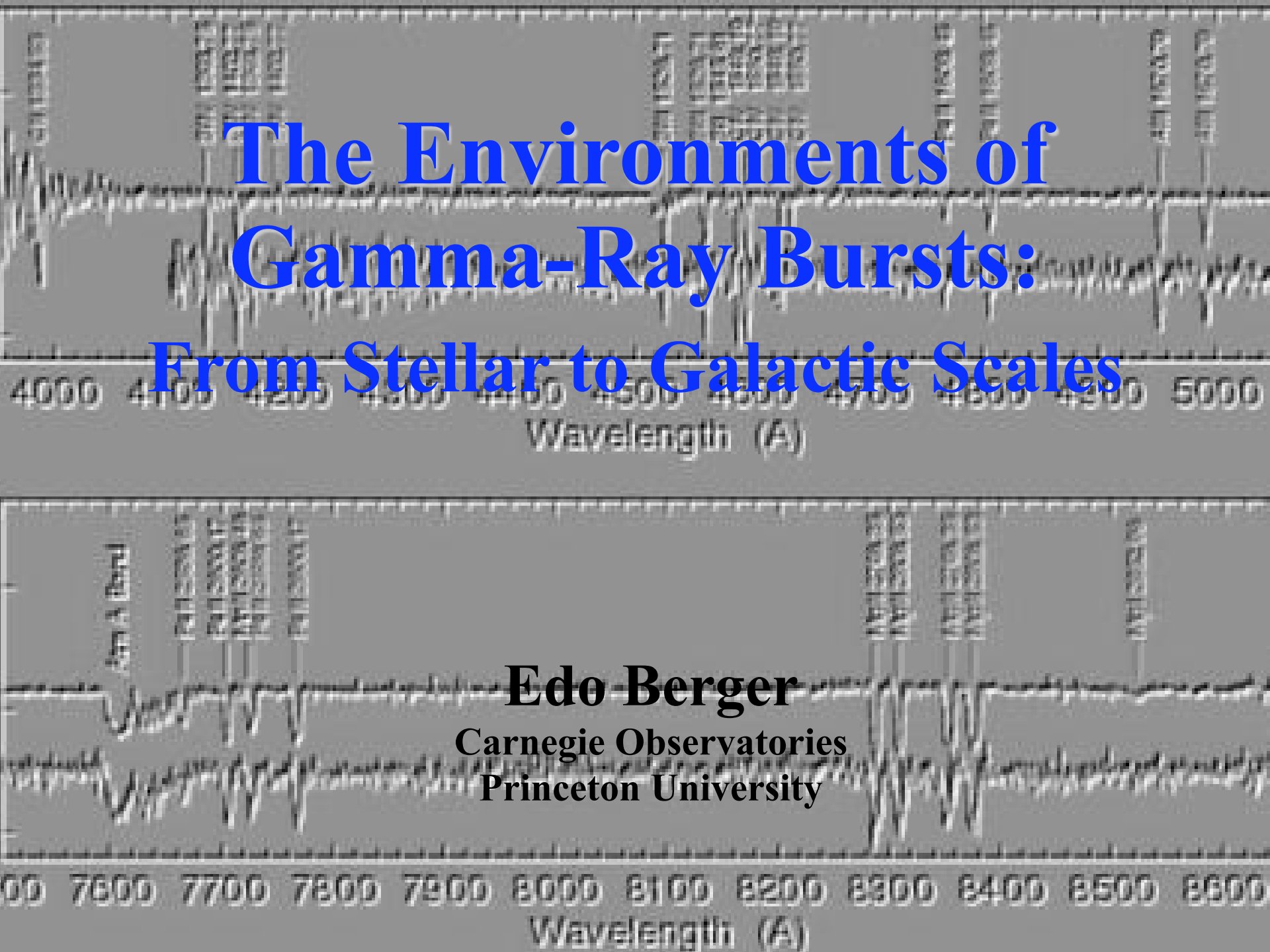


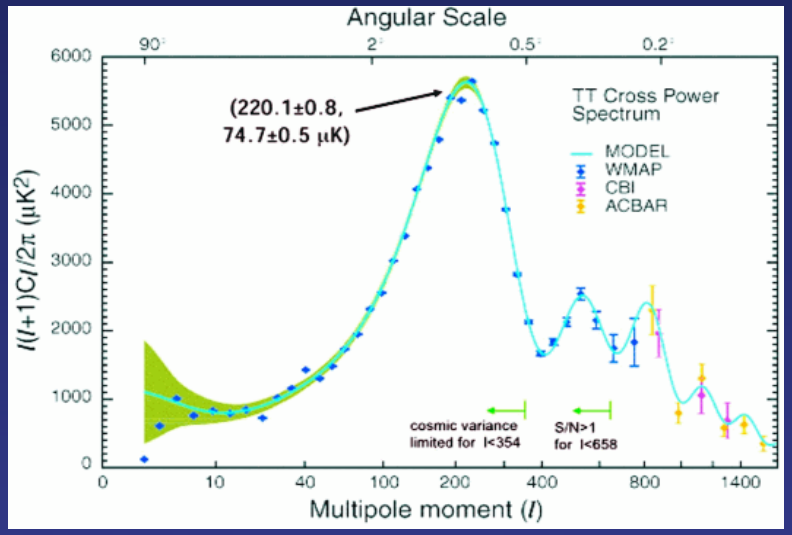
The Environments of Gamma-Ray Bursts: From Stellar to Galactic Scales

