The splashback radius of dark matter halos

Benedikt Diemer
ITC Fellow, Harvard-Smithsonian Center for Astrophysics

In collaboration with:
Andrey Kravtsov, Surhud More, Philip Mansfield, and many others

Einstein Fellows Symposium • Harvard University • 10/02/2018

Cosmology?

forward modeling

photometric redshifts

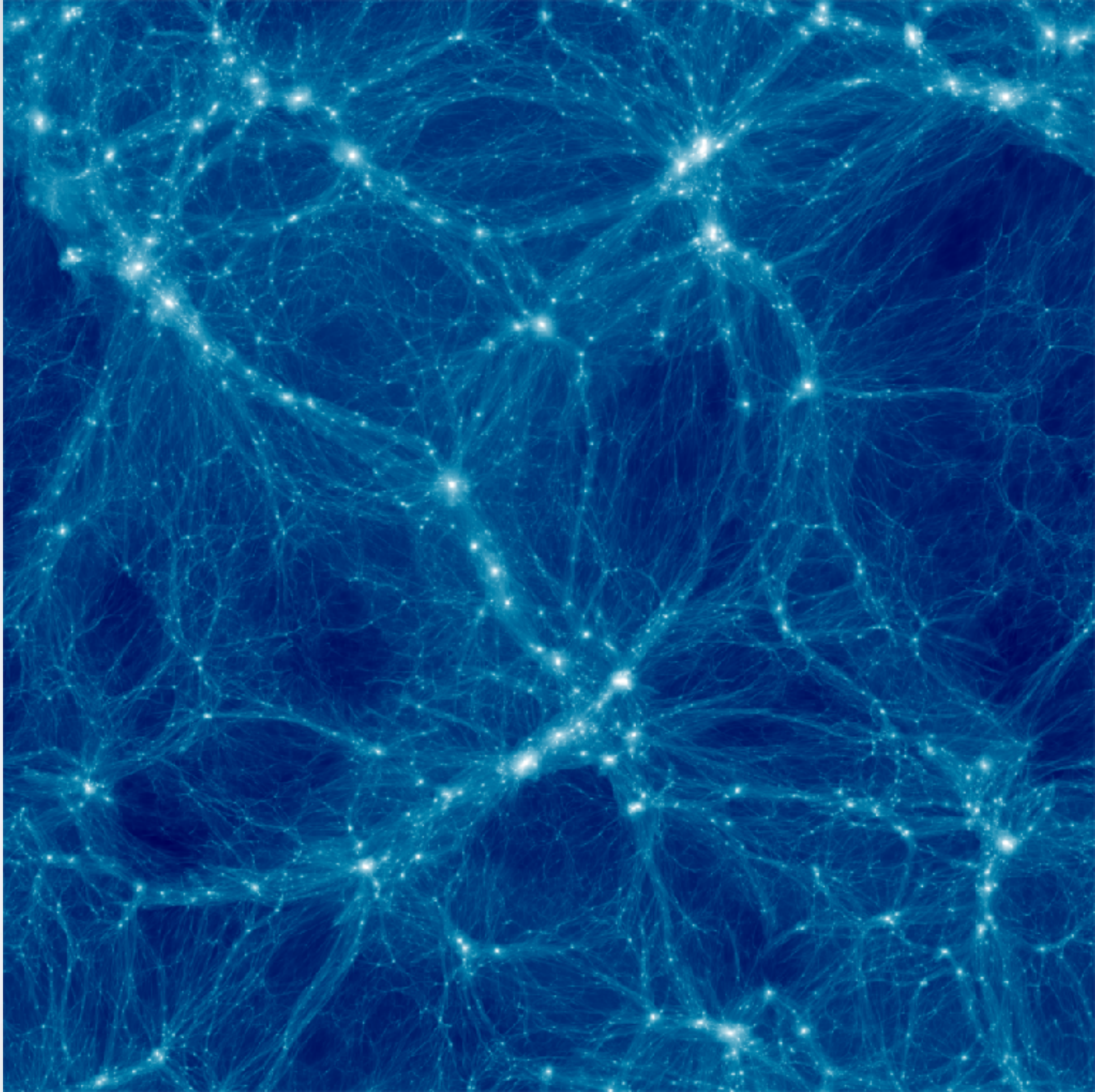
surveys

fuzzy dark matter

perturbation theory

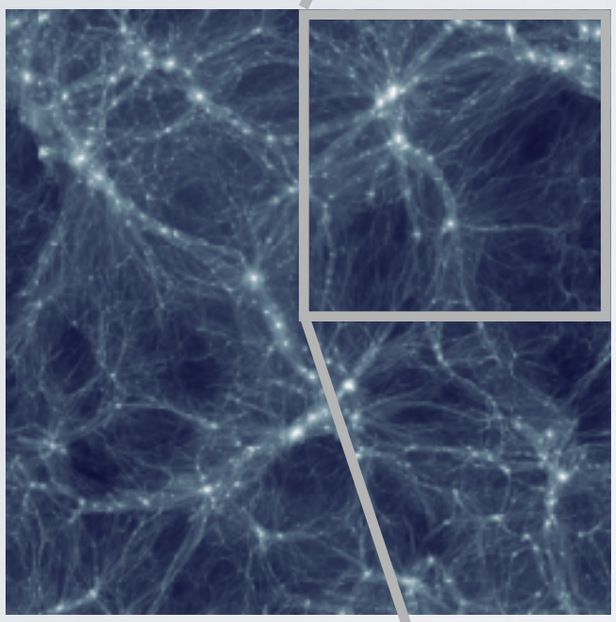
...sort of: structure formation!

89 Mpc

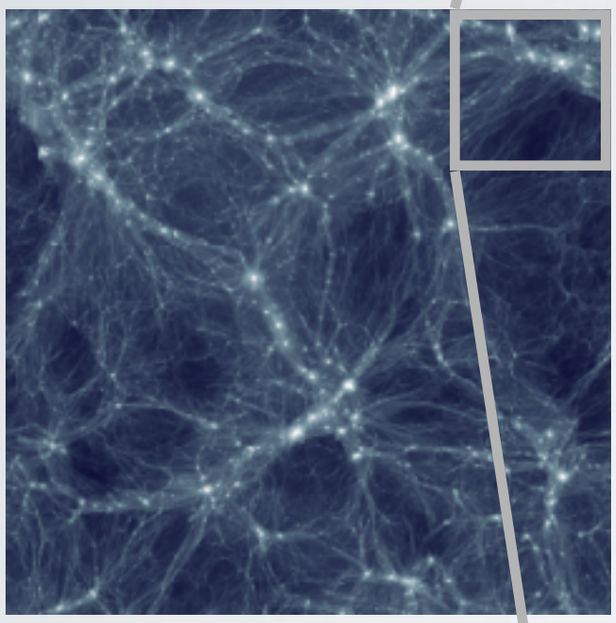


Visualization code:
Phil Mansfield
Algorithm:
Tom Abel, Oliver Hahn,
Ralf Kaehler

