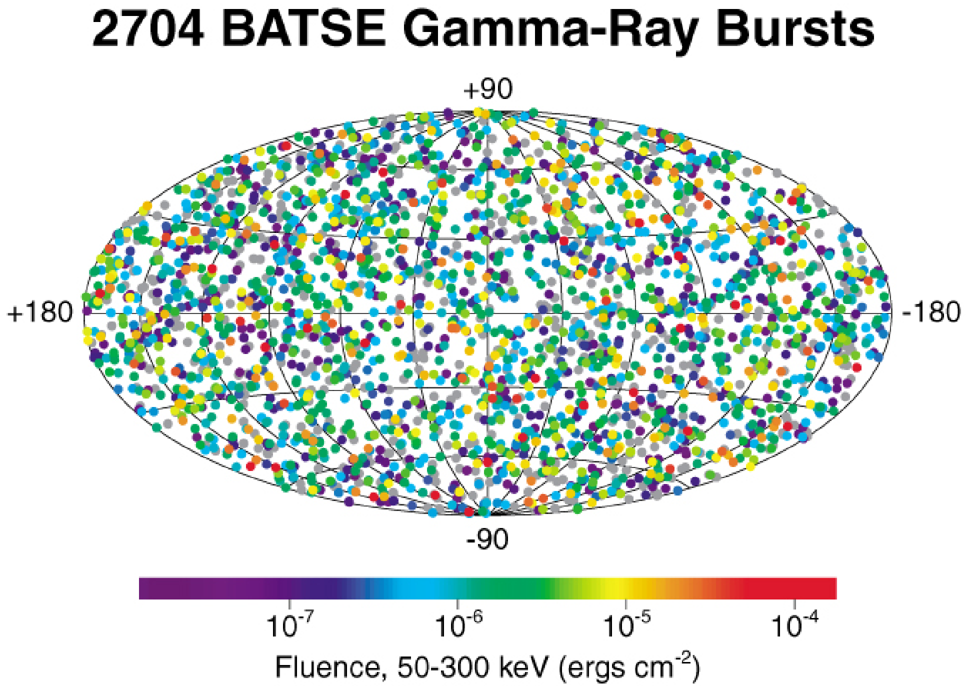
Gamma Ray Burst Cosmology
the experimental evidences



Guido Barbiellini

University and INFN, Trieste

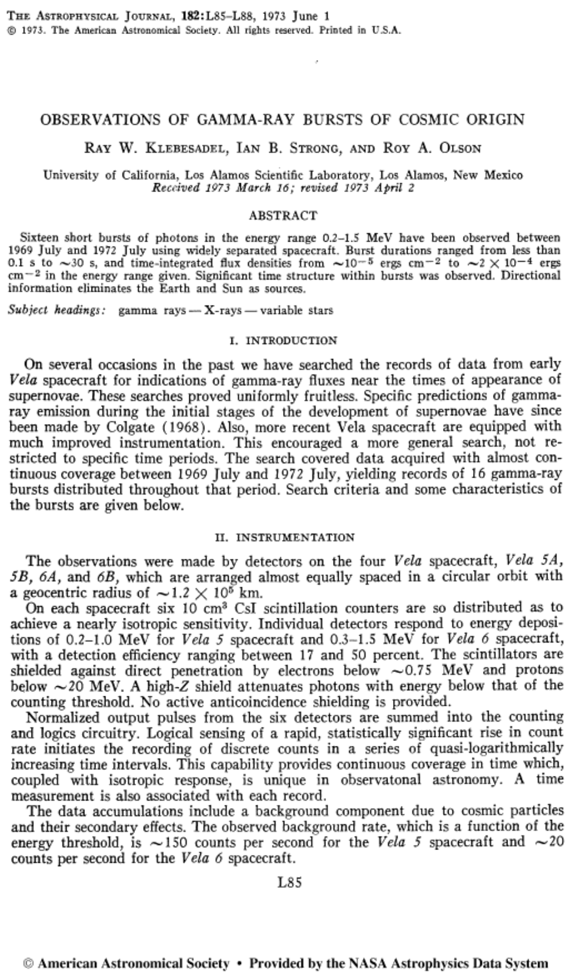
Napoli 13 gennaio 2005

Outline

- Introduction
  - GRB as "tool"
- History of GRB cosmology
- The phenomenology of GRB
- The afterglow
  - Jetted emission
  - X-ray lines
- The prompt emission
  - The "Amati" relation
- The progenitor
  - Connection with Massive Stars
  - SN & GRB connection
- Cosmology with GRB
- The Compton tail

GRB History

- Vela satellites discovery (1967 - 1973)



THE ASTROPHYSICAL JOURNAL, 182:L85–L88, 1973 June 1
© 1973. The American Astronomical Society. All rights reserved. Printed in U.S.A.

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Received 1973 March 16; revised 1973 April 2

ABSTRACT

Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to ~30 s, and time-integrated flux densities from ~10^{-5} ergs cm^{-2} to ~2×10^{-4} ergs cm^{-2} in the energy range given. Significant time structure within bursts was observed. Directional information eliminates the Earth and Sun as sources.

Subject headings: gamma rays — X-rays — variable stars

I. INTRODUCTION

On several occasions in the past we have searched the records of data from early *Vela* spacecraft for indications of gamma-ray fluxes near the times of appearance of supernovae. These searches proved uniformly fruitless. Specific predictions of gamma-ray emission during the initial stages of the development of supernovae have since been made by Colgate (1968). Also, more recent Vela spacecraft are equipped with much improved instrumentation. This encouraged a more general search, not restricted to specific time periods. The search covered data acquired with almost continuous coverage between 1969 July and 1972 July, yielding records of 16 gamma-ray bursts distributed throughout that period. Search criteria and some characteristics of the bursts are given below.

II. INSTRUMENTATION

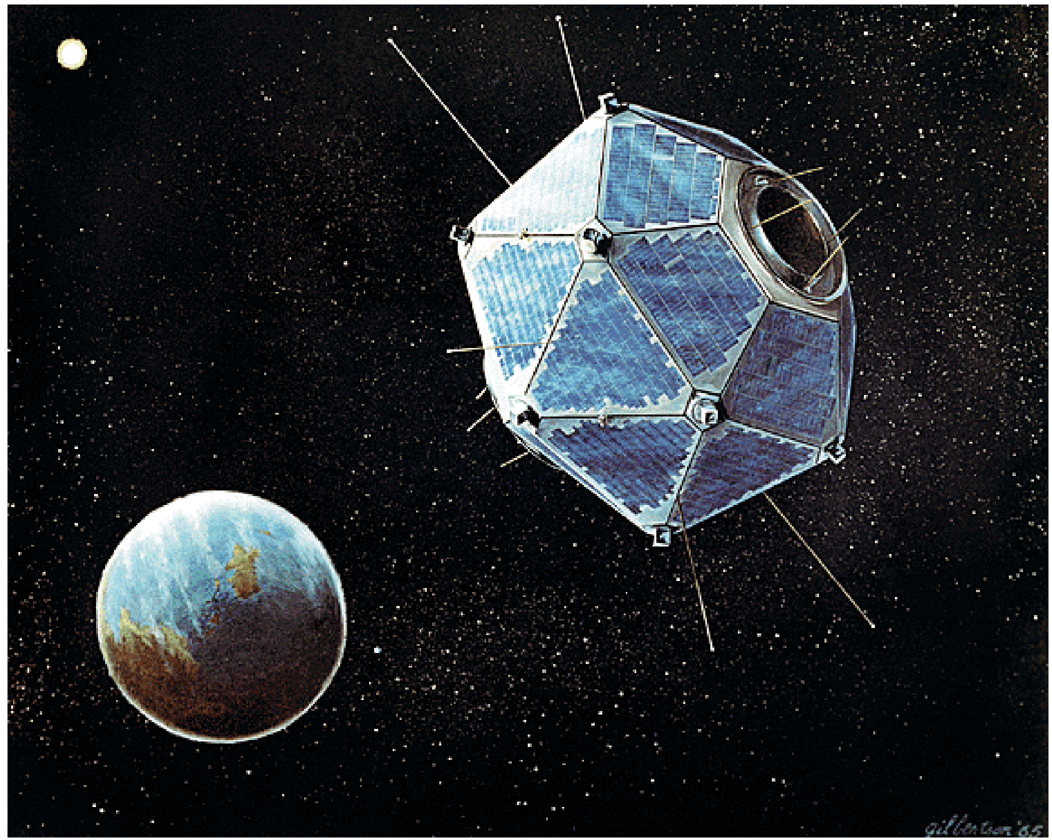
The observations were made by detectors on the four *Vela* spacecraft, *Vela 5A, 5B, 6A*, and *6B*, which are arranged almost equally spaced in a circular orbit with a geocentric radius of ~1.2×10^5 km.

On each spacecraft six 10 cm^3 CsI scintillation counters are so distributed as to achieve a nearly isotropic sensitivity. Individual detectors respond to energy depositions of 0.2–1.0 MeV for *Vela 5* spacecraft and 0.3–1.5 MeV for *Vela 6* spacecraft, with a detection efficiency ranging between 17 and 50 percent. The scintillators are shielded against direct penetration by electrons below ~0.75 MeV and protons below ~20 MeV. A high-*Z* shield attenuates photons with energy below that of the counting threshold. No active anticoincidence shielding is provided.

Normalized output pulses from the six detectors are summed into the counting and logics circuitry. Logical sensing of a rapid, statistically significant rise in count rate initiates the recording of discrete counts in a series of quasi-logarithmically increasing time intervals. This capability provides continuous coverage in time which, coupled with isotropic response, is unique in observatonal astronomy. A time measurement is also associated with each record.

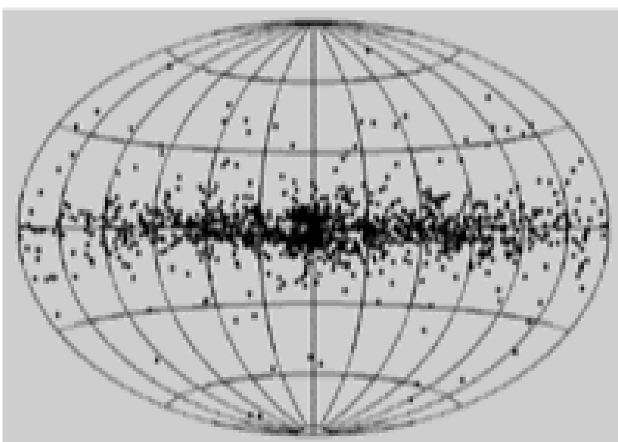
The data accumulations include a background component due to cosmic particles and their secondary effects. The observed background rate, which is a function of the energy threshold, is ~150 counts per second for the *Vela 5* spacecraft and ~20 counts per second for the *Vela 6* spacecraft.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

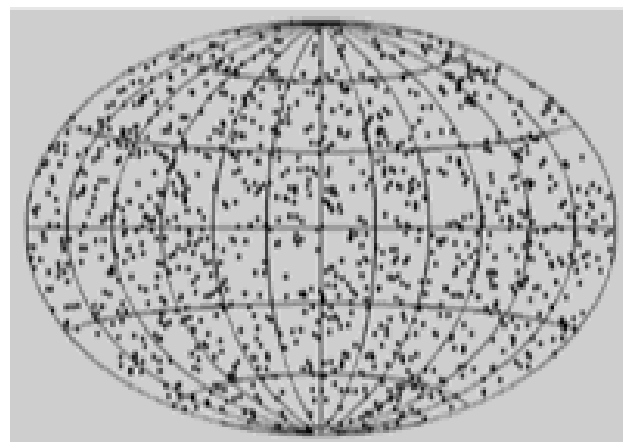


GRB History

Distribution of Gamma-Ray Bursts on the Sky



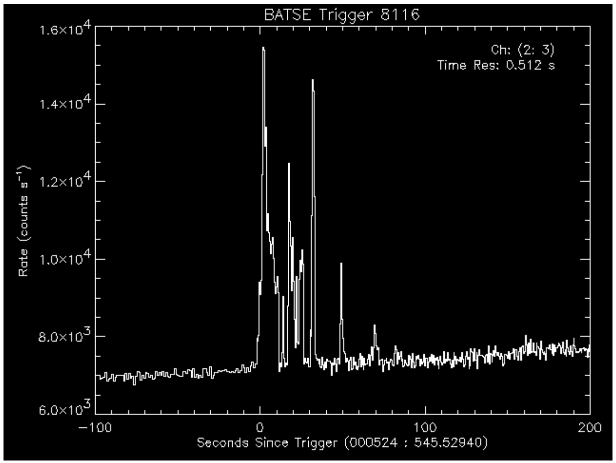
Expected



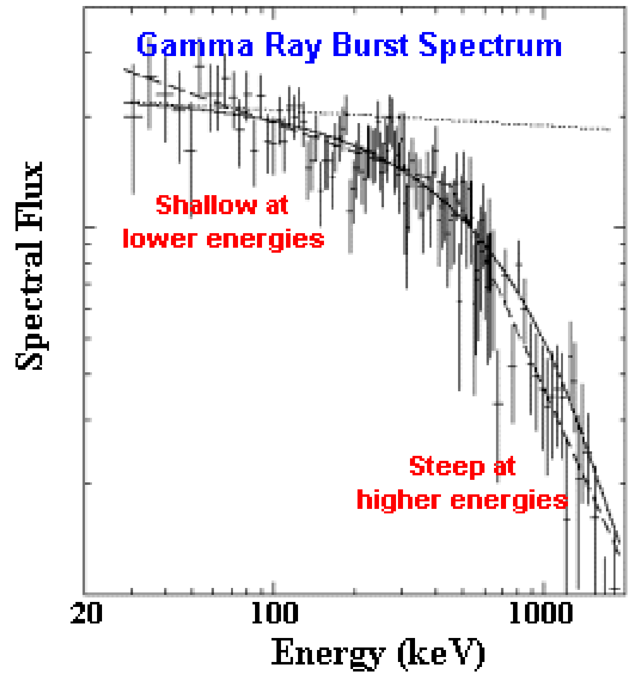
Observed

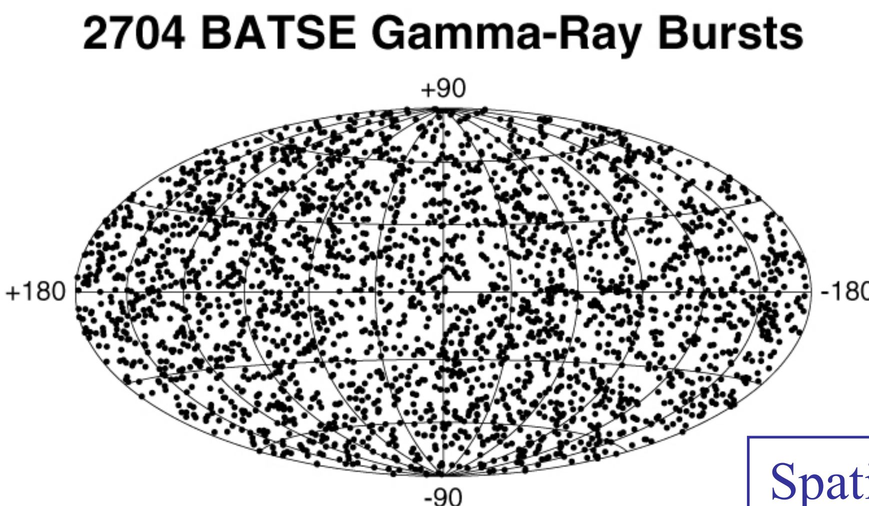
Gamma-Ray Bursts

Temporal behaviour



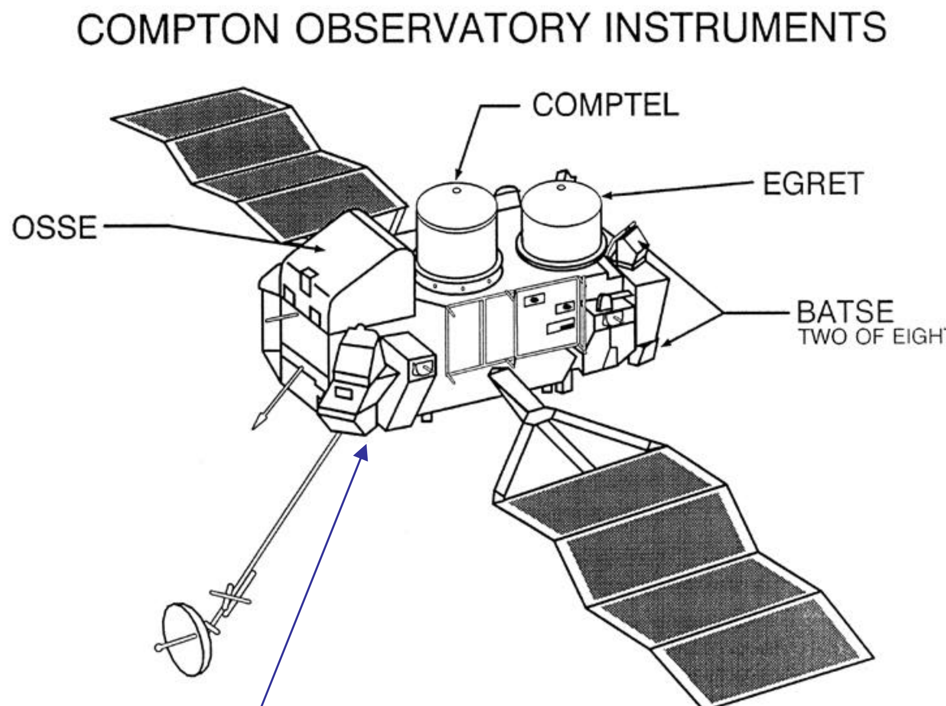
Spectral shape





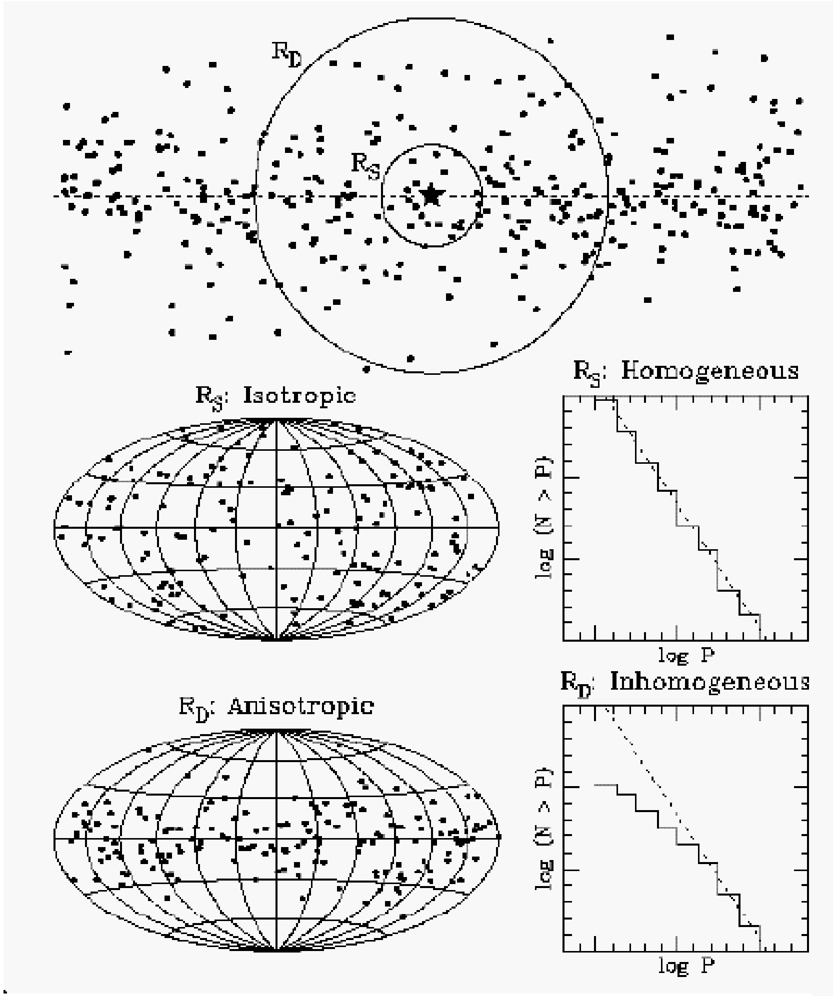
Spatial distribution

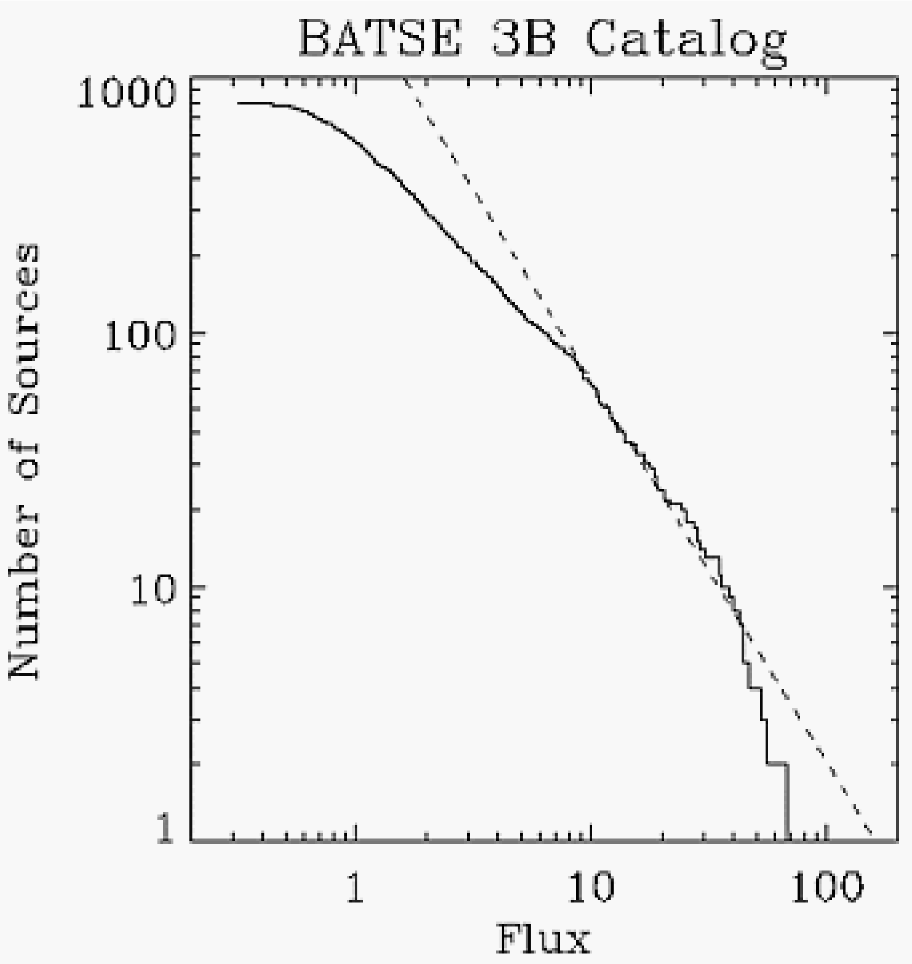
CGRO-BATSE (1991-2000)



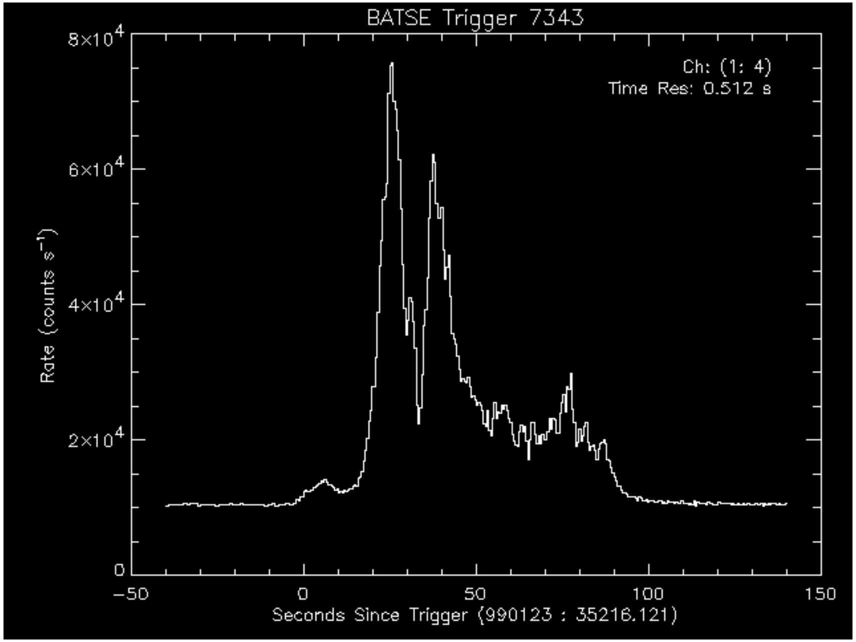
CGRO/BATSE (25 KeV÷10 MeV)

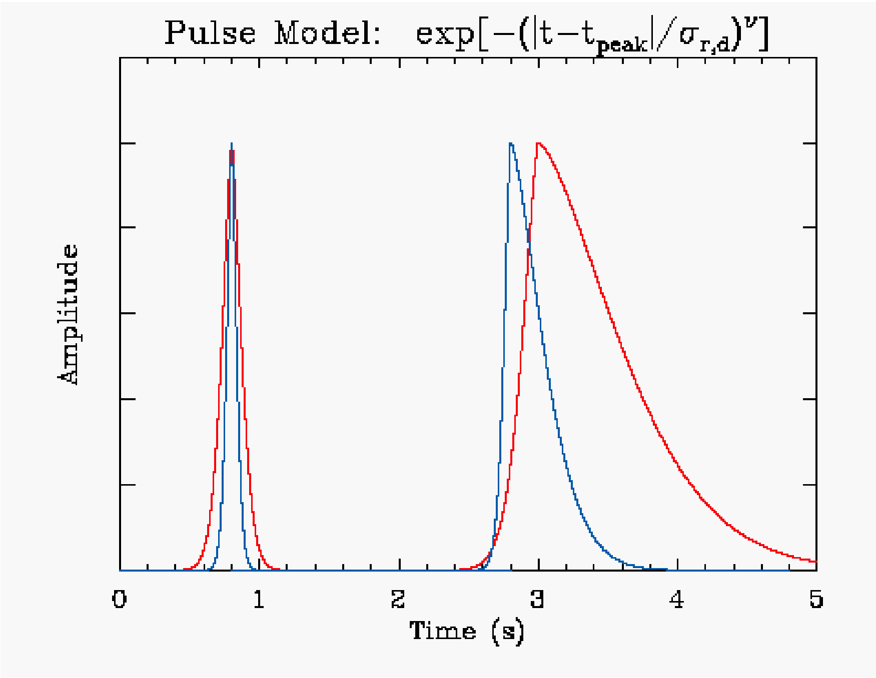
BATSE (1991 - 2000)





GRB Light curves





Rise Time ~ Geometry of the Shell

Decay Time ~ Cooling Time

Piran (1999)

Norris et al. (1996)

GRB time dilation?

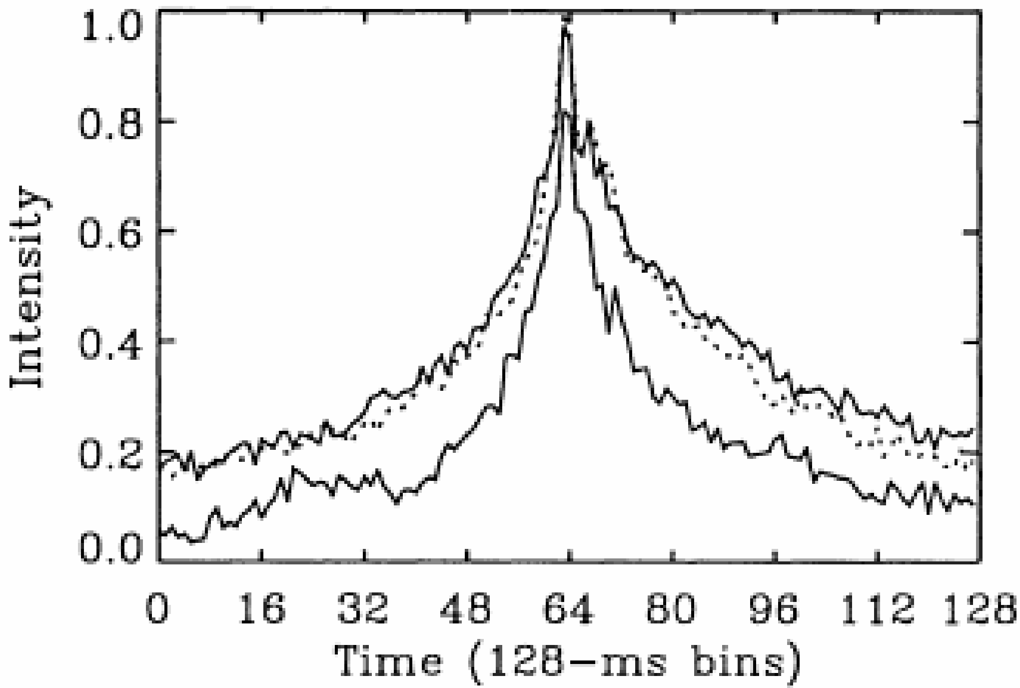


FIG. 3.—Average wavelet-threshold profiles of BATSE bursts in three brightness groups, with highest peak for each burst shifted into temporal alignment. Dimmest (*solid*, outer profile), dim (*dotted*), and bright groups (*solid*, inner profile).

