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Modelling suppression of galaxy formation due to a UV-background

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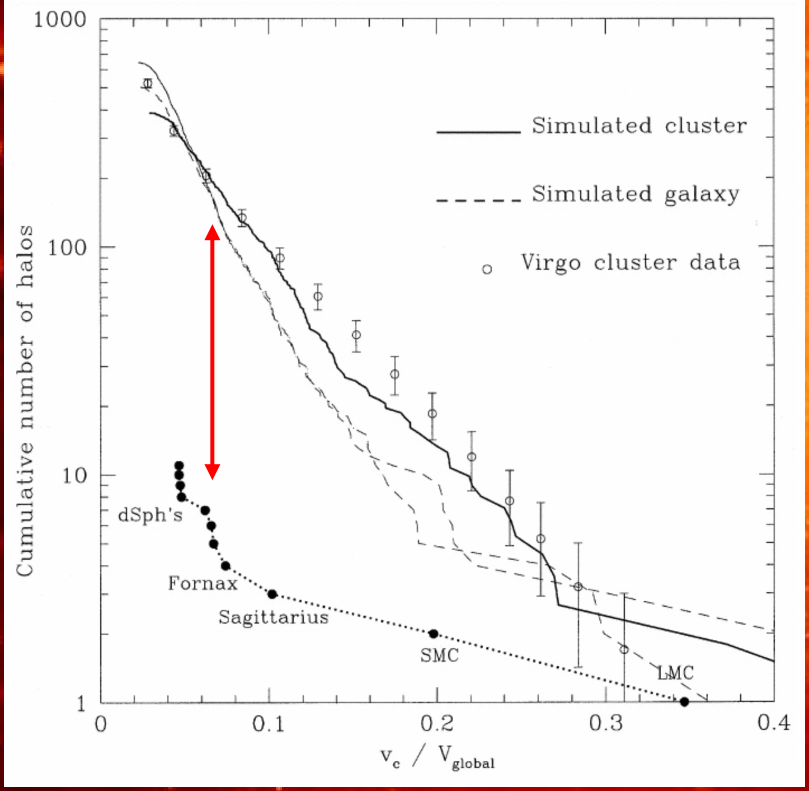
A photo-ionizing background suppresses dwarf galaxy formation

