Gamma-Ray Burst and Massive Star Formation

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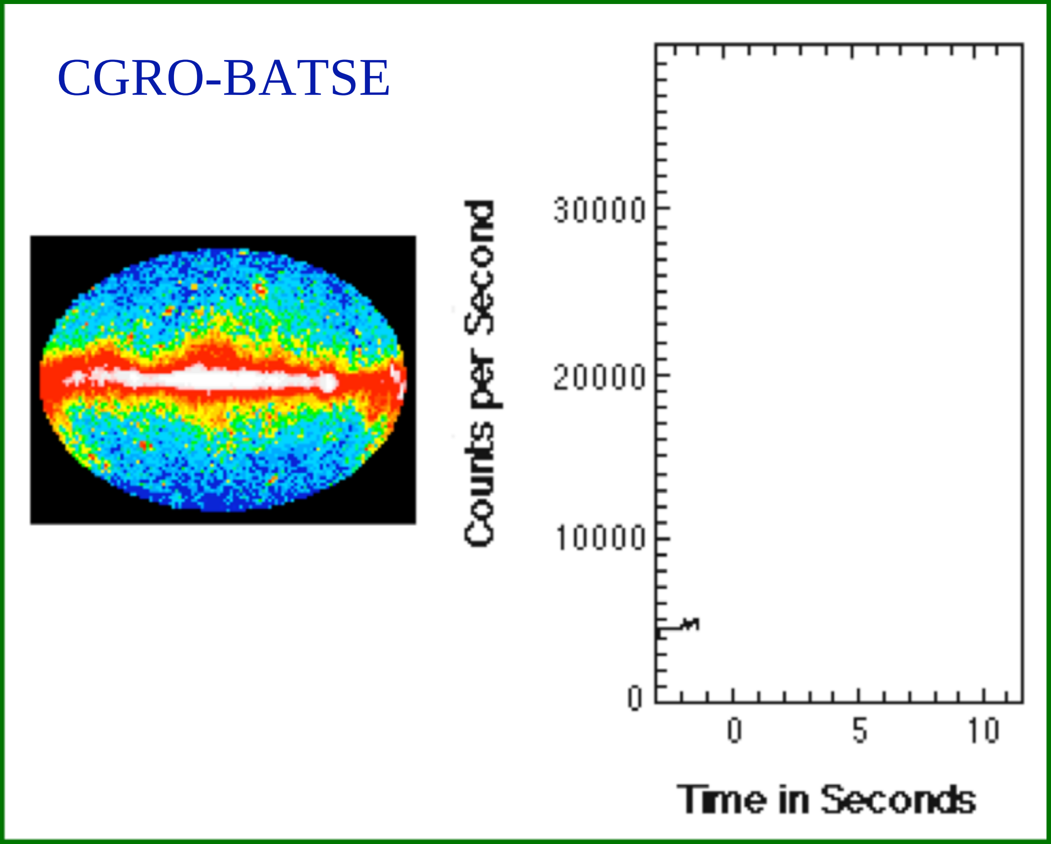
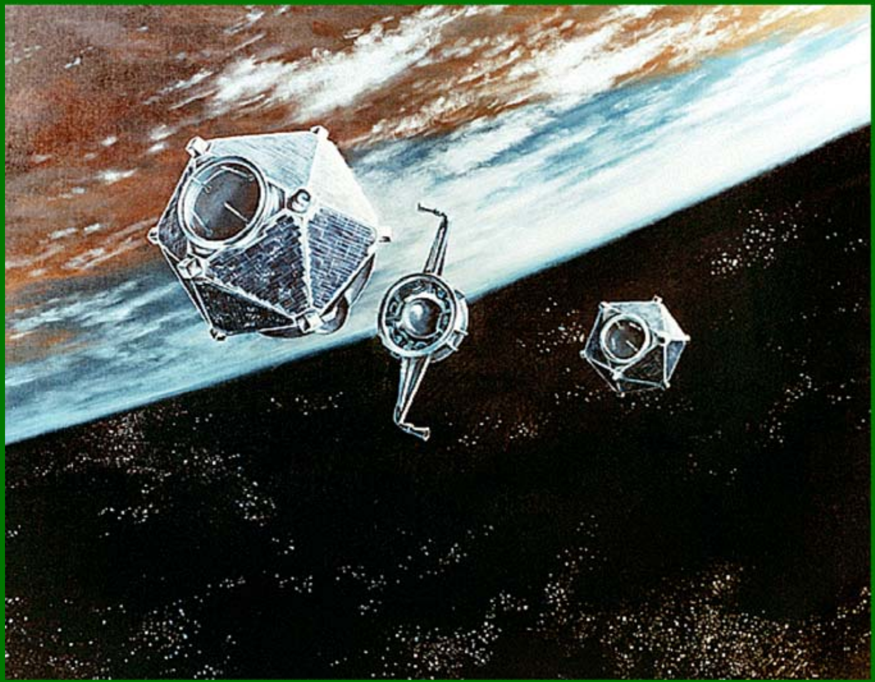
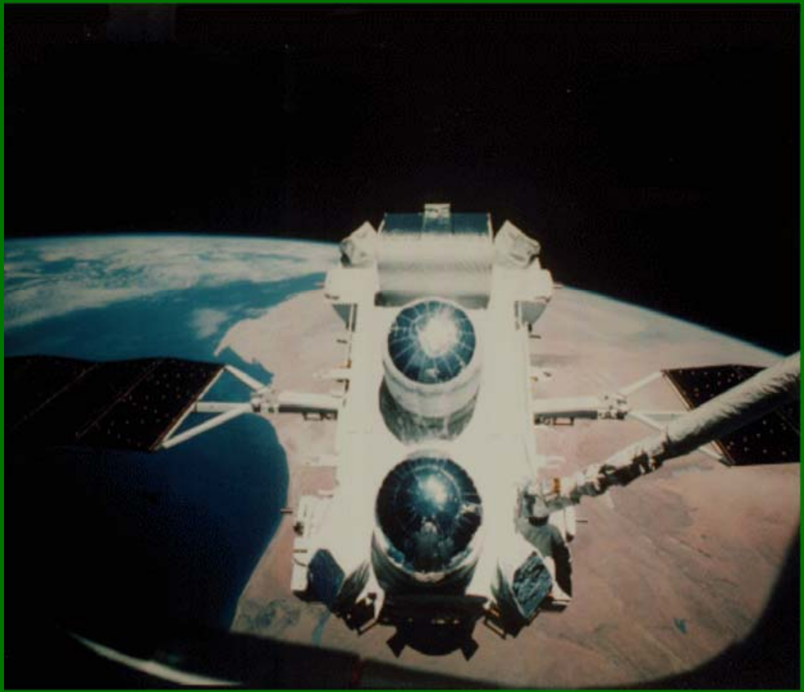
Santa Barbara, 23 October 2007

GRBs are brief flashes of soft γ-ray radiation (~100 keV), discovered in the 1970's, the origin of which was not known until 1997



