

# Clustering of LAT light curves: a clue to the origin of high-energy emission in GRBs

Nava, Vianello, Omodei, Ghisellini, Ghirlanda,  
Celotti, Longo, Desiante, Barniol Duran

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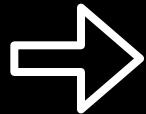
Lara Nava

Marie Curie Fellow  
The Hebrew University of Jerusalem



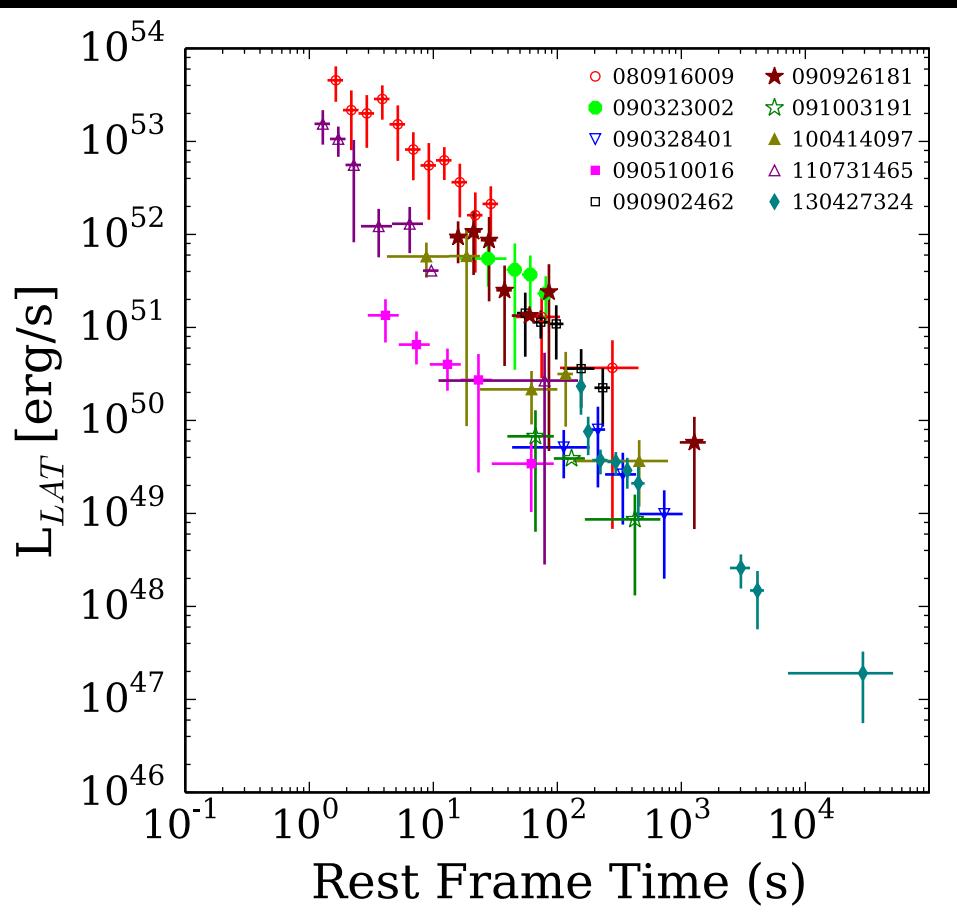
# SAMPLE SELECTION

- Emission > 0.1 GeV
- Temporally extended
- Redshift



10 GRBs  
(9 long + 1 short)

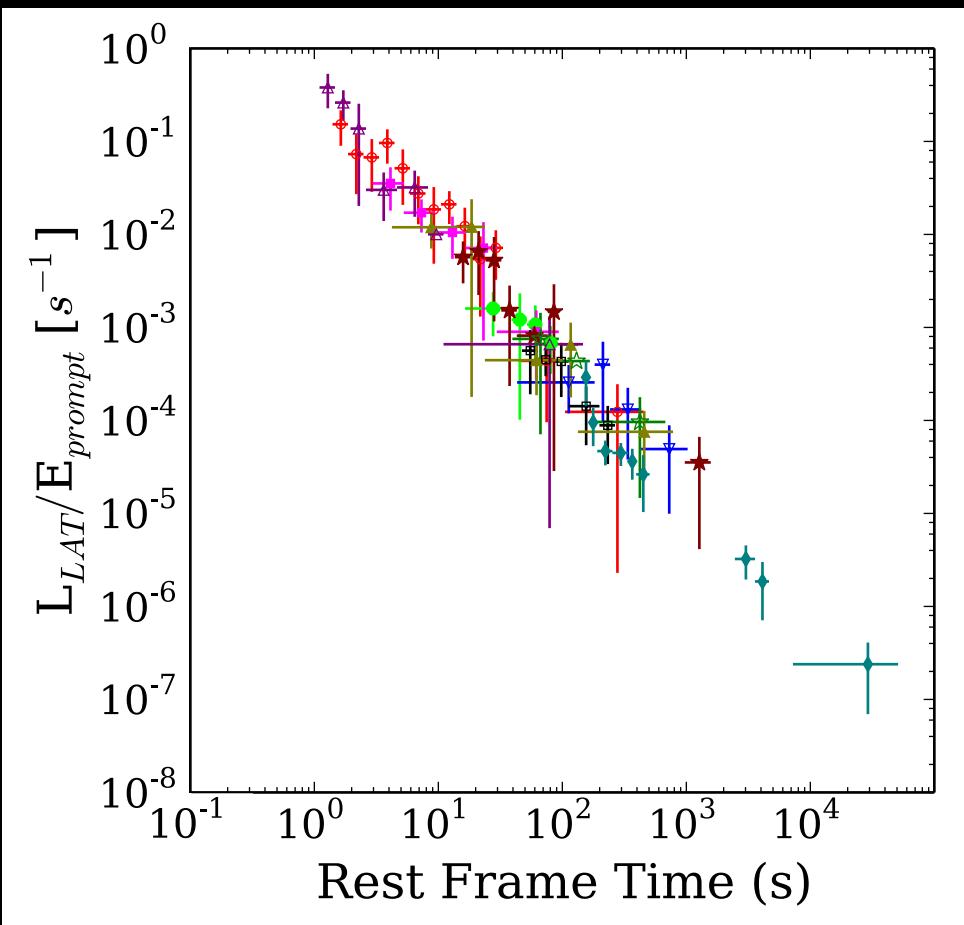
9 from First GRB LAT catalog (Ackermann et al 2013)  
+ 130427A (Ackermann et al. 2014)



