The physical characteristics of circumgalactic gas around simulated high-redshift galaxies

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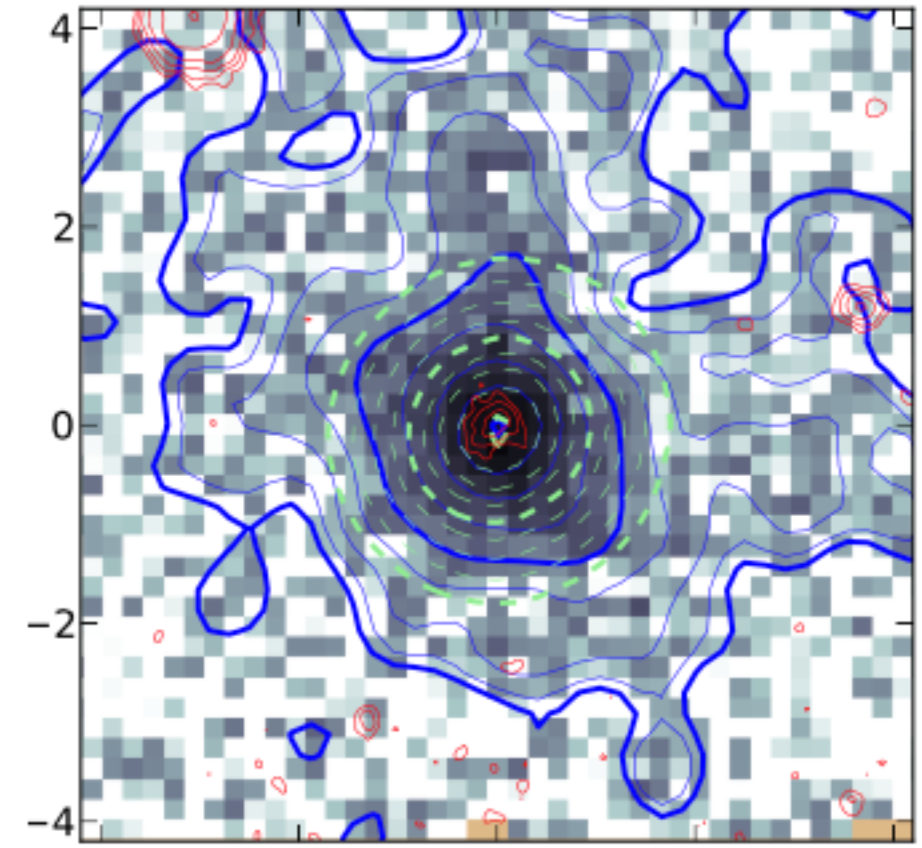
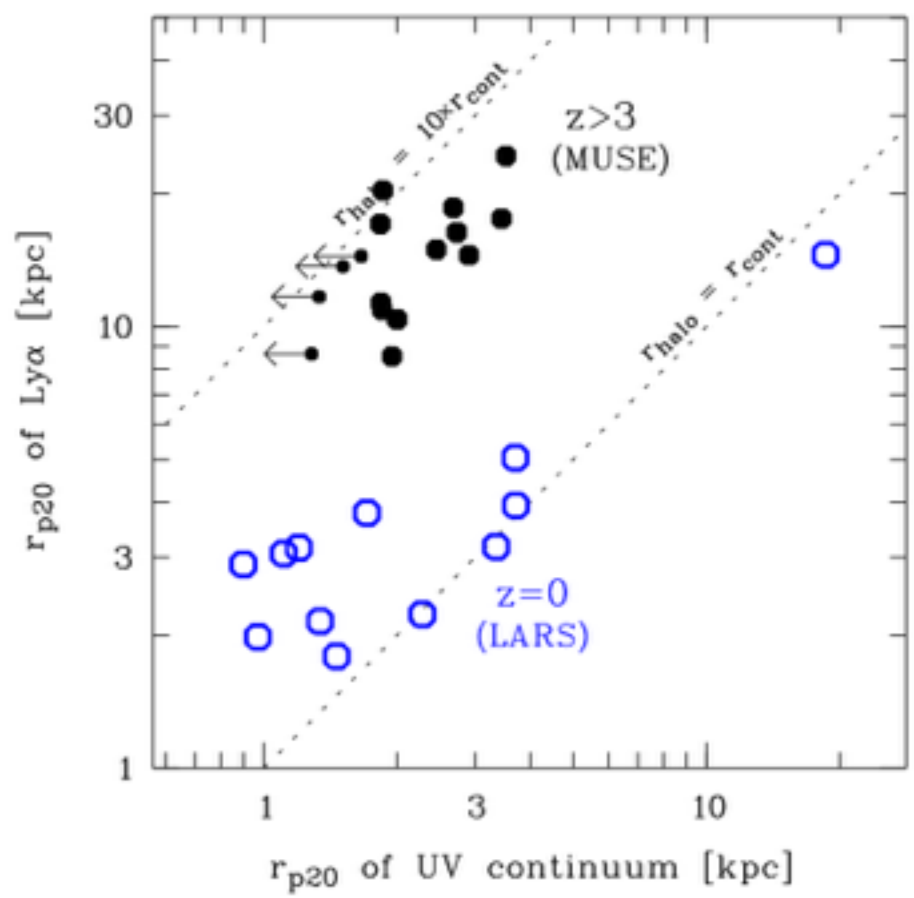
Overview

- What is spatially extended Lyman-alpha emission around high-z Lyman alpha emitters telling us about galaxy formation?
- Numerical simulations overview
- How does feedback from Type II supernovae affect the baryon content of simulated haloes?
    - Does it affect diffuse cosmological accretion?
- What are the physical properties of the circumgalactic ionized & neutral hydrogen in our simulations?
    - What is the impact of feedback on the diffuse, neutral circumgalactic medium (CGM)?