Norris et al. (1994)

GRB: where are they?

The great debate (1995)

Fluence: 10^{-7} erg cm^{-2} s^{-1}

Distance: 1 Gpc

Energy: 10^{51} erg

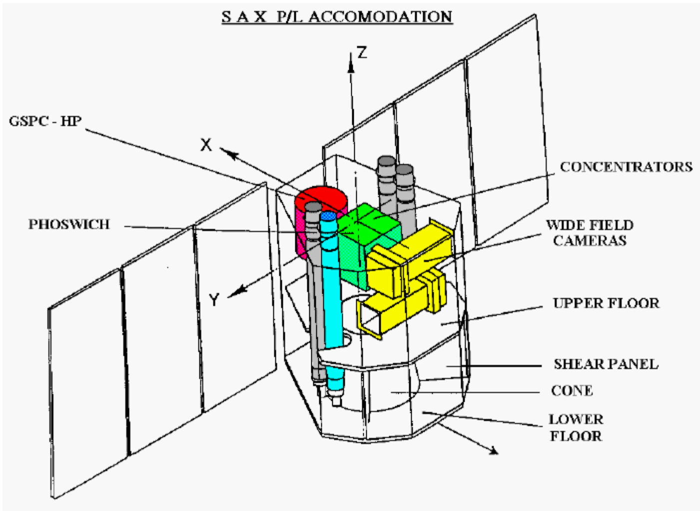
Distance: 100 kpc

Energy: 10^{43} erg

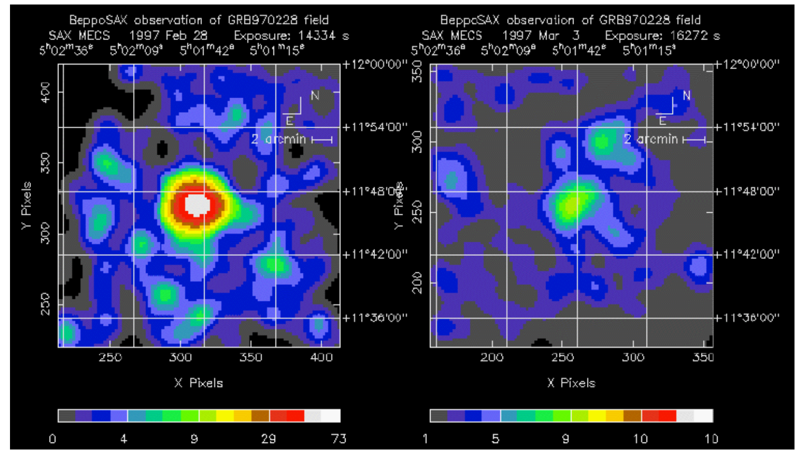
Cosmological - Galactic?

Need a new type of observation!

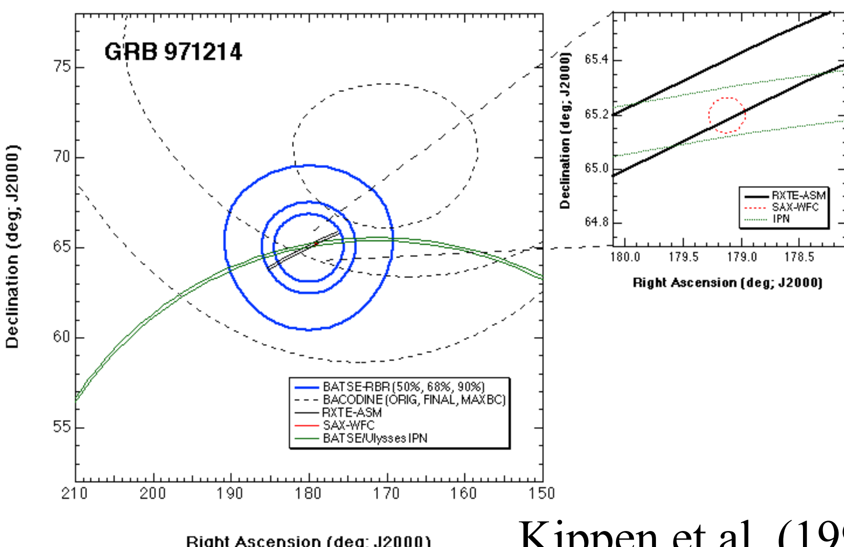
BeppoSAX and the Afterglows



- Good Angular resolution (< arcmin)
- Observation of the X-Afterglow

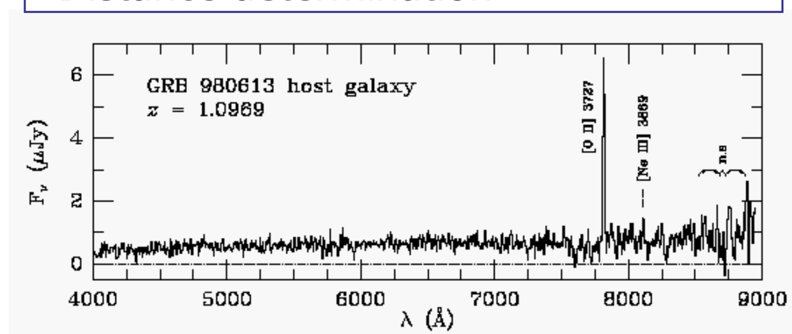


Costa et al. (1997)



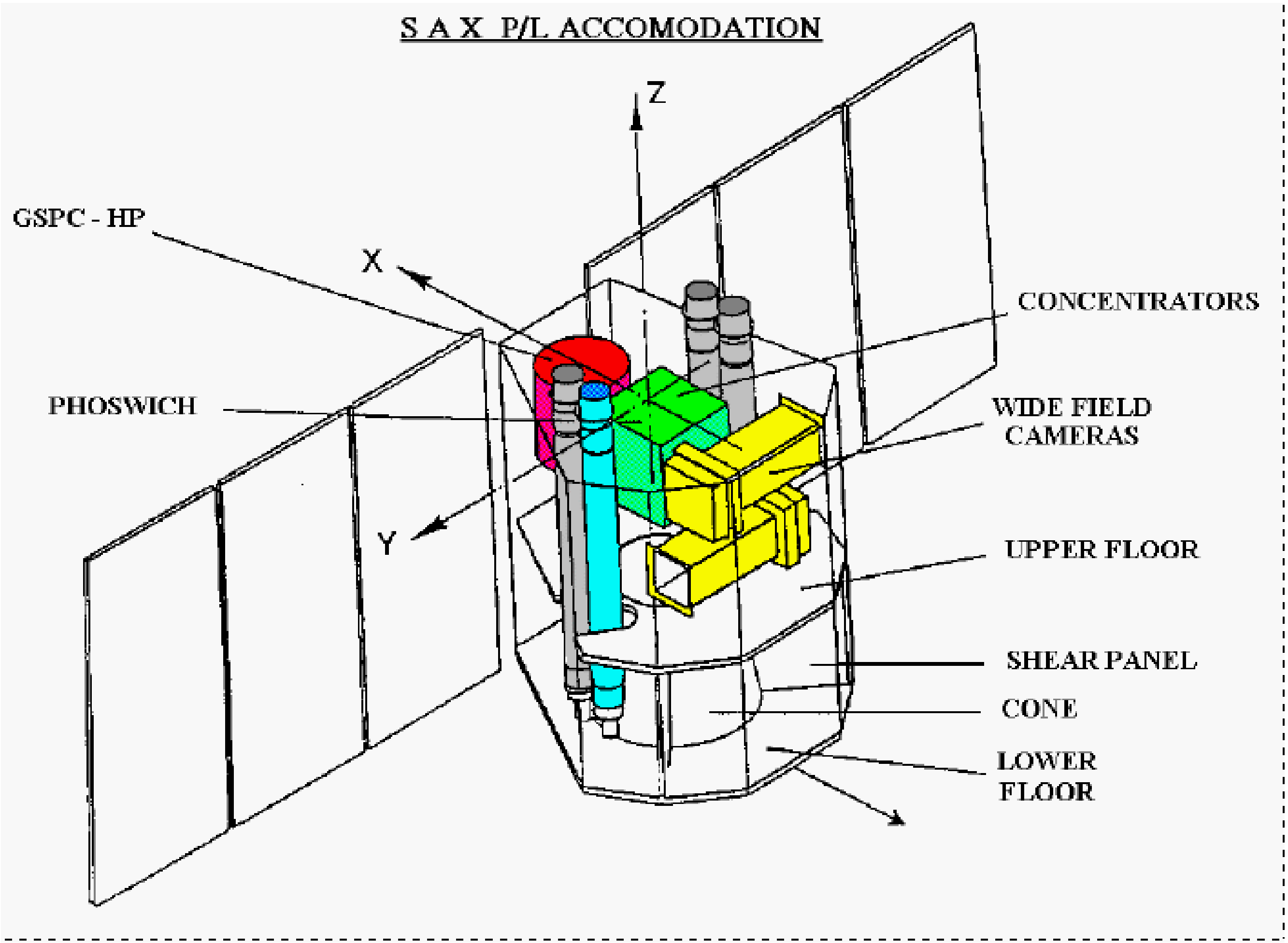
Kippen et al. (1998)

- Optical Afterglow (HST, Keck)
- Direct observation of the host galaxies
- Distance determination

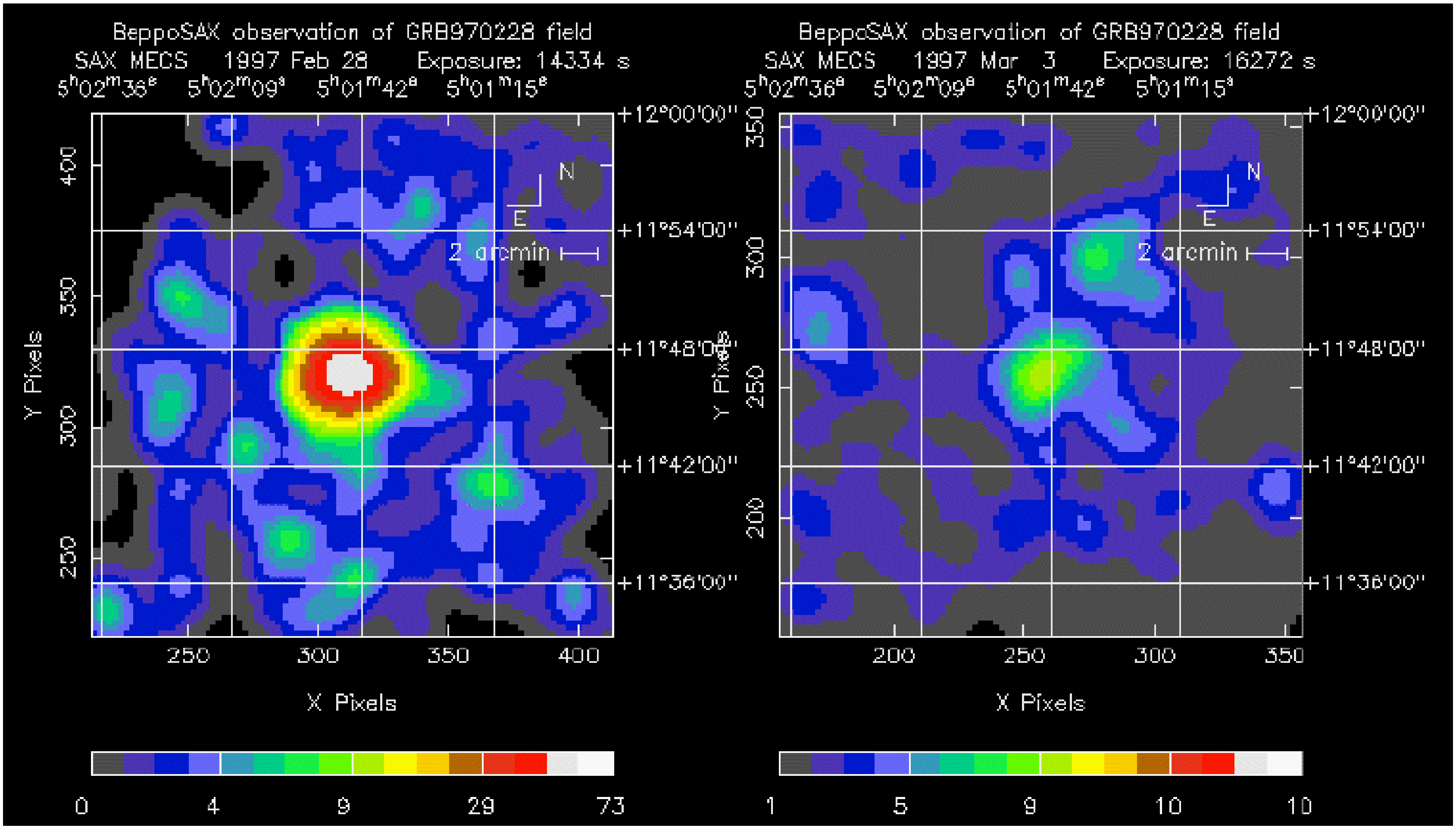


Djorgoski et al. (2000)

BeppoSAX (1995 - 2002)

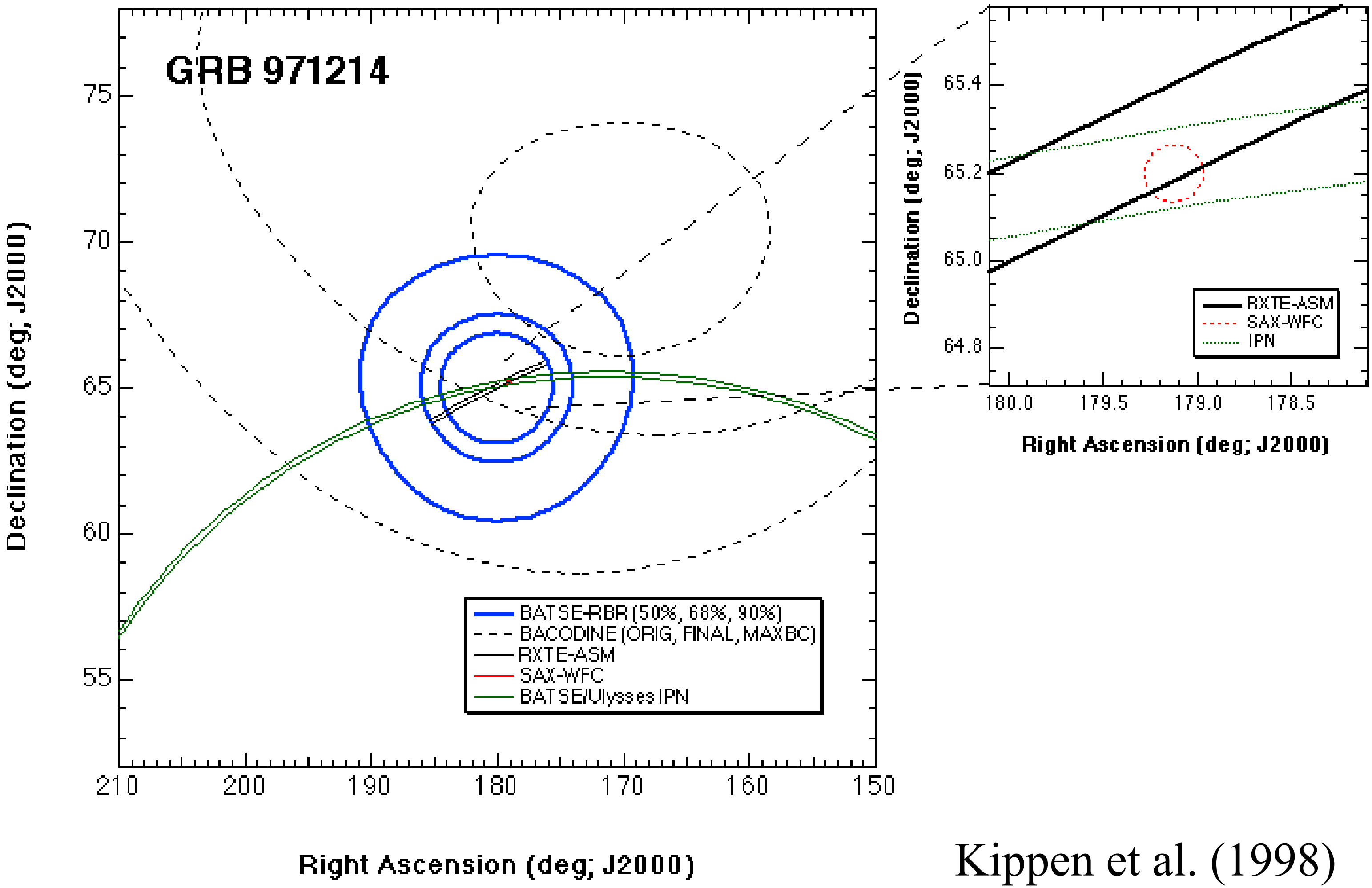


BeppoSAX



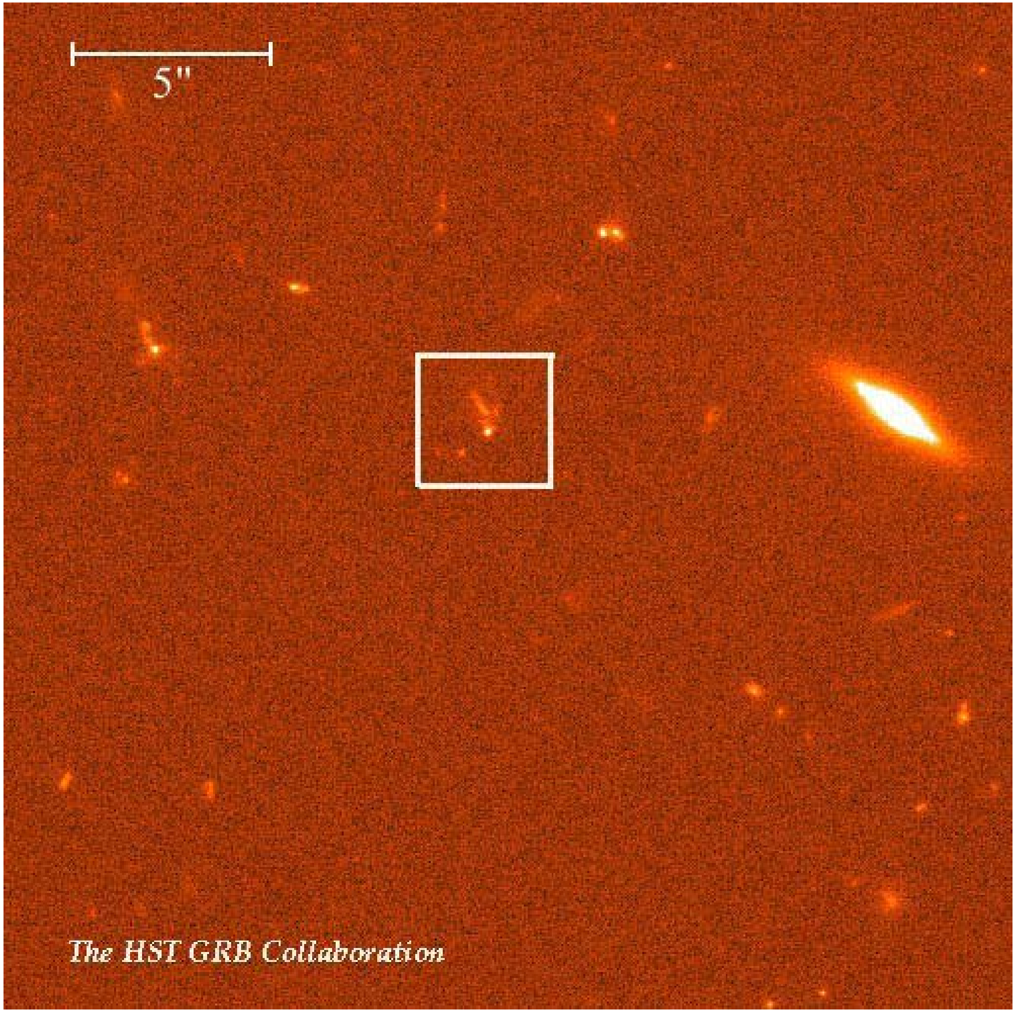
Costa et al. (1997)

BeppoSAX



Kippen et al. (1998)

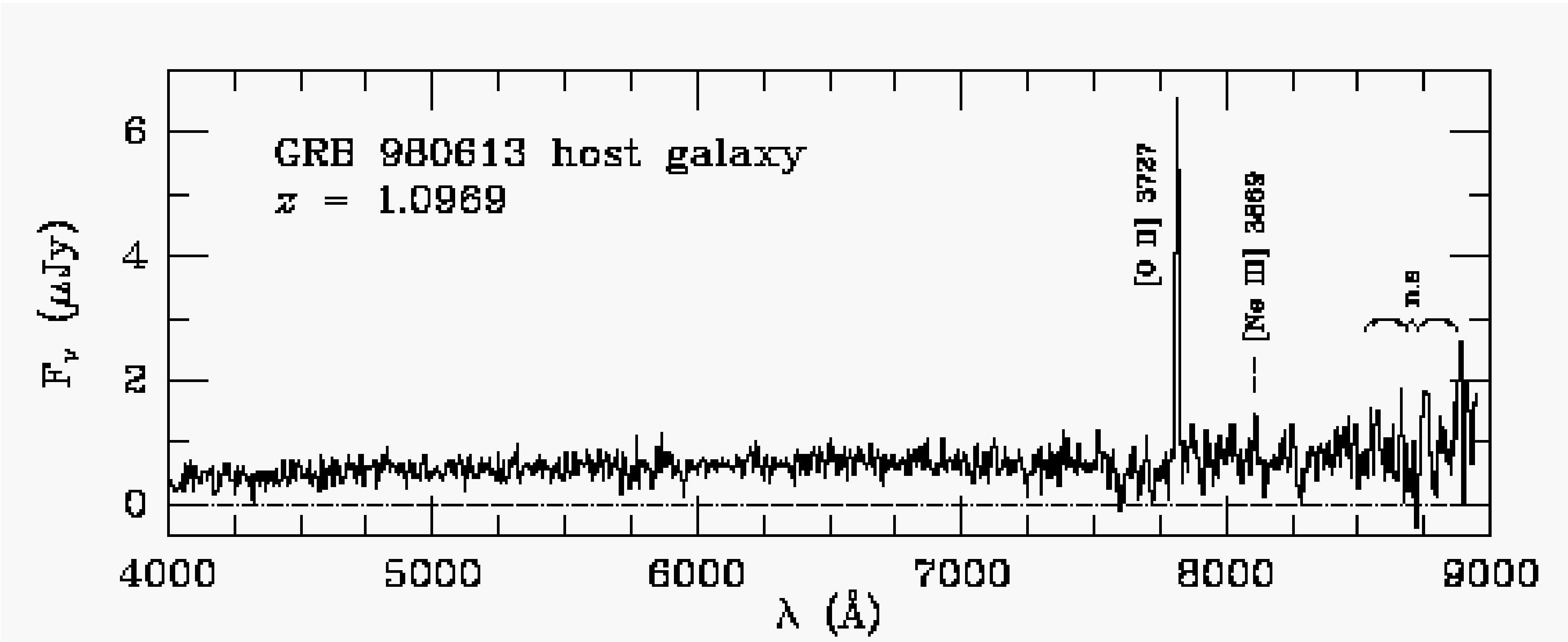
Afterglow Era



Host Galaxies identification

Fruchter et al (1999)

Afterglow Era



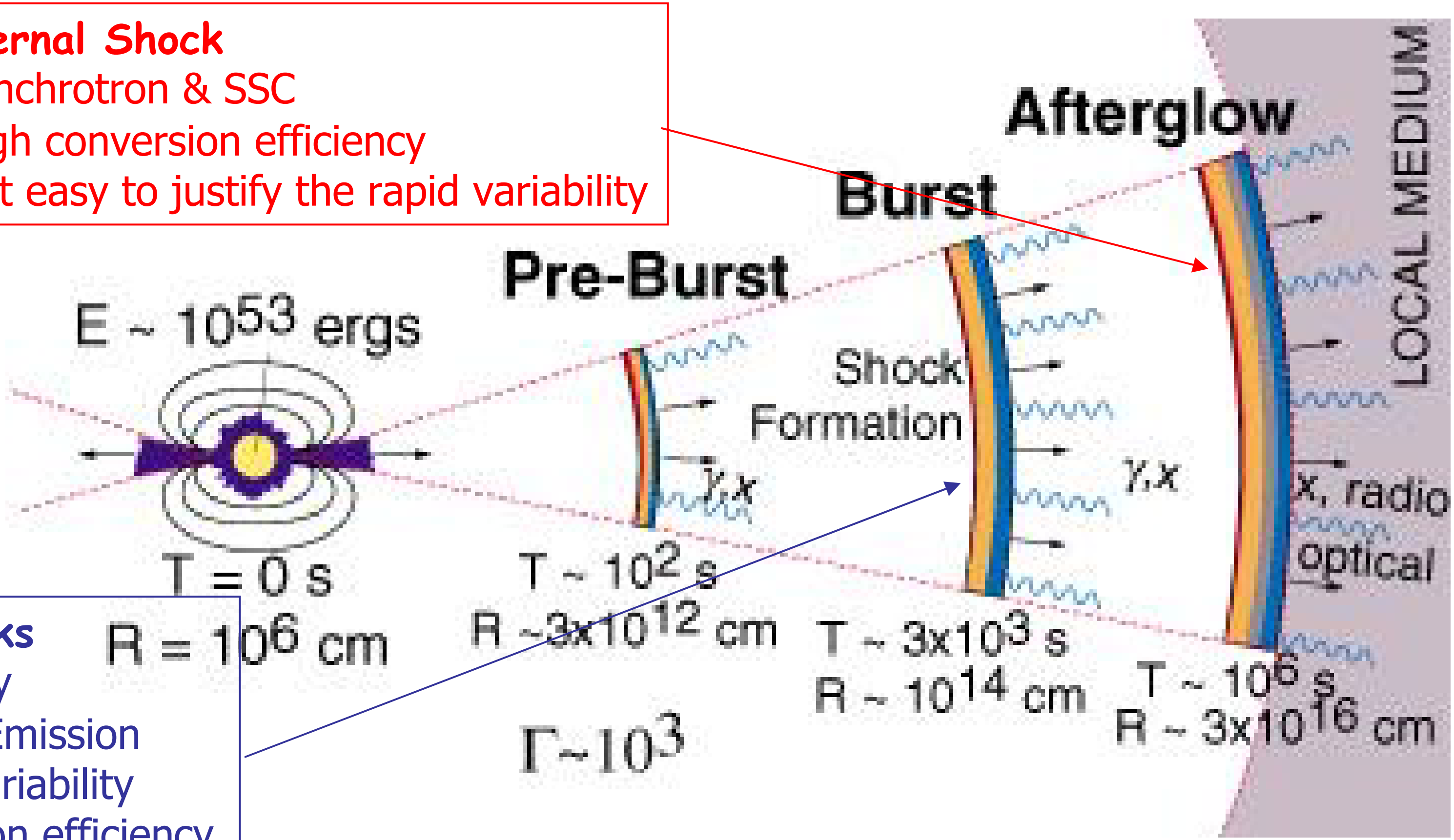
Redshift measurement

Djorgoski et al. (2000)