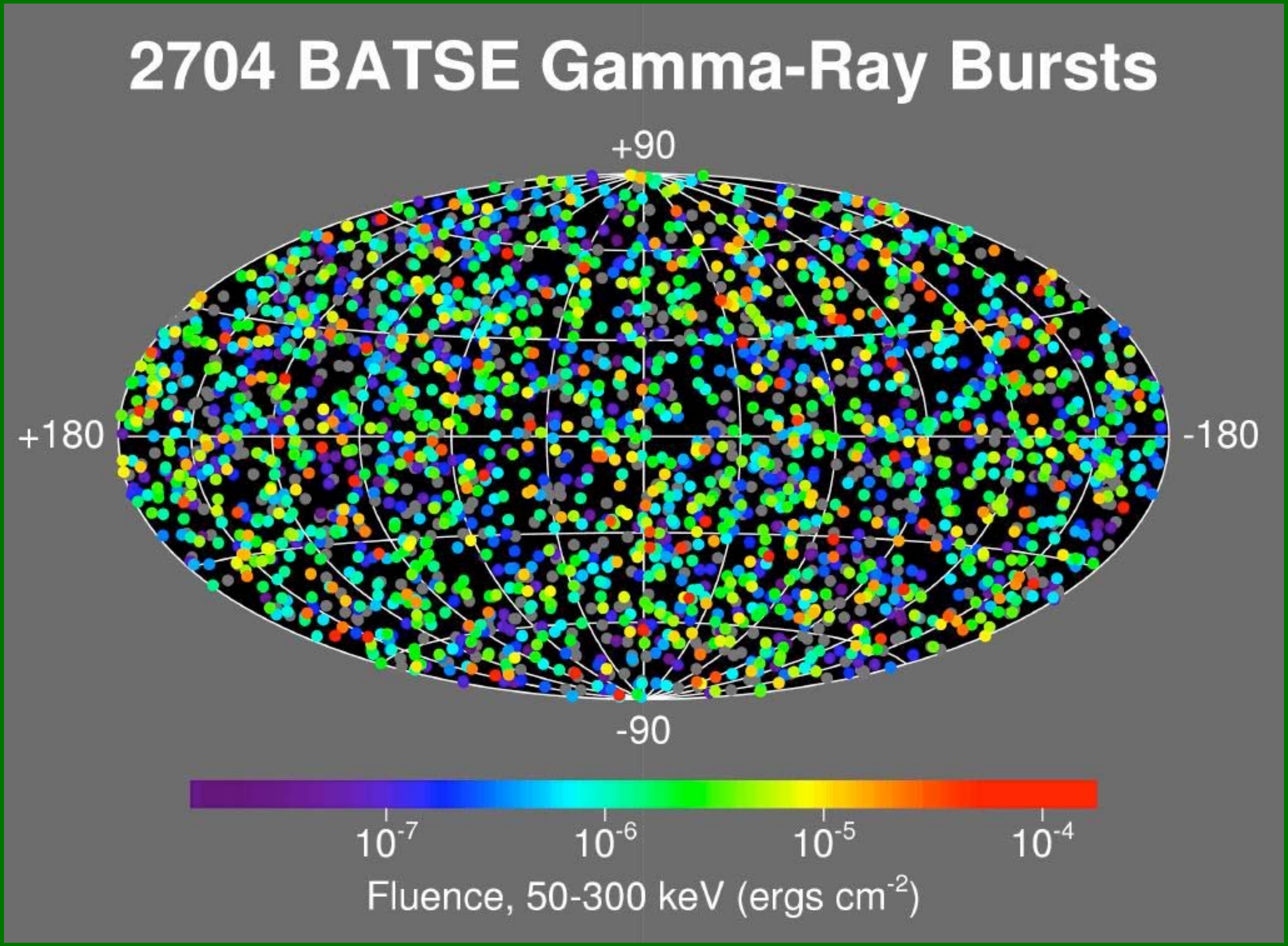


1991-2000:
BATSE onboard
the *Compton Gamma Ray Observatory*

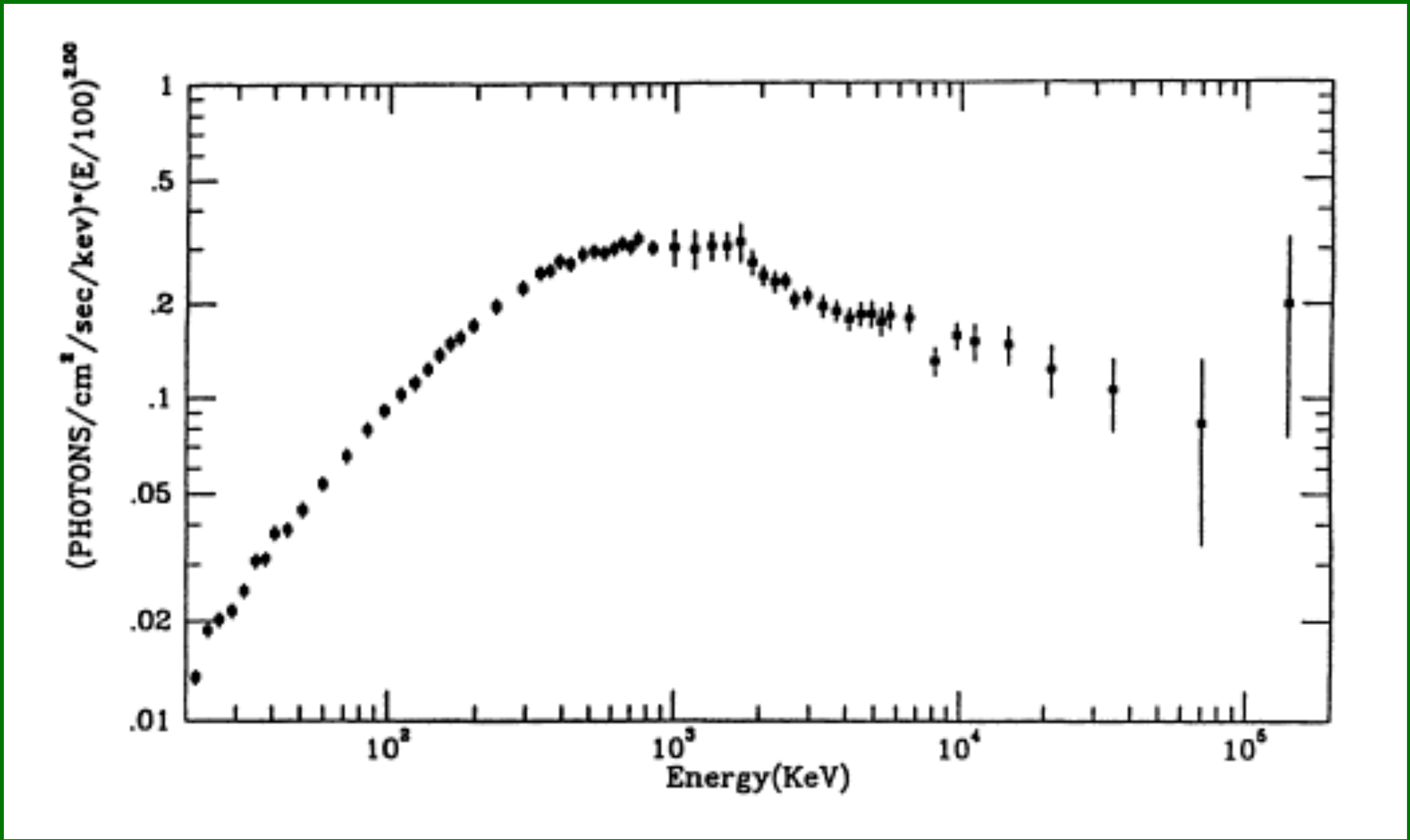


1960-1970: Vela satellites

The GRB distribution is isotropic



CGRO spectrum of a GRB



Light curves of GRBs

Fluence ~ $10^{-7} \div 10^{-4}\, erg/cm^2$

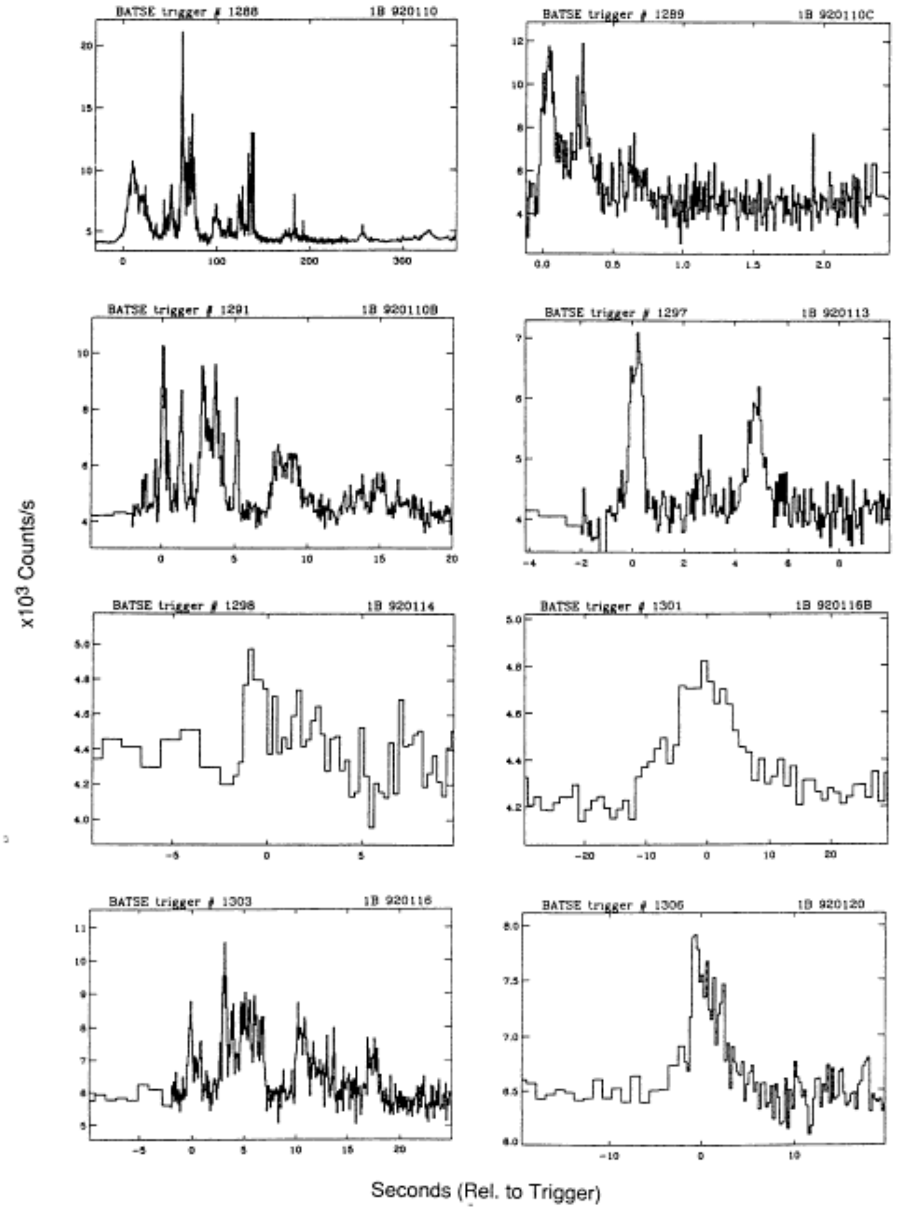
$t_{\mathrm{var}} \approx 10 ms$

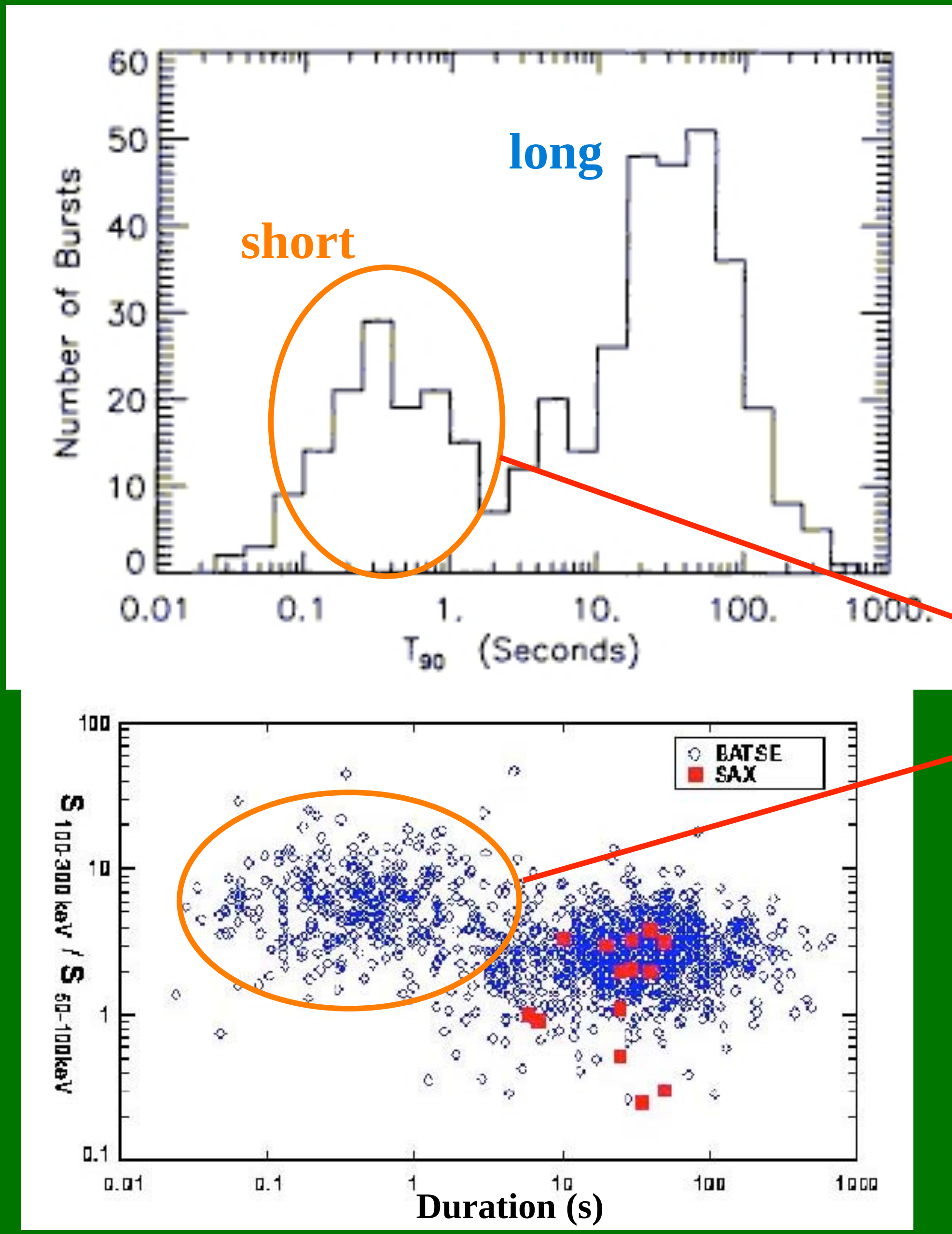
⬇

$\tau_{\gamma\gamma} >> 1$ if cosmological

relativistic conditions are implied: Lorentz factor Γ~100

CGRO-BATSE (Fishman & Meegan 1995)





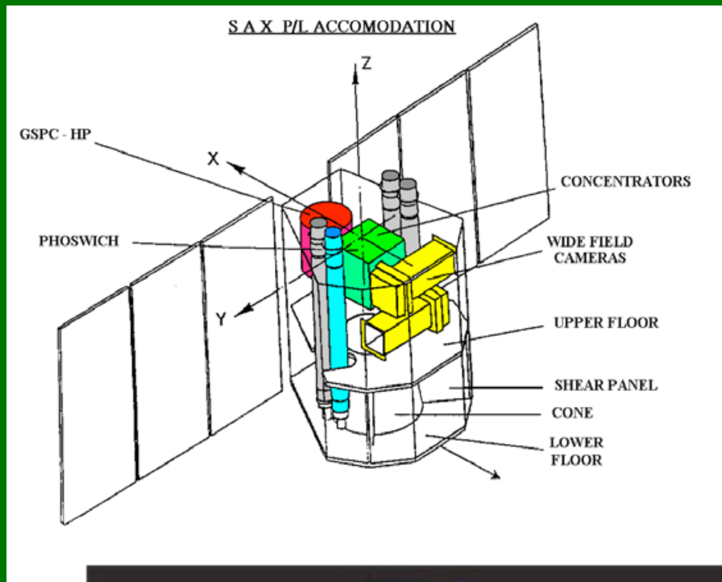
Bimodal distribution of GRB durations

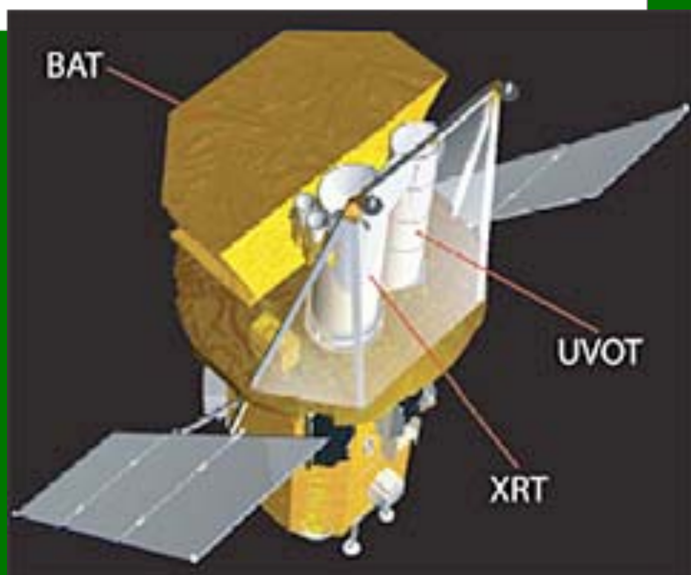
Different progenitors: SNe vs binary neutron star mergers

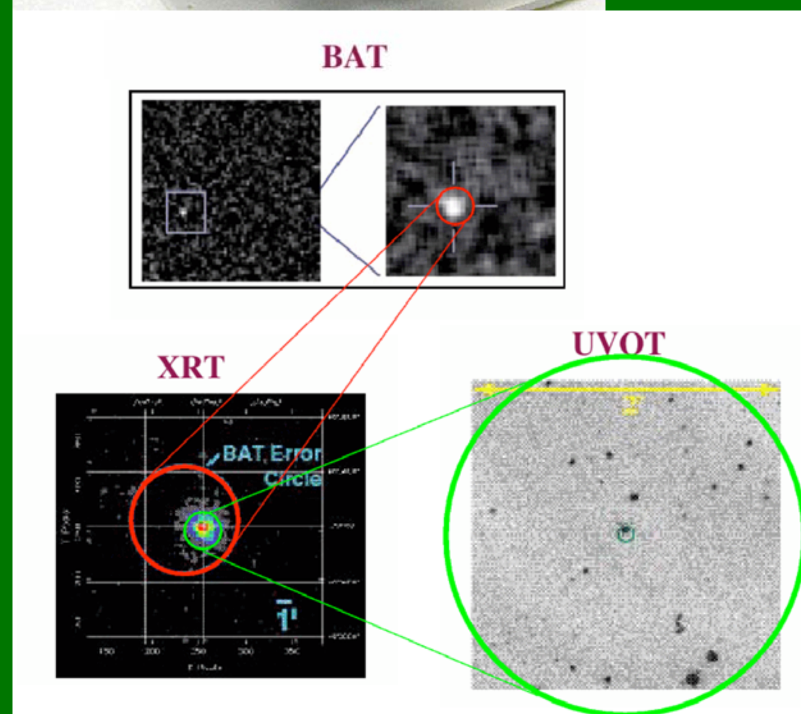
Kulkarni 2000

1996-2002: BeppoSAX

Wide Field Cameras



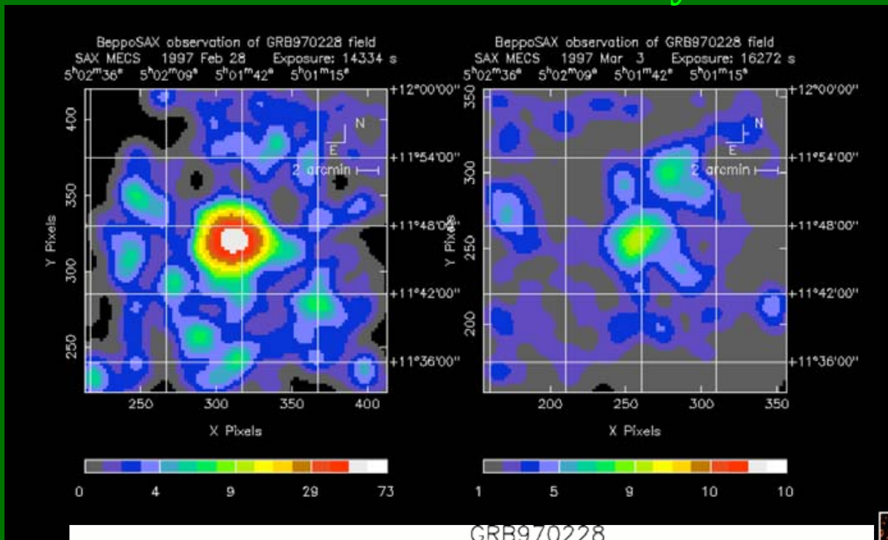




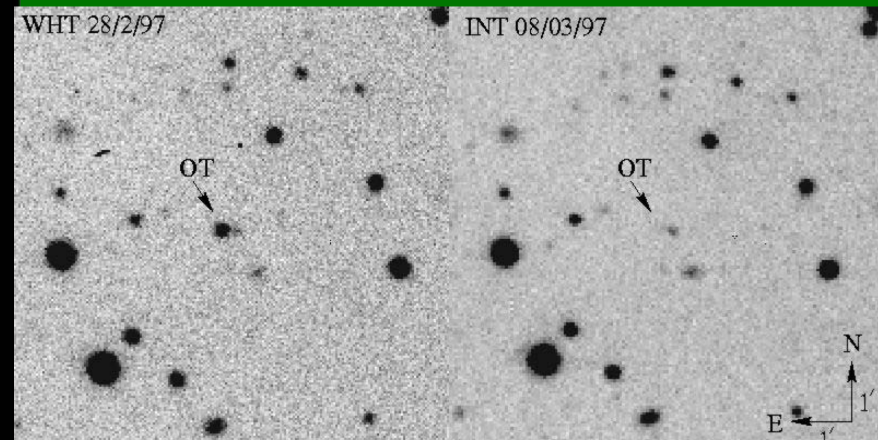
Swift: 20 Nov 2004

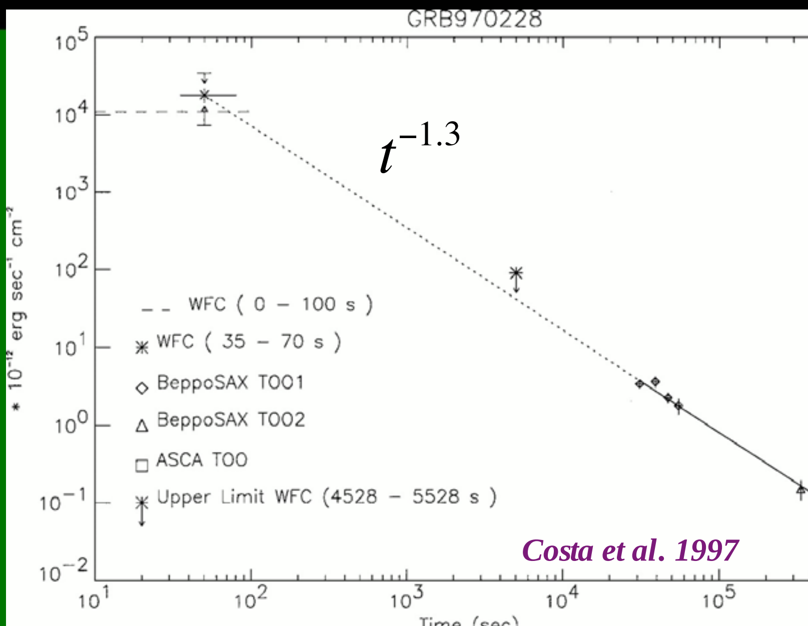
GRB970228: first detection of X-ray and optical afterglow

