Magnetar candidates: new discoveries open new questions

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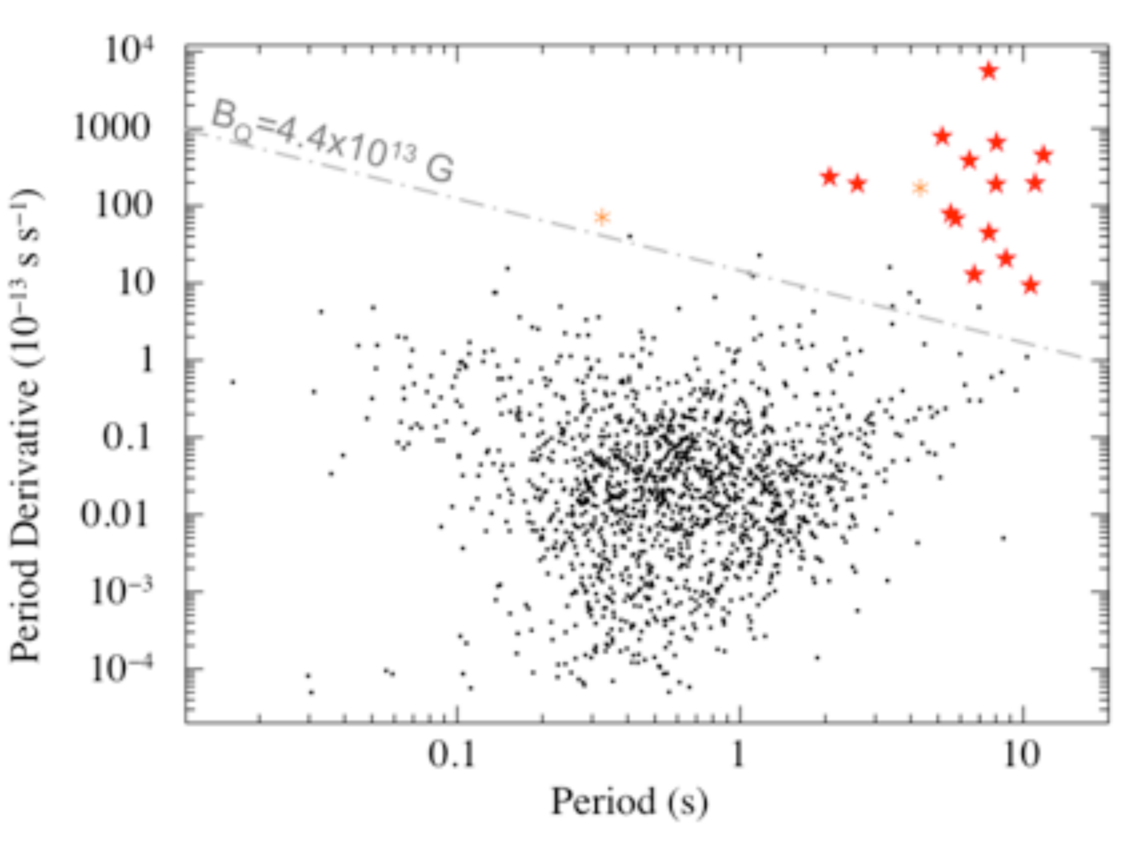
CSIC IEEC

Image Credit: ESA - Christophe Carreau

Isolated Neutron Stars: P-Pdot diagram



$$\dot{E}_{rot} = -\frac{2}{3c^3}|\ddot{m}|^2 = -\frac{2B^2R^6\Omega^4 \sin^2\alpha}{3c^3}$$

$$P\dot{P} = \left(\frac{8\pi^2 R_{ns}^6}{3c^3 I}\right) B_0^{\ 2} \sin^2\alpha$$

$$B_{critic} = \frac{m_e^2 c^3}{e\hbar} = 4.414\times10^{13}\,Gauss$$

Critical Electron Quantum B-field

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AXPs and SGRs general properties

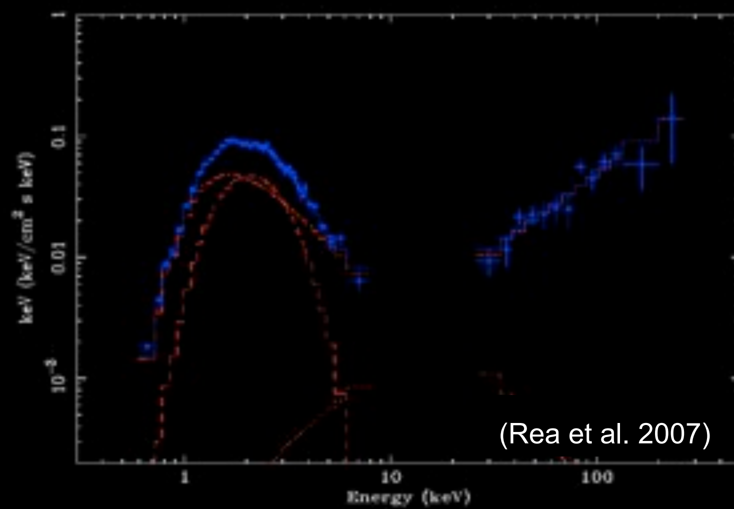
- bright X-ray pulsars Lx ~ 10^{33}-10^{36} erg/s

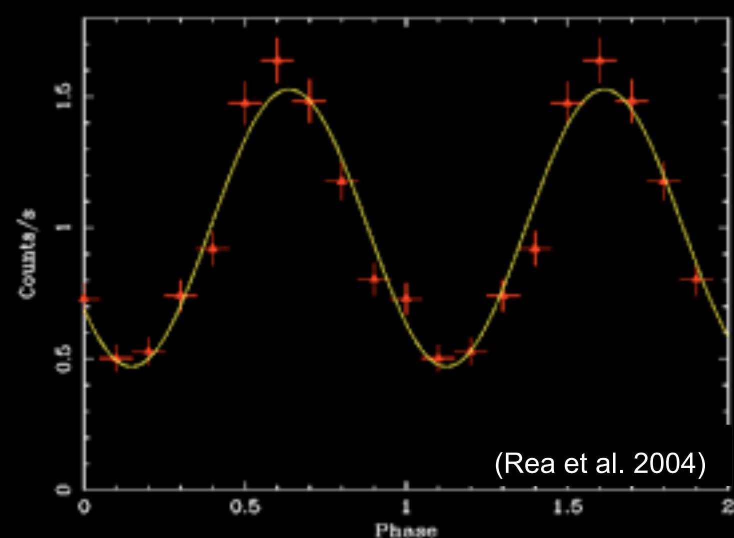
- strong soft and hard X-ray emission

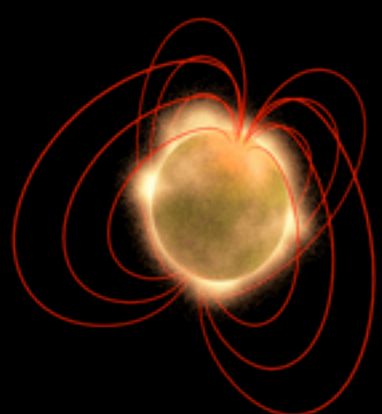
- rotating with periods of ~2-12s and period derivatives of ~10^{-11}-10^{-13} s/s

