Observational evidence for magnetars powering GRBs

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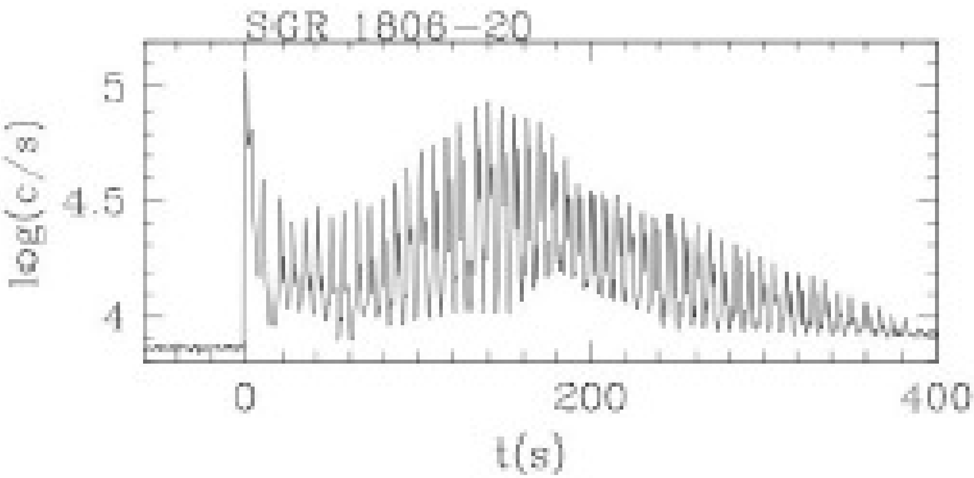
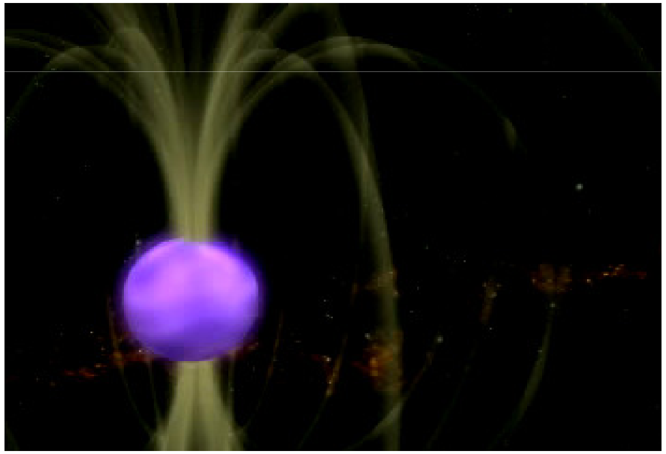
2004 December 27 – first big Swift "event"





Galactic magnetars have B-fields of order 10^{14} – 10^{15} gauss.

Can be rotating relative slowly (seconds).

Giant SGR flares release more than 10^{46} erg

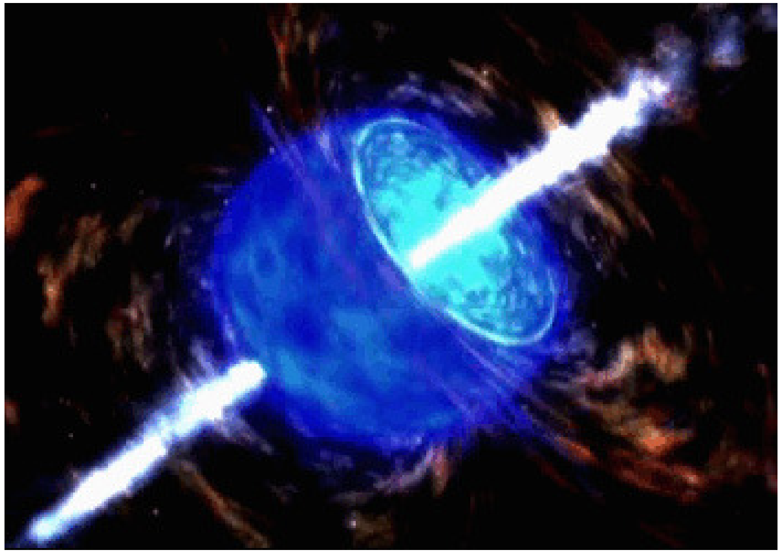
Could explain some of the (very) nearby short GRBs

