Characterizing WHIM in Simulations

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Intergalactic Interconnections:
Finding the cosmic web and the baryons
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Introduction

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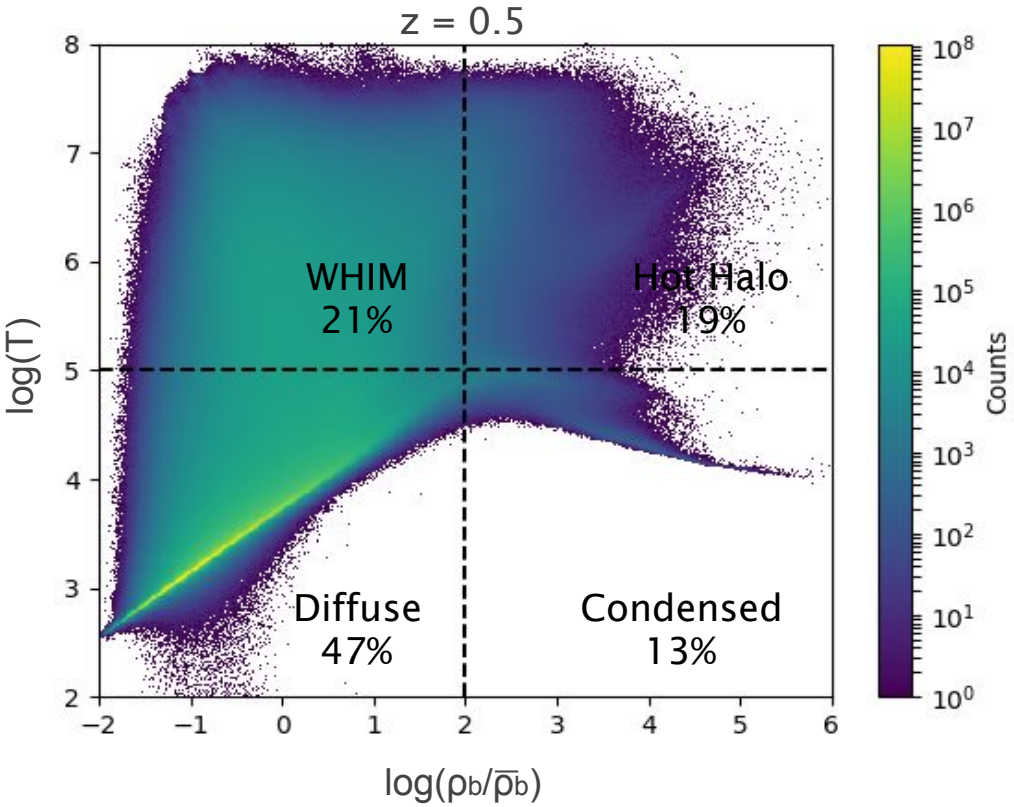
What is WHIM?

- Warm-Hot Intergalactic Medium
  - A web of hot diffuse gas
- Possible candidate for missing baryons
  - Hard to observe
- Affects Lyman Alpha observables
  - Tomographic reconstruction

Simulation

- Uses cosmological hydrodynamic code Nyx
- Has baryons and dark matter
- On a grid
- This simulation is 4096^3, or (100 Mpc/h)^3

