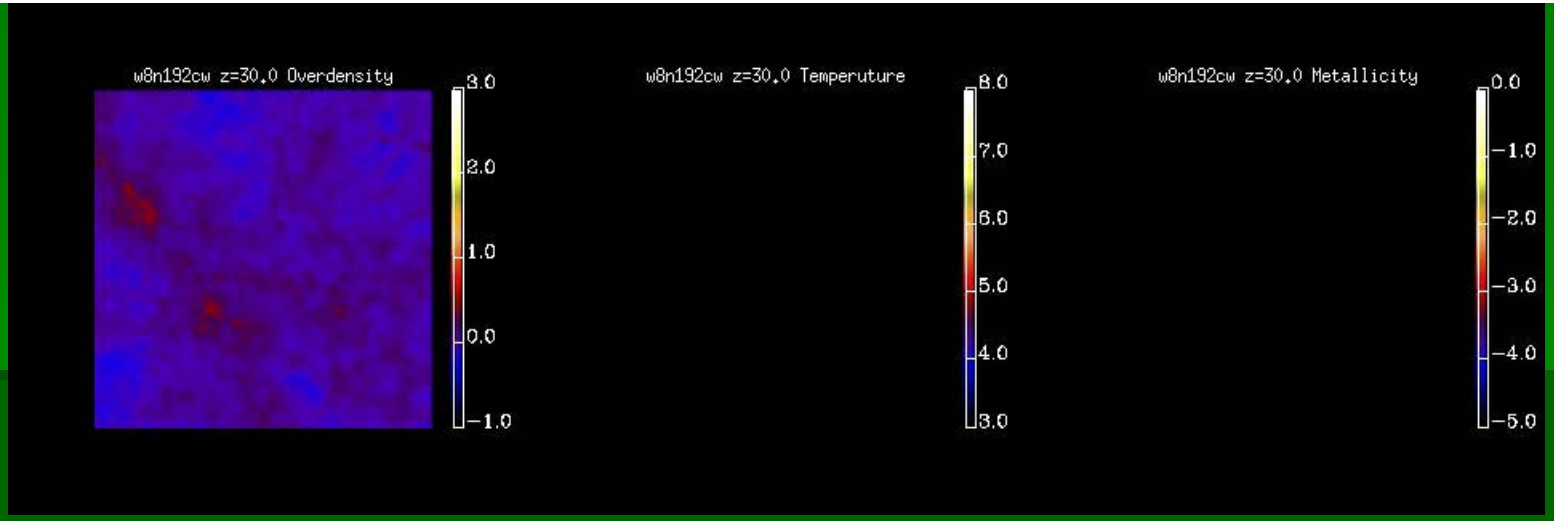
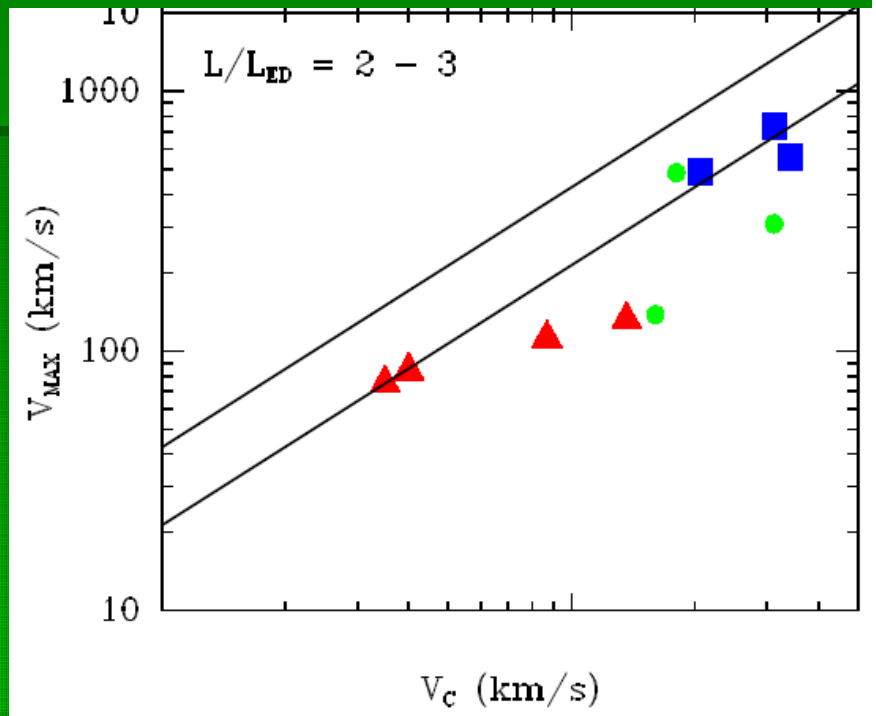