Simulation by Rob Crain

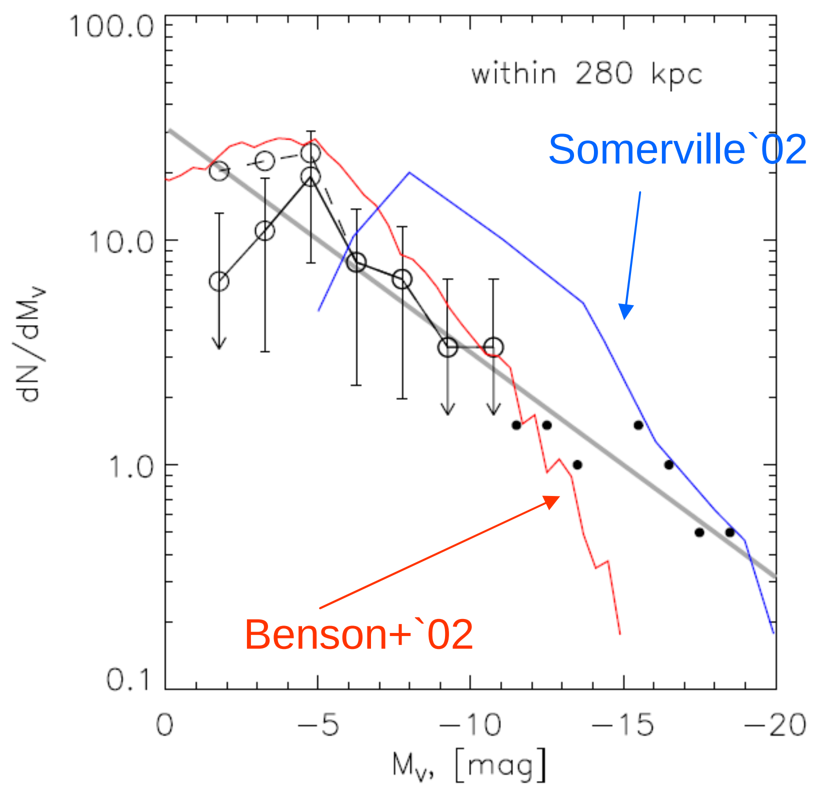
It might save CDM

Satellite problem



Moore+`99

LF of MW satellites



Koposov+`08

The filtering mass

- Growth of density fluctuation in the gas is suppressed for $k > k_F$ (Gnedin & Hui`98).

$$\frac{1}{k_{\mathrm{F}}^{2}(t)} = \frac{1}{D(t)} \int_{0}^{t} \mathrm{d}t' \frac{\ddot{D}(t') + 2H(t')\dot{D}(t')}{k_{\mathrm{J}}^{2}(t')} \int_{t'}^{t} \frac{\mathrm{d}t''}{a^{2}(t'')} .$$

