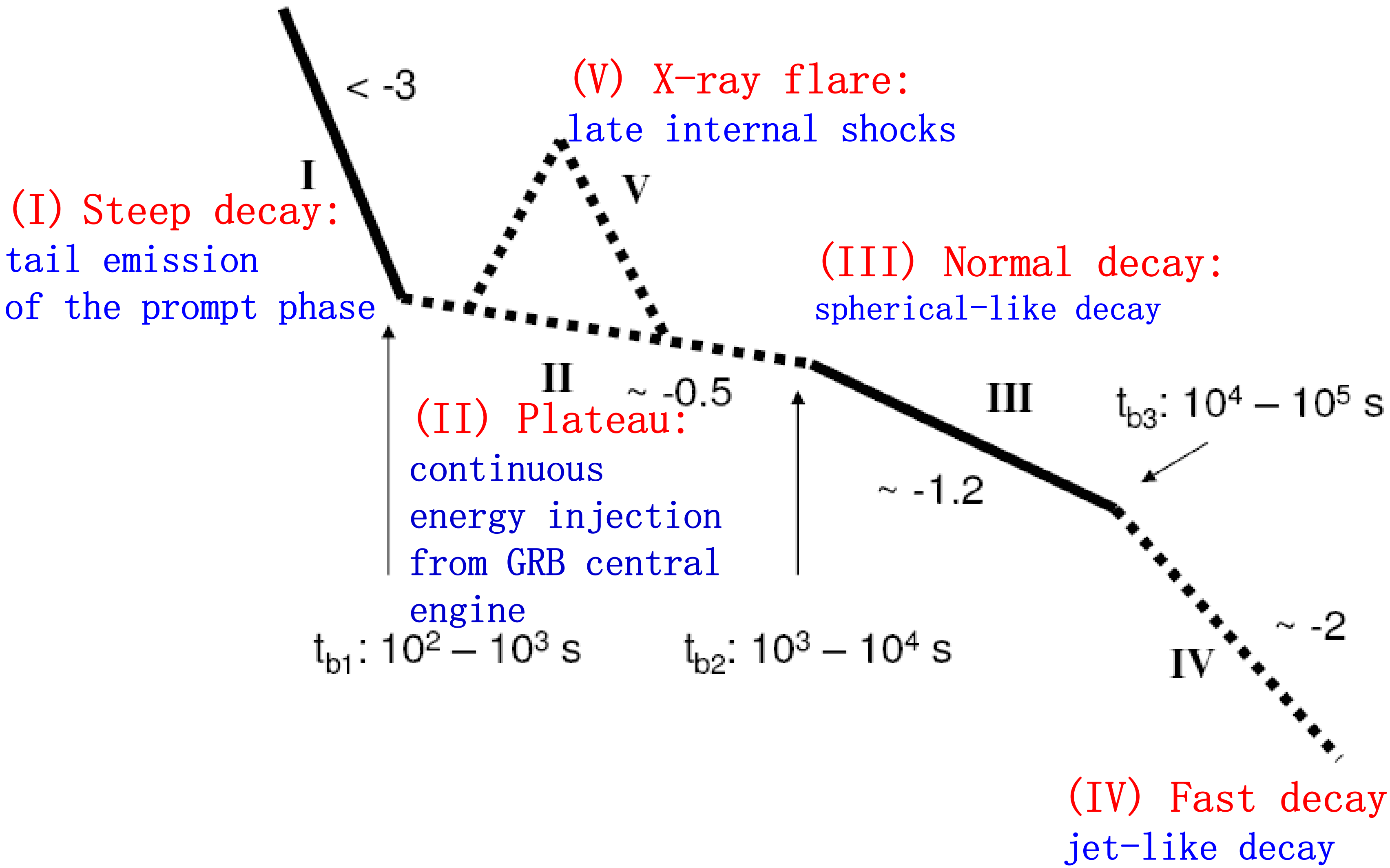
Fast Rotating Black Holes in GRBs 060729 and 080913?

