

The Metal Cycle at $z \sim 2-3$: Clues from the CGM?

with Ben Oppenheimer,
Romeel Davé, Amanda
Ford, Juna Kollmeier

1. Bulk galaxy properties
2. Metals in the CGM

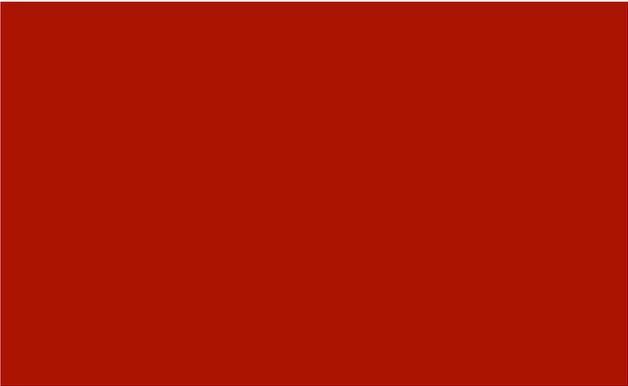


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The Baryon Cycle
Irvine, CA; June 14, 2012

The tools: cosmological-scale hydrodynamic simulations

- New suite of 2×512^3 particle, $32h^{-1}$ Mpc comoving SPH simulations evolved with Gadget-2
 - SPH particle gas mass = $4.45 \times 10^6 M_{\odot}$
 - Dark matter particle mass = $2.7 \times 10^7 M_{\odot}$
- Updated cooling routines following Wiersma et al. (2009)
- Uniform evolving metagalactic UV background from Haardt & Madau
 - Haardt & Madau (2012) backgrounds coming soon!
- New star formation feedback scalings



All results presented here at $z=2.2$

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New star formation feedback scalings

