Facets of Cosmic Accretion

Dark Matter
Baryons
Satellite Galaxies in the Local Group

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Part I

The Physical Nature of Cosmic Accretion of Baryons & Dark Matter into Halos and their Galaxies

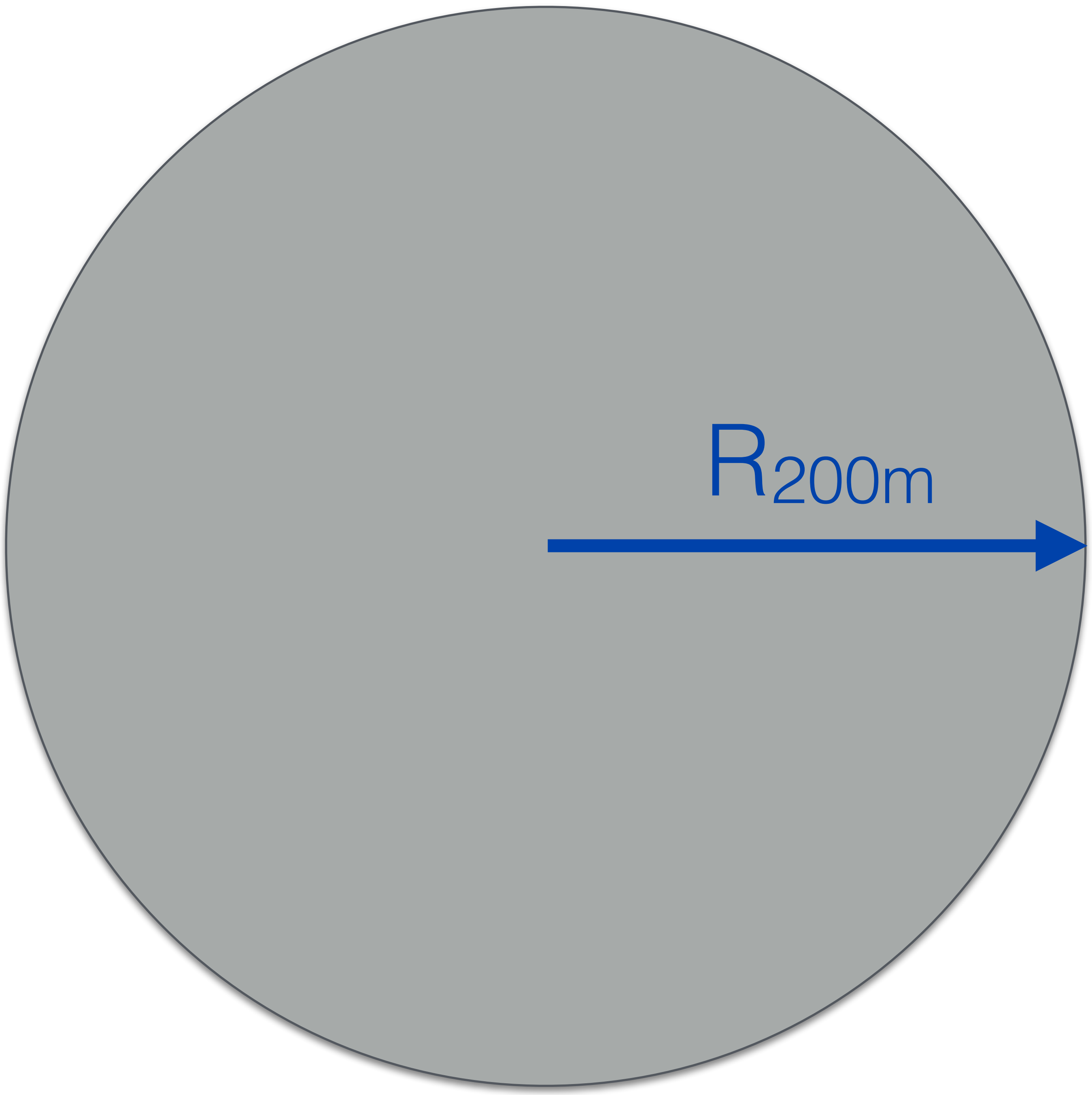
with Daisuke Nagai (Yale University)

Wetzel & Nagai 2014 arXiv:1412:0662

Outline

1. Background on Halo Formation & Cosmic Accretion
2. Physical Cosmic Accretion of Dark Matter
3. Physical Cosmic Accretion of Baryons
4. Physical Meaning of the Virial Radius

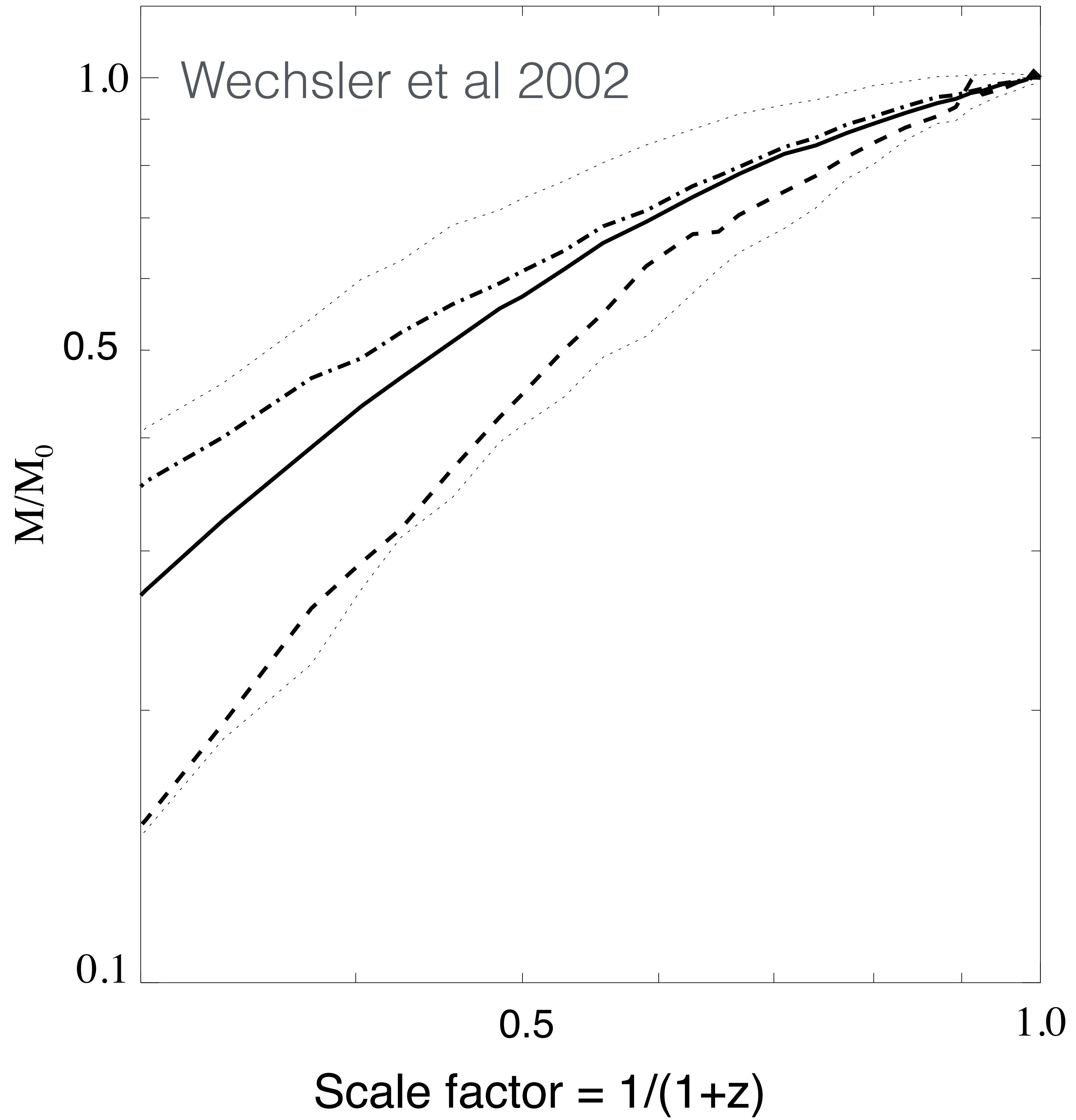
Halo



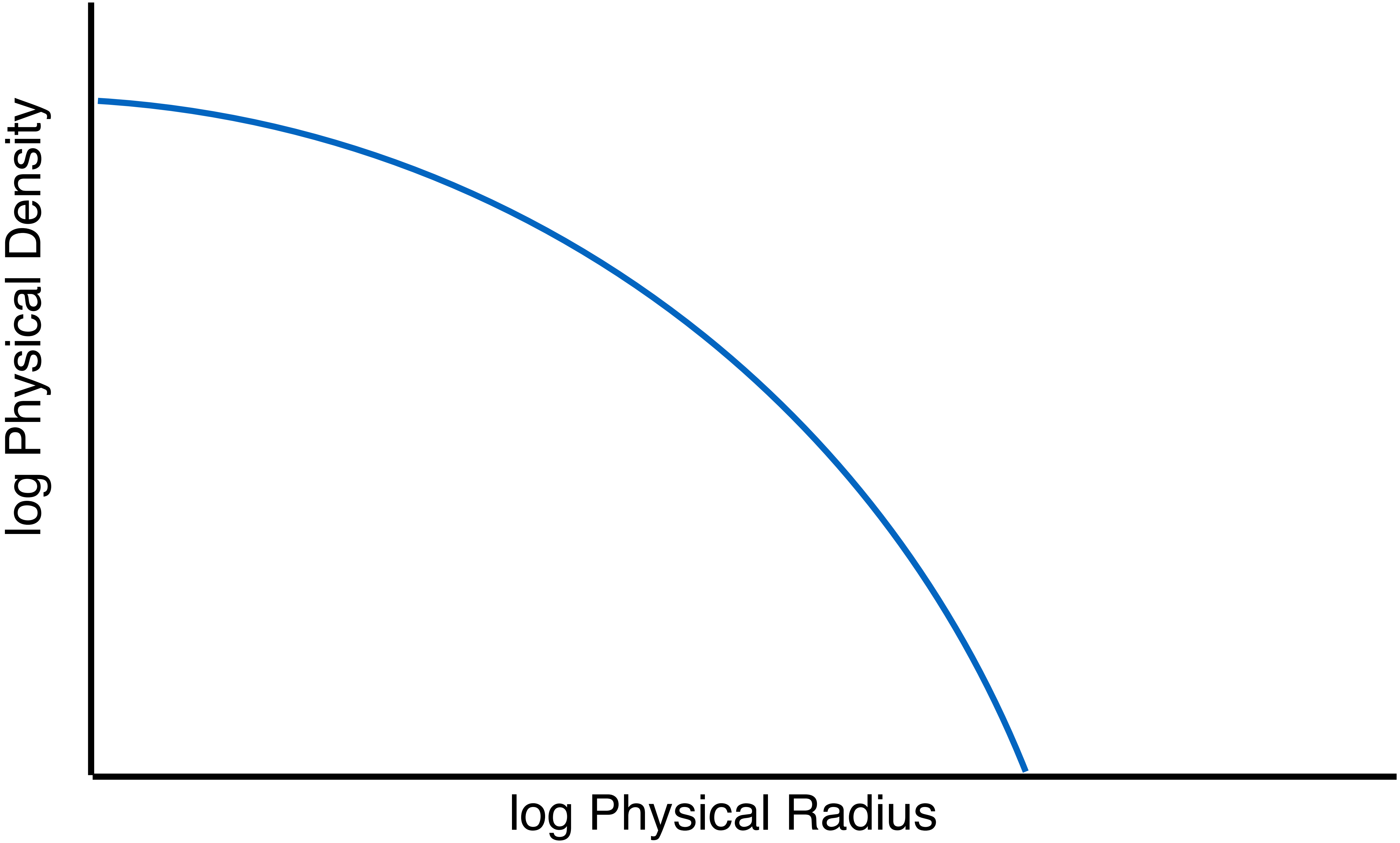
"Virial Radius" = R_{200m} = within which the average density is 200x cosmic matter density

"Virial Mass" = M_{200m} = mass within R_{200m}

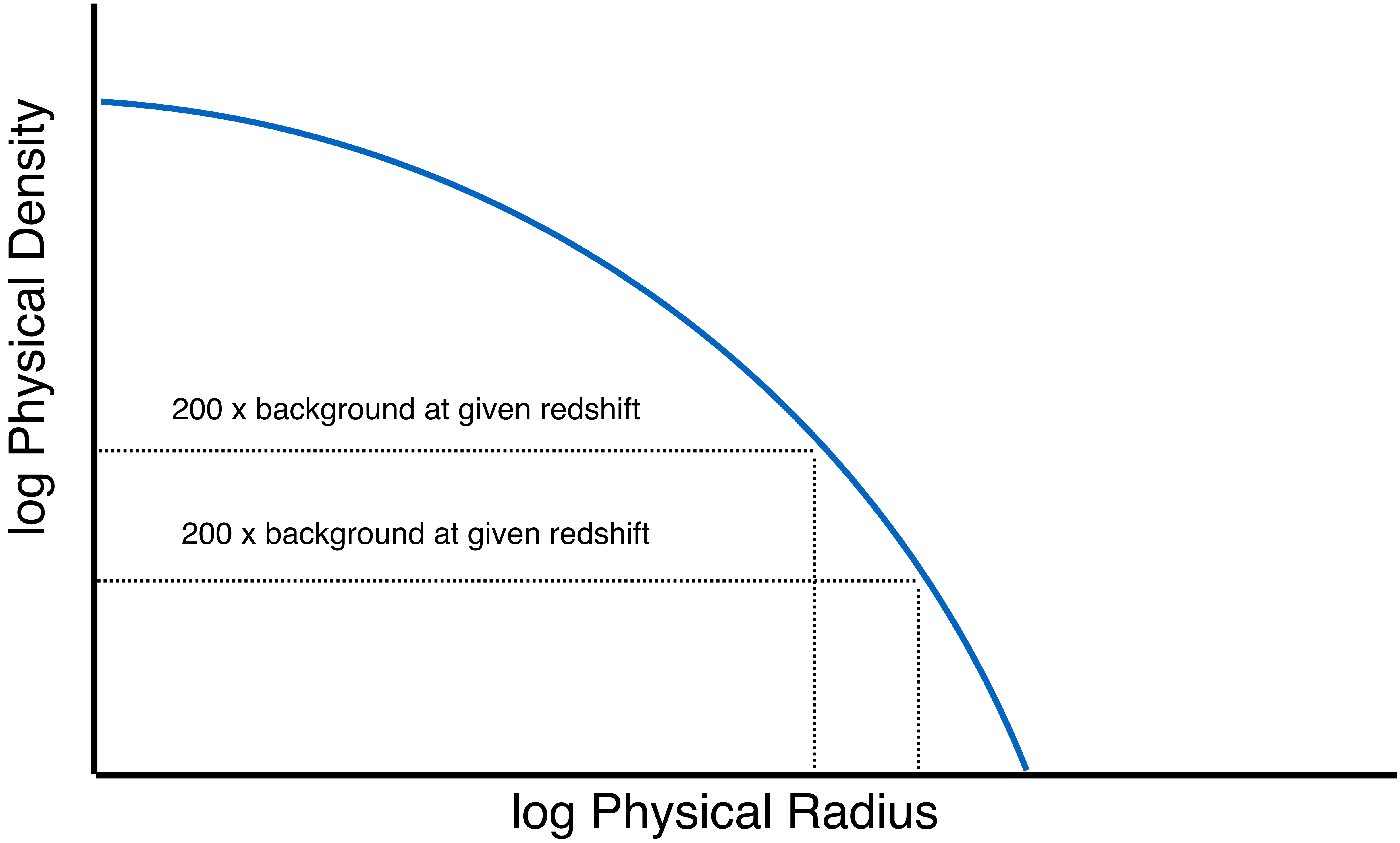
Standard picture of cosmic accretion into halos



