Gamma-ray Bursts

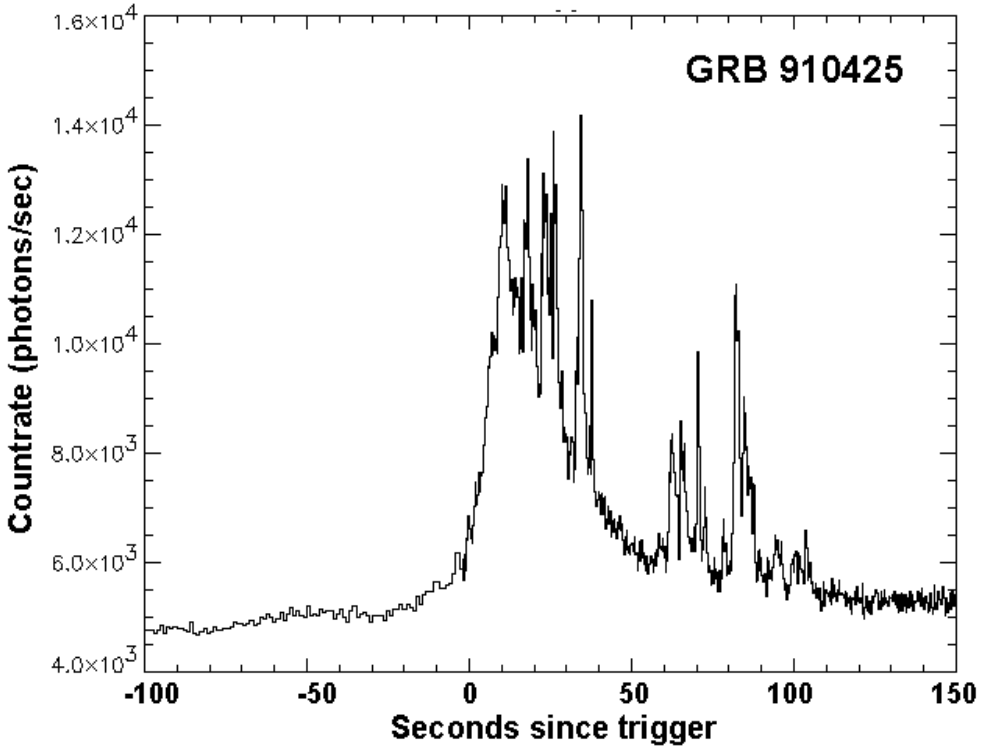
J. P. U. Fynbo, Niels Bohr Institute / Dark Cosmology Centre
(ESO student 1998-1999, ESO fellow 2000-2002)

- The beginning of the afterglow era
- The major highlights with emphasis on the rôle of ESO
- The future

What is a gamma-ray burst?

Brief (**ms - min**) and intense (**~10^{-7} erg cm^{-2} s^{-1}**) flash of soft (~**100 keV**) gamma-ray radiation

* Discovered by chance in the 60ies
* Rapid variability
* Non-thermal spectra
* About 1 per day with current sensitivities
* The key problem in revealing their nature was getting precise positions.



The beginning of the afterglow era

Nicely aligned with the arrival of the VLT ➔

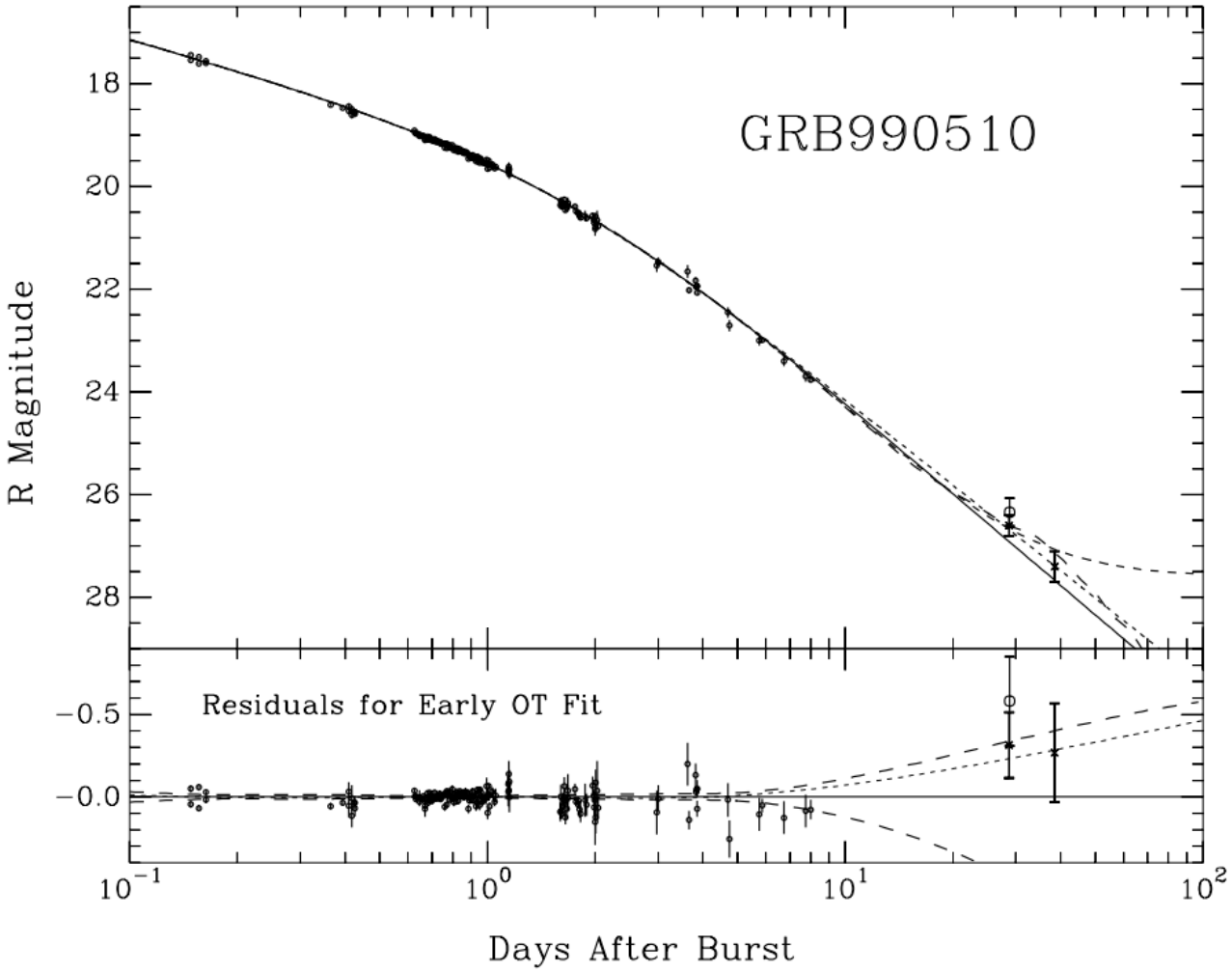
letters to nature

Transient optical emission from the error box of the γ-ray burst of 28 February 1997

J. van Paradijs[1,2], P. J. Groot[1], T. Galama[1], C. Kouveliotou[3,4], R. G. Strom[5,1], J. Telting[5,6], R. G. M. Rutten[5,6], G. J. Fishman[4], C. A. Meegan[4], M. Pettini[7], N. Tanvir[8], J. Bloom[8], H. Pedersen[9], H. U. Nørdgaard-Nielsen[10], M. Linden-Vørnle[10], J. Melnick[11], G. van der Steene[11], M. Bremer[12], R. Naber[13], J. Heise[14], J. in 't Zand[14], E. Costa[15], M. Feroci[15], L. Piro[15], F. Frontera[16], G. Zavattini[16], L. Nicastro[17], E. Palazzi[17], K. Bennet[18], L. Hanlon[19] & A. Parmar[18]

van Paradijs et al. 2000, ARA&A

First VLT campaign



VLT/FORS1:
Spectroscopic redshift: z = 1.62

Exquisite afterglow lightcurve. Evidence for beaming.

Host: R(AB)>26

Detection of polarization

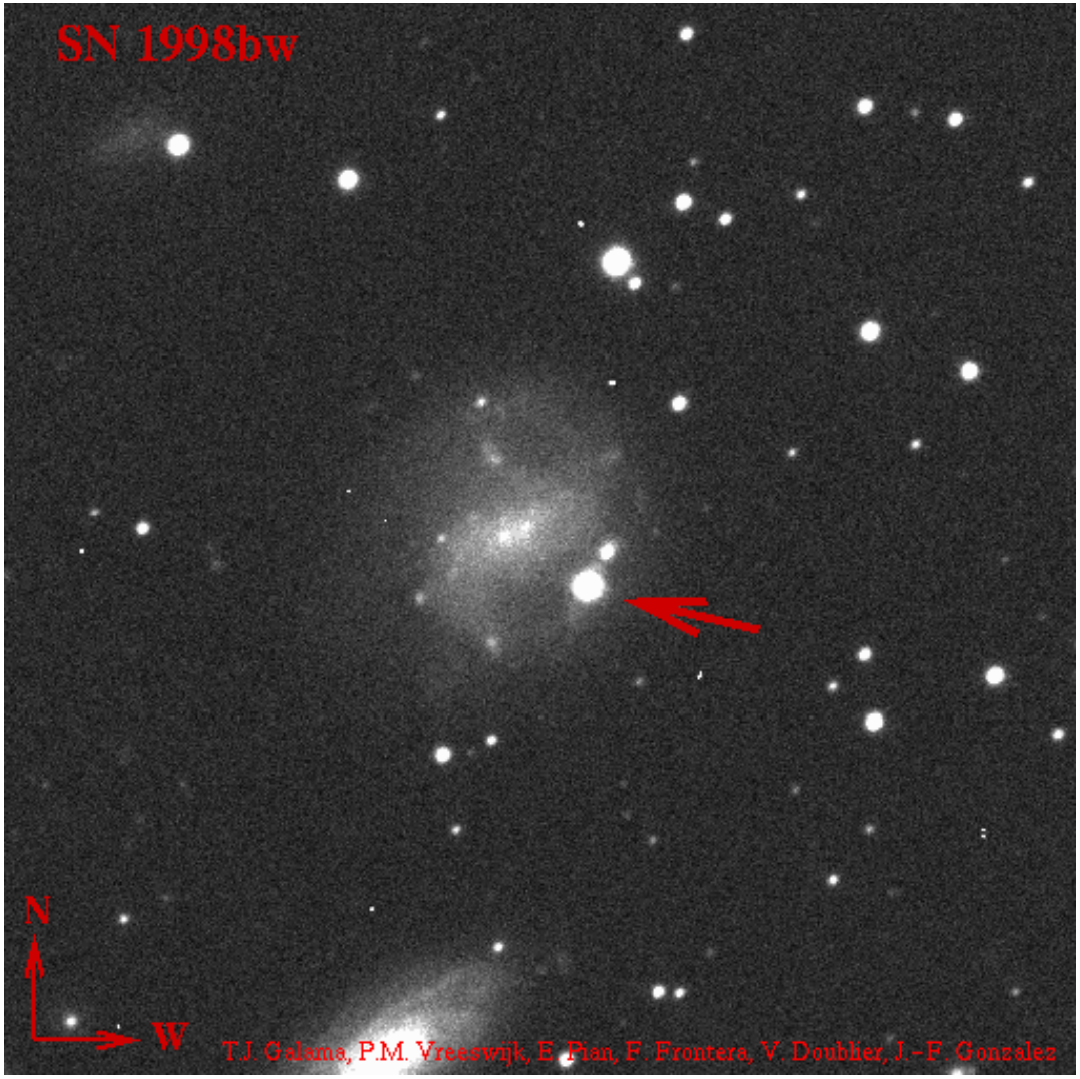
Wijers et al. (1999); Covino et al. (1999); Beuerman et al. (1999); Vreeswijk et al. (2001)

GRB980425: supernova

Galama et al. 1998; Patat et al. 2001; Fynbo et al. (2000); Sollerman et al. (2002)

