Spectral Lags in Gamma Ray Bursts

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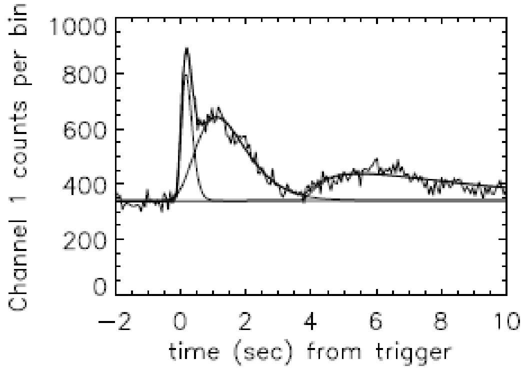
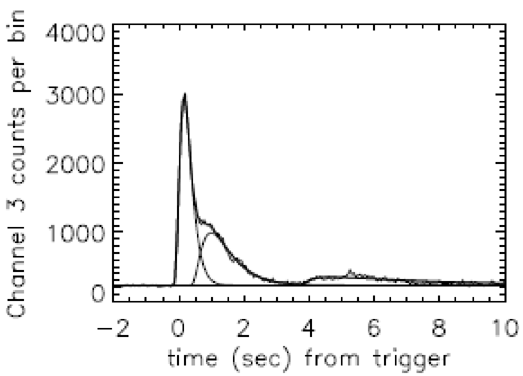
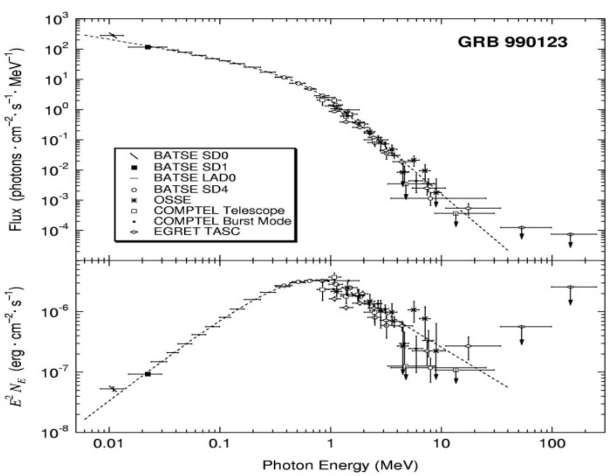






1.Prompt emission

▪ A diversity of the observed temporal profiles, complex structure. Few bursts show a simple pulse with a fast rise followed by a slower decay.

▪ The spectra: more uniform, generally well-fitted by two smoothly connected power-laws, the so-called Band-spectrum, (Band 1993).

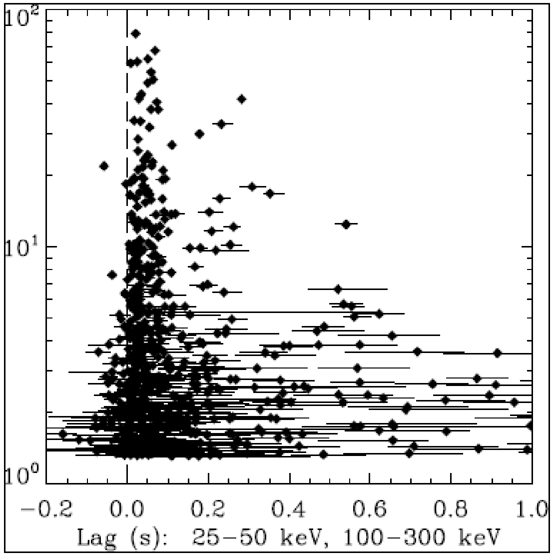
$$N(E) = A\left(\frac{E}{100}\right)^{\alpha} \exp\left(-\frac{E}{E_0}\right) \quad E \le E_0(\alpha - \beta)$$

$$N(E) = A\left(\frac{(\alpha - \beta)E_0}{100}\right)^{\alpha-\beta} \left(\frac{E}{100}\right)^{\beta} \exp(\beta - \alpha) \quad E \ge E_0(\alpha - \beta)$$

▪The shape of GRB pulses evolves with energy: at high energy pulses are narrower and peak earlier, but there are also exclusions.