Physical nature of cosmic accretion into galactic halos

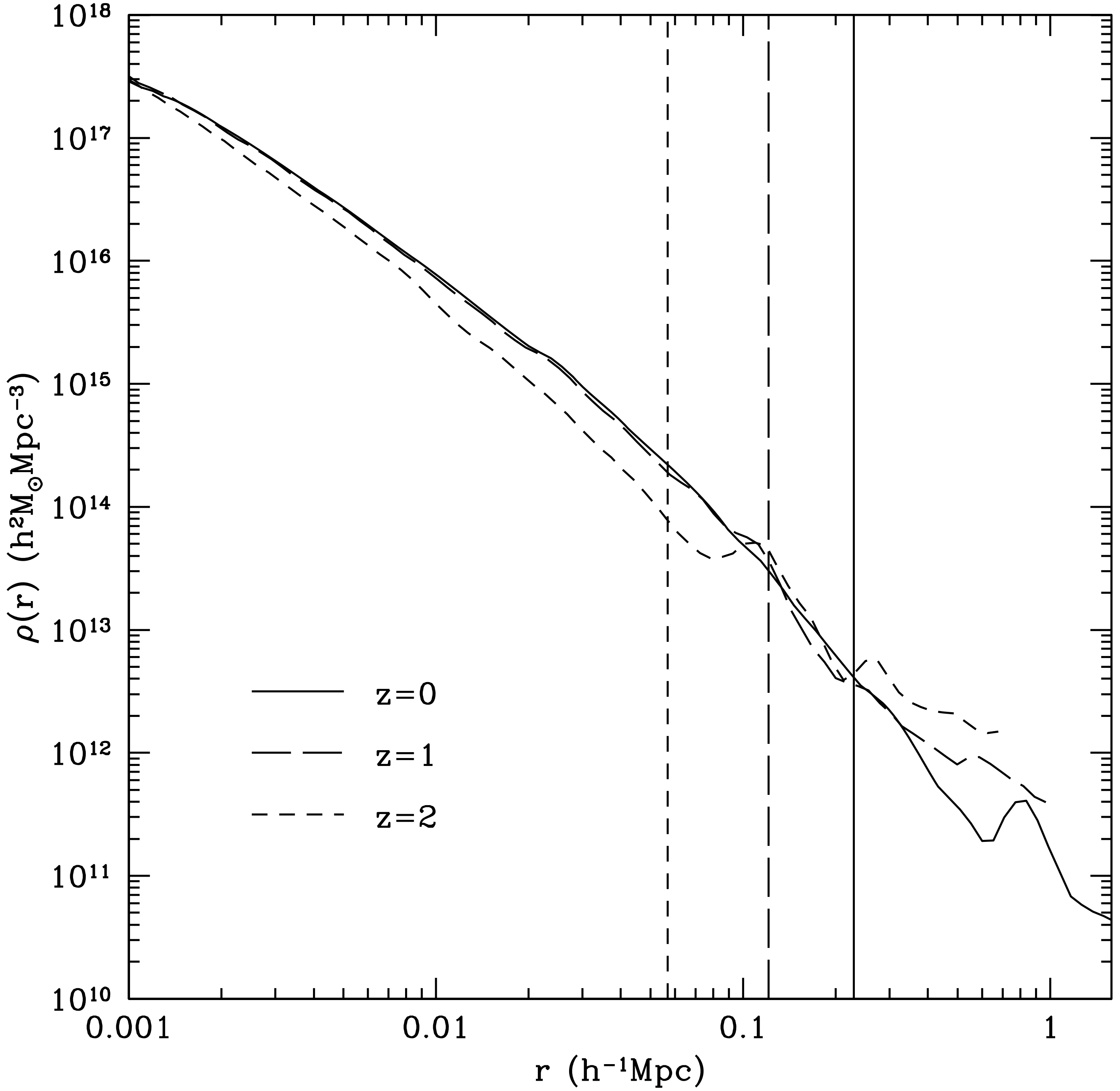


Physical nature of cosmic accretion into galactic halos



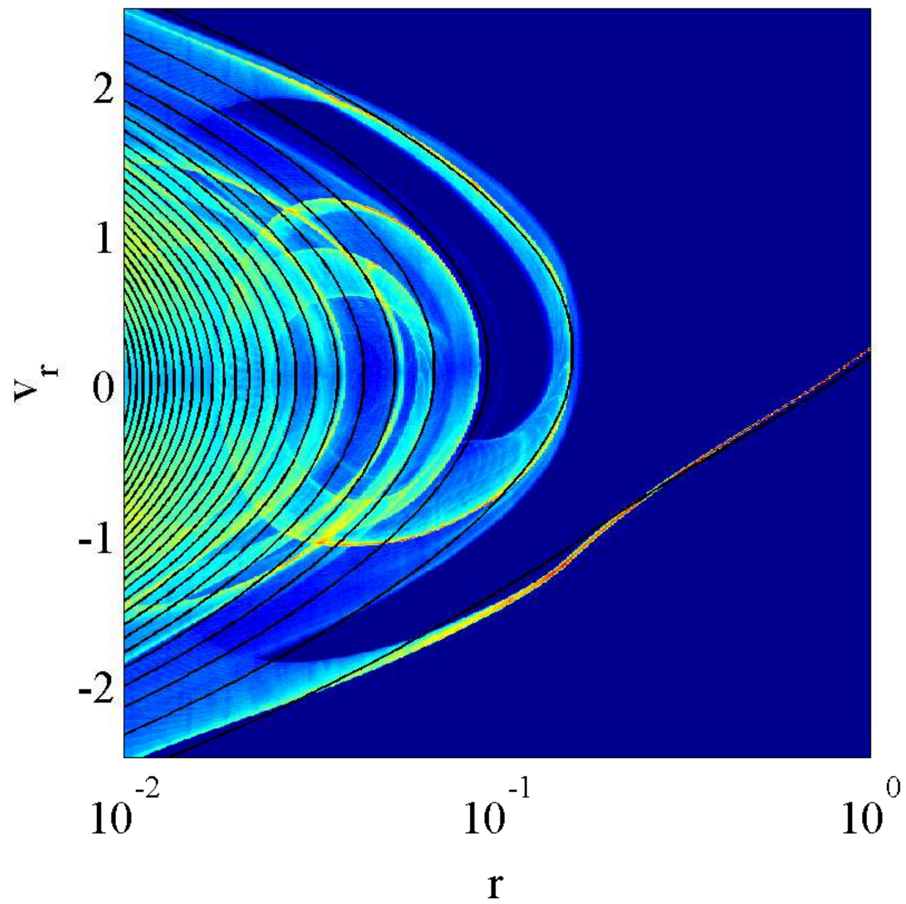
Evolution of dark matter in Milky-Way-mass halos

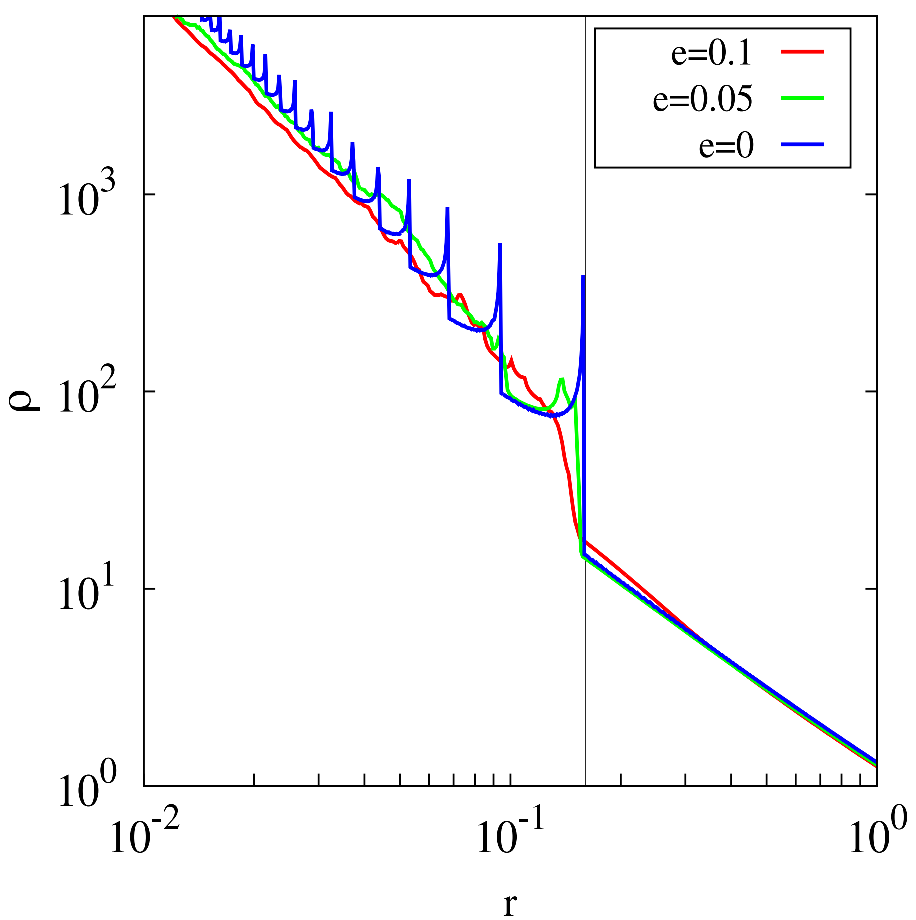
Cuesta et al 2008



Mass evolution: physical vs definitional

"Pseudo-evolution" Diemer, More & Kravtsov 2013





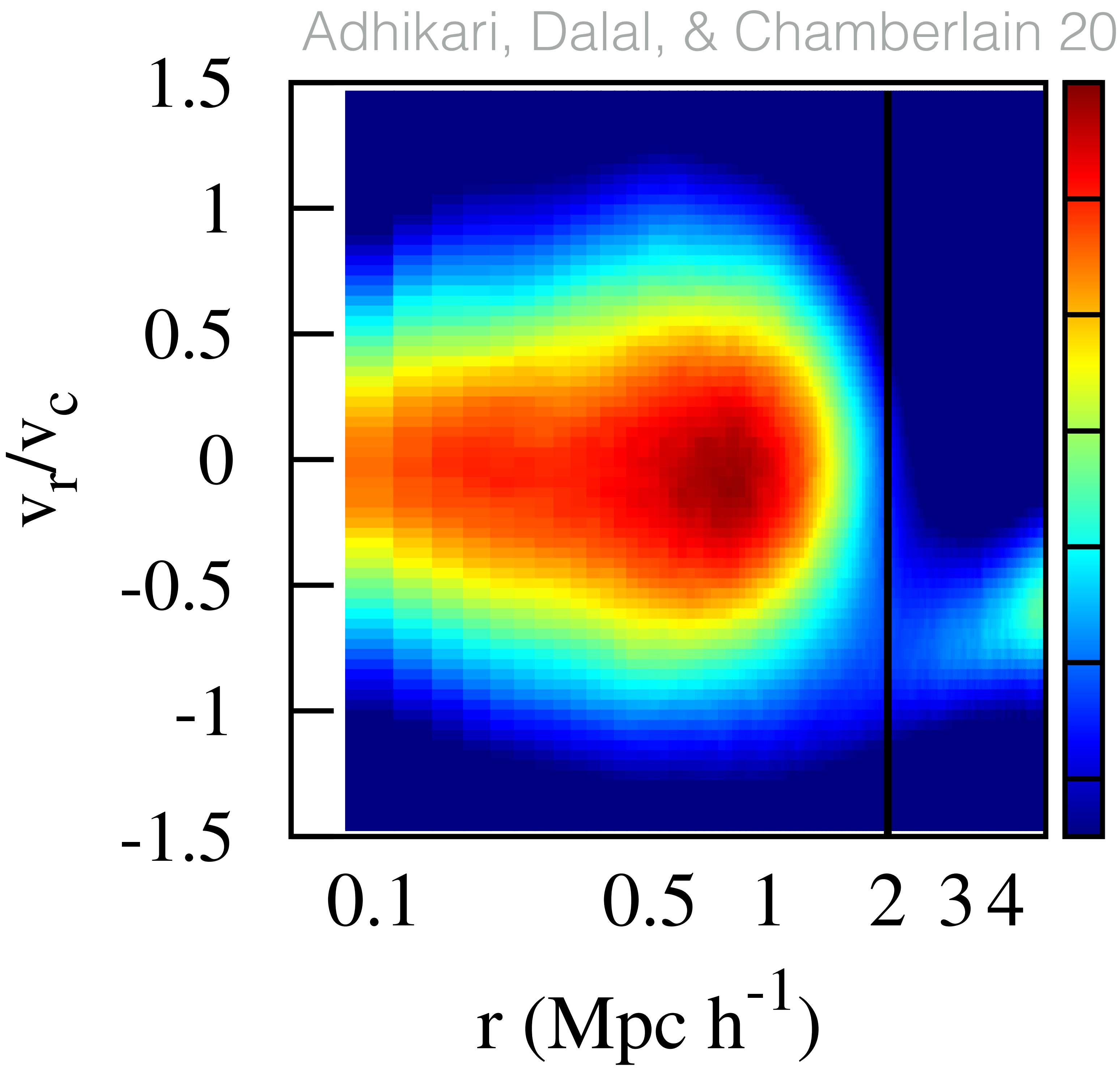
Simple idealized model for virial infall

Adhikari, Dalal & Chamberlain 2014

based on:
Gunn & Gott 1972
Fillmore & Goldreich 1984

$$\frac{\mathrm{d}^2 r}{\mathrm{d}t^2} = -\frac{G\,m(<r)}{r^2} + \frac{8\pi G}{3}\rho_\Lambda r$$

Phase space in cosmological N-body simulation



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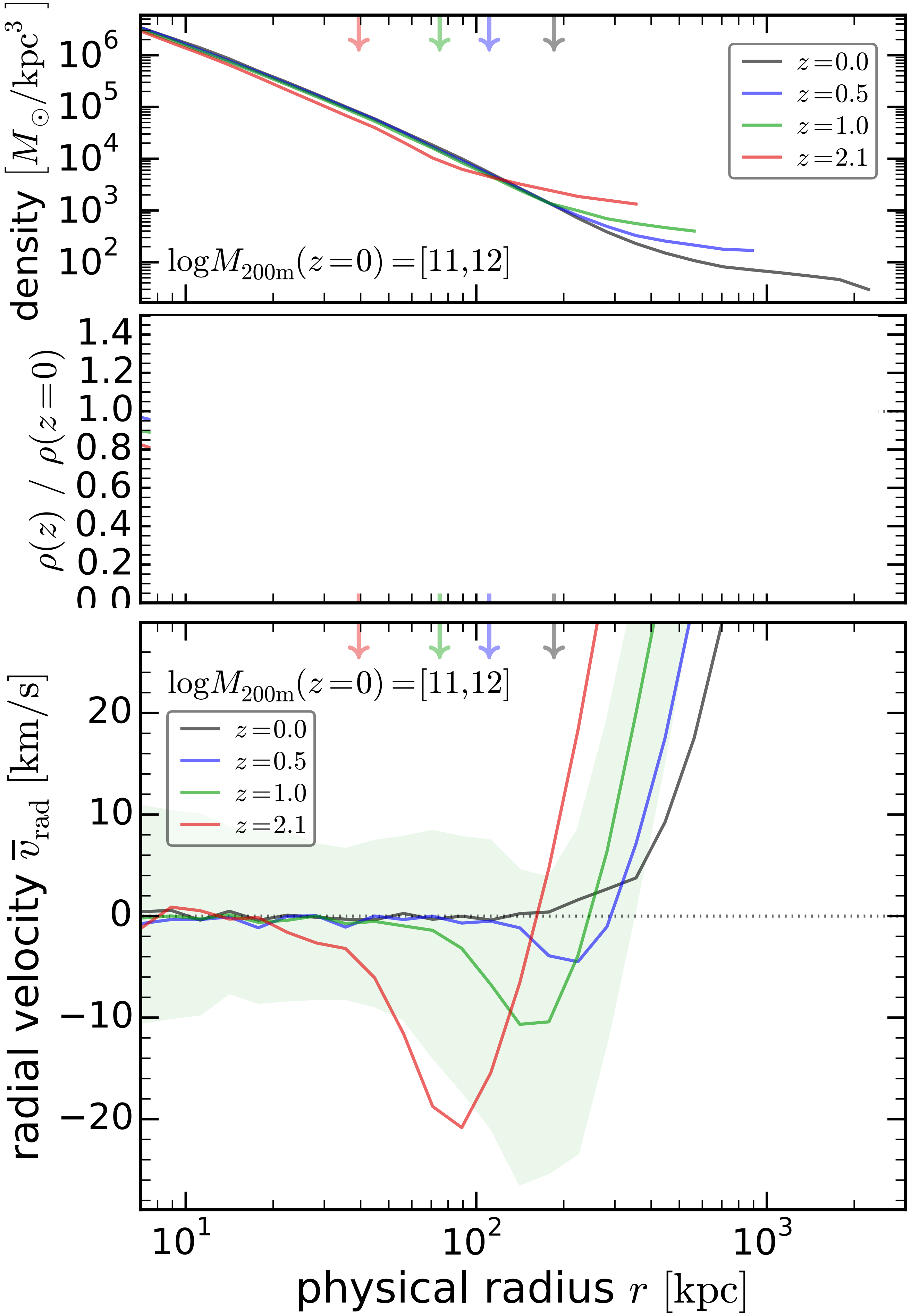
Cosmological hydrodynamic simulations

- ART Adaptive Eulerian Mesh code
- 36 Mpc box
- Particle mass: dark matter ~10^7 M_{sun}, stars ~10^6 M_{sun}
- Spatial resolution = 500 pc
- Suite of varying physics:
  - 1) dark matter only
  - 2) non-radiative gas
  - 3) gas with radiative cooling
  - 4) star formation & feedback:
    supernova II & Ia, stellar mass loss, metal enrichment