The Fireball "standard" model

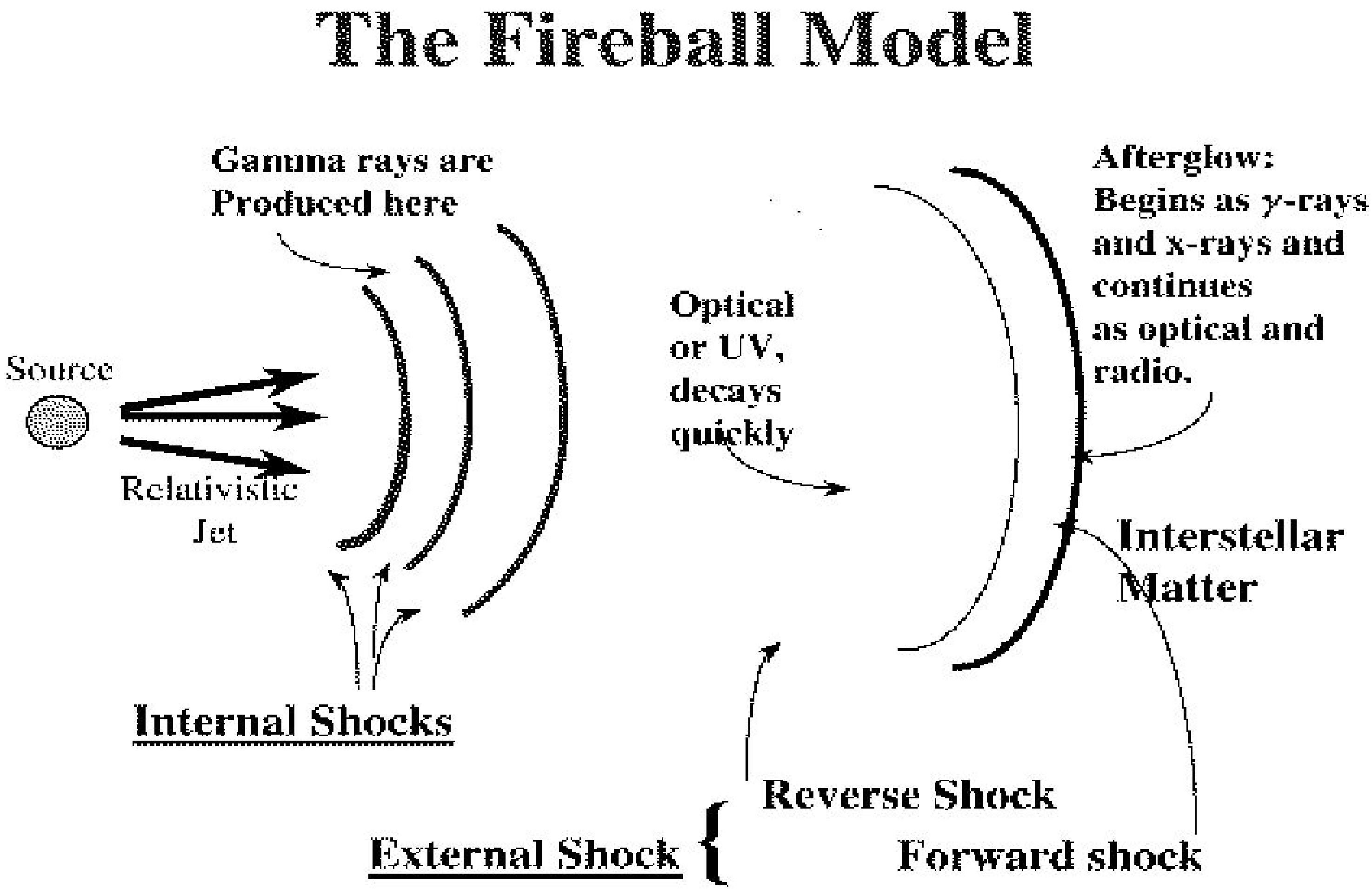
- Relativistic motion of the emitting region
- Shock mechanism converts the kinetic energy of the shells into radiation.
- Baryon Loading problem

External Shock
- Synchrotron & SSC
- High conversion efficiency
- Not easy to justify the rapid variability



Internal Shocks
- Source activity
- Synchrotron Emission
- Rapid time Variability
- Low conversion efficiency

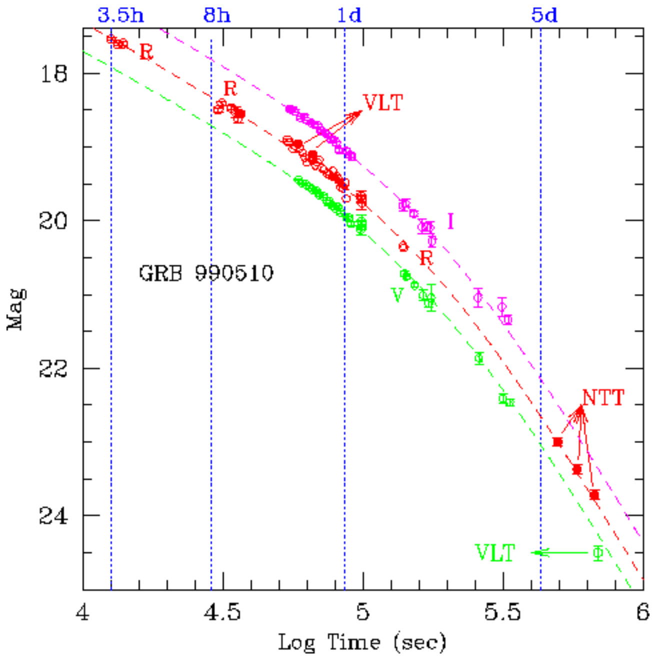
The Fireball Model



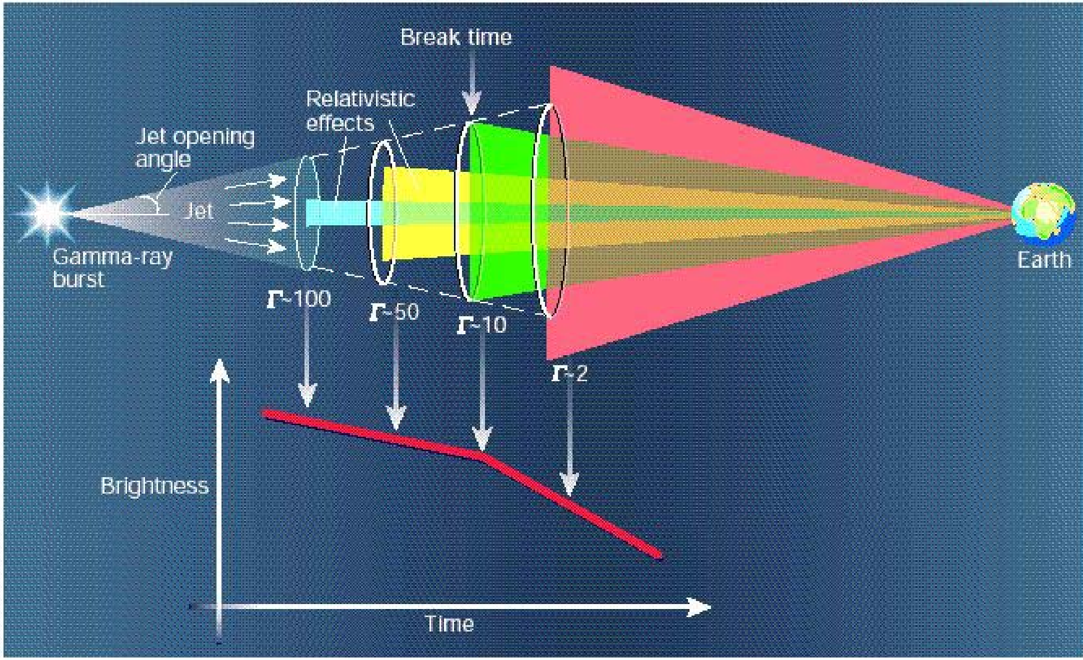
Cartoon by Piran (1999)

Afterglow Observations

Harrison et al (1999)

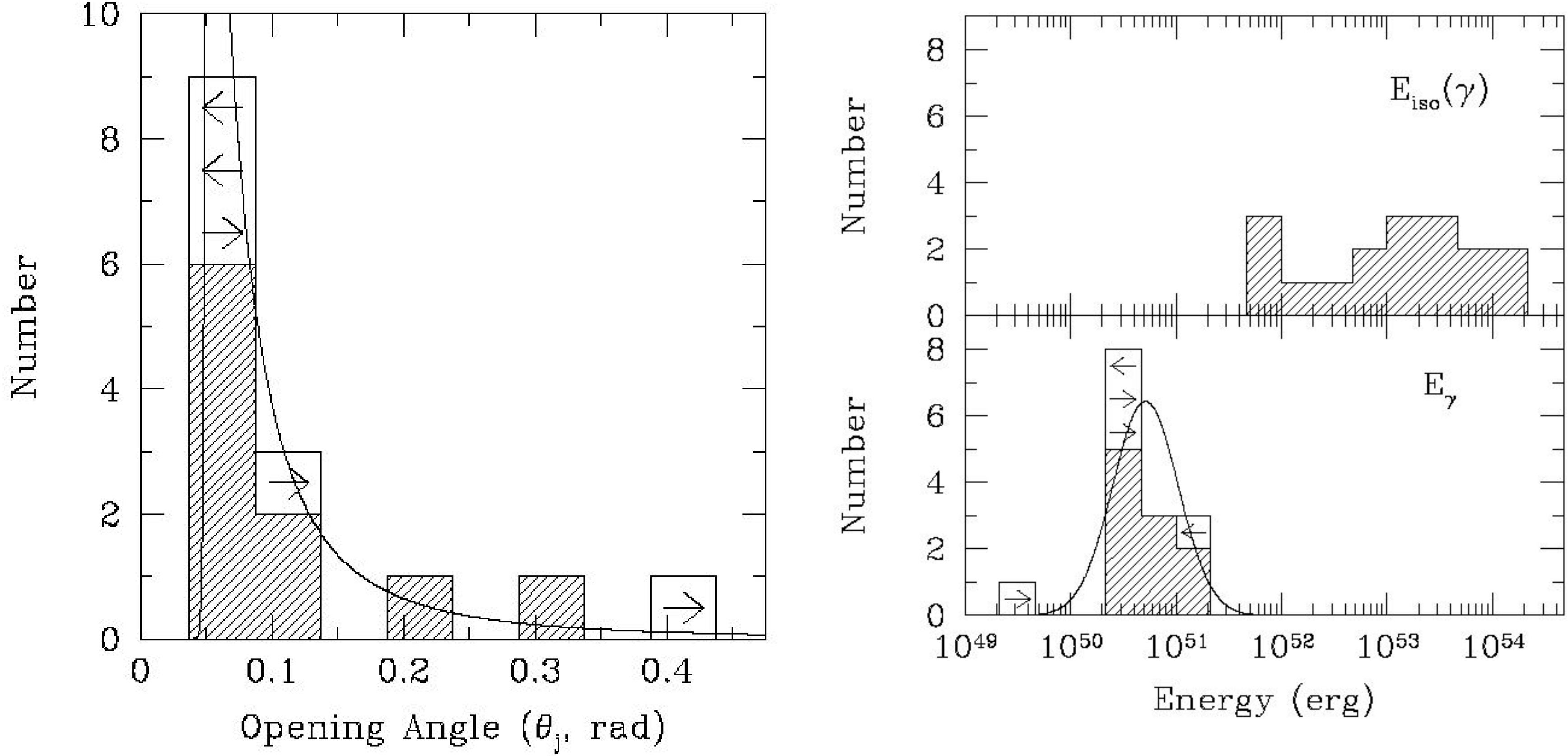


Achromatic Break



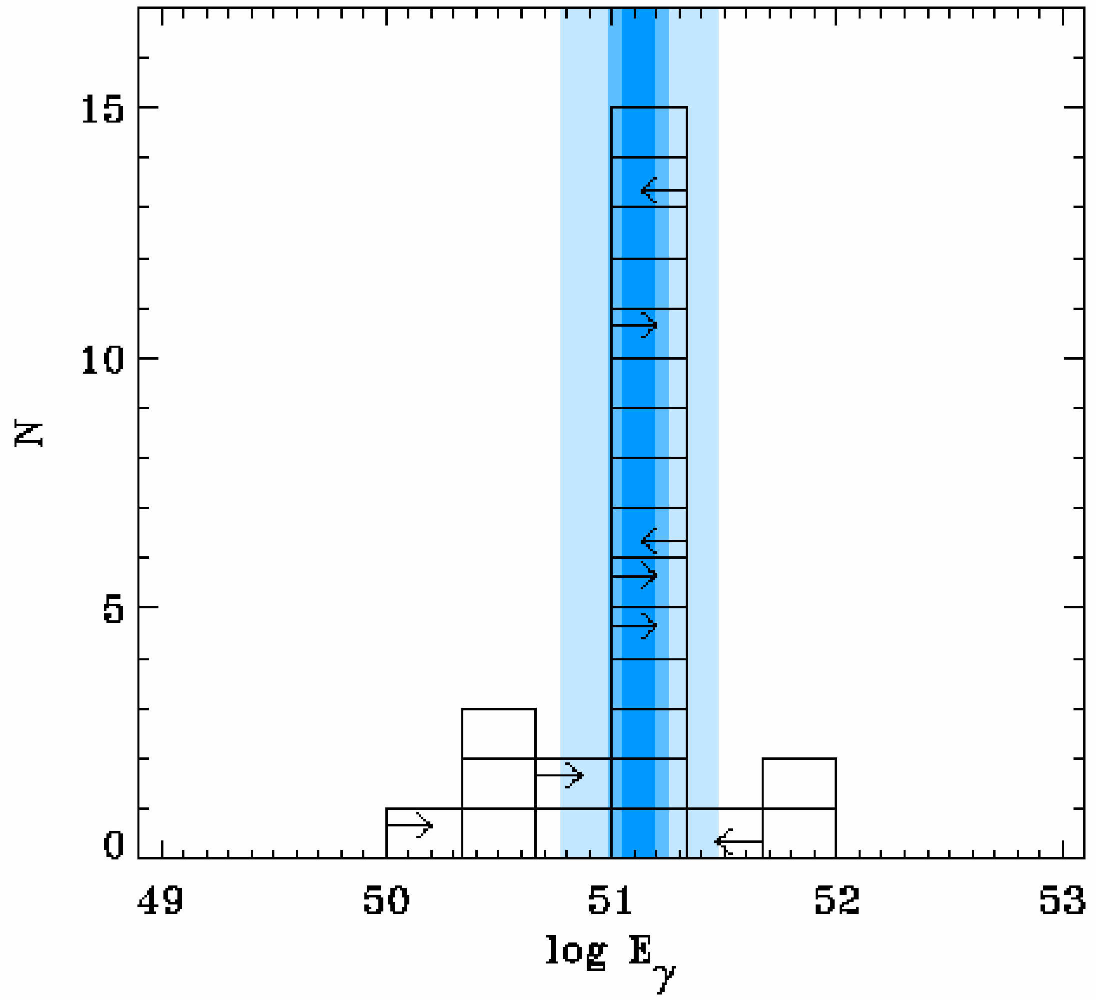
Woosley (2001)

Jet and Energy Requirements



Frail et al. (2001)

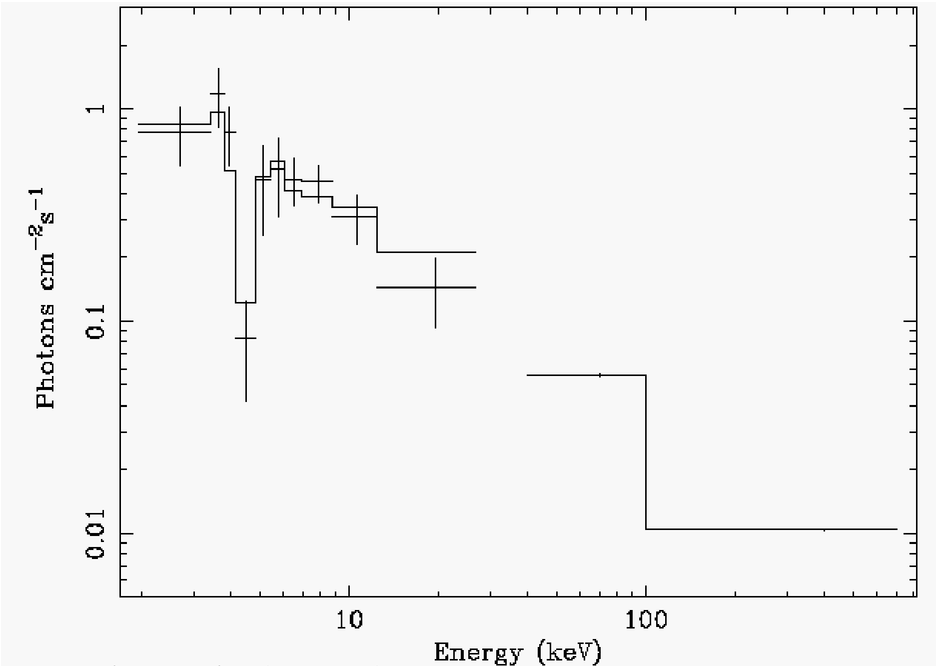
Jet and Energy Requirements



Bloom et al. (2003)

X-ray Lines

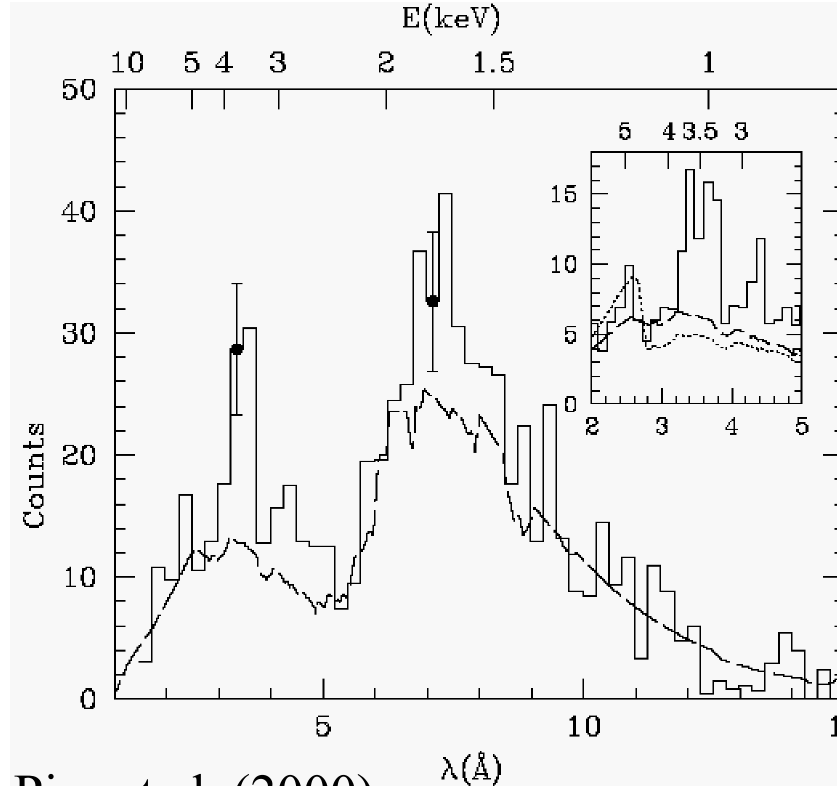
GRB 990705



Amati et al. (2000)

Transient Absorbtion Line

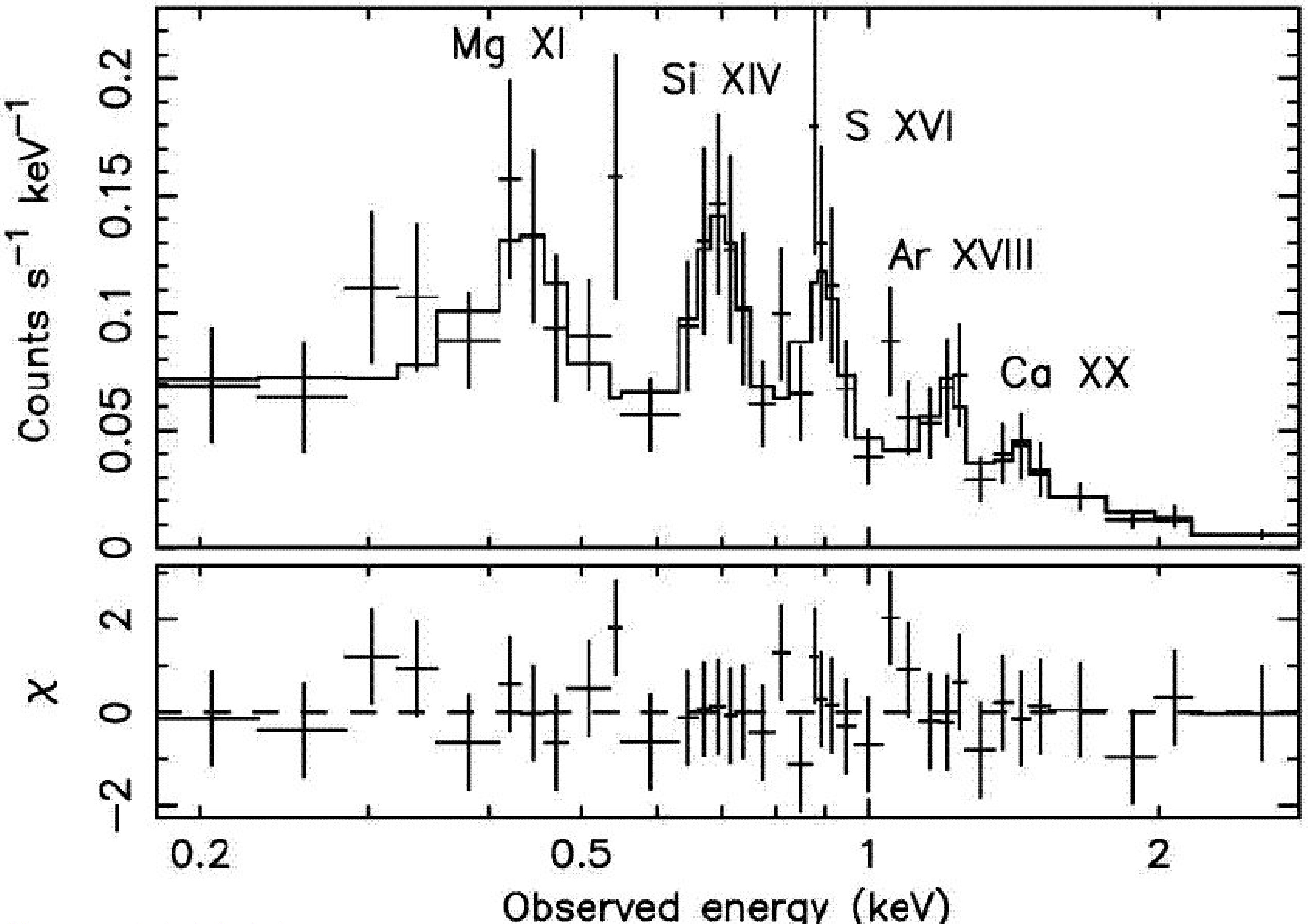
Emission Lines



Piro et al. (2000)

GRB 991216

X-ray Lines



GRB 011211

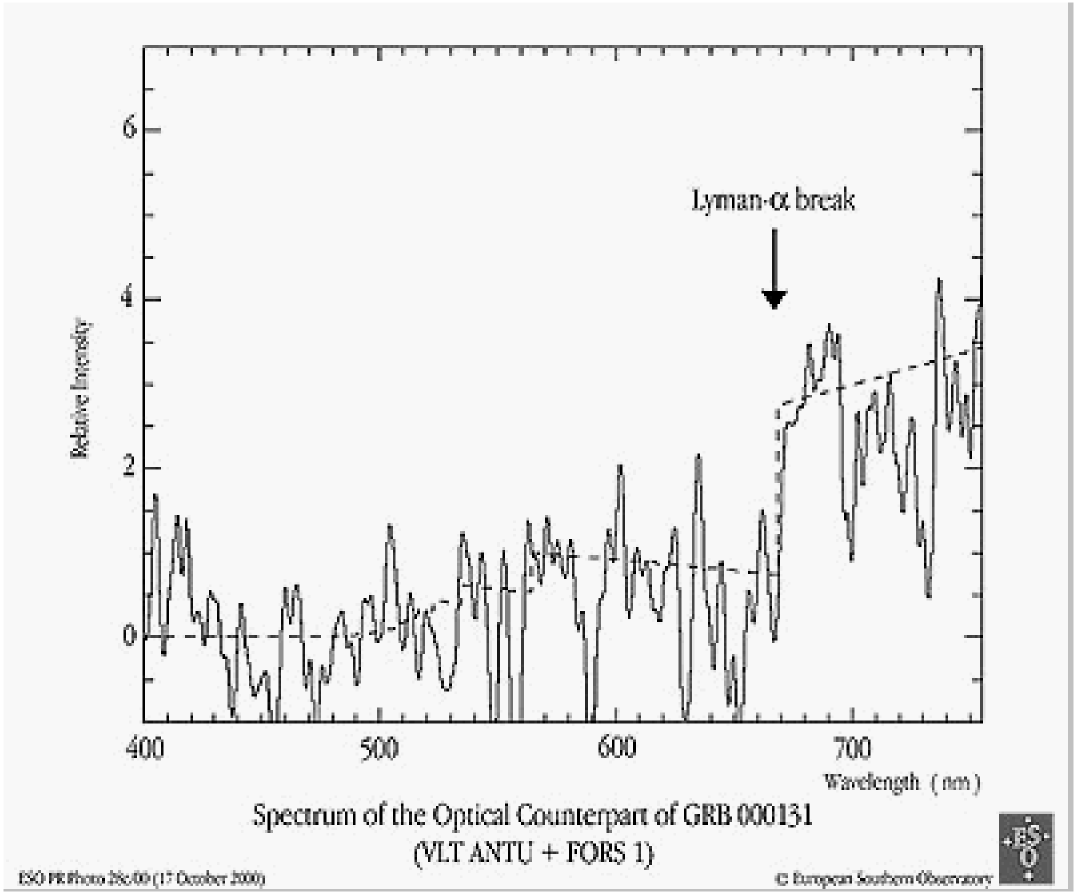
Reeves et al. (2002)

A “Cosmological” era?

- GRB cosmology
- Cosmological rulers
- High z events

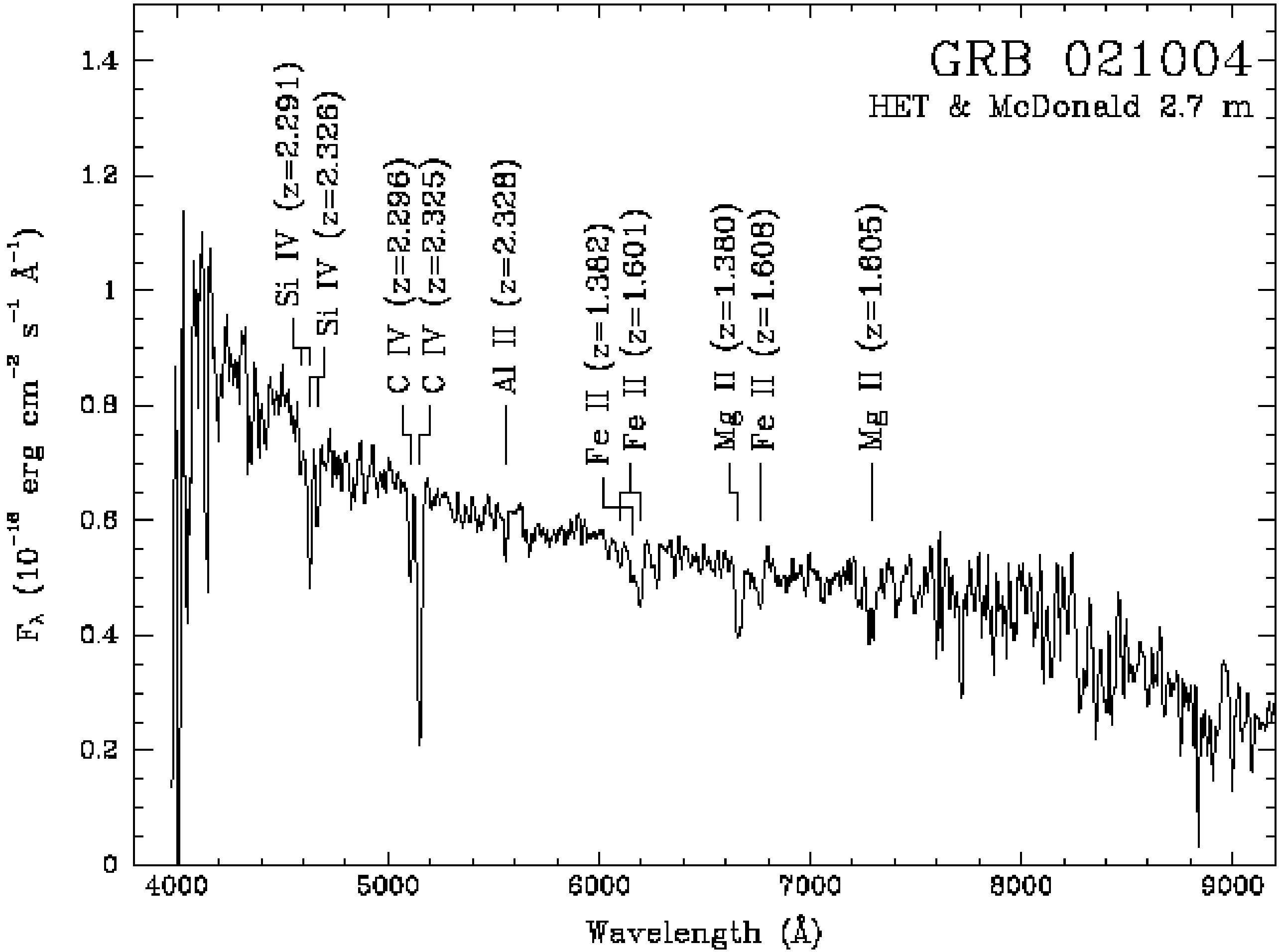
Cosmology with GRB

GRB 000131
z = 4.5



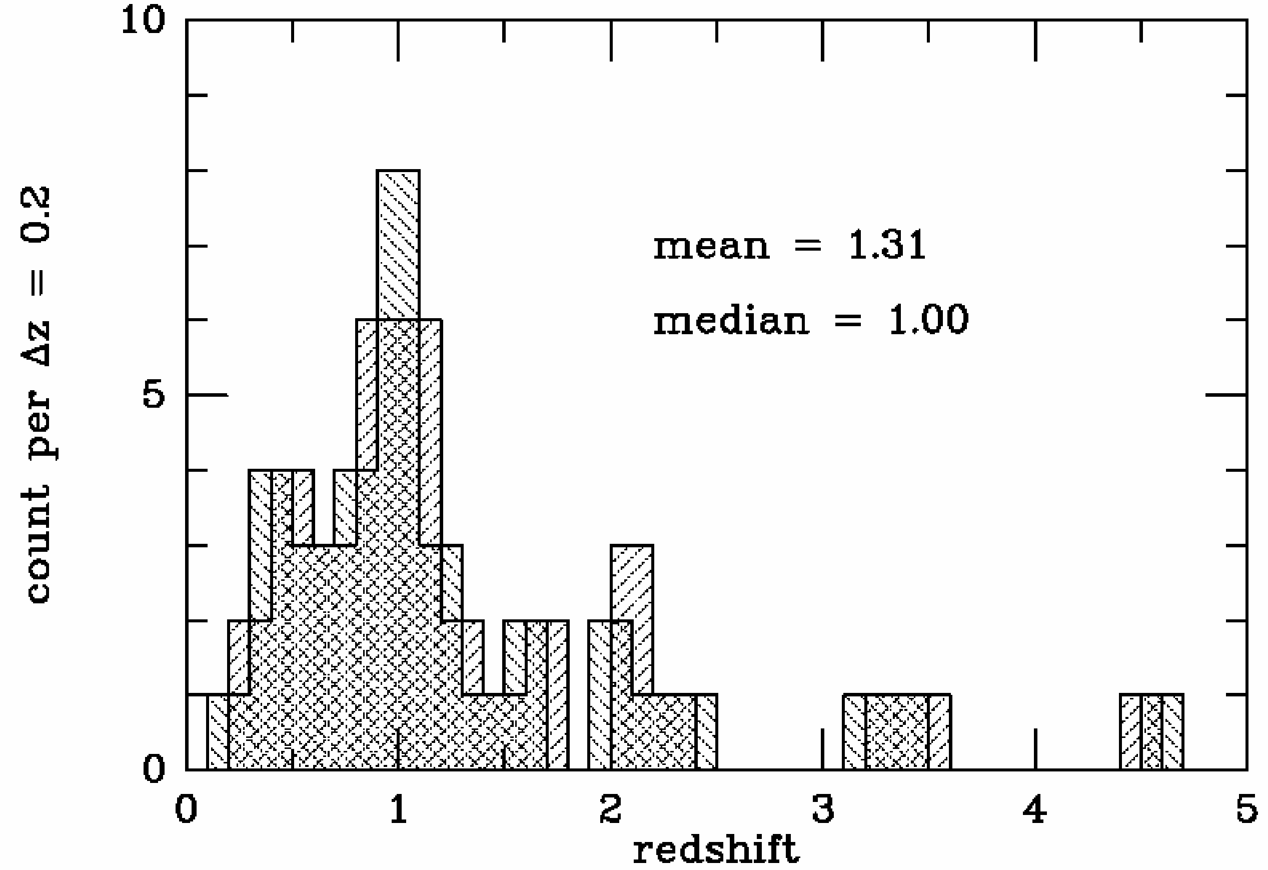
Andersen et al. (2000)