- pulsed fractions ranging from ~5-70 %

- magnetic fields of ~10^{14}-10^{15} Gauss





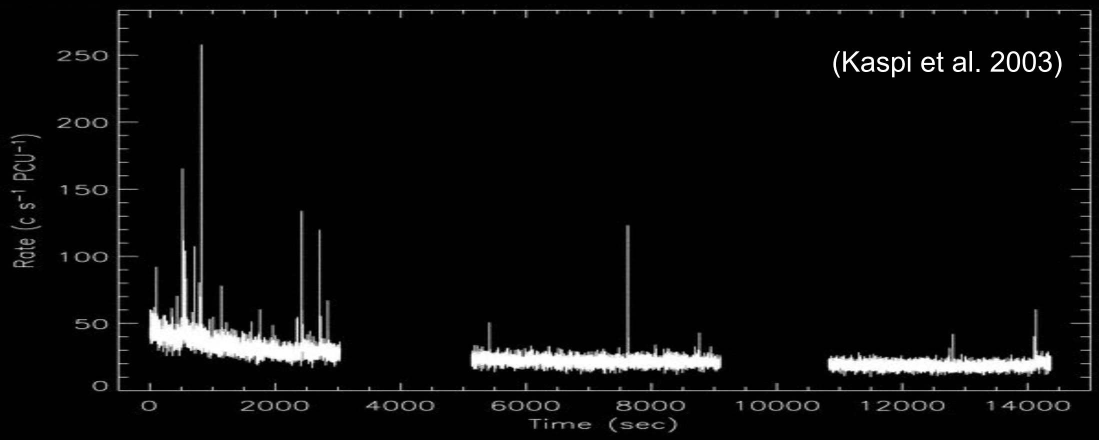


(see Mereghetti 2008, A&AR, for a review)

AXPs and SGRs general properties

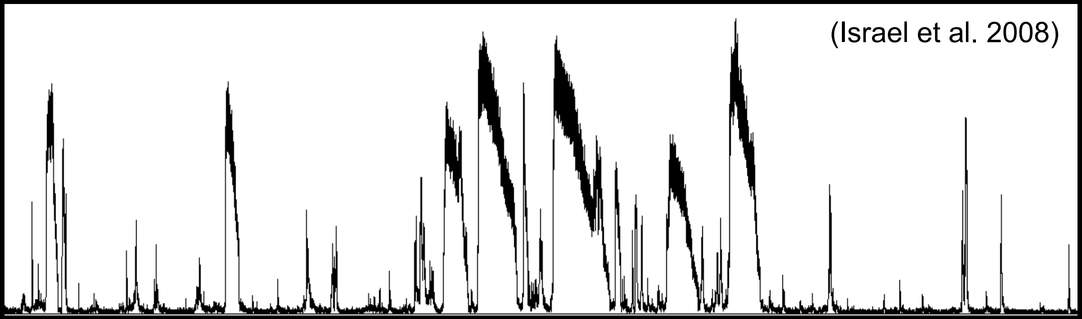
Short bursts

- the most common
- they last ~0.1s
- peak ~10^{41} ergs/s
- soft γ-rays thermal spectra



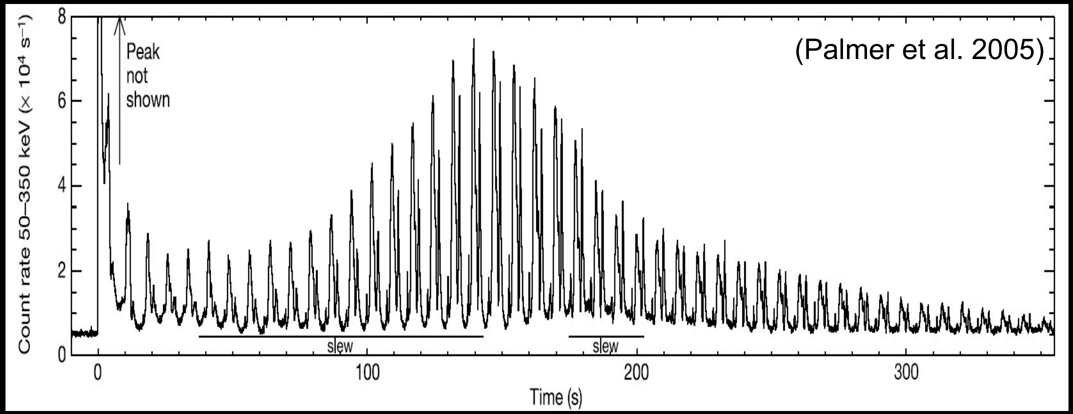
Intermediate bursts

- they last 1-40 s
- peak ~10^{41}-10^{43} ergs/s
- abrupt on-set
- usually soft γ-rays thermal spectra



Giant Flares

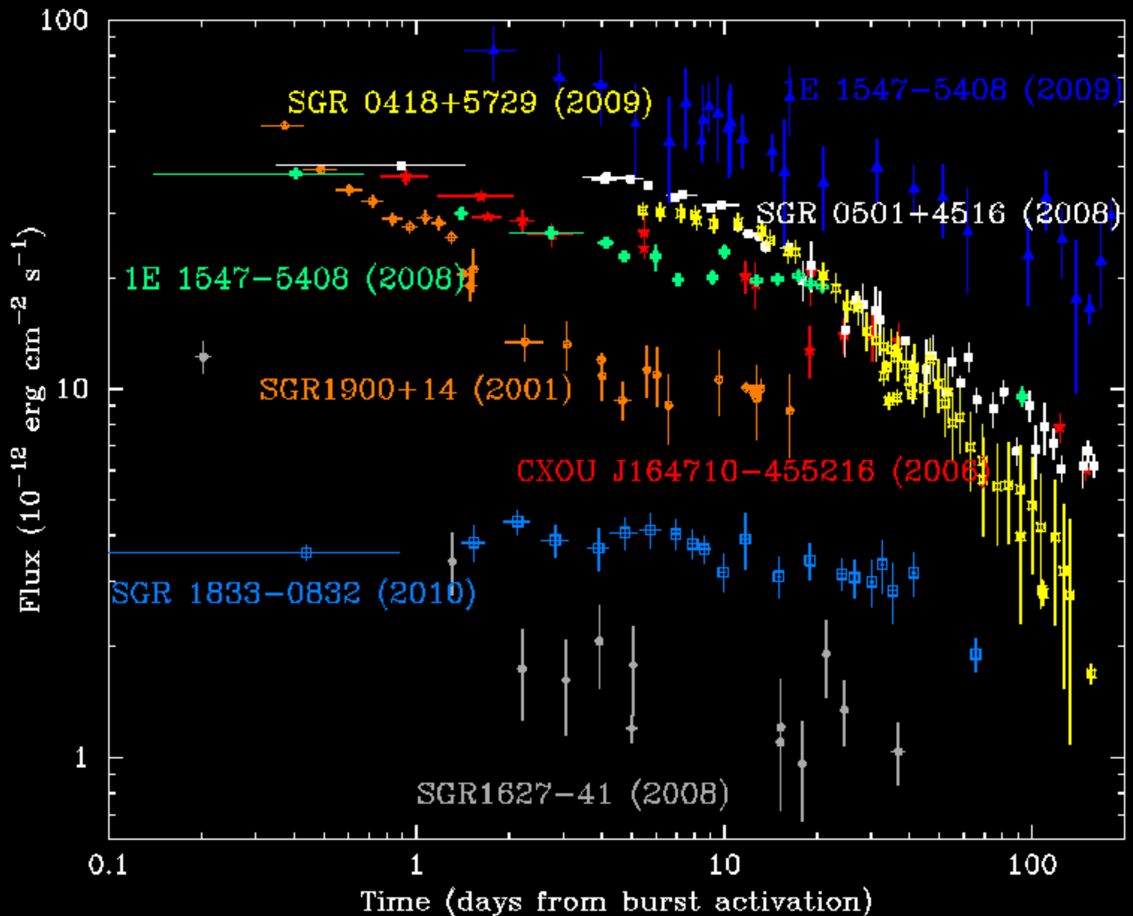
- their output of high energy is exceeded only by blazars and GRBs
- peak energy > 3×10^{44} ergs/s
- <1 s initial peak with a hard spectrum which rapidly become softer in the burst tail that can last > 500s, showing the NS spin pulsations.