Defining WHIM



WHIM Mass Fraction

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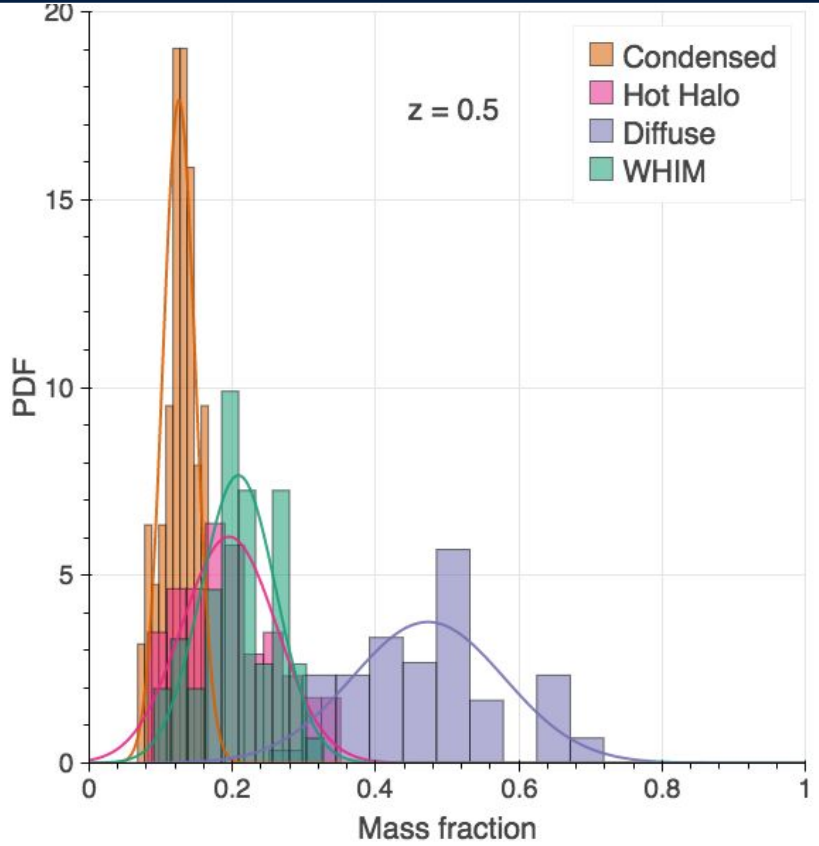
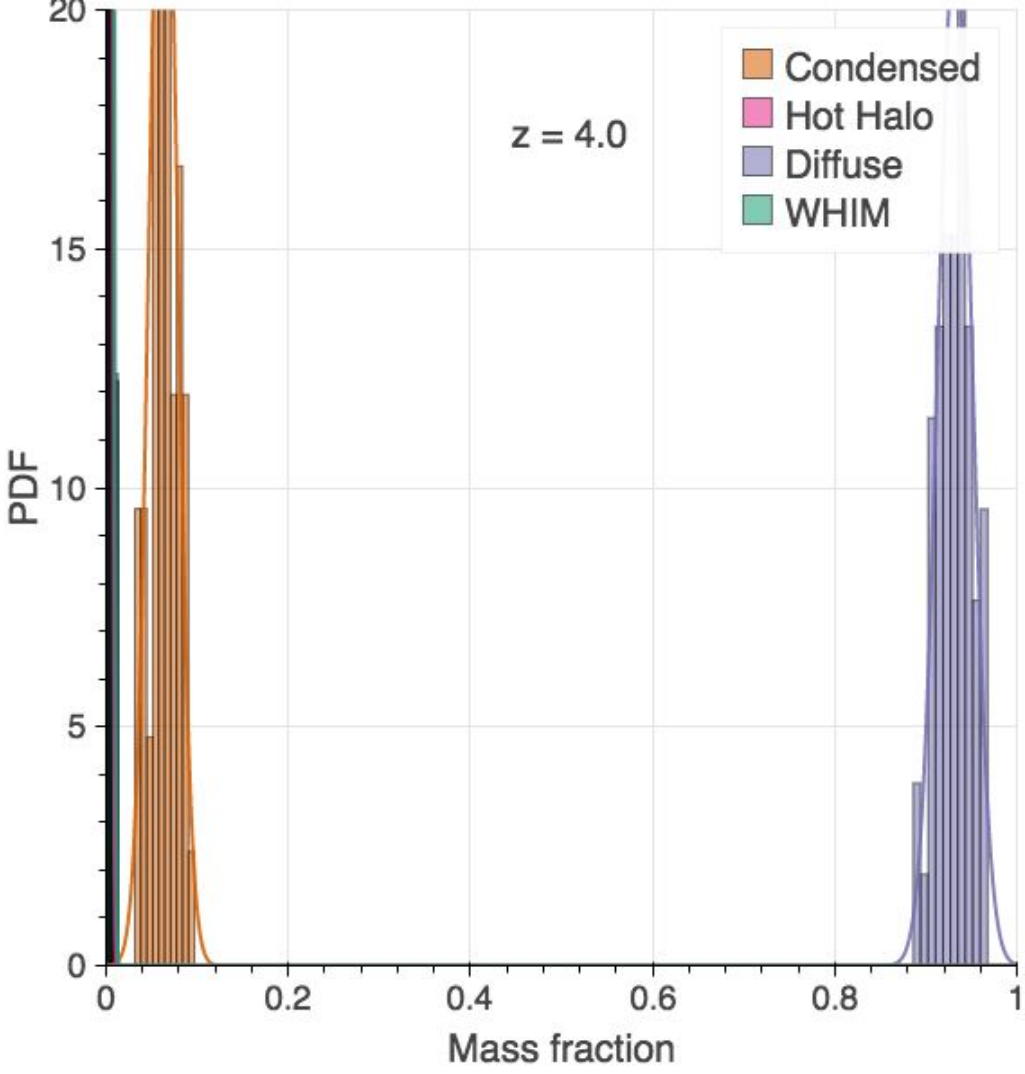
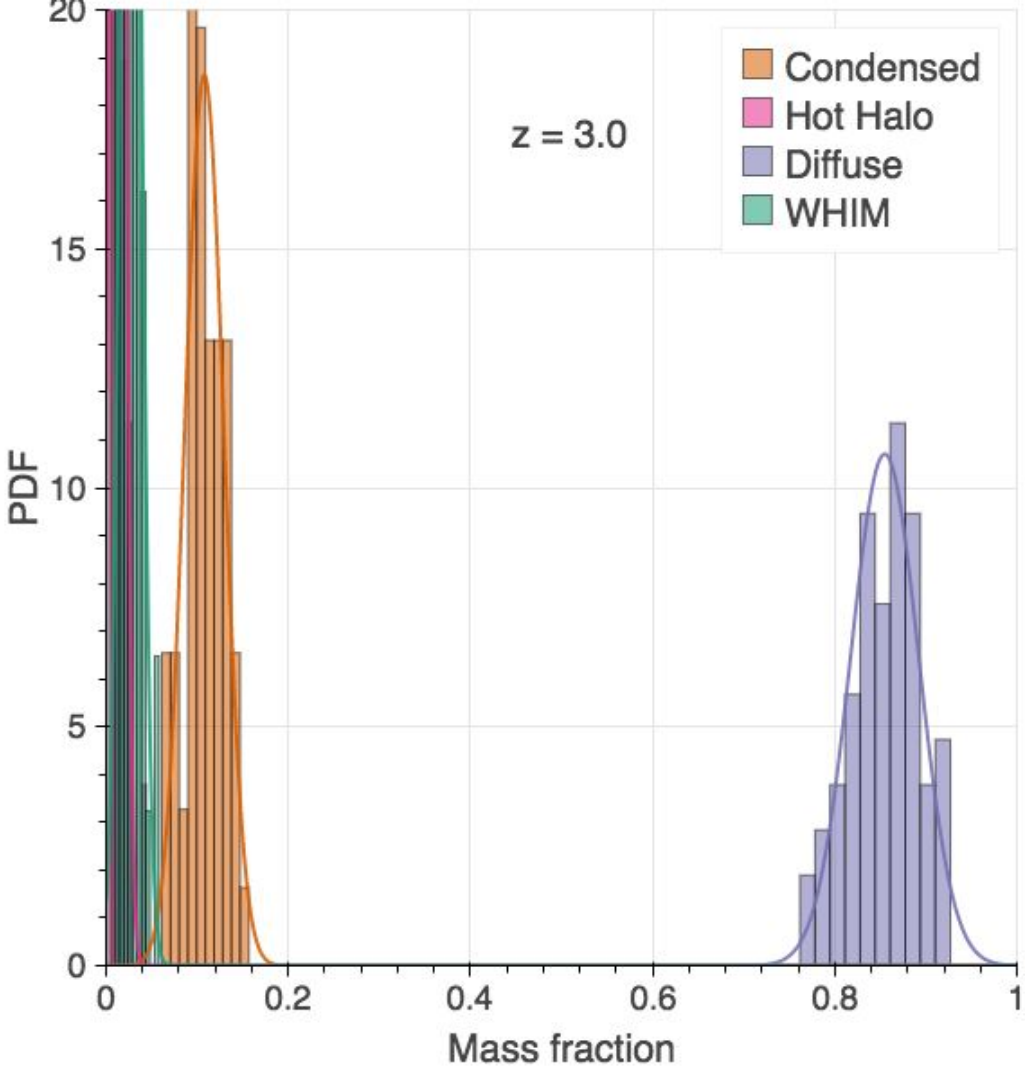
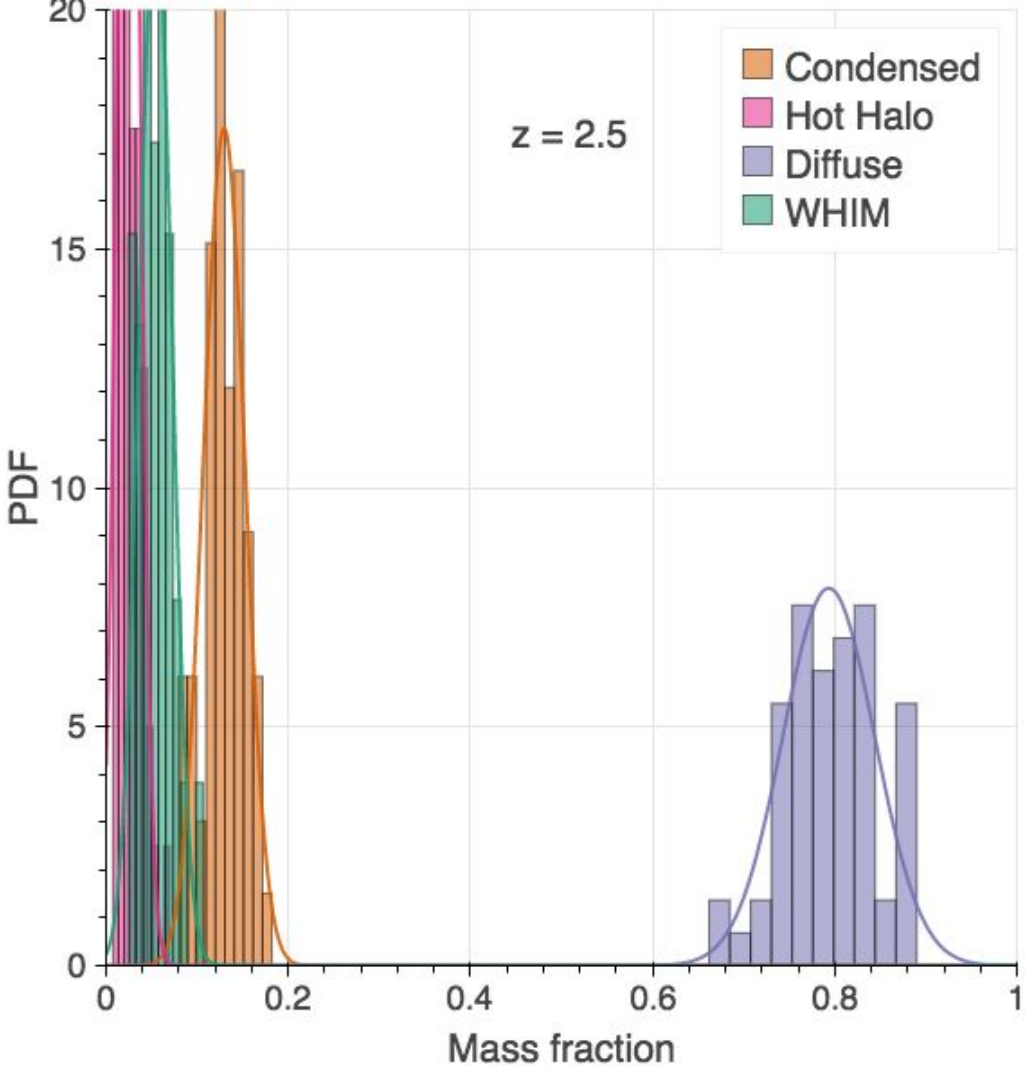
WHIM Mass Fraction

