circumgalactic gas as mediator of cosmic inflow

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12.5.2016

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Zoom simulations of 10^{12} halos to $z=2$

- at $\sim 10^4$ M_{sun} baryon resolution with AREPO
- [without outflows/AGN feedback]
- looking at: CGM structure, cosmological gas accretion
- [Monte Carlo] tracer particle analysis

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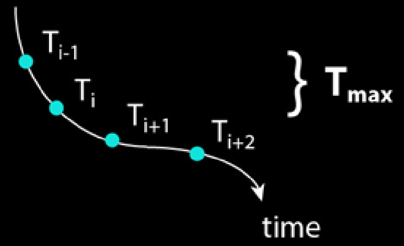
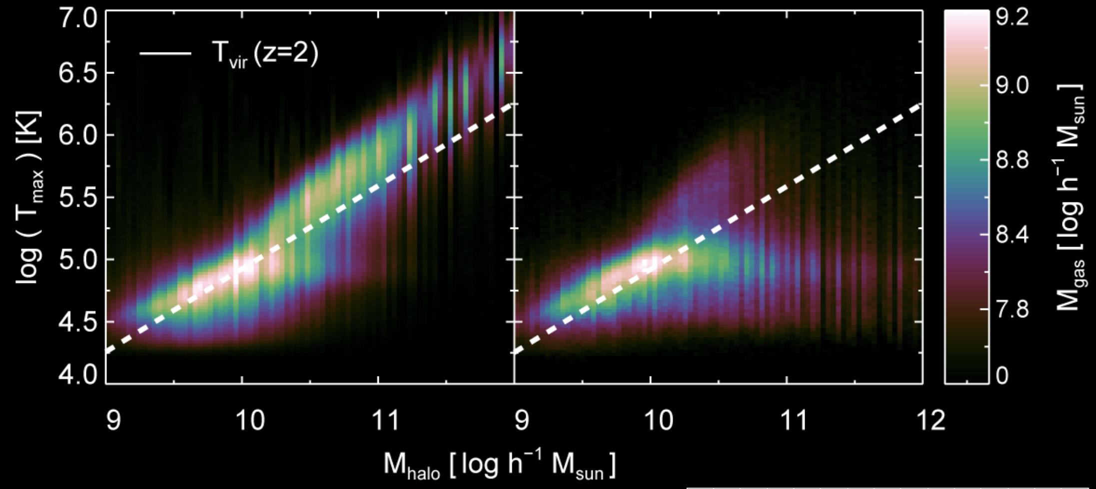
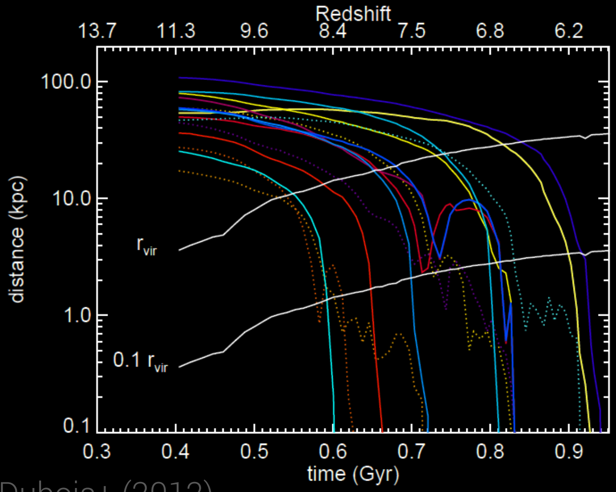


- For massive halos, no high T_{max} gas in the Gadget runs
- Approximate T_{vir} scaling in Arepo ('hot mode' dominant)

Nelson+ (2013) arepo (NEW) gadget (SPH) e.g. Keres+ (2005)



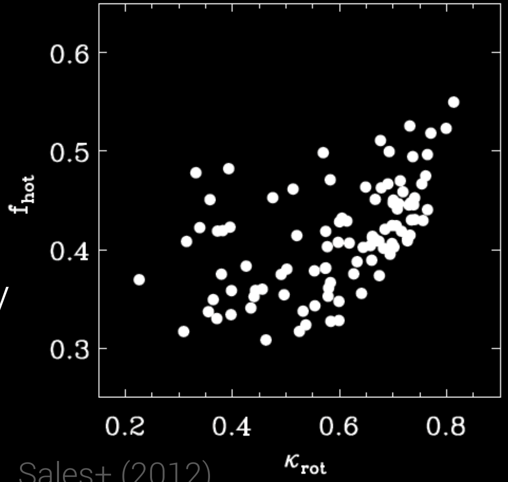


Dubois+ (2012)

Bulge and SMBH growth.

Motivation 1. Importance of cosmological gas accretion & the link to galaxy formation.

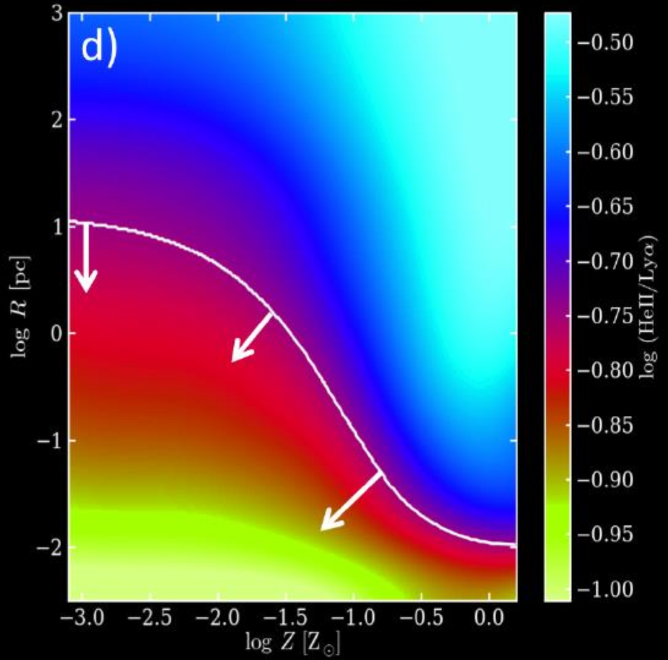
Disk-like morphology related to accretion mode.



Sales+ (2012)

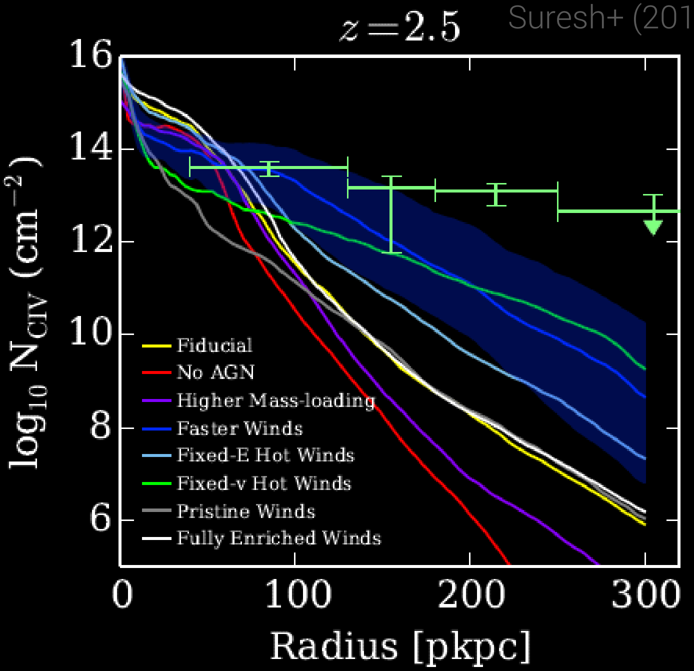
- High covering fractions of cold metal ions (M~12.5 at z~2)
- Origin unclear: high velocity outflows vs. cosmological inflows vs. (in situ condensation)?

