(Very preliminary…)

Lya RT with CoDaII simulation

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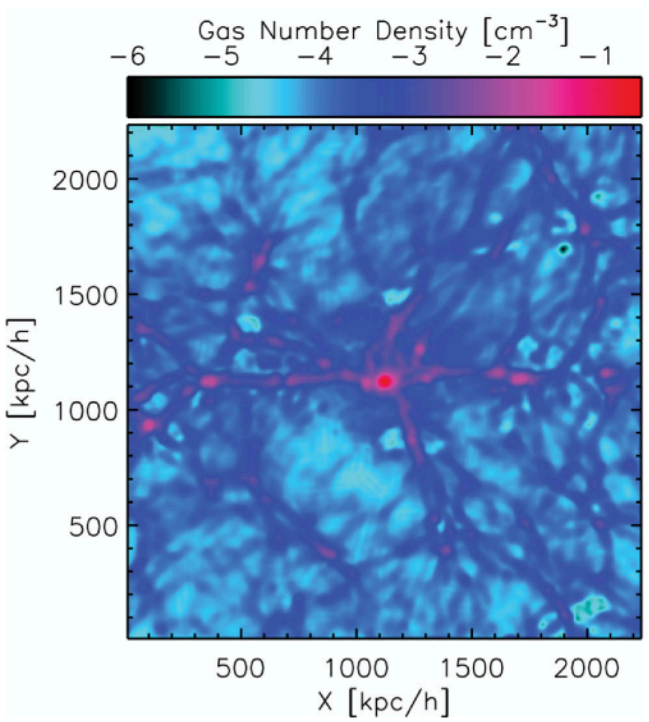
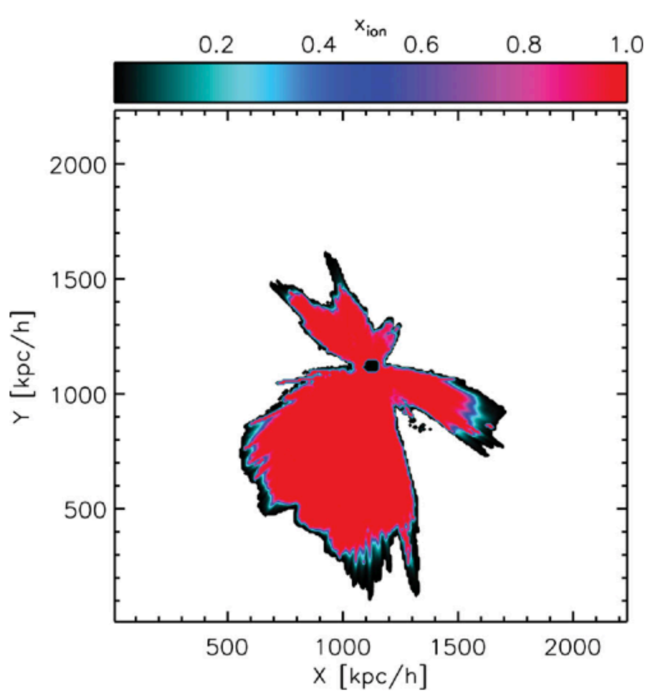
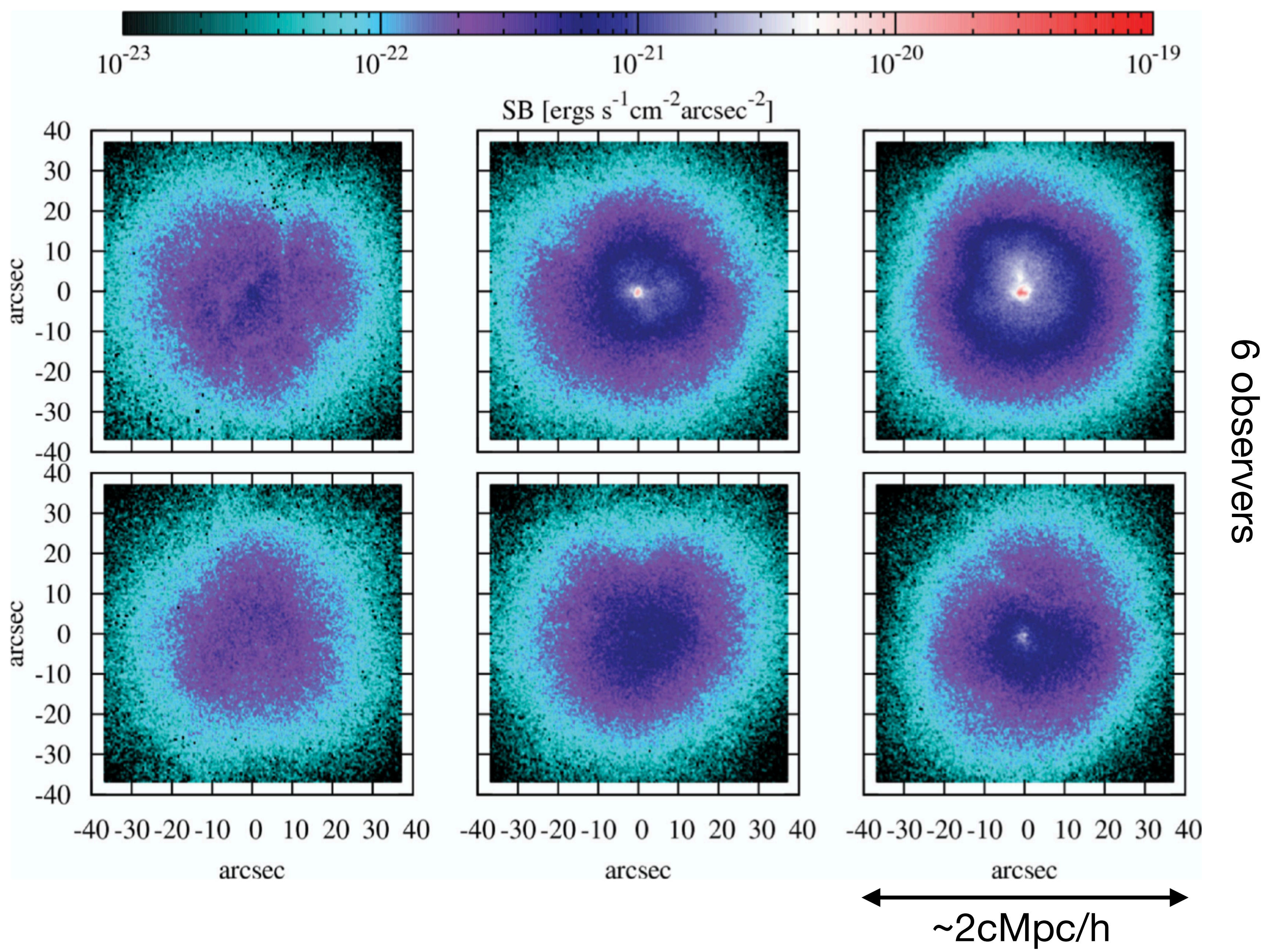
SPHINX-RASCAS-TRIPLE Online Workshop, 2, 4-5 Feb. 2021

Lya RT in Reionzation epoch



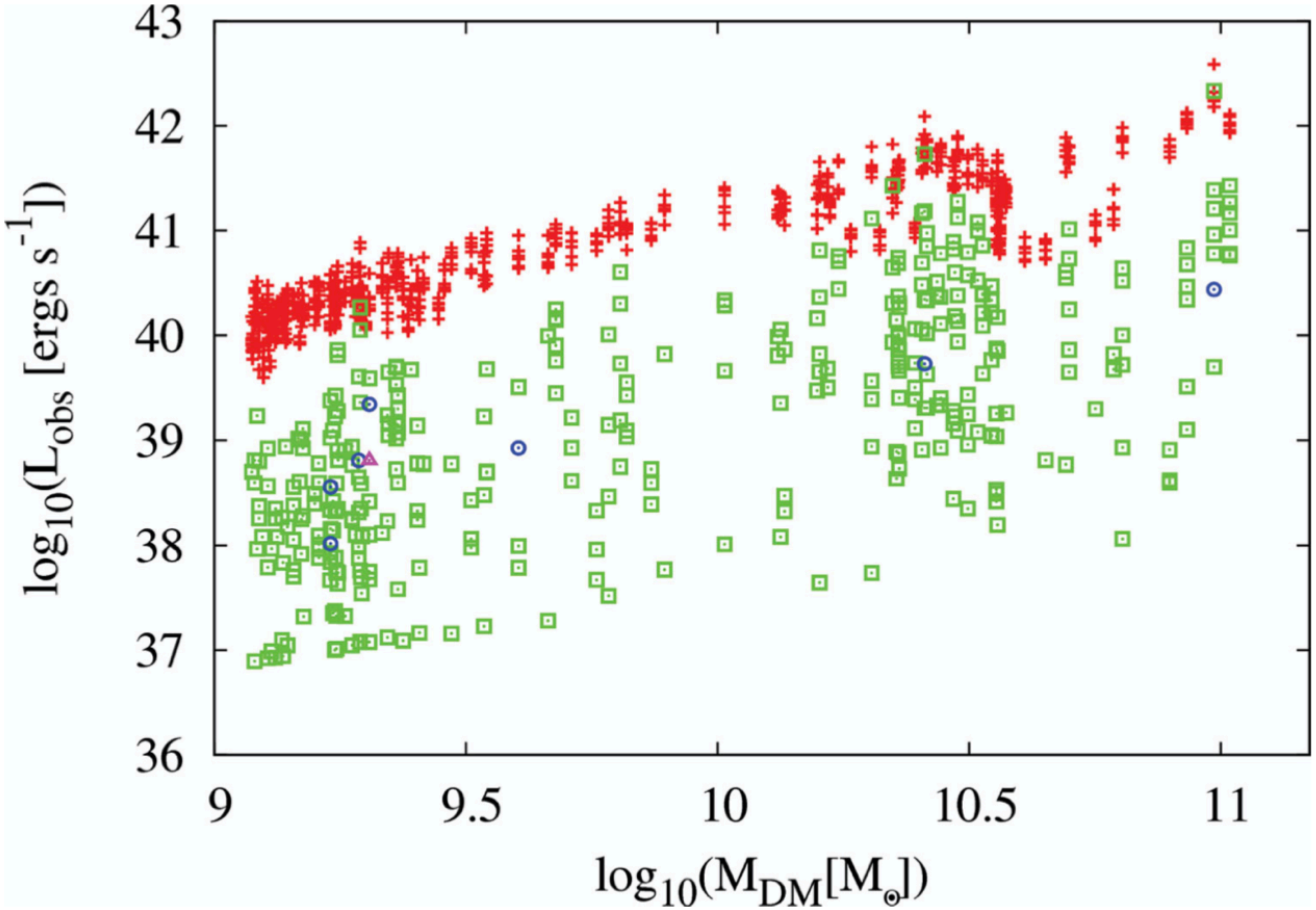




Jeeson-Daniel+(2012)

4.493kpc/arcsec at z=7.7

Lya RT in Reionzation epoch



Surface brightness cuts
1e-25 erg/s/cm²/arcsec²
1e-21
1e-20
5e-20

Jeeson-Daniel+(2012)

Ocvirk+(2020)

CosmicDawnII Simulation

Jeeson-Daniel+ (2012)

Table 1. Simulation properties. From left to right: model name; comoving box size, L; total number of particles (DM and gas); mass of DM particles, $m_{\rm DM}$; mass of gas particles, $m_{\rm gas}$; softening length, η.

Model	L (h^{-1} Mpc)	Number of particles	$m_{\rm DM}$ ($\mathrm{M}_\odot$)	$m_{\rm gas}$ ($\mathrm{M}_\odot$)	η (h^{-1} kpc)
L05	5	2×320^3	3.93×10^5	6.04×10^4	0.78
L10	10	2×320^3	3.14×10^6	4.83×10^5	1.56
L20	20	2×320^3	2.52×10^7	3.87×10^6	3.13
L30	30	2×320^3	8.49×10^7	1.30×10^7	4.69

Cosmological hydrodynamic simulation (SPH)

Ocvirk+(2020) CoDaII

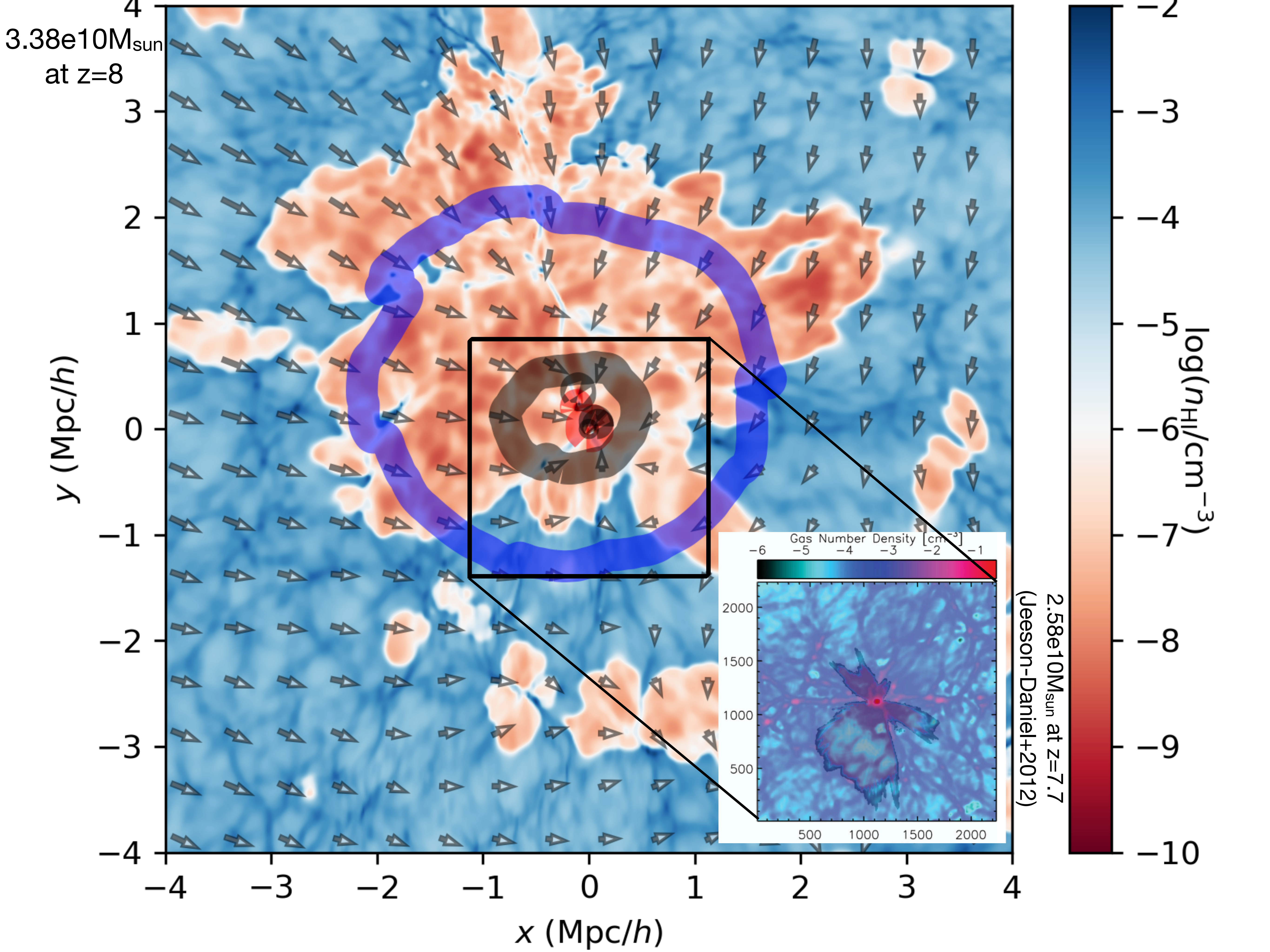
Setup	
Number of nodes (GPUs, cores used)	16384 (16384, 65536)
Grid size	4096^3
Comoving box size $\mathrm{L_{box}}$	94.44 Mpc (64 $\mathrm{h^{-1}}$Mpc)
Grid cells per node	128x128x64
Comoving force resolution dx	23.06 kpc
Physical force resolution at z=6	3.3 kpc
DM particle number N_{DM}	4096^3
DM particle mass M_{DM}	4.07 x 10^5 $\mathrm{M}_\odot$
Average cell gas mass	0.75 x 10^5 $\mathrm{M}_\odot$
Initial redshift z_{start}	150
End redshift z_{end}	5.8

Cosmological *radiation-*hydrodynamic simulation (unigrid)

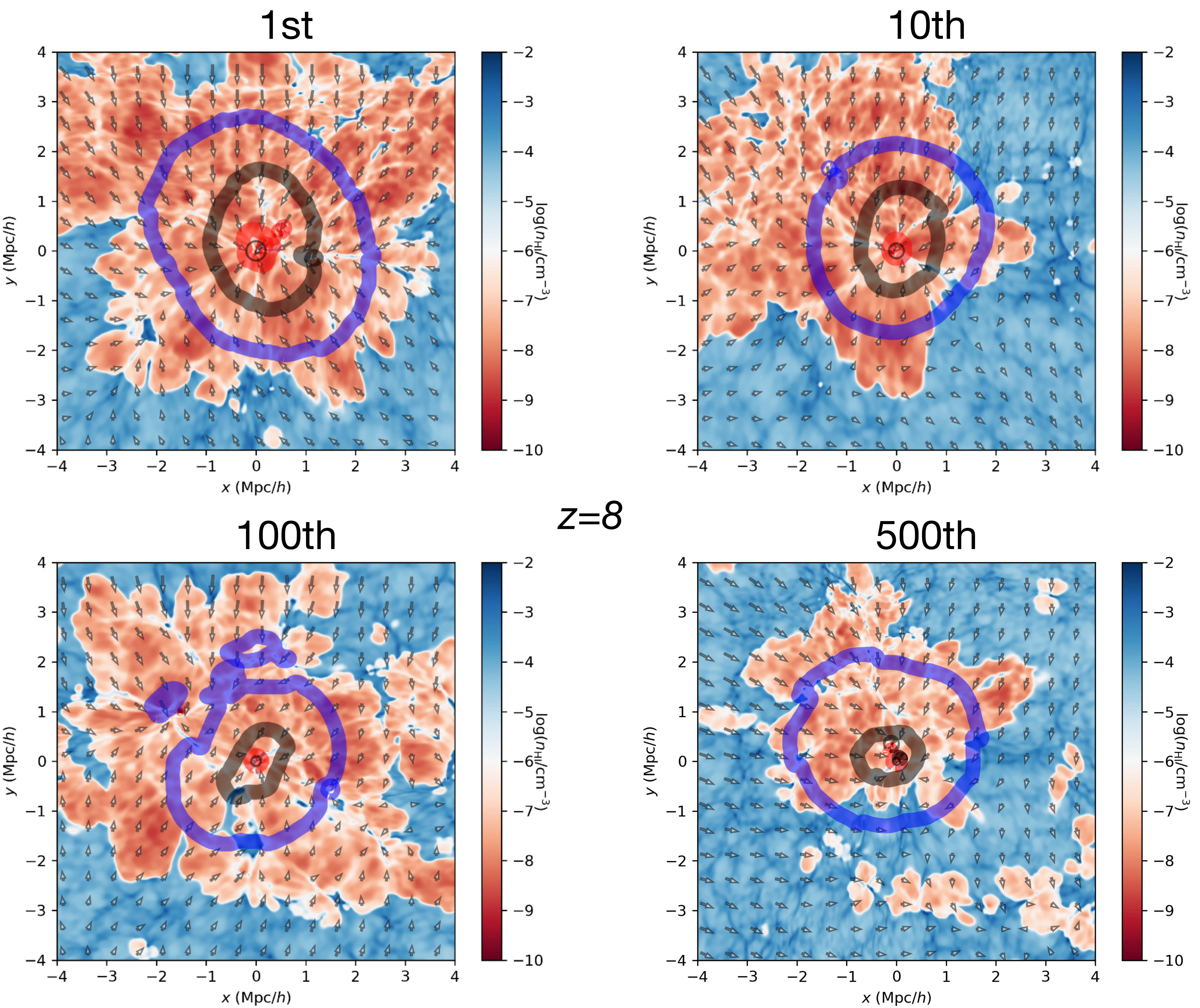
More realistic realization of the Universe