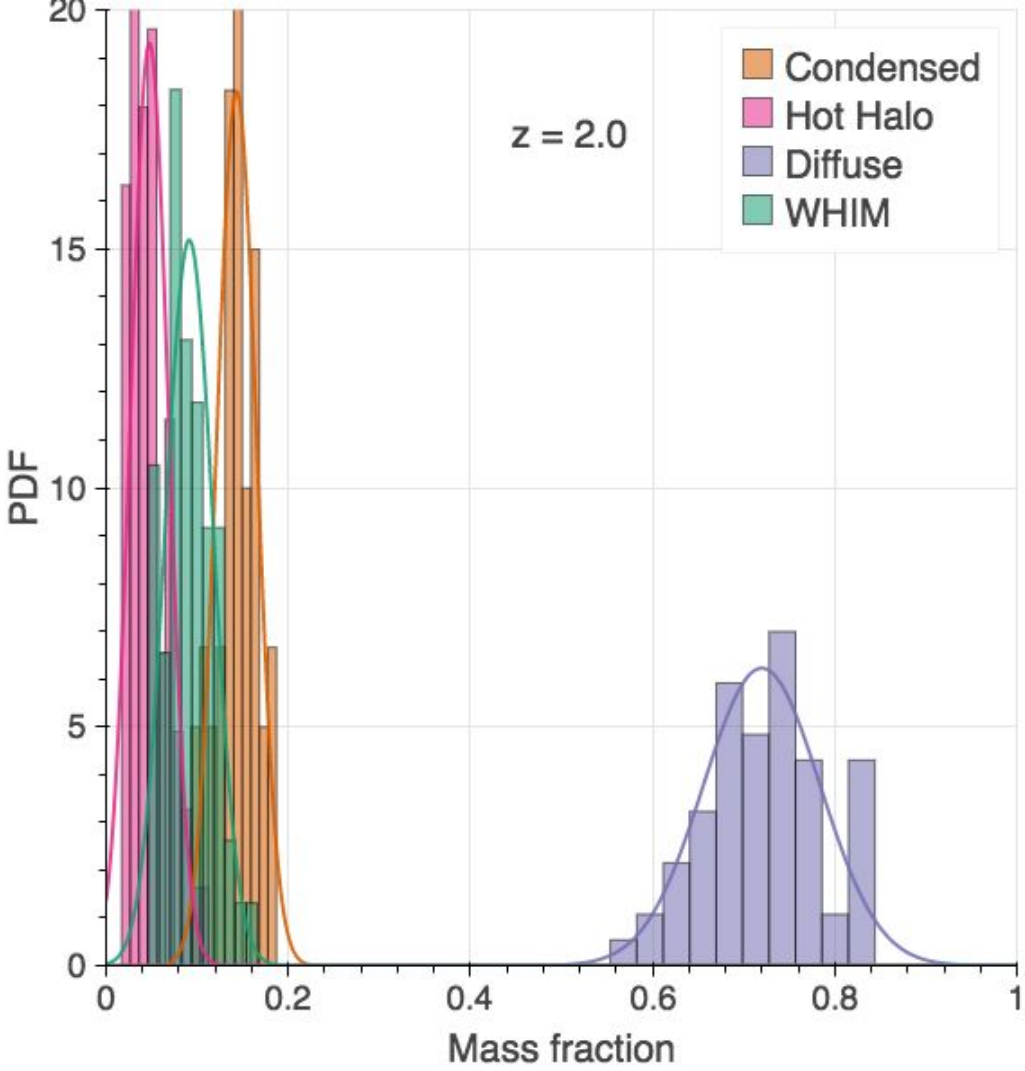
- Split (100 Mpc/h)^3 box into 64 (25 Mpc/h)^3 boxes
- Variance between boxes is large

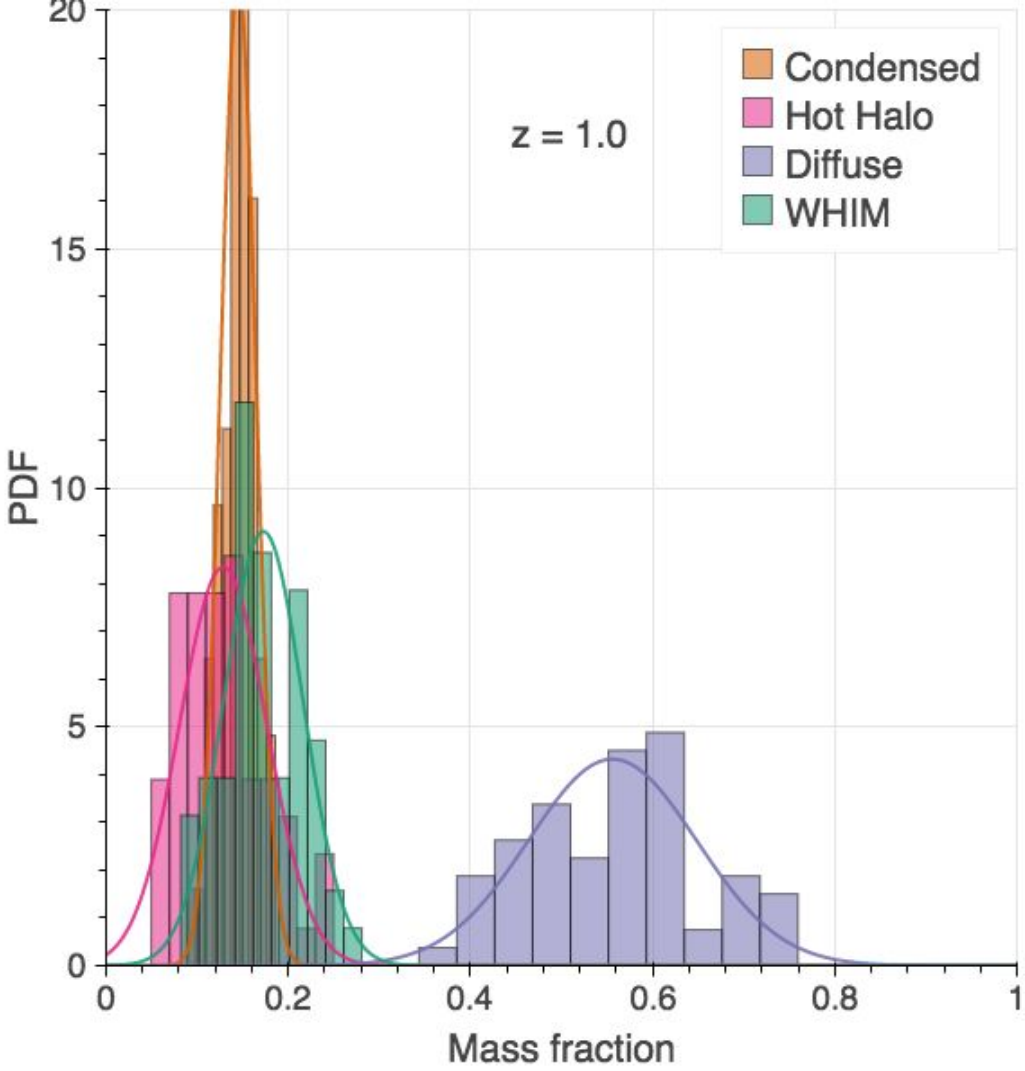



Condensed
Hot Halo
Diffuse
WHIM
z = 4.0
PDF
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
Mass fraction


Condensed
Hot Halo
Diffuse
WHIM
z = 3.0
PDF
0
5
10
15
20
0
0.2
0.4
0.6
0.8
1
Mass fraction


Condensed
Hot Halo
Diffuse
WHIM
z = 2.5
PDF
0
5
10
15
20
0
0.2
0.4
0.6
0.8
1
Mass fraction


Condensed
Hot Halo
Diffuse
WHIM
z = 2.0
PDF
0
5
10
15
20
0
0.2
0.4
0.6
0.8
1
Mass fraction