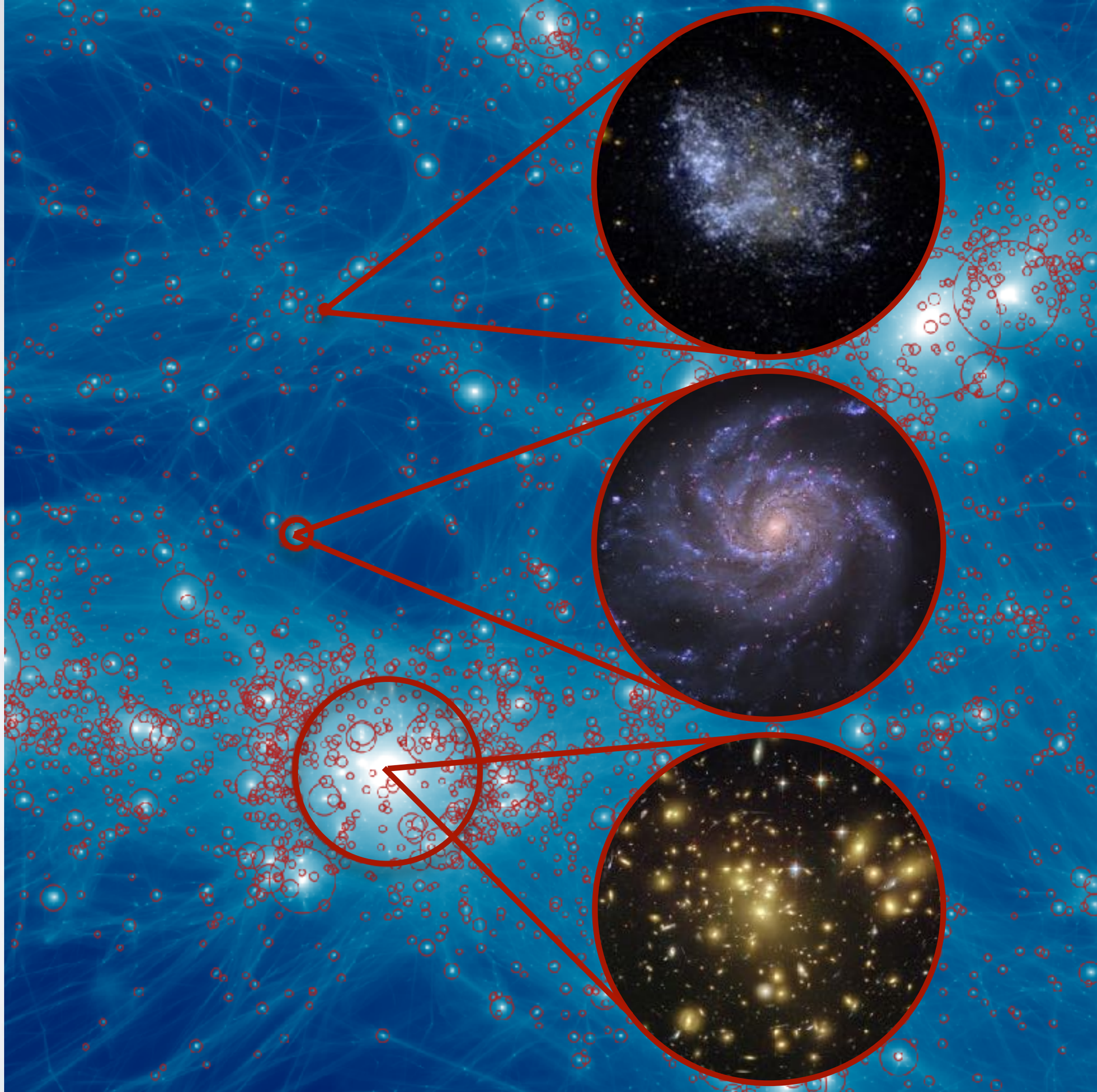
45 Mpc

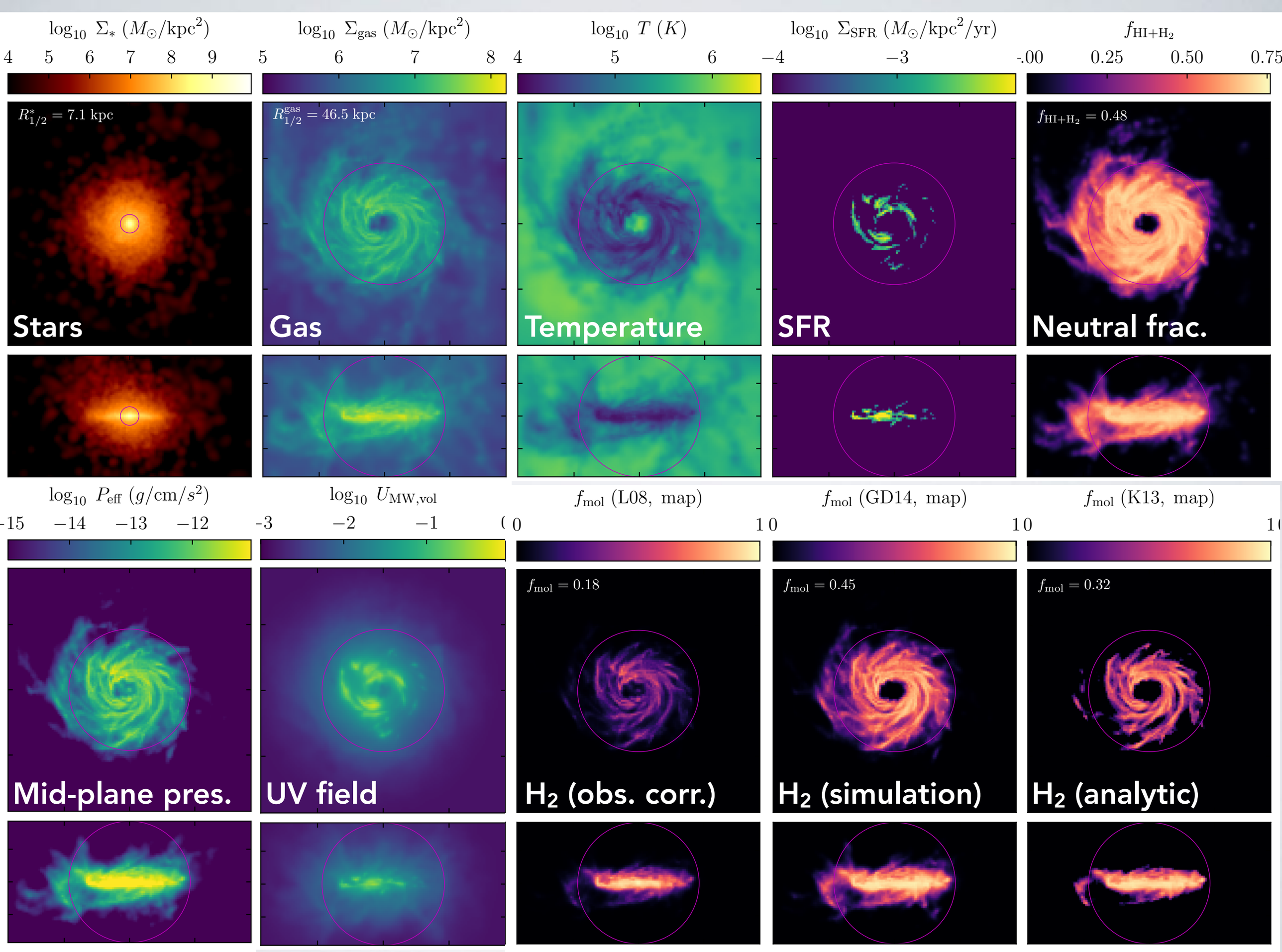


22 Mpc

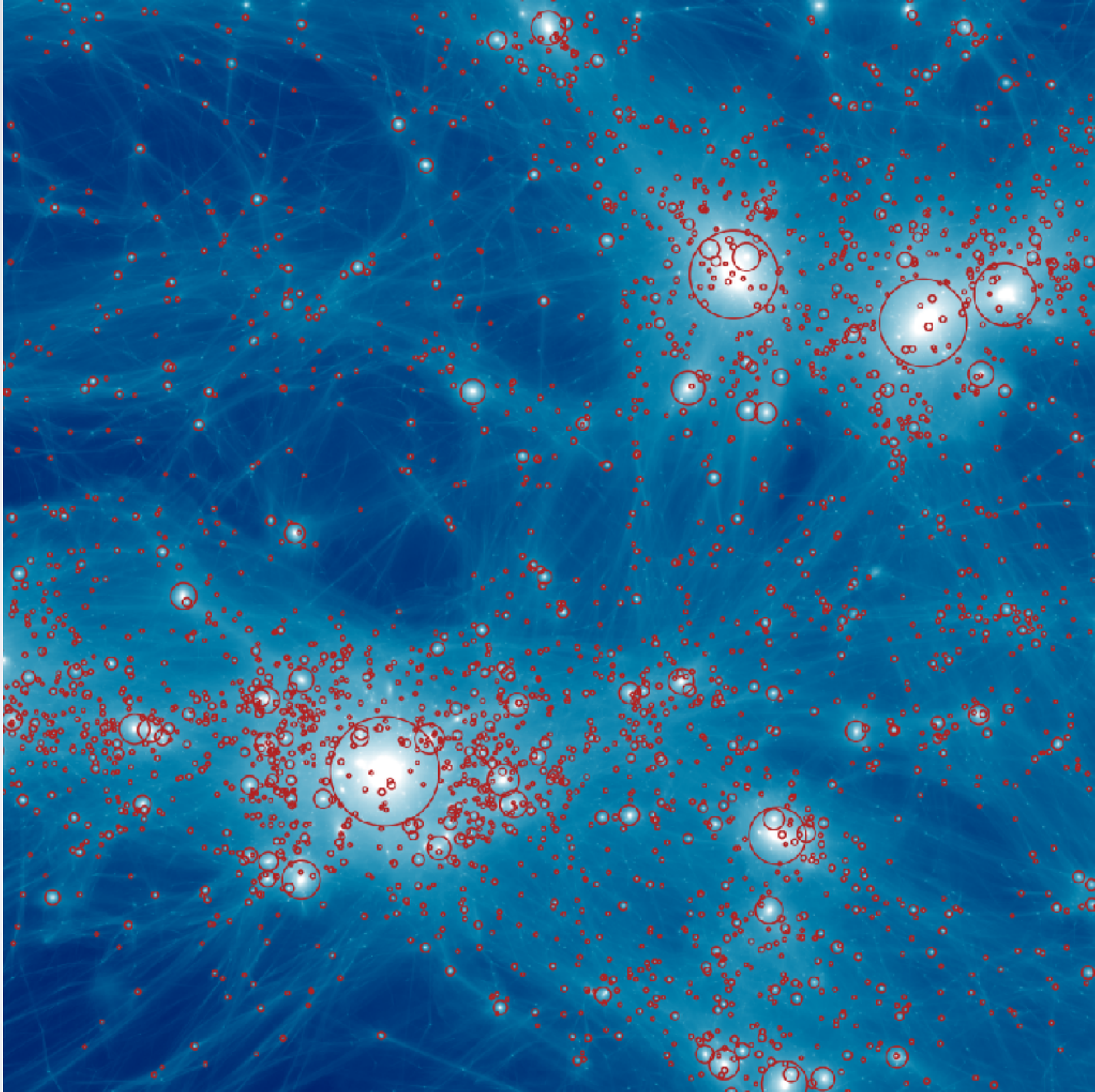


11 Mpc



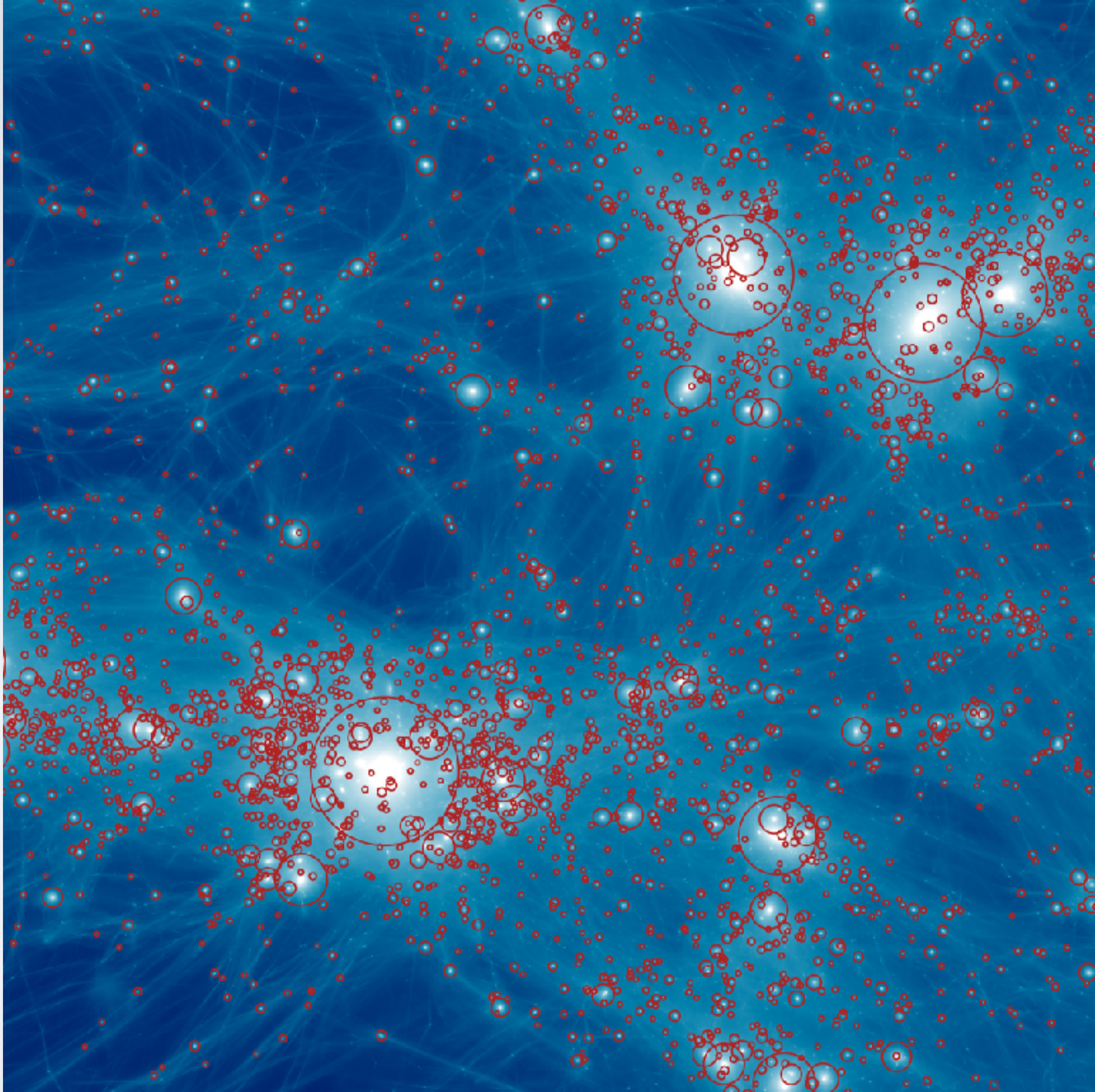

log10 Σ* (M⊙/kpc²)
4 5 6 7 8 9
log10 Σgas (M⊙/kpc²)
5 6 7 8
log10 T (K)
4 5 6
log10 ΣSFR (M⊙/kpc²/yr)
−4 −3 -.00
fHI+H2
0.25 0.50 0.75
R*1/2 = 7.1 kpc
Rgas1/2 = 46.5 kpc
fHI+H2 = 0.48
Stars
Gas
Temperature
SFR
Neutral frac.
log10 Peff (g/cm/s²)
-15 −14 −13 −12
log10 UMW,vol
-3 −2 −1 0
fmol (L08, map)
0 1
fmol (GD14, map)
0 1
fmol (K13, map)
0 1
fmol = 0.18
fmol = 0.45
fmol = 0.32
Mid-plane pres.
UV field
H2 (obs. corr.)
H2 (simulation)
H2 (analytic)

