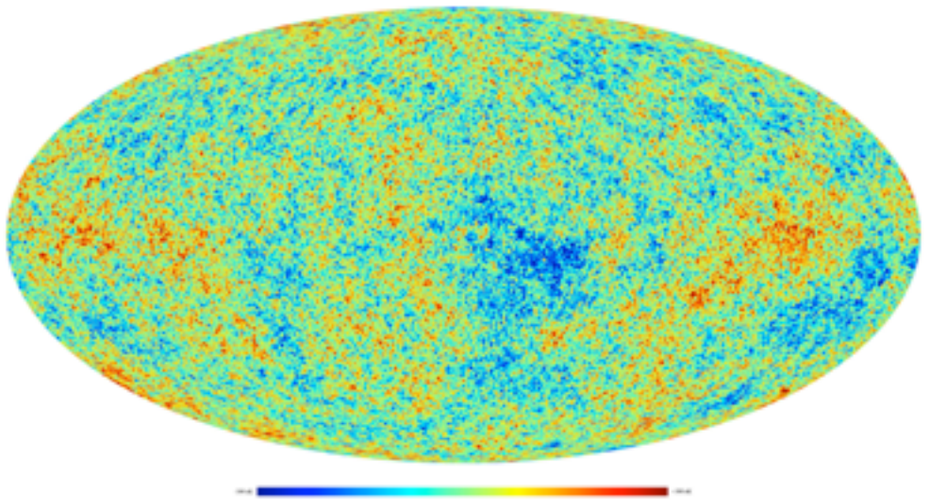
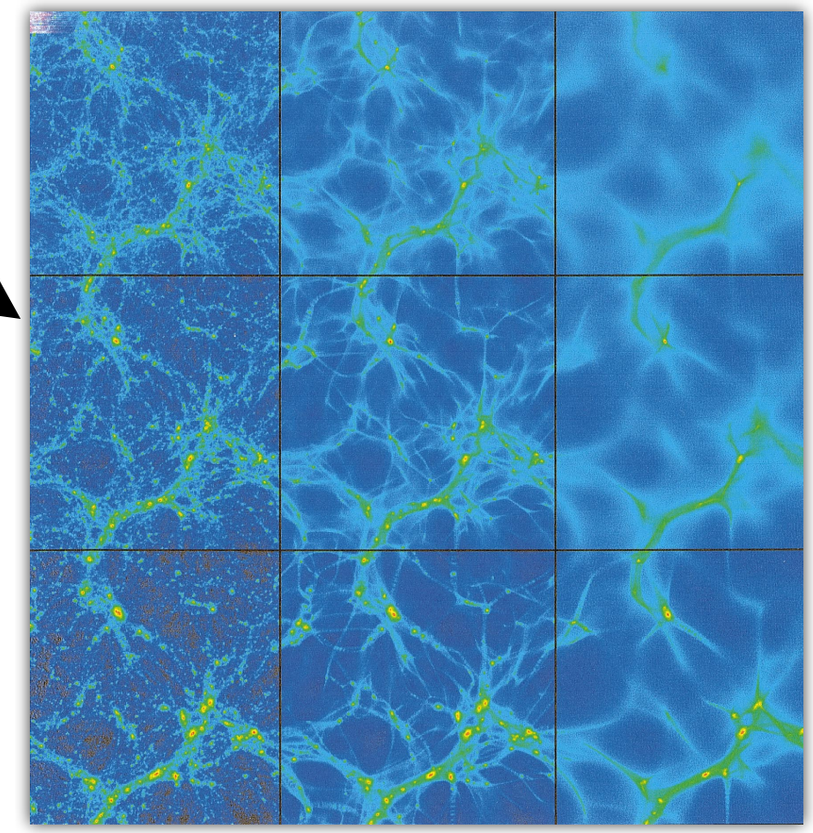


Simulations

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

COLD WARM HOT



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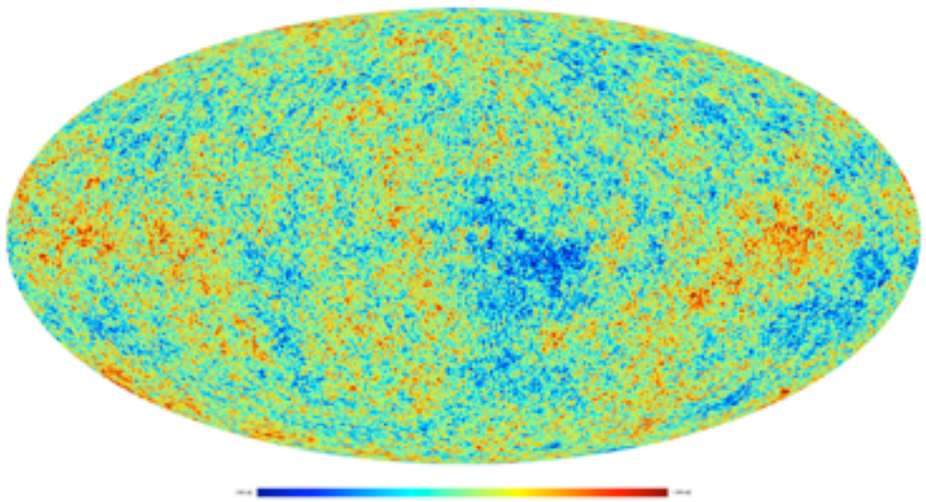

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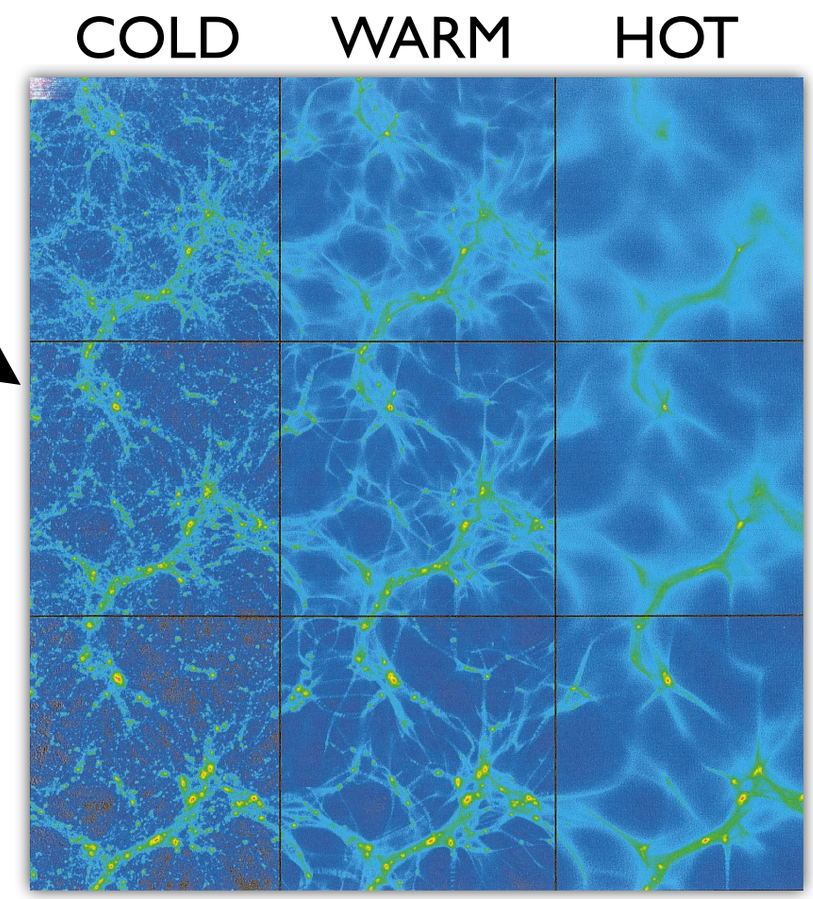
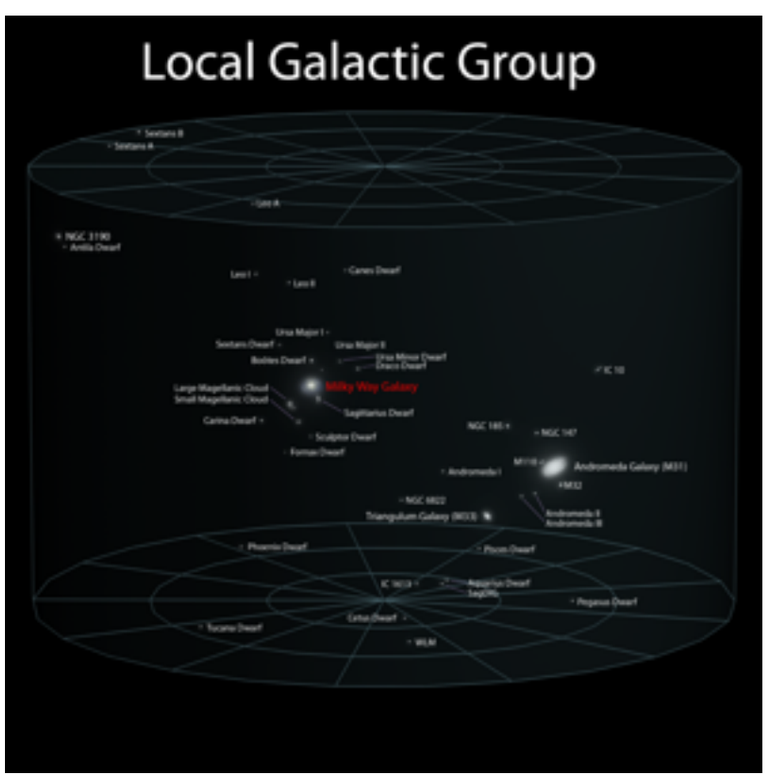
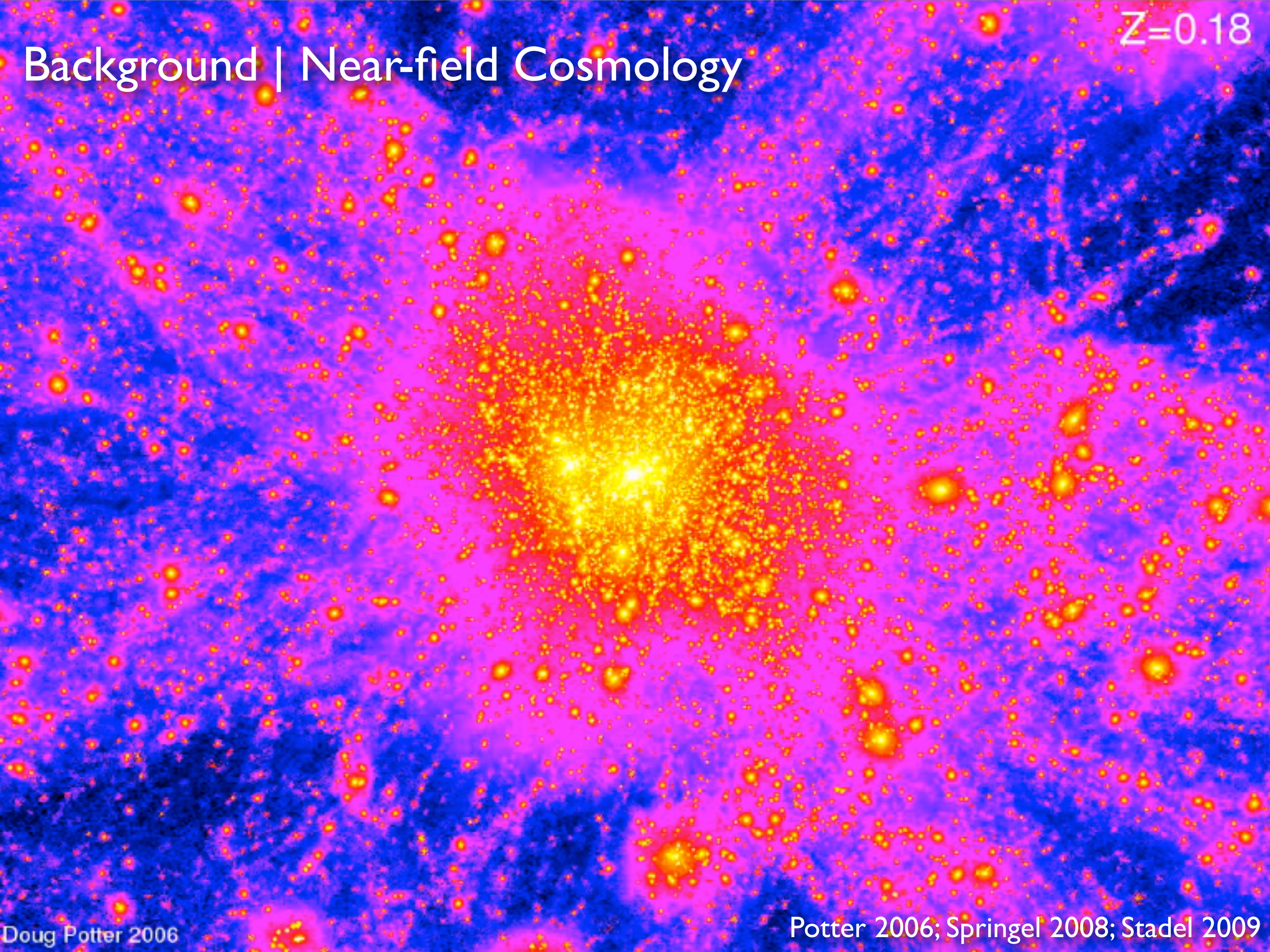




Observations

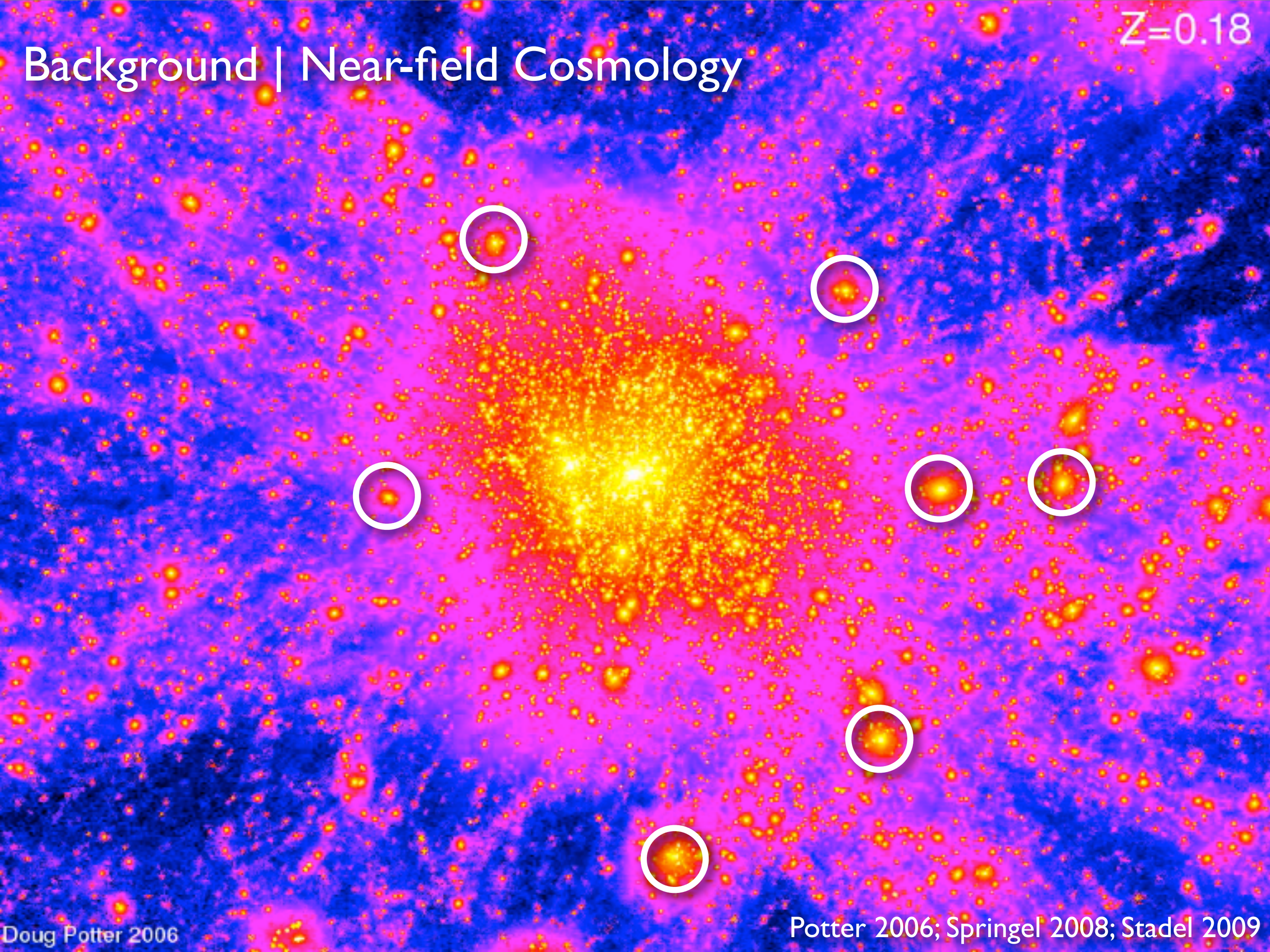
[e.g. dwarf galaxy counts; dwarf internal dark matter profile]

Background | Near-field Cosmology



Potter 2006; Springel 2008; Stadel 2009

Background | Near-field Cosmology



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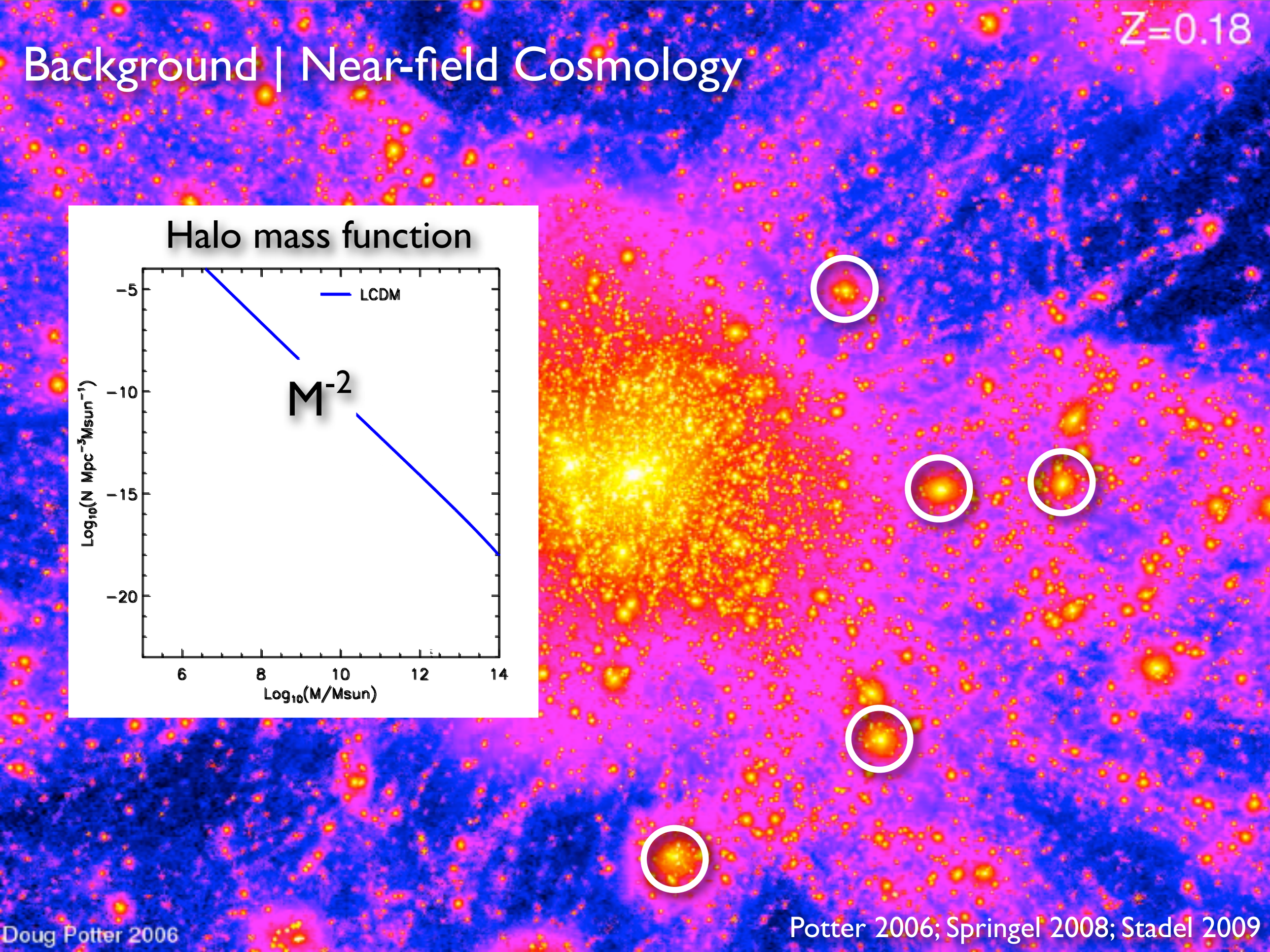

