The growth of galaxies and their gaseous haloes

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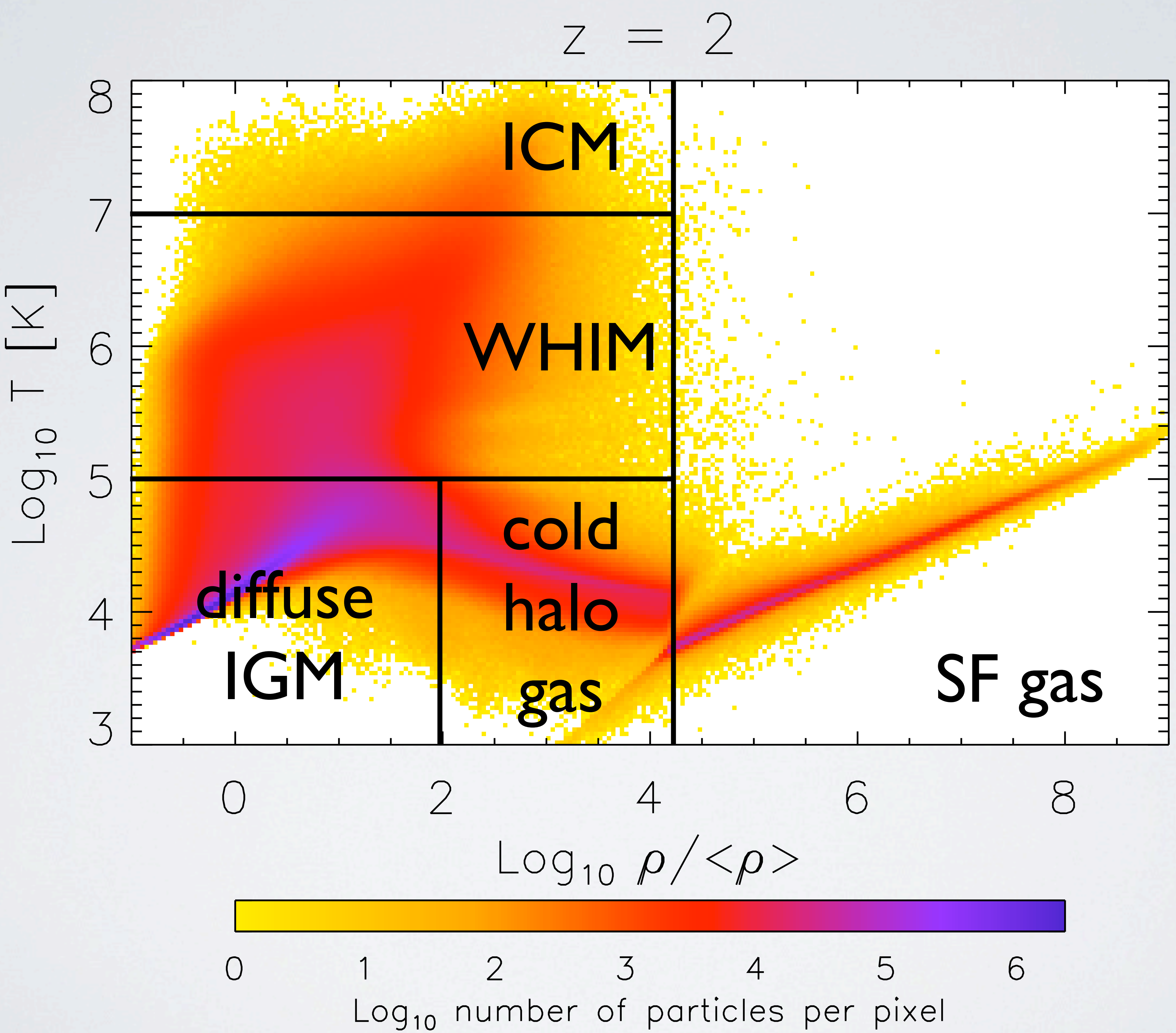
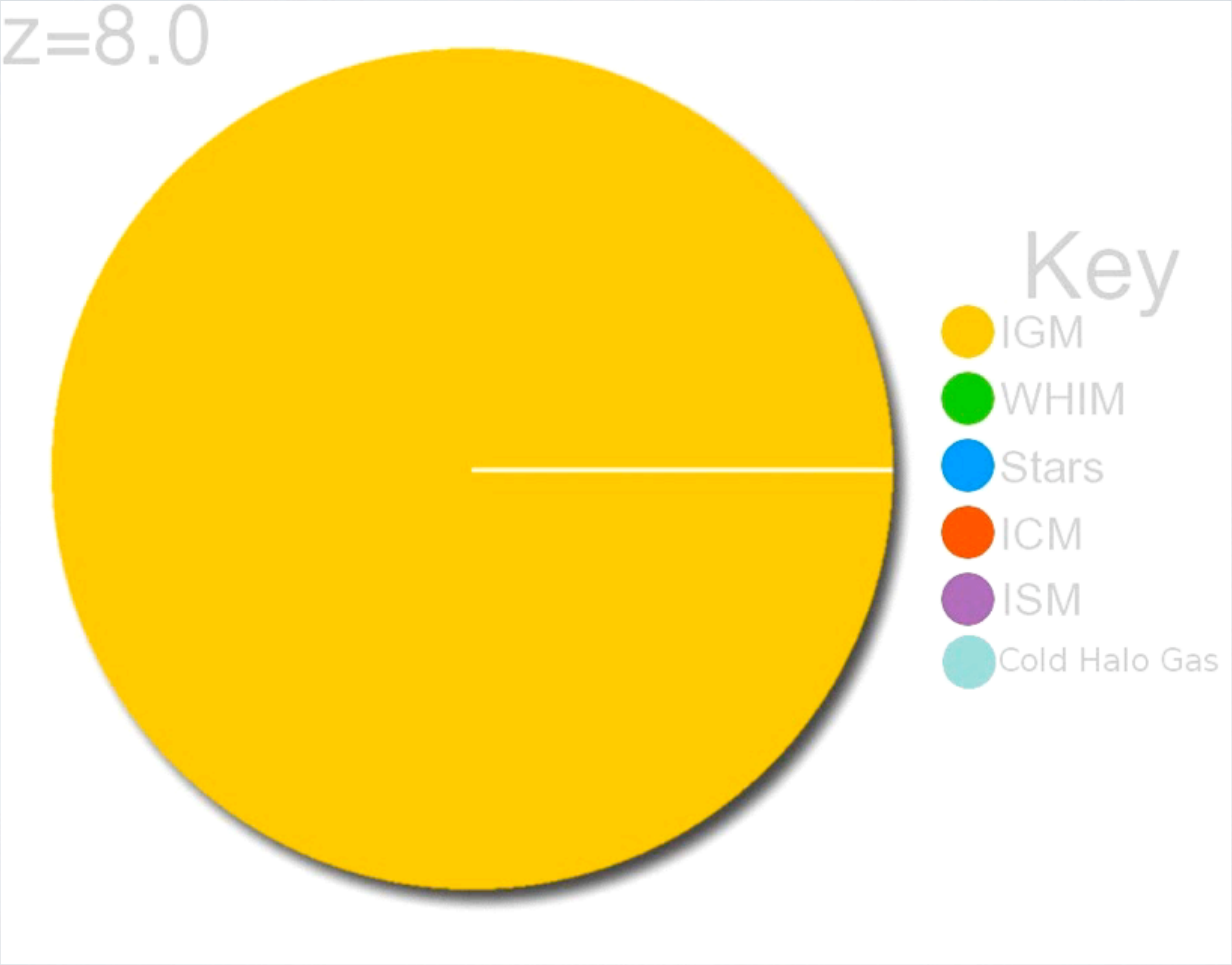
(with Joop Schaye)

Leiden University

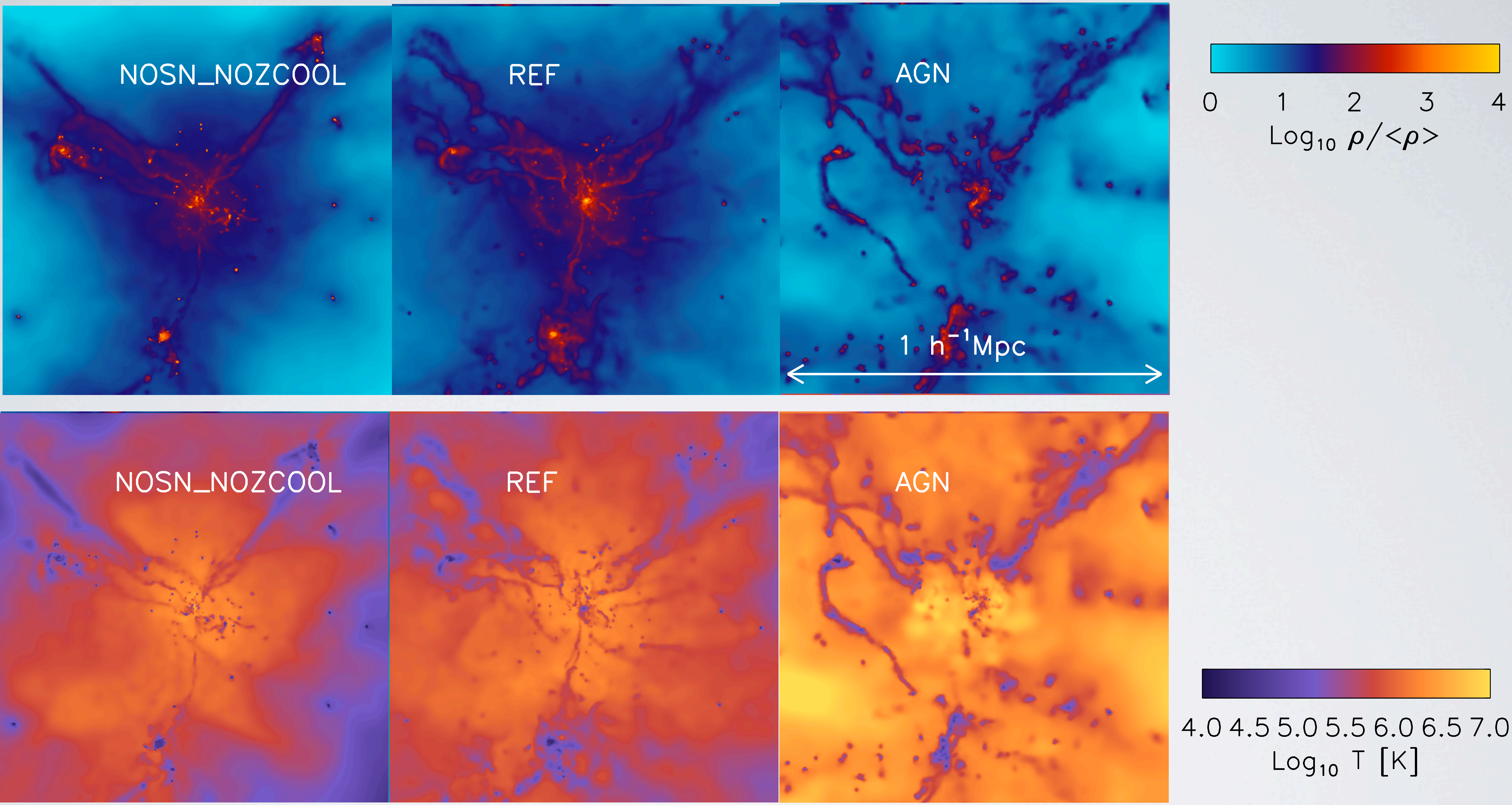
WHERE ARE THE BARYONS?



WHERE ARE THE BARYONS?

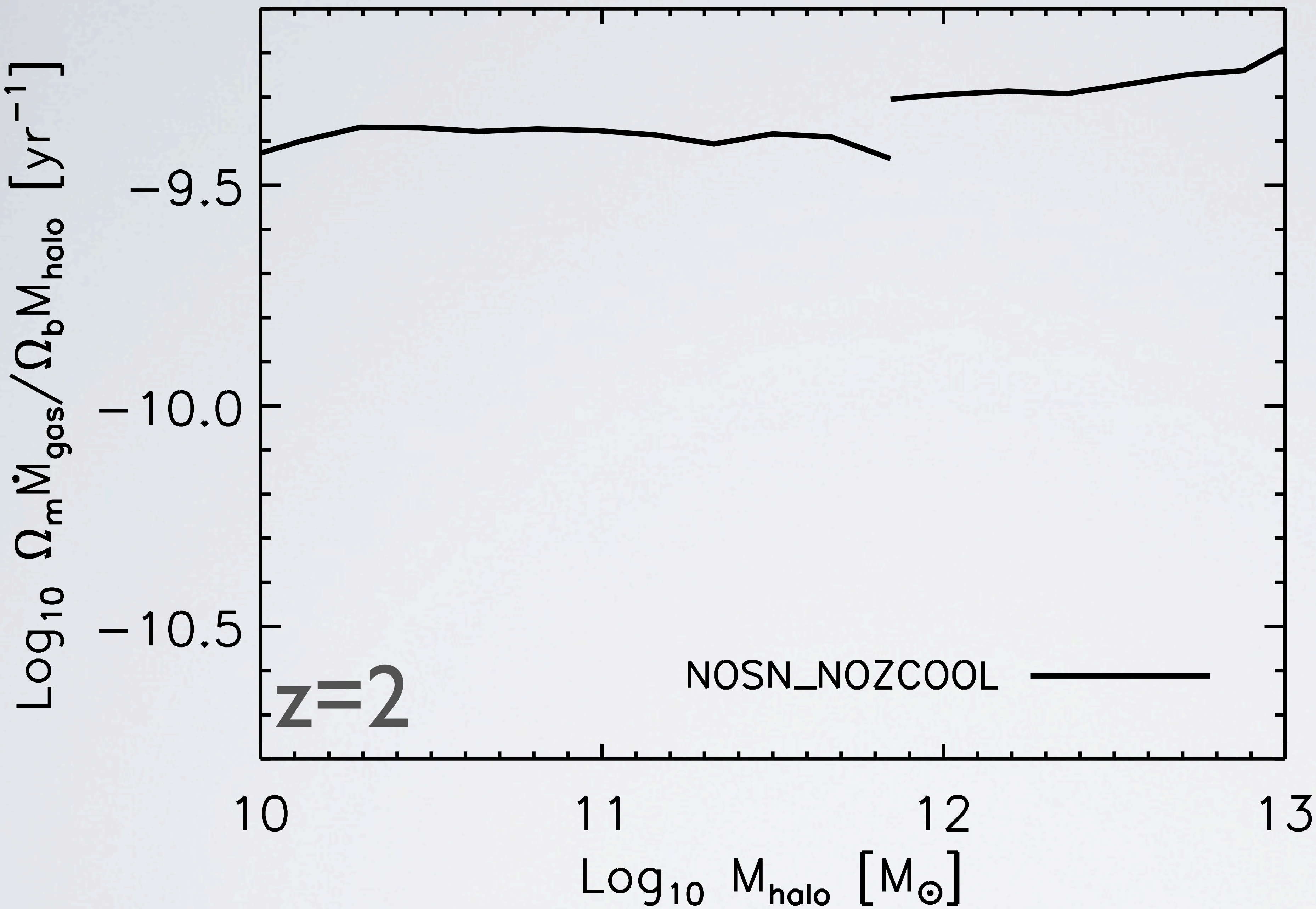


OWLS



- We study how gas accretes from the IGM onto haloes and from haloes onto galaxies to fuel star formation and how this is affected by cooling and feedback.