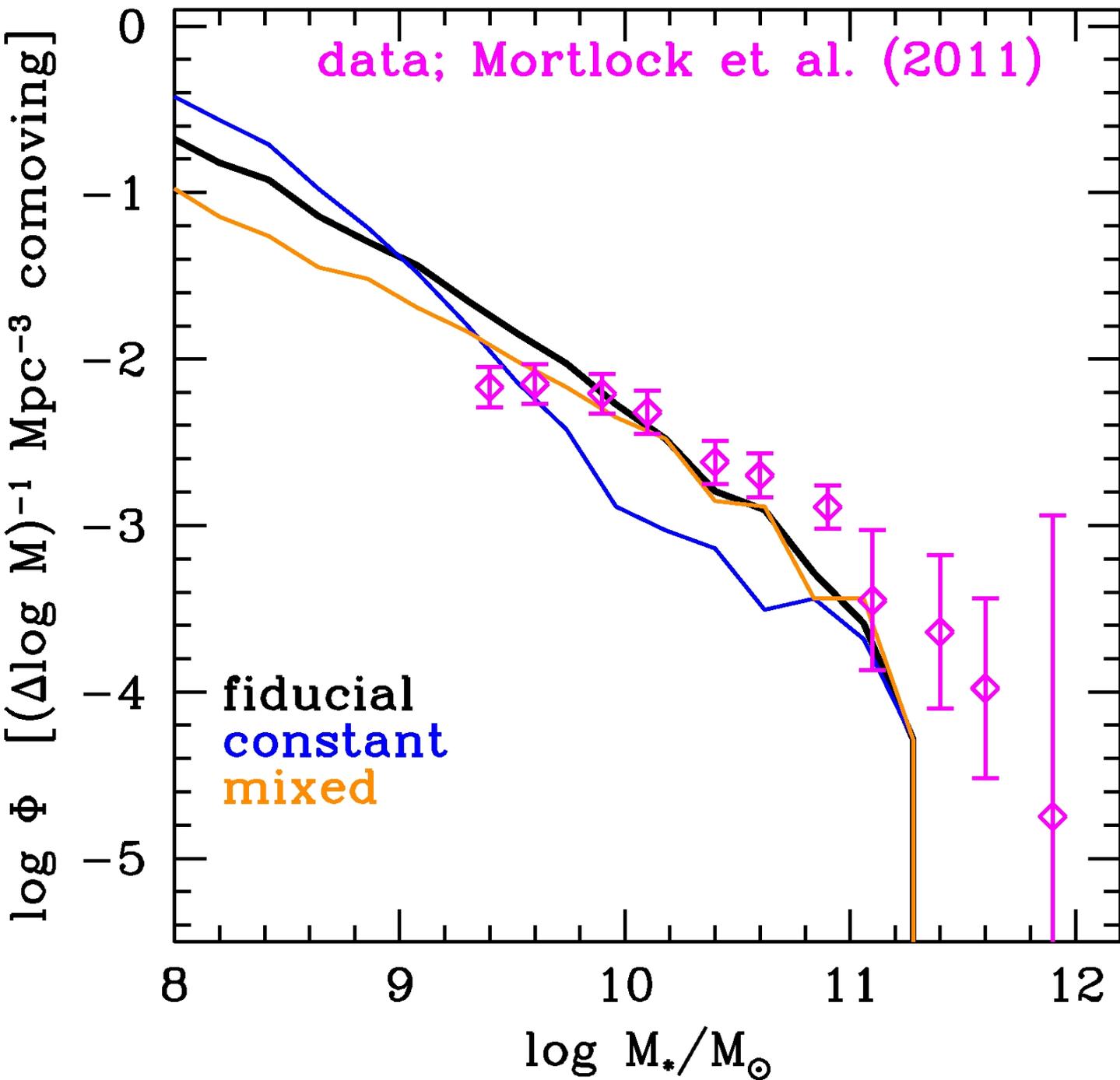
All results presented here at $z=2.2$

Only difference: how wind velocity and mass-loading scale (or not) with σ_{gal}

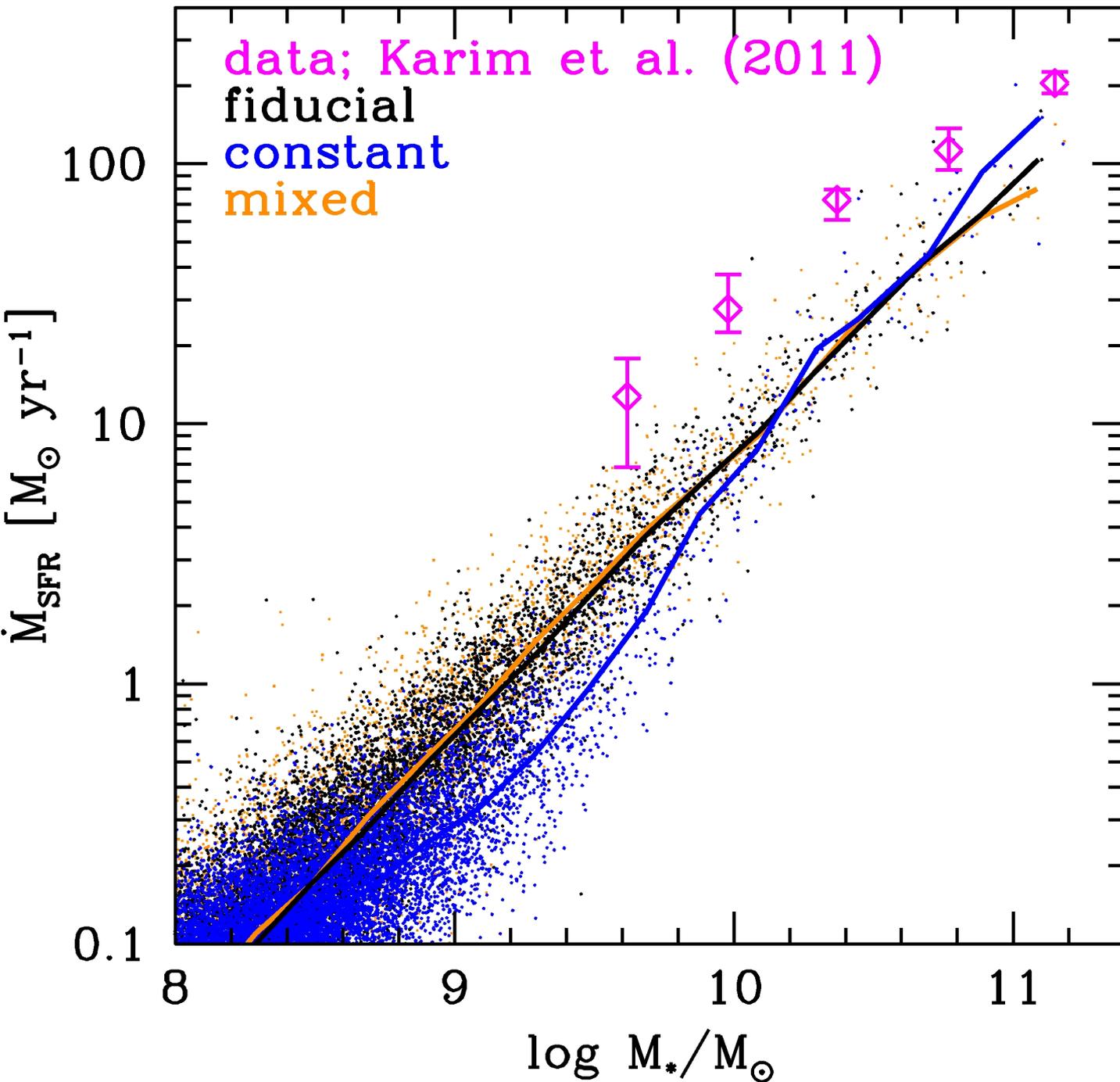


Wind Model	Wind velocity v_w	Mass-loading factor η_w
Fiducial: momentum-driven scaling (vzw)	$v_w = \sigma_{\text{gal}} / [150 \text{ km/s}]$	$\eta_w \propto \sigma_{\text{gal}}^{-1}$
Mixed: v^{-2} energy-driven scaling for dwarfs (ezw)	$v_w = \sigma_{\text{gal}} / [150 \text{ km/s}]$	$\sigma_{\text{gal}} > 75 \text{ km/s}: \eta_w \propto \sigma_{\text{gal}}^{-1}$ $\sigma_{\text{gal}} < 75 \text{ km/s}: \eta_w \propto \sigma_{\text{gal}}^{-2}$
Constant wind (cw)	$v_w = 680 \text{ km/s}$	$\eta_w = 2$

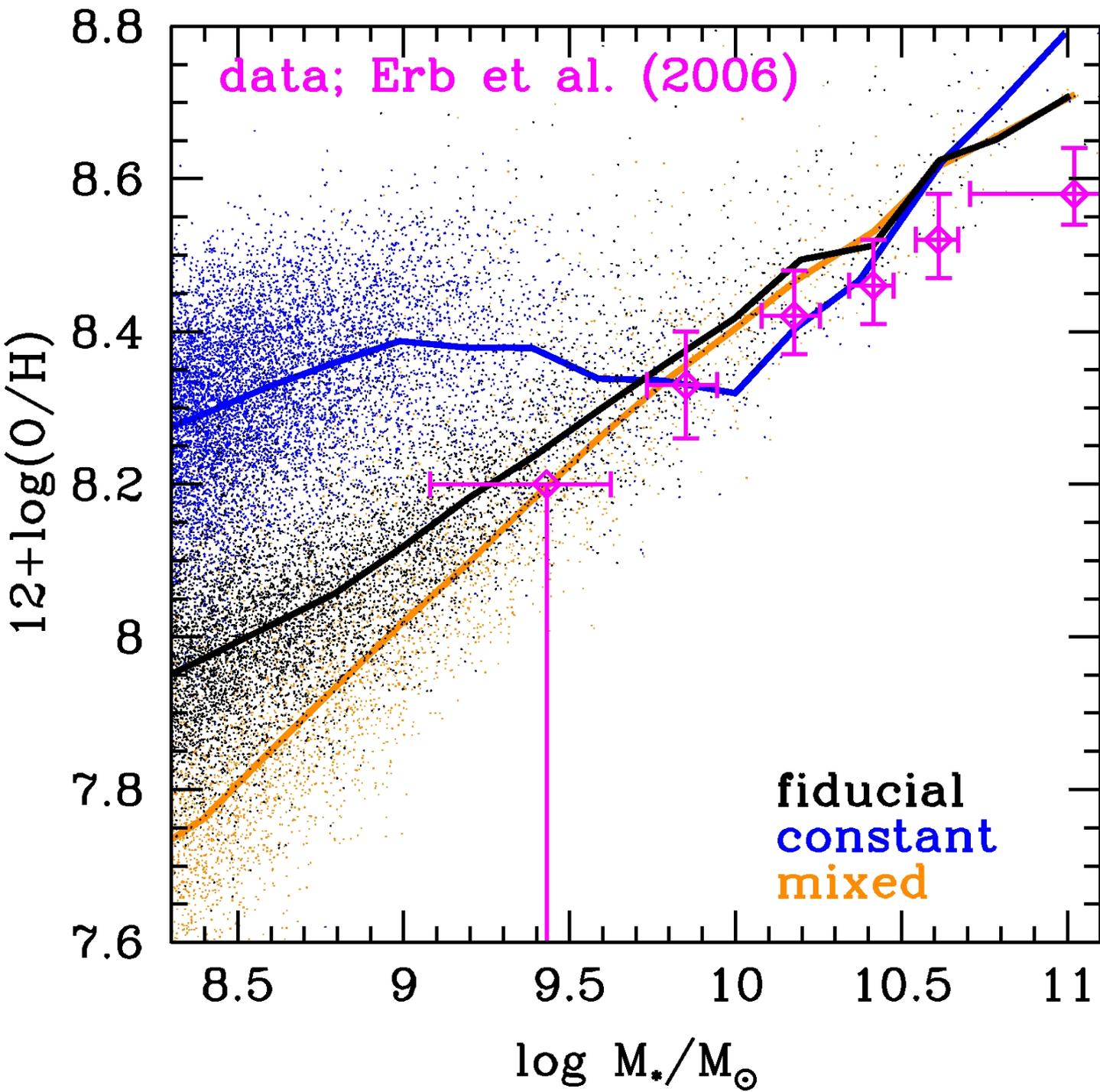
$$\eta_{\text{wind}} \equiv \frac{\dot{M}_{\text{wind}}}{\dot{M}_{\text{SFR}}}$$