- PL temporal decay  $t^{-1.2}$
- PL spectra  $\Gamma \sim -2.1$
- $L_{LAT} = K t^{-1.2}$  (dispersion of  $K$ : 2 orders of magnitude)

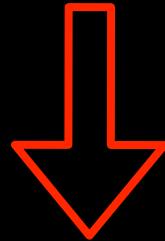
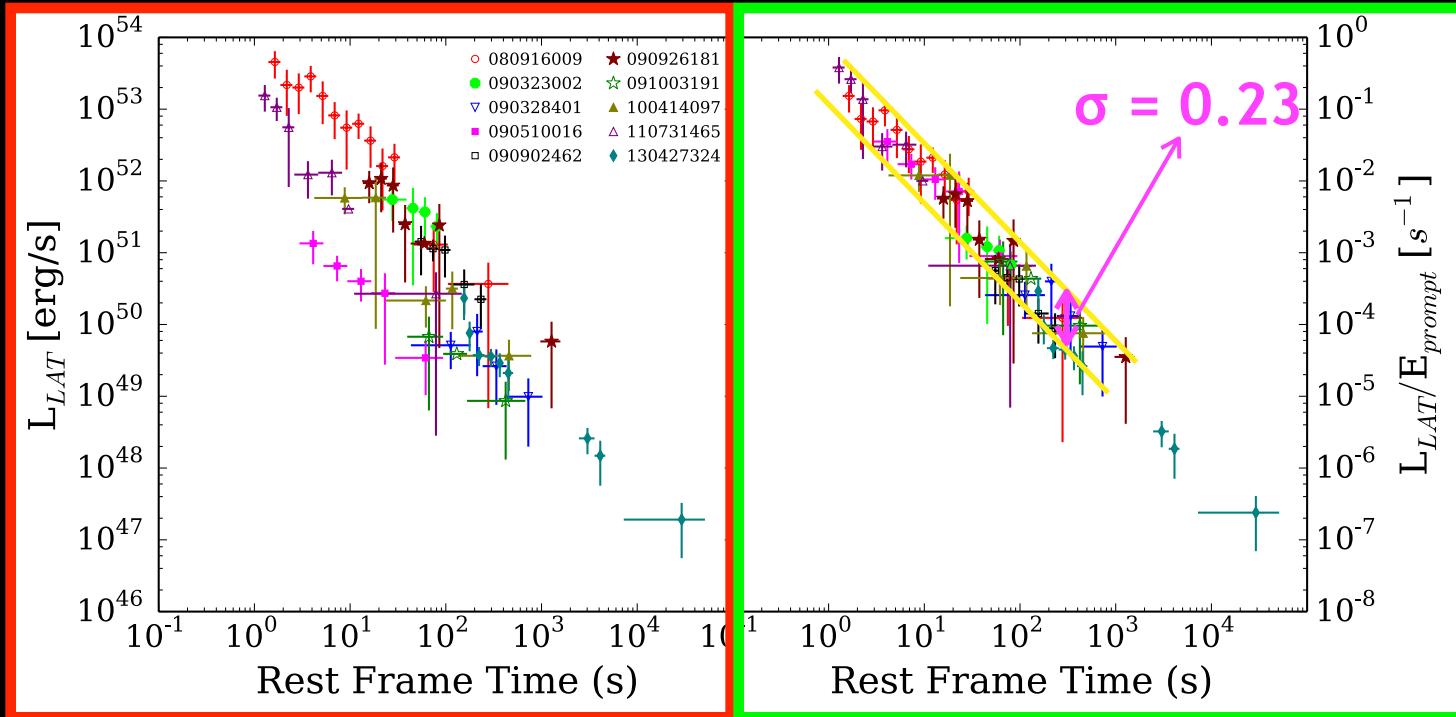
# Re-normalized light curves

$$L_{LAT}(t) \rightarrow \frac{L_{LAT}(t)}{E_{iso}}$$

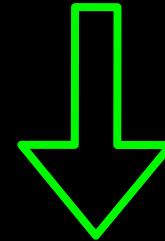


- Clustering!
- $L_{LAT}/E_{iso} = K' t^{-1.2}$
- dispersion is reduced!