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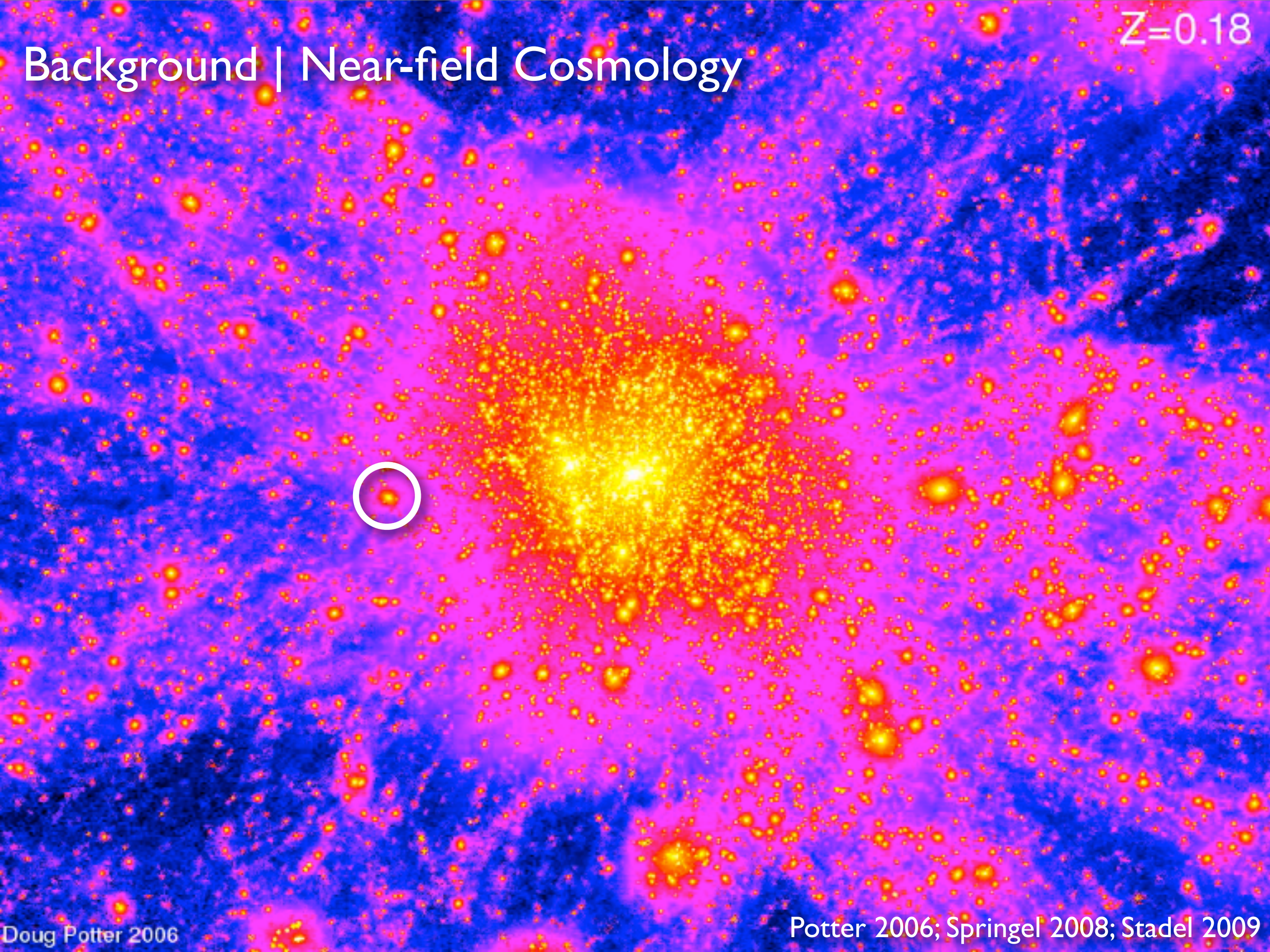

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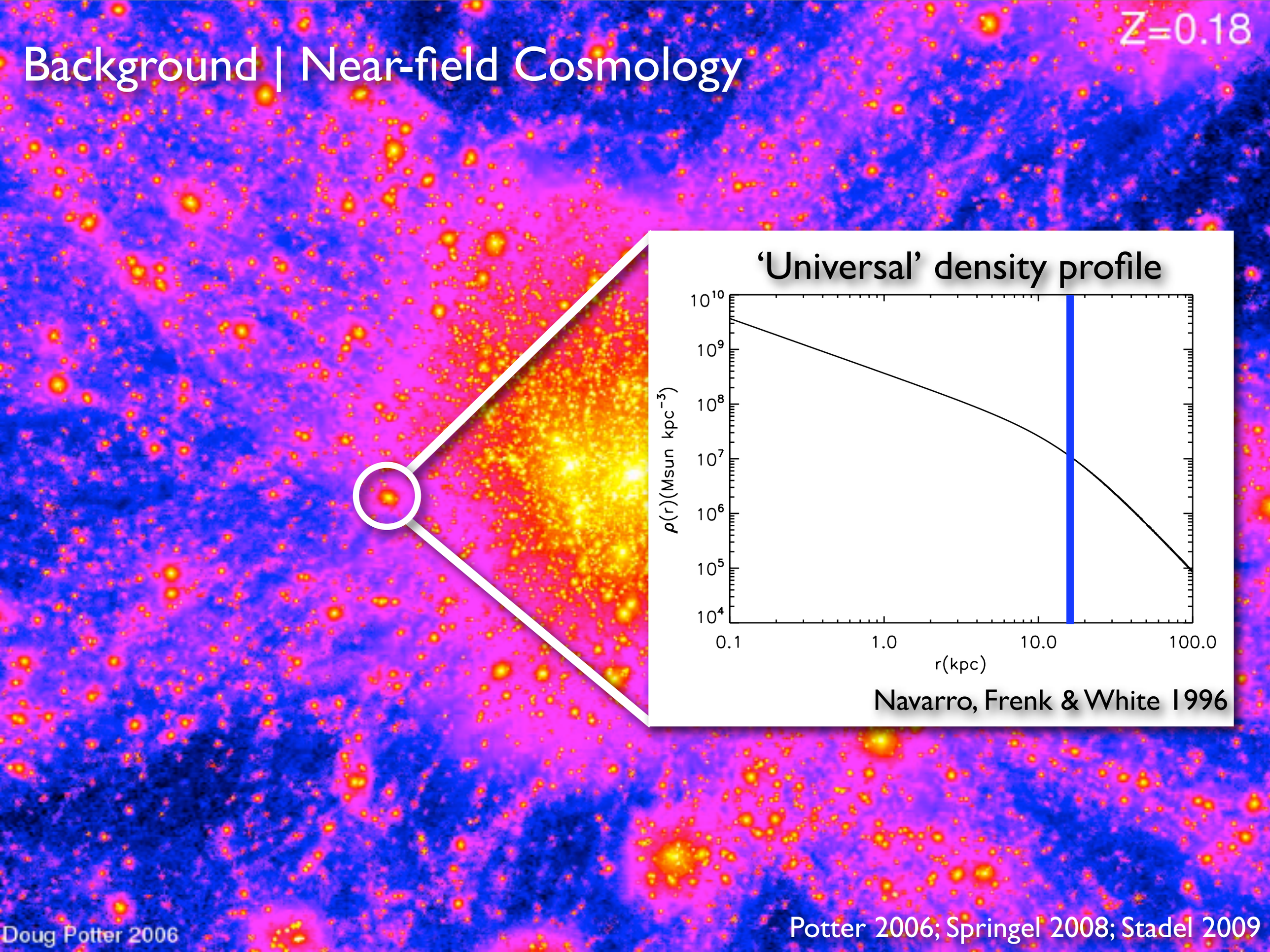

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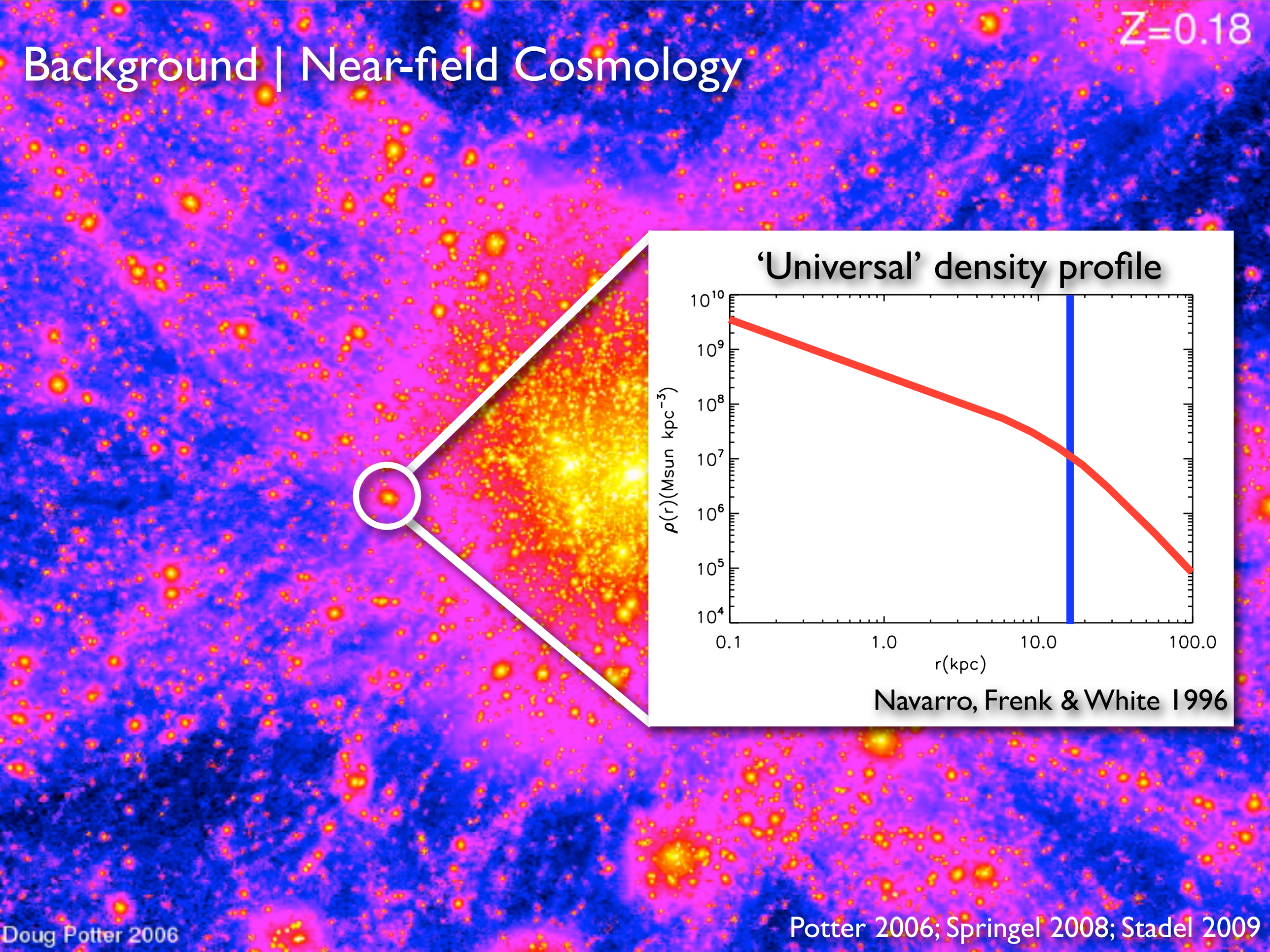

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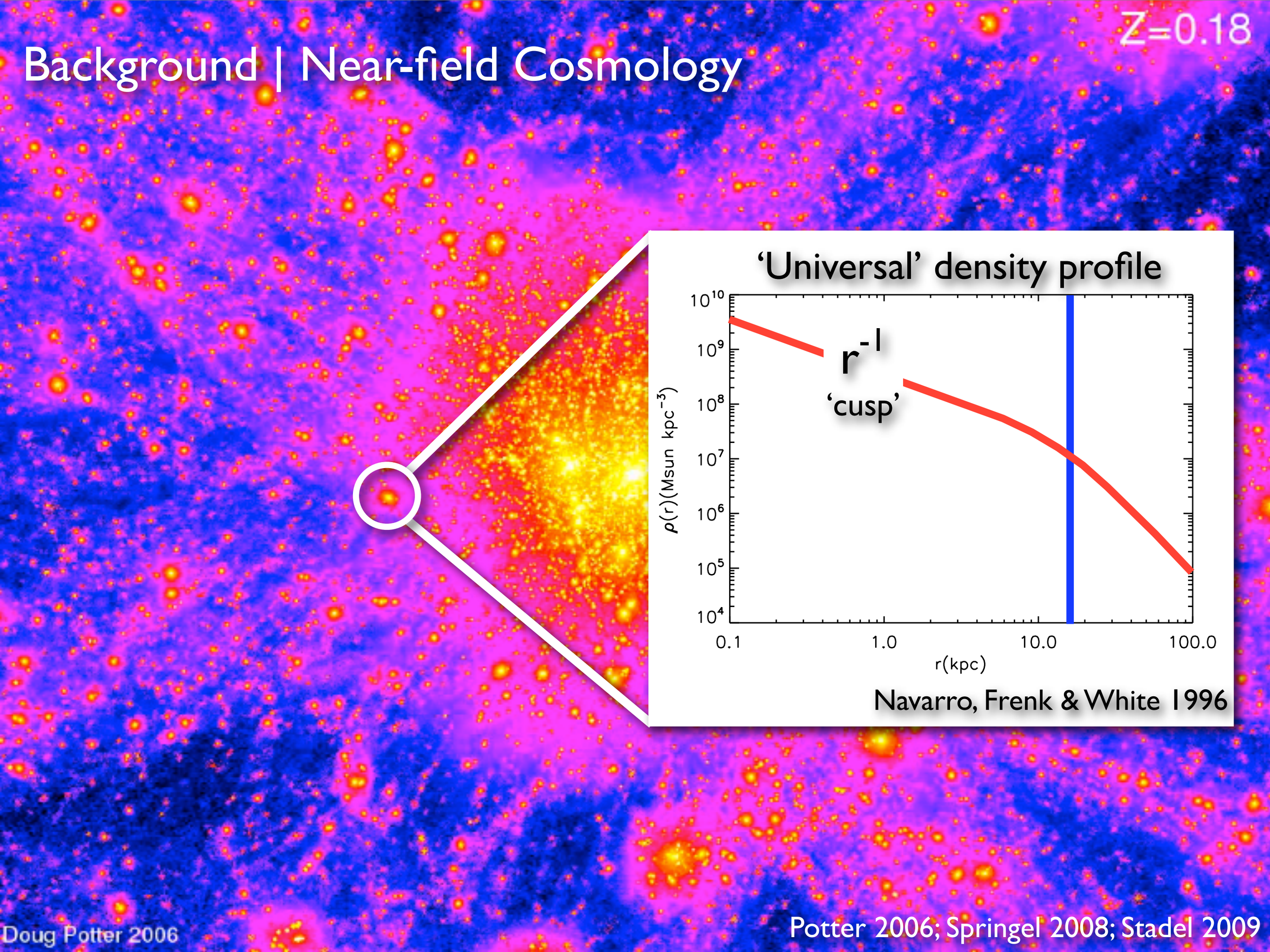

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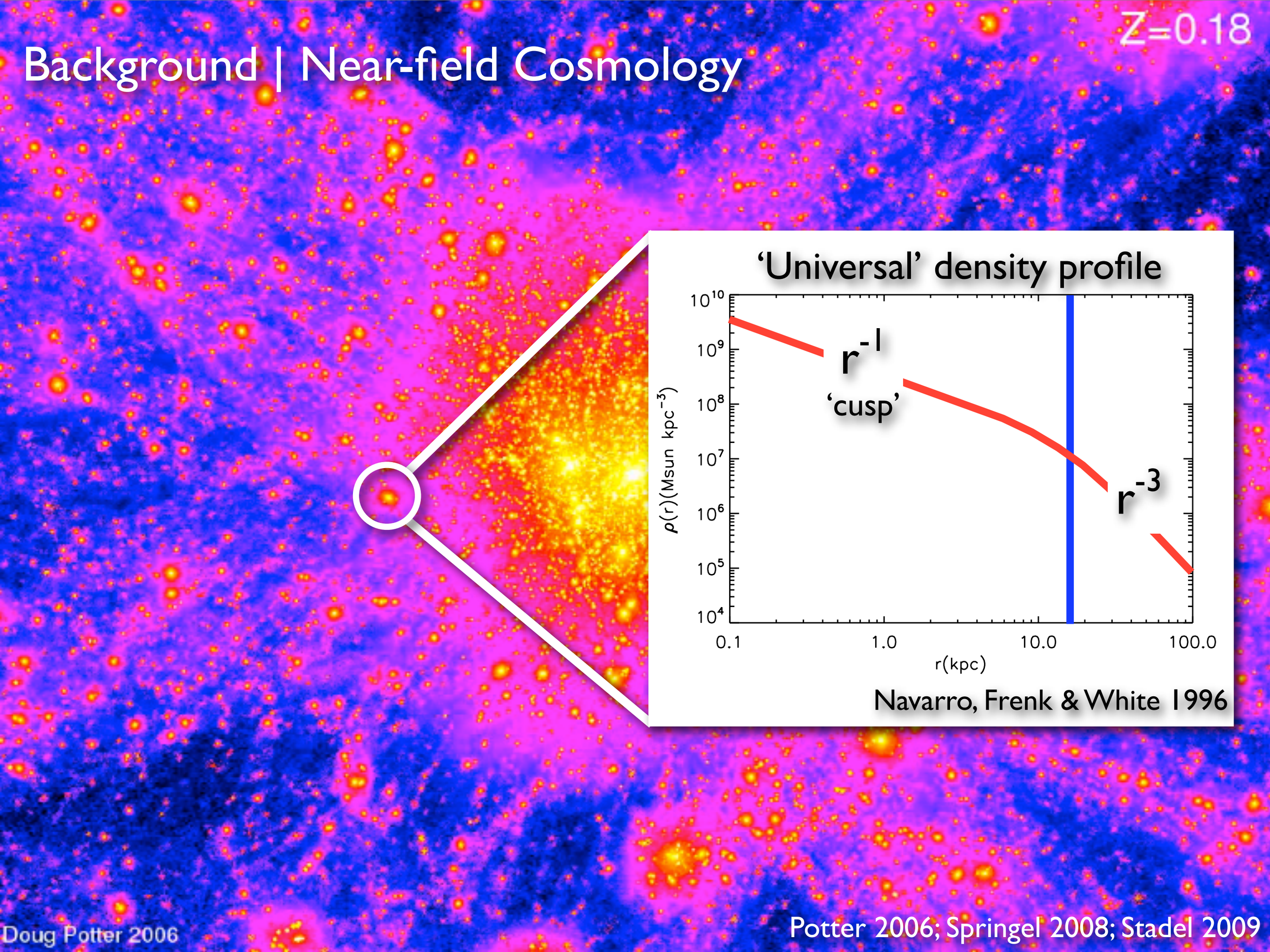

