Gamma -Ray Bursts: A personal View and Some New Developments

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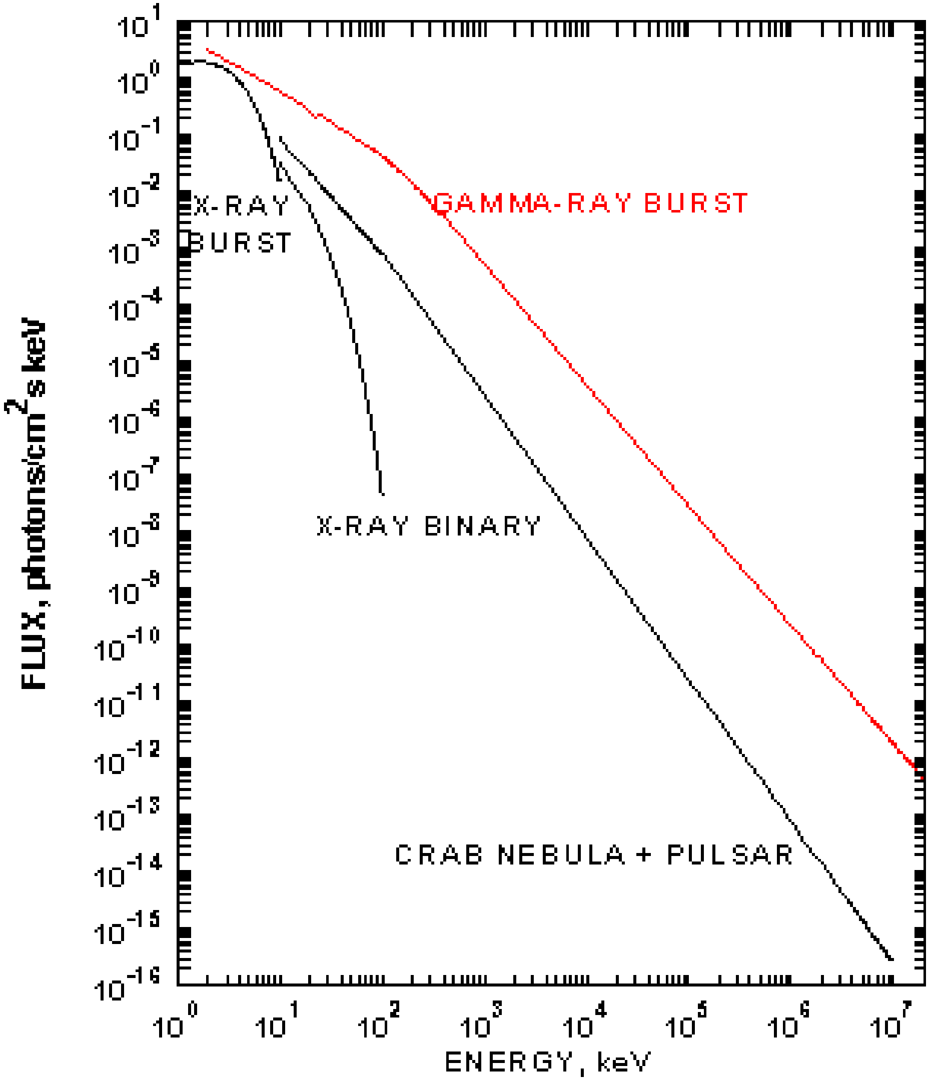
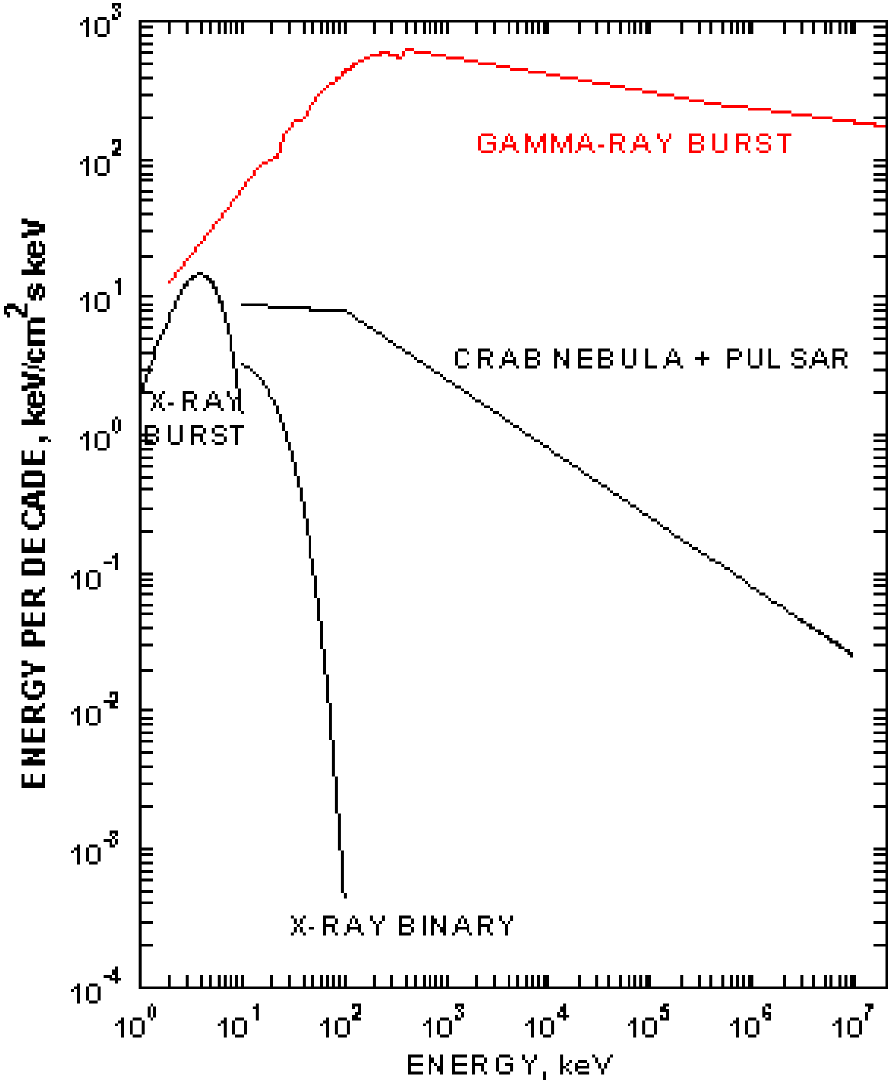
GRBs: Some General Facts

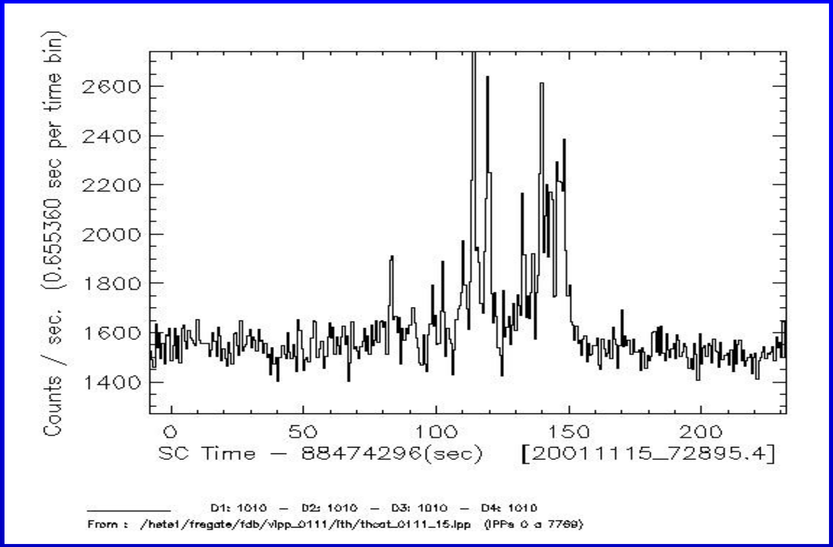
- Transient Cosmic Phenomena, of totally unknown origin, until recently.
- Flux: 10^{-8} - 10^{-5} *erg/ cm*^{2} *sec*
- Duration: *~0.1 - 100's sec*
- Spectra: Apparently thin, $E^{-\alpha}\, e^{-E/kT}$ *(a~1, kT~100 keV)*; different more recent parameterization: power law rather than exponential form above the peak energy

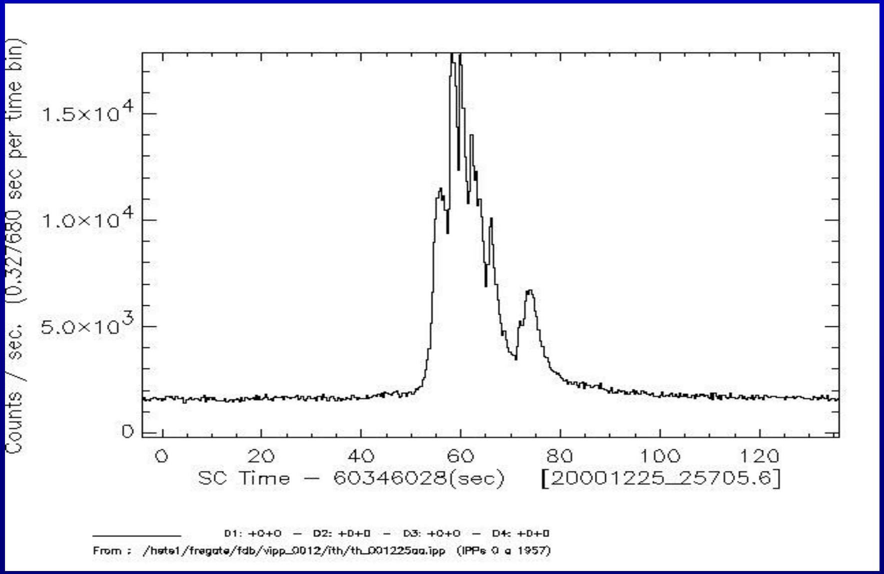
GRB ENERGY SPECTRA

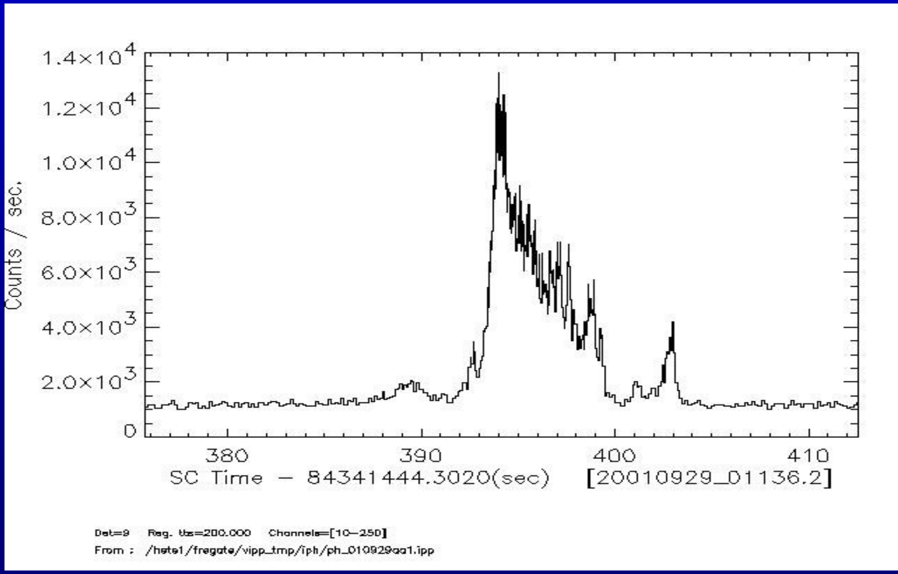




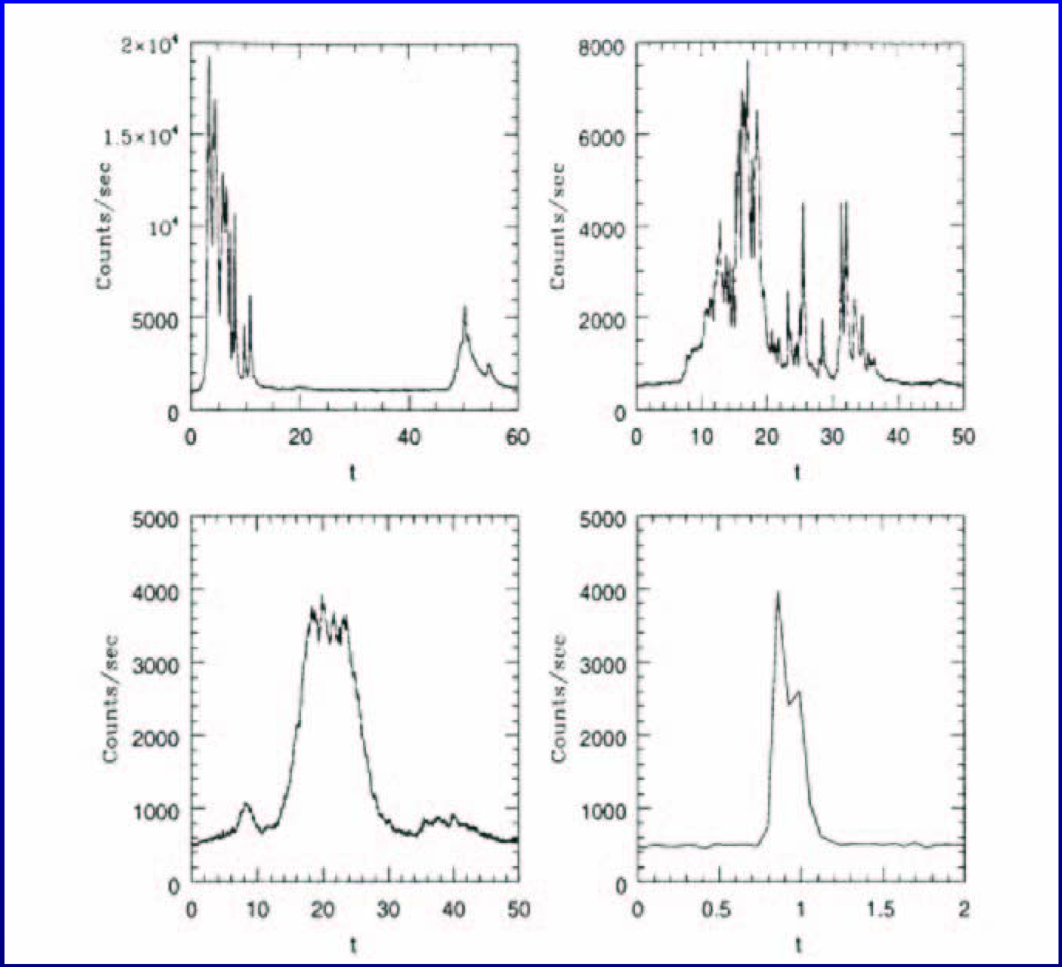
- Light curves exhibit extreme variety and variability







- Variety of GRB light curves



- The first suggestion of the cosmological origin of GRBs was made by Edward Teller in the mid-late 80’s.
- The corresponding luminosity would then be $L \sim 10^{-5}\, 10^{56}\, (R/1\ Gpc)^{2} = 10^{51}$ erg/sec.
- Assuming emission from the surface of a neutron star, one can compute the temperature (Paczynski 86)

$$T = \left(\frac{L}{\sigma 4 \pi R^2} \right)^{1/4} \approx 10^{11} K \left(\frac{L_{51}}{R_6^2} \right)^{1/4}$$

- The mean energy per particle turns out to be of the correct order of magnitude!
- The spectrum however cannot be the (apparently) thin observed one
  - The compactness parameter *L/R* which provides an estimate of the Thomson depth, gives $\tau \sim (L/R \,/\, 10^{29}) \sim 10^{15}$ *!!*
  - *The spectrum has to be black body*
- The emitting region must be dynamic. The dynamics of the emitting plasma are given by the conservation laws (Paczynski 86).

