

High Energy Radiation from Gamma-Ray Bursts Relativistic Flows

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- Gamma-Ray Bursts: what are they?
- The build up of the 'standard' scenario
- Is everything solved?

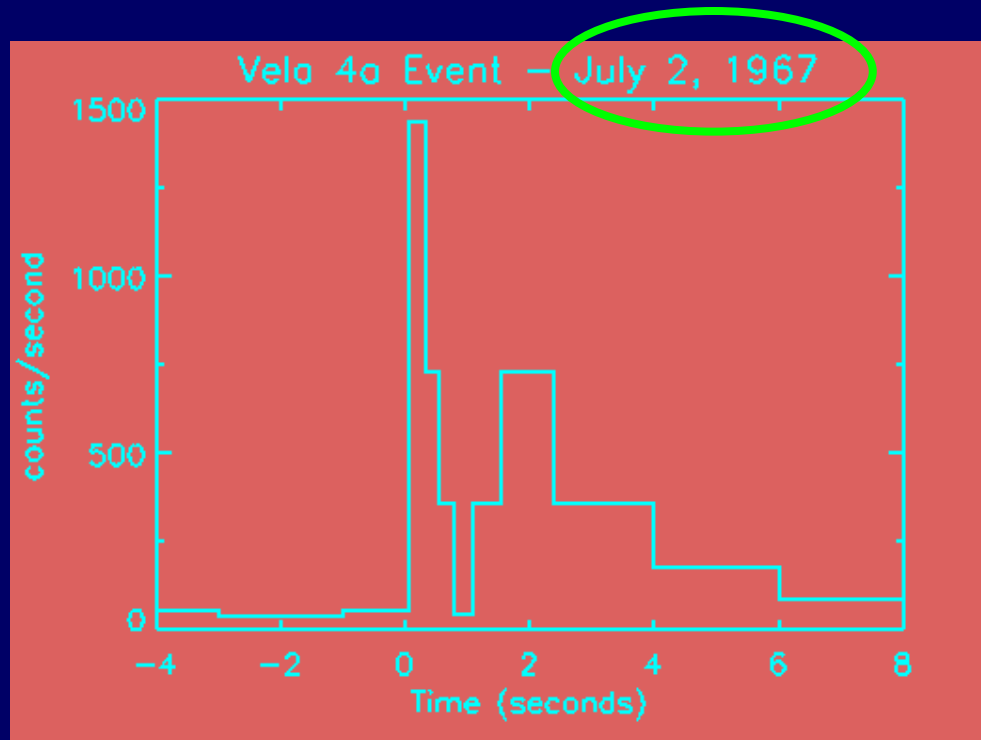
Highlights in Physics Today:

One hundred years After the Birth of Beppo Occhialini - Milano, 16.2.2007

Gamma-Ray Bursts: The story begins

Treaties banning nuclear tests between USA and USSR in early 60s

VELA Satellites: X and soft γ -ray detectors



Brief, intense
flashes of γ -rays

Klebesadel R.W., Strong I.B., Olson R., 1973 *Astrophysical Journal*, 182, L85

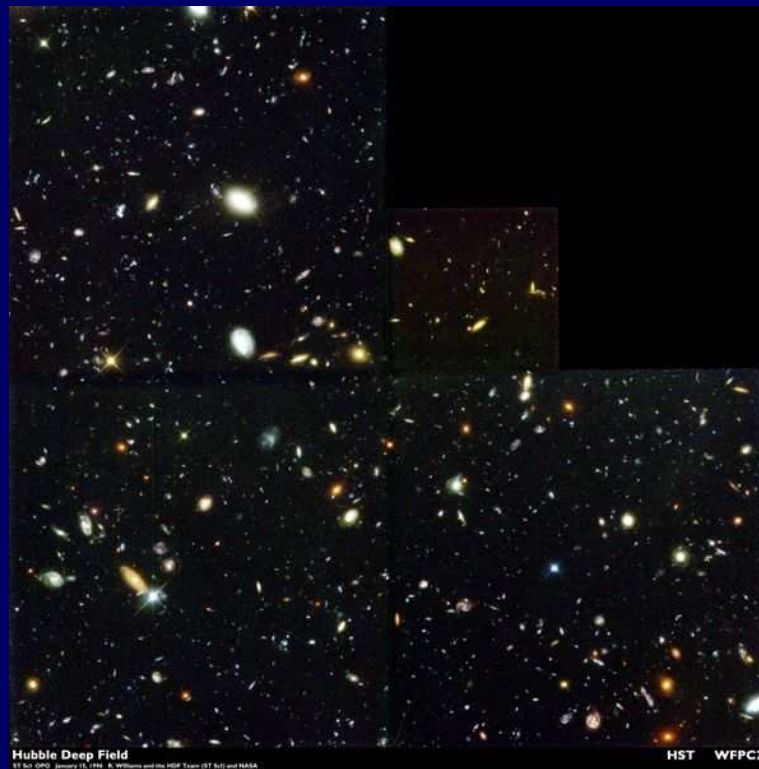
'Observations of Gamma-Ray Bursts of Cosmic Origin'

The story continues...

Tens of GRBs detected in the following years

Search for counterparts, but the angular resolution achieved is larger than a degree

NASA image



~ 0.04 deg

Hubble Deep Field

Fundamental question: where are they?

What are they?

Progenitors ?

More than 100 models proposed...

Energetics?

Energetics:

Galactic:

$d = 50 \text{ kpc}$

$\rightarrow E \sim 10^{42} \text{ erg}$

Extragalactic

$d = 7 \cdot 10^3 \text{ Mpc} \quad (z \sim 1) \rightarrow E \sim 10^{52} \text{ erg}$

Where are they located?

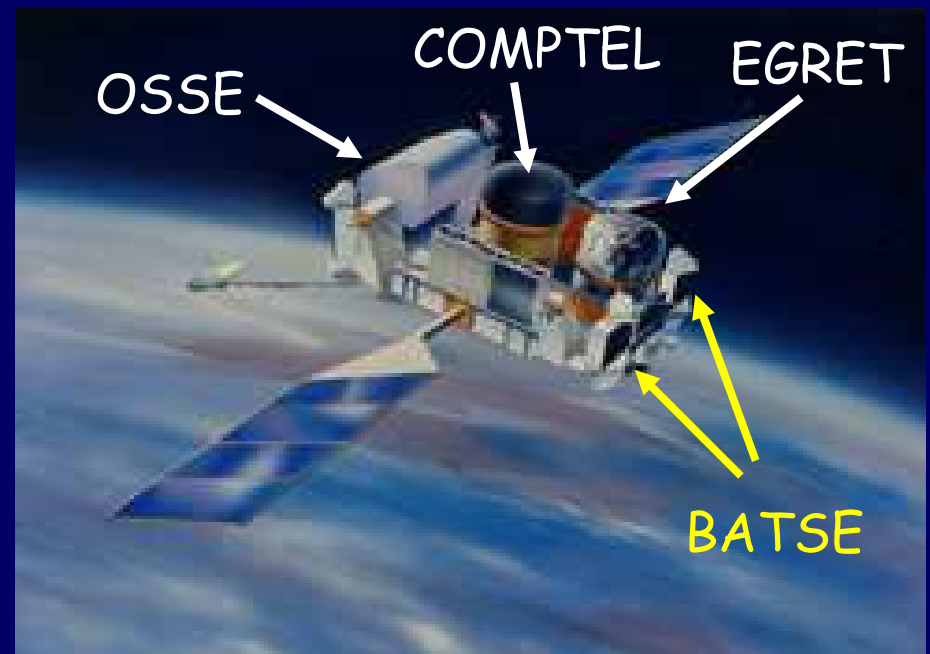
1991: The CGRO satellite

Burst And Transient Source Experiment

Energy range: 0.03-2 MeV

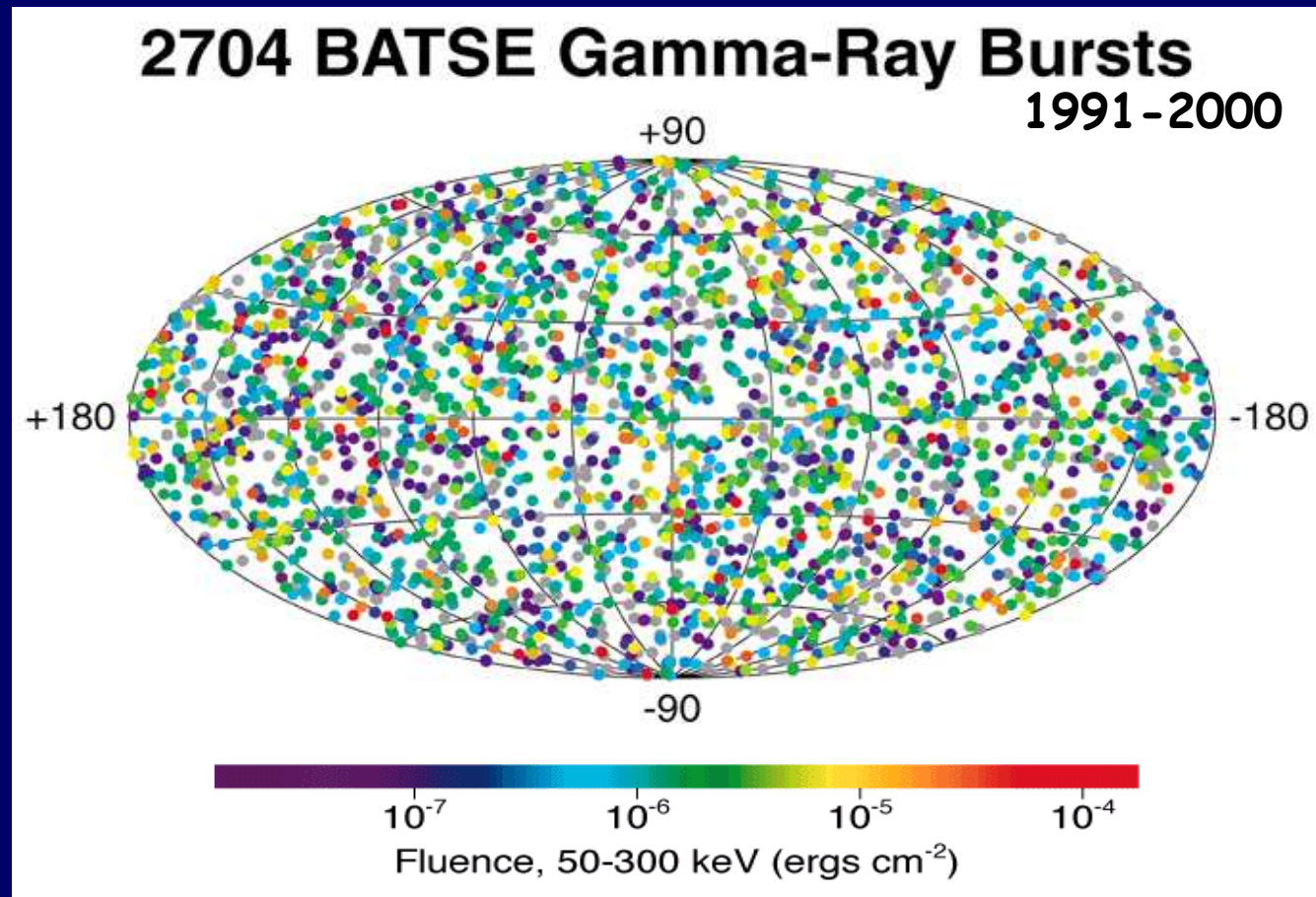
FOV $\sim 4\pi$ sr

GRB rate: ~ 1 event/day



Thousands of GRB allowed to study their distribution in the sky and their temporal and spectral properties