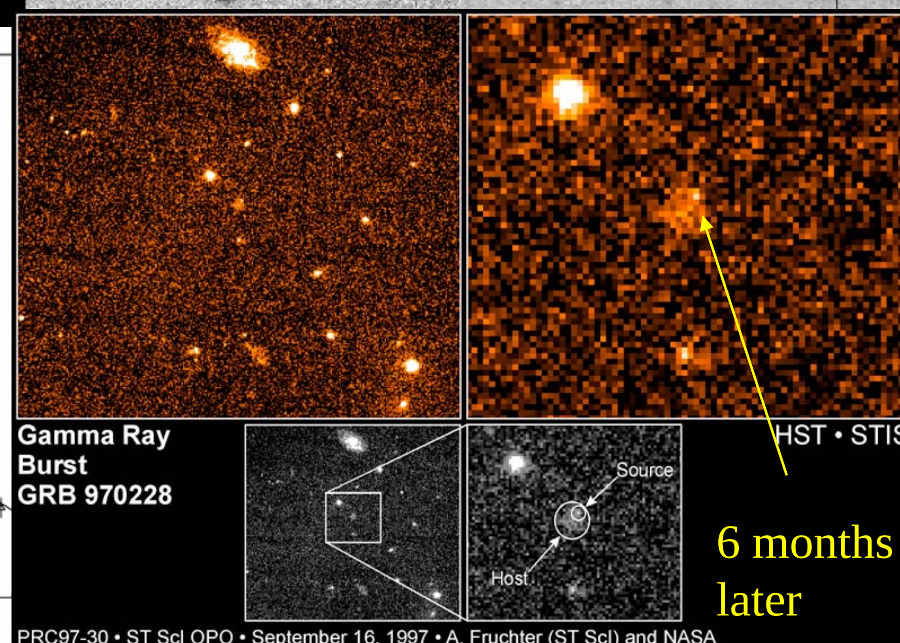
8 hours **3 days**



Van Paradijs et al. 1997

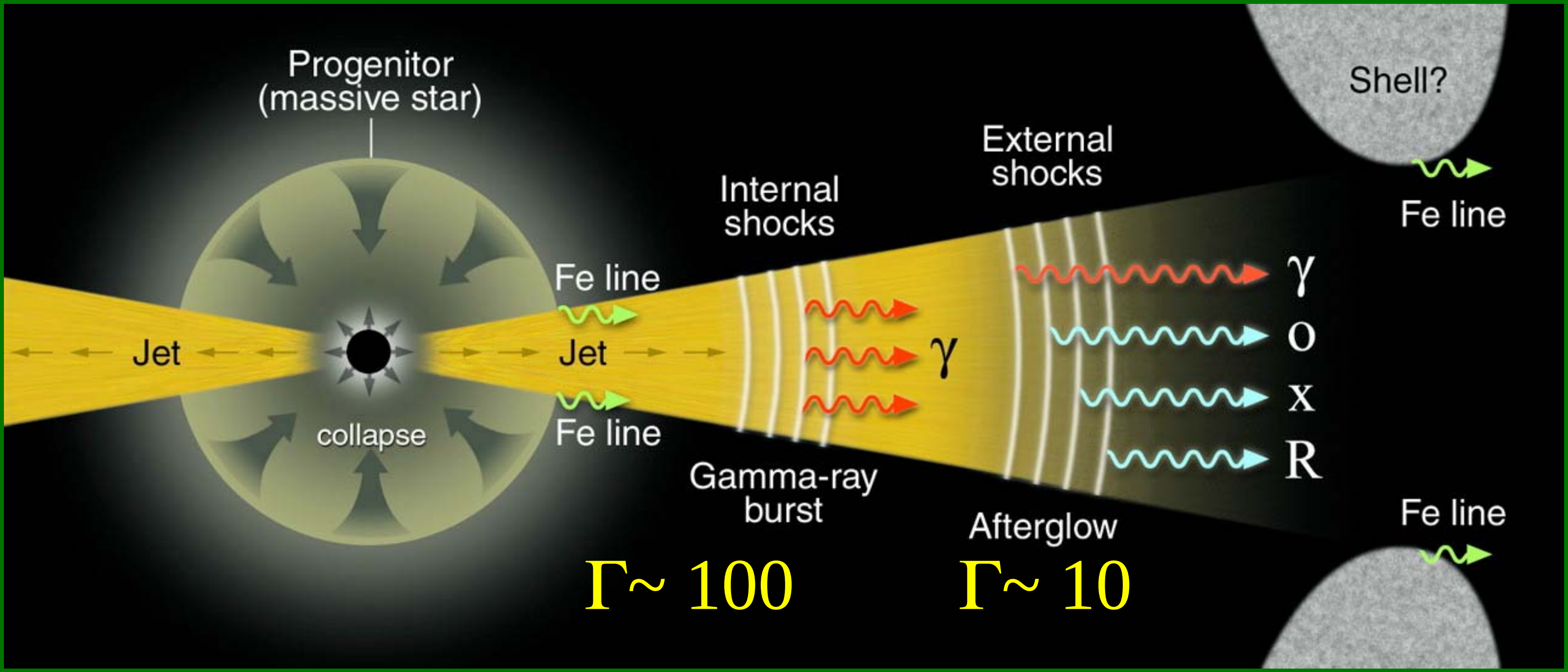


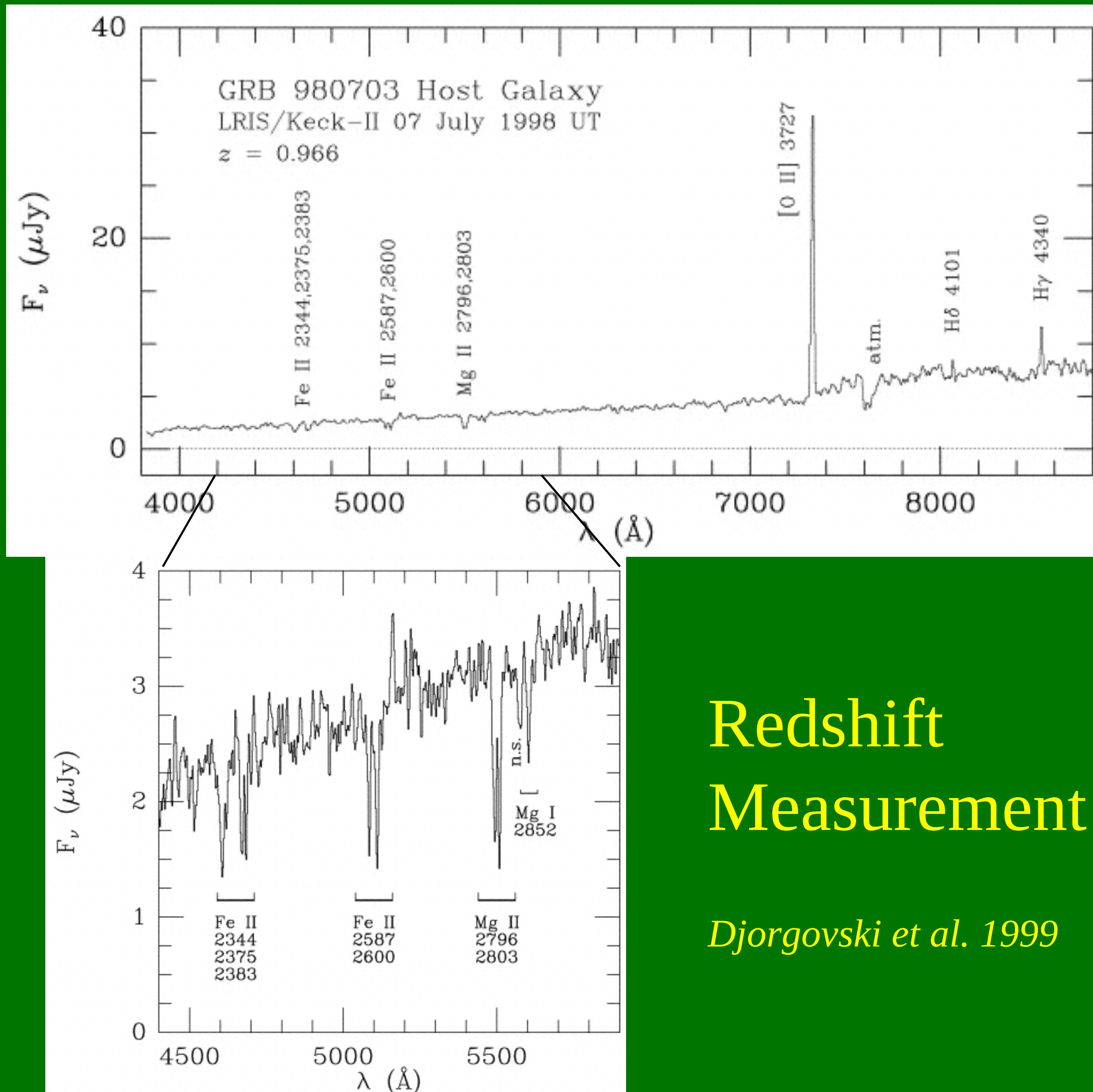




6 months later

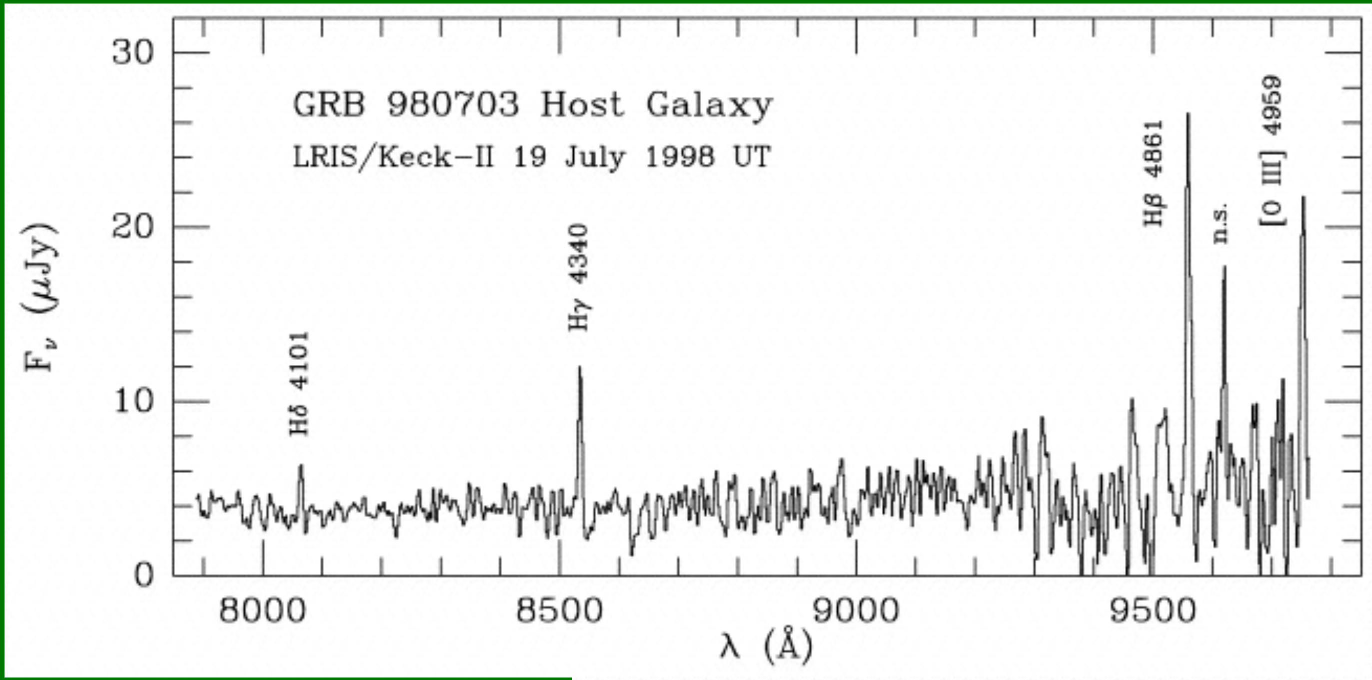
“Firecone” model: relativistic shocks in a jet



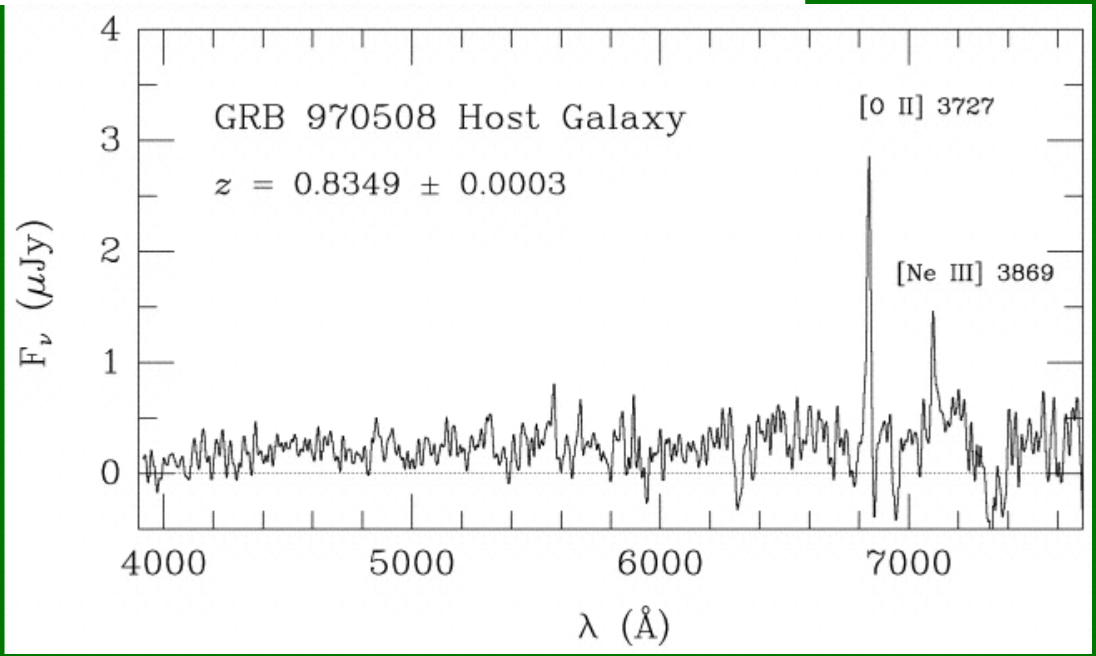


Redshift Measurement

Djorgovski et al. 1999

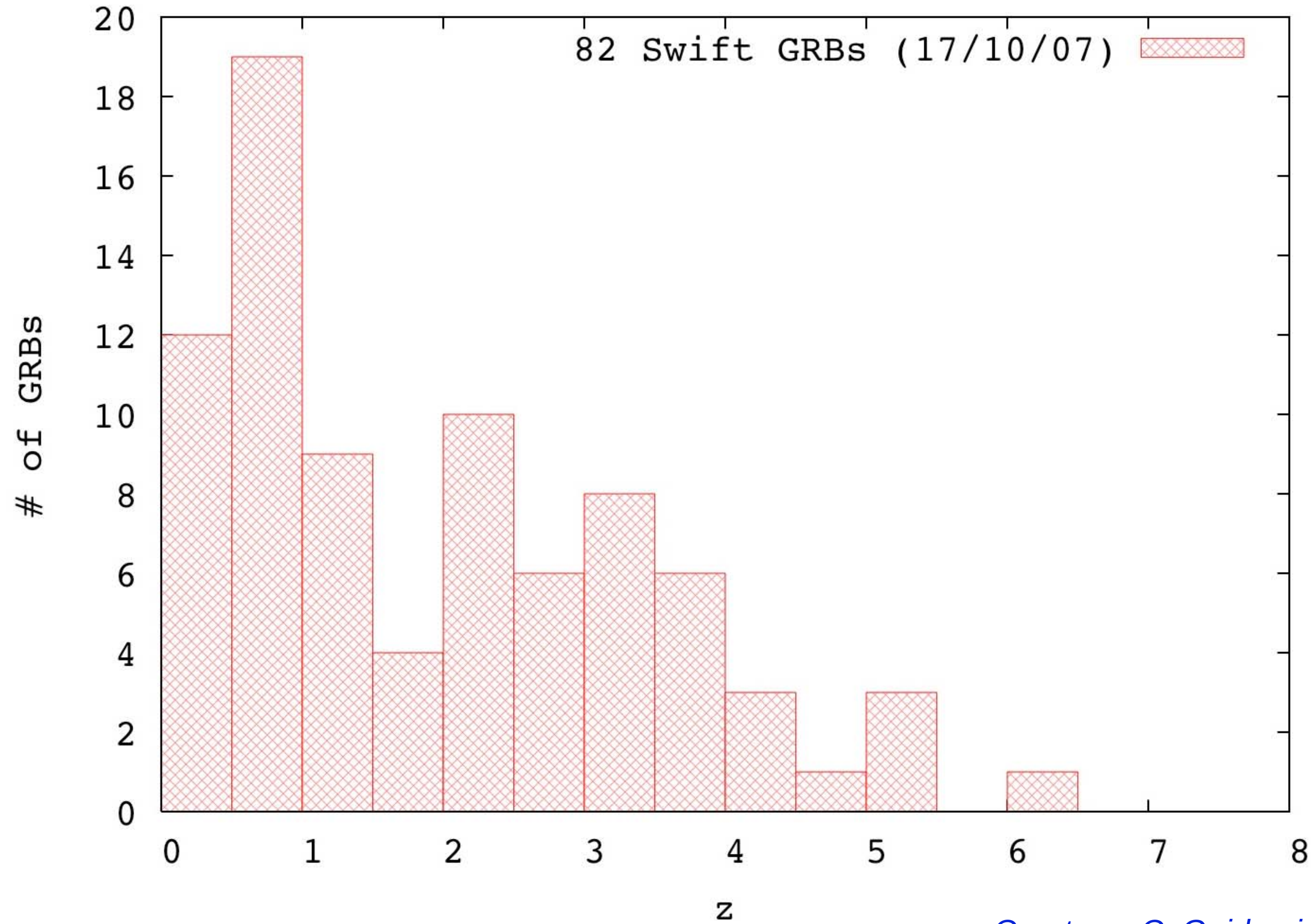


Bloom et al. 1998,1999



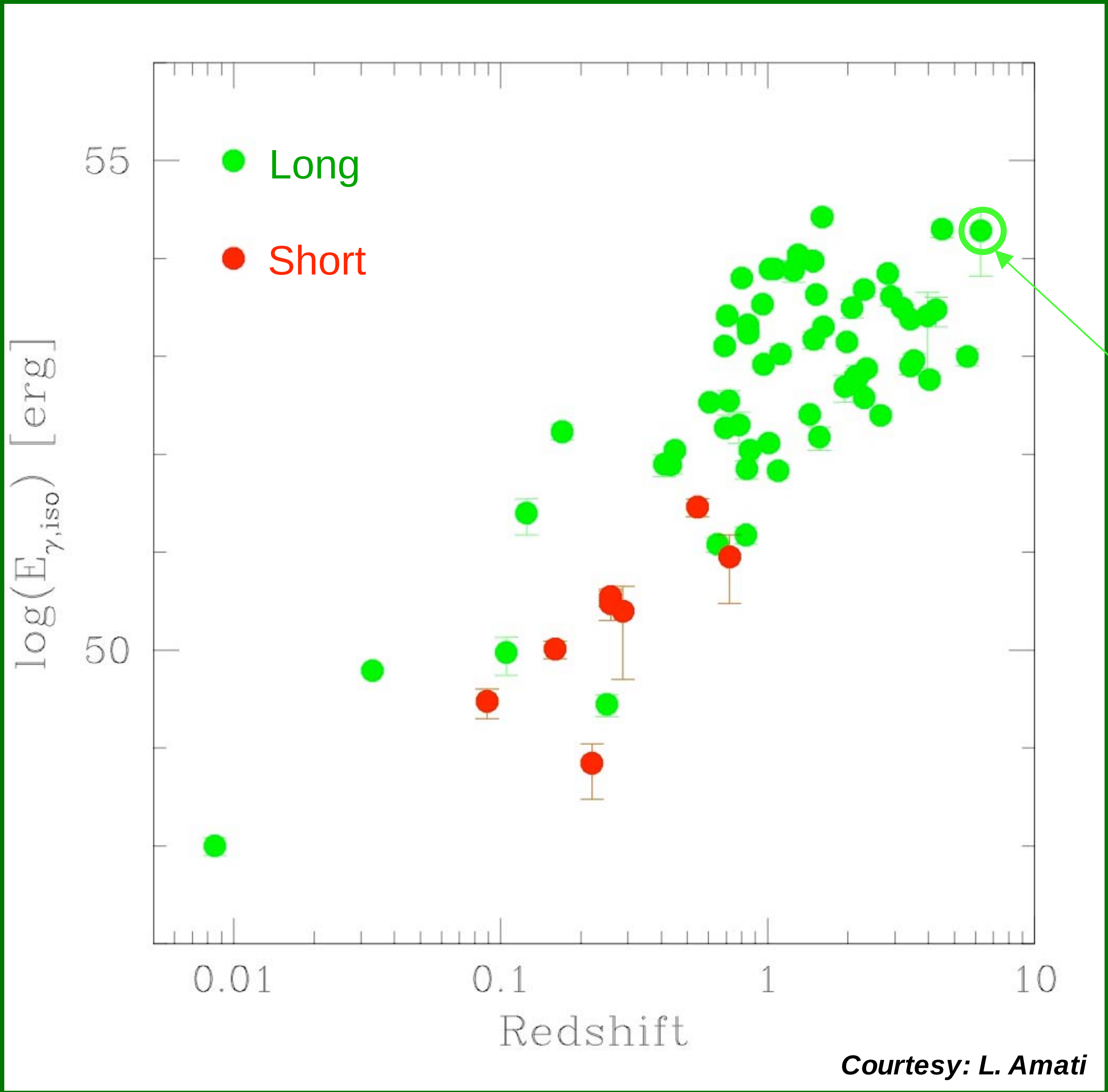
Host galaxies exhibit emission lines of star formation: [O II], [O III], Balmer and Paschen series

