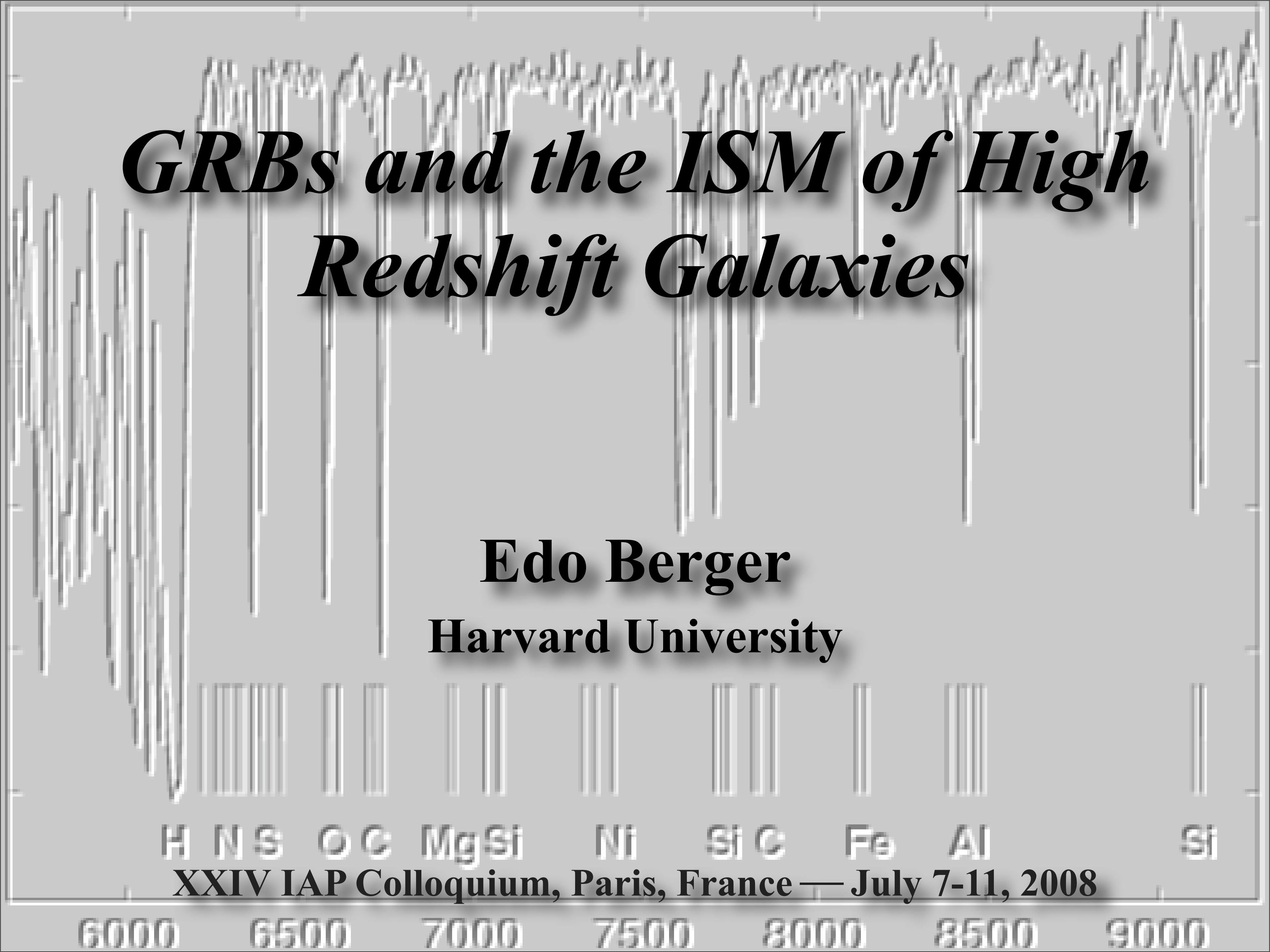
GRBs and the ISM of High Redshift Galaxies

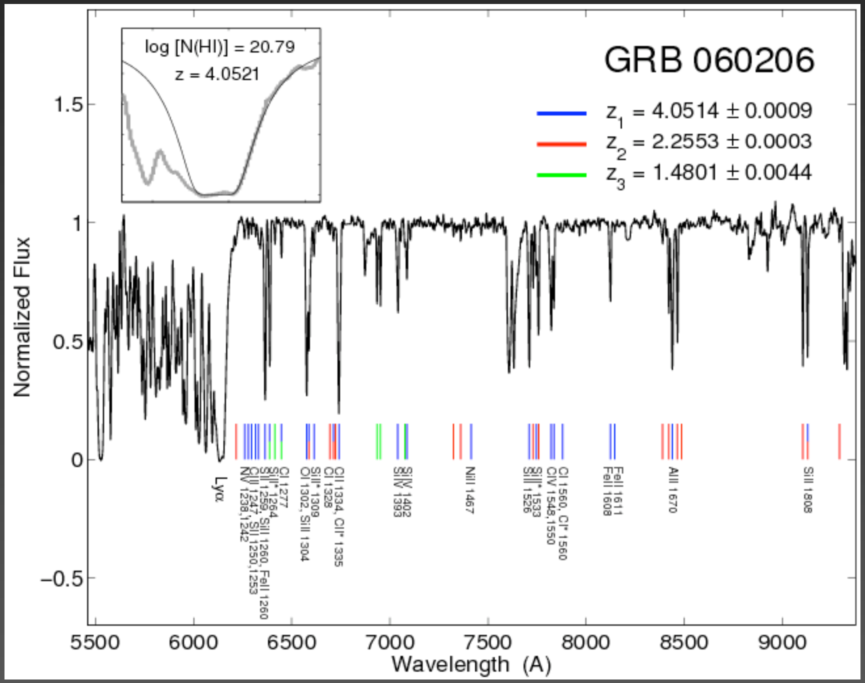
Edo Berger

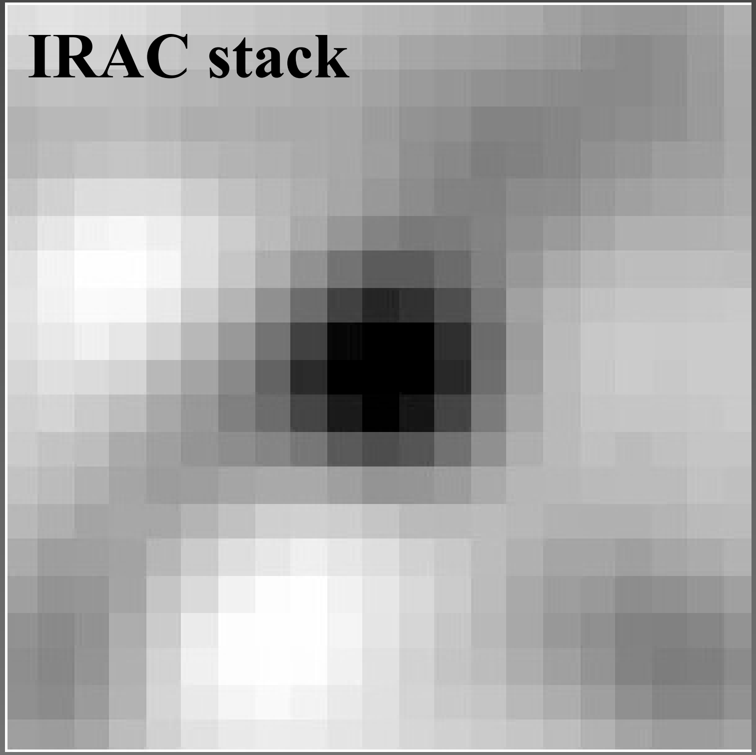
Harvard University



XXIV IAP Colloquium, Paris, France — July 7-11, 2008

1. *The ISM of High Redshift Galaxies*

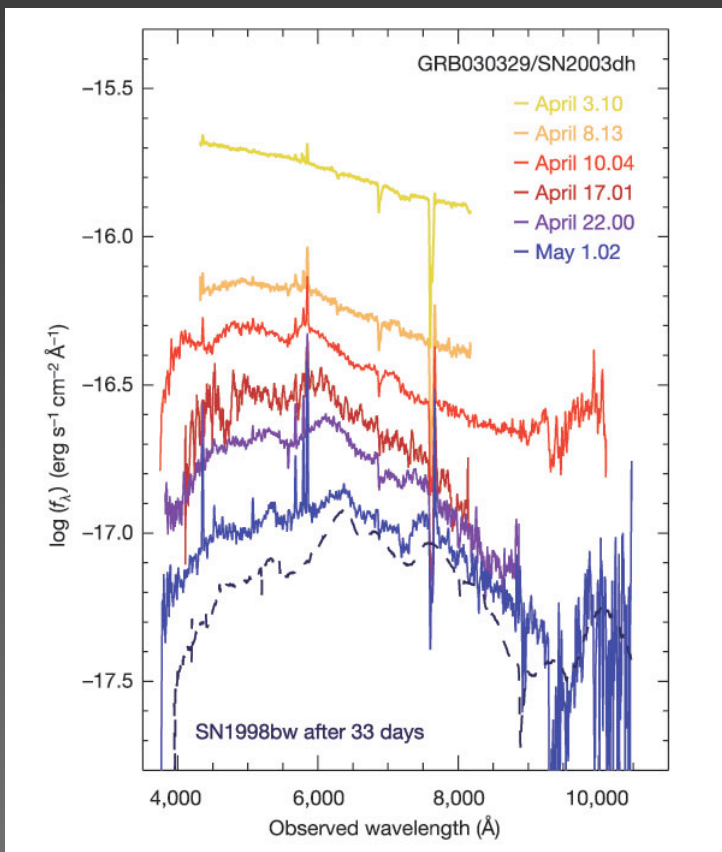




2. *DLA Counterparts & the Mass-Metallicity Relation at z > 2*

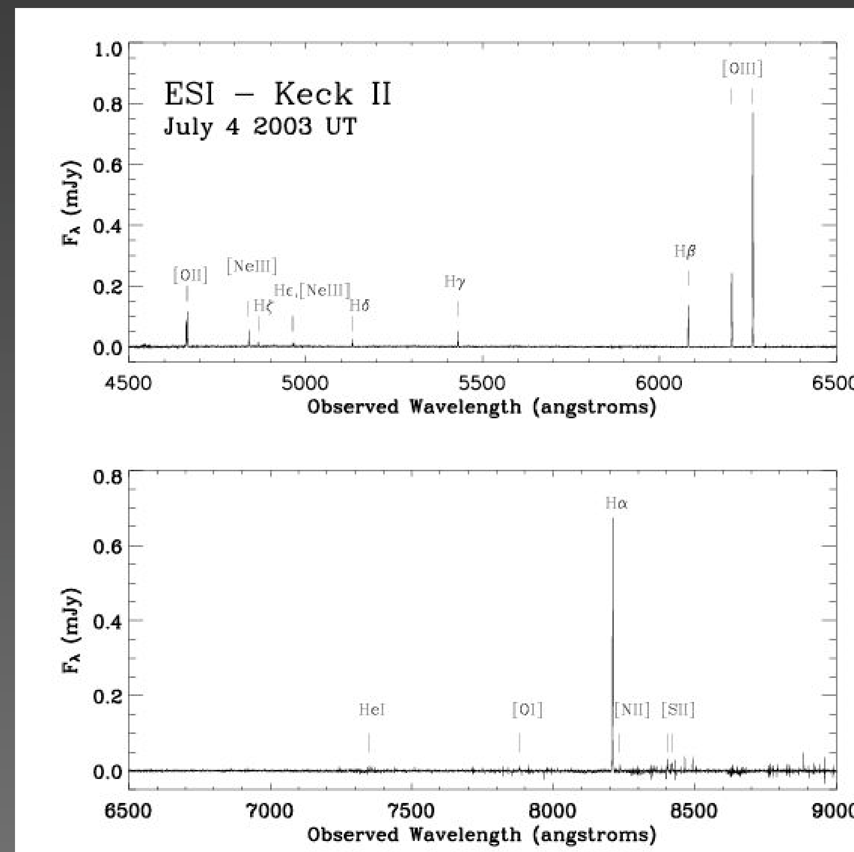
Long GRBs = The Death of Massive Stars

Association with type Ic core-collapse supernovae



Mathson et al. 2003; Hjorth et al. 2003

Location in star-forming galaxies



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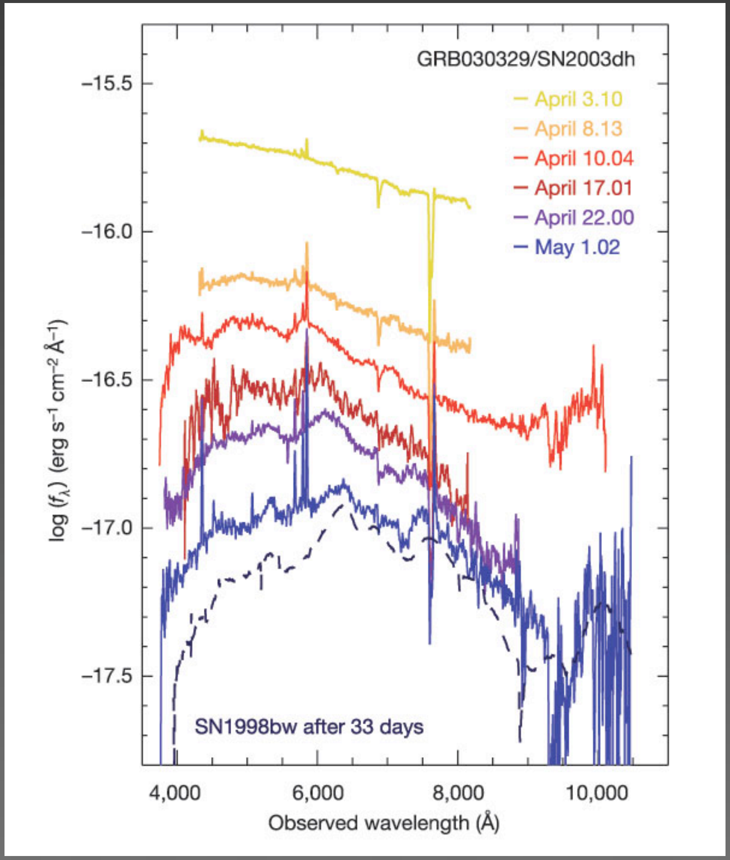

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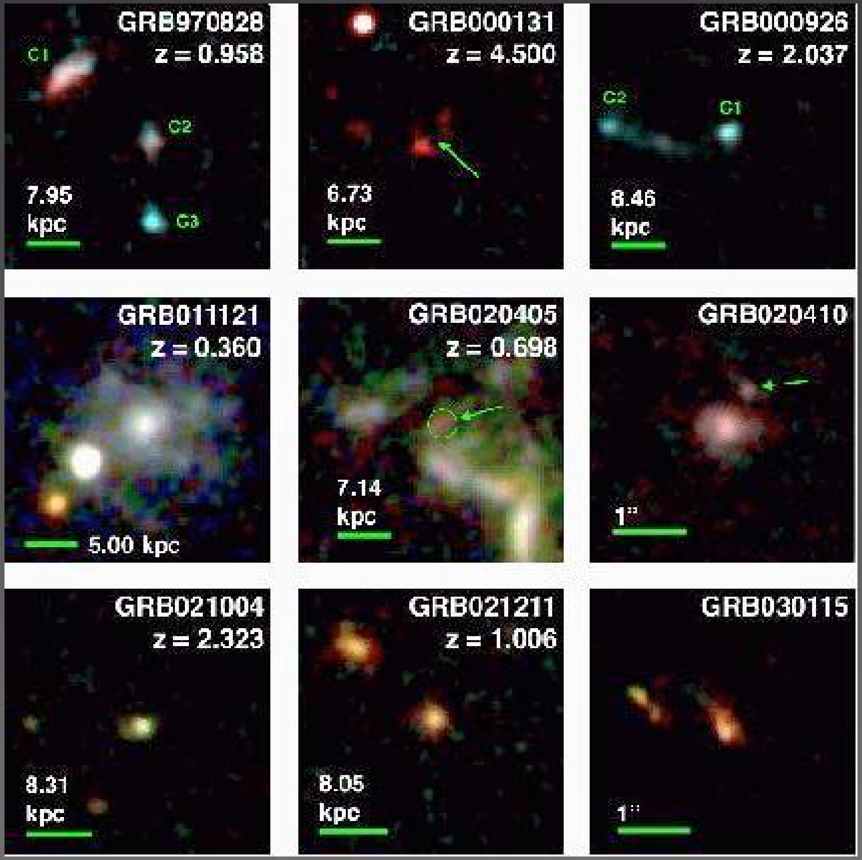
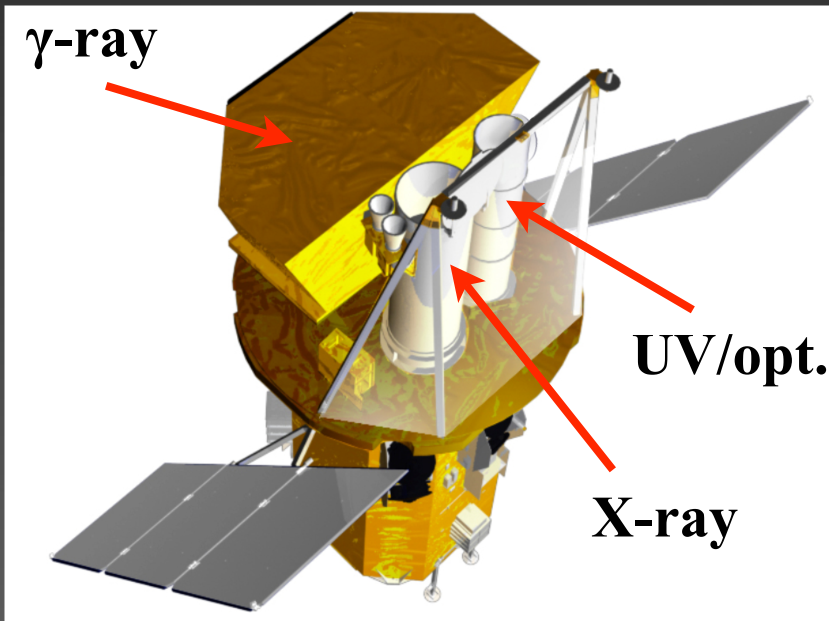
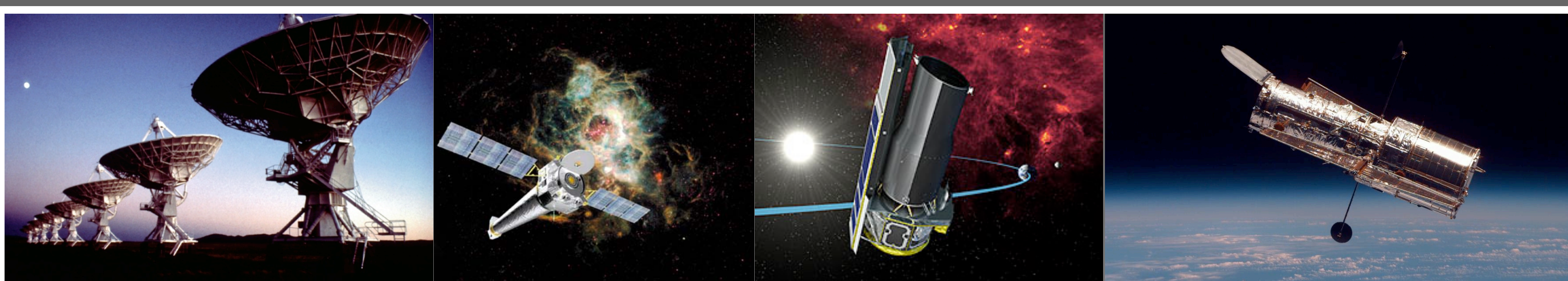


Wainwright, Berger & Penprase 2007

GRB Detection and Follow-up



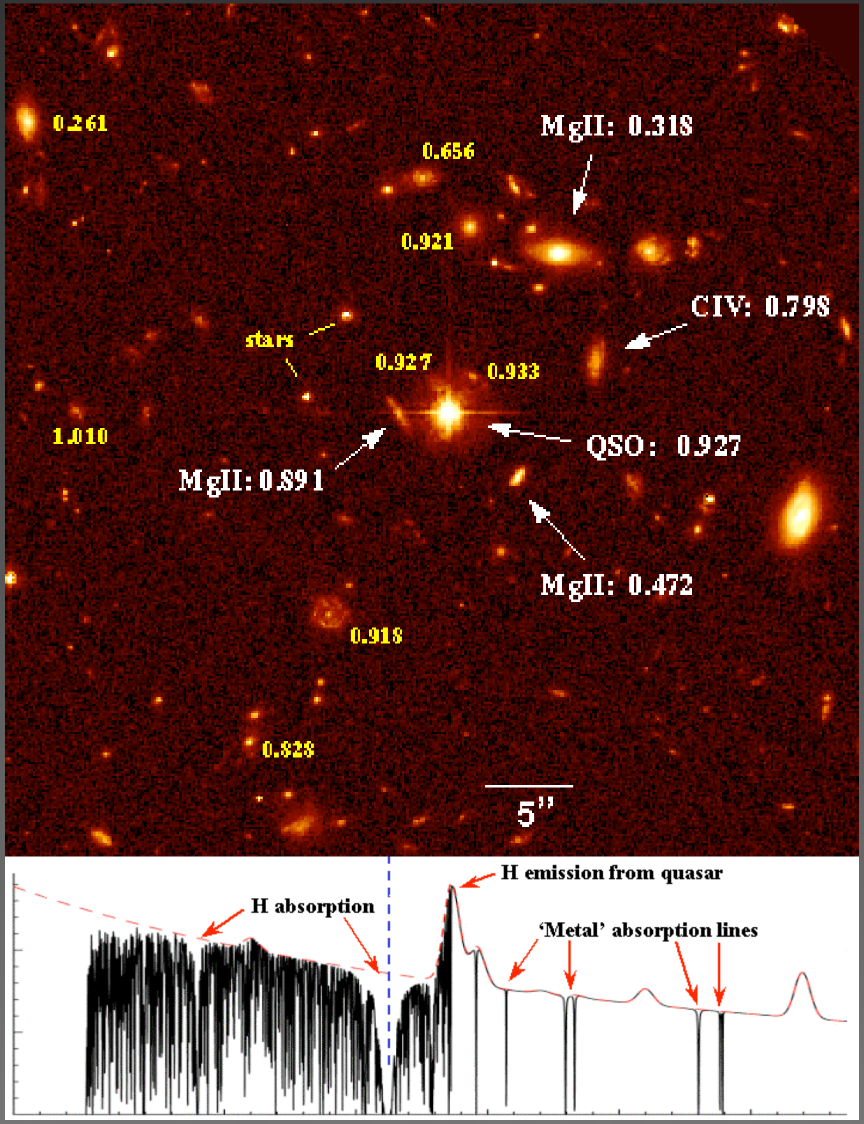
~100 GRBs/yr with arcsec positions



GRB Absorption Spectroscopy

<u>Comparison to quasars:</u>

- No Mpc proximity effect
- Small impact parameter
- In star forming regions
- Bright(er) [ind. of z]
- High(er) redshift
- Power law spectrum
- Fade away



