MAGNETARS: NSs WITH EXTREME PHYSICAL PROPERTIES IN THE eXTP ERA

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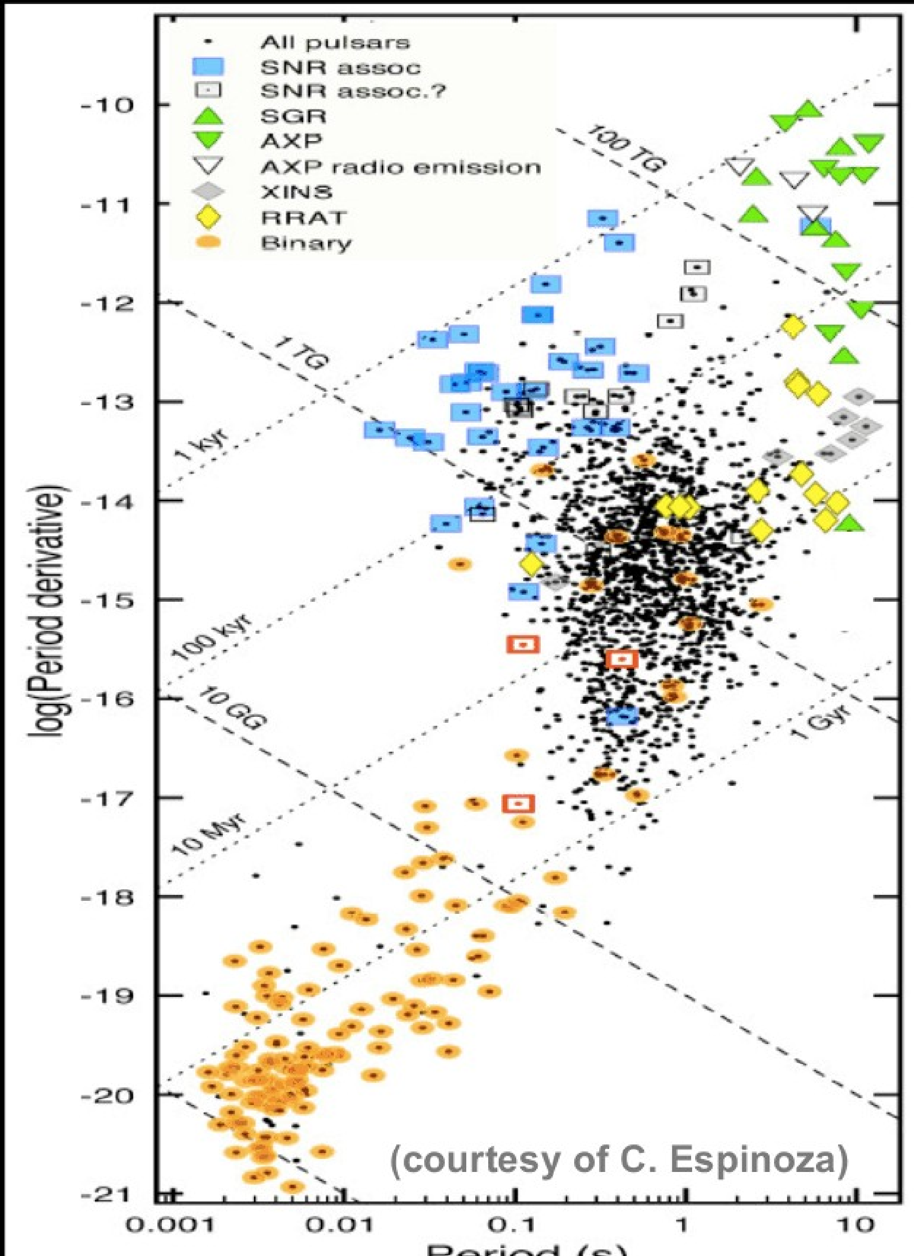
AND MANY OTHERS !

THE (ISOLATED) PULSAR ZOO

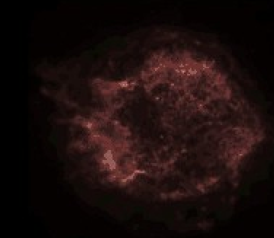


Magnetars: B-powered

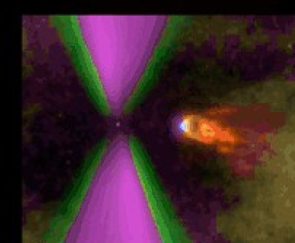
XDINS: kT-powered

Pulsars and RRATs: rotation-powered

CCOs: kT-powered

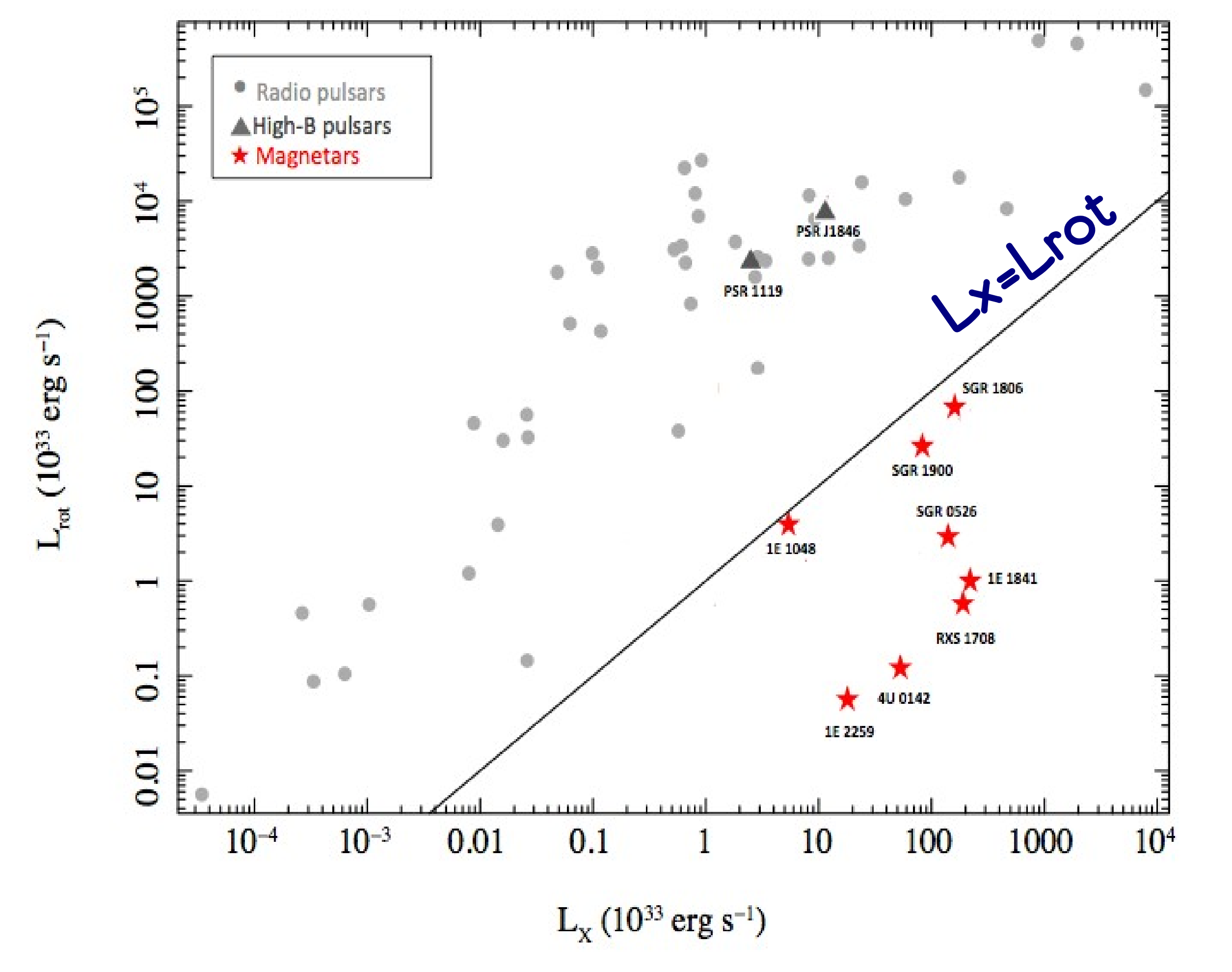


Recycled binaries: rotation-powered



MAGNETIC STARS

Loss of rotational energy is orders of magnitudes too small (10^{30}erg/s) with respect to the observed persistent Lx



No accretion from a companion (M>Mjup)

No Doppler modulation/shift in the spin pulses

MAGNEtic STARS

In analogy with isolated rotation-powered NS

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

10^{14-15} Gauss MAGNEtic sTARS

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

Definition:

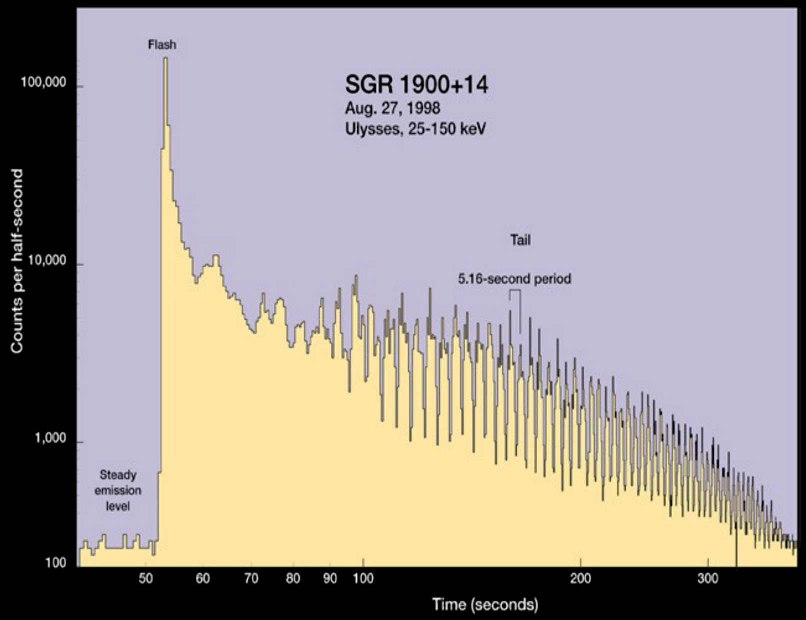
(Isolated) neutron stars where the **main source** of energy is the **magnetic field** [most observed NS have B = 10^9 - 10^{12} G and are powered by accretion, rotational energy, or residual internal heat].

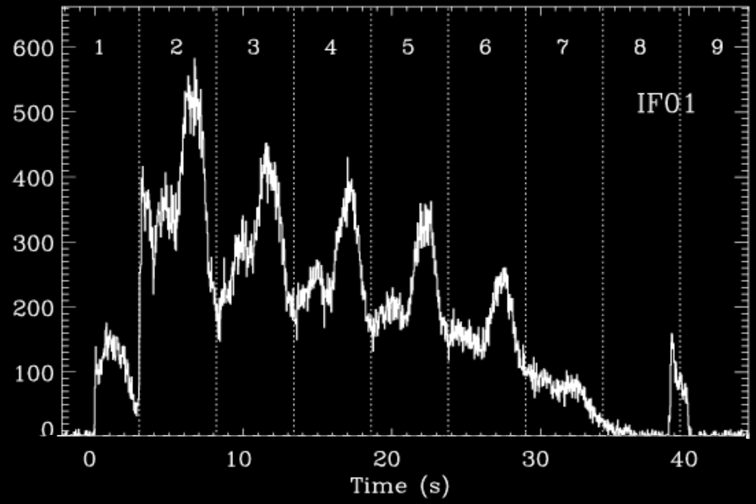
Several indirect evidences (for high B) collected through years !
IMPORTANT for what follows...
<u>The above eq. gives a good estimate of dipolar B !</u>

BURSTS/FLARES ($L >> L_{EDD}$)

Local and/or global MF re-configuration
Sometimes observed together with glitches and outbursts

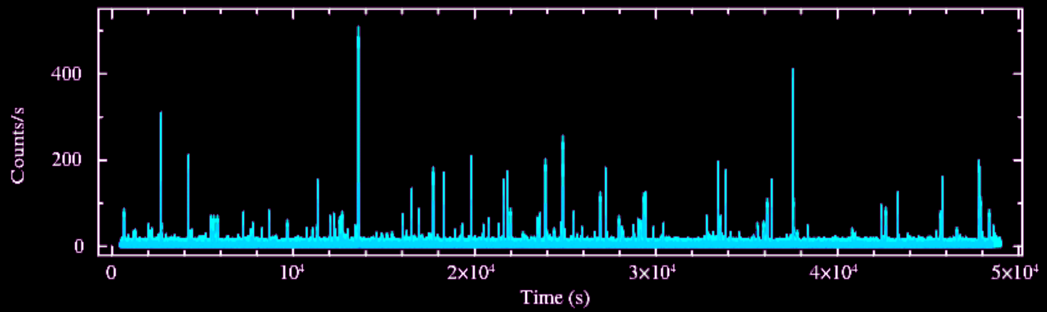
Giant flares: 3 from 3 different SGRs in 30years
Fluence: from 10^{44} up to 10^{47} ergs
Duration: 5-10 minutes
Ringing Tail: up to 10^{44} ergs and pulsed





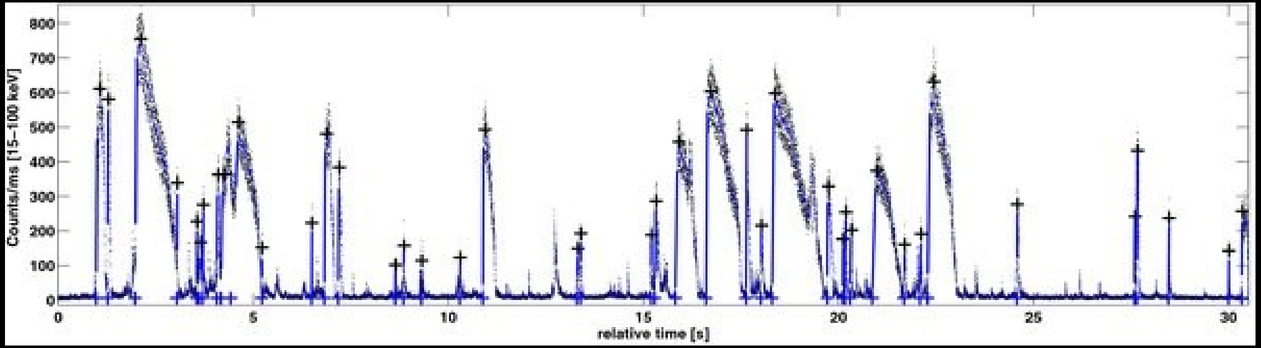
Intermediate flares: tens in SGRs (a few in AXPs)
Fluence: ~ 10^{42} up to 10^{44} ergs
Duration: 0.5-40 seconds
Ringing tail: sometimes

Bursts: thousands from SGRs/AXPs
Fluence: 10^{38} up to 10^{42} ergs
Duration: 10-500ms



A LOT OF PHOTONS BUT DIFFICULT TO OBSERVE

BURSTS/FLARES



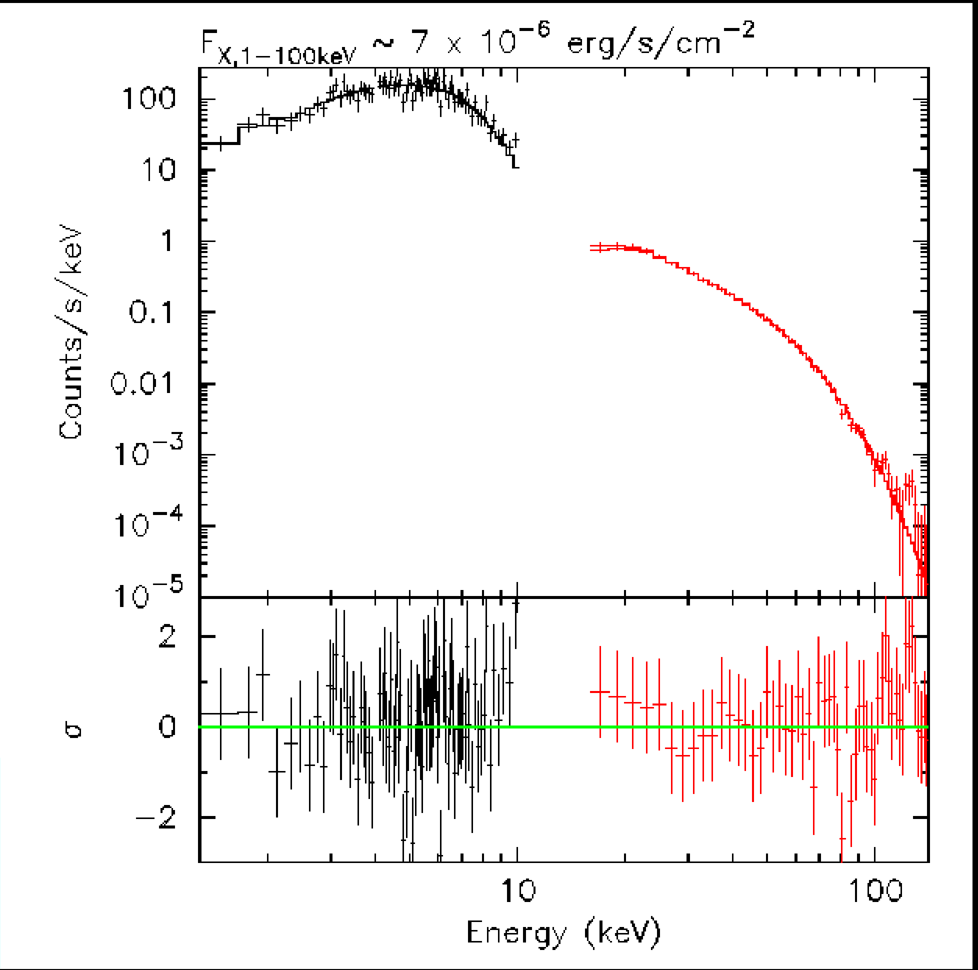
Tens of bursts/IFs when the source is active