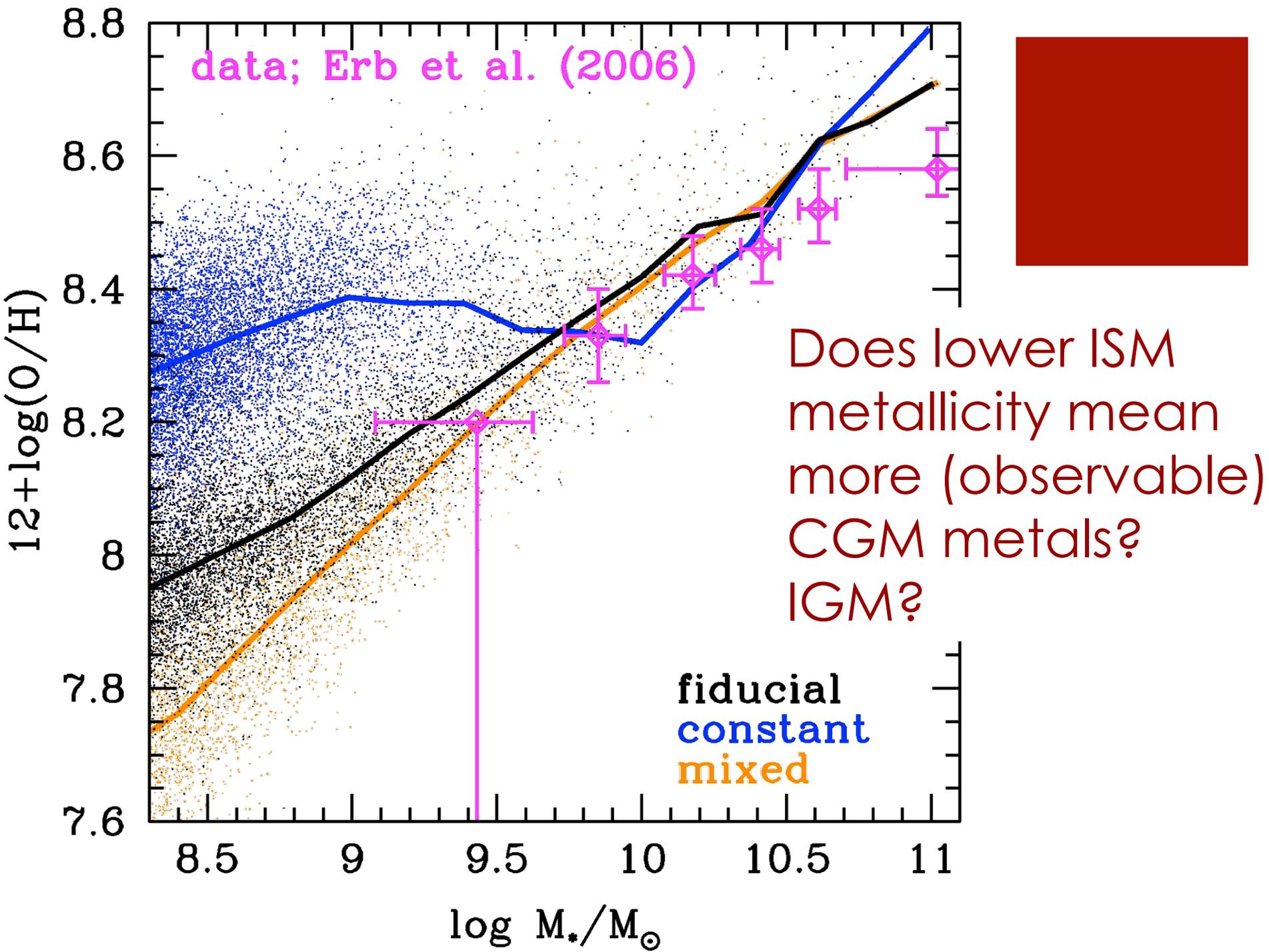
- 
- Steeper mass-loading \Rightarrow shallower stellar mass function
 - Constant wind velocity and mass loading gives characteristic upturn to mass function



- Steeper mass-loading \Rightarrow very little effect on star formation rates at fixed stellar mass
- Fast wind velocity and constant mass loading \Rightarrow lower SFRs
- Old problem: inferred SFRs from observations higher than in simulations (cf Davé et al. 2011, Narayanan & Davé 2012)



- Steeper mass-loading \Rightarrow steeper mass-metallicity relation (cf Peeples & Shankar 2011; Davé et al. 2012)
- Constant mass loading \Rightarrow flat mass-metallicity relation
- Find me later if you'd like to discuss possible tensions in normalization

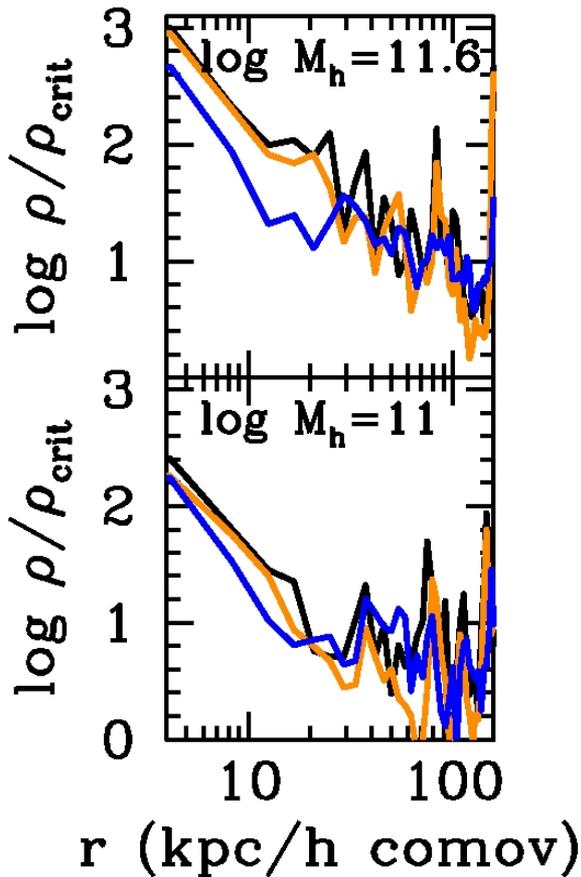


Physical properties of the circumgalactic medium

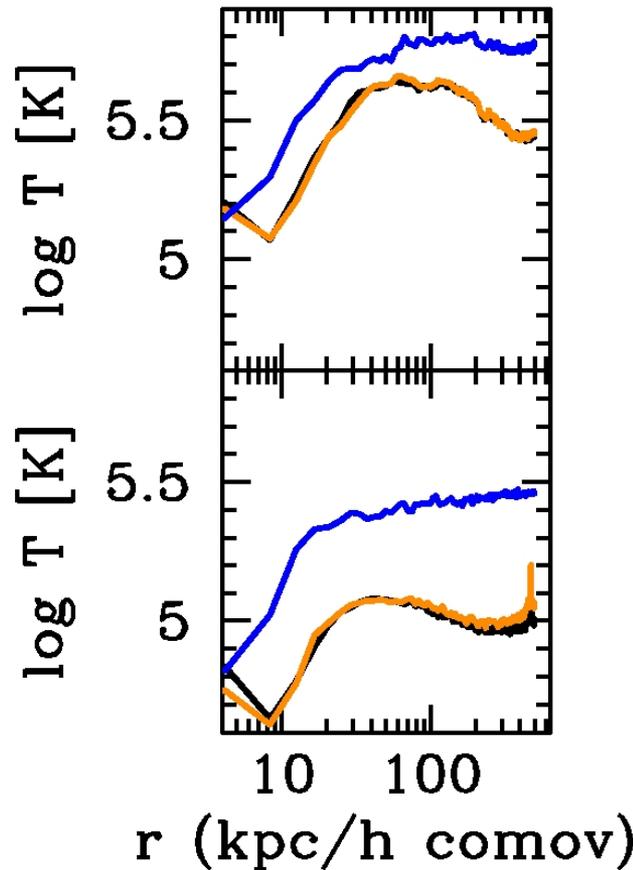


Outflows affect density, temperature, and metallicity
→ but so do halo mass, stellar mass, and star formation rate

