Magnetars in extended emission gamma-ray bursts

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Thanks to Paul O'Brien and Antonia Rowlinson

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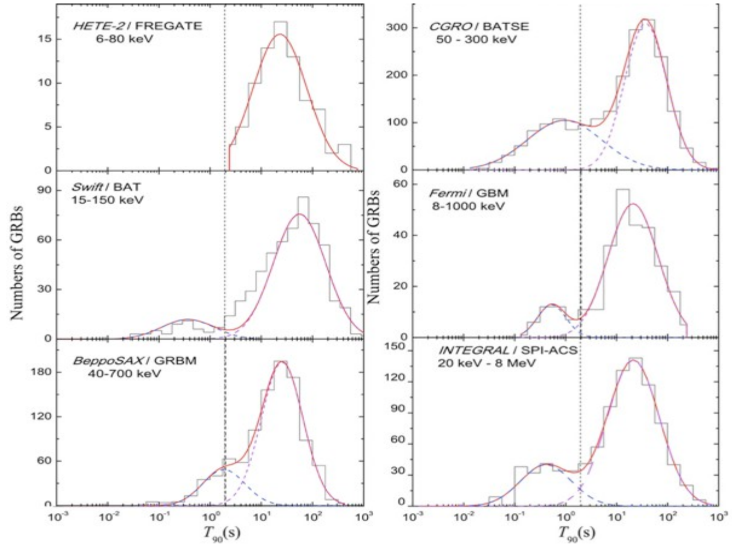
Properties of GRBs

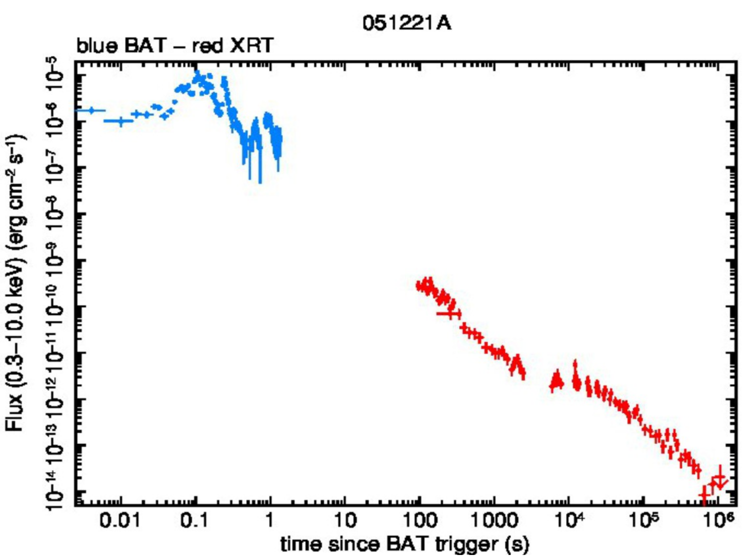
Short GRBs:

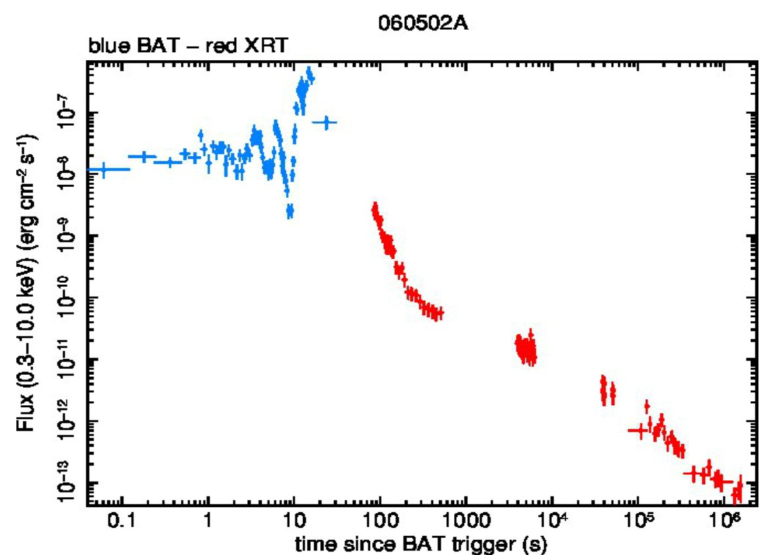
- $T_{90} < 2$ seconds
- Spectrally hard
- Often found with large offsets from host galaxies
- Long-lived (~ 1000 s) X-ray plateaus
- Binary mergers