z=0.0085 (nearby!).
No optical afterglow!, but a bright SN Ib/c

SN of the century (cf. Nando Patat)!
Very sub-luminous GRB

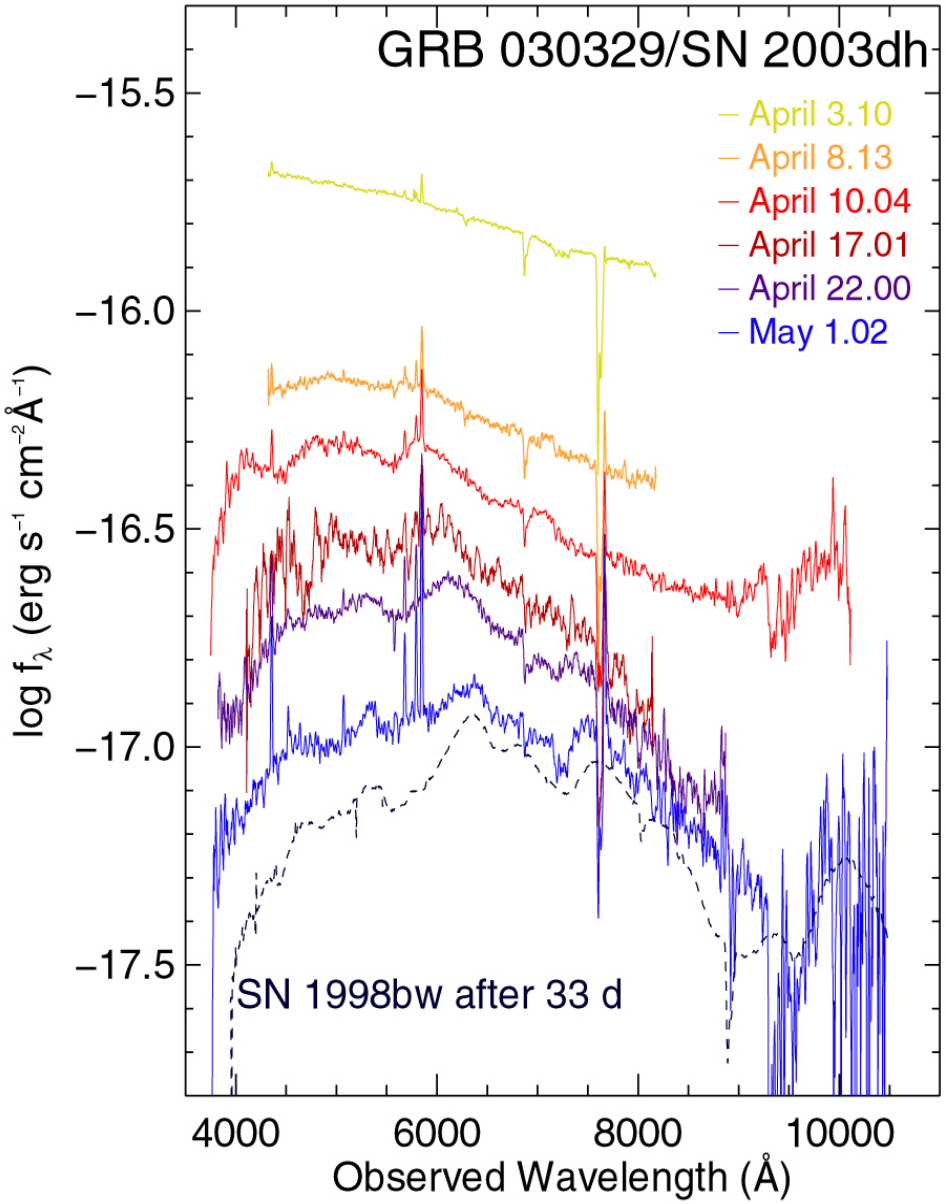


The GRB/SN connection

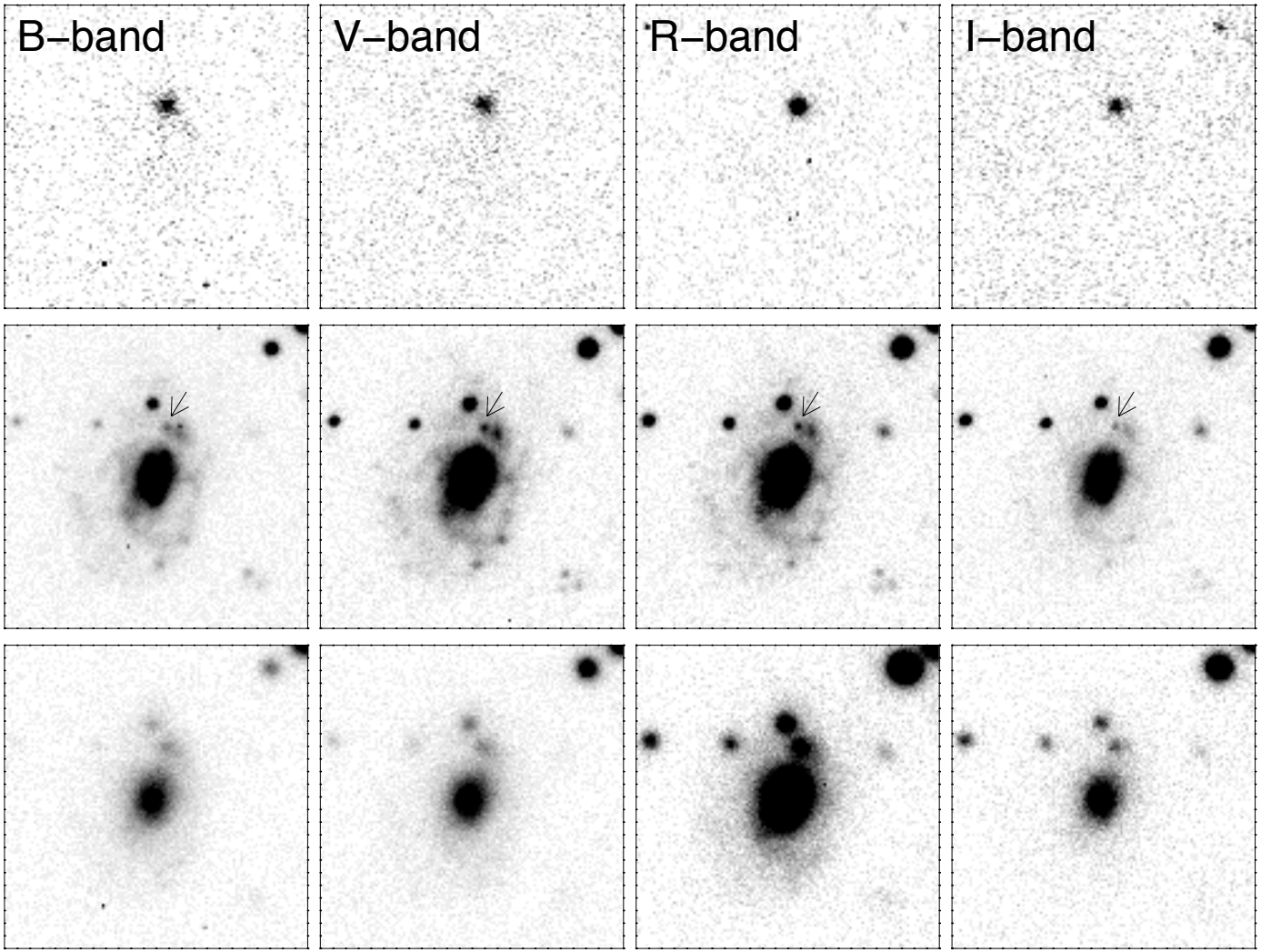
Woosley & Bloom 2006, ARA&A

- Strongest cases (All ESO)
  - –980425/1998bw (z=0.0085)
  - –030329/2003dh (z=0.1685)
  - –031203/2003lw (z=0.1055)
  - –060218/2006aj (z=0.033)
  - –081007/2008hw (z=0.5295)
  - –101219B/2010ma (z=0.55)
  - –120422A/2012bz (z=0.283)
  - –120714B/2012eb (z=0.398)

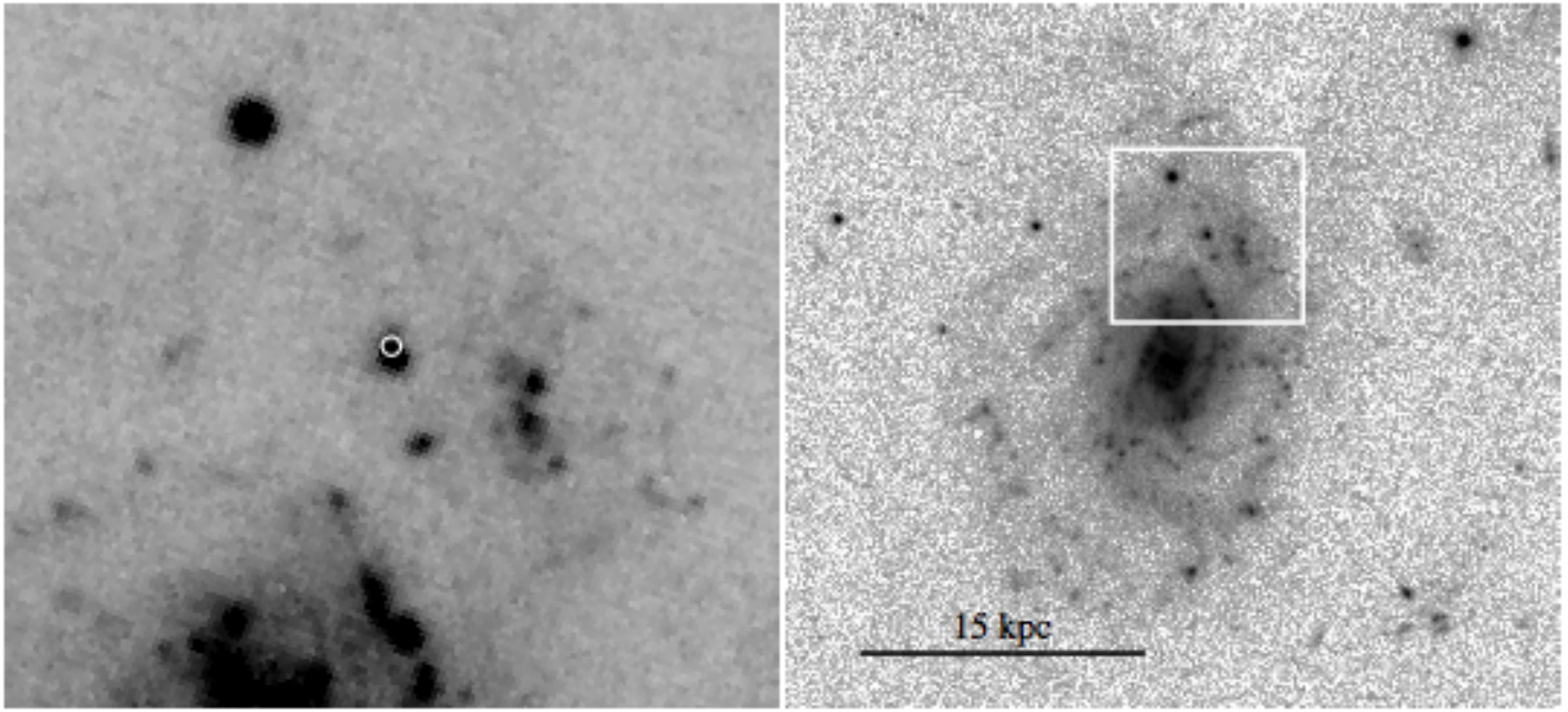
- GRB/SN types:
  - –All broad-lined SN I b/c
  - –Peak M_V~–19±0.5
  - –Several other convincing cases, similar peak M_V's



Hjorth et al. (2003)



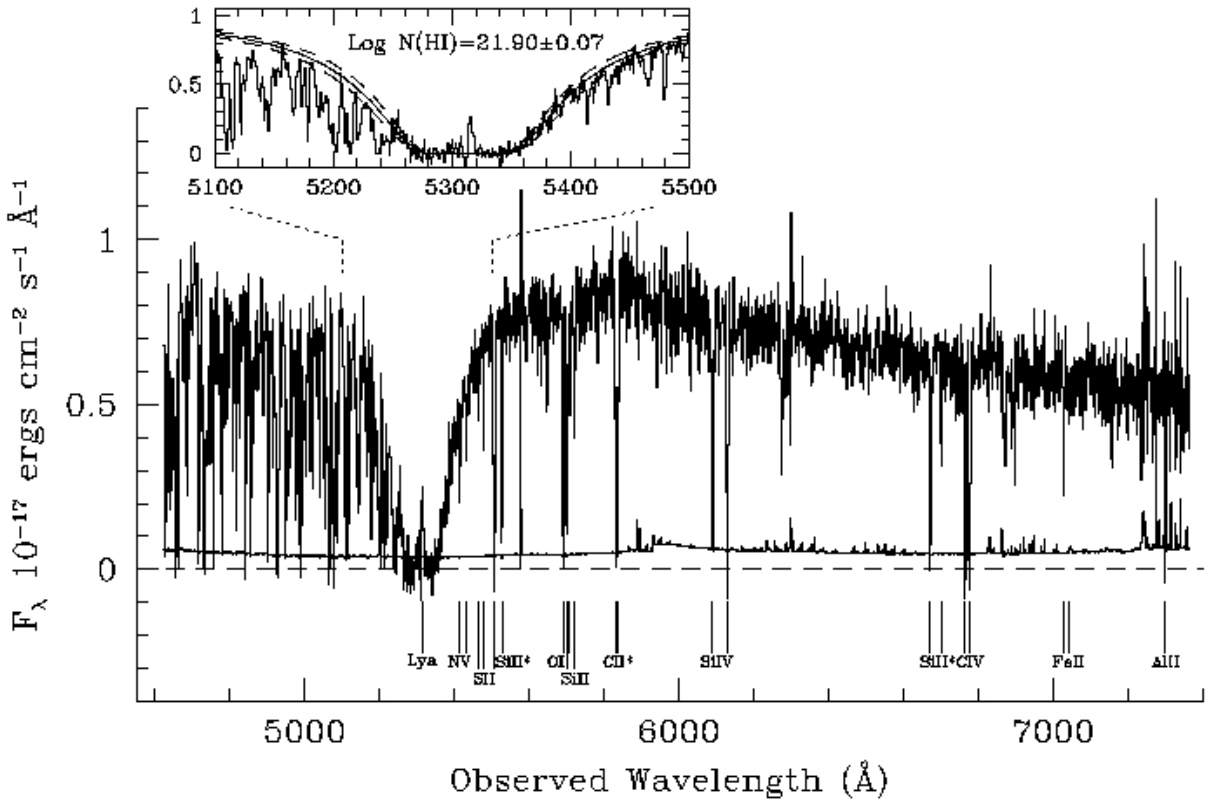
Fynbo et al. (2006); Della Valle et al. (2006); Ofek et al. (2007), Thöne et al. (2008); Xu et al. (2008); McBreen et al. (2008); see also Kochanek et al. (2008)


15 kpc

GRBs as probes of star-forming galaxies

- ✓ HI
- ✓ H_2
- ✓ Metallicities
- ✓ Extinction curves
- ✓ UV-photon escape fraction
- ✓ Unique selection of star-forming galaxies (#massive stars per LF bin)

