

$z=20.0$

C II

C IV

O VI

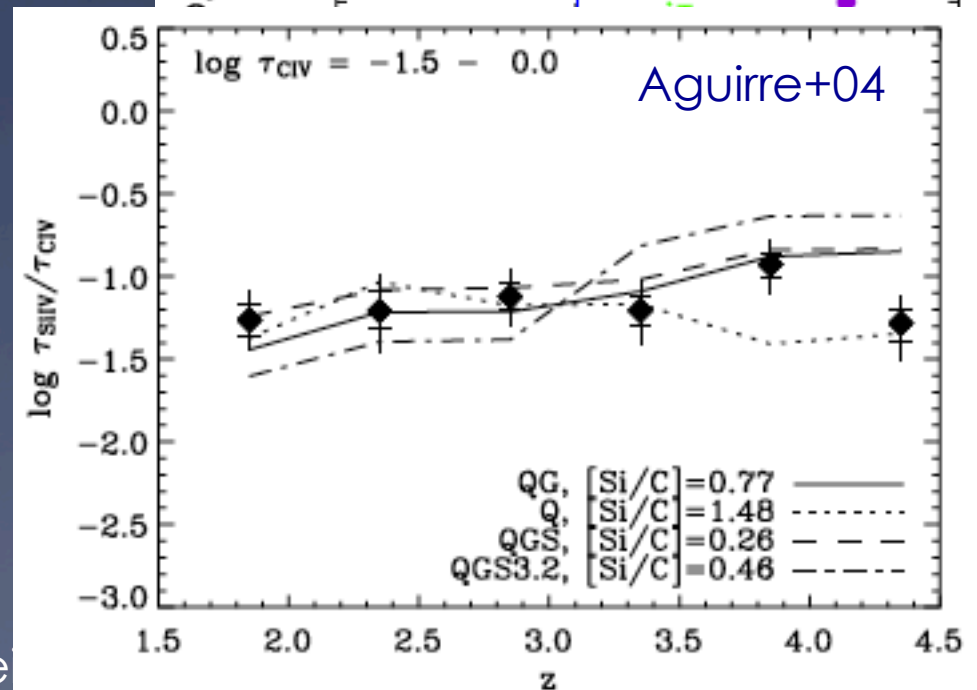
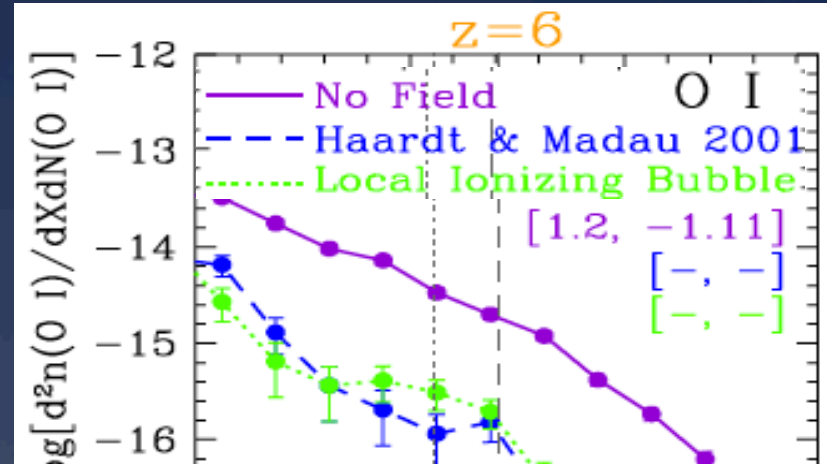
The Enrichment of the Intergalactic Medium

Romeel Davé (Arizona)

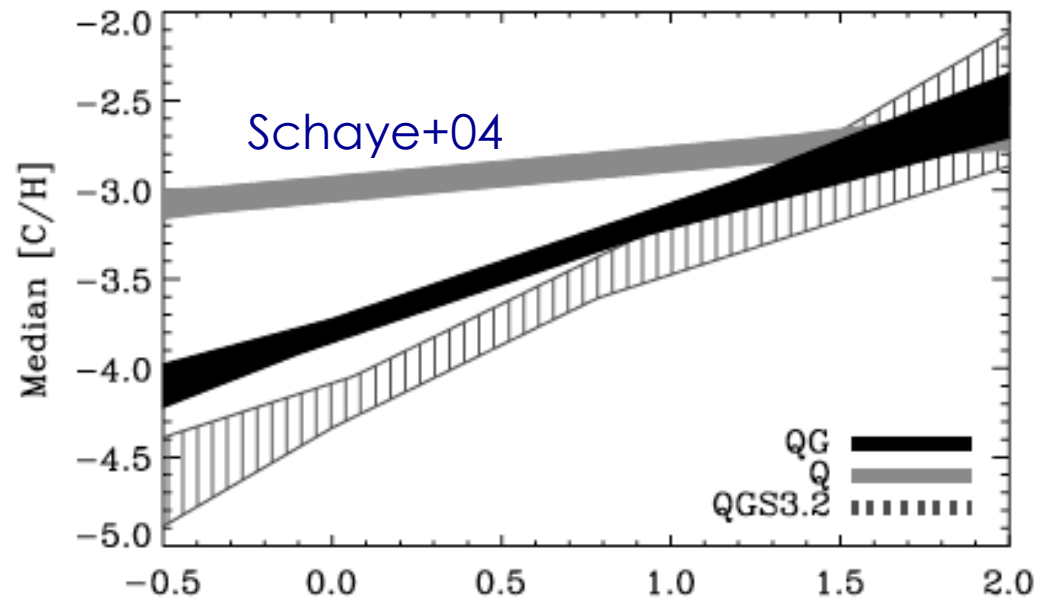
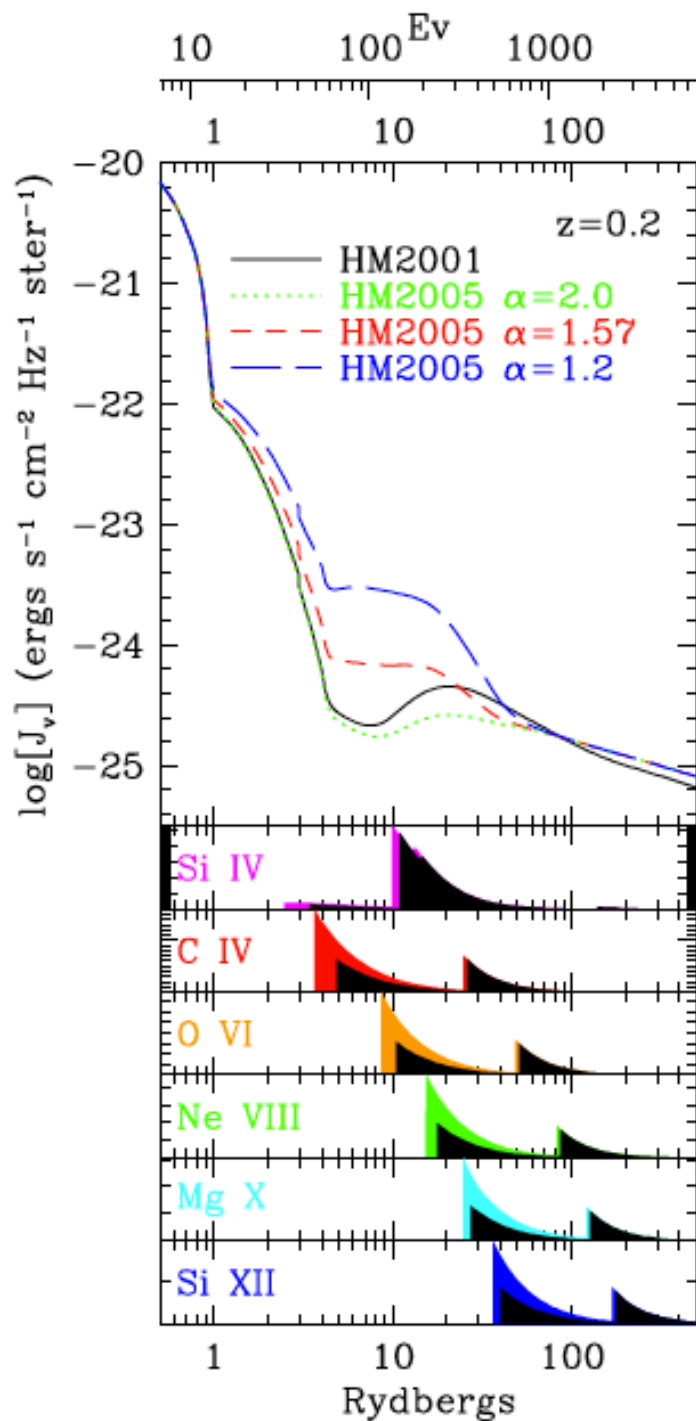
with Ben D. Oppenheimer,
Neal Katz, David Weinberg,
Amanda Ford, Molly Peeples