High precision radiography of ISM from z=2.3



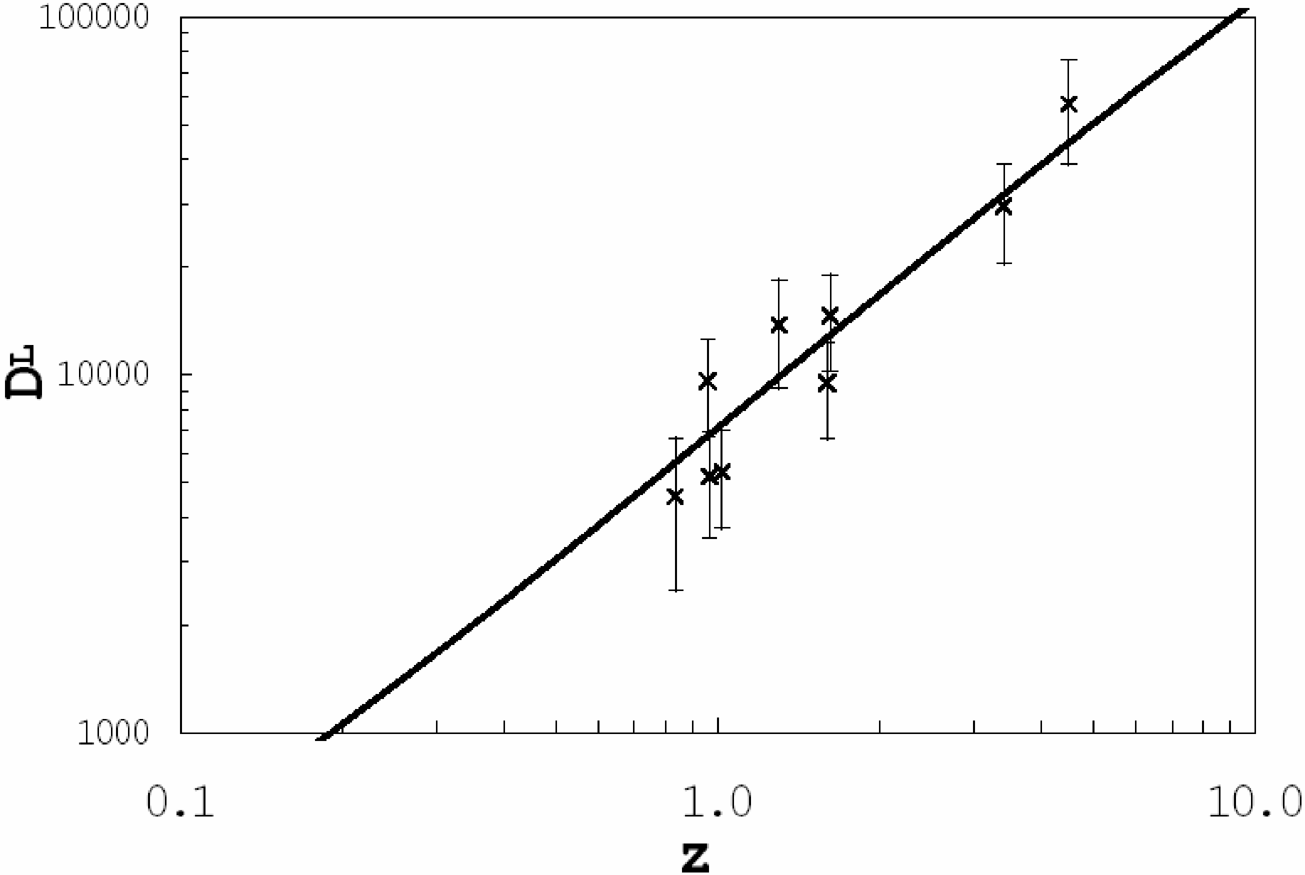
Schaefer et al. 2002

GRB and Cosmology



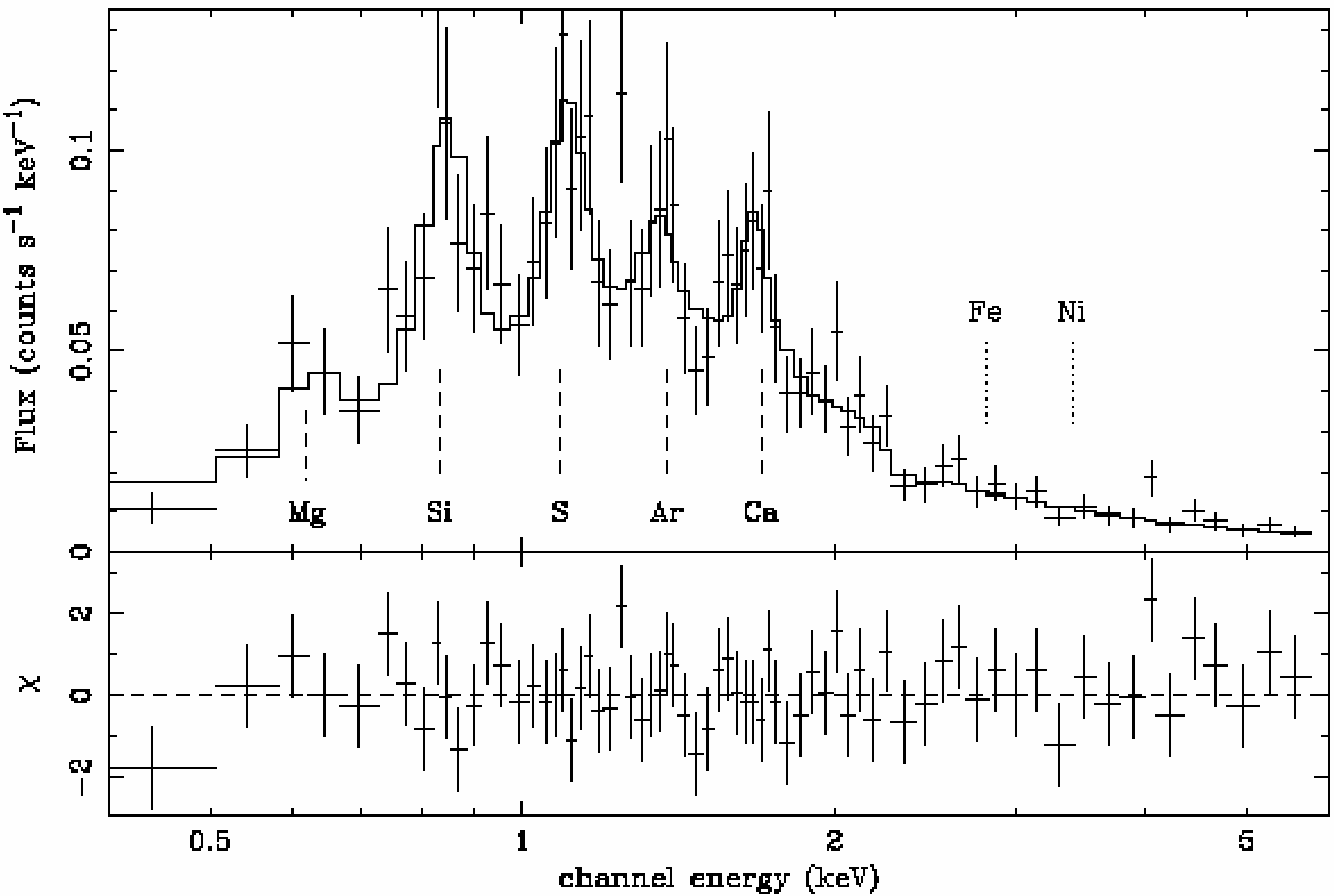
Djorgovski et al. 2003

GRB and Cosmology



Schaefer (2003)

X-ray Lines



GRB 030227

Watson et al. (2003)

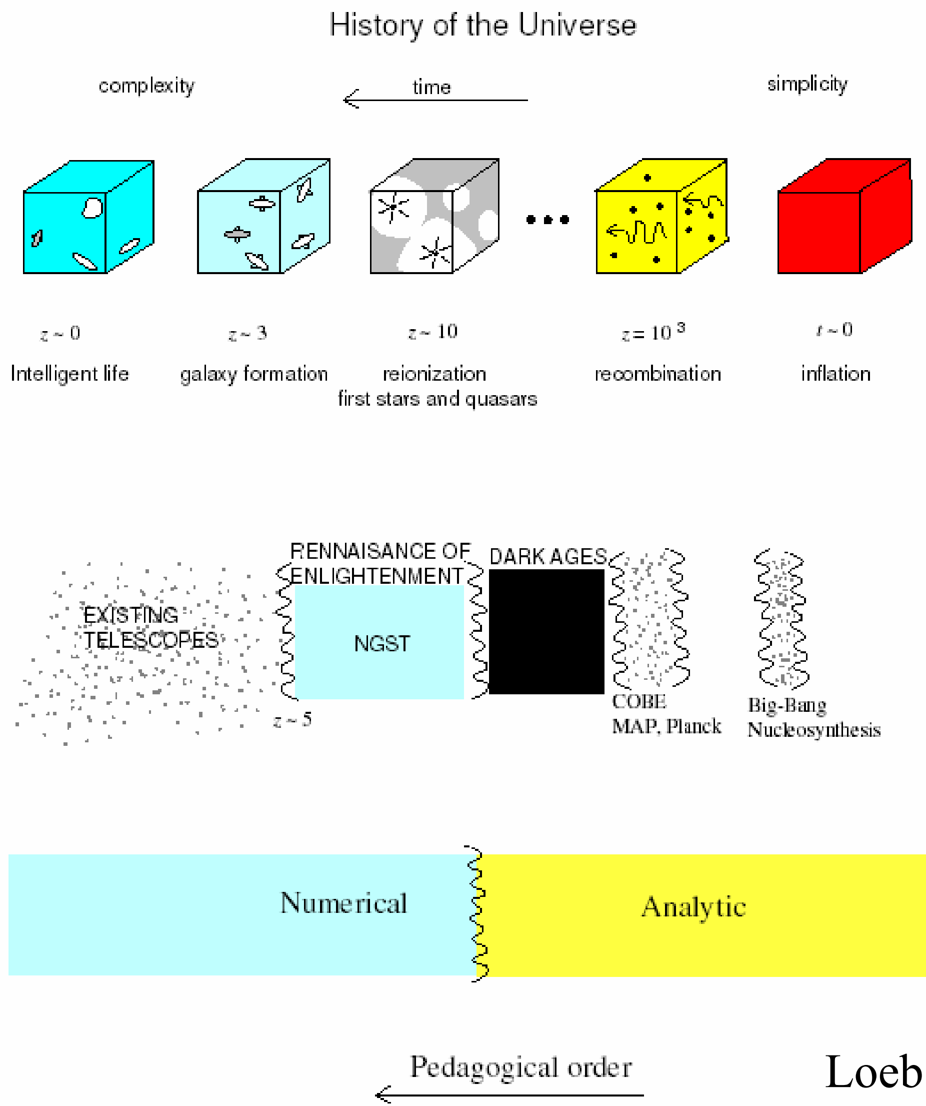
GRB and Cosmology

- Meszaros & Rees (2003) astro-ph/0305115
- GRB afterglow detection in the range (z = 10 – 30)

z	$\frac{\lambda_{\mathrm{Ly}\alpha,\mathrm{H}}}{\mu\mathrm{m}}$	$\frac{E_t}{\mathrm{keV}}$	$\frac{E_{Fe,\mathrm{K}\alpha}}{\mathrm{keV}}$	$F_E(10\mathrm{s})$	$F_E(10^2\mathrm{s})$	$F_E(10^3\mathrm{s})$	$F_E(10^4\mathrm{s})$	$F_E(10^5\mathrm{s})$
3	0.486	0.22	1.675	1.9^{-9}	6.8^{-10}	5.4^{-11}	4.3^{-12}	3.4^{-13}
6.5	0.912	0.22	0.893	6.1^{-10}	4.4^{-10}	3.5^{-11}	2.8^{-12}	2.2^{-13}
9.0	1.216	0.22	0.670	4.1^{-10}	4.1^{-10}	3.3^{-11}	2.6^{-12}	2.1^{-13}
12	1.581	0.22	0.515	3.0^{-10}	3.0^{-10}	3.2^{-11}	2.5^{-12}	2.0^{-13}
18	2.310	0.22	0.353	2.0^{-10}	2.0^{-10}	3.2^{-11}	2.6^{-12}	2.1^{-13}
30	3.770	0.22	0.216	1.3^{-10}	1.3^{-10}	3.5^{-11}	2.8^{-12}	2.2^{-13}

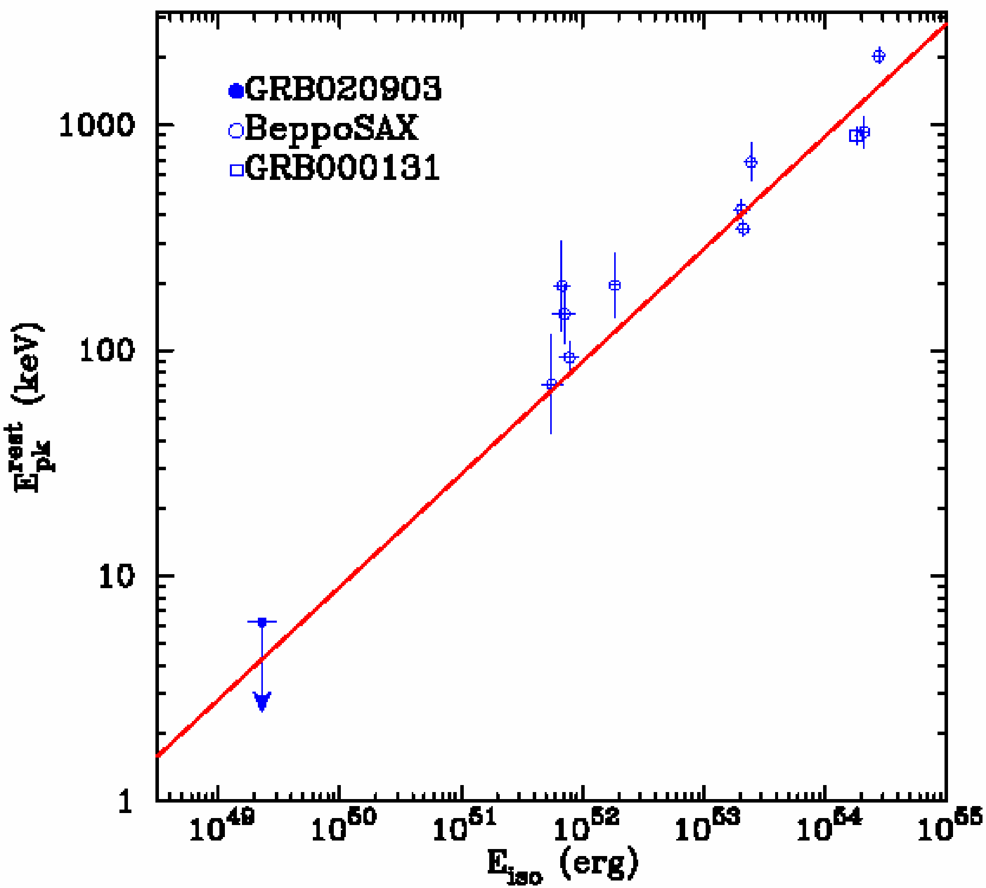
- X-ray flashes (E_{peak}, Rate ½ GRB, Isotropic) (Heise 2003) structured jets off-axis GRBs or high Z GRBs?

GRB Cosmology



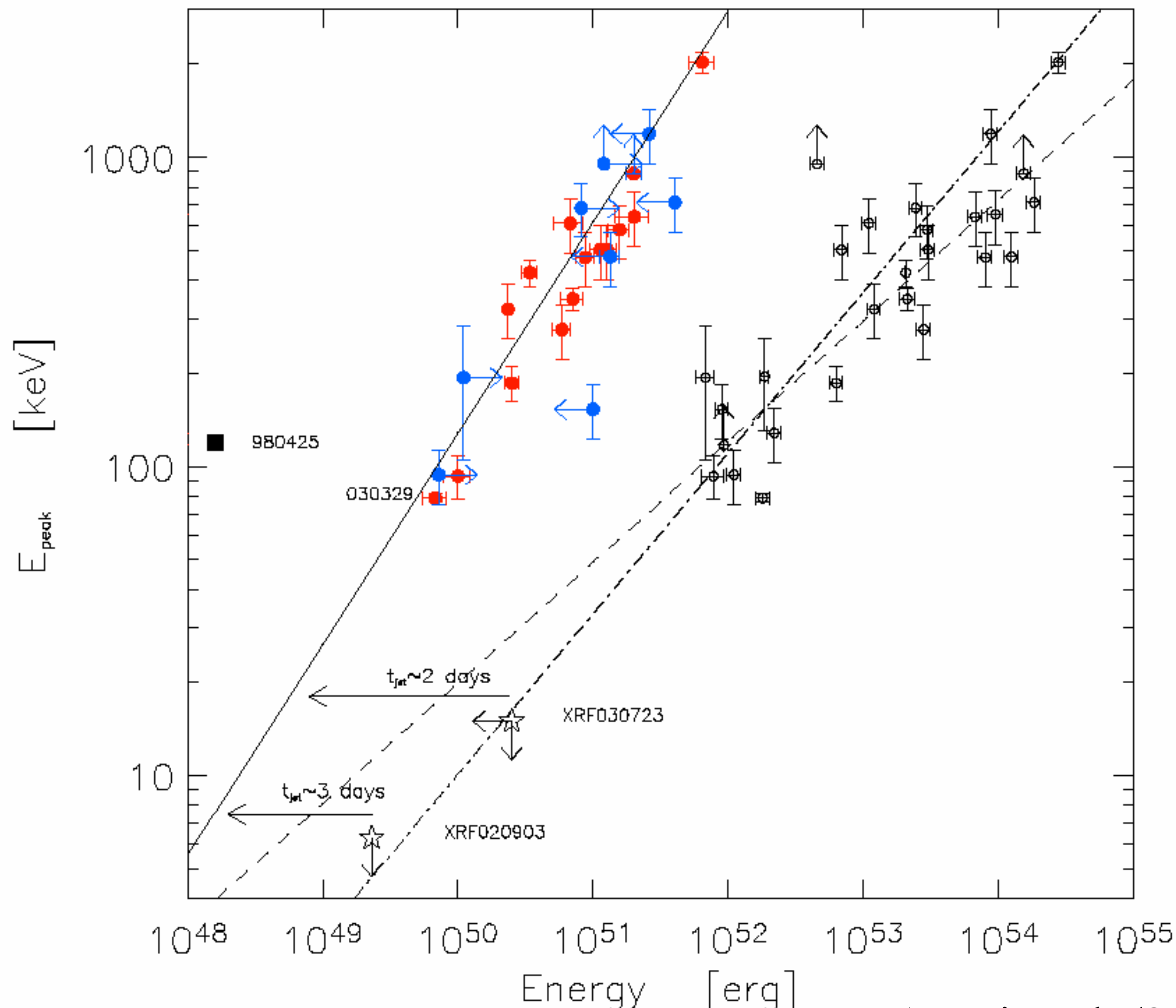
Loeb and Barkana (2000)

Peak Energy – Isotropic Energy



Sakamoto et al. (2003)

GRB for Cosmology

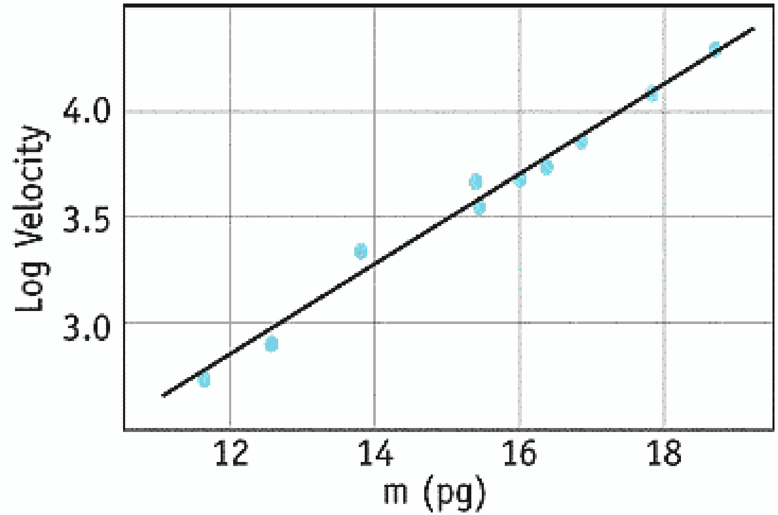


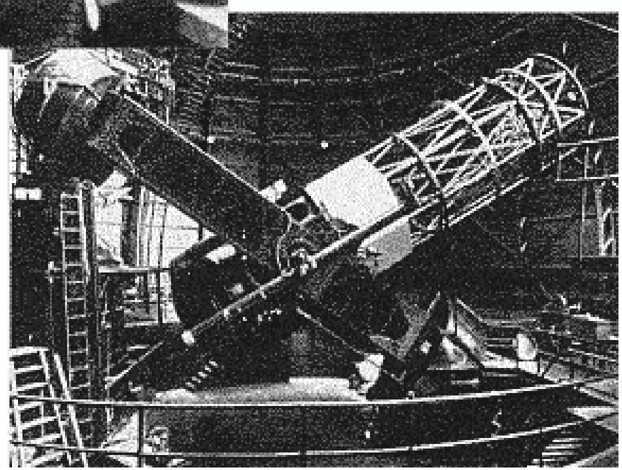
Amati et al. (2002)
Ghirlanda et al. (2004)

Hubble Cosmology

Discovery of Expanding Universe

Edwin Hubble





Mt. Wilson
100 Inch
Telescope

Hubble Cosmology

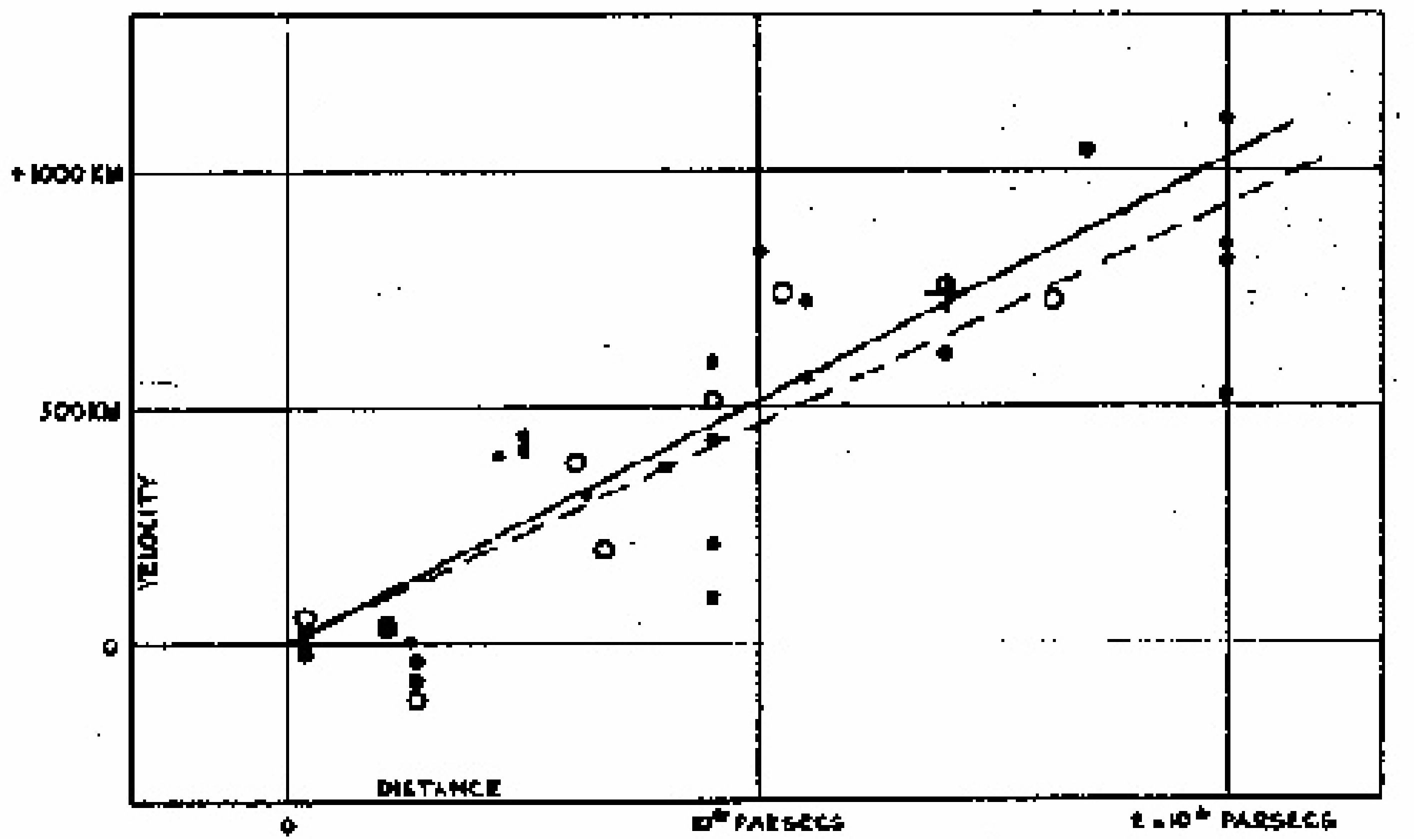
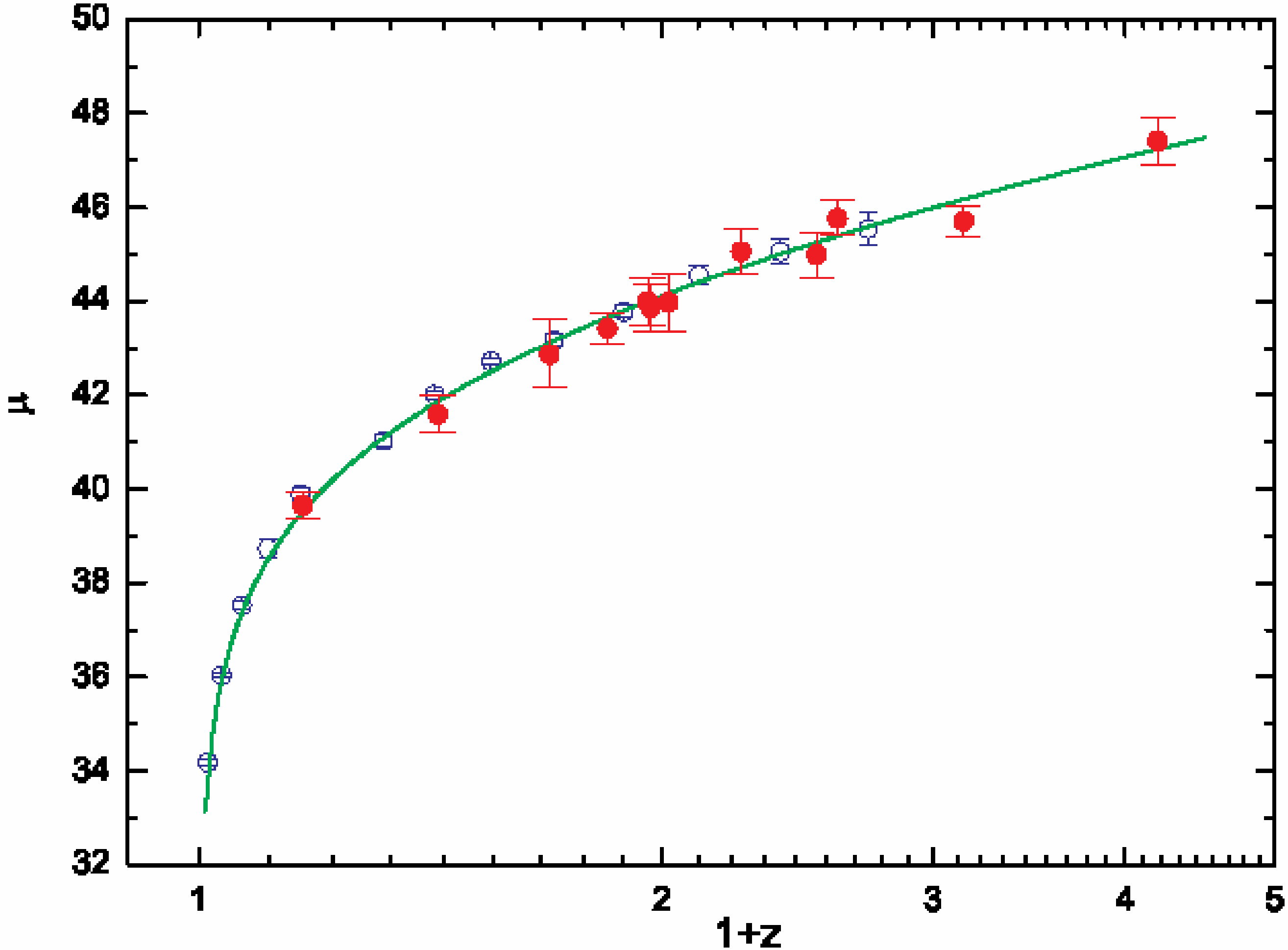


