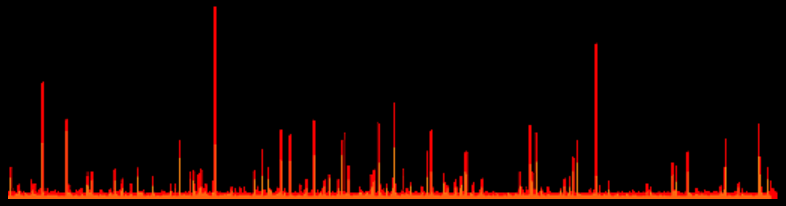
Magnetars: explosive neutron stars with extreme magnetic fields

Nanda Rea
Institute of Space Sciences,
CSIC-IEEC, Barcelona

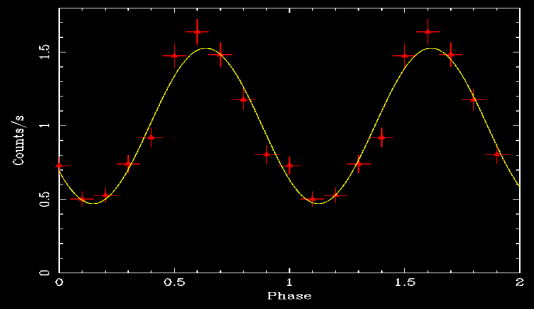
How magnetars are discovered?

Short x/gamma-ray bursts (initially though to be GRBs)



Soft Gamma Repeaters

Bright X-ray pulsars with 0.5-10keV spectra modelled by a thermal plus a non-thermal component



Anomalous X-ray Pulsars

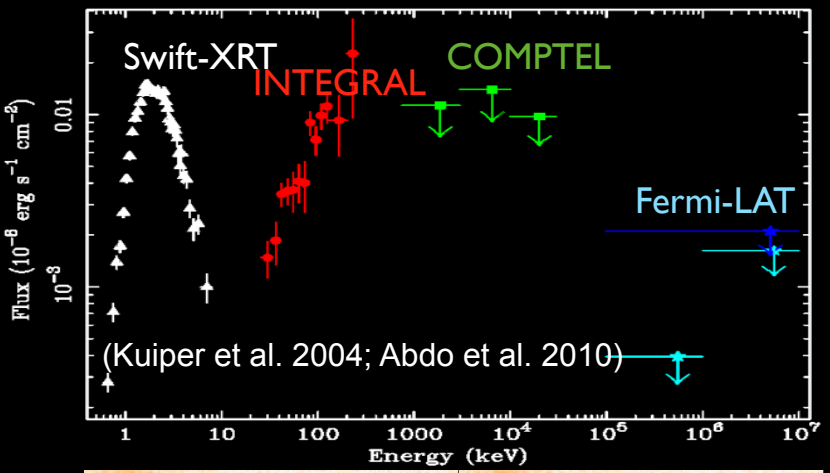
Bright X-ray transients!

Transients

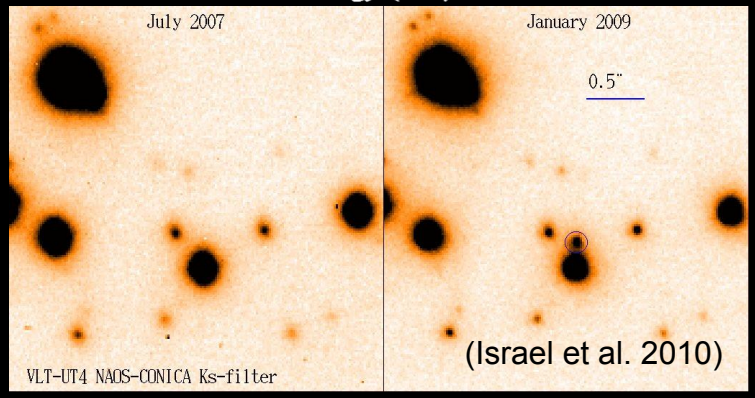
No more distinction between Anomalous X-ray Pulsars, Soft Gamma Repeaters, and transient magnetars: all showing all kind of magnetars-like activity.

Magnetars general properties

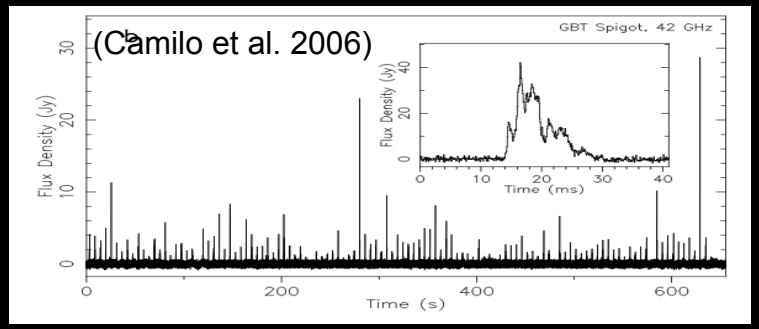
- X-ray pulsars Lx ~ 10^{33}-10^{36} erg/s
- strong soft and hard X-ray emission
- short X/gamma-ray flares and long outbursts
- pulsed fractions ranging from ~2-80 %
- rotating with periods of ~0.3-12s
- period derivatives of ~10^{-14}-10^{-11} s/s
- magnetic fields of ~10^{13}-10^{15} Gauss
- glitches and timing noise
- faint infrared/optical emission (K~20; sometimes pulsed and transient)
- transient radio pulsed emission



(Kuiper et al. 2004; Abdo et al. 2010)



(Israel et al. 2010)



(Camilo et al. 2006)

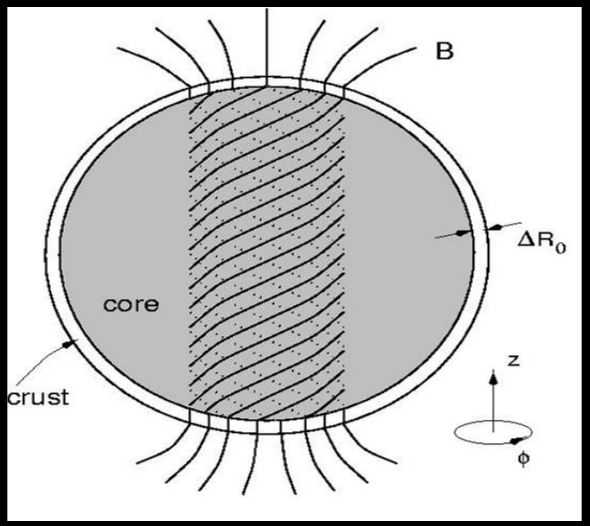
(see Woods & Thompson 2006, Mereghetti 2008, Rea & Esposito 2011 for a review)

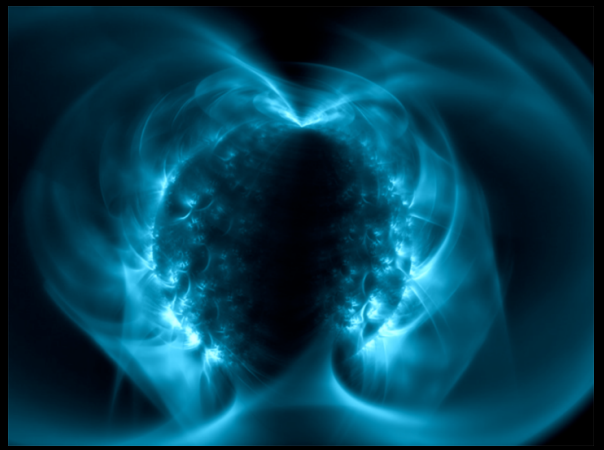
How magnetar persistent emission is believed to work?

- Magnetars have magnetic fields twisted up, inside and outside the star.

- The surface of a young magnetar is so hot that it glows brightly in X-rays.

- Magnetar magnetospheres are filled by charged particles trapped in the twisted field lines, interacting with the surface thermal emission through resonant cyclotron scattering.



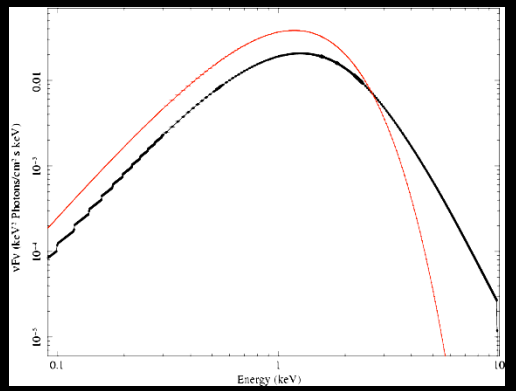


(Thompson, Lyutikov & Kulkarni 2002; Fernandez & Thompson 2008; Nobili, Turolla & Zane 2008a,b; Rea et al. 2008, Zane et al. 2009)

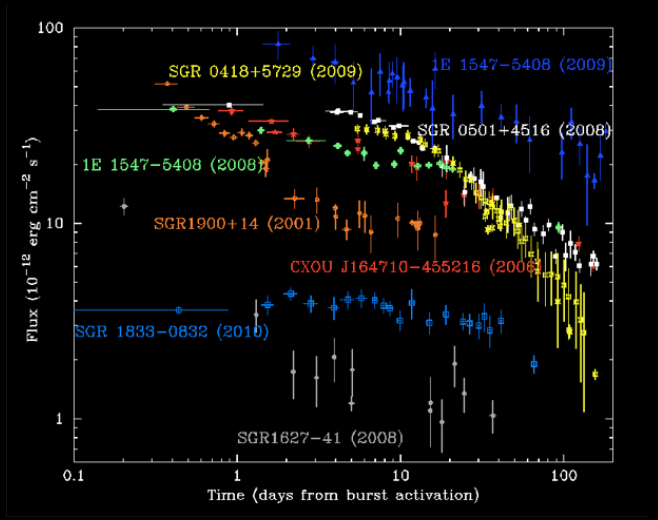
(Thompson & Duncan 1992; 1993; 1995;1996)

Where do we see the twisted magnetic fields?