where $k_{\mathrm{J}} \equiv \frac{a}{c_{\mathrm{s}}}(4\pi G \langle \rho_{\mathrm{tot}} \rangle)^{1/2}$ and $c_{\mathrm{s}} = \left(\frac{5}{3} \frac{k_{\mathrm{B}} T_0}{\mu m_{\mathrm{p}}} \right)^{\frac{1}{2}}$

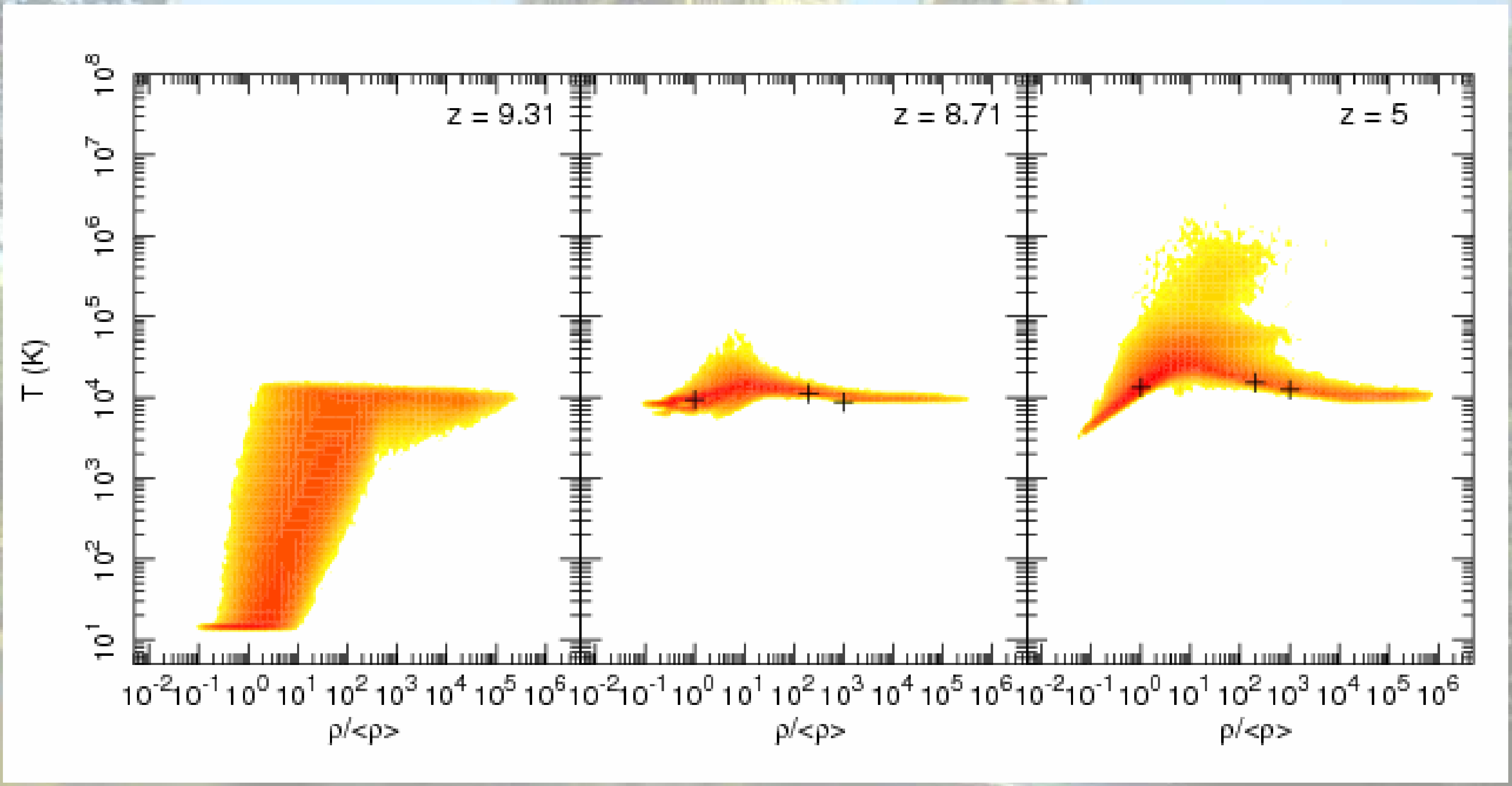
$$M_{\mathrm{F}} = \frac{4\pi}{3} \langle \rho_{\mathrm{tot}} \rangle \left(\frac{2\pi a}{k_{\mathrm{F}}} \right)^{3}$$

