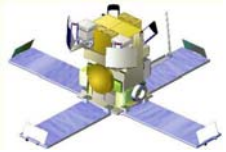
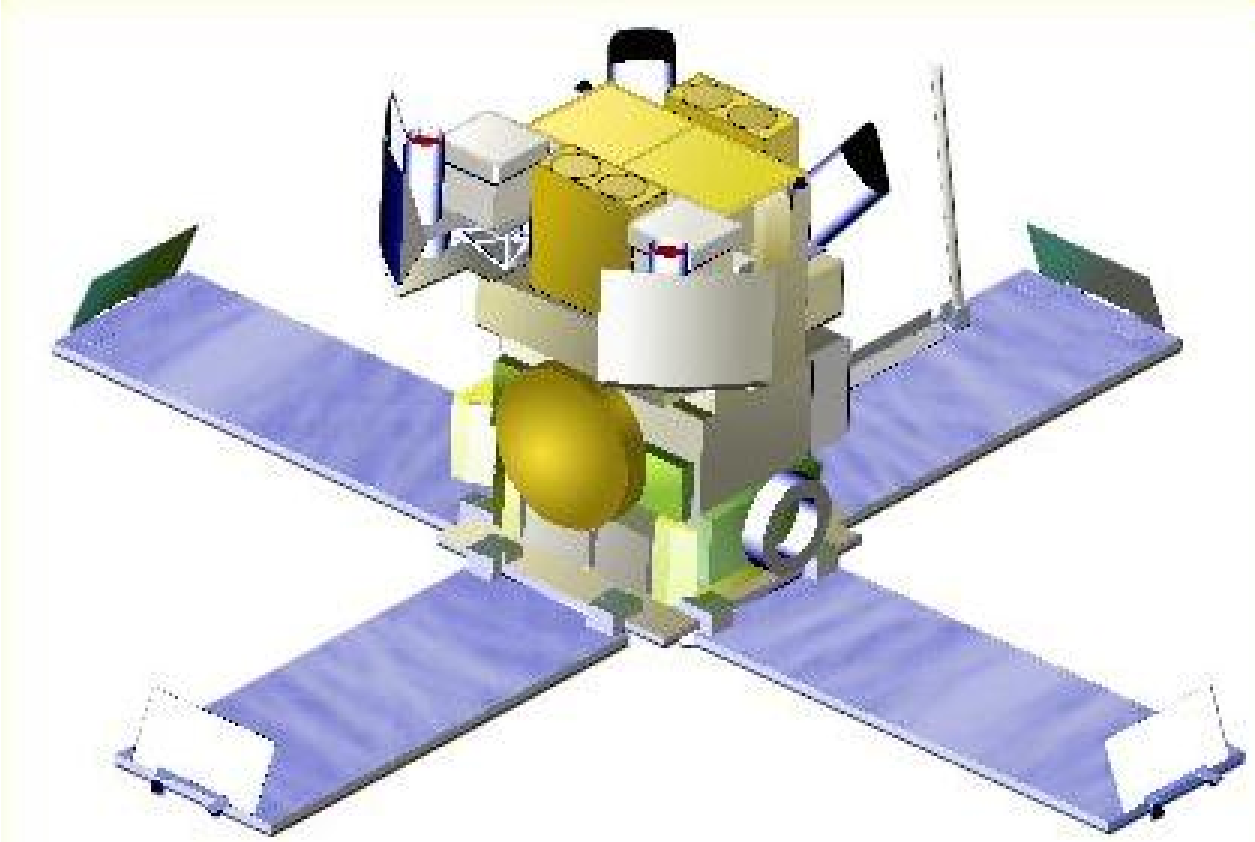
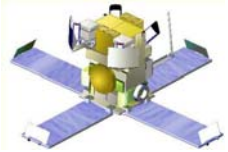


GRBs as Probes of First Light and the Reionization History of the Universe

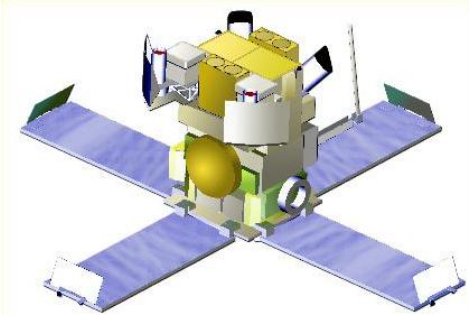
D. Q. Lamb (U. Chicago)



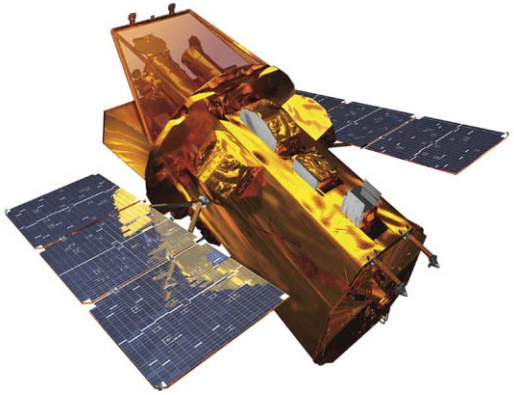
Conference on First Light and Reionization
Irvine, CA, 19-21 May 2005



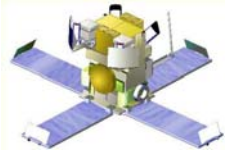
Status of GRB Missions



- HETE-2 continues to “go great guns:”
  - Currently in 4th year of mission
  - It is currently localizing ~ 25 GRBs yr^{-1}
  - It has localized 77 GRBs so far
  - 30 of these localizations have led to the detection of optical afterglows
  - 17 of these afterglows have led to redshift determinations

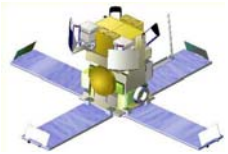


- Swift is now also “going great guns:”
  - Successfully launched 20 November 2004
  - Commissioning phase completed 5 April 2005
  - It is currently localizing ~ 90 GRBs yr^{-1} (~ 50 yr^{-1} well-suited for optical and NIR follow-up obs.)
  - It has localized 39 GRBs so far
  - 10 of these localizations have led to the detection of optical afterglows
  - 5 of these afterglows have led to redshift determinations