Swift GRBs redshift distribution



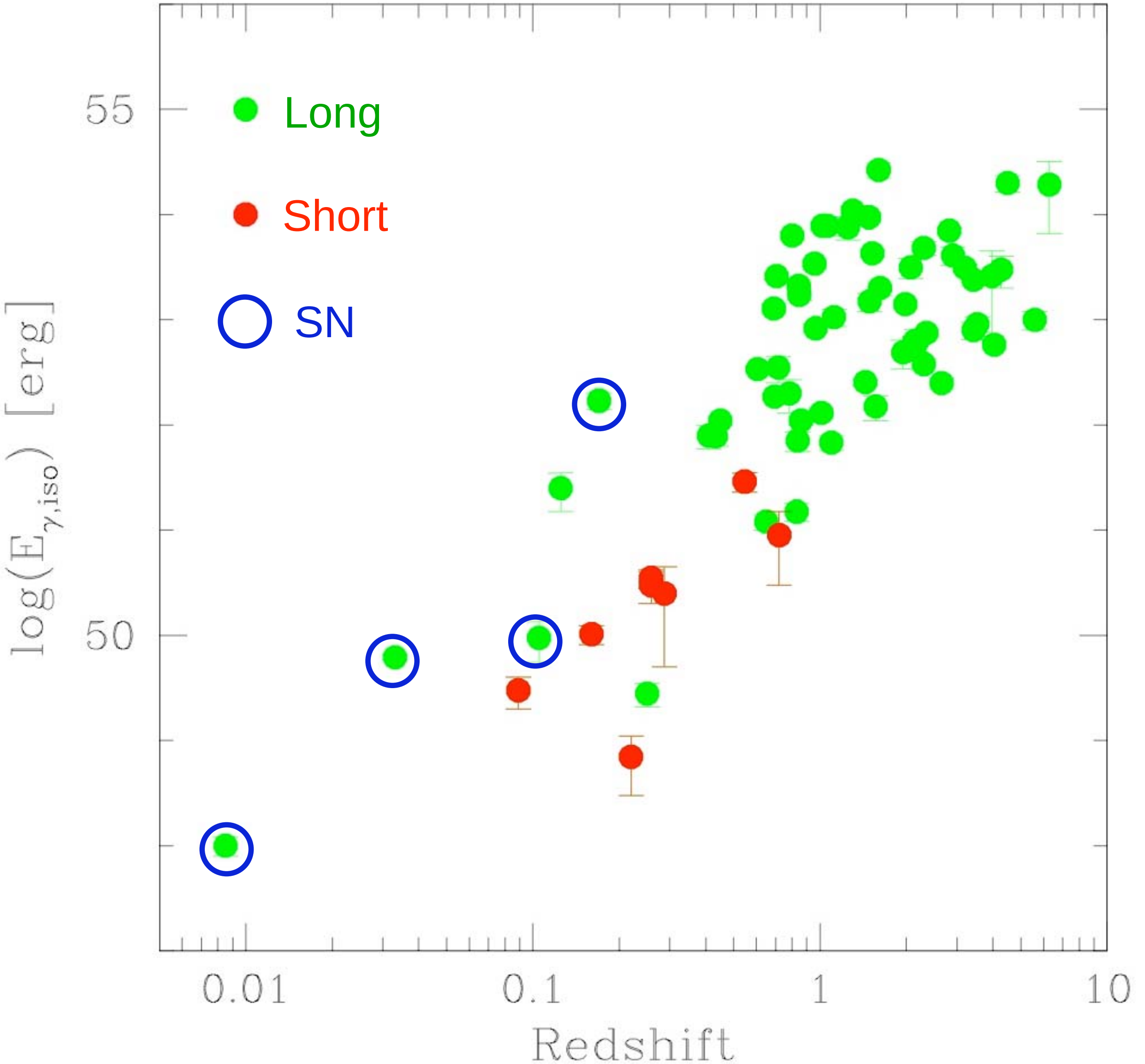
Courtesy: C. Guidorzi

Isotropic irradiated γ–ray energy vs redshift



GRB050904
z = 6.29

Isotropic irradiated γ–ray energy vs redshift



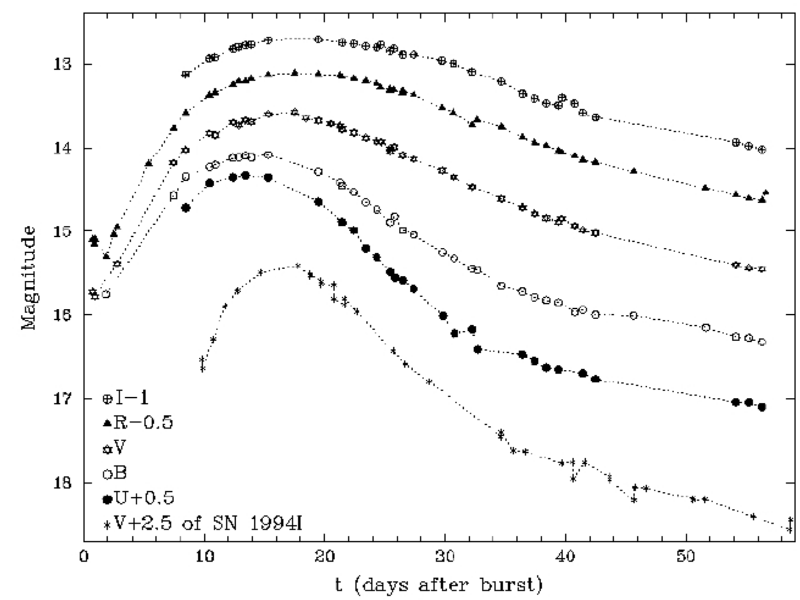
Courtesy: L. Amati

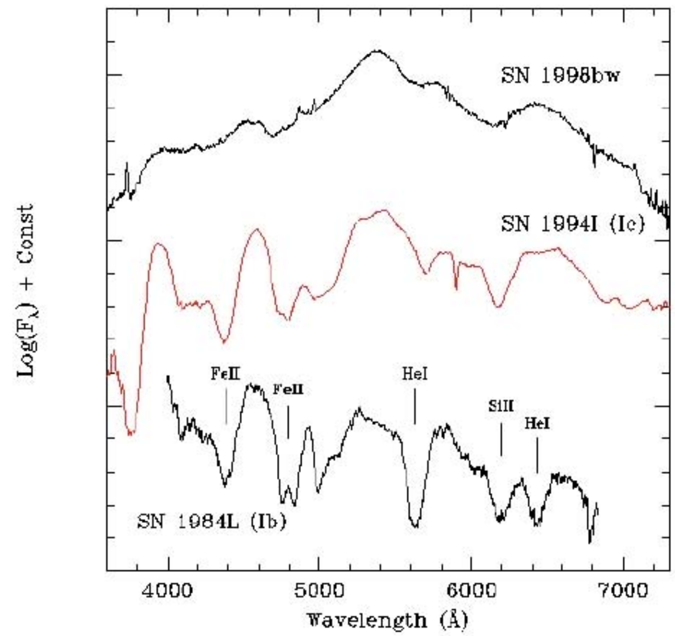
GRB980425
Supernova 1998bw (Type Ic)

SN 1998bw in Spiral Galaxy ESO184-G82

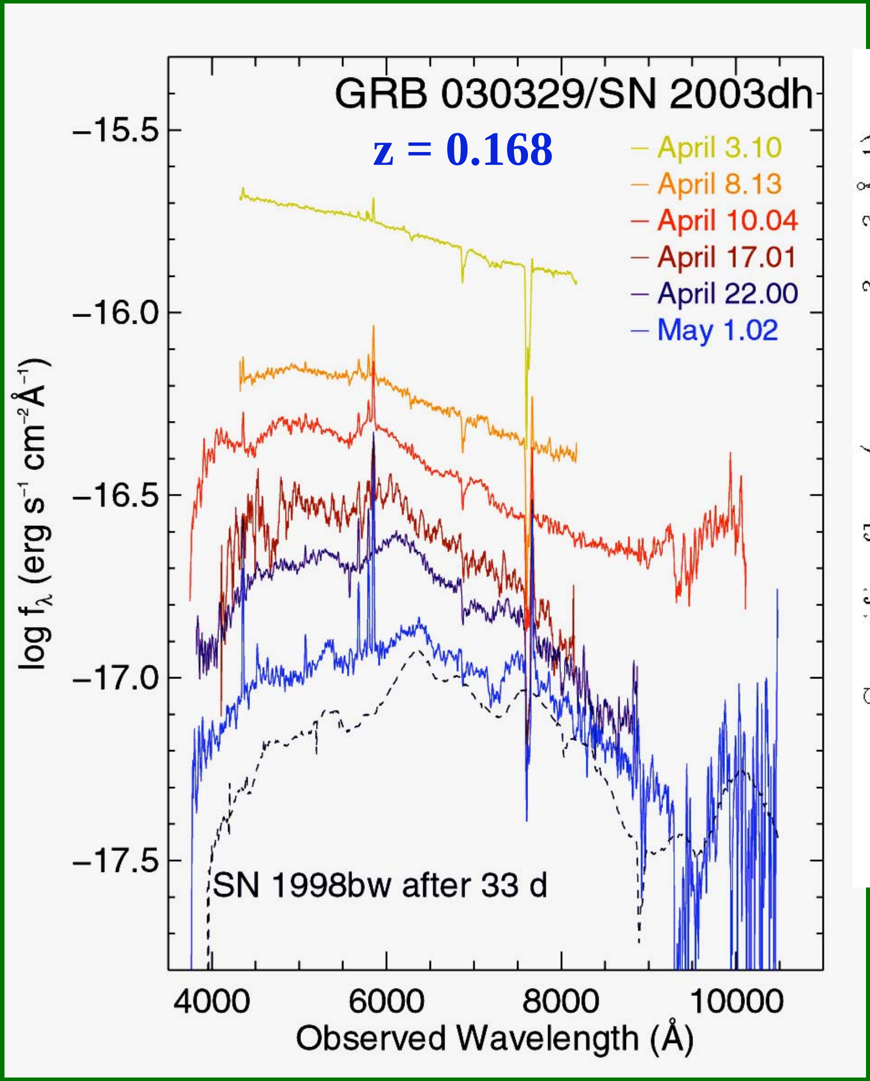
z = 0.0085

ESO PR Photo 39a/98 (15 October 1998)



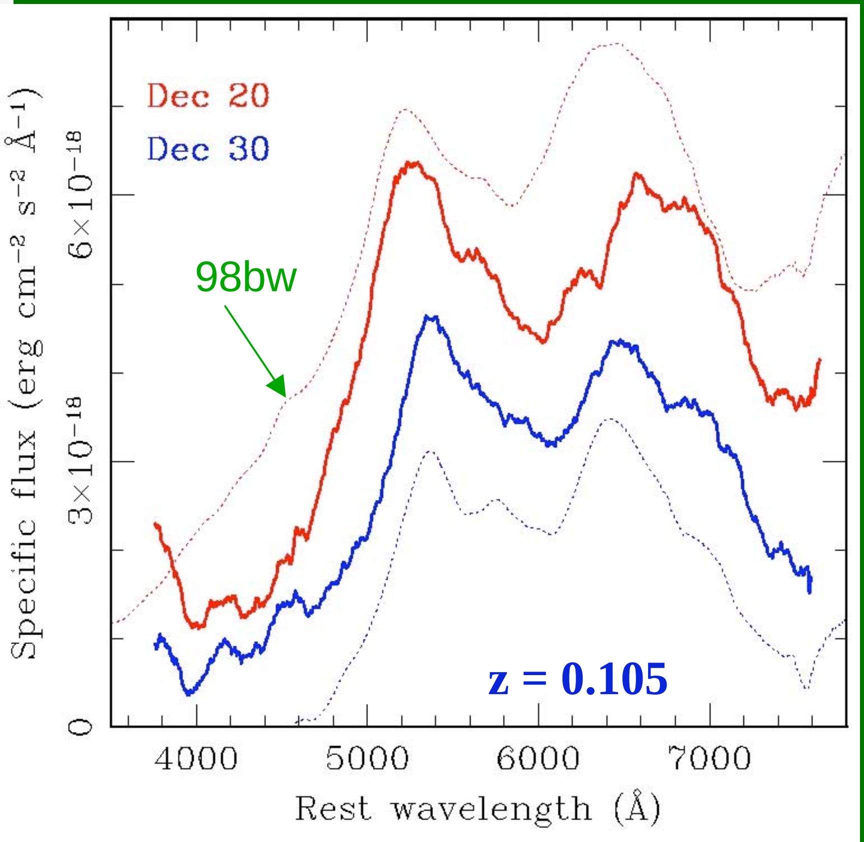


GRB-Supernovae with ESO VLT+FORS



Hjorth et al. 2003

GRB031203/SN2003lw

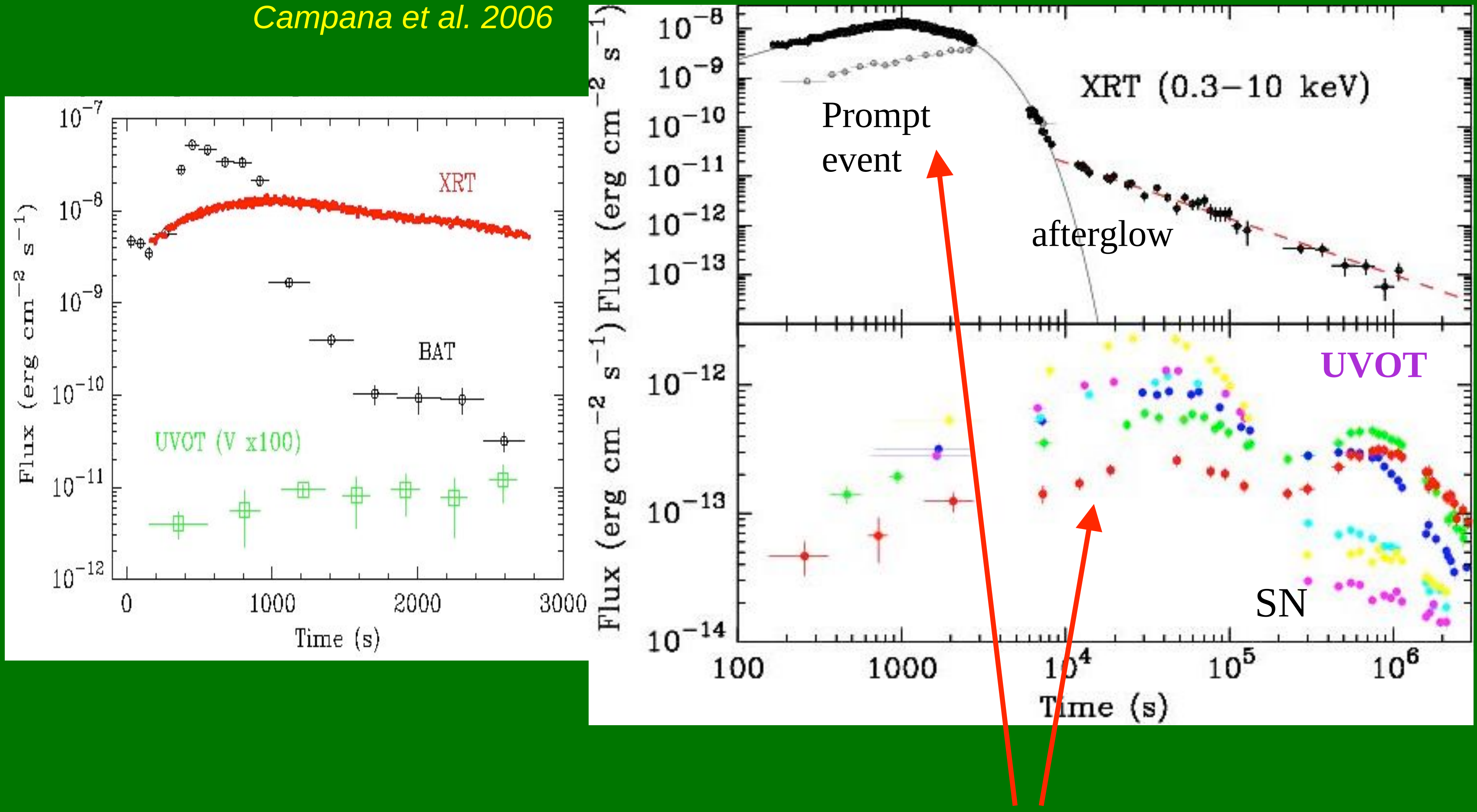


Malesani et al. 2004

GRB-SNe have kinetic energies exceeding those of normal SNe by an order of magnitude (e52 erg)

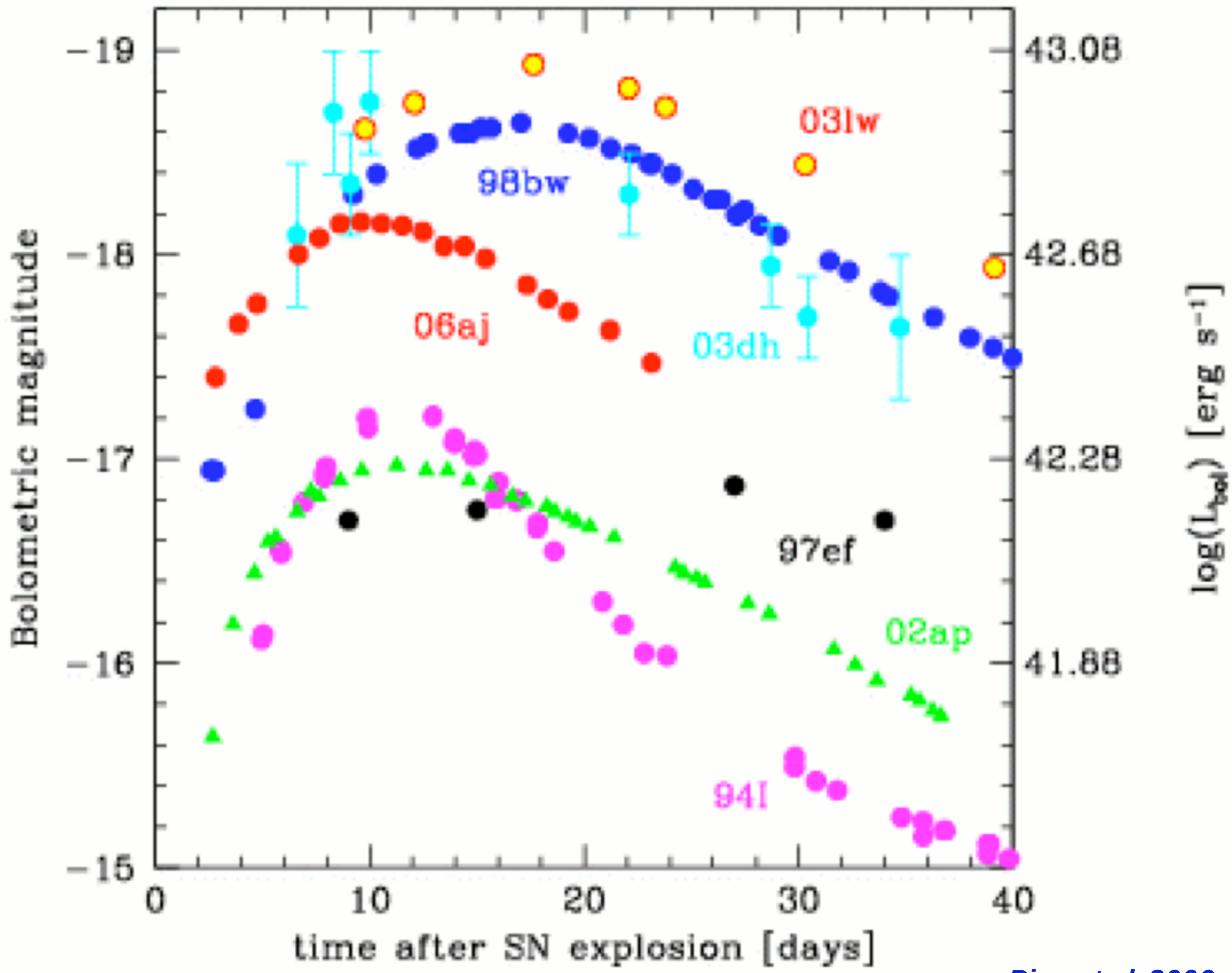
Swift was triggered by XRF060218 on Feb 18.149, 2006 UT

