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Magnetars in short and extended emission gamma-ray bursts

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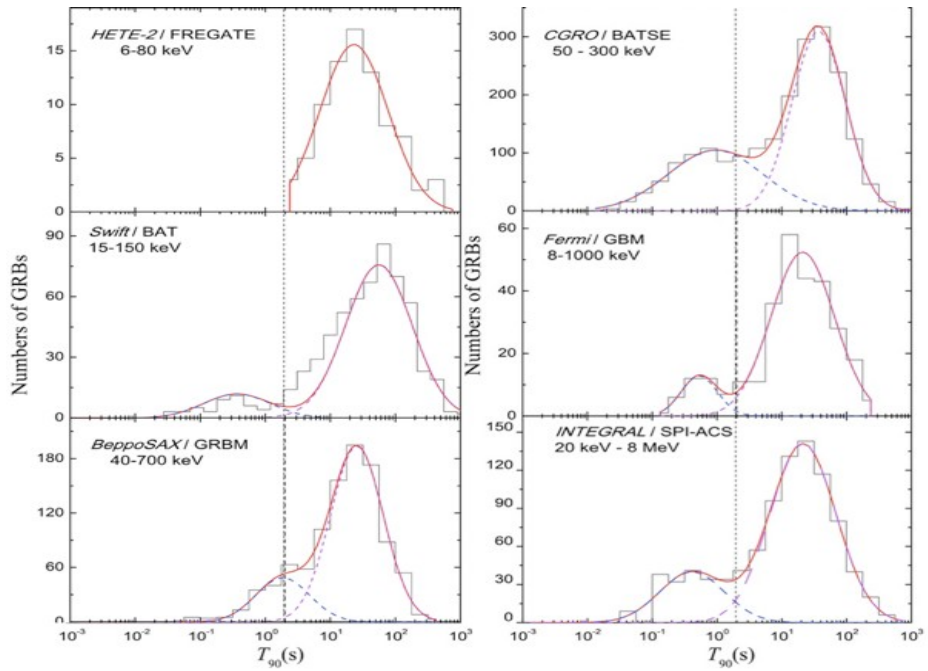
Properties of GRBs

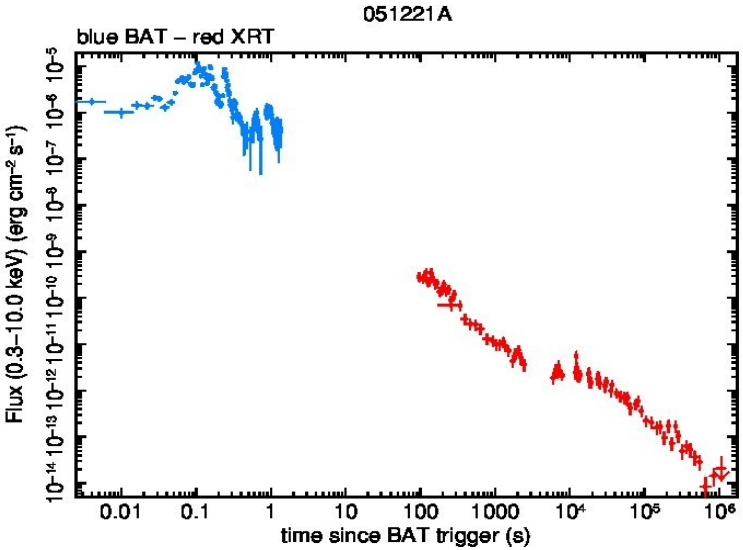
Short GRBs:

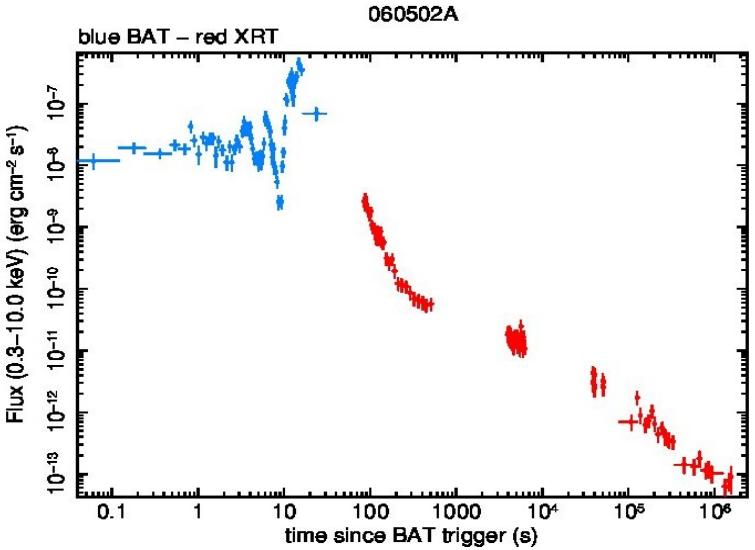
- T_{90} < 2 seconds
- Spectrally hard
- Large offsets from host galaxies
- Binary mergers



