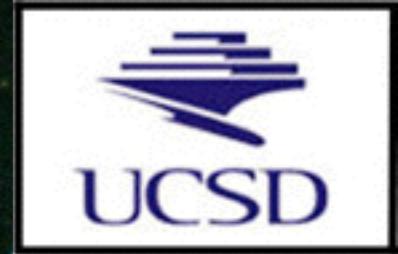
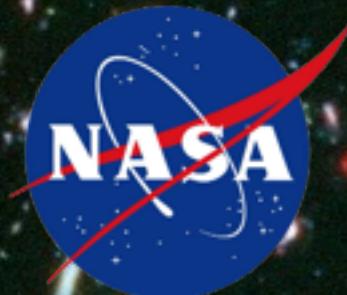


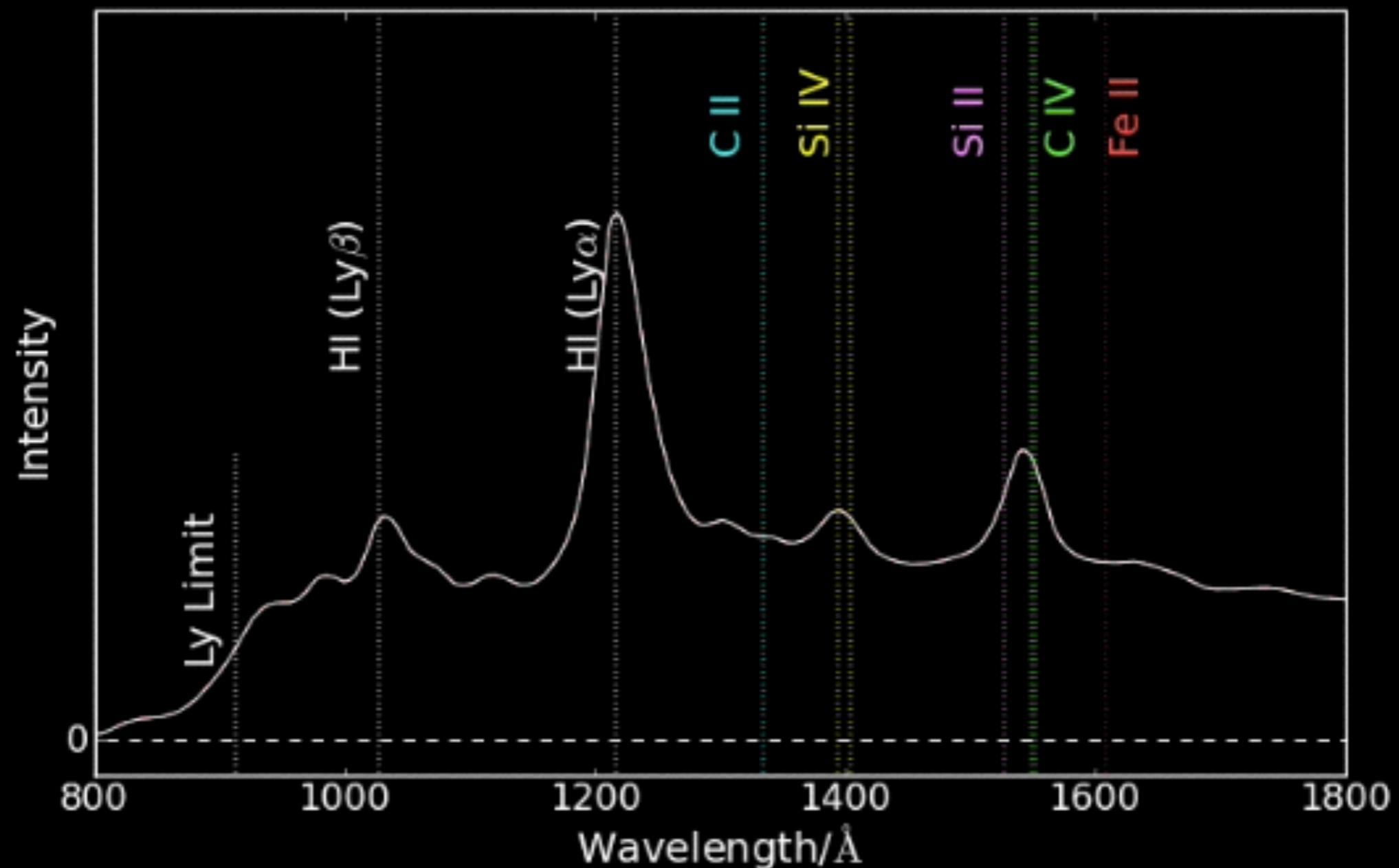
# Uncovering the Origin of the Rapid Decline in Metallicity of Hydrogen-Rich Galaxies at $z \sim 5$

Marc Rafelski

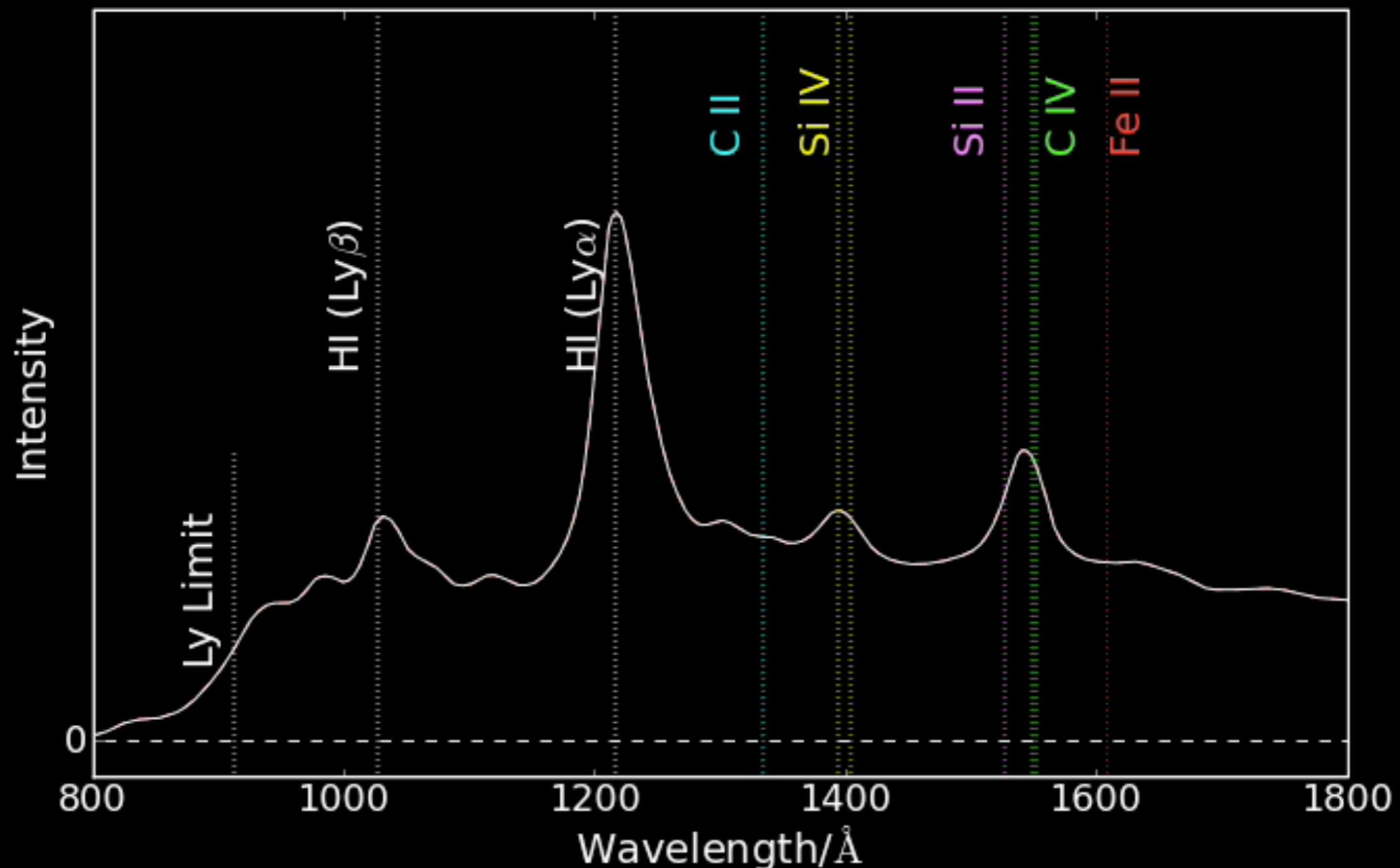
NASA Postdoctoral Program Fellow  
Goddard Space Flight Center  
TMT Meeting, June 24th, 2015