Campana et al. 2006



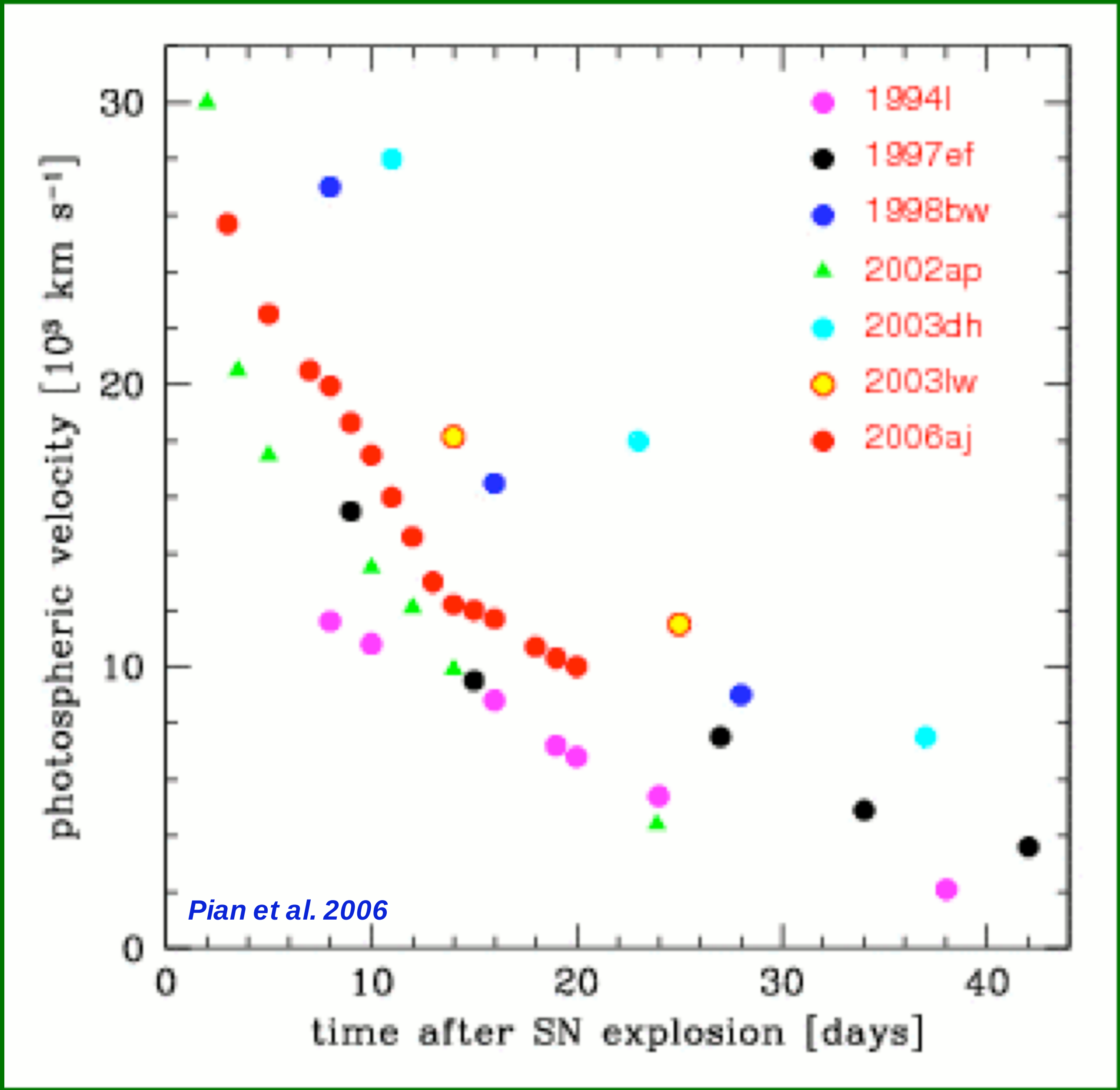
Shock breakout or jet cocoon interaction with CSM,
Or central engine, or synchrotron + inverse Compton ?

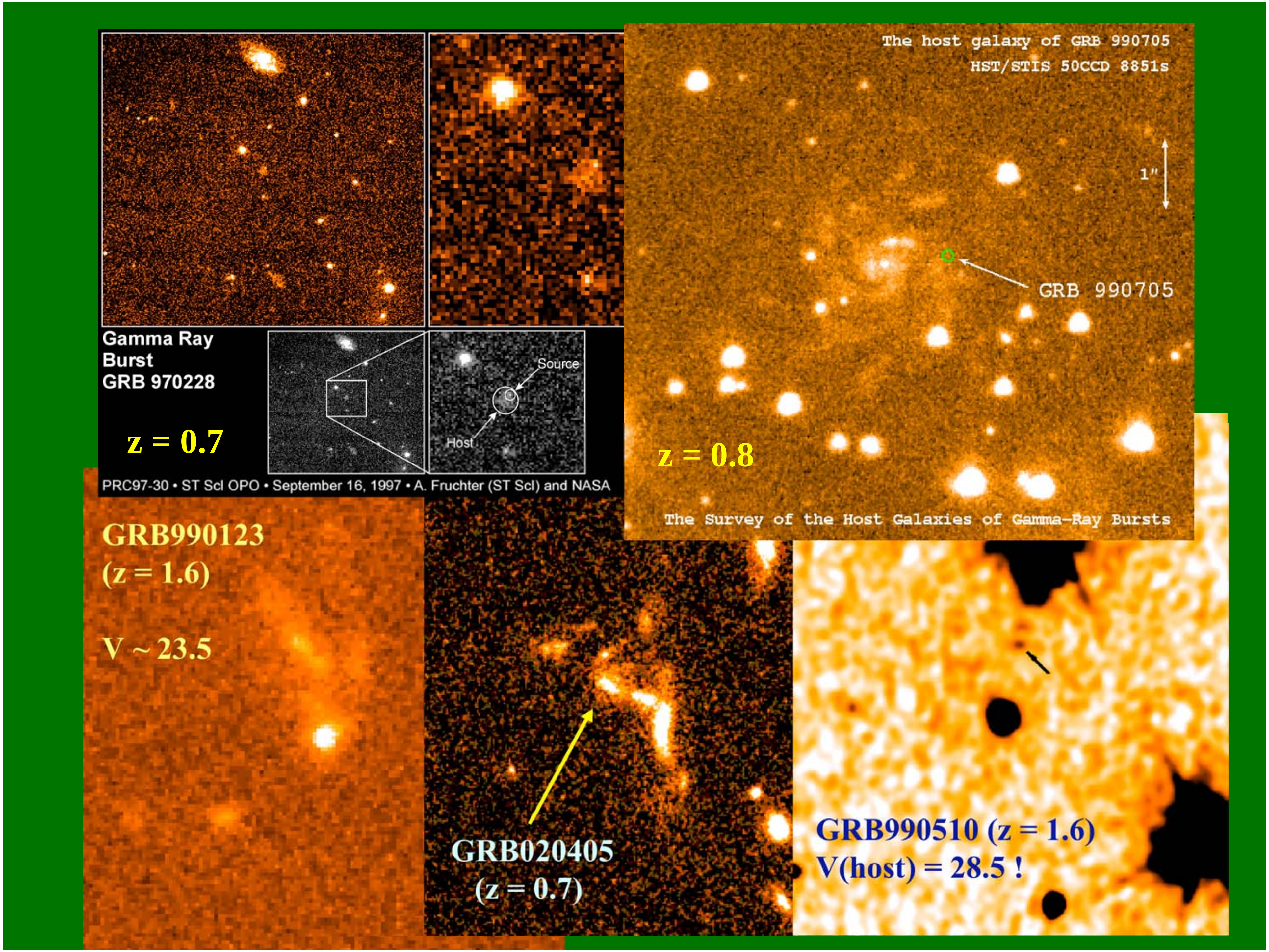
Light curves of Ic SNe: GRB-SNe, broad-lined SNe, normal SNe



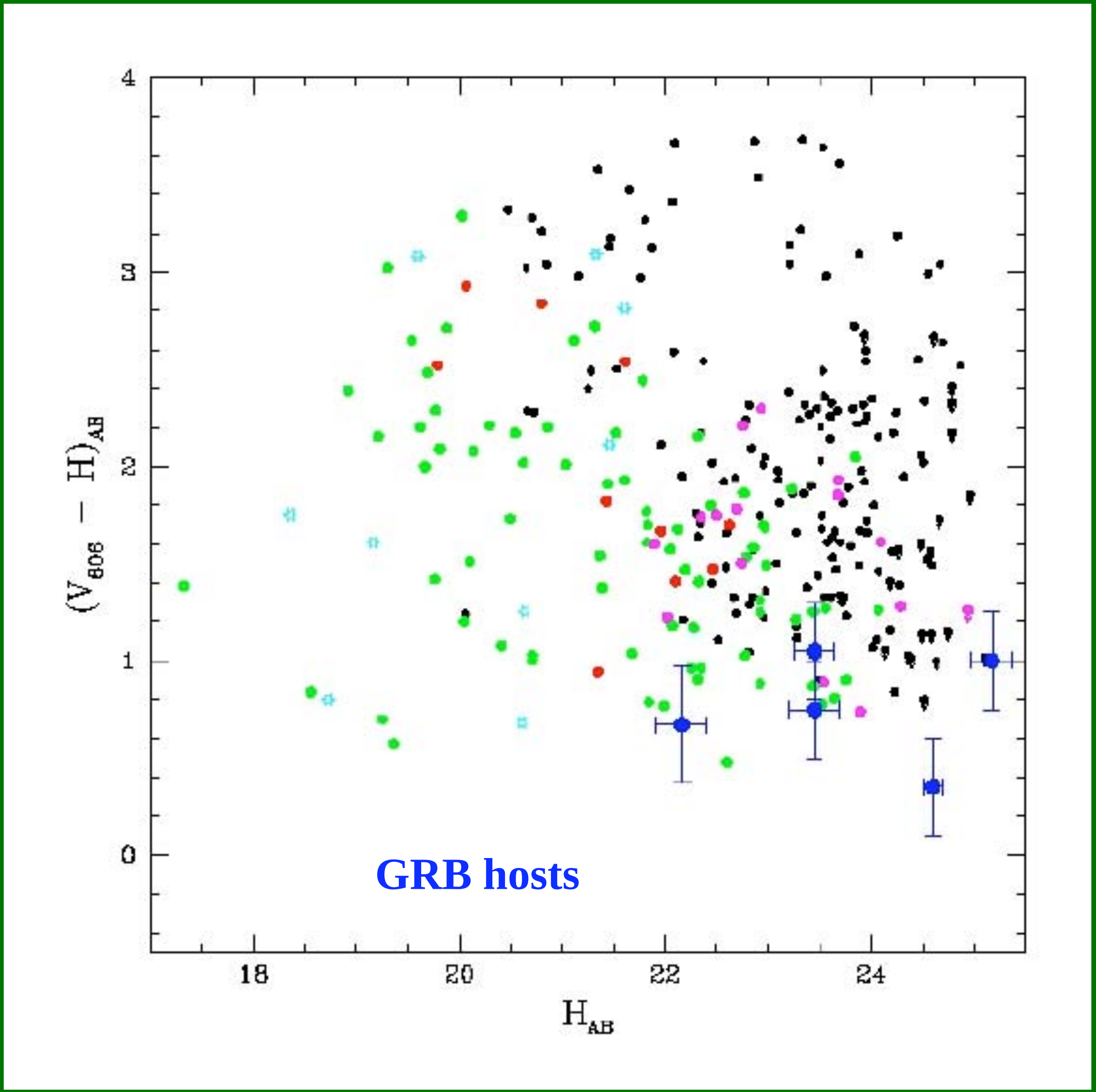
Pian et al. 2006

Photospheric velocities of Ic SNe





Gamma Ray
Burst
GRB 970228
Source
Host
z = 0.7
PRC97-30 • ST ScI OPO • September 16, 1997 • A. Fruchter (ST ScI) and NASA
The host galaxy of GRB 990705
HST/STIS 50CCD 8851s
1"
GRB 990705
z = 0.8
The Survey of the Host Galaxies of Gamma-Ray Bursts
GRB990123
(z = 1.6)
V ~ 23.5
GRB020405
(z = 0.7)
GRB990510 (z = 1.6)
V(host) = 28.5 !



Colors of host galaxies are very blue

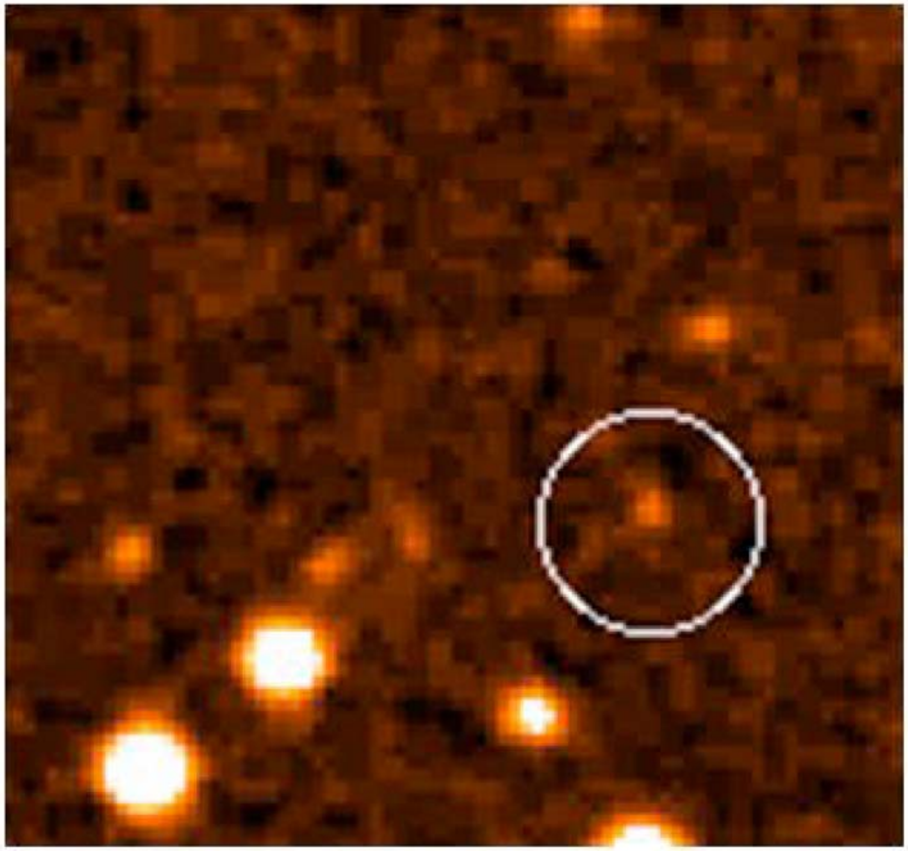
(compare, e.g., with Hubble Deep Field)

Fruchter et al. 1999

Long GRB host galaxies are generally small, compact, blue, underluminous, with low unextinguished star-formation rates (1-10 M⊙/yr), but <u>high *specific* star formation rate (Spitzer detects only 20% of GRB hosts down to</u> F(4.5 μm) ~ 3.5 μJy and F(24 μm) ~ 85 μJy)

(Le Floch et al. 2006)

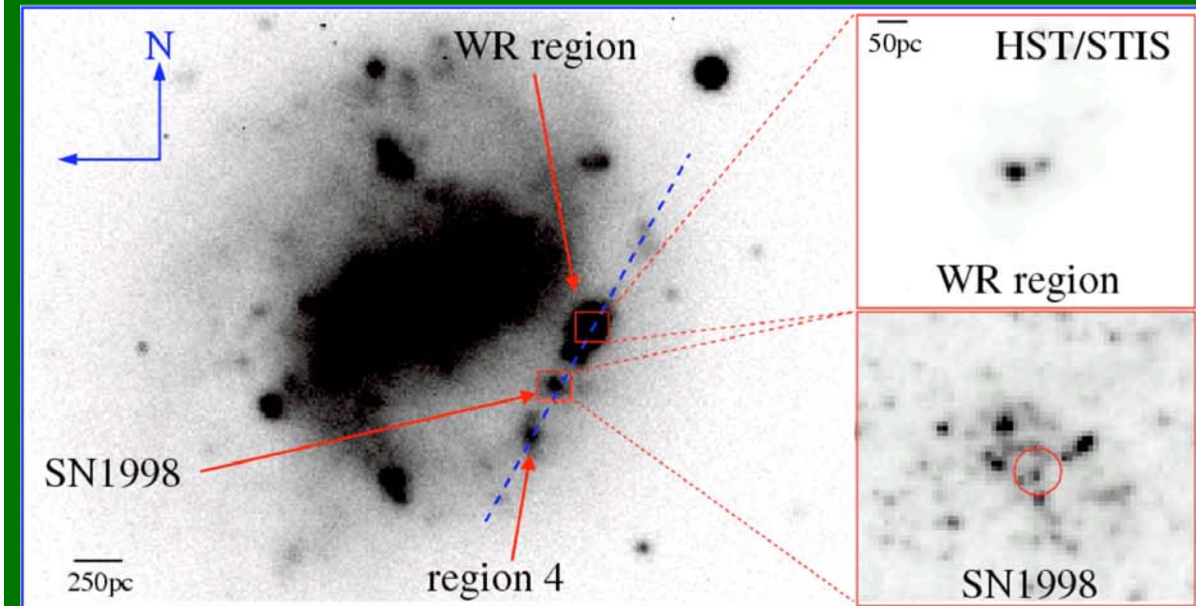
SN2006aj host (z = 0.033)

