A Unified Model for Gamma-Ray Bursts

Ultra-Relativistic Jets in Astrophysics

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Outline

Characteristic Observations

- Short & Long Gamma-Ray Bursts
- X-Ray Flashes, X-Ray Rich GRBs

A Unified Model of Short & Long GRBs, X-Ray Rich GRBs, and X-Ray Flashes

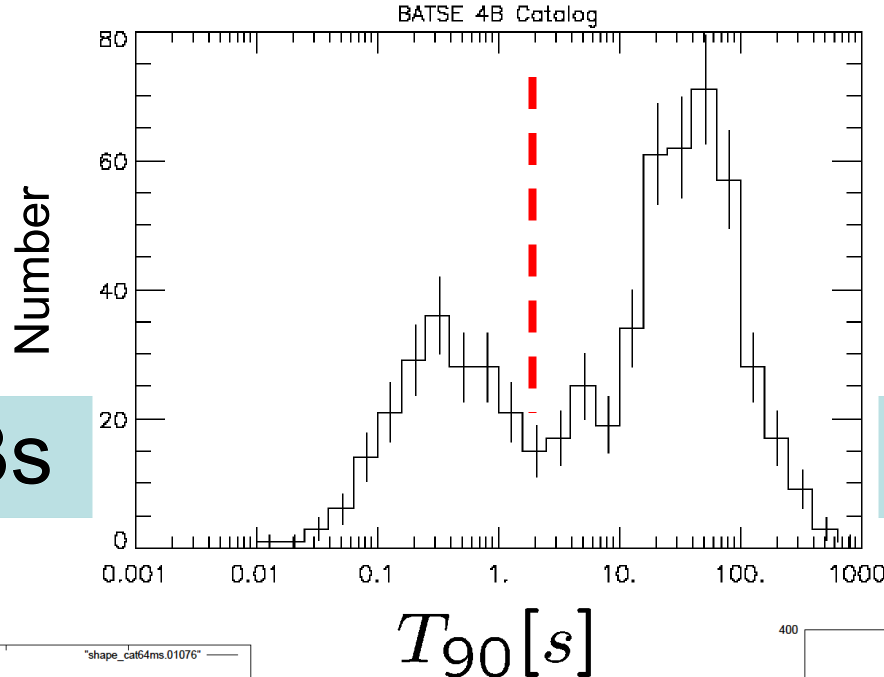
Statistical Simulations

- T90 duration distribution
- Ep-Eiso relation

Summary and Discussion

Short & Long Gamma-Ray Bursts (GRBs)

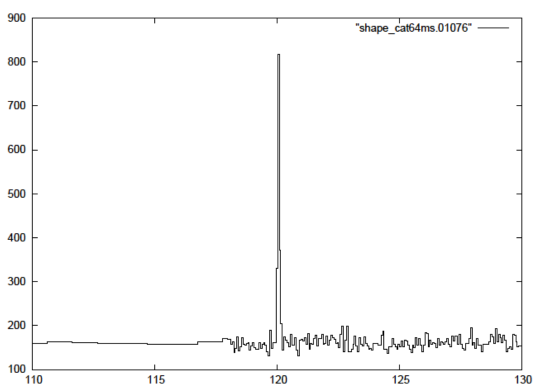
Distribution of T90 durations of GRBs is bimodal.

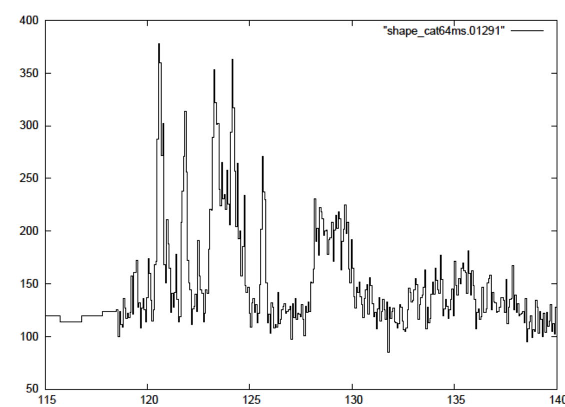


(BATSE Web page)

Short GRBs

Long GRBs





Long GRBs

Afterglow observations are accumulating.

⇨ Cosmological distance.

Relativistic motion.

Collimated jet.

Collapse of massive star. (GRB 030329 / SN 2003dh)

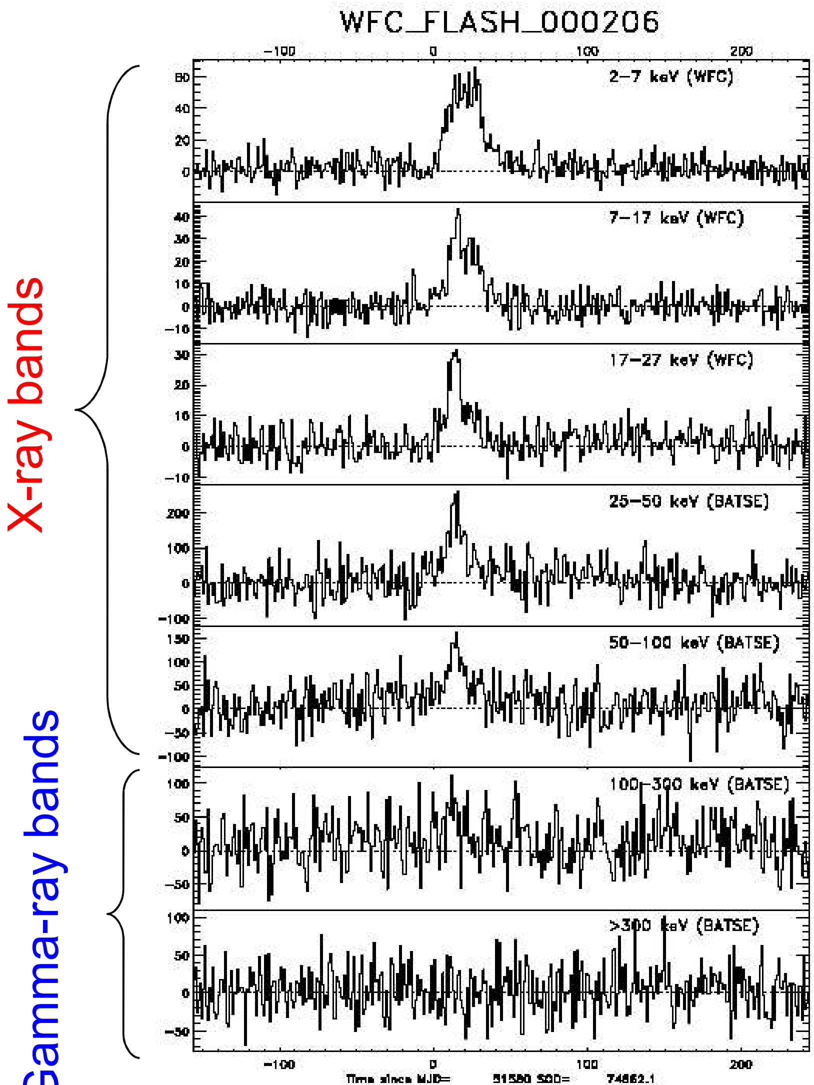
Short GRBs

Afterglows have been detected only for a few events.

⇨ ? ? ?

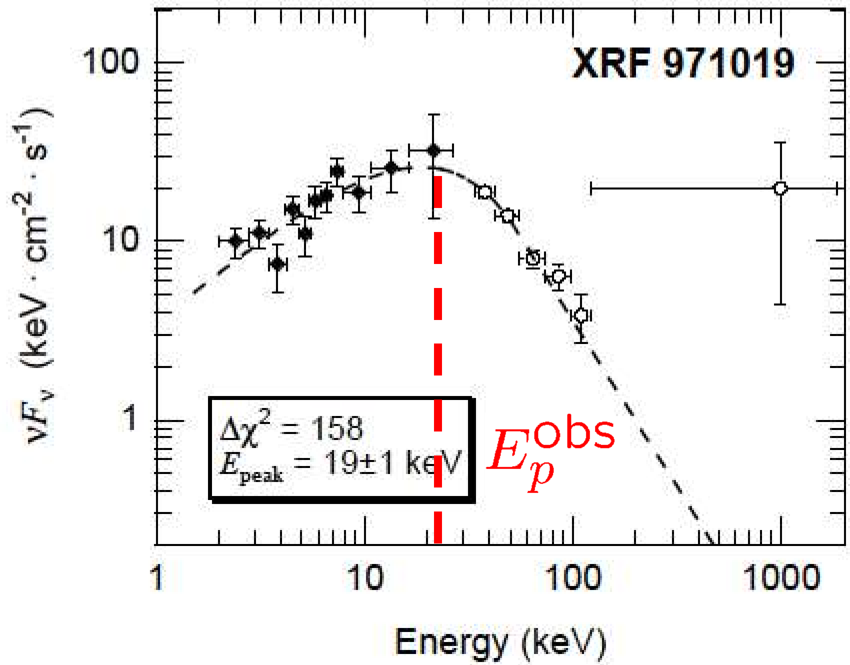
Compact star merger? Giant flare of SGR?
Collapse of massive star?