IF spectra: BB+BB and/or BB+PL

Fluxes: < few 10^{-5} erg/s/cm^2

Short burst → scaled (flux and duration) IF

Same for the GF ringing Tail

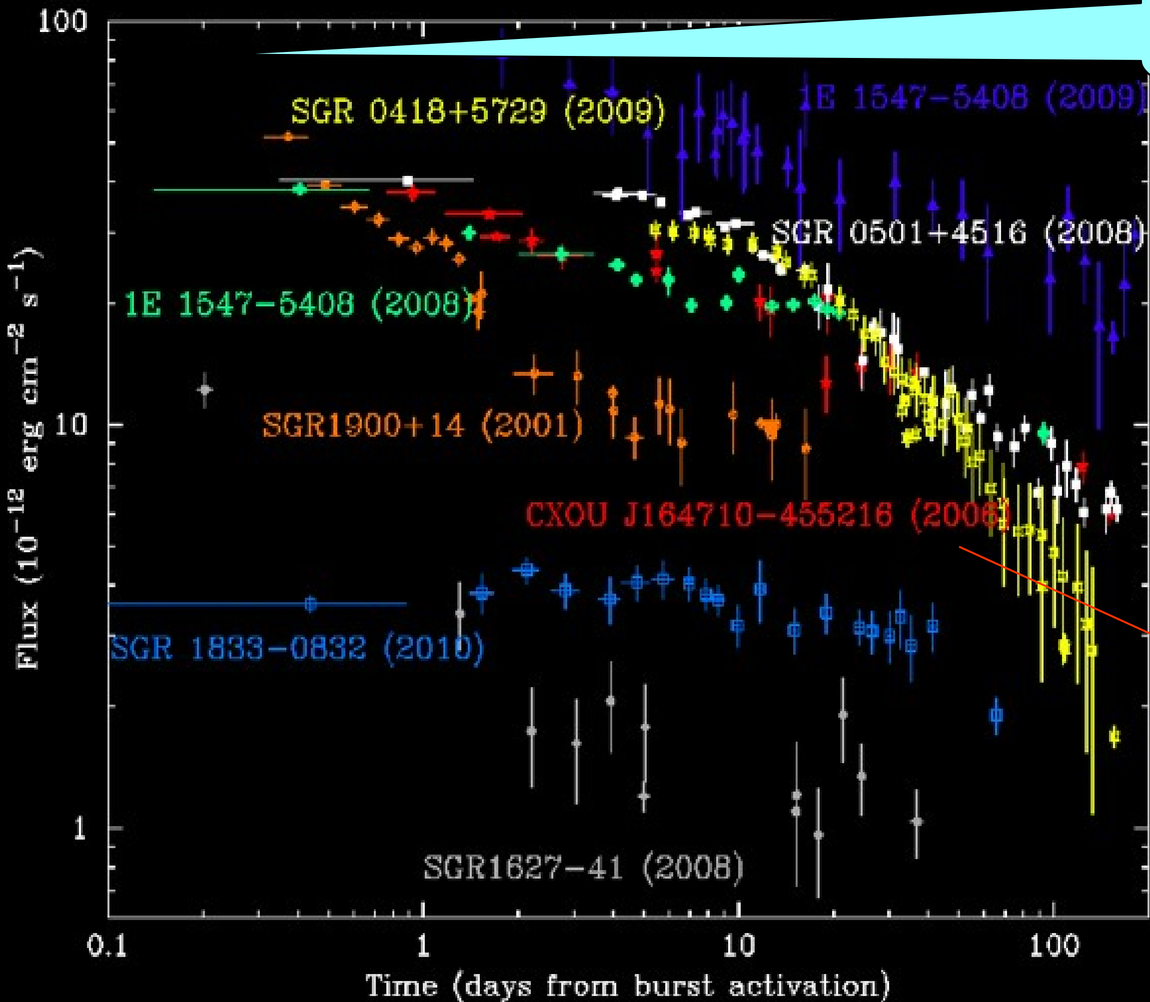


eXTP: WFM is able to detect and trigger activity phases

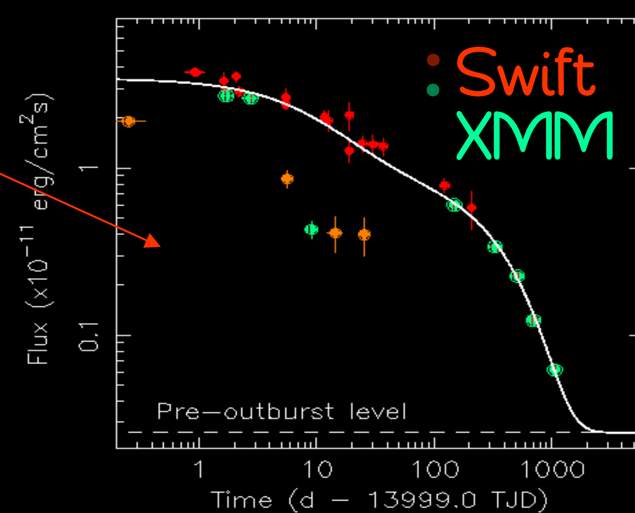
MAGNETAR OUTBURSTS

Transient flux enhancements/outbursts lasting months-years

Outburst peak Lx never exceeding ~10^{36} ergs/s



Outburst decays well suited for spec and timing studies as a function of Lx



MAGNETAR OUTBURSTS

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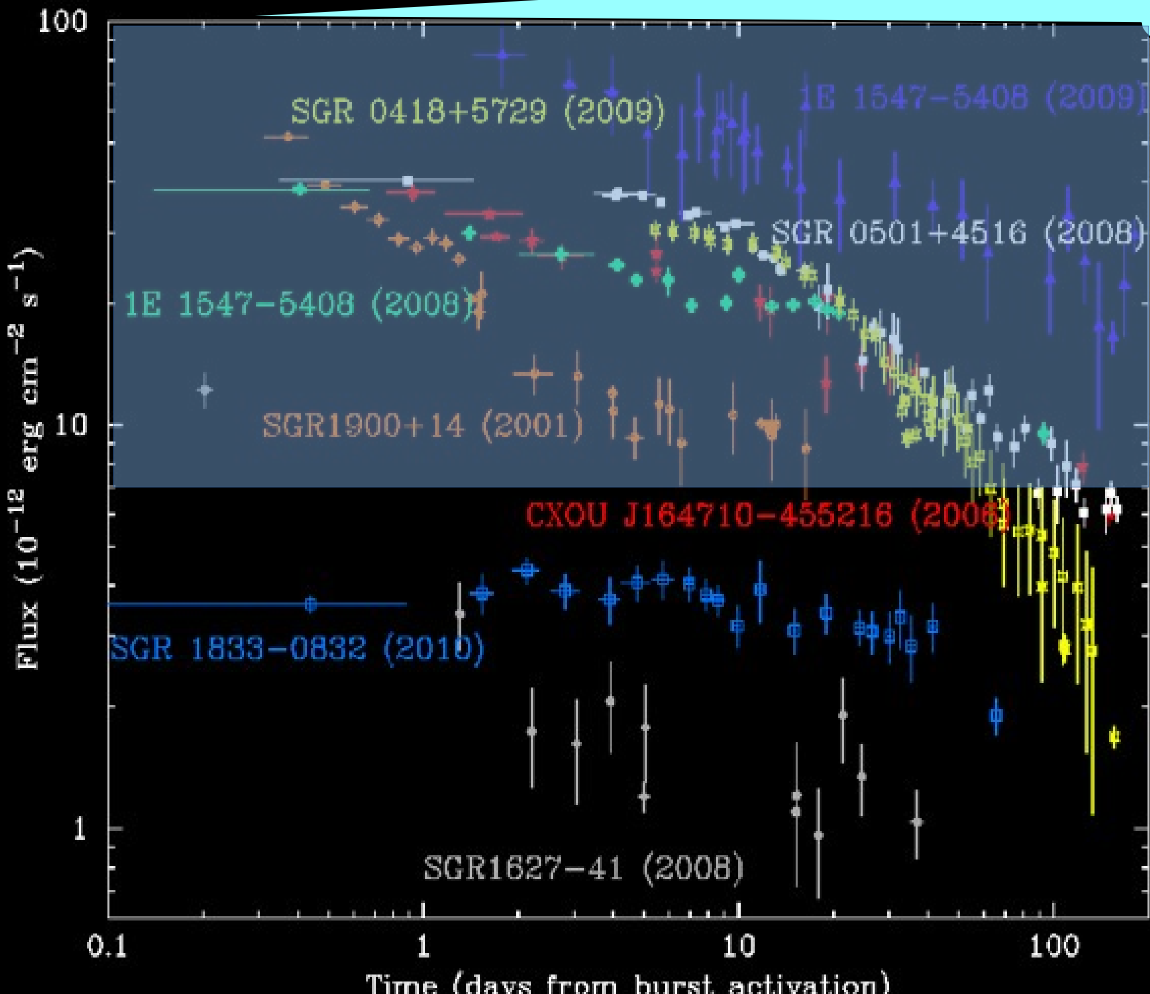
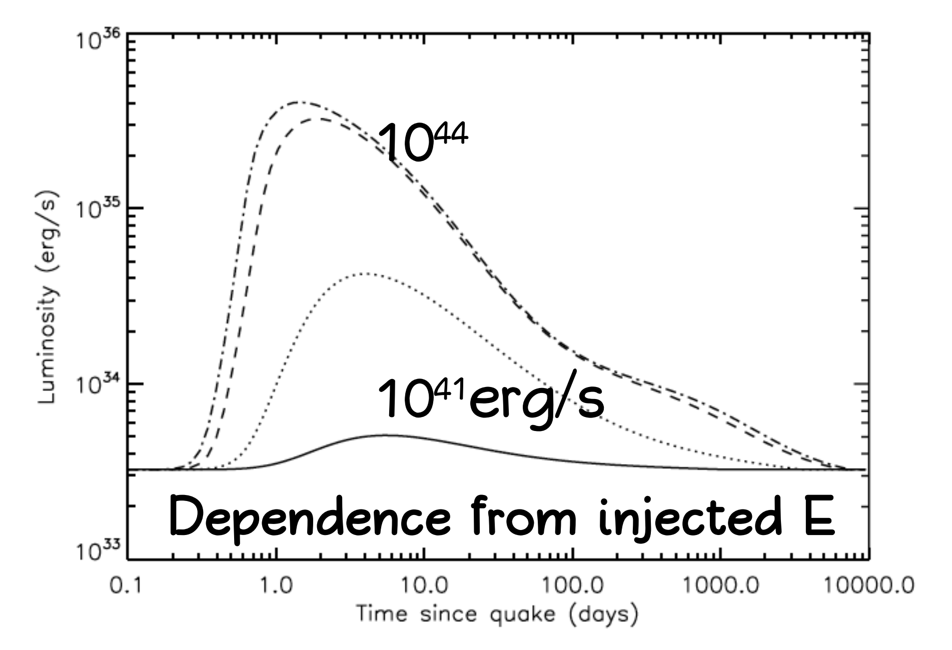


Outburst peak Lx never exceeding ~10^{36} ergs/s

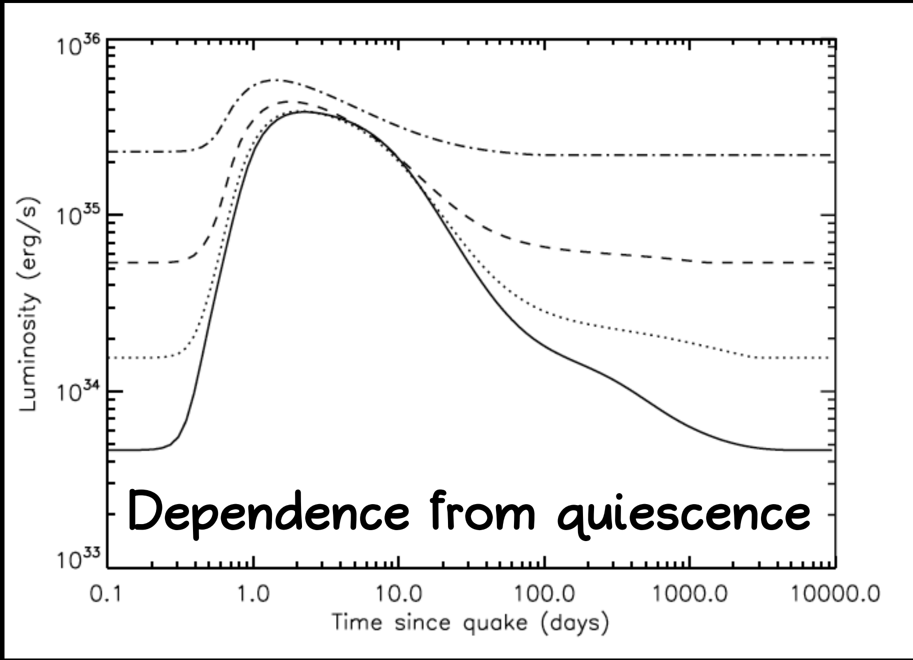
eXTP: flux levels well within the LAD, PFA and SFA capabilities

THE MAGNETAR OUTBURSTS

Maximum outburst luminosity is limited by neutrino emission to be Lx ~ 10^{36} erg/s (assuming magneto-thermal emission)



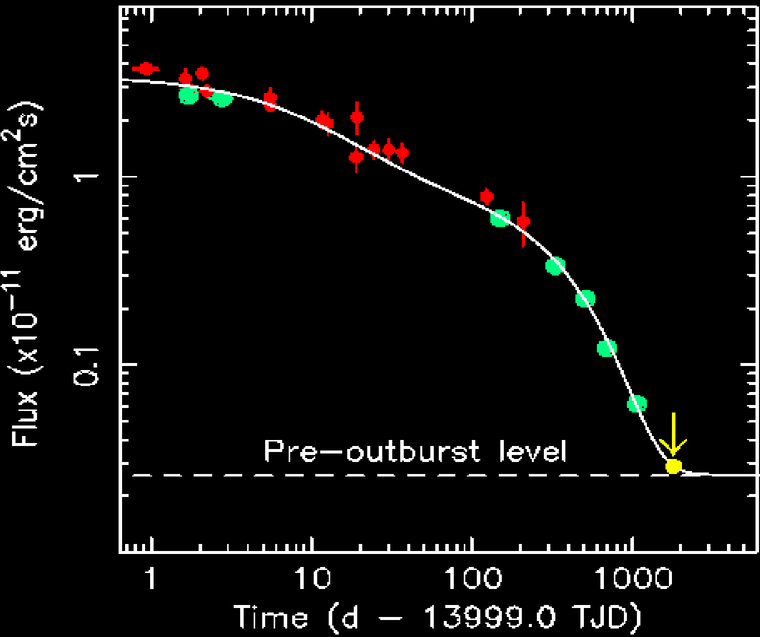
(Pons & Rea 2011)



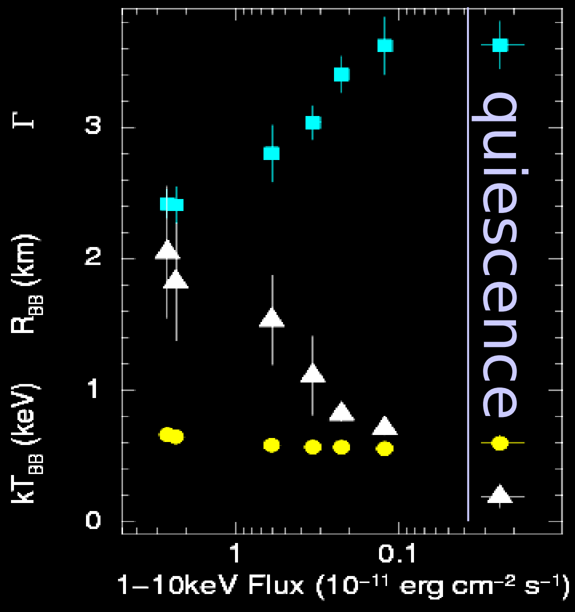
Outburst rate is regulated by age and internal field strength and configuration

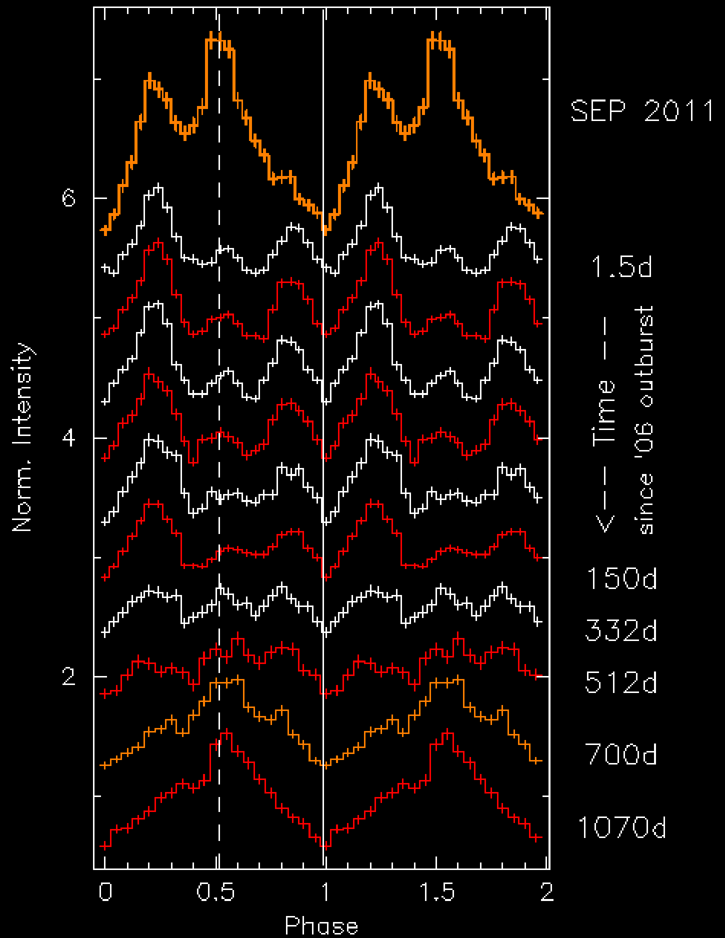
Currently we detect 1-2 outbursts per year (mainly Swift)

TIMING/SPECTRAL EVOLUTION (OUTBURST)



(Rodriguez et al 2014)

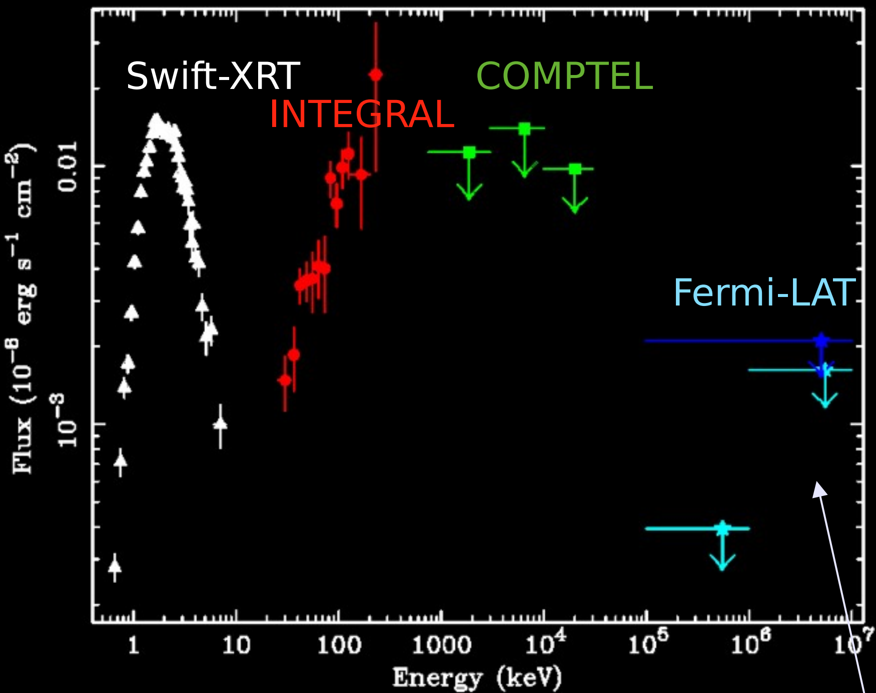




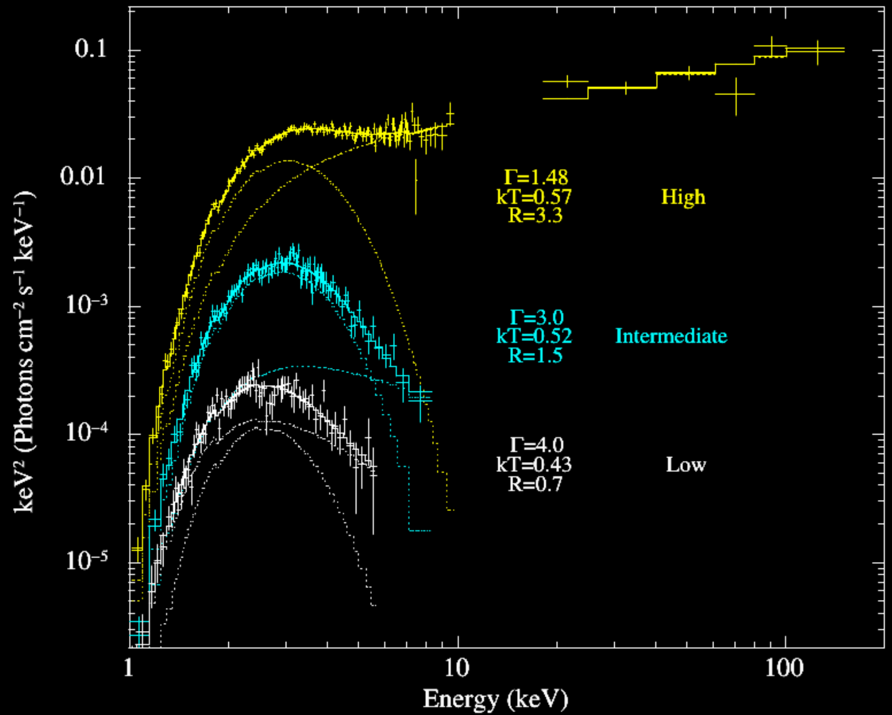
MAGNETARS GENERAL PROPERTIES

Detected up to few hundreds of keV as persistent sources

Evidence for a cut-off around a few MeV in the persistent emission!



(Abdo et al. 2010)

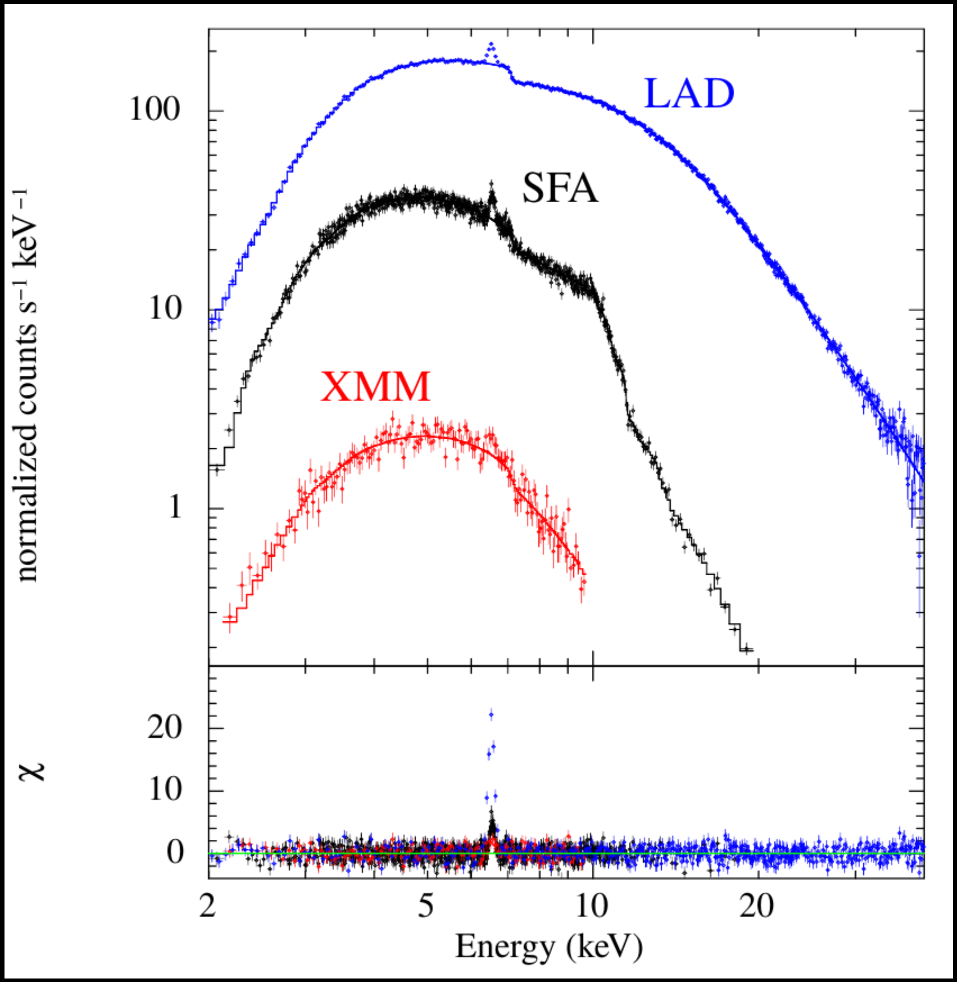


(Bernardini et al. 2011)

MAGNETARS OUTBURSTS AND eXTP

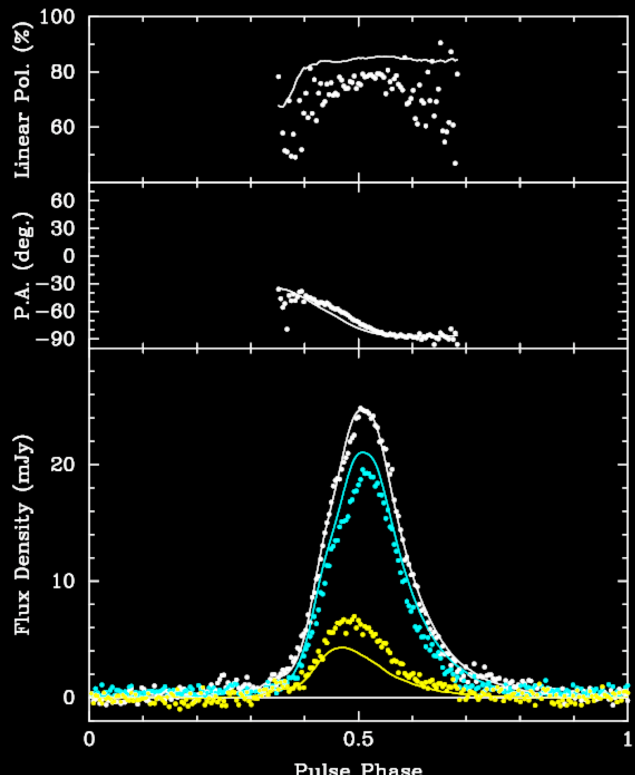
Reference spectra: originally obtained for a 3×10^{-10} erg/s/cm^2 source and 1ks