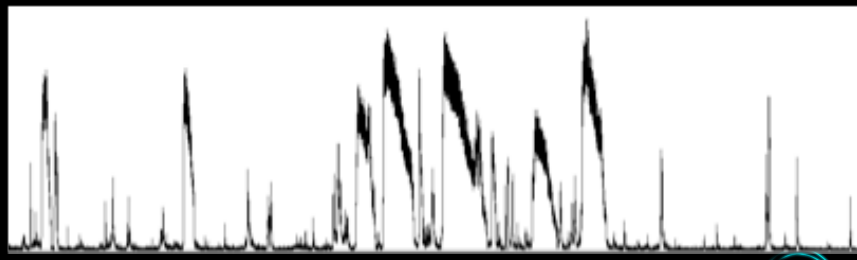
In their X-ray spectral shape....



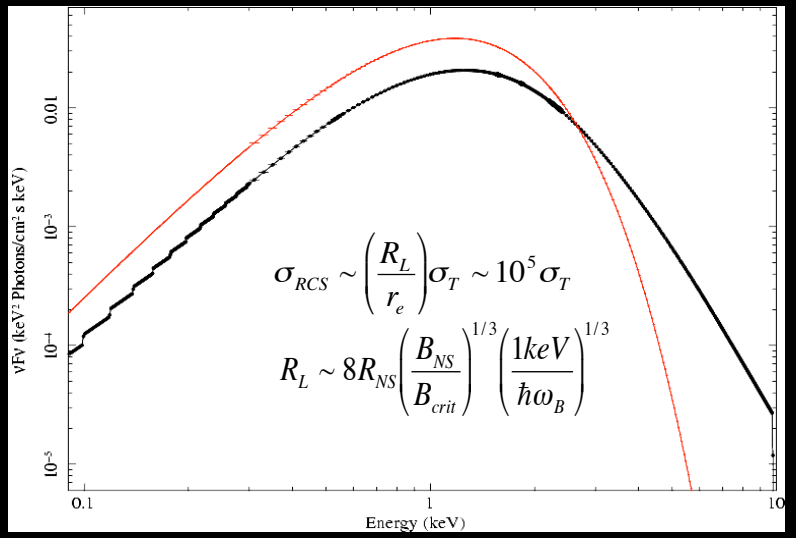
In their transient outbursts....



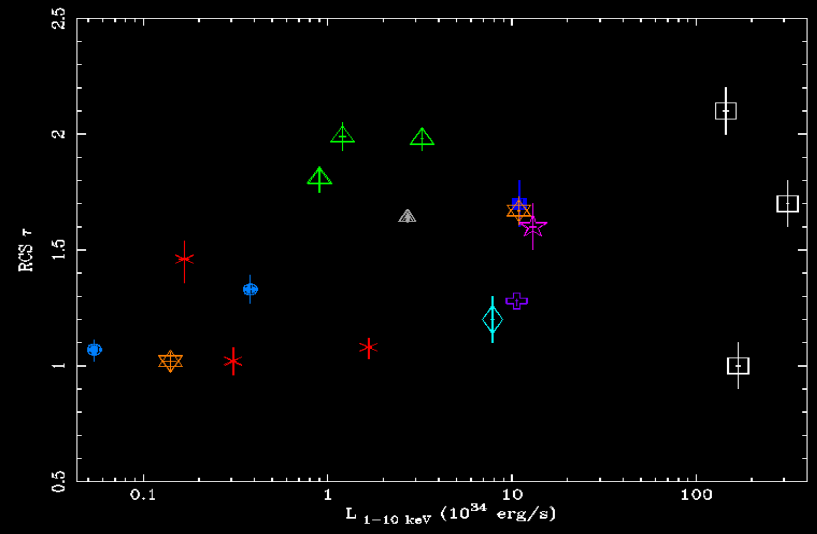
In their X-ray/gamma-ray flares...



Spectral shape: Resonant Cyclotron Scattering



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

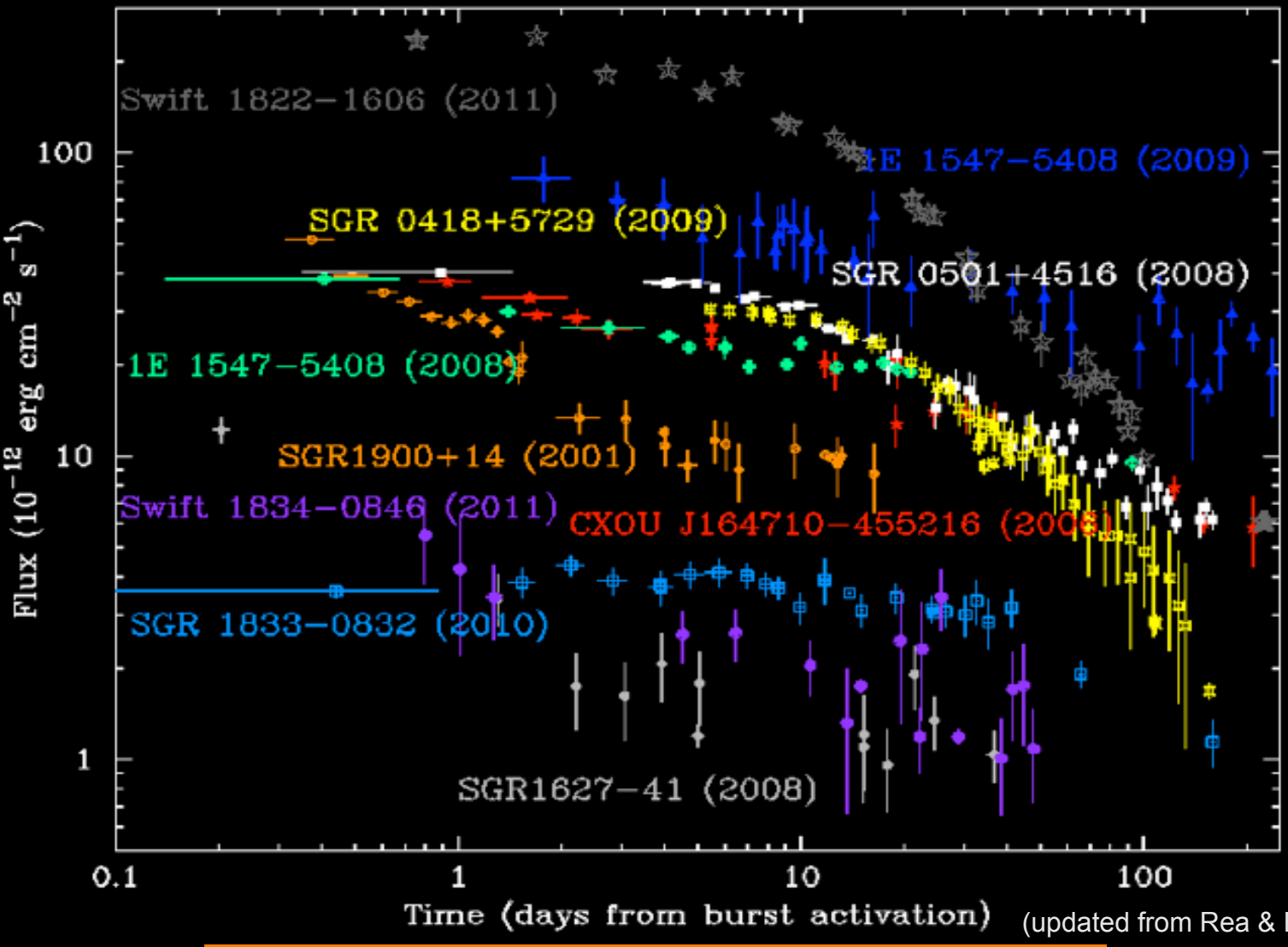


Magnetars' magnetospheric density is ~10^3 times the normal radio pulsar density!

(Lyutikov & Gavriil 2006; Rea, Zane, Turolla, Lyutikov & Gotz 2008; Zane, Rea, Turolla, Nobili 2009)

see A. Beloborodov and R. Hascoet's talk!