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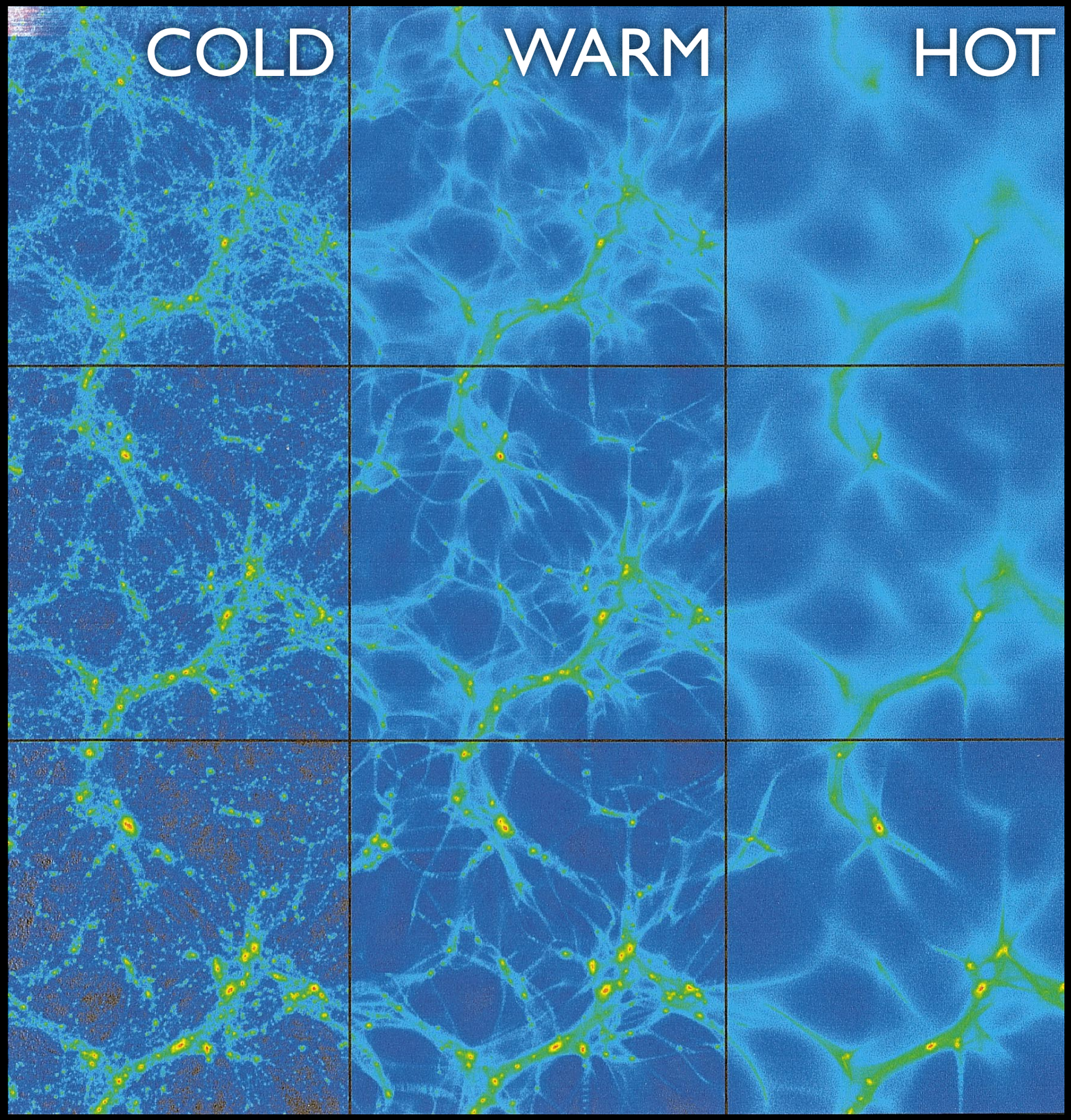
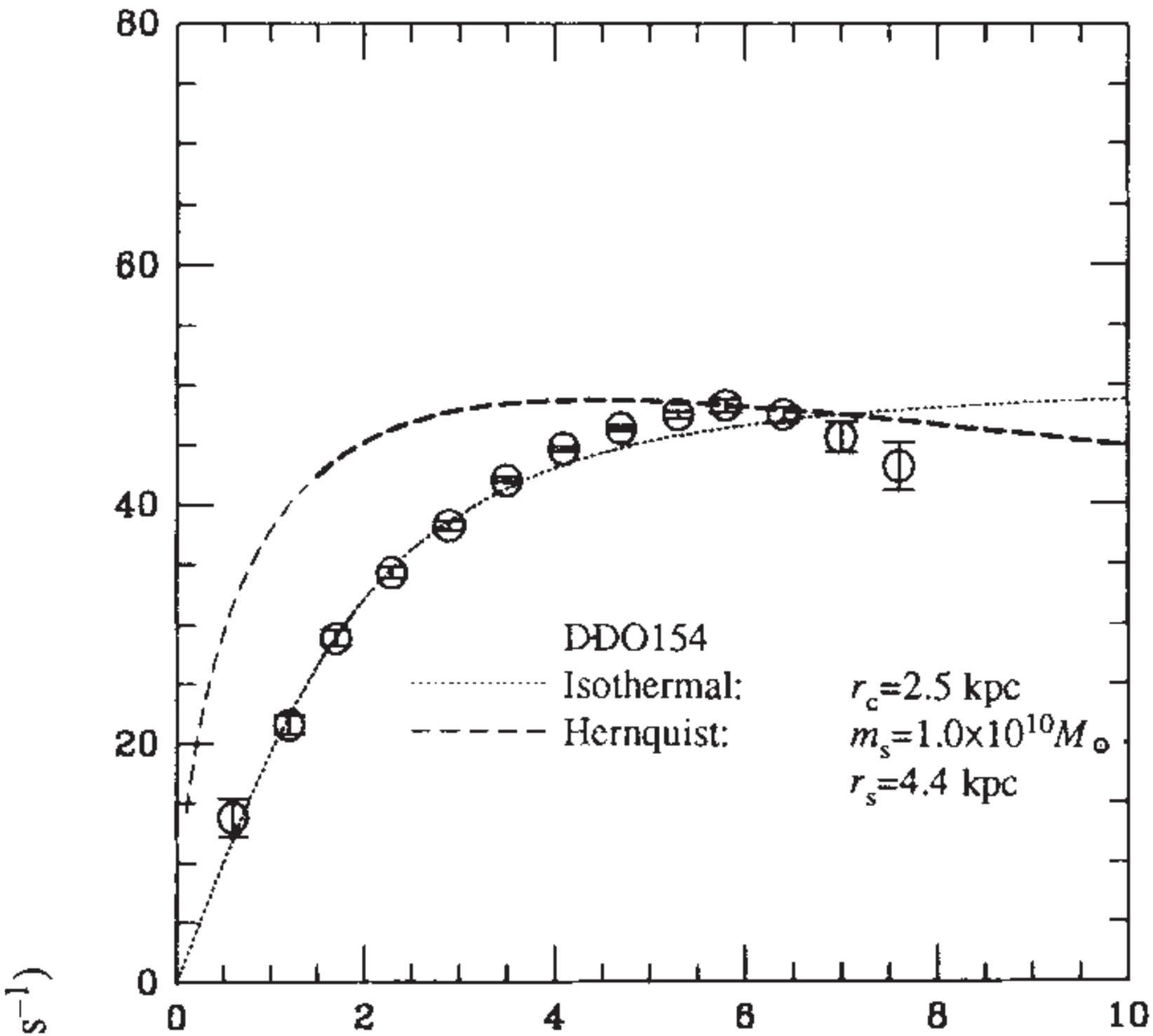
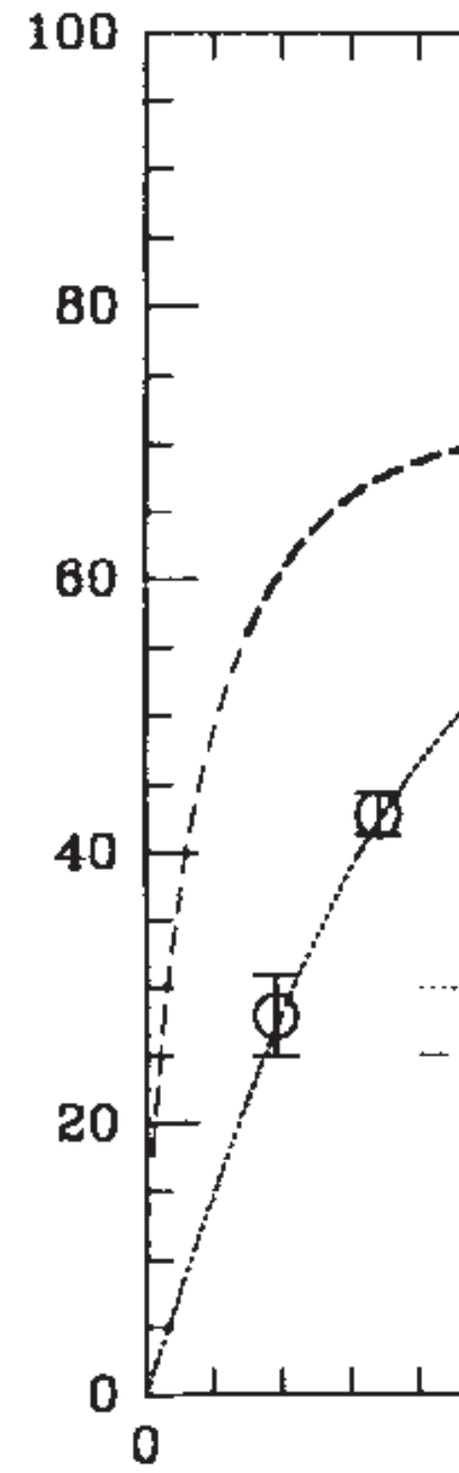


Bode et al. 2001

Background | The 'Cusp-Core' problem





Moore 1994; Flores & Primack 1994

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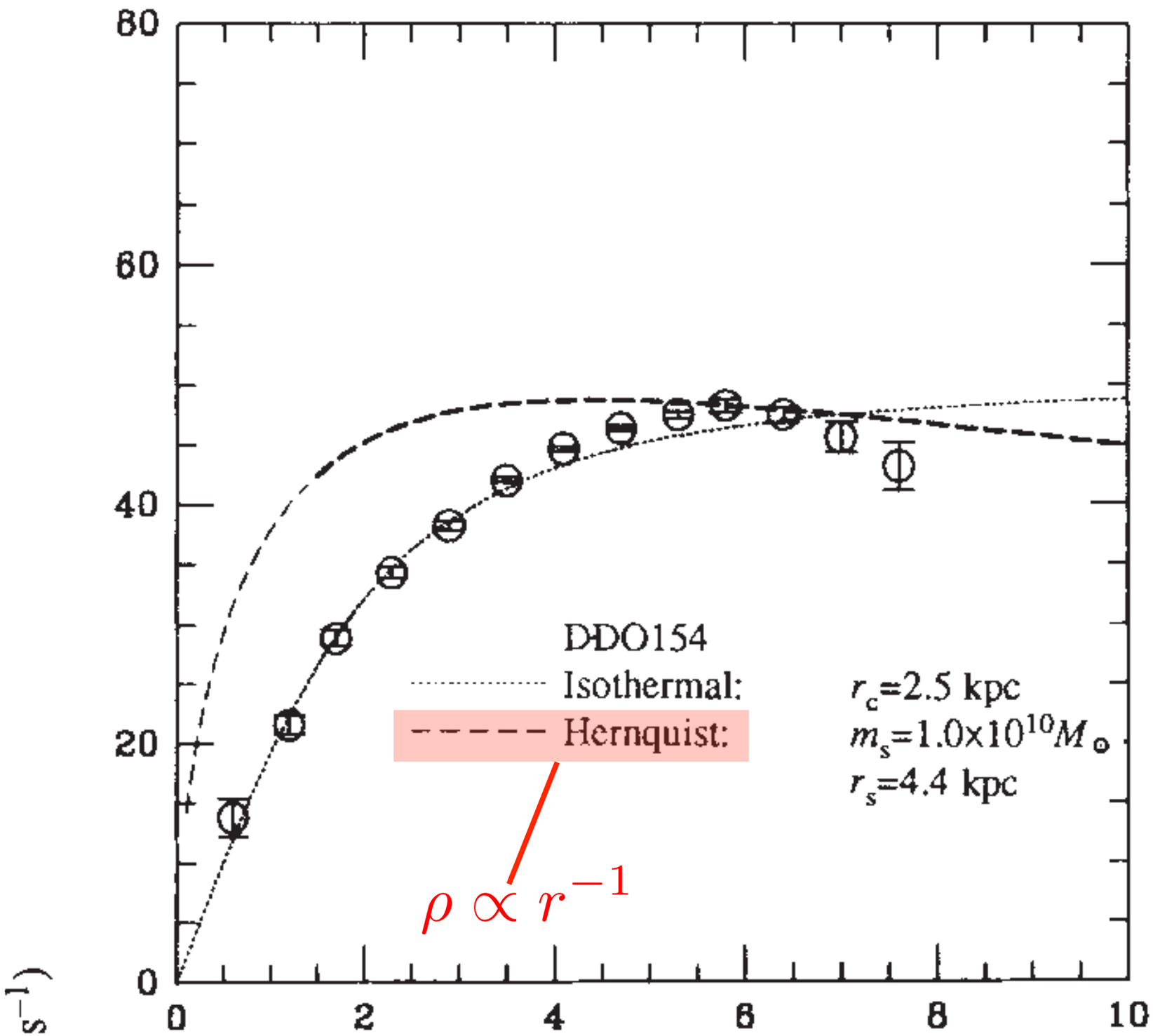

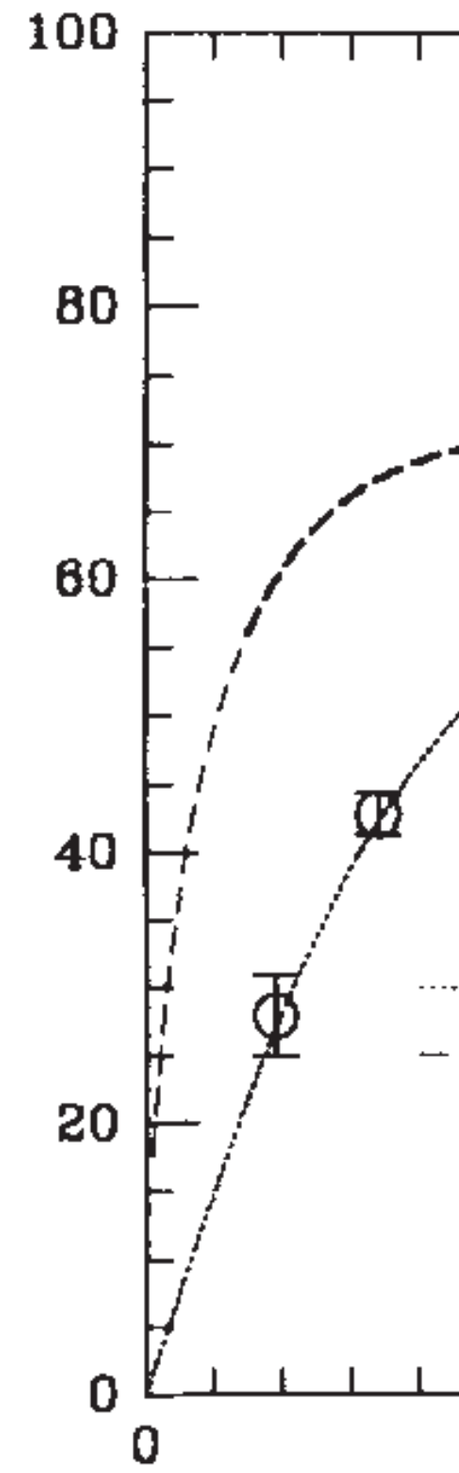

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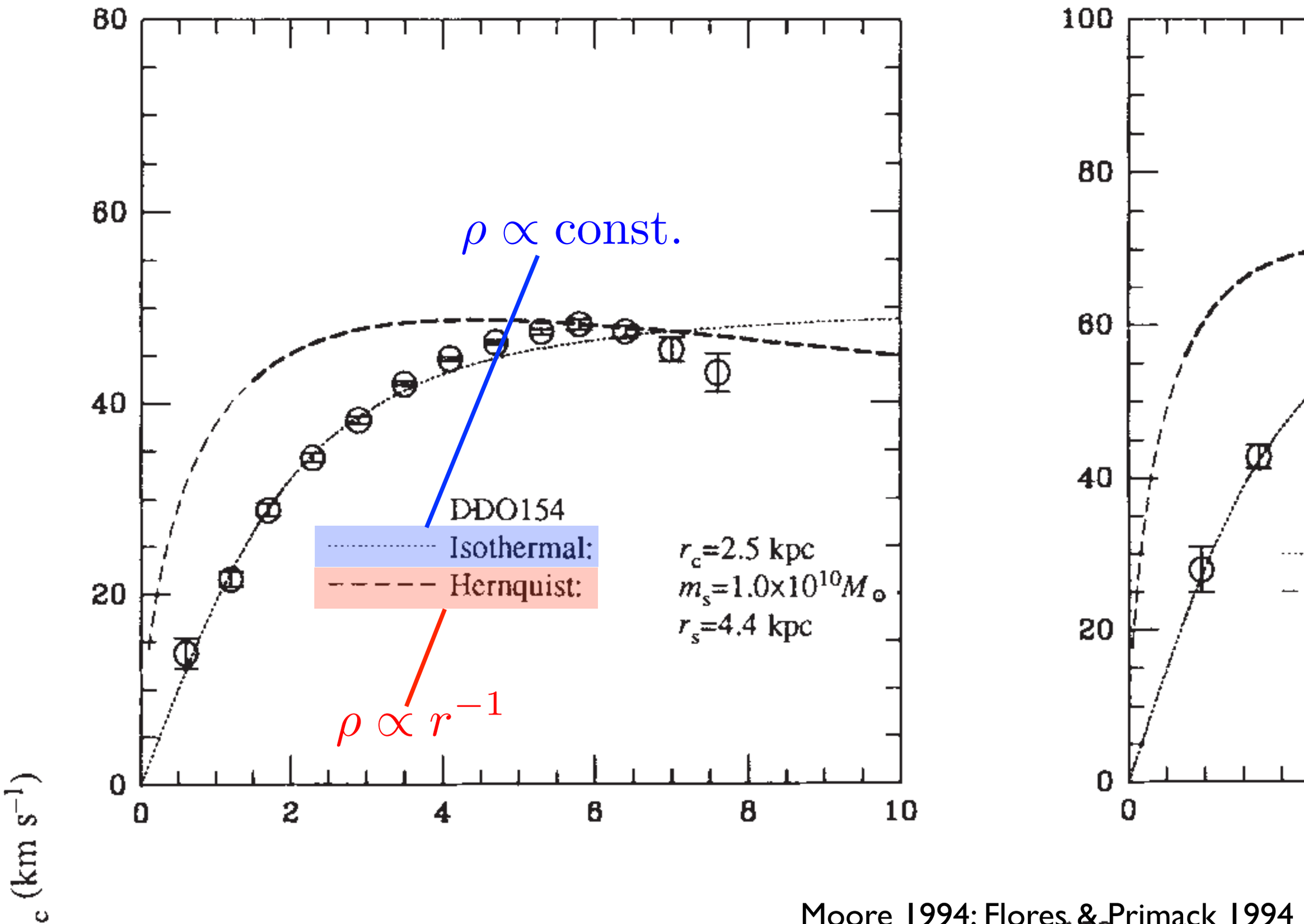

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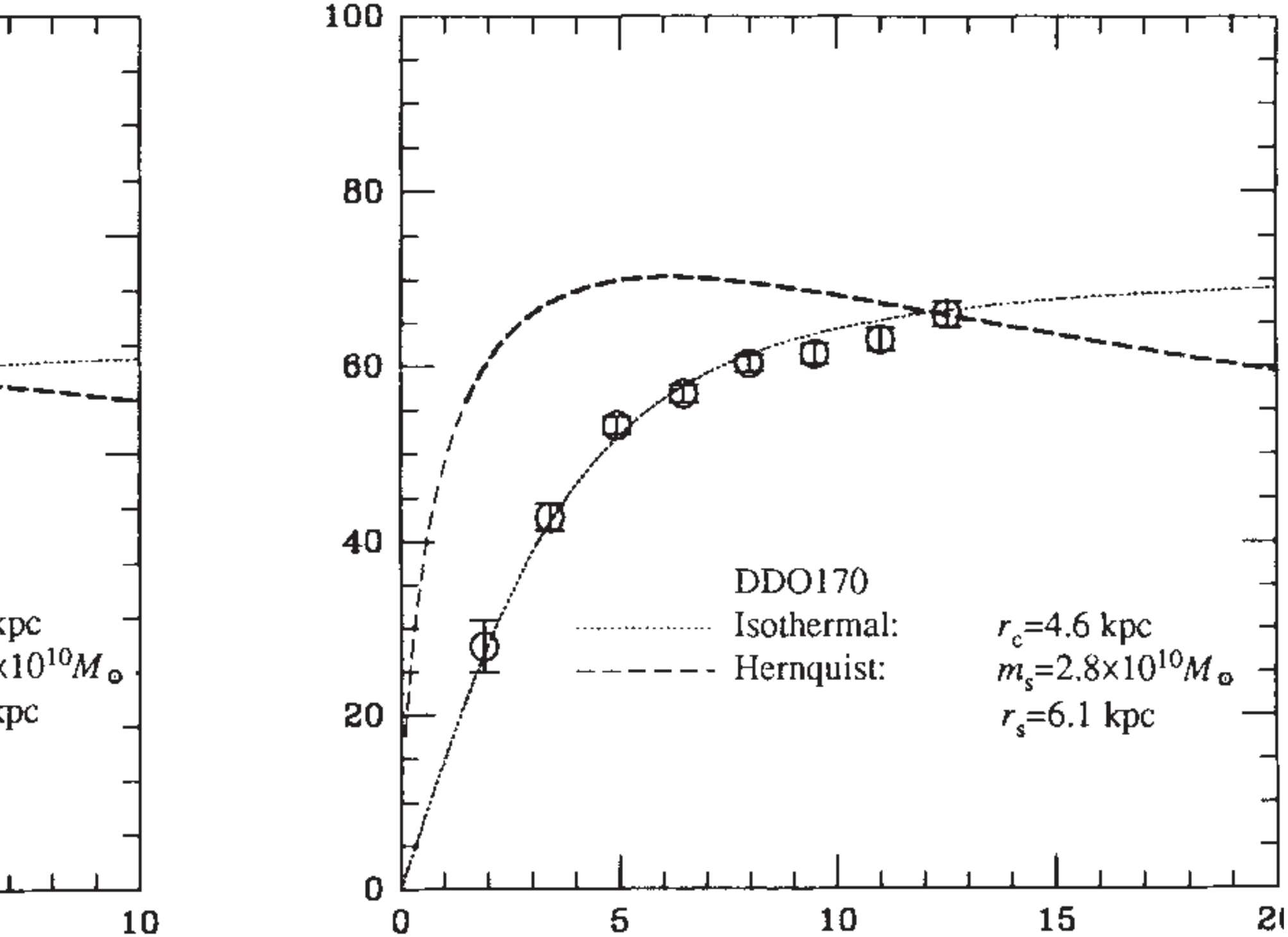

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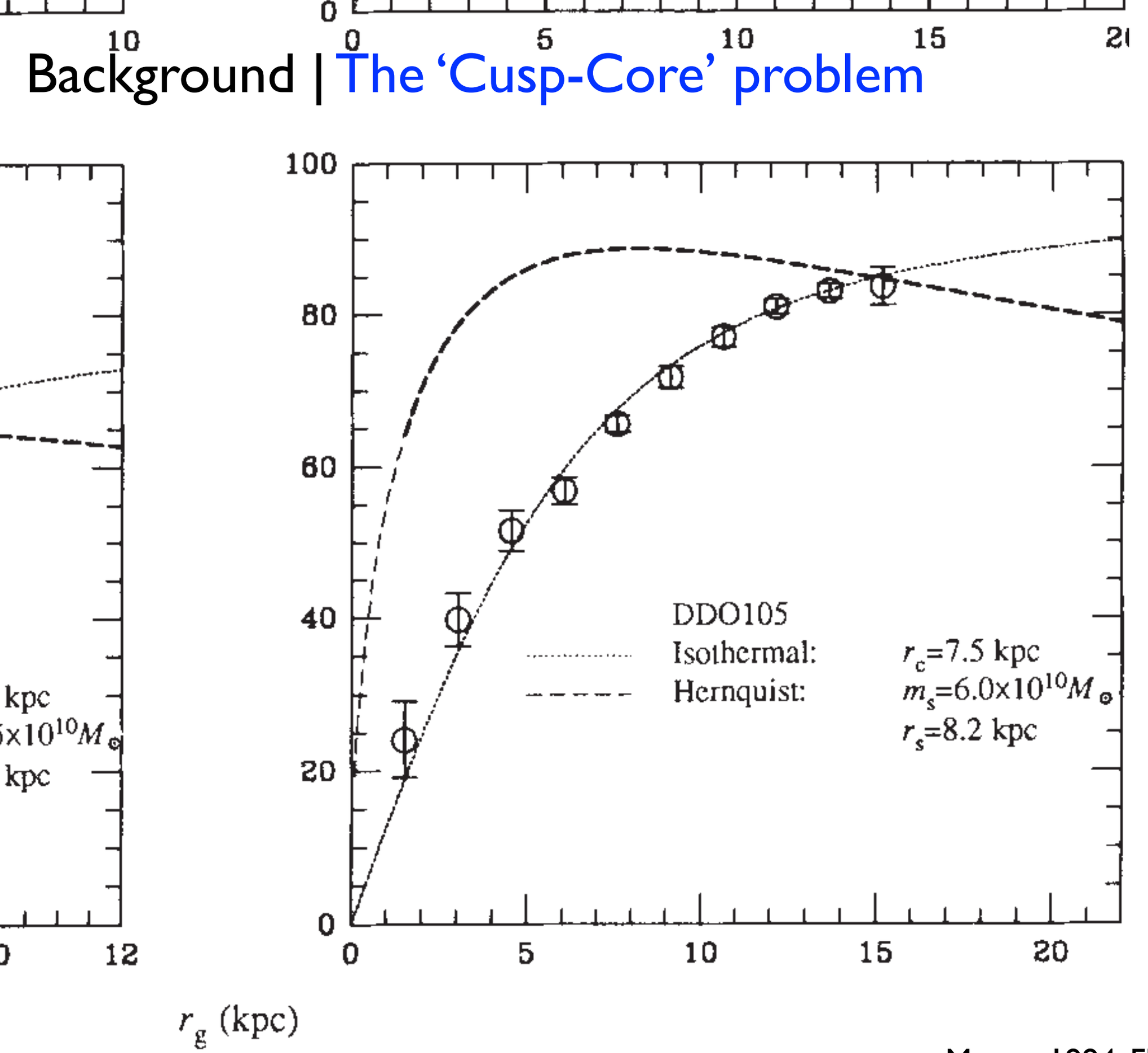