Condensed
Hot Halo
Diffuse
WHIM
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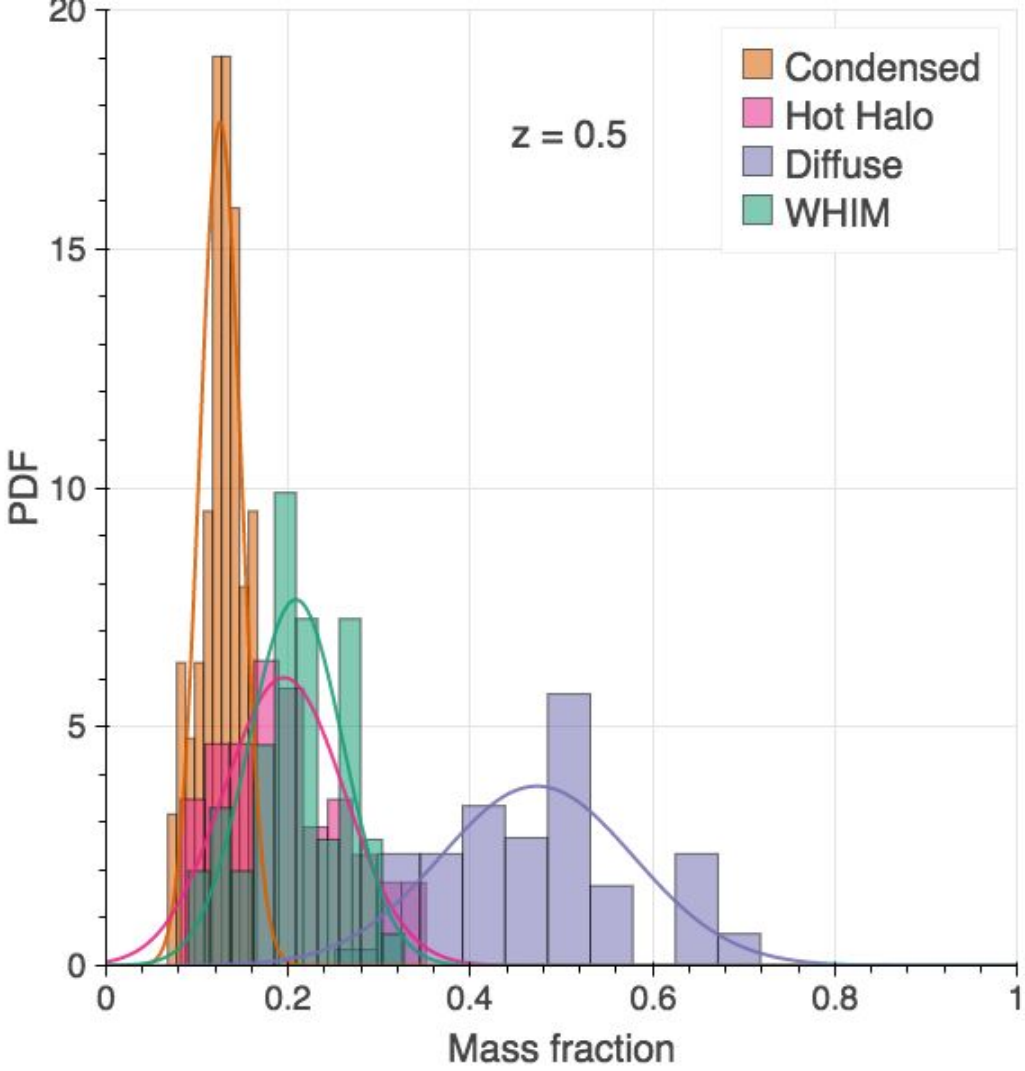
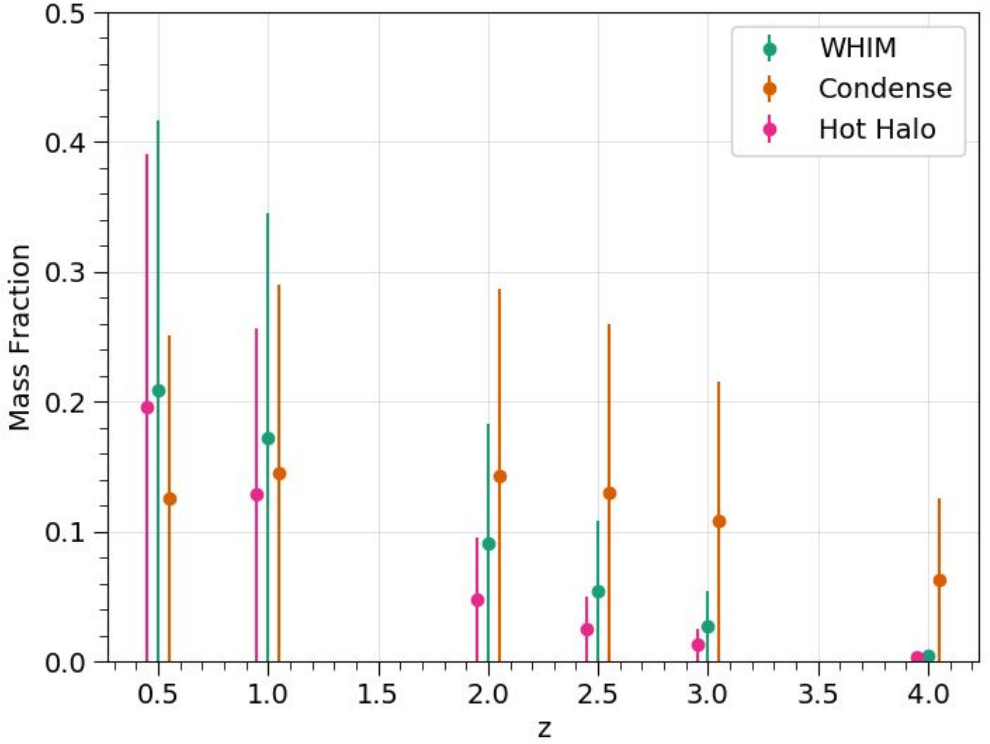
PDF
0
5
10
15
20
0
0.2
0.4
0.6
0.8
1
Mass fraction


Condensed
Hot Halo
Diffuse
WHIM
z = 0.5
PDF
Mass fraction
0
5
10
15
20
0
0.2
0.4
0.6
0.8
1

Mass Fraction vs. Redshift

- Across redshift, variance in mass fractions are large
- Must be careful in simulation mass fractions



