# GRBs in the SWIFT and Fermi era: a new view of the prompt and early afterglow emission

Francesco Massaro
Harvard - SAO - CfA

Annapolis
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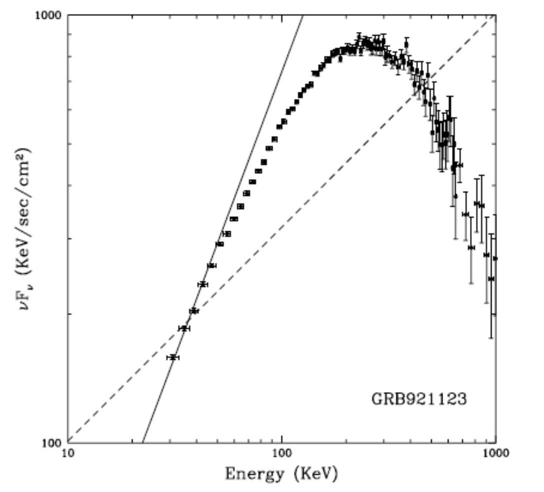
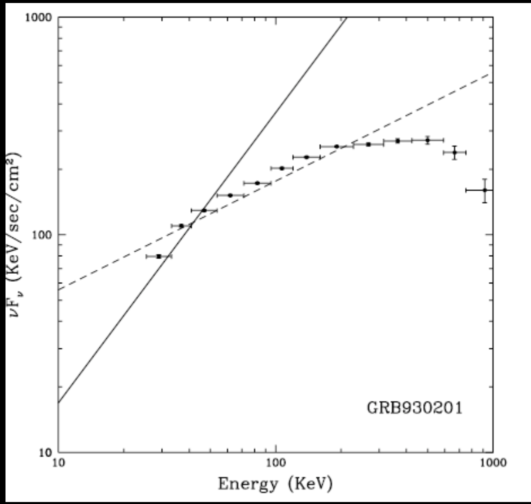
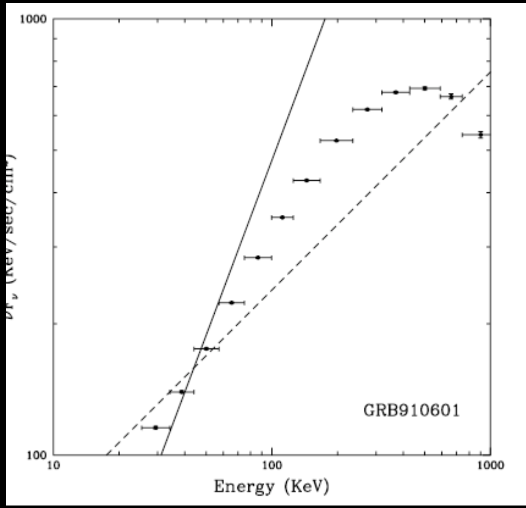
Thanks to:
J. Grindlay, R. Preece

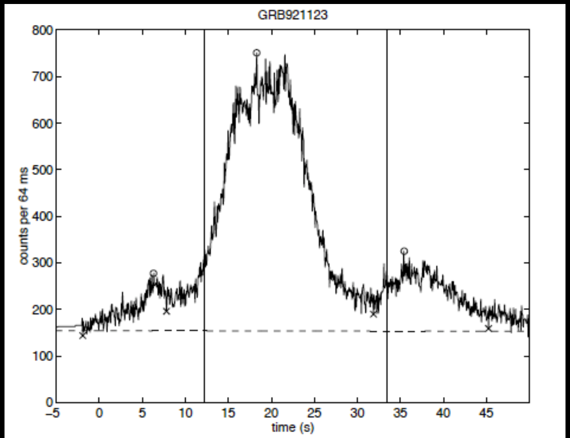
# GRBs Spectral Energy Distribution

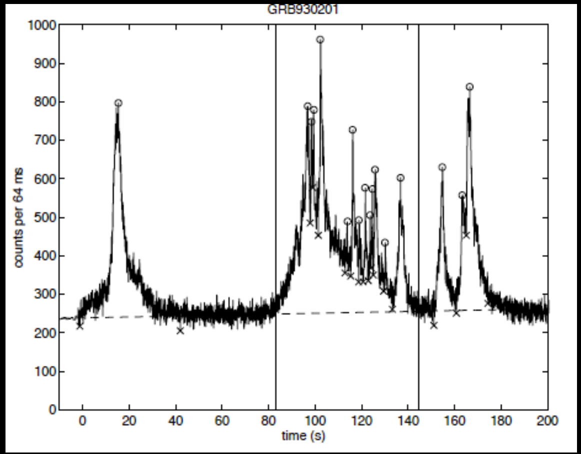
Observational evidence:
the SED is generally curved (convex and broadly peaked)

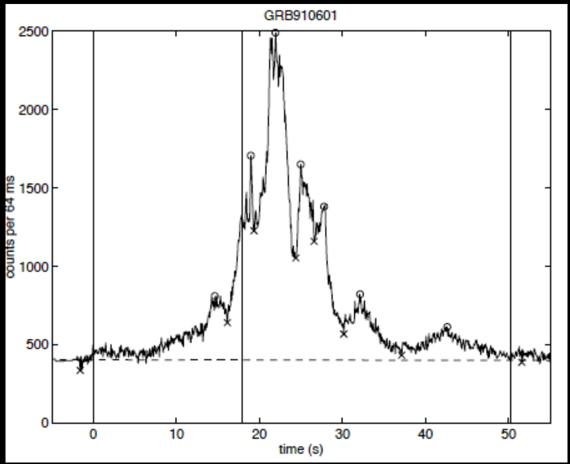


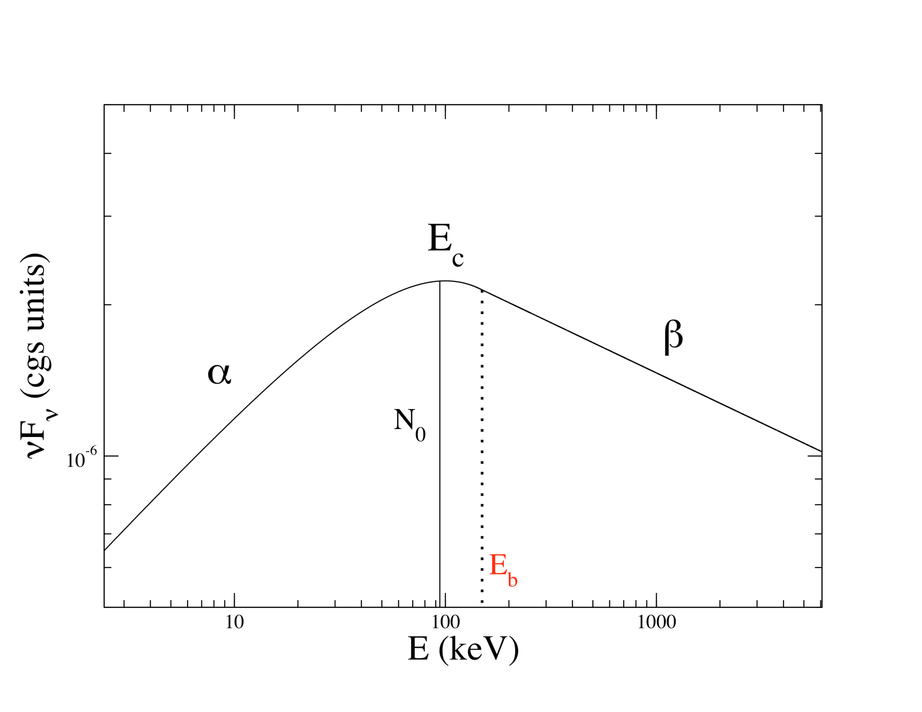



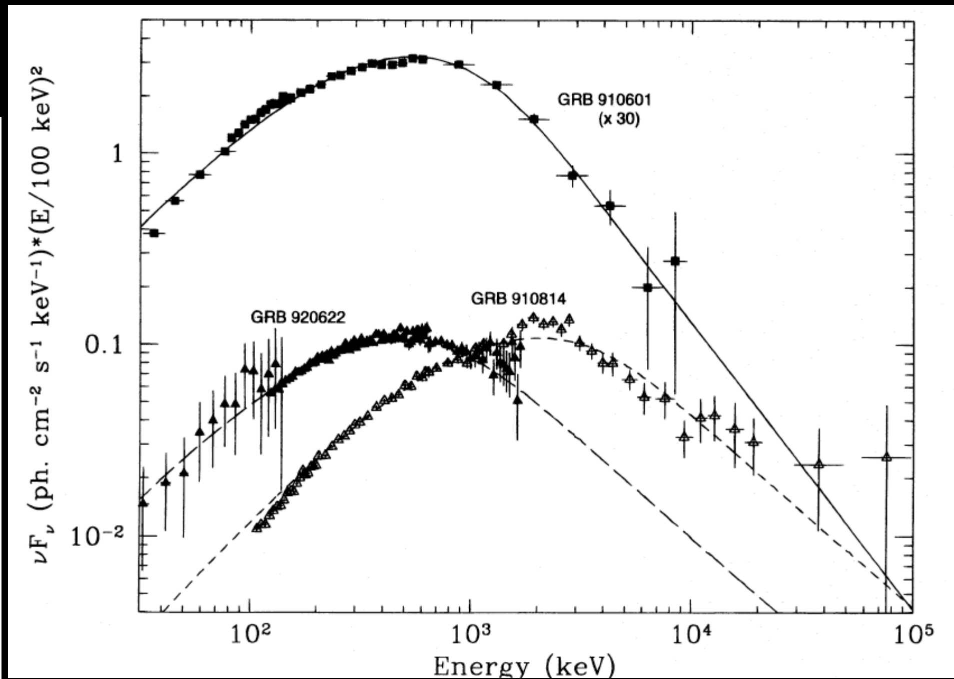




Cohen et al. 1997

# The Band Function

## Band Function




Tavani et al. 1996

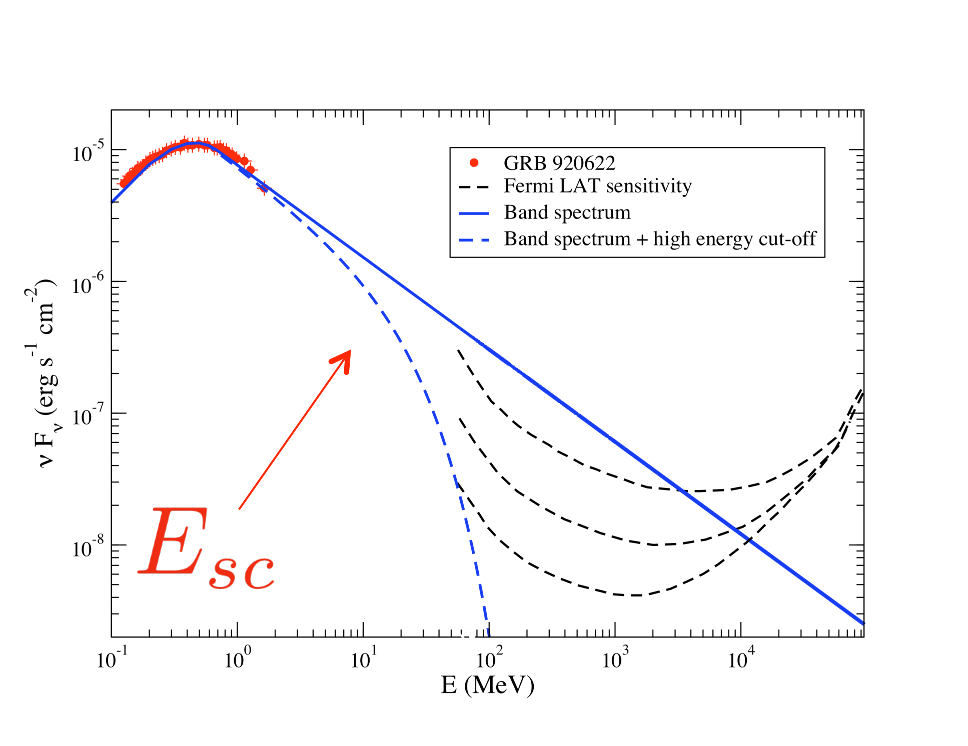
The SED shape is well described by this phenomenological model

$$F(E) = \begin{cases} F_0 \left(\frac{E}{100keV}\right)^{\alpha} \; exp\left(-\frac{E}{E_0}\right) & E \leq E_b \\ F_1 \left(\frac{E}{100keV}\right)^{\beta} & E \geq E_b \end{cases}$$

Band et al. 1993

# In the Fermi ERA…extrapolating the Band Function…

Band et al. 2009




Only 5-10% GRBs detected in the LAT during 1° year of Fermi obs.

