Magnetar Bursts
At All Scales

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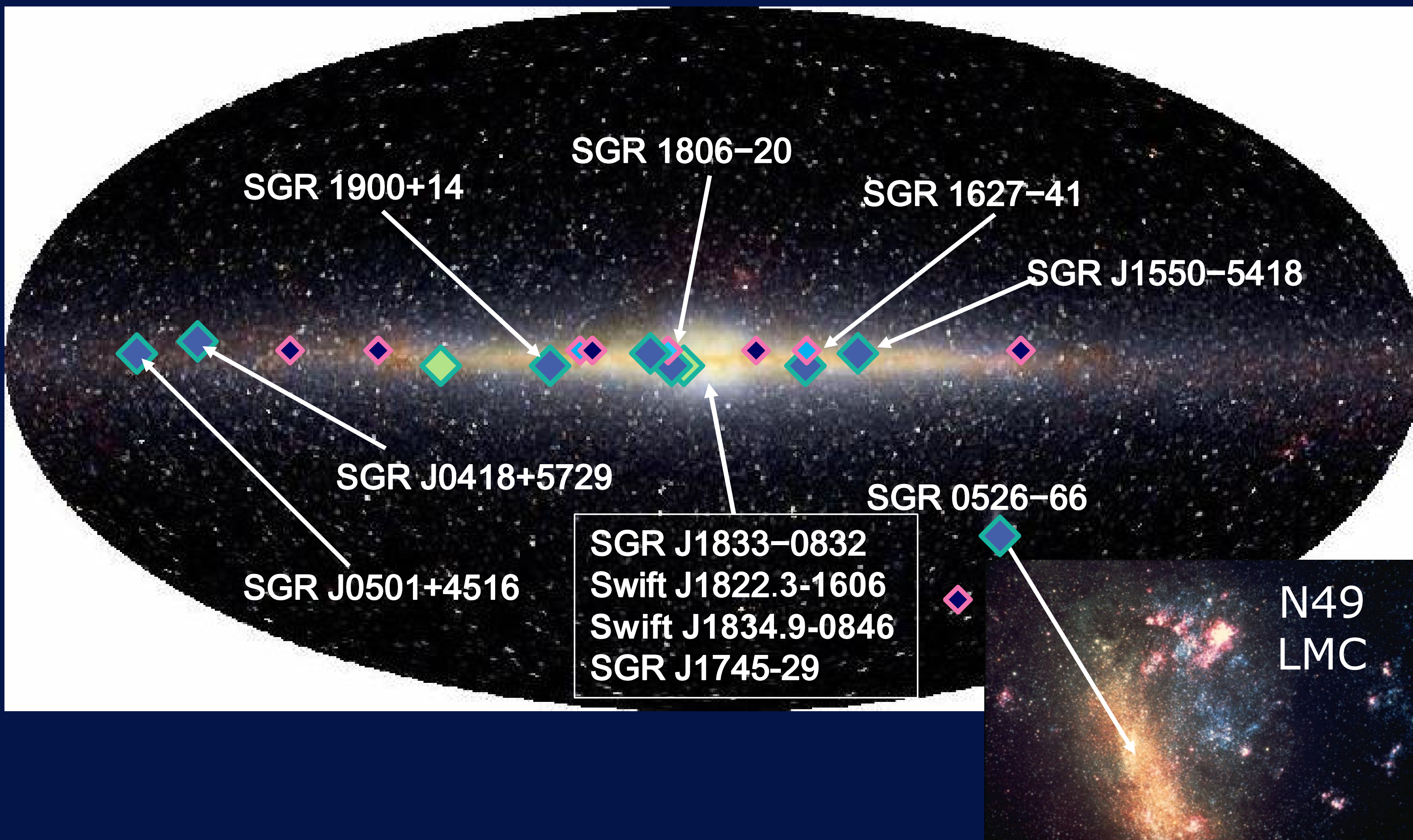
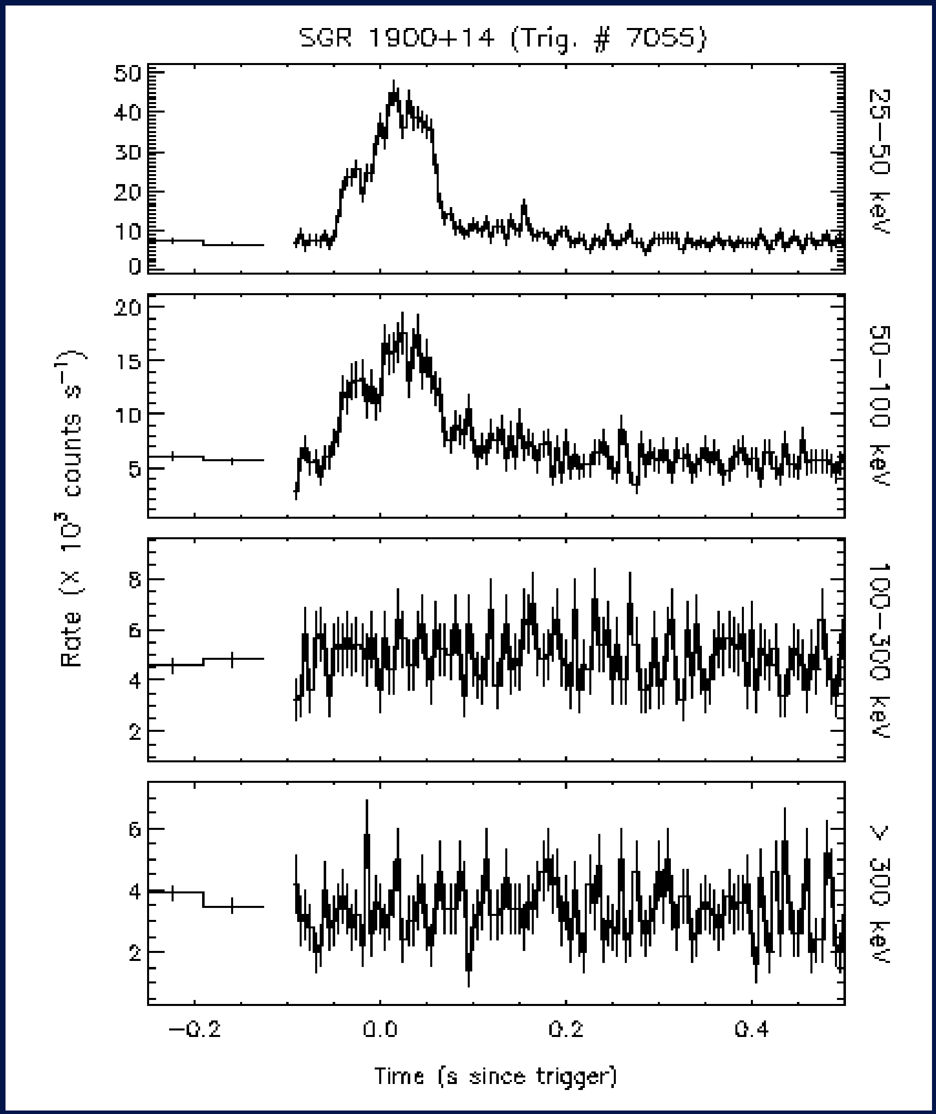
General Properties of Magnetars

- Characterized by bright hard X-ray / soft gamma ray bursts
- Slowly rotating systems (P_{spin} ~ 2 – 12 s)
- Rapidly spinning down (dP/dt~ 10^{-13} – 10^{-11} s/s)
- Bright X-ray sources (L ~10^{34}-10^{35} erg/s)
- Transient magnetars (L ~10^{32} erg/s in quiescence)
- Young systems as deduces from their galactic locations
- Unique X-ray spectral properties