The IGM is enriched by winds

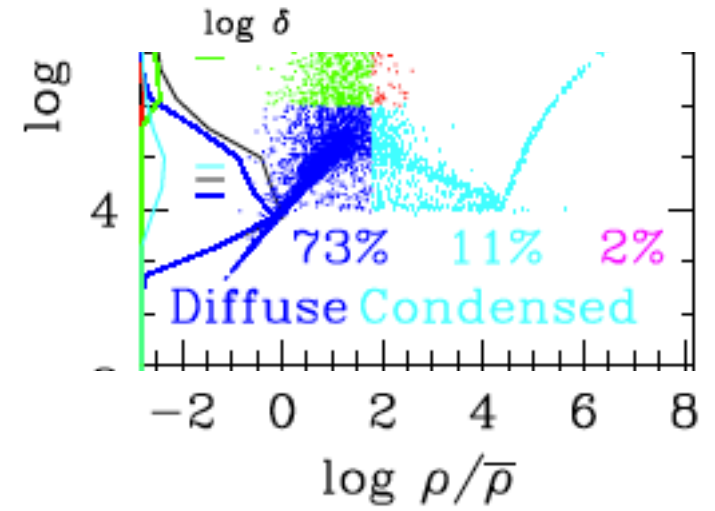
- * Tidal/ram pressure stripping insignificant
- * IGM enrichment...
 - * constrains outflows
 - * traces large-scale structure (even at $z > 6$!)
 - * preserves fossil record of early SF (abund. ratios)



Ionization-Density Relation The shape of J_{UV}



Γ) \rightarrow
 n
 yon



Constraints on Winds

wind speed ↑

Too few metals in IGM

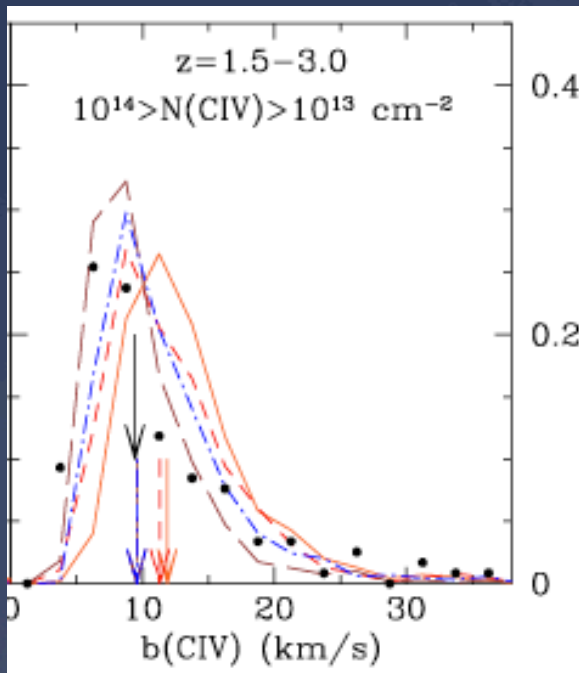
IGM too hot

Just right!