X-Ray Flashes (XRFs)



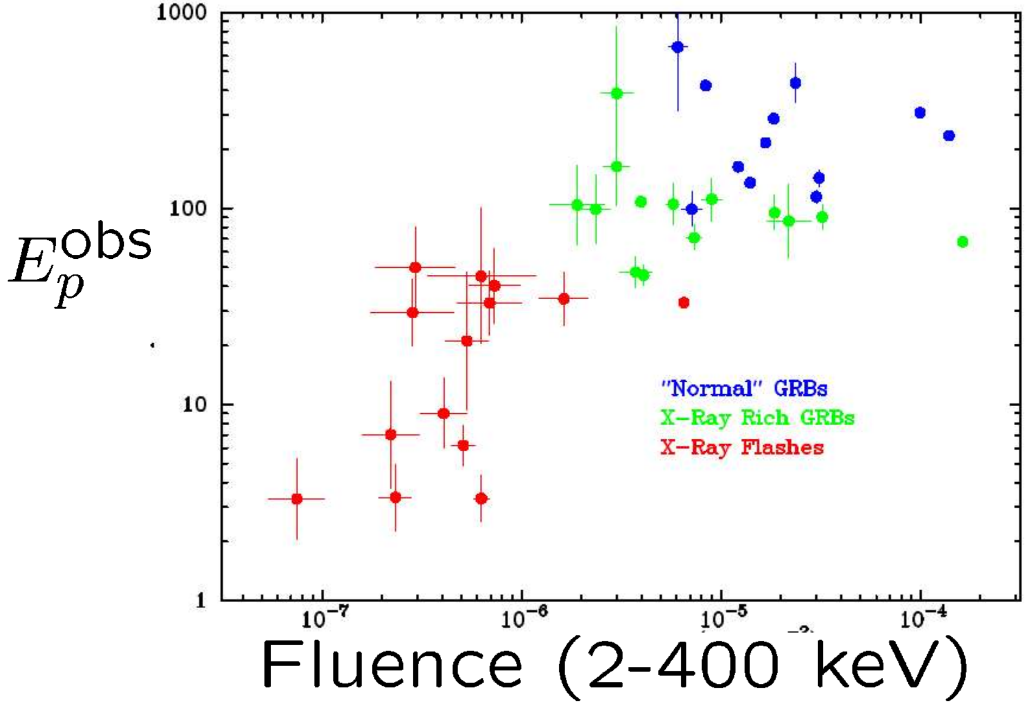
(Heise et al. 2001)

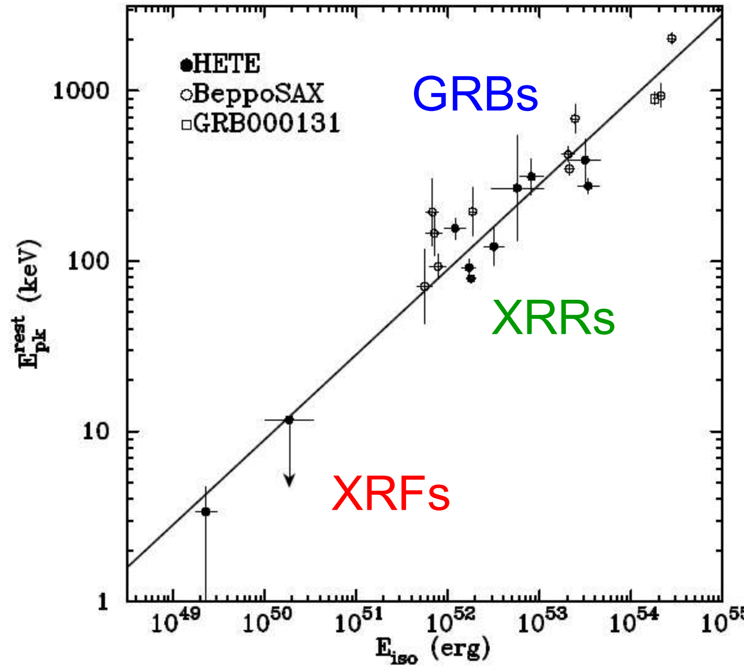
(Kippen et al. 2002)



Spectral properties of XRFs are similar to those of GRBs except that Ep is much smaller.

(Lamb et al. 2003)





$$E_p \propto (E_{iso})^{0.5}$$

HETE-2 observations confirmed that softer and dimmer (long) GRBs smoothly extend to XRFs through an intermediate class, X-Ray Rich GRB (XRR).

⇨ Origins of XRFs & XRRs are the same as (long) GRBs.

Event Rates

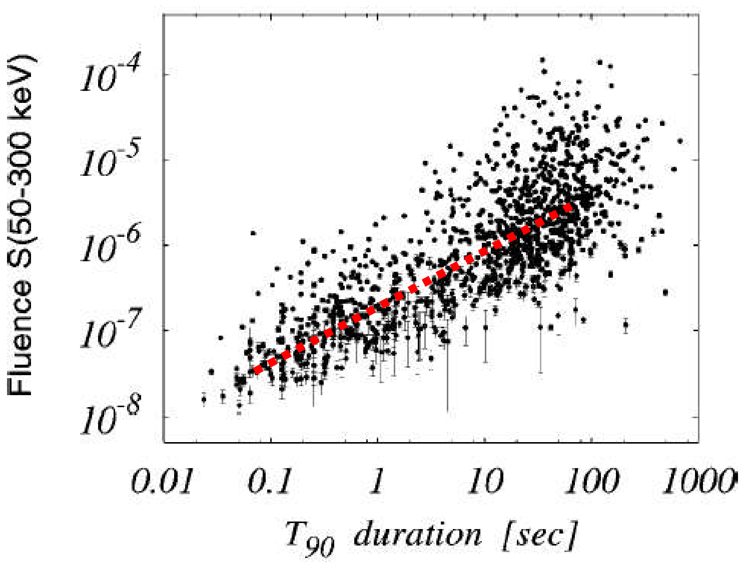
Long GRBs : Short GRBs ~ 3 : 1 (BATSE)

Long GRBs : XRRs : XRFs ~ 1 : 1 : 1 (HETE-2)

Similar event rates.

→ *All classes may be related.*

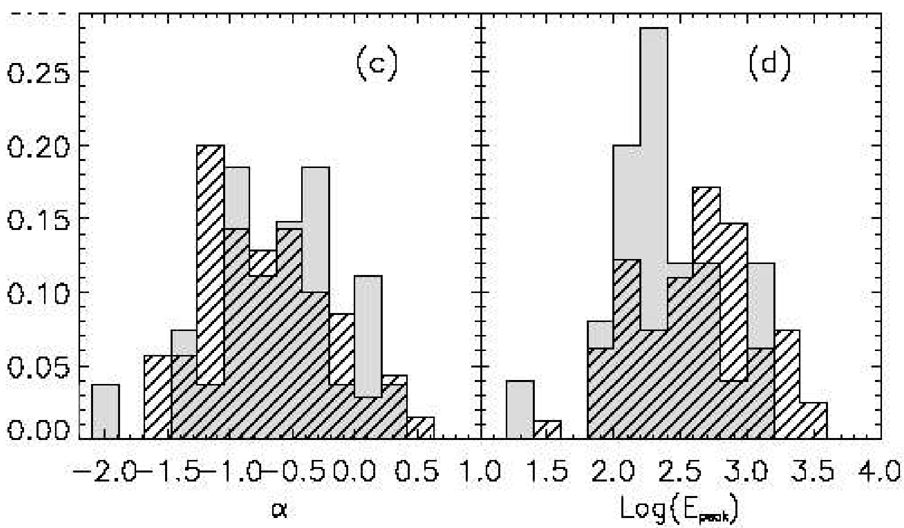
Similarities between Short & Long GRBs



GRBs are distributed continuously in the T90-Fluence plane.

Luminosities of short and long GRBs are similar.

