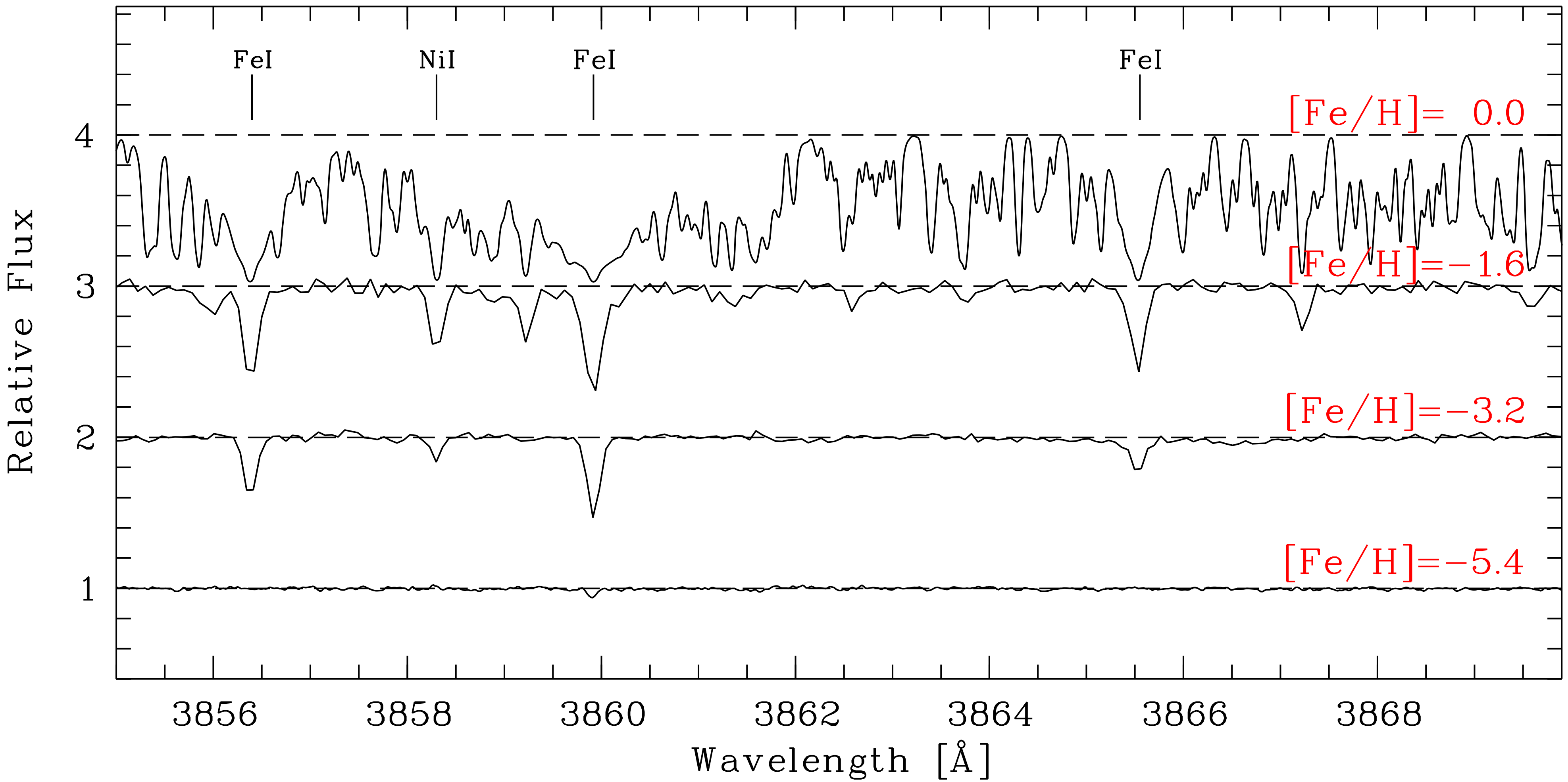
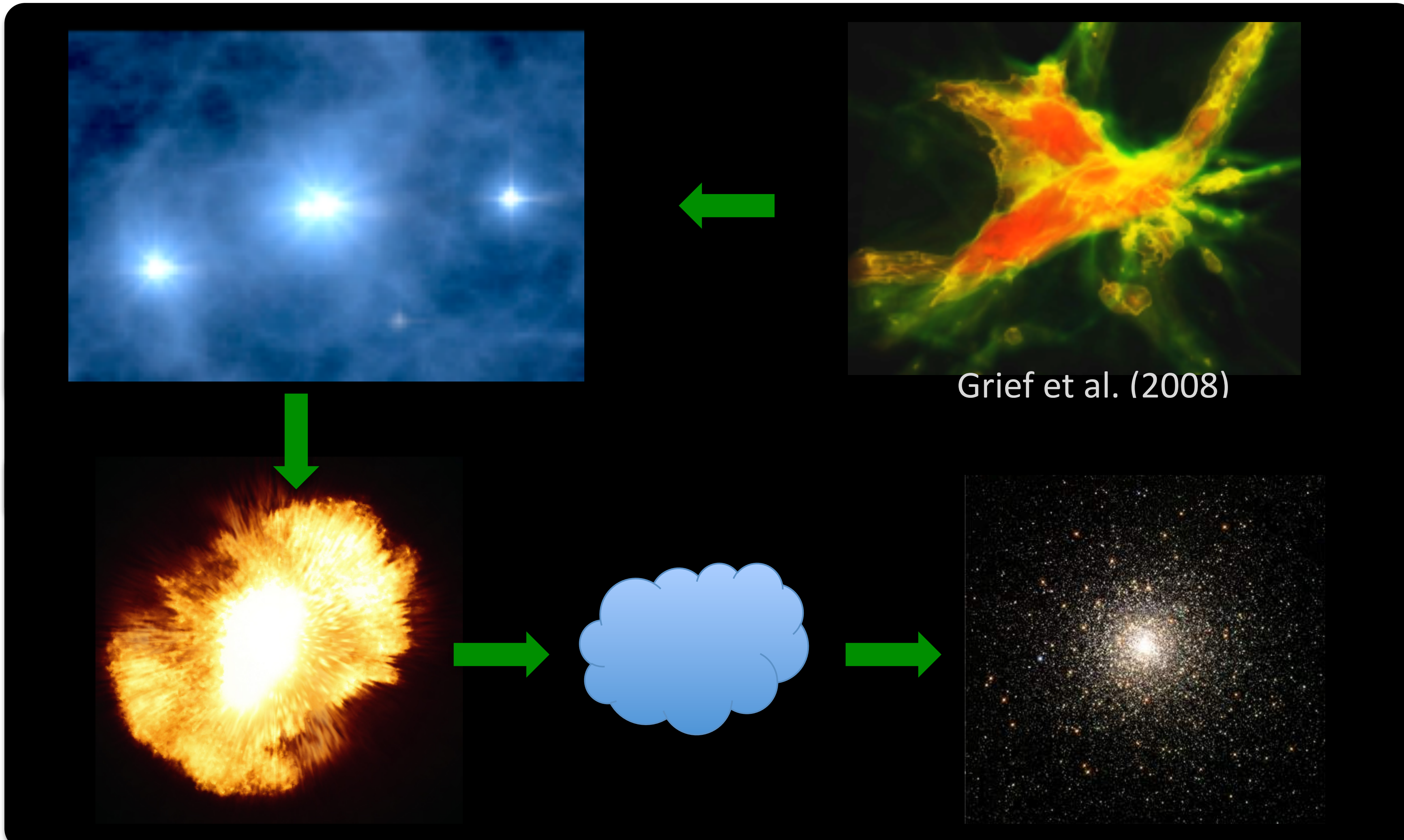
Near-Pristine Gas at High Redshifts: Prospects for the E-ELT

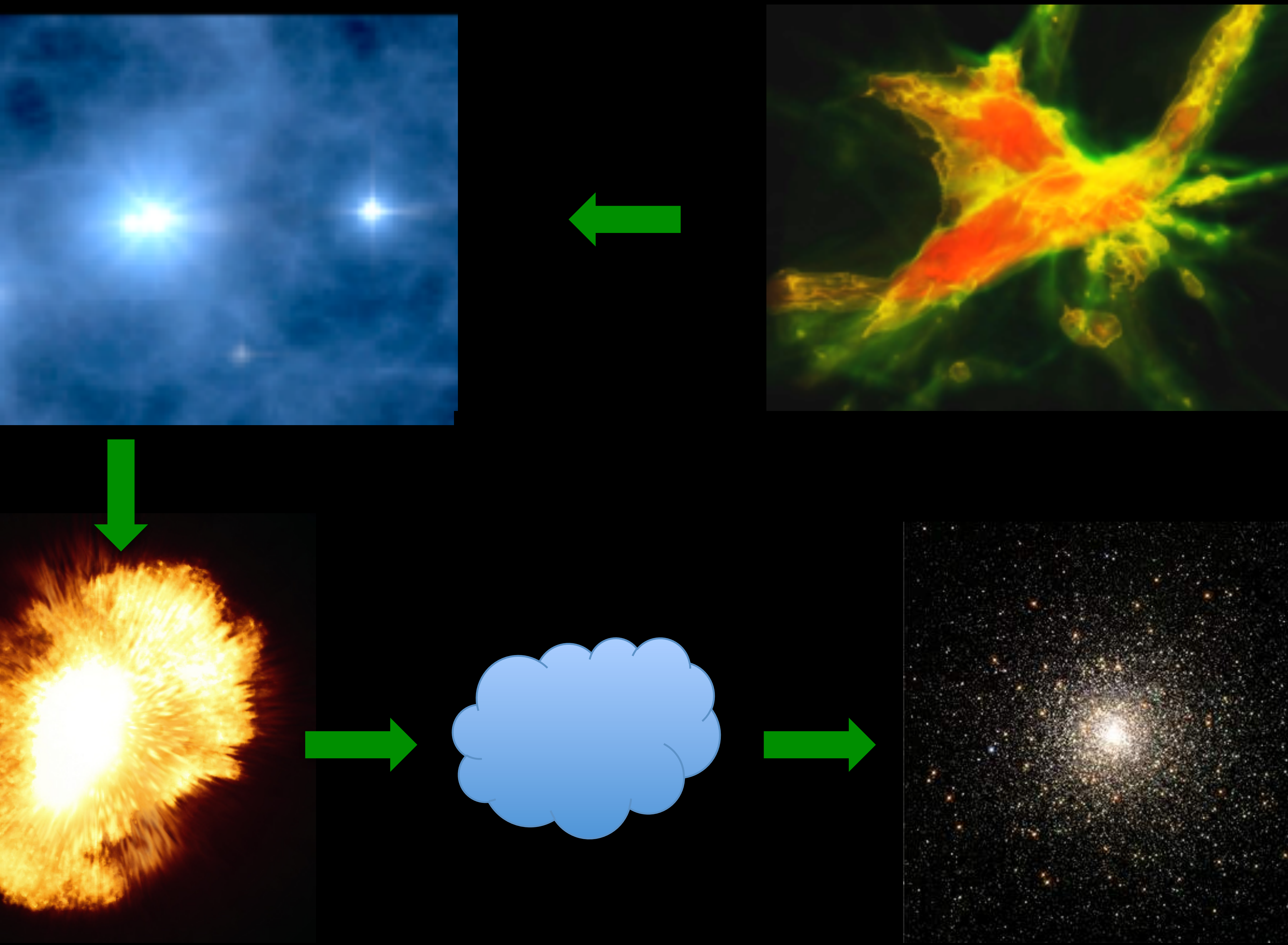
One approach: Galactic `archaeology’

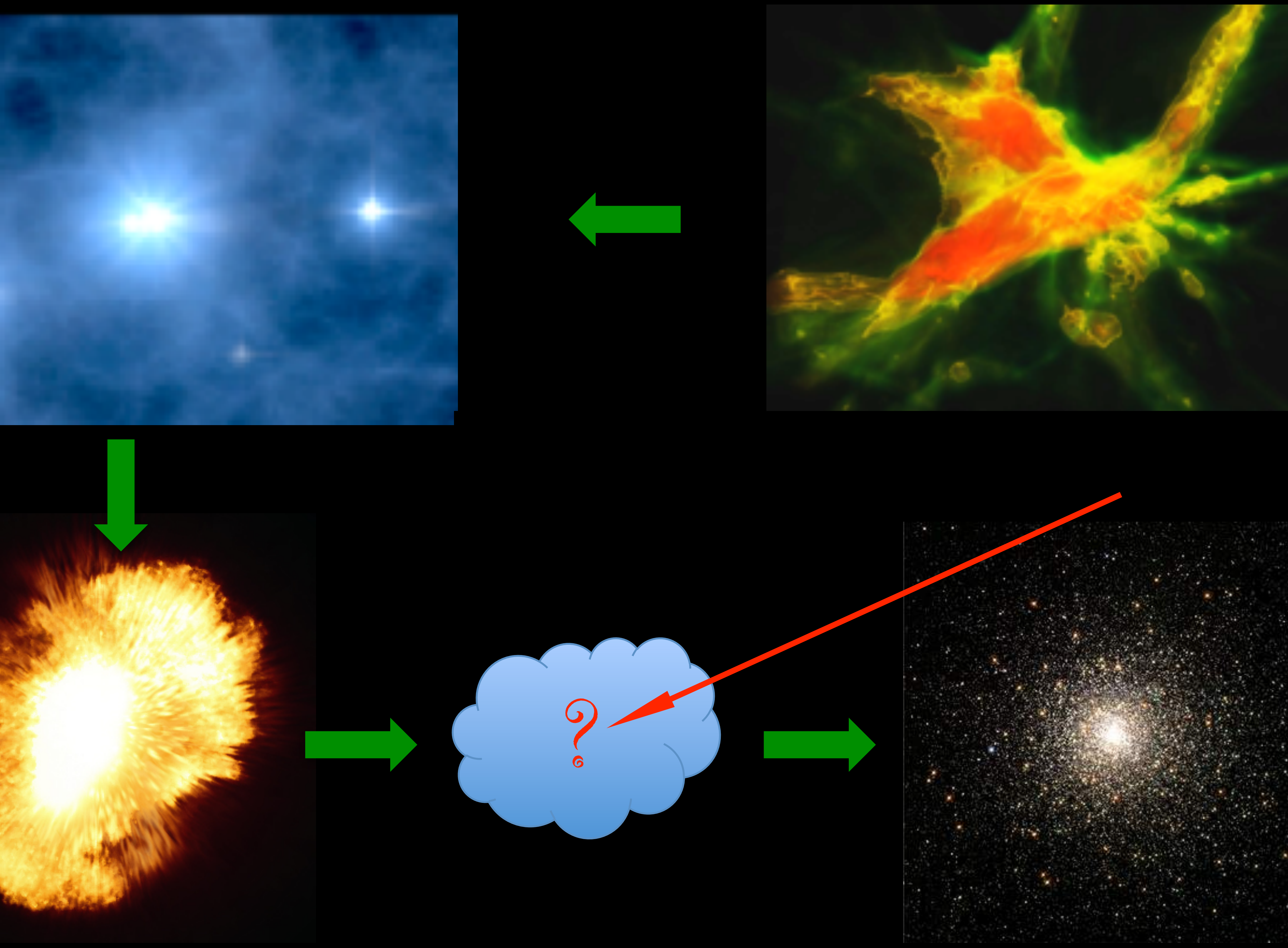

FeI
NiI
FeI
FeI
[Fe/H]= 0.0
[Fe/H]=−1.6
[Fe/H]=−3.2
[Fe/H]=−5.4
Relative Flux
1
2
3
4
3856
3858
3860
3862
3864
3866
3868
Wavelength [Å]