- $4\pi r^2 \Gamma n c \beta = \dot{M}$ Mass flux
- $4\pi r^2 \Gamma^2 w c \beta = \dot{E}$ Energy flux
- $w = p + \varepsilon + nmc^2$ Enthalpy

- The ratio of energy and mass fluxes gives the Bernoulli integral of relativistic flows

$$\frac{w\Gamma}{n} = \text{constant}$$

$$\text{for} \quad p, \varepsilon >> nmc^2, \; w \cong \varepsilon = aT^4, \; \gamma = \frac{4}{3}$$

$$\text{also} \;\; pV^{\gamma} = \text{const.} \quad \Rightarrow \quad aT^4 (R^2\Gamma)^{4/3} = \text{const.}$$

$$T^3 \propto \frac{1}{R^2\Gamma}, \qquad \frac{w\Gamma}{n} \propto \frac{T^4\Gamma}{R^{-2}\Gamma^{-1}} \Rightarrow T^4 \propto \frac{1}{R^2\Gamma^2}$$

$$\Downarrow$$

$$T \propto \frac{1}{R} \qquad \Gamma \propto R \quad \text{and} \qquad \Gamma \cdot T = \text{const.}$$

- T is the temperature in the fluid rest frame

- In a relativistic thermal, expanding gas:
  - The Lorentz factor increases linearly with distance (internal energy converts into directed one).
  - The rest frame temperature drops linearly with distance.
  - The apparent temperature (viewed by a head-on observer) ΓT remains constant.
  - The increase in Lorentz factor with distance stops when the gas becomes non-relativistic in its rest frame.
  - Then it coasts and slows down as it accumulates matter from the ambient medium.

- For an impulsive deposition of roughly 10^{51} ergs of energy on the surface of a neutron star:
  - The energy density would be dominated by electron-positron pairs.
  - The spectrum would be close to thermodynamic equilibrium (black-body) of temperature ~ 1 MeV.
  - The expansion of the gas would leave the temperature invariant.
  - The time scale of the explosion would be roughly $R_{NS}/c \sim 10^{-3}$ *sec*.

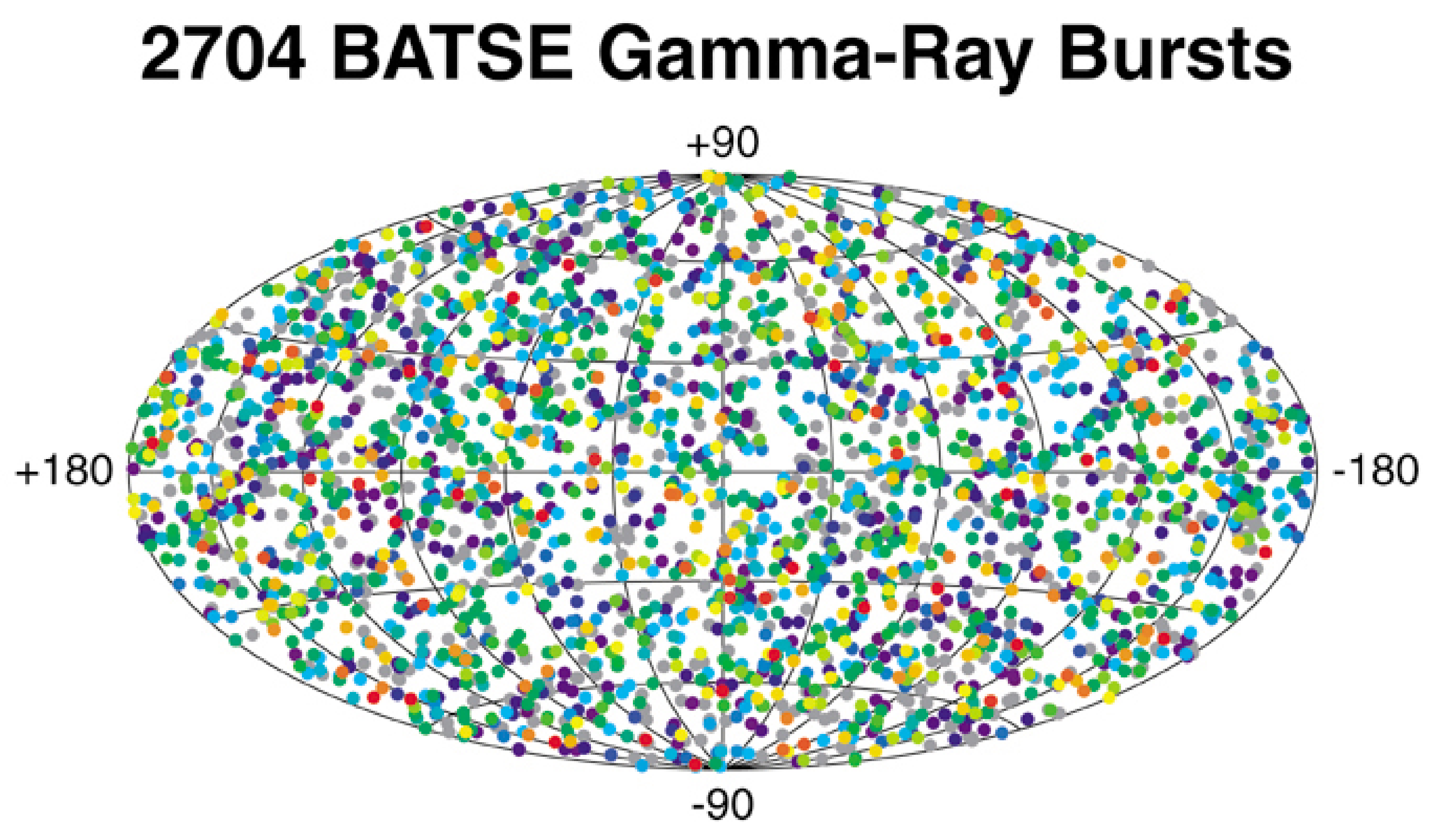
- In the presence of only pairs, the expanding gas would be in pair equilibrium only until a temperature $T \sim 30$ keV, i.e. to a distance $R \sim (10^{11\text{-}12}\ \mathrm{K}/30\ keV)\ R_{NS}$
  - Then the pairs would annihilate, the photons would escape and burst would end.
- A much slower energy injection would lead to photon energies different from those of GRBs (cannot work for galactic GRB).
  - The most serious issue is the prompt injection of energy at the required rate.

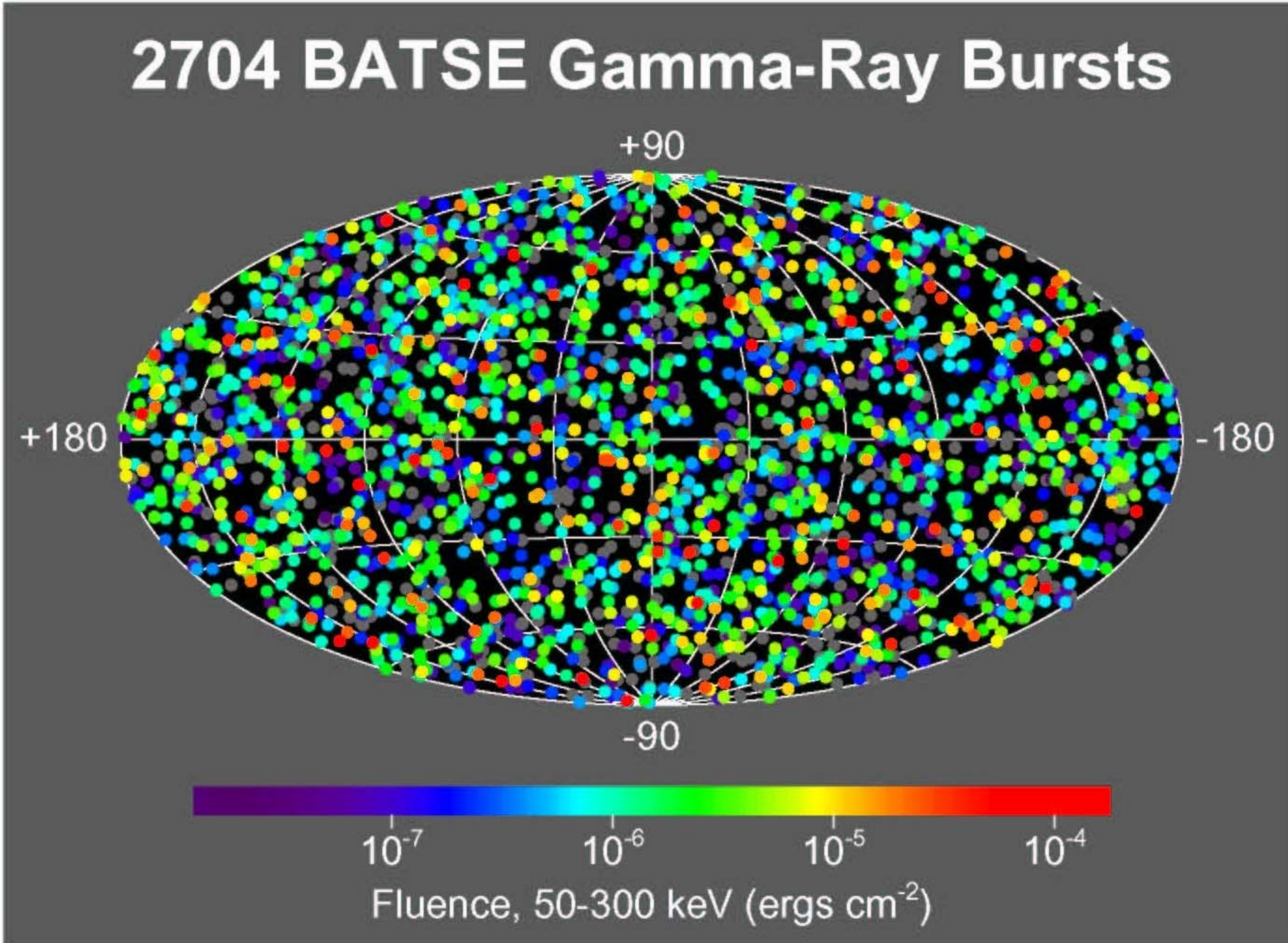
- The energy deposition rate has been and continues to be one of the main unresolved issues in understanding GRBs.

- Electron-positron pairs from neutrino - anti-neutrino annihilation in a hot neutron star could provide the required hot plasma
  - Goodman, Dar, Nussinov and Ramaty applied this to SN explosions (88).
  - Shemi, Eichler, Piran, and Schramm thought of applying this to colliding neutron stars to produce GRBs.

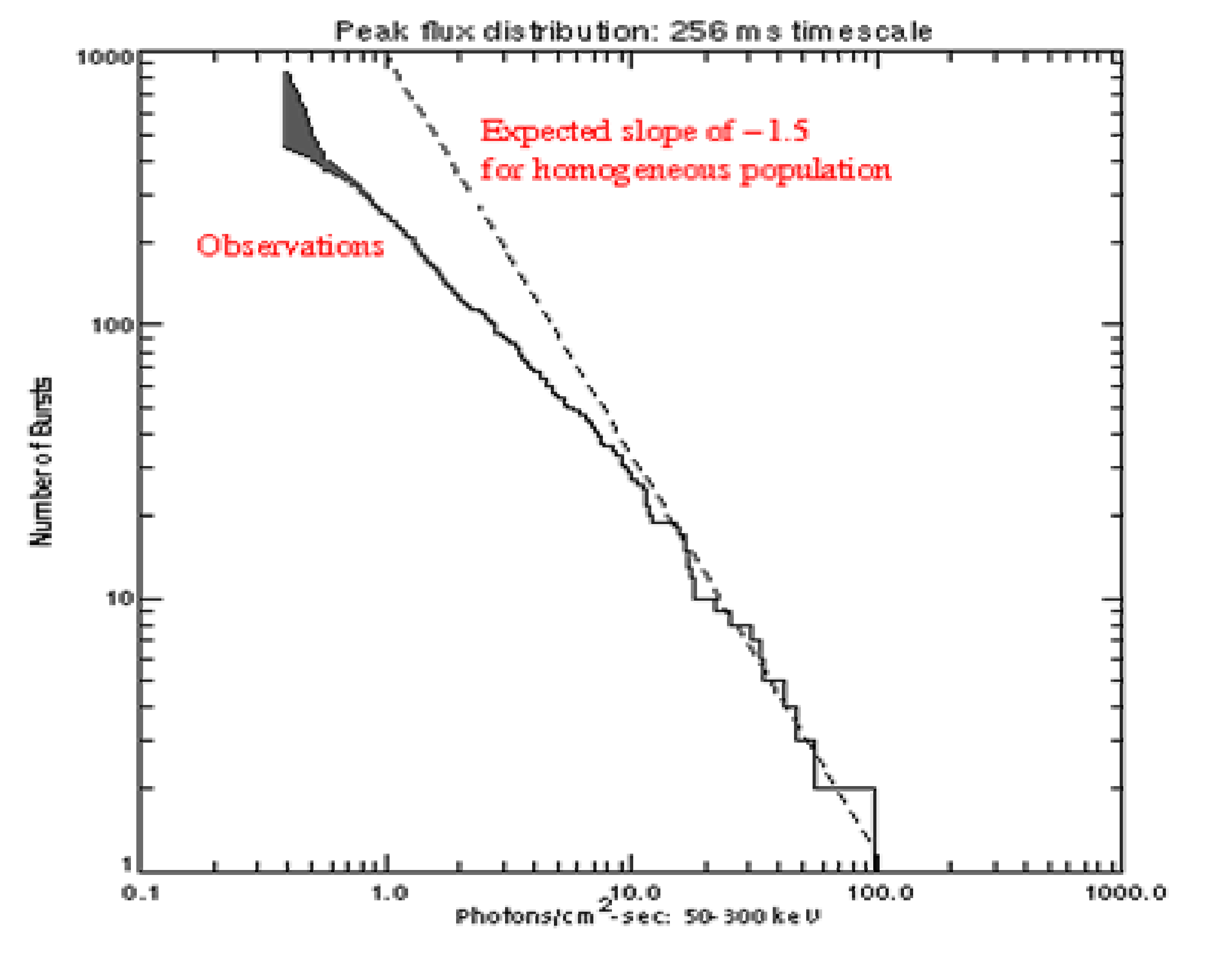
- The major observational development of the 90’s was the launch of CGRO and the BATSE detector.
- Very quickly it became apparent that the GRB distribution was isotropic.
- The *LogN* - *LogS* distribution was at the same time shown to be compatible with earlier results, indicating lack of faint events below those expected from distribution in a Euclidean Universe.
- Distribution inconsistent with galactic events.

- Distribution of BATSE GRBs on the sky




2704 BATSE Gamma-Ray Bursts
+90
+180
-180
-90
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Fluence, 50-300 keV (ergs cm^{-2})

- *Log N* - *Log S* for the BATSE GRBs.