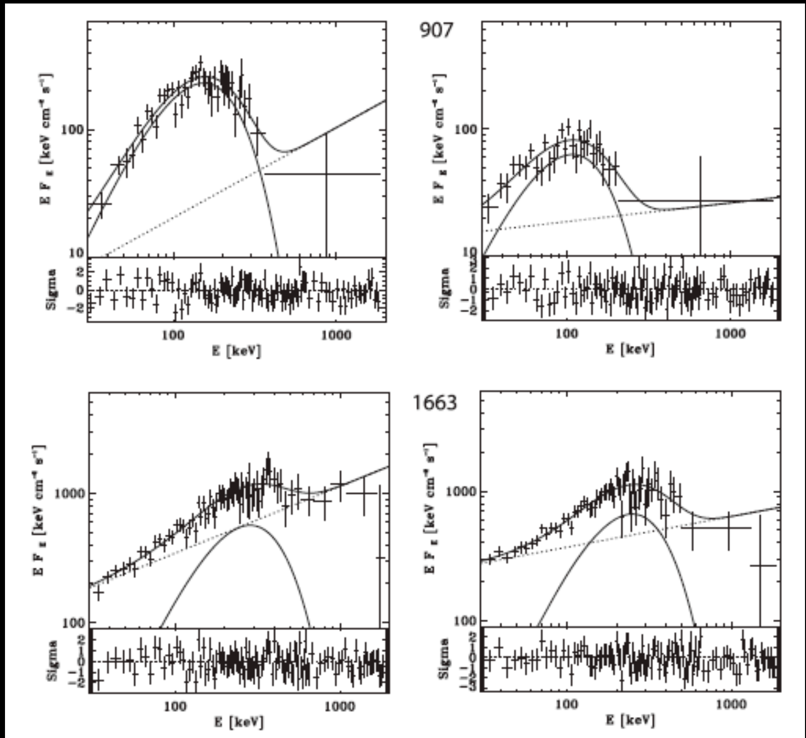
PREDICTIONS ??

now we are in agreement…

$$F(E) = \begin{cases} F_0 \left(\frac{E}{100keV}\right)^{\alpha} \; exp\left(-\frac{E}{E_0}\right) & E \leq E_b \\ F_1 \left(\frac{E}{100keV}\right)^{\beta} \; exp\left(-\frac{E}{E_{sc}}\right) & E \geq E_b \end{cases}$$

…so 5 parameters to define the Band function

# The thermal emission




Physical background !!!

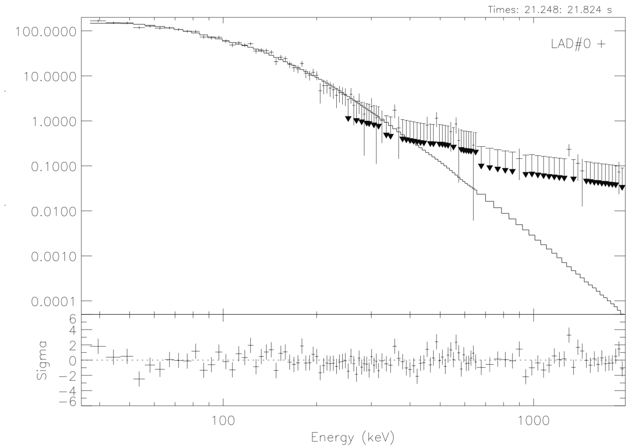
$$N_{\rm E}(E,t) = A(t)\,\frac{E^2}{\exp[E/kT(t)]-1} + B(t)\;E^s$$

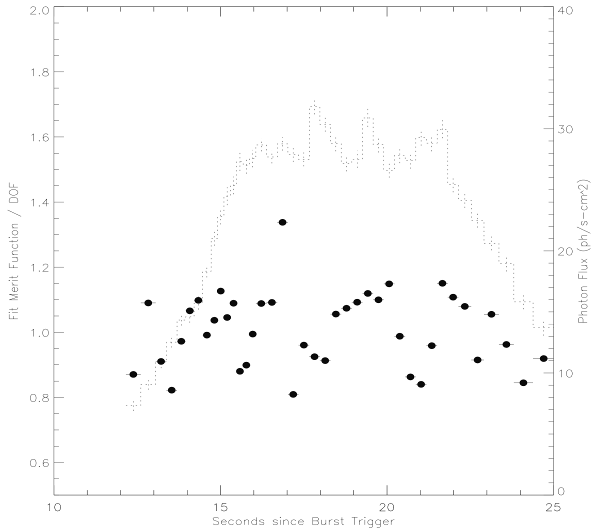
My view…it still has some problems

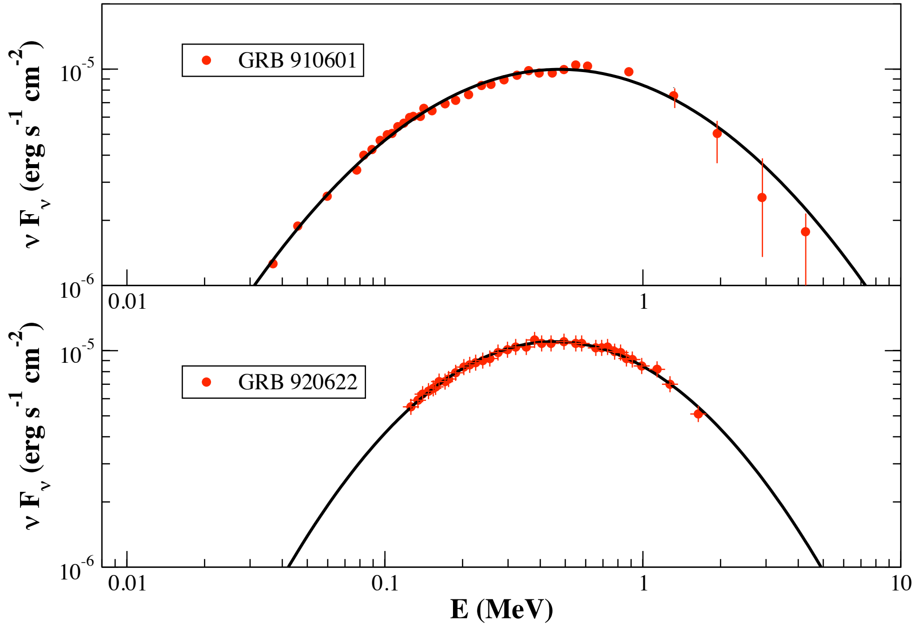
1. No signatures exp. cutoff
2. Powerlaw always necessary
3. Extrapolation of the powerlaw
4. No BB photon index at low energies
5. Connection low-high energies
6. It cannot describe all GRBs
7. No high values of curvature

(Ryde 2004)

# The log parabolic spectral shape




Log-parabola

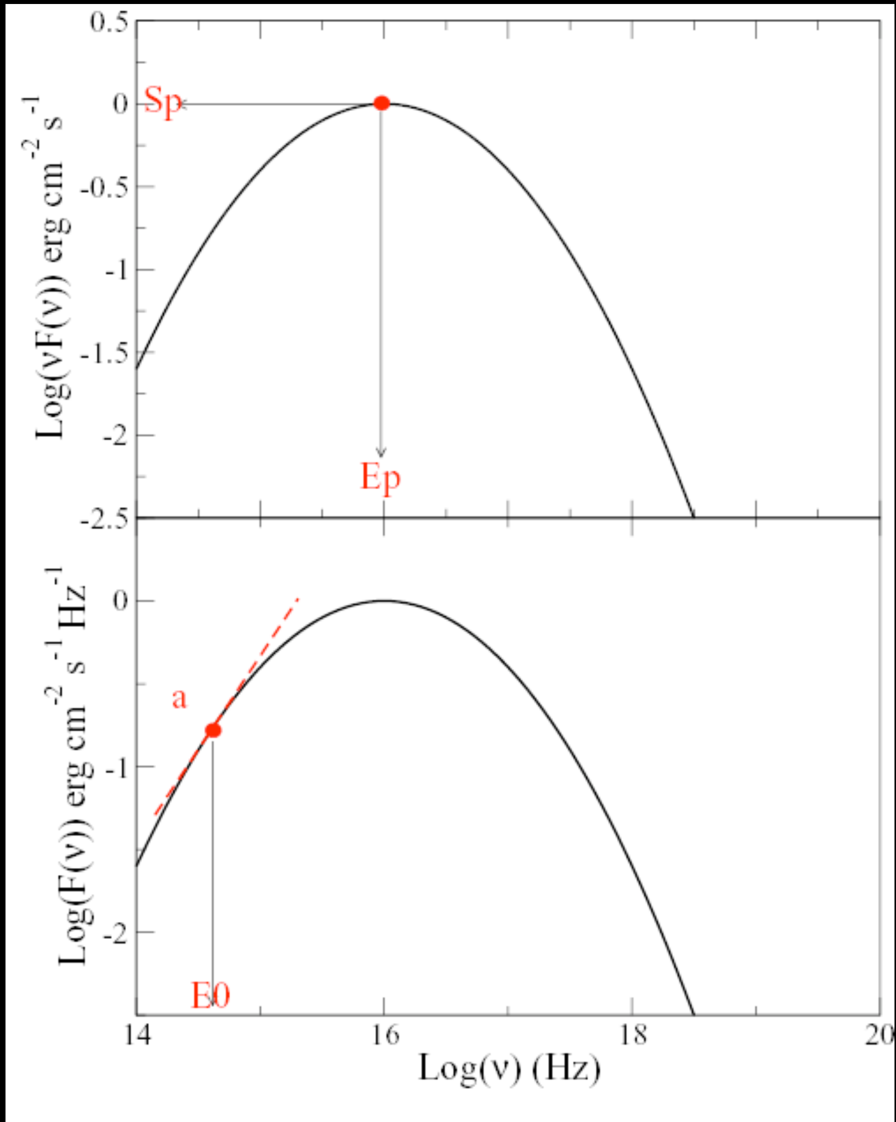
$$F(E) = F_0 \left( \frac{E}{100keV} \right)^{-a-b\ log(E/100keV)}$$

Energy dependent photon index $\Gamma(E) = a + 2\ b\ log(E/E_0)$

Massaro, Grindlay & Paggi 2010

# Log-Parabolic Spectral distribution

A log-parabolic spectral distribution is a distribution that is a parabola in the logarithm, and corresponds to a log-normal distribution.




$S(E)=Sp\ 10^{-b\ (Log(E/Ep)\hat{}2)}$

b: curvature at peak

$E_p$: peak energy

$S_{p:}$ SED height @ $E_p$

$F(E)=F_0(E/E_0)^{-(a+b\ Log(E/E_0))}$

b: curvature at peak

a: spectral index @ $E_0$

$F_0$: normalization @ $E_0$

# The log parabolic spectral shape

Log-parabolic means log-normal

$$y = \frac{1}{x}\ e^{-ln^2 x}$$

$$y = \frac{1}{x}\ e^{-(lnx)(lnx)}$$

$$y = \frac{1}{x}\ x^{(lnx)}$$

$$ln(y) = -ln(x) + ln^2(x)$$

Parabola is the natural way to approximate functions around a minimum or a maximum --> e.g. Taylor series

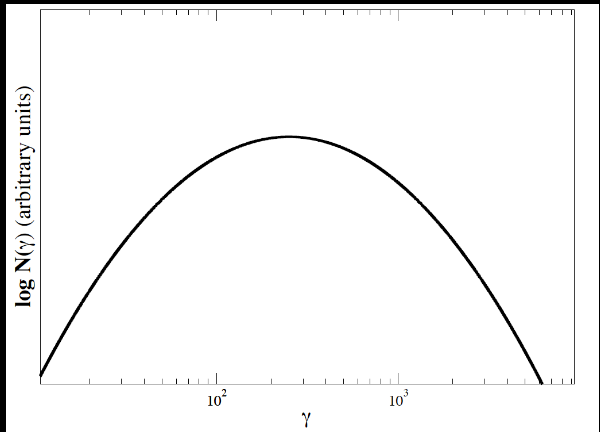
# The physics!!!