AXPs and SGRs general properties

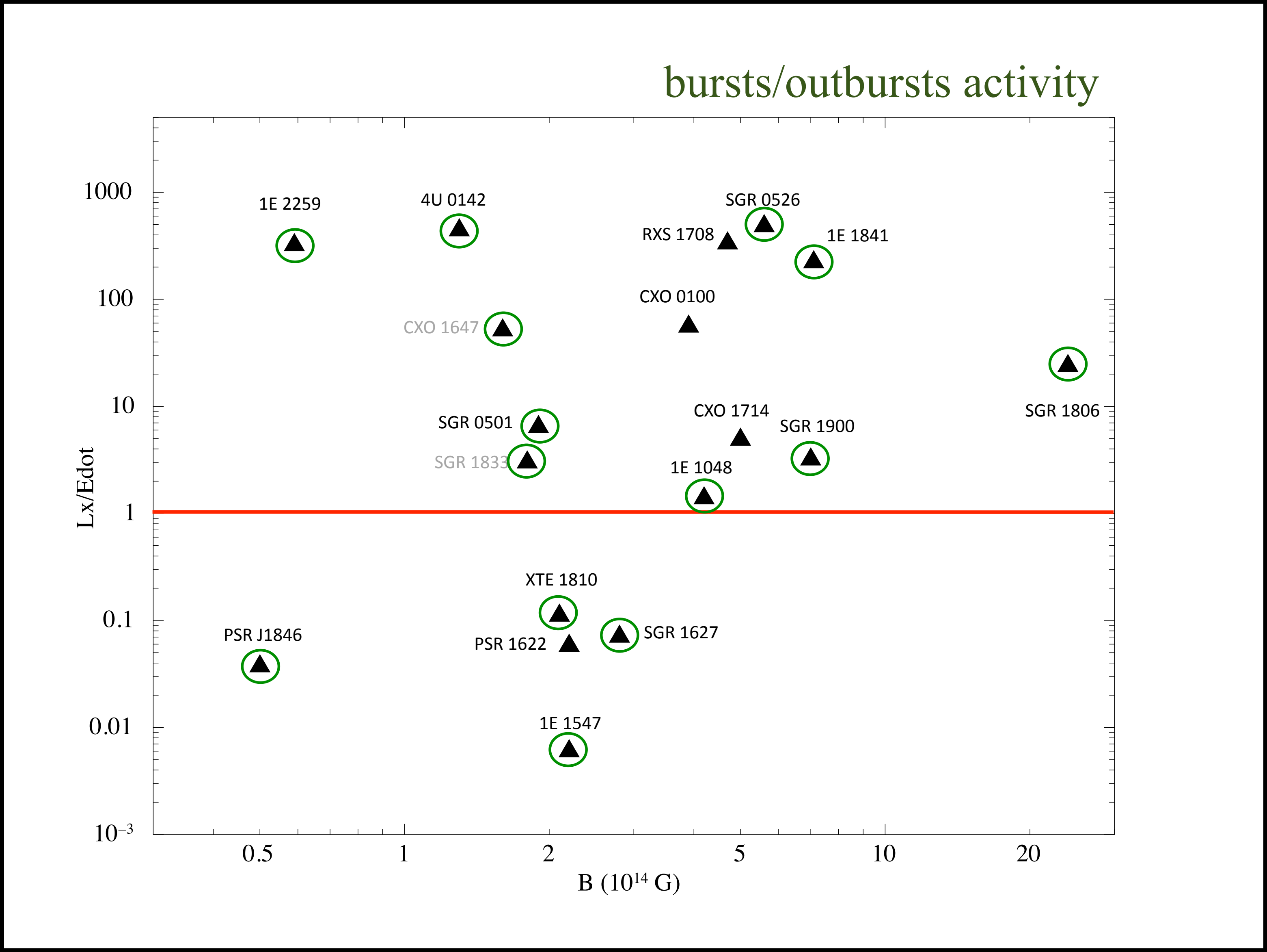
• transient outbursts lasting months-years

• in a few cases radio pulsed emission was observed connected with X-ray outbursts, with variable flux and profiles, and flat spectra



(Rea & Esposito 2010, APSS Springer Review)

AXPs and SGRs general properties



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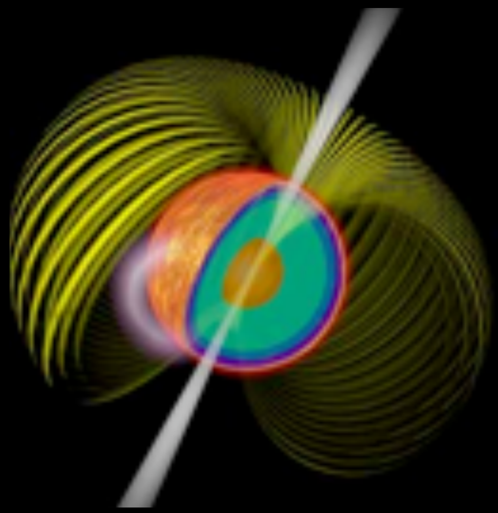
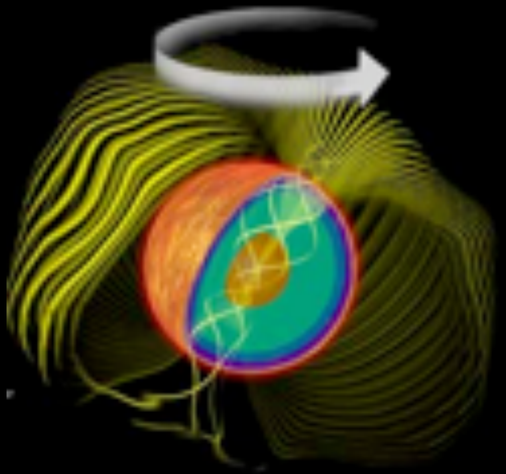
Why magnetars behave differently from normal pulsars?

- Their internal magnetic field is twisted up to 10 times the external dipole. At intervals, stresses build up in the crust which might cause causing glitches, flares...

- The surface of a young magnetar is so hot that it glows brightly in X-rays. Furthermore, the shifting magnetic field outside the star must drive electrical currents along arched magnetic field lines. streaming charged particles also slam against the star reaching the footpoints of magnetic field lines, heating spots on the surface.



High-B PSR

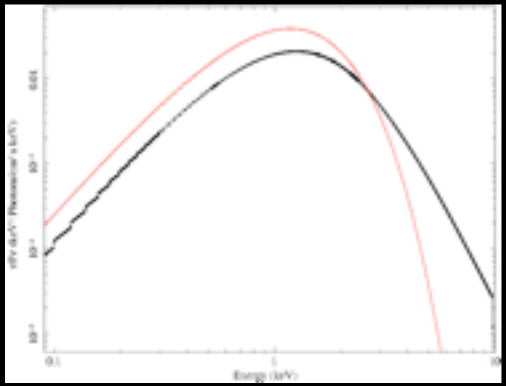


SGR/AXP

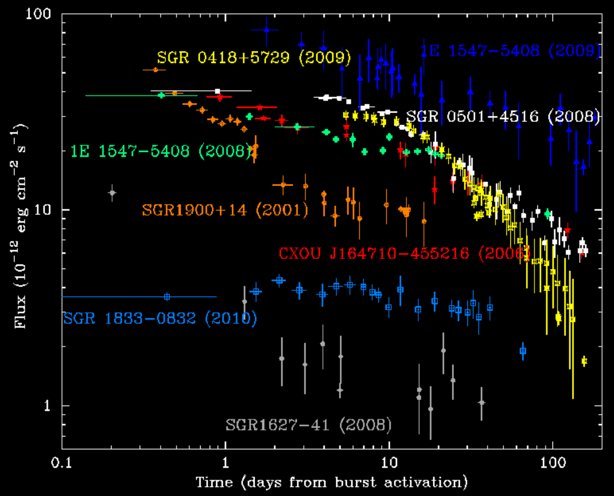
(Thompson & Duncan 1992; 1993; 1995;1996, 2001)

Where do we see the twisted magnetic fields?