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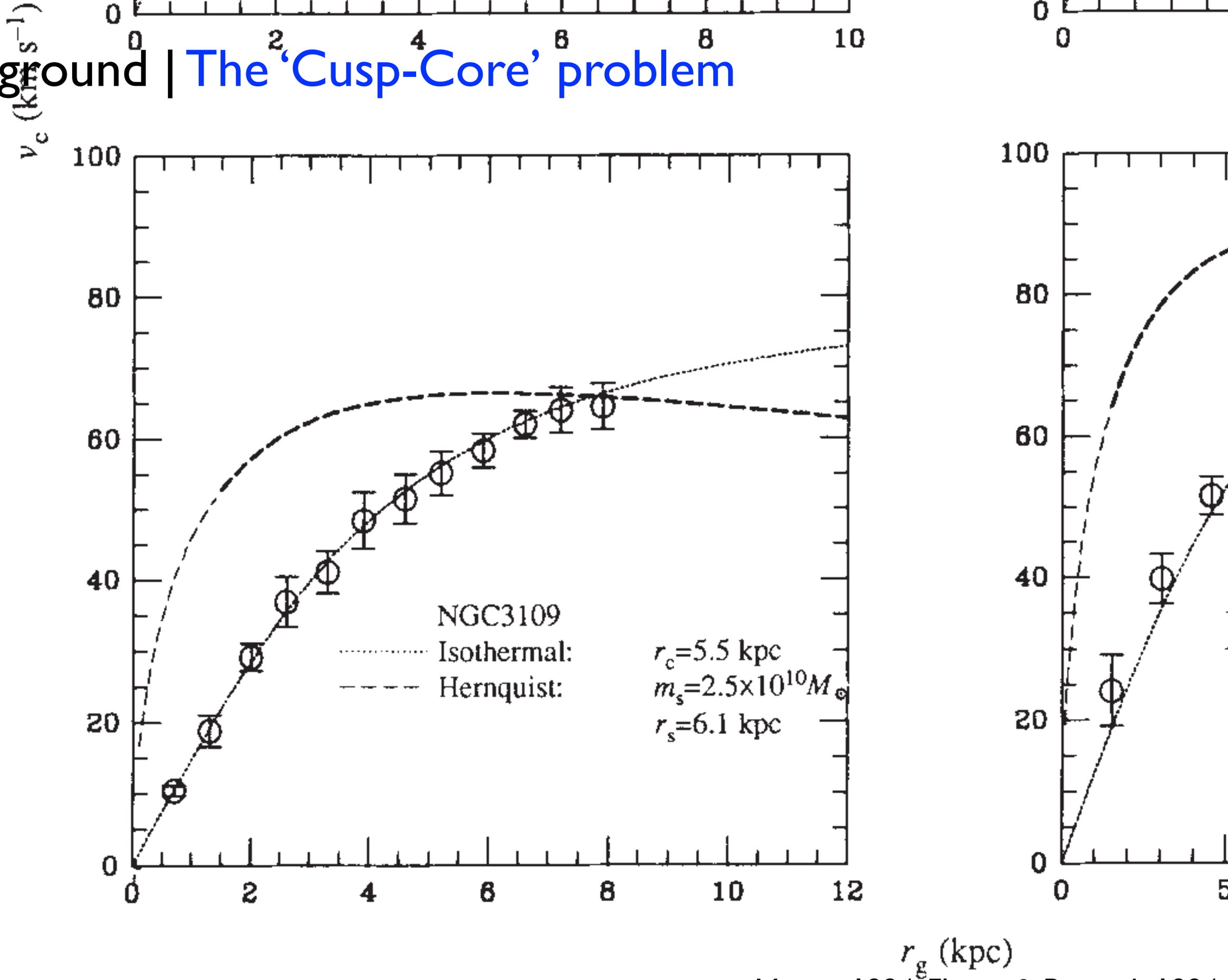
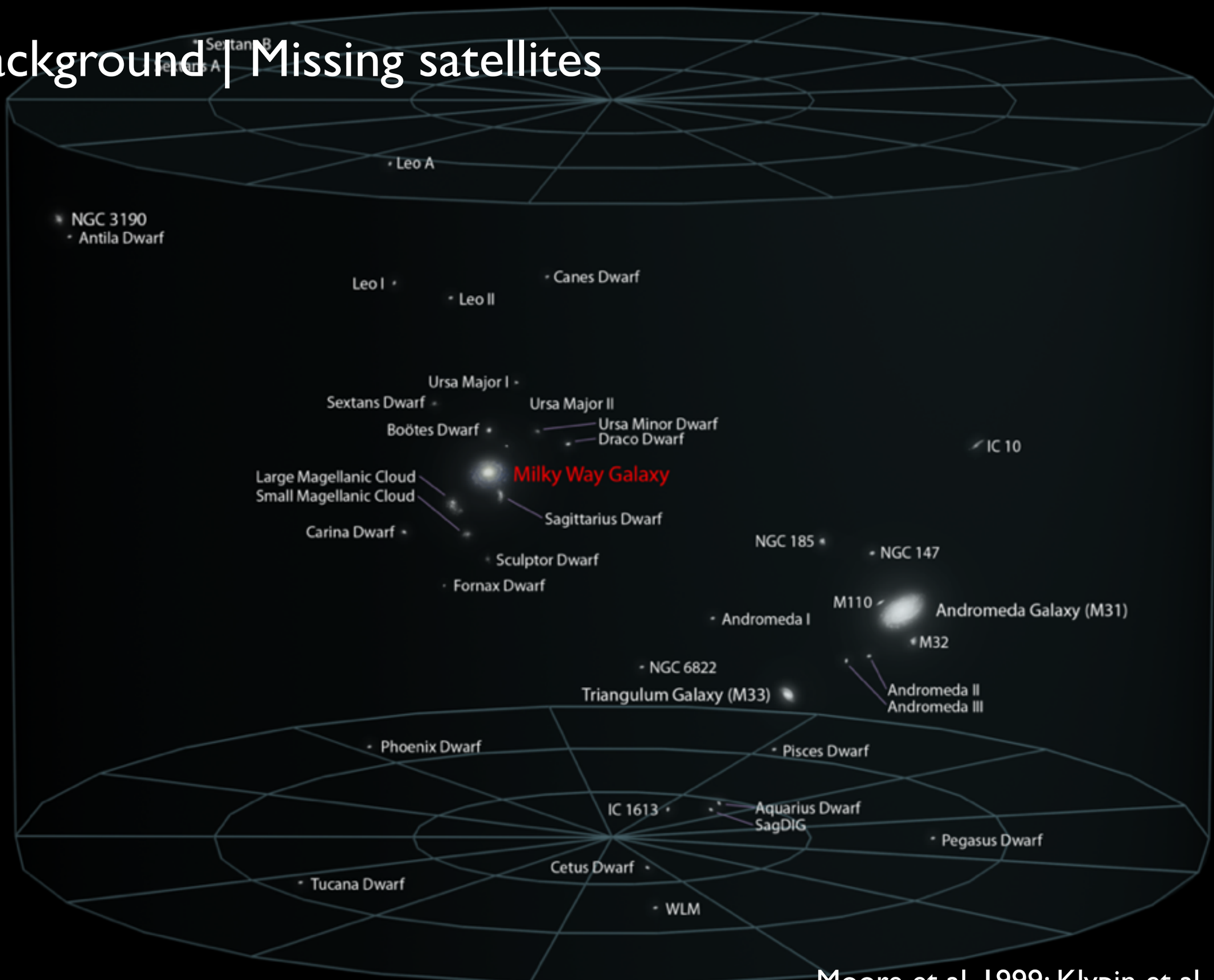


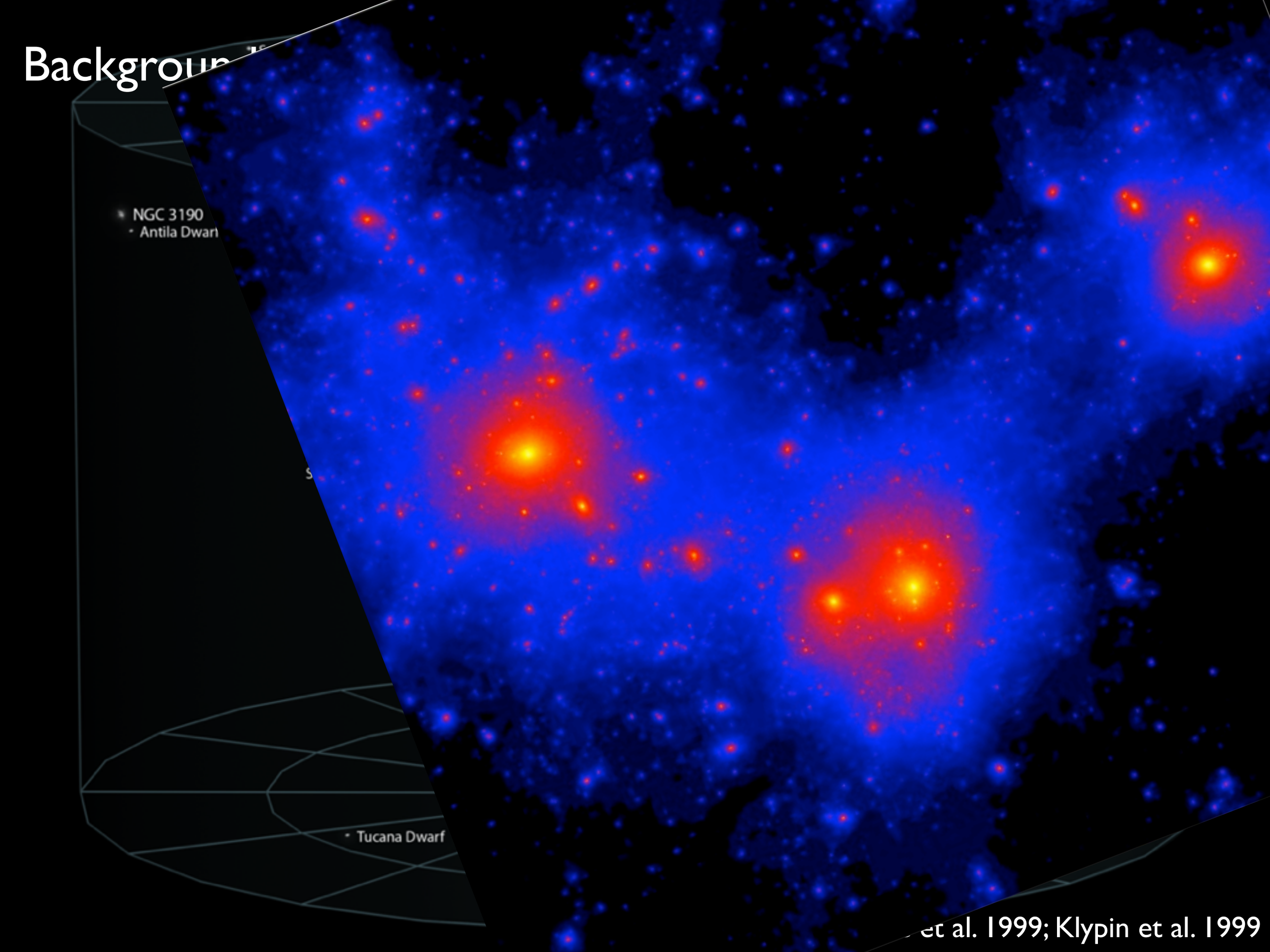
Moore 1994; Flores & Primack 1994

Background| Missing satellites



Moore et al. 1999; Klypin et al. 1999

Backgrou



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Background | Small scale “crisis” for LCDM?

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NO!

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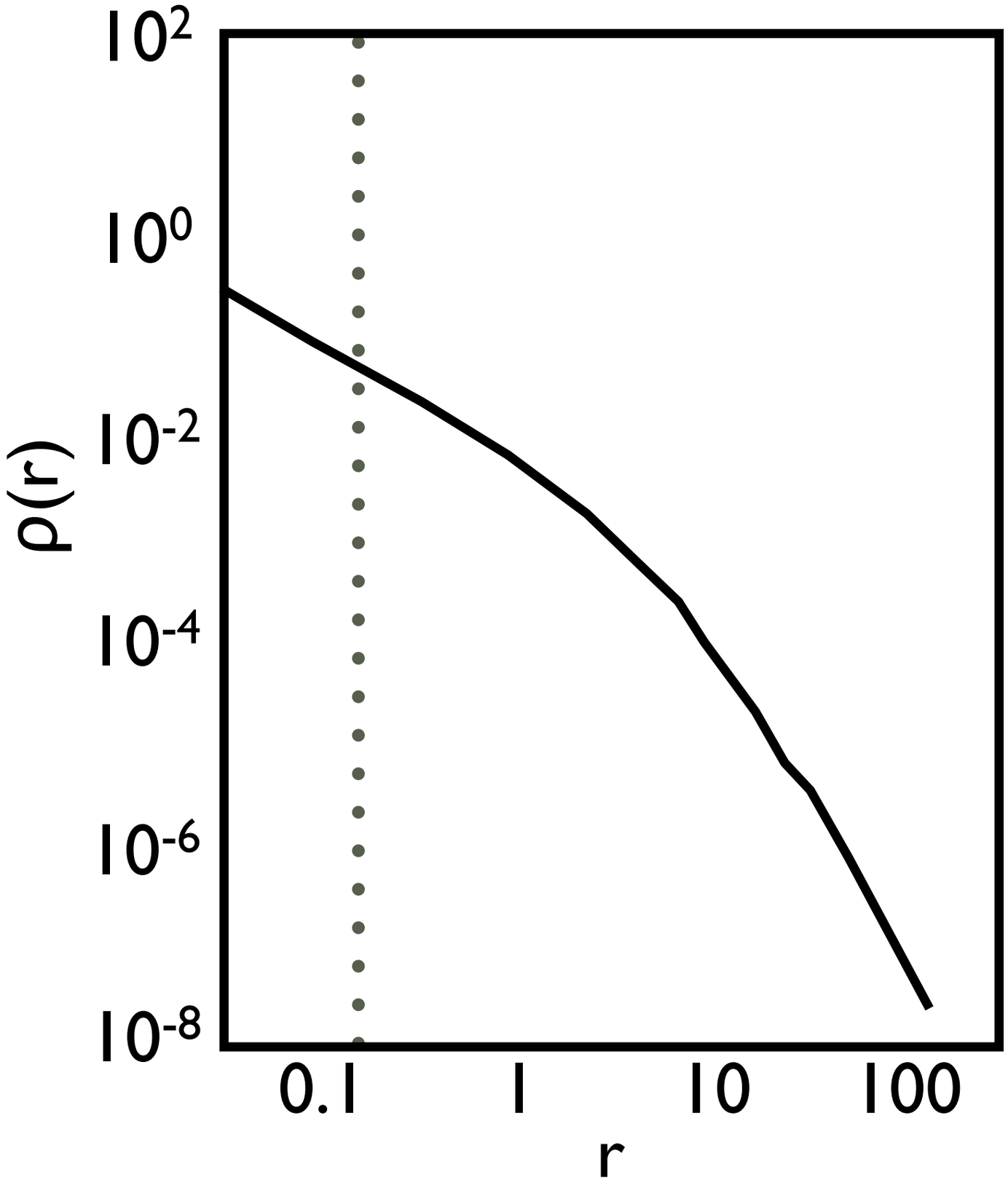
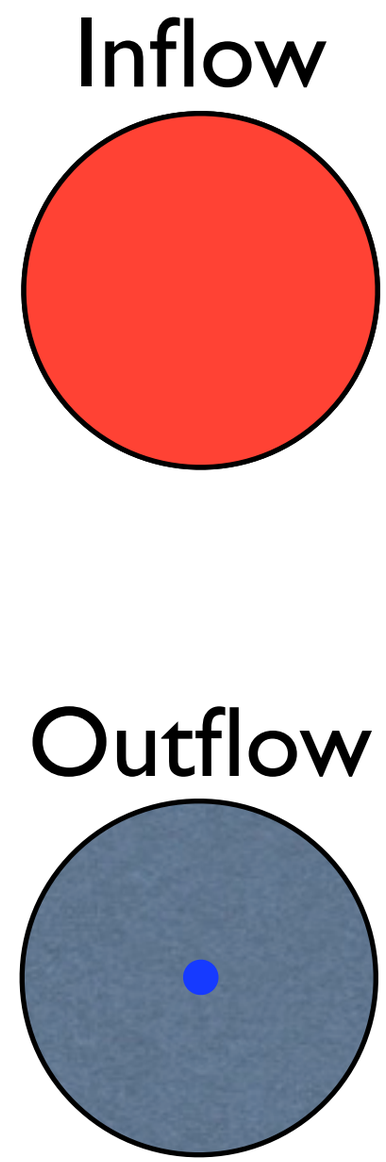
NO!

[THERE IS NO “SMALL SCALE CRISIS” IN LCDM. NOT UNTIL THE CALCULATION CAN BE DONE PROPERLY. WHICH IT CAN’T ... YET ...]

Motivation | The cusp/core problem





Read & Gilmore 2005; Navarro et al. 1996; Pontzen & Governato 2013

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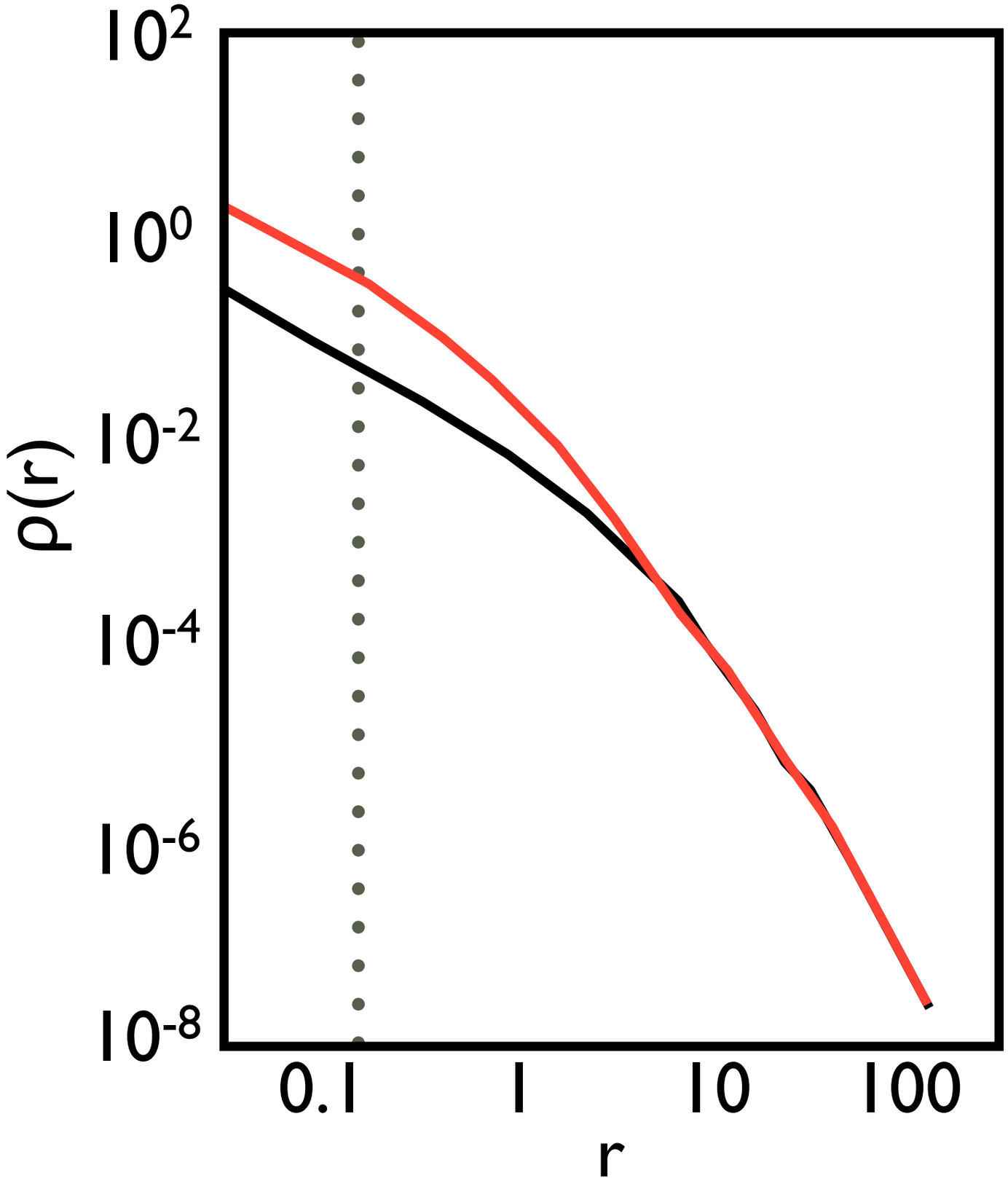