GRB progenitor models

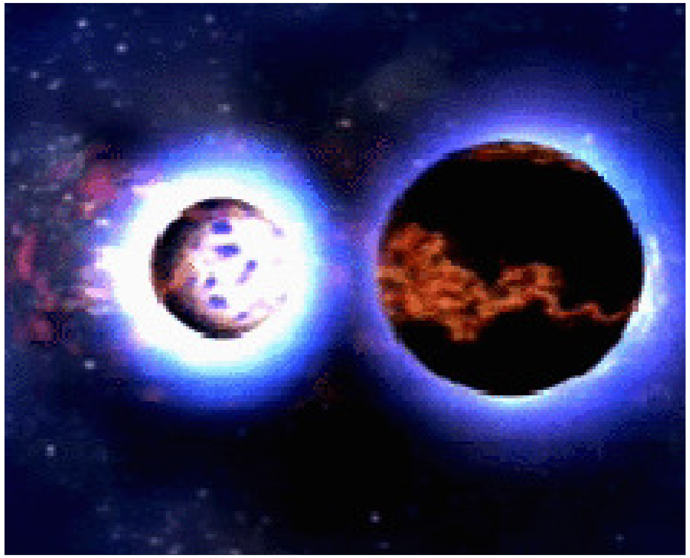
Some GRBs may be powered by an unstable, millisecond pulsar (a magnetar) (e.g., Usov 1992; Duncan & Thompson 1992; Metzger 2009; Dai et al. 2006)

Fast rotation plus very strong magnetic field may power a jet (and hypernova)

Extraction rotational energy ⇒ inject energy into the light curve ⇒ rapid decline when the magnetar collapses to a BH (Zhang & Mézsáros 2001)