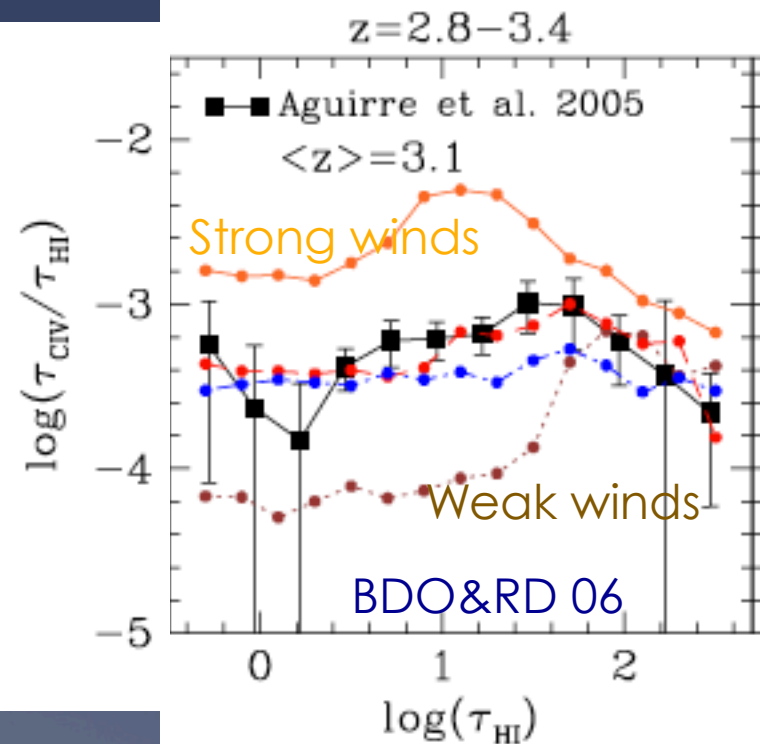
Diffuse IGM unenriched

Oppenheimer & RD 2006
Oppenheimer & RD 2008
Oppenheimer & RD 2009a,b

Too few metals produced



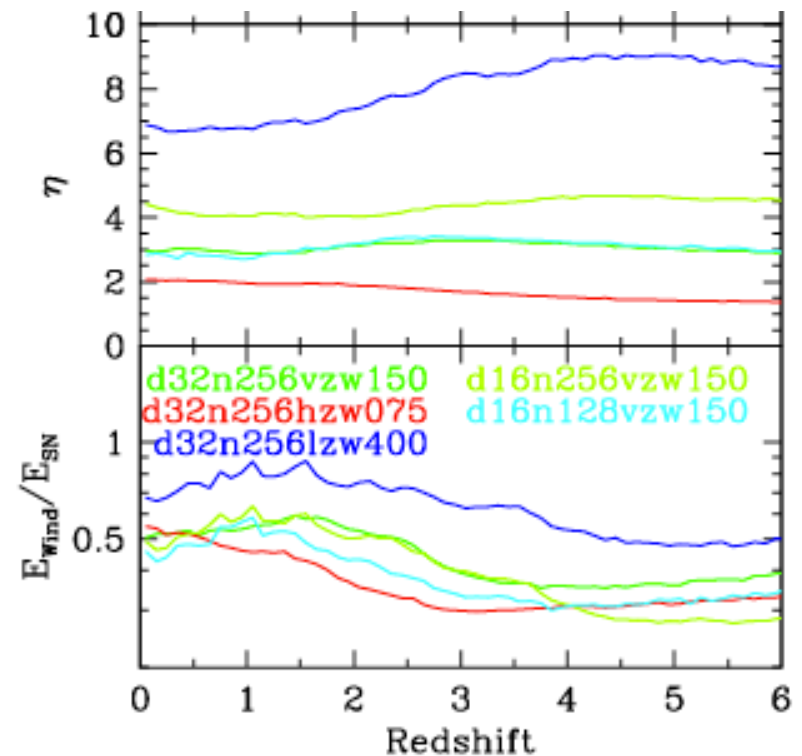
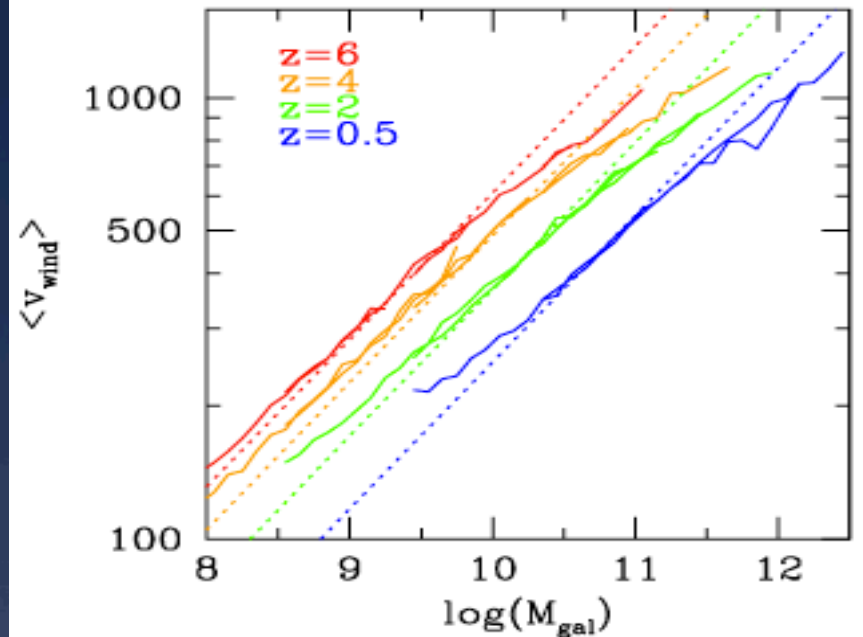
mass loading