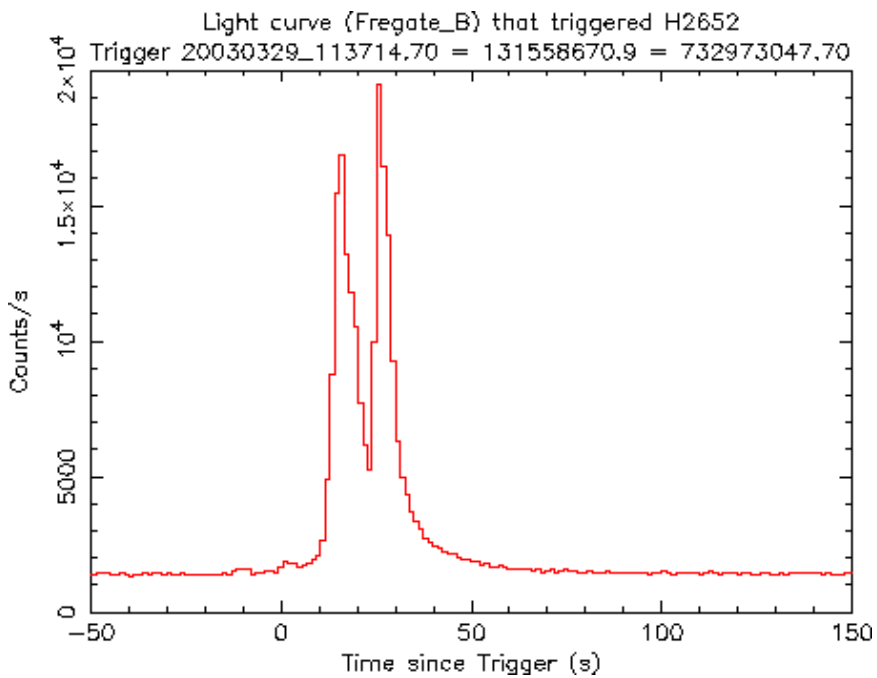
Outline of This Talk

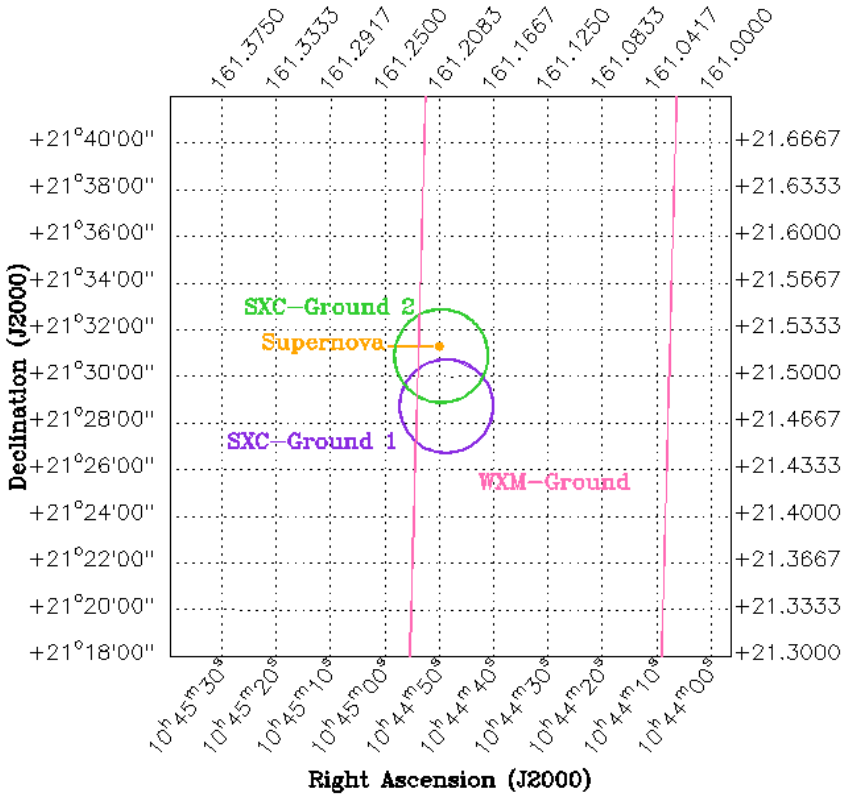
- GRB-SN Connection
  - GRB 030329/SN 2003dh
- Detectability of GRBs and their optical/NIR afterglows out to very high redshifts ($z > 5$)
  - GRBs
  - NIR afterglows
- GRBs as (possible) powerful probes of first light and reionization
  - GRBs in cosmological context
  - Star-formation history of universe
  - Reionization history of universe
  - Metallicity history of universe



GRB030329: HETE "Hits a Home Run"

Vanderspek et al. (2004)

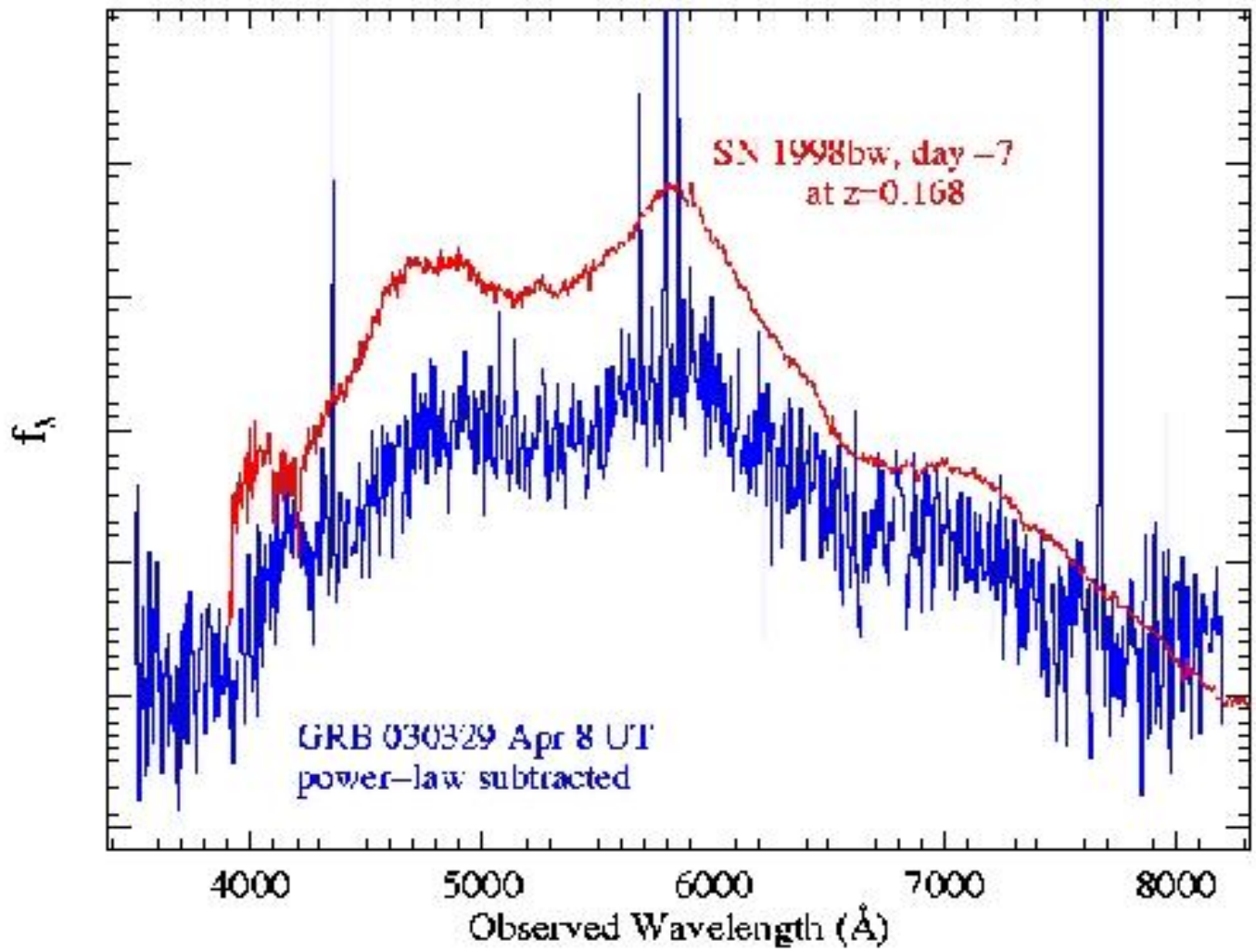


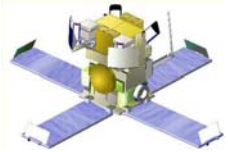


z = 0.1675 ⇔ probability of detecting a *bright* GRB this close by is ~1/5000 => unlikely that HETE-2 or *Swift* will see another such event

GRB030329:Spectrum of SN 2003dh

Stanek et al. (2003; see also Hjorth et al. 2003)

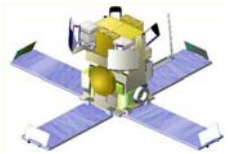




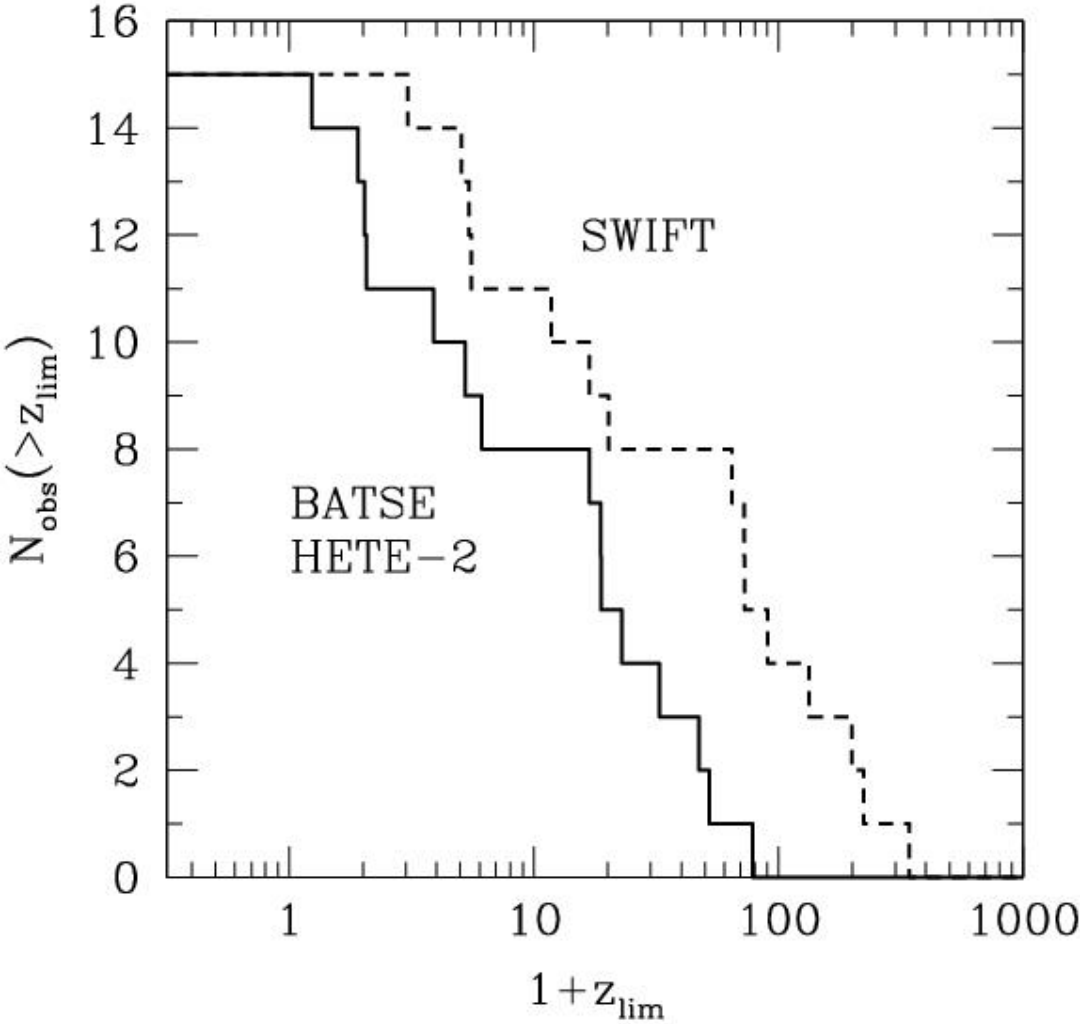
GRB030329: Implications

- HETE-2—localized burst GRB030329/SN 2003dh confirms the GRB – SN connection

- Result strengthens the expectation that GRBs occur out to $z \sim 20$, and are therefore *a powerful probe of first light and reionization*