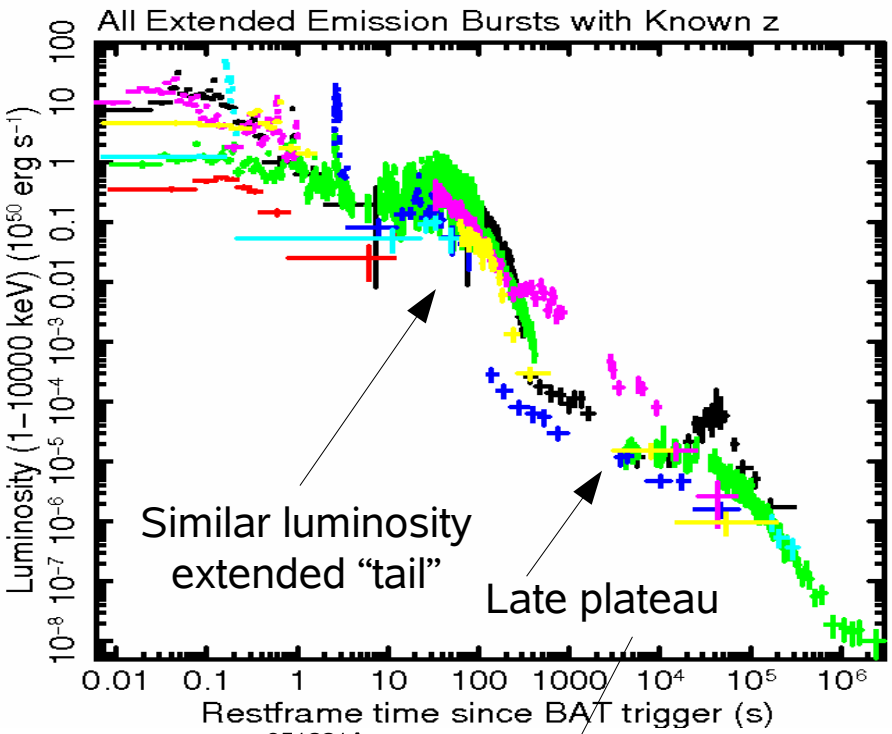
Long GRBs:

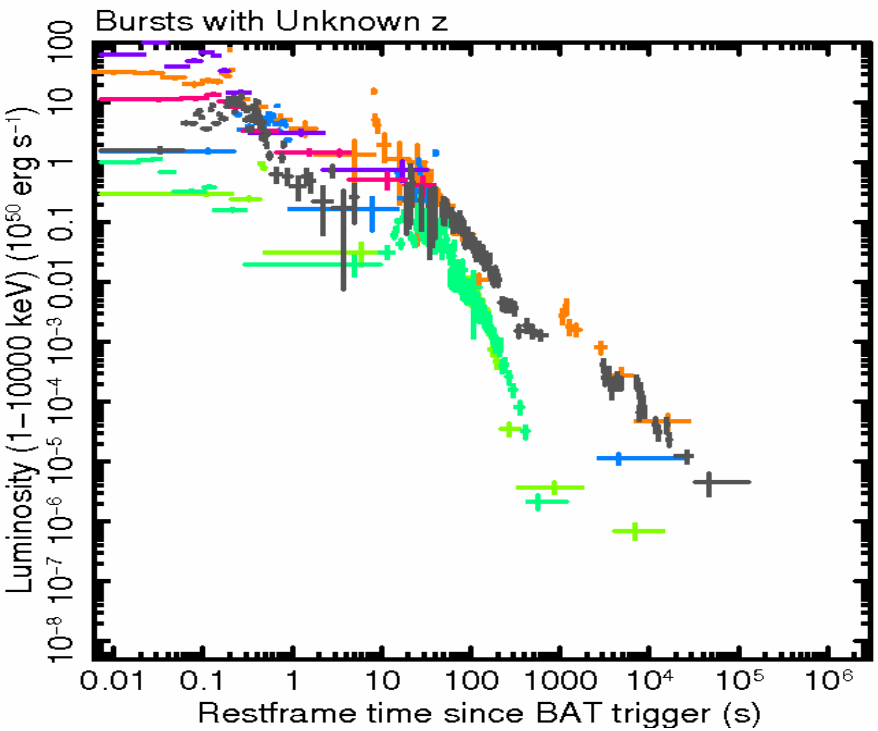
- T_{90} > 2 seconds
- Spectrally softer
- Found close to star forming regions
- Observed with type 1b/c supernovae

