An observational point of view on Magnetars

Sandro Mereghetti
INAF – IASF Milano

Conclusions

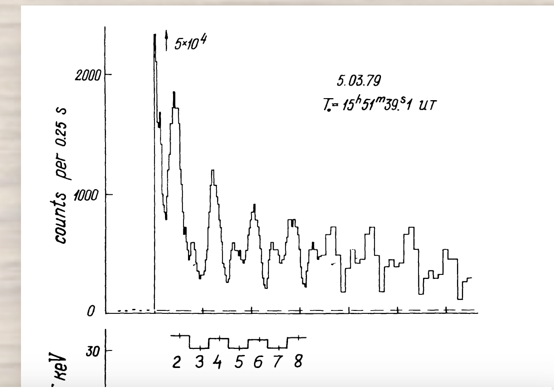
Timing behavior and variability indicate the presence of very dynamic magnetospheres with complex and variable topology

The phase-dependent absorption line in the "low-Pdot magnetar" SGR 0418 supports the presence high-B fields structures close to the NS surface

What matters for the magnetar behavior is the strength of the internal field

Soft Gamma-ray Repeaters

Discovered in 1979 as **transient** sources of hard X-ray bursts and giant flares (GF)



THE 5 MARCH 1979 EVENT AND THE DISTINCT CLASS OF SHORT GAMMA BURSTS: ARE THEY OF THE SAME ORIGIN?

E. P. MAZETS, S. V. GOLENETSKII, YU. A. GURYAN, and V. N. ILYINSKII

A NEW TYPE OF REPETITIVE BEHAVIOR IN A HIGH-ENERGY TRANSIENT

J. G. LAROS, E. E. FENIMORE, AND R. W. KLEBESADEL
Los Alamos National Laboratory
J.-L. ATTEIA, M. BOER, K. HURLEY, M. NIEL, AND G. VEDRENNE
CESR, Toulouse, France
S. R. KANE
Space Sciences Laboratory, UC Berkeley
C. KOUVELIOTOU,[1] T. L. CLINE, B. R. DENNIS, U. D. DESAI, AND L. E. ORWIG
NASA/Goddard Space Flight Center
AND
A. V. KUZNETSOV, R. A. SUNYAEV, AND O. V. TEREKHOV
Institute for Space Research, Moscow

Received 1987 April 14; accepted 1987 June 15

ABSTRACT

The source of GB 790107, an event originally classified as a γ-ray burst, has been seen to repeat approximately 100 times during the time interval from 1978 August 13 to 1986 June 27. Most of the repetitions occurred in late 1983. Two *Letters* present the initial observations of this new type of repetitive behavior in a high-energy burster. The emphasis of this *Letter*, which uses primarily 5–100 keV data from the UCB/Los Alamos experiment on the *International Cometary Explorer* spacecraft, is on arguments for the reality and

Anomalous X-ray pulsars

Identified in the 90's as a class of **persistent** X-ray pulsars with no signs of binary companions and $L_x >> dE_{rot}/dt$

THE VERY LOW MASS X-RAY BINARY PULSARS: A NEW CLASS OF SOURCES?

S. MEREGHETTI[1] AND L. STELLA[2,3]

Received 1994 November 21; accepted 1995 January 9

ABSTRACT

While the distribution of spin periods of high-mass X-ray binaries spans more than four orders of magnitude (69 ms–25 minutes) the few known X-ray pulsars accreting from very low mass companions ($<1\ M_\odot$) have very similar periods between 5.4 and 8.7 s. These pulsars also display several other similarities, and we ...naries (LMXBs) with similar magnetic field ...istories. If they are rotating at, or close to, ...sities of the order of a few times 10^{35} ergs ...ss of LMXBs characterized by lower lumi- ...LMXBs.

...tron — stars: rotation — X-rays: stars

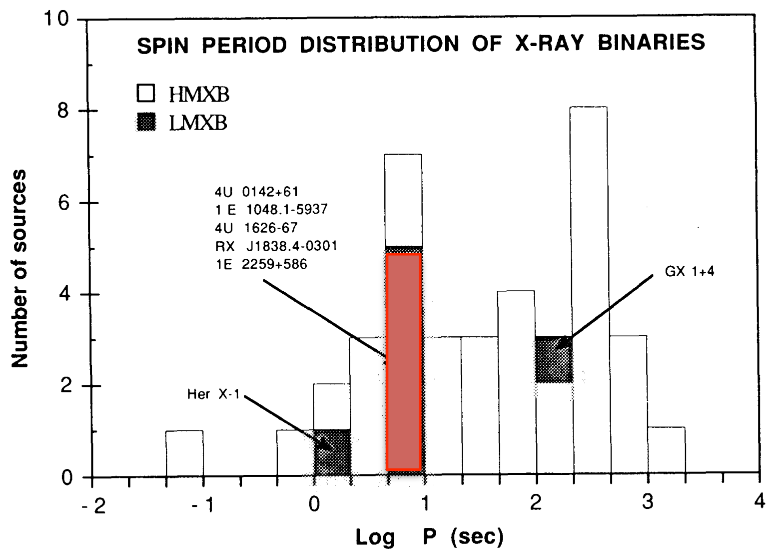


FIG. 1.—The distribution of the spin periods of accreting X-ray pulsars. With the exception of the peculiar systems Her X-1 and GX 1+4, the LMXBs X-ray pulsars have very similar periods between 5.4 and 8.7 s.

Letter to the Editor

On the nature of the 'anomalous' 6-s X-ray pulsars

J. van Paradijs [1,2], R.E. Taam [3], and E.P.J. van den Heuvel [1]

"Historically" two classes of sources:

Mereghetti 2008, Astr. & Astroph. Review 15, 225

- **Soft Gamma-ray Repeaters**
  - Have X-ray counterparts showing all the properties of AXPs
- **Anomalous X-ray pulsars**
  - Most of them emitted "SGR-like" bursts

We now believe that

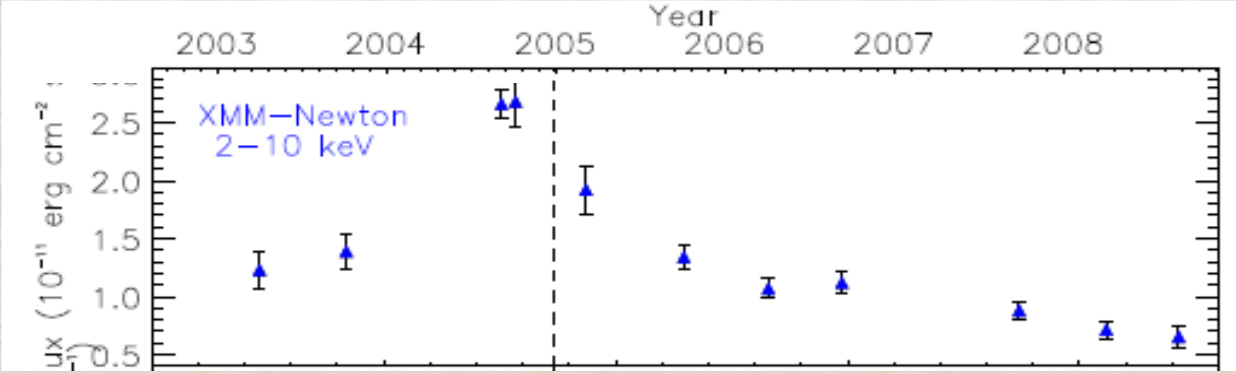
AXPs = SGRs = (candidate) magnetars

Thompson
Duncan
Beloborodov
Lyutikov
…

Magnetars emit:

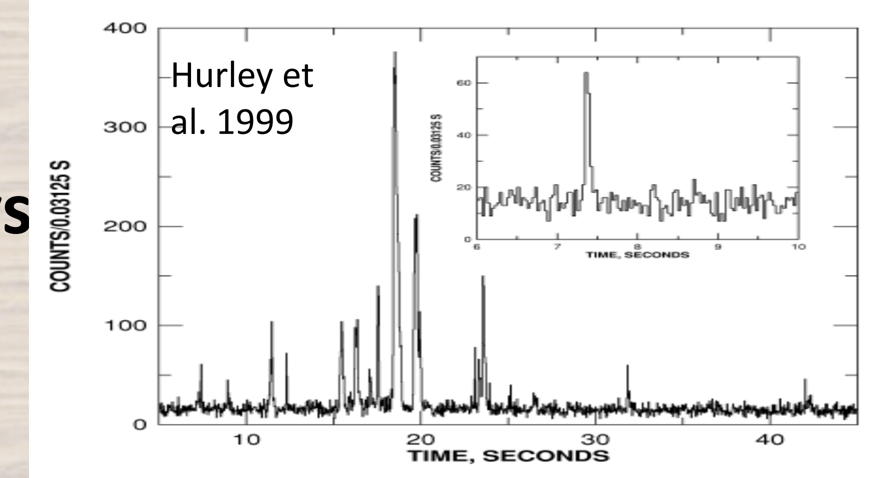
– **"Persistent" X-rays**

- $L_x \sim 10^{35\text{-}36}$ erg/s
- ~0.5-200 keV
- pulsed at few sec
- spin-down



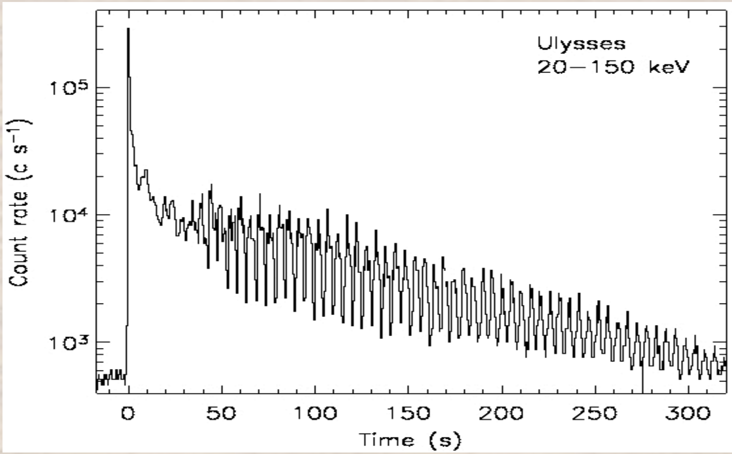
– **short bursts of soft gamma-rays**

- Lx ~$10^{39\text{-}41}$ erg/s
- kT~30-40 keV
- durations ~0.1-1 sec

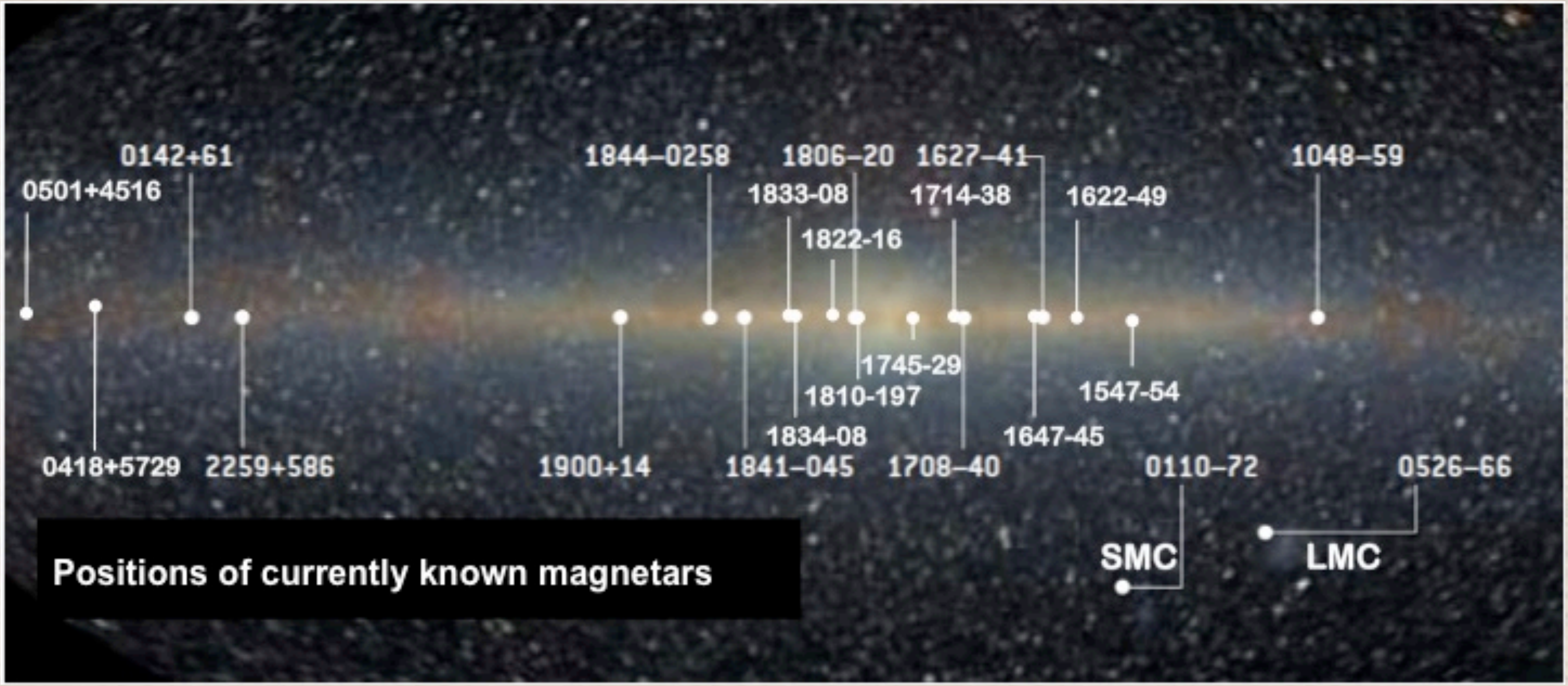


– **Giant Flares**

- $L_x > 10^{44}$ erg/s
- very rare events (only three observed)
- E ~ few 10^{46} erg