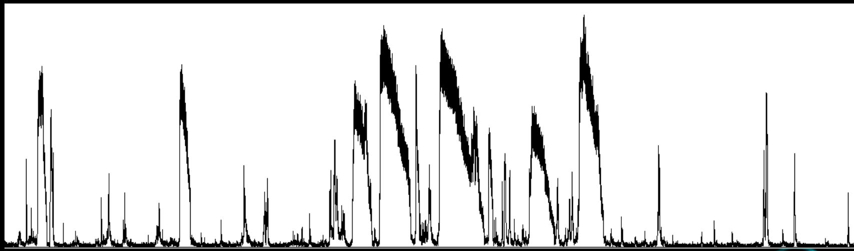
In their X-ray spectral shape....



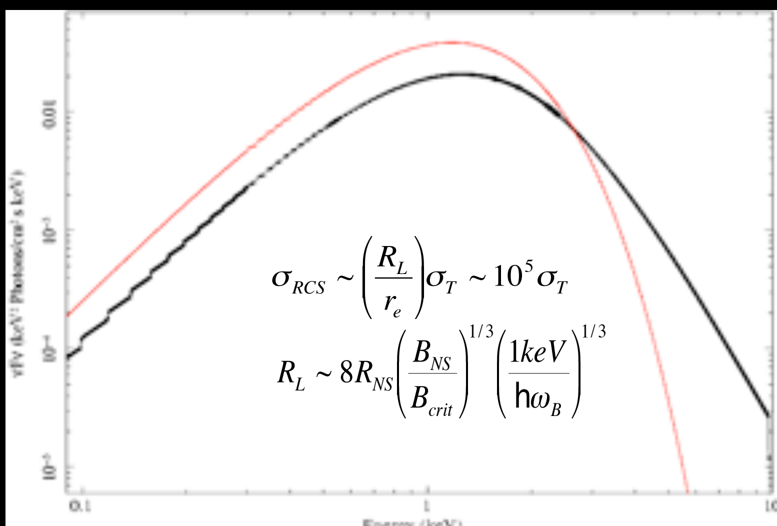
In their transient outbursts....



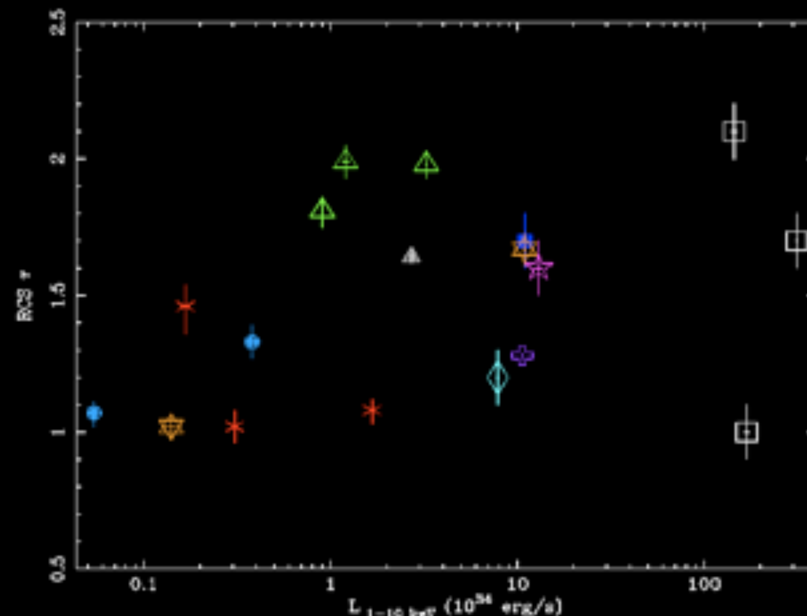
In their X-ray/gamma-ray flares...



Spectral shape: Resonant Cyclotron Scattering



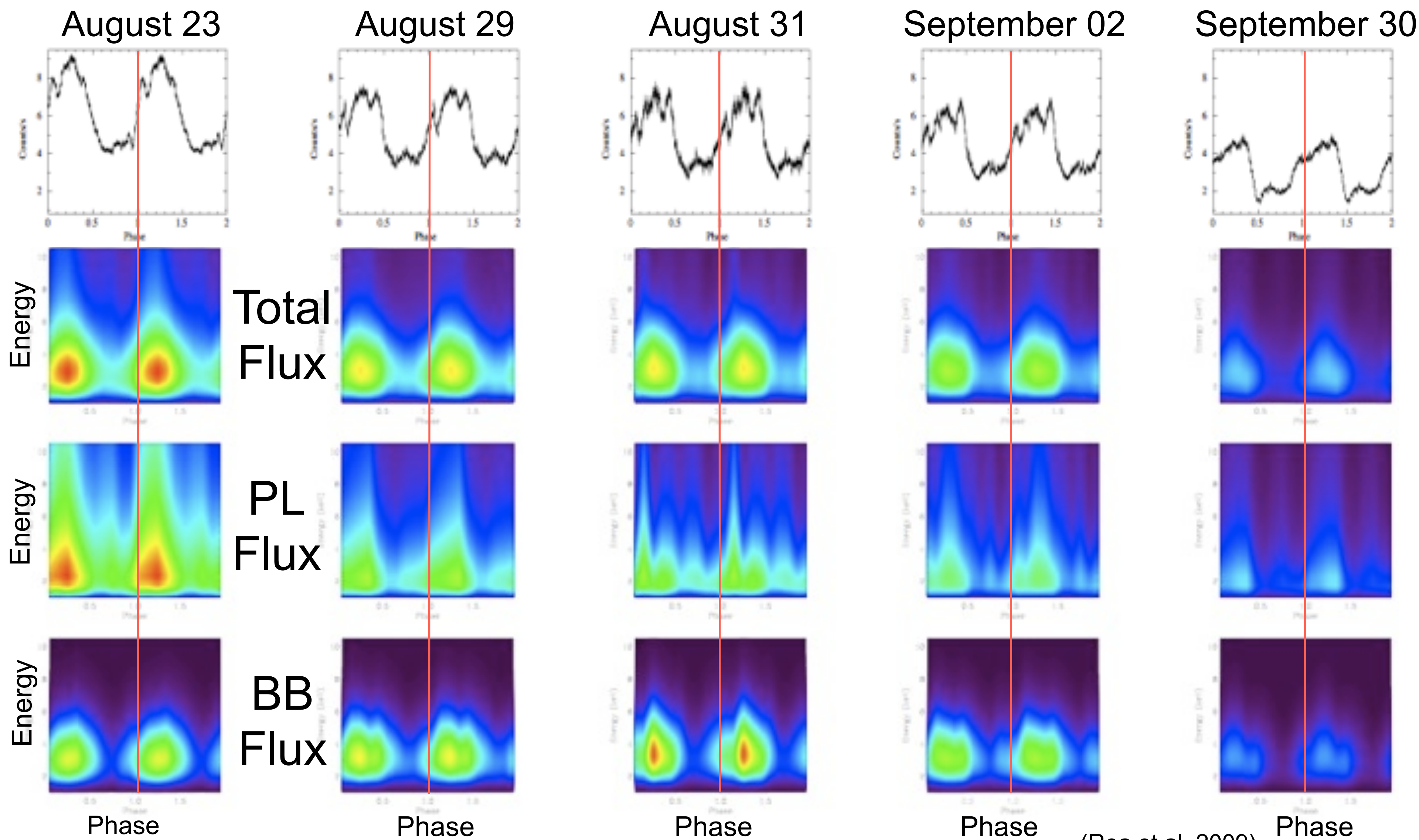
(Thompson, Lyutikov & Kulkarni 2002; Fernandez & Thompson 2008; Nobili, Turolla & Zane 2008a,b; Zane, Rea, Turolla & Nobili 2009))



Magnetars' magnetospheric density is ~10^3 times the normal radio pulsar density!