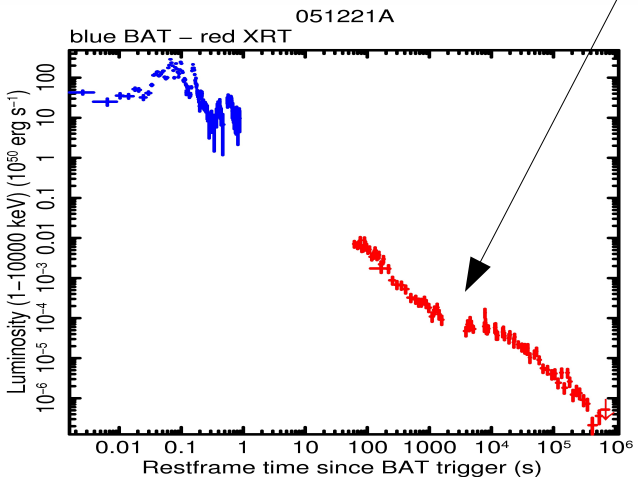




Extended emission GRBs

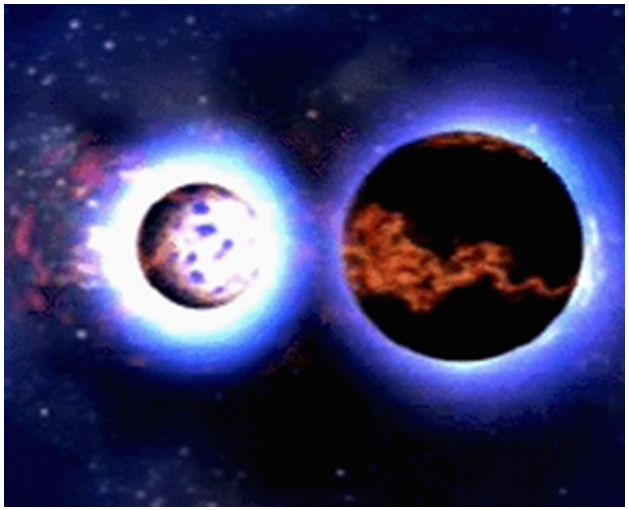




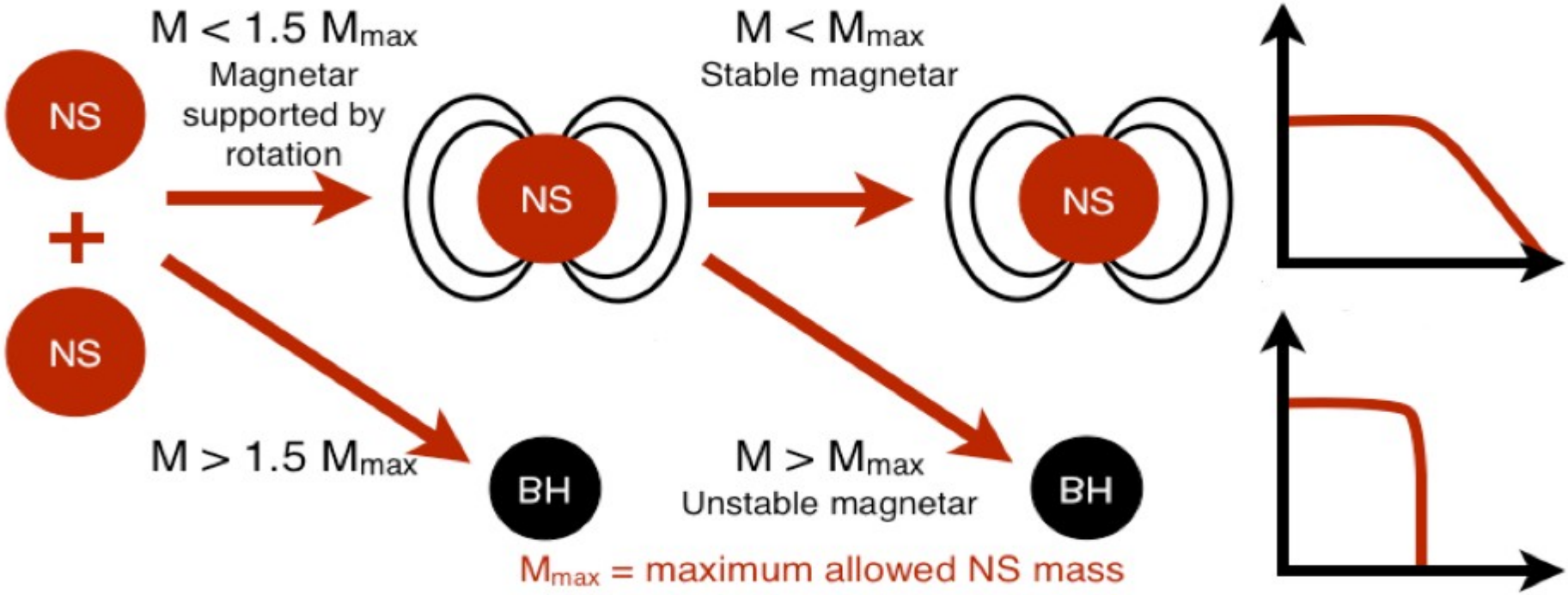


- High-energy rebrightening at around 10 seconds
- Seen in BAT (for *Swift* bursts)
- Typically lasts ~ 100 seconds
- Spectrally softer than prompt emission
- Remarkably uniform, suggestive of common central engine