WHIM Around Halos

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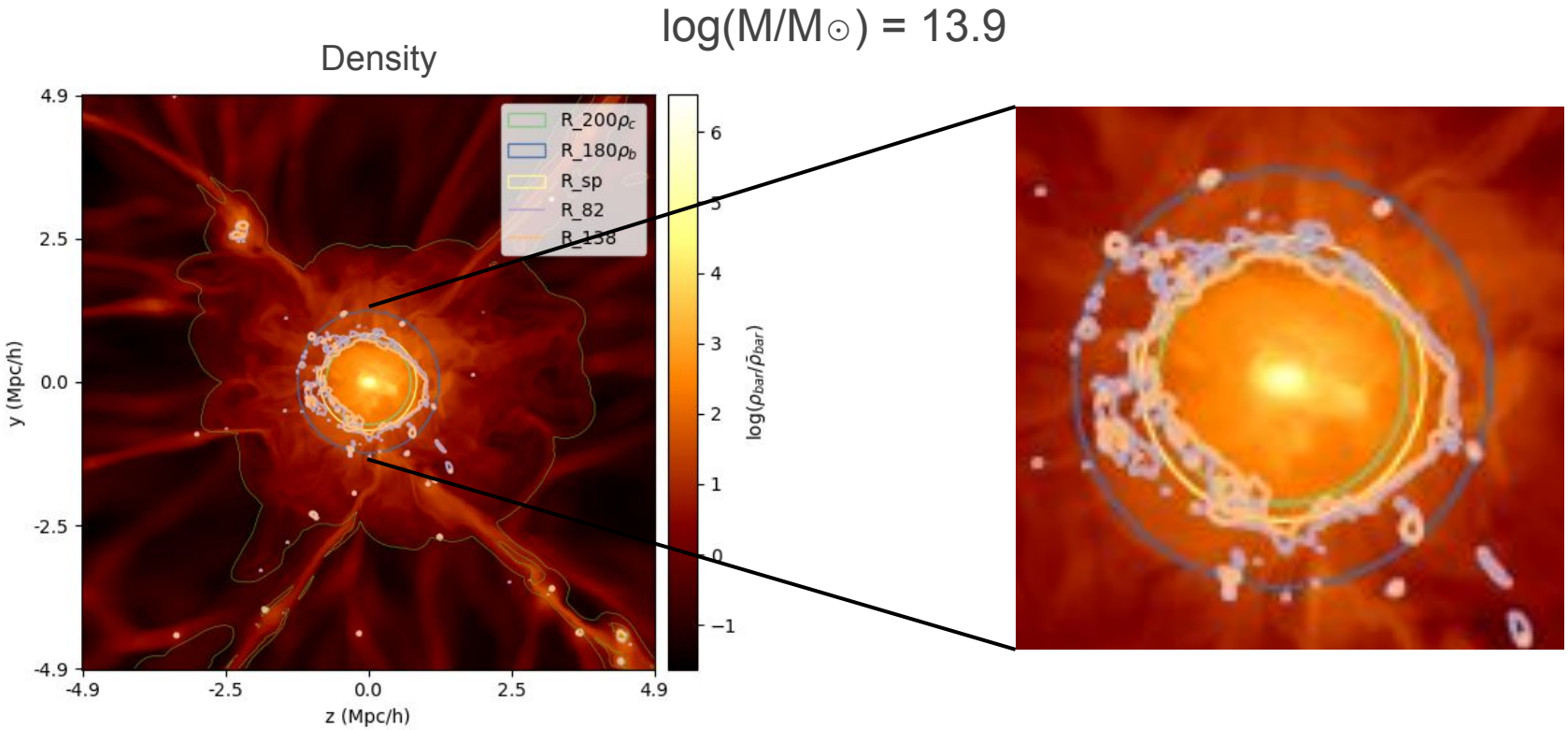
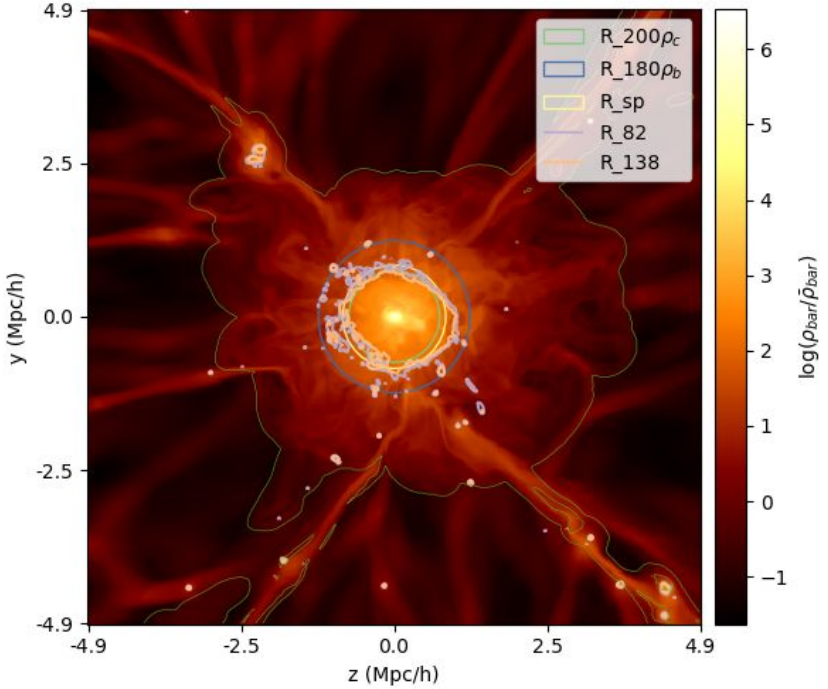
Finding the WHIM in Simulations