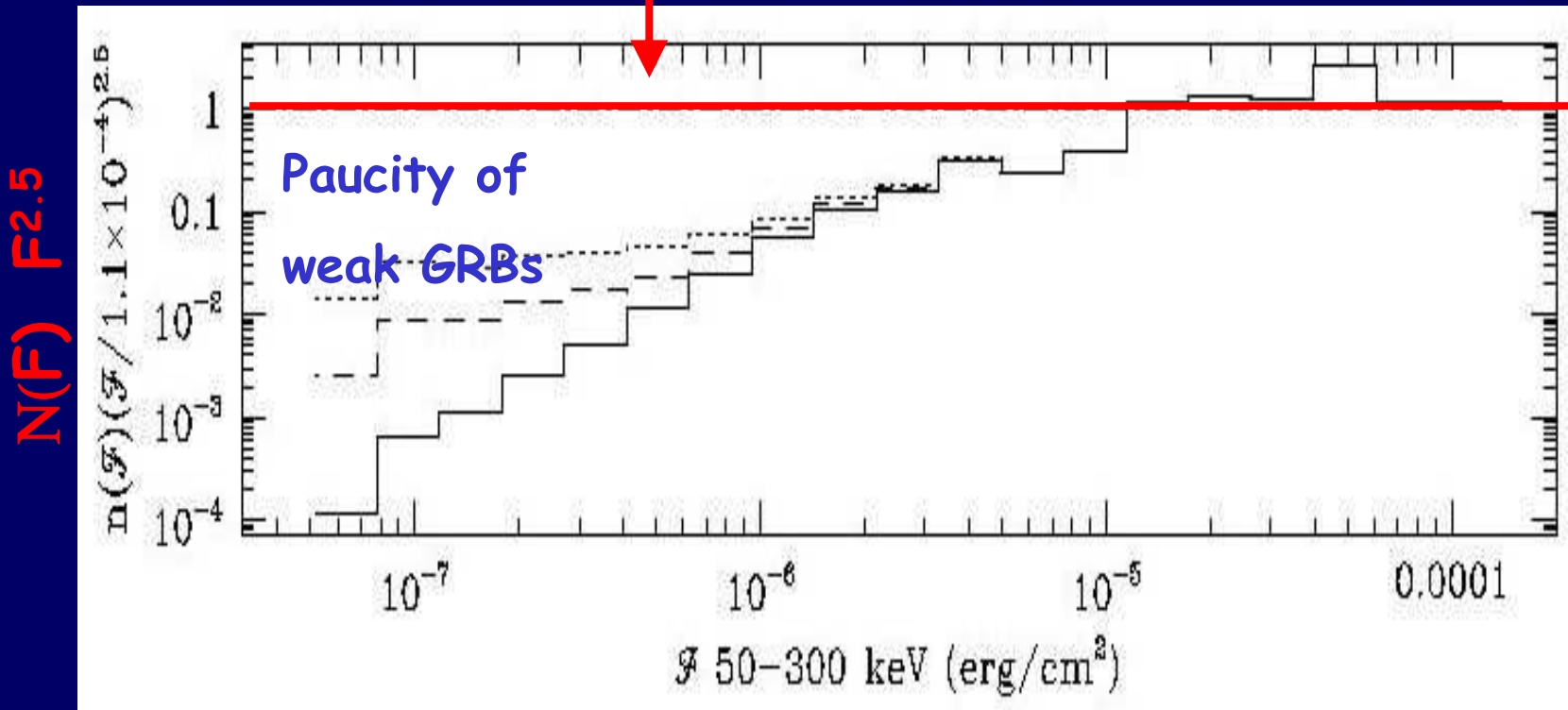
First major steps: isotropy



Dipole and quadrupole $< 1 \sigma$ from isotropy

First major steps: not uniformity

Homogeneous Euclidean distribution in distance



Inhomogeneous distribution in distance

Isotropy + Non uniformity

Very local (<100pc)?

Galactic halo (100 kpc)?



GRBs due to Neutron stars in the Galactic halo

[F. Lamb]

Cosmologic ?

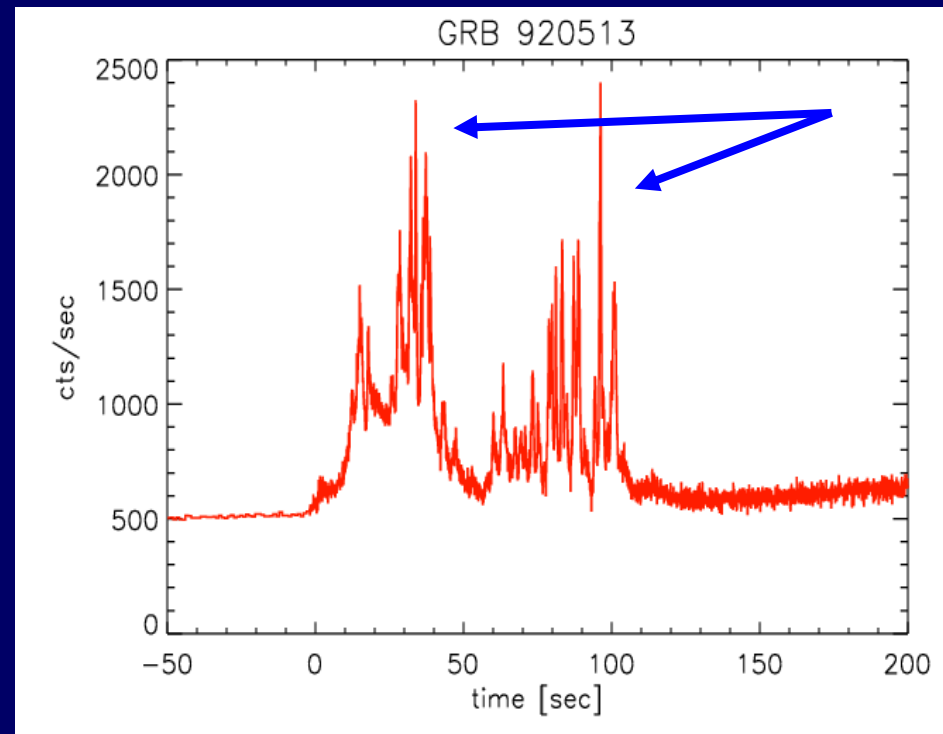
Explosions in galaxies with more energy than a Supernova

[B. Paczynski]

Temporal properties

Highly variable

Duration: ms - 1000 s

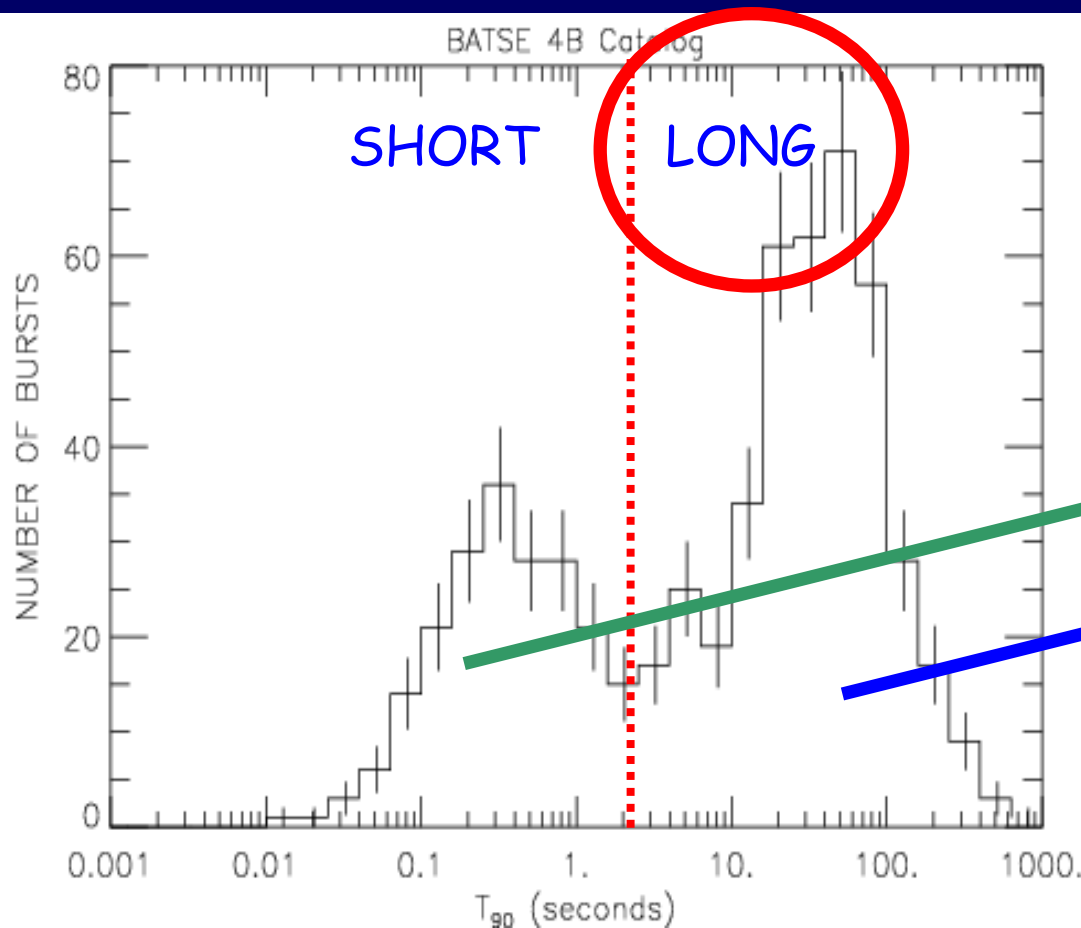


Light curve diversity [duration, structure]