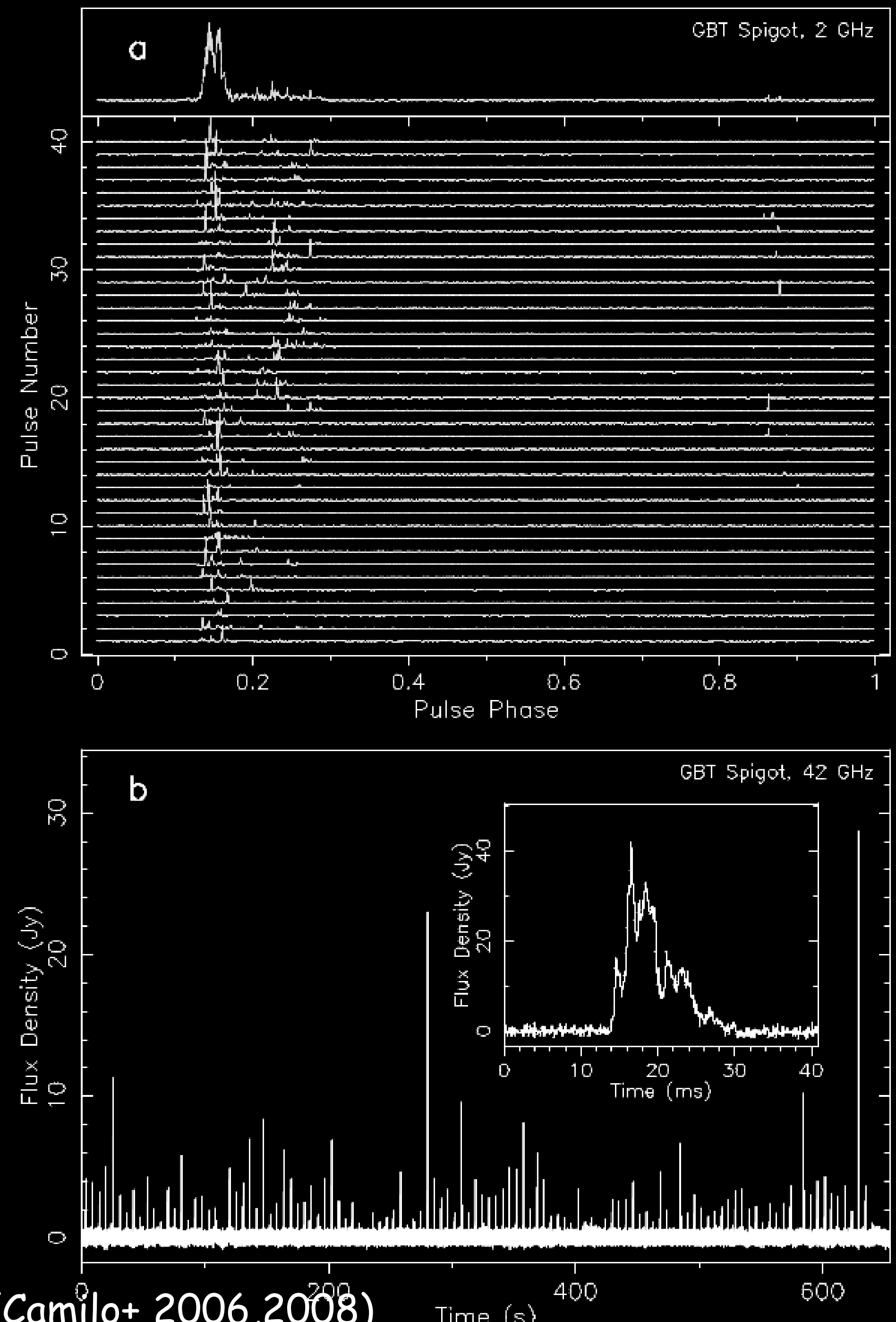
eXTP: 10ks observation of the initial phases of a magnetar outburst few $\times 10^{-11}$ erg/s/cm^2



MAGNETAR OUTBURSTS

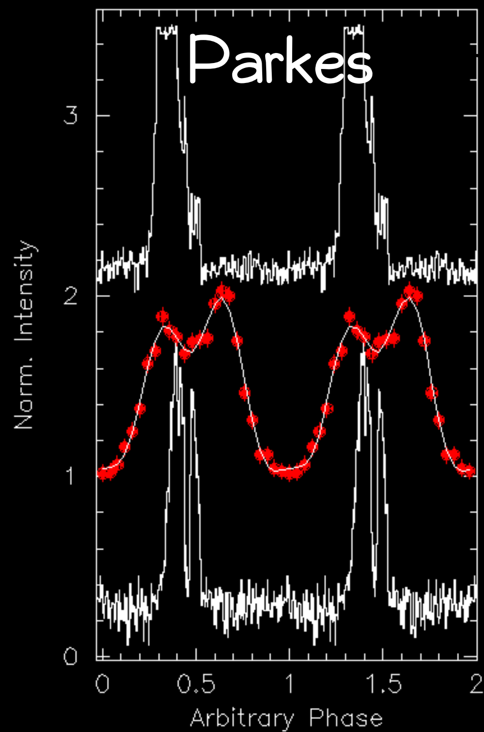
Radio pulsed emission was observed connected with X-ray outbursts for 4 magnetar, with variable flux and profiles, flat spectra, powerful single pulses (brightest pulsars in the sky for few months),
high linear and circular polarization.

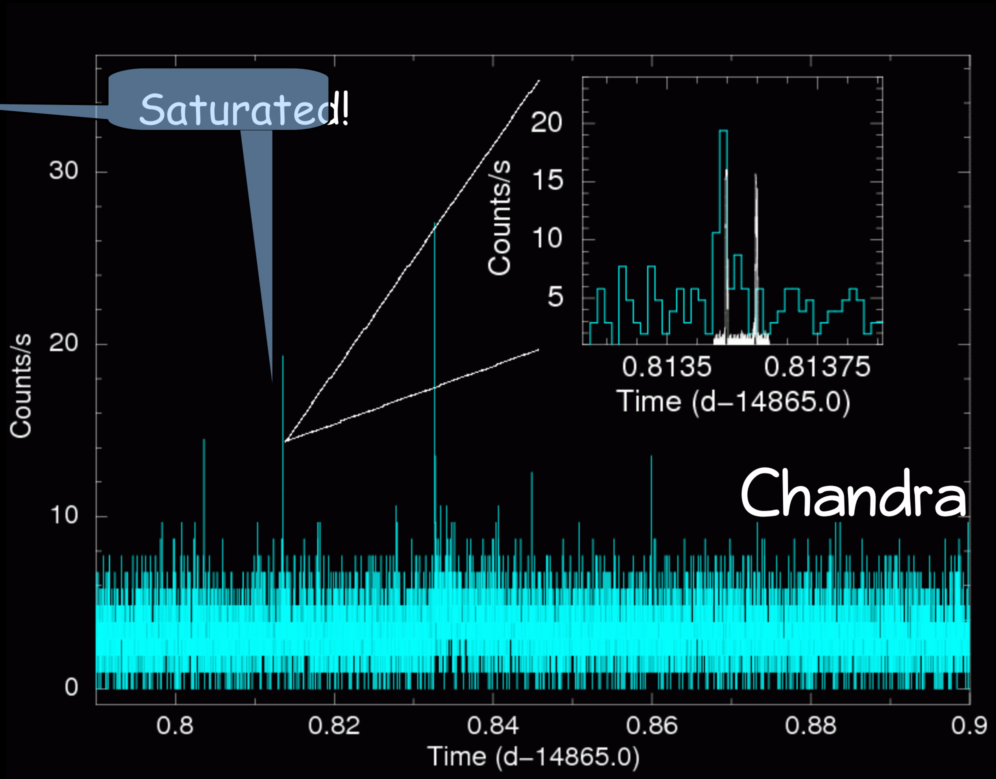




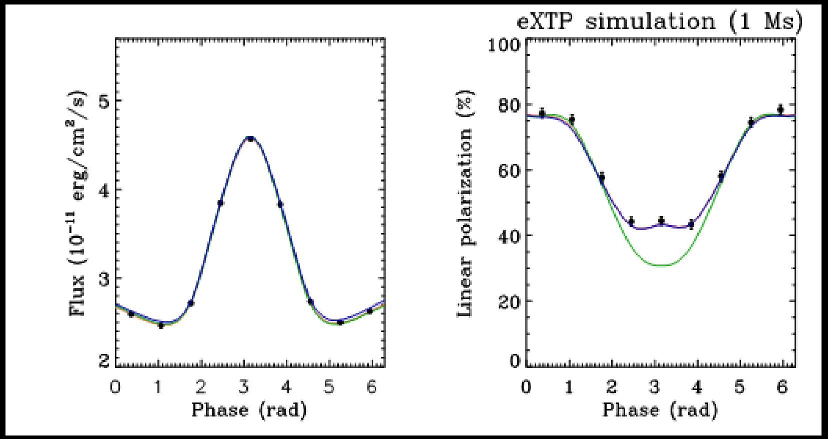
(Camilo+ 2006,2008)

BURSTS AND RADIO



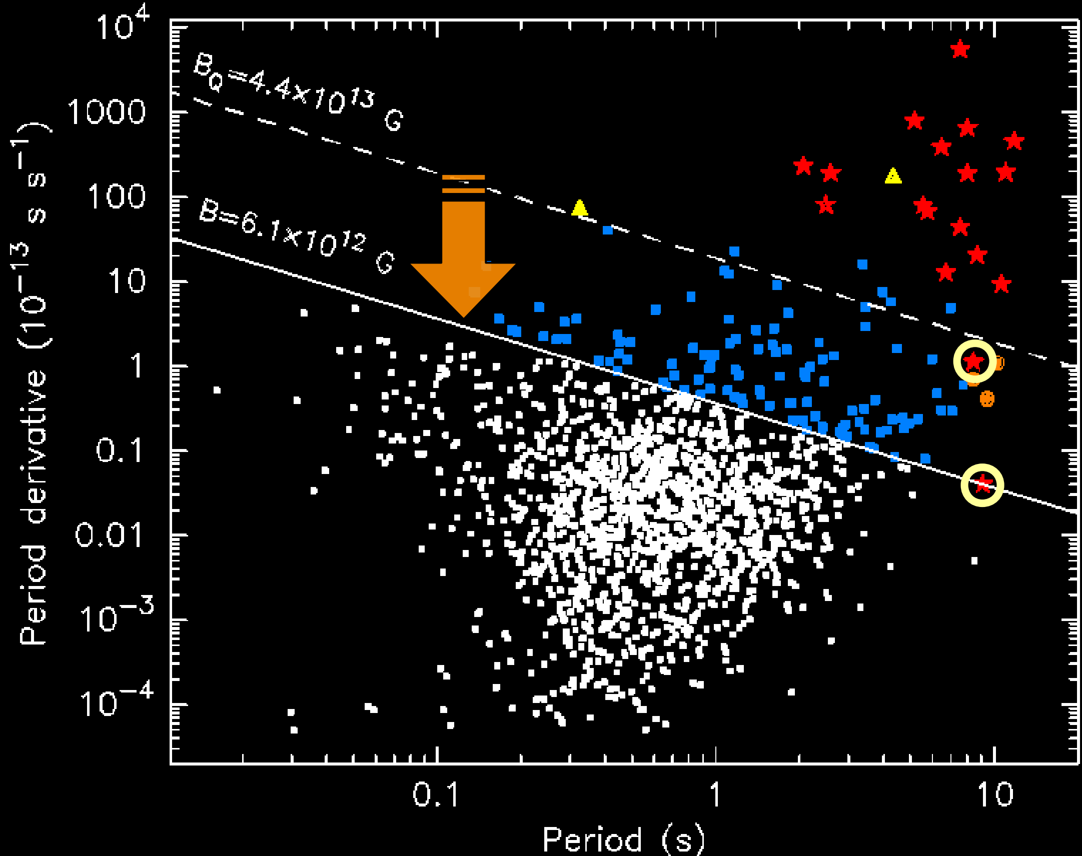


eXTP: fluxes are high enough to test with PFA if the X-ray emission is polarized too.
OK for LAD and SFA



LOW B MAGNETAR: IMPLICATIONS

How many hidden magnetars can we expect?
More than 20% of radio pulsars (~400) have Bp larger than SGR0418.



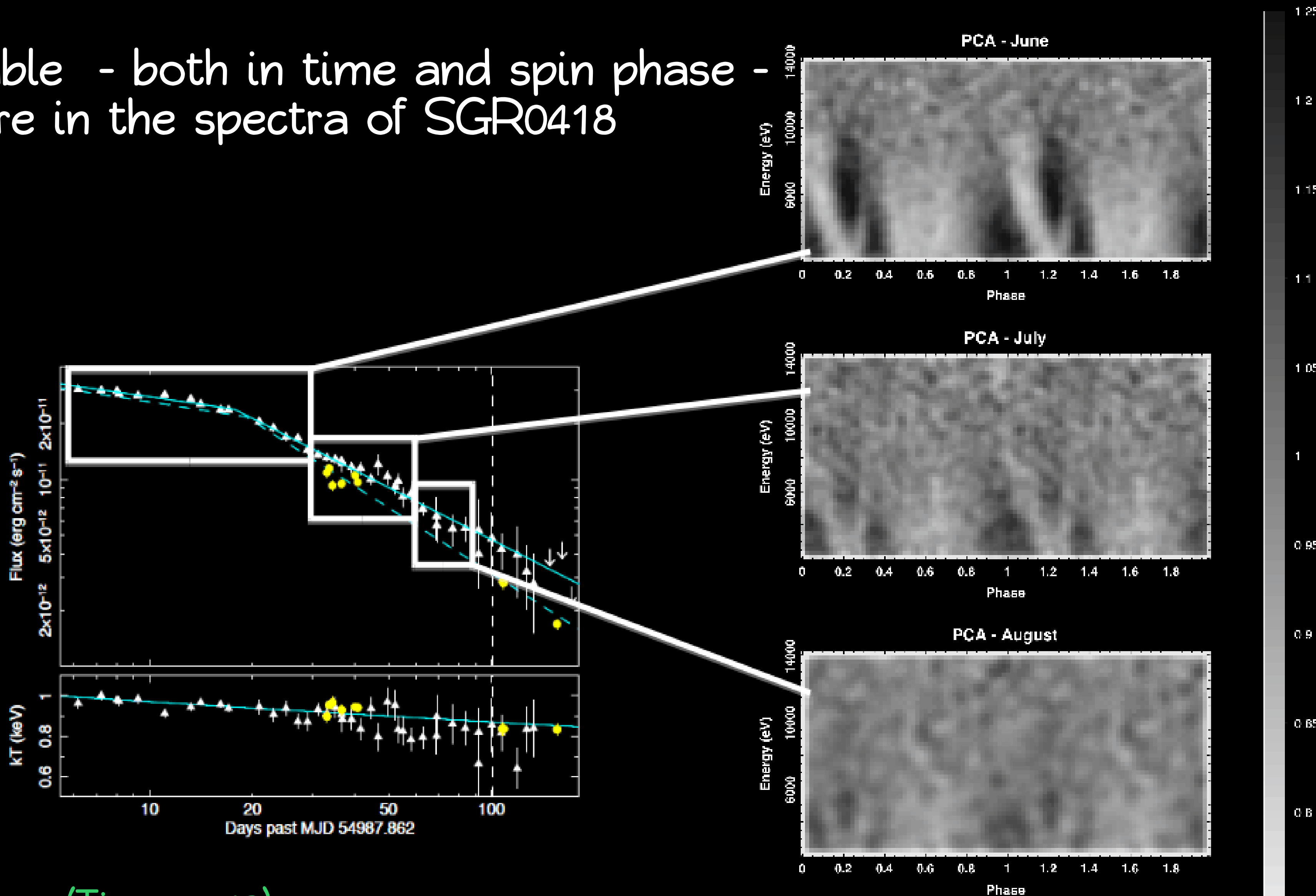
This revises the population of magnetars in our Galaxy

Many more burst-quiet (so far) radio pulsars are expected to show magnetars-like activity in the future !!!

eXTP: WFM is expected to detect bursts from new magnetars/radio pulsars

DIRECT MEASUREMENT OF B (ON SURFACE)

Variable - both in time and spin phase - feature in the spectra of SGR0418

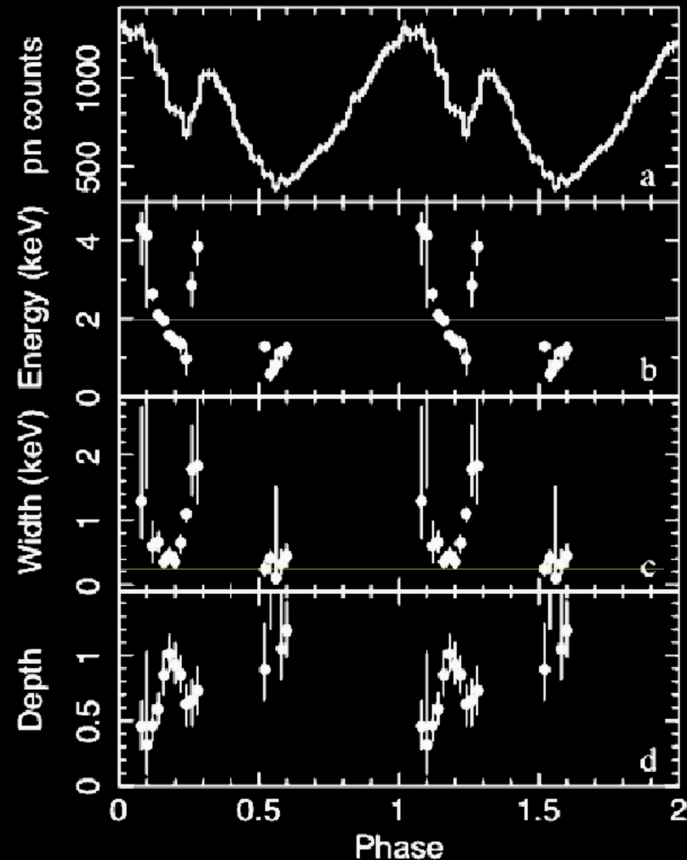


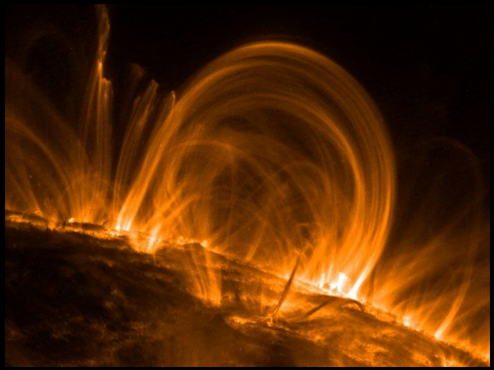
(Tiengo+ 13)

DIRECT MEASUREMENT OF B

E~1-5 corresponds to
$E_{cyc,proton}$ ~(2-10)x10^{14} G
⇒**MAGNETAR**-like magnetic field

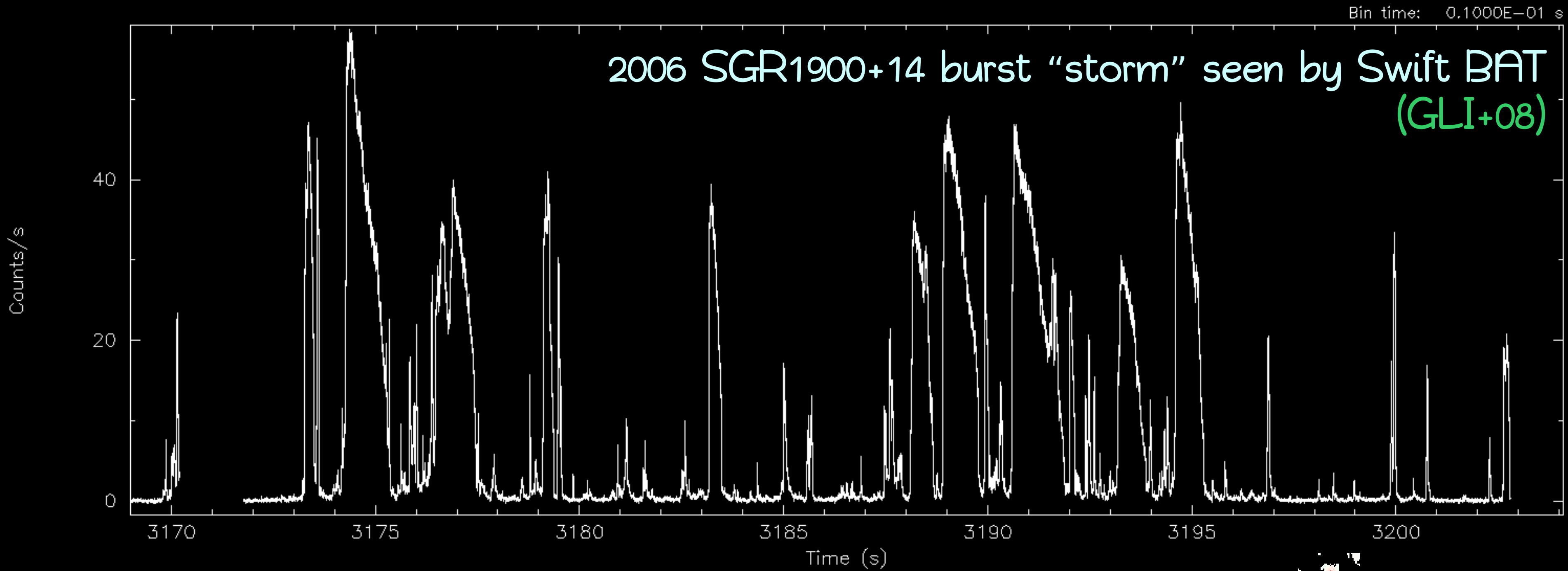
If proton cyclotron line, we need a **STRONGLY VARIABLE B**, that might vary. Likely a **VERTICAL** plasma structure emerging from the surface (coronal loop analogy; e.g., Beloborodov & Thompson 2007; , Masada et al. 2010)



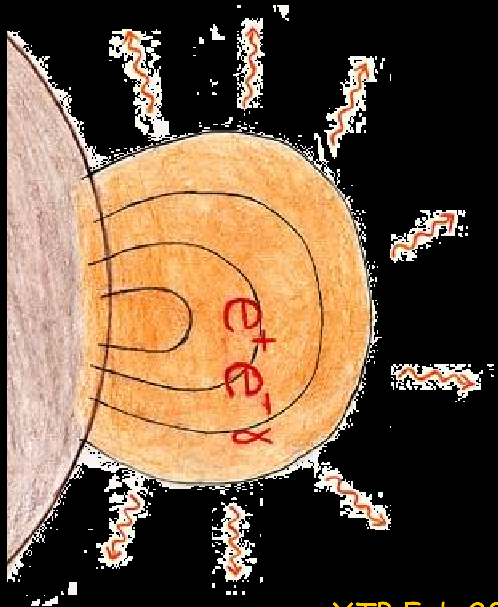


eXTP: Cyc. energies at the edge of LAD and PFA ranges (but depends on B), well within the SFA

MAGNETAR FLARES



Well suited for **time-resolved spectroscopy** on a large number of events. Matter-radiation interaction in a high-B environment. Testing the magnetically confined fireball model



Done for SGR1900 (2006) and 1E1547 (2009)

TIME RESOLVED FLARE SPECTROSCOPY

... similar but with different saturation values for L soft
Can we learn something ?