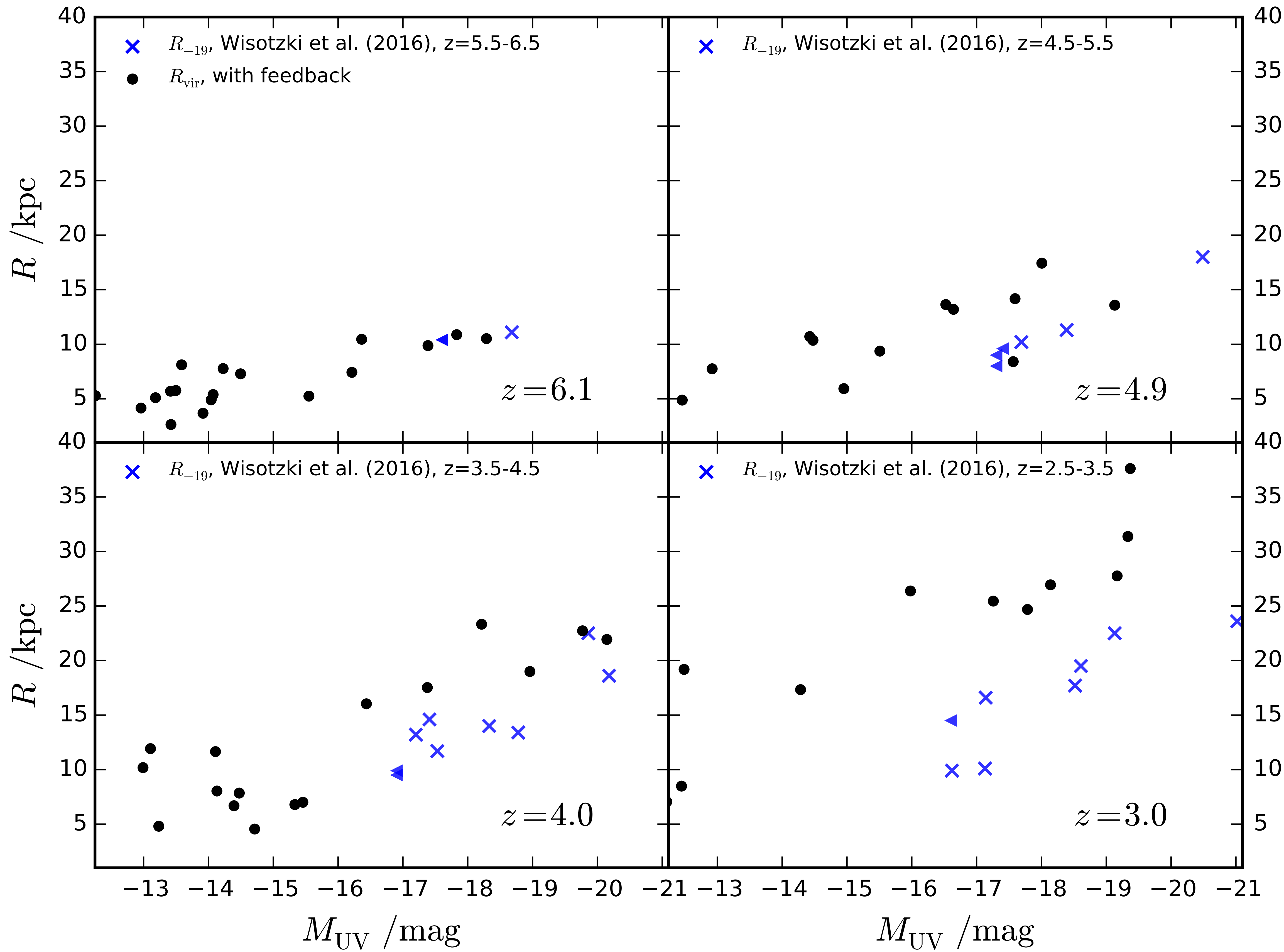
The neutral CGM at high-redshift in emission

- **Spatially extended** Lyman-alpha emission around **individual**, **faint** star-forming galaxies has now been observed with MUSE (Wisotzki et al. 2016) for z=3-6.
- These observations probe the neutral gas in the CGM of small high-redshift galaxies, offering an alternative to QSO absorption studies.
- Faint high-redshift galaxies can be readily simulated with high spatial resolution using cosmological simulations.
    - Aim is to use simulations to assist with physical interpretation of the observations.