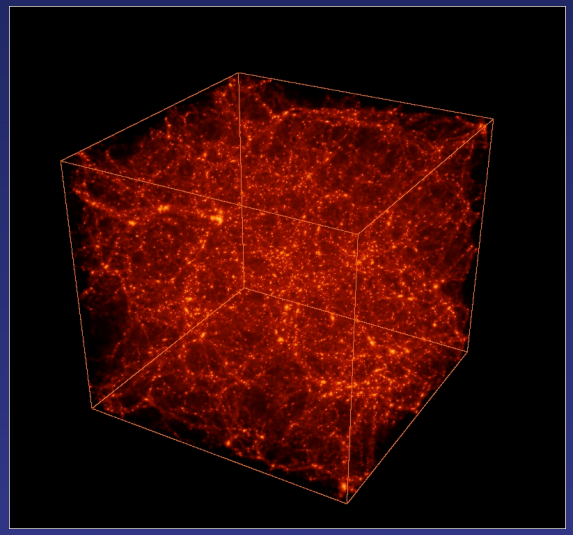
Edo Berger

Carnegie Observatories

Princeton University

Cosmic Structure Formation



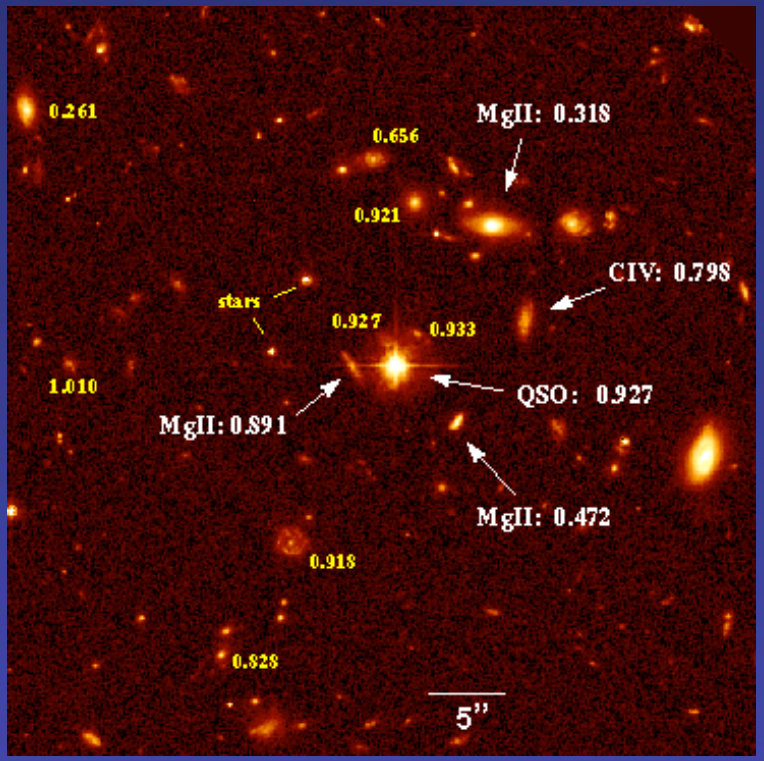


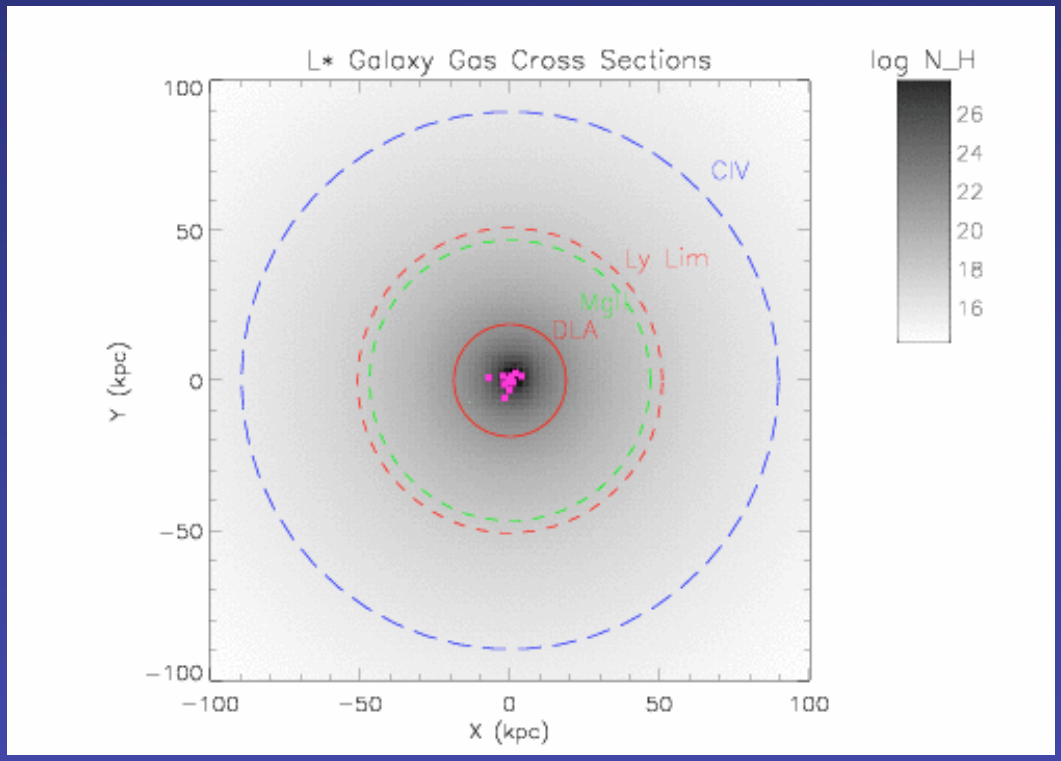
- GRBs pinpoint star-forming galaxies
- GRB afterglows probe all scales relevant for star formation
- Short GRBs may pinpoint galaxy clusters

Afterglow Absorption Spectroscopy

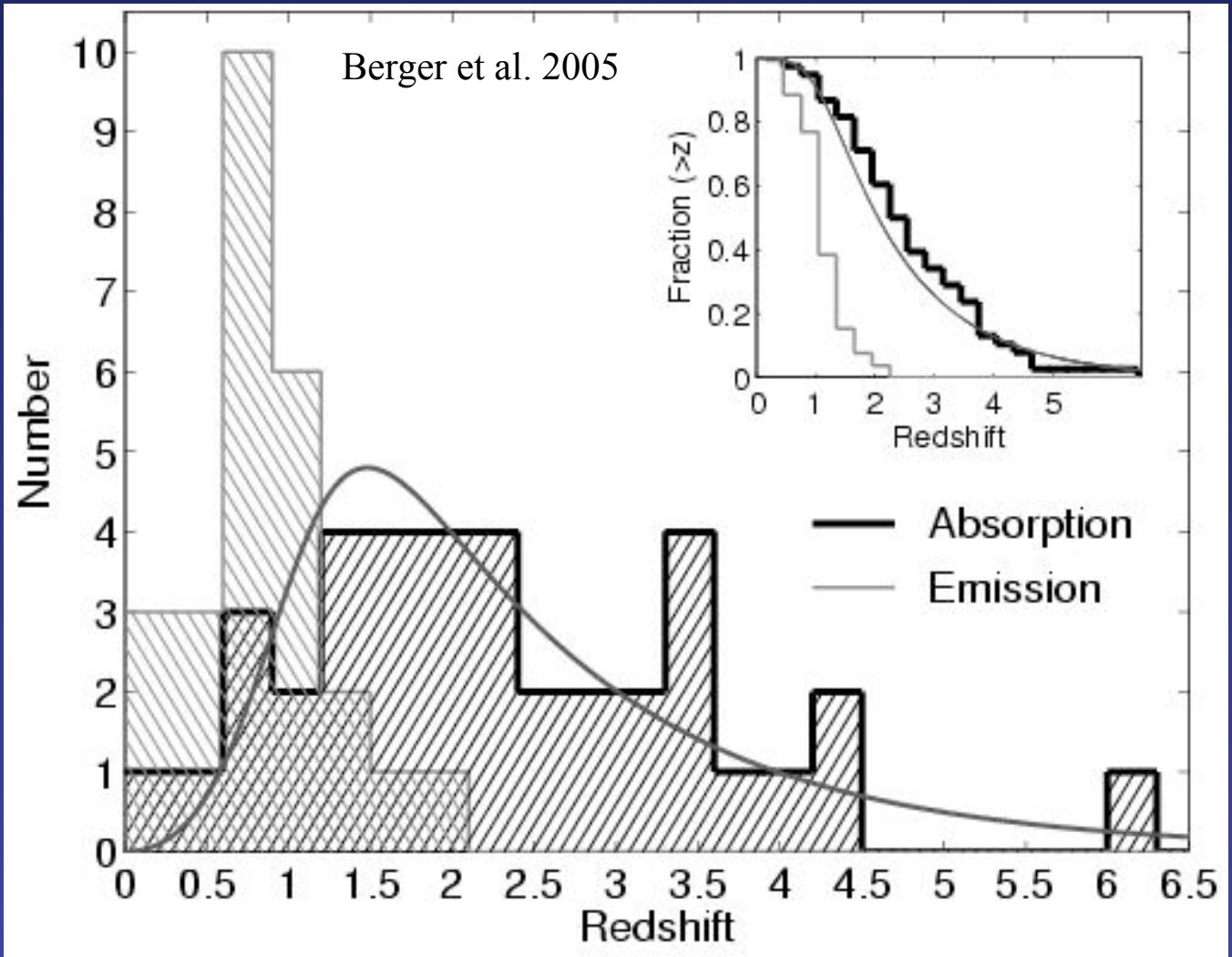
A complementary approach to quasar absorption studies

Advantages over quasars:
no proximity effect, small impact parameter, bright(er), high-*z*, fade