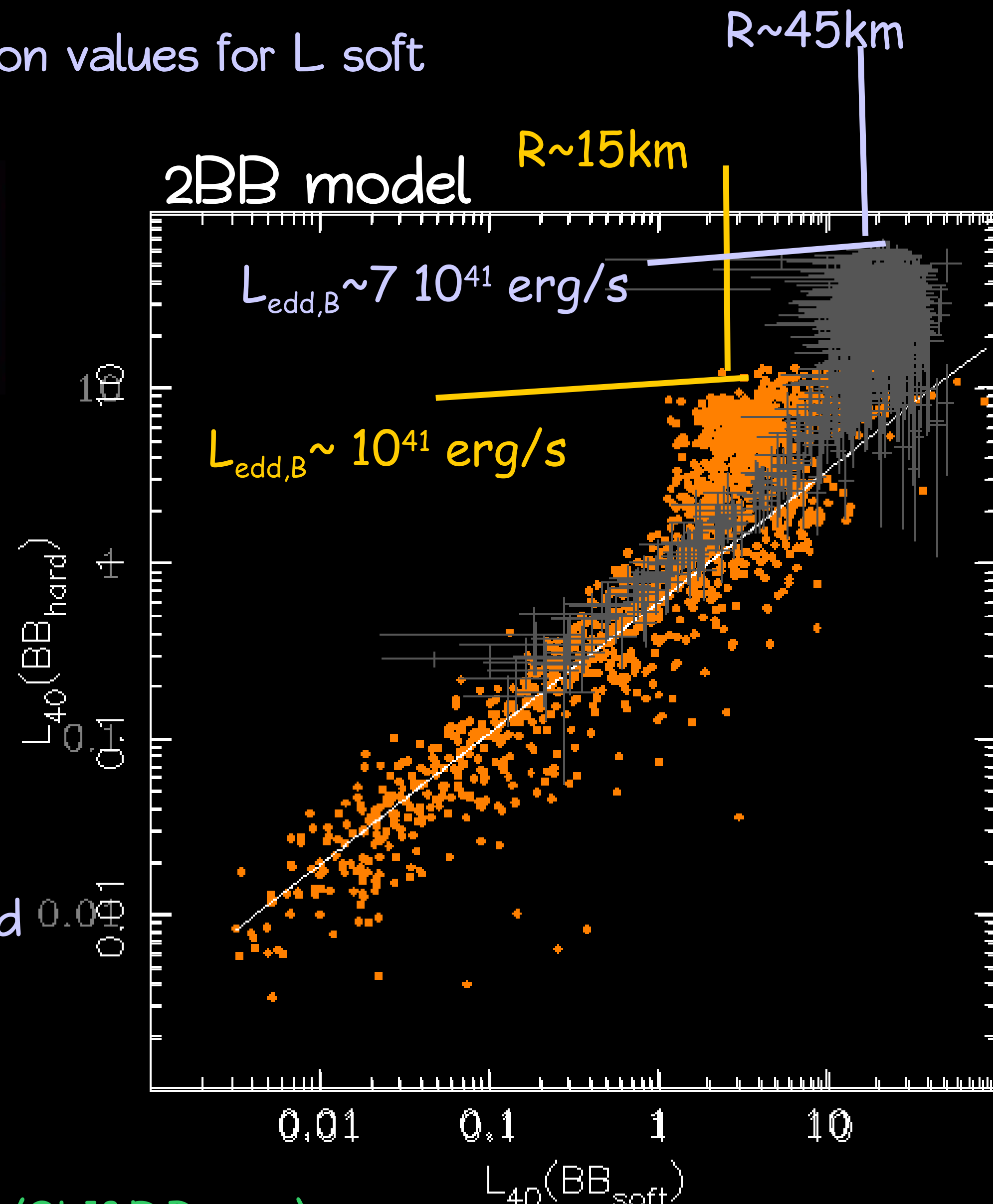
$$L_{Edd,B}(r) \approx 2 \times 10^{40} \left(\frac{B}{B_{QED}}\right)\left(\frac{r}{R_{NS}}\right)^{2/3} \mathrm{erg\ s^{-1}}$$

Deviding $L_{edd,B}$ measured for the two sources

$$\frac{B_{SGR1900}}{B_{1E1547}} \approx 7 \left(\frac{r_{1E1547}}{r_{SGR1900}}\right)^{2/3} \mathrm{erg\ s^{-1}} \approx 3 \div 4$$

[not that dissimilar to what expected from the timing measurements:
$B \sim 3.2\ 10^{19}\ (P\dot{P})^{1/2}$

$$\frac{B_{SGR1900}}{B_{1E1547}} \approx 2.5 \div 4.2$$]



(GLI&DO 2010)

SPECTRA: IMPLICATIONS

May we say something more if we observe a known/unknown SGR/AXP showing a saturation signature in the spectrum?

$$\left(\frac{d}{\mathrm{kpc}}\right) \approx 60 \cdot \left(\frac{\boxed{F_{\mathrm{max}}}}{10^{-5}\,\mathrm{cgs}}\right)^{-\frac{1}{2}} \left(\frac{\boxed{\mathrm{kT}}}{\mathrm{keV}}\right)^{-1} \left[\frac{B(r)}{10^{14}\,G}\right] \left(\frac{R_{\mathrm{NS}}}{10\mathrm{km}}\right)^{-\frac{1}{2}}$$

F_{max} and kT in measured from spectra, B(r) on the surface may be inferred from timing (P and Pdot)

The above relation gave for SGR1900 (B~6.4G) and 1E1547 (B~2.2G):

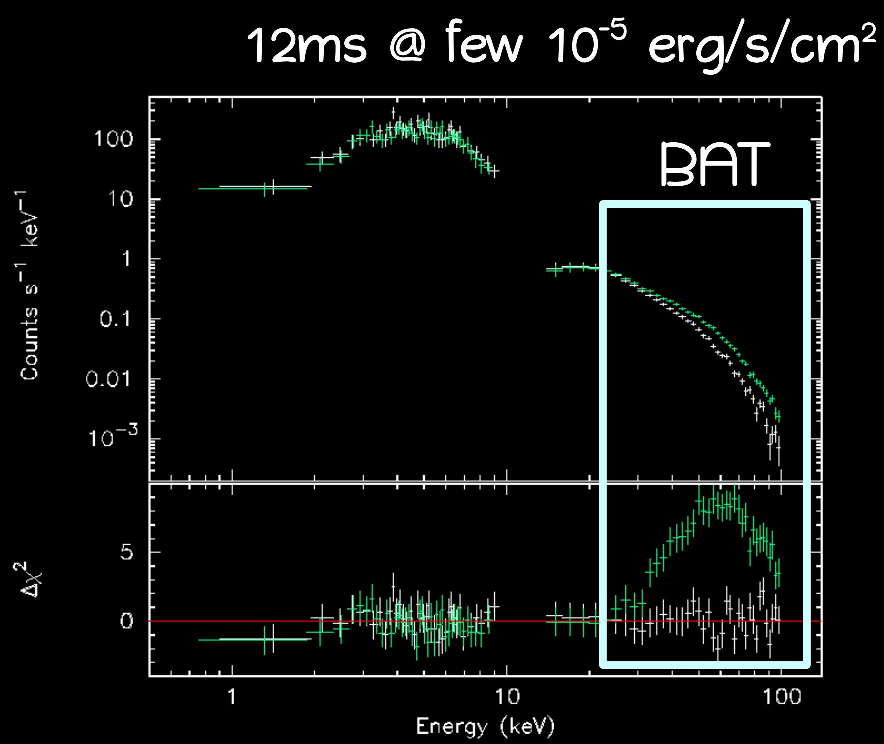
d ~ 9 kpc for SGR1900
d ~ 4.7 kpc for 1E1547

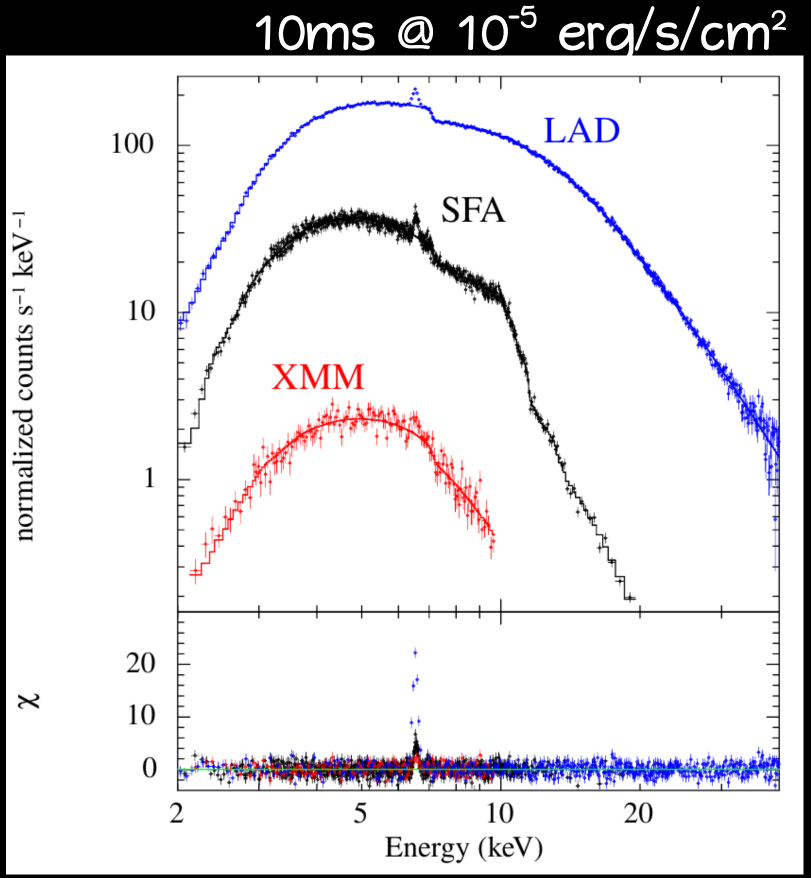
From literature we have:

d≈ 10-15kpc for SGR1900 uncertain
d≈ 4-5 kpc for 1E1547 reliable (scattering halo)

A magnetic "standard candle" !
To be confirmed for Magnetars with known distances

IF SPECTRA AND eXTP





eXTP: close to the LAD capabilities (small area above 30keV but no BG in 1s); still possible.
OK for PFA. Statistics for 1s IF of 10^{-6} erg/s/cm^2 ~ 0.1Ms at few 10^{-11} erg/s/cm^2 (tbc if feasible). OK for WFM too

CONCLUSIONS

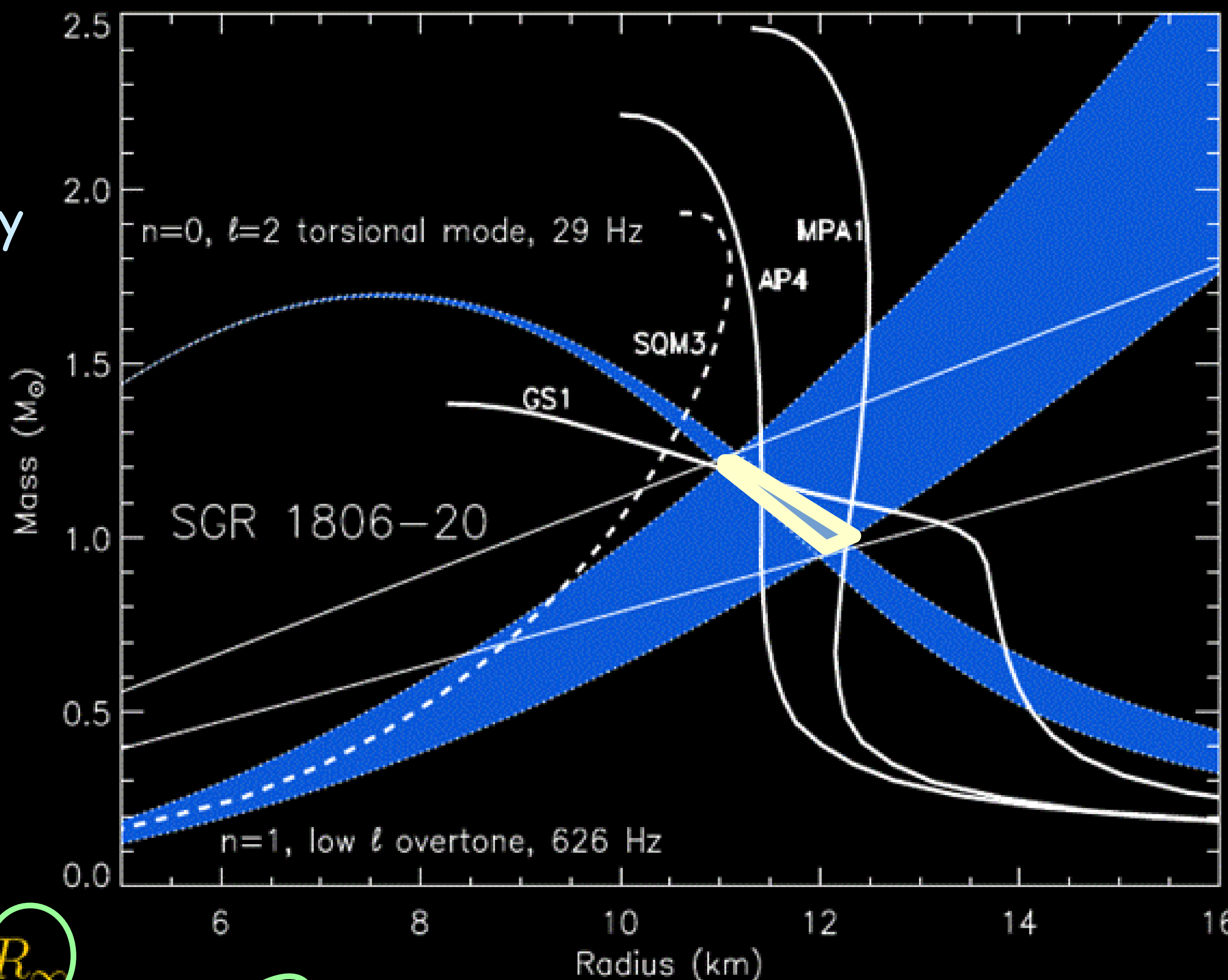
Magnetar phenomenology nicely fits within the eXTP instrument capabilities.

	WFM	LAD	SFA	PFA
Magnetar discovery		NA	NA	NA
Magnetar outbursts				
Magnetar quiescence				
Intermediate Flares				
Short Bursts				

GF QPOs + EOS

RXTE

Fund. mode and overtones are slightly model dependent.



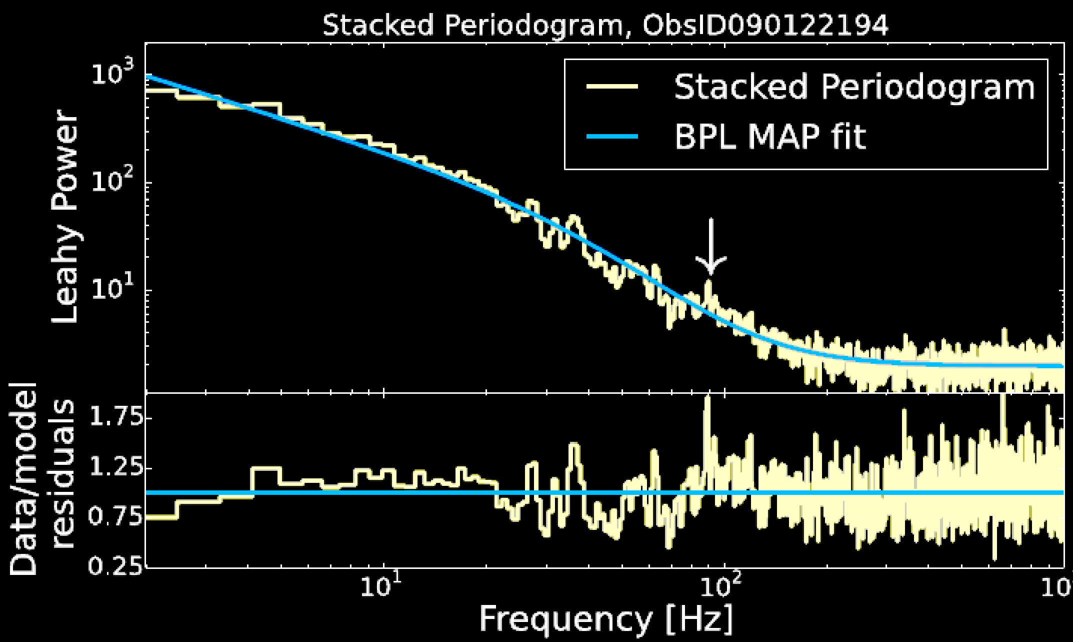
$$f_{n=0} \sim v_t / R_\infty$$
$$f_{n>0} \sim v_r \frac{1-2\beta}{\Delta} \sim v_r \frac{M}{R^2(l(l-1)}$$

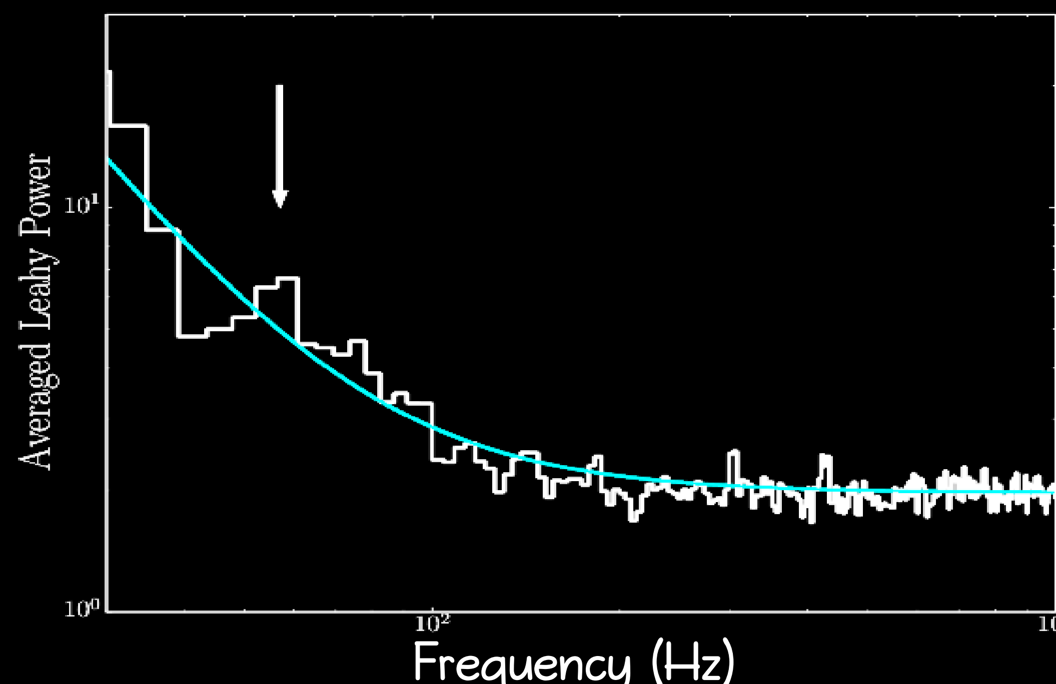
Strohmayer & Watts (2005)
Samuelsson & Andersson (2006)
Lattimer & Prakash (2006)

SHORT BURSTS AND QPOS

Recent reliable detections of QPOs by stacking photons from several short bursts of the same Magnetar (1E1547 and SGR1900 - 57Hz)

(Huppenkothen+ 2014,2015)



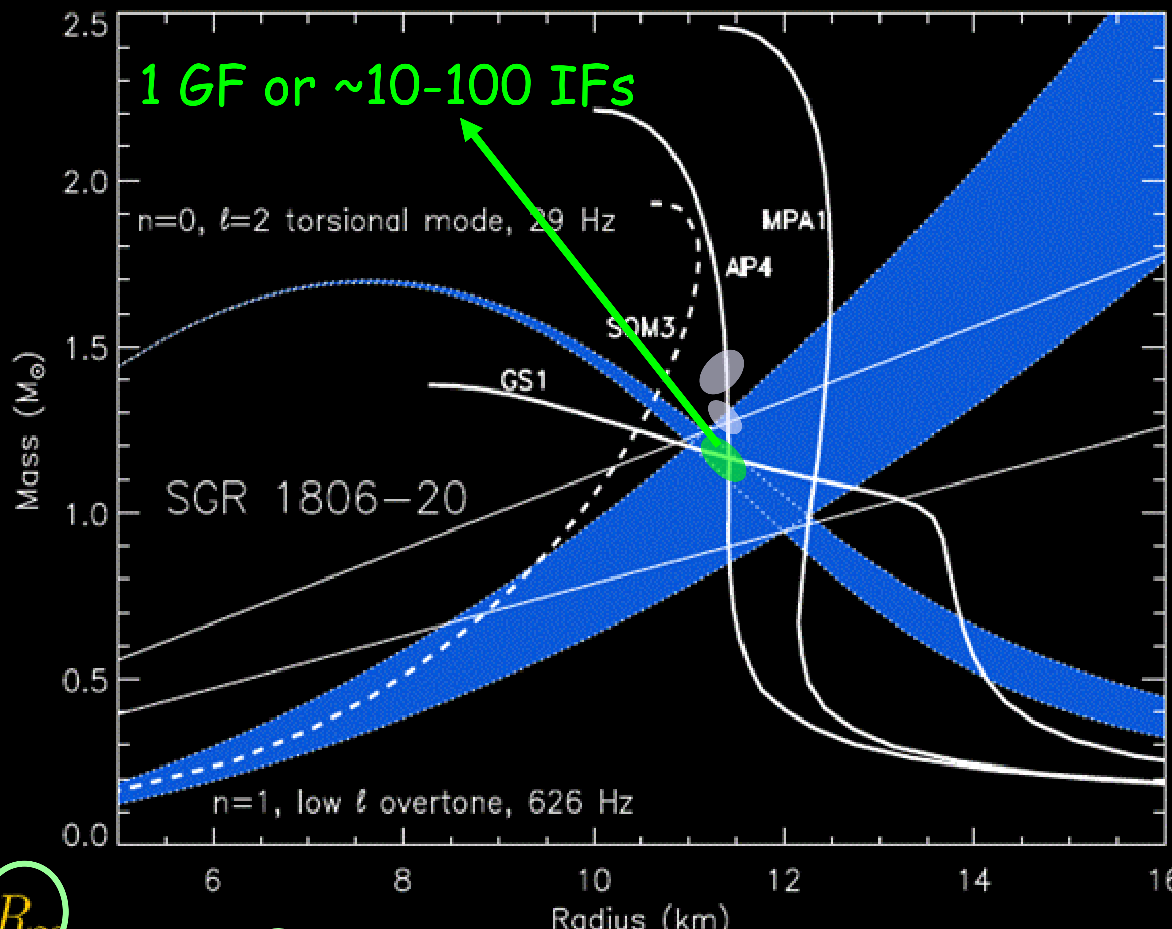


IF QPOs + EOS

eXTP

RXTE

What is now clear is that mode frequencies depend not only on M and R, but also on magnetic field strength, geometry, superfluidity, and crust composition.