FUELLING HALOES

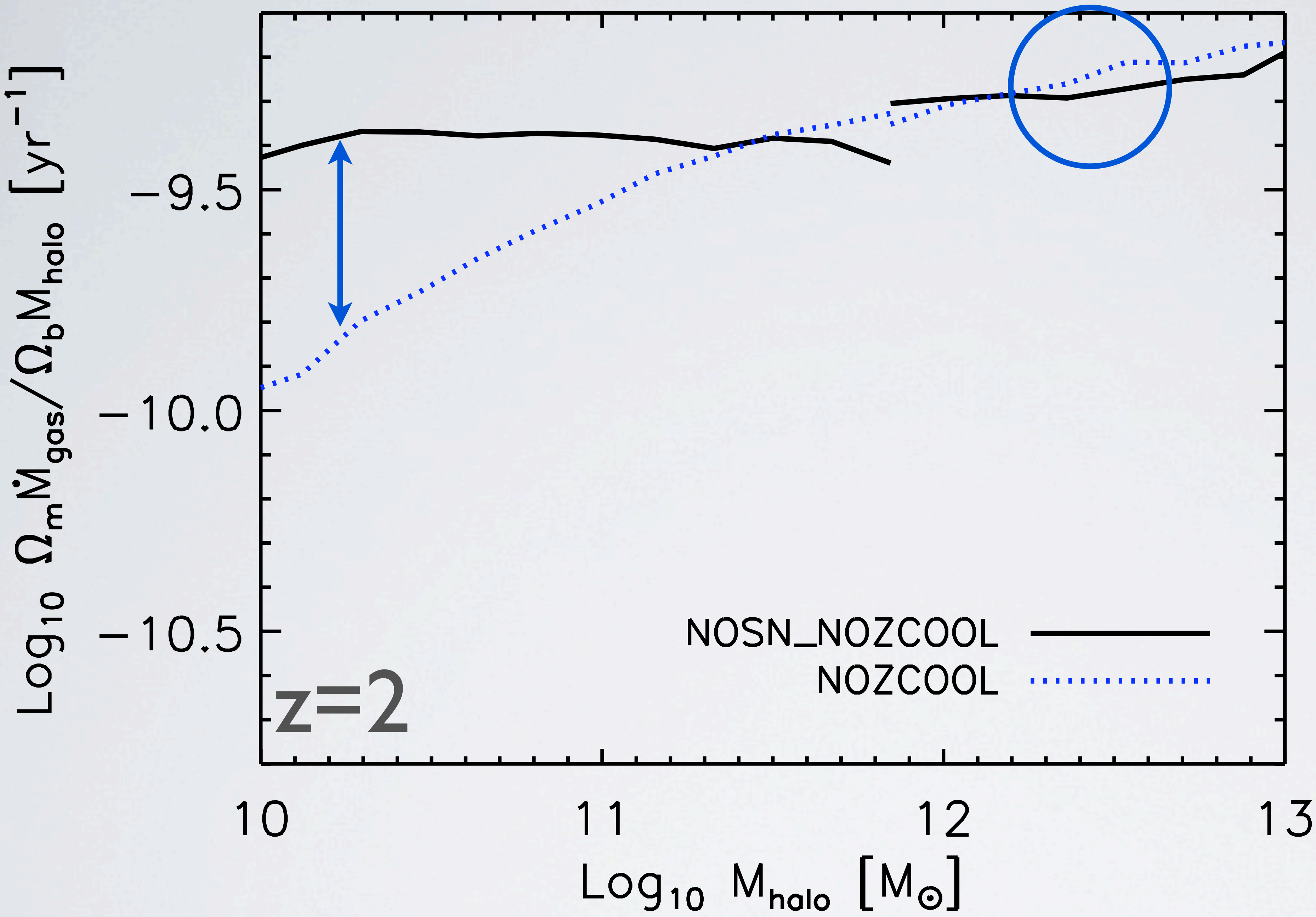


Specific accretion rate = $\frac{\text{accretion rate}}{\text{halo mass}}$

van de Voort et al. 2011a

- The dark matter accretion rate scales (almost) linearly with halo mass.
- Without feedback, the gas accretion rate onto haloes also increases (almost) linearly with halo mass.

FUELLING HALOES

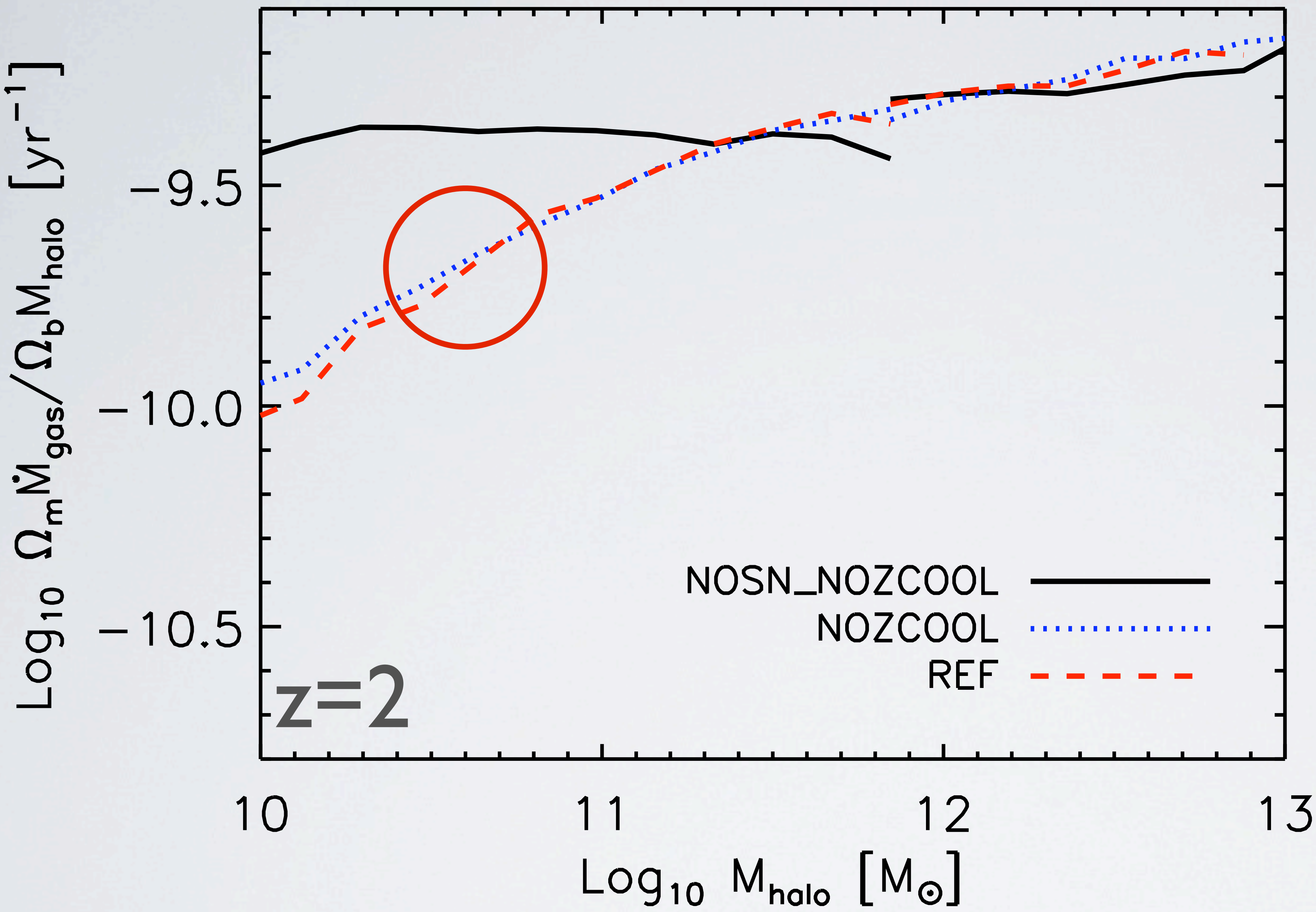


Specific accretion rate = $\frac{\text{accretion rate}}{\text{halo mass}}$

van de Voort et al. 2011a

- Supernova feedback reduces the halo accretion rate onto low-mass haloes (factor 2-3), because gas outside the halo is also affected and prevented from accreting.

FUELLING HALOES

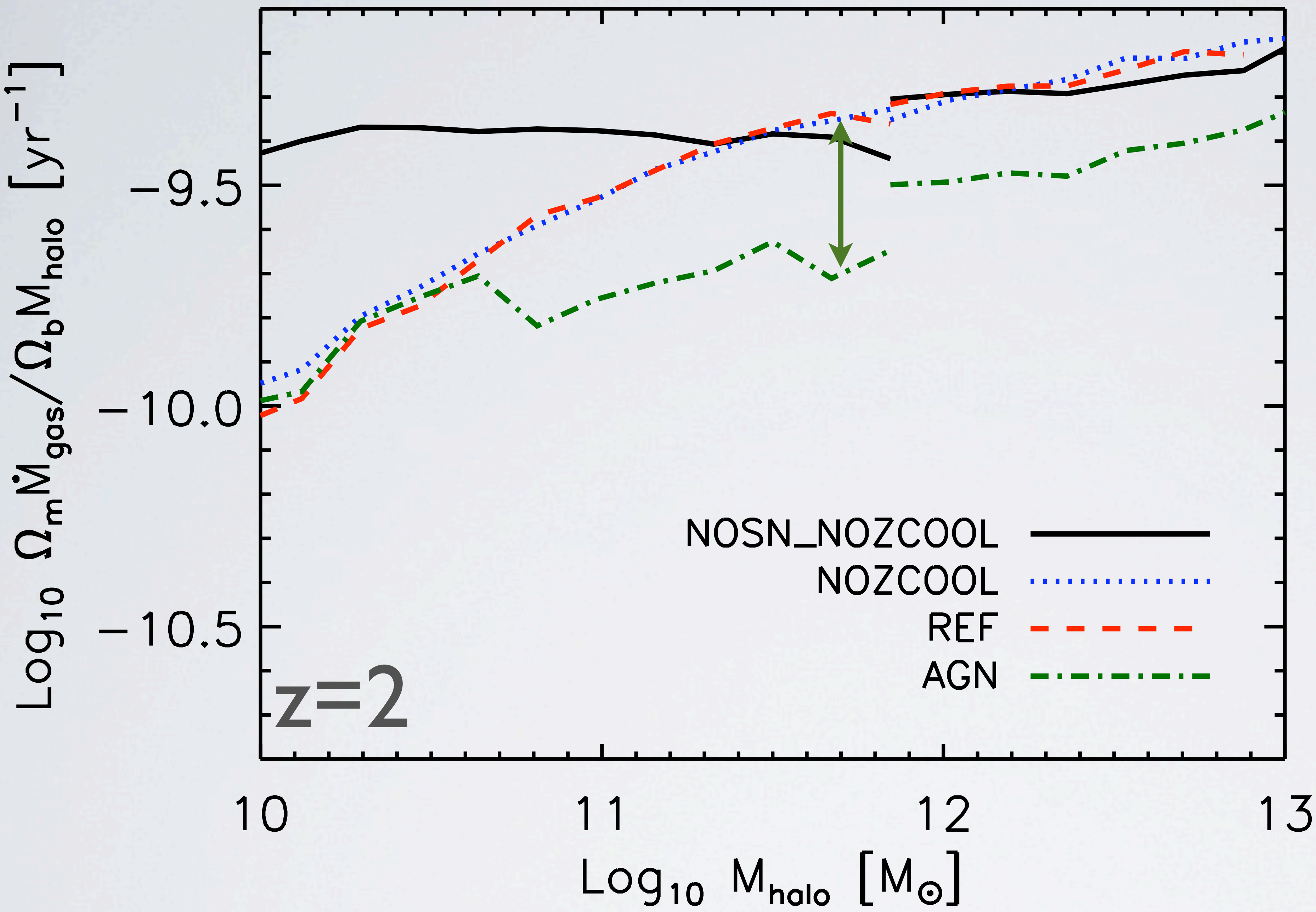


Specific accretion rate = $\frac{\text{accretion rate}}{\text{halo mass}}$

van de Voort et al. 2011a

- More cooling does not change the halo fuelling rate.

FUELLING HALOES

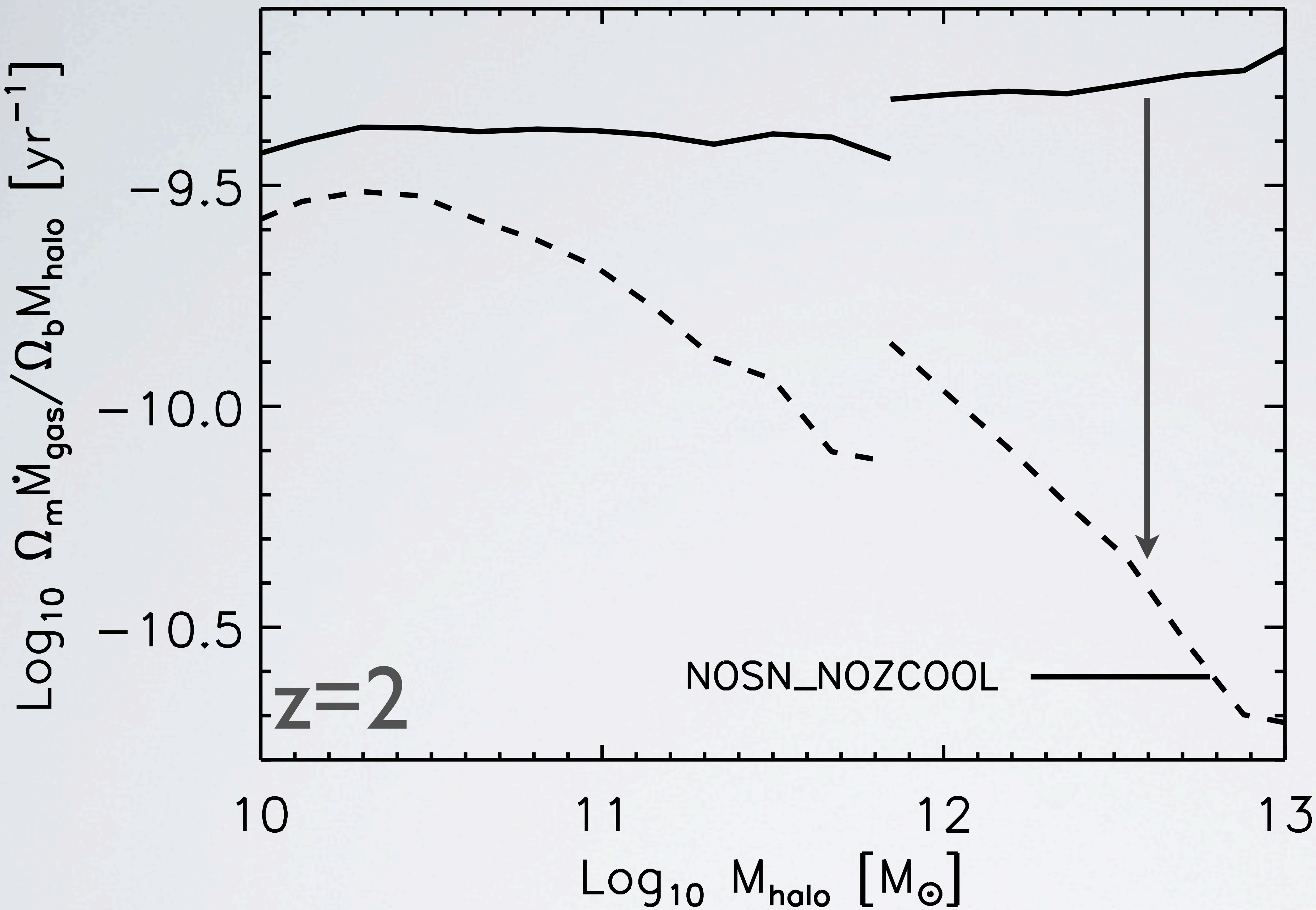


Specific accretion rate = $\frac{\text{accretion rate}}{\text{halo mass}}$

van de Voort et al. 2011a

- AGN feedback reduces the halo accretion rate onto high-mass haloes (factor 2-3), because gas outside the halo is also affected.