Magnetar Family Picture

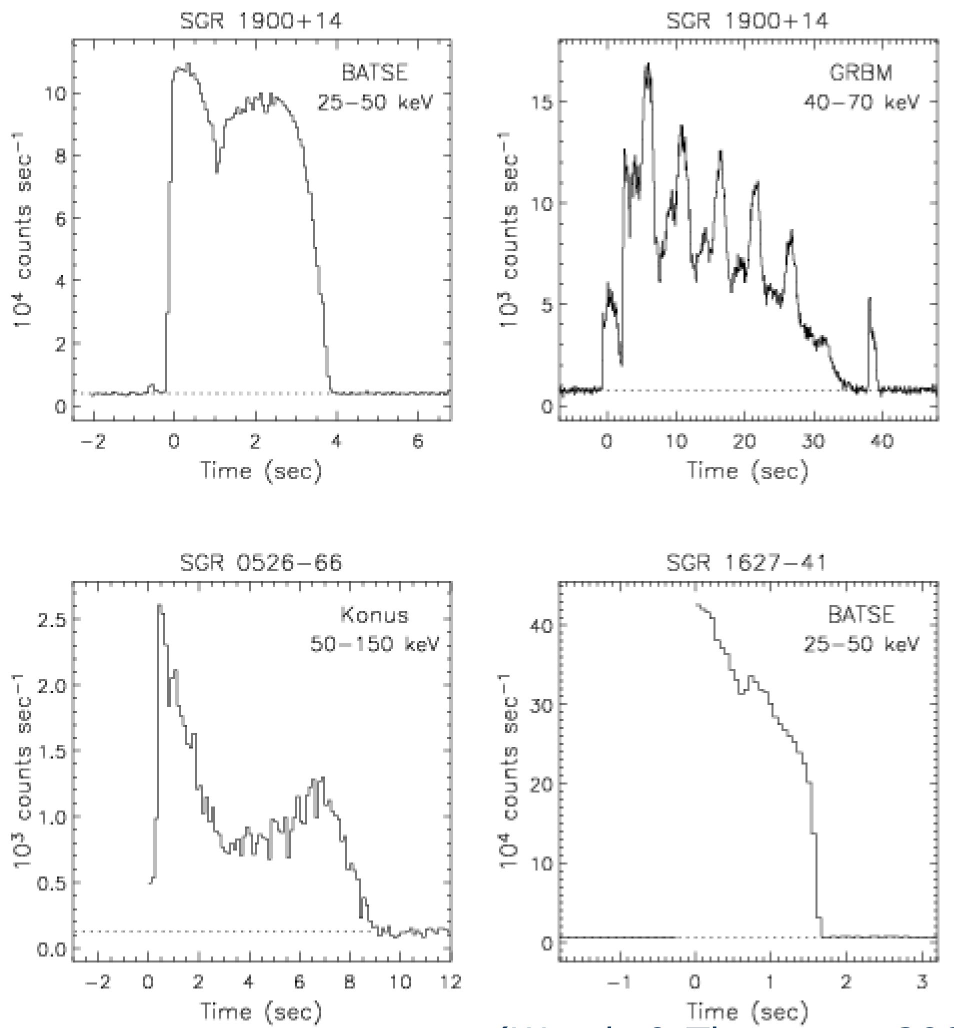


Typical SGR Bursts



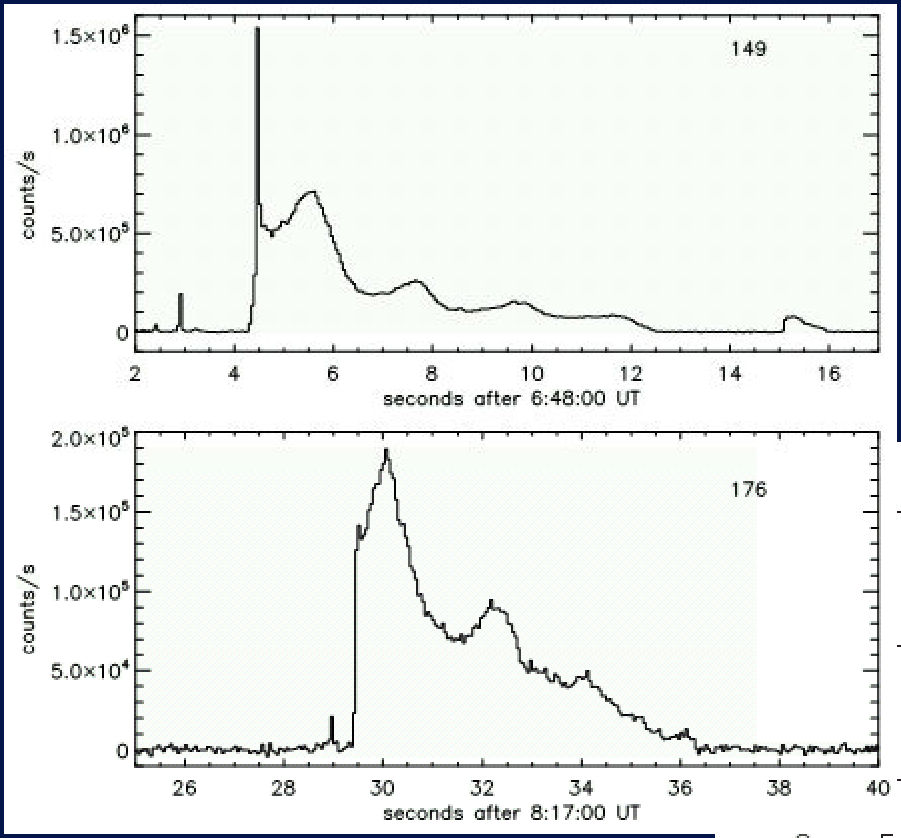
- Brief (~0.1–few s)
- Irregular times between bursts (seconds - years)
- Diverse time profiles
- Intense (~10^{36} – 10^{41} erg/s)
- Distinct from **giant flares** in duration, luminosity and energy spectrum

Intermediate Events

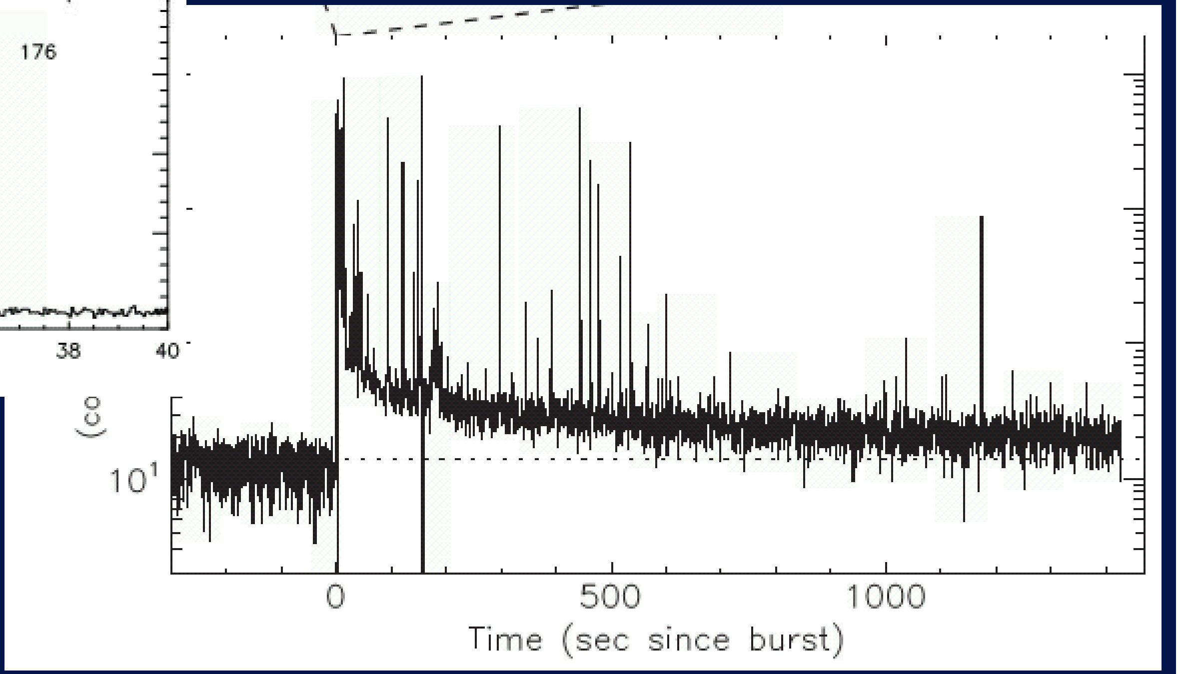


(Woods & Thompson 2006)

More Intermediate Events

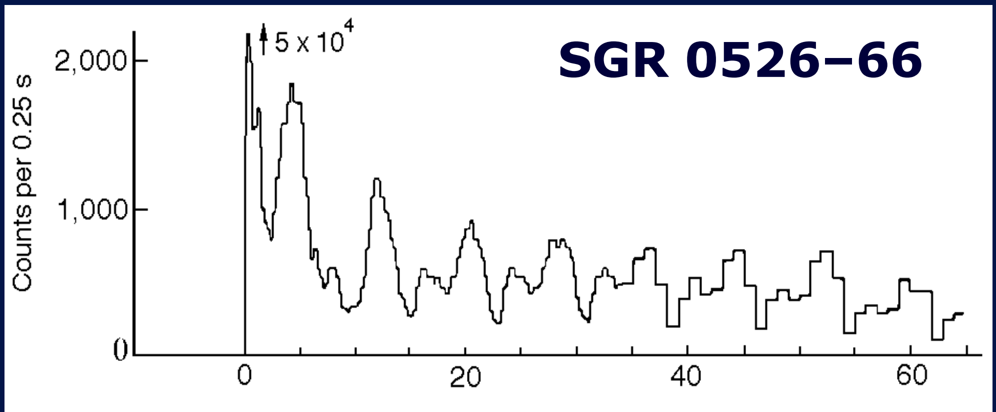


(Mereghetti et al. 2010)

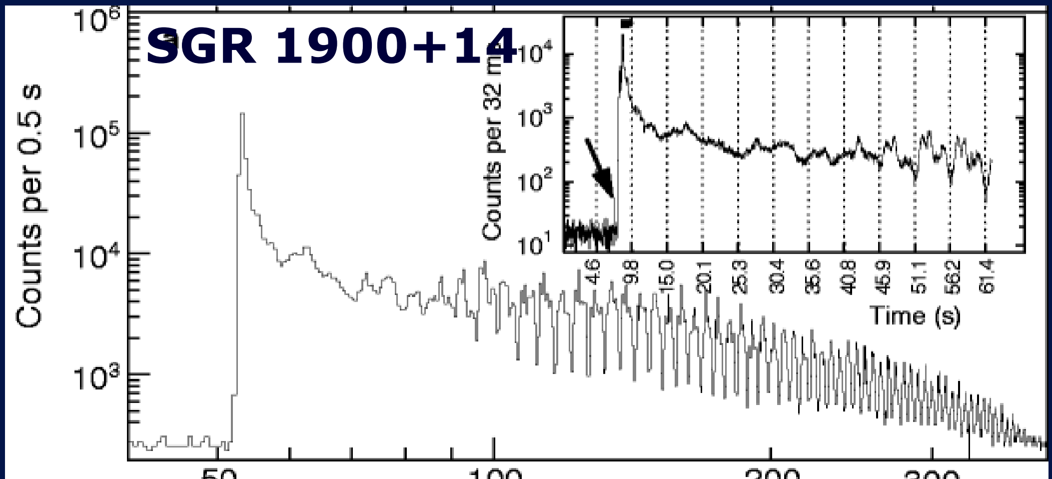


(Göğüş et al. 2010)

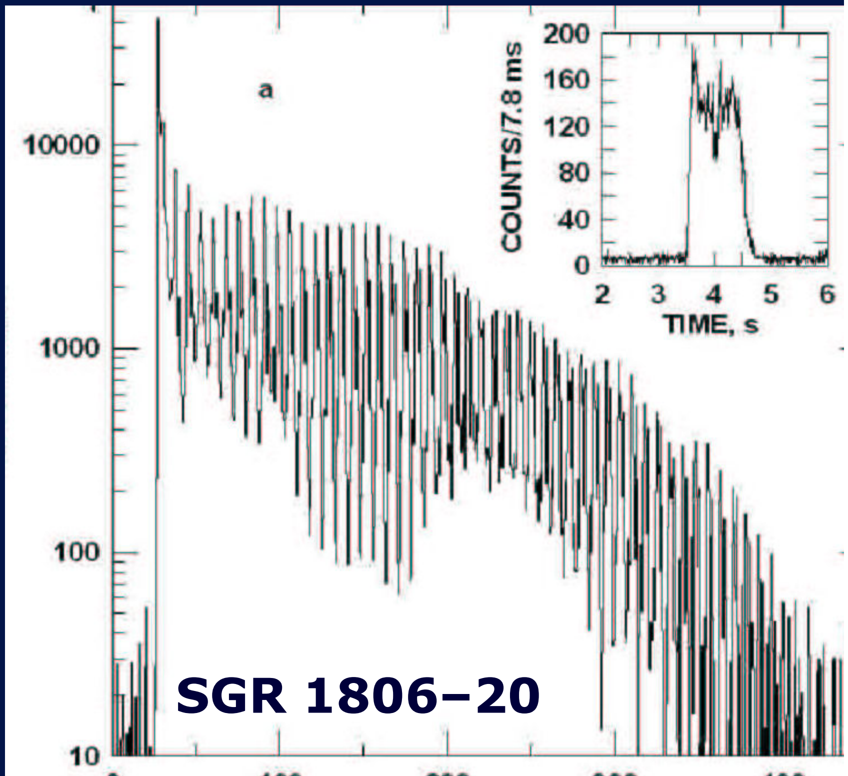
Giant Flares



(Mazets et al. 1979)



(Hurley et al. 1999)



(Hurley et al. 2005)

The Magnetar Perspective

A magnetar– *neutron star powered by its super-strong magnetic field (10^{14} -10^{15} G)* can account for the extraordinary March 5th event: burst energetics, short-hard spike; 8 s modulation (Duncan & Thompson 1992) super-Eddington luminosities (Paczynski 1992)

ROSAT observations of the point X-ray source in N49 → dissipation of magnetic energy (DT 1992)

DT (1992); Thompson & Duncan (1993): Formation of magnetars via efficient dynamo if P_0~1–3 ms

Bursts via Crust Cracking

B fields are so strong that drifting field lines can stress and eventually crack the crust (Thompson & Duncan 1995)

Stress = Shear modulus * Strain

$$(B^2 / 8\pi) = \mu * \theta$$

For NS crust, $\mu \sim 10^{31}$ erg/cm^3 (Baym & Pines 1971)

Most materials will crack at $\theta \sim 10^{-3}$

$$B = 2.5 \times 10^{15}\, G \sqrt{\frac{\mu}{10^{31}}} \sqrt{\frac{\theta}{10^{-3}}}$$

Upper Limit on Magnetar B-fields

Magnetic energy has to be less than the gravitational binding energy of the neutron star:

$$\left(\frac{B^2}{8\pi}\right)\left(\frac{4}{3}\pi R^3\right) \le \frac{GM^2}{R}$$

$$B \le 10^{18}\,G\left(\frac{M}{1.4M_s}\right)\left(\frac{R}{10\;km}\right)^{-2}$$

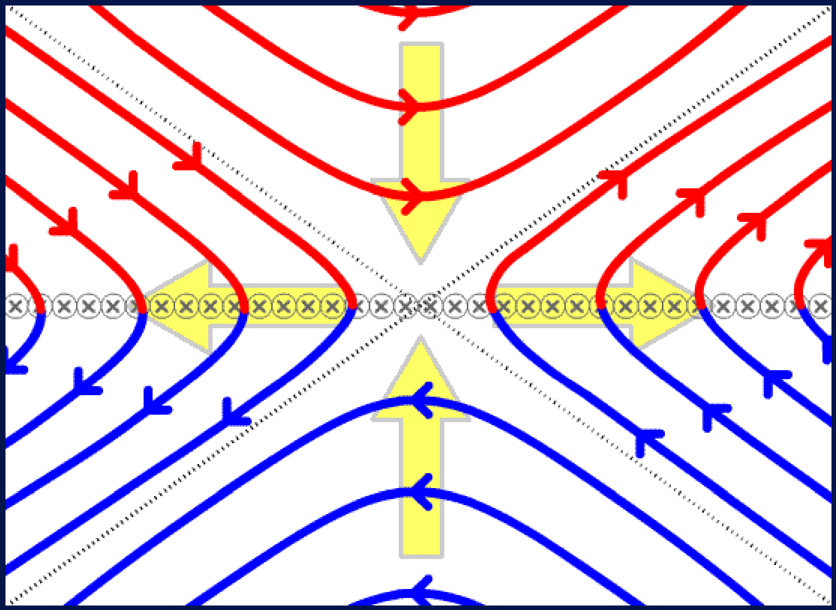
Consequences of Crust Cracking:

(Image by R. Duncan)

Thompson & Duncan 1995:

- Sudden crustal disturbance would inject magnetic (Alfven) waves into the magnetosphere
- Alfven waves would provide momentum and energy to produce trapped photon, e^- and e^+ fireball
- When photons escape, e^- and e^+ annihilate and the fireball radiates and cools, that is observed as bursts.