GRB030323



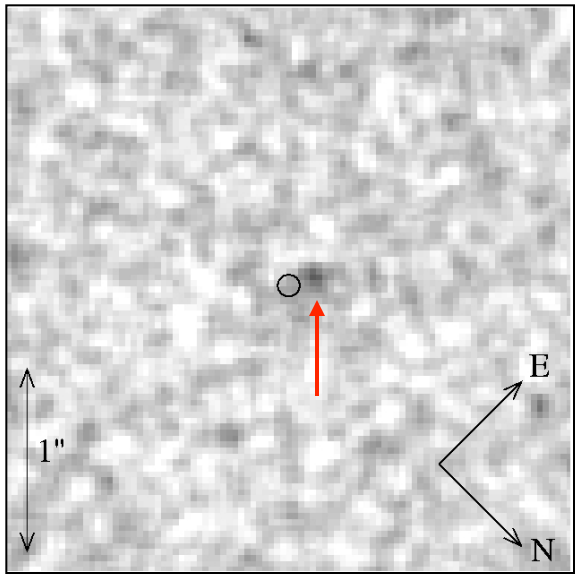
VLT + HST/ACS

z = 3.371

Host: V(AB)=28.0
SFR = 1 $M_\odot$/yr

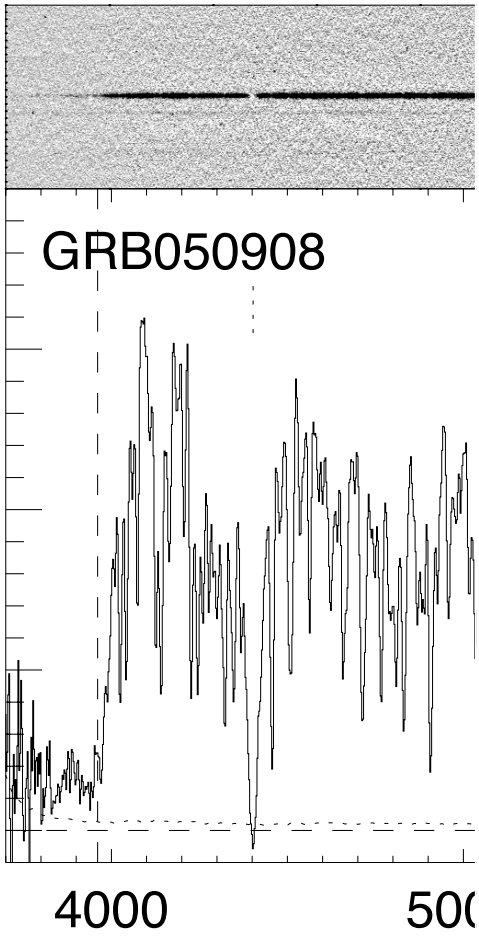
A_V<0.5 mag

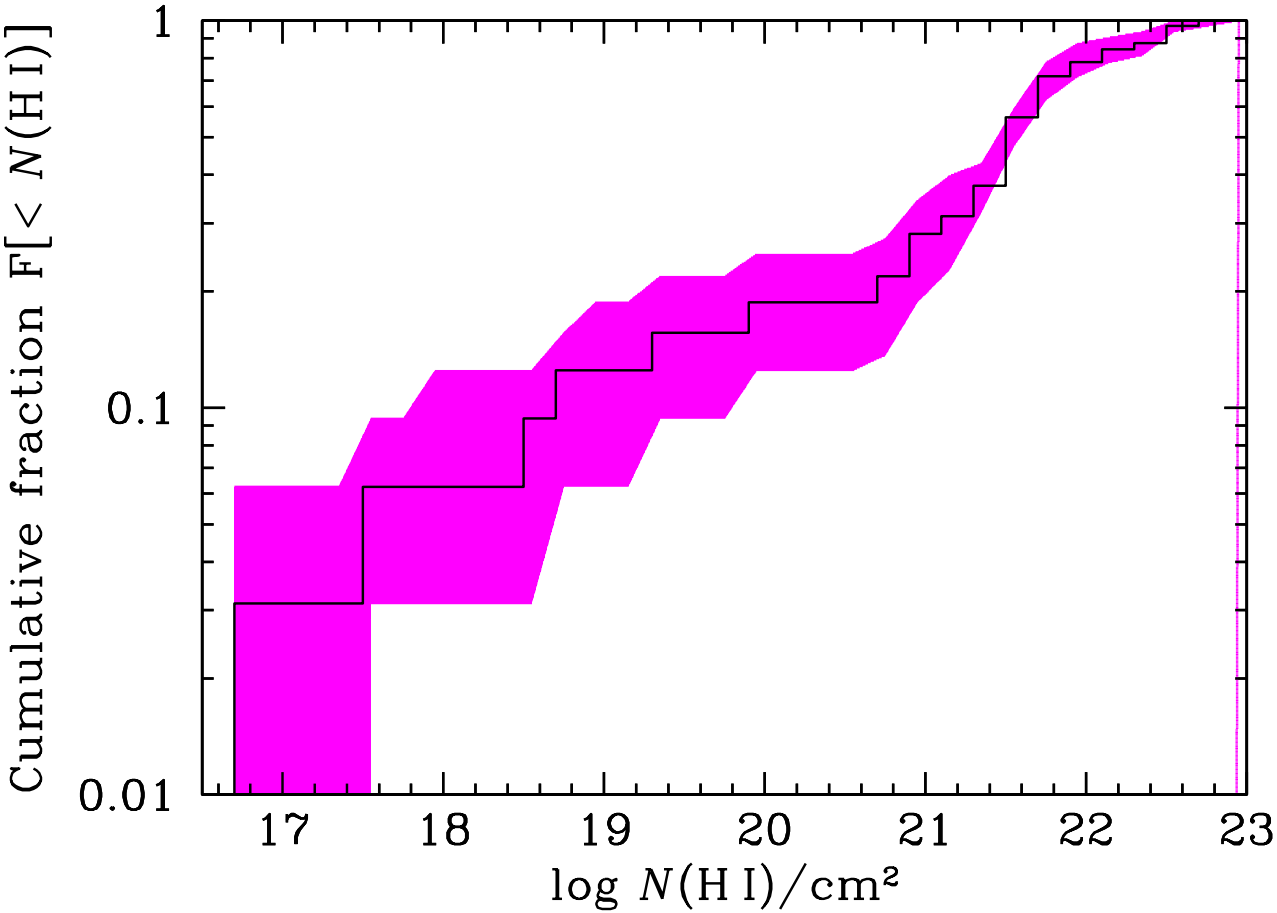
[Fe/H]=-1.5
[S/H]=-1.3



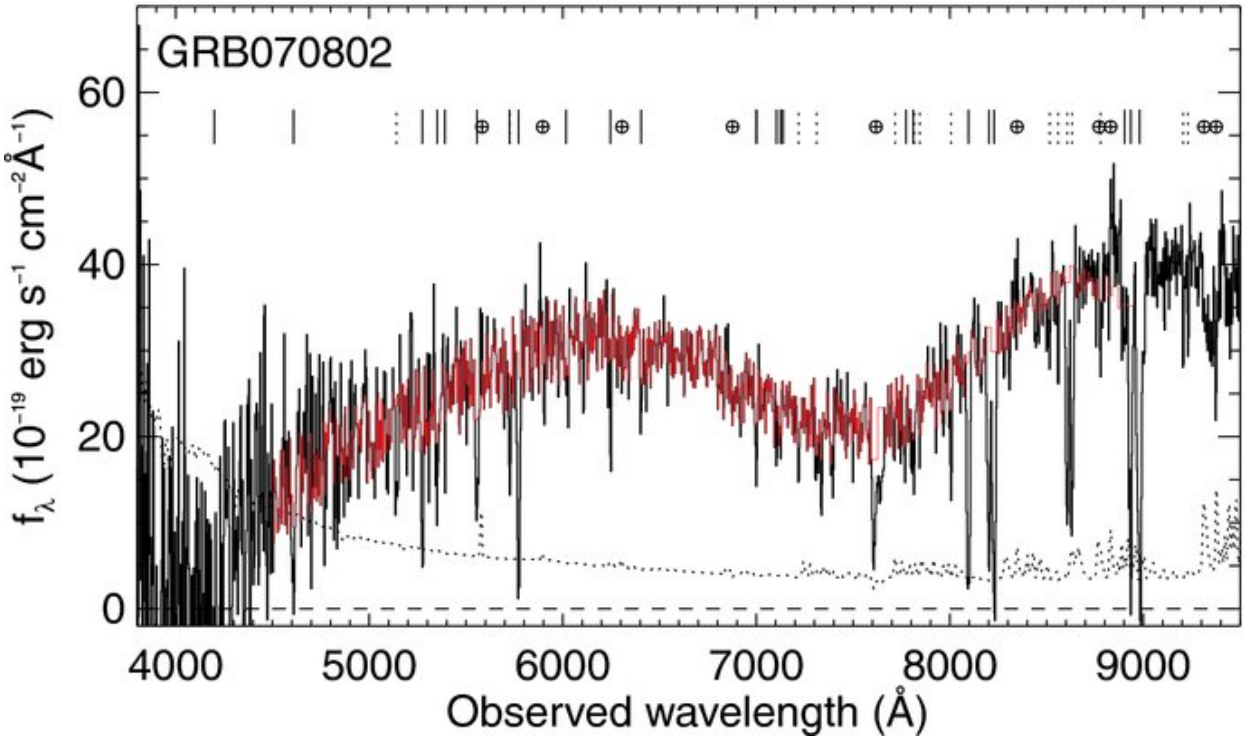
Vreeswijk et al. (2004)

The mean escape fraction of UV photons from star-forming galaxies: f_{escape}<7% (95% confidence)





Chen et al. (2007); Fynbo et al. (2009)

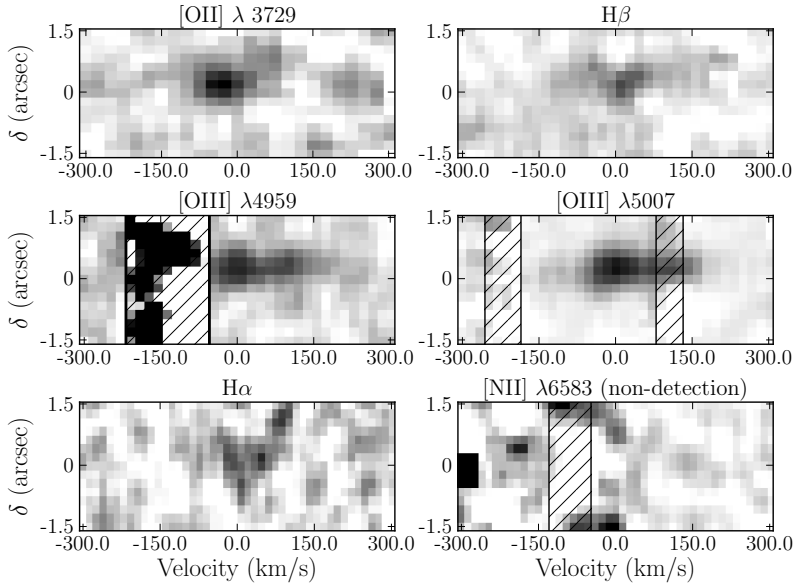


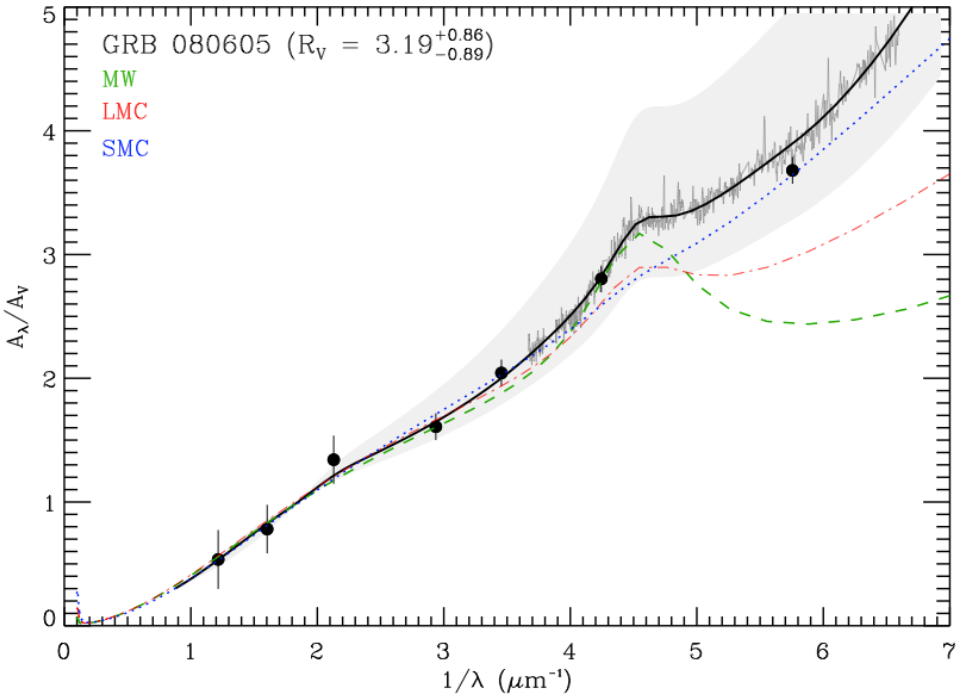
Elíasdóttir et al. (2009); Krühler et al. (2008)

FORS spectrum of the afterglow with 2175 Å extinction bump ($z=2.45$, $A_V \sim 1$mag)

X-shooter spectrum revealing emission lines from the host

(M. Sparre)





Zafar et al. (2012)

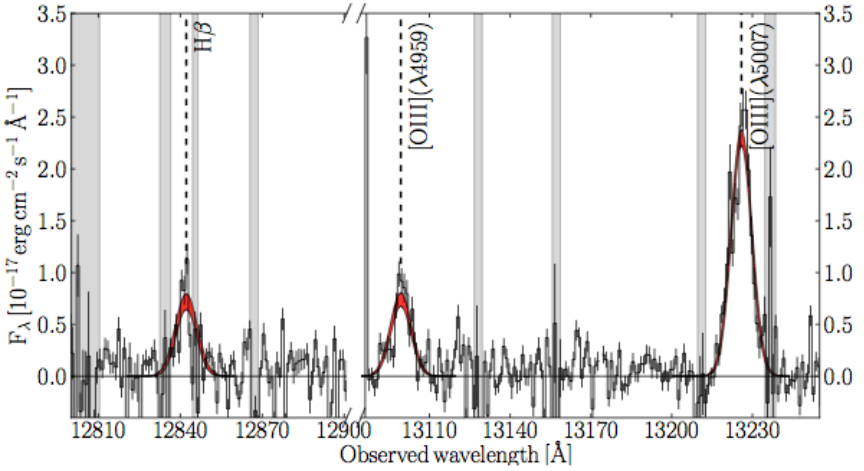
Afterglow derived extinction curve with 2175 Å extinction bump (z=1.65, A_V=0.5 mag)