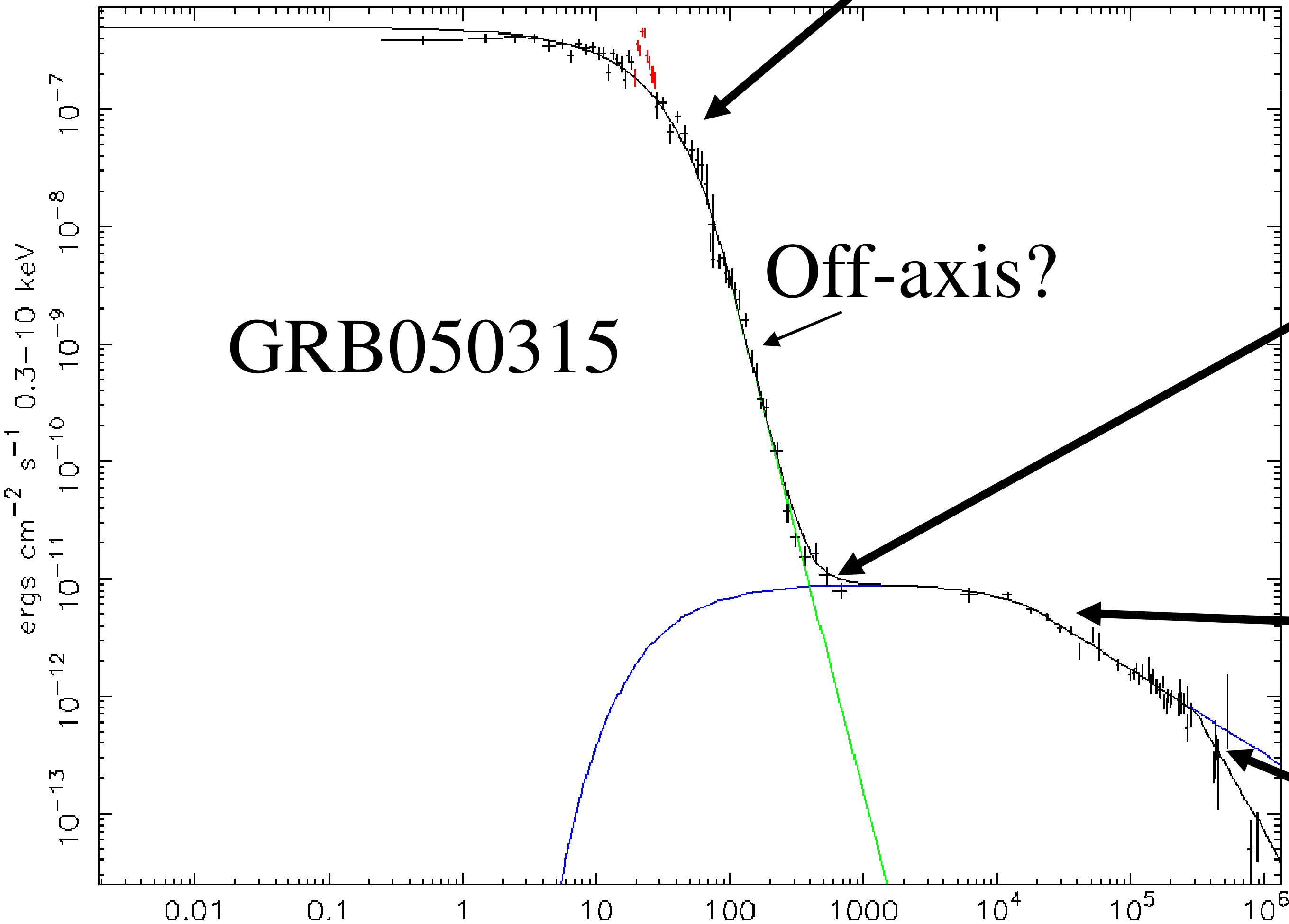
Collapsar – LGRBs



Binary Merger – SGRBs

Example GRB X-ray decay

Prompt emission stops



Second component becomes visible

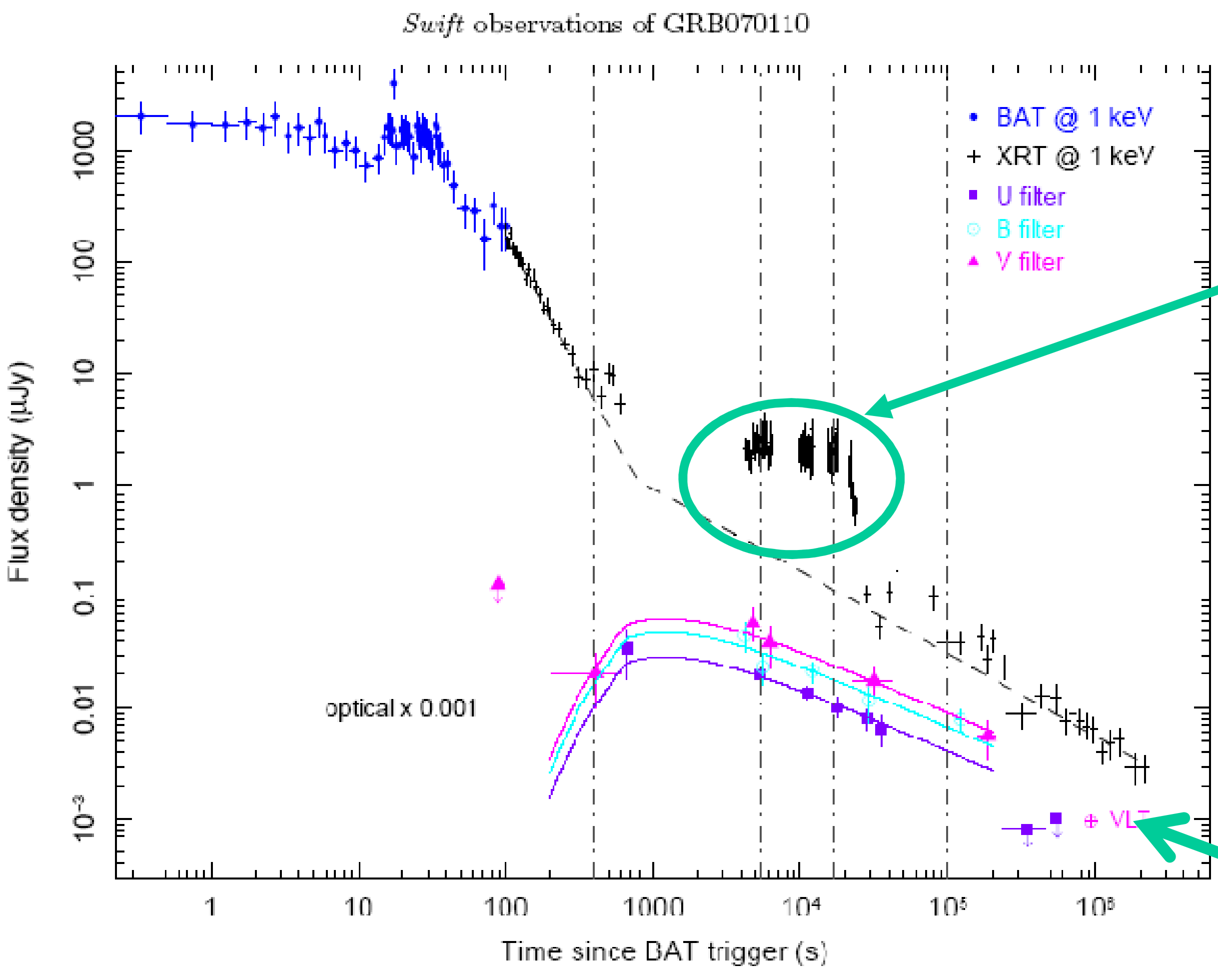
Final decay starts

Late break

(collimation?)