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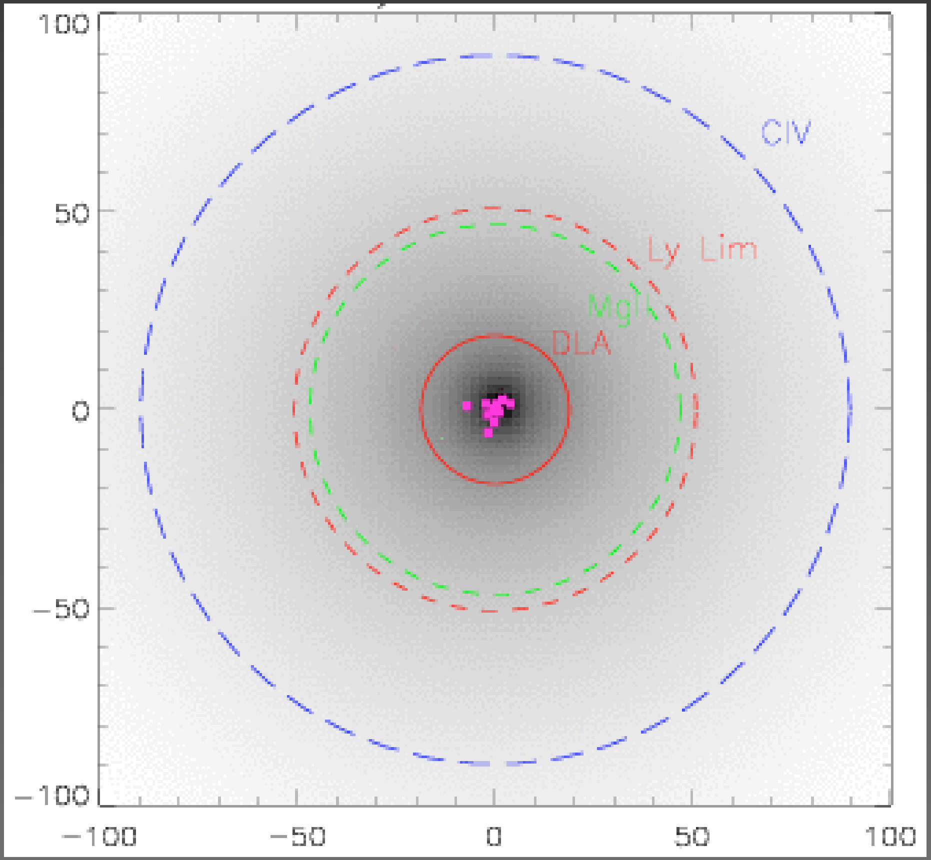
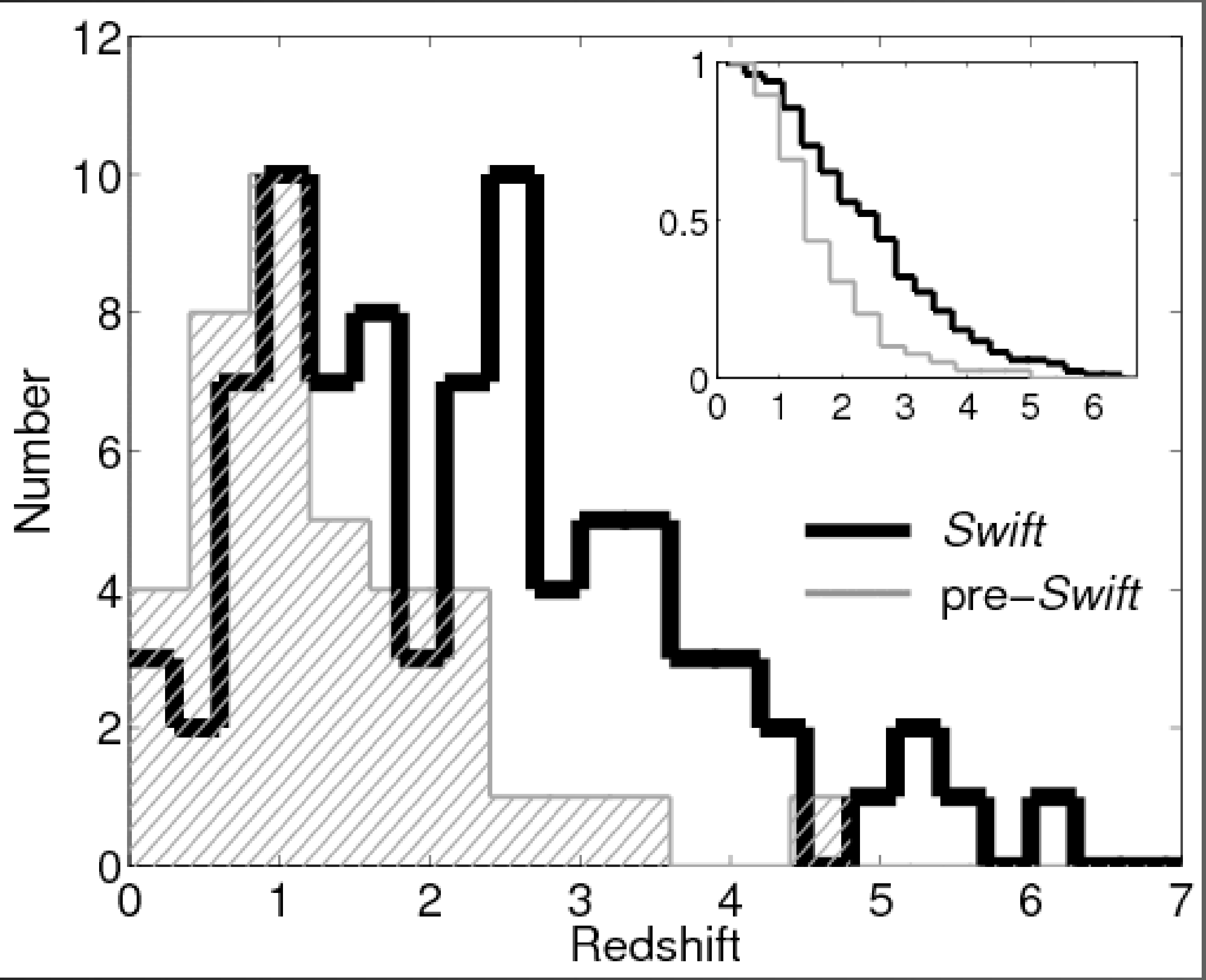


GRB Redshift Distribution



Berger et al. 2005; Jakobsson et al. 2006

Swift GRBs:

$z > 2.5$: 50%

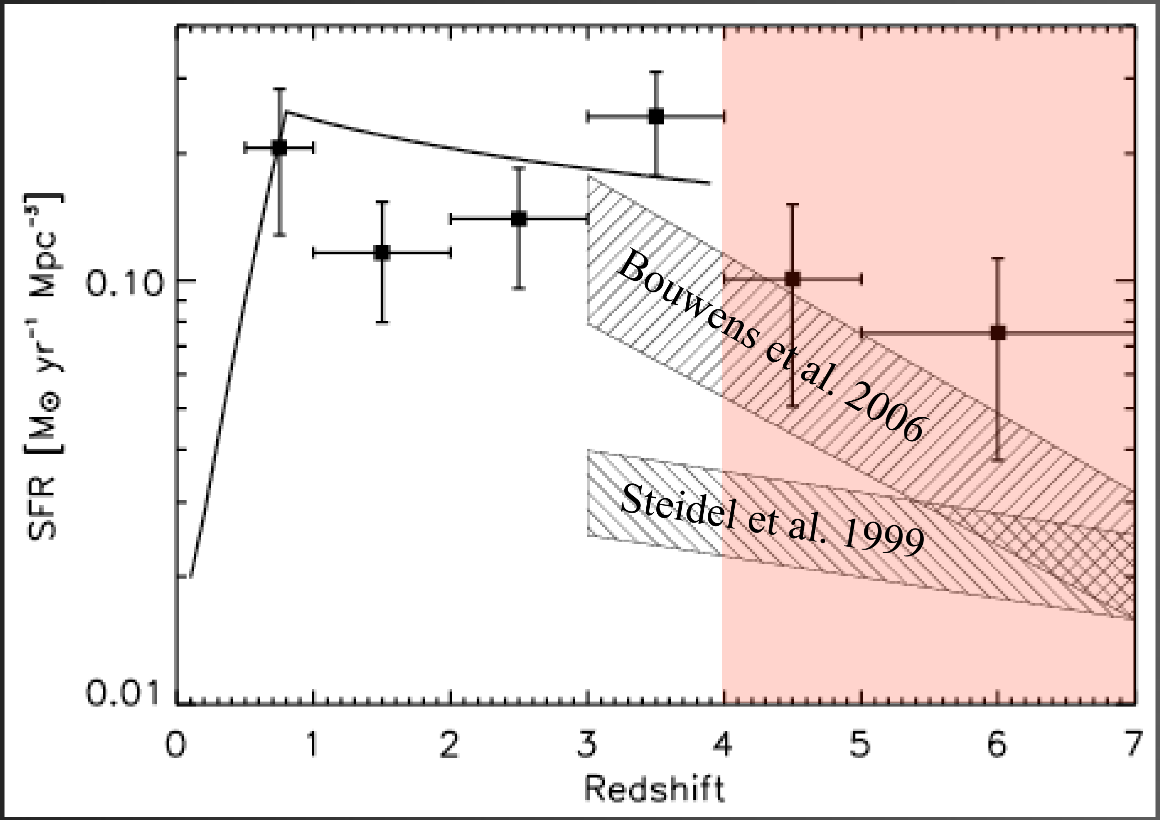
$z > 4$: 10%

$z > 5$: 5%

$z_{max} = 6.295$

GRB Redshift Distribution

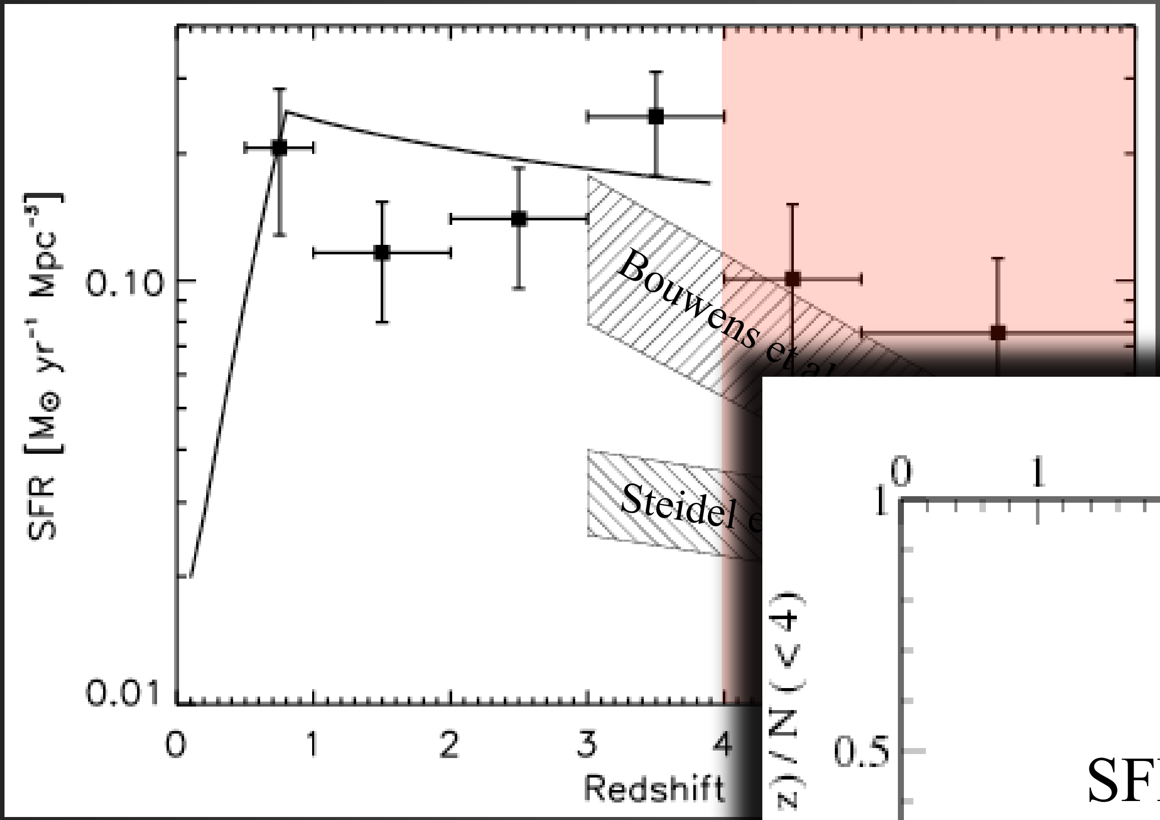
Chary, Berger, & Cowie 2007



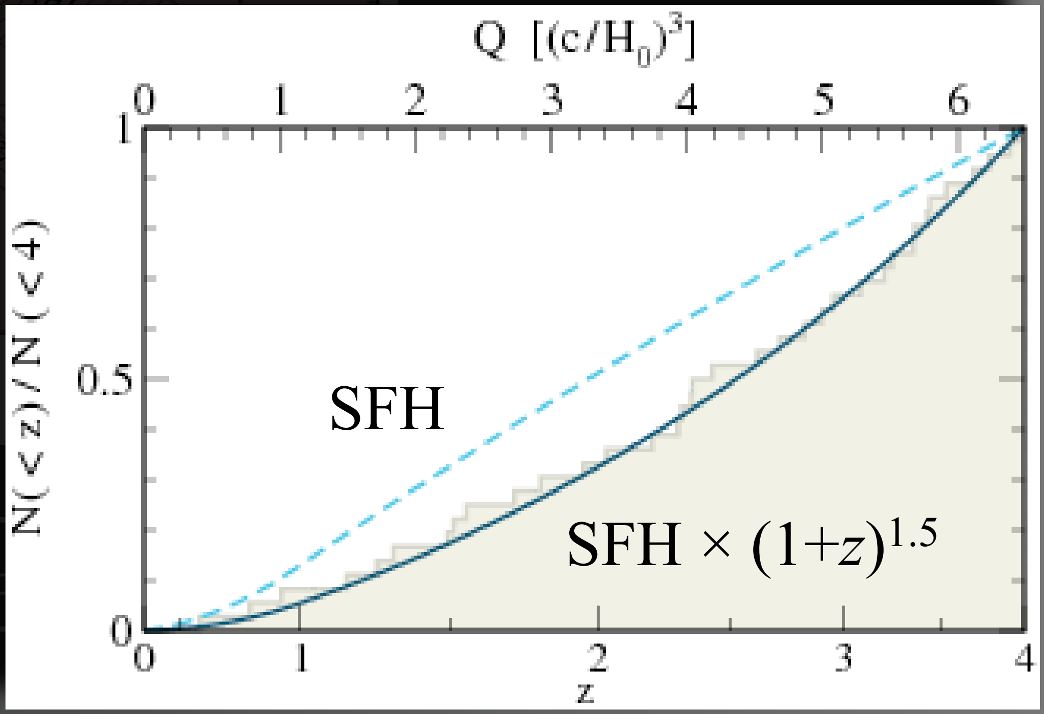
SFRD ~ GRB × (5±2)×10^9

GRB Redshift Distribution

Chary, Berger, & Cowie 2007

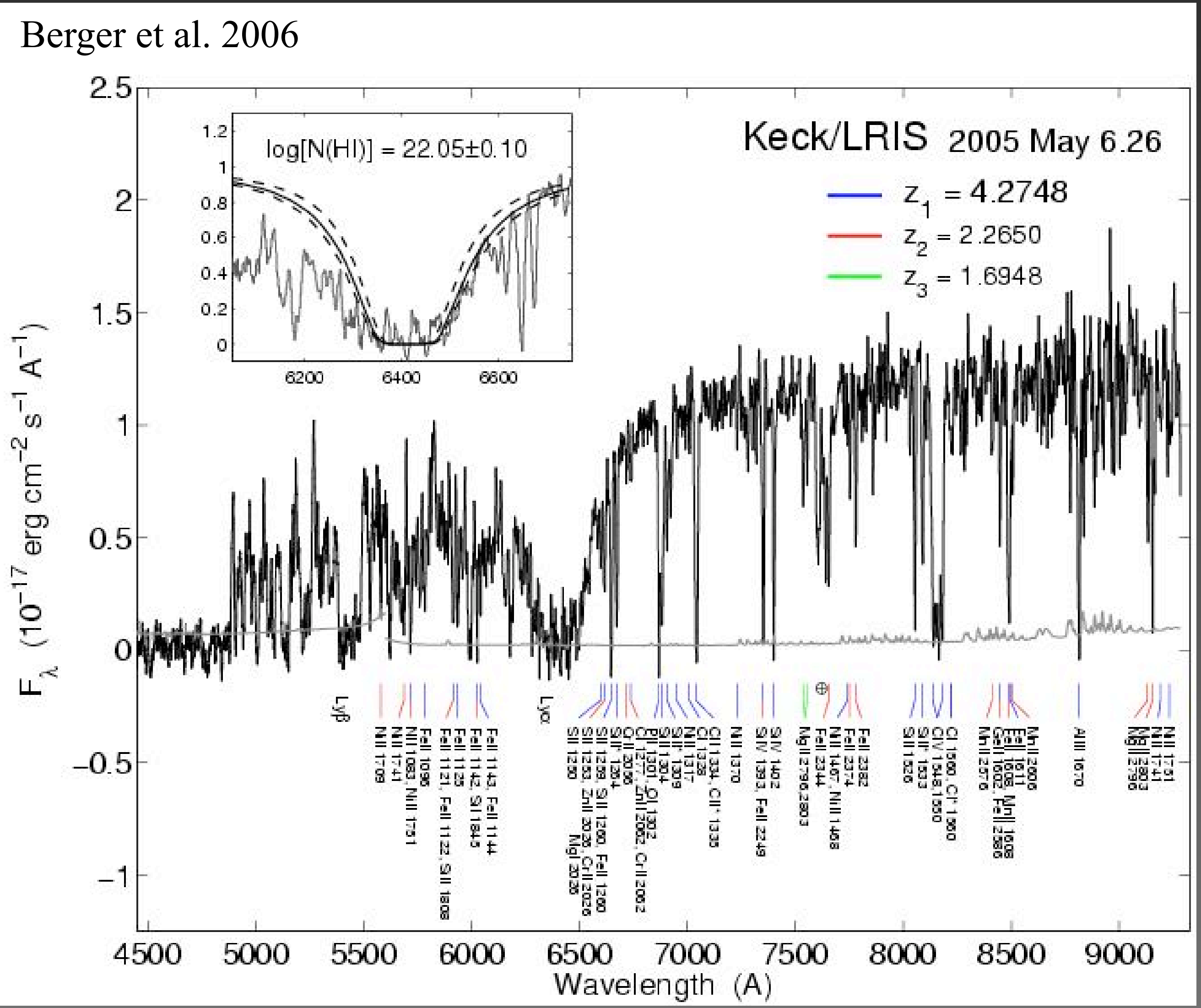


Kistler et al. 2008



SFRD ~ GRB × (5±

GRB Absorption Spectroscopy



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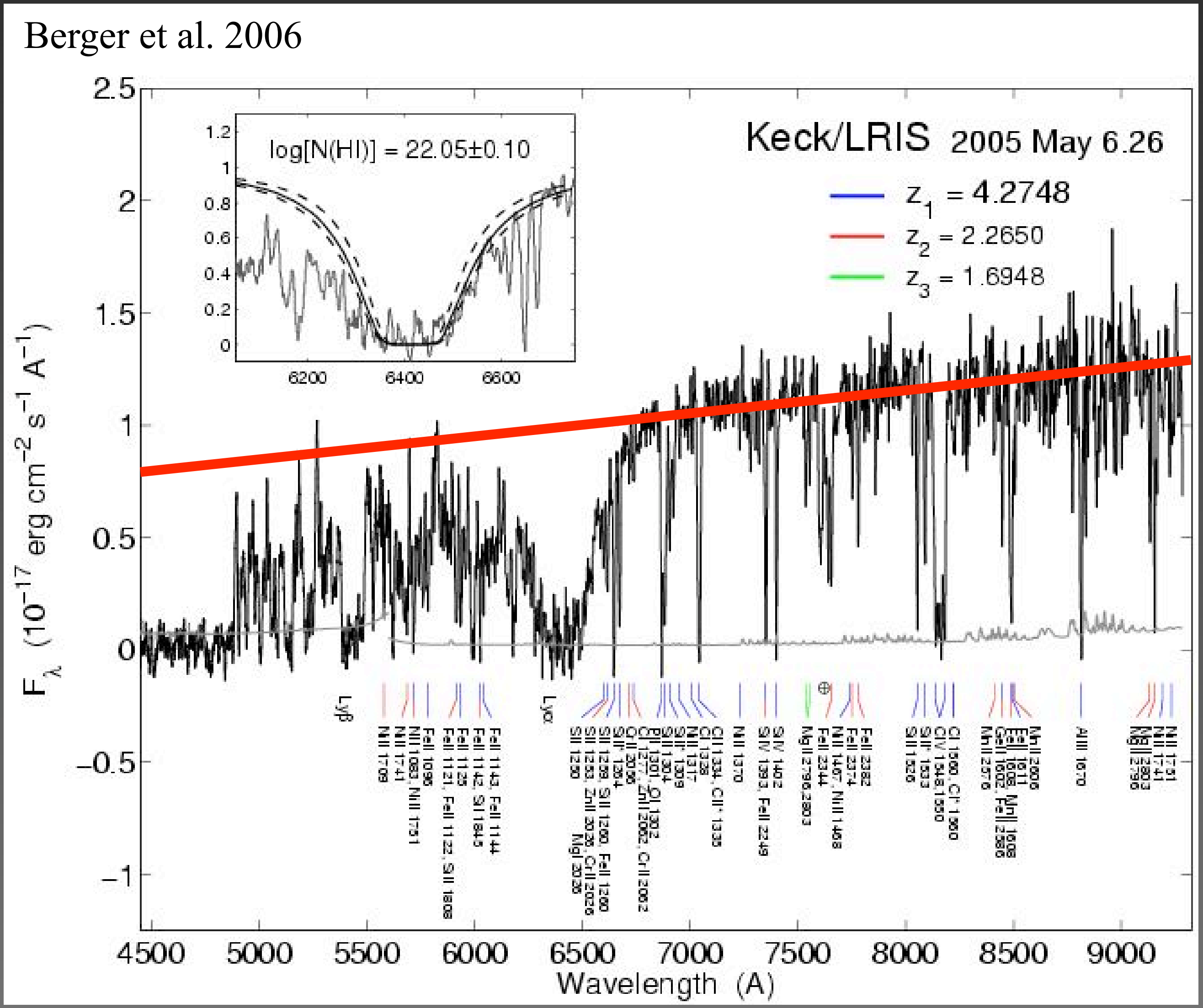
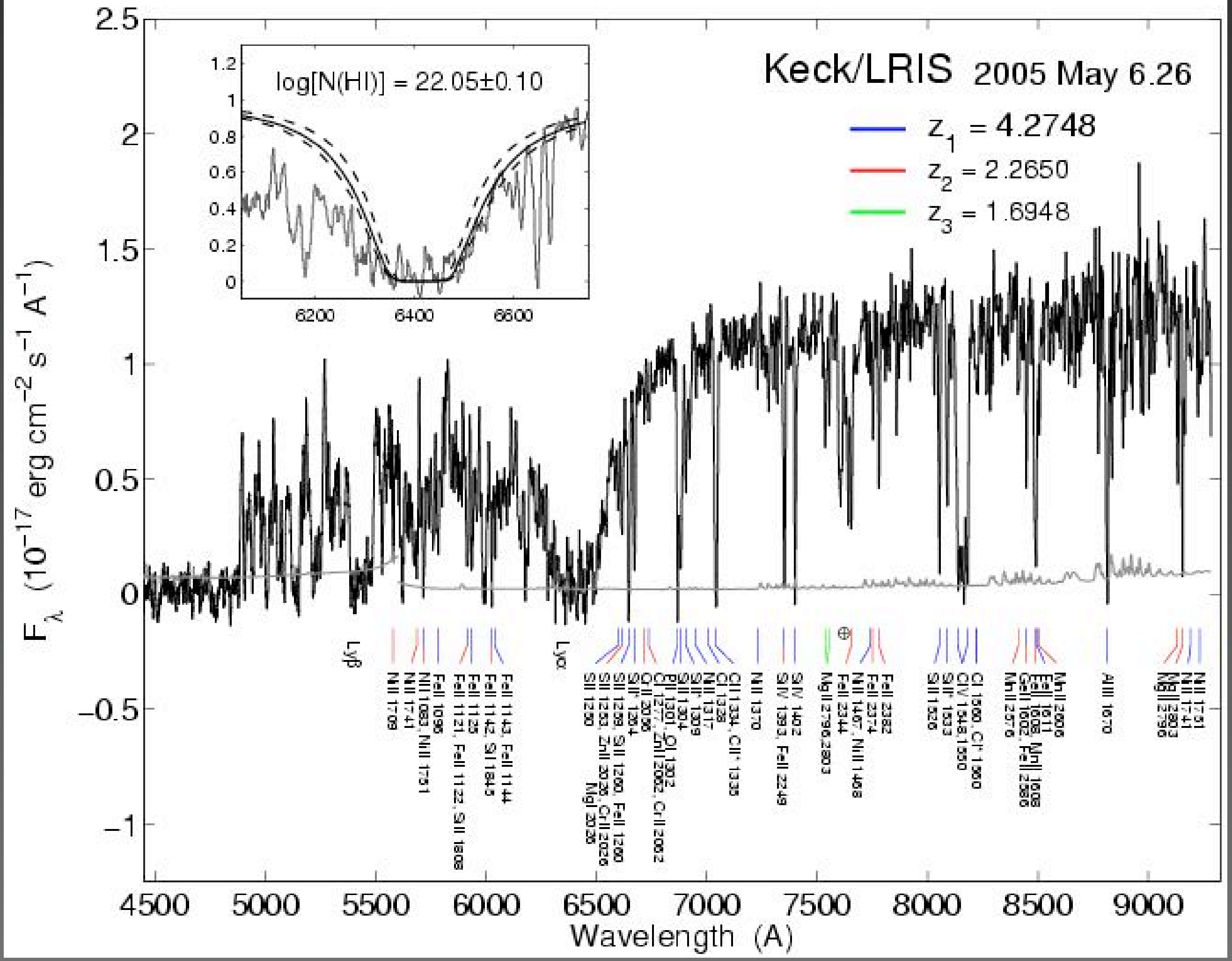


GRB Absorption Spectroscopy

Berger et al. 2006



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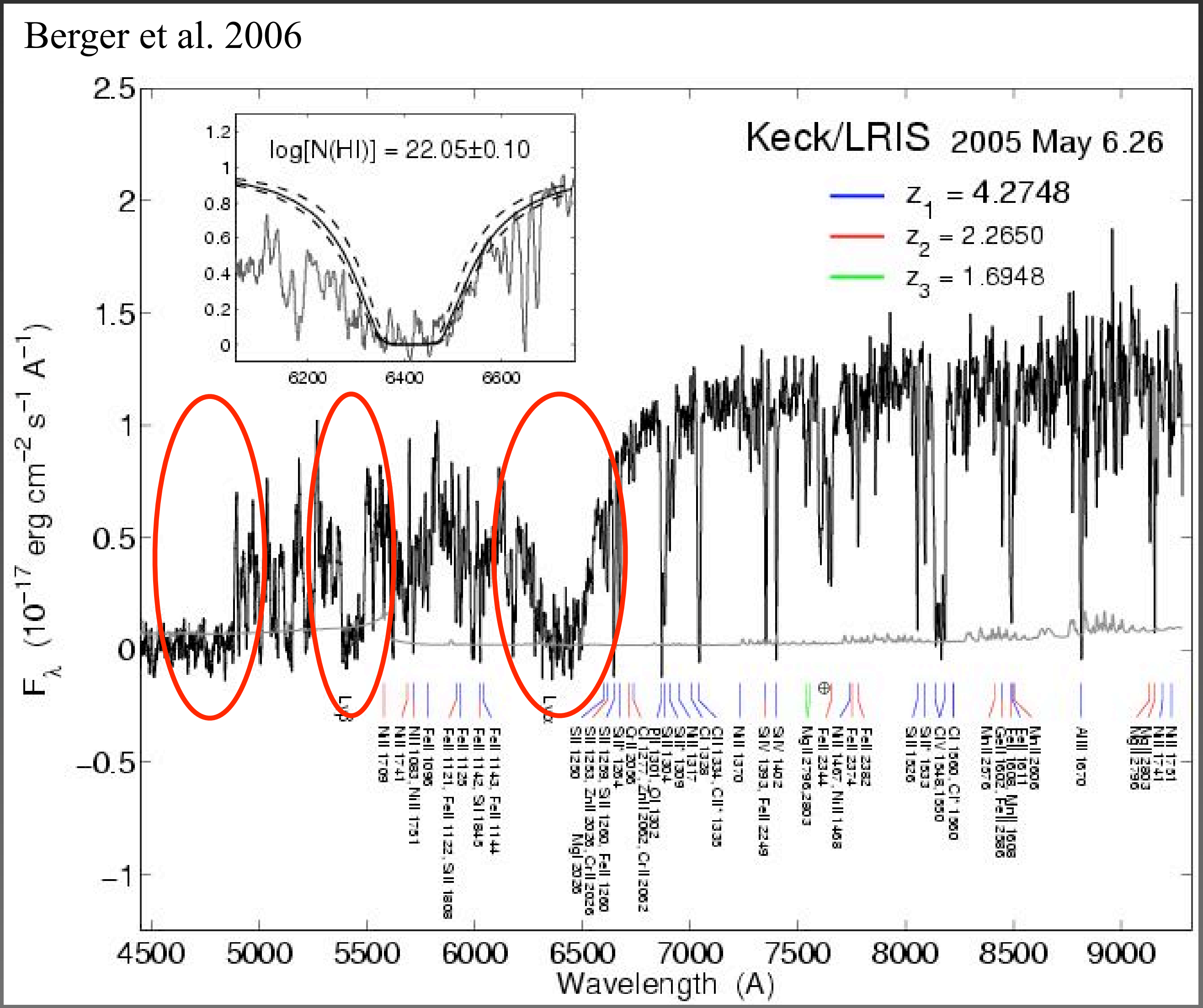

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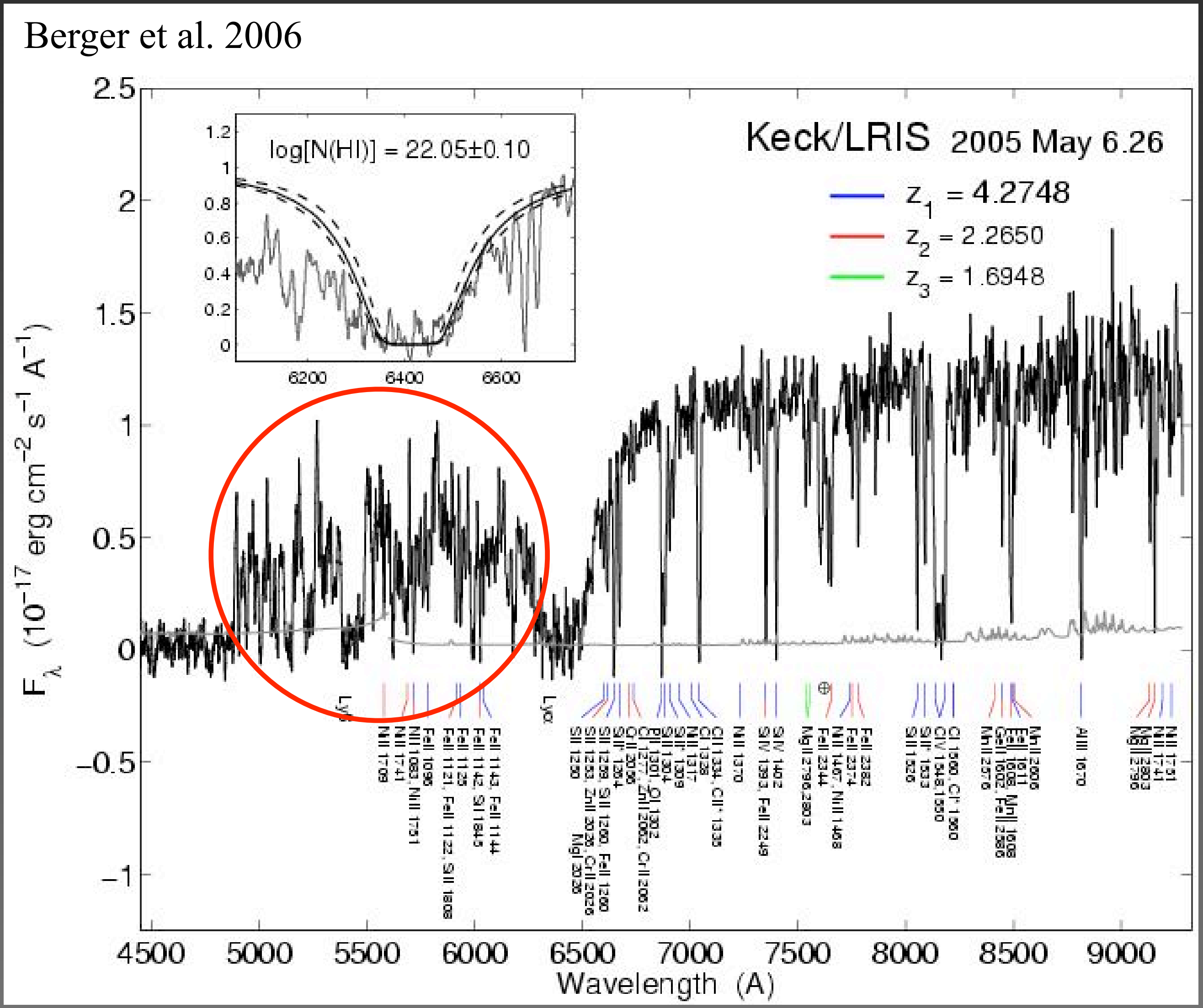

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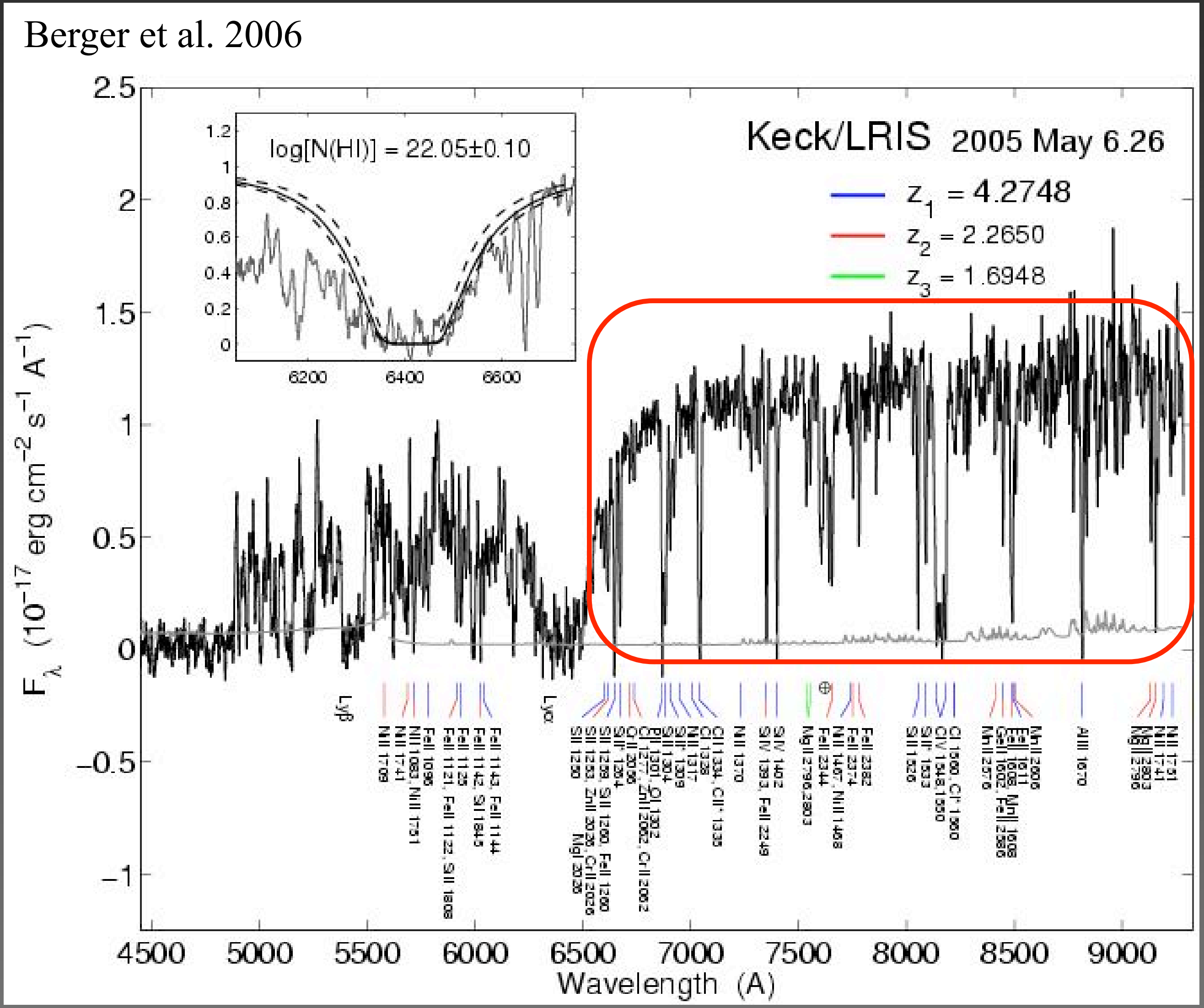