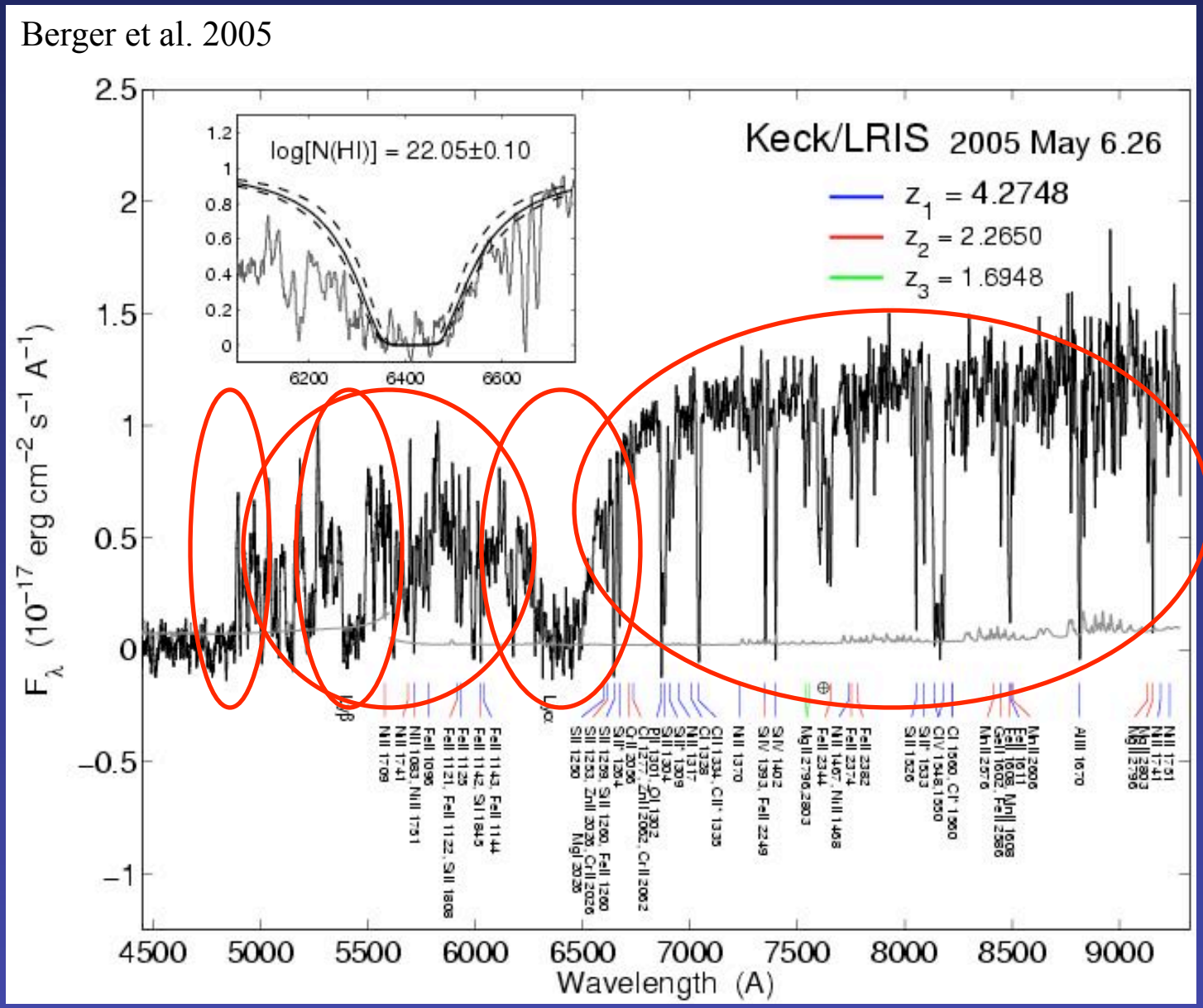
Redshift Distribution



Uniform to ~4.5, and similar to popular star formation models

GRB 050505: $z = 4.275$

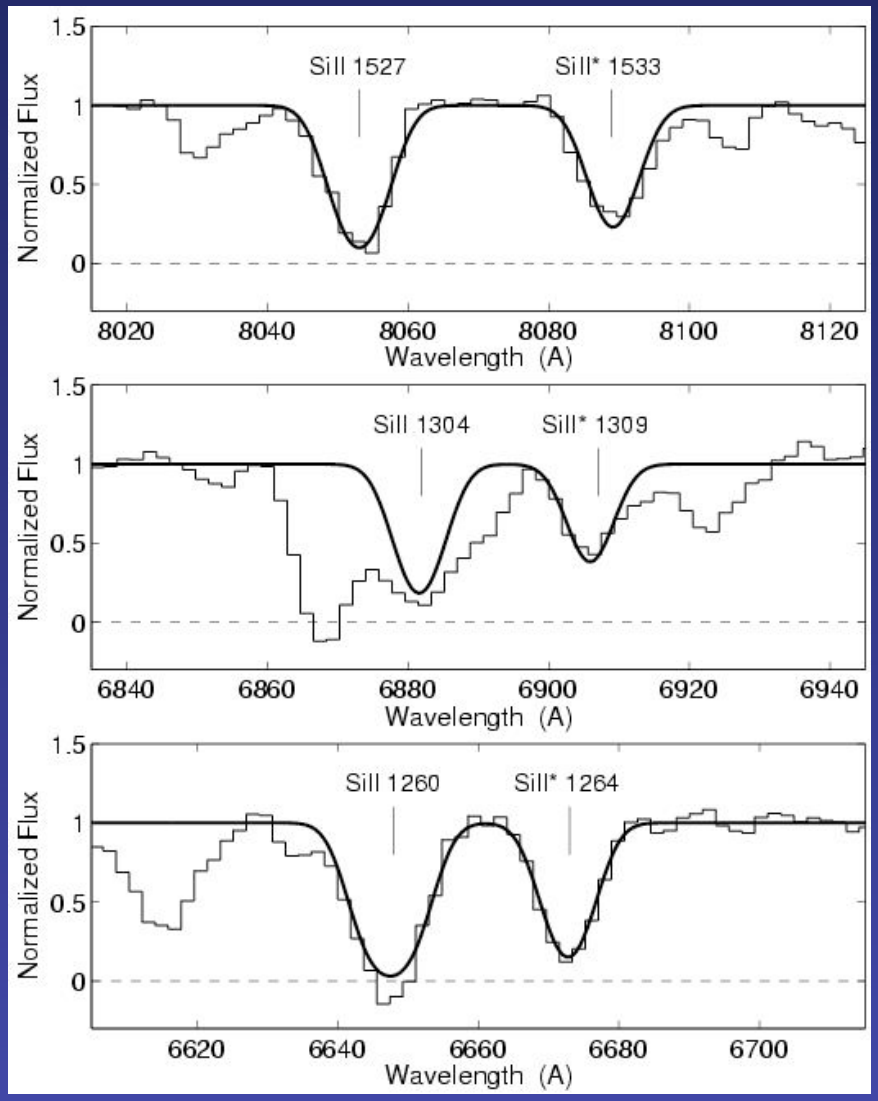
Berger et al. 2005



$Z \sim 0.06\ Z_\odot$

[Fe/S]: dust depletion

GRB 050505: SiII Fine-Structure



SiII* has never been detected in QSO sight-lines!

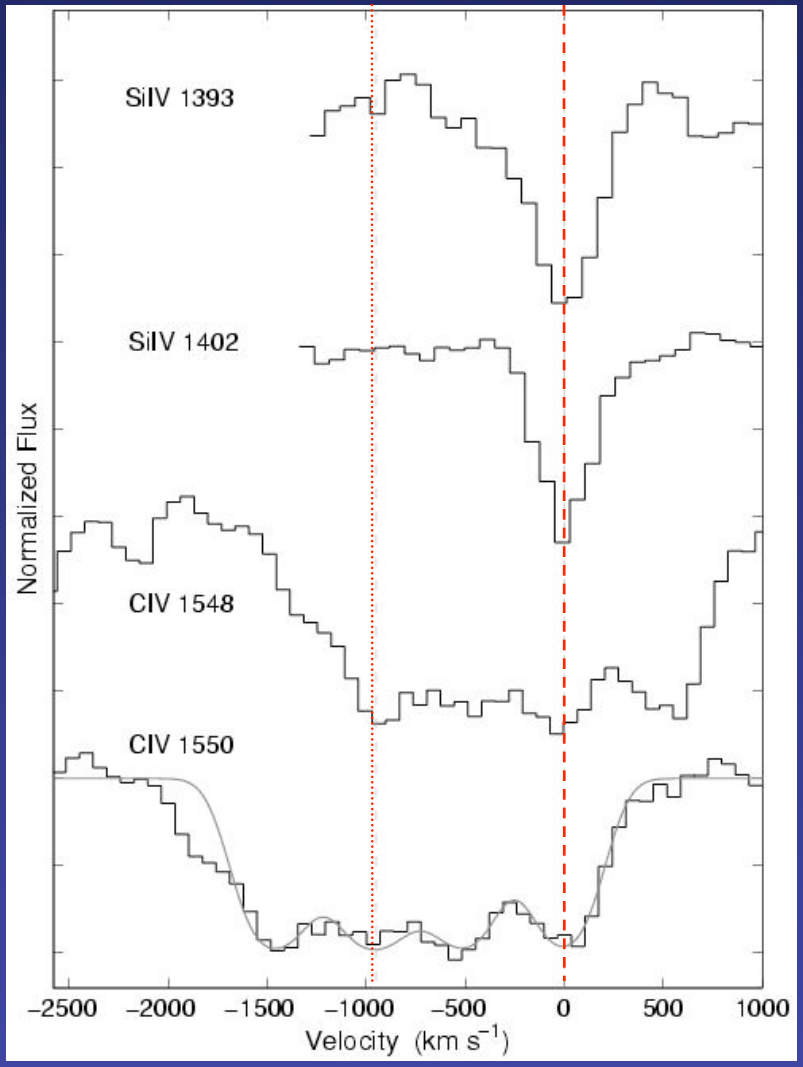
The fine-structure level is due to collisional excitation ⇒ high electron density

$\Rightarrow n_H \sim 10^2\text{-}10^4$ cm^{-3}

$\Rightarrow r \sim 3$ pc & $M \sim 10^3$ M$_\odot$

Berger et al. 2006

GRB 050505: Progenitor Properties



Berger et al. 2005

CIV extends over ~1000 km/s

Large-scale structure unlikely: for QSOs no correlation for >500 km/s (Rauch et al. 1996)

Wind from progenitor: WR winds easily account for 1000 km/s

SiIV absorption is sensitive to metallicity and mass (Leitherer & Lamers 1991)

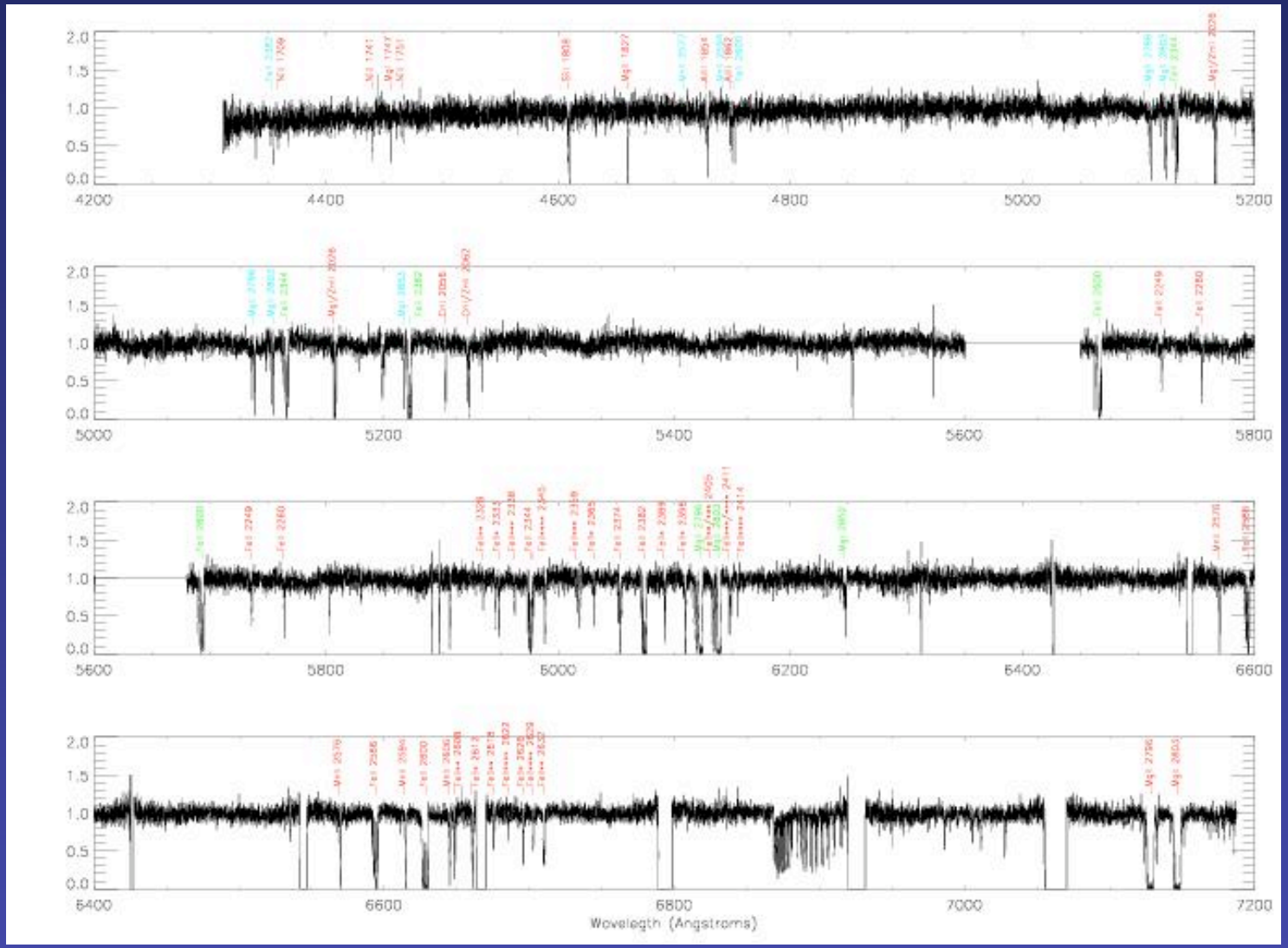
SiIV upper limit ⇒ WC Wolf-Rayet star, $Z < 0.1 Z_{\odot}$ and $M < 25\ M_{\odot}$