FUELLING HALOES & GALAXIES

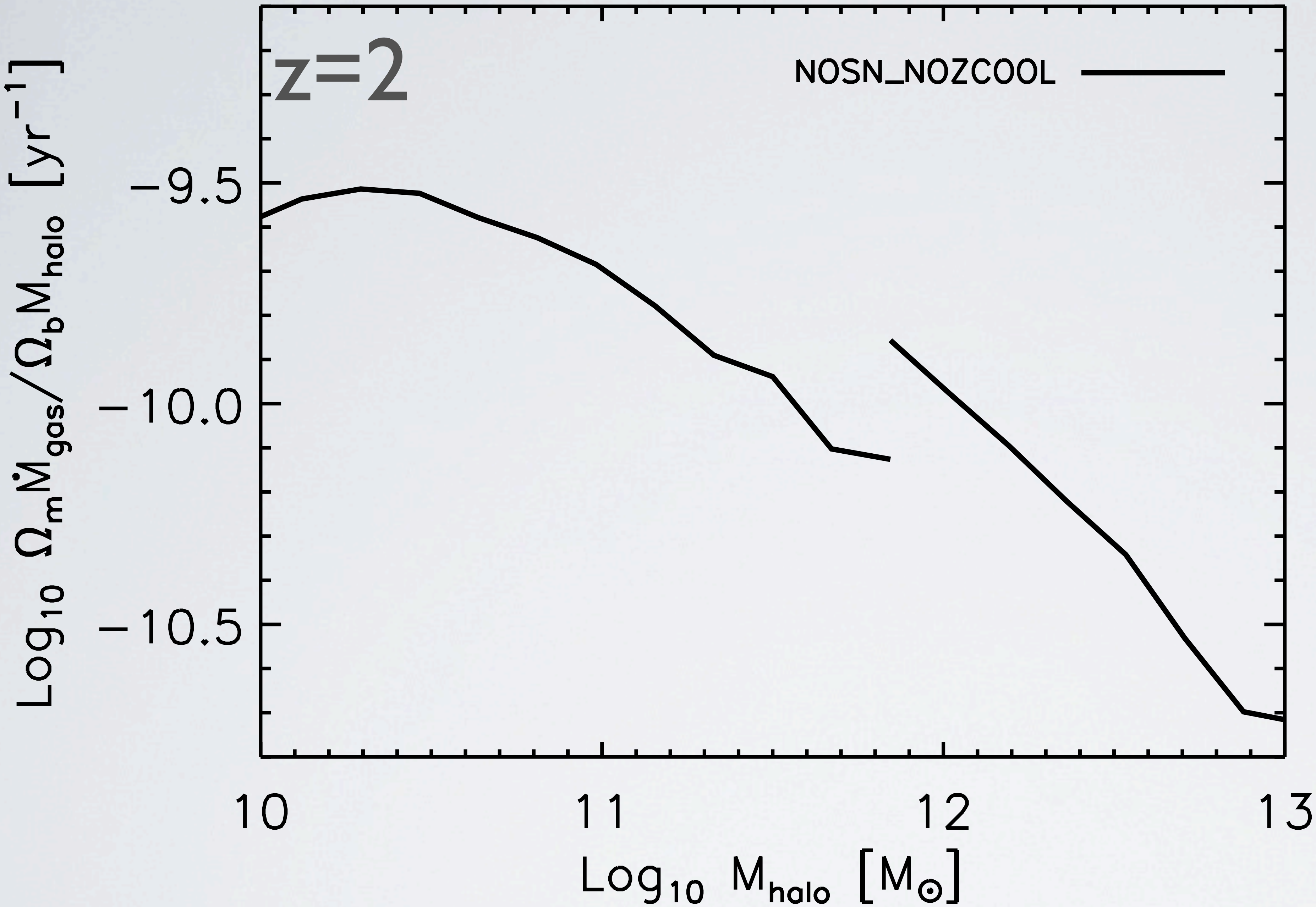


Specific accretion rate = $\frac{\text{accretion rate}}{\text{halo mass}}$

van de Voort et al. 2011a

- The galaxy accretion rate is always lower than the halo accretion rate.

FUELLING GALAXIES

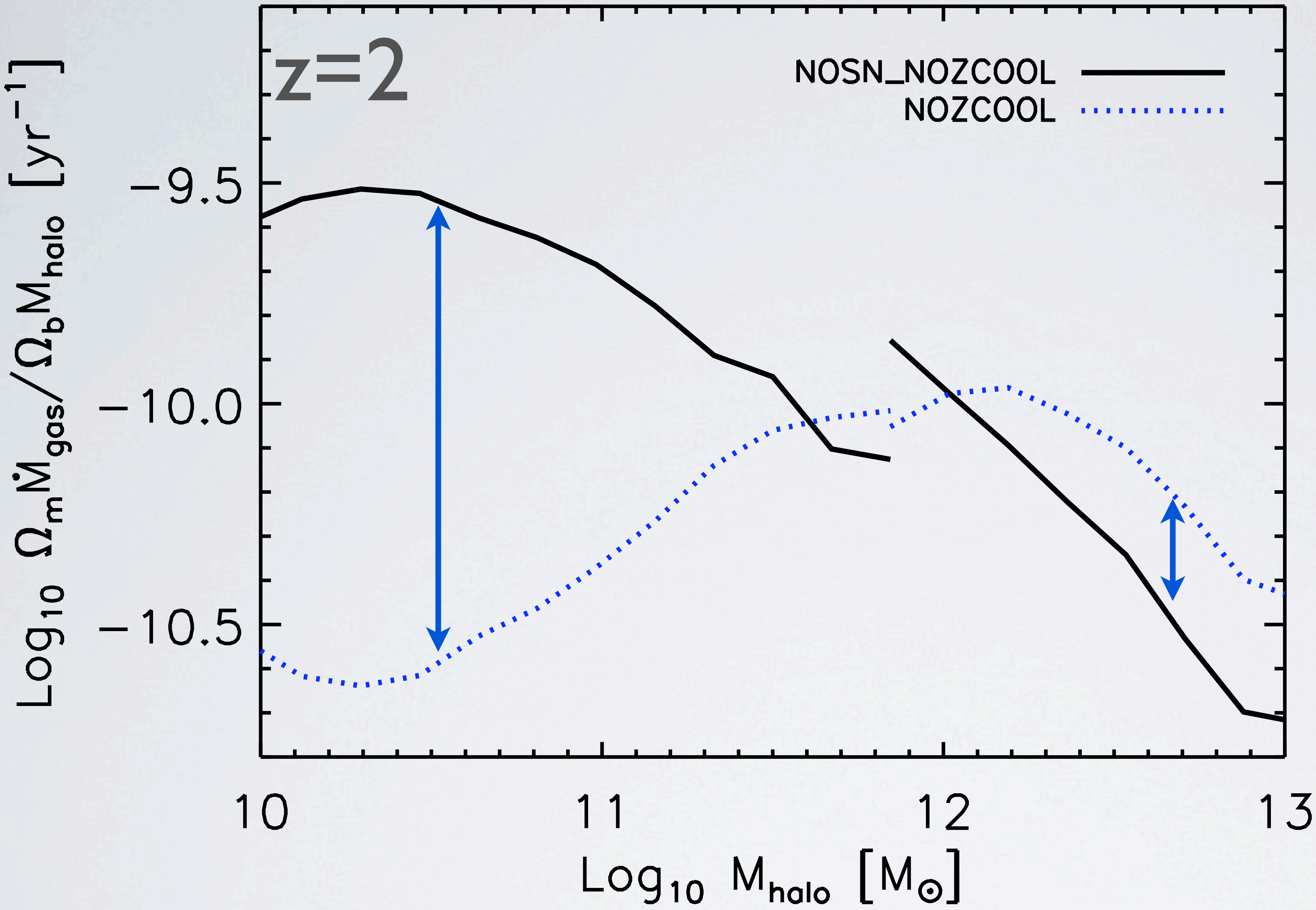


Specific accretion rate = $\frac{\text{accretion rate}}{\text{halo mass}}$

van de Voort et al. 2011a

- Without feedback, the galaxy accretion rate increases less steeply than linearly with halo mass.
- Without feedback, the specific galaxy accretion rate peaks around 10^{10} M_{sun}.

FUELLING GALAXIES

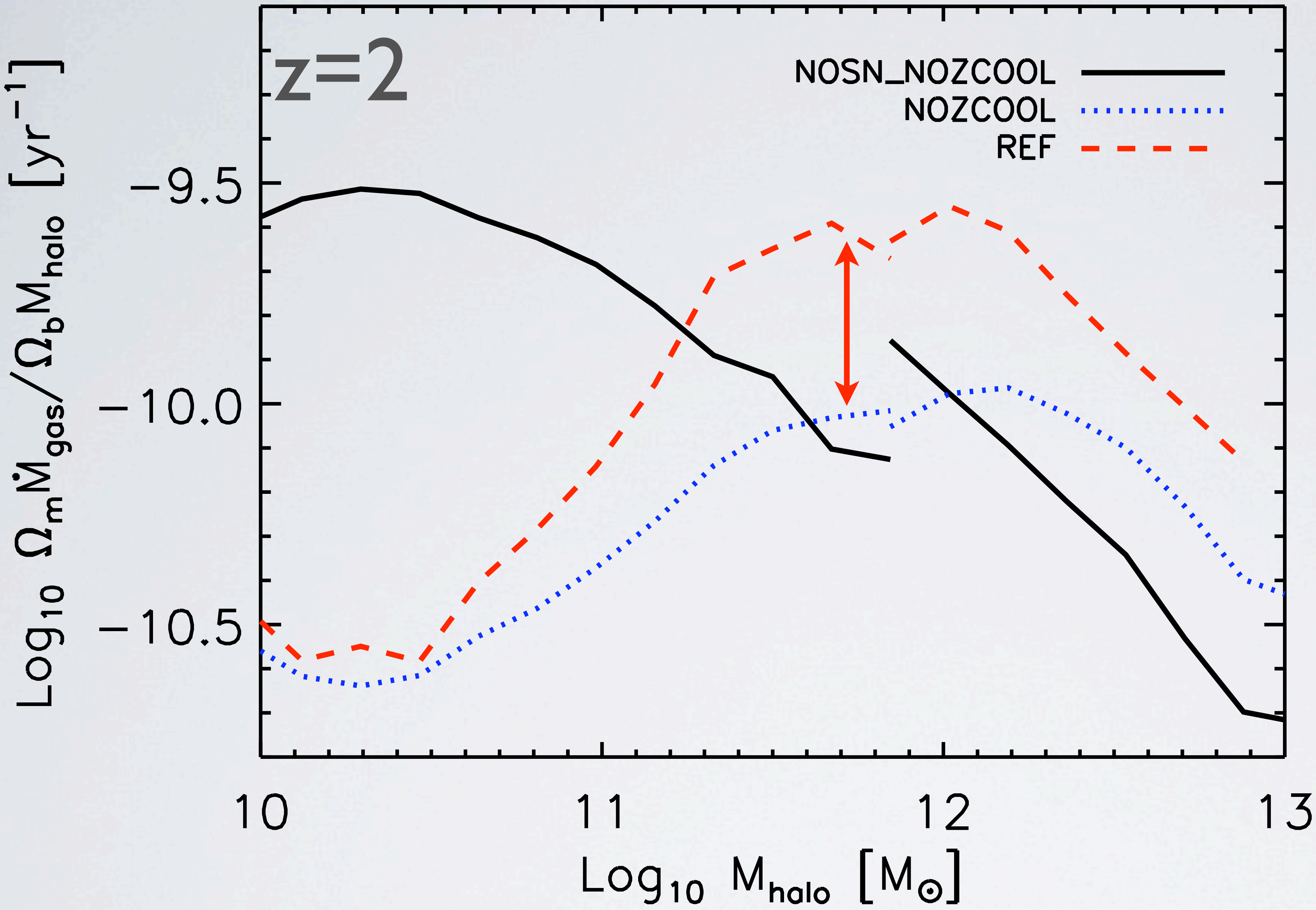


Specific accretion rate = $\frac{\text{accretion rate}}{\text{halo mass}}$

van de Voort et al. 2011a

- Supernova feedback reduces the galaxy accretion rate onto low-mass haloes strongly (order of magnitude).
- Increase for high-mass haloes, because more gas is left.

FUELLING GALAXIES

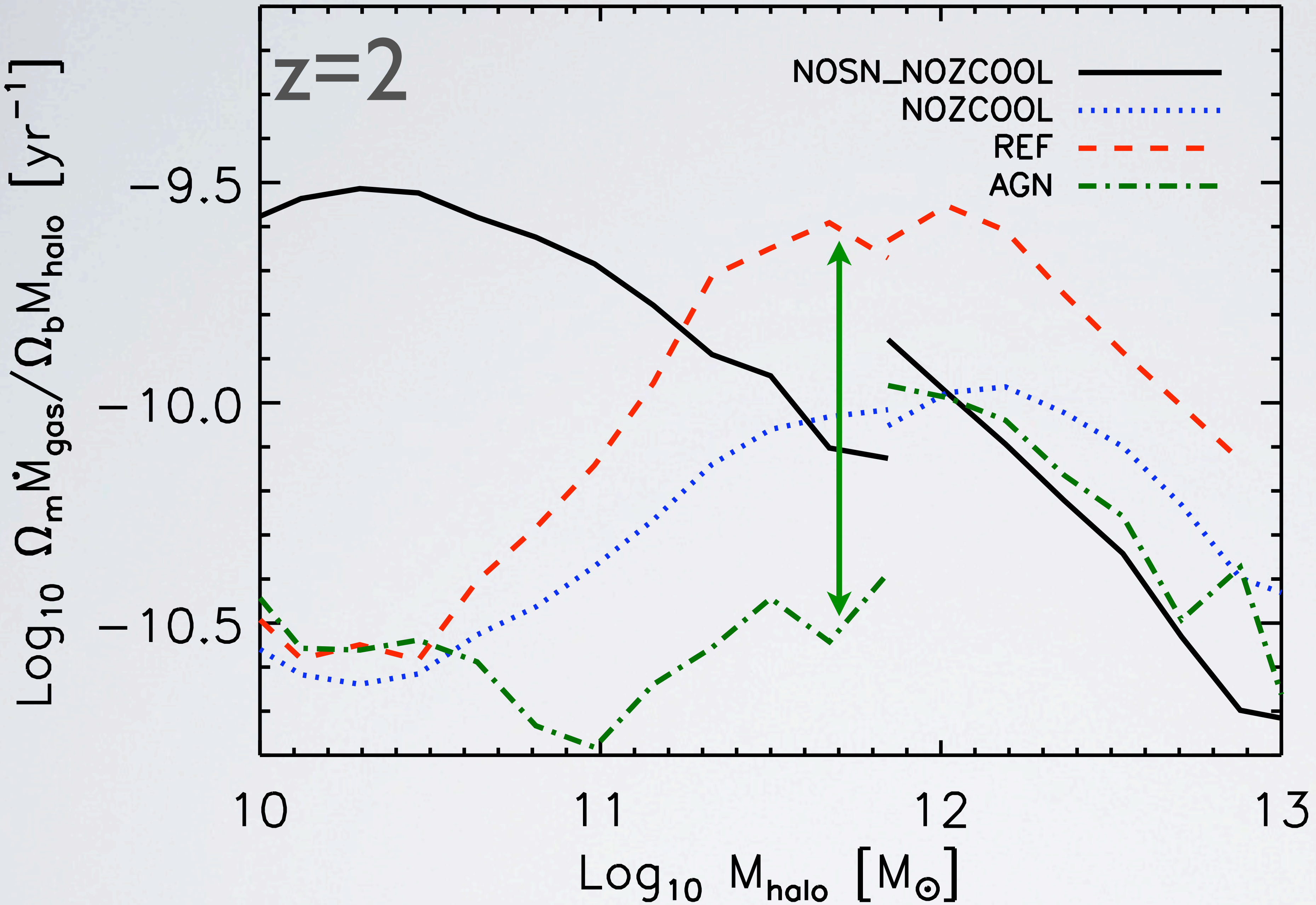


$$\text{Specific accretion rate} = \frac{\text{accretion rate}}{\text{halo mass}}$$

van de Voort et al. 2011a

- More cooling enhances the galaxy fueling rate.

FUELLING GALAXIES

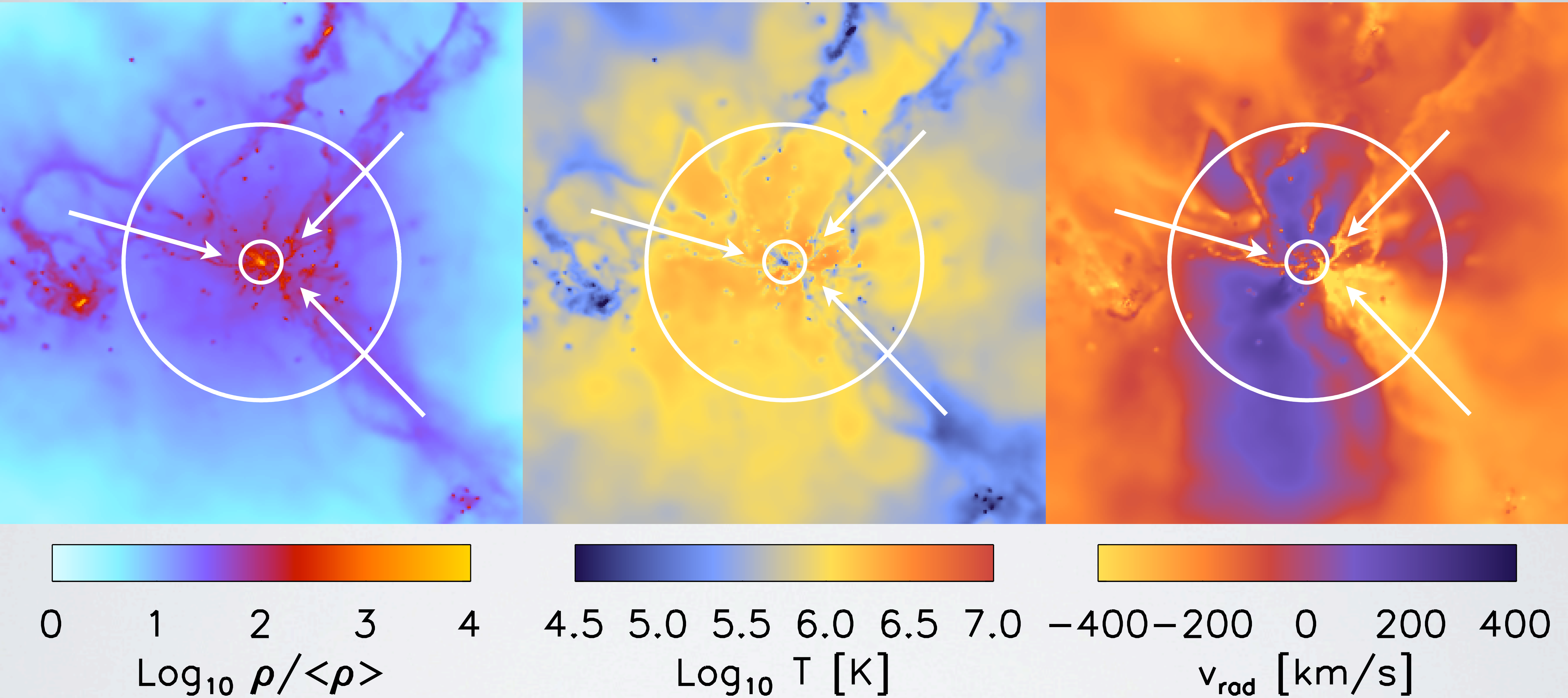


Specific accretion rate = $\frac{\text{accretion rate}}{\text{halo mass}}$

van de Voort et al. 2011a

- AGN feedback reduces the galaxy accretion rate onto high-mass haloes strongly (order of magnitude).
- With feedback, the specific galaxy accretion rate peaks around 10^{12} M_{sun}.