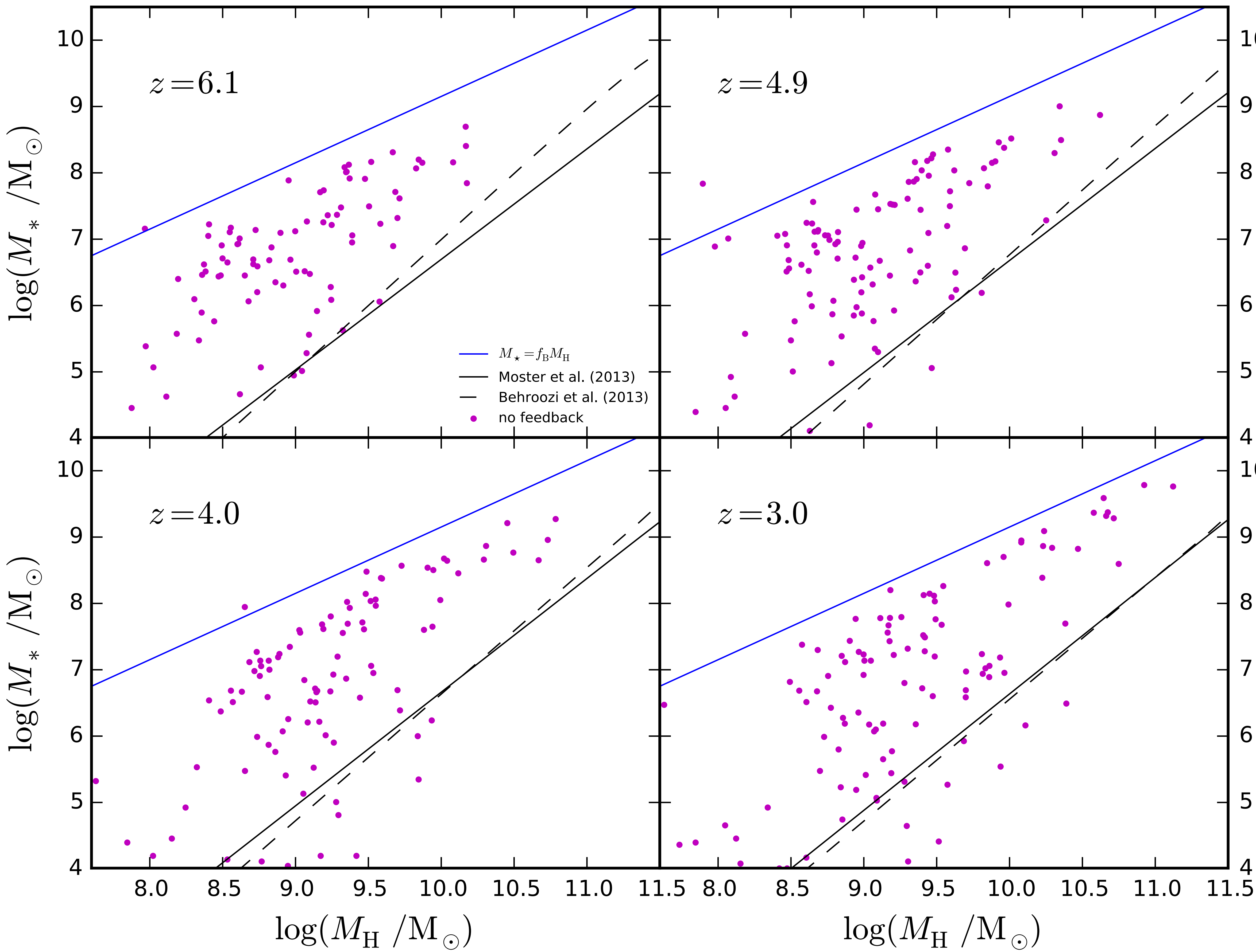
Observed extended Lyman-alpha emission probes a significant fraction of the CGM in haloes