- Gnedin`02 claimed that M_F agrees with the characteristic mass, M_c, below which galaxy formation is strongly suppressed.
- But Hoeft+`06 suggested that M_F significantly overestimates M_c.

This work

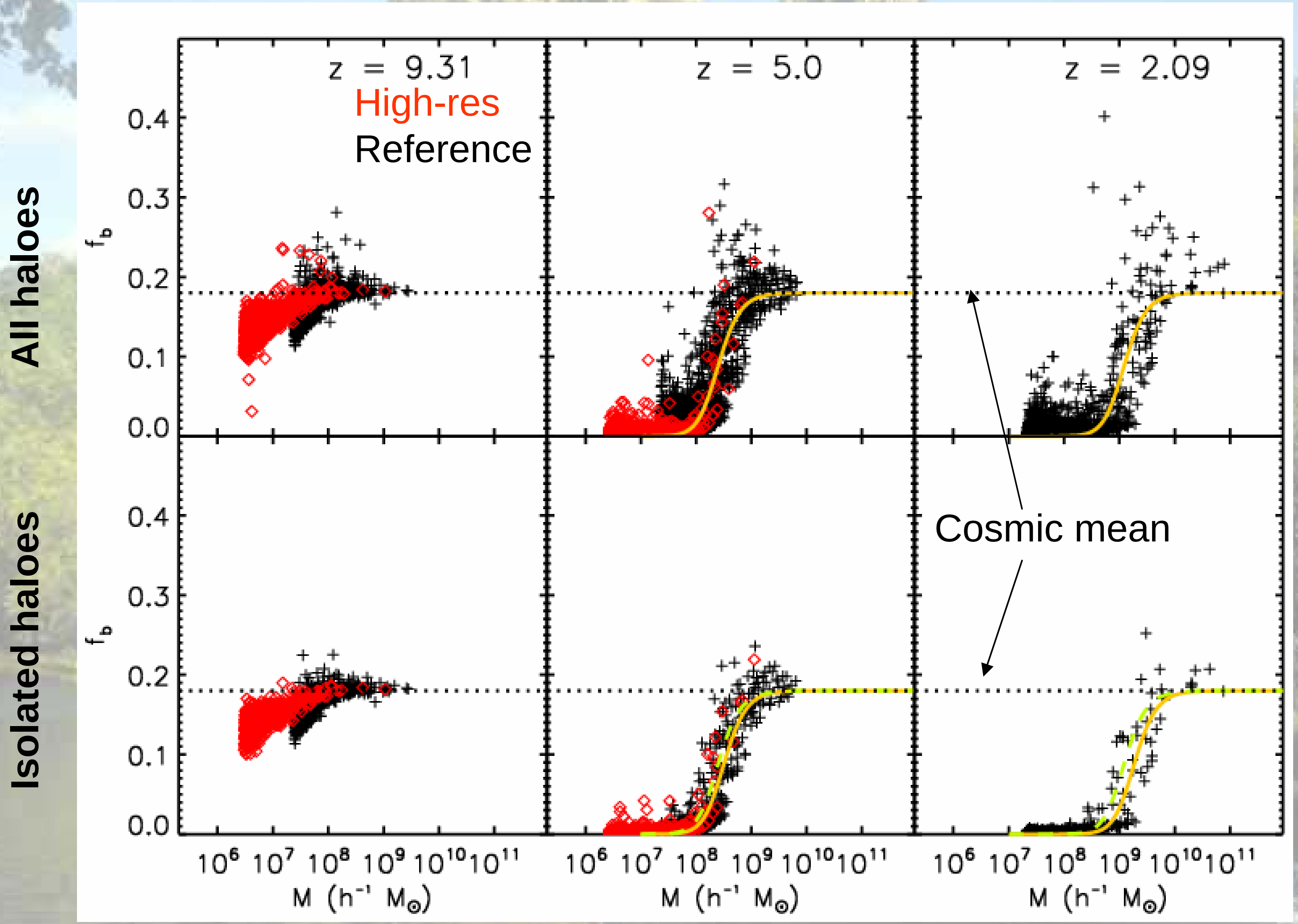
- High-resolution cosmological hydrodynamic simulations with a time-evolving, spatially uniform UV-background.
  - Reionization occurs at z = 9.
  - Haardt & Madau `01 UV-background
- Constructing a semi-analytic model that can reproduce simulation results.