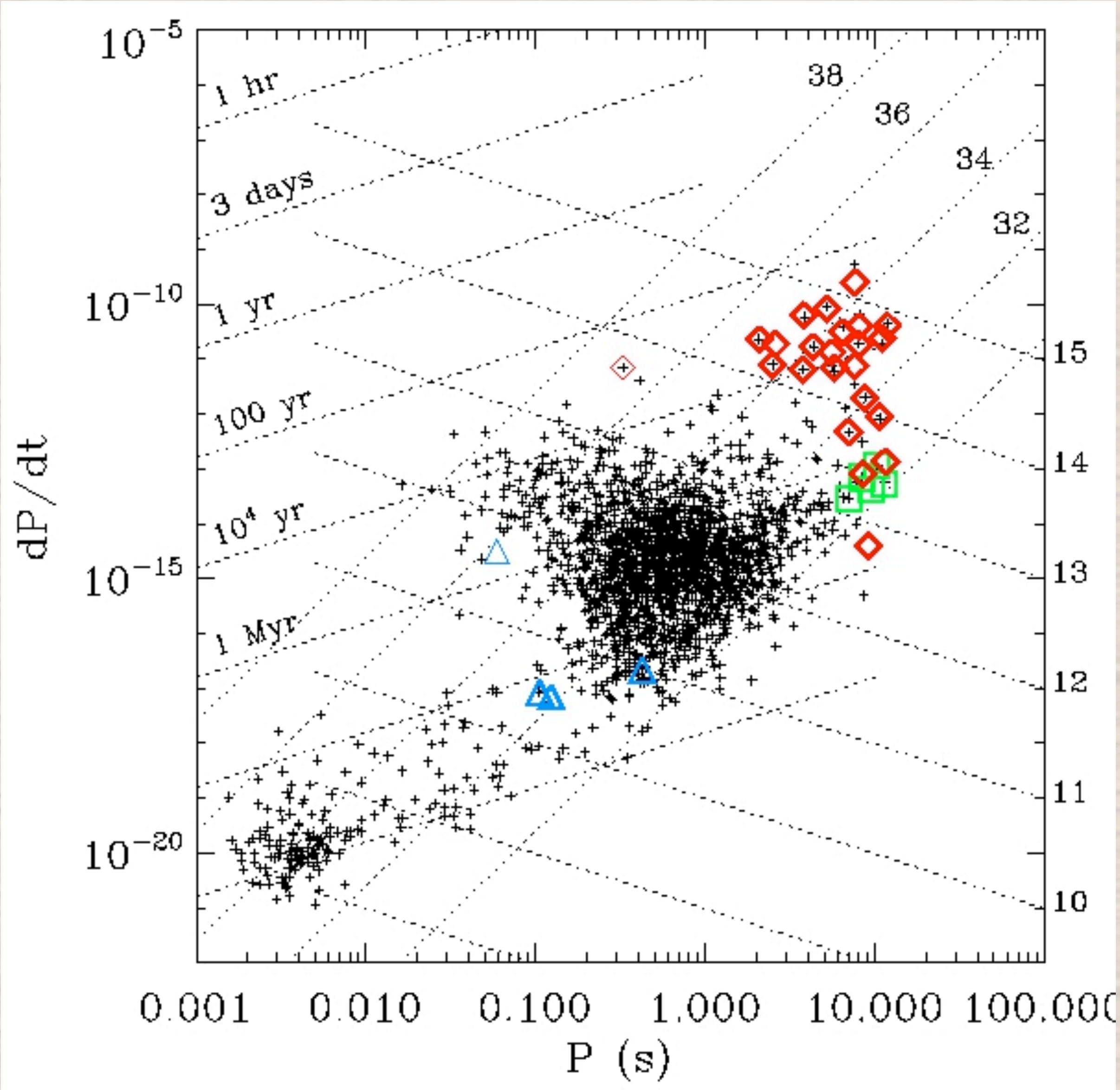


22 confirmed AXP/SGR in the Galaxy and Magellanic Clouds



NAME	P (s)	ASSOCIATIONS	RADIO	IR	OPTICAL	X SOFT	X HARD
CXO J0110-72	8.0	SMC				P	
4U 0142+61	8.7			D	P	P	P
1E 1048-59	6.4			D	P	P	D
1E 1547-54	2.1	G327.24-0.13	P	D		P T	P
CXO J1647-45	10.6	Westerlund 1				P T	
RXS 1708-40	11.0			D?		P	P
XTE J1810-197	5.5		P	D		P T	
1E 1841-045	11.8	Kes 73		D?		P	P
1E 2259+586	7.0	CTB 109		D		P	
SGR 0501+45	5.7			D		P T	P
SGR 0526-66	8	LMC , N49				P	
SGR 1627-41	2.6					P T	
SGR 1806-20	7.6	Star cluster	T	D		P	D
SGR 1900+14	5.2	Star cluster	T	D?		P	D
SGR 0418+57	9.1					P T	
PSR J1622-49	4.3	SNR ? G333.9+0.0	P		P	P T	
CXO J1714-38	3.8	CTB 37B				P	
Swift J1822-16	8.4					P T	
SGR 1833-08	7.6					P T	
Swift J1834-08	2.5	W41 ?				P T	
SGR 1745-29	3.8	Near Galactic center	P			P T	P
3XMM 1852	11.6					P T	

Spin periods: P = 2 – 12 s



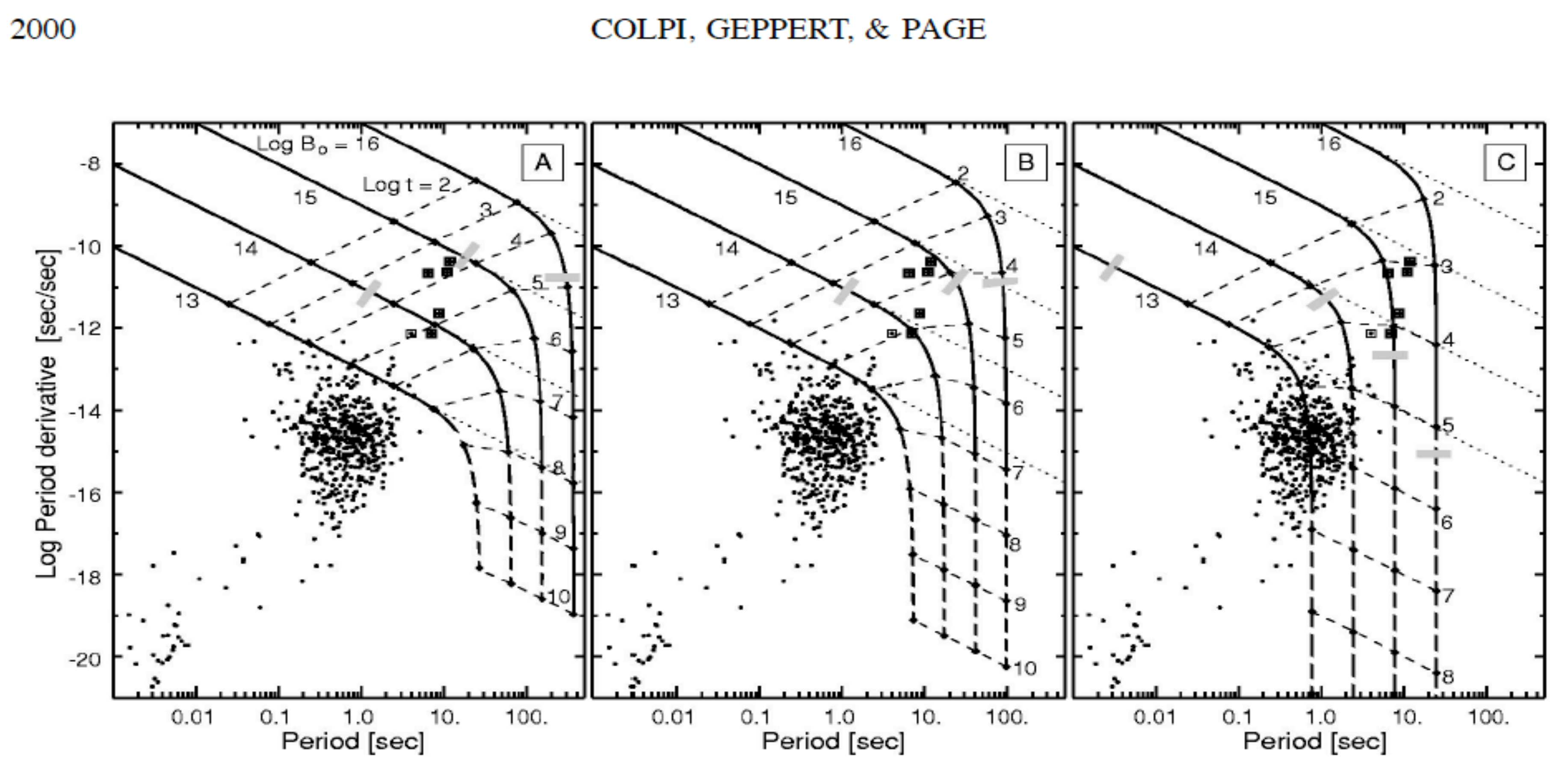
$$\tau = \frac{P}{2\dot{P}}$$

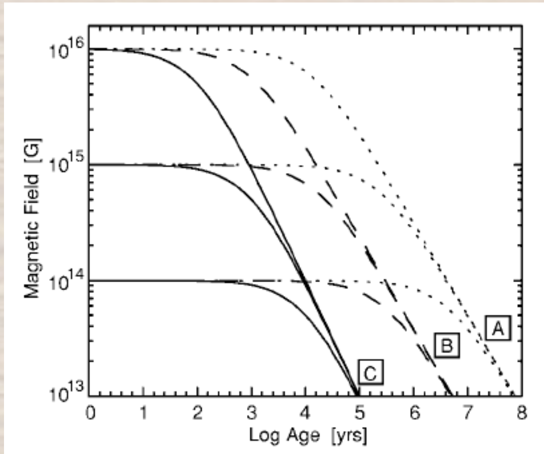
$$\frac{dE_{rot}}{dt} = 4\pi^2 I\dot{P}/P^3$$