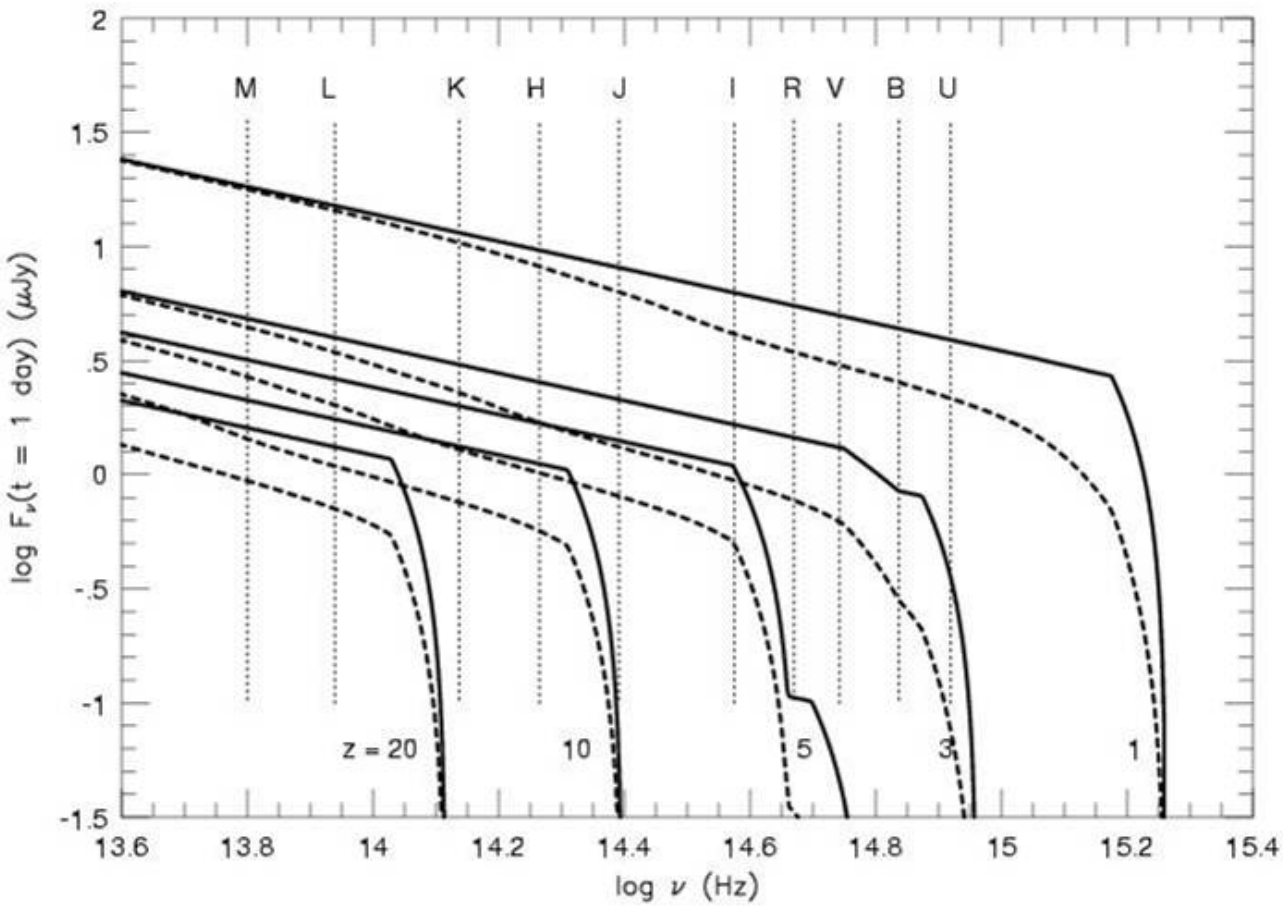


Detectability of GRBs at *z* > 5



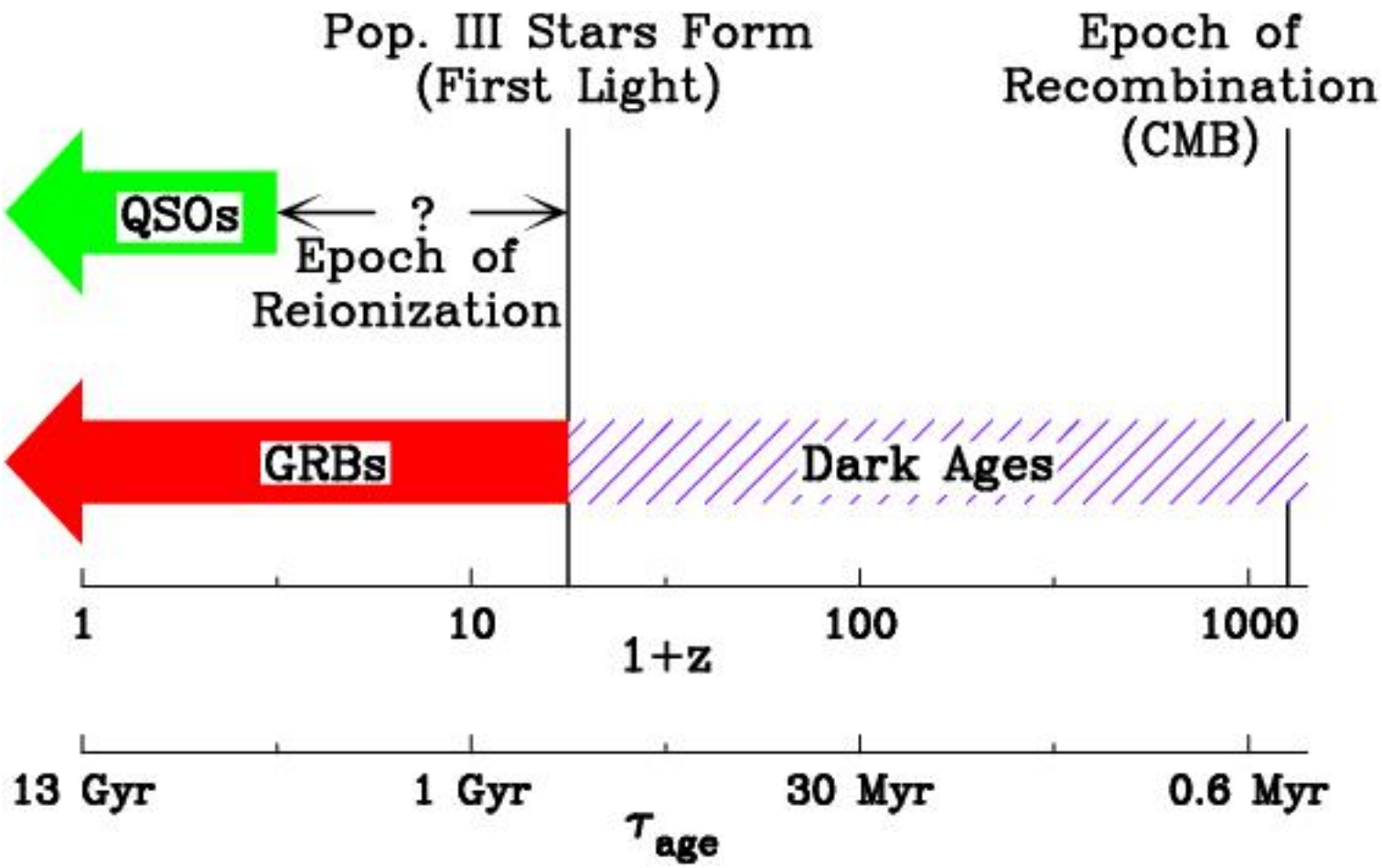
Lamb and Reichart (2000; see also Bromm and Loeb 2002)