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 into the forward shock from spin-down of a highly magnetised, rapidly rotating neutron star (magnetar)

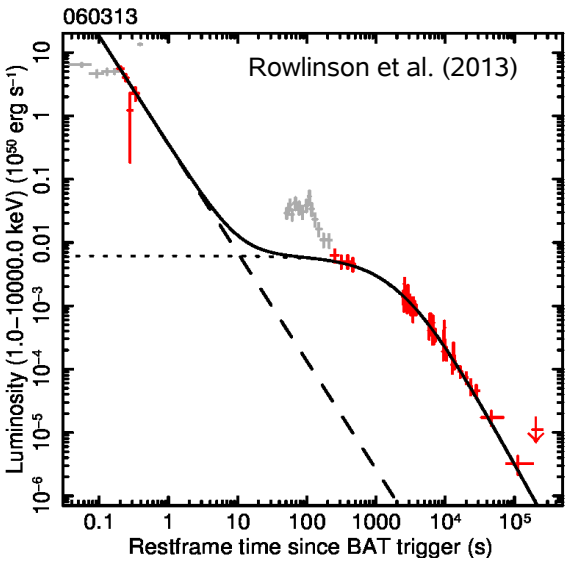


Magnetar central engine

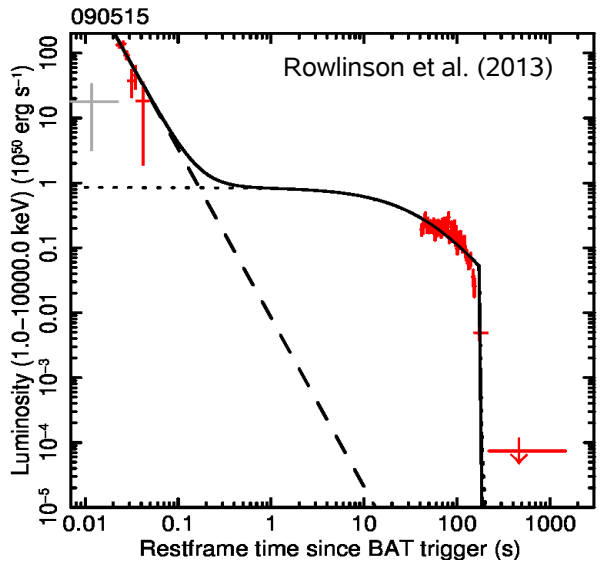
$$T_{em,3} = 2.05(I_{45} B_{p,15}^{-2} P_{0,-3}^{2} R_6^{-6})$$

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

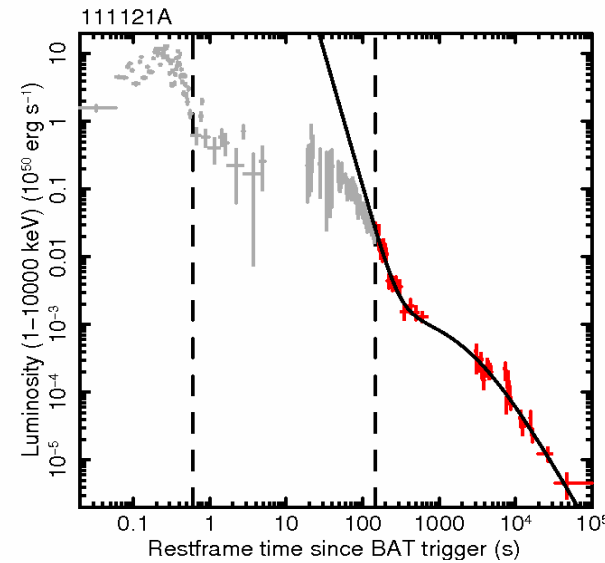
Zhang & Mészáros (2001)