(Yamazaki et al. 04)

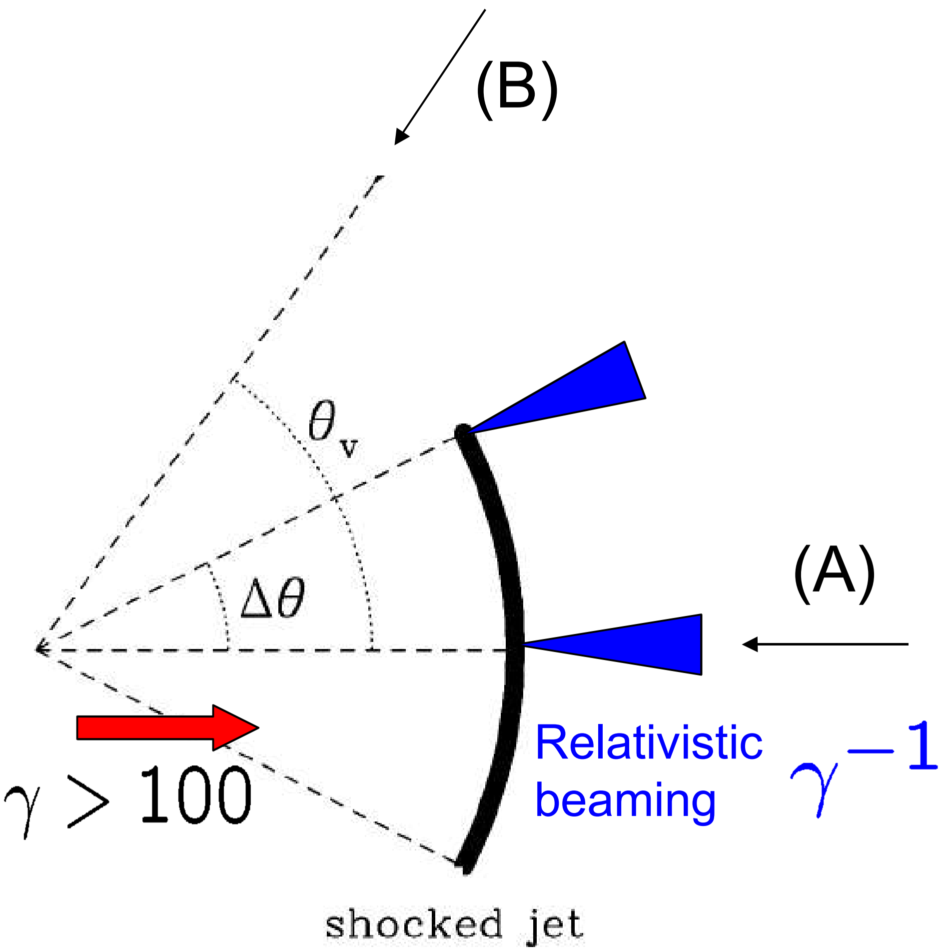


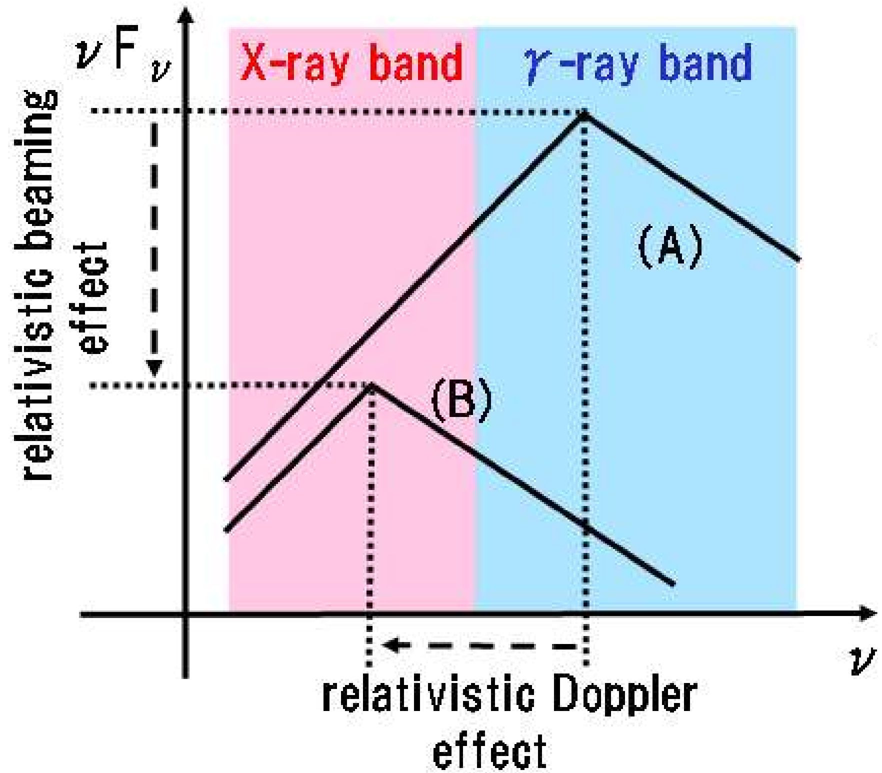
Spectra of first 2 s of long GRBs are similar to those of short GRBs.

(Ghirlanda et al. 04)

Relativistic Kinematic Effects

(Woods & Loeb 99, Granot et al. 99, Yamazaki et al. 02, 03)

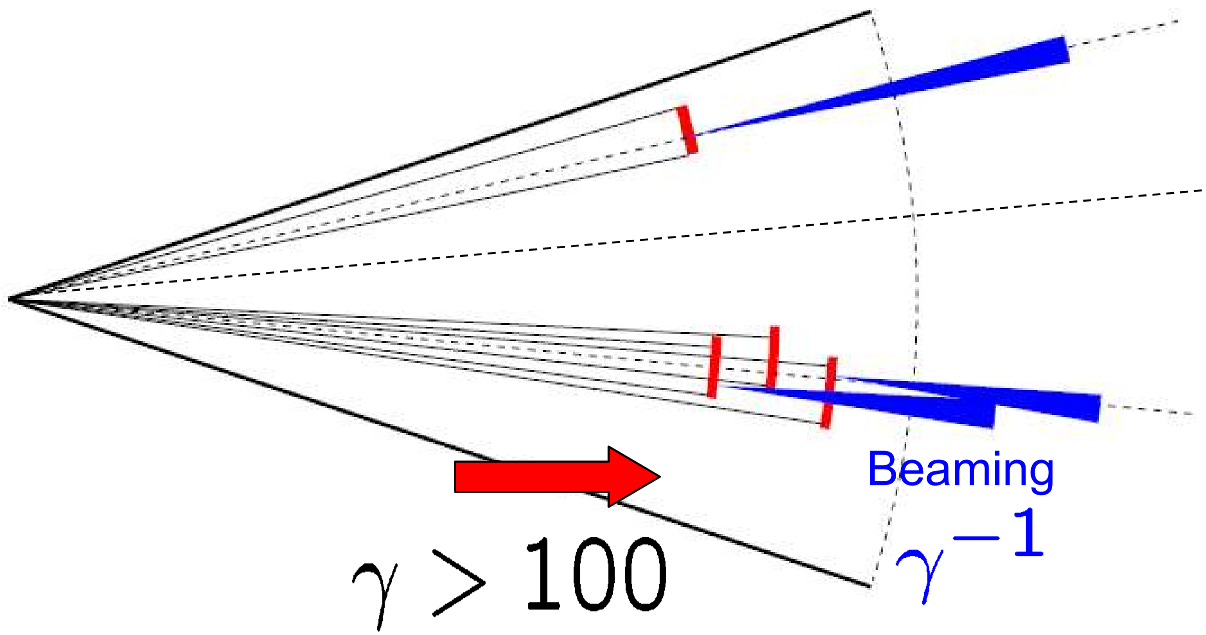




A Unified Model: Concept

We assume that a GRB jet consists of multiple subjets.