(Rea, Zane, Turolla, Lyutikov & Gotz 2008)

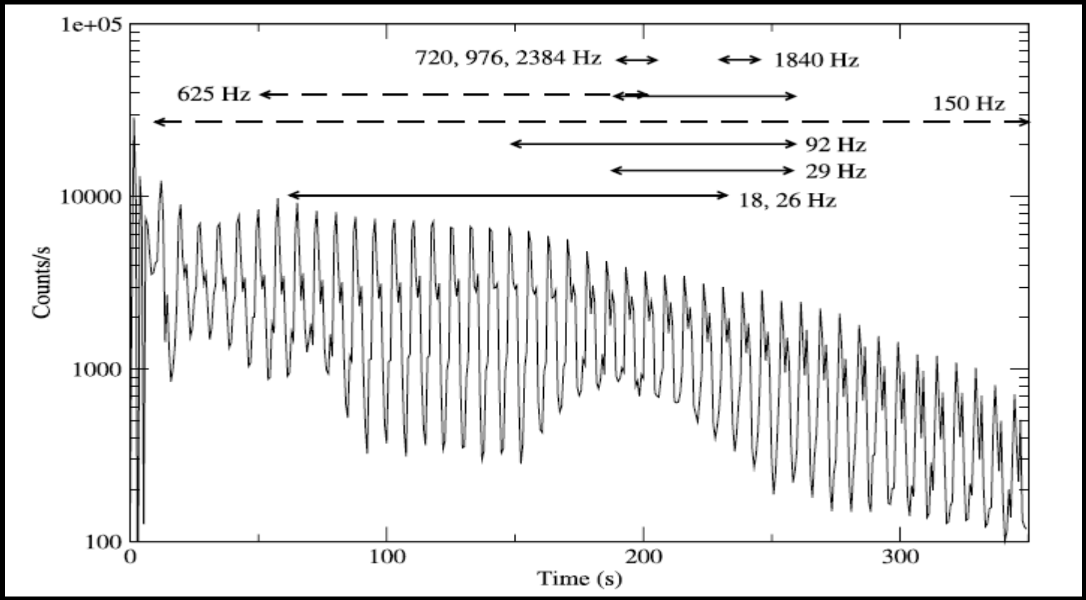
Magnetar outbursts



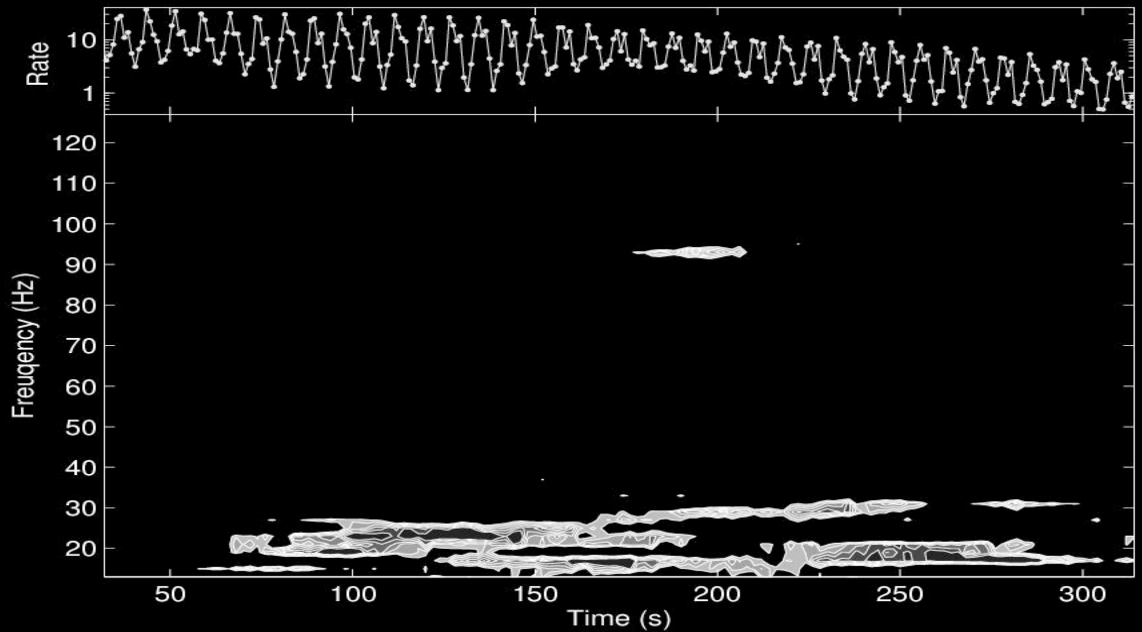
(Rea et al. 2009)

Other evidence of magnetic instability

- star-quakes on a neutron star!

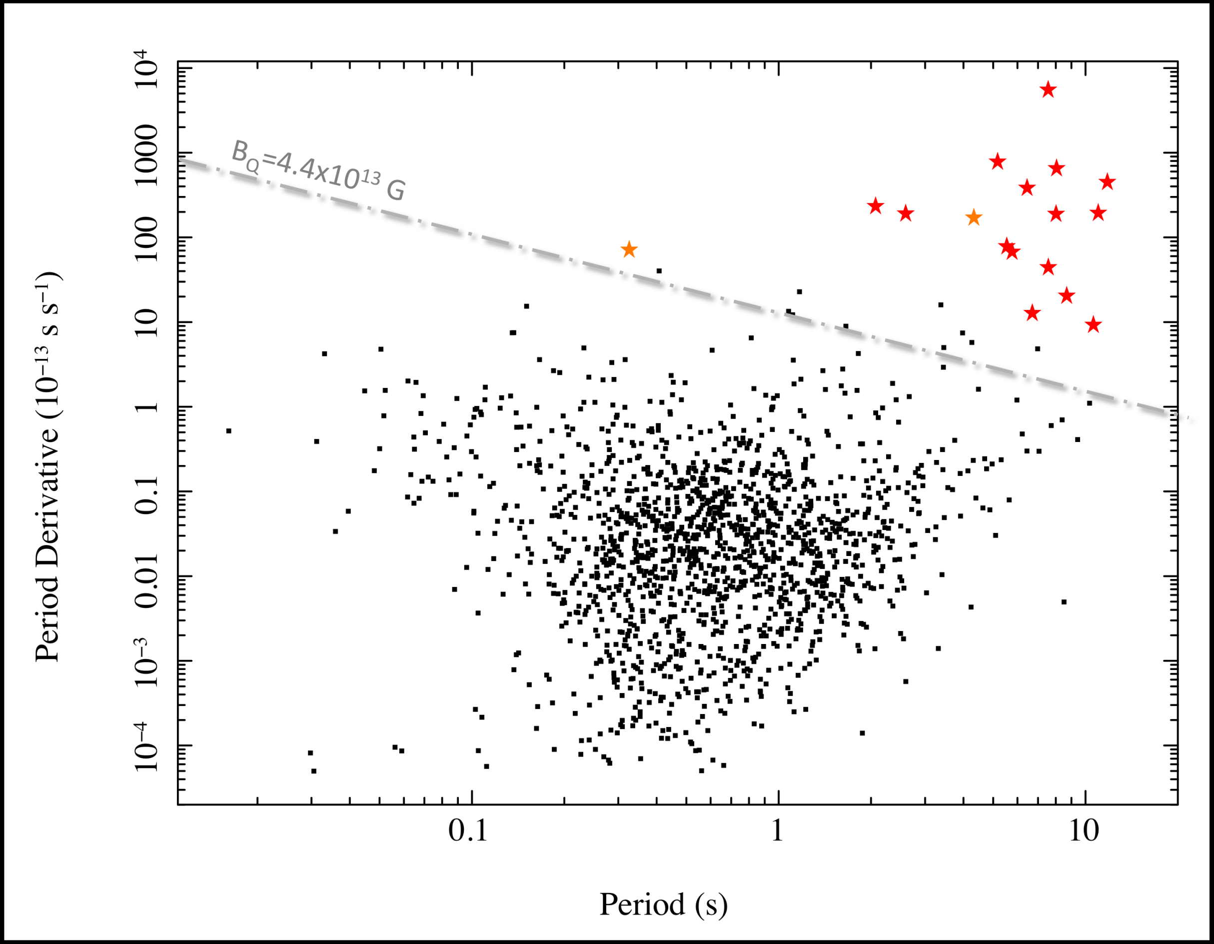


(Israel et al. 2005; Stromayer & Watts 2006)