$$\frac{dE}{dt} = \frac{1}{6c^3}B^2R^6\omega^4 sin^2\alpha$$

$$B = 3.2 \cdot 10^{19}\sqrt{P\dot{P}}\ \text{Gauss.}$$

Evidence of B decay from period clustering

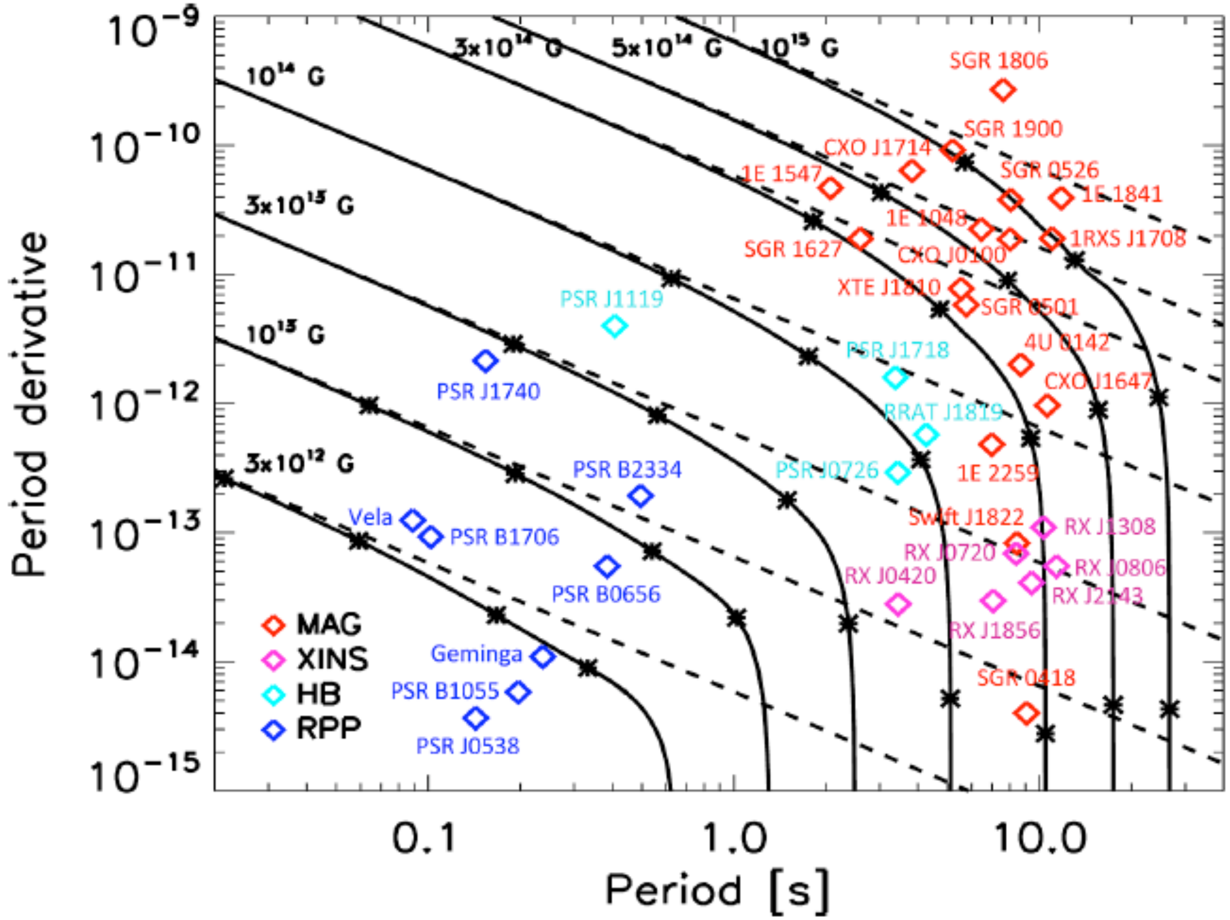




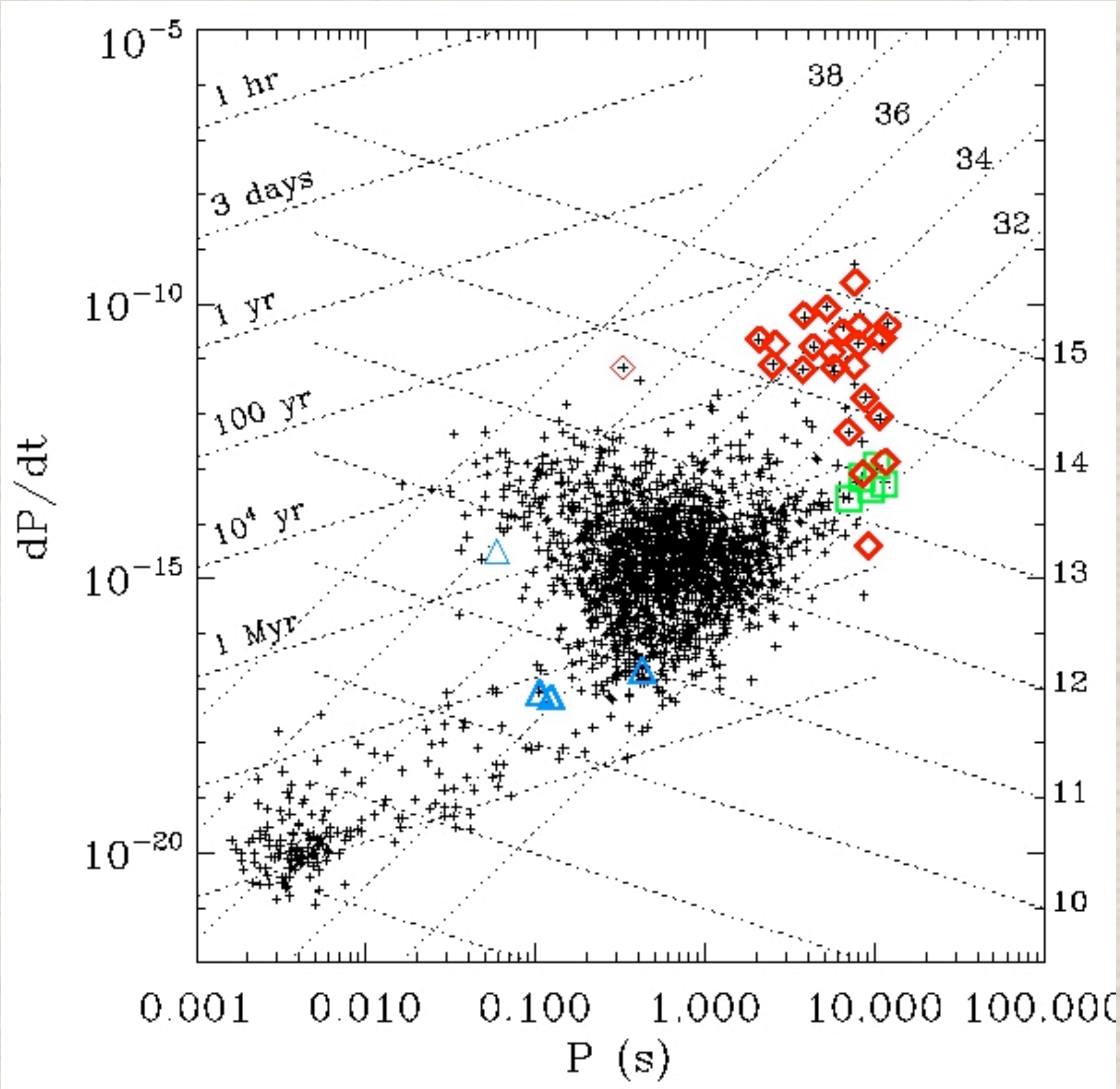
Magneto-thermal evolutionary computations

(Pons, Rea, & C …)

D. Viganò et al.



Spin down: P_{dot} ~ 10^{-12} -10^{-10} s/s



(...with important exceptions discussed later)

$$\tau = \frac{P}{2\dot{P}}$$

$$\frac{dE_{rot}}{dt} = 4\pi^2 I\dot{P}/P^3$$

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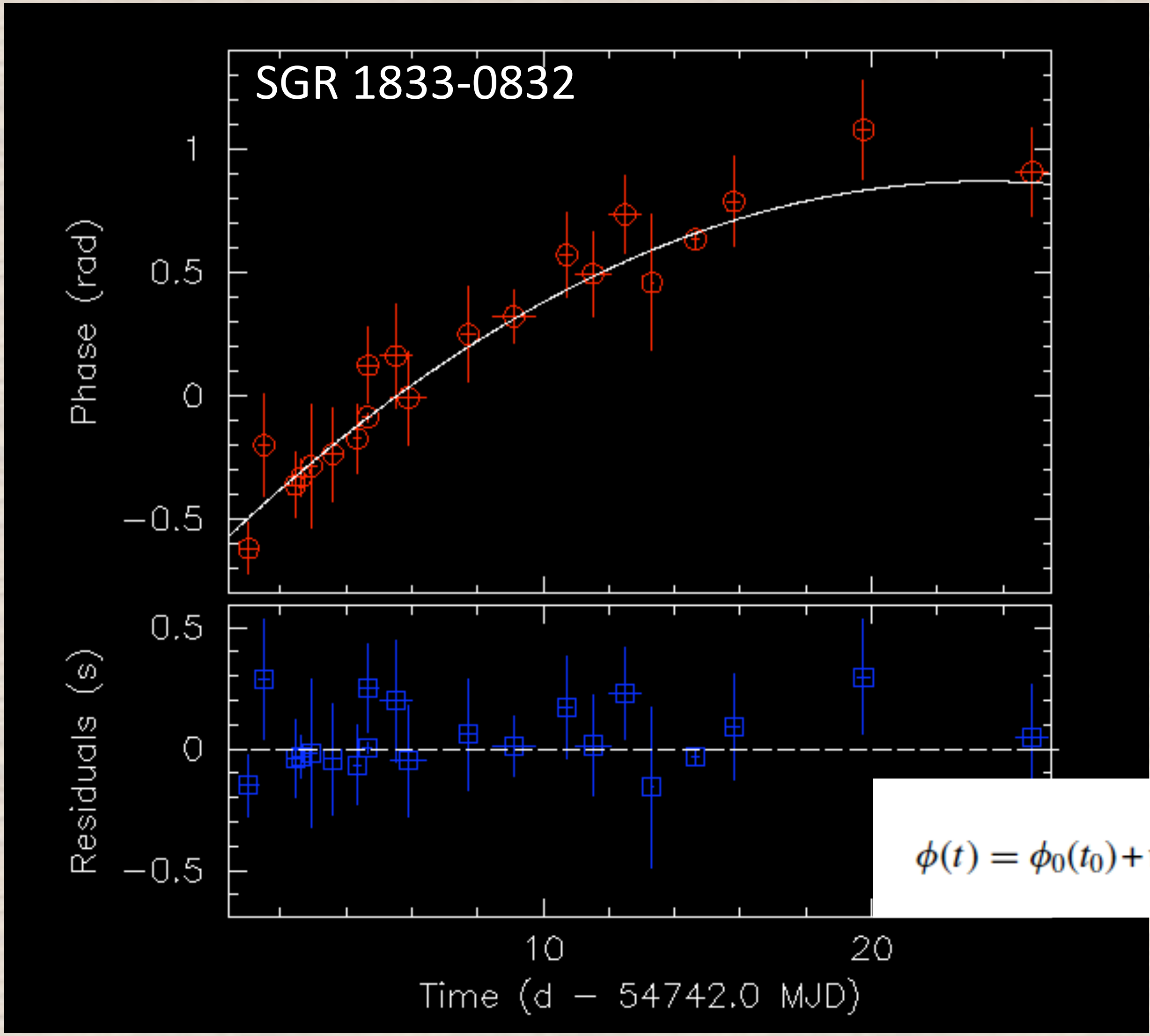
$$B = 3.2 \cdot 10^{19}\sqrt{P\dot{P}} \text{ Gauss.}$$