Since Kardashev 1962

$$\frac{\partial}{\partial t}N(\gamma,t) = \alpha_1(t)\frac{\partial}{\partial \gamma}[\gamma^2\frac{\partial}{\partial \gamma}N] + \frac{\partial}{\partial \gamma}[\alpha_2(t)\gamma + \beta(t)\gamma^2]N - \alpha_3(t)N + q(\gamma,t)$$

The general solution of the kinetic equation is well approximated by a log-parabolic function when:

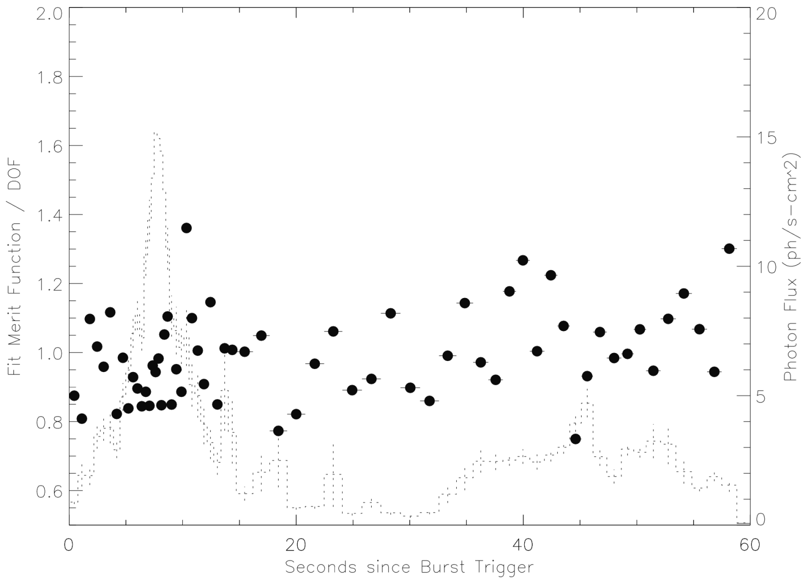
1. Not only Systematic but also stochastic acceleration
2. Radiative cooling + adiabatic expansion ……etc. etc.




$$log\frac{N(\gamma,t)}{N_o} = -s(t)log(\gamma/\gamma_o) - r(t)log^2(\gamma/\gamma_o)$$

Similar ideas: Ellison et al. 2001, Pelletier et al. 2003, Stawarz & Petrosian 2006.

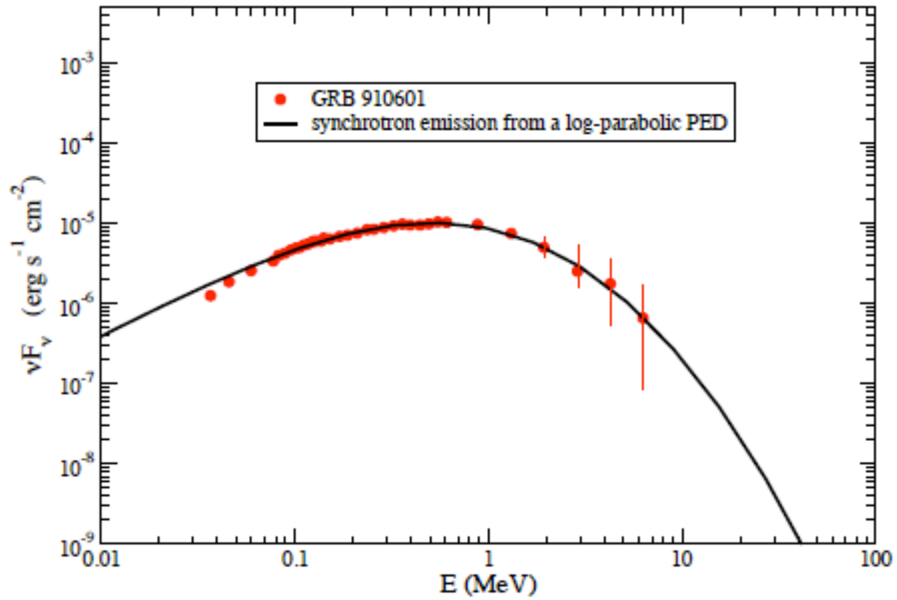
# The log-parabolic synchrotron spectra




$$N(\gamma)=N_0(\gamma/\gamma_0)^{-s-r\,\mathrm{Log}\,\gamma/\gamma_0}$$

Curvatures b ~ r/5

$$F(\nu)=F_0(\nu/\nu_0)^{-a-b\,\mathrm{Log}\,\nu/\nu_0}$$




b (BL Lacs): 0.05 - 0.5

b (GRBs): 0.2 - 1.2
(time resolved spectra)

# Something on the acceleration

Fermi acceleration mechanisms

$$\gamma = \gamma_0 \left(1 + \frac{\Delta\gamma}{\gamma}\right)^k$$

$$\log N_{el}(> \gamma) = B - \Gamma \log \gamma$$

Slope of the particle energy distribution

$$\Gamma = -\frac{\log[1 - \mathrm{P_{es}}]}{\log(1 + \Delta\gamma/\gamma)} \approx 1$$

$$n(> \gamma) \propto \gamma^{-1} \qquad \text{(integral form)} \quad ,$$

$$n(\gamma)d\gamma \propto \gamma^{-2} \qquad \text{(differential form)} \quad .$$

Cosmic rays…

# Something else on the acceleration

"Stochastic/statistical" acceleration

Assuming $P_{ret} \propto \frac{\gamma_0}{\gamma}$ ..... $\Gamma = -\frac{\log[1 - P_{es}]}{\log(1 + \Delta\gamma/\gamma)} \approx 1$

Slope of the particle energy distribution

$$\Gamma = -\frac{\log(\gamma/\gamma_0)}{\log(1 + \Delta\gamma/\gamma)}$$

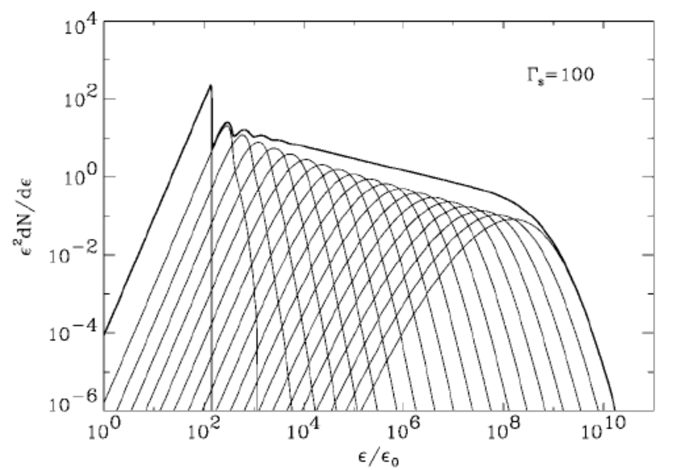


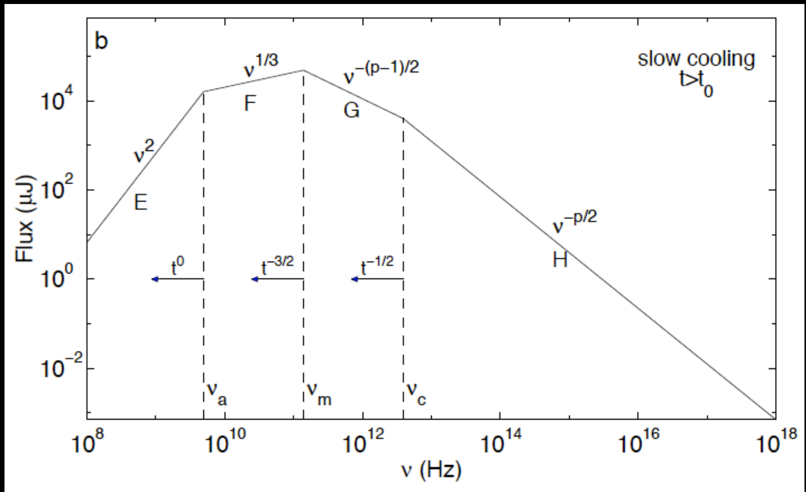

FIG. 3.—Spectrum of particles escaping downstream (*thick line*) as a function of momentum after 20 cycles for $\Gamma_s = 100$; the thin lines show the spectra of particles escaping downstream after each cycle.

Log-parabola

$$\log N_{el} = -r \log^2(\gamma/\gamma_0)$$

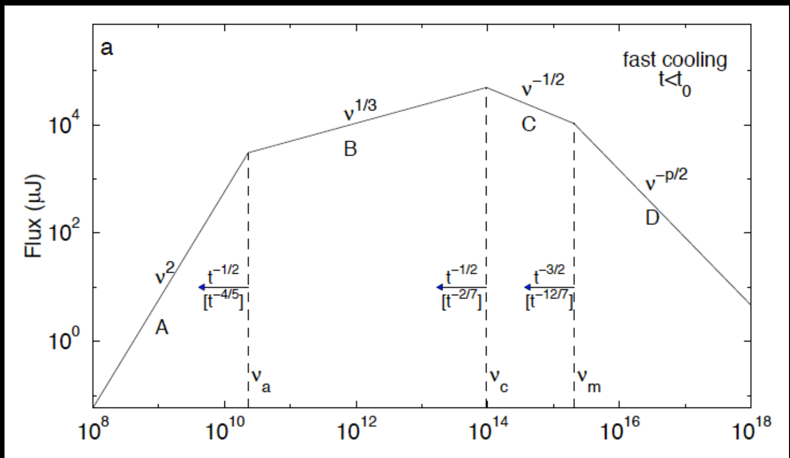
Another example
Lemoine & Pelletier 2003

# Synchrotron scenario

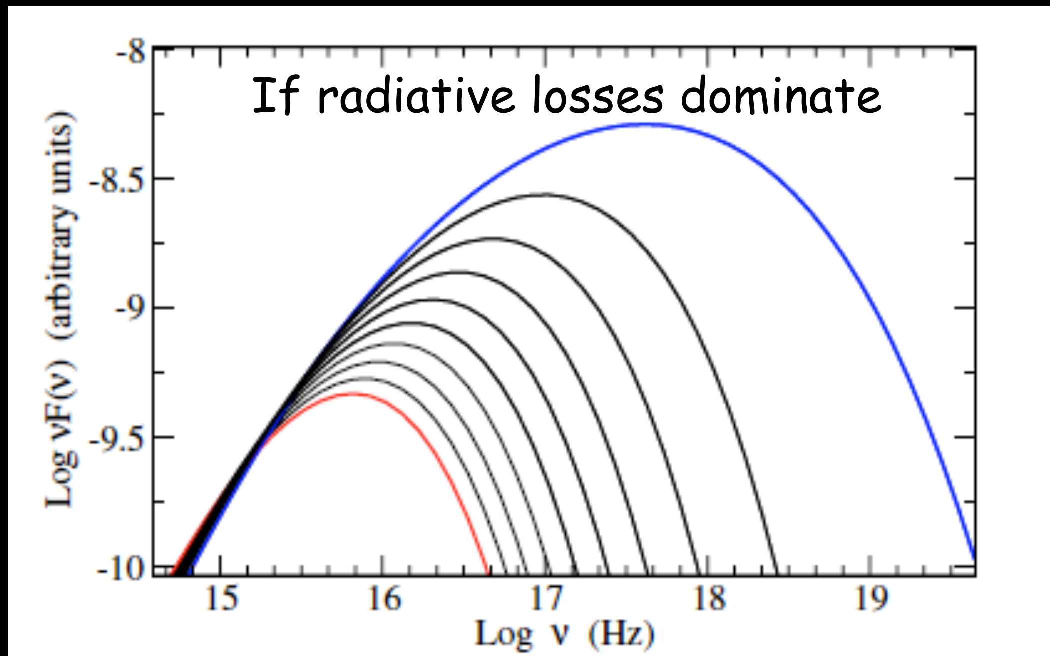



GENERAL ASSUMPTIONS:

1. Neglect 2° order Fermi acceleration
2. Assume continuum injection
3. Assume a powerlaw as initial condition
4. Fast or slow radiative cooling
5. Assume no re-acceleration e.g. turbolence




Synchrotron cooling time too fast…




Sari, Piran & Narayan 1998

# Adiabatic expansion

$$\frac{dE}{dt} = \left[ \left(\frac{dE}{dt}\right)_{sys} + \left(\frac{dE}{dt}\right)_{sto} - \left(\frac{dE}{dt}\right)_{syn} - \left(\frac{dE}{dt}\right)_{ic} \right] - \left(\frac{dE}{dt}\right)_{adb}$$

Hp. Self similar scenario:

$$R(t) = R_0 \left(\frac{t}{t_0}\right)^{p} \qquad \gamma(t) = \gamma_0 \left(\frac{t}{t_0}\right)^{-p}$$

Possible interpretation of the hardness intensity correlation (HIC):