Physical Cosmic Accretion of Dark Matter

from simulation with only dark matter



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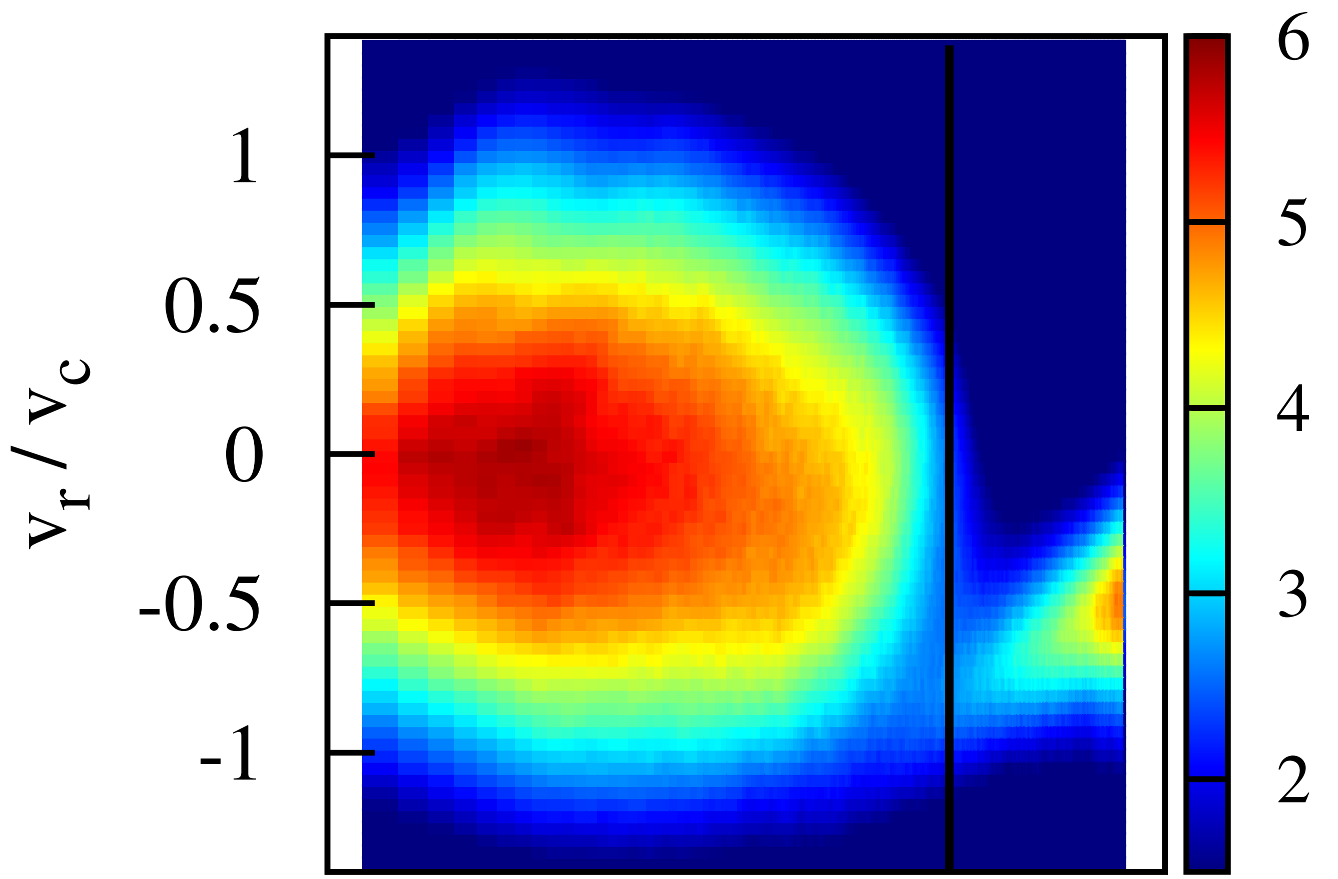

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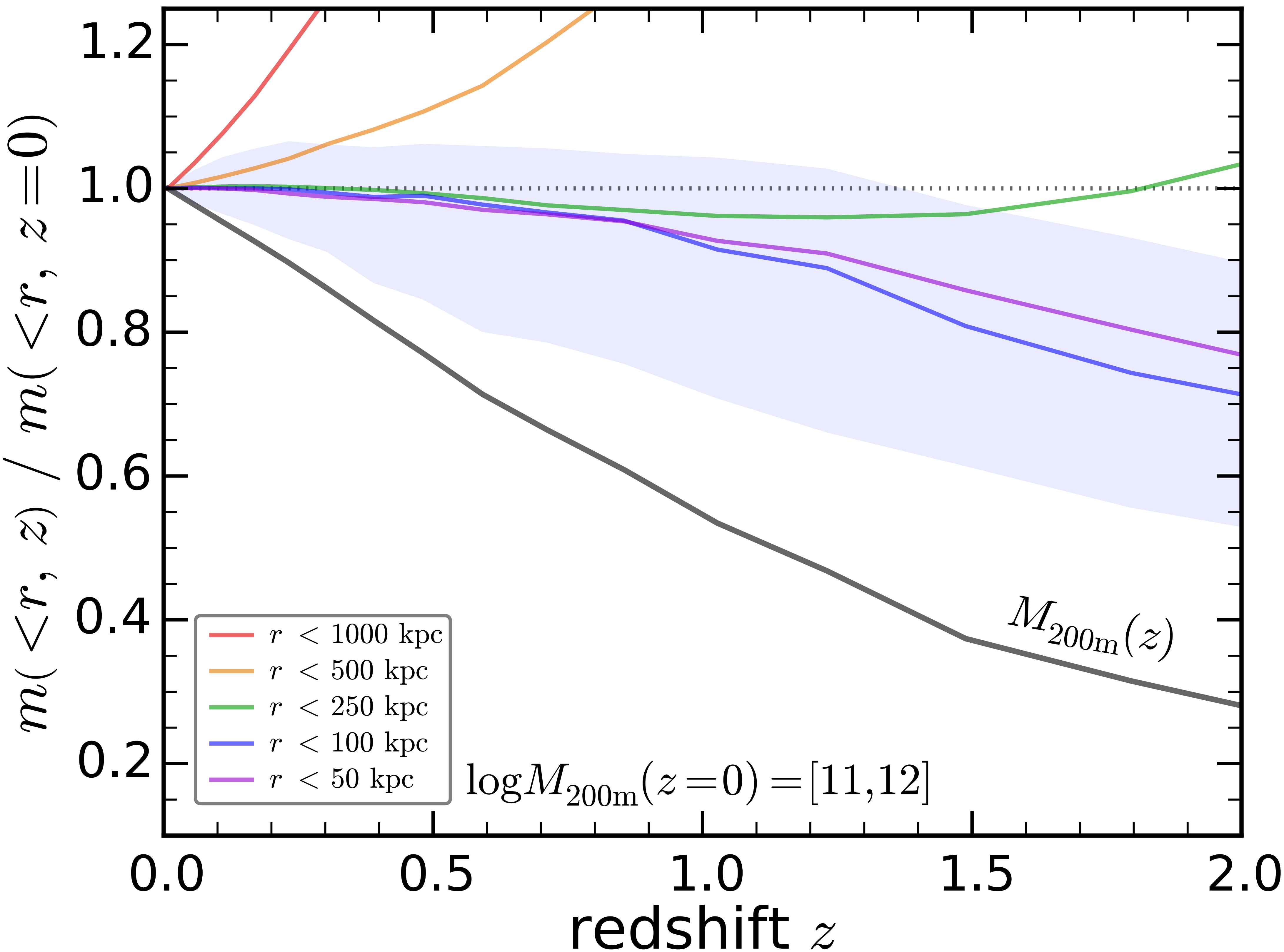
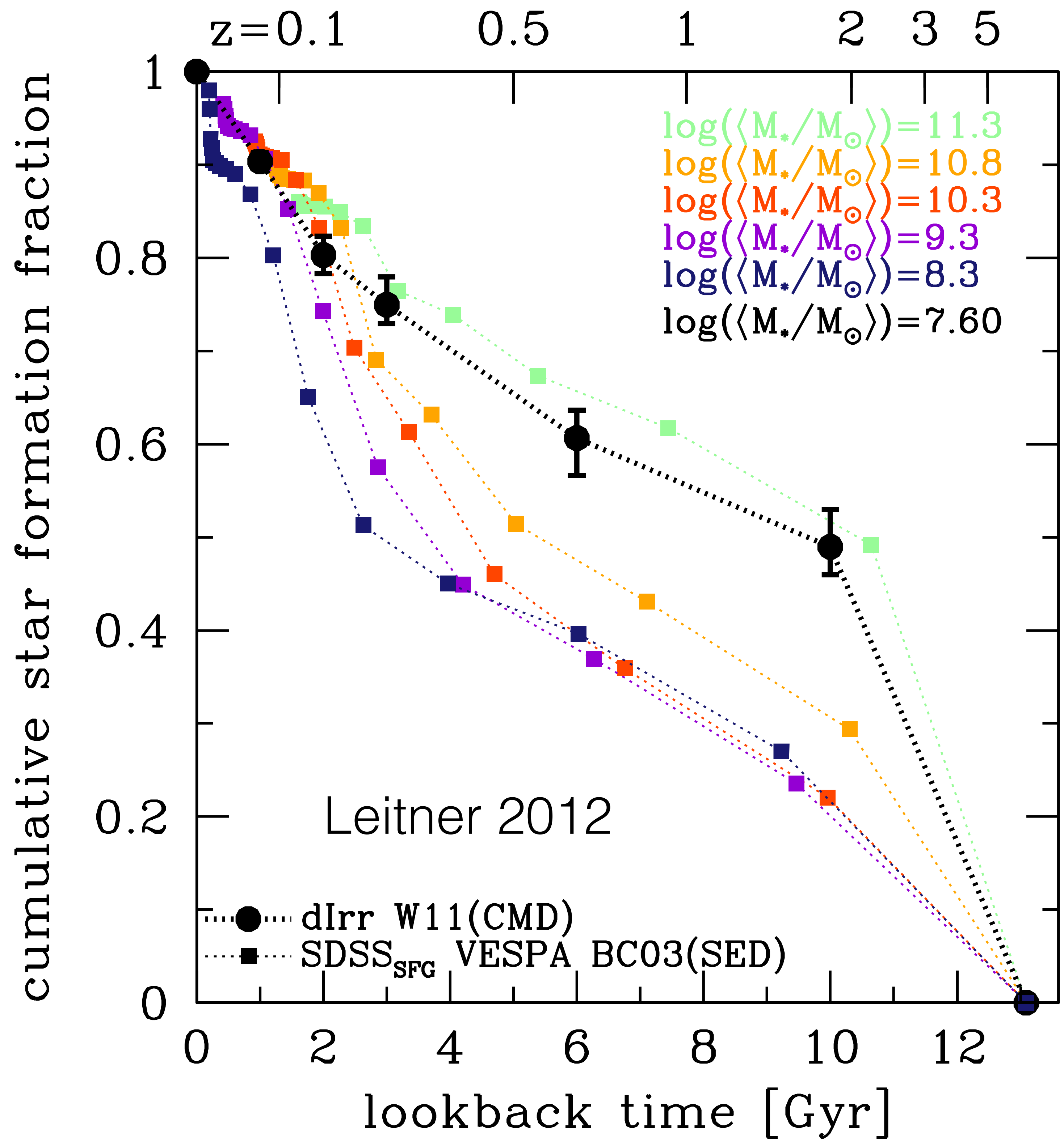


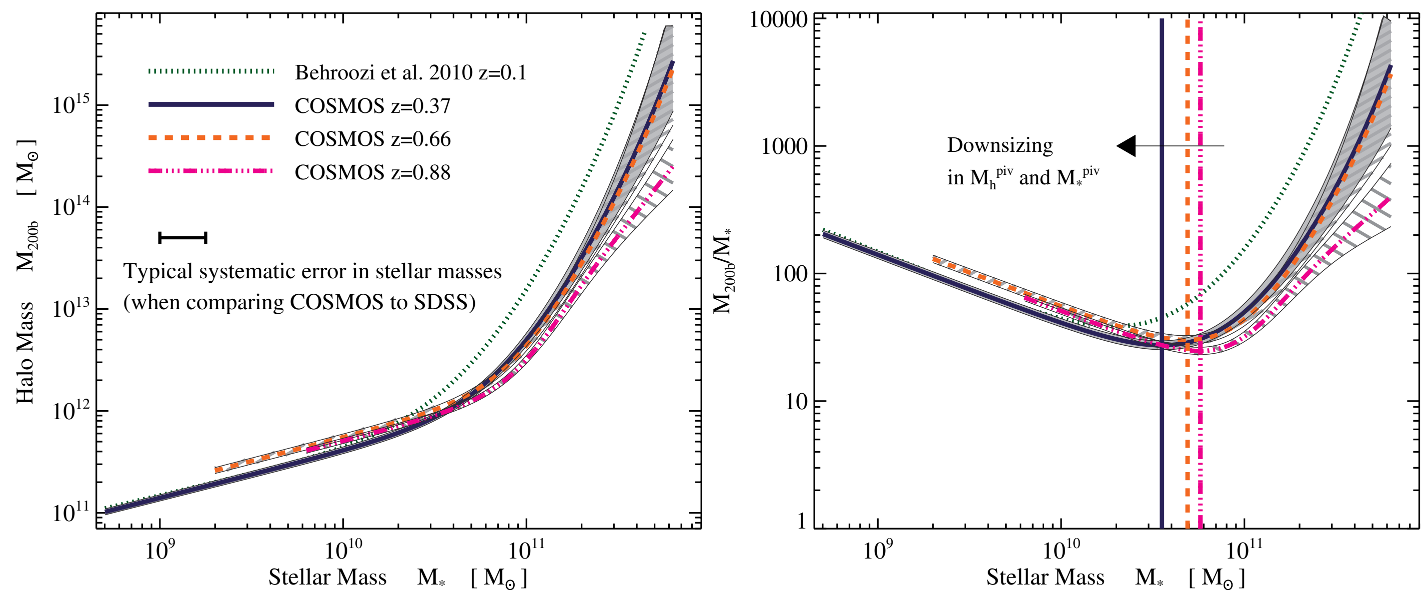


Late-time stellar mass growth is important

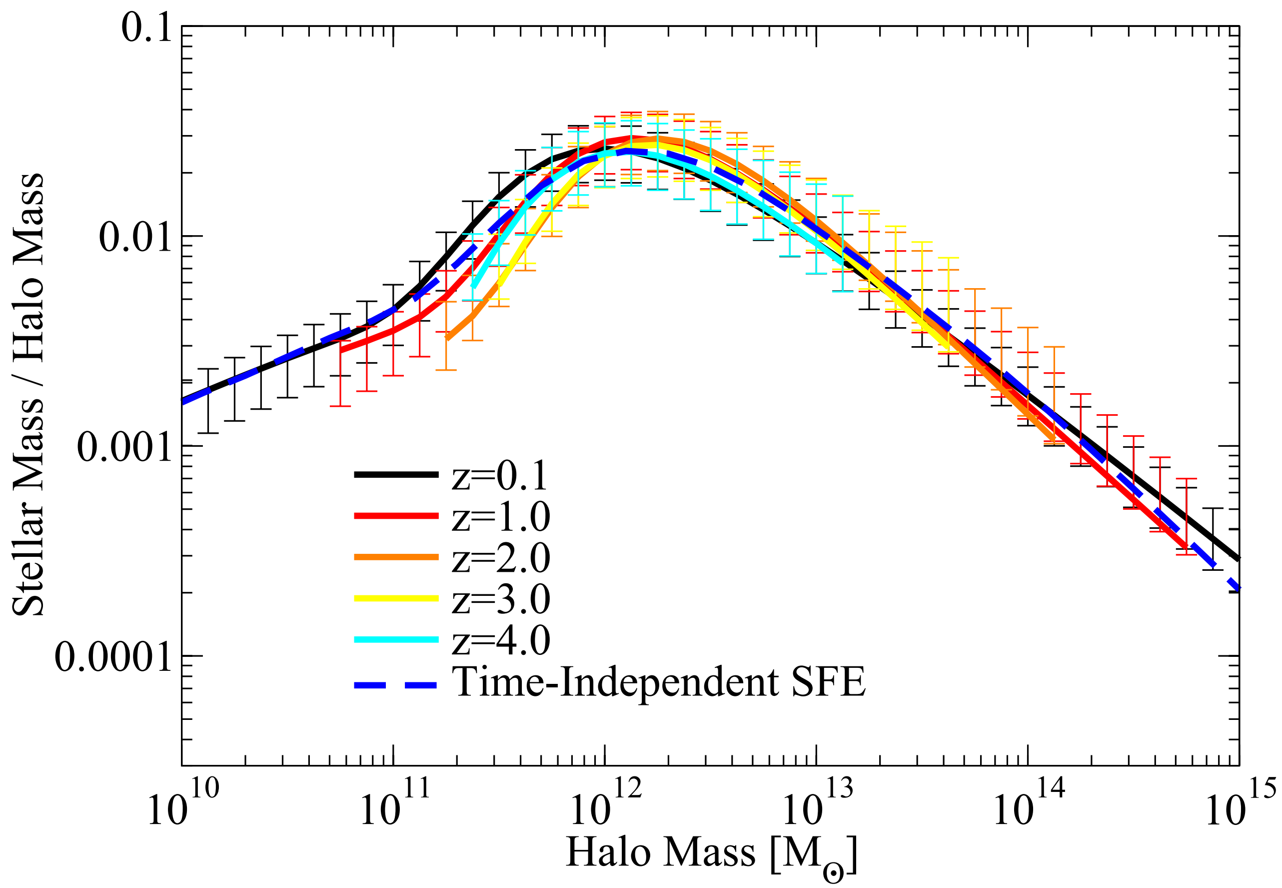
Most galaxies formed majority of their stellar mass at z < 1