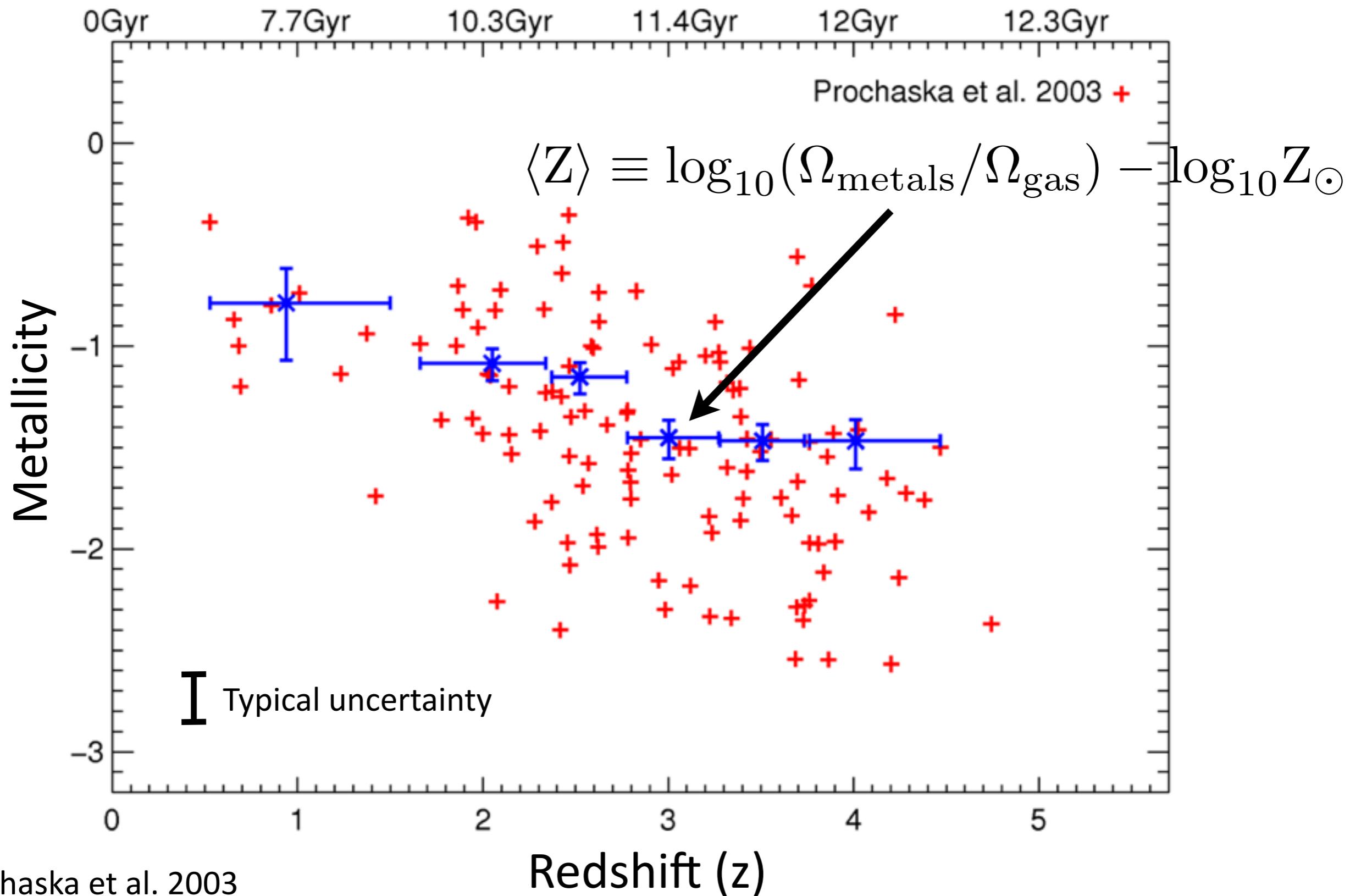
# I: Physical Setup of Damped Ly-alpha systems (DLAs)



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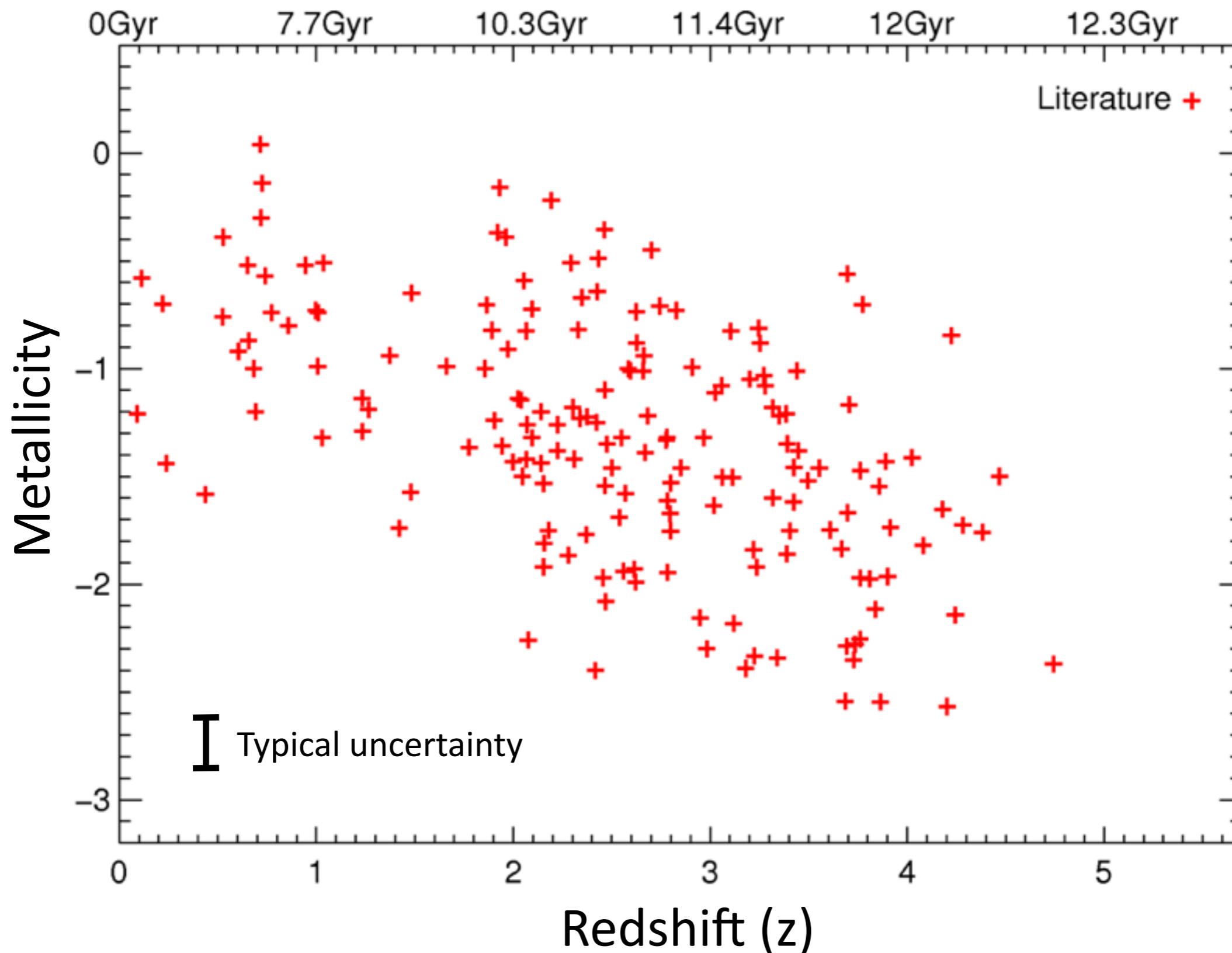