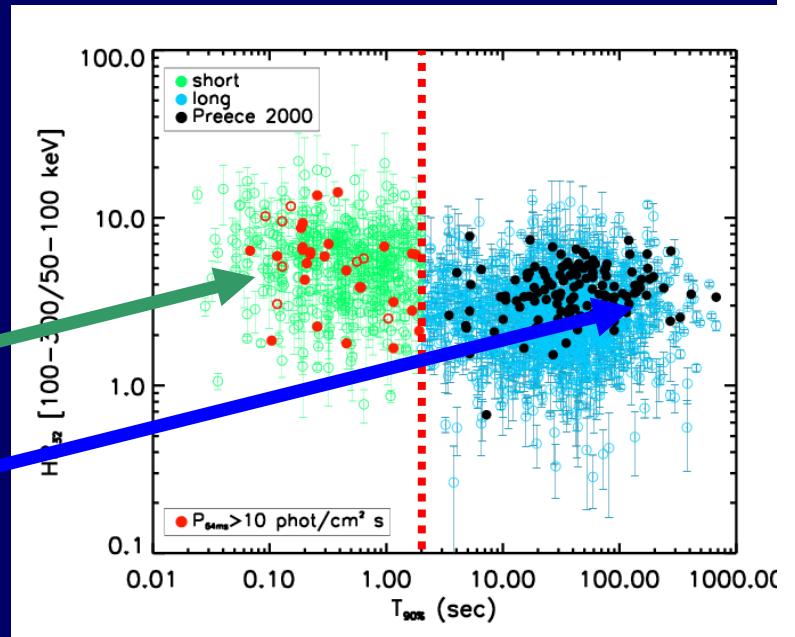
Widths of pulses \sim constant

Temporal properties: short vs long

Duration

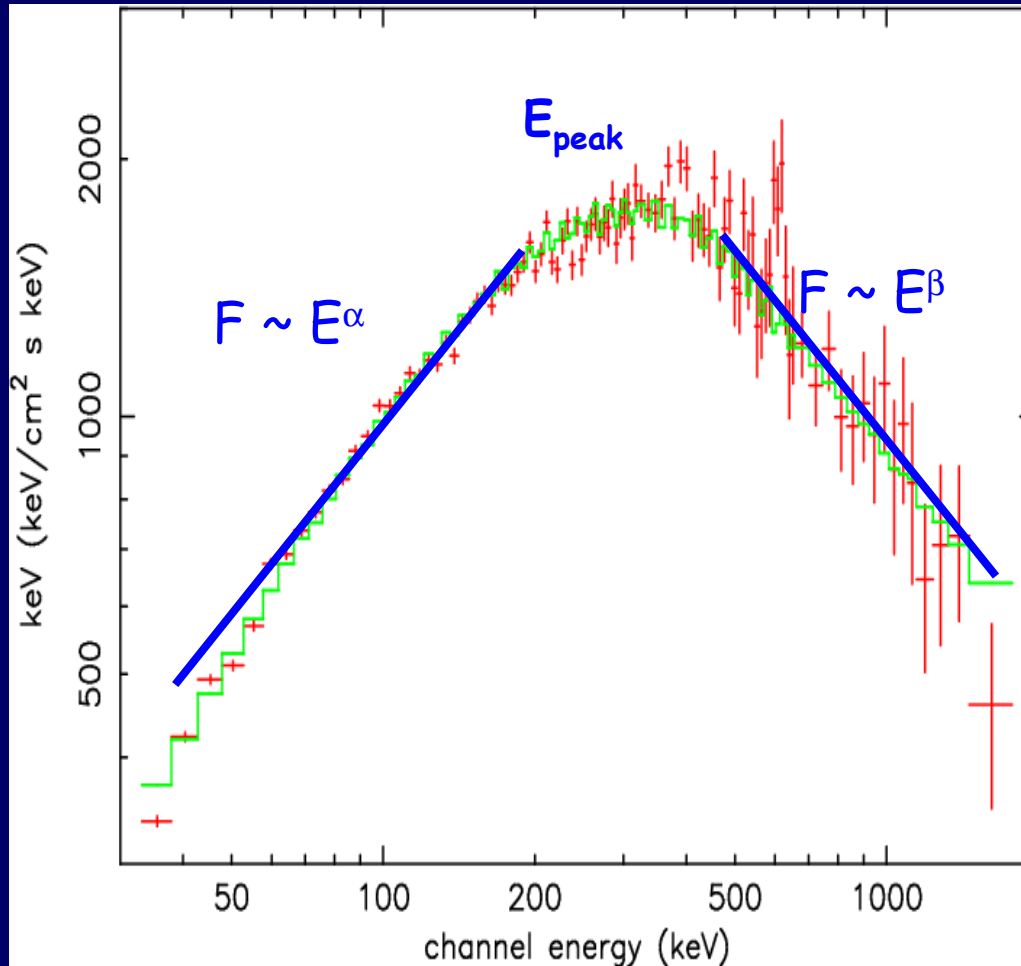


Spectral hardness



Bimodality in duration: different origin?

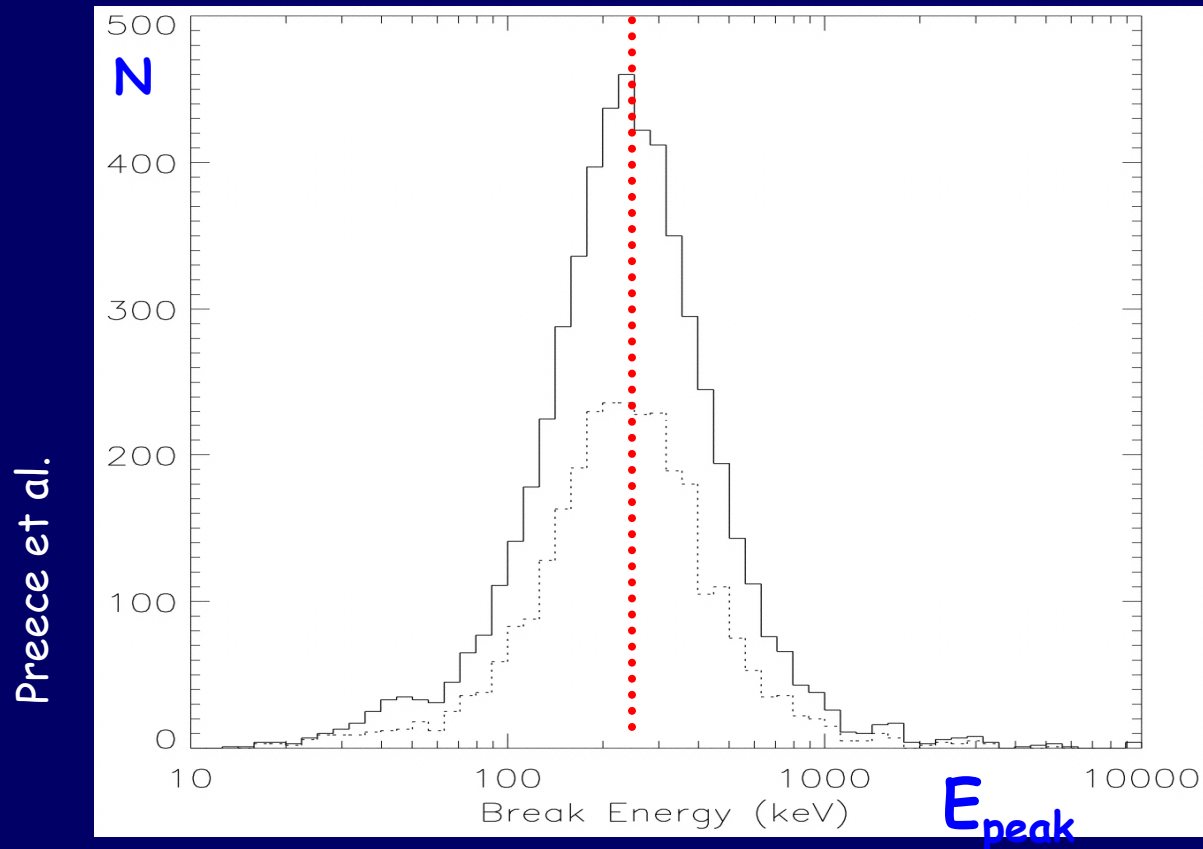
Spectral properties



featureless continuum
power-laws - peak in νF_ν

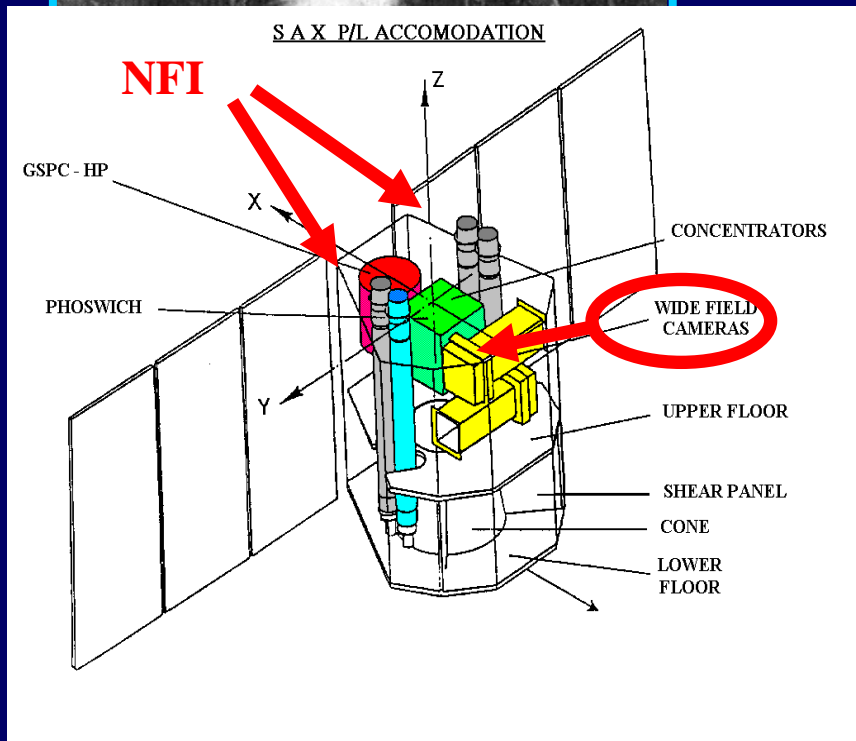
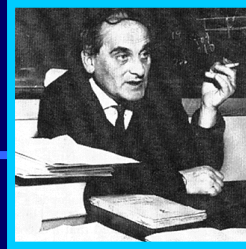
Non thermal spectra

Spectral properties: E_{peak}



Typical $E_{\text{peak}} \sim 250$ keV (observer frame)

1997: The SAX satellite



Italian-Dutch

"Satellite per l' Astronomia X"

Instruments

Wide Field Cameras:

5% of sky - positioning ~ 3'