Observations: strong connection between galaxy mass & halo mass

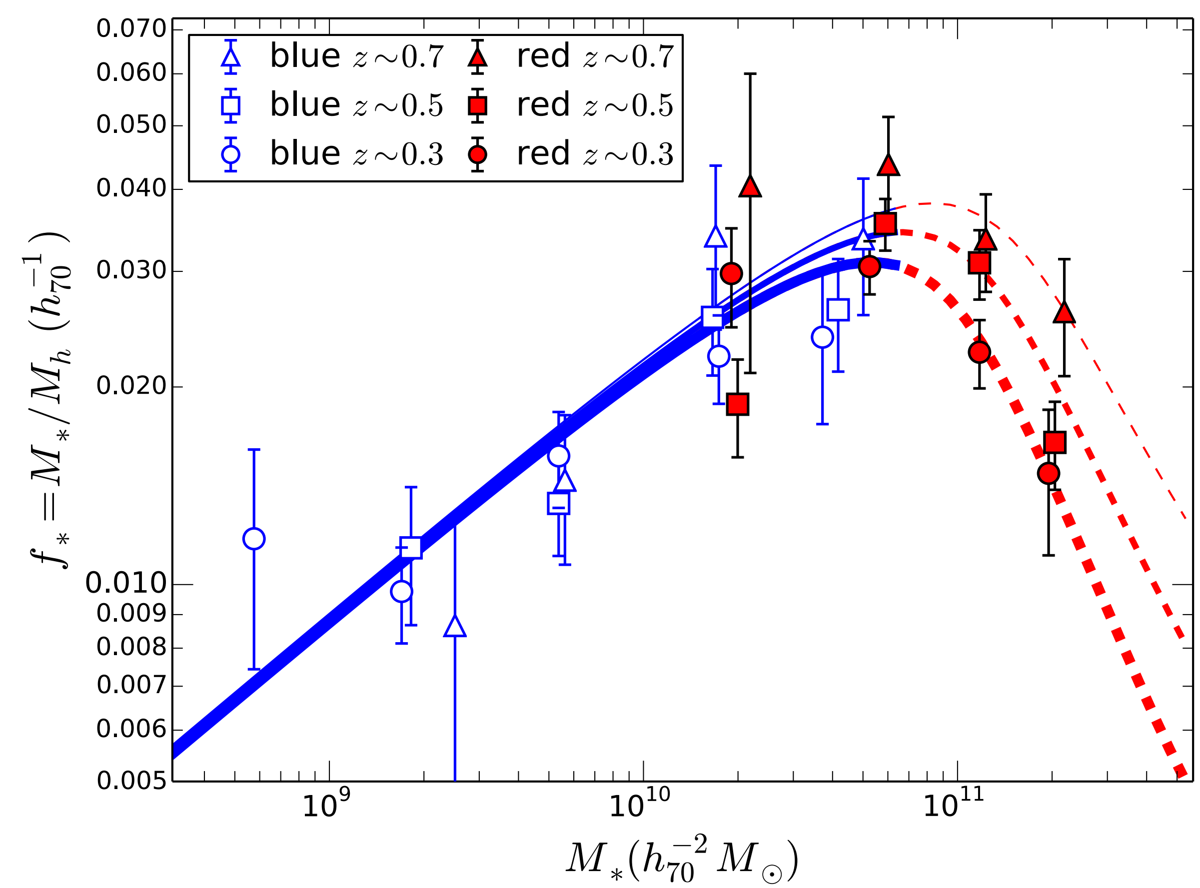
Leauthaud et al 2012



Behroozi et al 2013



Hudson et al 2013



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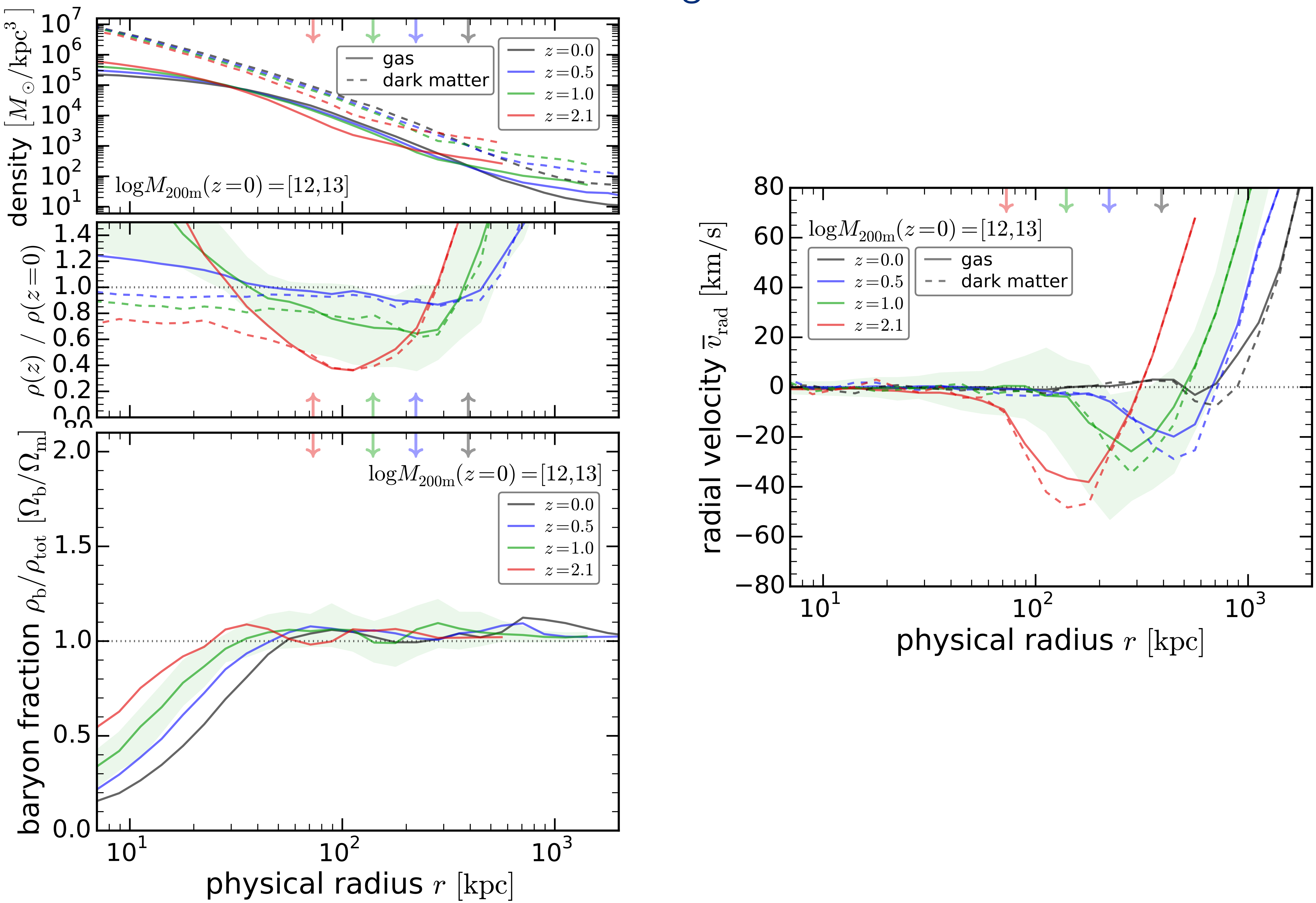
Physical Cosmic Accretion of Baryons

1. Impact of Gas Physics

2. Trends with star formation + stellar feedback

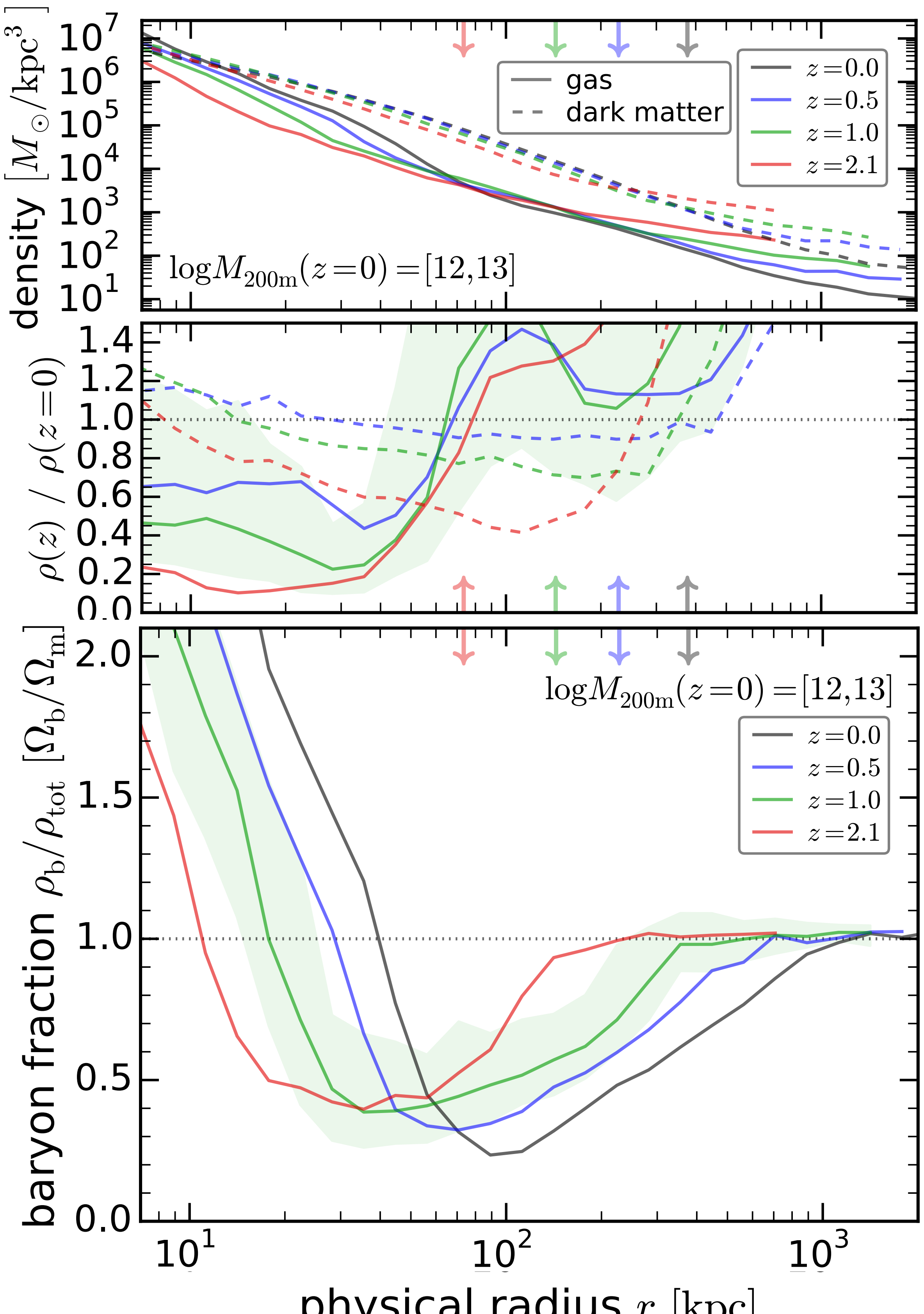
Physical accretion of gas & dark matter

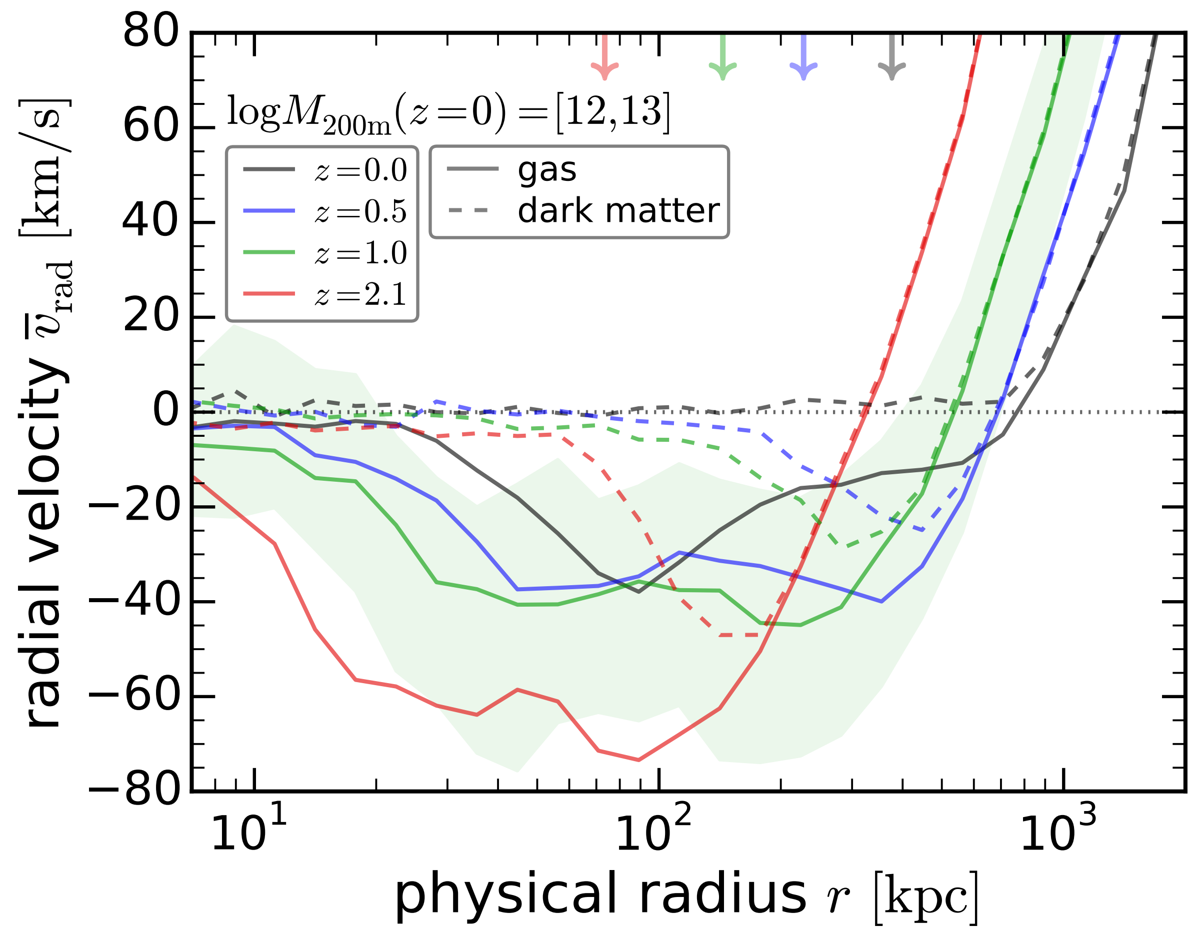
from simulation with gas - non-radiative