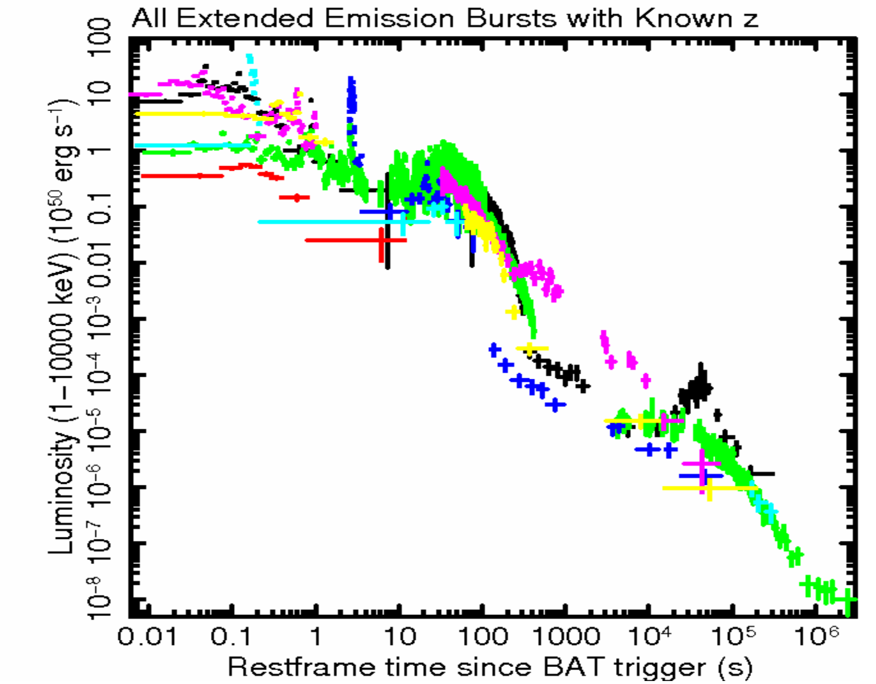
Long GRBs:

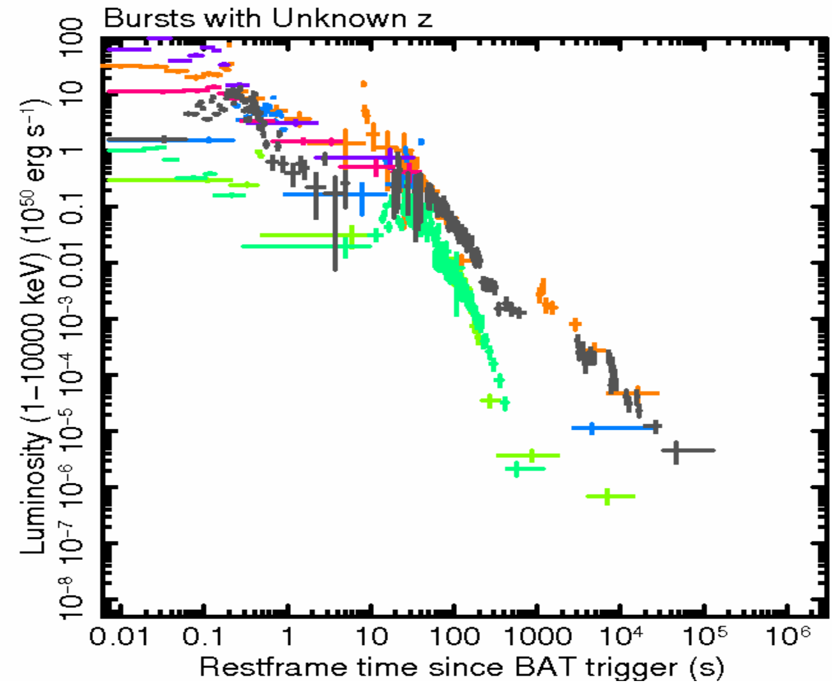
- $T_{90} > 2$ seconds
- Spectrally softer
- Found close to star forming regions
- Always observed with type 1b/c supernovae where possible
- Core collapse supernovae