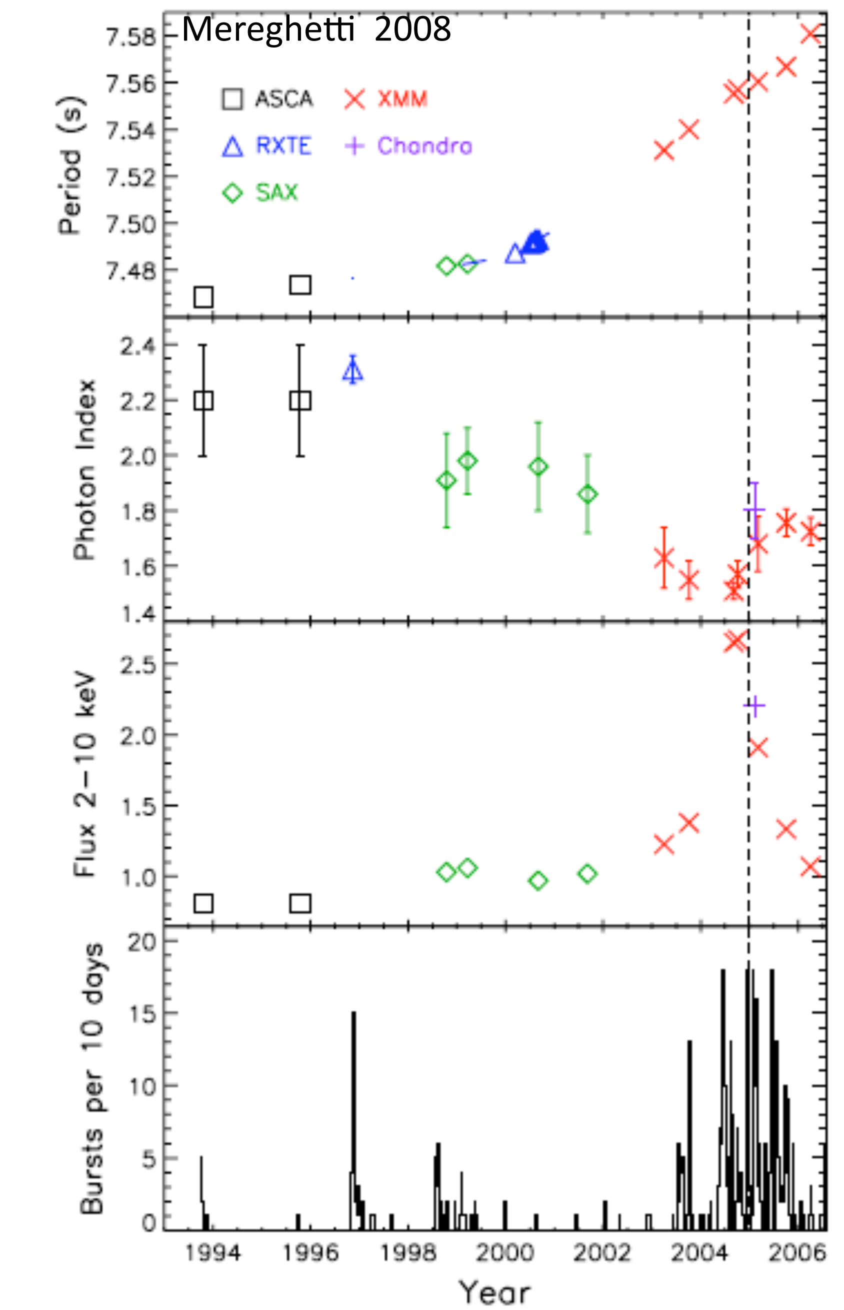


Usually, high Pdot can be detected after a few days of phase-connected timing

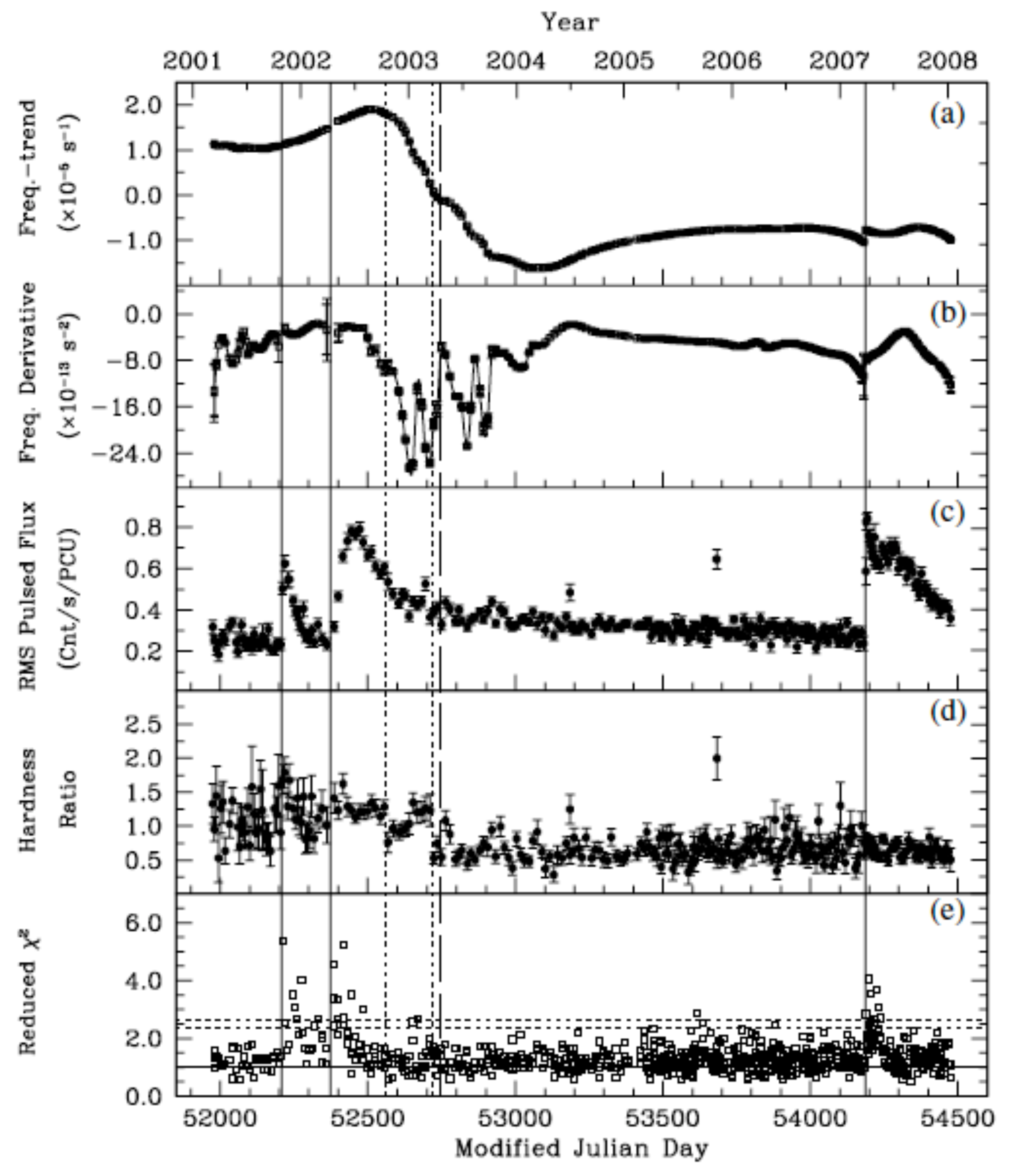
$$\phi(t) = \phi_0(t_0) + \nu_0(t-t_0) + \frac{1}{2}\dot{\nu}_0(t-t_0)^2 + \frac{1}{6}\ddot{\nu}_0(t-t_0)^3 + \cdots$$

SGR 1806-20

Mereghetti 2008



Variations in spin-down rate are common in AXP/SGR

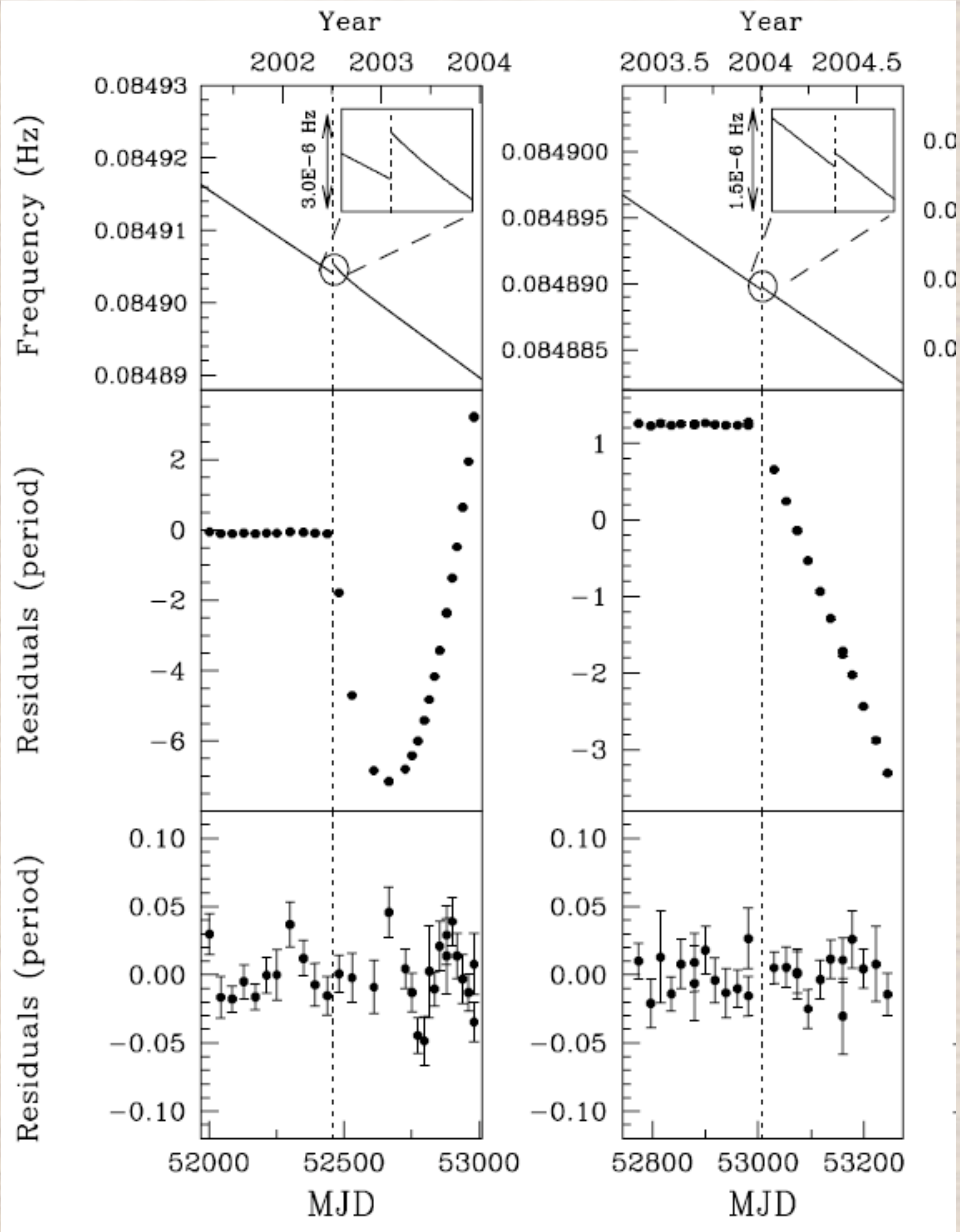


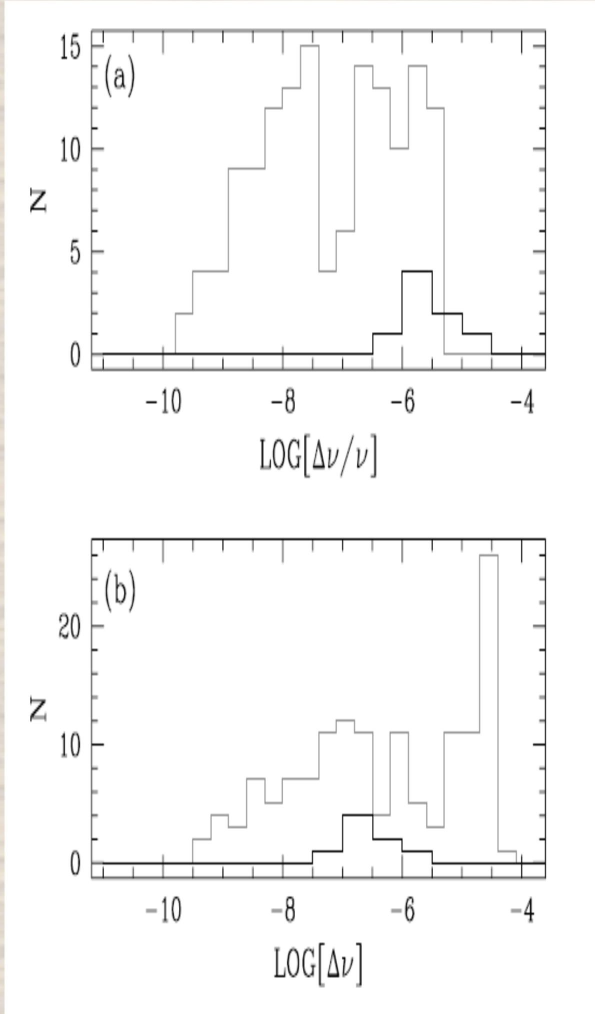
Spin-down rate and pulsed-flux variations

1E1048-5937

(Dib et al. 2009)