# Metal Abundances versus redshift (2003 sample)



Prochaska et al. 2003

# Metal Abundances versus redshift with new data from literature



# Two Surveys of high redshift DLAs with Keck Telescopes

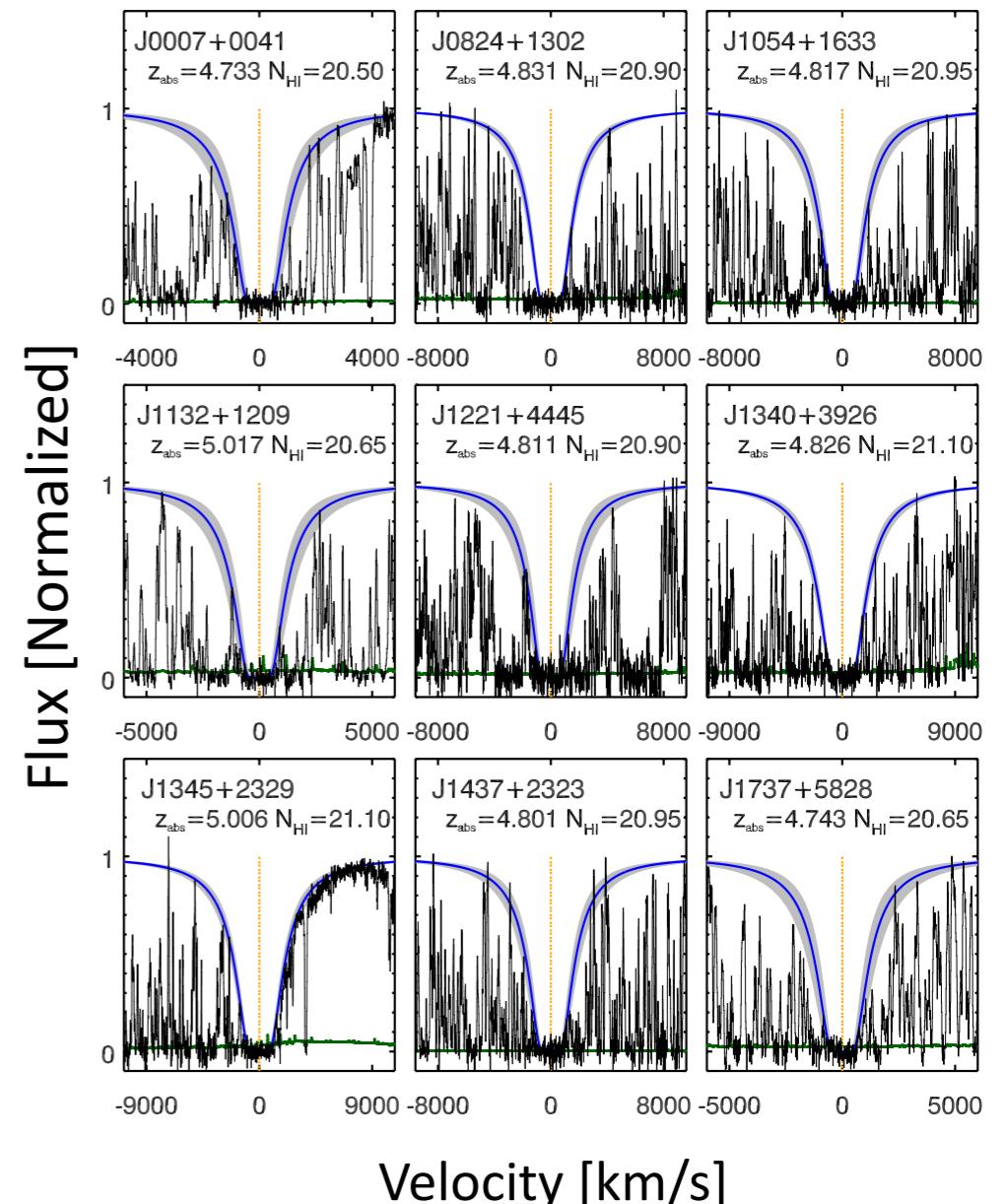
ESI: R~7,000 (~40km/s) HIRES: R~50,000 (~6km/s)

## 1) 2012 sample

- 50 QSO's with 70 candidate DLAs
- 46 SDSS 'candidate'  $z > 4$  DLAs
- 18 confirmed DLAs at  $2.4 < z < 4$
- 32 confirmed DLAs at  $z > 4$

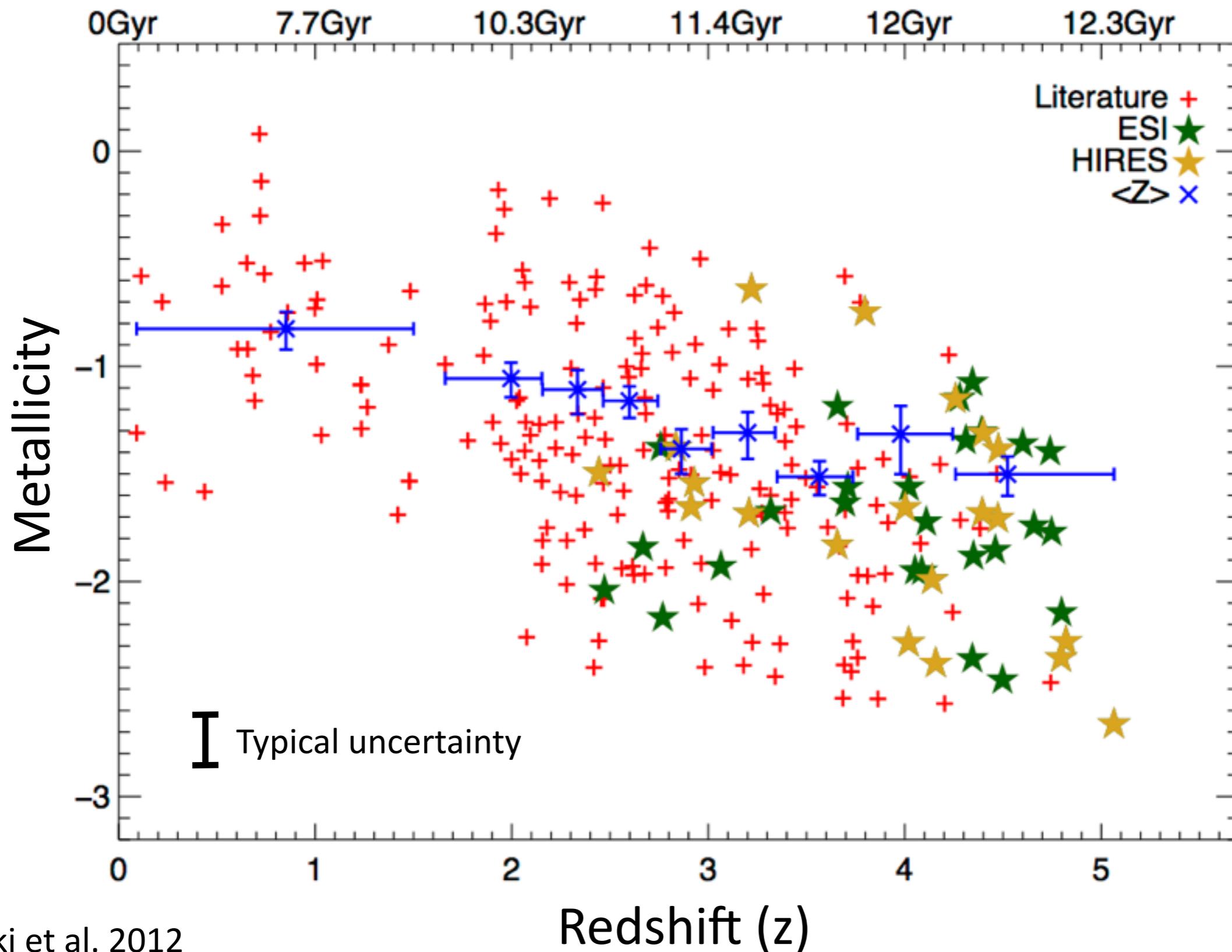
## 2) 2014 sample

- 28 QSO's  $z > 4.7$
- 42 'candidate'  $z > 4.7$  DLAs
- 9 confirmed DLAs at  $z > 4.7$   
(8 from GMOS survey)



