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How Baryons Alter The Distribution of Dark Matter: A Brief Overview

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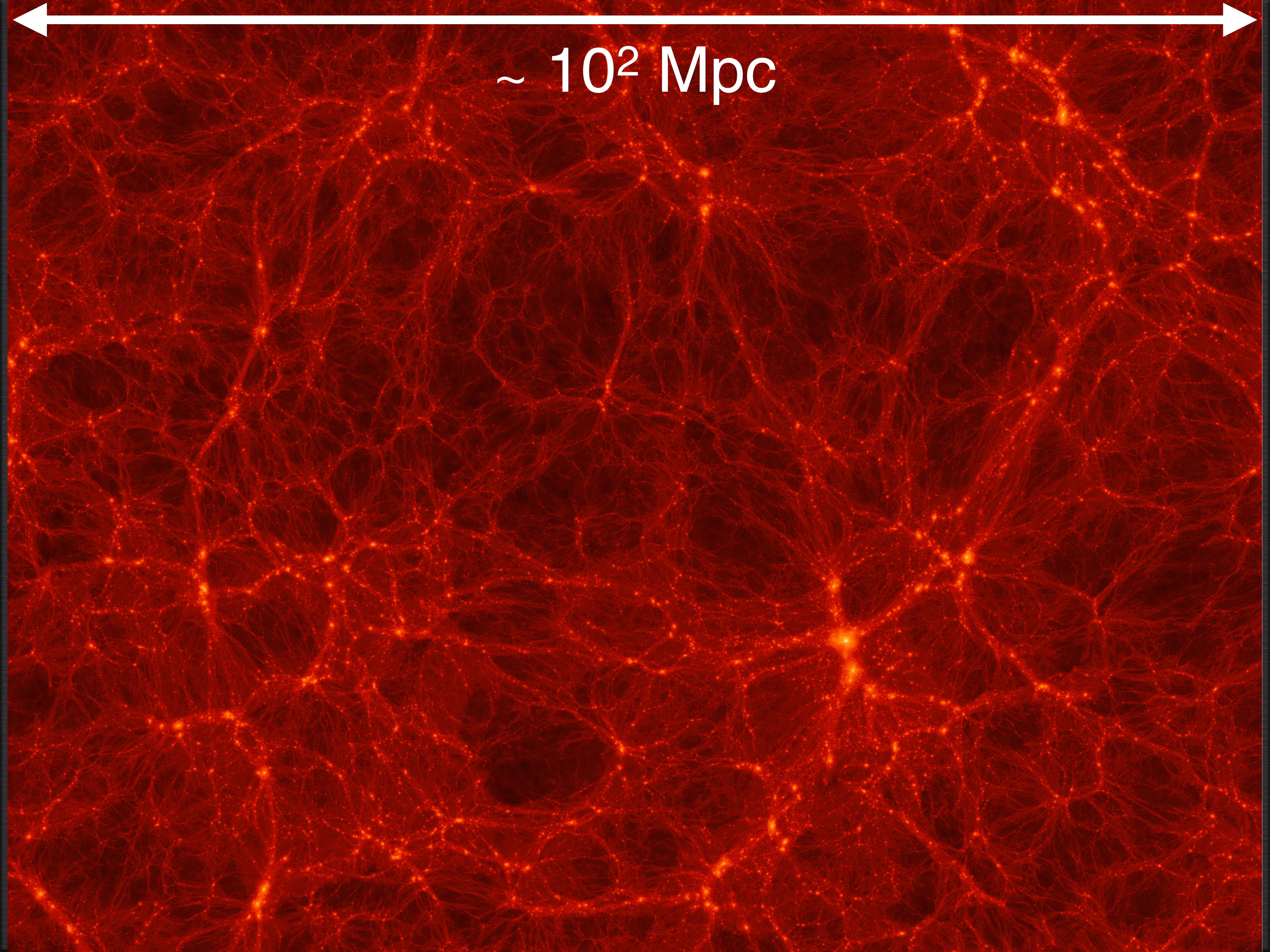
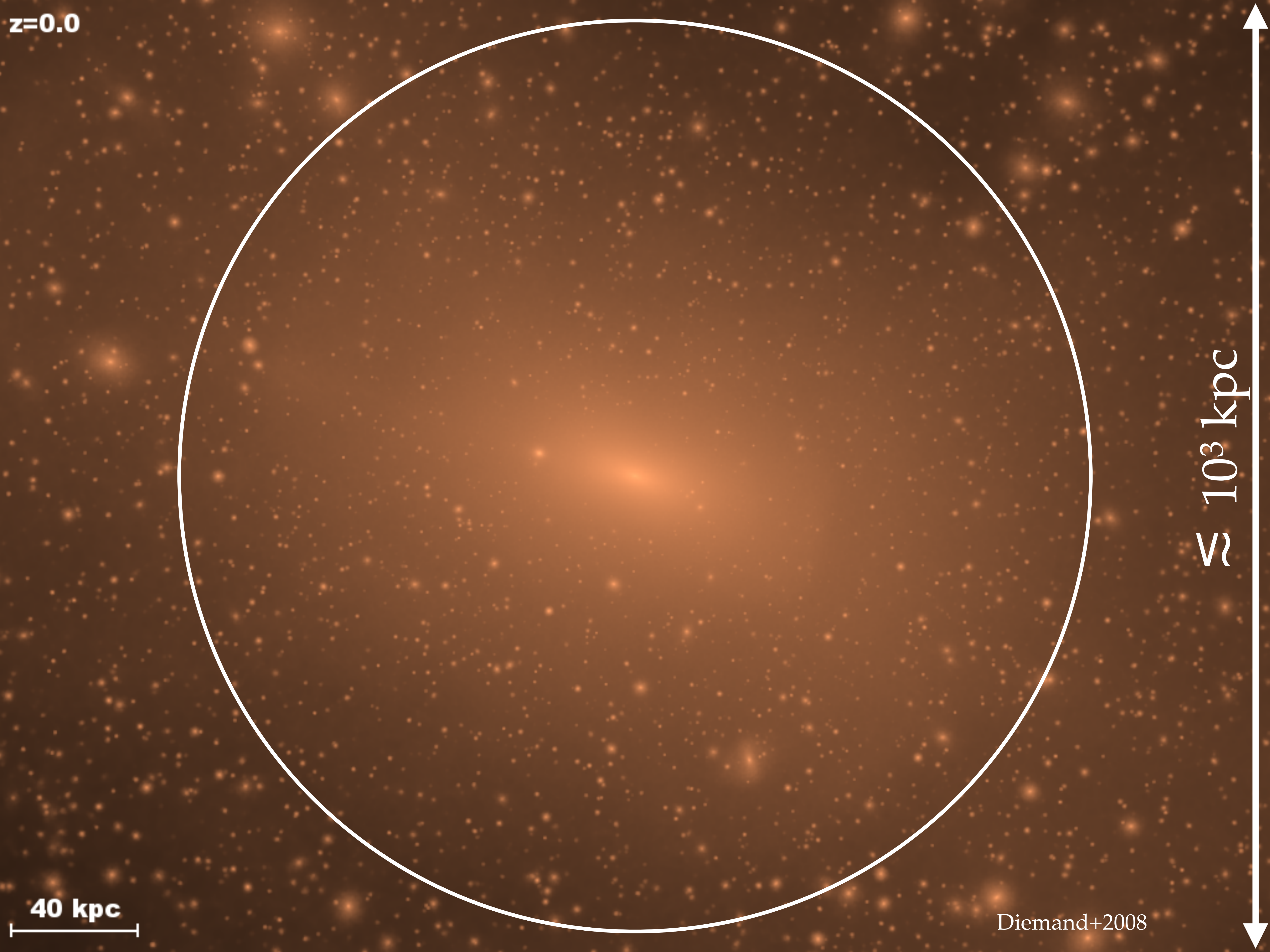
Outline

- Moving dark matter on large scales
- Dark matter distribution on halo scales: the shapes of halos
- Moving dark matter in halo interiors: the evolution of halo profiles
- Dark matter associated with dark matter subhalos


~ 10^2 Mpc



z=0.0
$\gtrsim 10^3$ kpc
40 kpc
Diemand+2008

z=0.0

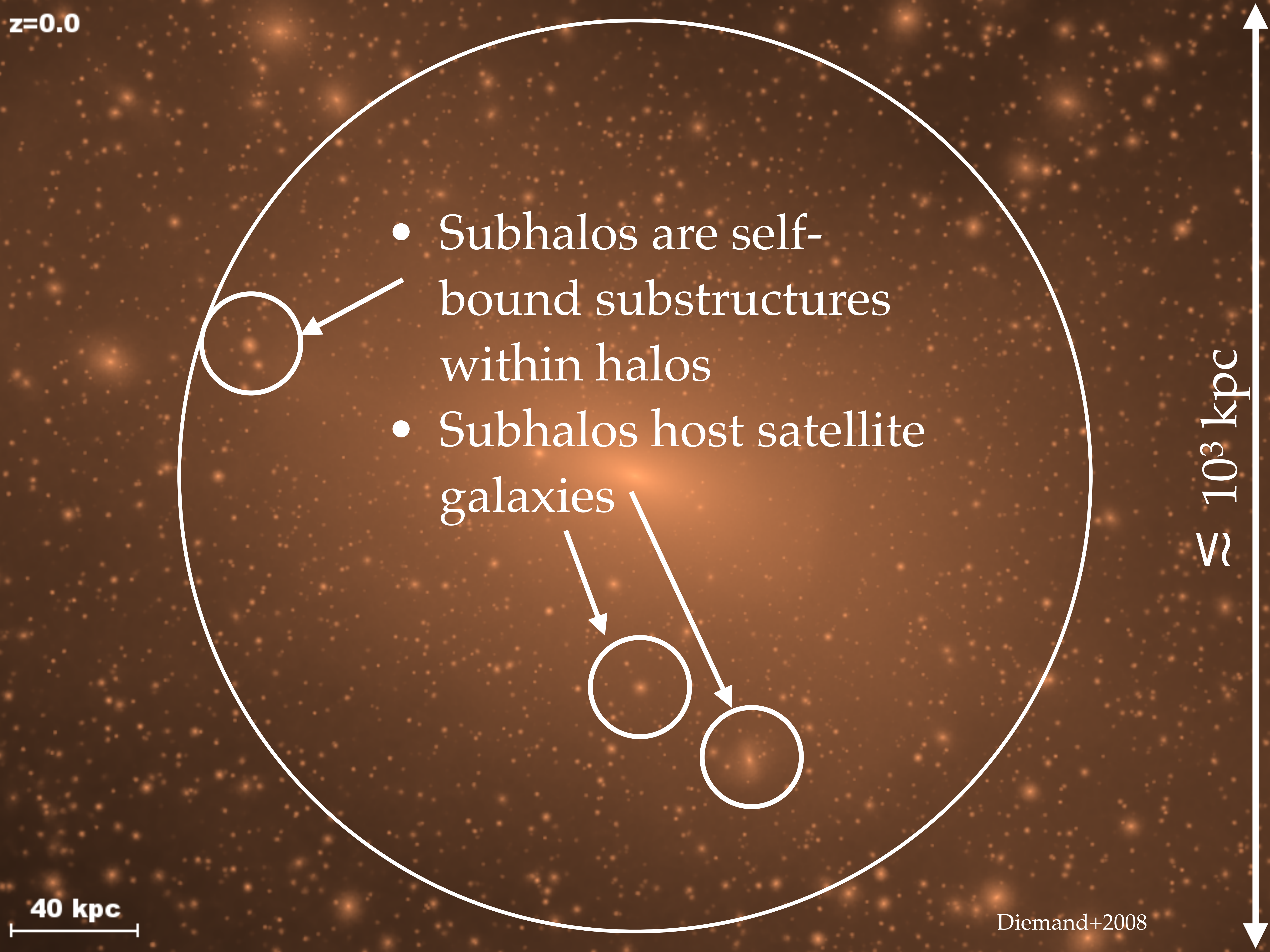
- Halos are the building blocks of nonlinear structure.
- Halos separate linear inflow from nonlinear "viralized" regions.
- Halos are regions that are overdense by a factor of ~200 or so relative to the mean density of the Universe.

$\lesssim 10^3$ kpc

40 kpc

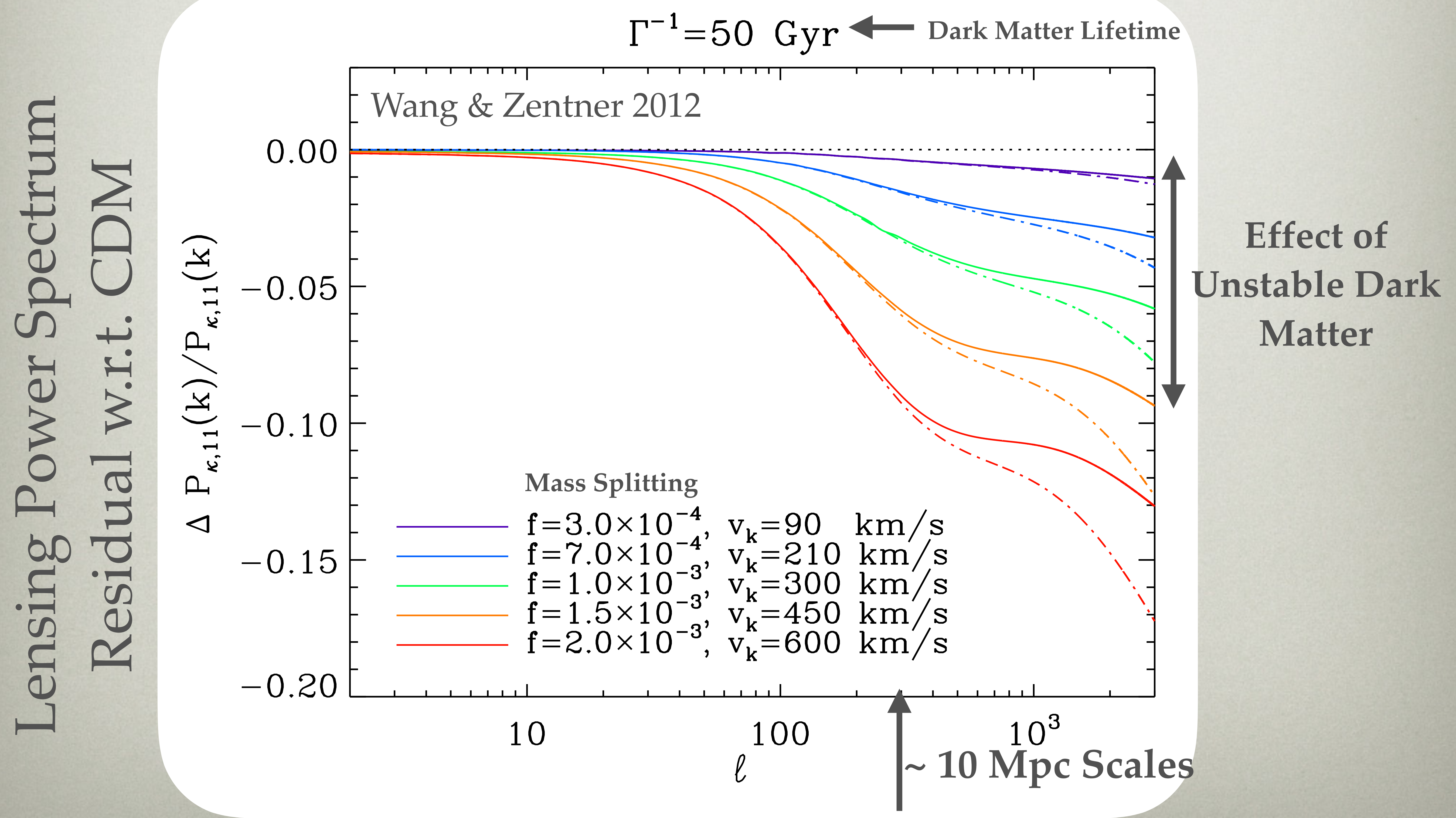
Diemand+2008

- Subhalos are self-bound substructures within halos
- Subhalos host satellite galaxies



Large Scales

- Why do we care?