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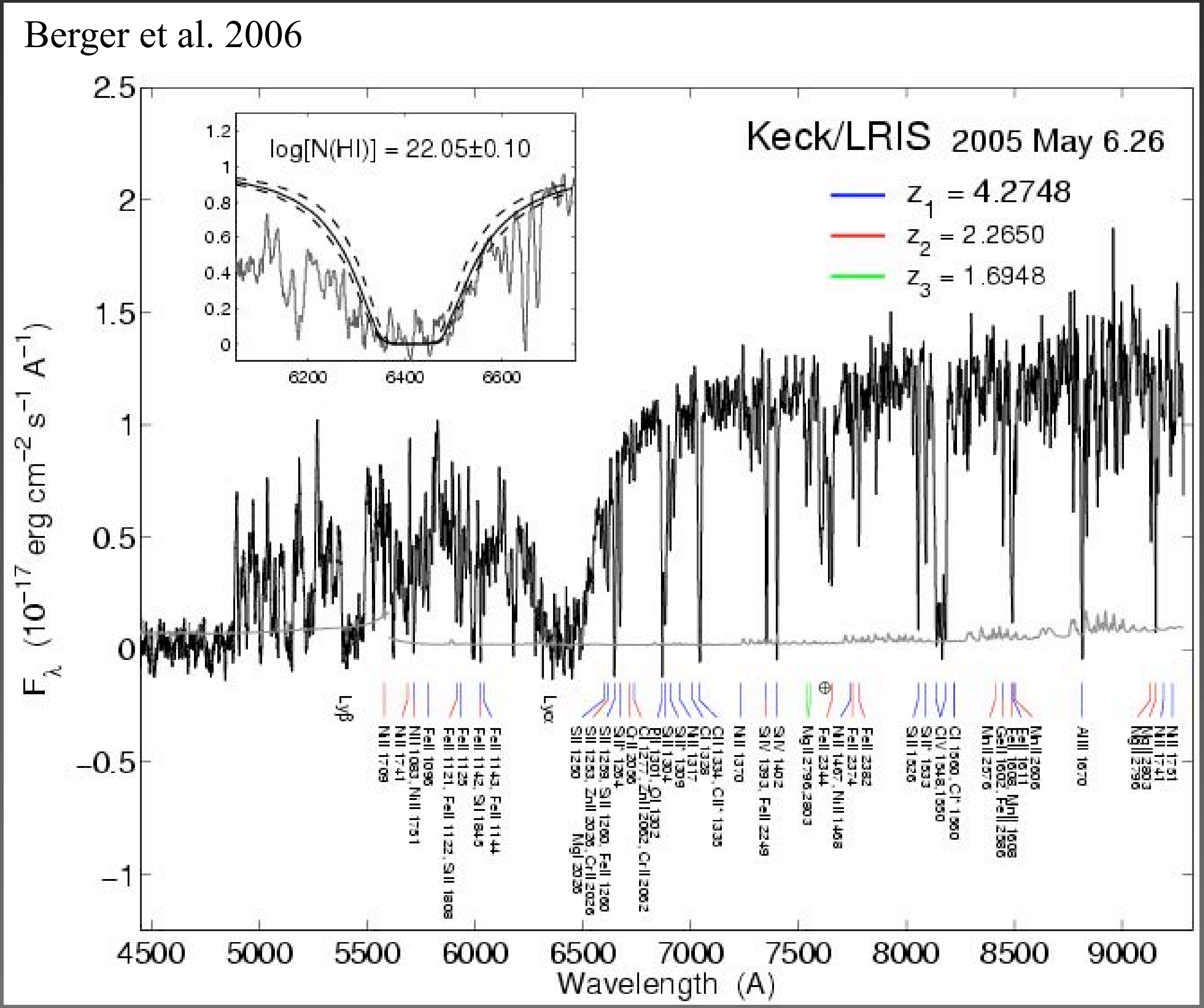
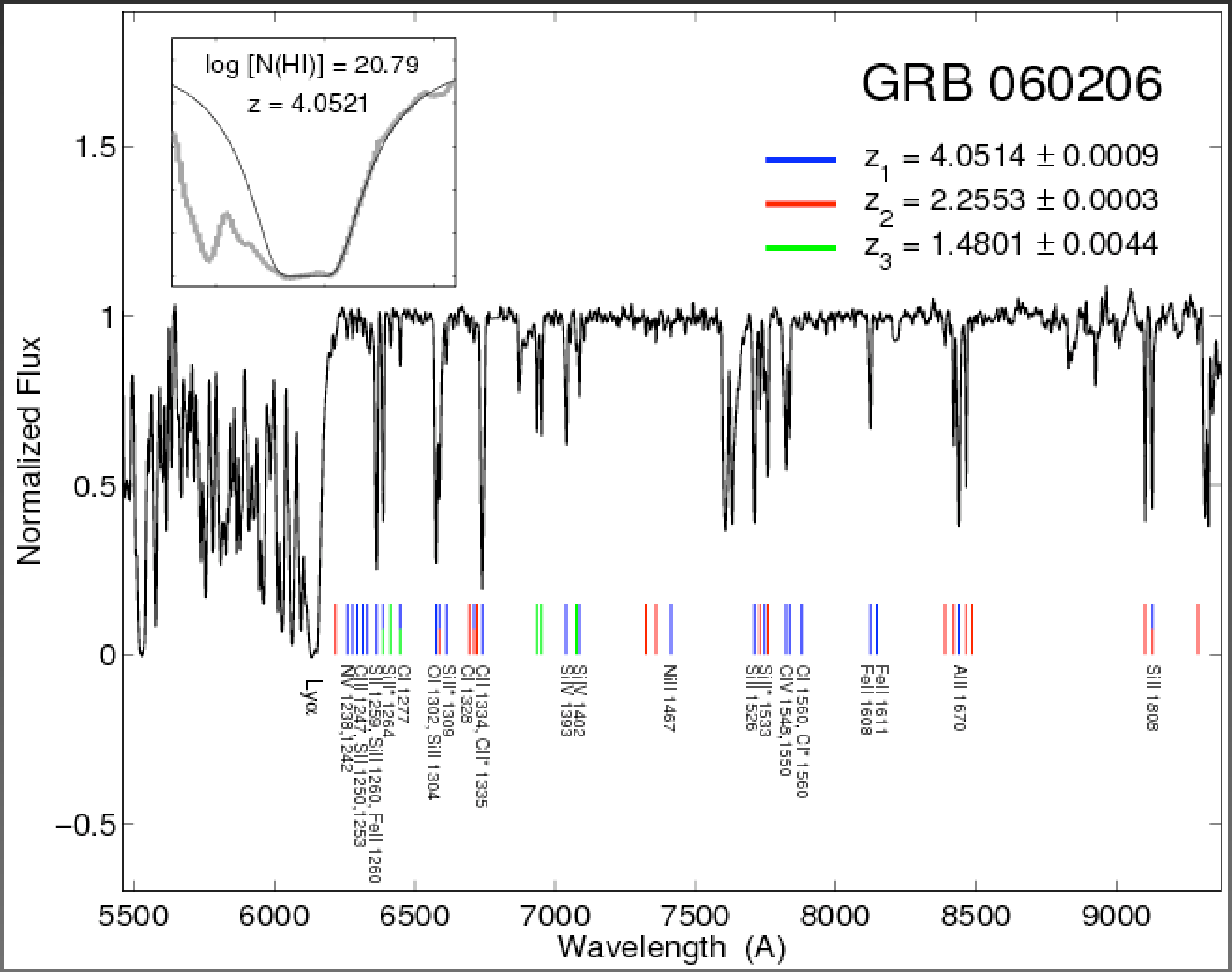


$\log N_H = 22.1 \pm 0.1$

$[S/H] = -1.2 \pm 0.1 = 0.06\ Z_\odot$

GRB Absorption Spectroscopy



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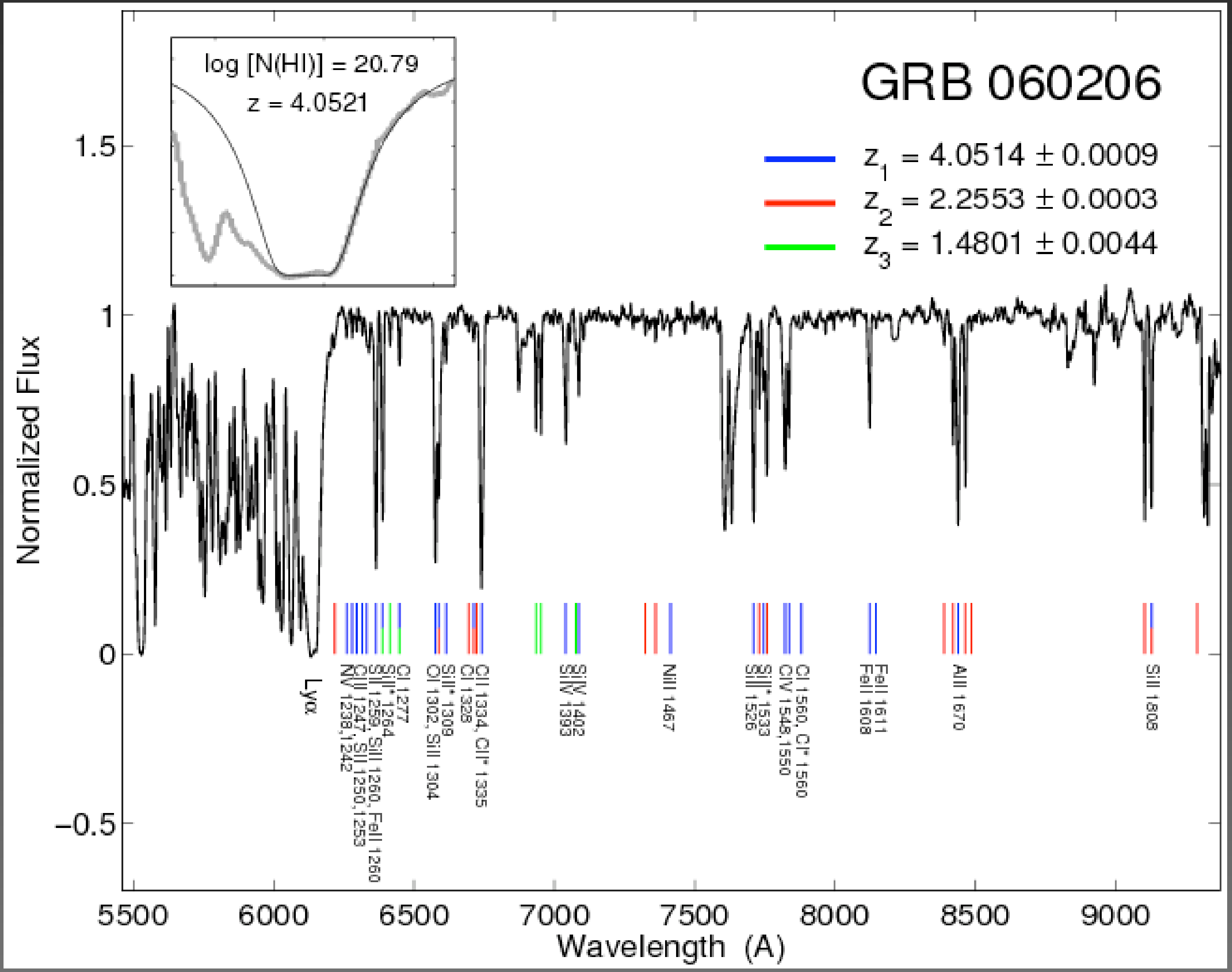
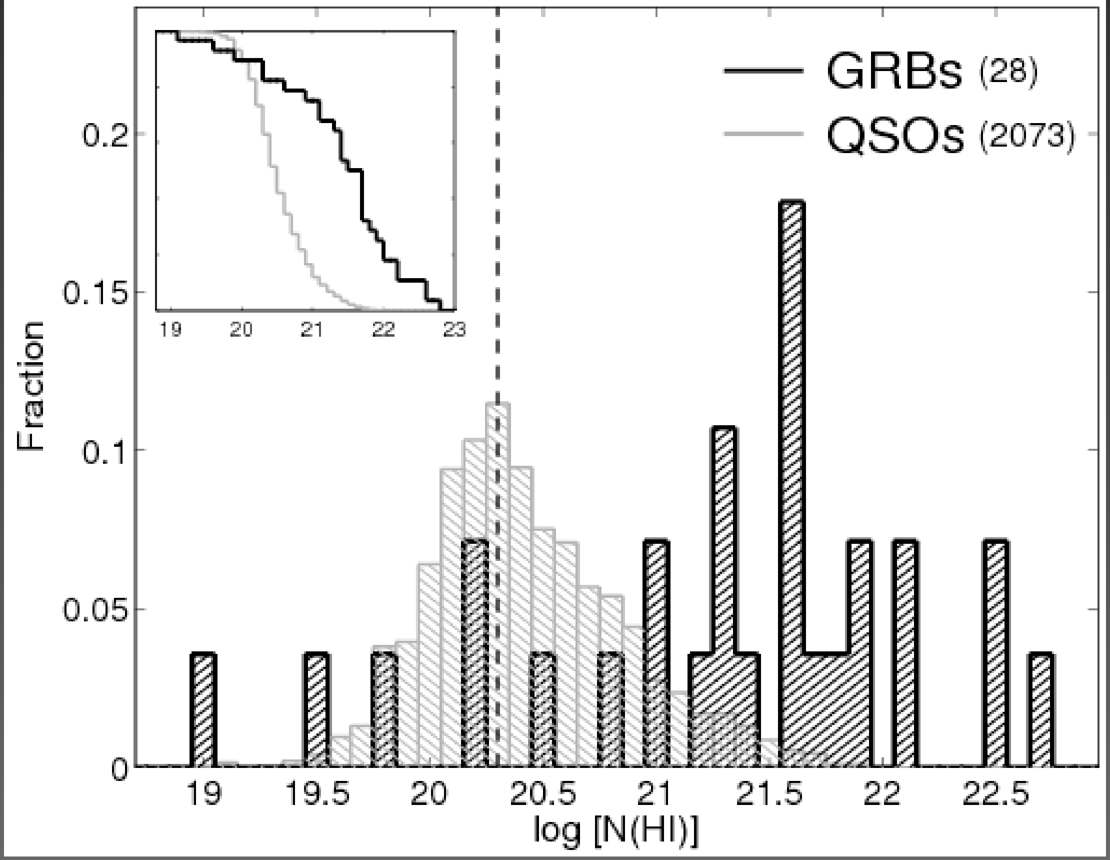


log N_H =20.8 ± 0.1 [S/H] = -1.0 ± 0.2 = 0.1 $Z_\odot$

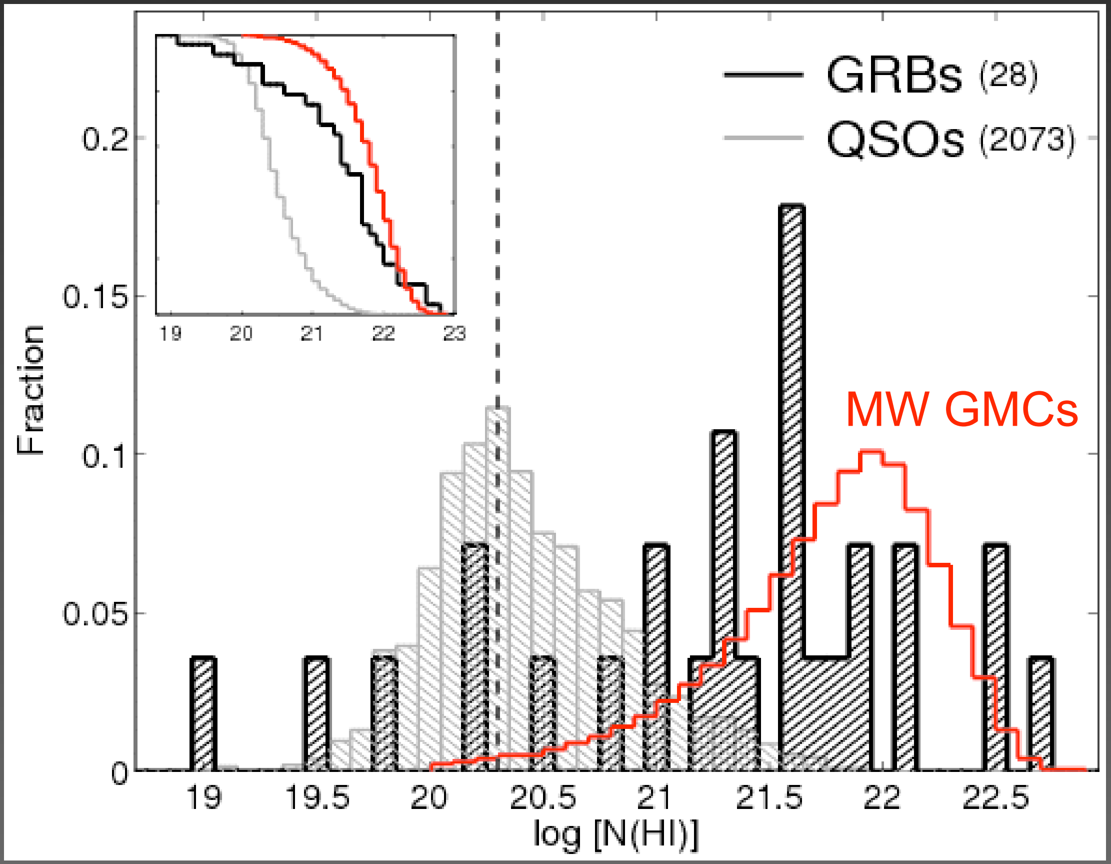
GRB-DLAs



Berger et al. 2006; Prochaska et al. 2007; Savaglio et al. 2007

$\langle N(HI)_{GRB} \rangle \sim 10 \times \langle N(HI)_{QSO} \rangle$

GRB-DLAs



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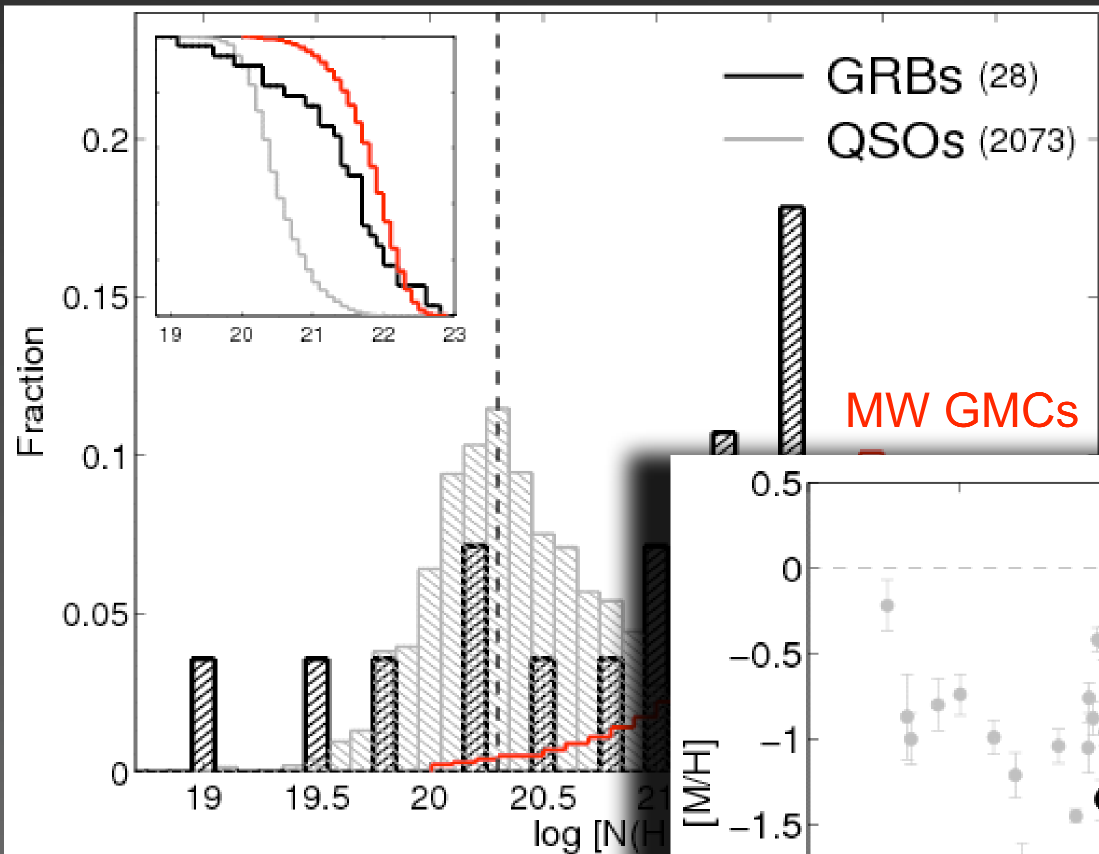
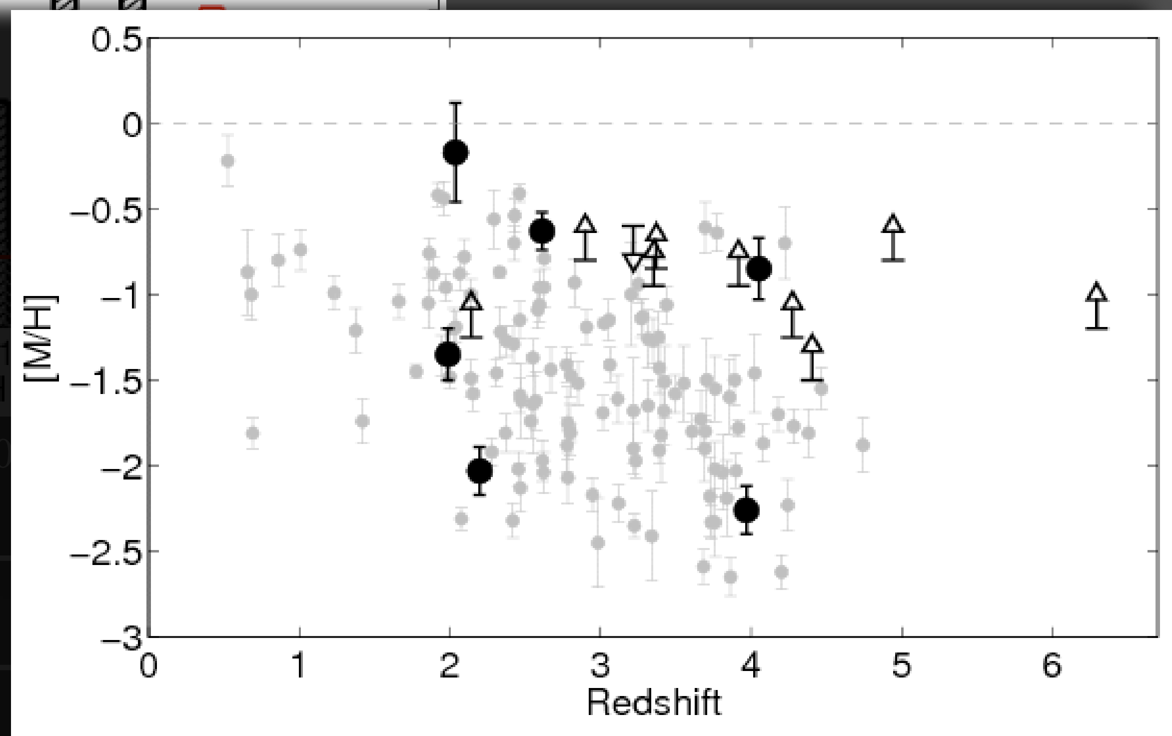
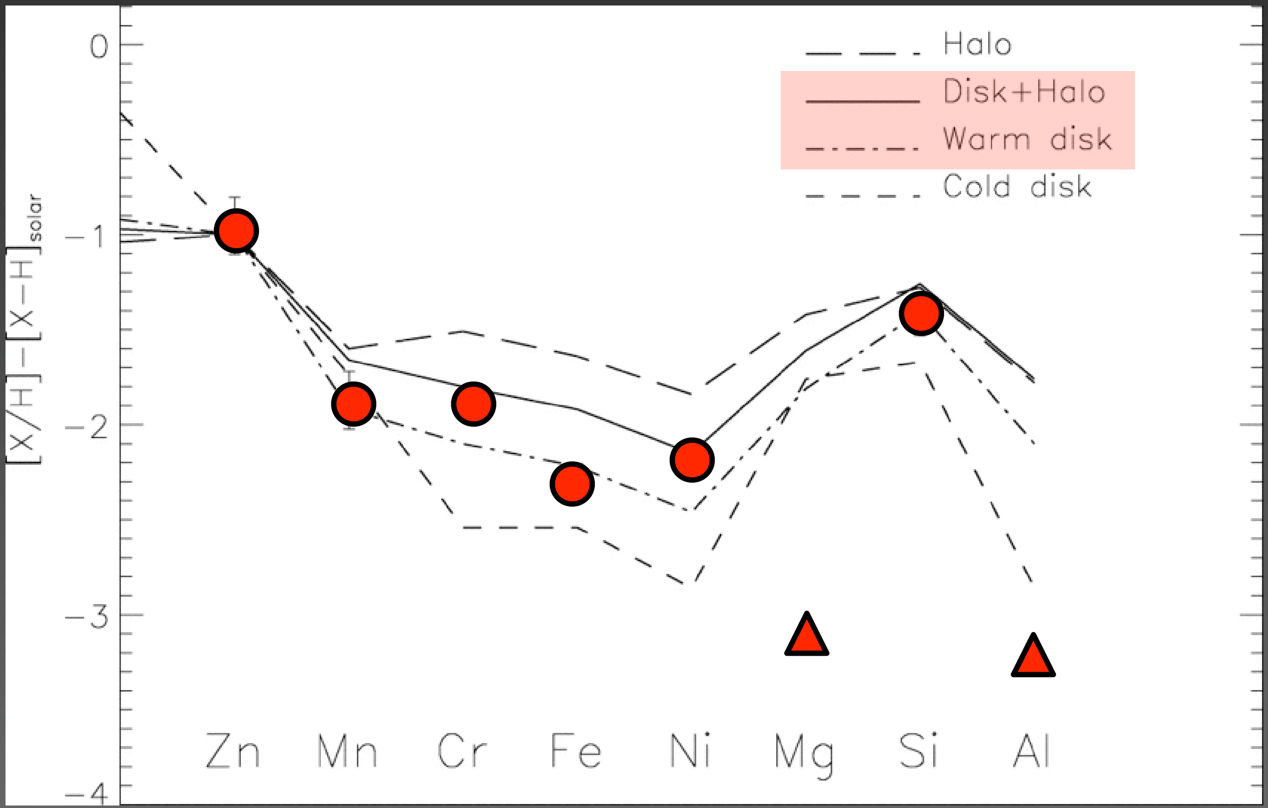