Feedback and Early Galaxies

Romeel Davé
Kristian Finlator
Ben D. Oppenheimer
University of Arizona

Outflows typical at high-z

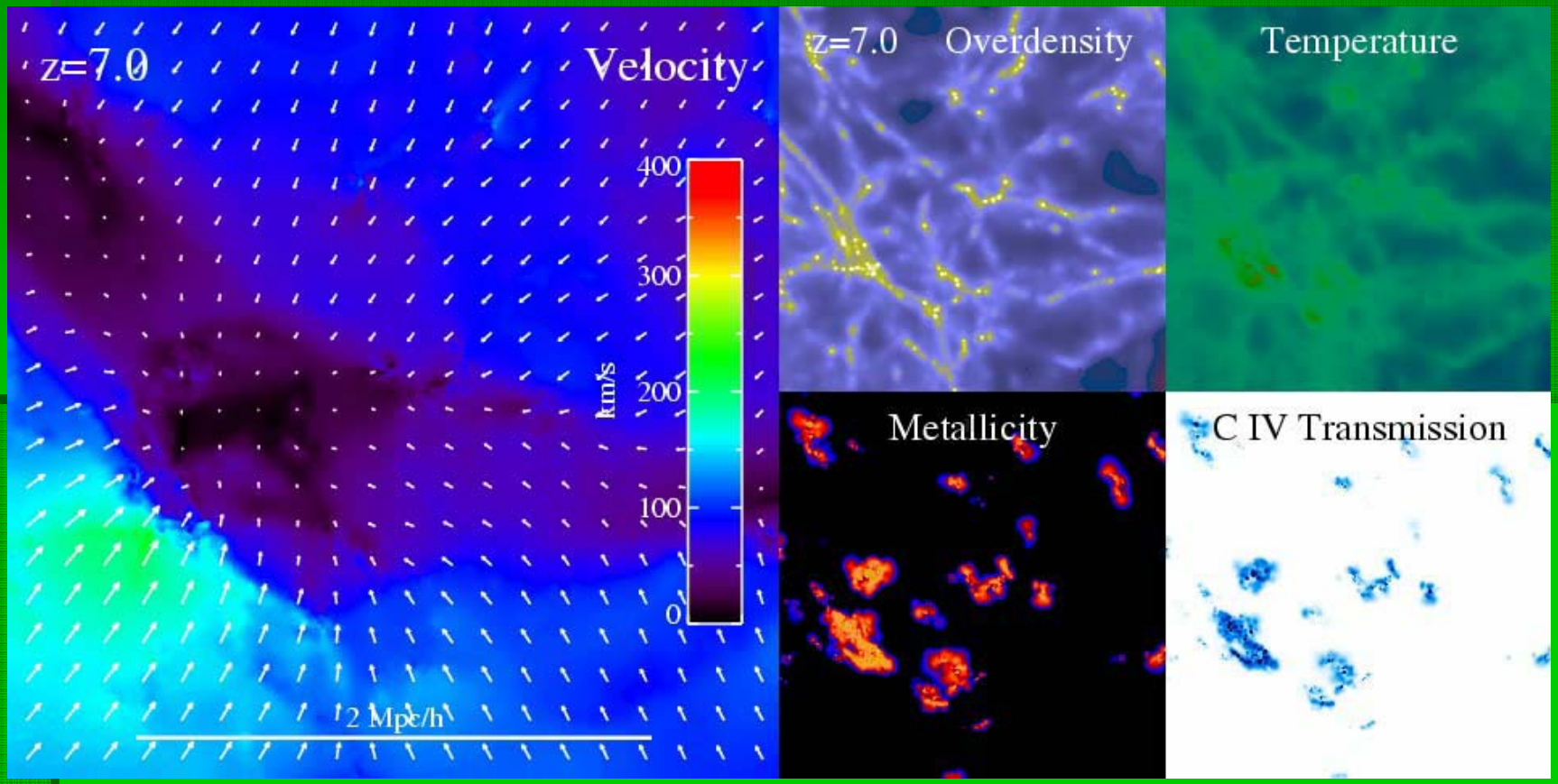
- Common in z~1+ systems:
  - Σ_{SFR}>>0.1 $M_{\odot}$/kpc^2
  - Δv_{ISM}~ hundreds km/s
- Local starbursts, z~1 SFG:
  $v_w \propto v_{circ}$
  Momentum-driven winds?
- If so, outflow rate $\eta \propto 1/v_{circ}$
- Outflows enrich IGM...
  What do outflows do to galaxies?