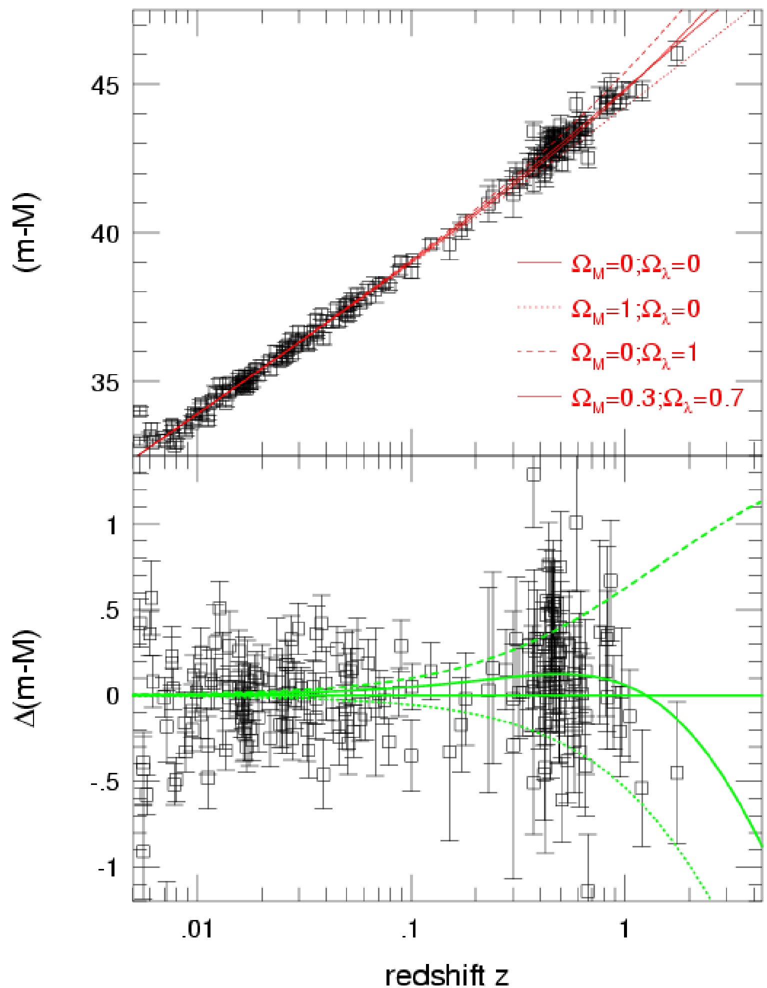
FIGURE 1

GRB for Cosmology



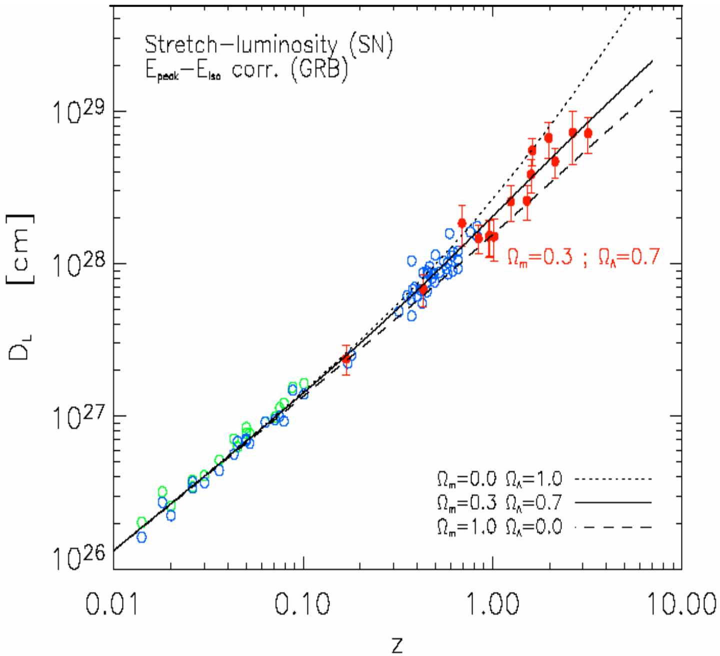
Dai, Liang & Xu (2004)

The SNIa “cosmology”

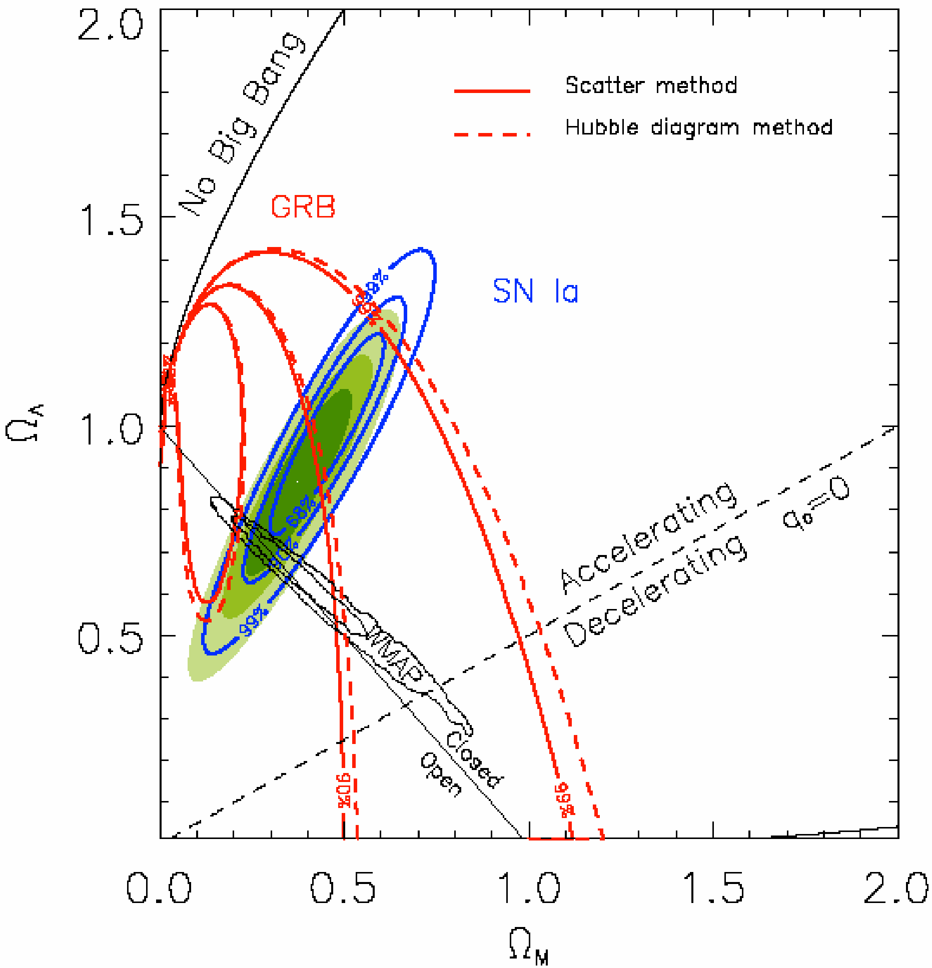


Tonry et al. 2003

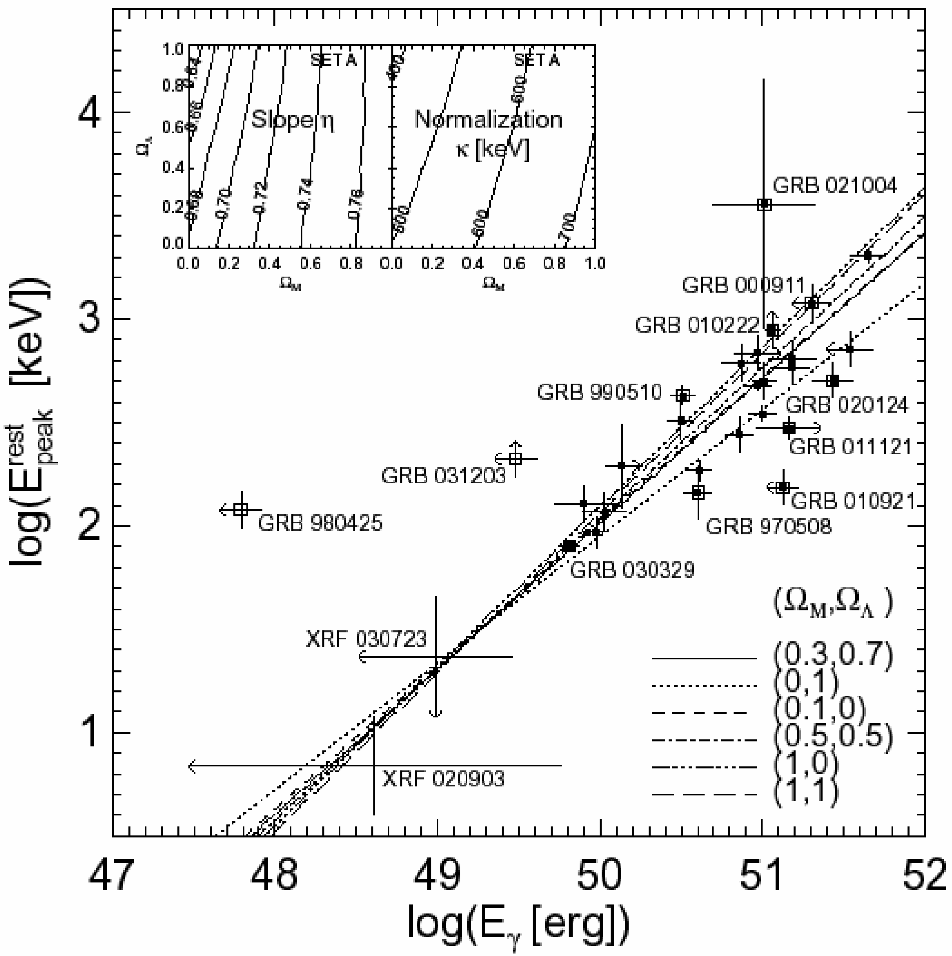
GRB for Cosmology



Ghirlanda et al. (2004)

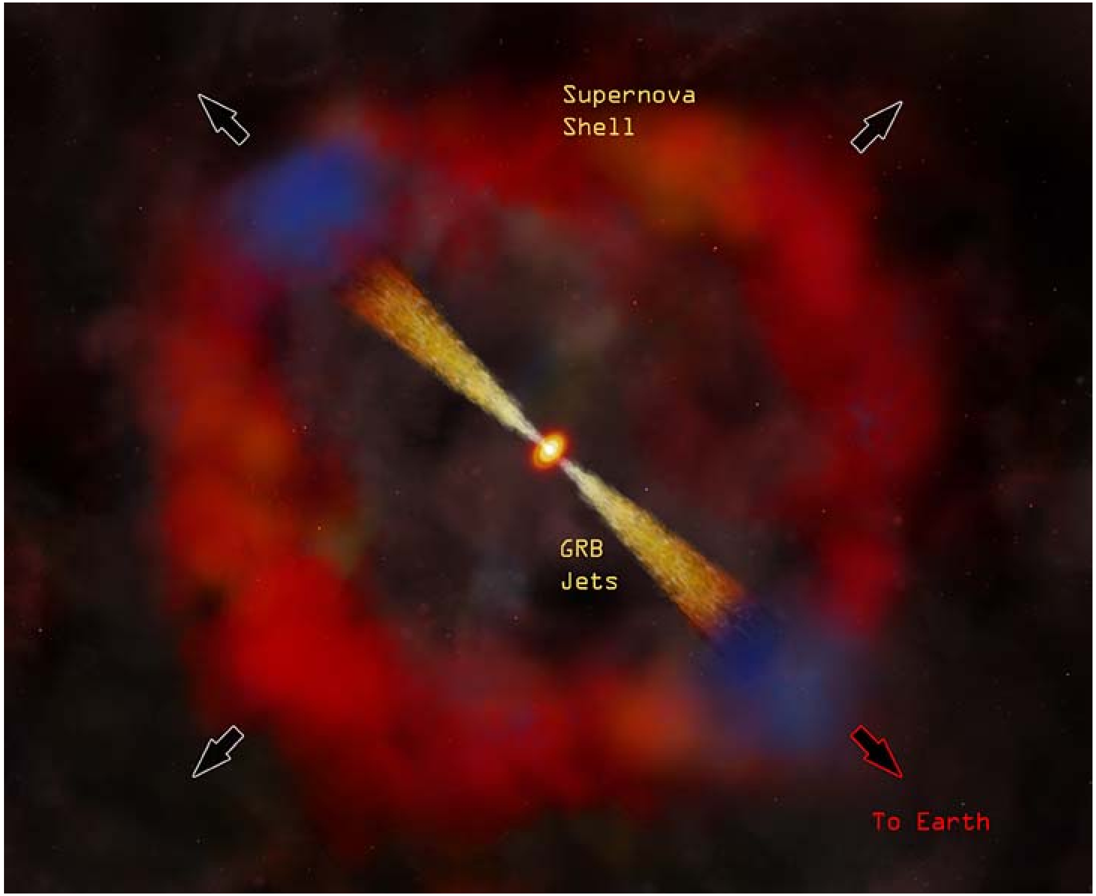


GRB for Cosmology



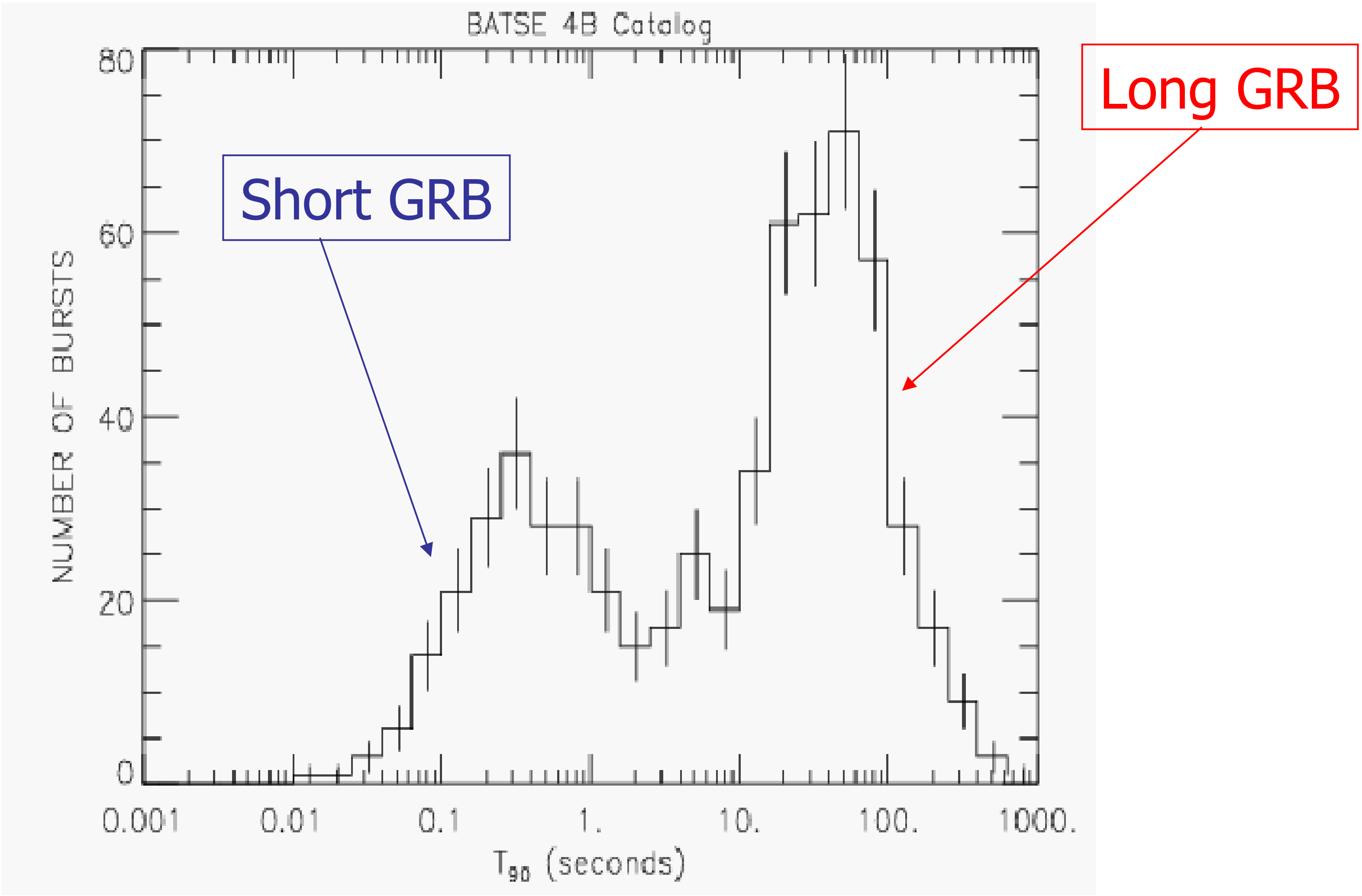
Friedman and Bloom (2004)

GRB progenitors



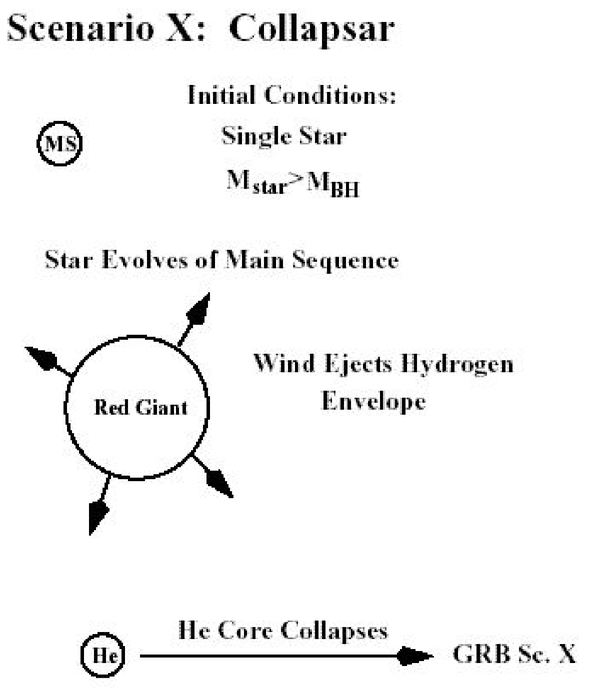
GRB 020813 (credits to CXO/NASA)

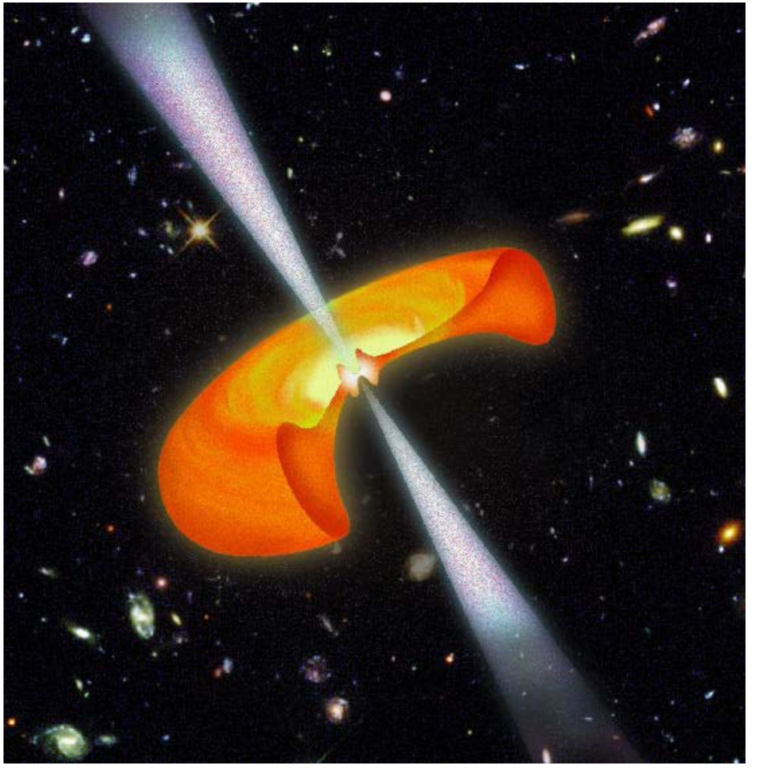
Progenitors



Collapsar model

Woosley (1993)

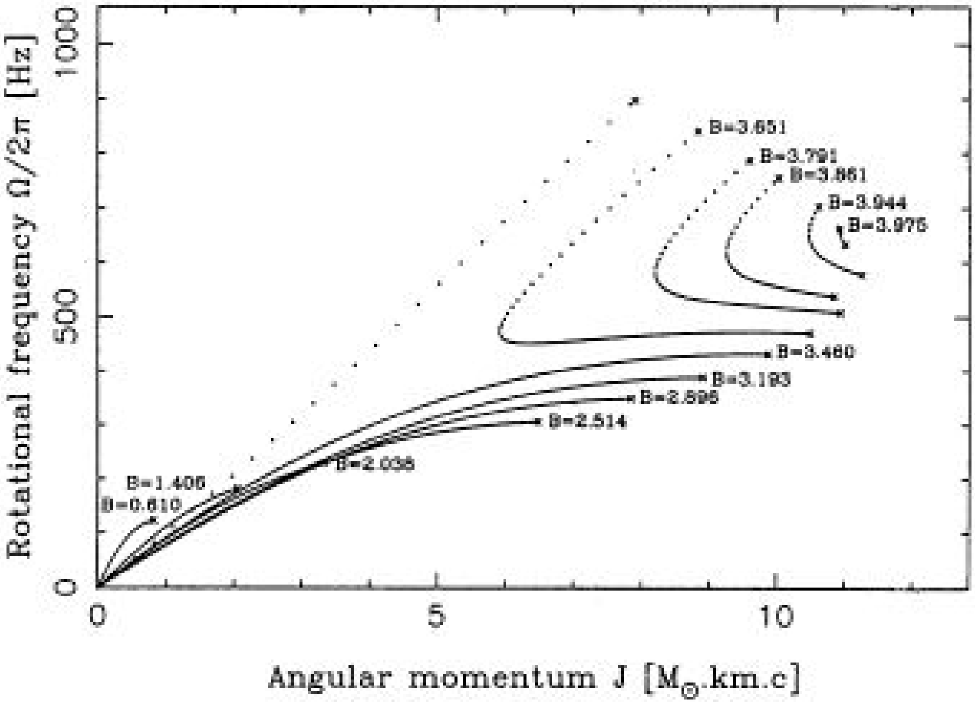


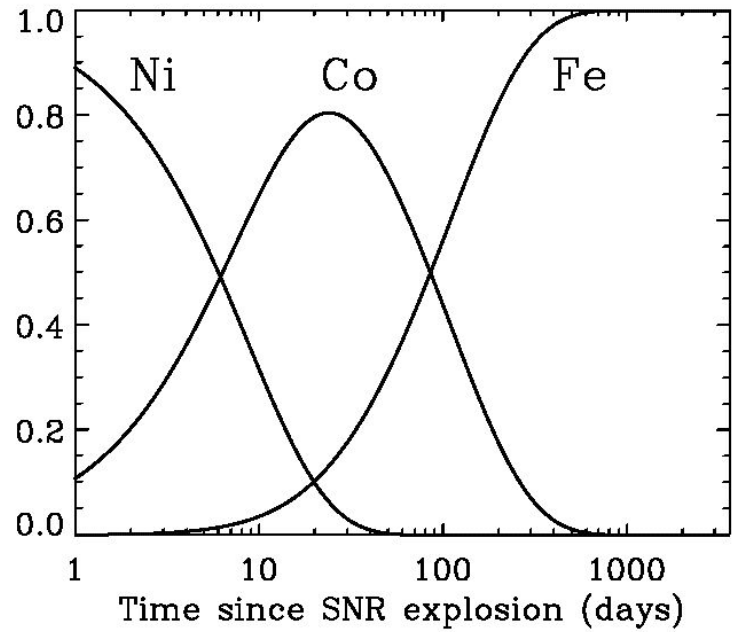


- Very massive star that collapses in a rapidly spinning BH.
- Identification with SN explosion.