# Dispersion of the $E_{iso}$ -normalised light curves

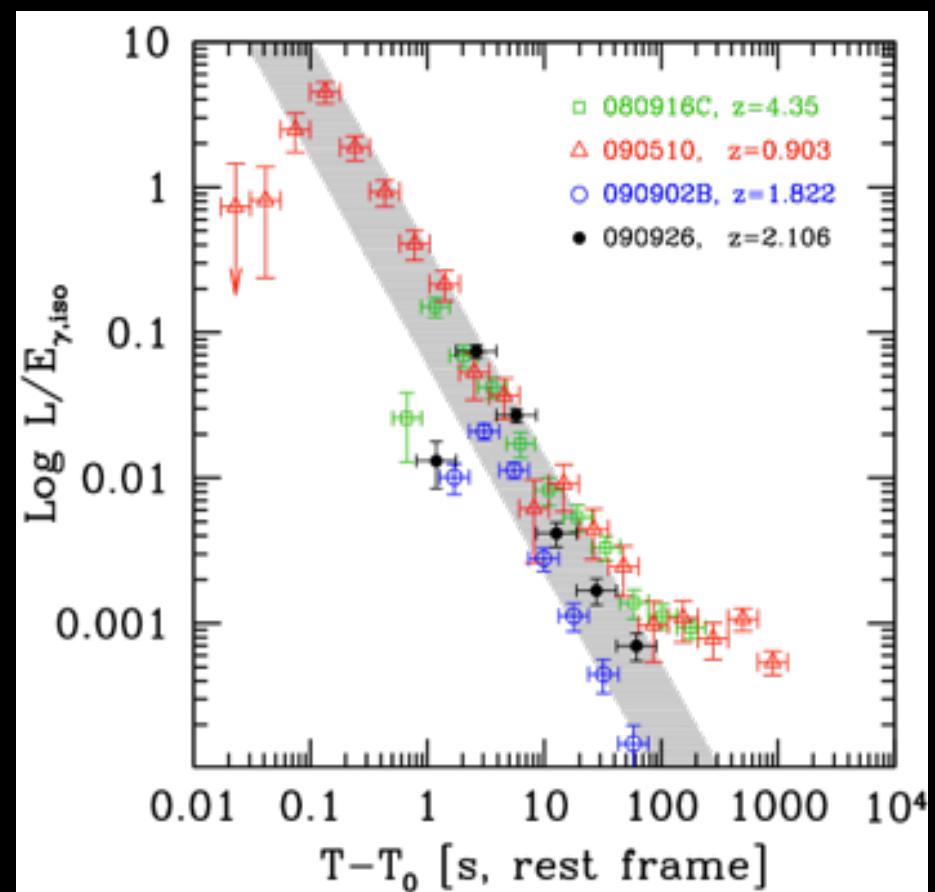
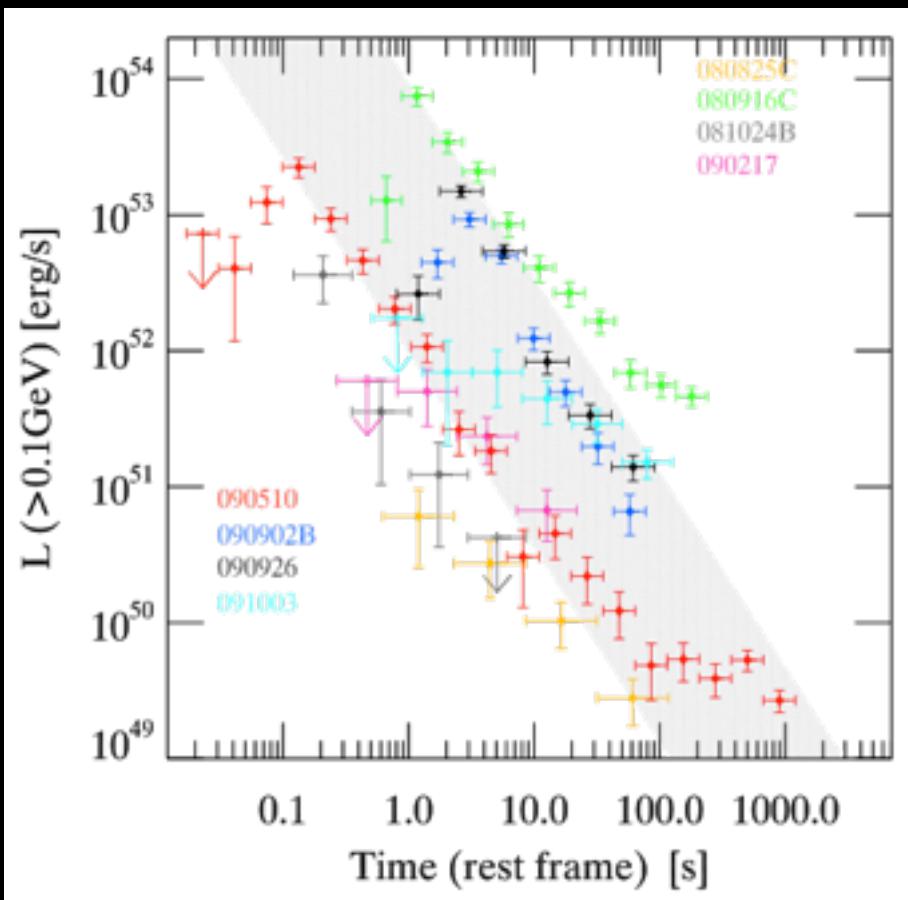