Physical accretion of gas & dark matter

from simulation with gas - radiative cooling





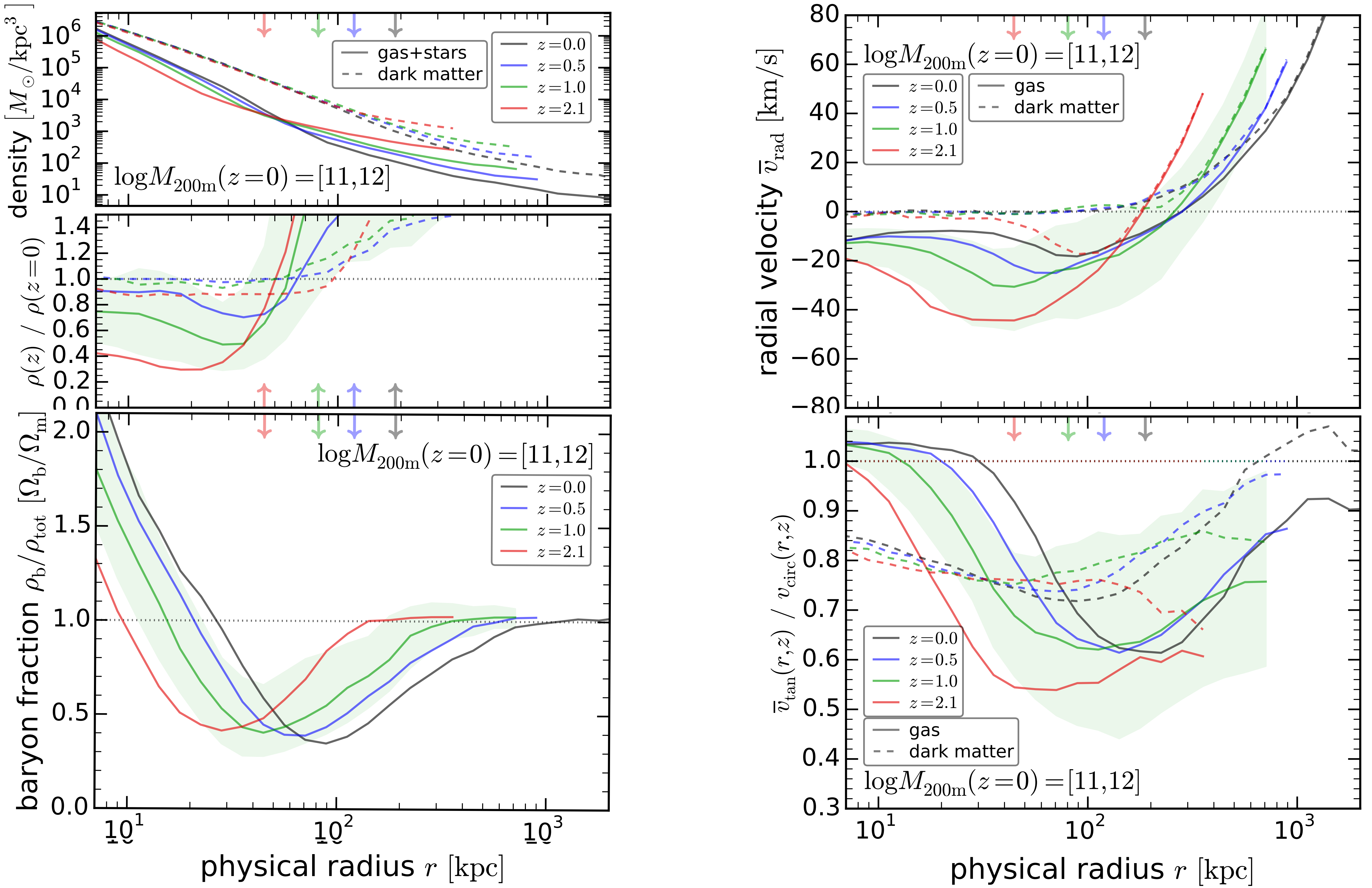
Physical Cosmic Accretion of Baryons

1. Impact of Gas Physics

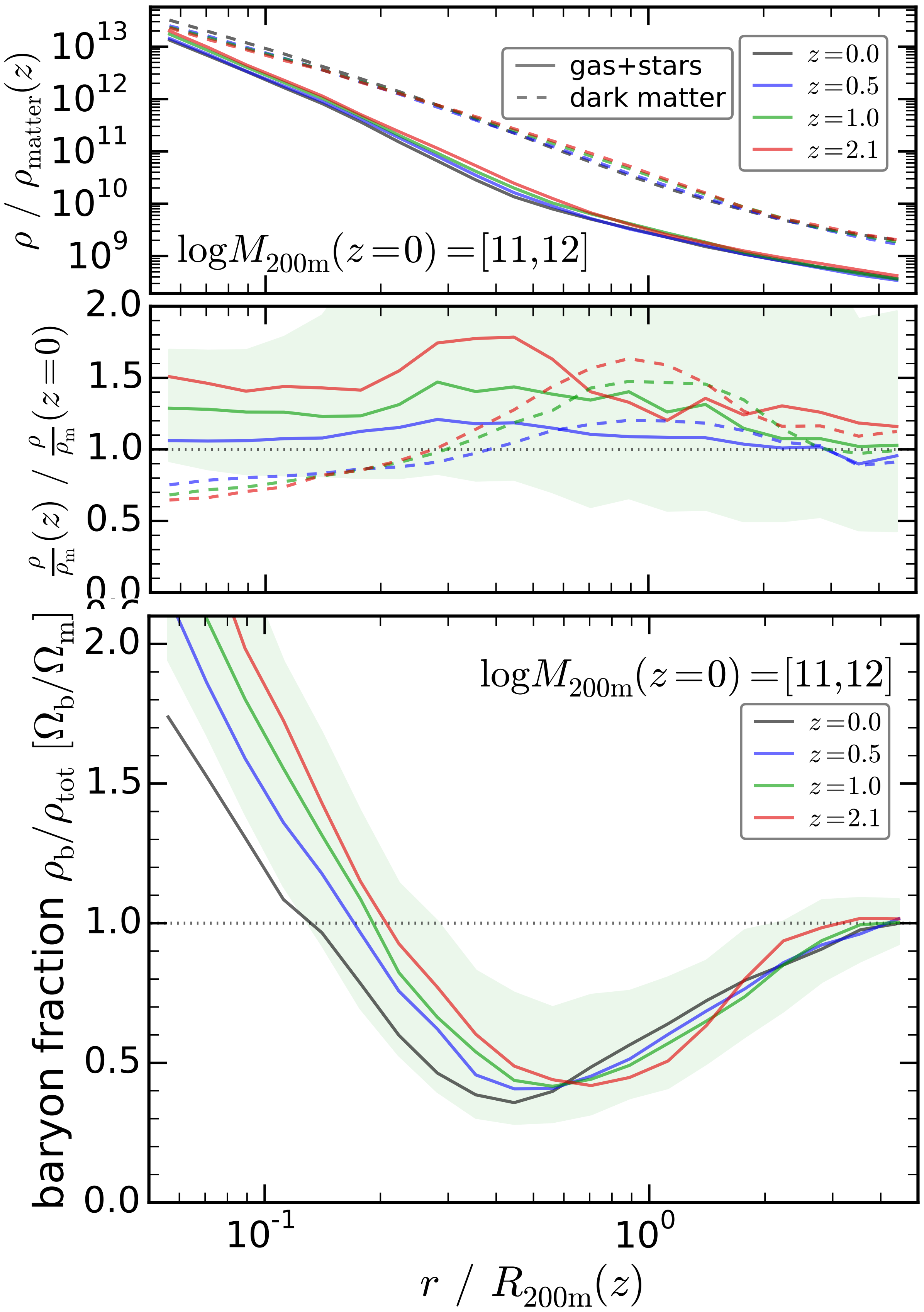
2. Trends with star formation + stellar feedback

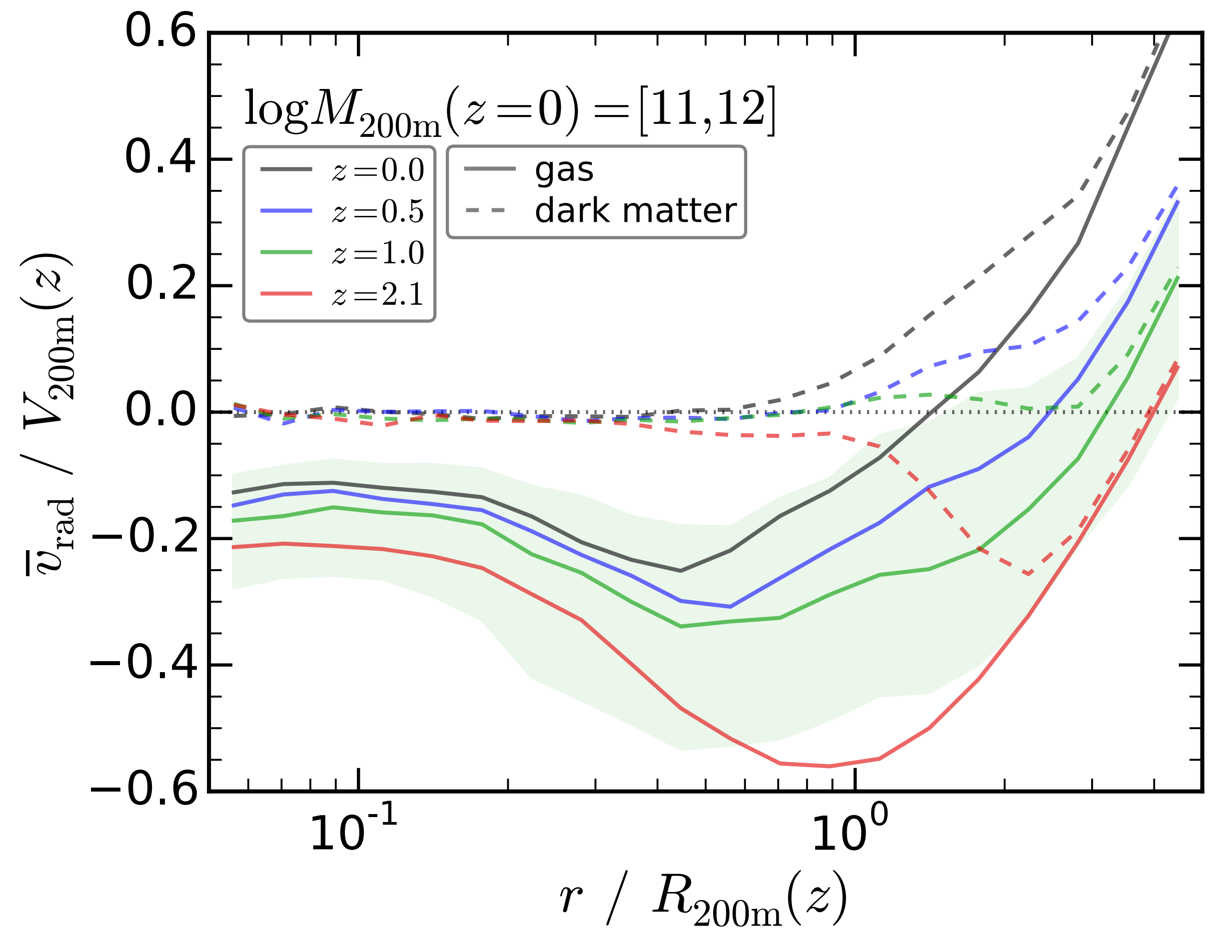
Physical accretion of baryons & dark matter

from simulation with star formation + feedback



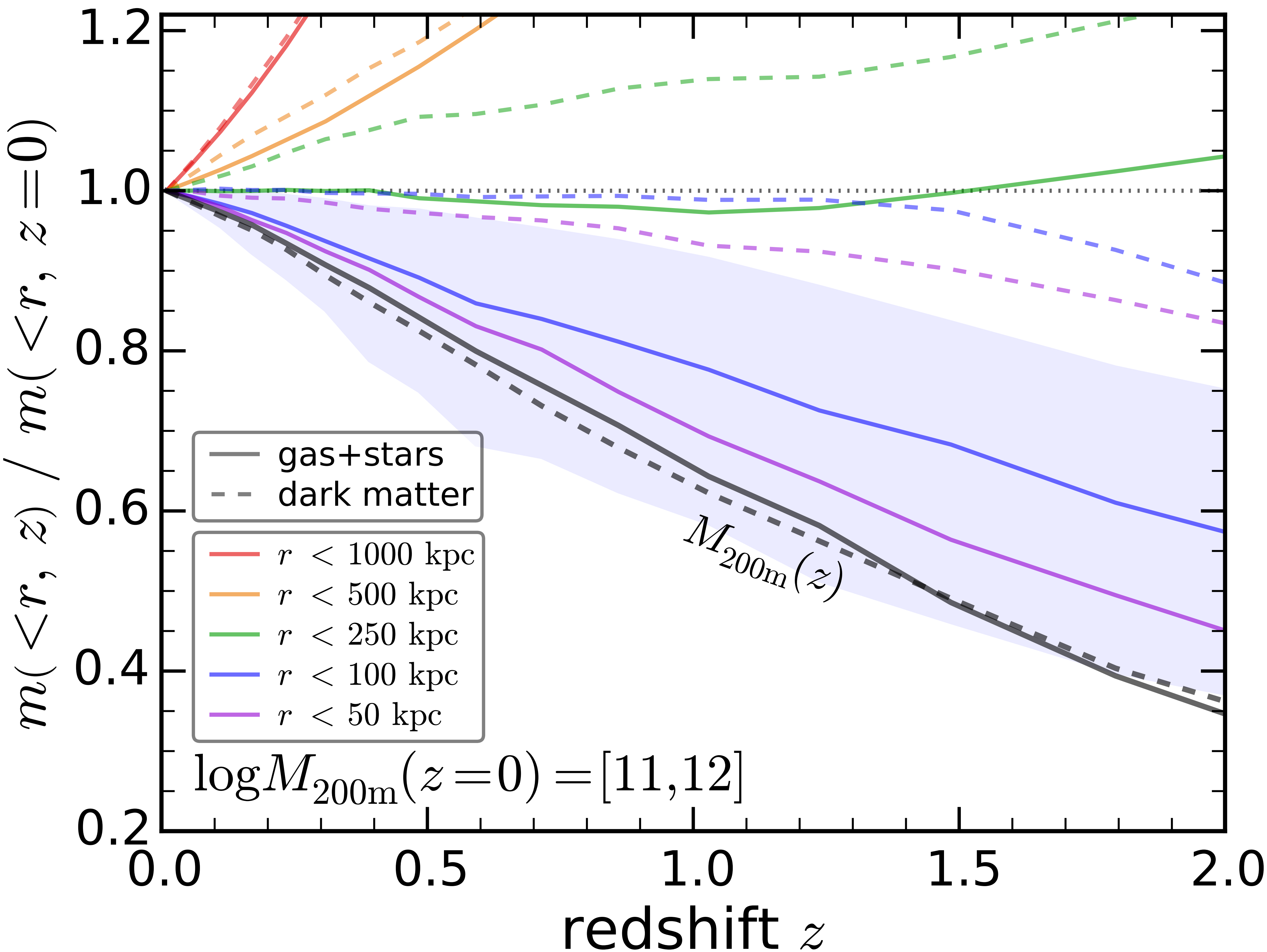
Physical significance of R_{200m}?





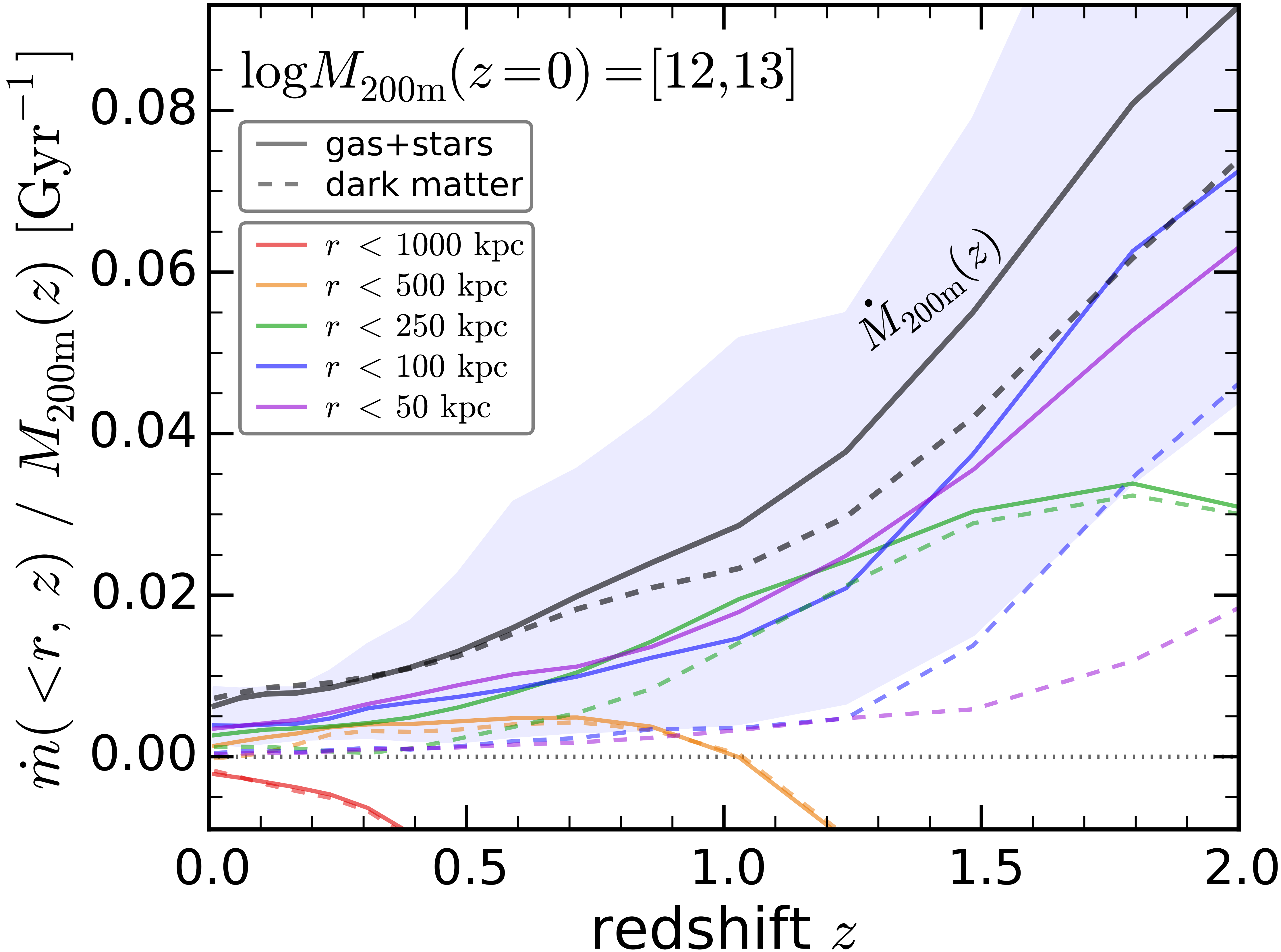
Physical accretion of baryons & dark matter

from simulation with star formation + feedback



Physical accretion of baryons & dark matter

from simulation with star formation + feedback



Summary: Physical Accretion of Dark Matter & Gas

- Dark Matter growth is subject to pseudo-evolution
  - at z <~ 1, no significant growth of density/mass at any radius