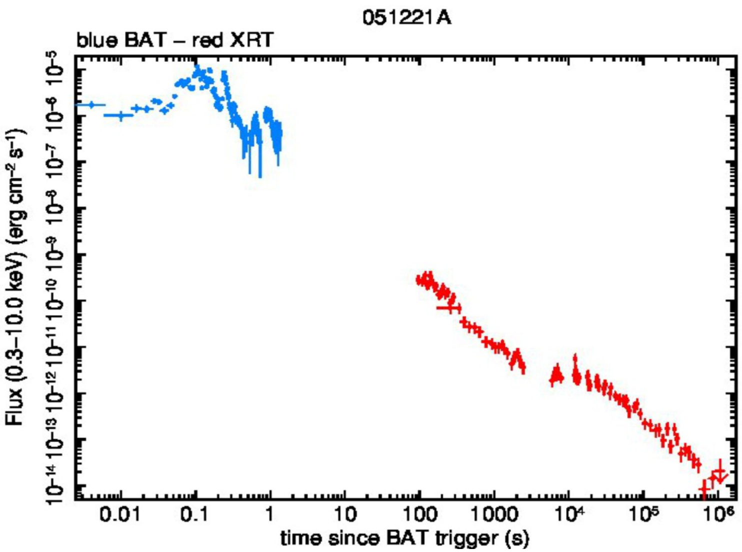


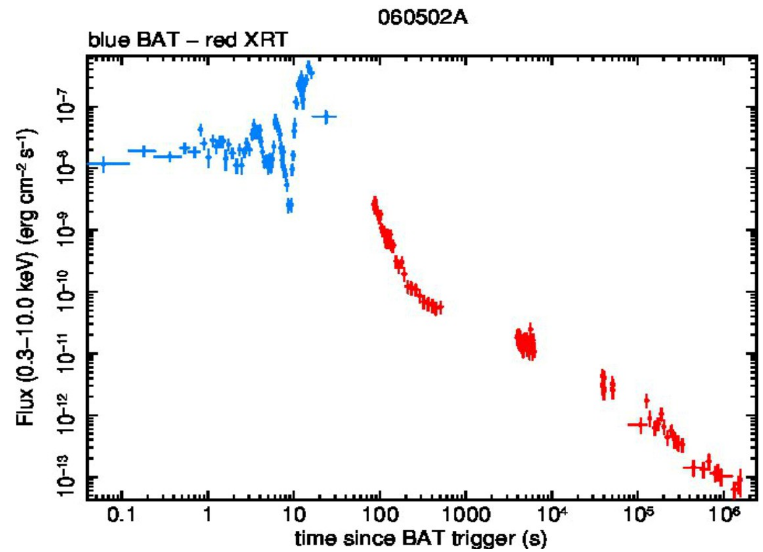


A Third Class?