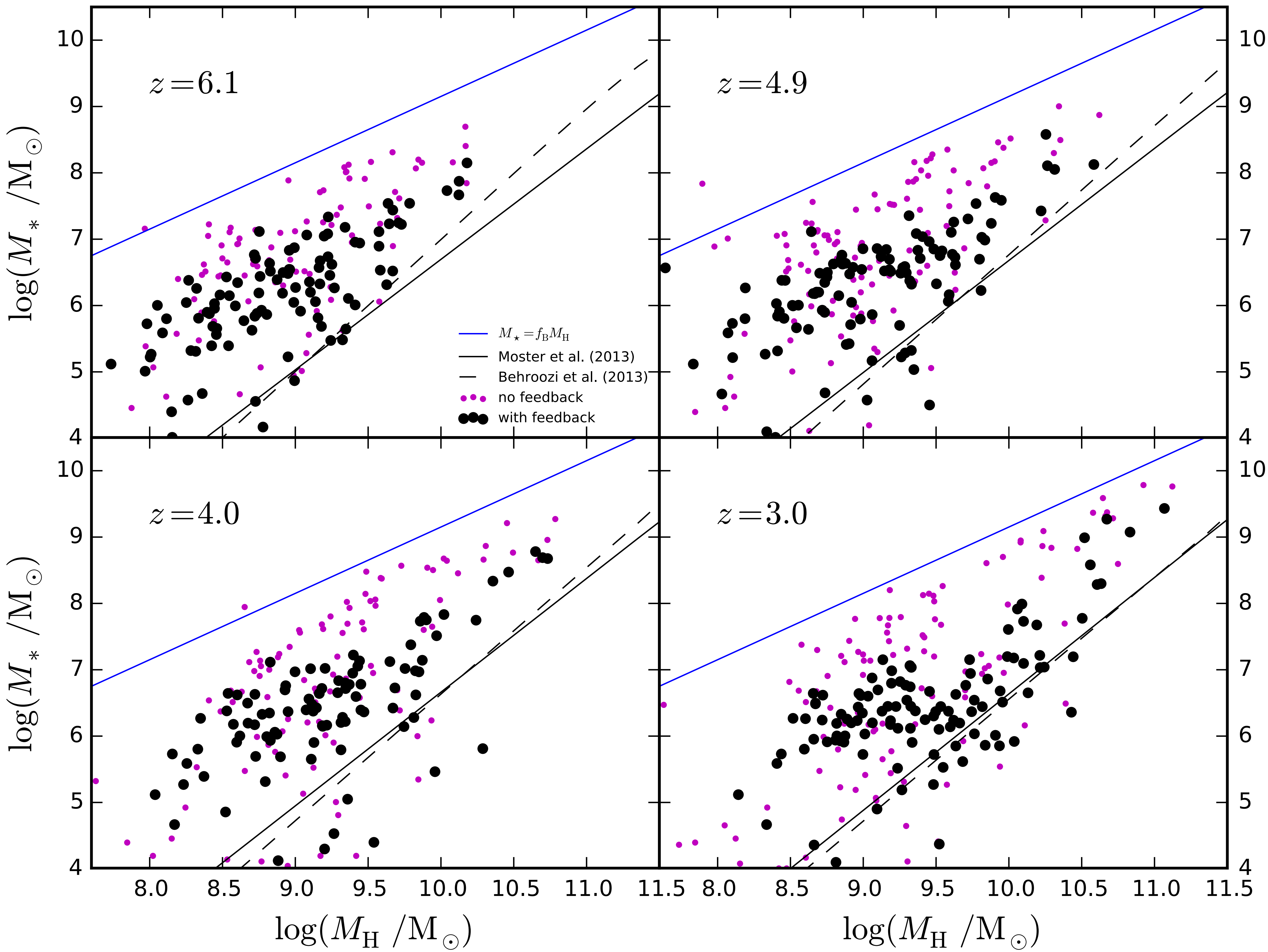
Simulations overview

- Suite of cosmological zoom simulations performed using RAMSES & initial conditions from MUSIC.
- Spatial resolution is 15pc at the highest refinement level.
    - However, in the CGM, the resolution is typically ~ 200pc.
- Dark matter particle mass is 10^4 $\mathrm{M}_\odot$
- Simulations stop at z=3 (the low-redshift limit for Lyman alpha with MUSE).
- Sample currently includes 11 targeted haloes with masses ranging between $M_\mathrm{H} = 10^{10}\,\mathrm{M}_\odot$ and $M_\mathrm{H} = 10^{11}\,\mathrm{M}_\odot$ at z=3, representative of Wisotzki sample.
    - Descendants at z=0 would have halo masses ranging between $M_\mathrm{H} \approx 10^{10.6}\,\mathrm{M}_\odot$ (1/10 Milky Way) and $M_\mathrm{H} \approx 10^{11.8}\,\mathrm{M}_\odot$(Milky Way).
- Standard RAMSES implementation of metal enrichment, radiative cooling, self-shielding and photo-heating from a uniform UV background.
- Subgrid models for thermo-turbulent star formation (Devriendt in prep, Kimm et al. 2016) and mechanical SNe feedback (Taysun Kimm).