Xue-Feng Wu[1,2], Kenji Toma[1], Dirk Grupe[1], Bing Zhang[3], Dave Burrows[1], Peter Meszaros[1]

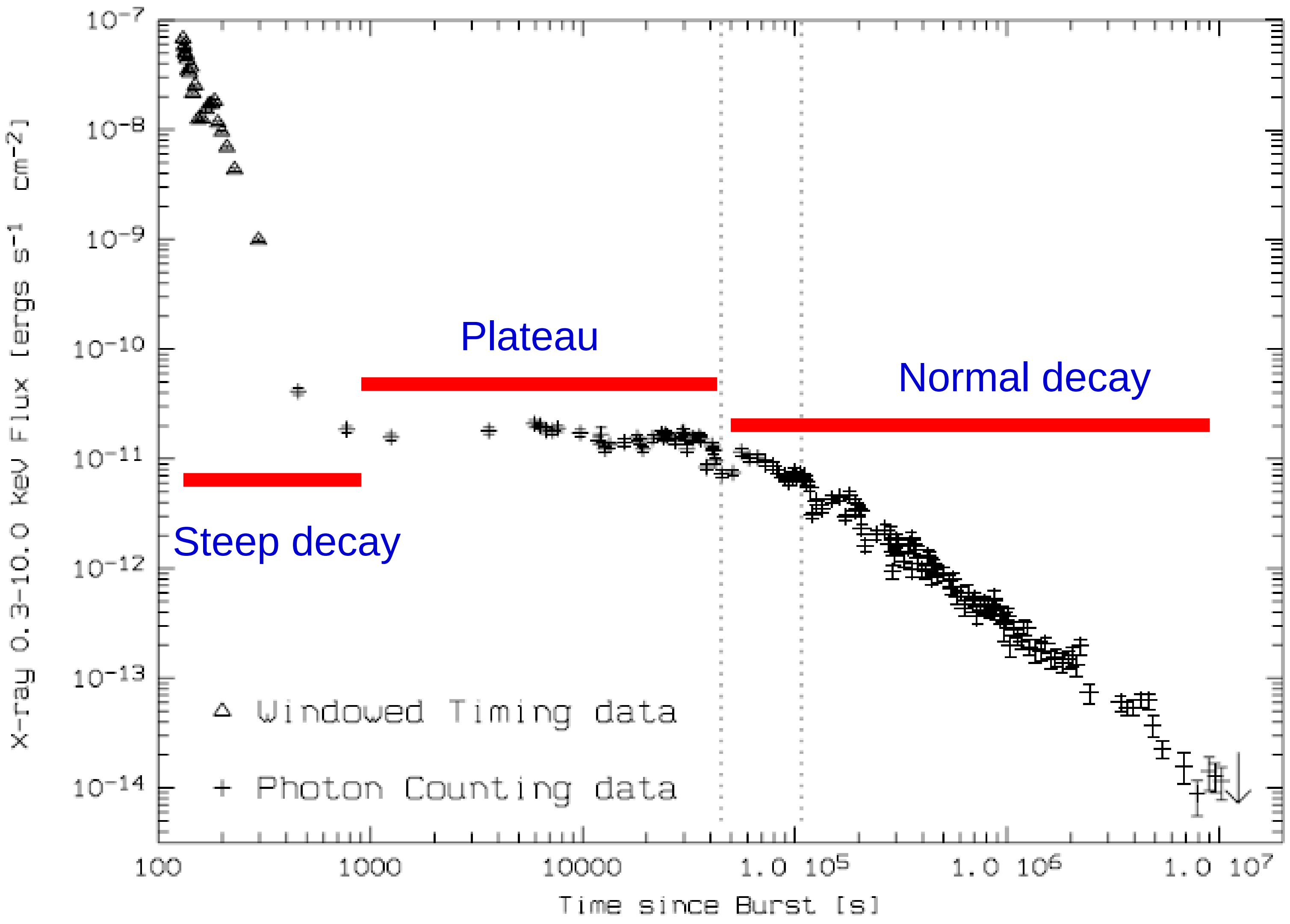
[1] Penn State University
[2] Purple Mountain Observatory
[3] University of Nevada, Las Vegas

