Properties of Dark Matter Halos:

Environment Density, Mass Loss, and Connection to Galaxy Size

Deep Learning Applied to Galaxy Evolution:

Identifying Star-Forming Clumps in CANDELS Galaxies

Chateaubriand Fellowship Program

Christoph Lee (UCSC)

January 25th, 2019 UCSC

Joel Primack (UCSC), Peter Behroozi (UA), Aldo Rodriguez-Puebla (IA-UNAM), Doug Hellinger (UCSC), Avishai Dekel (HUJI/UCSC), Viraj Pandya (UCSC), Graham Vanbenthuysen (UCSC), Marc Huertas-Company (Paris Observatory), Yicheng Guo (University of Missouri)

Selected Publications

7. Properties of dark matter haloes as a function of local environment density 2: observer based methods

 Graham Vanbenthuysen; Christoph T. Lee; Joel R. Primack; Viraj Pandya; Aldo Rodríguez-Puebla, in prep (2019)

6. Detection of Stellar Clumps in CANDELS Galaxies Using Deep Learning

 Christoph T. Lee; Marc Huertas-Company; Yicheng Guo; Joel R. Primack, in prep (2019)

5. Dark Matter Halo Properties Determined by Local Density, Not Cosmic Web Location

 Tze Goh; Joel R. Primack; Christoph T. Lee; Miguel Aragon-Calvo; Doug Hellinger; Peter Behroozi; Aldo Rodríguez-Puebla; Elliot Eckholm; Kathryn Johnston, MNRAS, 483, 2101 (2019)

4. Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos: Causes and Consequences of Mass Loss

 Christoph T. Lee; Joel R. Primack; Peter Behroozi; Aldo Rodríguez-Puebla; Doug Hellinger; Avishai Dekel, MNRAS, 481, 4038 (2018)

3. Does the Galaxy-Halo Connection Vary with Environment?

 Radu Dragomir; Aldo Rodríguez-Puebla; Joel R. Primack; Christoph T. Lee, MNRAS, 476, 741 (2018)

2. Properties of dark matter haloes as a function of local environment density

 Christoph T. Lee; Joel R. Primack; Peter Behroozi; Aldo Rodríguez-Puebla; Doug Hellinger; Avishai Dekel, MNRAS, 466, 3834 (2016)

1. Halo and subhalo demographics with Planck cosmological parameters: Bolshoi-Planck and MultiDark-Planck simulations

 Aldo Rodríguez-Puebla; Peter Behroozi; Joel Primack; Anatoly Klypin; Christoph Lee; Doug Hellinger, MNRAS, 462, 893 (2016)

Outline

Introduction to dark matter halos

Dark matter halo properties: environment density

Dark matter halo properties: mass loss

Clump detection in CANDELS galaxies with Deep Learning

Summary

Introduction to dark matter halos

Introduction: ΛCDM

Most of the matter in the universe is dark, and exists in dark matter 'halos' — gravitationally bound and virialized overdensities of dark matter particles.

Baryonic galaxies form within dark matter halos, but stars comprise less than 5% of the total mass of the halo.

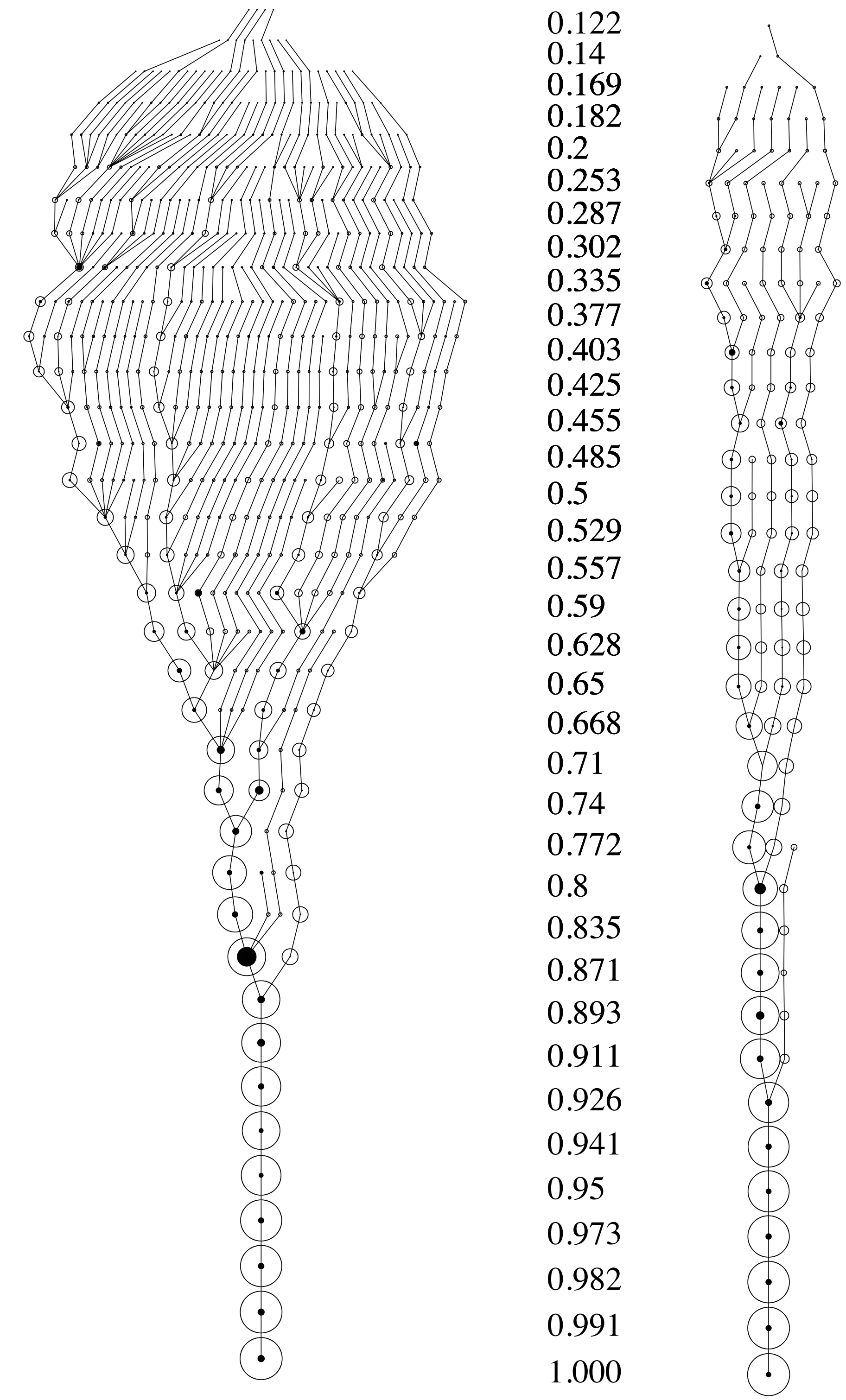
Low mass halos collapse first, then merge to form higher mass halos.

At a given redshift, $M_C(z)$ is mass of 'typical' collapsing halo. Halos less massive than M_C are ubiquitous, halos more massive are rare.

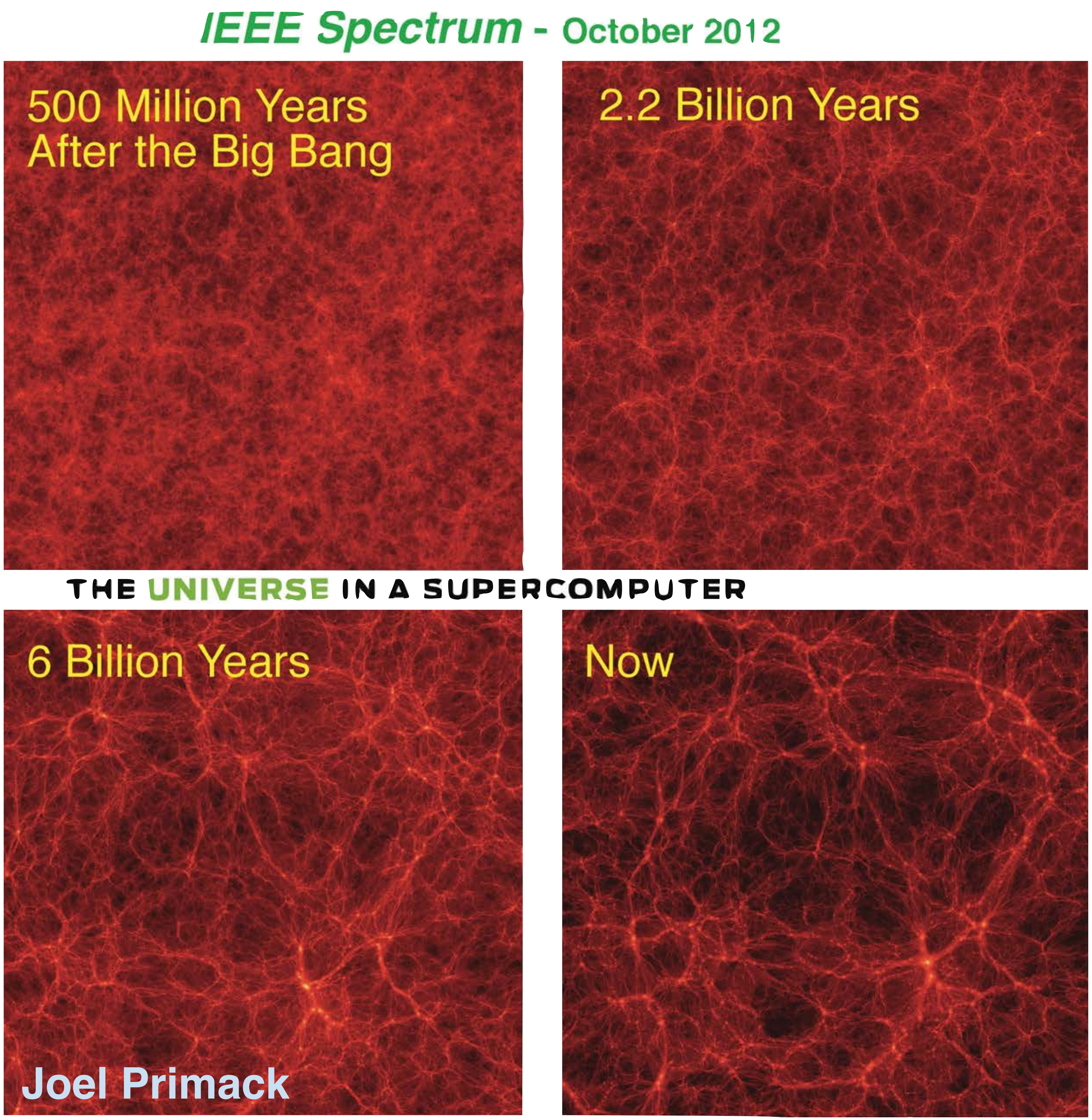
Planck 2013 Parameters

z	$\log_{10} M_C$ [M_{sun}/h]
0	12.7
0.5	11.97
1	11.21
2	9.82

WECHSLER ET AL. 2002



Introduction: ΛCDM



Large scale structure traces a hierarchical 'cosmic web' with voids, filaments, sheets, and nodes (clusters) on many length scales

How do halo properties differ in different density environments?

What can this tell us about the galaxies those halos host?

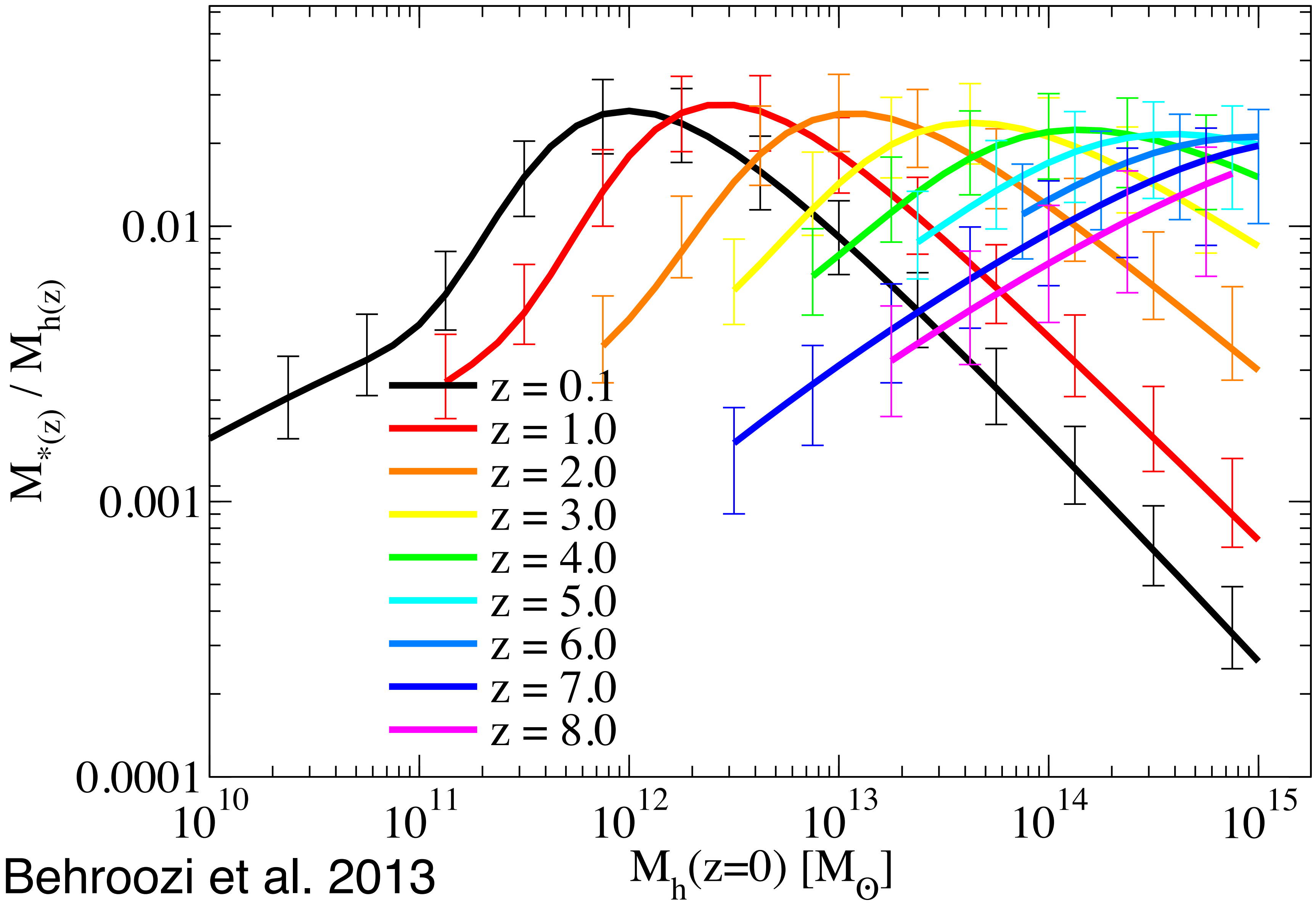
Key Questions:

1. How are dark matter halos in low density regions different from those in higher density regions?

2. Why do some halos lose mass, and what are the consequences of mass loss?

Motivation

GOAL: Understand how galaxies evolve.



Behroozi et al. 2013

Galaxy properties reflect the properties of the halos in which they form – the

Galaxy-Halo connection.

By deeply understanding halo properties, we can shed light on the galaxies they host.

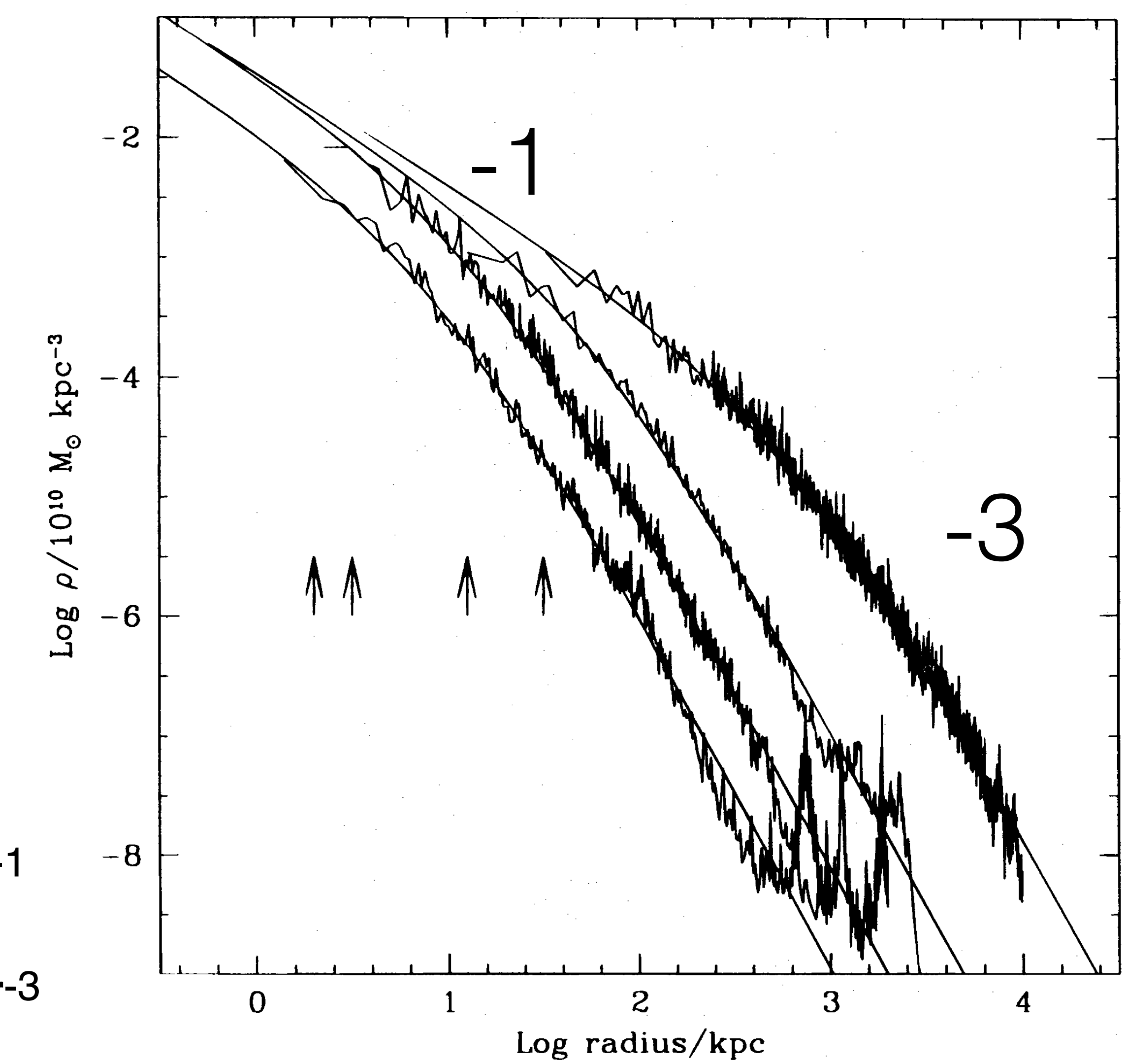
Even though these are fundamental questions about halos, this is the first time they have been addressed in detail using modern simulations.

Properties of CDM Halos: C_{NFW}

$$C_{NFW} = R_{vir} / R_s$$

NFW Profile:
2 parameter fit (ρ_0, R_s)

$$\rho(r) = \frac{4\rho_s}{\frac{r}{R_s}\left(1 + \frac{r}{R_s}\right)^2}$$



Scale radius (R_s): radius at which log ρ - log r slope of profile changes from -1 to -3

Inner part of halo ($<R_s$) falls off proportional to r^{-1}

Outer part of halo ($>R_s$) falls off proportional to r^{-3}

Halo formation can be split into an initial fast growth phase and subsequent slow growth phase

Fast growth is characterized by rapid violent accretion and tends to build up an r^{-1} profile (increasing R_s, so **C_{NFW} remains low**)

Slow growth is characterized by gentle accretion onto the outer part of the halo and tends to build an R^{-3} profile (R_s stays constant, but R_{vir} grows, **increasing C_{NFW}**)

Properties of CDM Halos: λ_B

Introduced by Bullock+01:

$$J = \sum_{i=1}^{N} m_i \, \boldsymbol{r}_i \times \boldsymbol{v}_i \qquad \lambda_B \equiv \frac{J}{\sqrt{2}MVR}$$

'Spin Parameter'

Defined within radius R, with mass enclosed M and circular velocity V.

Halos acquire angular momentum through tidal torques.

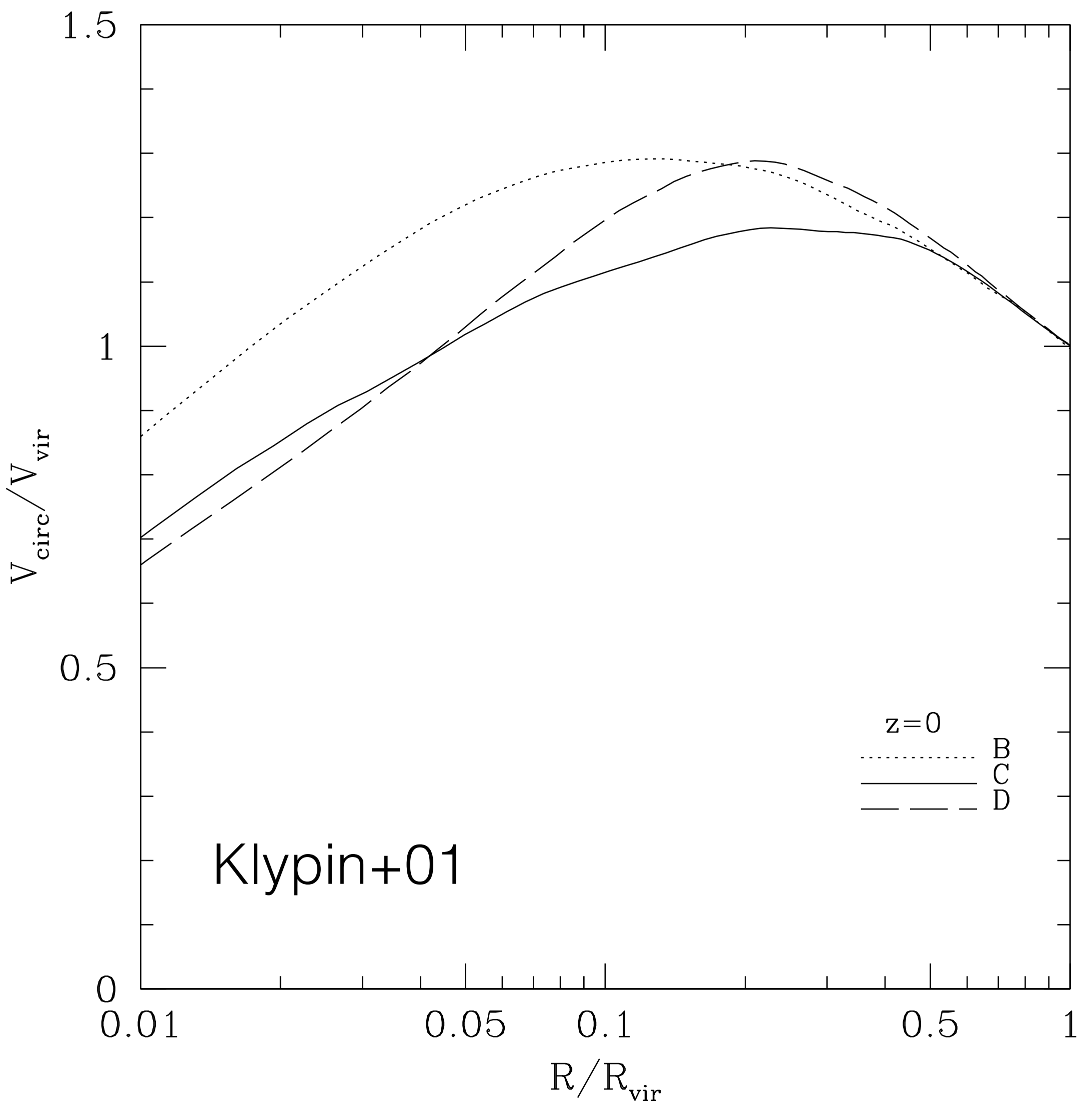
Tidal torques most influential at early times when pre-collapsed halos are maximally extended, diminish as universe expands.

Angular momentum is also strongly affected by mergers.

Properties of CDM Halos: V_{max}

Circular Velocity: $V_{circ}(R)$

Velocity required for test particle to maintain circular orbit at radius R, assuming spherical halo

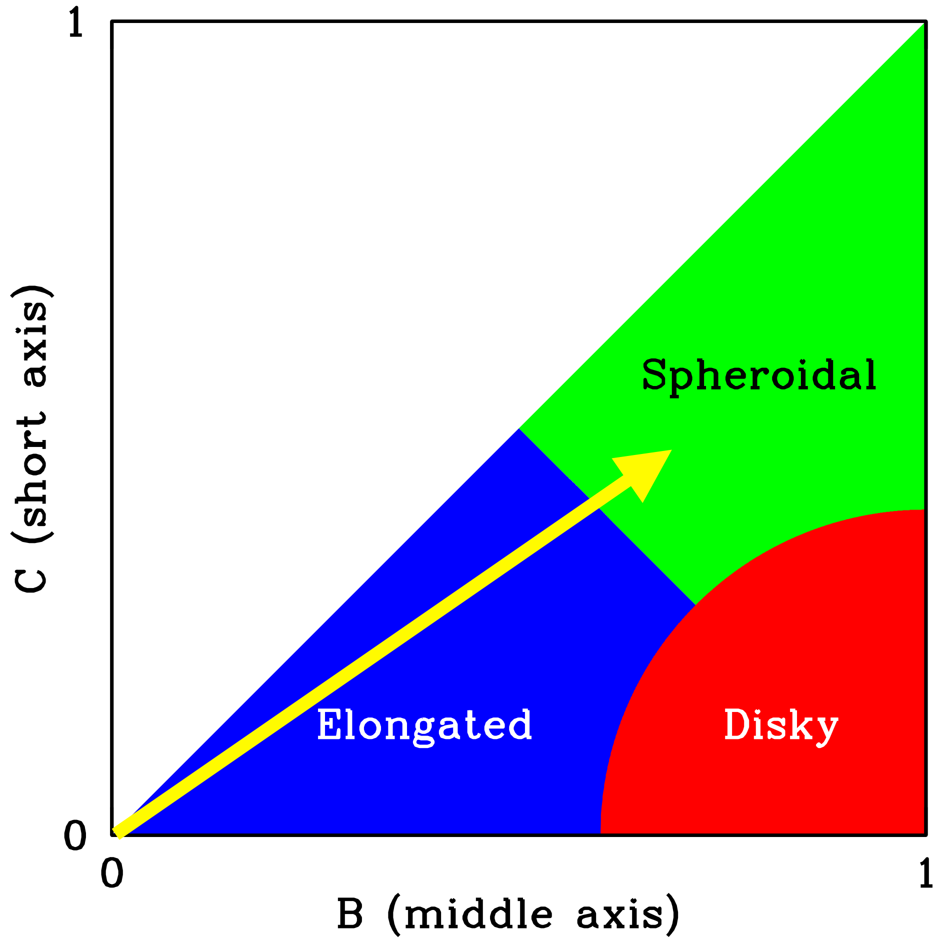


Can be analytically related to C_{NFW}, assuming NFW profile. Measuring V_{max} then provides alternative way to determine concentration.

Max Circular Velocity: V_{max}

V^2_{max} = max(GM(R)/R) where M(R) is mass enclosed within R

Properties of CDM Halos: Prolateness and Tidal Force



Prolateness:

$$\boxed{P = 1-([(b/a)^2 + (c/a)^2] / 2)^{1/2}}$$

Length of vector (b/a, c/a), normalized to be equal to 1 at the maximum.

Think of as ‘elongation’. P = 0 is perfect sphere, P = 1 is maximally elongated ‘pencil’.

Most halos fall somewhere between 0.2-0.6.

Tidal Force (TF)

We define tidal force in dimensionless units as the ratio of the halo virial radius to the minimum Hill radius of all of its neighbors (R_{vir}/R_{Hill}).

The Hill radius is the largest radius at which material can remain gravitationally bound to a secondary halo due to the presence of a primary halo.

Numerical Simulations

Bolshoi Planck

- 250 Mpc/h per side
- Particle mass ~2 x 10^8 M_{sun}
- Force resolution 1 kpc/h
- Complete to 50 km/s
- ~ 8 billion particles
- ~10 million halos at z = 0

Cosmological dark matter simulation

Planck 2013 parameters

ROCKSTAR

- Halo finder developed by Peter Behroozi
- Used 6d phase space + 1d time FOF algorithm
- Consistent Trees code determines gravitationally consistent merger trees

Properties of Dark Matter Halos as a Function of Local Environment Density

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, A. Dekel

MNRAS, 2017

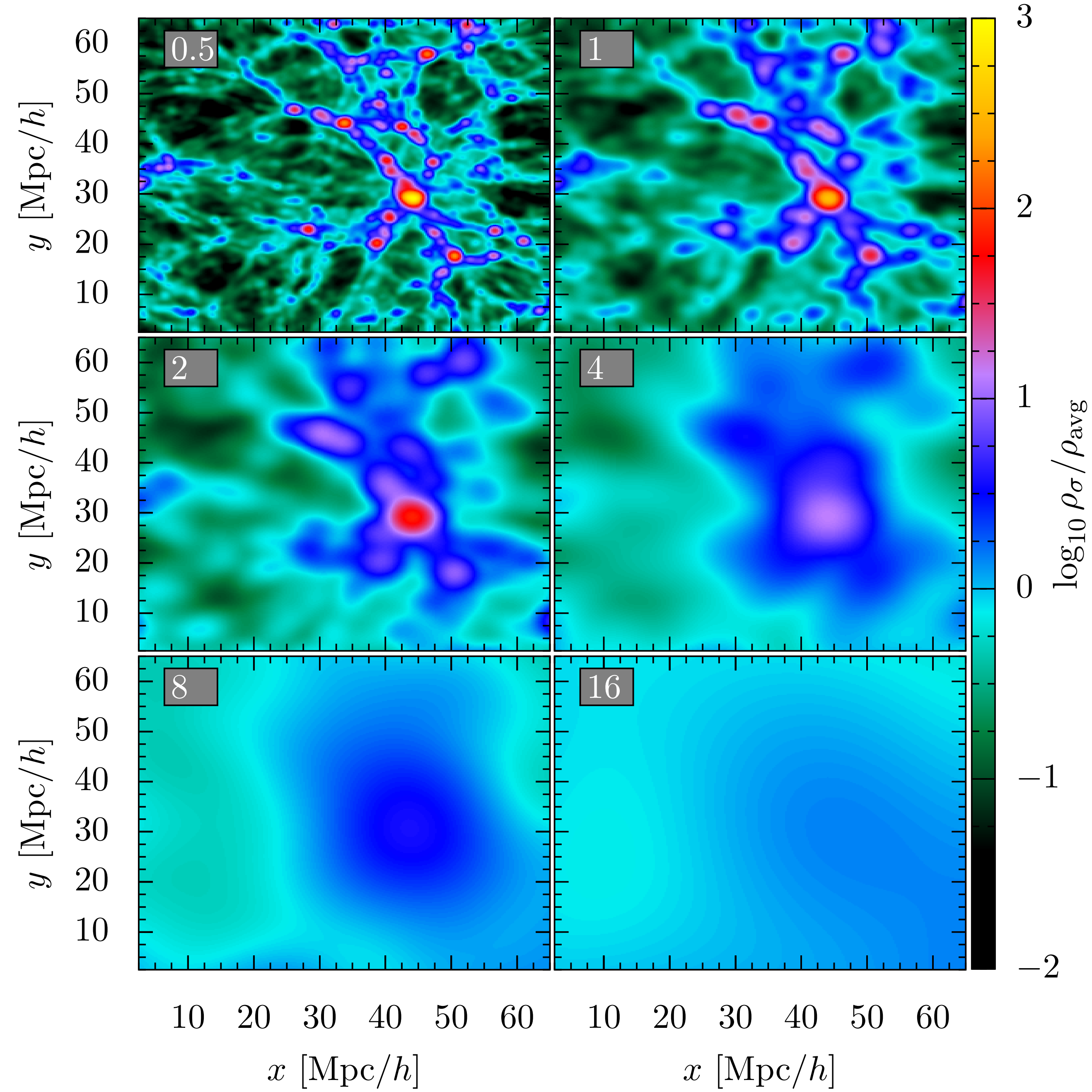
arXiv:1610.02108

We focus on central (distinct) halos in the Bolshoi-Planck cosmological dark matter simulation

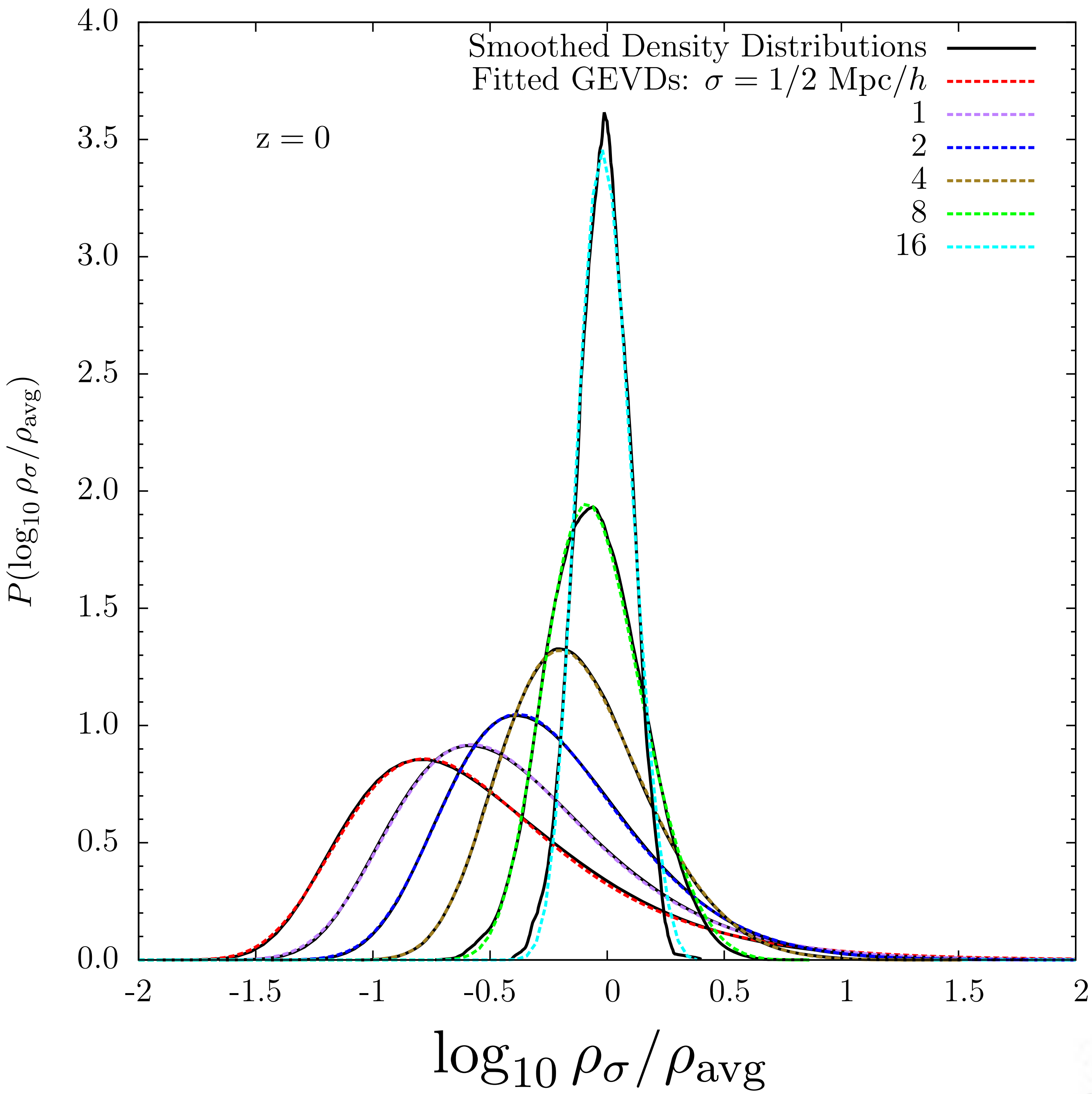
(i.e. NO subhalos at z = 0)