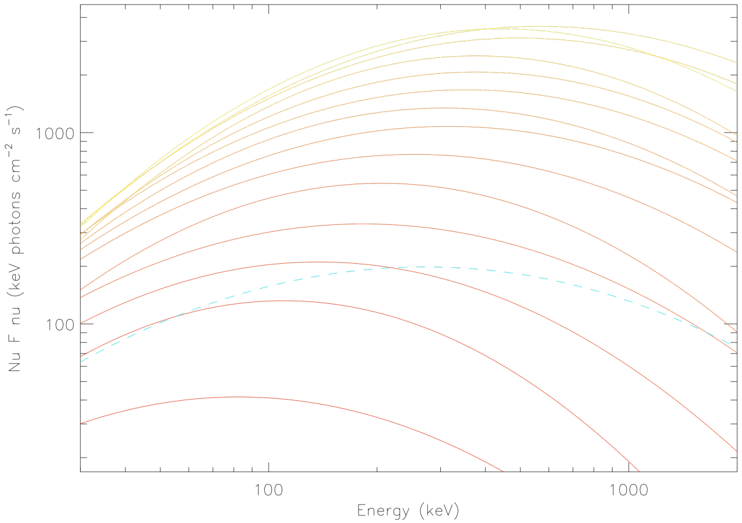
$$E'_p \sim \left(\frac{t}{t_0}\right)^{-4p} \quad , \quad S'_p \sim \left(\frac{t}{t_0}\right)^{-6p} \qquad S'_p \propto (E'_p)^{3/2}$$

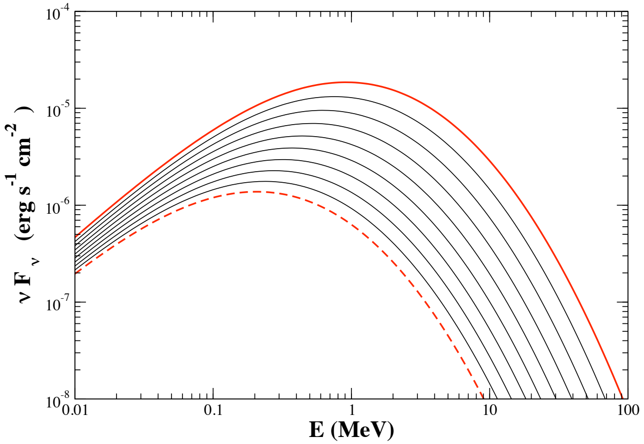
The HIC has a peak index of ~ 1.6

Massaro & Grindlay 2010

# Spectral curvature behavior

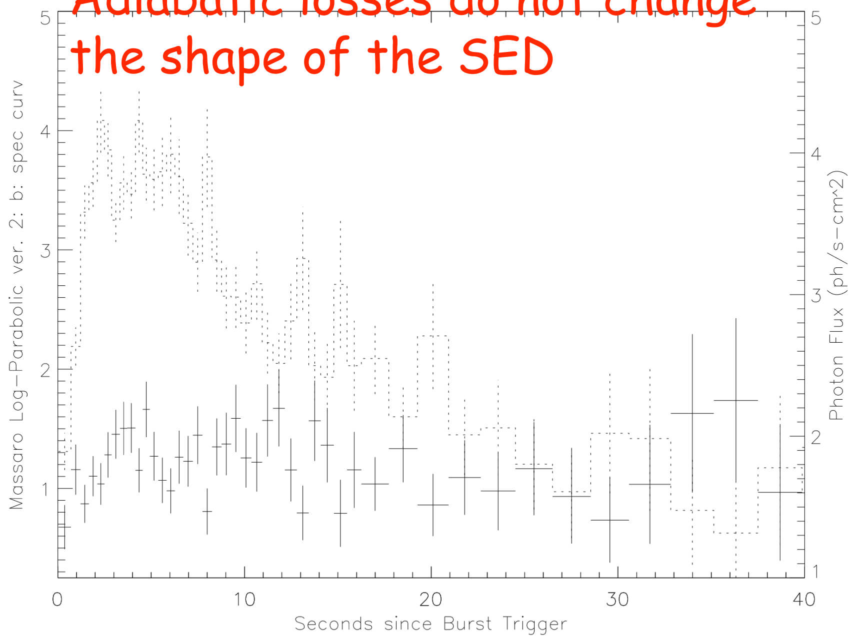
Simulated spectral evolution



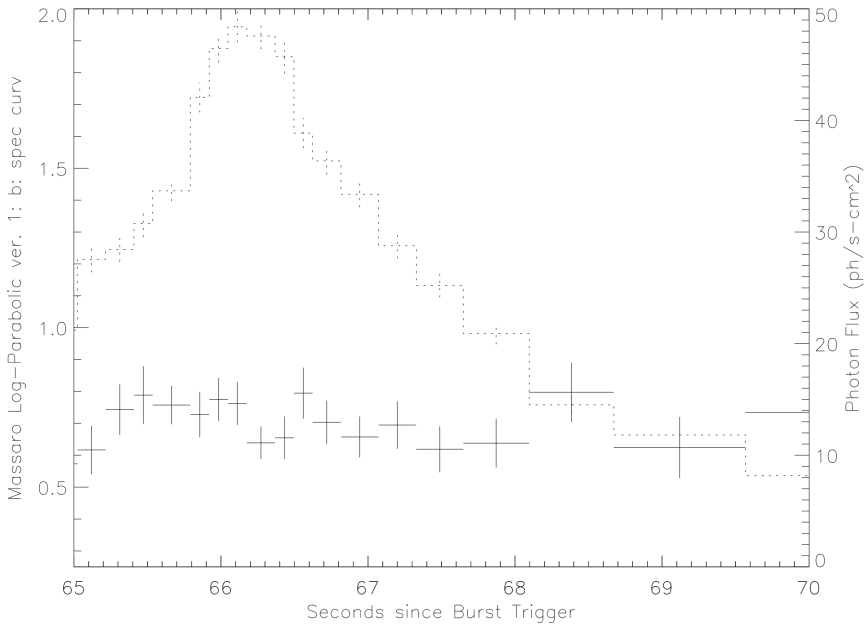



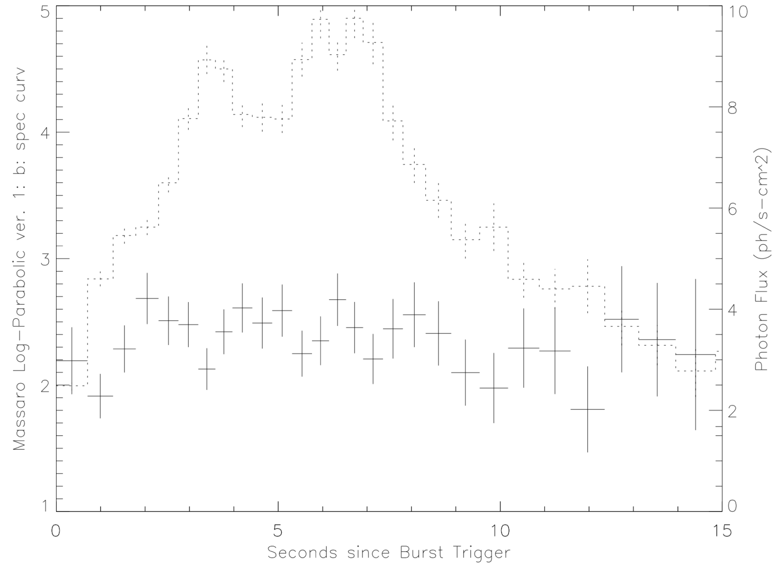

Observed spectral behavior

Adiabatic losses do not change the shape of the SED

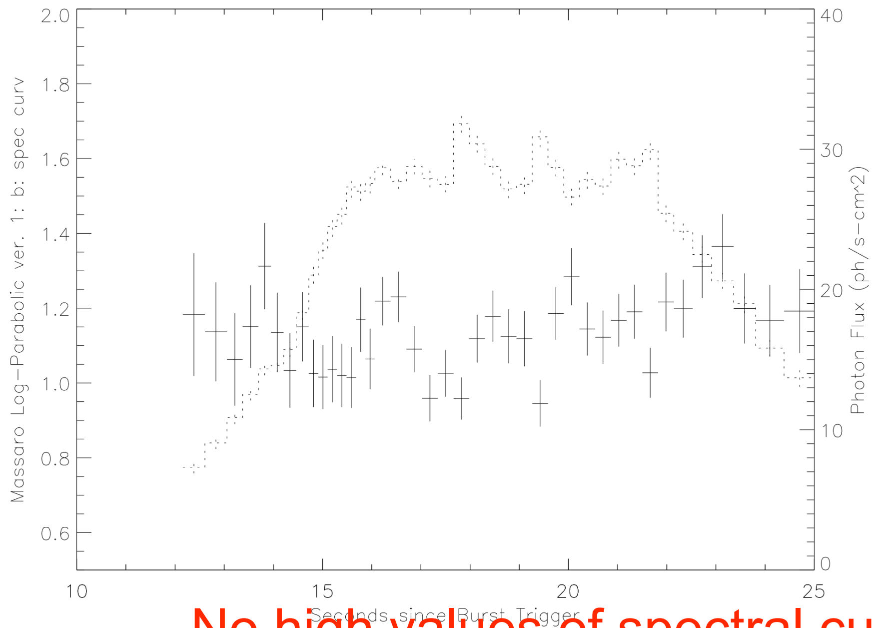


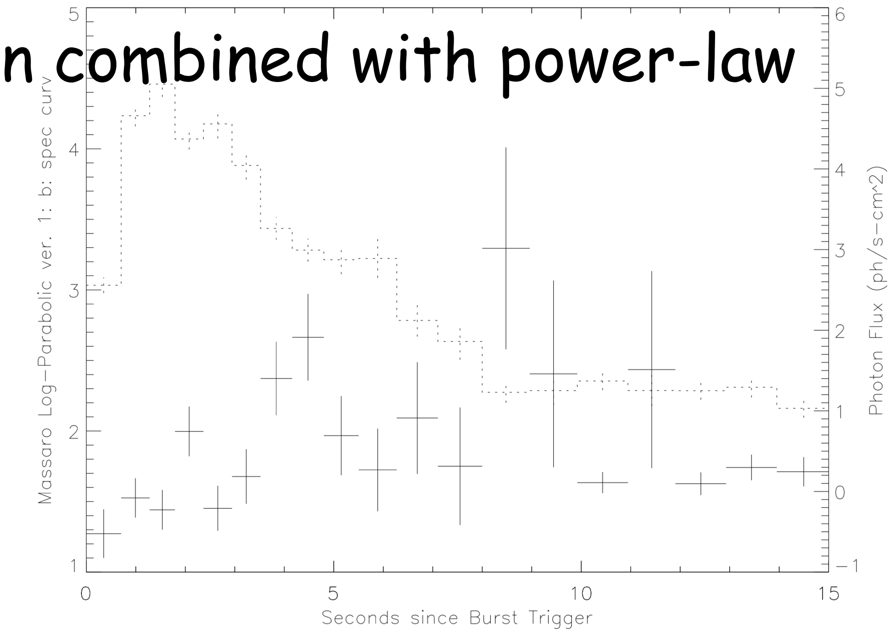

We do not see drastic variations of the curvature during GRB single pulses




# Unlikely to be thermal emission combined with power-law




No high values of spectral curvature (thermal expected b~15)

# CONCLUSIONS

1. Log-parabola vs Band or Photospheric models
   From the statistical point of view 5 parameters vs 3 parameters
   (in agreement with Fermi LAT GRBs detections)

2. From the physical point of view
   a priori physical background

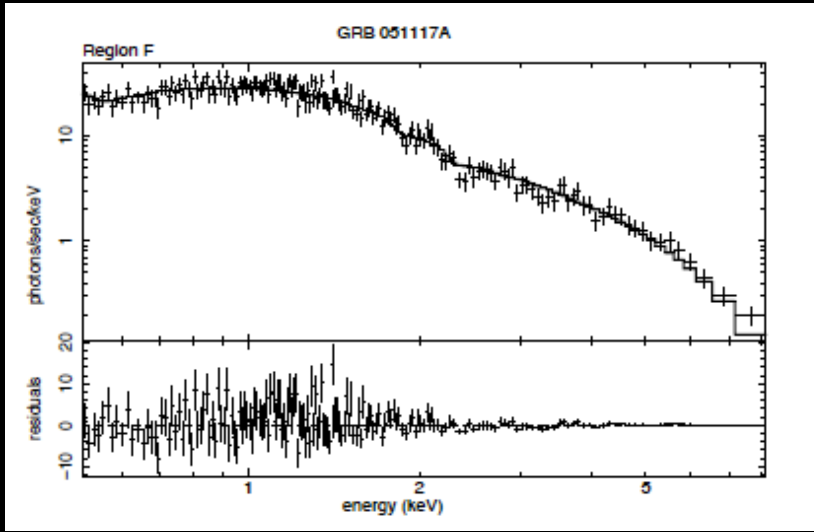
3. Time integrated spectra are well described in terms
   of the Band function because there is: spectral evolution
   (power-law at low and at high energy)