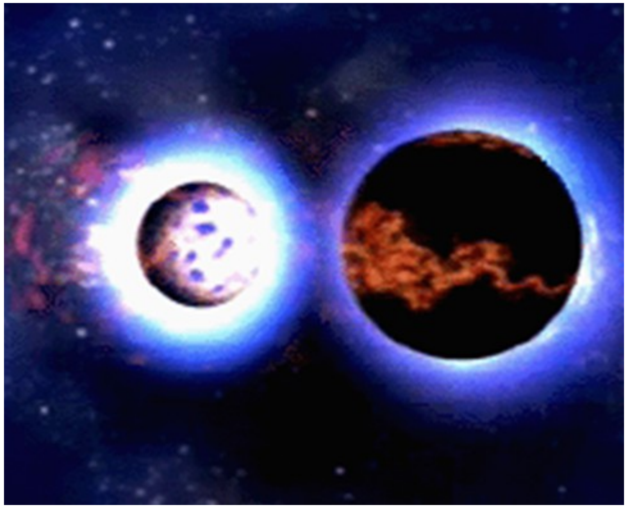




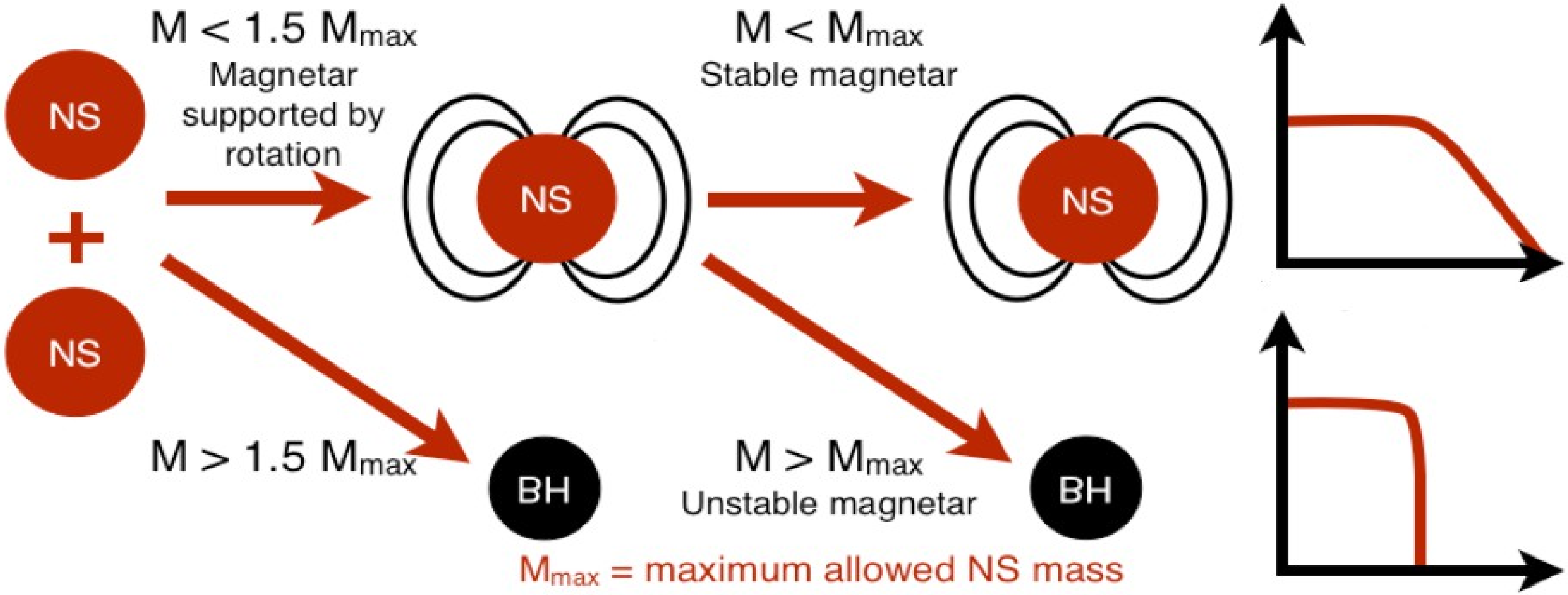




Magnetar central engine



- Prompt emission from relativistic jets, launched by initial merger
- Initial decay from the 'curvature effect,' created by high latitude emission
- Plateau created by energy injection from spin-down of a highly magnetised, rapidly rotating neutron star (magnetar)

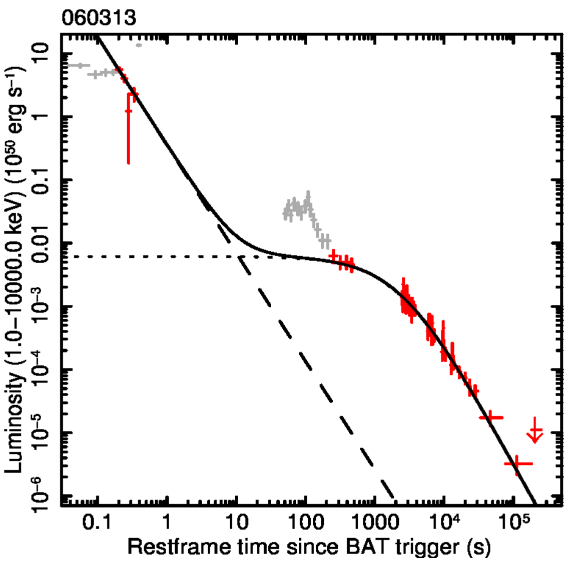


Magnetar central engine

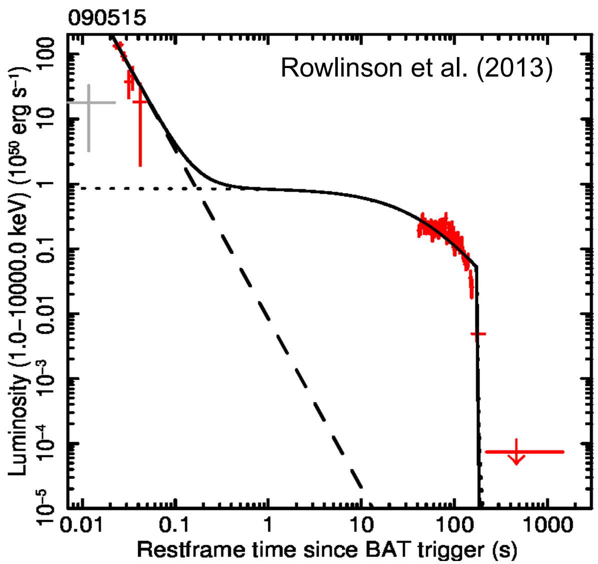
$$T_{em,3} = 2.05(I_{45} B_{p,15}^{-2} P_{0,-3}^{2} R_6^{-6})$$

$$L_{0,49} \sim (B_{p,15}^{2} P_{0,-3}^{-4} R_6^{6})$$

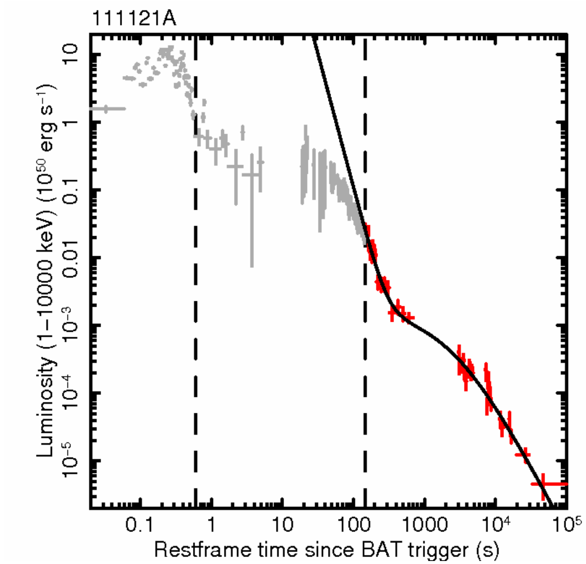
Zhang & Mészáros (2001)