Martin 2005

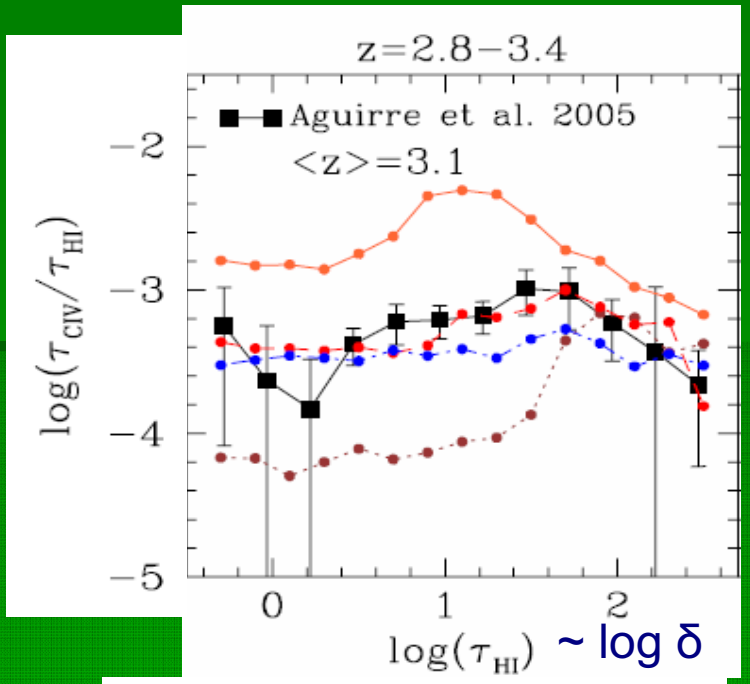
Outflows in Gadget-2

- Kick particles with v_w, in **vxa** direction.
- Monte Carlo: $Prob_{outflow} = \eta Prob_{SF}$
- v_w and η related to galaxy properties.



IGM enrichment

- A tale of 3 winds:
  - Momentum-driven scalings
  - Weak ($E<E_{SN}$)
  - Constant (v_w~500km/s,η=2)



wind speed

IGM too hot

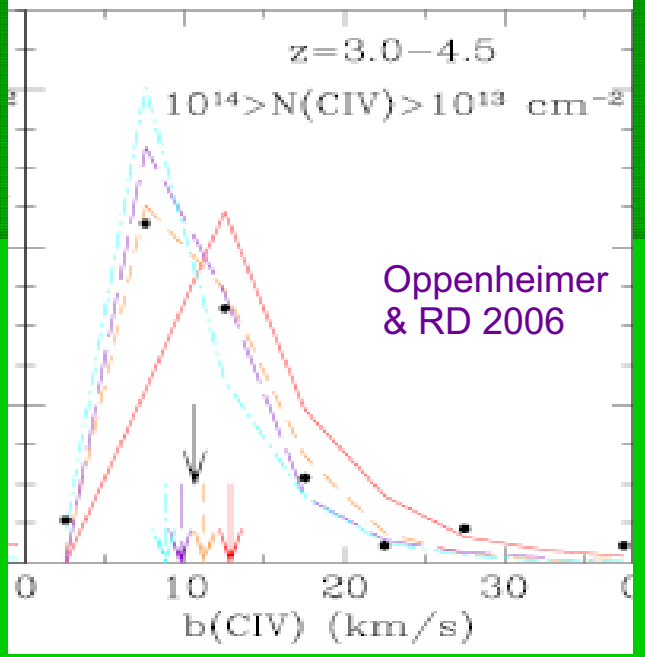
Too few metals in IGM

Momentum-driven wind scalings!