Wind Properties

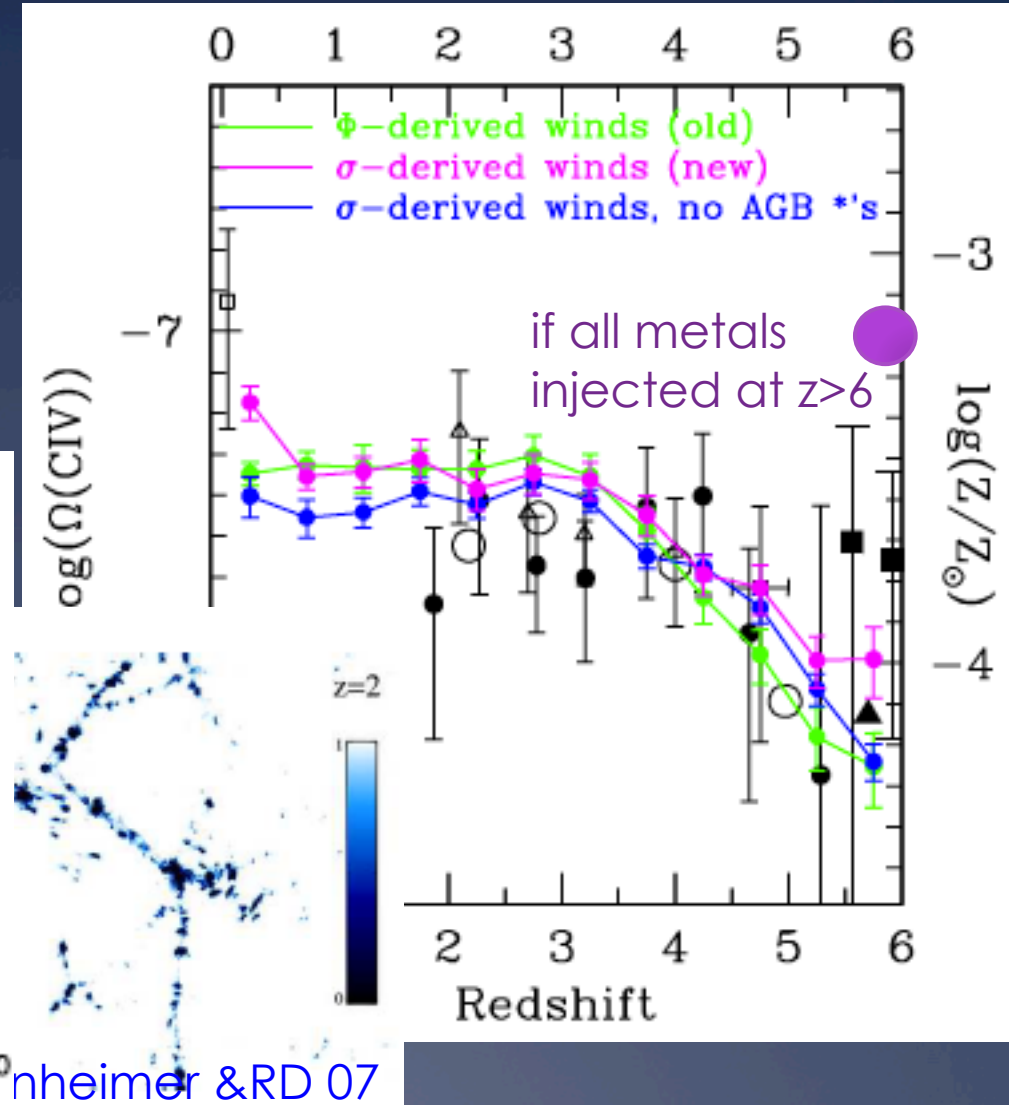
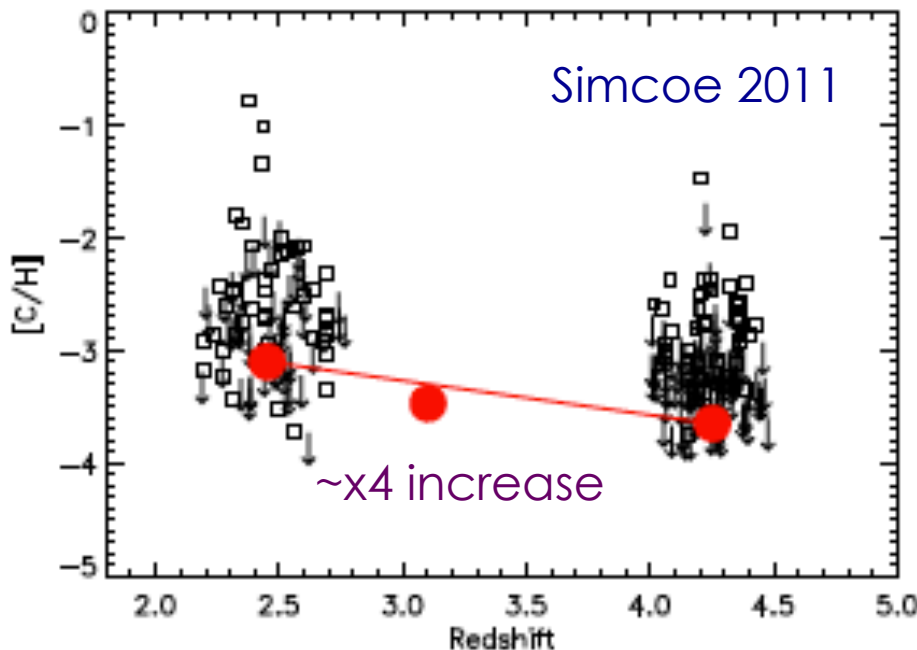
- * Favored: $v_{\text{wind}} \sim v_{\text{esc}}$, $\eta \sim 1/v_c$:
Momentum driven?
- * Mass loading factor $> \sim 1 \rightarrow$
 $M_{\text{winds}} > \sim M_*$
- * $v_{\text{wind}} \sim$ hundreds km/s
 - * $E_{\text{wind}} < \sim E_{\text{SN}}$, but not by much!
- * Similar to observed winds
 - * *Observed galaxies can enrich the IGM!*