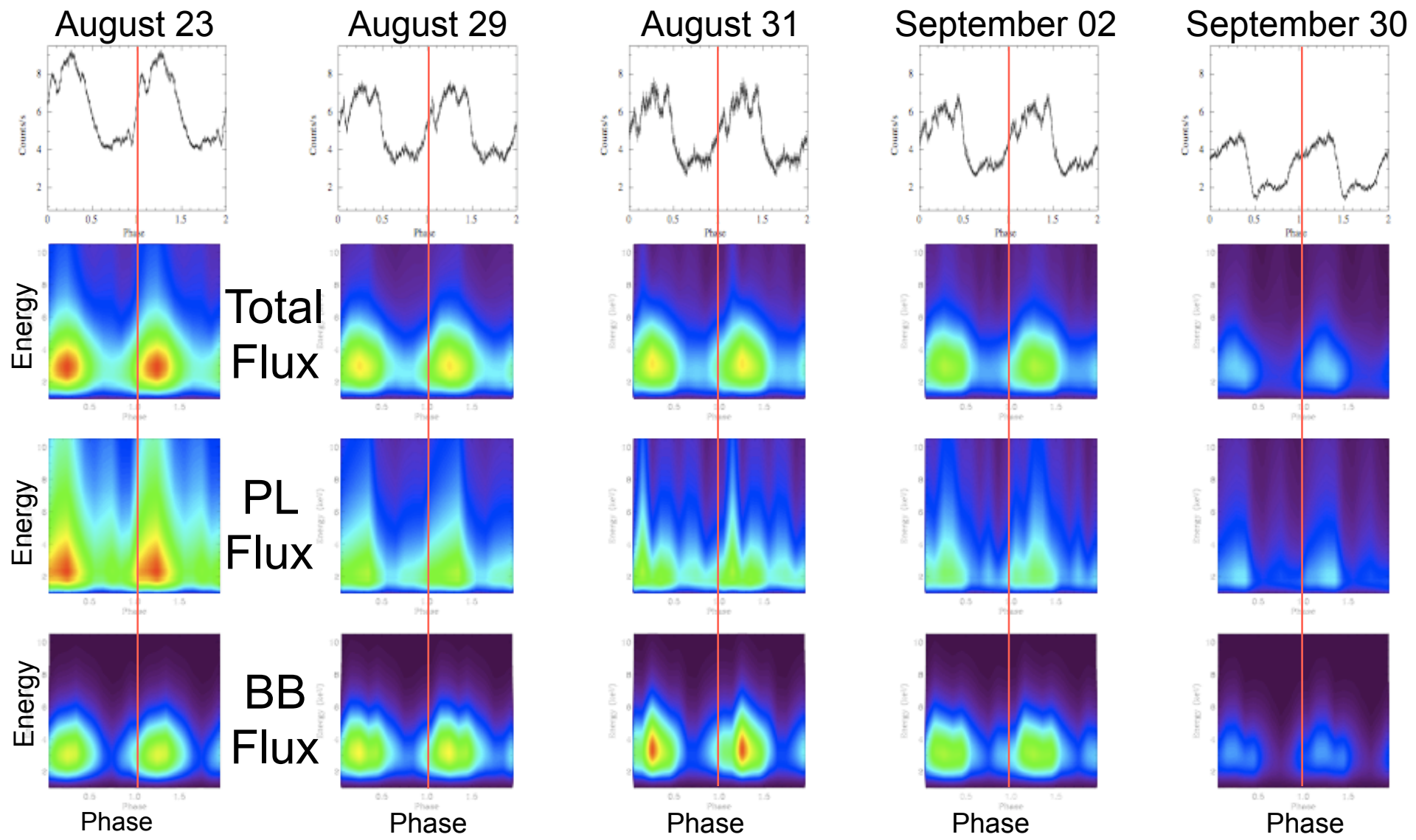
Magnetar Outbursts



(updated from Rea & Esposito 2011)

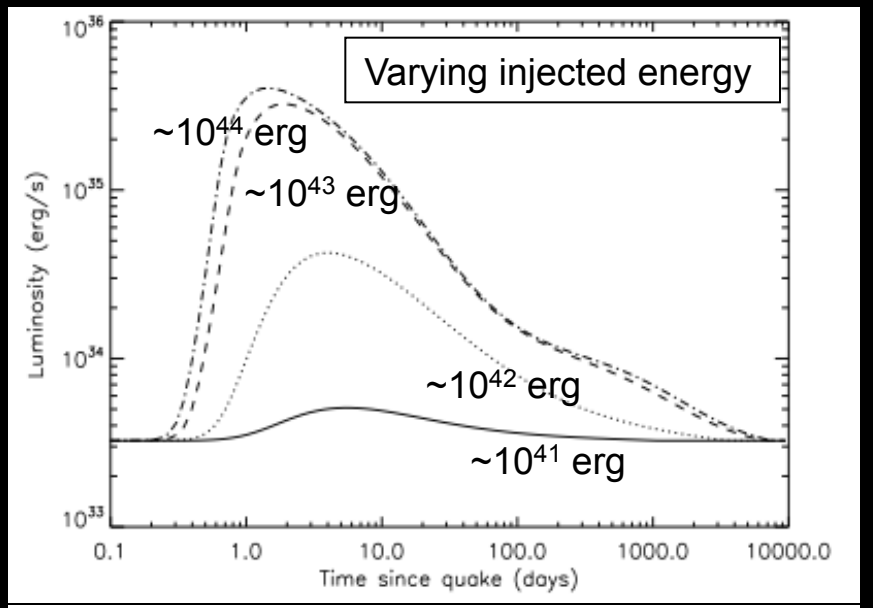
see G. Rodriguez-Castillo, L. Lin and A. Tiengo's talk!

Magnetar outbursts



(Rea et al. 2009, MNRAS, 396, 2419)

How magnetar outbursts and flares are believed to work?



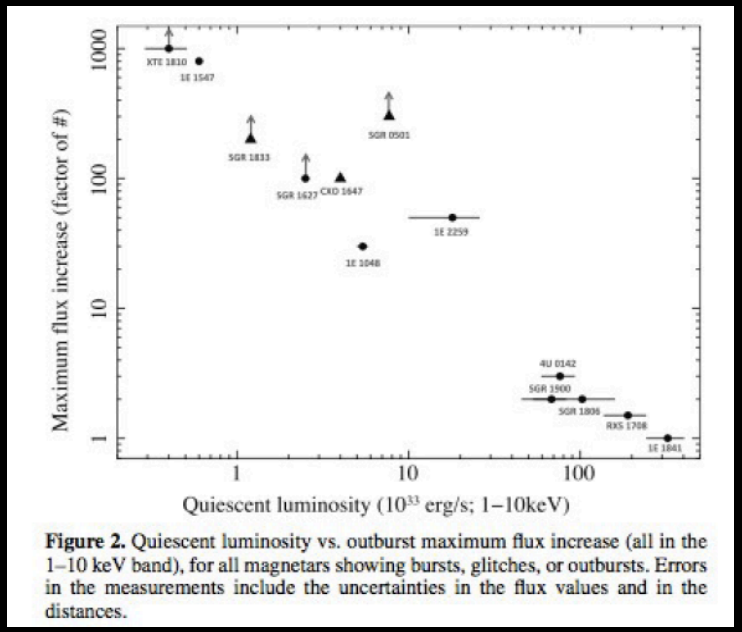
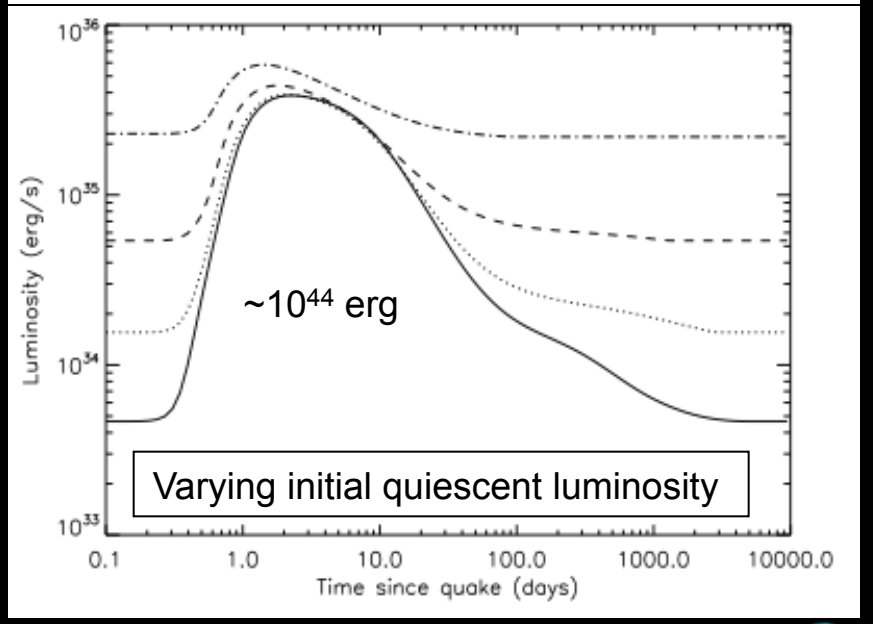


Figure 2. Quiescent luminosity vs. outburst maximum flux increase (all in the 1–10 keV band), for all magnetars showing bursts, glitches, or outbursts. Errors in the measurements include the uncertainties in the flux values and in the distances.