Too few metals produced

Diffuse IGM unenriched

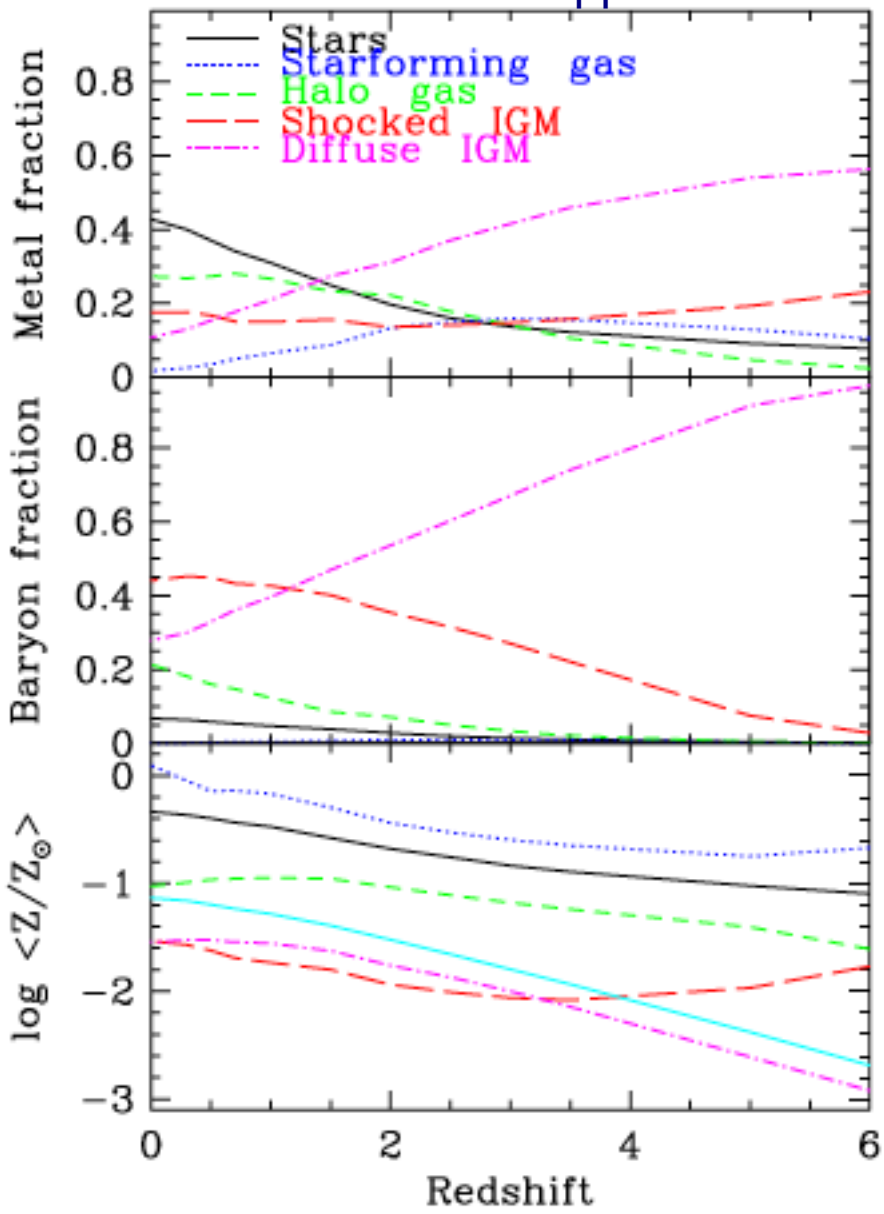
mass loading



Missing metals

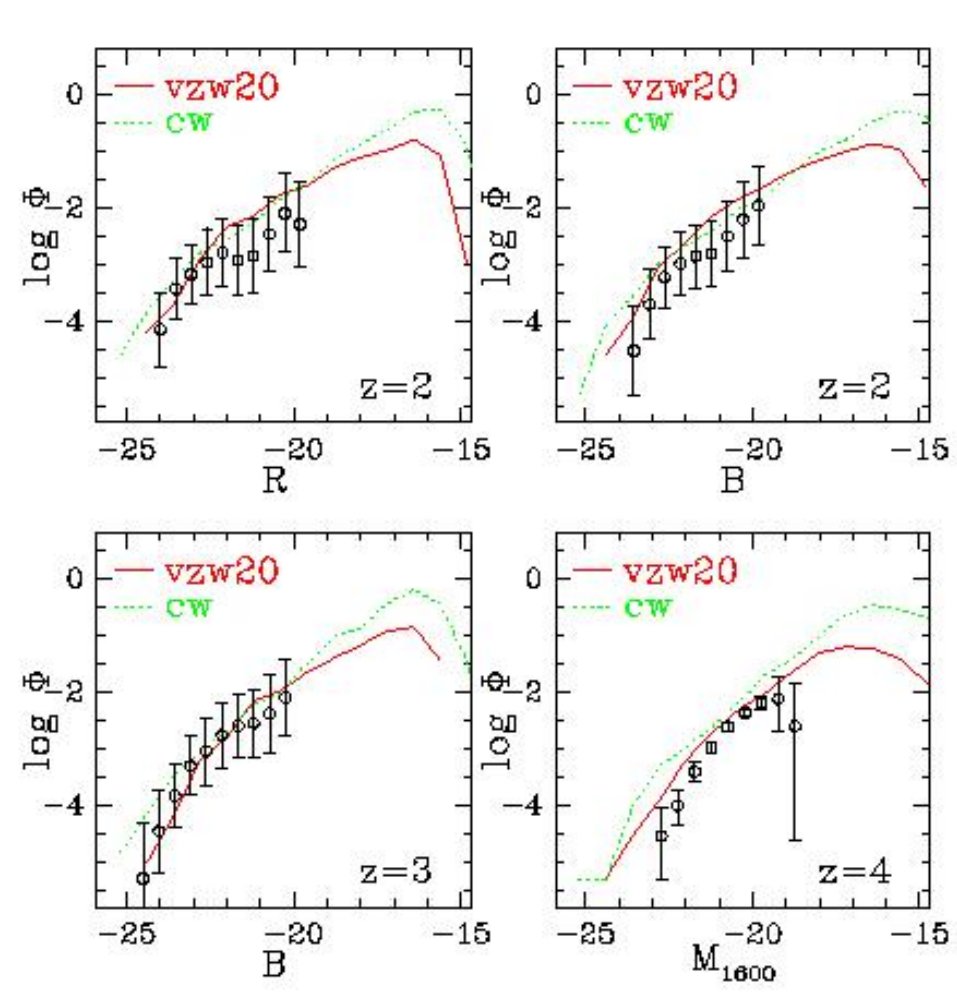
- Pettini 99: Metals in z~3 galaxies << Metals produced by stars.
- Strong outflows?
- Simulations: 40% of metals in diffuse IGM @ z=3; only 10% in stars, 10% in cold gas.
- Shocked IGM (WHIM) has ~20% at all z.
- But is it only *metals* ejected, or *mass?*