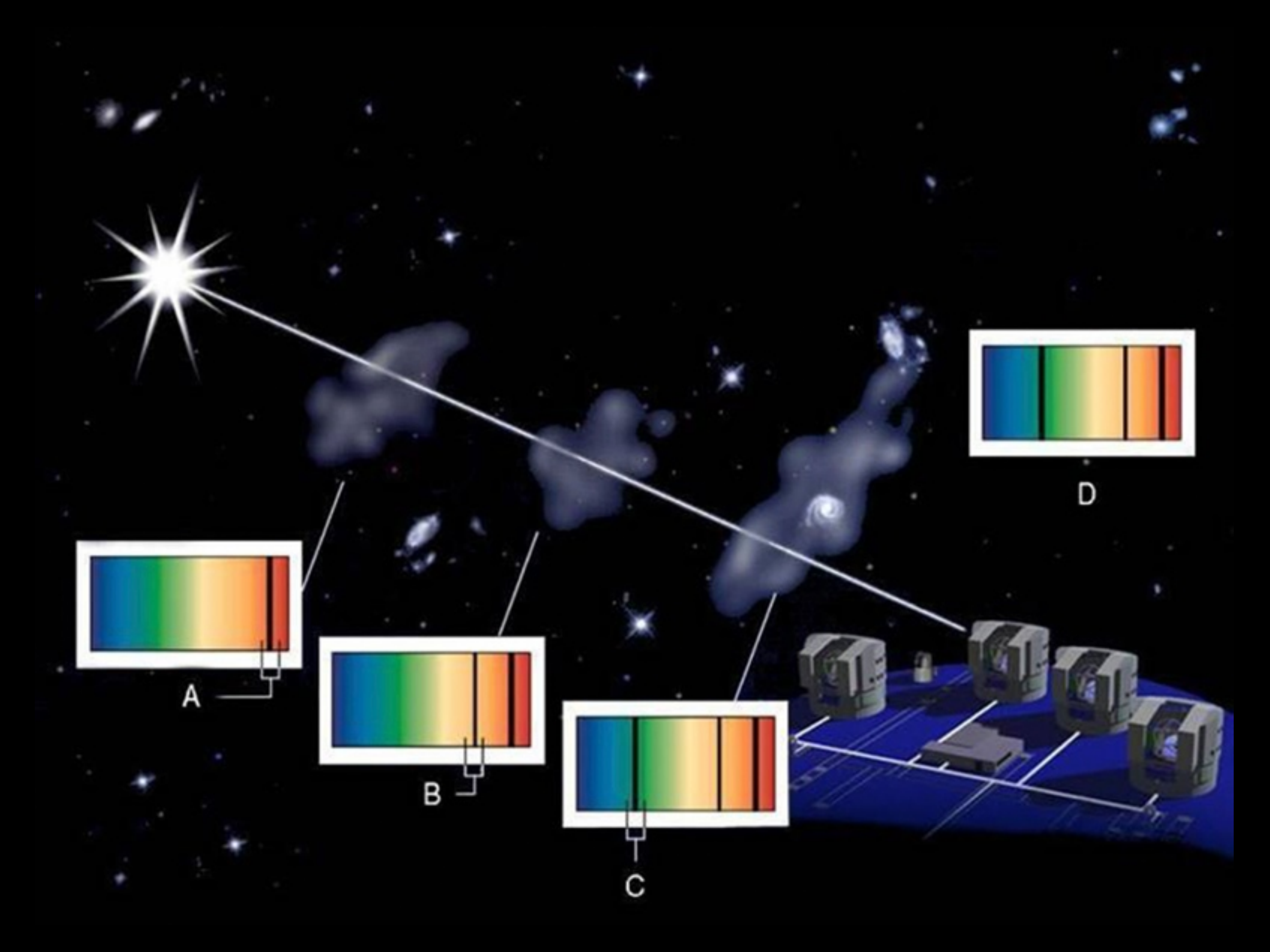
Frebel 2010

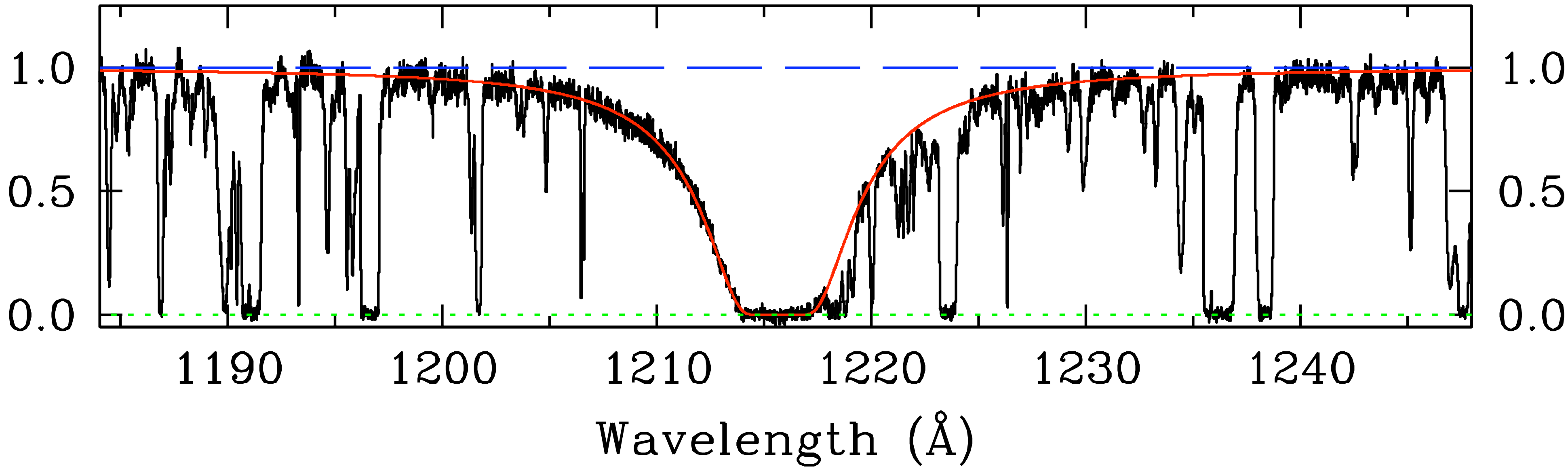
Studying the First Stars



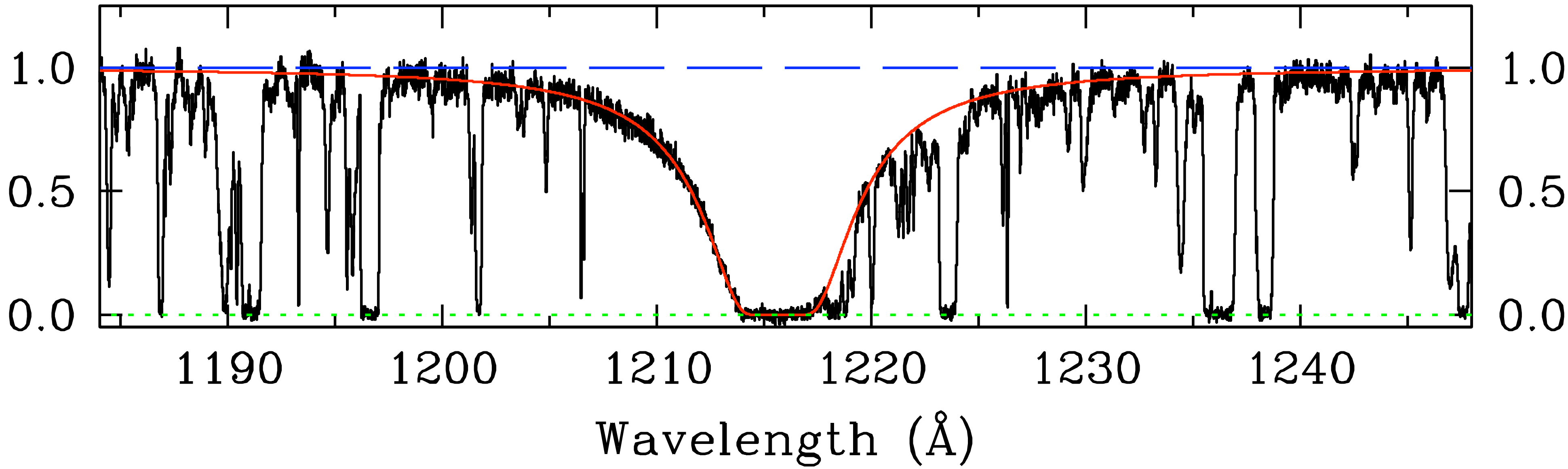





A
B
C
D

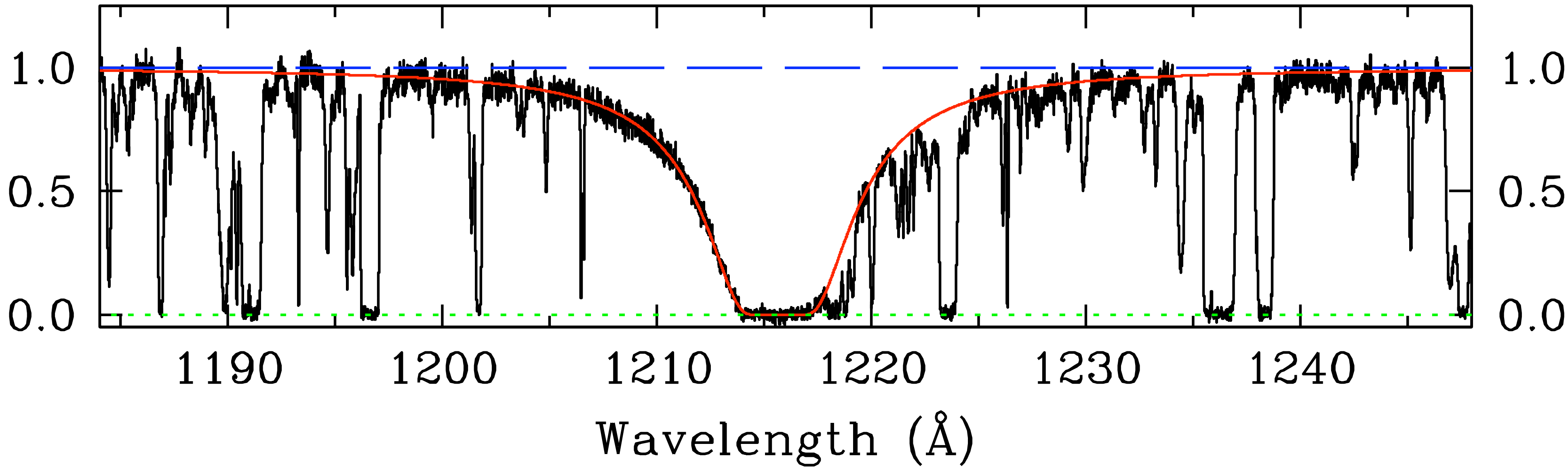


1.0
0.5
0.0
1190
1200
1210
1220
1230
1240
Wavelength (Å)



`Damped Ly α systems' (DLAs) ≡

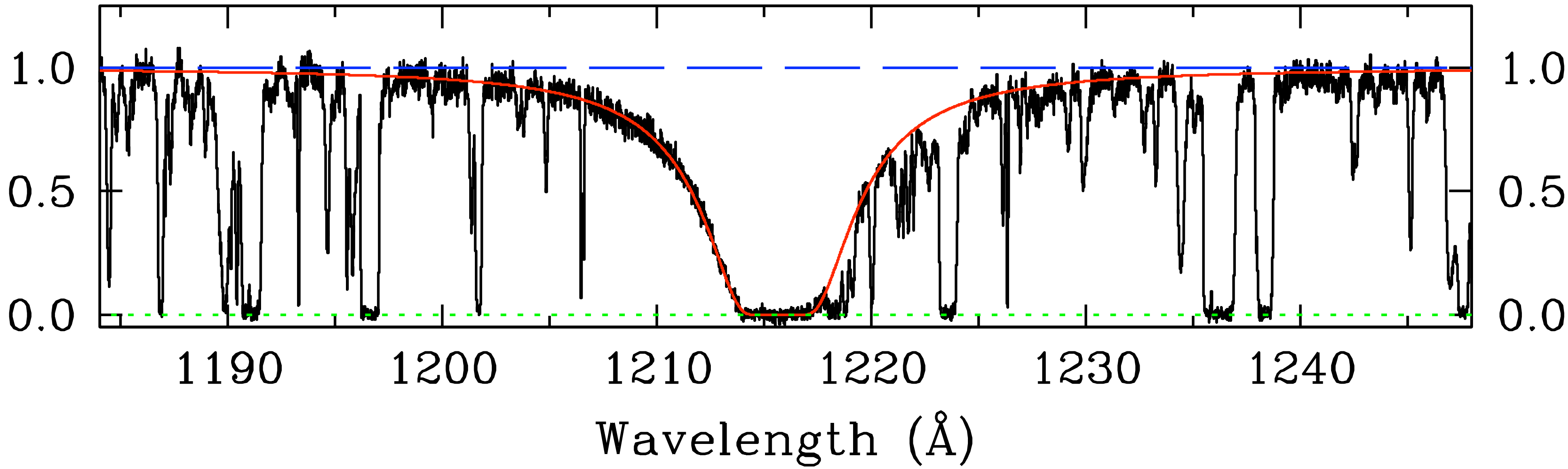
neutral gas of high density.



`Damped Lyα systems' (DLAs) $\equiv$

neutral gas of high density.

Ideal for accurate measures of physical properties.



`Damped Lyα systems' (DLAs) $\equiv$

neutral gas of high density.

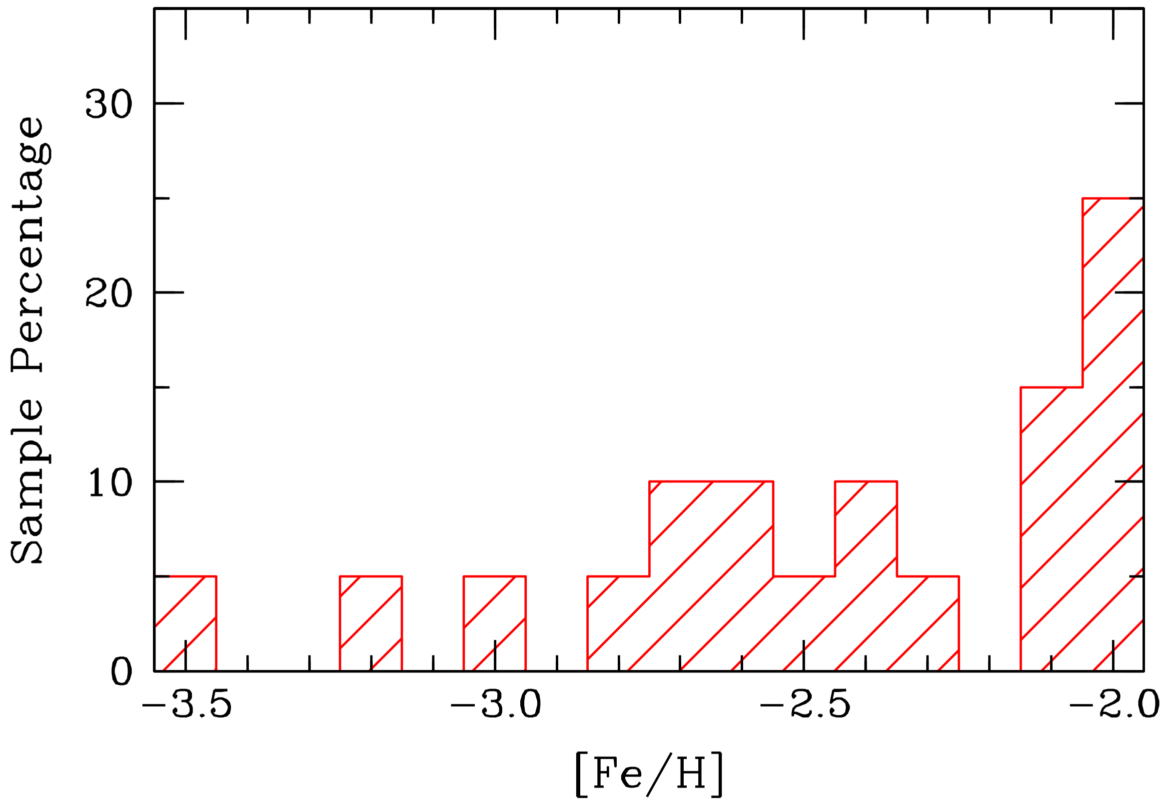
✓ Ideal for accurate measures of physical properties.

✓ Highly complementary to local stellar studies.

The metal-poor DLA survey

22 DLAs with [Fe/H] < -2

C,N,O abundances in the metal-poor regime



Cooke et al. 2011, 12

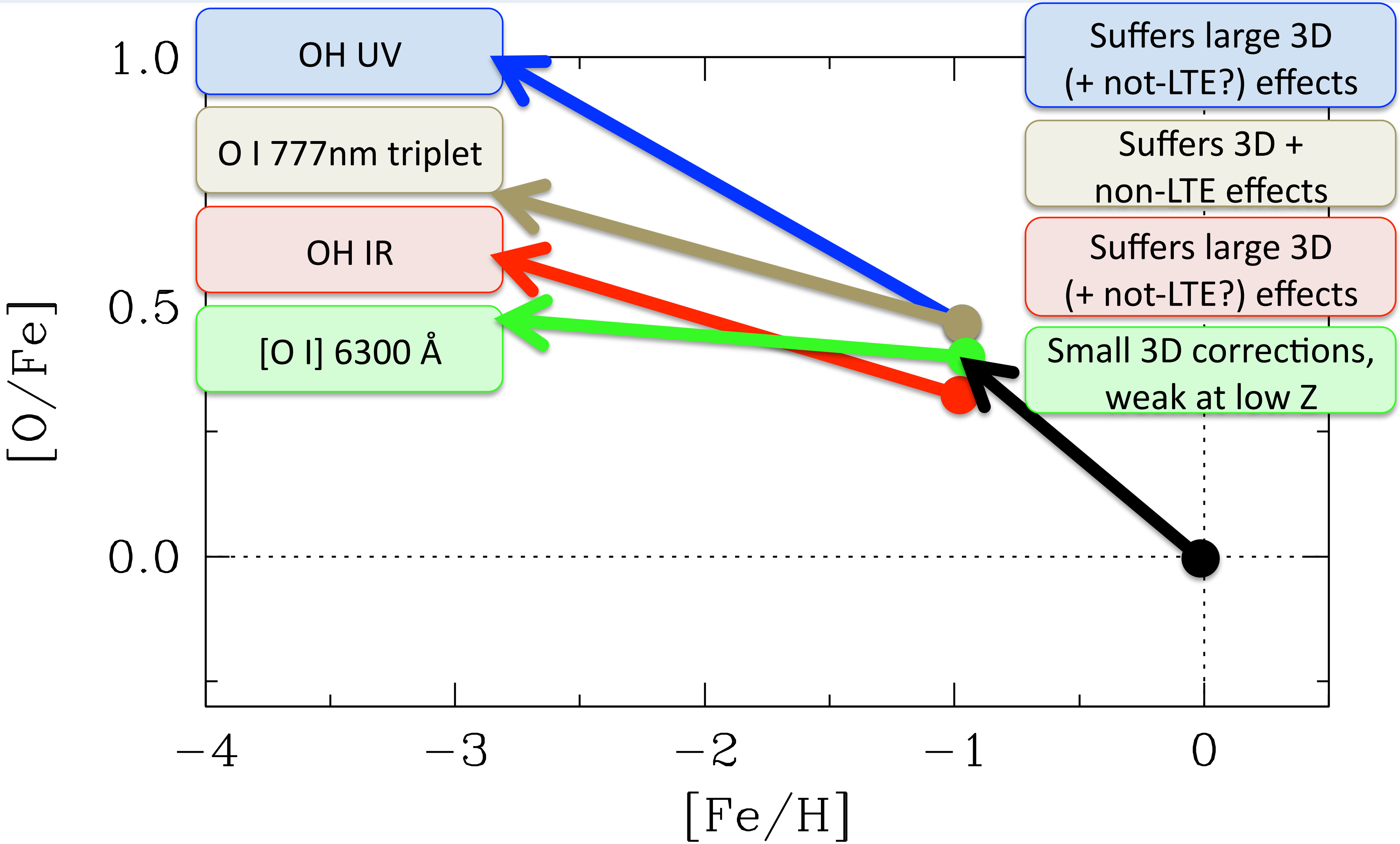
The metal-poor DLA survey

22 DLAs with [Fe/H] < -2

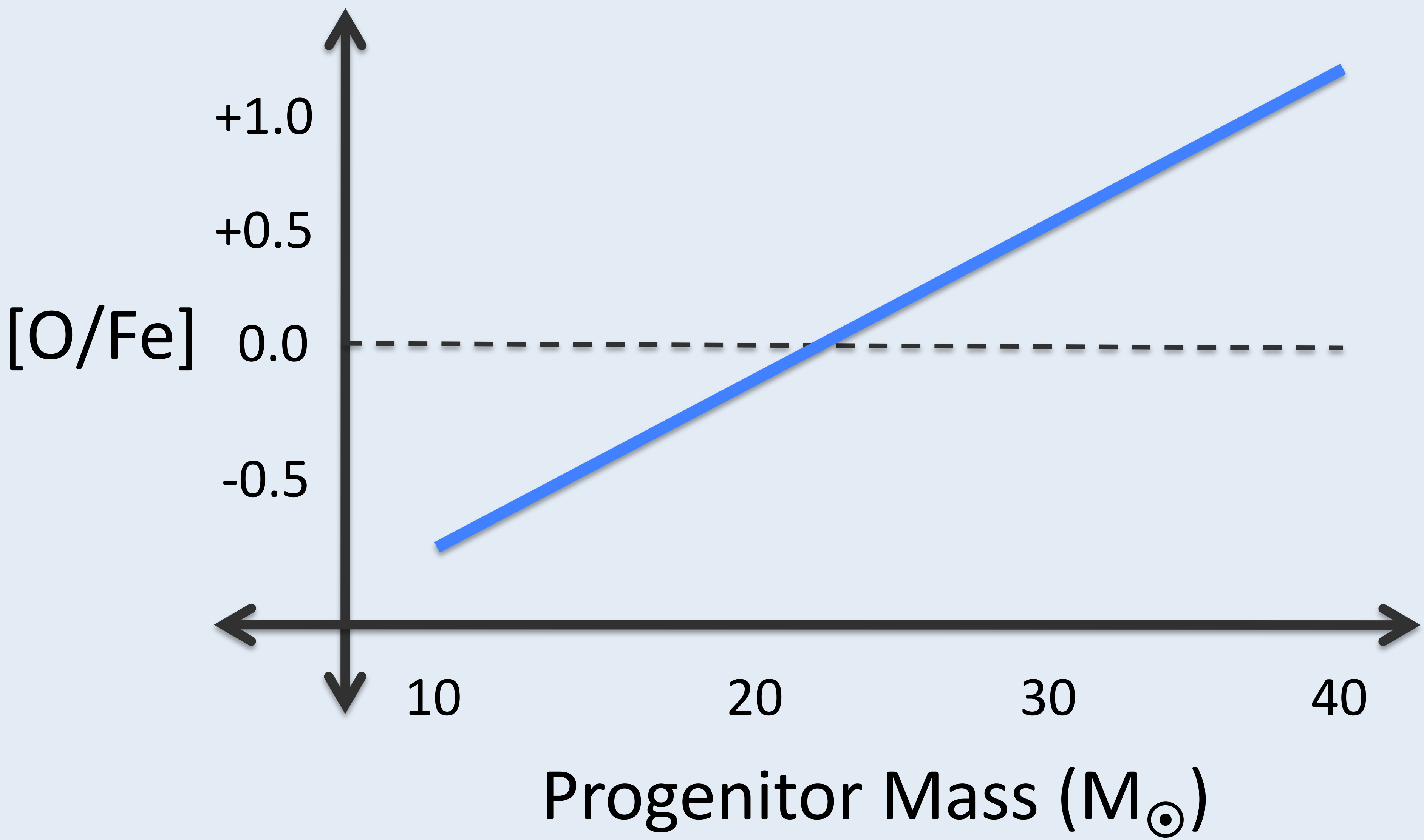
C,N,O abundances in the metal-poor regime