We compute local density using a gaussian smoothed Cloud-In-Cell counting algorithm with voxels of width 0.25 Mpc/h

All Rockstar halos are tagged with smoothed local density on many scales



Density Distributions



- Shape of Distributions indicate length scale at which nonlinear structures emerge
- Large smoothing scales probe narrower range of densities than small scales
- Statistics at high density end limited by voxel size
- Distribution well fit by Generalized Extreme Value Distribution (GEVD)

$$z = \frac{x - \mu}{\beta}$$

$$f(x) = \frac{1}{\beta}\exp\left[-(1+kz)^{-1/k}\right](1+kz)^{-1-1/k}$$

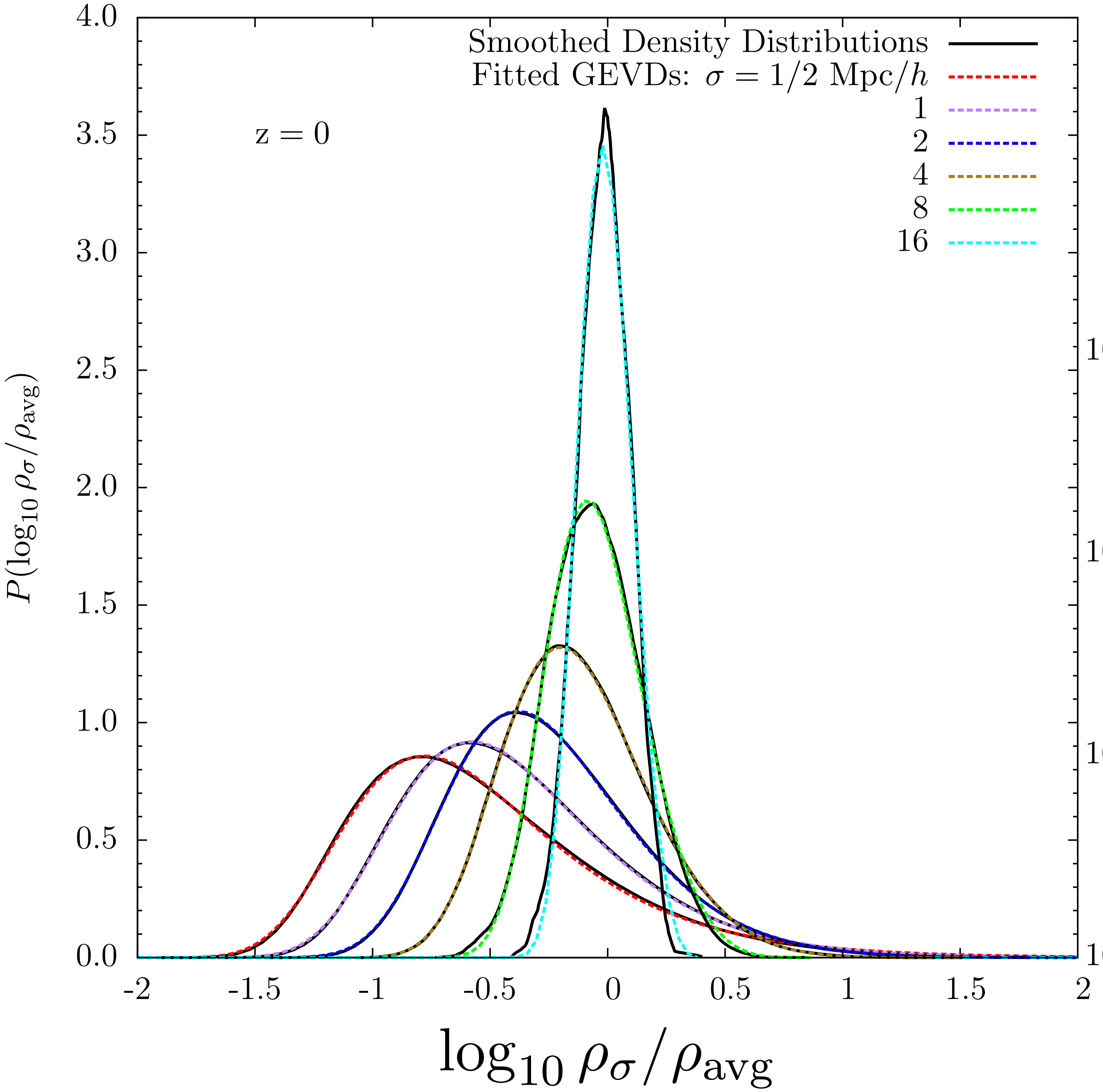
Properties of Dark Matter Halos as a Function of Local Environment Density

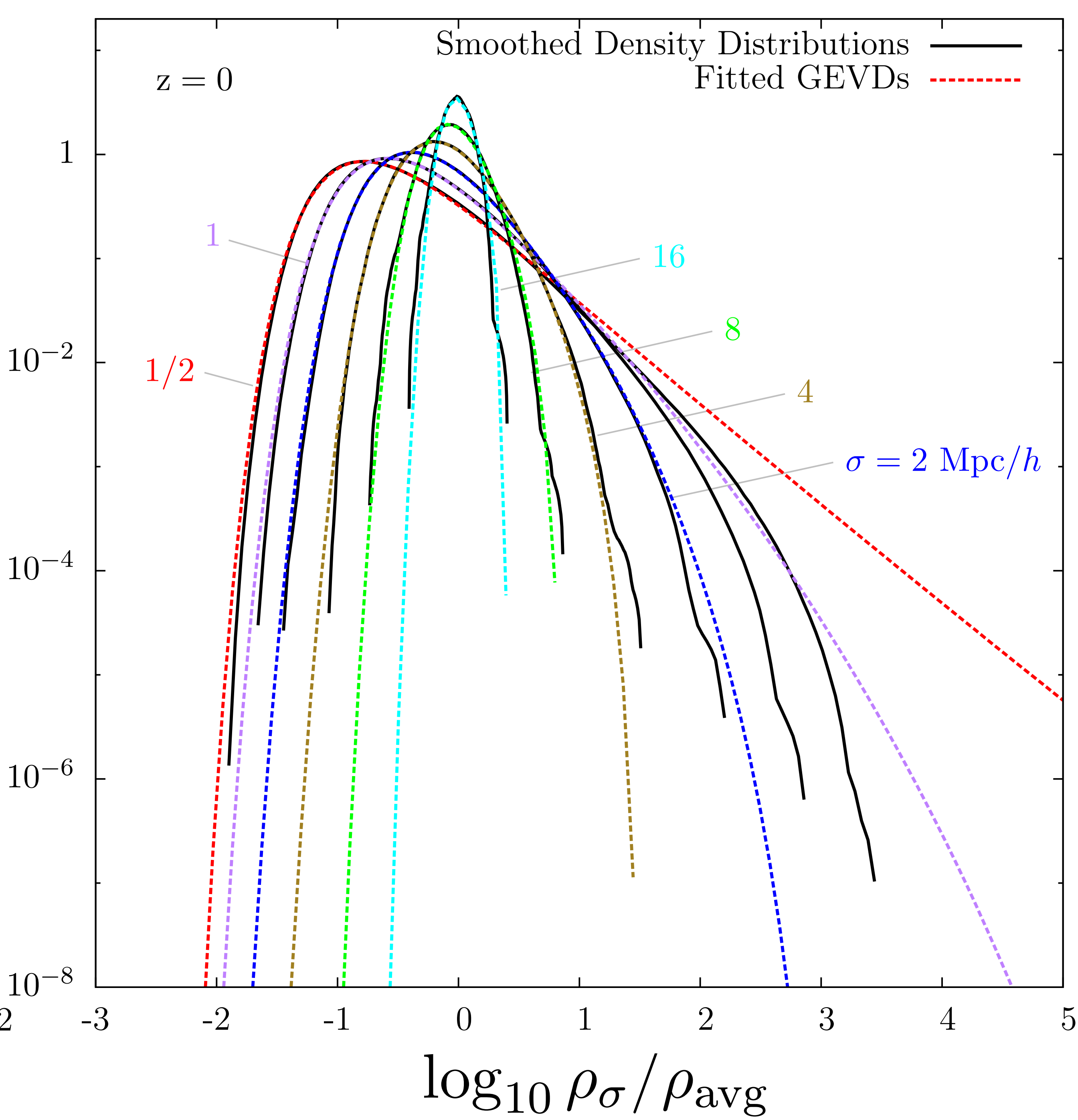
C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, A. Dekel

MNRAS, 2017

arXiv:1610.02108

Density Distributions

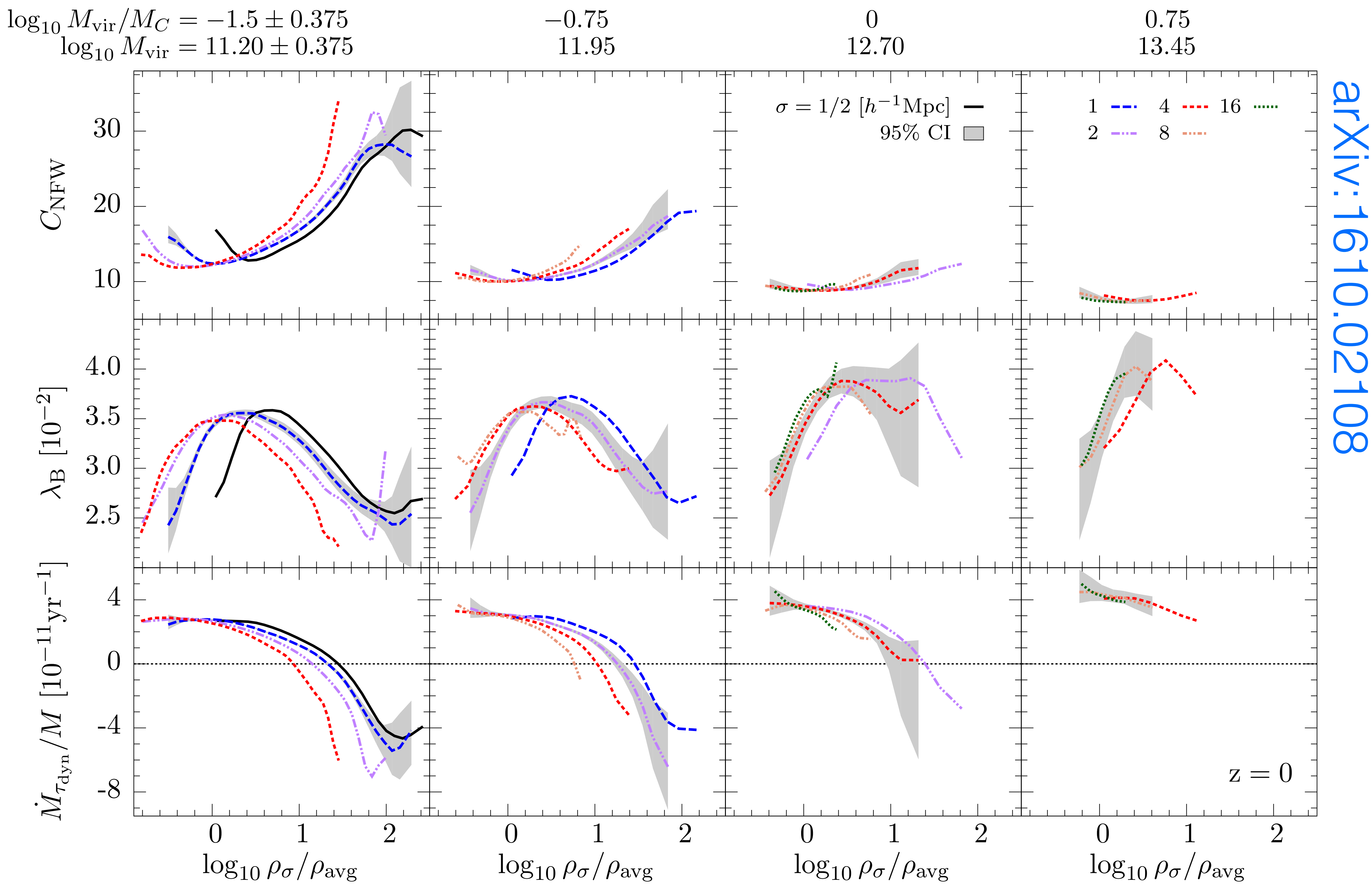




Properties of Dark Matter Halos as a Function of Local Environment Density

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, A. Dekel

MNRAS, 2017

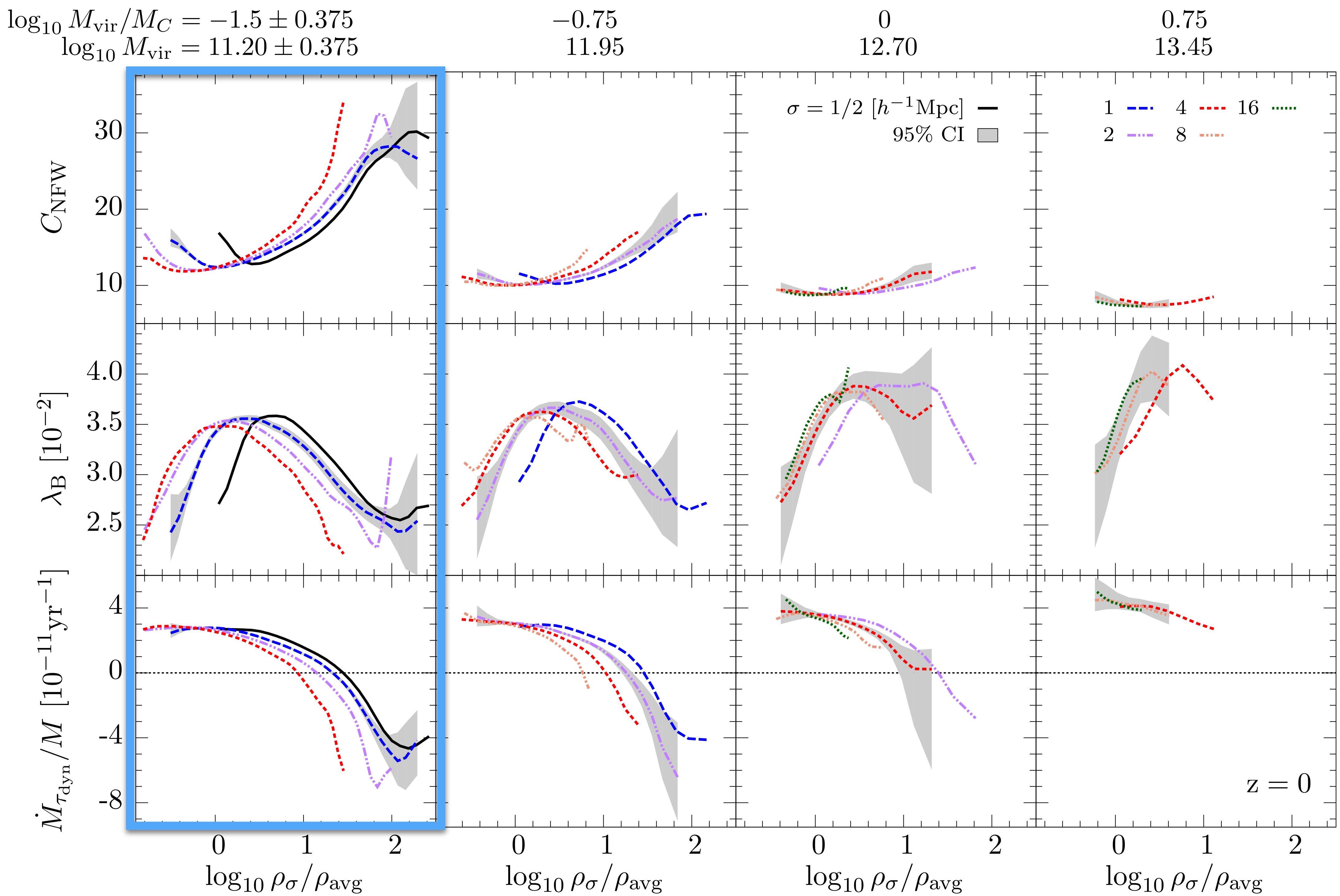


Small Galaxies **~ Milky Way** **Big Galaxies** **Groups**

Properties of Dark Matter Halos as a Function of Local Environment Density

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, A. Dekel

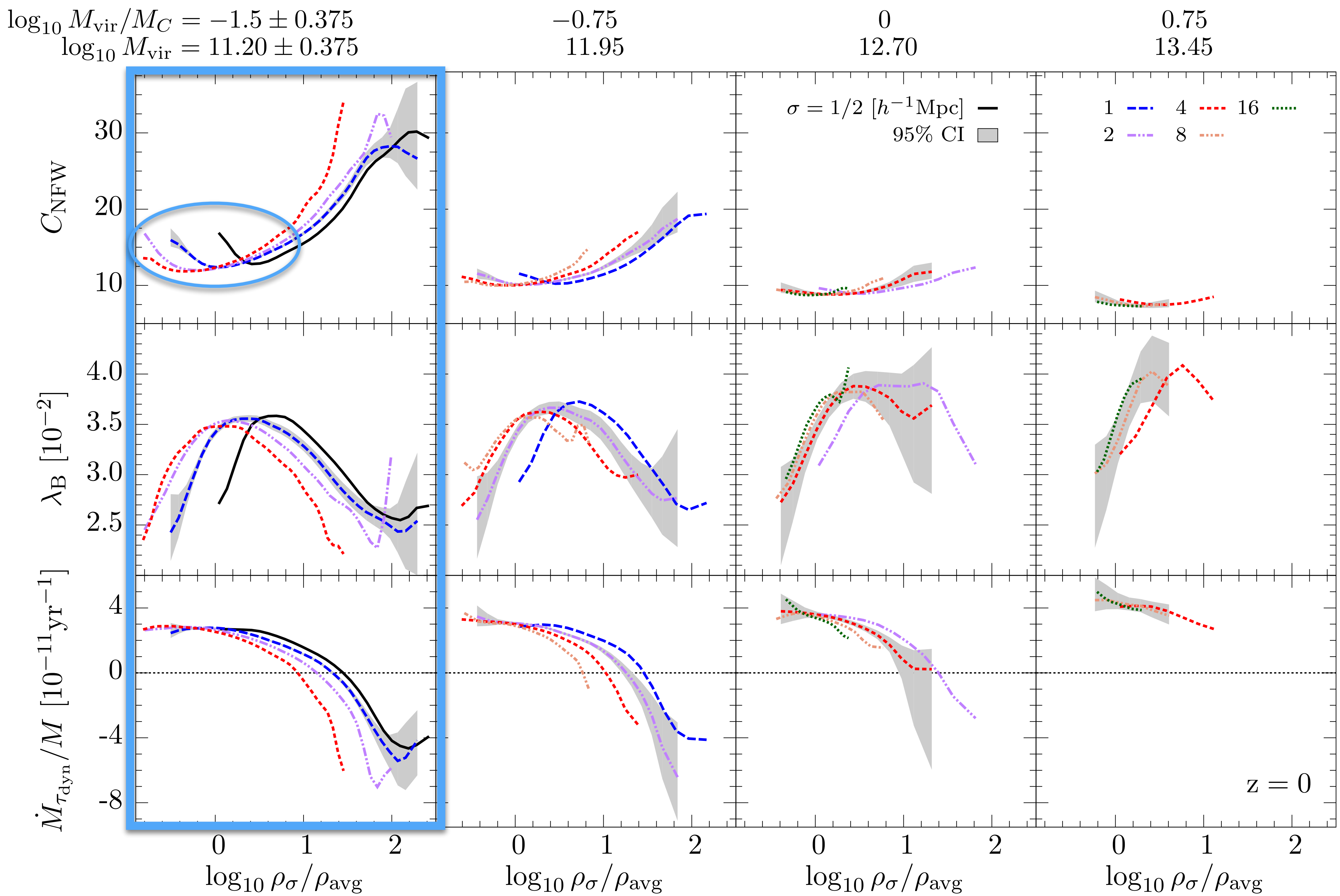
MNRAS, 2017



arXiv:1610.02108

Properties of Dark Matter Halos as a Function of Local Environment Density

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, A. Dekel — *MNRAS*, 2017



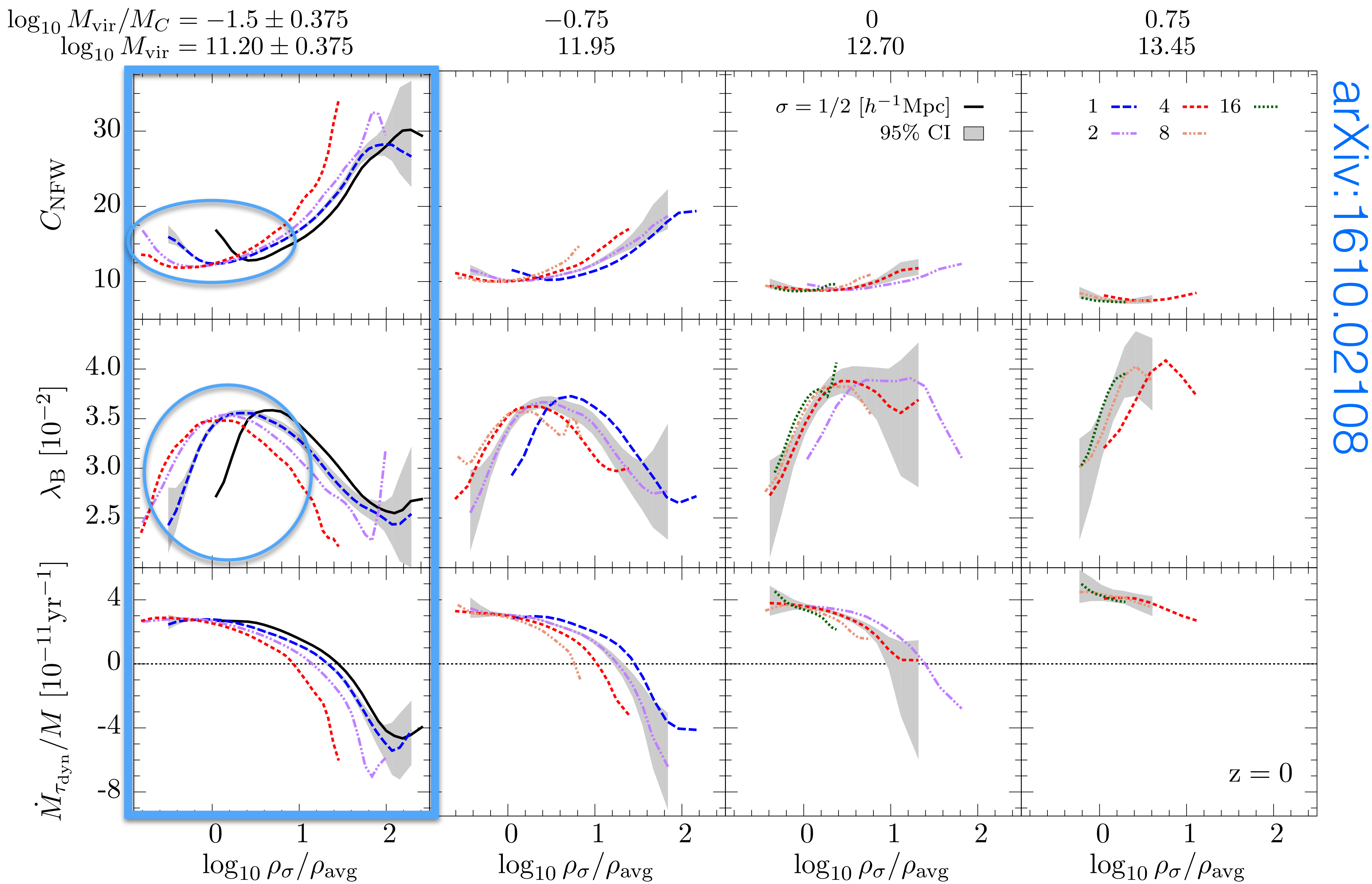
arXiv:1610.02108

Concentration increases from 12 to 16 (~30%) for 1 Mpc/h smoothing

Properties of Dark Matter Halos as a Function of Local Environment Density

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, A. Dekel

MNRAS, 2017



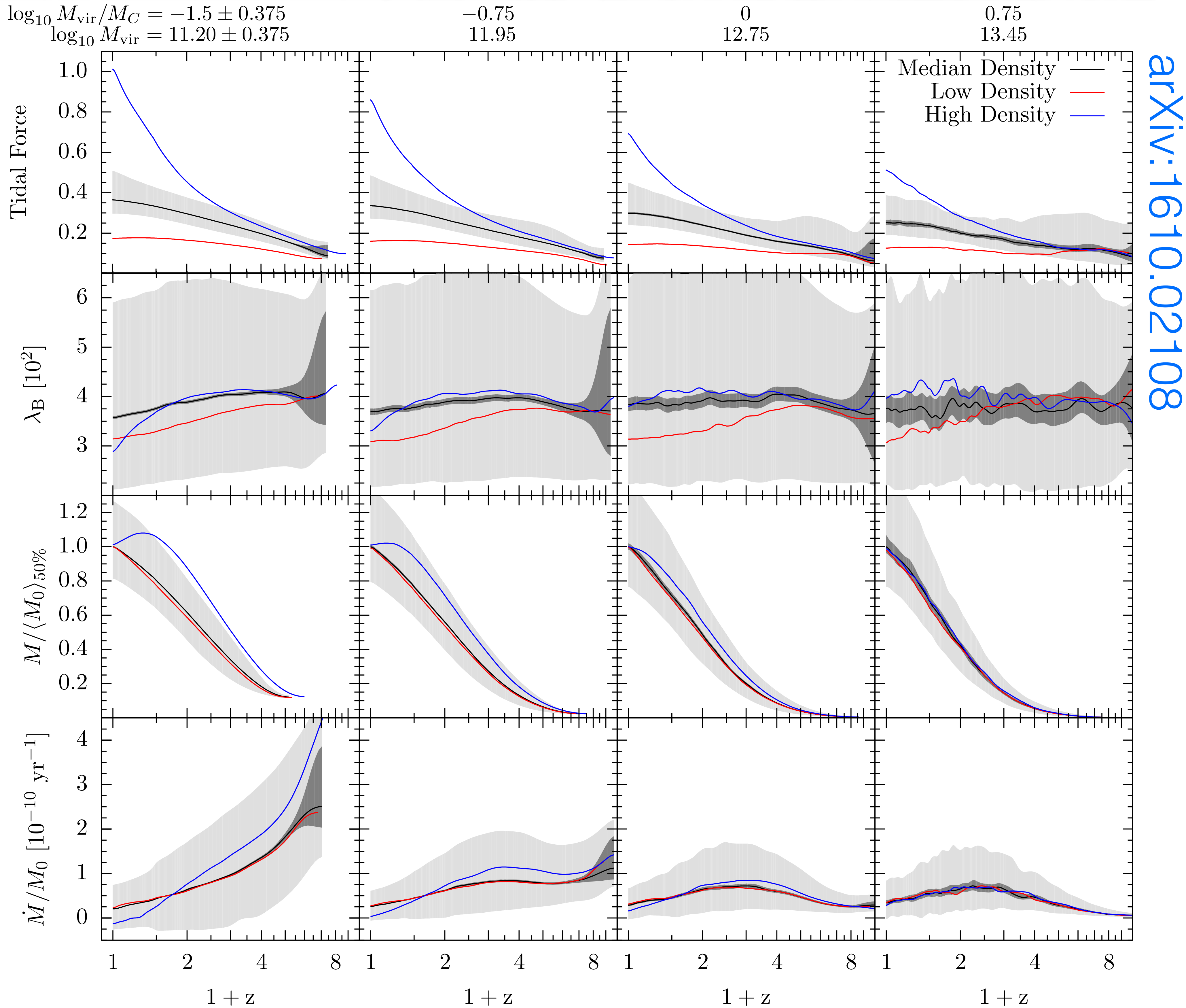
Concentration increases from 12 to 16 (~30%) for 1 Mpc/h smoothing

Spin parameter drops from 0.035 to 0.025 (~30%)

Properties of Dark Matter Halos as a Function of Local Environment Density

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, A. Dekel

MNRAS, 2017

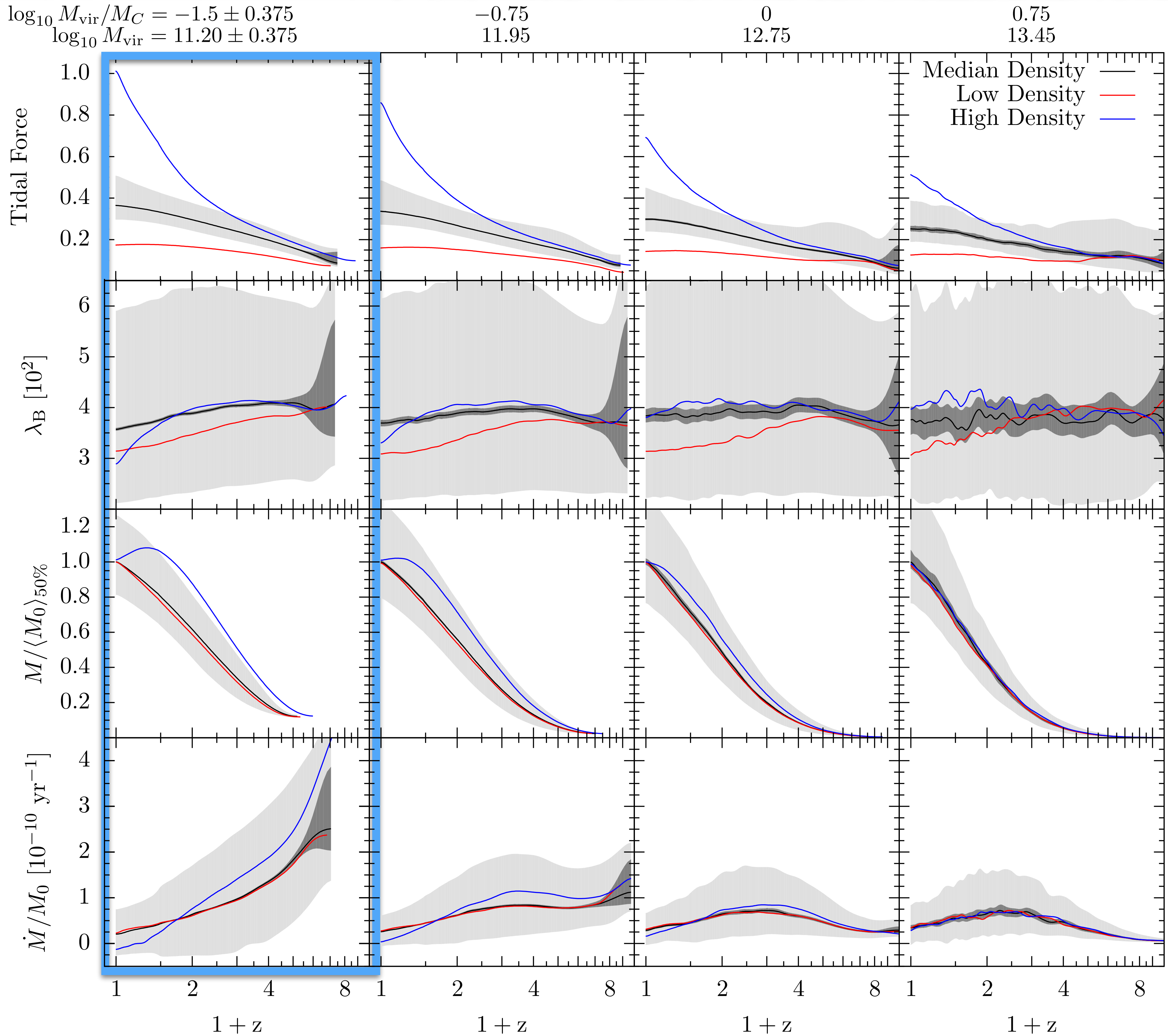


Christoph Lee, UCSC

Properties of Dark Matter Halos as a Function of Local Environment Density

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, A. Dekel

MNRAS, 2017



arXiv:1610.02108

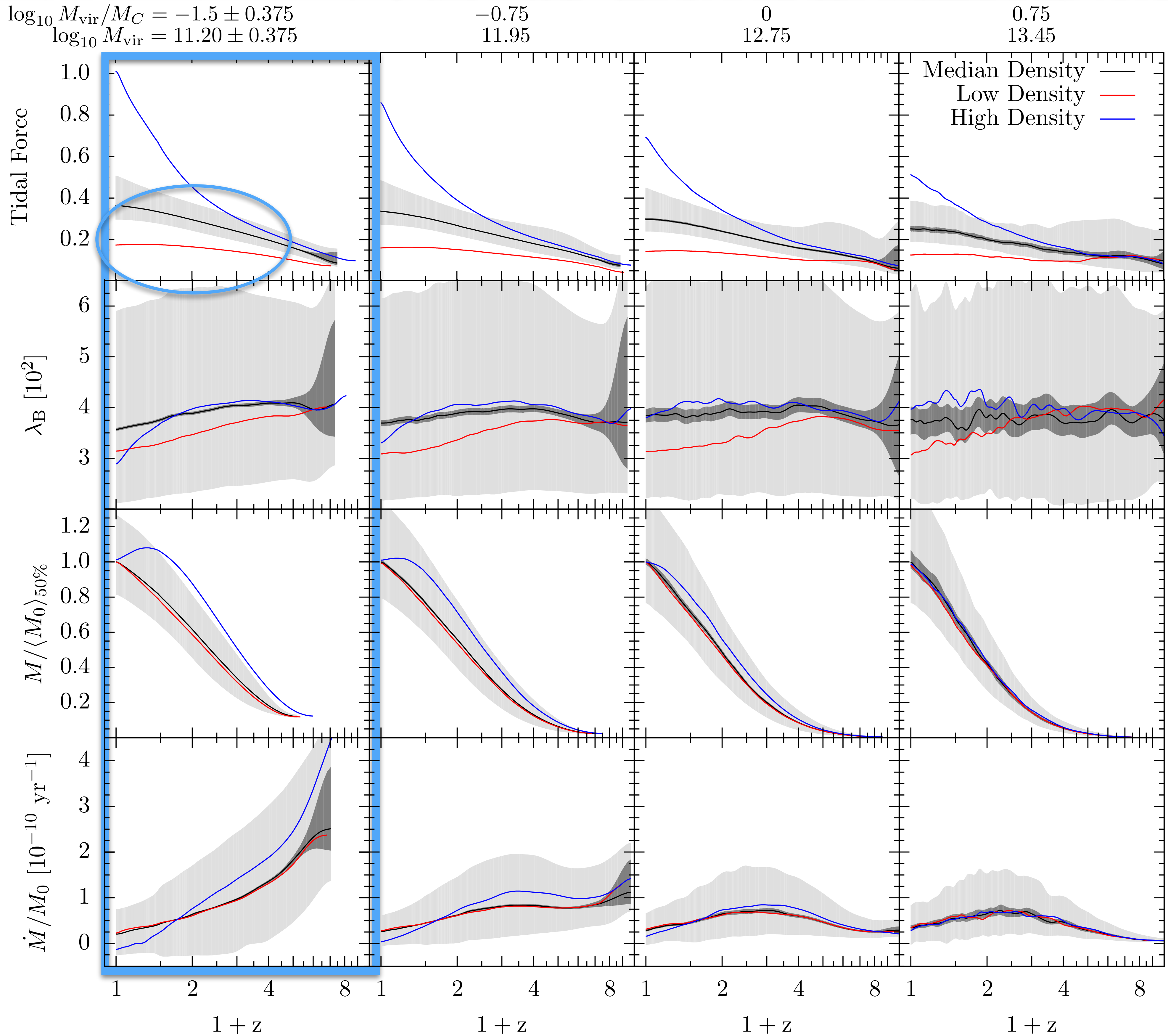
Properties of Dark Matter Halos as a Function of Local Environment Density