At 0.1 $Z_{\odot}$ the minimum mass for a wind is 45 $M_{\odot}$ ⇒ binary

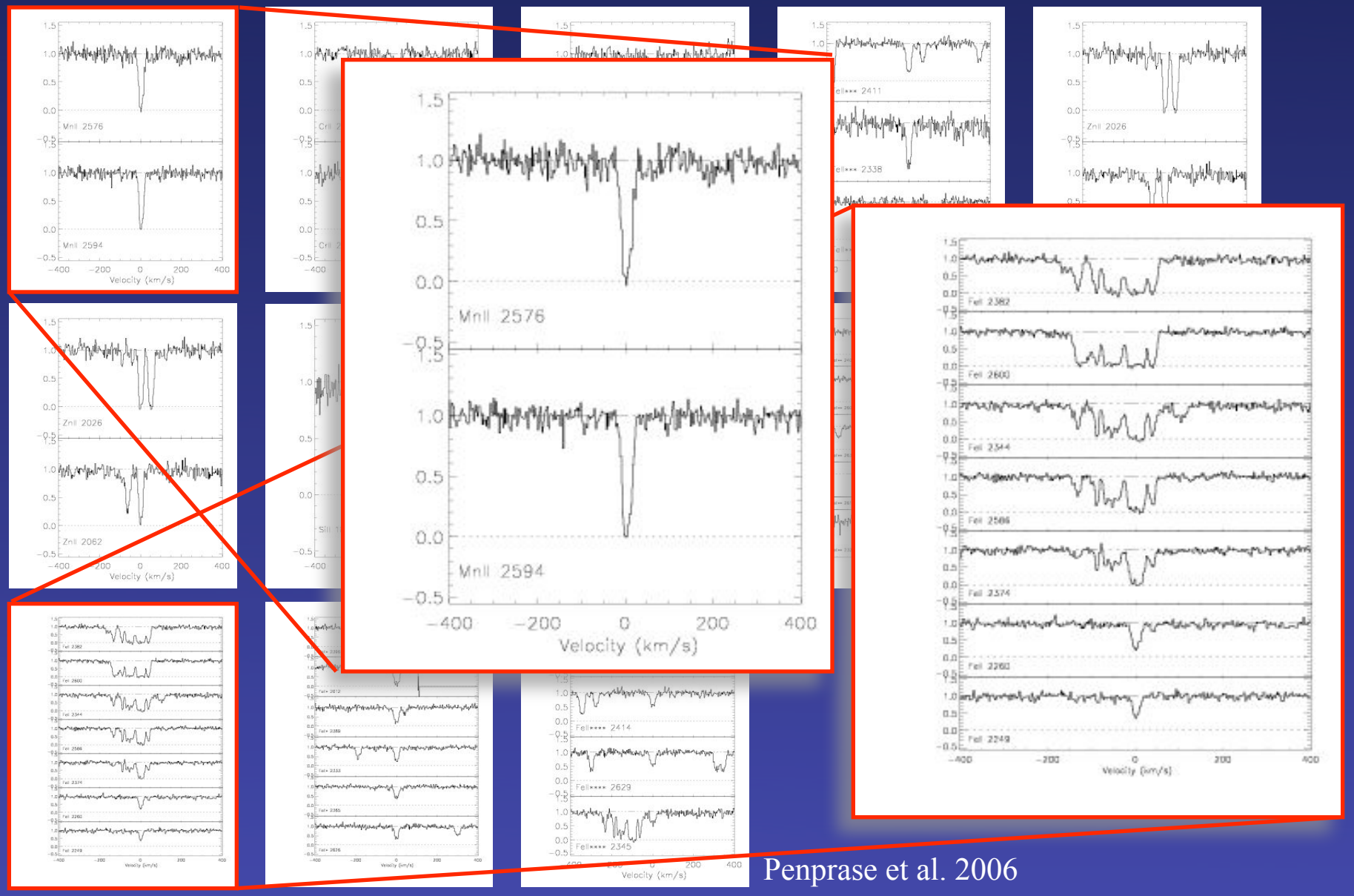
GRB 051111: Fine-structure Transitions

z = 1.54948; Keck/HIRES

Penprase et al. 2006



GRB 051111: Fine-structure Transitions

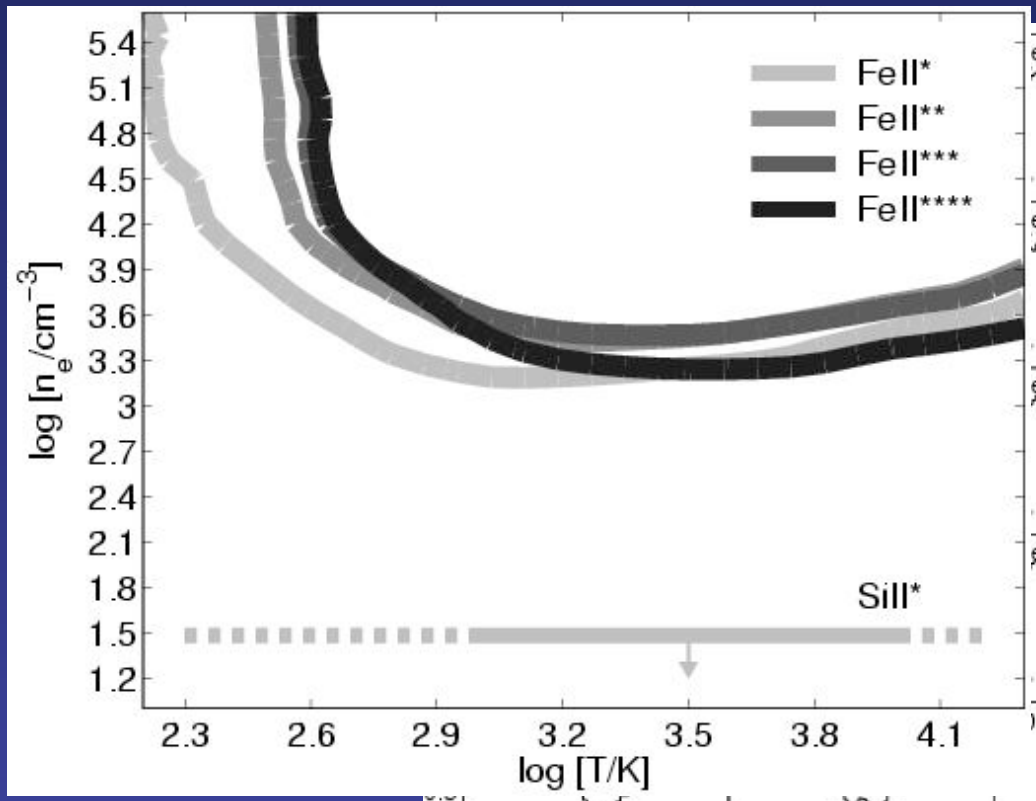


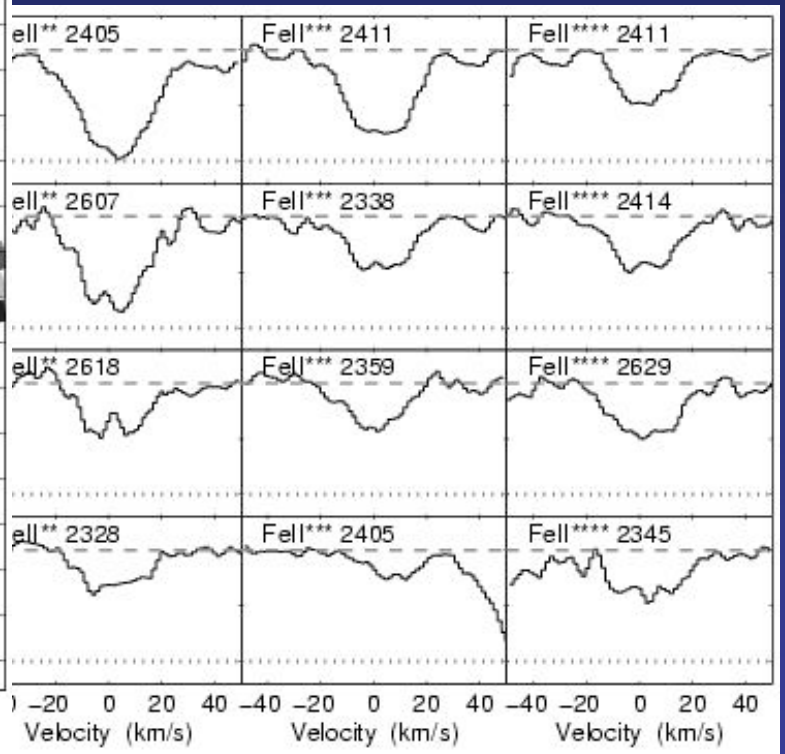
Penprase et al. 2006

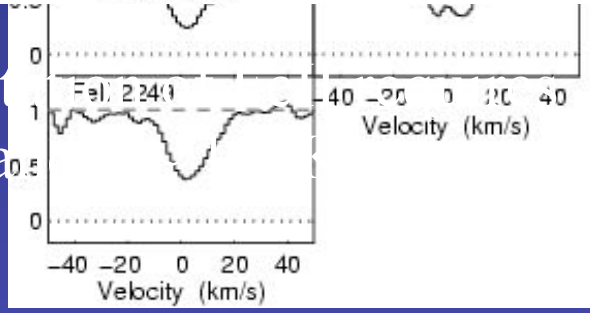
GRB 051111: Fine-structure Transitions

Berger et al. 2005b