Berger et al. 2006; Prochaska et al. 200

⟨N(HI)GRB⟩ ~ 10 x



GRB-DLAs: Abundances & Depletion



Penprase, Berger, et al. 2006

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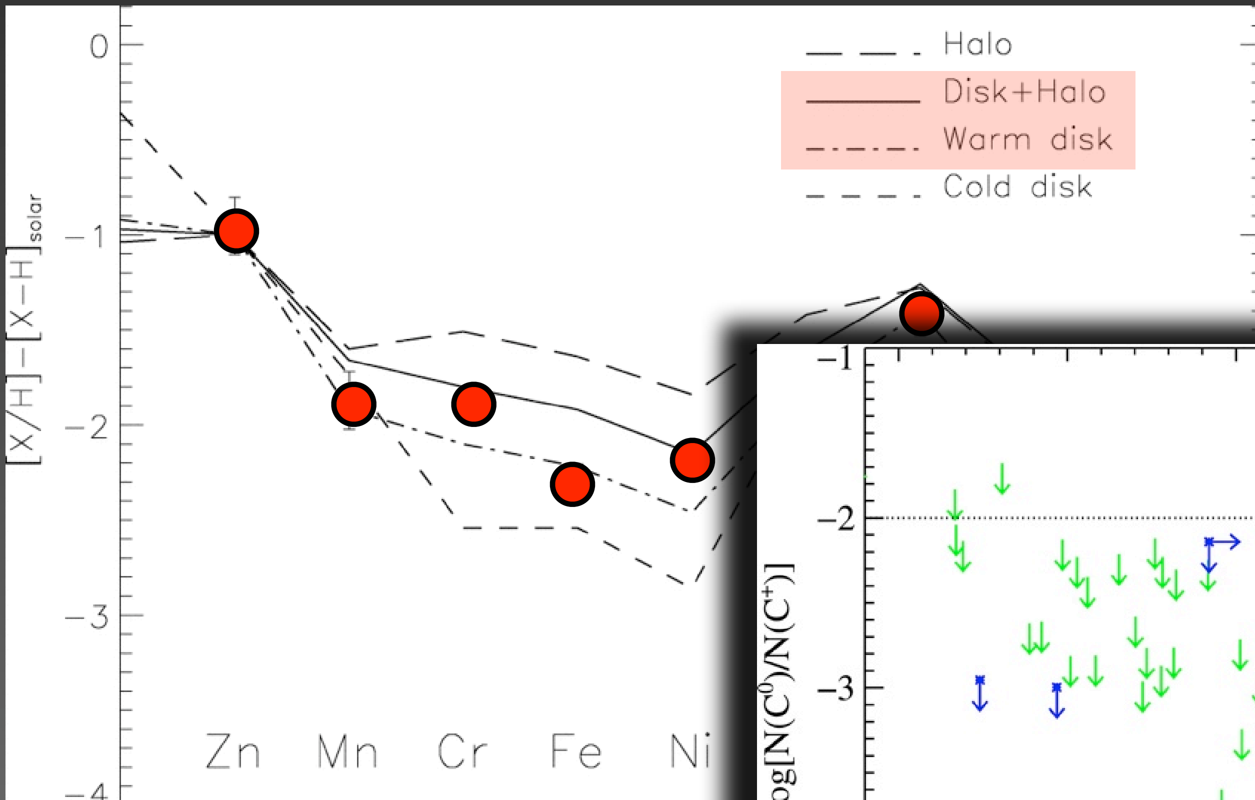
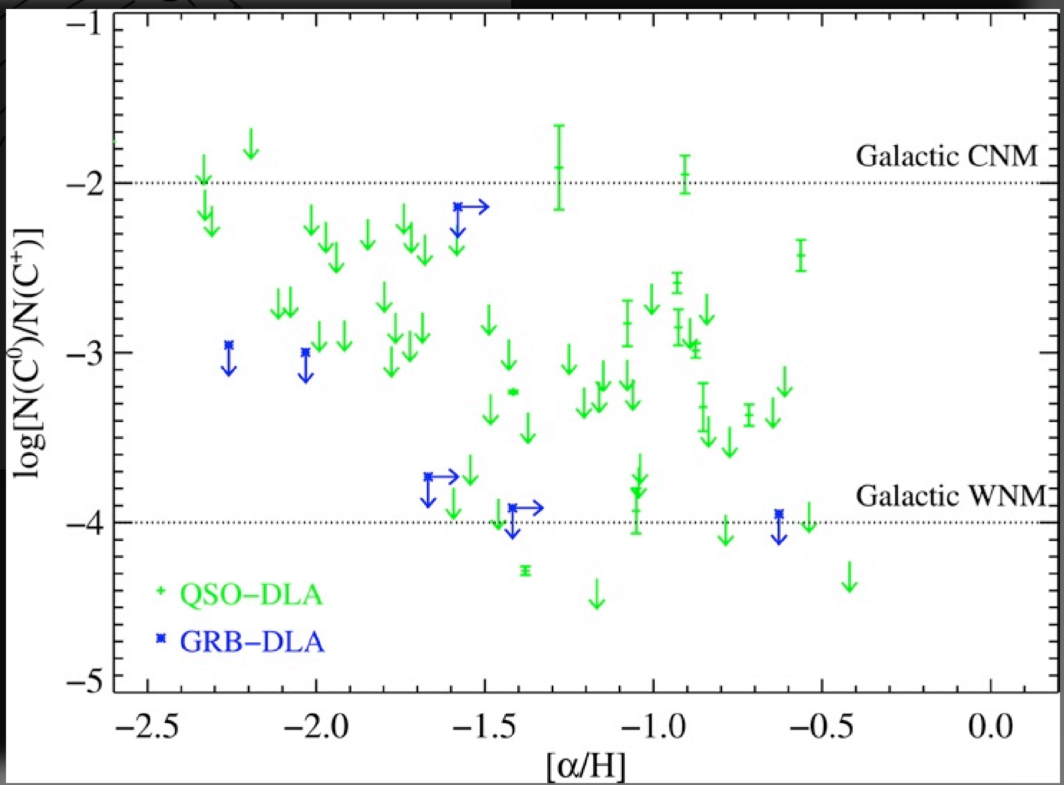


Penprase, Berger, et al. 2006

Prochaska et al. 2007



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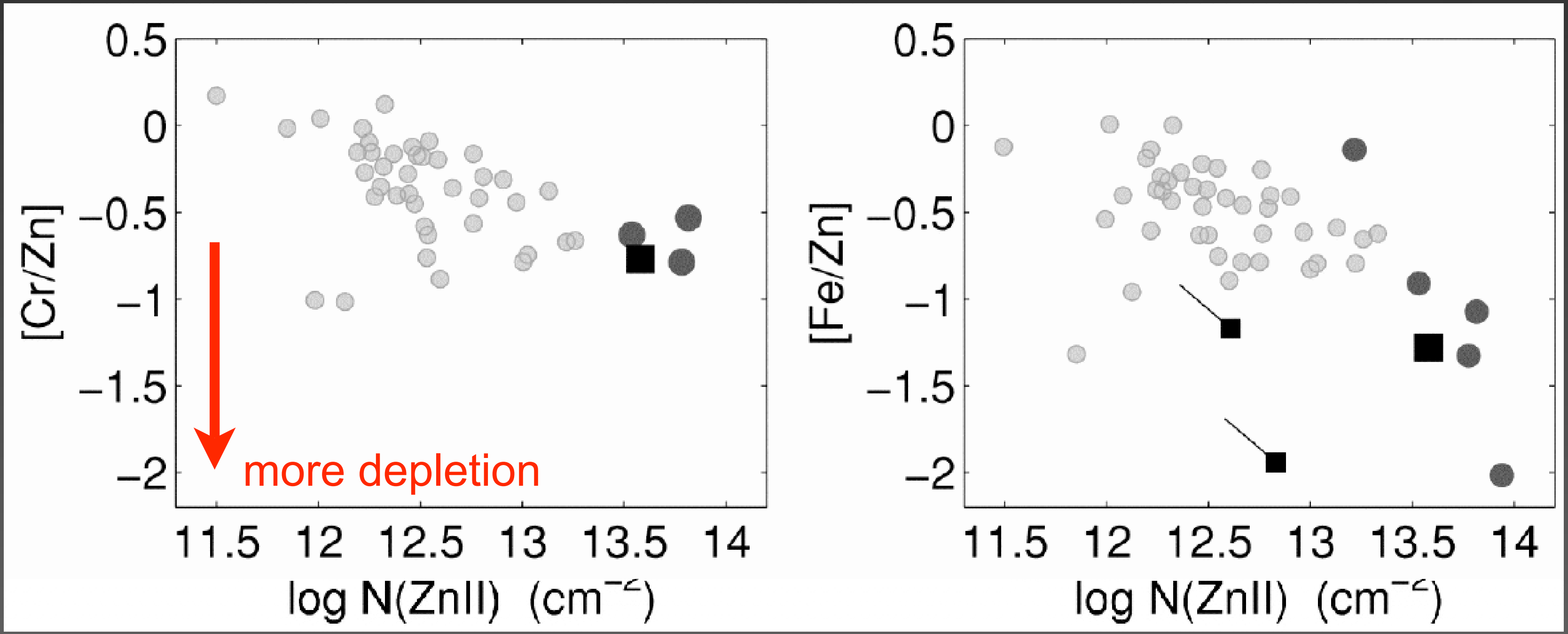

Significant depletion but no evidence for dust reddening at a commensurate level

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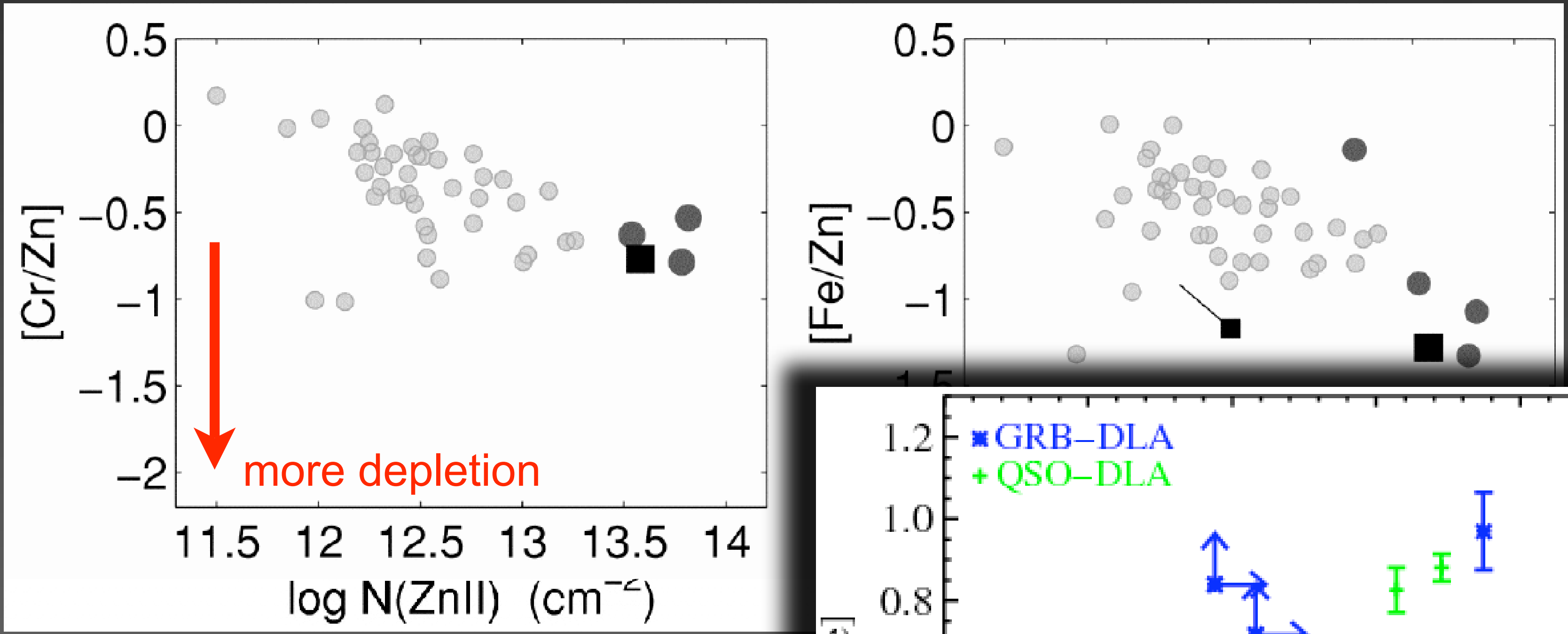
Penprase, Berger, et al. 2006



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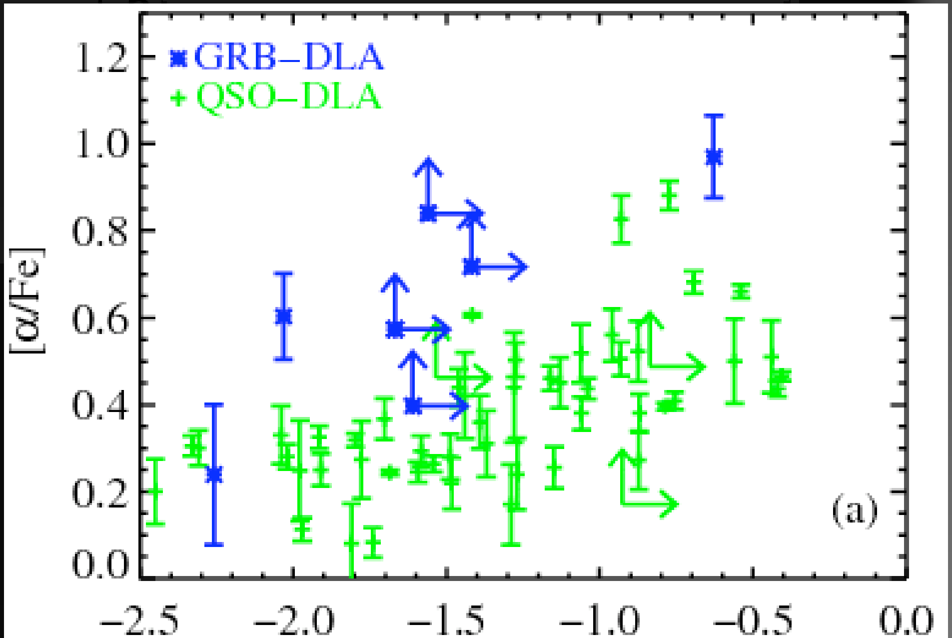
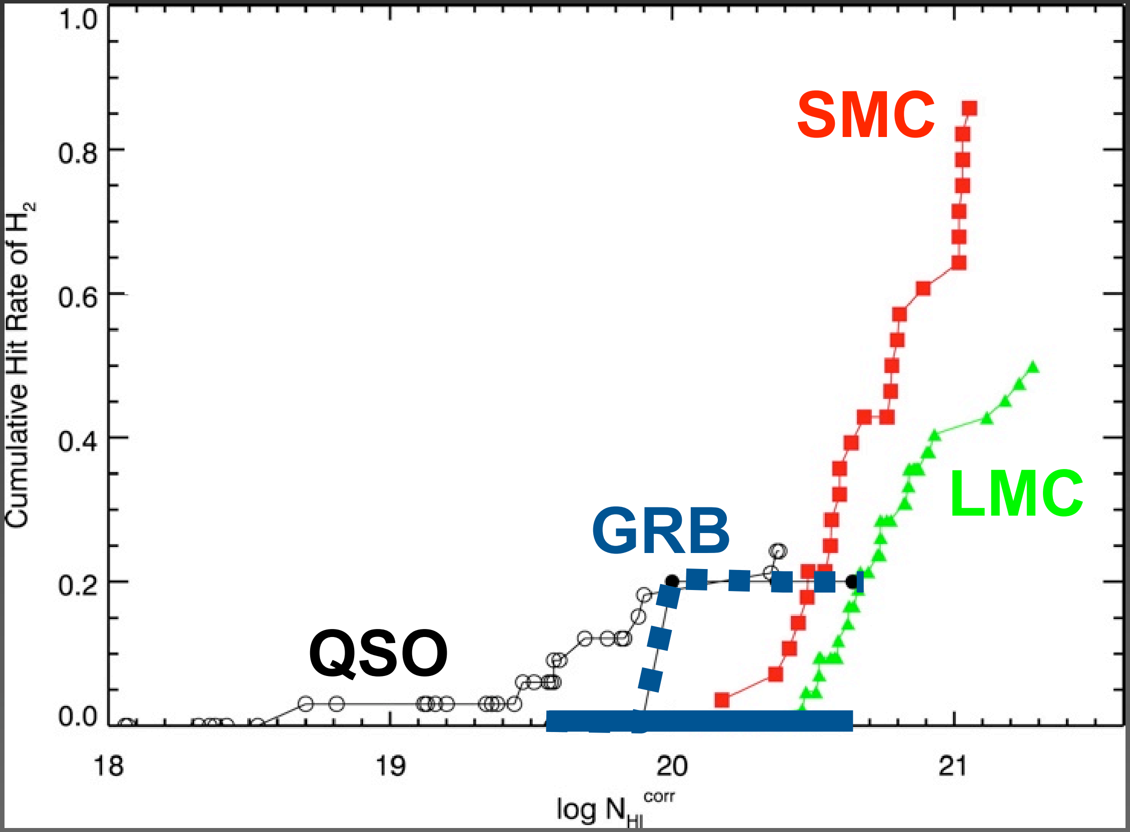