Supranova

Salgado et. al. (1994)

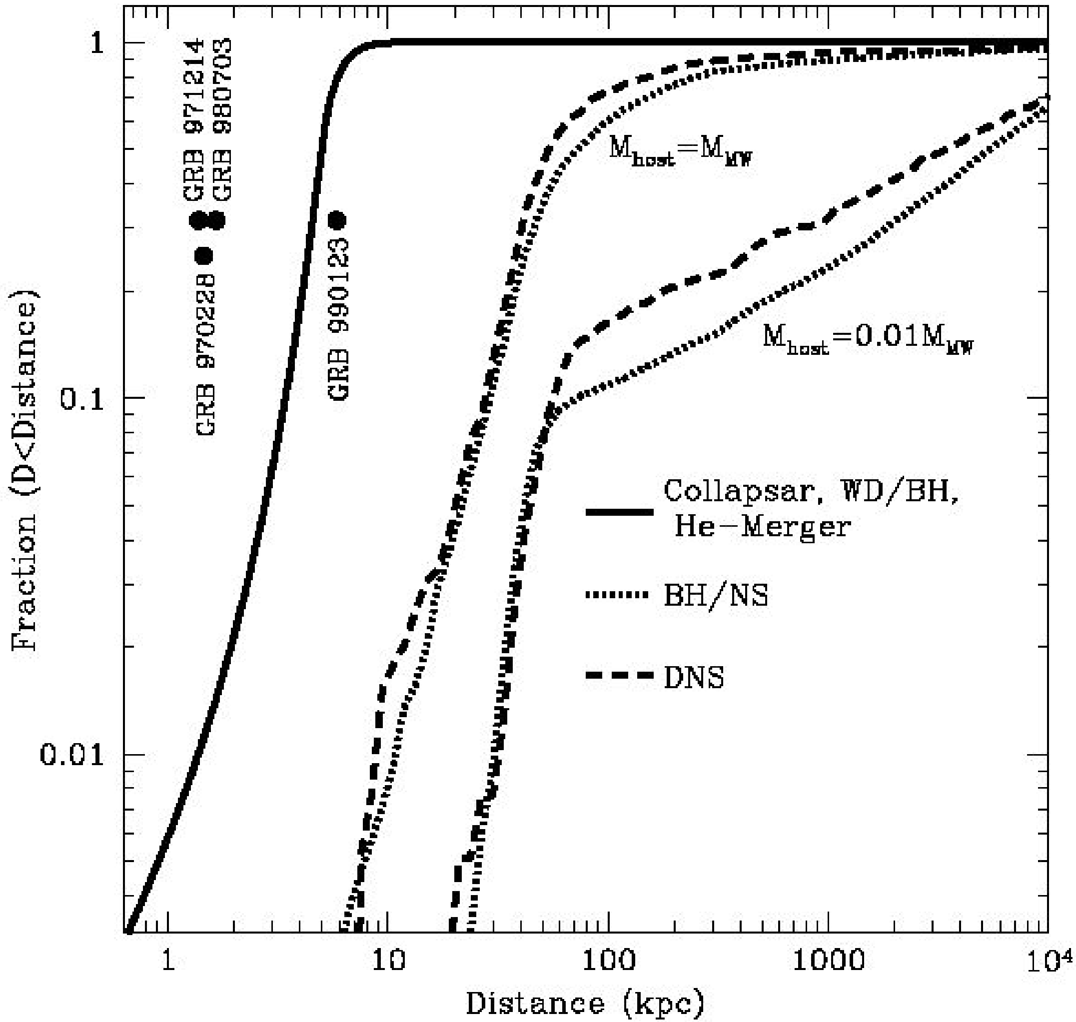




SupraMassive NS
Baryon Clean Environment

Vietri & Stella (1998)

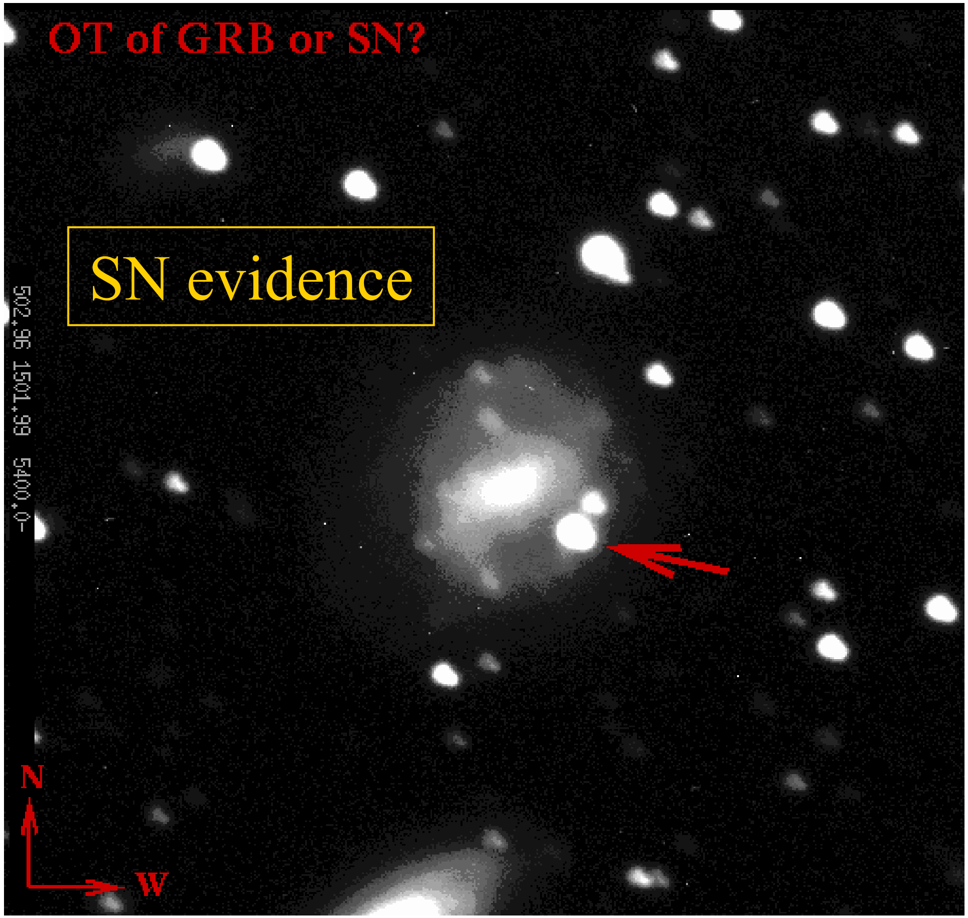
GRB progenitors



Fryer et al. (1999)

Distance from Host Galaxy

SN- GRB connection

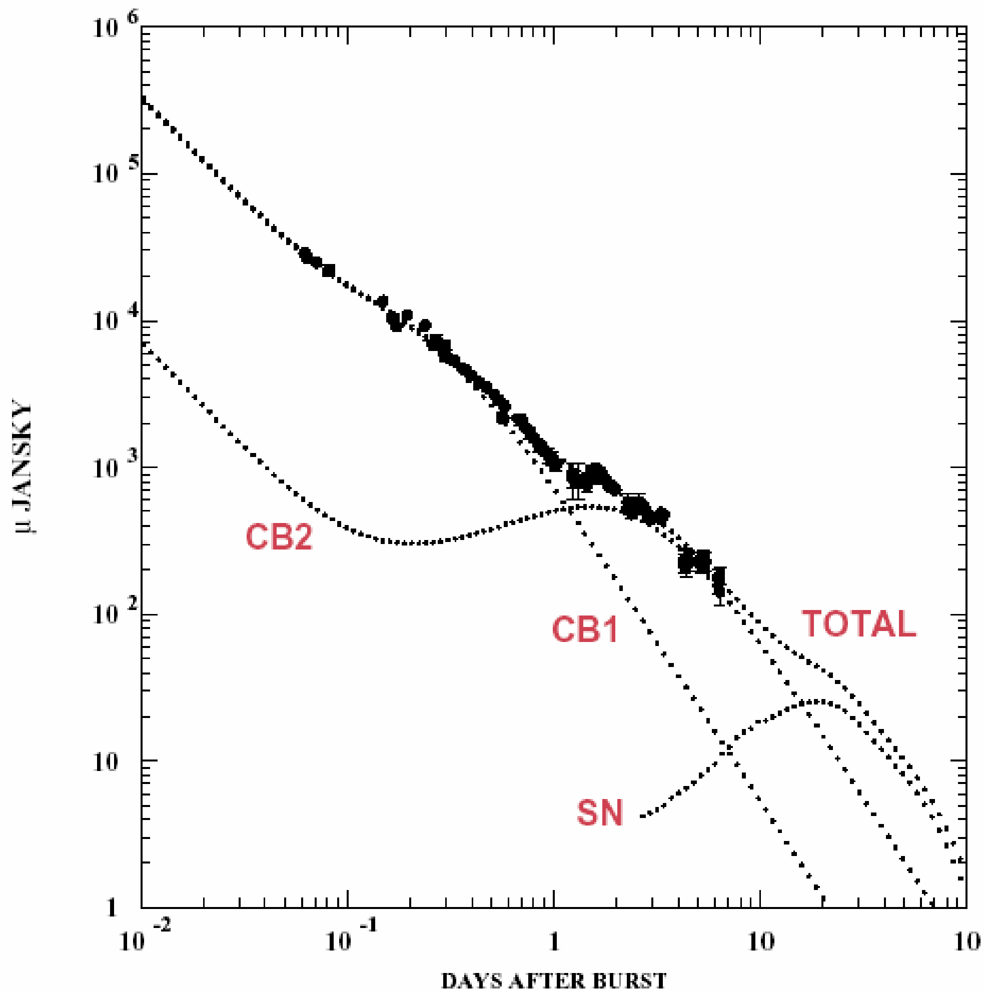


SN 1998bw - GRB 980425

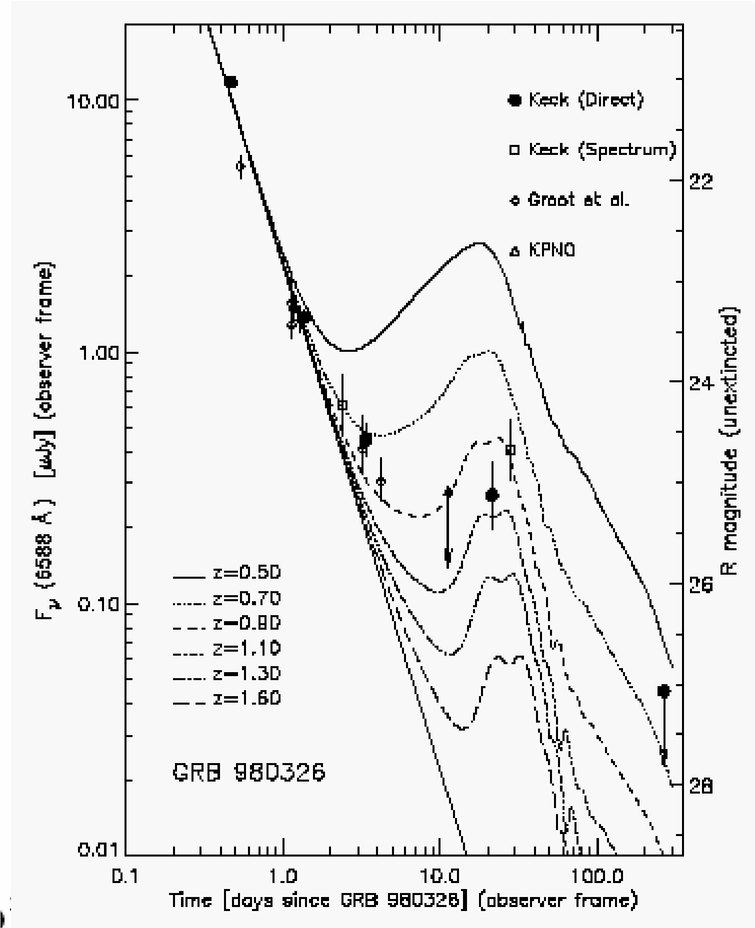
chance coincidence $O(10^{-4})$

(Galama et al. 98)

GRB & SN



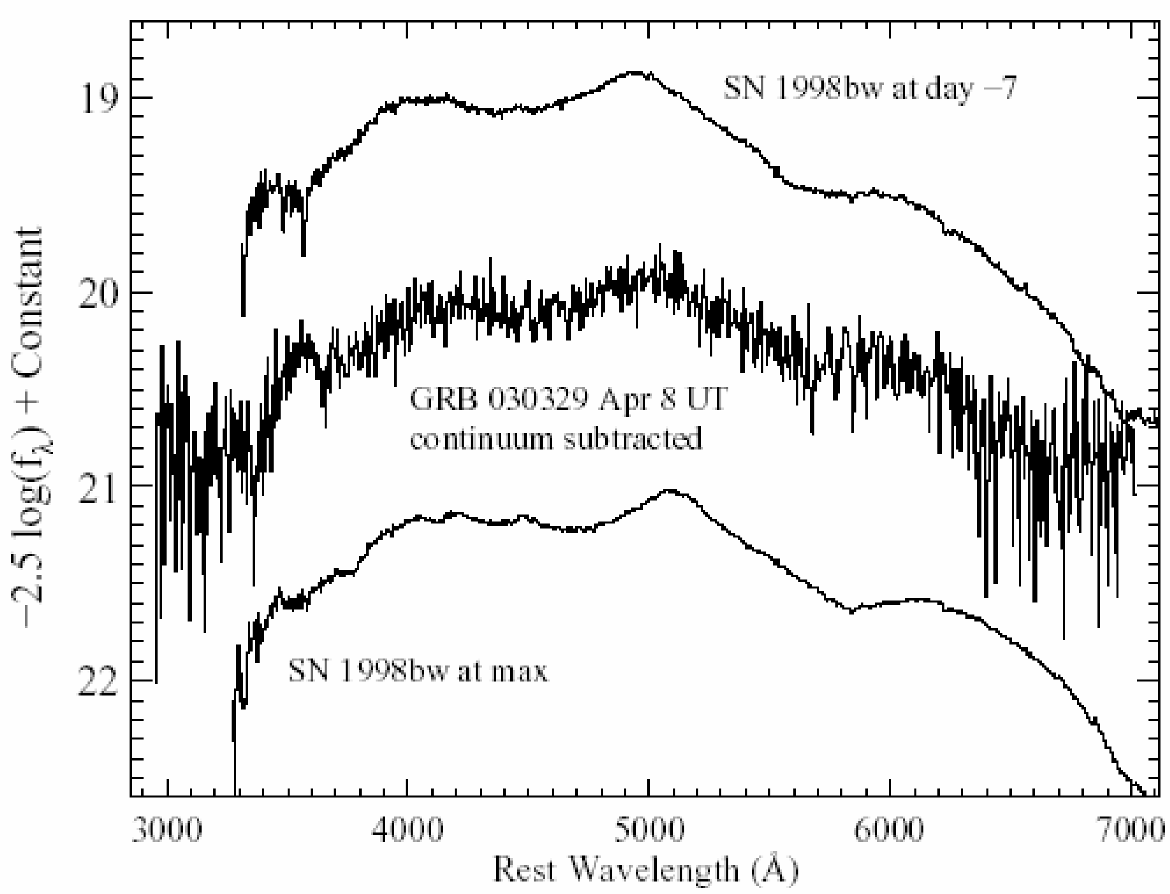
Dado, Dar & De Rujula (2003)



GRB 980326

(Bloom et al. 99)

GRB 030329: the "smoking gun"?

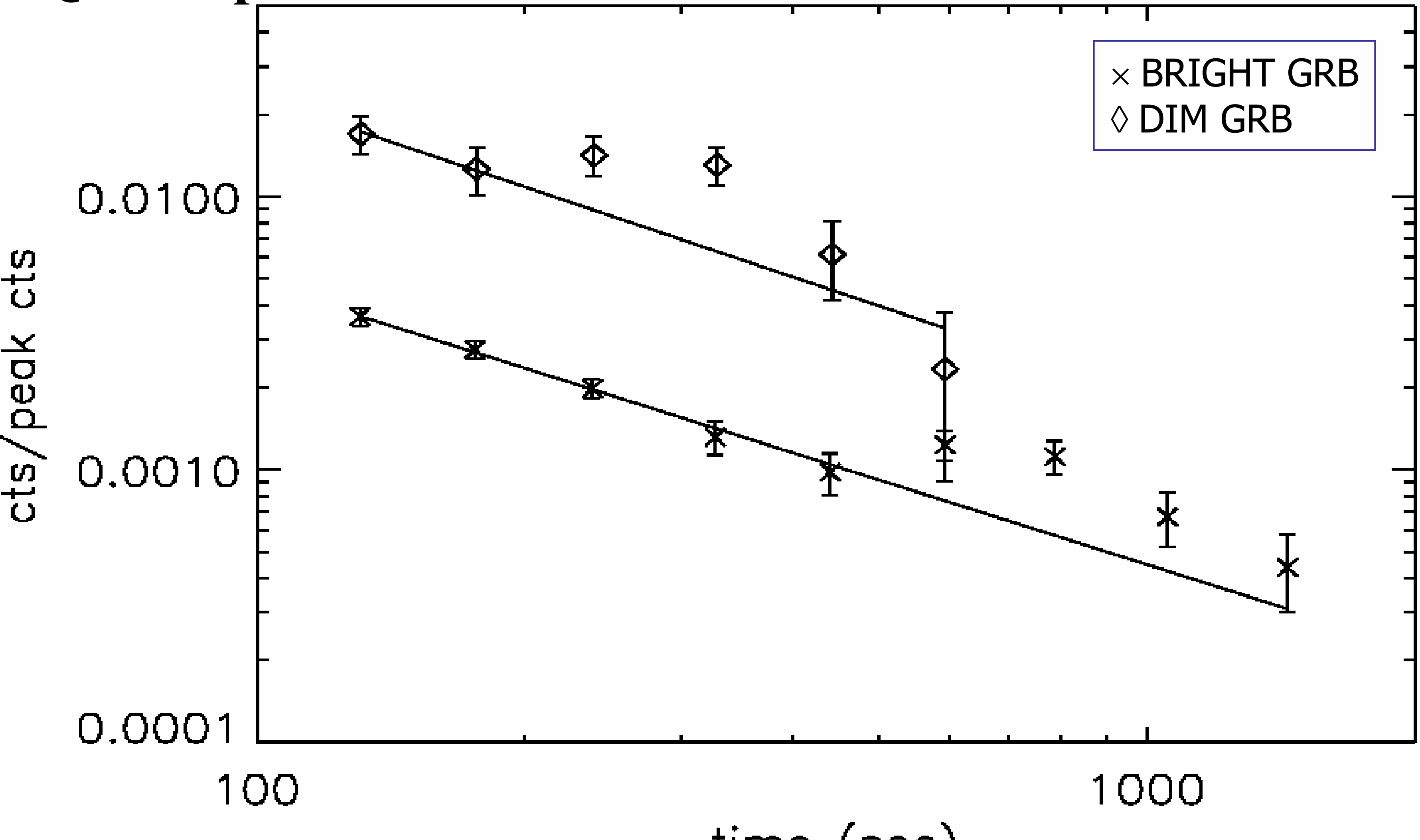


(Matheson et al. 2003)

Bright and Dim GRB

(Connaughton 2002)

Q = cts/peak cts



GRB tails

Connaughton (2002), ApJ 567, 1028

Search for Post Burst emission in prompt GRB energy band

Looking for high energy afterglow (overlapping with prompt emission) for constraining Internal/External Shock Model

Sum of Background Subtracted Burst Light Curves

Tails out to hundreds of seconds decaying as temporal power law $\delta = 0.6 \pm 0.1$

Common feature for long GRB

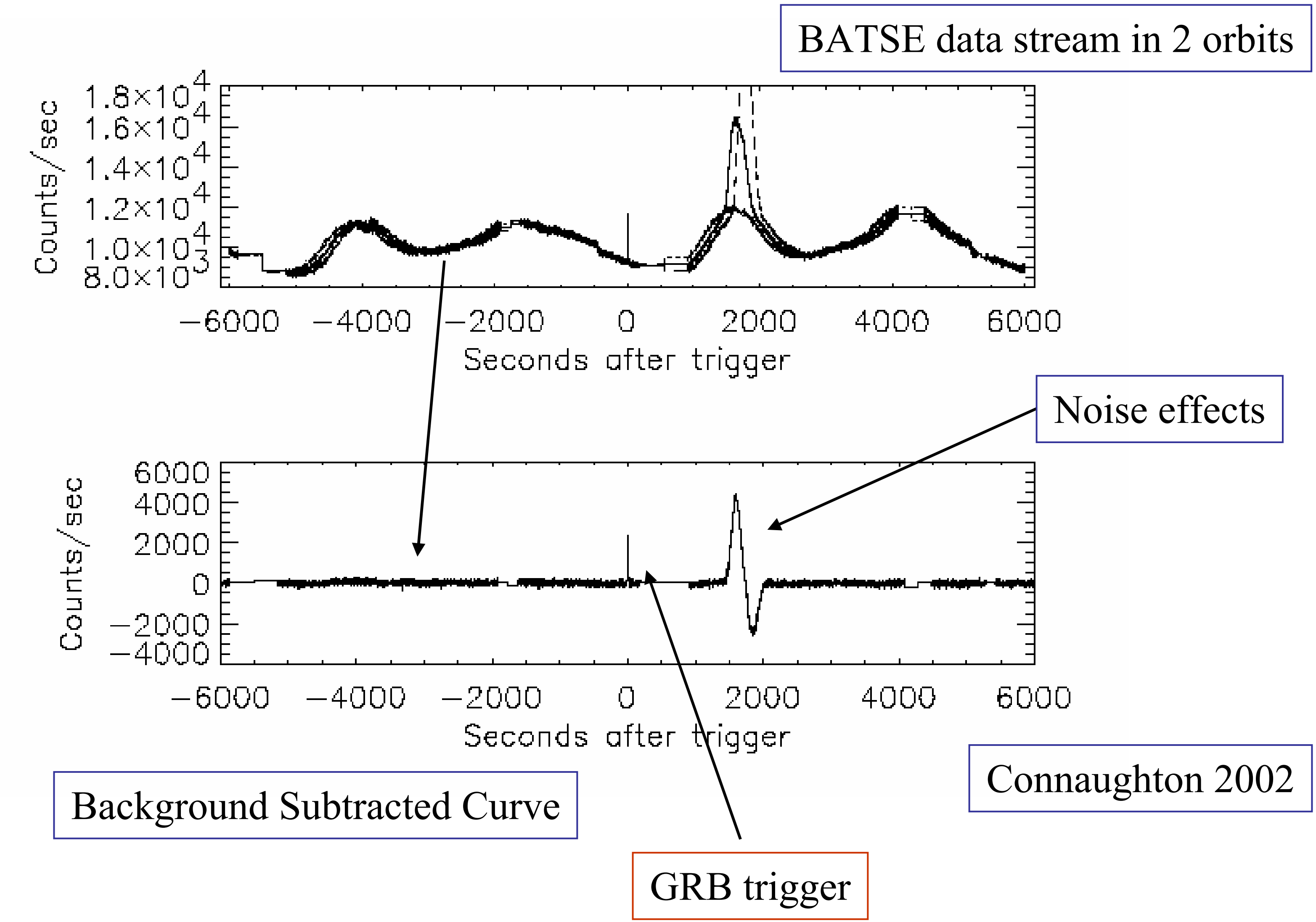
Not related to presence of low energy afterglow

GRB tails

- Method
  - BATSE LAD data
  - Procedure of subtracting background (sensitivity 10^{-9} erg cm^{-2} s^{-1})
  - Long and "intermediate" GRB
  - Division on GRB peak flux
  - Spectral Hardness
- Sample:
  - 2365 GRB (April 1991 – March 1999)
  - 526 spacecraft reorientation
  - 595 another GRB in "equal" orbits
  - 426 affected by telemetry gaps
  - 296 background fit
  - 400 long GRB, 120 short GRB

Connaughton 2002

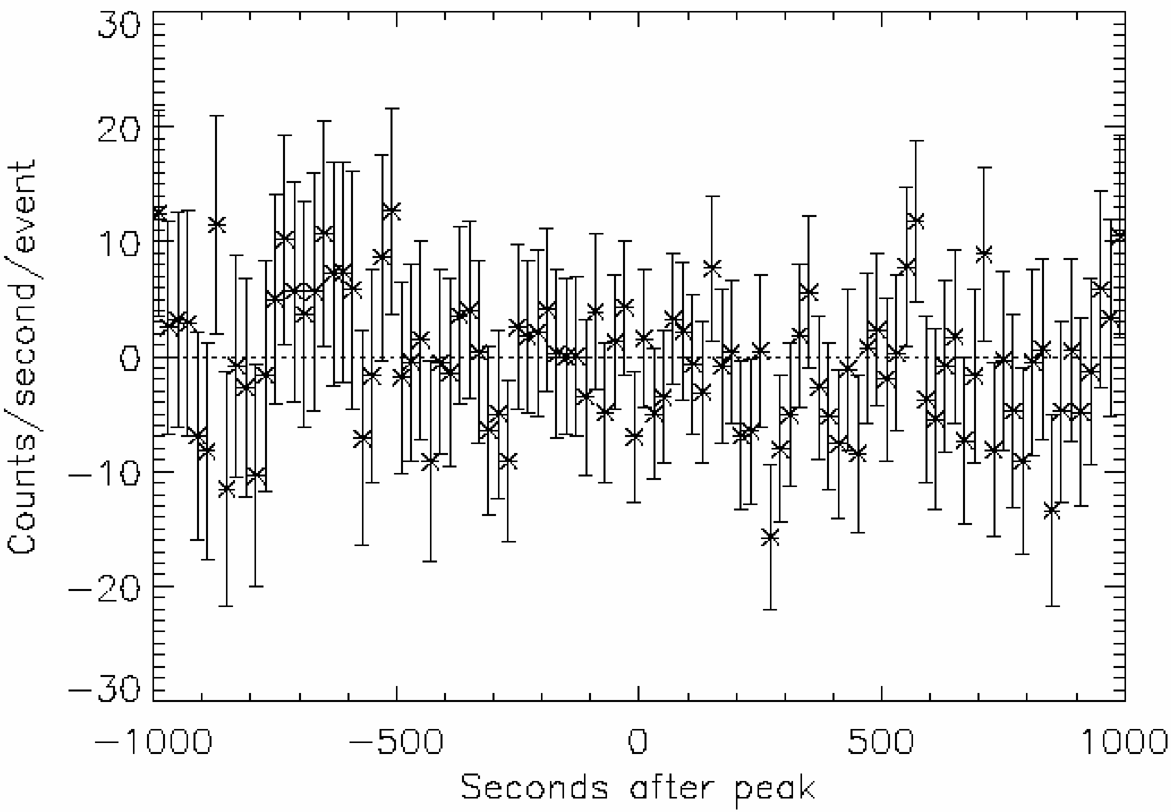
GRB tails



BATSE data stream in 2 orbits
Counts/sec
1.8×10^4
1.6×10^4
1.4×10^4
1.2×10^4
1.0×10^4
8.0×10^3
−6000 −4000 −2000 0 2000 4000 6000
Seconds after trigger
Noise effects
Counts/sec
6000
4000
2000
0
−2000
−4000
−6000 −4000 −2000 0 2000 4000 6000
Seconds after trigger
Connaughton 2002
Background Subtracted Curve
GRB trigger

GRB tails

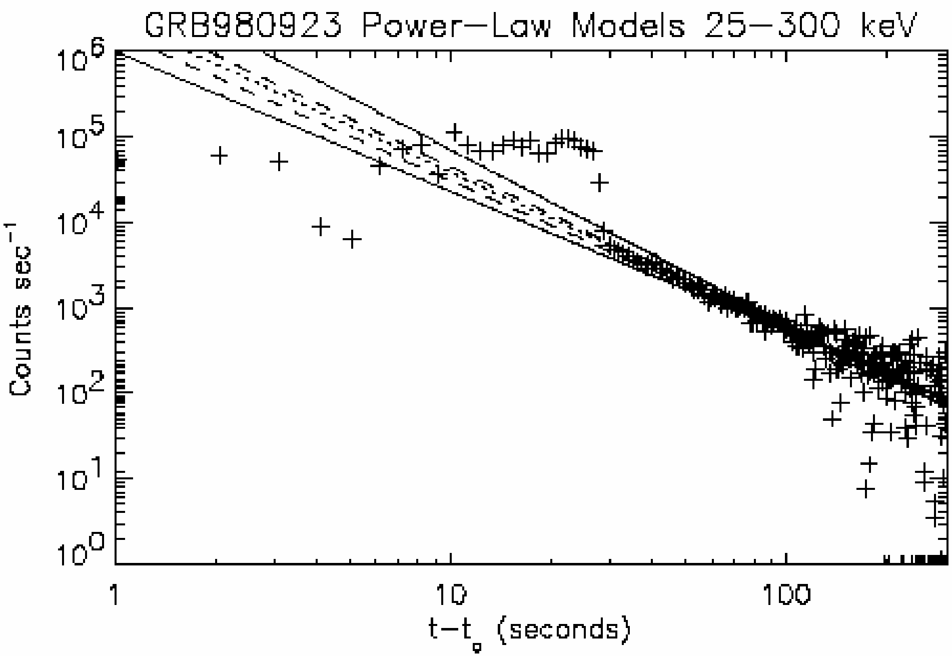
Background subtracted BKG curve



Average = -0.5 ± 0.7 counts s^{-1} $event^{-1}$

Connaughton 2002

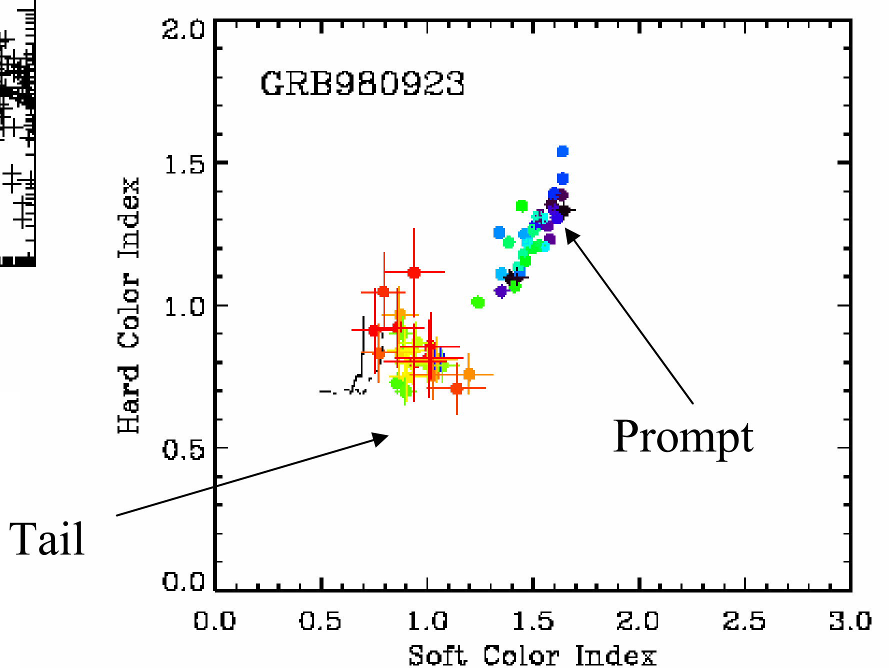
GRB tails



Giblin et al 1999

Giblin et al 2002

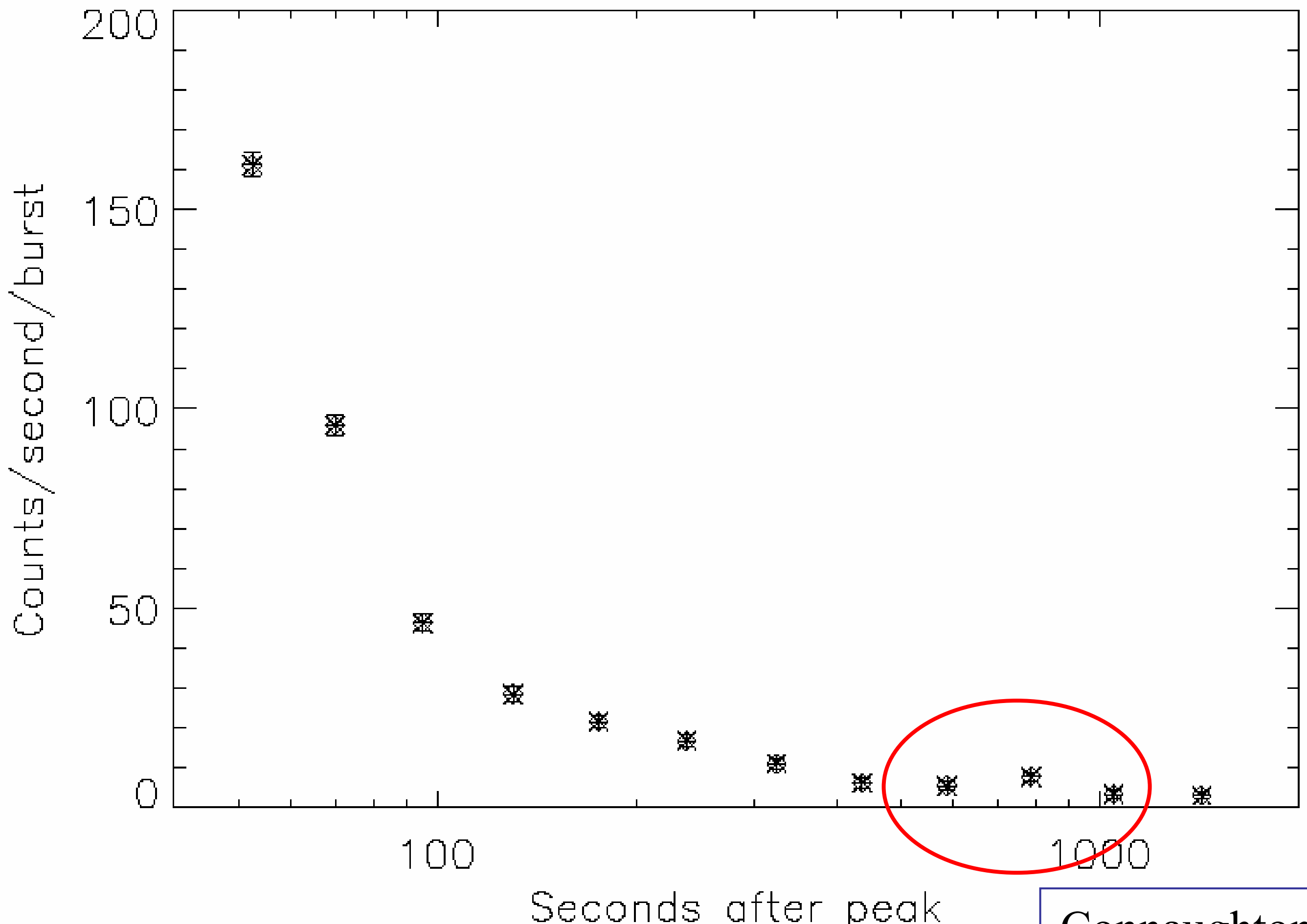
(100-300 keV)/(50-100 keV)