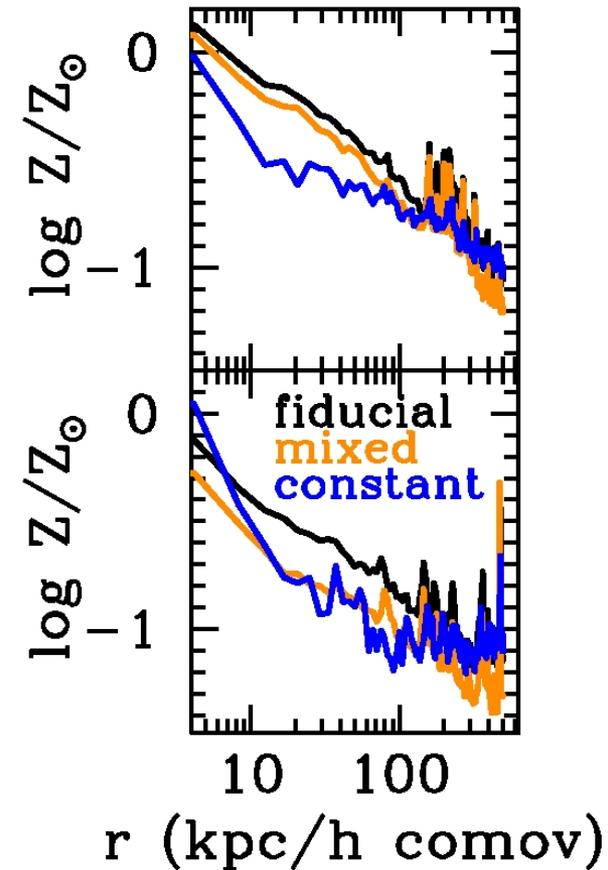
Density



Temperature

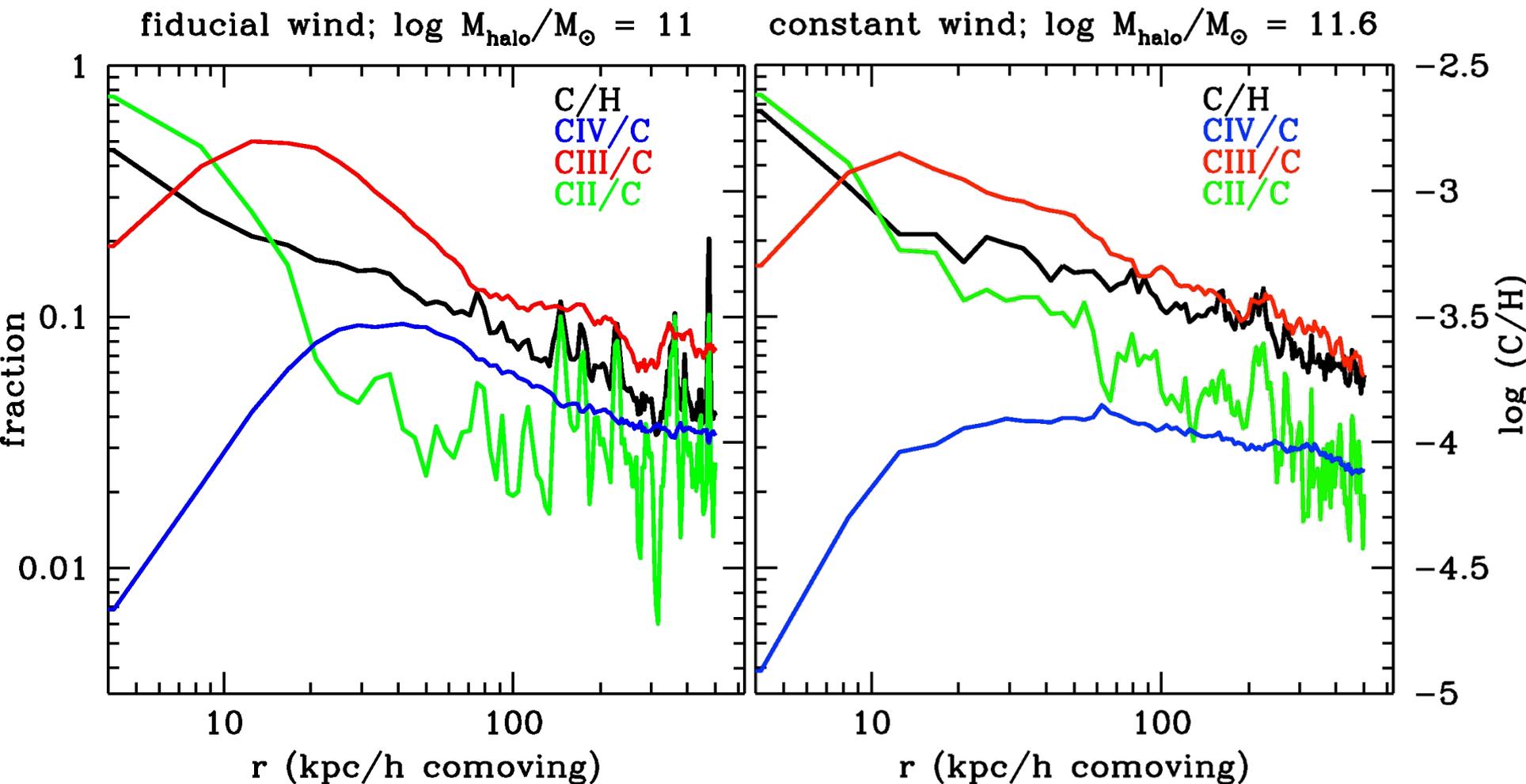


Metallicity



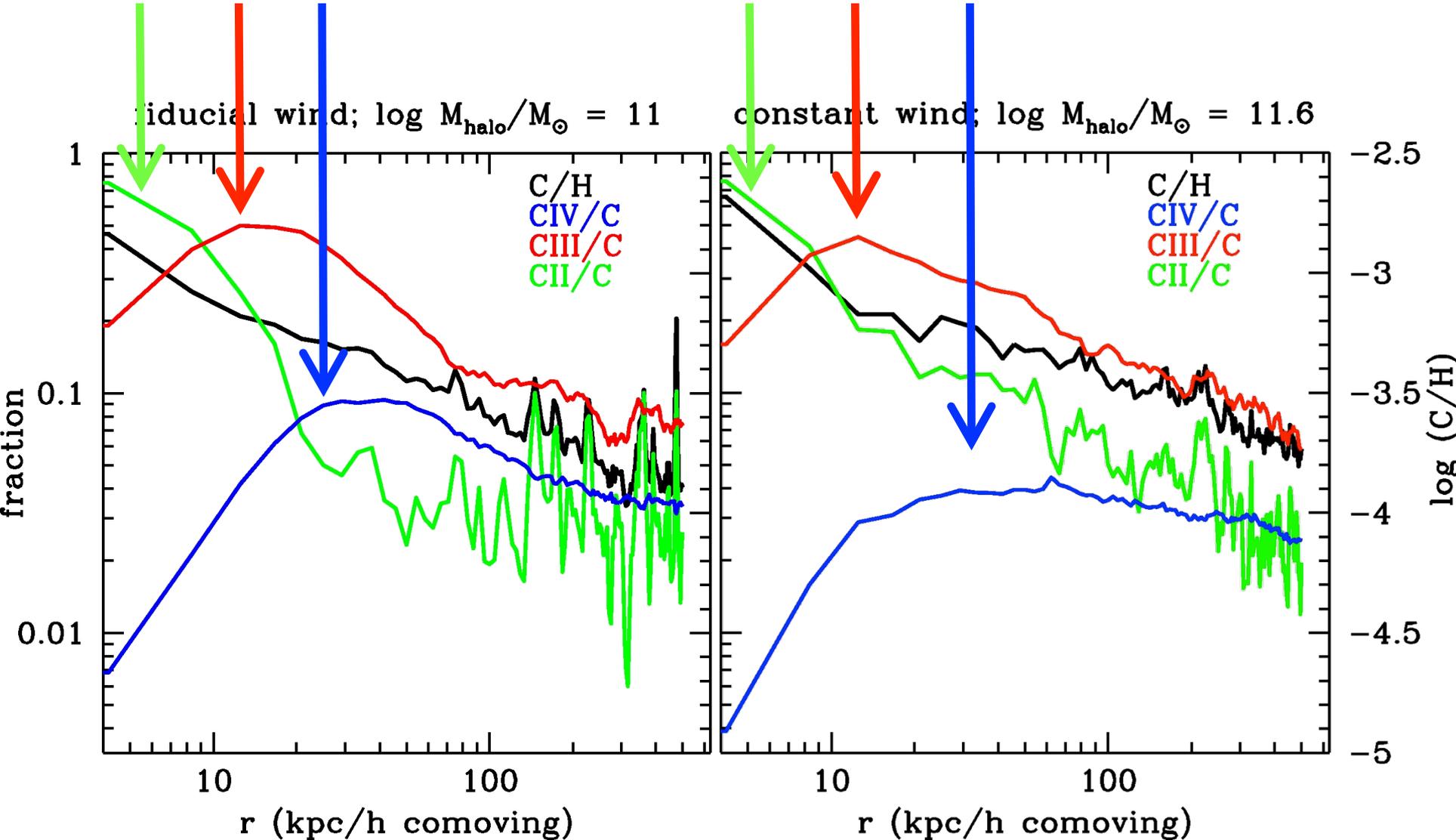
3-d radial profiles (means) of 50 matched isolated galaxies in two bins of halo mass