Cooke et al. 2011, 12

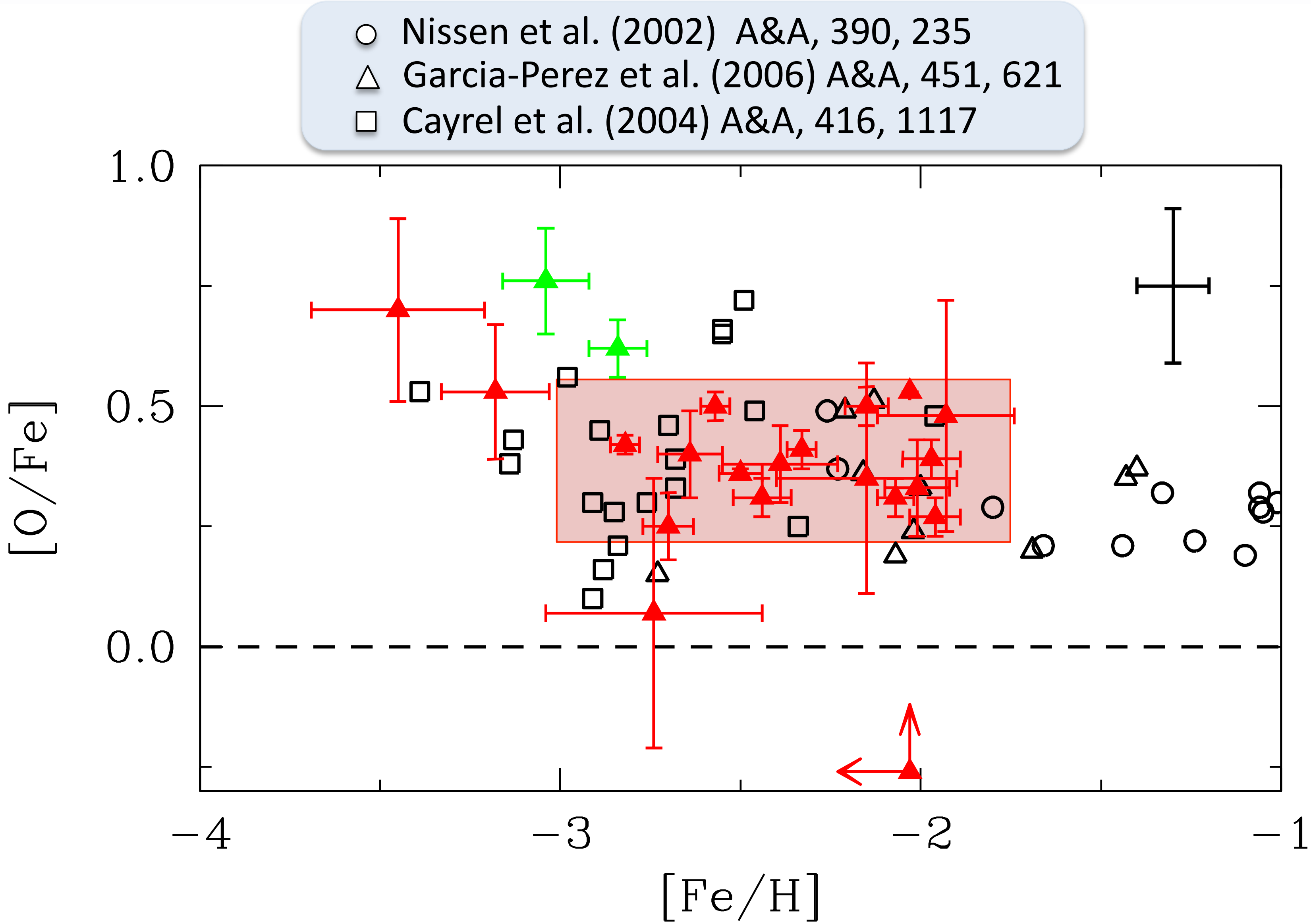
The *"Oxygen Problem"*



[O/Fe] ≈ stellar IMF

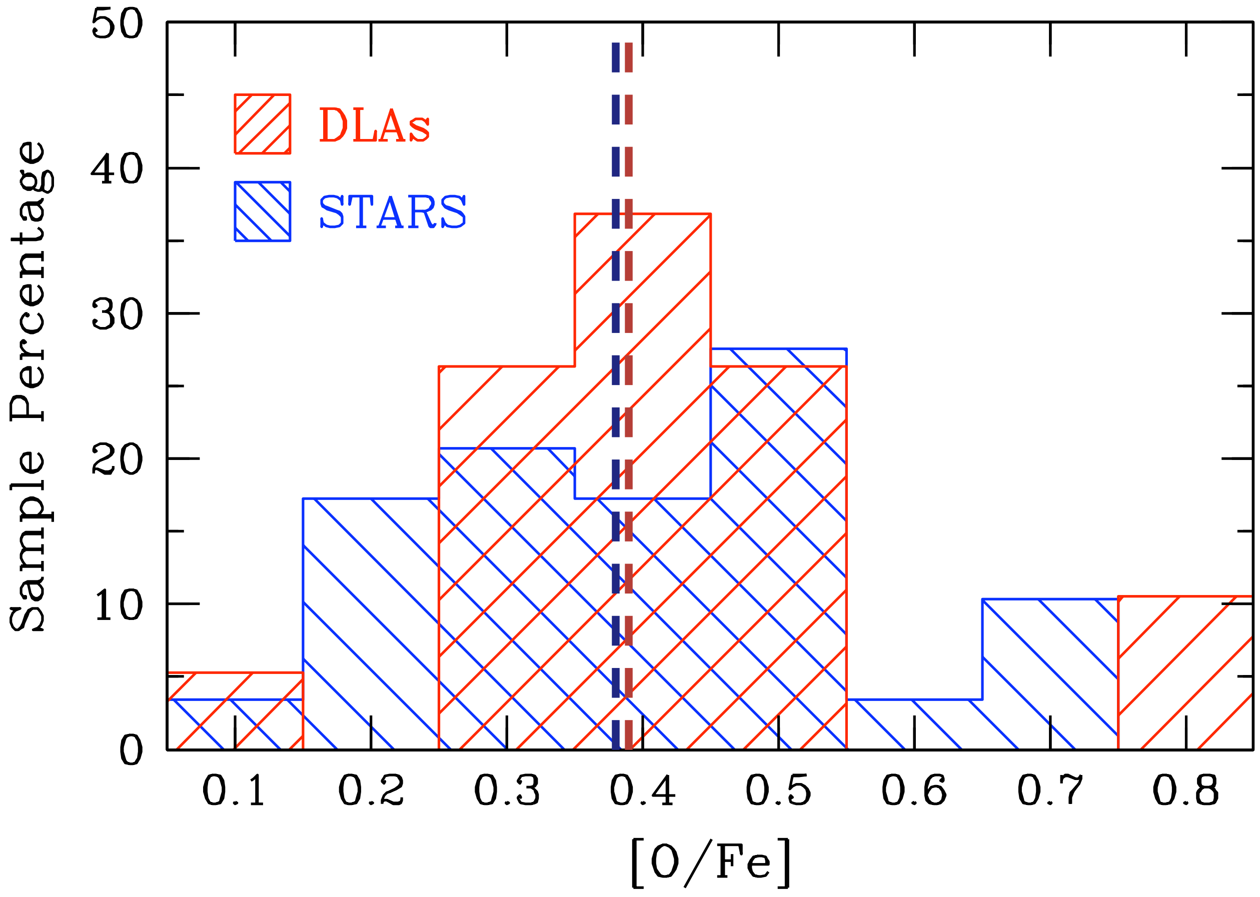


The O/Fe ratio at low metallicity



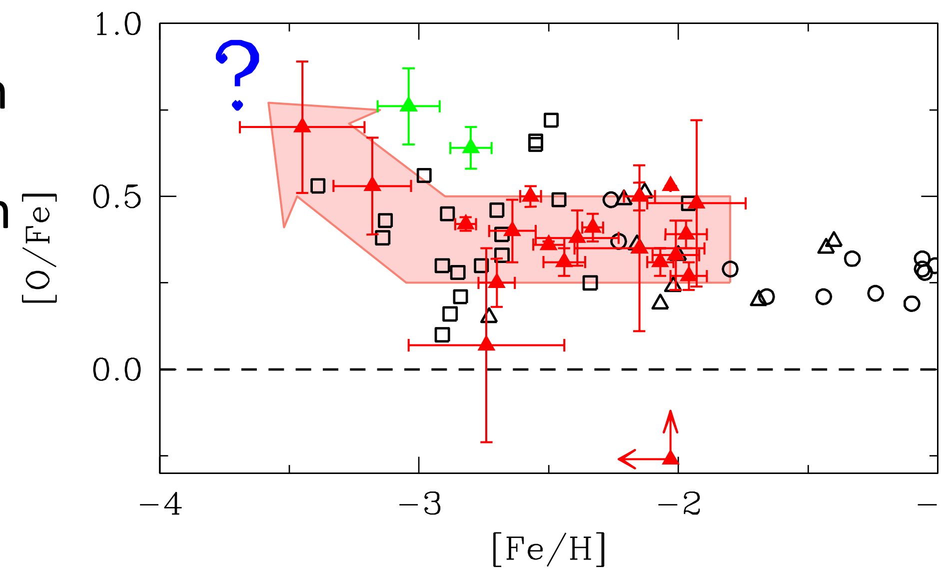
The O/Fe ratio at low metallicity

For [Fe/H] < -2,
halo stars and DLAs
are indistinguishable
in [O/Fe] when stellar
[O/H] is measured
from [O I] λ6300 line.



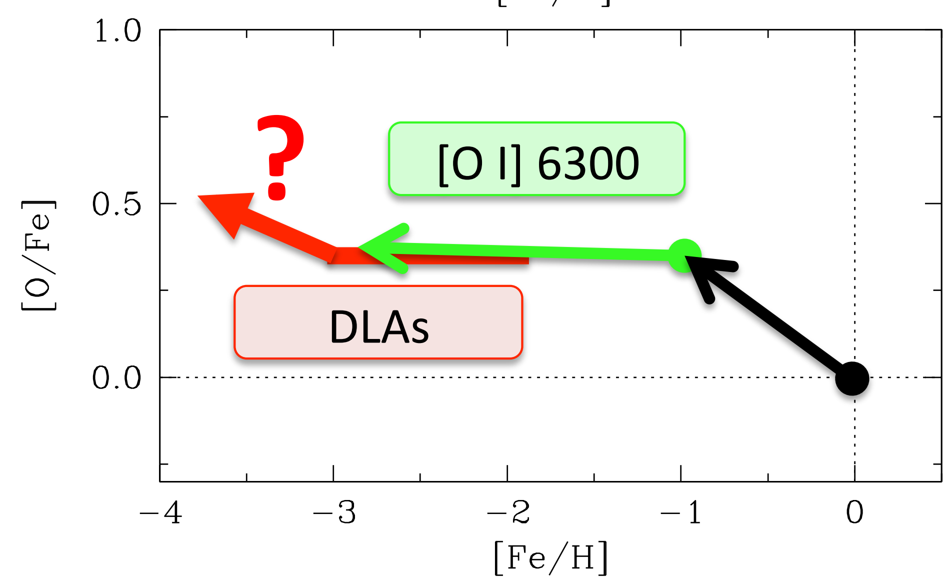
The O/Fe ratio at low metallicity

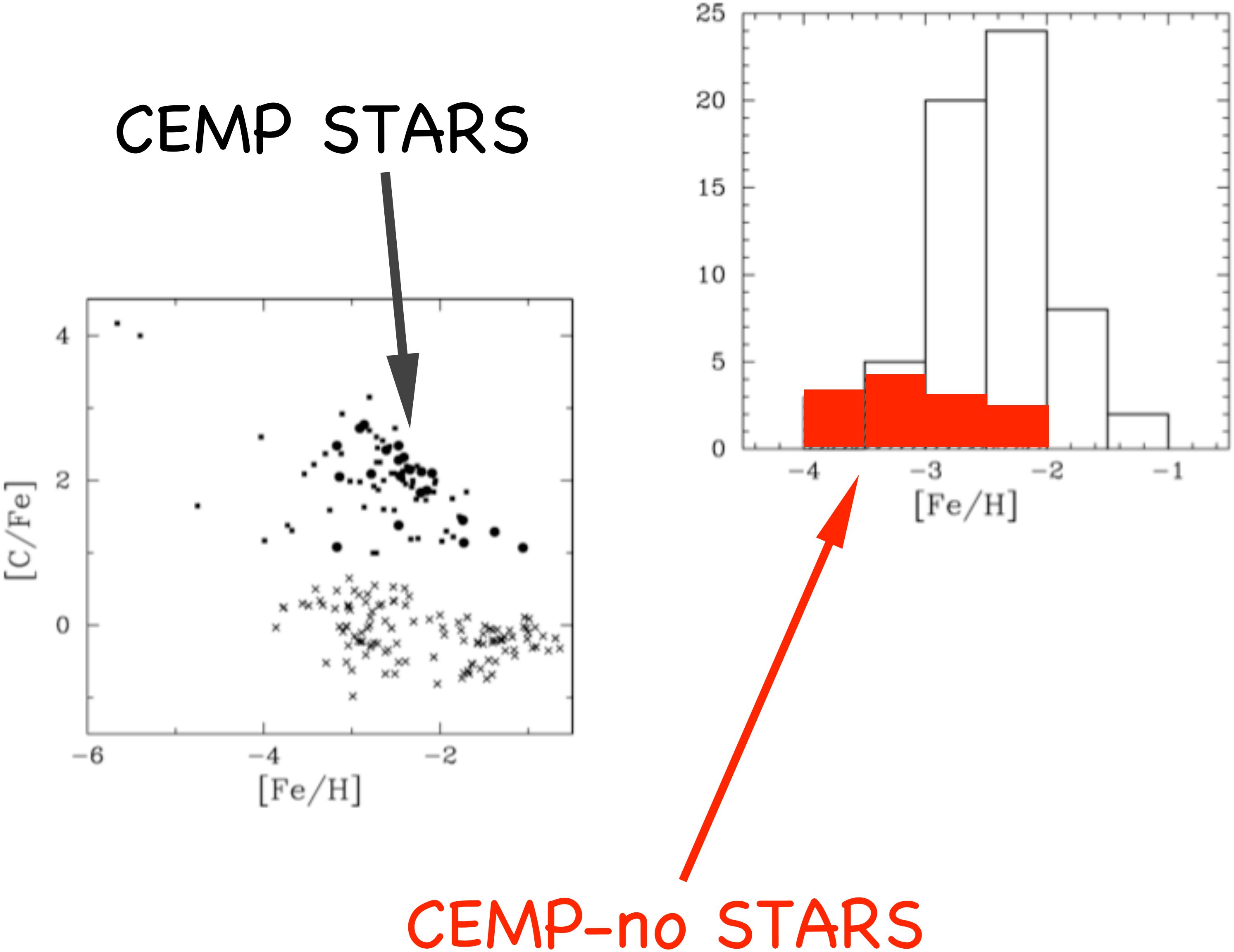
- DLAs exhibit surprisingly little dispersion
- [O/Fe] in DLAs agree well with that from stars in the halo of our Galaxy.
- DLAs are helping to resolve this much debated trend below [Fe/H] < -1.0



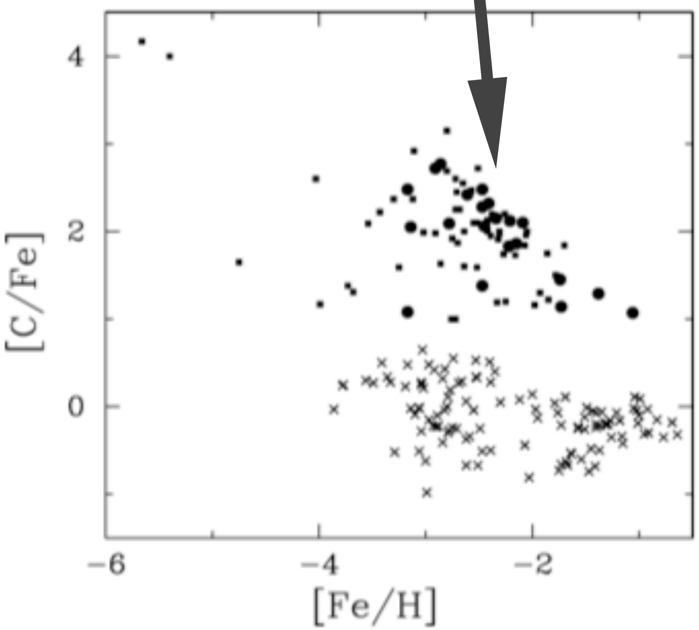
Two main results:

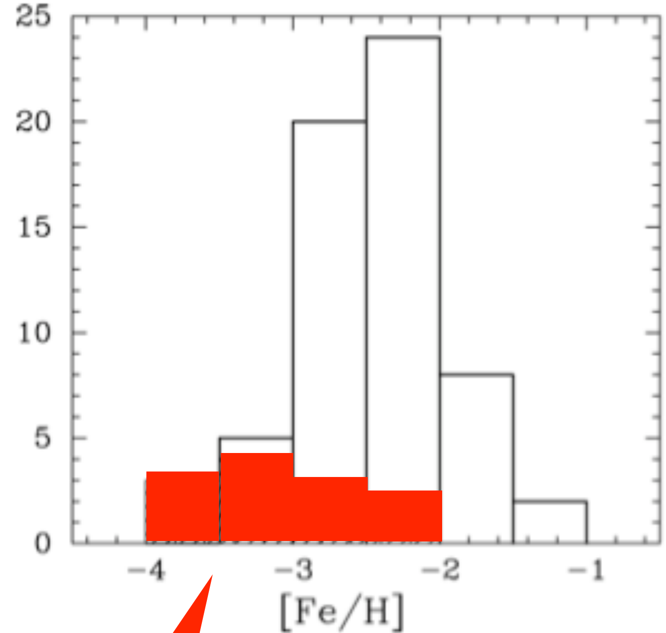
1) [<O/Fe>] ≈ +0.35
2) Tentative evidence for a slight increase in [O/Fe] when [Fe/H] < -3.0




CEMP STARS
[C/Fe]
[Fe/H]
[Fe/H]
CEMP-no STARS

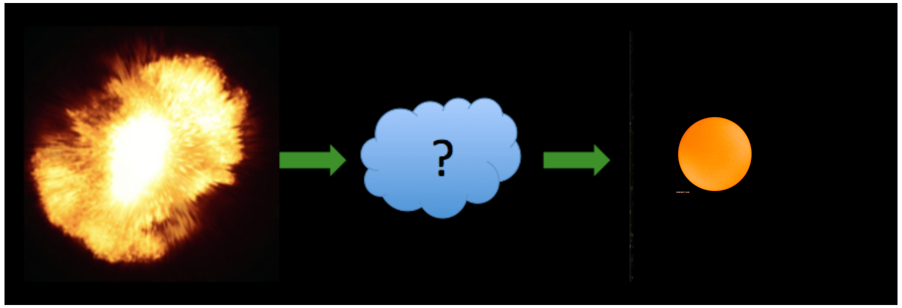
CEMP STARS





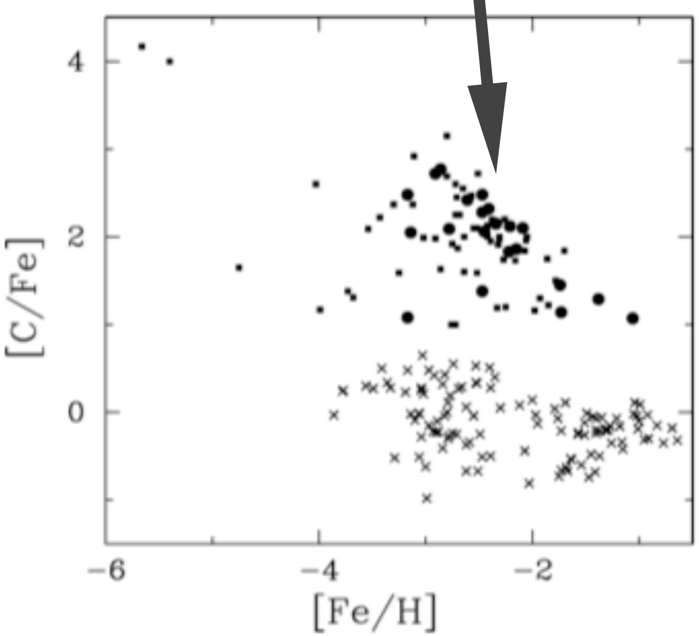
CEMP-no STARS

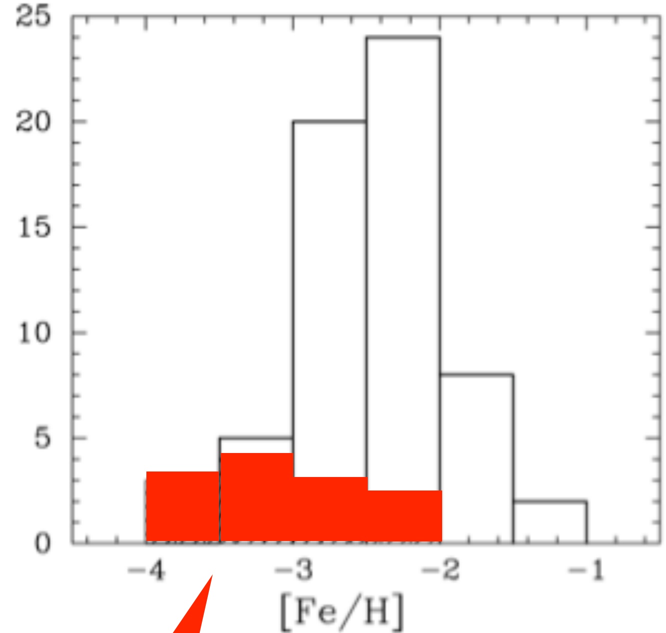
Pop III SN



Pop II CEMP
halo star

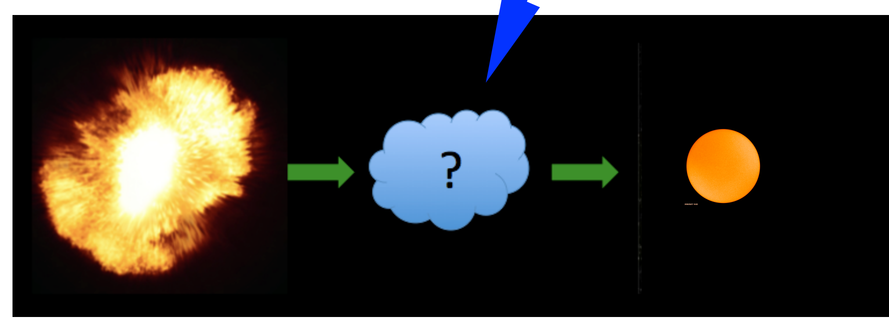
CEMP STARS





CEMP DLAs

Pop III SN

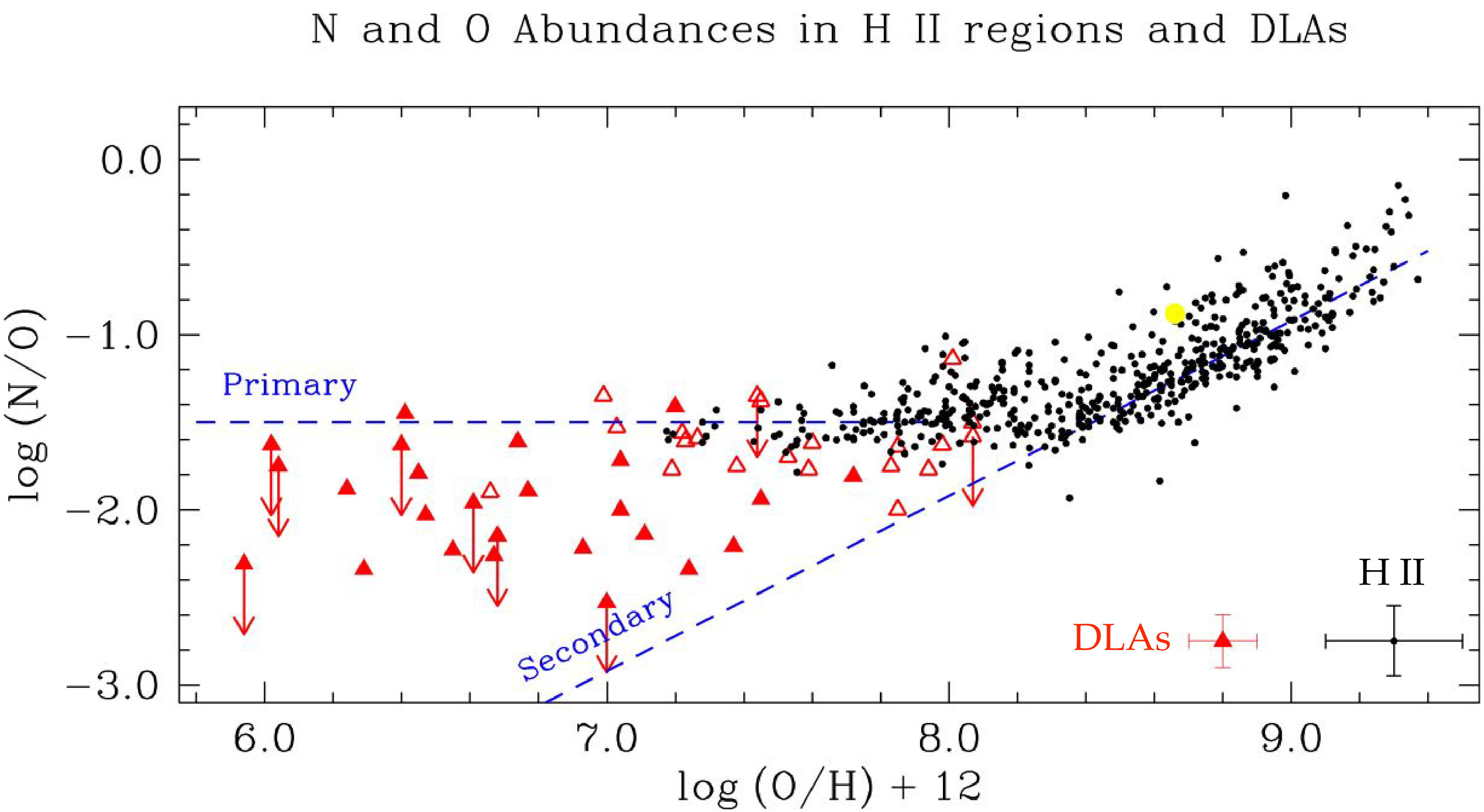


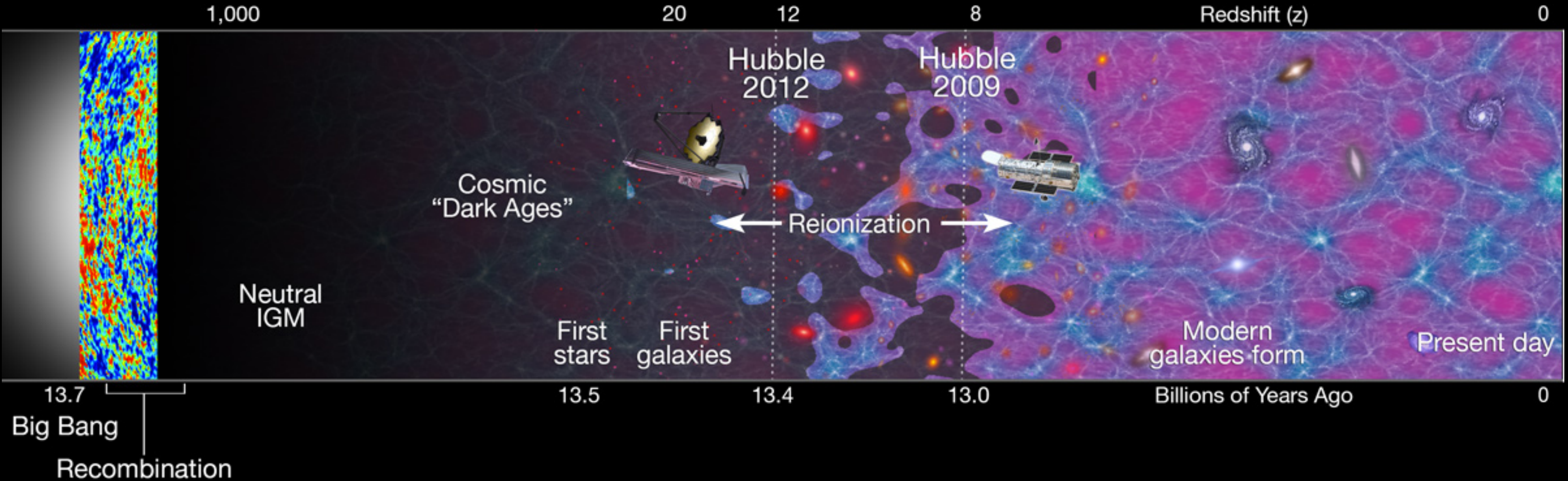
CEMP-no STARS

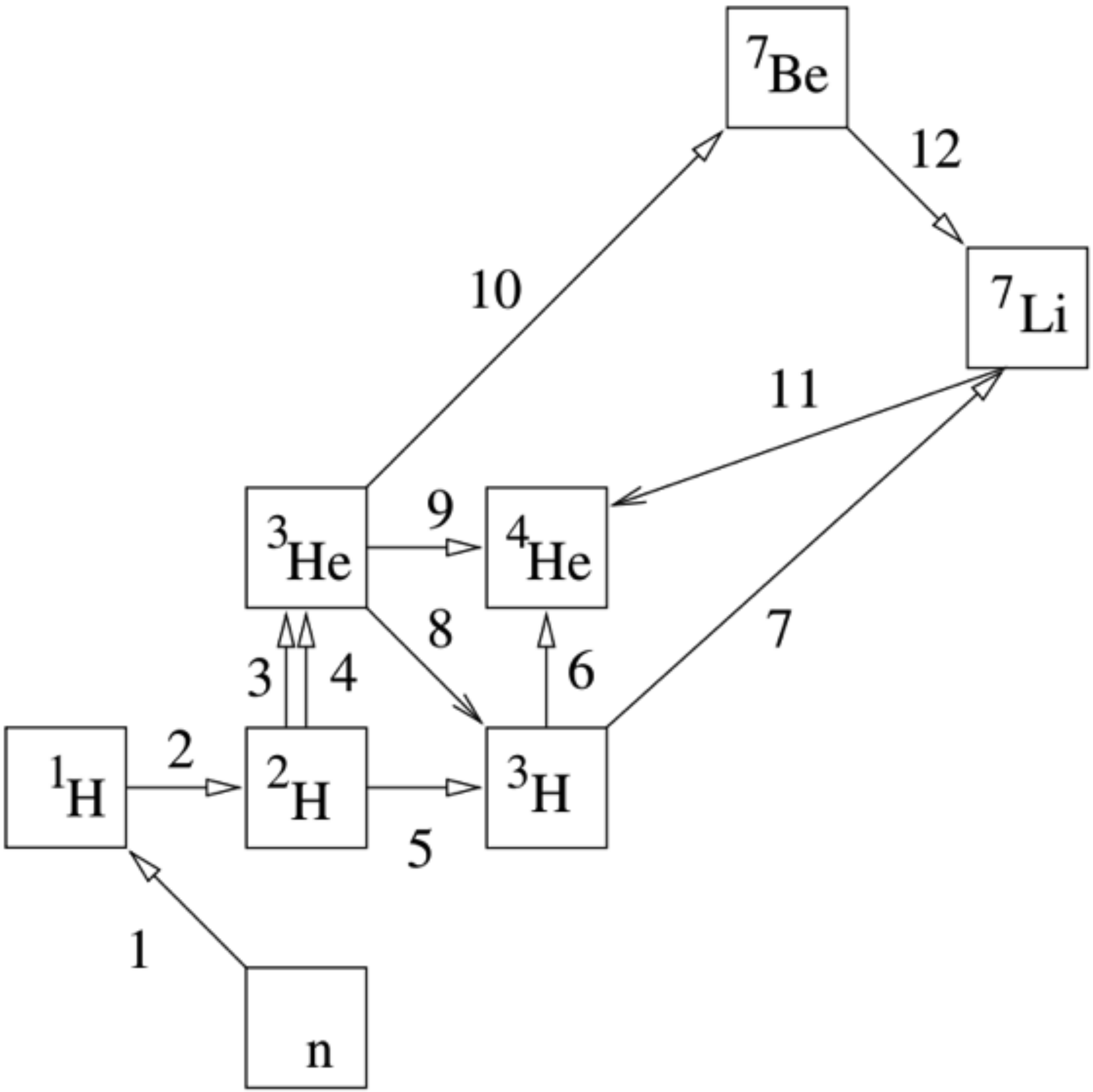
Pop II CEMP halo star

Cooke et al. 2011a

Nucleosynthesis of Nitrogen



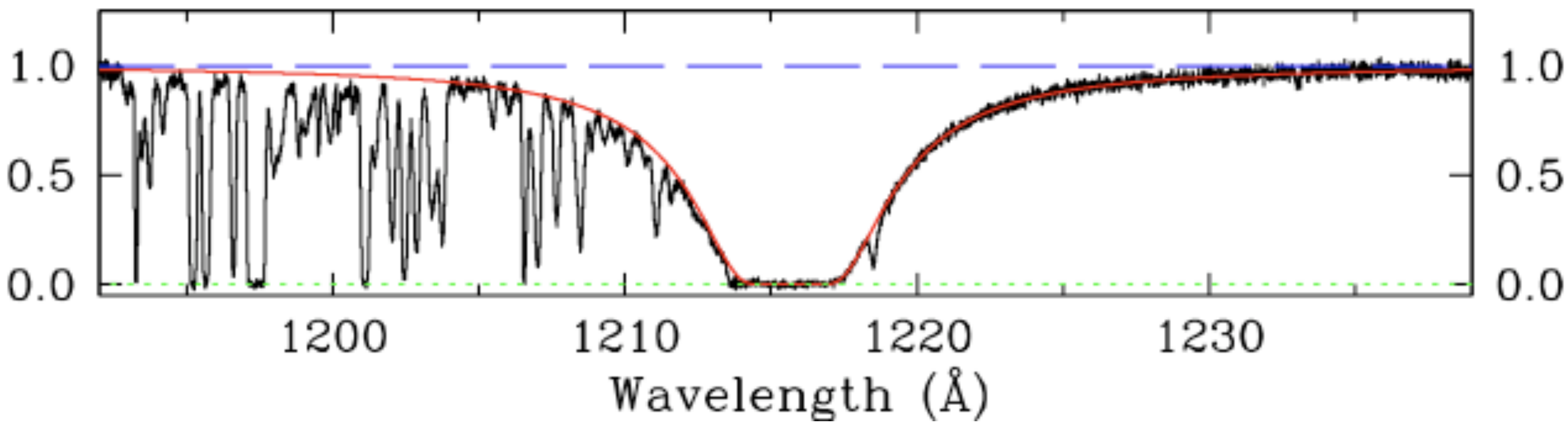

1,000
20
12
8
Redshift (z)
0
Hubble 2012
Hubble 2009
Cosmic "Dark Ages"
Reionization
Neutral IGM
First stars
First galaxies
Modern galaxies form
Present day
13.7
13.5
13.4
13.0
Billions of Years Ago
0
Big Bang
Recombination