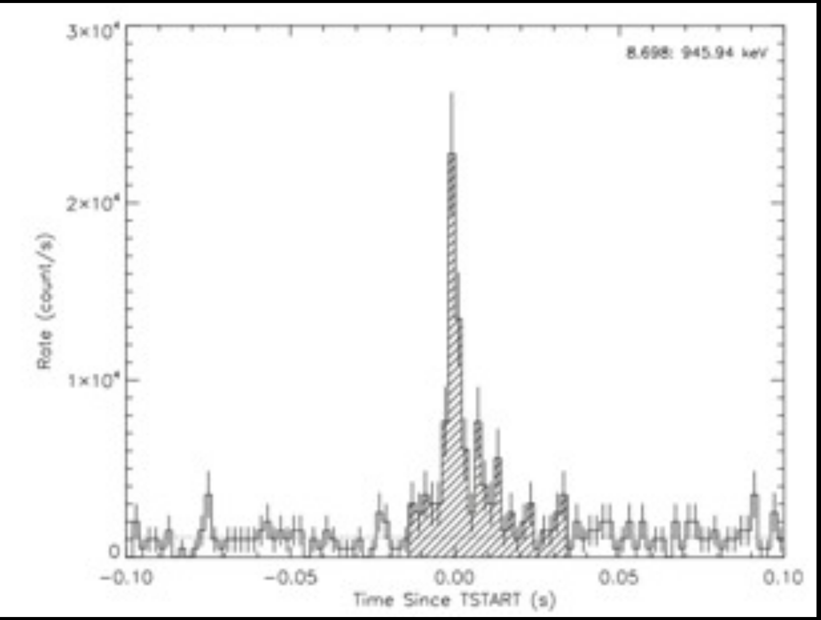
Summarizing...

"A high dipole field does not always make a magnetar, but a magnetar has necessary a high dipole field !"



SGR 0418+5729: transient SGR discovered in June 2009

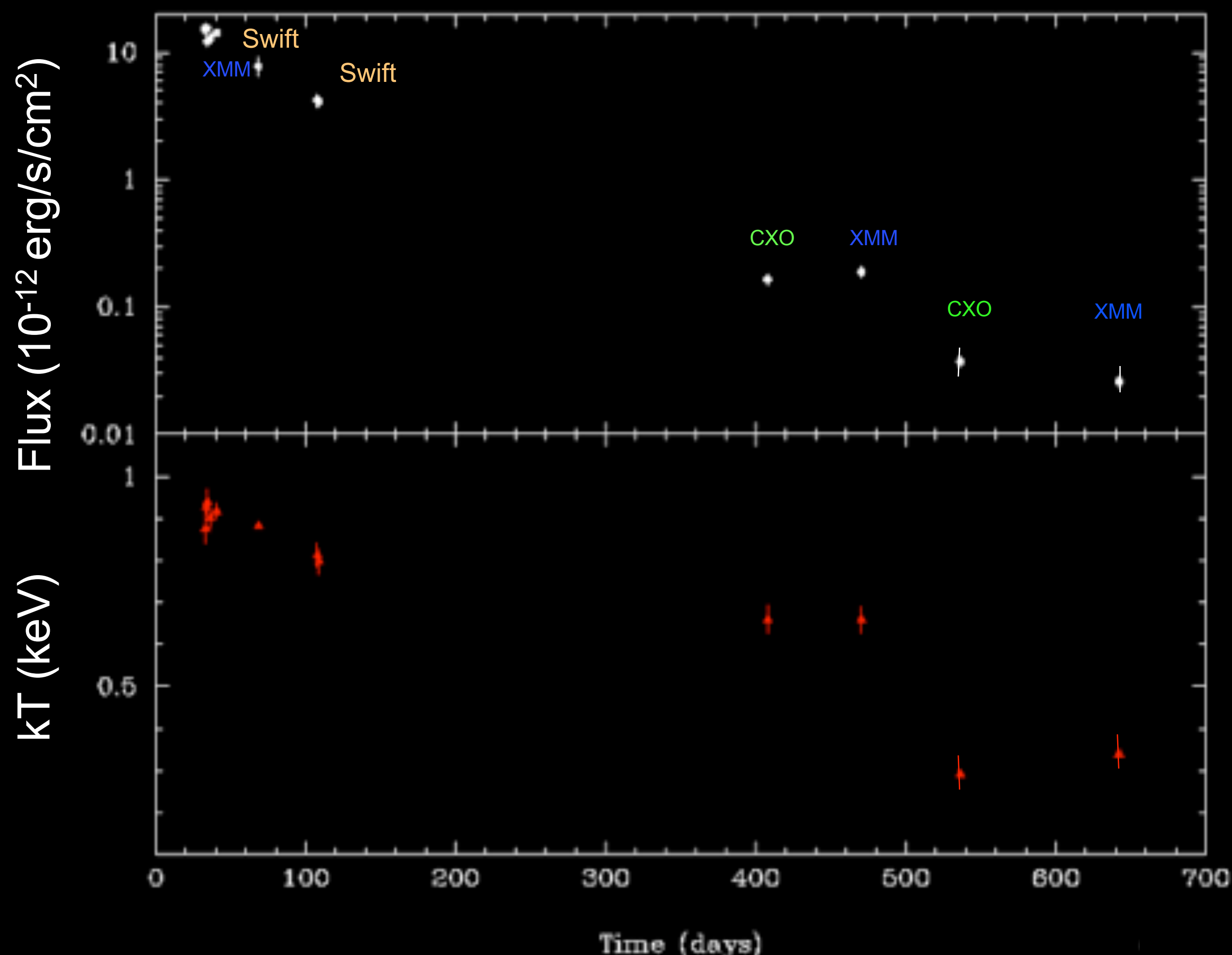
Typical SGR X-ray bursts



(van der Horst et al. 2010)

SGR 0418+5729: outburst decay

Typical SGR X-ray outburst decay and cooling



Lx~10^{34} erg/s

Lx~10^{31} erg/s

(Esposito et al. 2010; Rea et al. 2010)

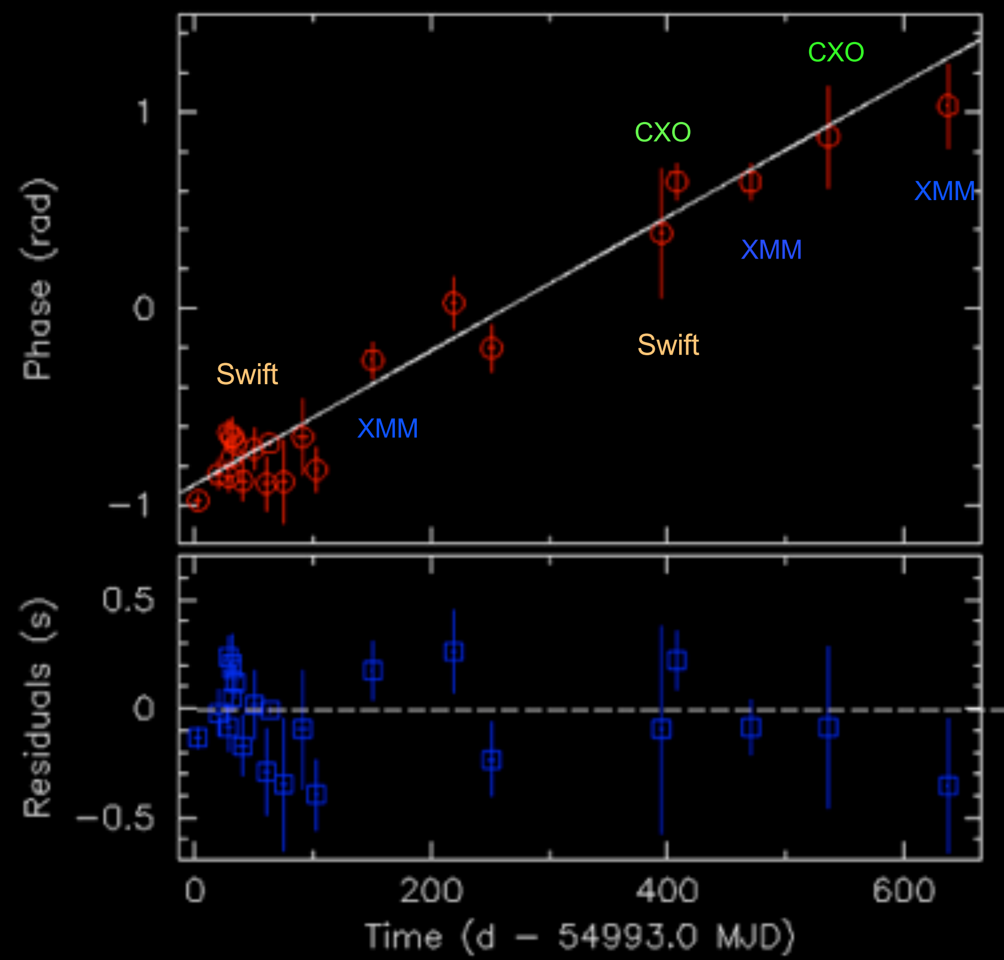
SGR 0418+5729: phase-coherent timing solution