RD & Oppenheimer 07



Luminosity functions

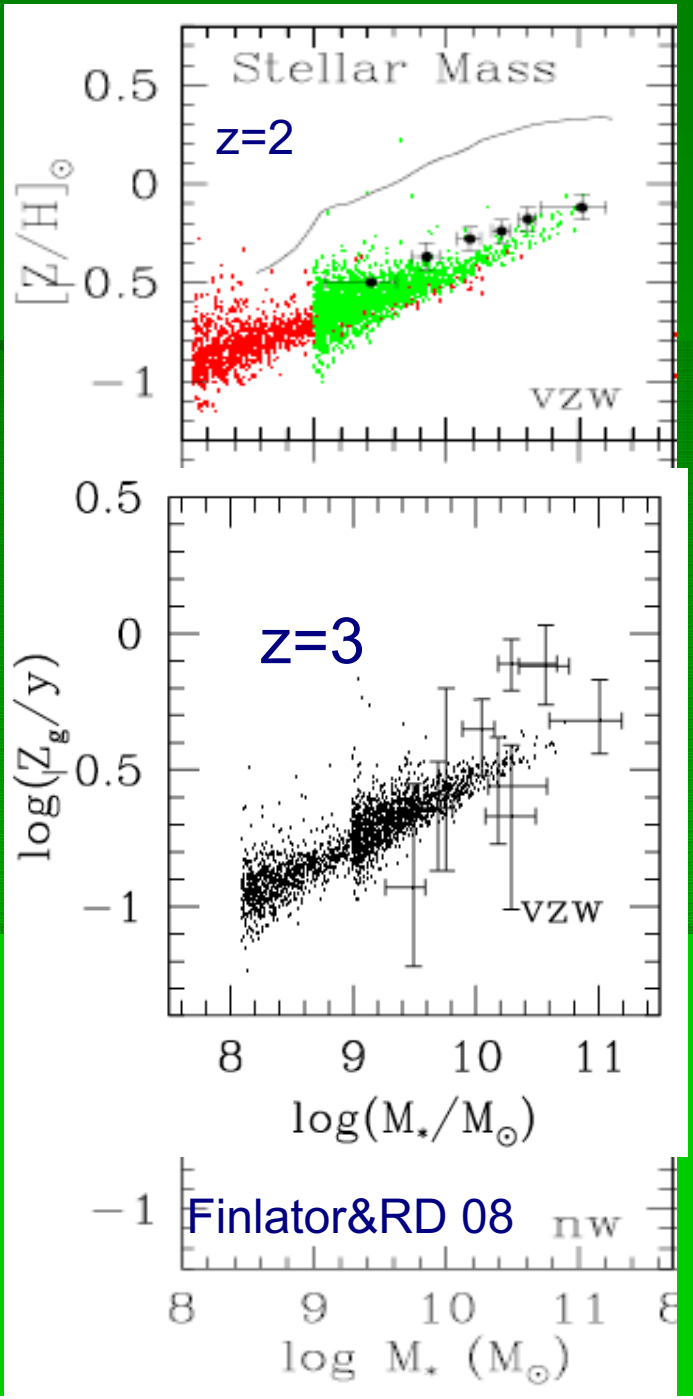
- z~6 UVLF: large SF suppression required: Outflows are highly mass-loaded.
- ACC=SFR+OUT □ SFR∝ACC/(1+η)
- z~2-4 rest-UV+ optical LF's show α~1.7.
- Outflows affect faint end of LF: prefers higher η in small galaxies.