(O'Brien et al. 2006; Willingale et al. 2007)

First magnetar example: GRB 070110 (Troja et al. 2007)



After the initial (impulsive event) see a late excess or "internal plateau" followed by a very steep decay.

Propose "internal plateau" due to the spin-down of a magnetar which thencollapses.

Not seen in the optical which appears to show a fairly "standard" afterglow.

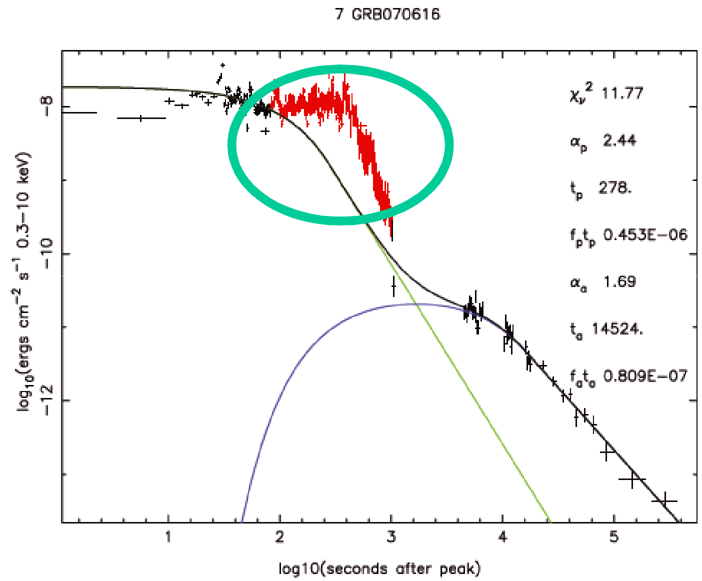
A larger sample
(Lyons et al. 2010)

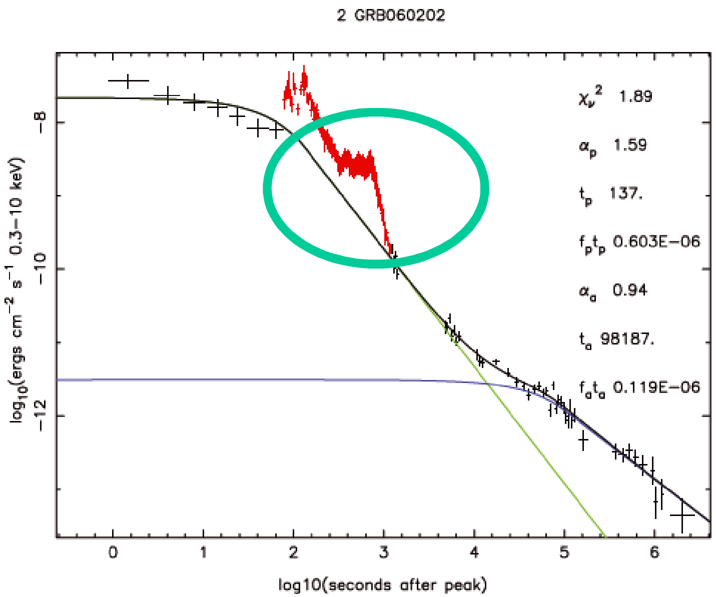
Analysed all Swift GRBs up to the end of 2008.

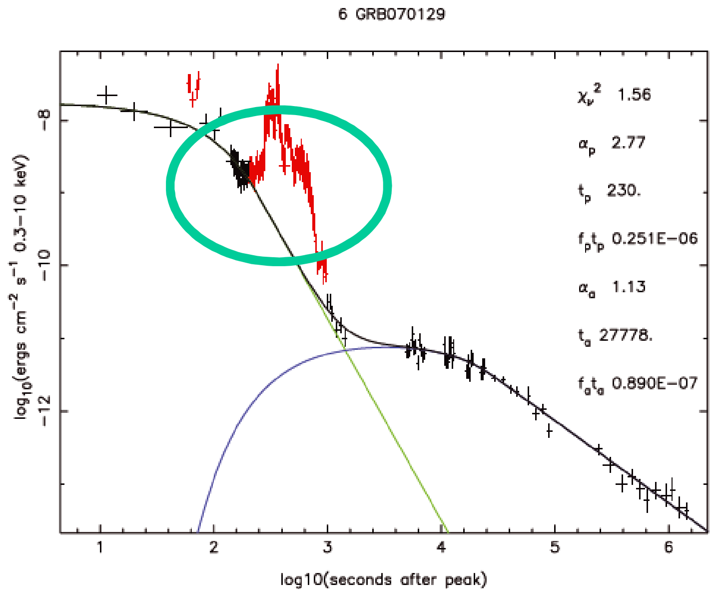
Find 10 magnetar candidates.