Large Scales

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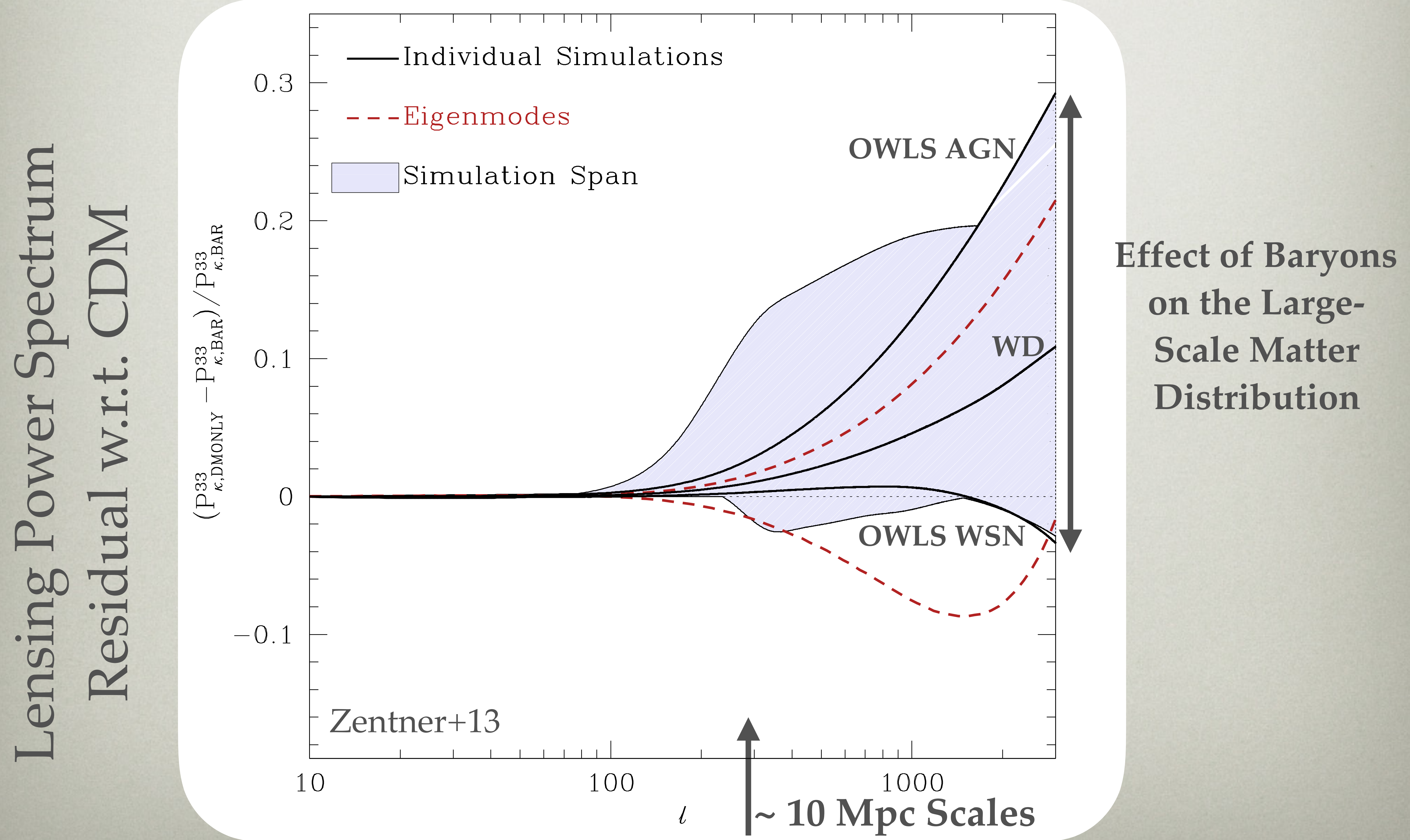

Large Scales

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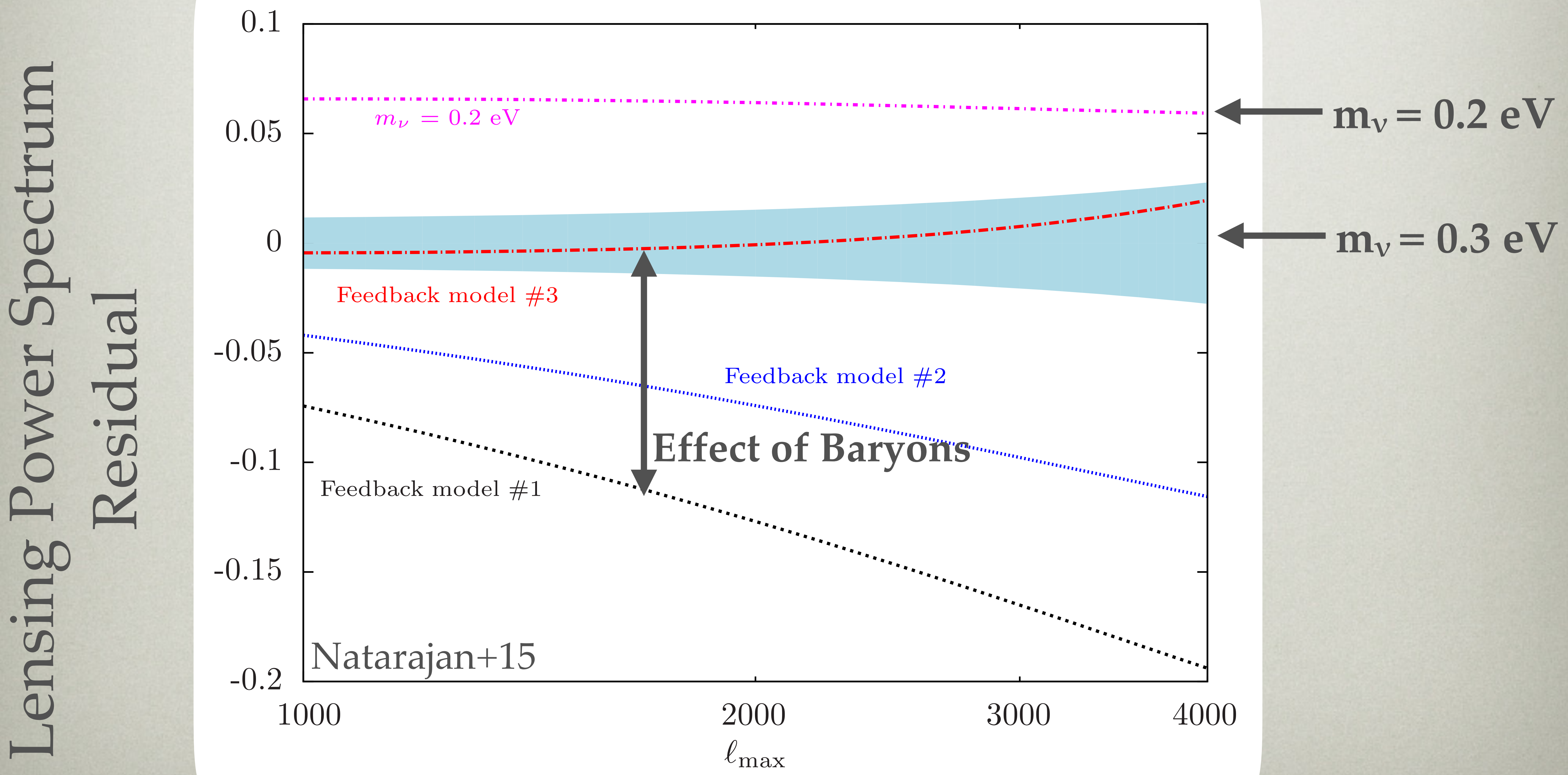
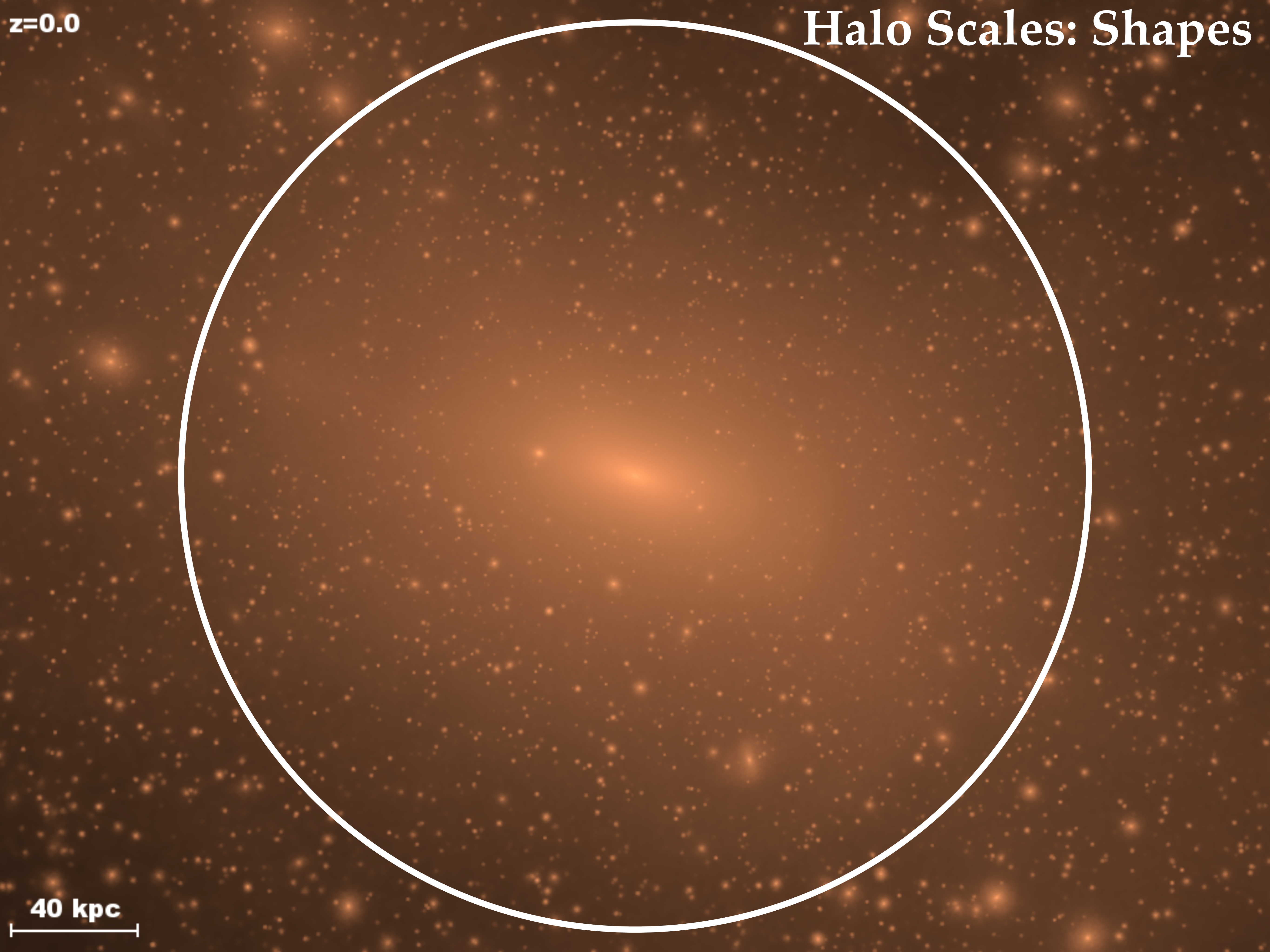


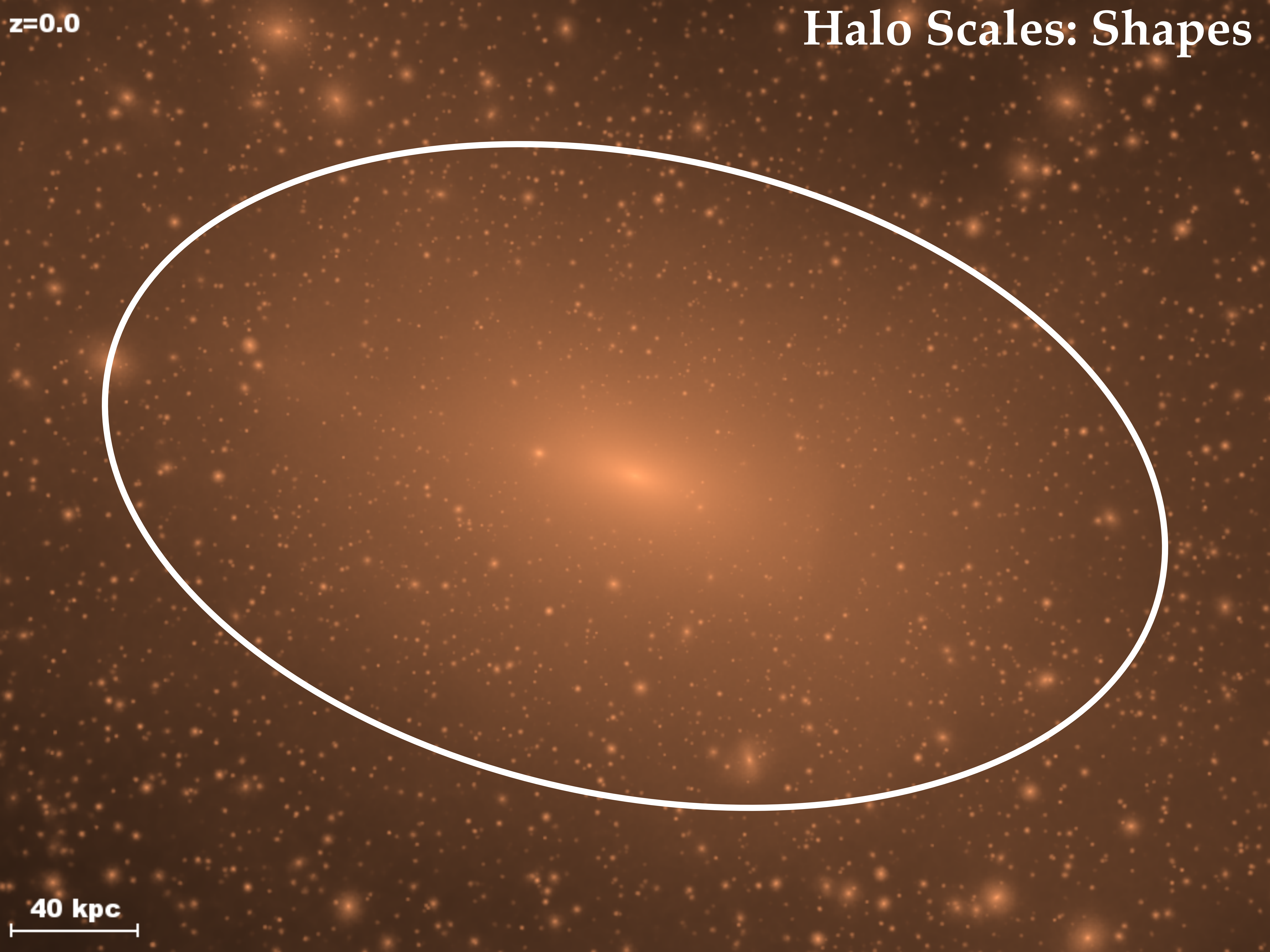
Takeaway

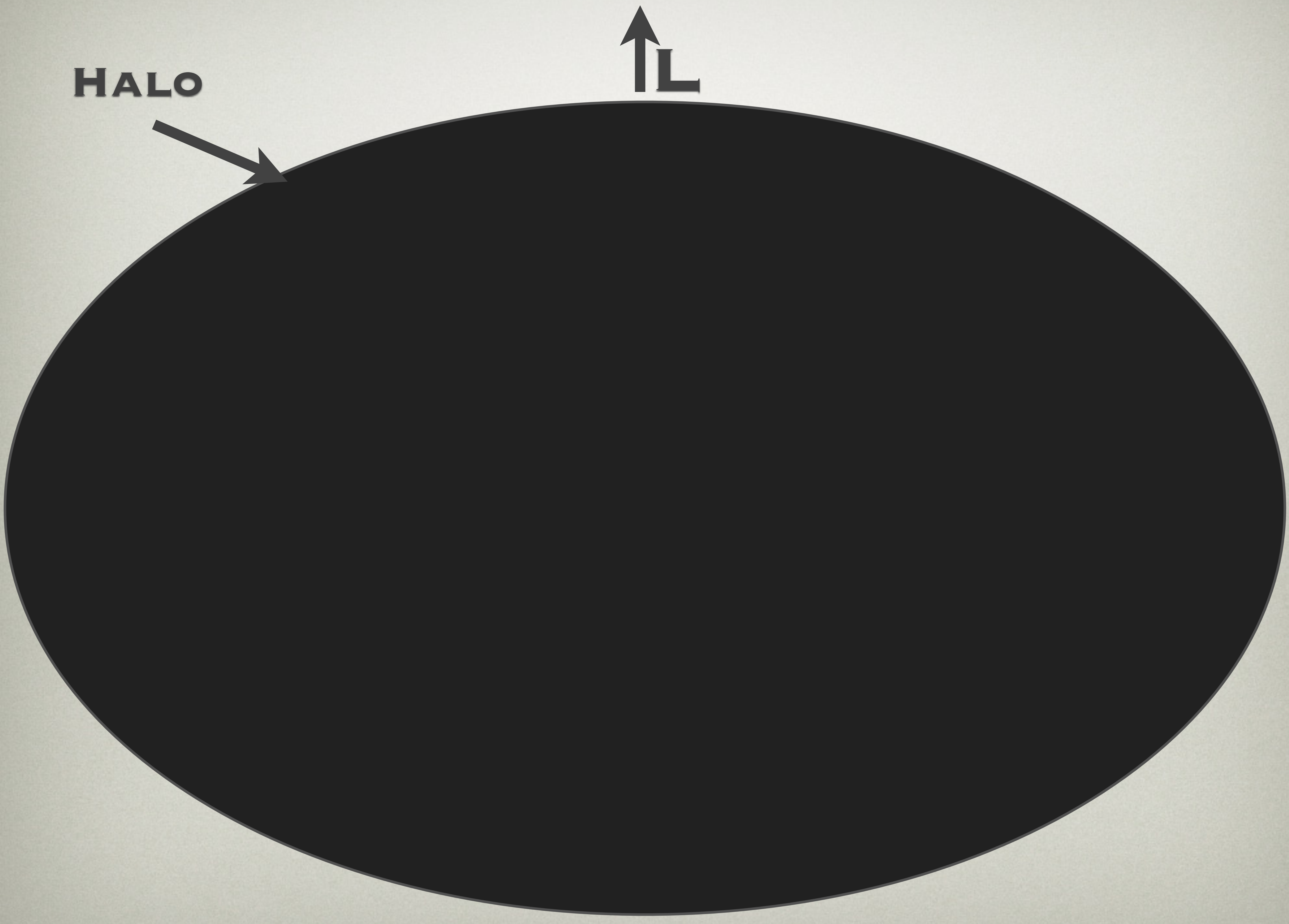
- Baryonic processes can modify the clustering of dark matter in a complicated manner.
- This represents a challenge to cosmological (particularly lensing) probes of dark matter, dark energy, and neutrino mass.