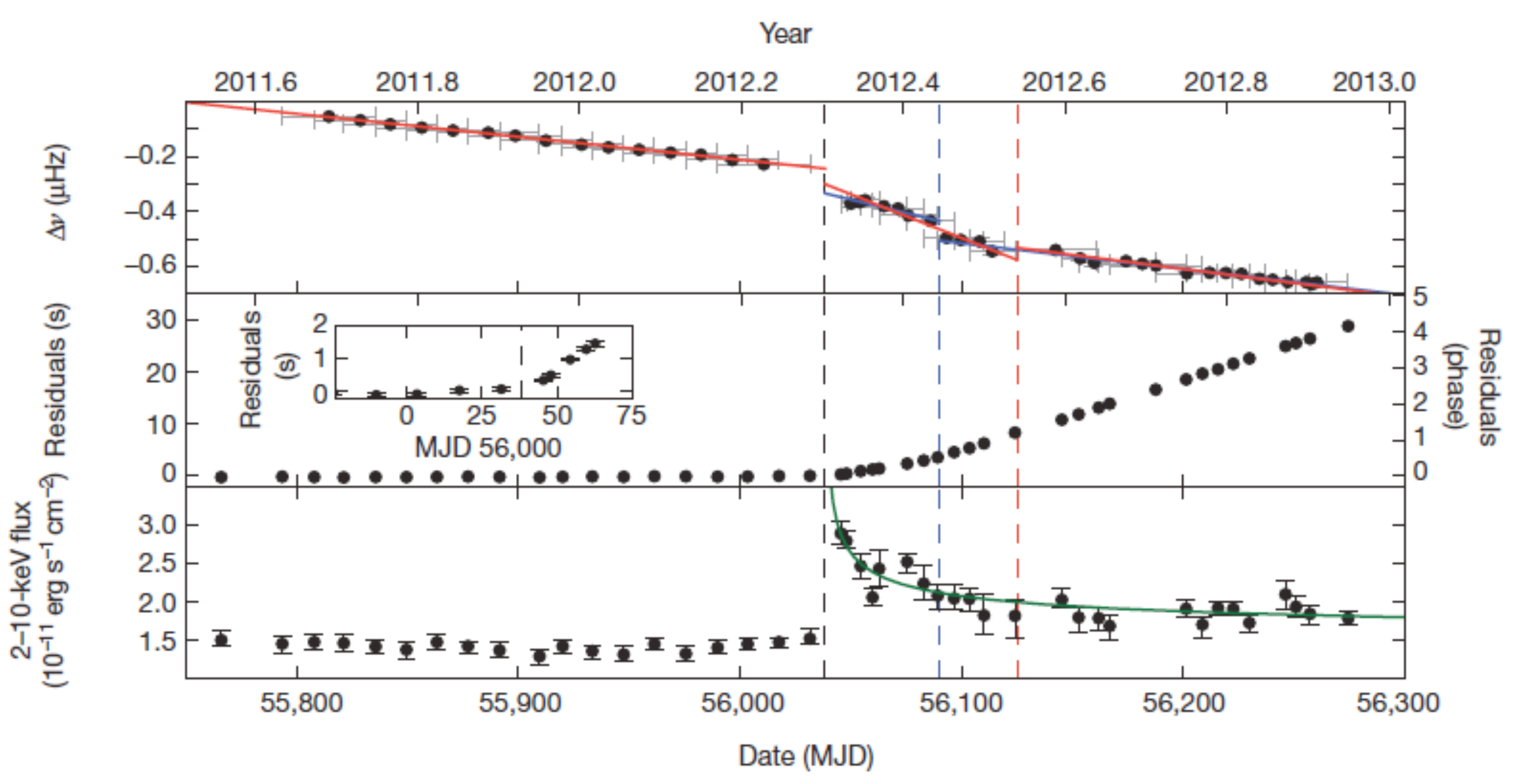
Glitches


Year
2002
2003
2004
2003.5
2004
2004.5
Frequency (Hz)
3.0E−6 Hz
1.5E−6 Hz
Residuals (period)
Residuals (period)
MJD
MJD

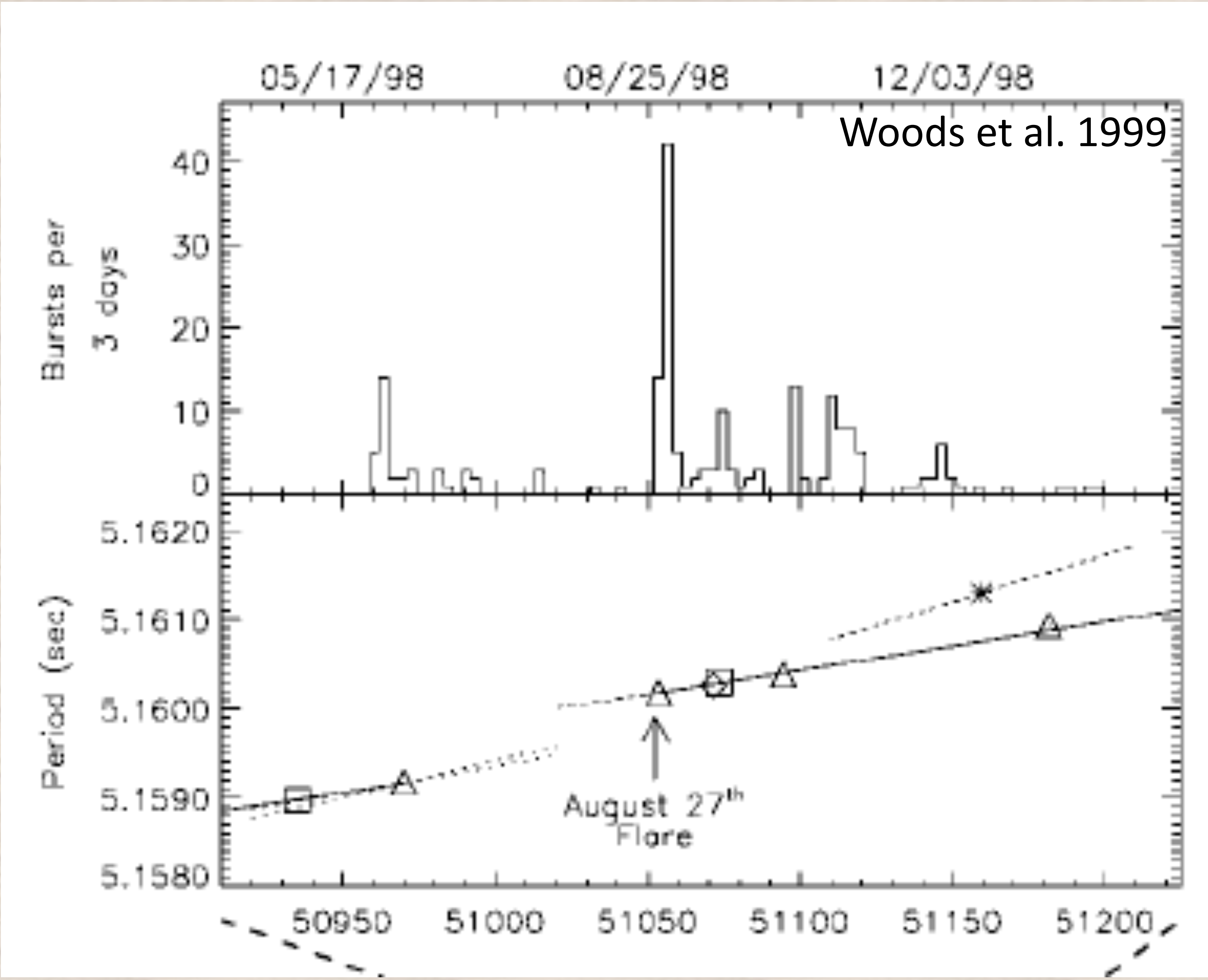

(a)
N
LOG[Δν/ν]
(b)
N
LOG[Δν]

An anti-glitch in a magnetar

R. F. Archibald[1], V. M. Kaspi[1], C. -Y. Ng[1,2], K. N. Gourgouliatos[1], D. Tsang[1], P. Scholz[1], A. P. Beardmore[3], N. Gehrels[4] & J. A. Kennea[5]



Strong spin-down after (?) the giant flare of SGR 1900+14



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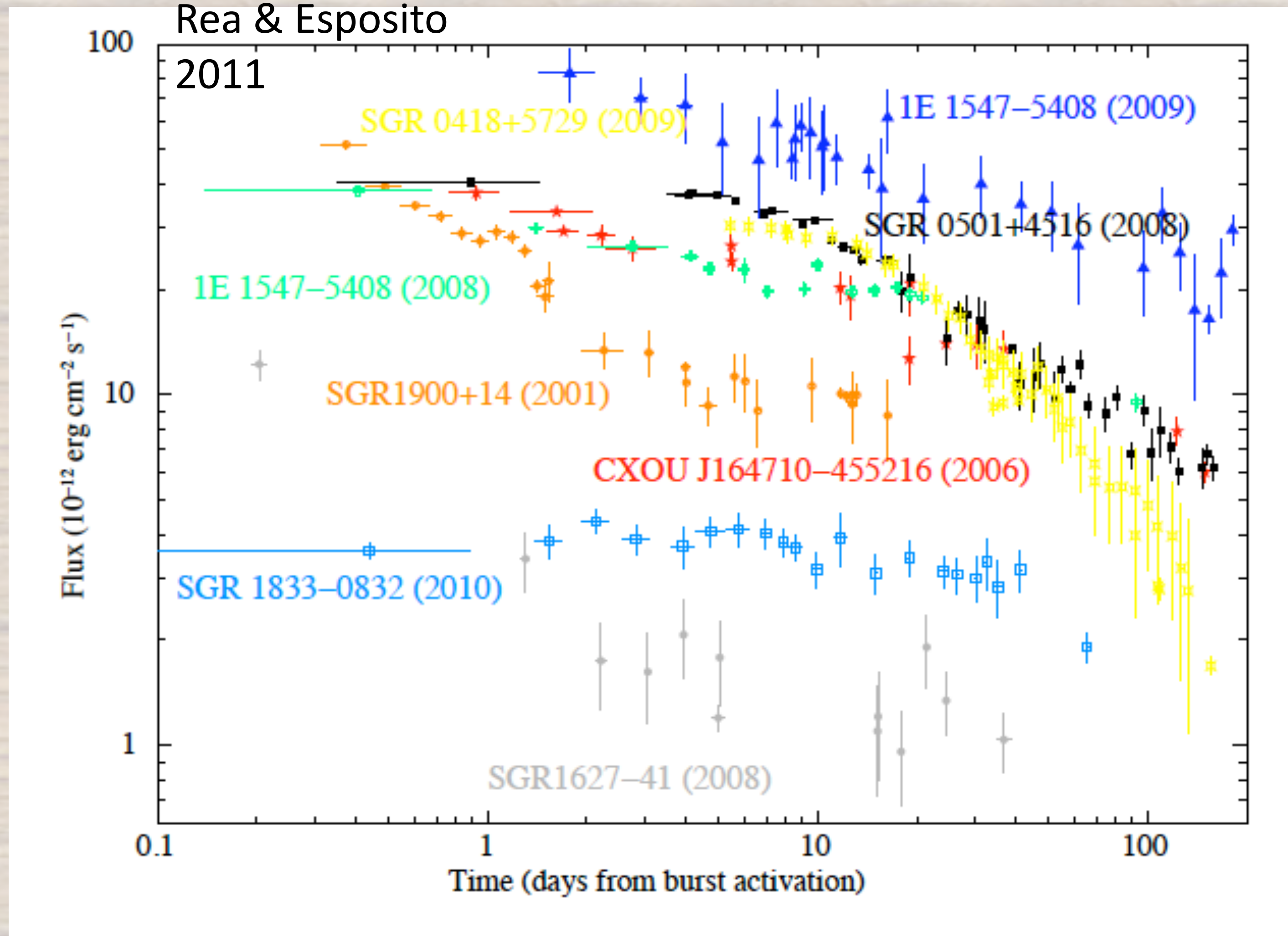
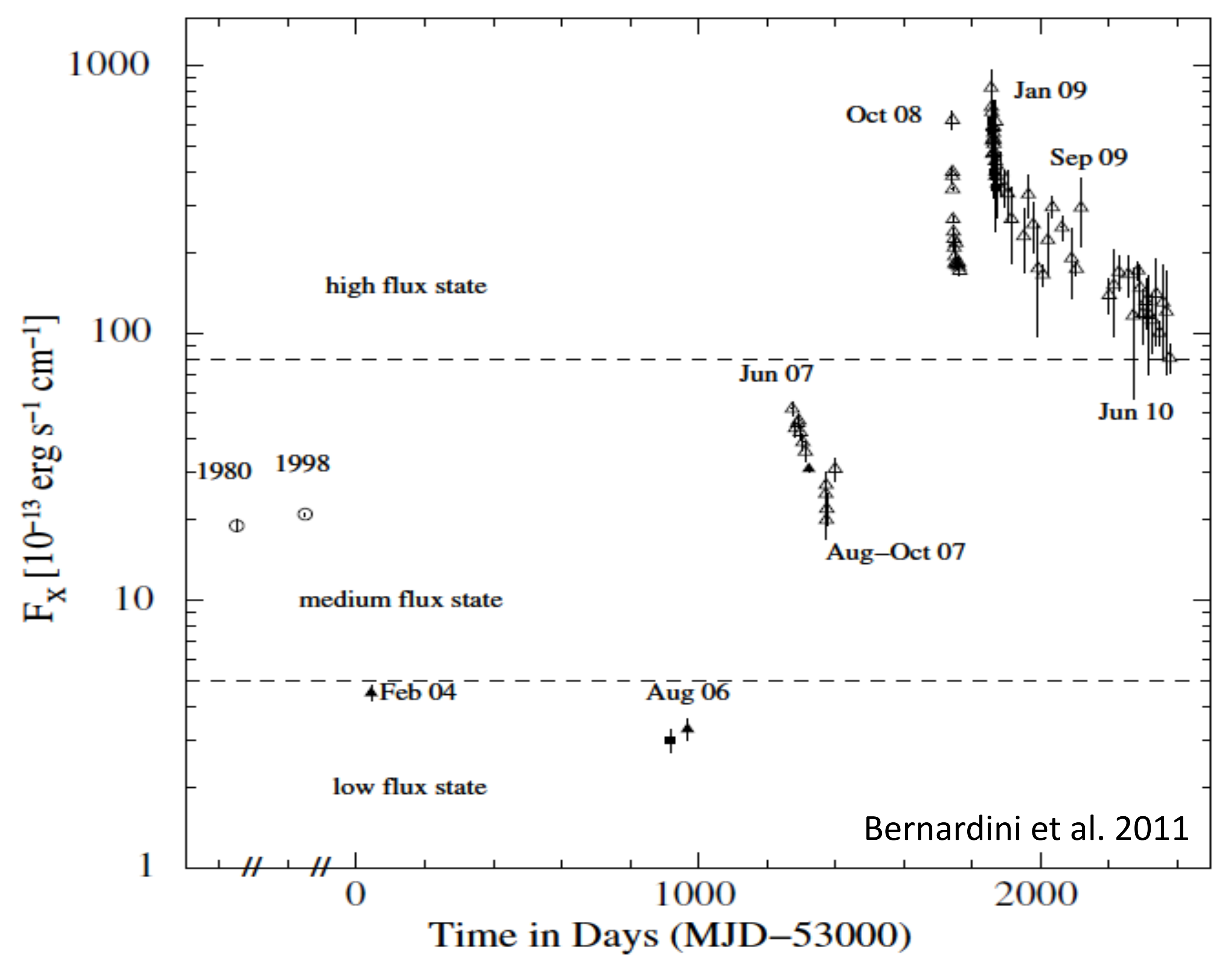
Most AXPs/SGRs are transient sources