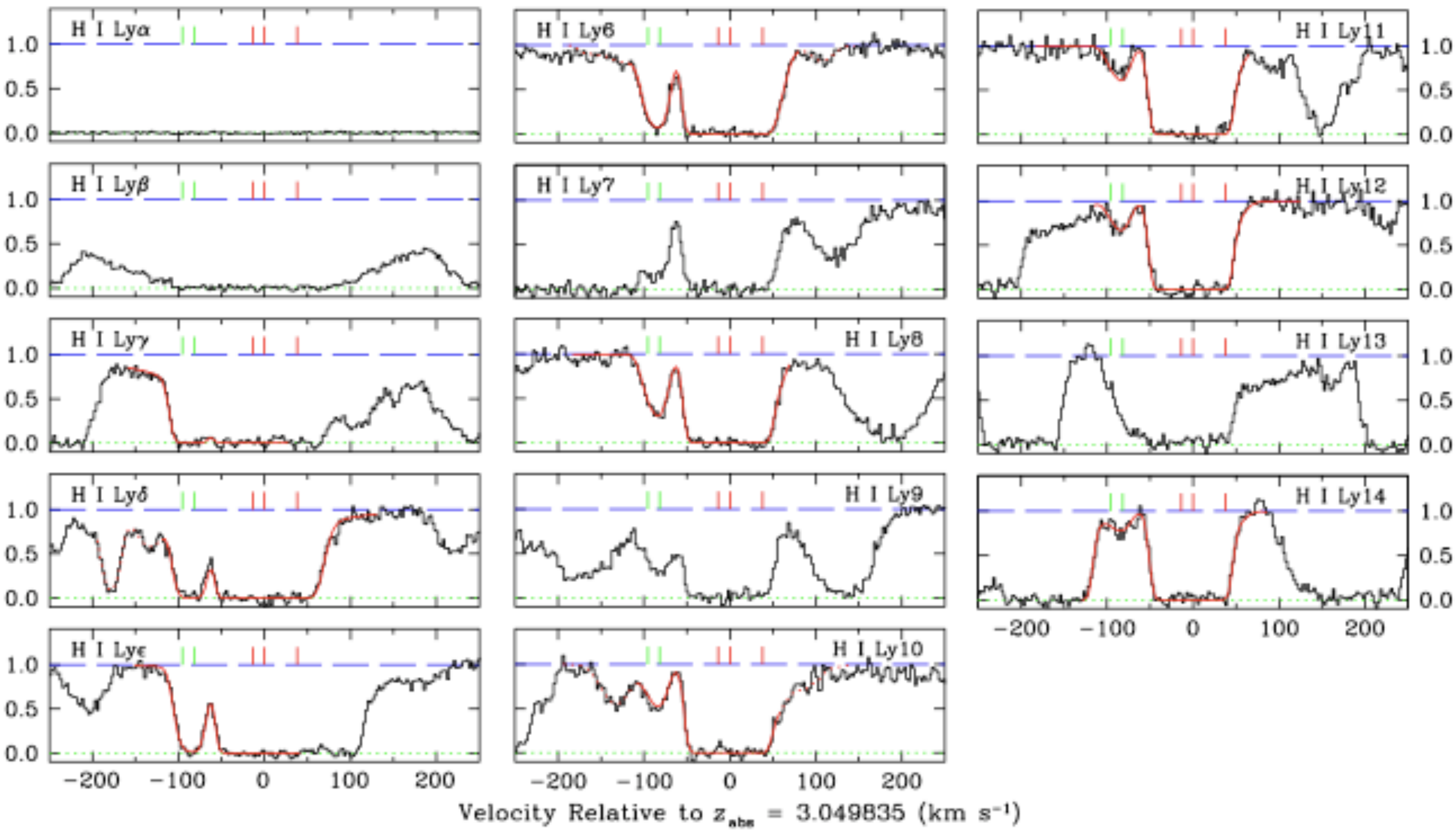
1. $p \longleftrightarrow n$
2. $p(n,\gamma)d$
3. $d(p,\gamma)^3\mathrm{He}$
4. $d(d,n)^3\mathrm{He}$
5. $d(d,p)t$
6. $t(d,n)^4\mathrm{He}$
7. $t(\alpha,\gamma)^7\mathrm{Li}$
8. $^3\mathrm{He}(n,p)t$
9. $^3\mathrm{He}(d,p)^4\mathrm{He}$
10. $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$
11. $^7\mathrm{Li}(p,\alpha)^4\mathrm{He}$
12. $^7\mathrm{Be}(n,p)^7\mathrm{Li}$

J1419+0829, z= 3.050, Fe/H = 1/200 solar

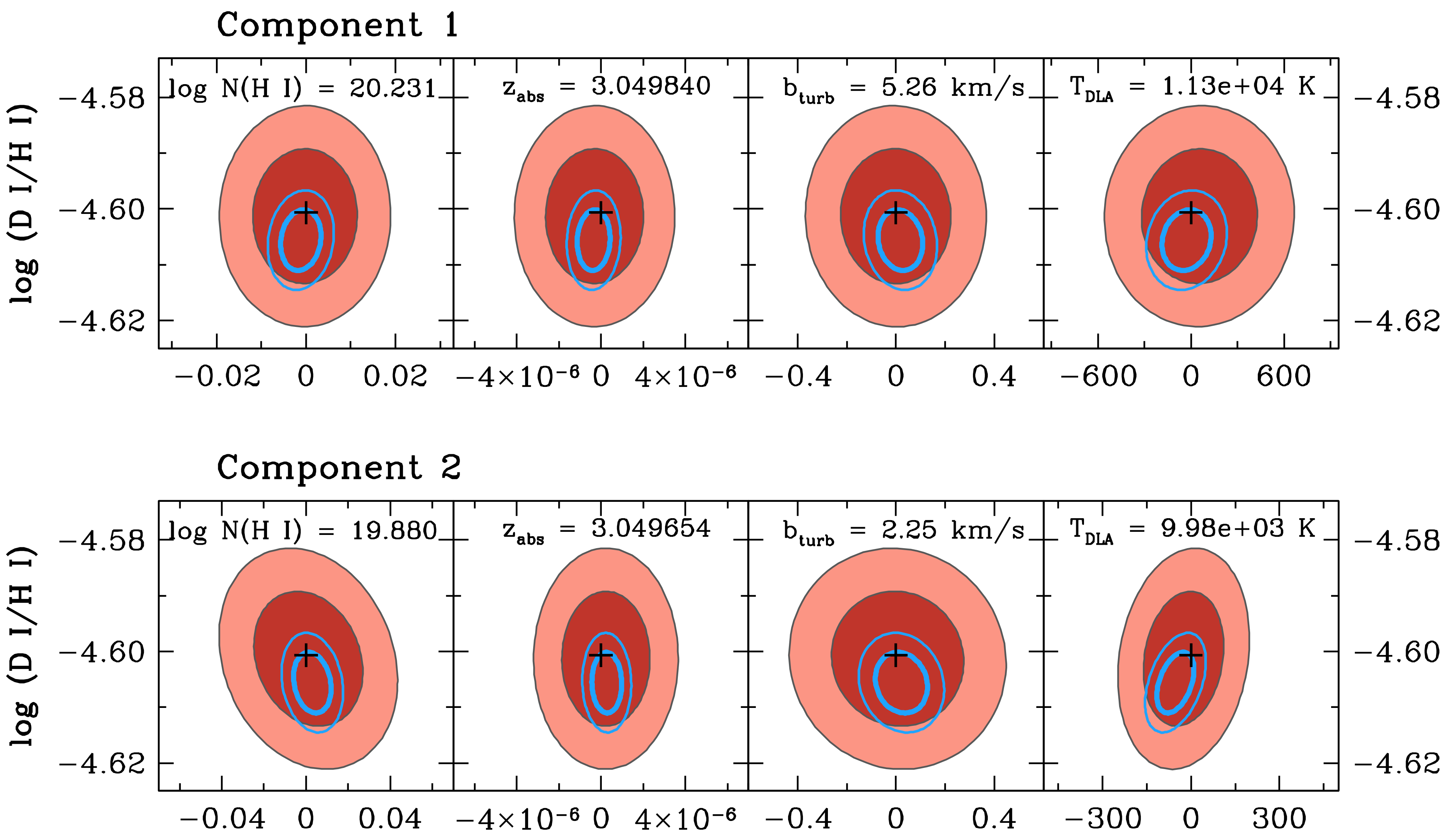
J1419+0829, z= 3.050, Fe/H = 1/200 solar



J1419+0829, z= 3.050, Fe/H = 1/200 solar

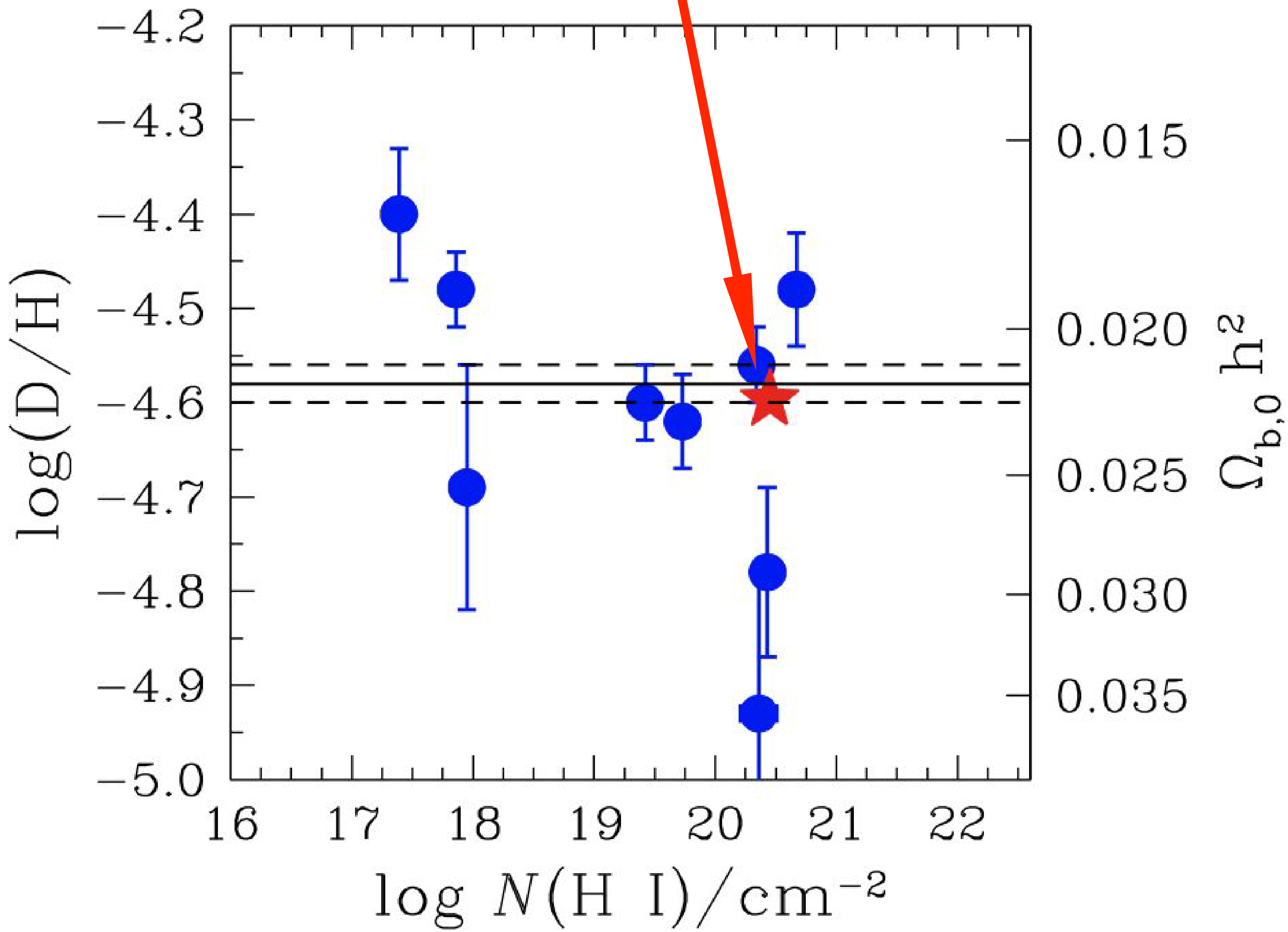


Spectral analysis tailored specifically to the determination of D/H and its error



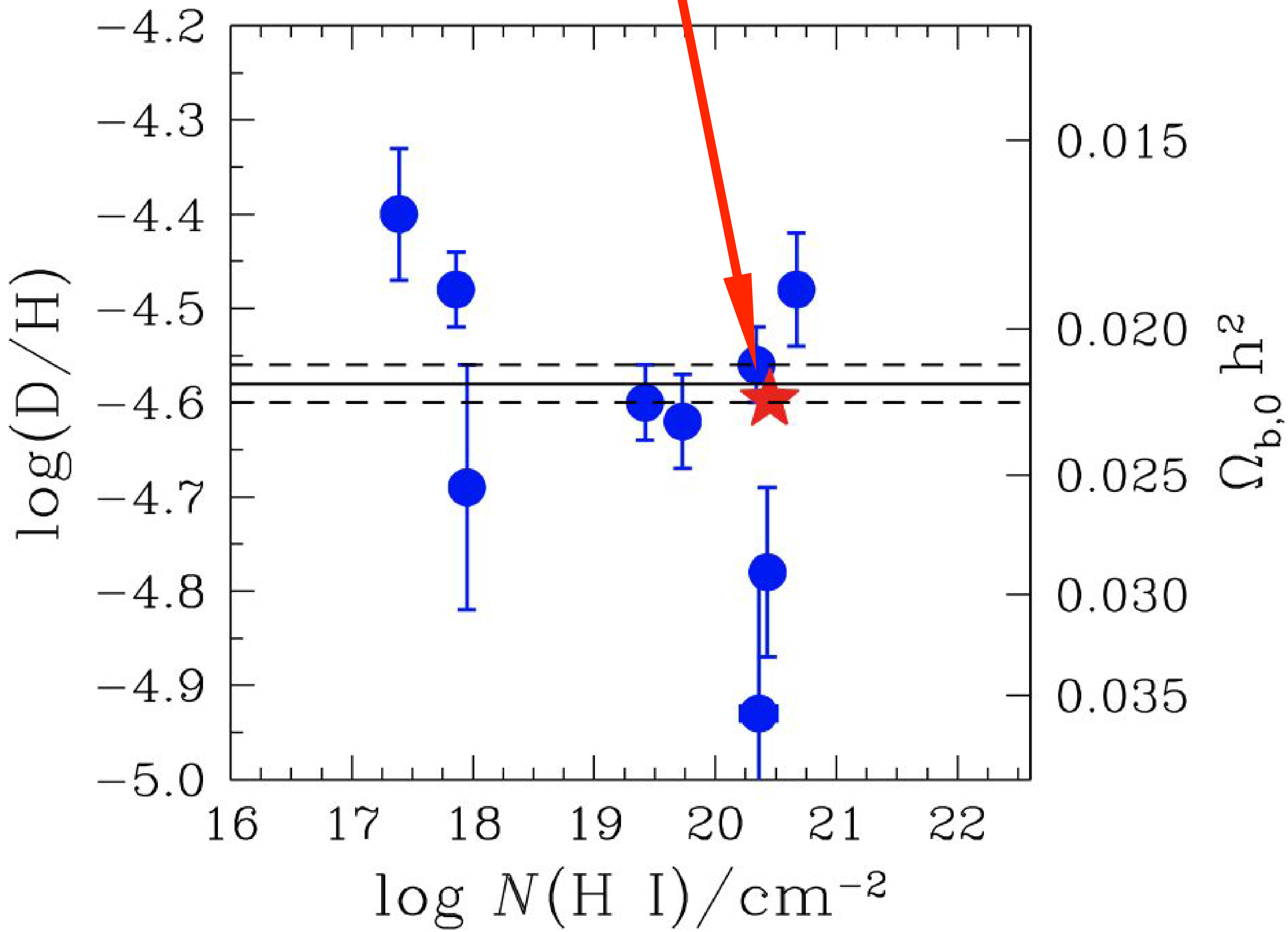
$$(D/H)_{DLA} = (2.53 \pm 0.05) \times 10^{-5}$$

(Random + Systematic Error)



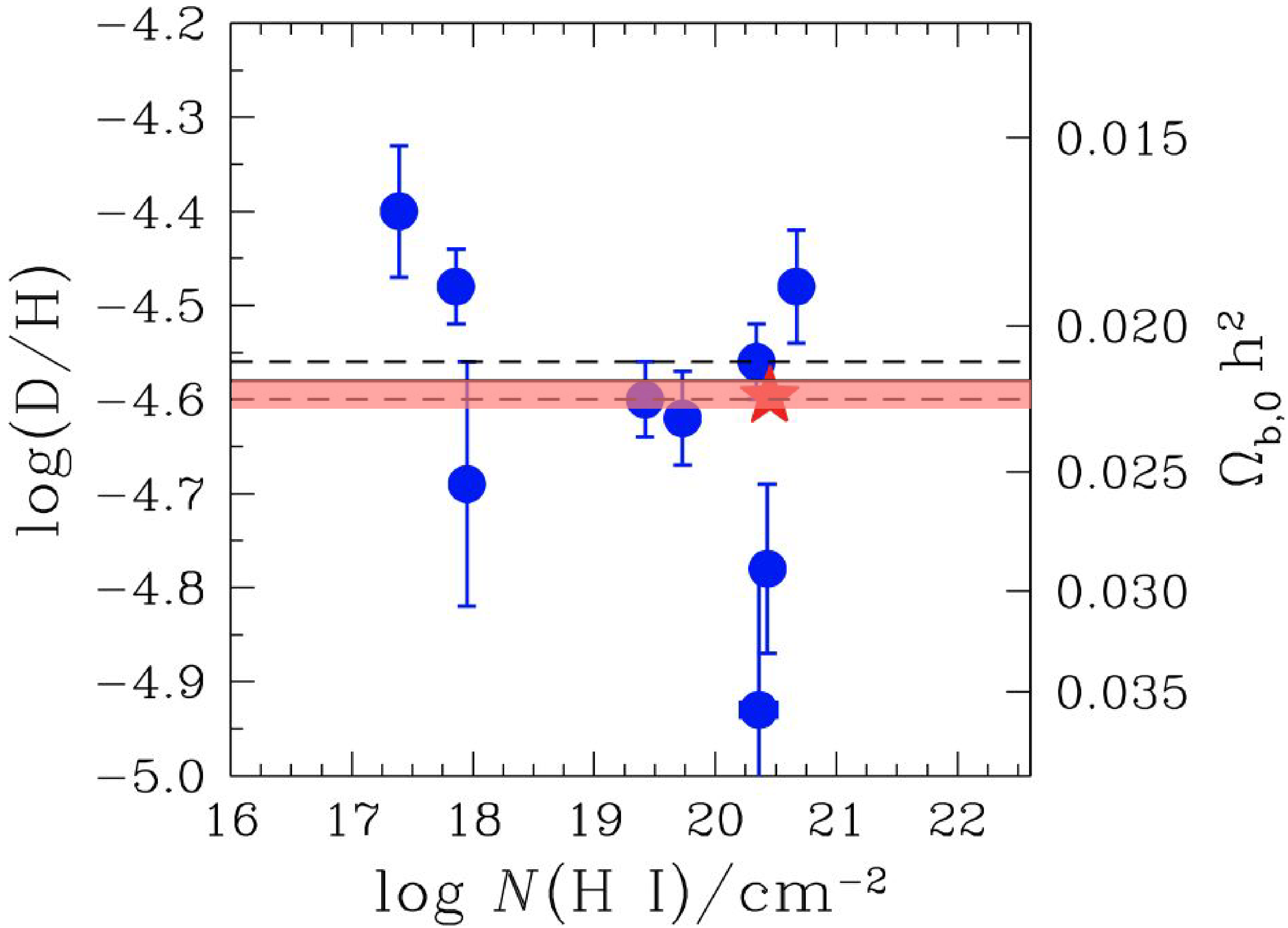
$$100\,\Omega_{b,0}h^2(\mathrm{BBN}) = 2.23 \pm 0.09$$