Stable



Unstable



Stable & extended emission

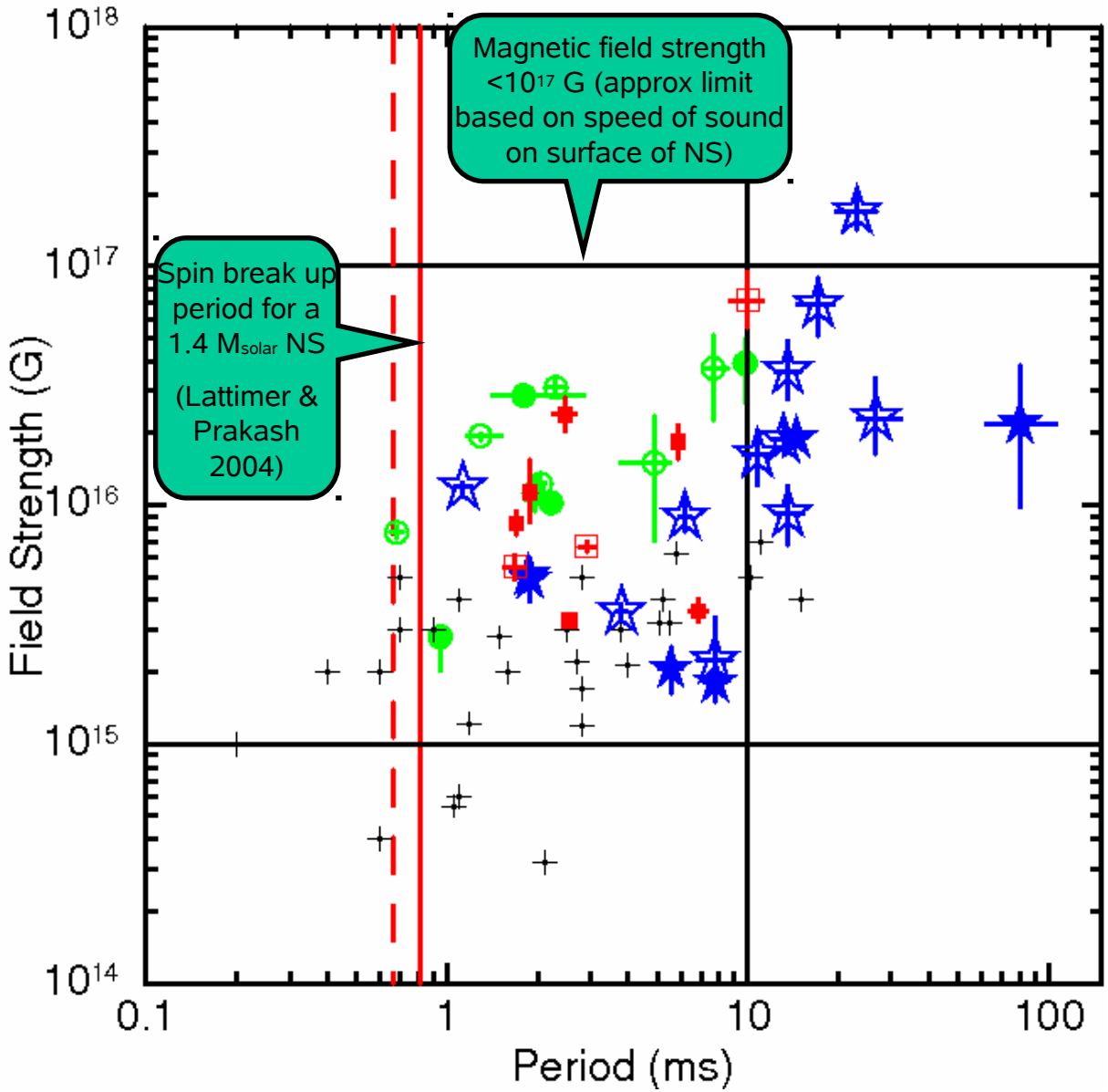
- Extended tail may affect spin period
- Assume EE draws entirely on rotational energy reservoir
- Assume constant dipole field