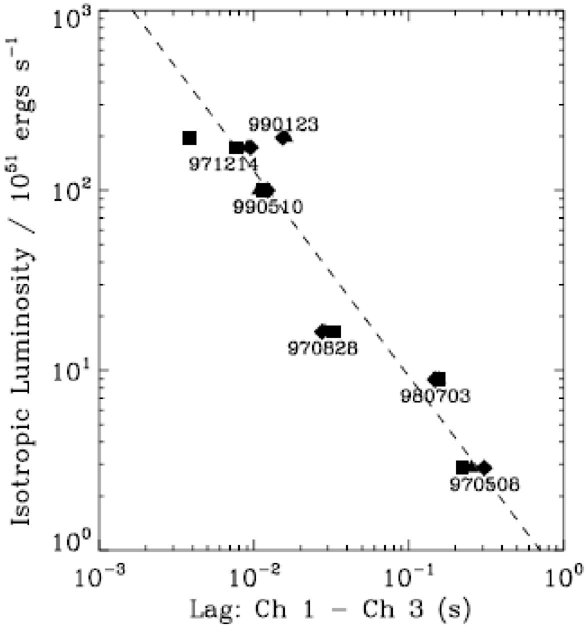
▪The spectral lag is defined as the difference in time of arrival of high and low energy photons and is considered to be positive when the high energy photons arrive earlier than the low energy ones.

2. Spectral lags, observations



- BATSE sample (1459 long GRB) is dominated by relatively short positive lags ($< 350ms$)
- Few pulses with negative lags, (Chen et al. 2004).

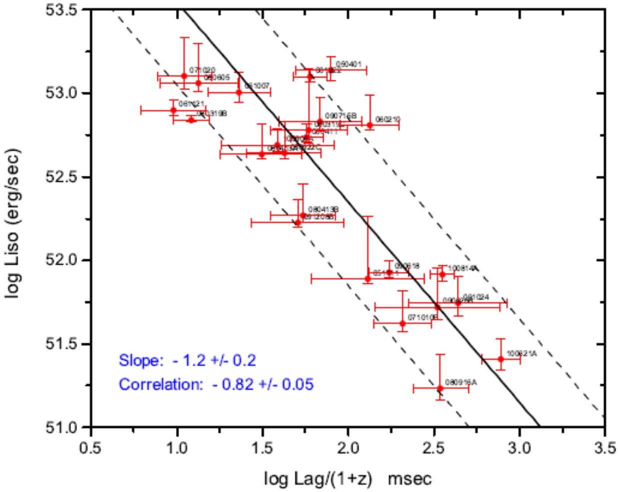
Norris, Scargle & Bonnel, 2001



- Norris, Marani & Bonnel, (2000) found an anticorrelation between lags and burst luminosity for 7 bursts with known redshift:

$$L = 1.3\,10^{53}\ (\Delta t_{13}/0.01\ \mathrm{s})^{-1.15} \quad \mathrm{erg.s^{-1}}$$

Norris, Marani & Bonnel, 2000



Ukwatta et al. 2011

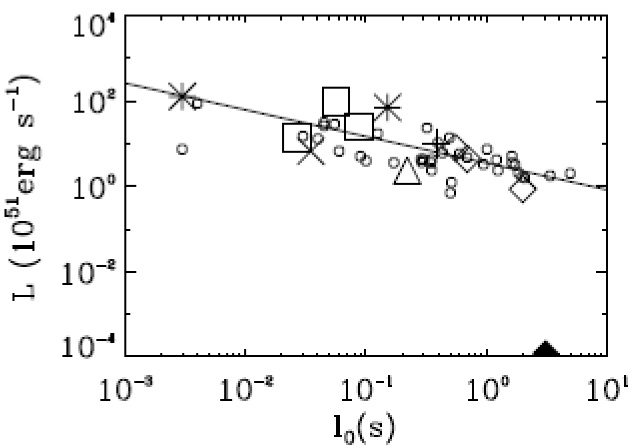


Fig. 2.— Isotropic pulse peak luminosity L vs. pulse peak lag (l_0) for fit pulses of BATSE GRBs having known luminosities. The sample consists of pulses from GRB 971214 (asterisk), GRB 980703 (open diamond), GRB 970508 (triangle), GRB 990510 (square), GRB 991216 (X), and GRB 990123(plus), and the underluminous GRB 980425 (filled diamond). Symbol size denotes approximate uncertainty. Also plotted are 38 pulses from 22 BATSE GRBs without known redshifts (small circles); $z = 1$ is assumed.