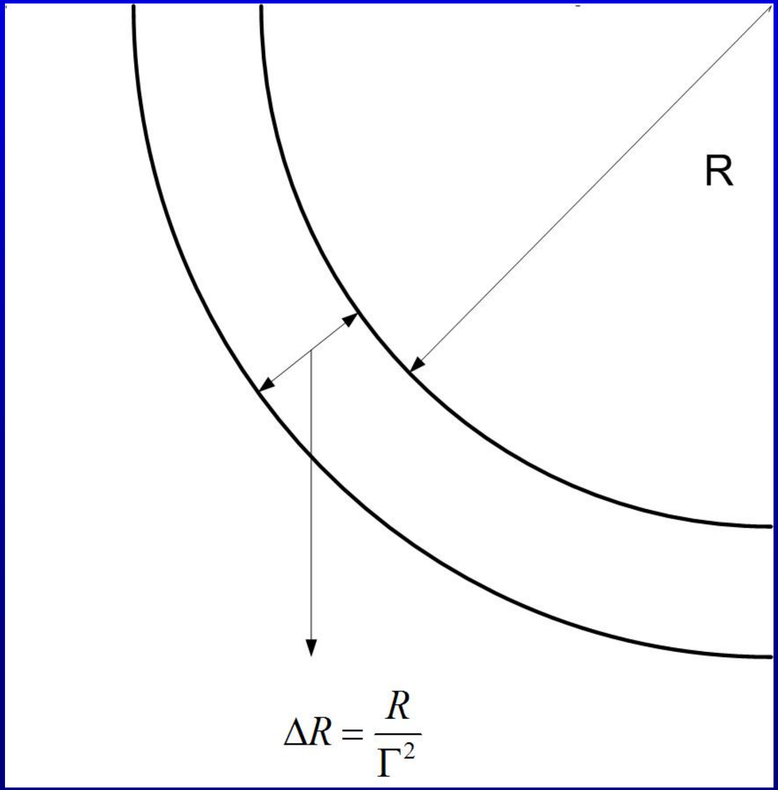
- Consideration of cosmological origin of GRBs taken more seriously.
  - Relativistic outflows as a means of reducing the photon-photon opacity (Krolik & Pier 1992; Baring & Harding 1993; Epstein et al. 1992).
  - Lorentz factors necessary $\Gamma \sim 100 - 1000$.

- Consideration of baryon contamination in the expanding relativistic gas (Shemi & Piran 1990; Rees & Meszaros 1992). This has the following consequences:

- Part of the burst energy is retained in the baryons, which can now become relativistic (+)
- If too much baryon contamination the flow becomes non-relativistic (-).

- The need for relativistic flows determines the amount of entrained mass:
  - The asymptotic Lorentz factor is the ratio of *Energy / Rest Mass* in ejecta.
  - The flow must remain optically thick to Thomson scattering, if efficient conversion of internal energy to kinetic is to be achieved.

- The ejecta are confined to a region of width $\Delta R \sim (1-\beta) R \sim R/\Gamma^2$
- Duration of burst $\Delta t \sim \Delta R/c \sim R/c\Gamma^2 \sim 30\, R_{16}/\Gamma_2^{\,2}$ sec.



- Some numbers

$$\mathrm{M}_{\mathrm{solar}} c^2 = 10^{54} \ \text{ergs}$$

$$\text{with } E_{GRB} \approx 10^{51} \text{ ergs}, \qquad \Gamma_\infty \approx 100$$

$$\text{the baryon mass is } \Delta M \approx \frac{E}{\Gamma_\infty c^2} = 10^{-5} \mathrm{M}_{\mathrm{sol}} \frac{E_{51}}{\Gamma_2}$$

The Thomson depth of the matter is

$$\tau = \sigma_T \frac{M}{\Delta R\, R^2} \Delta R = \sigma_T \frac{M}{R^2} = \sigma_T \frac{10^{52} M_{-5}}{R^2} \approx 10^{28} \frac{M_{-5}}{R^2}$$

$$\text{for } \tau \approx 1, \quad R \approx 10^{14} M_{-5}^{1/2} \text{ cm}$$

- Initial radius is ~10^7 cm ⇨ ample of space to achieve the asymptotic value of Γ.

- After achieving its asymptotic Γ value, the blast wave propagates sweeping ISM. Its evolution is given largely by energy conservation.
- The Lorentz factor of the flow remains constant until the burst accumulates a mass ΔM_{acc} on its *rest frame* comparable to its total energy *E*

$$(n_0\Gamma)R^3\,\Gamma m_p c^2 \approx E$$

$$R \approx 10^{15}\left(\frac{E_{51}n_0}{\Gamma_2^2}\right)^{2/3}\ \mathrm{cm}$$

- Beyond this point the evolution of Γ follows from energy conservation

$$E \approx \frac{4\pi}{3} n_0 R^3 \Gamma^2 \mathrm{m_p c^2} \qquad \text{if adiabatic}$$

$$E \approx \frac{4\pi}{3} n_0 R^3 \Gamma \, \mathrm{m_p c^2} \qquad \text{if radiative}$$

$$\Gamma \propto E^{1/2} n_0^{-1/2} R^{-3/2} \qquad \text{if adiabatic}$$

$$\Gamma \propto E \, n_0^{-1} \, R^{-3} \qquad \text{if radiative}$$

- When combined with the time scale at the observer's frame

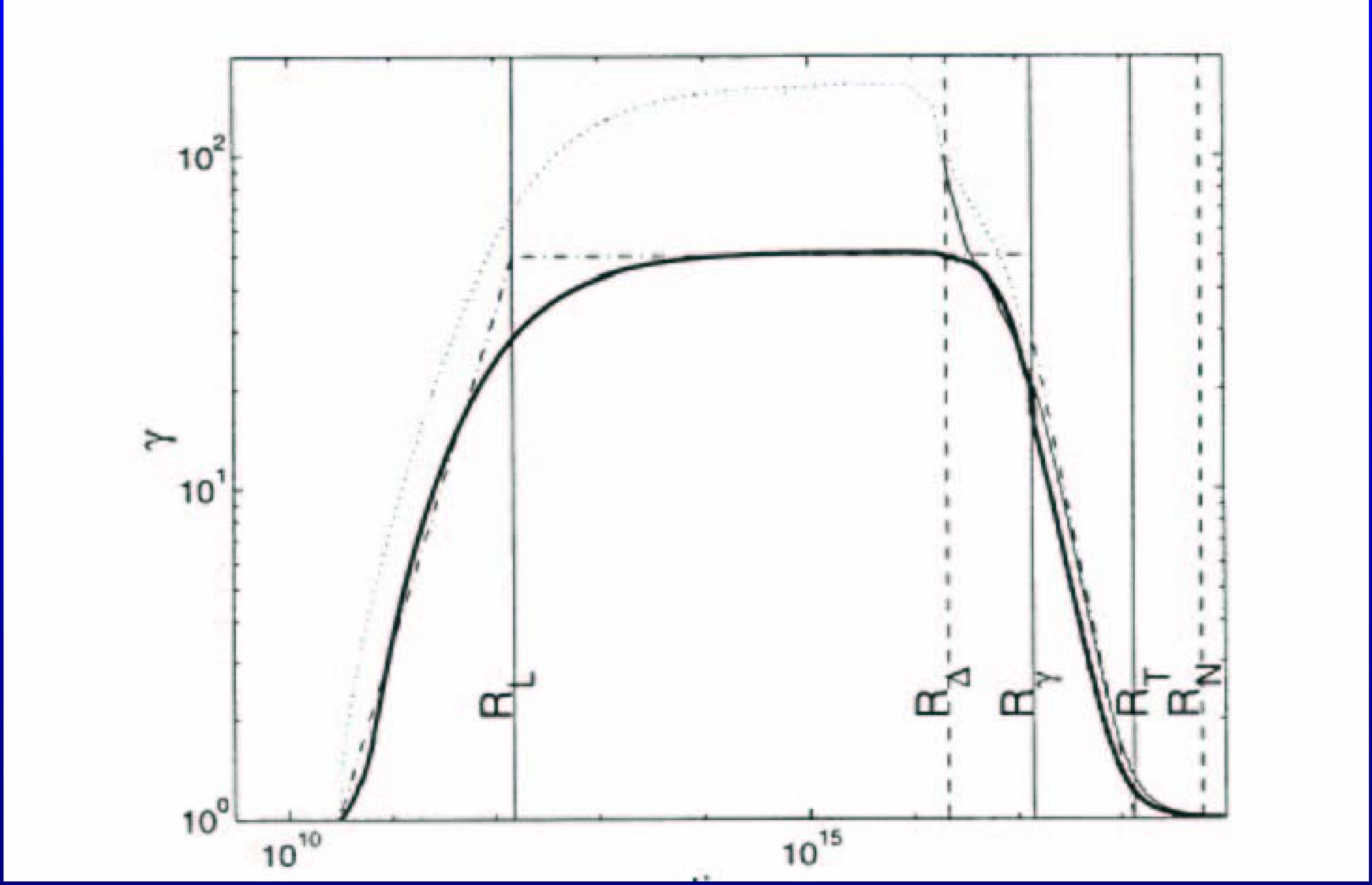
$$\Delta t_{\text{lab}} \cong \frac{R}{c\,\Gamma^2}$$

  - give the Lorentz factor as a function of time

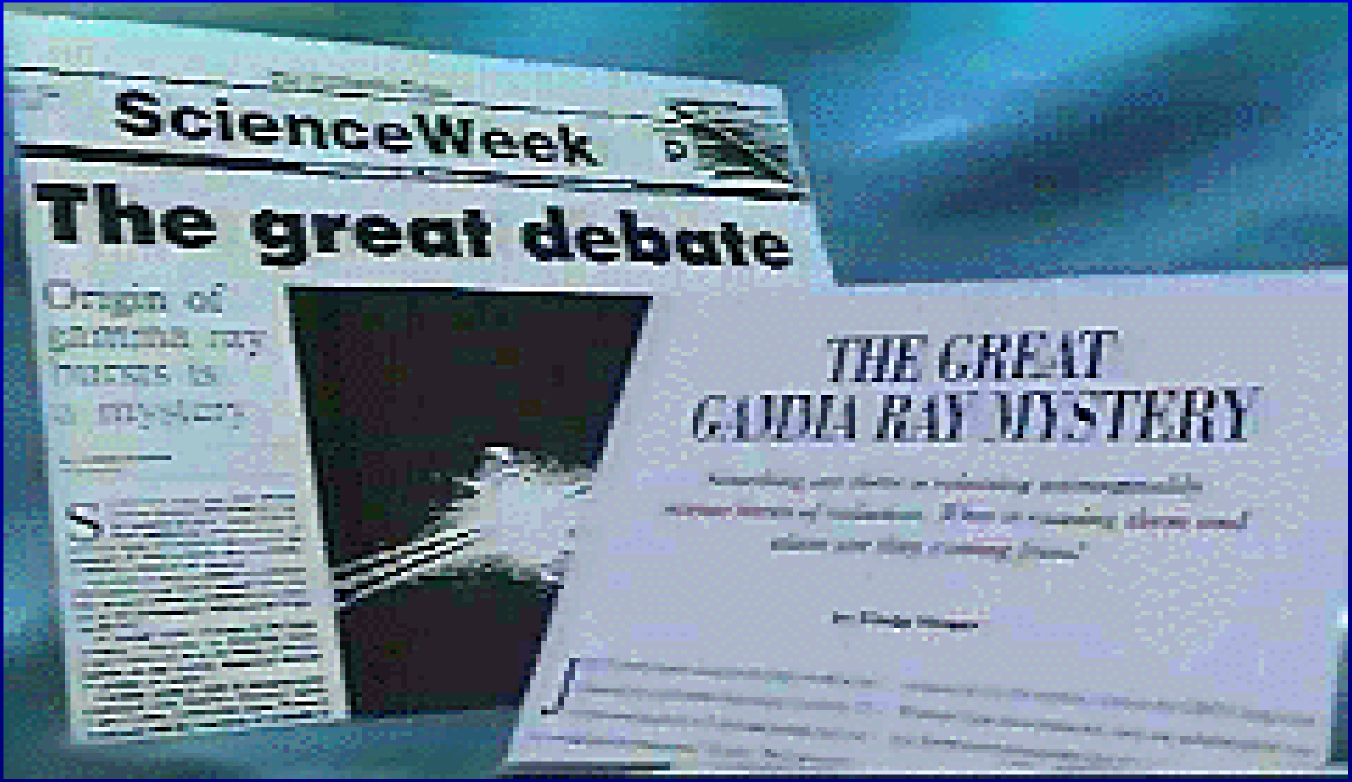
$$\Gamma = \left(\frac{E}{n_0}\right)^{1/8} t^{-3/8} \qquad \text{if adiabatic}$$

$$\Gamma = \left(\frac{E}{n_0}\right)^{1/7} t^{-3/7} \qquad \text{if radiative}$$

– Evolution of Lorentz factor as a function of distance (in cm) (Kobayashi, Piran, Sari 98).



– Despite the mounting evidence, the community was divided half way on the distance of GRBs. Clearly there were not galactic but they could be made isotropic if put at a distance 100 kpc (galactic halo) (1995)



THE BIG BREAK

- The BeppoSAX satellite, equipped both with wide field of view cameras and narrow field of view more sensitive X-ray telescopes was able to follow up a GRB and record a fading X-ray source.
- Follow up optical work was able to find a fading optical counter part and determine a redshift *($z \sim 0.8$)*.

X-RAY COUNTERPARTS

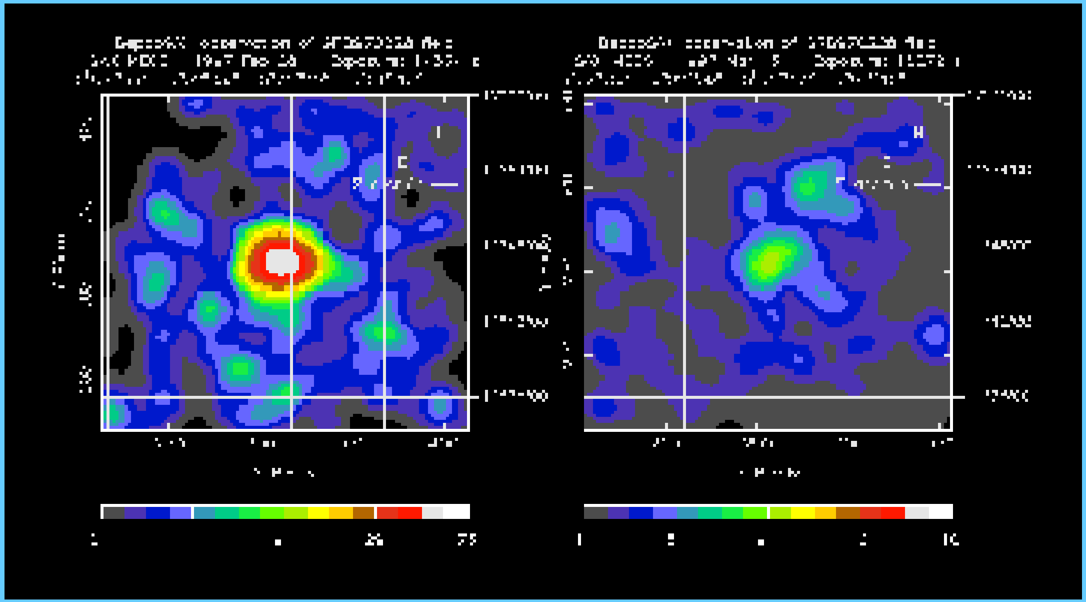
- TWO YEARS AGO, IT BECAME POSSIBLE TO LOCATE BURSTS ACCURATELY AND QUICKLY, AND OBSERVE THEIR FADING X-RAY COUNTERPARTS

- THE ITALIAN/DUTCH X-RAY ASTRONOMY SATELLITE BEPPOSAX ACHIEVES THIS WITH A COMBINATION OF WIDE FIELD X-RAY CAMERAS AND NARROW FIELD X-RAY TELESCOPES