All are long GRBs.

The internal plateau and rapid declines are only seen in X-rays.

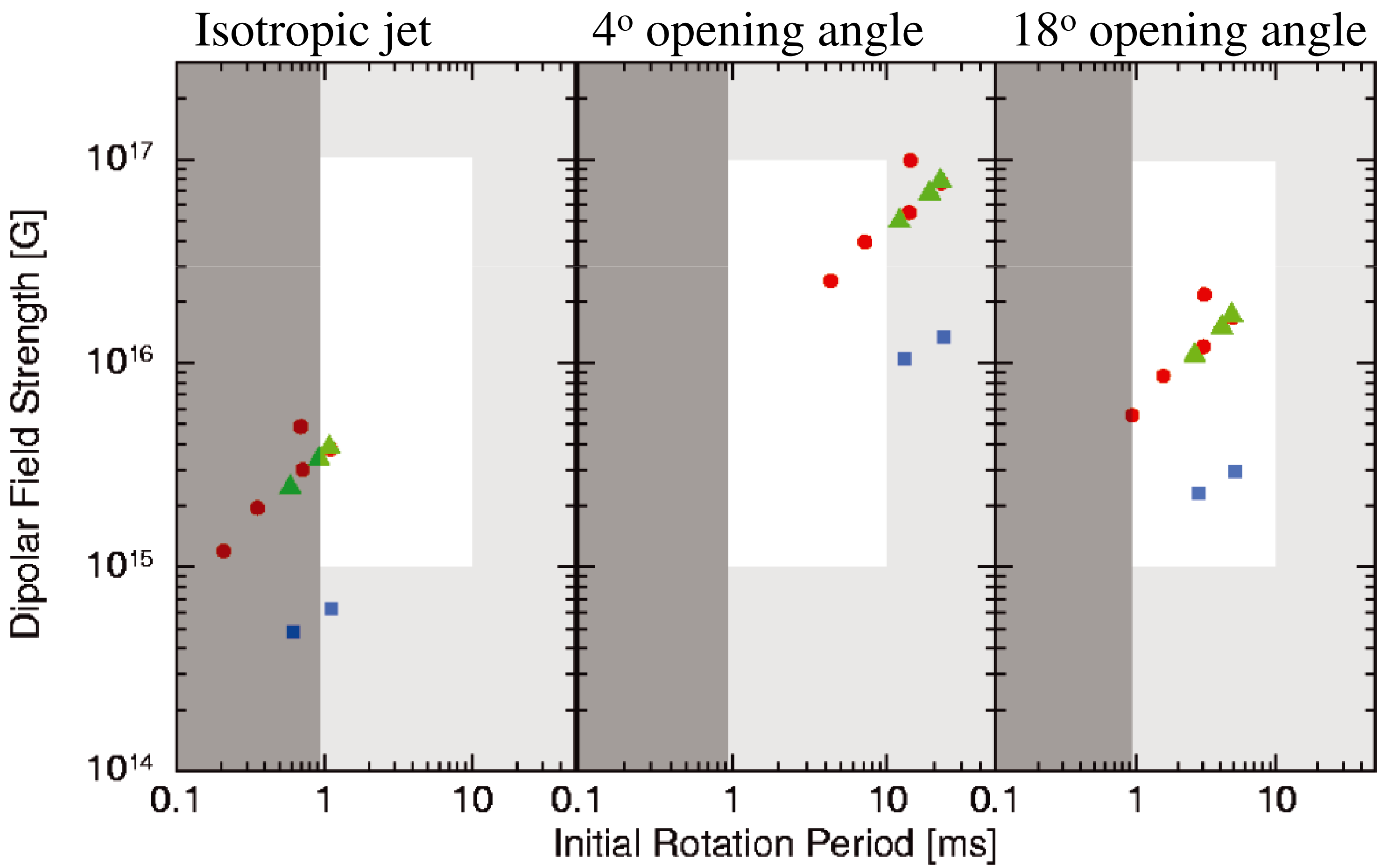






Derive magnetar parameters

$$L \propto B_p^2 / P_0^4 \quad \text{and } T_{em} \propto P_0^2 / B_p^2$$

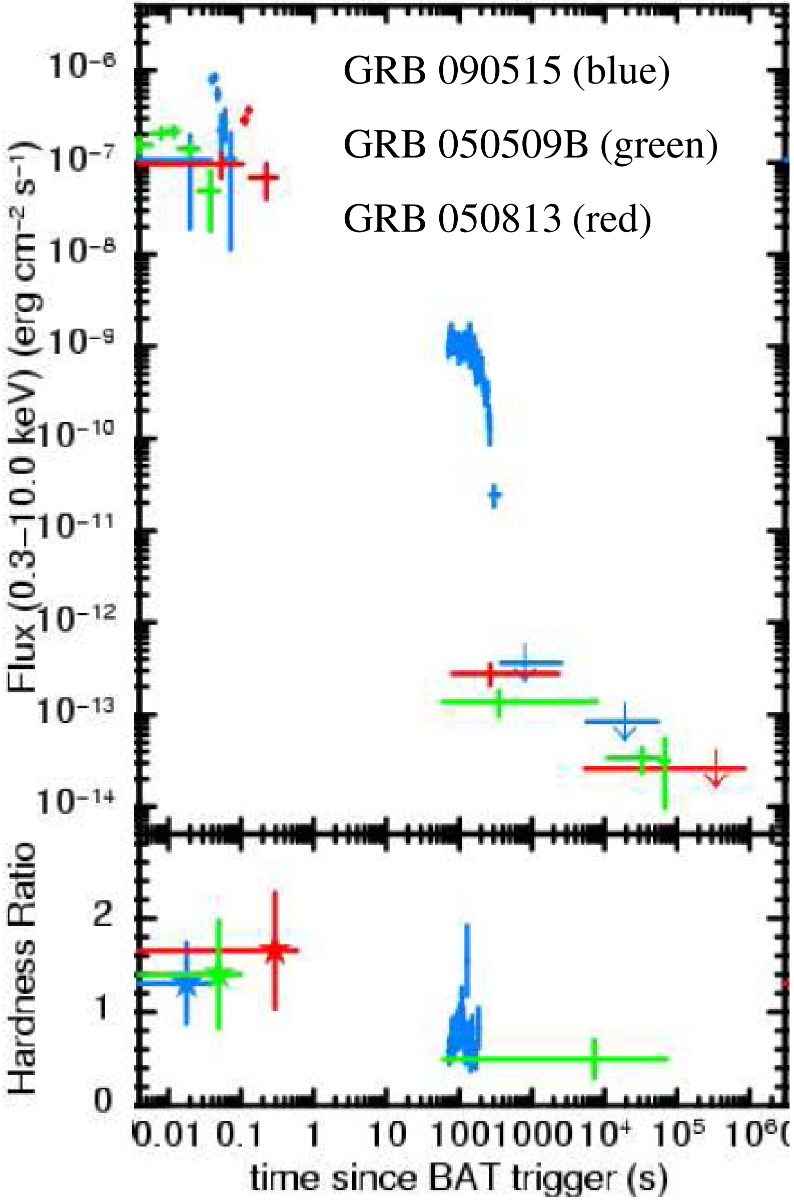


Expect a relation between the pulsar initial spin period (P_0), dipole field strength (B_p), luminosity (L) and the characteristic timescale (T_{em}) for spin-down:

$$L \propto B_p^2 / P_0^4 \quad \text{and } T_{em} \propto P_0^2 / B_p^2$$

(assume standard values for mass and radius of NS)

GRB 090515 – a short magnetar
(Rowlinson et al. 2010 – see poster 5.04)

