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

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1. Bulk galaxy properties
2. Metals in the CGM

The Baryon Cycle
Irvine, CA; June 14, 2012
The tools: cosmological-scale hydrodynamic simulations

- New suite of $2 \times 512^3$ particle, $32h^{-1}\text{ Mpc}$ comoving SPH simulations evolved with Gadget-2
  - SPH particle gas mass = $4.45 \times 10^6 \text{ M}_\odot$
  - Dark matter particle mass = $2.7 \times 10^7 \text{ M}_\odot$

- 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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All results presented here at $z=2.2$
Only difference: how wind velocity and mass-loading scale (or not) with $\sigma_{\text{gal}}$

<table>
<thead>
<tr>
<th>Wind Model</th>
<th>Wind velocity $v_w$</th>
<th>Mass-loading factor $\eta_w$</th>
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<td><strong>Fiducial:</strong> momentum-driven scaling ($vzw$)</td>
<td>$v_w = \sigma_{\text{gal}} / [150 \text{ km/s}]$</td>
<td>$\eta_w \propto \sigma_{\text{gal}}^{-1}$</td>
</tr>
</tbody>
</table>
| **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

Data: Mortlock et al. (2011)
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
Does lower ISM metallicity mean more (observable) CGM metals? IGM?
Physical properties of the circumgalactic medium

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

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
Typical densities and temperatures traced by absorbing ions 100kpc away from $z=0.25$ galaxies

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

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

Density | Temperature | Metallicity | Stars
---|---|---|---
constant |  |  |  
fiducial |  |  |  
mixed |  |  |  

1 Mpc
Need to compare models at fixed *stellar* mass
log M$\star$=10

constant

fiducial

mixed
\[ \log M_\star = 8.7 \]

constant

fiducial

mixed
CGM is the border between ISM and IGM

Fiducial momentum-driven wind scaling

Constant wind

32 h$^{-1}$ Mpc comoving