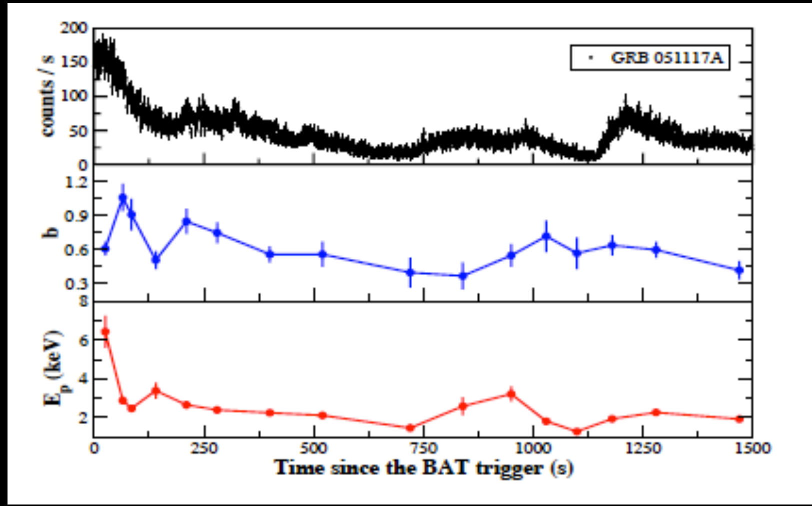
4. Time resolved spectra are very well described in terms of
   log-parabolic model (up to now no exceptions)

5. No drastic variation of the spectral curvature
   during GRB single pulses (CAREFUL must be tested)
   (signatures of adiabatic expansion and re-acceleration)

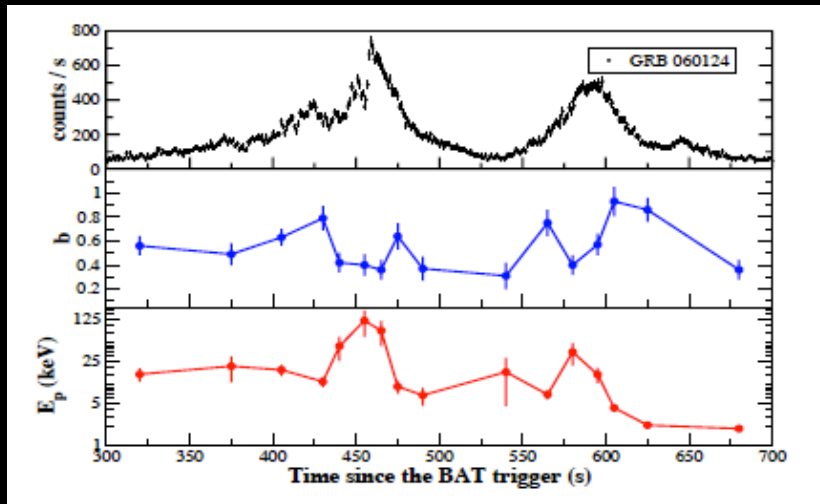
and something more..

# X-ray flares in GRB afterglows



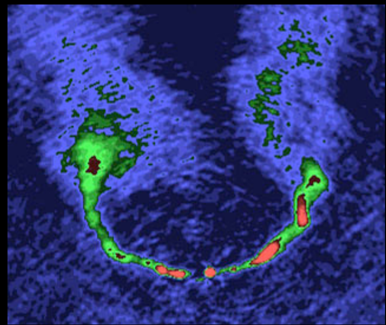



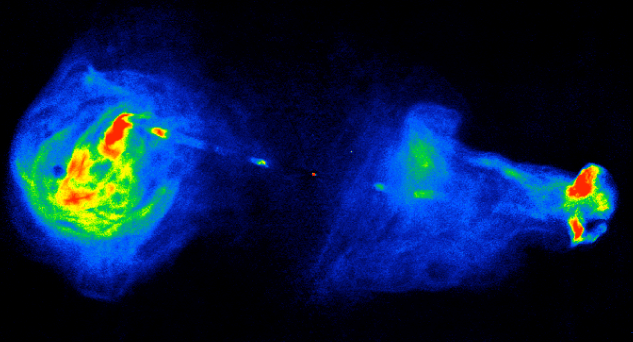

1. Anticorrelation between Ep and b
2. No drastic variations of b
3. Inconsistent with thermal (i.e. Blackbody) emission
4. Same model adopted for GRB prompt emission and not only

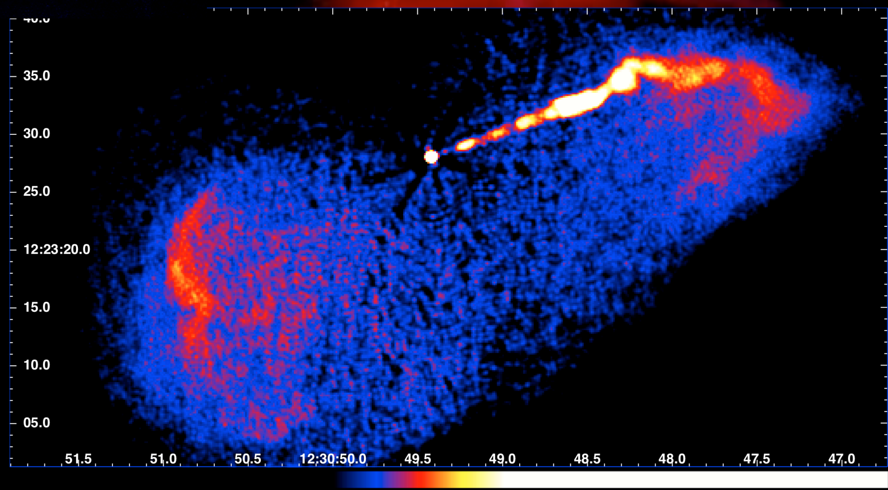



Everything in poster 03.14

# GRB conference in  Rome 2004

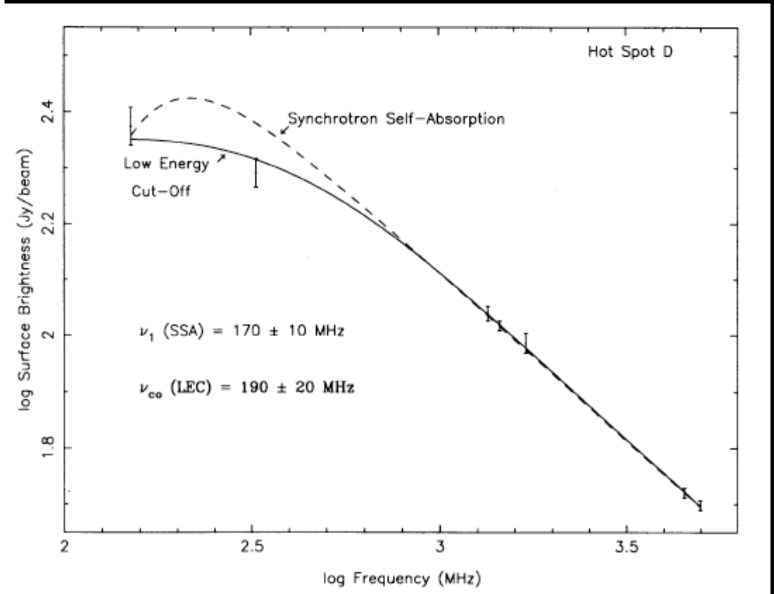


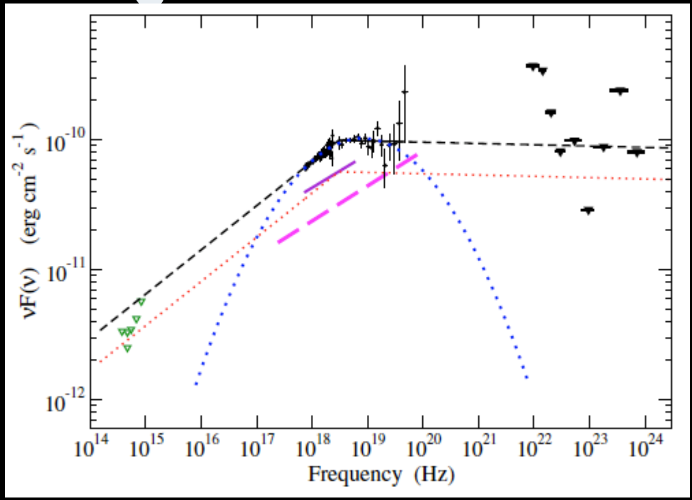





R. Blandford concluding remarks

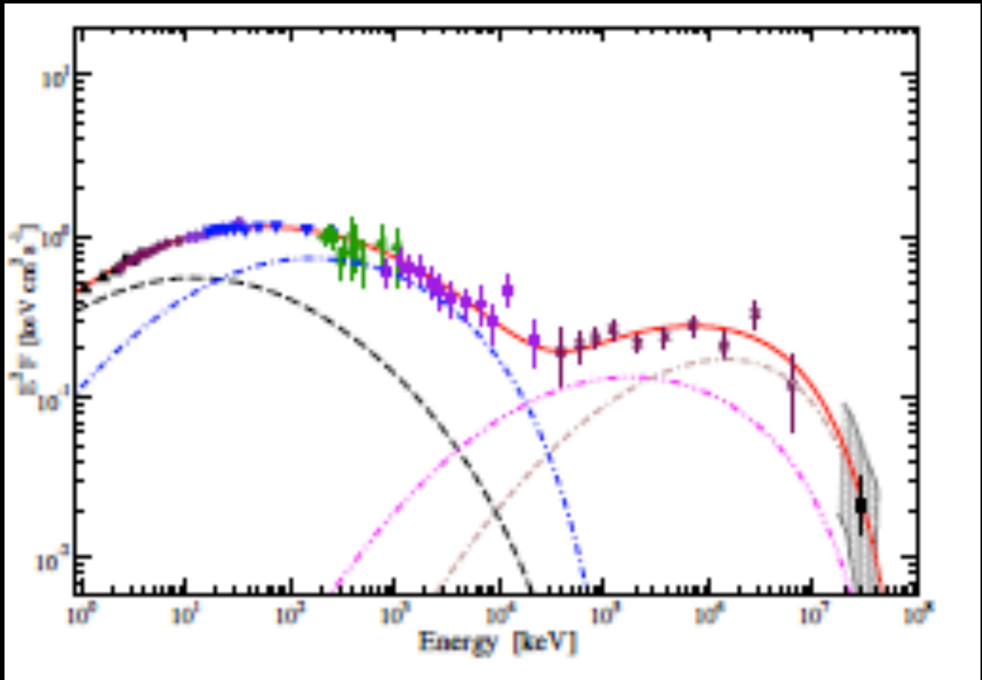
# Curved spectra in jets



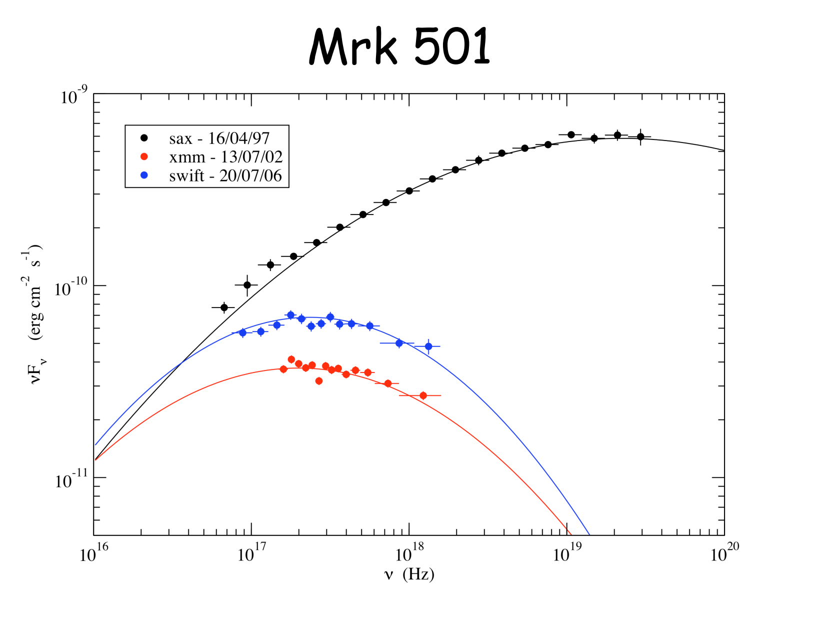

Vela plerion (Mangano et al. 2005)

Cygnus A (FR II)
(Carilli et al. 1991)