- Baryonic growth is not subject to pseudo-evolution
  - Physical growth at all radii because gas is dissipational
  - Accretion rate at all radii (roughly) tracks that at R_{200m}

- Most meaningful radius to measure cosmic accretion of both dark matter & gas is 2 R_{200m}

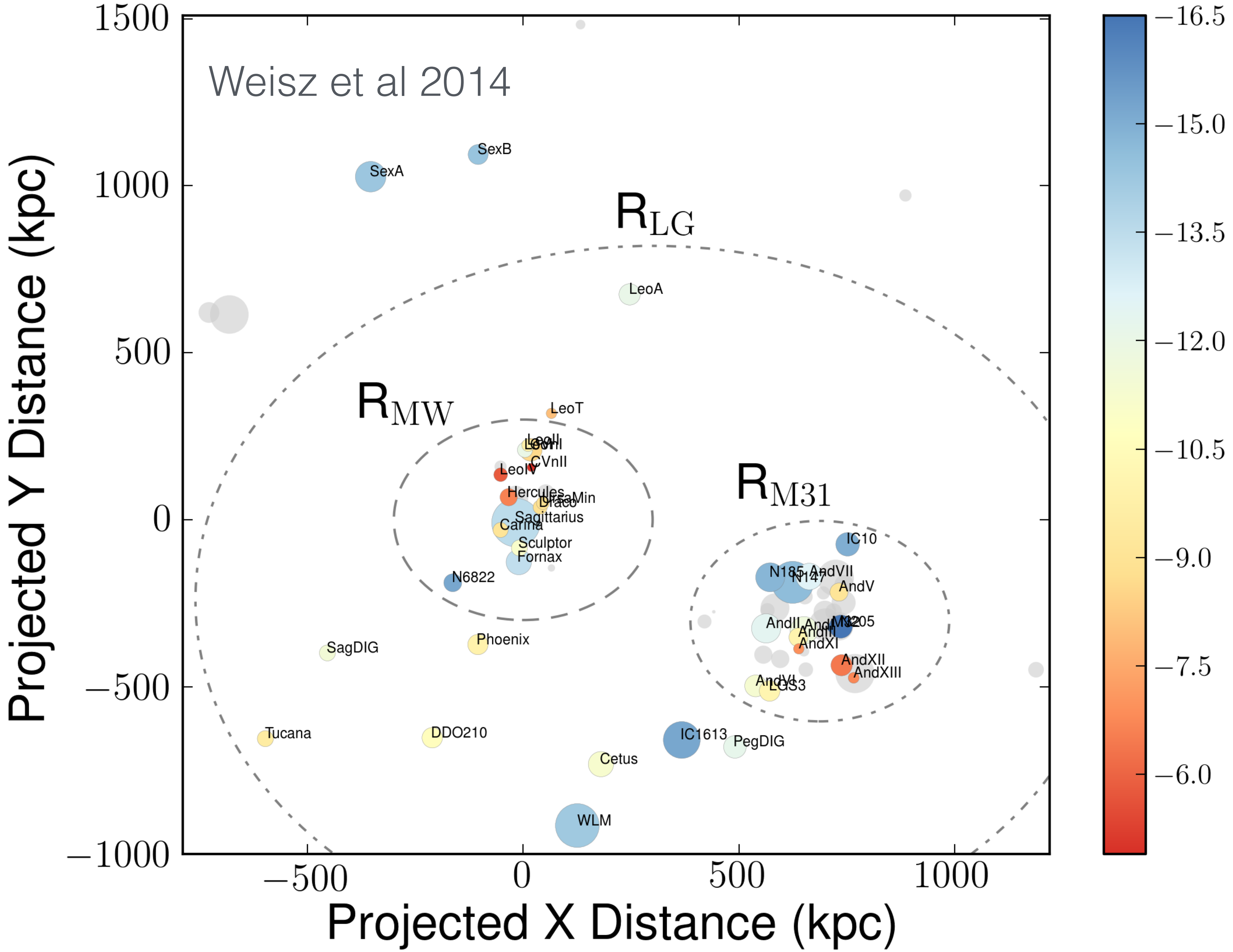
Part II

Satellite Dwarf Galaxies in the Local Group

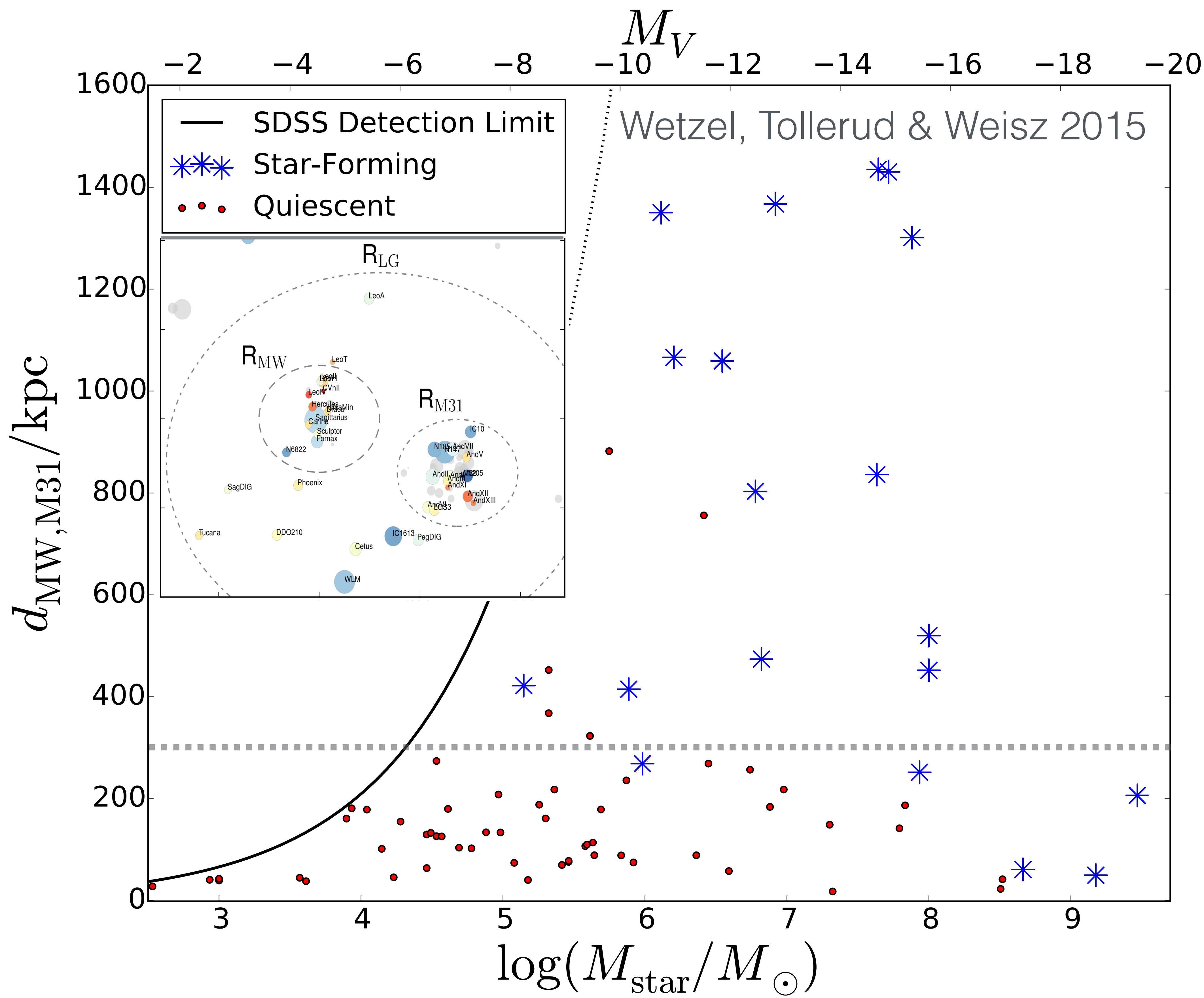
with Alis Deason (Santa Cruz), Shea Garrison-Kimmel (Irvine),
Erik Tollerud (Yale), Dan Weisz (Washington),
Vasily Belokurov (Cambridge), Phil Hopkins (Caltech)

Deason, Wetzel & Garrison-Kimmel 2014
Wetzel, Deason & Garrison-Kimmel 2015
Wetzel, Tollerud & Weisz 2015
Deason, Wetzel, Garrison-Kimmel & Belokurov 2015