Hakkila et al. 2008

- A sample of 43 Swift bursts: 24 bursts have positive lags 16 lags consistent to zero and 3 negative lags.
- For the sample of bursts with positive lags, it is confirmed the correlation between lag and luminosity.

$$\log\left(\frac{L_{iso}}{erg/s}\right) = (54.7 \pm 0.4) - (1.2 \pm 0.2) \log \frac{Lag/(ms)}{1+z}$$

Hakkila et al. 2008:

- each pulse appears to be characterized by its own lag; lag is a consequence of pulse evolution rather than a burst property. Pulse peak lags are defined as the differences between the *pulse peak times* in different energy channels;
- pulse lag, pulse luminosity and pulse duration strongly correlate:

$$L = 6.1\, 10^{52}\ (\Delta t_{13}/0.01\ \mathrm{s})^{-0.62} \quad \mathrm{erg.s^{-1}}$$

$$L = 3.4\, 10^{52}\ t_p^{-0.85} \quad \mathrm{erg.s^{-1}}$$

3. Lag is a consequence of the spectral evolution

By performing a linear expansion of the pulse shape and spectral properties around the maximum in BATSE band 1 (20-50 keV), pulse peak lags are related to spectral evolution .

- The count rate $N_{ij}(t)$ in energy band $[E_i, E_j]$

$$N_{ij}(t) = A(t) \int_{x_i}^{x_j} \mathcal{B}_{\alpha\beta}(x)\, dx \qquad x_{i,j} = E_{i,j} / E_p(t)$$

BATSE bands 1 [20, 50 keV] and 3 [100, 300 keV]

$$N_3(t) = N_1(t) \times \mathcal{F}_{13}\left[E_\mathrm{p}, \alpha, \beta\right]$$

- Lag is estimated by the difference $\Delta t_{13} = t_1 - t_3$
- Lag is related to spectral evolution:

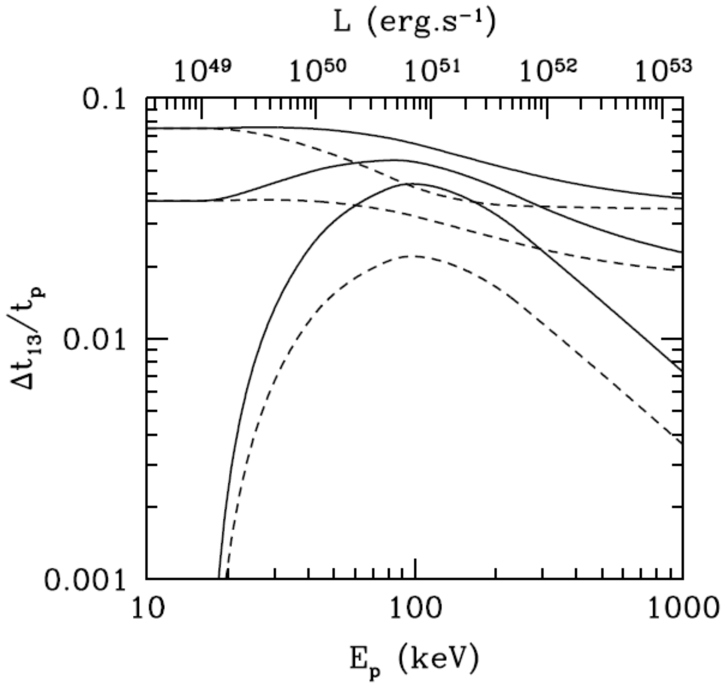
$$\boxed{\frac{\Delta t_{13}}{t_\mathrm{p}} \simeq \frac{f_{13,E}\, \dot{e}_\mathrm{p} + f_{13,\alpha}\, \dot{a} + f_{13,\beta}\, \dot{b}}{C_1}}$$

(Hafizi & Mochkovitch, 2007)

$$\dot{e}_\mathrm{p} = \frac{\dot{E}_\mathrm{p}}{E_\mathrm{p}}\, t_\mathrm{p}, \quad \dot{a} = \frac{\dot{\alpha}}{\alpha}\, t_\mathrm{p}, \quad \dot{b} = \frac{\dot{\beta}}{\beta}\, t_\mathrm{p}$$

- The “curvature parameter” C_1 :

$$\frac{C_1}{t_\mathrm{p}^2} = \frac{\ddot{N}_1(t_1)}{N_1(t_1)} \qquad (C_1 < 0)$$