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, A. Dekel

MNRAS, 2017

In low density regions:

Tidal Force always lower on average



arXiv:1610.02108

Properties of Dark Matter Halos as a Function of Local Environment Density

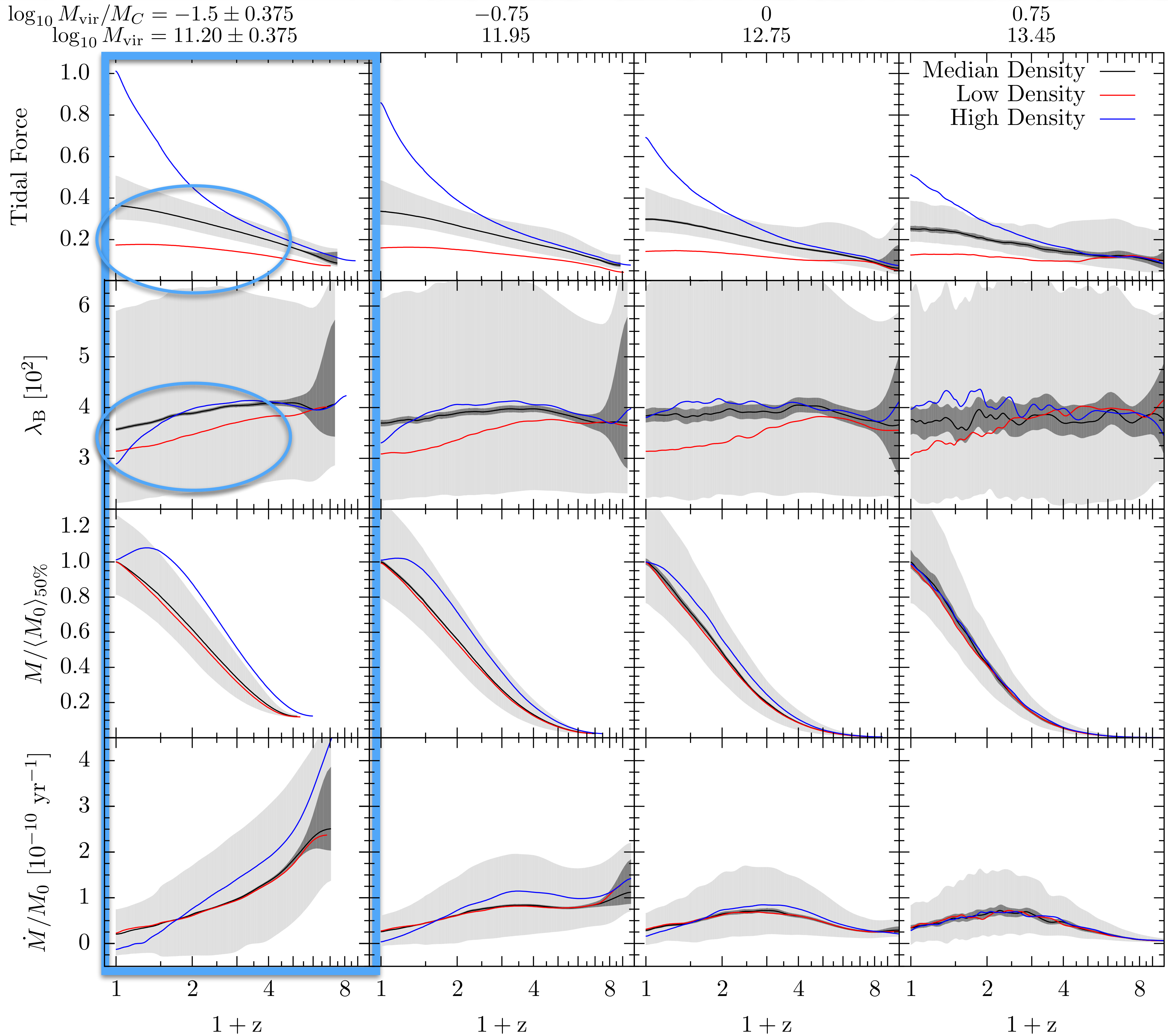
C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, A. Dekel

MNRAS, 2017

In low density regions:

Tidal Force always lower on average

Spin parameter always lower on average



arXiv:1610.02108

Properties of Dark Matter Halos as a Function of Local Environment Density

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, A. Dekel

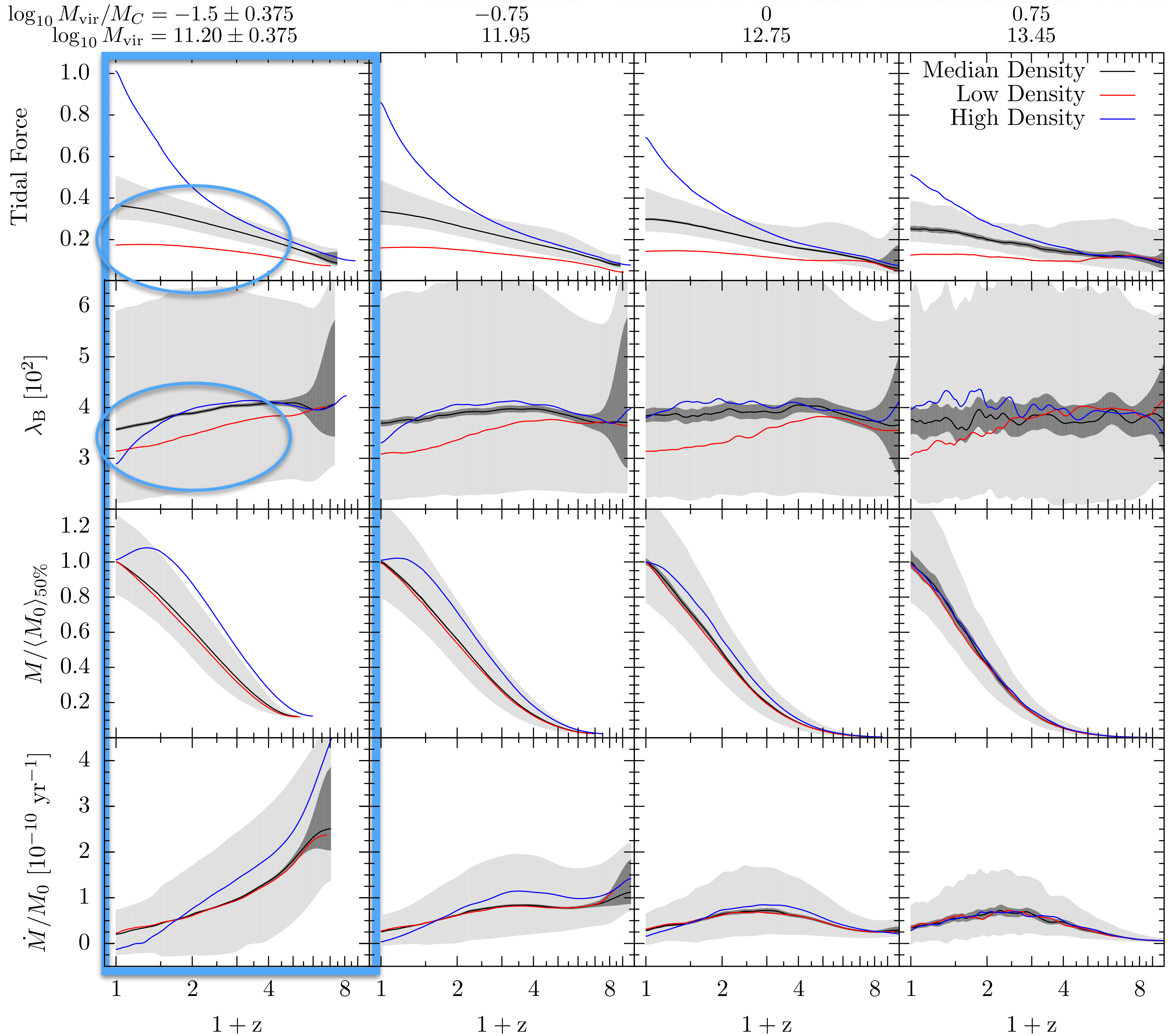
MNRAS, 2017

In low density regions:

Tidal Force always lower on average

Spin parameter always lower on average

Explanation: halos didn't have as many neighbors to torque them up as they formed / evolved.



arXiv:1610.02108

Christoph Lee, UCSC

What about using observational densities?

Using Bolshoi-Planck and SDSS:

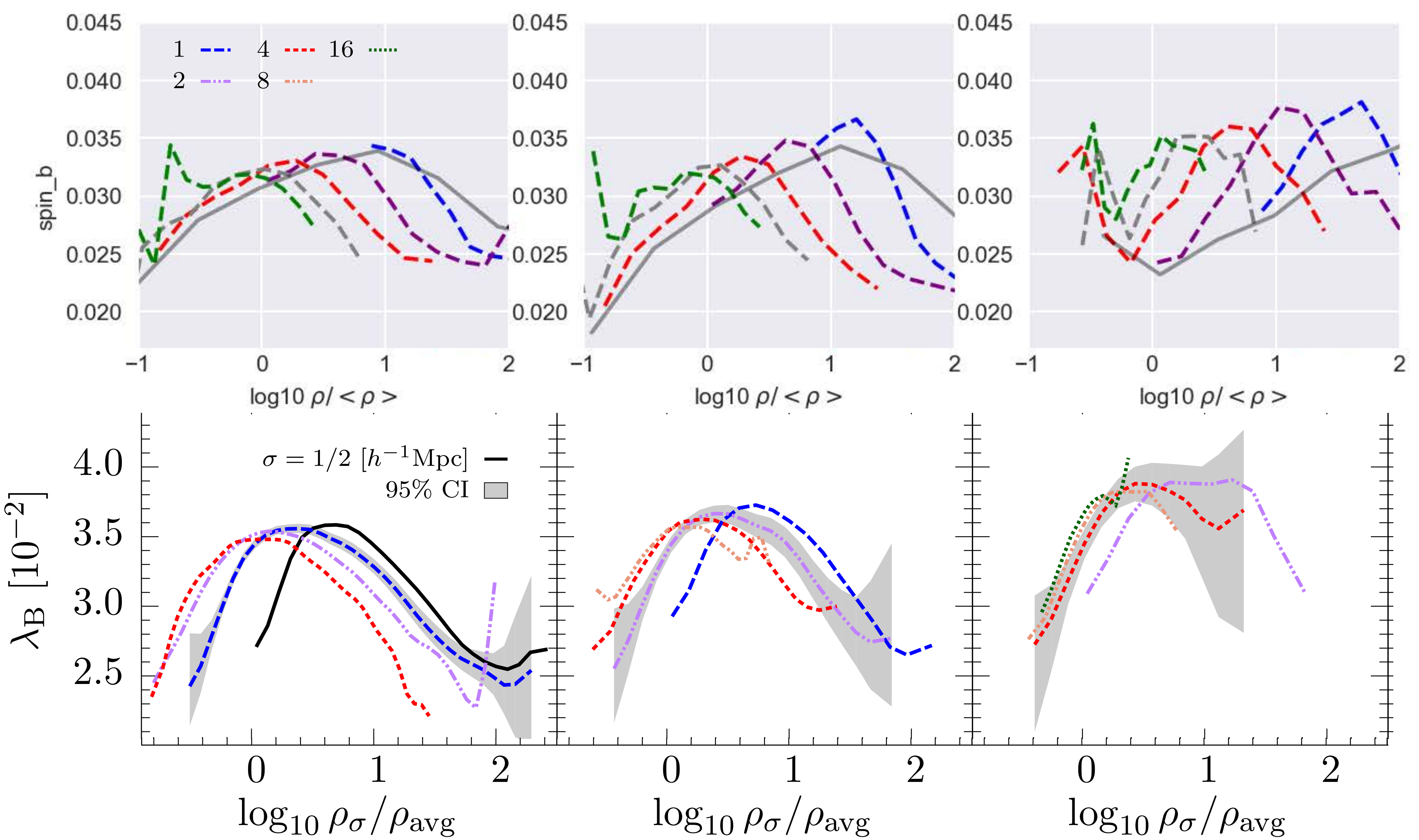
- Compute observer centric densities in both the simulation and SDSS (Nth nearest neighbor, counting galaxies/halos within spheres, Voronoi volume).
- Check whether halos in low density regions still have lower spin parameters, higher concentrations.
- Check dependence of galaxy size on density measured the same way as in the simulations.
- Use an abundance-matched catalog to directly compare how actual galaxy size compares to galaxy size predicted using halo spin parameter.
- **Preliminary results indicate that galaxies are not smaller in low density regions, i.e. that spin parameter does not control size for these halos.**
- We are testing other predictors of galaxy size as well, such as a concentration based estimator developed by Fangzhou Jiang.

In collaboration with Graham Vanbenthuysen, Viraj Pandya, Joel Primack, Peter Behroozi, Aldo Rodriguez-Puebla

What about using observational densities?

Using Bolshoi-Planck and SDSS:

- Compute observer centric densities in both the simulation and SDSS (Nth nearest neighbor, counting galaxies/halos within spheres, Voronoi volume).
- Verify whether halos in low density regions still have lower spin parameters.



Dark Matter Halo Properties vs. Local Density and Cosmic Web Location

Tze Goh; Joel R. Primack; **Christoph T. Lee**; Miguel Aragon-Calvo; Doug Hellinger; Peter Behroozi; Aldo Rodríguez-Puebla; Elliot Eckholm; Kathryn Johnston; *MNRAS,* 2019

Using Bolshoi Planck cosmological dark matter simulation, with cosmic web identified via Miguel Aragon-Calvo's SpineWeb framework.

Abstract:

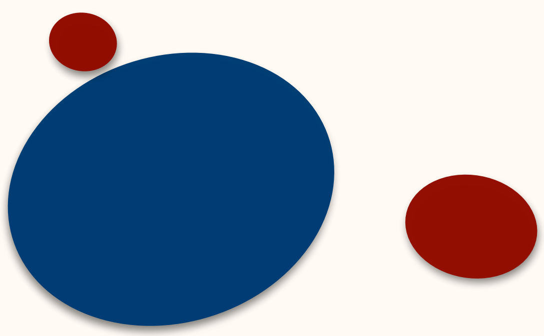
We study the effects of the local environmental density and the cosmic web environment (filaments, walls, and voids) on key properties of dark matter halos using the Bolshoi-Planck ΛCDM cosmological simulation. The $z = 0$ simulation is analysed into filaments, walls, and voids using the SpineWeb method and also the VIDE package of tools, both of which use the watershed transform. The key halo properties that we study are the **specific mass accretion rate, spin parameter, concentration, prolateness, scale factor of the last major merger, and scale factor when the halo had half of its $z = 0$ mass**. For all these properties, we find that there is no discernible difference between the halo properties in filaments, walls, or voids when compared at the same environmental density. As a result, we conclude that environmental density is the core attribute that affects these properties. This conclusion is in line with recent findings that properties of galaxies in redshift surveys are independent of their cosmic web environment at the same environmental density at $z \sim 0$. We also find that the local web environment of the Milky Way and the Andromeda galaxies near the centre of a cosmic wall does not appear to have any effect on the properties of these galaxies' dark matter halos except for their orientation, although we find that it is rather rare to have such massive halos near the centre of a relatively small cosmic wall.

We compare the properties of halos in different cosmic web environments, but at the same environmental density.

We find that density rules — that is, at the same local density, there is no significant difference in the distributions of the halo properties we consider between halos in walls, filaments, or voids.

Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos:

Causes and Consequences of Mass Loss



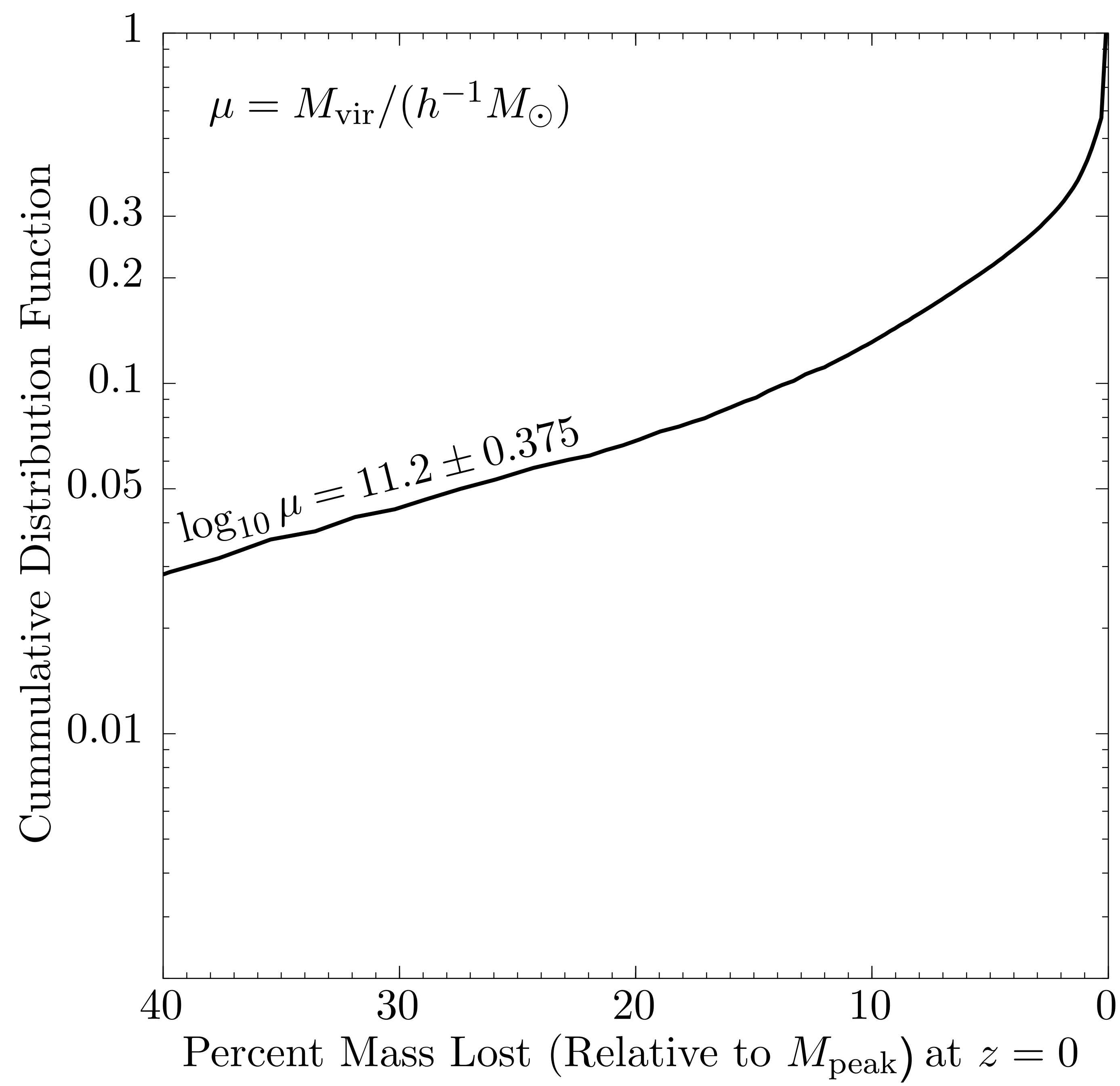
Christoph Lee (UCSC)

August 11, 2017 UCSC Galaxy Workshop

Joel Primack (UCSC), Peter Behroozi (UCB), Aldo Rodriguez-Puebla (IA-UNAM), Doug Hellinger (UCSC), Jessica Zhu (UCSC), Austin Tuan (UCSC), Avishai Dekel (HUJI/UCSC)

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

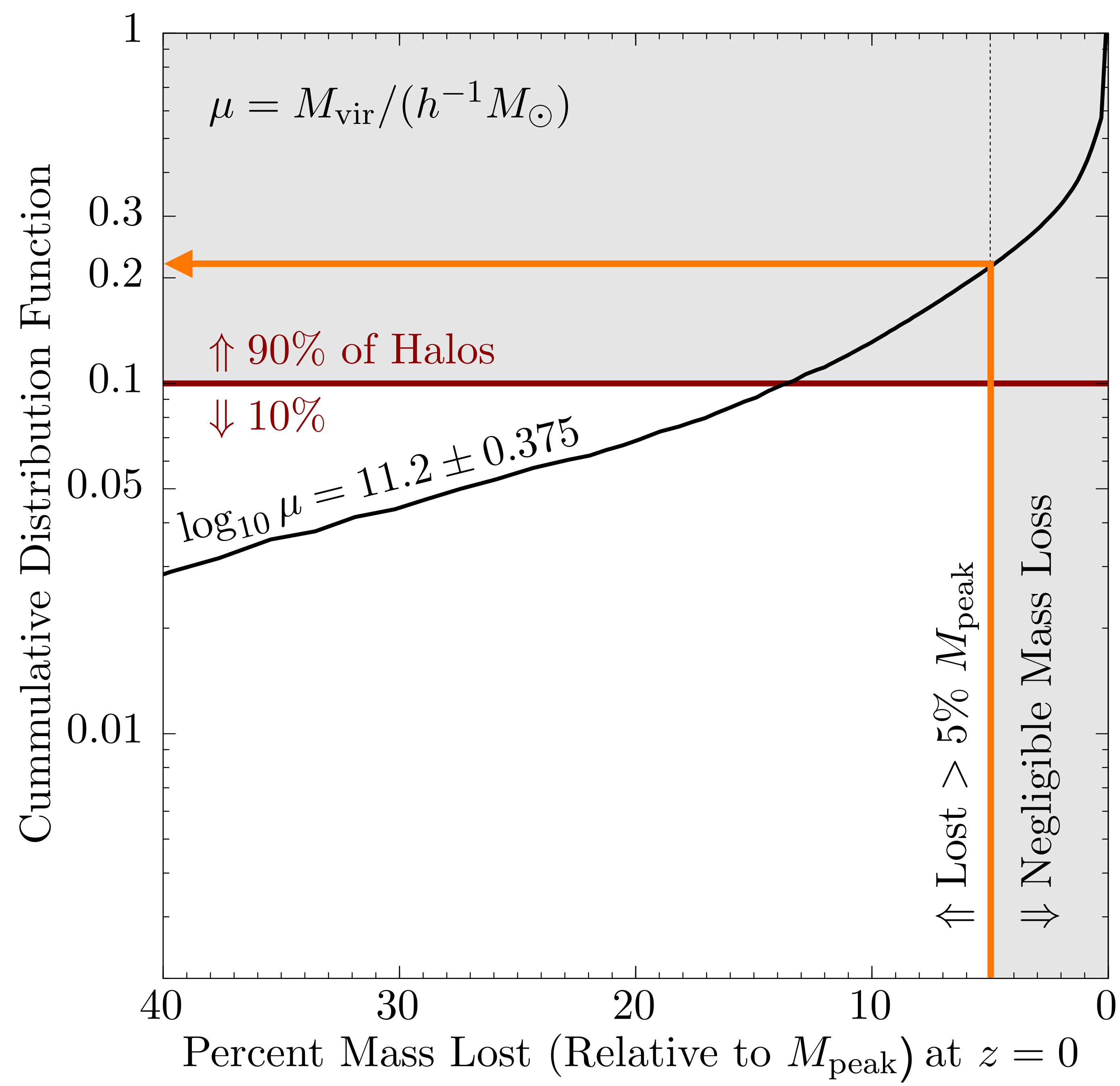
Is mass loss common?



Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos: Causes and Consequences of Mass Loss

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

Is mass loss common?

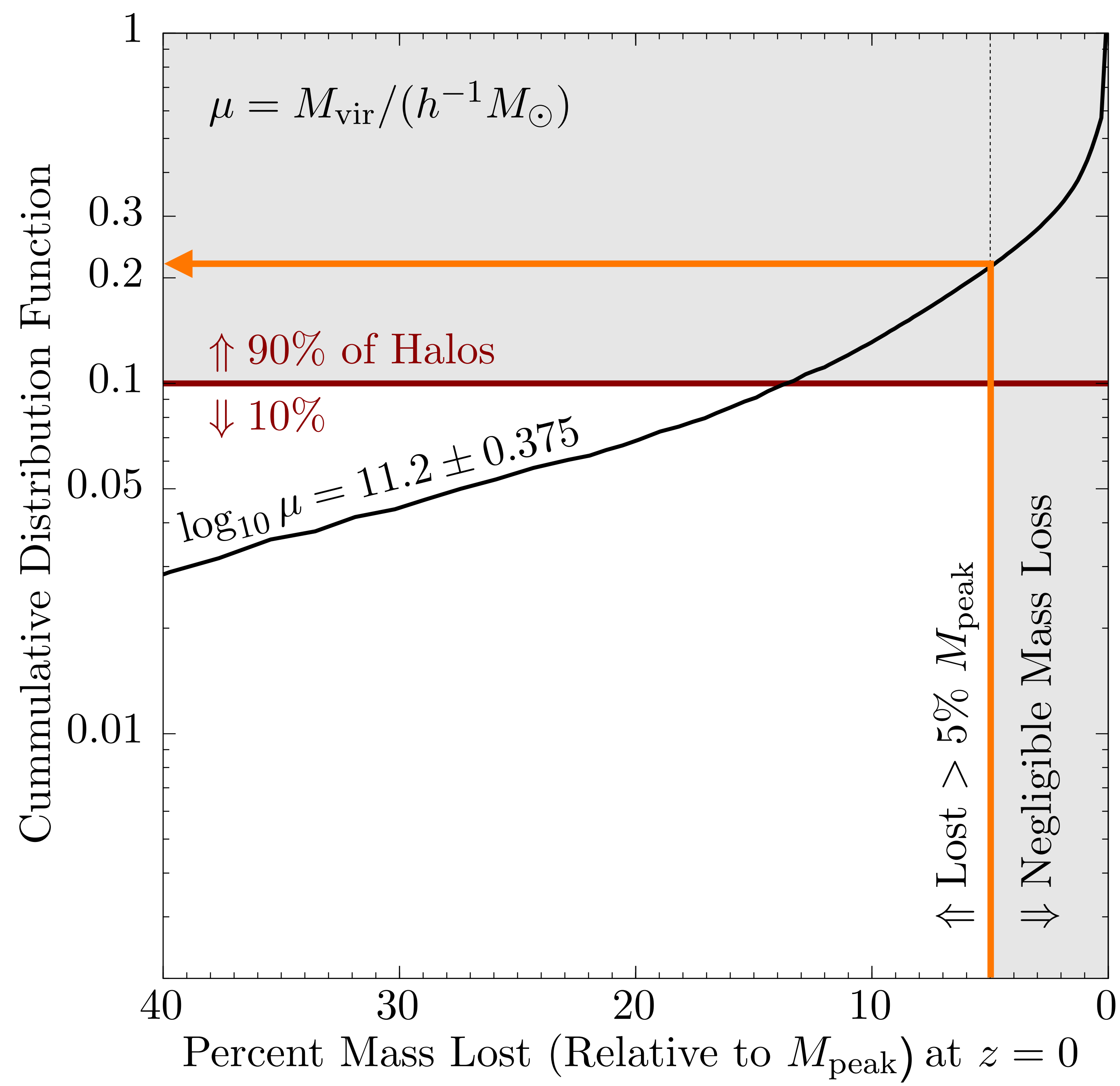


Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos: Causes and Consequences of Mass Loss

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

Is mass loss common?

At $z = 0$, 22% of low mass halos ($\log \mu = 11.2$) have lost more than 5% of their peak mass.

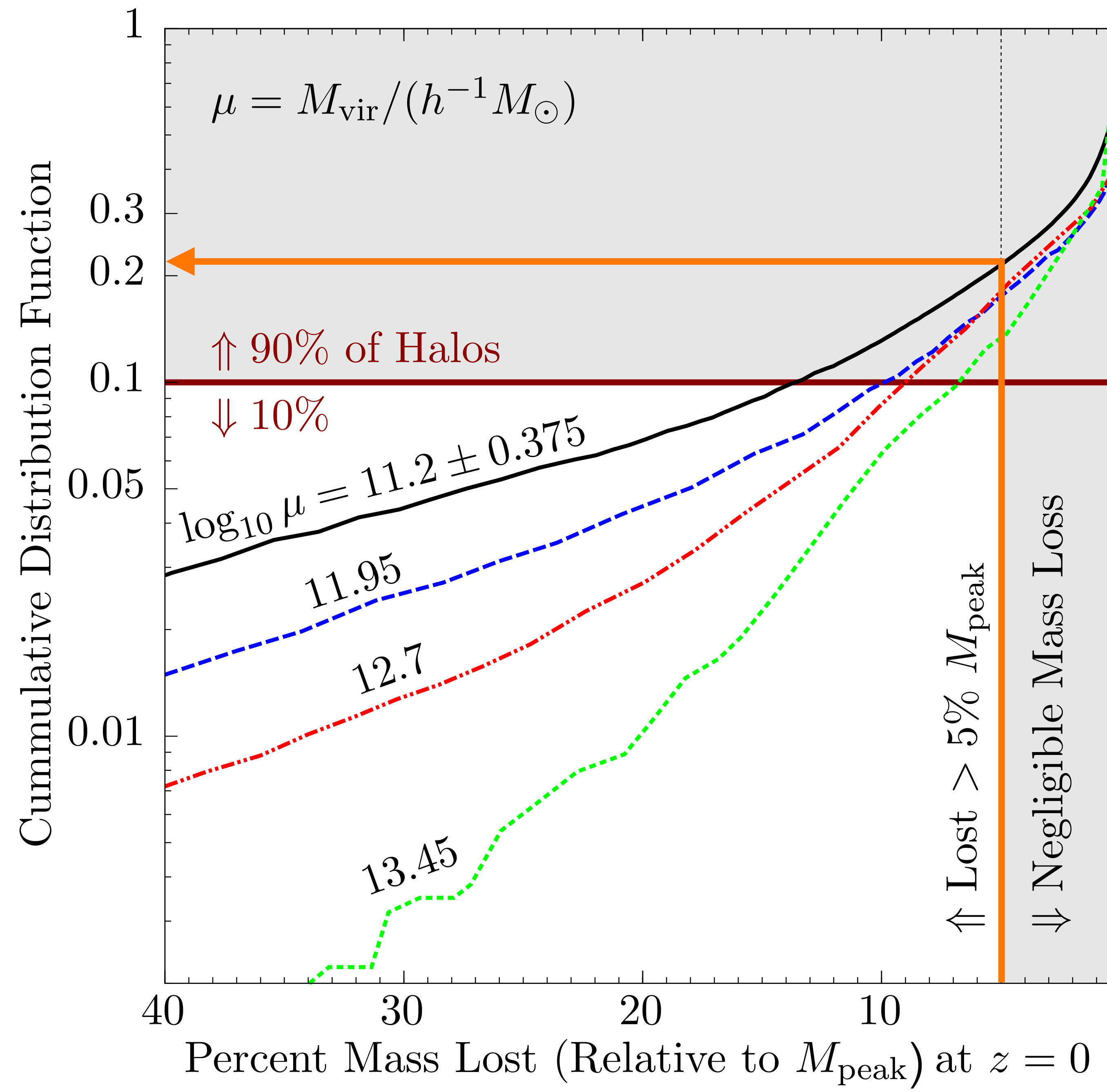


Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos:
Causes and Consequences of Mass Loss

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

Is mass loss common?

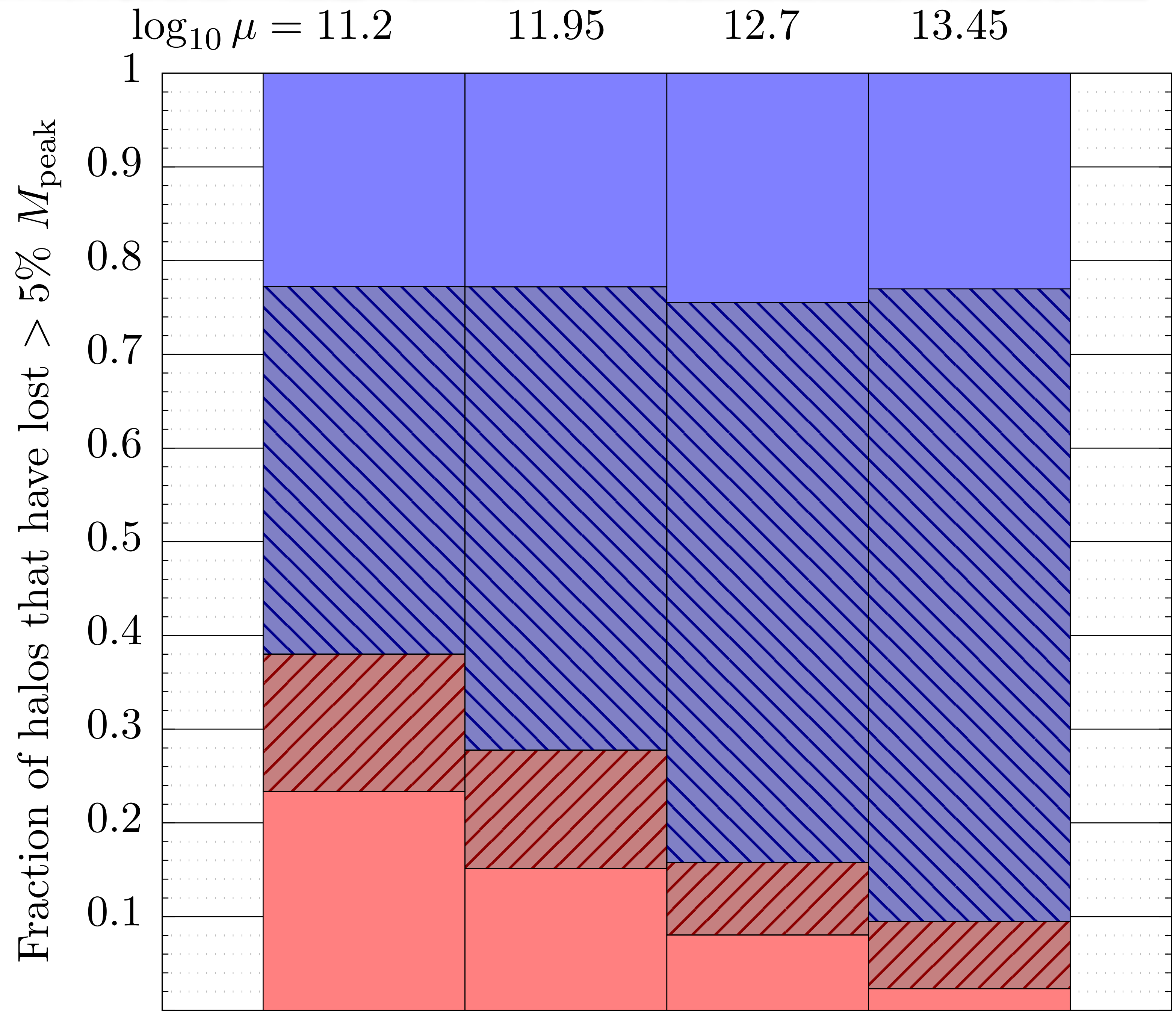
At $z = 0$, 22% of low mass halos ($\log \mu = 11.2$) have lost more than 5% of their peak mass.



Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos: Causes and Consequences of Mass Loss

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

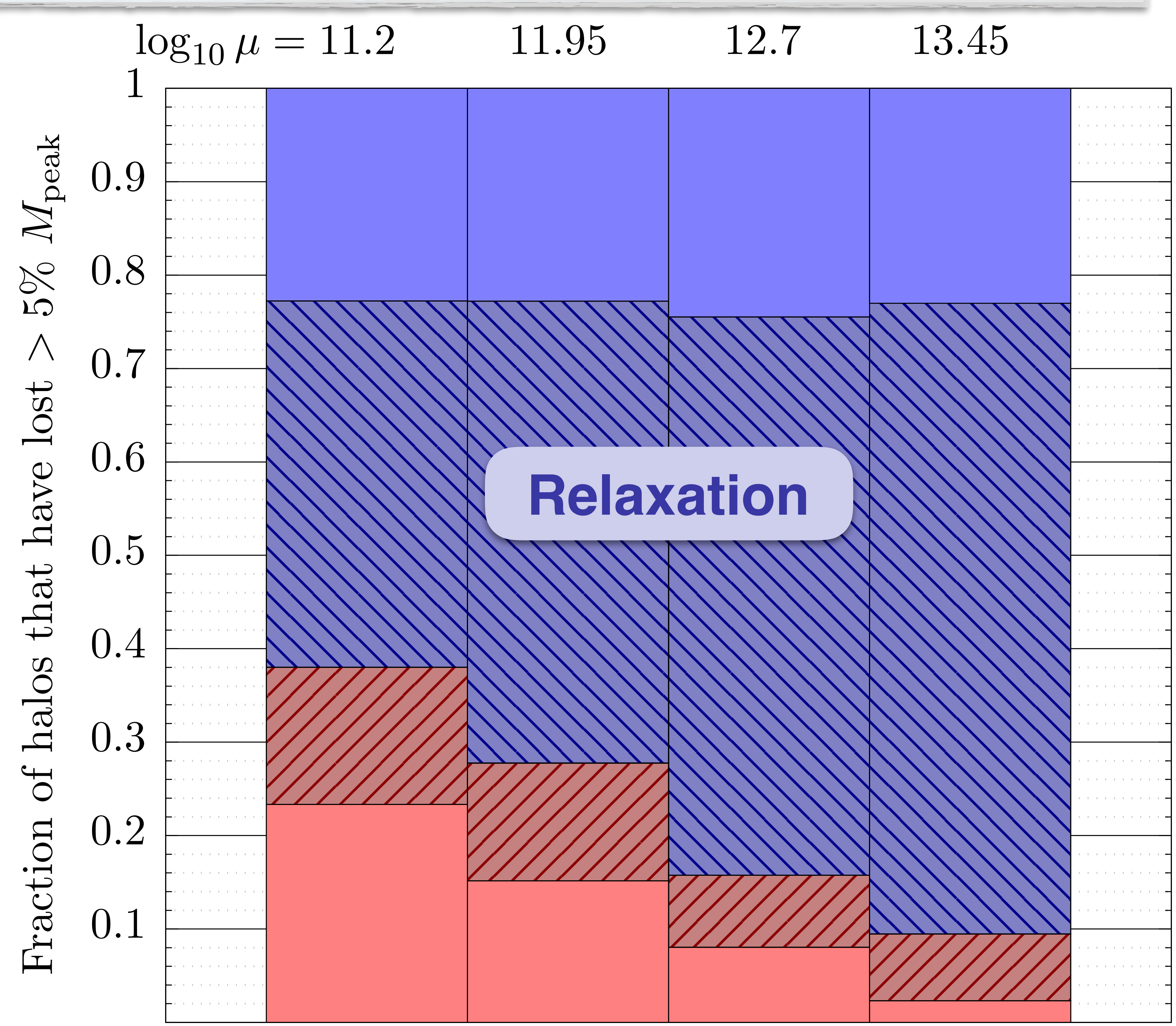
Why do halos lose mass?



Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos: Causes and Consequences of Mass Loss

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

Why do halos lose mass?

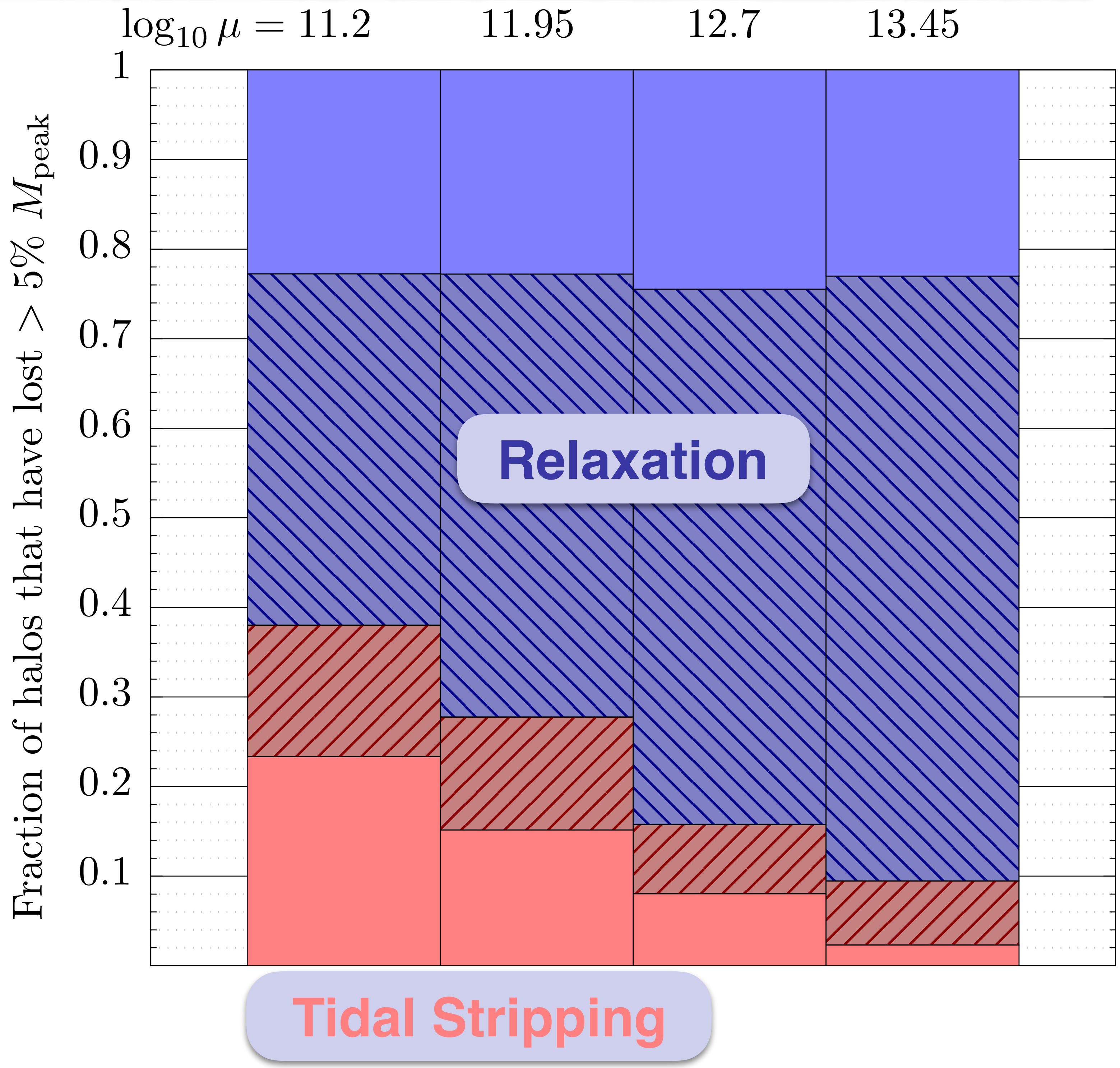


Most halos lose mass via relaxation after a major (or minor) merger.

Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos:
Causes and Consequences of Mass Loss

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

Why do halos lose mass?



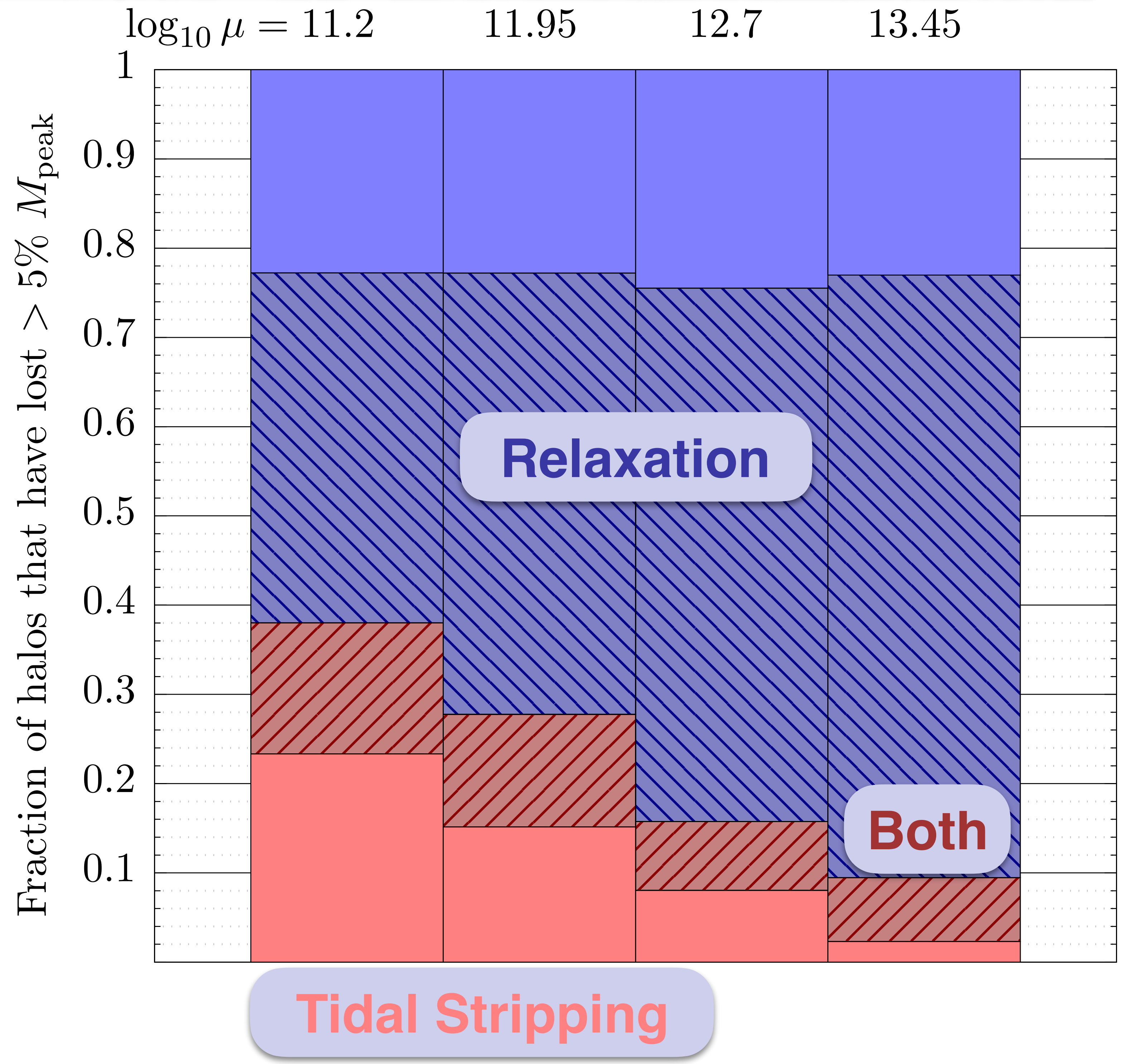
Most halos lose mass via relaxation after a major (or minor) merger.

Low mass halos can also lose mass through tidal stripping.

Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos:
Causes and Consequences of Mass Loss

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

Why do halos lose mass?



Most halos lose mass via relaxation after a major (or minor) merger.

In some cases, halos are subject to both of these effects.

Low mass halos can also lose mass through tidal stripping.

Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos:

Causes and Consequences of Mass Loss

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

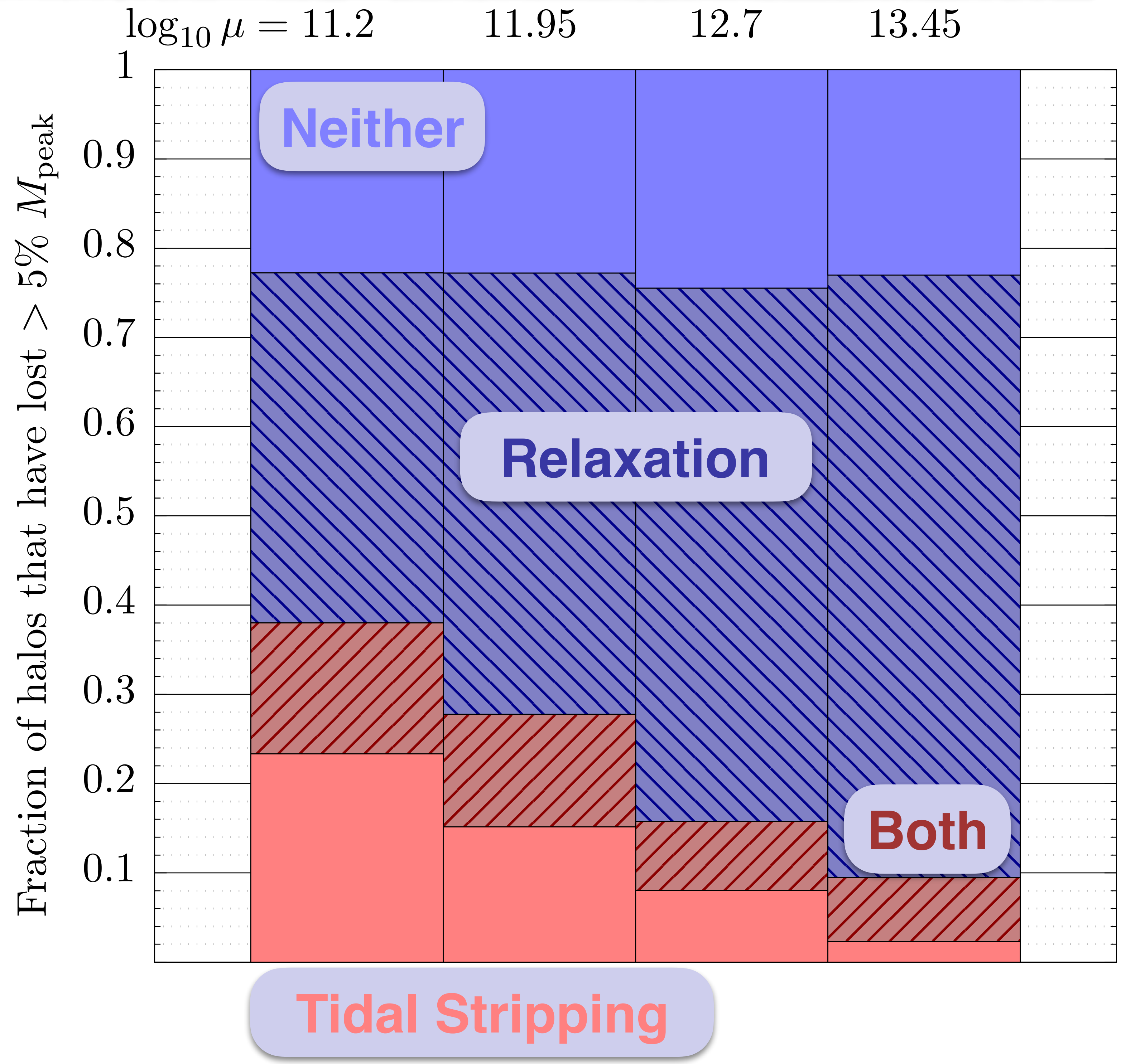
Why do halos lose mass?

Some halos have not had a recent major merger or experienced recent tidal stripping. These likely had recent minor mergers.

Most halos lose mass via relaxation after a major (or minor) merger.

In some cases, halos are subject to both of these effects.

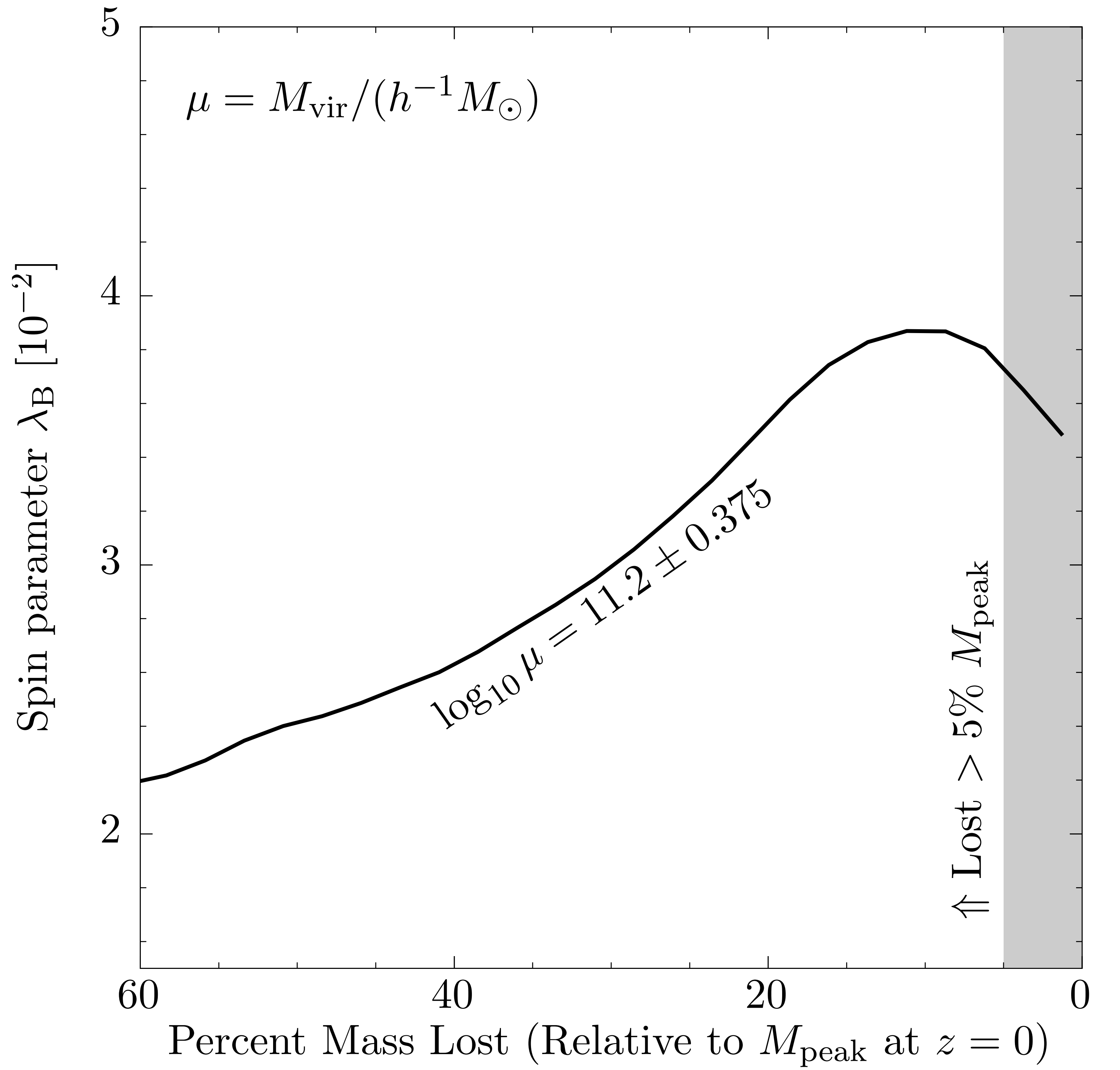
Low mass halos can also lose mass through tidal stripping.



Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos:
Causes and Consequences of Mass Loss

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

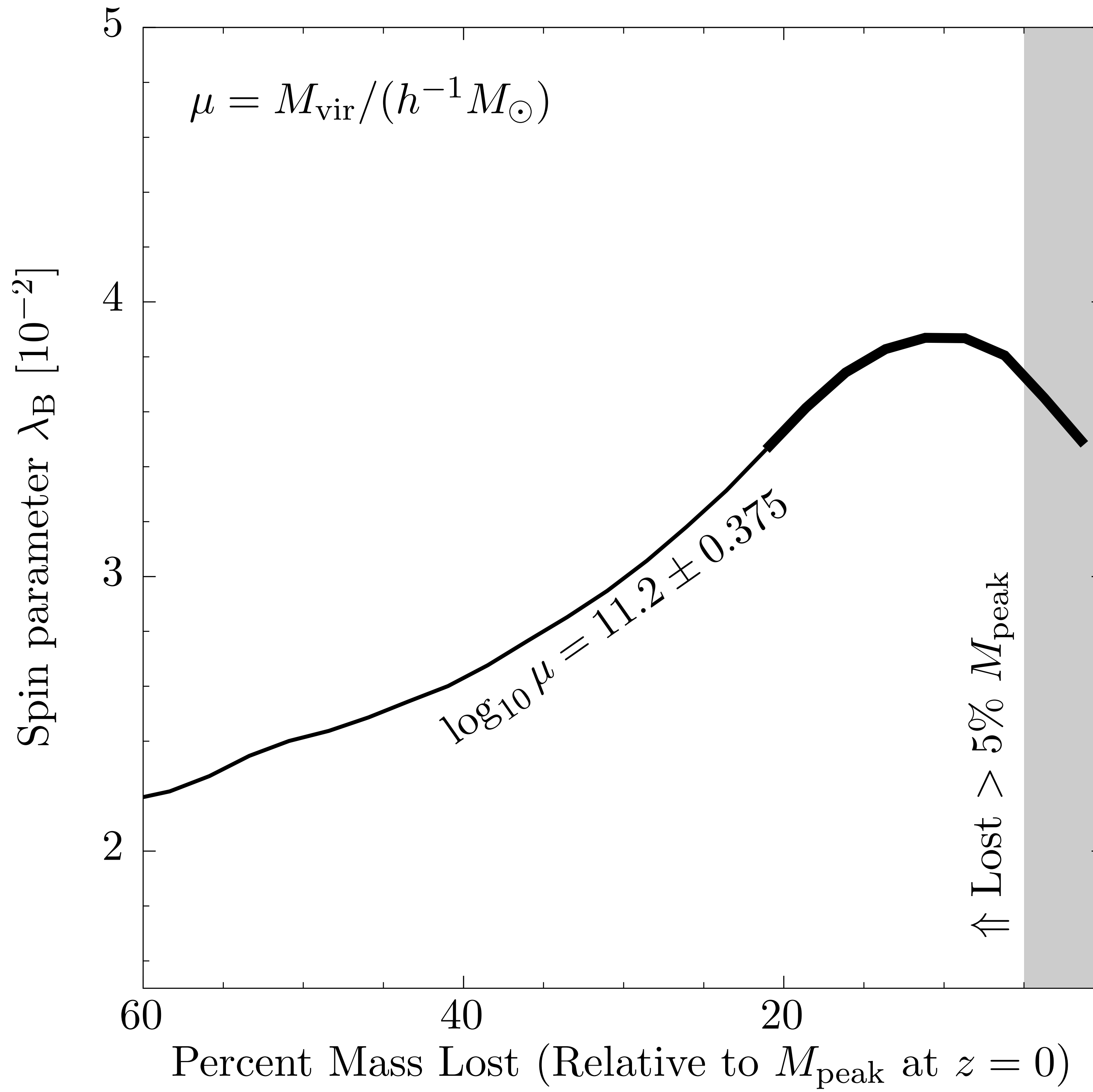
What happens when halos lose mass?



Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos:
Causes and Consequences of Mass Loss

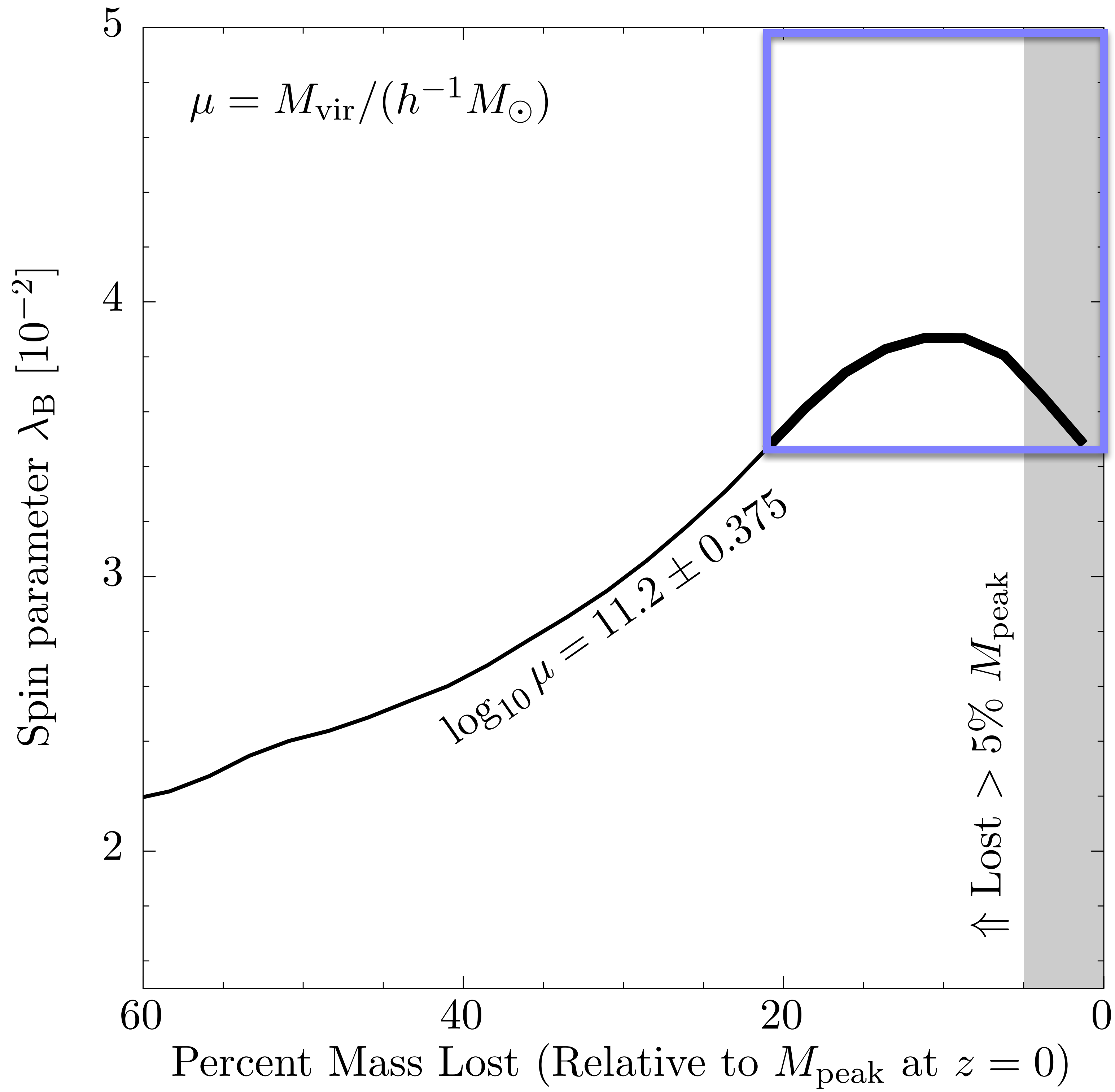
C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

What happens when halos lose mass?



What happens when halos lose mass?

Post-merger relaxation dominates in 5-20% mass loss regime



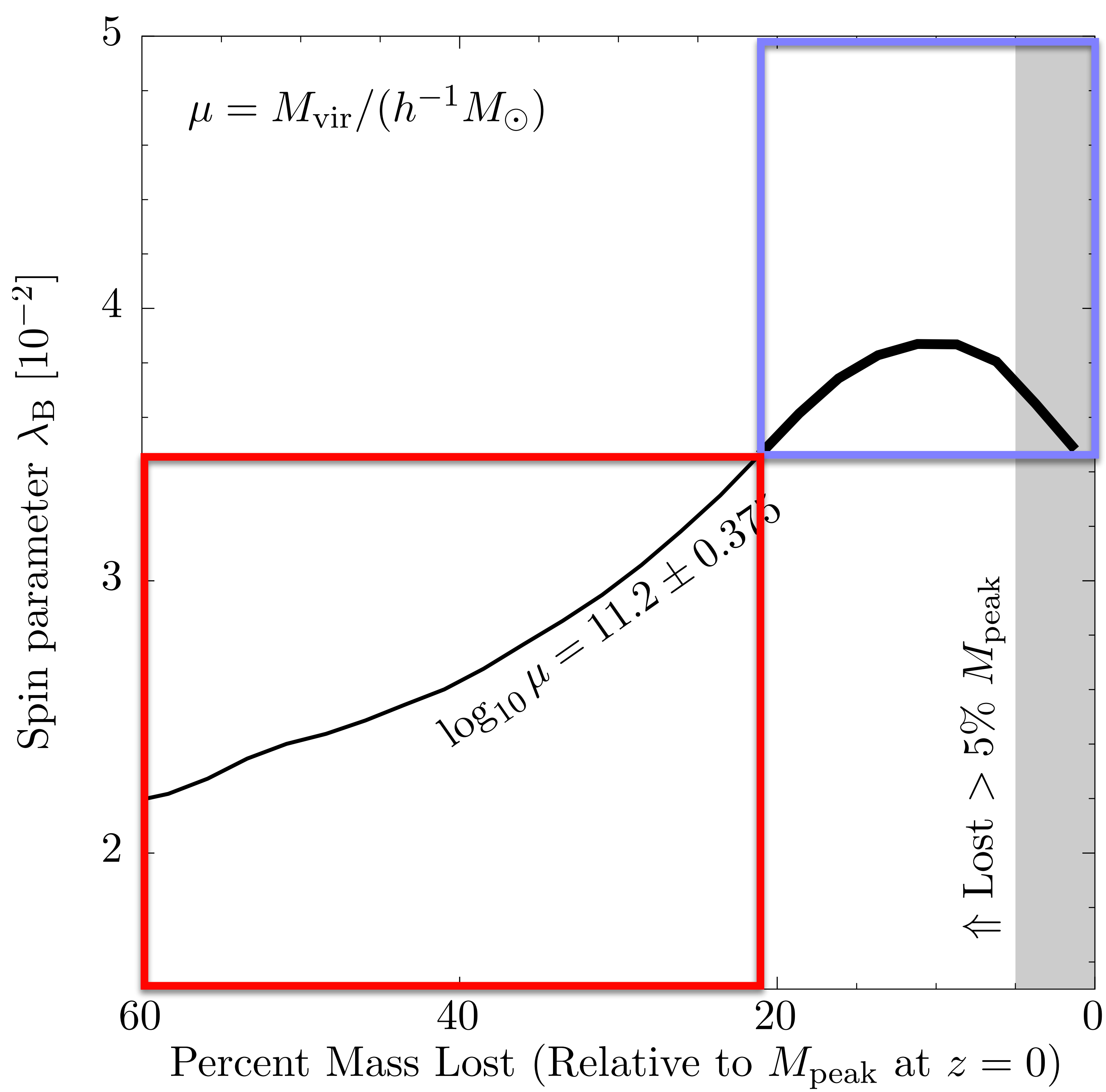
Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos: Causes and Consequences of Mass Loss

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

What happens when halos lose mass?

Post-merger relaxation dominates in 5-20% mass loss regime

Tidal stripping dominates in more than ~20% mass loss regime for low mass halos



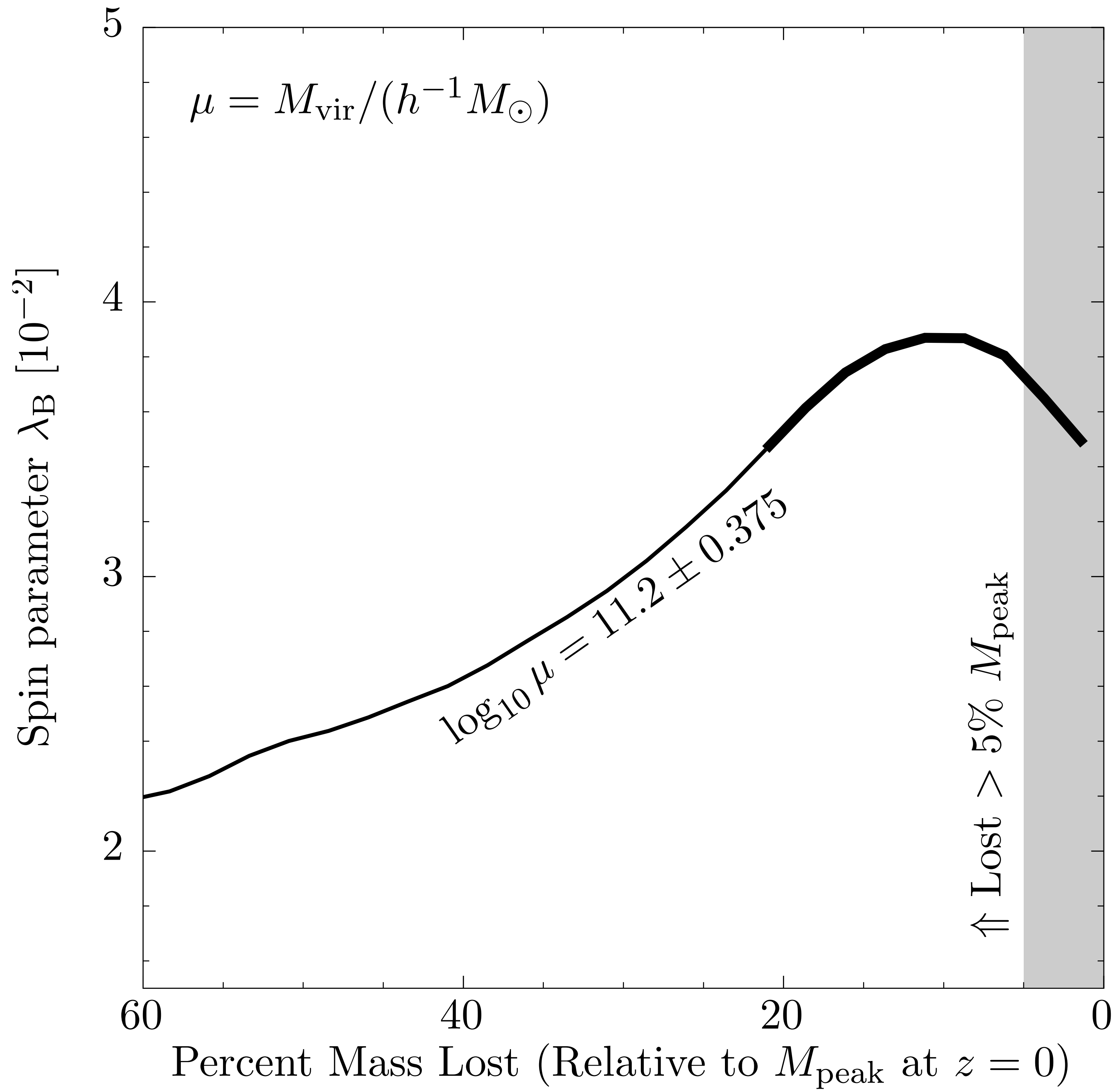
Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos: Causes and Consequences of Mass Loss

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

What happens when halos lose mass?