Detectability of GRB Optical Afterglows at *z* > 5



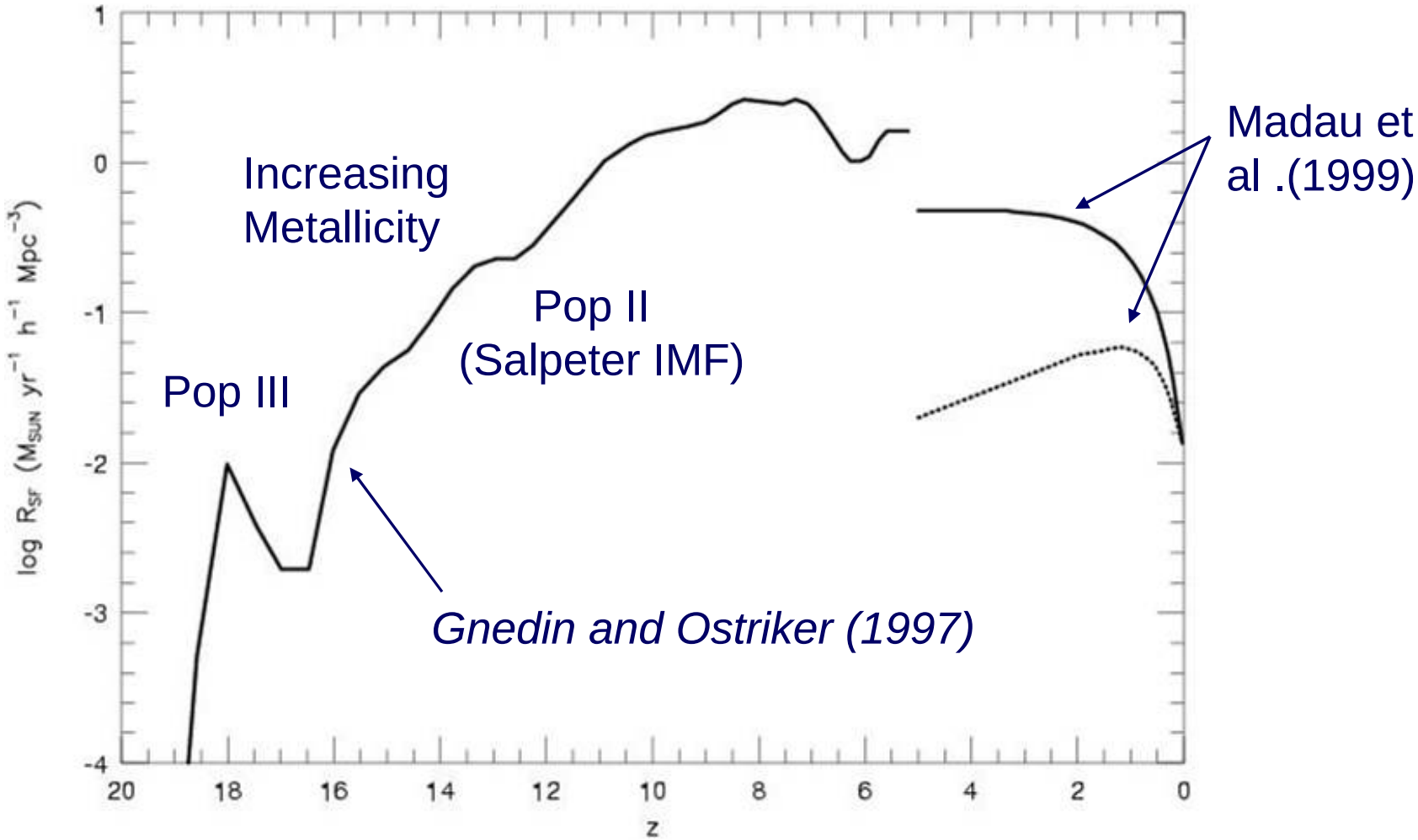
Lamb and Reichart (2000; see also Ciardi and Loeb 2001)

GRBs in Cosmological Context



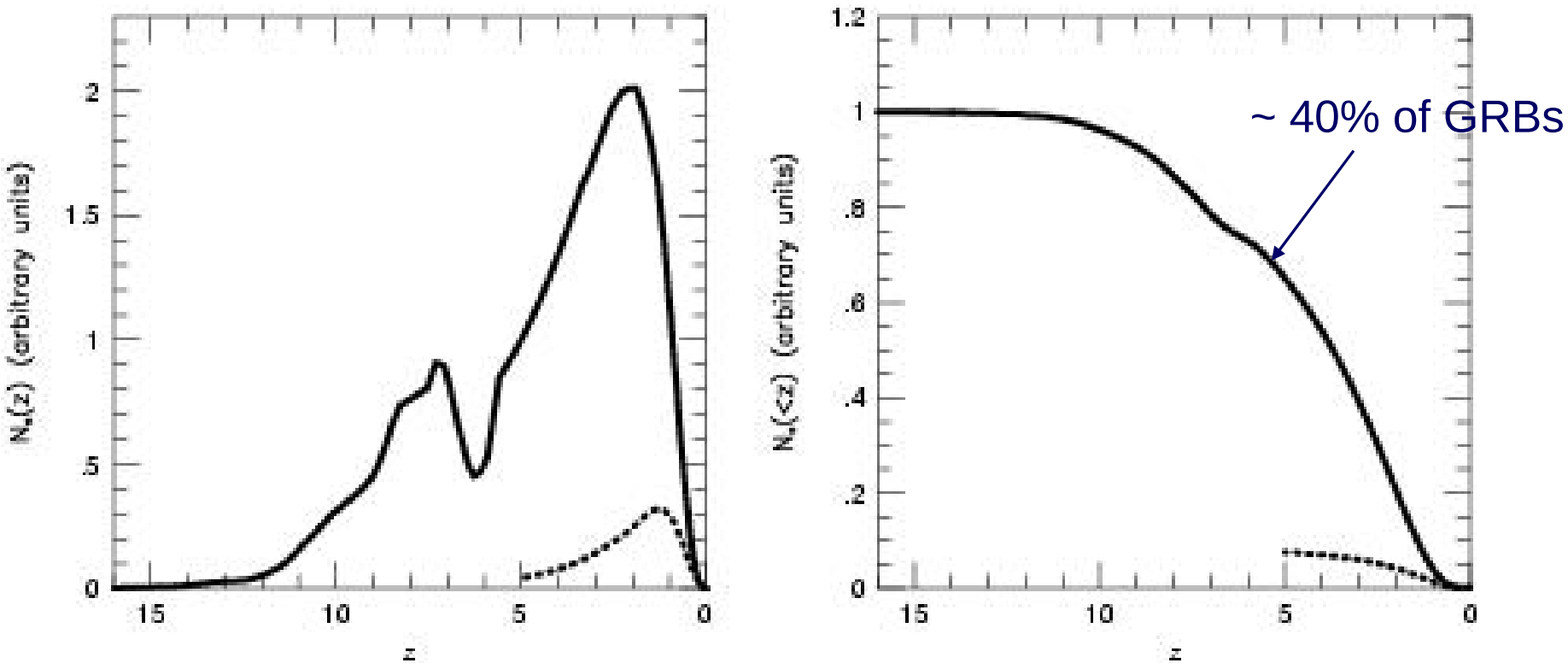
Lamb (2000)

Possible Star-Formation Rate



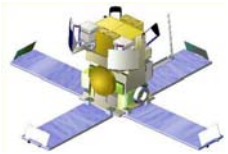
Lamb and Reichart (2000)