Arrigoni Battaia+ (2015)

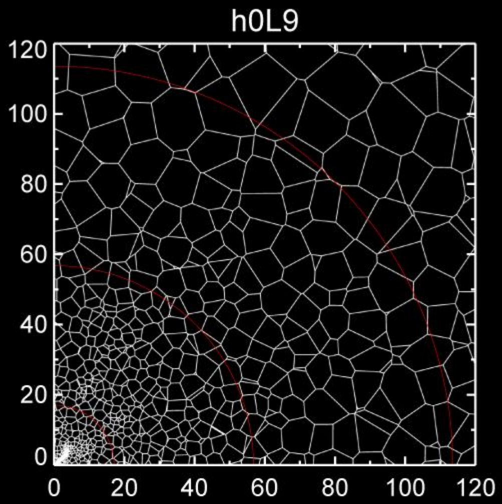


Motivation 2. Observational Interpretation & Constraints on Galaxy Formation Models

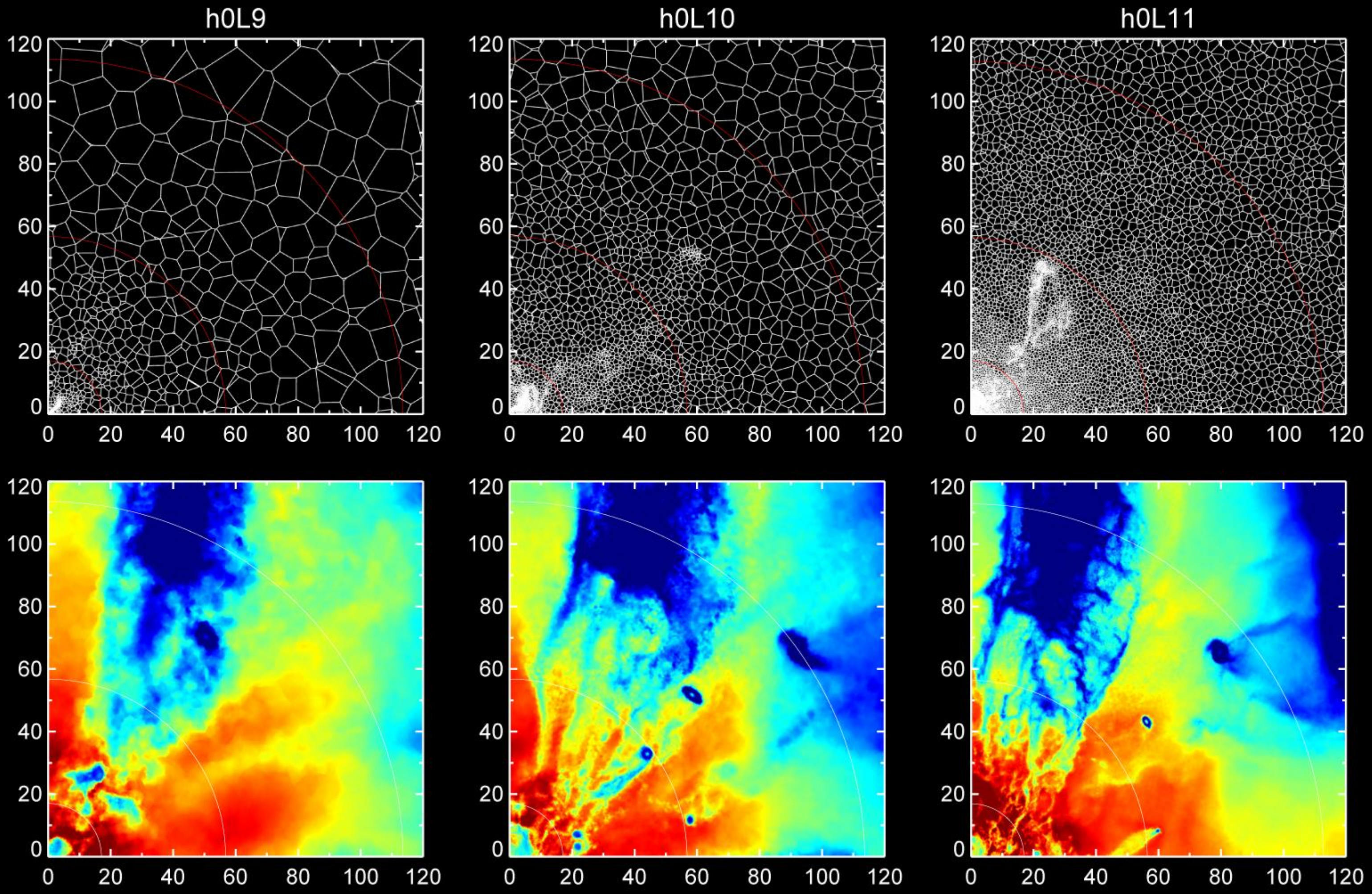
Suresh+ (2015)



- Problem: small size scale of absorbers
  - Photo-ionization estimates: sub-pc to 100s of pc
  - Similar: multi-sightline lensed QSOs (Rauch+ 2001, Petitjean+ 2000) for CIV, MgII



Illustris
Eagle
Nelson+ (2013)
...