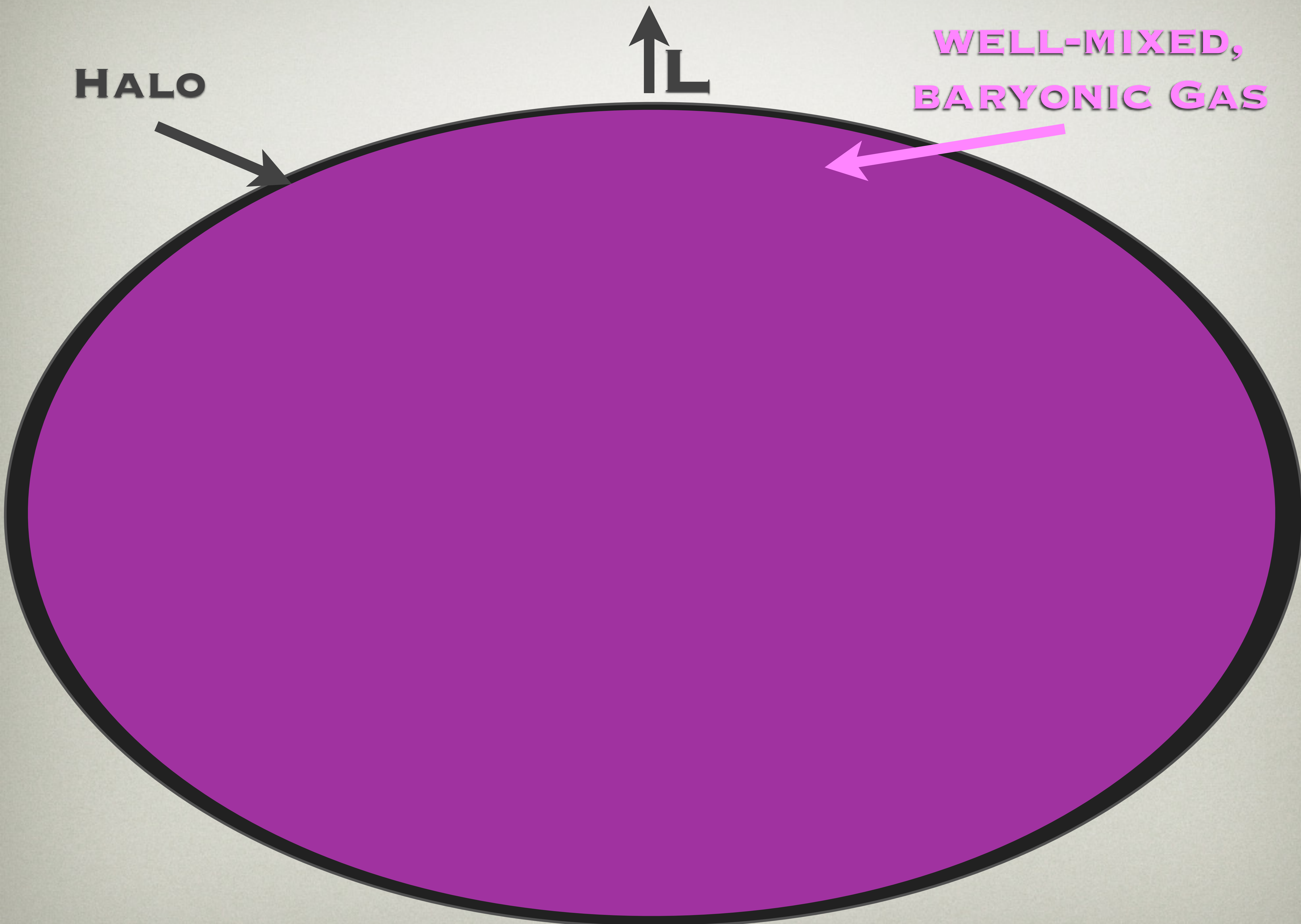
Halo Scales: Shapes

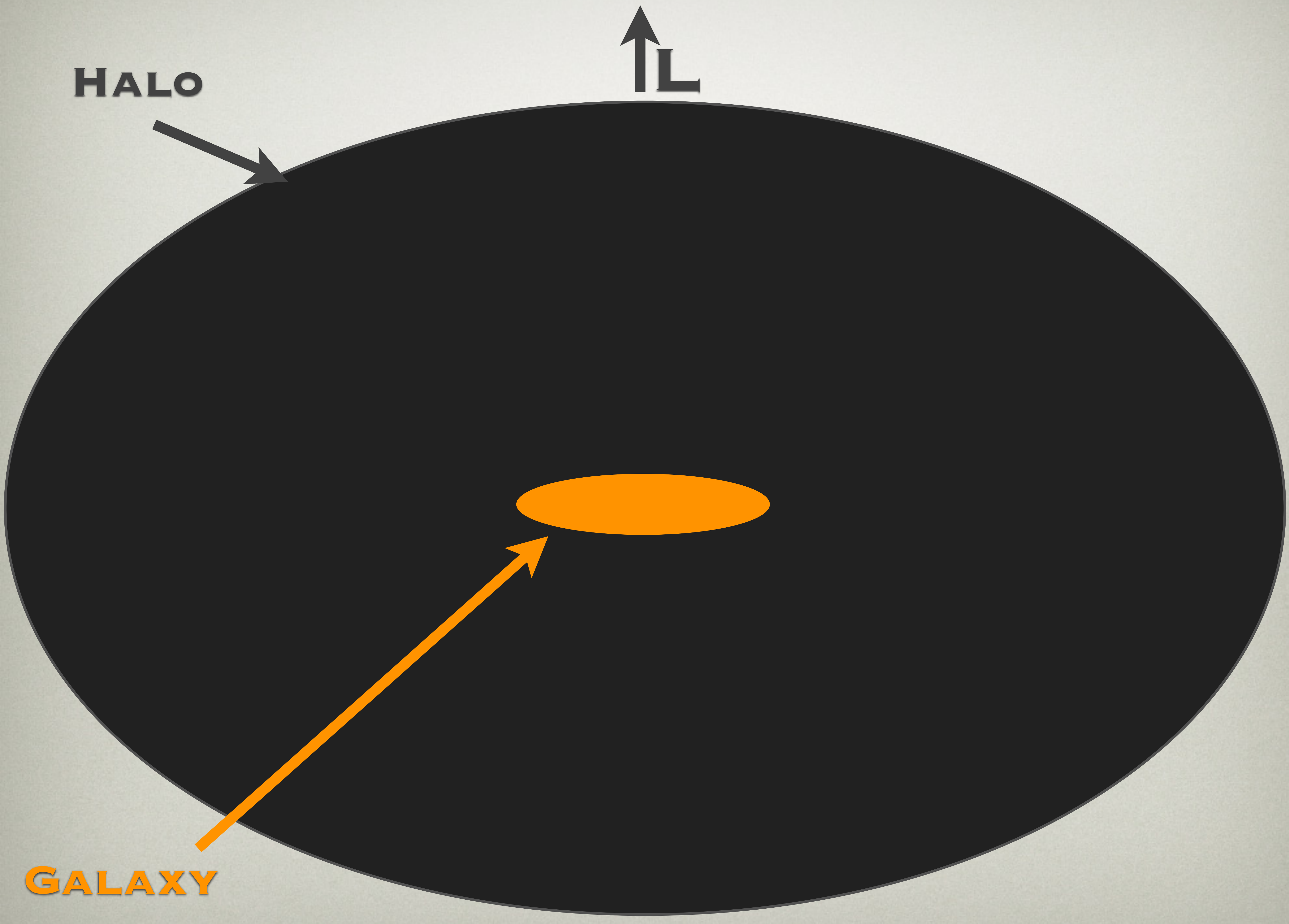


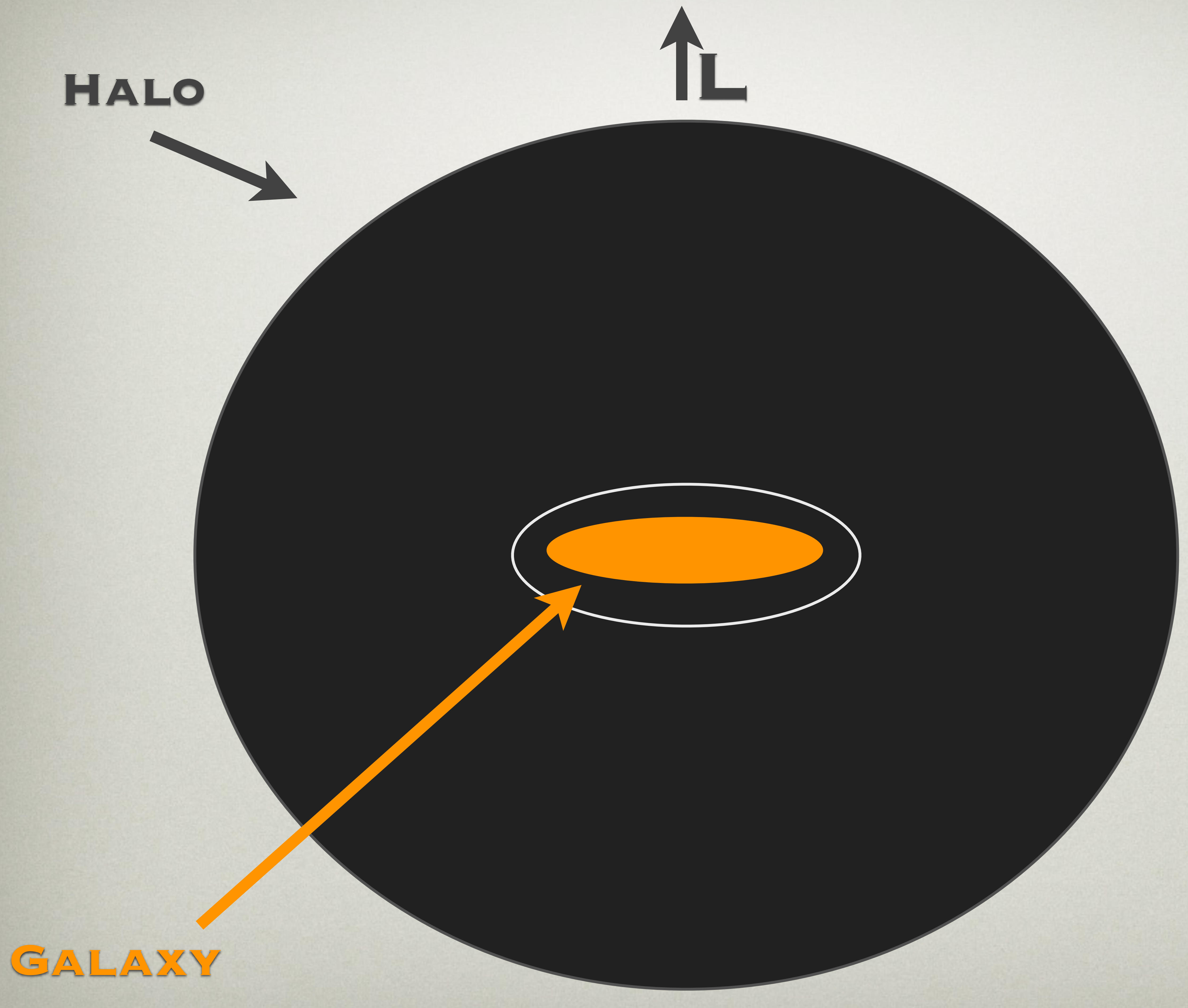
Halo Scales: Shapes




Halo
L


Halo
L
well-mixed,
baryonic Gas

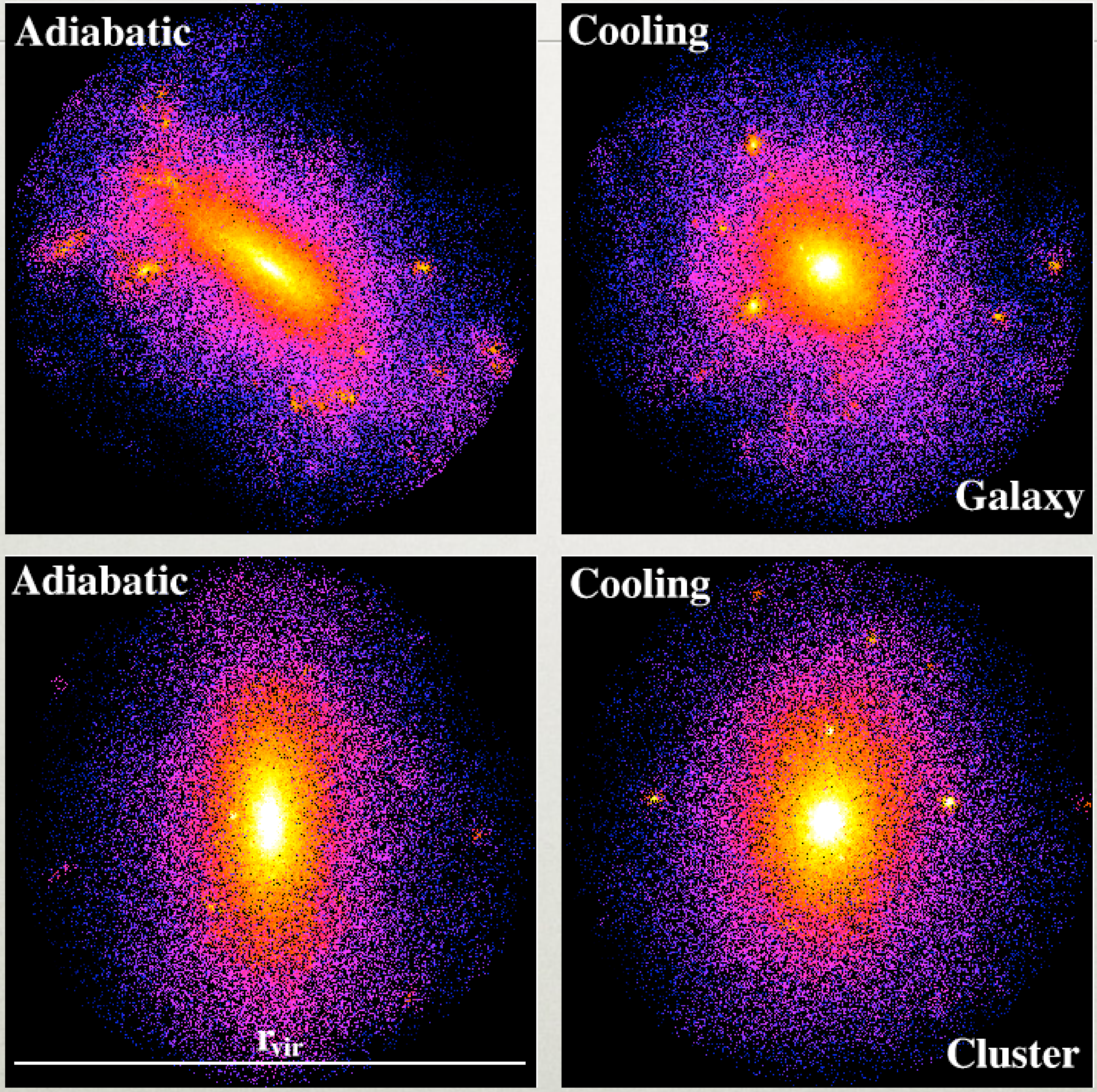

L
Halo
Galaxy



Halo
L
Galaxy

With Baryons

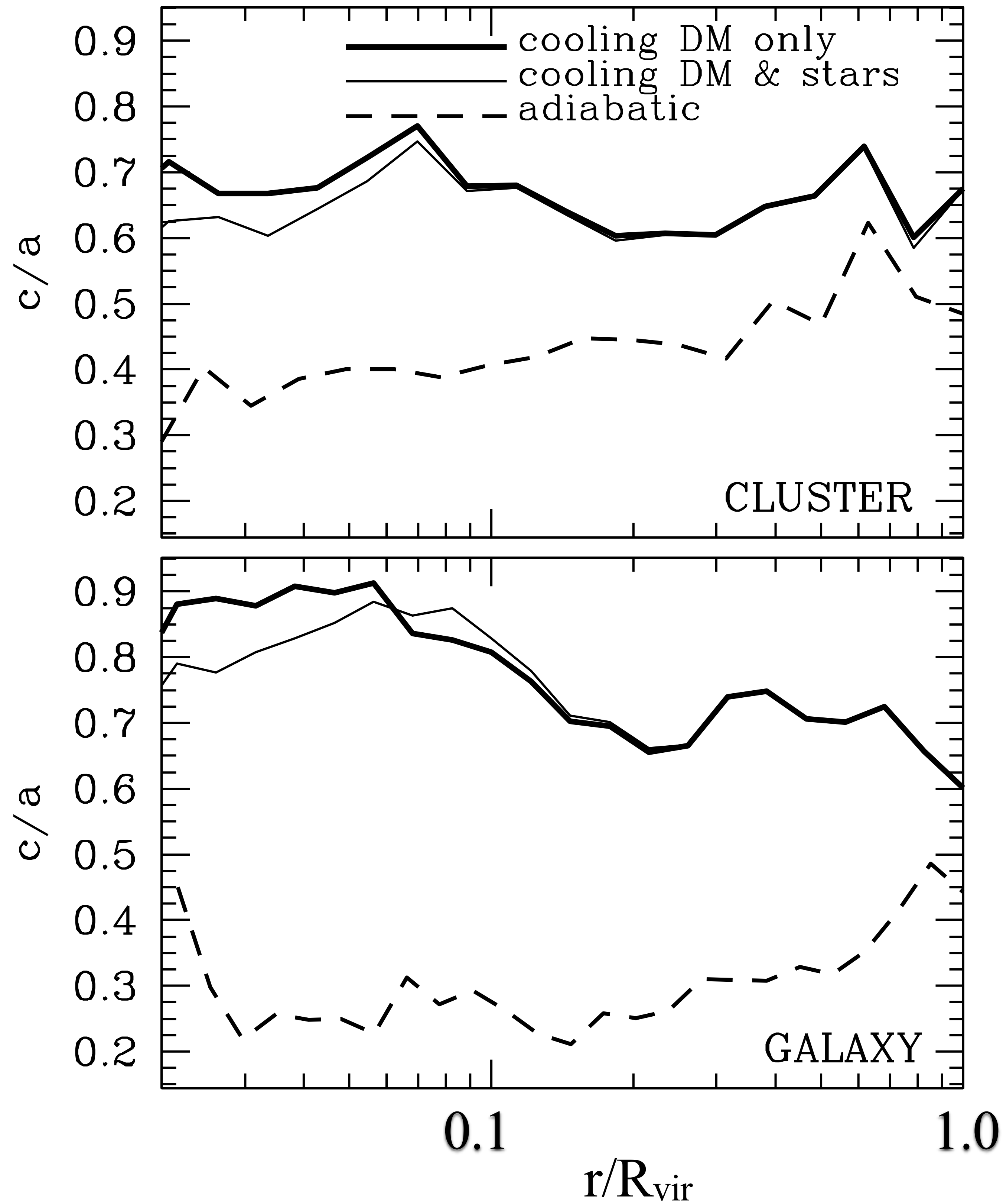
No Baryon cooling   With Baryon cooling



Kazantzidis+05

- Halos become more spherical when baryons are included

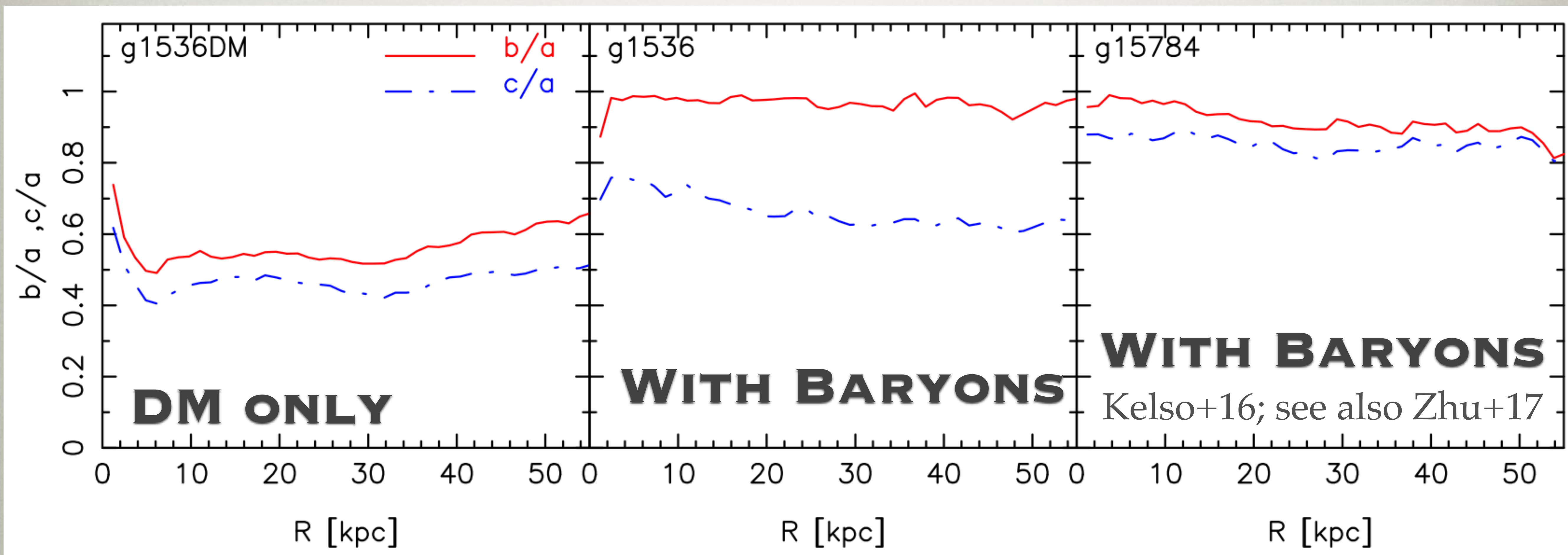
With Baryons



Baryons tend to make halos more spherical than they appear in gravity-only N-body simulations.