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Strohmayer & Watts (2005)
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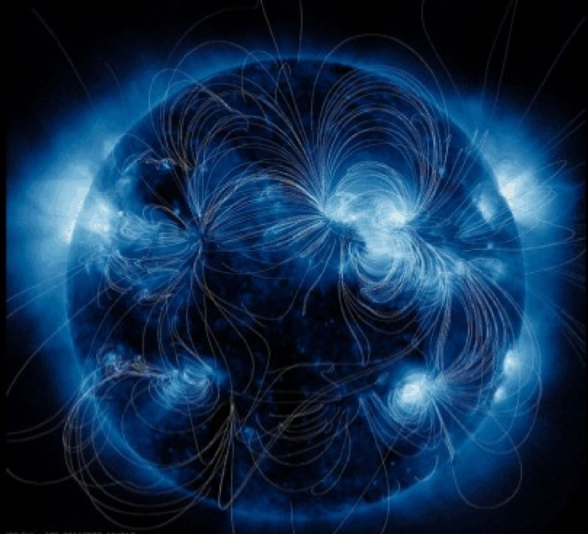
Short Bursts				

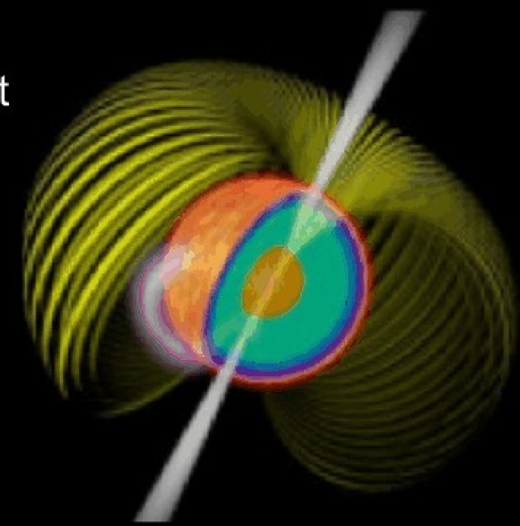
MAGNETAR THEORY IN A NUTSHELL

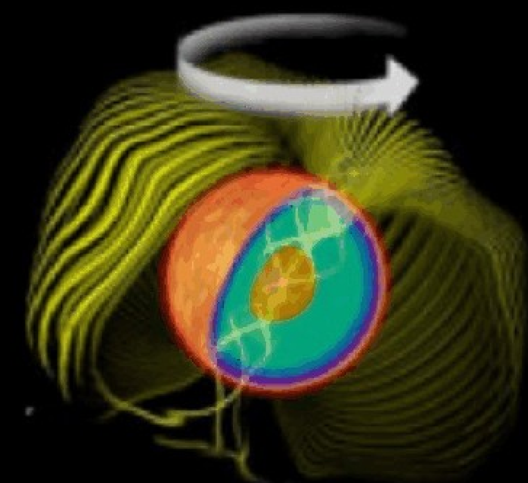
- Magnetars have highly twisted and complex magnetic field morphologies, both inside and outside the star. The surface of young magnetars are so hot that they are bright in X-rays.

- 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...

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





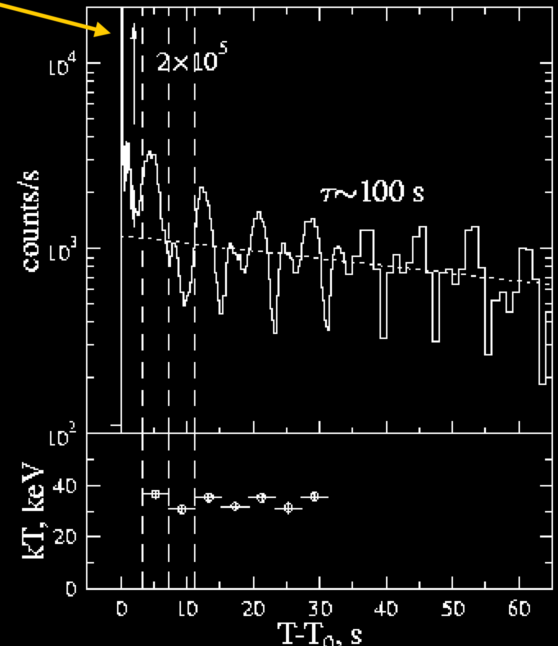


(Thompson & Duncan 1993; Thompson, Lyutikov & Kulkarni 2002; Fernandez & Thompson 2008; Nobili, Turolla & Zane 2008a,b)

SHORT HISTORY

January 7, 1979: a soft γ-ray burst was detected from the Galactic center region (SGR1806-20)

March 5, 1979: a hard, intense γ-ray burst was detected from the N49 SNR in the LMC (55 kpc); >1000 times Eddington luminosity. It was followed by weaker bursts (SGR0506-66).



Many exotic theories proposed.

13 years later …… first theoretical scenarios proposed invoking a large magnetic field:
Duncan & Thompson 1992, ApJ 392, L9
Paczyński, B., Acta Astronomica 42, 145, 1992
Thompson & Duncan 1995, MNRAS 275, 255

THE QUALITATIVE SCENARIO

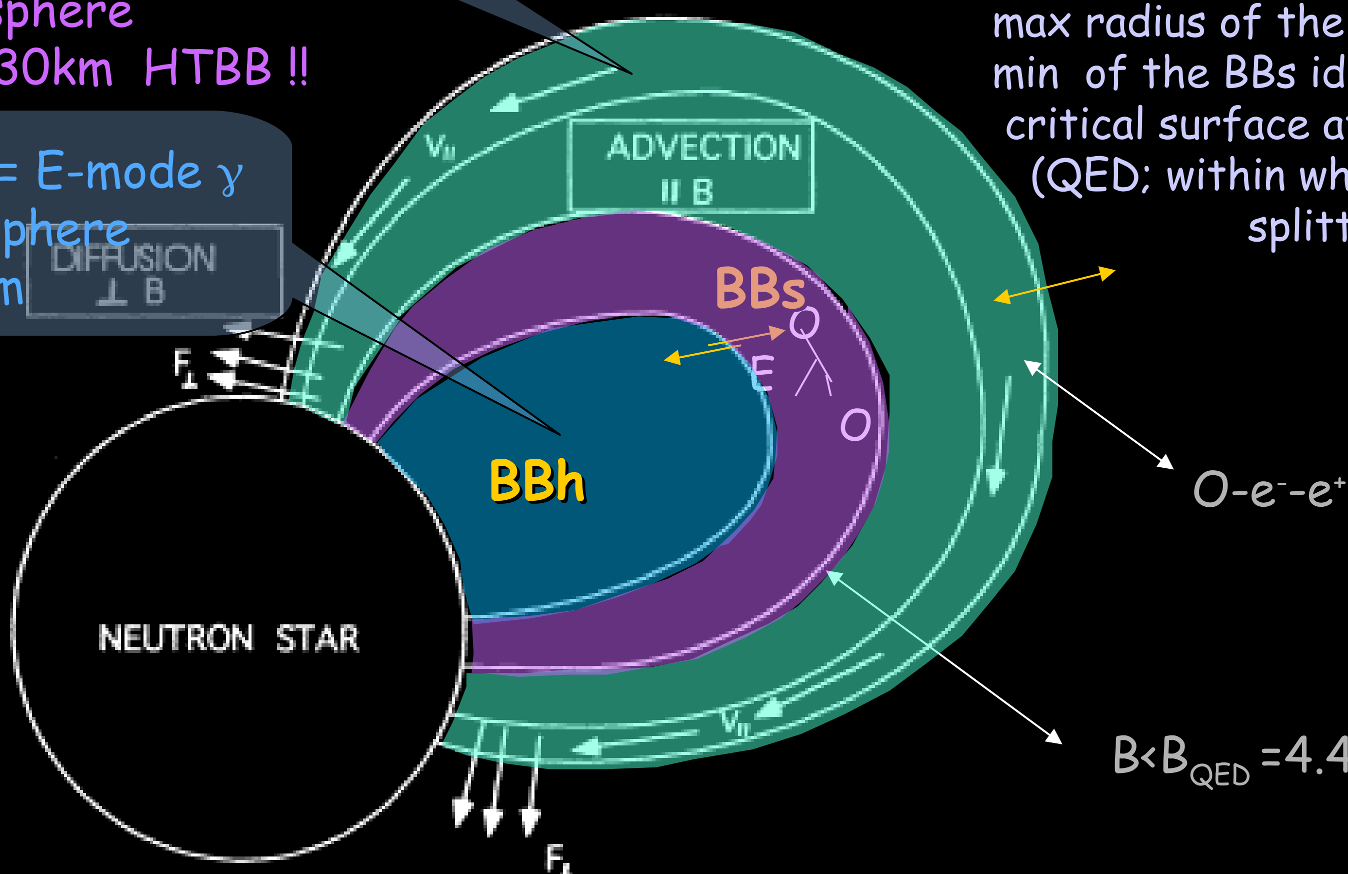
A possible interpretation: different way with which E- and O-mode polarised photons propagate into the magnetosphere; scattering cross section of E-mode may be reduced by B and the scattering photosphere is smaller (~R NS).

LTBB = O-mode γ photosphere R~100km

E-O-mode γ splitting photosphere R~25-30km HTBB !!

HTBB = E-mode γ photosphere R~15km

The R~25km corresponding to the max radius of the BBh and the min of the BBs identify a critical surface at which B=Bcrit (QED; within which photon splitting is possible).



QPOs AND GLOBAL SEISMIC OSCILLATIONS

Similar phenomenology and frequencies in the two sources during GFs
→ same physical process

SGR1806-20: 18 – 30.4, 61, 92.5, 150 – 626 - 1840 Hz
SGR1900+14: 28.5, 52.5,84, 155.5 Hz

TOROIDAL GSOsIndependent from B (below < 10^{15} Gauss).
Fundamental: n=0 l =2 ; ν~30Hz ; Harmonics are restricted to l > 2
30.4, 61, 92.5, 150Hz QPOs accounted for (l=2,4,7,13) in SGR1806-20
[l=2,4,7,13 for SGR1900+14]

Toroidal modes $_0T_2$ (44.2 min), $_1T_2$ (12.6 min) and $_0T_3$ (28.4 min)

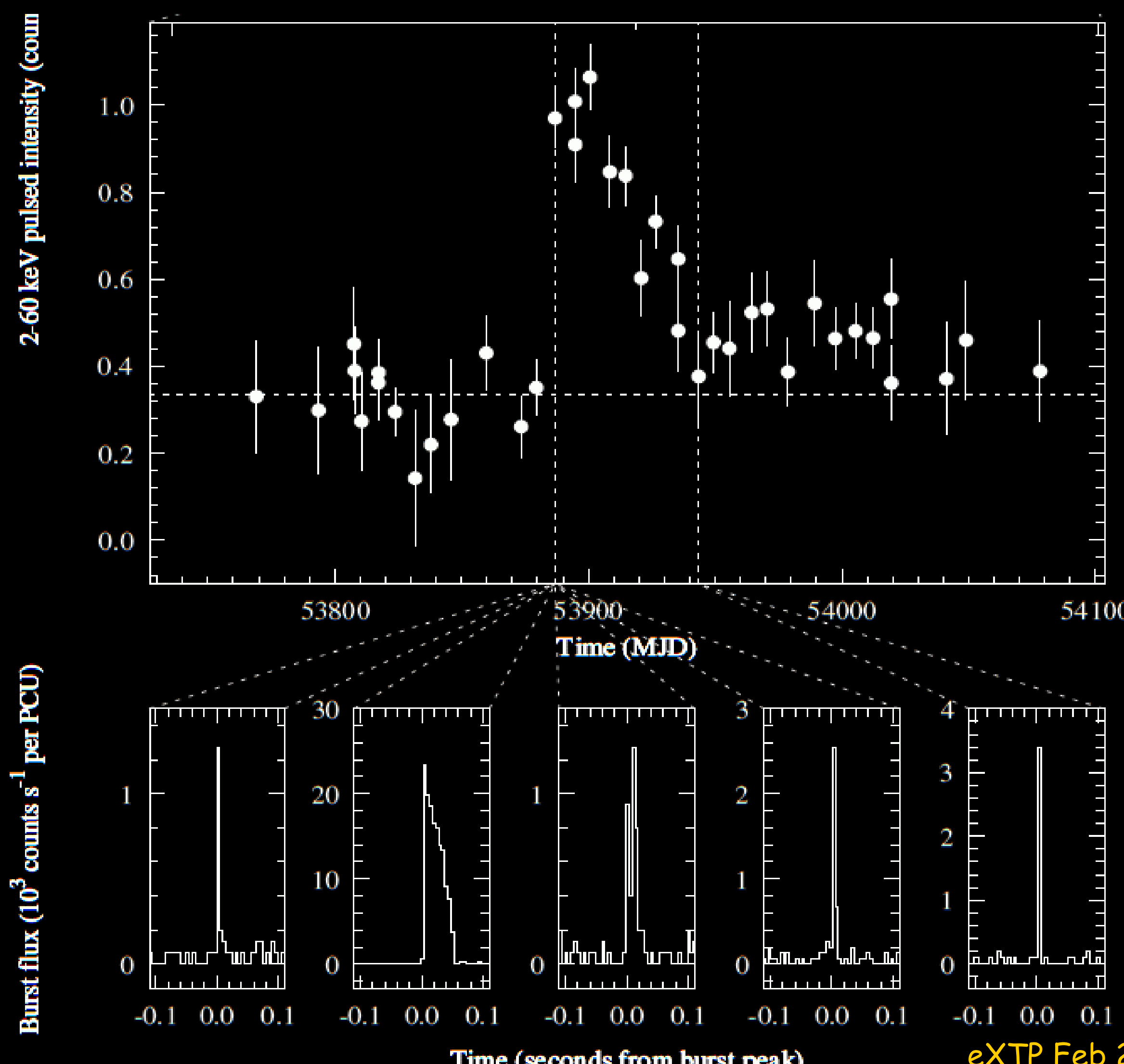
$\Delta R/R = (3/2)^{1/2}\, \nu(_2t_0)/\nu(_1t_1) \sim 0.06\text{-}0.12$

If the 626HZ QPOs are the n=1 modes and under a number of assumptions

(Duncan 1998, McDermott 1988, Watts 2006)

RELATED OBJECTS ?

magnetar-like X-ray bursts from the young pulsar PSR J1846−0258, at the center of the supernova remnant Kes 75 (surface dipolar magneticfield of 4.9×10^{13} G)

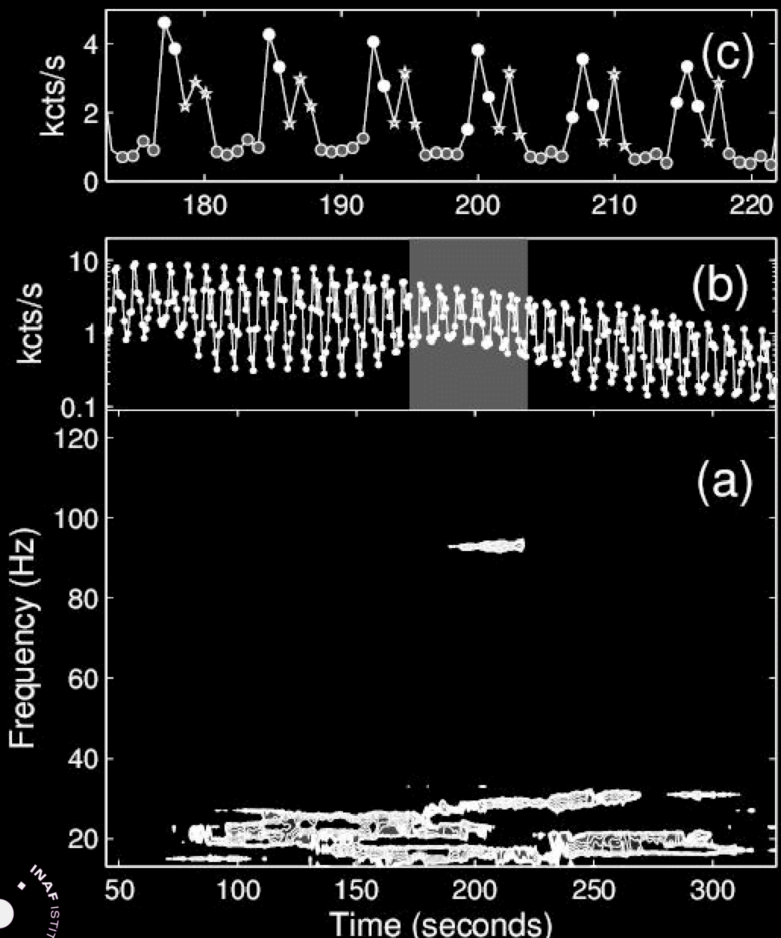


(Gavriil+ 2008)

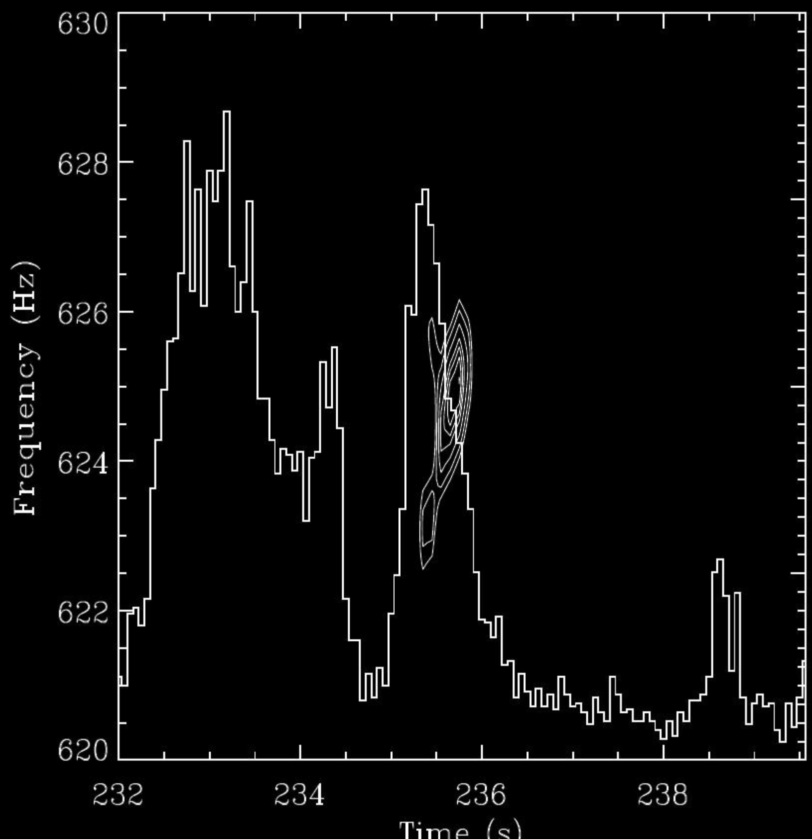
SGR1806-20: QPOs IN THE RXTE GF TAIL

27th December 2004 hyperflare
Up to 10^{46}-10^{47} ergs released during the first ~ 0.6s (@ a distance of 8-15kpc),
1 erg /cm^2 at Earth !!

Transient, evolving with time, pulse phase-dependent QPOs



(GLI+ 2005)

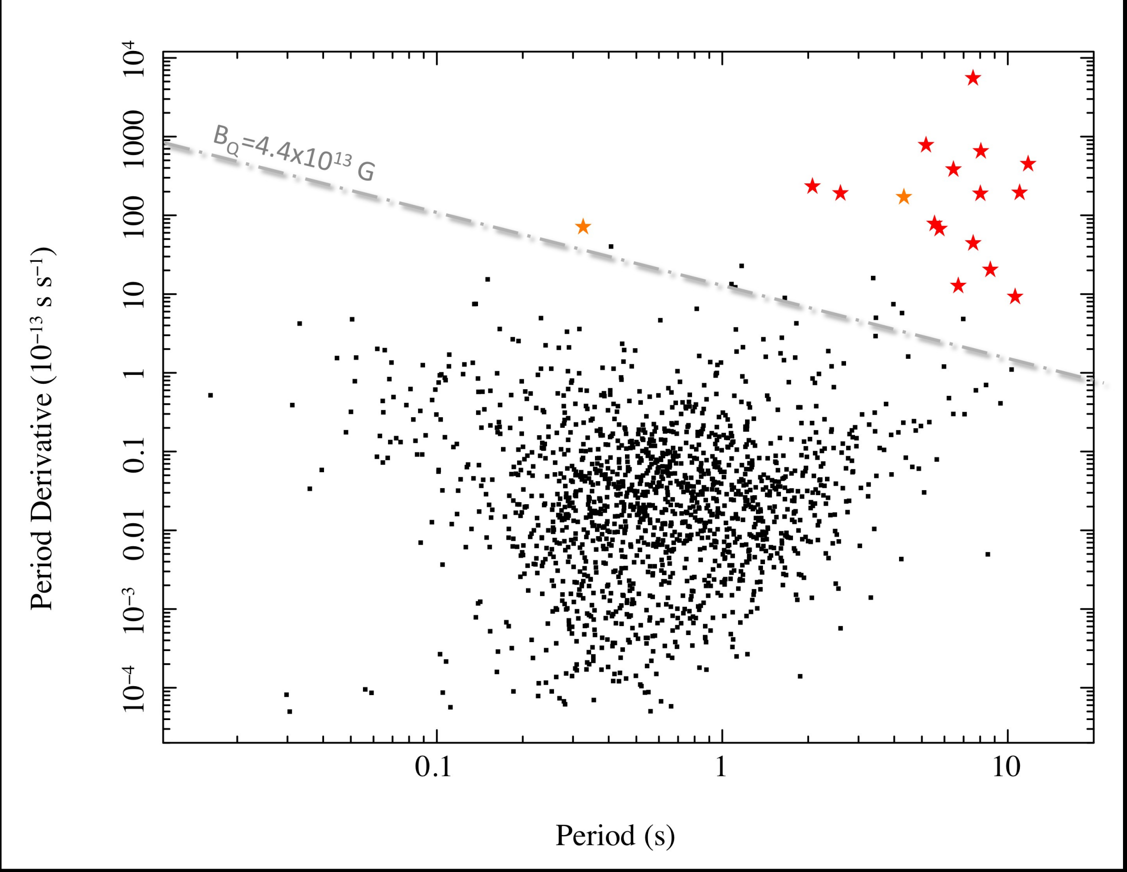


(Strohmayer & Watts. 2005)

BURSTS/FLARES/OUTBURSTS

$B = B_Q$ marks a natural line deviding Rps from magnetars as was thought to be an important ingredient for the magentar physics.