Stable



Unstable



Stable & extended emission

- Extended tail may affect spin period
- Assume EE draws entirely on rotational energy reservoir
- Assume constant dipole field

$$\Delta E = 2\pi^2 I (P_i^{-2} - P_0^{-2})$$

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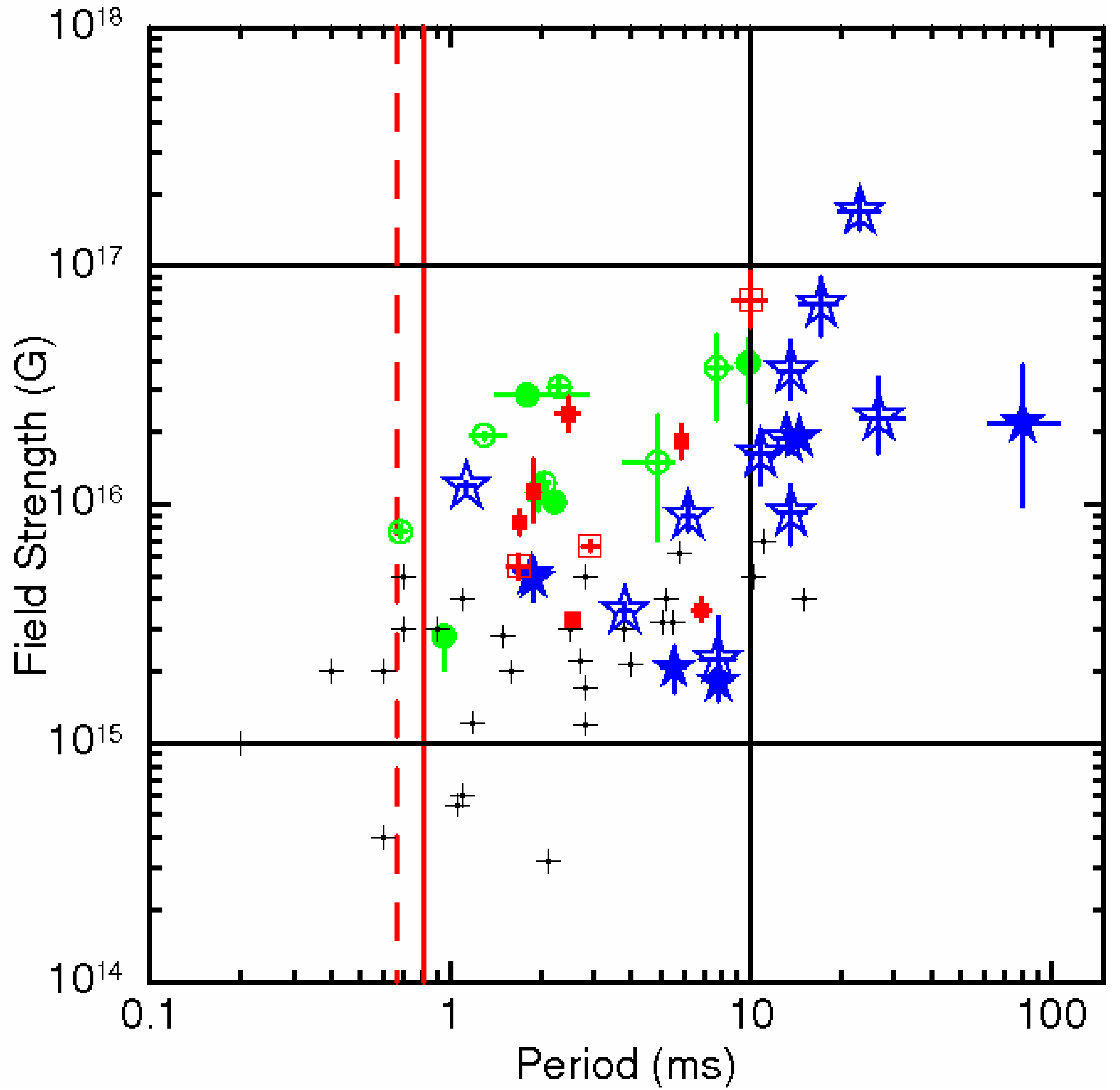
Results