Fe II Fe II* Fe II** Fe II*** Fe II****







Collisional excit

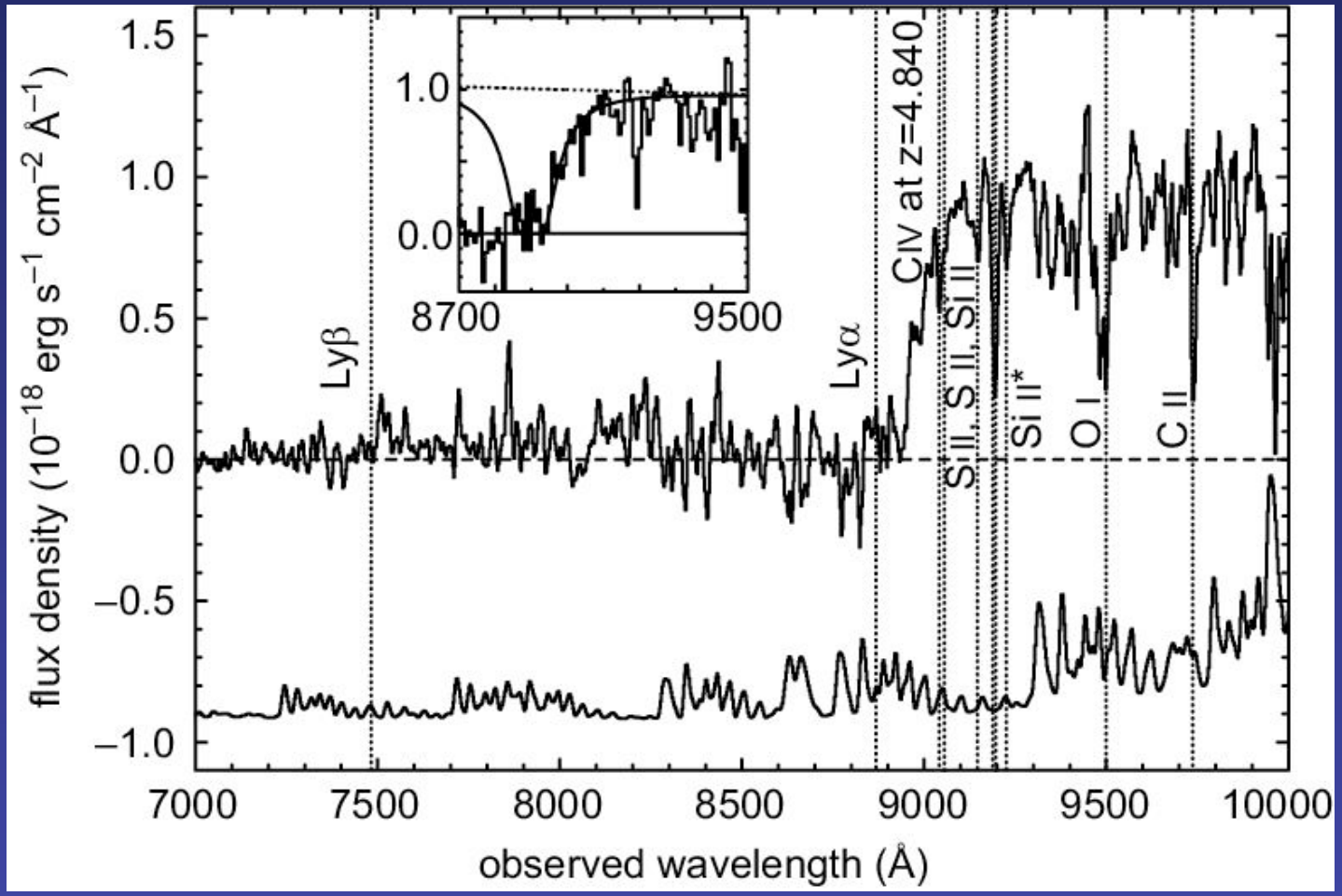
$n_e \sim 4000$ cm^{-3} a

Berger et al. 2006

GRB 050904: $z = 6.295$

$z = 6.295$; $\log N_H \sim 21.3$; $Z \sim 0.1\ Z_\odot$

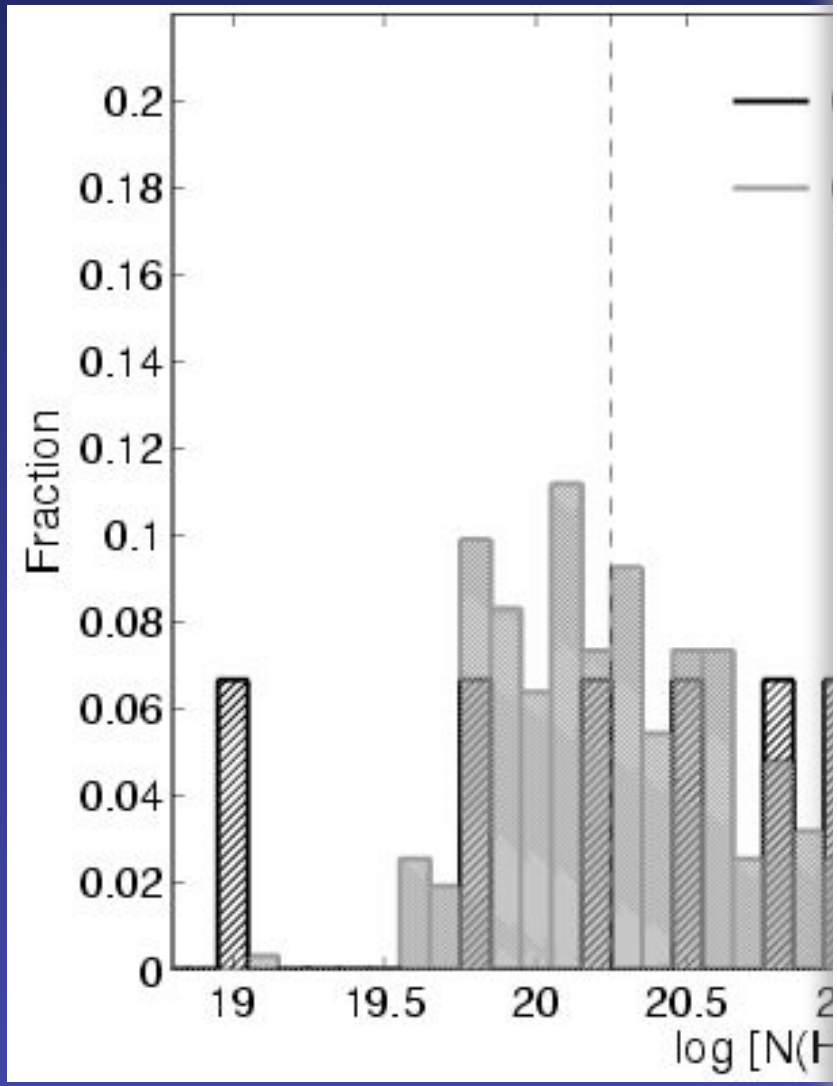
Kawai et al. 2005

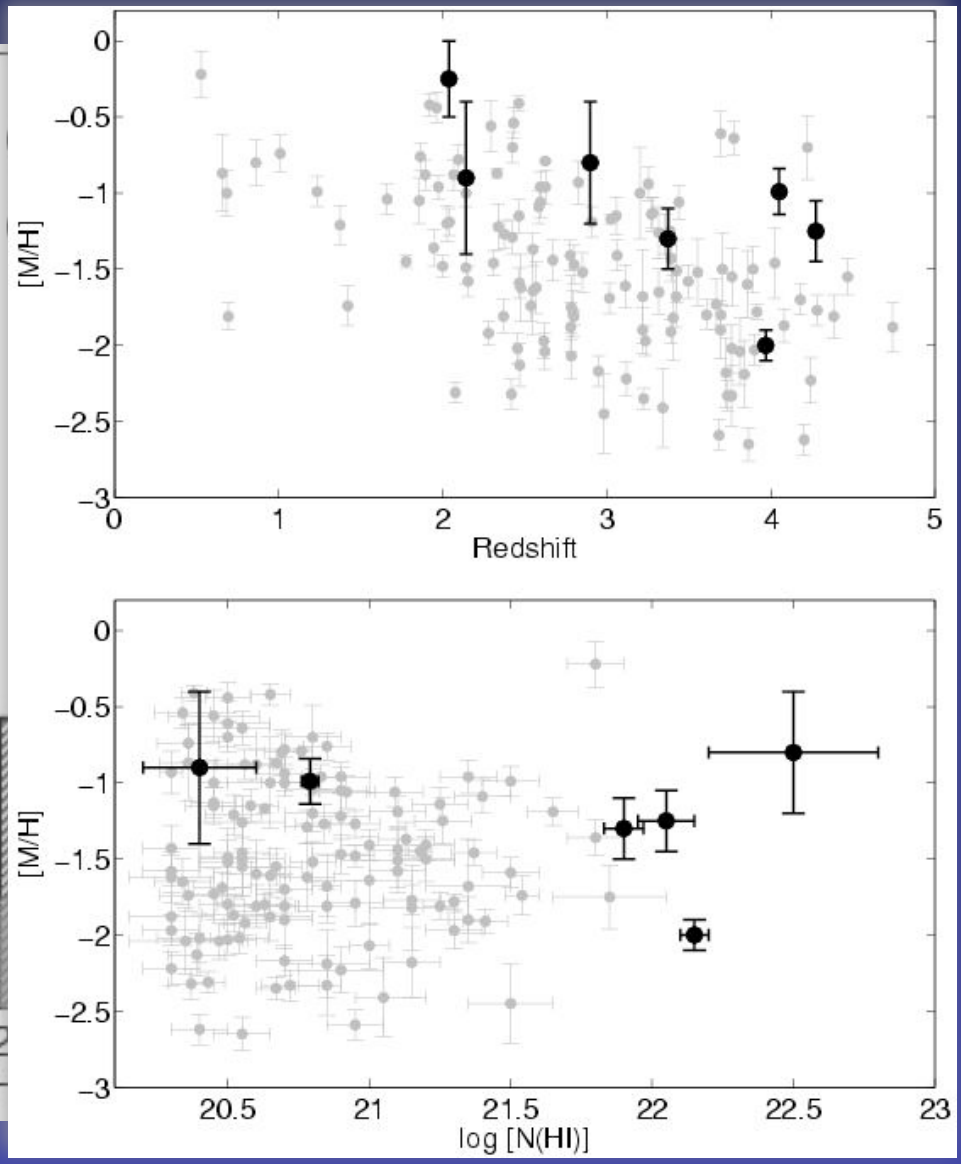


IGM absorption inconsistent with Lyβ; $x_H < 0.6$ (95% c.l.)

GRB-DLAs

Berger et al. 2005



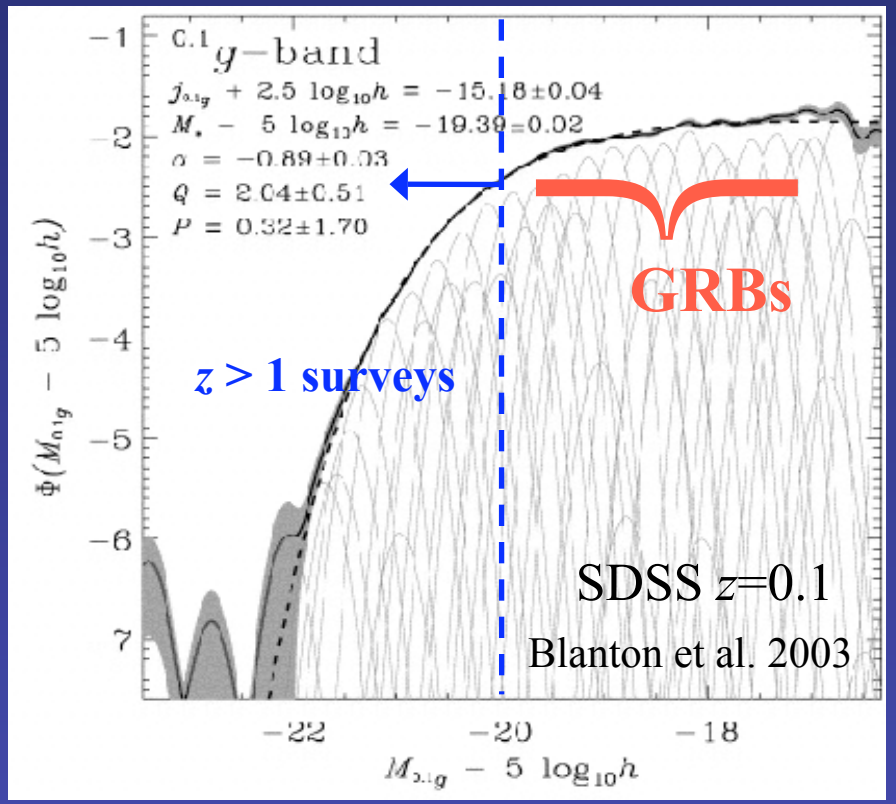


The Advantages of GRB Host Galaxies