(50-100 keV)/(25-50 keV)

GRB tails

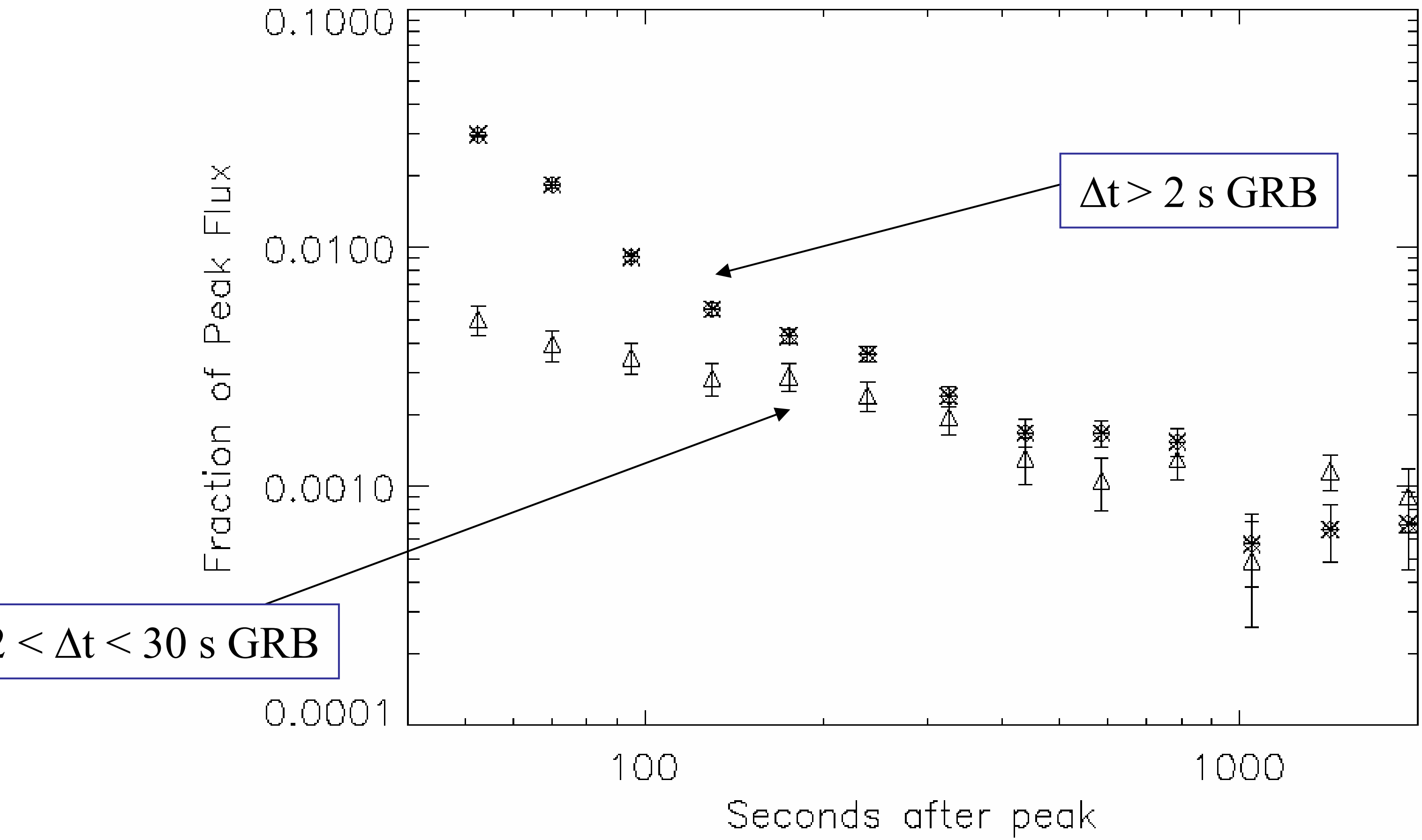
Sum of 400 long GRB bkg subtracted peak alligned curve



Connaughton 2002

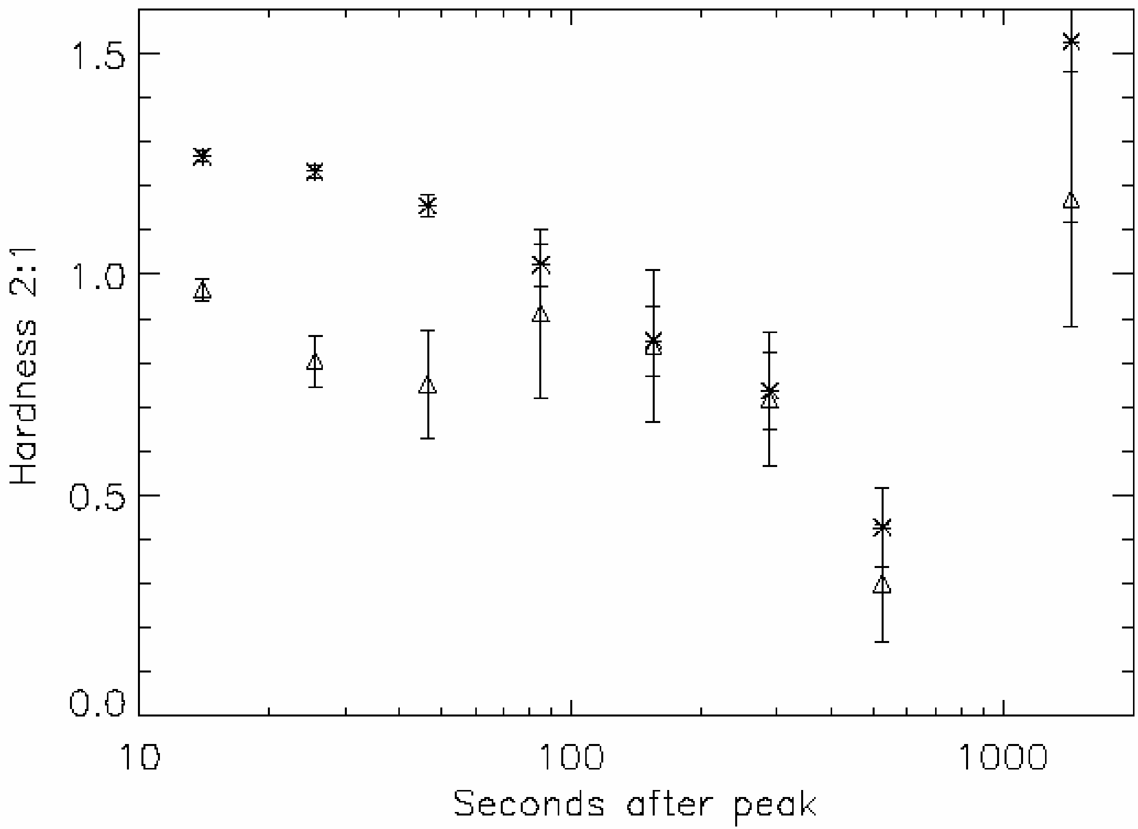
GRB Tails

Sum of 400 long GRB bkg subtracted peak alligned curve



Connaughton 2002

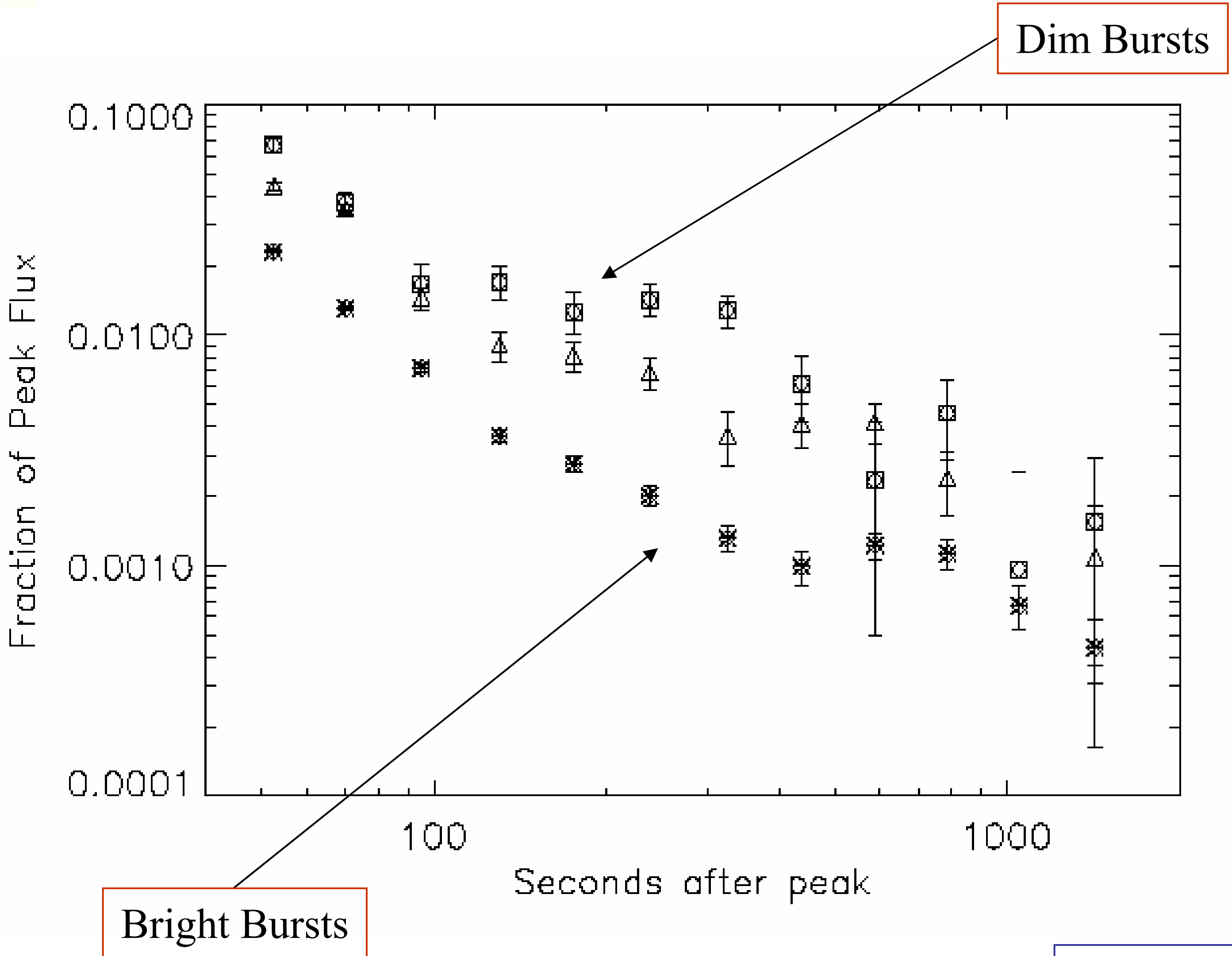
GRB tails



(50-100 keV)/(20-50 keV)

Connaughton 2002

GRB tails



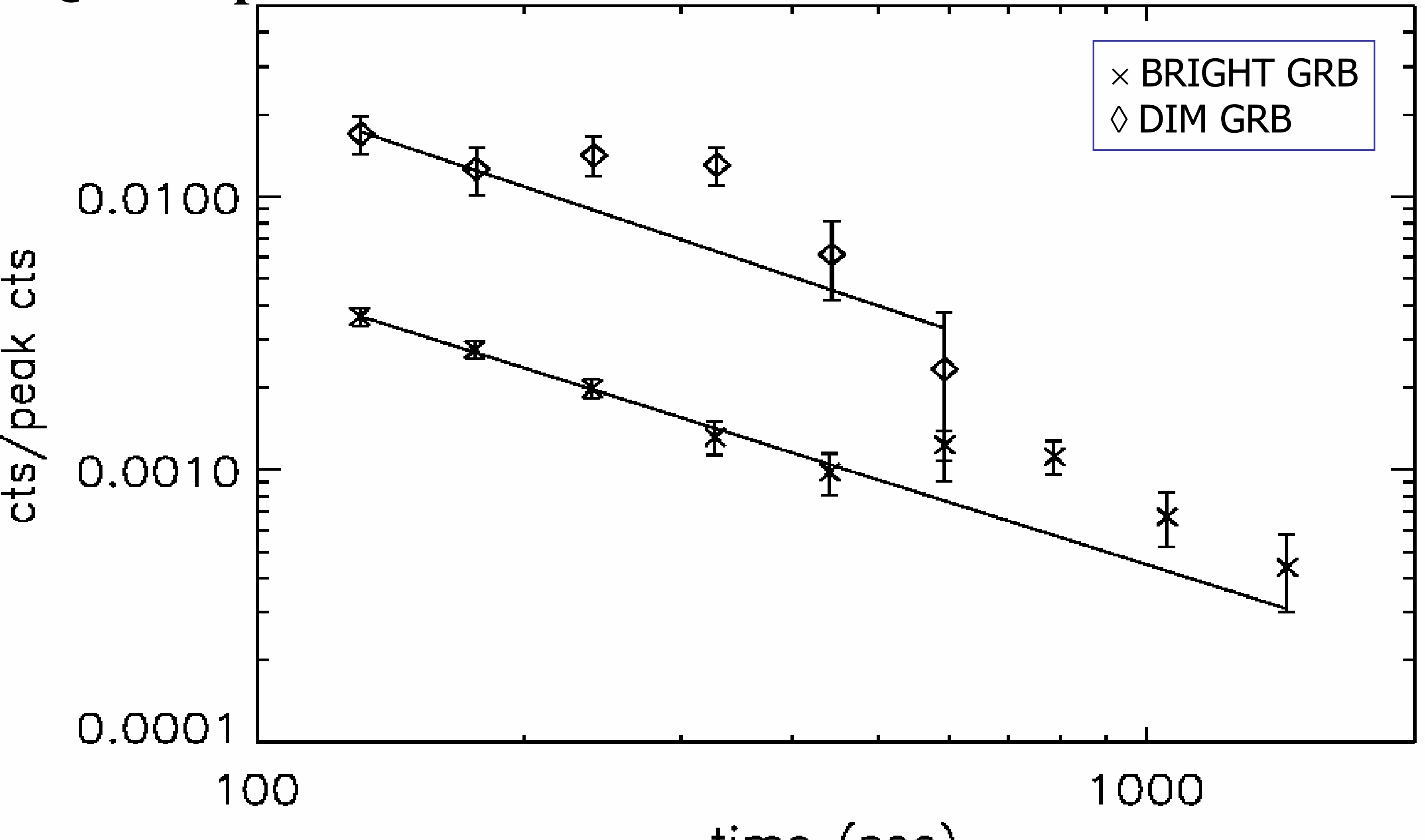
Connaughton 2002

Bright and Dim Bursts

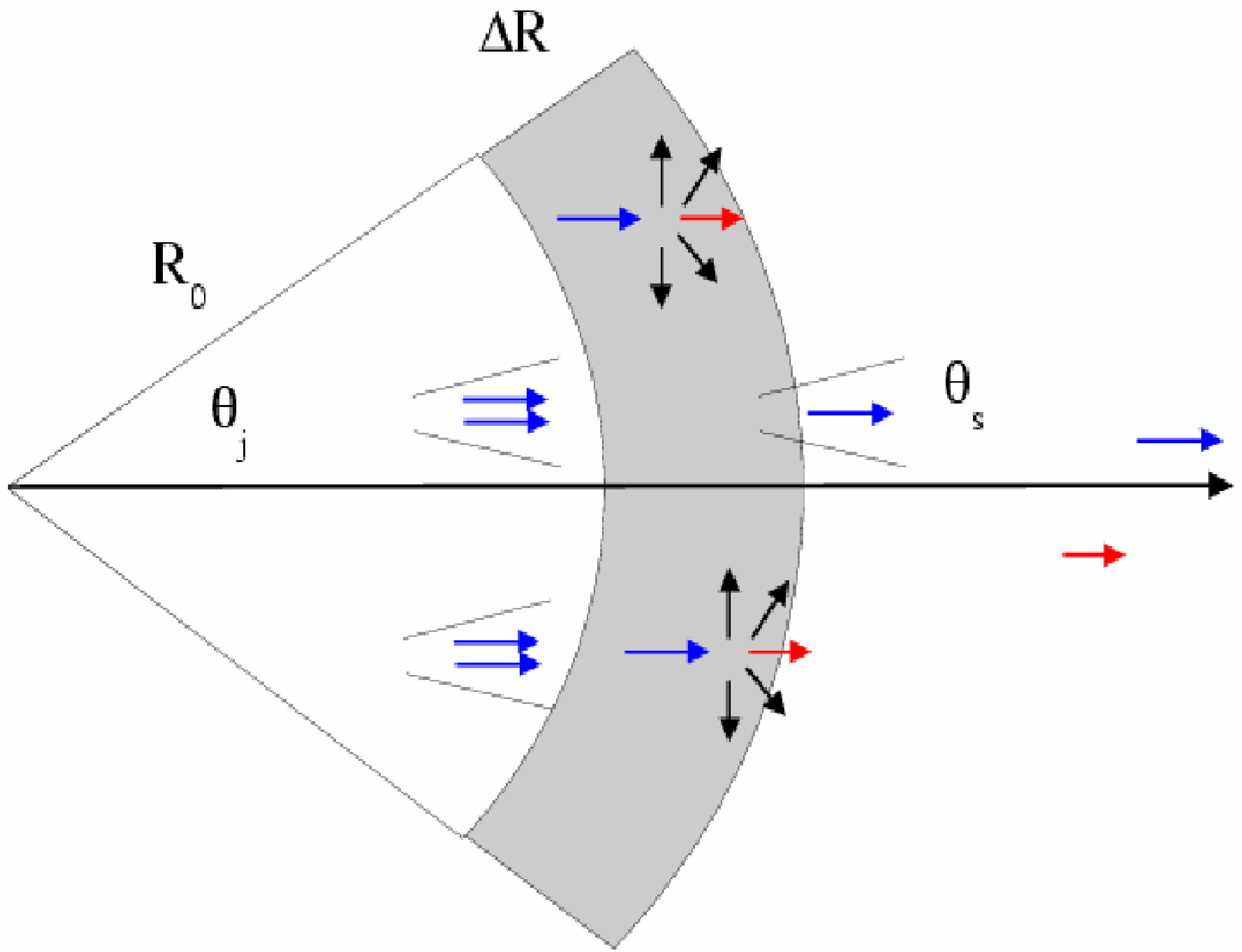
- 3 equally populated classes
- Bright bursts
  - Peak counts >1.5 $cm^{-2}\ s^{-1}$
  - Mean Fluence 1.5×10^{-5} erg cm^{-2}
- Dim bursts
  - peak counts < 0.75 $cm^{-2}\ s^{-1}$
  - Mean fluence 1.3×10^{-6} erg cm^{-2}
- Mean fluence ratio = 11

Bright and Dim GRB

Q = cts/peak cts



The Compton Tail



Barbiellini et al. (2004) MNRAS 350, L5

The Compton tail

- "Prompt" luminosity

$$\langle L_{\rm s} \rangle = \langle \frac{dn_{\rm s}}{d\Omega\ dt} \rangle \simeq \frac{n_{\rm p}\ e^{-\tau}}{\pi\theta_{\rm s}^2\ t_{\rm grb}} \cdot \frac{\theta_{\rm s}^2}{\theta_{\rm j}^2}$$

- Compton "Reprocessed" luminosity

$$\langle L_{\rm c} \rangle = \frac{n_{\rm p}\ (1 - e^{-\tau})}{2\pi\ t_{\rm geom}} \qquad t_{\rm geom} \sim \frac{(R_0 + \Delta R)\theta_{\rm j}^2}{c}$$

- "Q" ratio

$$Q = \frac{\langle L_{\rm c} \rangle}{\langle L_{\rm s} \rangle} = (e^{\tau} - 1) \cdot \frac{c\ t_{\rm grb}}{(R_0 + \Delta R)}$$

Bright and Dim Bursts

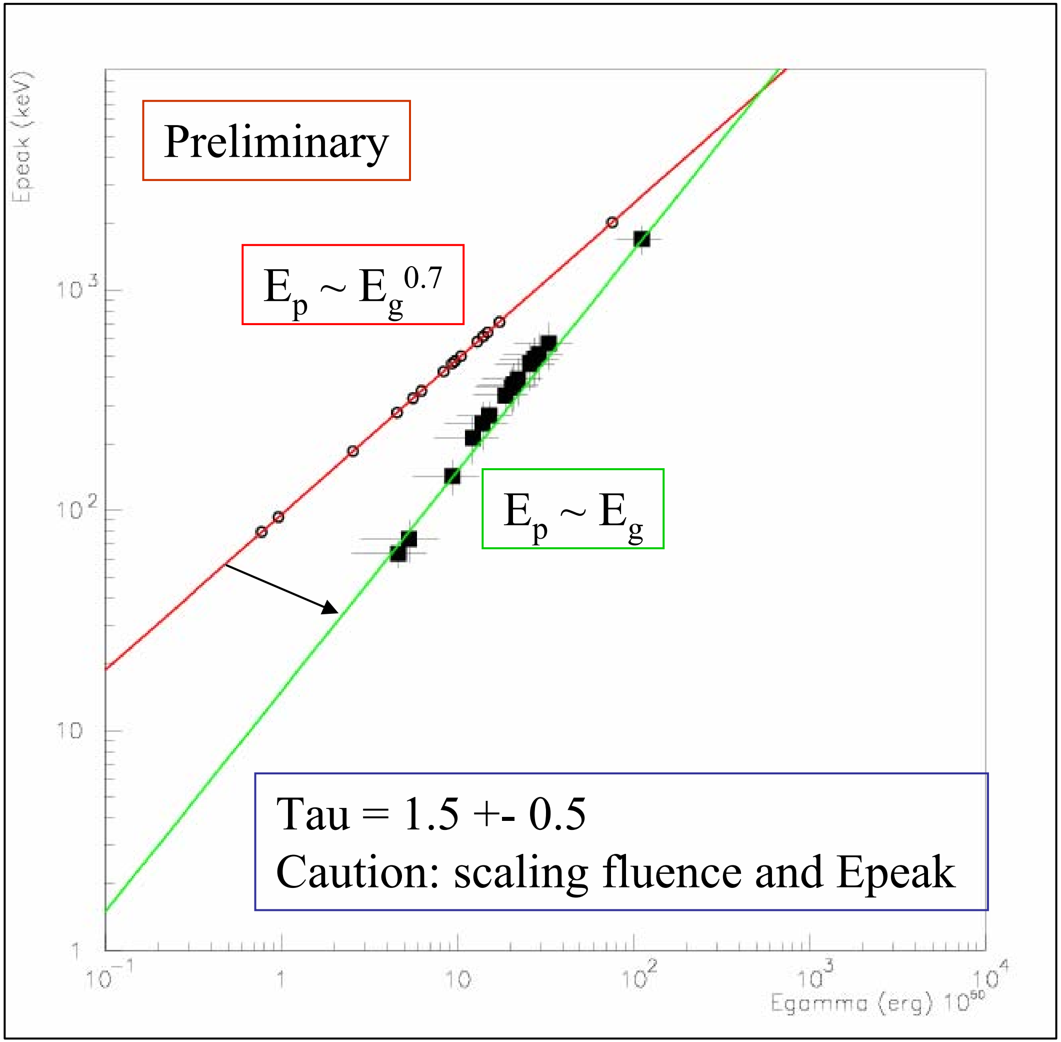
- Bright bursts (tail at 800 s)
  - Peak counts >1.5 $cm^{-2}\ s^{-1}$
  - Mean Fluence 1.5×10^{-5} erg cm^{-2}
  - $Q = 4.0 \pm 0.8\ 10^{-4}$ ($5\ \sigma$) fit over PL
  - $\tau = 1.3$
- Dim bursts (tail at 300s)
  - peak counts < 0.75 $cm^{-2}\ s^{-1}$
  - Mean fluence 1.3×10^{-6} erg cm^{-2}
  - $Q = 5.6 \pm 1.4\ 10^{-3}$ ($4\ \sigma$) fit over PL
  - $\tau = 2.8$
- Mean fluence ratio = 11
- "Compton" correction
- Corrected fluence ratio = 2.8