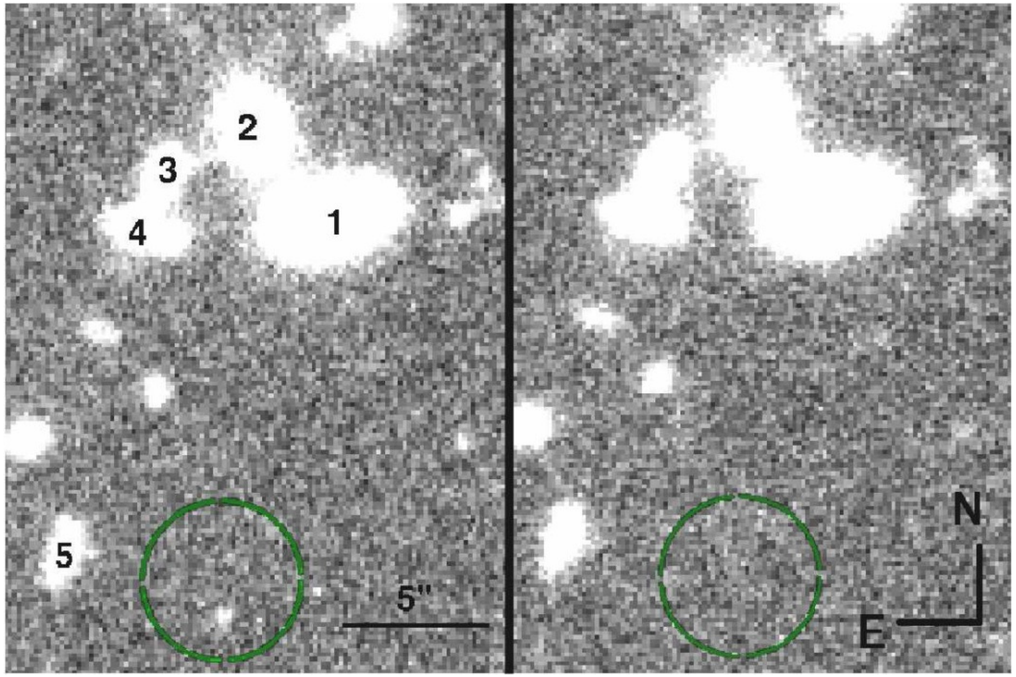


T90 = 0.036s

Fluence = 2x10^{-8} erg s^{-1} (15-150 keV)

Highest short GRB X-ray flux at100s

Very unusual given low γ-ray fluence