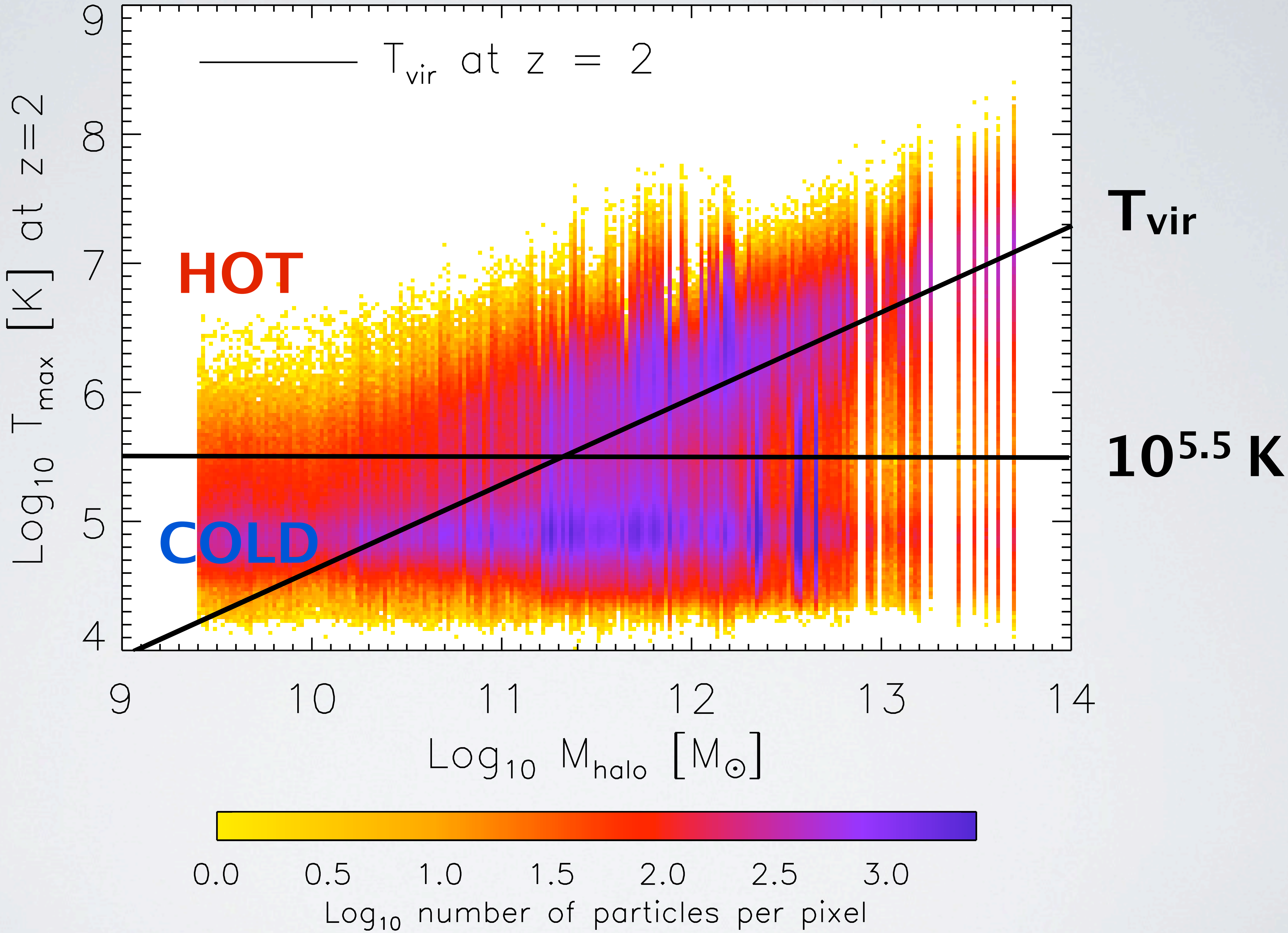
10^{12} M_{SUN} HALO AT Z=2



- Diffuse gas shock heats at the virial radius to the virial temperature, whereas dense filaments stay colder.
- Inflow happens preferentially along cold streams.

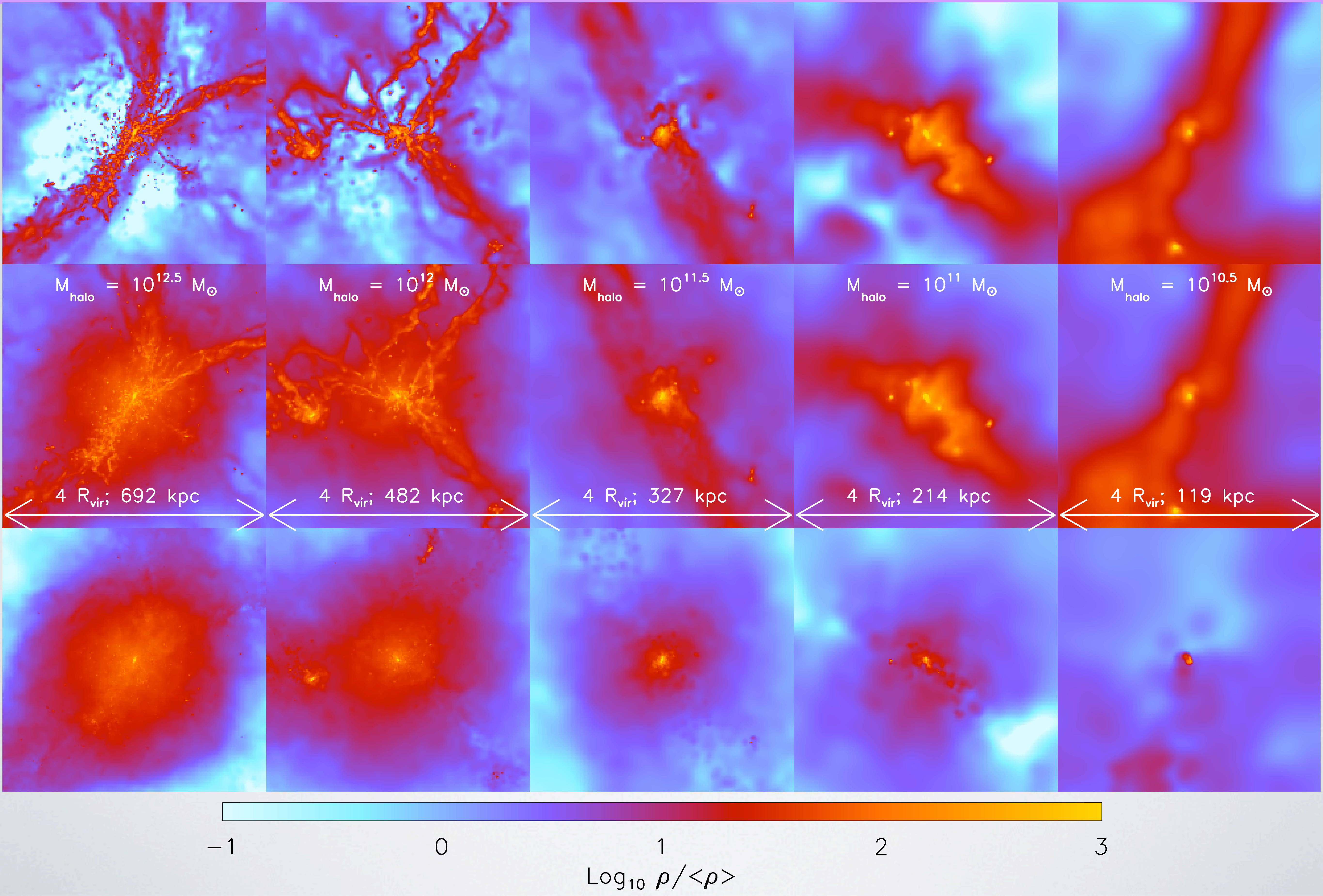
Birnboim & Dekel 2003, Keres et al. 2005, Dekel & Birnboim 2006, Ocvirk et al 2008, Brooks et al. 2009, Dekel et al. 2009, Keres et al. 2009, van de Voort et al. 2011, Powell et al. 2011, Faucher-Giguère et al. 2011

HOT AND COLD GAS

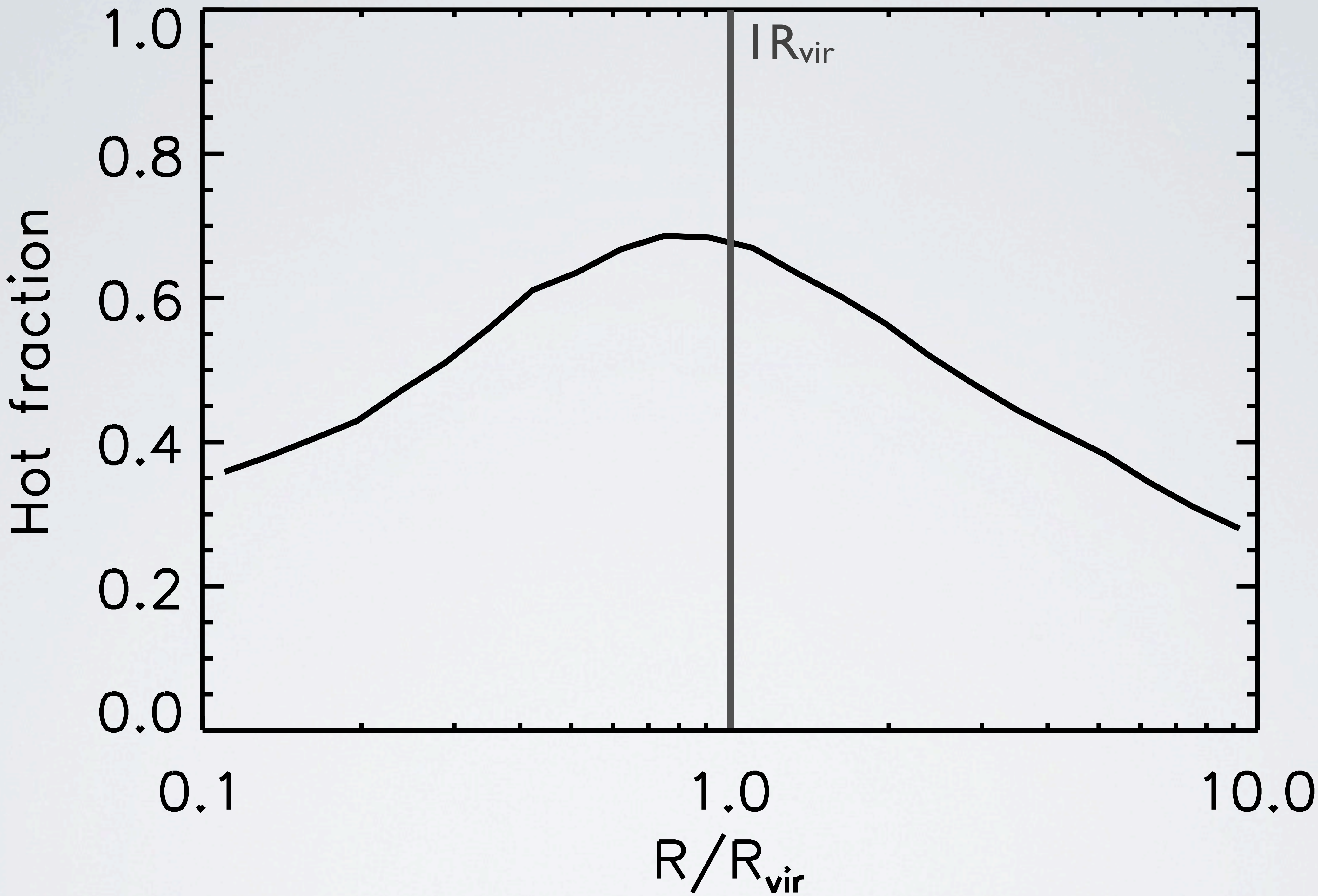


- This is the maximum PAST temperature.