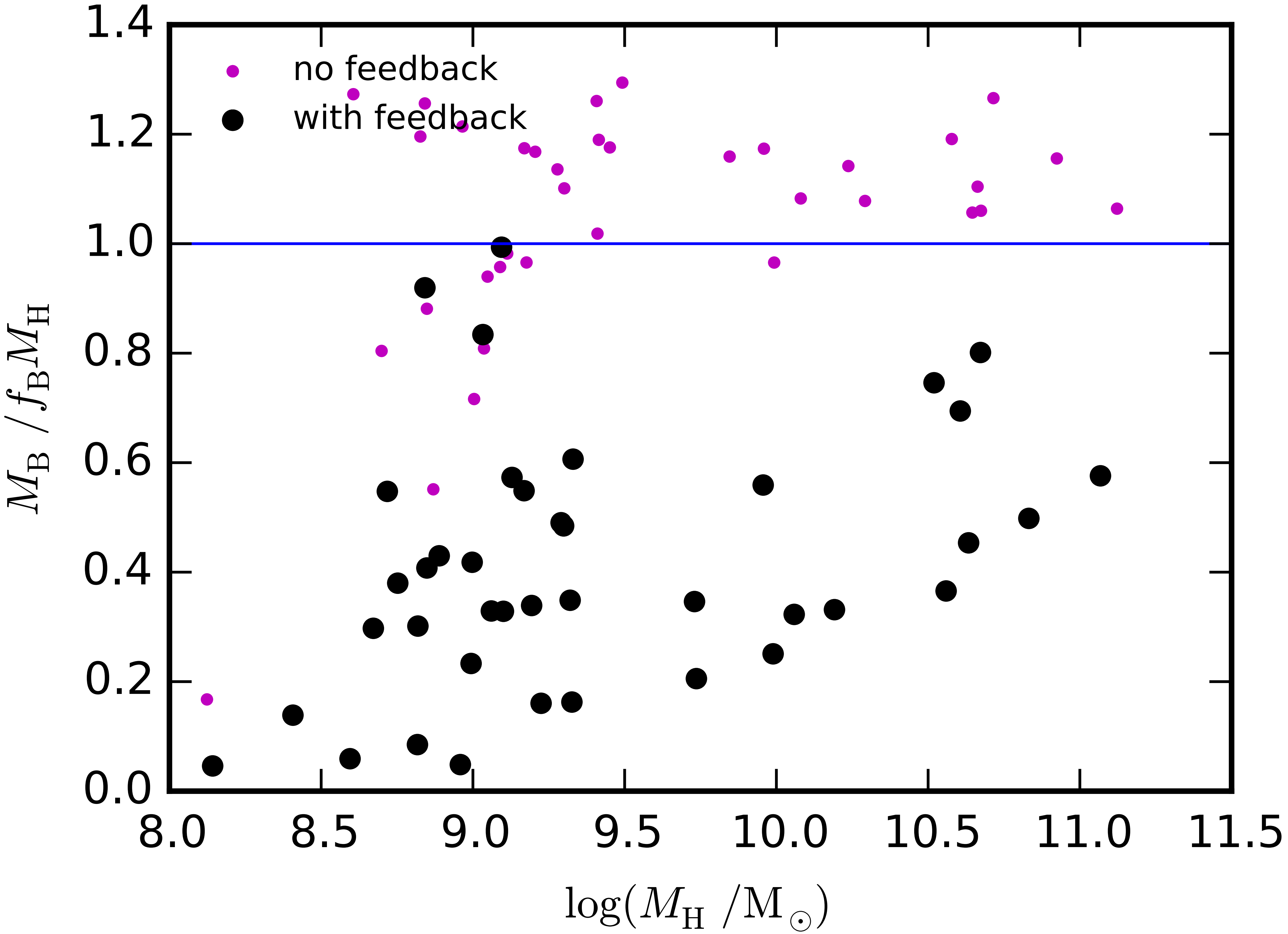
Stellar masses: no feedback



Stellar masses: with feedback

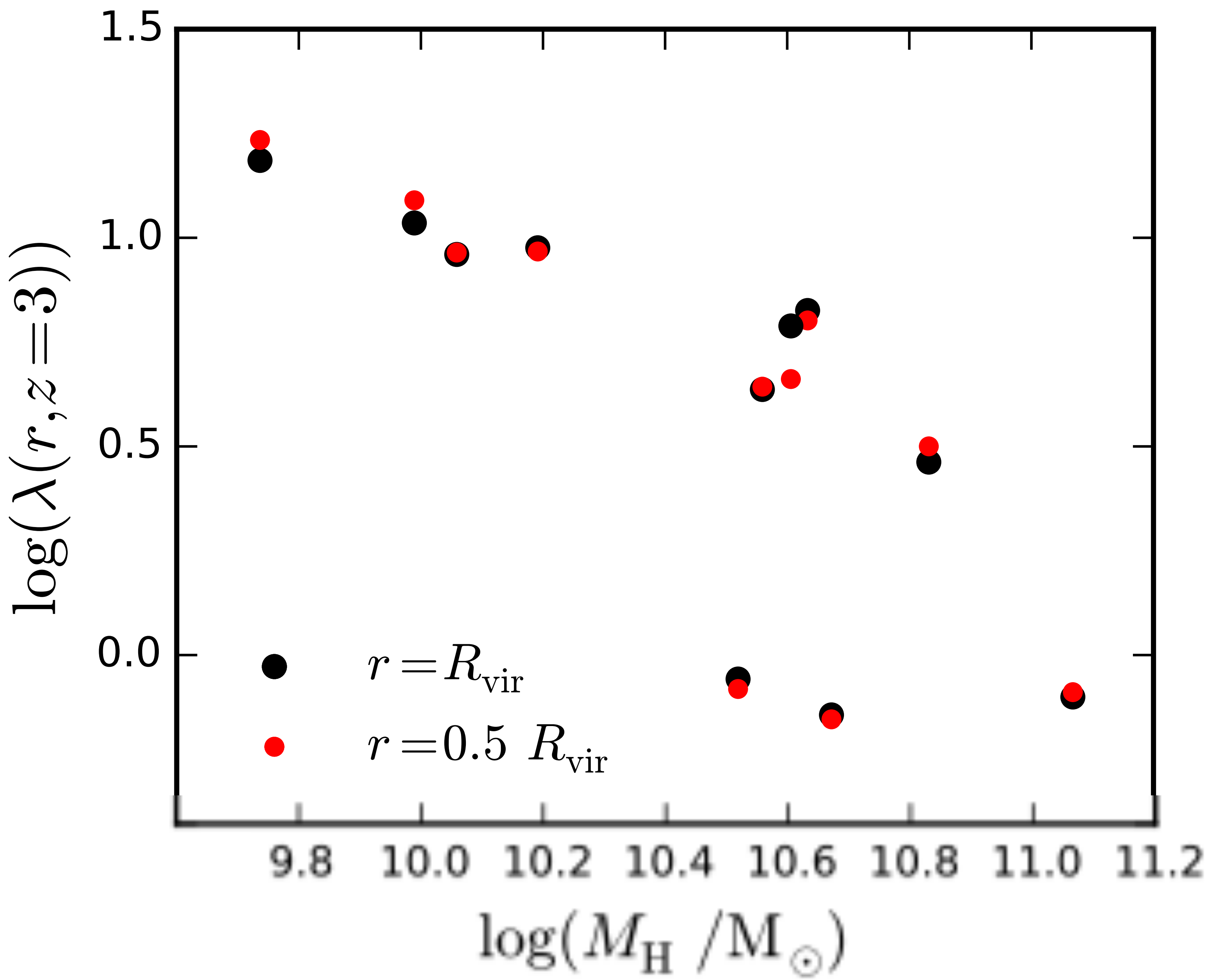


Baryon fractions



Integrated outflow / loading factors