Bursts via Reconnection

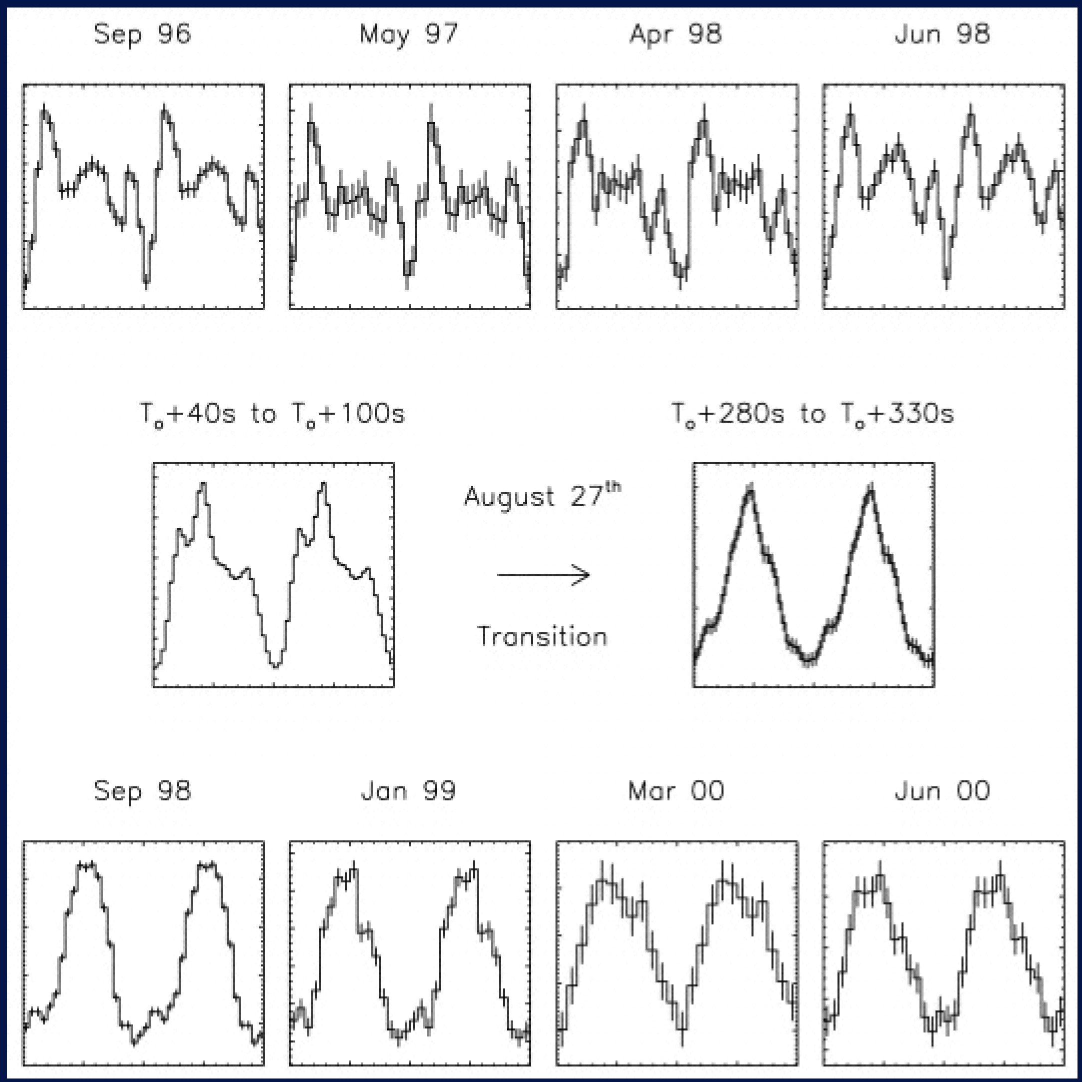


(Wikipedia)

When brought together, oppositely oriented magnetic field lines will split and reconnect in a lower energy configuration, and release magnetic energy (TD 1995, Lyutikov 2003).

Solar flares are bright, energetic and observed in X-rays / soft gamma rays.

Magnetic Field Reconfiguration



(Woods et al. 2001)

Crack Scale and Burst Size

Large scale fracturing → Giant events and possible field reconfiguration

Relatively large size cracking → Intermediate events and oscillating tail

Local cracking → short bursts

Fallback Disk: An Alternative Model

Spin period clustering (Alpar 2000)

X-ray enhancements (Ertan et al. 2003, Çalışkan et al. 2013)

IR/Optical emission (Ertan & Çalışkan 2006): IR disk around 4U 0142+61: passive (Wang, Kaplan & Chakrabarti 2006), active (Ertan et al. 2007)

Hard X-ray emission (Trümper et al. 2010)

Energetic bursts <u>cannot be</u> explained with accretion

Reclassification of Magnetars Based on Their Bursting Behavior

Prolific Bursters	Prolific Transients	AXPs with SGR-like Bursts	Transients with Low Burst Rates
SGR 1900 + 14	SGR 1627 - 41	1E 1048-5937 1E 2259+586	SGR 0418 + 5729
SGR 1806 – 20	SGR 1550 - 5418	4U 0142+61 1E 1841-045	SGR 1833 - 0832
SGR 0526 – 66	SGR 0501 + 4516	CXO J164710.2-455216	Swift 1822.3 – 1606
		XTE J1810-197	Swift 1834.9– 0846
		AX J1818.8 - 1559?	SGR 1745 – 29

SGR Burst Spectra (Time Integrated)

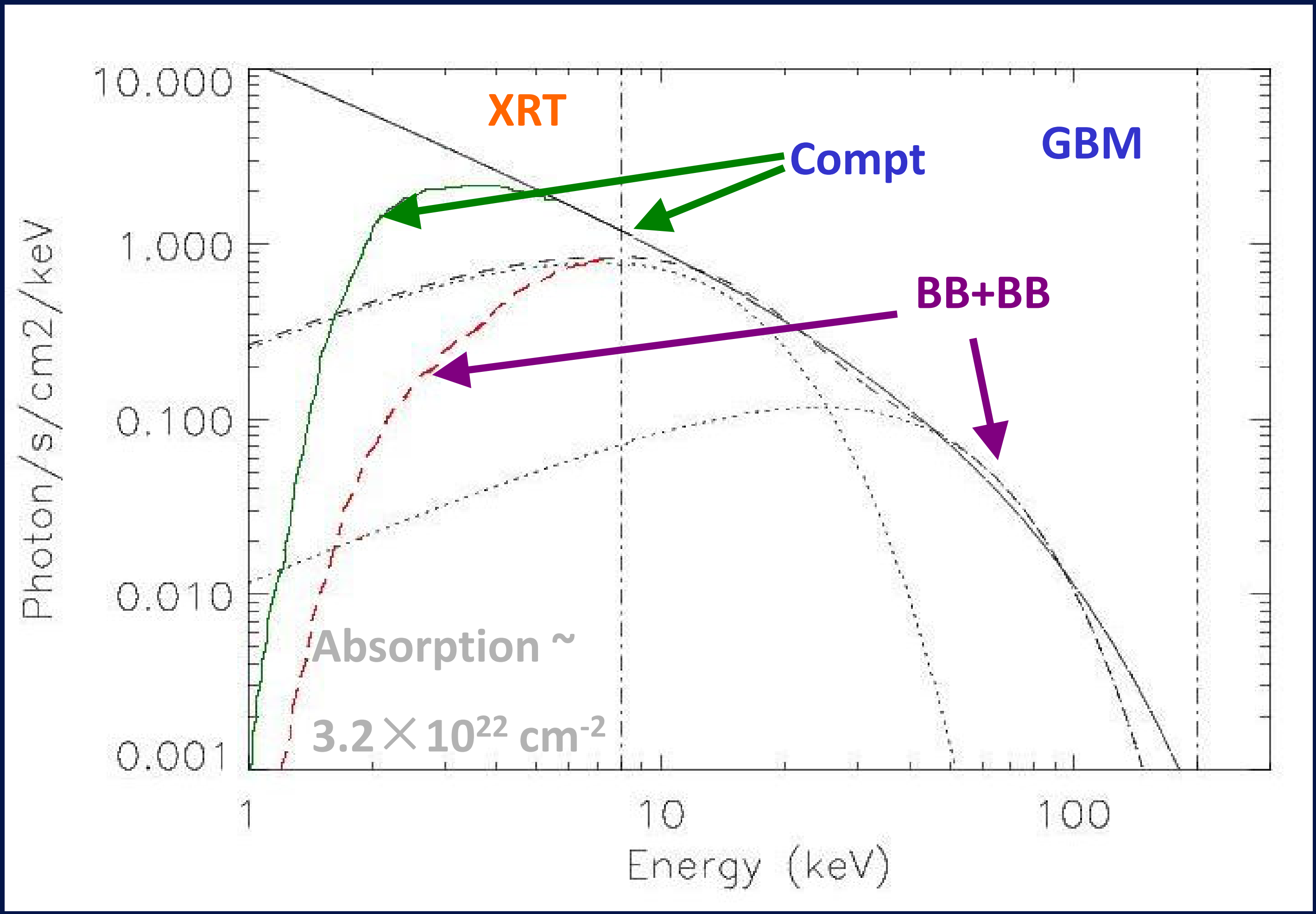
Swift/XRT CXO, XMM	RXTE/PCA RXTE/HEXTE	Swift/BAT INTEGRAL	Fermi/GBM
0.5 – 10 keV	2 – 30keV 15 – 150 keV	15 – 150 keV	8 – 200 keV
PL	BB + BB Compt	BB + BB OTTB	BB Compt BB + BB OTTB
Scholtz & Kaspi 12	Kaneko et al. in prep.	Israel et al. 08 Mereghetti et al. 09	von Kienlin et al. 12 van der Horst et al. 12 Lin et al. 12