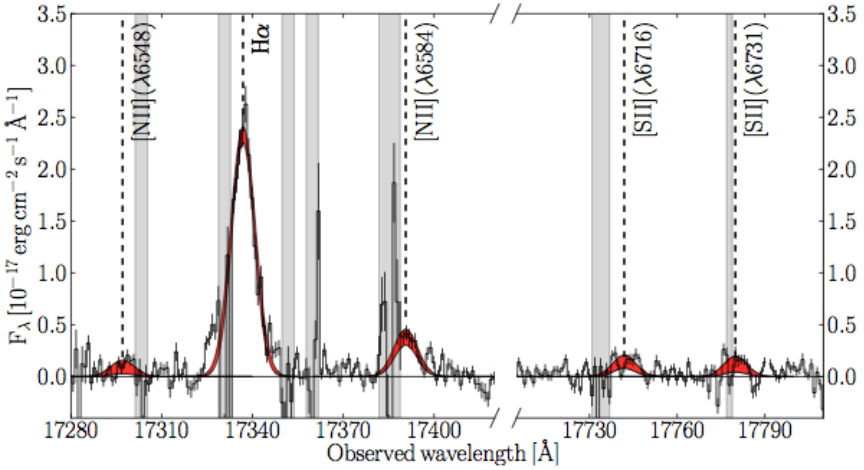
X-shooter spectrum of the host

SFR = 30 $M_\odot$/yr

Oxygen abundance 40-110% solar

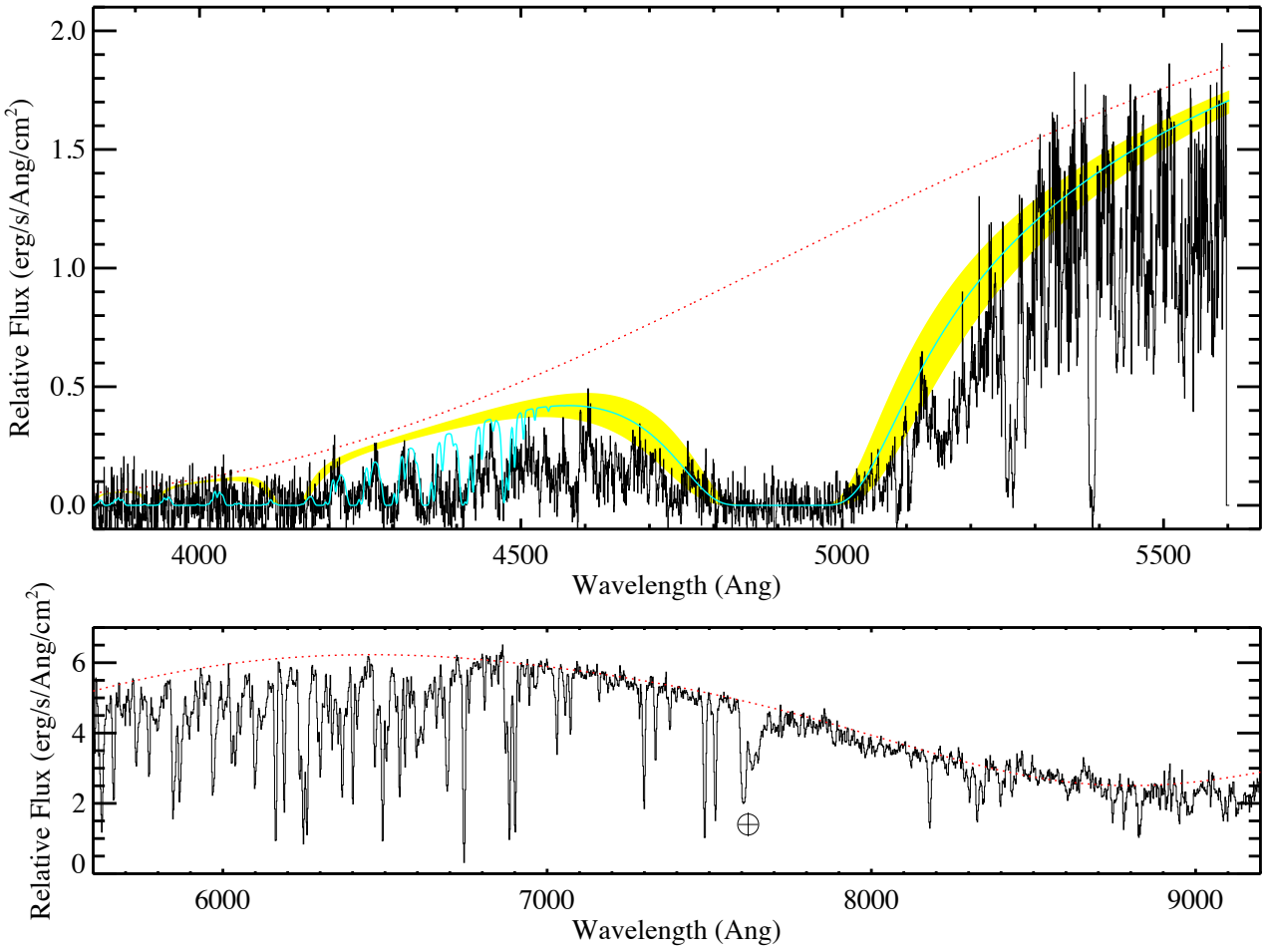
Krühler et al. (2012)





GRB080607

Spectroscopy started 20 min post burst – Bloom and Perley
R>24 when observable from La Palma (12 hr later)



Prochaska et al. (2009)

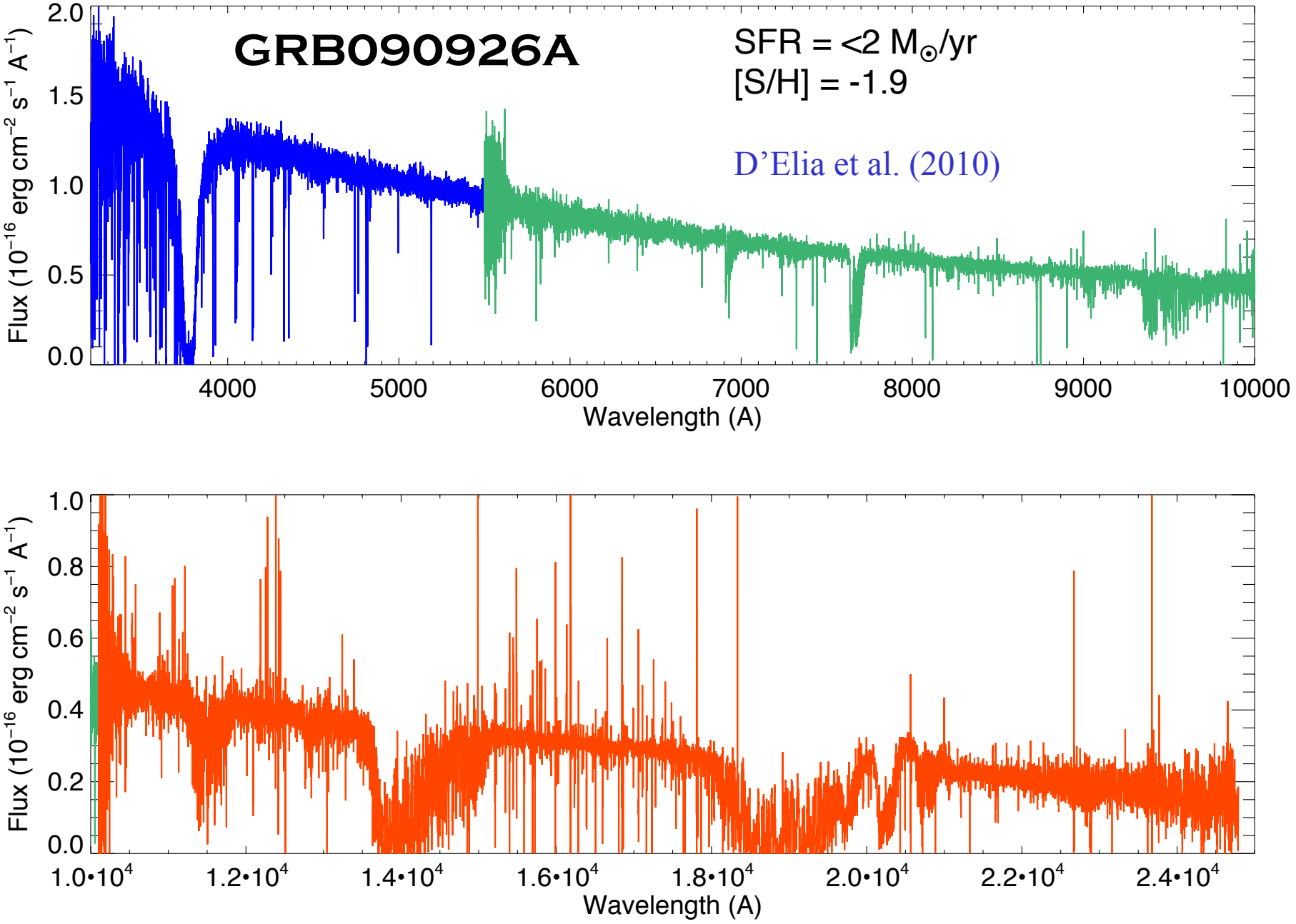
Keck ☹

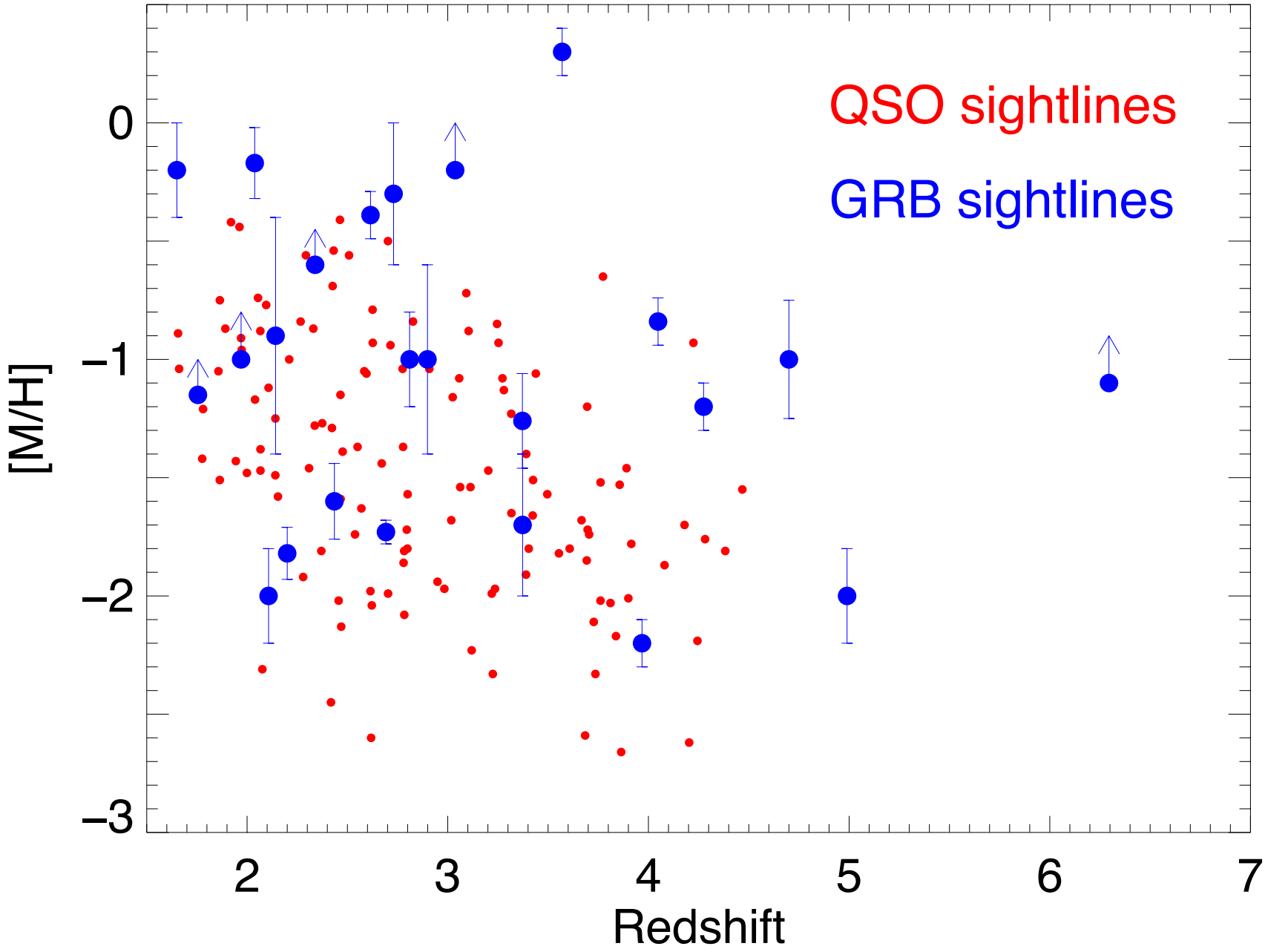
z = 3.04
logN_{HI}=22.7
H_2 and CO
Forest of metal lines!
Solar metallicity

A_V=3.3 mag
2175Å extinction bump.