$R = 10^{15}$ cm
$\Delta R \sim R$
$\theta \sim 0.1$

$$E = e^{\tau} E_{\rm obs}$$

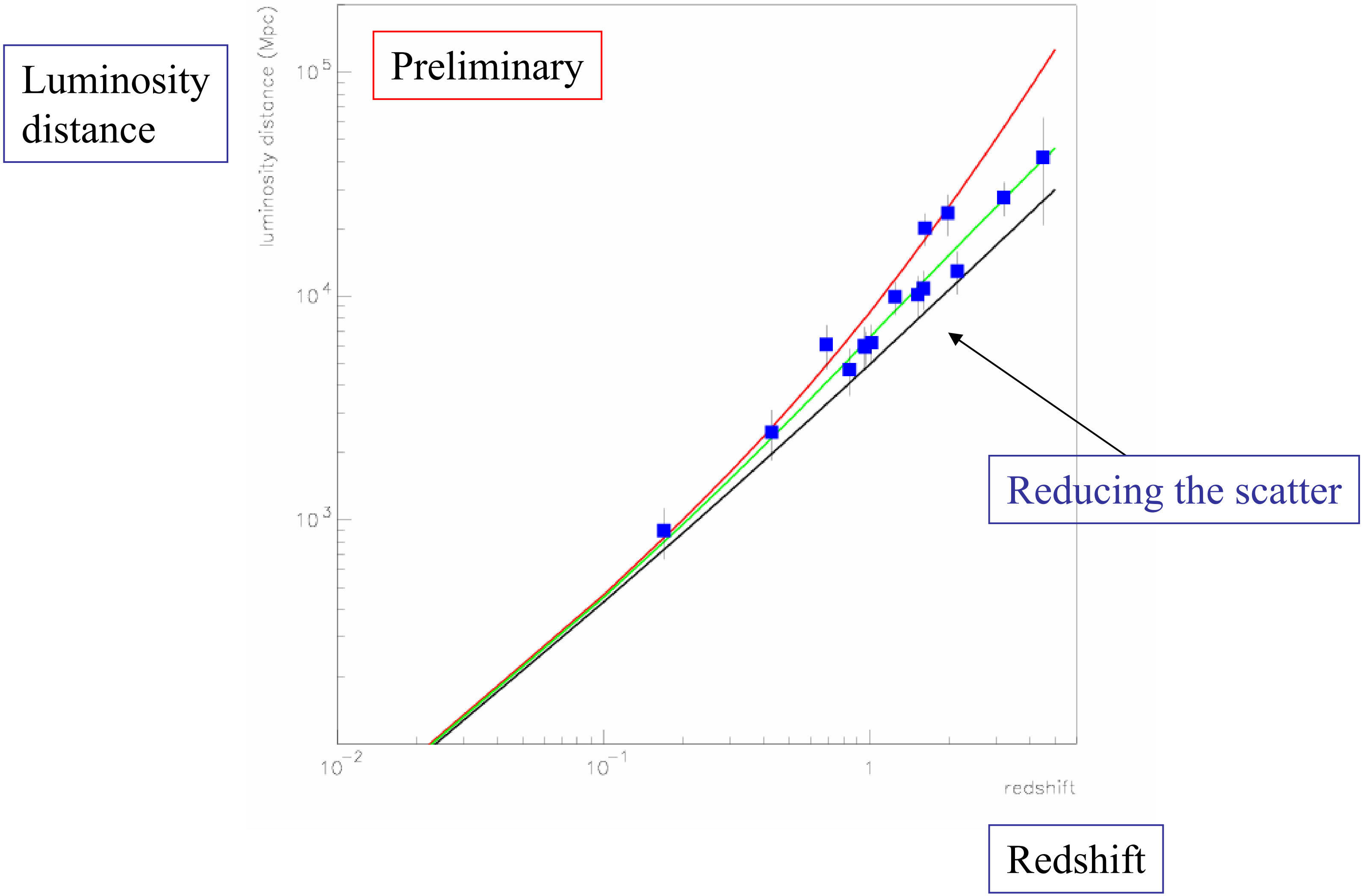
Effect of Attenuation

Epeak



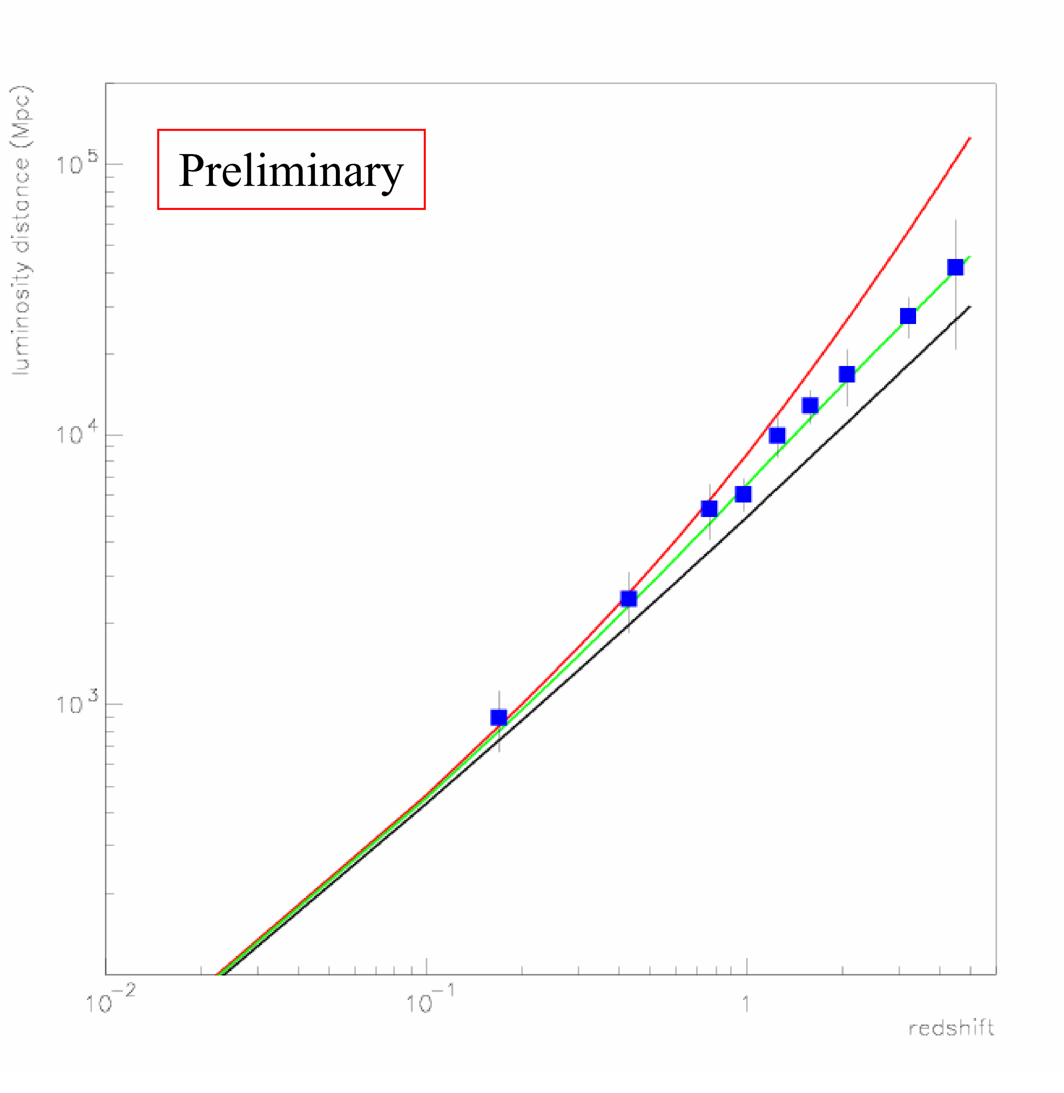
Egamma

Effects on Hubble Plots



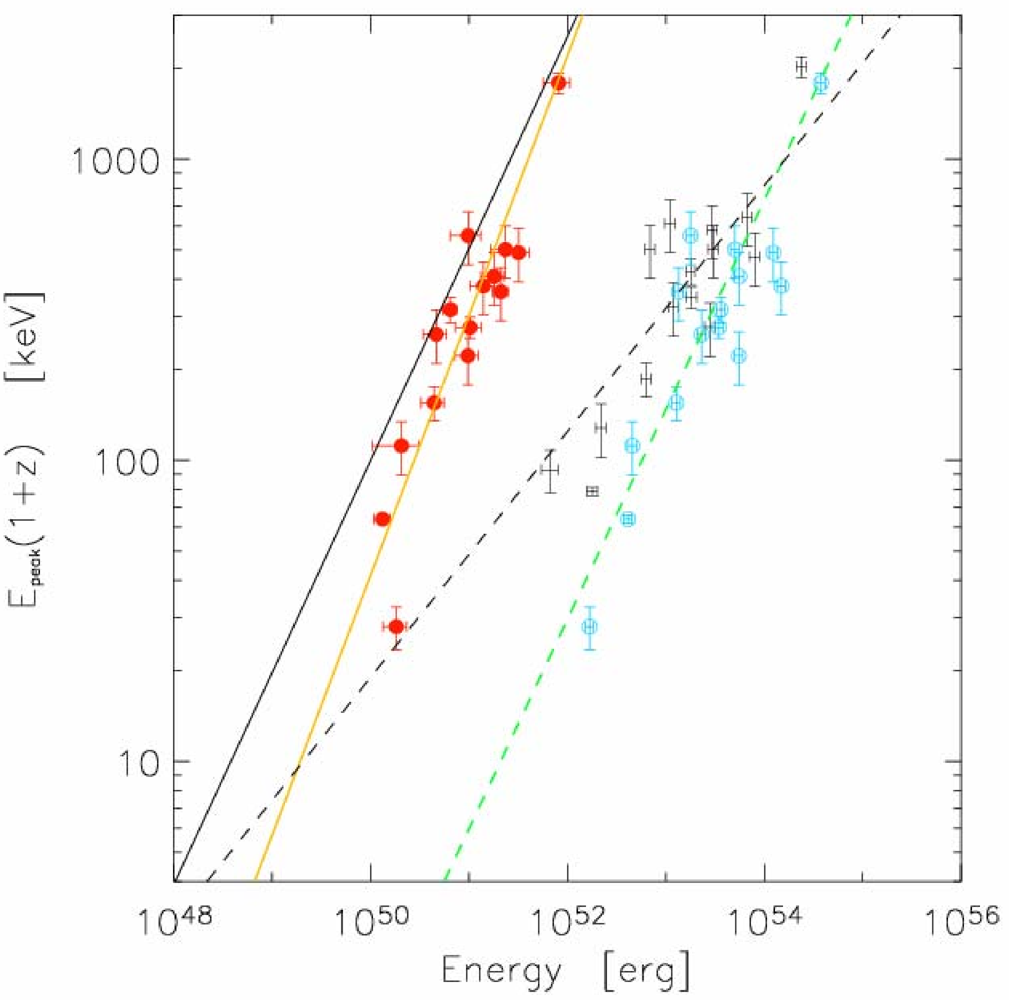
Effects on Hubble Plots

Luminosity distance



Redshift

Effect of Attenuation

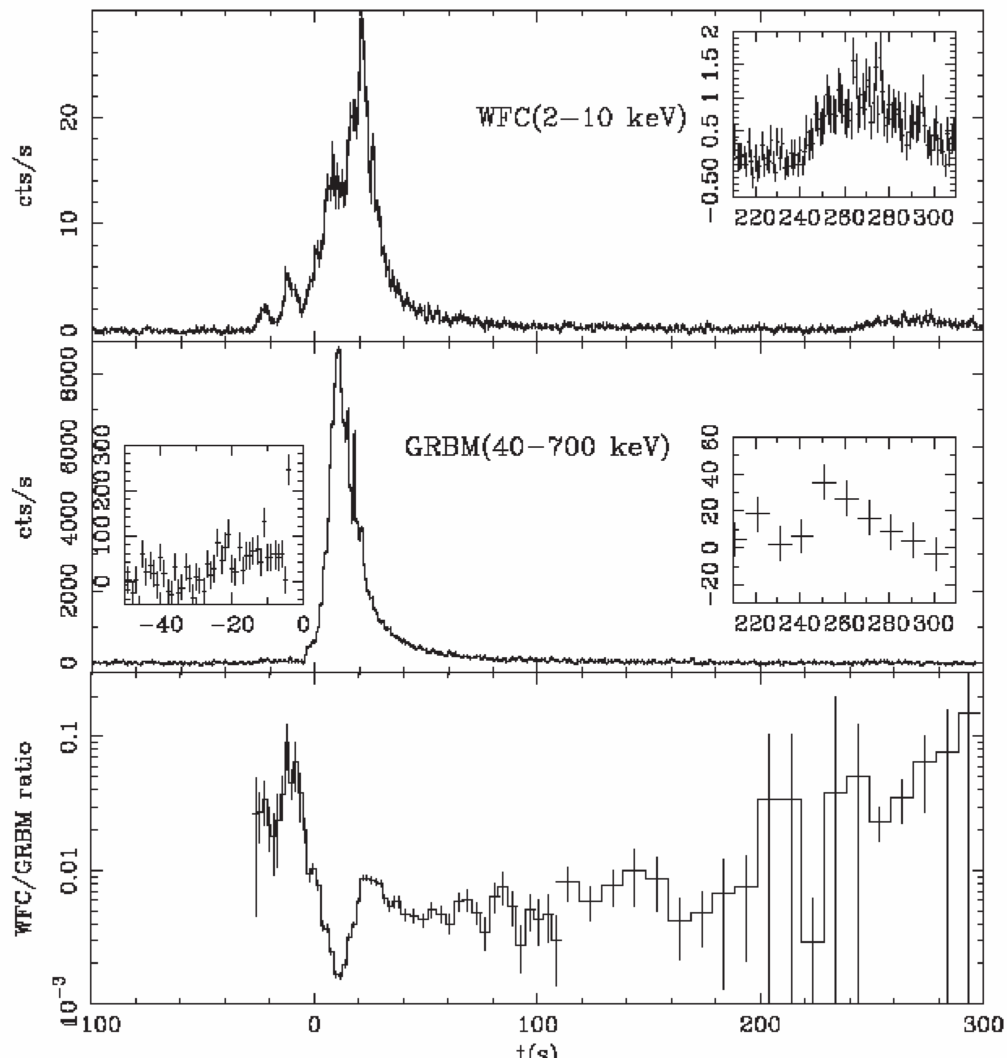


Effects of attenuation

- τ=1.0 (Thomson)
- Same τ for all bursts
- Including KN corrections
- Amati correlation:
  - Slope=0.69+0.02
  - χ^2=78/22 dof (Corr. prob. 1.6E-3)
- Ghirlanda correlation
  - Slope=0.86+0.06
  - χ^2=32.6/13 dof (Corr prob 1E-5)

Recent evidences

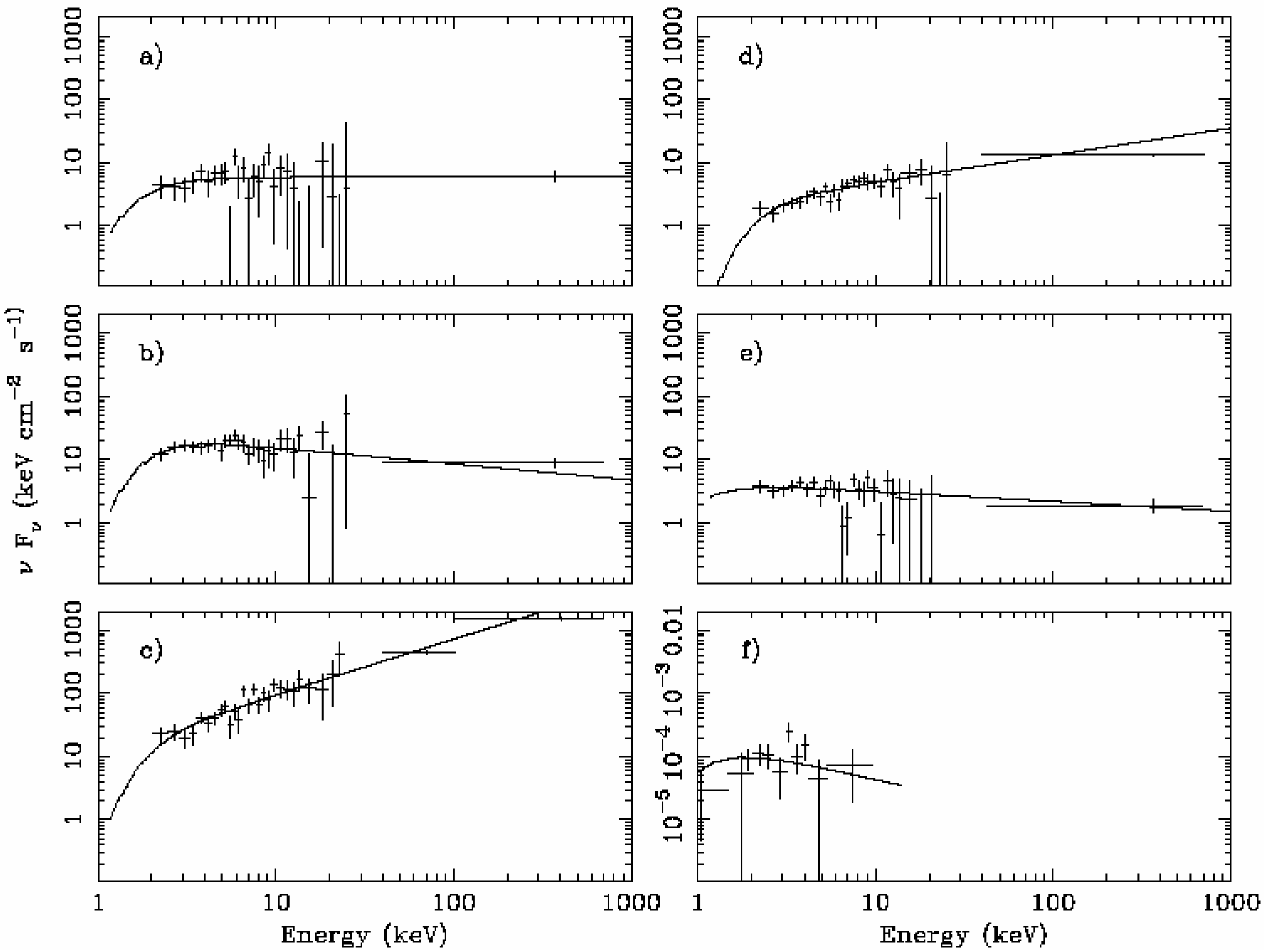
GRB 011121



Piro et al. (2005)

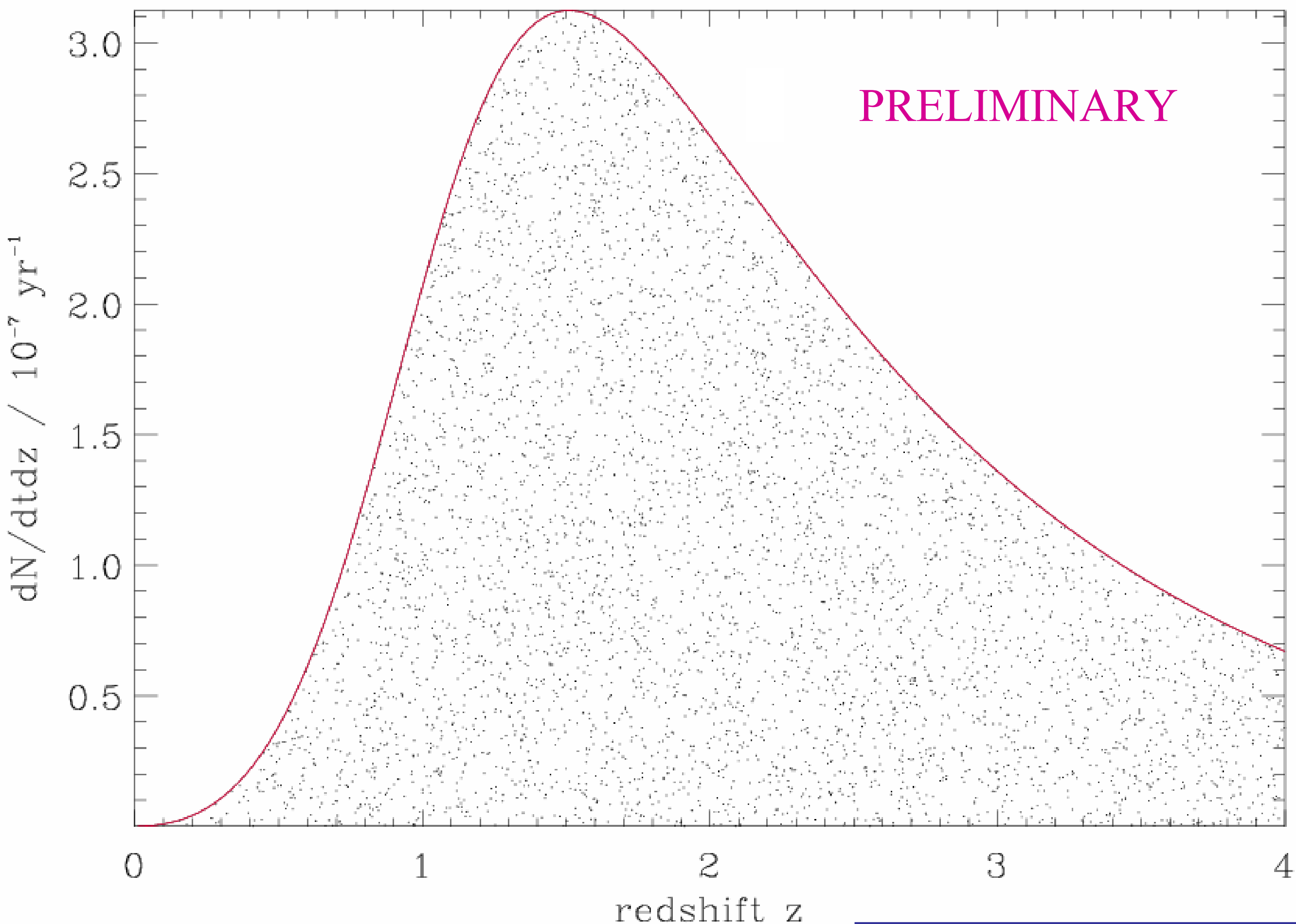
Recent evidences

GRB 011121



Piro et al. (2005)

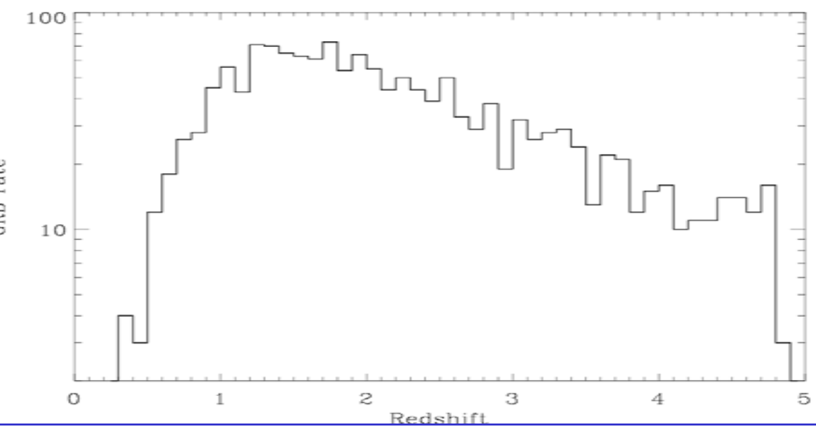
GRB and Cosmology



Redshift random Extraction

GRB fluence distribution

GRB RATE∝SFR

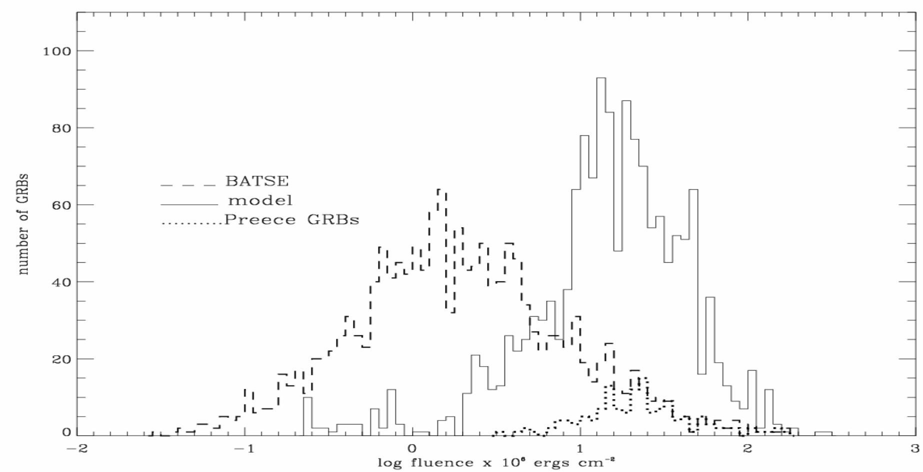


$$\frac{dN}{dzdt} \sim \frac{dV}{dz}\frac{R_{GRB}(z)}{1+z}$$

$$R_{SF1}(z) = 0.3h_{65}\,\frac{\exp\,(3.4z)}{\exp\,(3.8z)+45}\;M_{\odot}\;\mathrm{yr}^{-1}\;\mathrm{Mpc}^{-}$$

Madau & Pozzetti 2000

FLUENCE DISTRIBUTION USING AMATI RELATION



Bosnjak et al. (2005)

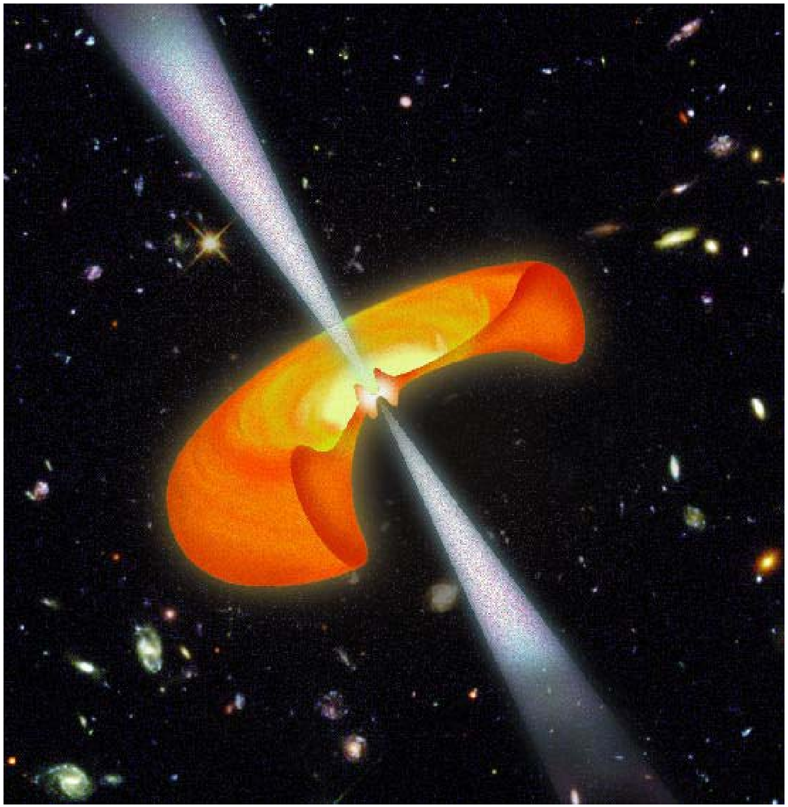
y random extraction of Epeak (Preece et . 2000) and GRB redshift for a sample of RBs we reproduce bright GRB fluence stribution.

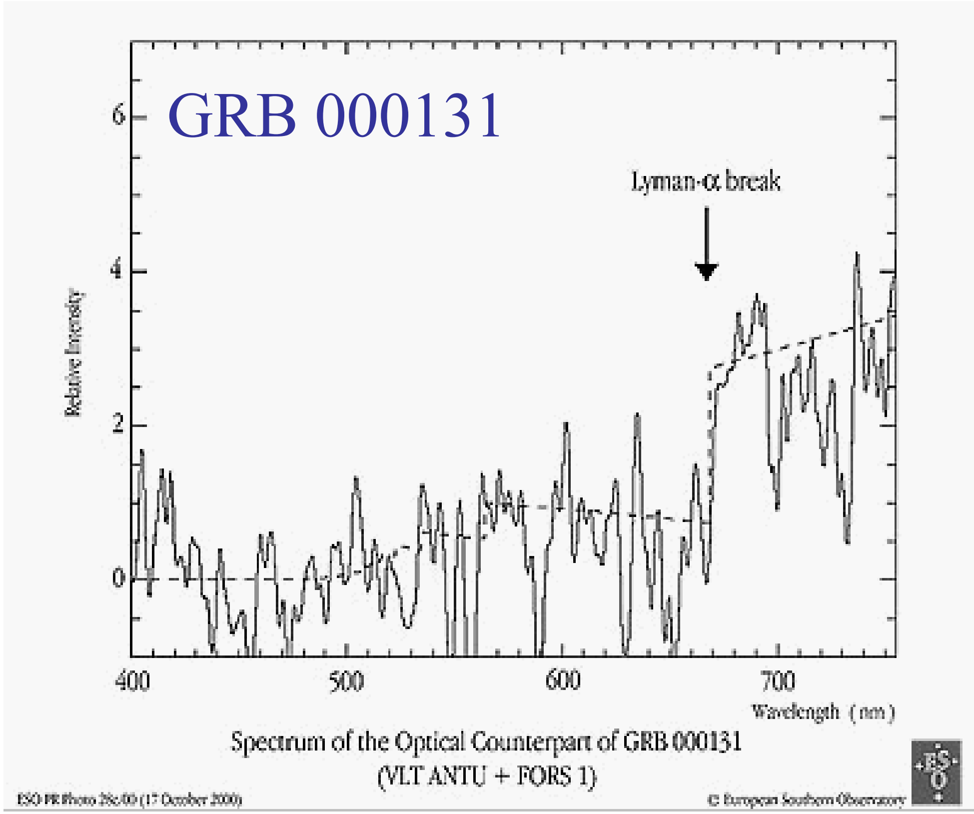
Conclusions

- Presence of Material around GRB
- Detailed Analysis on Bkg light curve
- Hard X point source transients 10^{-3} ph cm^{-2} s^{-1}
- Effects on Std fireball evolution still to be explored
- Work in progress:
  - Estimating the effect of τ on GRB Fluence Distribution
  - Trying to constrain the τ distribution
- Importance of estimating τ
- Possible test on Hete2 and SAX results

Conclusions

GRB: Massive Stars





GRB Cosmology