Rea & Esposito 2011



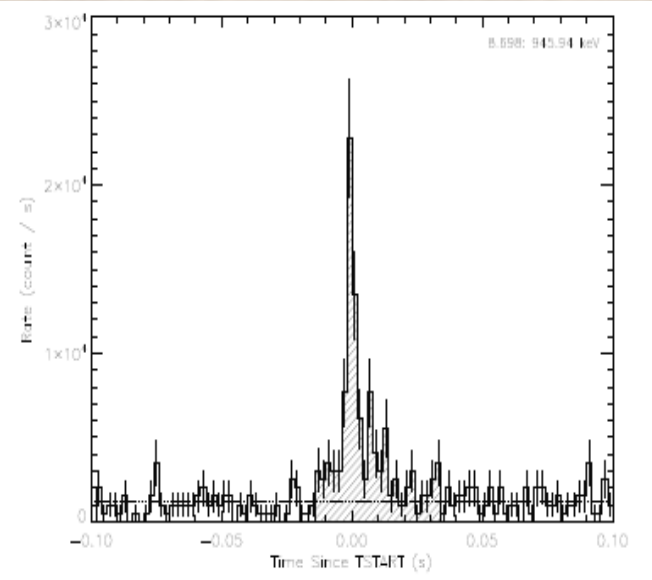
Multiple outbursts of 1E1547.0-5408

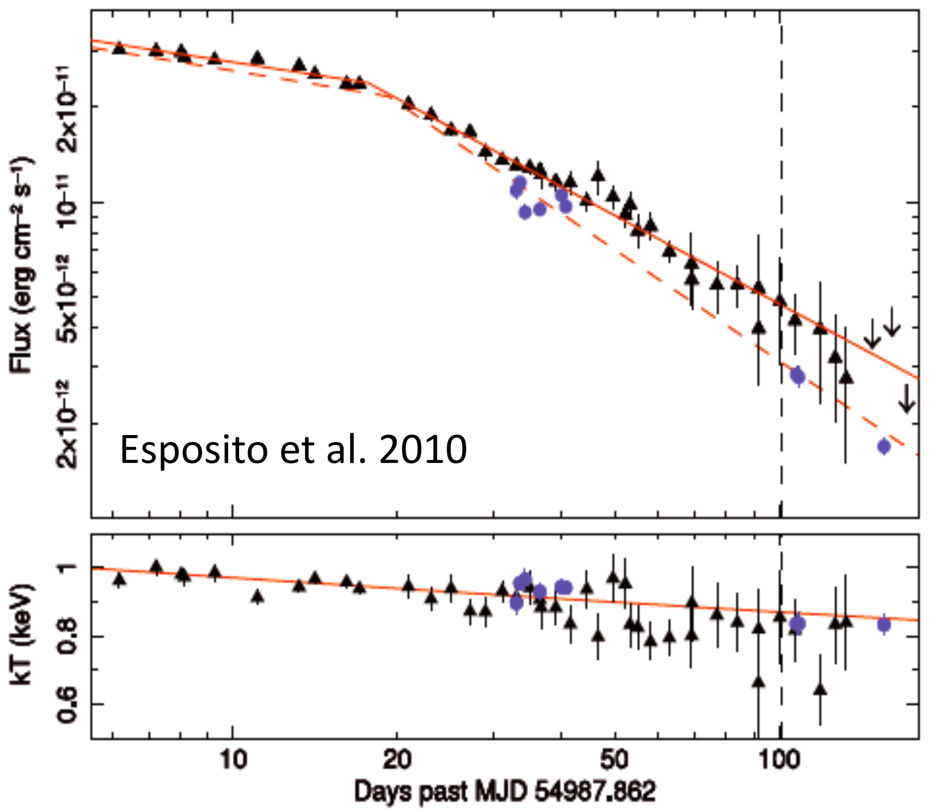


SGR 0418+5729: a low-B magnetar?

- Two **BURSTS** detected on 2009 June 05
- spin **PERIOD** of 9.1 s (*van der Horst et al. 2010*)
- Apparently all the features of a (transient) **SGR**
  - Rapid, large flux increase and decay
  - Emission of bursts
  - Soft X-ray spectrum

van der Horst et al.2009

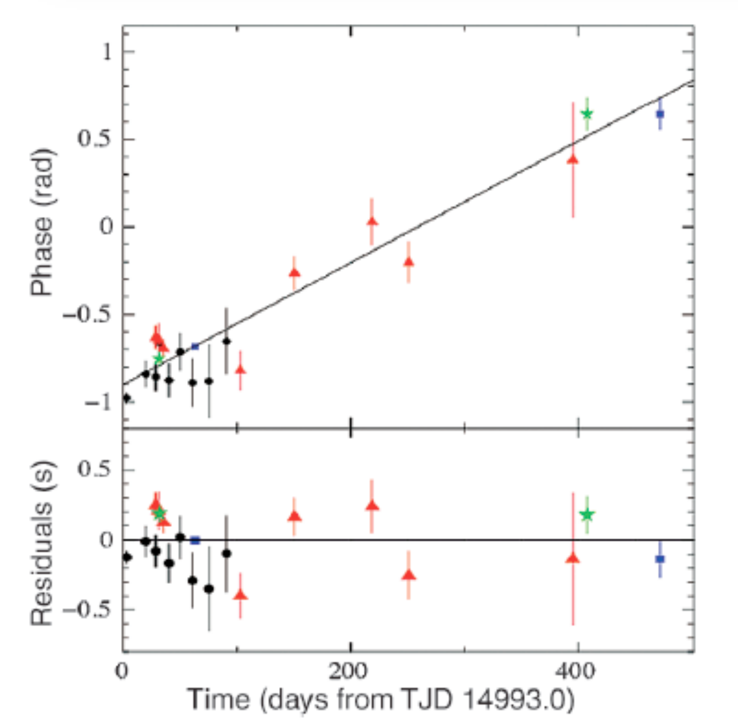


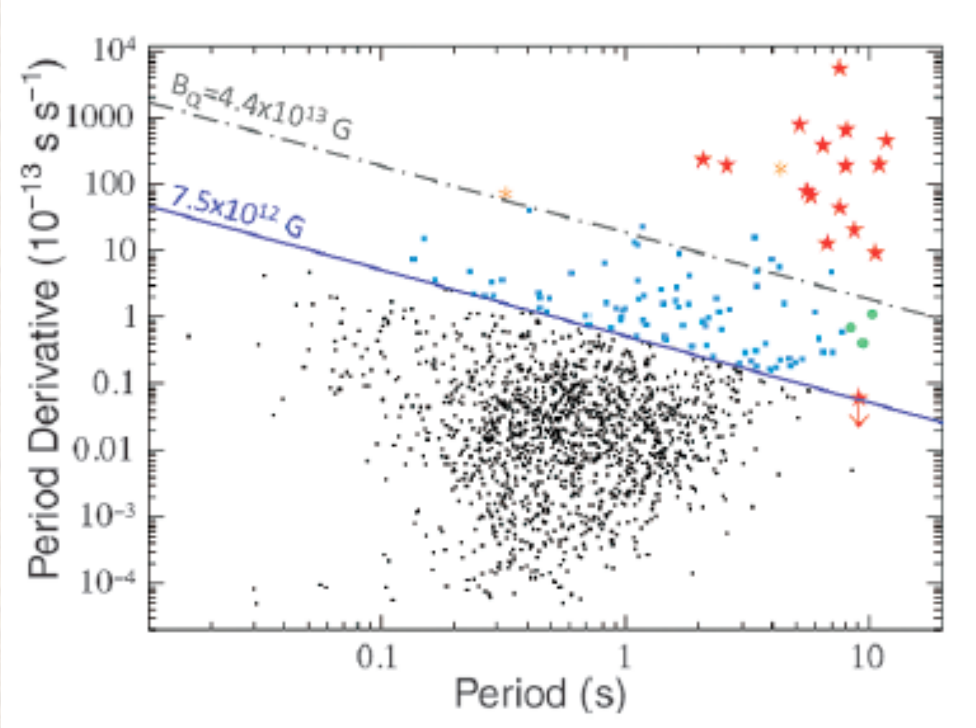


Esposito et al. 2010

A Low-Magnetic-Field Soft Gamma Repeater

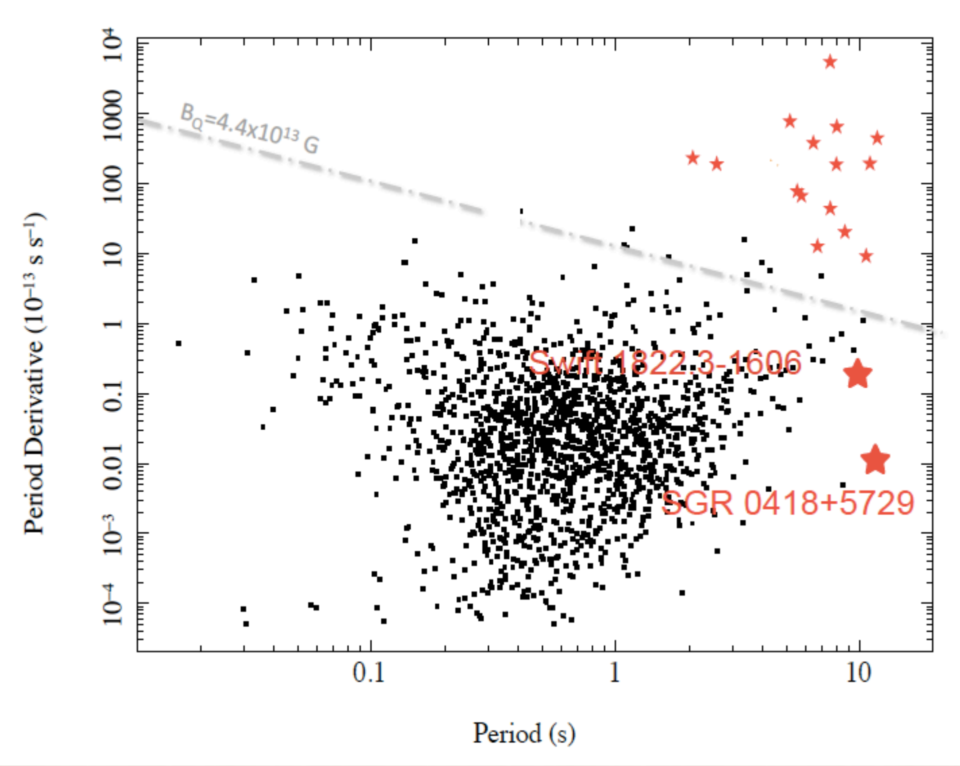
N. Rea,[1*] P. Esposito,[2] R. Turolla,[3,4] G. L. Israel,[5] S. Zane,[4] L. Stella,[5] S. Mereghetti,[6] A. Tiengo,[6] D. Götz,[7] E. Göğüş,[8] C. Kouveliotou[9]