Simulation



Phase diagram: Reionization occurs at z = 9. Plus sins indicate equilibrium temperatures at $\Delta = \rho/\langle\rho\rangle = 1, 200$, and 1000.

Baryon fraction of simulated haloes

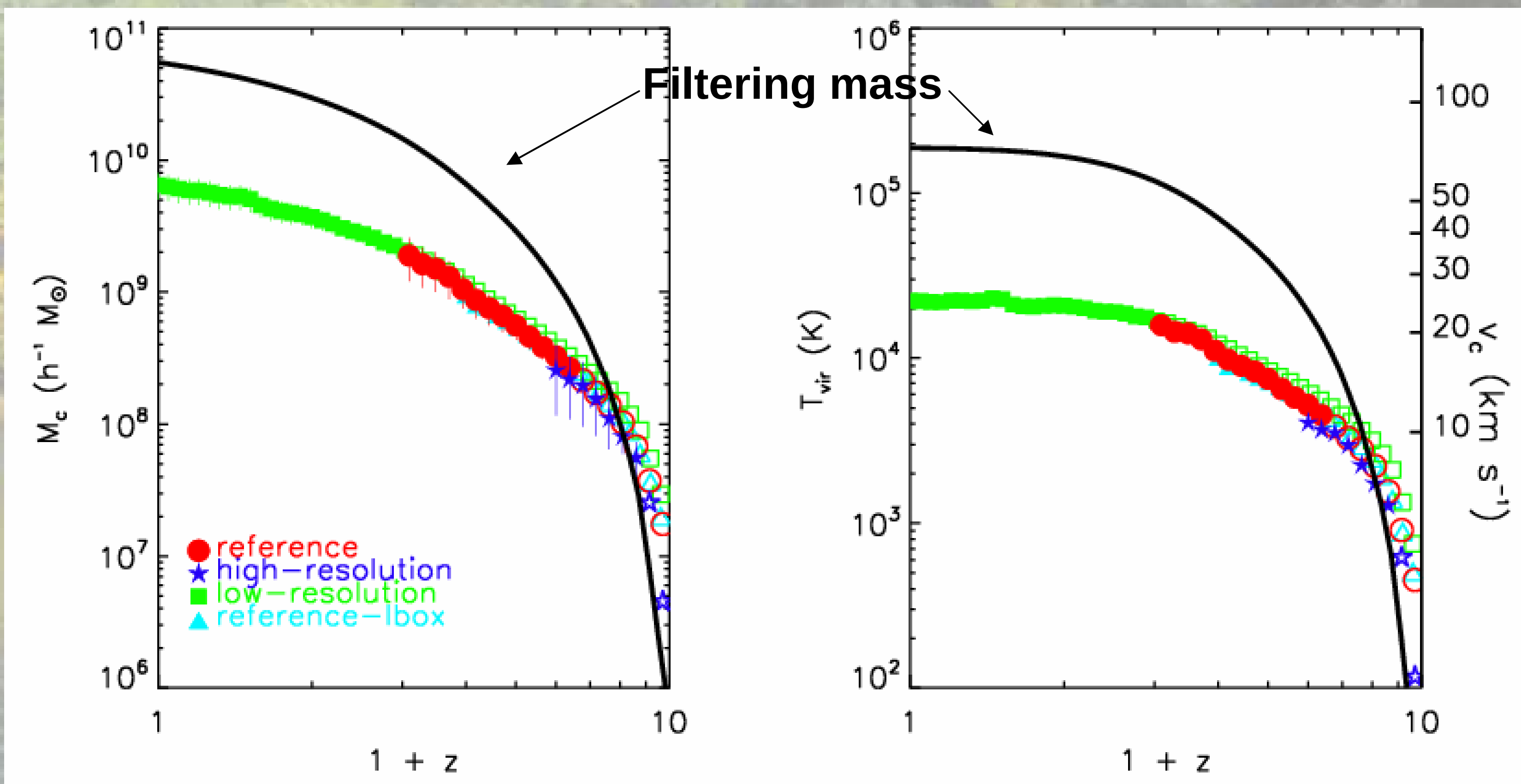


Characteristic mass

- A fitting function by Gnedin`00

$$f_{\rm b}(M,z) = \langle f_{\rm b} \rangle \left\{ 1 + (2^{\alpha/3} - 1) \left(\frac{M}{M_{\rm c}(z)} \right)^{-\alpha} \right\}^{-\frac{3}{\alpha}}$$

- The baryon fraction is half the cosmic mean at $M = M_c$.



Modelling the accretion and evaporation of photo-ionized gas

Semi-analytic modelling

1. Constructing merger trees from the simulations
2. Before reionization, each halo has the cosmic mean baryon fraction.

$$f_{\rm b} \equiv \frac{M_{\rm b}}{M_{\rm DM} + M_{\rm b}} = \langle f_{\rm b} \rangle \equiv \frac{\Omega_{\rm b}}{\Omega_0}$$

Gas accretion

- After reionization, IGM temperature is a function of density (or overdensity, $\Delta=\rho/\langle\rho\rangle$), i.e. $T_{acc} = T_{eq}(\Delta_{acc})$.
  - If $T_{acc} < T_{vir}$, gas can accrete to the halo, i.e. $f_b = \langle f_b \rangle$
  - If $T_{acc} > T_{vir}$, gas cannot accrete; the baryon mass is the sum of the baryon mass in its progenitor haloes.