+

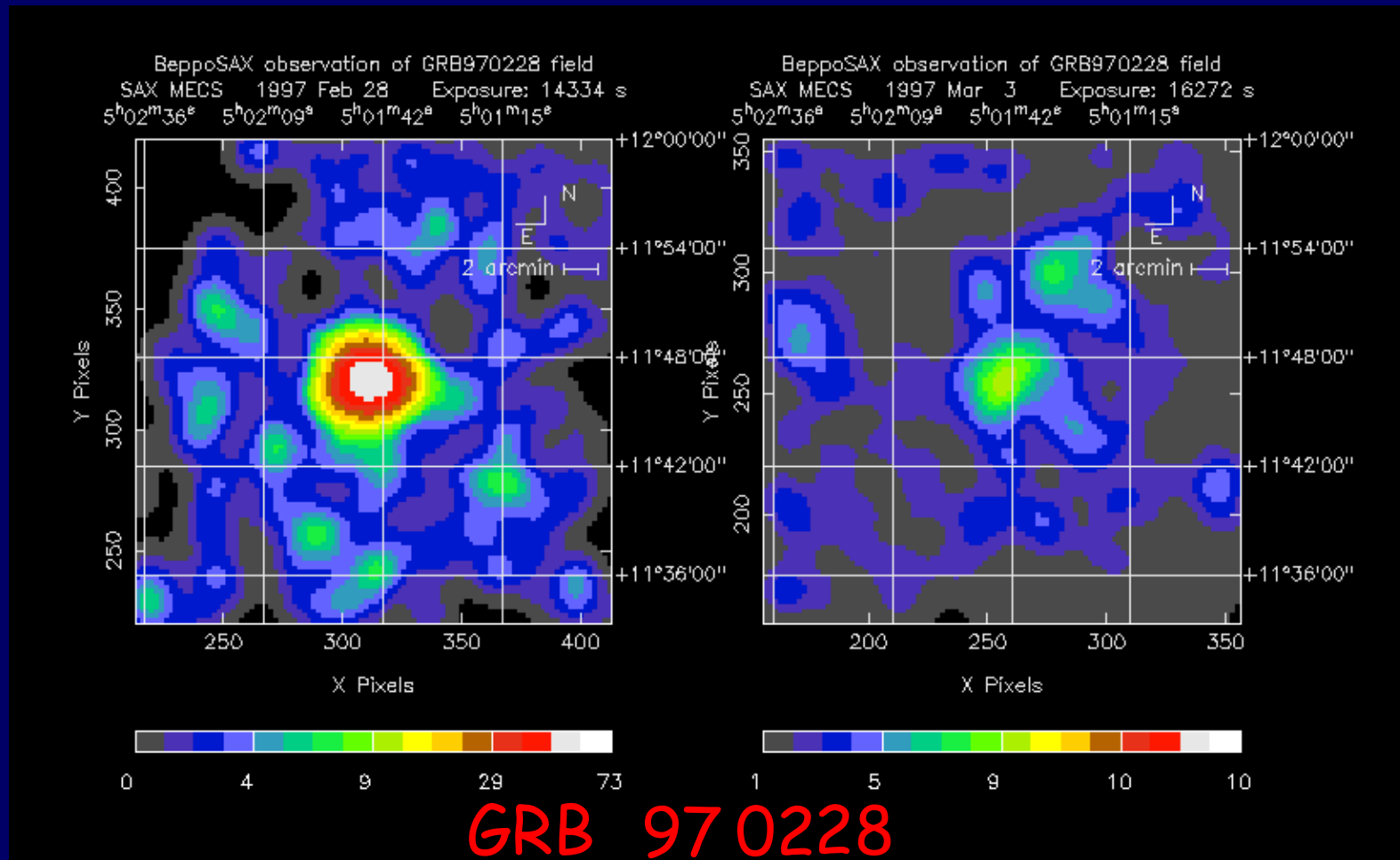
Narrow Field Instruments

tens arcmin resolution

Slewing in several hours

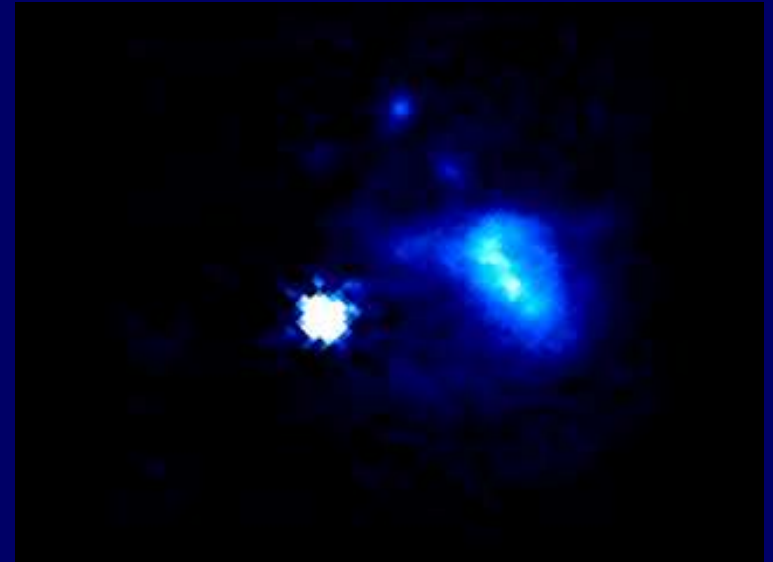
Discovery of first afterglow!

3 March



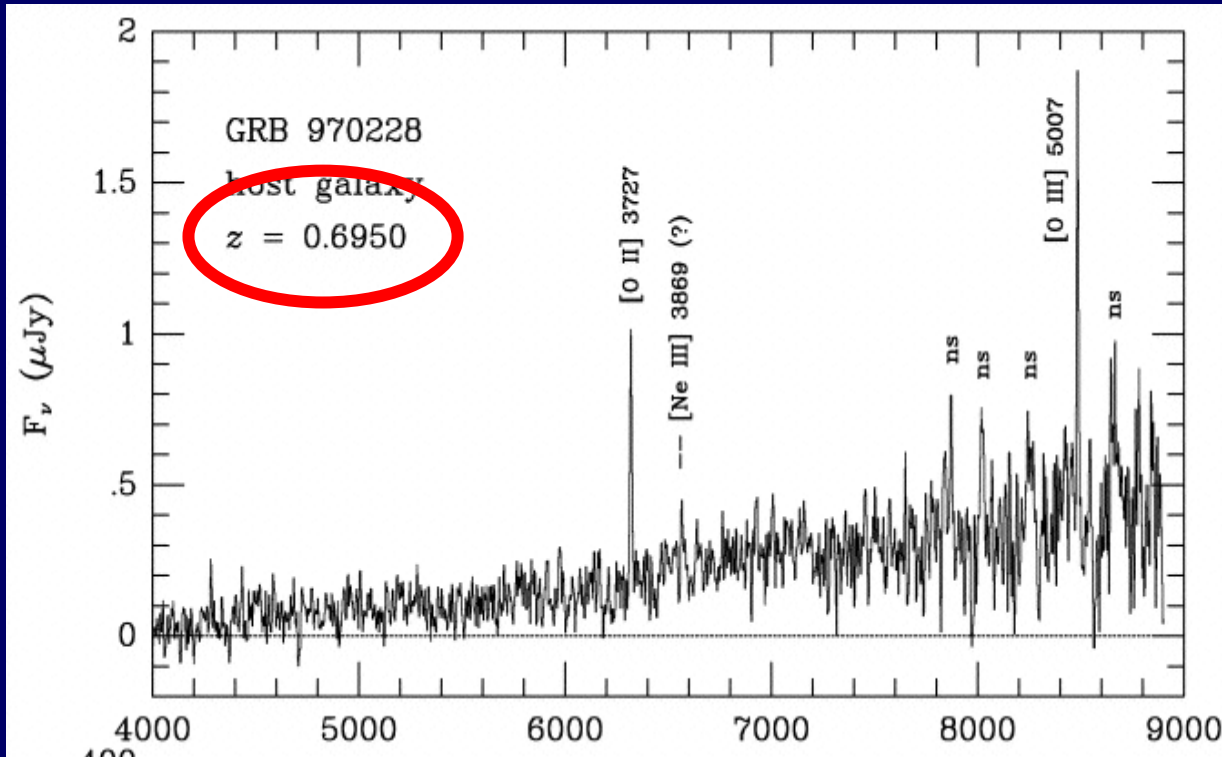
Optical afterglows

GRB localization



Fading optical transient

Optical id. host galaxy: redshifts



Cosmological origin !

~70 / 3000 with z : <0.1 - 6.3

(Batse, SAX, HETE-II, Integral, Swift, ...)

Energetics

$$E \sim 10^{54} \text{ erg} \sim M_{\text{sun}} c^2 \quad \rightarrow \quad \text{SN like event}$$

Variability: $t \sim \text{ms}$

$$R \sim t c \sim 3 \cdot 10^7 \text{ cm} \sim 10 R_s \text{ for } M_{\text{BH}} 10 M_{\text{sun}}$$

Large energy release in small volume

Isotropic equivalent energy 10^{49} - 10^{54} erg

Relativistic motion

Compactness problem:

$$\tau_{\gamma\gamma} \sim (L/R^2) R \sim L/R \gg 1 \quad \text{for photons above threshold}$$



Fast variability

$$R_{\text{tr}} \sim 10^{13} \text{ cm} \rightarrow t \sim R/c \sim 300 \text{ s}$$

while observed $t \sim \text{ms}$

Both issues accounted for if plasma is in relativistic motion $\Gamma \sim 300$

Fireball

Large energy release in small volume \rightarrow Fireball

- Thermal equilibrium: $\gamma\text{-}\gamma \leftrightarrow e^+ e^-$
- High pressure \rightarrow Adiabatic expansion \rightarrow Acceleration
- $T \sim 50 \text{ keV}$: $\gamma\text{-}\gamma \leftarrow e^+ e^-$
- Transparency

But temporal and spectral properties

Toward a 'standard' scenario

Non-thermal spectra → Dissipation in optically thin regime

Thermal fireball energy

→ Kinetic energy (baryon pollution)

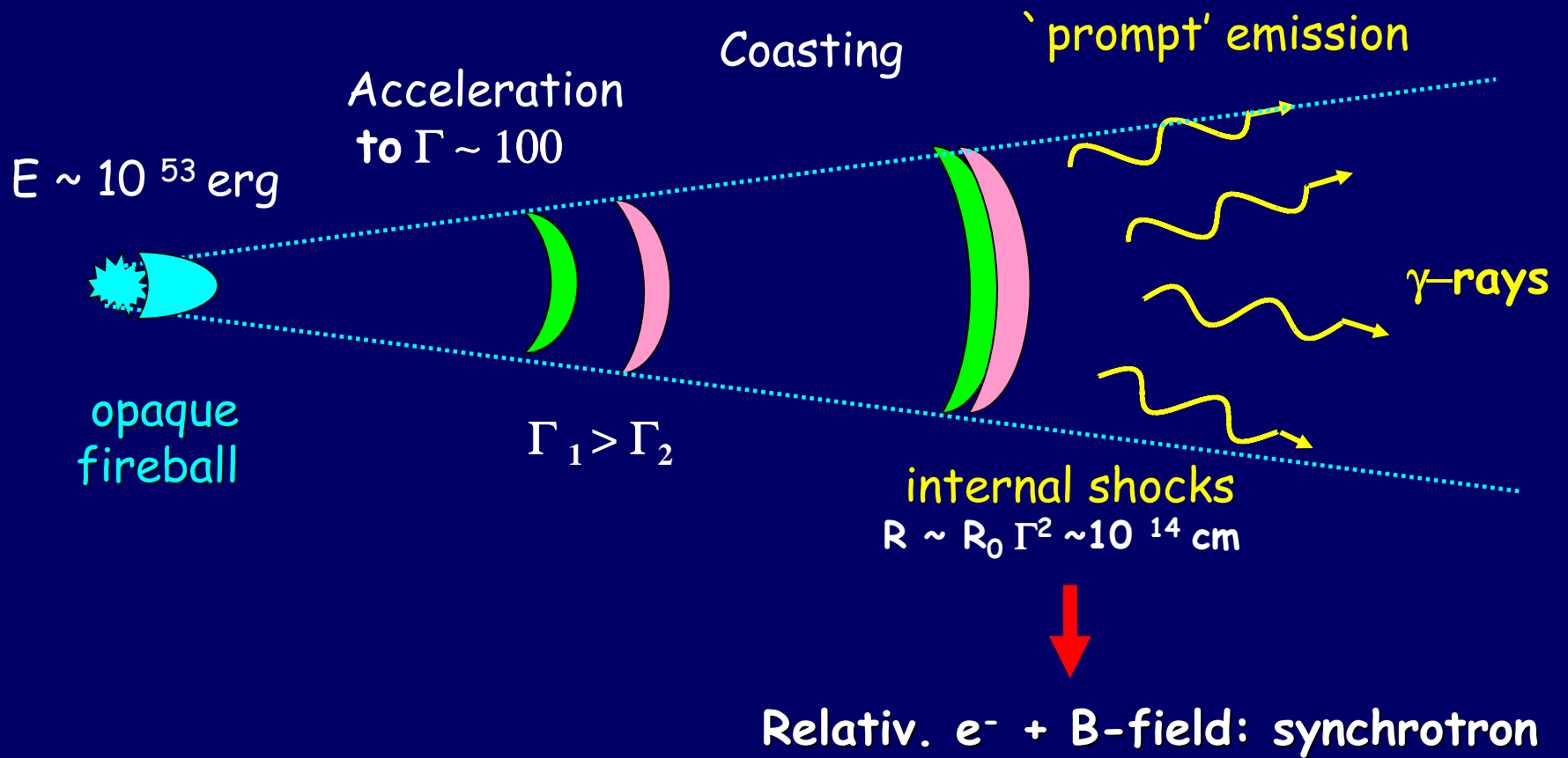
→ Kinetic energy dissipation

Constant pulse width → Repetition of same process

Internal shocks due to flow inhomogeneities

→ Relativistic particle acceleration

→ Synchrotron emission



Typical synchrotron frequency

$$\nu_{\text{syn}} = 3.6 \times 10^6 B \gamma^2 \Gamma / (1+z) \text{ Hz}$$

Magnetic field: $L_B = \epsilon_B L_{\text{kin}} \rightarrow R^2 \Gamma^2 B^2 c = \epsilon_B L_{\text{shell}}$