R_{500c}



Halo finder: Rockstar
(Behroozi et al. 2013)

R_{200c}

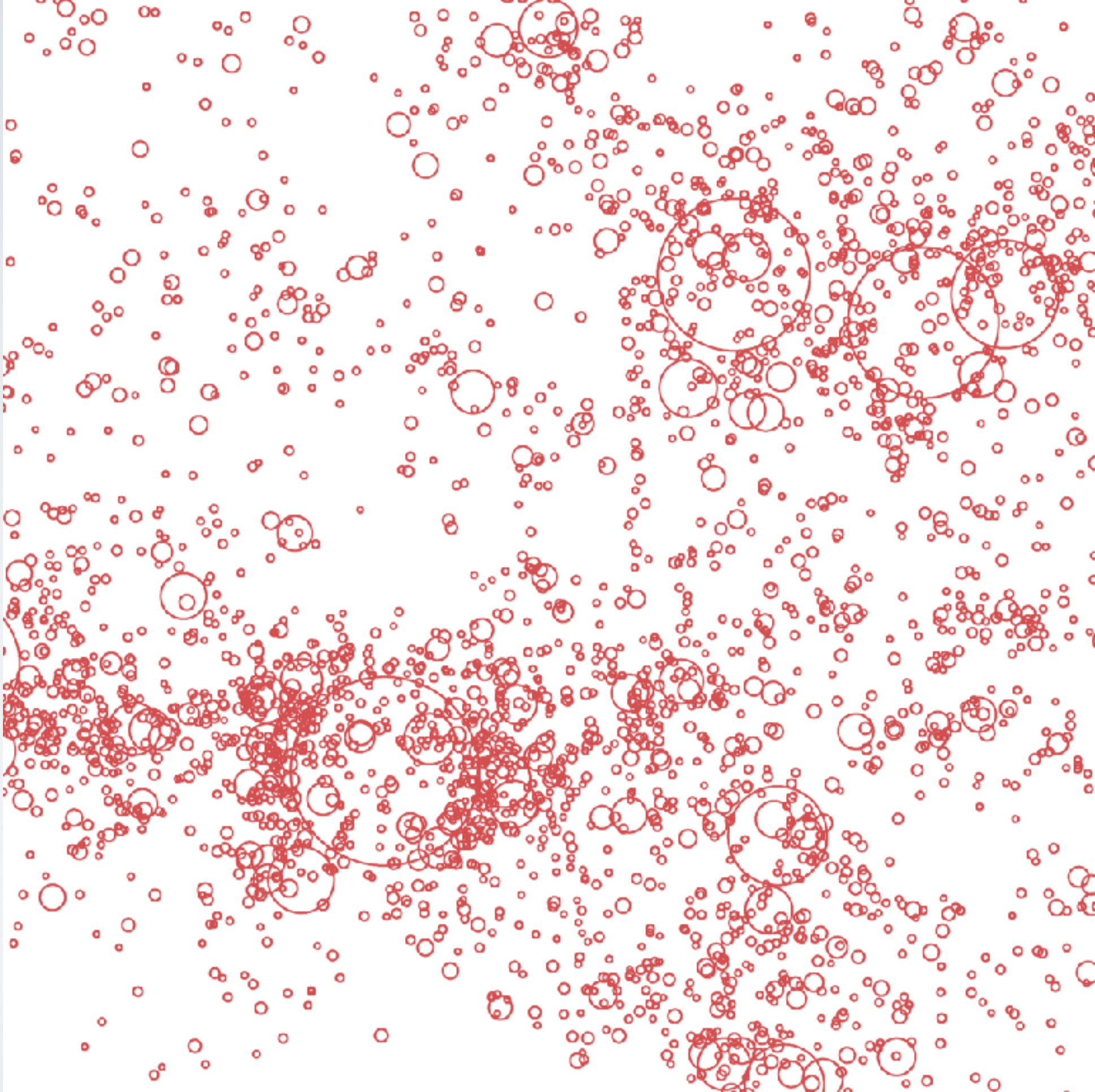


Halo finder: Rockstar
(Behroozi et al. 2013)

R_{vir}

Halo finder: Rockstar
(Behroozi et al. 2013)

R_{vir}



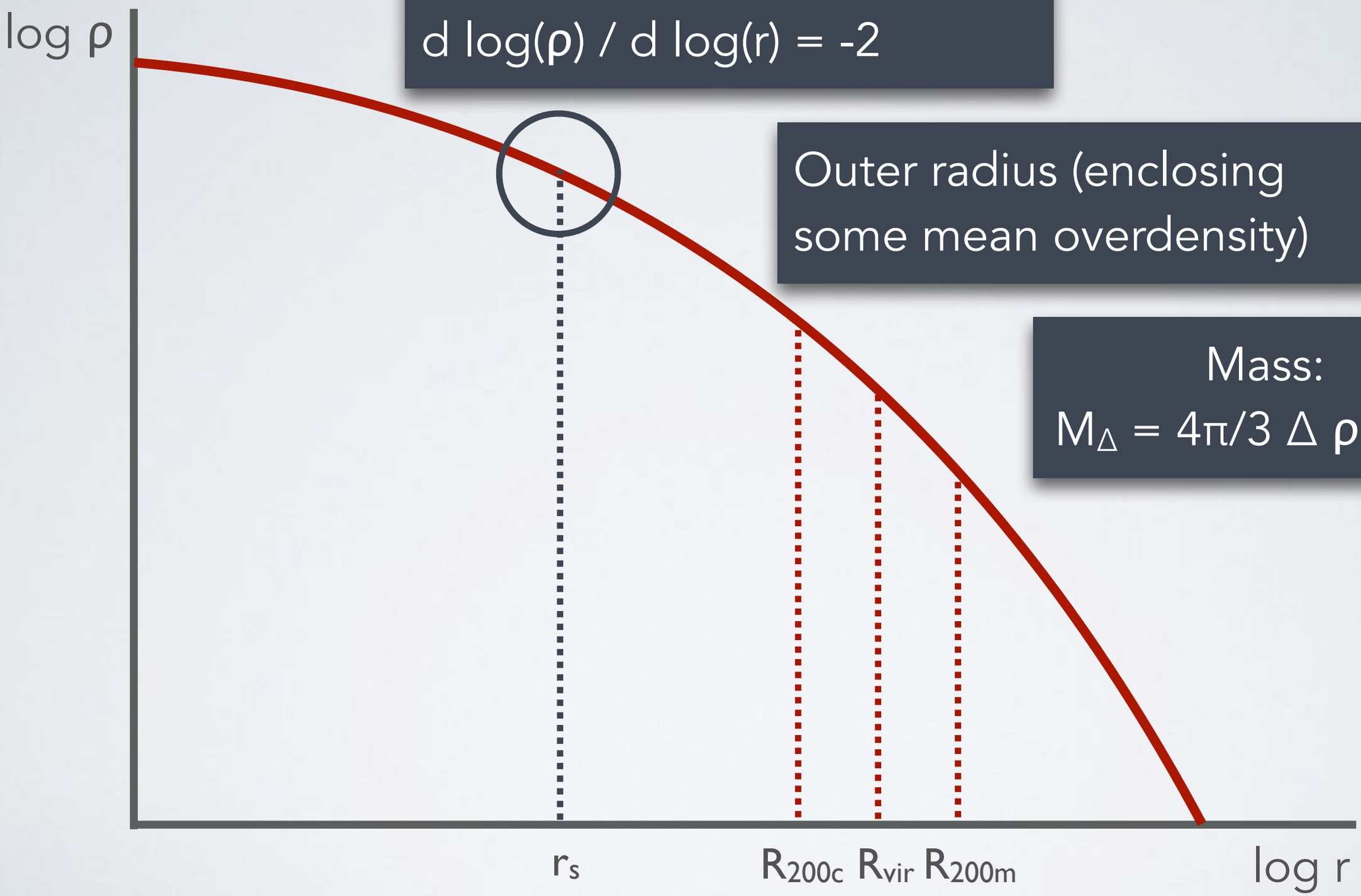
Halo finder: Rockstar
(Behroozi et al. 2013)

Density profile

Scale radius:
d log(ρ) / d log(r) = -2

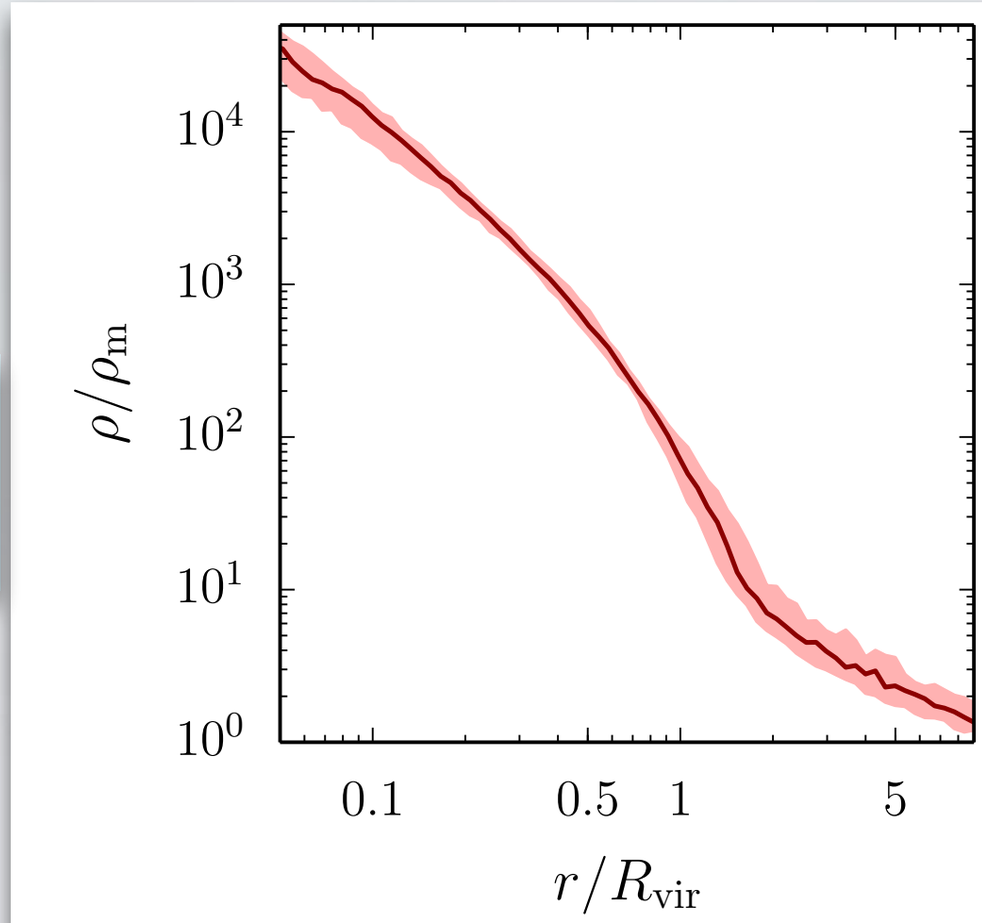
Outer radius (enclosing some mean overdensity)