$$M_{\mathrm{b}} = \sum^{\mathrm{prog}} M_{\mathrm{b}}$$

Photo-evaporation

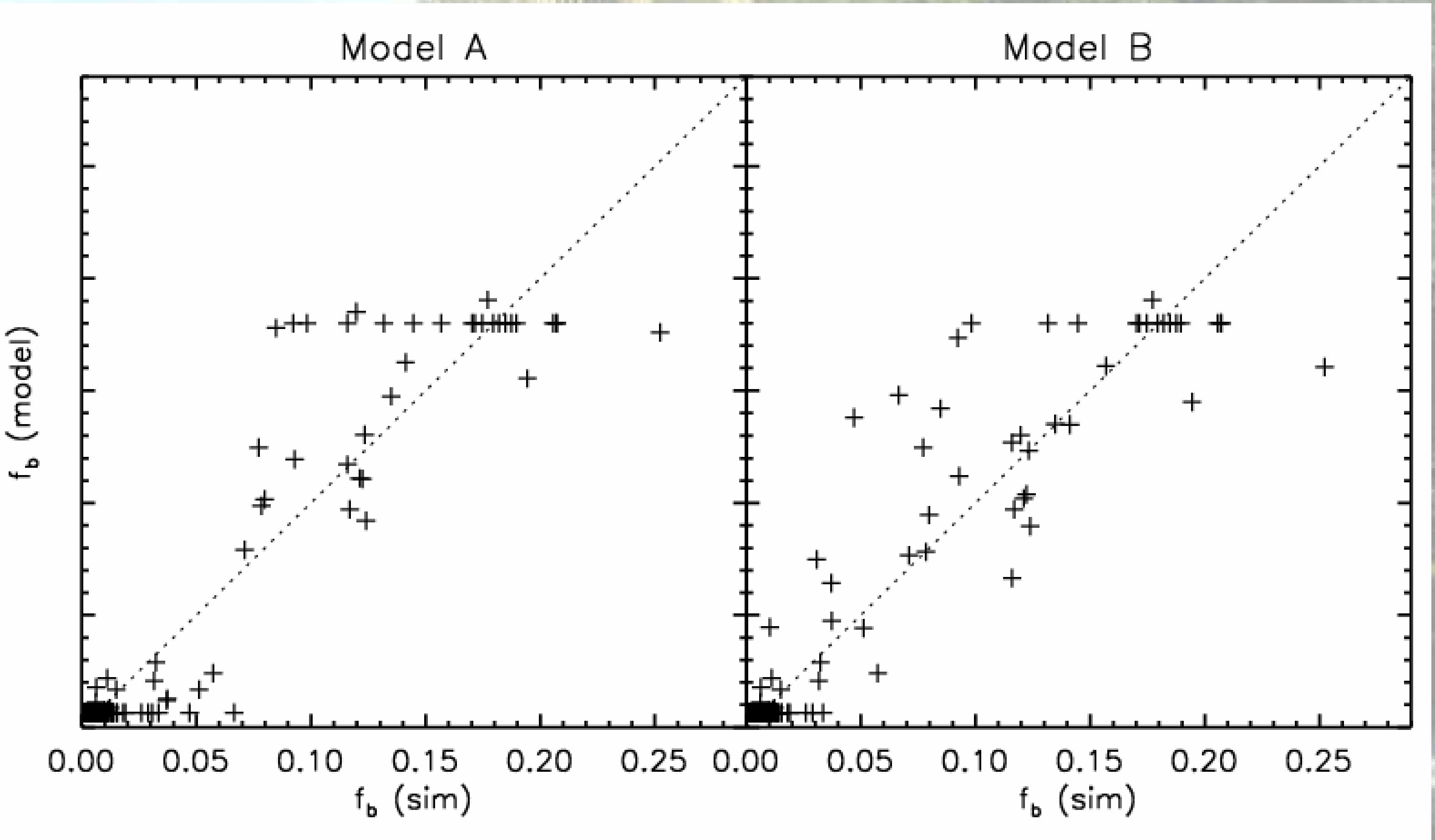
- If $T_{eq}(\Delta_{cond}) > T_{vir}$ where $\Delta_{cond} >> \Delta_{vir}$, condensed gas can escape from the halo with a timescale $t_{evp} = r_{vir}/c_s(\Delta_{cond})$.
- The baryon mass, M_b, is reduced to M_b' during a timestep δt.