Post-merger relaxation dominates in 5-20% mass loss regime

Tidal stripping dominates in more than ~20% mass loss regime for low mass halos



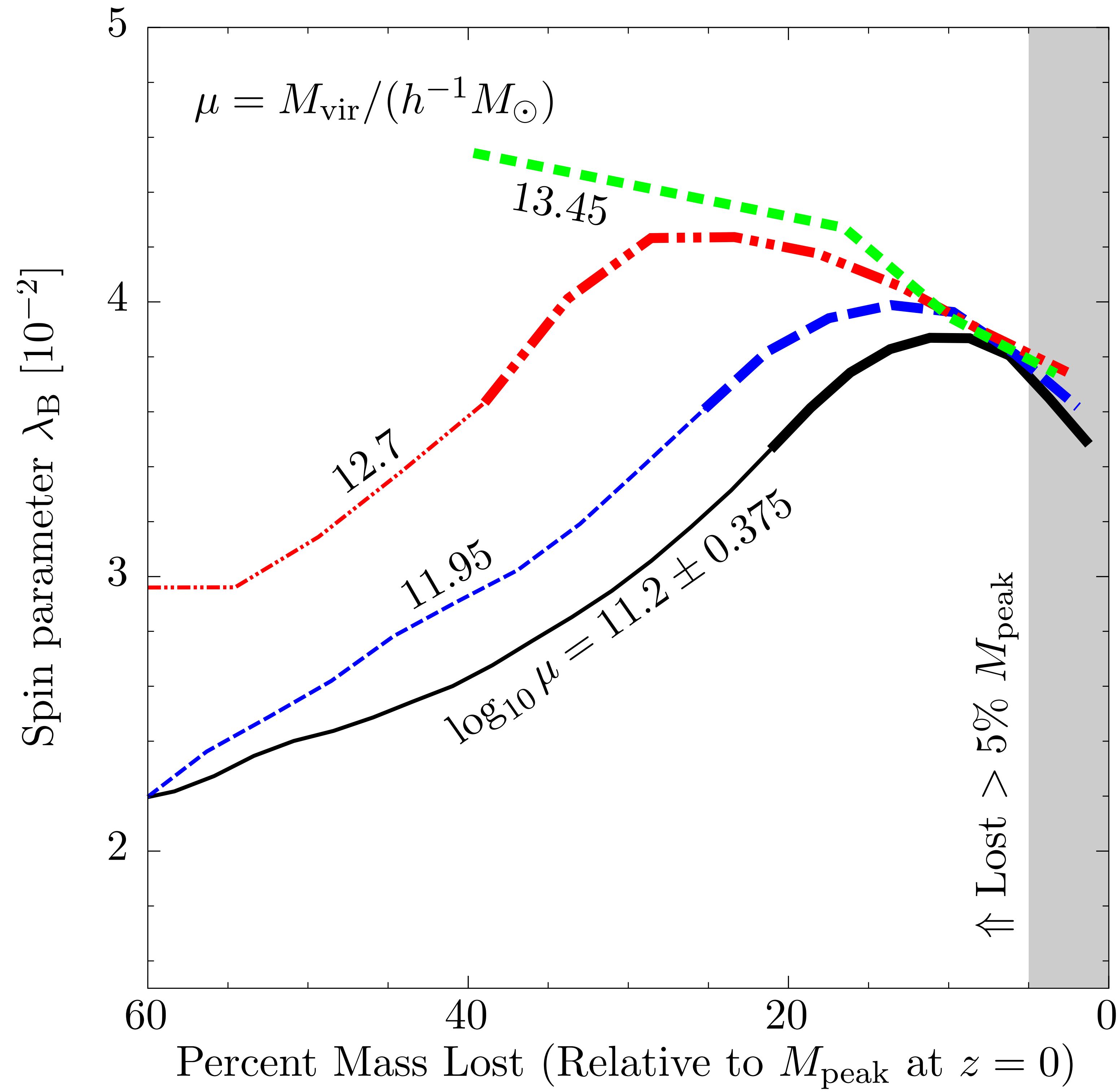
Tidal Stripping and Post-Merger Relaxation of Dark Matter Halos: Causes and Consequences of Mass Loss

C. Lee, J. Primack, P. Behroozi, A. Rodriguez-Puebla, D. Hellinger, J. Zhu, A. Tuan, A. Dekel

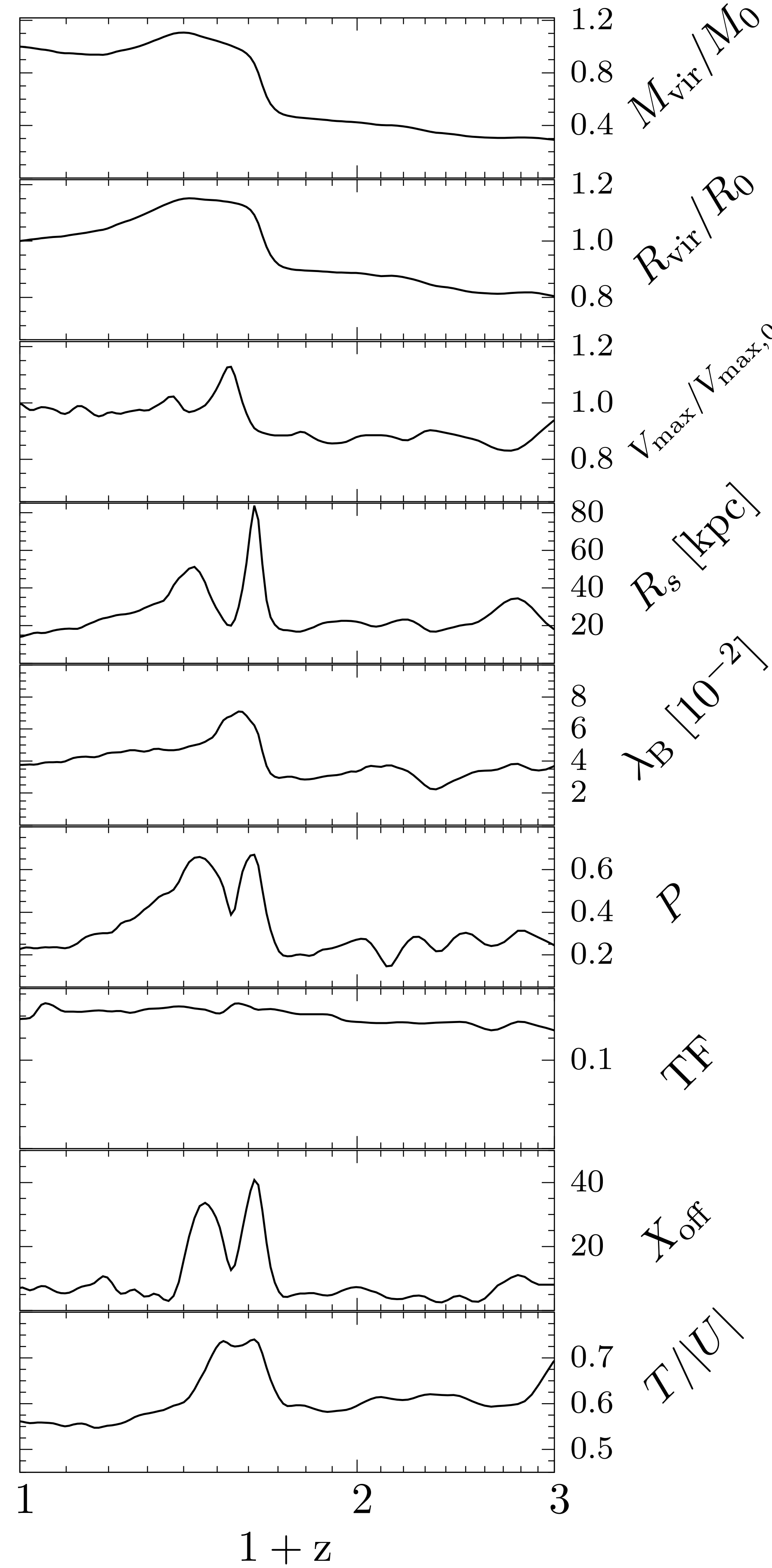
What happens when halos lose mass?

Post-merger relaxation dominates in 5-20% mass loss regime

Tidal stripping dominates in more than ~20% mass loss regime for low mass halos

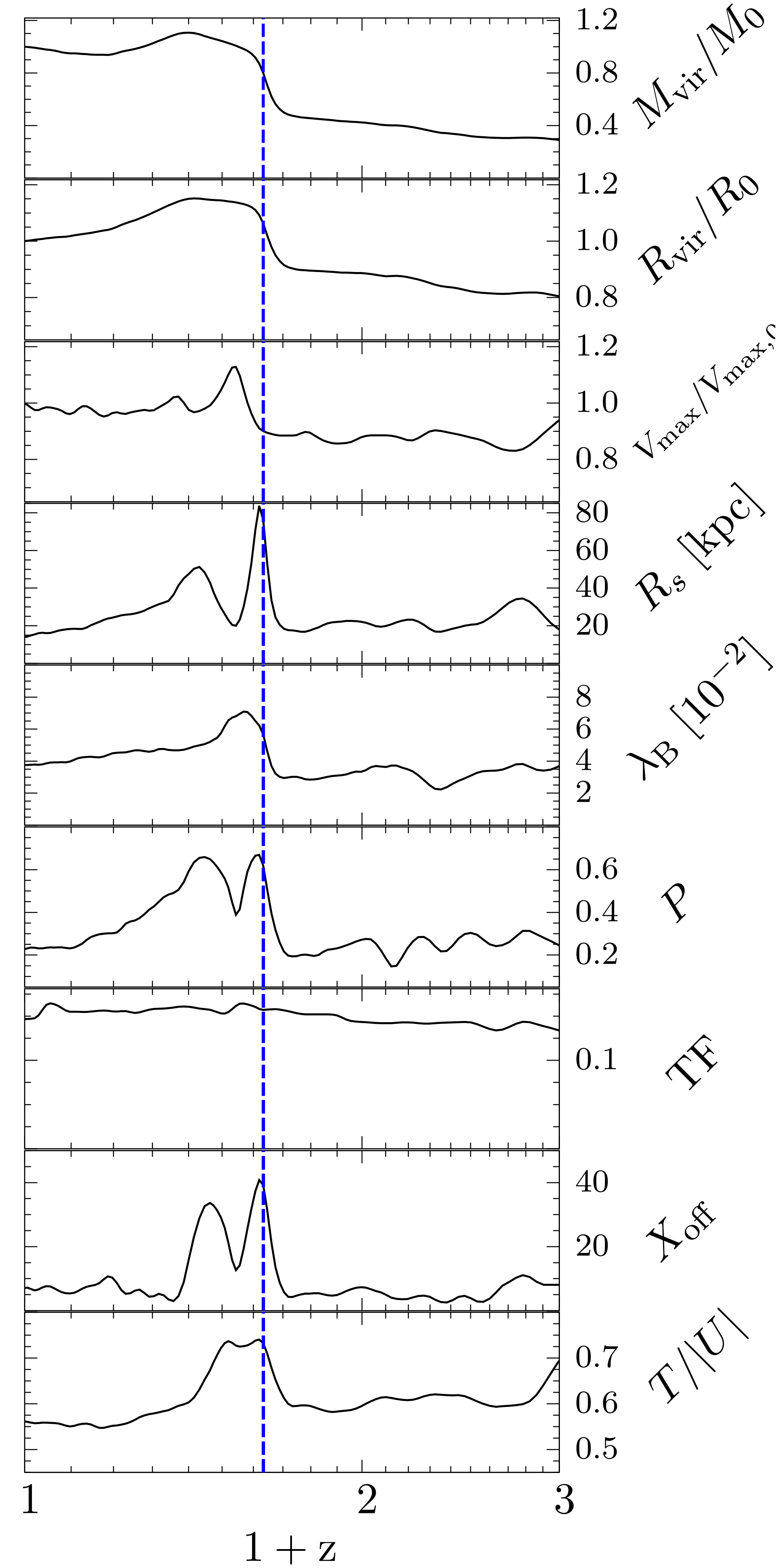


What happens when halos lose mass?

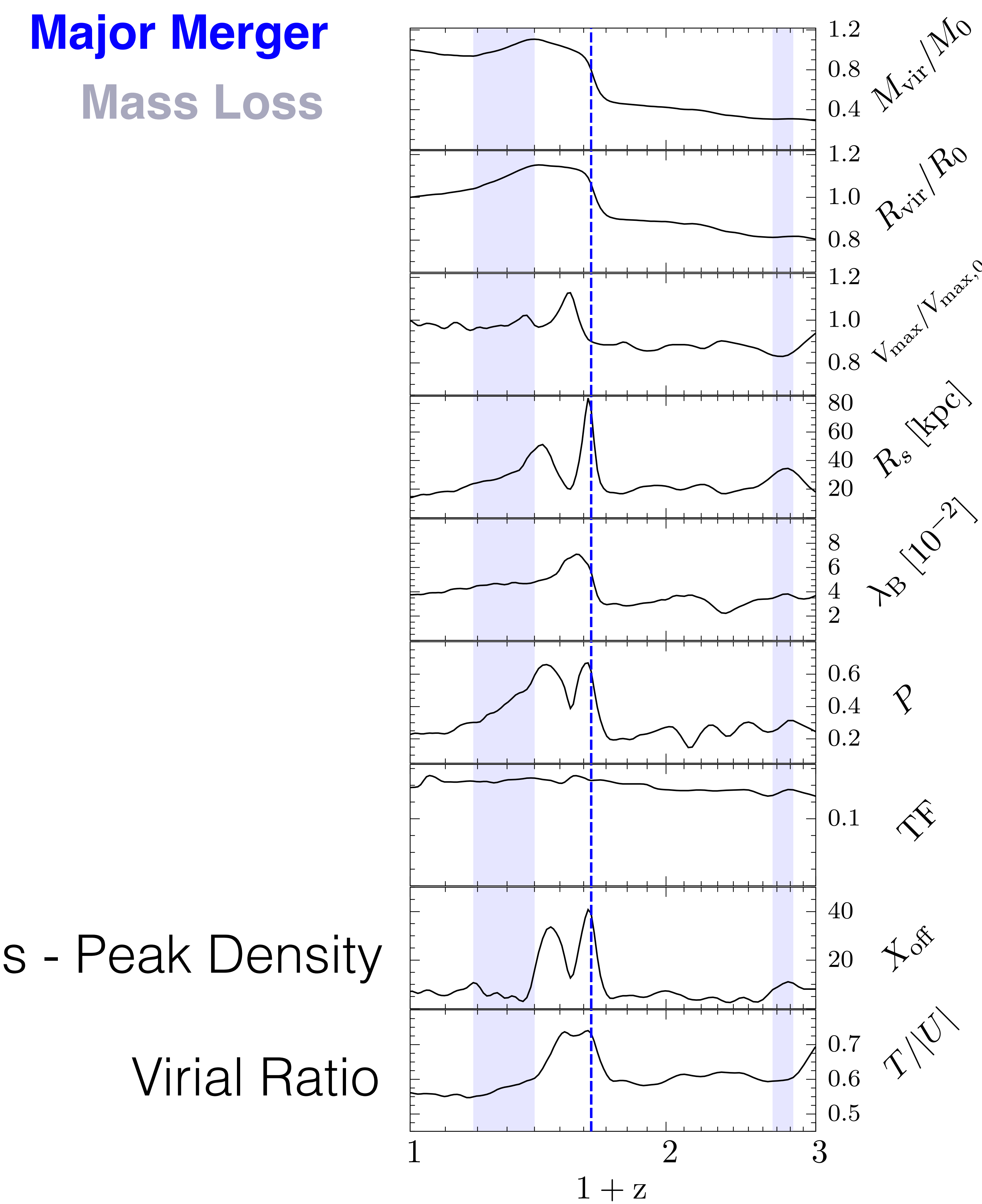


What happens when halos lose mass?

Major Merger



What happens when halos lose mass?



X_{off} = Center of Mass - Peak Density

Virial Ratio

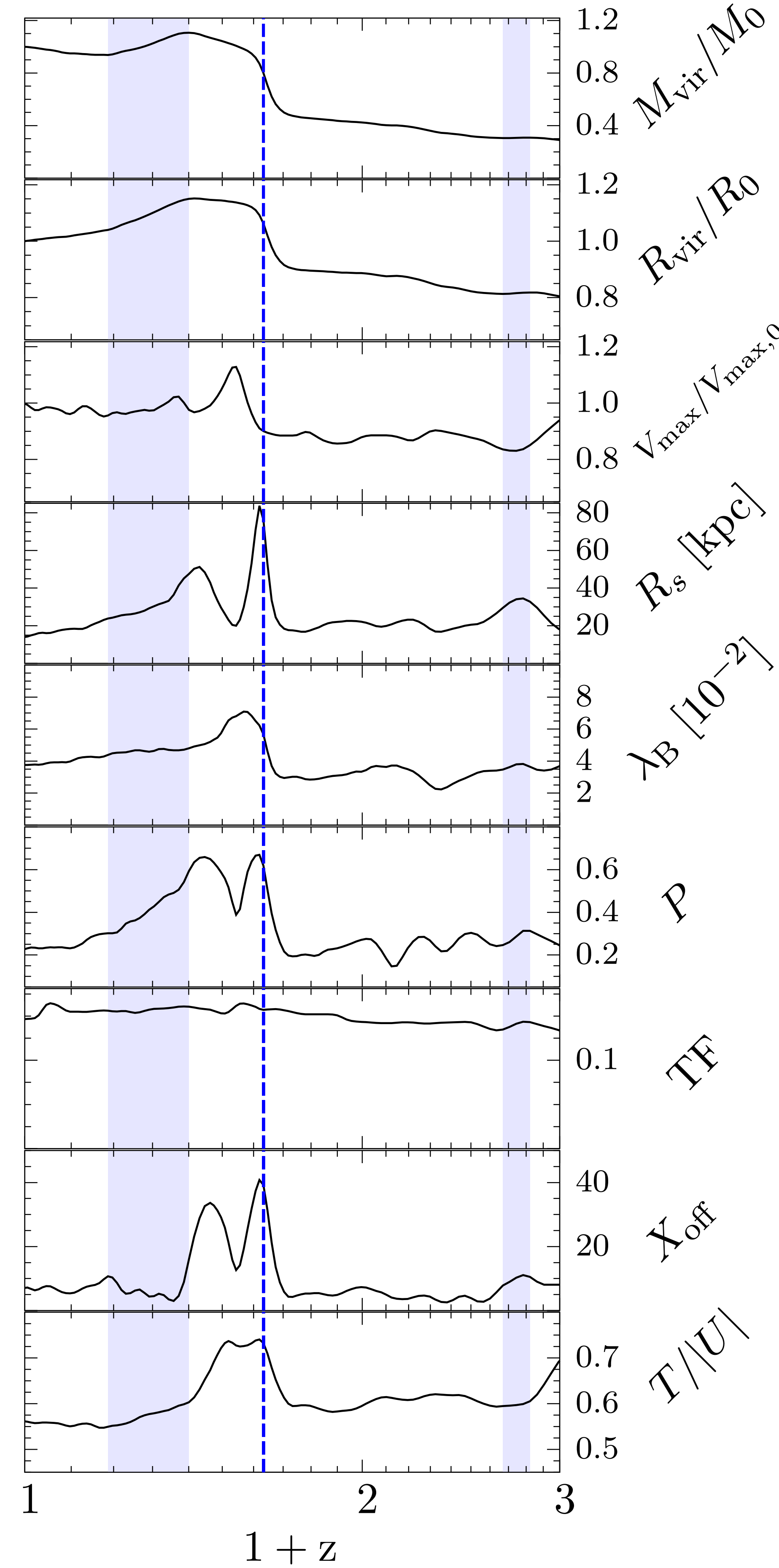
What happens when halos lose mass?

Major Merger

Mass Loss

Major mergers typically (temporarily) cause:

Initial **increase** in scale radius, spin parameter, prolateness, X_off, and virial ratio



X_{off} = Center of Mass - Peak Density

Virial Ratio

What happens when halos lose mass?

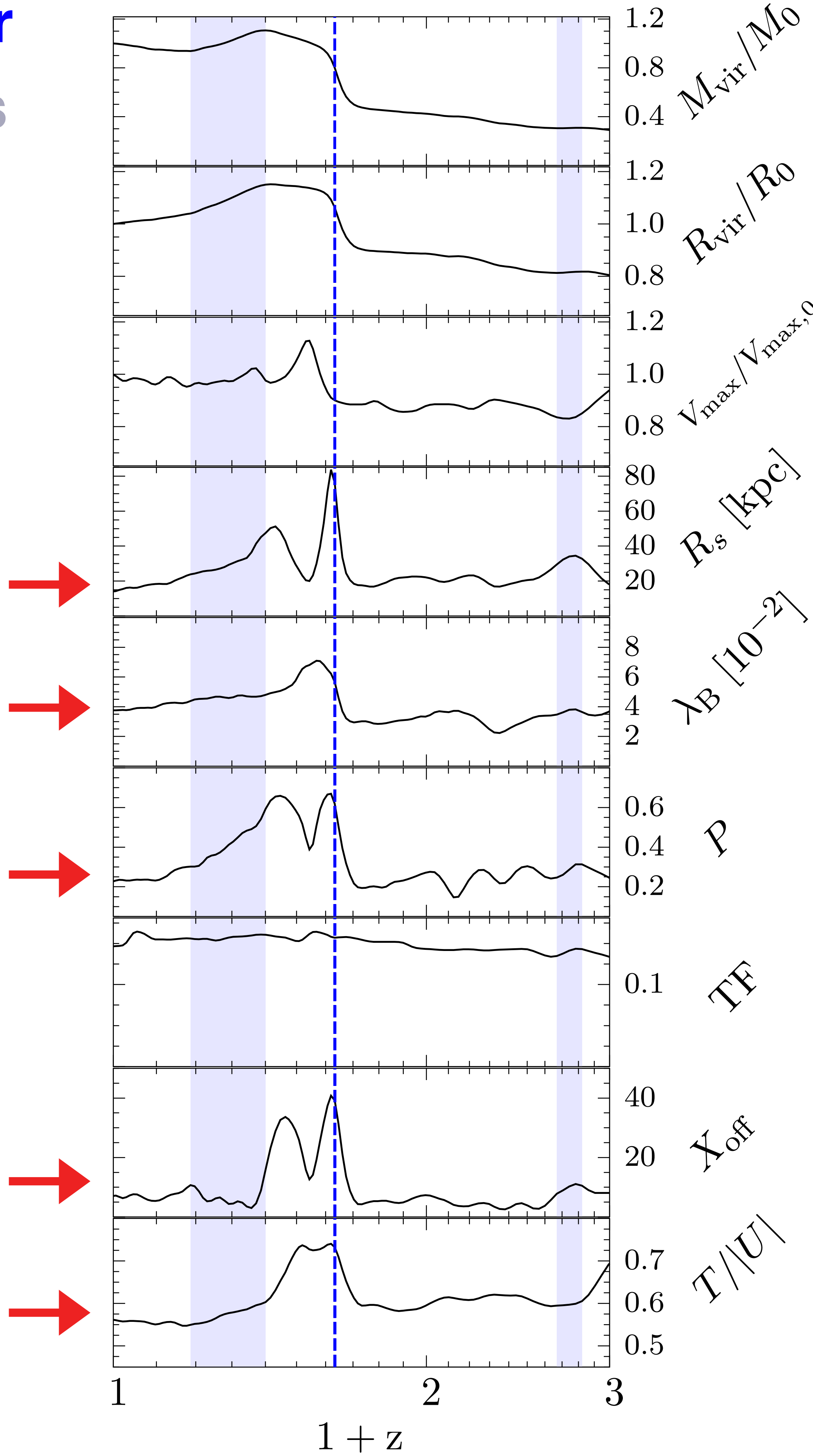
Major Merger

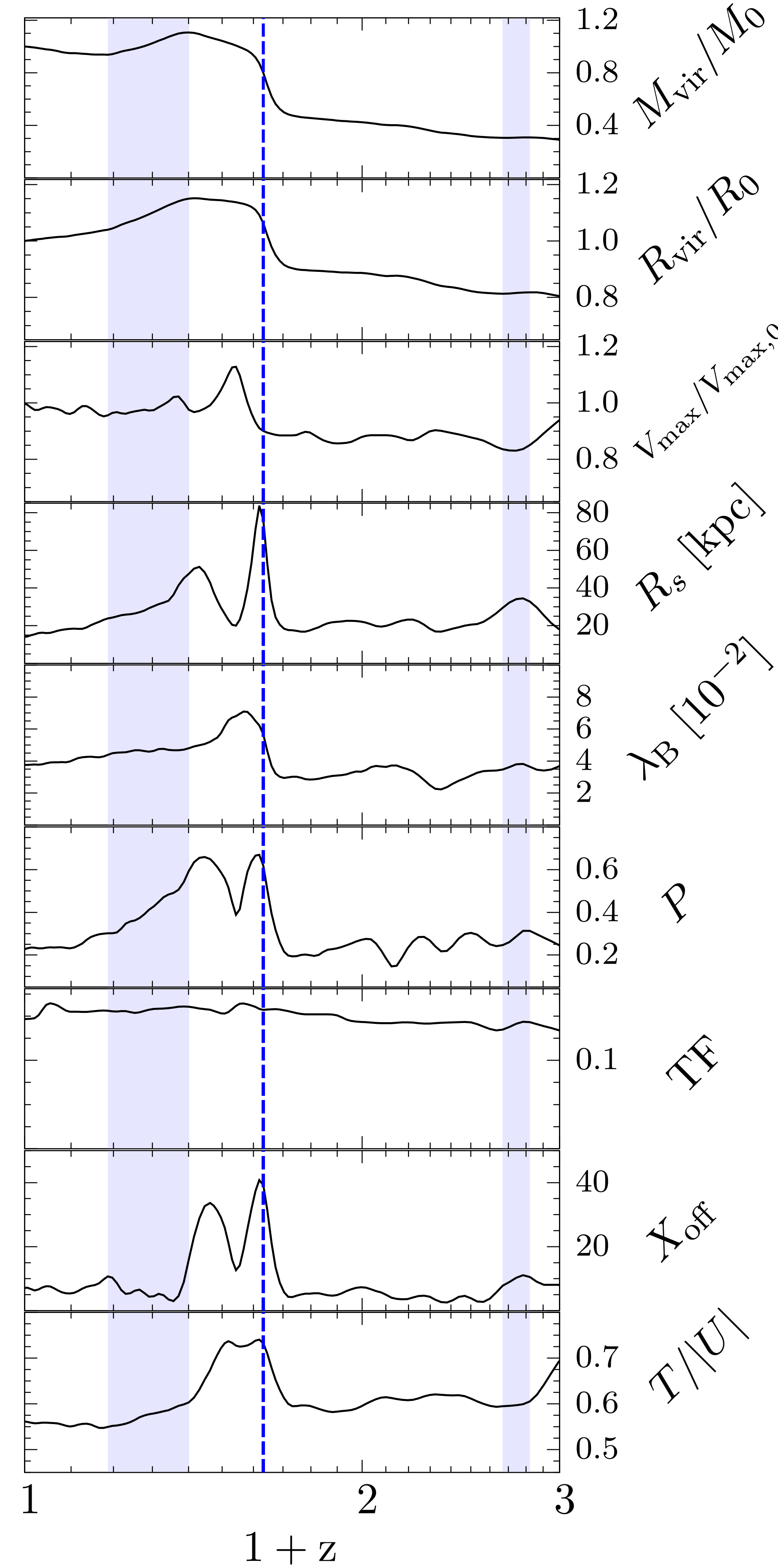
Mass Loss

Major mergers typically (temporarily) cause:

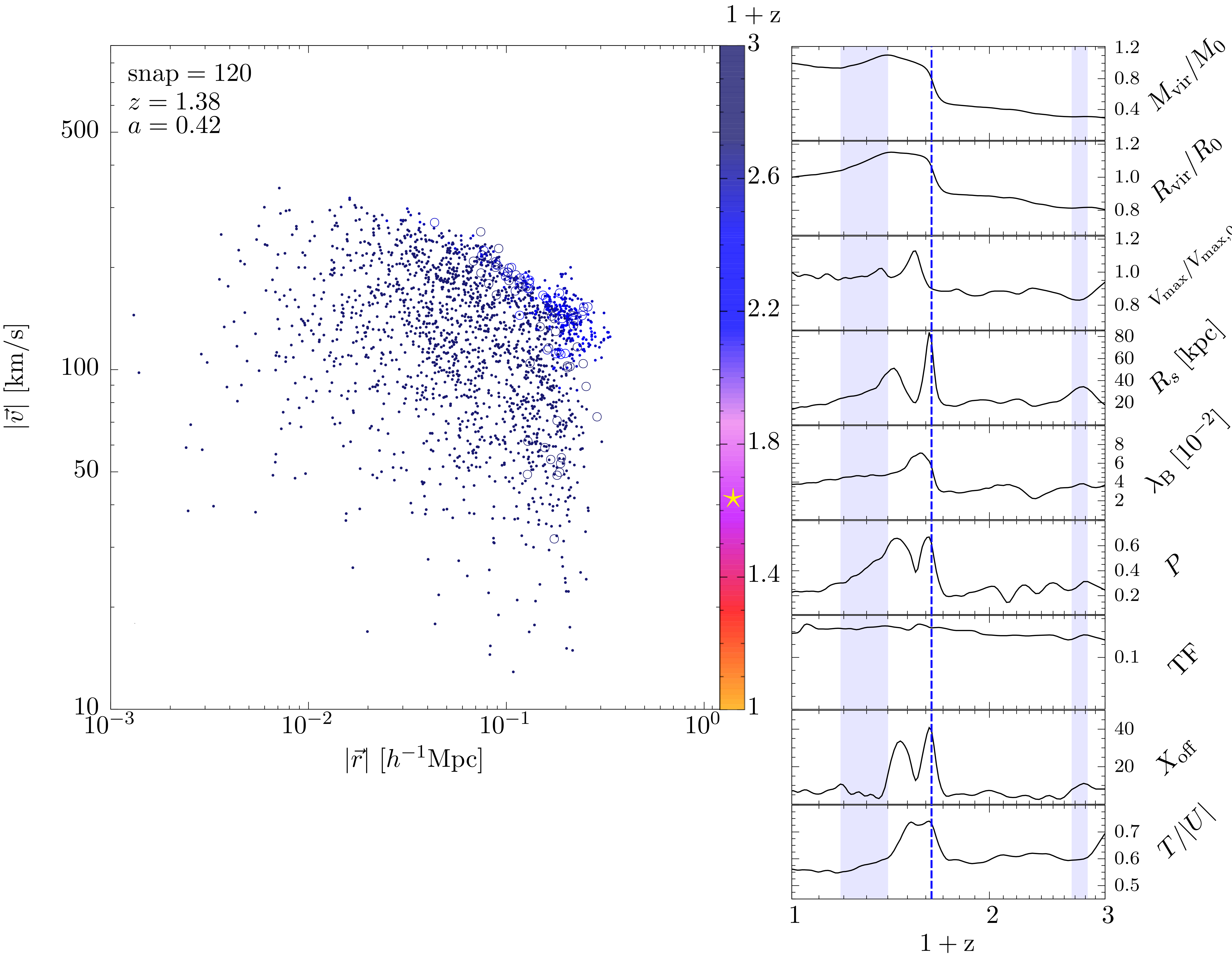
Initial **increase** in scale radius, spin parameter, prolateness, X_off, and virial ratio

As they relax, they shed high energy material and slowly **settle back to lower values of** scale radius, spin parameter, prolateness, X_off, and virial ratio

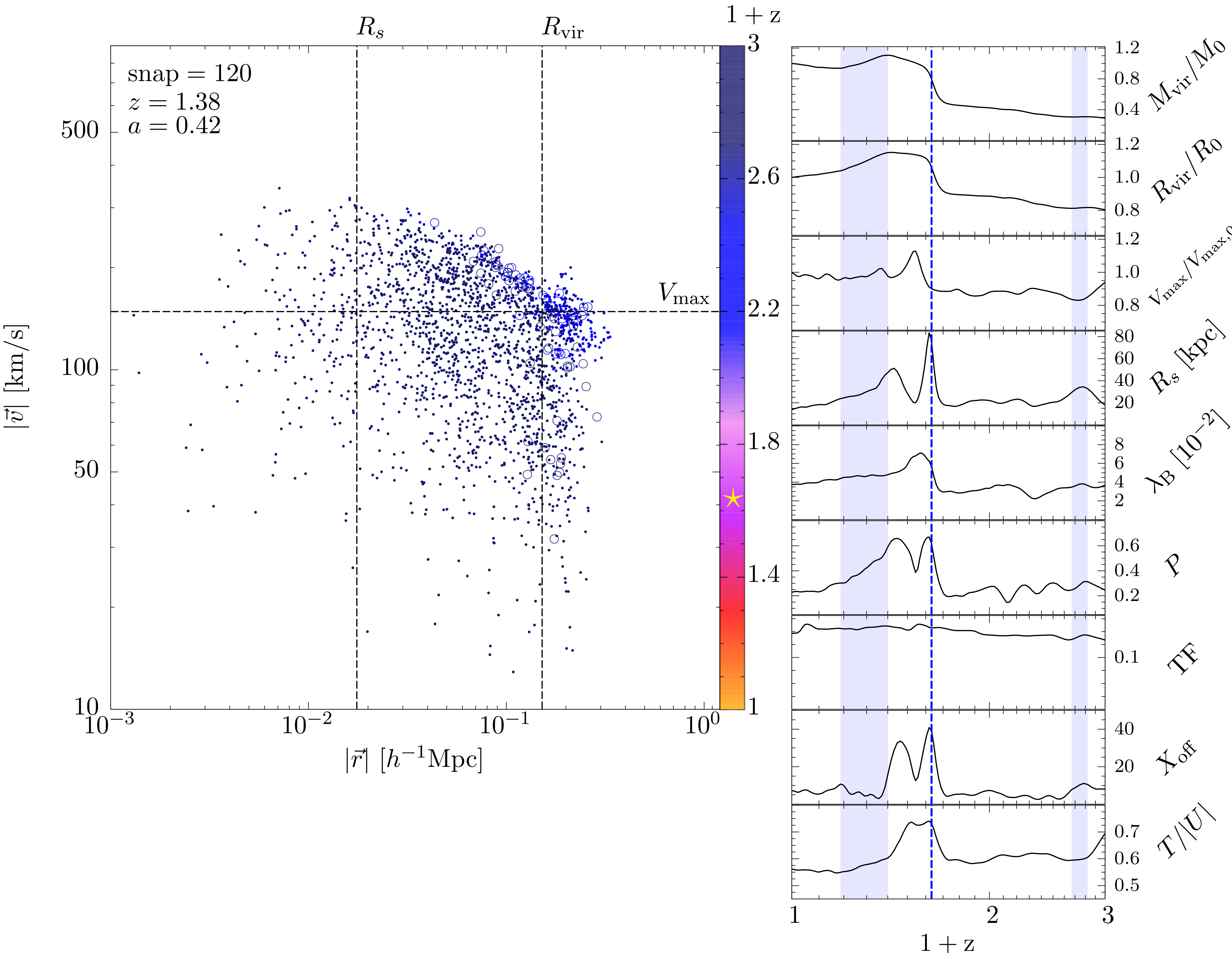




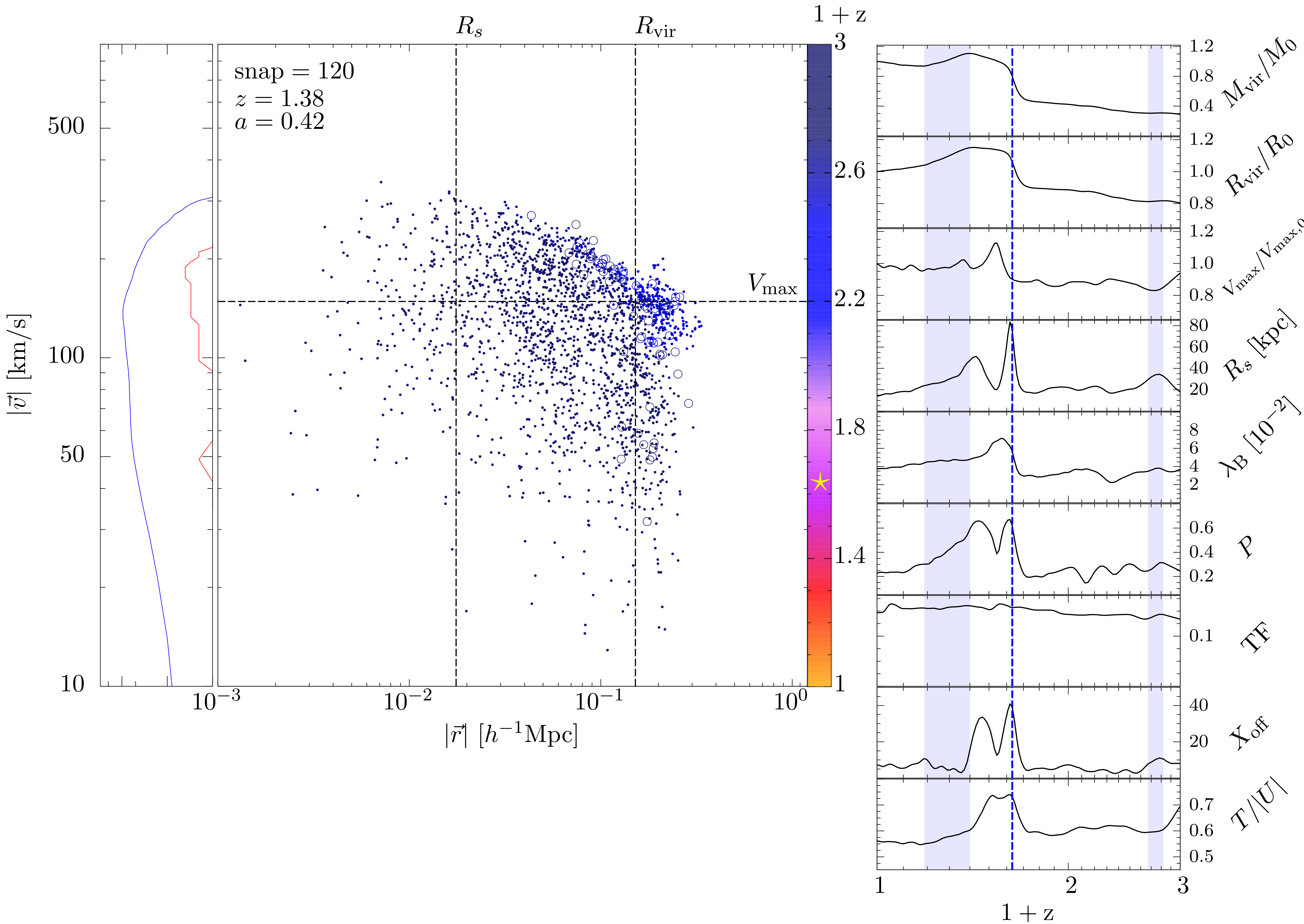
$M_{\rm vir}/M_0$
$R_{\rm vir}/R_0$
$V_{\rm max}/V_{\rm max,0}$
R_s [kpc]
λ_B [10^{-2}]
P
TF
$X_{\rm off}$
$T/|U|$
$1+z$



snap = 120
z = 1.38
a = 0.42
|v| [km/s]
|r| [h^-1 Mpc]
1 + z
M_vir/M_0
R_vir/R_0
V_max/V_max,0
R_s [kpc]
λ_B [10^-2]
P
TF
X_off
T/|U|