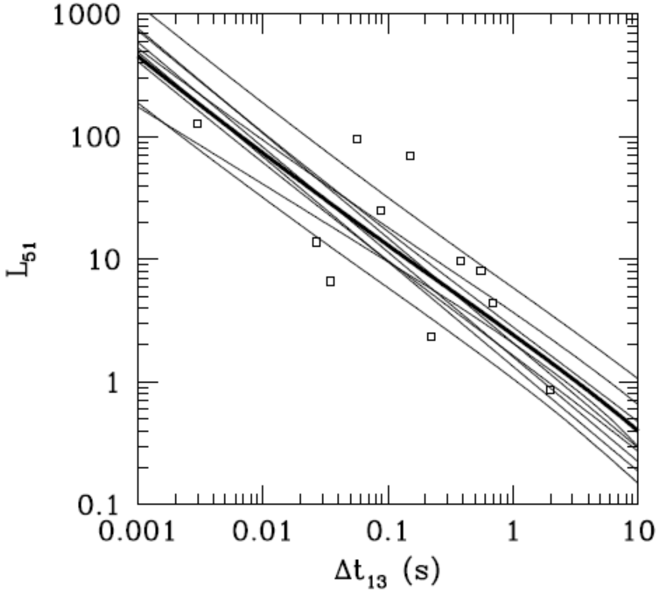


▪Hard to soft spectral evolution ;
the maximum of E_p, α and β generally precedes that of the count rate in most pulses implying $\dot{e}_p < 0$, $\dot{a} > 0$ and $\dot{b} > 0$.

Lags are positive, and the reduced lag is nearly constant.

Full lines correspond to $\dot{e}_p = -0.5$, $\dot{a} = \dot{b} = 0.2, 0.1, 0$
Full lines correspond to $\dot{e}_p = -0.25$, $\dot{a} = \dot{b} = 0.2, 0.1, 0$

Boçi, Hafizi & Mochkovitch, 2010



Boçi, Hafizi & Mochkovitch, 2010

$$\frac{\Delta t_{13}}{t_{\rm p}} \simeq \frac{f_{13,E}\,\dot{e}_{\rm p} + f_{13,\alpha}\,\dot{a} + f_{13,\beta}\,\dot{b}}{C_1}$$

$$L = 3.4\,10^{52}\,t_{\rm p}^{-0.85} \quad {\rm erg.s}^{-1}$$

the lag-luminosity relation

GRBs satisfy an "Amati-like" relation between $E_{\rm p}$ and L:

$\alpha=-1,\ \beta=-2.25,\ \dot{e}_p=-0.5,\ \dot{a}=\dot{b}=0.1,\ |C_1|=10$

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$\alpha=-1,\ \beta=-2.25,\ \dot{e}_p=-0.25,\ \dot{a}=\dot{b}=0.1,\ |C_1|=10$