The Local Group

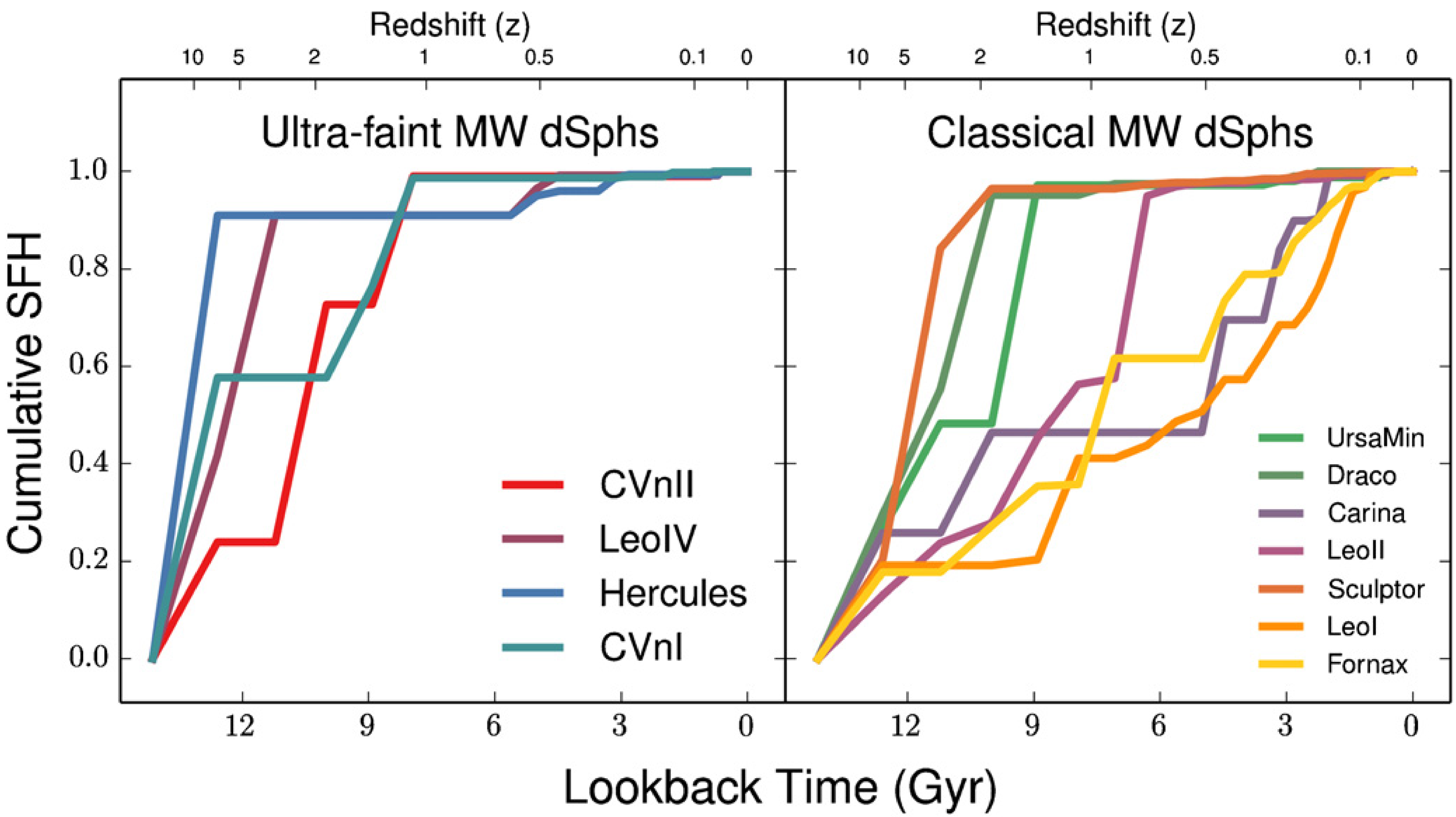


Star formation in dwarf galaxies in the Local Group



Star-formation histories at different masses

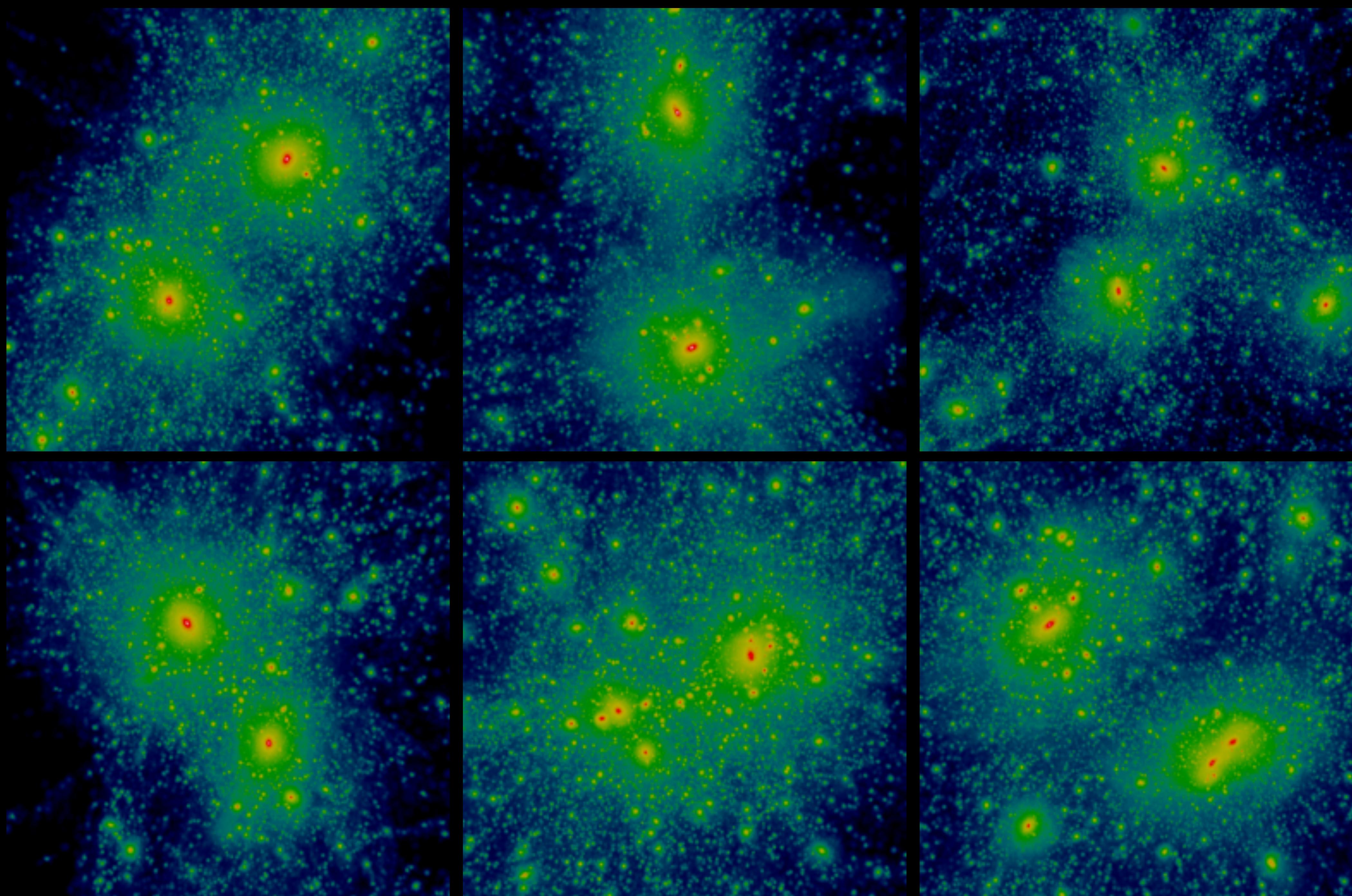
Weisz et al 2014



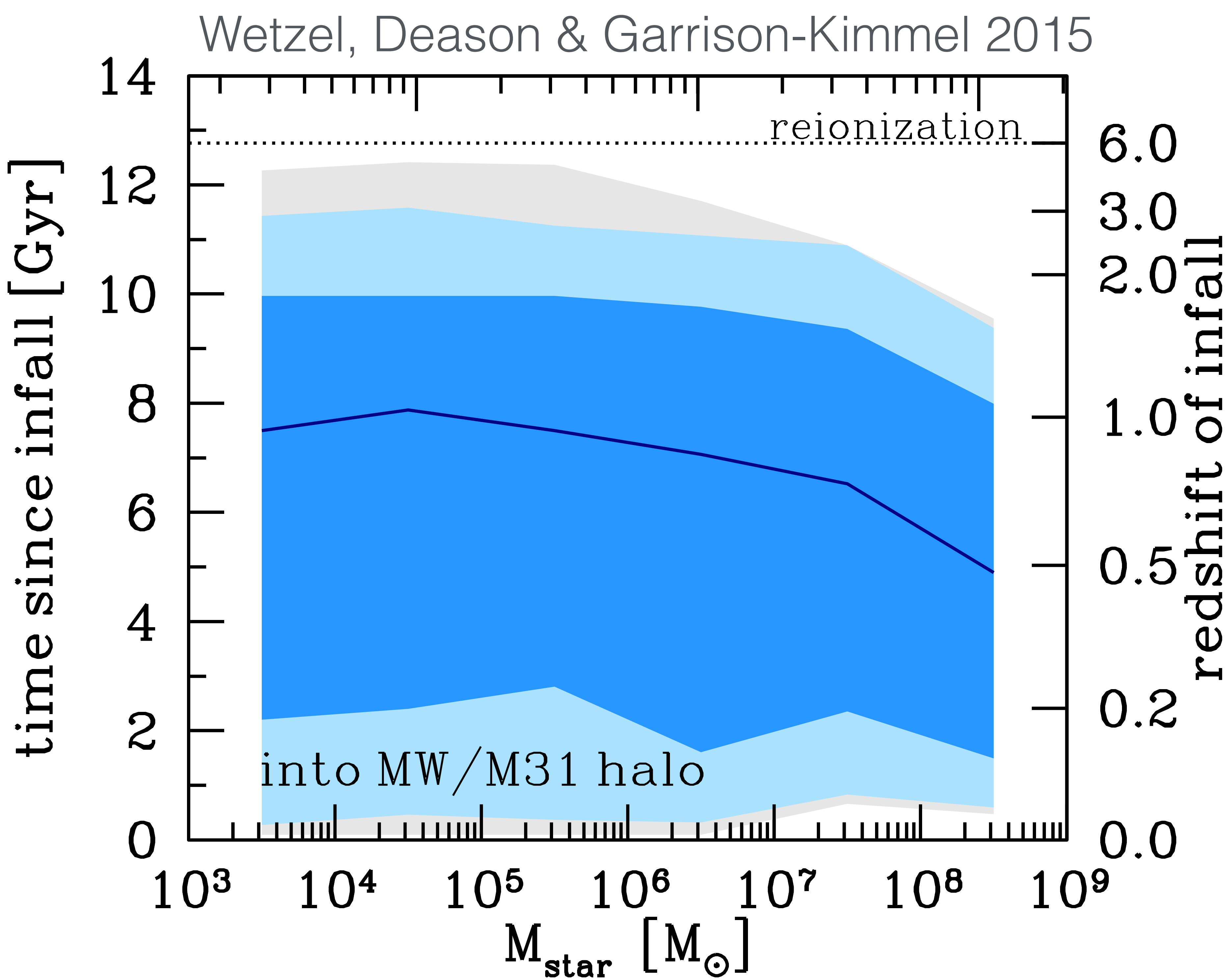
ELVIS Suite

Cosmological zoom-in *N*-body simulations of Local-Group-like halo pairs

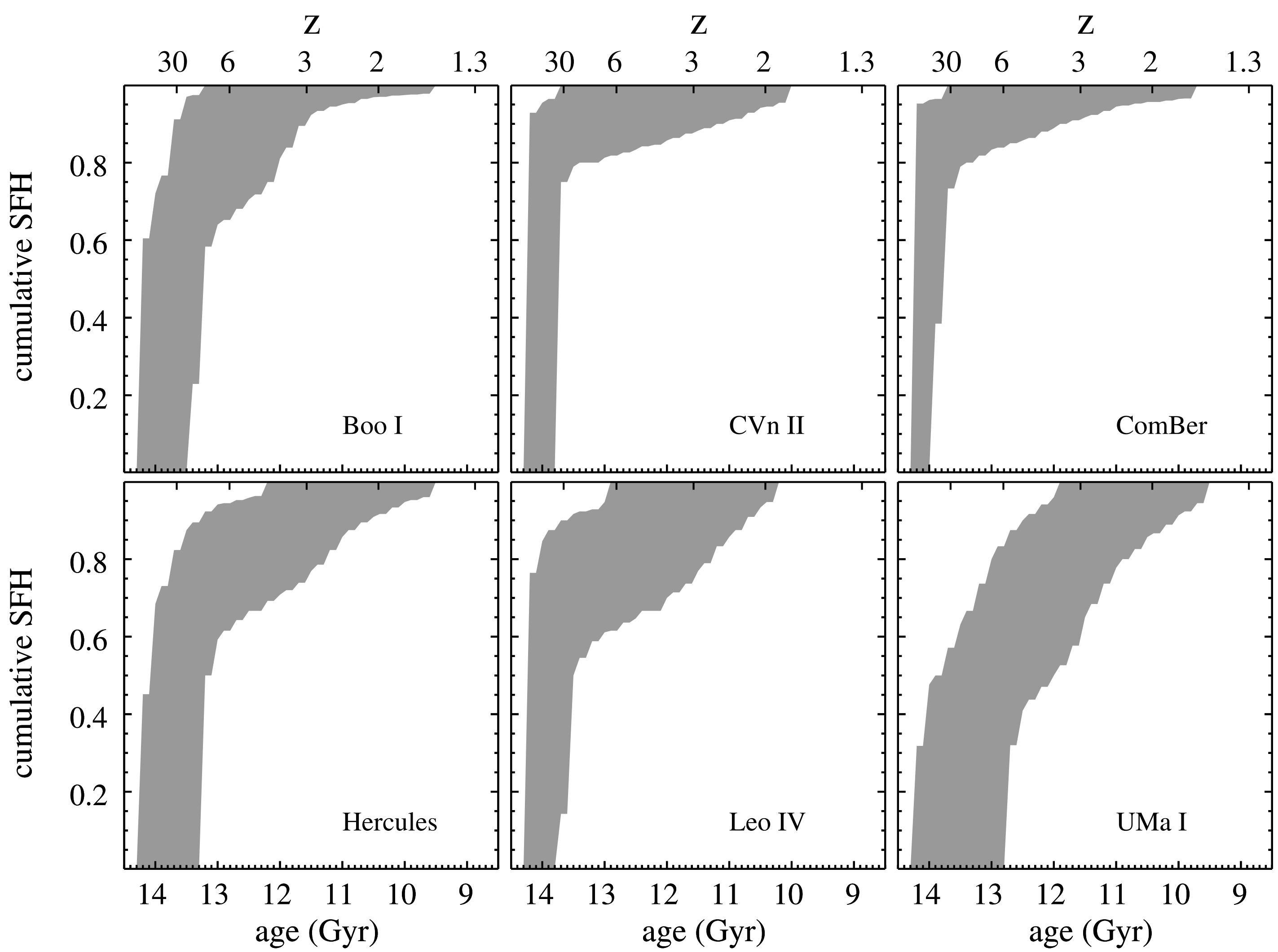
Garrison-Kimmel et al 2013



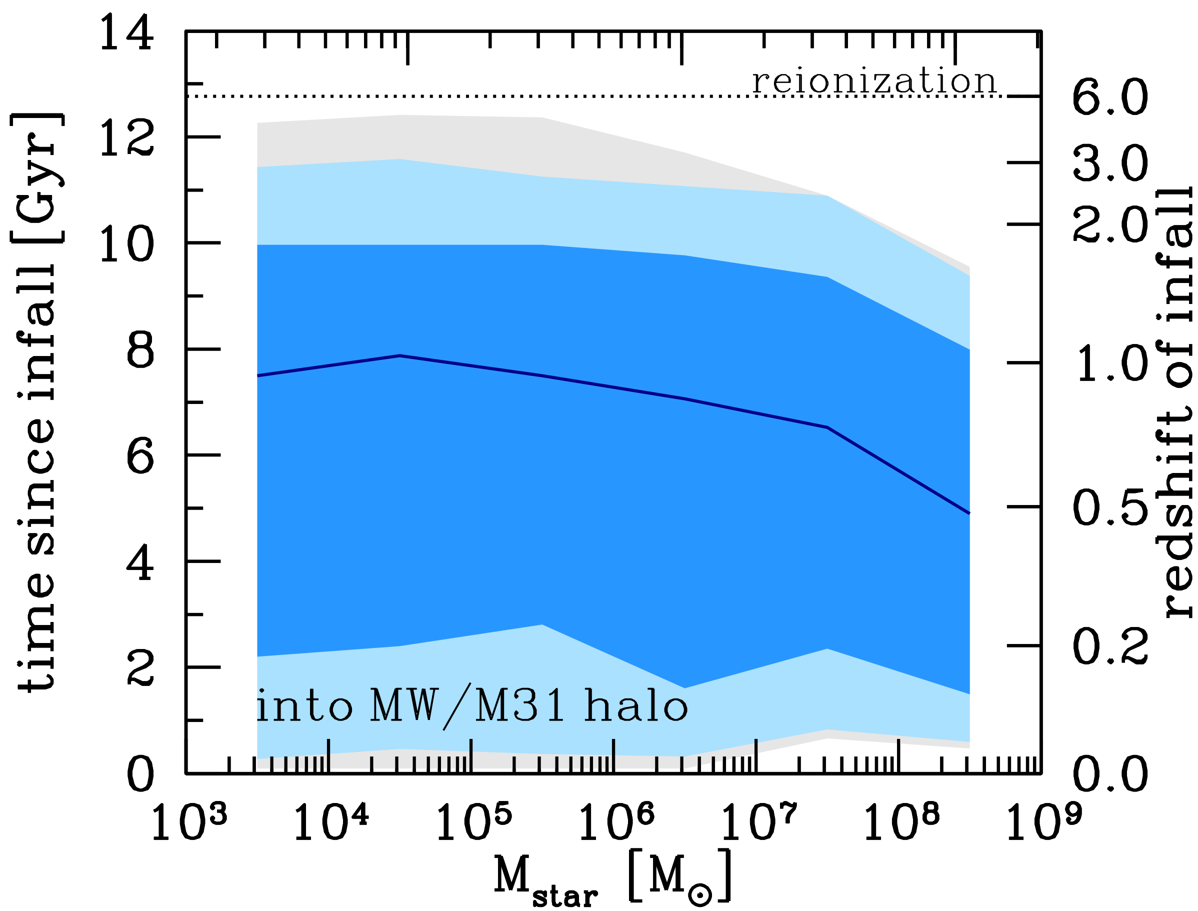
When did satellite galaxies fall into MW halo?