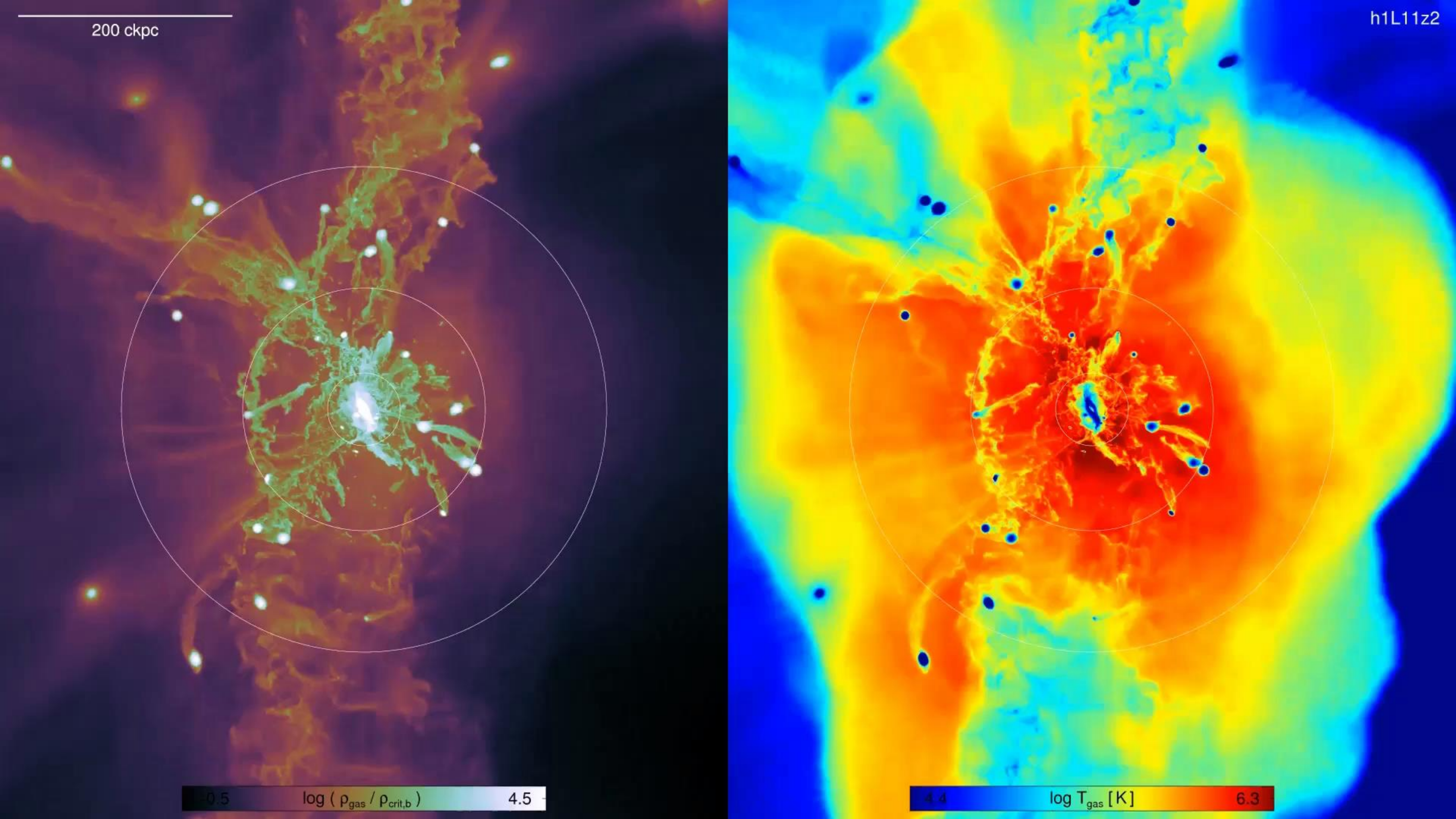


h0L9
h0L10
h0L11
0
20
40
60
80
100
120

Res	m_{baryon} [$M_\odot$]	m_{DM} [$M_\odot$]	$\epsilon_{grav}^{comoving}$ [pc]	$\epsilon_{grav}^{z=2}$ [pc]	r_{cell}^{min} [pc]	r_{cell}^{halo} [kpc]
L9	1.0×10^6	5.1×10^6	1430	480	31	2.7
L10	1.3×10^5	6.4×10^5	715	240	11	1.6
L11	1.6×10^4	8.0×10^4	357	120	3.3	0.8

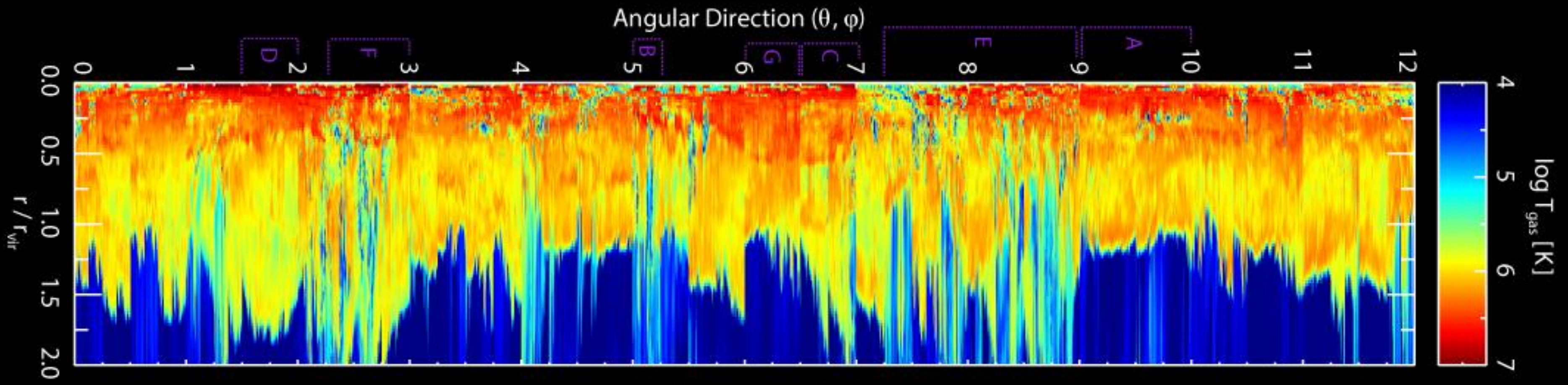
Halo #	M_{halo}^{par} [log $M_\odot$]	r_{vir}^{par} [kpc]	N_{HR}^{L11} [10^6]	r_{LR}^{min} [r_{vir}]dm	r_{LR}^{min} [r_{vir}]tr
h0	12.1	114	70.0	1.77	2.16
h1	12.1	104	66.7	2.12	2.75
h2	11.9	92	24.2	2.83	3.02
h3	11.9	96	33.9	2.74	3.23
h4	12.0	103	68.4	2.13	2.89
h5	12.0	103	59.9	1.04	1.04
h6	12.1	97	74.4	1.32	1.59
h7	11.9	94	52.8	0.94	1.93

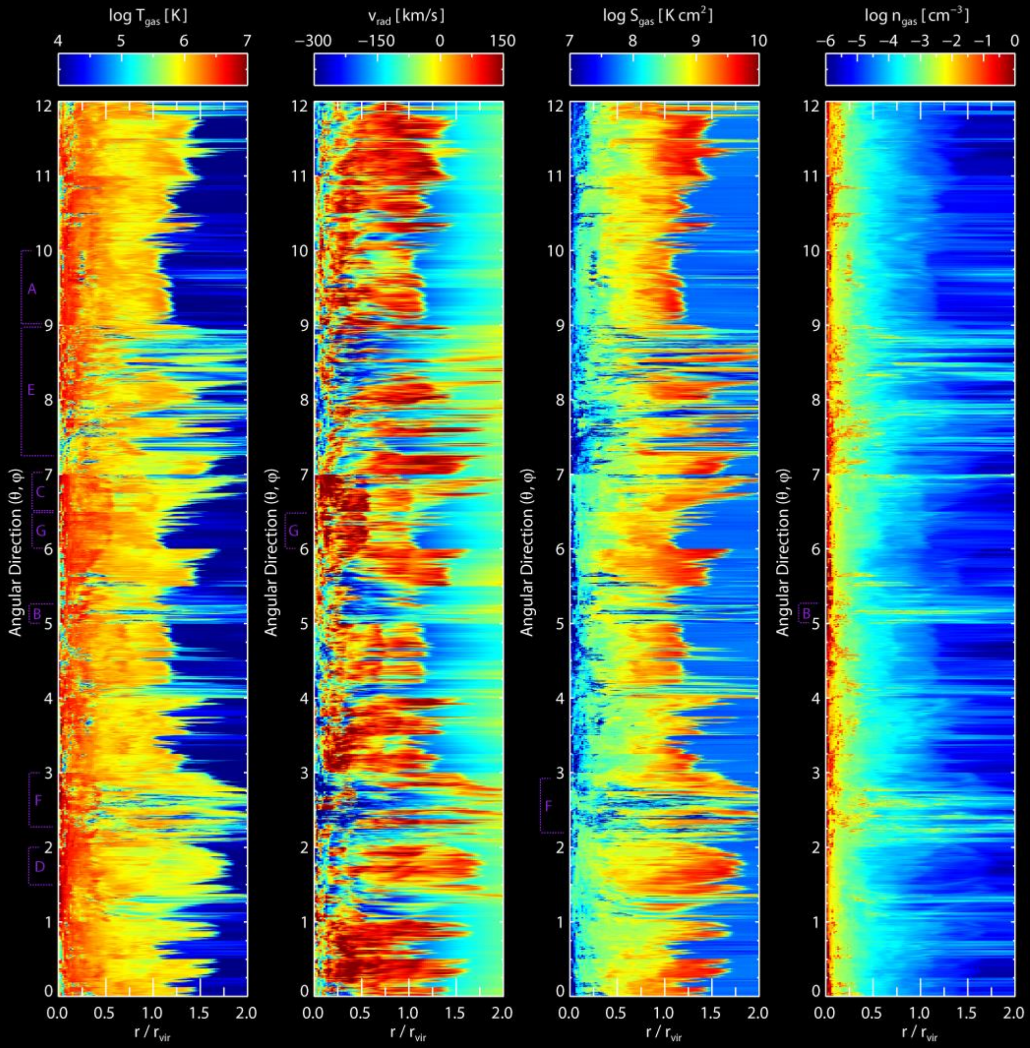
- Random halos
- Very simple physics:
- S&H03 ISM model
- KS stochastic SF (n~0.1 cm^{-3})
- No winds/resolved SF-FB
- No BHs/AGN FB
- Passive stellar enrichment only
- Primordial cooling network (+Rahmati SS) only
- Spatially uniform time-variable UVB heating (FG)