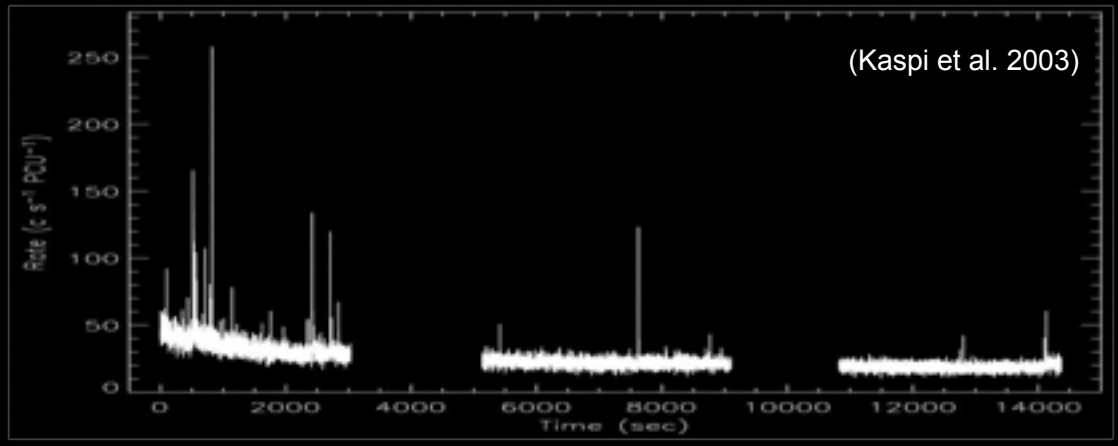


(Pons & Rea 2012, ApJ Letters, 750, L6)

Magnetar flaring activity

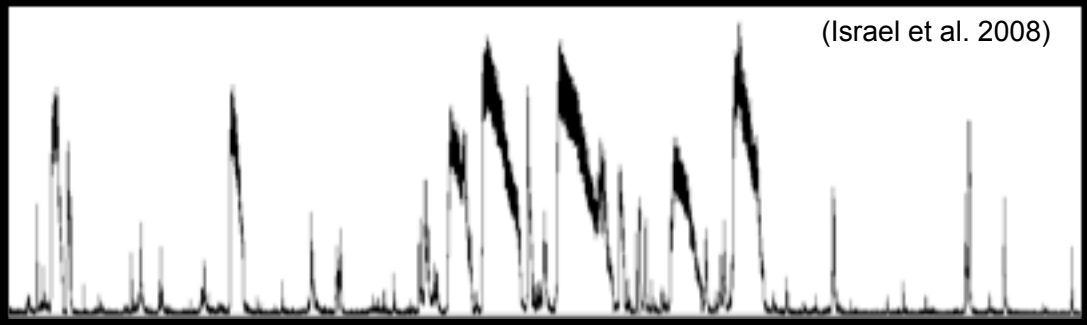
Short bursts

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



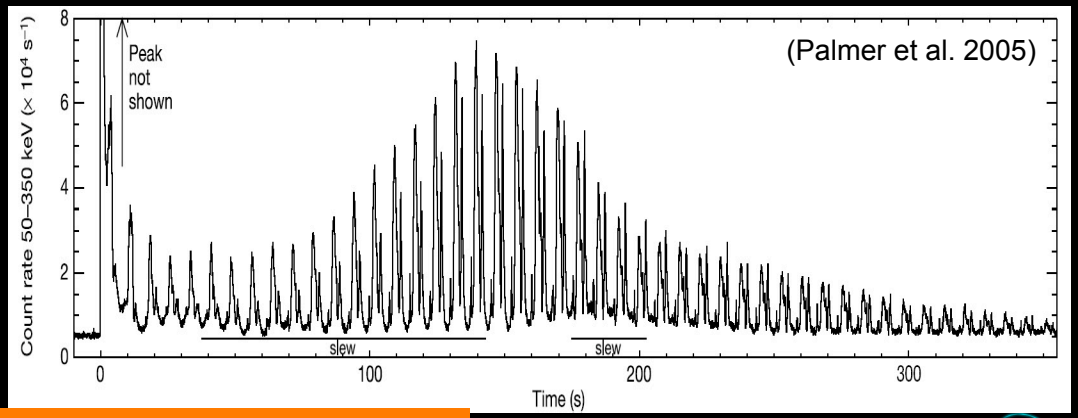
Intermediate bursts

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



Giant Flares

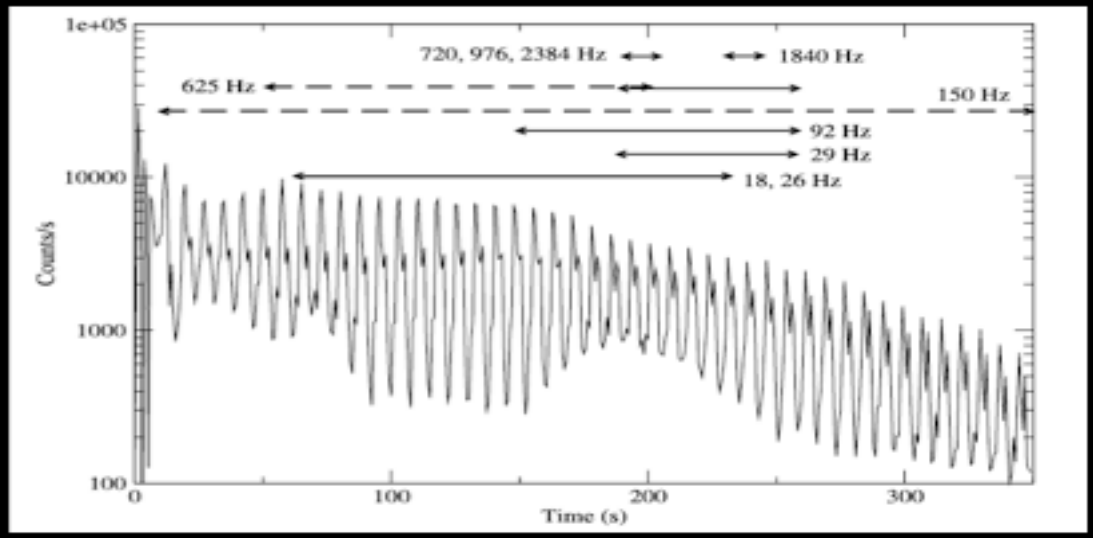
- their output of high energy is exceeded only by blazars and GRBs
- peak energy > 3x10^{44} ergs/s
- <1 s initial peak with a hard spectrum which rapidly become softer in the burst tail that can last > 500s, showing the NS spin pulsations, and quasi periodic oscillations (QPOs)



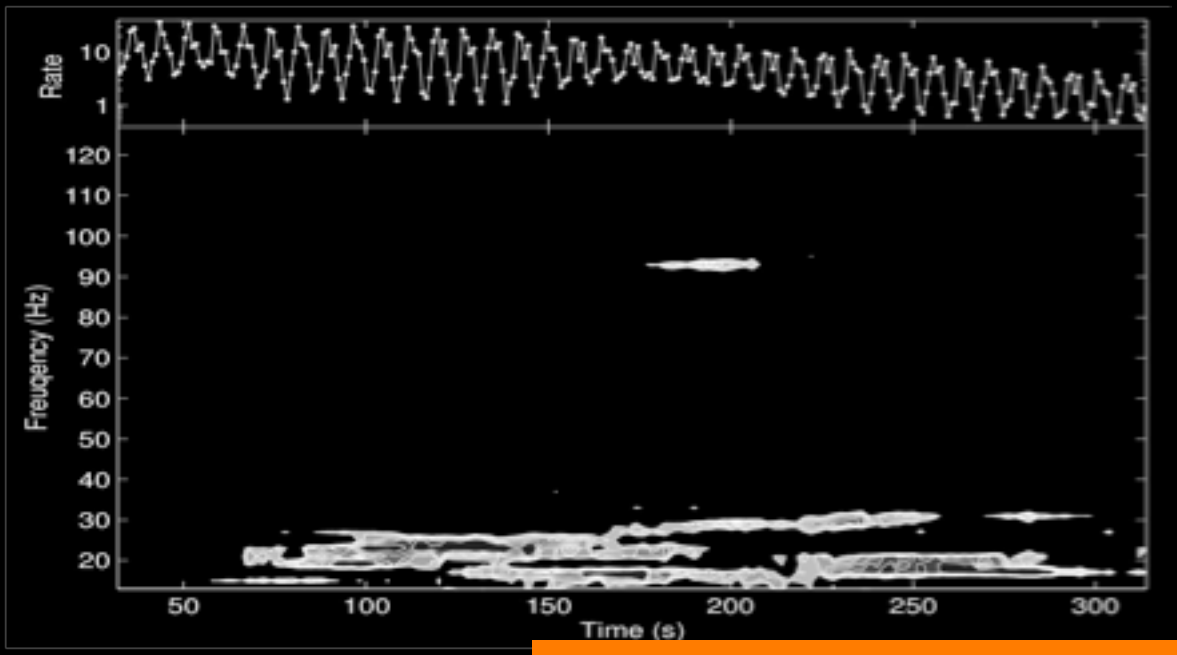
see E. Gogus and C. D'Angelo's talk!

Other evidence of magnetic instability

- star-quakes on a neutron star!