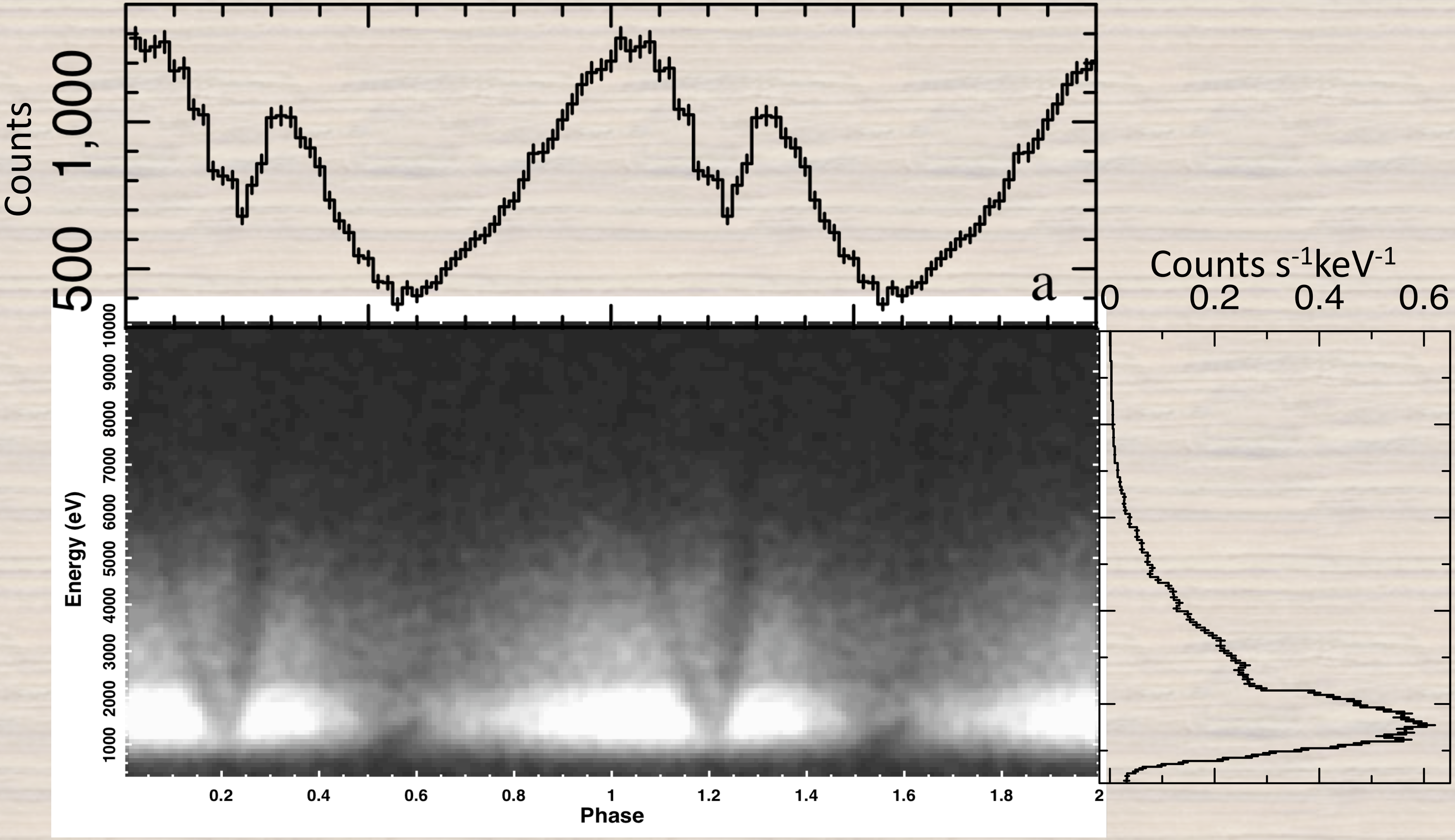
$$\dot{P} < 6.0 \times 10^{-15} \mathrm{s\ s}^{-1}$$

Pdot = 4 10^{-15} s s^{-1} (*Rea et al. 2013*) ⇒ $B_{dip} \approx 6 \times 10^{12}$ G



A variable absorption feature in the X-ray spectrum of a magnetar

Andrea Tiengo[1,2,3], Paolo Esposito[2], Sandro Mereghetti[2], Roberto Turolla[4,5], Luciano Nobili[4], Fabio Gastaldello[2], Diego Götz[6], Gian Luca Israel[7], Nanda Rea[8], Luigi Stella[7], Silvia Zane[5] & Giovanni F. Bignami[1,2]



Remarkable feature with unique properties !

- High statistical significance

  (>> any other absorption line reported in isolated NS)

- More than factor 5 variation in line energy (range ~1- 5 keV)

  never seen before for any NS X-ray line (e.g. cyclotron lines in accreting X-ray binaries)

- Persisted for ~ two months (at least)

We interprete it as a proton cyclotron line in a field of B $\approx$ (1-10) 10^{14} G

(to be compared to B $\approx 6\ 10^{12}$ G inferred from P and Pdot)

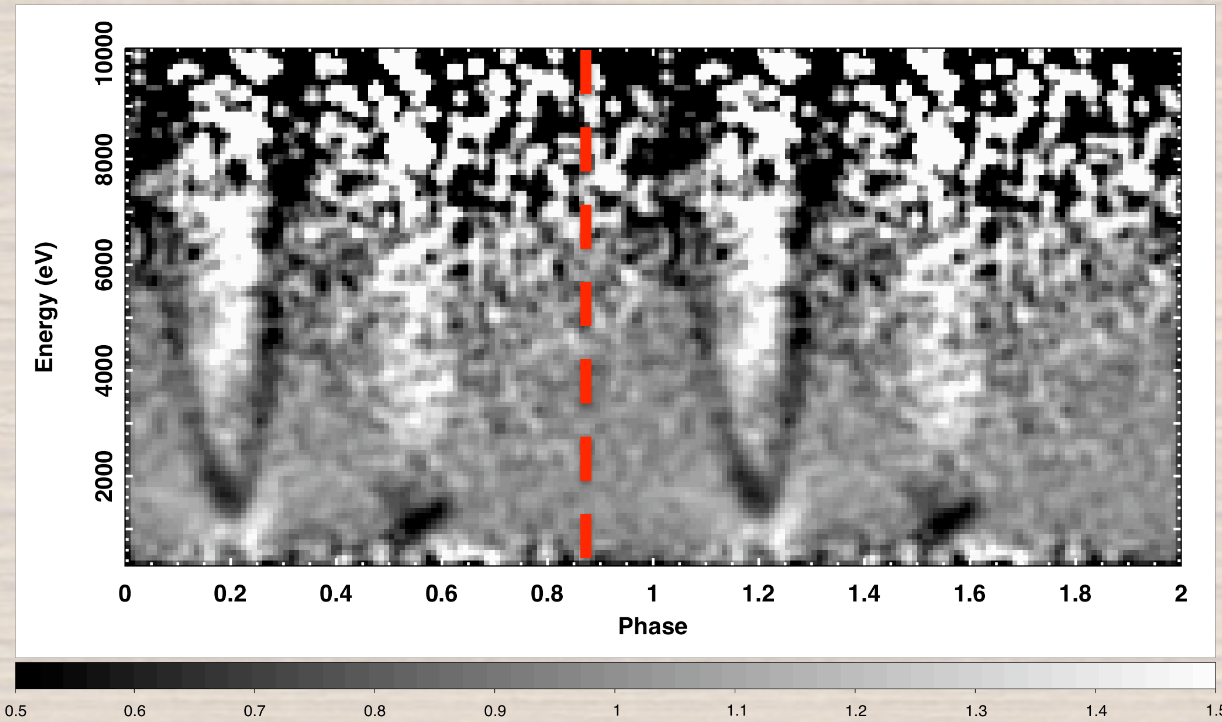
Interpretation within magnetar model

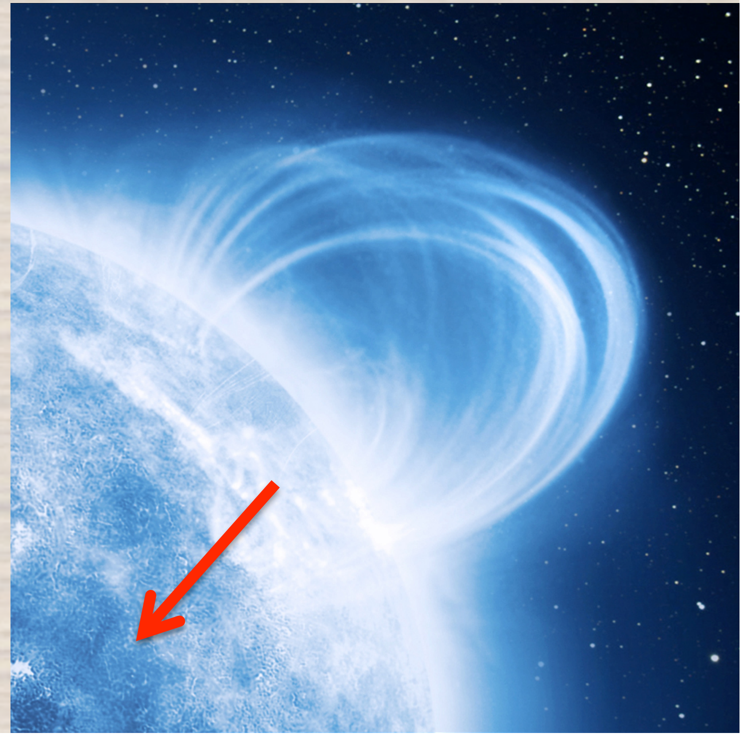
– **PROTON CYCLOTRON**:

- $E_{cycl,p}$= 0.6 B_{14} keV ⇒ **B ~ (2-20) x 10^{14} G** ⇒ **MAGNETAR** field
- We need a **STRONGLY VARIABLE B**, that might vary:
  - along the **SURFACE** (small-scale multipolar B components)

  OR

  ✓ along a **VERTICAL** plasma structure (coronal loop analogy; e.g., *Beloborodov & Thompson 2007; Masada et al. 2010*)





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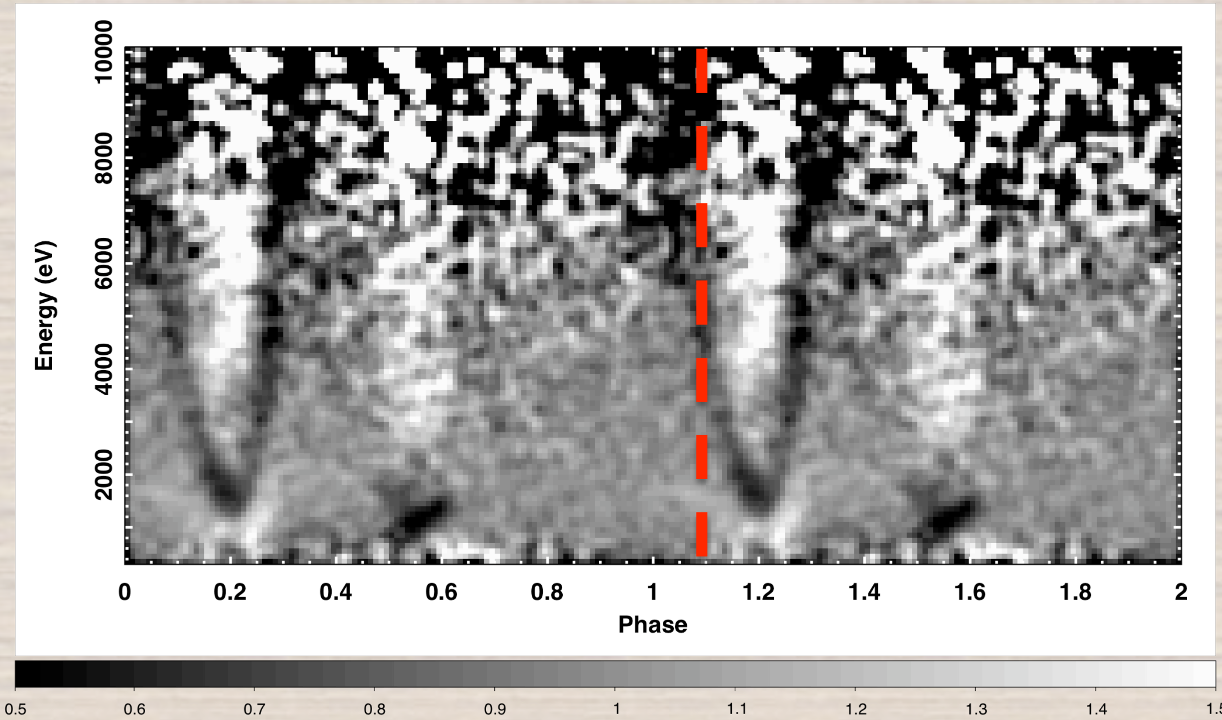