HOT AND COLD GAS

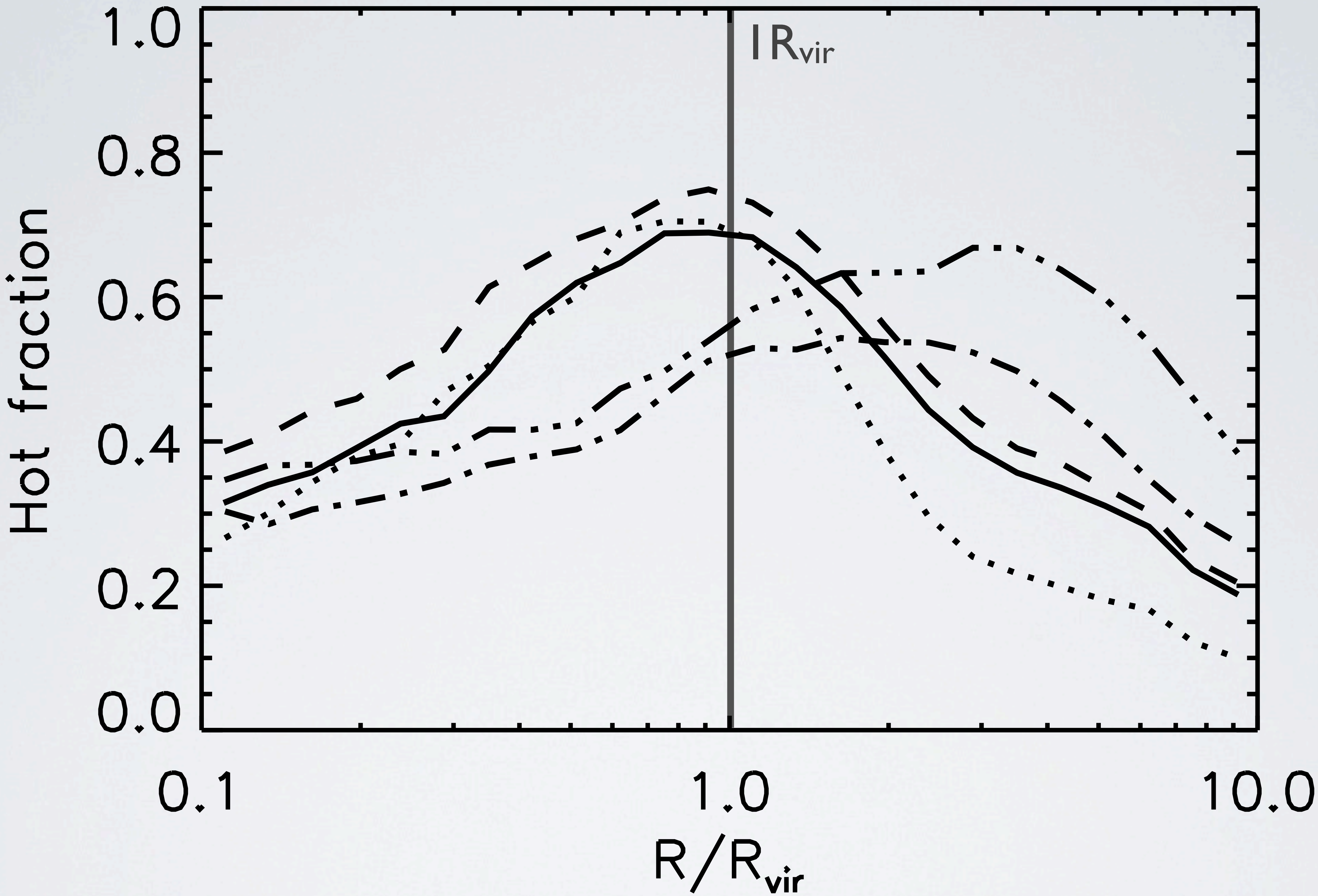


HOT FRACTION



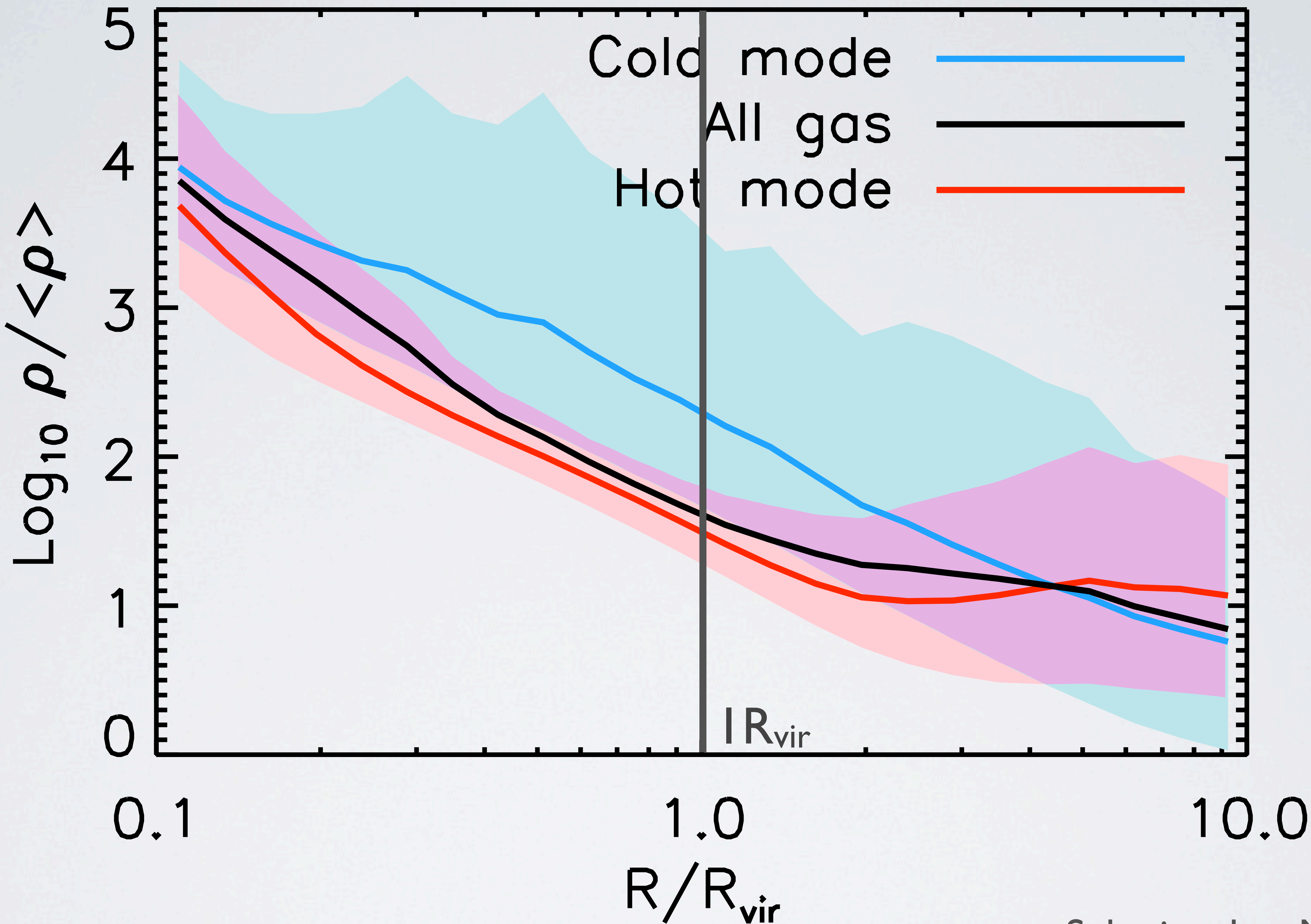
- For haloes around 10^{12} M_{sun} at z=2, hot-mode gas dominates around R_{vir}, cold-mode gas dominates inside $0.3R_{vir}$.

HOT FRACTION



- Strong feedback pushes hot-mode gas out to large radii.

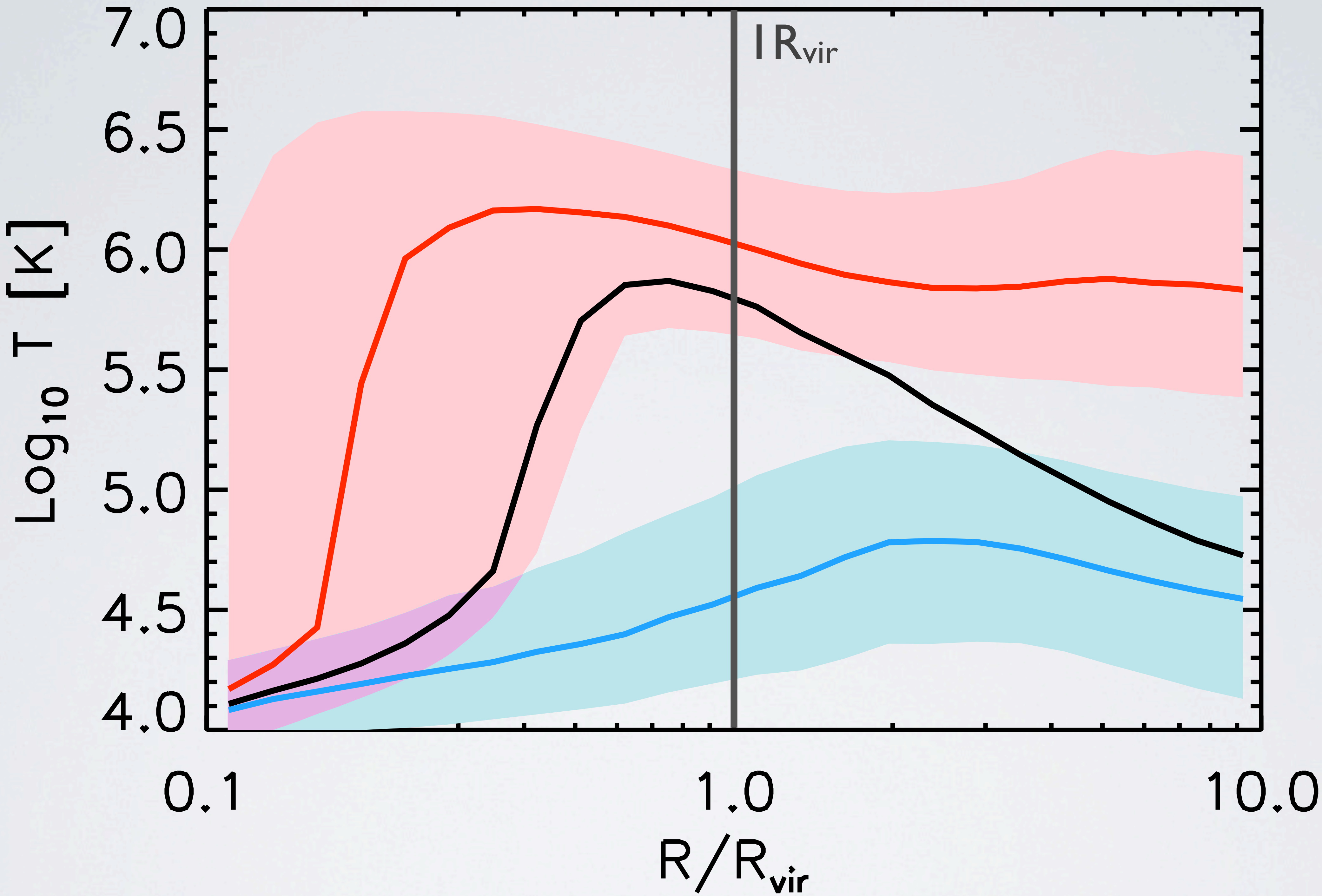
DENSITY



Submitted to MNRAS

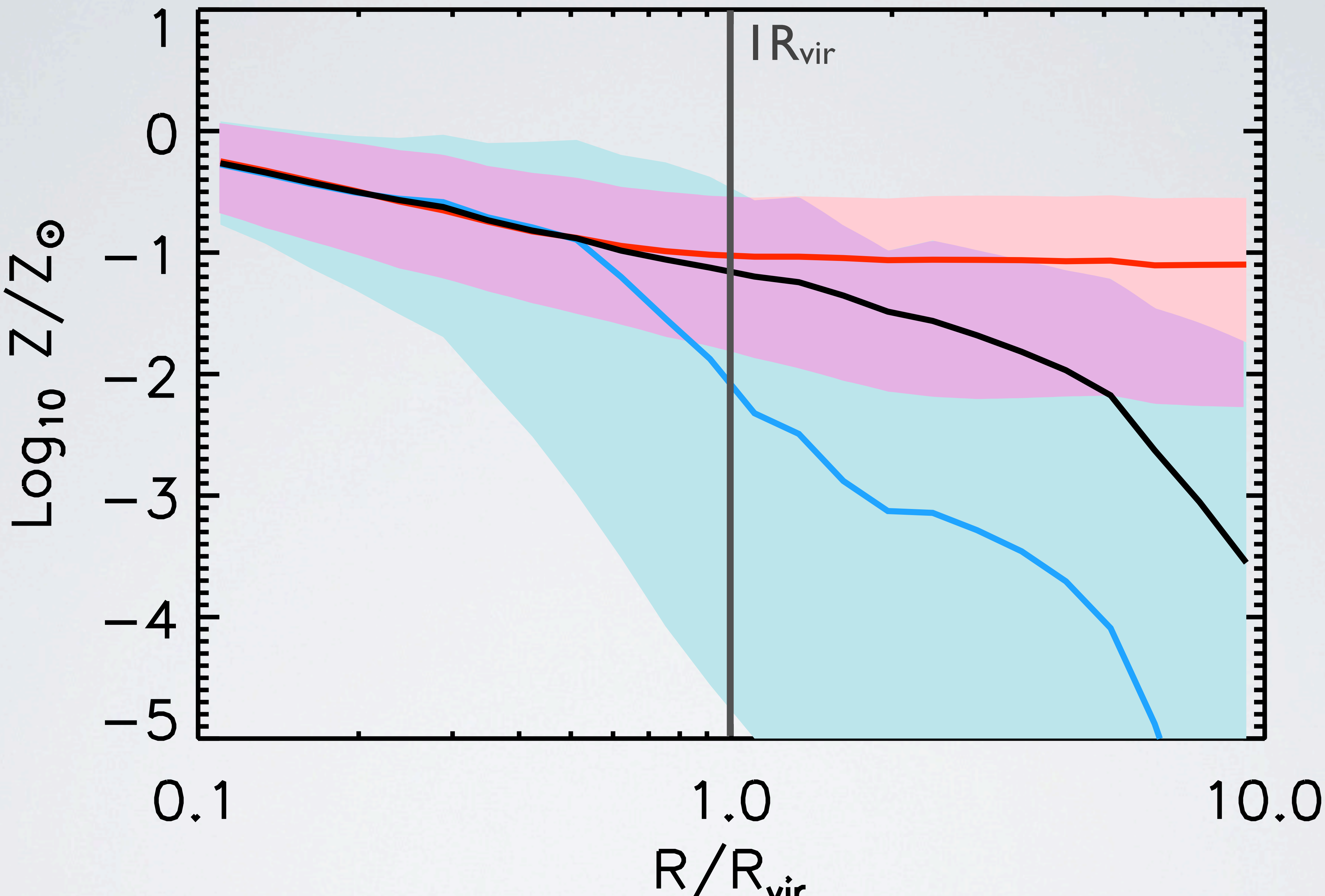
- Cold-mode gas is denser by up to an order of magnitude and has a much larger scatter than hot-mode gas.

TEMPERATURE



- The cold-mode temperature decreases slowly from $2R_{vir}$.
- The hot-mode temperature first increases towards the centre until it drops sharply at $0.2R_{vir}$.

METALLICITY



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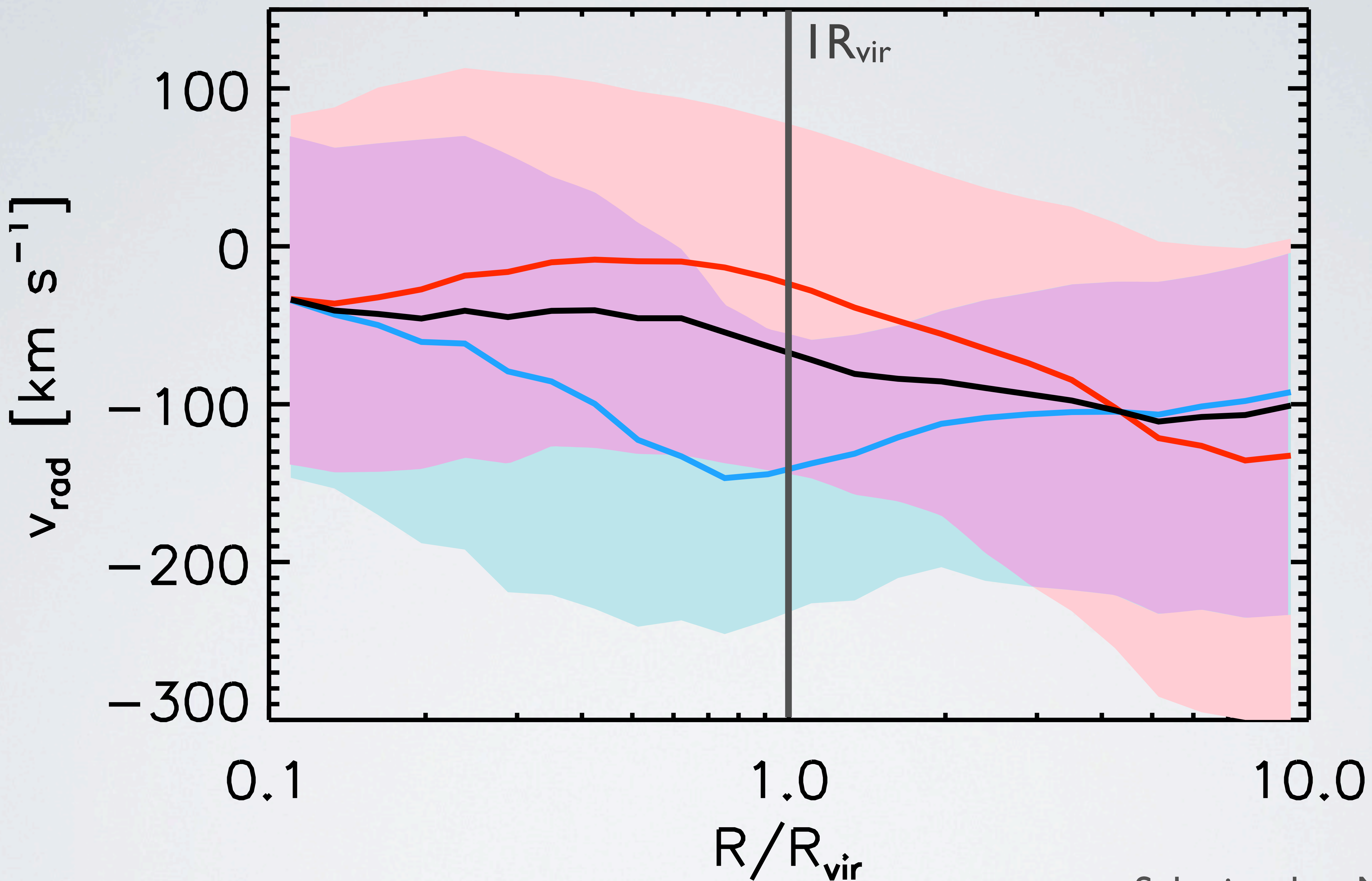
- Cold-mode gas has a lower metallicity (at large enough radii) and a much larger scatter than hot-mode gas.