T_0+8h T_0+2d

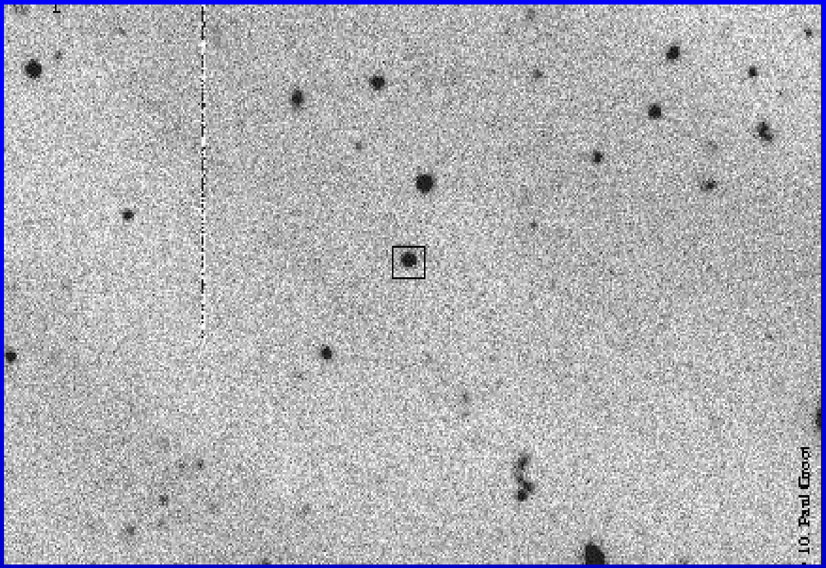
GRB970228

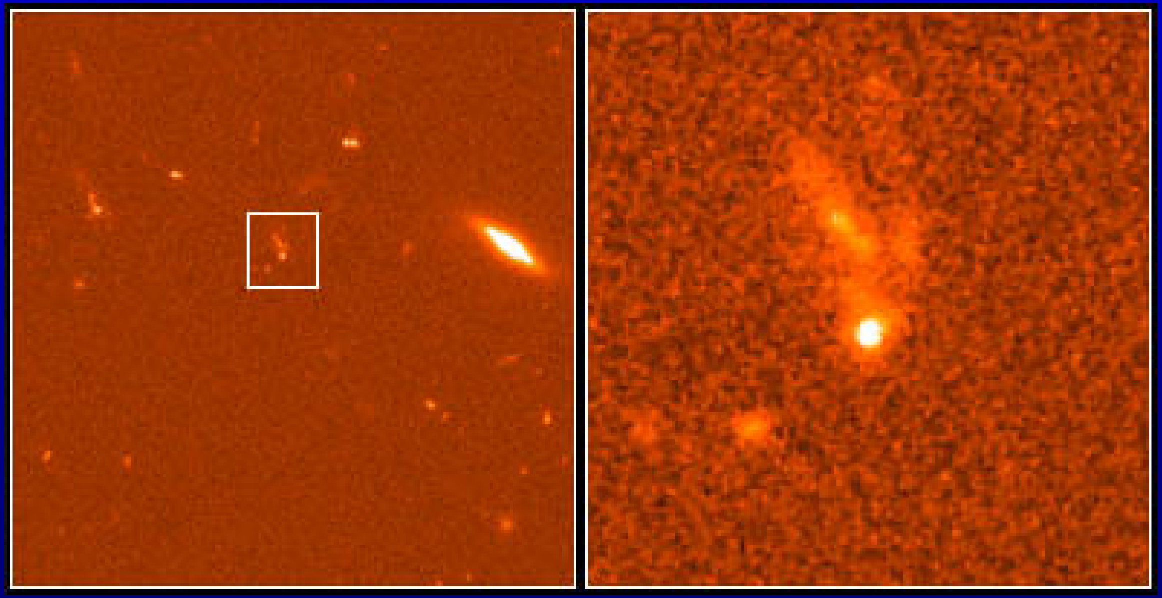
1’



1-10 keV

– Optical counterparts of GRBs 970508 990123

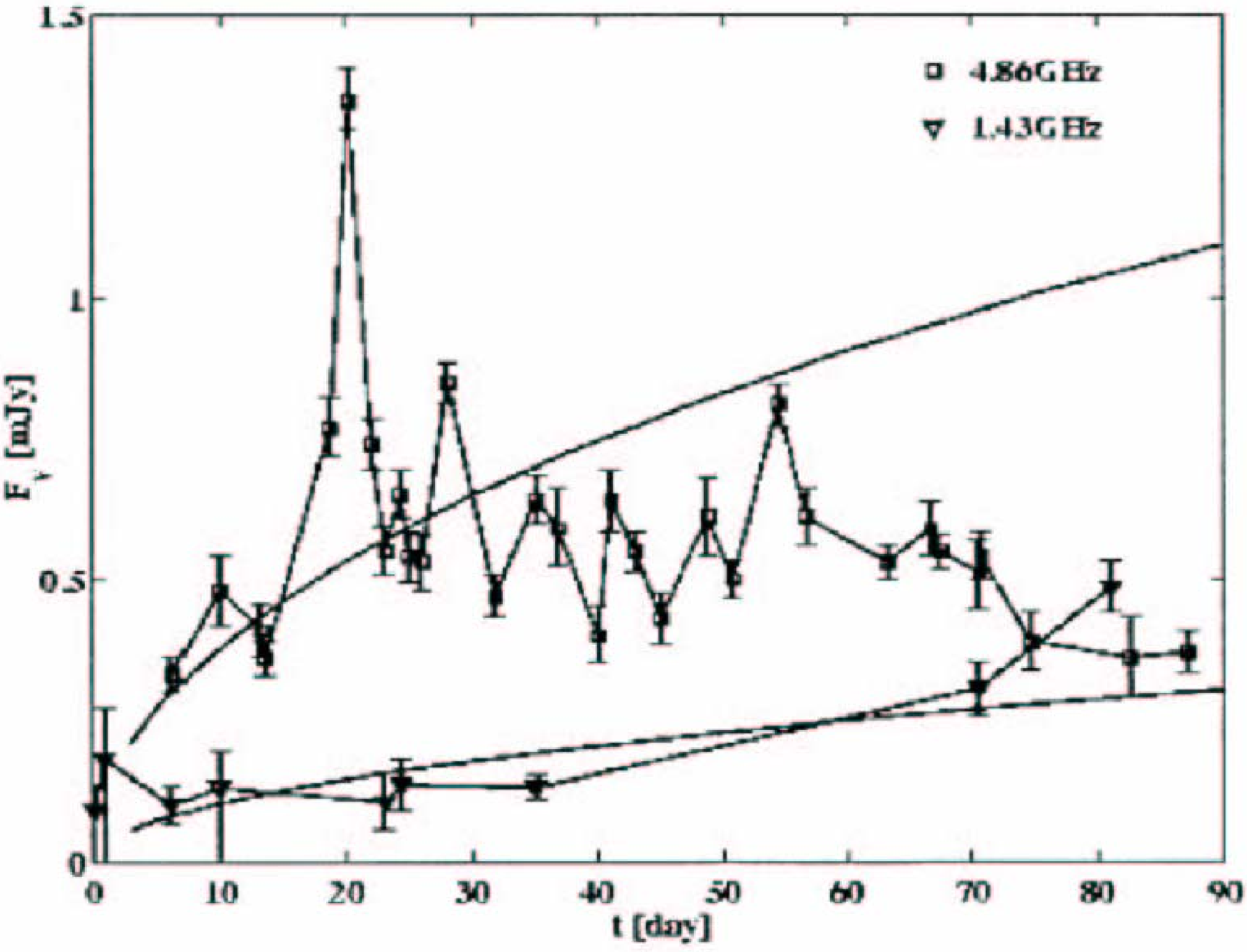




- With the discovery of GRB afterglows the theoretical emphasis shifted to modeling these aspects of GRBs.
- It is generally accepted that both the prompt emission and the afterglow is due to synchrotron radiation by electrons accelerated at the relativistic blast wave of the GRB.
- At least for the optical afterglow, the presence of polarization (~2%) argues in favor of this interpretation.

- Successes of Fireball Model:
  - Decouples the energy source from the radiating plasma.
  - Provides naturally power laws in time variation.
  - Relativistic outflow consistent with observations of radio scintillations and their disappearance after a well defined time; for typical values of ISM scattering medium distance scintillation would stop for a size $R \sim 10^{17}\ cm$; along with the observed time of 30 days leads to a expansion speed $V \sim R/30\ days \sim 3\ 10^{10}\ cm!!$

The Light Curve of the Radio Afterglow of GRB970508 from Frail et al. Nature 398, 261 (97)



Jets !!!!

- For a relativistically moving "blob"

$$\dot{E}_{obs} \approx \Gamma^4 \dot{E}_{int}$$

If this is a section of an spherical shell

$$\dot{E}_{int} \approx L_{tot} \theta^2 \approx \frac{L_{tot}}{\Gamma^2}$$

$$\dot{E}_{obs} = L_{obs} \approx \frac{L_{tot}}{\Gamma^2}\Gamma^4 \approx L_{tot}\Gamma^2$$

$$E_{obs} \approx L_{obs} \Delta t_{obs} \approx L_{tot}\Gamma^2 \frac{\Delta t_{int}}{\Gamma^2} \approx E_{iso}$$

- The observations of GRB with $E_{iso} > 10^{53}$ erg (most notably GRB990123 $E_{iso} \sim 10^{54}$), in conjunction with our prejudices on the GRB energy reservoir (collapse, NS collisions) forced the issue of "beamed" GRB.
- GRB should have a "jet" structure with small ($\theta \sim 0.1$) opening angles.
- As the $\Gamma < 1/\Theta$ (Θ is the jet opening angle) the afterglow decay should exhibit achromatic breaks.

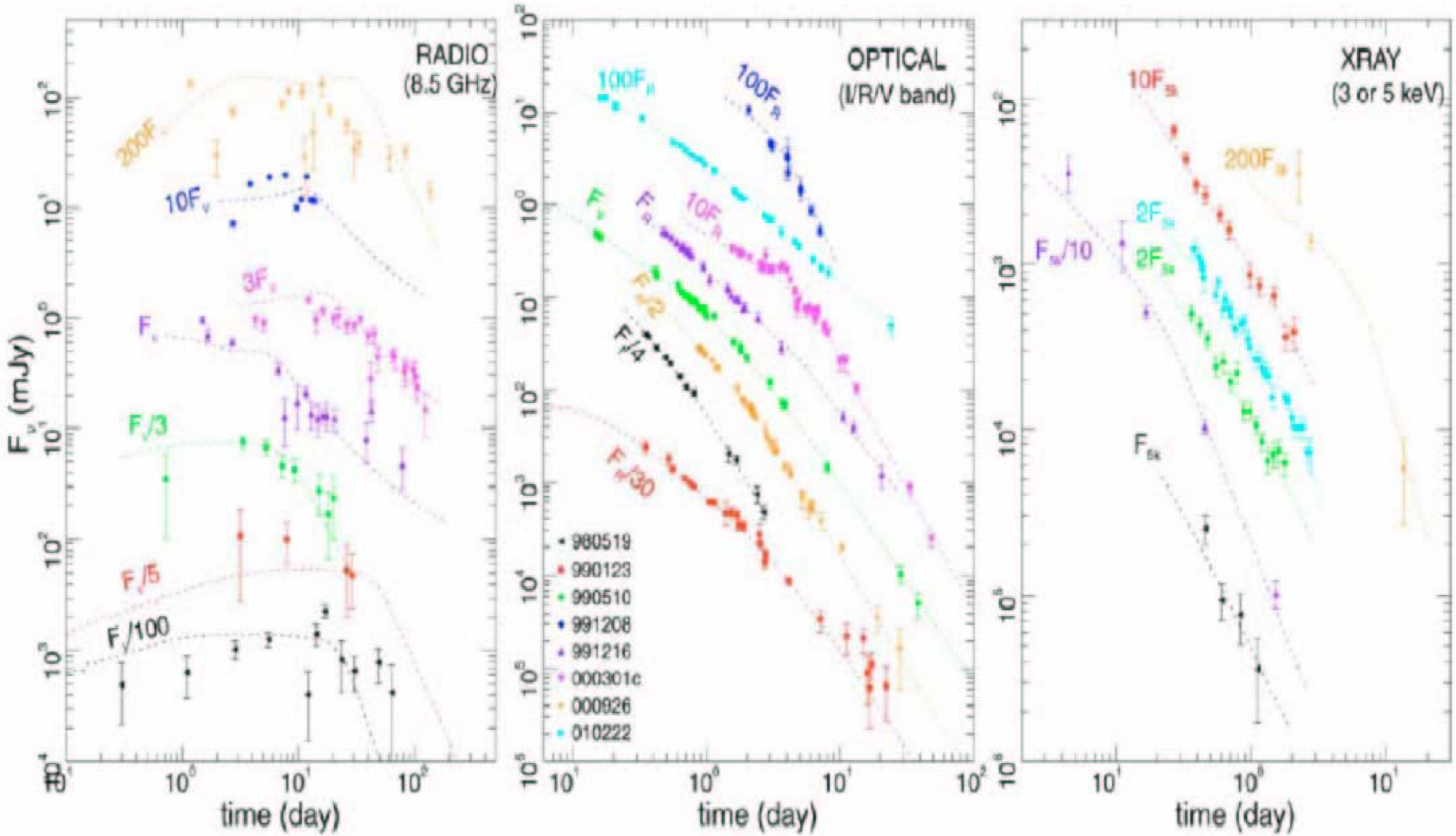


FIG. 1.—Radio, optical, and X-ray emission and model light curves for the GRB afterglows 980519, 990123, 990510, 991208, 991216, 000301c, 000926, and 010222 (the definition of the symbols in the lower left-hand corner of the middle graph applies to all panels). The numerical light curves have been obtained by the minimization of χ^2 between the model emission and the radio, millimeter, submillimeter, near-infrared, optical, and X-ray data (only a part of the used data is shown in this figure). The parameters of each model are given in Fig. 2. Optical data have been corrected for Galactic dust extinction. The spread around the model curves exhibited by the radio emission of 980519, 991208, 991216, 000301c, and 000926 can be explained by fluctuations due to scatterings by the inhomogeneities in the Galactic interstellar medium (Goodman 1997). Fluxes have been multiplied by the indicated factors, for clarity.