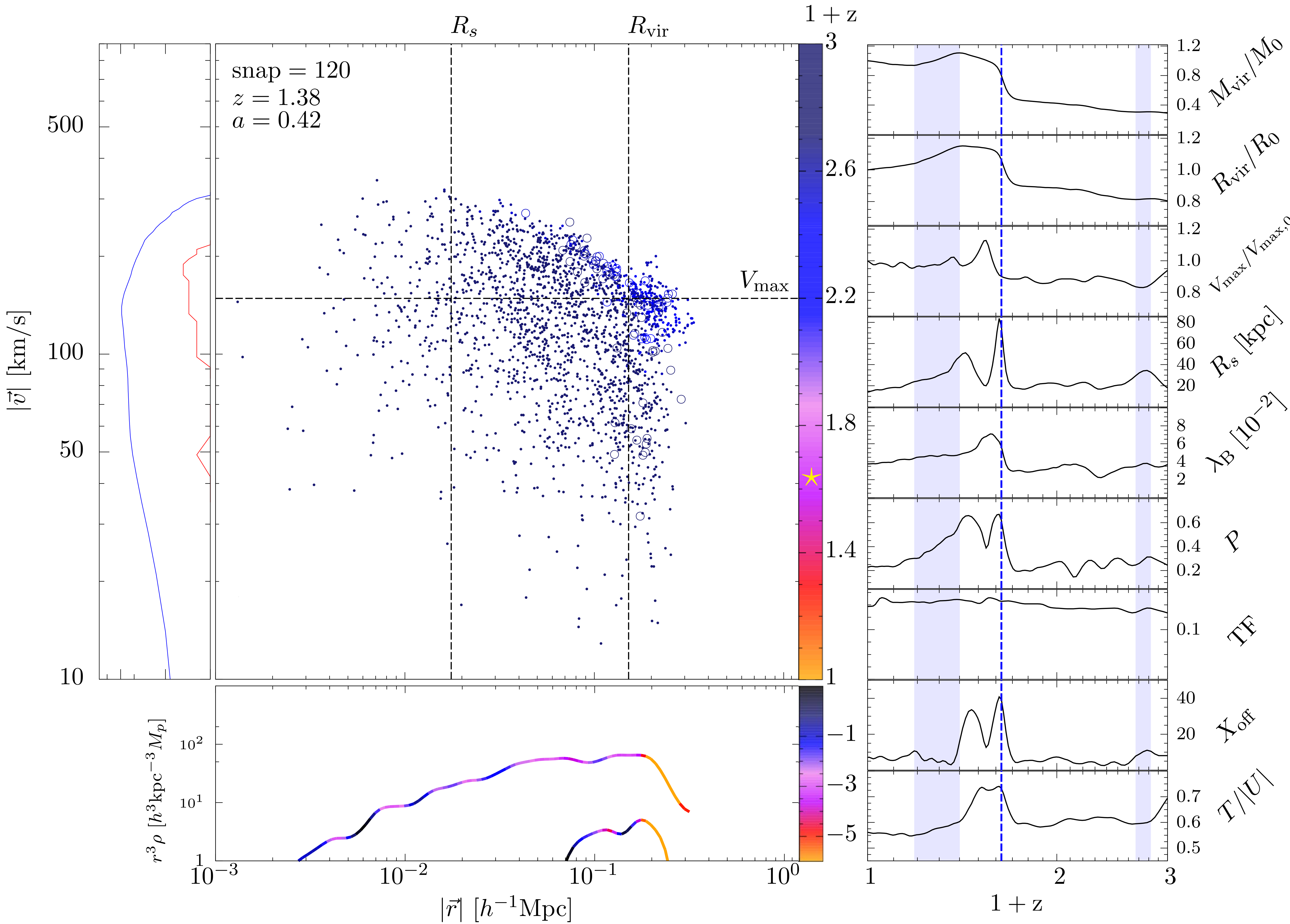


snap = 120
$z = 1.38$
$a = 0.42$
R_s
$R_{\rm vir}$
$V_{\rm max}$
$|\vec{v}|$ [km/s]
$|\vec{r}|$ [h^{-1}Mpc]
1 + z
$M_{\rm vir}/M_0$
$R_{\rm vir}/R_0$
$V_{\rm max}/V_{\rm max,0}$
R_s [kpc]
λ_B [10^{-2}]
P
TF
$X_{\rm off}$
$T/|U|$



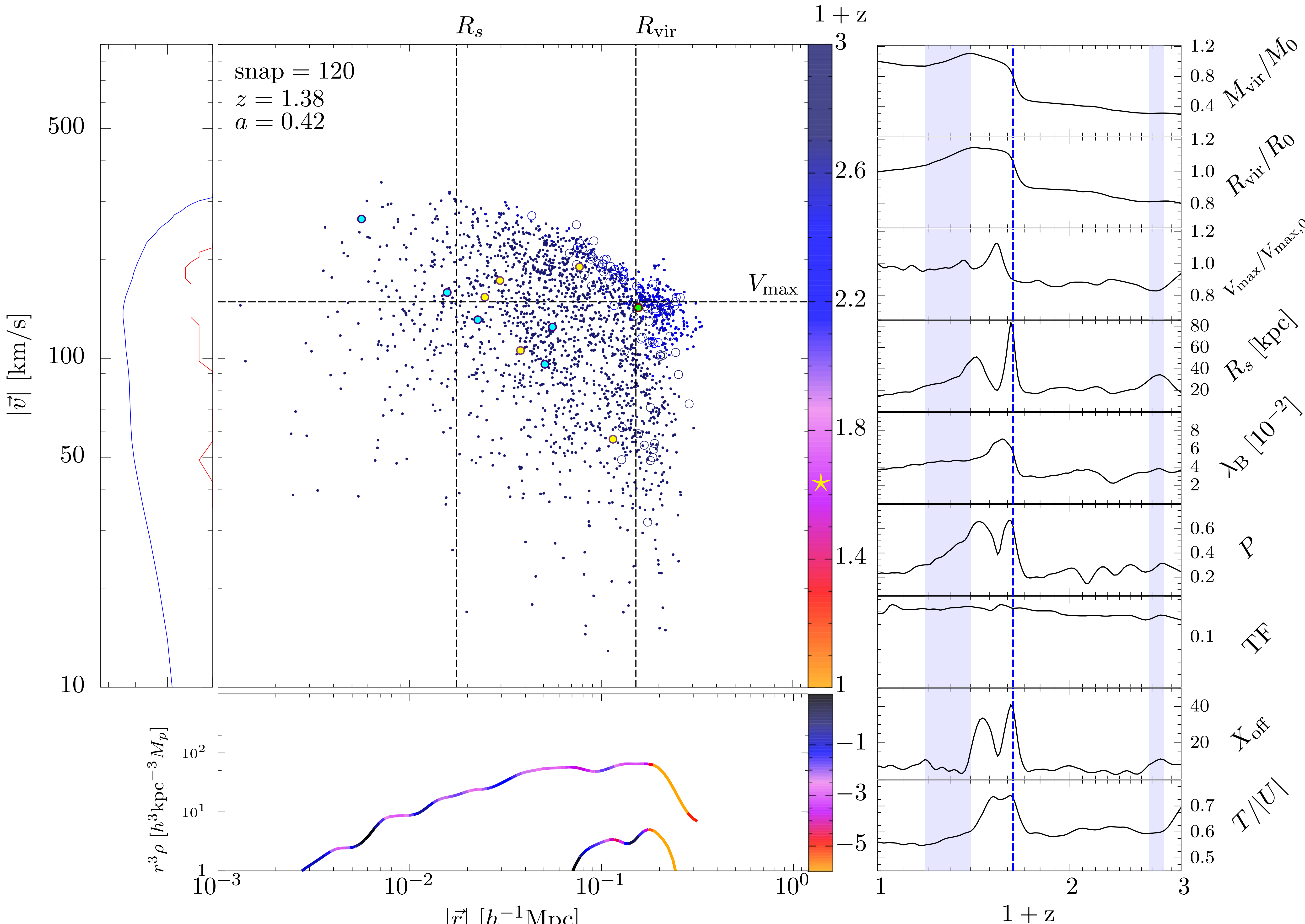
Christoph Lee, UCSC

January 25th, 2018 UCSC



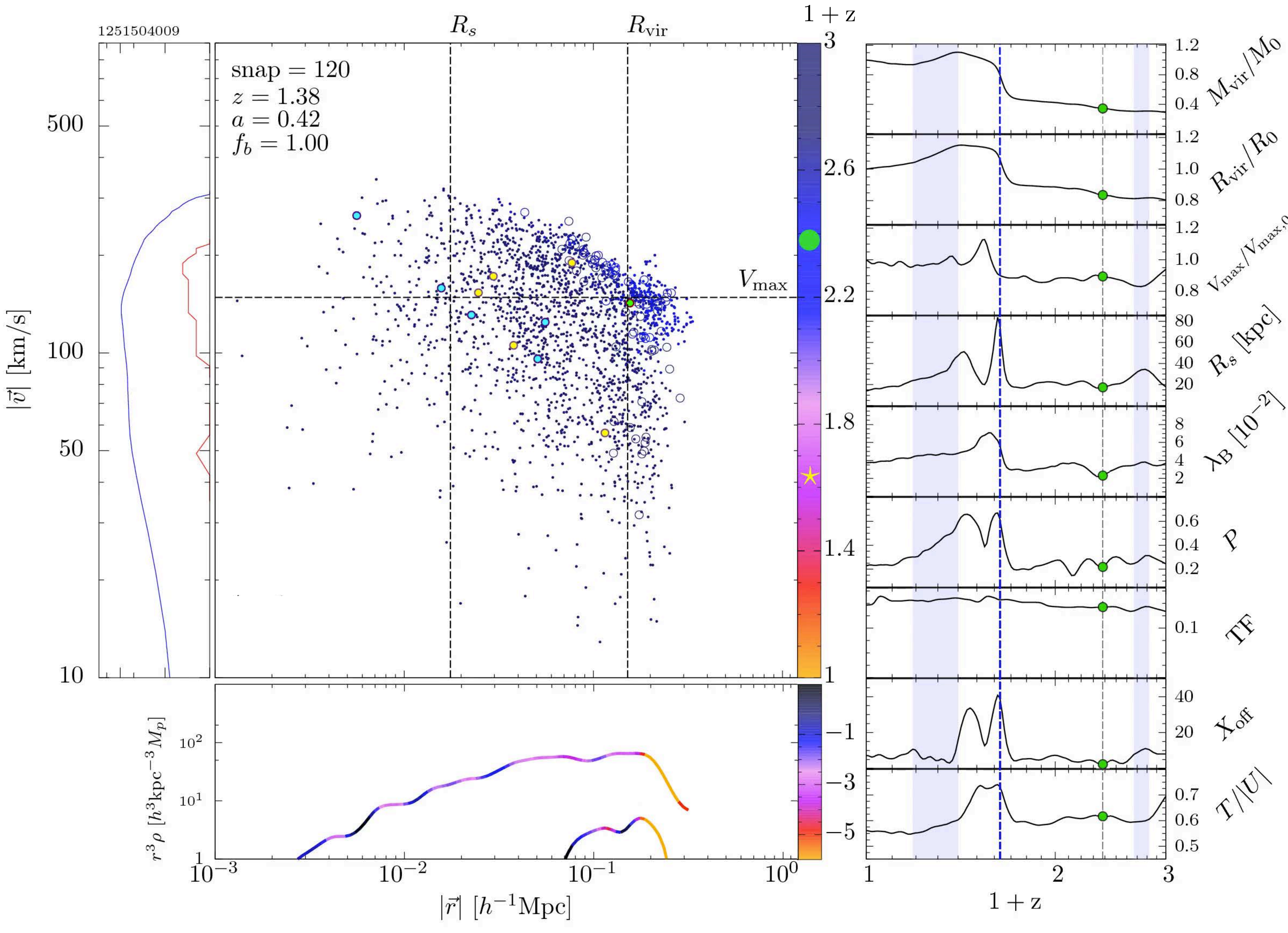
Christoph Lee, UCSC

January 25th, 2018 UCSC



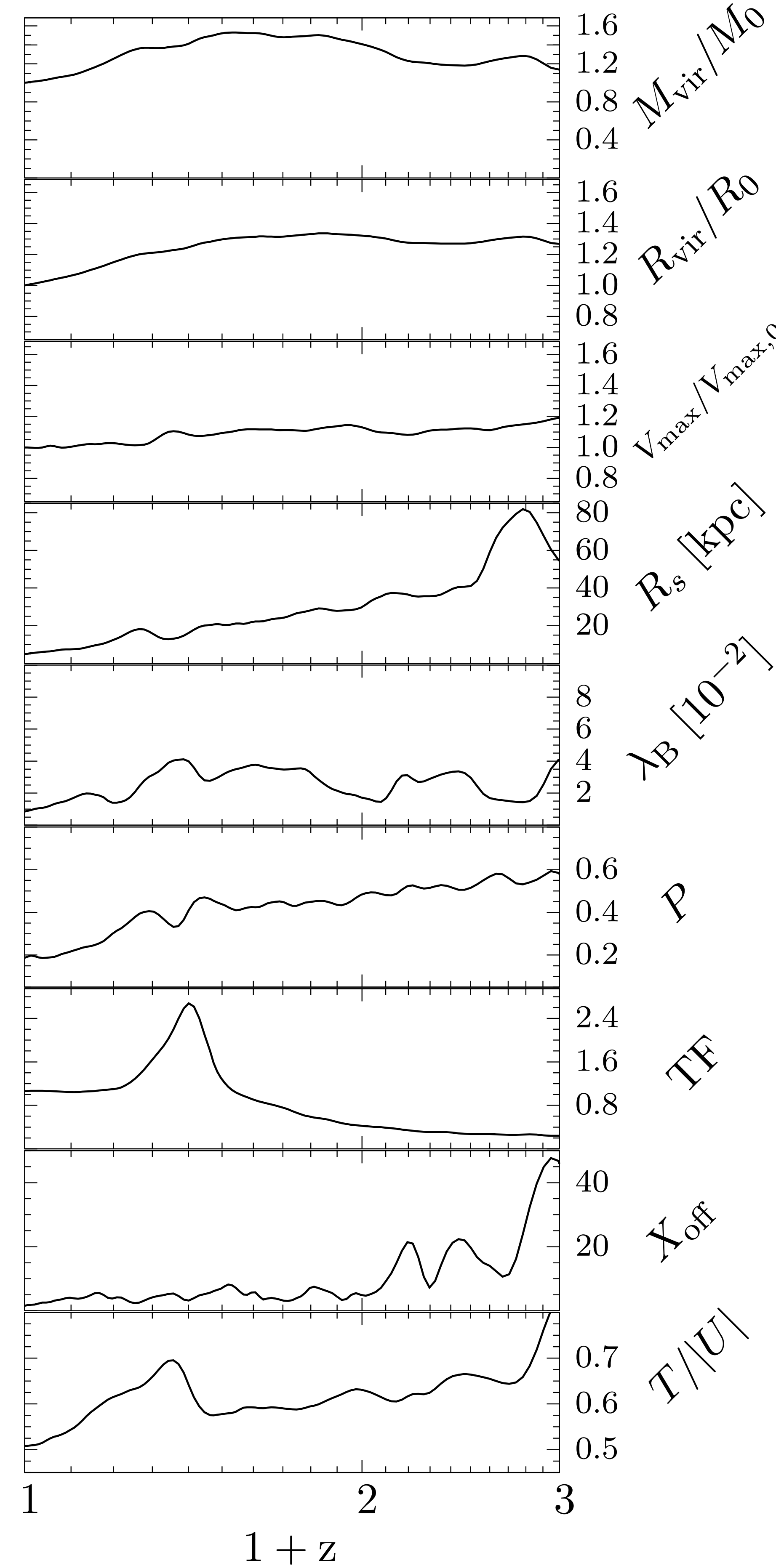
Christoph Lee, UCSC

January 25th, 2018 UCSC



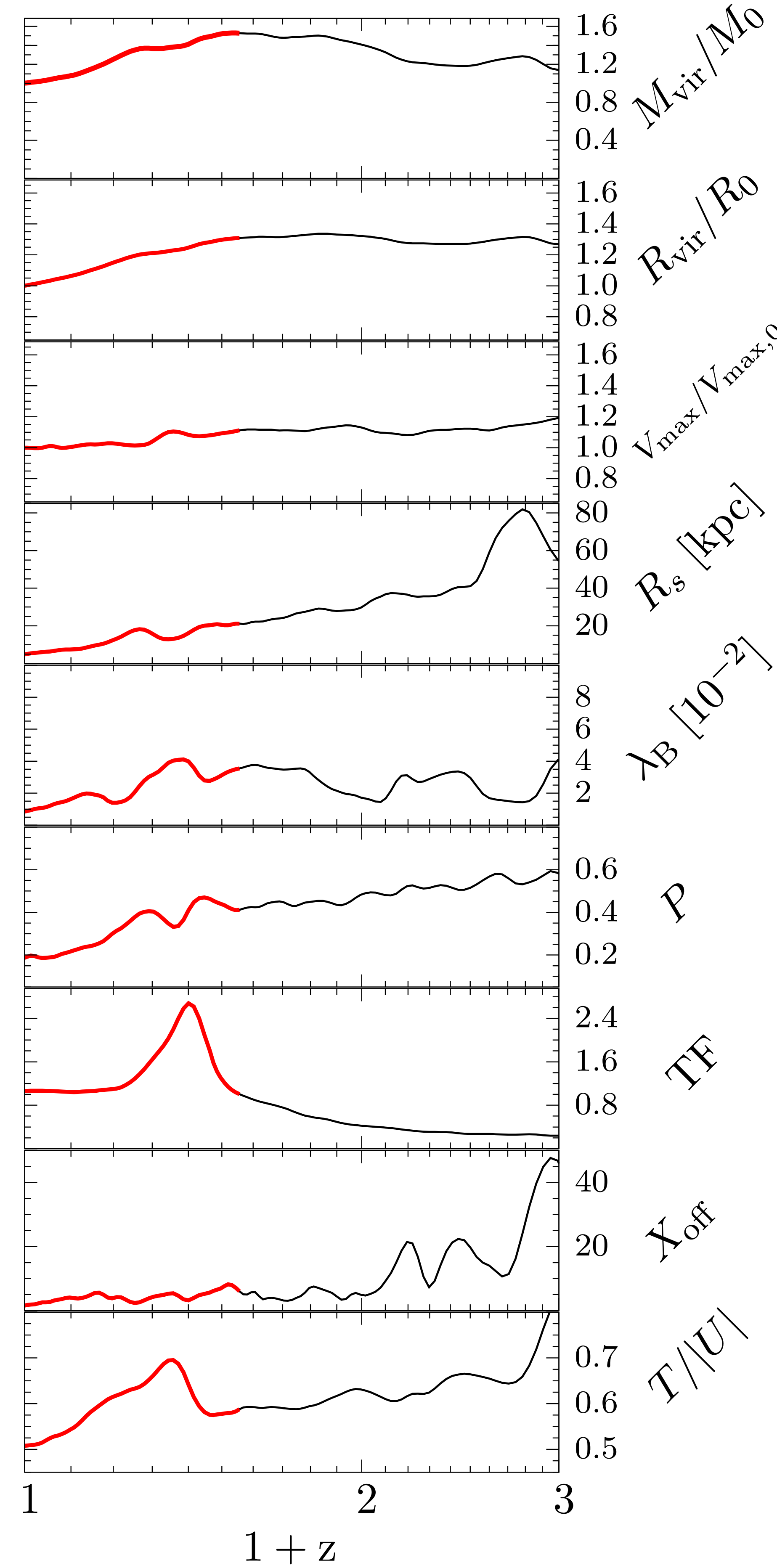
1251504009
R_s
R_{vir}
$1+z$
snap = 120
$z = 1.38$
$a = 0.42$
$f_b = 1.00$
V_{max}
$|\vec{v}|$ [km/s]
$r^3\rho$ [h^3kpc$^{-3}M_p$]
$|\vec{r}|$ [h^{-1}Mpc]
M_{vir}/M_0
R_{vir}/R_0
$V_{max}/V_{max,0}$
R_s [kpc]
λ_B [10^{-2}]
P
TF
X_{off}
$T/|U|$

What happens when halos lose mass?

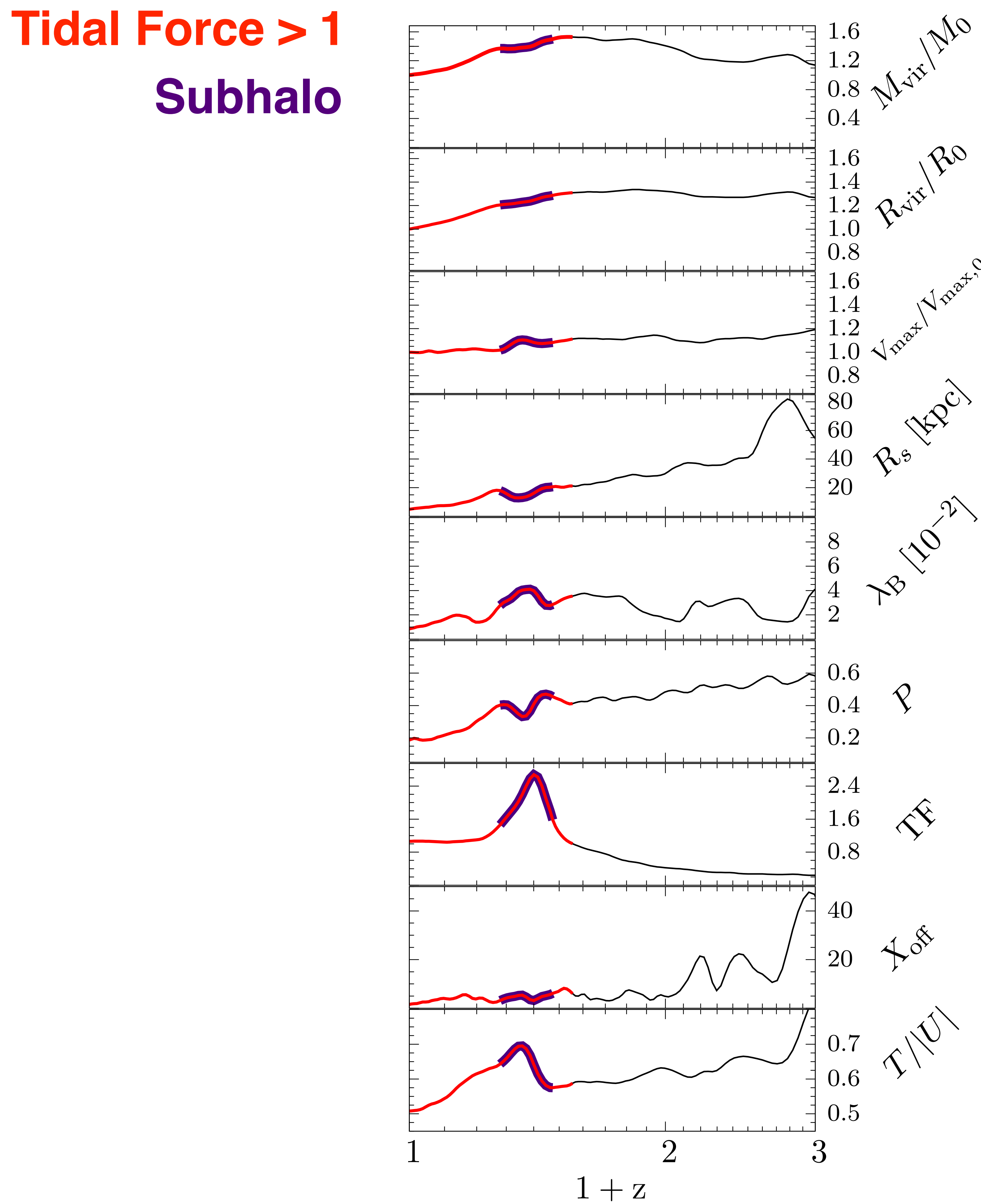


What happens when halos lose mass?

Tidal Force > 1



What happens when halos lose mass?

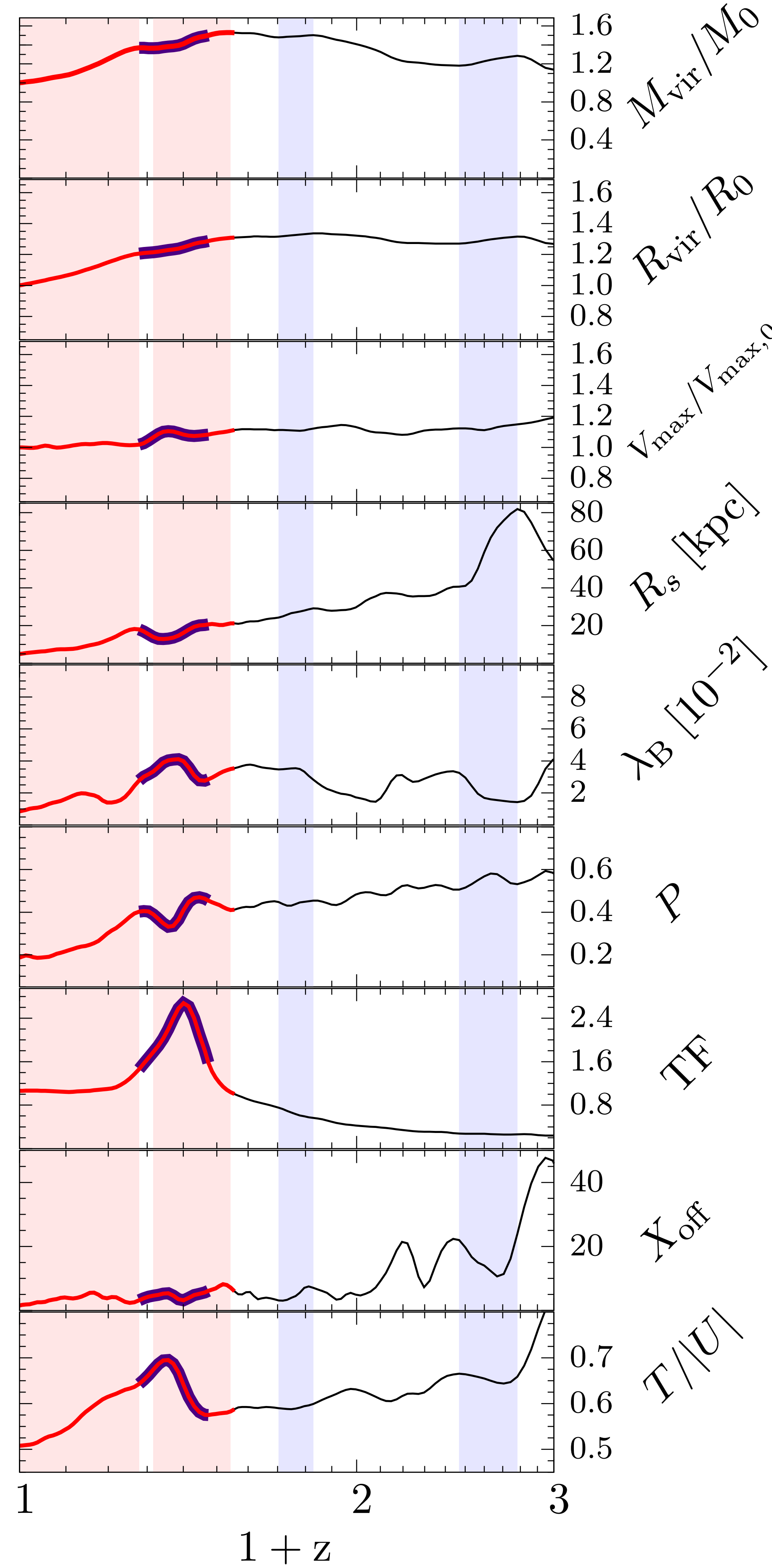


What happens when halos lose mass?

Tidal Force > 1

Subhalo

Mass Loss

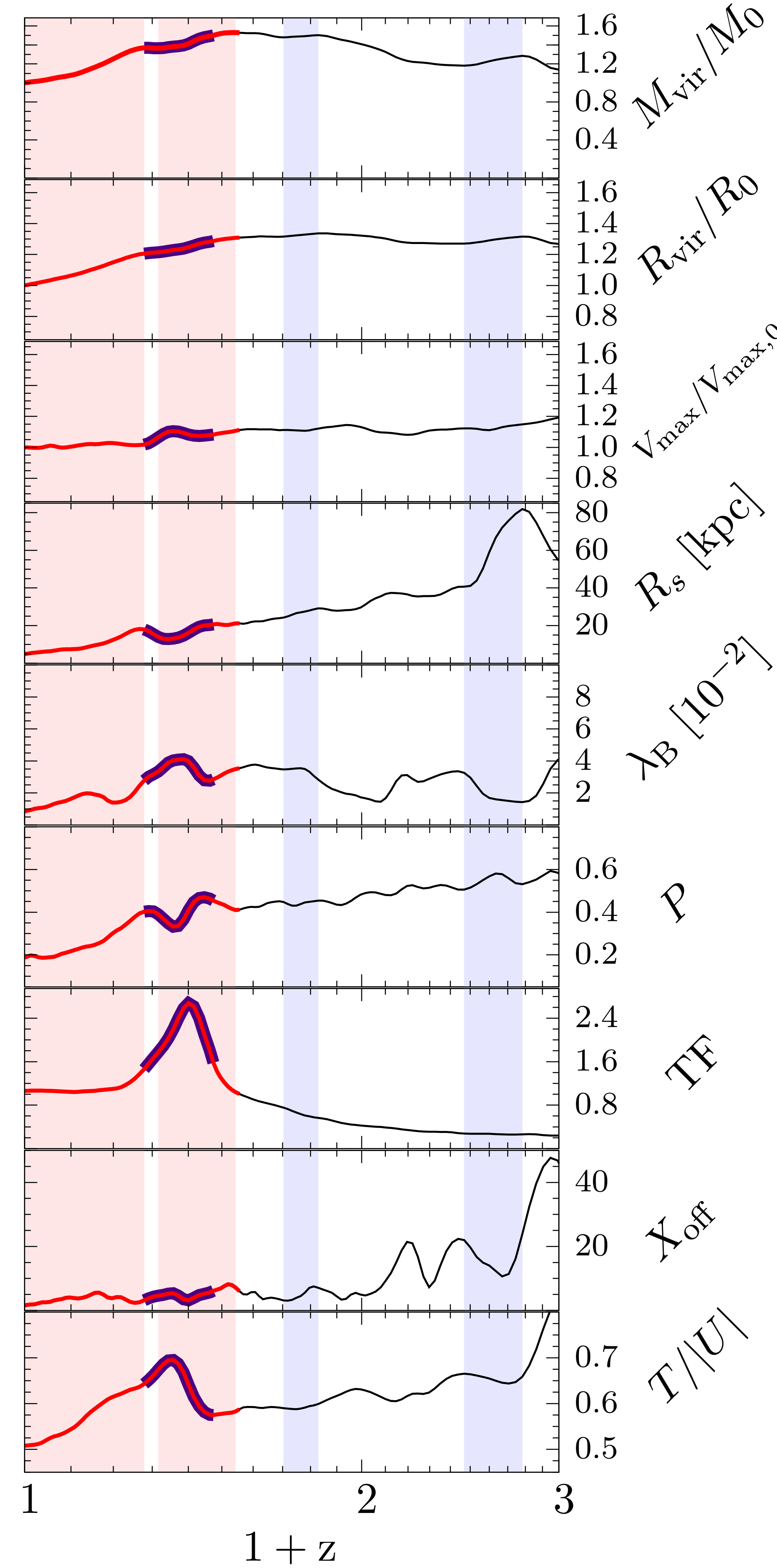


What happens when halos lose mass?

Tidal Force > 1

Subhalo

Mass Loss



Tidal stripping typically causes:

Decrease in scale radius, spin parameter, and prolateness

due to preferential removal of high energy material from outer halo and steepening of outer density profile

What happens when halos lose mass?