Gemini-N, r-band at 6300s

See a (fading) r=26.4 source

GRB090515

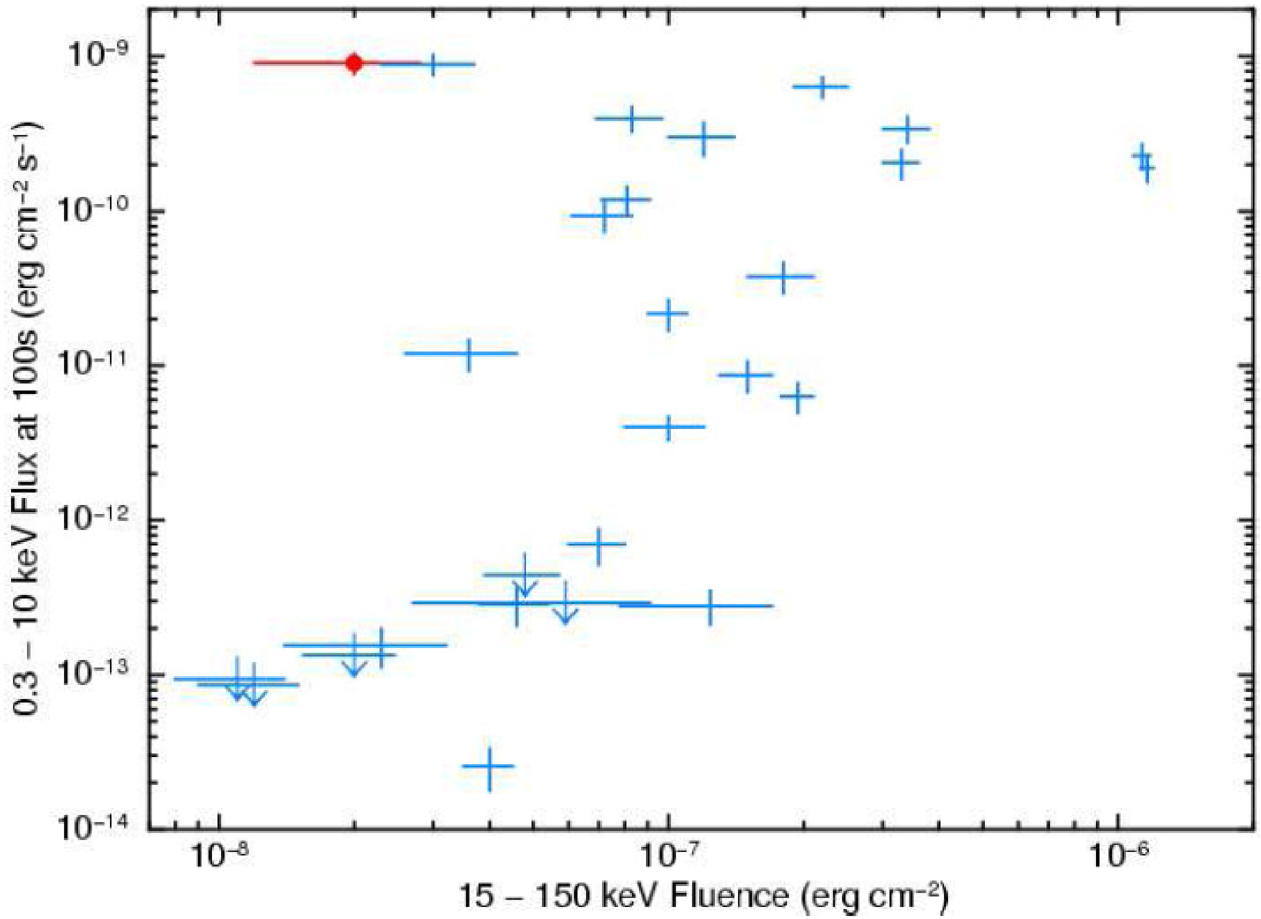
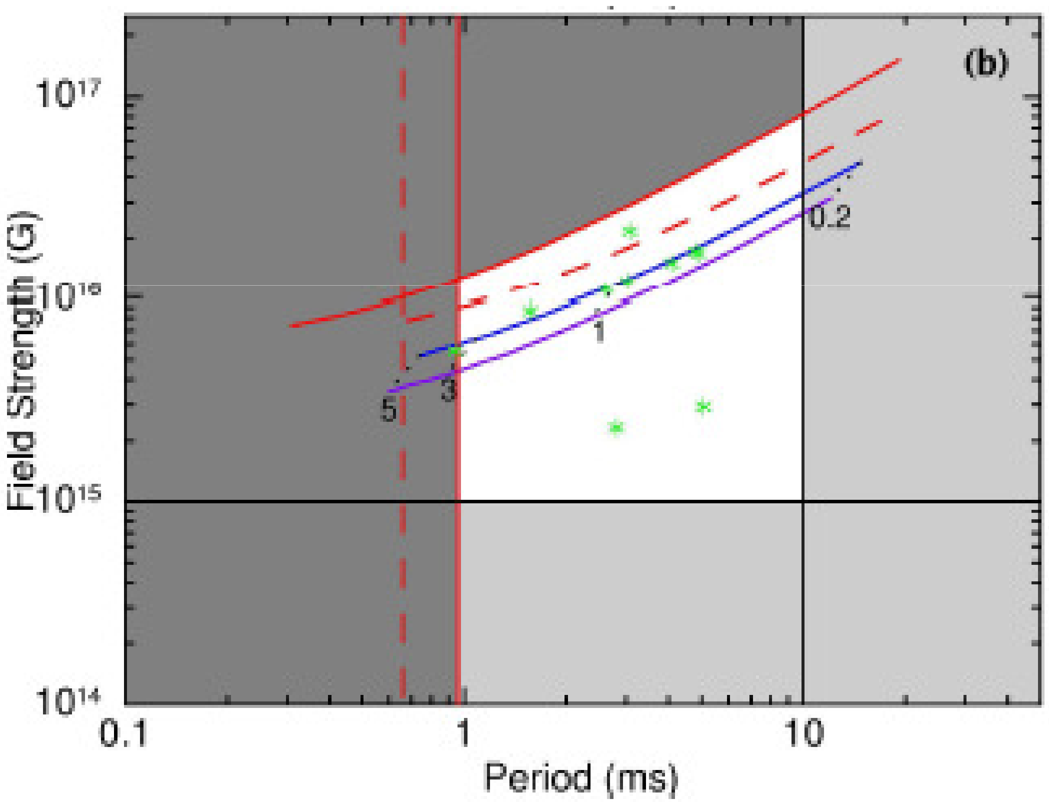