NON-Typical SGR timing properties

P = 9.1s

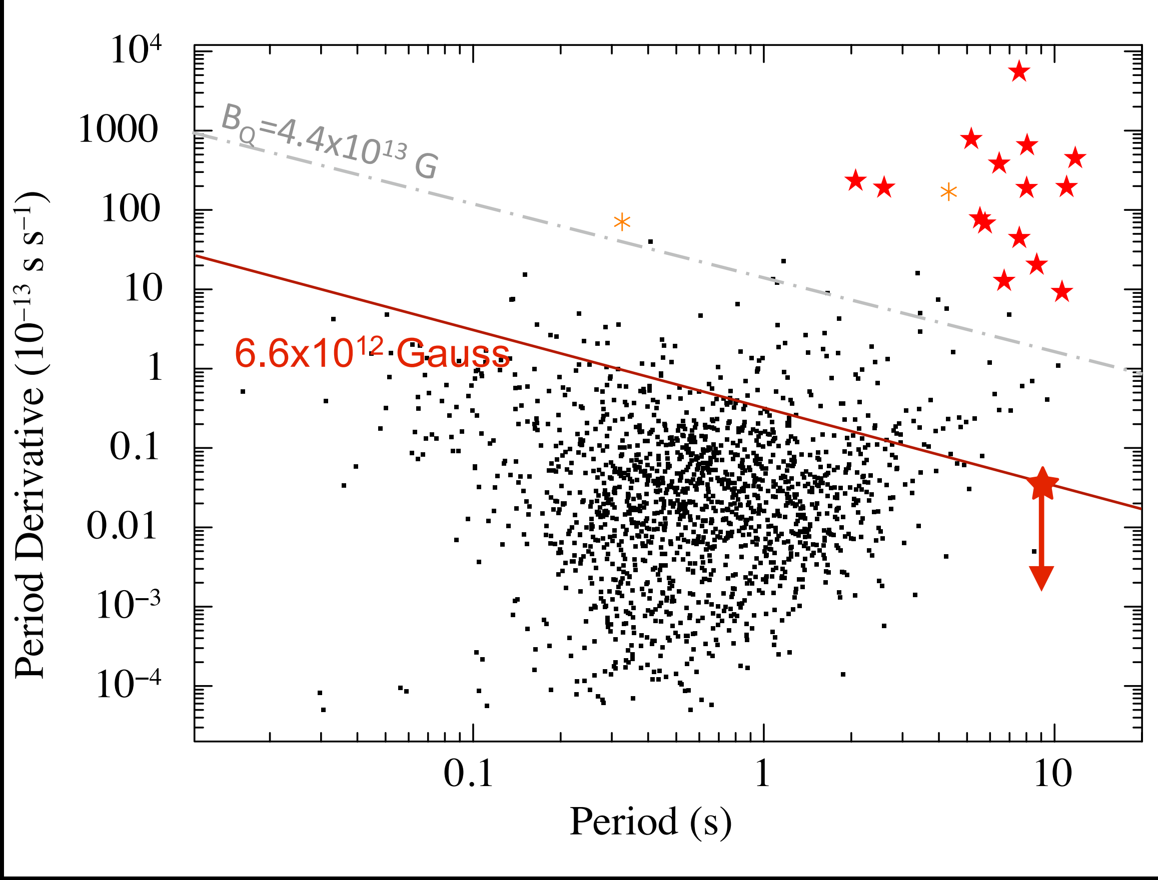
$\dot{P} < 4.7\times10^{-15}$ s/s

Magnetic field is:
$B < 6.6\times10^{12}$ G



SGR 0418+5729: a low-B soft gamma repeater

SGR 0418+5729 is the first soft gamma repeater ("magnetar"?) with a low surface dipolar B-field.



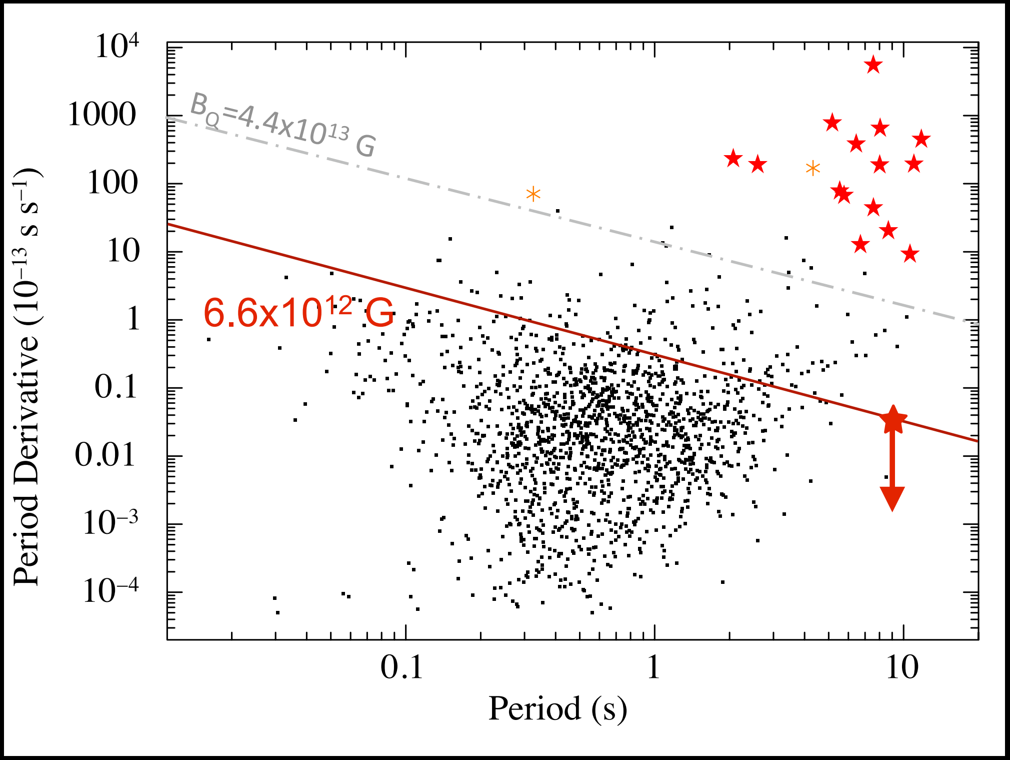
(Rea et al. 2010, Science, 330, 944)

What have we learned...

(model independent)

1. The surface dipolar magnetic field is not a crucial ingredient to show SGR-like activity

2. The QED critical field B_Q is not a limit for SGR-like emission



(Rea et al. 2010, Science, 330, 944)

ESA Press Release 2010: Are most pulsars really magnetars in disguise?