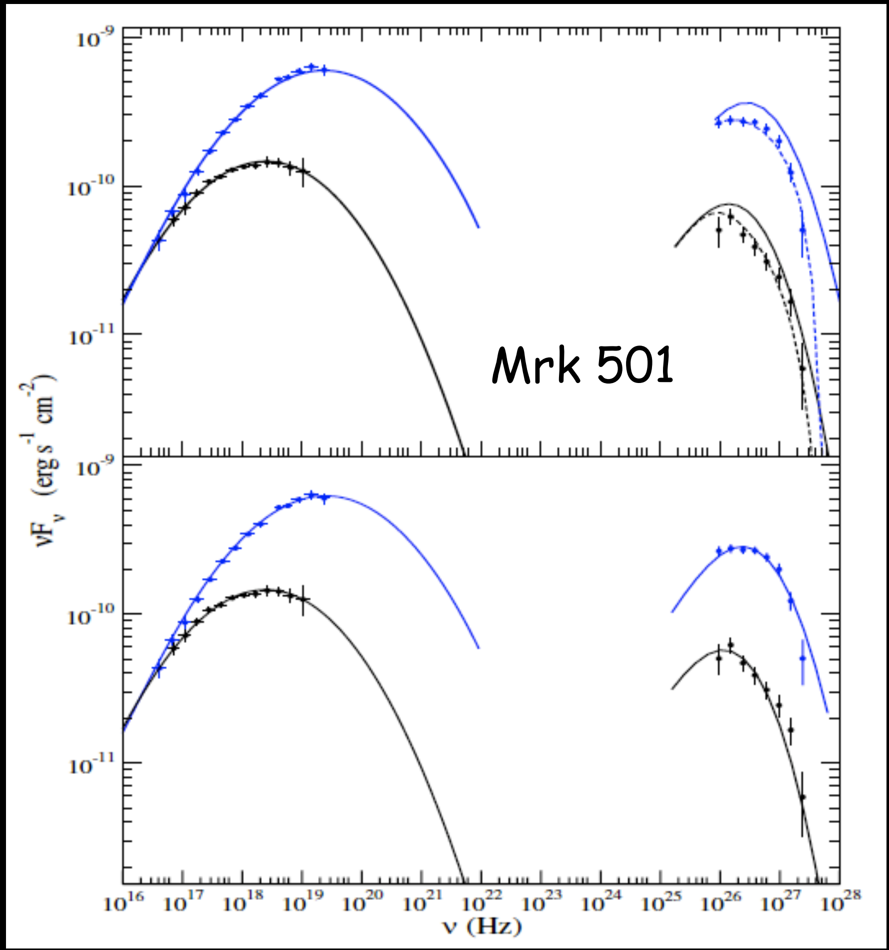


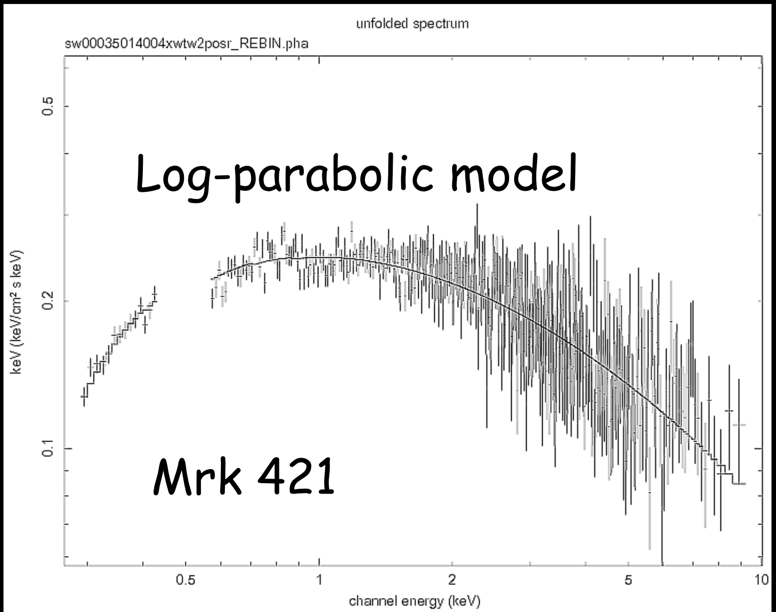

Crab Pulsar (Campana et al. 2008)

# Curved spectra in jets

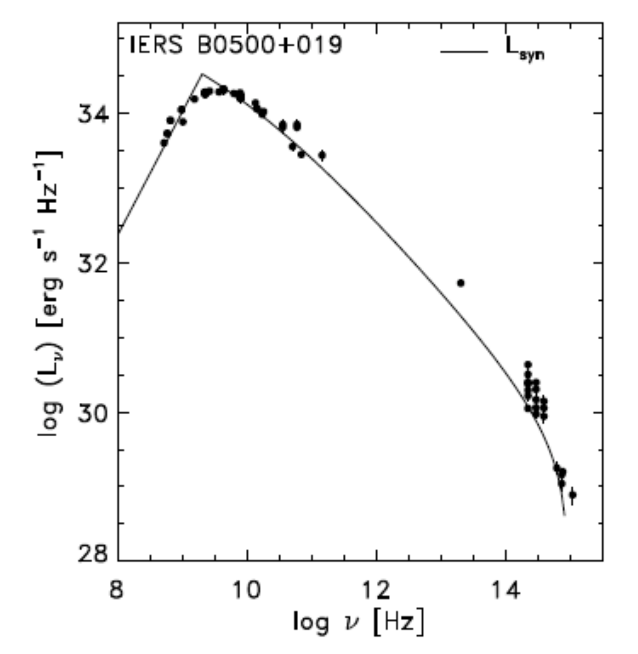



BL Lacs
(Massaro et al. 2006, 2008)

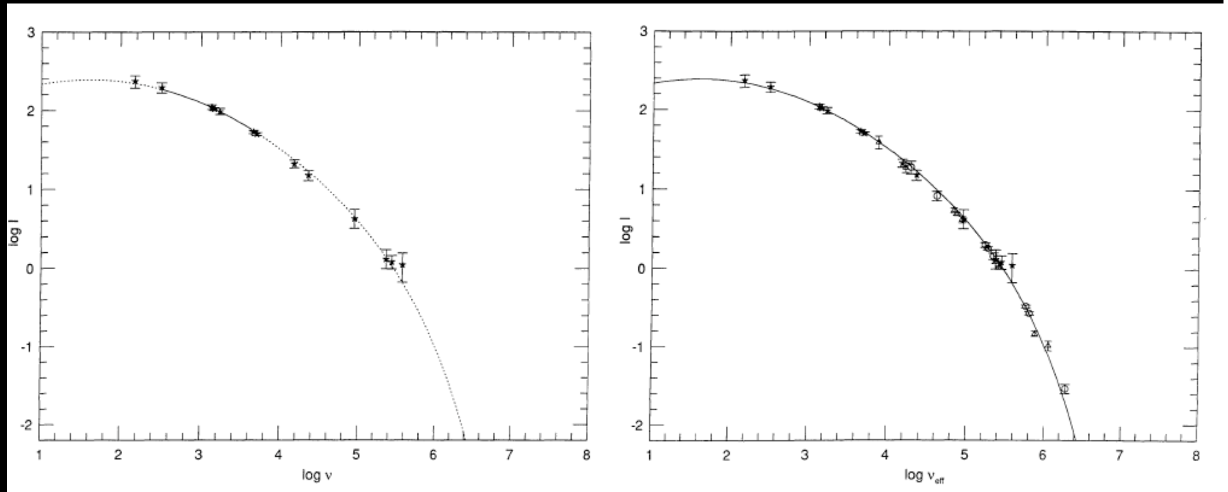


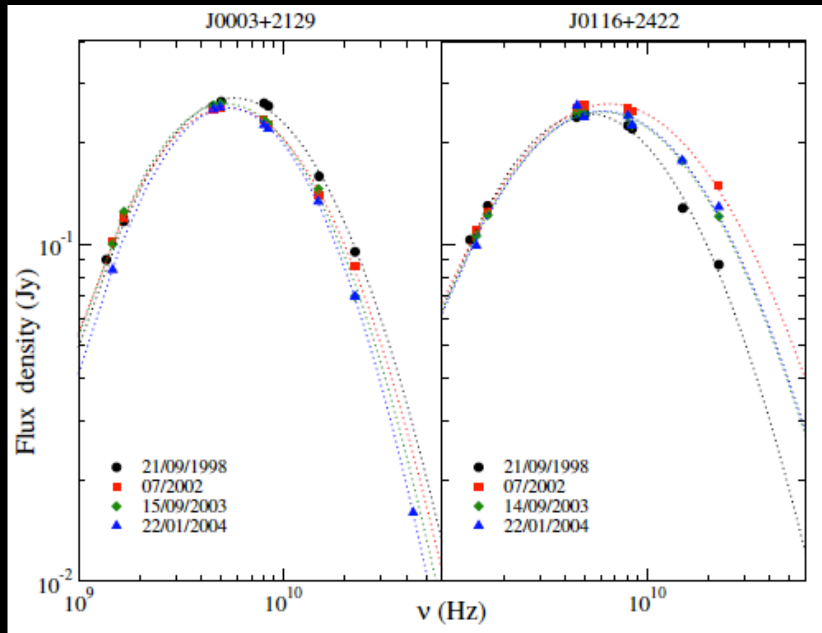
# Curved spectra in jets




GPS radio sources
(Ostorero et al. 2009)




Radio galaxies (Katz-Stone et al. 1993)

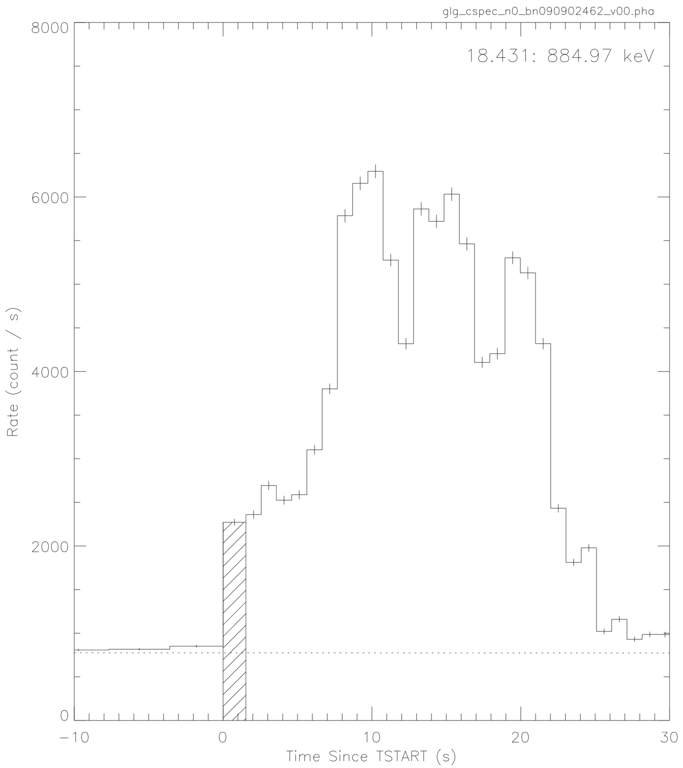



High Frequency Peakers
(Maselli et al. 2009)

# The End

# Backup slides

# GRB 090902B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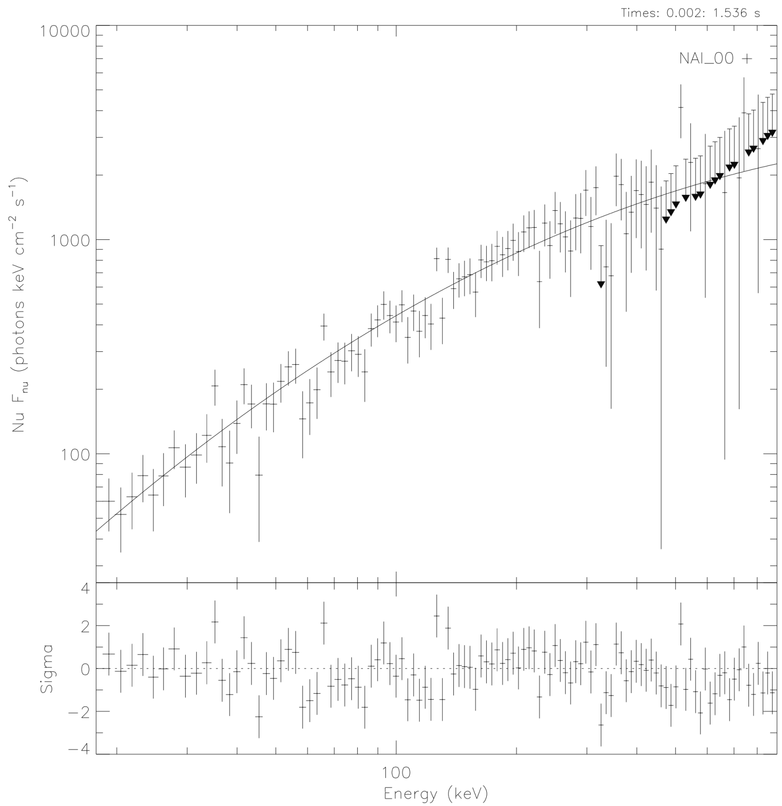
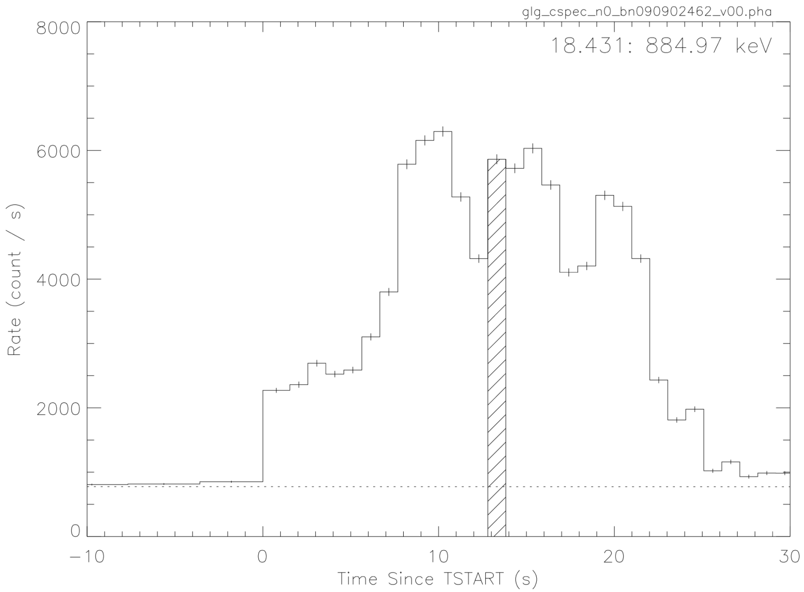
18.431: 884.97 keV
Rate (count / s)
Time Since TSTART (s)