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

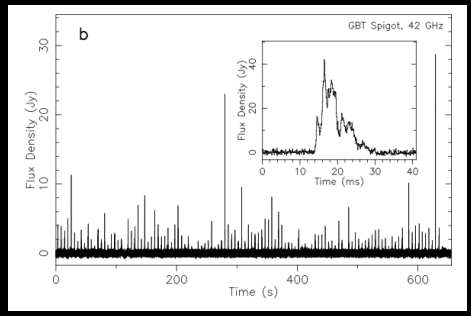


see M. Gabler and R. Ciolfi's talk!

New insights....

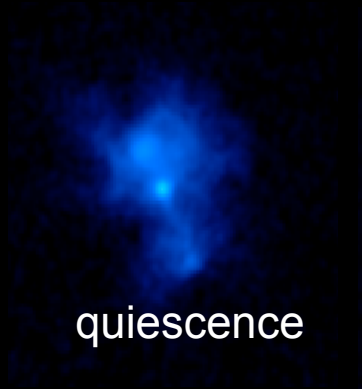
1. Magnetars can be radio pulsar during outbursts.

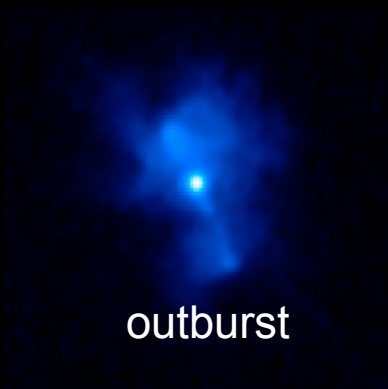
(Camilo et al. 2006, Nature 442, 892)



2. A “normal” X-ray pulsar showed magnetar activity.

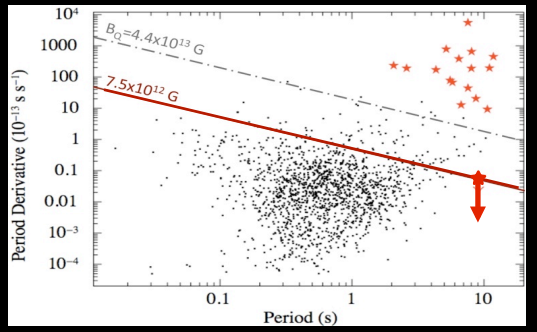
(Gavriil et al. 2008, Science, 319, 1802; Kumar & Safi-Harb, ApJ 678, L43)


quiescence

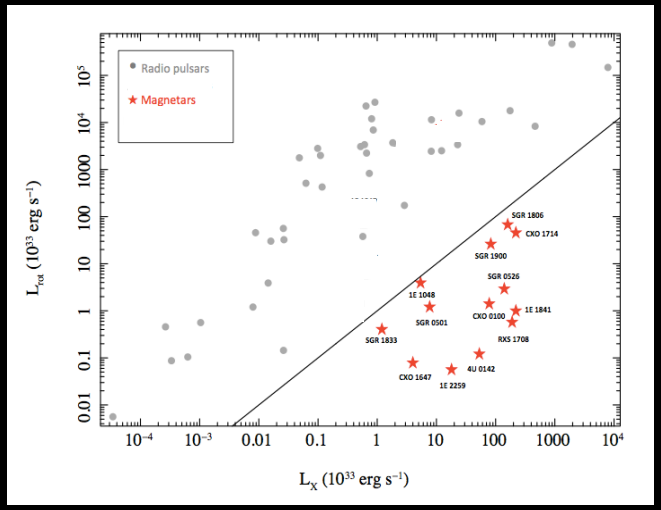

outburst

3. A magnetar was discovered having a low B-field.

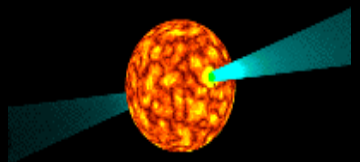
(Rea et al. 2010, Science, 330, 944)



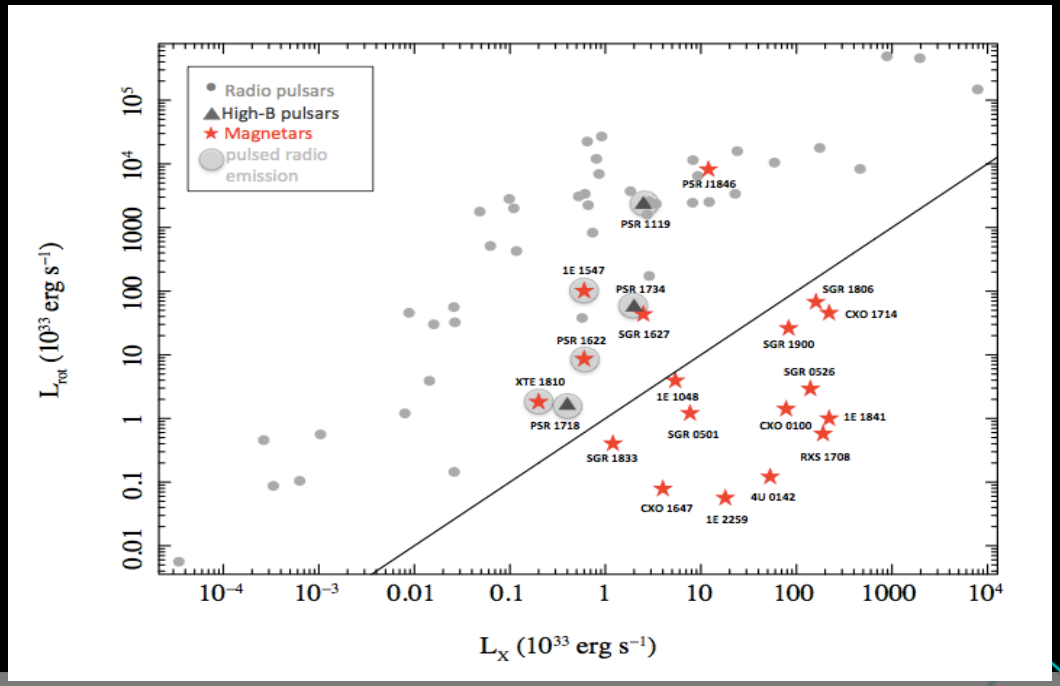
Magnetar radio emission might be powered by rotation



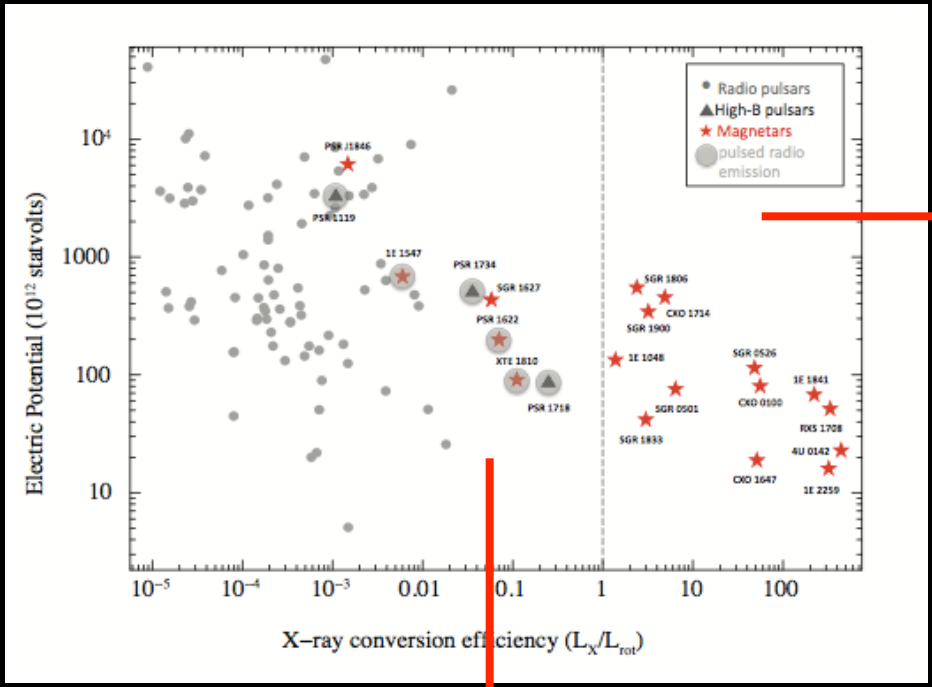
For a long time we believed that magnetars have X-ray luminosity exceeding their rotational power.

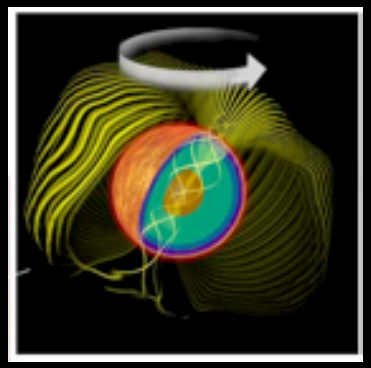


All radio magnetars have quiescent luminosities lower than their rotational power. Can their radio emission be powered by rotation?

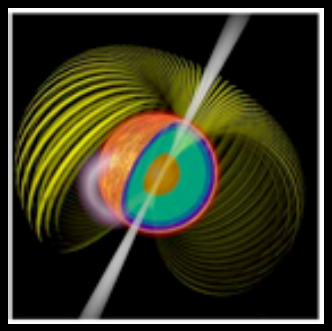


Magnetar radio emission might be powered by rotation





Large twisted field. High density and strong currents. Pair cascades inhibited in the magnetosphere.