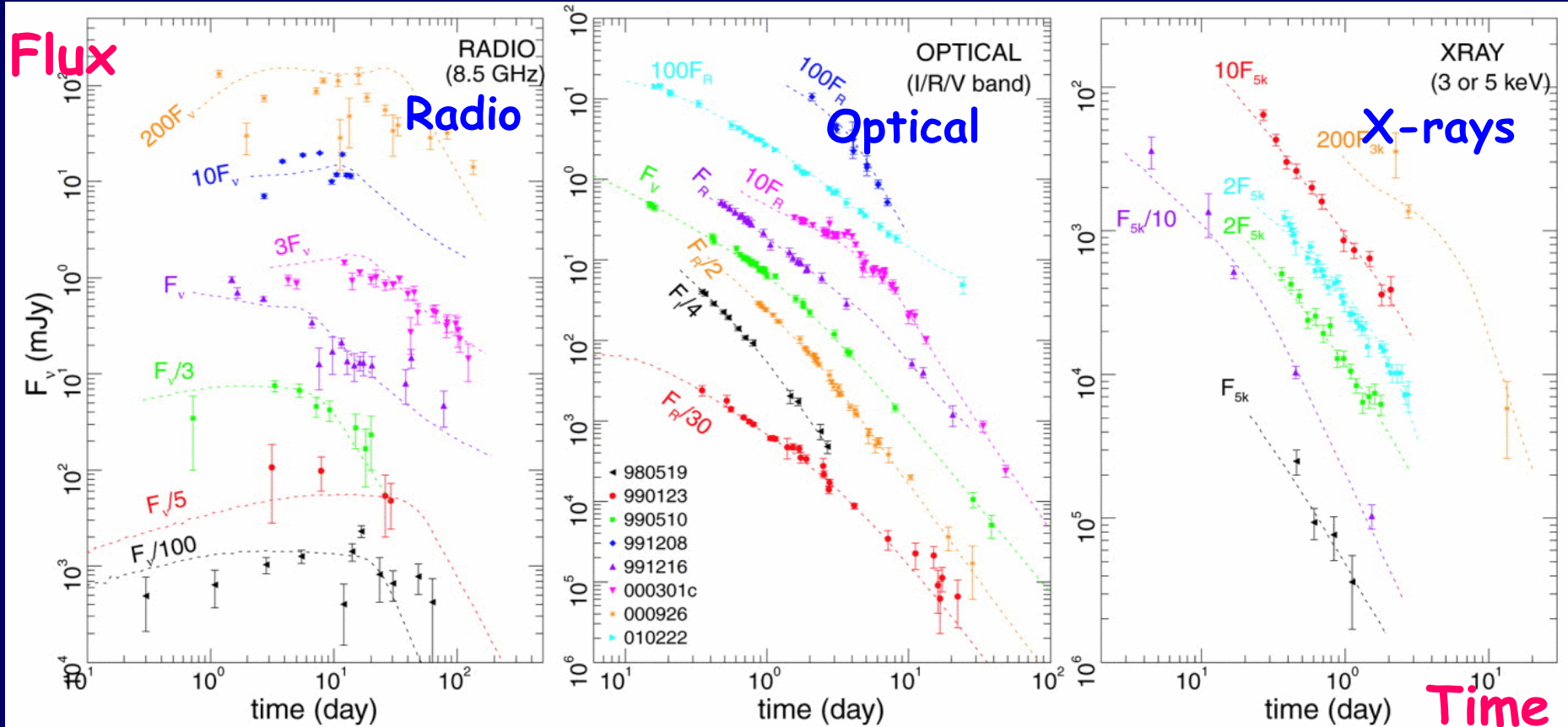
Size: $R \sim R_0 \Gamma^2$ (internal shock)

Electron energy: $\gamma m_e c^2 = \epsilon_e m_p c^2 (\Gamma' - 1) \sim \epsilon_e m_p c^2$

$$h\nu_{\text{syn}} \sim 400 \text{ keV} \frac{\epsilon_B^{1/2} \epsilon_e^2 L_{\text{kin,shell}}^{1/2}}{\Gamma^2 R_{0,7} (1+z)}$$

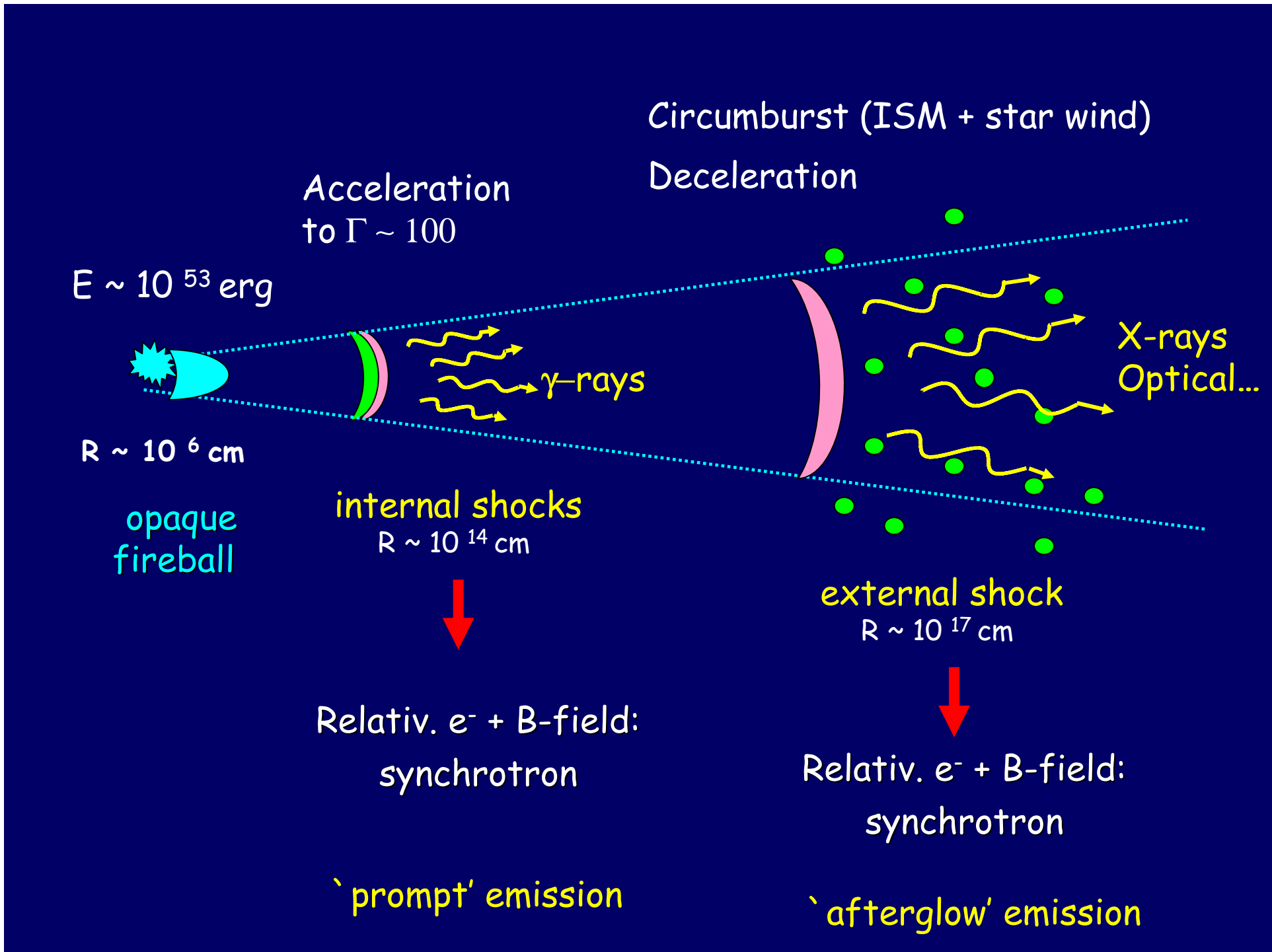
Afterglow emission

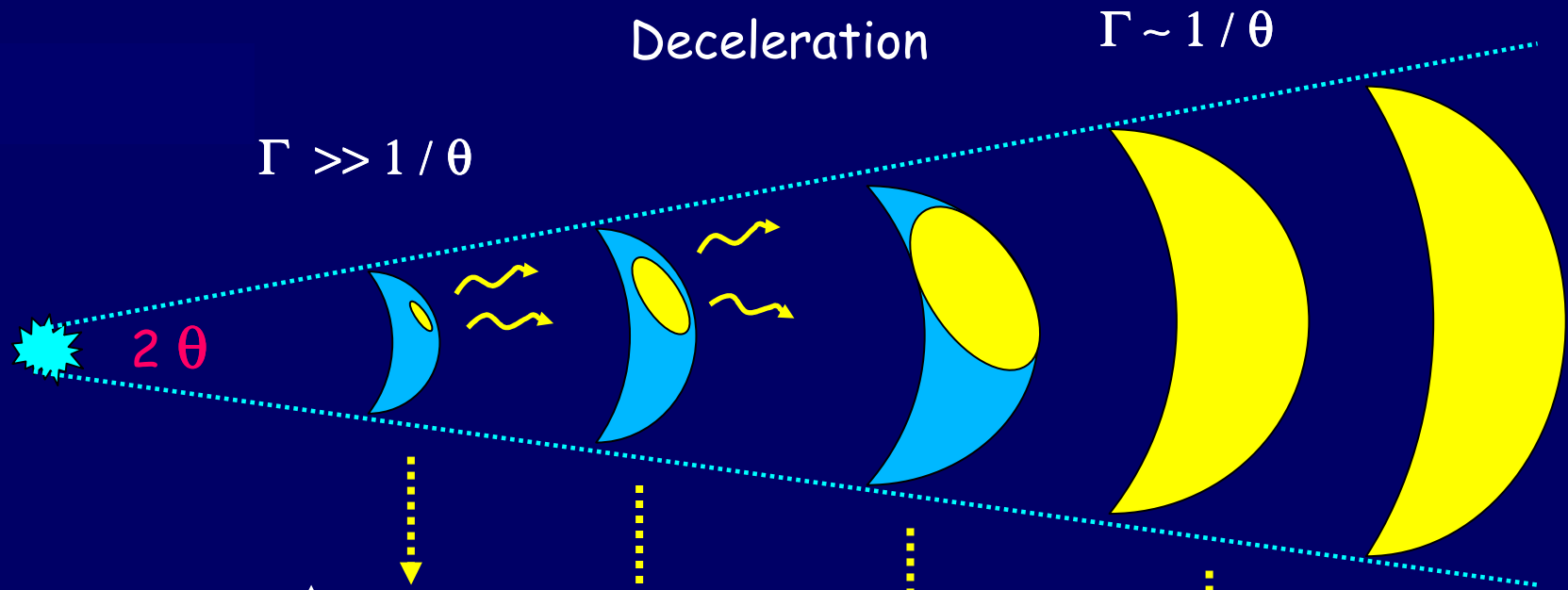
Panaitescu & Kumar



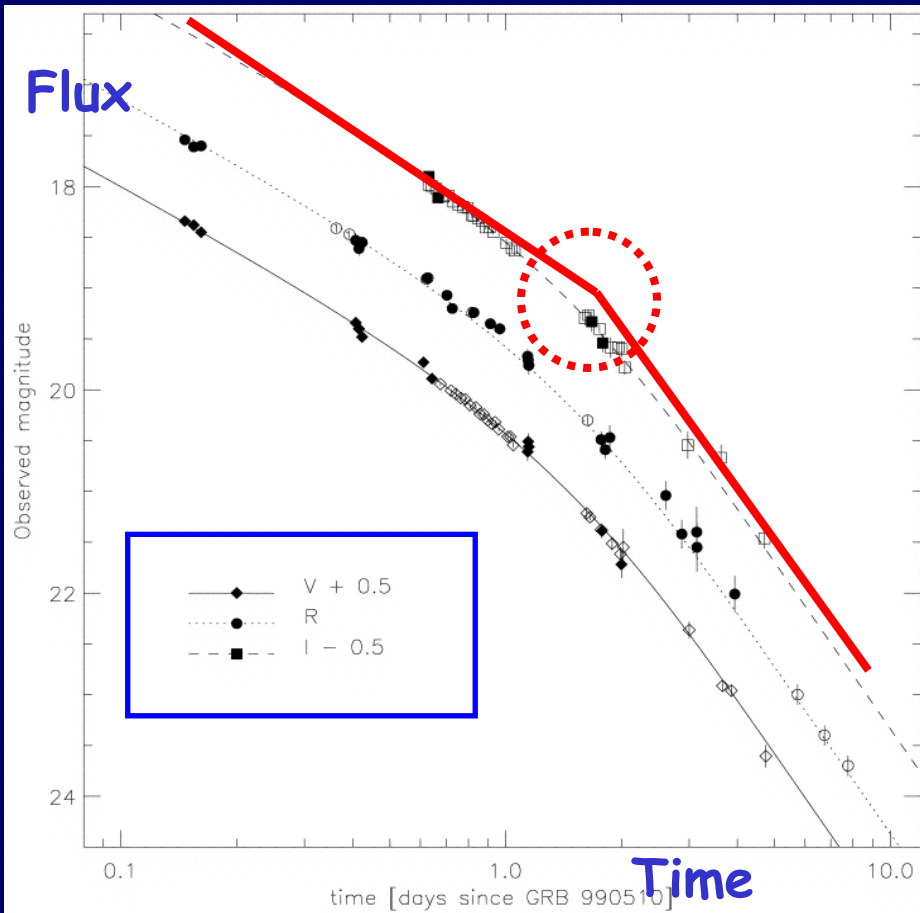
External shock = shock onto circumburst gas

Deceleration when $M_{ISM} \sim m/\Gamma$





Collimated outflows?