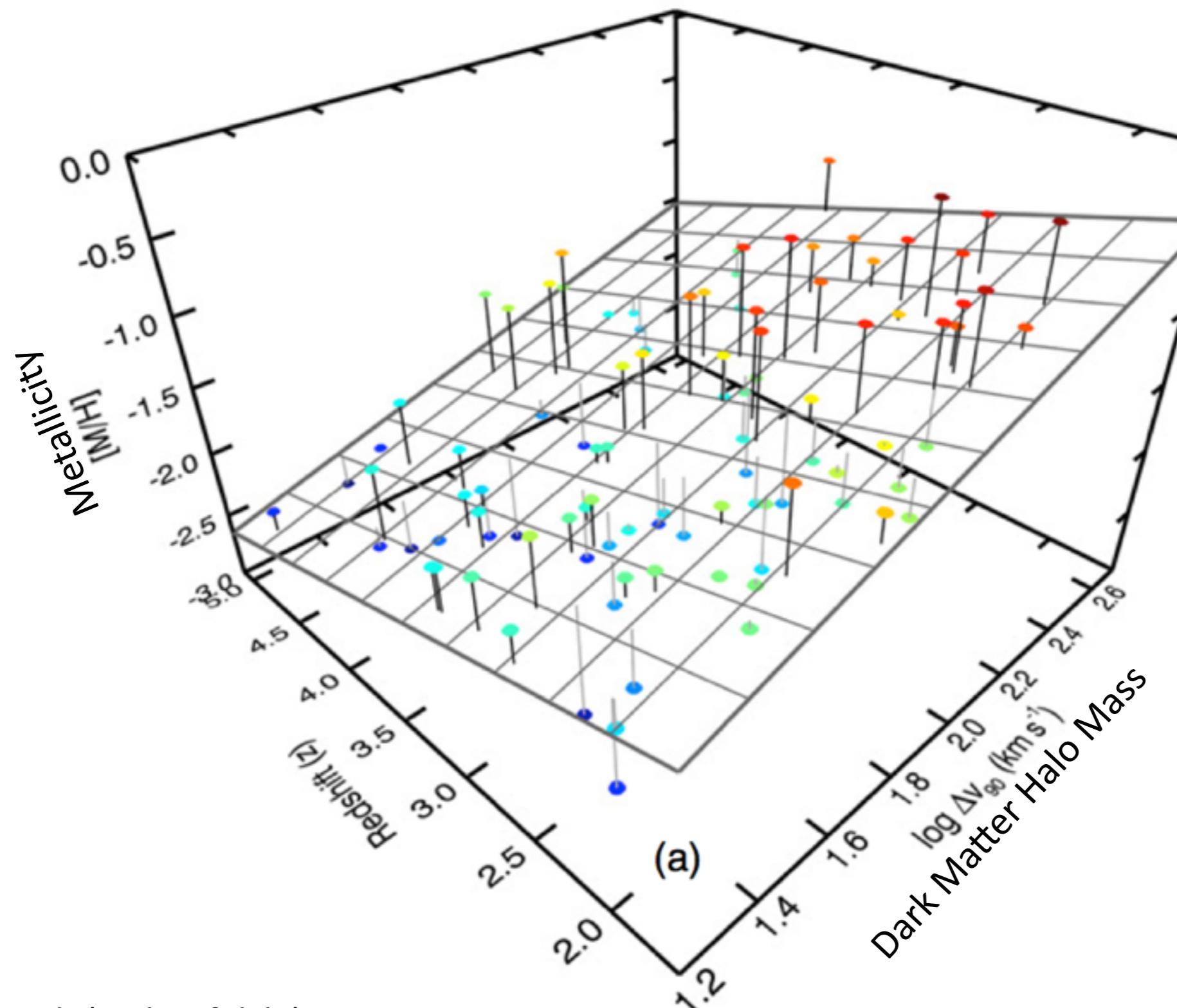
Rafelski et al. 2012 & 2014

# Survey 1: Metallicity evolution from Rafelski et al. 2012



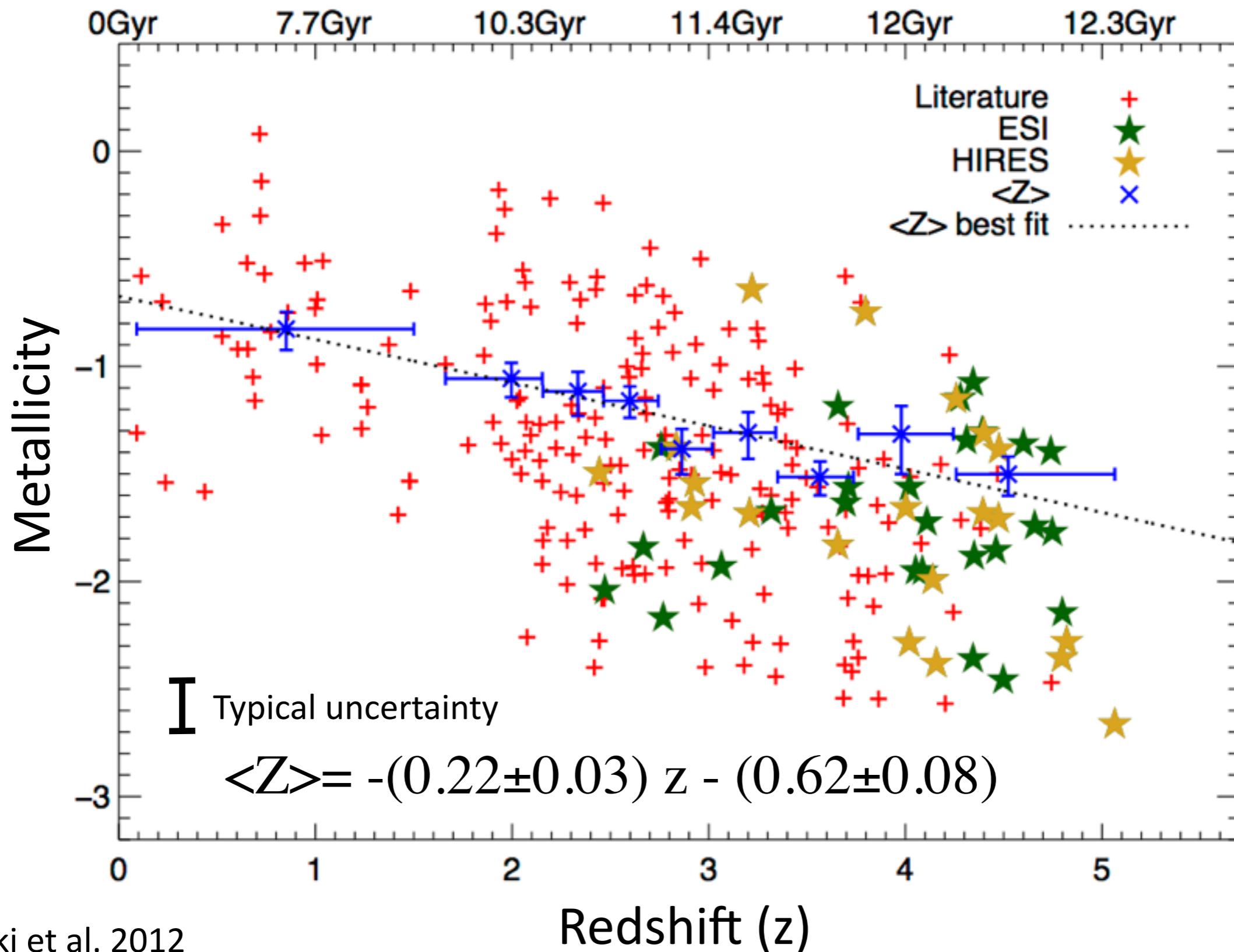
Rafelski et al. 2012

# Metal dependence on the mass of Dark Matter Halo



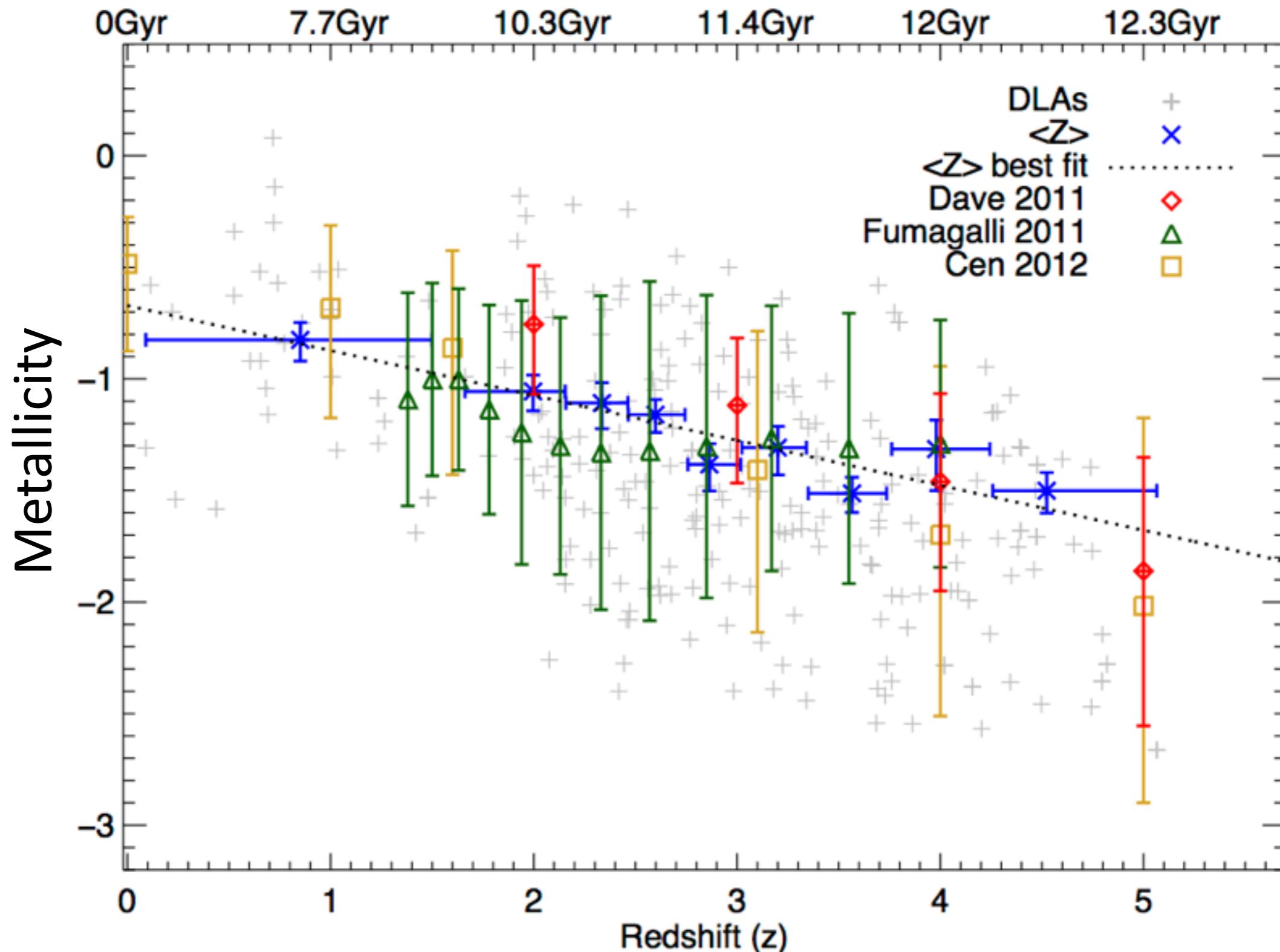
Neeleman et al. (incl Rafelski) 2013