Oppenheimer&RD+08,09



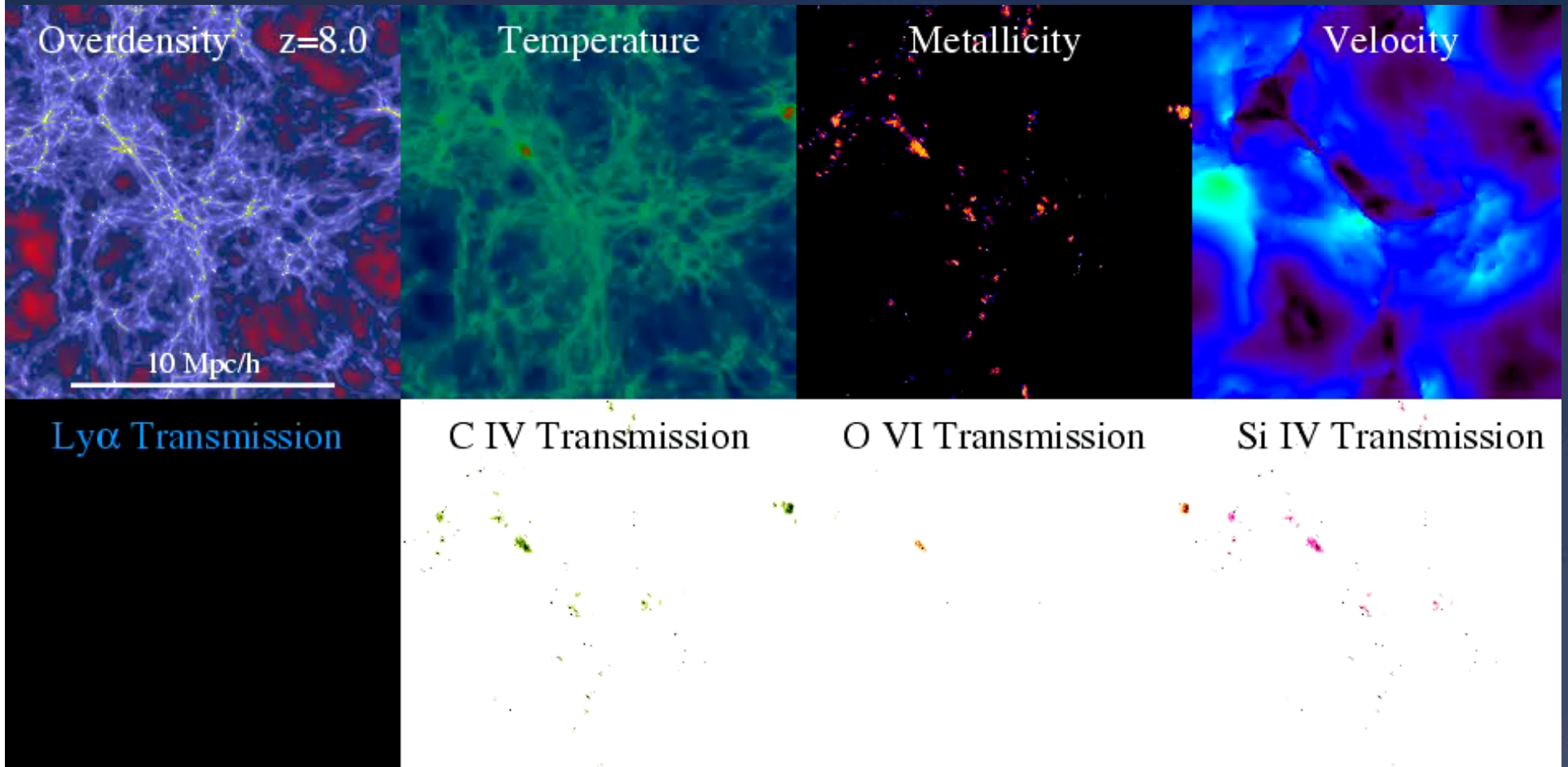
Redshift Evolution: $z \sim 6-2$

- * Flat $\Omega_{\text{CIV}} \neq$ Flat Z_{IGM}
- * Filling factor $< \sim 0.1$ @ $z > 2$
- * Early enrichment ($z > 6$) disfavored by Ω_{CIV} drop.



nheimer & RD 07

Physicals vs Observables

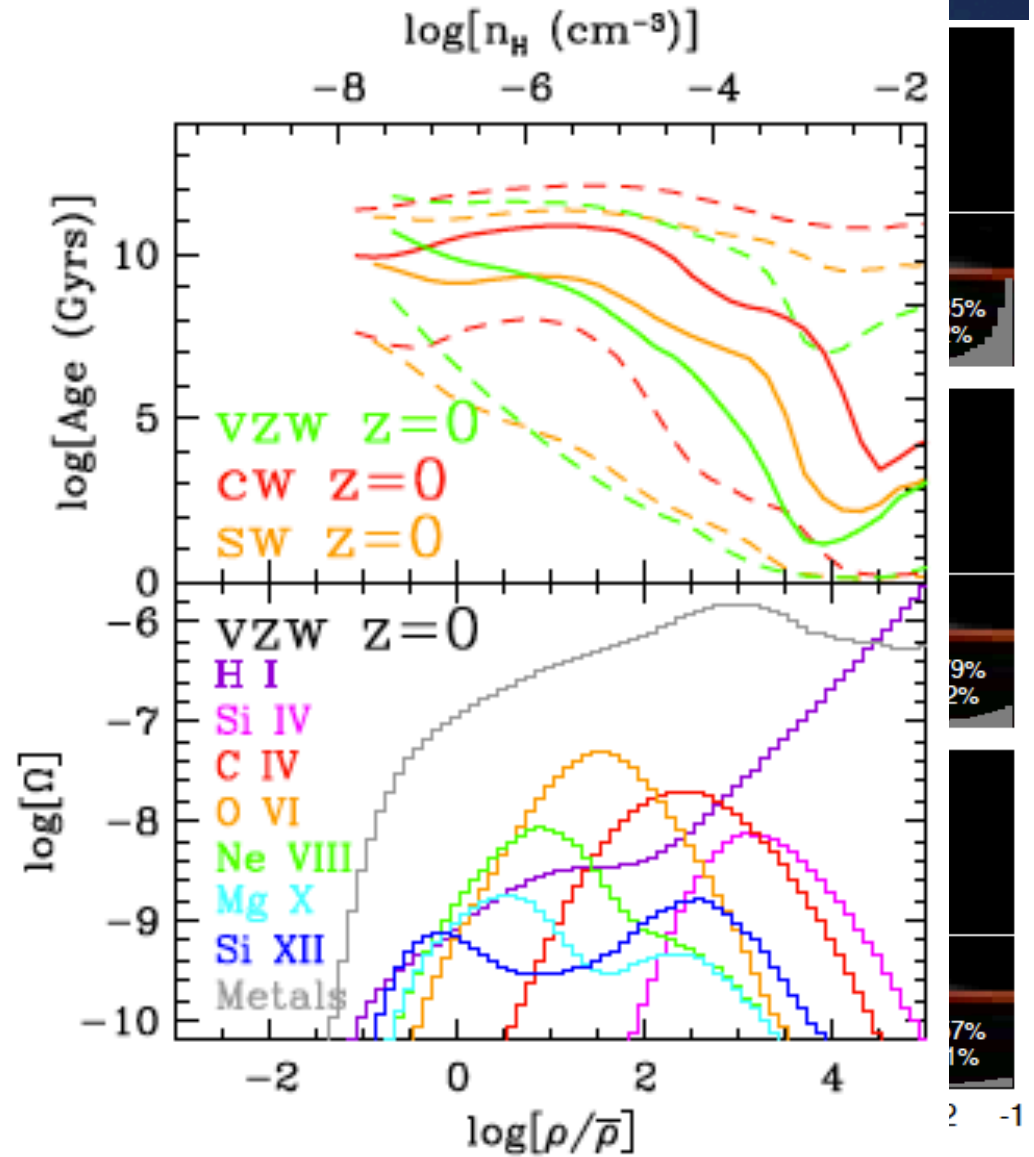
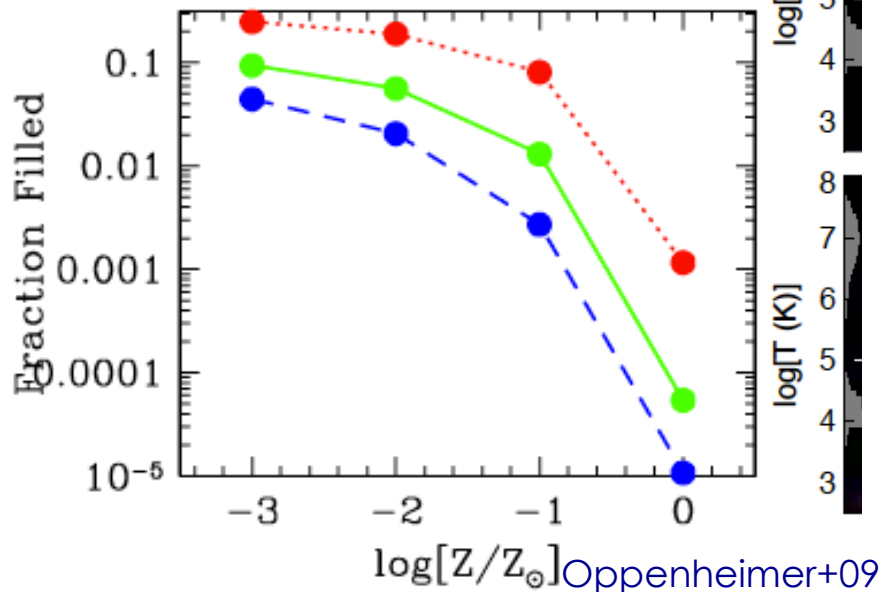