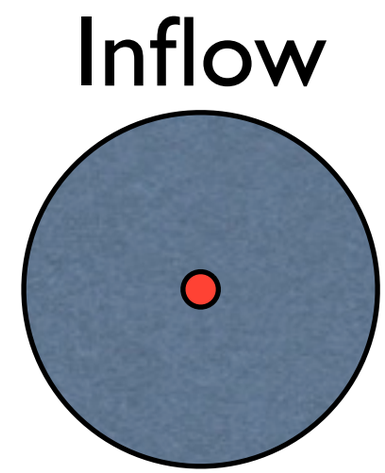

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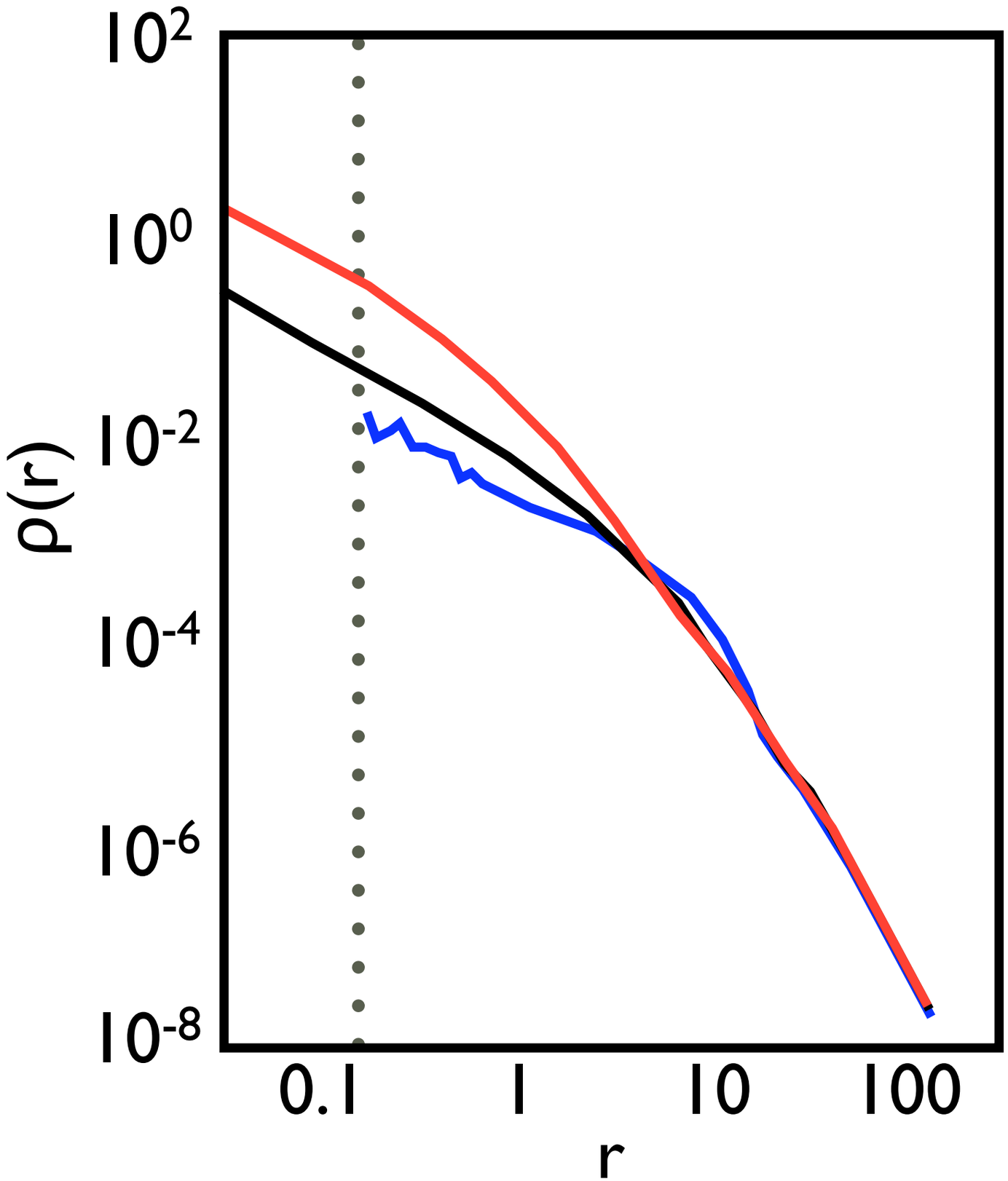

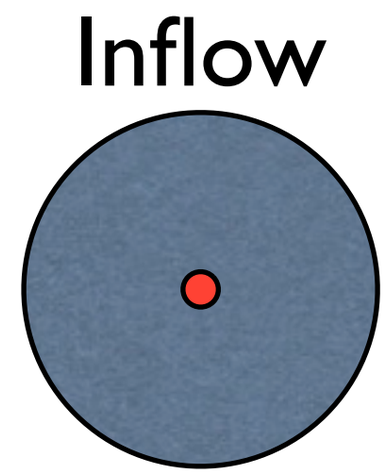

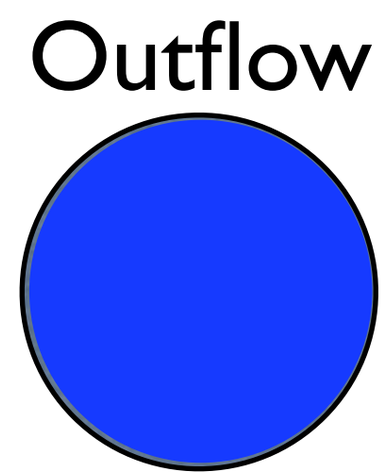

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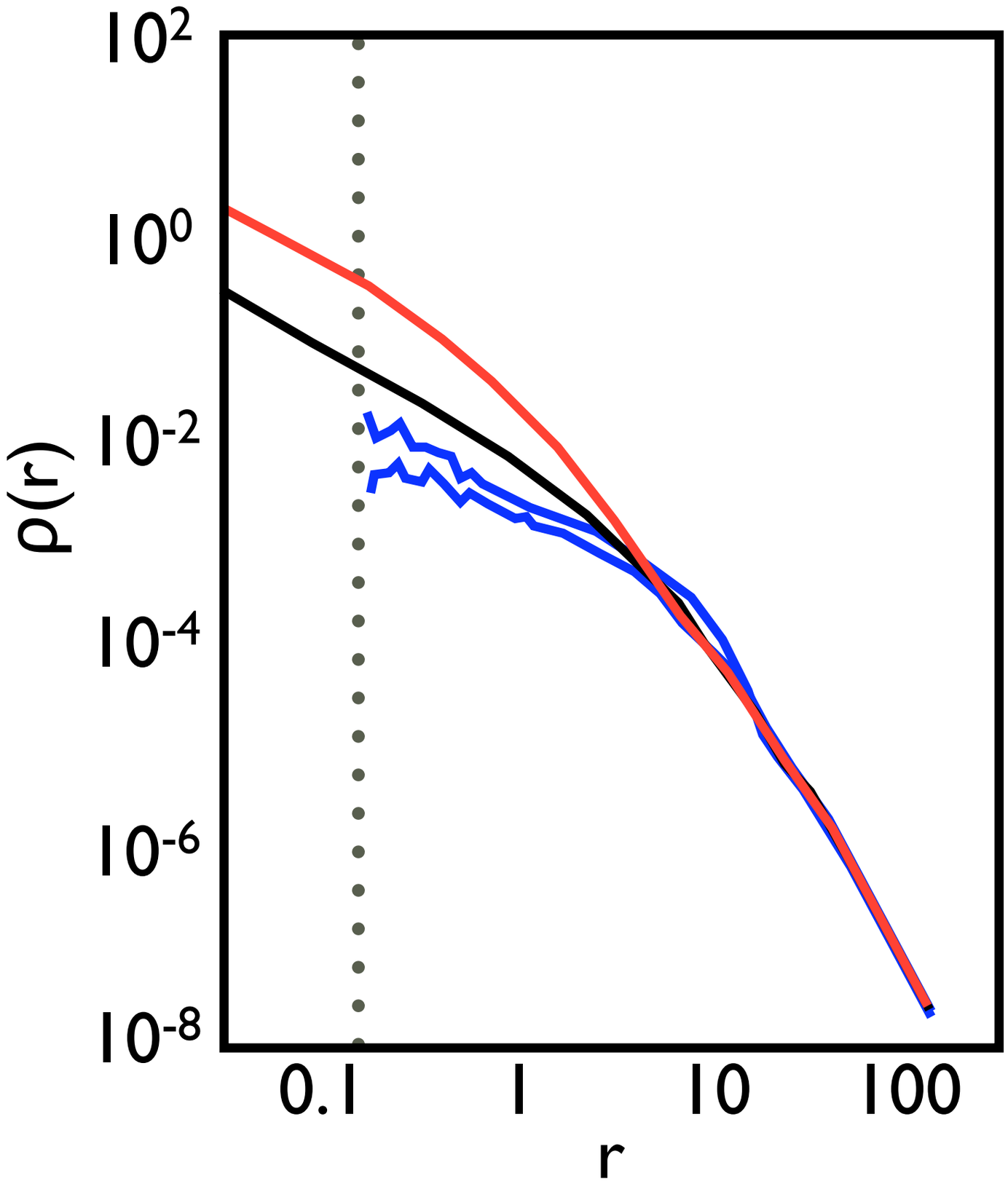

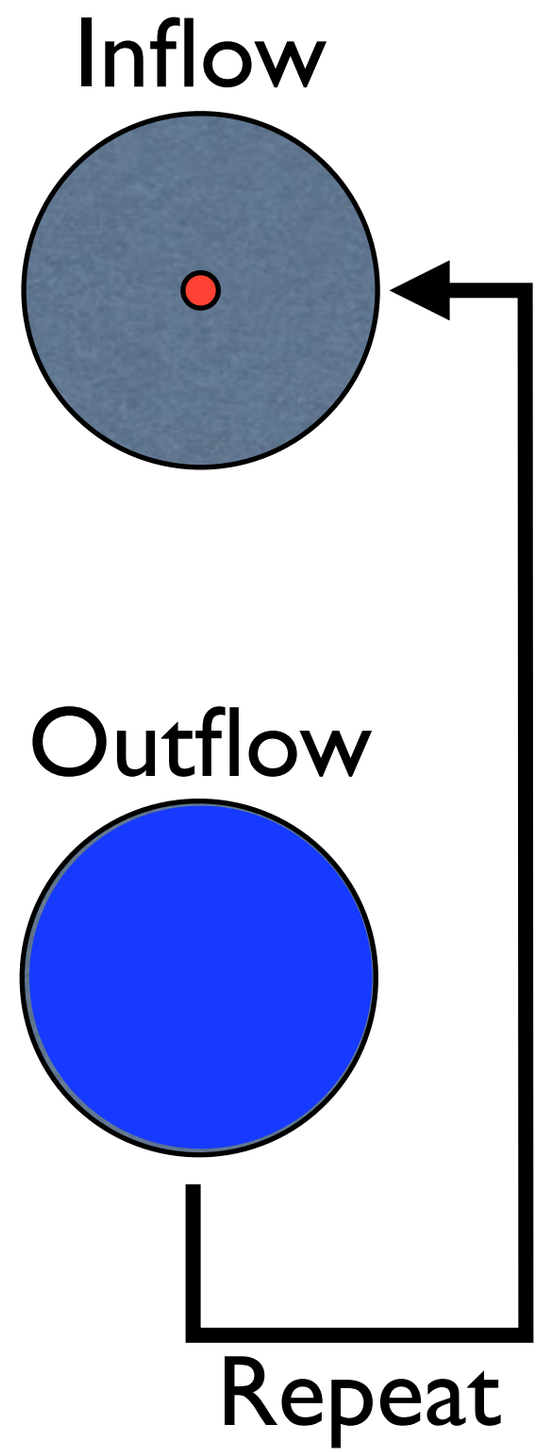

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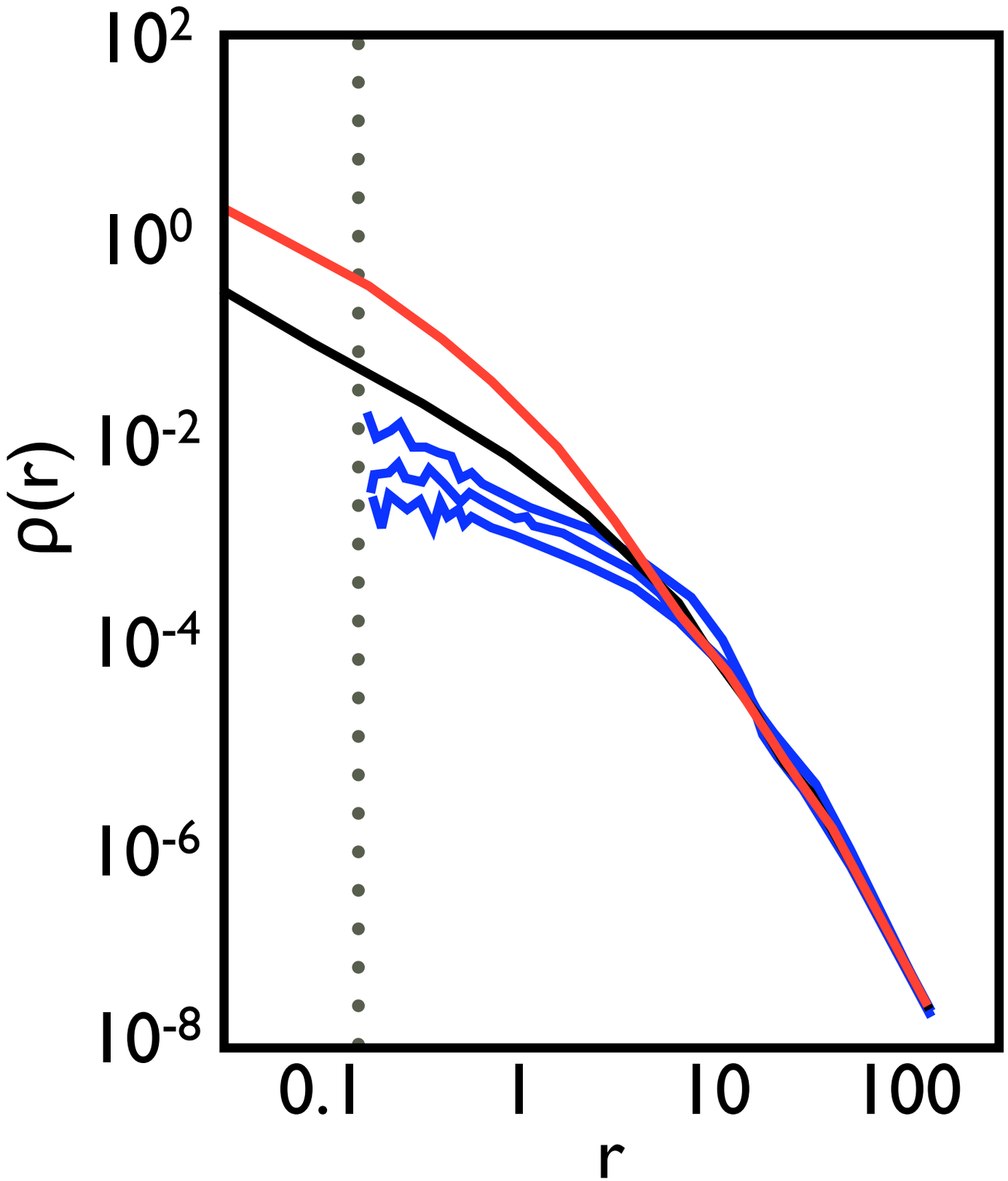

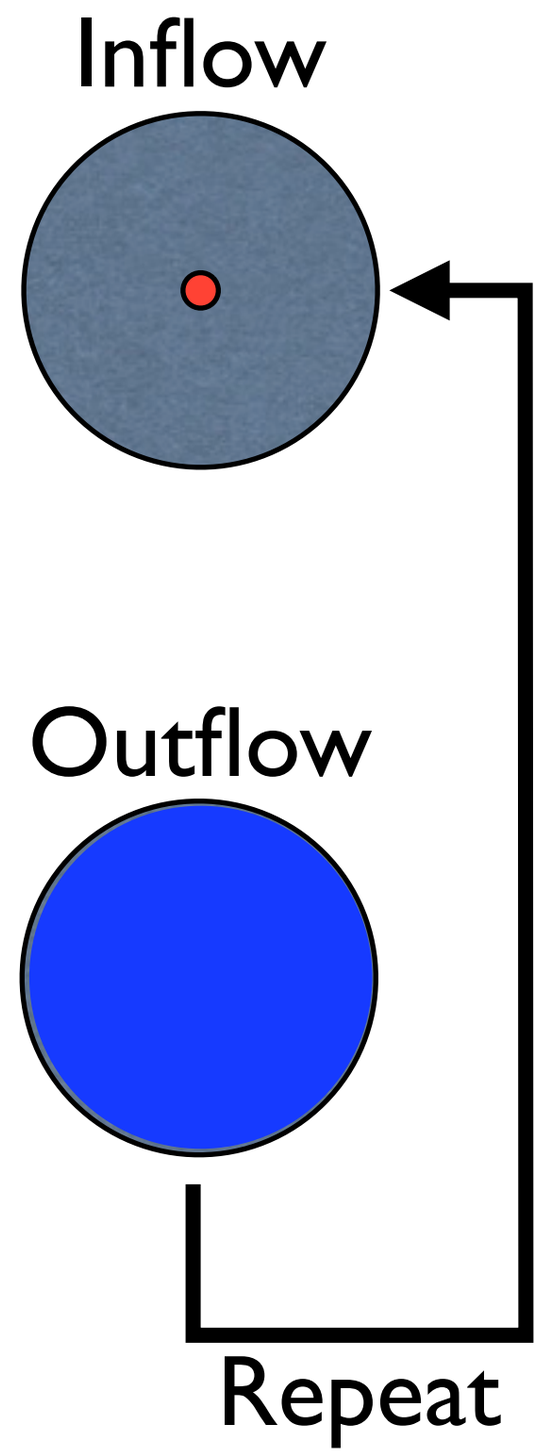

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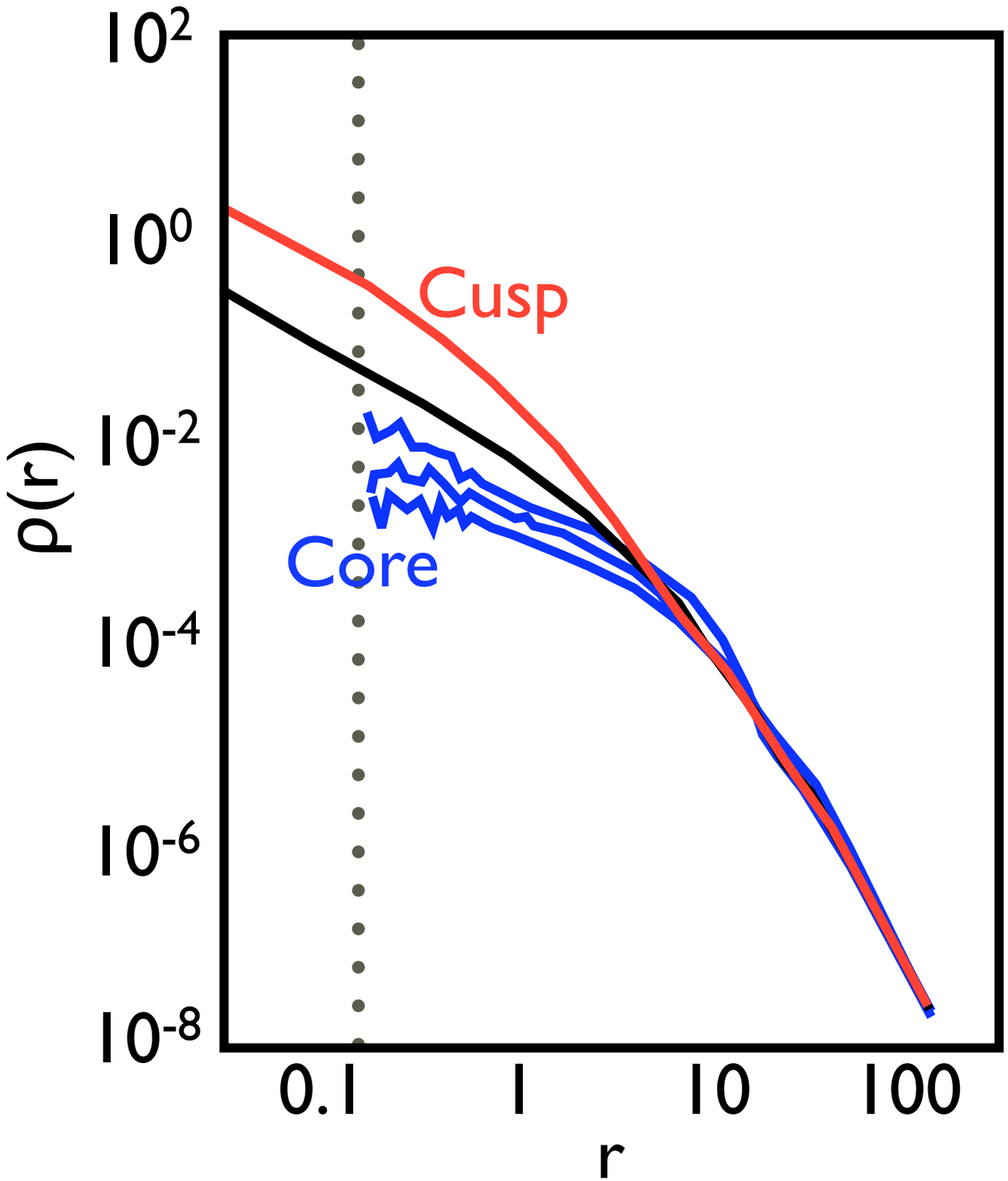