RD, Finlator, Oppenheimer 06

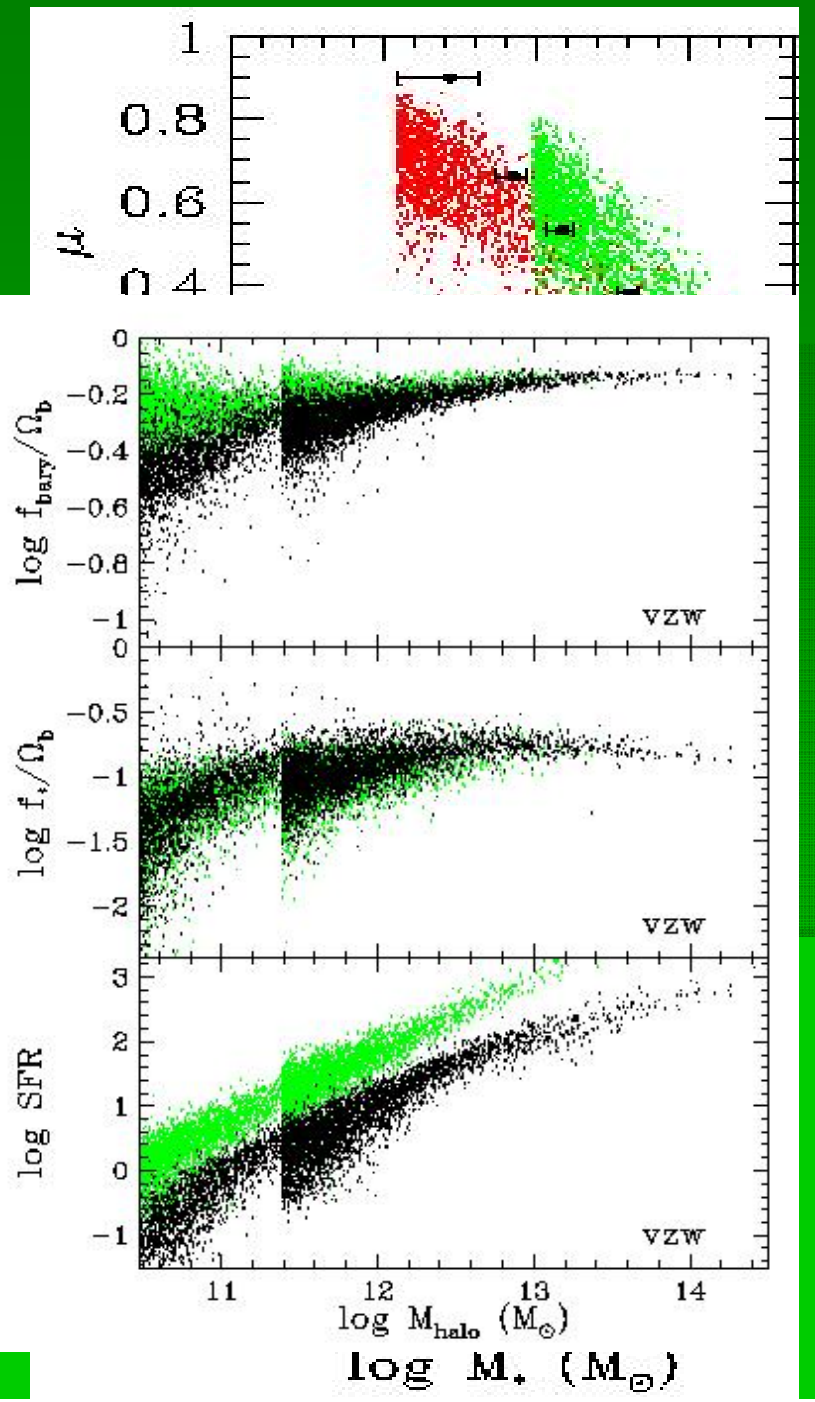
Mass-metallicity

- Life is simple: High-mass galaxies hold winds, low-M galaxies lose winds.
- ...Or is it?
- Constant wind model fails!
- Mom-driven wind model ($v_w \propto v_{esc}$) works...why?
- $Z \sim y\ SFR/ACC \sim y/(1+\eta)$
- $Z(M_*) \sim M_*^{1/3}$, so $\eta \sim M_*^{-1/3} \sim v_c^{-1}$
- Z_{gas} set by an equilibrium between *recent* accretion+outflow.



Baryon fractions

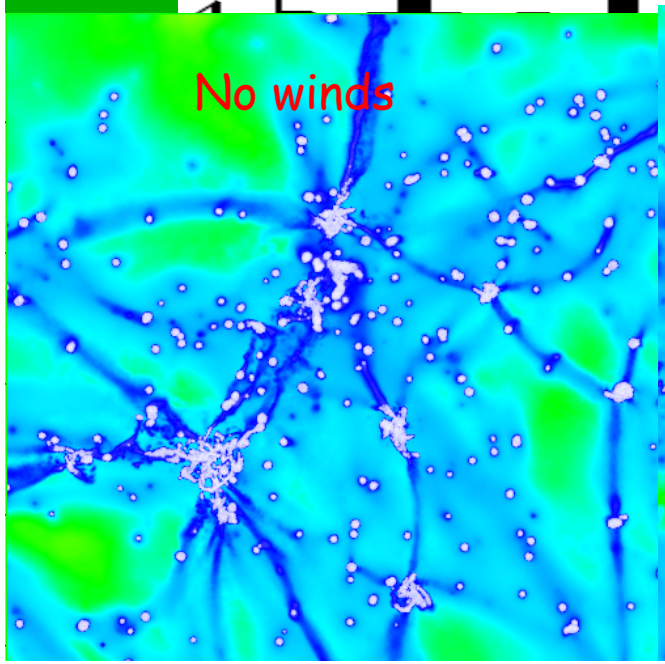
- Winds keep galaxies gas-rich; but only winds with high mass loading in small galaxies.
- Galaxies lose substantial mass early.
- MW sized halo at z=0 has half its “share” of baryons.

