Fast Rotating Black Holes in GRBs 060729 and 080913?

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A canonical X-ray light curve

(I) Steep decay:
\[ t_{b1} : 10^2 - 10^3 \text{ s} \]
- tail emission of the prompt phase

(II) Plateau:
\[ t_{b2} : 10^3 - 10^4 \text{ s} \]
- continuous energy injection from GRB central engine

(III) Normal decay:
\[ t_{b3} : 10^4 - 10^5 \text{ s} \]
- spherical-like decay

(IV) Fast decay:
\[ \sim -2 \]
- jet-like decay

(V) X-ray flare:
\[ \sim -1.2 \]
- late internal shocks

Zhang et al. 2006; Nousek et al. 2006; O’Brien et al. 2006
GRB 060729 X-ray light curve

GRB 080913 X-ray/optical light curve

Energy injection model for X-ray Plateau

injected luminosity:

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

forward shock energy:

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

where \( q \) can be estimated from \( \alpha_2, \alpha_2, \beta_2 (= \beta_3) \)
total energy of GRB 060729

(1) The isotropic gamma-ray energy release during the prompt emission (Grupe et al. 2007):
   \[ E_{\gamma,\text{iso}} = 1.6 \times 10^{52} \text{ erg}; \]

(2) The initial isotropic kinetic energy in the forward shock is
   \[ E_{k,\text{iso},i} \geq 10^{52} \text{ erg}; \]

(3) The forward shock energy increases almost linearly with time during the plateau phase:
   \[ E_{k,\text{iso}} \propto t^{1-q} \sim t, \]
   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
   \[ E_{k,\text{iso}} \geq E_{k,\text{iso},i}(t_{b2}/t_{b1}) \sim 10^{54} \text{ erg} \]

(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:
   \[ \theta_j \geq 15^\circ E_{k,\text{iso},54}^{-1/4} A_{*,-1}^{1/4} \]
   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
   \[ E_{\text{jet}} \geq 3.4 \times 10^{52} E_{k,\text{iso},54}^{1/2} A_{*,-1}^{-1/2} \text{ ergs} \]

(1) The isotropic gamma-ray energy release during the prompt emission (Grupe et al. 2007):
\[ E_{\gamma,\text{iso}} = 7 \times 10^{52} \text{ erg} \]

(2) The initial isotropic kinetic energy in the forward shock is
\[ E_{k,\text{iso},i} \sim 10^{52} - 10^{53} \text{ erg} \]

(3) The forward shock energy increases almost linearly with time during the plateau phase:
\[ E_{k,\text{iso}} \propto t^{1-q} \sim t^2 \]
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
\[ E_{k,\text{iso}} = E_{k,\text{iso},i} \left( \frac{t_{b2}}{t_{b1}} \right)^{\frac{3}{4}} \sim 10^{54} - 10^{55} \text{ erg} \]

(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 \( t = 10^6 \text{ s} \):
\[ \theta_j \geq 0.20 E_{k,\text{iso},54}^{-1/8} n_3^{1/8} \text{ rad} \]
where \( n \) is the ISM number density and its value is well constrained by detailed afterglow modeling.

(6) The total (beaming-corrected) jet energy of GRB 080913 is therefore
\[ E_{\text{jet}} \geq 2.0 \times 10^{52} E_{k,\text{iso},54}^{3/4} n_3^{1/4} \text{ erg} \]

Magnetar or Black hole in GRBs 060729 & 080913?

- Fast rotating black hole
- B-field
- Forward shock
- Extractable energy from a rapidly rotating black hole is:
  \[ E_{BH} = f(a) M_{BH} c^2 \]
  \[ < 0.29 M_{BH} c^2 \]
  \[ = 5 \times 10^{53} \left( \frac{M_{BH}}{M_{\odot}} \right) \text{ erg} \]

- Millisecond magnetar
- Poynting flux
- Extractable energy from a rapidly rotating black hole is:
  \[ E_M = \frac{1}{2} I \Omega^2 \]
  \[ < 2.0 \times 10^{52} \left( \frac{P}{1 \text{ ms}} \right)^2 \text{ erg} \]

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

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