Bright/massive and dusty host
SFR = 10 $M_\odot$/yr

Imagine E-ELT


GRB090926A
SFR = <2 M⊙/yr
[S/H] = -1.9
D'Elia et al. (2010)
Flux (10^-16 erg cm^-2 s^-1 A^-1)
Wavelength (A)
2.0
1.5
1.0
0.5
0.0
4000
5000
6000
7000
8000
9000
10000
1.0
0.8
0.6
0.4
0.2
0.0
1.0•10^4
1.2•10^4
1.4•10^4
1.6•10^4
1.8•10^4
2.0•10^4
2.2•10^4
2.4•10^4



D'Elia et al. (2010), Thöne et al. (2012); Sparre et al. in prep.; D'Elia et al., in prep; Savaglio et al (2012)

GRB host galaxies: TOUGH

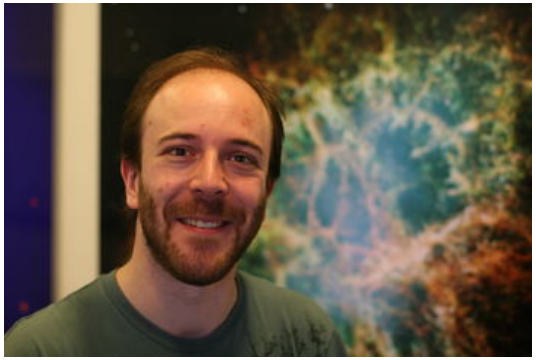
The Optically Unbiased GRB Host (TOUGH) sample

-Large observational effort (VLT large program, PI Hjorth, + X-shooter GTO follow-up)

69 GRB host galaxies selected $0.033 < z < 6.295$

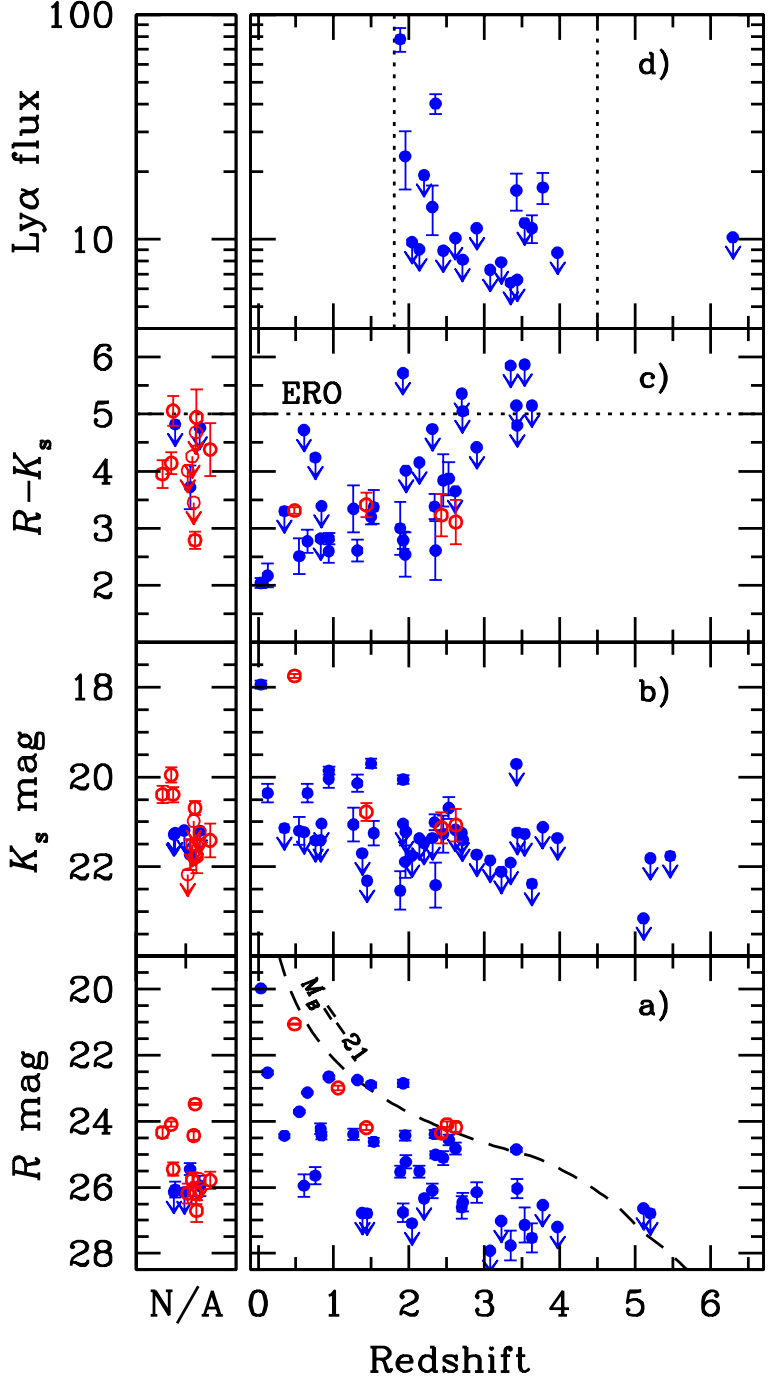
6 core TOUGH papers (recently on astro-ph)

The TOUGH survey



Daniele Malesani
The real tough guy

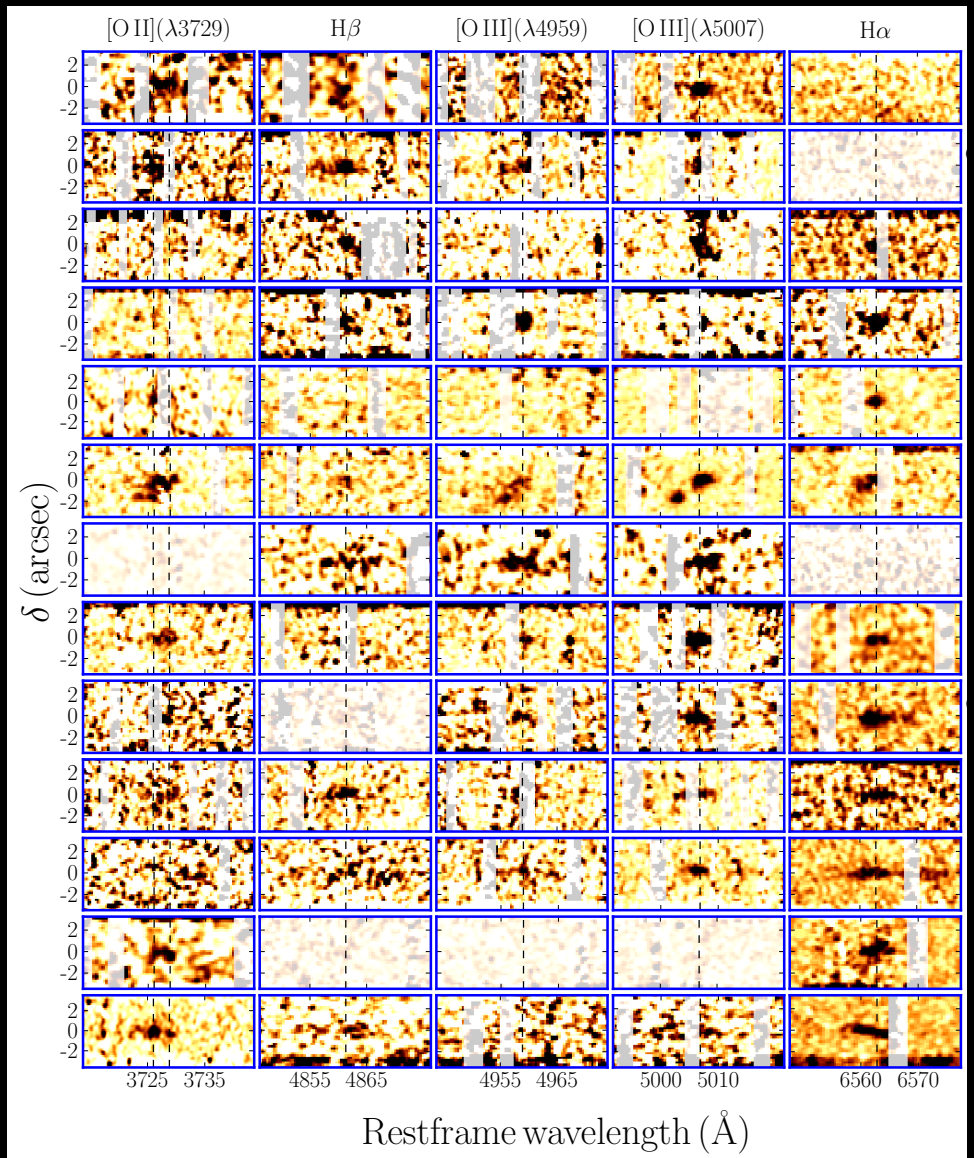
- ✓ 80% of hosts detected in R
- ✓ 42% detected in Ks
- ✓ 77% have redshift measurement
- ✓ <z>=2.14
- ✓ Most hosts are sub-luminous
- ✓ Most hosts are blue, but some are EROs.
- ✓ Lyα emission is frequent, but not ubiquitous



Hjorth, Malesani et al. (2012); Jakobsson et al. (2012); Milvang-Jensen et al. (2012); Krühler et al. (2012)

Redshift campaign

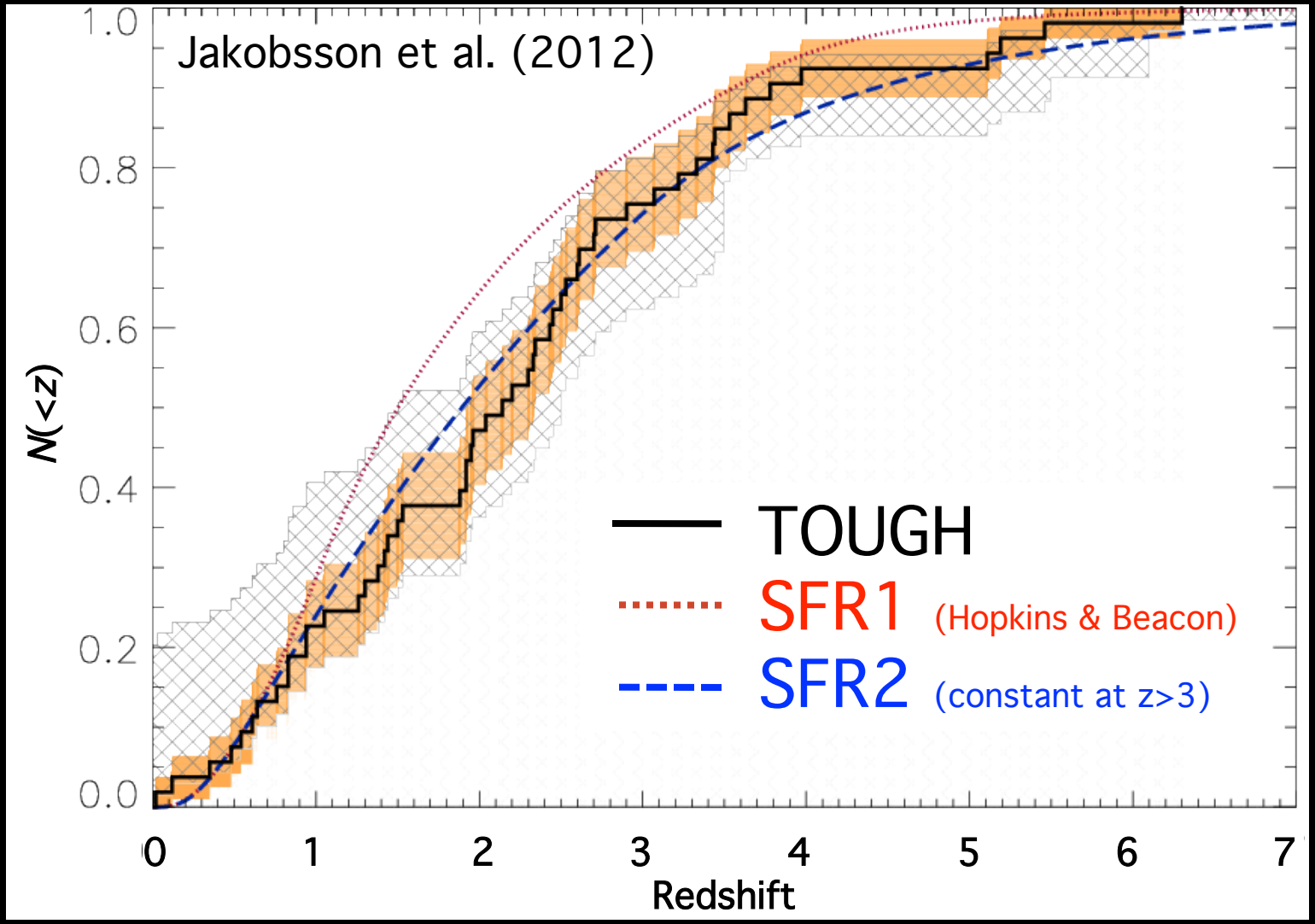
X-shooter campaign NIR coverage: z = 1.5-2.6



Krühler et al. 2012

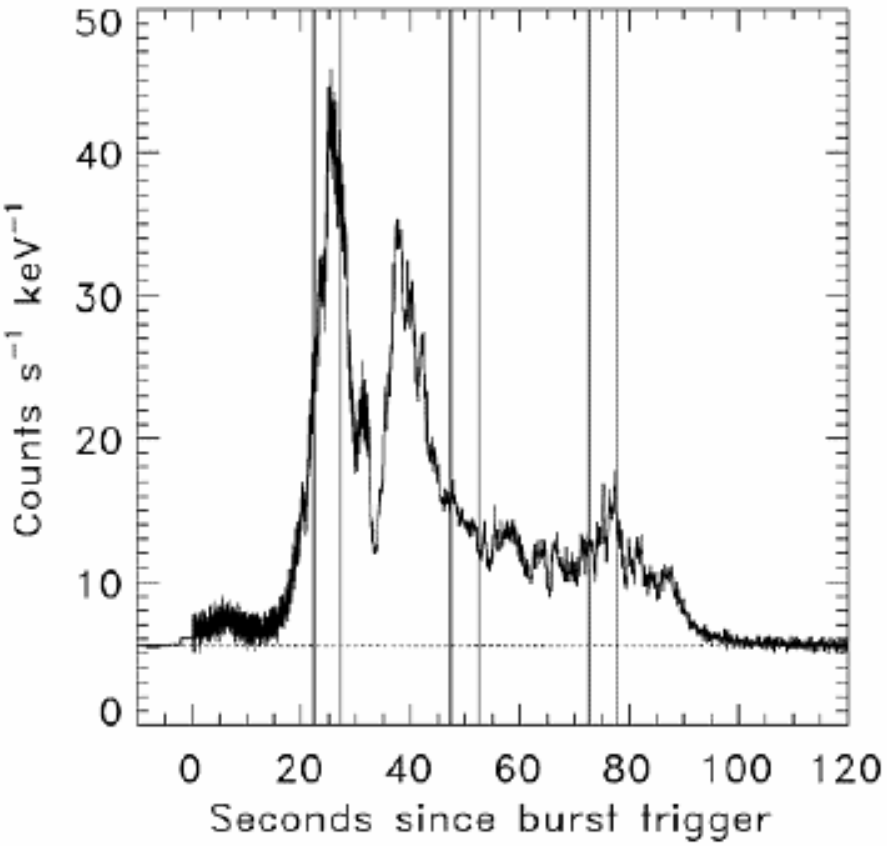
Redshift distribution

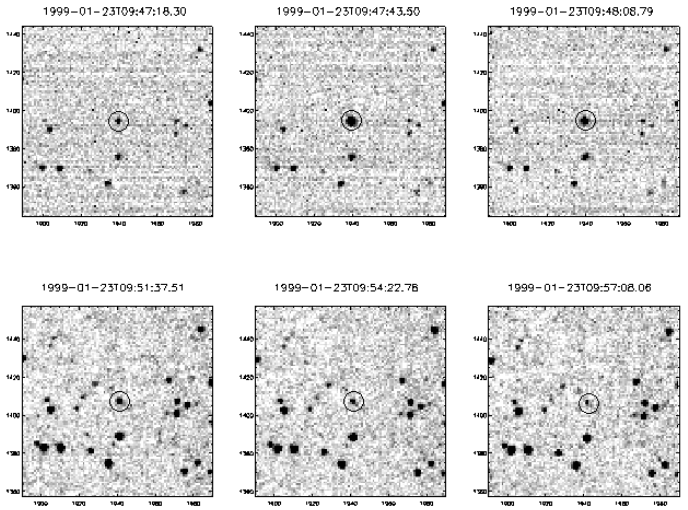
Excess of GRBs at z>2 compared to simple model: effect of metallicity or IMF?