Possible Differential and Cumulative Distributions of GRBs



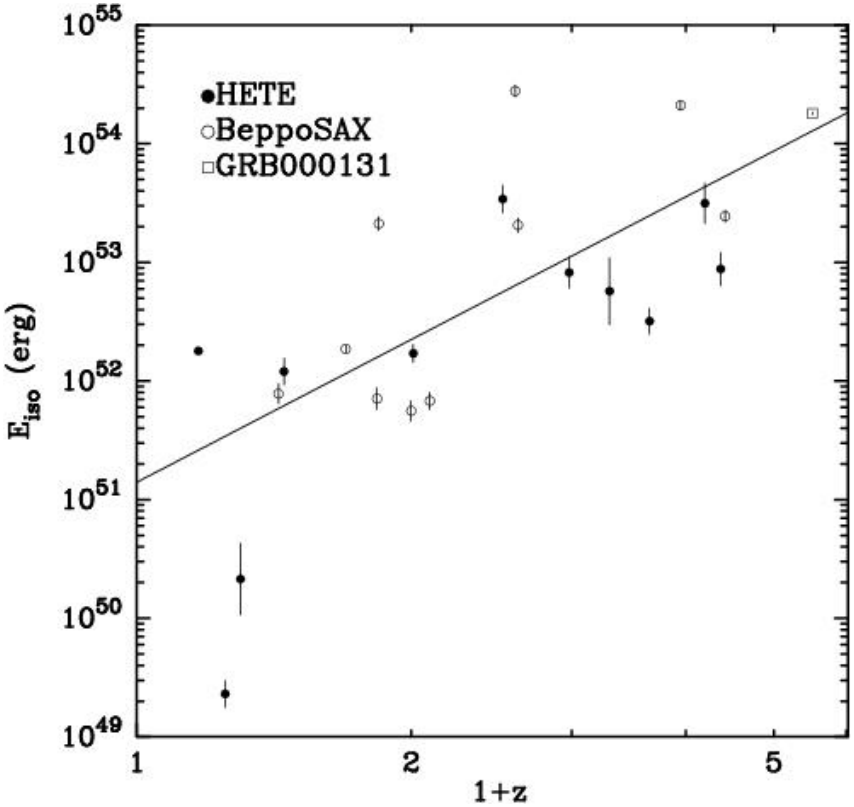
- 15-40% of GRBs may lie at $z > 5$

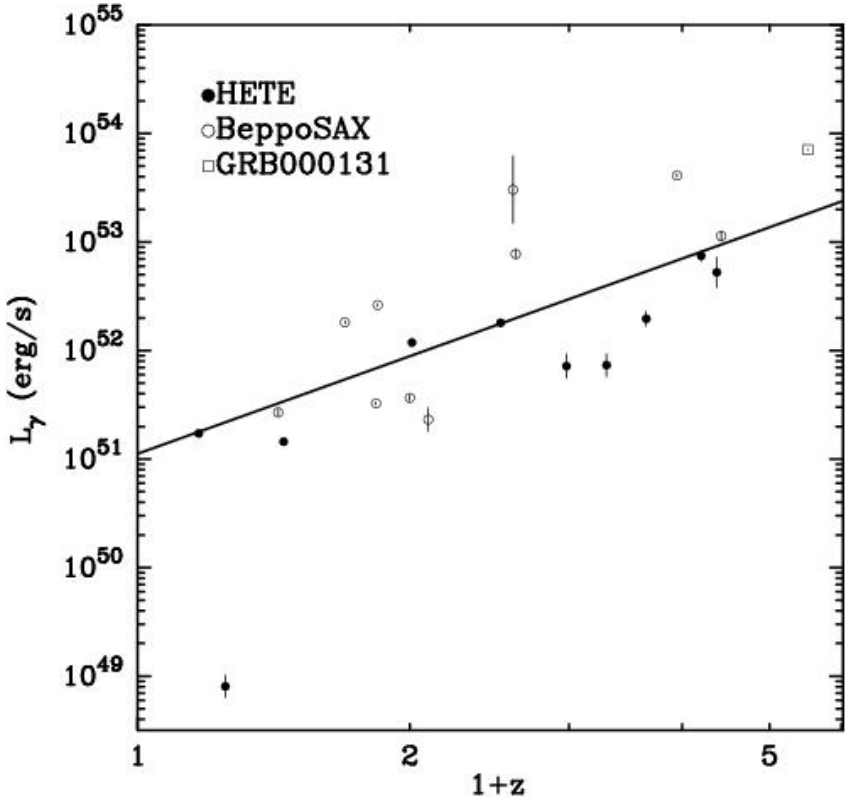
Lamb and Reichart (2000)



Evidence for Evolution of GRBs with Redshift

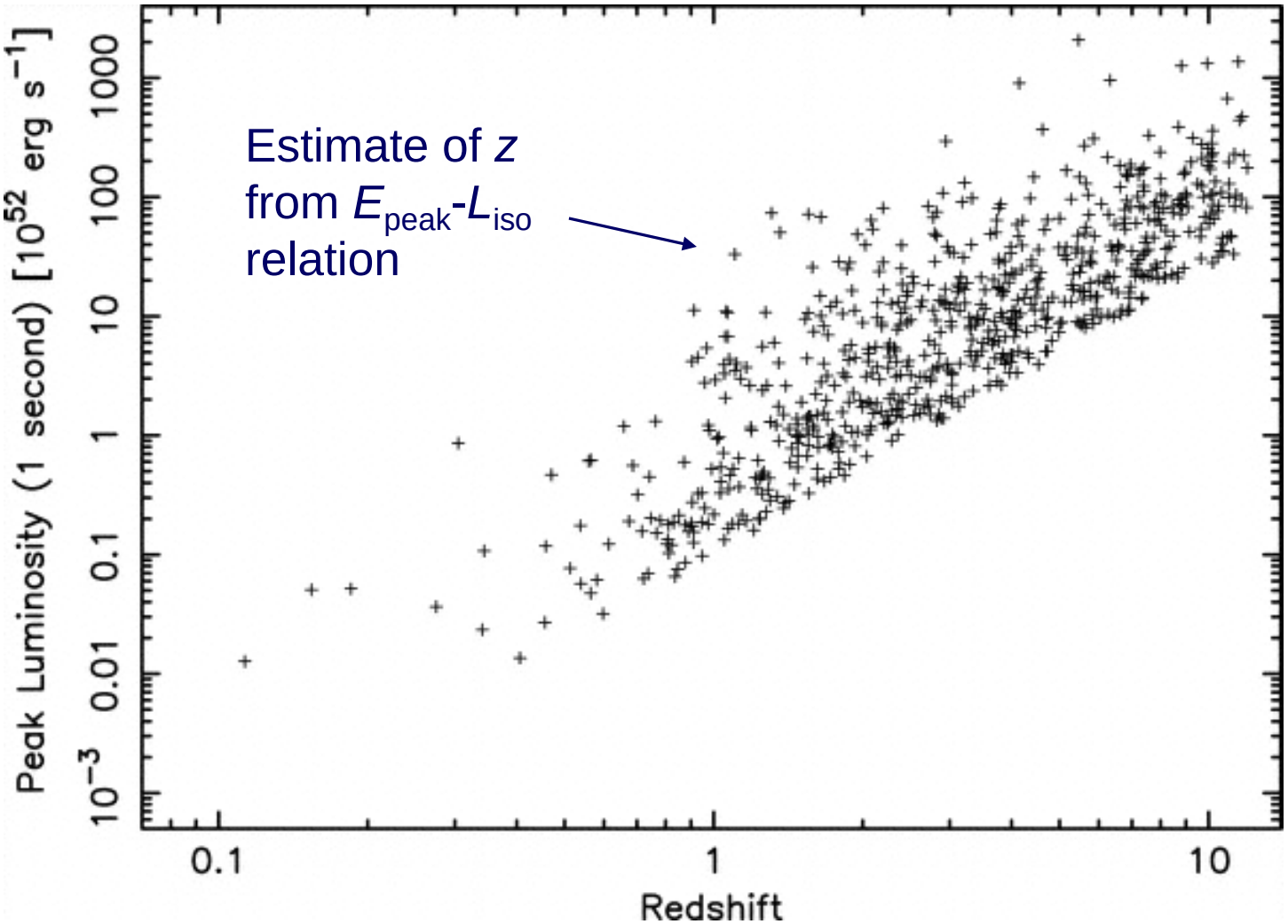
Graziani, Lamb, and Donaghy (2004)



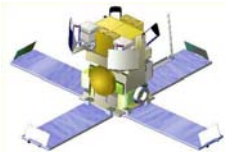


HETE-2 has provided moderate evidence that E_{iso} and $L_{gamma} \sim (1+z)^3$

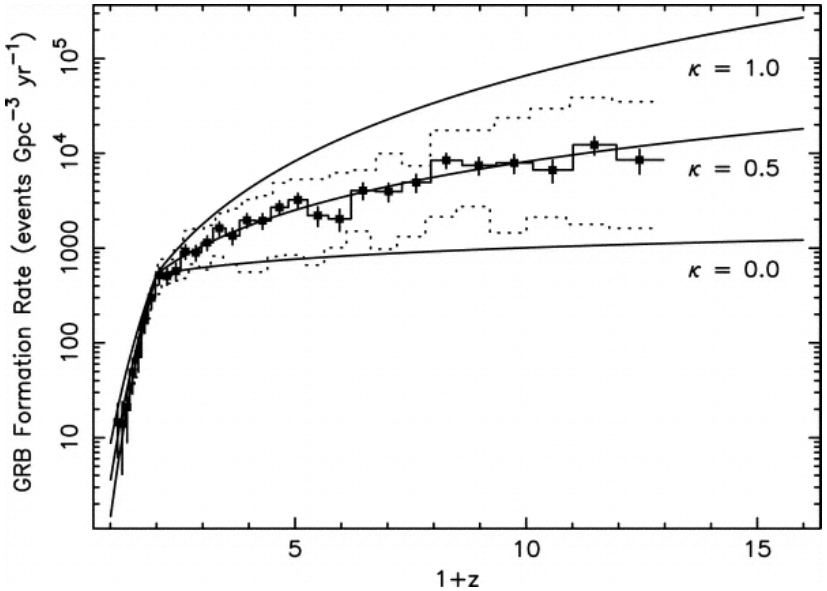
GRB Distribution as Function of Redshift



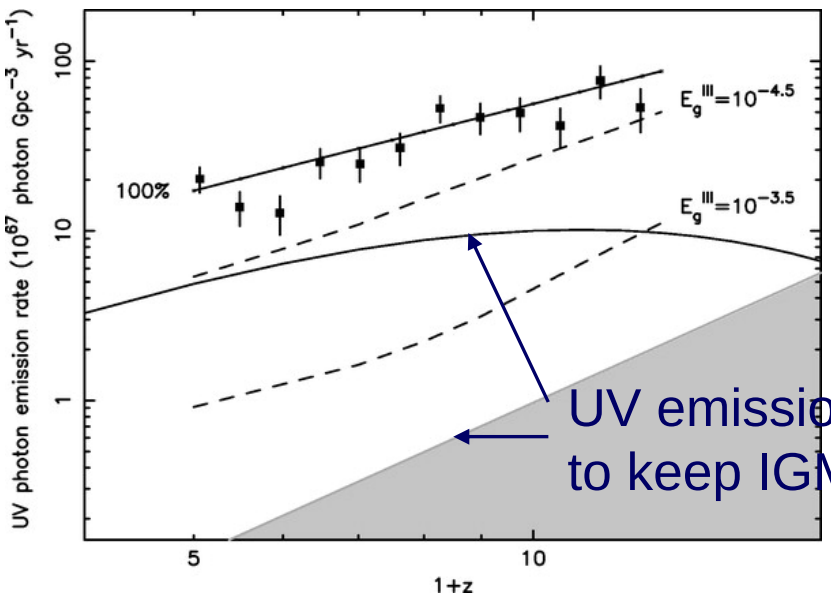
Yonetuko et al. (2004)