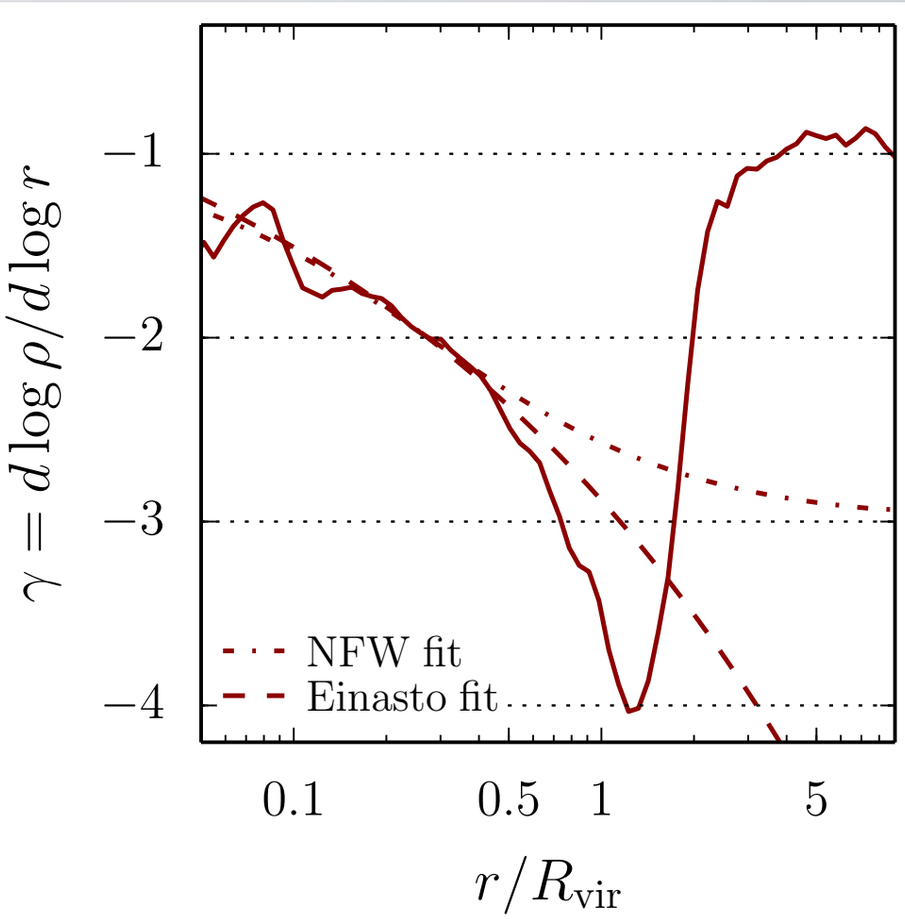
Mass:
$M_\Delta = 4\pi/3\ \Delta\ \rho_{ref}\ R_\Delta^3$



Einasto 1965 • Frenk et al. 1988 • Hernquist 1990 • Dubinski & Carlberg 1991
Navarro et al.1995/1996/1997/2004

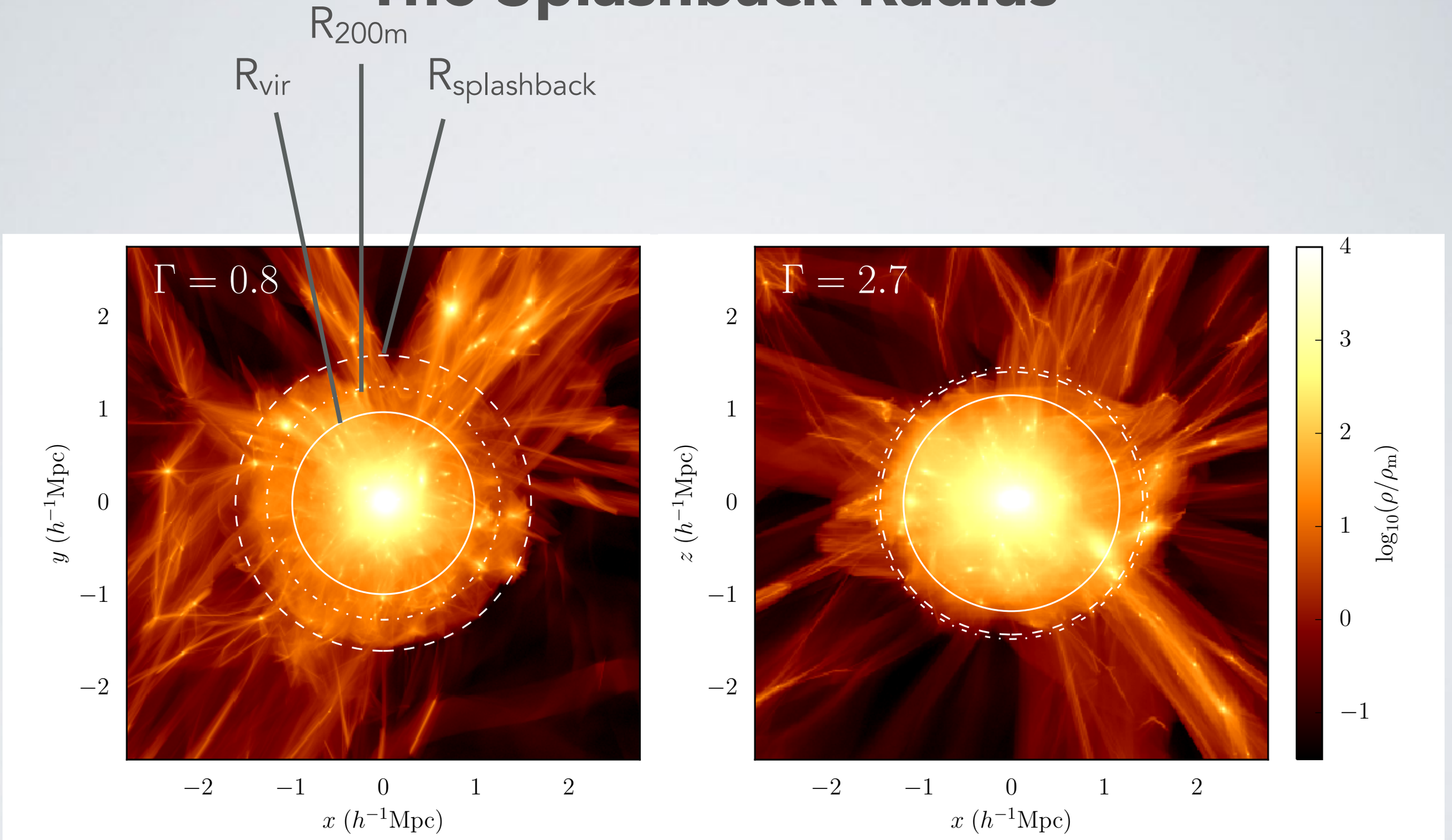
Large halos ($M>10^{15}$)





Diemer & Kravtsov 2014

The Splashback Radius

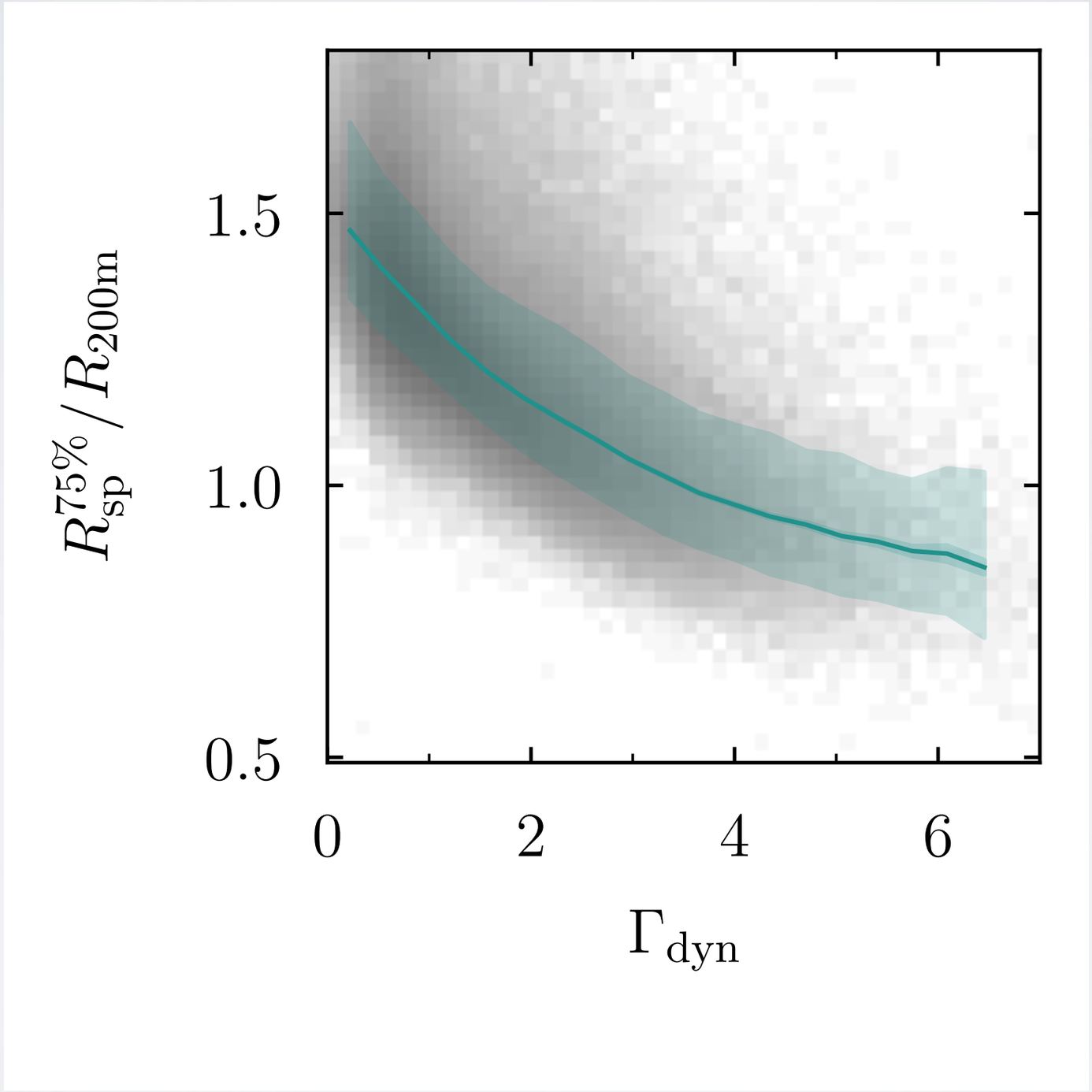


Low accretion rate

High accretion rate

Diemer & Kravtsov 2014 • More, Diemer & Kravtsov 2015 • Adhikari et al. 2014

The Γ-R_{sp}relation



Diemer et al. 2017

Do the Milky Way and Andromeda halos overlap?