Lya RT with CoDaII simulation

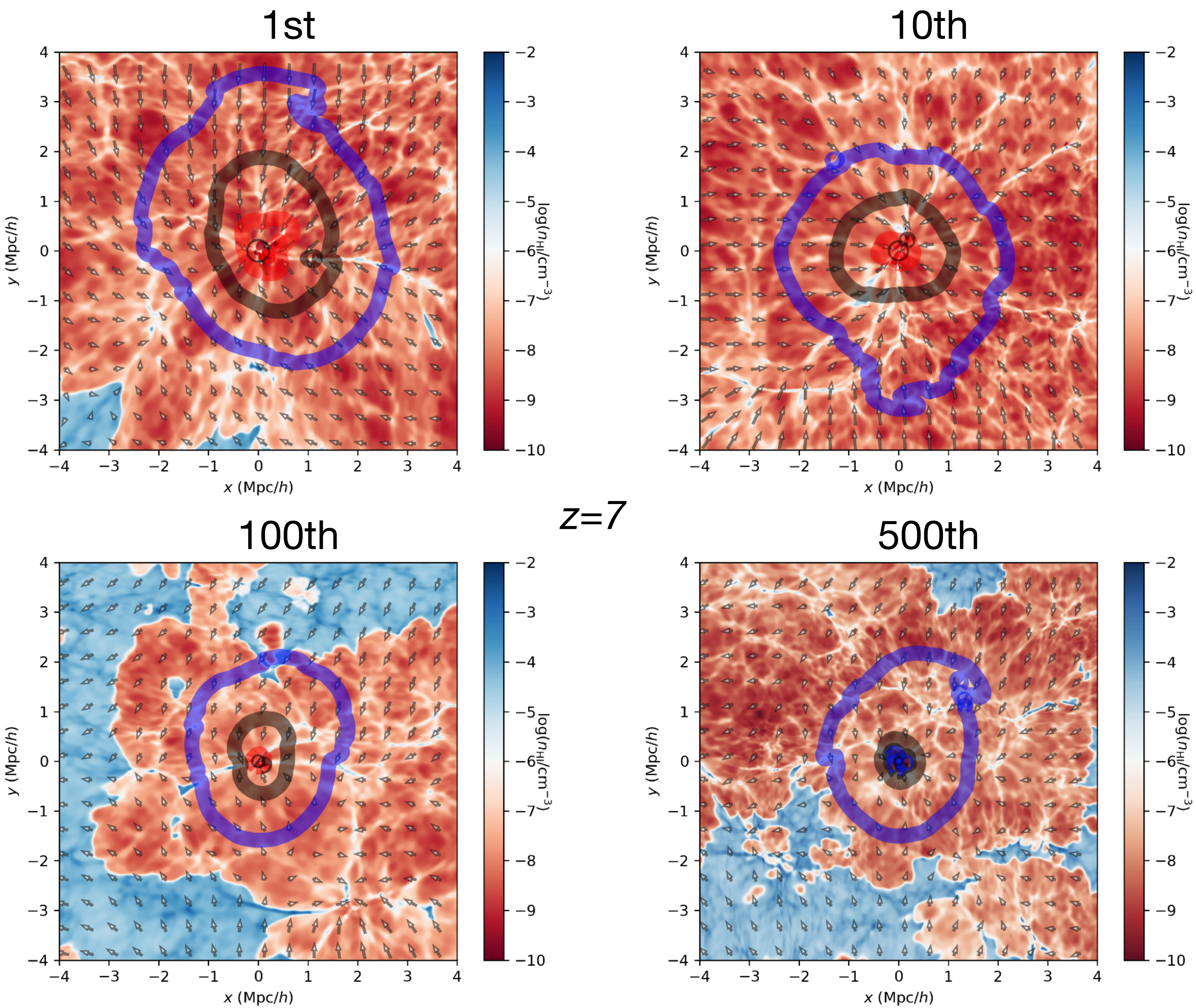
- Larger cosmological volume
    - Larger halo mass range
    - Larger spatial extent around halos
- Higher resolution for IGM
    - Regular grid better for RT (cf. SPH)
- Redshift evolution
    - z=8, 7, 6

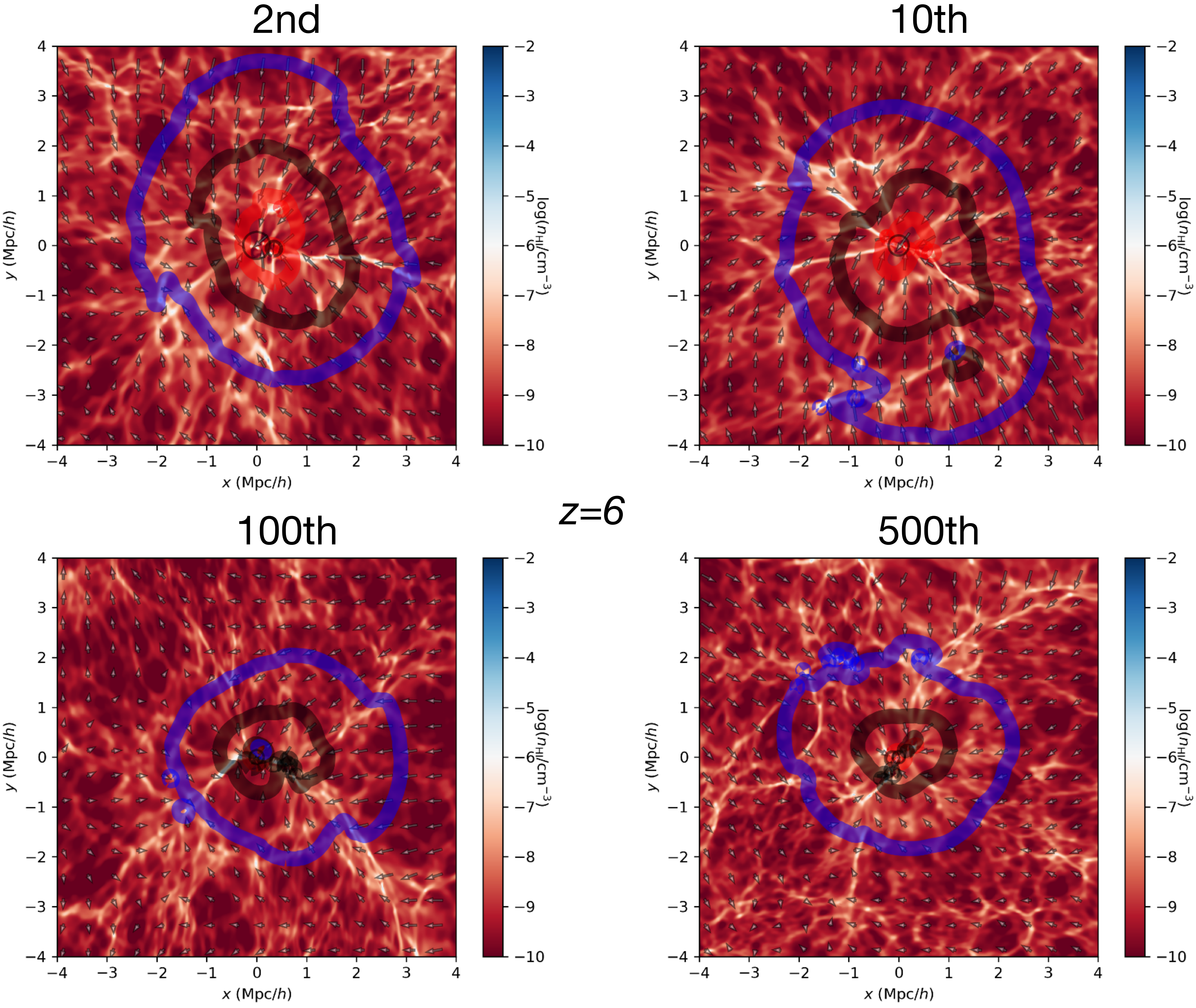


3.38e10Msun
at z=8
y (Mpc/h)
x (Mpc/h)
log(n_{HI}/cm^{-3})
Gas Number Density [cm^{-3}]
2.58e10Msun at z=7.7
(Jeeson-Daniel+2012)



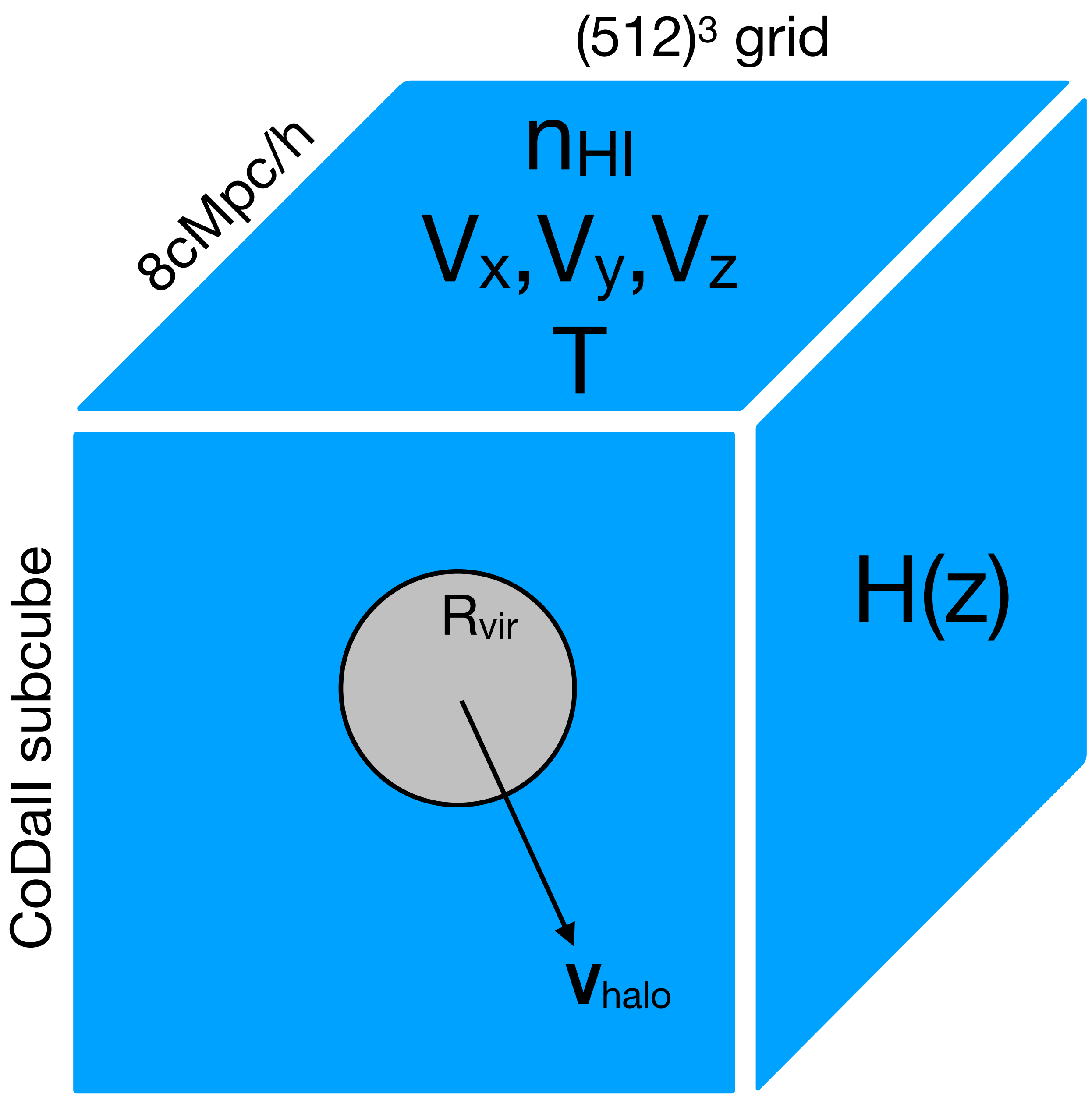
1st
10th
100th
500th
z=8
x (Mpc/h)
y (Mpc/h)
log(n_HI/cm^-3)


1st
10th
100th
500th
z=7
x (Mpc/h)
y (Mpc/h)
log(n_HI/cm^-3)
4
3
2
1
0
−1
−2
−3
−4
−2
−3
−4
−5
−6
−7
−8
−9
−10

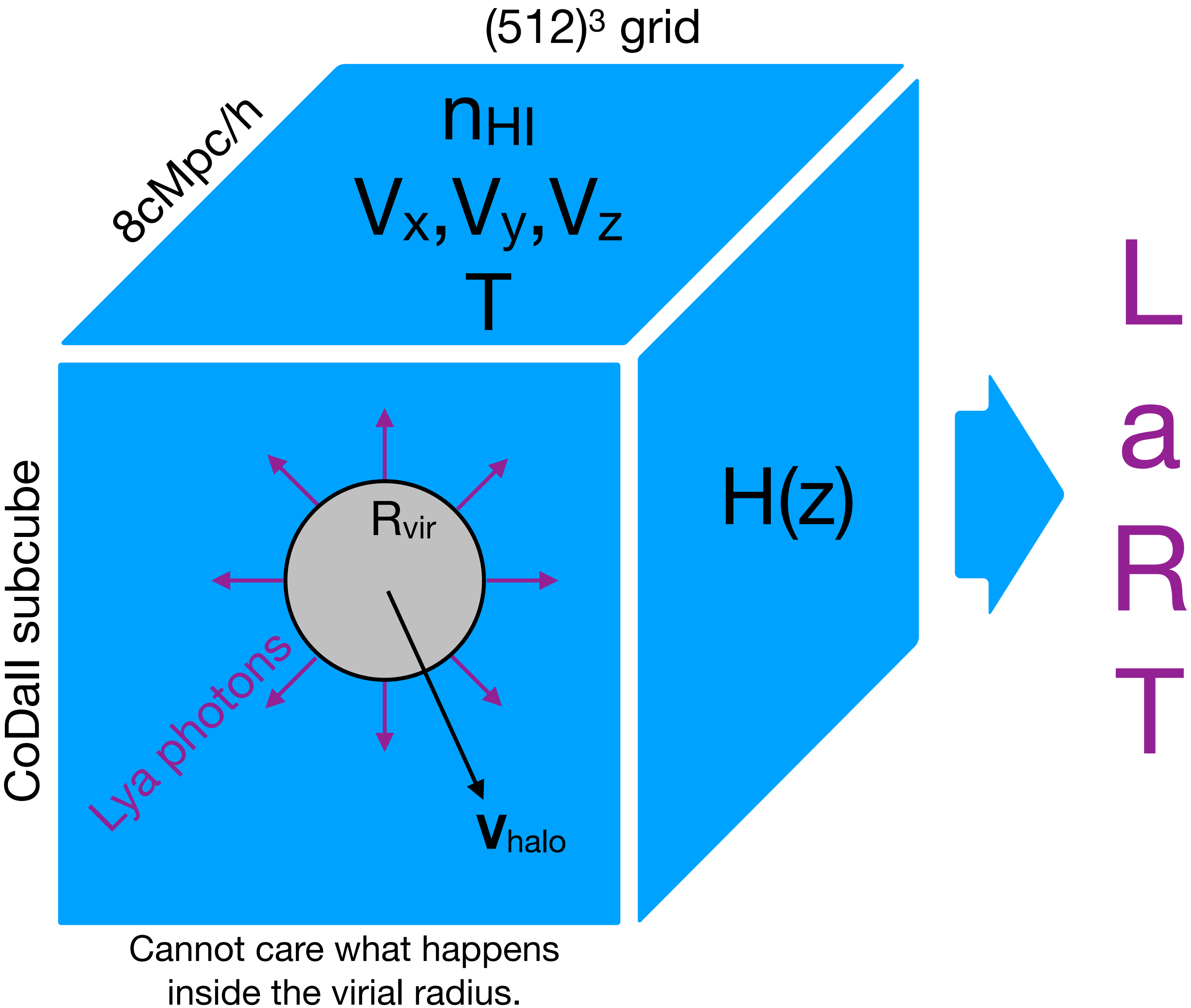

2nd
10th
100th
500th
z=6
x (Mpc/h)
y (Mpc/h)
log(n_HI/cm^-3)

LaRT

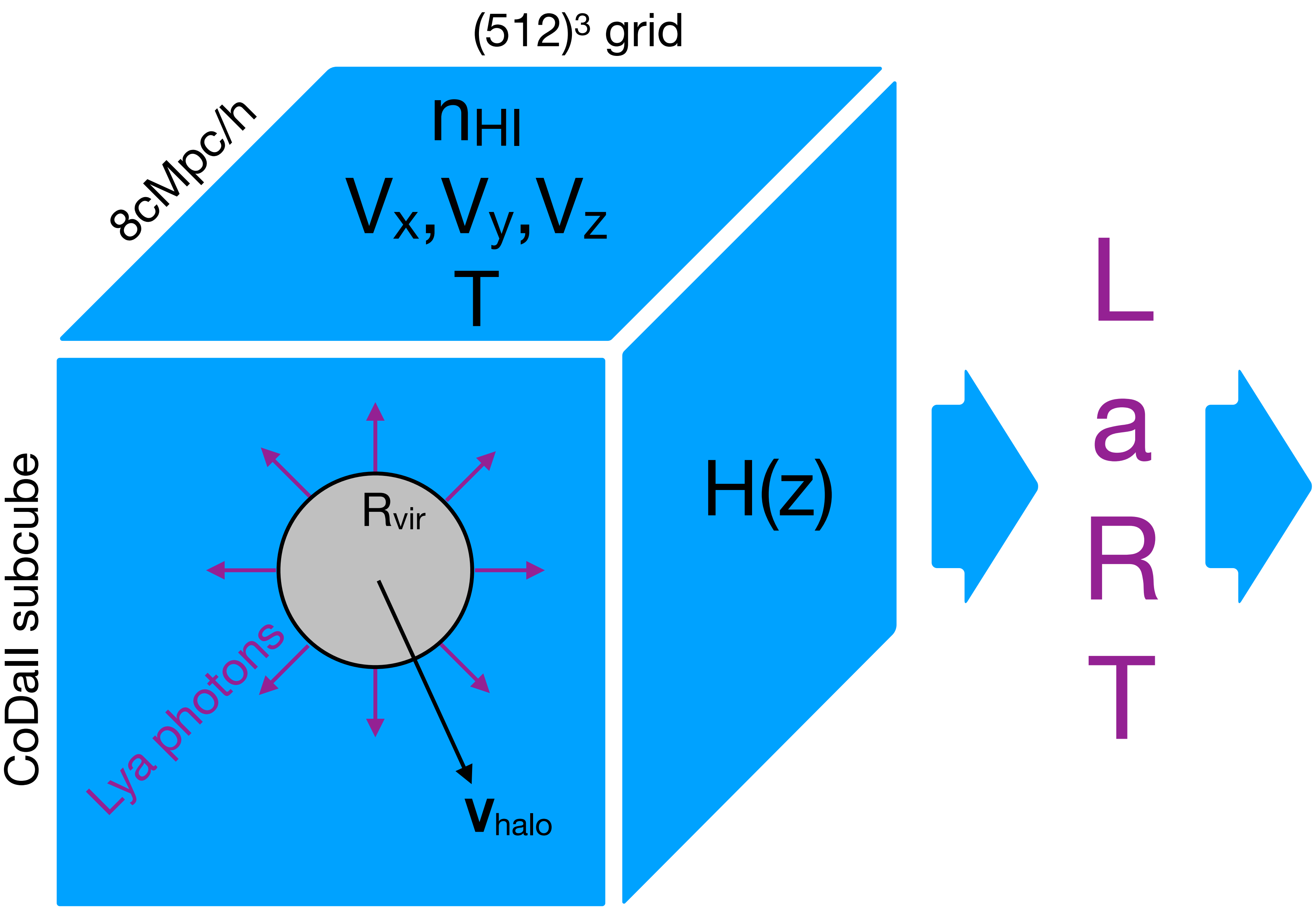
- Developed by Kwang-il Seon (KASI)
- Lya Monte-Carlo radiative transfer code
  - Written in modern Fortran
  - MPI
  - Can consider arbitrary 3D distributions of medium on a regular Cartesian grid
- https://seoncafe.github.io/LaRT.html
- Cosmic expansion effect implemented