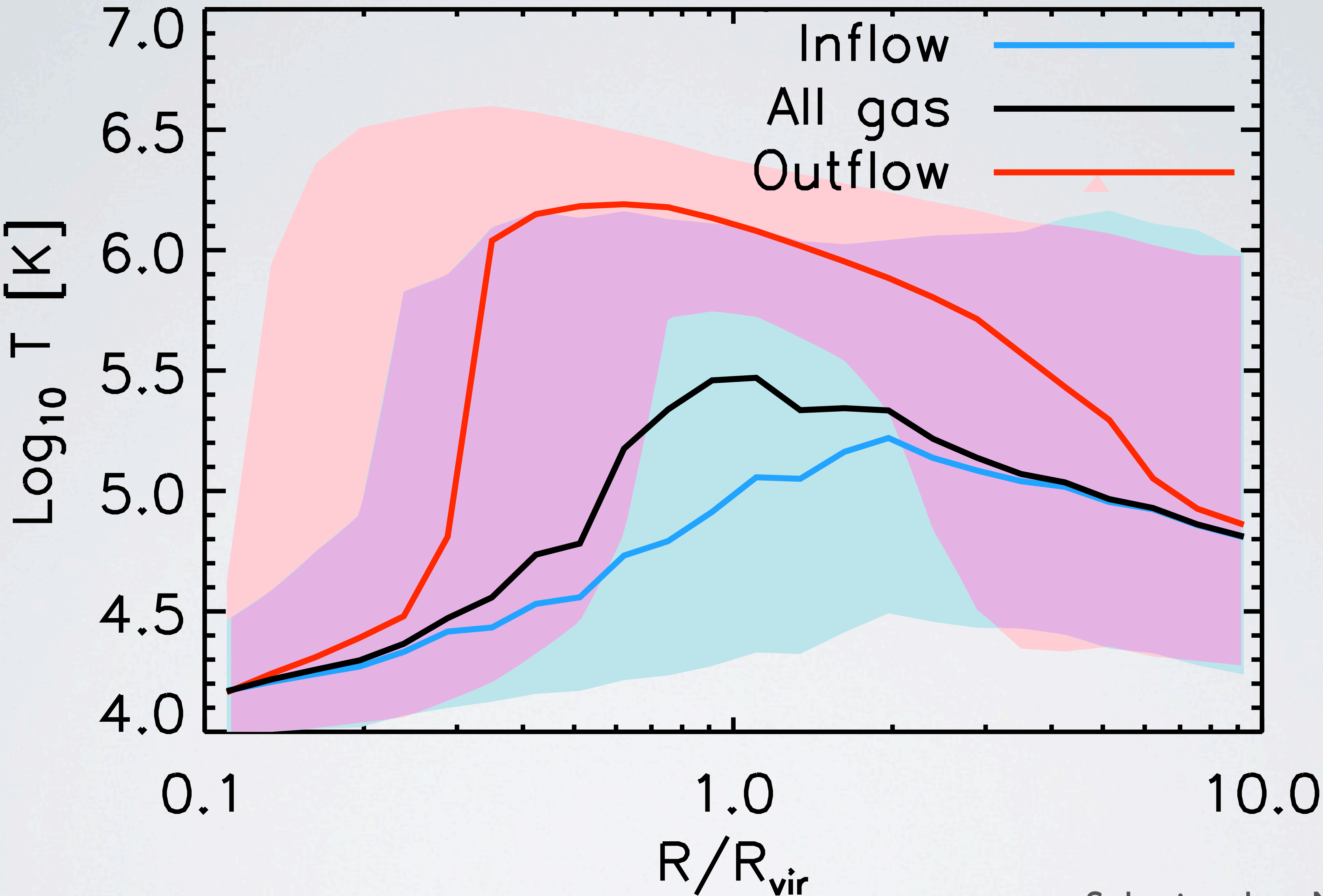
RADIAL VELOCITY



Submitted to MNRAS

- Cold-mode gas is much more strongly inflowing than hot-mode gas, especially around R_{vir}.

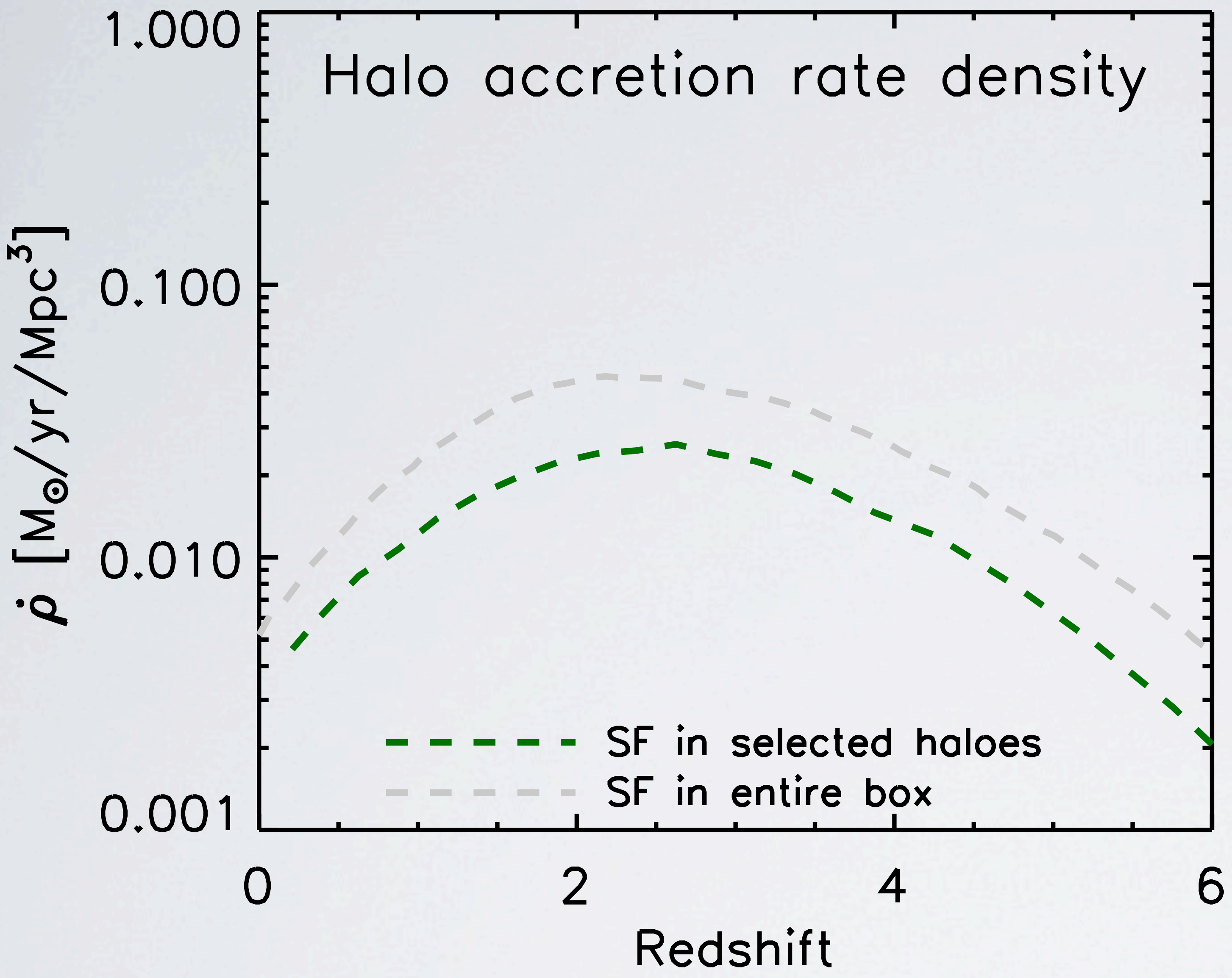
INFLOW & OUTFLOW



Submitted to MNRAS

- Similar, but weaker, bimodal behaviour is present when we separate inflowing from outflowing gas.

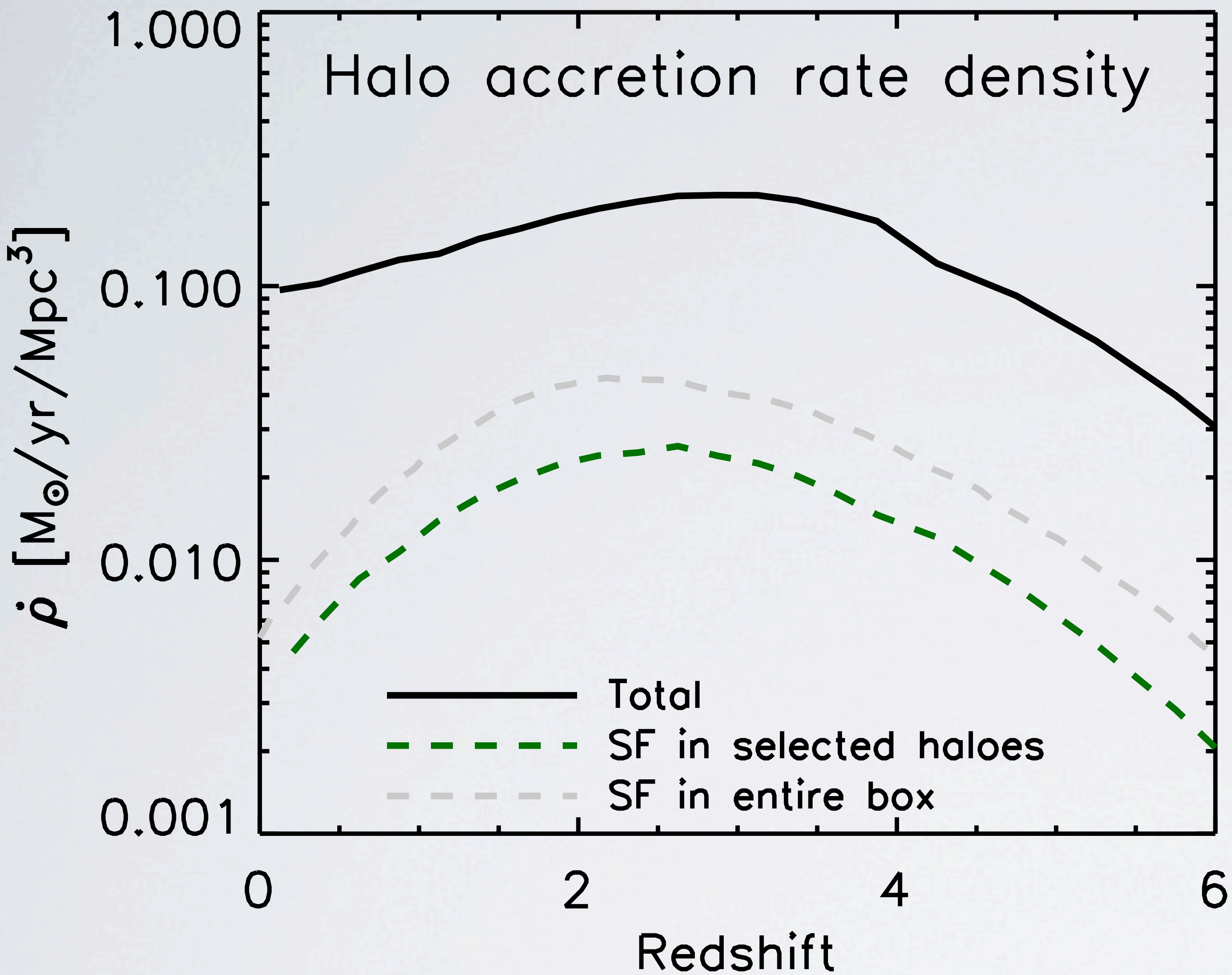
GLOBAL GAS ACCRETION



van de Voort et al. 2011b

- After redshift 2 the observed cosmic SFR density drops by an order of magnitude.
- This drop is reproduced in the simulation with AGN feedback.

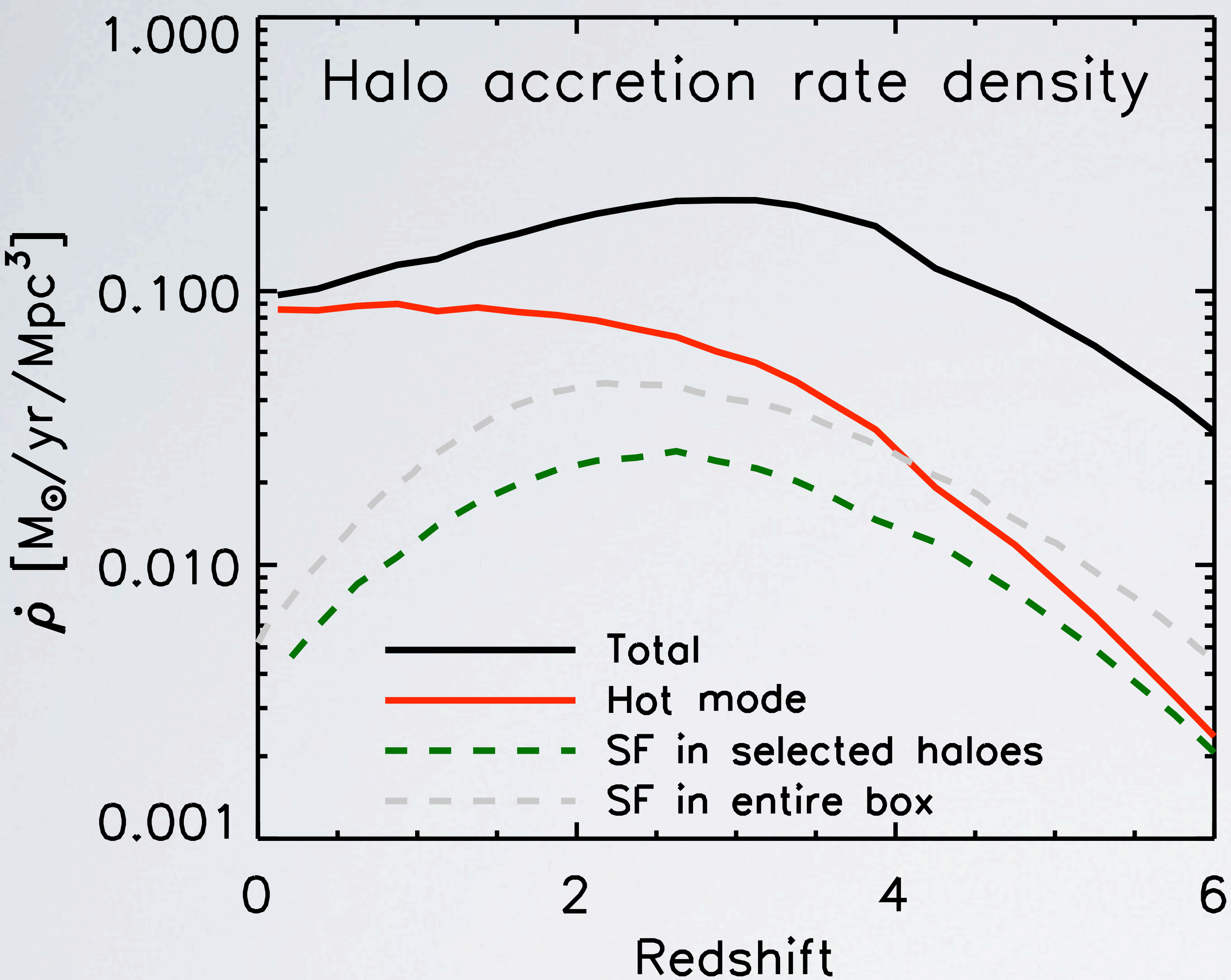
GLOBAL GAS ACCRETION



van de Voort et al. 2011b

- Most gas that flows into haloes never forms stars.