A canonical X-ray light curve



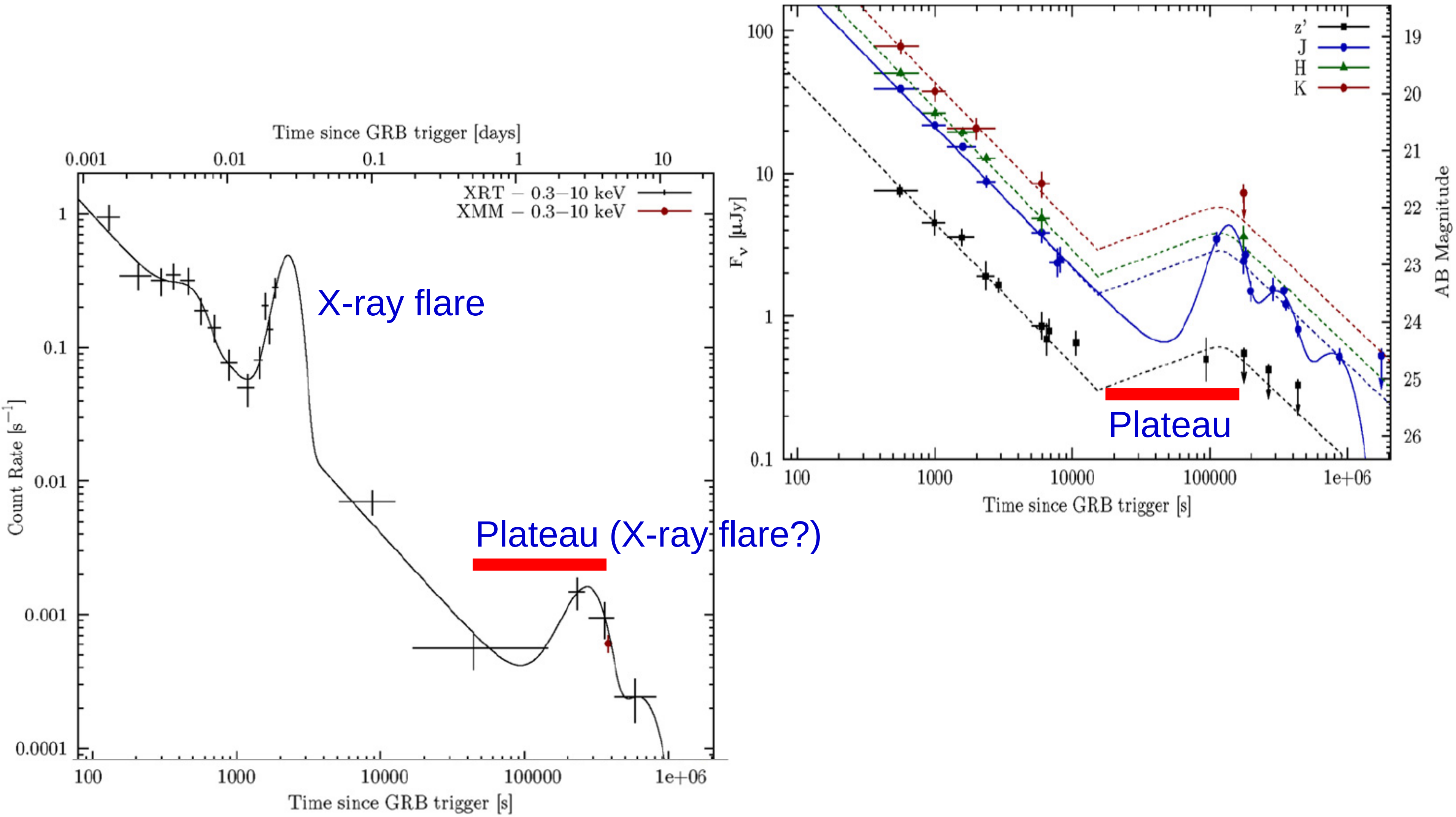
Zhang et al. 2006; Nousek et al. 2006; O'Brien et al. 2006