SGRBs (Green, blue): Rowlinson et al. 2013

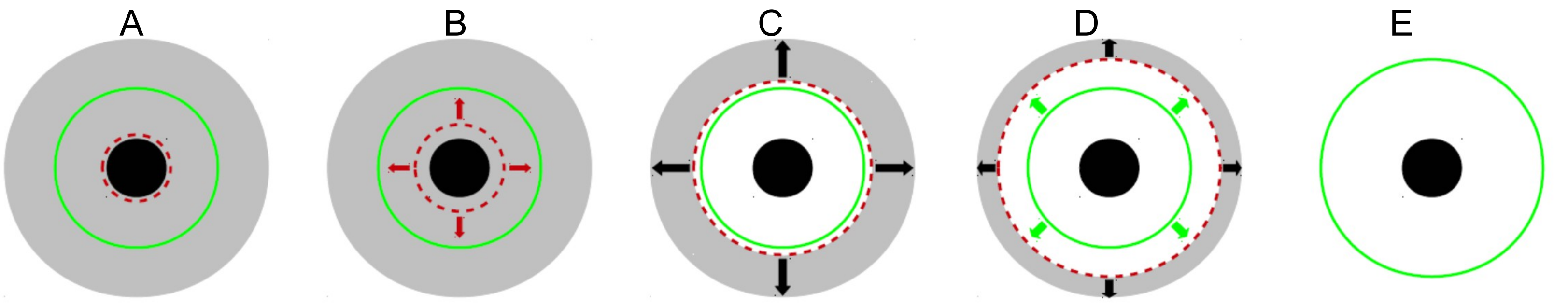
LGRBs (Black): Lyons et al. 2010; Dall'Osso et al. 2011; Bernardini et al. 2012

(Gompertz et al. 2013, MNRAS, 431, 1745)



Magnetic propulsion

- Marginally bound material ejected by the merger can return to the central object on time scales of a few seconds (e.g. Lee et al. (2009))
- Returning material encounters an extremely strong, rapidly rotating magnetic field



Material orbits at the same speed as the NS surface at the co-rotation radius (r_c; green line) and nominally comes under the influence of the magnetic field at the Alfvén radius (r_m; red line). Both are influenced by dipole field (B) and spin period (P).

A) r_m is suppressed by a high accretion rate (and/or high P and/or low B). $r_c > r_m$ so material is orbiting faster than the field lines at the point of encounter. Interaction SLOWS material, spinning up the magnetar and allowing accretion onto the surface.

B) As accretion falls off, r_m expands.

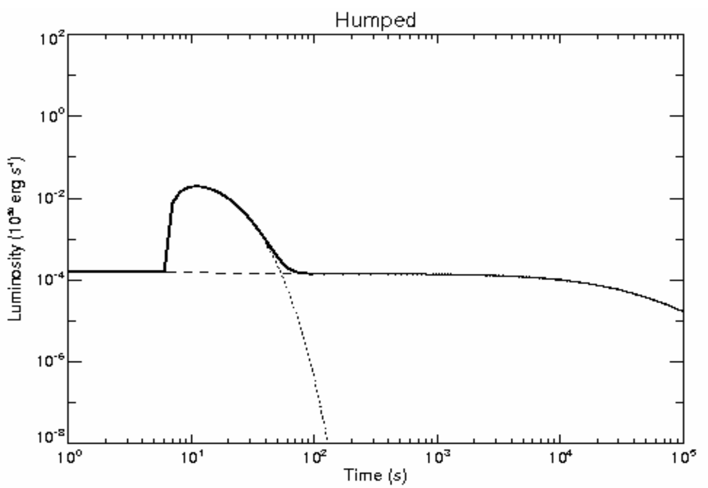
C) When $r_m > r_c$ material is orbiting slower than the field lines when they encounter each other. Interaction ACCELERATES material, ejecting it from the system. This is the propeller regime.

D) Loss of angular momentum to expelled material causes r_c to expand.

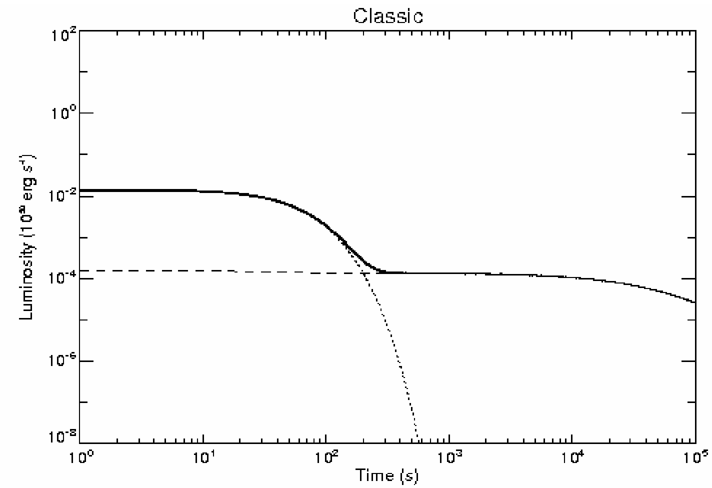
E) When disc is depleted, r_c slowly expands as spin lost to dipole emission.

