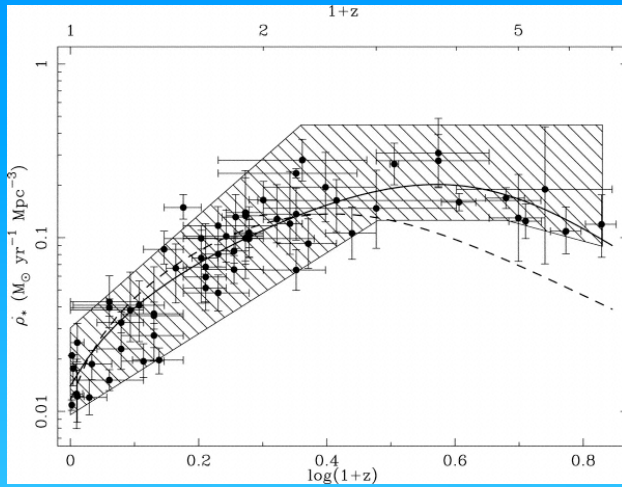


# Where are the *missing cosmic metals* in the Universe?

The "missing metals" problem - where are the metals at high redshift? (Pettini, 1999, astro-ph/9902173, Pettini, 2006, astro-ph/0603066).



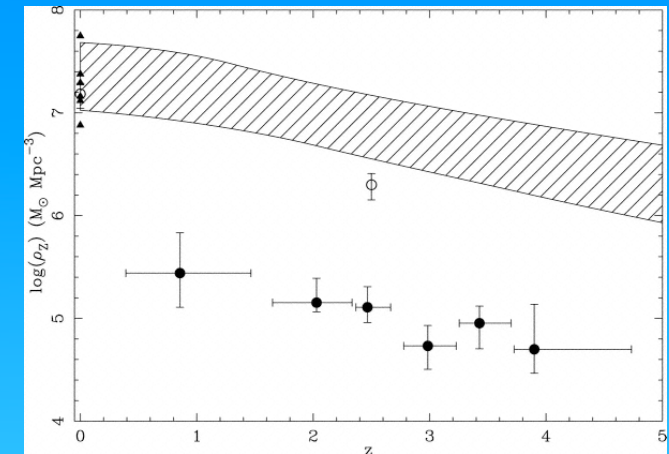
The cosmic star formation history  
Hopkins et al., 2005, ApJ, 630, 108

The **cosmic star formation history** (SFH, e.g. Lilly et al., 1996, ApJ, 460, L1) together with a **specific yield,  $y$** , (derived using a specific **IMF**) results in a prediction for the total expected amount of metals:

$$\rho_{Z,\text{expected}} = \langle y \rangle \int_0^t \dot{\rho}_*(t) dt$$

Integrating with a yield of  $y=1/42$  (Madau et al., 1996, MNRAS, 283, 1388) **up to  $z=2.5$**  results in:

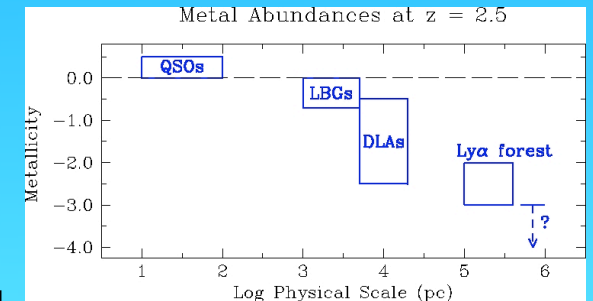
$$\rho_{Z,\text{expected}} \simeq 4 \times 10^6 M_{\odot} \text{Mpc}^{-3}$$



The evolution of the mass density in metals  
Hopkins et al., 2005, ApJ, 630, 108

The **combined observed metallicity** in the **Ly $\alpha$  forest** (Cowie et al., 1995, AJ, 109, 1522), the **damped Ly $\alpha$  systems** (Prochaska et al., 2003, ApJ, 595, 9) and the **Lyman break galaxies** (Steidel et al., 1999, ApJ, 519, 1) is only 40% of the expected value at  $z \sim 2.5$ .

Where are the missing metals?



Pettini, 2006, astro-ph/0603066).

**In unaccounted galaxy populations?**

1. In **sub-millimetre galaxies** (Bouché et al., 2005, MNRAS, 364, 319).
2. **Ultraviolet-selected BX galaxies** at  $z \sim 2.2$  (Bouché et al., 2006, MNRAS, 367, 16).
3. **Distant red galaxies** at  $z=2.5$  (Bouché et al., 2006, MNRAS, 367, 16).

**In as of yet unobserved hot ( $T \sim 10^6$  K) medium?**

1. Simulations indicate that a lot of metals at  $z > 2.5$  could be found in **hot, shocked gas** in haloes around starforming galaxies (Ferrara et al., 2005, ApJL, 634, L37).
2. A significant fraction of the metals might also be found in **diffuse hot intergalactic gas** (Davé & Oppenheimer, 2006, astro-ph/0608268).

**Implications for supernova feedback.**

1. **How much metals** are ejected from galaxies as a function of their mass?
2. At what **redshift** does this ejection predominantly occur? (e.g. Johansson & Efstathiou, 2006, MNRAS, 371, 1519, figs 2&3).