GRB Rate as Function of Redshift



- GRB rate increases with *z*
- Kappa factor corrects for jet-like character of GRBs

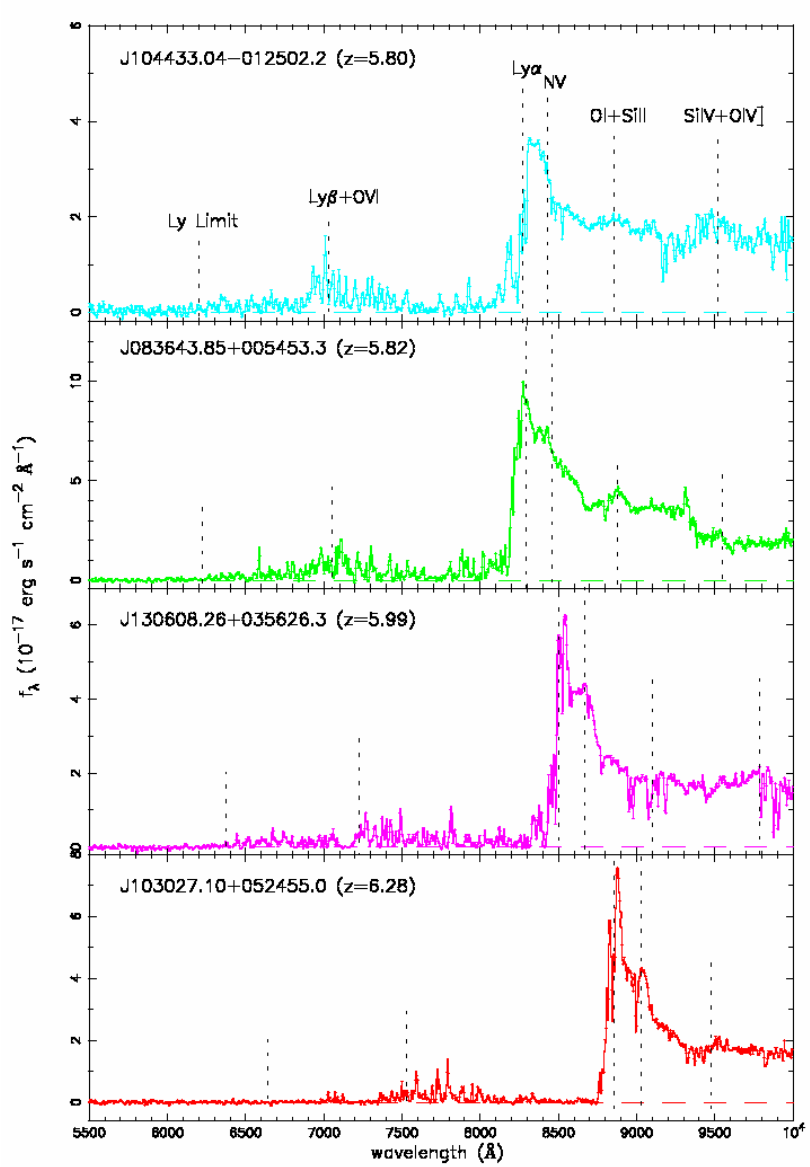


- UV emission from Pop III inferred from Pop III GRB rate

UV emission needed to keep IGM ionized

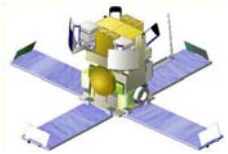
Murakami et al. (2005)

SDSS Quasars at z > 5.8

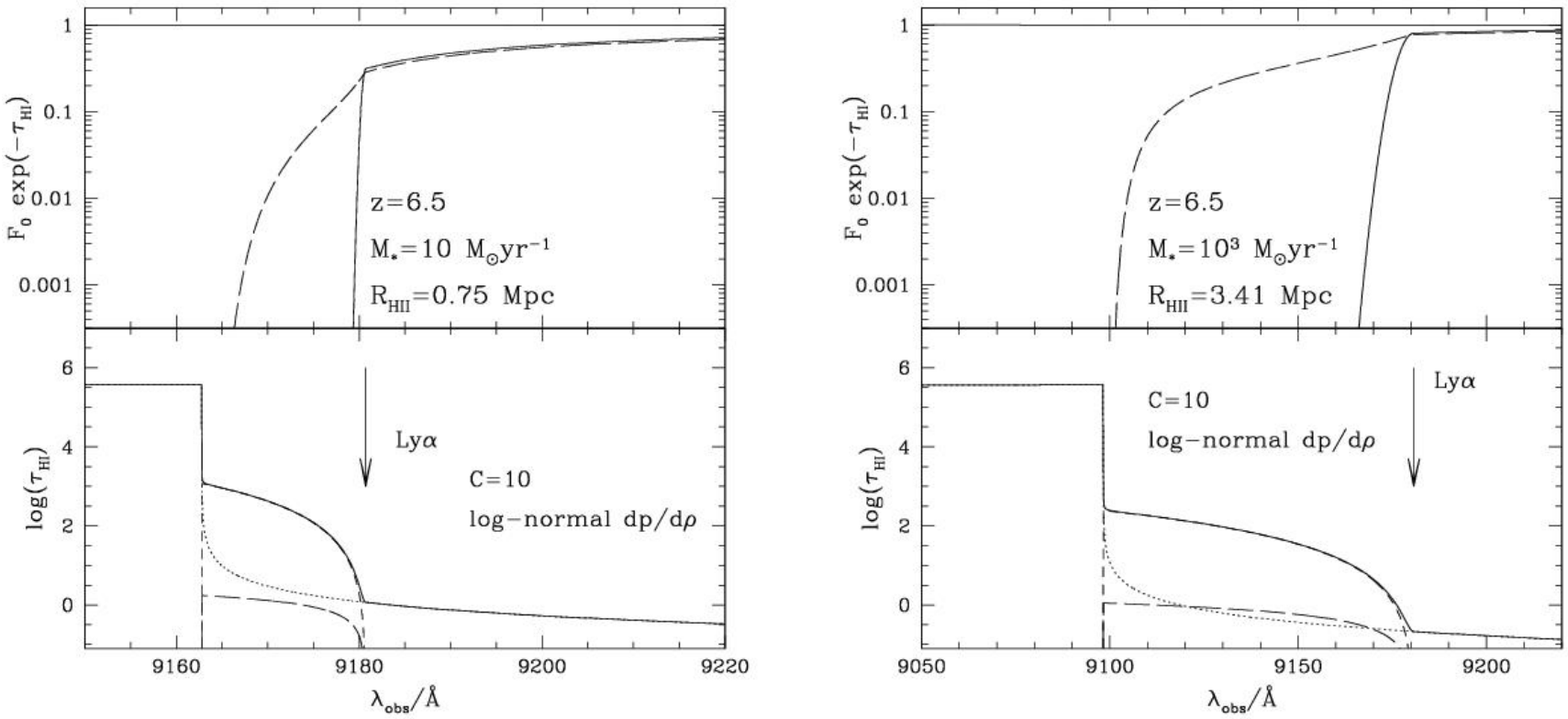


- Clear evidence of Gunn-Peterson trough blueward of Ly alpha and Ly beta
- Strong Ly alpha emission lines (hard to model)
- Strong proximity effect (alters ionization state of IGM

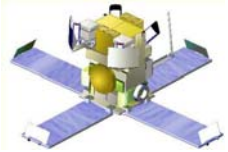
Fan et al. (2000); Becker et al. (2001); Djorgovsky et al. (2004);…