(Nakamura 00, Kumar & Piran 00)



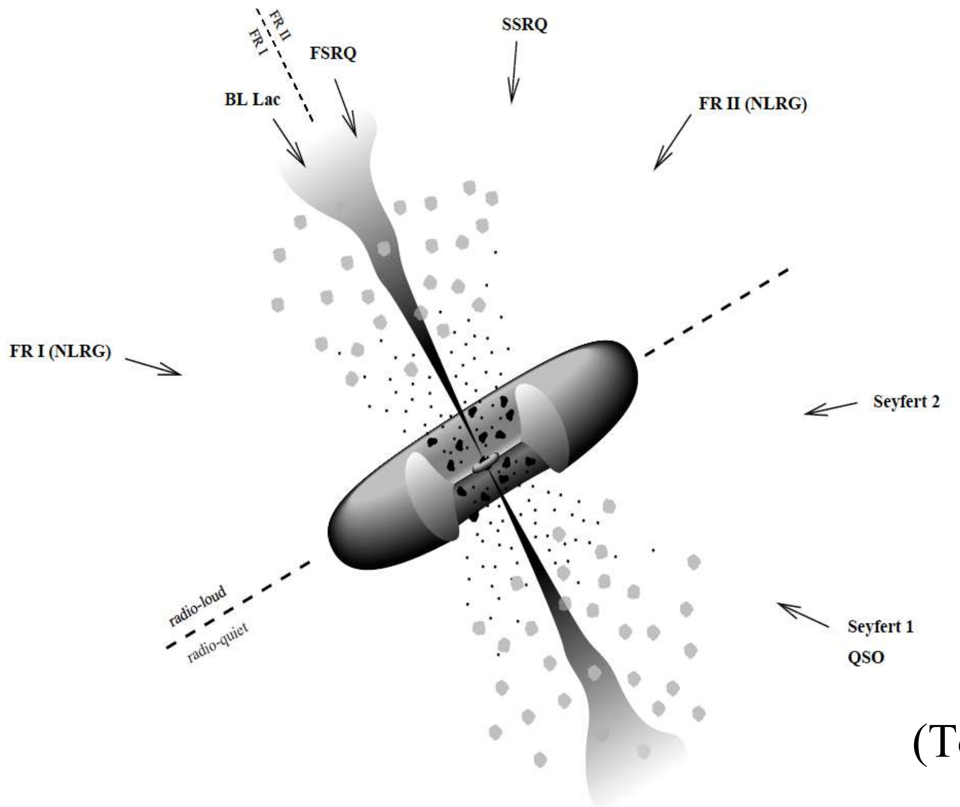
Single pulse
Short GRB

Off-axis for all subjets
XRR or XRF

Multiple pulses
Long GRB

Viewing angle effects cause diversity of phenomena.

Unified Picture of AGN



(Torres et al. 03)

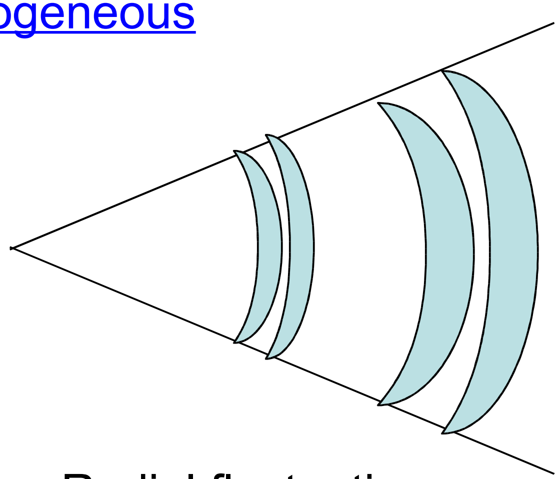
Different phenomena arise from viewing angles effects.

Similar number of events of different phenomena is natural in such a structure.

What is subjet?

Multiple subjet model = *Inhomogeneous jet model*

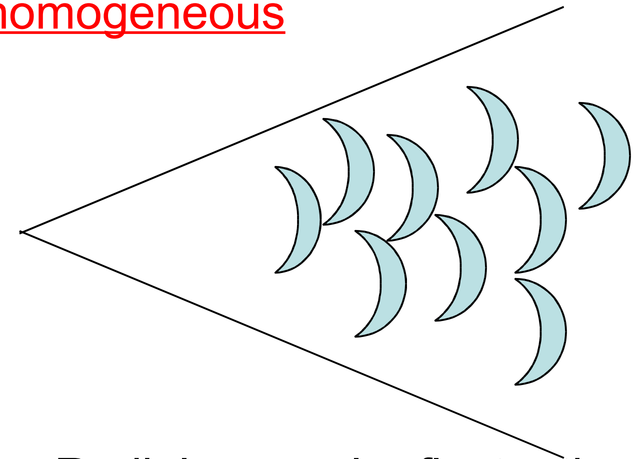
Homogeneous



Radial fluctuation

Continuous emission

Inhomogeneous

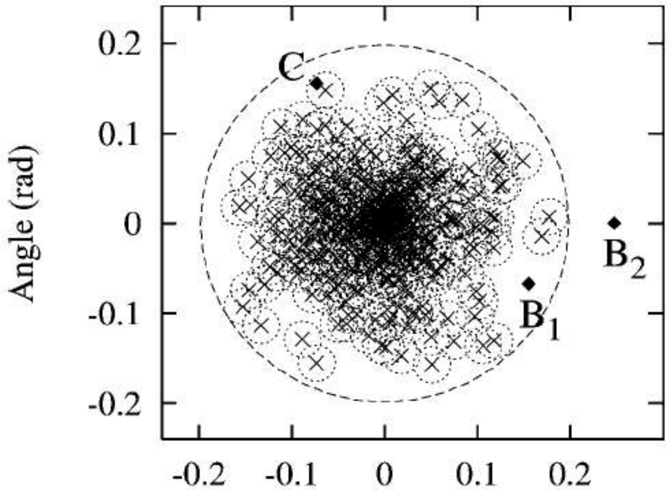


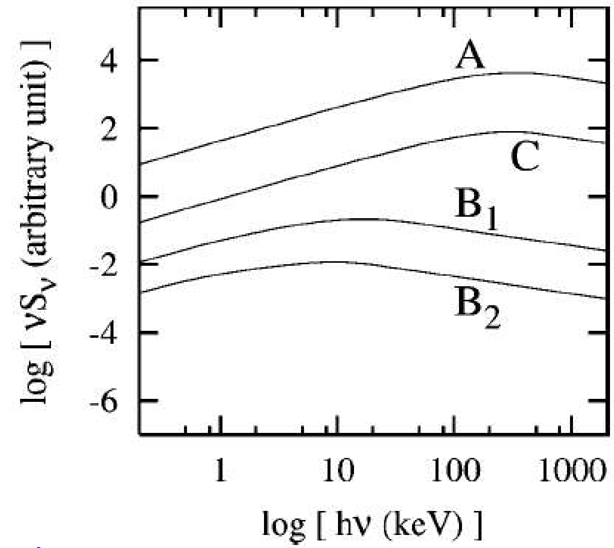
Radial + angular fluctuations

Discrete emission patches

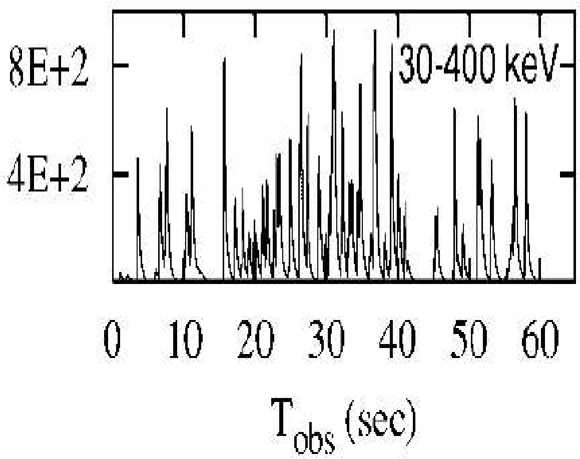
But we do not calculate the detailed process of each internal shock.