Synthetic light curves

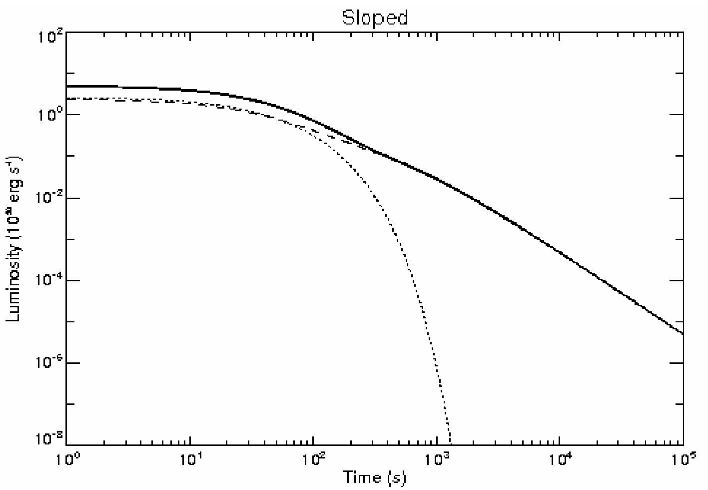
540 synthetic light curves were created, using varying P, B, M_d, R_d and M_{NS}



37%



21%



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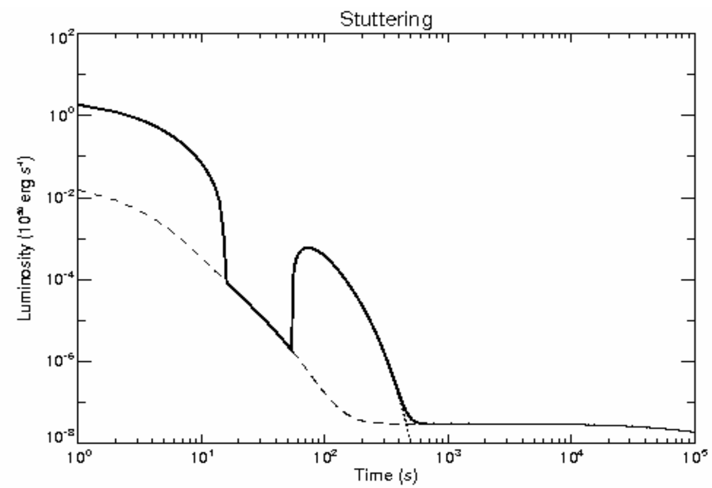