Prochaska et al. 2007

(Absence of) Molecular Hydrogen

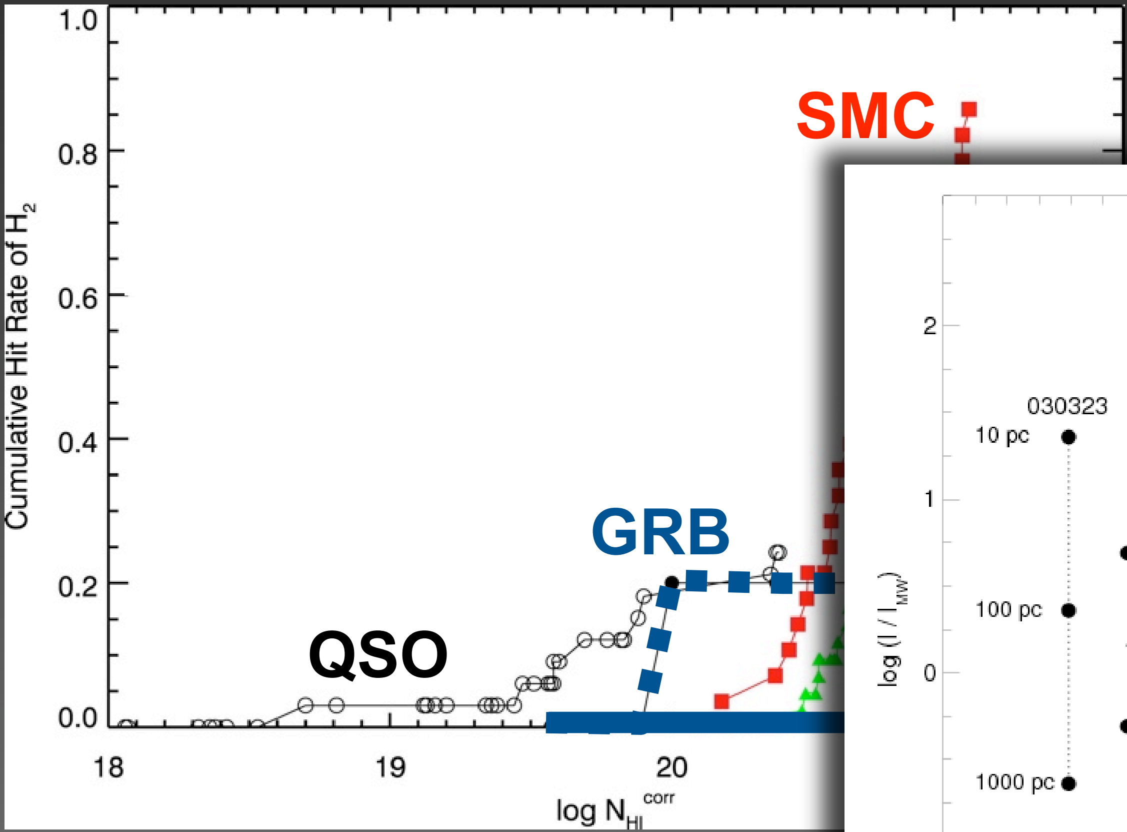
Tumlinson et al. 2007



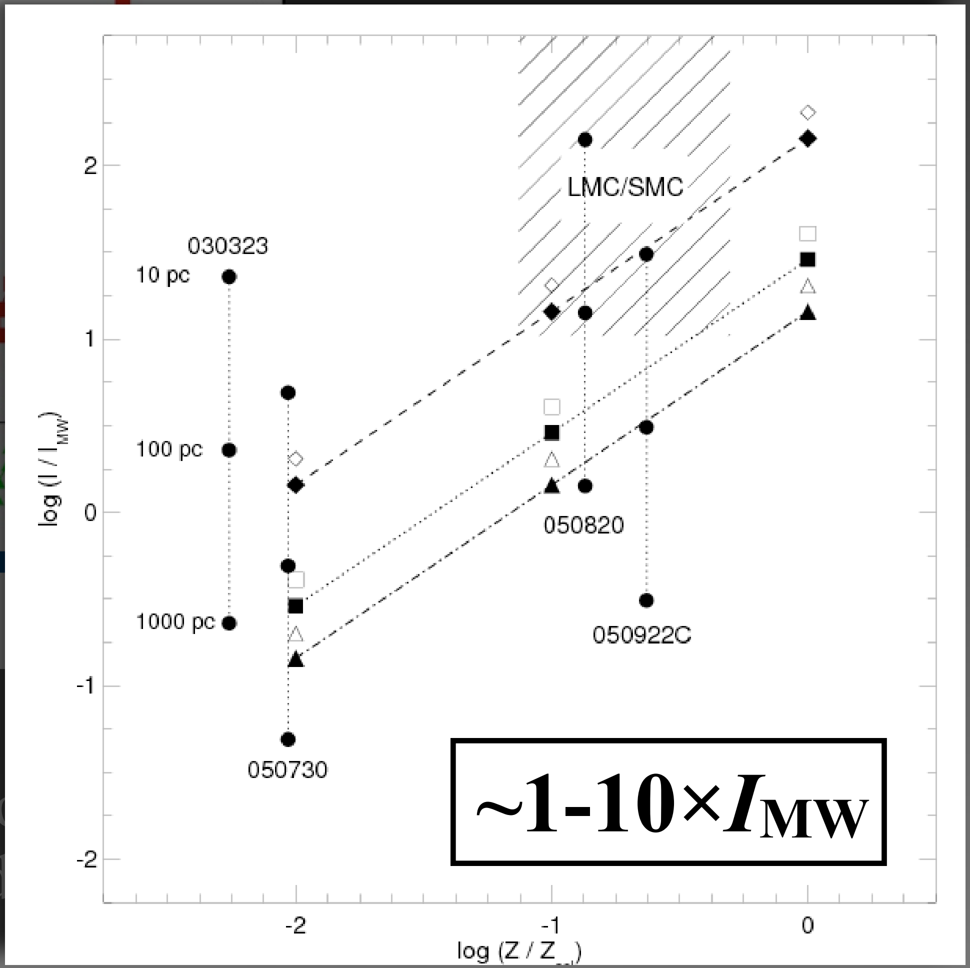
- Low metallicity (no dust)?
- Destruction by UV radiation from the GRB?
- Destruction by ambient UV radiation field?
- Small numbers?

(Absence of) Molecular Hydrogen

Tumlinson et al. 2007



Whalen et al. 2008



- Low metallicity (no dust)?
- Destruction by UV radiation fr
- Destruction by ambient UV rad
- Small numbers?

GRB-DLA Host Galaxies

GRBs offer an alternative galaxy-selection technique

Redshifts & metallicities measured from absorption spectra

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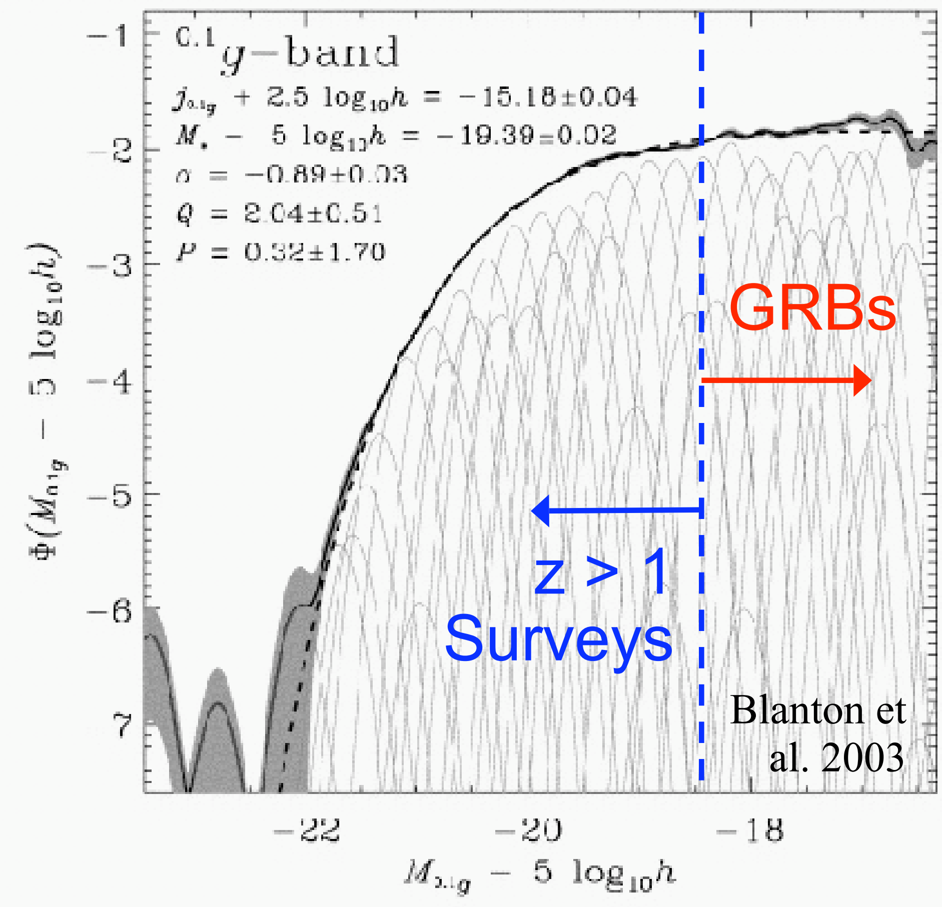
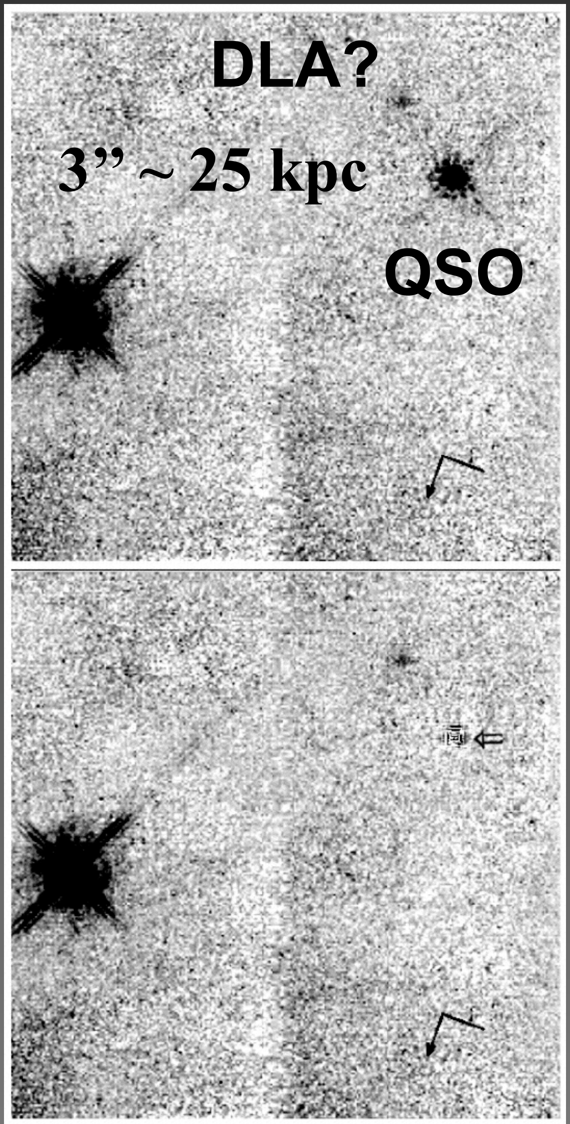
What is the connection between DLAs and star formation?



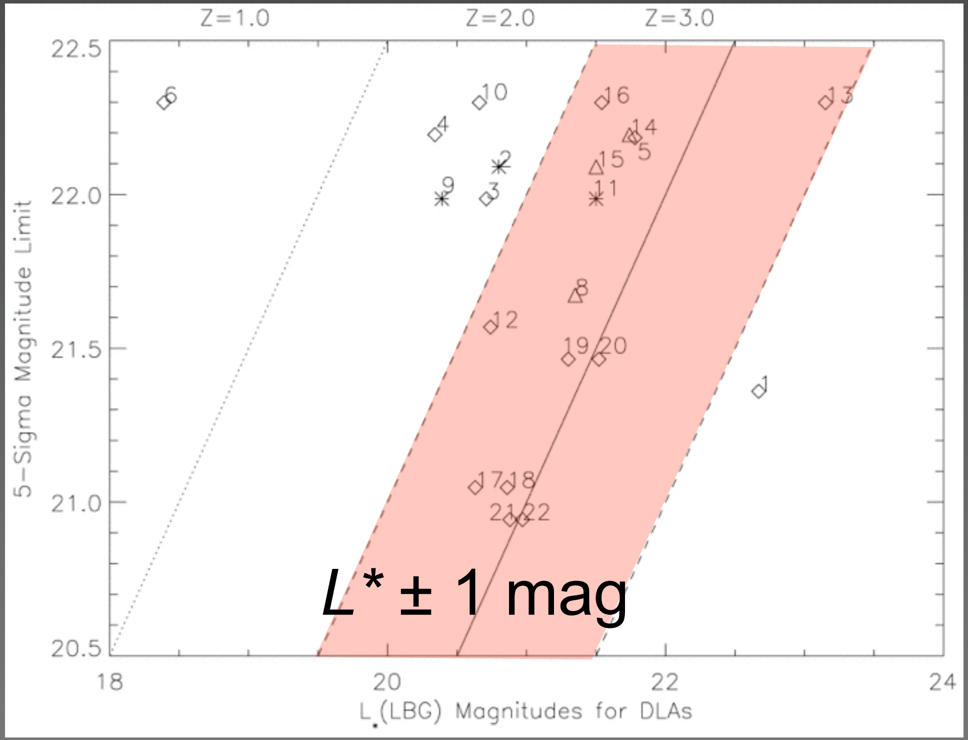
QSO-DLA Counterparts

Colbert & Malkan 2002



HST/NICMOS [H(5σ)=22 mag; 1/22 detected]

Most DLAs are <u>not</u> drawn from the bright end of the LBG population



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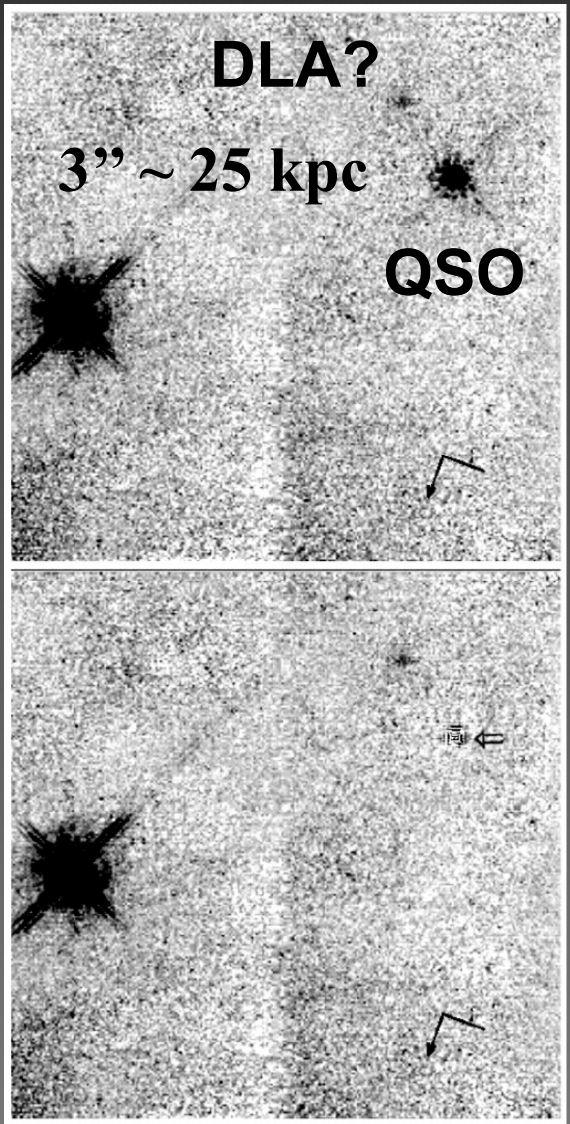
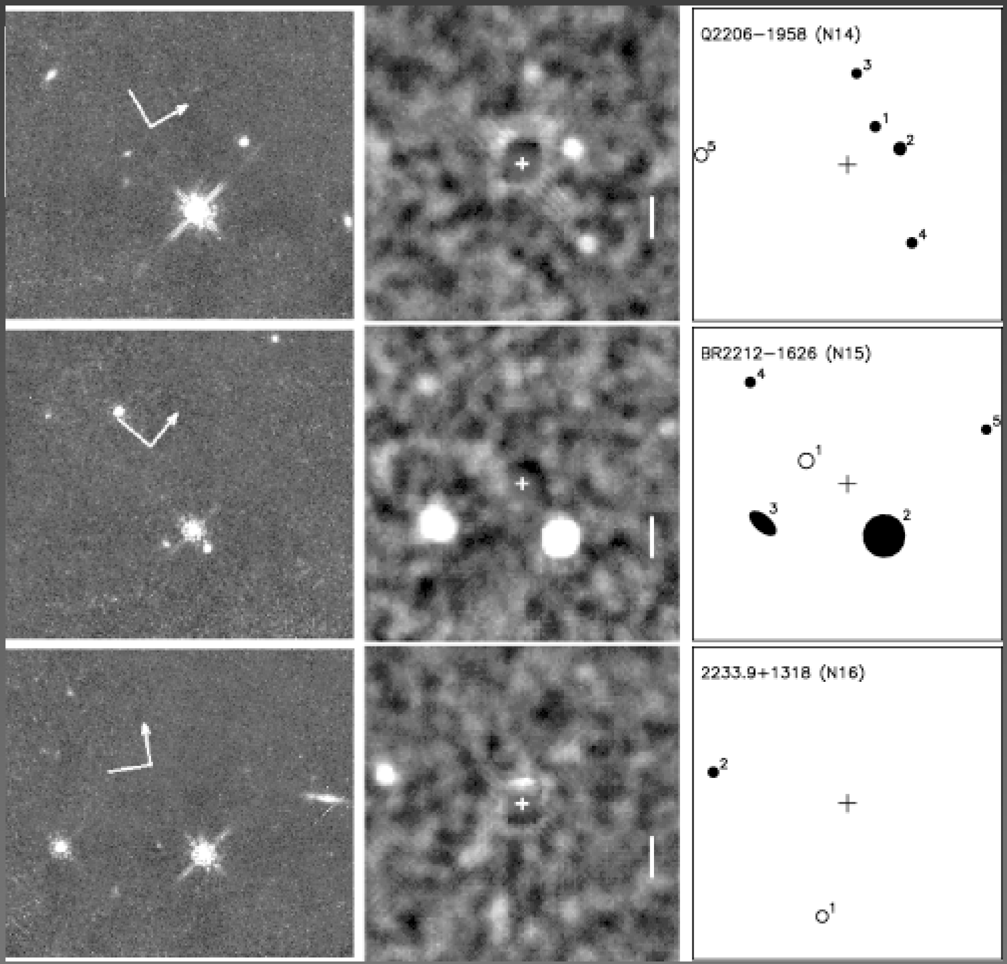


HST/NICMOS [H(5σ)=22 mag; 1/22 detected]

Warren et al. 2001



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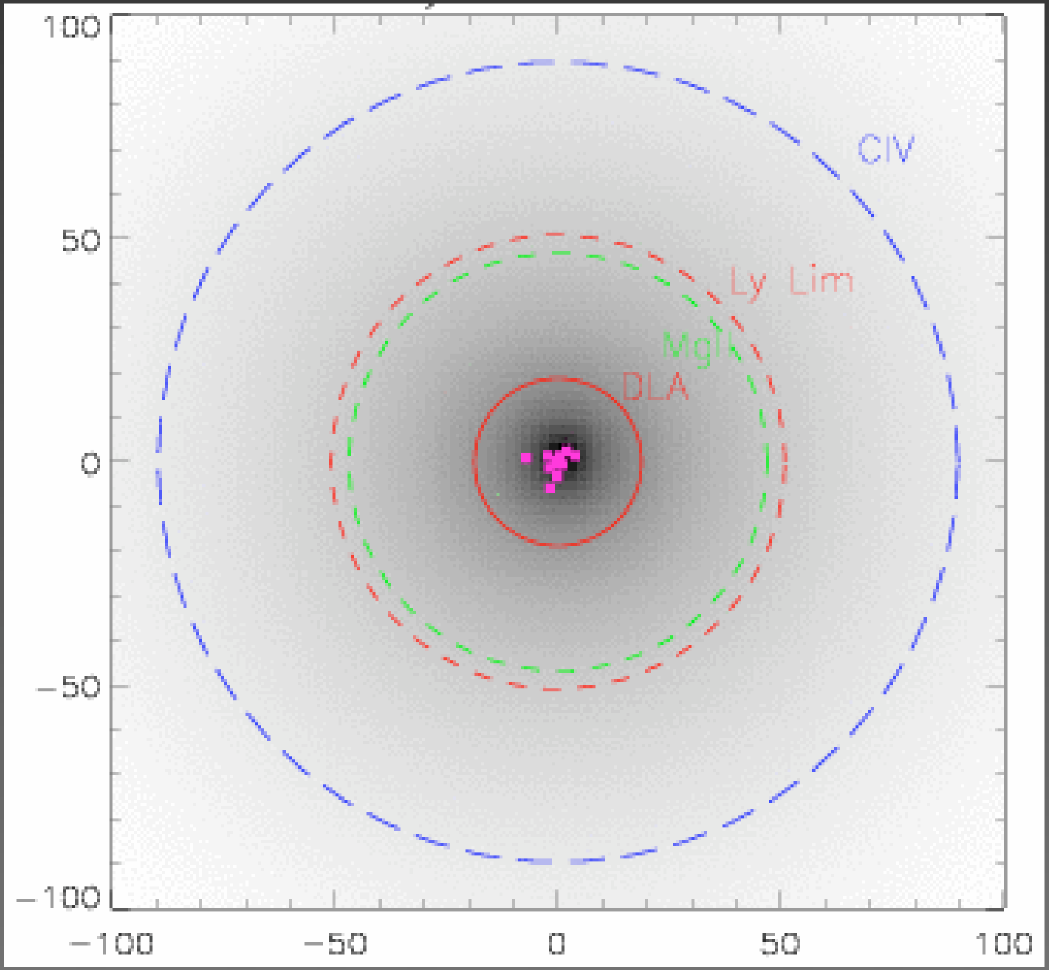