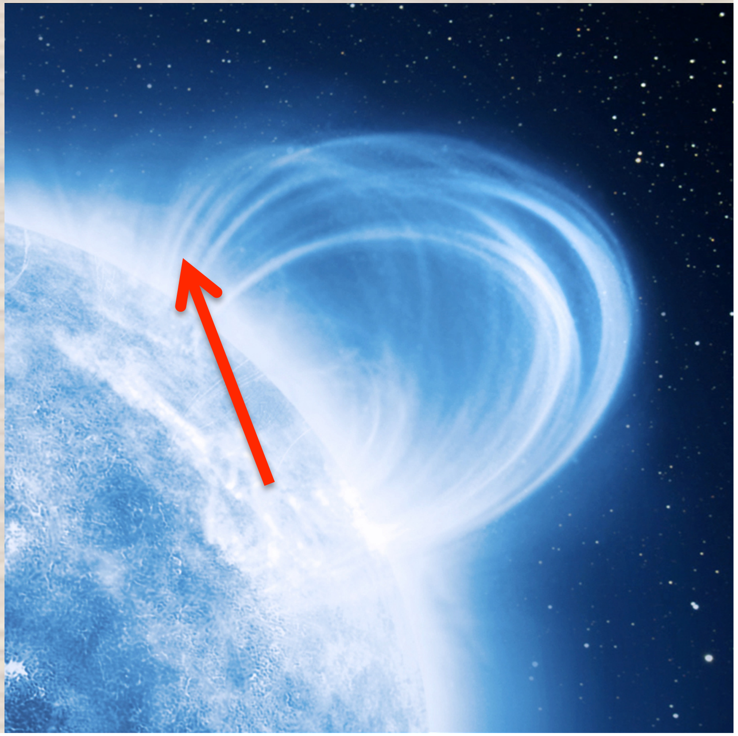

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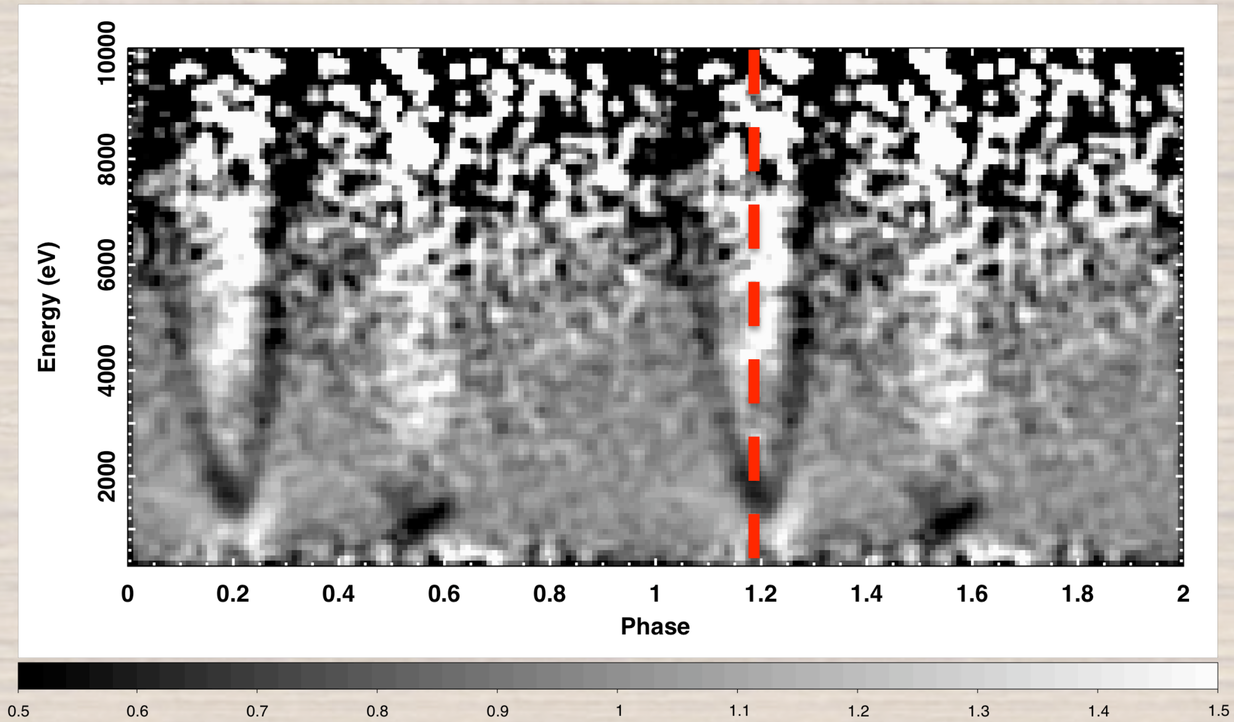

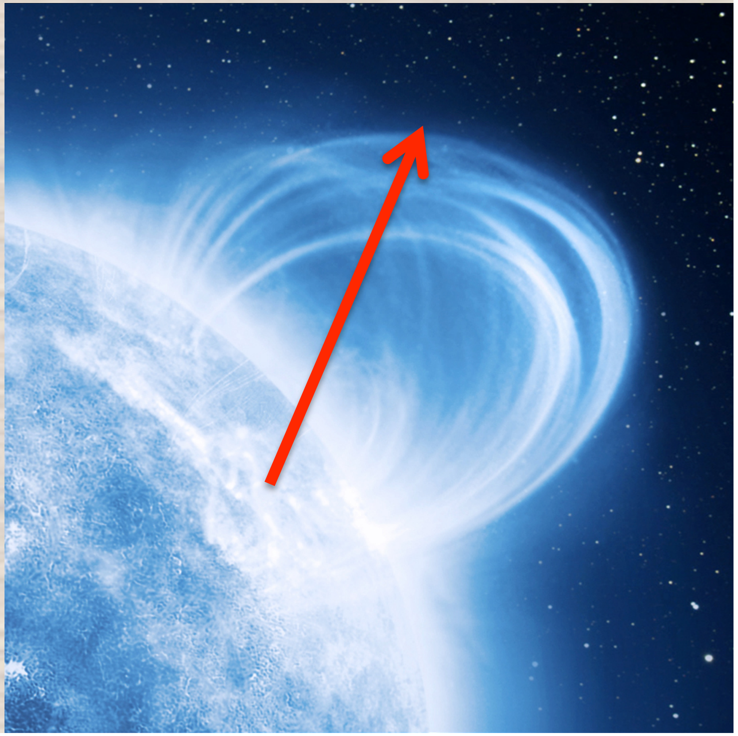

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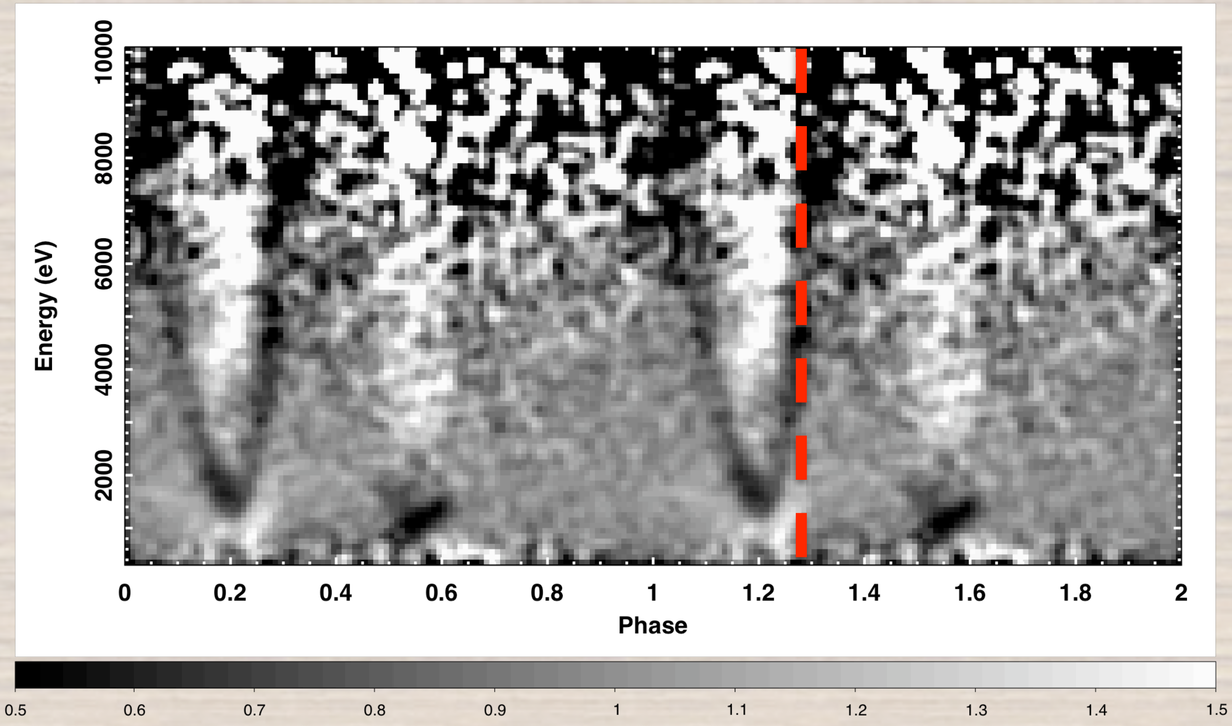

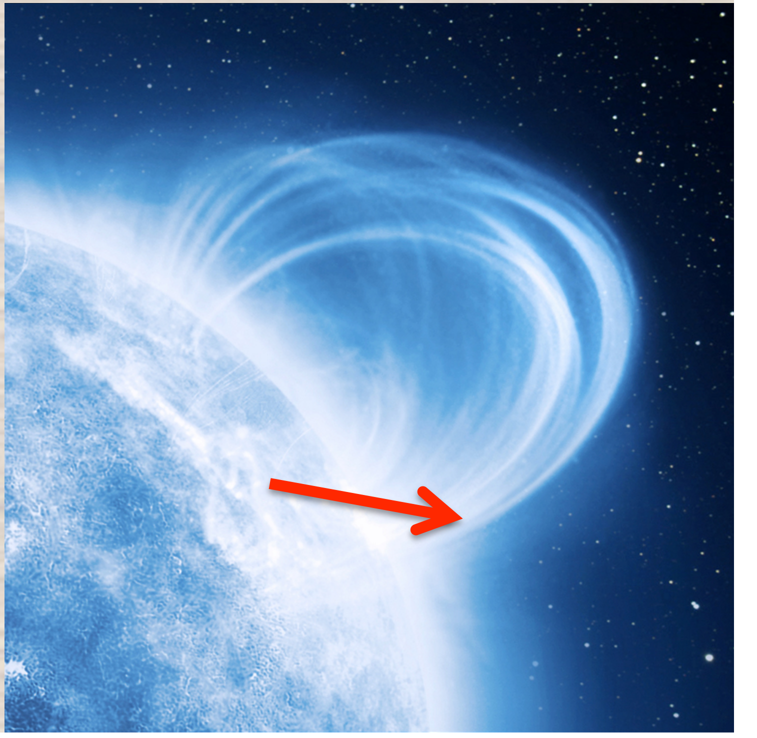

Timing behavior (Pdot variations, glitches, etc…) and variability (flux, spectra, pulse shapes) point to very dynamic magnetospheres with complex and variable topology

What matters for the magnetar behavior is the strength of the internal field

The phase-dependent absorption line in the "low-Pdot magnetar" SGR 0418 supports the presence high-B fields structures close to the NS surface

FOUR FINAL REMARKS

1. RELEVANCE FOR GRBs:

   Do magnetar exist ? YES

   Do millesecond magnetar exist ? MAYBE

2. VARIETY

   Distribution of initial parameters / age / birth mechanism

3. TIMING "IRREGULARITIES" and RADIATIVE CHANGES

   What causes what ?

4. HOW TO PROGRESS

   Variability