"Magnetar activity" (bursts, outbursts, ...) detected so far only in high-B sources ($B_p > 5x10^{13}$ G) : AXPs+SGRs (*) PSR J1846-0258, and PSR J1622-4950, a RRAT (*)

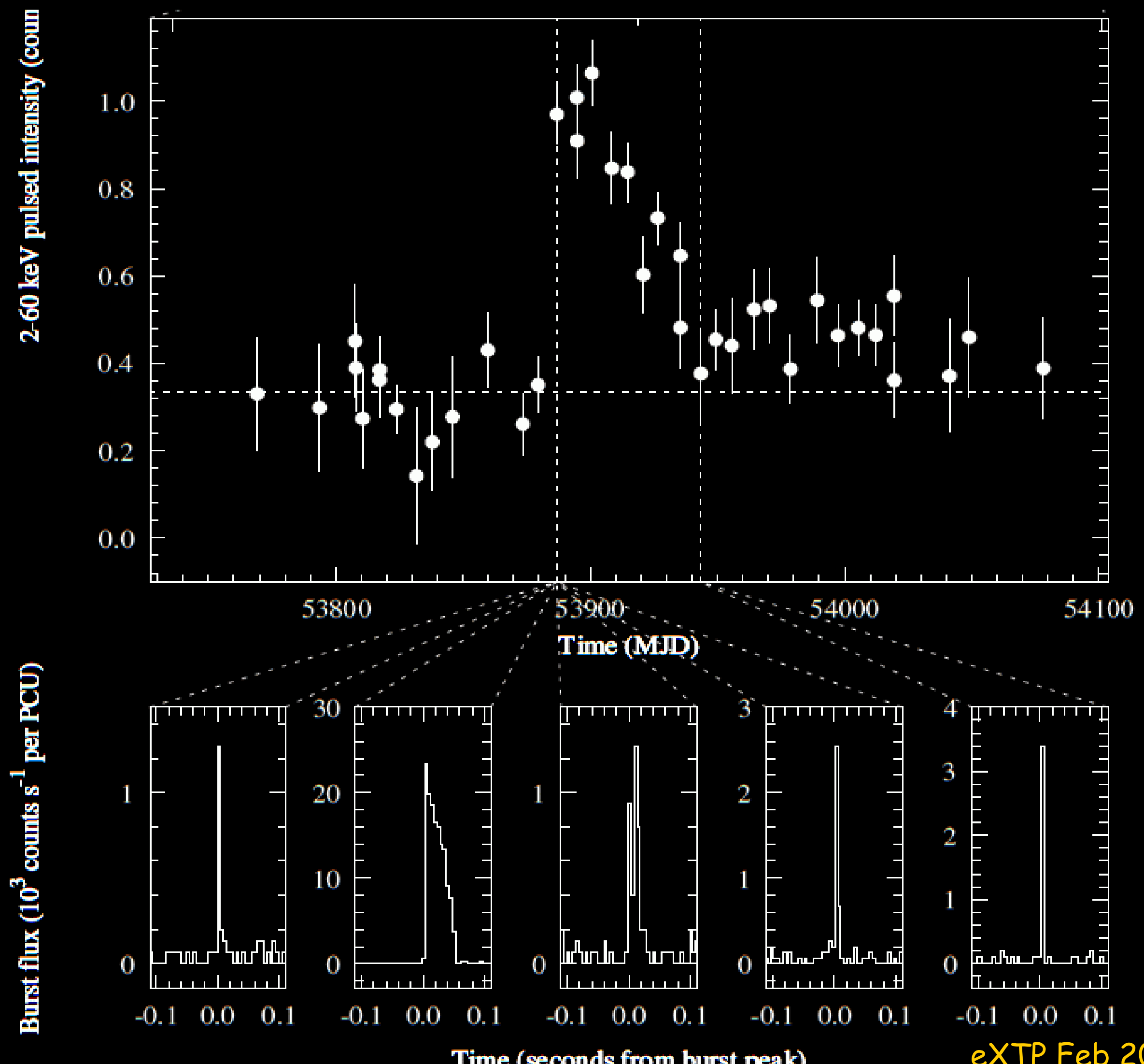


The ATNF Catalogue lists 18 PSRs with $B_p > 5x10^{13}$ G (HBPSRs)

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

RELATED OBJECTS ?

magnetar-like X-ray bursts from the young pulsar PSR J1846−0258, at the center of the supernova remnant Kes 75 (surface dipolar magneticfield of 4.9×10^{13} G)



(Gavriil+ 2008)

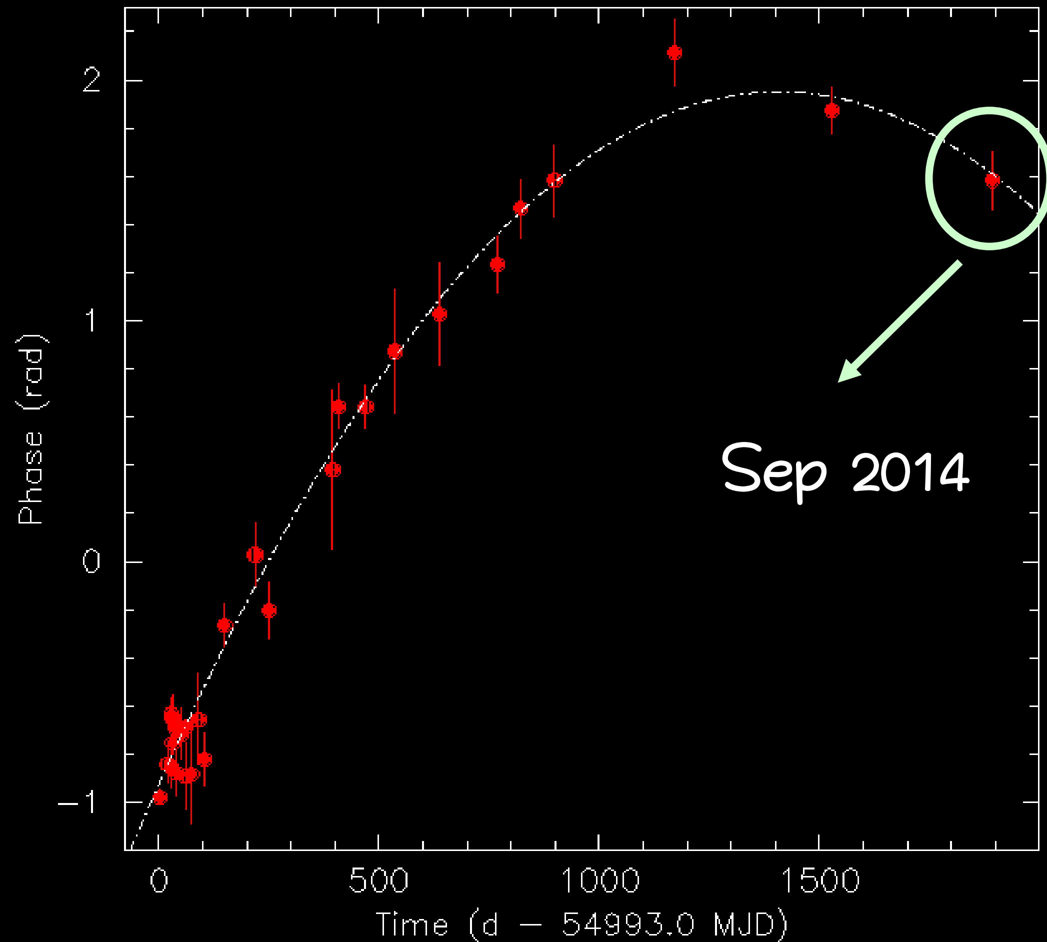
SGR0418 : LOW B !

Pdot component finally detected (7σ) !!

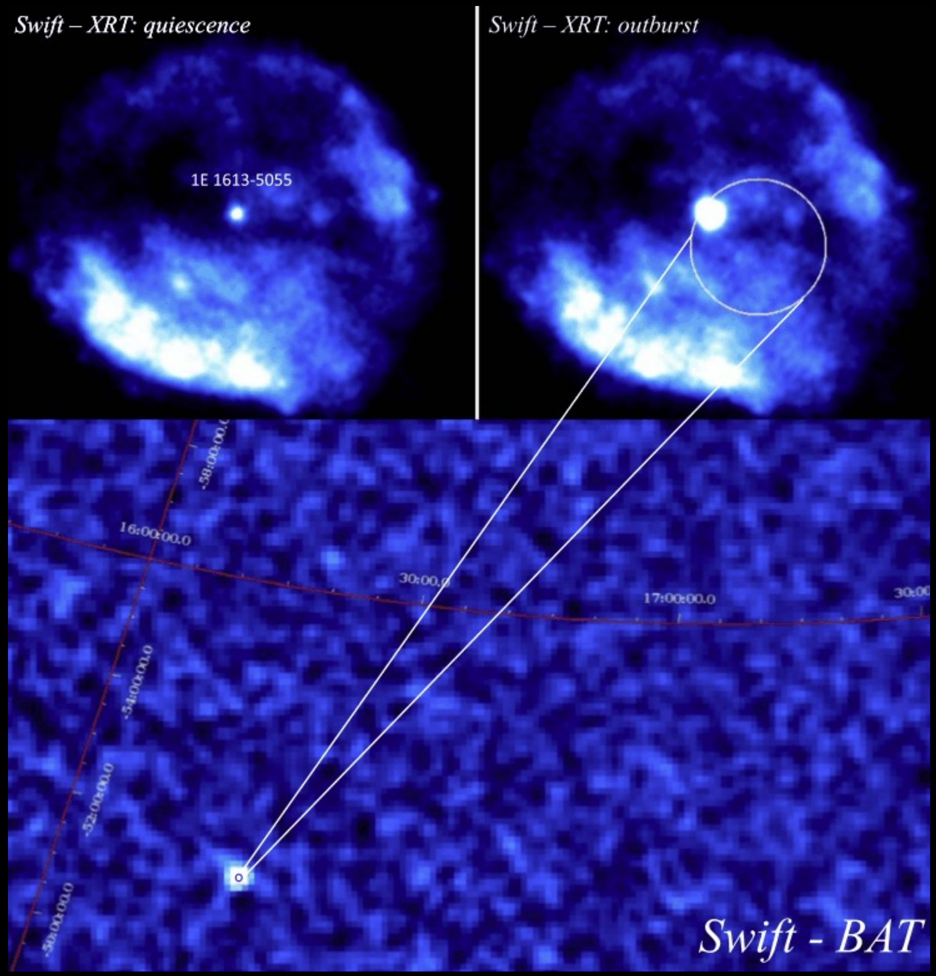
$\dot{P}$=4(1)x10^{-15} s/s ,
B=6(2)x10^{12} Gauss <<B_Q

SGR 0418+5729 is the first magnetar with a low surface dipolar B-field.

SWIFTJ1822 being the second one with B ~ 10^{14} G

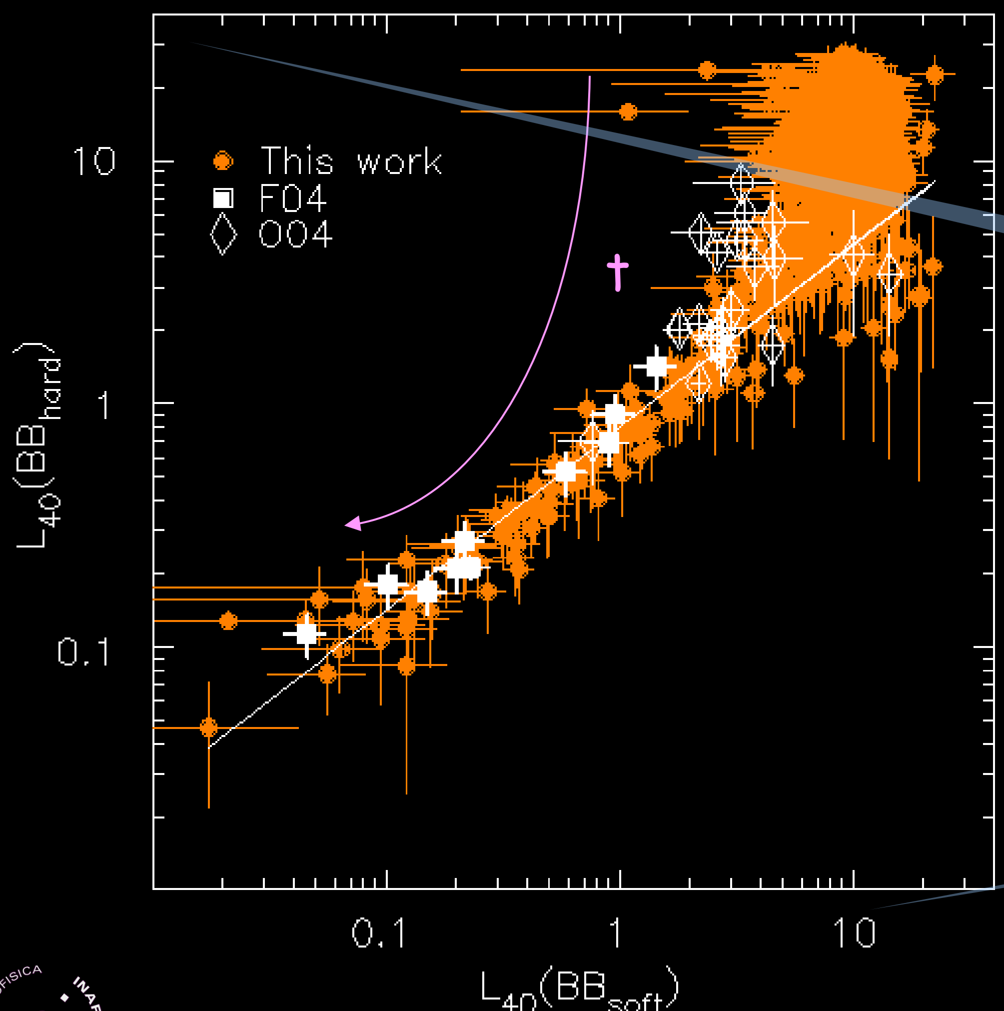


(Rea et al. 2012, GLI+ in prep)


Swift – XRT: quiescence
Swift – XRT: outburst
1E 1613-5055
16:00:00.0
30:00.0
17:00:00.0
-54:00:00.0
-52:00:00.0
-50:00:00.0
Swift - BAT

TIME RESOLVED IF SPECTROSCOPY

Time resolution: 4-100ms
Assumed model: 2 BlackBodies



BBs and BBh Luminosities correlate below 3×10^{41} erg/s (iso-L). Above such value only LBBh evolves (we assumed 10kpc distance).

Max LBBh is ~3×10^{41} erg/s at 10keV and 15km = magnetic Eddington luminosity (Paczynsky 1992) for B of 8e14 G [similar to that inferred form P and Pdot].

$$L_{Edd,B}(r) \approx 2\, L_{Edd}\, (B(r)/10^{12})^{4/3}$$

Max LBBs ~ 10^{41} erg/s at 100km hints to the maximum efficiency of the MF to substain the radiation pressure.

(GLI+ 2008, confirmed by Younes et al. 2014)

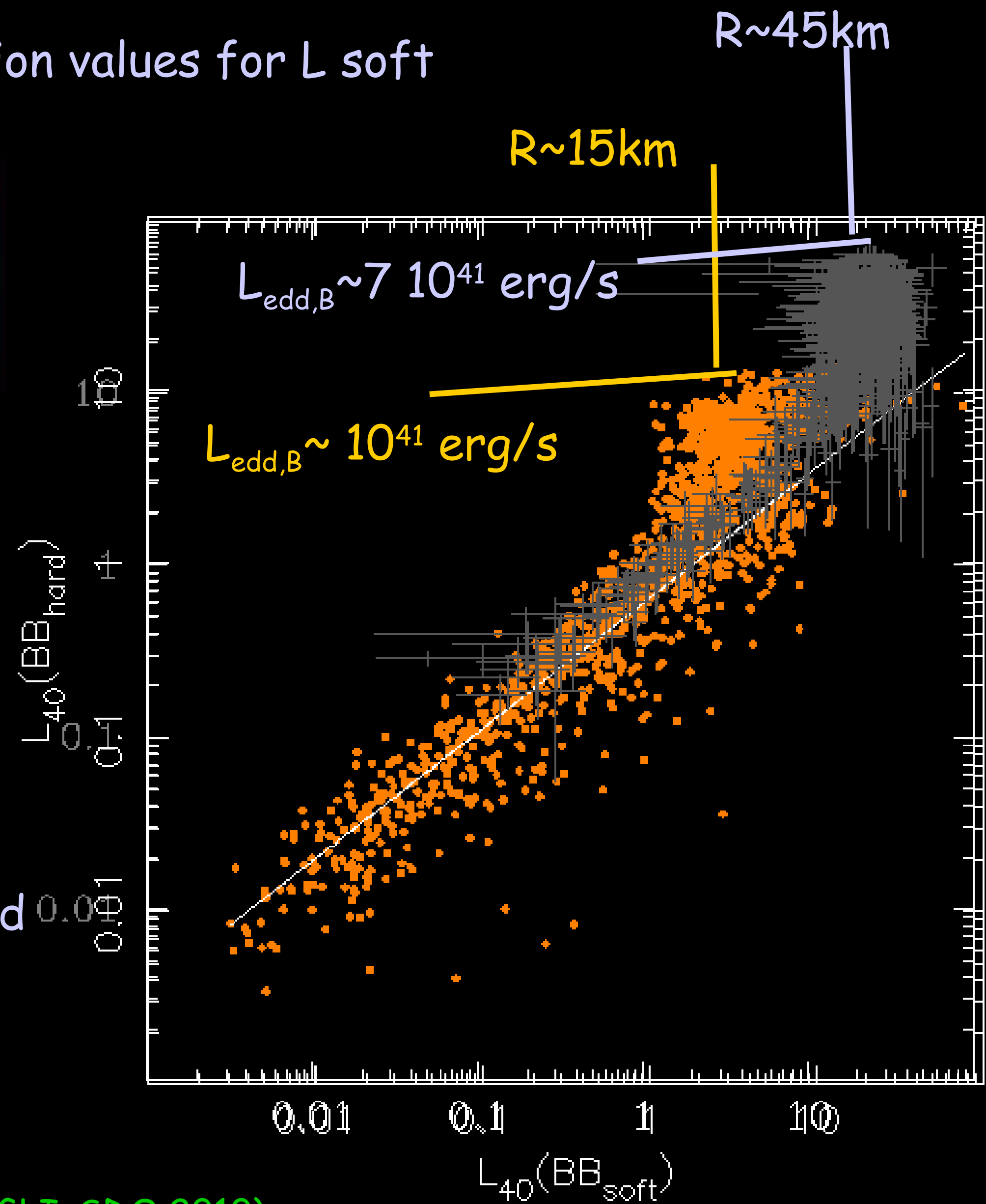
TIME RESOLVED IF SPECTROSCOPY

... similar but with different saturation values for L soft
Can we learn something ?

$$L_{Edd,B}(r) \approx 2\times10^{40}\left(\frac{B}{B_{QED}}\right)\left(\frac{r}{R_{NS}}\right)^{2/3} \mathrm{erg\ s^{-1}}$$

Deviding $L_{edd,B}$ measured for the two sources

$$\frac{B_{SGR1900}}{B_{1E1547}} \approx 7\left(\frac{r_{1E1547}}{r_{SGR1900}}\right)^{2/3} \mathrm{erg\ s^{-1}} \approx 3 \div 4$$



[not that dissimilar to what expected from the timing measurements:
$B \sim 3.2\ 10^{19}\ (P\dot{P})^{1/2}$

$$\frac{B_{SGR1900}}{B_{1E1547}} \approx 2.5 \div 4.2$$

]

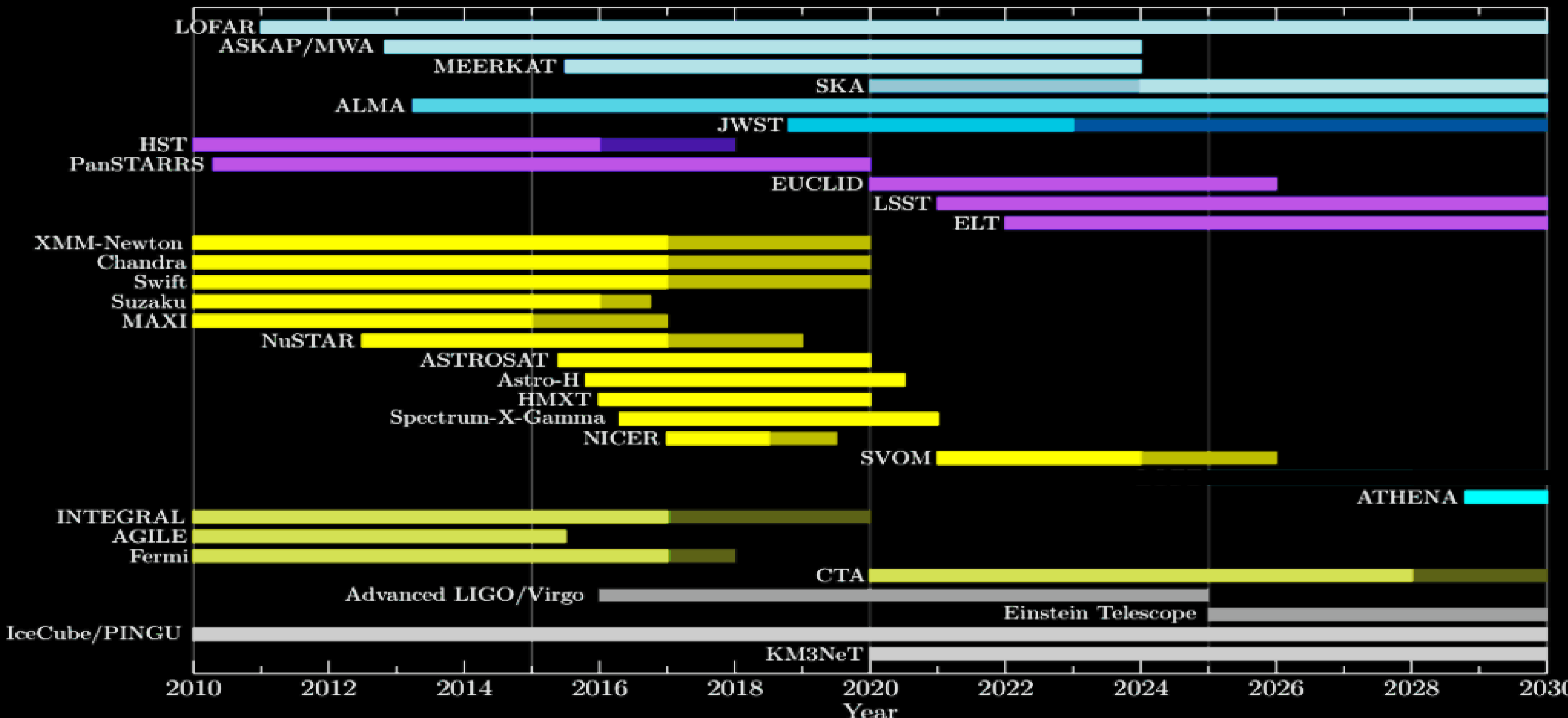
(GLI+SDO 2010)

WHAT'S NEXT ?