Kazantzidis+05

MW-like Sims With Baryons

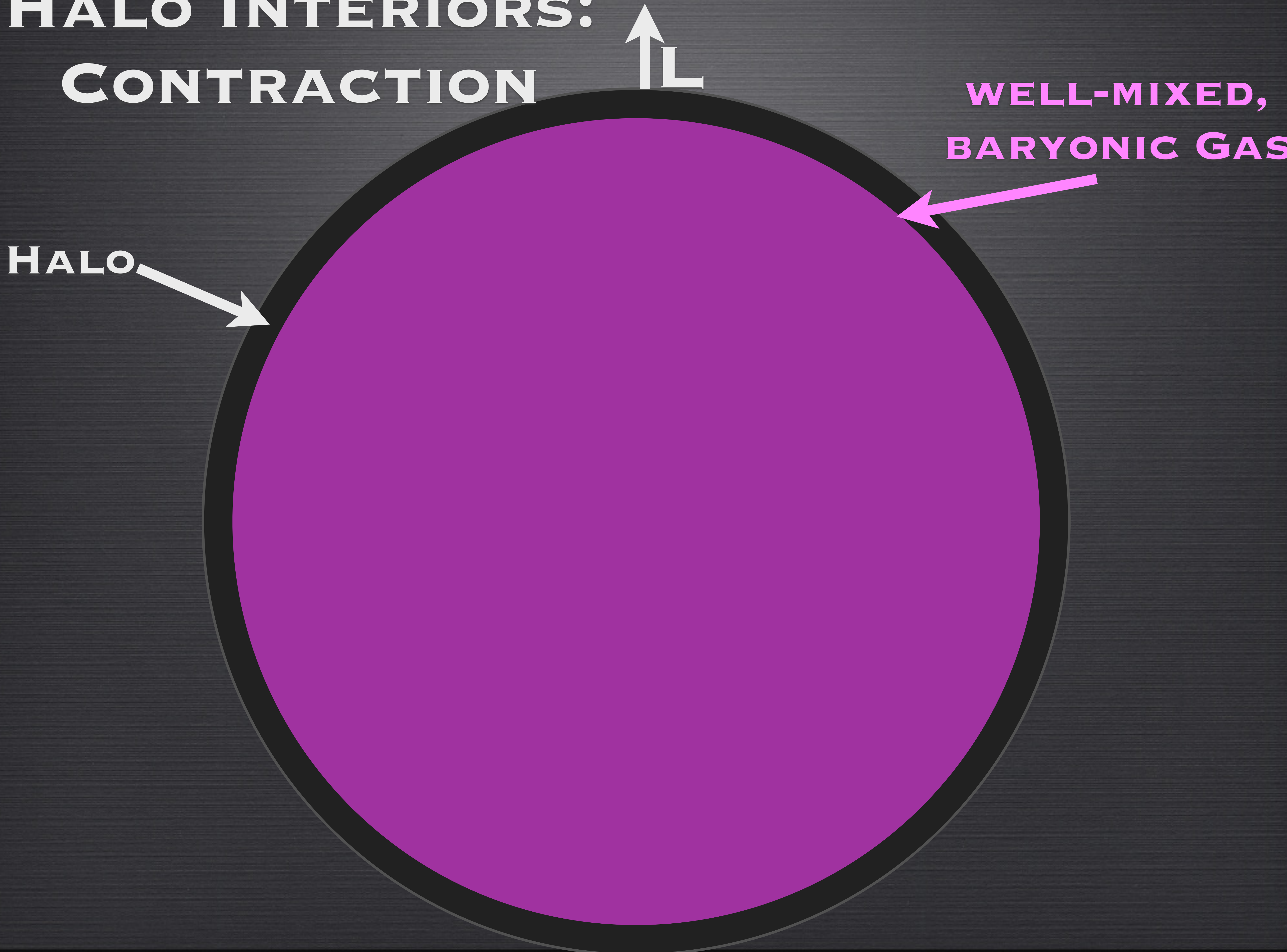


- This effect is evident in zoom-in simulations tailored to mimic the Milky Way

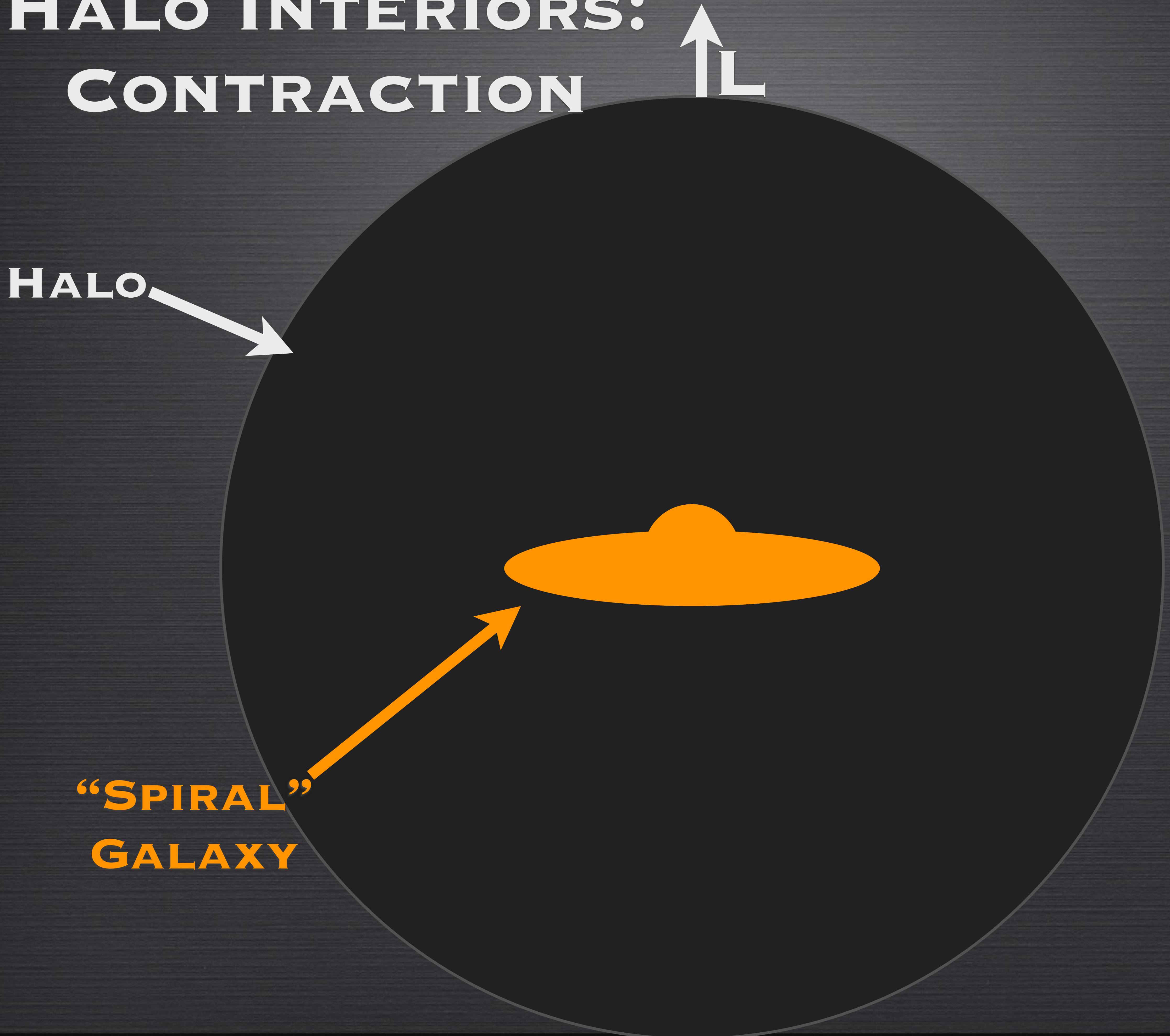
Takeaway

- Baryons alter the shapes of dark matter halos, generally making them more spherical.
- Difficult to use the shapes of halos to determine the degree of relaxation halos have experienced.
- This “sphericalization” also extends to the velocity ellipsoid
- A simple, standard halo model is a better description of the local dark matter density than N-body only simulations might suggest.