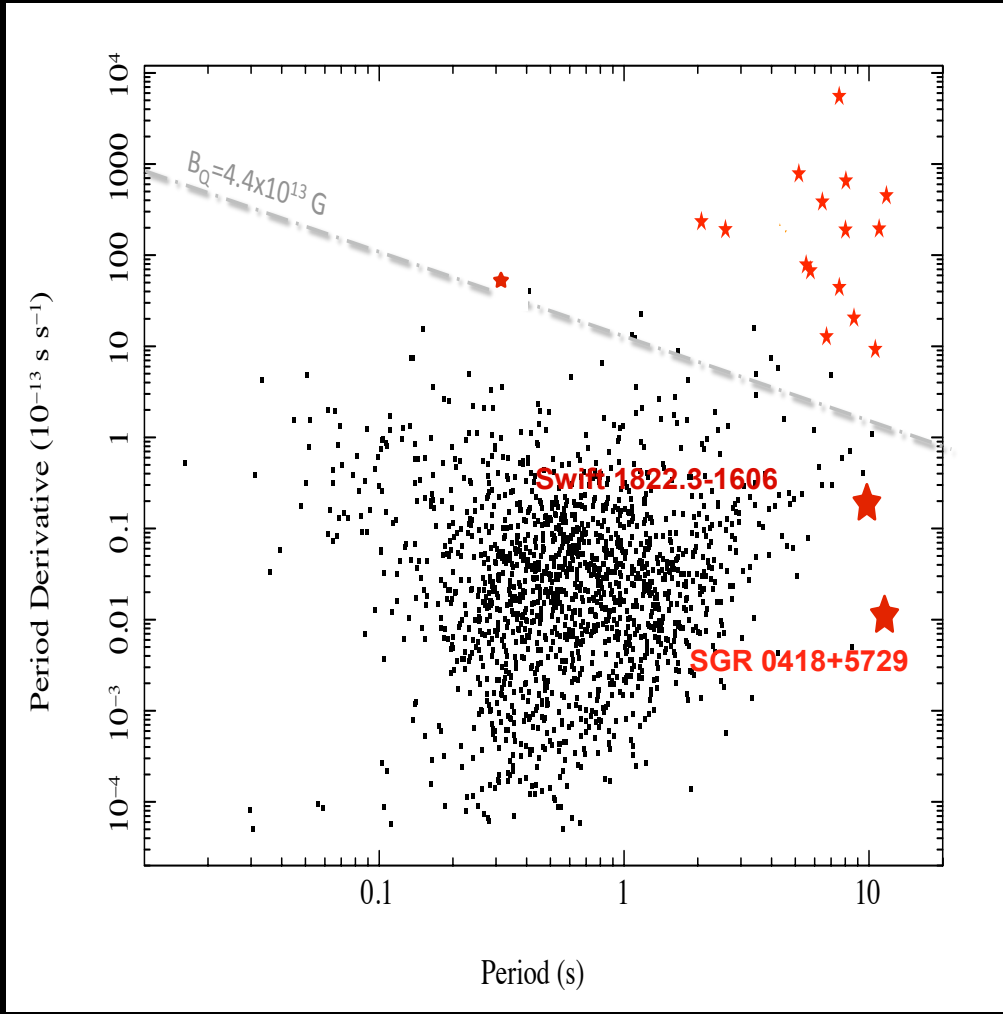
Low twists. Low density, weak currents.Enough Edot, hence pair cascade can proceed. Flat spectra because of high magnetospheric densities.

Strong predicting tool!

(Rea et al. 2012, ApJ Letters, 748, L12, and highlighted in *Science* as Editors' choice)

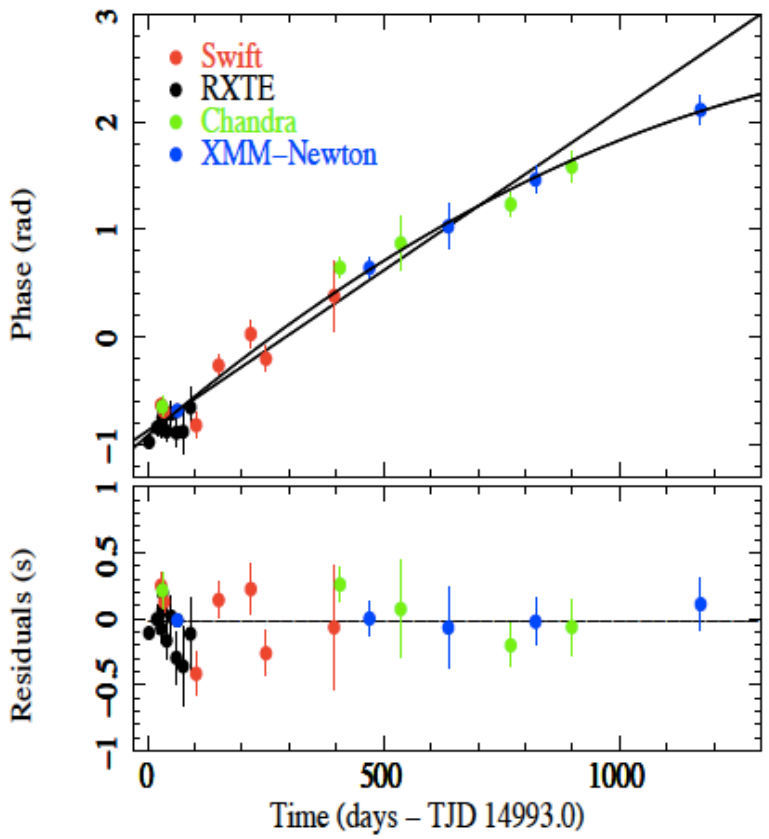
Low magnetic field magnetars

We know now of two low field magnetars: SGR 0418+5729, and Swift 1822.3-1606

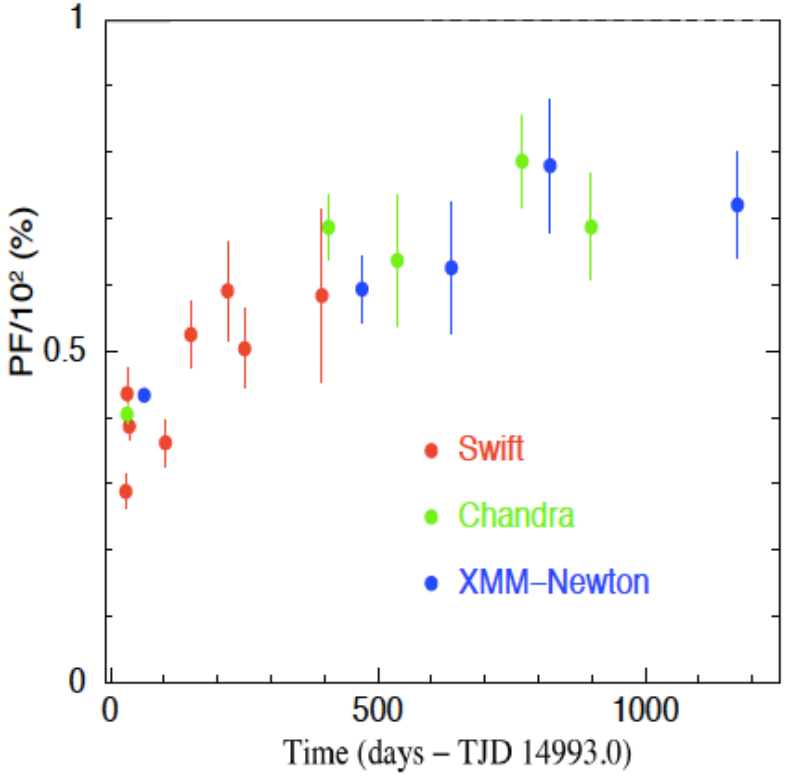


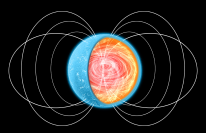
(Rea et al. 2010, Science, 330, 944; Rea et al. 2012, ApJ, 754, 26; Sholtz et al. 2012, ApJ 759, 45; Rea et al. 2013, ApJ in press)