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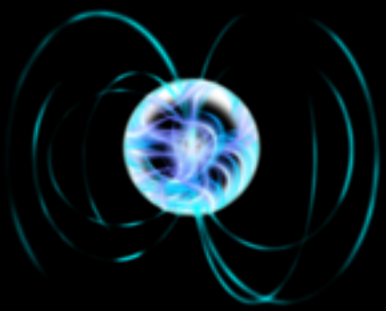
Does the magnetar model still hold?

(model dependent)

One possibility is that the magnetar activity can be driven by a strong internal toroidal field which might not be reflected in the external dipole if the neutron star is old enough that have dissipated most of its total magnetic energy.



$$B_{\rm tor}^2 \sim 6 L_{\rm X} t_{\rm c} / R_{\rm NS}^3$$

$L_x < 1.4 \times 10^{31}$ erg/s
$kT \sim 0.3$ keV
$d \sim 2$ kpc
$t_c > 25$ Myr

→ $B_{tor} \sim 2 \times 10^{14}$ G

Barely ok to power occasional bursts with its last bit of magnetic energy.

(Thompson & Duncan 1995; Thompson & Duncan 1996; Perna & Pons 2011)

Is SGR 0418+5729 an old magnetar?

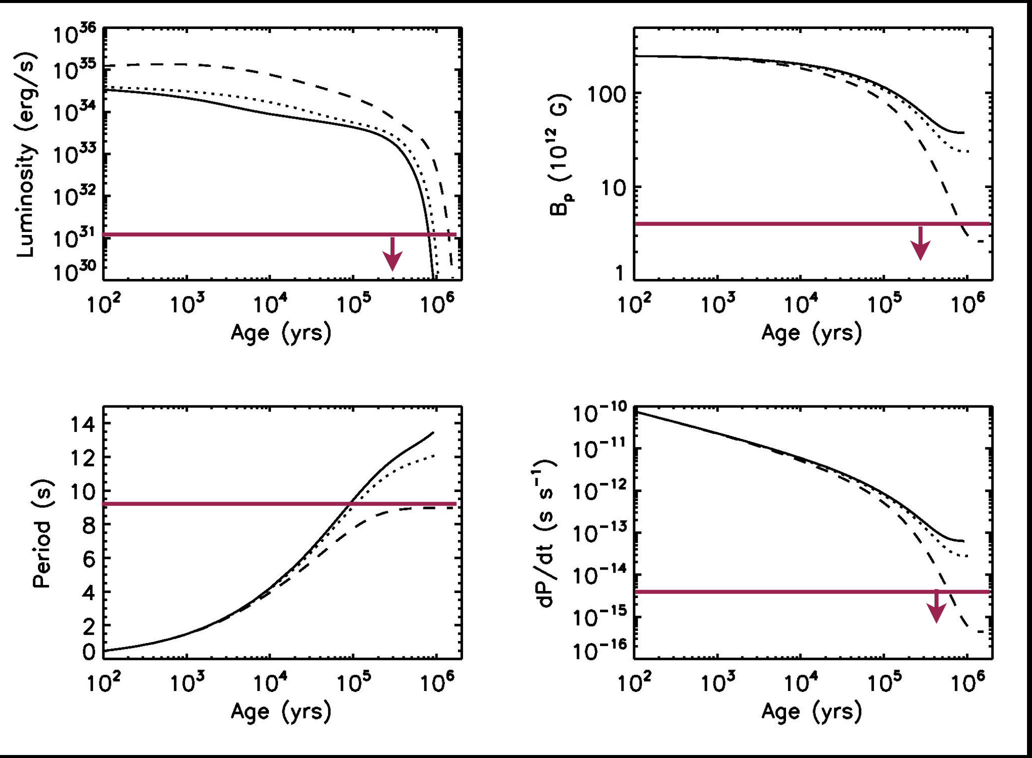
(model dependent)

• Coupled magnetic and thermal evolution
(Pons, Miralles & Geppert 2009)

• Standard cooling scenario, M=1.4 Msolar, toroidal+poloidal crustal field, external dipole
(Page et al. 2004)

• Initial conditions:
P_0 = 10 ms, B_{dip} = 2.5x10^{14} G,
B_{tor} = 0 (solid) , 4x10^{15} (dotted),
4x10^{16} G (dashed)

• Current stage:
P ~ 9 s, $\dot{P}$ ~ 4x10^{-16} s/s,
B_{dip} ~ 2x10^{12} G, L_X ~ 10^{31} erg/s
for an age ~ 1.5 Myr

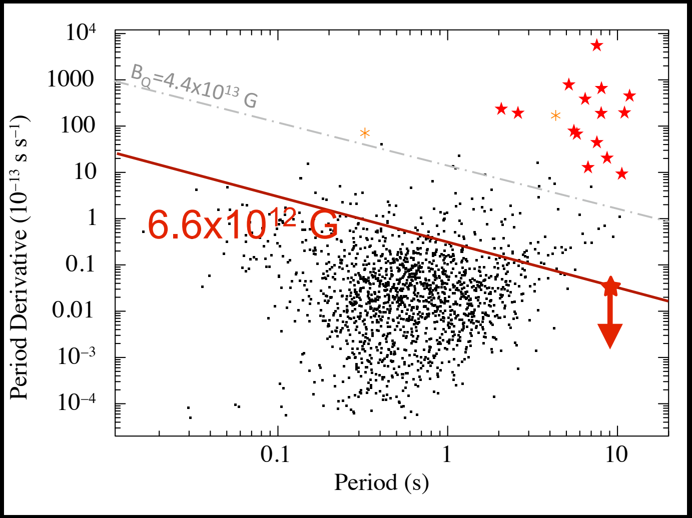


(Turolla, Zane, Pons, Esposito & Rea 2011, ApJ submitted)

Summary

1. The magnetar model should now cope with low-dipolar B neutron stars. How low can this dipolar B be for the model to hold on the assumption of a strong toroidal-internal B field?

Until B_{int}/B_{dip} ~ 100 the magnetar model is still ok!

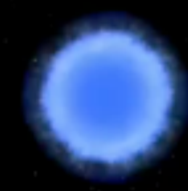


2. The discovery of transient magnetars and of low magnetic field magnetars imply that magnetar-like activity is more diffuse in the pulsar population than what believed so far.

More than 20% of the known radio pulsars have a higher B_{dip}! There is then a continuum of magnetar-like activity among pulsars: B_Q is not crucial!

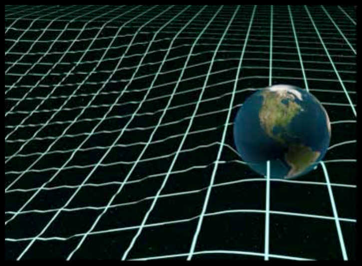
Consequences

1. SN explosions



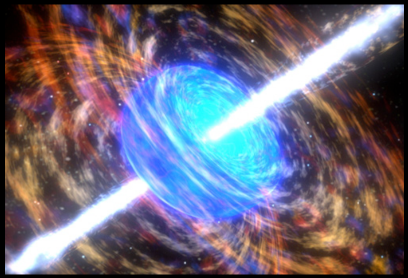
A large number of strong-B neutron stars call for a key ingredient of the NS formation model: an extreme internal B should then be a common place rather than an exception

2. GW radiation from newly born magnetars



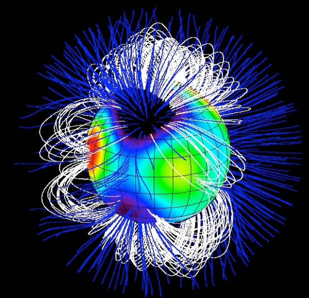
The GW background radiation produced by the formation of highly magnetic neutron stars is probably underestimated given the recent results.

3. Gamma-ray bursts



If at least 50% of the formed neutron stars have a strong B-field, hence GRBs due to the formation of such stars are way more frequent than predicted.

3. Massive Stars



If strong-B neutron stars are formed by the explosion of highly magnetic stars, there should be many more of such stars than predicted thus far

Too B or not too B?