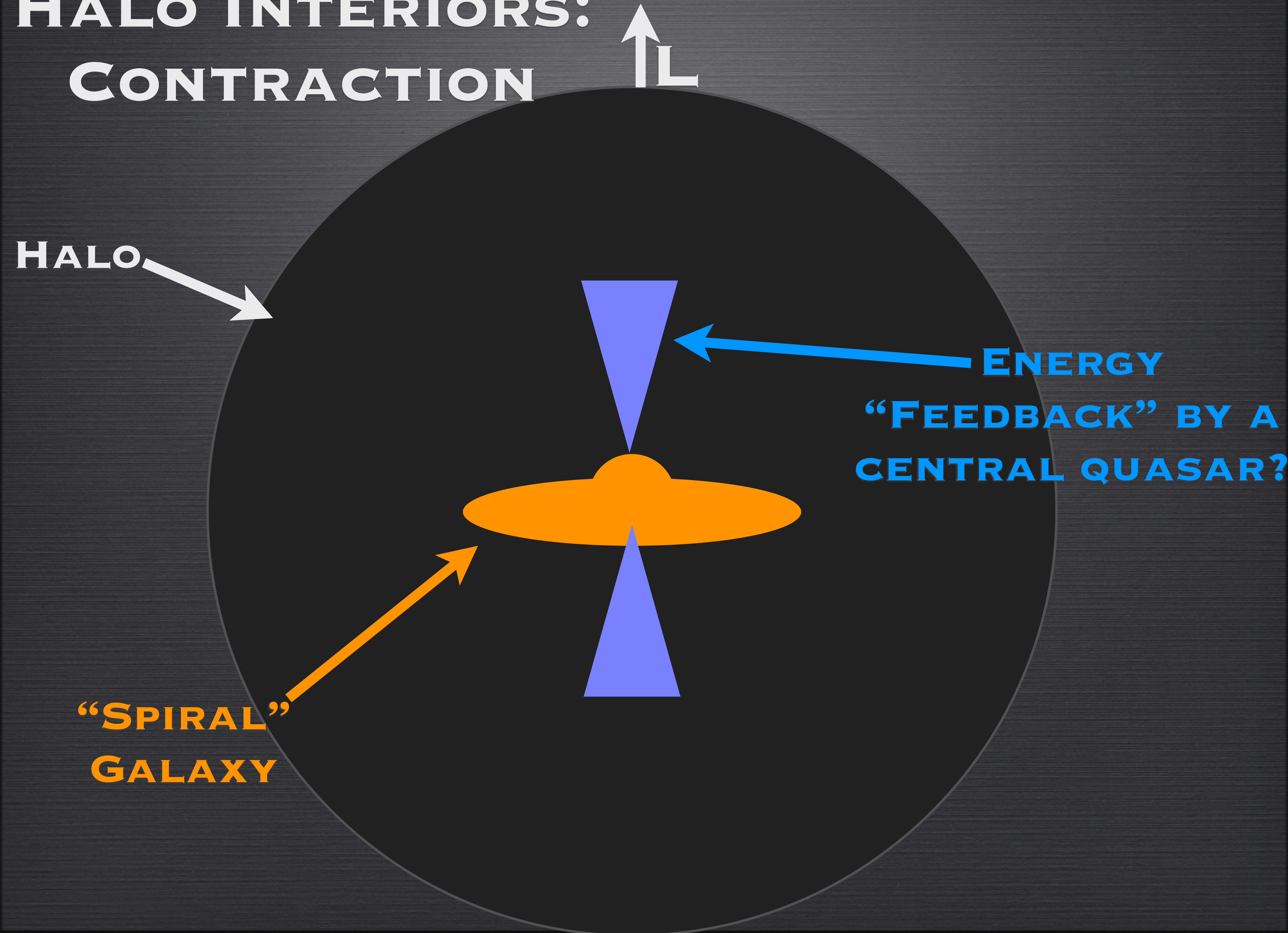
Halo Interiors: Contraction



Halo Interiors: Contraction



Halo Interiors: Contraction



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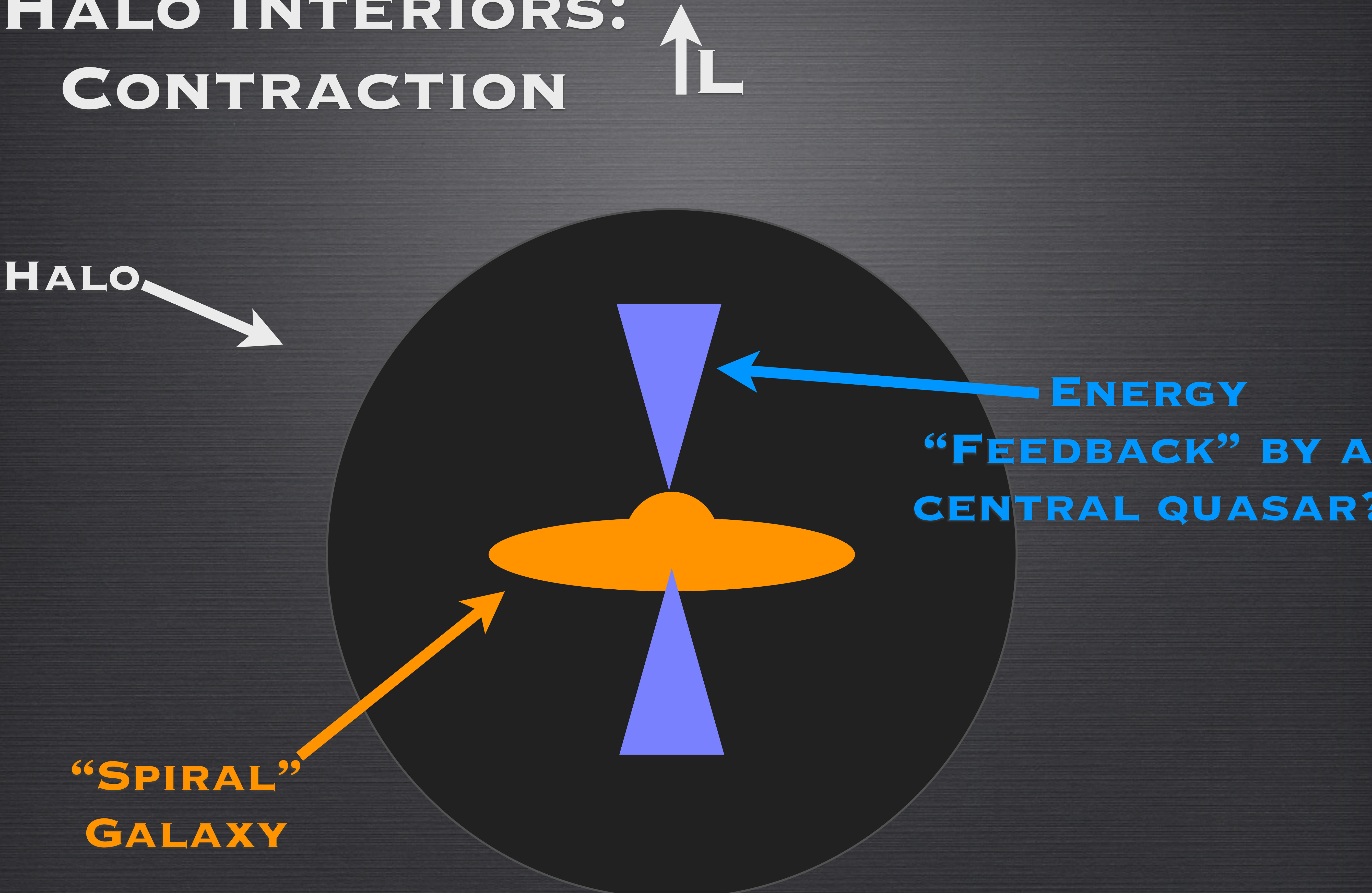
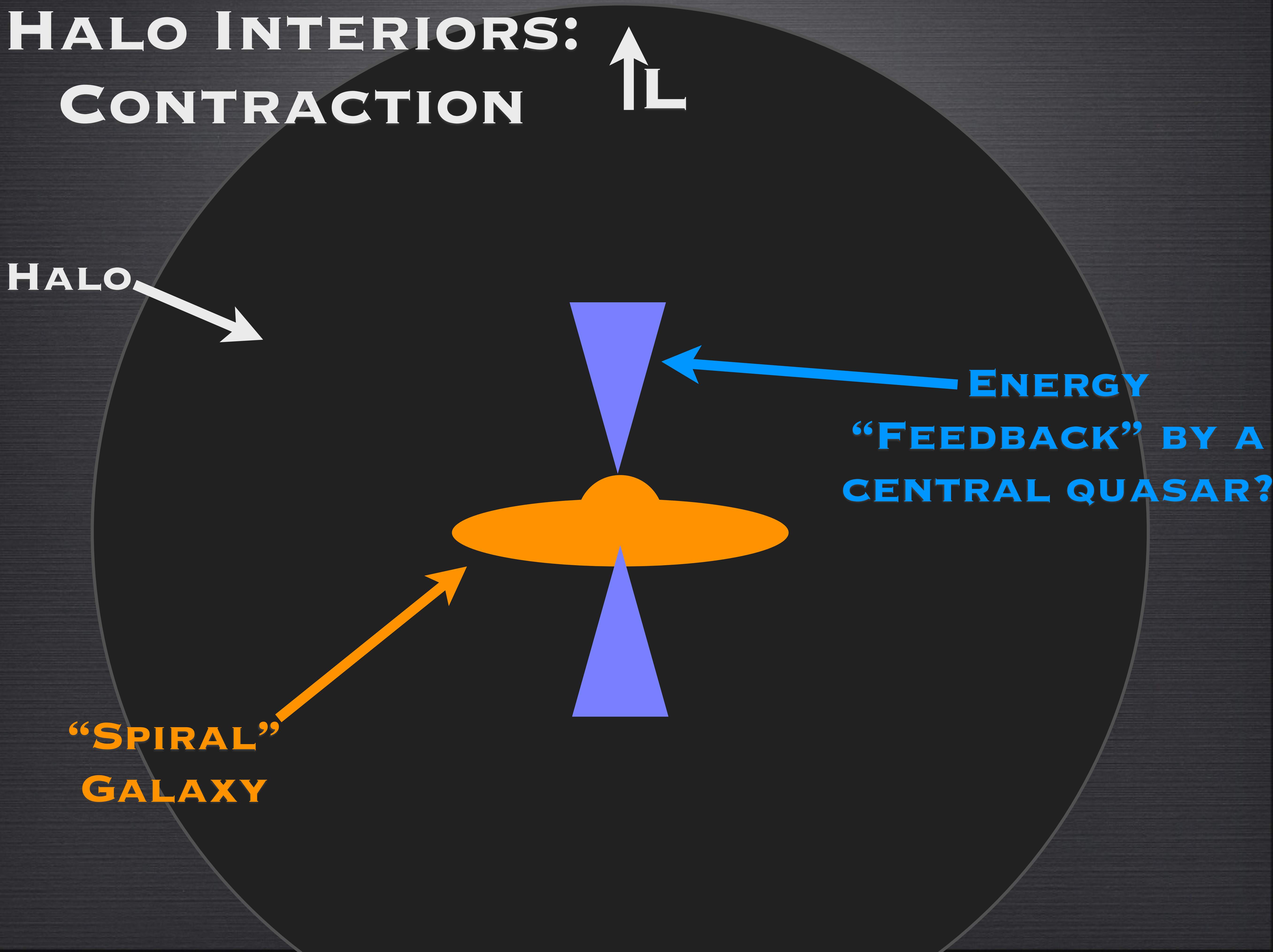
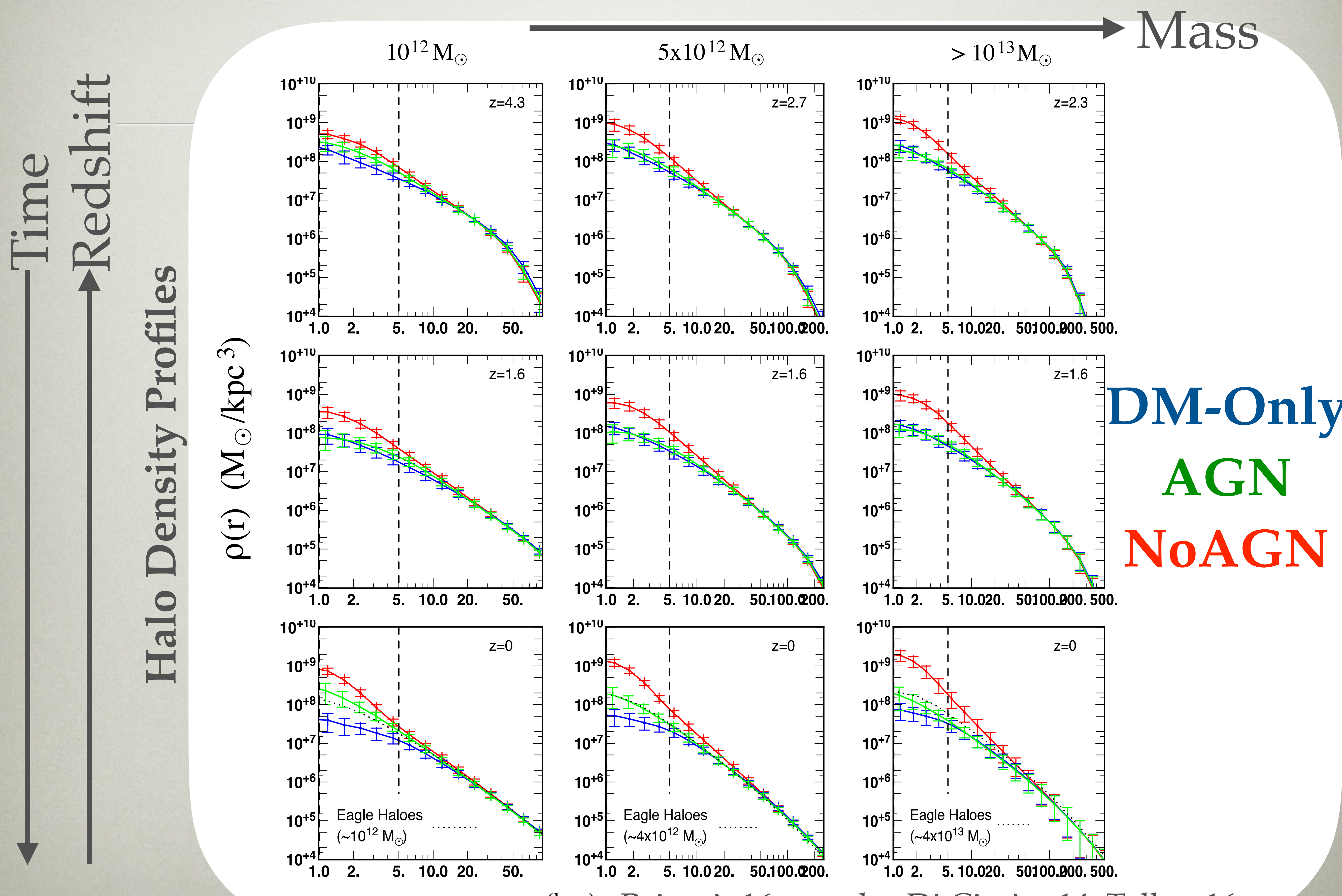