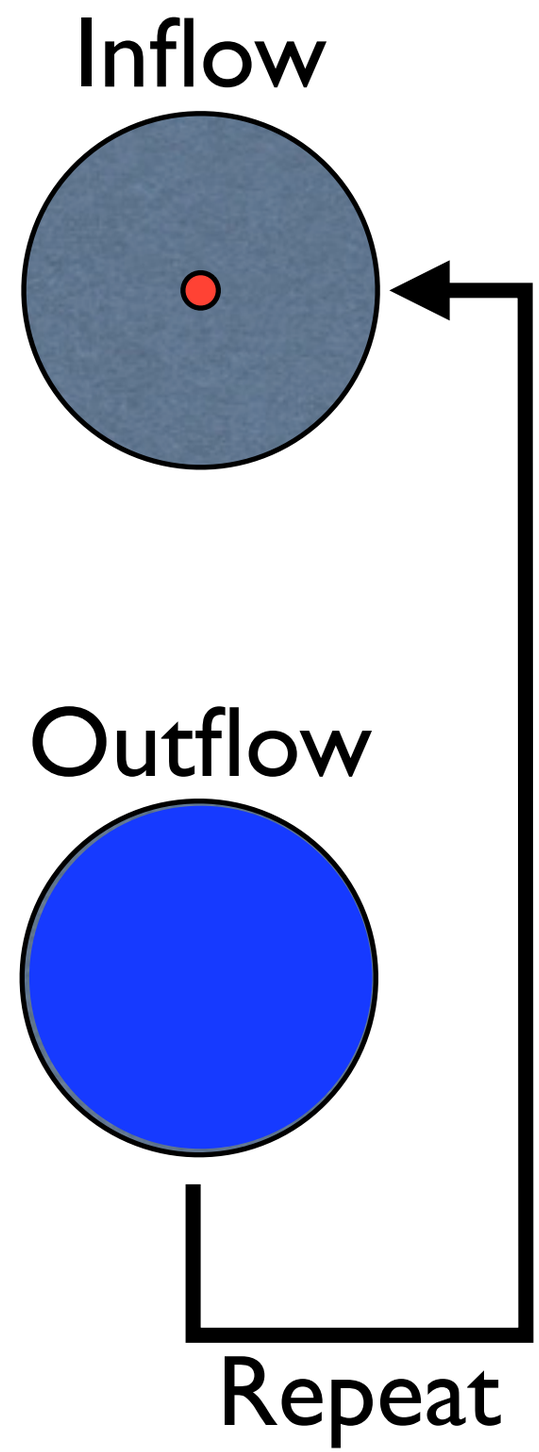

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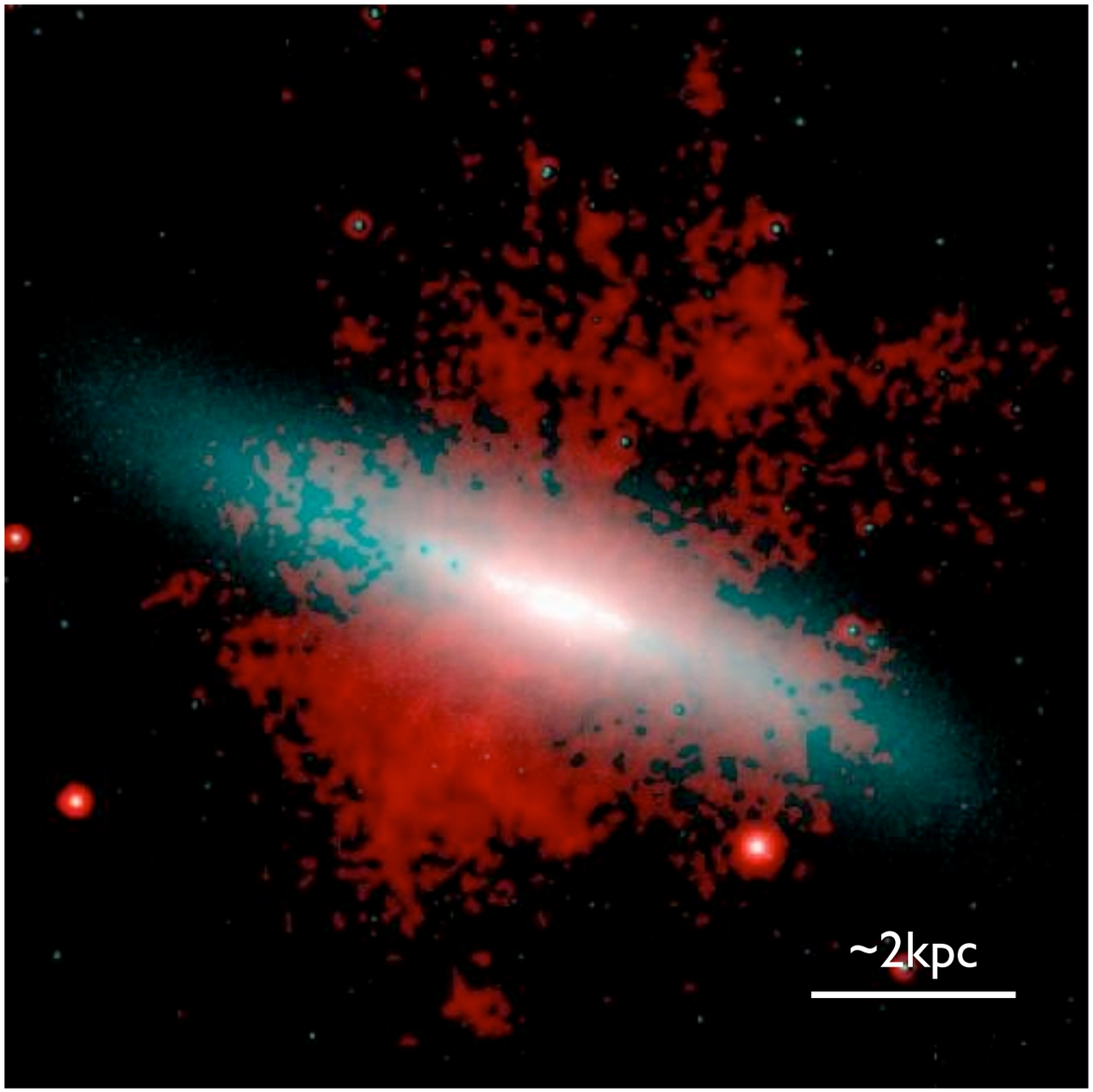
Resolving Feedback

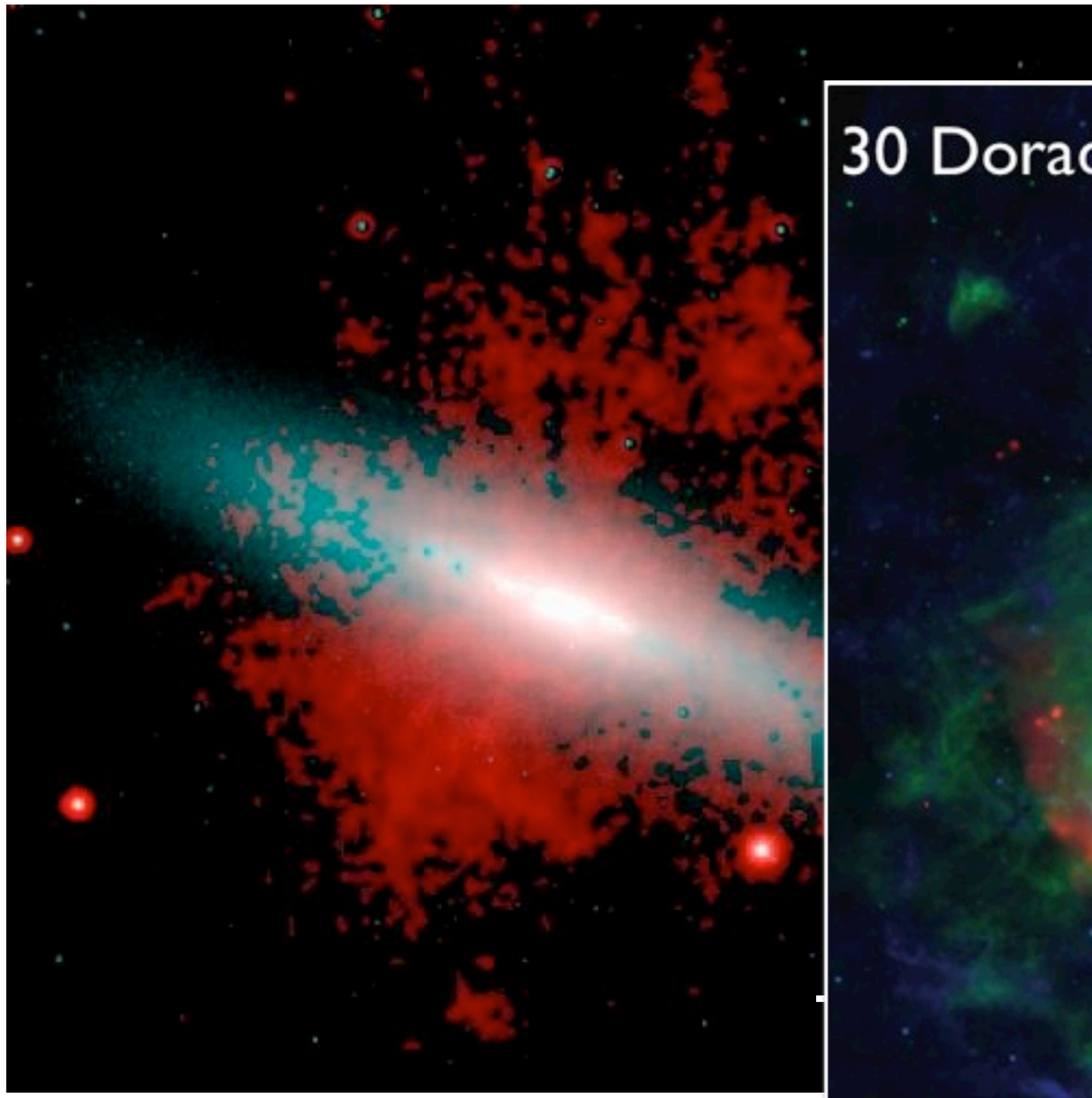
[In which we discuss ‘Ab Initio’ modelling of dwarf galaxies]

Predictive simulations of dwarfs | Resolving feedback



Warm H2 in the M82 Galactic wind | Veilleux et al. 2009

Predictive simulations of dwarfs | Resolving feedback



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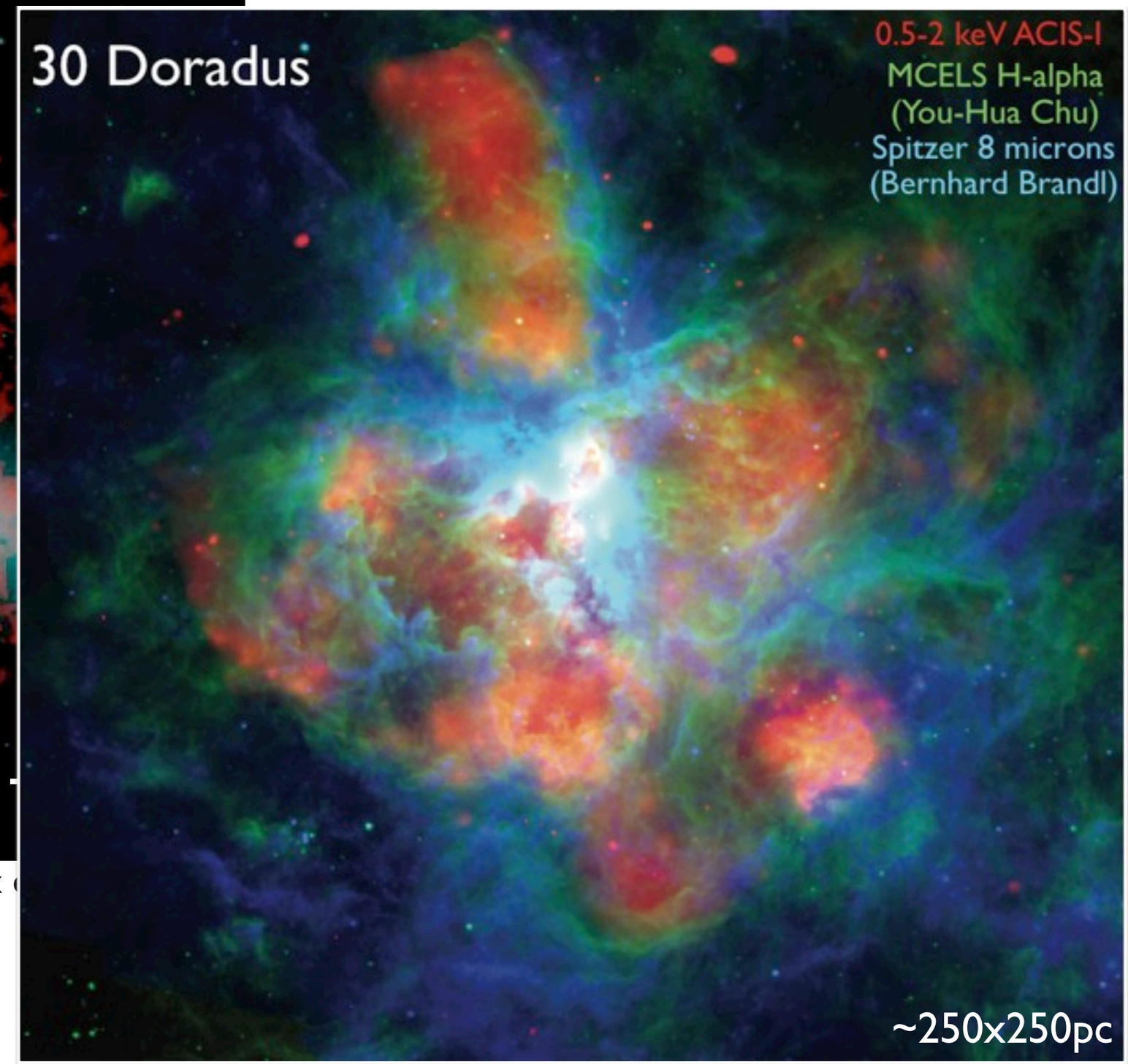
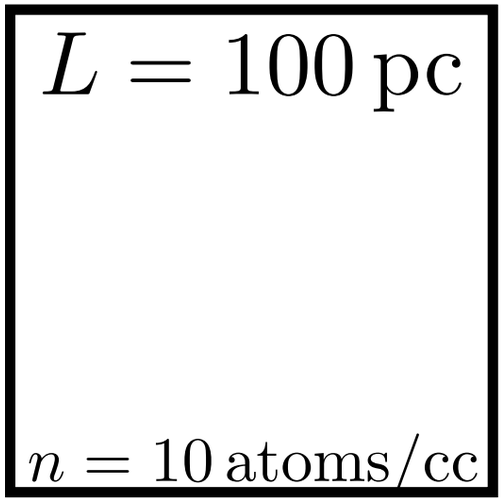


Image composite credit: Leisa Townsley

Predictive simulations of dwarfs | Resolving feedback

$E_c = 10^{51}\,\mathrm{ergs}$



$\Rightarrow T_c = 1.7 \times 10^4\,\mathrm{K}$

$$T_c = \frac{2}{3k_b}\frac{E_c}{nL^3}$$

Agertz et al. 2013; Dalla Vecchia & Schaye 2008

Predictive simulations of dwarfs | Resolving feedback

$E_c = 10^{51}\,\mathrm{ergs}$

$L = 100\,\mathrm{pc}$

$n = 10\,\mathrm{atoms/cc}$

$\Rightarrow T_c = 1.7 \times 10^4\,\mathrm{K}$

$L = 10\,\mathrm{pc}$

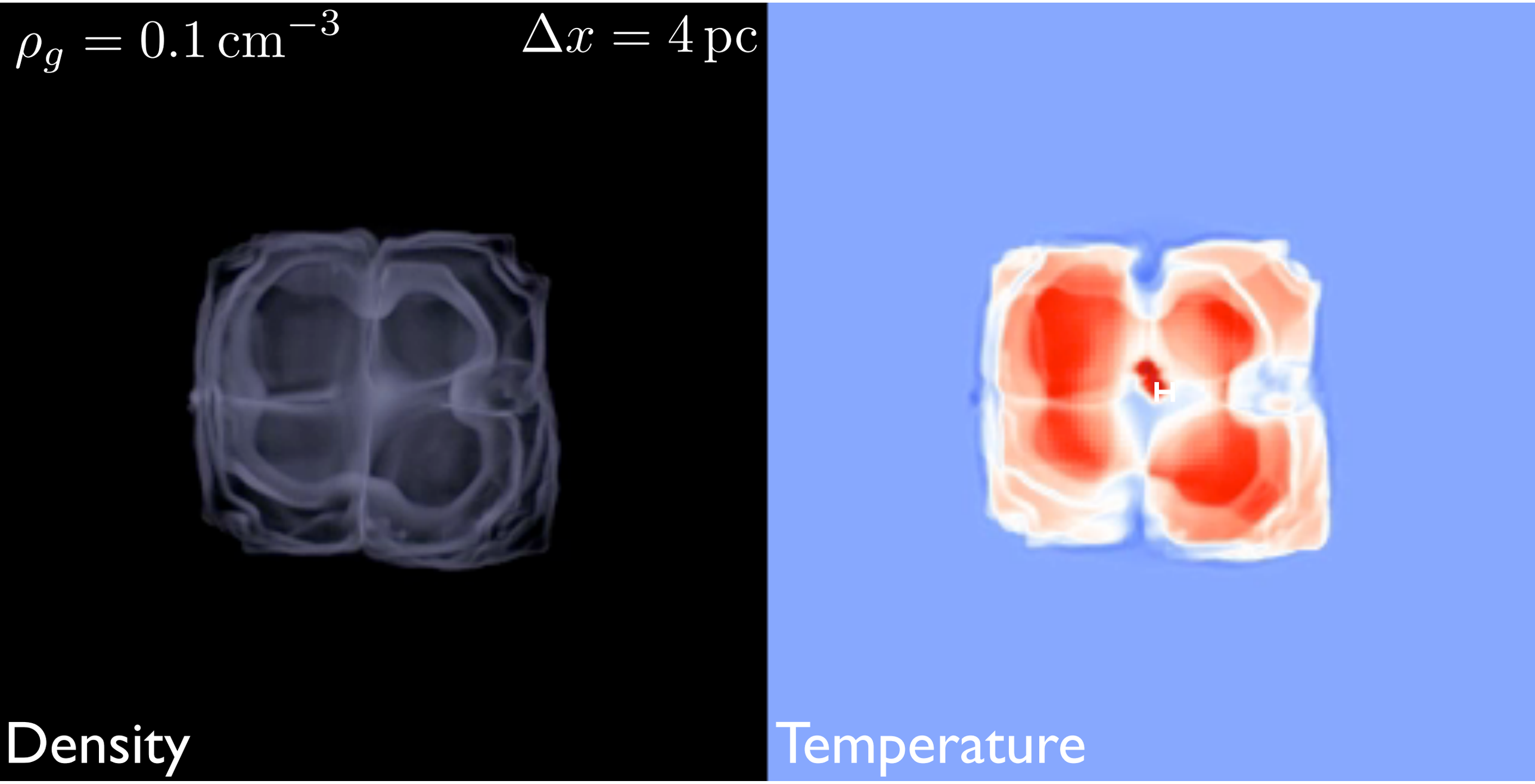
$n = 100\,\mathrm{atoms/cc}$

$\Rightarrow T_c = 1.7 \times 10^6\,\mathrm{K}$

$$T_c = \frac{2}{3k_b}\frac{E_c}{nL^3}$$

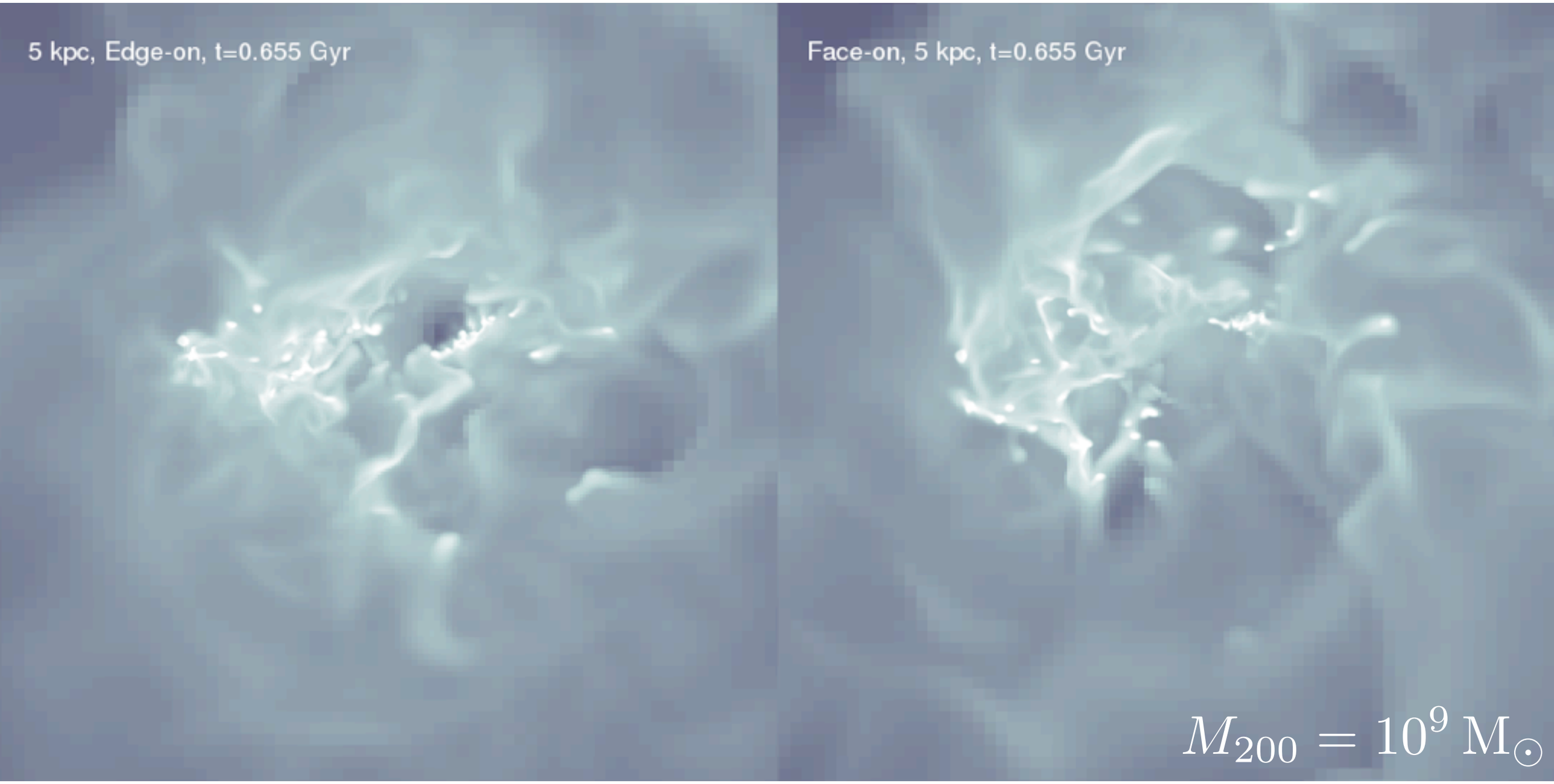
Agertz et al. 2013; Dalla Vecchia & Schaye 2008