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

Wider GRB context

- Stable magnetars
- Unstable magnetars
- Long GRB candidates
- EE GRBs

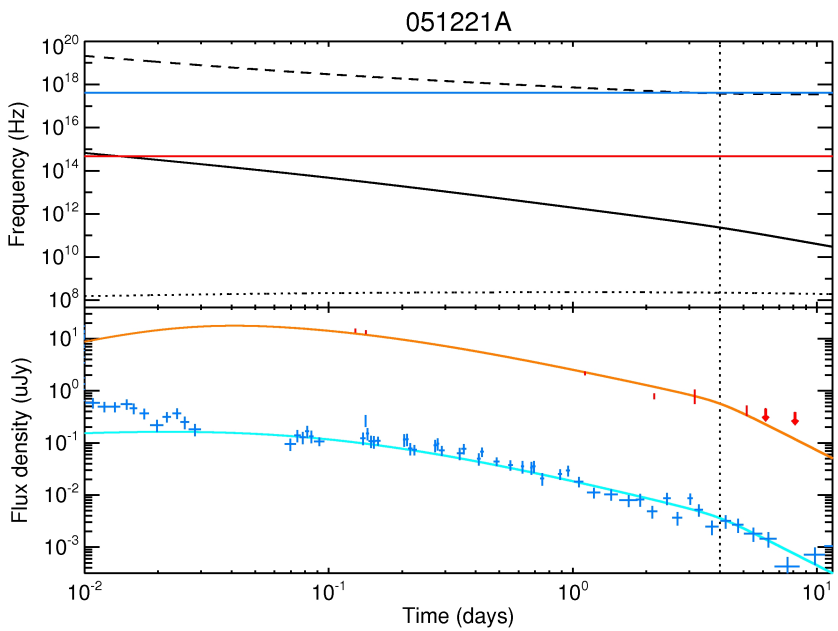
- EE GRB light curves energetically compatible with a magnetar central engine
- Magnetar parameters in the EE sample indistinguishable from SGRB sample
- Difference in formation mechanism or environment?
- Unequal mass binary?
- Magnetic propeller?
  (see Gompertz, O'Brien & Wynn, 2014)