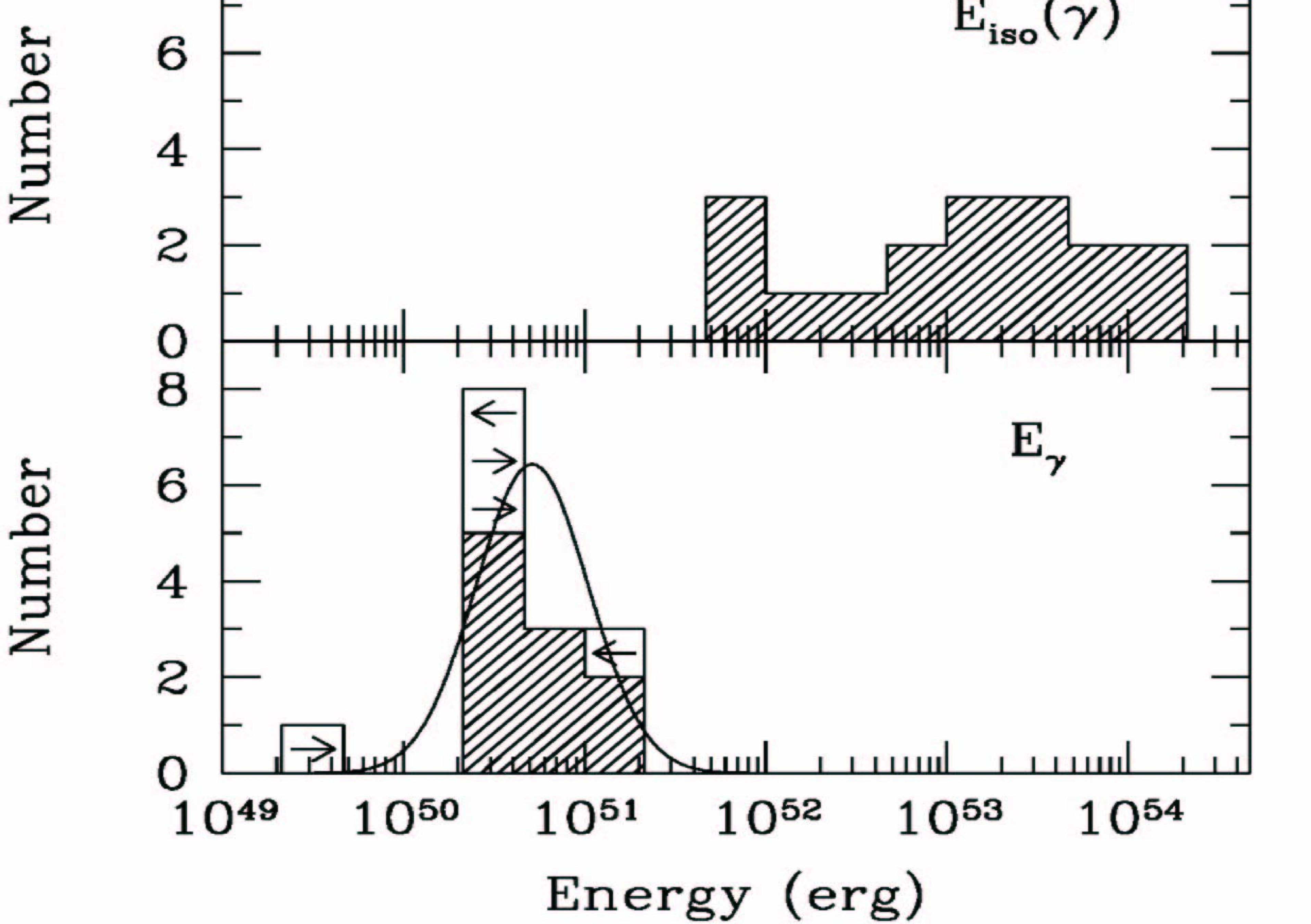
The plot thickens !!

- The presence of breaks allows an independent and direct measurement of the jet opening angle and Lorentz factor at the time the of the break

$$\Gamma = \left(\frac{E}{n_0}\right)^{1/8} t_b^{-3/8} \approx \frac{1}{\Theta}$$

- Along with the redshift, *z*, of a given GRB one can correct for GRB opening (~ Θ^2) to obtain the total energy $E_{tot} \sim \Theta^2 E_{iso}$

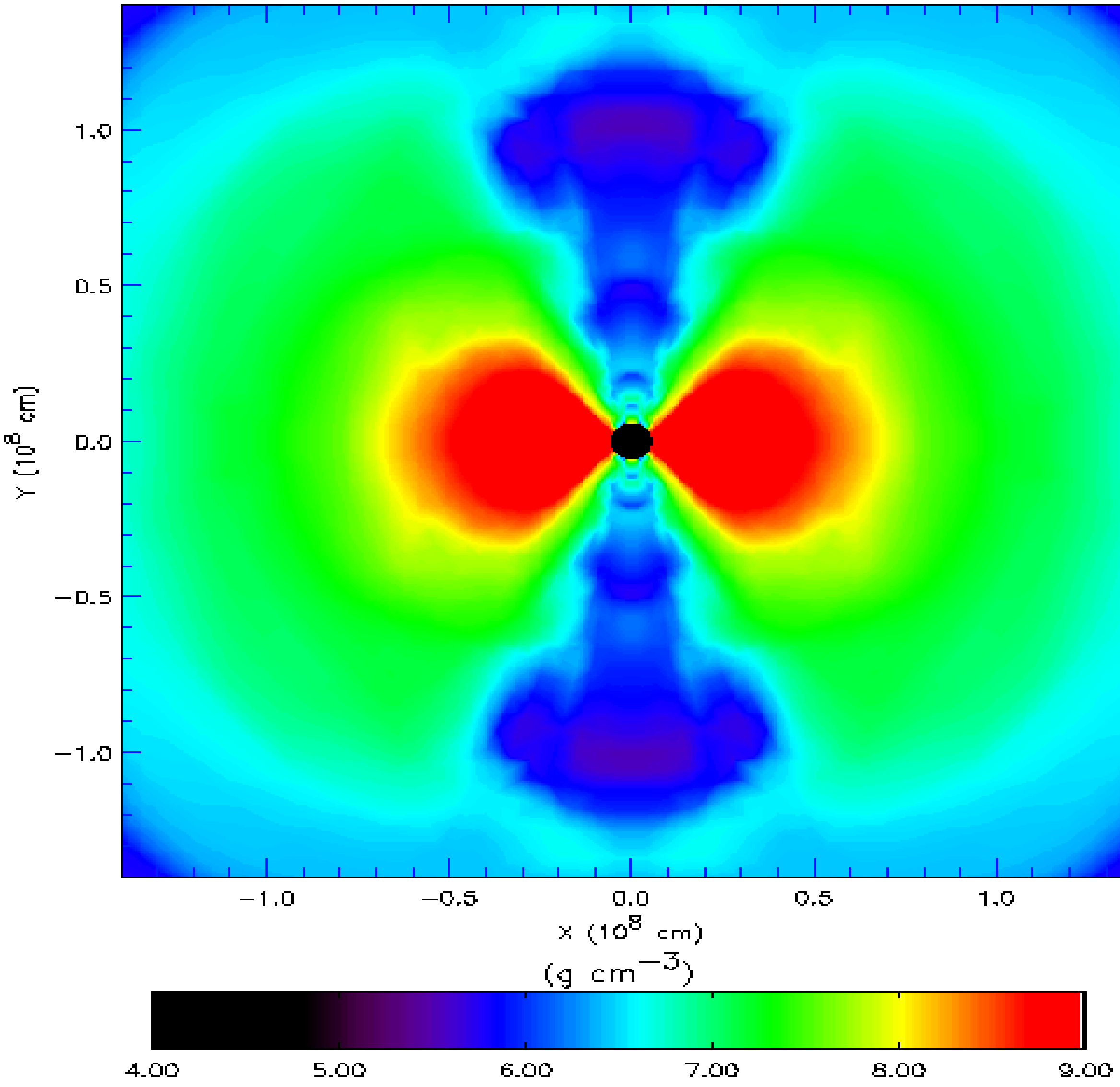
- On the basis of the “central engine” models (as of today) there should not exist any correlation between the jet opening angle and its luminosity.
- Frail et al. (2001) in correlating the break time with isotropic luminosity they found that the break time correlates with GRB flux in a way to yield a constant energy reservoir.
- GRB ’s of larger flux should have smaller opening angles, in a way that yields constant total energy!!



Number
Eiso(γ)
Number
Eγ
0
2
4
6
8
10^49
10^50
10^51
10^52
10^53
10^54
Energy (erg)

Outstanding Issues

- 1. The "Central Engine"
  - The energy budget similar to SN. Association of at least one GRB with a SN (Woosley).
  - NS - NS or NS - BH collisions. Tend to be disfavored because of association of GRB positions with star formation regions.
  - The high *Γ's* involved suggest MHD origin of the central engine (e.g. msec magnetar, Usov 1992).
  - BH - star tori, possible association with Gravitational Wave emission (van Putten 01).



1.0
0.5
0.0
−0.5
−1.0
Y (10^8 cm)
−1.0
−0.5
0.0
0.5
1.0
X (10^8 cm)
(g cm^−3)
4.00
5.00
6.00
7.00
8.00
9.00

- 2. Why (Low Energy) Gamma Rays?
  - The issue of the peak energy E_p of GRB still remains unexplained. Suspiciously close to $m_e c^2$
  - Relativistic motion with Lorentz factors 100 - 1000 should yield dispersions much larger than observed.
  - Assuming gamma rays to be due to synchrotron yields $E_p \sim \Gamma^4$, very hard to reconcile with observed distribution (Malozzi et al. 1995).

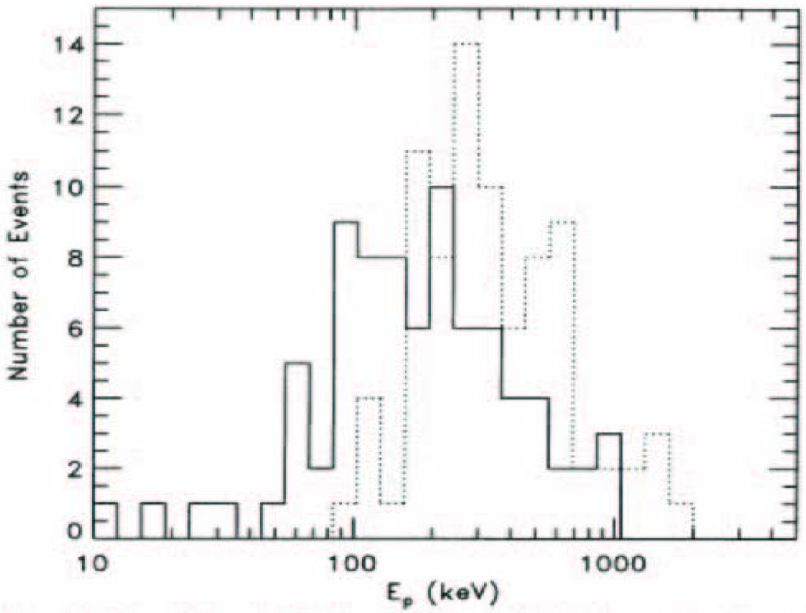
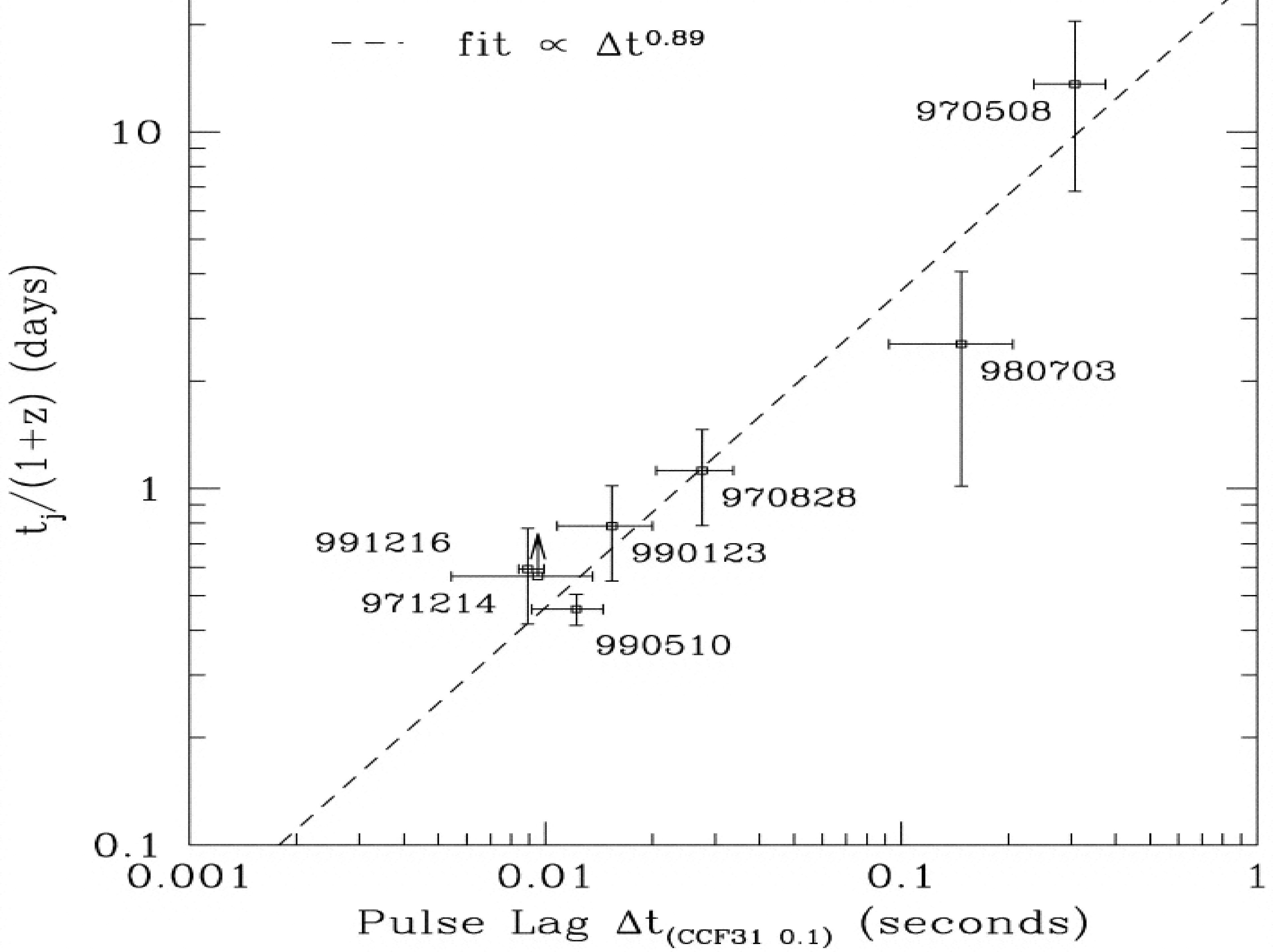


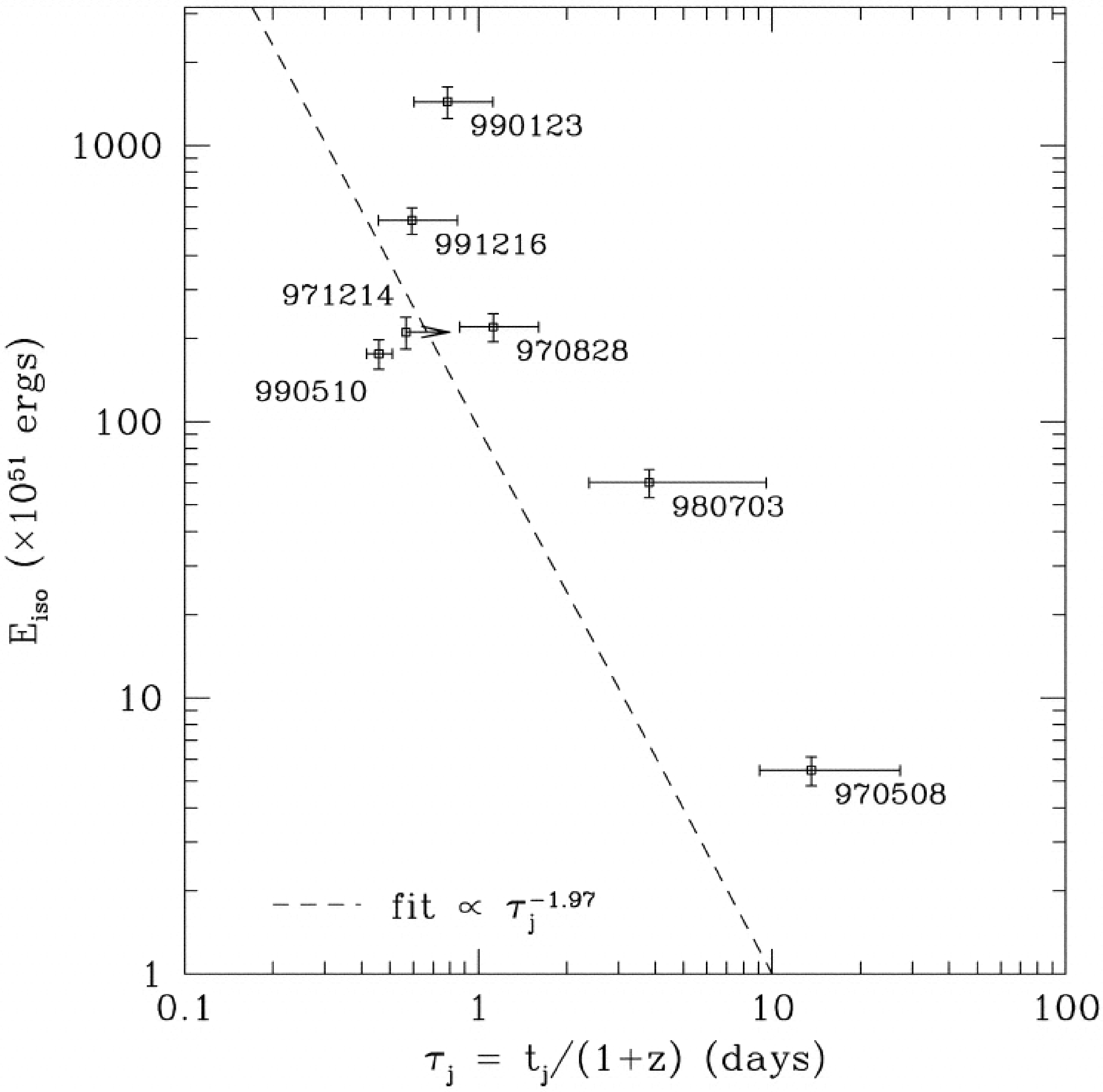
FIG. 1.—The differential E_p distribution of the brightest 20% (*dotted line*) and the dimmest 20% of bursts as a function of peak flux.