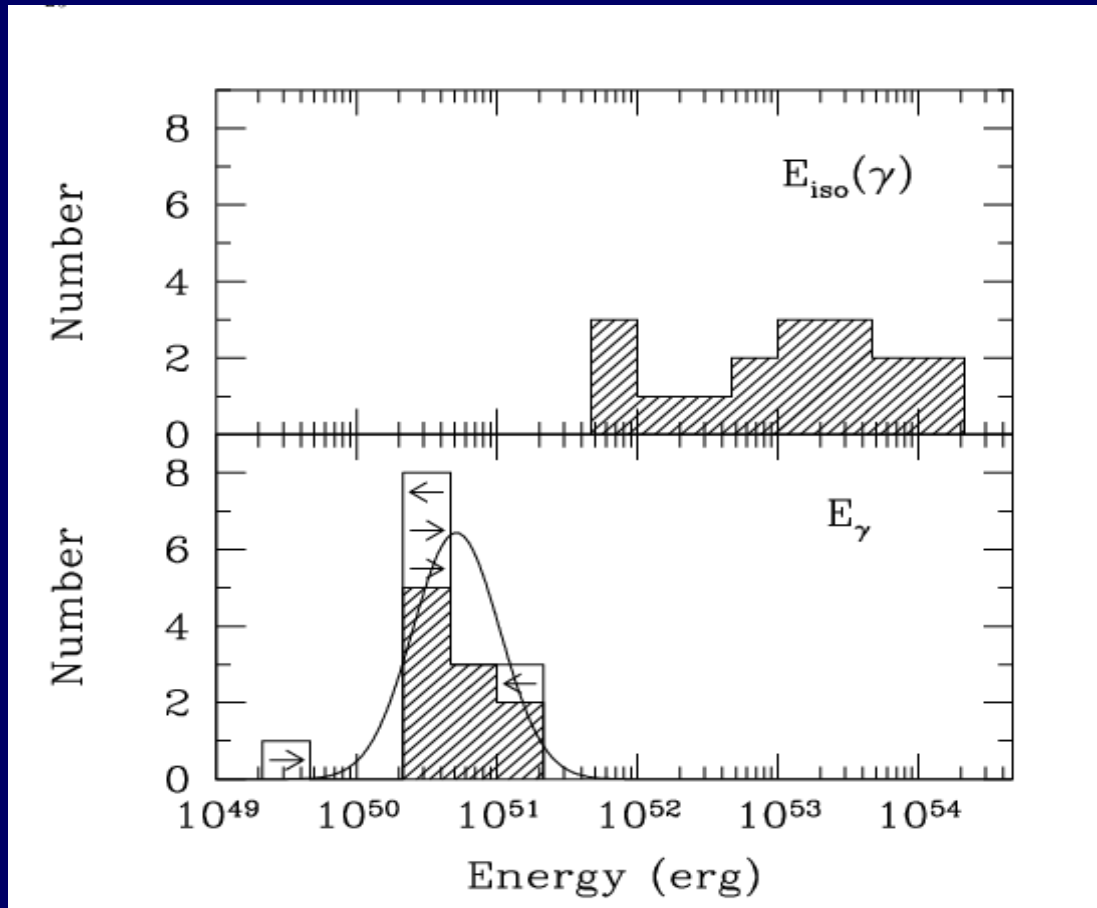


Achromatic breaks:
evidence for
collimated outflows
= Jets

Intrinsic energy

t_{break} 'measures' θ

$$E = E_{\text{iso}} (1 - \cos \theta)$$

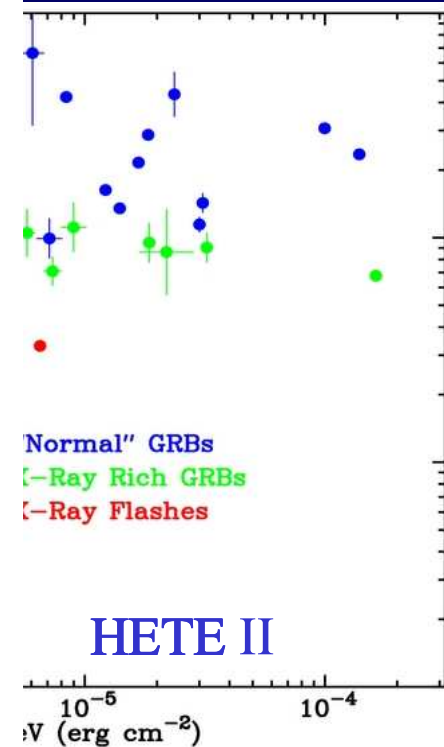
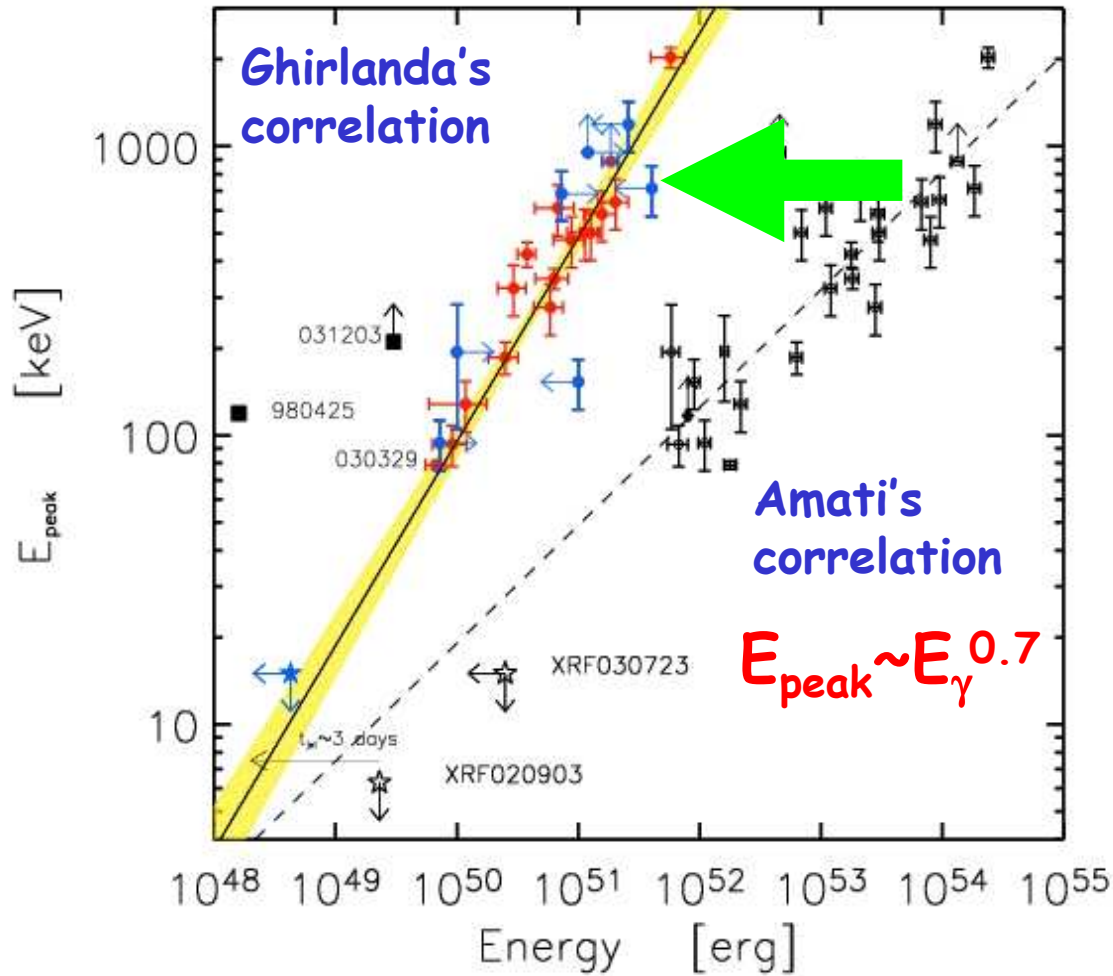


Frail et al. 2001

All same intrinsic energy ?

Standard candles ?

Ghirlanda, Ghisellini, Lazzati 2003



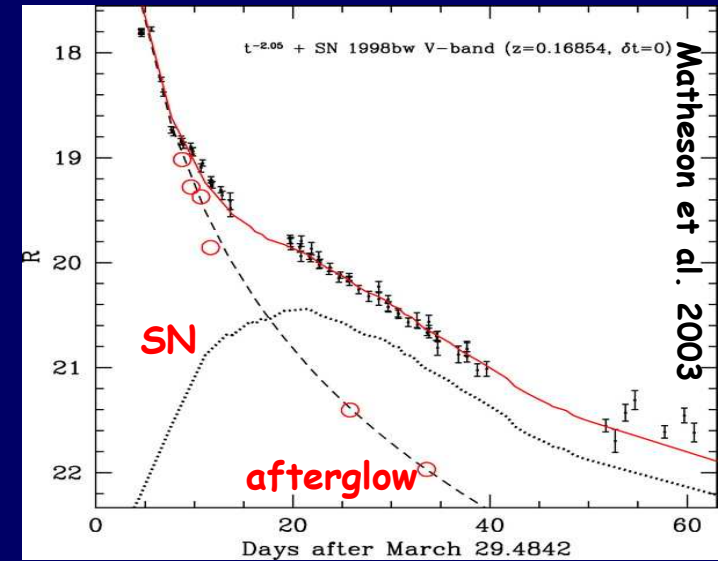
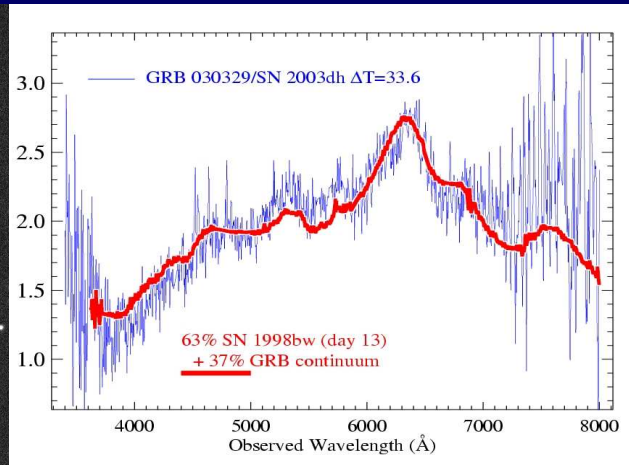
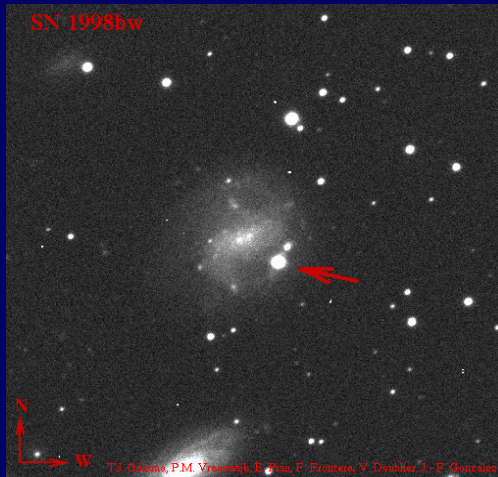
ess?

ard

candles ?!