An Example (Yamazaki et al. 2004)



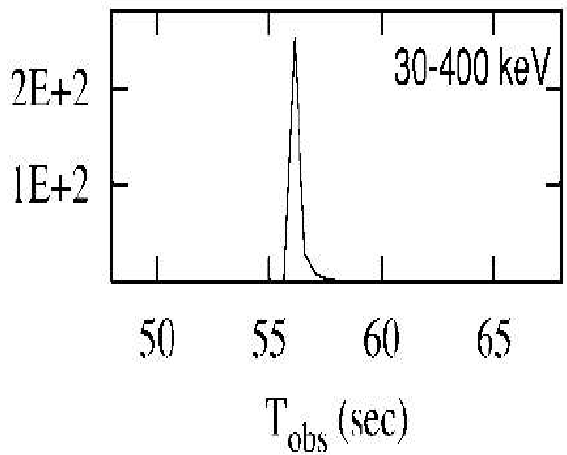


A: $n_s \gg 1$



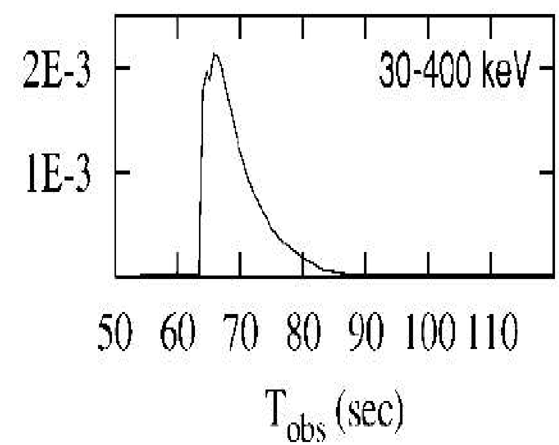
Long GRB

C: $n_s = 1$



Short GRB

B2: $n_s = 0$

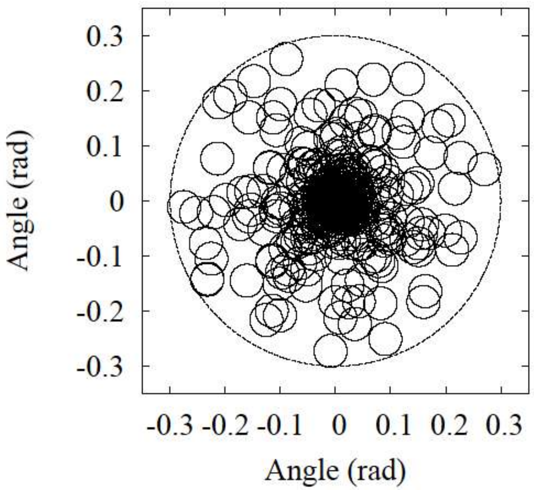


XRR or XRF

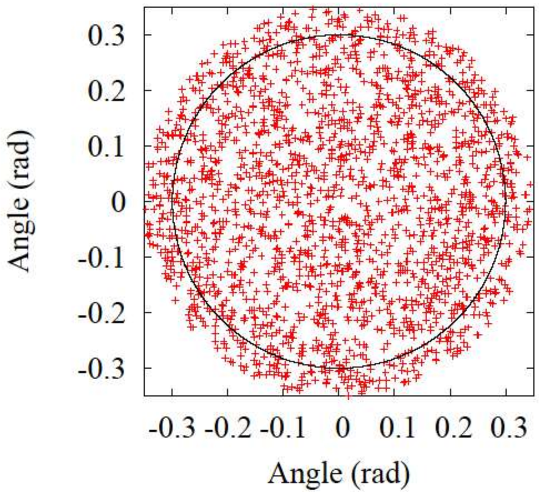
T90 Duration Distribution of GRBs

Subjet configuration is fixed.

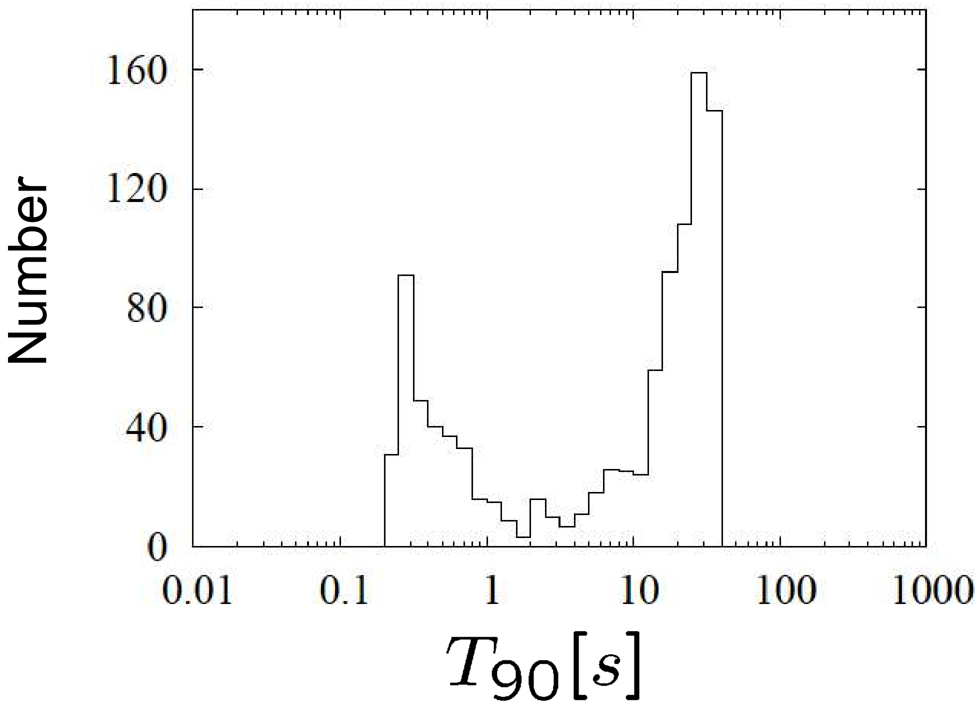
All the subjets have the same intrinsic properties.



Simulated lines of sight

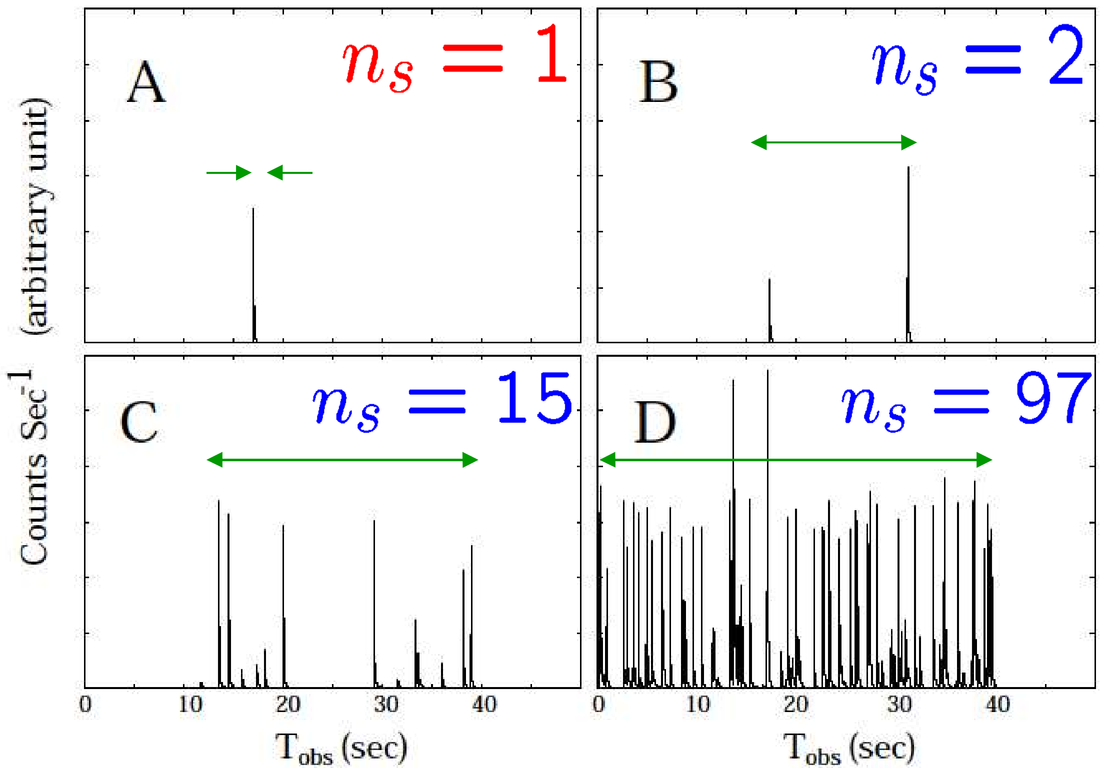


Result of Monte Carlo Simulation



Bimodal! Why?