But observations are of various ions, not
density, temperature, metallicity



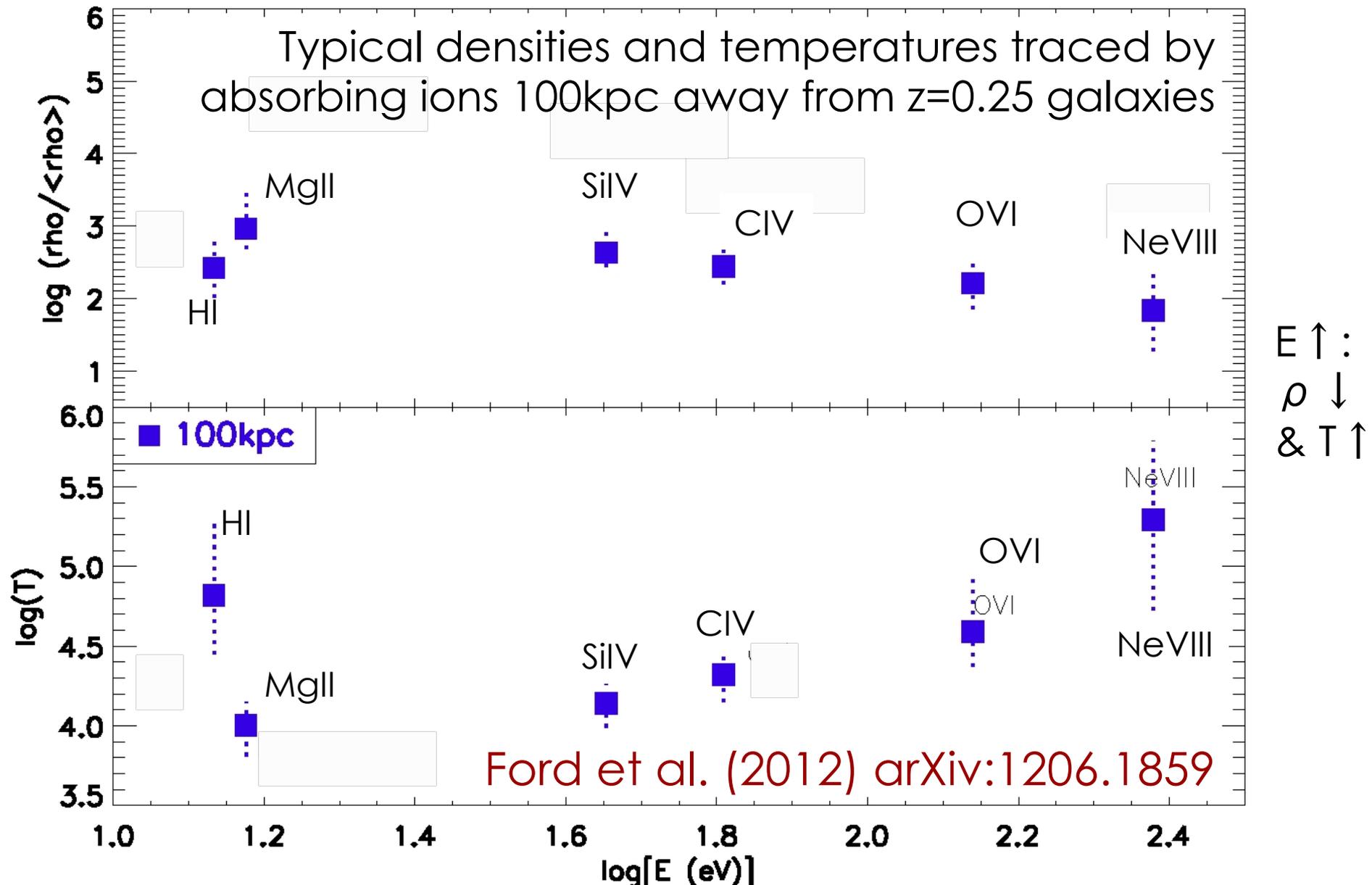
3-d radial profiles (means) of 50 matched isolated galaxies each

Higher ionization ions peak at larger radii

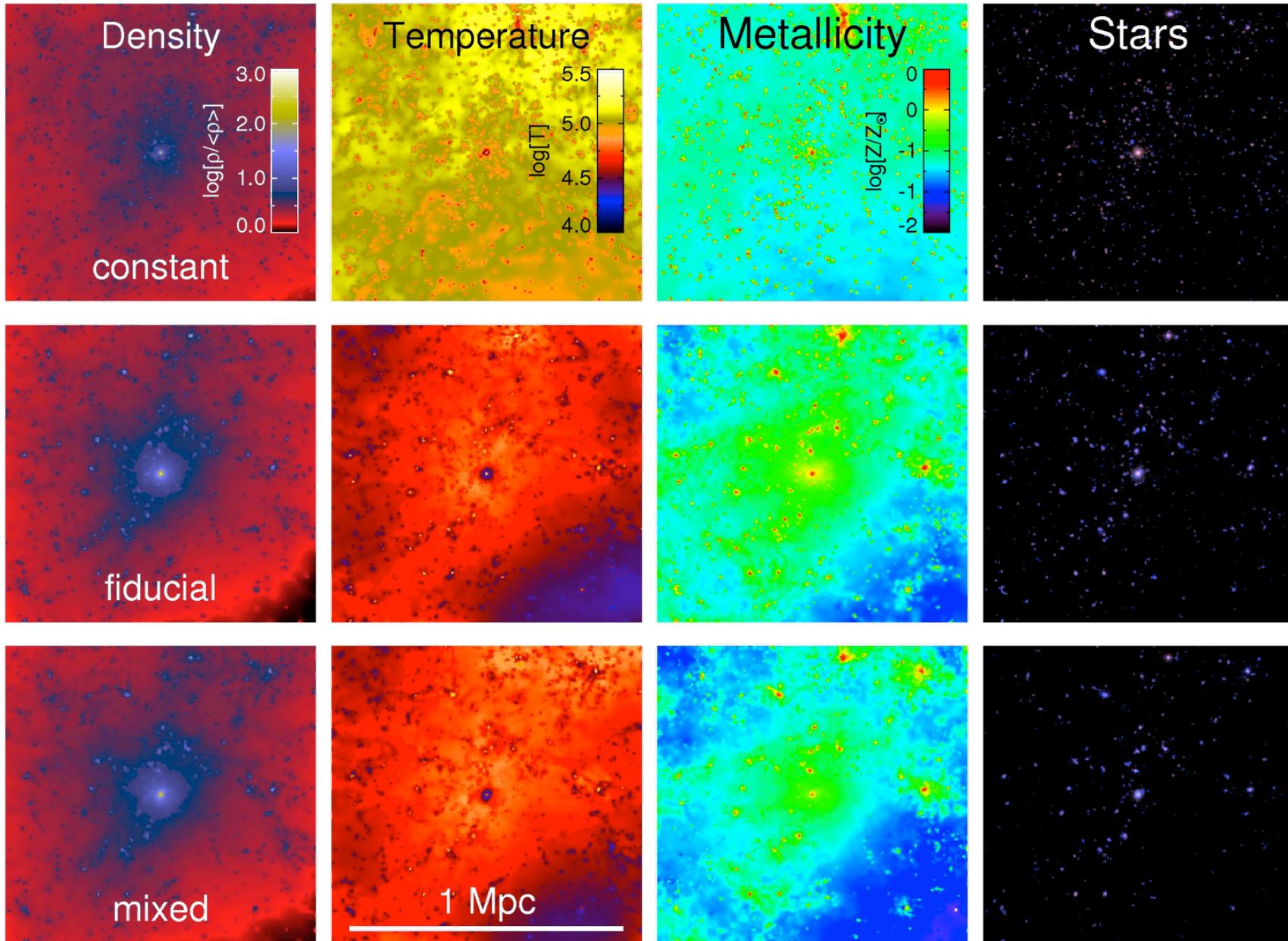


3-d radial profiles (means) of 50 matched isolated galaxies each

Go see Amanda Ford's poster!