Comptonized model (Compt): a single power law with a high E exponential cutoff

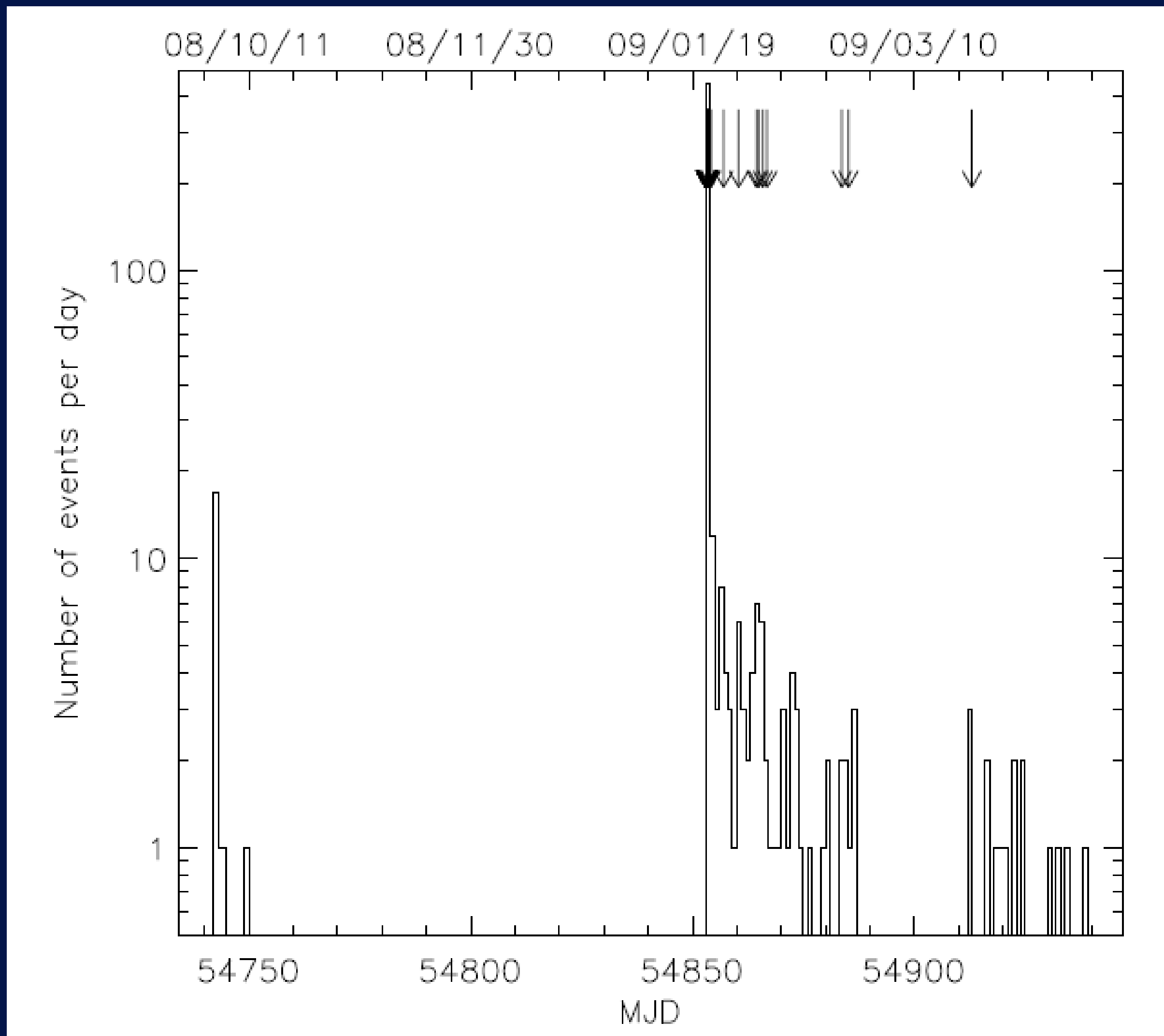
Broadband Spectral Studies

SGR 1900+14: The storm, XRT+BAT, 0.5-150 keV (Israel et al. 2008)

SGR J1550-5418 normal bursts, XRT+GBM, 0.5-200 keV (Lin et al. 2012)

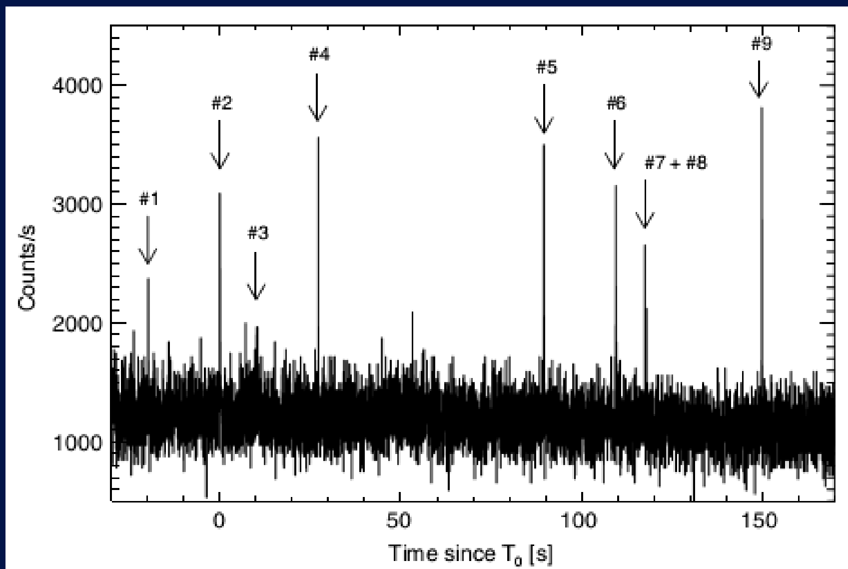


SGR 1550–5418 in 2008 – 2009



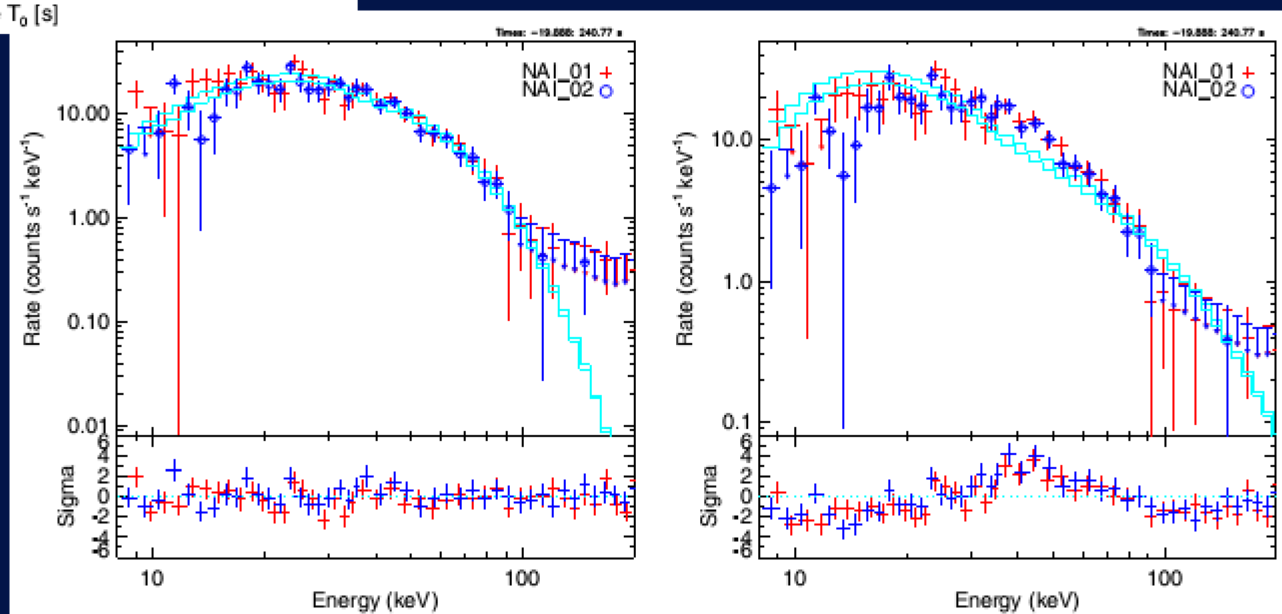
(von Kienlin et al. 2012)

SGR 1550–5418: Oct 08 & Mar 09



22 relatively weak events in Oct 2008 are best described with a single blackbody function.

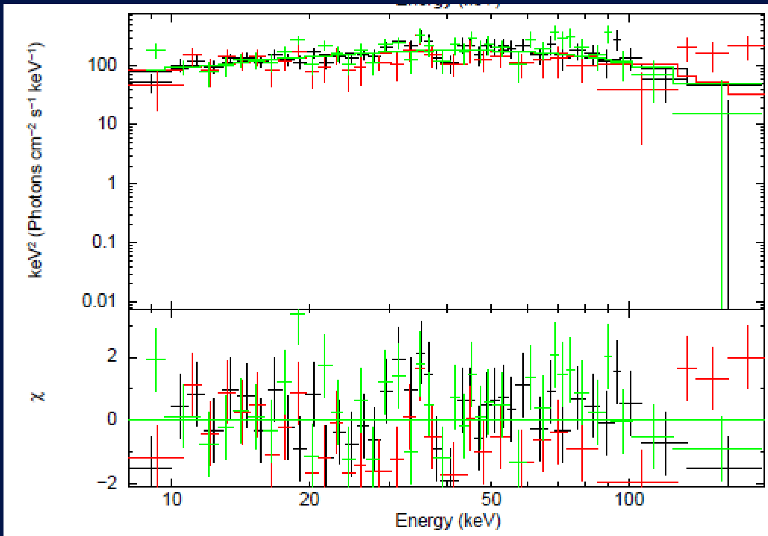
15 events seen March 2009 are better fit with OTTB

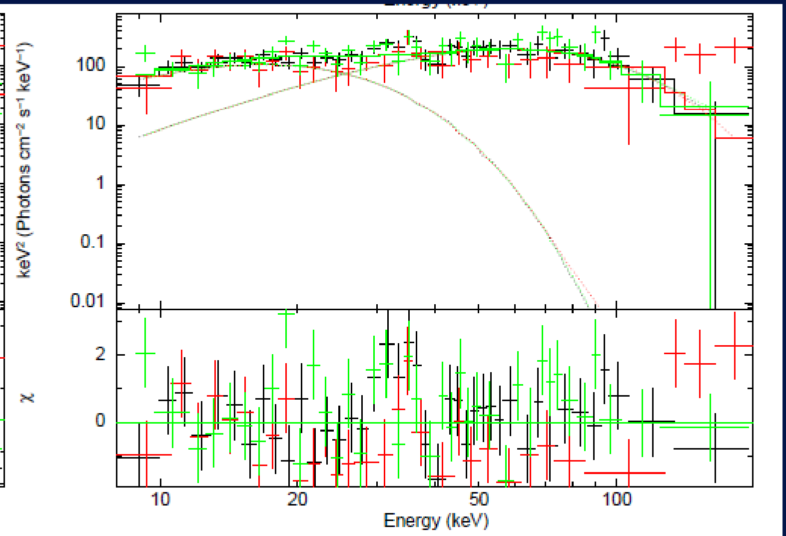


(von Kienlin et al. 2012)

SGR 1550–5418 in January 2009
GBM only

286 integrated spectra are well described with BB + BB, and equally well with the Compt model.