$$L_{LAT} \simeq 3 \times 10^{52} t^{-1.2} \text{ erg/s}$$



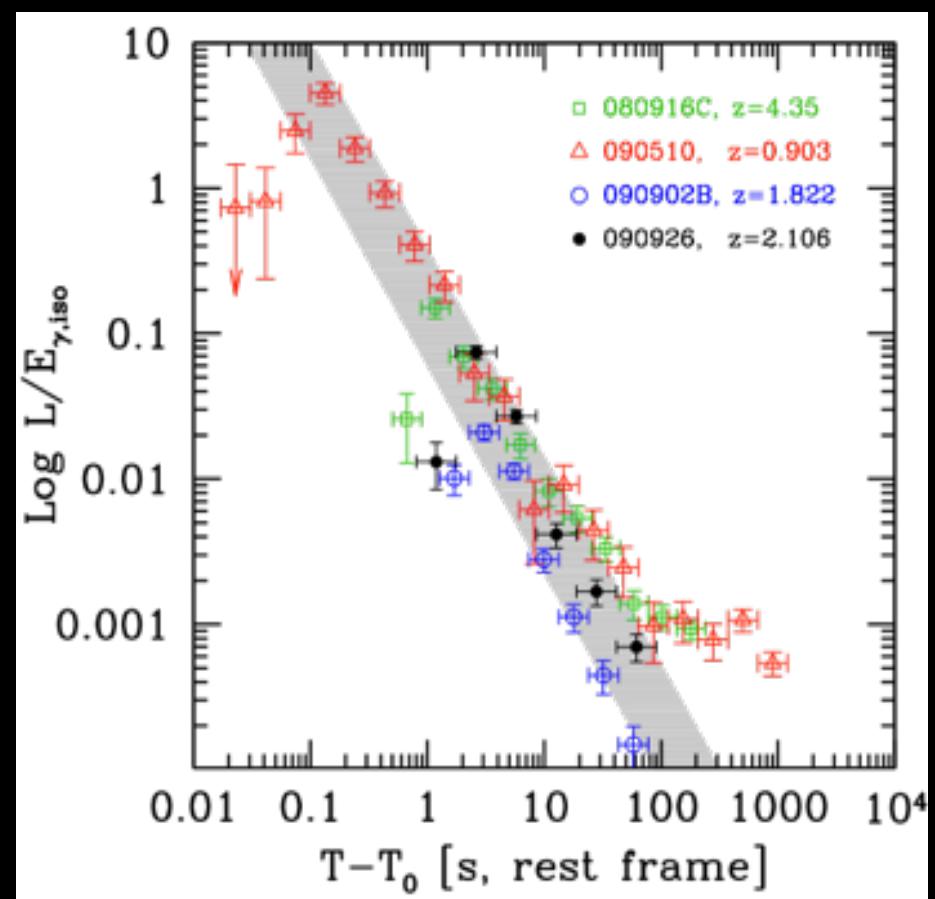
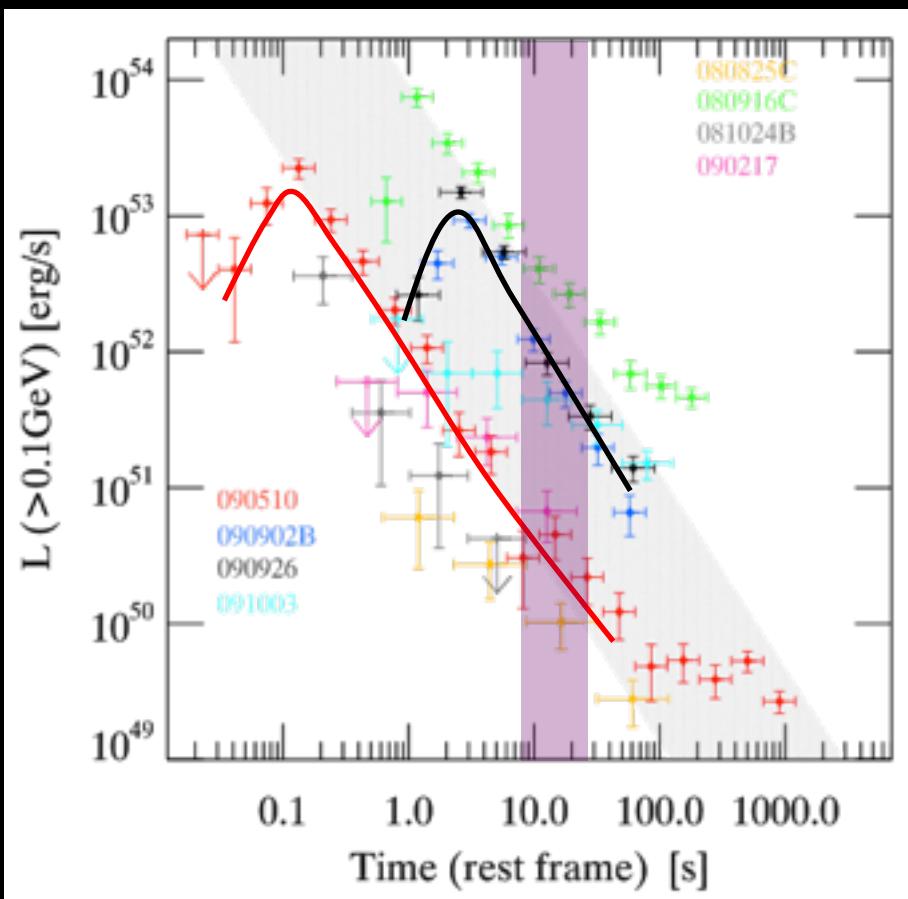
$$\log \frac{L_{LAT}}{E_{iso}} \simeq -1 \pm 0.23 - 1.2 \log t$$

# Confirmation of a result found by Ghisellini, Ghirlanda, Nava, Celotti, 2010 with 4 GRBS



# Looking for the physical mechanism

★ Self-similar mechanism  
★ Short and Long



# Summary: features that any successful interpretative model must explain

- PL temporal decay  $t^{-1.2}$
- PL spectra  $\Gamma \sim -2.1$
- $L_{LAT} \approx 3 \cdot 10^{52} t^{-1.2} \text{ erg/s}$
- $L_{LAT} = K t^{-1.2}$  (dispersion of K: 2 orders of magnitude)
- $L_{LAT}/E_{iso} = K' t^{-1.2}$  (small dispersion)
- $\log \frac{L_{LAT}}{E_{iso}} \approx (-1 \pm 0.23) - 1.2 \log(t)$

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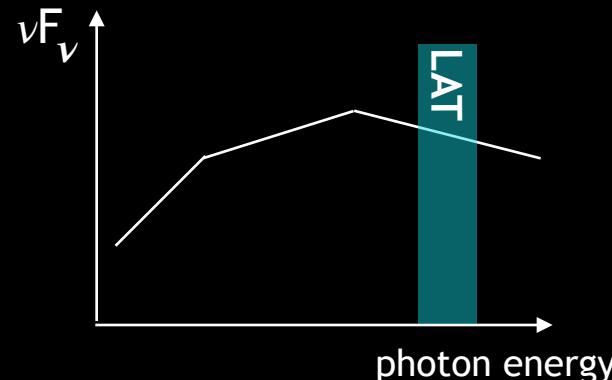
# Synchrotron emission from external shocks???