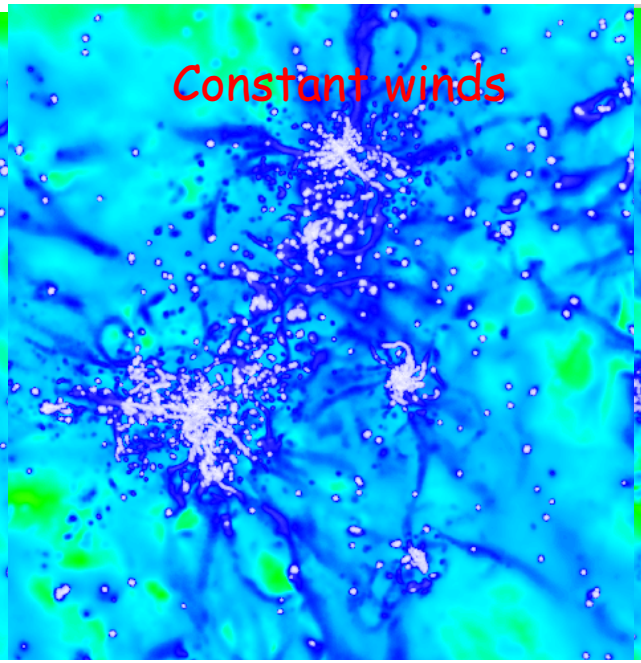


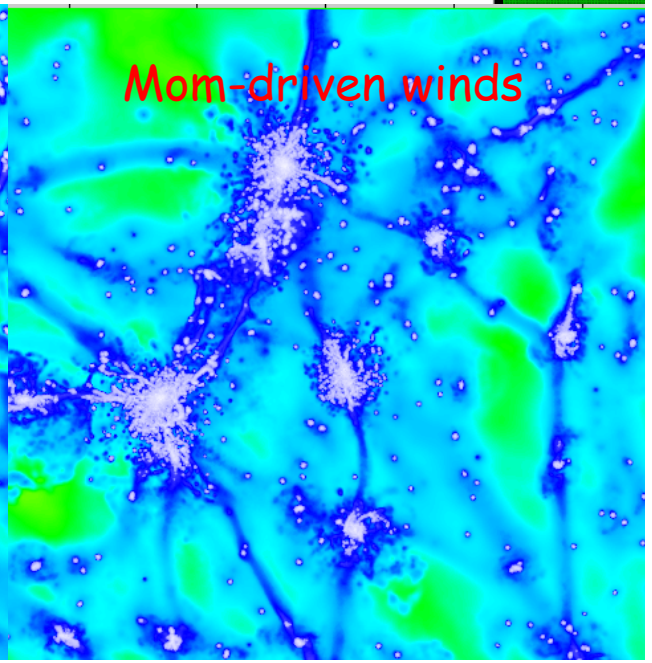
DLA Kinematics: Outflows?

- Wide separation ($\Delta v > v_{rot}$) DLAs hard to produce; protogalactic clump infall fails (Pontzen etal).
- Momentum-drive winds puff out gas, produces wide-separation systems.