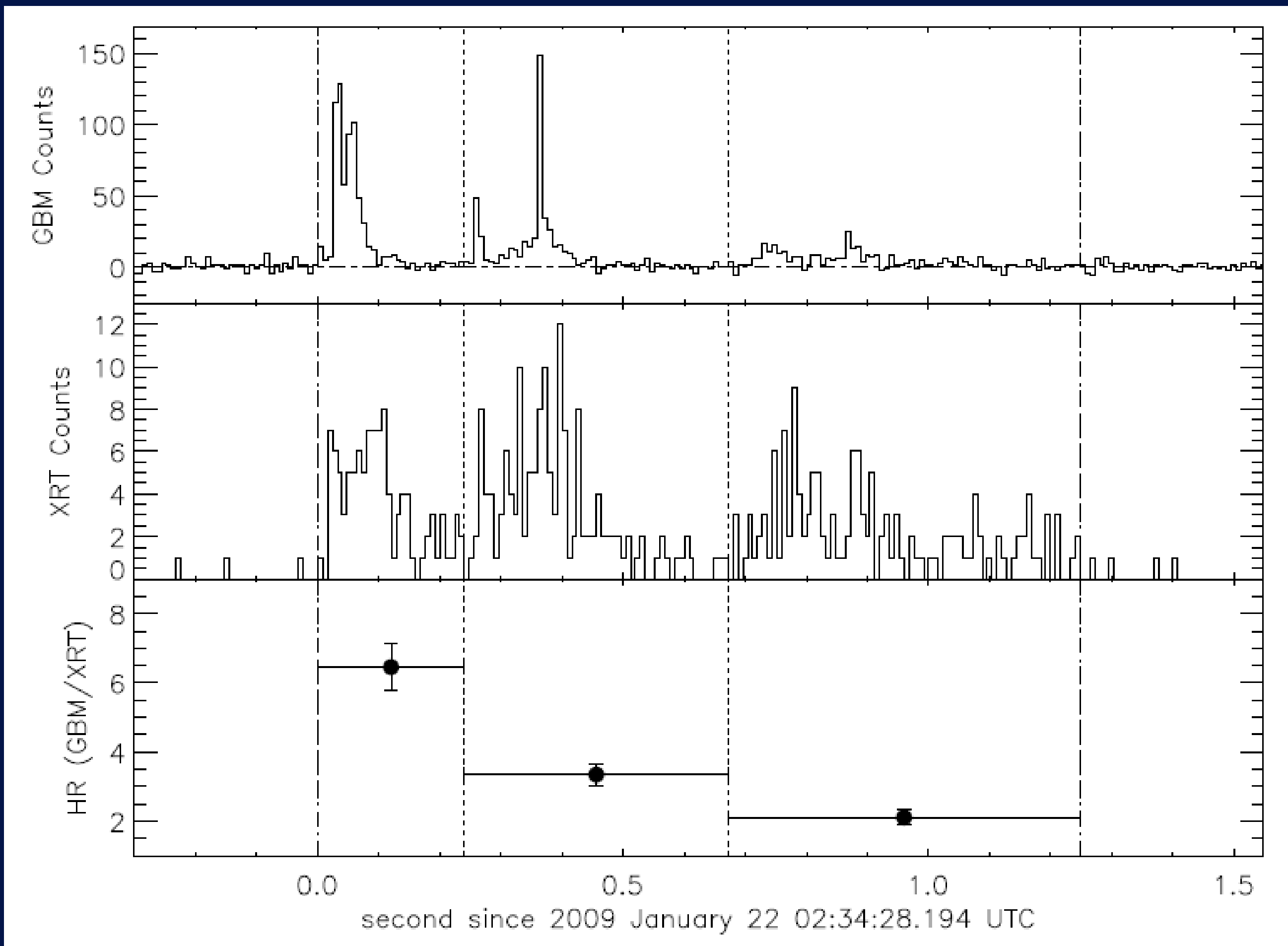




Compt **BB+BB**

(von der Horst et al. 2012)

XRT-GBM Simultaneous Event

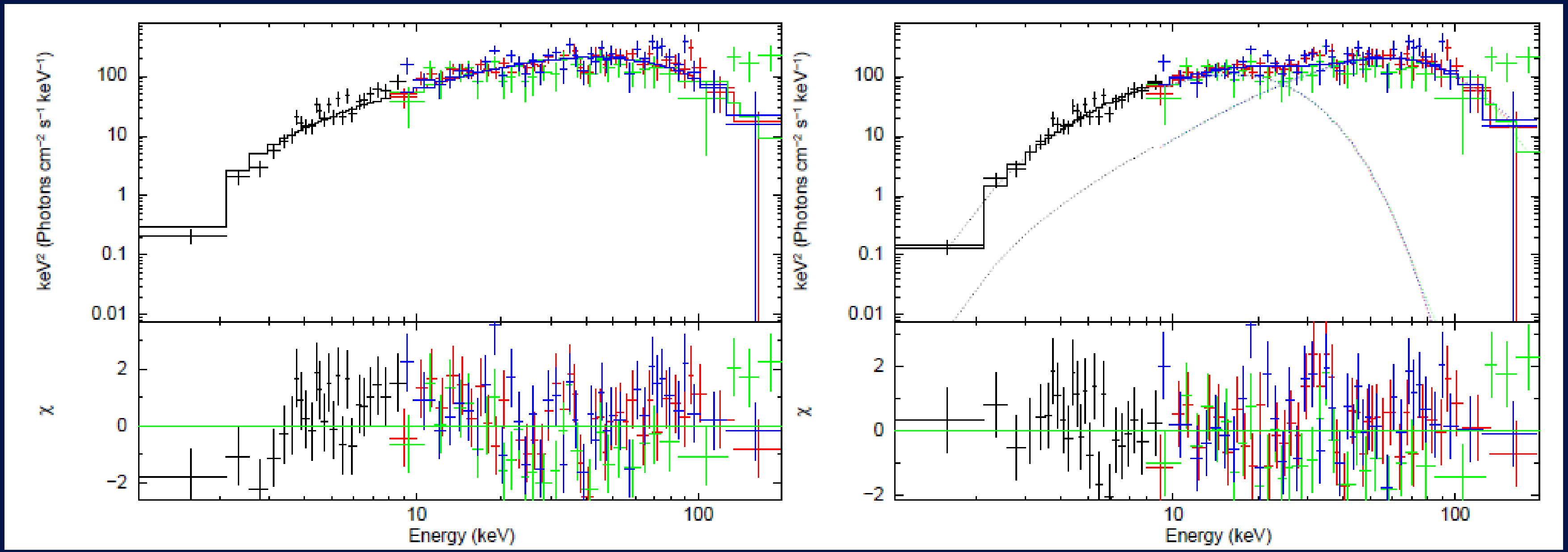


42 simultaneous bursts were identified in the January 2009 active episode

(Lin et al. 2012)

SGR 1550–5418: Broadband Spectral Analysis

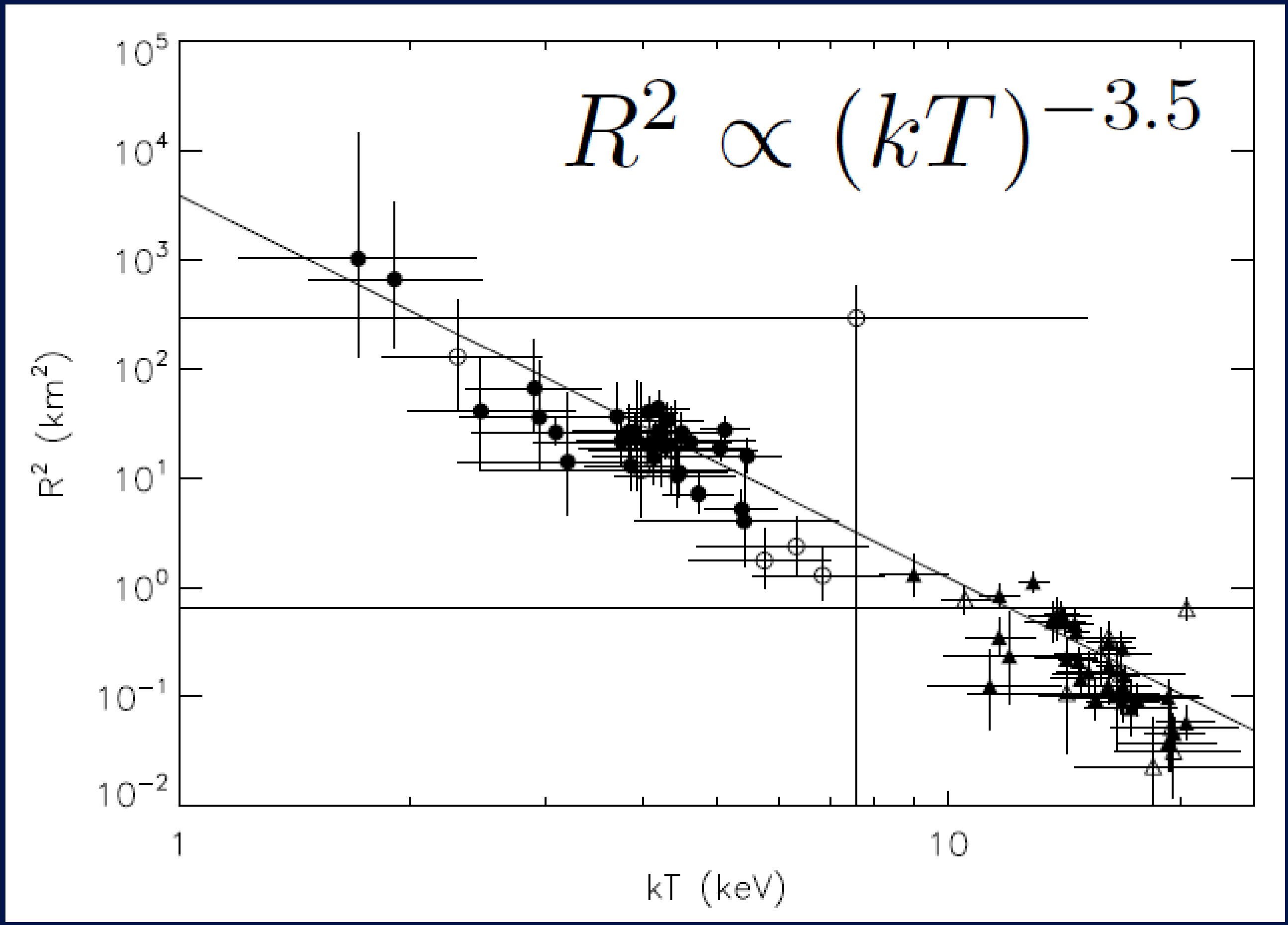
Compt **BB+BB**



Joint spectral fits: BB + BB model fits are significantly better than the Compt model.