Tidal stripping typically causes:

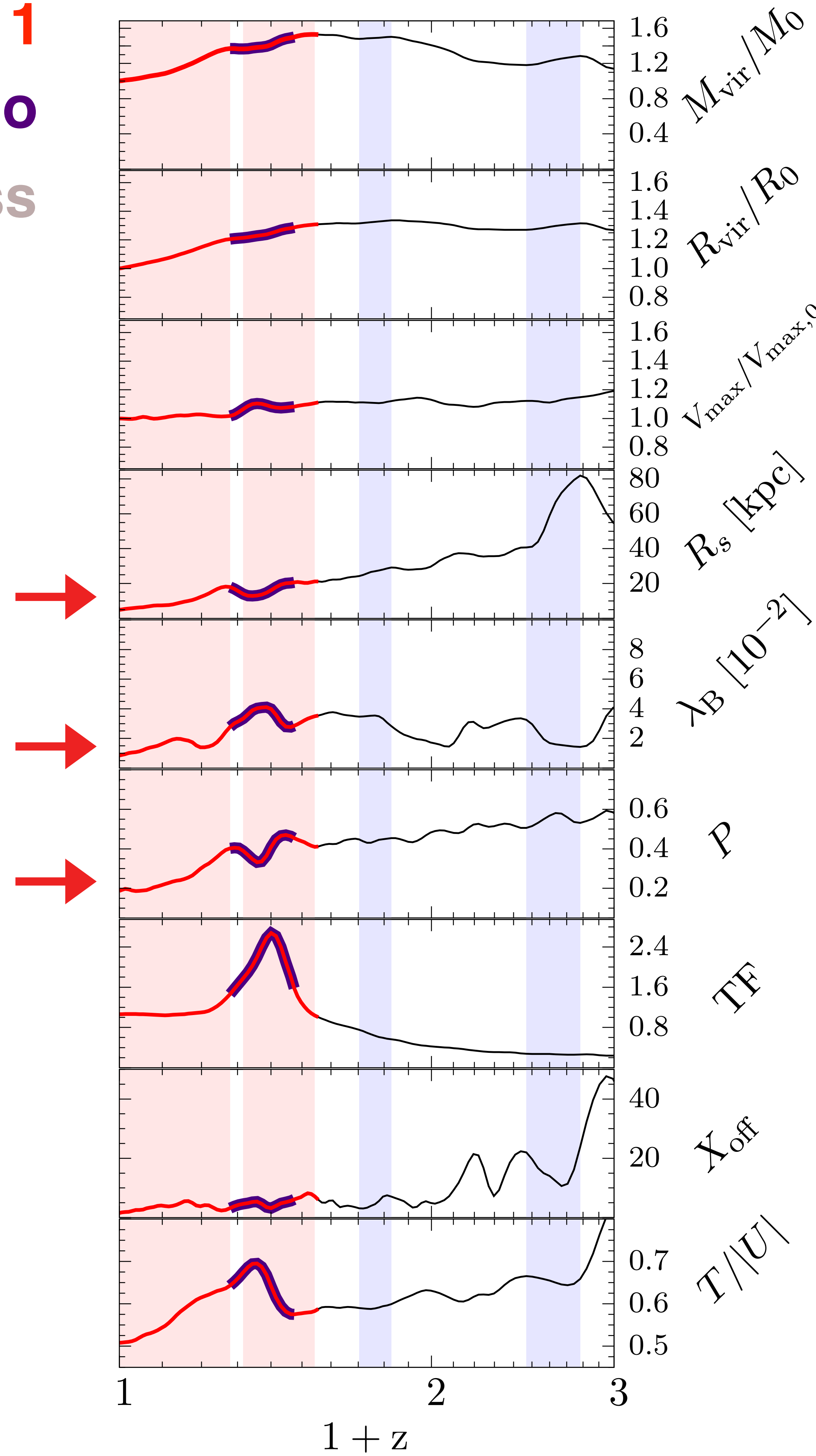
Decrease in scale radius, spin parameter, and prolateness

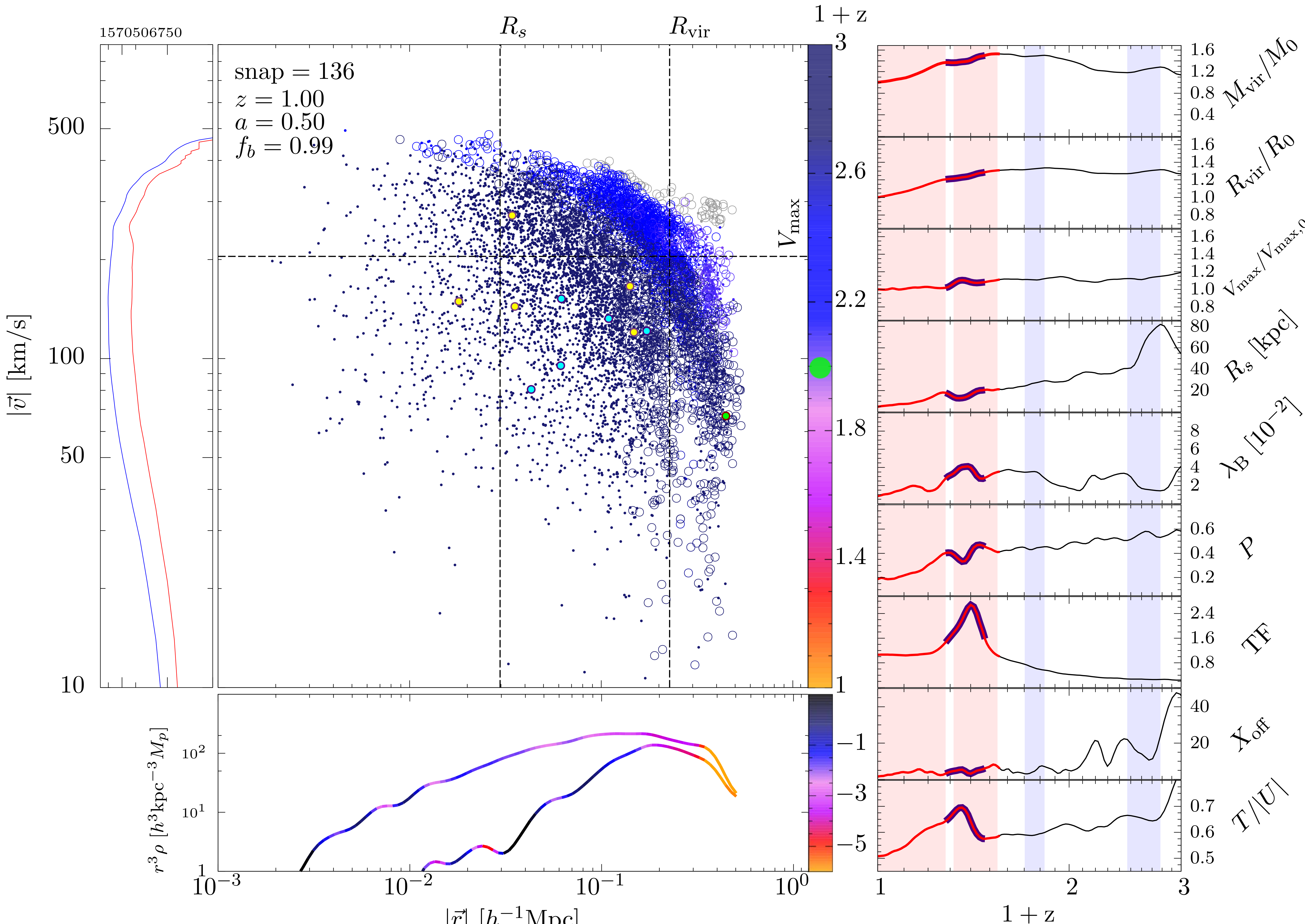
due to preferential removal of high energy material from outer halo and steepening of outer density profile

Tidal Force > 1

Subhalo

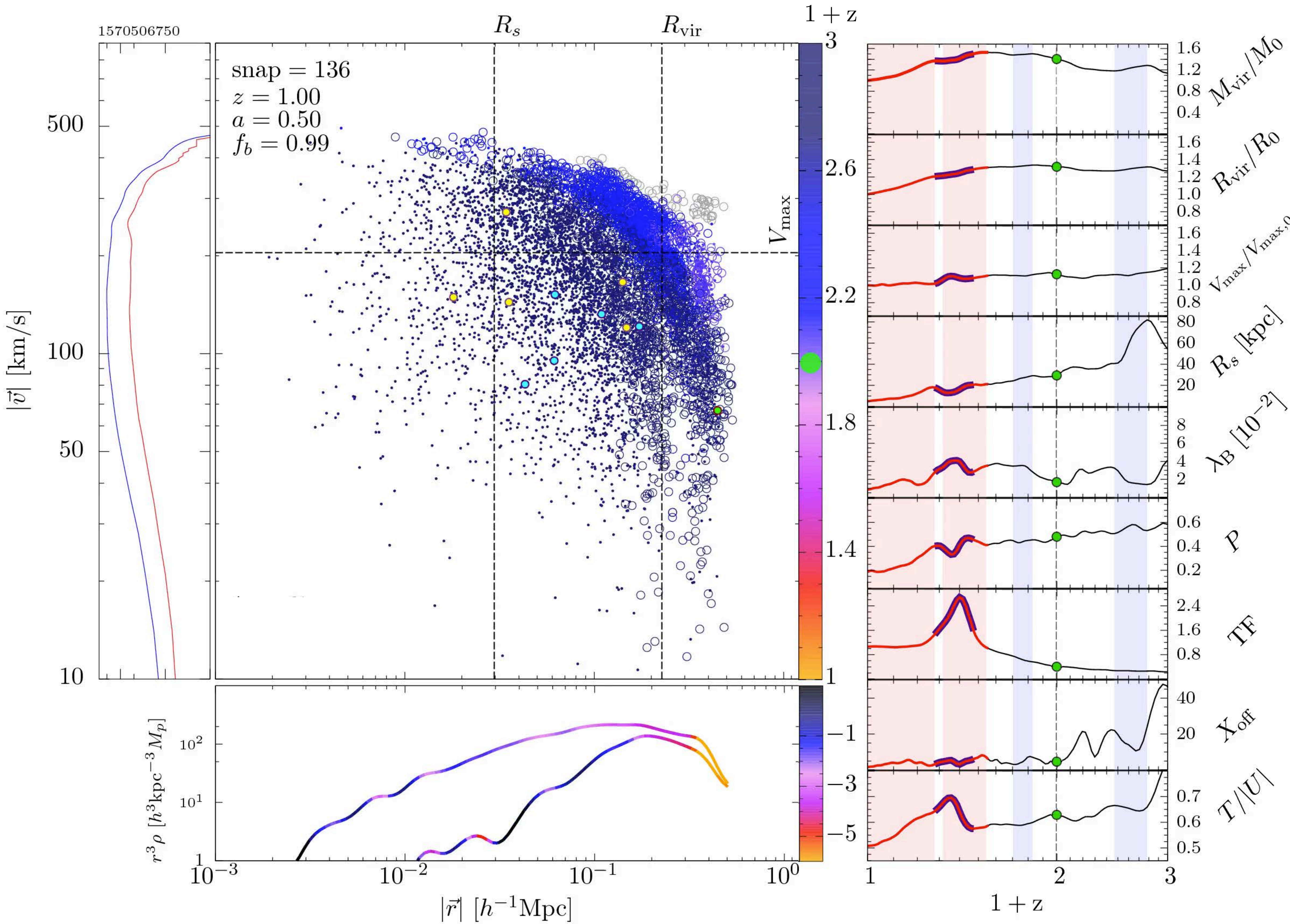
Mass Loss





Christoph Lee, UCSC

January 25th, 2018 UCSC


1570506750
snap = 136
z = 1.00
a = 0.50
$f_b = 0.99$
R_s
$R_{\rm vir}$
1 + z
$V_{\rm max}$
$|\vec{v}|$ [km/s]
$|\vec{r}|$ [h^{-1}Mpc]
$r^3\rho$ [h^3kpc$^{-3}M_p$]
$M_{\rm vir}/M_0$
$R_{\rm vir}/R_0$
$V_{\rm max}/V_{\rm max,0}$
R_s [kpc]
λ_B [10^{-2}]
P
TF
$X_{\rm off}$
$T/|U|$

Summary

- Low mass halos in **LOW** density regions at z = 0 experience consistently low tidal forces over time, have consistently low spin parameters, slightly higher concentrations, similar accretion rates, and are more prolate compared to median density halos.
- Low mass halos in **HIGH** density regions at z = 0 experience increasingly strong tidal forces over time compared to median density halos. These tidal forces cause: reduced accretion rates, increased concentrations, reduced spin parameters, and sphericalization.
- Halo mass loss is relatively common at z = 0 (10-20% of all halos have lost more than 5% of their peak mass).
- We identify two primary mass loss mechanisms: tidal stripping and relaxation following a merger.
- Major mergers often result in 5-15% mass loss, while tidal stripping can remove significantly more, depending on tidal force history.
- Tidal stripping results in reduced scale radius (increased NFW concentration), spin parameter, and prolateness.
- Mergers cause increased scale radius (lower NFW concentration), spin parameter, prolateness, X_off, and virial ratio, followed by a gradual settling as the halo relaxes.

Deep Learning Applied to Galaxy Evolution:

Identifying and Characterizing Star-Forming Stellar Clumps

Chateaubriand
Fellowship Program

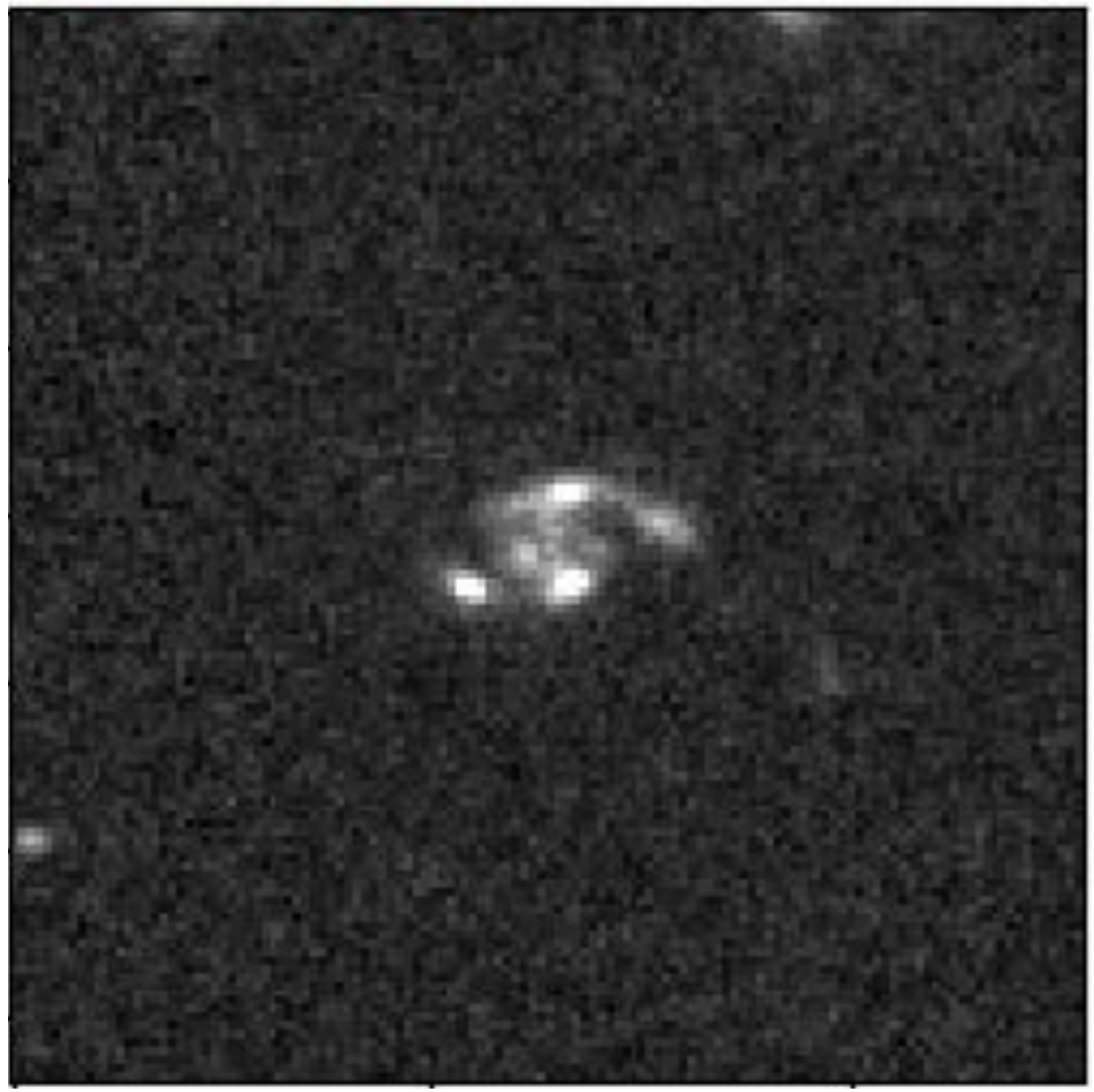
Christoph Lee (UCSC)

January 25th, 2018 UCSC

Joel Primack (UCSC), Marc Huertas-Company (Paris Observatory), Yicheng Guo (University of Missouri)

Deep Learning applied to Galaxy Evolution: Clump Detection

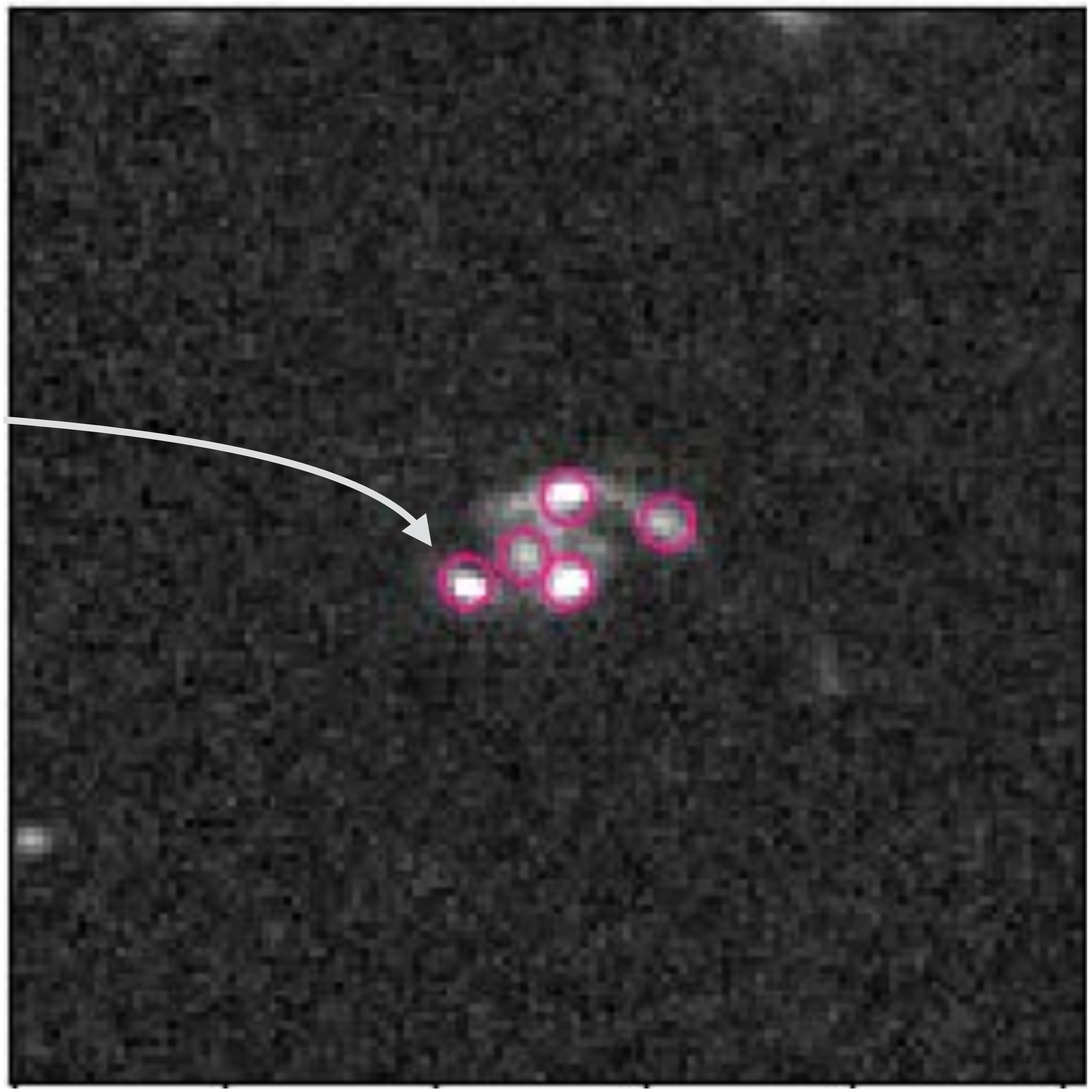
Goal: *accurately predict the presence and properties of star-forming clumps in high redshift galaxies*.



Deep Learning applied to Galaxy Evolution: Clump Detection

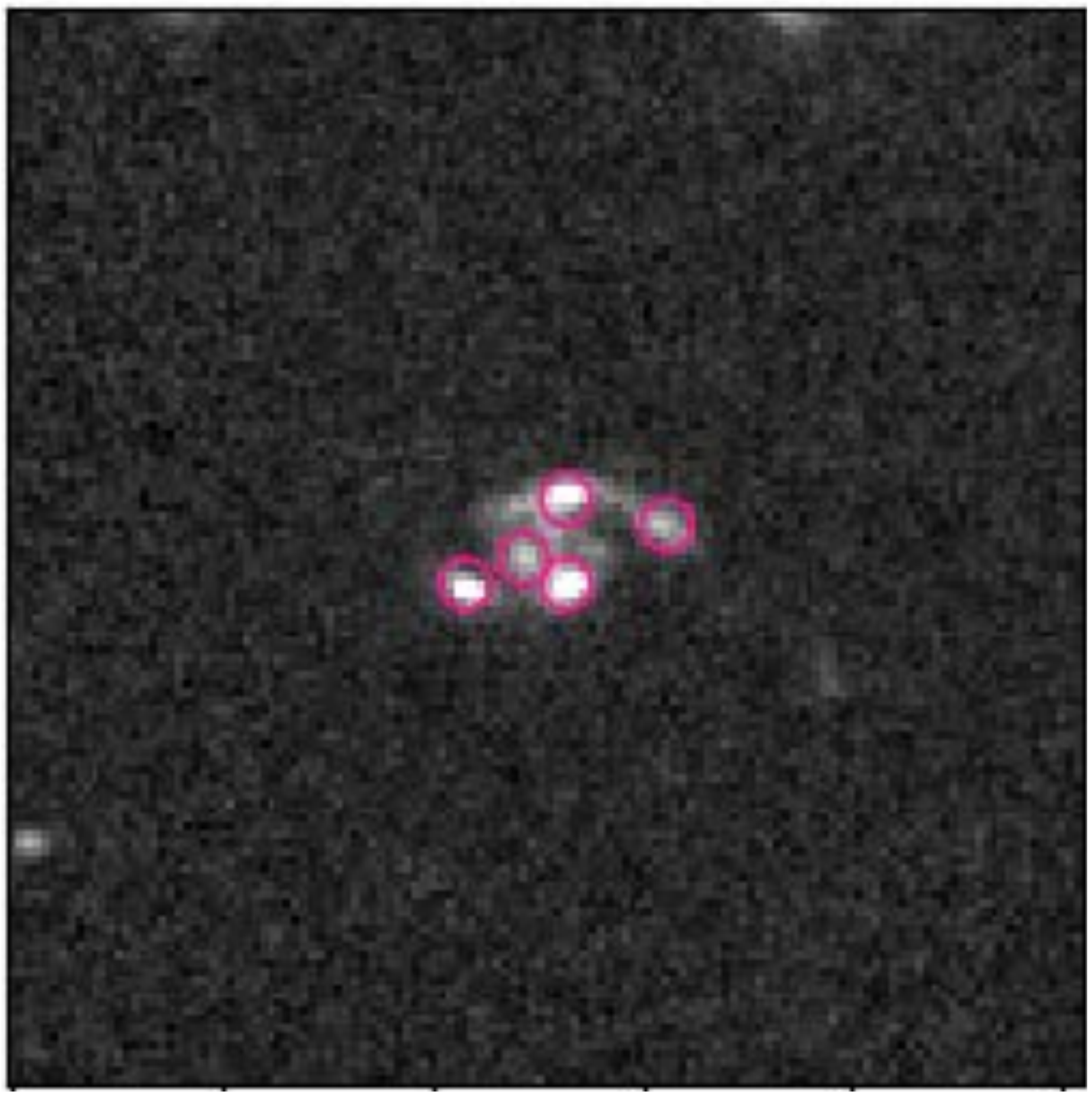
Goal: *accurately predict the presence and properties of star-forming clumps in high redshift galaxies*.

Star Forming Clumps



Deep Learning applied to Galaxy Evolution: Clump Detection

Goal: *accurately predict the presence and properties of star-forming clumps in high redshift galaxies*.



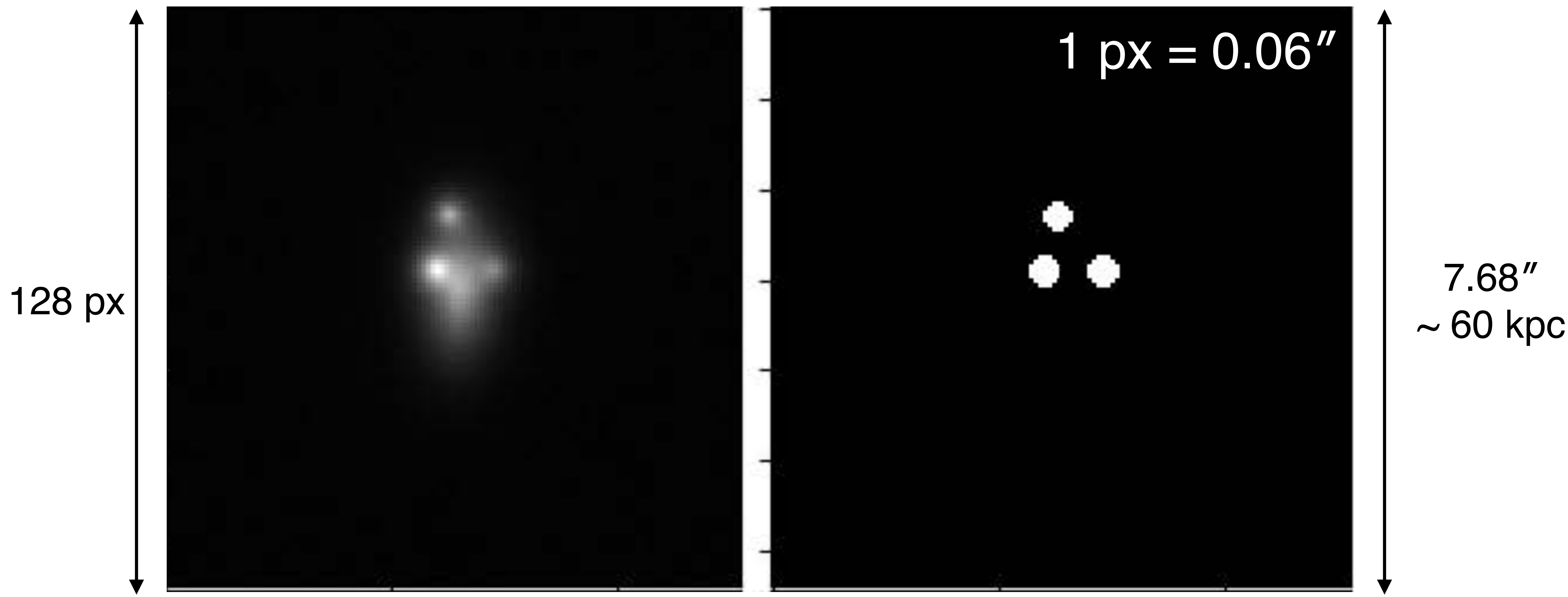
Why?

Massive star-forming clumps are thought to play an important role in the evolution of galaxy structure, stellar feedback, and black hole growth.

In galaxy simulations, one of the biggest uncertainties is what feedback prescription to use. Stellar clumps are a key diagnostic tool to constrain the feedback prescription and crucial in understanding how galaxies evolve.

Deep Learning applied to Galaxy Evolution: Clump Detection

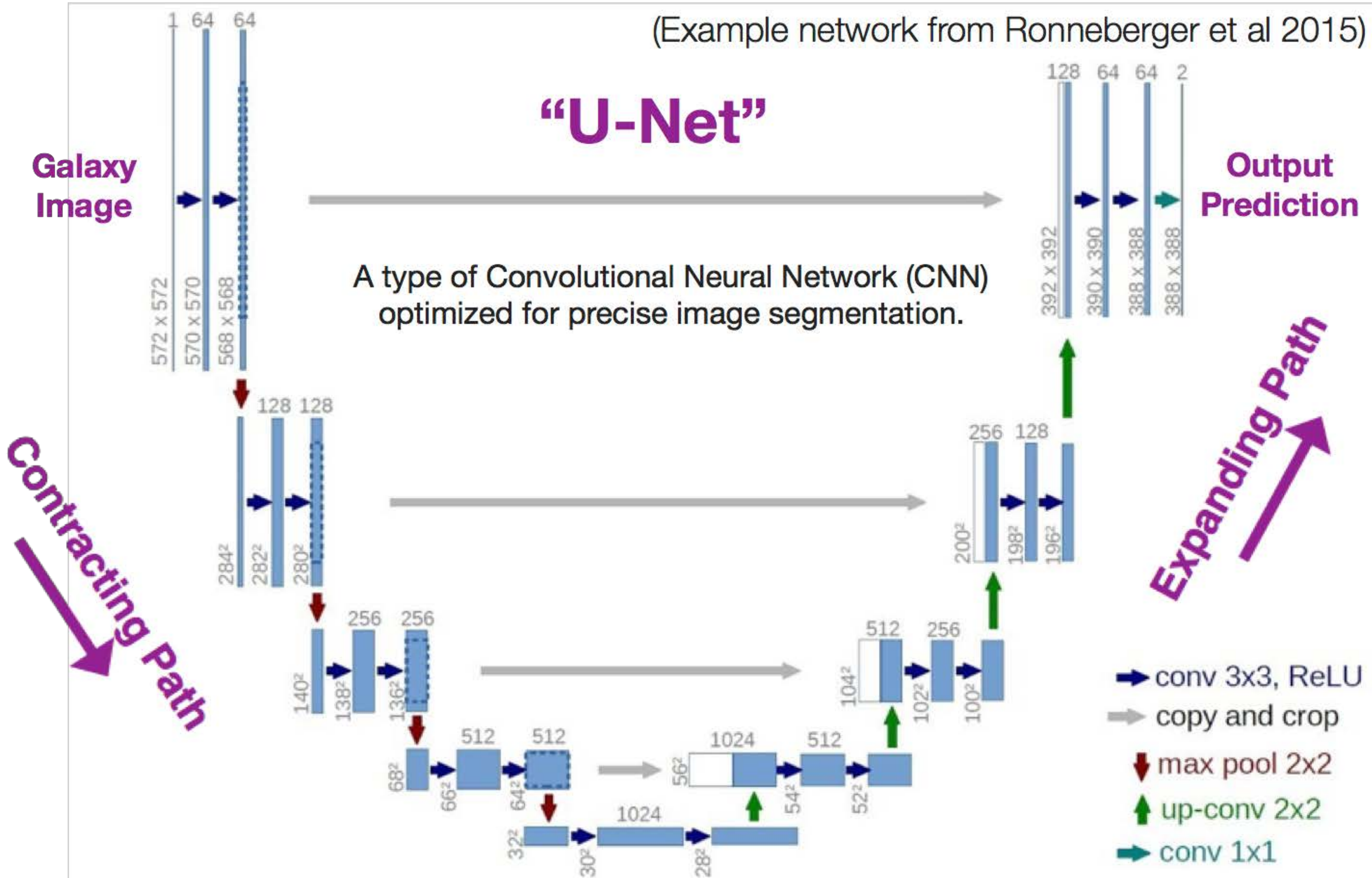
GalSim Training Image　　Clump Mask



To do this, we've trained a deep learning (**U-Net**) model using simple GalSim mock images of clumpy galaxies, paired with mask images showing the clump locations for each training image.