Kumar & Barniol Duran 2009, 2010;  
Gao+2009; Ghisellini+2010; Ghirlanda+2010;  
De Pasquale+2010

cooling energy & injection energy

$$h\nu_c \simeq 7.1 \times 10^{-7} \epsilon_{B,-2}^{-3/2} E_{K,54}^{-1/2} n^{-1} t^{-1/2} \text{ GeV}$$

$$h\nu_m \simeq 0.017 \left[ \frac{f(p)}{f(2.2)} \right]^2 \epsilon_{B,-2}^{1/2} \epsilon_{e,-1}^2 \xi_{e,-1}^{-2} E_{K,54}^{1/2} t^{-3/2} \text{ GeV}$$



specific luminosity ABOVE the cooling and injection energies

$$L_E \simeq 6.1 \times 10^{51} \left[ \frac{f(p)}{f(2.2)} \right]^{p-1} \left[ \frac{E}{1 \text{ GeV}} \right]^{-\frac{p}{2}} \epsilon_{B,-2}^{\frac{p-2}{4}} \epsilon_{e,-1}^{p-1} \xi_{e,-1}^{2-p} E_{K,54}^{\frac{p+2}{4}} t^{-\frac{3p-2}{4}} \text{ erg/s/GeV}$$

spectral index

temporal decay

$$-\frac{3p-2}{4} \approx -1.2 \Rightarrow p \approx 2.2 \Rightarrow \text{ph. index} = -\frac{p+2}{2} \leq -2$$

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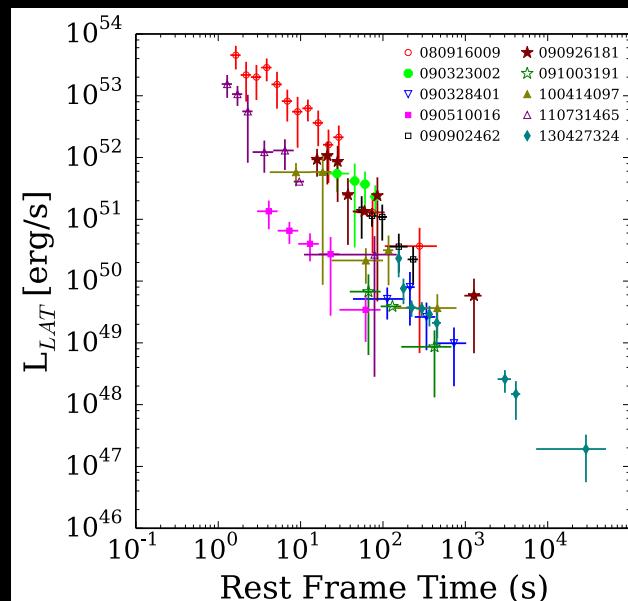
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$$L_E \simeq 6.1 \times 10^{51} \left[ \frac{f(p)}{f(2.2)} \right]^{p-1} \left[ \frac{E}{1 \text{ GeV}} \right]^{-\frac{p}{2}} \epsilon_{B,-2}^{\frac{p-2}{4}} \epsilon_{e,-1}^{p-1} \xi_{e,-1}^{2-p} E_{K,54}^{\frac{p+2}{4}} t^{-\frac{3p-2}{4}} \text{ erg/s/GeV}$$

luminosity integrated in LAT energy range 0.1-10 GeV (rest frame)

$$L_{LAT,52} \simeq 2.8 \left[ \frac{f(p)}{f(2.2)} \right]^{1.2} \epsilon_{B,-2}^{0.05} \epsilon_{e,-1}^{1.2} \xi_{e,-1}^{-0.2} E_{K,54}^{1.05} t^{-1.15} \text{ erg/s}$$

Explained!



- PL temporal decay  $t^{-1.2}$
- PL spectra  $\Gamma \sim -2.1$
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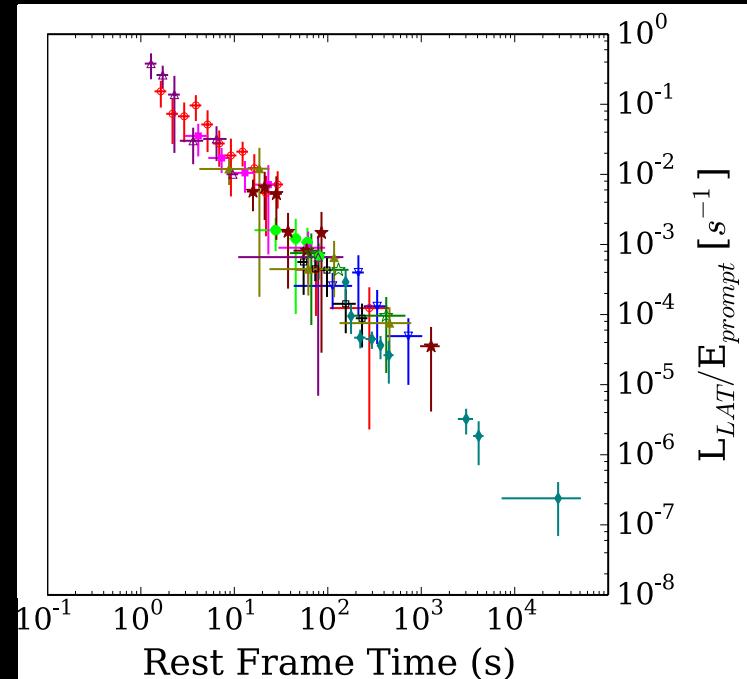
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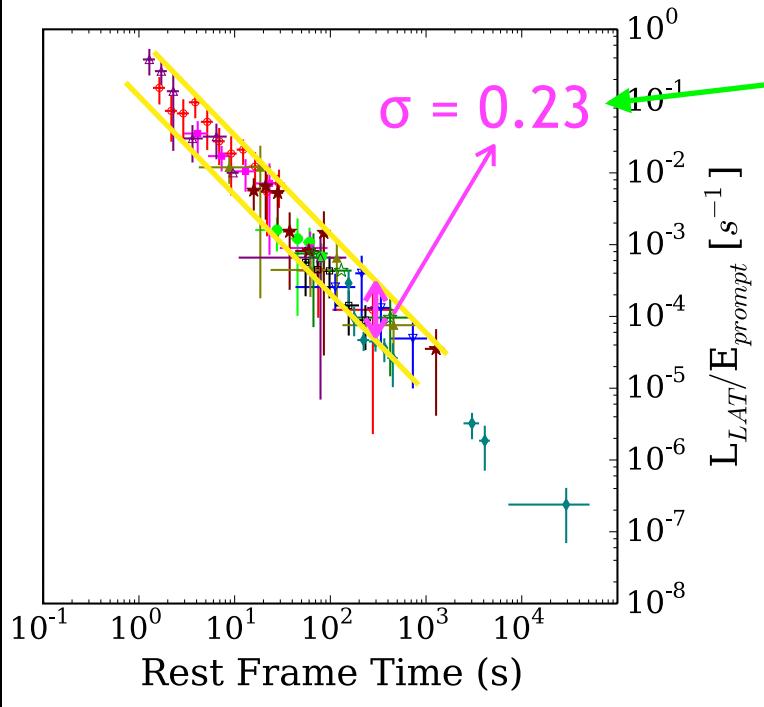
+