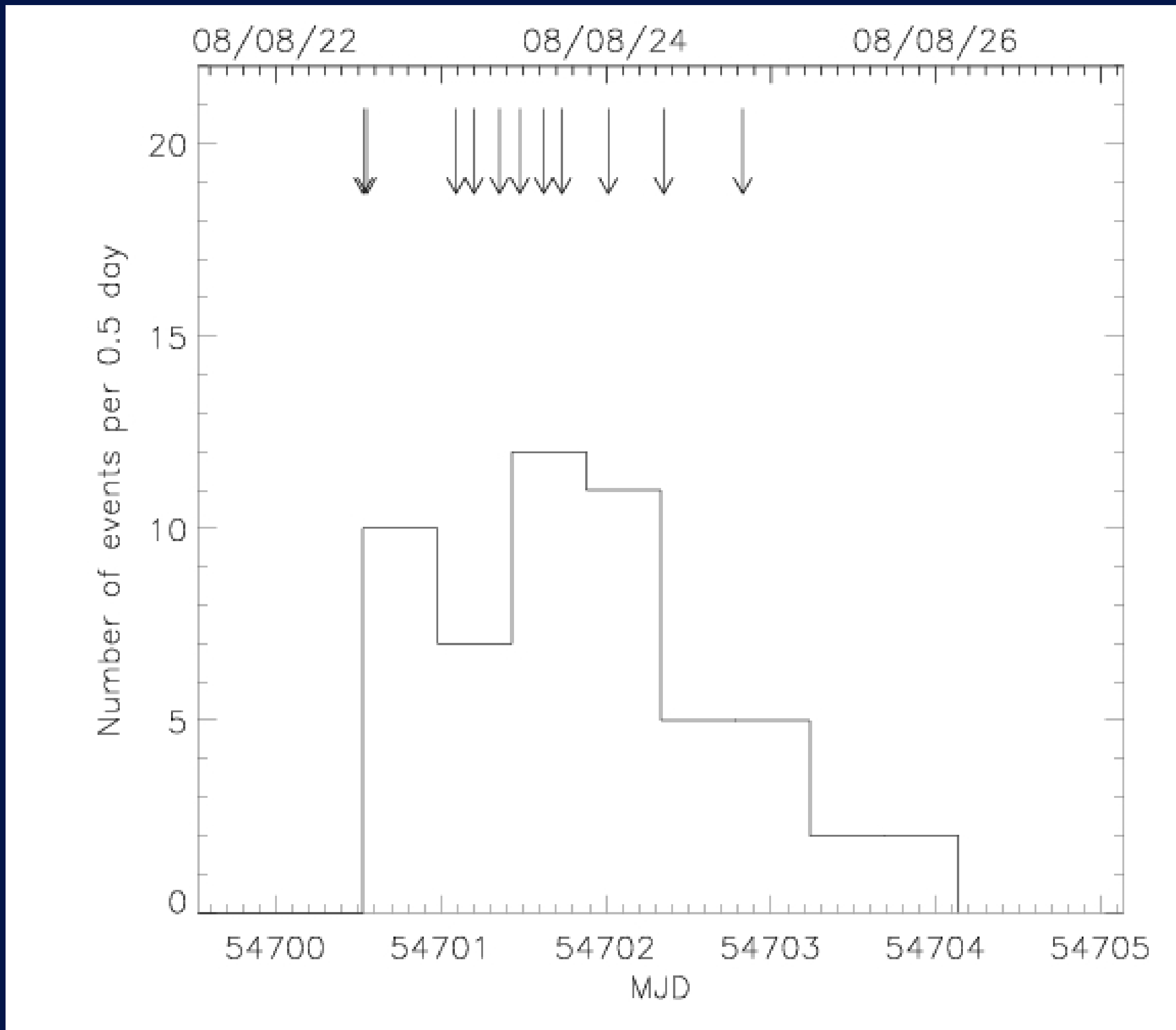
(Lin et al. 2012)

SGR 1550–5418: Broadband Spectral Analysis



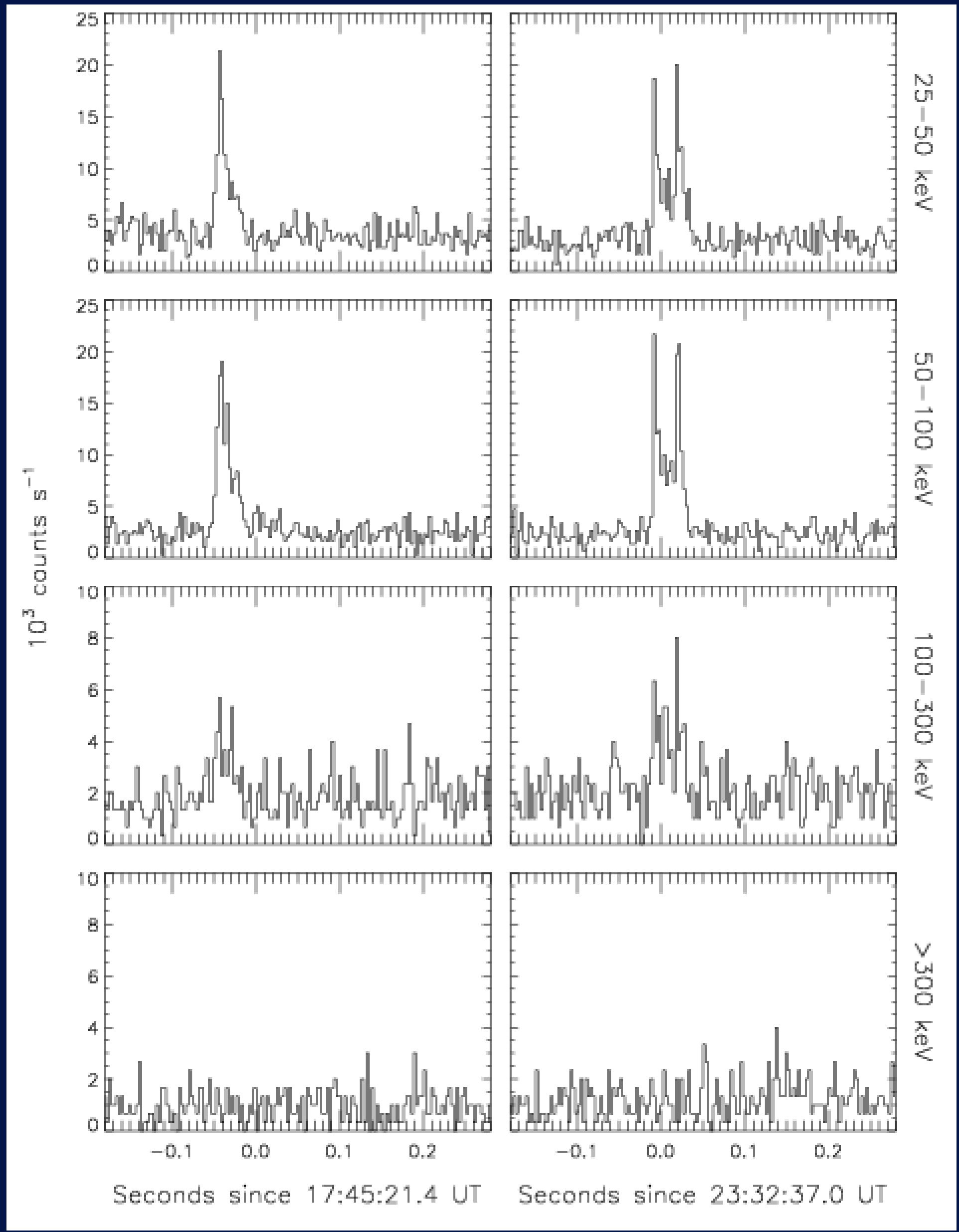
(Lin et al. 2012)

2nd Outburst of SGR 0501+4516



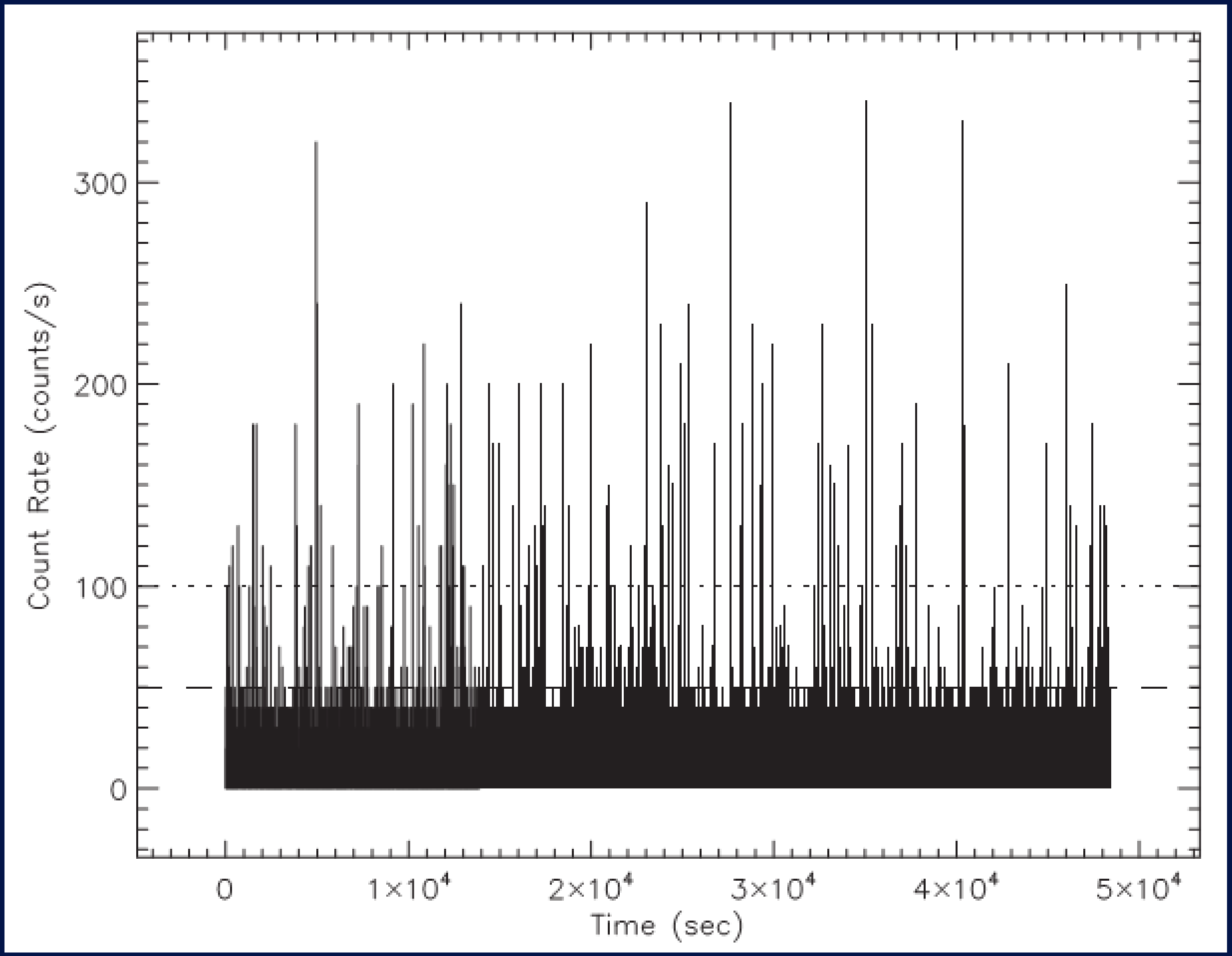
1st Outburst of SGR 0501+4516 in July 1993

On 1993 July 25, BATSE triggered on two short and soft events originating from similar locations →



(Göğüş et al. 2010)

XMM–Newton View of SGR 0501+4516



(Lin et al. 2012)

49 ks observation collected 100s of short bursts

Crucial to study the link between low fluence bursts and persistent emission

Talk by L. Lin

Search for QPOs

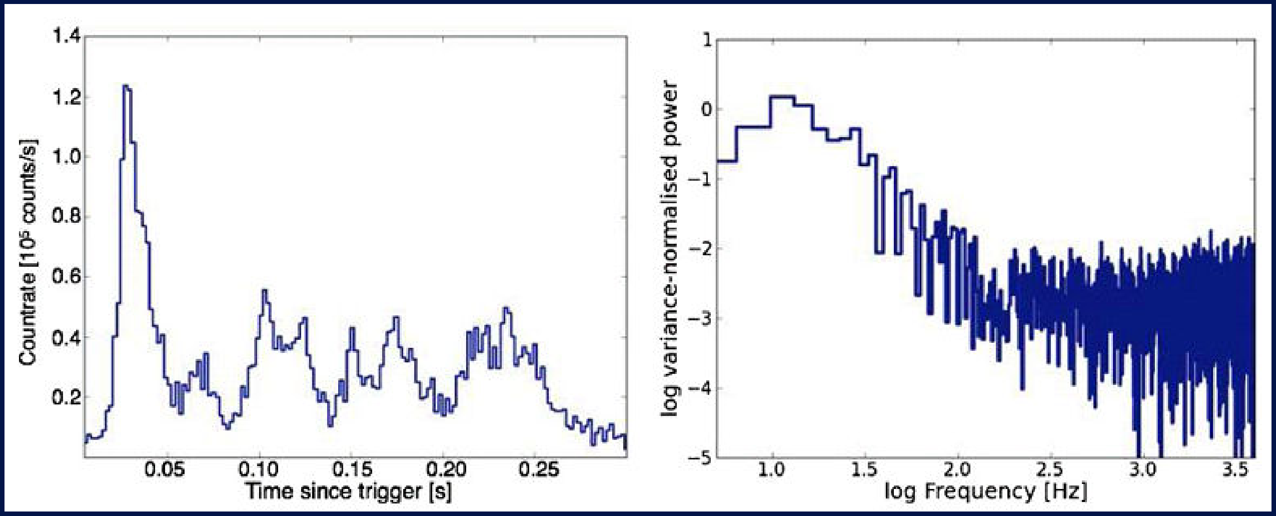
High frequency QPOs were detected in the data of two giant flares (Israel et al. 2005; Strohmayer & Watts 2006, …)

There are thousands of short bursts. Are there hidden oscillations in short bursts as well?