Low magnetic field magnetars: SGR 0418+5729



P = 9.07838822(5)s and Pdot =4(1)x10^{-15} s/s



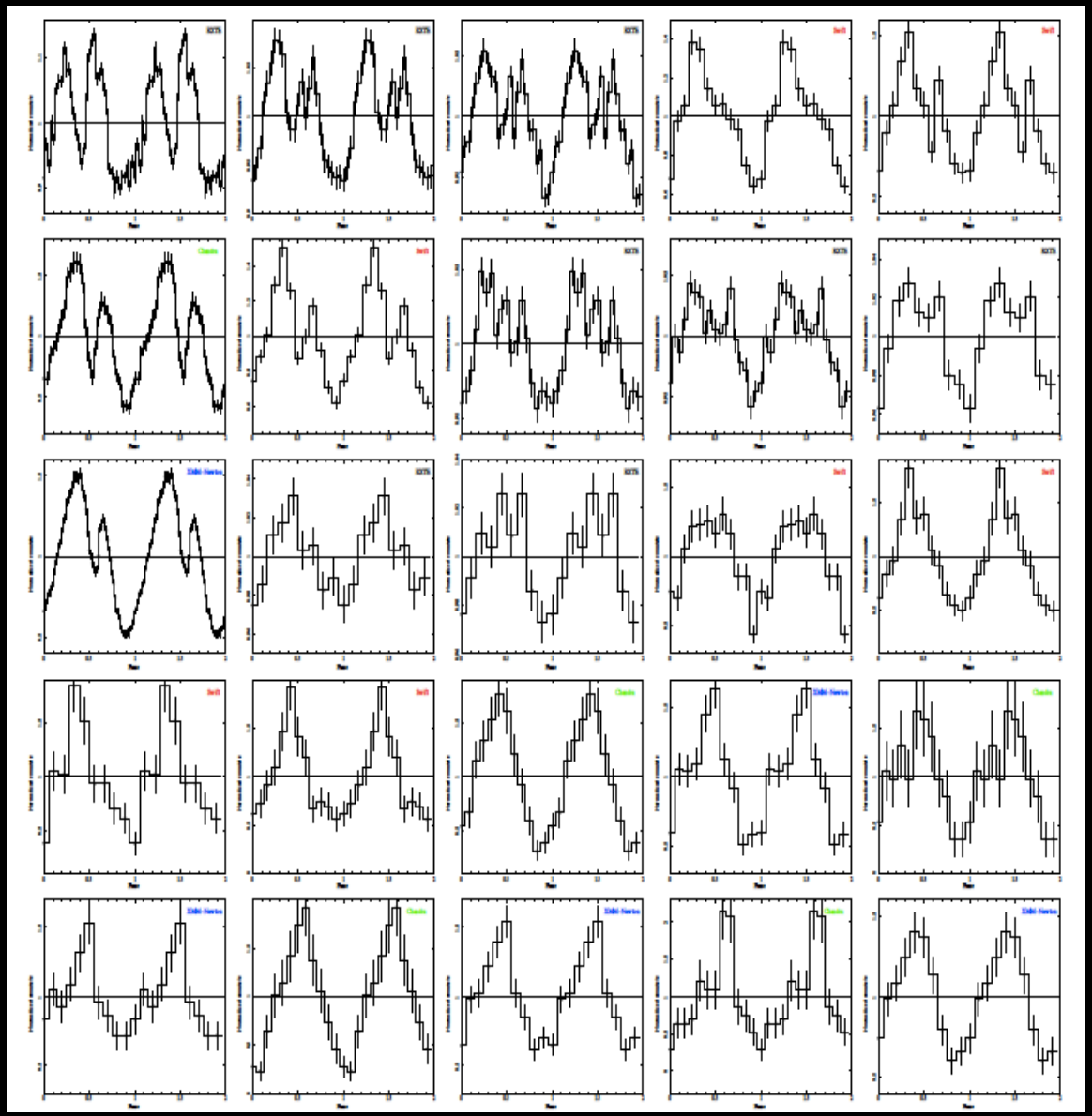


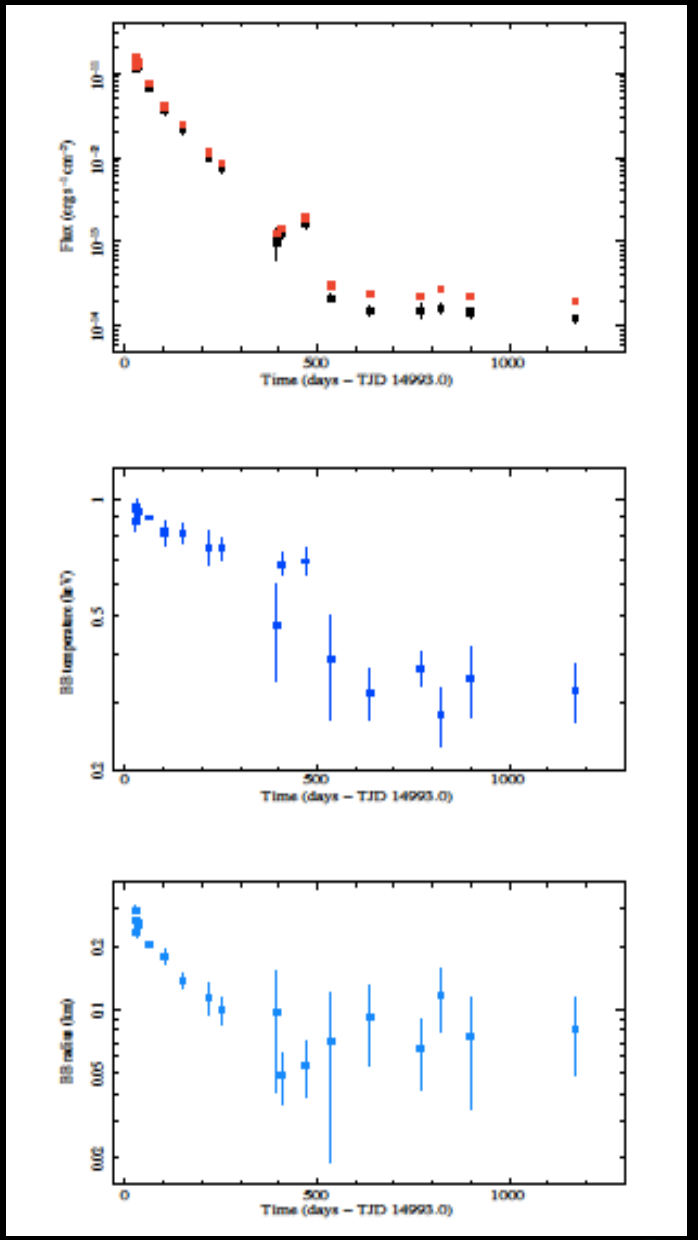
NASA Press Release today at 16:00!

Magnetic field is:
B =6x10^{12} G
(3.5 sigma)

(Rea et al. 2013, ApJ in press)

Low magnetic field magnetars: SGR 0418+5729





(Rea et al. 2013, ApJ in press)

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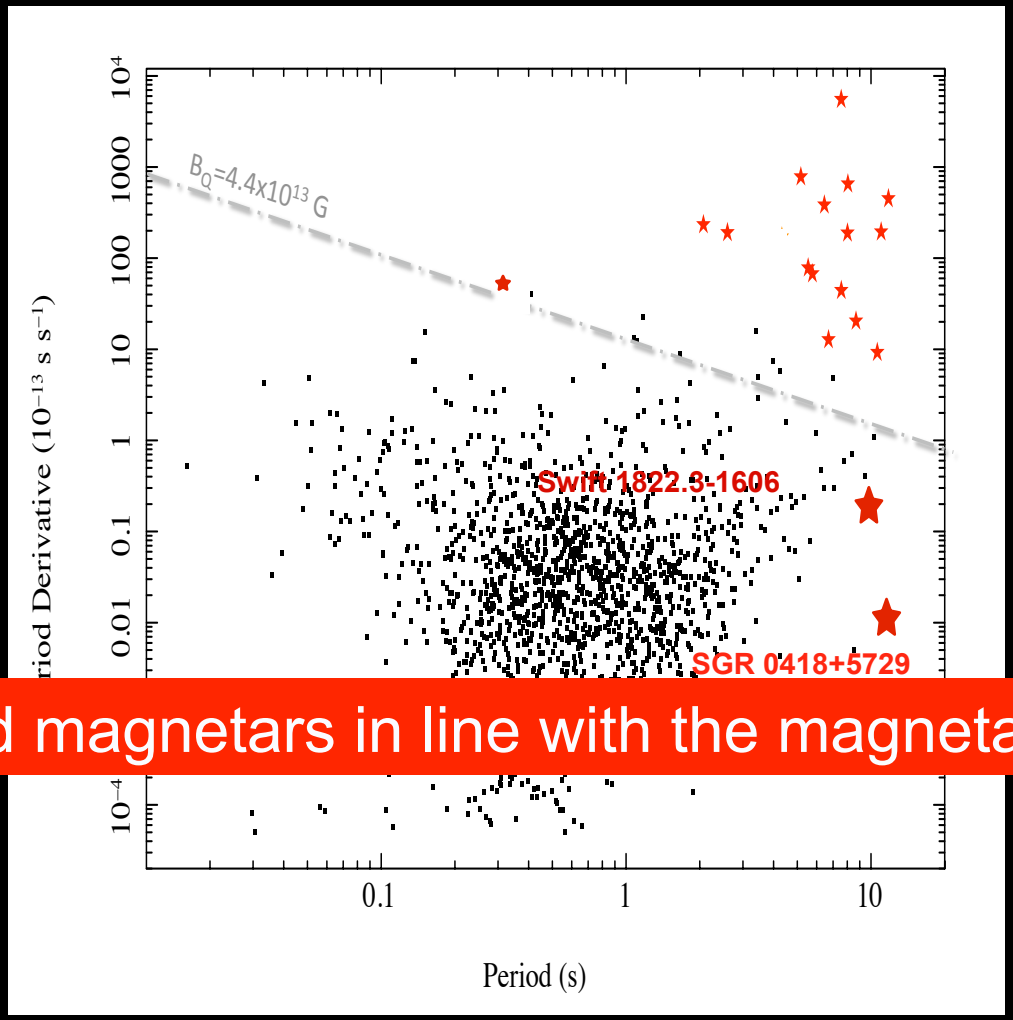
We know now of at least two low field magnetars: SGR 0418+5729, and Swift 1822.3-1606