Halo Interiors: Contraction



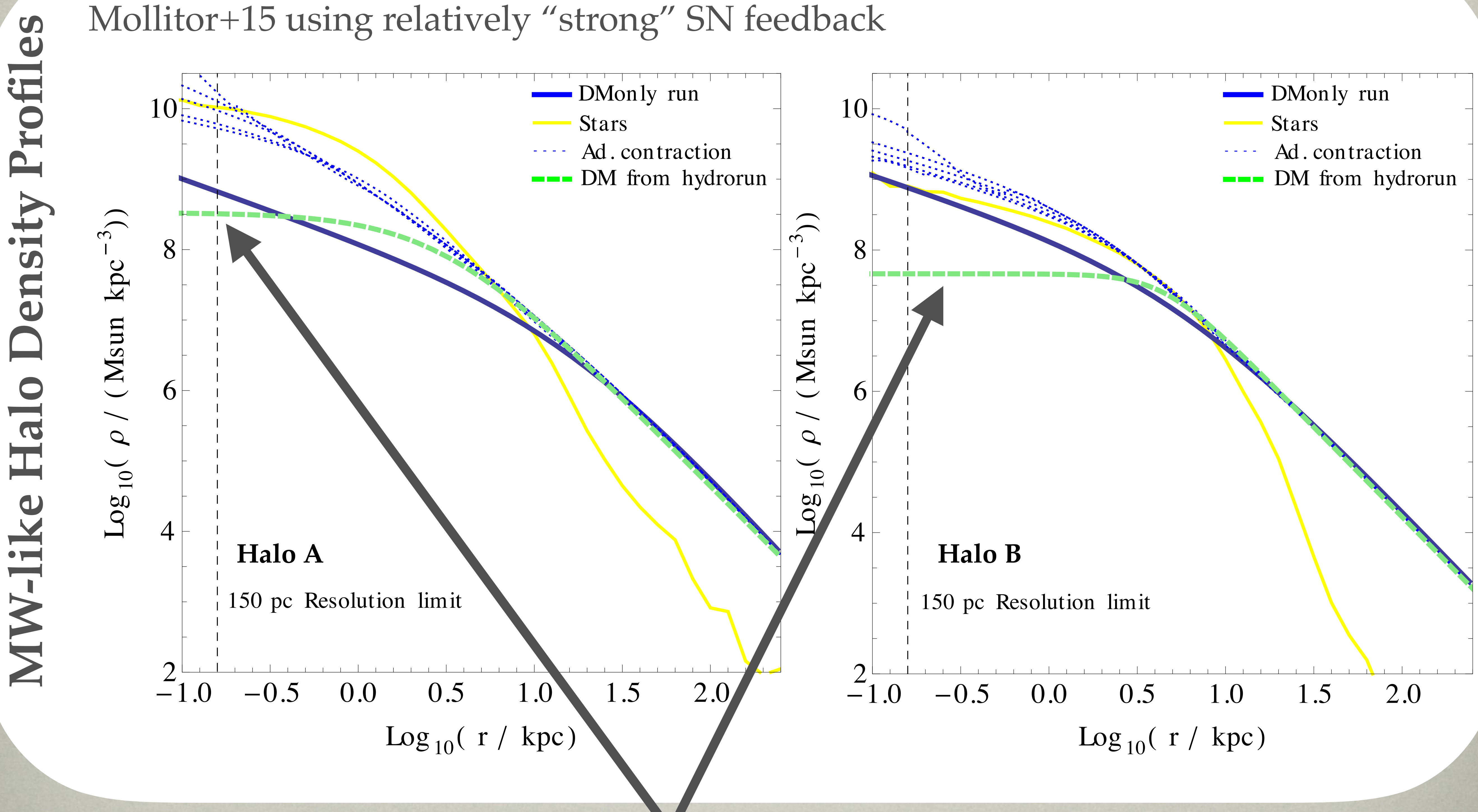
Halo Profiles



Peirani+16, see also Di Cintio+14; Tollet+16

Halo Profiles

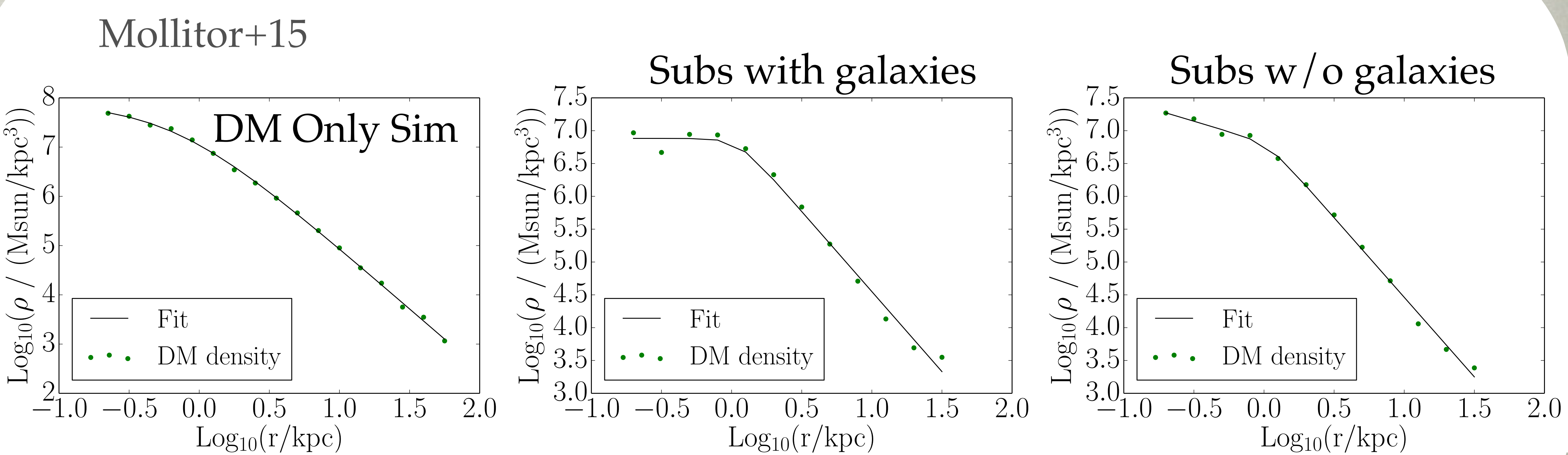
Mollitor+15 using relatively "strong" SN feedback



DM Core evacuated by feedback

Subhalo Profiles

Subhalo Density Profiles



- Simulations with strong SN feedback can induce inner profile shallowing in subhalos both with and without galaxies within them.

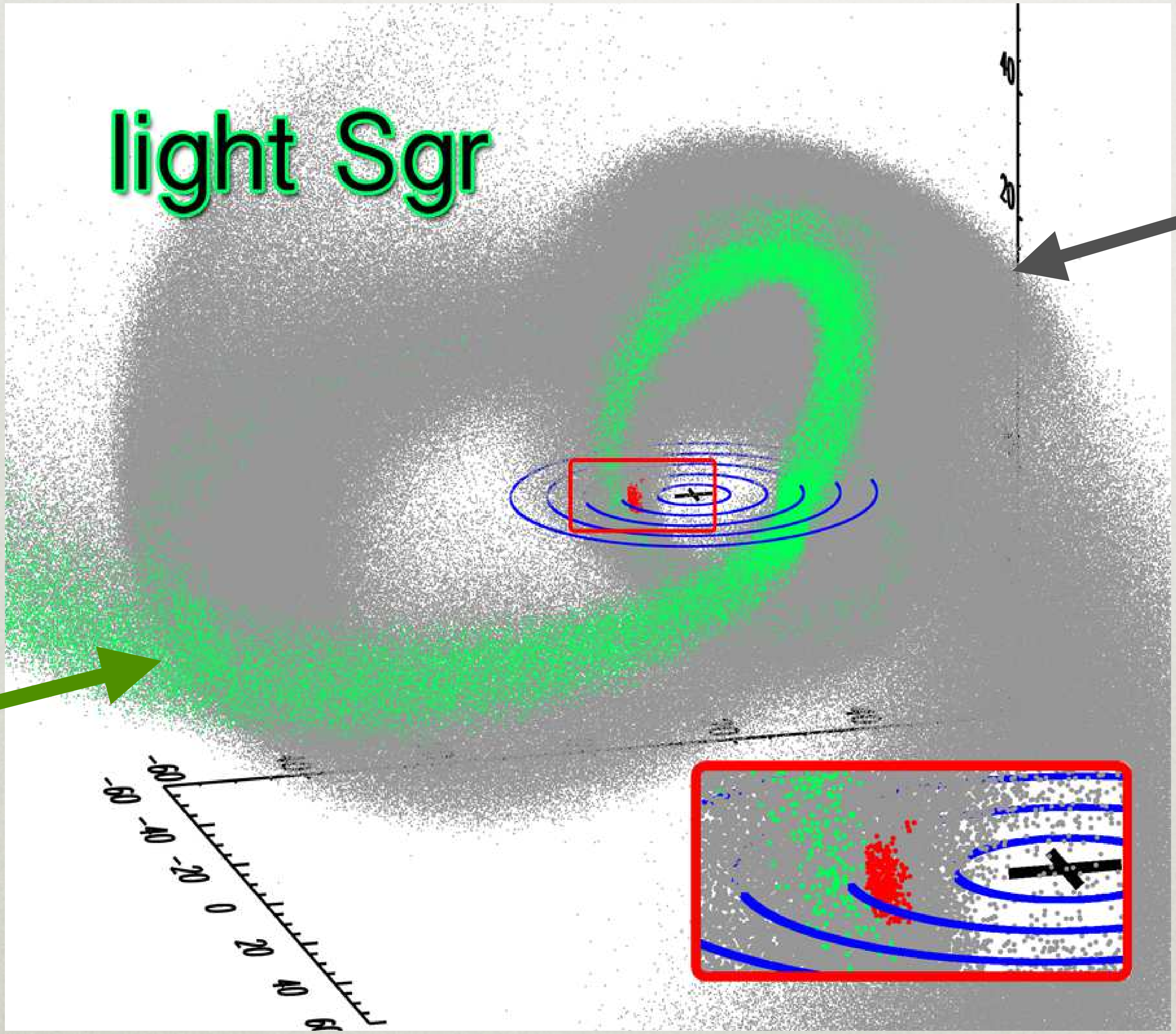
Takeaway

- Baryons can alter the density profiles of both MW-like halos and their subhalos.
- The manner in which they are modified depends upon simulation physics and implementations as well as physical complexities such as time since AGN activity or star formation.
- Statements about DM that rely on particular assumptions about density profiles cannot yet be taken robustly.

Sagittarius

- The Sagittarius dwarf galaxy is a galaxy that is currently being stripped of material due to its interaction with the Milky Way.
- Sagittarius' tidal streams were observed in SDSS.
- It has been proposed that this could lead to enhanced direct search rates because the Sagittarius material has a large relative velocity to the Solar System (e.g., Freese+04; Savage+06; Nataragan+11; …)

Sagittarius



Dark Matter

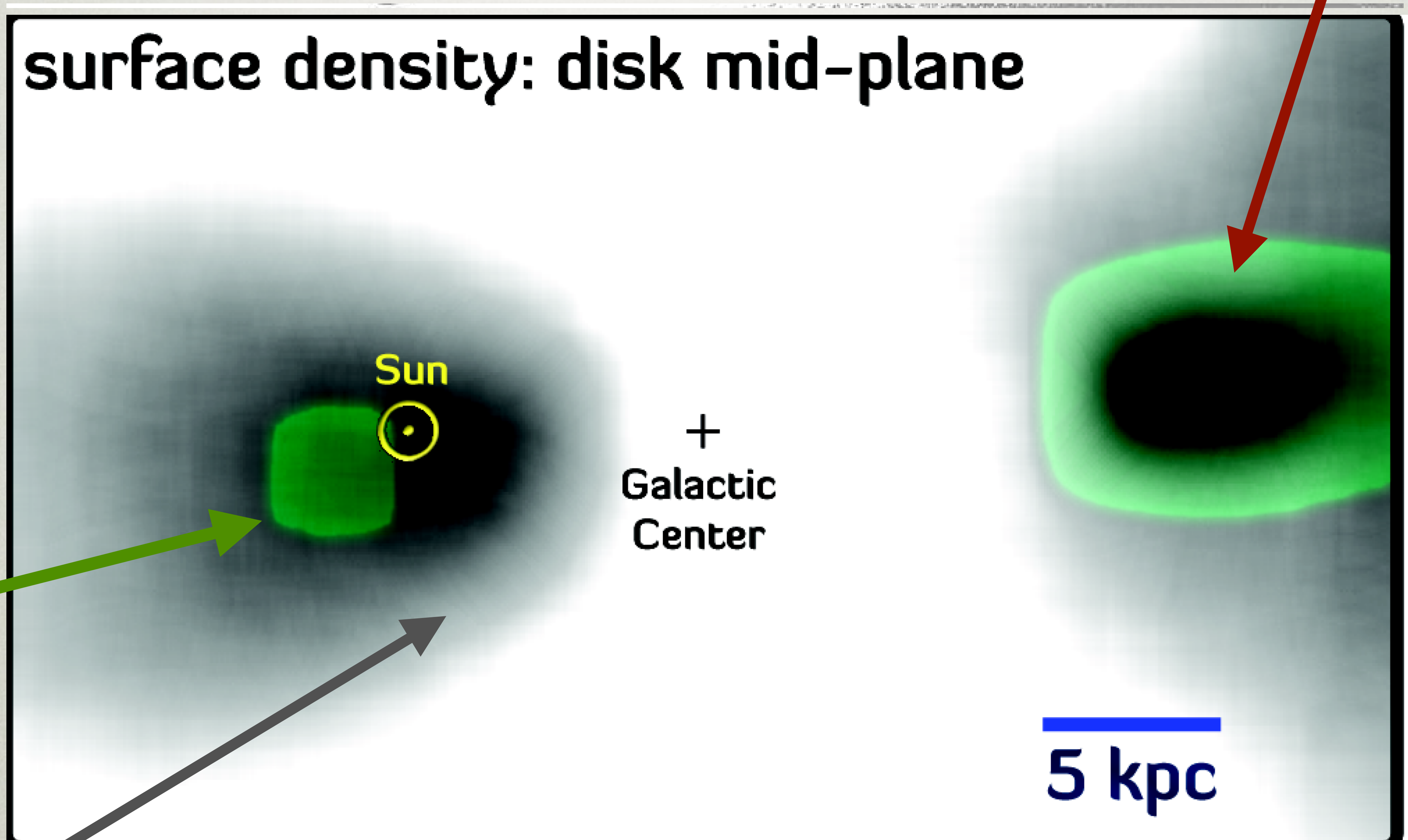
Stars

Purcell+13

Sagittarius

Present Location Sag. Galaxy

Purcell+13



Stars

Dark Matter: Speed relative to Solar System ~ 400 km/s

Takeaway

Purcell+13

- Dark matter from the Sagittarius disruption should be quite extended and likely penetrates the Solar System despite the fact that the stellar material from Sagittarius impacts the stellar disk several kpc from the Solar System.
- Dark matter from Sagittarius can make up ~1% (at most 5%) of the local dark matter but impacts the Solar System with v_{Sag} ~ 400-500 km/s.

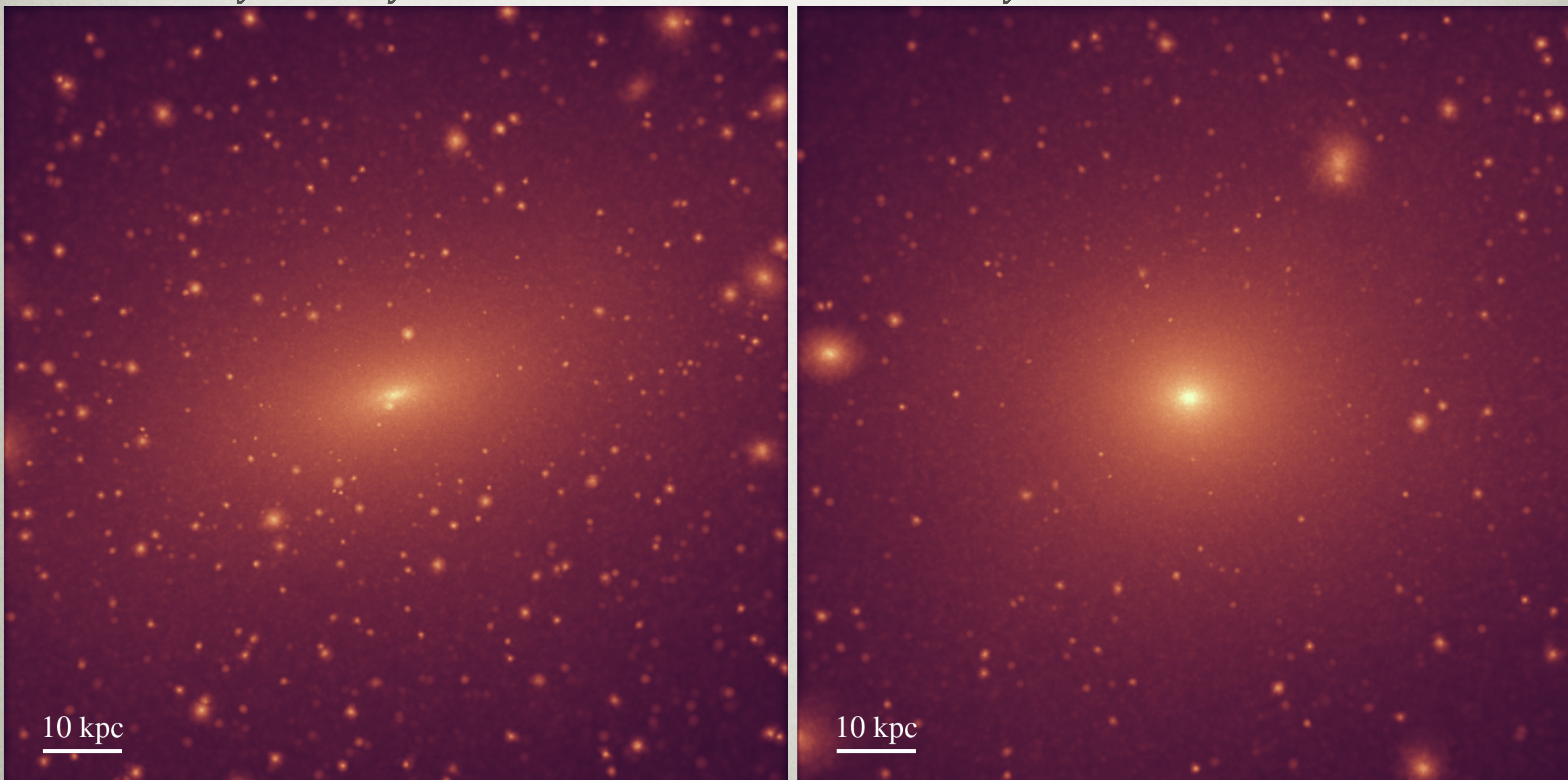
Takeaway

- Using these simulations we find (Purcell+13)
  - Possibly large (20-100%) increases in DD rates for low-mass dark matter ($\lesssim$ 20 GeV)
  - A significant (up to factor of 2) decrease in the amplitude in the annual modulation signal for low-mass dark matter
  - A shift in phase of the annual modulation by as much as 30 days.