Deep Learning applied to Galaxy Evolution: Clump Detection

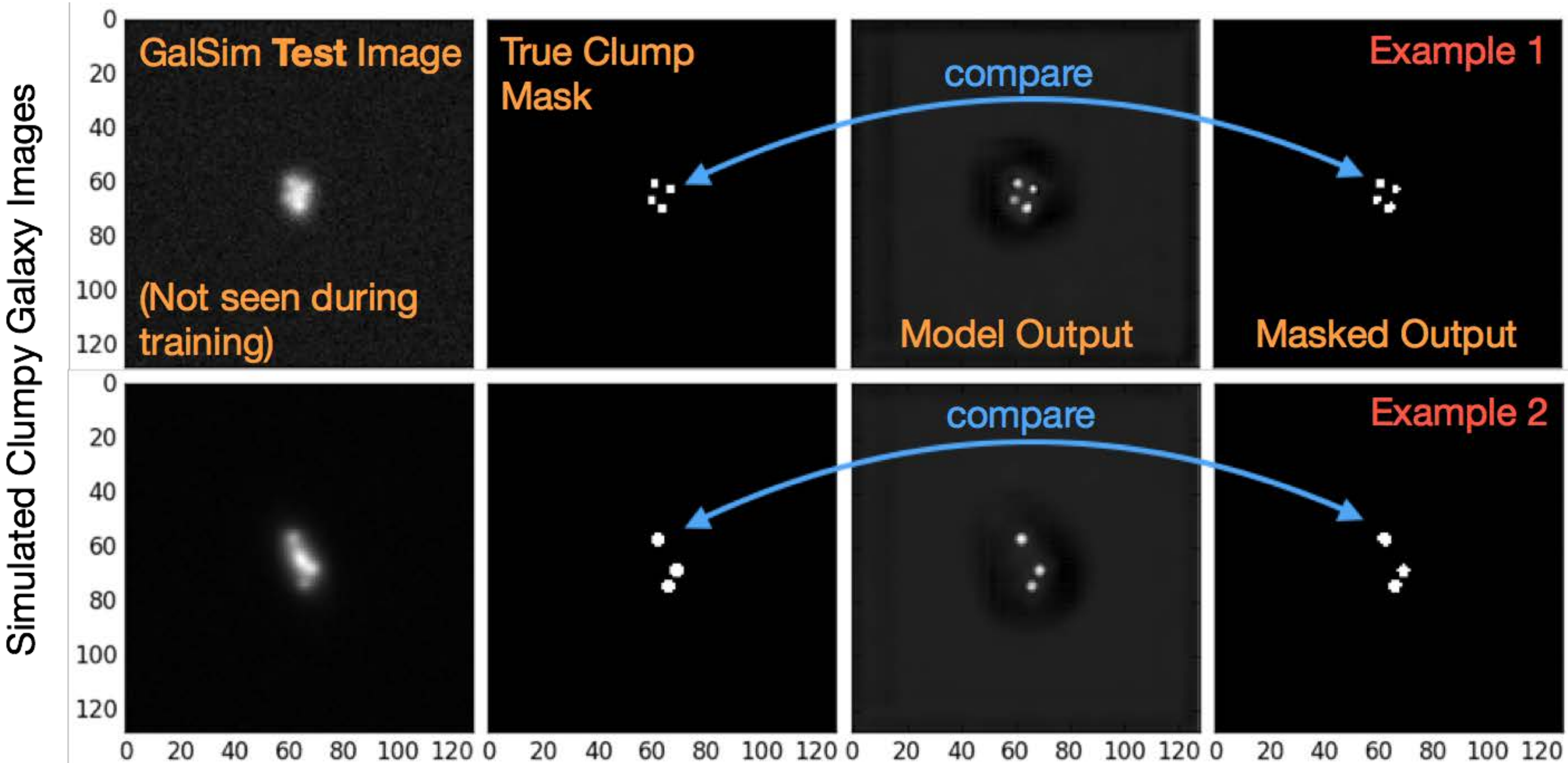
Model Design: U-Net



Deep Learning applied to Galaxy Evolution: Clump Detection

Training and testing with GalSim mock clumpy galaxies

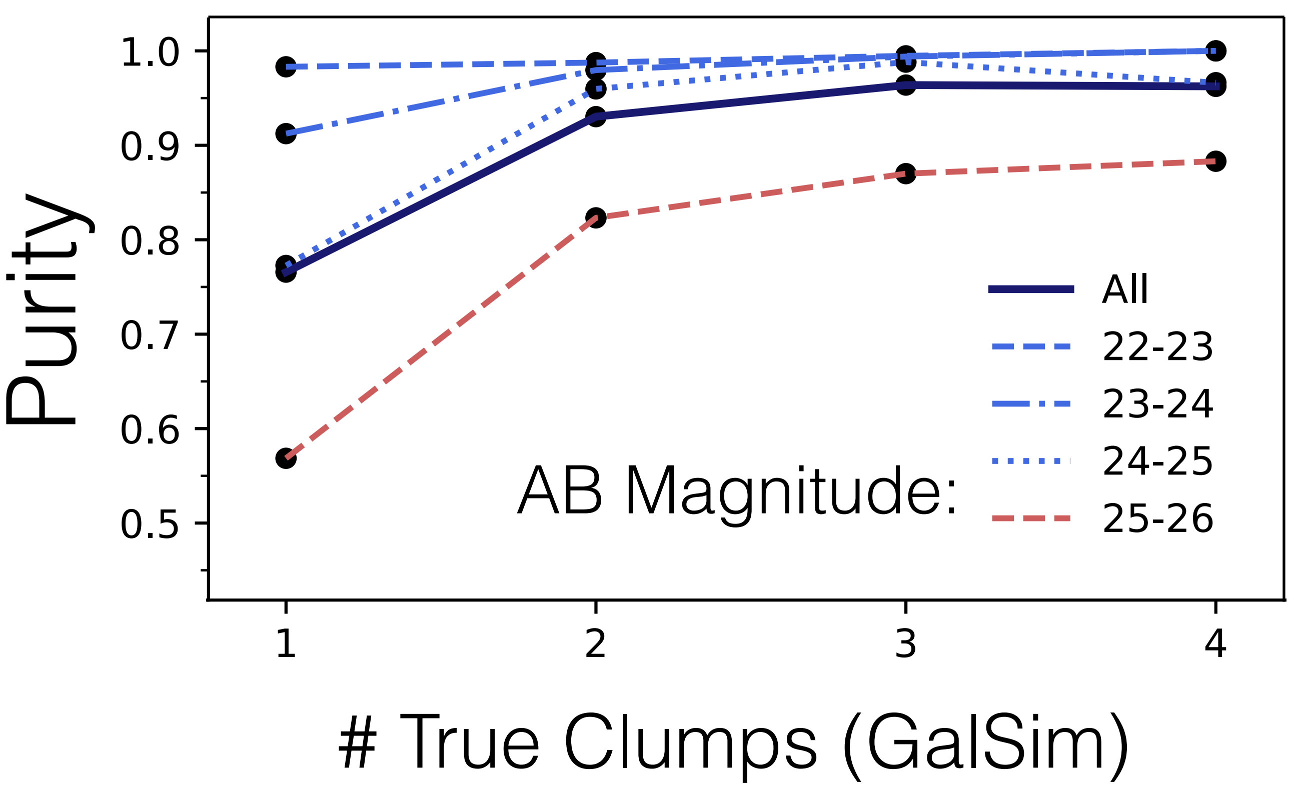
How well does the model recover clumpy regions from the GalSim test set? (Almost exactly!)

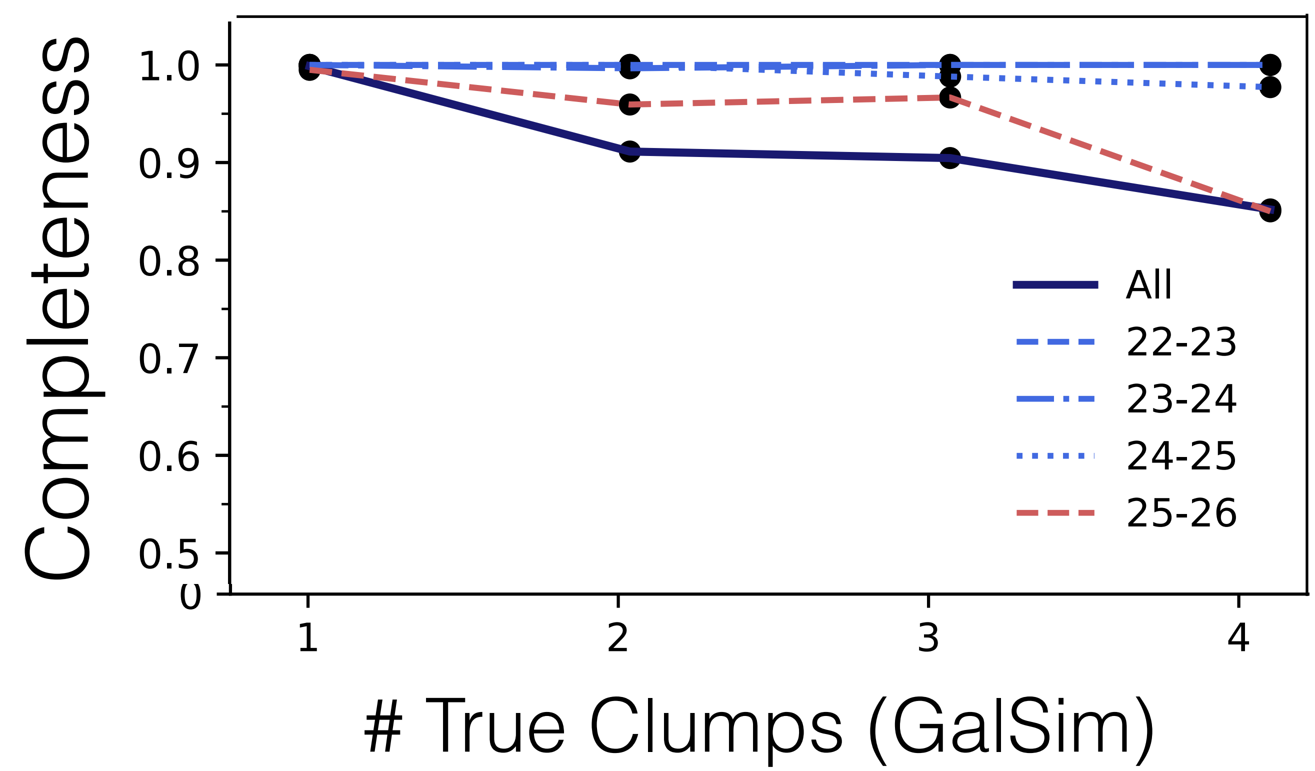


Deep Learning applied to Galaxy Evolution: Clump Detection

<u>Training and testing with GalSim mock clumpy galaxies</u>

How well does the model recover clumpy regions from the GalSim test set?
(Almost exactly!)



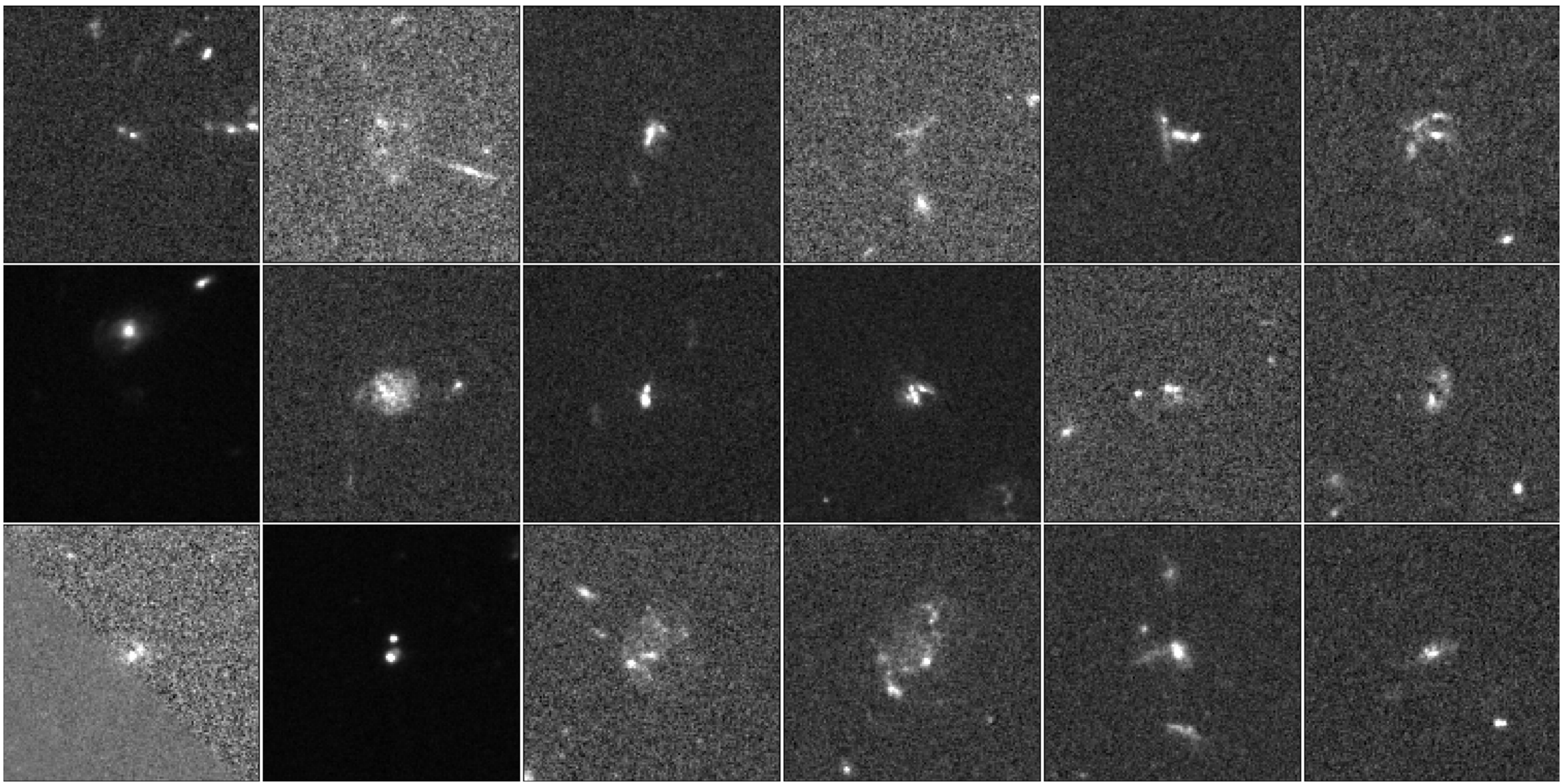


Purity (# True clumps / # SExtractor clumps): Of all the clumps detected by the model, how many are correct? Best performance is about 95-99% for galaxies with multiple, non-overlapping clumps, except for the faintest galaxies (m > 25).

Completeness (# True clumps / # GalSim clumps): How many of the true clumps did the model recover? Best performance is nearly 100%, except for the faintest galaxies (m > 25).

Deep Learning applied to Galaxy Evolution: Clump Detection

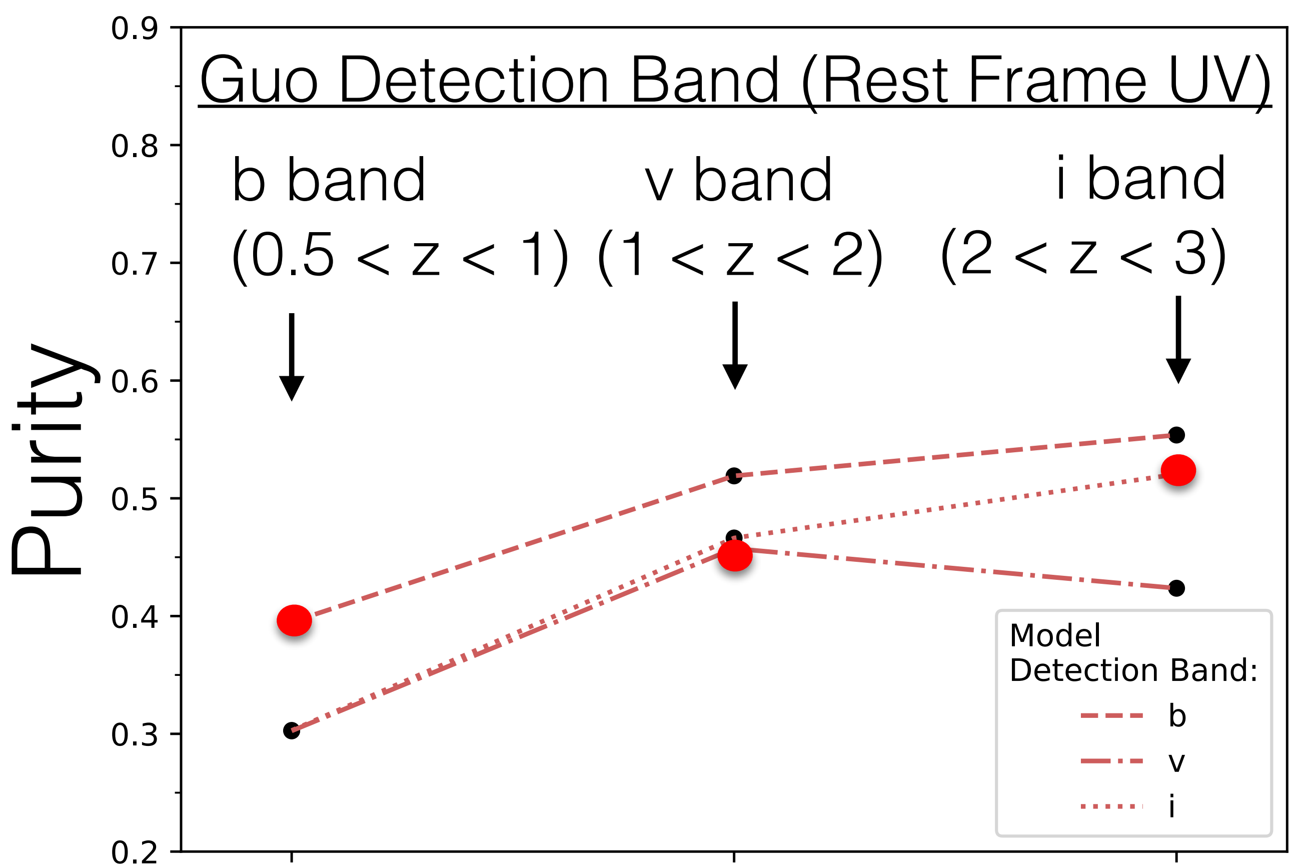
We then apply the clump-detection model to real CANDELS galaxies, including the same clumpy galaxies analyzed by Yicheng Guo et al 2018, to determine how well the model predictions agree with the clumps identified in Guo's catalog.

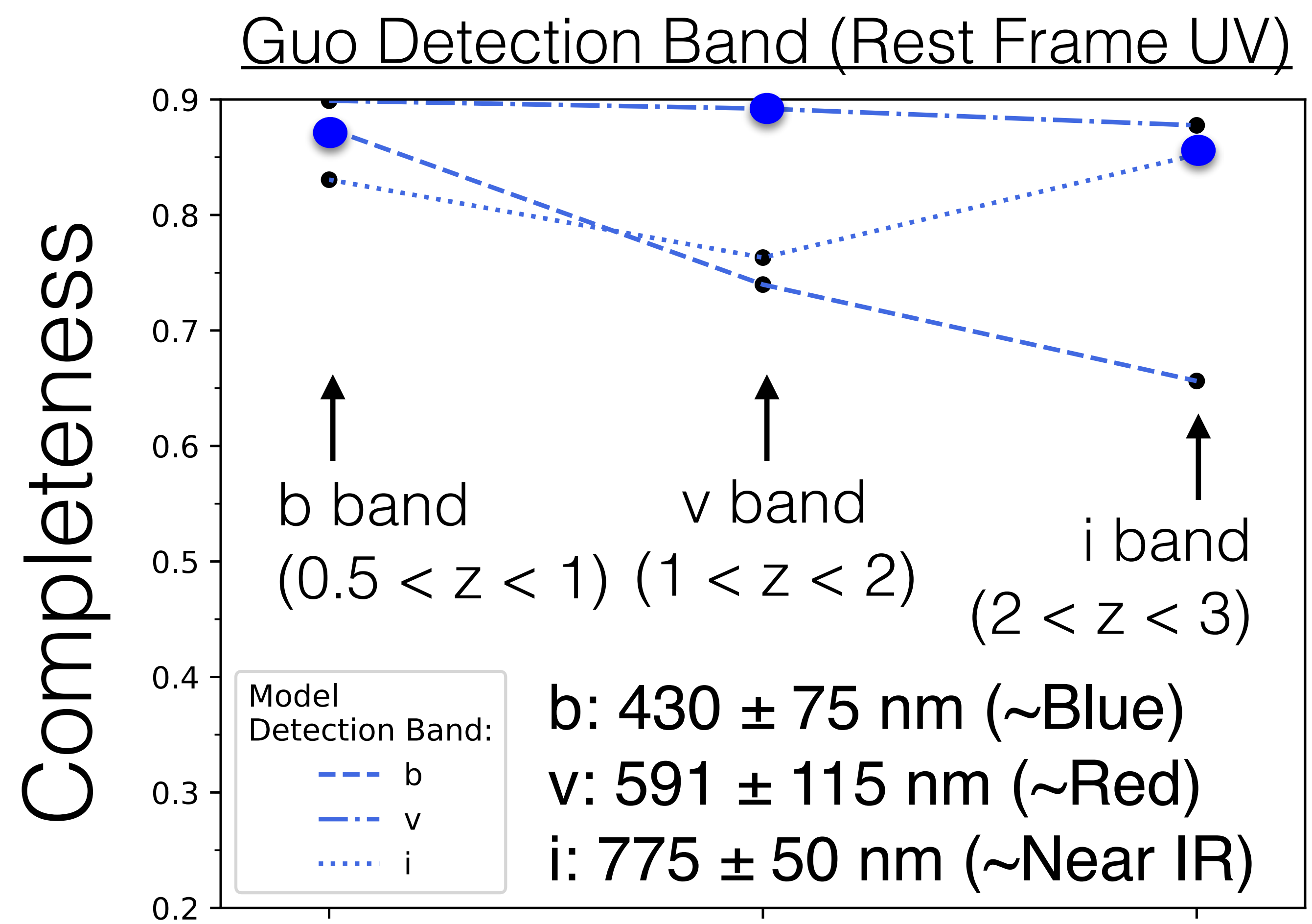


Deep Learning applied to Galaxy Evolution: Clump Detection

Comparison with existing clump catalog for CANDELS galaxies

How do the clumpy regions identified by the model compare to the clumpy regions identified by the Guo analysis?





Purity (# True clumps / # SExtractor clumps): Of all the clumps detected by the model, how many are correct? About **40-50%** in cases where SExtractor detection band matches Guo detection band (red dots).

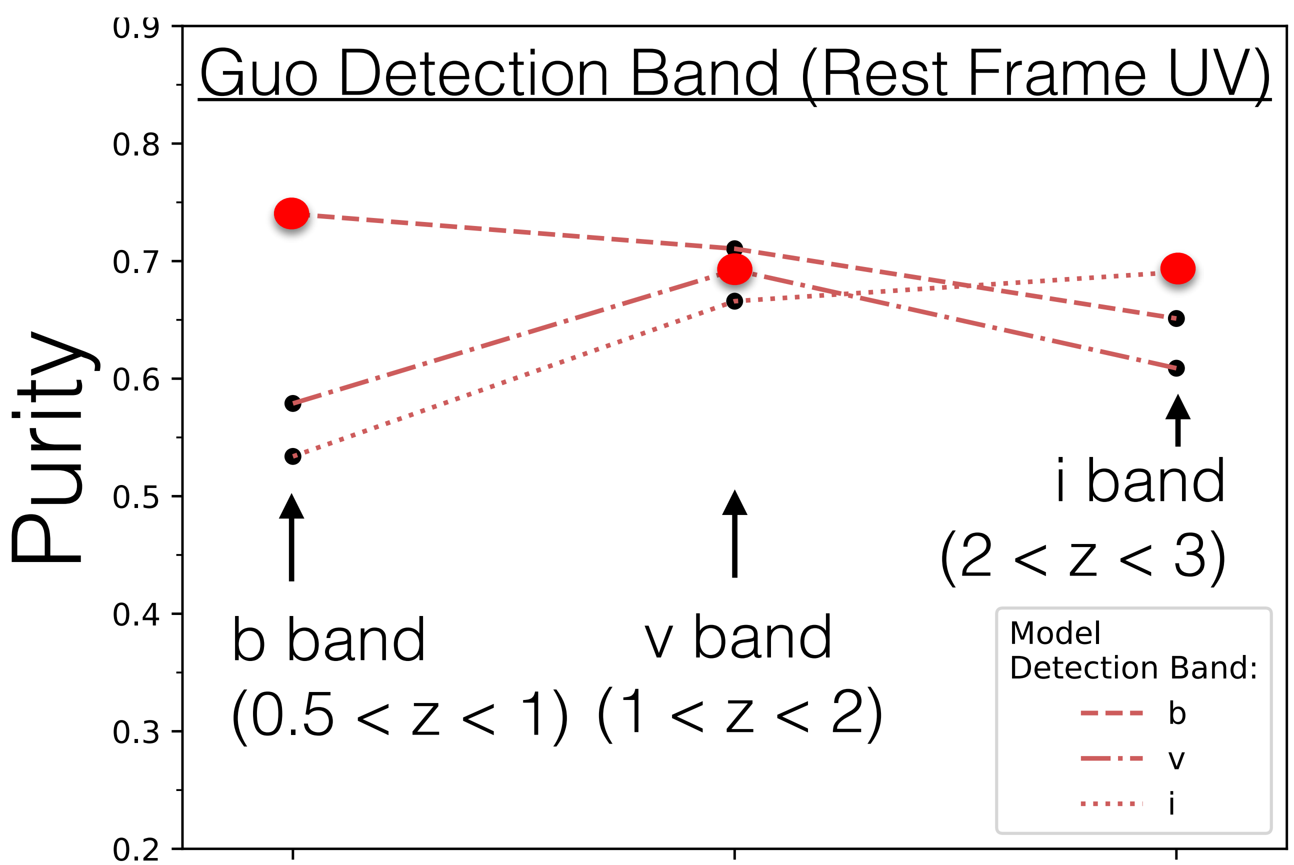
Completeness (# True clumps / # GalSim clumps): How many of the true clumps did the model recover? About **85-90%**, in cases where SExtractor detection band matches Guo detection band (blue dots).

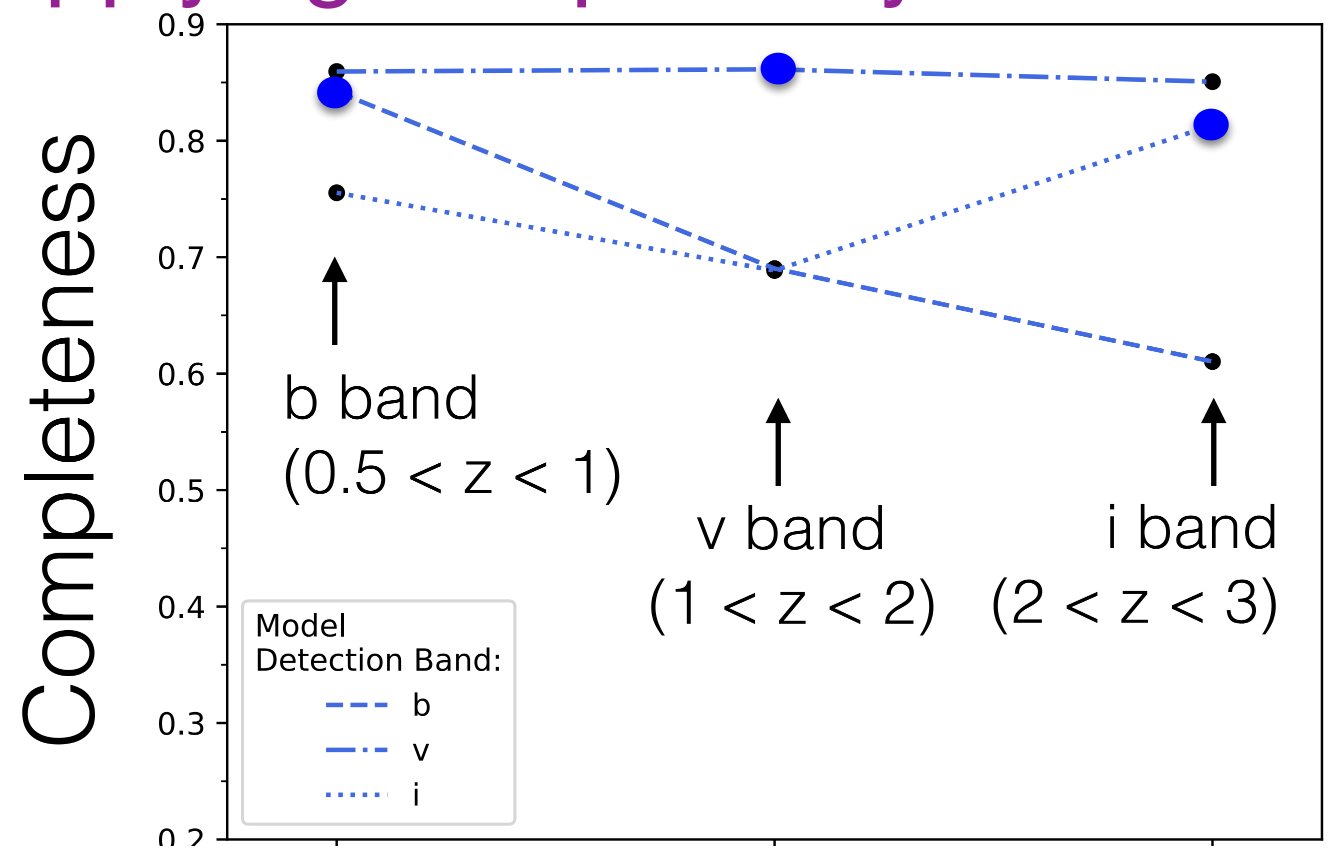
Deep Learning applied to Galaxy Evolution: Clump Detection

Comparison with existing clump catalog for CANDELS galaxies

How do the clumpy regions identified by the model compare to the clumpy regions identified by the Guo analysis?

After applying compatibility cuts

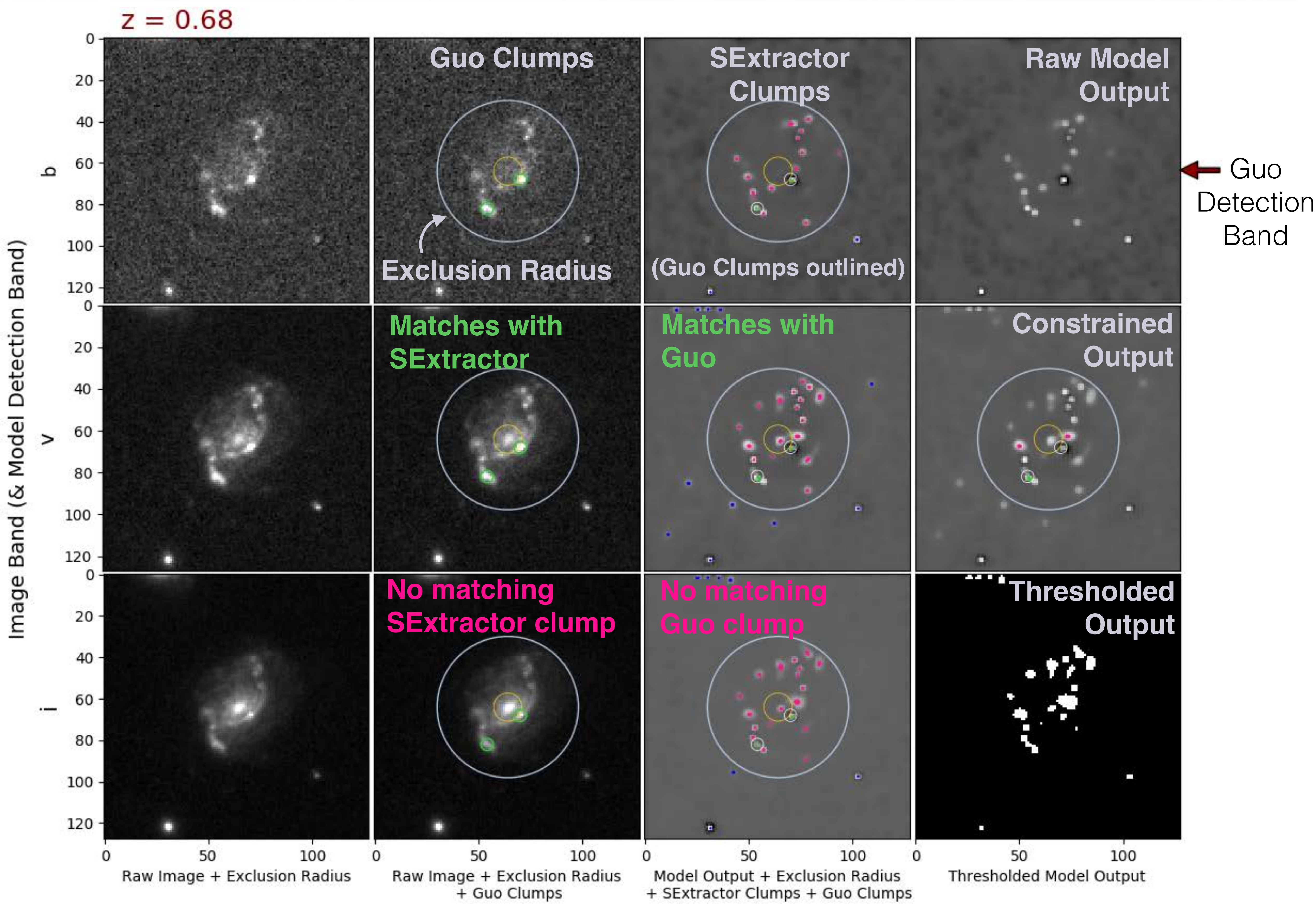




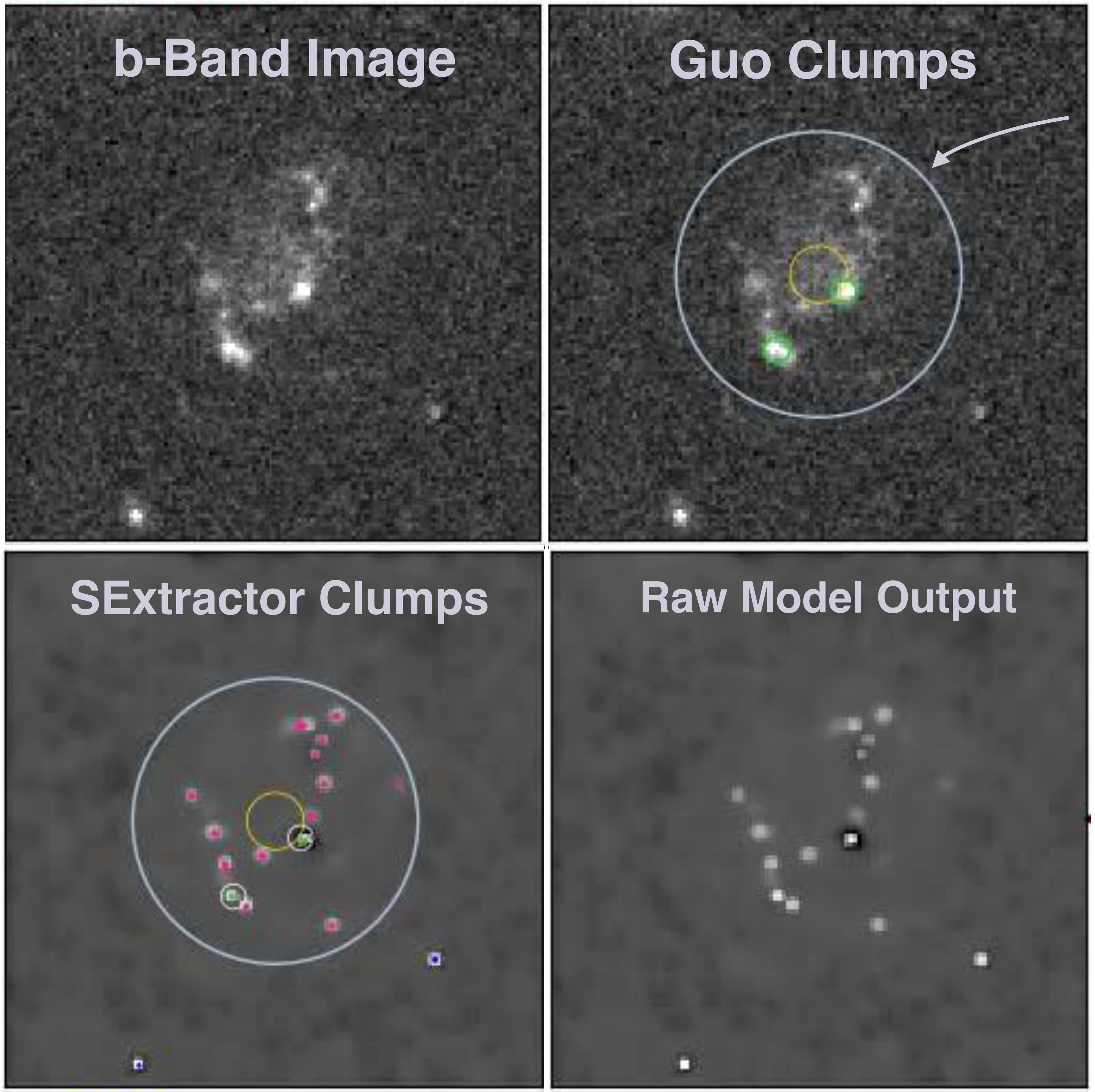
Purity (# True clumps / # SExtractor clumps): Of all the clumps detected by the model, how many are correct? About **70%** in cases where SExtractor detection band matches Guo detection band (red dots).

Completeness (# True clumps / # GalSim clumps): How many of the true clumps did the model recover? About **85-90%**, in cases where SExtractor detection band matches Guo detection band (blue dots).

Deep Learning applied to Galaxy Evolution: Clump Detection



Deep Learning applied to Galaxy Evolution: Clump Detection



Exclusion Radius (2.5 R_e)

R_e is half-light radius measured in H-band (~1.6 μm)

Green = Agreement

Red = Unmatched

Summary and Continuing Work…

- U-Net model enables image segmentation, allowing us to generate clump likelihood images from input galaxy images.
- Our training set consists of 50,000 fake clumpy galaxies (and associated clump masks) generated using GalSim toolkit.
- U-Net model paired with SExtractor identifies clumps in our test set with nearly perfect purity and completeness.
- When run on the same CANDELS galaxies used by Yicheng Guo in his 2015 and 2018 papers, the U-Net model achieves about 70% purity and 85% completeness
- Guo focused only on star forming clumps detected in rest-frame UV, but we can now find clumps in any wave band — including clumps that are not star forming.
- Guo's analysis was limited to several thousand galaxies, but we can now extend this multi-band clump analysis to the full CANDELS survey of ~100,000 galaxies.
- Using the U-Net developed here, our collaborators are extending this analysis to find clumps in "CANDELized" images (realistic images degraded to HST resolution) from high resolution hydrodynamical galaxy simulations.