Predictive simulations of dwarfs | Resolving feedback



Read et al. 2015, submitted

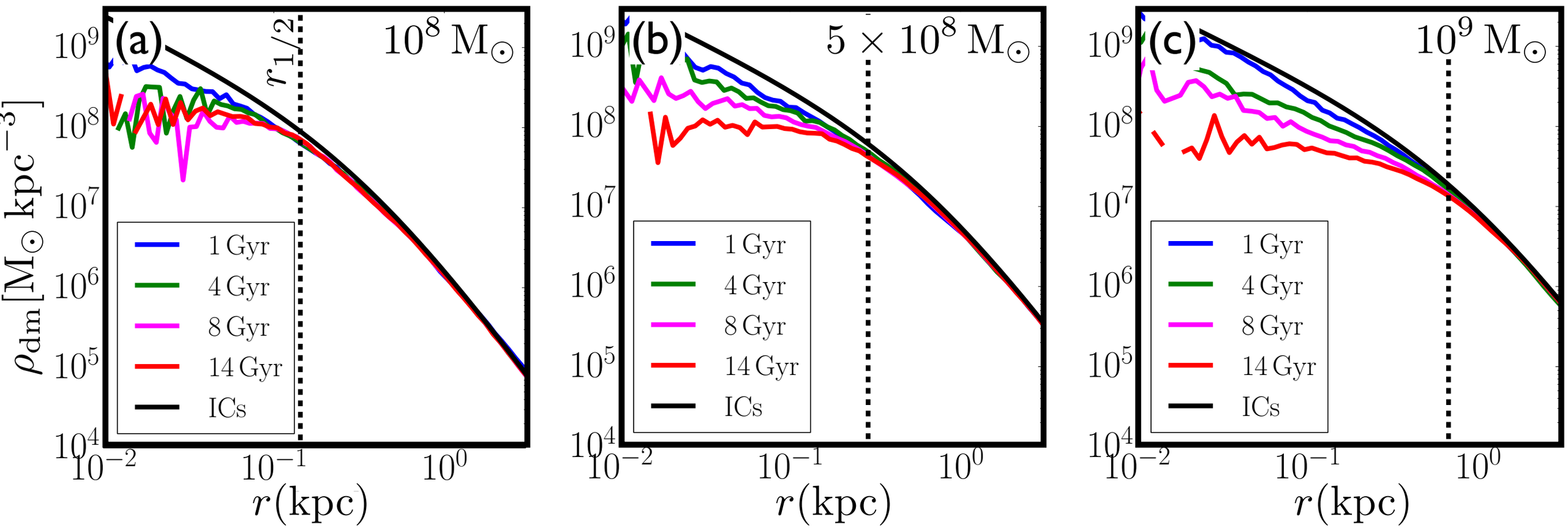
Predictive simulations of dwarfs | Resolving feedback



$\Delta x = 4\,\mathrm{pc}$ | $M_* \sim 300\,\mathrm{M}_\odot$ | $M_{dm} = 250\,\mathrm{M}_\odot$ | $n_{\mathrm{th}} = 300\,\mathrm{atoms\,cm^{-3}}$

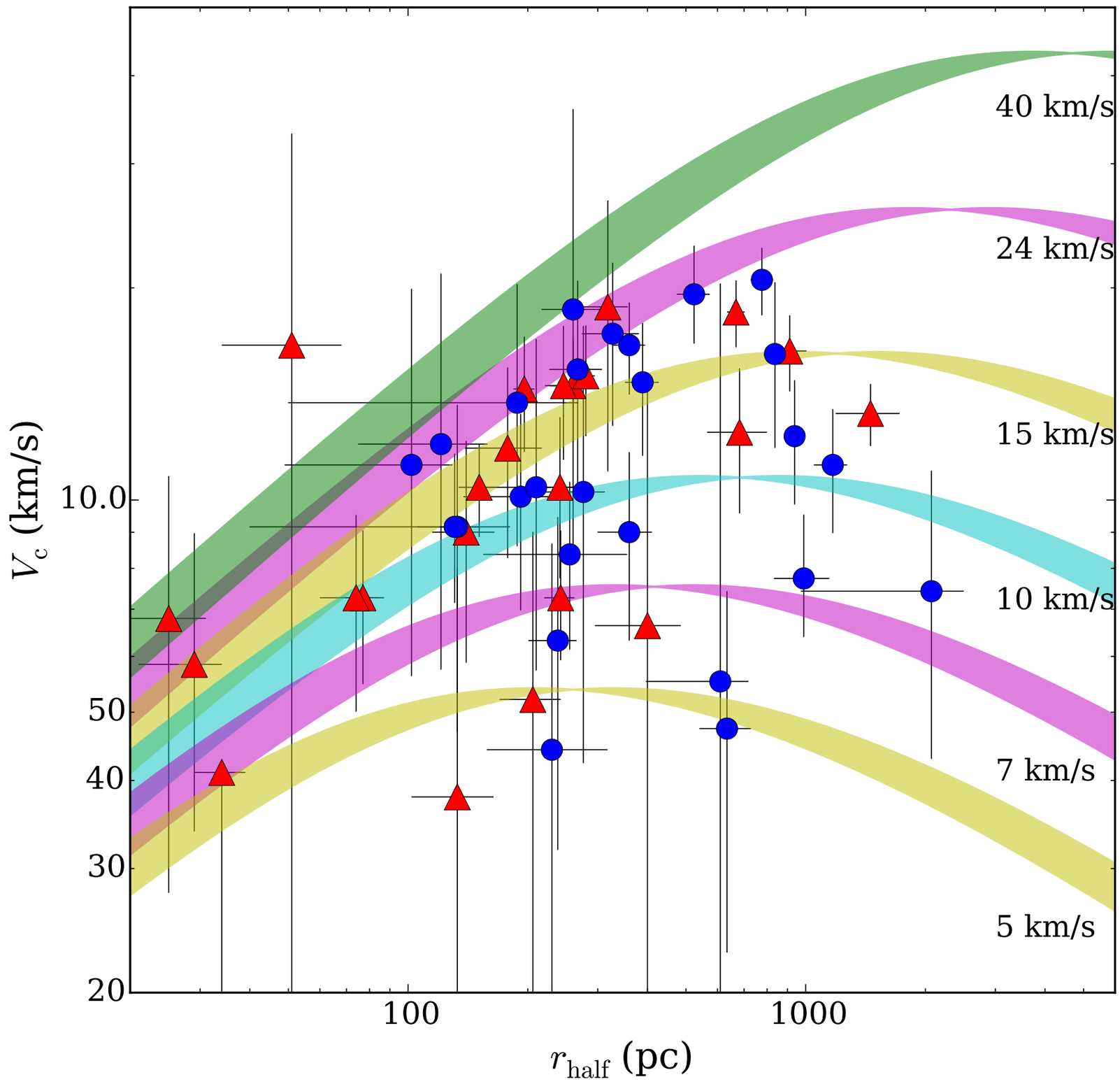
Read et al. 2015, submitted

Predictive simulations of dwarfs | Resolving feedback



Read et al. 2015, submitted; and see Navarro et al. 1996; Read & Gilmore 2005; Pontzen & Governato 2012

Cusp-core transforms | #1 :: galaxy masses



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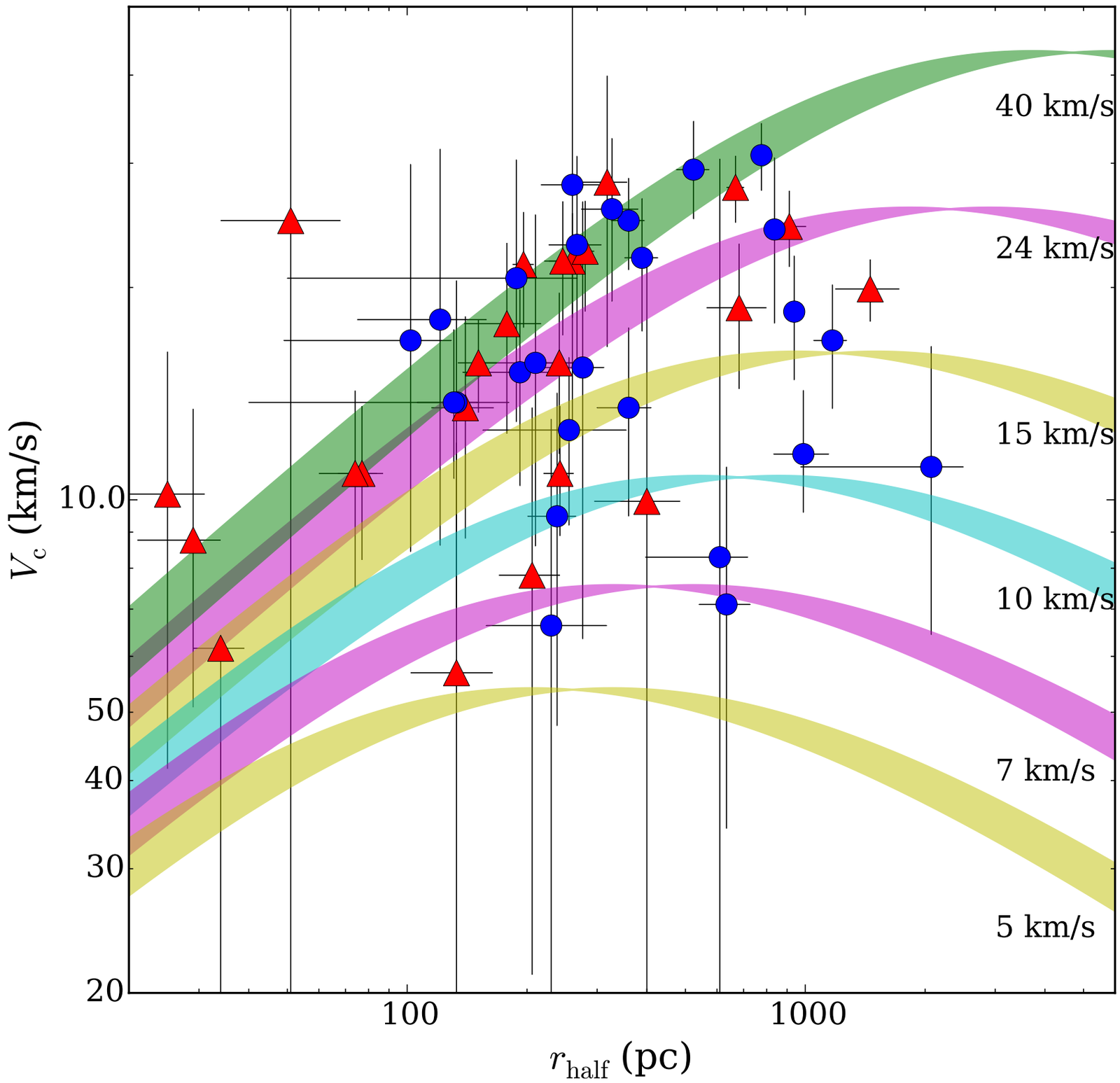
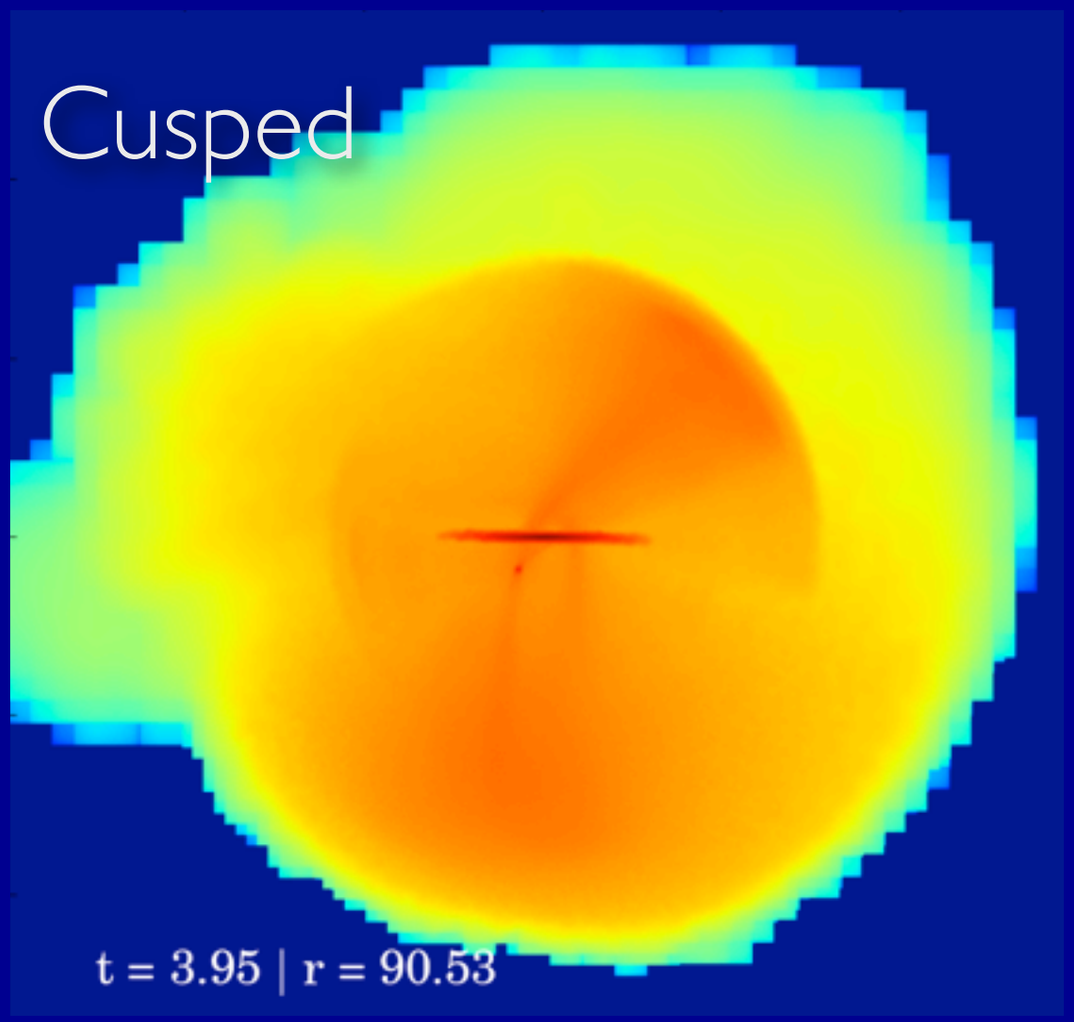
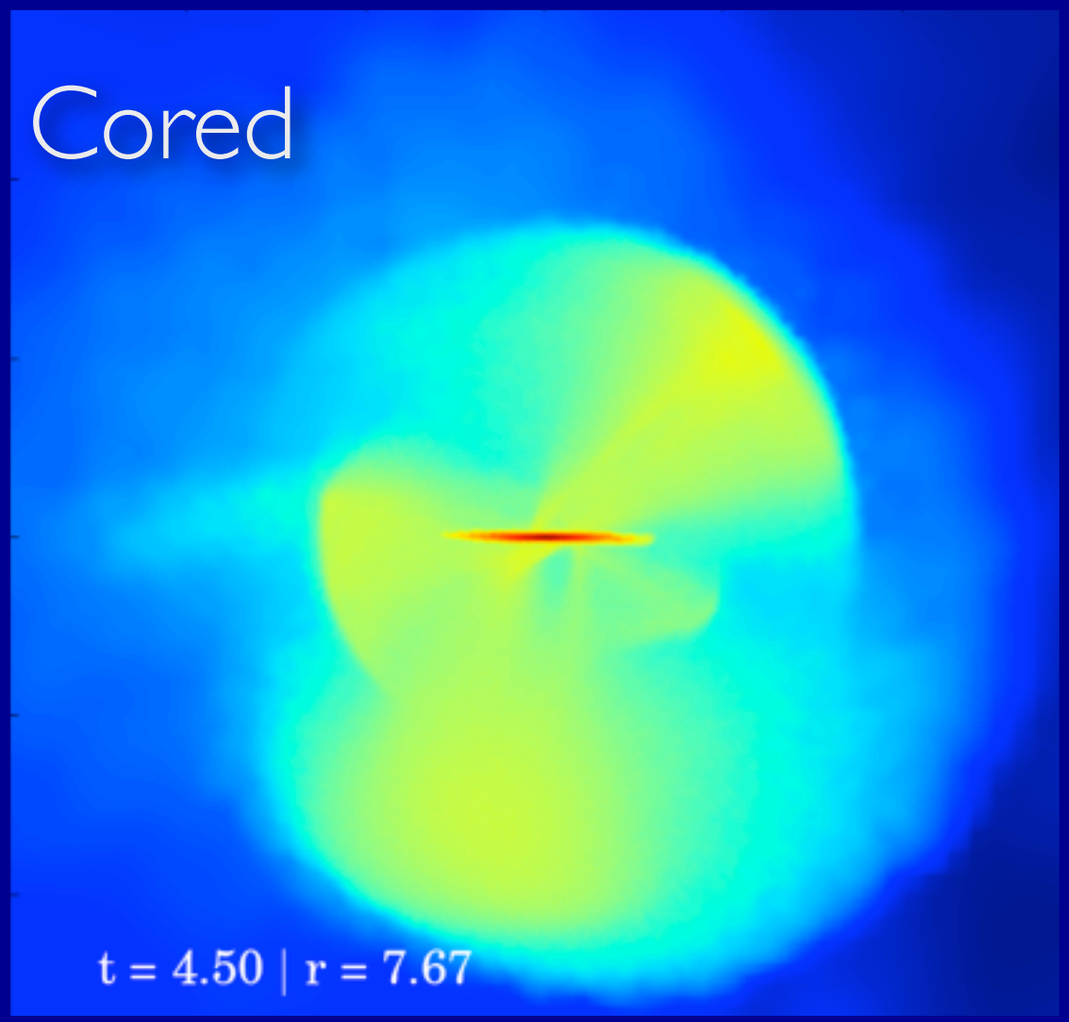


Read et al. 2015, submitted

Cusp-core transforms | #2 :: missing satellites





Read et al. 2015 submitted | and see Read et al. 2006; Peñarrubia et al. 2010; Zolotov, Brooks et al. 2012/13

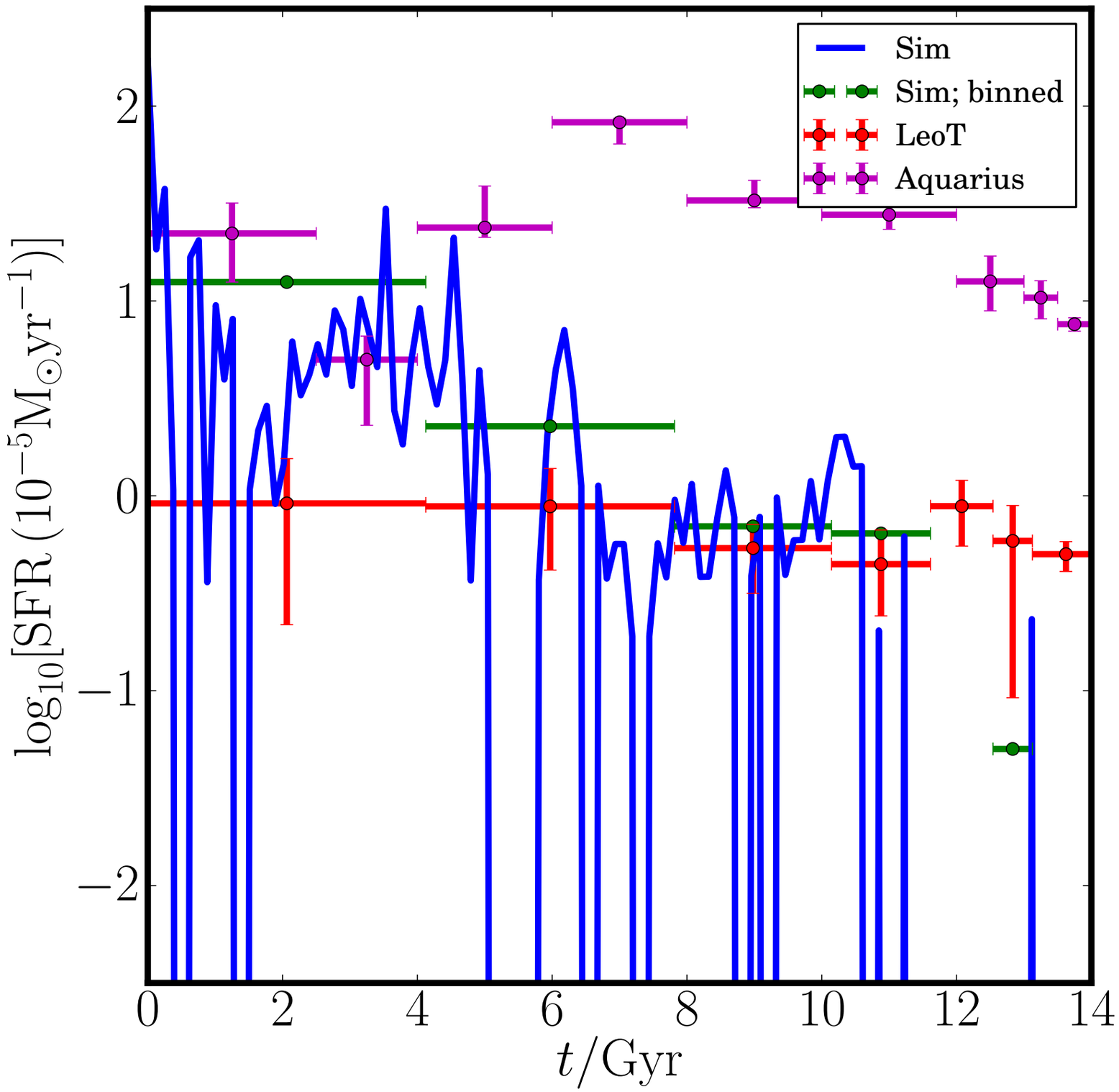
Conclusions

- We are beginning to run **predictive** simulations of dwarf galaxies, including baryons. These **always form *dynamically important* dark matter cores** if star formation proceeds for long enough.