Untill ~2020 OK ! (burst detection and studies, outburst decay, etc.) NO GF

Between 2020 and 2030 only SVOM will likely detect burst from magnetars
But no further missions to characterize the new magnetars and/or outbursts

After 2028 ATHENA/SKA (2020) can study magnetars but no HE triggers !!
XIPE recently selected for ESA M4 phase-A



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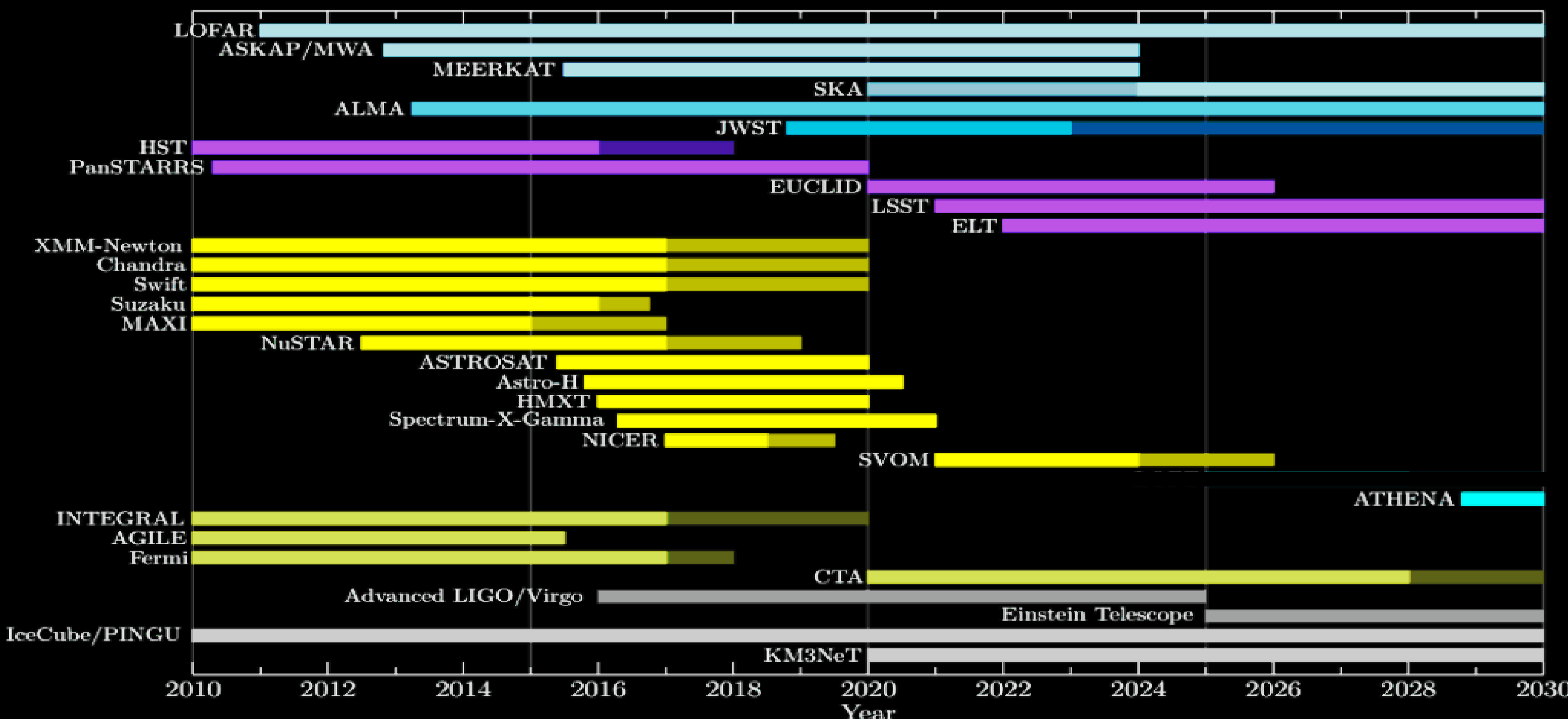

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WHAT'S NEXT ?

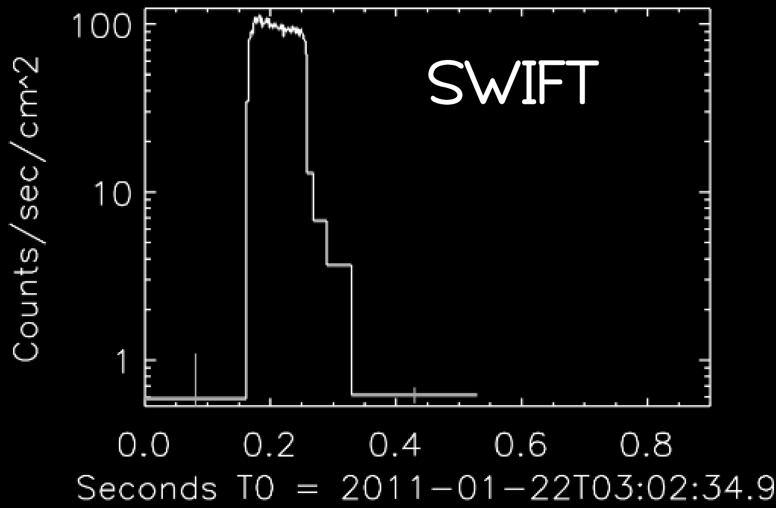
- No suitable instruments (RXTE dismissed), XMM and Chandra would saturate for the greatest part of any GF ringing tail.
  LOFT likely not selected by ESA.

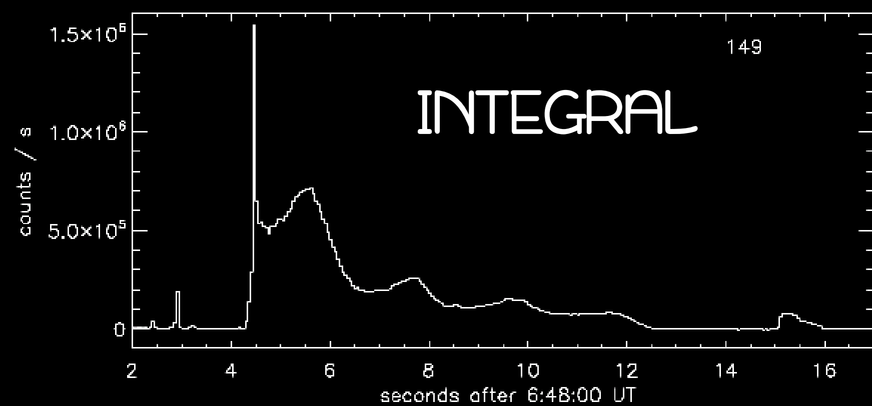
  Fermi GBM is likely the only instrument currently able to study the next GF

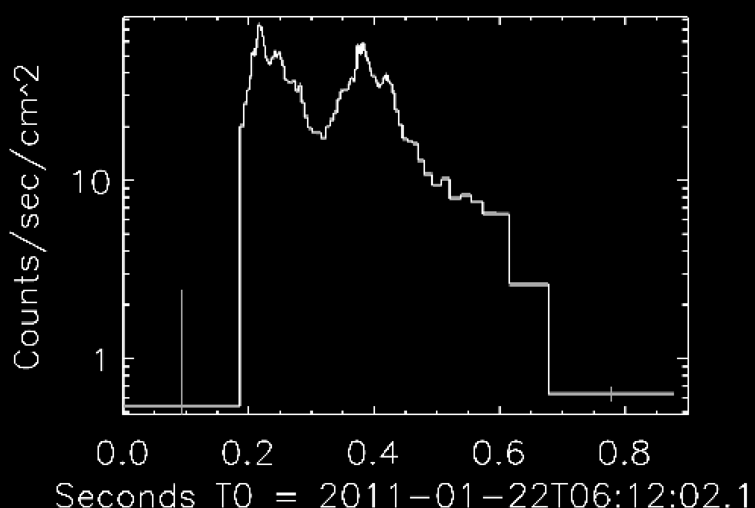
1E1547.0-5408 2009 BAT BURST LCs

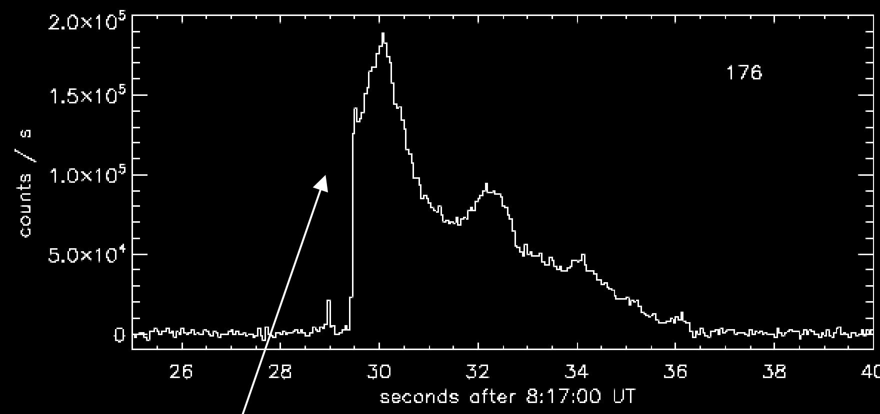
Several IFs detected after the outburst onset on 22ns January 2009

$\sim 10^{43}$ ergs (Mereghetti et al. 2009)





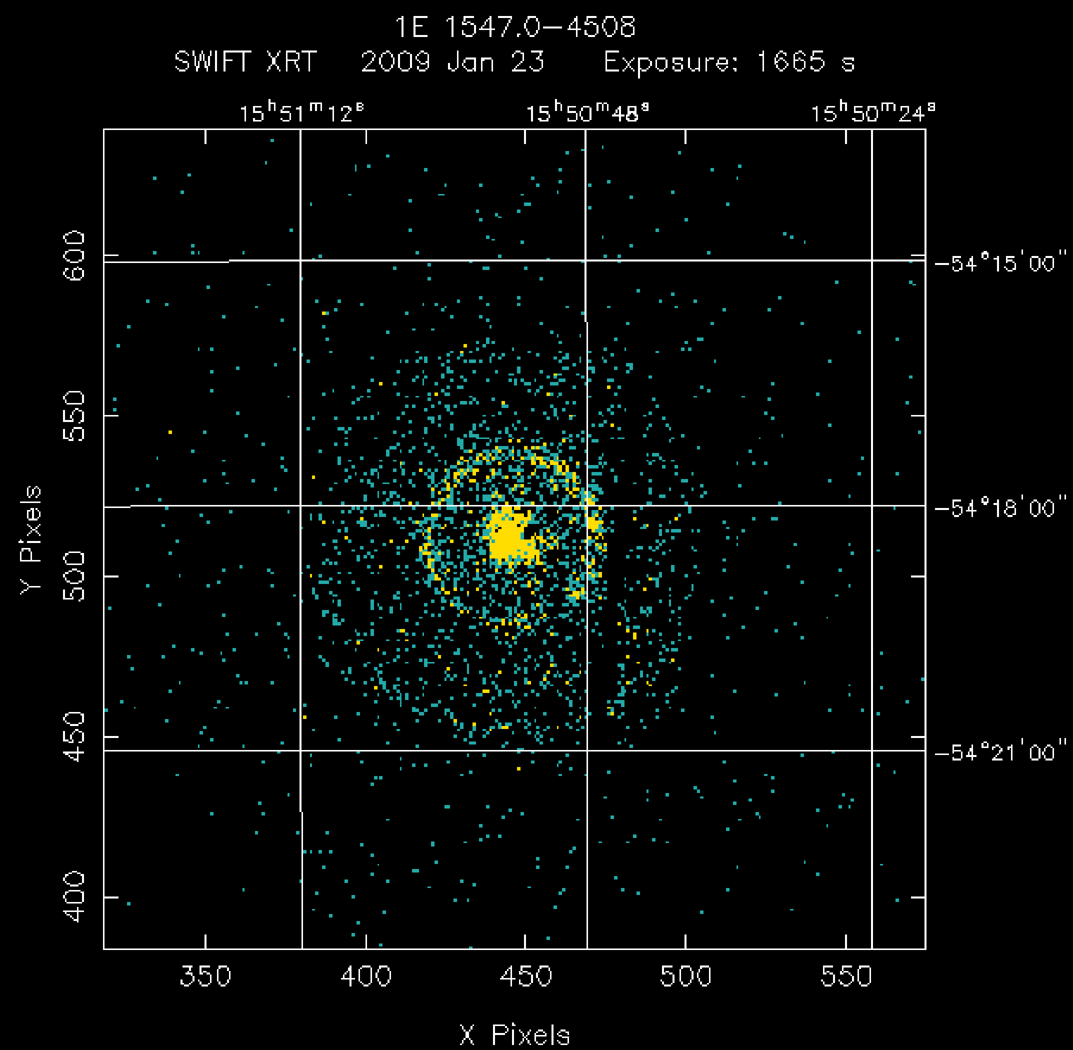




Rise time of ~ 50ms testifies of a different mechanism with respect to GFs (ms rise time)

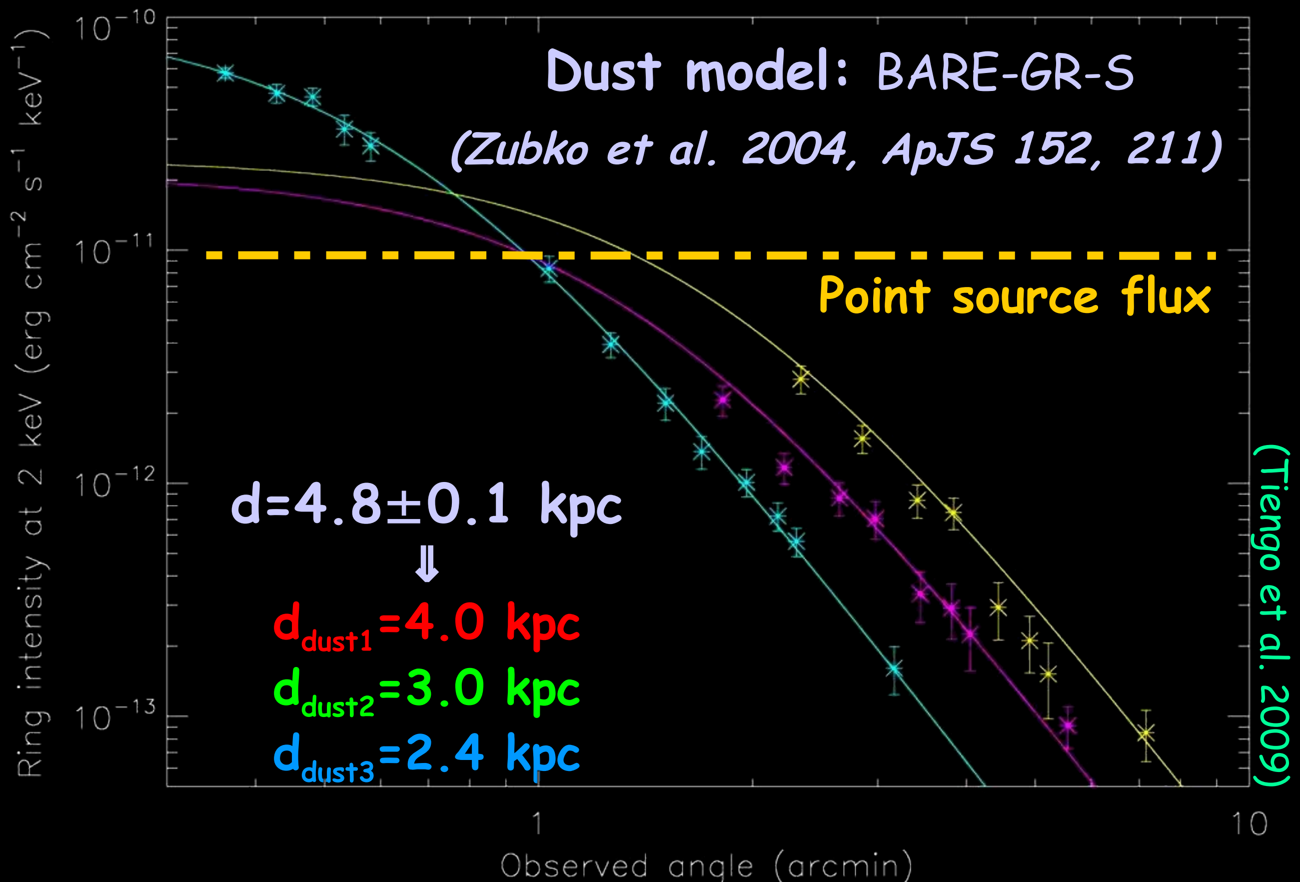
1E1547.0-5408'S ENVIRONMENT

An expanding scattering halo clearly detected in Swift



(Tiengo et al. 2009)

RINGS LIGHTCURVE = HALO PROFILE



Different dust models give equally good fits but different source distance ⇒ distance strongly depends on maximum grain size

However, this dust model is the one which provides the best fits for the X-ray halo of bright Galactic persistent X-ray sources, SNR.

QPO INTERPRETATION

- Initially were considered purely crustal modes (Duncan 1998)

- Later was realised that the strong B-field couples the crustal oscillations with the core leading to magneto-elastic waves (Glampedakis et al. 2006, Levin 2006,2007)

- QPOs with f < 200 Hz may be explained with a set of magneto-elastic waves (van Hoven & Levin 2011, Gabler et al. 2012, Colaiuda & Kokkotas 2011)

- QPOs with f > 200 Hz are difficult to explain due to the presence of a continuum spectrum (van Hoven & Levin 2011).

- Recent studies with superfluid models of magnetars show that magneto-elastic oscillations exhibit new features in the QPO frequency range. In particular these new features might explain also the high frequency QPOs (Gabler 2013, Passamonti & Lander 2013)

Next important steps:

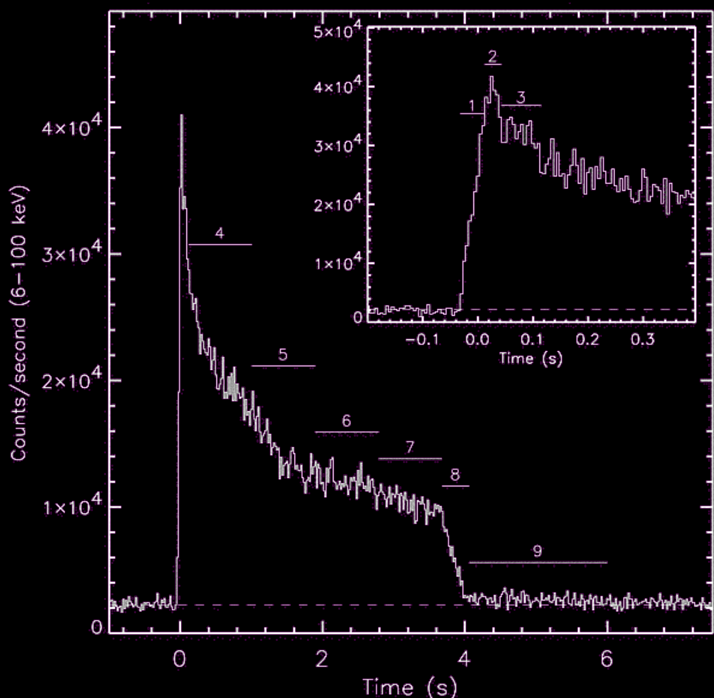
- study the dynamics of the magnetar model with a magnetosphere, in order to understand how the internal vibration of a magnetar modulate the X-ray radiation of the fireball.

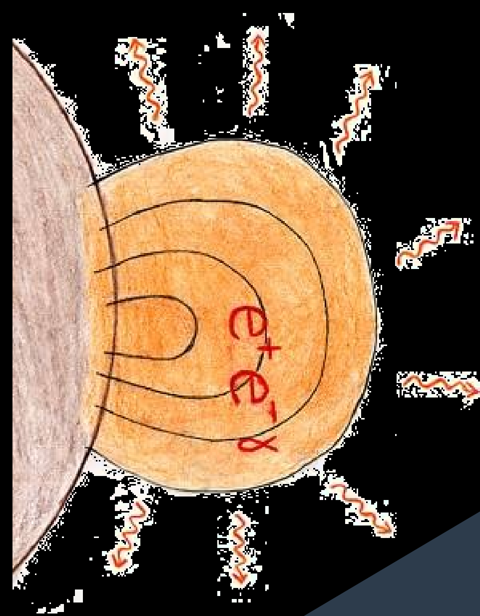
- Study with more accurate models the effects of superfluidity and superconductivityon the QPO spectrum.

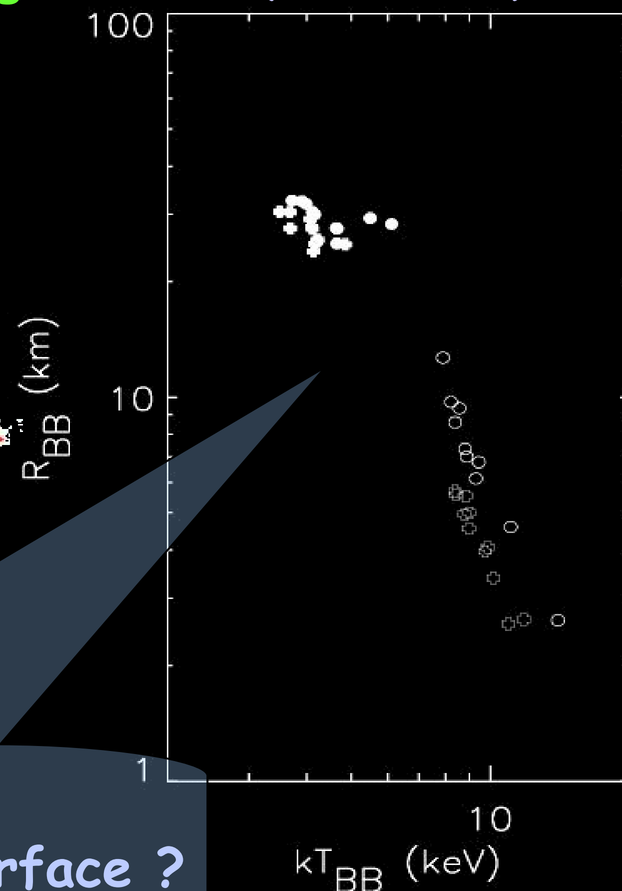
WHY?

Magentar scenario assumes that bursts/Ifs are similar to a magnetically trapped fireball → **information on B and on photon propagation through high B might be inferred**.

Previous 1-100keV band results (HETE-II) showed a good agreement with a 2BB model. Limits: Poor statistics and only one good case (Olive+ 04).







Open questions:

HTBB: a trapped FB? LTBB: heated surface ?