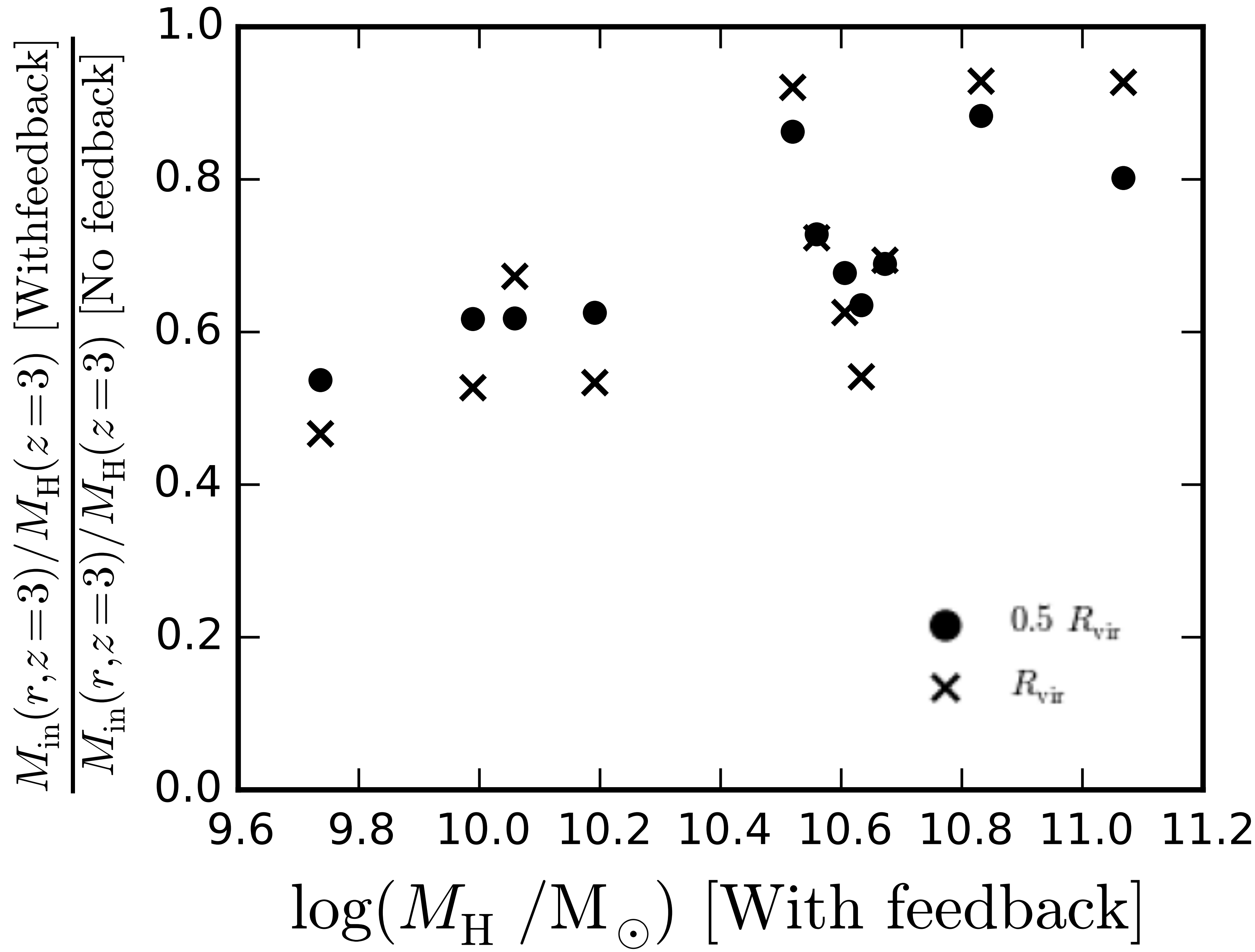
$$\lambda_{\rm int}(r,t) \equiv \frac{\int_0^t \dot{M}_{\rm out}(r(t'),t')\,{\rm d}t'}{\int_0^t \psi(<r(t'),t')\,{\rm d}t'},$$