- Such cores:
  - Cause **rotation curves to rise much more slowly** [cusp/core problem]
  - Lower stellar dispersions ➠ **underestimate masses** [‘too big to fail’]
  - Make galaxies susceptible to tides ➠ **destroy satellites** [missing satellites]

- If LCDM is right, **dark matter cusps will be found:**
  - In galaxies with truncated star formation; and/or
  - At radii beyond the half light radius

Predictive simulations of dwarfs | Resolving feedback



Read et al. 2015, submitted

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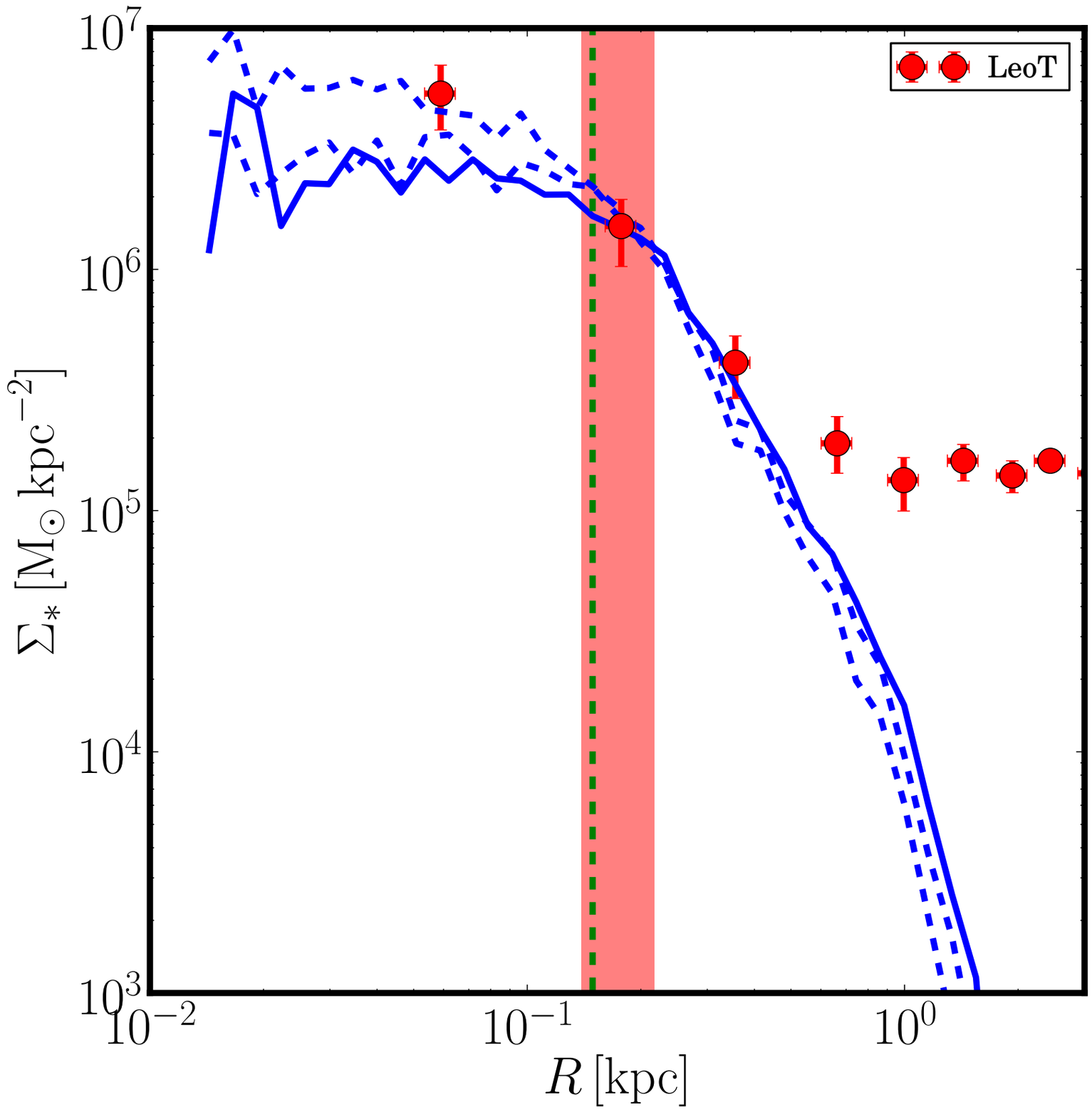

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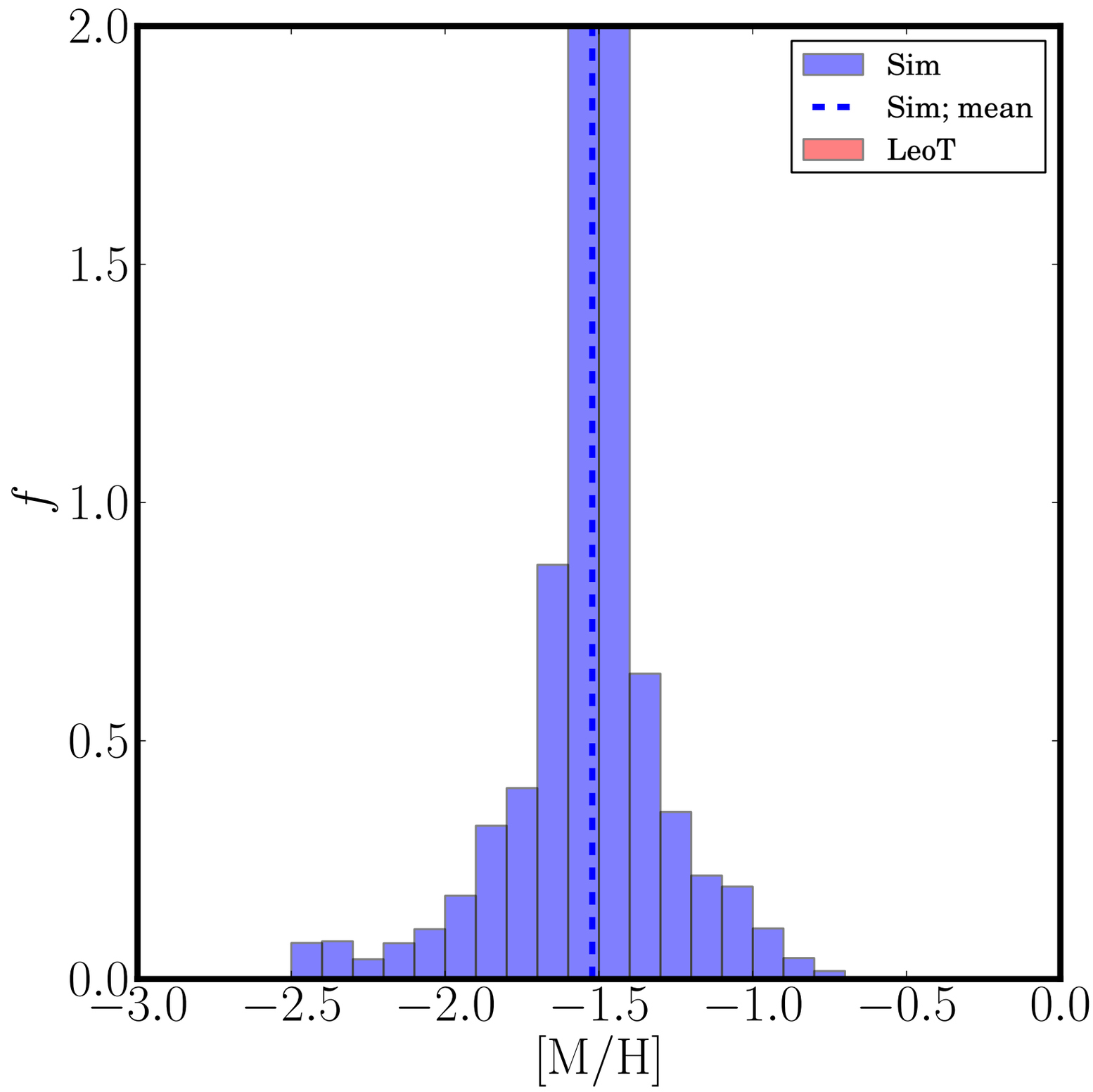

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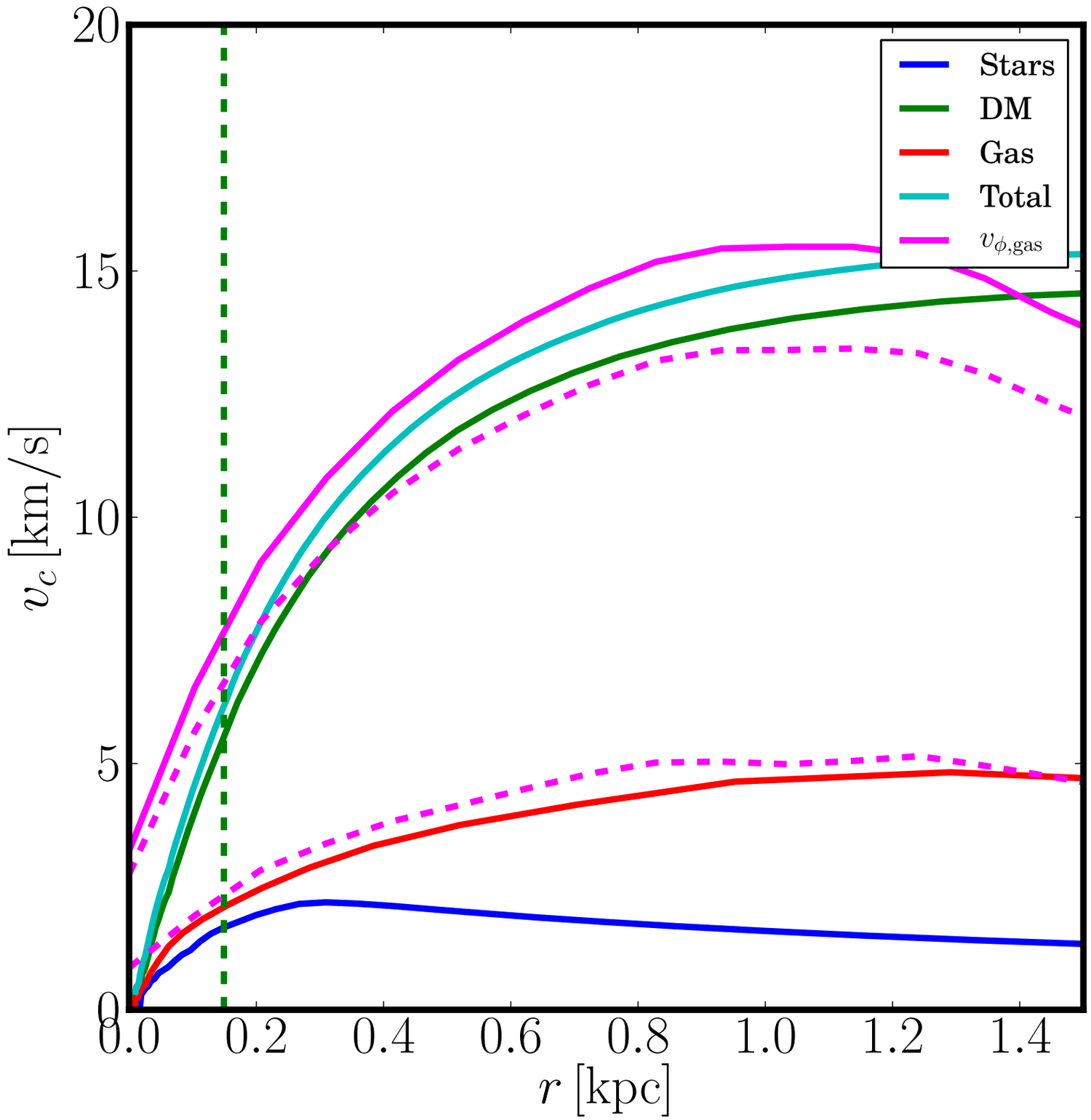

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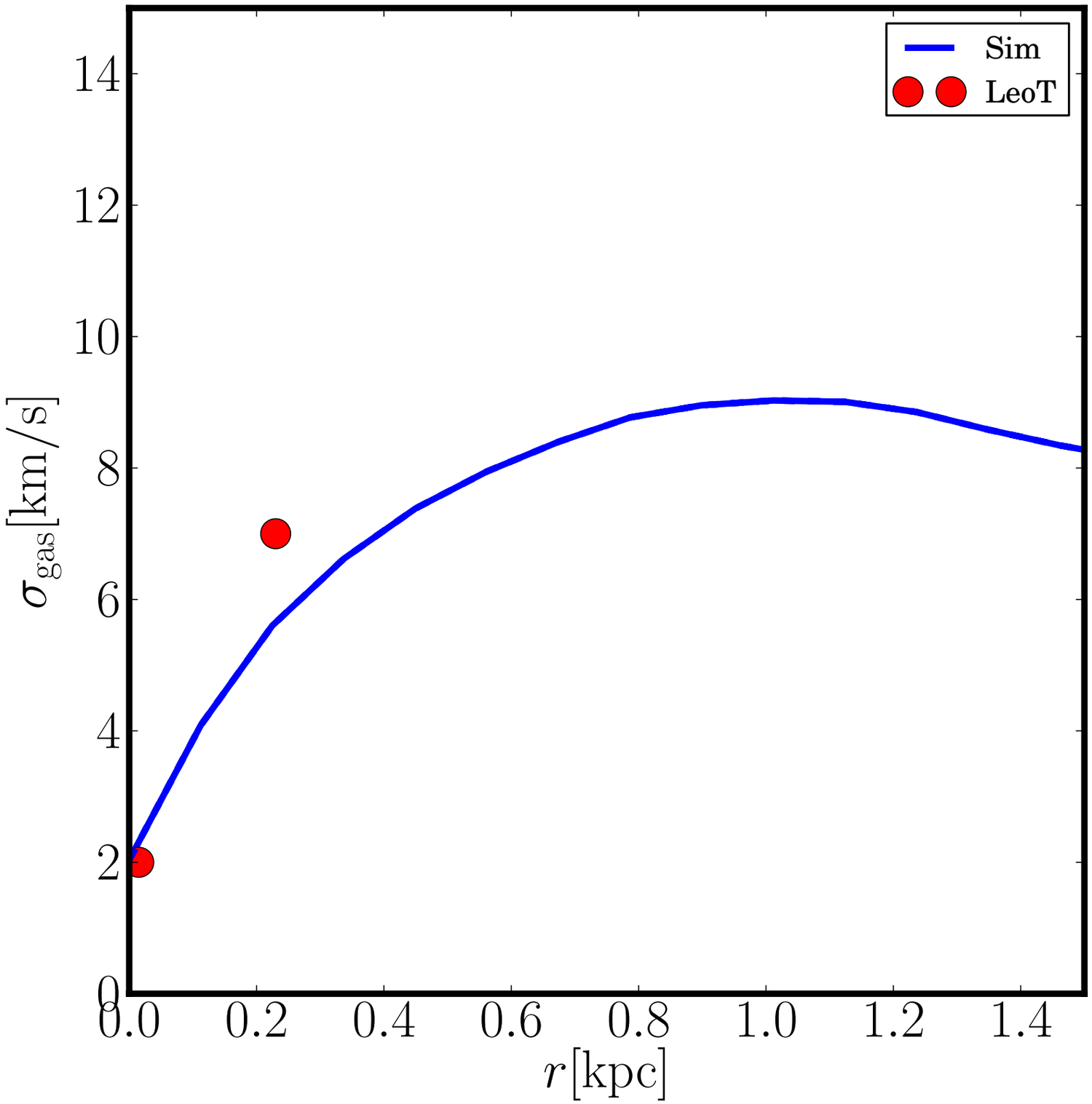

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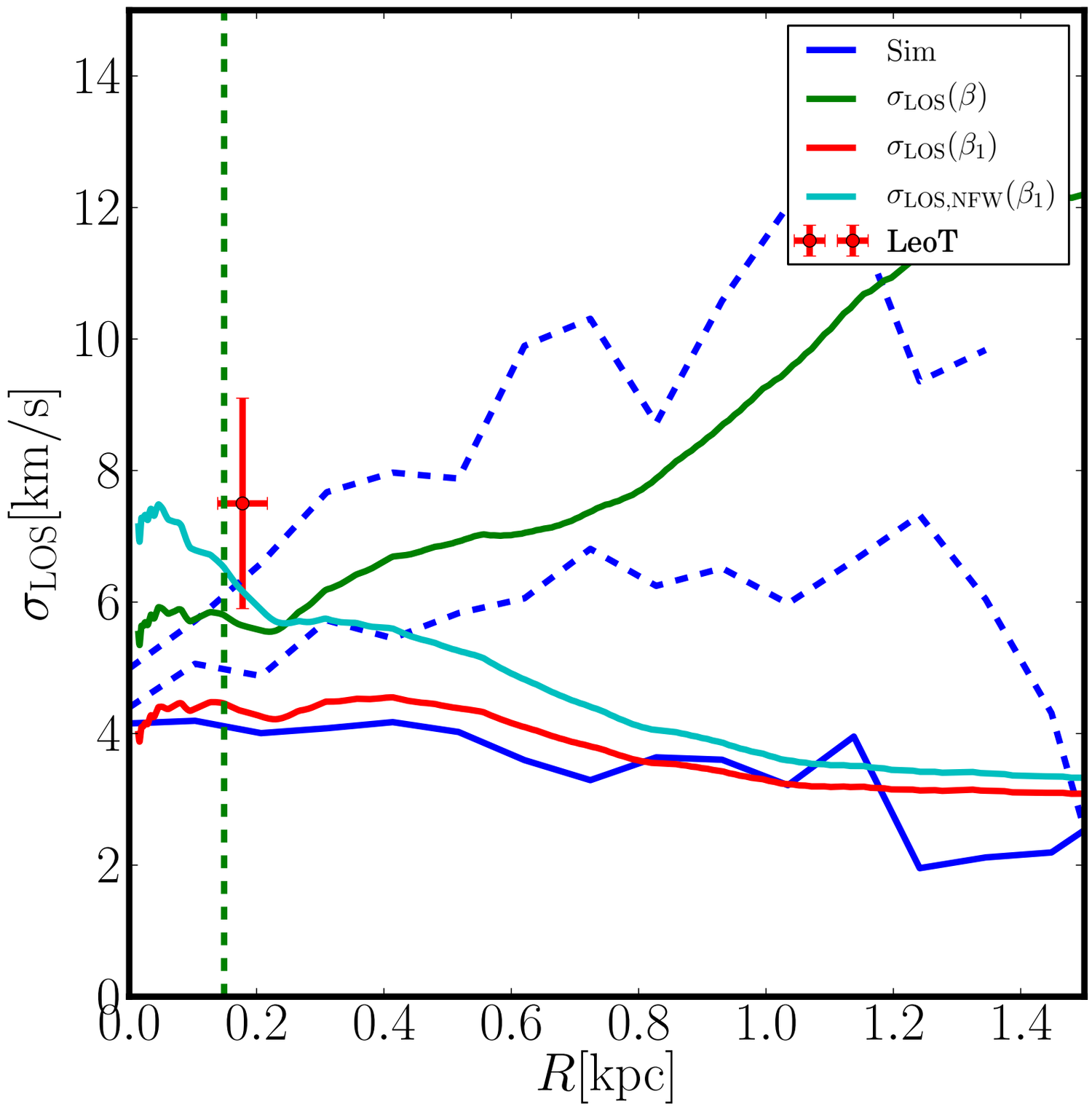

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