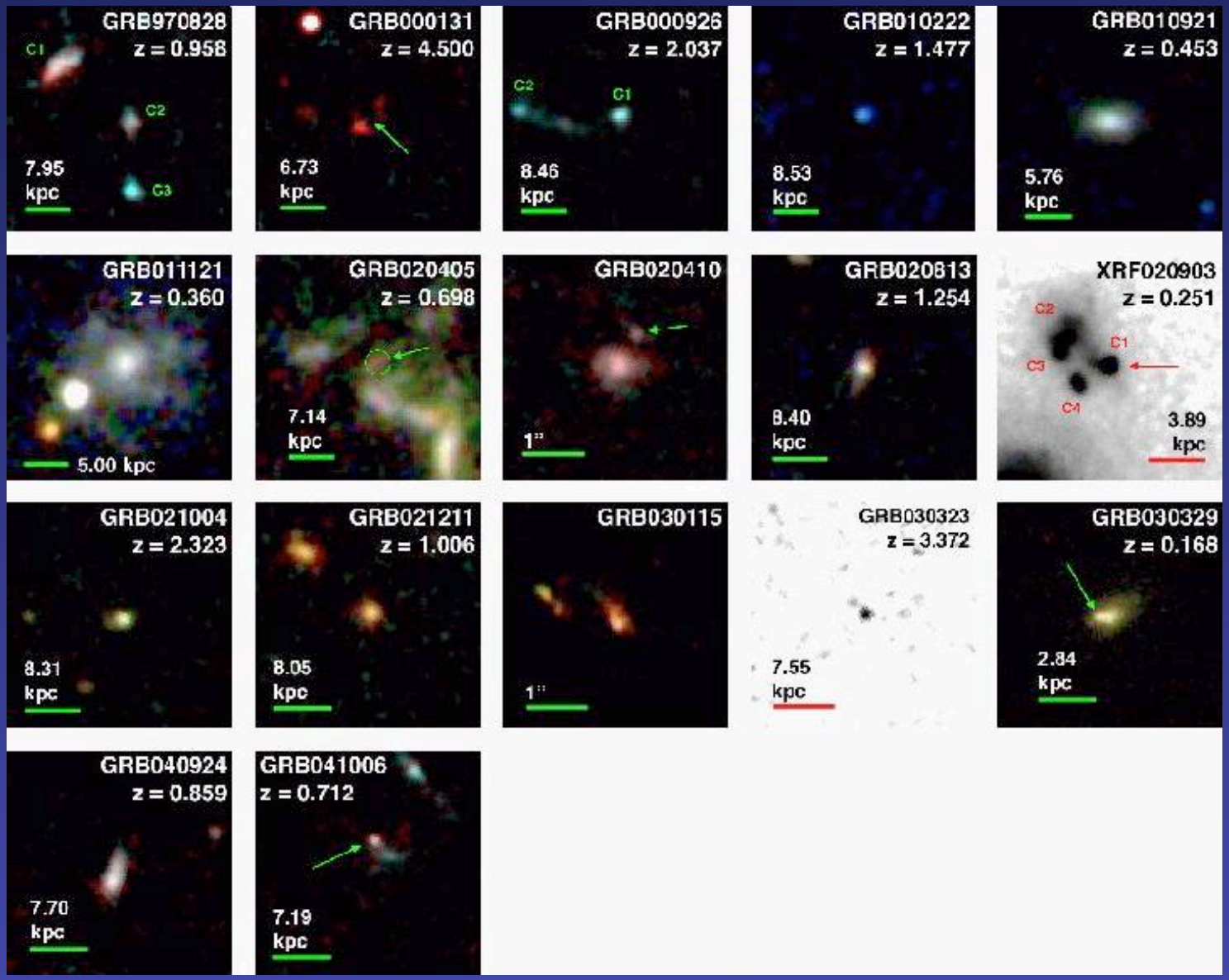
GRBs offer an alternative galaxy-selection technique which is not susceptible to current selection effects

- ✓ Redshift obtained from absorption spectra
- ✓ Selection independent of dust thanks to dust-penetrating γ–rays
- ✓ Selection independent of emission properties in any band
- ✓ Uniform selection at all *z*
- ✓ GRBs can be detected at very high redshifts ($z > 10$)

- ✖ small sample (~65 galaxies)
- ✖ biases?