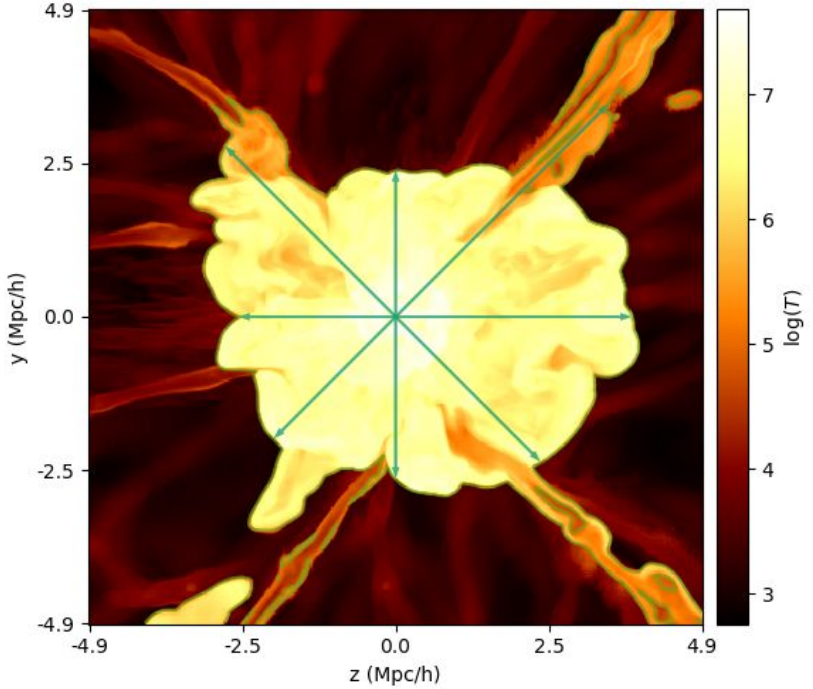
Finding the WHIM in Simulations

log(M/M⊙) = 13.9

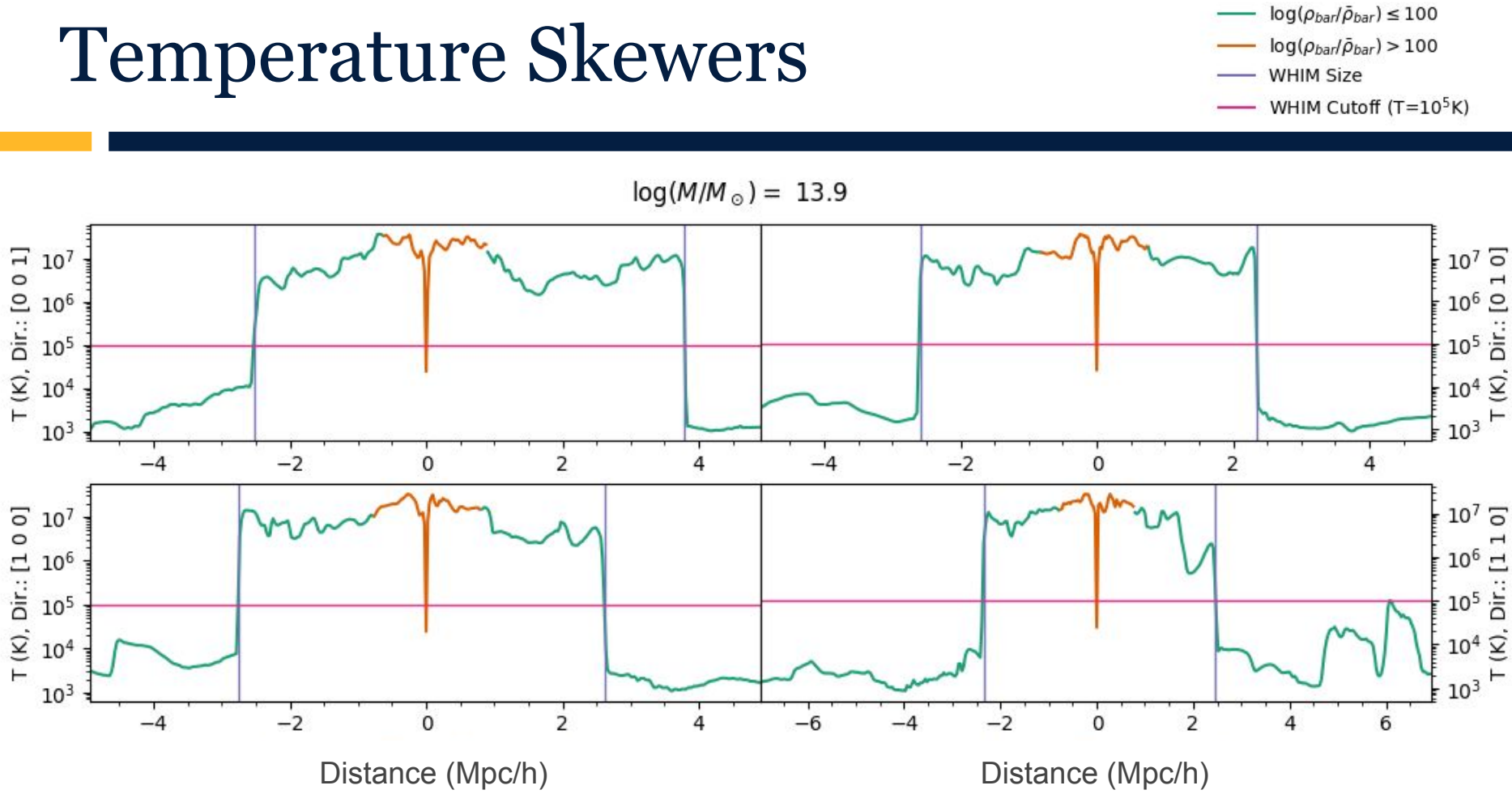
Density



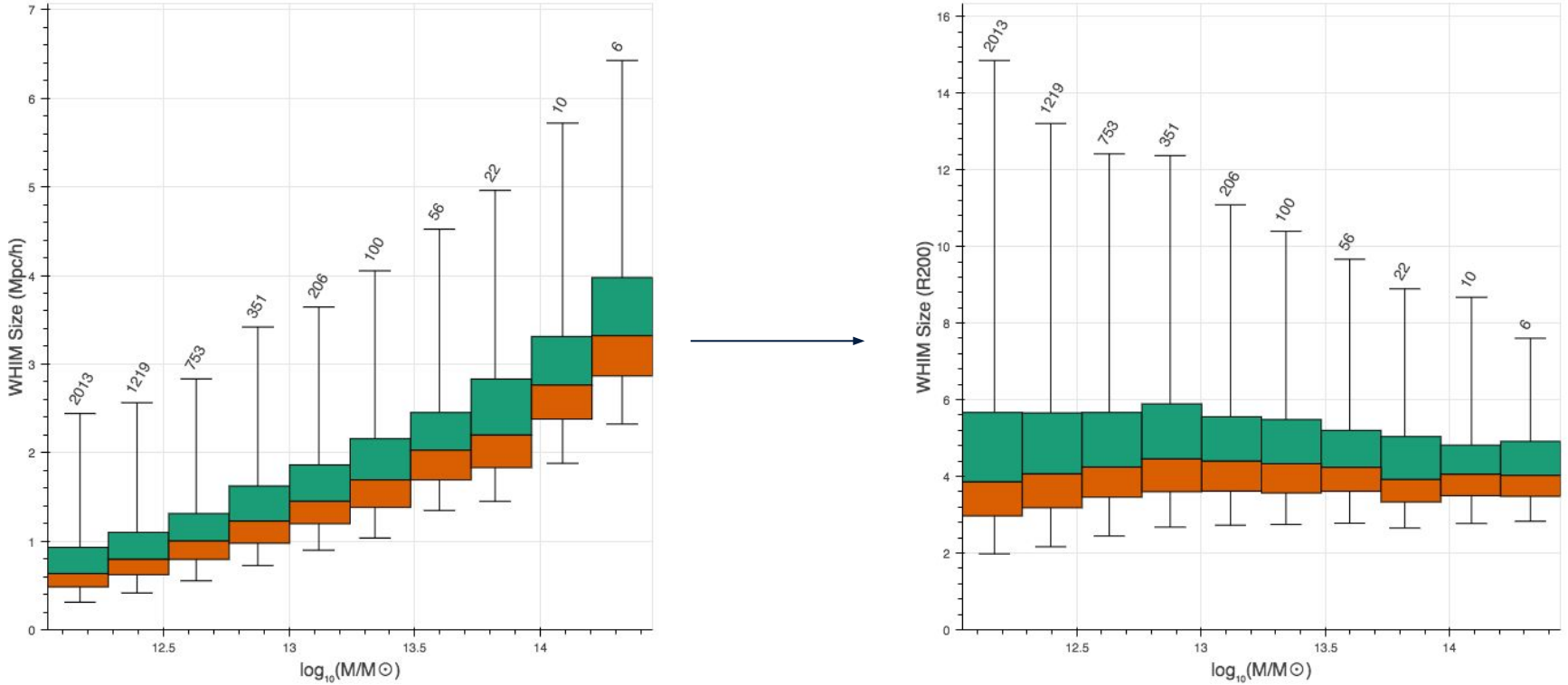
Temperature

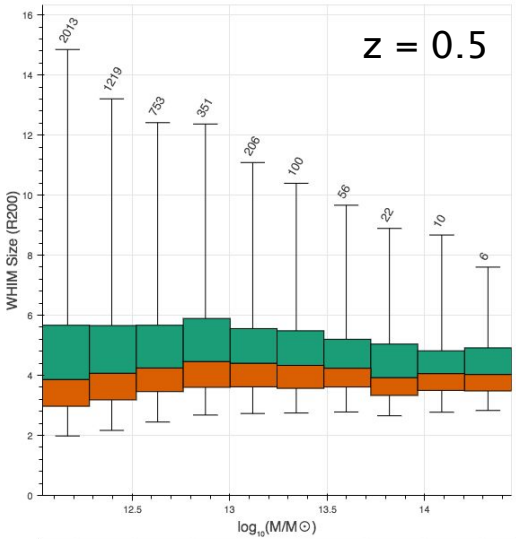


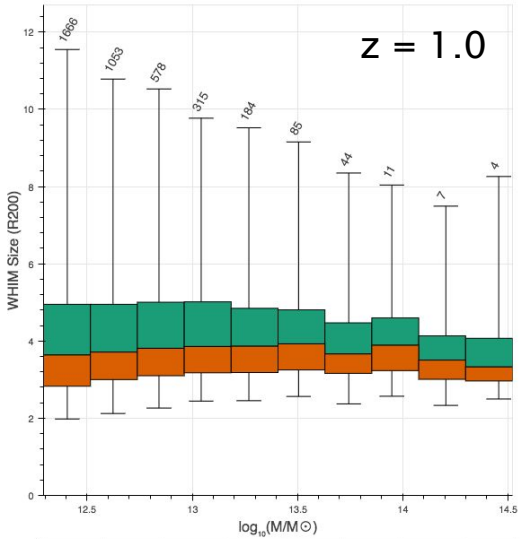
Temperature Skewers

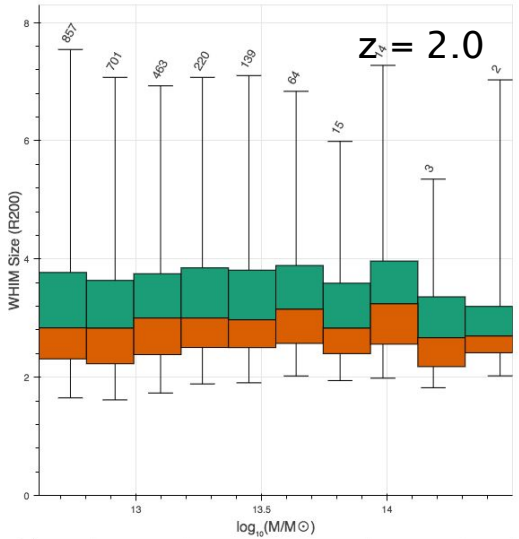


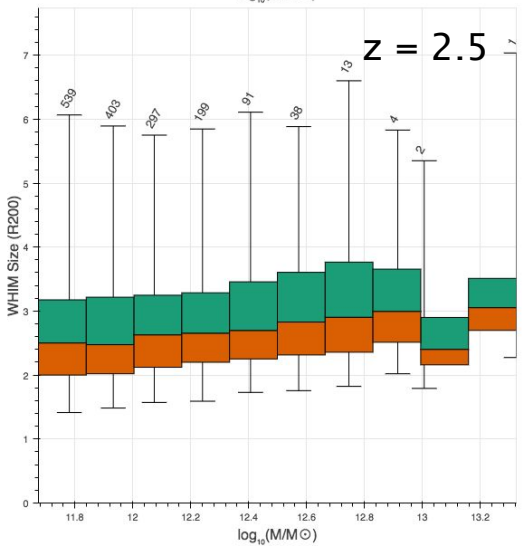
WHIM Size vs. Halo Mass

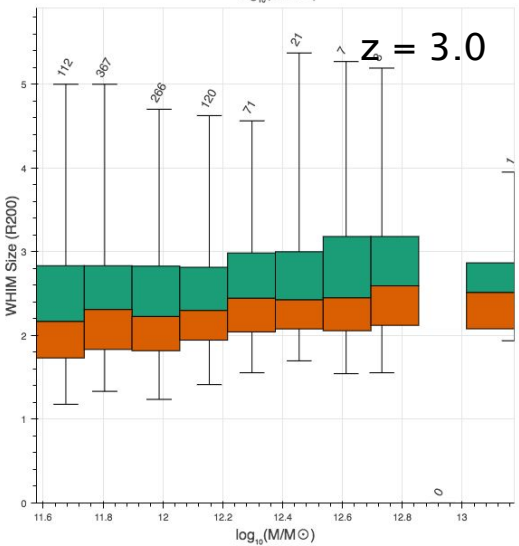


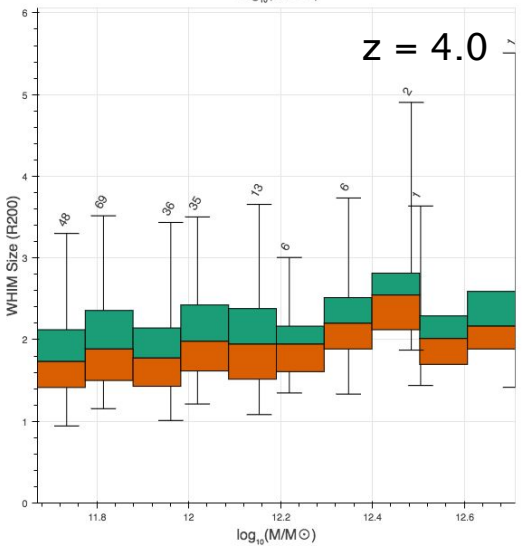

z = 0.5
WHIM Size (R200)
log10(M/M⊙)
2013