Huppenkothen et al. (2013): the most rigorous search for QPOs in the GBM data of 27 SGR 0501+4516 bursts using Bayesian statistics

→ no evidence for QPOs in the unbinned specta

→ there is a candidate (7 Hz) in the binned spectra of a burst

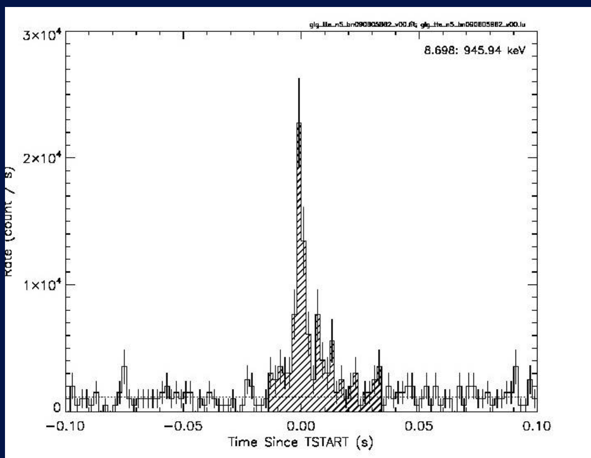


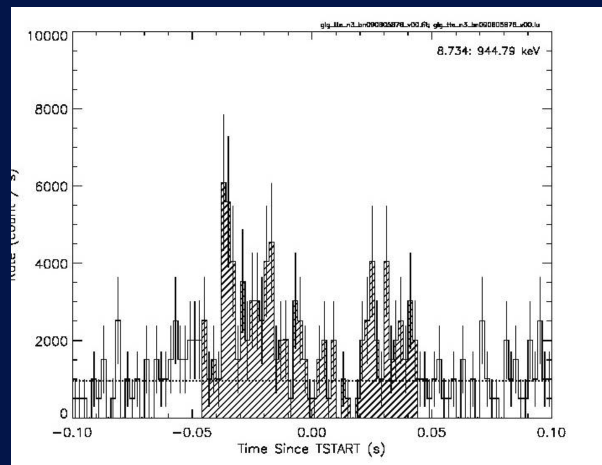
The candidate can be due to a quasi periodic process or an unmodelled effect of noise

Search in other bursts is ongoing

(Huppenkothen et al. 2013)

SGRs with Low Burst Rates



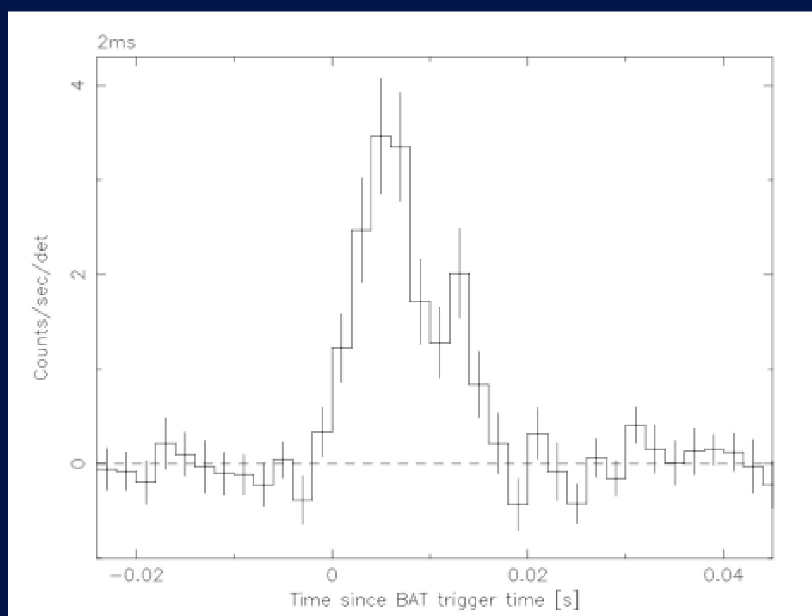


SGR 0418+5729

(van der Horst et al. 2010)

$B_d = 6\times10^{12}$ G

(Rea et al. 2010; 2013)



SGR 1833 – 0832

(Göğüş et al. 2010)

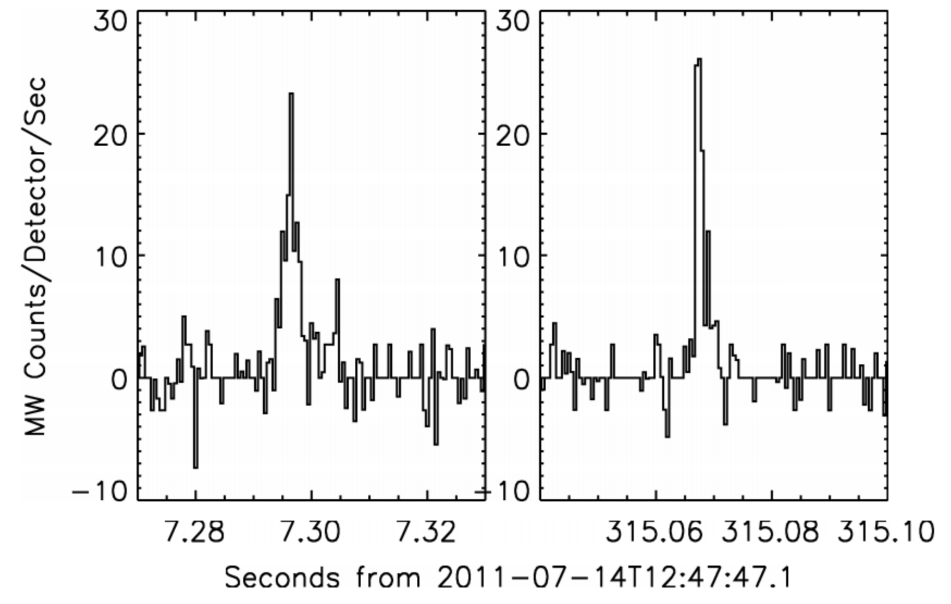
$B_d = 2\times10^{14}$ G

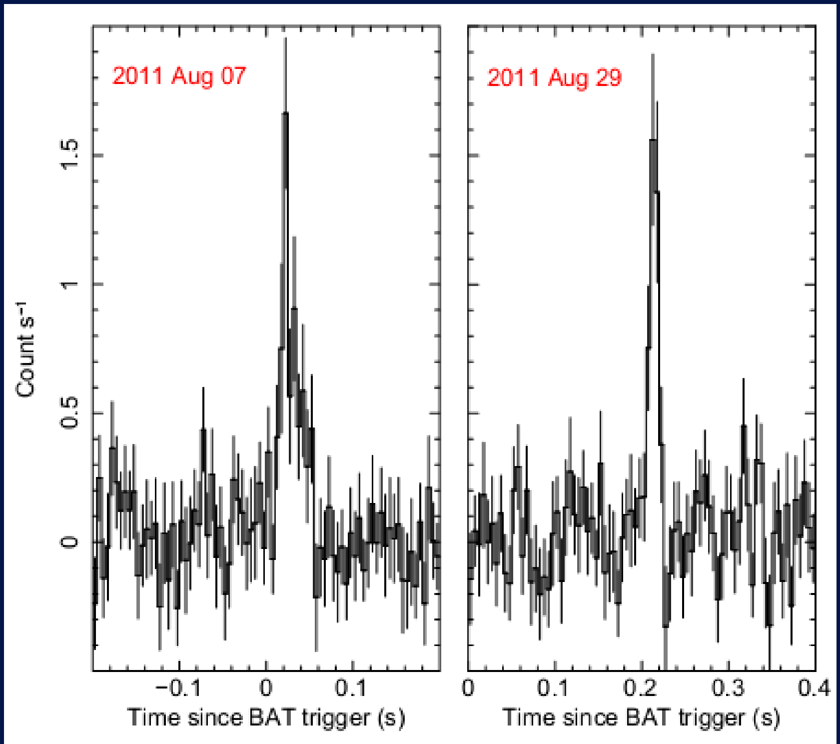
SGRs with Low Burst Rates

SGR 1822.3–1606 →

$B_d = 2.7 \times 10^{13}$ G

(Rea et al. 2012)





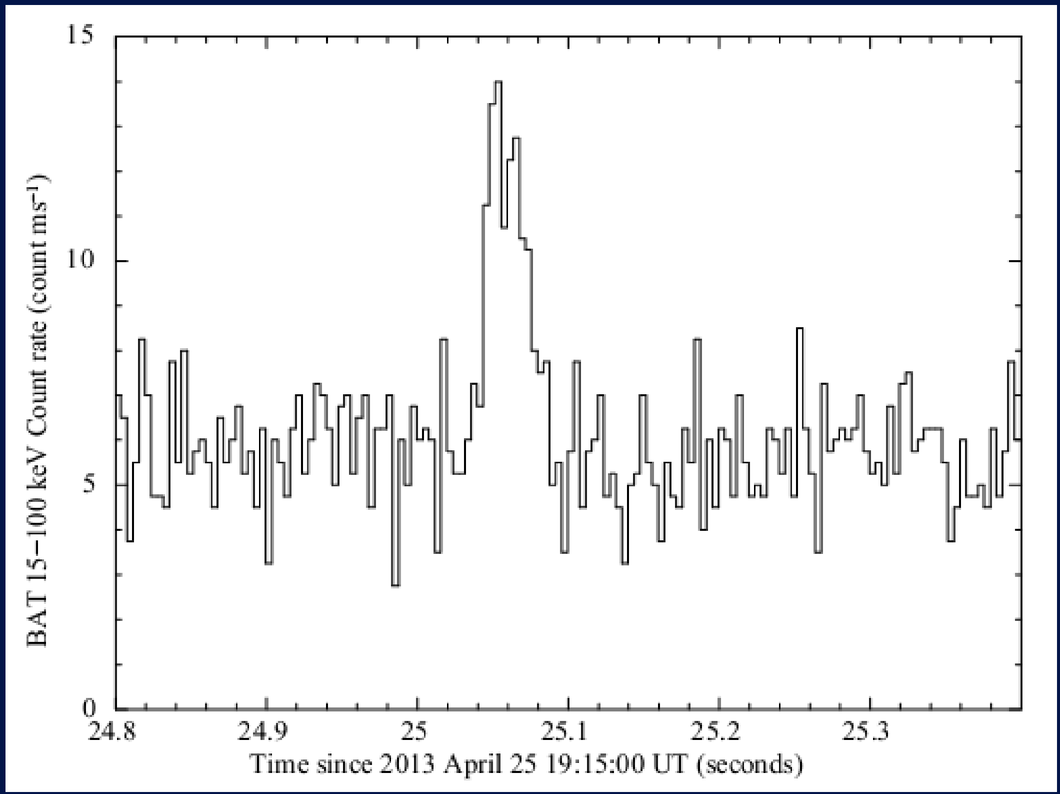
SGR 1834.9–0846

(Esposito et al. 2012)