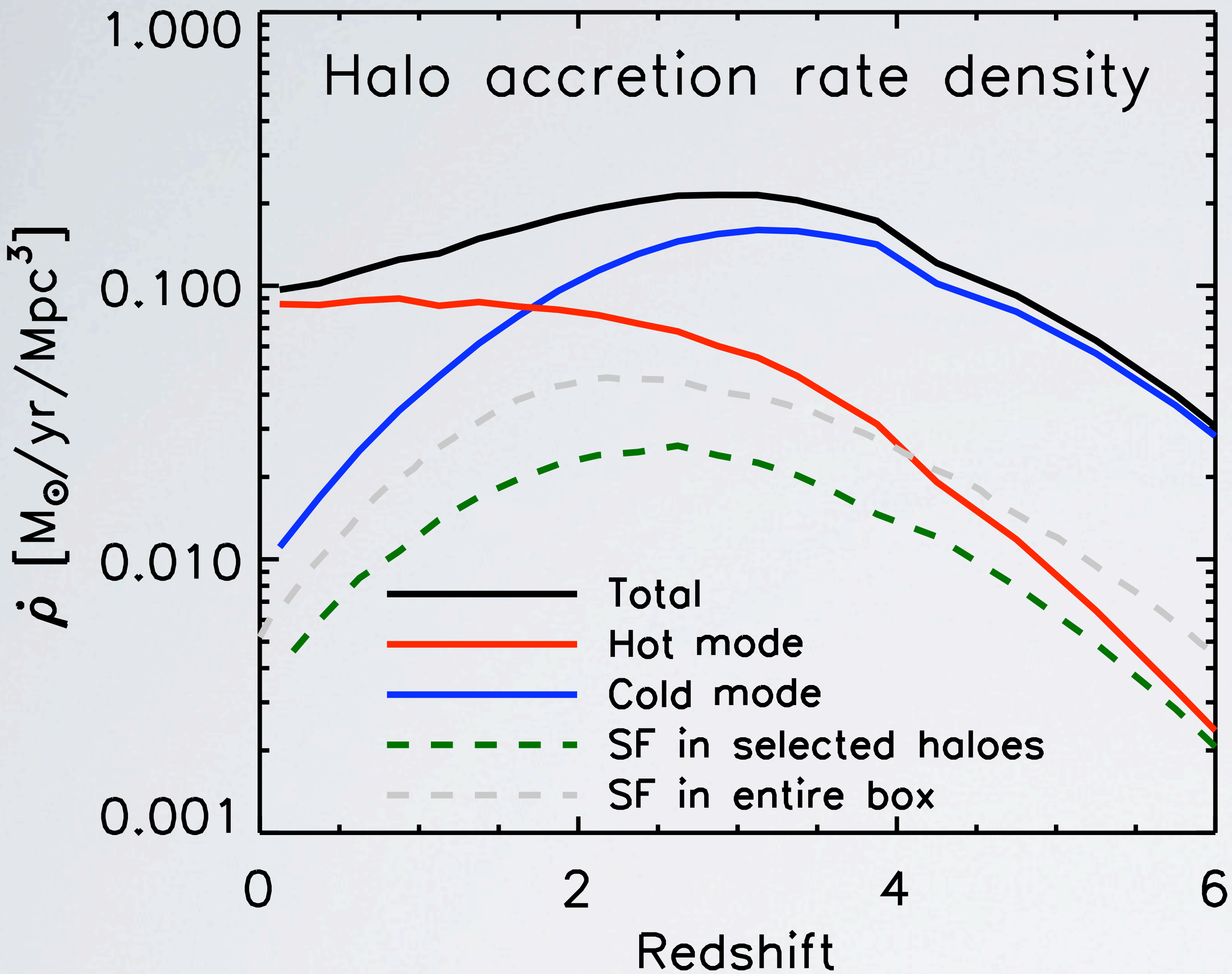
GLOBAL GAS ACCRETION



van de Voort et al. 2011b

- Both hot and total halo accretion rate densities cannot explain the decreasing cosmic SFR density.

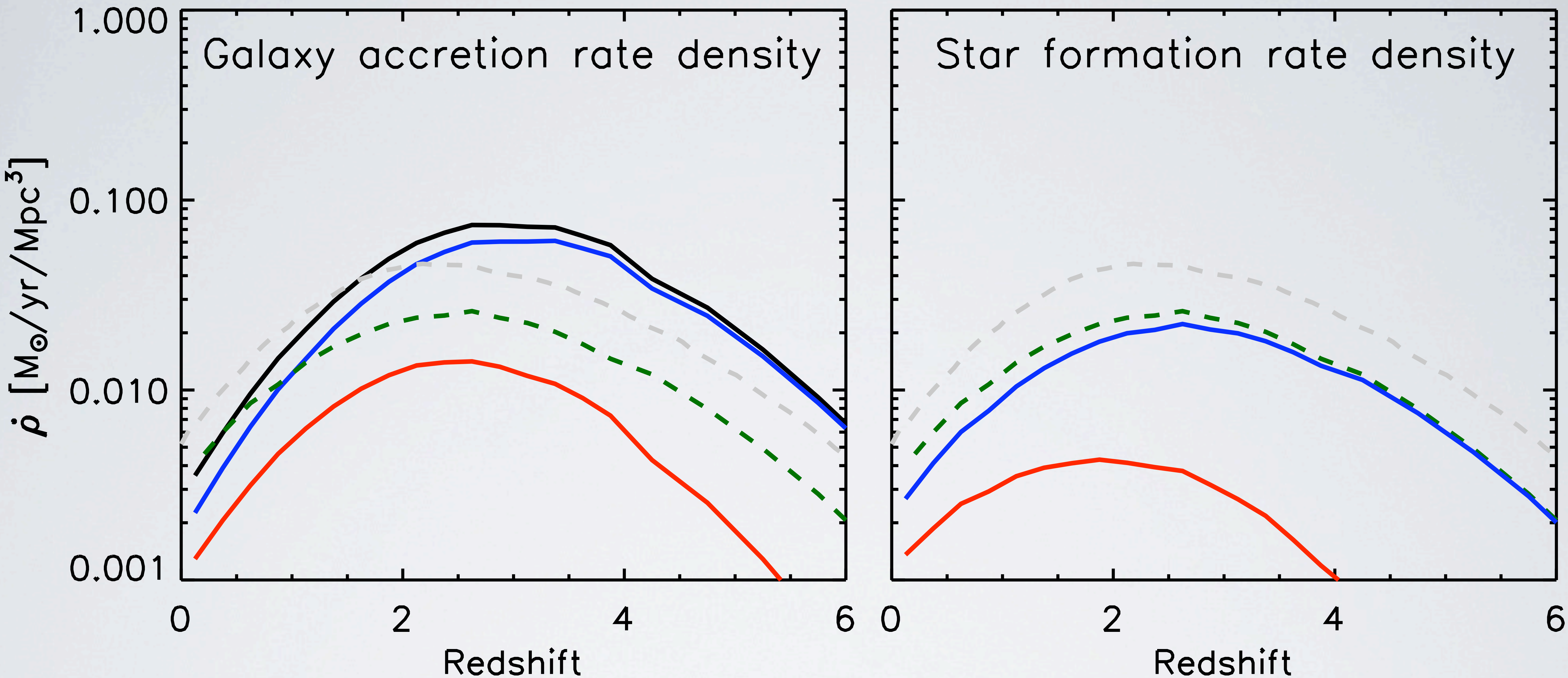
GLOBAL GAS ACCRETION



van de Voort et al. 2011b

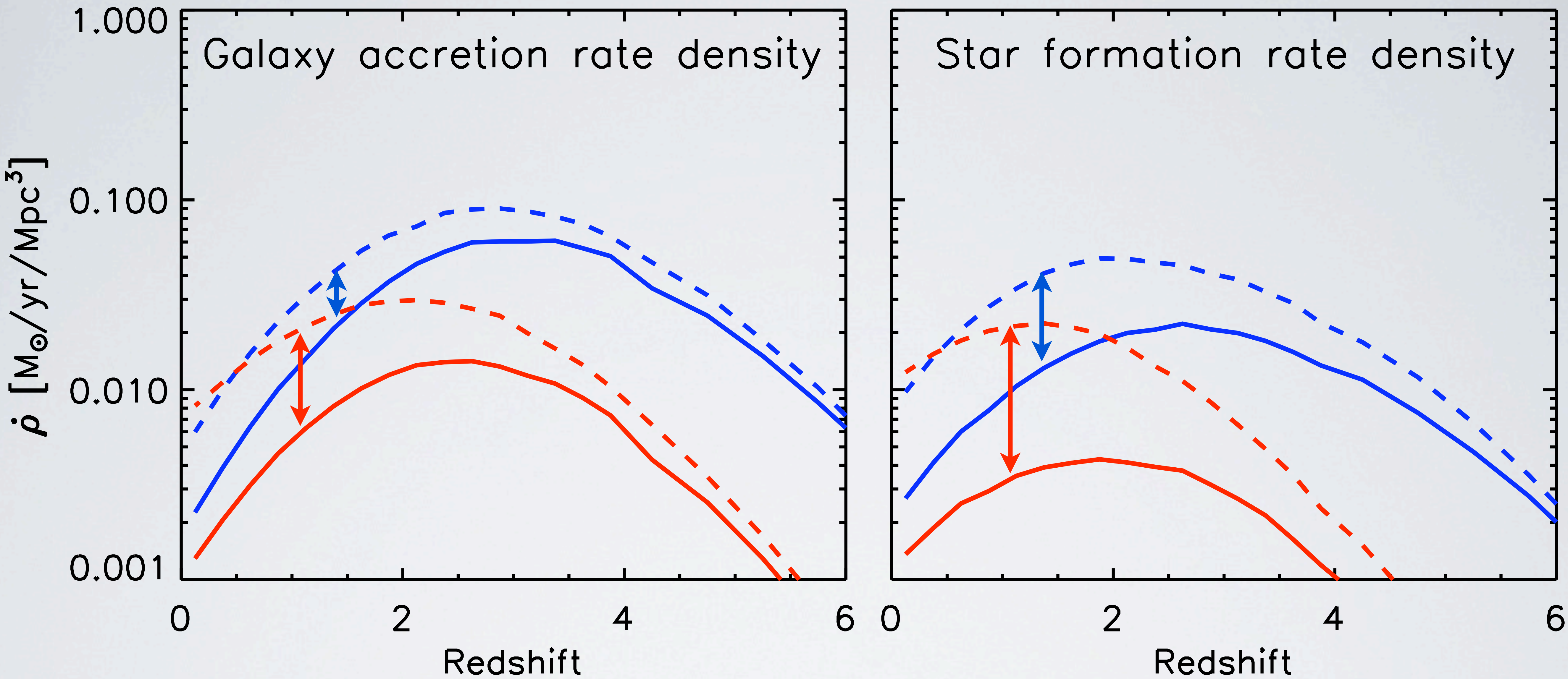
- The global cold accretion rate density declines strongly after redshift 3.
- The drop in the global SFR density is caused by the decline in the cold halo accretion rate density.

GLOBAL GAS ACCRETION



- The drop in the global SFR density is caused by the decline in the cold galaxy accretion rate density.
- Cold mode accretion provides most of the fuel for star formation at all redshifts, if AGN feedback is included.

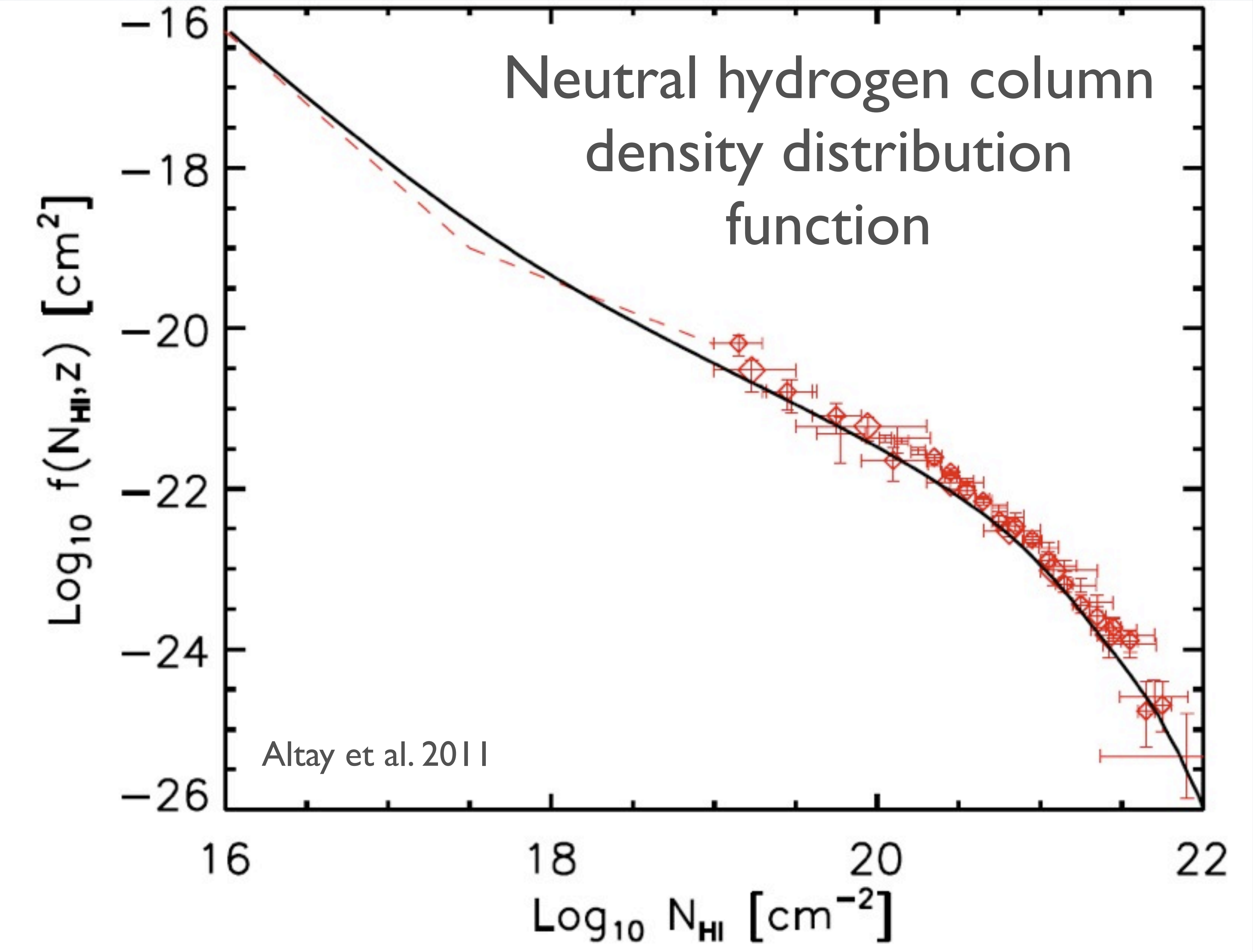
GLOBAL GAS ACCRETION



- Hot accretion is suppressed most, up to an order of magnitude.
- Without AGN feedback, the global accretion rate density at redshift 0 would be dominated by hot accretion.

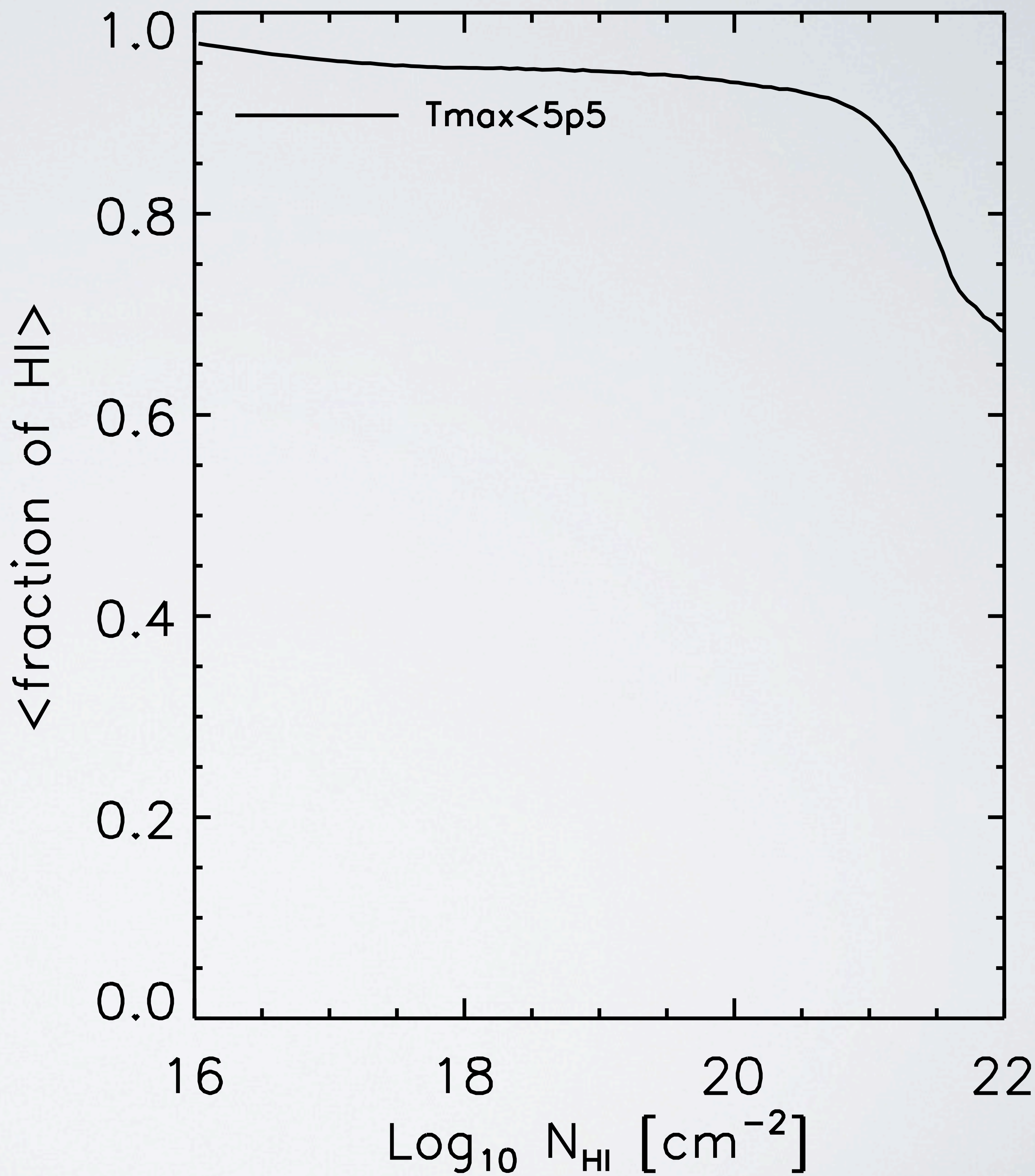
Can we observe cold accretion flows?