1219
753
351
206
100
56
22
10
6


z = 1.0
WHIM Size (R200)
log10(M/M⊙)
1866
1053
578
315
184
85
44
11
7
4


z = 2.0
WHIM Size (R200)
log10(M/M⊙)
857
701
463
220
139
64
15
3
2

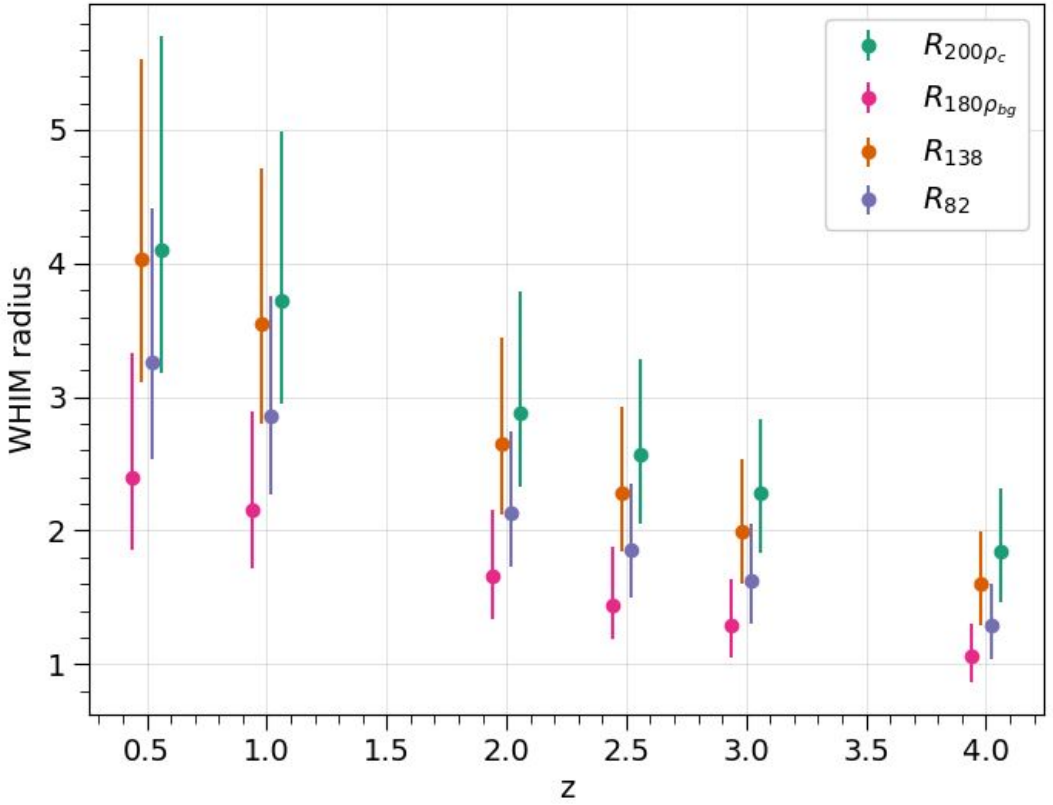

z = 2.5
WHIM Size (R200)
log10(M/M⊙)
539
403
297
199
91
38
13
4
2
1


z = 3.0
WHIM Size (R200)
log10(M/M⊙)
112
367
286
120
71
21
7
1
0


z = 4.0
WHIM Size (R200)
log10(M/M⊙)
48
69
36
35
13
6
6
2
1
1

WHIM Size vs. Redshift

- WHIM size scales with virial radius
- WHIM gets larger as structure forms



What sets WHIM size?