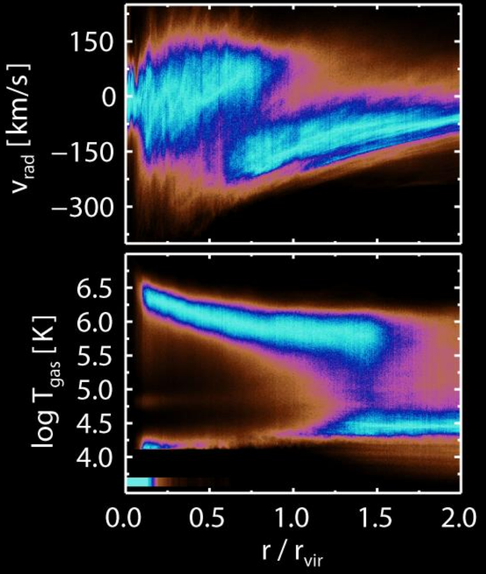
200 ckpc
h1L11z2
-0.5
log (ρgas / ρcrit,b)
4.5
4.4
log Tgas [K]
6.3

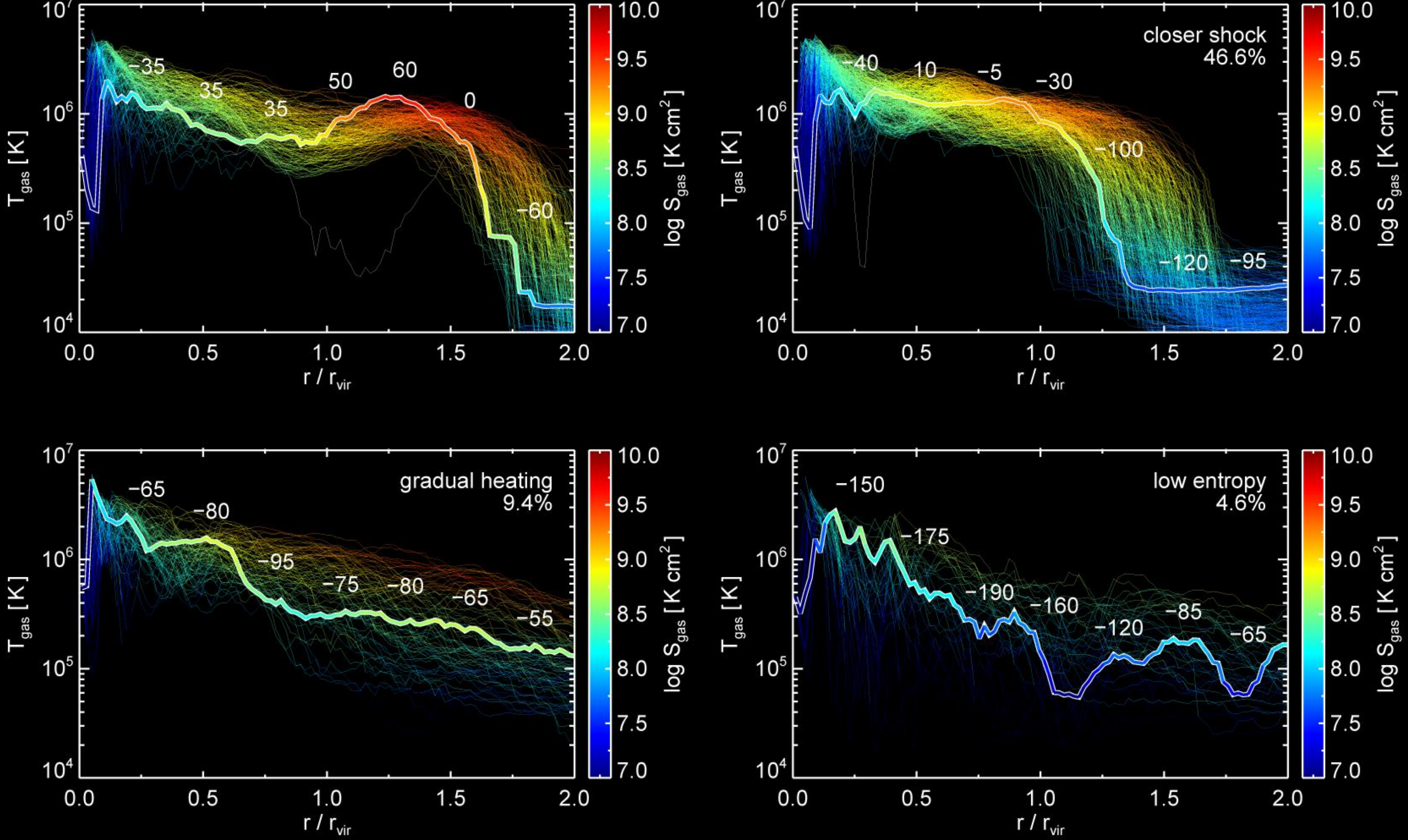
Radial sightline analysis to quantify the (instantaneous) angular structure of halo gas.



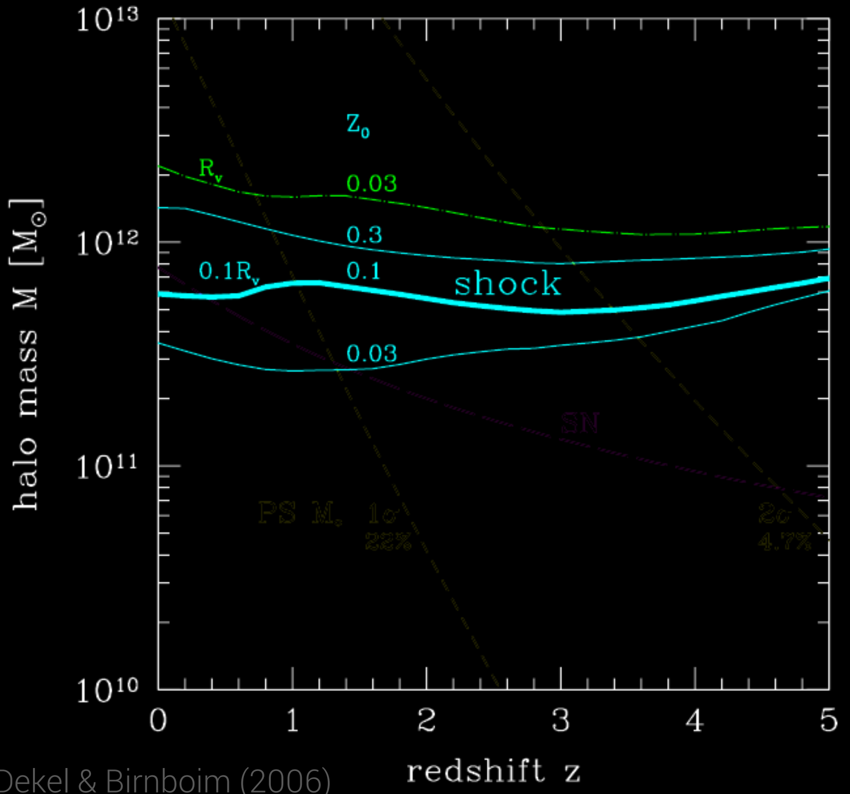


- Sharp temperature increases also associated with entropy jumps and radial stalling.
- Cold gas at smaller radii remains rapidly inflowing, associated with overdensities at > r_{vir}.
- Gradual/broad temperature falloff actually a superposition of very narrow shocks at rad(φ).




closer shock
46.6%
gradual heating
9.4%
low entropy
4.6%
-35
35
35
50
60
0
-60
-40
10
-5
-30
-100
-120
-95
-65
-80
-95
-75
-80
-65
-55
-150
-175
-190
-160
-120
-85
-65
T_{gas} [K]
r / r_{vir}
log S_{gas} [K cm^2]

We are in the ~transition regime where a 'stable' virial shock should exist co-incident with cold inflow at $r < r_{vir}$.