$\alpha=-1,\ \beta=-2.25,\ \dot{e}_p=-0.1,\ \dot{a}=\dot{b}=0,\ |C_1|=10$

Without an "Amati-like" relation

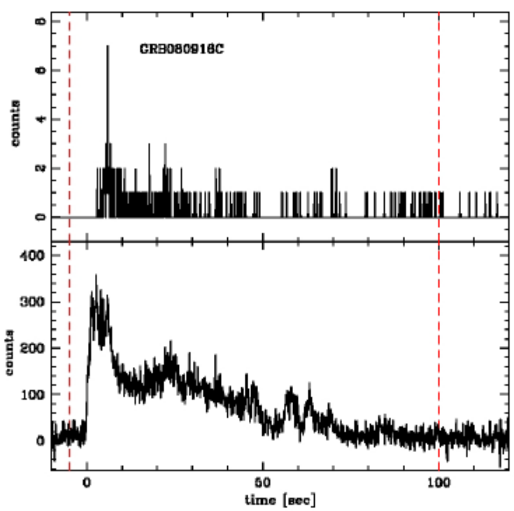
$E_p = 250{,}500{,}1000\,keV$

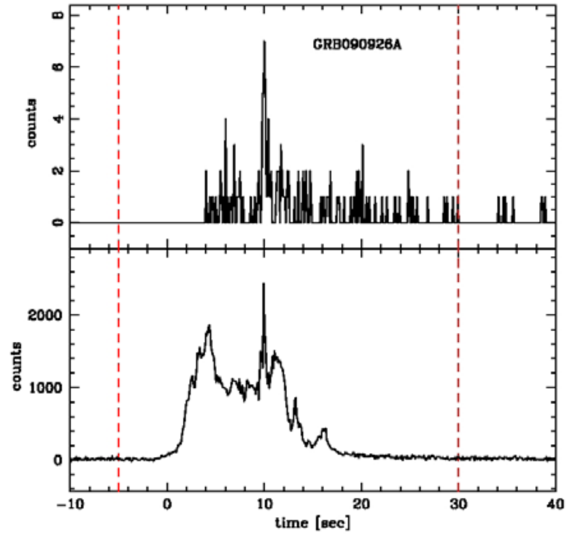
$\alpha=-1,\ \beta=-2.25,\ \dot{e}_p=-0.5,\ \dot{a}=\dot{b}=0.1,\ |C_1|=10$

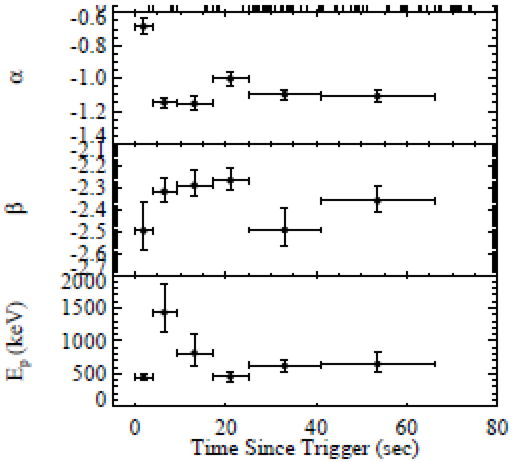
$\alpha=-1,\ \beta=-2.25,\ \dot{e}_p=-0.5,\ \dot{a}=\dot{b}=0.1,\ |C_1|=3$

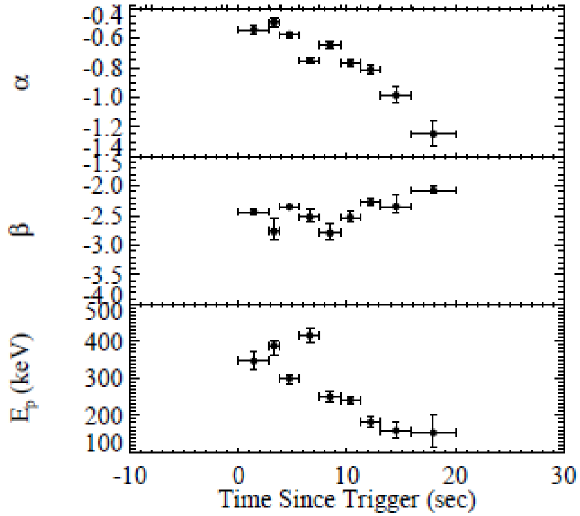
$\alpha=-1,\ \beta=-2.25,\ \dot{e}_p=-0.5,\ \dot{a}=\dot{b}=0.1,\ |C_1|=30$