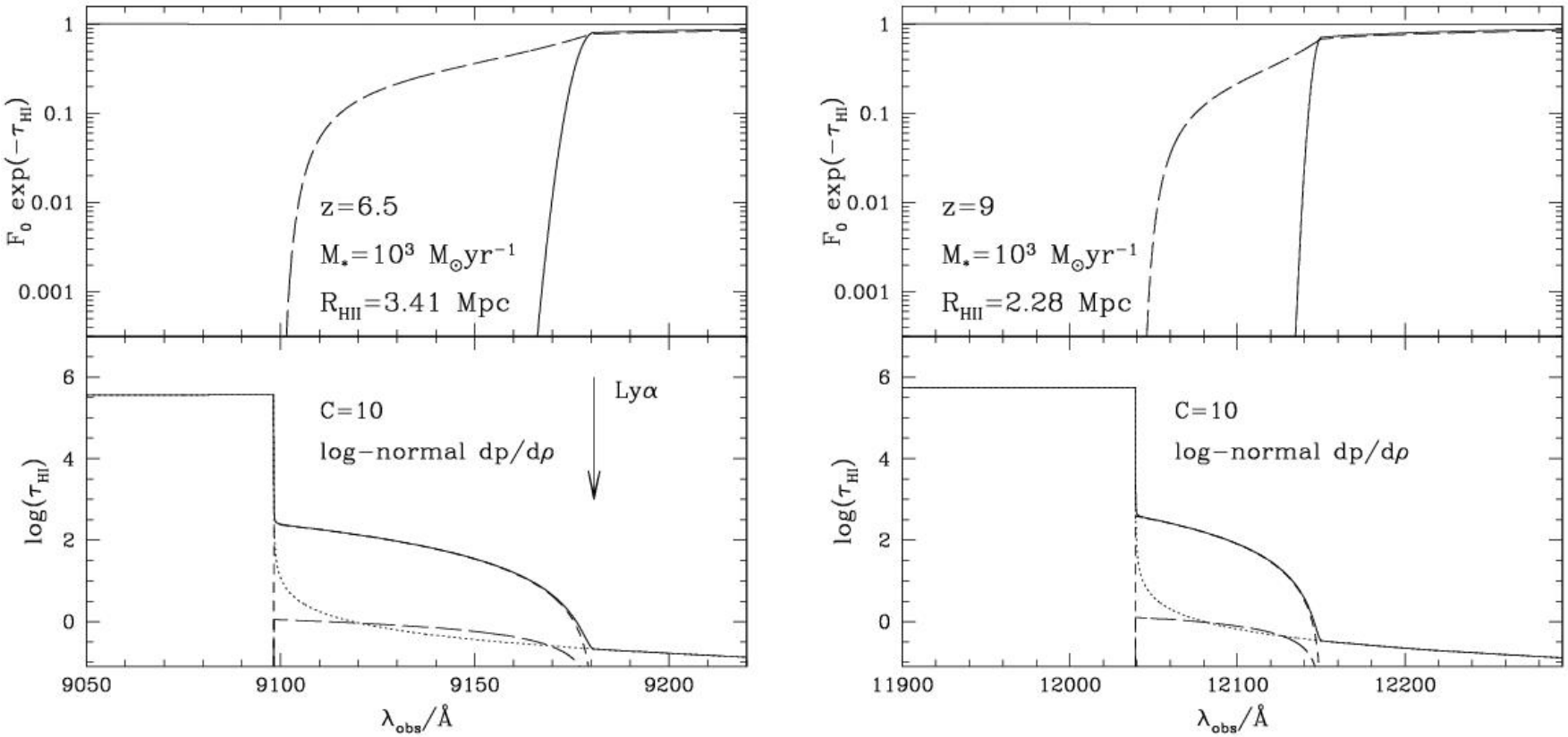
NIR Spectra of GRBs as Probe of Reionization



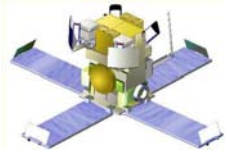
Lamb and Haiman (2004)



NIR Spectra of GRBs as Probe of Reionization



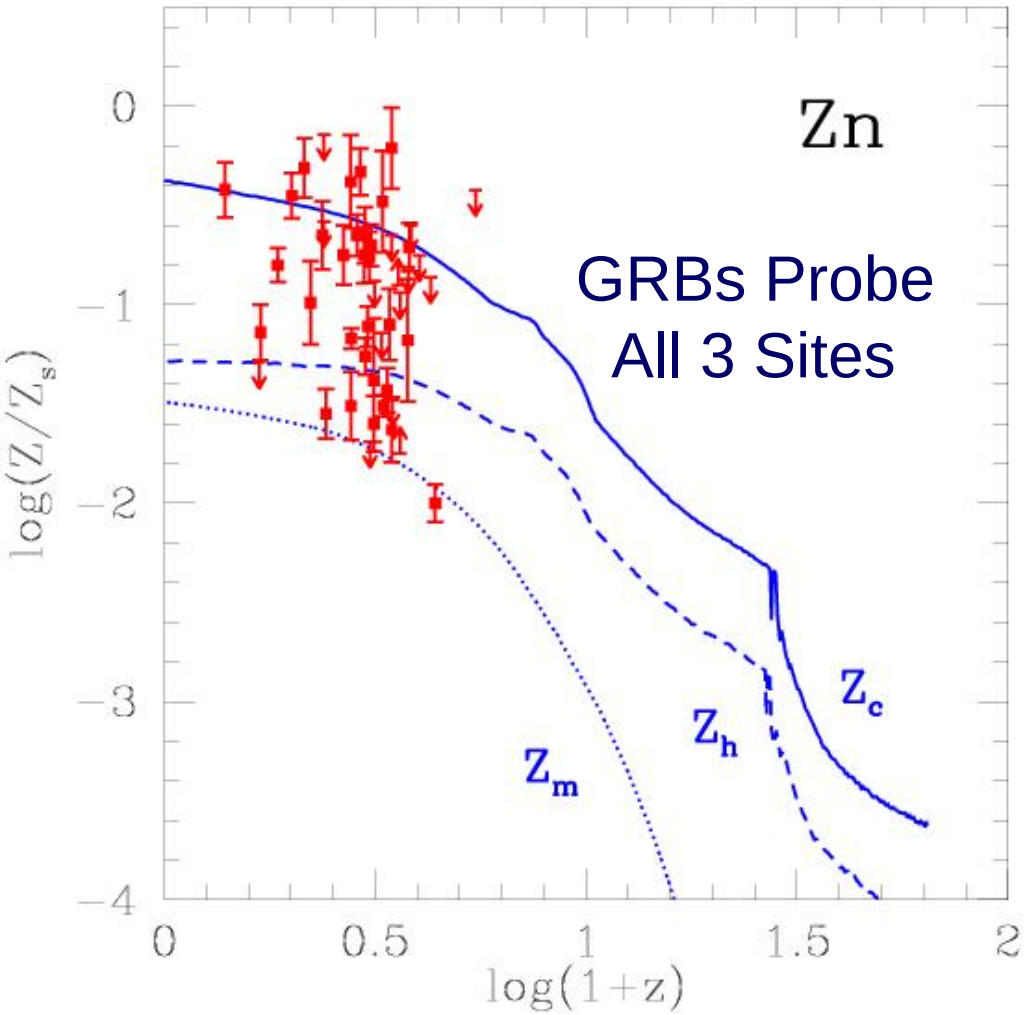
Lamb and Haiman (2004)



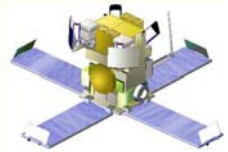
Advantages of GRBs as Probes of Reionization

- GRBs are by far the most luminous events in the universe and are therefore easy to find
- GRBs are expected to lie at very high redshifts ($z > 5$)
- Optical and NIR/IR afterglows of GRBs are detectable out to very high redshifts
- GRBs produce no “proximity effects” (i.e., no dynamical disturbance or ionization of the IGM)
- GRBs have simple power-law spectra and dramatically outshine their host galaxies, making it relatively easy to determine the shape of the red edge of the Gunn-Peterson trough

Predicted Elemental Abundances as Function of Redshift



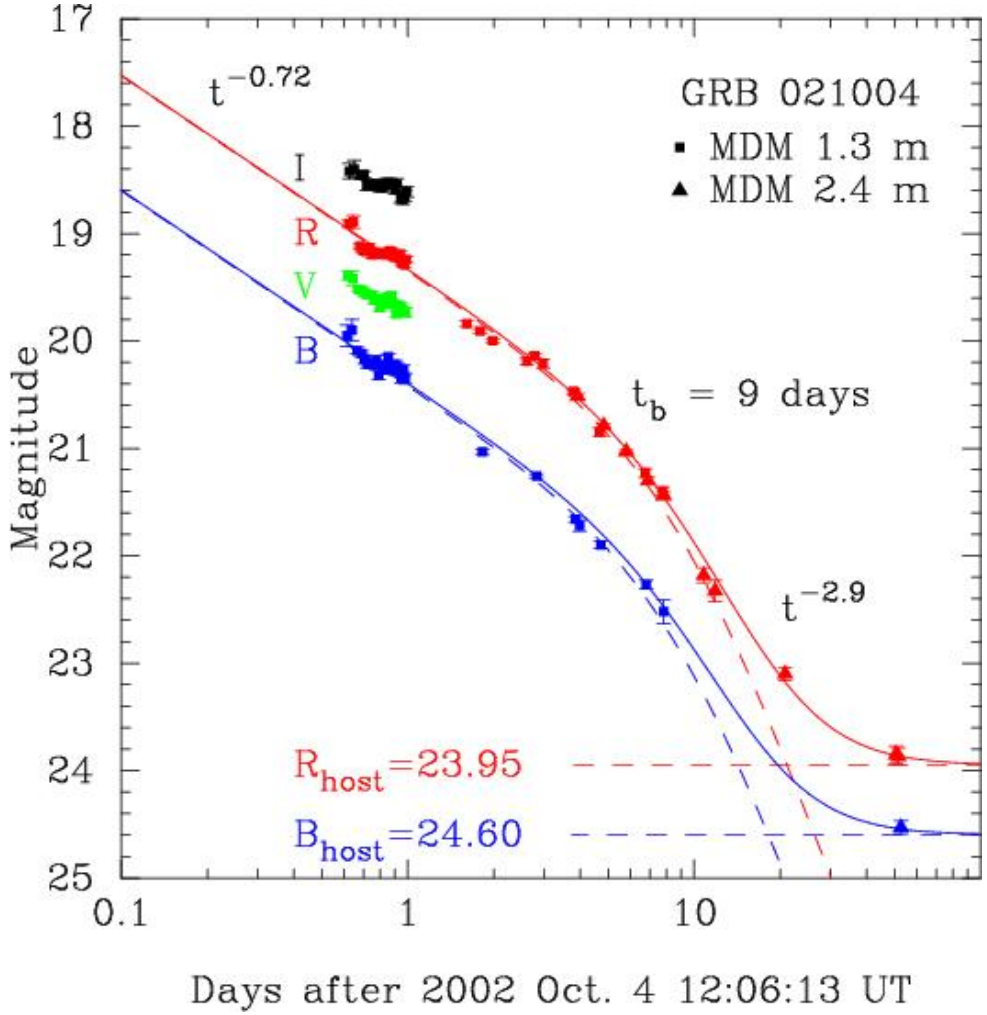
Predictions from *Valageas and Silk (1999)*