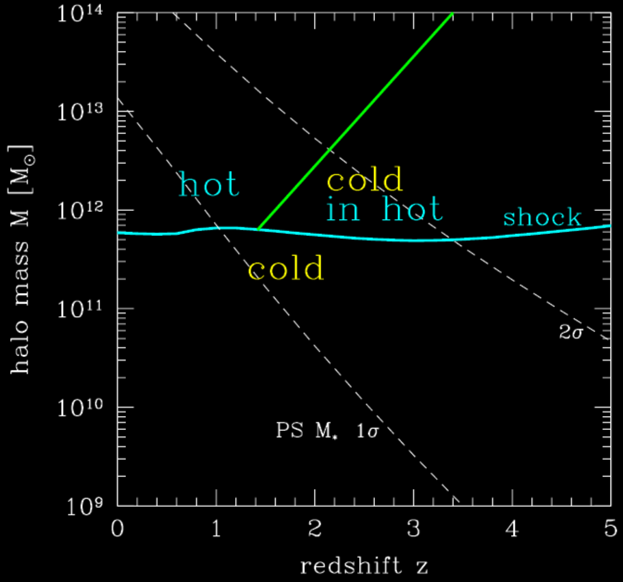


Dekel & Birnboim (2006)

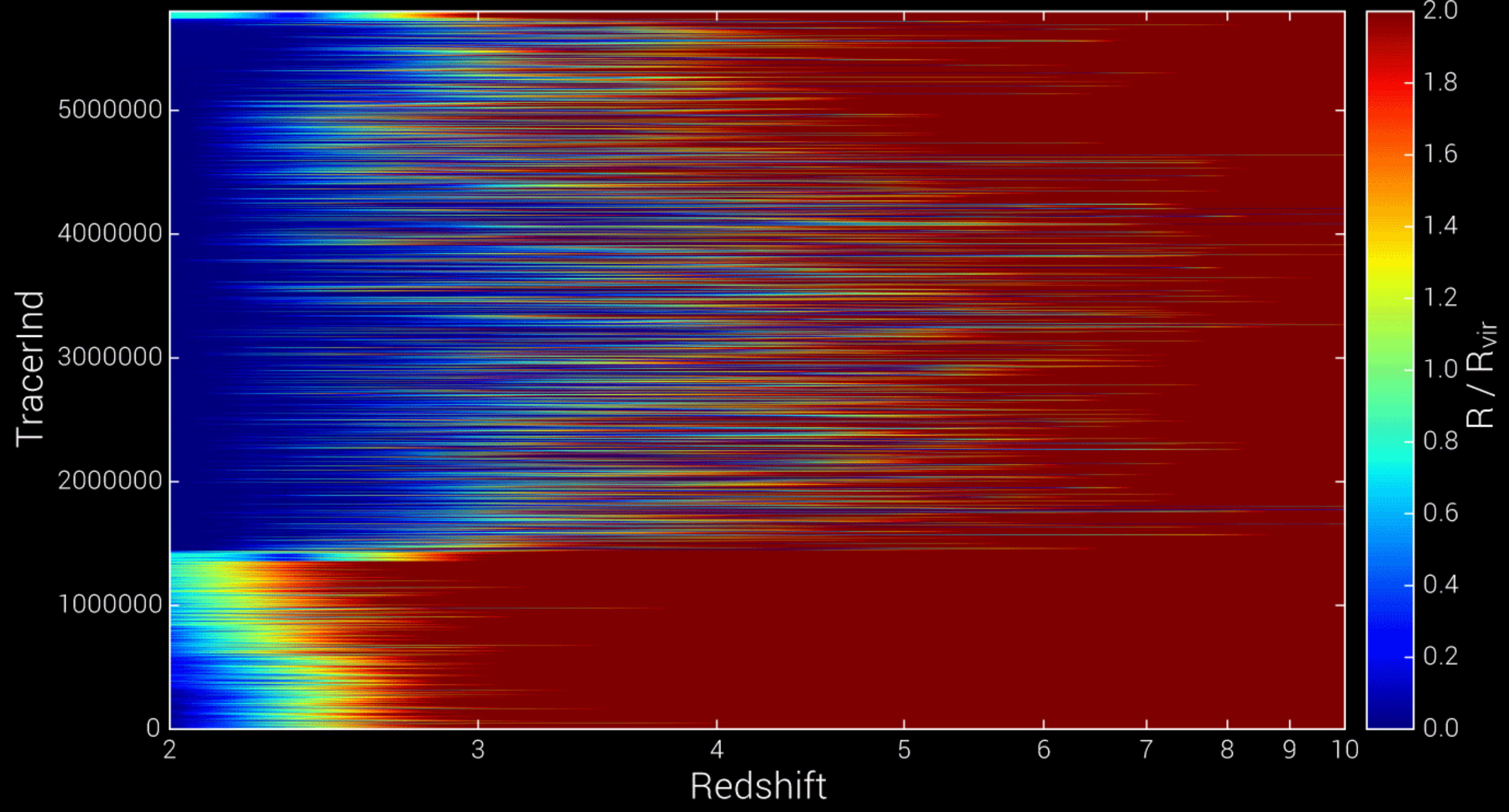
$$\frac{t_{\rm cool}}{t_{\rm comp}} \simeq 0.48 \, \frac{\rho_{-28}^{-1} T_6 \, \Lambda_{-22}^{-1}(T, Z)}{r_{\rm s} \, |u_0|^{-1} \, (1 - 3\tilde{u}_{\rm s})^{-1}} \simeq 1$$

(Timescale arguments): halo mass threshold.

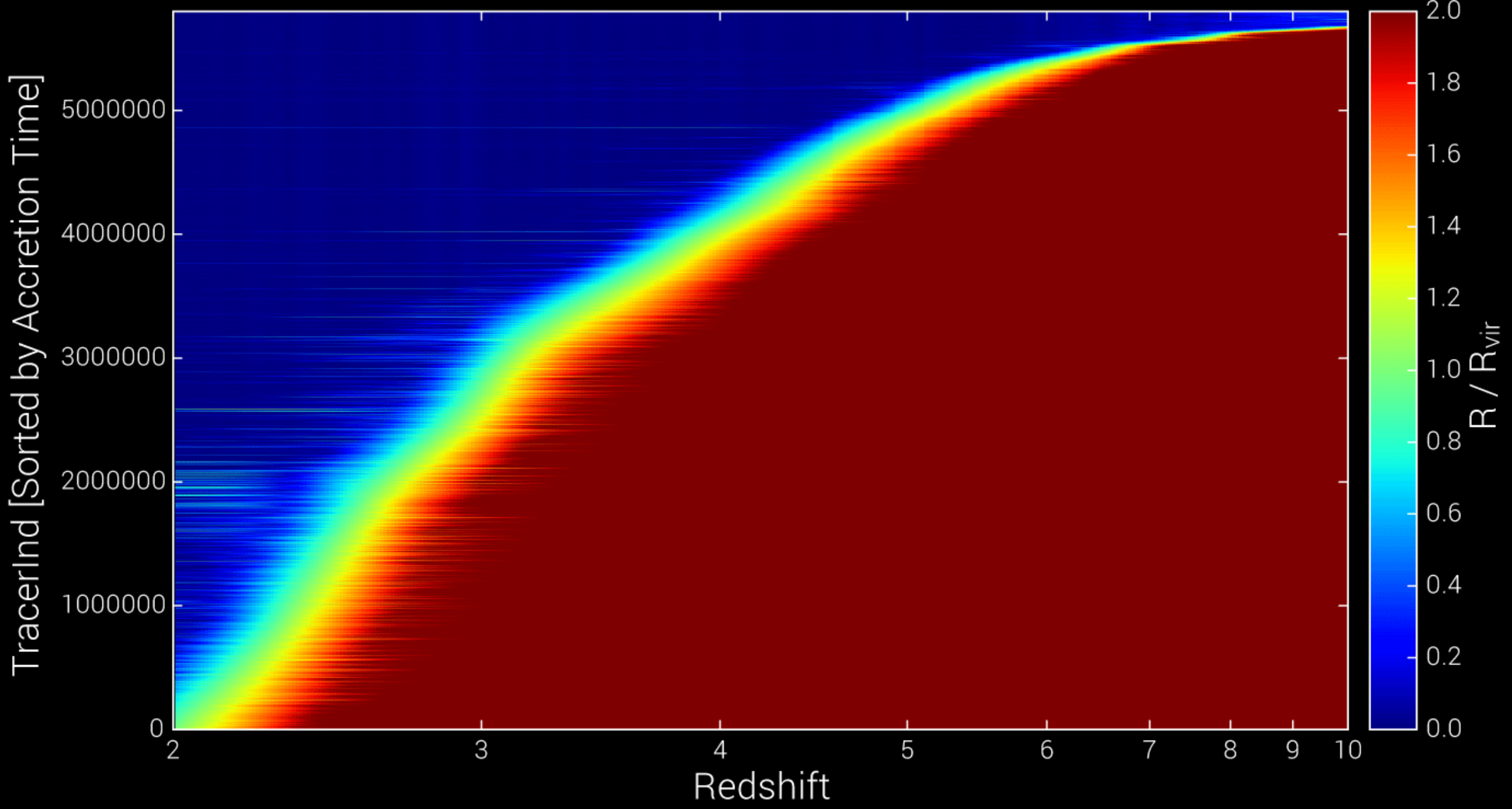
Given a stream density contrast:



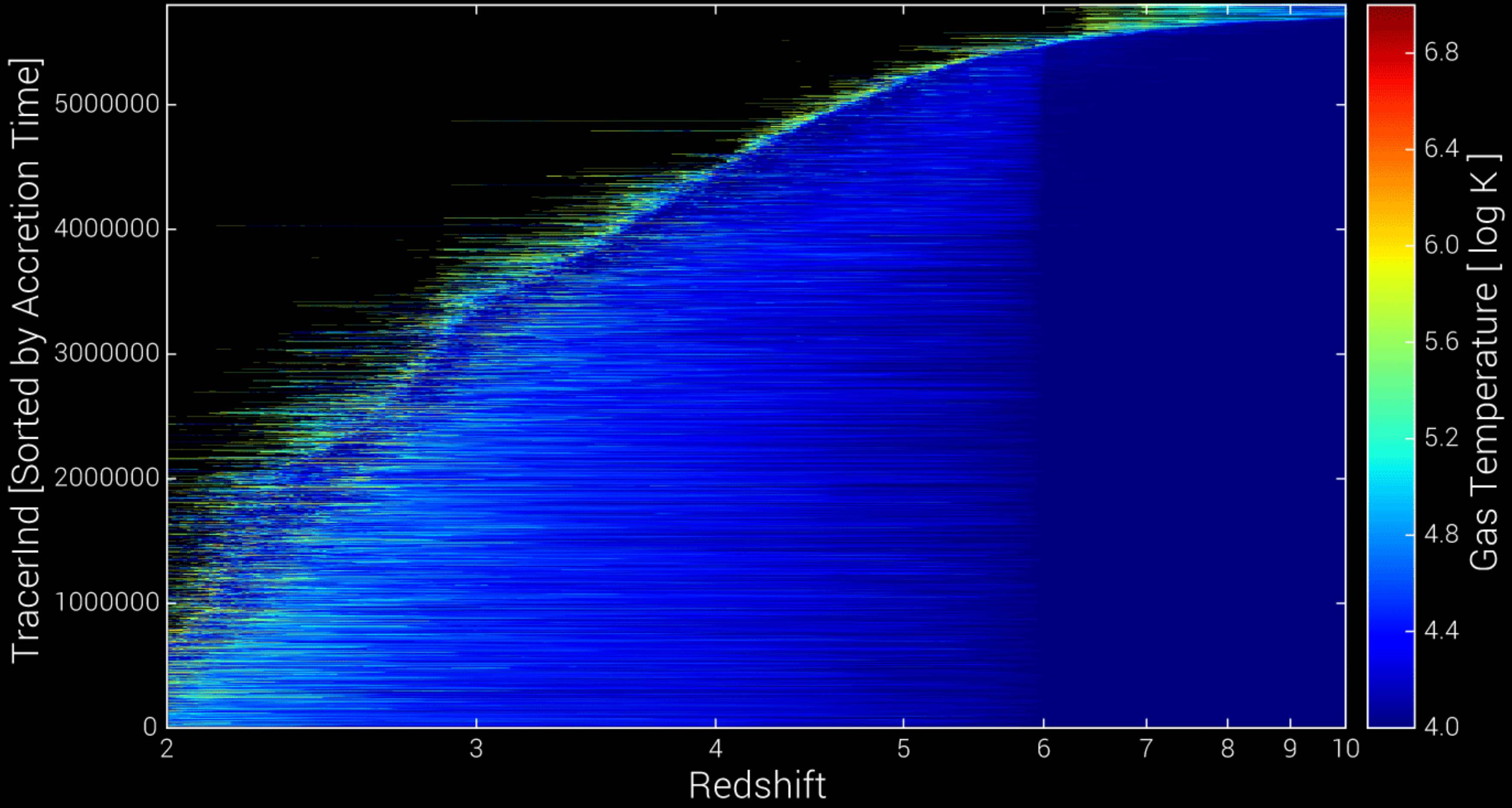
Time evolution tracks of all tracers in a halo at z=2.



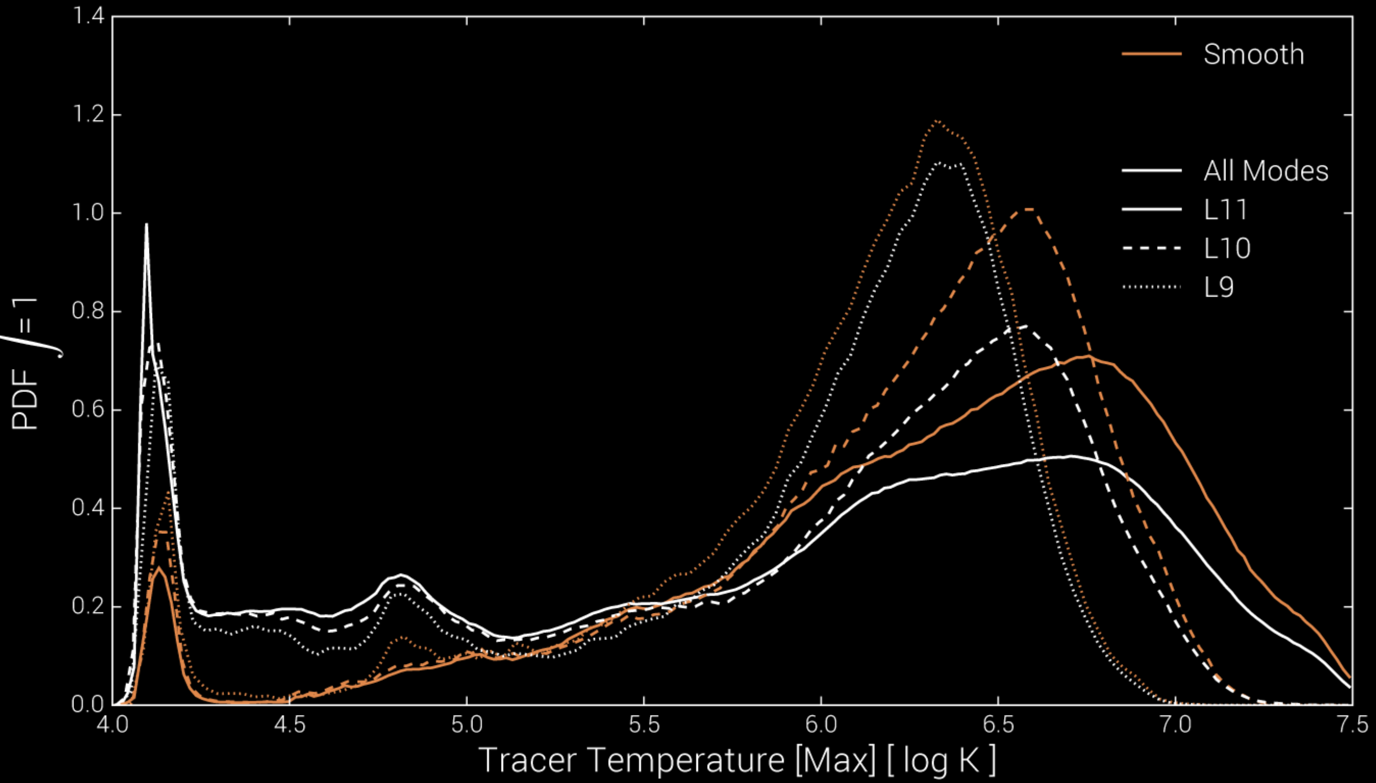
Time evolution tracks of all tracers in a halo at z=2.