(Random + Systematic Error)

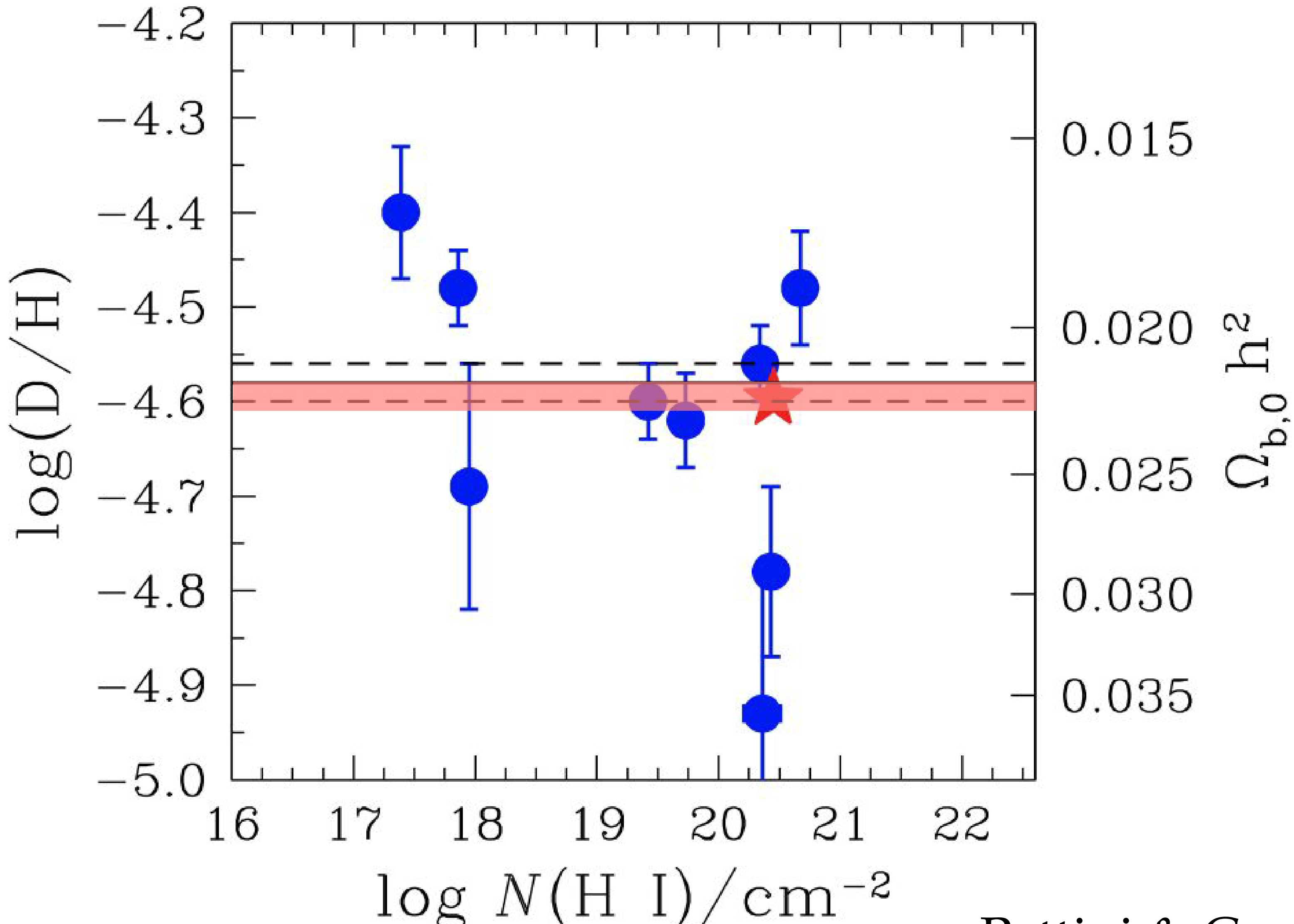


$$100\,\Omega_{\mathrm{b},0}h^2(\mathrm{CMB}) = 2.22 \pm 0.042$$

Keisler et al. 2011

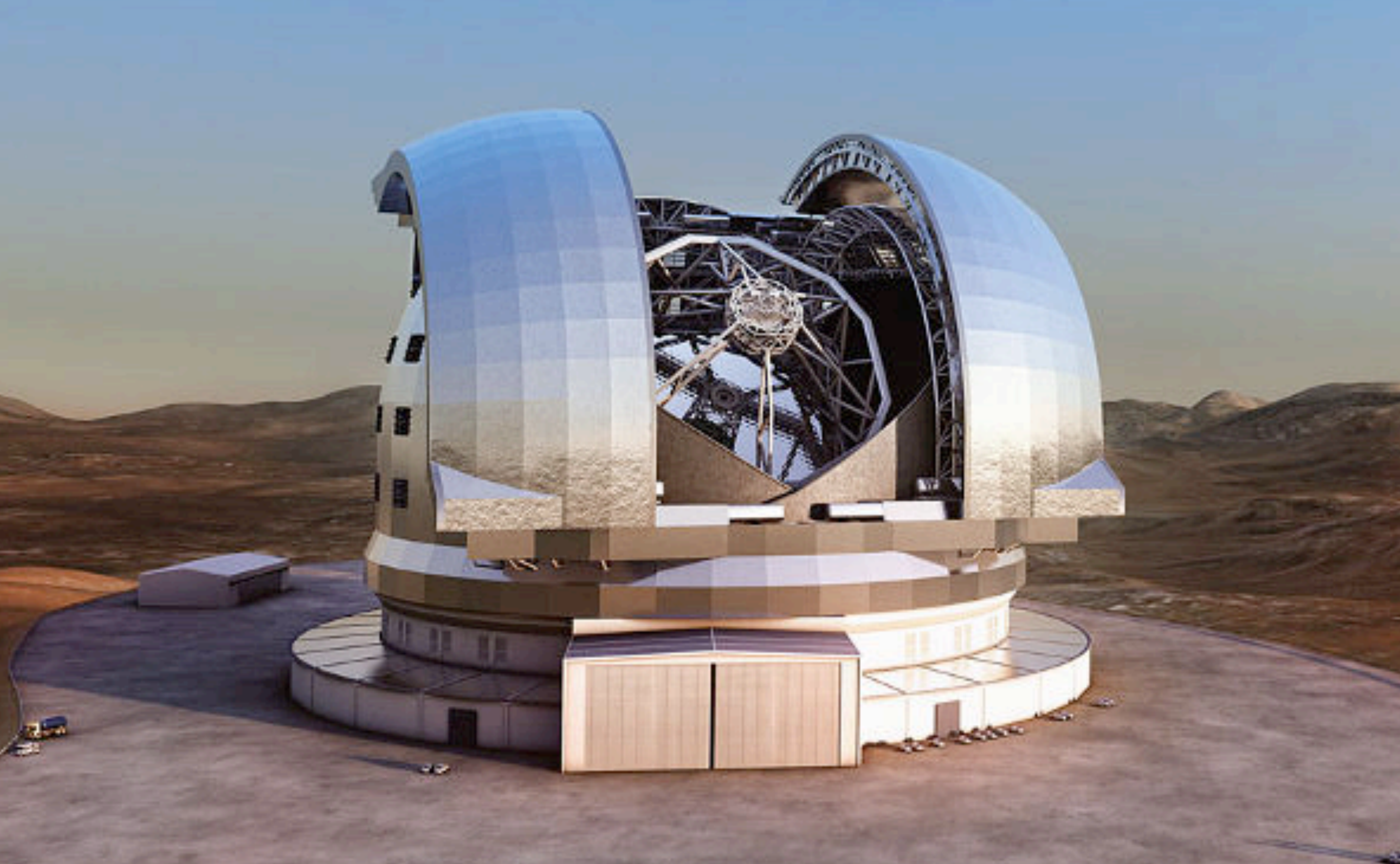


$$\mathrm{N}_\nu = 3.0 \pm 0.6$$



Pettini & Cooke 2012

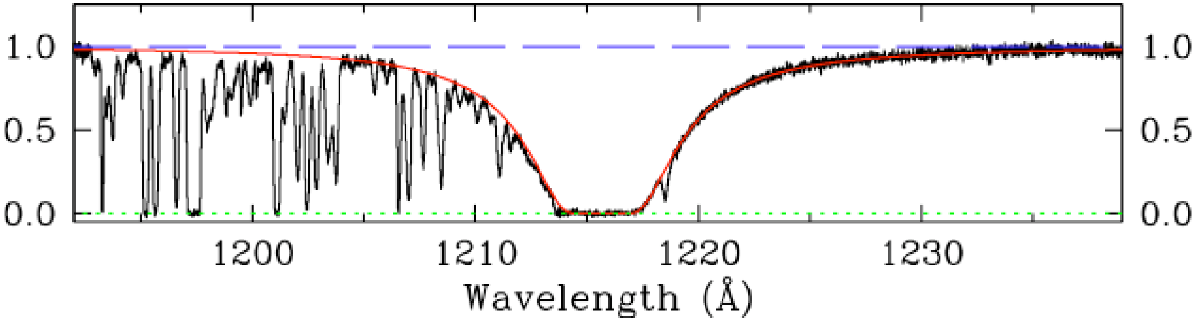
Why the E-ELT?