Times: 0.002: 1.536 s
NAI_00 +
Nu F$_{nu}$ (photons keV cm$^{-2}$ s$^{-1}$)
Sigma
Energy (keV)

# GRB 090902B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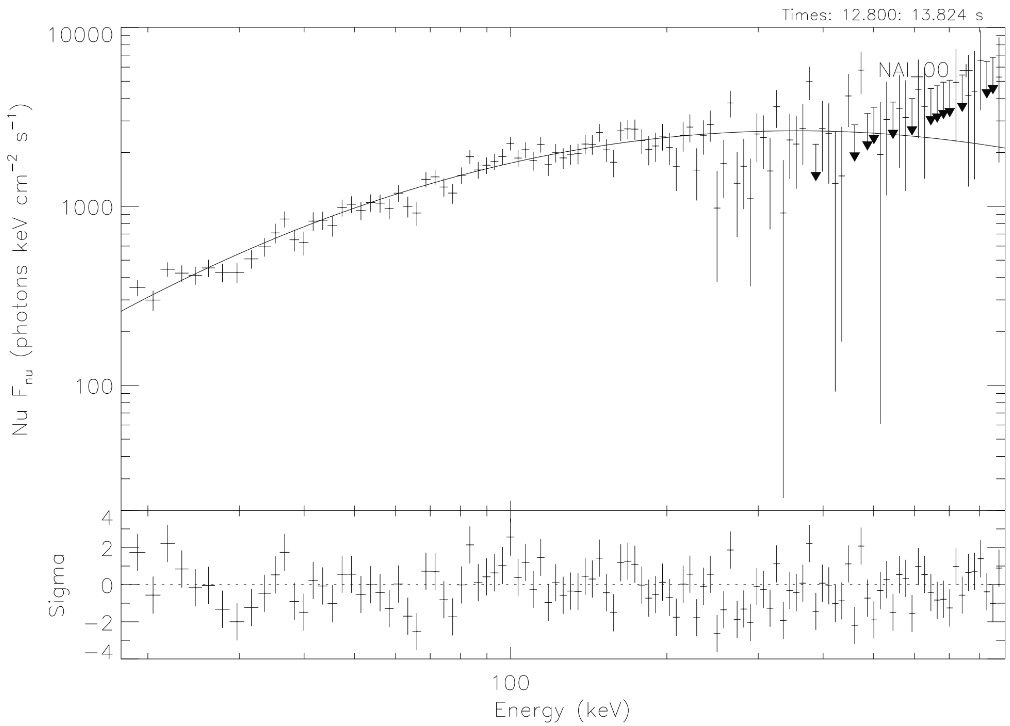
18.431: 884.97 keV
Rate (count / s)
Time Since TSTART (s)


Times: 12.800: 13.824 s
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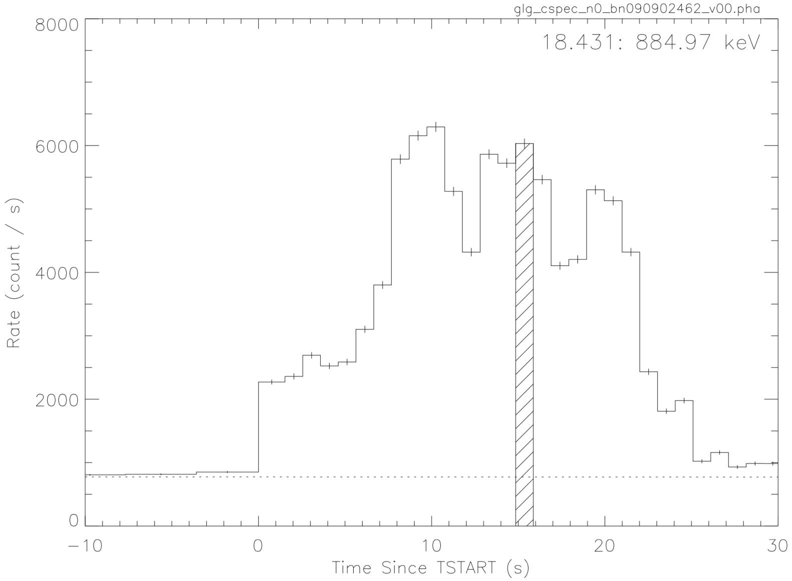
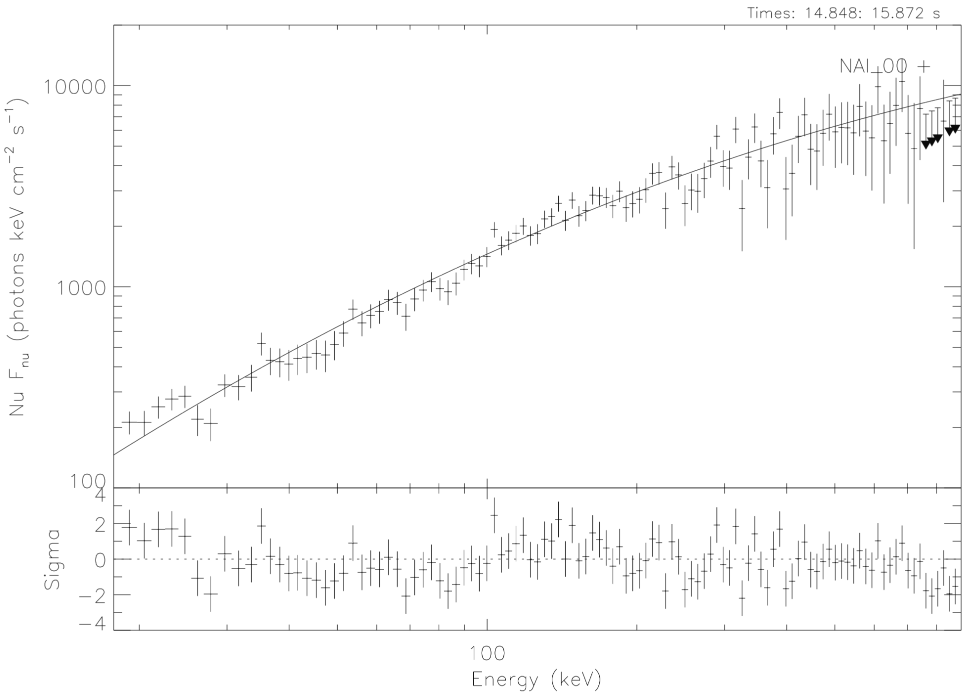
Nu F$_{nu}$ (photons keV cm$^{-2}$ s$^{-1}$)
Sigma
Energy (keV)

# GRB 090902B

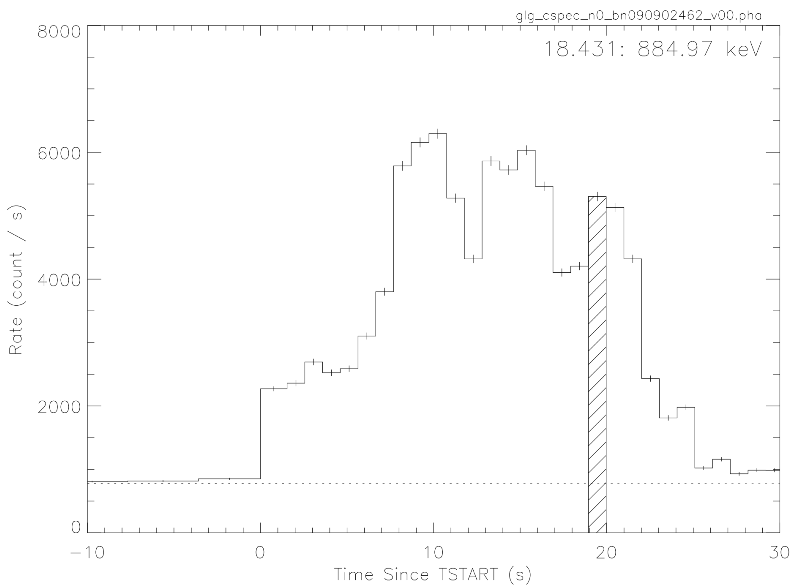


glg_cspec_n0_bn090902462_v00.pha
18.431: 884.97 keV
Rate (count / s)
Time Since TSTART (s)

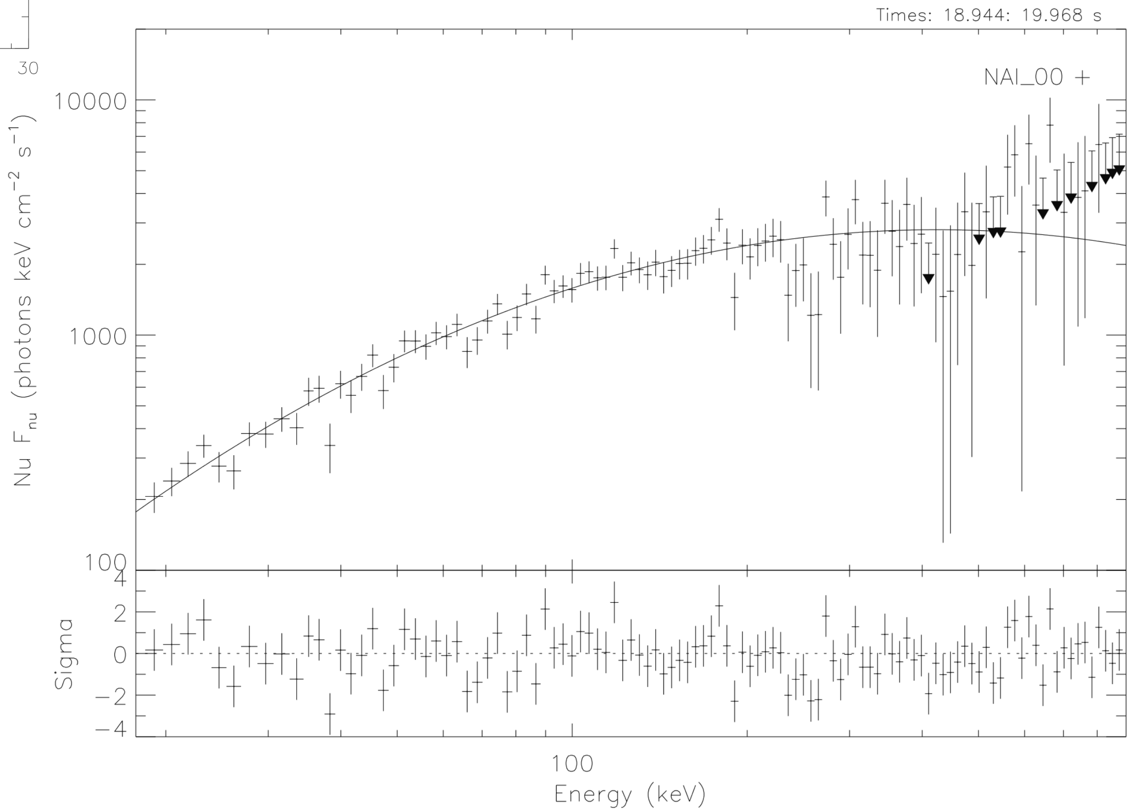



Times: 14.848: 15.872 s
NAI_00
Nu F_nu (photons keV cm^-2 s^-1)
Sigma
Energy (keV)