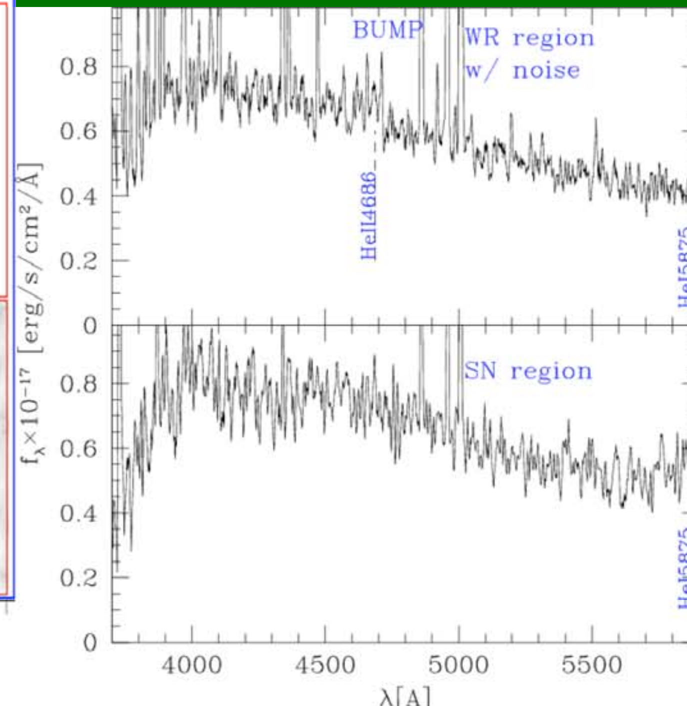


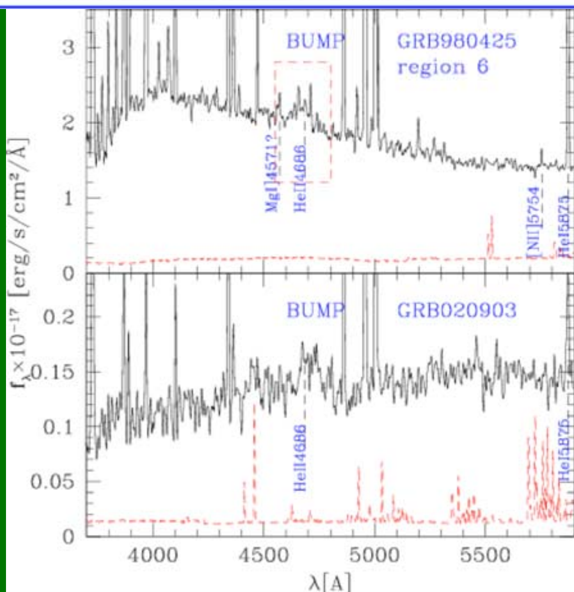
Credit: DSS2

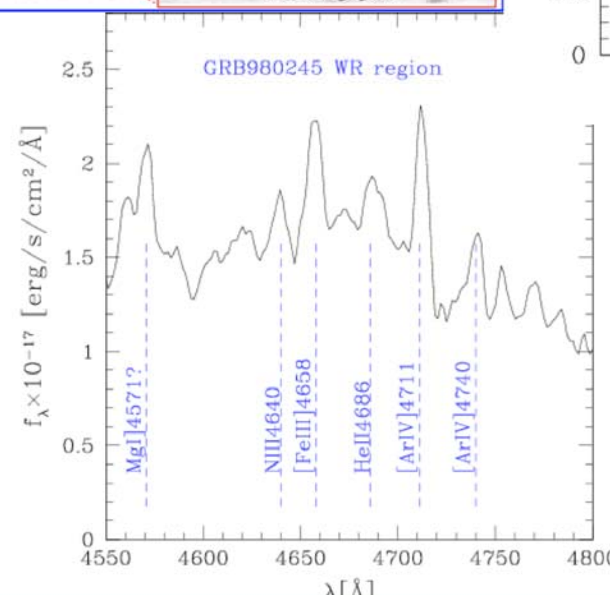
Pian et al. 2006

The close environment of GRB980425/SN1998bw (36 Mpc)





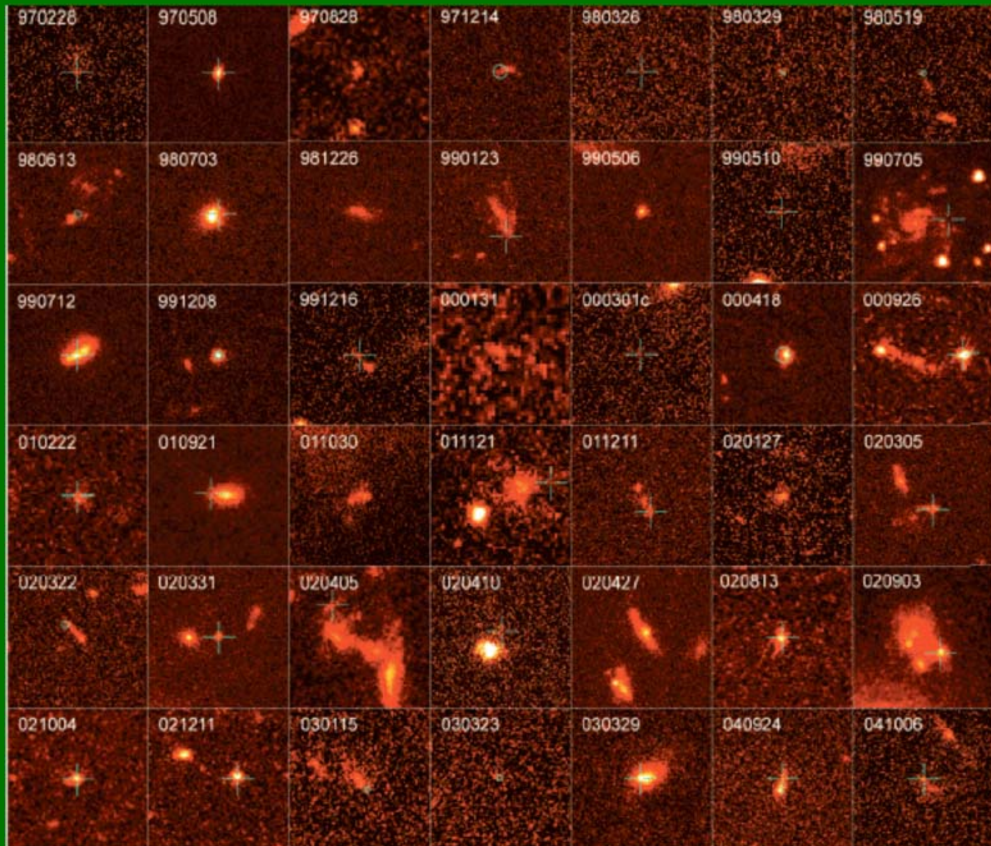




Is the SN1998bw Progenitor a massive Star runaway from a Super-star-cluster?

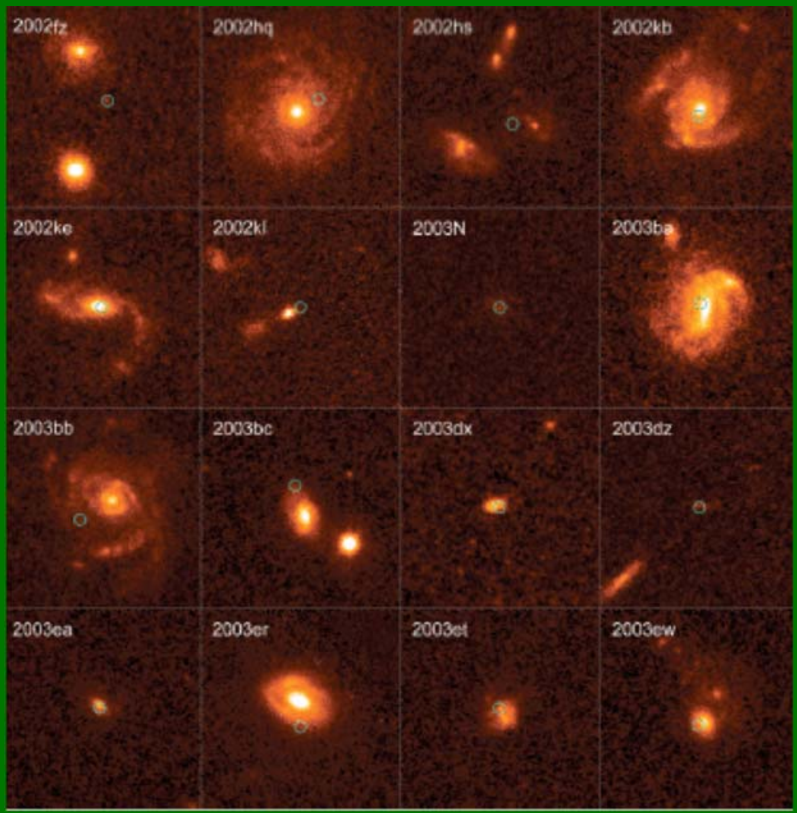
Hammer et al. 2006

GRB and Core Collapse SNe hosts observed with Hubble Space Telescope



GRBs

CC-SNe from Hubble High-z SN Search + HST GOODS



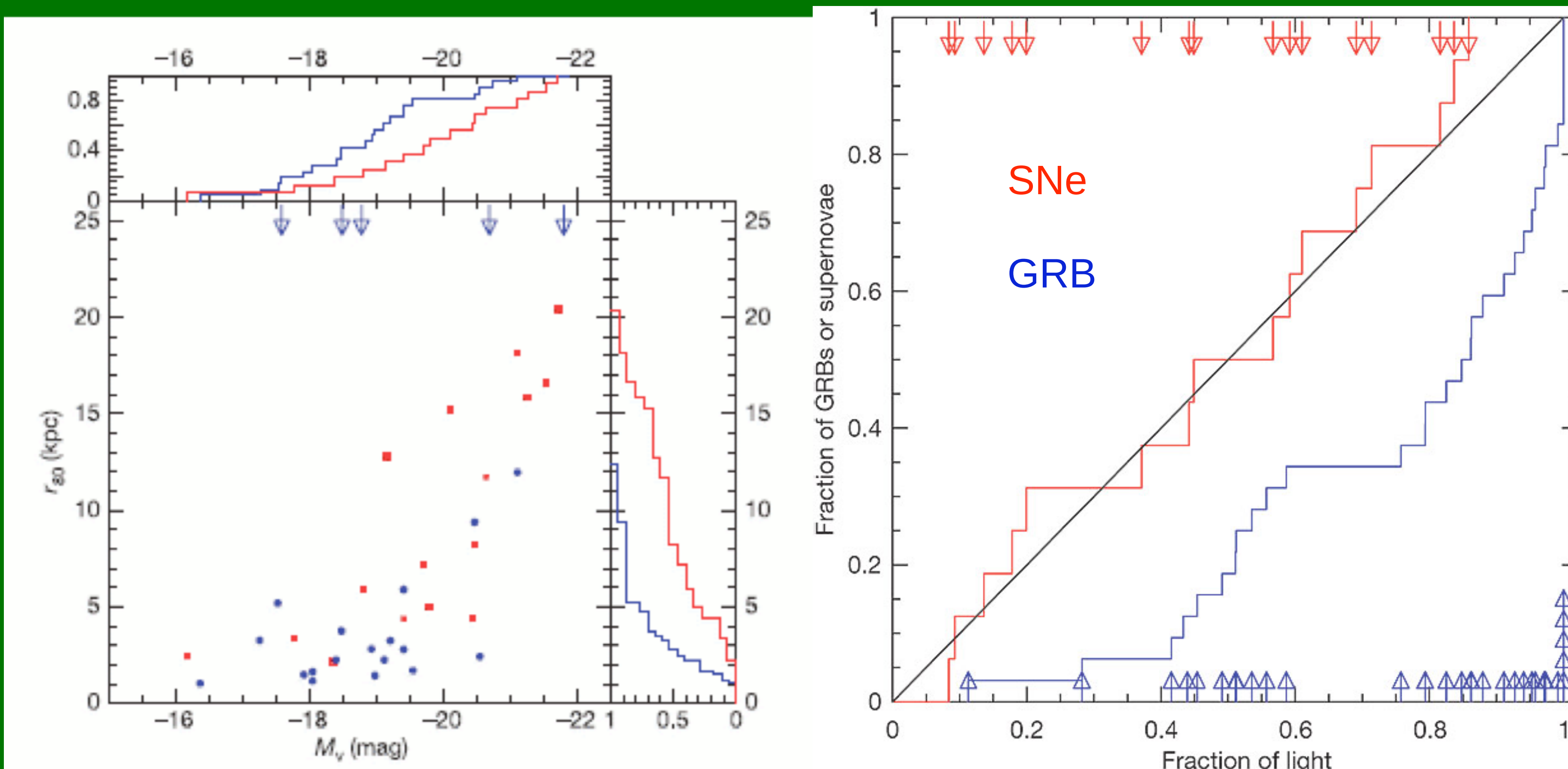
$z < 1.2$

Morphologies are significantly different

Fruchter et al.2006

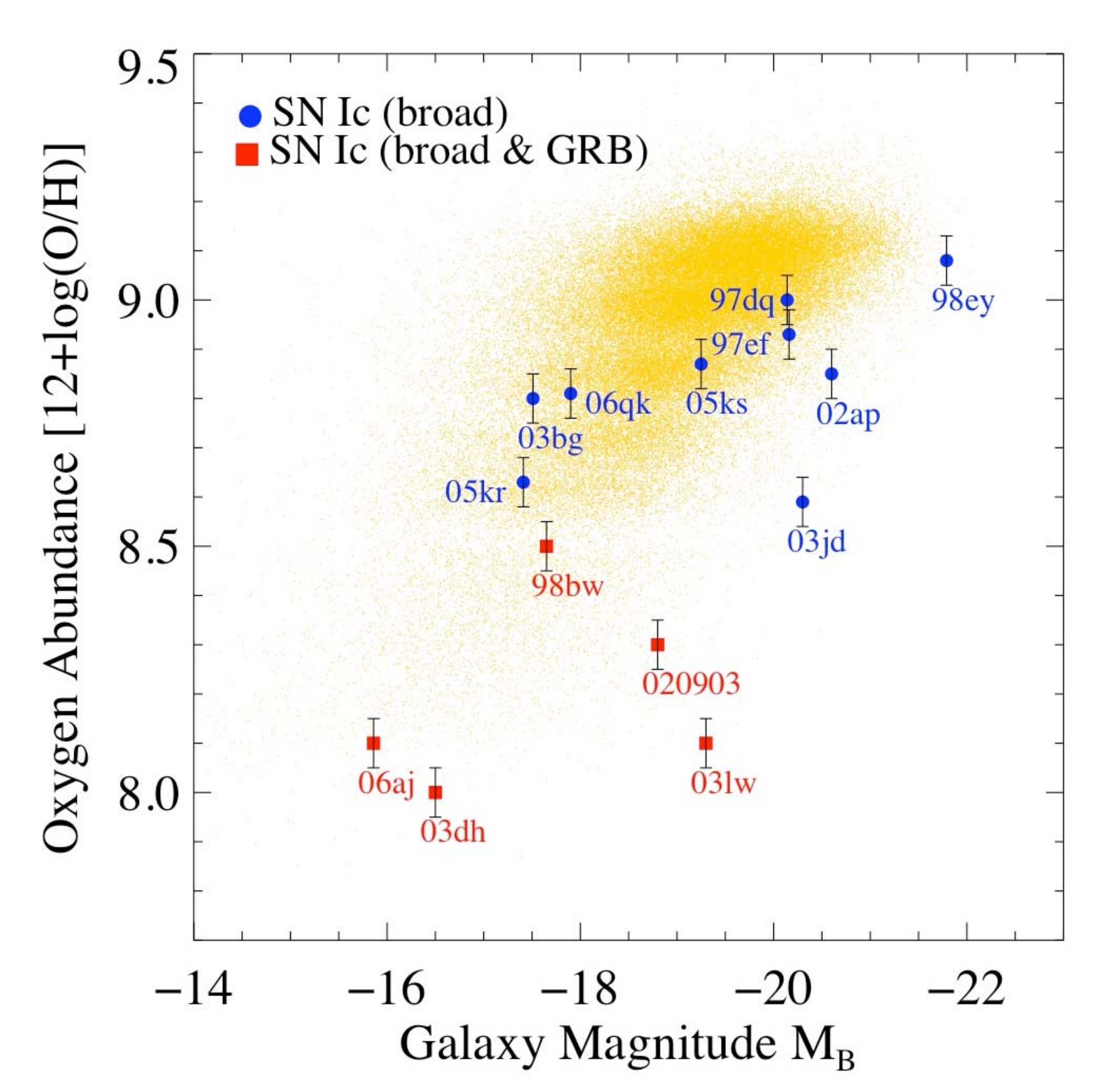
Distributions of light, absolute magnitude, 80% light-radii in SNe and GRBs hosts:

What causes the difference between GRB and core-collapse SN hosts?