GRB 060729 X-ray light curve



Grupe et al. 2007, ApJ, 662, 443

GRB 080913 X-ray/optical light curve

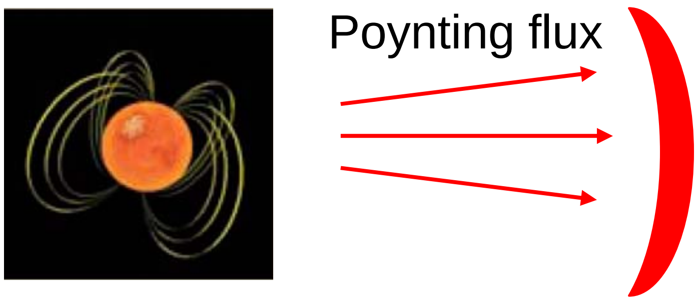


Greiner et al. 2009, ApJ, 693, 1610

Energy injection model for X-ray Plateau

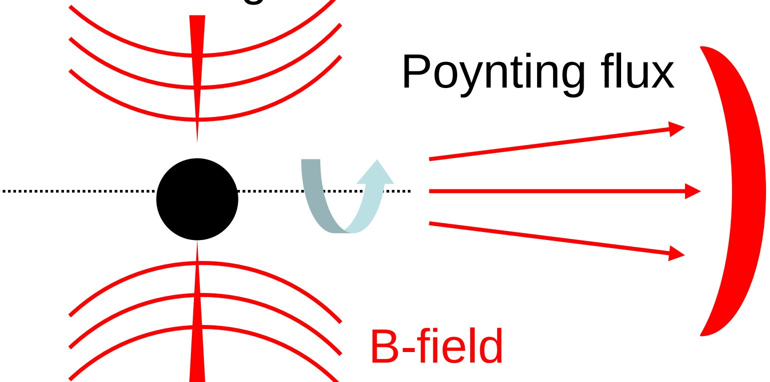
injected luminosity:

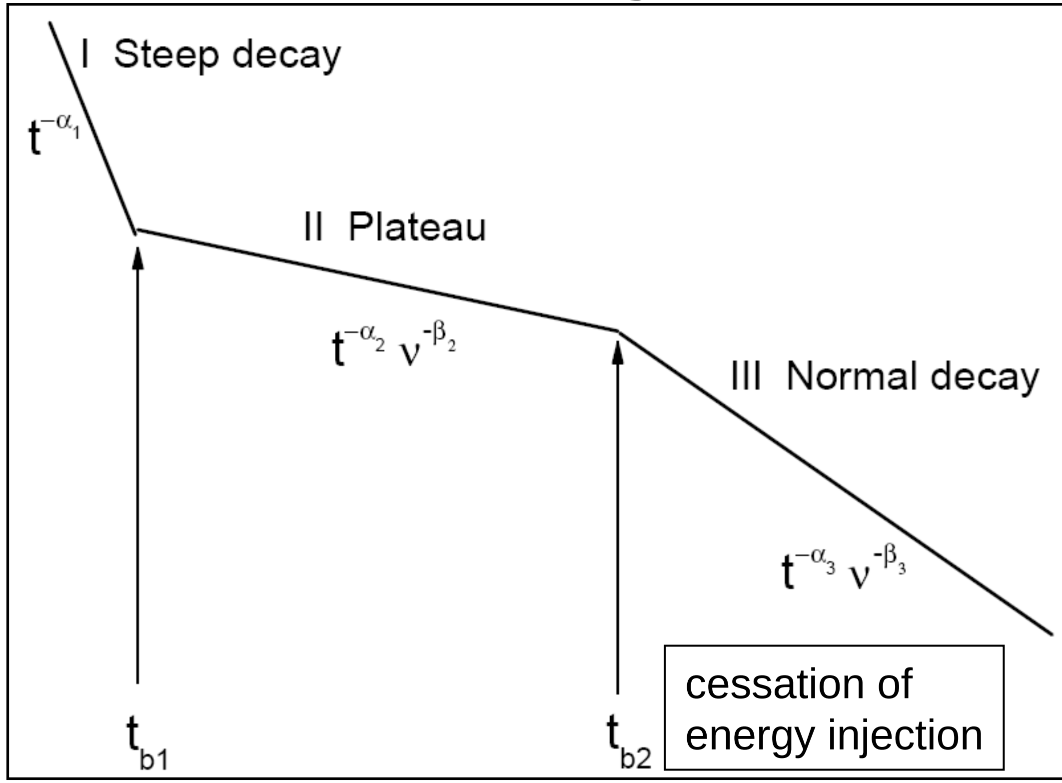
$$L = \begin{cases} L_0 (t/T_*)^q, & t < T_* \\ L_0 (t/T_*)^{-2}, & t > T_* \end{cases}$$