GRBs have <1" offset ⇒

no ambiguity about which galaxy is the DLA counterpart

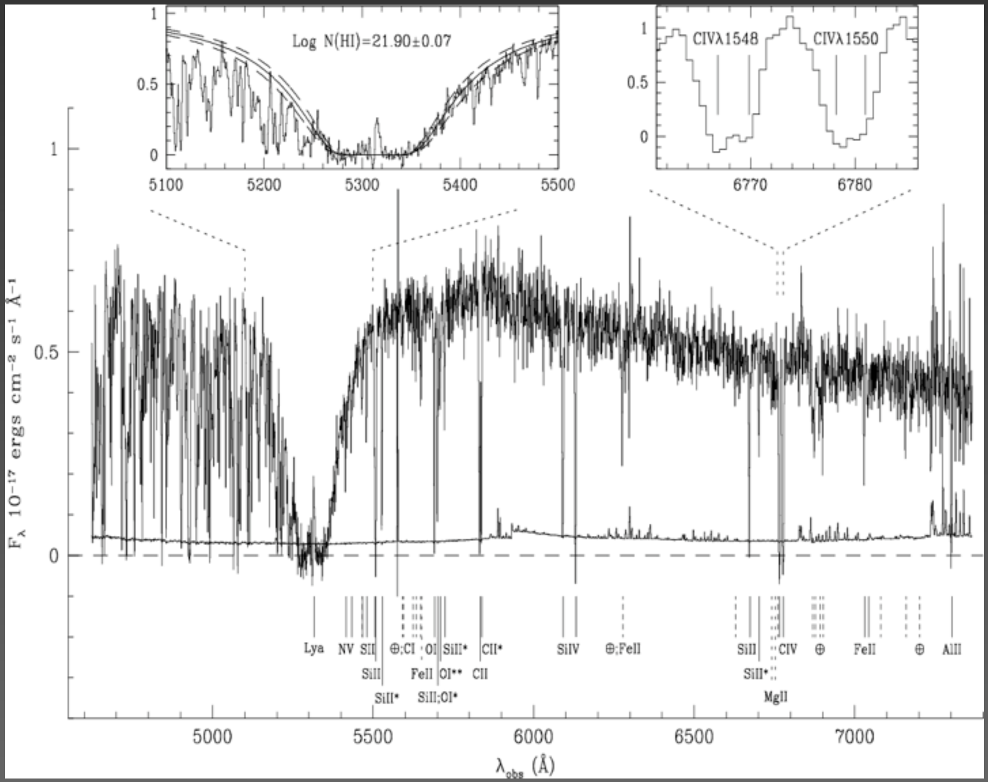
GRBs fade away ⇒

galaxy can be imaged to *L≪ L* & regardless of PSF*

GRB-DLA Counterparts

z = 3.372

Vreeswijk et al. 2004



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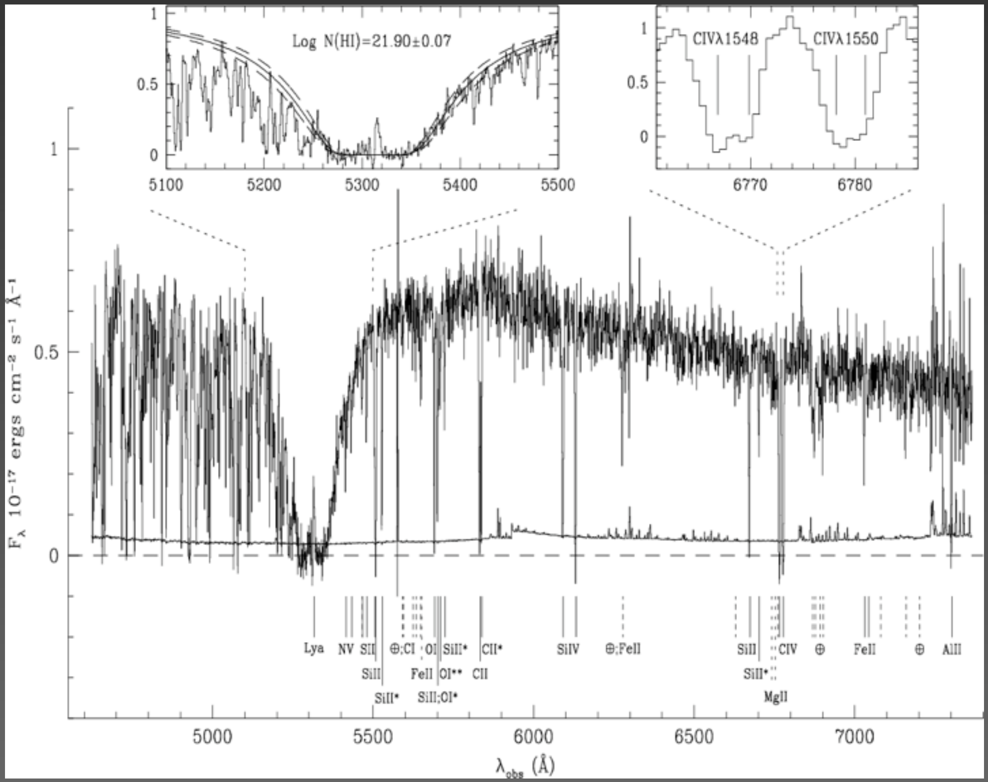
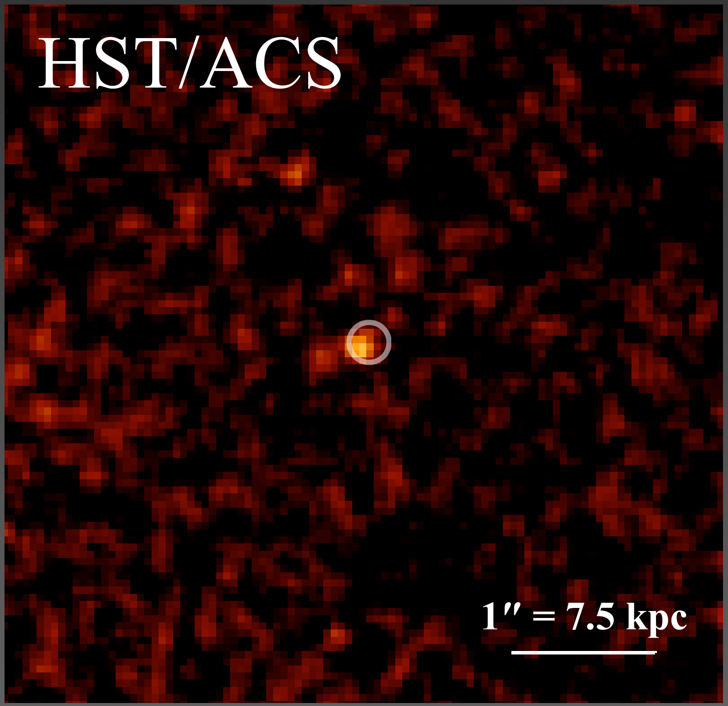




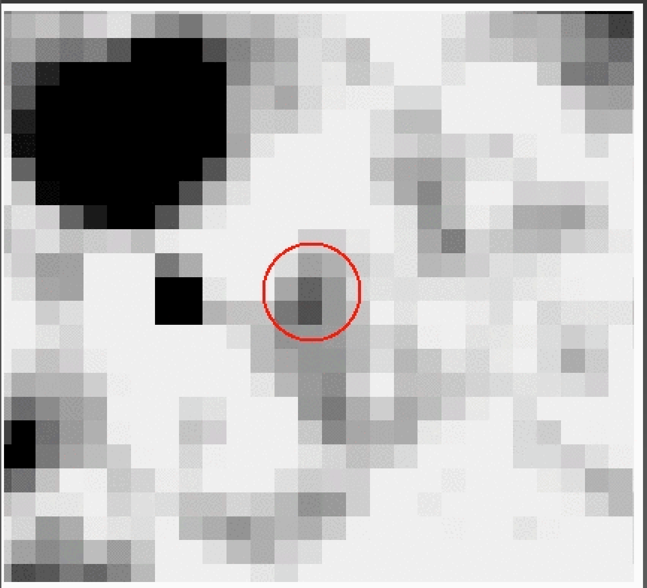
Wainwright, Berger et al. 2005

F606W(AB) ≈ 28.1 mag
$L \sim 0.02\, L^*$
SFR ~ 1 M$_\odot$/yr

} Too faint for other techniques
No spectroscopic confirmation

GRB-DLA Counterparts

Chary, Berger, & Cowie 2007



$z = 4.942$

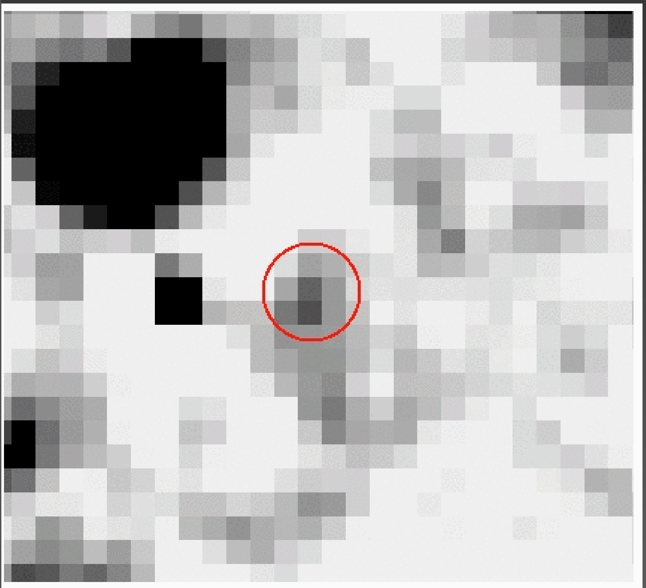
$F_\nu = 0.23 \pm 0.04\ \mu\mathrm{Jy}$

$L_V \approx 1.3\times10^{10}\ L_\odot \sim 0.15\ L^*$

$[\mathrm{S/H}] = -0.85 \pm 0.20 = 0.15\ Z_\odot$

GRB-DLA Counterparts

Chary, Berger, & Cowie 2007



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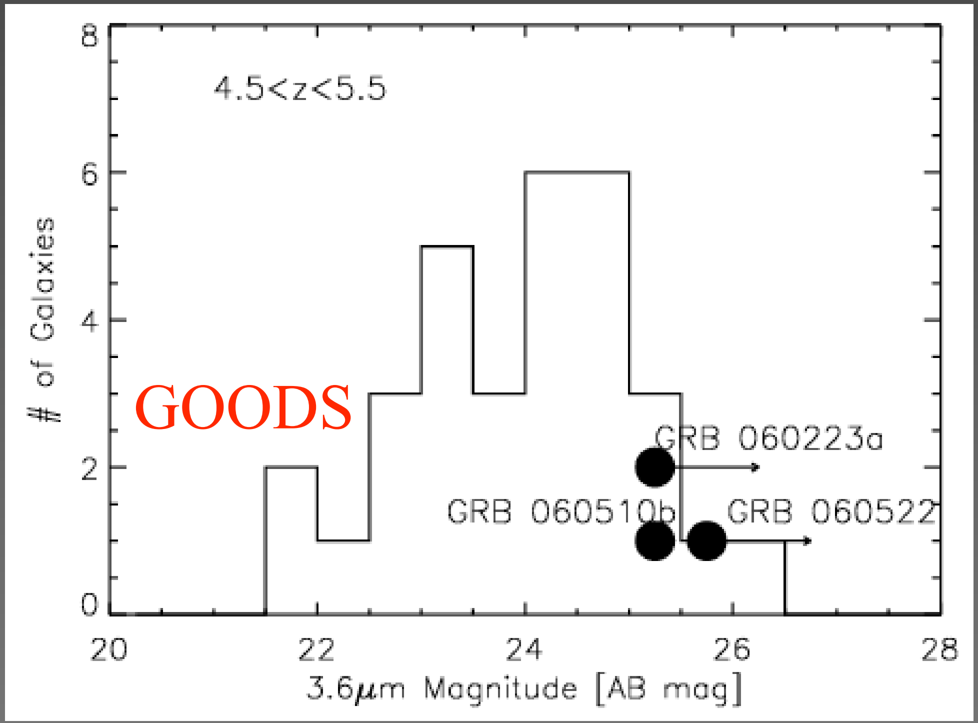
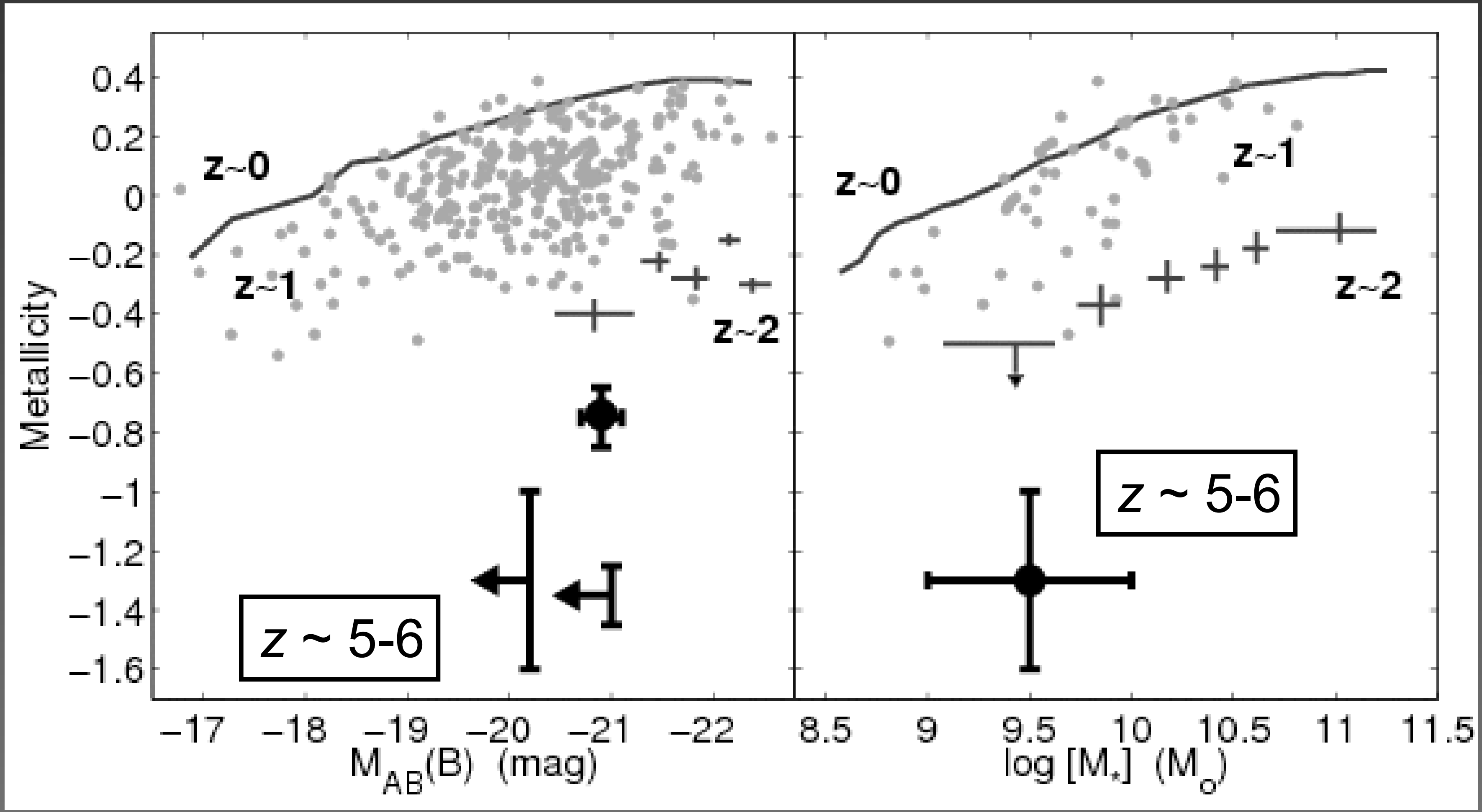


The Mass-Metallicity Relation at *z* > 3

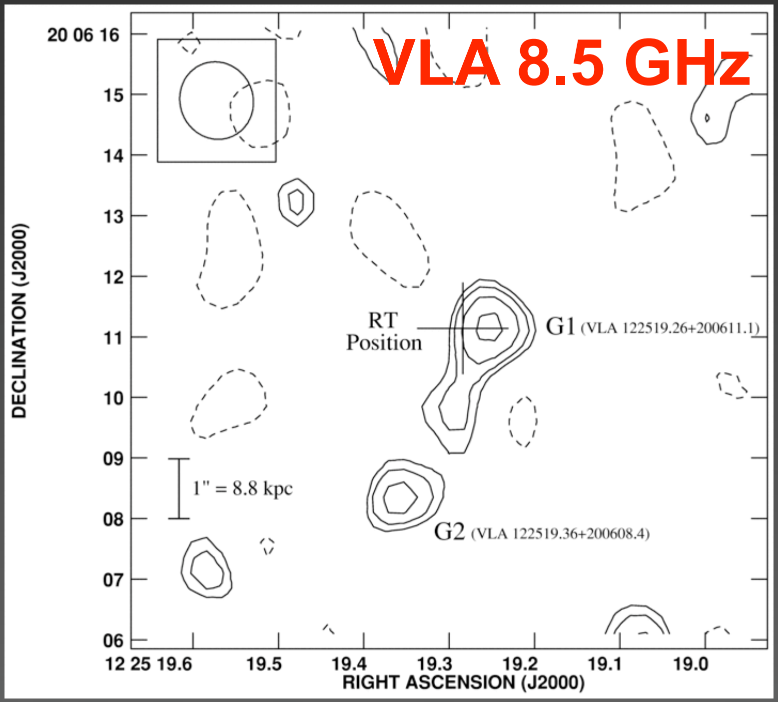
Chary, Berger, & Cowie 2007



z ~ 0: Tremonti et al. 2004; *z* ~ 1: Kobulnicky & Kewley 2004; Savaglio et al. 2005; *z* ~2: erb et al. 2006

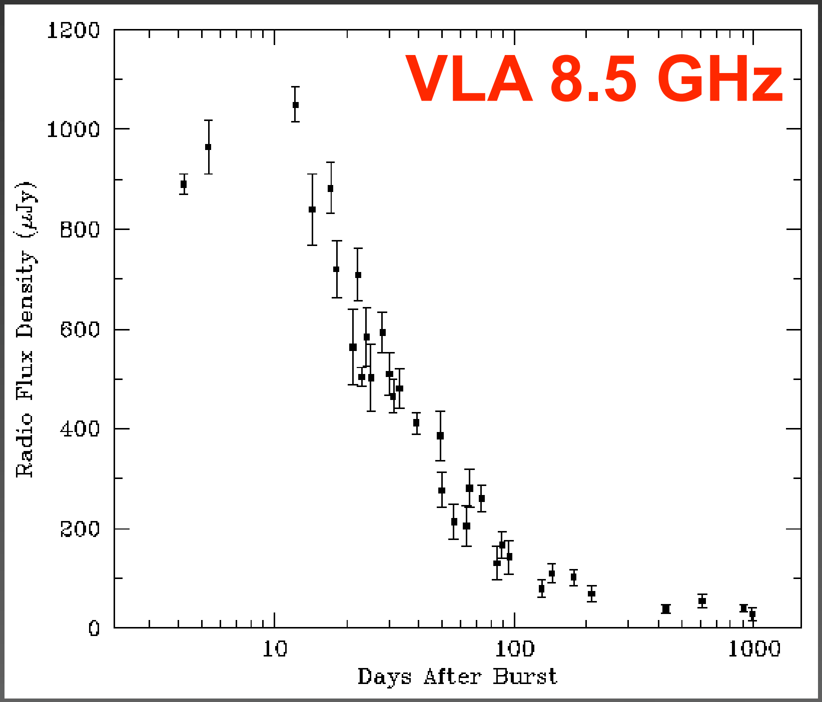
Obscured Star Formation

Berger, Cowie, et al. 2003



$z = 1.119$
$R = 23.5$ mag
$R-K = 2.2$ mag
$SFR_{opt} = 55\ M_\odot/yr$

Berger et al. 2001



$z = 0.966$
$R = 22.4$ mag
$R-K = 2.8$ mag
$SFR_{opt} = 10\ M_\odot/yr$

Obscured Star Formation

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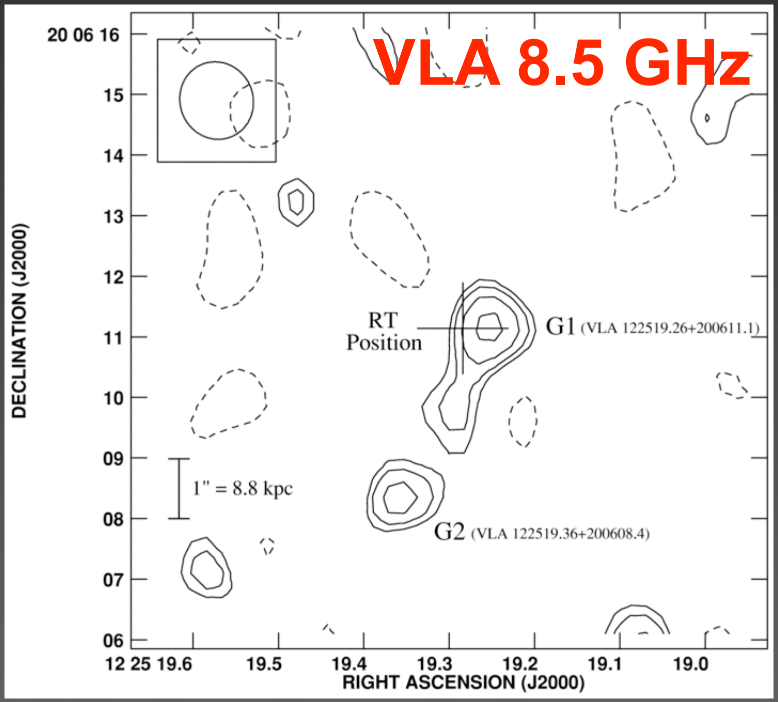

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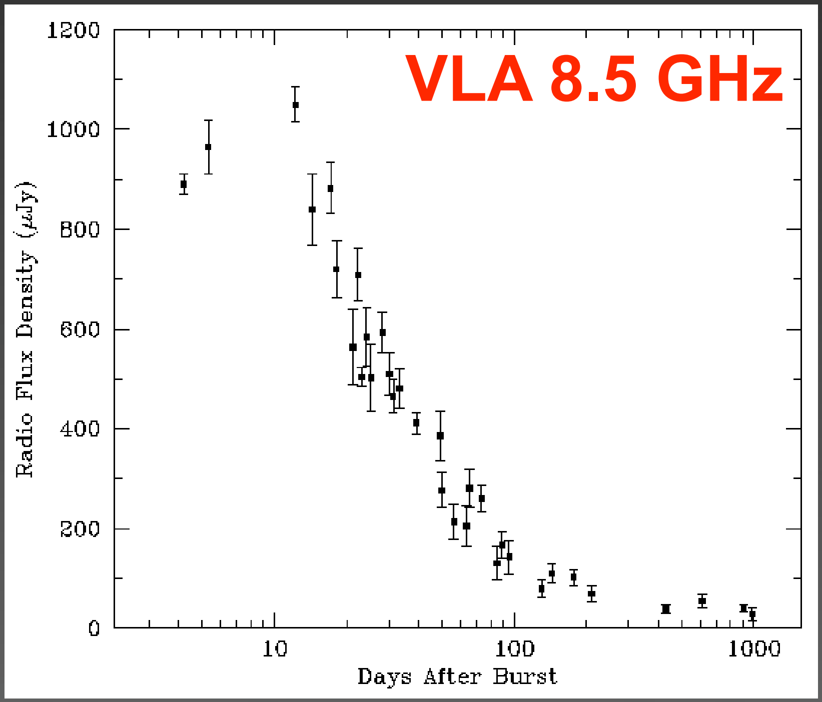