Progenitors

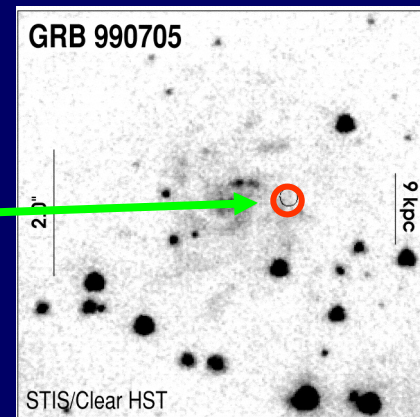
GRBs associated with SN (Ib,c)



A few spectroscopic ident (underluminous?) Afterglow re-brightening

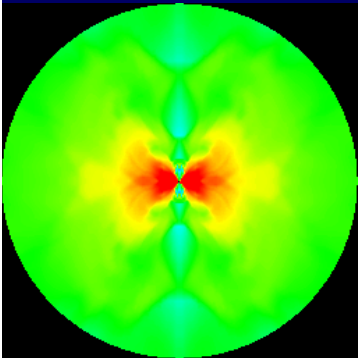
Host galaxies

- Faint ($m_R \sim 25$) galaxies
- Sites of star formation
- Low metallicities



Bloom et al. 2002

Progenitors



core collapse of massive stars ($M > 30 M_{\text{sun}}$)
long GRBs

Collapsar or Hypernova

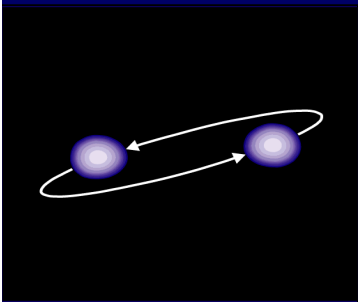
(MacFadyen & Woosley 1999)

GRB simultaneous with SN

Supranova - two step collapse

(Vietri & Stella 1998)

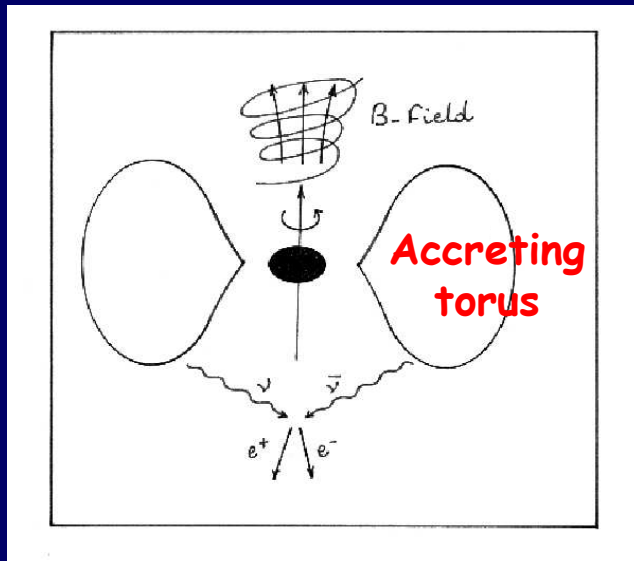
GRB delayed by few months-years



compact object mergers (NS-NS, NS-BH)
short GRBs

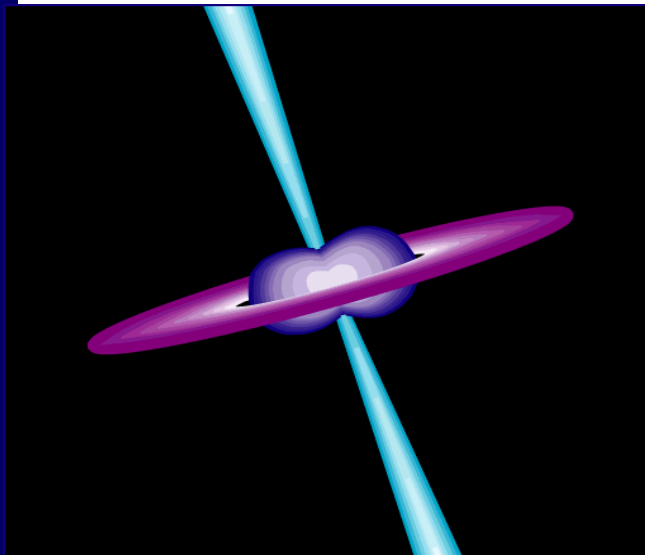
Discriminants: host galaxies, location within host, duration, environment, redshift distribution, ...

The engine



Formation of a spinning BH + dense torus,
sustaining $B \sim 10^{14}\text{-}10^{15}$ G

Extraction BH spin energy ($0.29 M_{\text{BH}} c^2$)



Extract $E > 10^{52}$ erg

$t_{\text{GRB}} \sim 10^4 t_{\text{dyn}}$

Is the standard scenario OK?

Efficiency?

Typical E_{peak} ?

Hard-to-soft evolution ?

Non-thermal spectra?

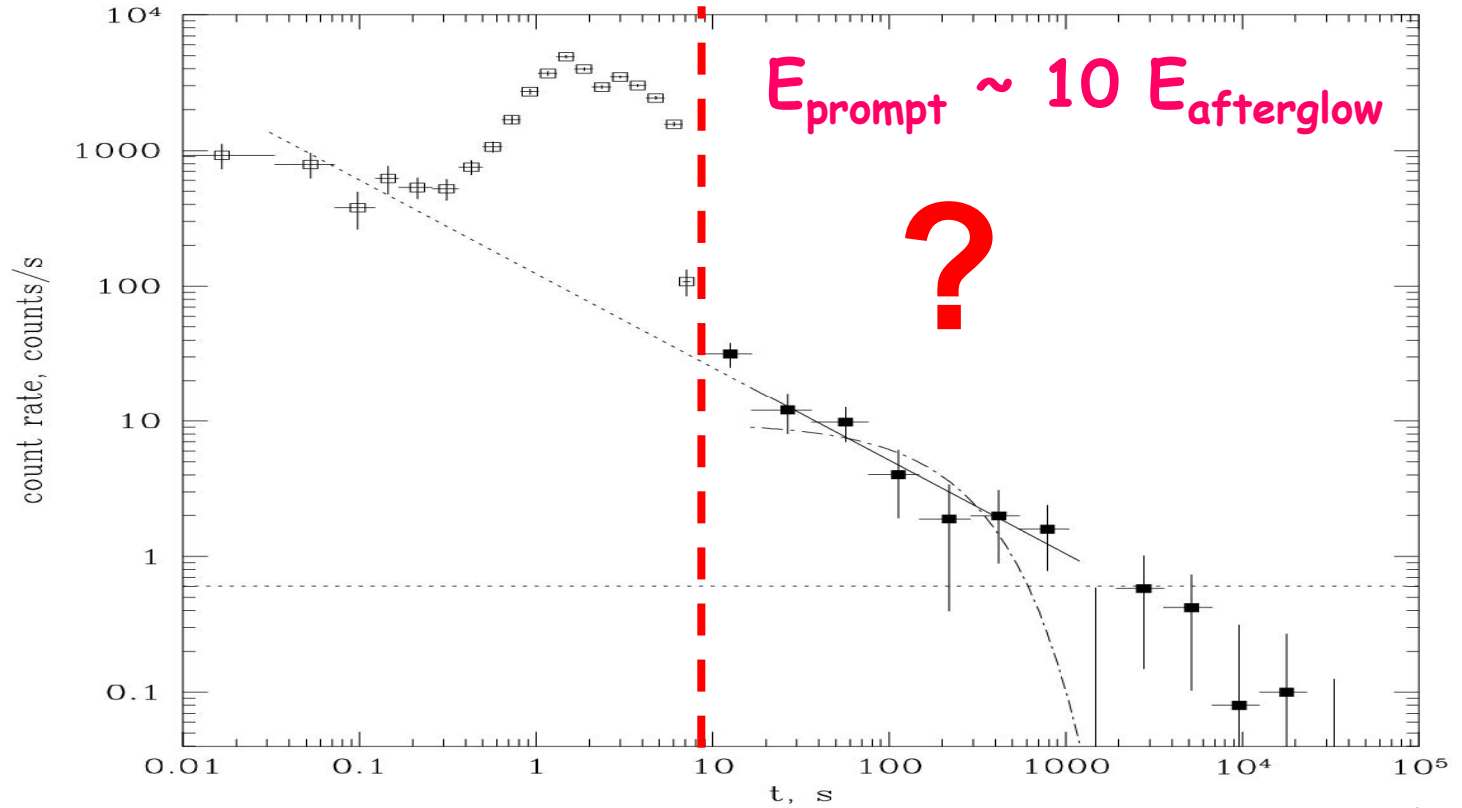
Is the standard scenario OK?

Efficient

Typical

Hard-to

Non-the



Burenin et al.

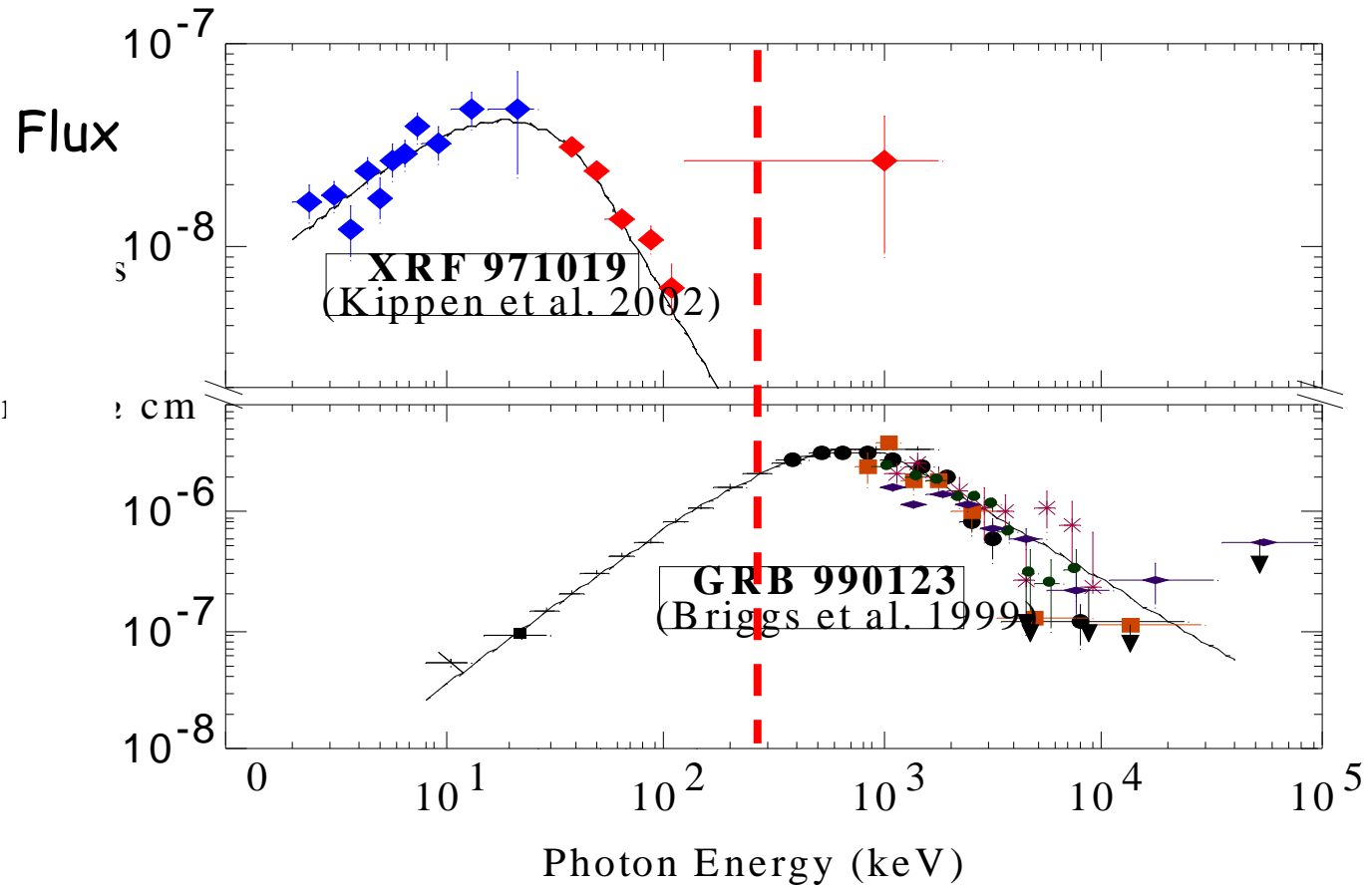
Is the standard scenario OK?