# Survey 1: Cosmic Metallicity Evolution Fit



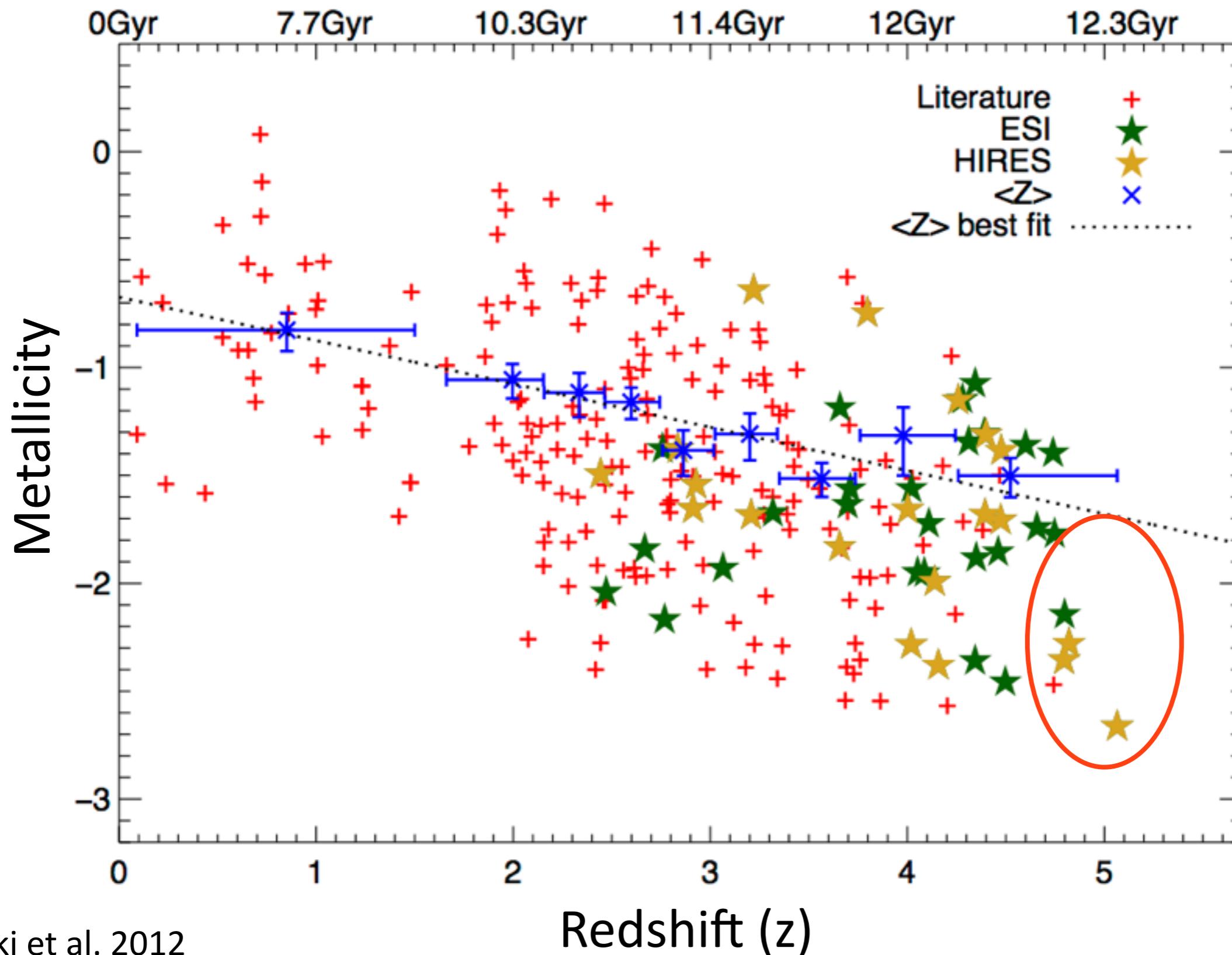
Rafelski et al. 2012

# Metal Abundances Compared to Simulations

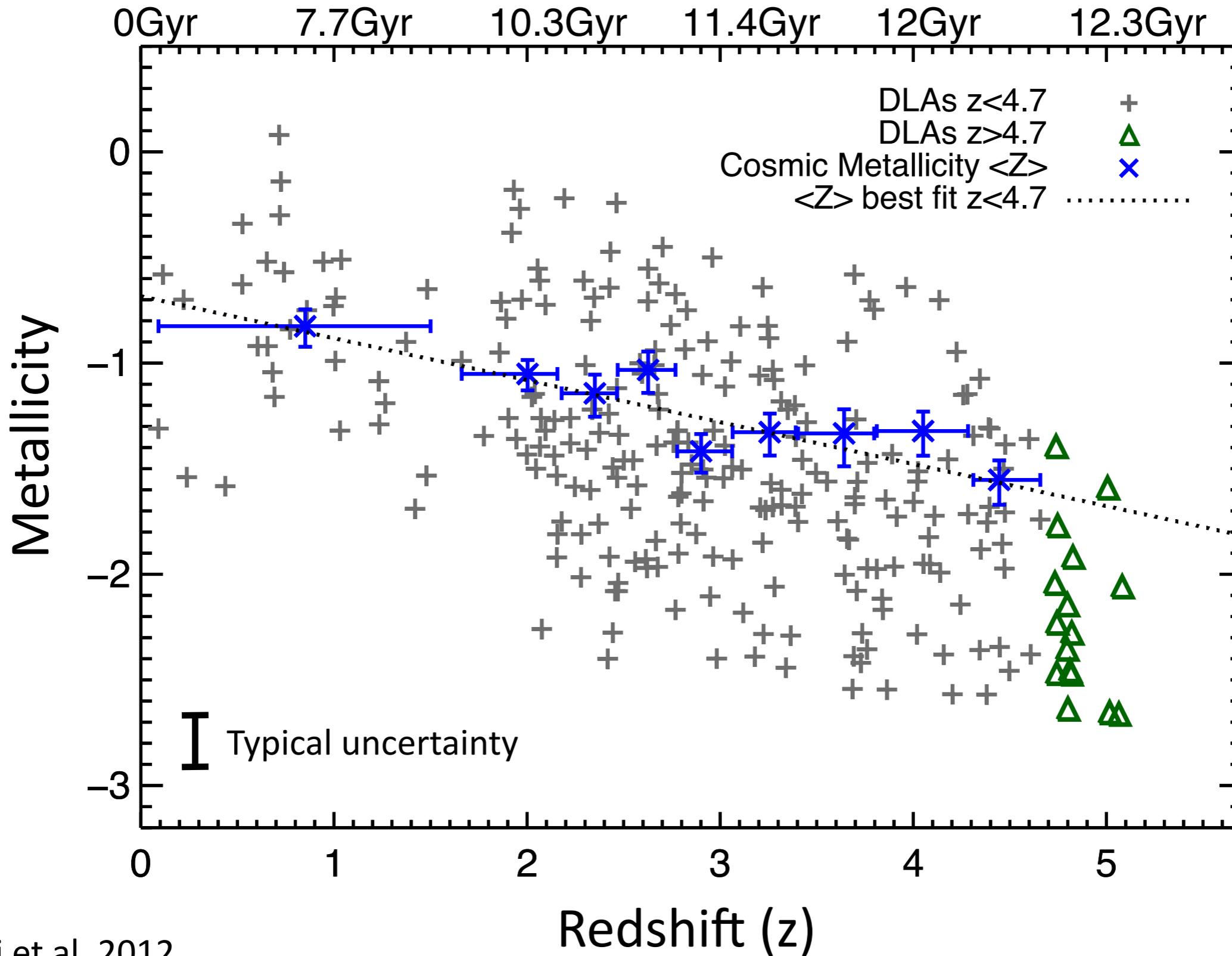


Rafelski et al. 2012

# Possible deviation in metallicity evolution from linear trend?



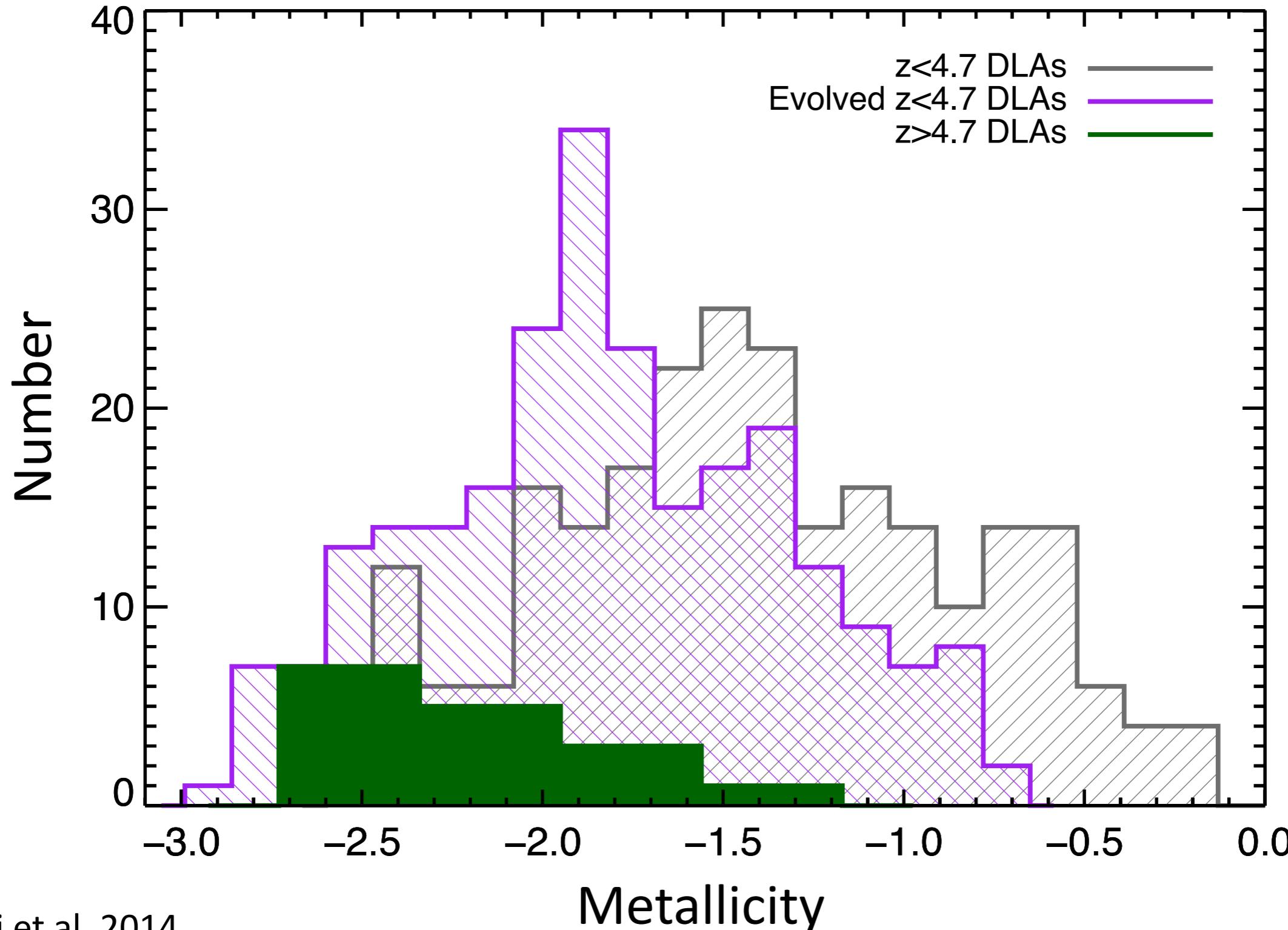