Movie by B. Oppenheimer

<http://luca.as.arizona.edu/~oppen/IGM/general.html>

Redshift Evolution: $z \sim 2-0$

* Metals migrate back towards galaxies. Oldest metals pushed into voids.



Metals at low-z: OVI Turbulence in the IGM?

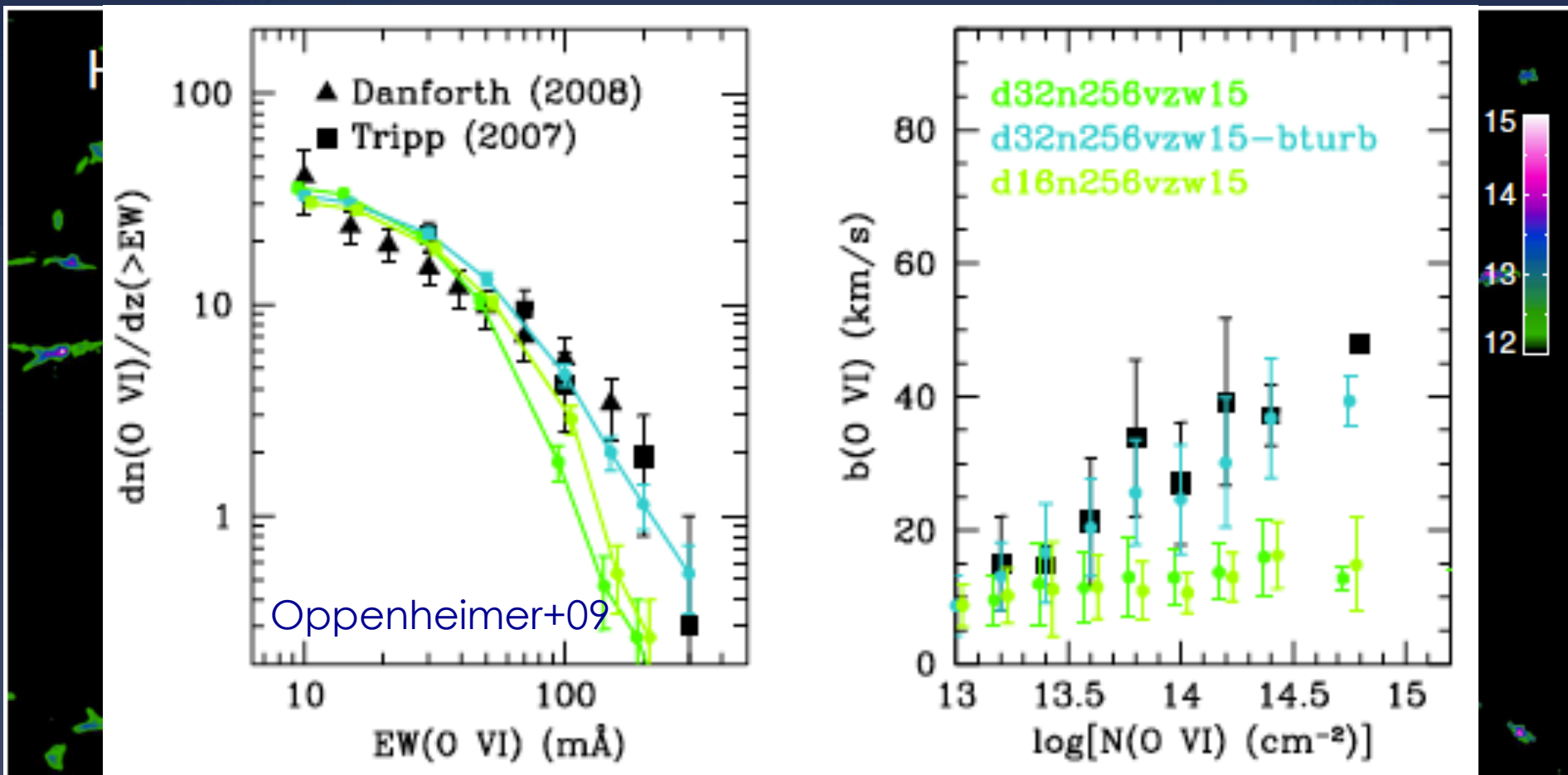
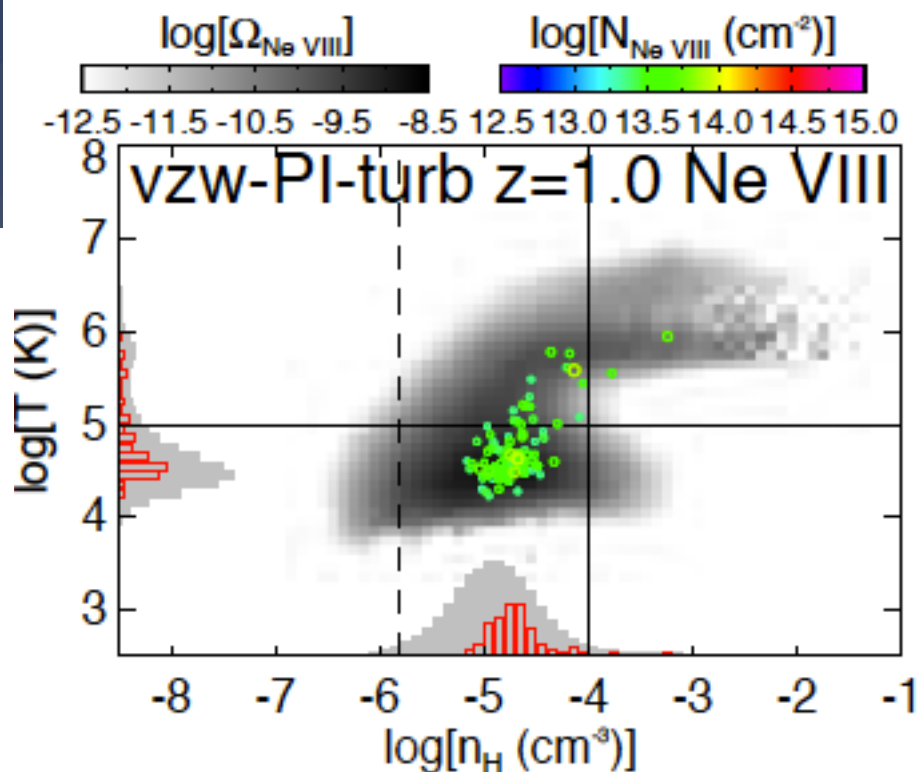
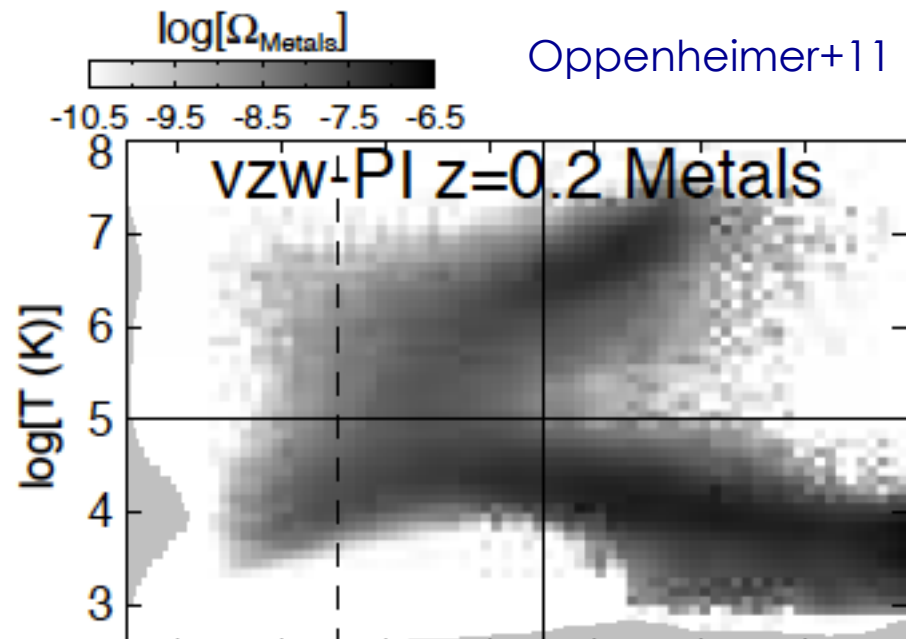
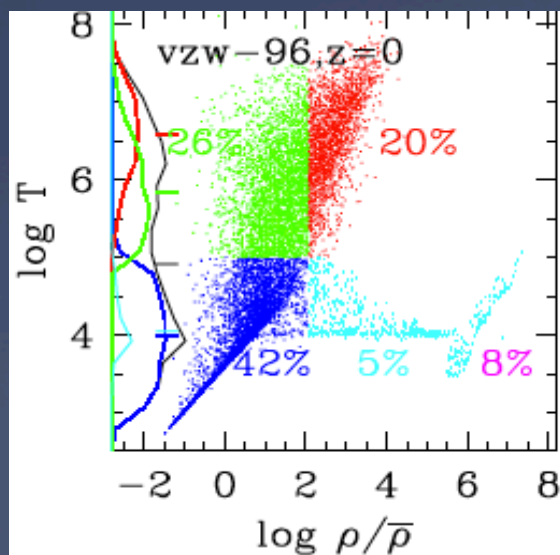