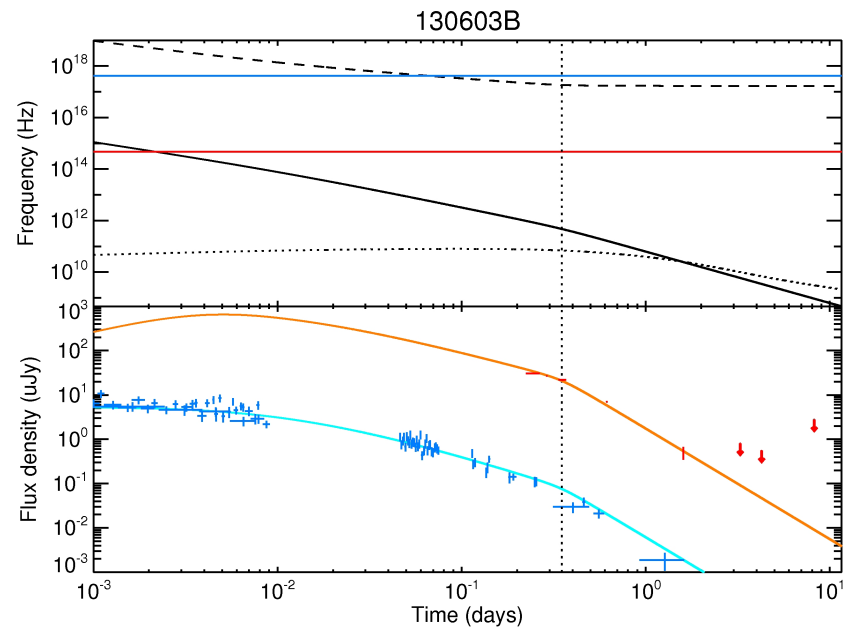


Gompertz et al. 2013, MNRAS, 431, 1745

The broadband view

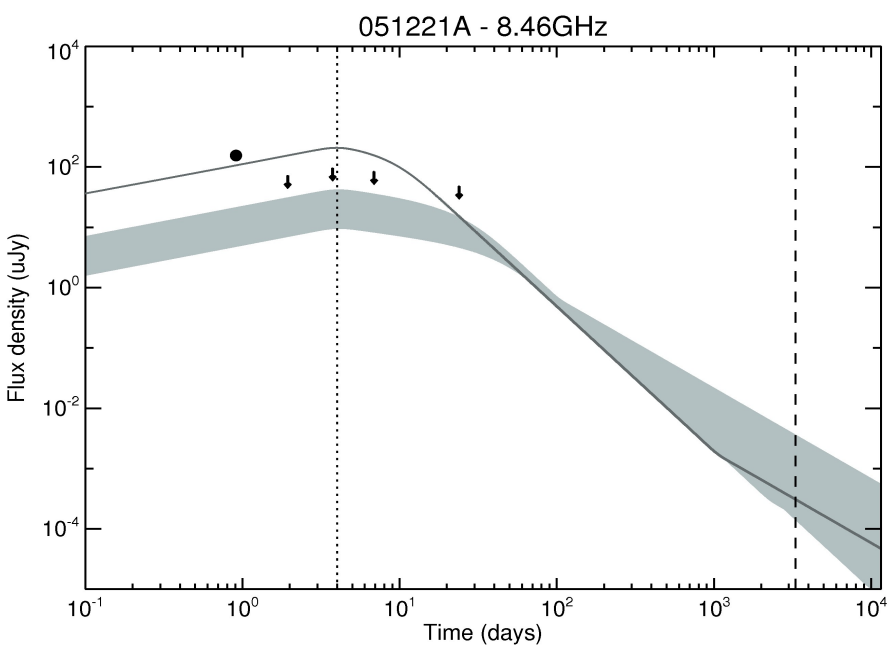
- Standard dipole fitting assumes certain conversion efficiency from X-ray light curves.
- Gives no information on emission at longer wavelengths.
- Perform broadband modelling of forward shock emission with dipole (and EE) profile as time-varying energy injection.
- Available data is not constraining to self-absorption break (very few radio observations, even fewer detections) or cooling break (if above X-ray frequency).
- Many combinations of physical parameters can match available data.

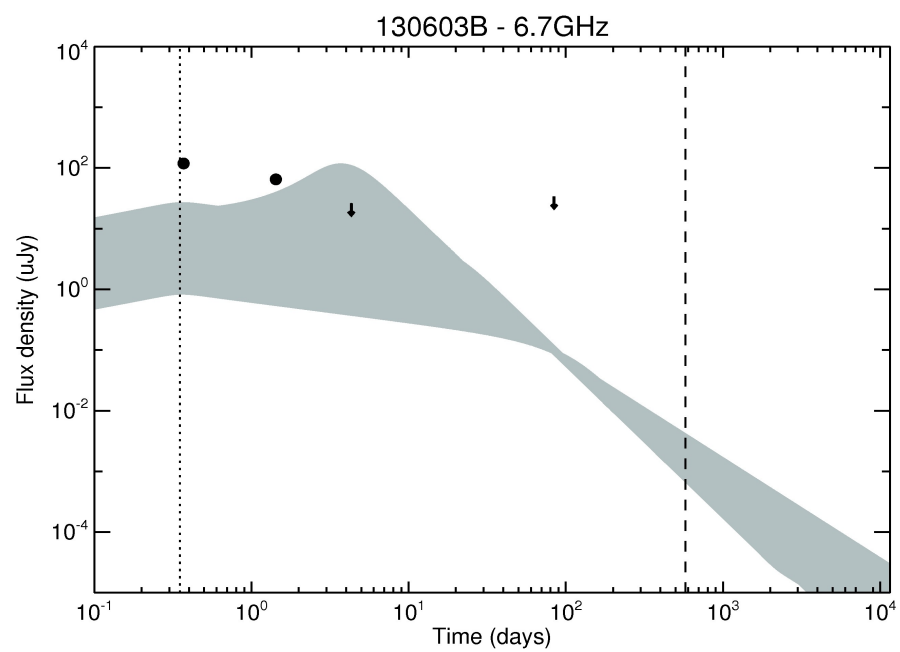




Radio signature

- Order of magnitude parameter space search for 3 physical parameters (ε_e, ε_B and n) and 3 energy terms (Prompt, EE and dipole contributions).
- Each successful match provides a family of parameters that are self-consistent within the magnetar model.
- Can be used to create the expected radio signature for a magnetar injecting energy into a forward shock.
- Difficult to reproduce early-time radio observations with forward shock alone. Evidence for reverse shock?