Brown et al 2014

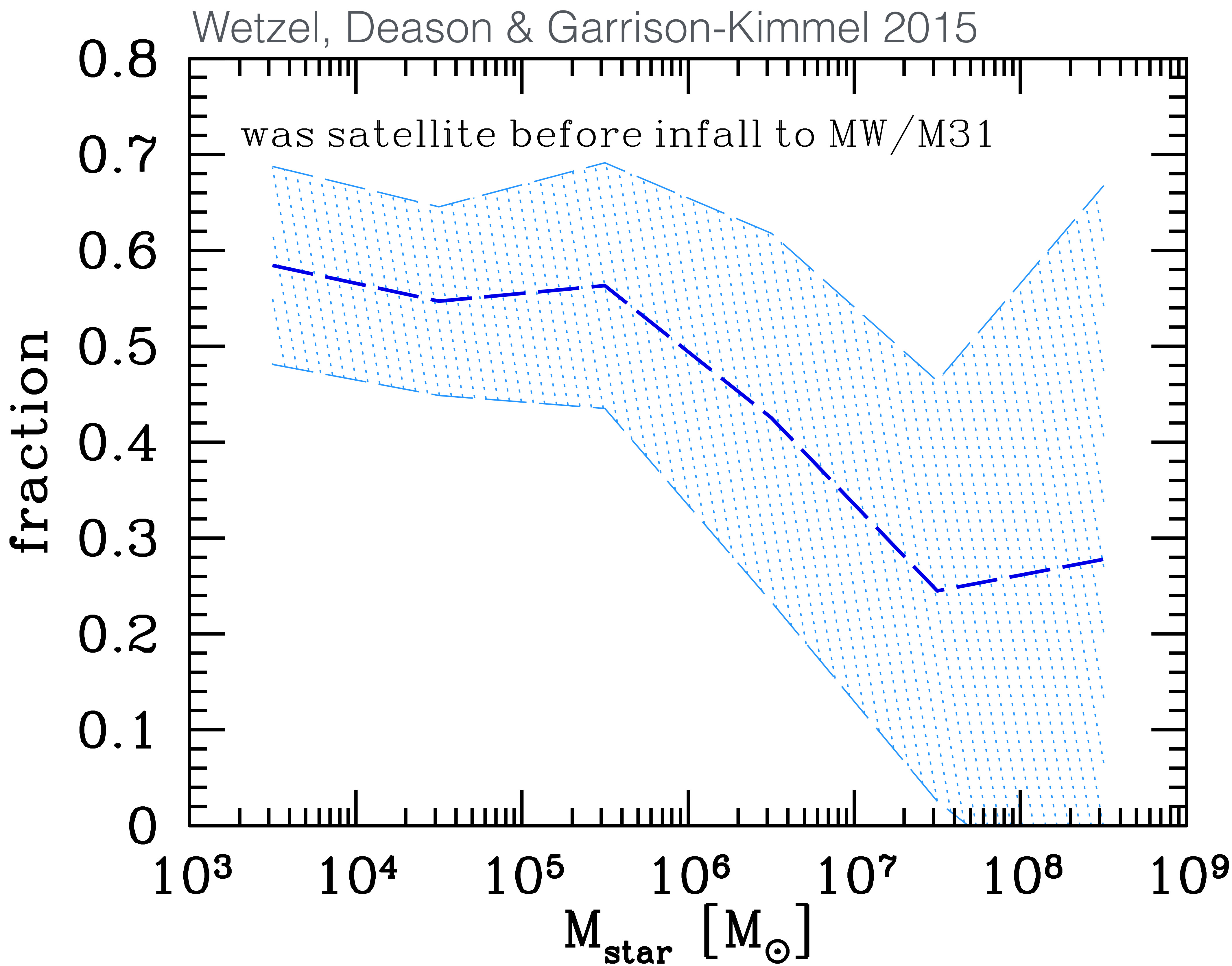


Wetzel, Deason & Garrison-Kimmel 2015

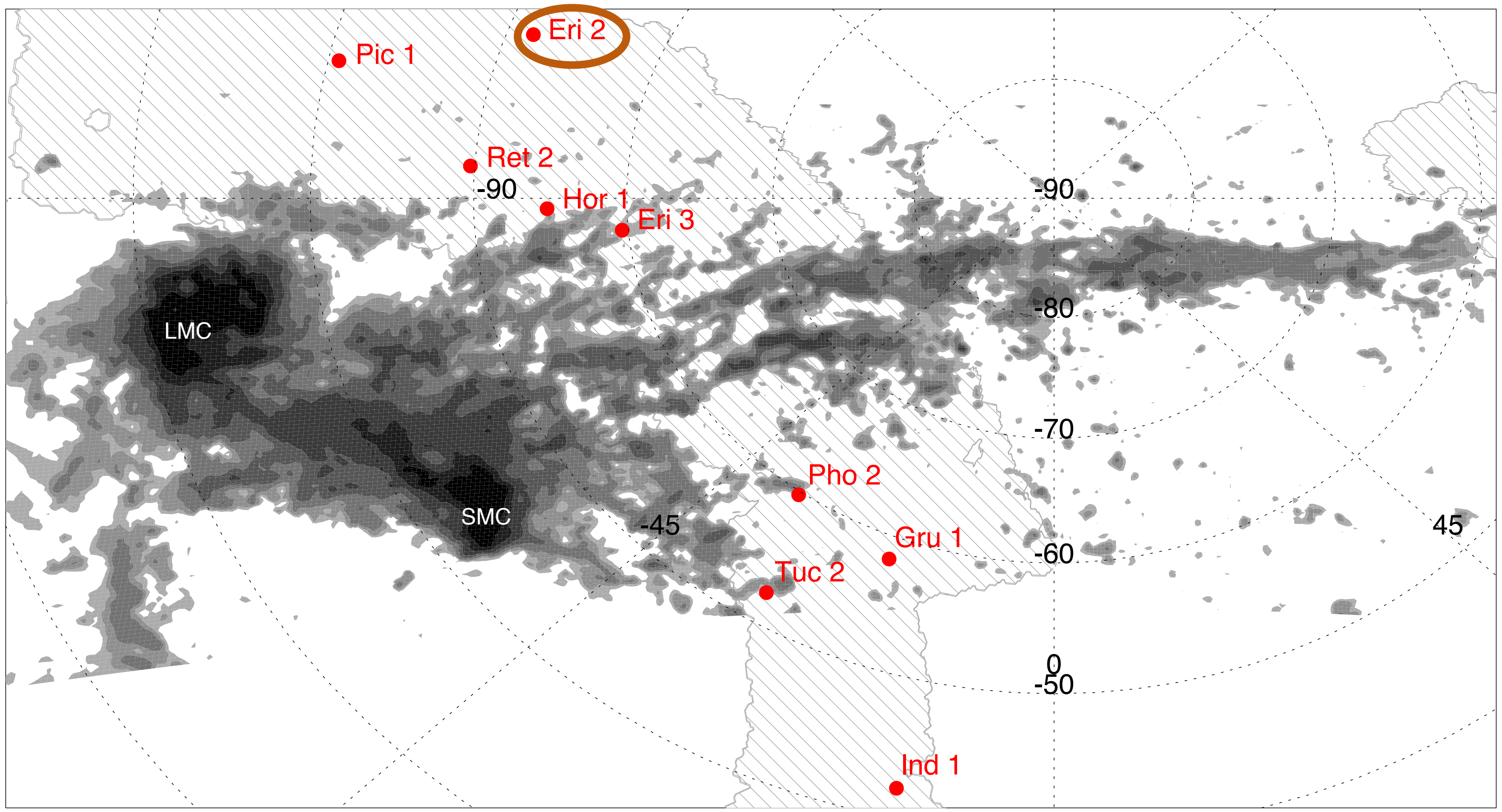


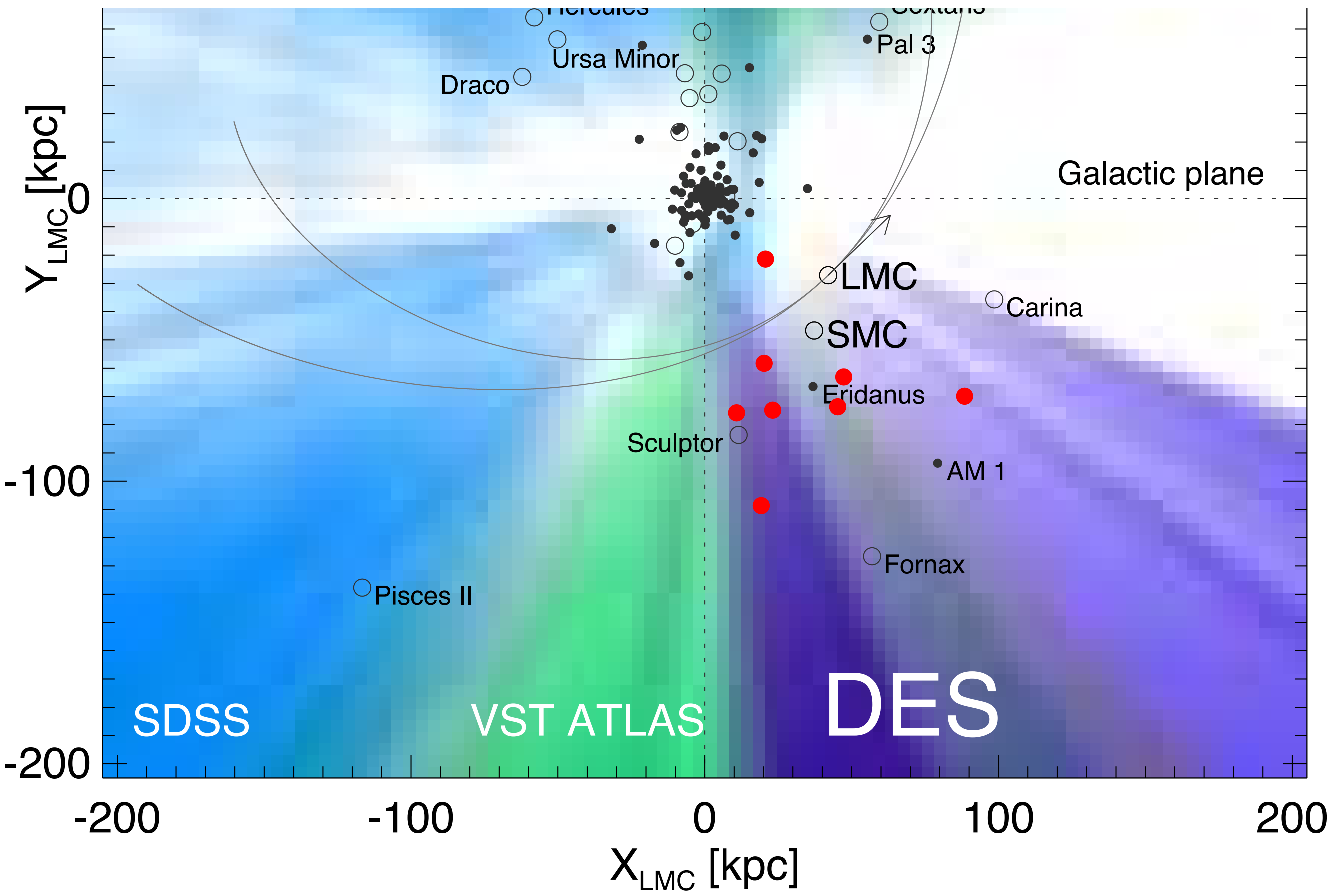
Ultra-faint dwarf galaxies quenched via reionization (+ feedback) and not via the MW halo environment

Group preprocessing of satellite dwarf galaxies



Discovery of several dwarf galaxies near the LMC



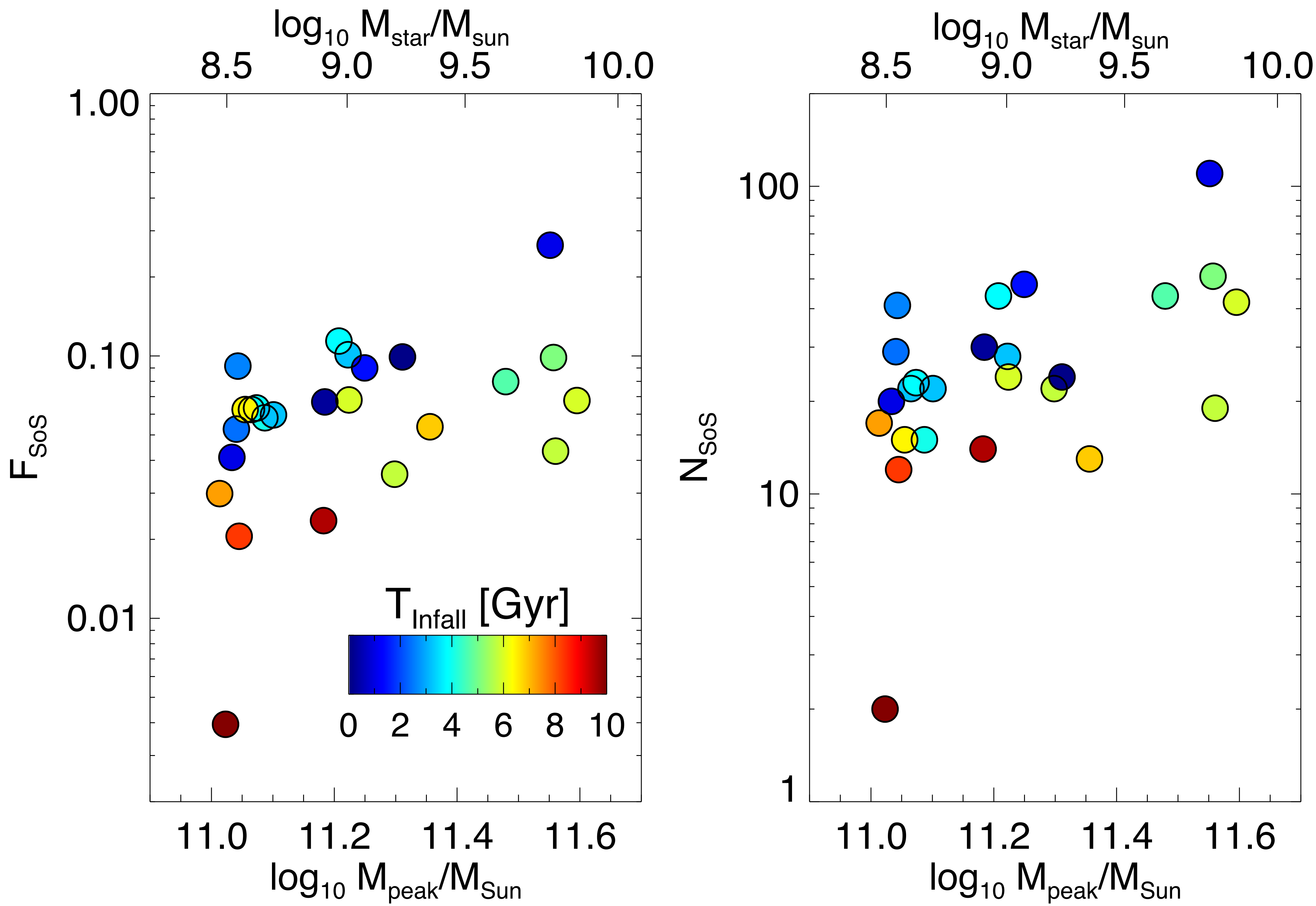


Koposov et al 2015
Bechtol et al 2015

also: Hydra II
Martin et al 2015

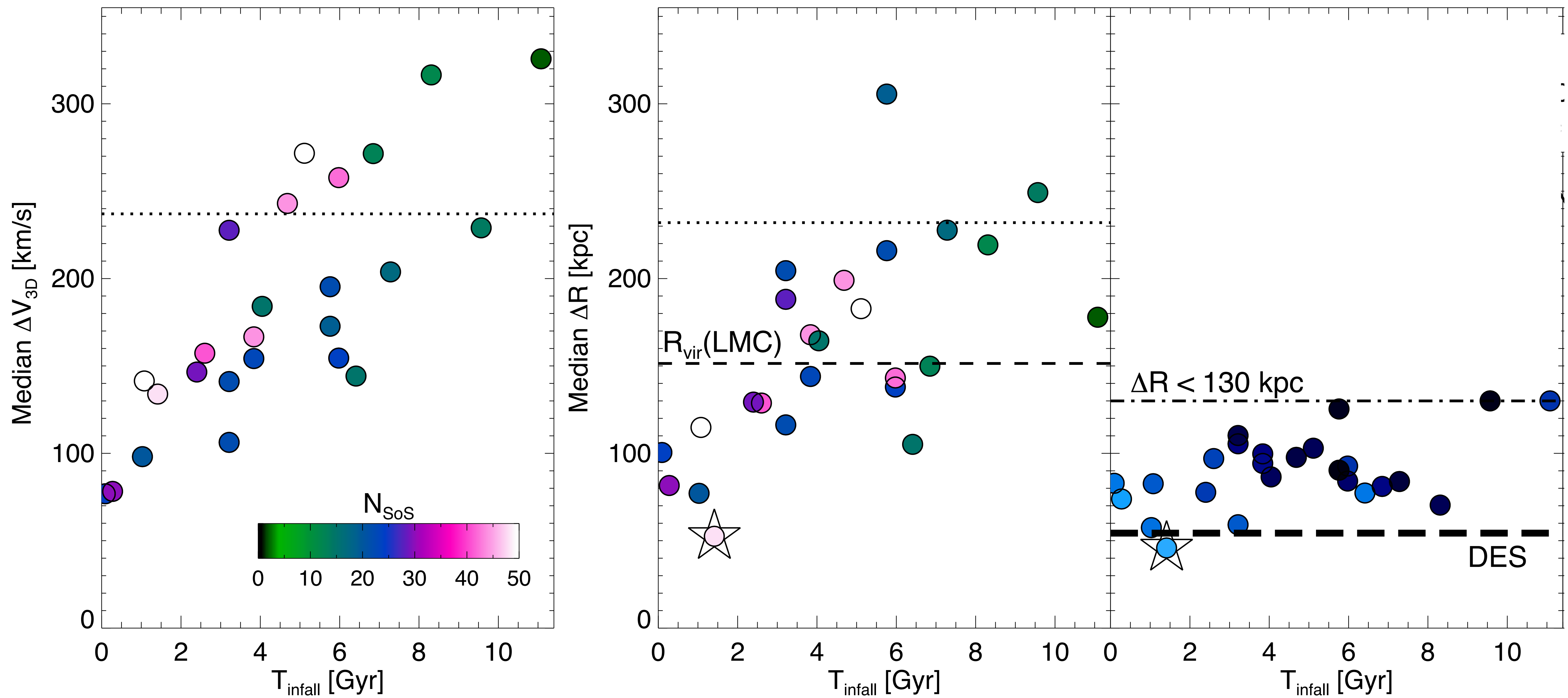
How many dwarf galaxies are satellites of LMCs in LCDM?

Deason, Wetzel, Garrison-Kimmel, & Belokurov 2015 (out today)

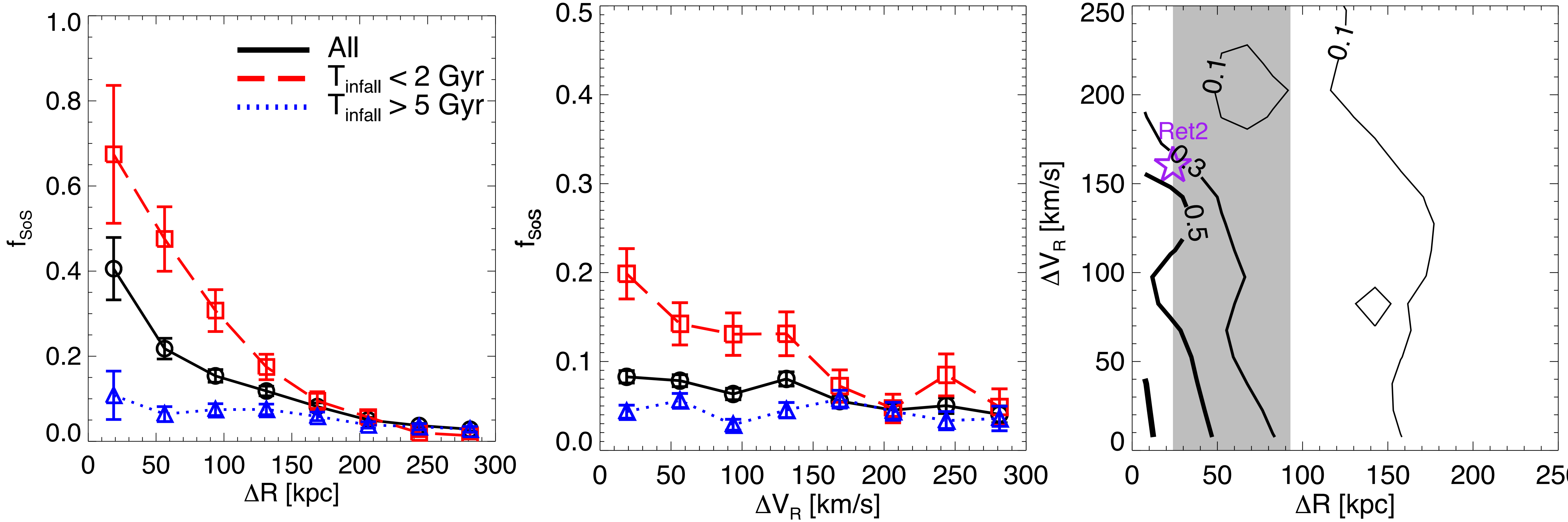


Groups of satellite dwarf galaxies are dissociated by MW tidal field over time

Deason, Wetzel, Garrison-Kimmel, & Belokurov 2015 (out today)



Predictions: which dwarfs were satellites of LMC



Name	ΔR [kpc]	$P_{LMC\ sat}$	$P_{LMC\ sat}$ ($T_{infall} < 2$ Gyr)
Reticulum 2	23.9	0.38	0.65
Eridanus 2	337.4	0.02	0.01
Horologium 1	38.5	0.31	0.57
Pictoris 1	70.0	0.19	0.41
Phoenix 2	54.3	0.23	0.49
Indus 1	80.0	0.18	0.37
Grus 1	92.8	0.16	0.31
Eridanus 3	48.2	0.26	0.52
Tucana 2	36.7	0.32	0.58
Total:		2.0	3.9

Satellite Dwarf Galaxies in the Local Group

- None of the ultra-faint satellites of MW today were in/near MW halo at $z > 6$
    - Star-formation quenched via reionization and not via MW halo environment
- >50% of all satellites in MW/M31 with $M_{star} < 10^6\ M_{sun}$ were preprocessed in a group before falling into MW/M31 halo
- ~4 of the newly discovered dwarf galaxies near LMC were satellites of LMC prior to MW infall