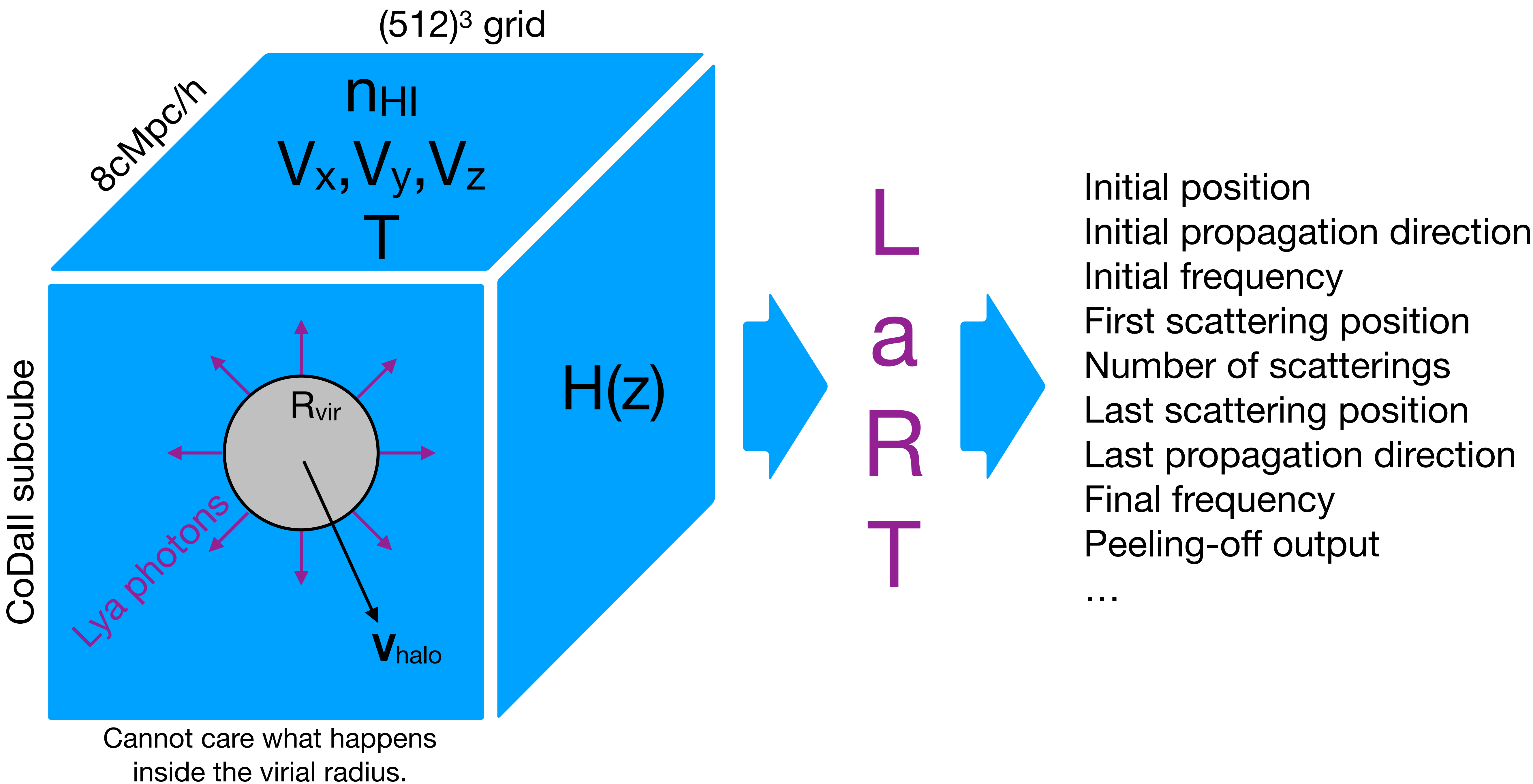
Cannot care what happens
inside the virial radius.



(512)³ grid
8cMpc/h
nHI
Vx,Vy,Vz
T
H(z)
CoDaII subcube
Rvir
Lya photons
Vhalo
Cannot care what happens
inside the virial radius.
L
a
R
T



Cannot care what happens
inside the virial radius.



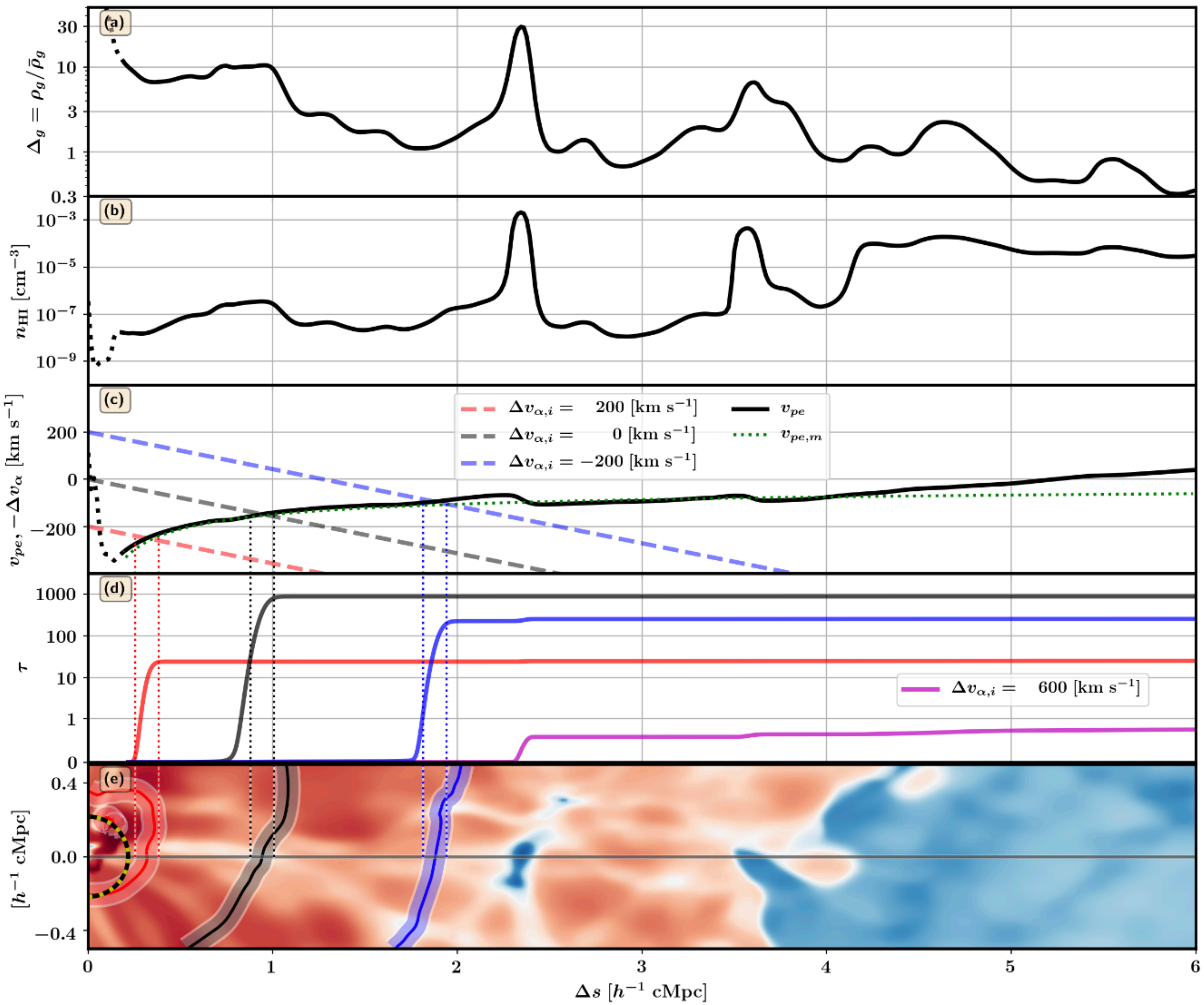
(512)³ grid
8cMpc/h
n_{HI}
V_x, V_y, V_z
T
H(z)
CoDaII subcube
R_{vir}
Lya photons
$\mathbf{v}_{halo}$
Cannot care what happens inside the virial radius.
LaRT
Initial position
Initial propagation direction
Initial frequency
First scattering position
Number of scatterings
Last scattering position
Last propagation direction
Final frequency
Peeling-off output
...

Gas density

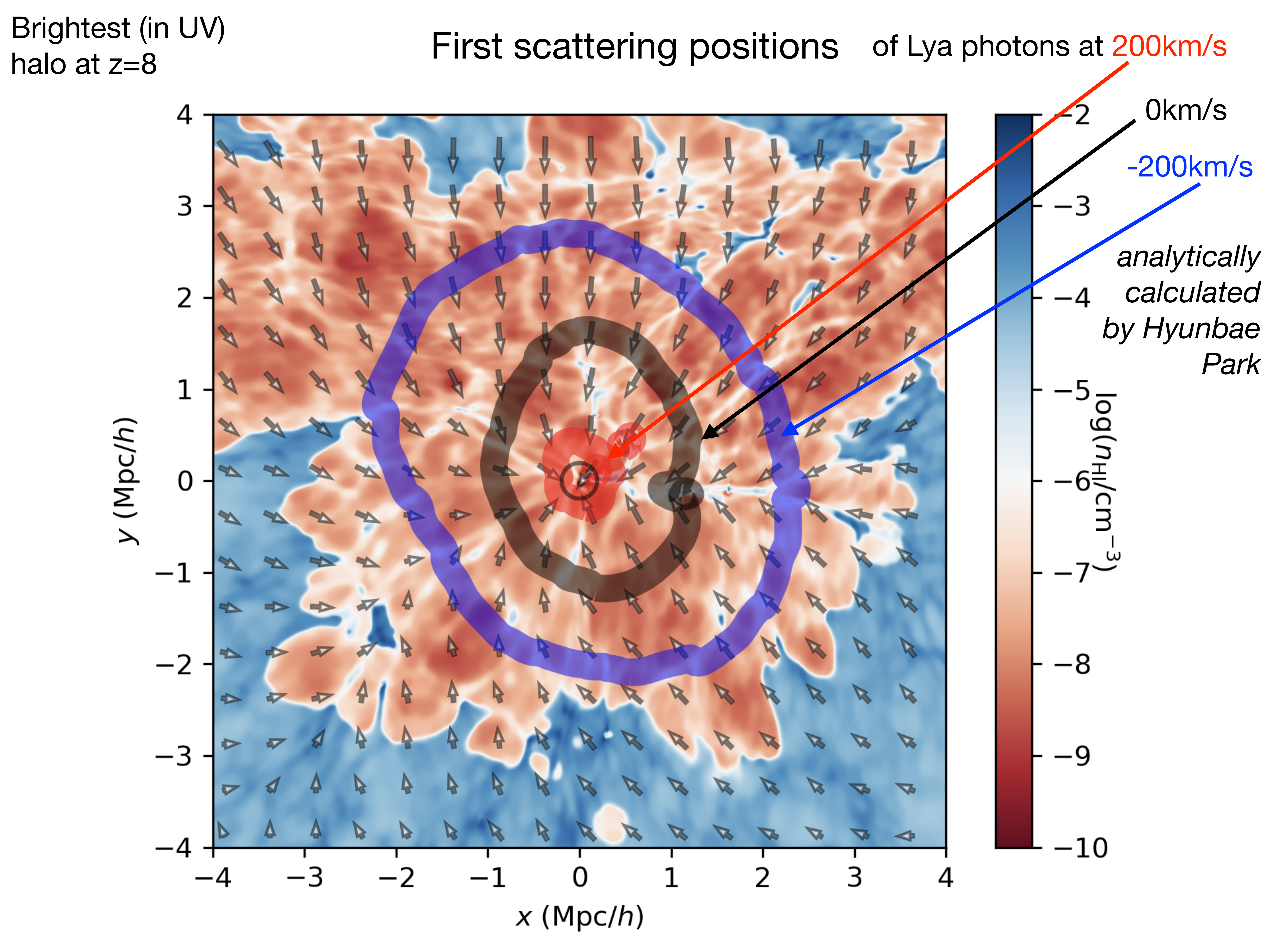
HI density

IGM velocity
wrt halo

Optical depth

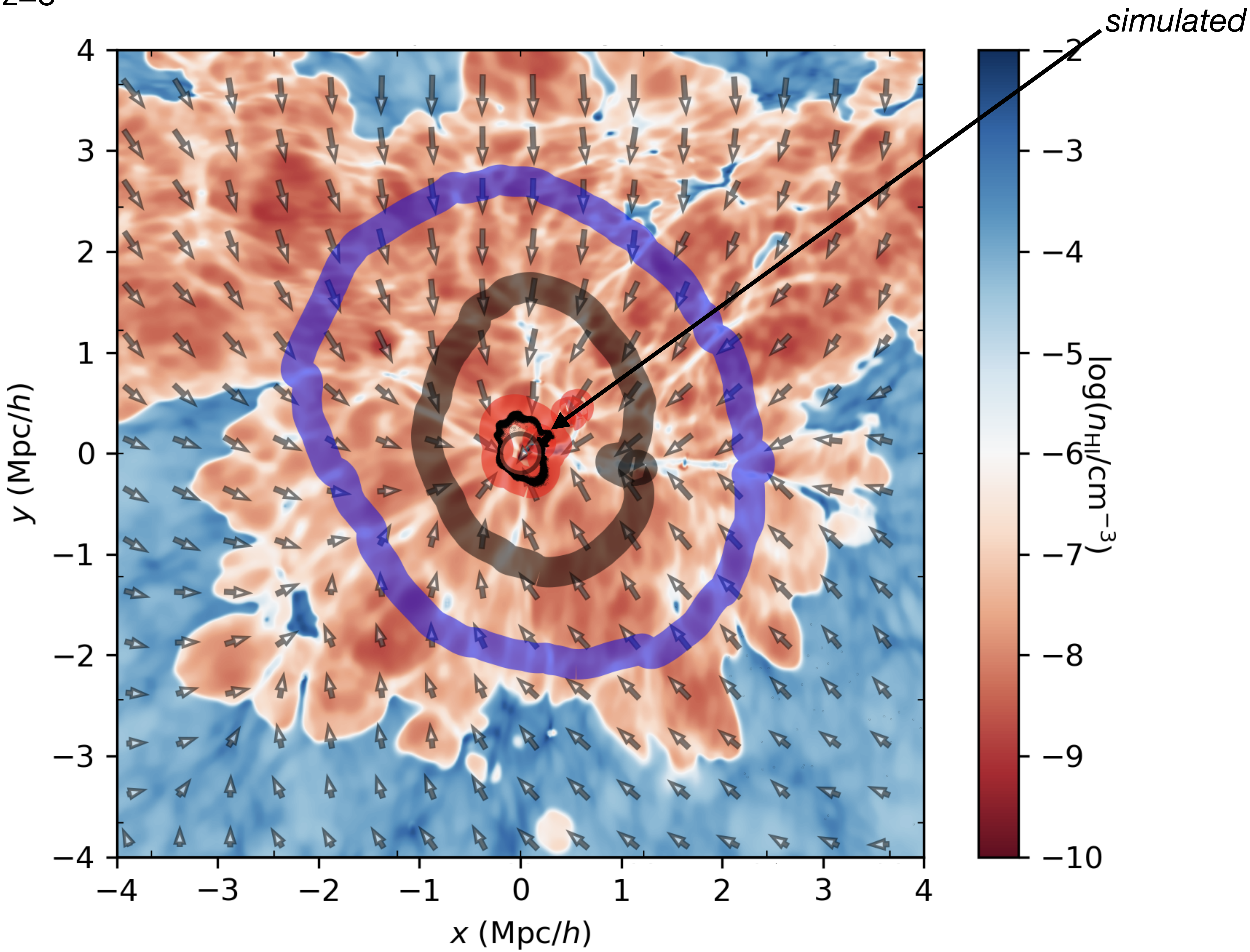


Hyunbae Park+(in prep.)


Brightest (in UV)
halo at z=8
First scattering positions
of Lya photons at 200km/s
0km/s
-200km/s
analytically
calculated
by Hyunbae
Park
y (Mpc/h)
x (Mpc/h)
log(n_HI/cm^-3)

Brightest (in UV)
halo at z=8

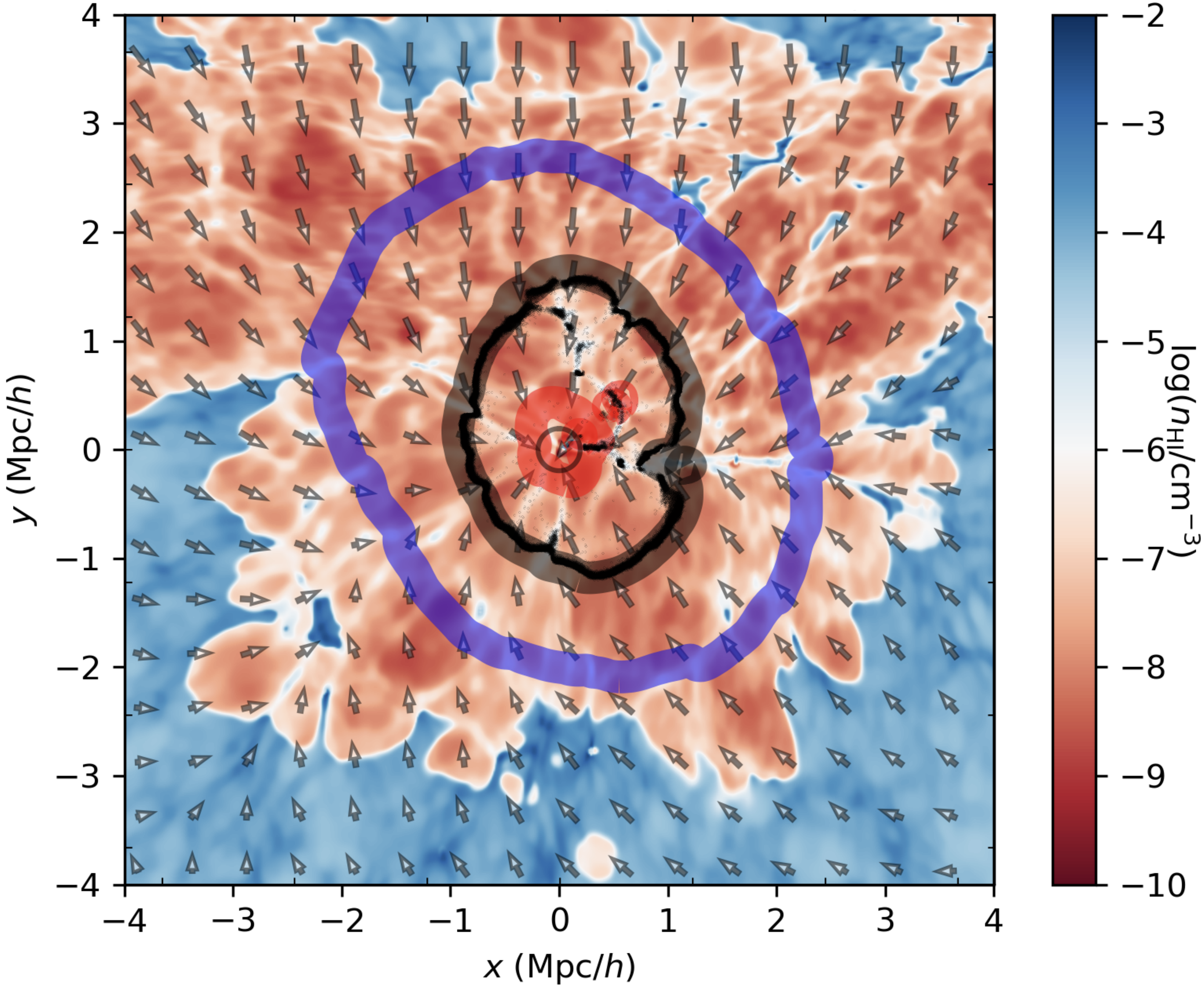
First scattering positions of Lya photons at 200km/s