$$E_K = E_{\text{prompt}} \left( \frac{1 - \eta_\gamma}{\eta_\gamma} \right)$$

=

$$\frac{L_{LAT}}{E_{iso}} \propto \epsilon_e^{1.2} \frac{1 - \eta_\gamma}{\eta_\gamma} t^{-1.2}$$





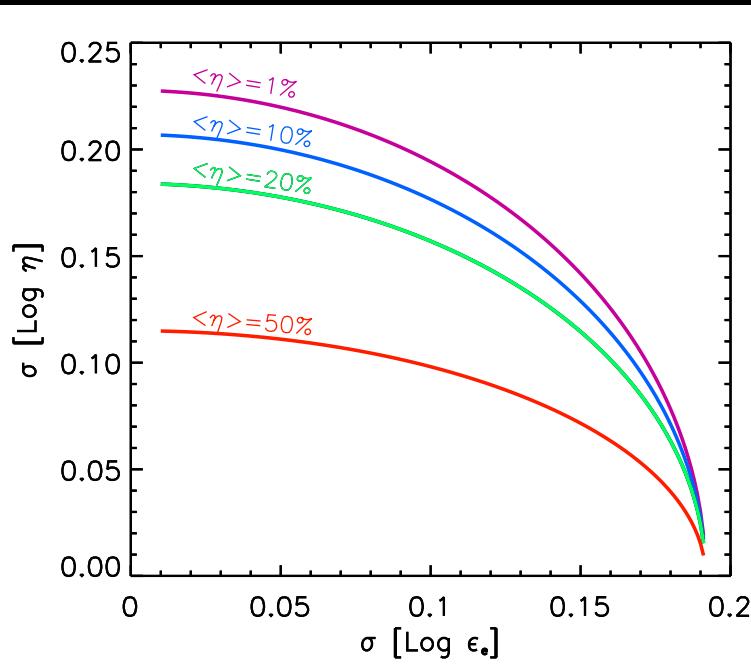
observations

$$\log \frac{L_{LAT}}{E_{iso}} \approx -1 \pm 0.23 - 1.2 \log t$$

theory

$$\log \frac{L_{LAT}}{E_{iso}} = \log(N) + 1.2 \log(\epsilon_e) + \log\left(\frac{1 - \eta_\gamma}{\eta_\gamma}\right) - 1.2 \log(t)$$

$$\sigma_{L/E} = \sqrt{(1.2\sigma_\epsilon)^2 + [(1 - \eta_\gamma)\sigma_\eta]^2}$$

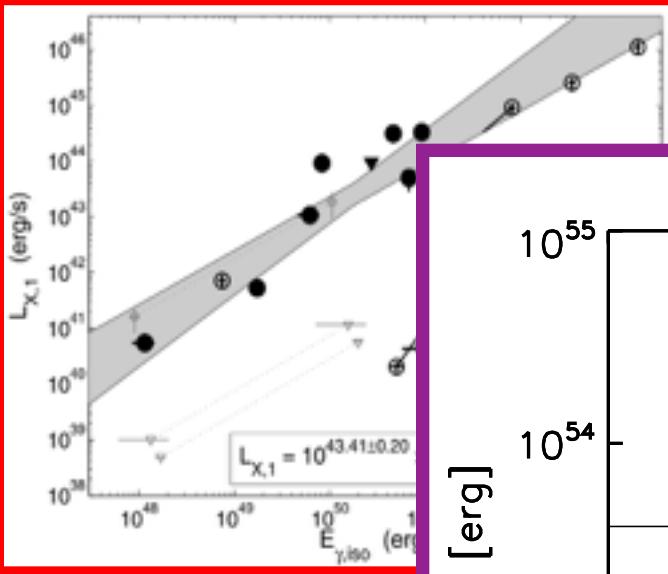


Dispersion of L/E

dispersion of  $\epsilon_e$  and  $\eta$   
(maximum dispersion)