Why Bimodal? (Toma et al. 05)

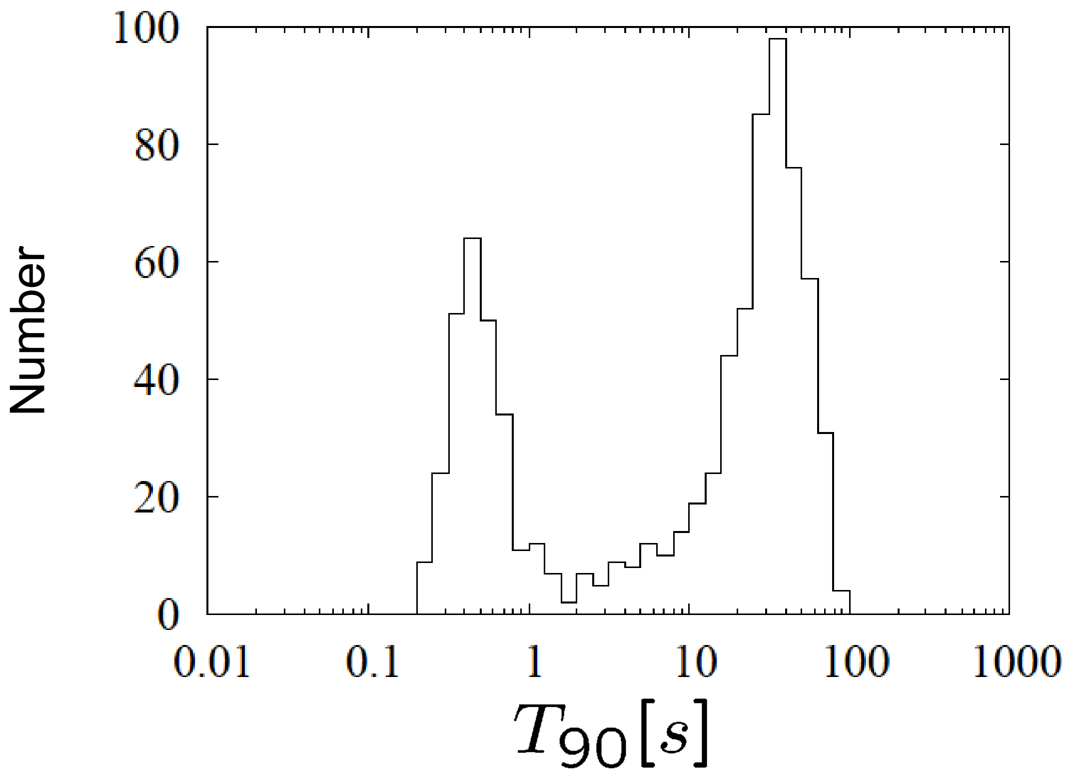


$n_s = 1$ → Pulse Width (~0.1 s)

$n_s \geq 2$ → Interval between pulses (~10 s)

These two different timescales naturally lead to a division of the burst T90 durations into short and long ones.

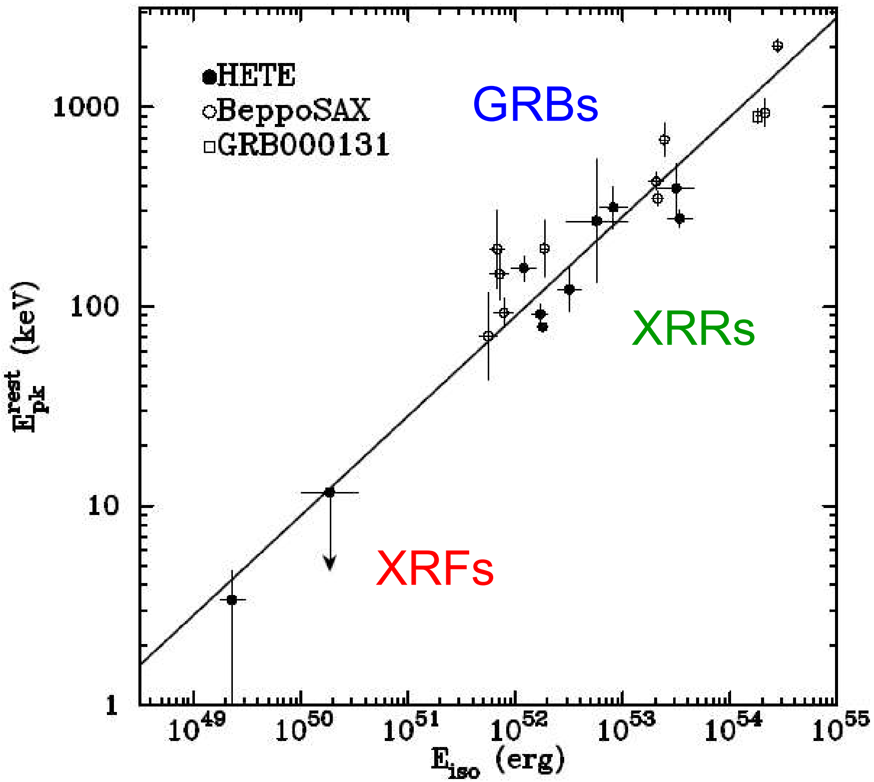
Source redshifts are varied according to the cosmic star formation rate.



The distributions of the short and long bursts look like lognormal.

Ep-Eiso Relation

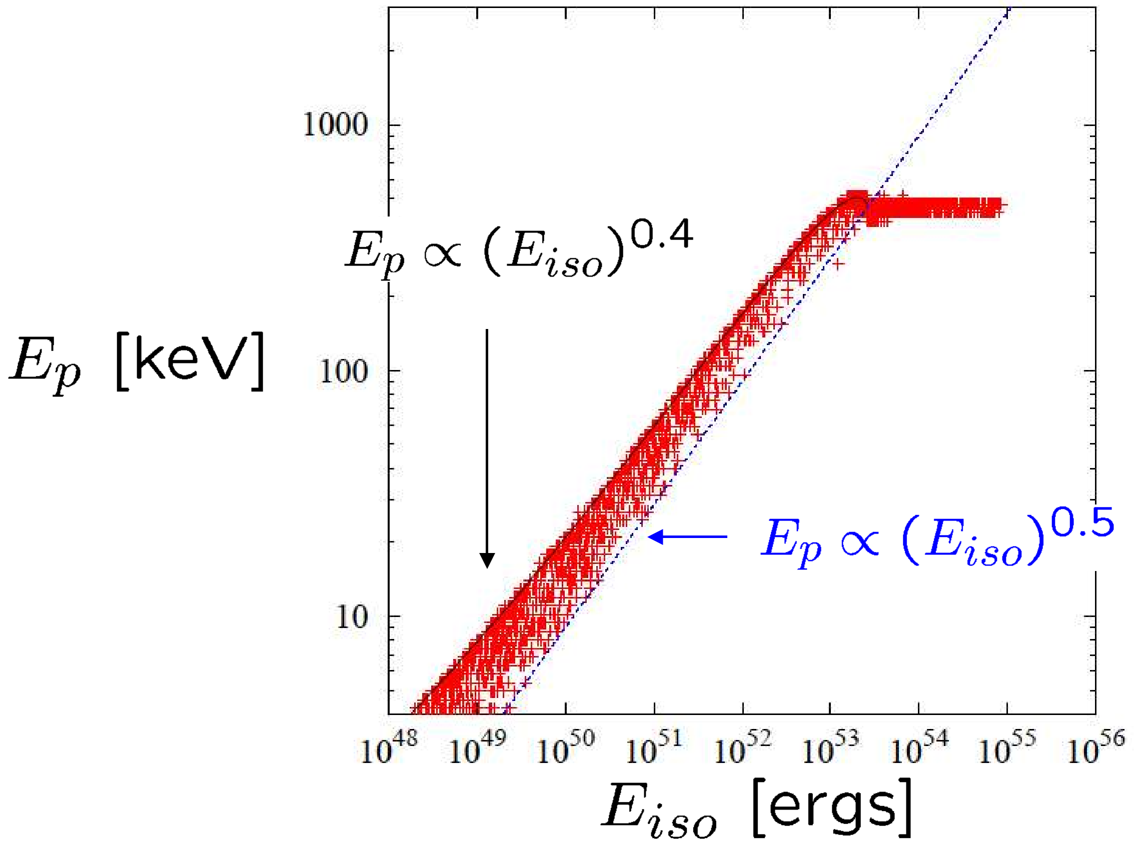
Bursts with known redshifts (Lamb et al. 2003)