Effect of feedback on diffuse accretion

$$M_{\rm in}(r,z) = \int_0^t \dot{M}_{\rm in}(r(t'),t')\,{\rm d}t'$$

$$\frac{M_{\rm in}(r,z=3)/M_{\rm H}(z=3)\ [\text{With feedback}]}{M_{\rm in}(r,z=3)/M_{\rm H}(z=3)\ [\text{No feedback}]}$$



Physical properties of neutral/ionized circumgalactic gas

- Do we have diffuse neutral hydrogen in the circumgalactic medium?
    - In outflows?
- How does mass/momentum/energy compare between diffuse ionized/neutral inflows/outflows?
- Do ionized/neutral outflows conserve mass/momentum/energy as they propagate through the halo?
- Stack haloes and simulation outputs. Use a large enough time window to capture complete evolution of gas flows (between halo centre and the virial radius).

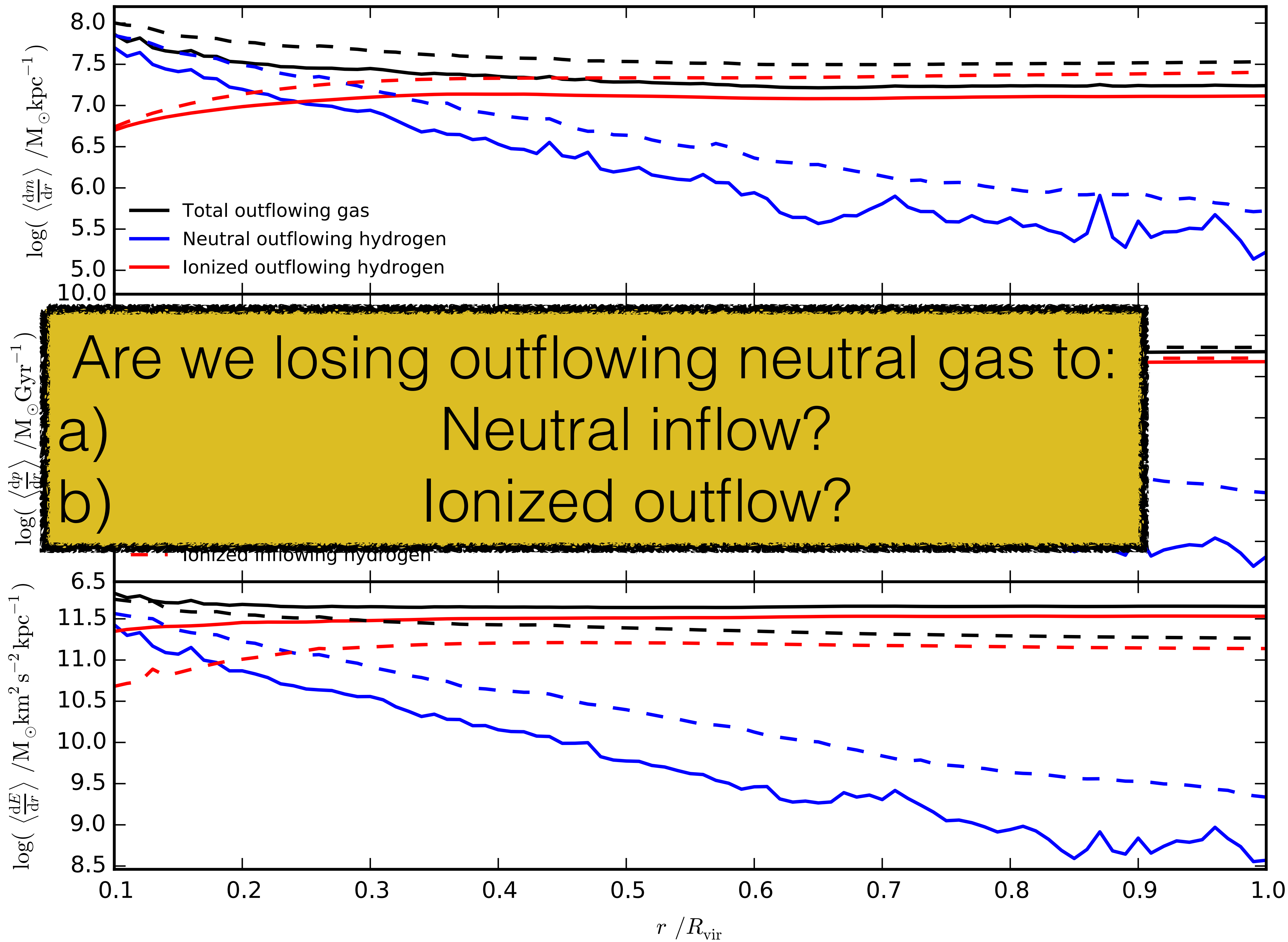
Integrated physical properties of neutral/ionised hydrogen