HI ABSORPTION



HI ABSORPTION

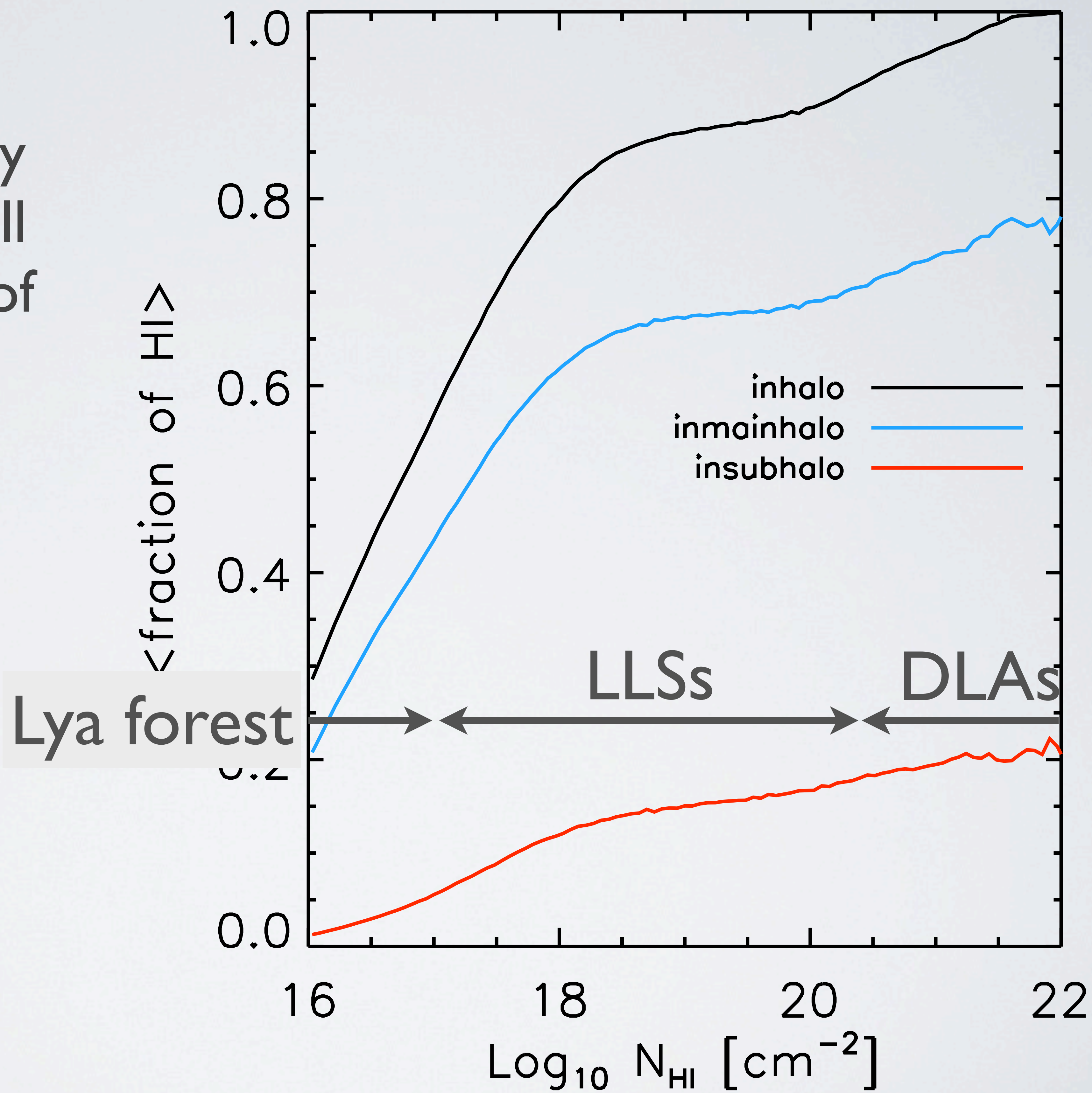
- Almost all of the HI absorbing gas at z=3 has never gone through a shock near the virial radius



van de Voort et al. 2011c

HI ABSORPTION

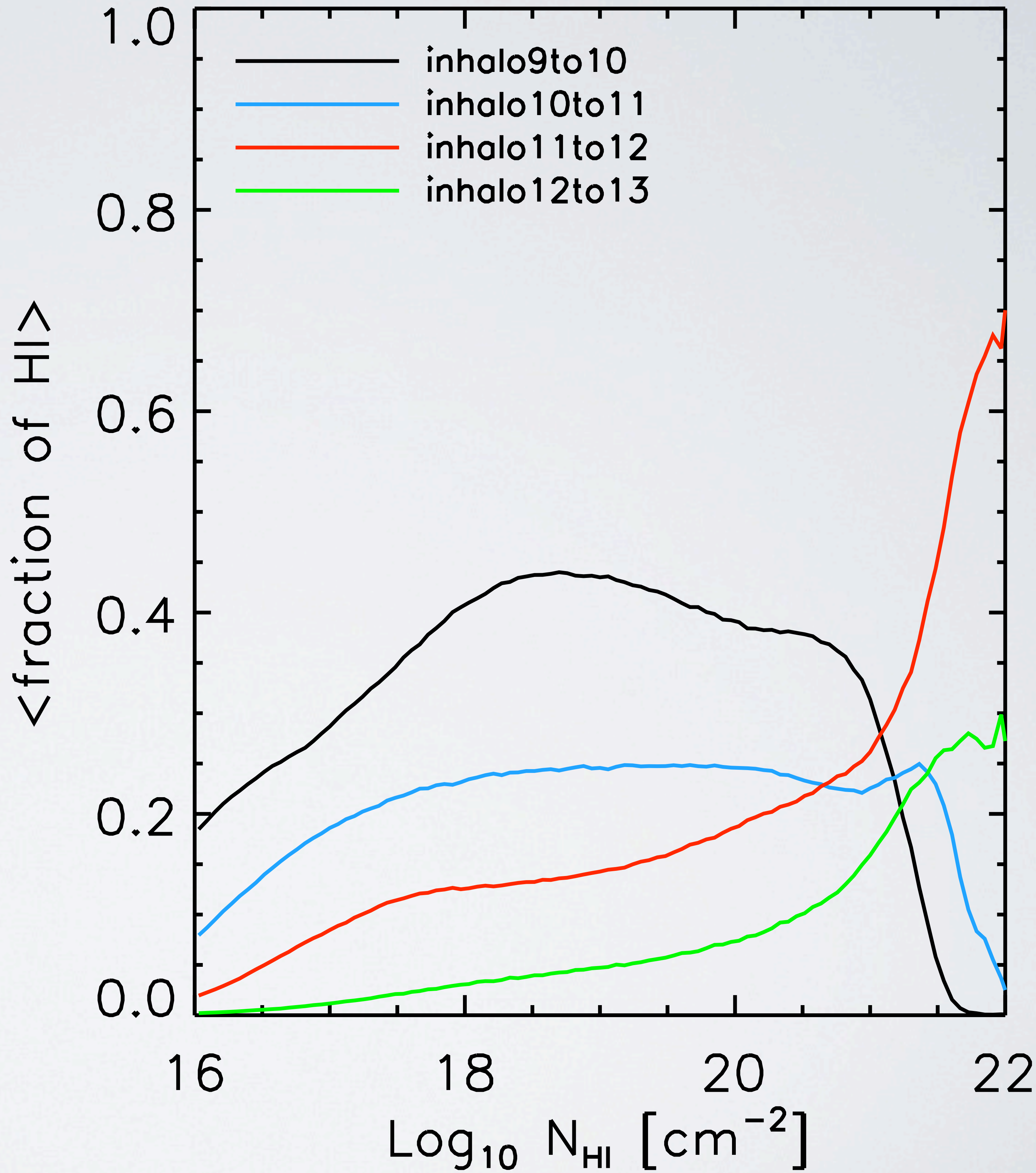
- Haloes contain only a few per cent of all gas, but almost all of the HI gas.
- The majority of Lyman-limit and damped Lyman-α systems reside inside haloes.
- Only 20 per cent are in resolved substructures.



van de Voort et al. 2011c

HI ABSORPTION

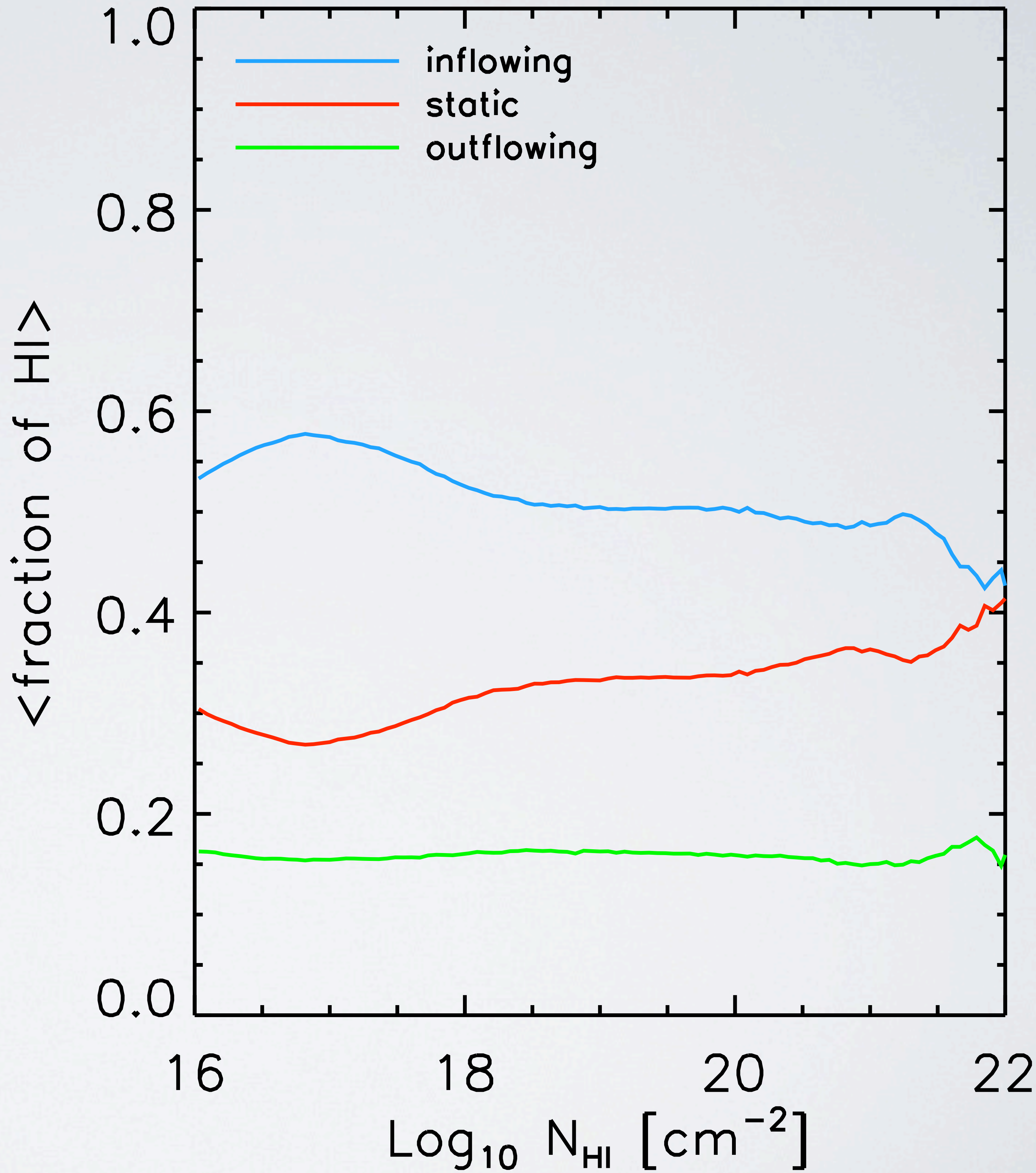
- For all but the highest column densities, the absorption is dominated by low-mass haloes



van de Voort et al. 2011c

HI ABSORPTION

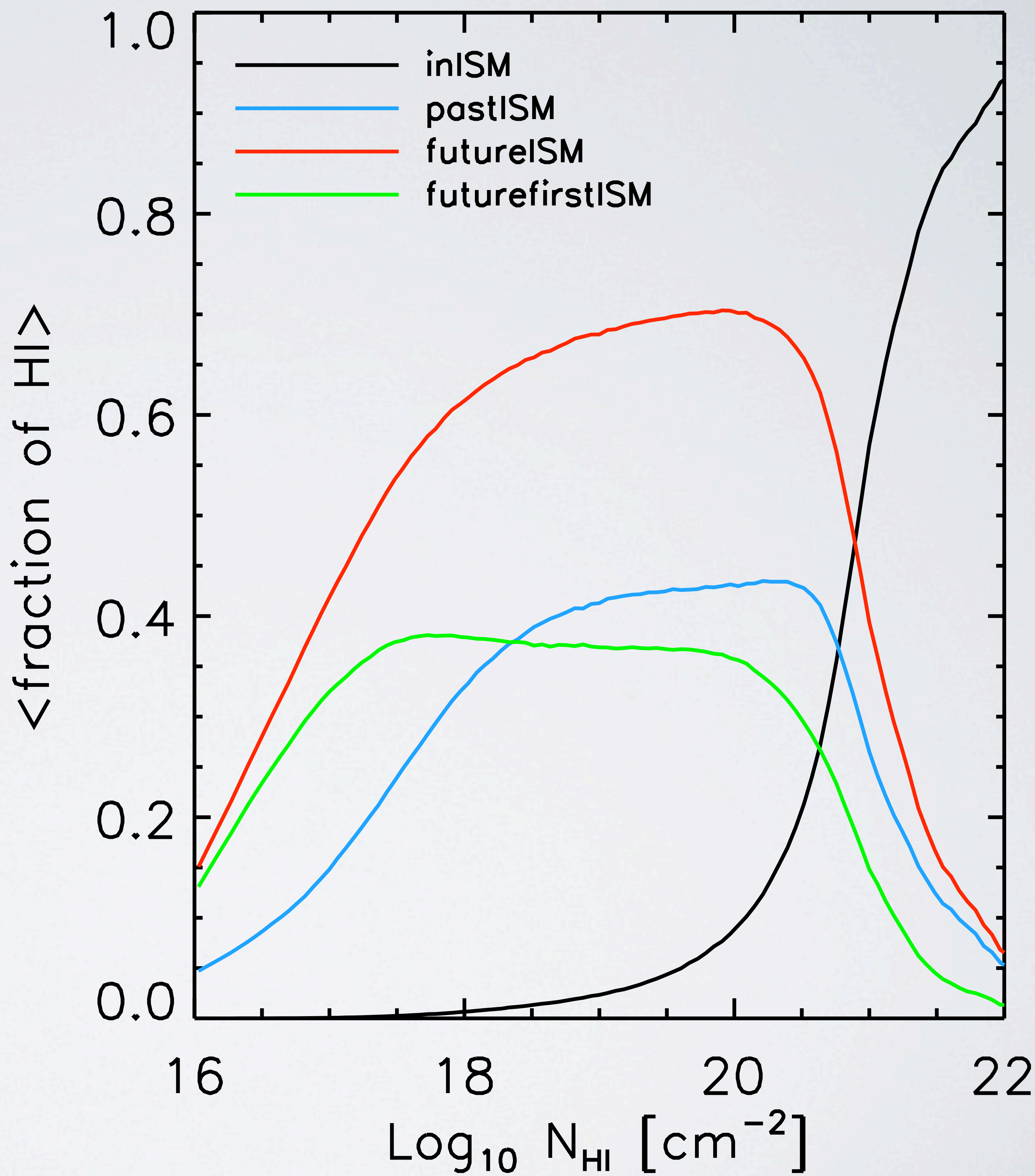
- The majority of the HI absorbing gas is falling towards a nearby galaxy, though static and outflowing gas cannot be neglected.



van de Voort et al. 2011c

HI ABSORPTION

- Strong DLAs arise from the ISM of galaxies.
- Most LLSs at z=3 will accrete onto a galaxy within 1.2 Gyr and ~half of those will enter the ISM for the first time.



van de Voort et al. 2011c

CONCLUSIONS

- Efficient feedback decreases the accretion rate onto haloes and, more so, onto galaxies.
- Cooling is not important for fuelling haloes, but it is for fuelling galaxies.
- Galaxies are fed mostly, but not only, by cold accreted gas.
- Cold-mode gas is essential in order to reproduce observations of HI absorption.