Brightest (in UV)
halo at z=8

First scattering positions of Lya photons at 0km/s

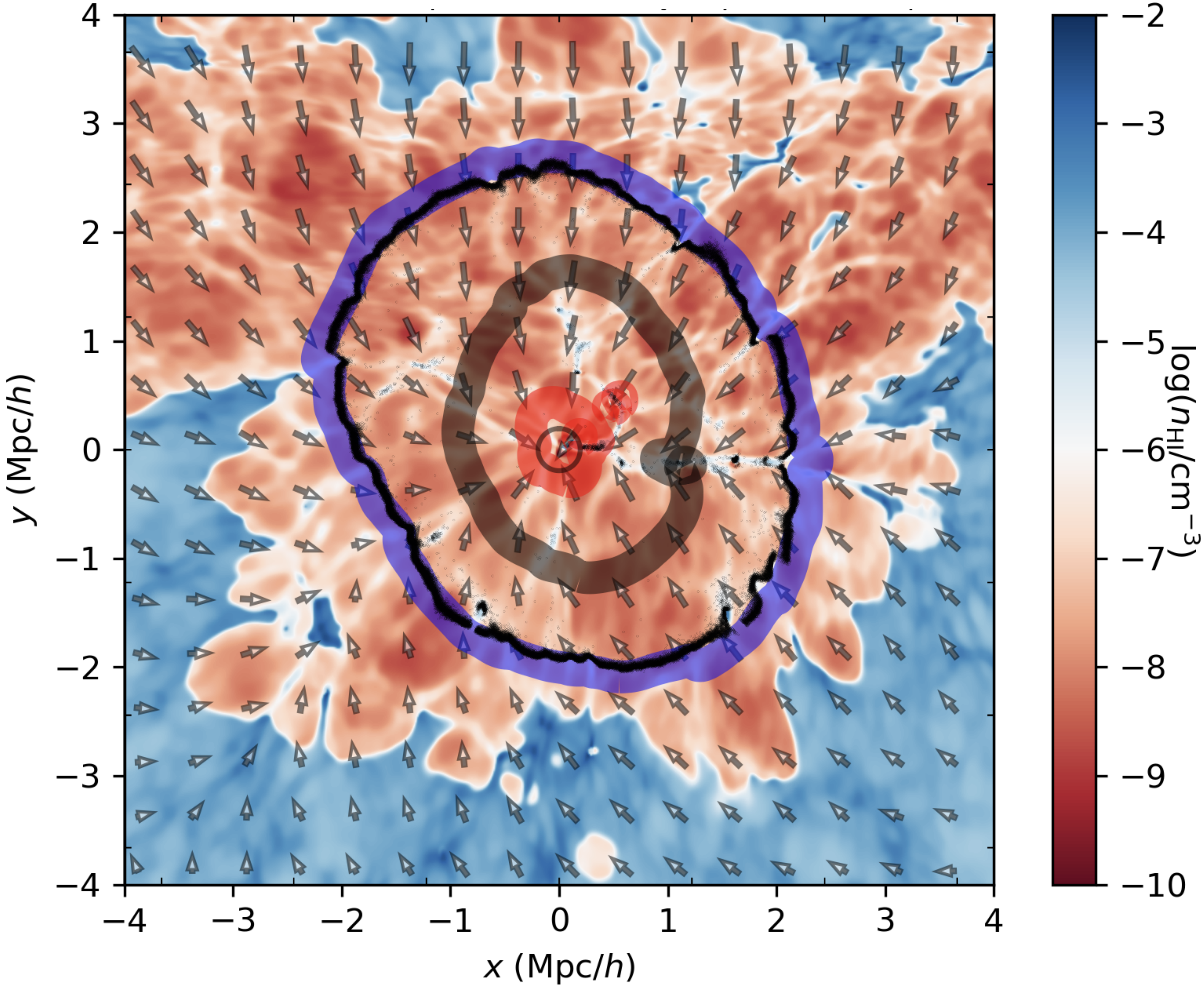
simulated



Brightest (in UV)
halo at z=8

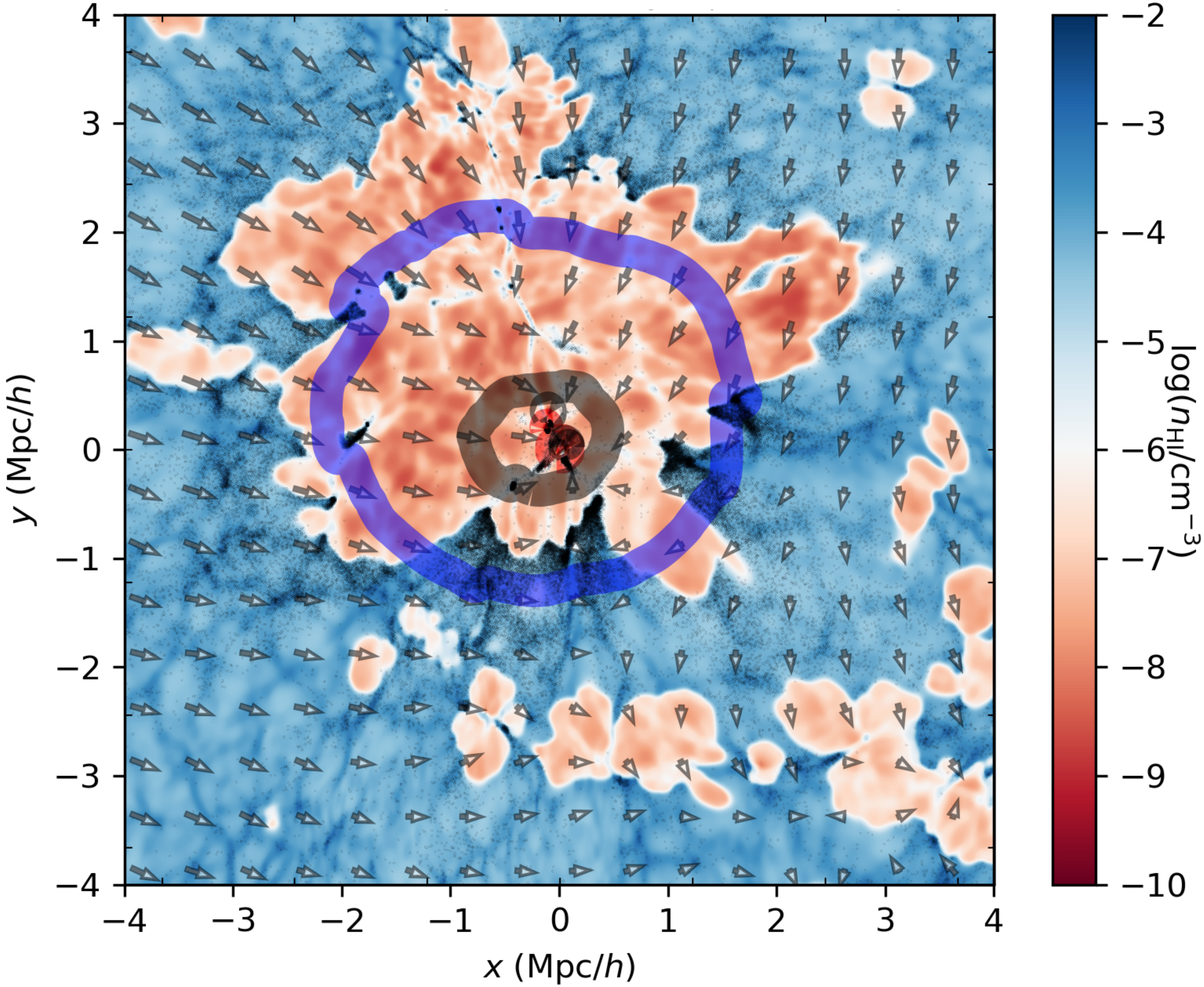
First scattering positions of Lya photons at -200km/s