R_{sp} ~ 540 kpc

R_{sp} ~ 425 kpc

R_{vir} = 313 kpc

R_{vir} = 244 kpc

Milky Way,

$M_{vir} = 8 \times 10^{11}\ M_{\odot}$

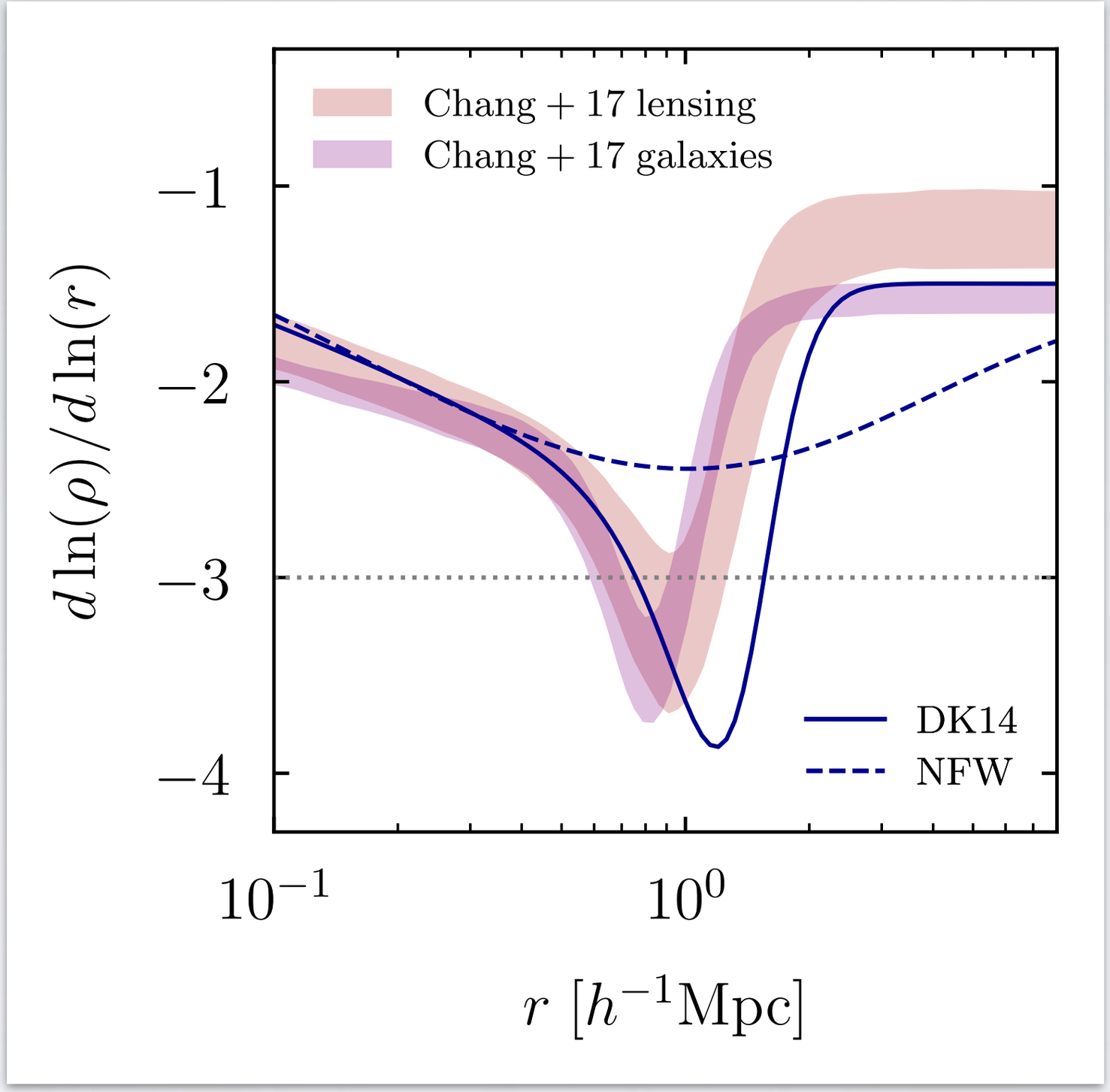
Andromeda,

$M_{vir} = 1.7 \times 10^{12}\ M_{\odot}$

distance = 780 kpc

More, Diemer & Kravtsov 2015 • Diaz et al. 2014

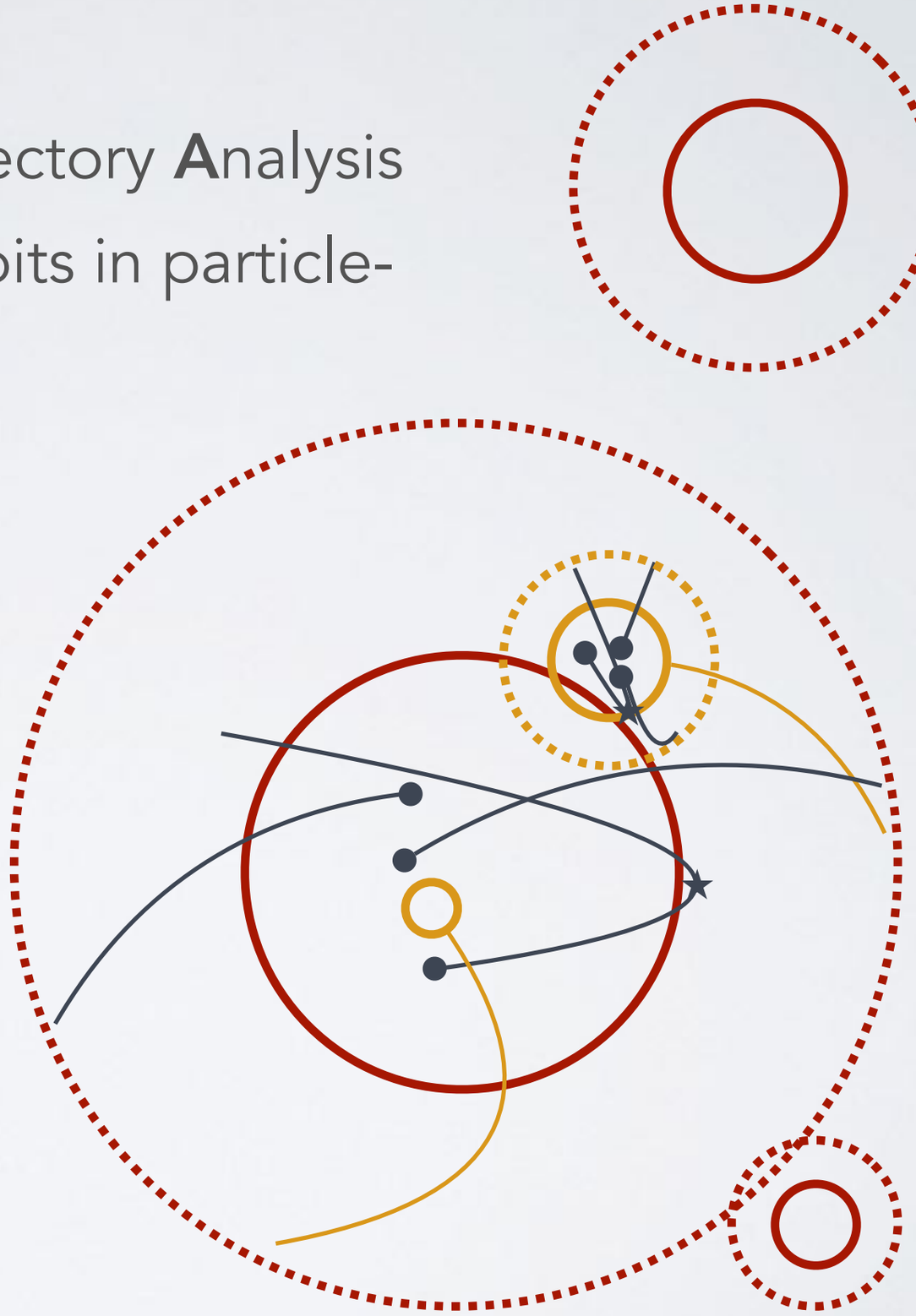
R_{sp} in cluster member profiles (DES)



Diemer & Kravtsov 2014 • Chang et al. 2017 • cf. Baxter et al. 2017 • Umetsu & Diemer 2017
Rykoff et al. 2014 • More et al. 2016 • Zu et al. 2016 • Busch & White 2017

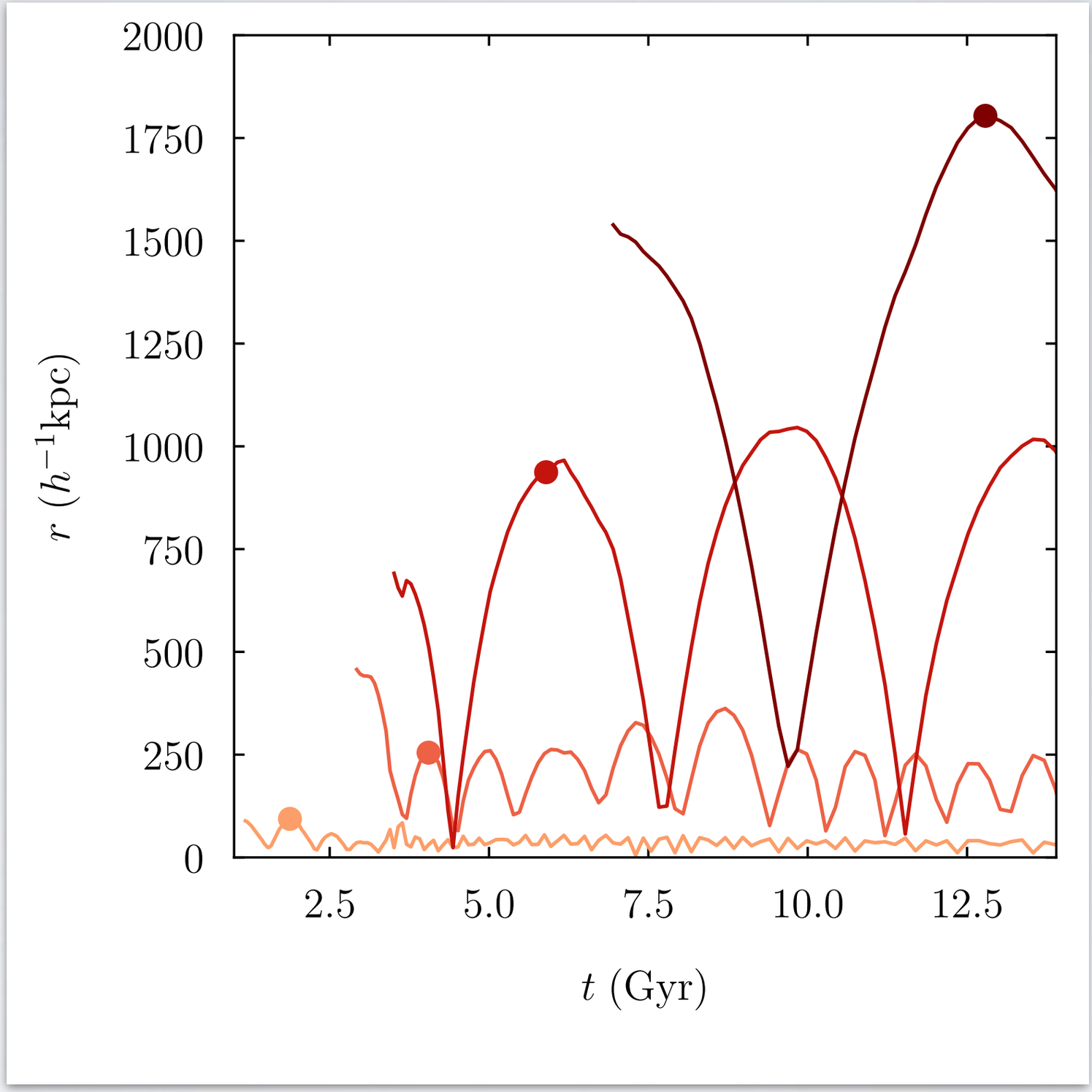
SPARTA

- **S**ubhalo and **PAR**ticle **T**rajectory **A**nalysis
- Framework for tracking orbits in particle-based simulations
- MPI-parallelized, pure C