GRBs as Probe of Elemental Abundance History of Universe

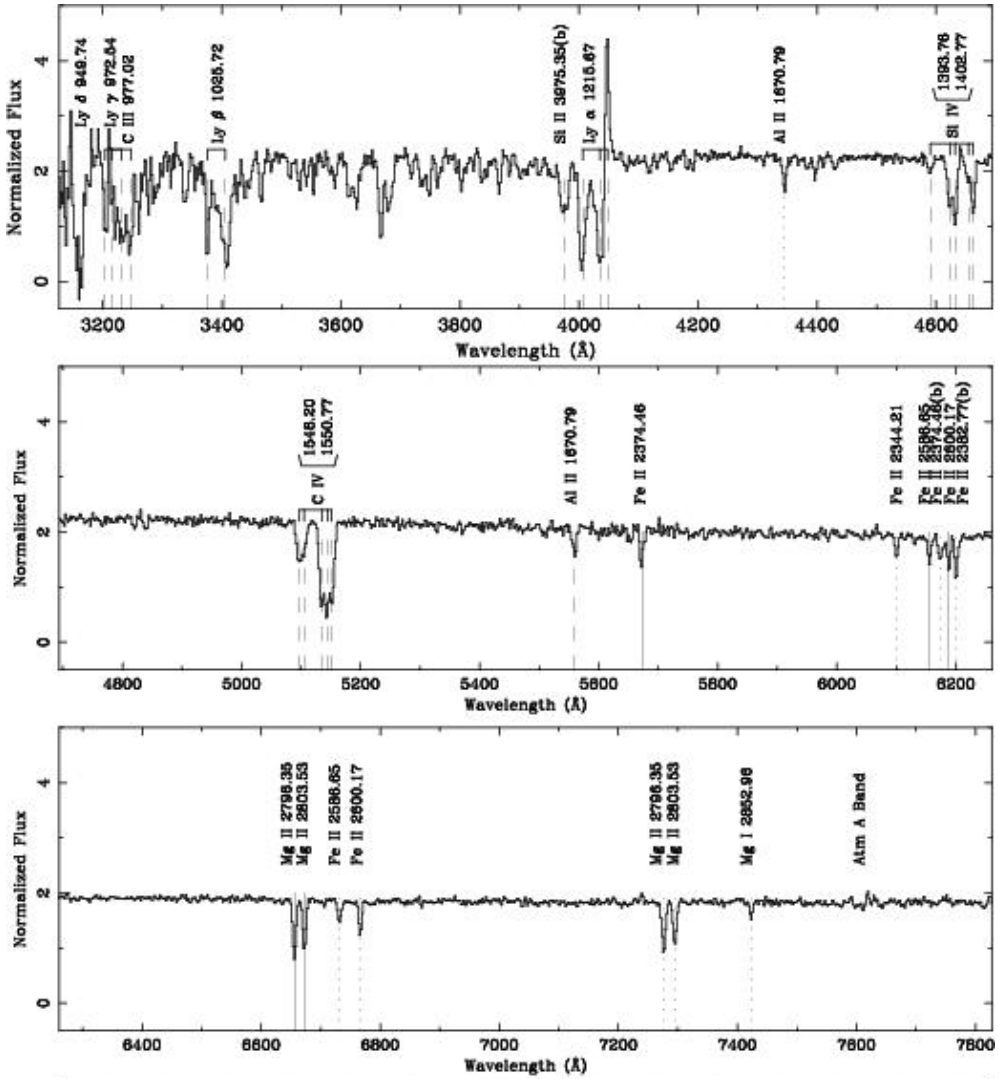
- High-resolution IR and near-IR spectra can measure column density and thermal velocity of clouds within GRB host galaxy –perhaps even within the star-forming region in which GRB occurs
- EWs of absorption lines provide an estimate of the total star formation that has occurred in damped Ly-alpha and Ly-alpha forest clouds as a function of column density N_H of the cloud and redshift z
- EWs of absorption lines trace history of heavy element production in universe as function of redshift

GRB 021004 Optical Afterglow



Mirabal et al. (2003)

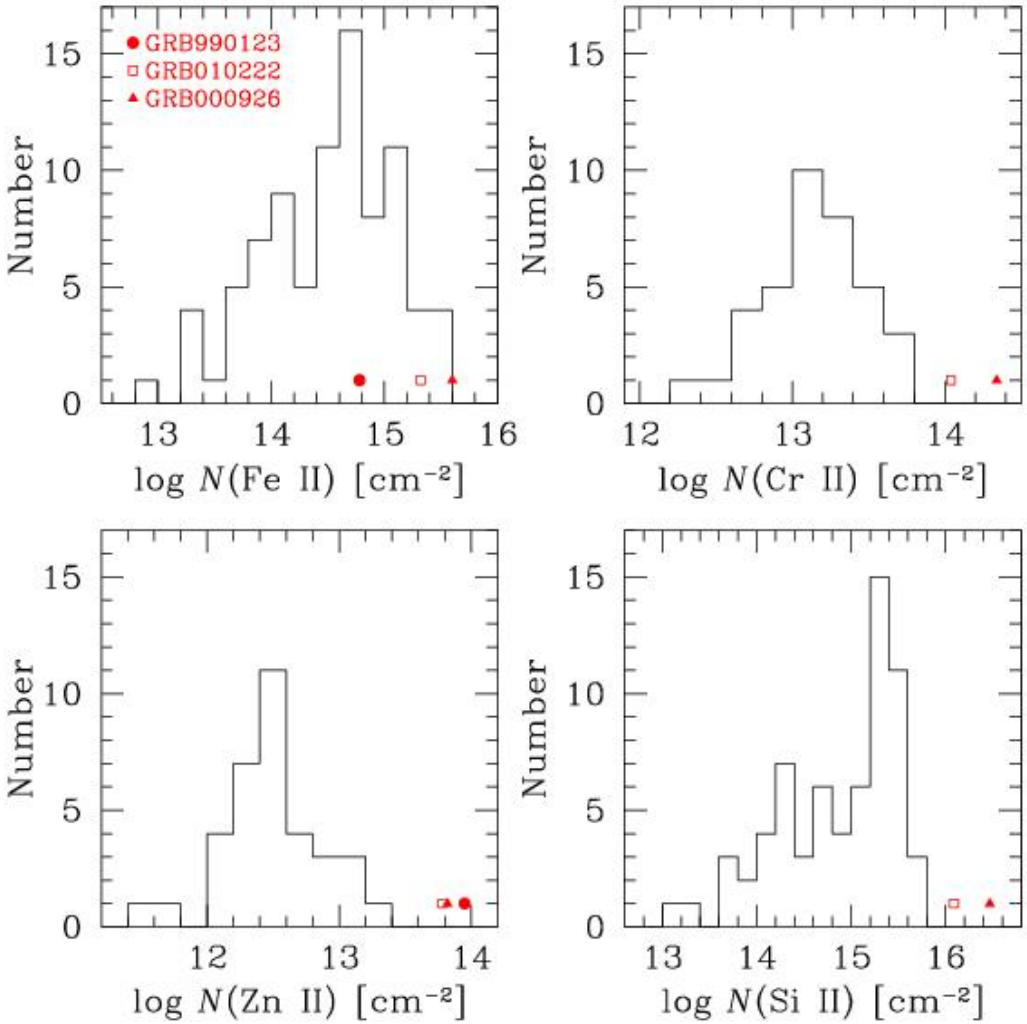
ALS in Optical Afterglow Spectrum of GRB 021004



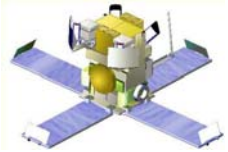
- LRIS spectrum taken 2002 Oct. 8.5
- Three ALS seen:
  - $z_1 = 1.380$
  - $z_2 = 1.602$
  - $z_3 = 2.328$

Mirabal et al. (2003)

Column Densities of Elements



Savaglio, Fall and Fiore (2003)



Conclusions

- HETE-2 and follow-up observations have confirmed the connection between GRBs and core-collapse supernovae
- This strengthens likelihood that GRBs exist out to very high redshifts ($z > 5$)
- GRBs and their optical/NIR afterglows are easily visible out to redshifts $z \sim 20$
- GRBs may therefore provide a powerful probe of
  - Moment of first light
  - Star-formation history of the universe
  - Elemental abundance history of the universe
  - Reionization history of the universe