$B_d = 1.4 \times 10^{14}$ G

(Kargaltsev et al. 2012)

SGRs with Low Burst Rates



SGR 1745–29

(Kannea et al. 2013)

$B_d = 3 \times 10^{14}$ G

(Gotthelf et al. 2013)

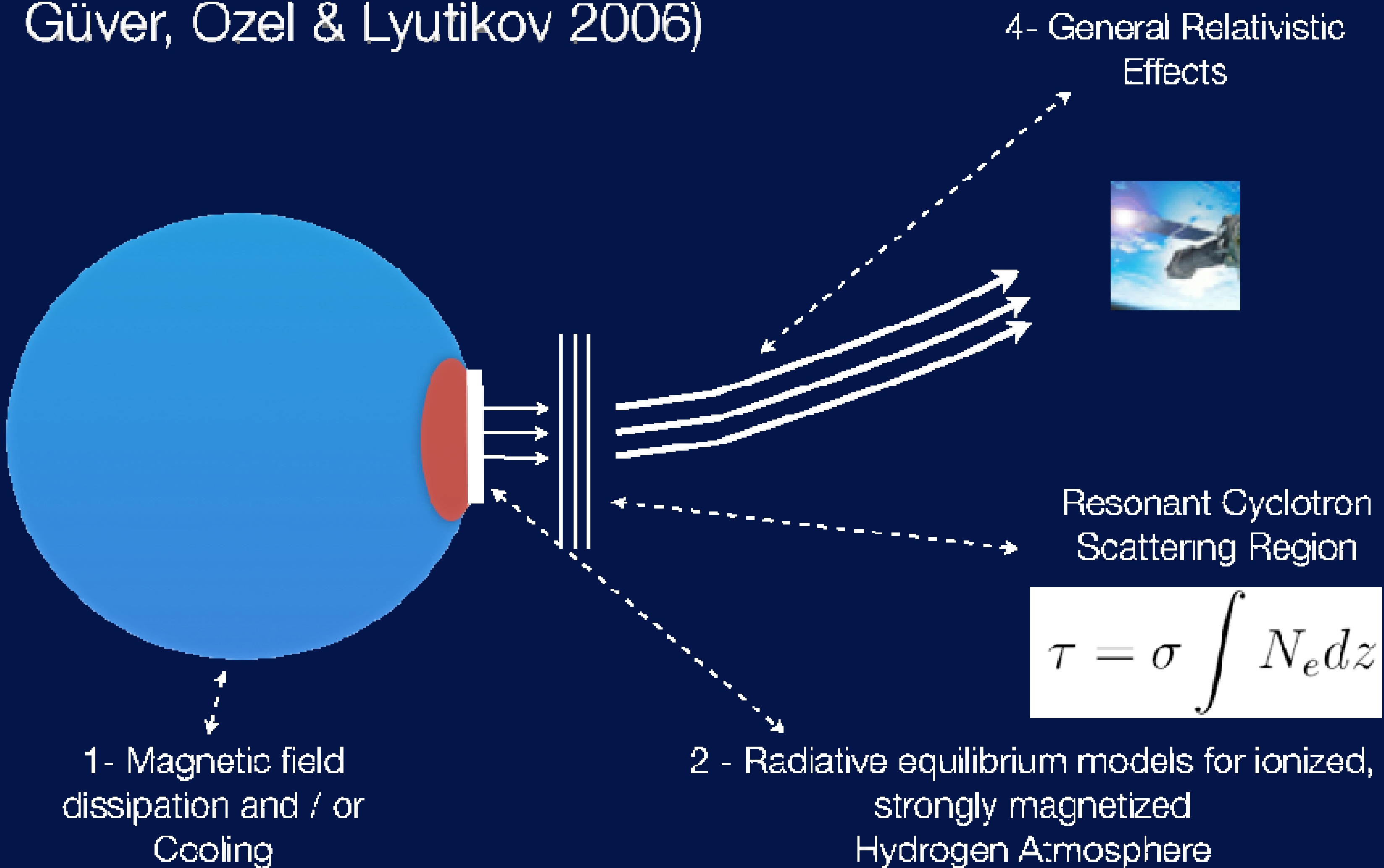
SGRs with Low Burst Rates

How can sources with low dipole magnetic fields (e.g., SGR 0418+5729 or SGR 1822.3–1606) generate bursts?

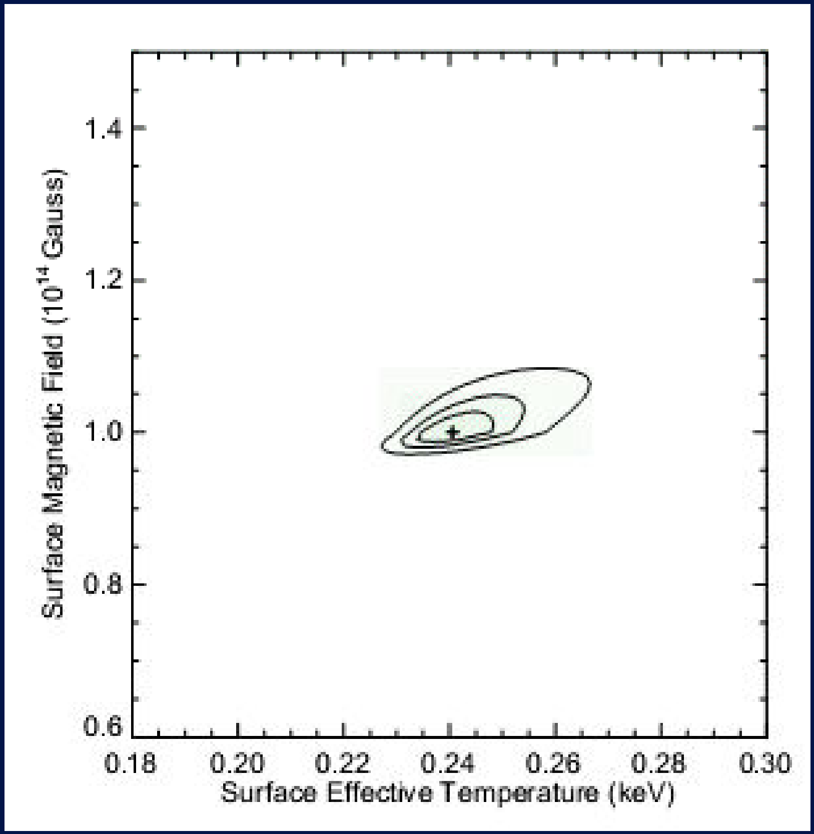
XMM – Newton observations of SGR 0418+5729 on 2009 August 12 for 65 (36) ks might have observational clues.

Surface Thermal Emission and Magnetospheric Scattering Model :

(Özel 2003; Lyutikov & Gavriil 2006;
Güver, Özel & Lyutikov 2006)



Surface B-field of SGR 0418+5729



The NS atmosphere models with $B=10^{12}$ G or 10^{13} G do not fit

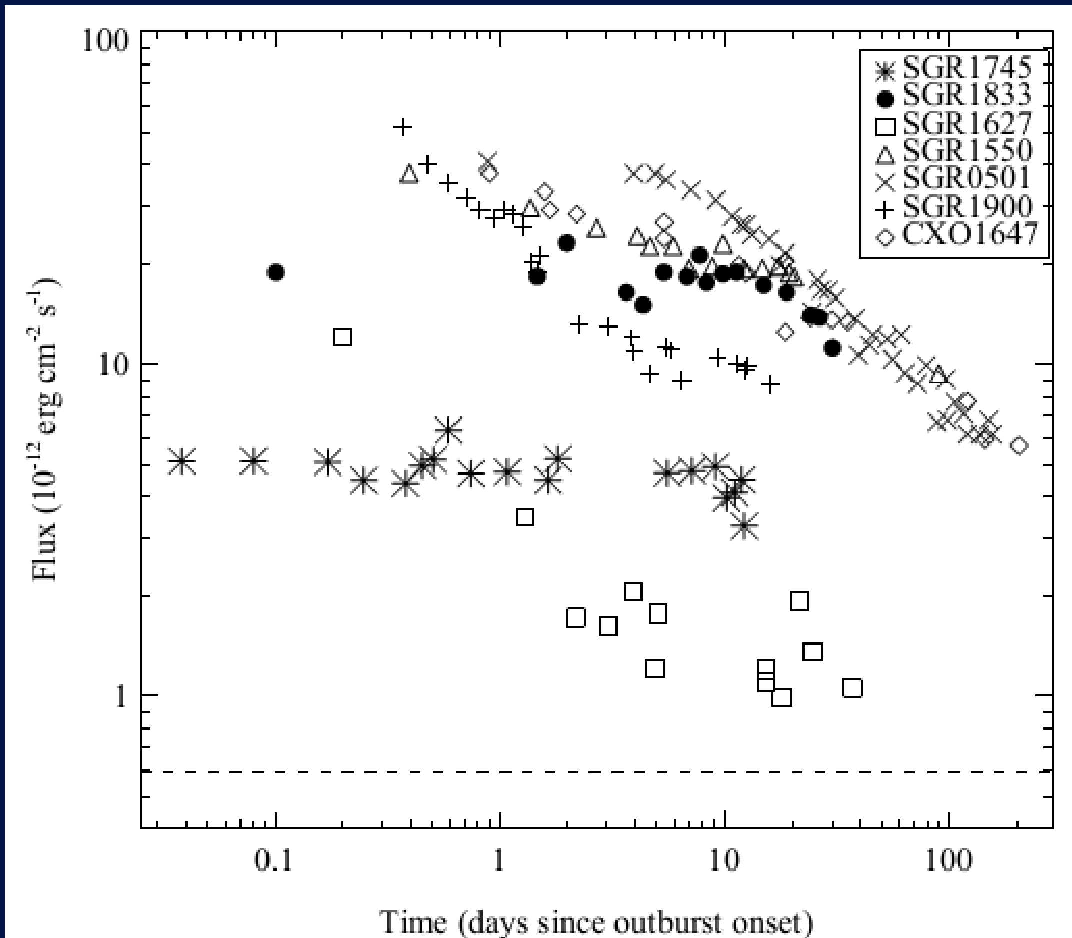
STEMS provides a good fit, yielding $B_s = 1.0 \times 10^{14}$ G

This is the phase averaged value, it can be stronger in local settings; it is strong enough to generate bursts

Implies significantly non-dipolar magnetic field.

(Güver, Göğüş & Özel 2011)

SGR 1745–29 & SGR 1833–0832 Flux Decay



X-ray flux of SGR 1745–29 is constant for ~10 days following the onset

Similar flux trend was seen in SGR 1833 – 0832

Continuous heating of the crust by trapped fireball?

(Kannea et al. 2013)

T_{90} of Burst Active Episode

Time since the onset of an outburst during which 90% of all observed bursts are recorded.

Source	$T_{90-BurstActivity}$
SGR 1550–5418 (2009)	4.6 days
SGR 1627–41 (1998)	4.1 days
SGR 0501+4516 (2008)	3.7 days
SGR 1900+14 (1998)	93 days
SGR 1806–20 (2003/04)	very long

Burst active episode of a prolific transient lasts for ~4 days.

Summary

Transient SGRs: prolific vs. low burst rate

SGR burst spectral studies: crucial, especially in broadband

SGR burst temporal studies: difficult but can be rewarding

Better understanding of persistent emission and its link (?) to bursts are critical — XMM-Newton has been very instrumental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E1.12 Highly Magnetized Neutron Stars

Themes:

What is required to produce SGR-like bursts?

Are all high-B NSs different manifestations of the same underlying objects, or do they represent distinct evolutionary sequences?