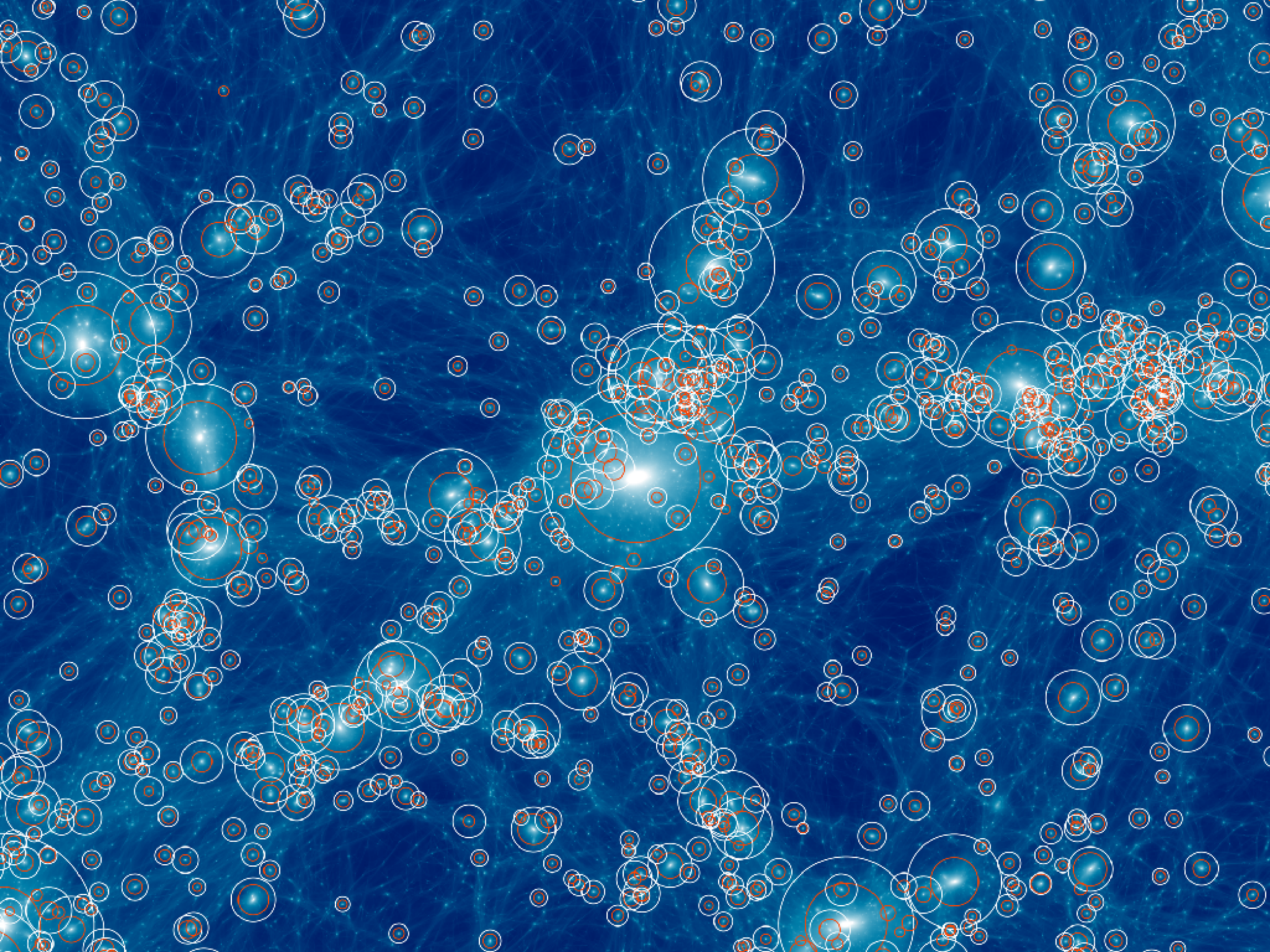


Diemer 2017

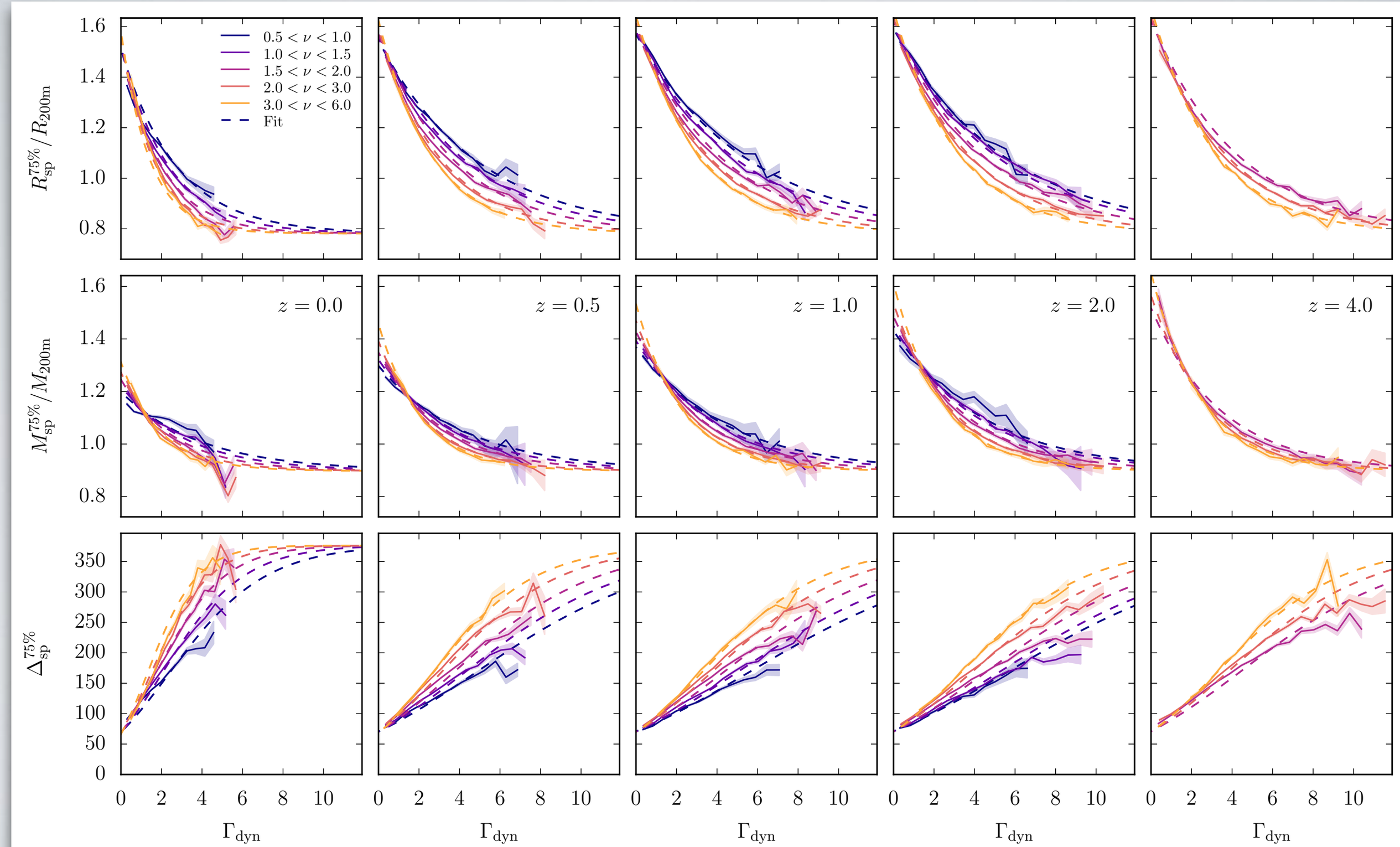
What do the orbits look like?



Diemer 2017



The Γ-R_{sp}relation



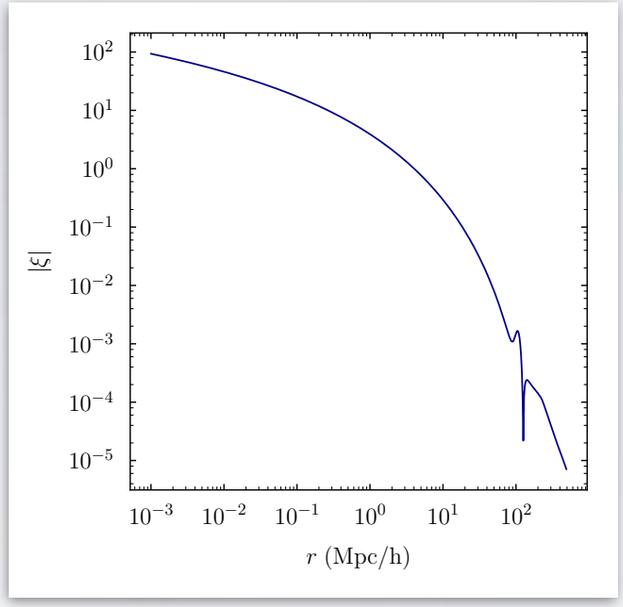
Diemer et al. 2017

COLOSSUS

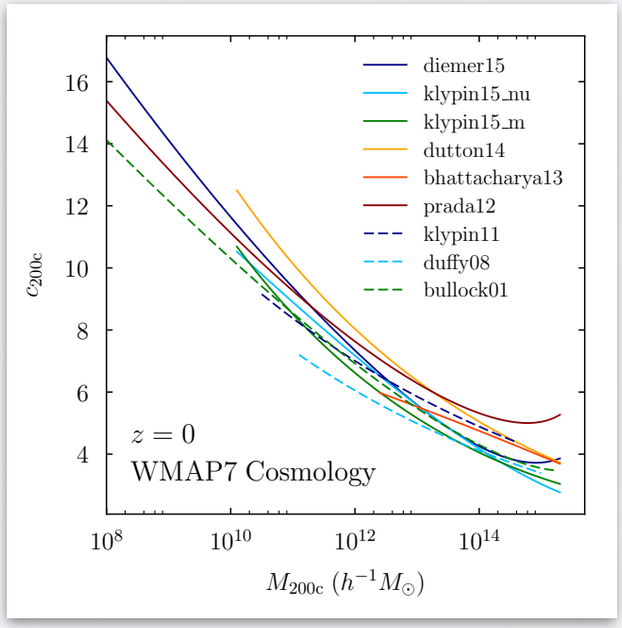
Cosmology, halos, and large-scale structure

benediktdiemer.com/code/colossus


```
from colossus.cosmology import cosmology

cosmo = cosmology.setCosmology('WMAP9')
xi = cosmo.correlationFunction(10.0)
```