Efficient

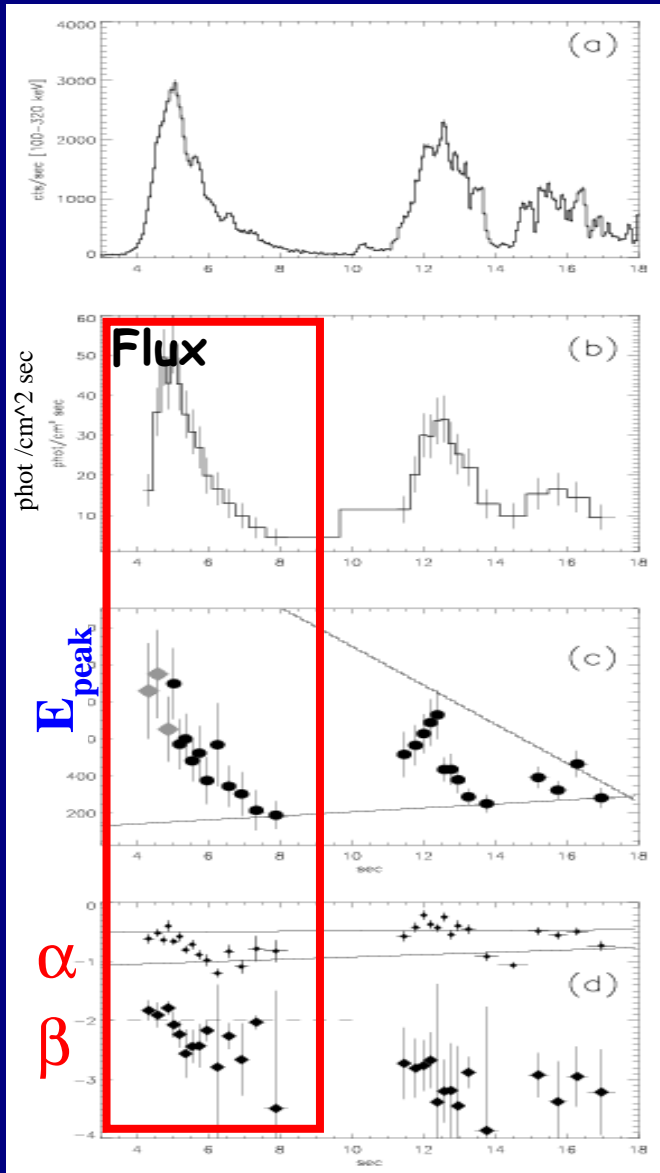
Typical

Hard-to

Non-the



In the standard scenario OK?



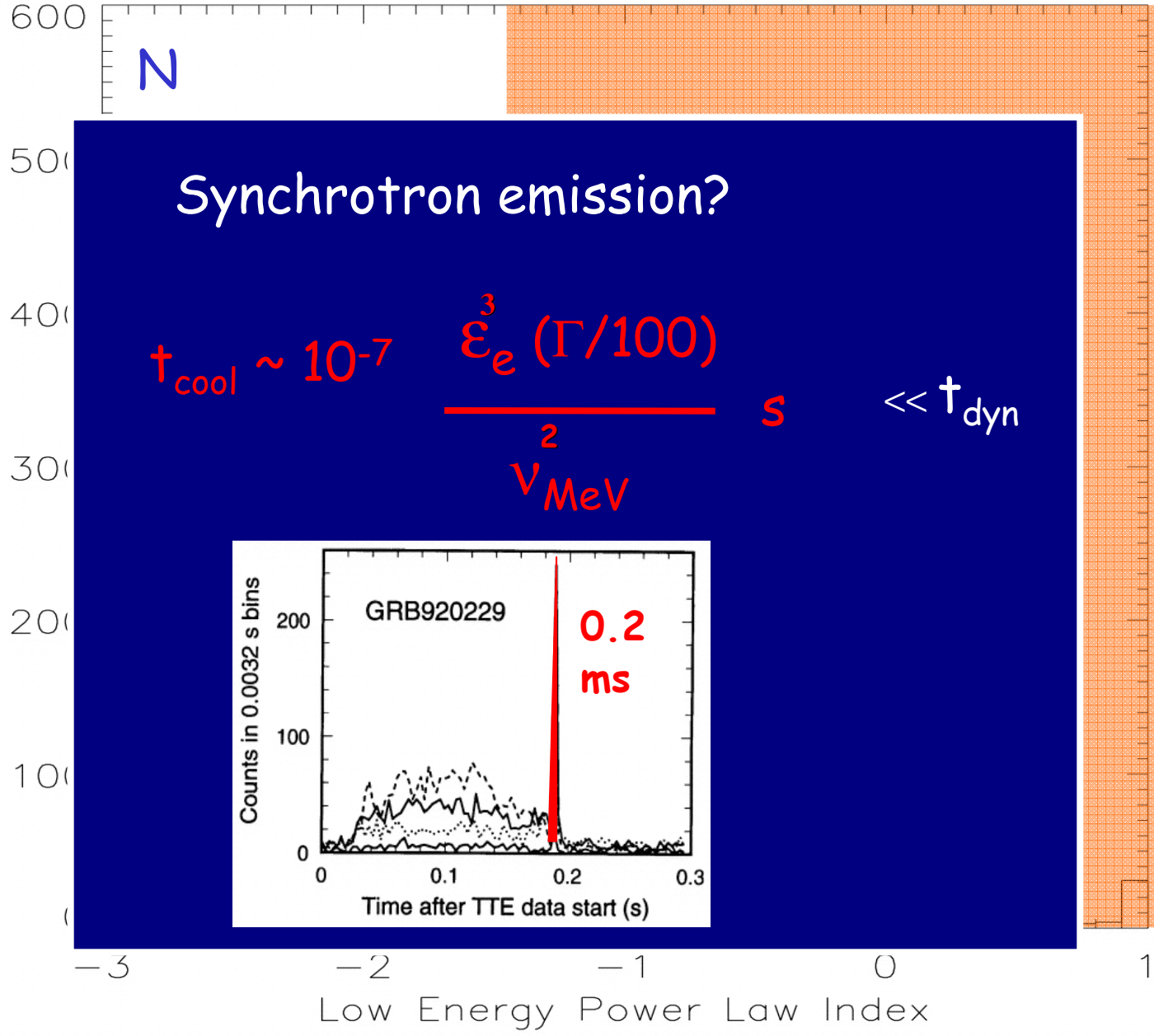
Hard to Soft evolution

E_{peak} , $\alpha(t)$, $\beta(t)$ decrease independent of flux

Internal shocks should be similar: why spectral evolution?

M
H
T
Z

In the standard scenario OK?



of

thro:

v

Is the standard scenario OK?

Efficiency?

Typical E_{peak} ?

Hard-to-soft evolution ?

Non-thermal spectra?

Alternatives: Thermal comptonization/Compton drag...
Cold fireball/El.m. energy transport...

Why to bother further?

Physics:

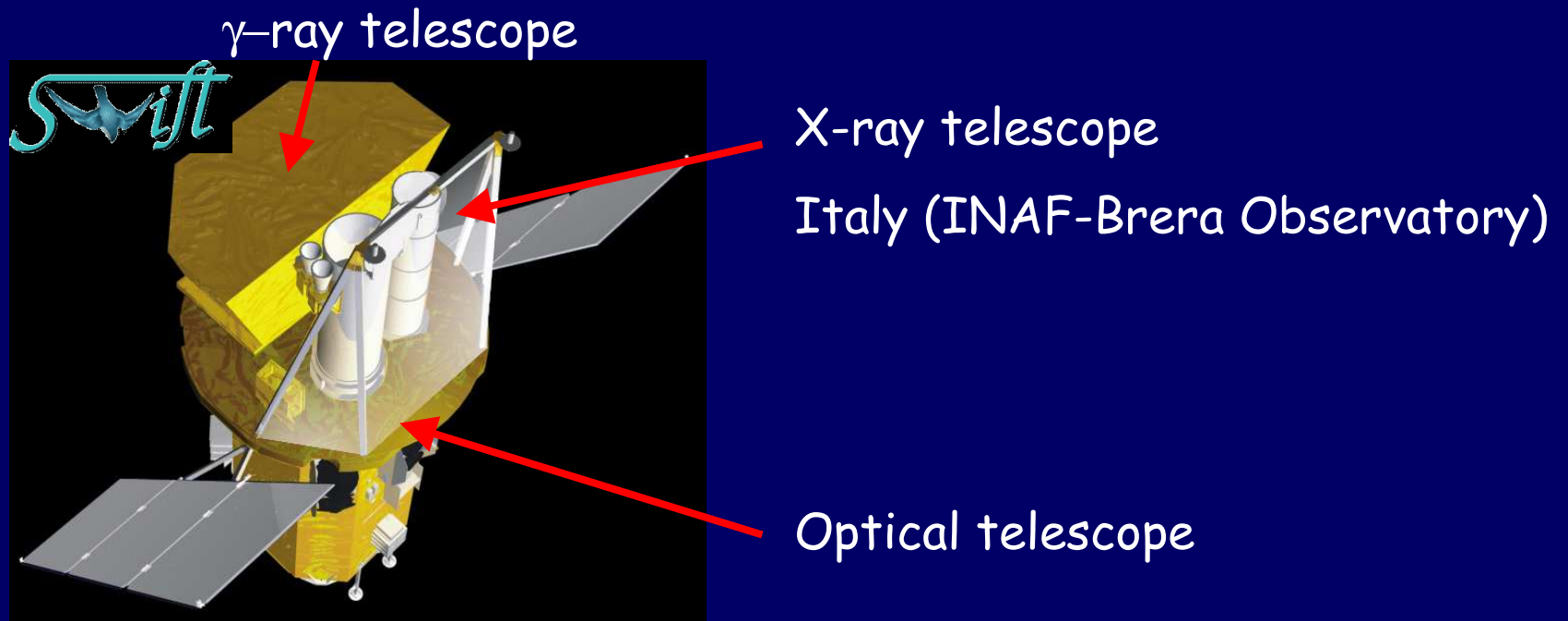
- extreme relativistic fluid
- black hole formation + energy extraction
- evolution of massive stars

Cosmology:

- $z = 6.3 \rightarrow$
- IGM
 - Star Formation first objects

Cosmological parameters: GRBs standard candles?

2003: The Swift satellite



- GRB at $z=6.3$
- Short localization (redshift, host, afterglow...)
- Afterglows at early times
- ...

Some open issues

- Nature of fireball and dissipation
- The powerhouse: energy extraction
- Connection with SN (1% of Ic?) Supranovae? Rates?
- Reality/origin of energetics relations ?
- High redshift GRBs
- Short GRBs
- Density of circumburst matter - lines?
- Dark GRBs
- Orphan GRBs
- Structure of jet
- Luminosity/collimation angle evolution?
- ...

With help of SWIFT & GLAST plus

Neutrinos - UHECR - GW ...

Thank you !