simulated



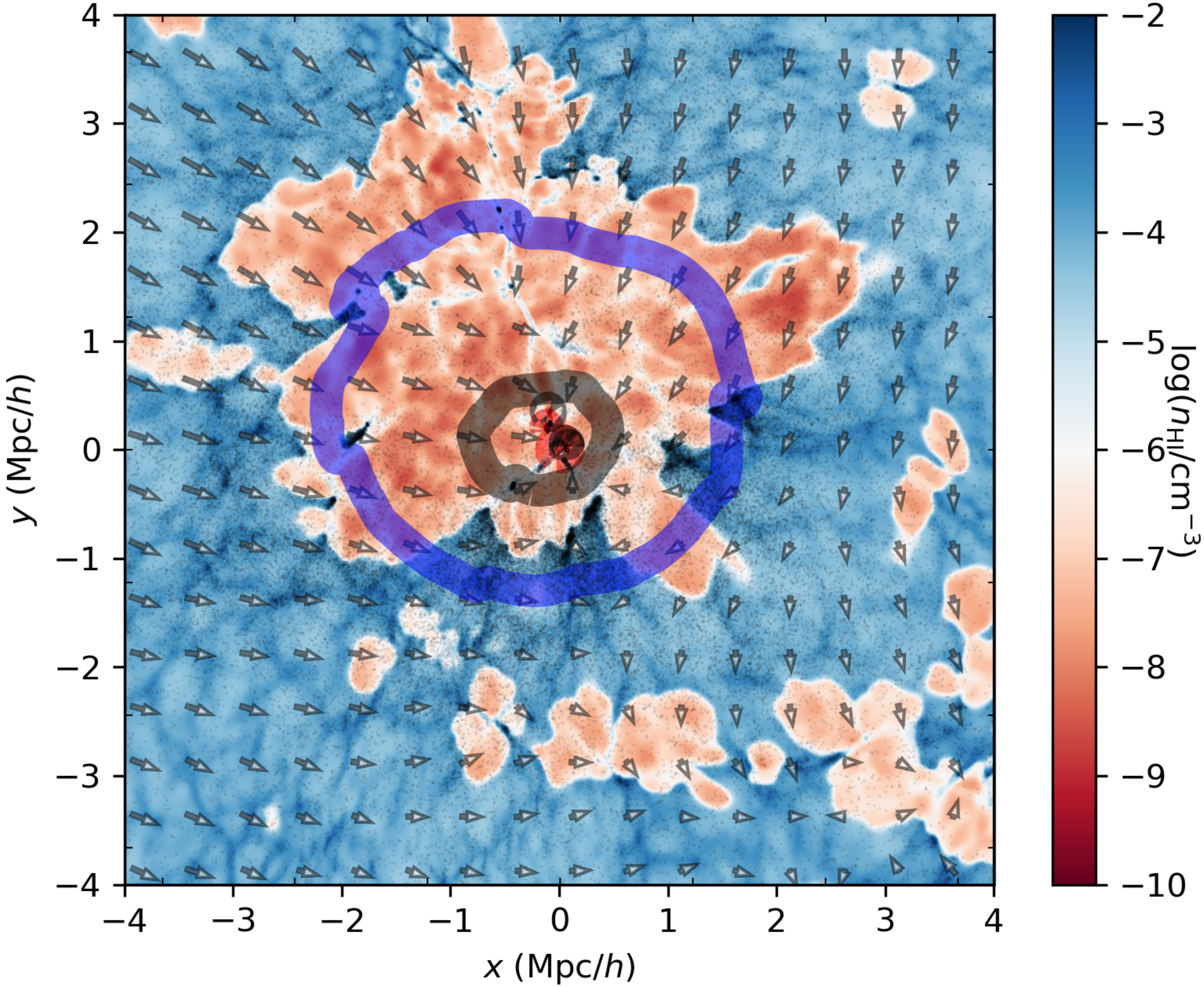
500th brightest (in UV) halo at z=8

First scattering positions of Lya photons at 200km/s



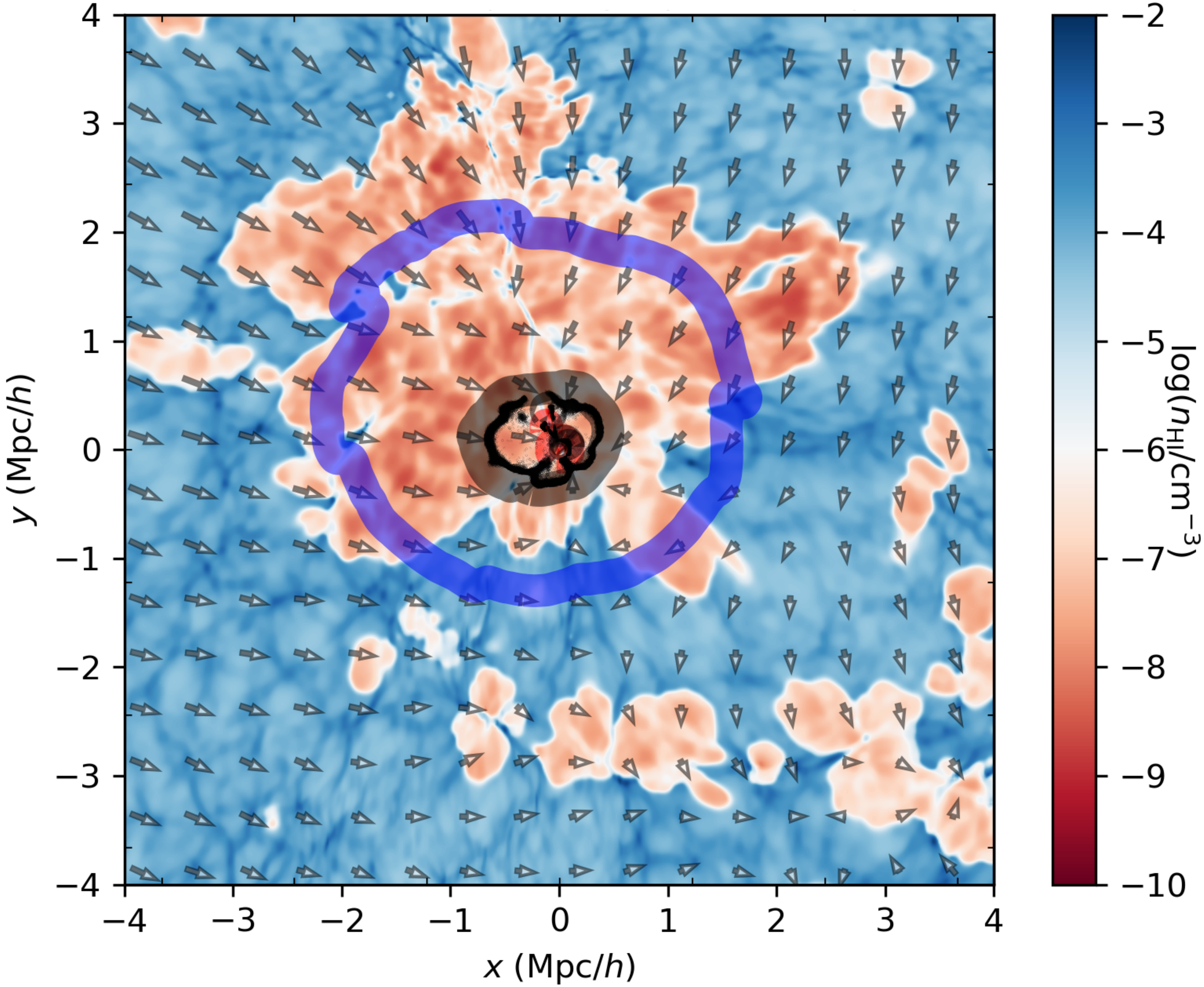
500th brightest (in UV)
halo at z=8

Last scattering positions of Lya photons at 200km/s



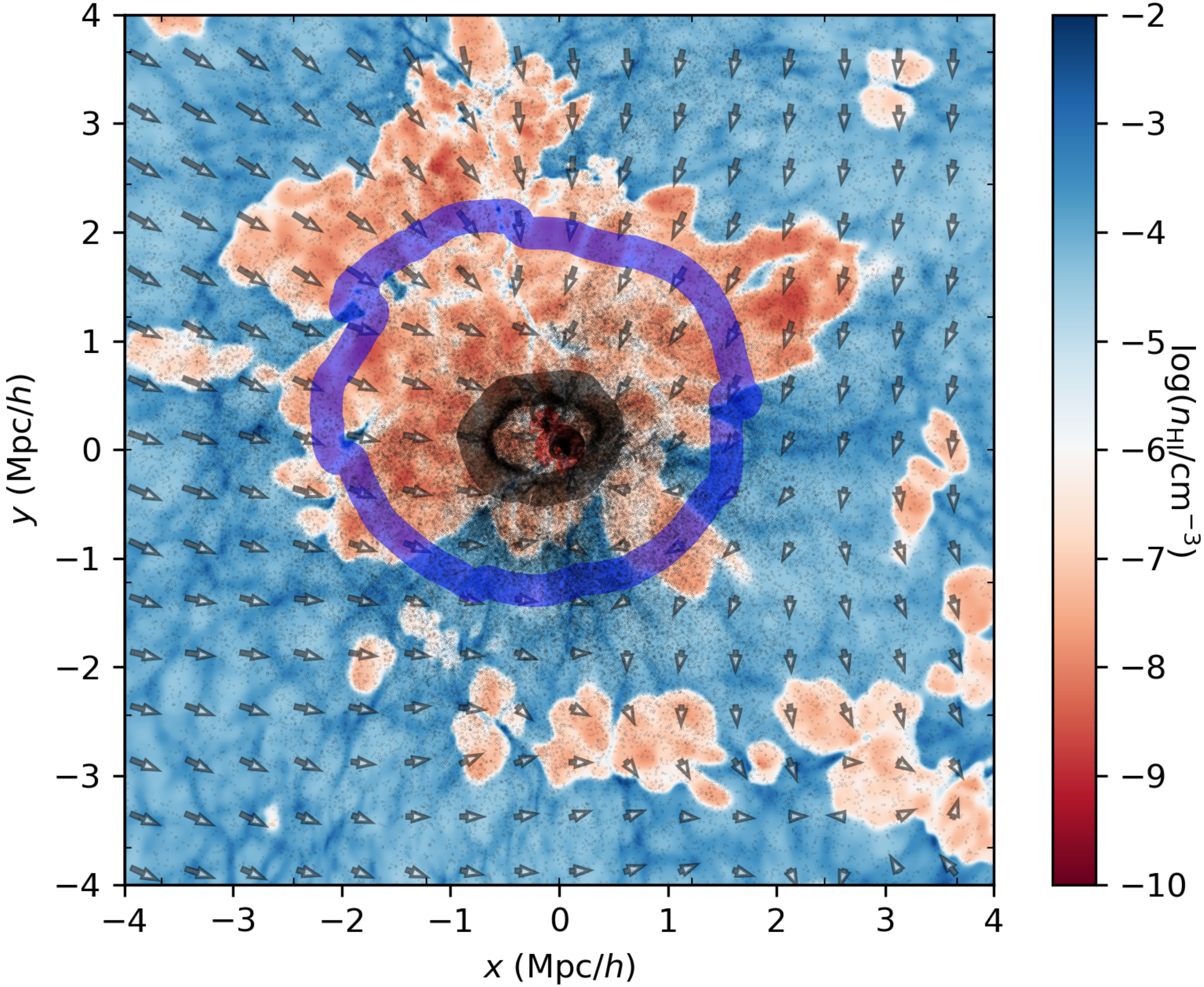
500th brightest (in UV)
halo at z=8

First scattering positions of Lya photons at 0km/s



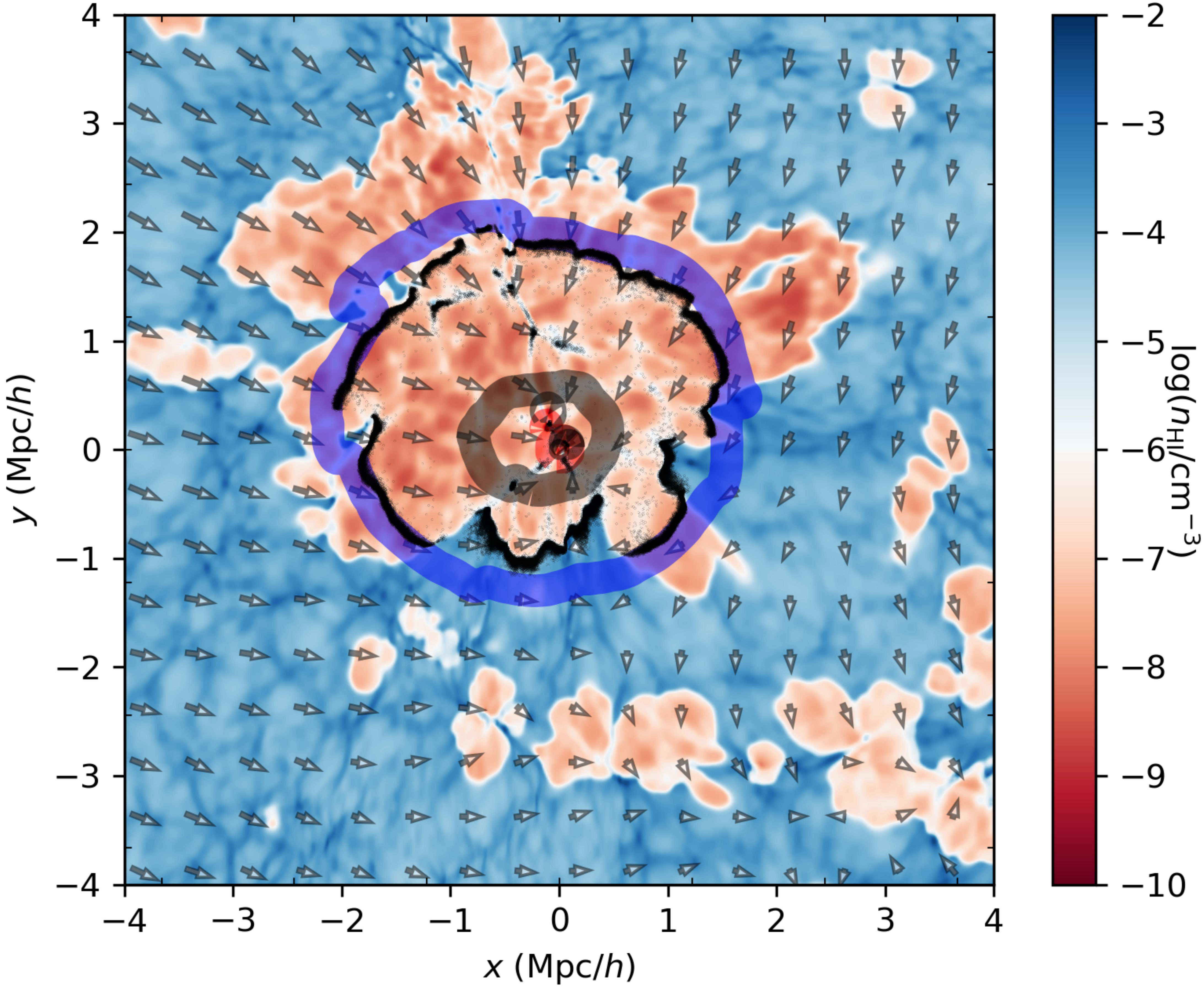
500th brightest (in UV)
halo at z=8

Last scattering positions of Lya photons at 0km/s



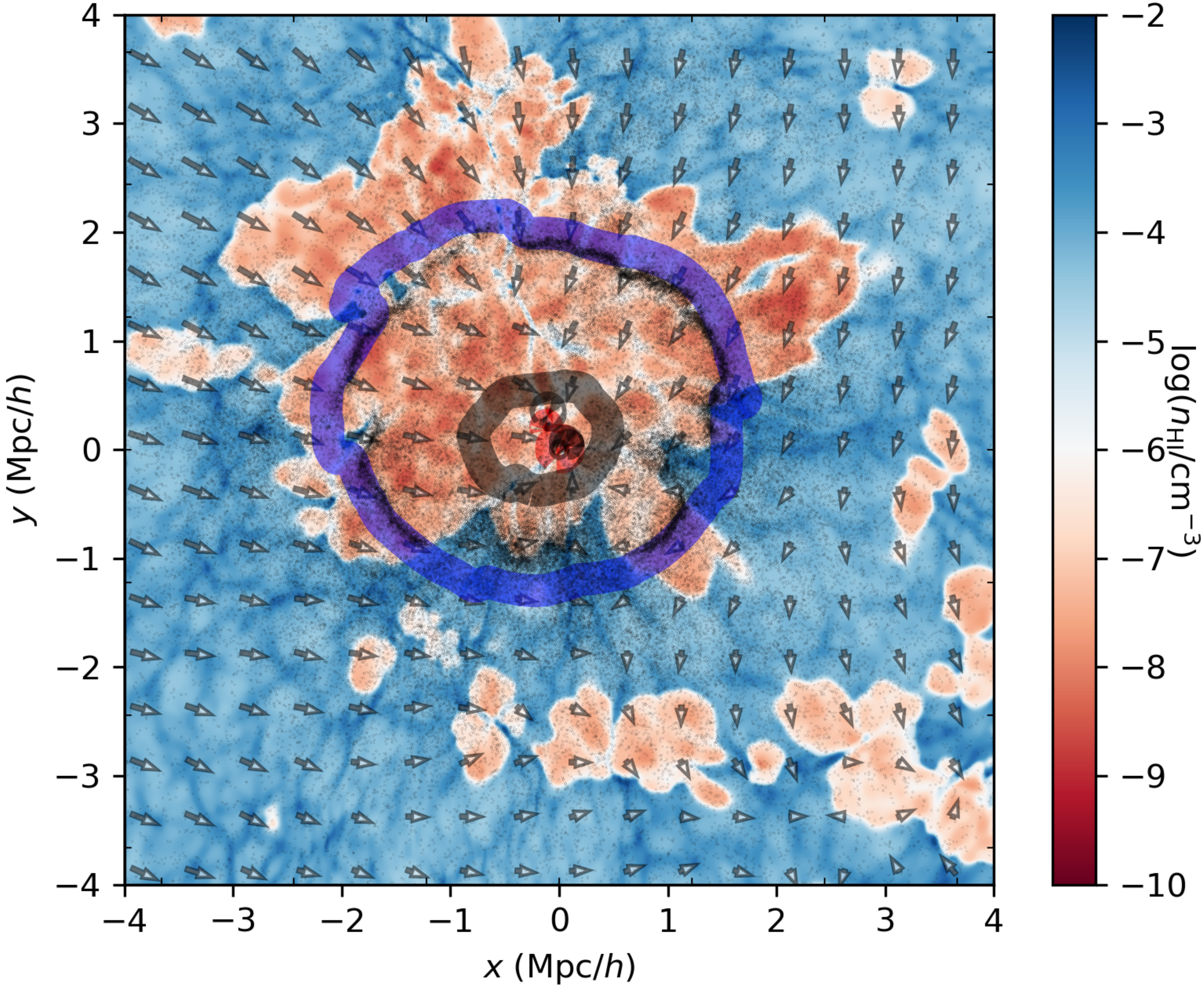
500th brightest (in UV)
halo at z=8

First scattering positions of Lya photons at -200km/s



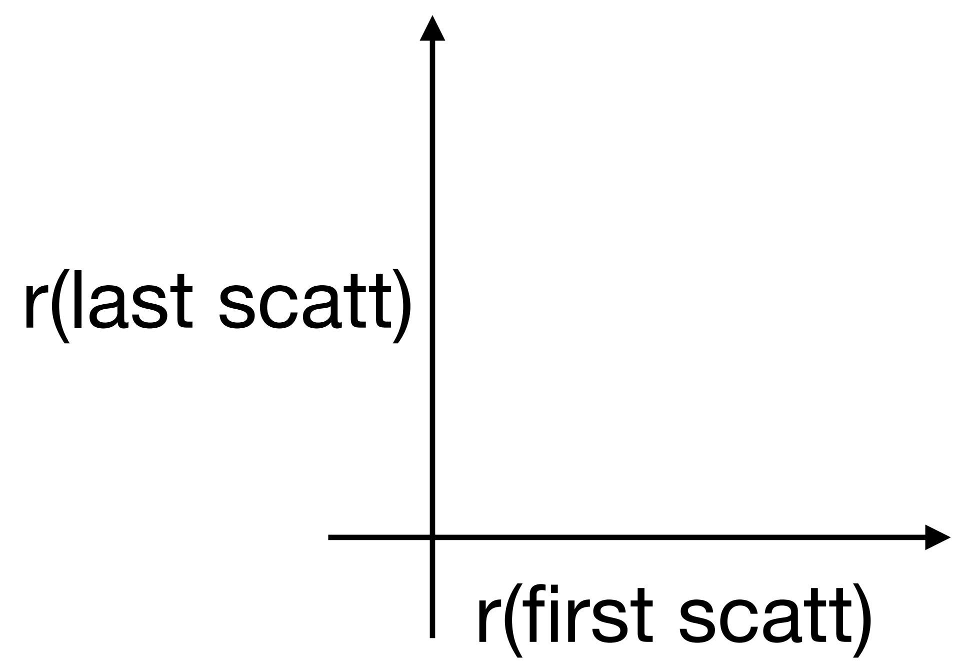
500th brightest (in UV)
halo at z=8

Last scattering positions of Lya photons at -200km/s



200km/s

0km/s

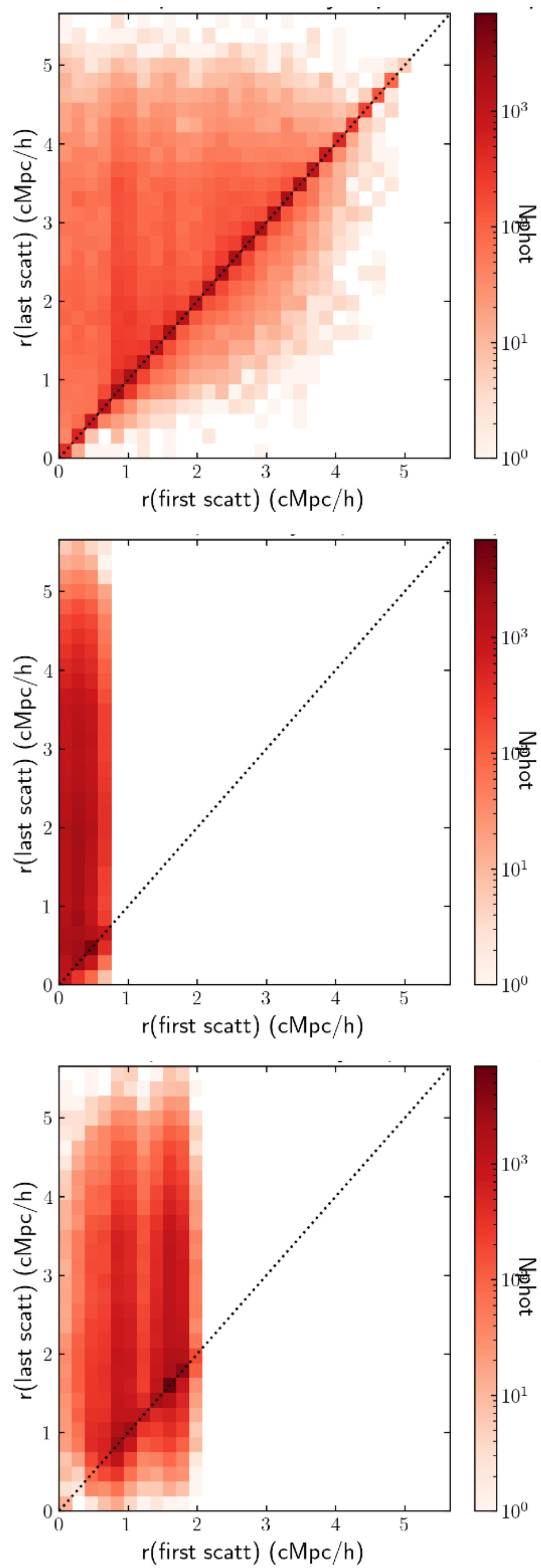


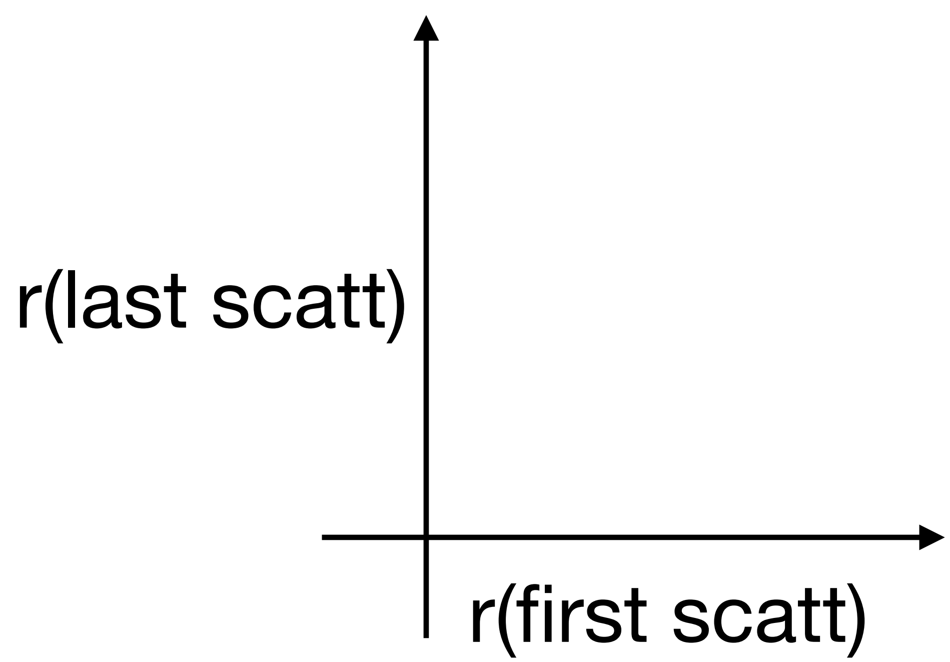
-200km/s

200km/s

0km/s

-200km/s

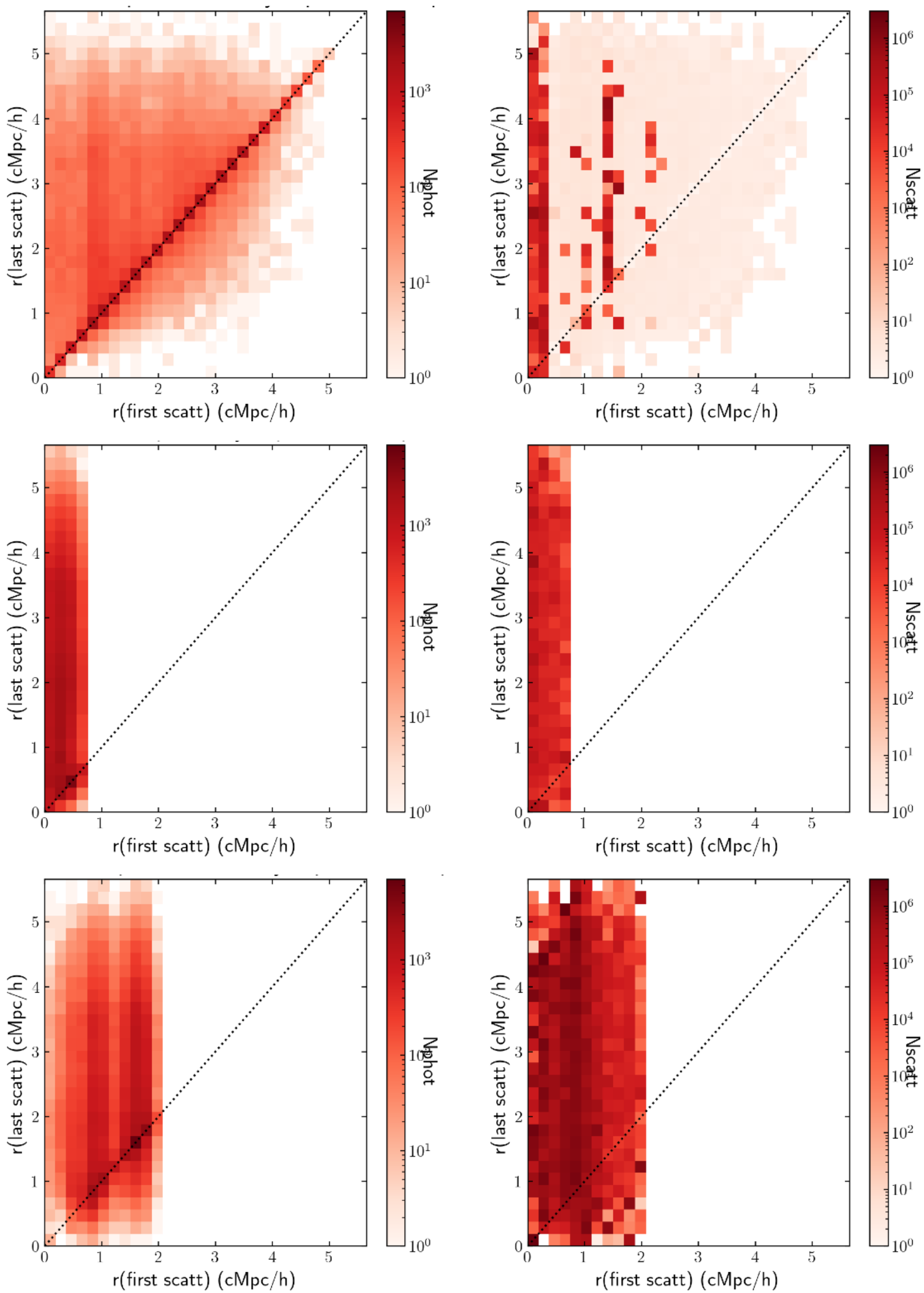




200km/s

0km/s