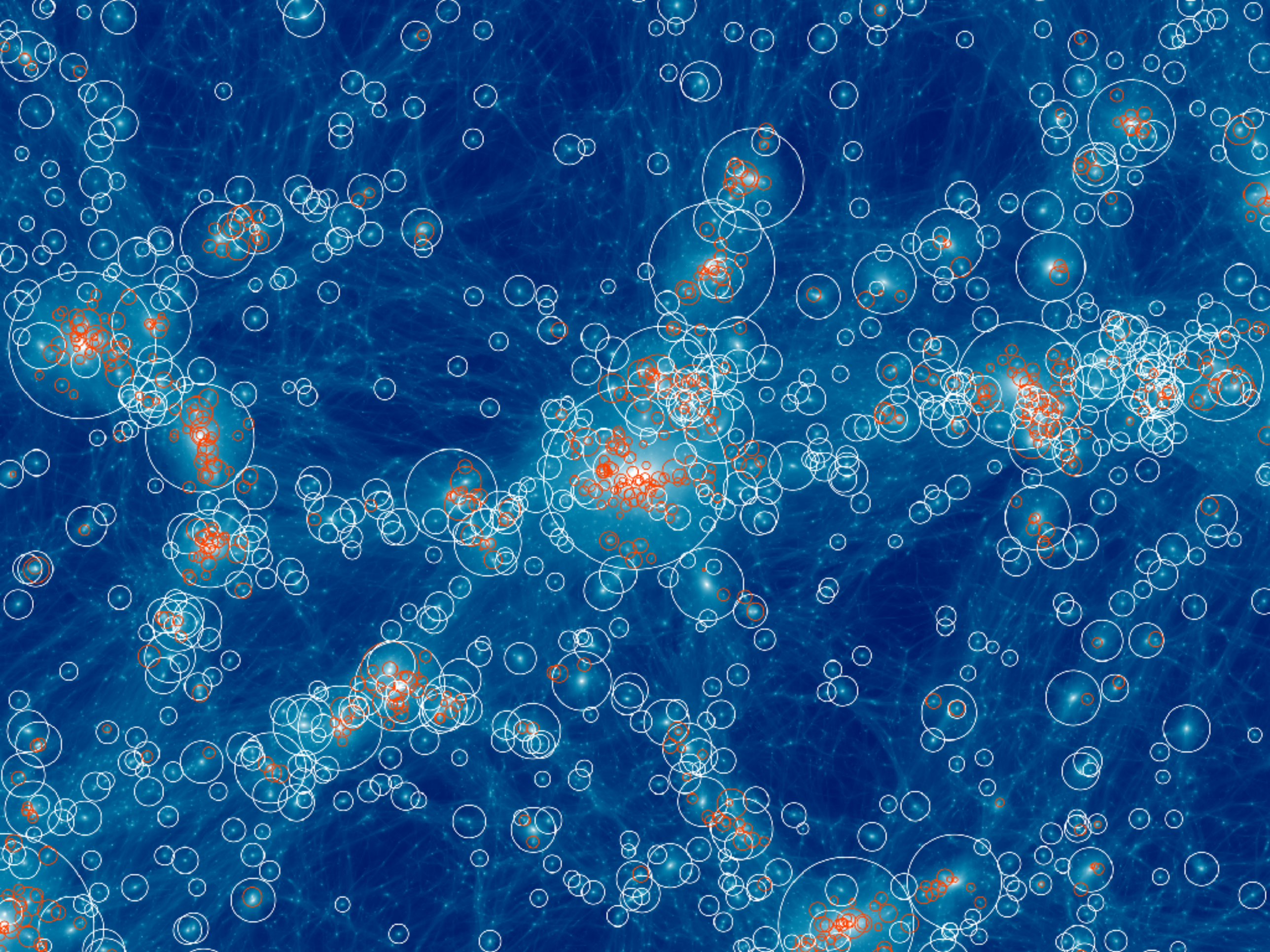

```
from colossus.halo import concentration as hc

cosmology.setCosmology('bolshoi')
c = hc.concentration(1E12, 'vir', 0.0,
      model = 'bullock01')
```



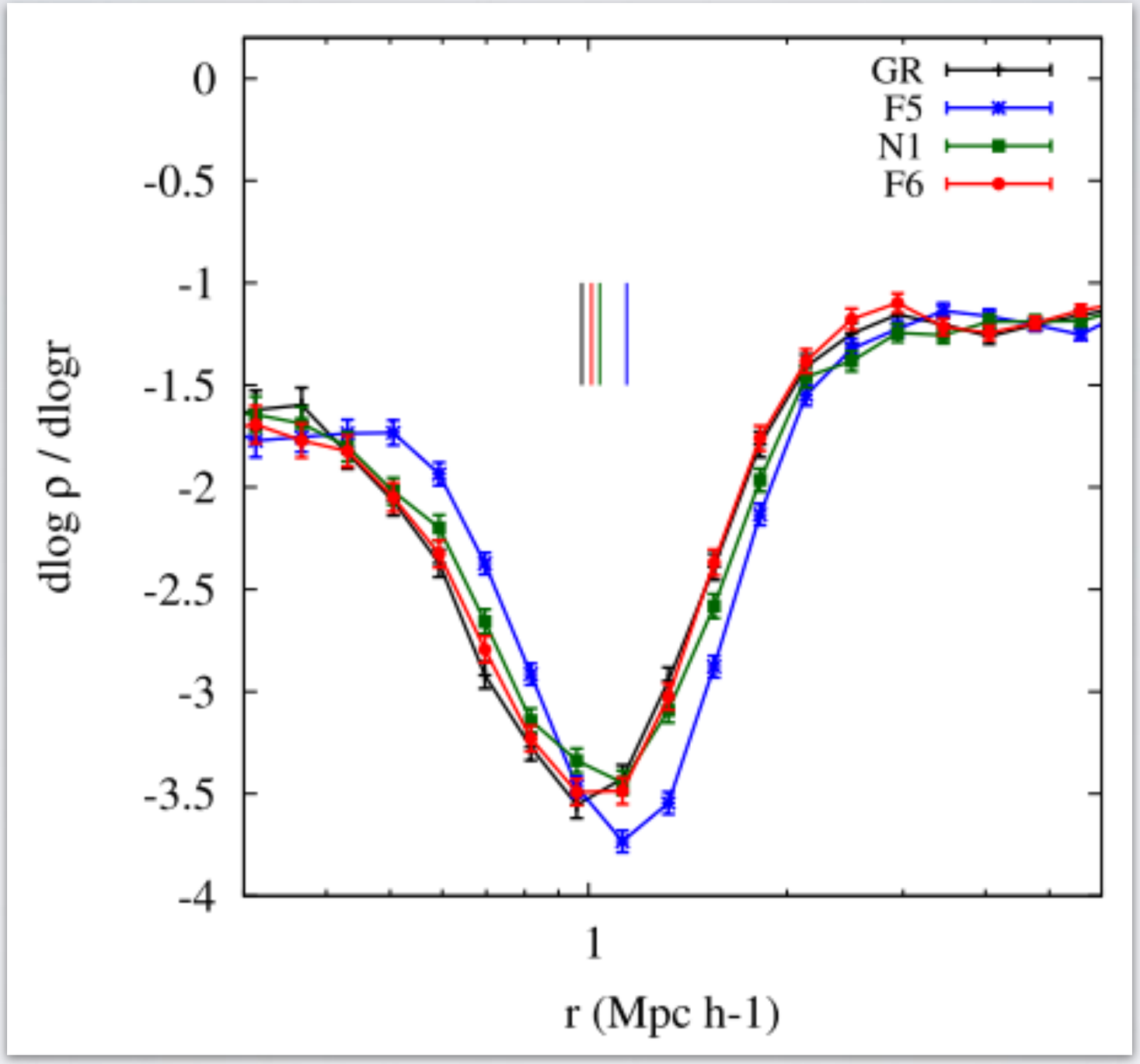
Modules:

- Cosmology
- Power spectrum
- Gaussian random peaks
- Halo mass function
- Bias
- Density profiles
- Halo mass definitions
- Concentration
- Splashback
- …