- 3. How do we take energy out of the protons?
  - The presence of baryons is a fundamental staple of the Relativistic Blast Wave model.
  - Absolutely necessary for the transport of energy away from the “central engine”.
  - How can we fine tune the baryon loading so that we do not put more baryons in the flow than necessary (too much would choke the flow too little would make the flow thin and would not accelerate).

- 4. How can Γ know about Θ?
  - While E_{iso} is determined from the Gamma ray fluence, i.e. the prompt burst, at which point we are looking into the fireball at angles << Θ, the burst must already know about the value of Θ!! (which is determined from the afterglow properties)(Frail et al. 2001)
  - Salmonson & Galama (2002) find that the timing properties of the prompt emission know about the break time scales in that smaller lags in gamma rays lead to faster break times.
  - Lag-Peak Luminosity relation (Norris, Marani &Bonnell 2000).

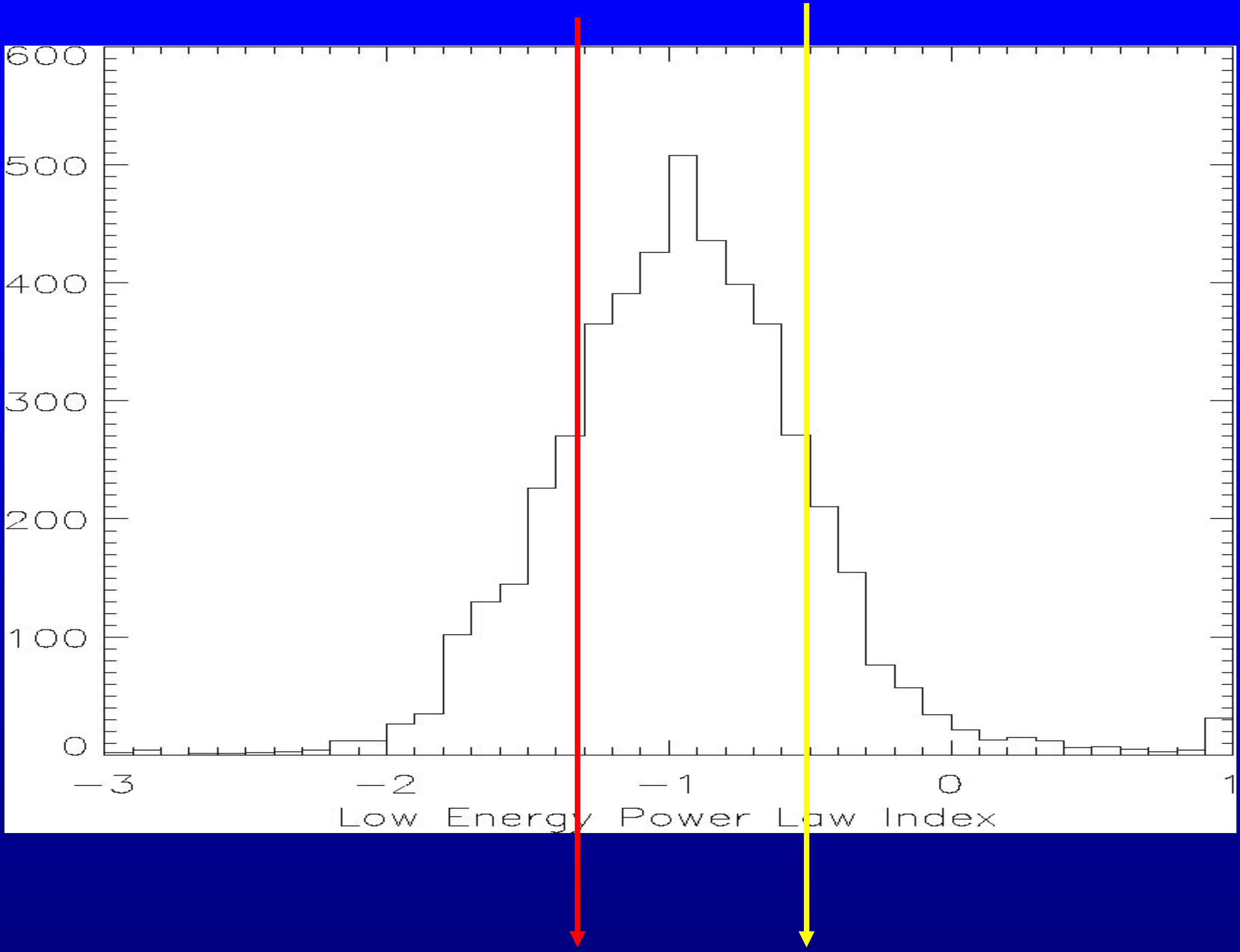


fit ∝ Δt^0.89
970508
980703
970828
990123
991216
971214
990510
10
1
0.1
0.001
0.01
0.1
1
t_j/(1+z) (days)
Pulse Lag Δt(CCF31 0.1) (seconds)



990123
991216
971214
970828
990510
980703
970508
fit ∝ $\tau_j^{-1.97}$
1000
100
10
1
0.1
1
10
100
E_{iso} ($\times 10^{51}$ ergs)
$\tau_j = t_j/(1+z)$ (days)

- 5. What determines the spectral indices?



How to get photons out baryons and get the νF_ν peak at 1 MeV

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ApJL, 578, L15

(Oct 10, 2002 issue)

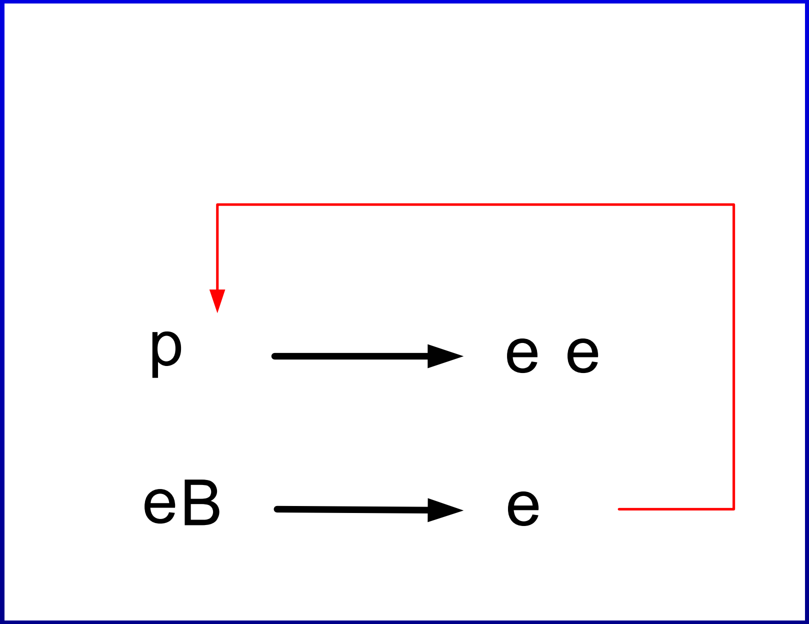
Fine tuning of baryon loading not necessary!

- If the GRB central engine is completely due to electromagnetic processes (a fast spinning dipole?) matter inertia is generally negligible; Lorentz factors ~ 10^6 are not unreasonable.
- Baryon loading may result from "sweeping" ambient medium. For $E \sim 10^{51}$ *erg*, sweeping $N \sim 10^{48}$ baryons (I.e. for $R \sim 10^{16}$ *cm)*, will reduce the Lorentz factor to $\Gamma \sim 1000$.

- Usually appeal is made to plasma effects for converting substantial fraction (~50%) of the thermal proton energy to electrons of Lorentz factors sufficiently large to produce synchrotron emission of E~100 - 1000 keV (in the lab frame).

- Use photo-proton reaction to produce pairs.
- Use the photons produced by the pairs to develop a self-contained network.
- Test for stability of this system to internally produced radiation (criticality).

- Consider the following set of reactions.
- Let $b = B/B_{cr}$ be the magnetic field.
- Electrons produce photons by synchrotron of energy $E_S \sim b\,\gamma^2$ $(\gamma_e \sim \gamma_p)$.
- Proton energy threshold for reaction $\gamma E_S \sim 2\, m_e c^2$,
- $\boldsymbol{b\,\gamma^3 \sim 2}$



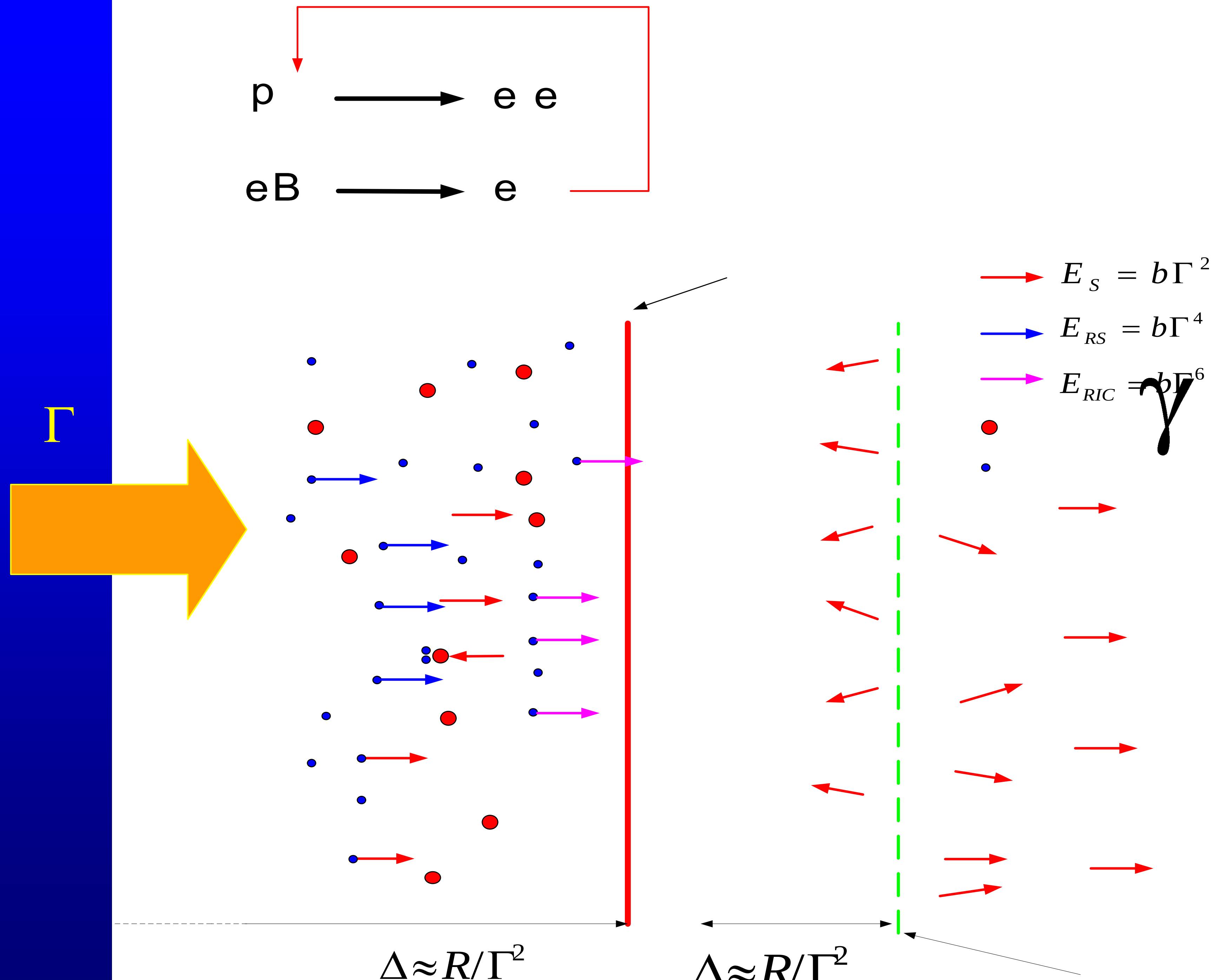
- For the reaction to be self-sustained, at least one of the photons should pair produce before escape
- $$\boxed{\tau_{p\gamma} \approx R\sigma_{p\gamma} n_p > 1/N_\gamma \approx b\gamma}$$
- $N_\gamma \sim \gamma / b\gamma^2 = 1/b\gamma$ is the number of synchrotron photons produced by each electron.
- For a proton population $N_p(\gamma) = n_o \gamma^{-\beta}$, $(\gamma >> 1)$
  $n_p = \gamma N_p(\gamma) = n_o \gamma^{-\beta+1}$

□ $$\boxed{R\sigma_{p\gamma} n_o \geq b^{1-\beta/3}}$$ Kirk & Mastichiadis 92

- Consider that the synchrotron photons are scattered by a mirror upstream and caught up again by the blast wave.
- Their energy will be $E_S \sim b\,\gamma^2\,\Gamma^2$ (Γ is the blast wave Lorentz factor).
- This modifies the kinematic threshold to
- $$b\,\gamma^3\,\Gamma^2 \sim 2$$
- And the criticality condition to:

$$\boxed{\Delta_{com}\sigma_{p\gamma}n_{0,com} \geq b^{1-\beta/3}\,\Gamma^{-(1+2\beta/3)}}$$

– Kazanas & Mastichiadis 99



p → e e
eB → e
$E_S = b\Gamma^2$
$E_{RS} = b\Gamma^4$
$E_{RIC} = b\Gamma^6$
Γ
γ
$\Delta \approx R/\Gamma^2$
$\Delta \approx R/\Gamma^2$

- $\Delta_{com} \approx \Delta \cdot \Gamma \approx \frac{R}{\Gamma^2} \cdot \Gamma \approx \frac{R}{\Gamma}$ is the comoving width of the shell.
- $n_{0,com} = \Gamma n_0$ is the comoving density of the shell.
- The most conservative assumption would be that there is no accelerated proton component and that all proton behind the shock have an energy $E \sim \Gamma\, m_p c^2$.