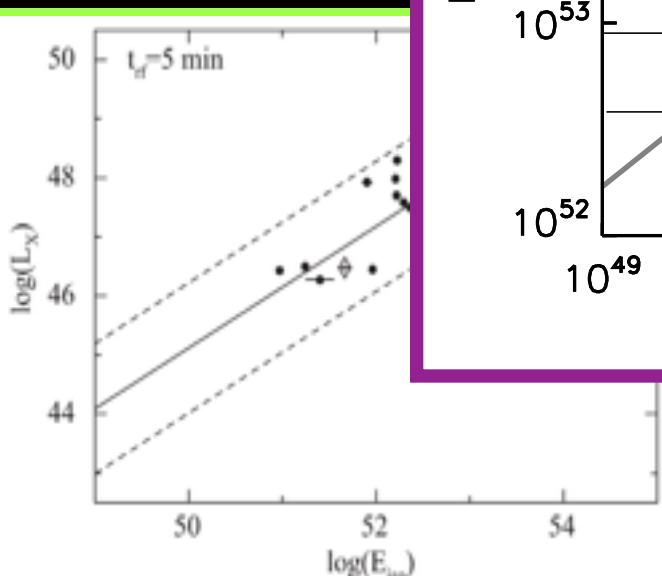
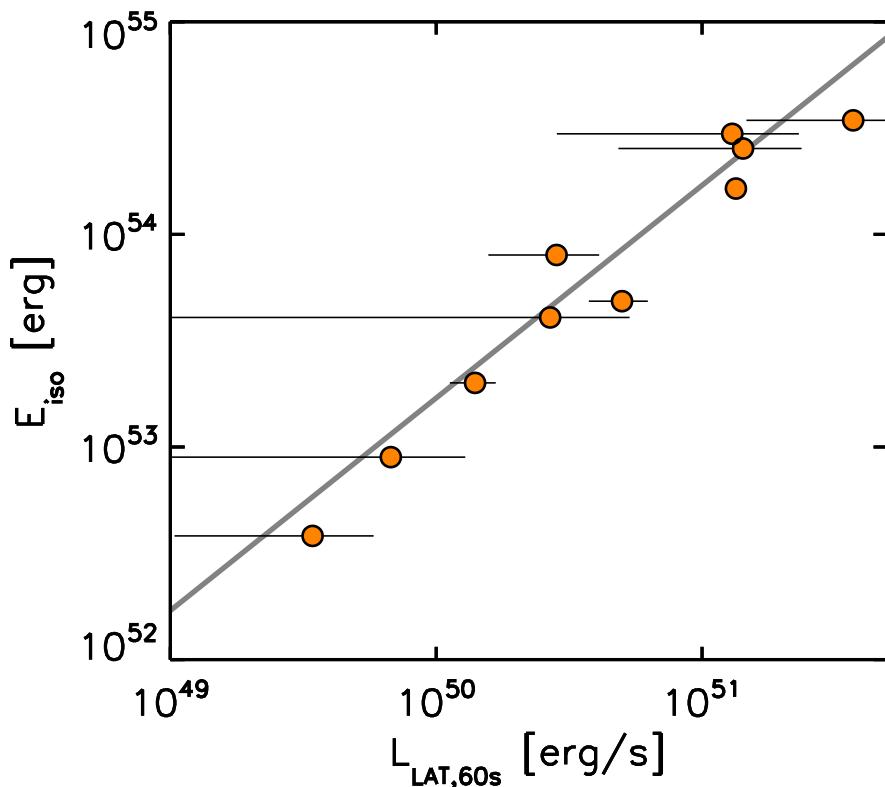
# Similar analysis

$$\frac{L_{\text{LAT}}}{E_{\text{iso}}} \propto \epsilon_e^{1.2} \frac{1 - \eta_\gamma}{\eta_\gamma} t^{-1.2}$$



Berger 2007  
X-ray luminosities at 1 day

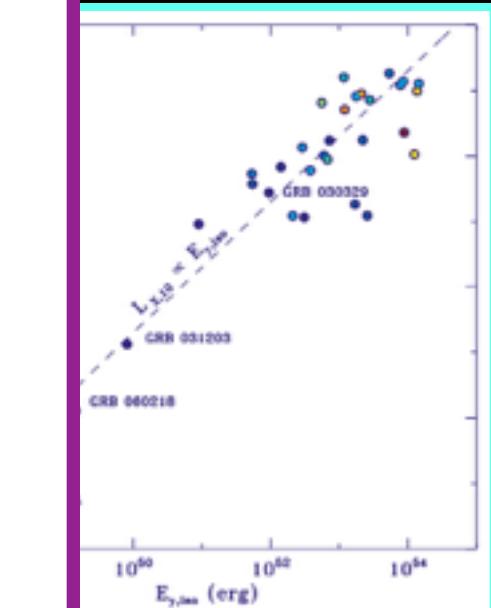
$\eta = 3\text{-}30\%$



Burwitz et al., 2010 - BATSE complete sample

X-ray luminosity 5 min

assume  $\epsilon_e = 0.1$  and derive  $\eta = 3\text{-}30\%$



# Synchrotron Self Compton

not as an explanation for the LAT emission...  
but to check the consistency of the synchrotron model

How SSC can invalidate the proposed model:

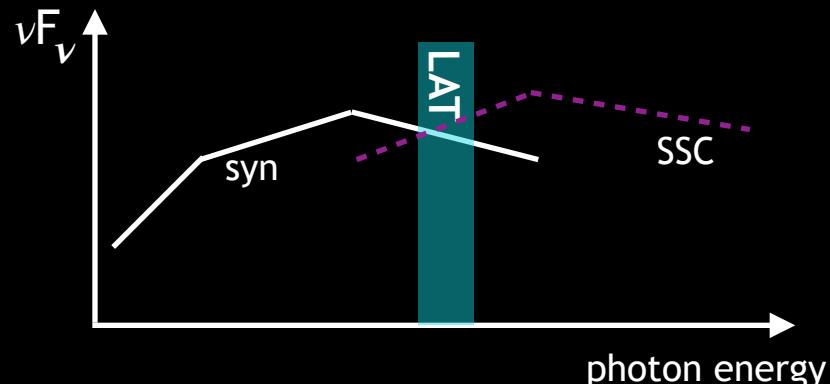
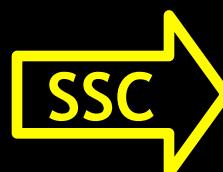
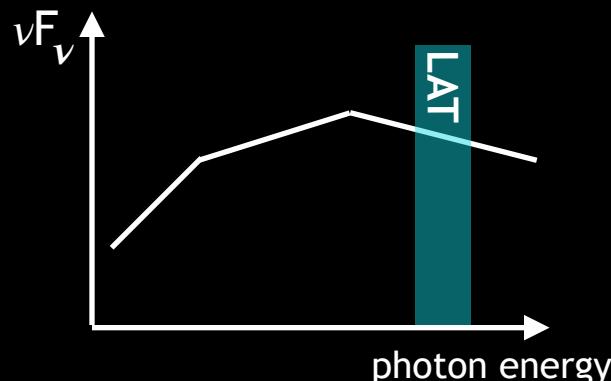
1. *SSC could modify the synchrotron spectrum:*