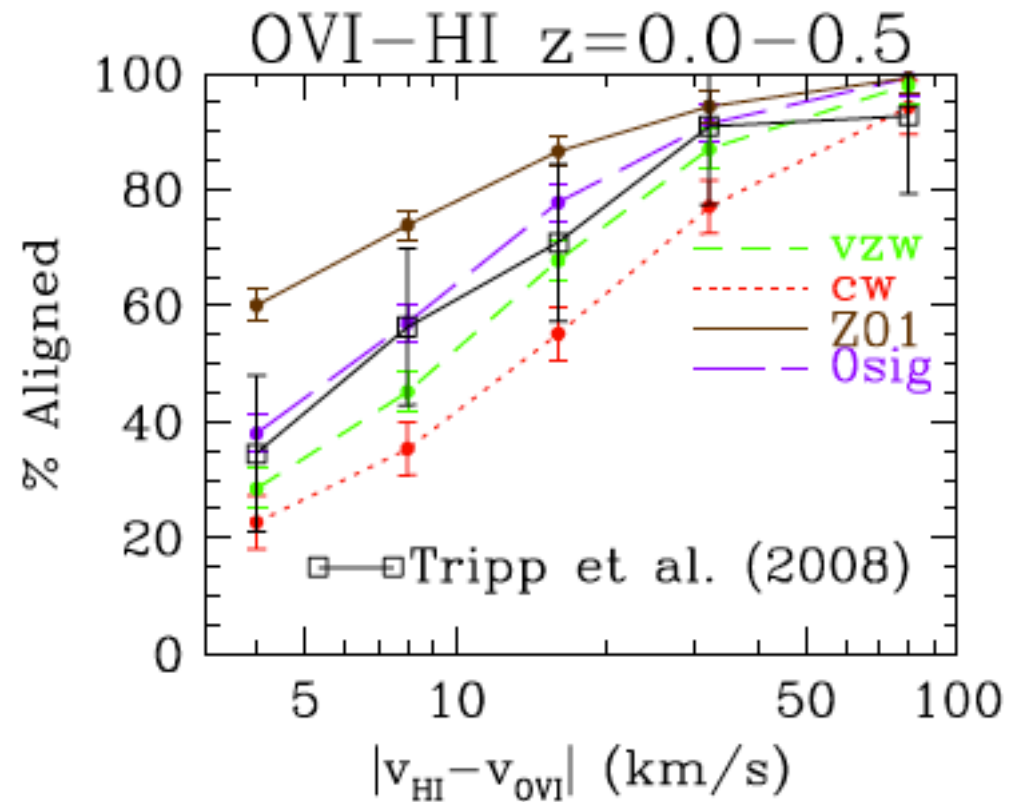
Photo-ionised high ions: OVI, NeVIII(!)

- * Even high ions can be photo-ionised.
 - * UV background is *hard!*
- * OVI poor tracer of WHIM
 - * Need OVII, OVIII, CV... X-rays.