See also Robertson & Ellis; Salvaterra et al.; Elliott et al.; ...

GRB990123: A bright GRB with a bright optical flash – the birth of the RRM



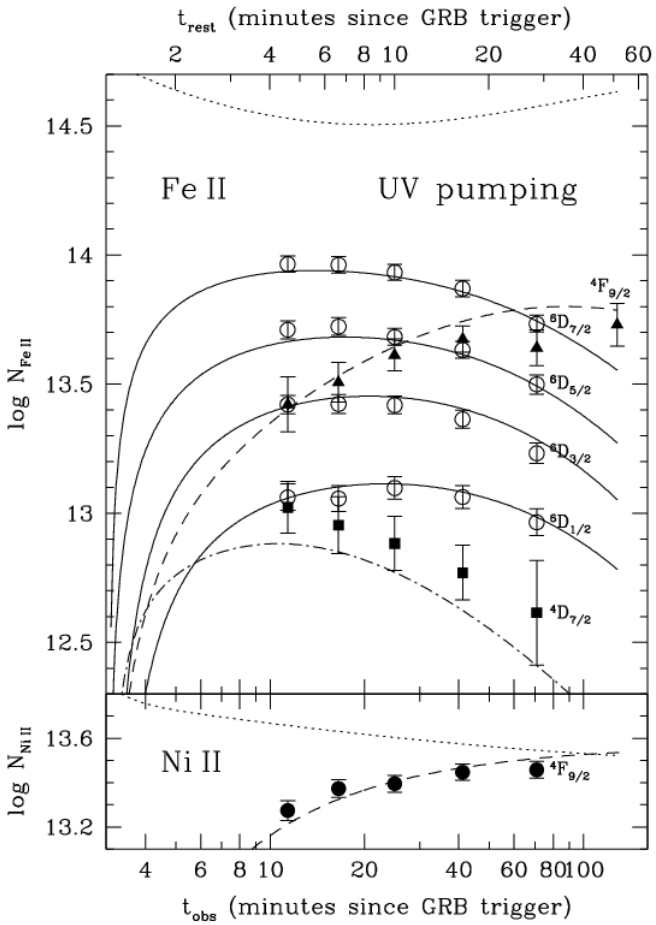


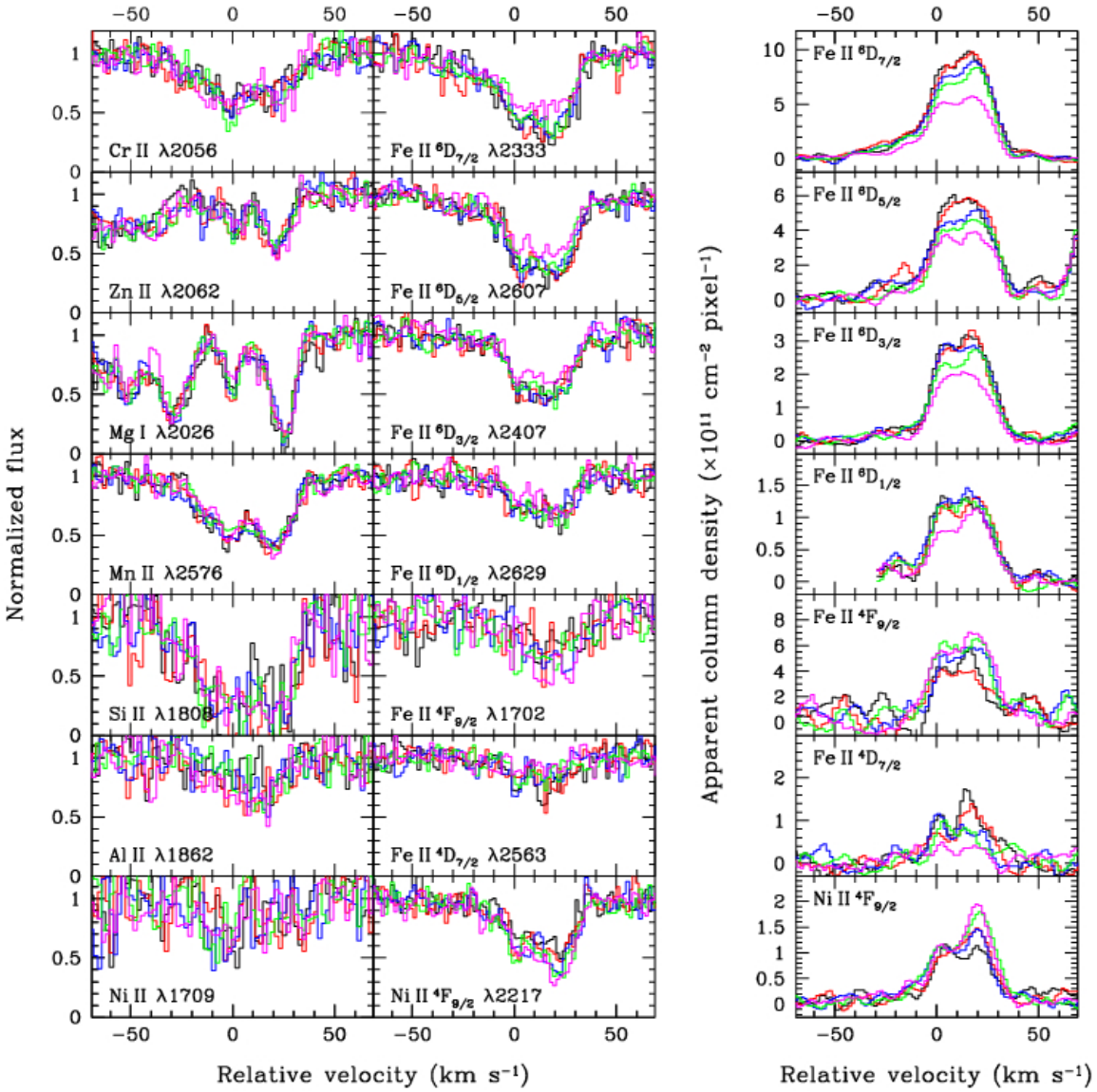
The VLT Rapid-Response Mode: implementation and scientific results

Paul M. Vreeswijk[a,b], Andreas Kaufer[c], Jason Spyromilio[d], Ricardo Schmutzer[c], Cédric Ledoux[c], Alain Smette[c], Annalisa De Cia[b]

SPIE Astronomical Instrumentation 2010, 7737-22

Results from RRM with UVES



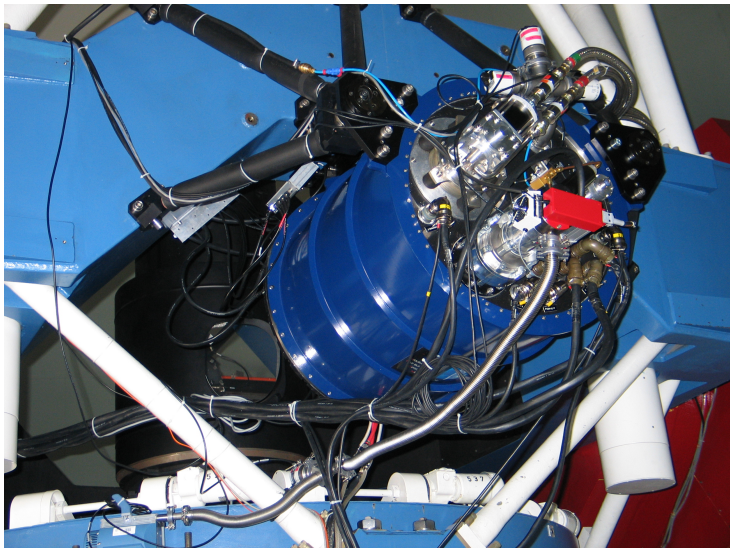


Vreeswijk et al. 2007, See also Prochaska et al. 2007; D'Elia et al. (2009); De Cia et al. (2012)

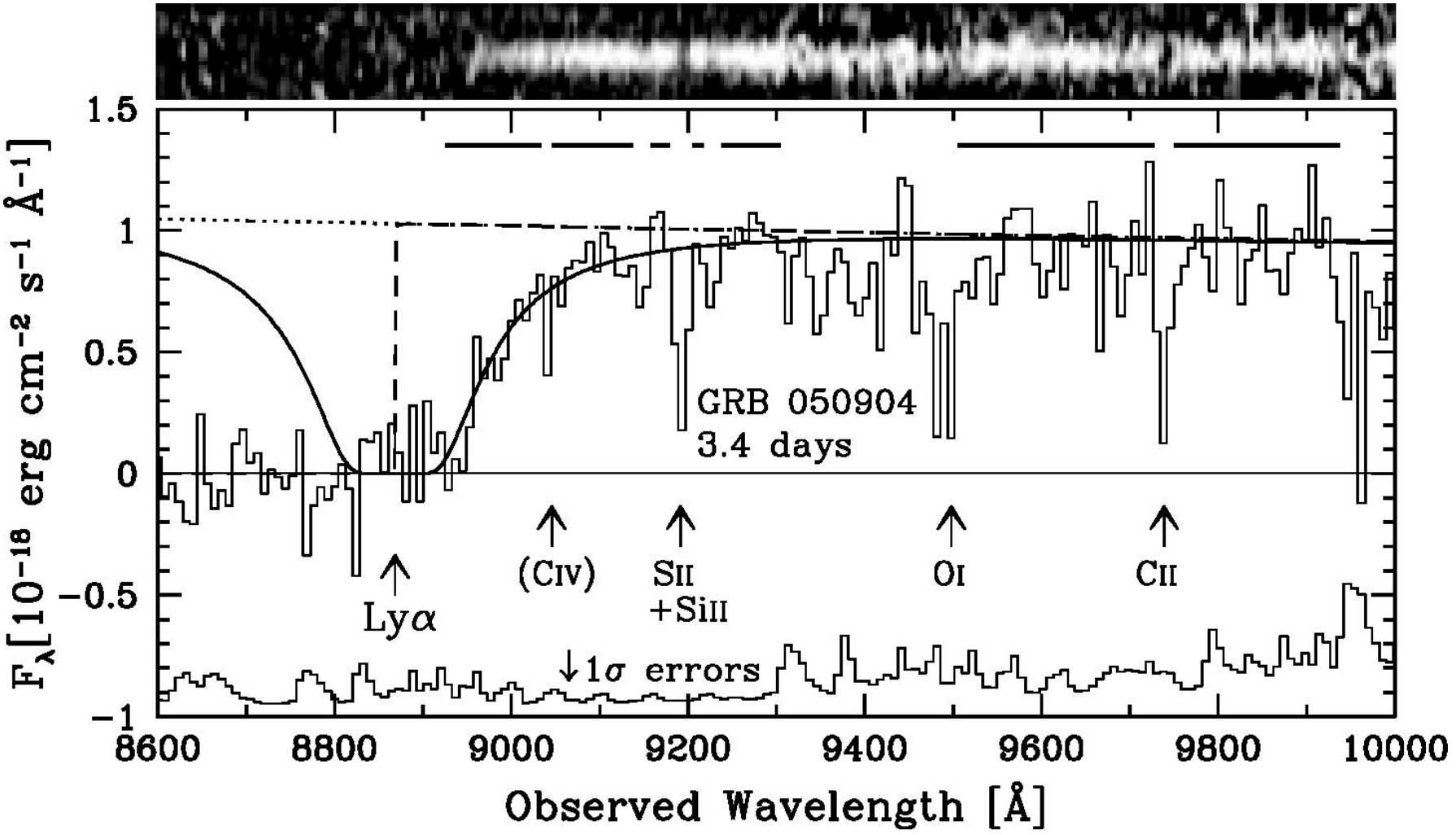
The first Gyr

The importance of near-IR imaging

- GROND at the 2.2m excellent instrument
- Proposal to upgrade X-shooter with H-band acq. Camera (needed to optimally utilize the RRM)