# GRB 090902B

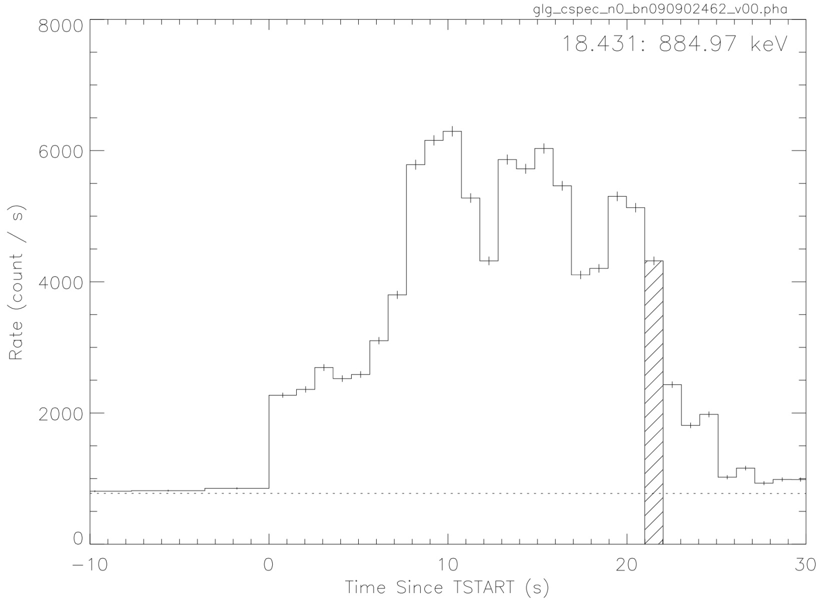


glg_cspec_n0_bn090902462_v00.pha
18.431: 884.97 keV
Rate (count / s)
Time Since TSTART (s)

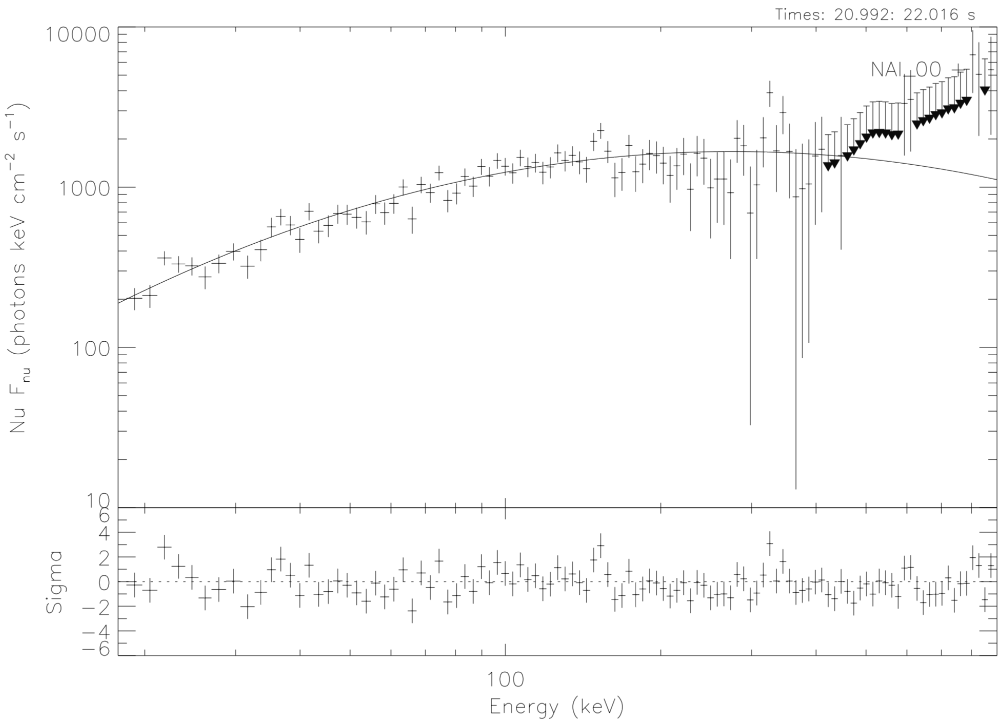



Times: 18.944: 19.968 s
NAI_00
Nu F_nu (photons keV cm^-2 s^-1)
Sigma
Energy (keV)

# GRB 090902B



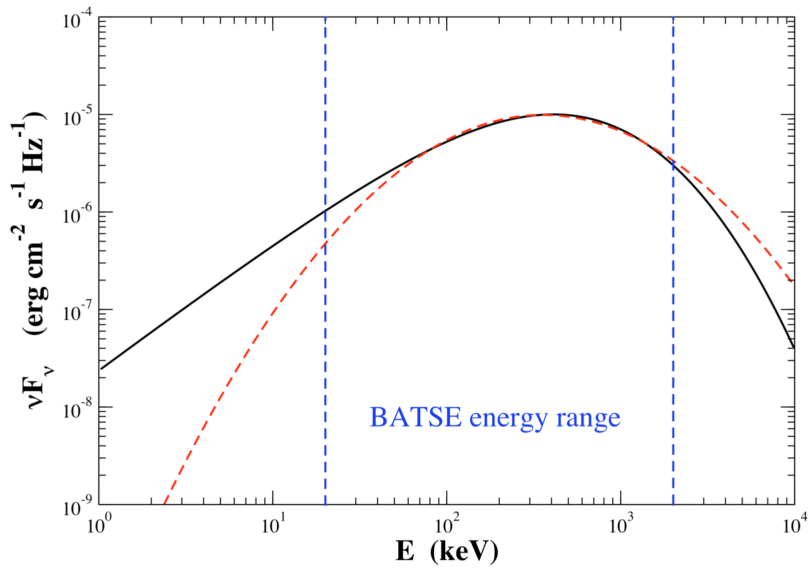
glg_cspec_n0_bn090902462_v00.pha
18.431: 884.97 keV
Rate (count / s)
Time Since TSTART (s)

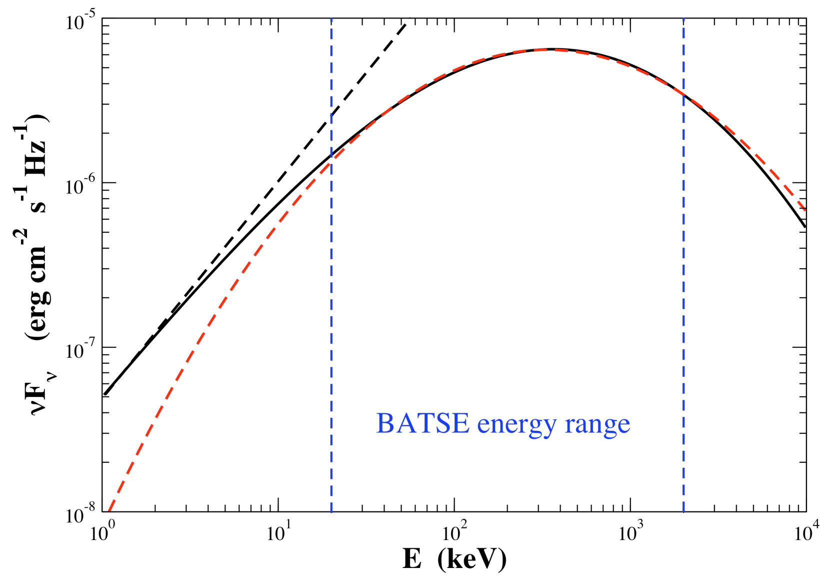



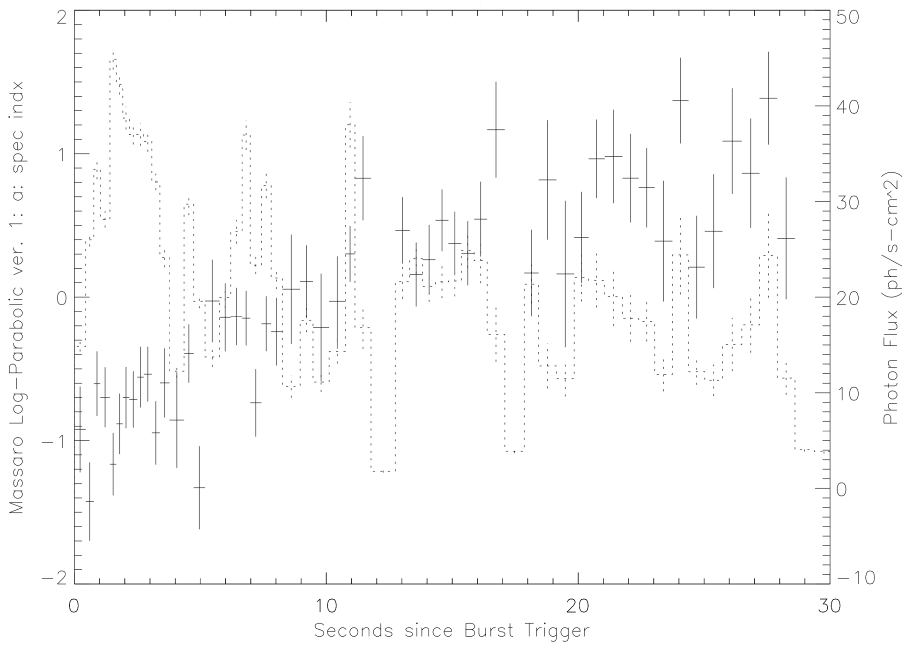
Times: 20.992: 22.016 s
NAI_00
Nu F_nu (photons keV cm^-2 s^-1)
Sigma
Energy (keV)

# The synchrotron line of death

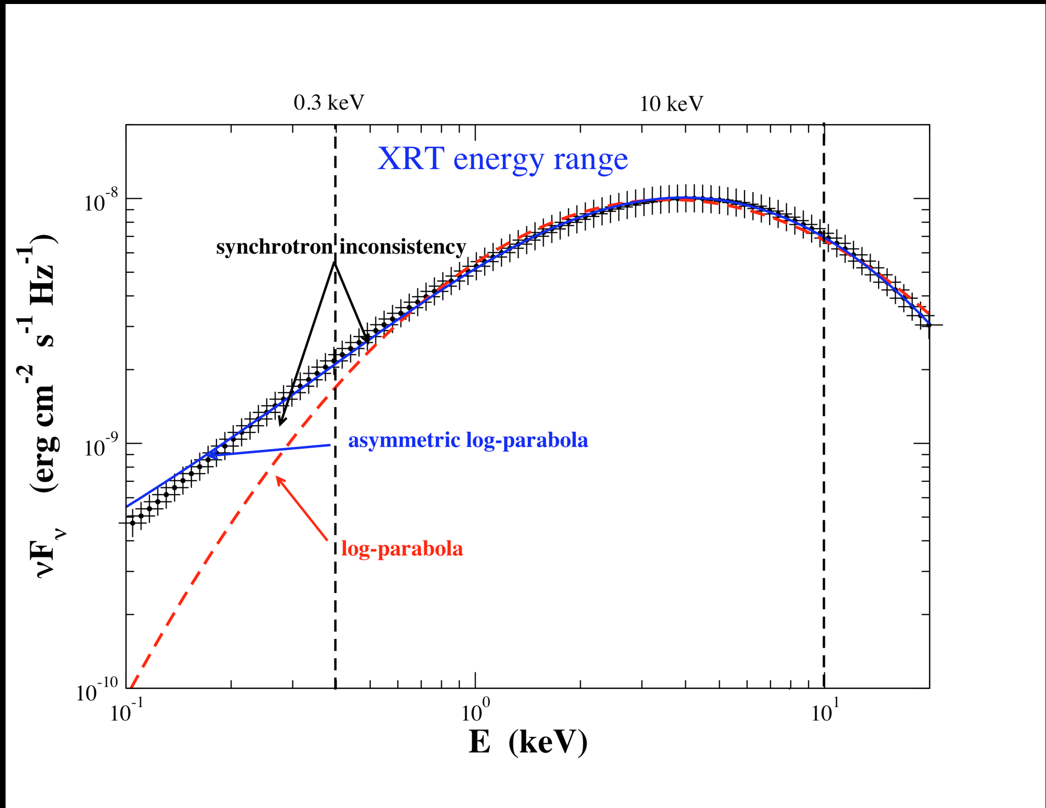
Preece et al. 1998



# The synchrotron line of death




## Asymmetric log-parabola

$$F(E) = K \left(\frac{E}{E_0}\right)^{-a-b\ log(1+E/E_a)}$$