Fruchter et al. 2006

Comparison of GRB-SNe and CC-SNe hosts metallicities

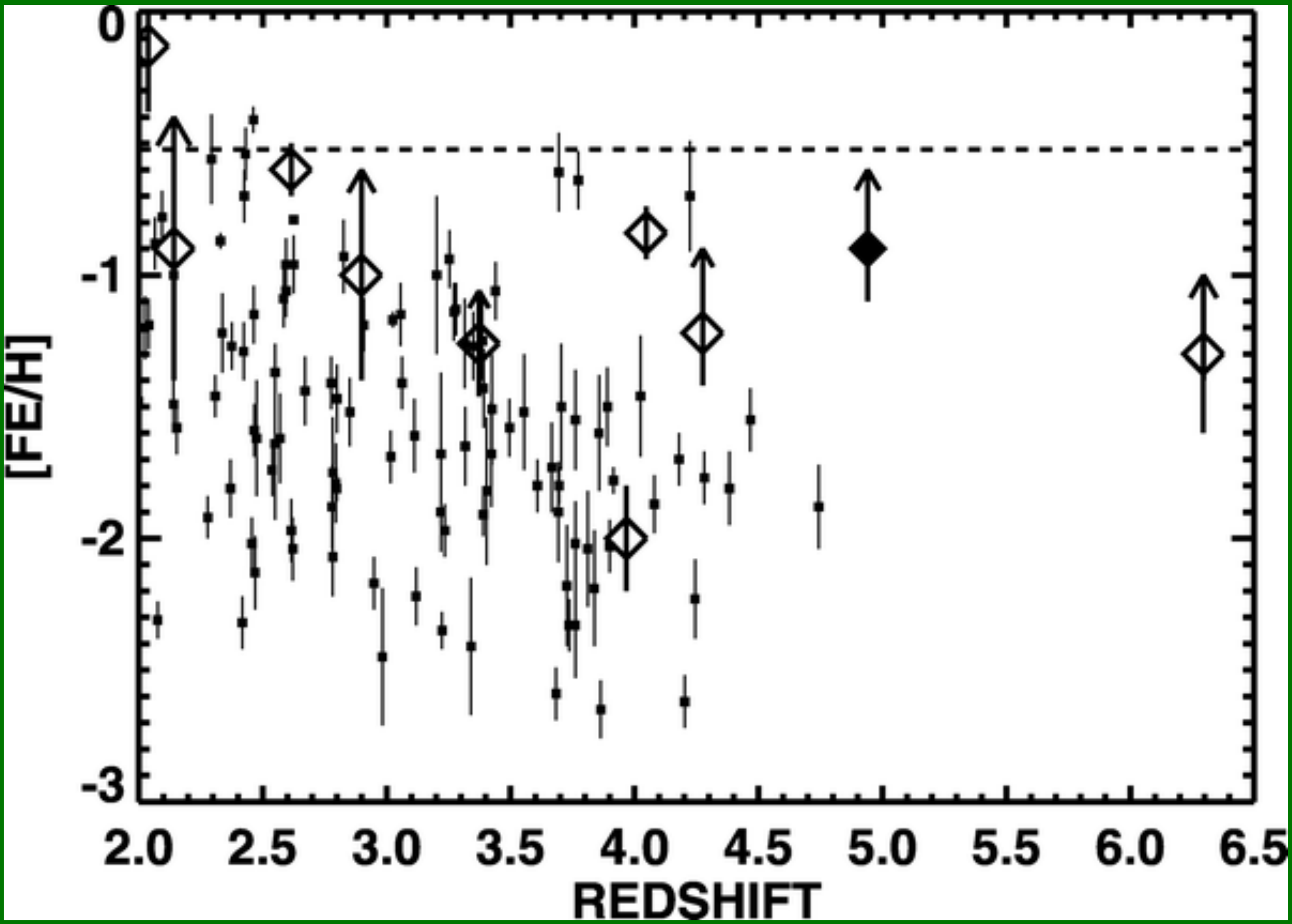


GRB-SNe hosts are
Less metallic than
Core-collapse SNe
Hosts

(the yellow points are
Local star-forming
Galaxies in the SDSS)

Modjaz et al. 2007

GRB060510B host (z = 4.941) is more metallic than most DLAs at high z



Price et al. 2007

Summary

Long GRBs are produced by the explosion of massive stars as Type Ic SNe..
They reside in star-forming environments, but not in starbursts

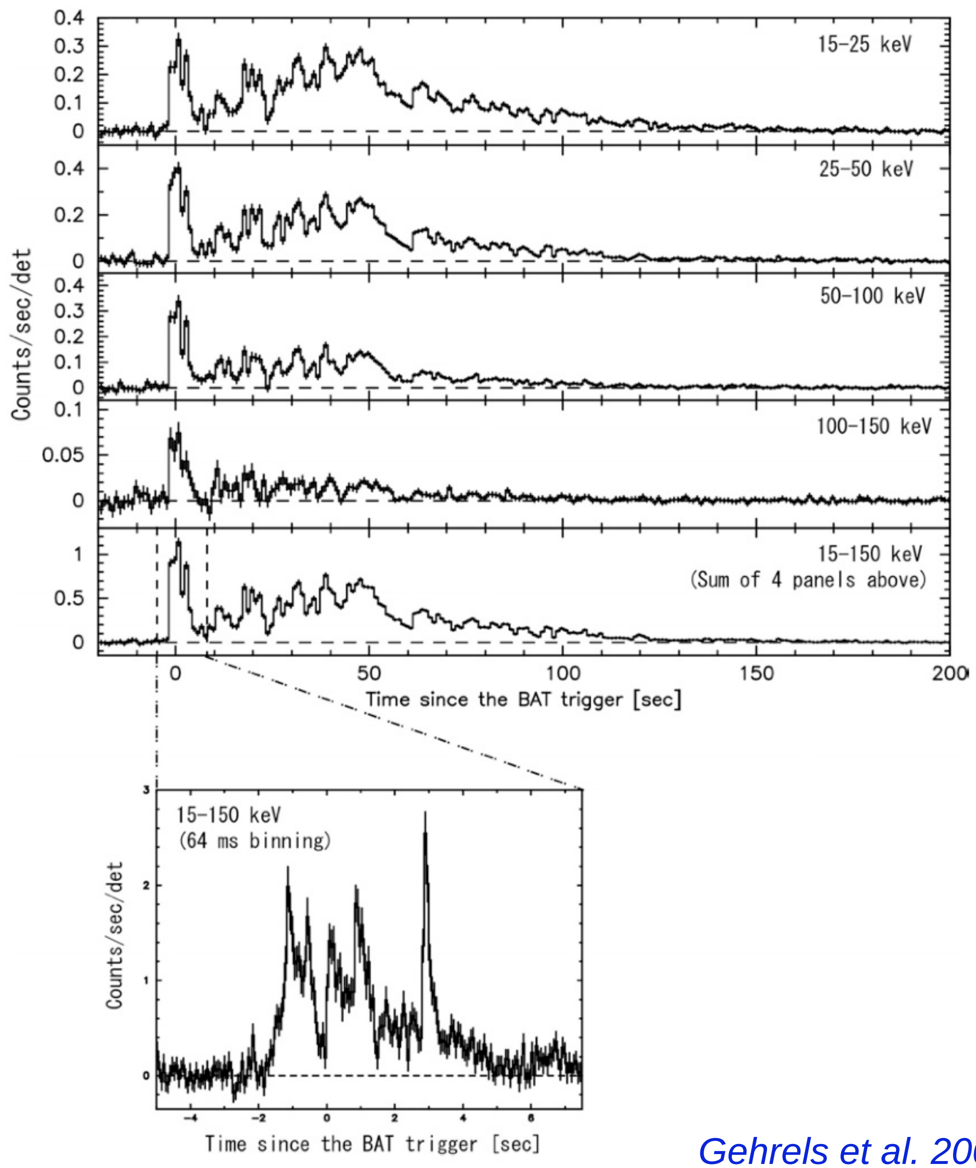
Long GRB progenitors may have escaped their formation site. They may
Have lost their envelopes during the journey

The long GRB and CC-SNe hosts differ significantly in luminosity and
Morphology: may lower metallicity in GRB hosts be responsible for this?

Metallicity plays a controversial role, see GRBs at high redshift

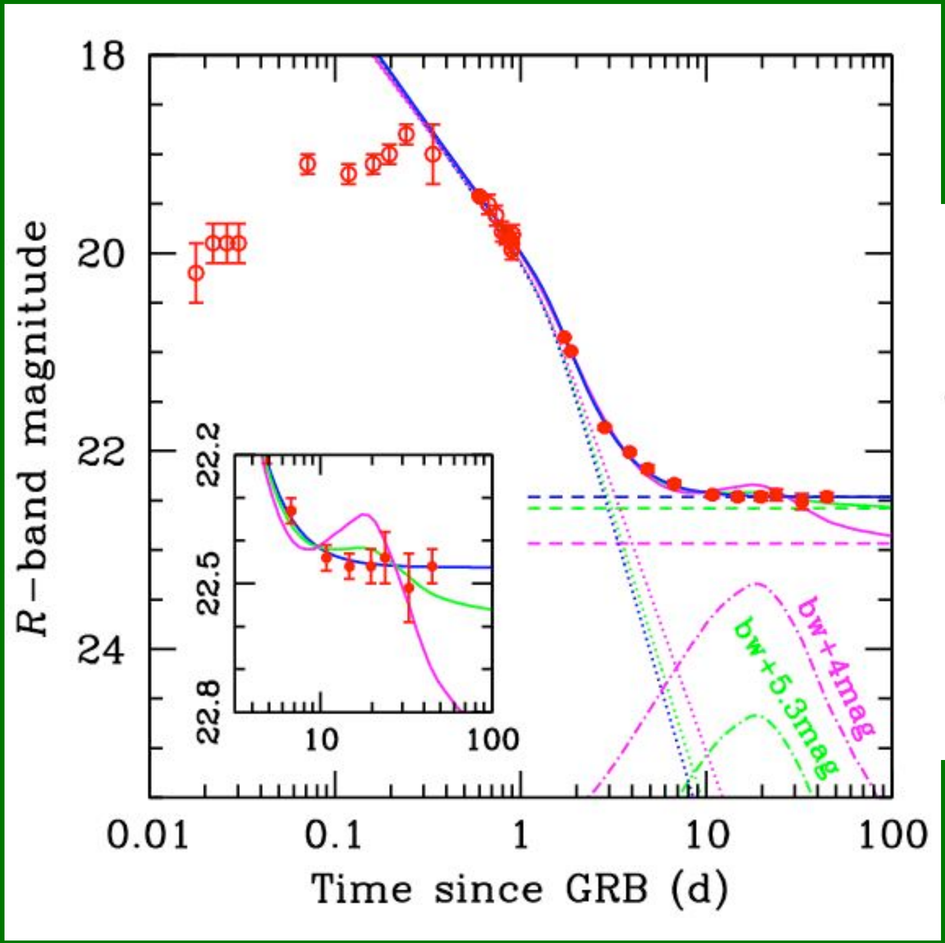
GRBs identified with the current techniques cannot be directly used as
unbiased probes of the global and integrated star formation history of
the universe.

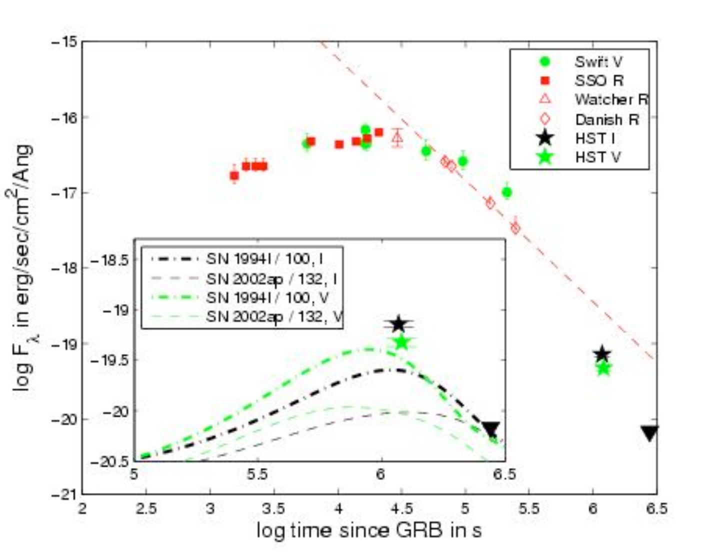
GRB060614 (z = 0.125)



Gehrels et al. 2006

Light curves of the optical afterglow of the Long GRB060614 (z = 0.125)