Subhalos & Baryons

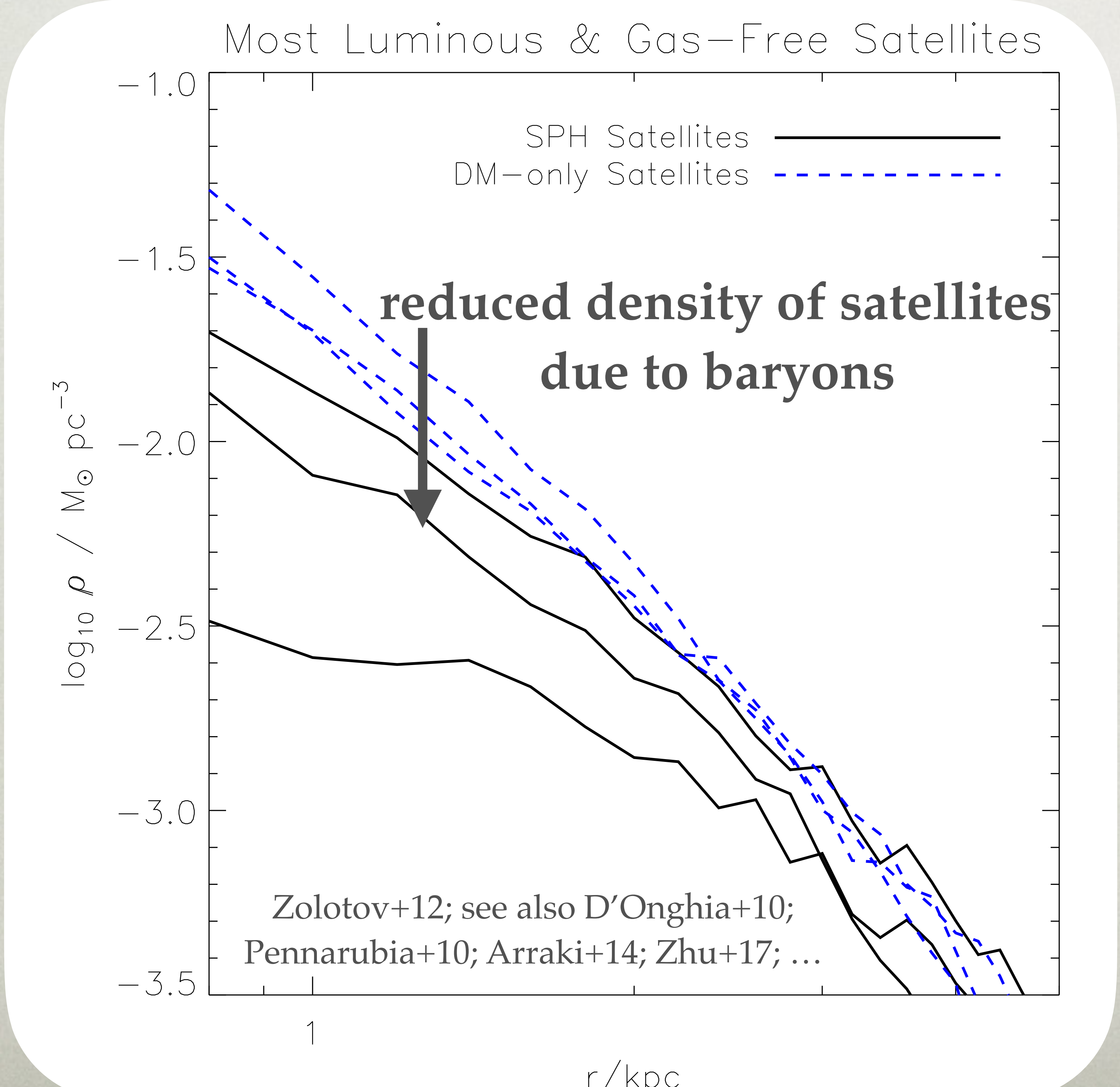
Garrison-Kimmel+17

DM Only, N-body Simulation | **Galaxy Formation Simulation**

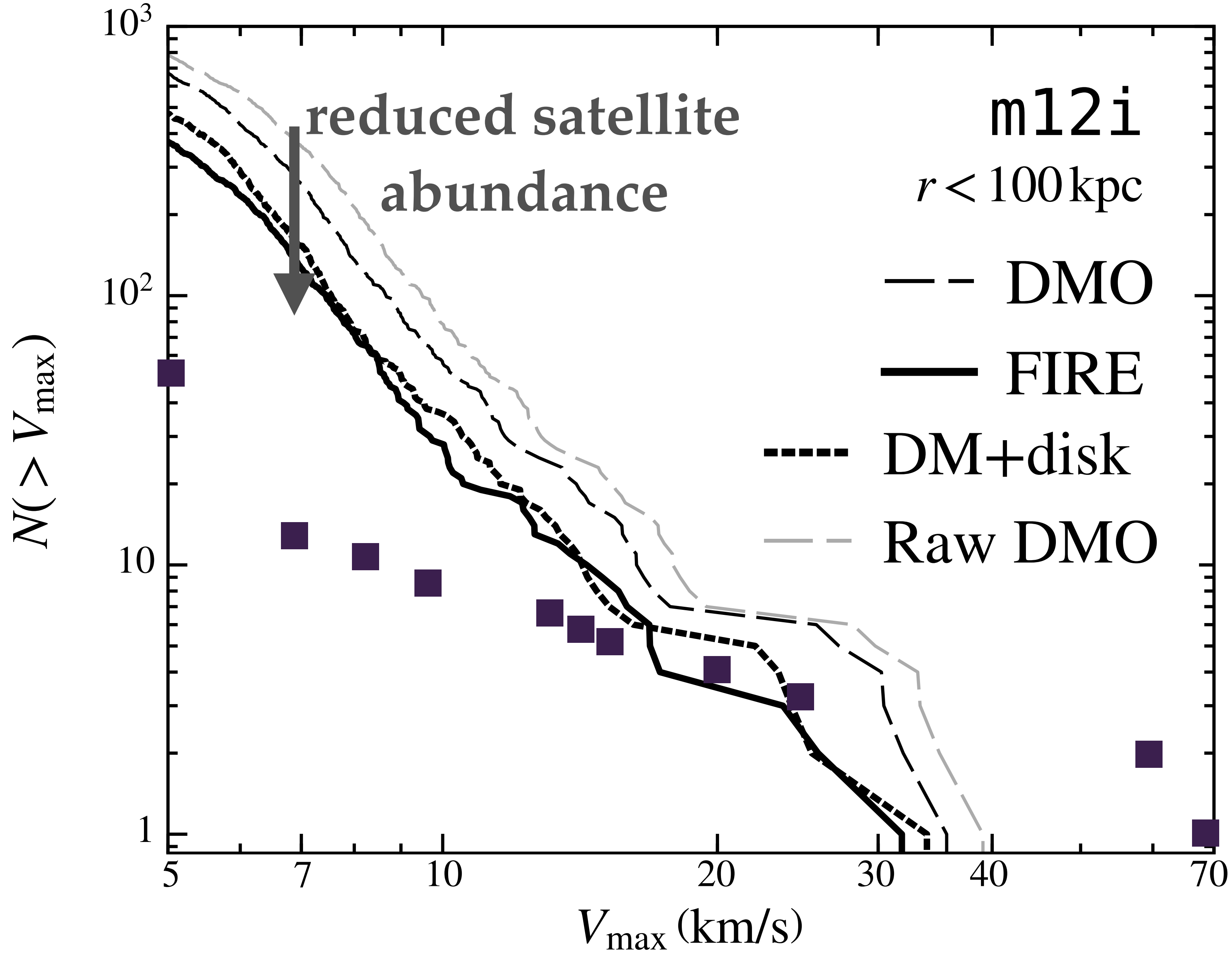


Also, Zolotov+12, Brooks+13, Peirani+16, …

Subhalos & Baryons

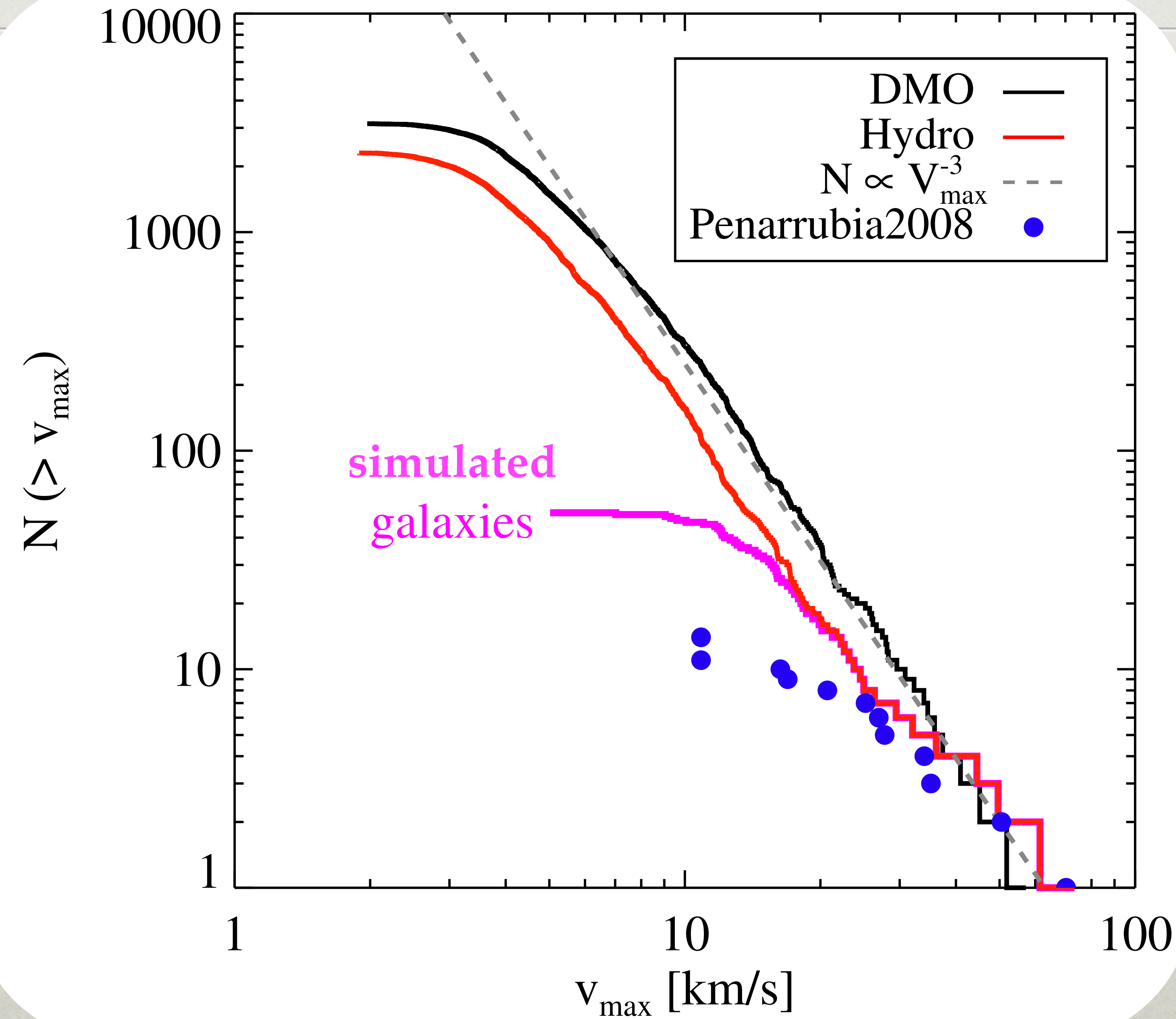


Subhalos & Baryons



Garrison-Kimmel+17; see also D'Onghia+10; Pennarubia+10; Arraki+14; Zhu+17; …

Subhalos & Baryons



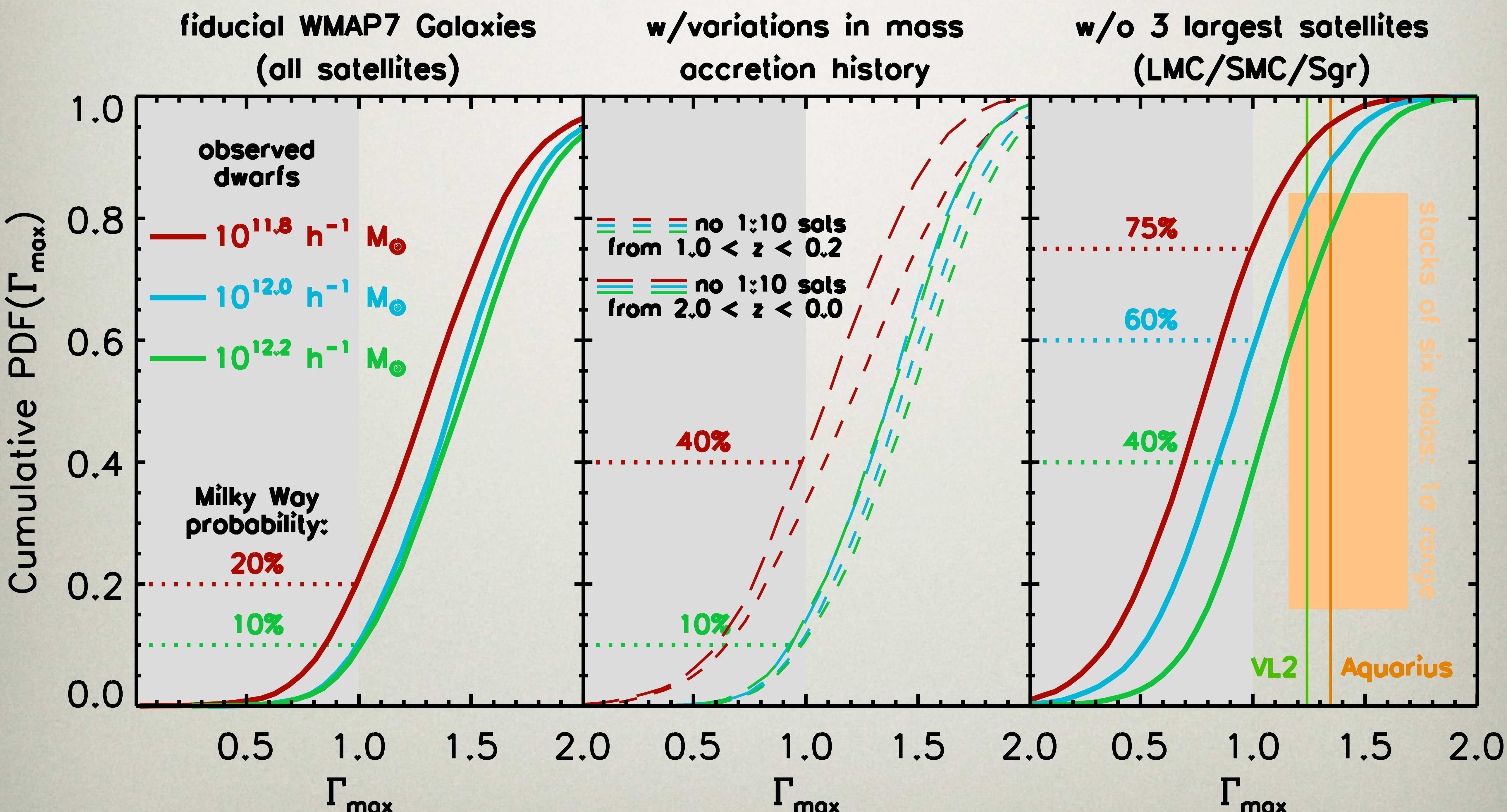
Zhu+17; see also Garrison-Kimmel+17;
D'Onghia+10; Pennarubia+10; Arraki+14; …

Takeaway

- Baryonic effects reduce the densities of small dark matter satellite halos as well as their abundance in state-of-the-art simulations.
- These effects include ionizing radiation from the MW itself as well as energy injection from SNe.
- The dominant effect is the additional tidal force that halos experience due to the MW disk.
- This reduction in subhalo abundance can have important consequences for small-scale CDM predictions.