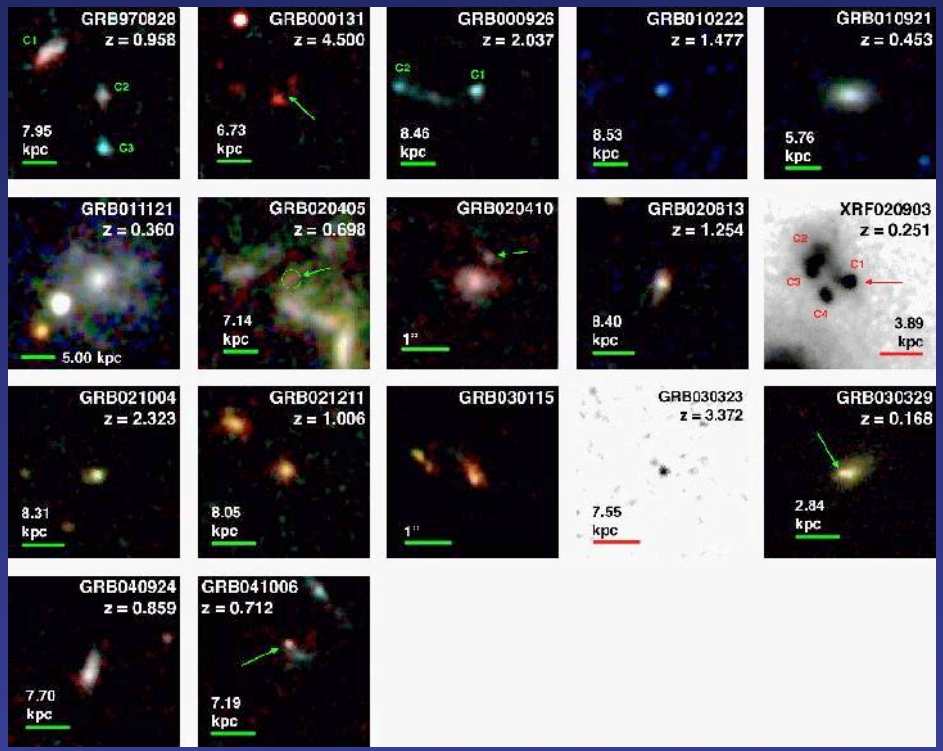


Host Galaxy Morphologies



Wainwright, Berger, & Penprase 2005

Host Galaxy Morphologies



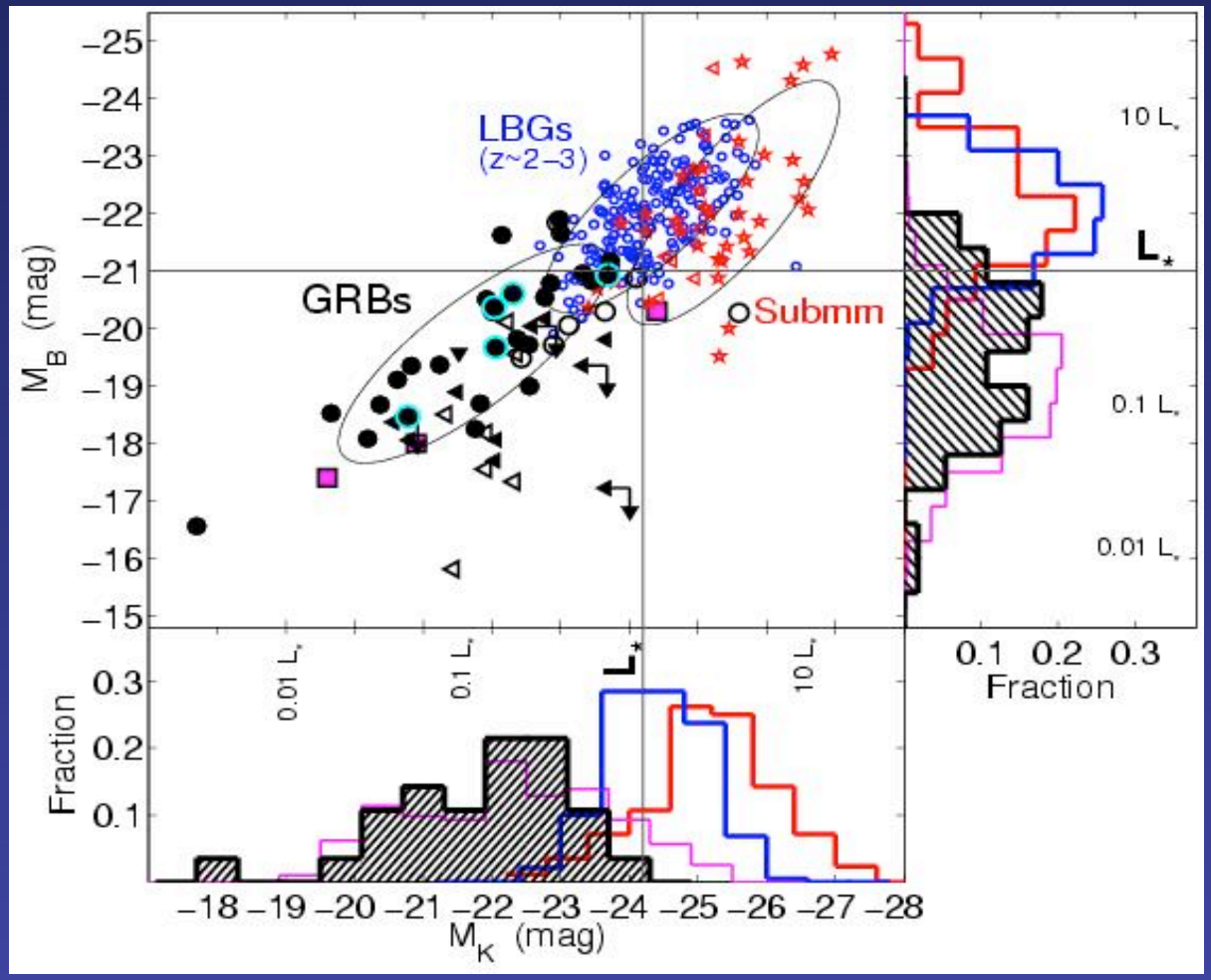
Wainwright, Berger, & Penprase 2005

~50% of GRB hosts exhibit a merger/disturbed morphology; 2-3 times higher than in field galaxies of similar magnitude.

The lack of ordered spiral structure may indicate recent merger activity

"The high fraction of galaxies which show signs of merging and interaction indicate that … GRBs are less likely to occur in stable disk galaxies"