millisecond magnetar
or
fast rotating black hole

forward shock





forward shock energy:

$E_{k,iso} \propto t^{1-q}$,

where *q* can be estimated from α_2, α_2, $\beta_2 (= \beta_3)$

total energy of GRB 060729

(1) The isotropic gamma-ray energy release during the prompt emission (Grupe et al. 2007):

$E_{\gamma,iso} = 1.6 \times 10^{52}$ erg;

(2) The initial isotropic kinetic energy in the forward shock is

$E_{k,iso,i} \geq 10^{52}$ erg;

(3) The forward shock energy increases almost linearly with time during the plateau phase:

$E_{k,iso} \propto t^{1-q} \sim t$,

Because

$$q = 2(\alpha_2 - \beta_2 + 1)/(1 + \beta_2) = -0.037 \pm 0.101$$

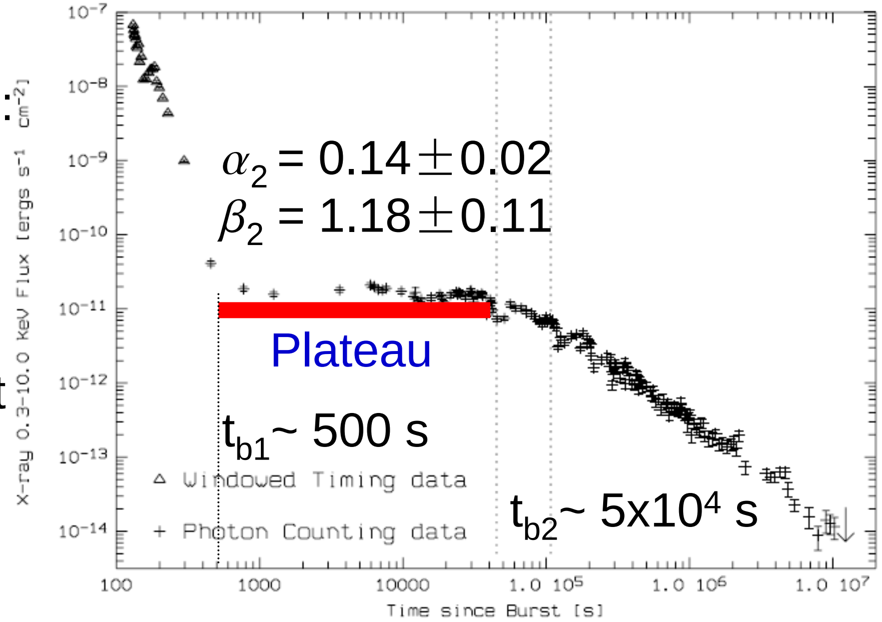
(4) The final isotropic kinetic energy in the forward shock is