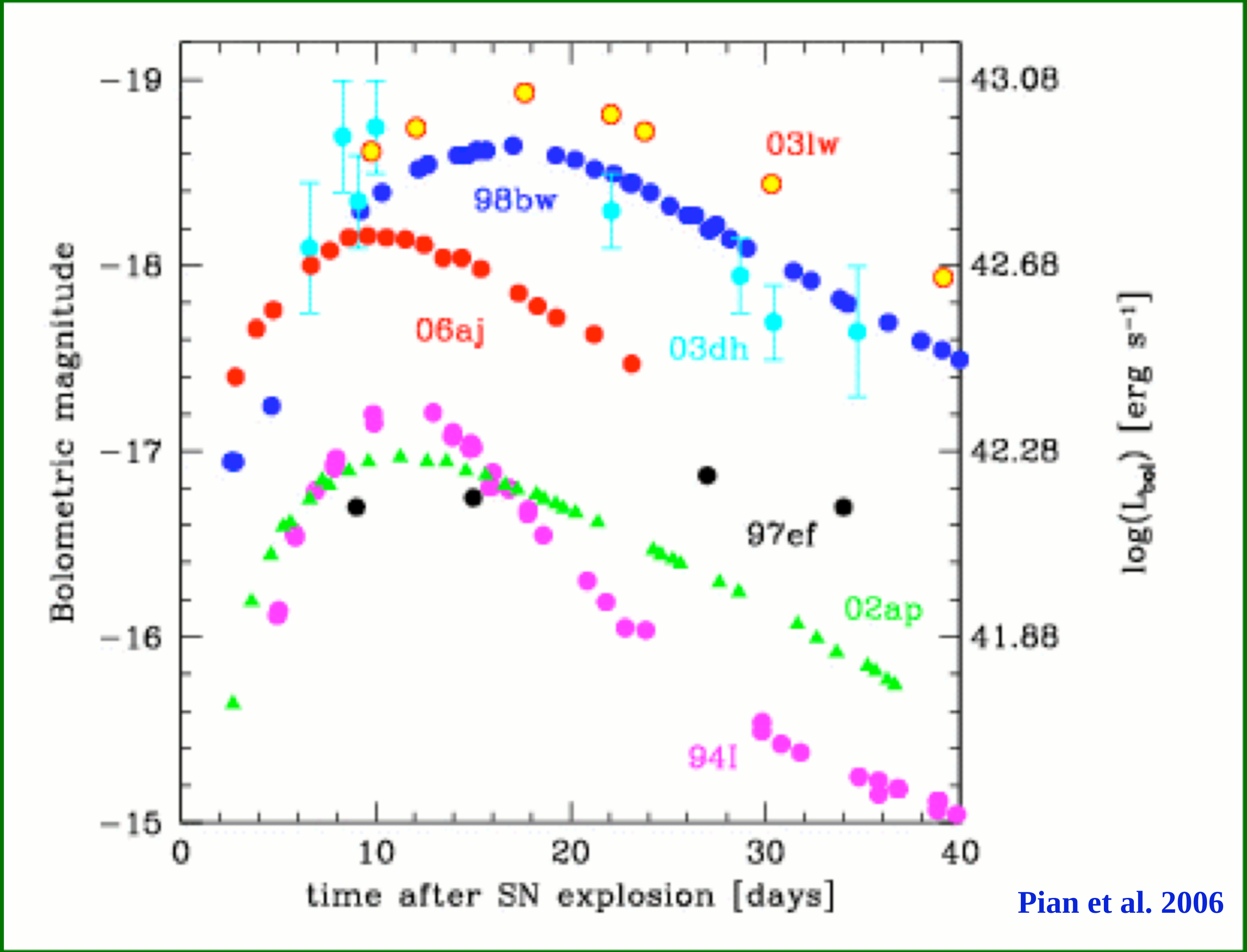




Gal-Yam et al. 2006

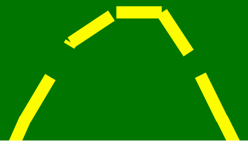
Della Valle et al. 2006

Light curves of Ic SNe: GRB-SNe, broad-lined SNe, normal SNe



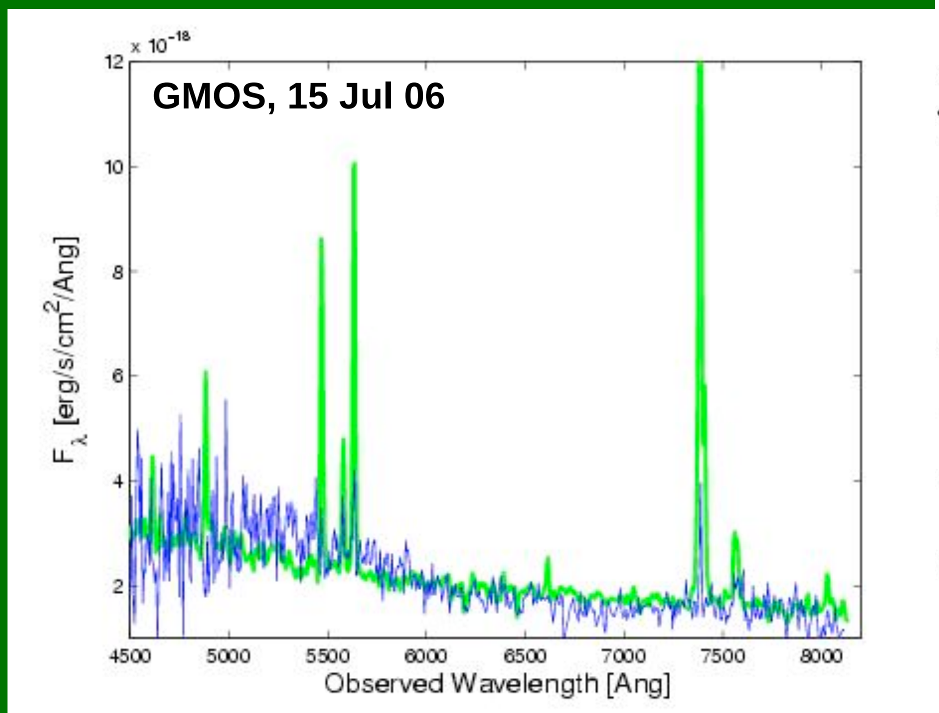
Pian et al. 2006

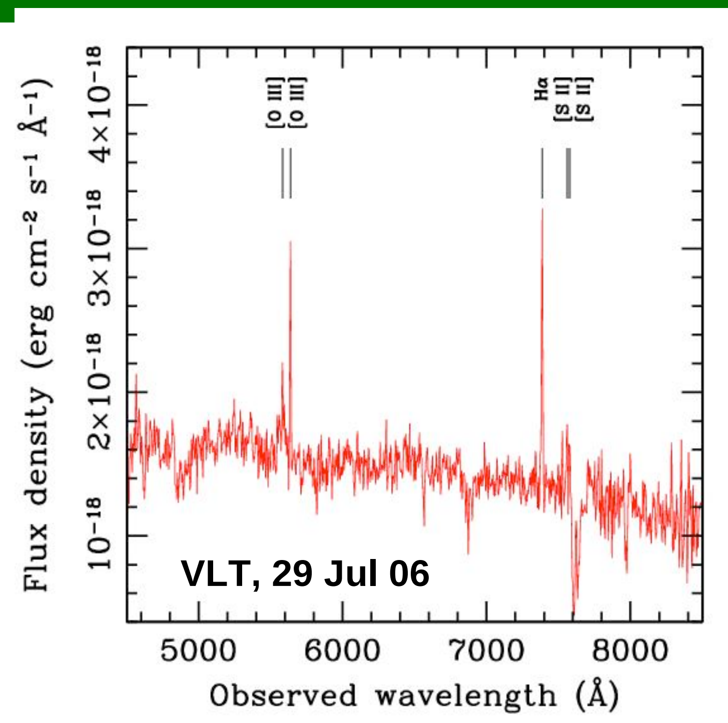
-14



Courtesy: M. Della Valle

spectra of GRB060614 (z = 0.125): no SN features



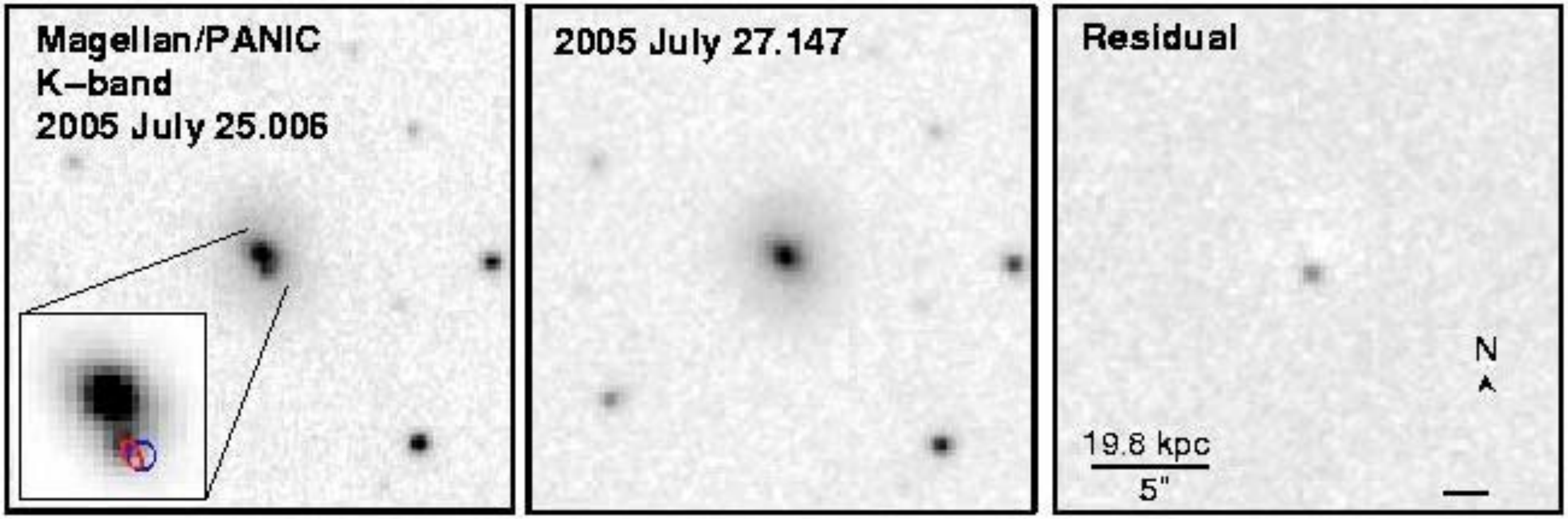


Gal-Yam et al. 2006

Della Valle et al. 2006

The *specific* star formation rate of the host galaxy of GRB060614 is one order of magnitude lower than typical for long GRB hosts

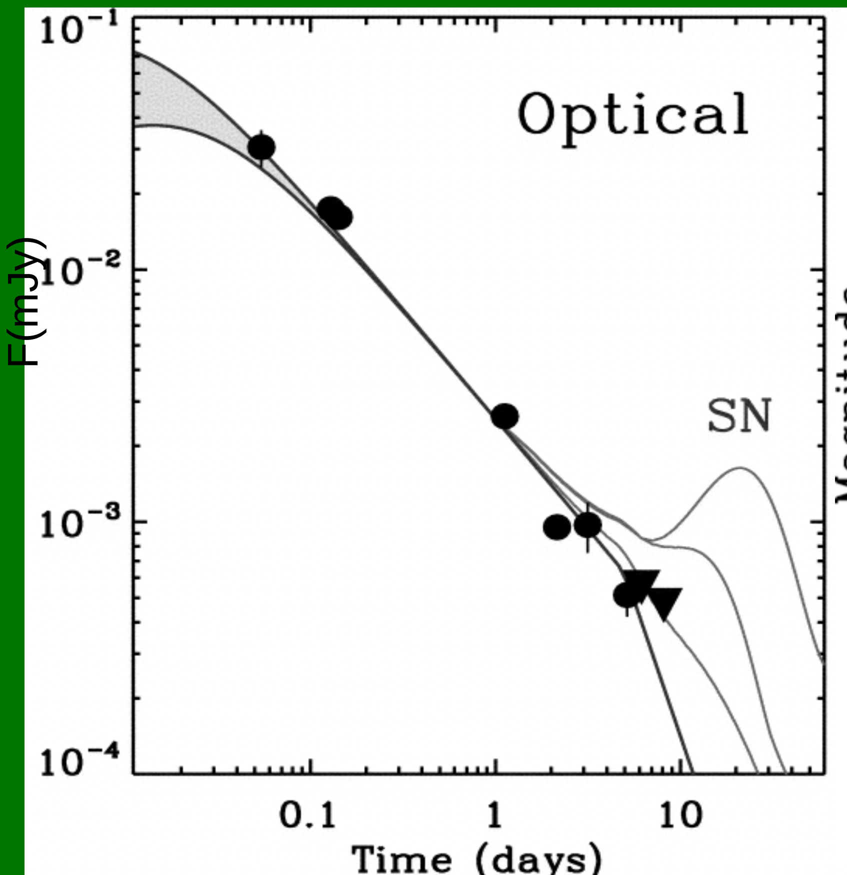
Optical afterglow of the short GRB050724 (T = 0.25 s)



Berger et al. 2005

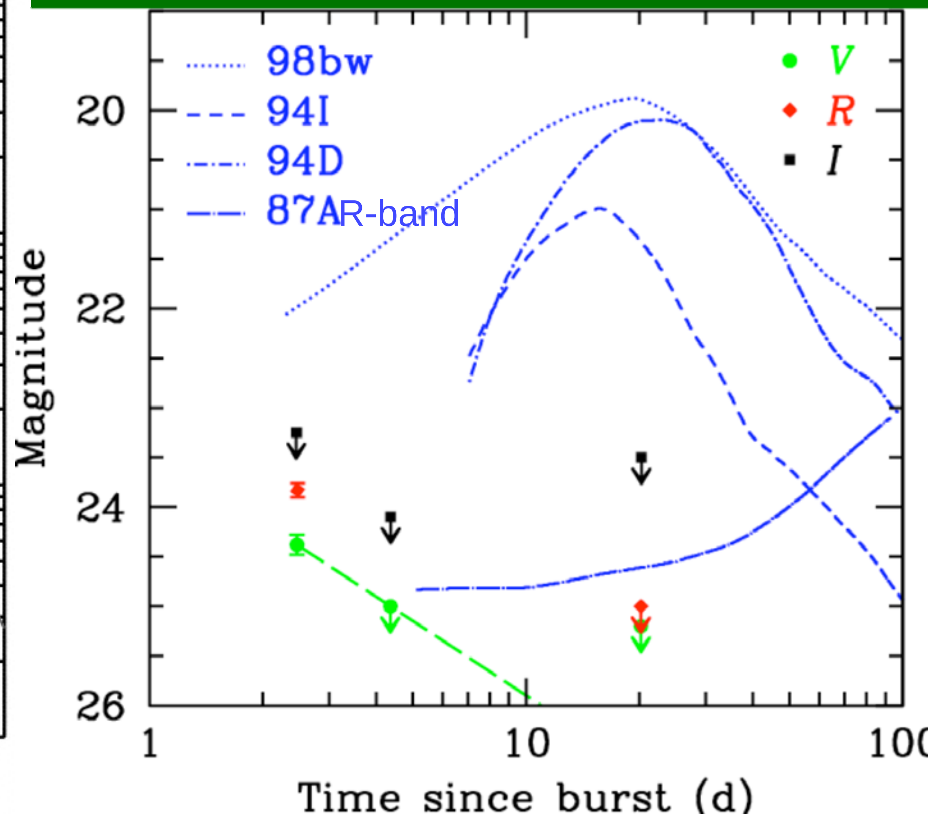
Supernova search in short GRBs

GRB051221A (z = 0.546)



Soderberg et al. 2006

GRB050709 (z = 0.16)

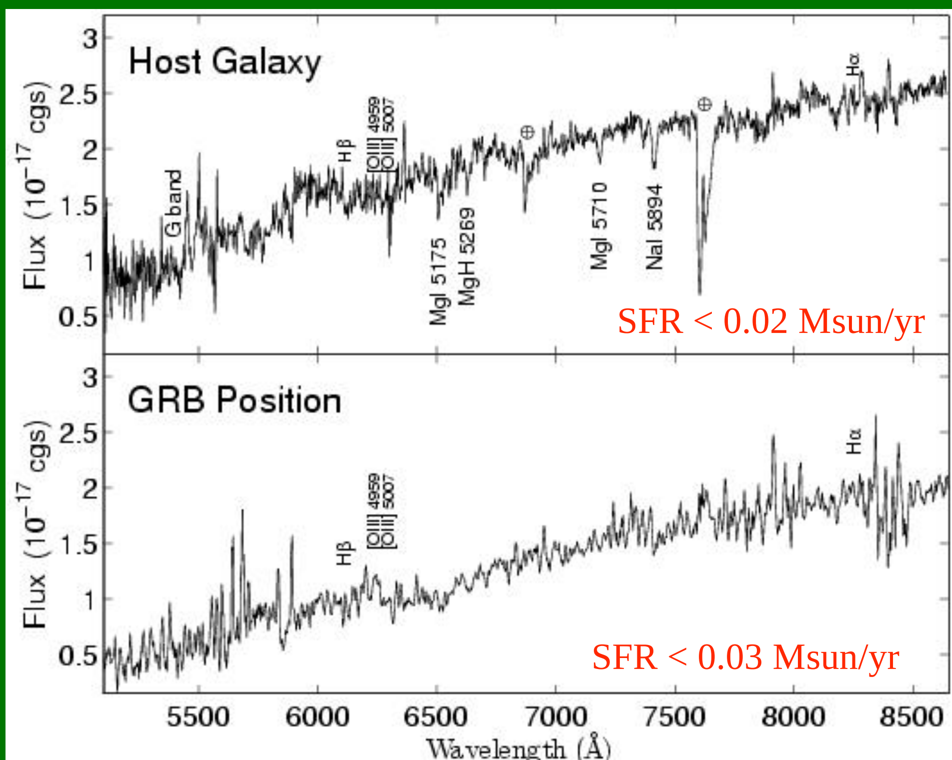


Covino et al. 2005

Host Galaxies of Short GRBs

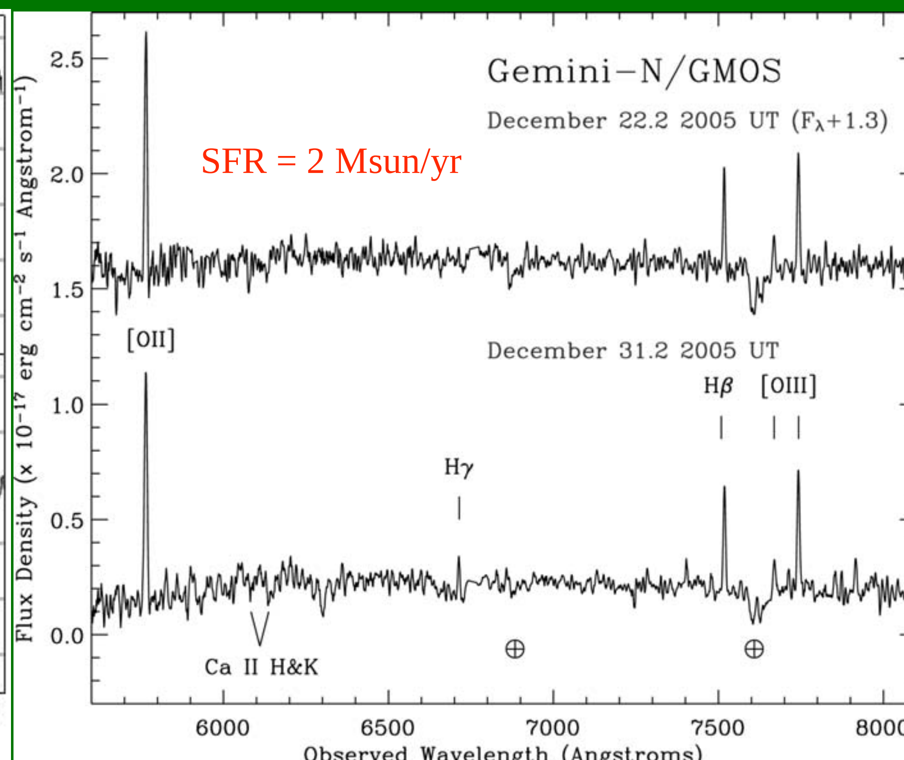
Morphologies and star formation rates vary widely

GRB050724 (z = 0.257)

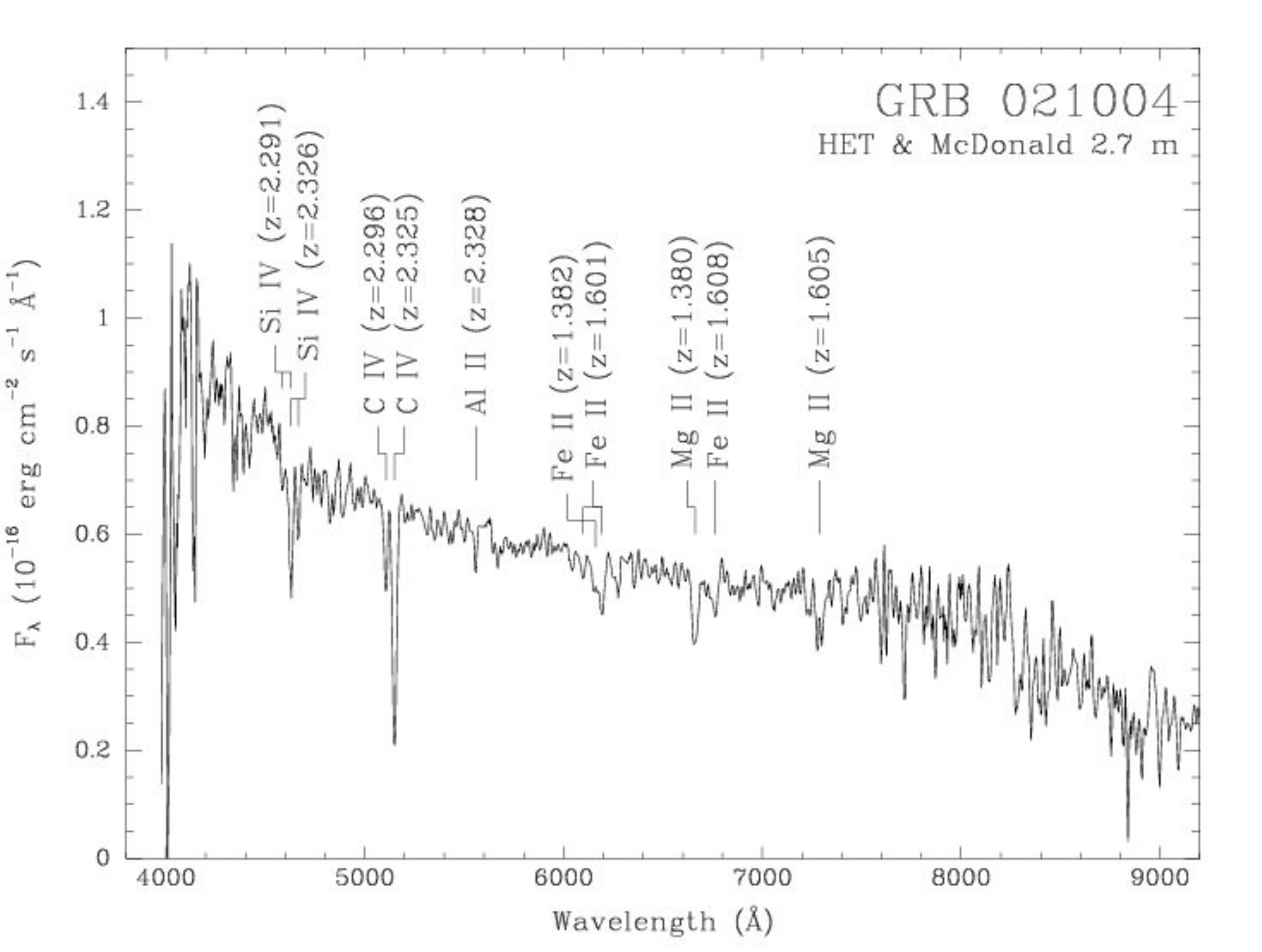


Berger et al. 2005

GRB051221A (z = 0.546)



Soderberg et al. 2006


GRB 021004
HET & McDonald 2.7 m
Si IV (z=2.291)
Si IV (z=2.326)
C IV (z=2.296)
C IV (z=2.325)
Al II (z=2.328)
Fe II (z=1.382)
Fe II (z=1.601)
Mg II (z=1.380)
Fe II (z=1.608)
Mg II (z=1.605)
F_λ (10^{-16} erg cm^{-2} s^{-1} Å^{-1})
Wavelength (Å)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
4000
5000
6000
7000
8000
9000