Luminosity Function of Star-Forming Galaxies

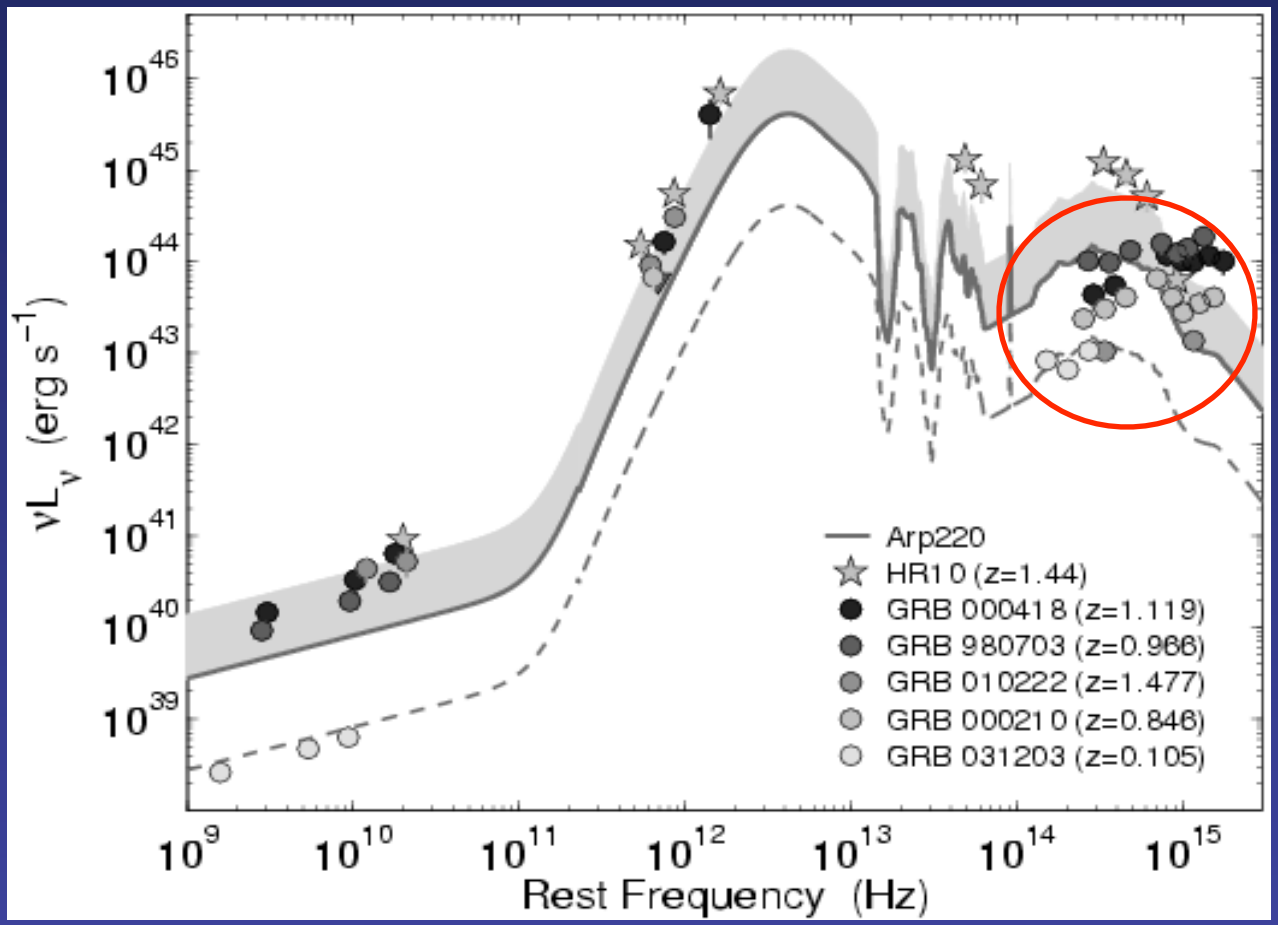


Berger et al. 2006

~2/3 of the star formation takes place in galaxies well below *L

Obscured Star Formation in GRB Hosts

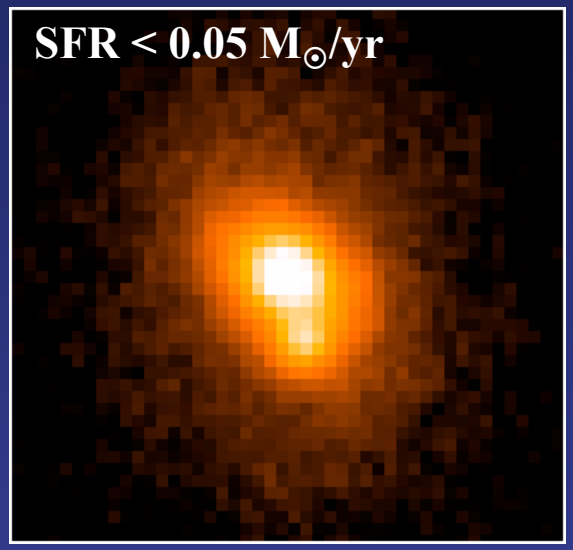
Berger et al. 2003

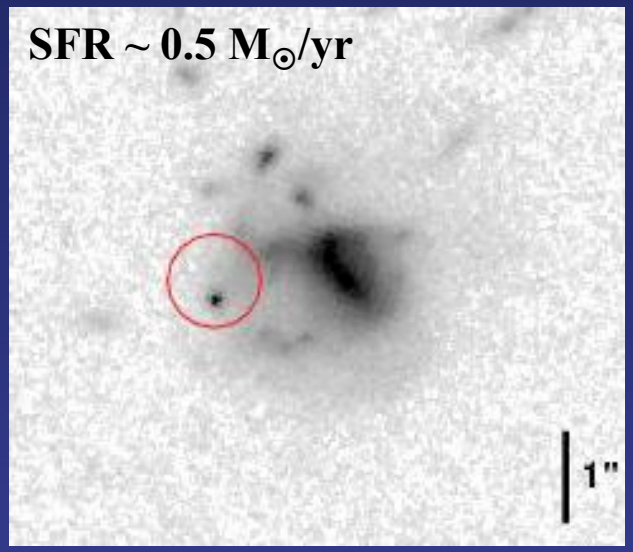


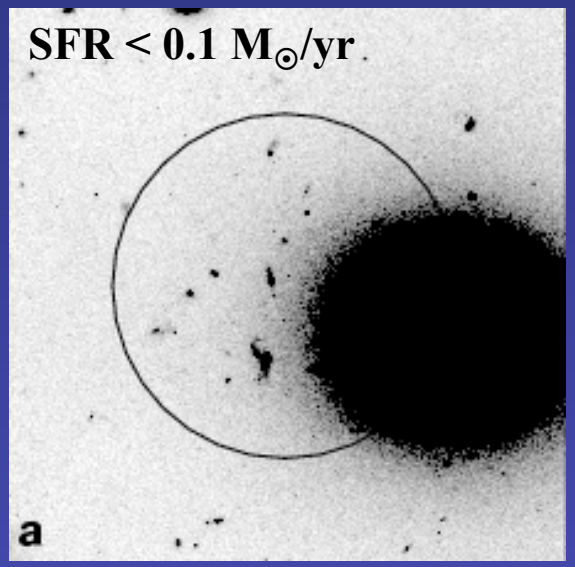
~ 15% detection rate; ~100-500 $M_\odot$ /yr

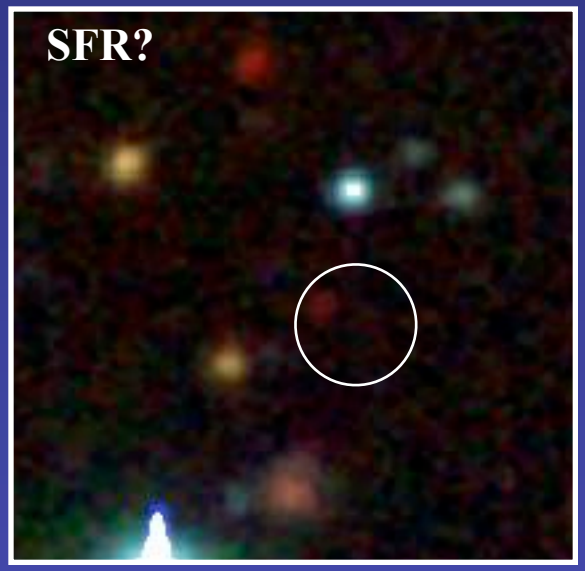
blue optical colors ⇒ missed in blank sky submillimeter surveys

Short GRB Host Galaxy Properties





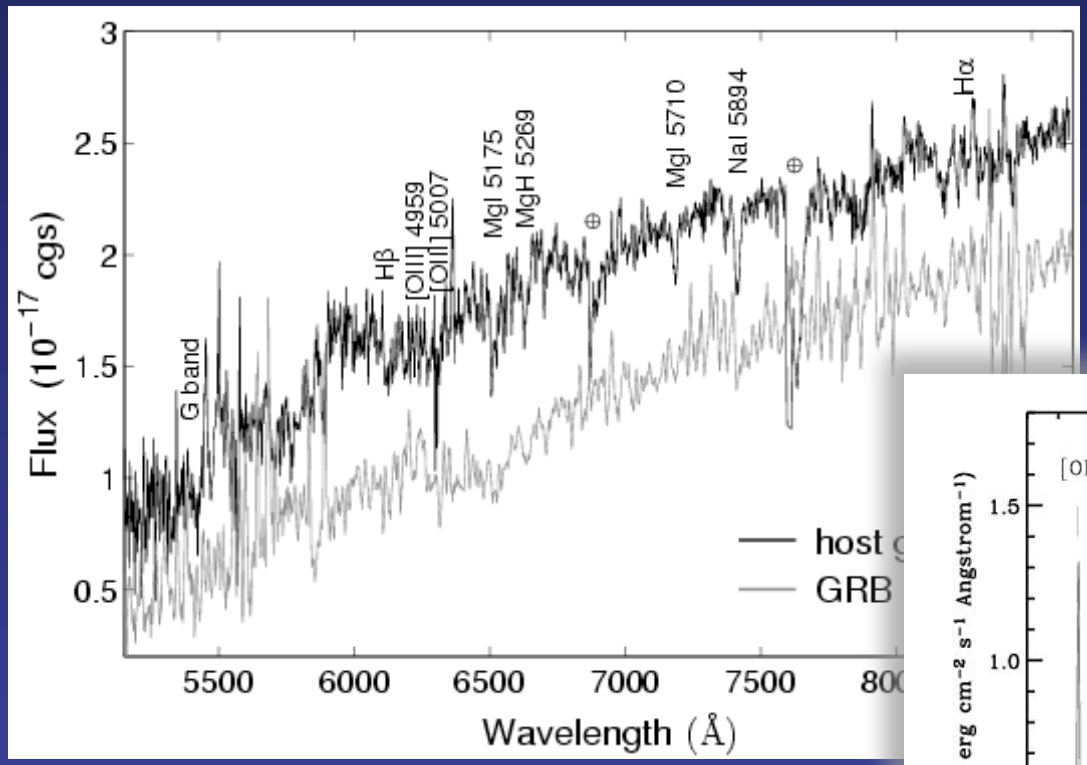




Short GRBs occur in both elliptical and star-forming galaxies

(Berger et al. 2005, Bloom et al. 2005, Fox et al. 2005, Soderberg et al. 2006)

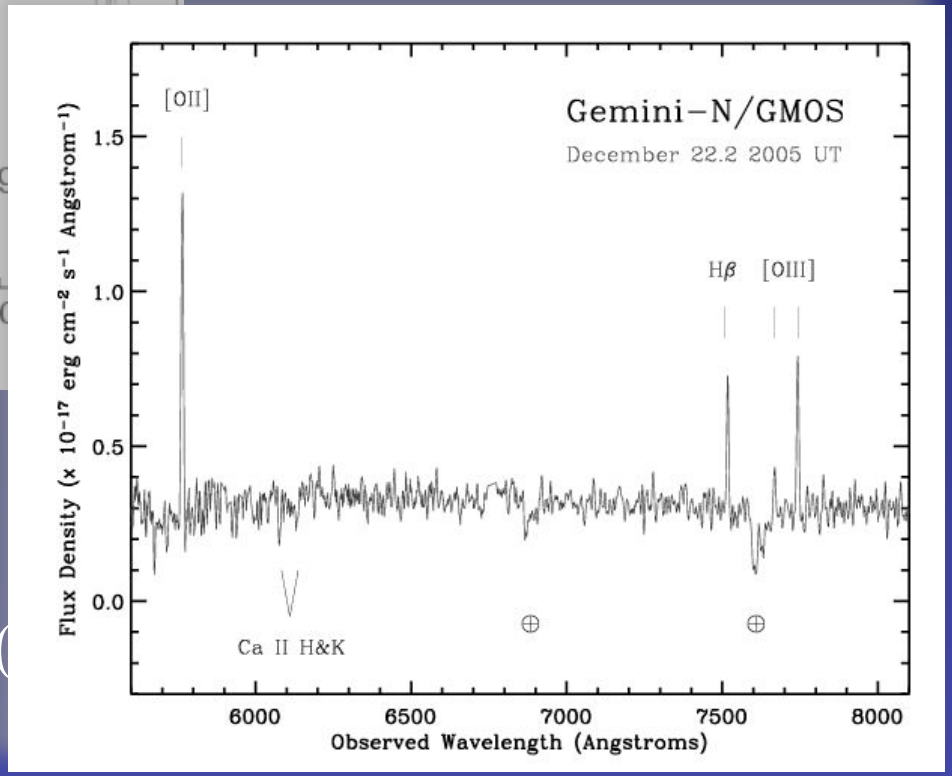
Short GRB Host Galaxy Properties



Berger et al. 2006

z =0.257 elliptical galaxy

Soderberg et al. 2006



z =0.546 star-forming galaxy (
1 $M_\odot$/yr and $Z \sim Z_\odot$)

GRB Absorption Spectroscopy

GRBs probe all the scales relevant for understanding star formation at high redshift: winds, star-forming regions, ISM

- GRB-DLAs provide a unique way to tie DLAs and star-formation
- The host luminosity function extends further down than other surveys; consistent with ~2/3 of the star formation being missed
- GRB hosts are typically low-mass systems (low metallicity?)
- Possibly a larger fraction of interacting/merging systems
- Hosts of short GRBs show evidence for old stellar populations
- We discovered a "missing link" bona-fide cluster at z~1.8