Oldest stars

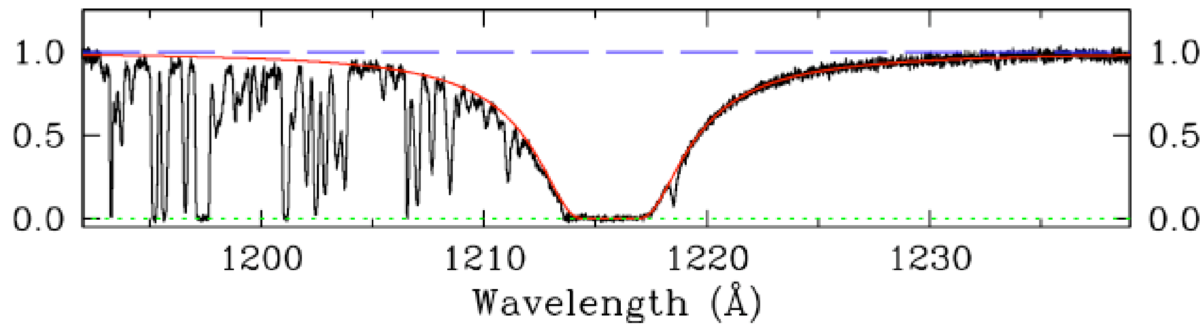
Oldest stars

Metal-poor DLAs

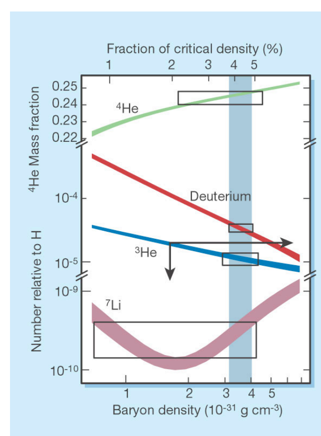


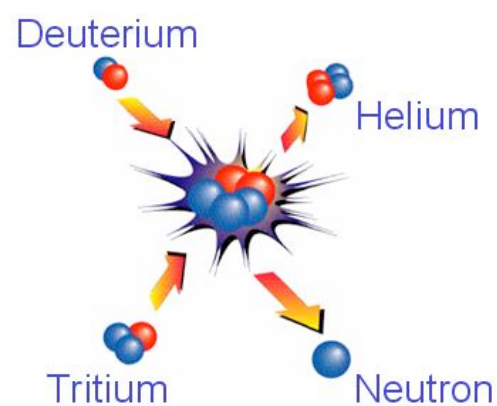
Oldest stars

Metal-poor DLAs



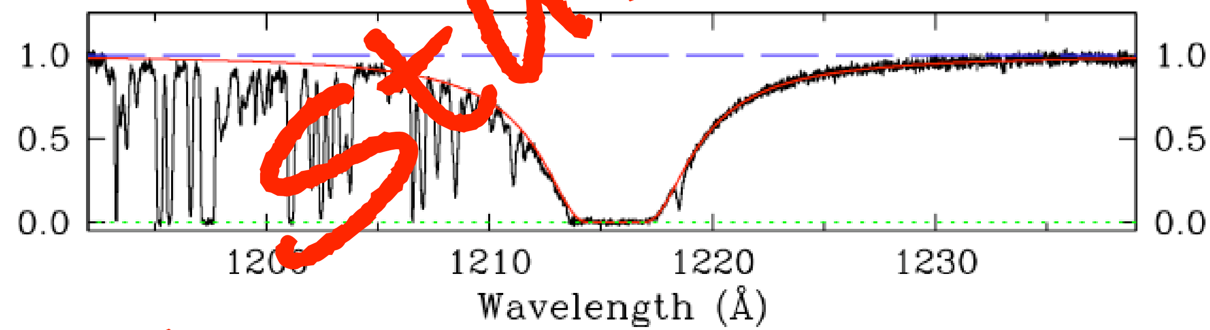
Light Elements



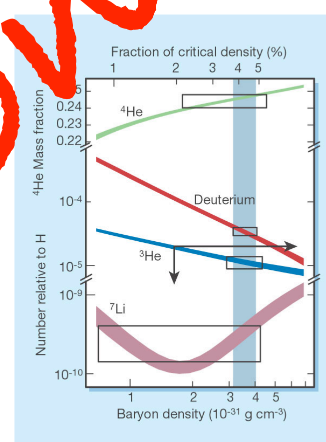


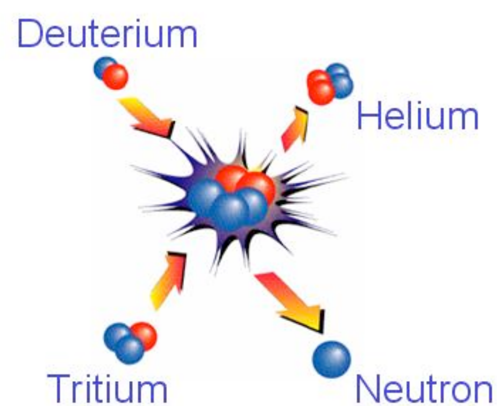
Oldest stars

Metal-poor DLAs

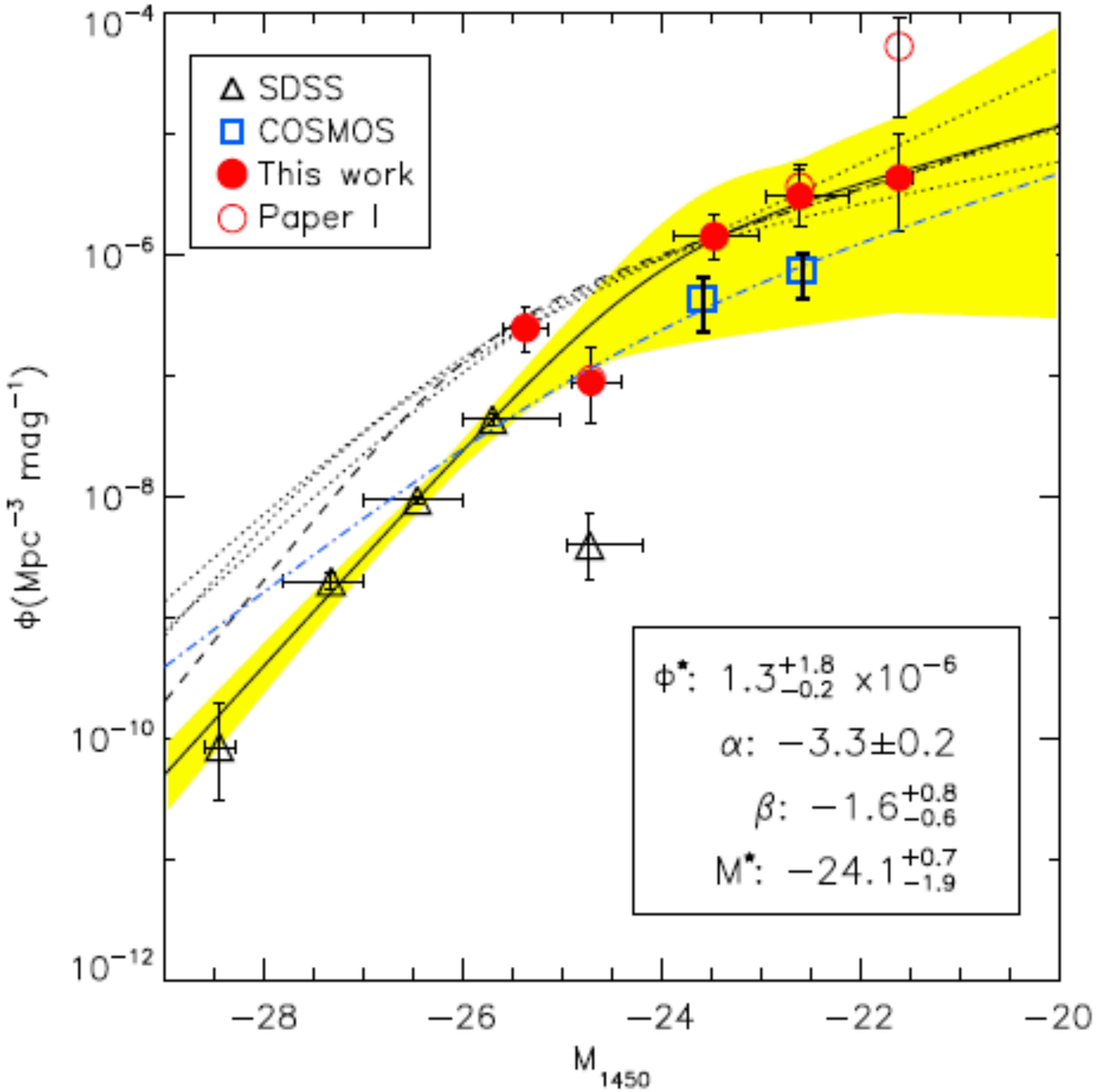


Light Elements



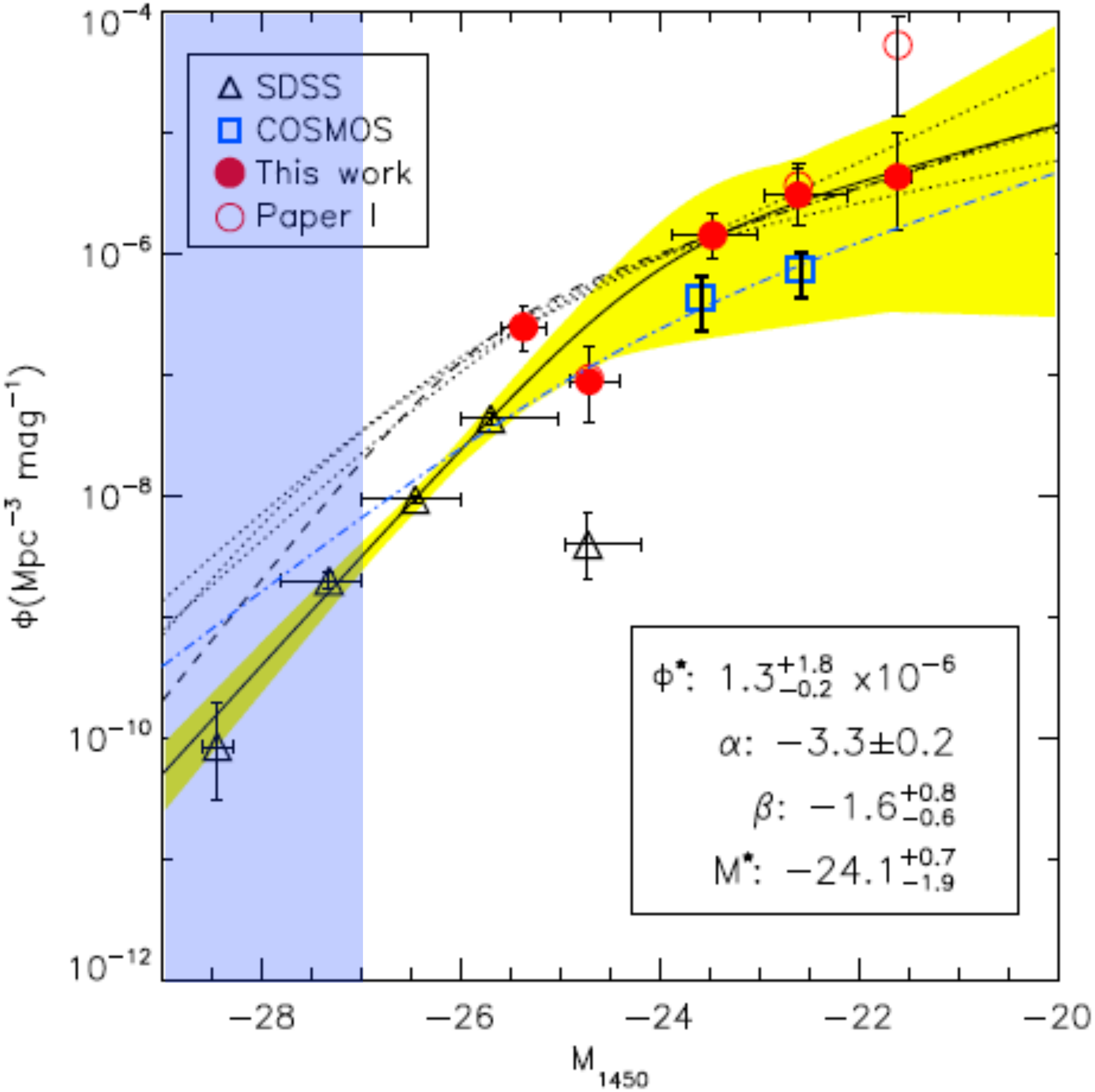


Photon Starved

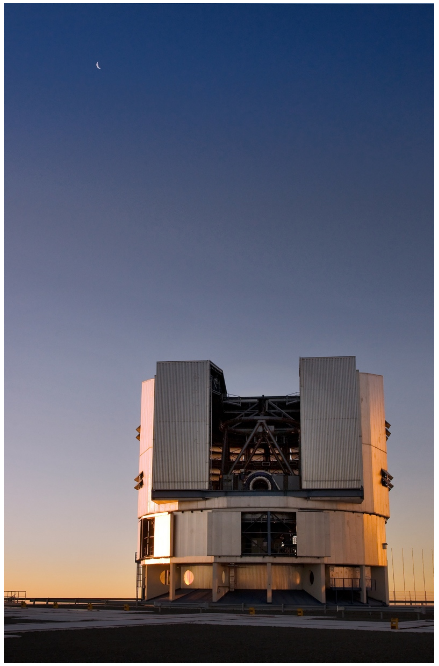


QSO Luminosity Function

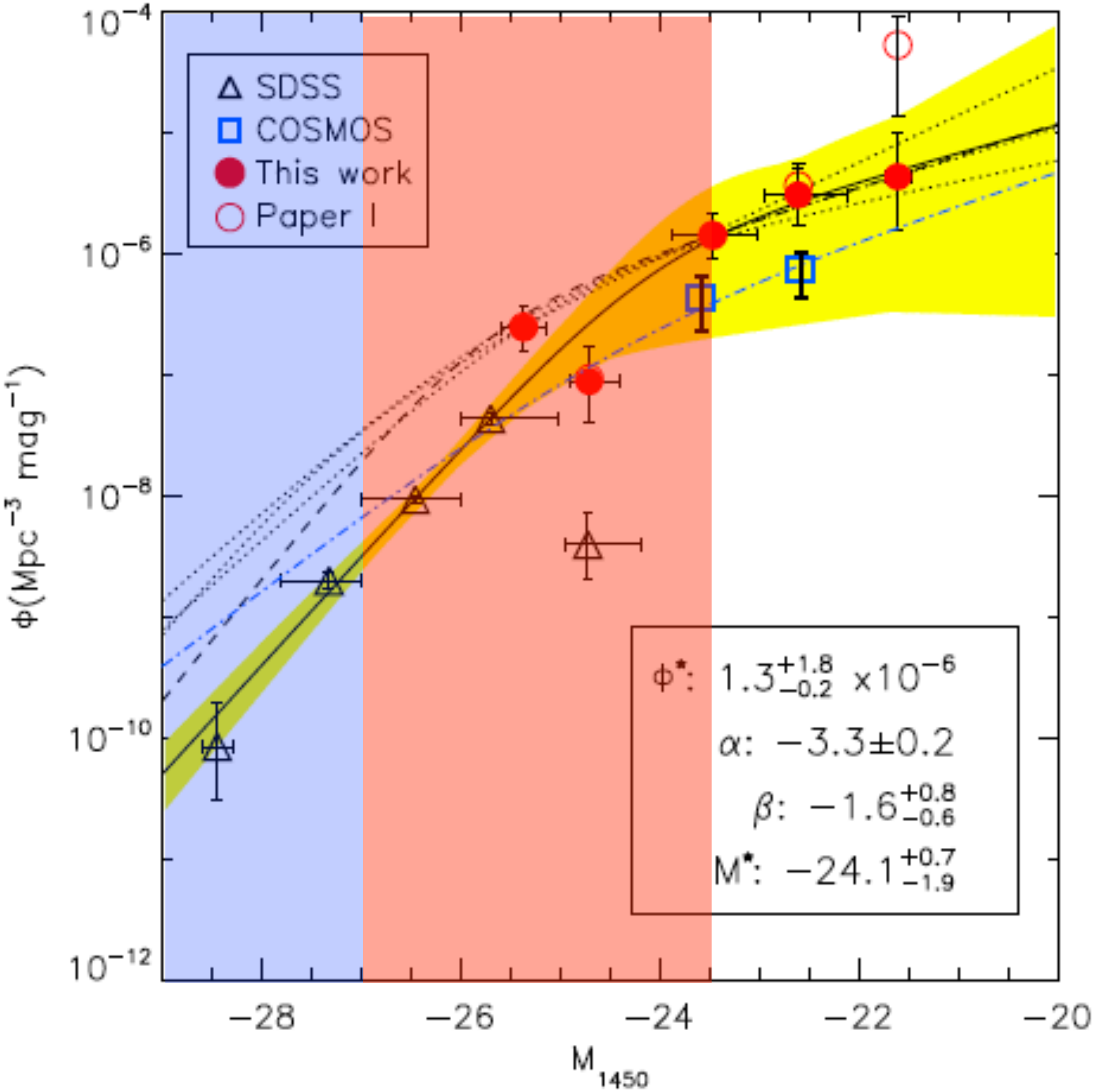
Glikman et al. 2011



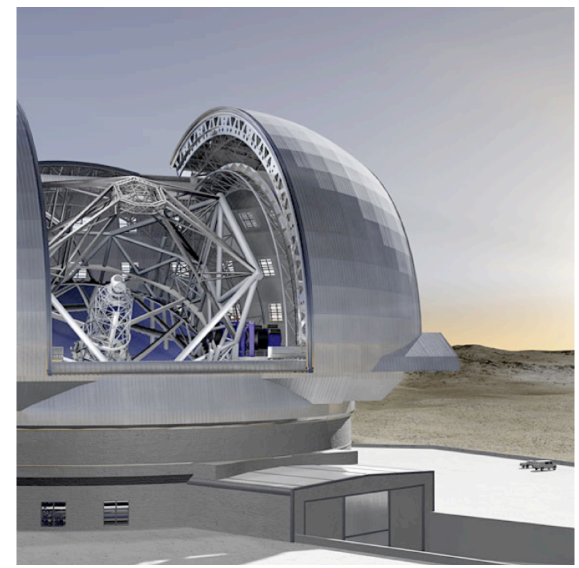
QSO Luminosity Function



Glikman et al. 2011

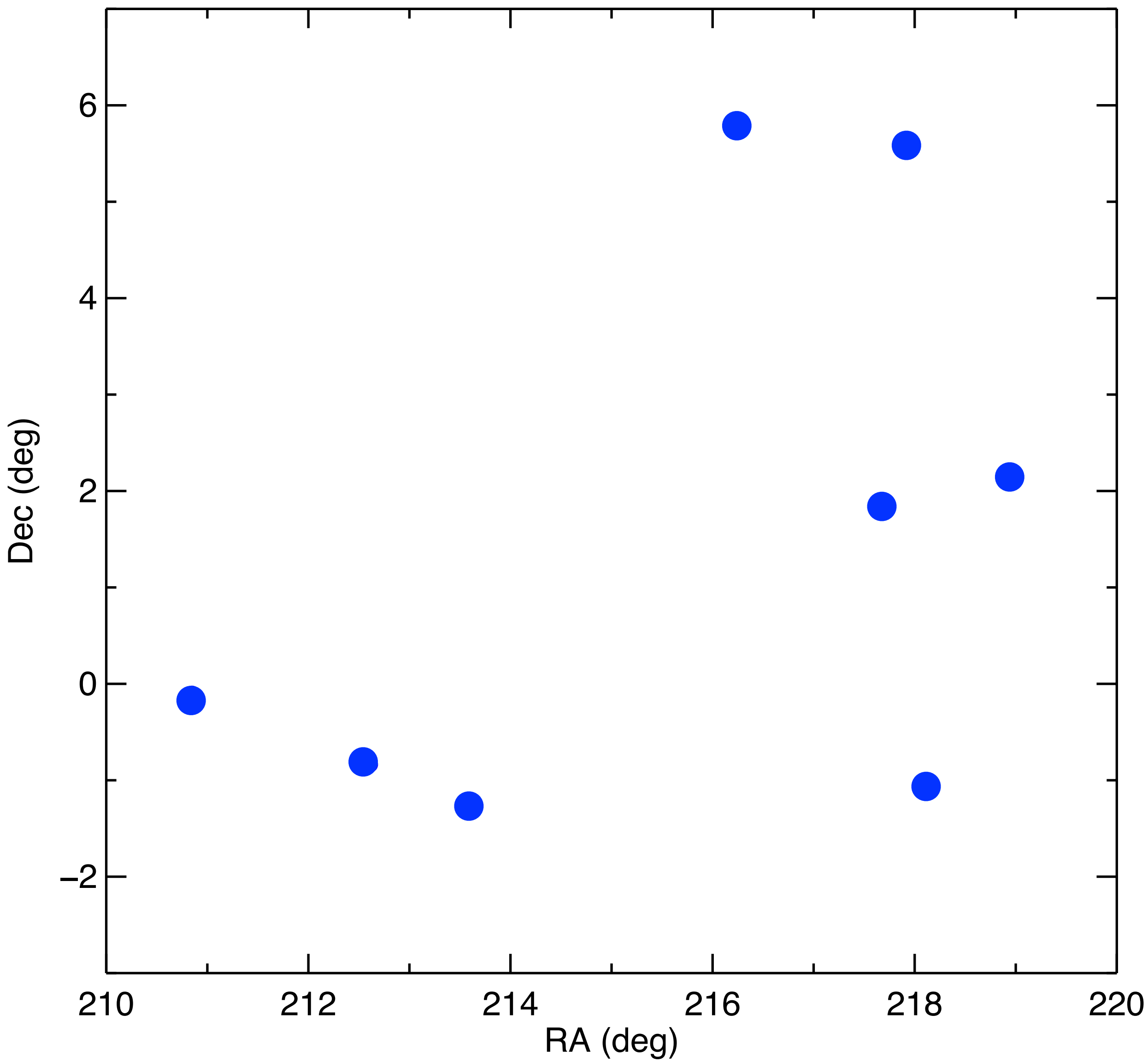


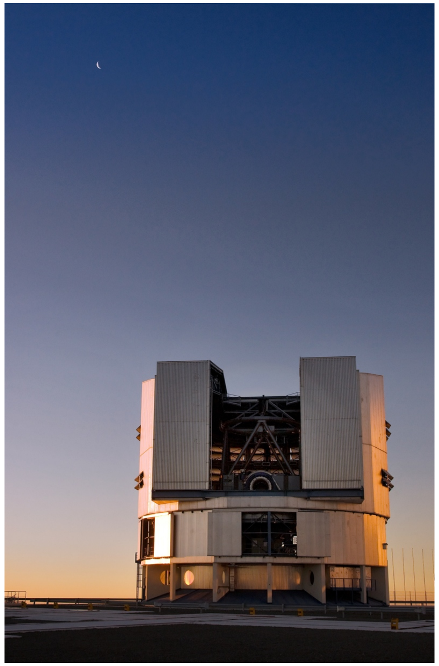
QSO Luminosity Function



Glikman et al. 2011

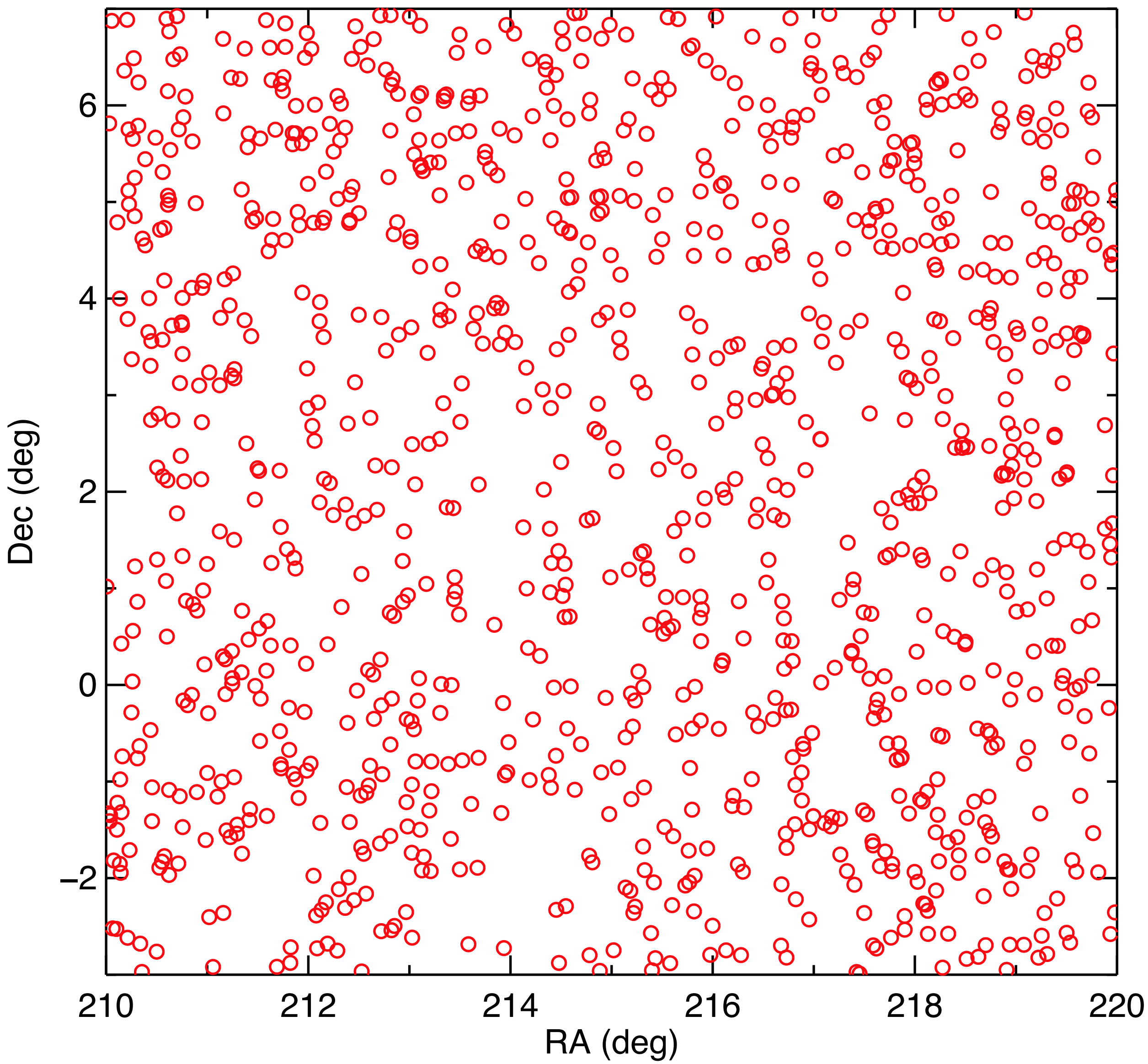
8 SDSS QSOs with $z \geq 2, r \leq 18$

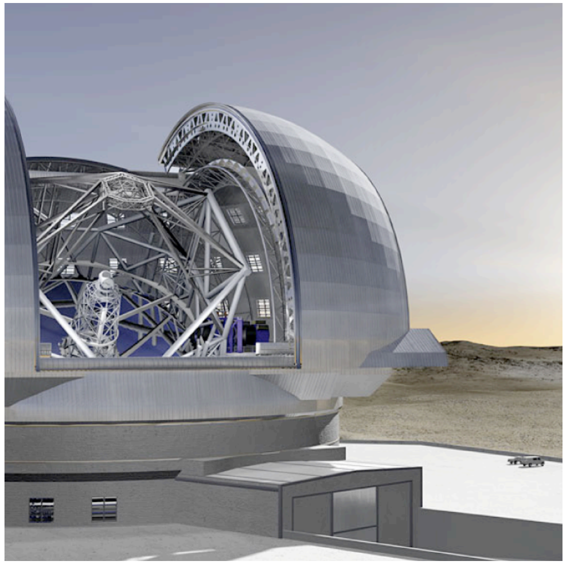




(courtesy of G. Becker)