- Then the kinematic threshold becomes:
- $$b\,\Gamma^5 \sim 2$$
- The dynamic threshold modifies to
- $n_0 R \sigma_{p\gamma} > b\Gamma \qquad n_0 R \sigma_{p\gamma} \Gamma^4 \sim 2$
- $$\Gamma > 380 \, (n_0 R_{16})^{-1/4}$$

Assuming the magnetic field to be in equipartition, and Θ to be the jet half-opening angle (in units of π) and E_{51} the burst energy (in units of 10^{51} ergs), the kinematic threshold reads:

$$\Gamma > 235\ (\Theta R_{16})^{1/5} E_{51}^{-1/10}$$

The kinematic threshold is easier to satisfy than the dynamic one, suggesting that the bursts may be operating in the *linear* regime.

The photon energies

- Synchrotron photons of energy $E_S \sim b\Gamma^2$
- Inverse Compton by the cold electrons at energy $E_{IC,c} \sim b\Gamma^4$
- Inverse Compton by the hot ($E \sim \Gamma$) electrons at energy $E_{IC,h} \sim b\Gamma^6$
- All these energies in the blast wave frame

- At the observer's frame these energies will be:

- $E_S \sim b\Gamma^2\,\Gamma = b\Gamma^3 \sim 10\,\Gamma_2^3\,eV$

- $E_{IC,c} \sim b\Gamma^4\,\Gamma = b\Gamma^5 \sim 1\ MeV$ (threshold)

- $E_{IC,h} \sim b\Gamma^6\,\Gamma = b\Gamma^7 \sim 10\,\Gamma_2^7\ GeV$ *(GLAST)*

- *The energy of* $b\Gamma^5$ *is ~ 1MeV independent of* Γ *because of the threshold condition.*

- The synchrotron photons are never lost!
  - Because the blast wave follows the photons it produces, even the earliest emitted photons are only a distance $\Delta \sim R/c\Gamma^2$ away.
  - Any obstruction that scatters these photons produces a photon layer of width Δ and depth to Thomson scattering of order

□ $\tau_{\gamma,T} \sim n_0 R\, \sigma_T \Gamma^4 \alpha f_p \sim 1\, n_0 R_{16}\, \Gamma_2^{\,4} \alpha f_p$

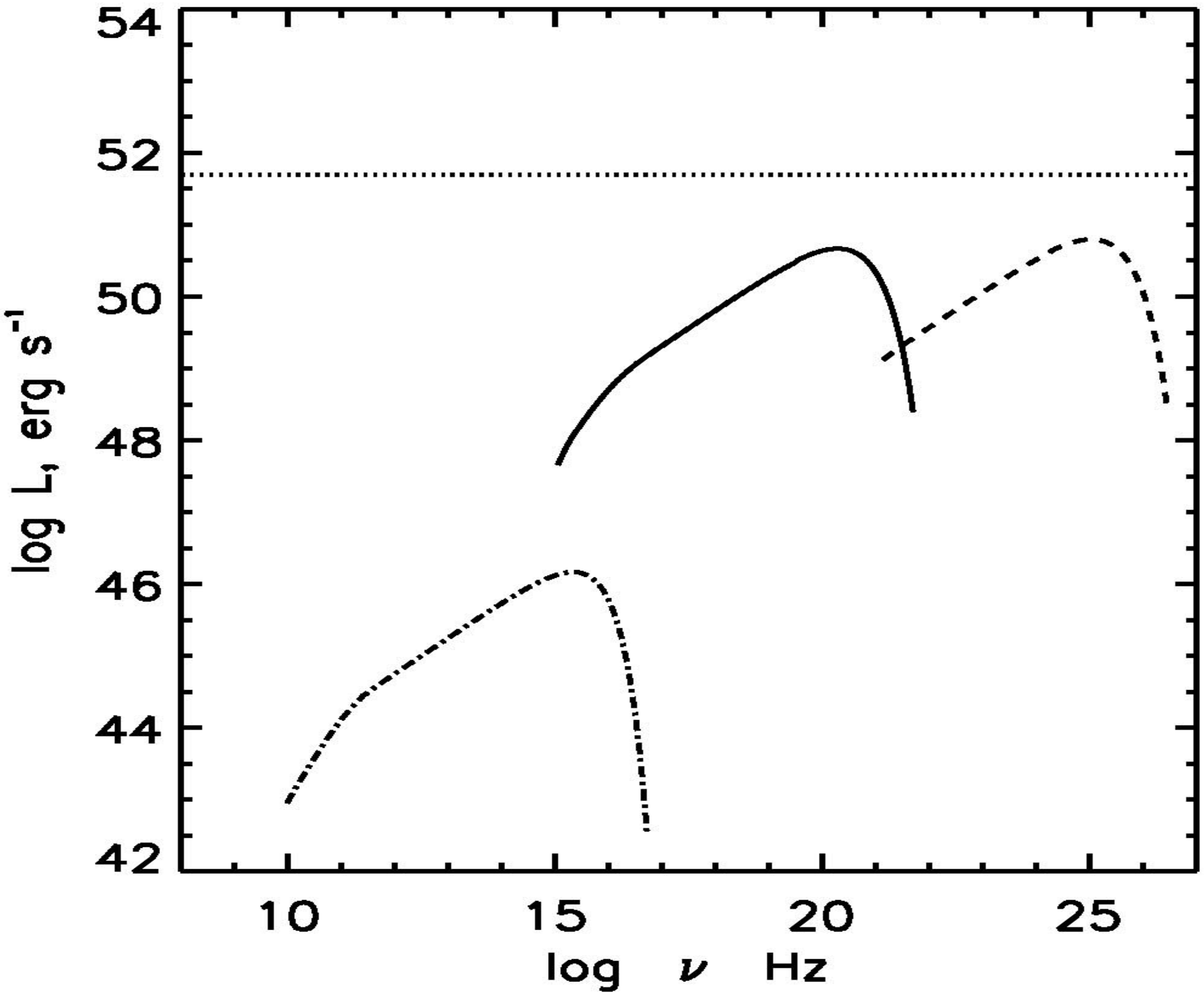
  - the electrons of the blast wave plow through this photon layer producing the scattered radiation (α is the mirror albedo, f_p .is the # of pairs per proton produced).

Time scales and albedo

- The duration of the burst is of order $\Delta\tau \sim R/c\Gamma^2 \sim 30\ R_{16} / \Gamma_2^2$ sec.

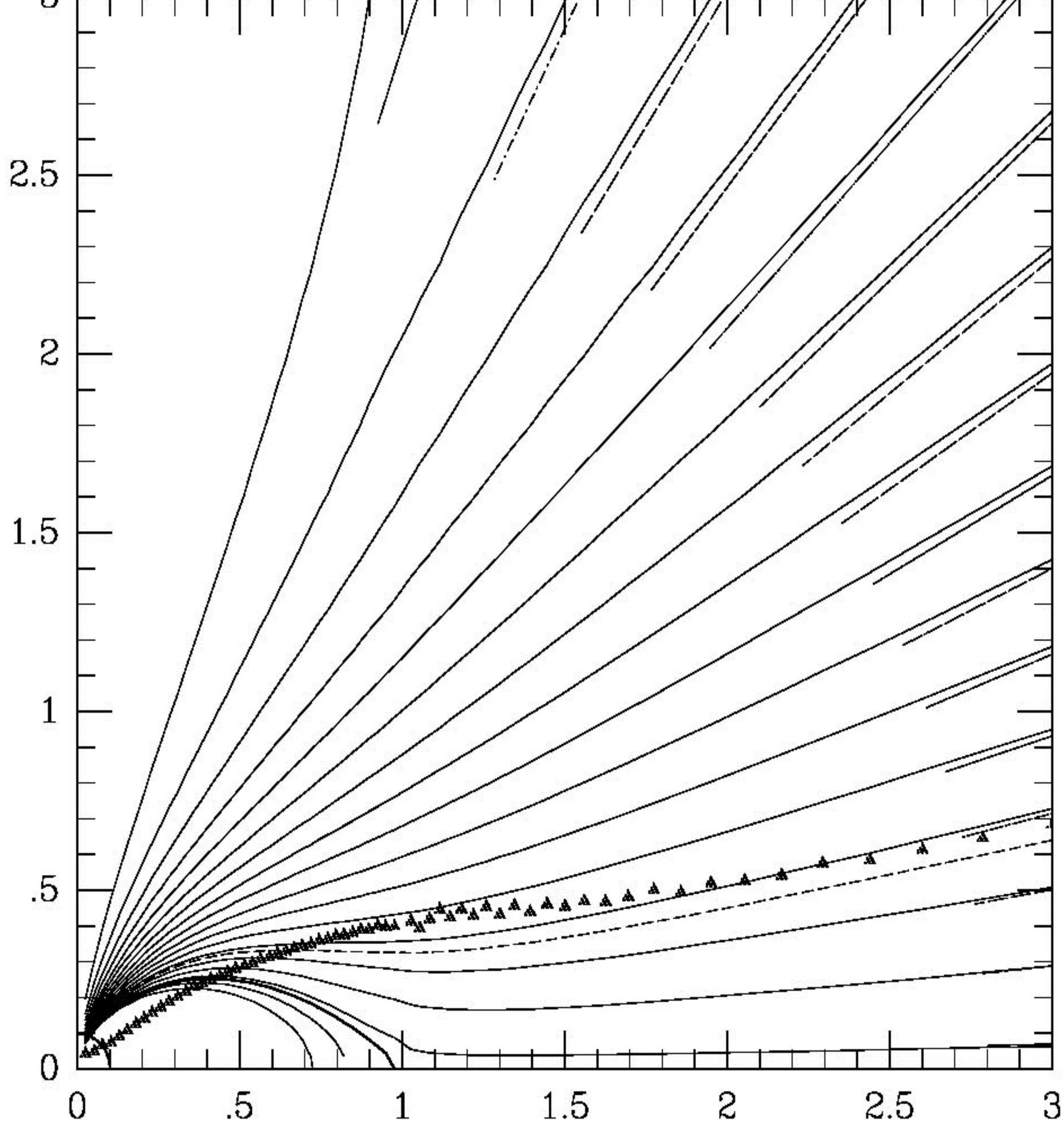
- The shortest GRB time scales are of order $\Delta\tau \sim \Delta/c\Gamma^2 \sim R/c\Gamma^4 \sim 3\ R_{16} / \Gamma_2^4$ millisec !!

- The synchrotron emission peaks at O-UV; then use of atomic cross sections (10^{-16} cm^2) maybe justified, yielding $\alpha \sim 1\, n_0\, R_{16}$. If matter fully ionized more column necessary.

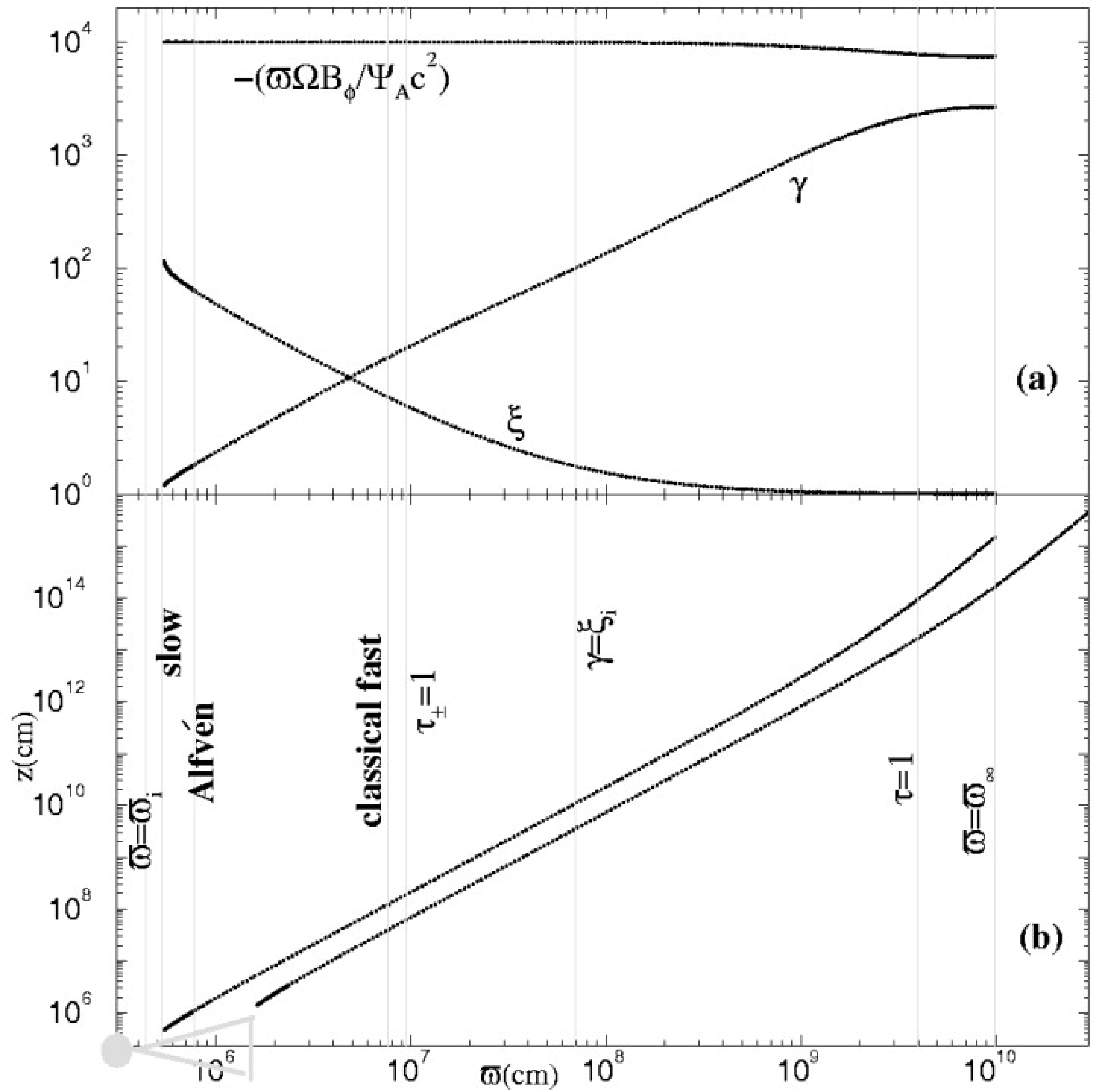

54
52
50
48
46
44
42
log L, erg s^{-1}
10
15
20
25
log ν Hz

GRB and the "Linear Accelerator"

- A rotating dipole can serve as the basis of MHD GRB models (Usov 1992)
- The axisymmetric dipole gives a first approximation of the geometry and asymptotic structure of such winds.
- MHD winds (both dipolar and self-similar) *accelerate linearly* with distance to the point that $\sigma \sim 1$ (Contopoulos & Kazanas 2002; Vlahakis & Konigl 2001). Acceleration then stops when collimation begins.