4. Time delays between Fermi LAT and GBM light curves



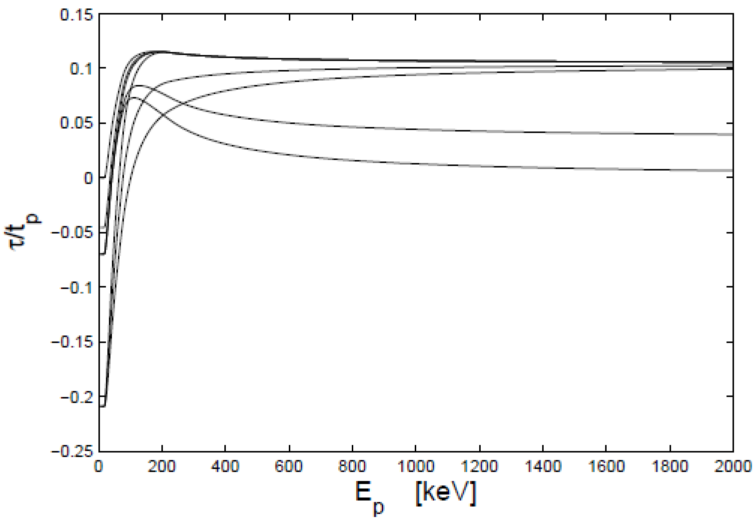




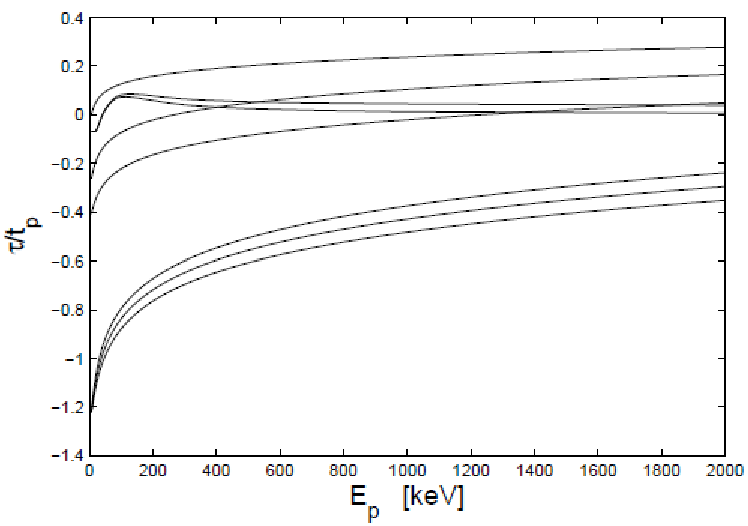


- Fermi Gamma–Ray Space Telescope detects gamma signals in a wide range of energy, 8 keV to 300 GeV.
- Some GRBs exhibit a delay between the signal measured by the Fermi Gamma-ray Burst Monitor (GBM) and the onset of MeV-GeV counterpart detected by the Fermi Large Area Telescope (LAT). (Zhang et al.2011)
- The time lags between LAT (100 MeV-300GeV) and GBM (8 keV-1MeV) light curves are negative, on the order of some seconds. (Castignani et al. 2014)

5. Does spectral evolution explain the negative lags?



Reduced lags between BATSE band 1 [20-50] keV and band 3 [100-300] keV pulses



Reduced lags between pulses in energy bands (8 keV-1MeV) and (100 MeV-300GeV).

- LAT emission peaks seem to roughly track some peaks of the GBM emission.
- Time-resolved joint spectra are consistent with being the same (Band–function) spectral component.
- A rough anti-correlation between α and β in individual GRBs. (Zhang et al.2011)
- We extend the analysis of the pulse properties to Fermi energy ranges.

$$\frac{\tau}{t_p} = \frac{f_{LH,E_p}\dot{e}_p + f_{LH,\alpha}\dot{a} + f_{LH,\beta}\dot{b}}{C_1}$$

$\alpha = -1.1,\ \beta = -2.3,\ \dot{e}_p = -1,\ \dot{a} = 0.6,\ \dot{b} = 0$

$\alpha = -1.1,\ \beta = -2.3,\ \dot{e}_p = -1,\ \dot{a} = 0.6,\ \dot{b} = -0.13$

$\alpha = -1.1,\ \beta = -2.3,\ \dot{e}_p = -1,\ \dot{a} = 0.2,\ \dot{b} = -0.2$

$\alpha = -1.1,\ \beta = -2.3,\ \dot{e}_p = -1,\ \dot{a} = 0,\ \dot{b} = -0.2$

$\alpha = -1.1,\ \beta = -2.3,\ \dot{e}_p = -1,\ \dot{a} = 0.6,\ \dot{b} = -0.2$

$\alpha = -1.1,\ \beta = -2.3,\ \dot{e}_p = -1,\ \dot{a} = 0.6,\ \dot{b} = -0.6$

$\alpha = -1.1,\ \beta = -2.3,\ \dot{e}_p = -0.5,\ \dot{a} = 0.6,\ \dot{b} = -0.6$

$\alpha = -1.1,\ \beta = -2.3,\ \dot{e}_p = 0,\ \dot{a} = 0.6,\ \dot{b} = -0.6$

6. Conclusions

- The spectral lag (positive or negative) is consequence of spectral evolution.
- Not only the evolution of peak energy, gives rise to lags, but the evolution of spectral indices would affect the values of spectral lags.
- Hard to soft spectral evolution (the Ep, α, β evolution) leads to positive lags. A different evolution of β (increase of β) related to α, would produce negative lags.

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THANK YOU!