$$E_p \propto (E_{iso})^{0.5}$$

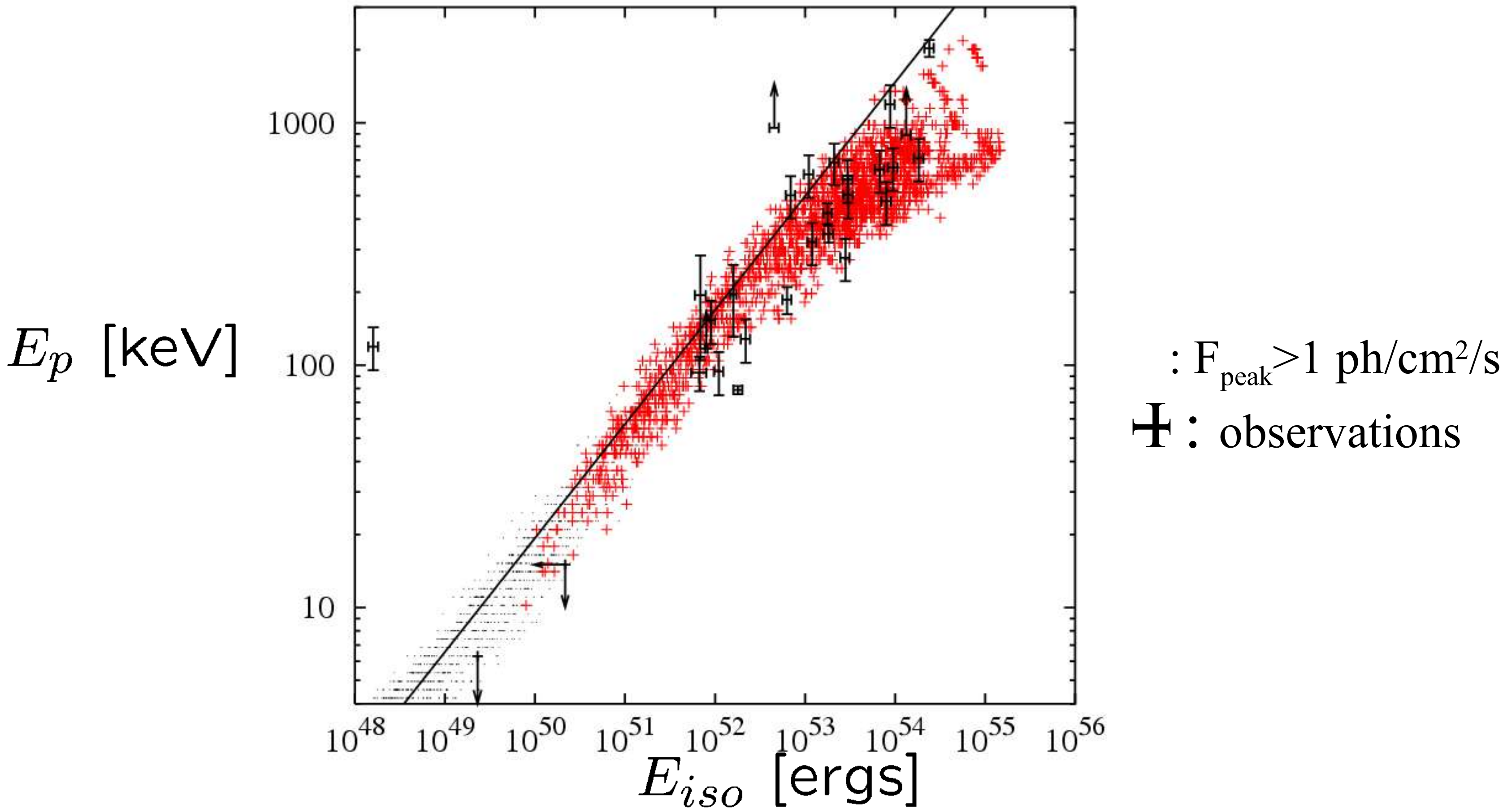
Result of Monte Carlo Simulation in the Multiple Subjet Model (Toma et al., astro-ph/0504624)

All the subjets are assumed to have the same intrinsic properties.



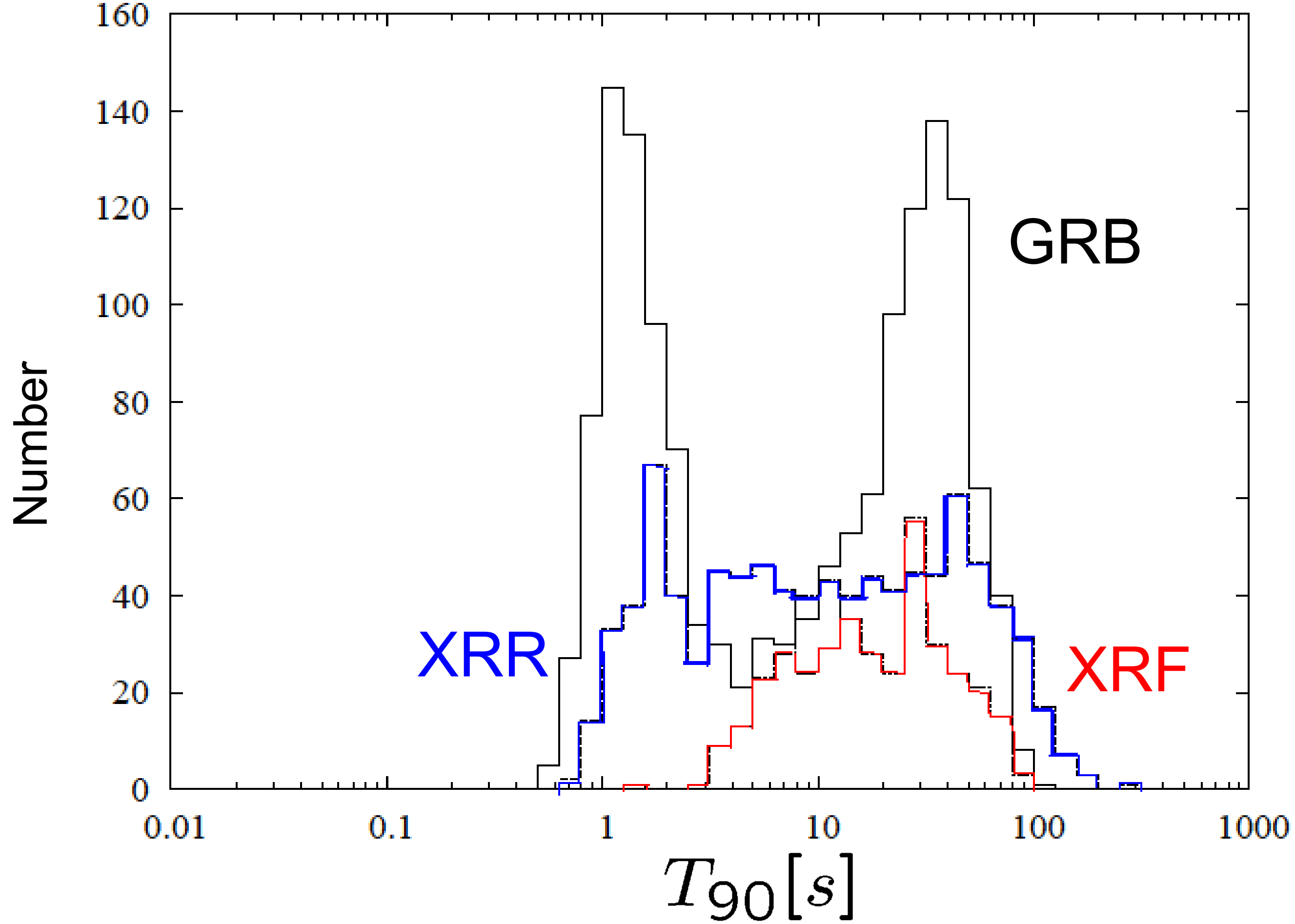
Off-axis events naturally follows $E_p \propto (E_{iso})^a$ with $0.4 < a < 0.5$.

Intrinsic Ep of each subjet is assumed to be distributed log-normally according to $E_p \propto (L_{iso})^{0.5}$.



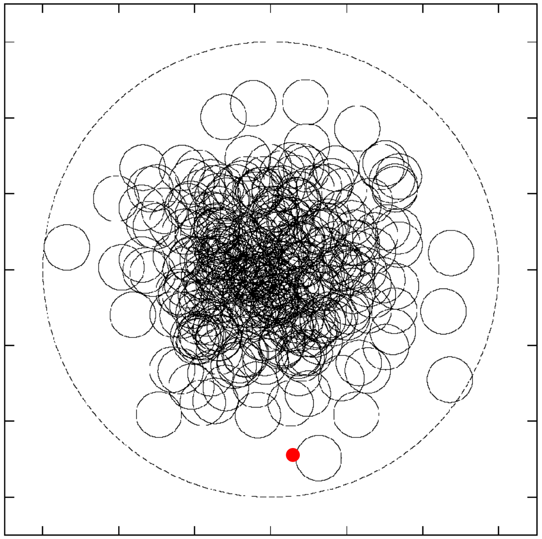
Multiple subjet model is consistent with the observations.