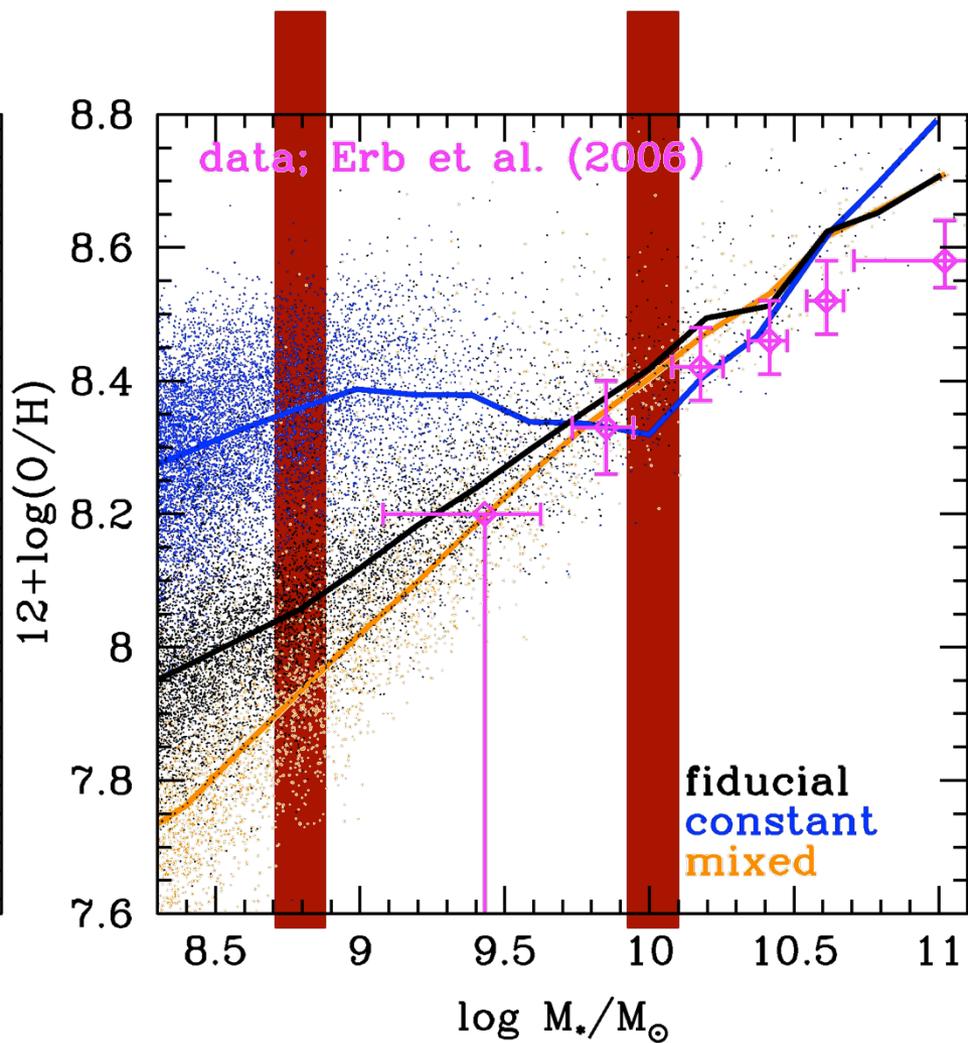
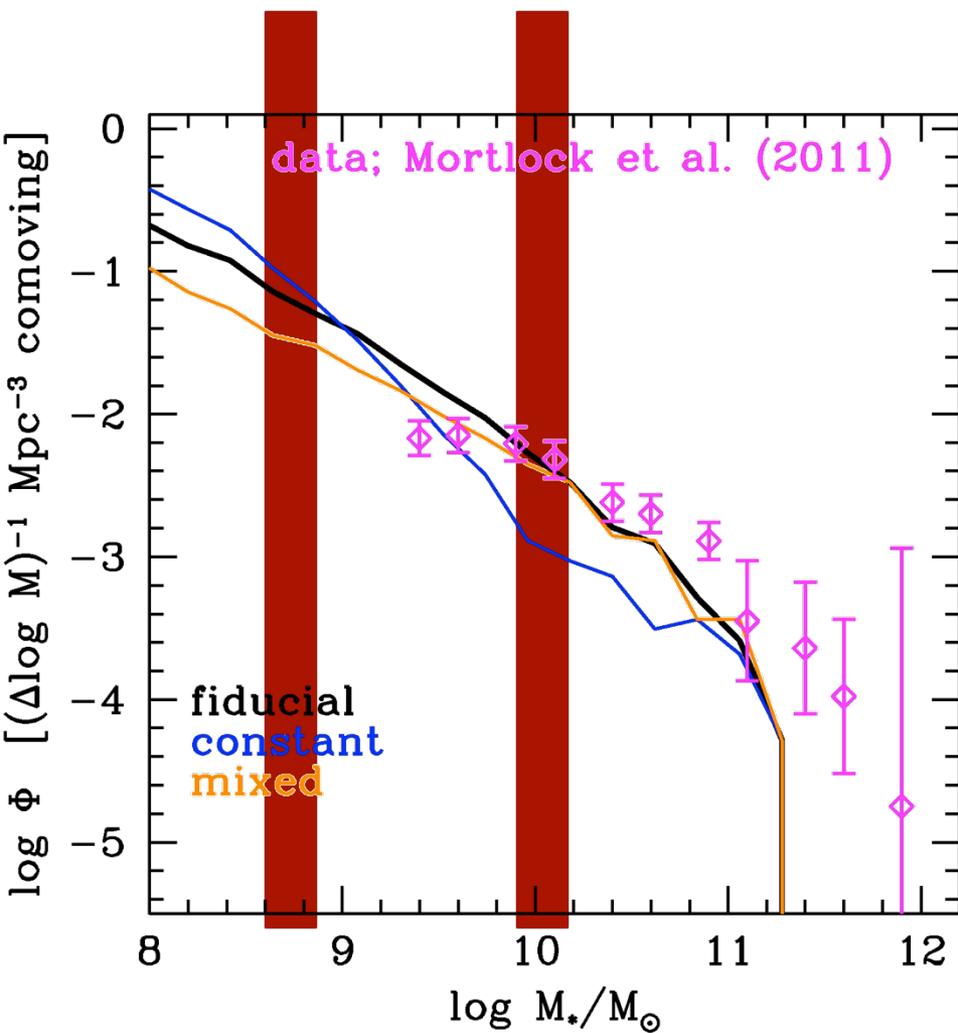