Time evolution tracks of all tracers in a halo at z=2.



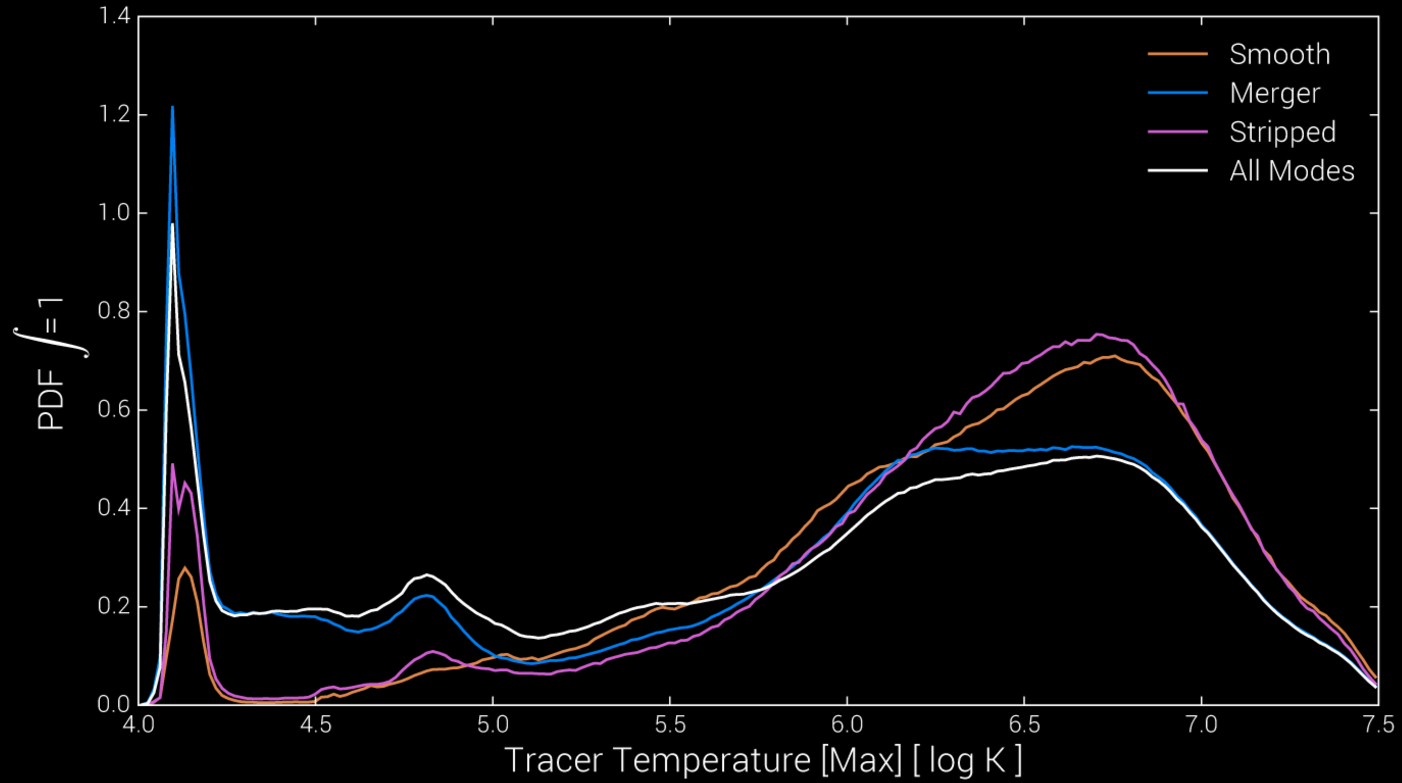
Broad distribution of past maximum temperatures, with a dominant peak centered at >~ the halo virial temperature.



Define an 'accretion mode' depending on group membership at $t<=t_{acc}$.

- Smooth accretion is more susceptible to high past temps.
- Convergence of heating history…

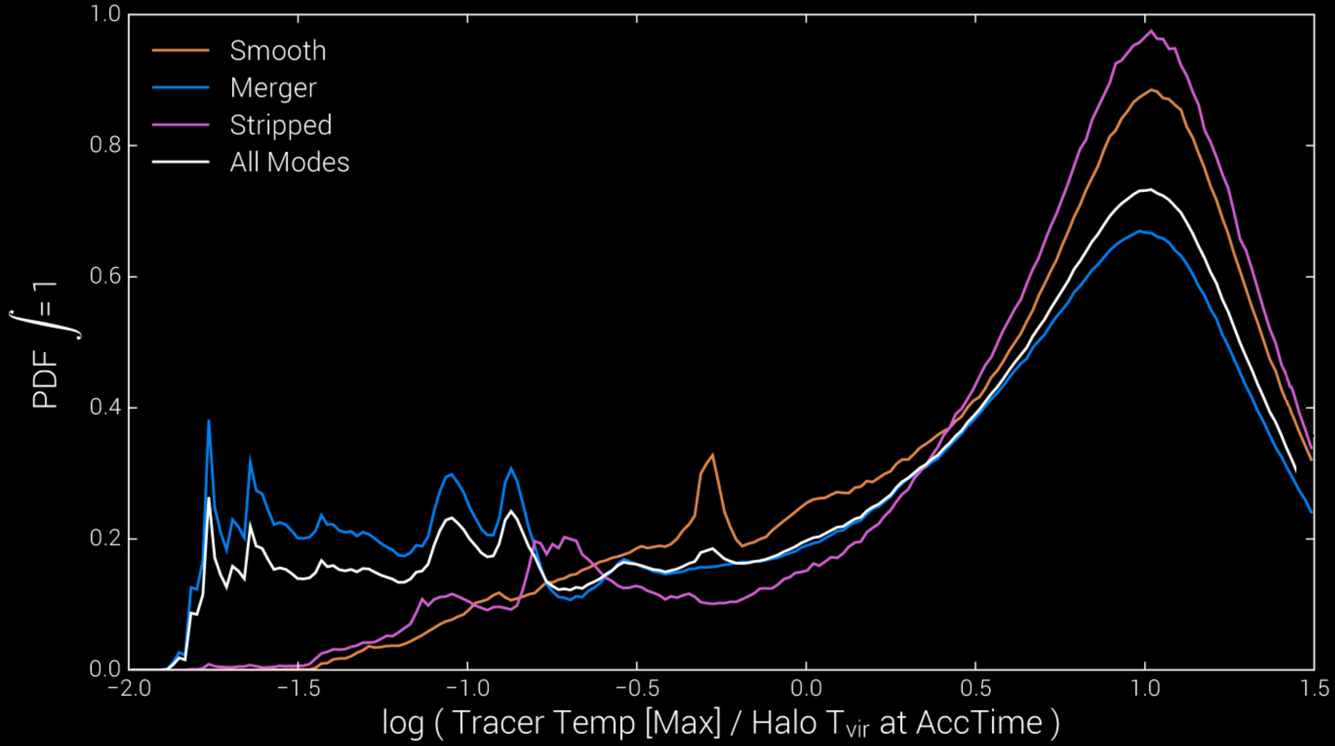
Broad distribution of past maximum temperatures, with a dominant peak centered at >~ the halo virial temperature.