Distribution of T90 durations (2-25 keV)

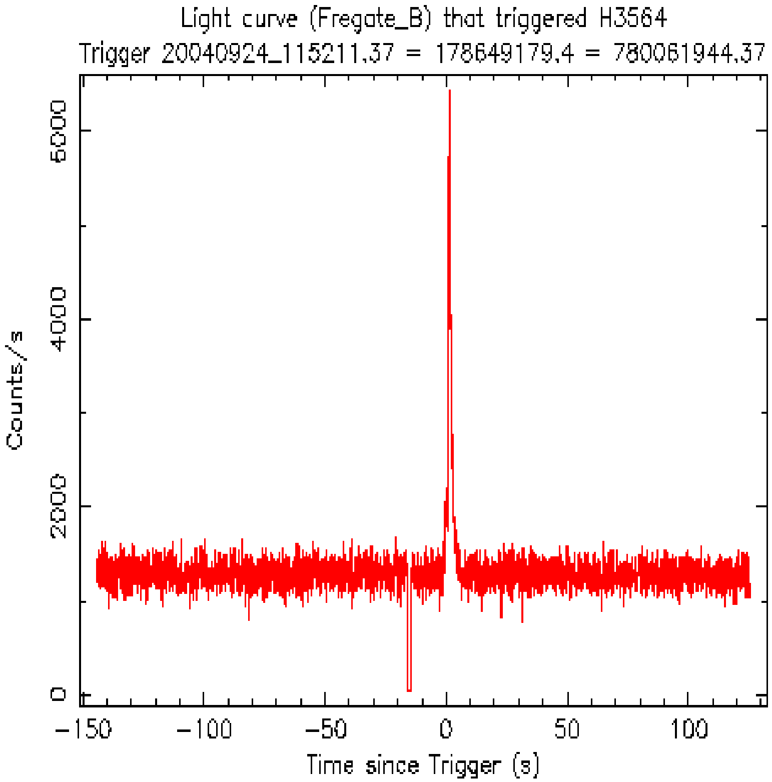


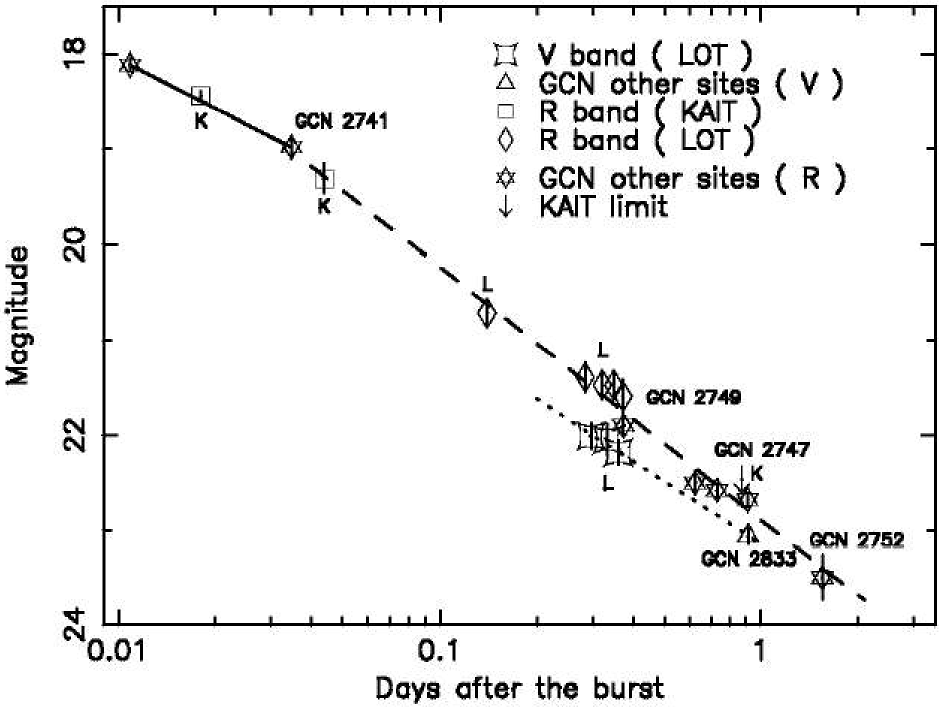
Simulated event rate is GRB: XRR: XRF = 4: 3: 1.

Short XRR 040429 (by HETE-2)



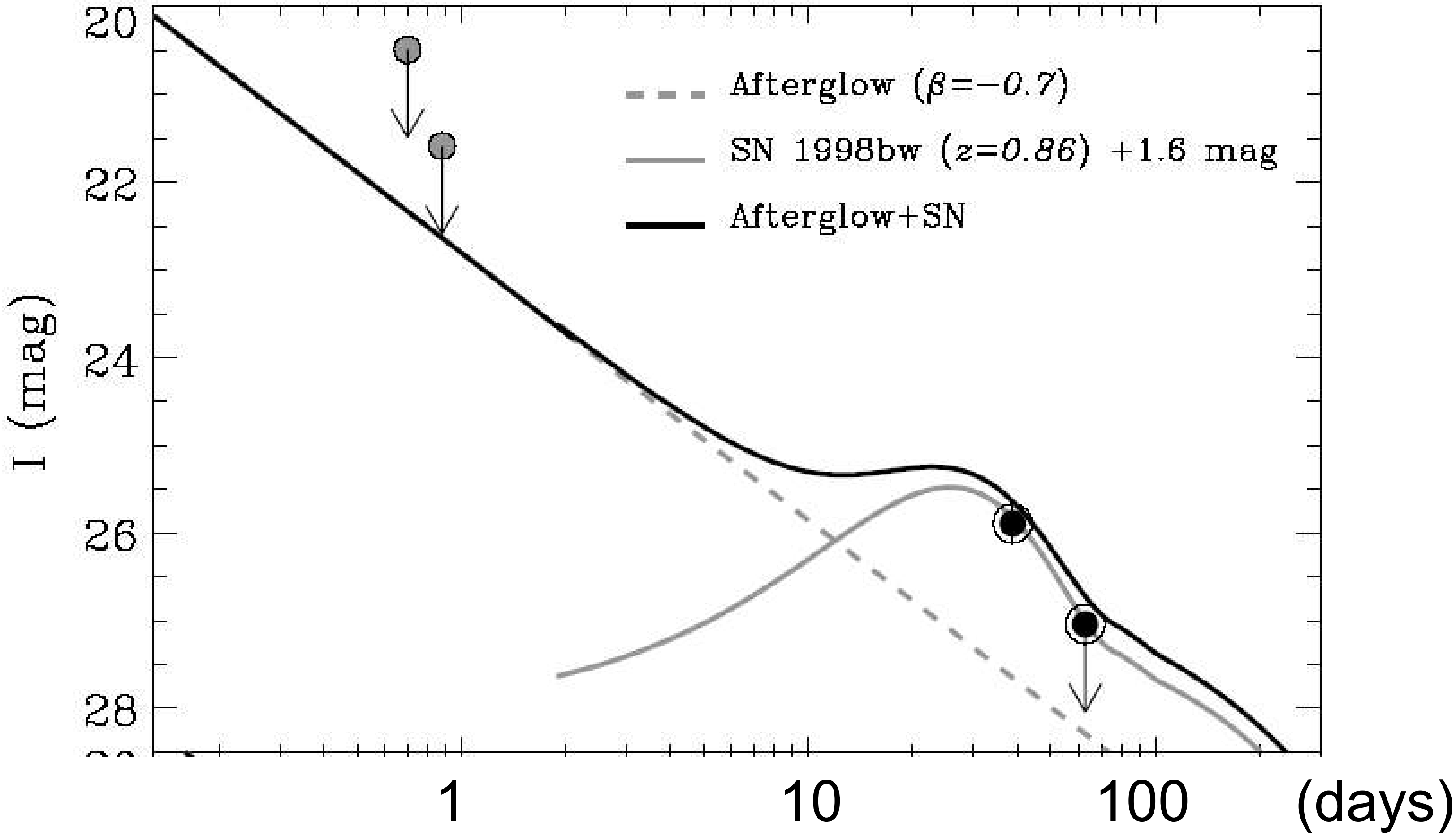
Ep = 51.8 keV
Duration (30-400keV) = 0.6 sec
z = 0.859





(Huang et al. 05)

(Soderberg et al. 05)



Supernova bump was detected!

This observation supports our unified picture of short & long GRBs.

Summary and Discussion

We propose a unified model of short and long GRBs, X-ray rich GRBs, and X-ray flashes.

The results of statistical simulations of our unified model are consistent with the observations.

We argue that the origin of the short GRBs is the same as that of long GRBs, and predict that supernova bumps appear from afterglows of short GRBs.