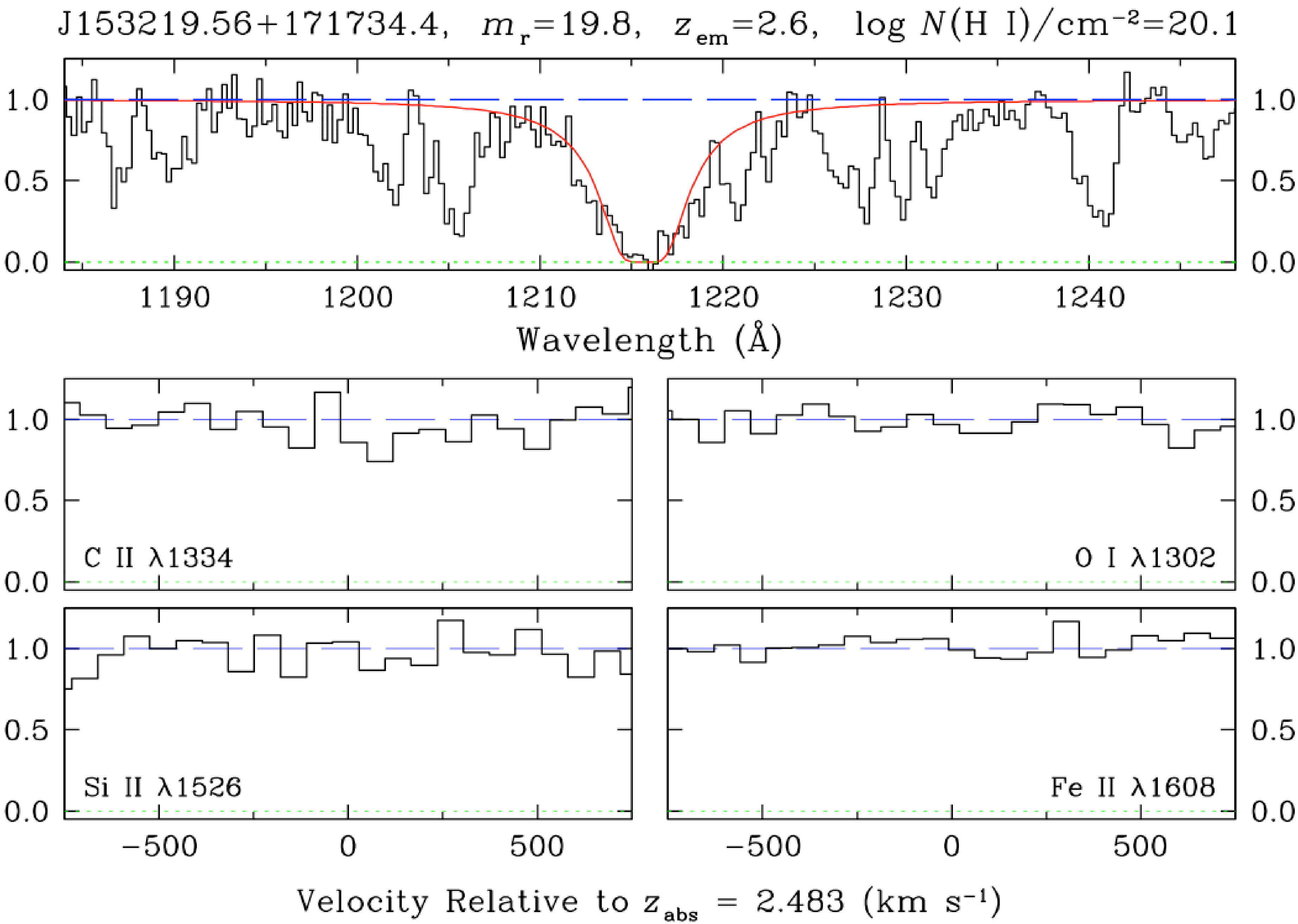
~ 1000 SDSS QSOs with $z \geq 2, r \leq 21$





(courtesy of G. Becker)

Here's an example:



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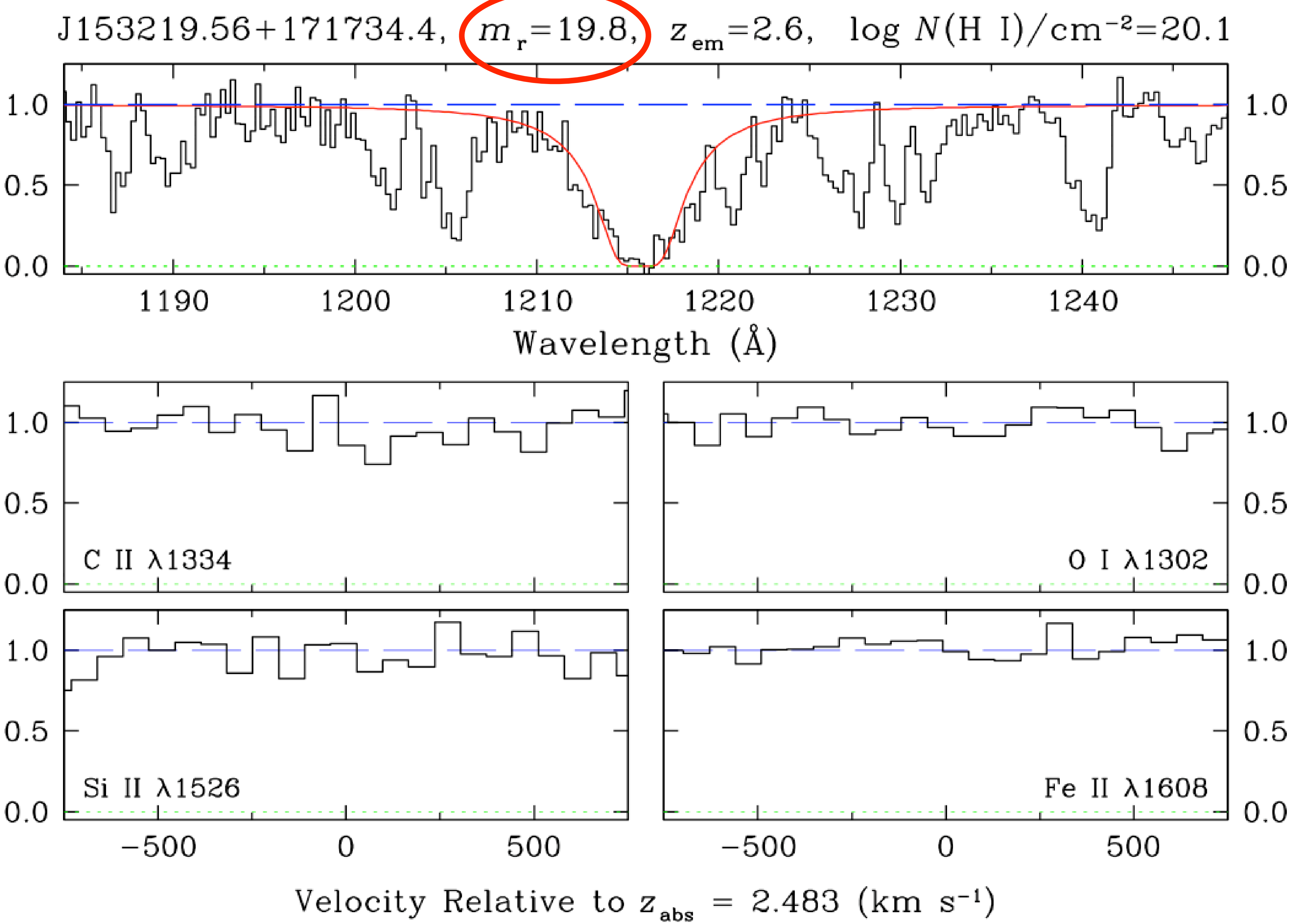
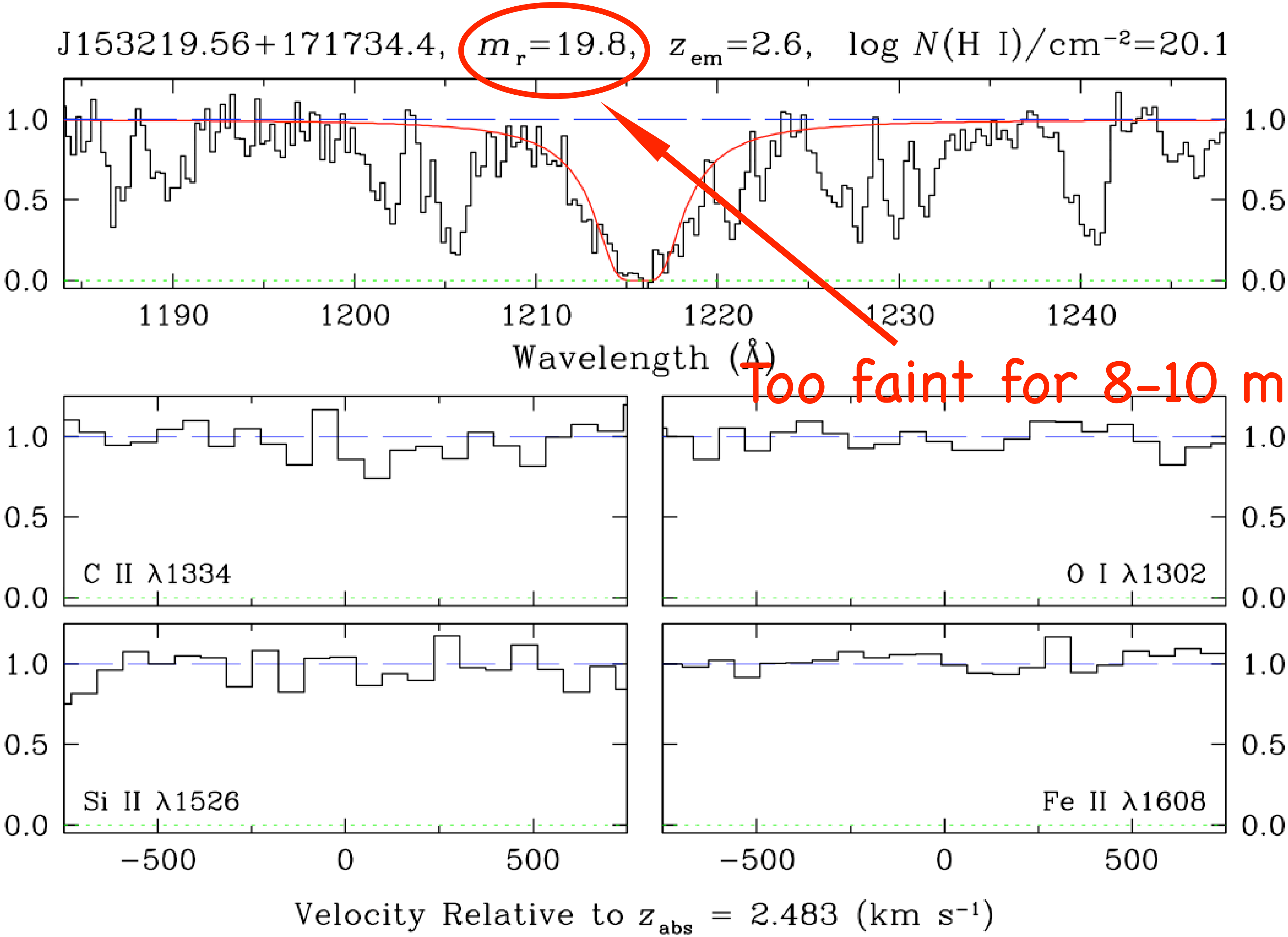


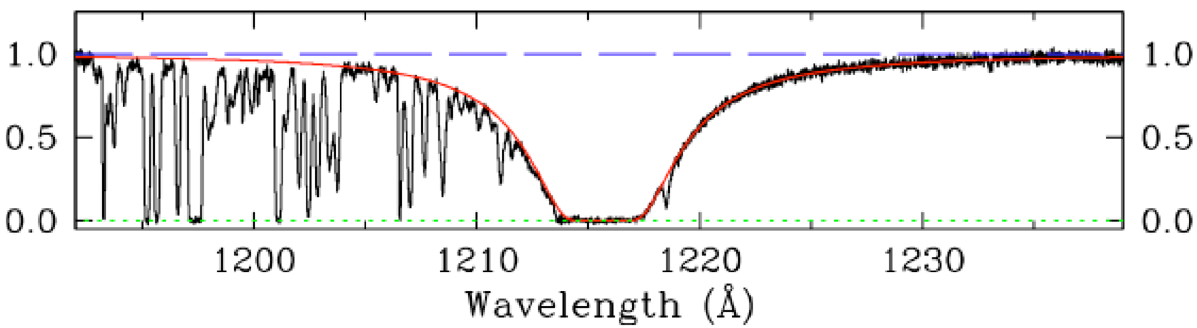
Here's an example:



Too faint for 8-10 m !

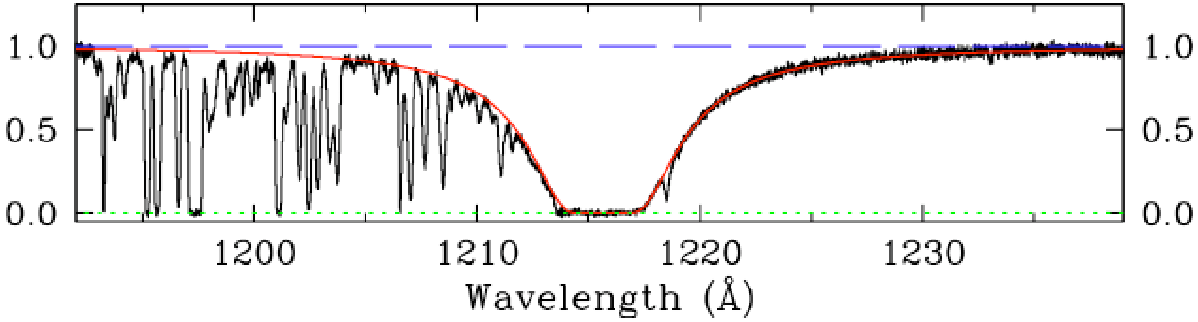
Full Chemical Fingerprints
in MW Stars with [Fe/H] < -5

Full Chemical Fingerprints in MW Stars with [Fe/H] < -5

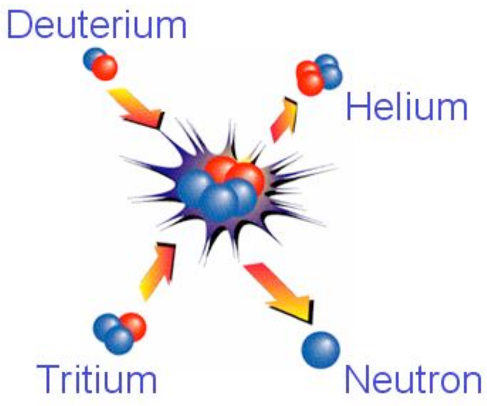


Fe-peak element ratios at [Fe/H] < -3

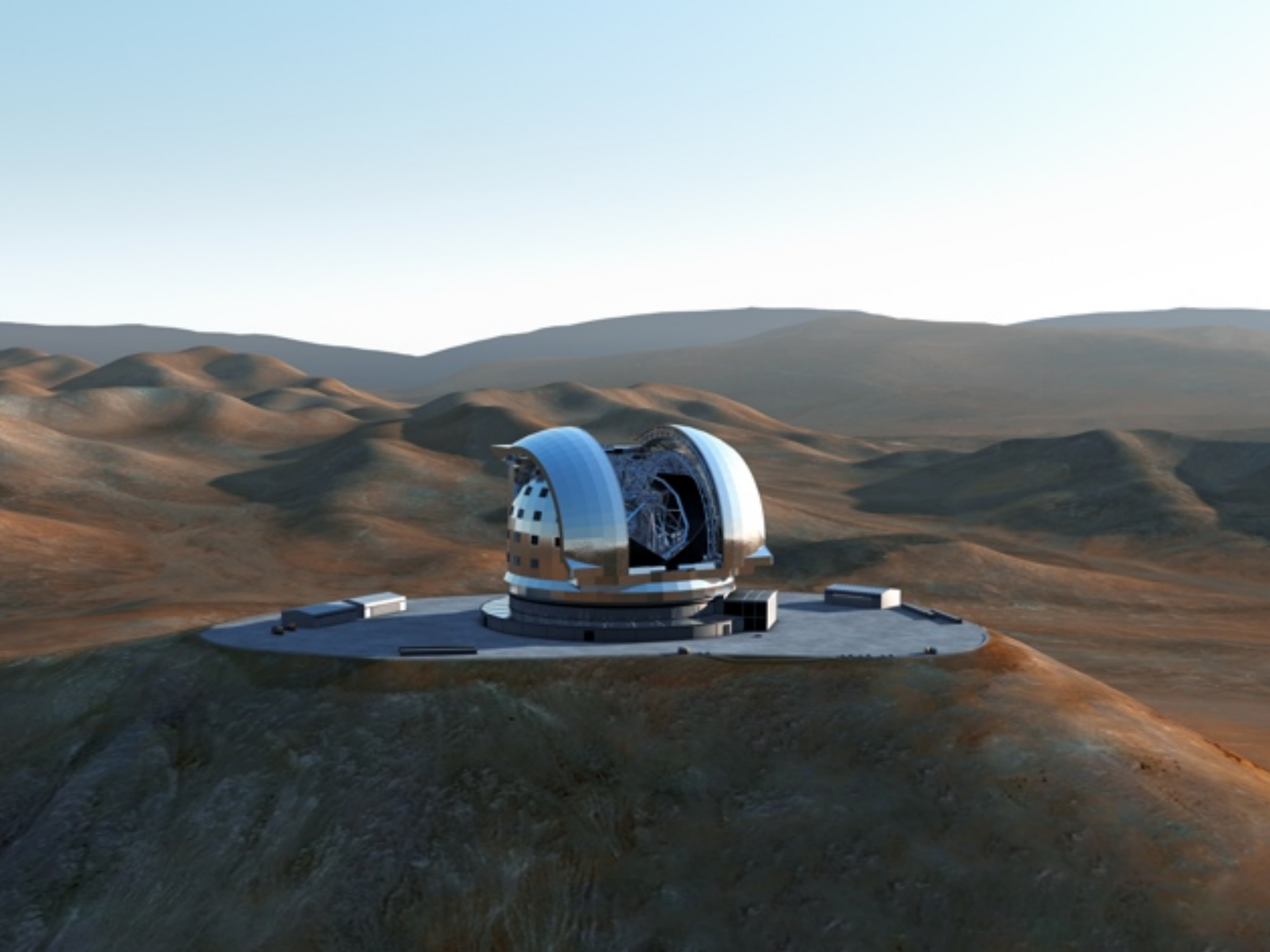
Full Chemical Fingerprints in MW Stars with [Fe/H] < -5



Fe-peak element ratios at [Fe/H] < -3



Significantly more precise measures of $\Omega_{\rm b}({\rm BBN})$




The Future