$$\frac{L_{\text{LAT}}}{E_{\text{iso}}} \propto \epsilon_e^{1.2} \frac{1 - \eta_\gamma}{\eta_\gamma} t^{-1.2}$$



$$\frac{L_{\text{LAT}}}{E_{\text{iso}}} \propto \epsilon_e^{1.2} \frac{1 - \eta_\gamma}{\eta_\gamma} t^{-1.2} \sqrt{\frac{\epsilon_B}{\epsilon_e}}$$

2. *SSC could dominate the emission*



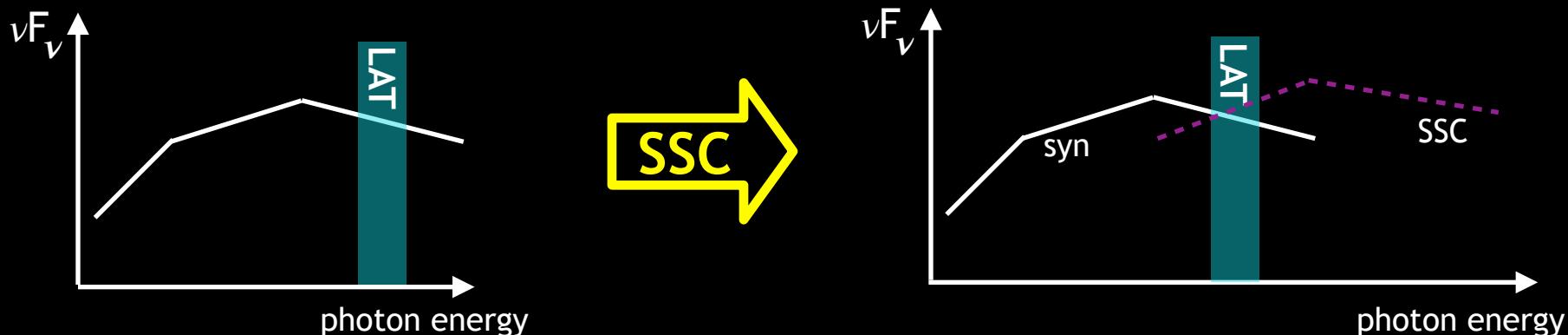
# Synchrotron Self Compton

Tang,Tam,Wang 2014 - Wang,Liu,Lemoine 2013 - Wang et al., 2010  
and estimates done by us following Nakar,Ando,Sari,2009

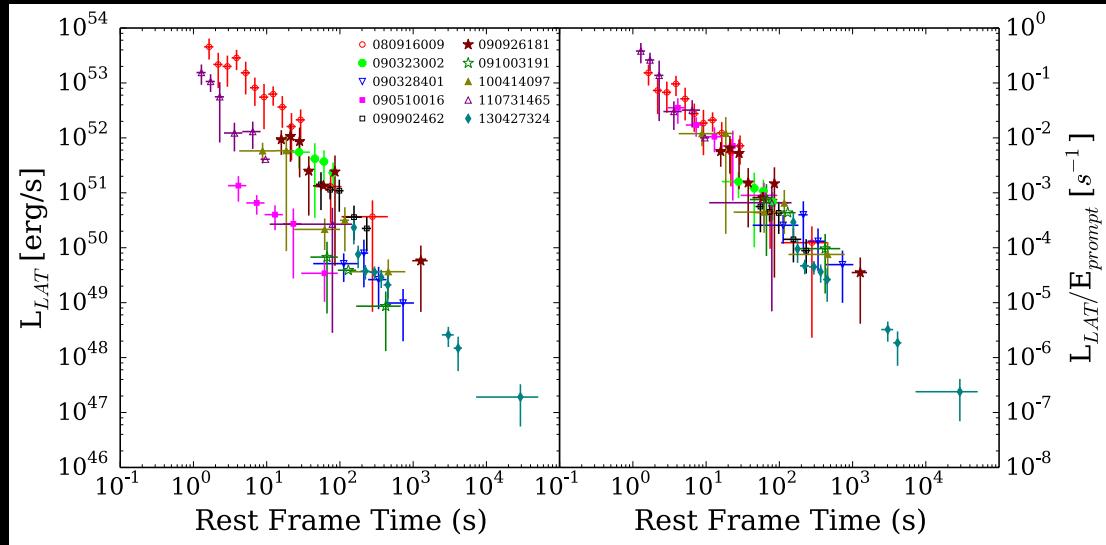
1. *SSC could modify the synchrotron spectrum:*  
*No! LAT energy range is always in KN regime*

$$\frac{L_{\text{LAT}}}{E_{\text{iso}}} \propto \epsilon_e^{1-\eta_\gamma} t^{-1.2}$$
$$\frac{L_{\text{LAT}}}{E_{\text{iso}}} \propto \epsilon_e^{1.2} \frac{1 - \eta_\gamma}{\eta_\gamma} t^{-1.2} \sqrt{\frac{\epsilon_B}{\epsilon_e}}$$

2. *SSC could dominate the emission*  
*Never! But...we can explain the high-energy photons!!!*



# — Conclusions —



- Clustering (=linear relation between  $L_{LAT}$  and  $E_{prompt}$ ) supports synchrotron origin for LAT extended emission
- It's possible to use the clustering to infer the width of the distributions of  $\varepsilon_e$  and  $\eta_\gamma$ : narrow distributions