12%

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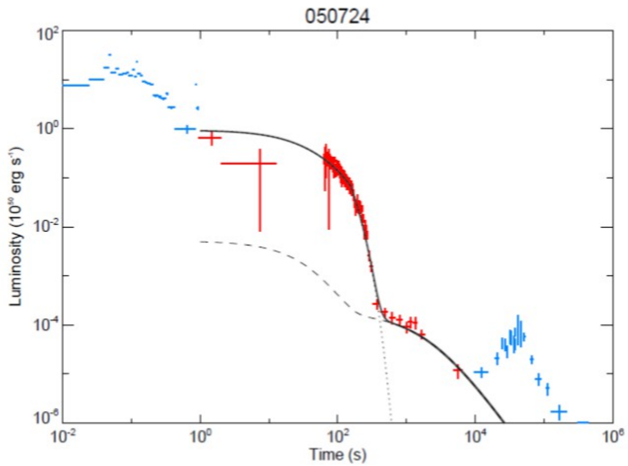
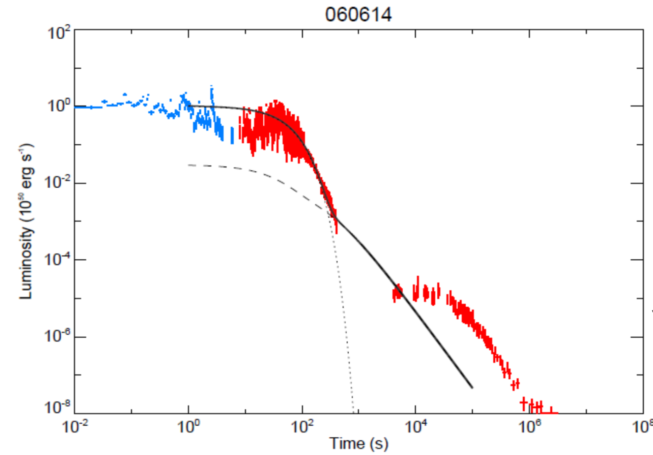
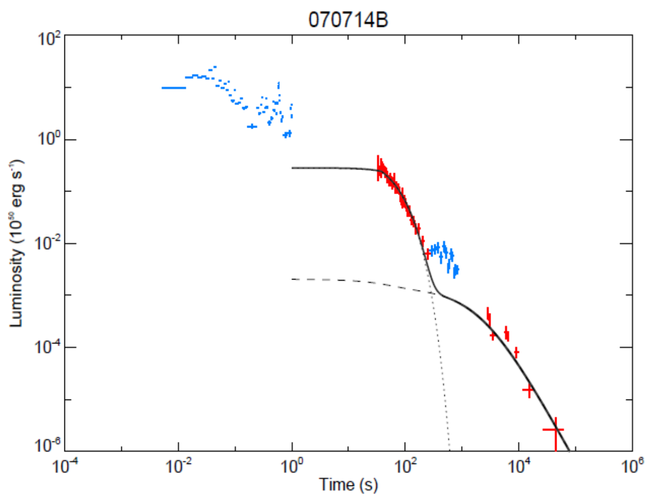
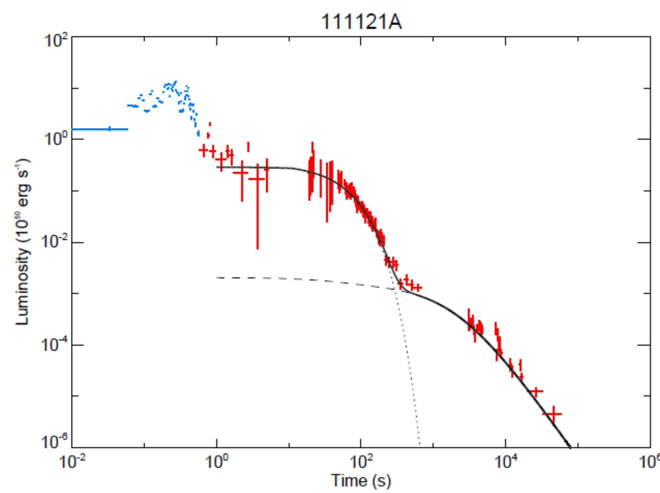
Fitting





Poor fit at late times; maybe B varies?





Assumed 40% KE to EM propeller efficiency; 5% for dipole; <0.9c ejection velocity

Uses MPFIT (Markwardt 2009)

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Results

Gompertz et al. 2014, MNRAS, 438, 240

GRB	P (ms)	B ($10^{15} G$)	M_d ($M_\odot$)	R_d (km)
050724	0.93 ±0.04	0.88 ±0.04	$(2.63 \pm 0.13) \times 10^{-2}$	1217 ±4
051227	0.69 [L]	0.45 ±0.19	$(1.10 \pm 0.18) \times 10^{-2}$	695 ±41
060614	0.69 [L]	1.17 ±0.05	$(1.20 \pm 0.01) \times 10^{-2}$	1300 ±4
061006	1.51 ±0.21	1.48 ±0.07	$(2.01 \pm 0.37) \times 10^{-2}$	400 ±2
061210	0.69 [L]	0.18 ±0.05	$(3.20 \pm 2.88) \times 10^{-3}$	674 ±753
070714B	0.69 [L]	0.31 ±0.05	$(6.91 \pm 0.28) \times 10^{-3}$	1378 ±72
071227	1.54 ±0.12	0.57 ±0.08	$(7.63 \pm 1.02) \times 10^{-3}$	1131 ±17
080123	3.75 ±0.46	1.92 ±0.16	$(5.82 \pm 1.10) \times 10^{-3}$	742 ±6
111121A	0.69 [L]	0.31 ±0.03	$(4.80 \pm 0.10) \times 10^{-3}$	1538 ±43

- Derived disk masses between 3×10^{-3} to 3×10^{-2} solar masses.
- Outer disk radii between 400 – 1500 km.
- Consistent with theoretical predictions (e.g. Lee et al. 2009)
- P and B still lie in allowed parameter space.
- Best fits require an exponential accretion profile rather than a power law – as expected in the presence of strong outflows (Fernández & Metzger 2013).
- Propeller fits require efficient (> 10%) conversion of KE to EM.

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Summary

- SGRB X-ray plateaus are consistent with energy injection from a millisecond magnetar
- EE GRBs also have dipole fields and spin periods consistent with an underlying magnetar if EE is driven entirely by rotational energy
- There appears to be nothing 'special' about the field strengths and spin periods of any magnetars underlying EE GRBs when compared to the short sample as a whole – the difference may arise from the environment or formation mechanism
- Extended emission could be powered by a magnetic propeller if the conversion efficiency of KE to EM is high (> 10%) and accretion follows an exponential profile
- EE GRBs may be an even more diverse class than currently appreciated