2.5
2
1.5
1
.5
0
0
.5
1
1.5
2
2.5
3



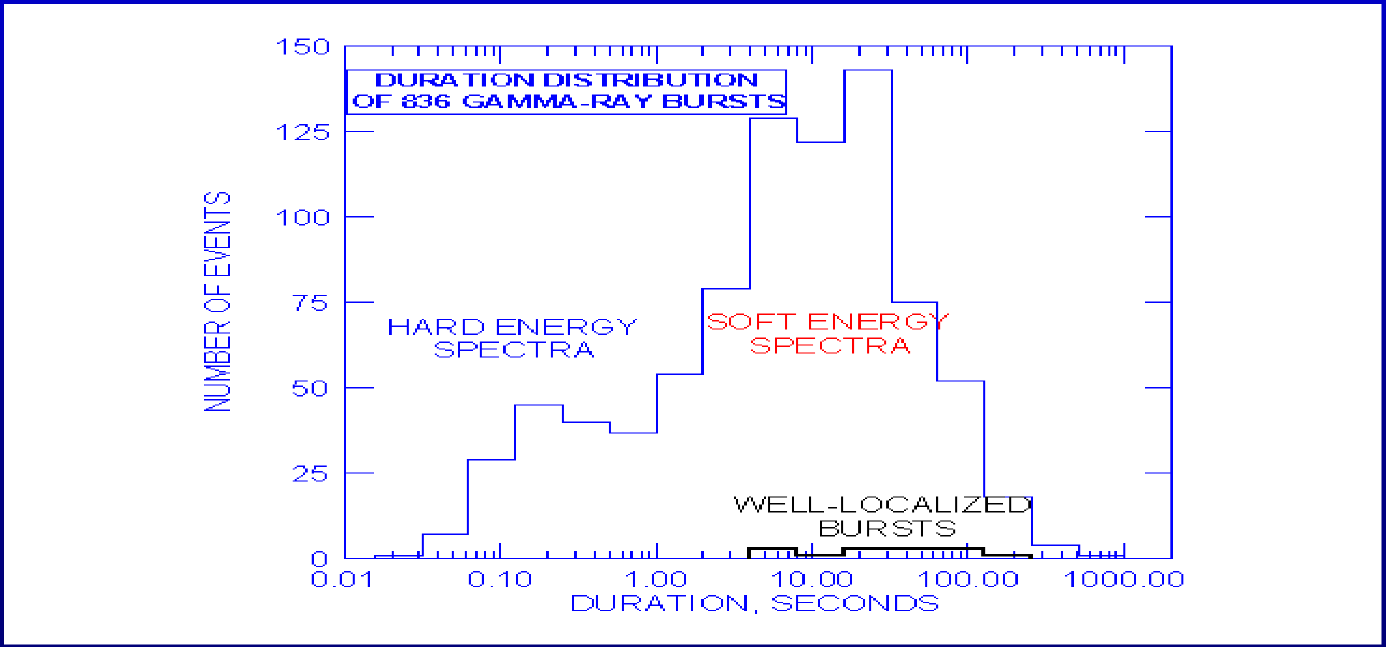
$-(\varpi\Omega B_\phi/\Psi_A c^2)$
γ
ξ
(a)
(b)
slow
Alfvén
classical fast
$\tau_\pm=1$
$\gamma=\xi_i$
$\tau=1$
$\varpi=\varpi_i$
$\varpi=\varpi_\infty$
z(cm)
ϖ(cm)

- Lorentz factor proportional to ϖ (cylindrical distance; identical to radial distance for conical flow; $R^{1/2}$ for parabolic flow)
- *Flow cross section inversely proportional to "inertial loading*[2]*" at the source* (I.e. inversely proportional to σ^2 at the "light cylinder").
- Sources of lower inertia (higher initial Γ) will have wider cross sections and will "sweep" more matter upon expansion; They will therefore show a "break" in their light curves, interpreted as smaller opening angles.

- Higher initial Lorentz factor will presumably lead to higher peak luminosities and smaller lags between various GRB energies (Norris, Marani &Bonnel 2000).
- Arguing along the above lines one obtains $E_{iso} \sim 1/\,T_b$ which has the qualitative but not the quantitative behavior of the Salmonson & Galama (2002) relation.
- Also, shorter lags, indicating larger Lorentz factor should lead to GRB with shorter T_b, as found by Salmonson & Galama (2002).

Conclusions

- The progress in the understanding of GRB with multi-band observations has been dramatic. The relativistic BW has been confirmed and so is the cosmological origin of (the long) GRBs



- There is good evidence of beaming (restricted emission in angle) and intriguing evidence between the beaming and dynamical properties of GRB (MHD origin of bursts??) .
- Better understanding of the GRB physics requires improvement of our systematics over as broad a band as possible.
  - *SWIFT* will be the next mission to provide a large number of positional identifications.
  - Ground observations (large, small observatories) will be instrumental in determining the GRB systematics.
  - *GLAST* will expand the GRB band, likely to yield a new window in GRB physics.

- The correlation between prompt and afterglow properties suggest possible connection between the properties of GRB and that of their engines, possibly to be delineated by the next set of observations.

for $\quad p >> nmc^2, \; w \cong p = aT^4, \; \gamma = \dfrac{4}{3}$

also $\; pV^{\gamma} = \text{const.} \quad \Rightarrow \quad aT^4 (R^3)^{4/3} = \text{const.}$

$$T \propto \frac{1}{R}, \qquad \frac{w\Gamma}{n} \propto \frac{R^{-4}\Gamma}{R^{-3}} = \frac{\Gamma}{R} = \text{const.}$$

$$\Downarrow$$

$$\Gamma \propto R \quad \text{and} \quad \Gamma \cdot T = \text{const.}$$

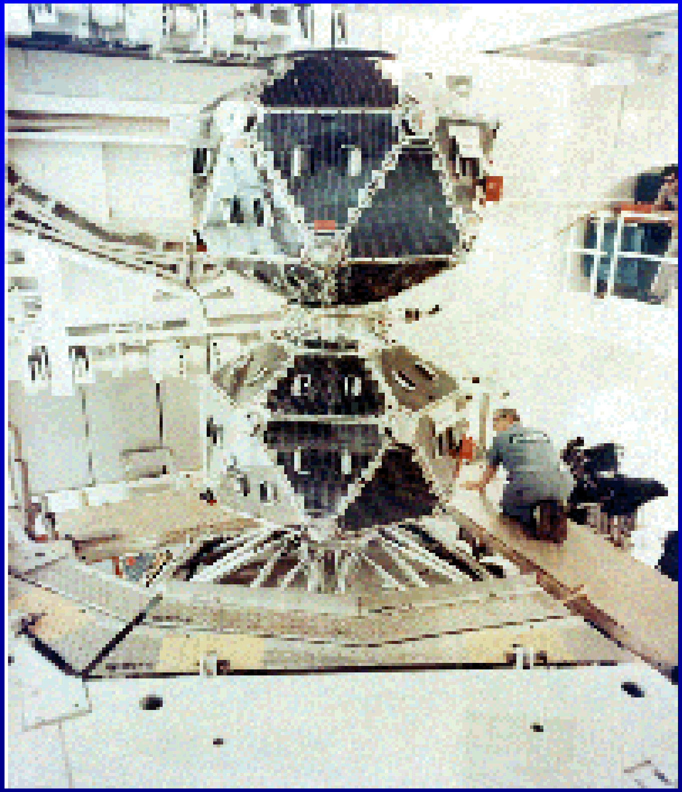
$$E \approx \frac{4\pi}{3} n_0 R^3 \Gamma^2 \mathrm{m_p c^2}$$ if adiabatic

$$E \approx \frac{4\pi}{3} n_0 R^3 \Gamma \, \mathrm{m_p c^2}$$ if radiative

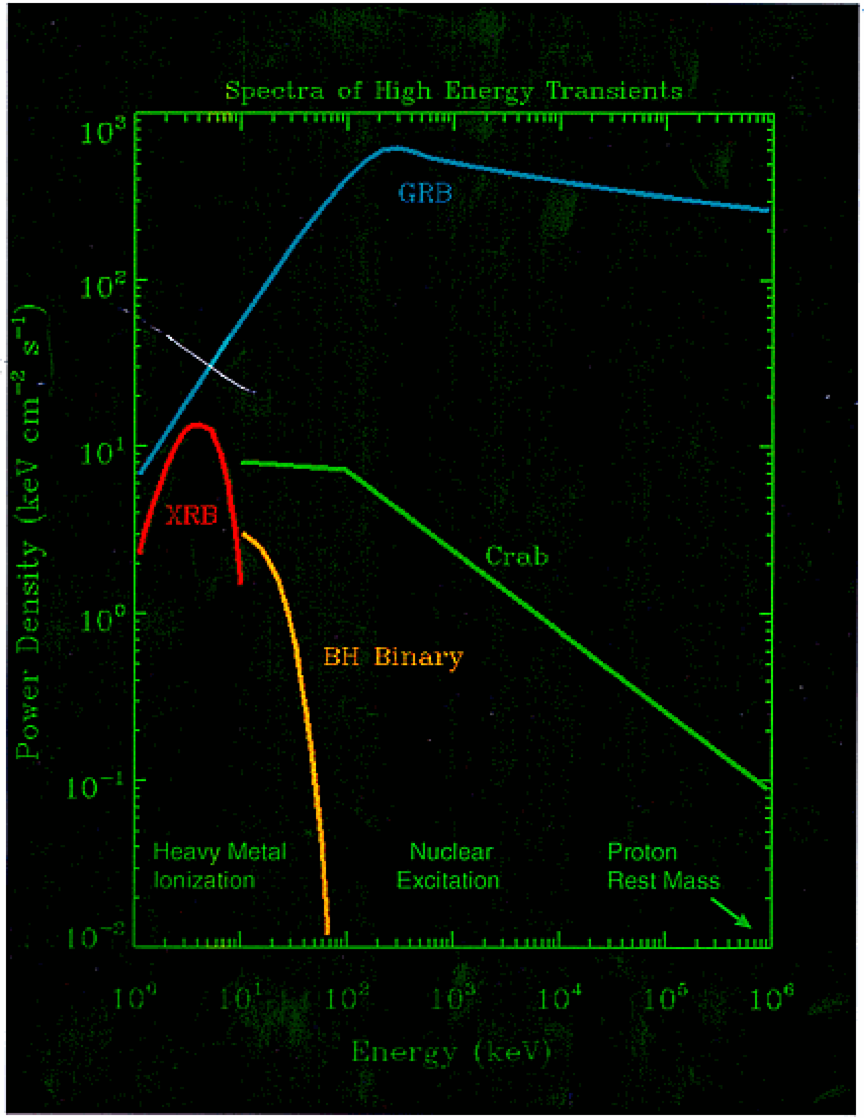
$$\Gamma \propto E^{1/2} n_0^{-1/2} R^{-3/2}$$ if adiabatic

$$\Gamma \propto E \, n_0^{-1} \, R^{-3}$$ if radiative

- Discovered by the VELA satellites, launched to verify compliance with nuclear test agreements.

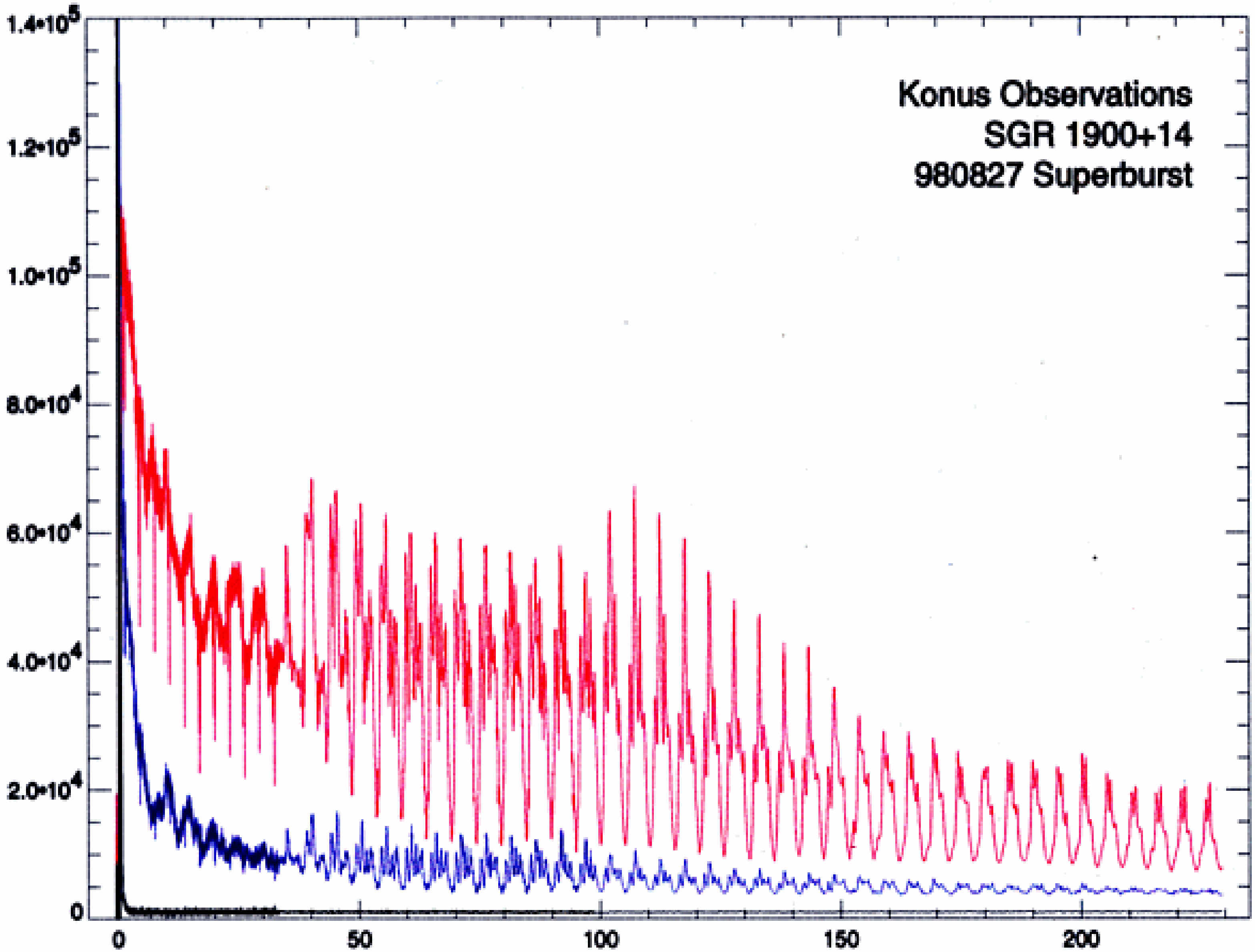


- **Most characteristic property**: Spectrum peaks in soft gamma rays (200 keV) and extends to much higher energies



- Discovered by very broad field of view instruments, their origin remained speculative, because of the lack of any emission that would reveal their distance.
- Spectral features in the 20-50 keV range in the KONUS spectra were thought to be due to cyclotron absorption indicating neutron star origin (many doubted their significance).
- It was generally thought to be associated with neutron stars (for lack of any association with known objects).

- 1st localization: The March 5, 1979 event, was localized and found to originate from within the SN remnant N49 in the LMC.
- The high flux ($5\ 10^{-4}\ erg/cm^2\ sec$) and known distance (55 kpc) suggested a luminosity of $L \sim 10^{44}\ erg/\ sec$, regarded with disbelief.
- The oscillatory behavior of this burst along with a redshifted annihilation line and the SN remnant location suggested association with neutron stars.



Konus Observations
SGR 1900+14
980827 Superburst
1.4•10^5
1.2•10^5
1.0•10^5
8.0•10^4
6.0•10^4
4.0•10^4
2.0•10^4
0
0
50
100
150
200

- With only one localization of the brightest GRB the situation became quite confused.
- The positional identification was attacked as a case of *a posteriori* statistics (Jim Felten argued that this was not true, based on *how* J. Laros determined its position).
- The general belief was that this was an extraordinary event and that most GRBs were galactic phenomena.
- Their distribution was apparently isotropic while the *LogN - LogS* relation indicated deviation from the 3/2 relation at low *S*.