Mass

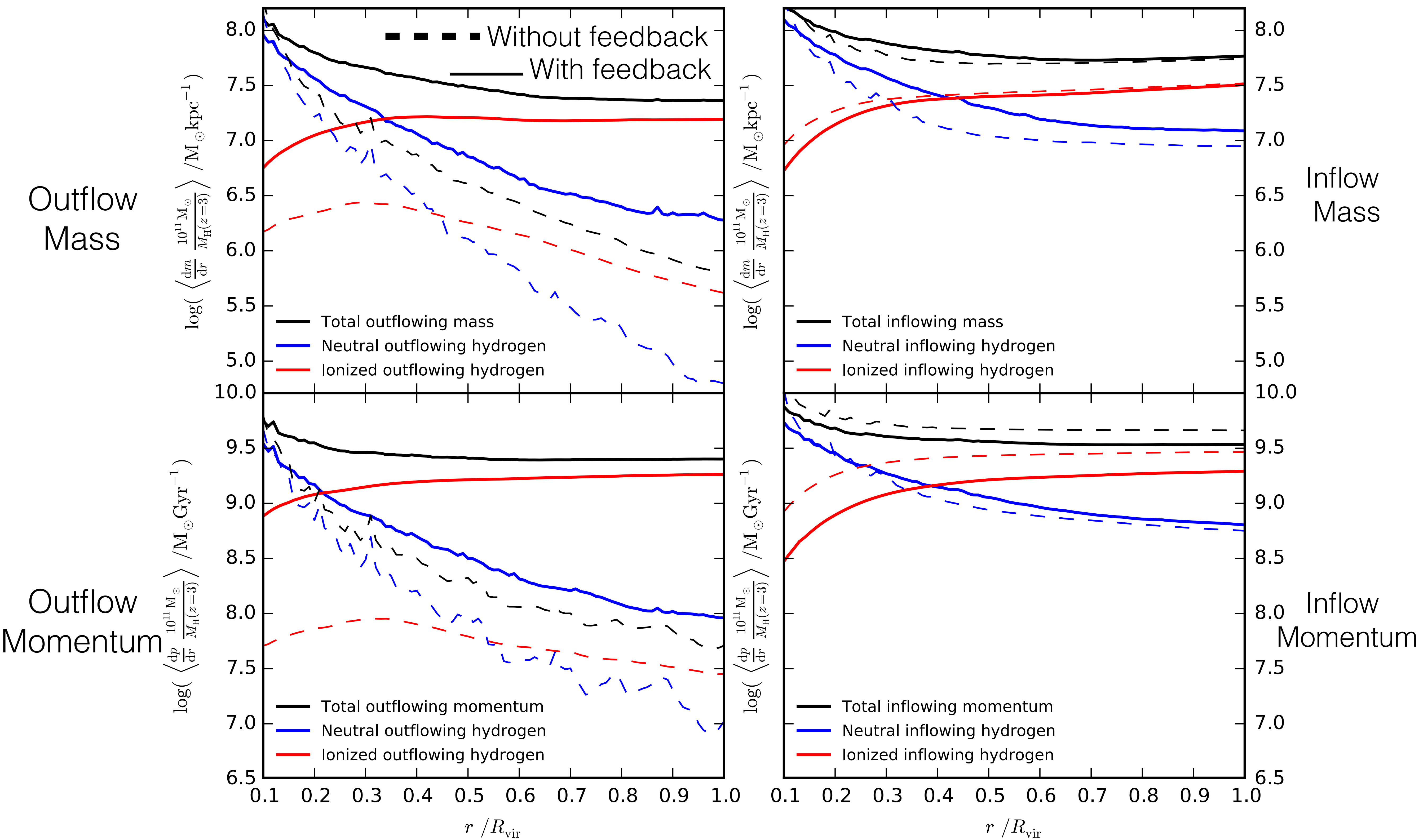
Momentum

(=mass outflow rate)

Energy



Effect of feedback on flows in the CGM



Upcoming projects/interests

- Comparison with MUSE data on spatially extended Lyman-alpha emission.
- QSO absorption analysis at z=3 - Lyman-limit systems.
- Ramses-RT simulations underway - Joakim Rosdahl.
    - What is the impact of local UV radiation on neutral/ionized decomposition?
    - Same set-up as existing cosmological zooms.
- Alternative refinement schemes (Rosdahl & Blaizot, 2012).
- Tracer particles & the baryon cycle.

Summary

- Simulation sample designed to be representative of faint star-forming galaxies observed in spatially extended Lyman-alpha emission with MUSE
- Supernova feedback reduces the baryon content of haloes by ~ 50%
  - The inclusion of feedback appears to reduce diffuse accretion onto the halo by 20-50%.
    - This works by slowing ionized inflowing hydrogen
- Simulations contain both neutral and ionized hydrogen in the outflowing CGM
  - Ionized phase dominates the outflow
  - Including feedback increases the mass in outflowing neutral hydrogen (factor 2 - 50) and in neutral inflows (ejected gas clouds falling back?)