# Survey 2: Metallicity evolution from Rafelski et al. 2014



Rafelski et al. 2012

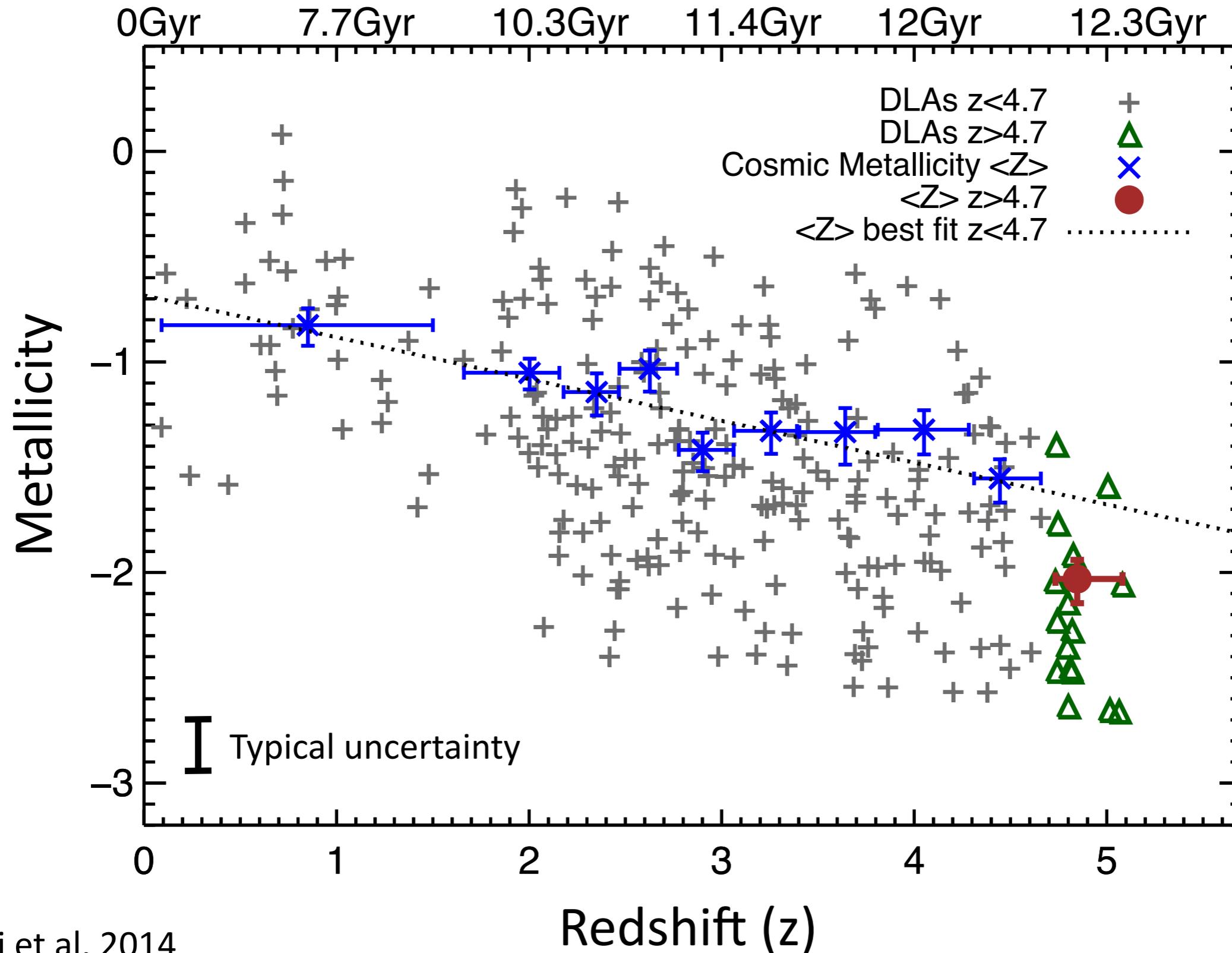
# Distribution of metallicities very different at $z > 4.7$

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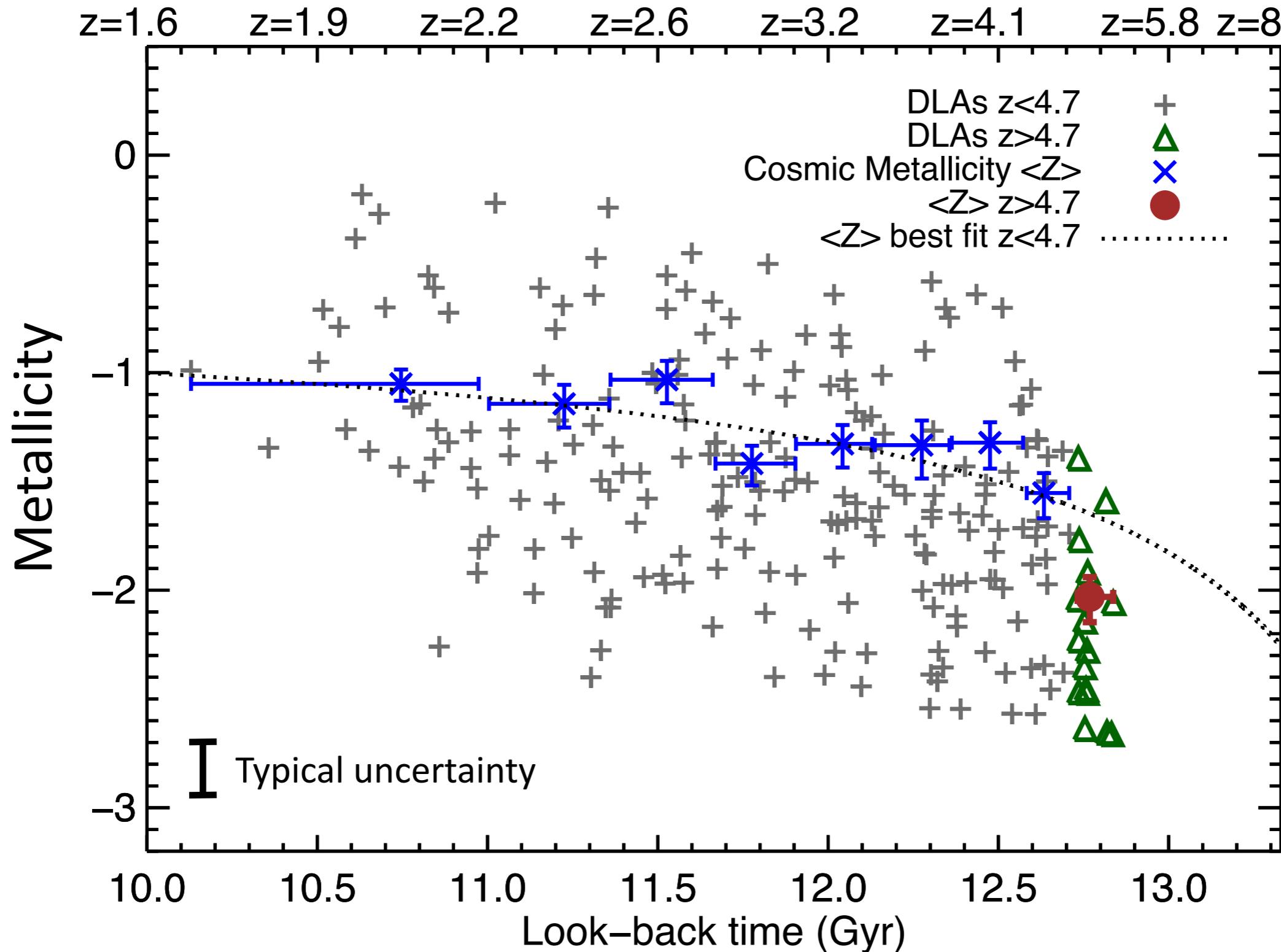
Rafelski et al. 2014