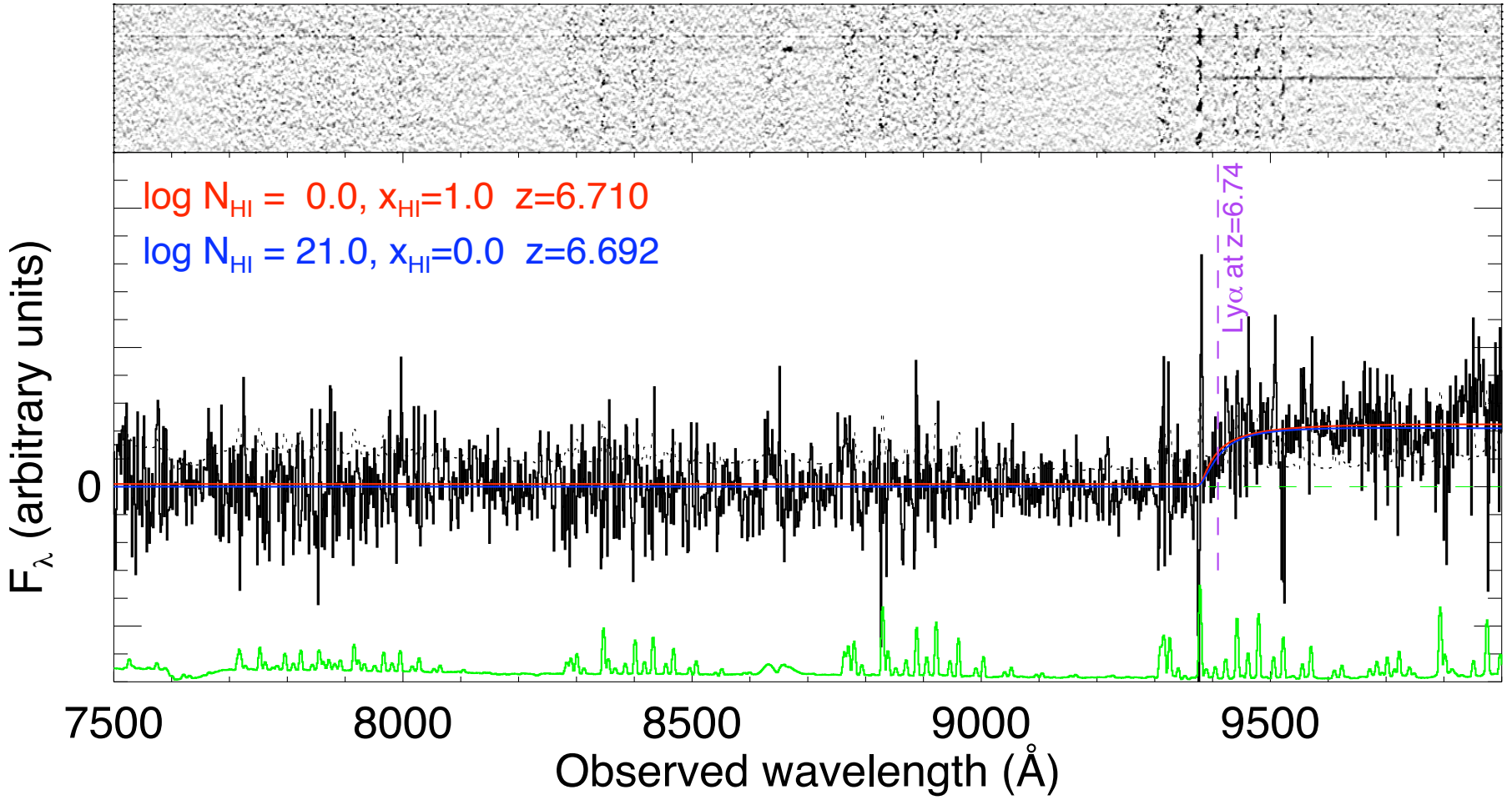
GRB050904: z=6.3



ESO PR Photo 27d/05 (September 12, 2005)

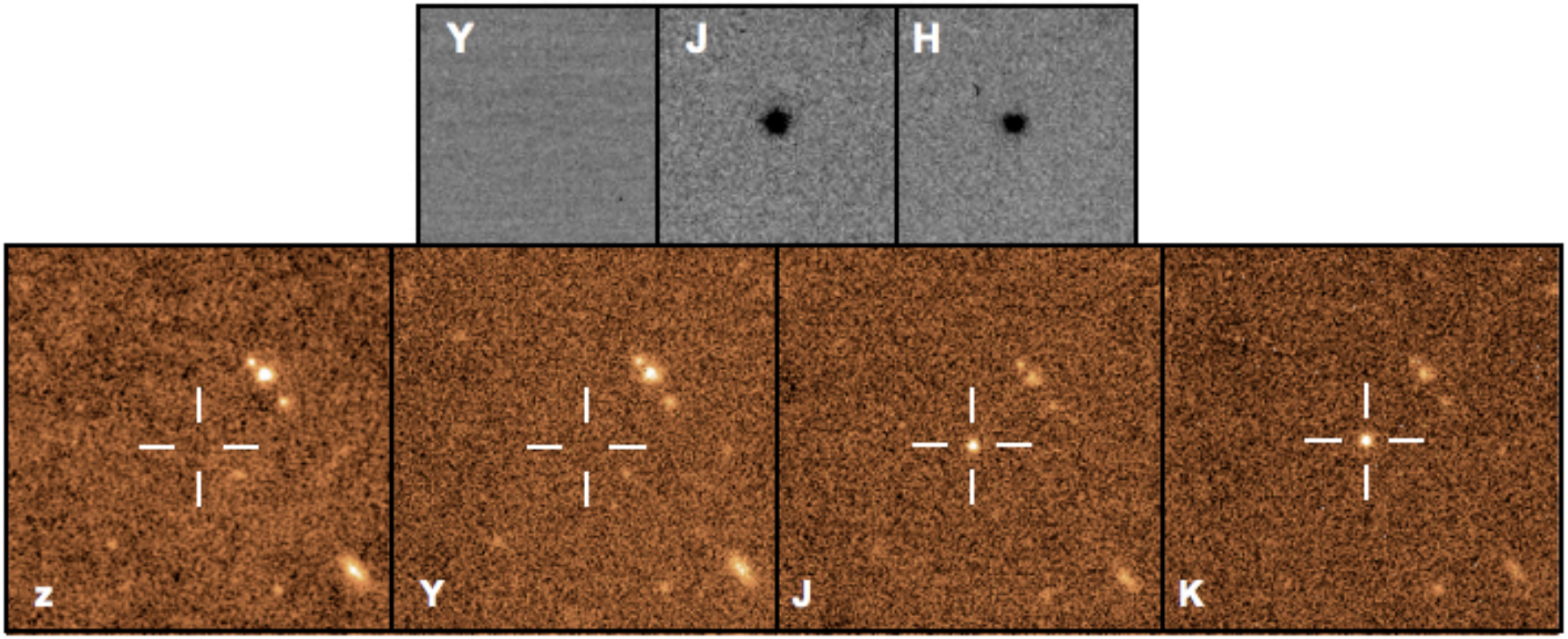
Kawai et al. 2005, Totani et al. 2006, Tagliaferri et al. 2005; Boër et al. 2006

GRB080913: z=6.73



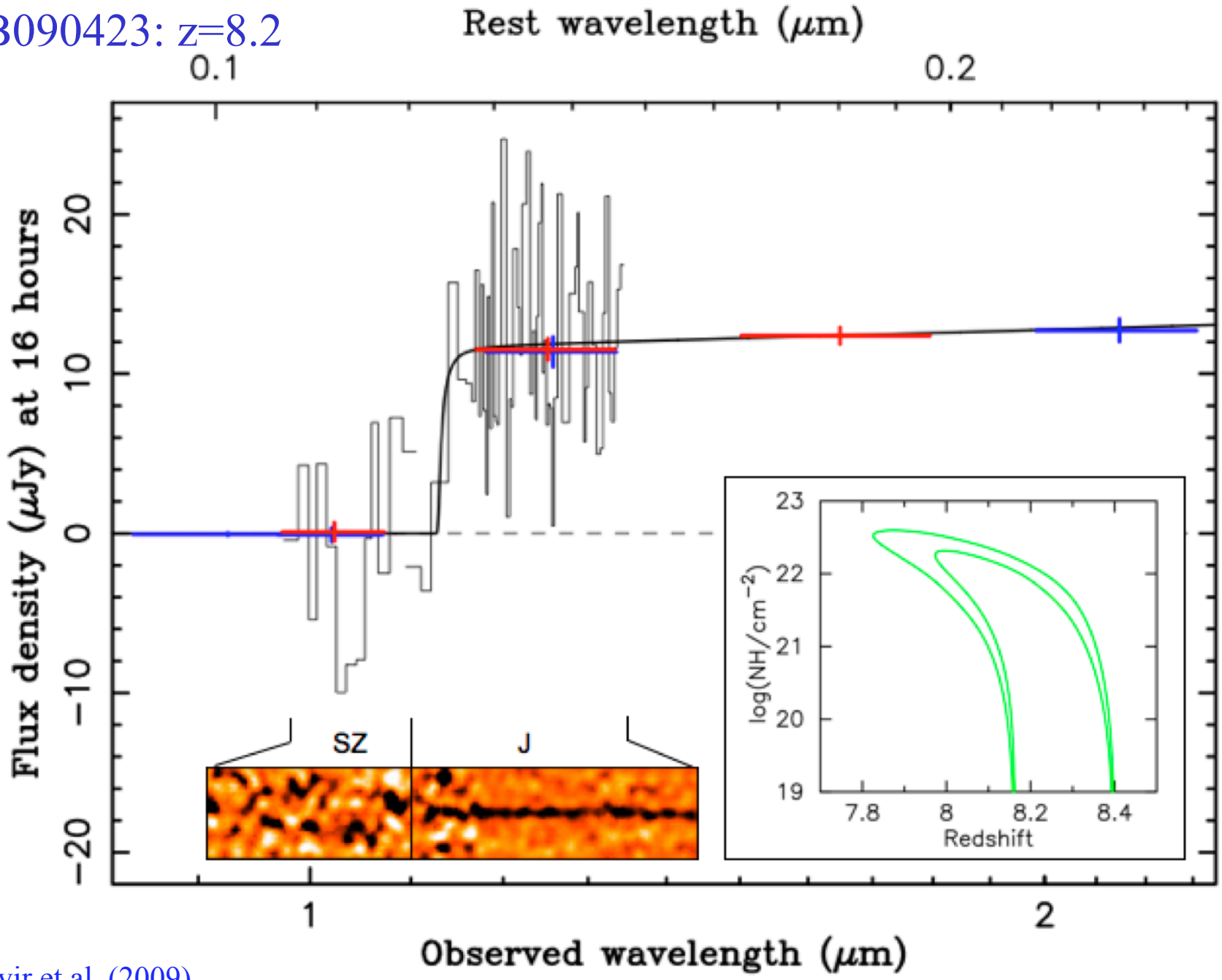
Greiner et al. (2009), Patel et al. (2010)

GRB090423: z=8.2



Tanvir et al. (2009). Independent study in Salvaterra et al. (2009) based on a TNG/Amici spectrum.

GRB090423: z=8.2



Tanvir et al. (2009)

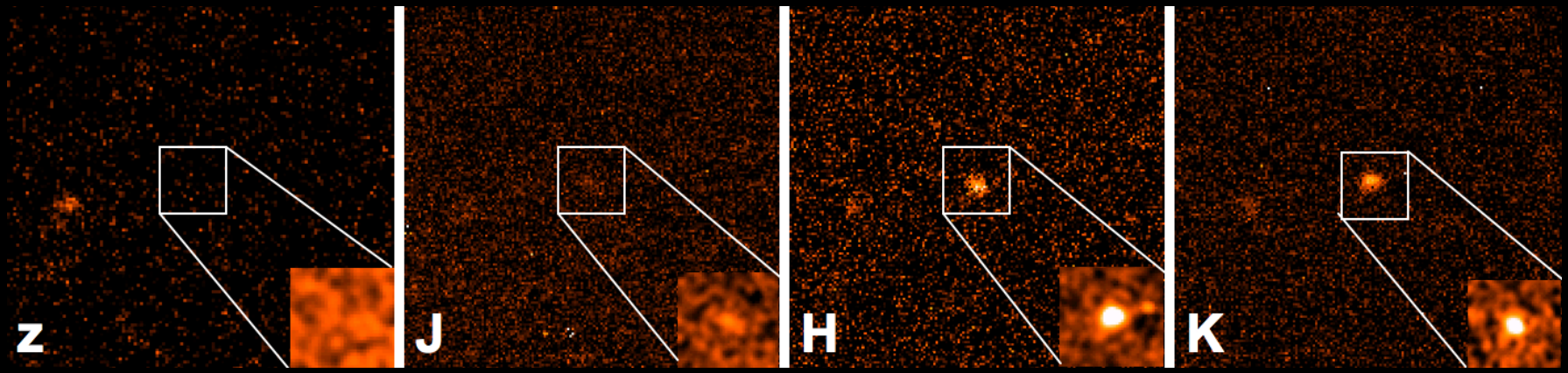
GRB 090429B – less than a week later

Optically dark e.g.

z > 21.8 at 13 minutes (GROND: Olivares et al. GCN 9283)

z > 23.5 at ~1 hour (VLT: D'Avanzo et al. GCN 9284)

z > 24.1 at ~3 hours (Gemini-N)



Infrared bright (Gemini-N at ~3 hours):

J(AB)=22.8

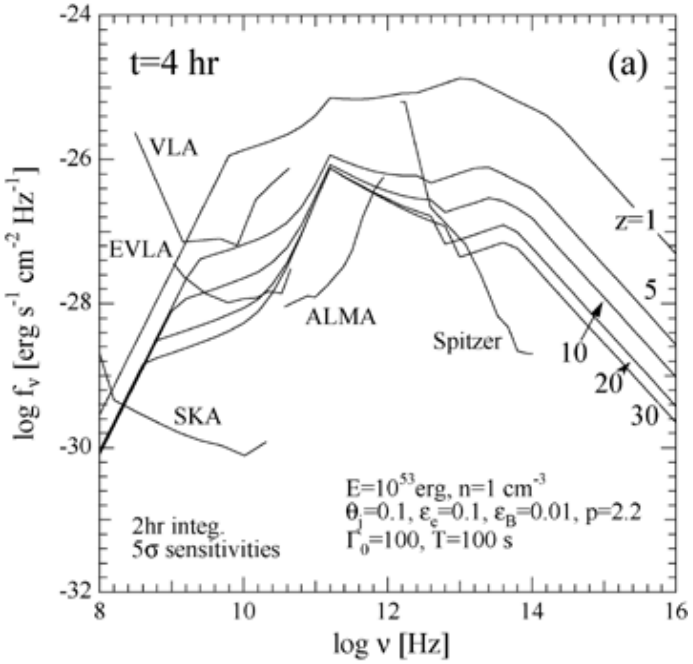
H(AB)=21.5

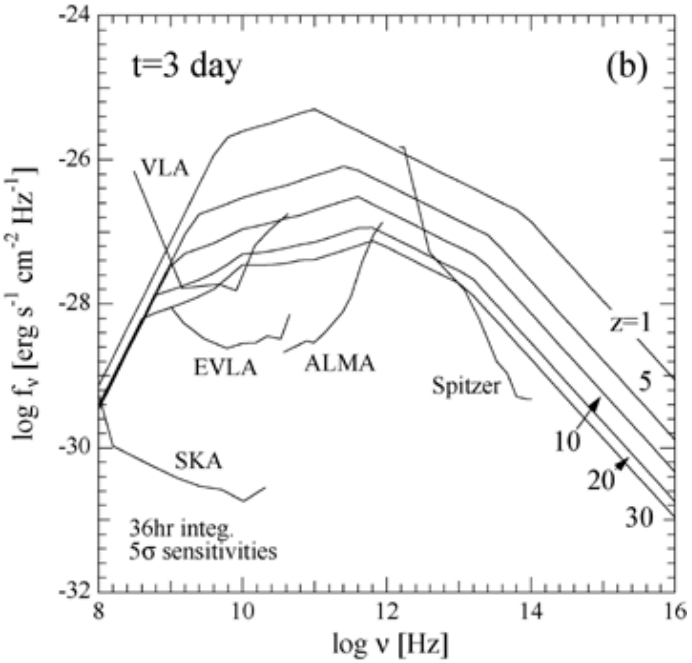
K(AB)=21.2

Cucchiara et al. (2011)

The future:

- ✓ ALMA, E-ELT and eventually SKA will open great new possibilities
- ✓ Swift still going strong and new missions are coming (e.g., SVOM).