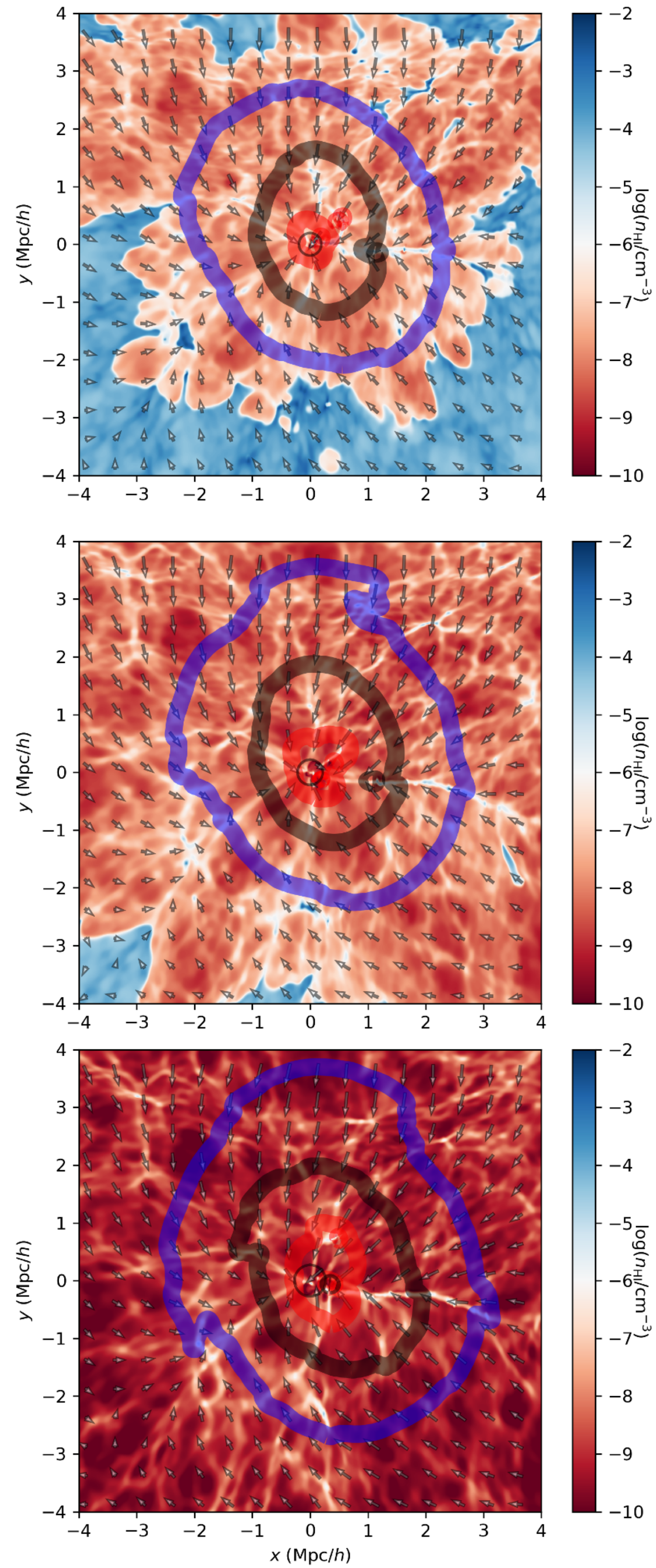
-200km/s



z=8 H(z)/c=3.39e-3

z=7 H(z)/c=2.84e-3

z=6 H(z)/c=2.33e-3



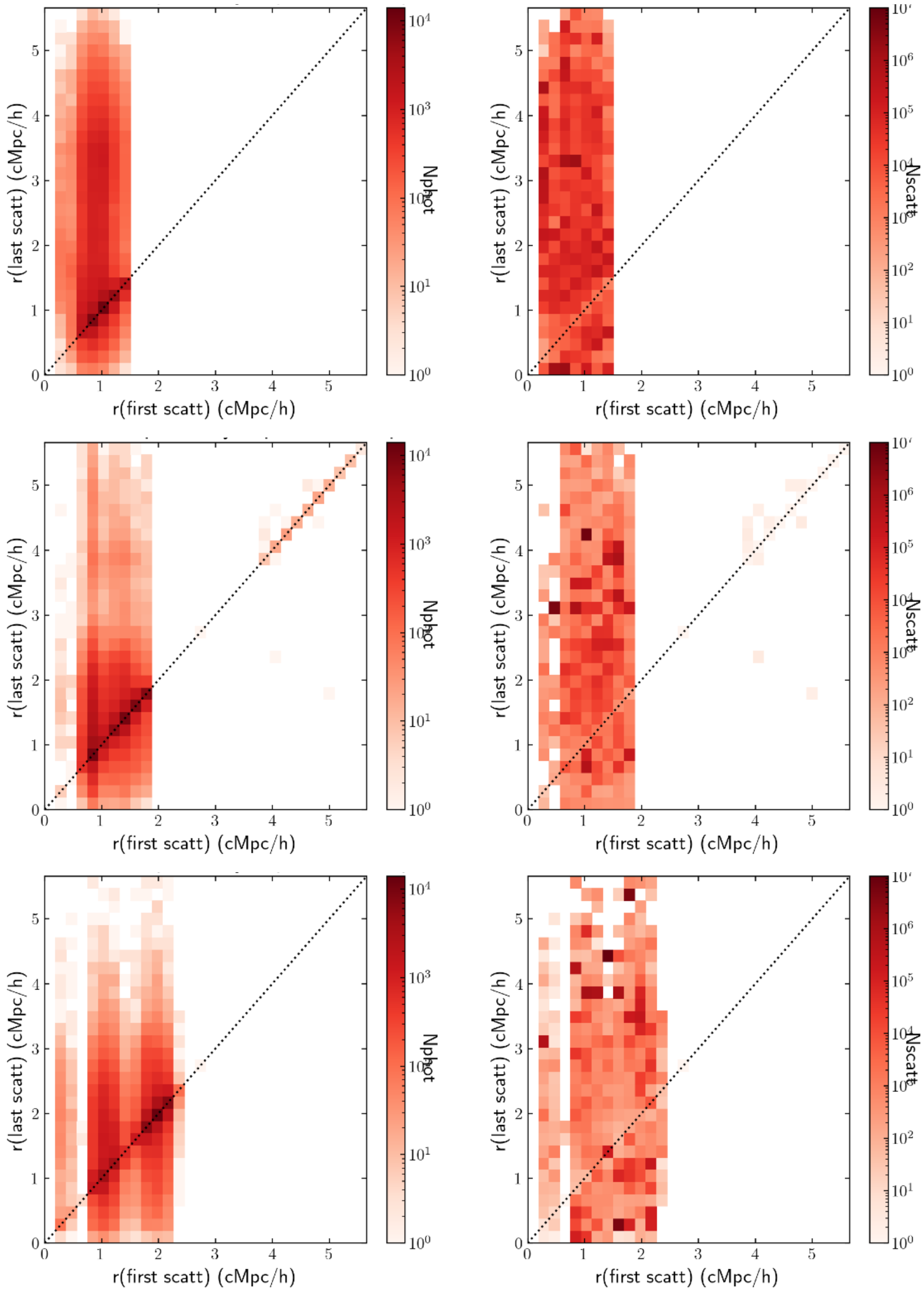
t

IGM - more ionized
Halo - more massive
Cosmic expansion - slower

z=8

z=7

z=6

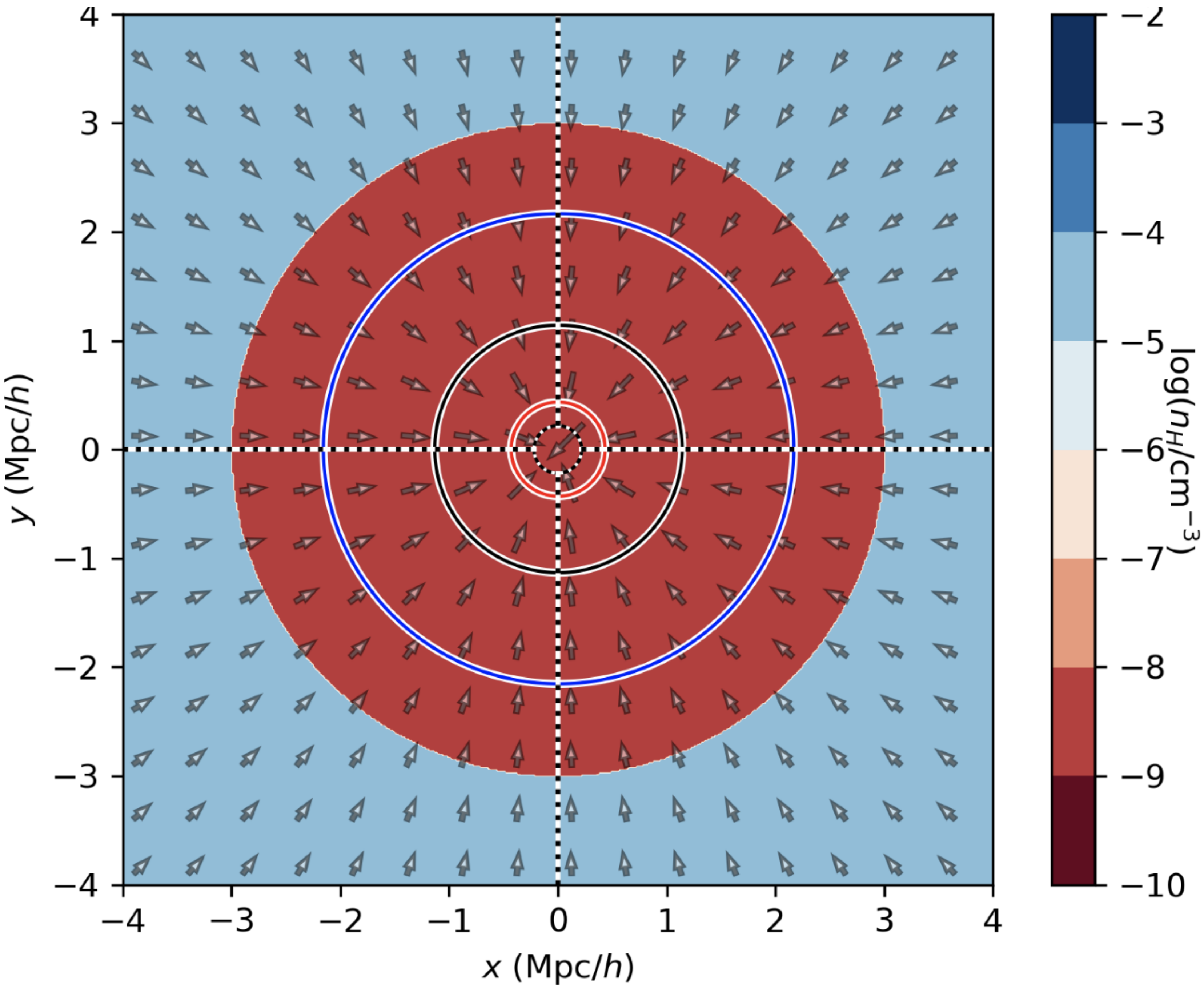


0.45% escape
wo scattering

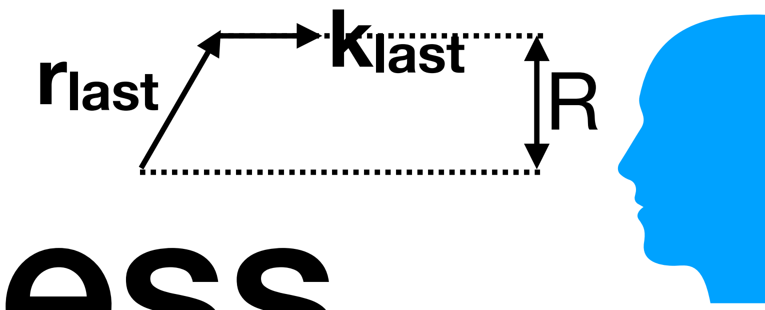
5.3%

Toy model

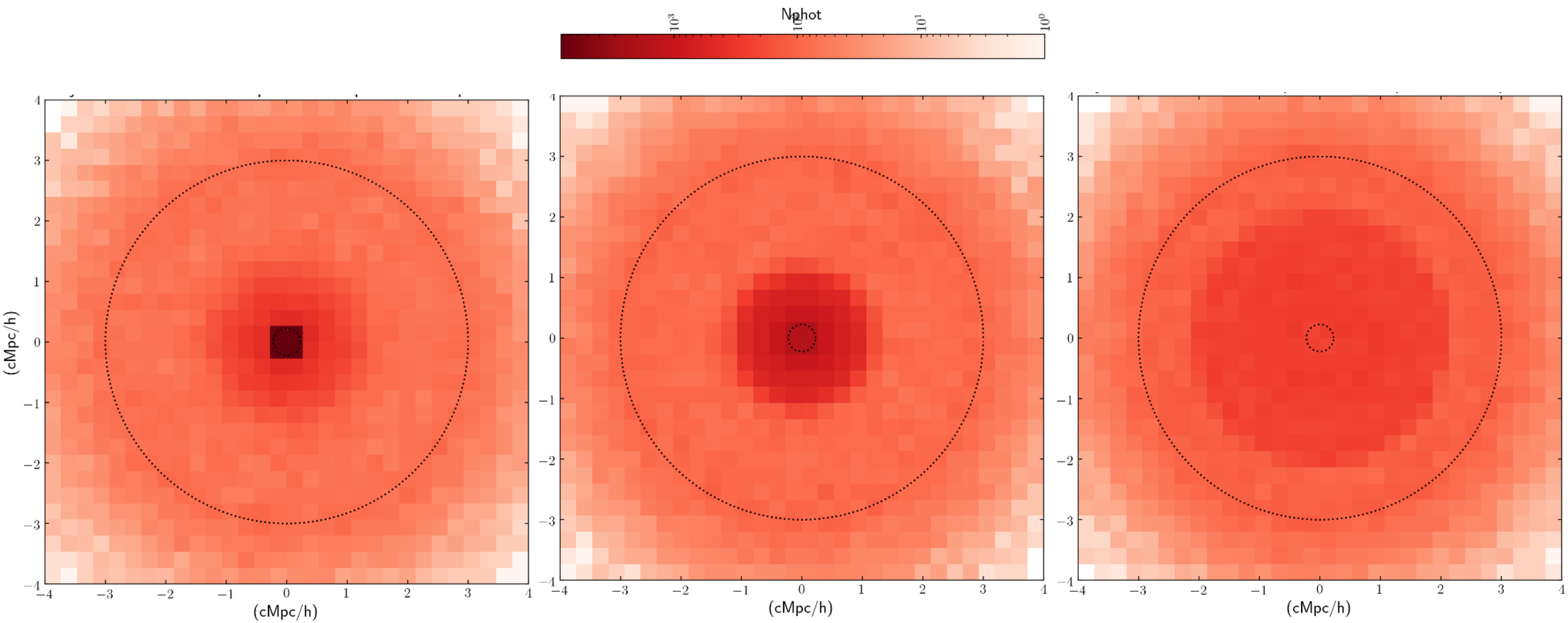
Spherical symmetry
Halo mass: 1e12M_{sun}
IGM density: step-like
IGM Infall motion: $(GM(<r)/r)^{0.5}$
Ionizing bubble size: 3cMpc/h
Lya photon initial position: R_{vir} surface
H(z): at z=7



$$R = r_{last} \left(1 - (\mathbf{r}_{last} \cdot \mathbf{k}_{last})^2 \right)^{0.5}$$

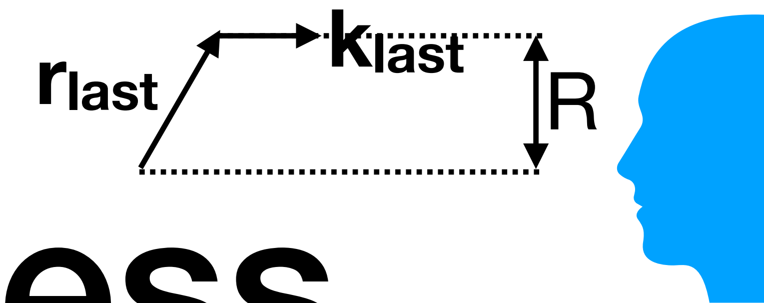


Surface Brightness

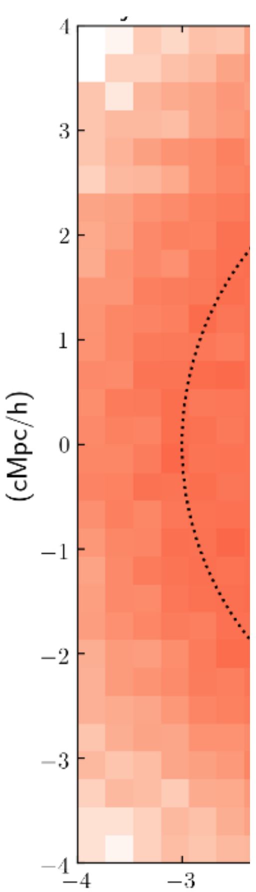


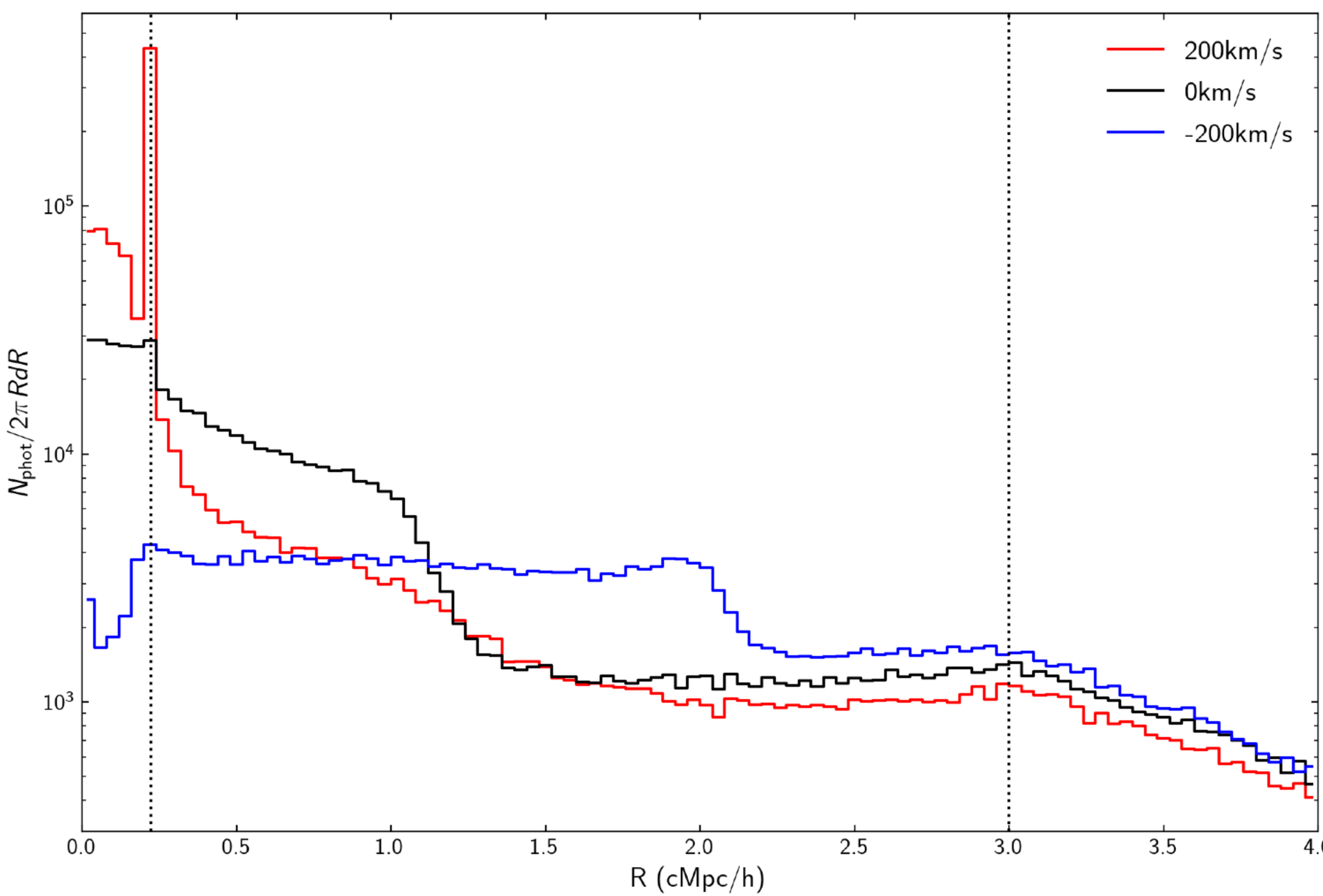
200km/s	0km/s	-200km/s
26% escape wo scattering	1.1%	0.053%

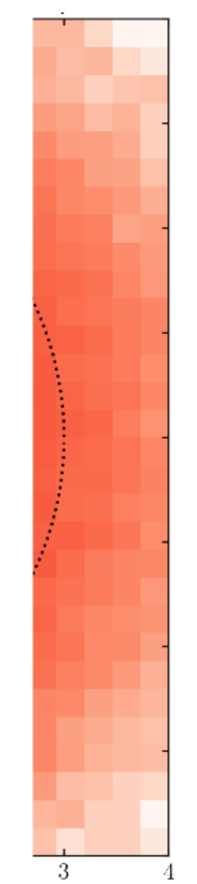
$$R = r_{last} \left(1 - (\mathbf{r}_{last} \cdot \mathbf{k}_{last})^2 \right)^{0.5}$$