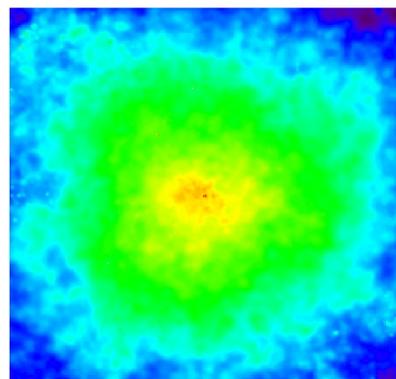
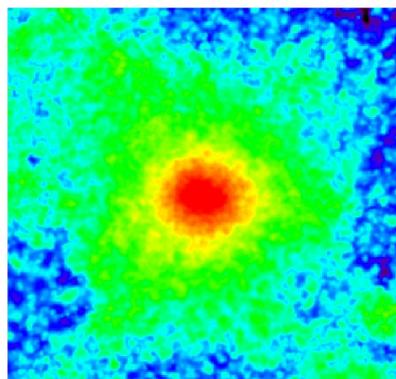
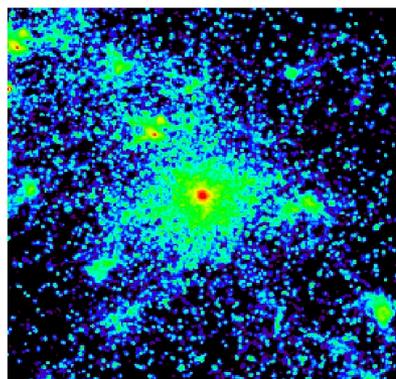
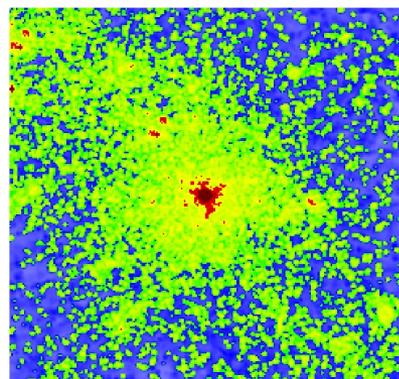
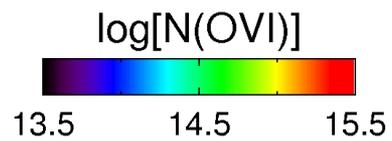
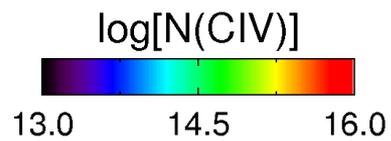
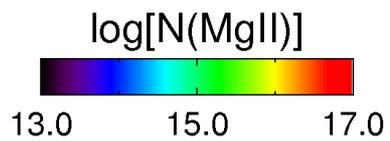
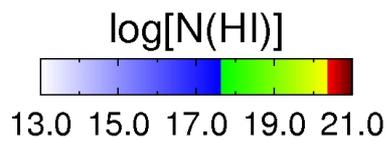
But observations are in projection, not 3-d ...



50 matched galaxies with $\log M_{\text{halo}}/M_\odot = 11$

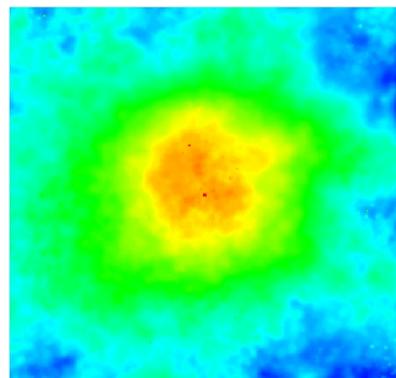
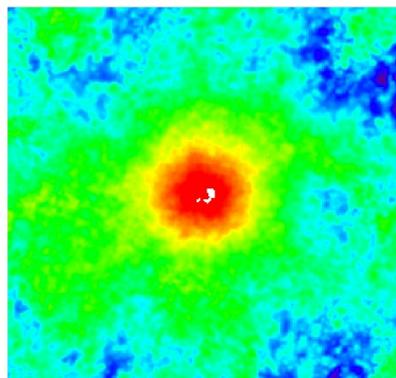
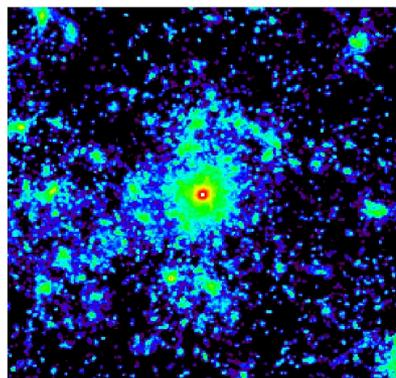
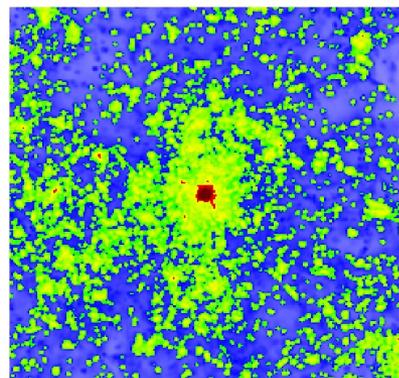
Need to compare models at fixed *stellar* mass



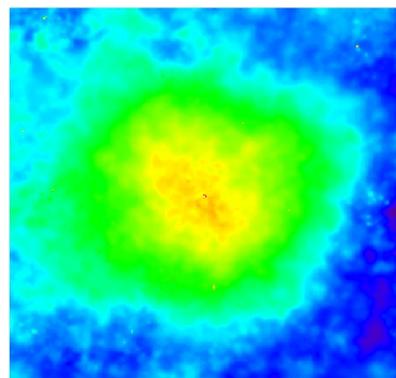
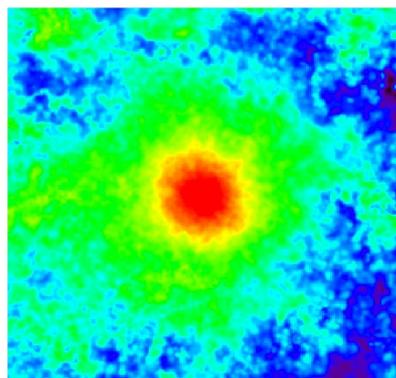
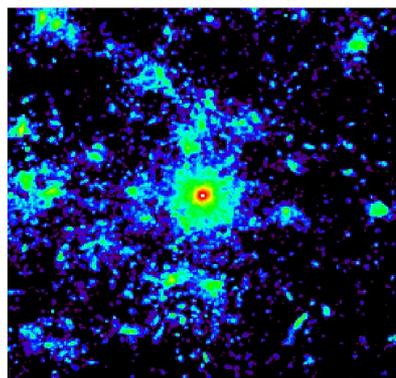
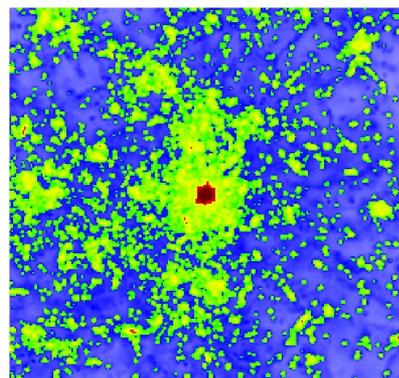