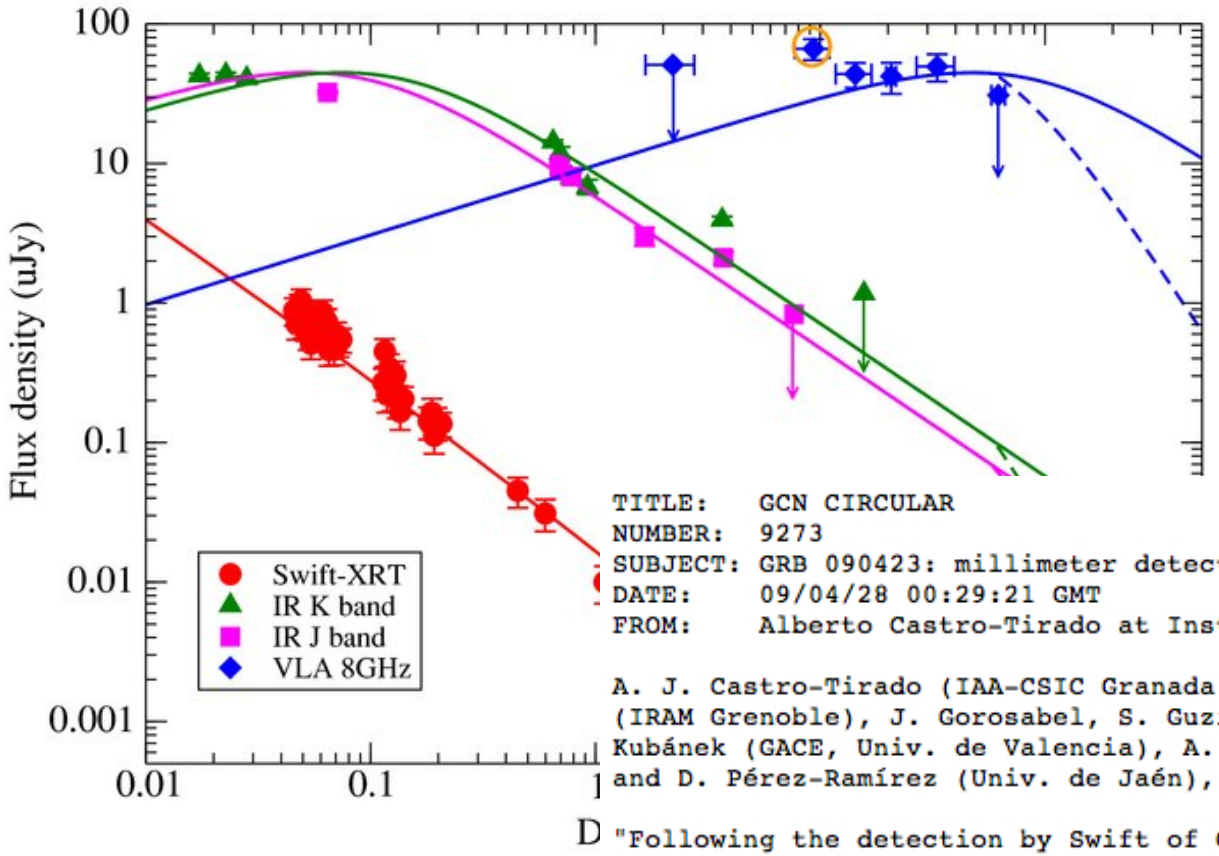




GRB afterglows with ALMA

Inoue, Omukai & Ciardi (2007)

GRB090423 at z=8.23
(Chandra et al. 2010, Castro-Tirado et al.)



TITLE: GCN CIRCULAR
NUMBER: 9273
SUBJECT: GRB 090423: millimeter detection
DATE: 09/04/28 00:29:21 GMT
FROM: Alberto Castro-Tirado at Inst.de Astro. de Andalucia <ajct@iaa.es>

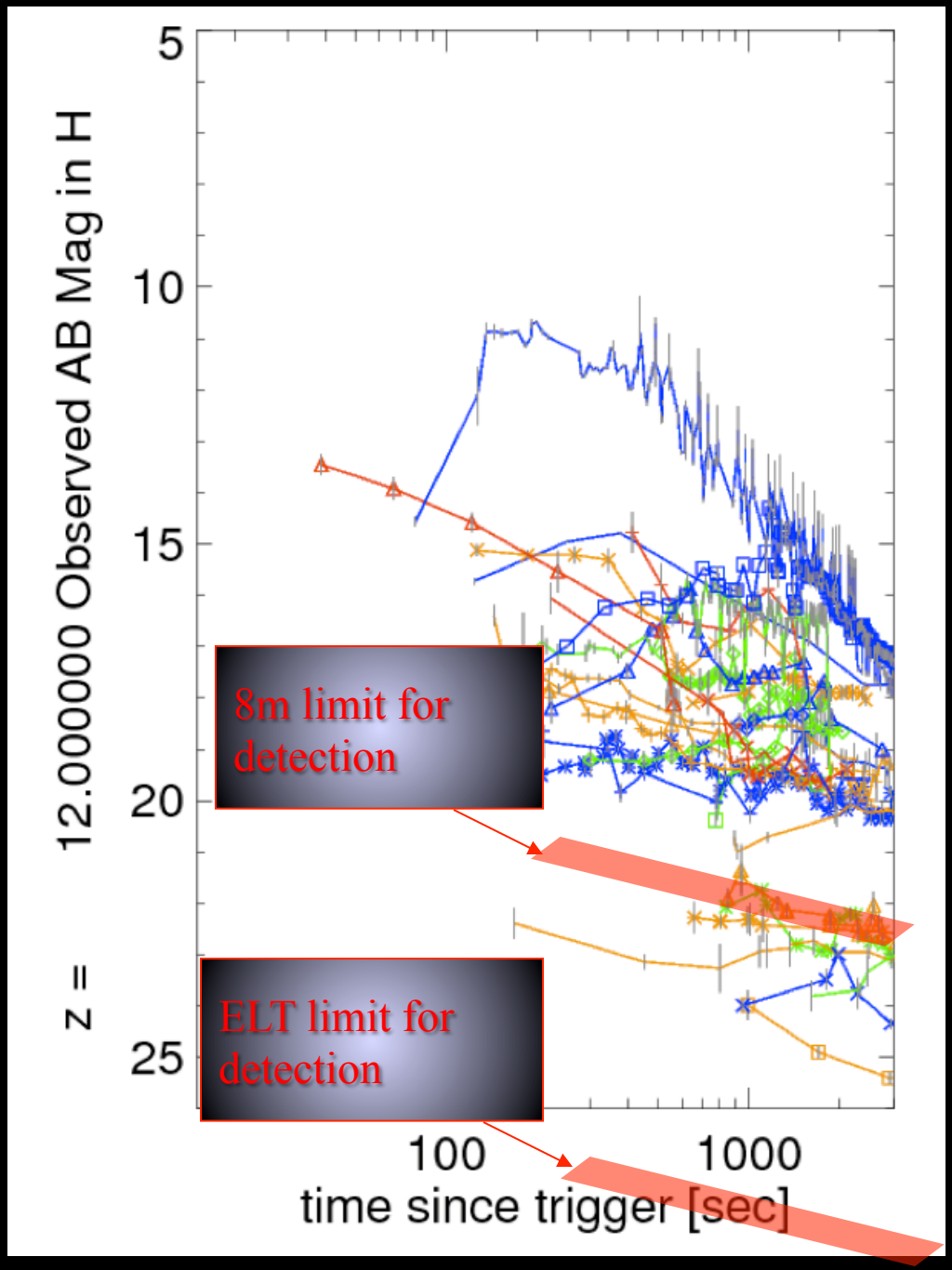
A. J. Castro-Tirado (IAA-CSIC Granada), M. Bremer and J.-M. Winters (IRAM Grenoble), J. Gorosabel, S. Guziy, M. Jelínek (IAA-CSIC), P. Kubánek (GACE, Univ. de Valencia), A. de Ugarte Postigo (ESO Santiago) and D. Pérez-Ramírez (Univ. de Jaén), report:

"Following the detection by Swift of GRB 090423 (Krimn et al. GCNC 9198), millimeter observations were conducted on Apr 23 & 24 at the Plateau de Bure Interferometer. Consistent with the nIR afterglow (Tanvir et al. GCNC 9202) we clearly detect a source at 3-mm with a flux density of ~0.2 mJy (preliminary) on the combined dataset. Pending of confirming its variability we propose this as the likely millimeter afterglow to GRB 090423. Considering the reported redshift values around z ~ 8, this is the most distant radio source detected to date. Further observations are scheduled. We acknowledge the Bure staff for its excellent support."

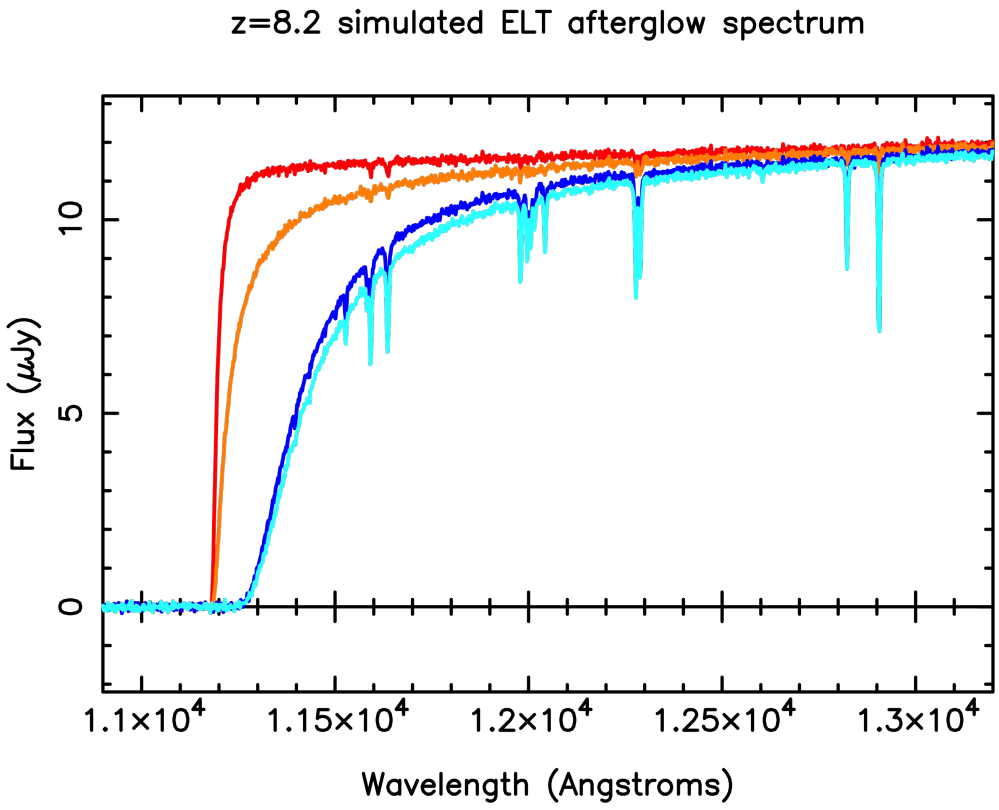
GRBs: can be very bright!

Brighter afterglows easily detectable at very high redshifts (in part because cosmological time dilation means we can get on target earlier in the rest frame)

Slide from Nial Tanvir



Slide from Nial Tanvir



Log(NH) (host)	NF (IGM)
20	0
20	0.8
22	0
22	0.8

Little gas in host ⇒ good characterization of IGM.

Much gas in host ⇒ superb metallicity determinations.

Simulated GRB090423 spectrum taken by ELT rather than VLT (remember this was a faint afterglow!)

Conclusions:

- ✓ GRBs provide complementary information on a large number of important problems in astrophysics (stellar death, star-formation, starburst galaxies, galaxy luminosity function, chemical evolution, extinction curves, re-ionization, intervening absorbers, etc.)
- ✓ ESO has facilitated a large number of breakthroughs!
- ✓ We have so far only scratched the surface of the science one can do with GRBs!

Thanks for your attention!