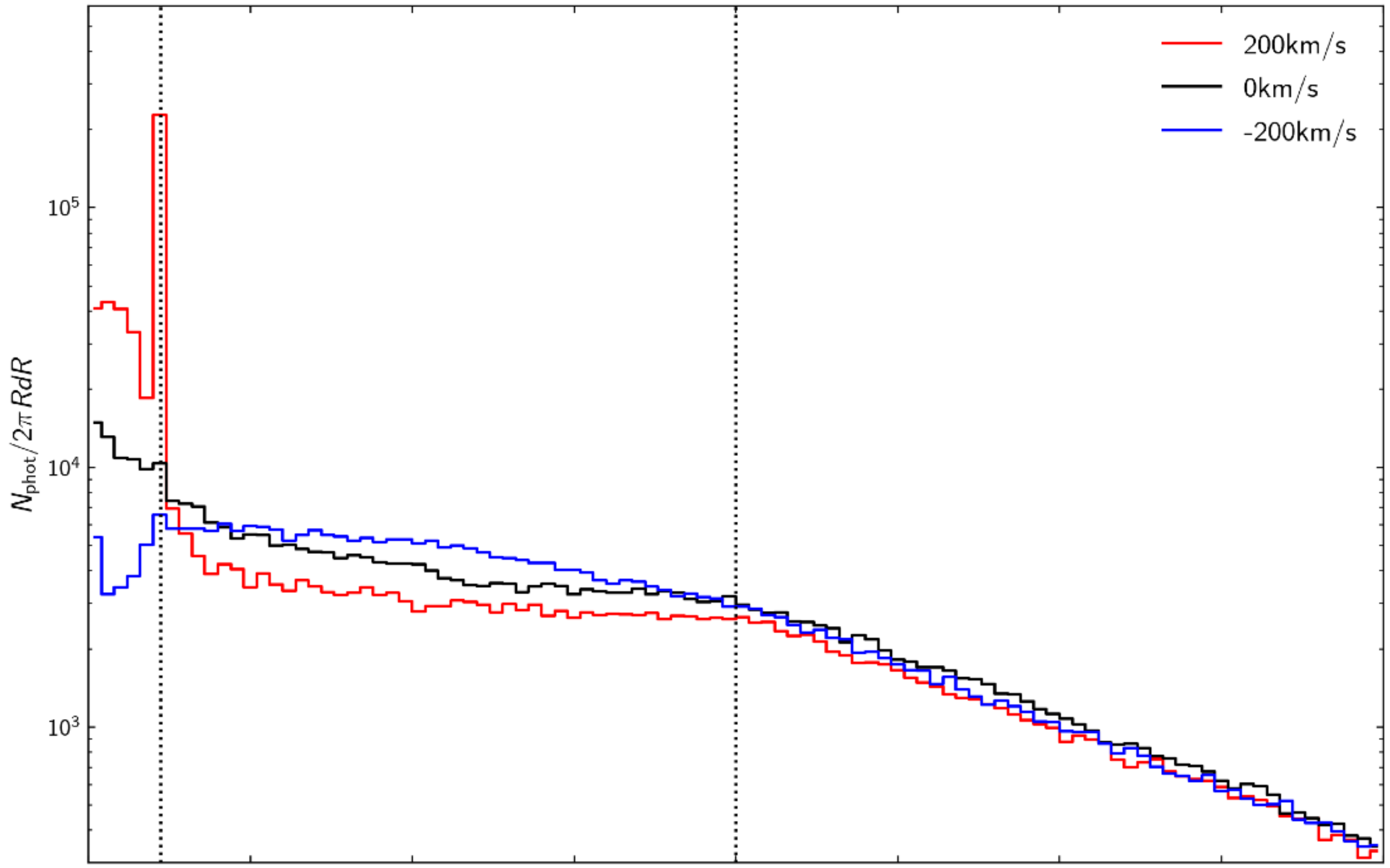
Surface Brightness



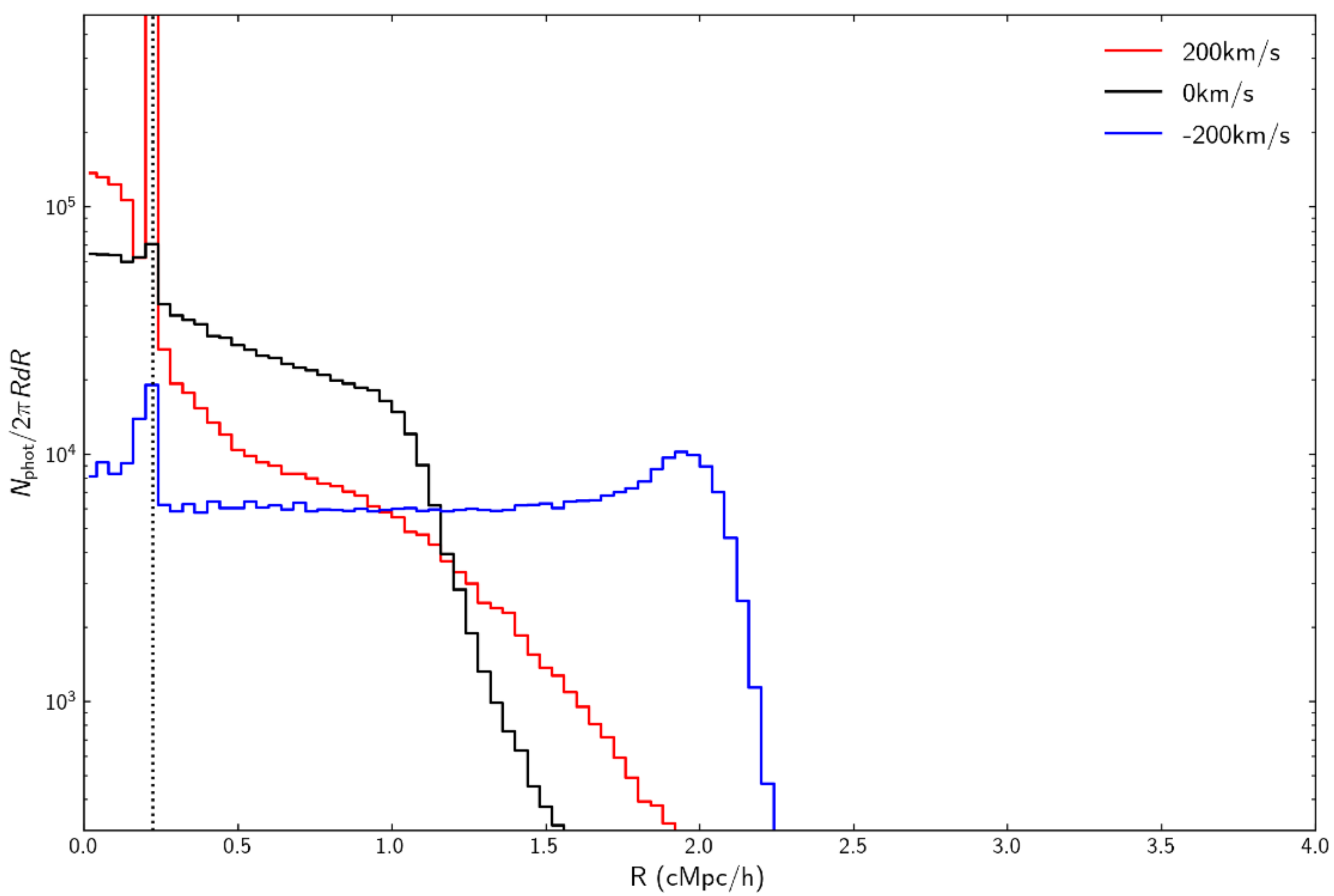


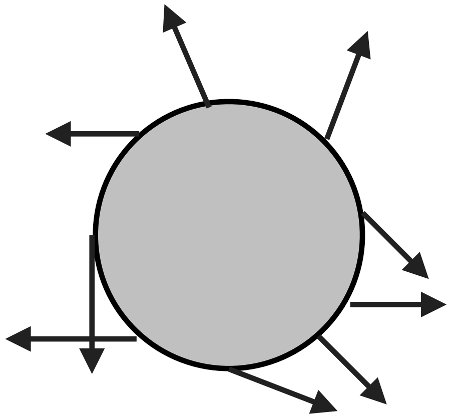


2cMpc/h
ionizing
bubble

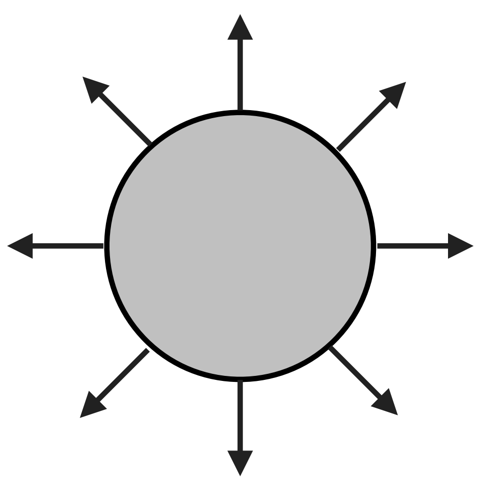


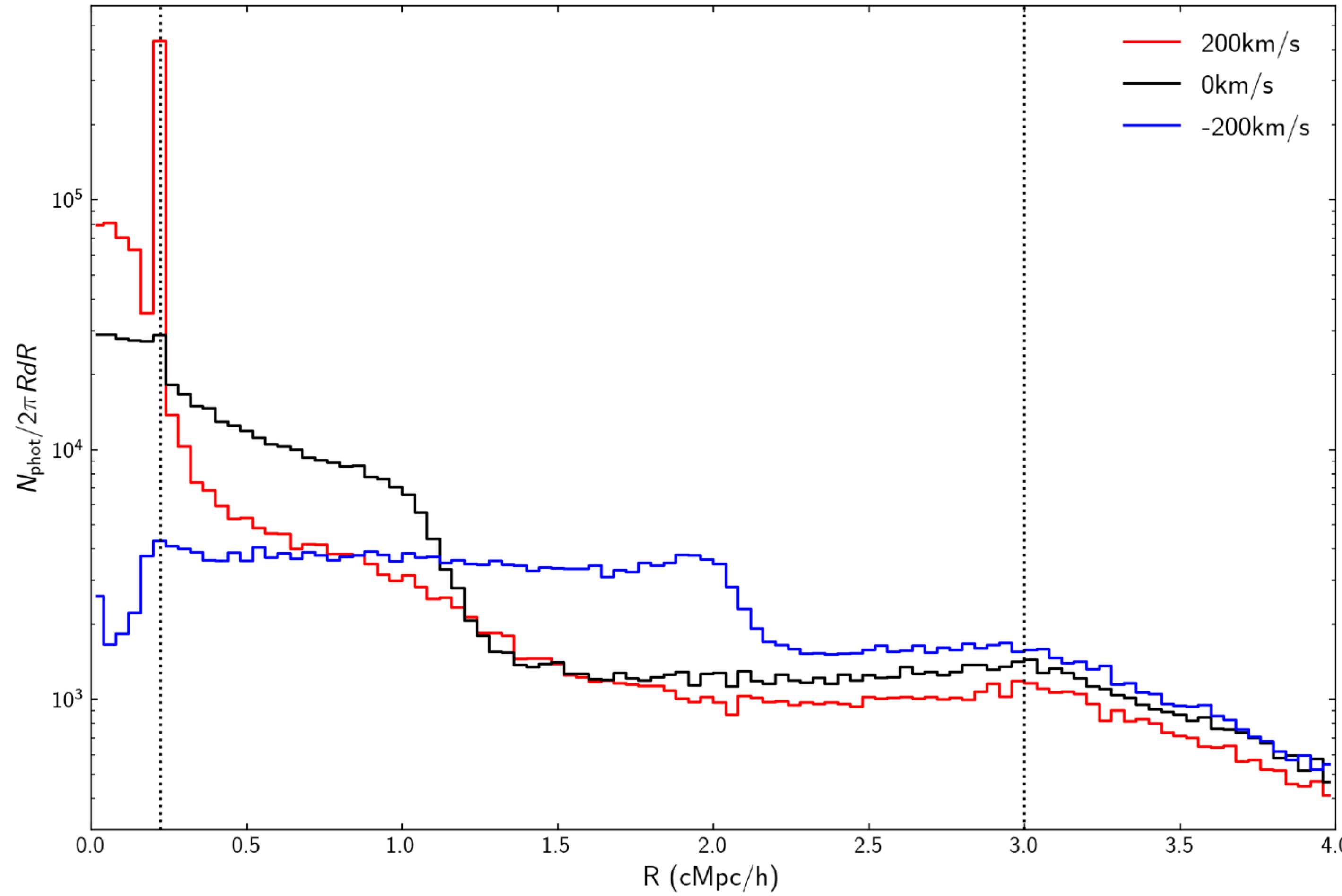
Whole box
ionized

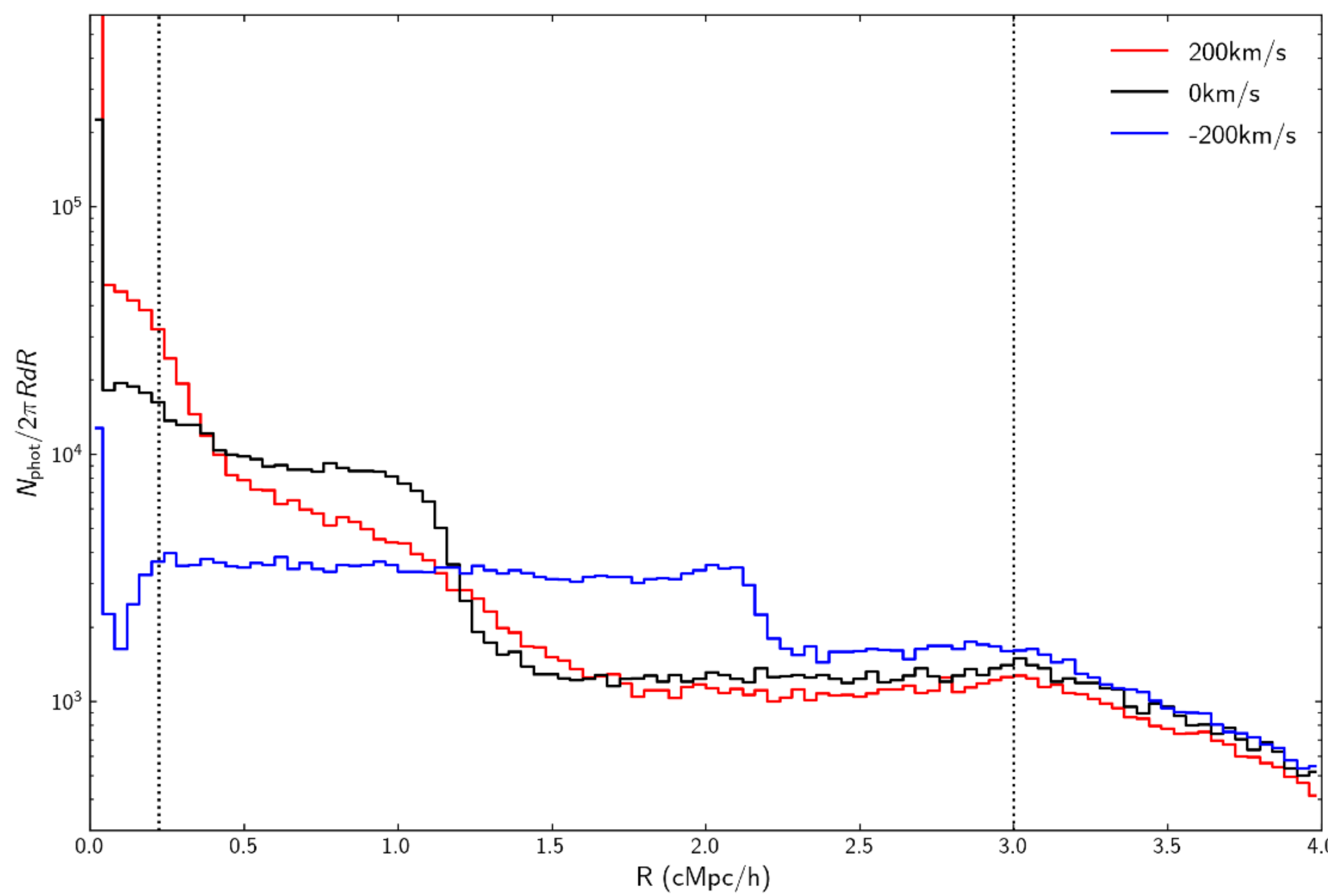




Photons'
initial
propagation
direction



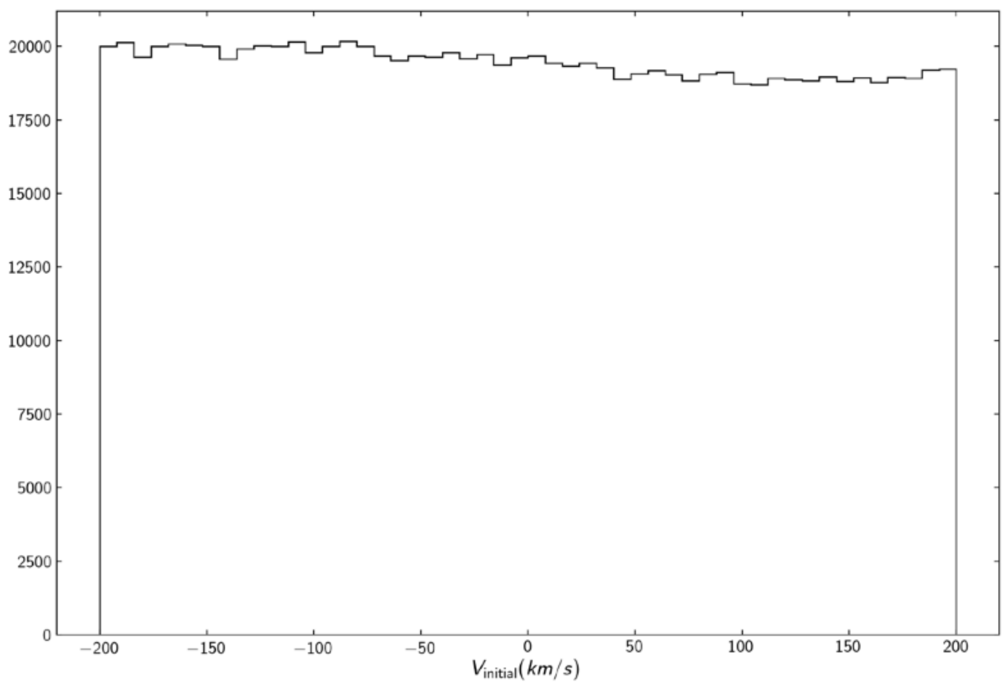


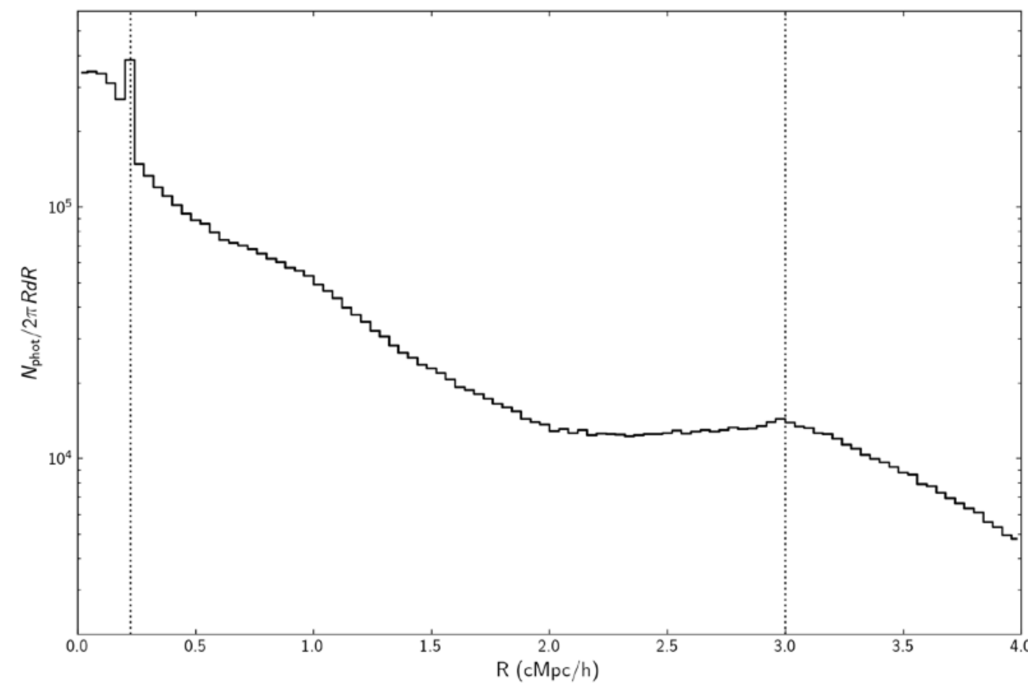


3cMpc/h
ionizing
bubble

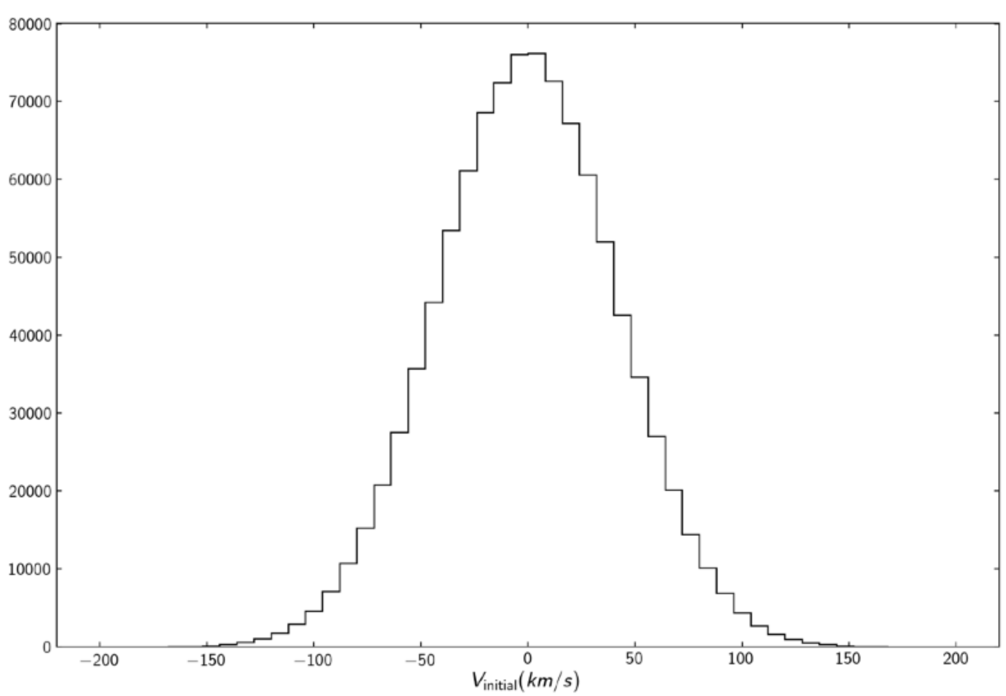
Input spectrum

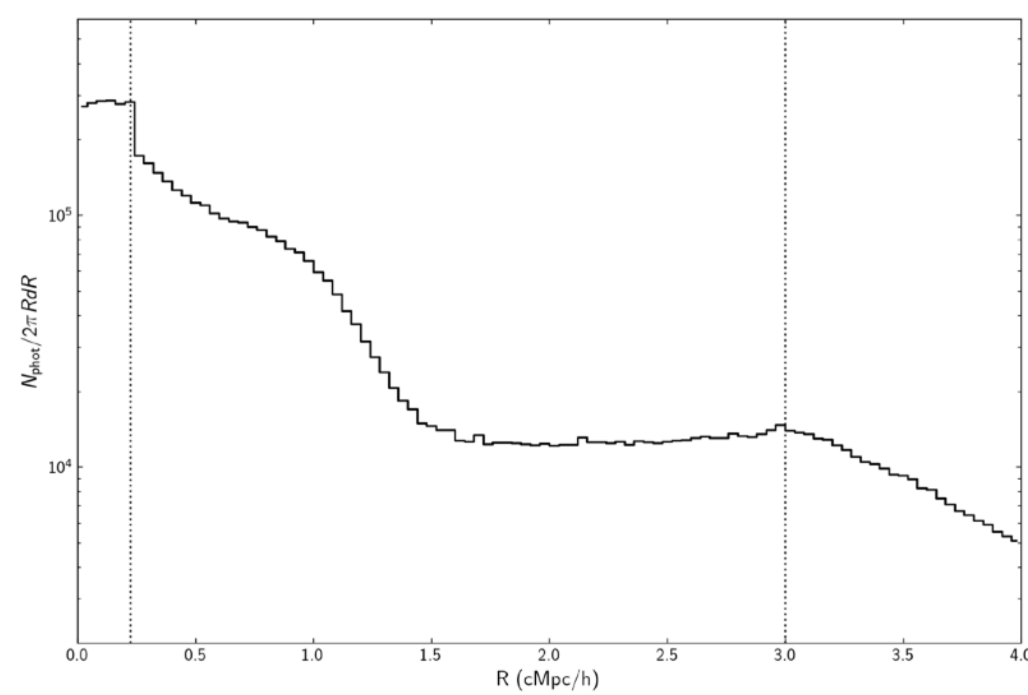
Input spectrum



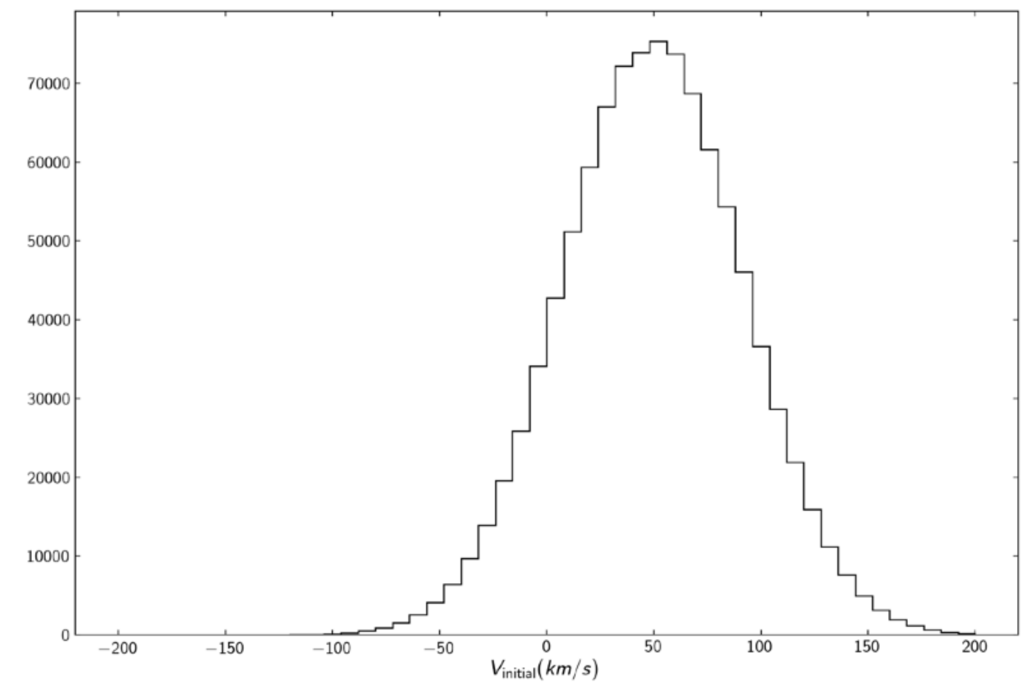


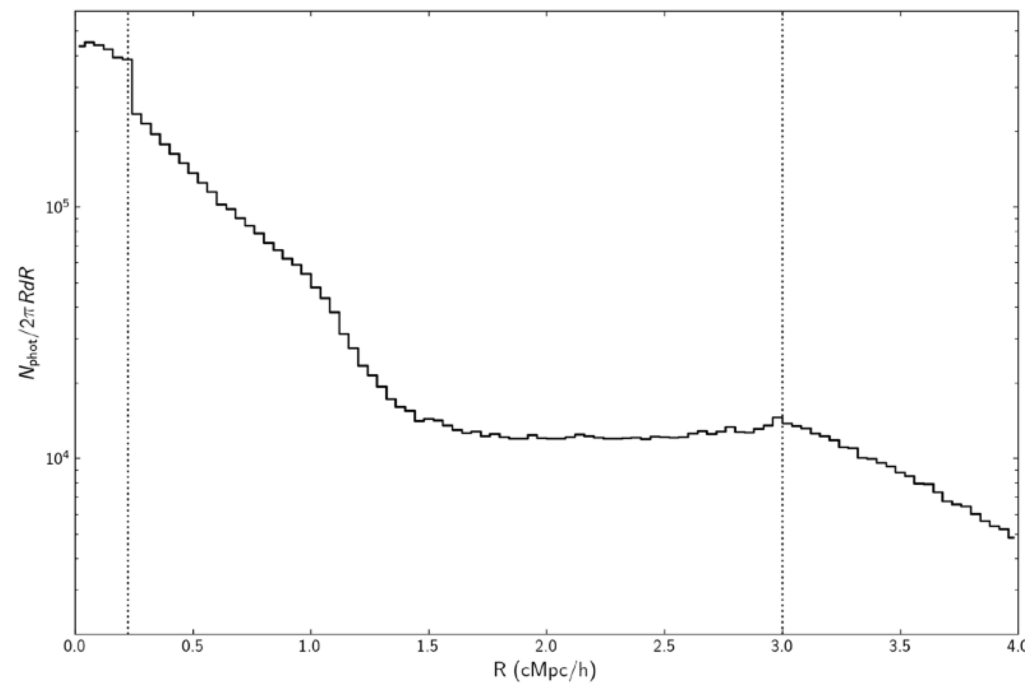