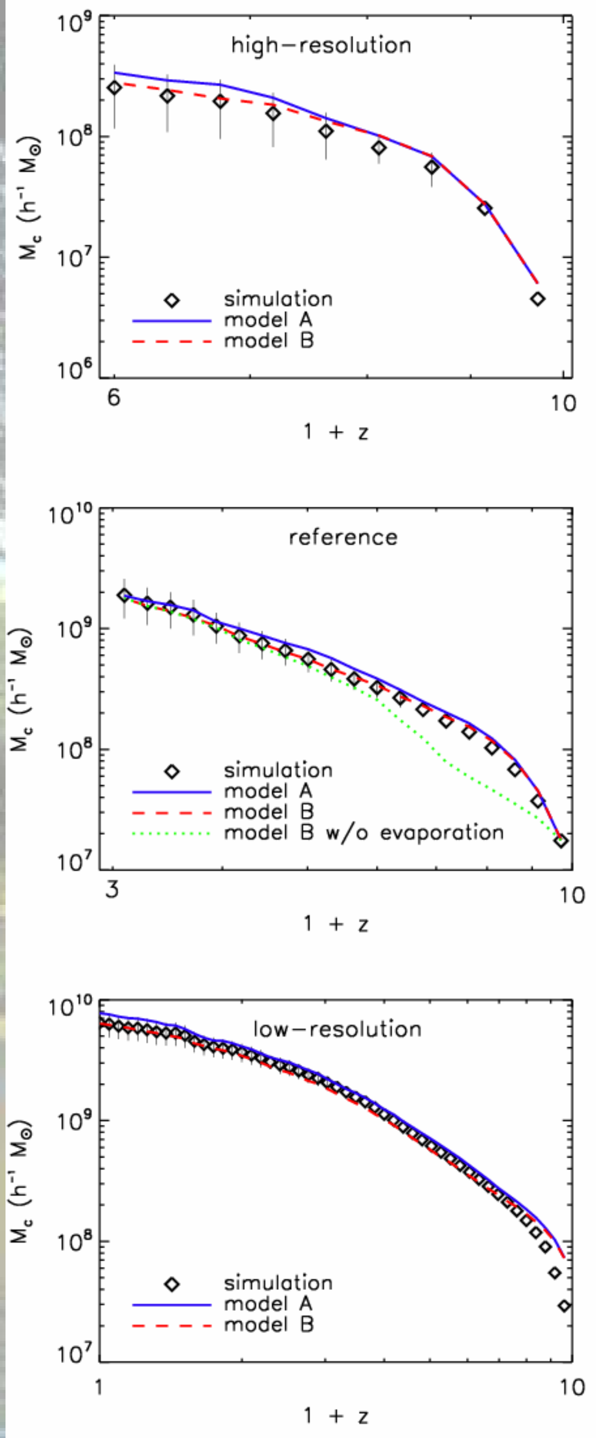
$$M_b' = \exp\left(-\frac{\delta t}{t_{evp}}\right) M_b.$$

- We use $\Delta_{cond} = 10^6$.

Models against a simulation

- Model A: $\Delta_{acc} = 1/3\ \Delta_{vir}$
- Model B: $\Delta_{acc} = f(f_b)\ \Delta_{vir}$ (a function of f_b)





M_c predicted by the models

- Model A is good enough.
- Model B reproduces the simulations perfectly.
- Evaporation is important at high-z.

Summary

- Gas cannot accrete to a halo if it's hotter than halo's virial temperature.
- The overdensity of accreting gas is well approximated by 1/3 Δ_{vir}.
- The filtering mass significantly overestimates the effect of a UV-background.
  - SA models have overestimated the effect...
  - The satellite problem might still exist.
  - Use our model!!

Appendix

- Model B
  - If less baryons are brought by progenitors, more gas is available for accretion.
  - It may increase the density of the accreting gas.

$$M_{\rm b}^{\rm max} = \frac{\langle f_{\rm b} \rangle}{1 - \langle f_{\rm b} \rangle} M_{\rm DM}$$

$$M_{\rm acc} = M_{\rm b}^{\rm max} - \sum^{\rm prog} M_{\rm b}$$

$$\Delta_{\rm acc} = \beta \frac{M_{\rm acc}}{M_{\rm b}^{\rm max}} \Delta_{\rm vir}.$$

β = 2/3 works well.