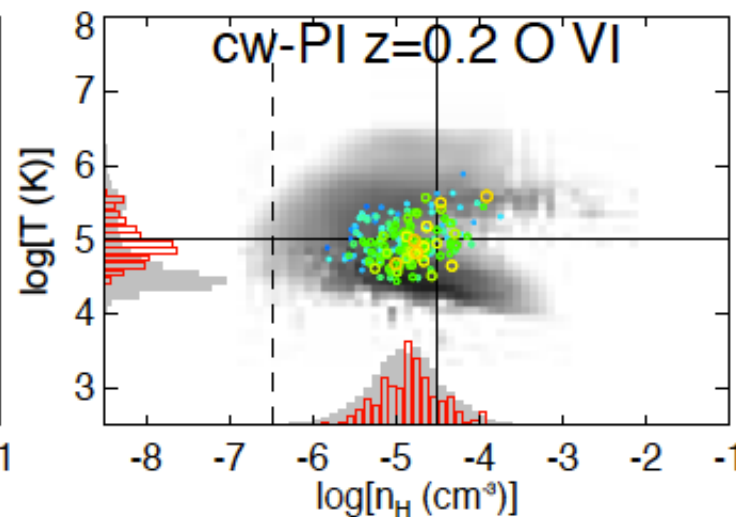
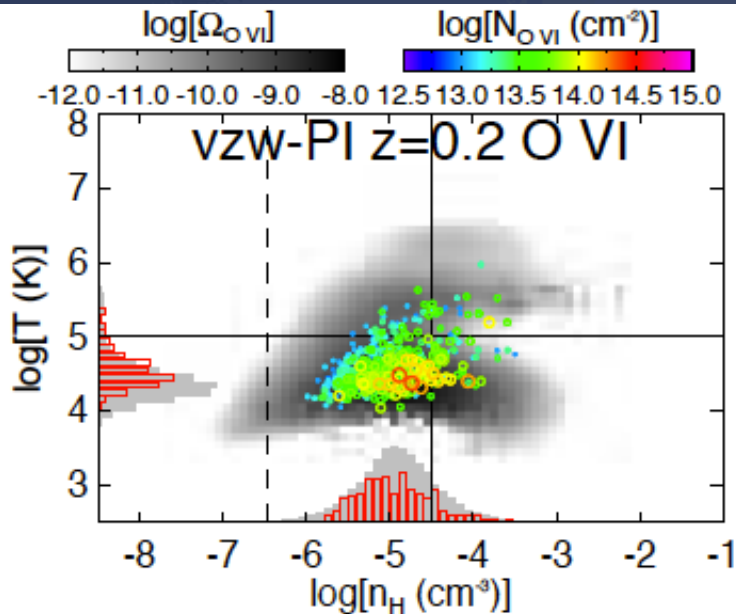


Alignment Statistics

- * Sensitive test of ionisation level.
- * Data suggest lots of photo-ionised OVI



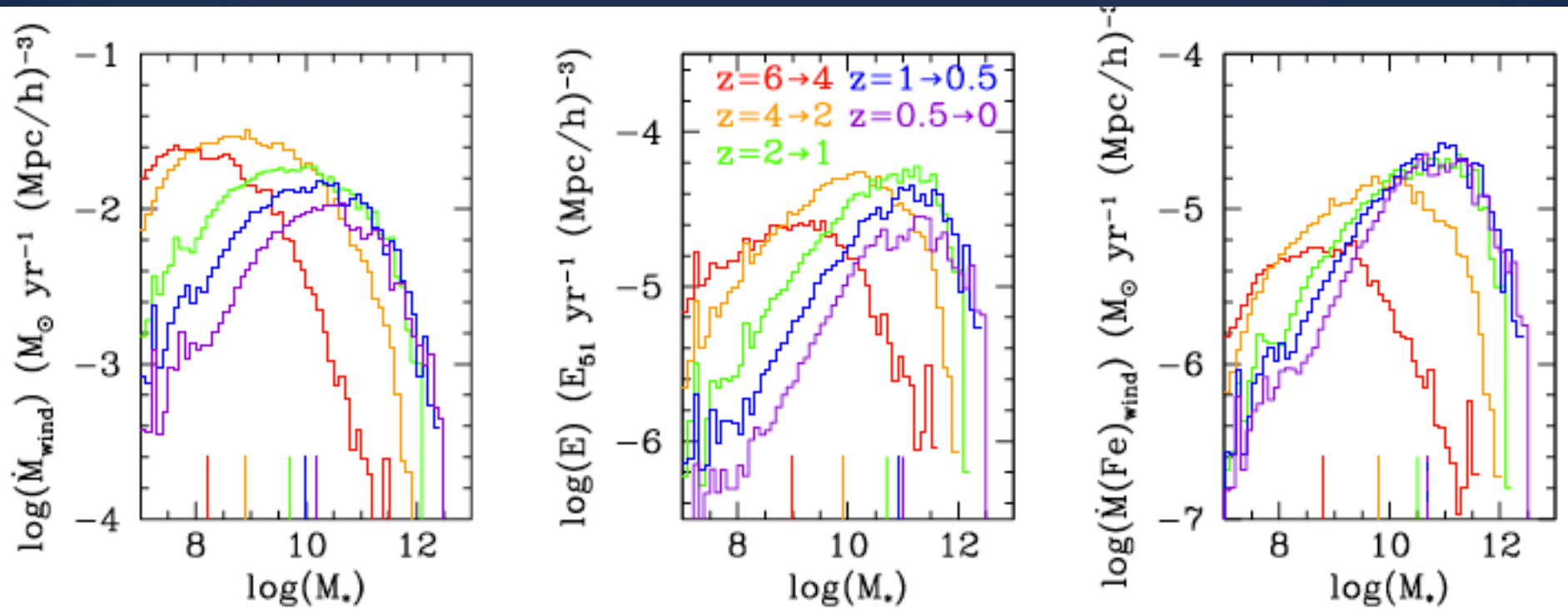
Oppenheimer+11



Summary

- * IGM metals are a sensitive tracer of galactic outflows.
 - * More mass in outflows than in stars (globally)!
- * IGM is enriched by normal galaxies, following cosmic SF. From $z \sim 2-0$ metals migrate back towards galaxies.
- * CIV, OVI, ... data are best matched by winds that
 - * eject more material from small galaxies.
 - * have modest speeds that do not overheat IGM.
- * Weakest absorbers mostly photo-ionised, even OVI & NeVIII.
- * Unresolved theoretical issues:
 - * Large fraction of E and/or p needs to go into winds: How?
 - * Metal mixing: How and how much?
 - * How do winds interact with ambient/infalling gas?

Which Galaxies Enrich IGM?



- * Enriching mass evolves upwards with time
- * At high-z, generally sub- L^*