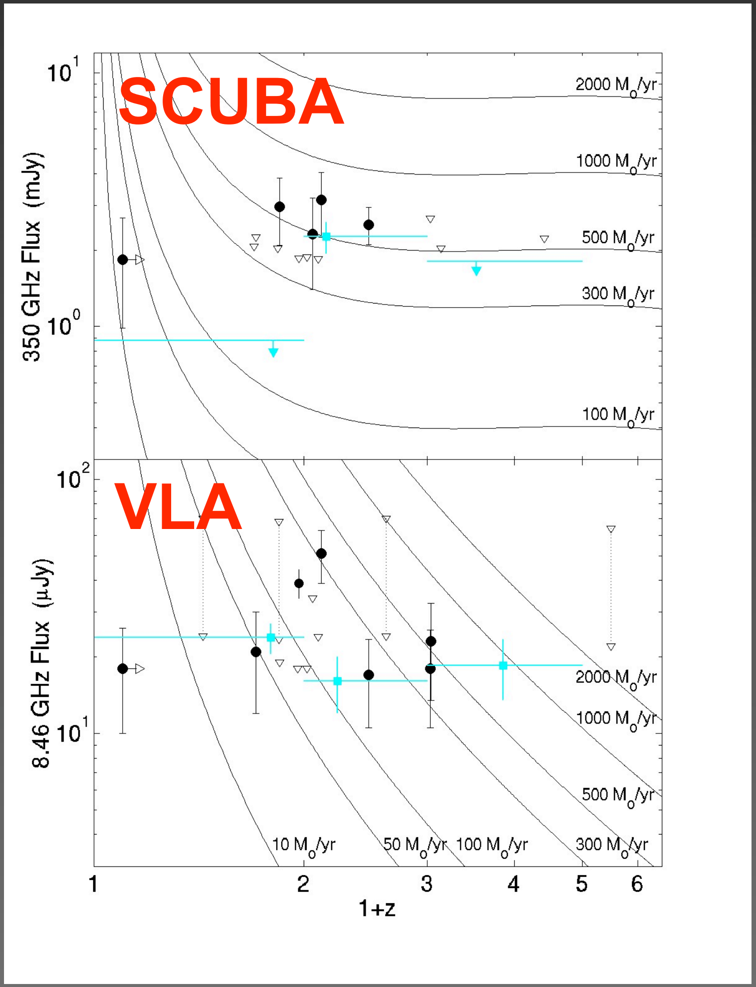
$z = 1.119$
$R = 23.5$ mag
$R-K = 2.2$ mag
$SFR_{opt} = 55\ M_\odot/yr$

$SFR \sim 100\text{-}300\ M_\odot/yr$

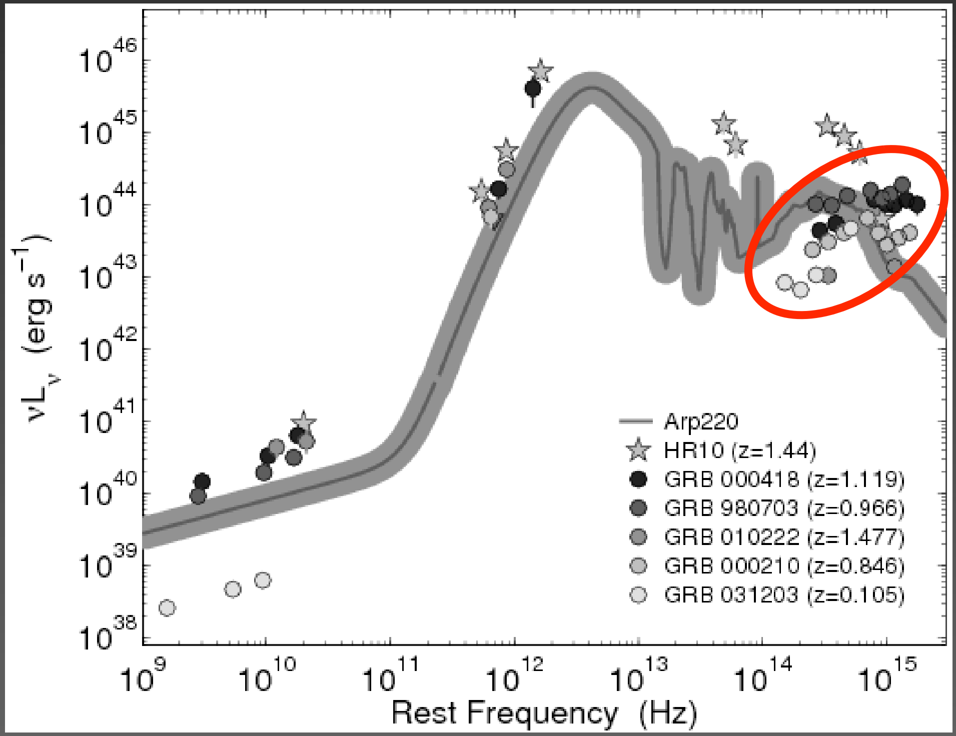
$L_{FIR} \sim (1\text{-}3)\times 10^{12}\ L_\odot$

$z = 0.966$
$R = 22.4$ mag
$R-K = 2.8$ mag
$SFR_{opt} = 10\ M_\odot/yr$

Obscured Star Formation



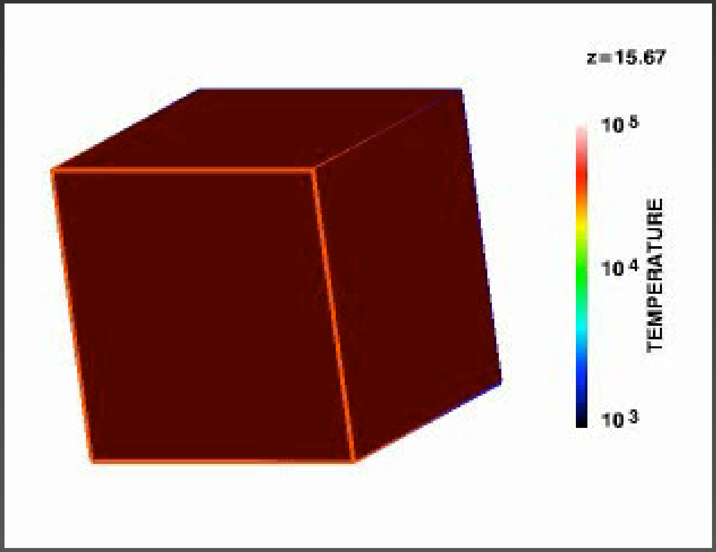
Berger, Cowie, et al. 2003

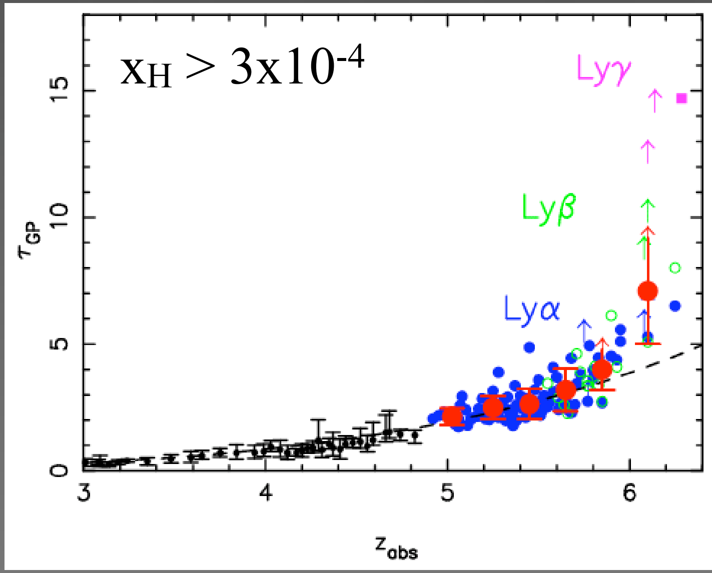


- ~10% detection rate in radio/submm
- *SFR* ~ 100-300 M⊙/yr
- Detected hosts are LIRGs/ULIRGs *but* very blue

Cosmic Re-ionization

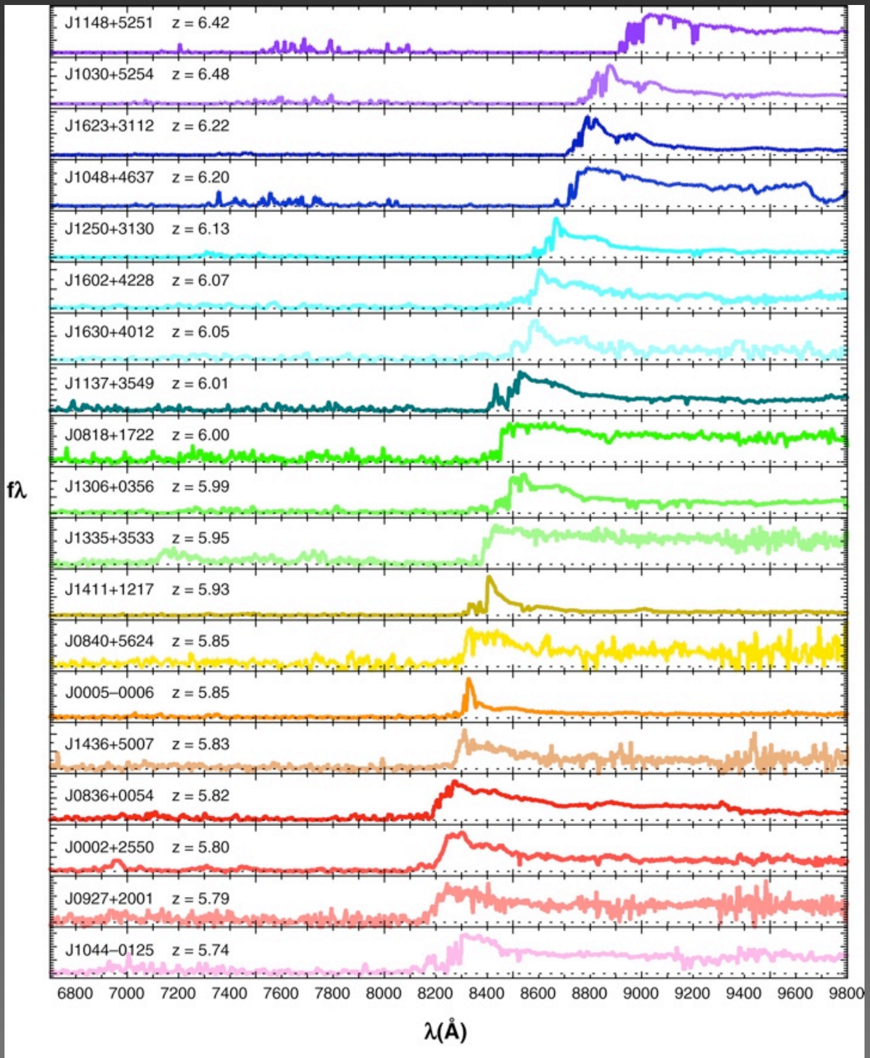
Gnedin et al.





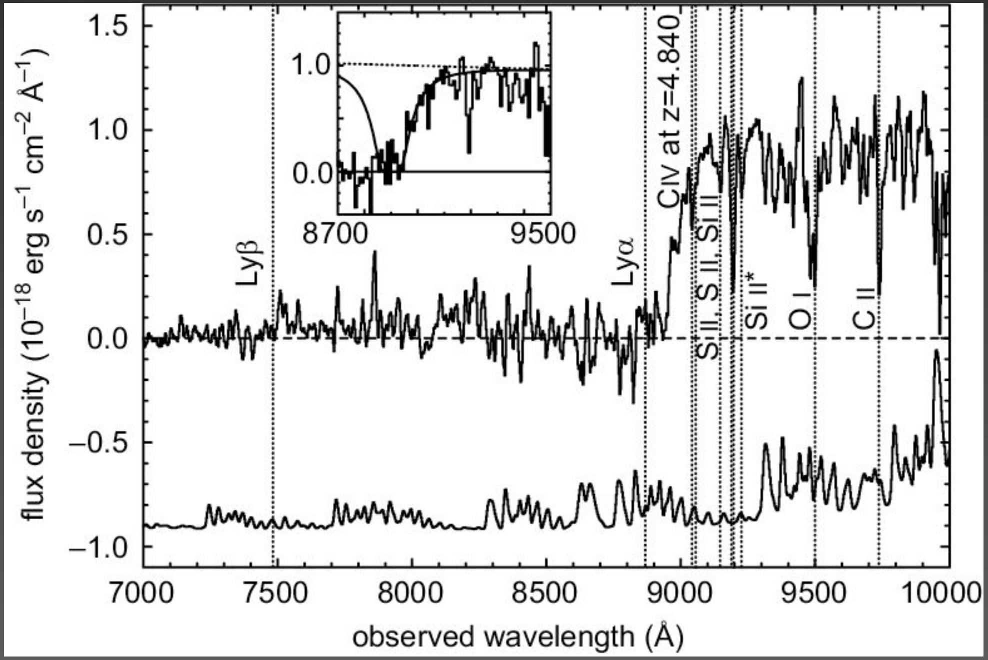
⇐

Fan et al. 2006



Fan X, et al. 2006.
Annu. Rev. Astron. Astrophys. 44:415–62

GRBs and Cosmic Re-ionization



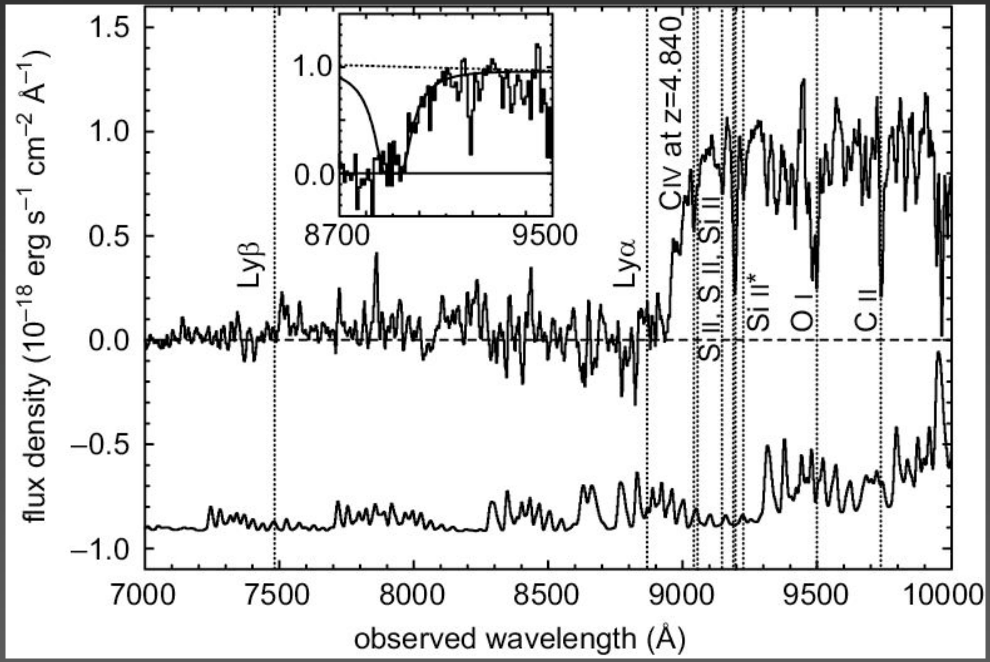
Kawai et al. 2005

$z = 6.295$

$\log N_H \sim 21.3$

$Z \sim 0.05\ Z_{\odot}$

GRBs and Cosmic Re-ionization



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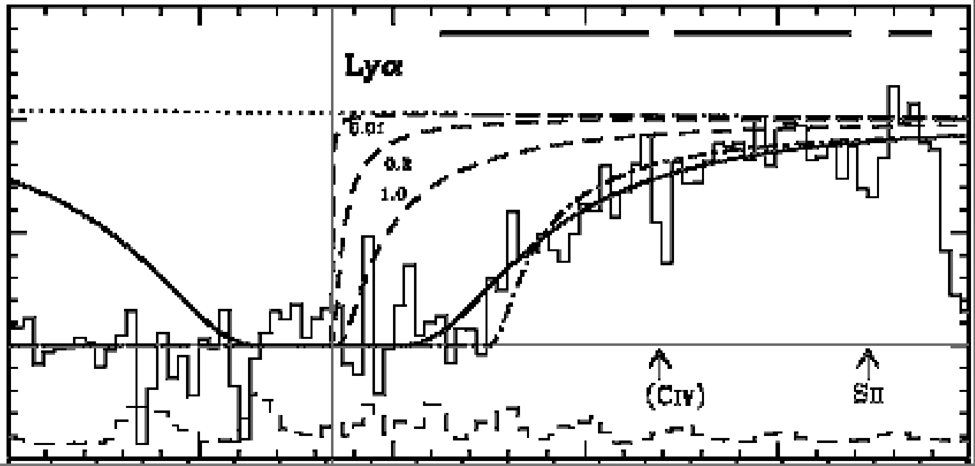
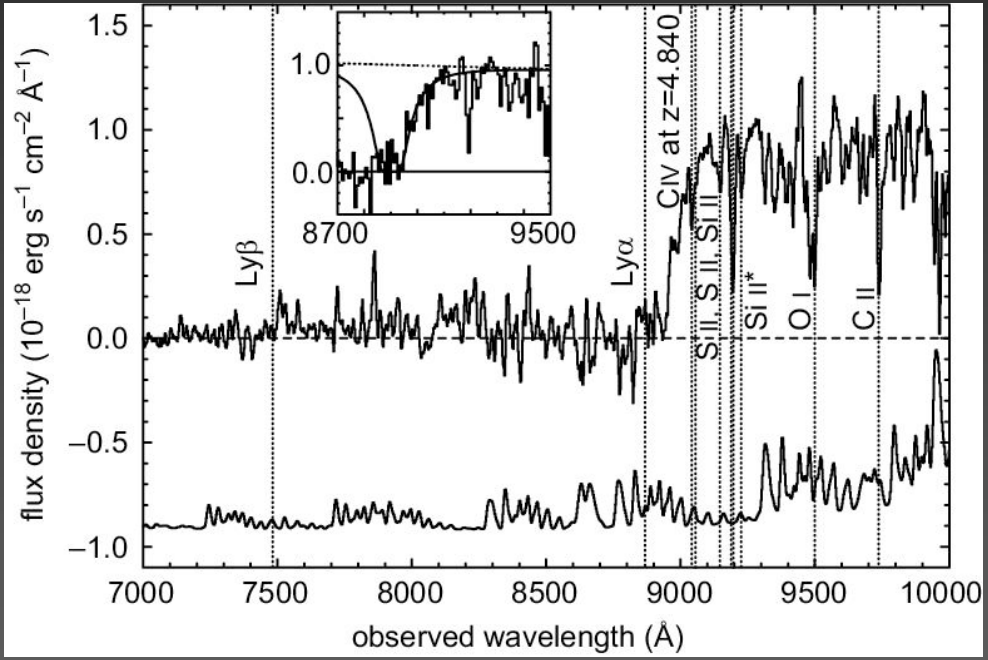


GRBs and Cosmic Re-ionization



Kawai et al. 2005

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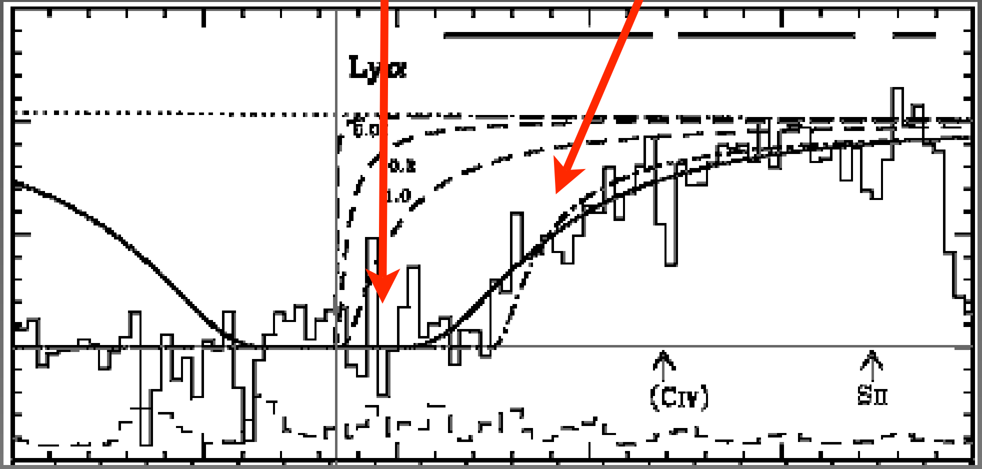
$Z \sim 0.05\ Z_\odot$

$\tau \sim 10^5$ $\tau \sim 1$



$x_H < 0.6$

Summary

- Long GRBs are the end product of some massive stars
- GRBs have been detected to $z \sim 6.3$
- Afterglow spectroscopy reveals DLAs in ~90% of the cases
- The HI columns and metallicities are on average higher than in QSO-DLAs
- Evidence for depletion in the warm ISM of the hosts but with no commensurate extinction
- The availability of precise positions and the declining flux allow deep searches for DLA countparts
- Initial observations with *Spitzer* reveal counterpart with ~0.1 L^*
- Some GRB hosts have highly obscured star formation