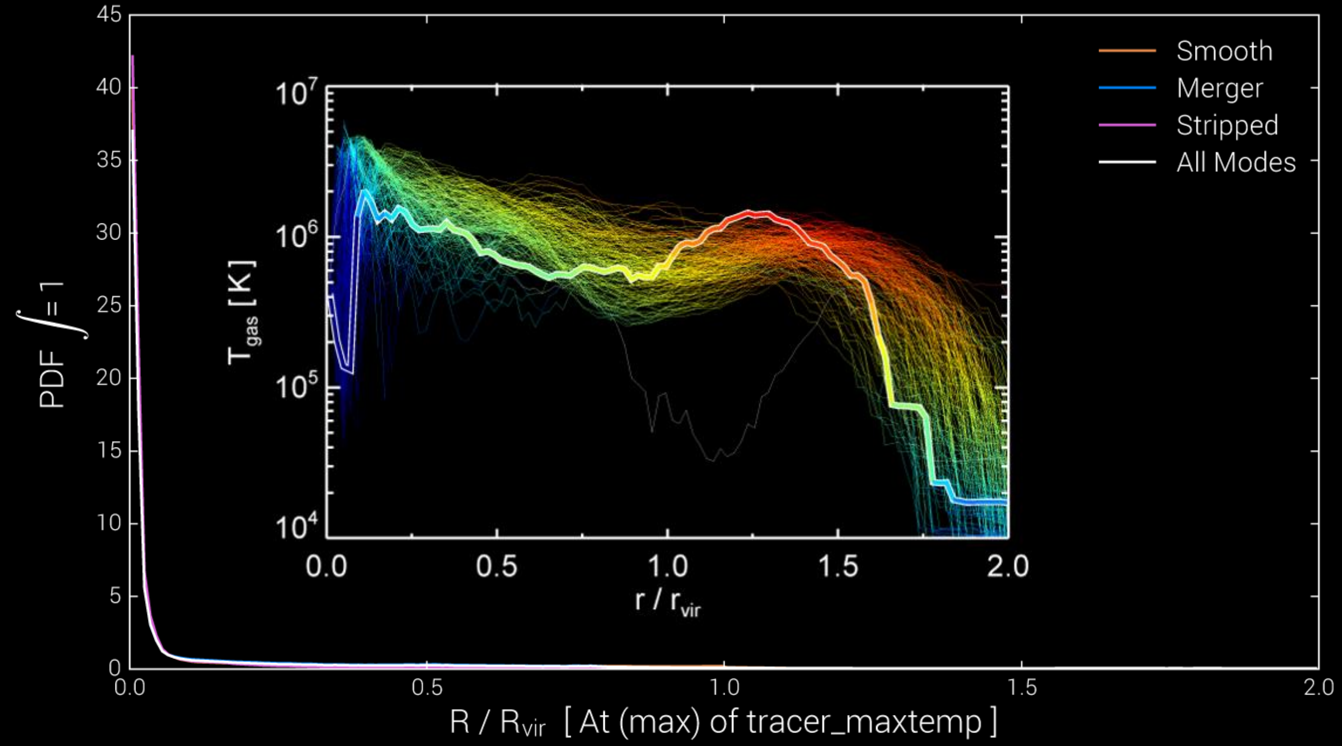
- Define an ‘accretion mode’ depending on group membership at $t \le t_{acc}$.
- Smooth accretion is more susceptible to high past temps.
- Convergence of heating history…
- Merger material has a higher fraction classified as ‘cold’.

Normalizing out both halo temperature and its time evolution.

- (For all gas which has entered the halo by z=2)
- Dominant peak at $>T_{vir}$ with long tail towards lower temperatures.
- Again: strong segregation by mode, protection from heating mostly in gas inflow via substructure.

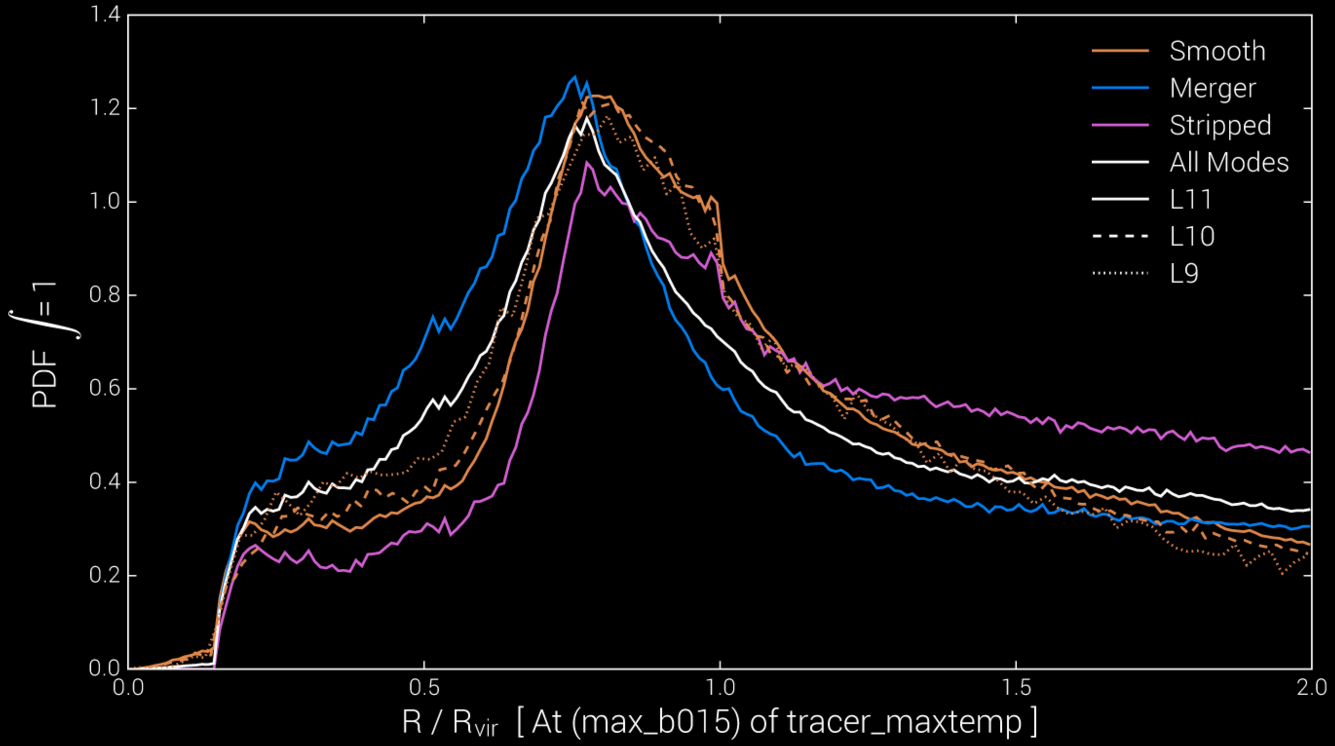


Where does the heating occur?



- Distribution peaks at the disk-halo interface.

Where does the heating occur?



- Distribution peaks at the disk-halo interface.
- Outside the galaxy: clear signature of a unimodal virial shock.
- Smooth accretion: somewhat broadened heating region at larger radii.

a few conclusions

- Resolution discrepancy in the halo vs. the galaxy presents a challenge.
- Coexistence of different gas components at the same radii, with the virial shock at ~resolution thickness but variable in r.
- Mixing layer at the disk-halo interface poorly convergent but dominates extrema of the gas thermal history.
- In the CGM: radii of T_{max} demonstrates most heating at $\sim r_{vir}$ independent of mode.

and directions

- If we want to understand (or interpret) the observed CGM…
  - No need to let collapse decide spatial resolution: adaptive (de-)refinement in the halo. (Suresh+ in prep)
- If we care more about the galaxies…
  - Moving beyond the 0^{th} order and stellar mass, gas state at >>r is enormously constraining.