Figure 3. The fluence in the energy band 15 - 150 keV versus the 0.3 - 10 keV flux for all Swift SGRBs which were observed at 100s after the trigger time. The filled circle marks the location of GRB 090515. (070724A has a flare)

GRB 090515



Parameters at various z:

Blue line, M=1.4 $M_\odot$; purple , M=2.1 $M_\odot$.

Green points: LGRBs, Lyons et al. (2010)

Impose causality limit:

sound speed ≤ light speed

Red solid,1.4 $M_\odot$; red dashed, 2.1 $M_\odot$

Consistent with LGRB cases for z ~0.3-5

Summary and tests

- 10 long and 1 short GRBs show an "internal plateau" followed by a steep decline
- Evidence for energy injection by a magnetar (tapping rotational energy) before it collapses to a black hole – must not imply a total energy larger than that available from rotation (recent results on massive pulsars increases parameter space)
- Possible test in future using detection of gravity-waves (GW):
  - A merger or a collapsar GW signal (e.g. Abadie et al. 2010)
  - Spin-down GW signal (e.g Corsi & Meszaros 2010)
  - Magnetar collapse to a black hole GW signal (e.g. Novak 1998)
- Nearby cases (few 100Mpc) would provide a test-case where a simultaneous EM and GW light-curves show correlated multiple signals
- **Need a functioning GRB space mission when advanced-LIGO working!!**