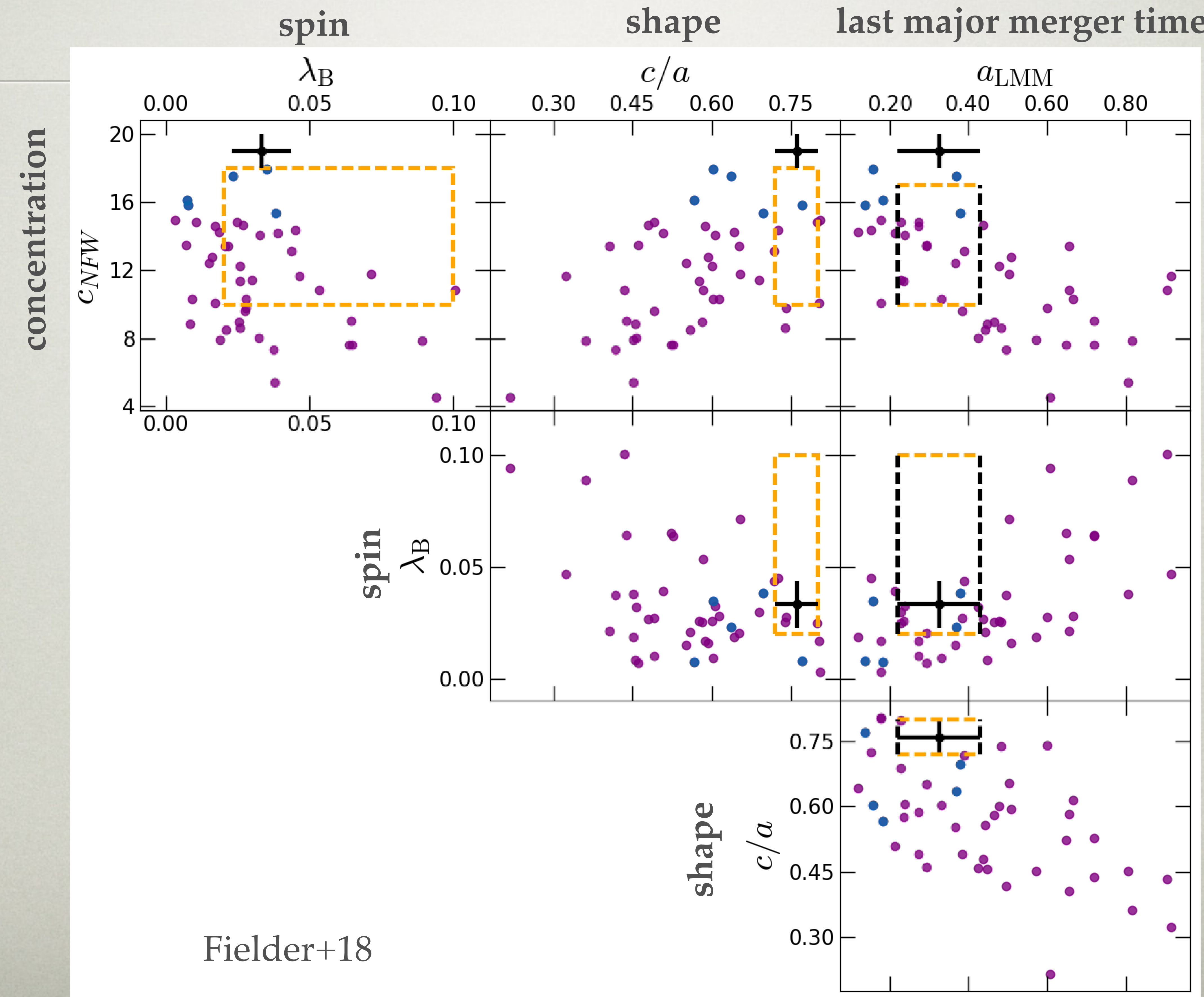
Subhalo Populations

Purcell & Zentner+12

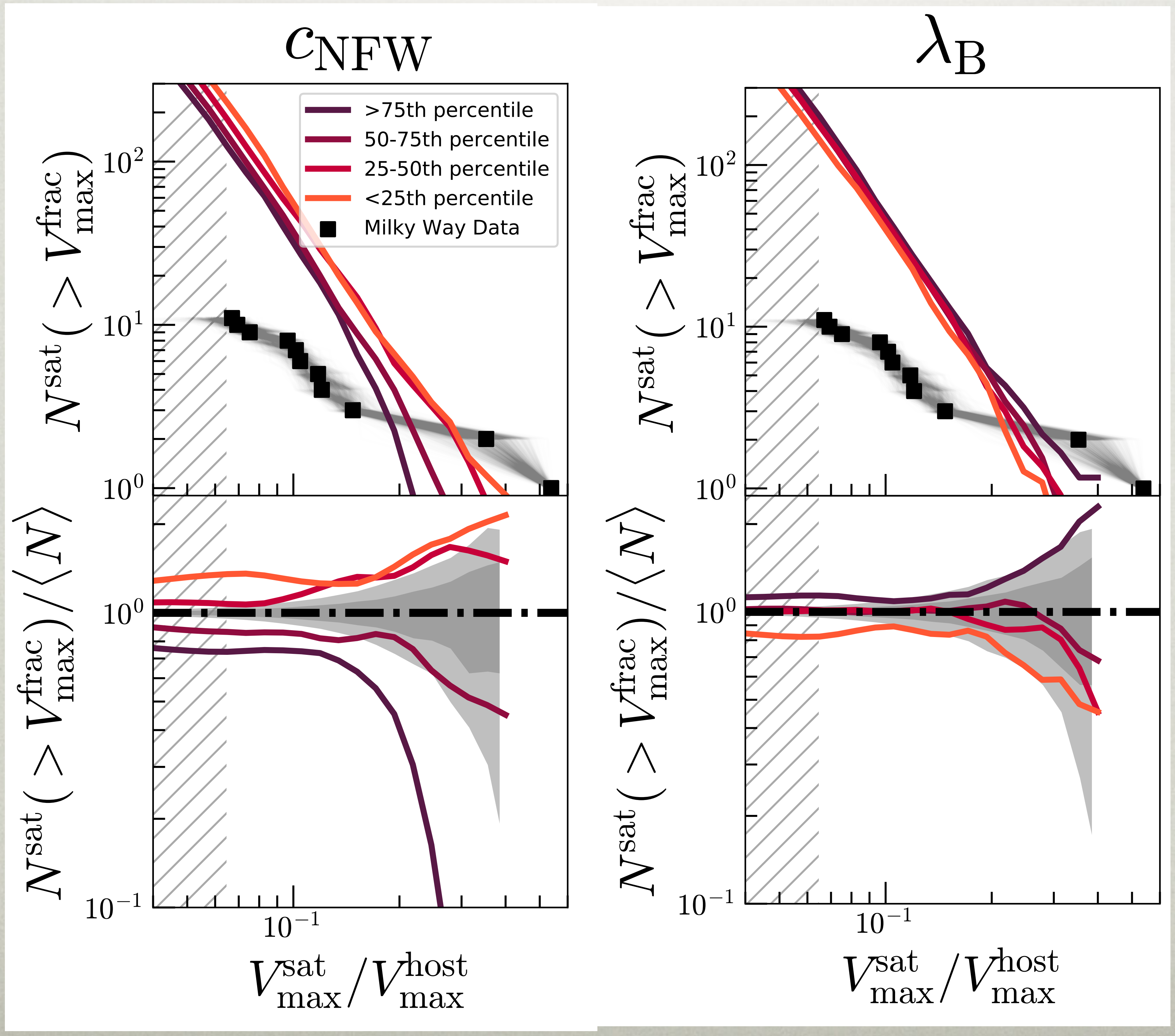


Measure of Subhalo Density →

Subhalo Populations



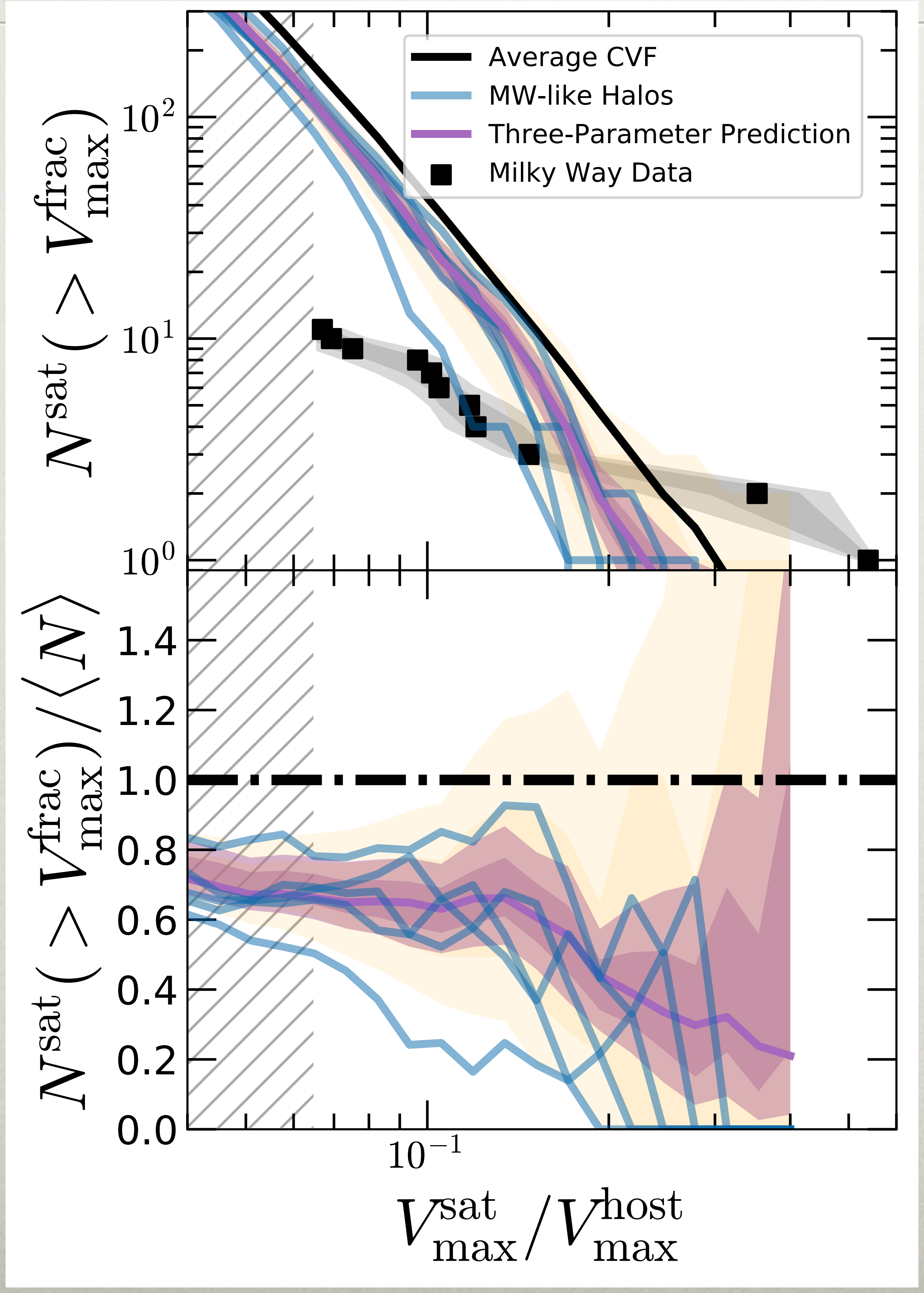
Subhalo Populations



Fielder+18

Subhalo Populations

Fielder+18

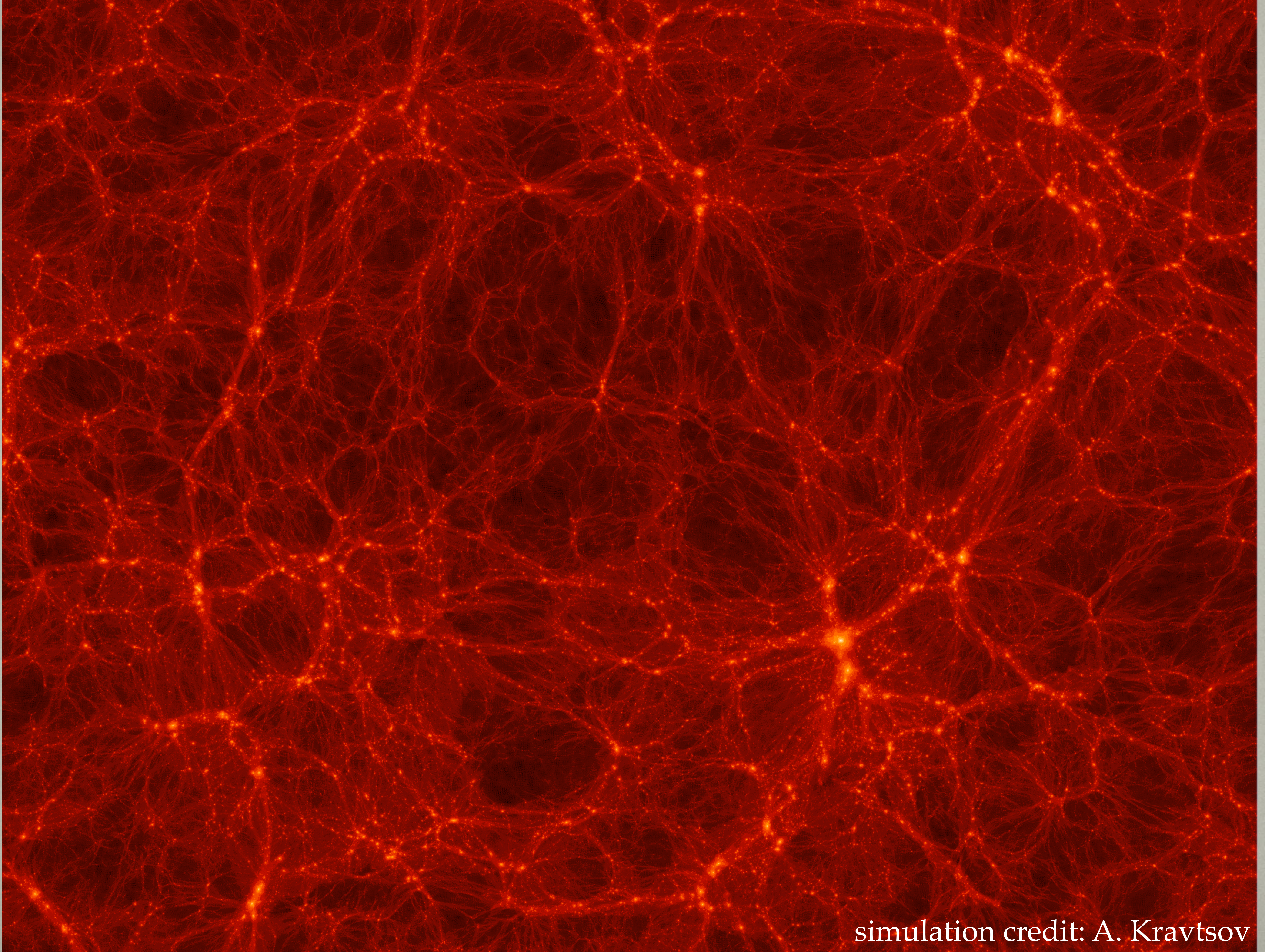


Takeaway

- Given our rough knowledge of the structural properties of the MW halo, we can develop a model (based on simulations) for subhalo abundance conditioned on these properties (at fixed halo mass)
- Our model predicts that MW-like halos should have 20-50% fewer subhalos than the average subhalo abundance for all halos of the same mass.

Summary

- Baryonic processes can lead to subtle rearrangements of dark matter on surprisingly large scales compared to N-body simulations.
- Baryonic processes can alter halo shapes and profiles, but to a degree that remains uncertain.
- Subhalo abundances and inner profiles can likewise be modified to an uncertain degree by baryonic processes.
- MW-like halos may host somewhat fewer subhalos than average halos of their mass.


simulation credit: A. Kravtsov