$E_{k,iso} \geq E_{k,iso,i}(t_{b2}/t_{b1}) \sim 10^{54}$ erg

(5) A lower limit of the half-opening angle of this GRB jet is obtained due to the lack of a jet break in the X-ray light curve up to t = 642 days:

$$\theta_j \geq 15^\circ E_{k,iso,54}^{-1/4} A_{*,-1}^{1/4}$$

where A_* is the wind parameter is its value is well constrained by detailed afterglow modeling.



(6) The total (beaming-corrected) jet energy of GRB 060729 is therefore

$$E_{\rm jet} \geq 3.4 \times 10^{52} E_{k,iso,54}^{1/2} A_{*,-1}^{-1/2} \text{ ergs}$$

Grupe et al. 2009, arXiv: 0903.1258

total energy of GRB 080913

(1) The isotropic gamma-ray energy release during the prompt emission (Grupe et al. 2007):

$E_{\gamma,iso} = 7\times10^{52}$ erg;

(2) The initial isotropic kinetic energy in the forward shock is

$E_{k,iso,i} \sim 10^{52}$ -10^{53} erg;

(3) The forward shock energy increases almost linearly with time during the plateau phase:

$E_{k,iso} \propto t^{1-q} \sim t^2$,

where q=1.0 is from the best numerical fit to the optical afterglow (see the right figure)

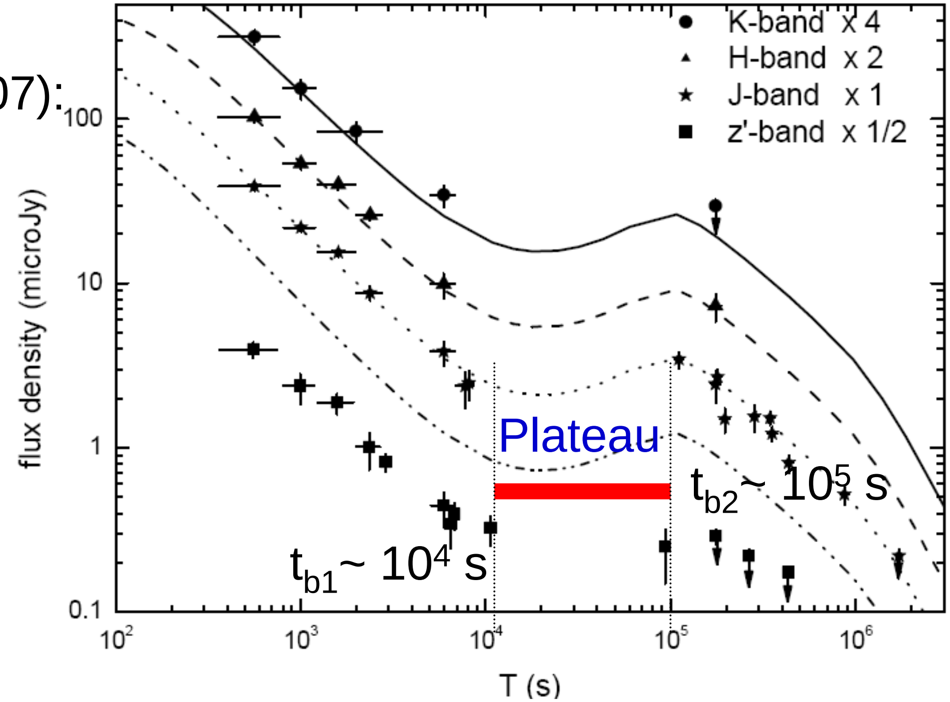
(4) The final isotropic kinetic energy in the forward shock is

$E_{k,iso} = E_{k,iso,i} (t_{b2}/t_{b1}) \sim 10^{54} – 10^{55}$ erg

(5) A lower limit of the half-opening angle of this GRB jet is obtained due to the lack of an optical jet break up to t = 10^6 s:

$\theta_j \geq 0.20\ E_{k,iso,54}^{-1/8}\ n_3^{1/8}$ rad

where n is the ISM number density and its value is well constrained by detailed afterglow modeling.