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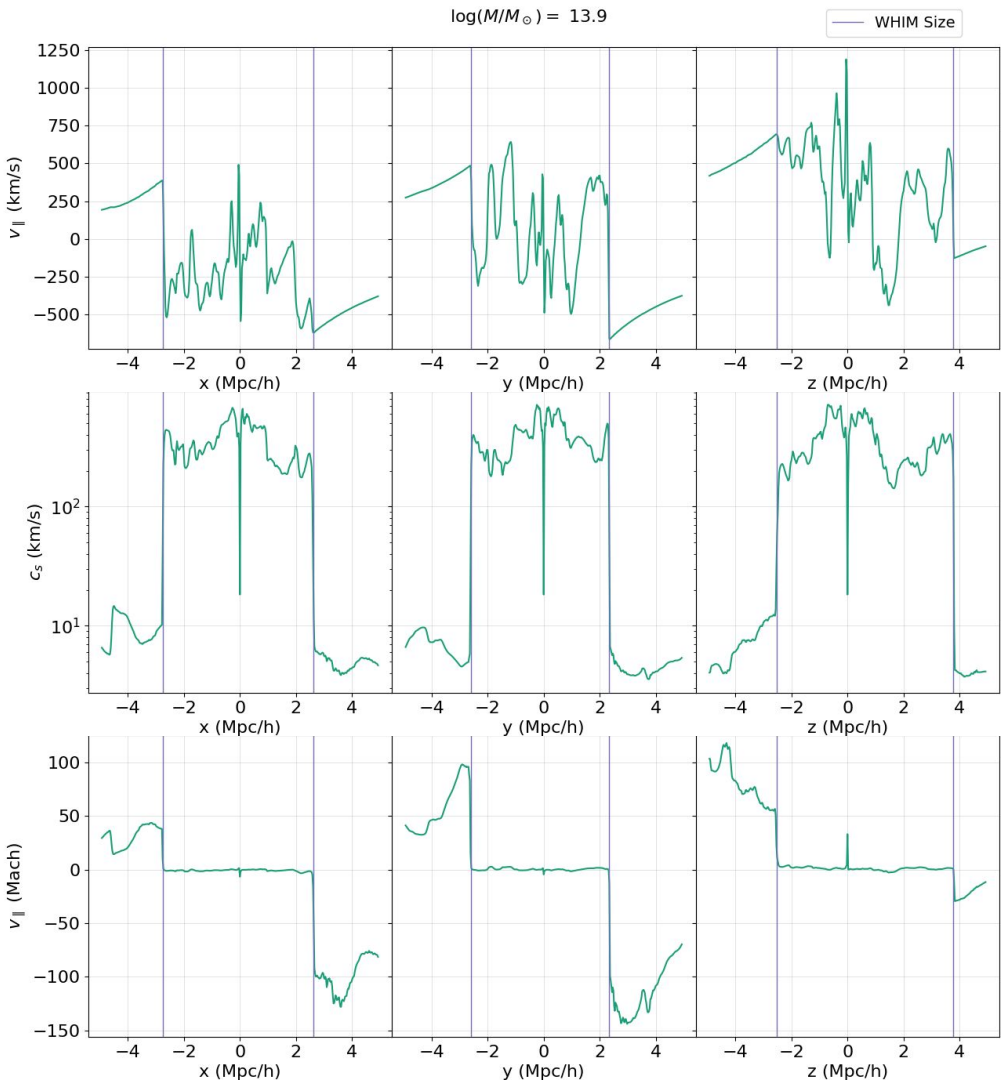
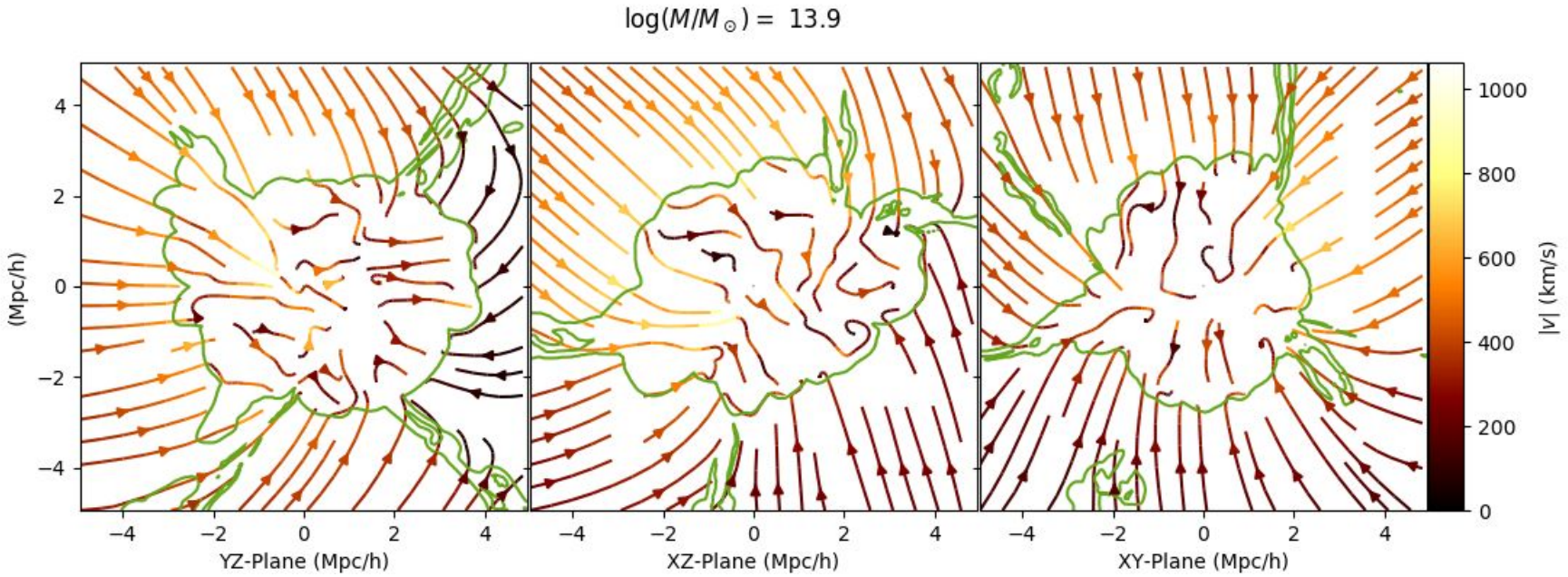
Gas Velocities

- Gas moves smoothly until WHIM radius
- Speed of sound increases inside WHIM radius since $c_s \sim \sqrt{T}$
- Gas streamlines collide at high Mach number and shocks heat gas



Gas Streamlines



- WHIM radius set by intersecting streamlines

Detecting WHIM

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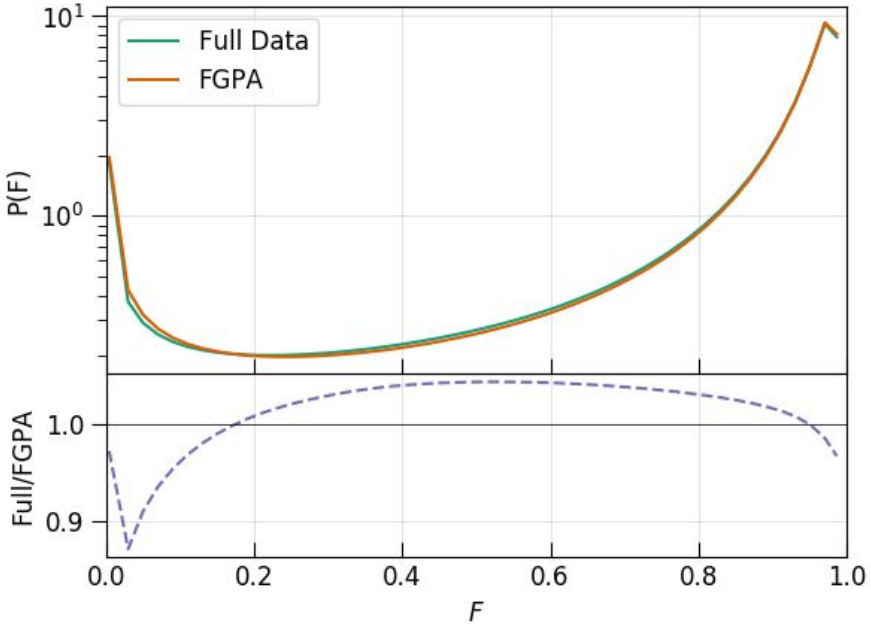
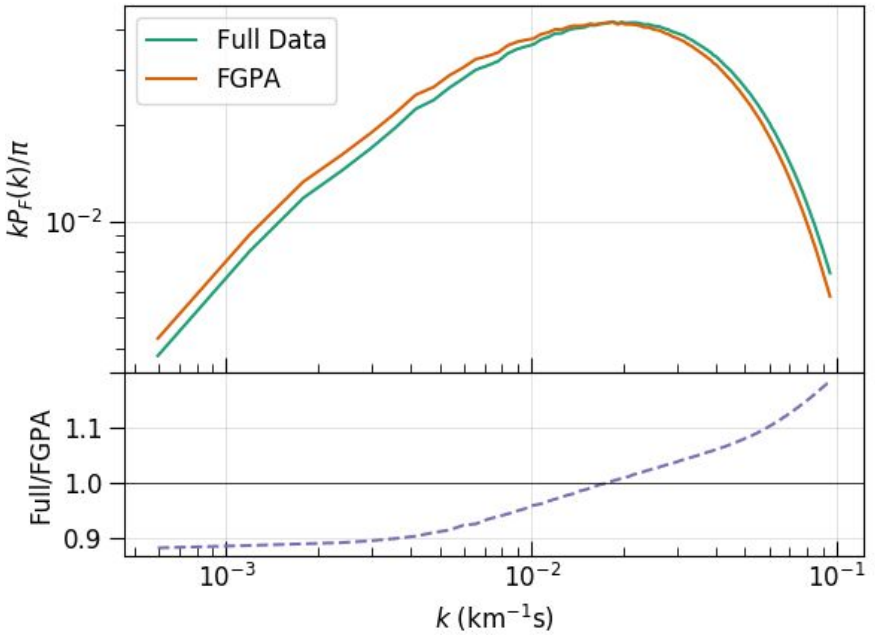
Detecting WHIM

PDF



1D Power Spectrum



Summary

- Mass fractions evolve over time: WHIM is ~0% at z=4 and ~20% at z=0.5
- Mass fractions in simulations have high variance
- WHIM radial size is roughly constant in units of virial radii
- WHIM size seems to be set by gas flow lines crossing at high Mach number
- May be able to detect WHIM through LyA observables

Thanks!

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Splashback Radius

- R_{sp} is defined as first minimum of:
  y = dlog(ρ)/dlog(r)
- WHIM seems to be at minimum also, but further out