$\log M_{\star}=10$

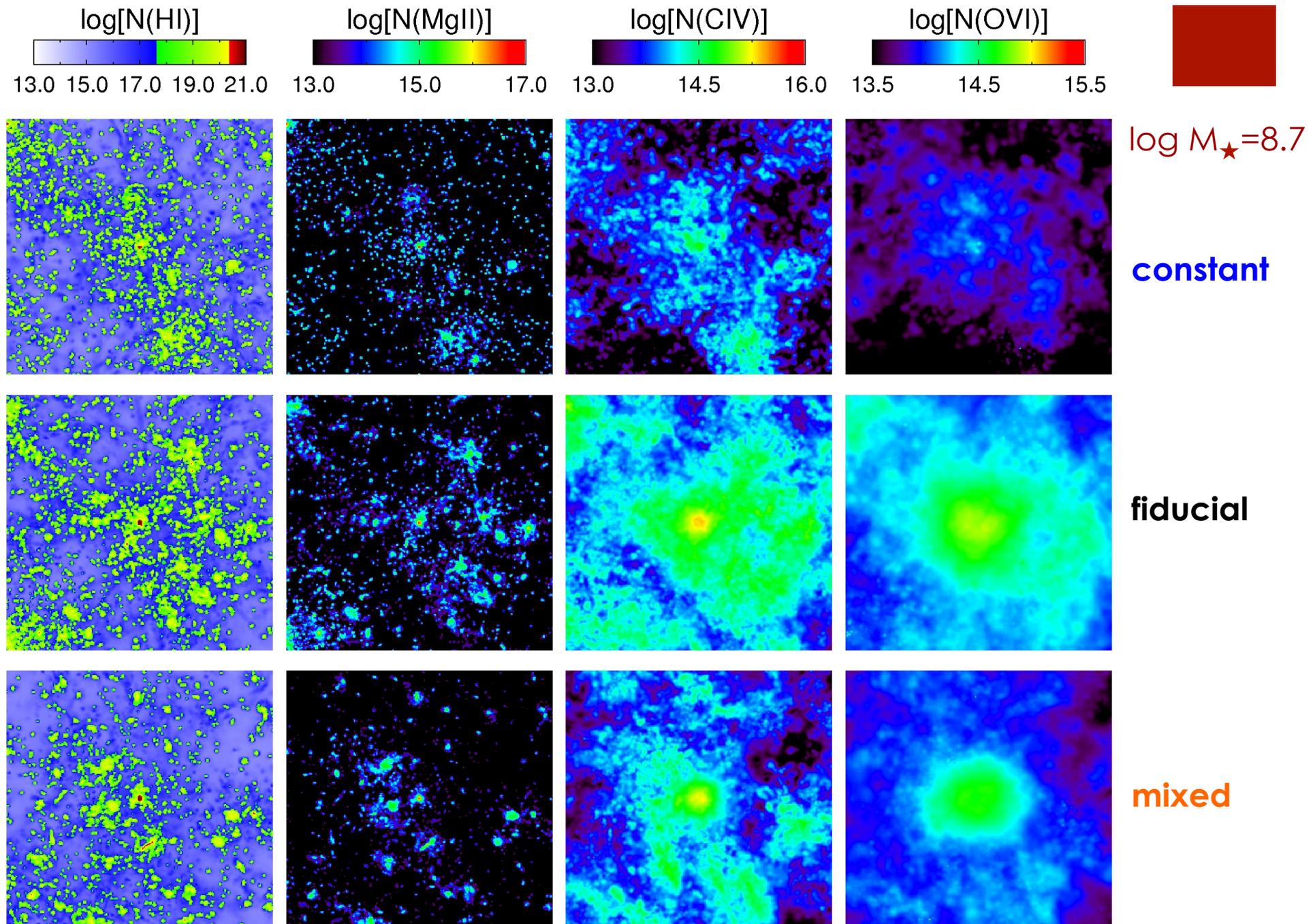
constant



fiducial



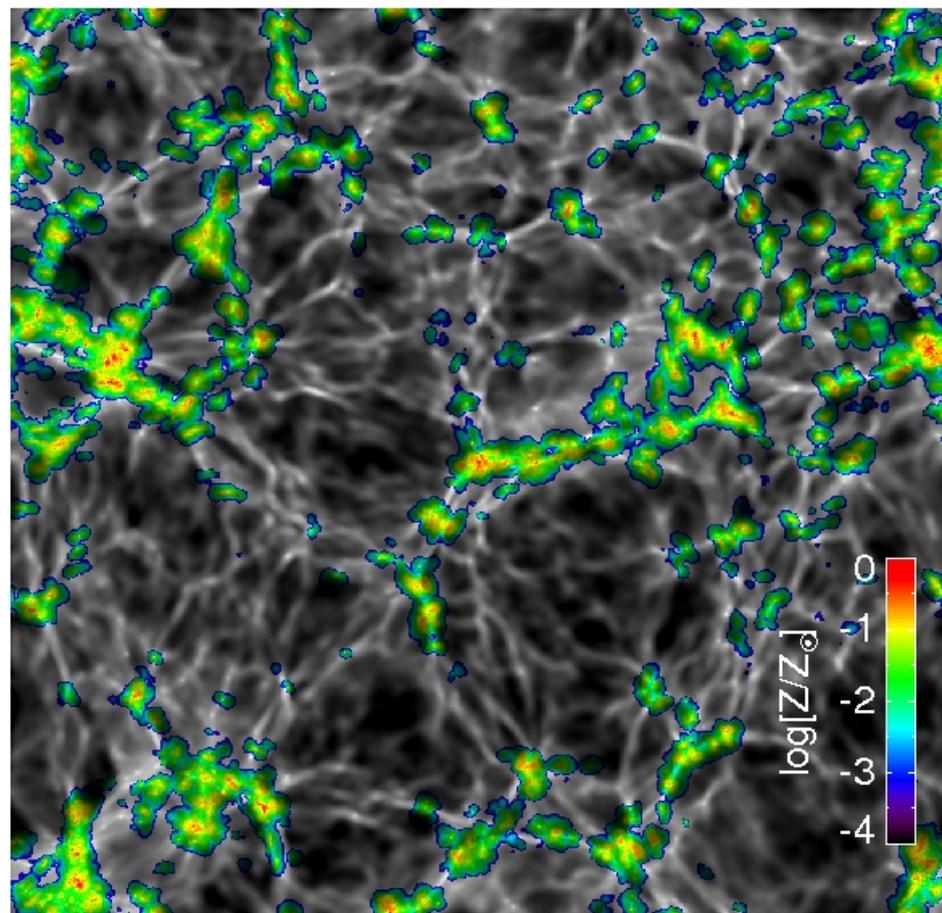
mixed



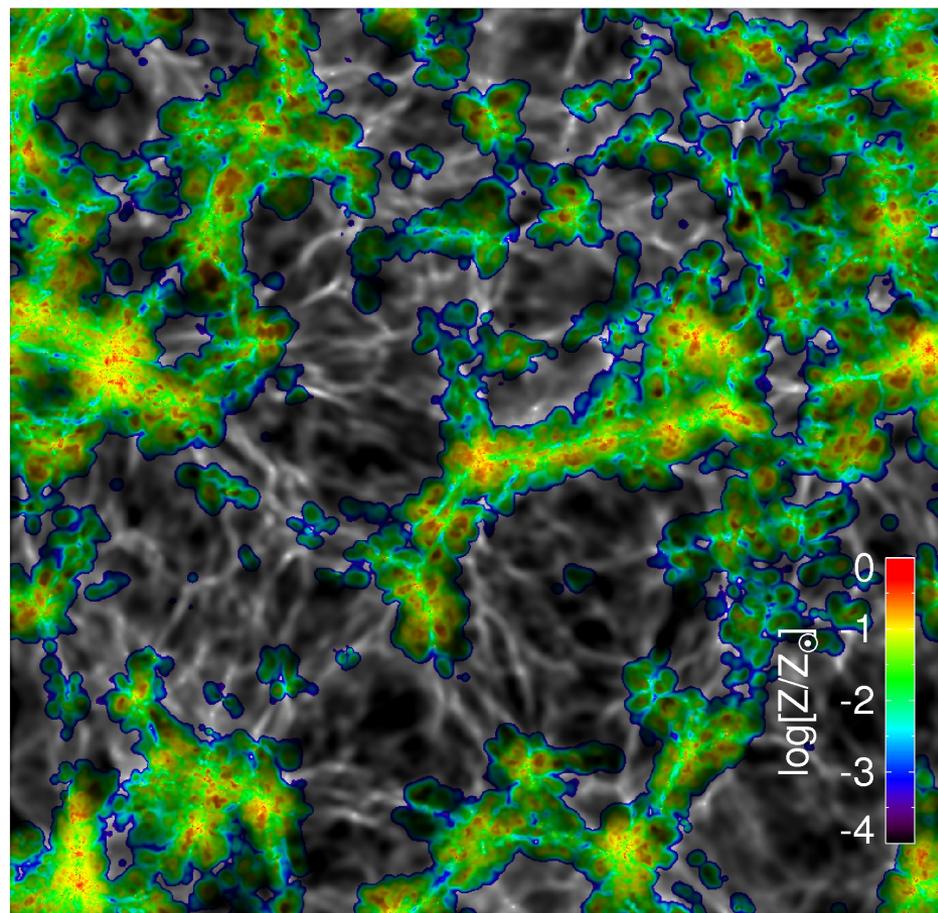
CGM is the border between ISM and IGM



Fiducial momentum-driven wind scaling



Constant wind



32 h⁻¹ Mpc comoving