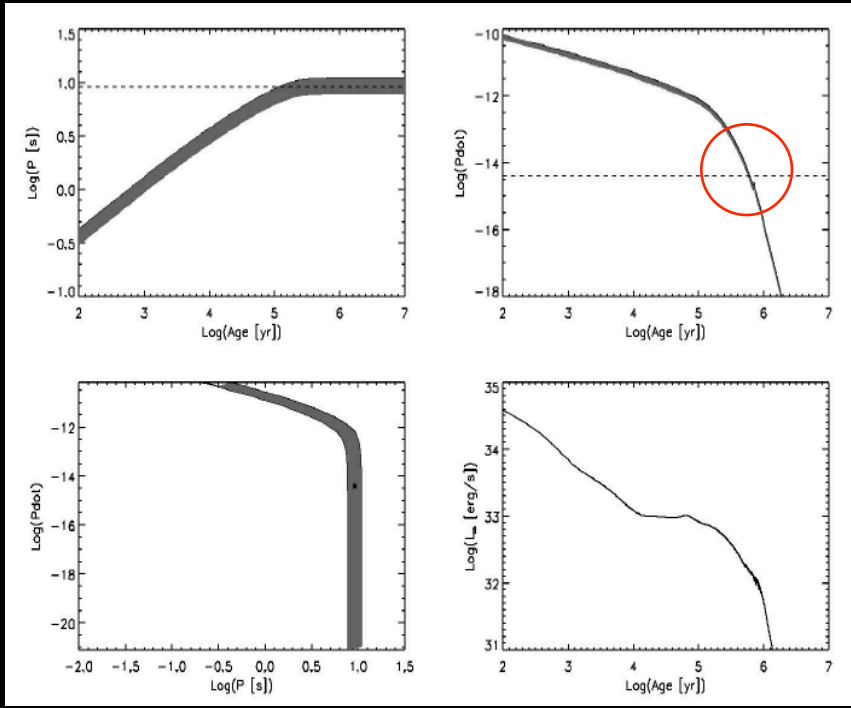


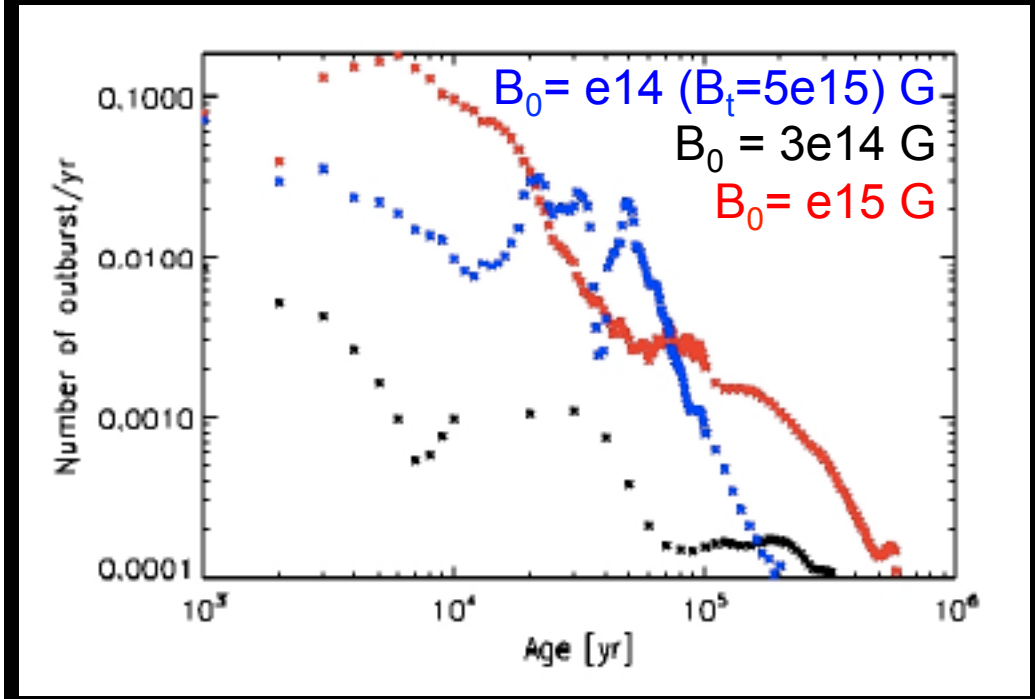
Are low field magnetars in line with the magnetar model?

(Rea et al. 2010, Science, 330, 944; Rea et al. 2012, ApJ, 754, 26; Sholtz et al. 2012, ApJ 759, 45; Rea et al. 2013, ApJ in press)

Low field magnetars: they are many!

Can a neutron star with 6×10^{12} Gauss dipolar field, as SGR 0418+5729, show magnetar-like outburst and flares?



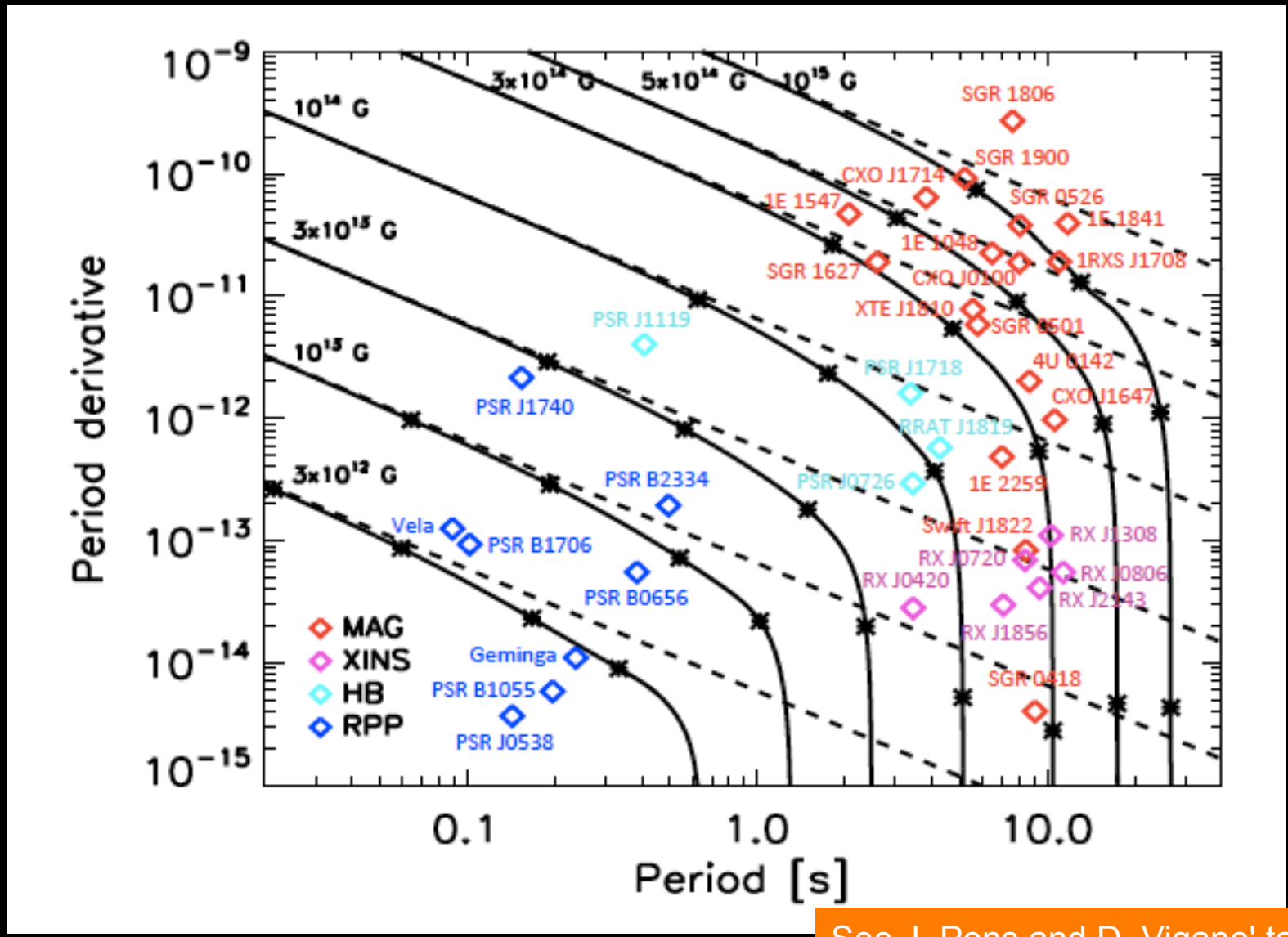


See J. Pons and D. Vigano' talks!

(Rea et al. 2013 in press; Vigano', et al. 2013, submitted)

Magnetic evolution of neutron stars: toward a unification

http://neutronstarcooling.info/



See J. Pons and D. Vigano' talks!

(Vigano', Rea, Pons, Perna, Aguilera & Miralles 2013, MNRAS submitted)

What is a magnetar then?

A magnetar is a neutron star which showed magnetic-powered emission!

- Regardelss of the measured surface dipolar field (SGR0418)

- Regardless of being in part powered by rotation (Kes75)