Surface brightness profile

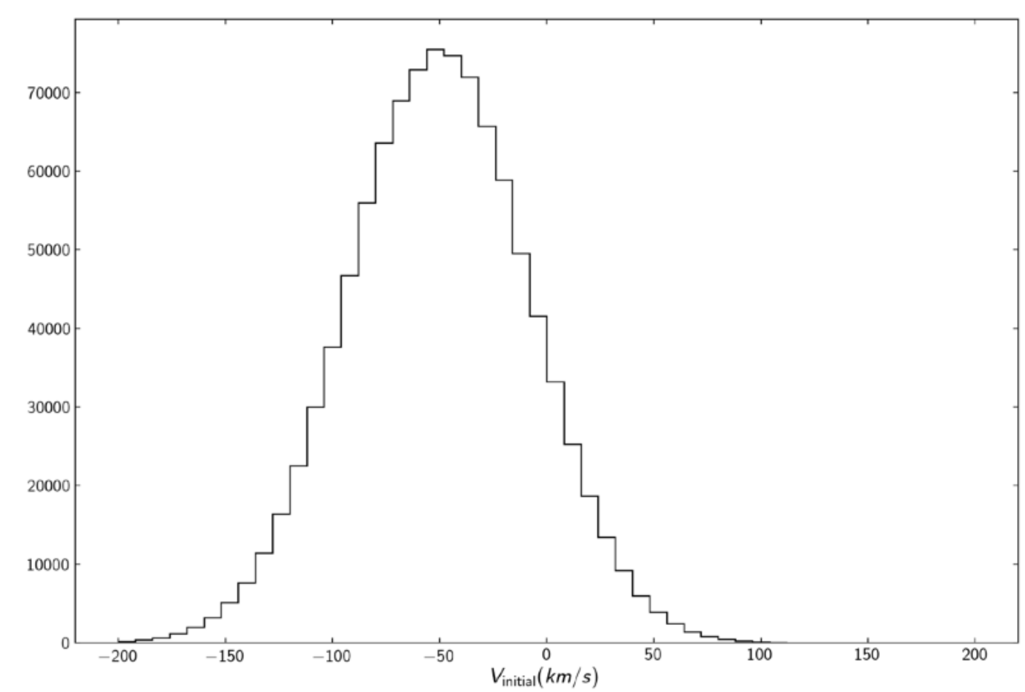


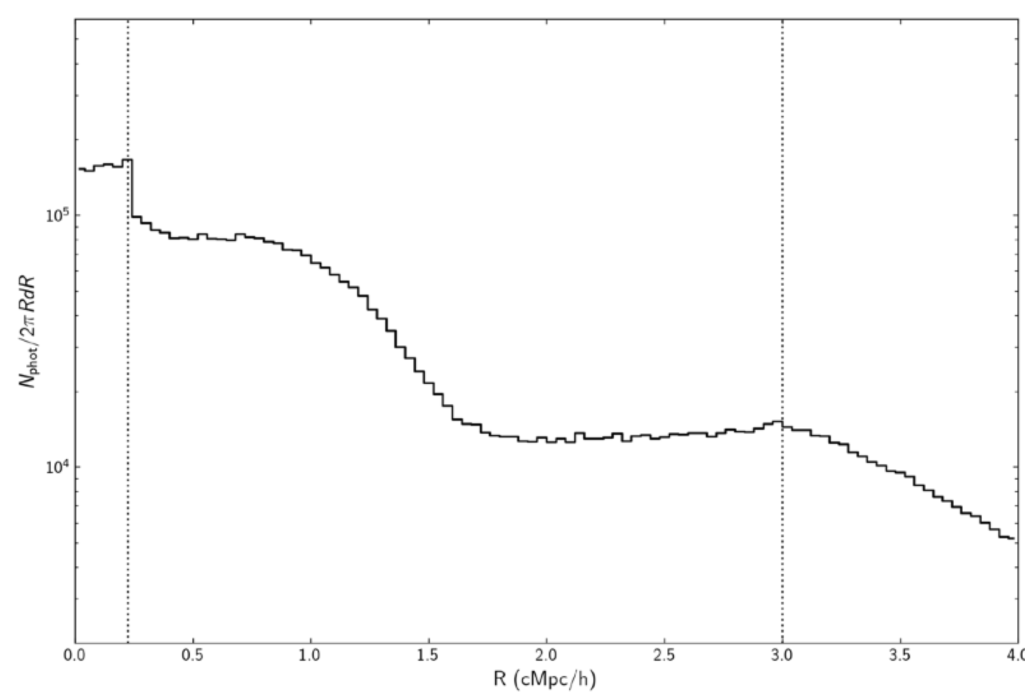


Input spectrum



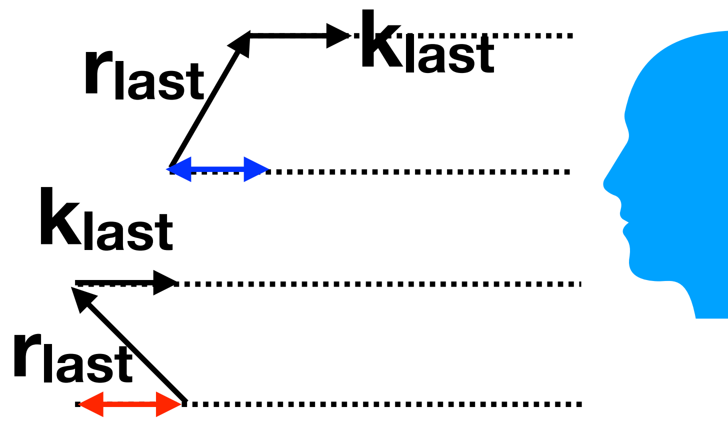


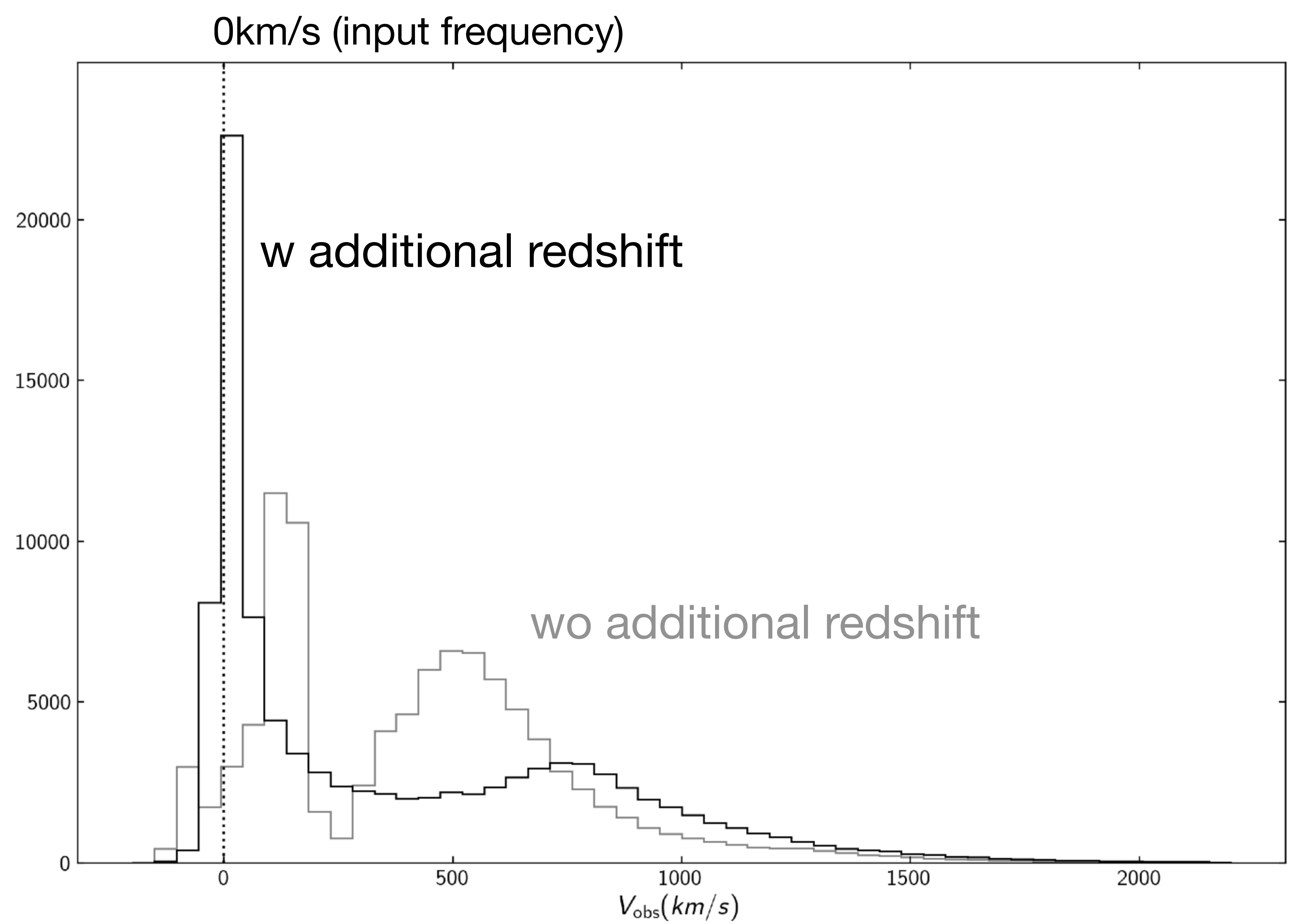




Additional redshift by - $\mathbf{r}_{\mathbf{last}} \cdot \mathbf{k}_{\mathbf{last}}$

Spectrum





Could be non-negligible…!

Next steps

- To properly implement an input spectrum
- To examine spectrum & SBP simultaneously
- For toy model
  - To explore further by changing halo mass, H(z), IGM density, temperature
- For CoDaII halos
  - To generate observables by using peeling-off method for multiple observers