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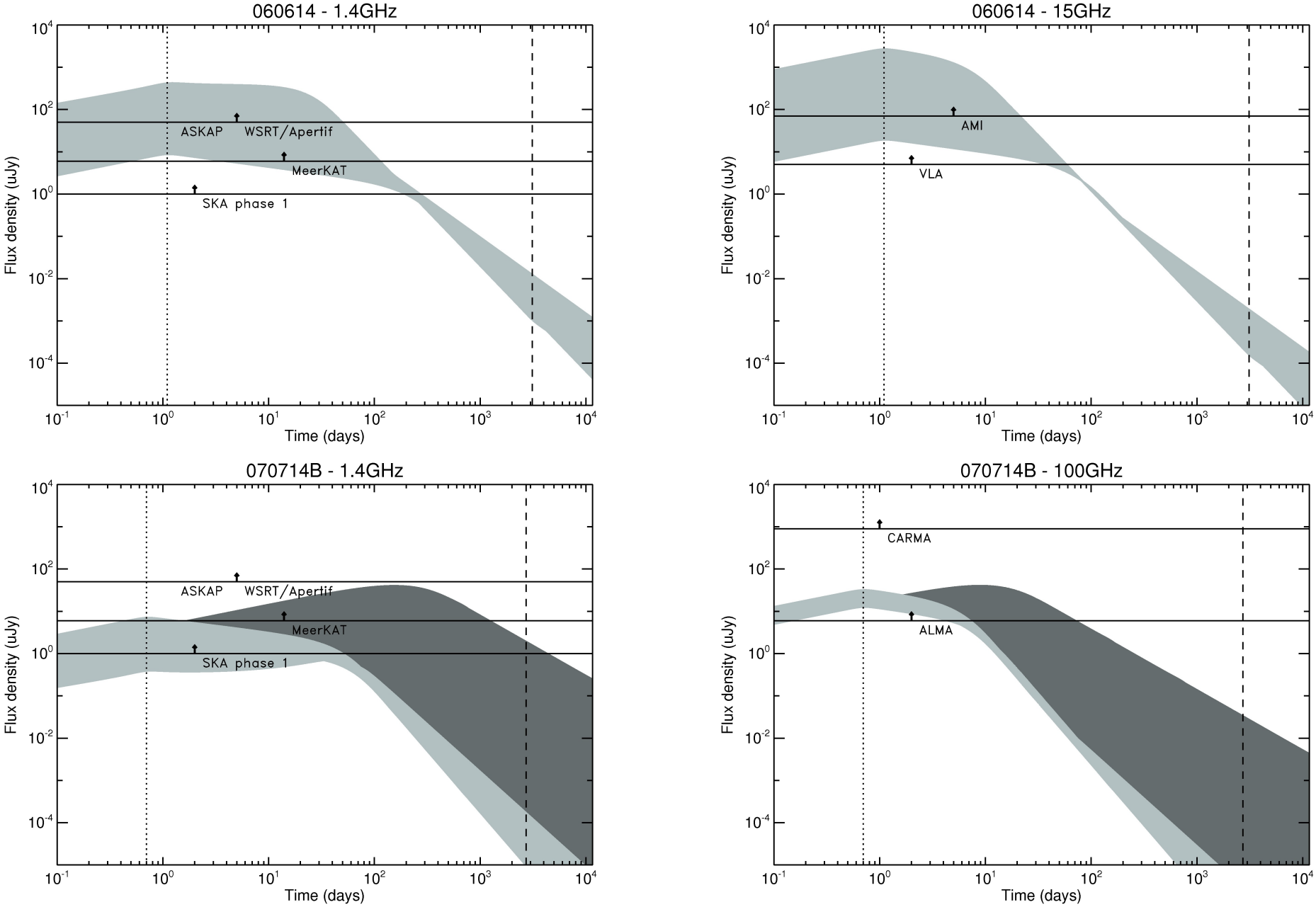
Detectability

arXiv:1411.5477



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Summary

- Short and EE GRB light curves are both consistent with energy injection from a magnetar central engine

- Magnetar properties appear to be identical in both classes; difference may be down to formation or environment

- A magnetic propeller provides a possible source of EE, since it is predicated on the presence of a fall-back disc, regardless of magnetar properties

- Broadband observations are consistent with forward shock energy injection, but reverse shocks required at early times

- Paucity of observations means a wide range of potential physical parameters

- Previous radio observations provide some constraints to parameter space, but have not yet fully probed the model. Detections are likely to be from reverse shocks.

- New observatories, in particular ALMA and the upgraded VLA, are now able to fully probe the radio signature if on target within ~ 2 weeks

- SKA (phase 2) will be able to go deeper than our lowest prediction for around a year after trigger!