Code contributions: Andrey Kravtsov, Matt Becker

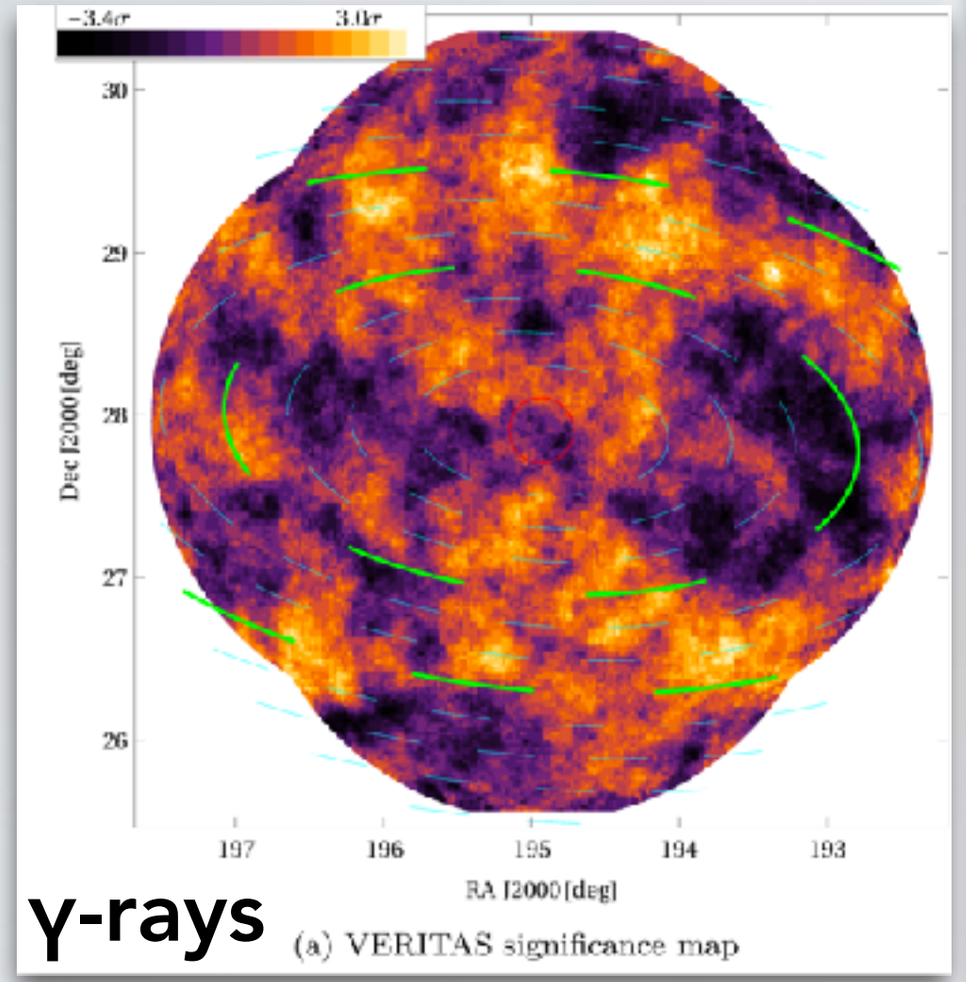


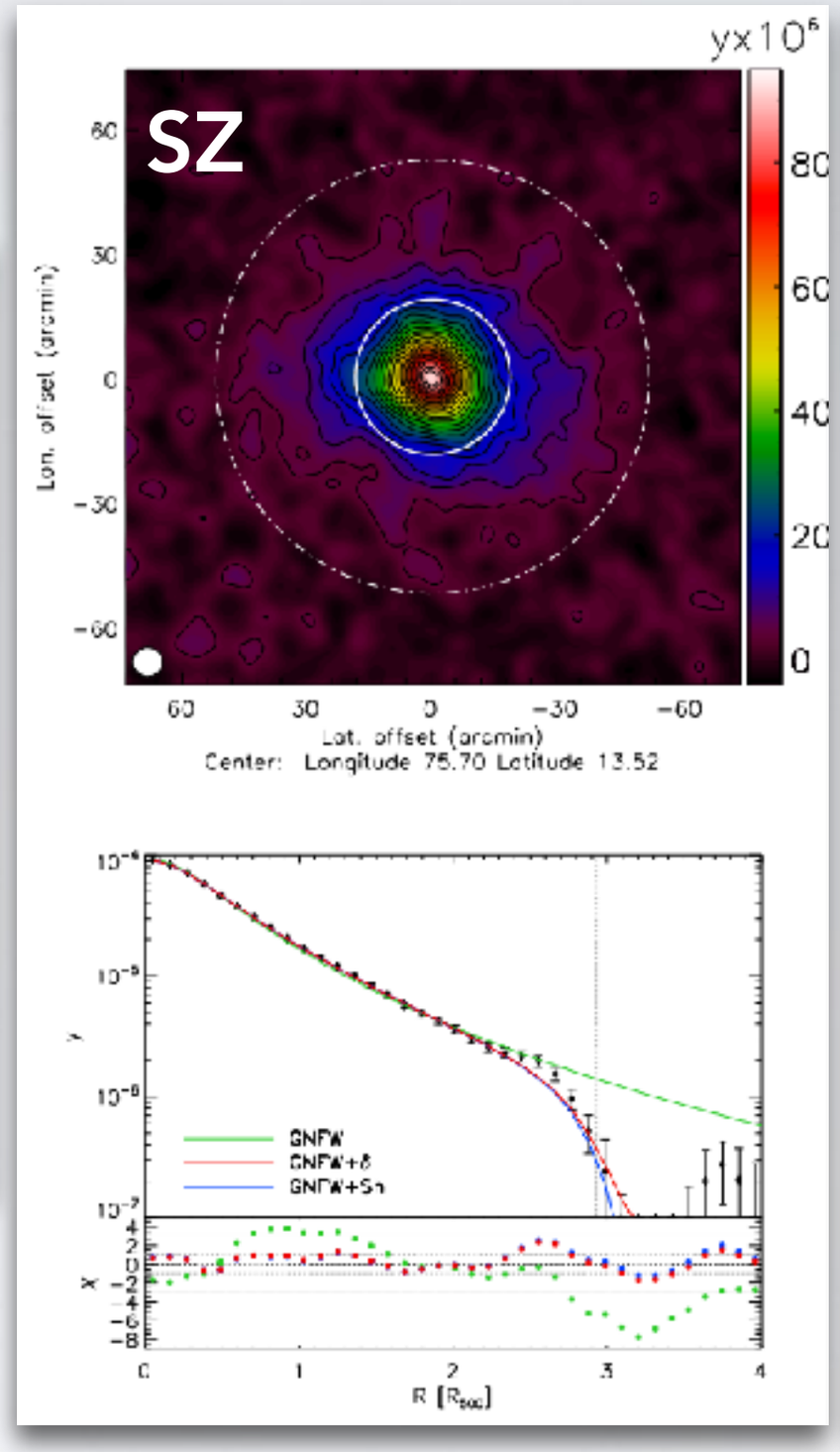
Cosmology with the splashback radius?

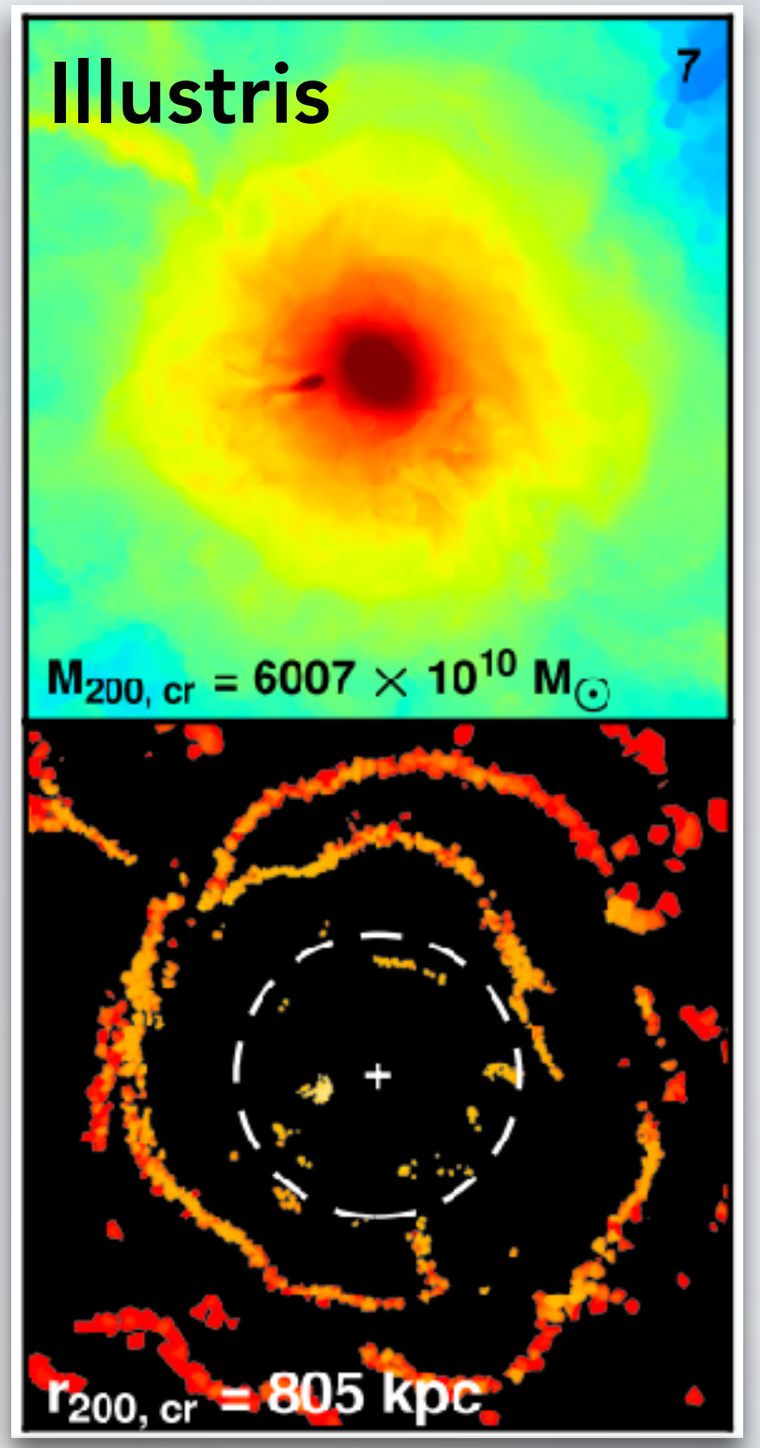


Adhikari et al. 2018

A splashback-accretion shock relation?





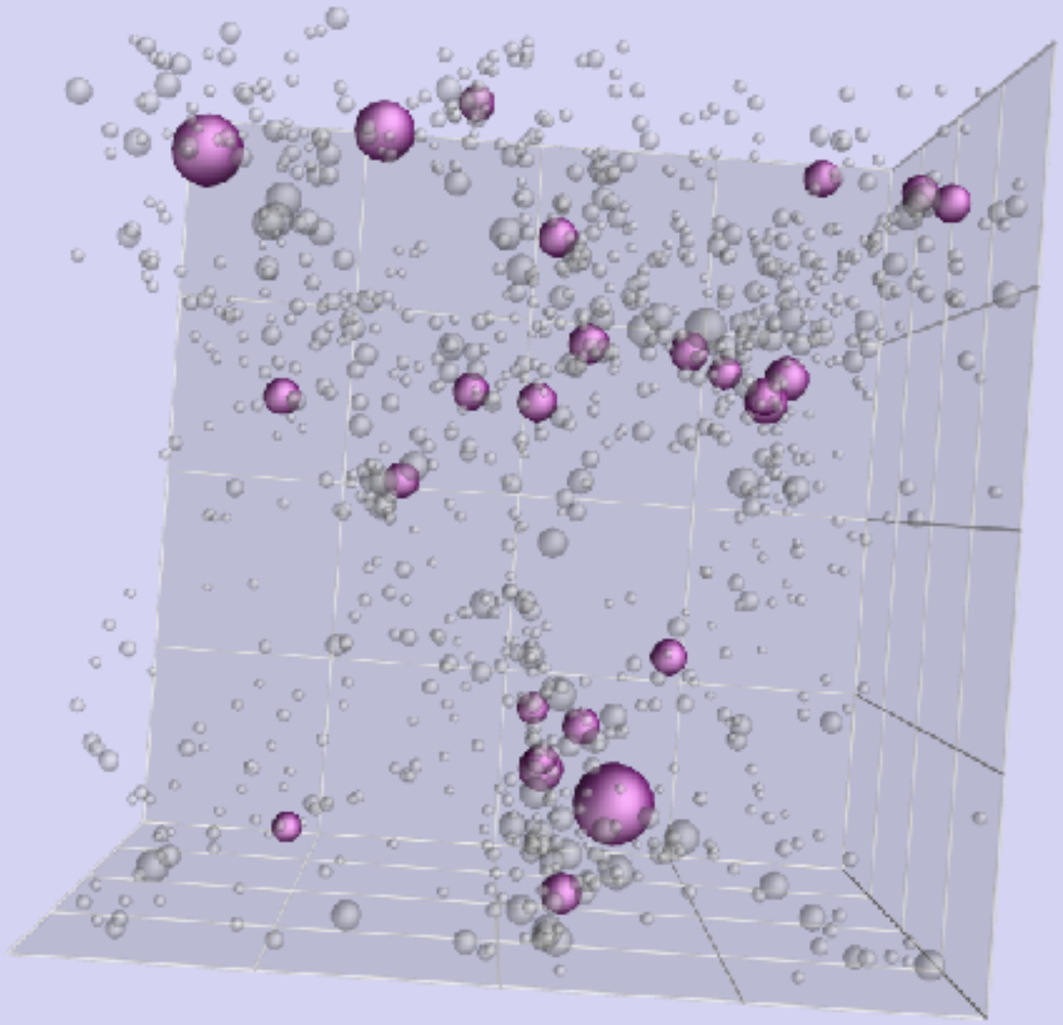


Keshet et al. 2017ab • Hurier et al. 2017 • Schaal & Springel 2015 • Shi 2016

Diemer & Facio 2017 • The Fabric of the Universe

The Fabric of the Universe

The Fabric of the Universe



Conclusions

- The **structure of CDM halos** is not a solved problem

- The **splashback radius** provides a physical halo boundary

- **SPARTA** provides entirely new ways of analyzing N-body simulations

Diemer & Kravtsov 2014 • ApJ 789, 001 • arXiv 1401.01216
More, Diemer & Kravtsov 2015 • ApJ 810, 036 • arXiv 1504.05591
Mansfield, Kravtsov & Diemer 2017 • ApJ 841, 034 • arXiv 1612.01531
Diemer 2017 • ApJS 231, 05 • arXiv 1703.09712
Diemer et al. 2017 • ApJ 843, 140 • arXiv 1703.09716