S. Hong, Katz, RD etal, in prep

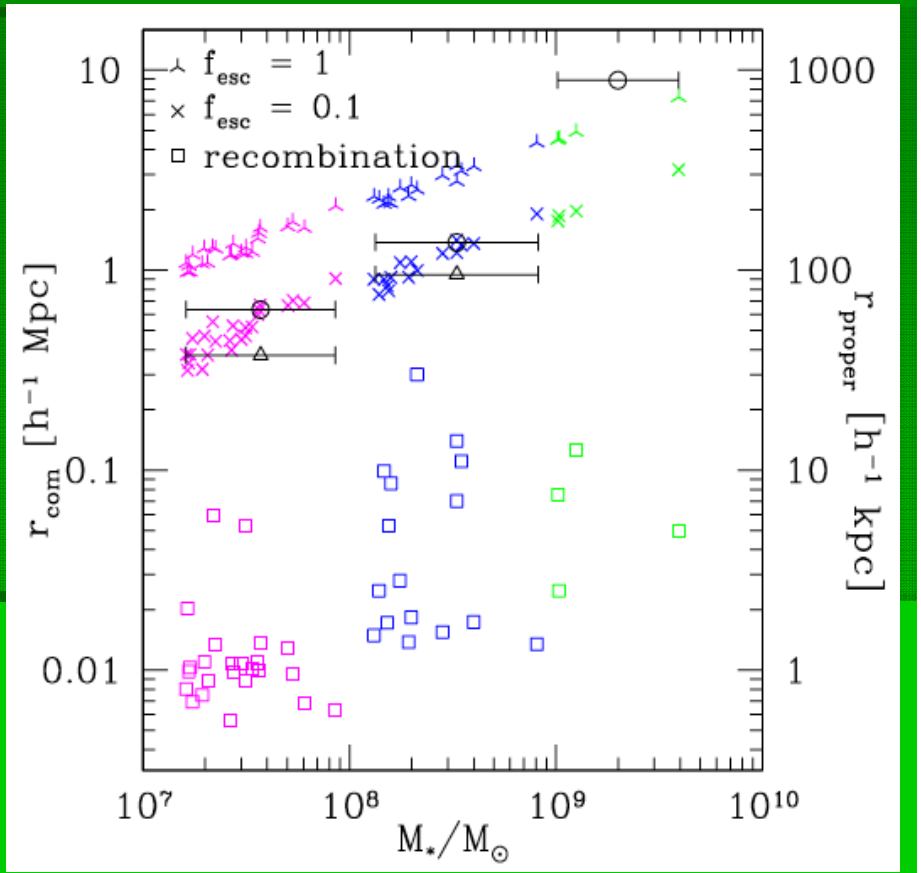






Enough photons for reionization?

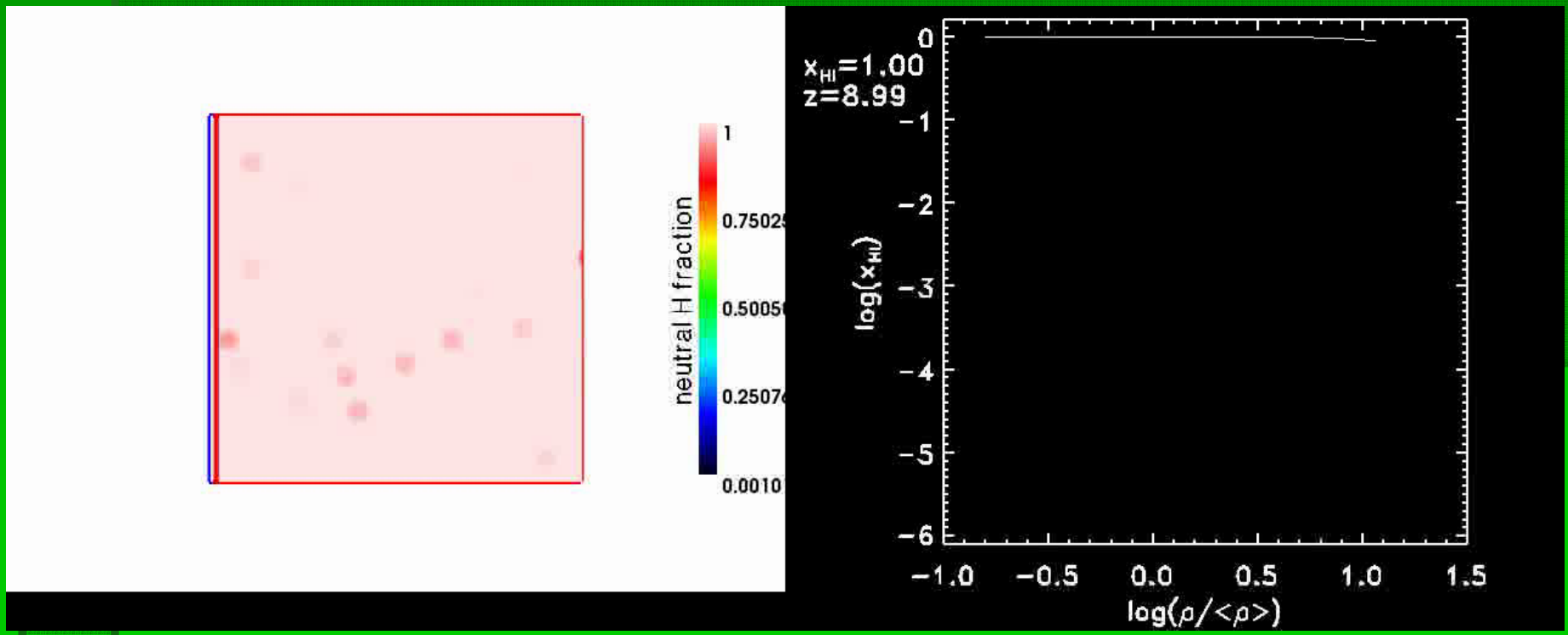
- If we suppress SF, does that hamper ability to reionize?
- Compare correlation length with ionizing radius (spherical).
- Even for f_{esc}=0.1, galaxies can ionize to their neighbor at z=9.
- So not a problem to reionize the Universe early.



RD, Finlator, Oppenheimer 06

Let's do it right: Rad Hydro

- Variable Eddington tensor scheme (like OTVET, without the “OT”, i.e. optically thin assumption).
- Kristian Finlator's thesis: Combine w/Gadget.



Summary

- Galaxy formation at high-z driven by galactic outflows.
- Mass in outflows >~ mass in stars
- Required to enrich IGM, suppress SF, establish MZR, keep galaxies gas rich.
- One particular scaling (momentum-driven) works remarkably well to match data.
- Such scalings are consistent with directly observed outflows at z~0-3.
- There is a lot of mass, metals, and energy moving across cosmic scales!