$E_{k,iso}$ (ergs)	θ_j (rad)	n (cm^{-3})	γ_0	p
3.7×10^{52}	0.22	3000	3000	2.2
L_0 (erg s^{-1})	T_* (s)	ε_e	ε_B	q
2.4×10^{50}	7.8×10^{3}	0.04	10^{-5}	1.0

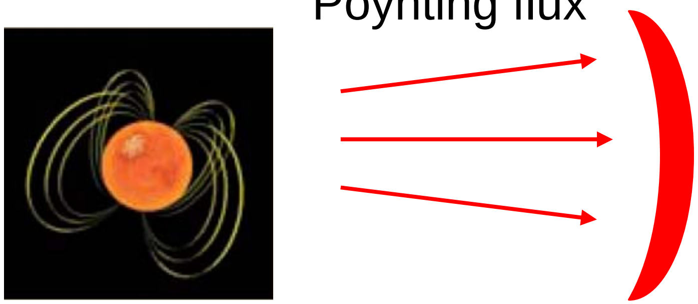
A numerical fit to GRB 080913 (Liu, Wu, Lu, 2009, arXiv:0907.1767)

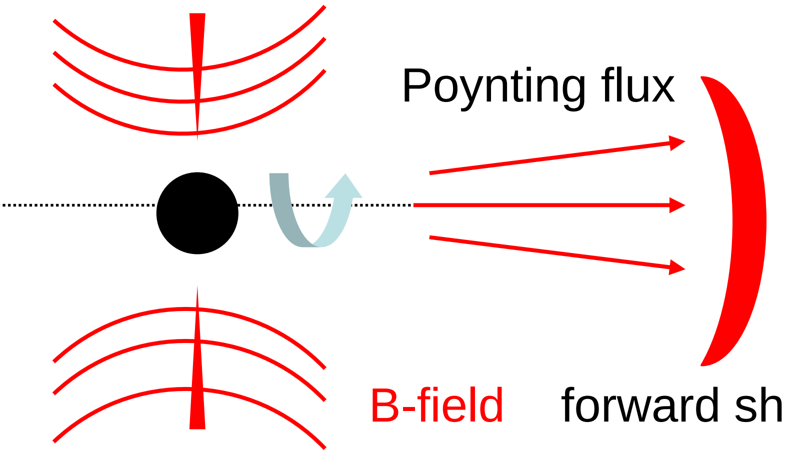
(6) The total (beaming-corrected) jet energy of GRB 080913 is therefore

$E_{jet} \geq 2.0\times10^{52}\ E_{k,iso,54}^{3/4}\ n_3^{1/4}$ erg

Greiner et al. 2009, ApJ, 693,1610; Zhang et al. 2009, ApJ, 703, 1696

Magnetar or Black hole in GRBs 060729 & 080913?





the extractable energy from a rapidly rotating black hole is

$$E_M = (1/2)\, I\, \Omega^2$$
$$< 2.0 \times 10^{52}\, (P / 1\ \mathrm{ms})^{-2}\ \mathrm{erg}$$

For GRBs 060729 and 080913, $E_{jet} >$ (2 - 4) $\times 10^{52}$ erg, so their central engine is most likely fast or massive rotating black hole, not millisecond magnetar!

the extractable energy from a rapidly rotating black hole is

$$E_{BH} = f(a) M_{BH} c^2$$
$$< 0.29\, M_{BH} c^2$$
$$= 5 \times 10^{53}\, (M_{BH} / M_{sun})\ \mathrm{erg}$$