# Metal Abundances versus redshift from Rafelski et al. 2013

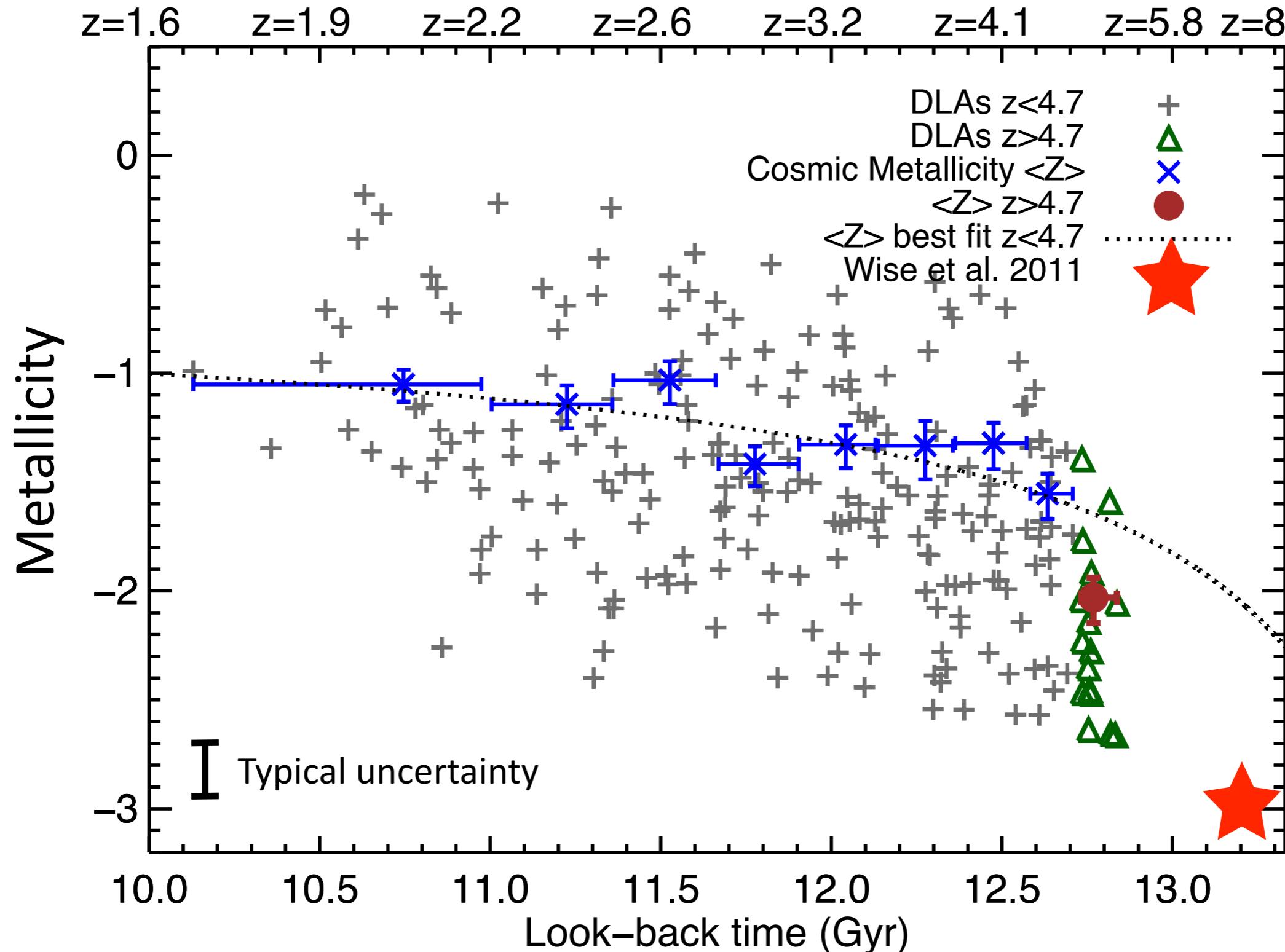


Rafelski et al. 2014

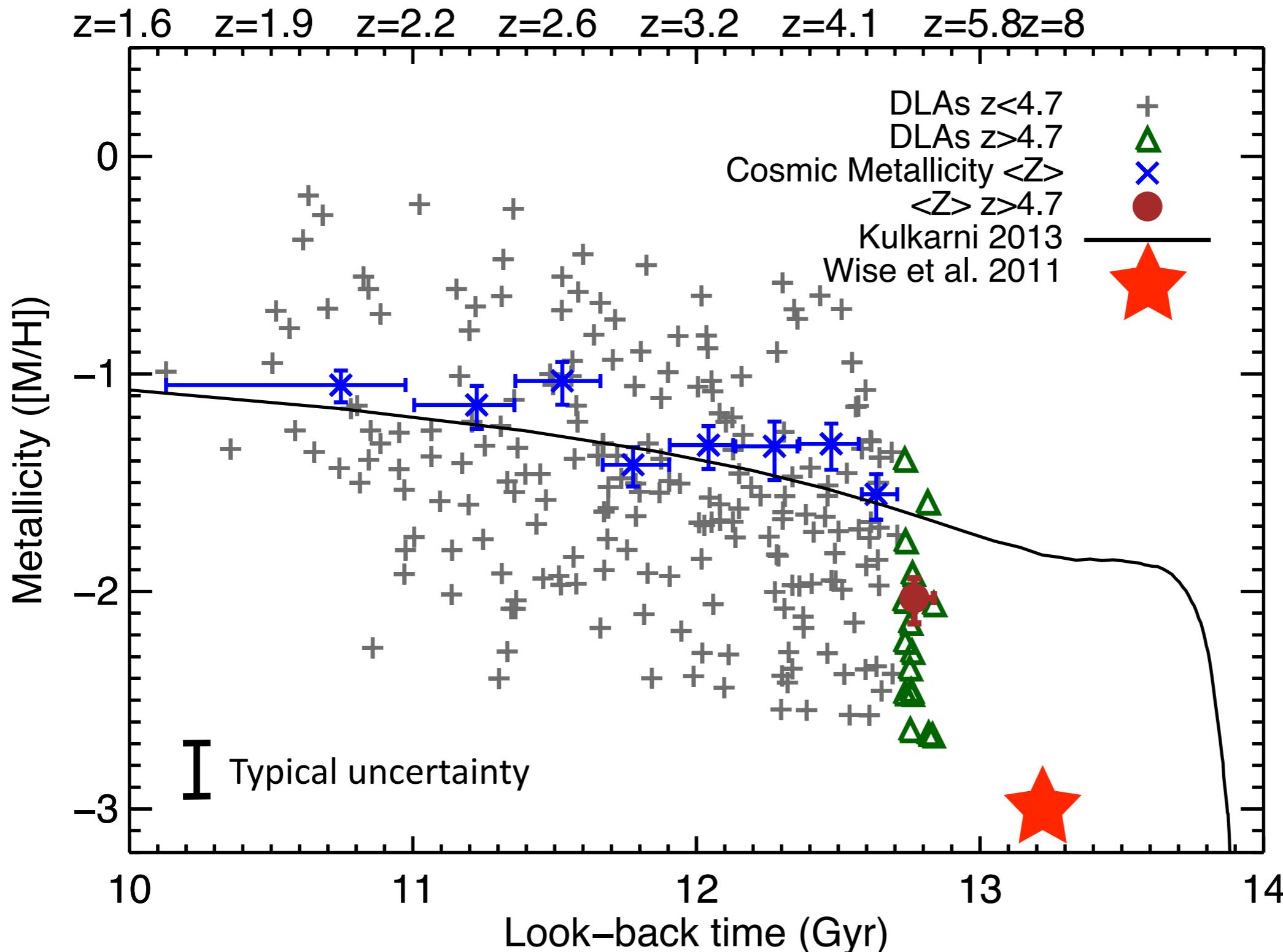
# Metal Abundance versus look-back time



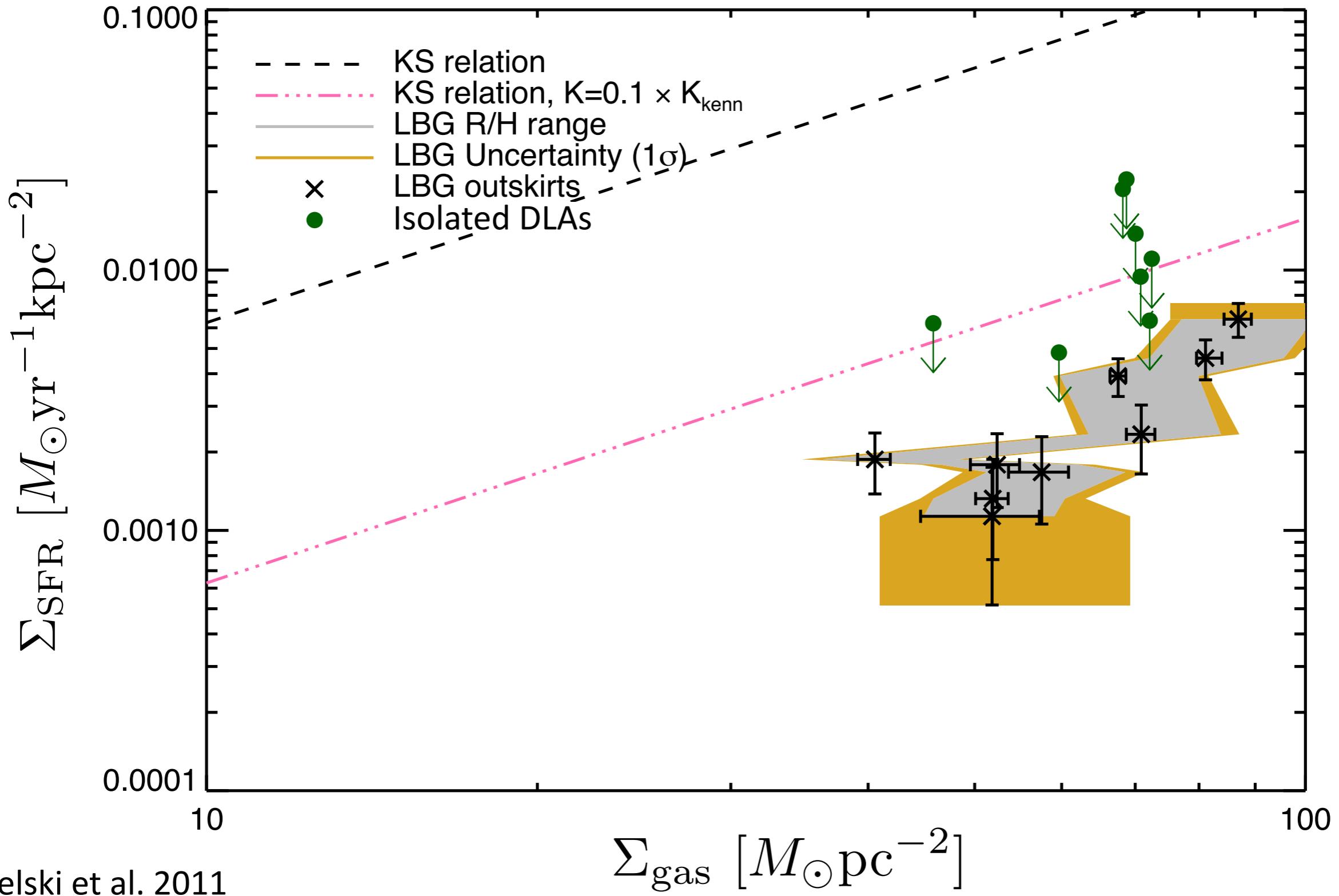
# Comparison to Wise et al. 2012 simulation with Pop III stars



# Comparison to ISM model (Kulkarni+ 2013) including Pop III stars

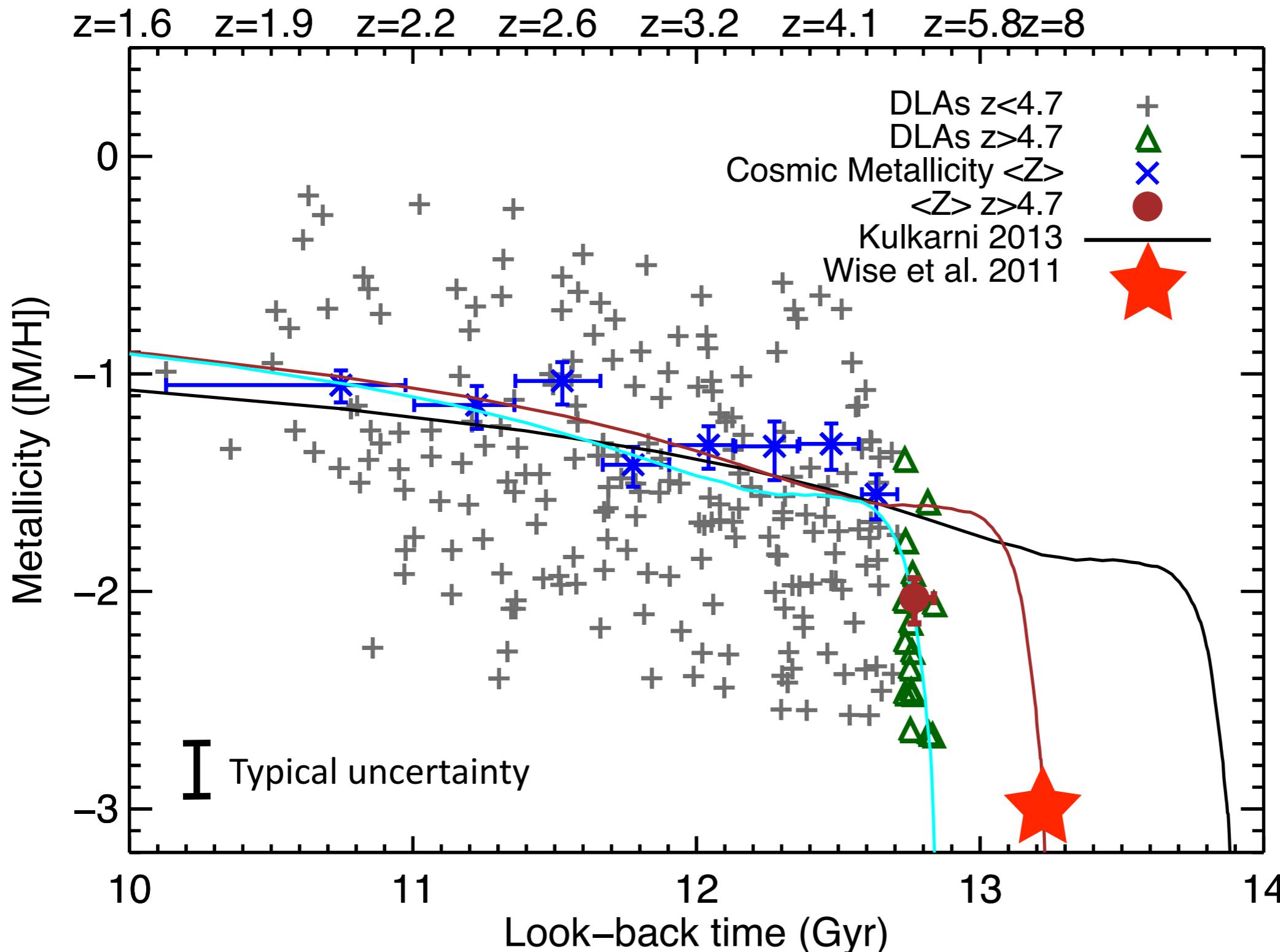


# Lower star formation efficiency of HI (DLA) gas



Rafelski et al. 2011

# Comparison to ISM model (Kulkarni+ 2013) including Pop III stars



# Summary

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- Measured a 7 sigma linear evolution in metallicity with redshift, lower metallicity at high redshift
- Rapid Metallicity enrichment at  $z \sim 5$
- New population of DLAs? Change in enrichment (Pop III-> II)?
- Increase sample of  $z > 5$  DLAs.
- Need to measure abundance ratios at  $z > 5$ .
- The light-gathering power of the TMT coupled with the high-resolution spectrometers HROS and NIRES will enable measurements of these intrinsically faint quasars and uncover the origin of the rapid decline in metallicity of hydrogen-rich galaxies (DLAs) at  $z \sim 5$