B AND THE CAVALLO-FABIAN-REES LIMIT

The Cavallo-Fabian-Rees ΔL limit violation is independent from any assumption or models: total energy released within Δt is related to the total mass within the source dimension R

$\Delta t > (3/2\pi)\,(\sigma_t/m_p c^4)\,(\Delta L/\eta) \rightarrow \Delta L/\Delta t = \eta\ 2 \times 10^{42}\ \mathrm{erg/s^2}$ (Cavallo & Rees 1978)

For QPOs (600-1800Hz) in SGR1806 the highest ΔL is 10^{41} erg/s

$\Delta L/\Delta t = 2^{3/2}\,\pi\, L\, a_{rms}\, \nu_{QPO} \sim 10^{44}\ \mathrm{erg/s^2}$

σ_t is the only "variable" -> differs from the Thomson x-section due to B.
In the E mode (Meszaros 79) σ_t is reduced by a factor $\approx (\varepsilon B_q/(m_e c^2 B))^2$

$B \geq 3\ Bq(0.1/\eta)^{1/2} \approx 10^{14}$G @30km -> 4×10^{15}G at NS surface

ε~14keV from the BB component with kT~5keV and R~30km as measured in the ringing tail

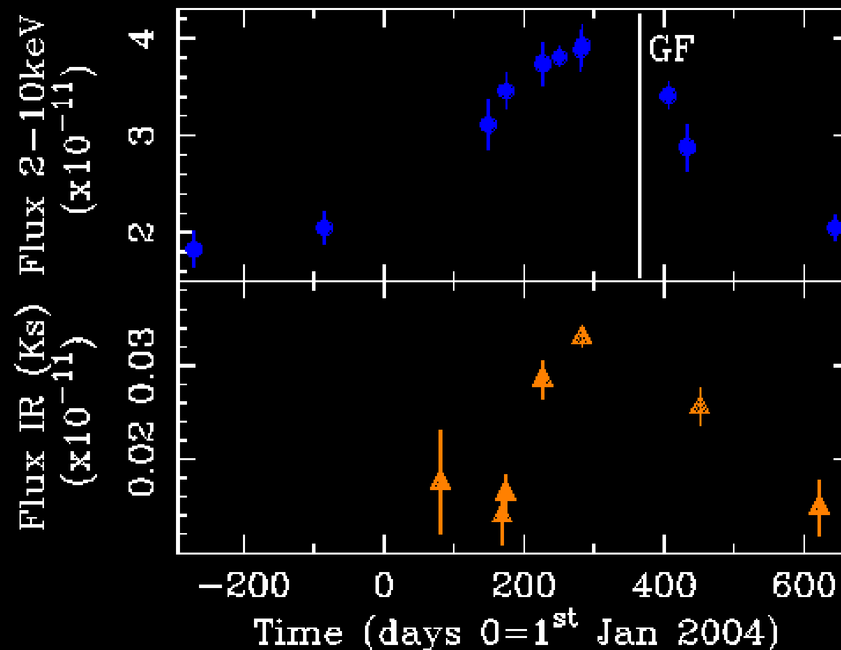
(Vietri et al. 2006)

BURSTS/FLARES ($L \gg L_{EDD}$)

- GFs have been observed during outbursts

- Similar trend in the IR/optical band
No prompt emission in IR/optical

- No evidence for permanent changes (spectra, radius or temperature of the thermal component) but Pdot and possible glitch

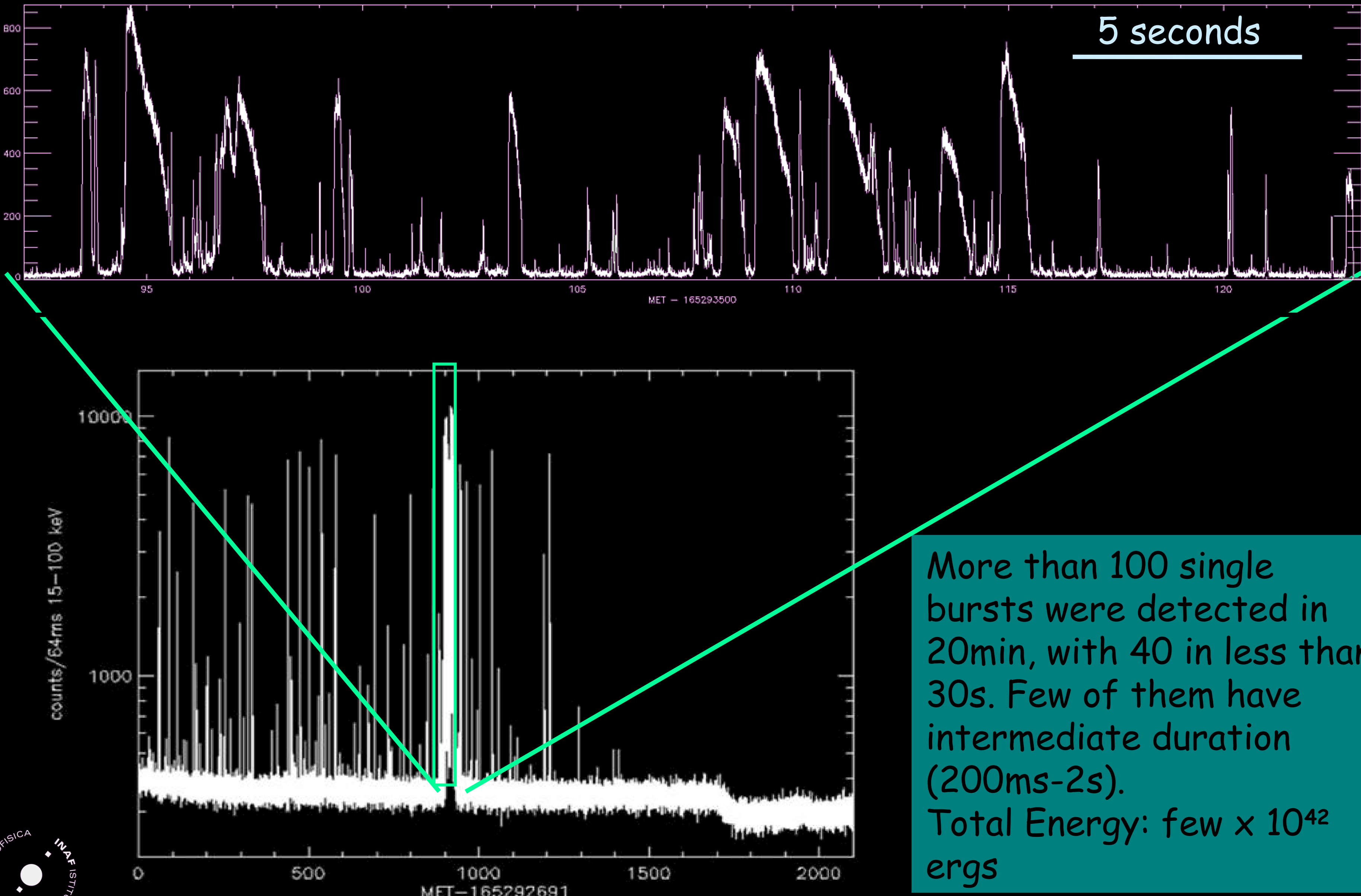


- IFs and SBs detected bot in outburst and in persistent emission. More when the source is active.

- In the latest 10 yr the greatest part of new magnetars has been discovered through the detection of SBs by SWIFT and Fermi (~1 per year)

IFs: THE 2006 BURST STORM FROM SGR1900

SGR1900+14 as observed by Swift on 29th March 2006



More than 100 single bursts were detected in 20min, with 40 in less than 30s. Few of them have intermediate duration (200ms-2s).
Total Energy: few x 10^{42} ergs

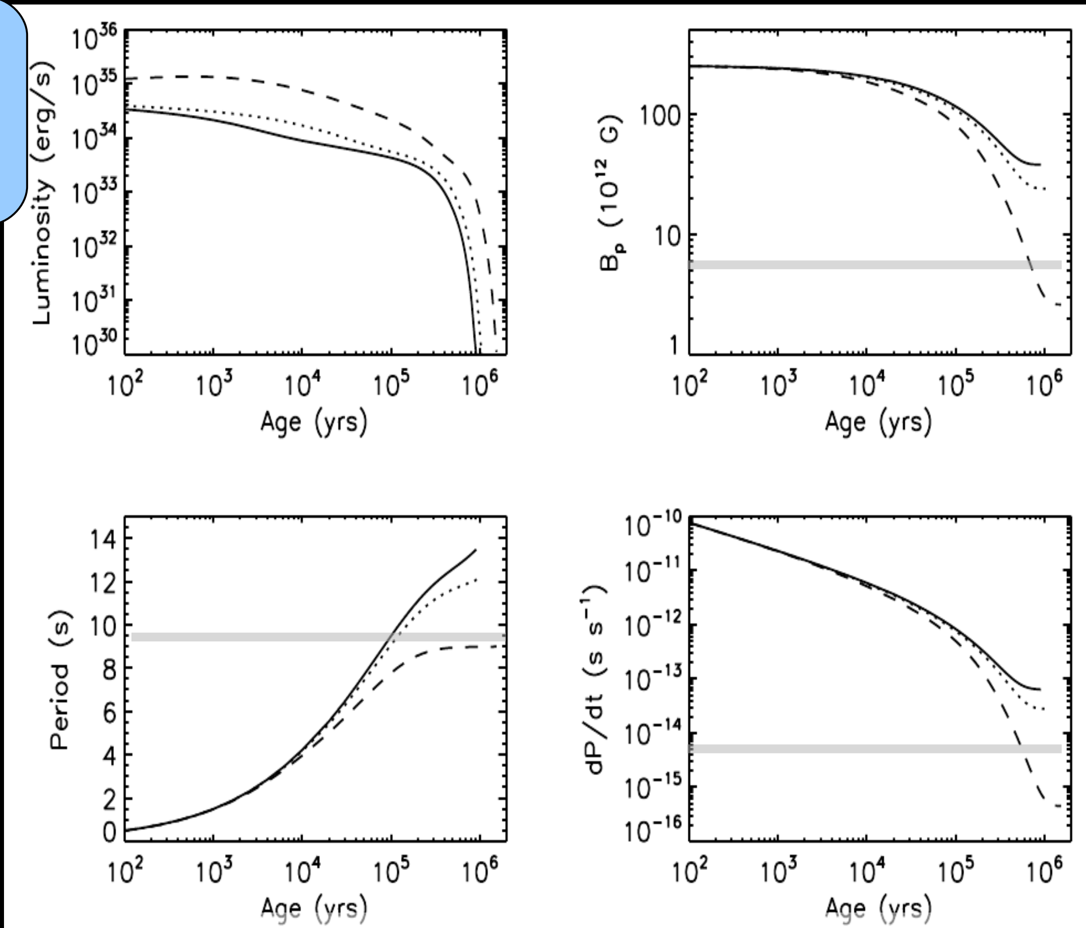
ARE "LOW-FIELD" SGRS OLD MAGNETARS ?

Recent simulations of the magneto-thermal evolution of a magnetar including enhanced neutrino emission from the breaking (and neutron Cooper pairs) show that SGR0418 properties are in agreement if :

- o initial B_{tor} ~4 x 10^{16} Gauss
- o characteristic age > 1 Myr.

(SWIFTJ1822.3:
B_{tor}~7 x 10^{14} G,
t > 0.5 Myr)

Note that the large toroidal field results in smaller values of P and Pdot. This explains why objects with different ages have similar P.

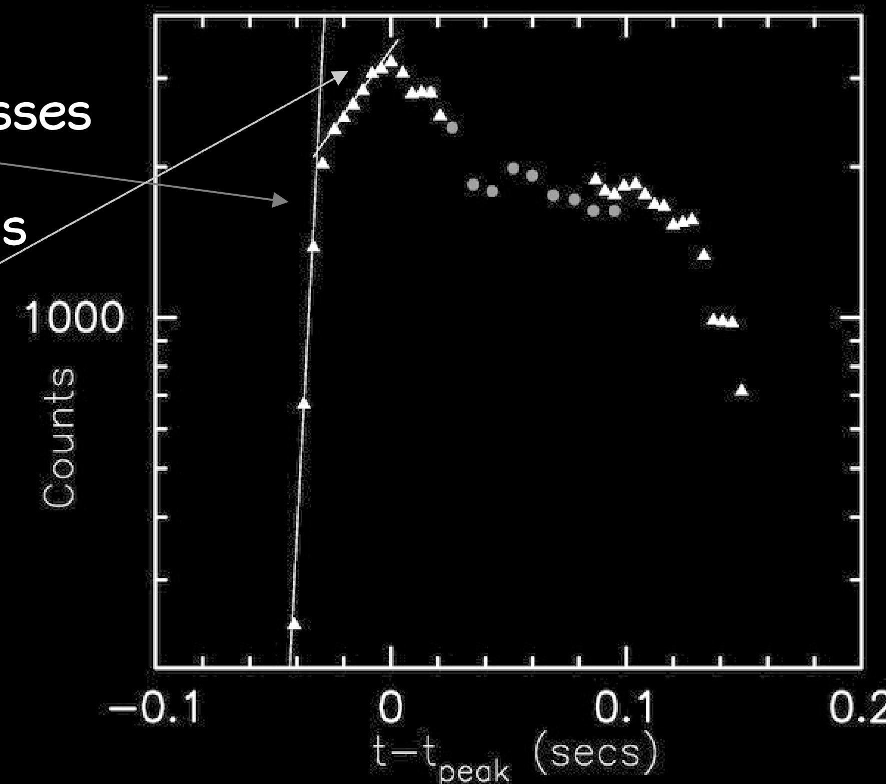


SGR 0418 (Turolla et al. 2011)

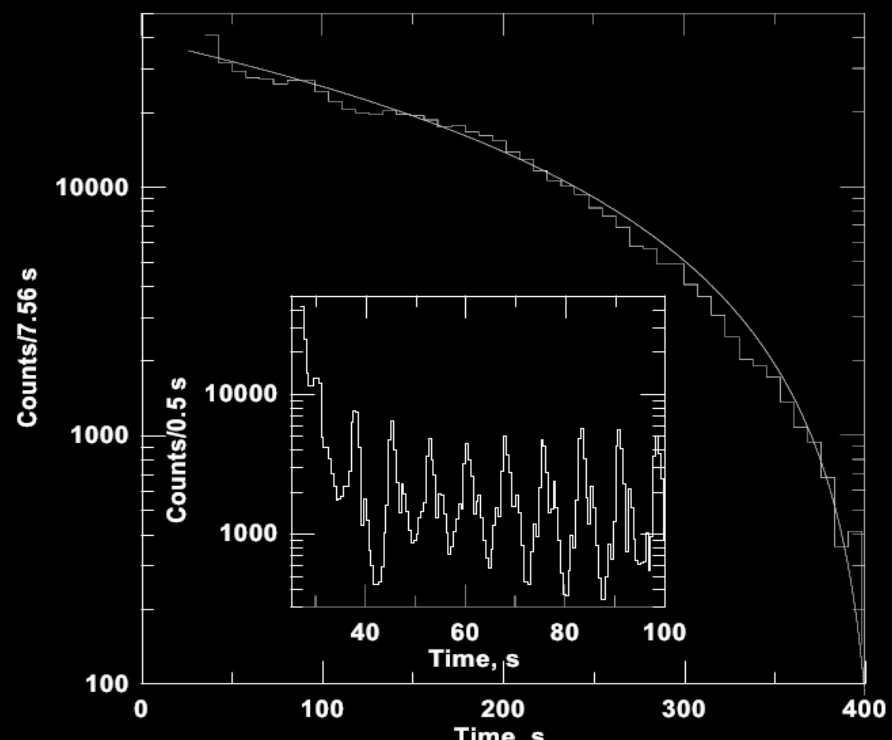
TIMESCALE STUDIES IN SGR1806 GF

Different timescales are observed
- an initial 0.3ms -> reconnection processes in the magnetosphere.
- a ~5 ms -> naturally explained in terms of propagation of a surface fracture -> triggering oscillations similar to those observe during earthquackes

(postulated by Thompson & Duncan 2001).



(Schwartz et al. 2005)



- α decay index of 0.606 close to the α=2/3 expected for a contracting and evaporating magnetically confined plasma

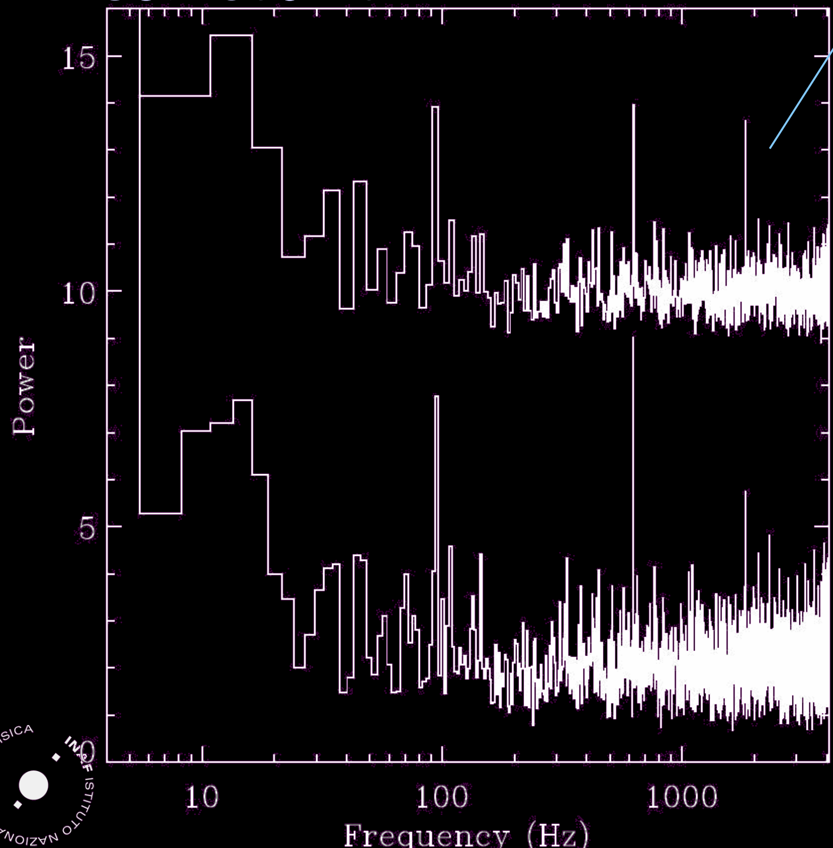
(Hurley et al. 2005)

TRANSIENT QPOs

QPOs detection confirmed by RHESSI obs. Additionally… transient QPOs at 720 and 976 Hz. Moreover 625 and 1840 Hz were detected.

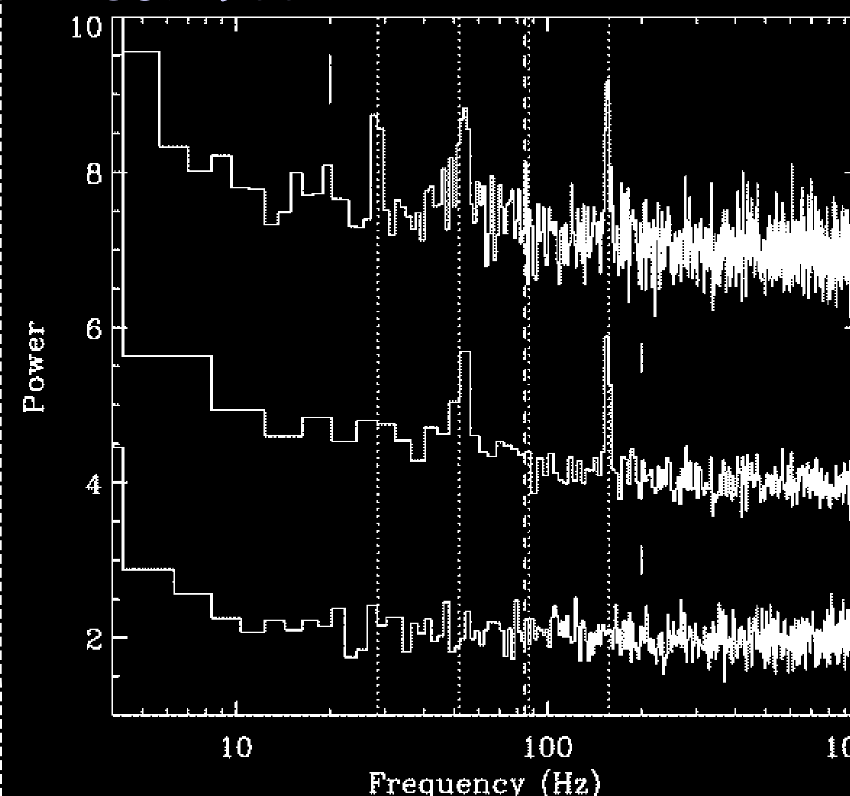
Likely the highest freq. signal ever detected in (X-ray) astronomy !!

SGR1806-20



A RXTE re-analysis of the 1998 GF of SGR1900 revealed QPOs at the following frequencies: 28.5, 52.5,84 and 155.5 Hz.

SGR1900+14

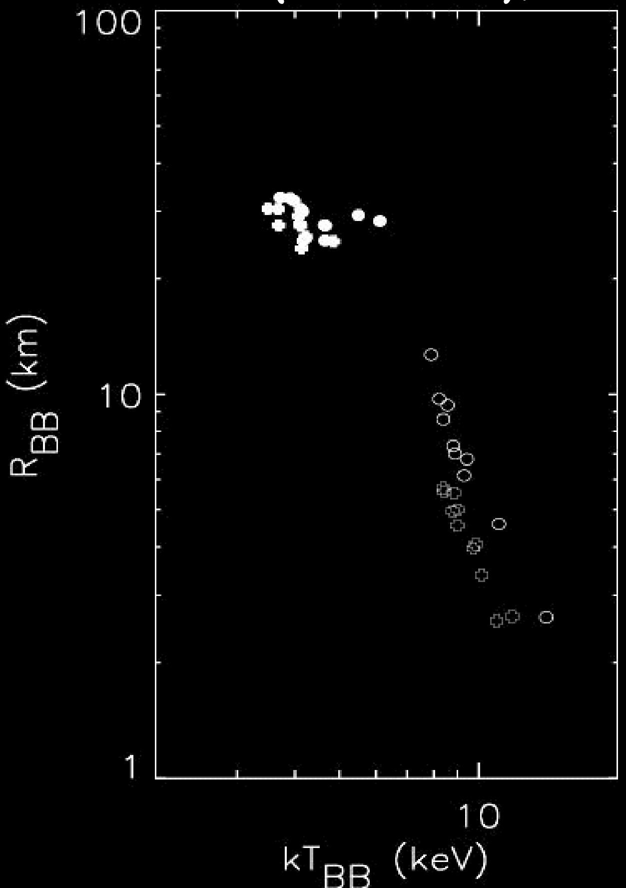


(Strohmayer & Watts. 2005; Watts & Strohmayer 2006)

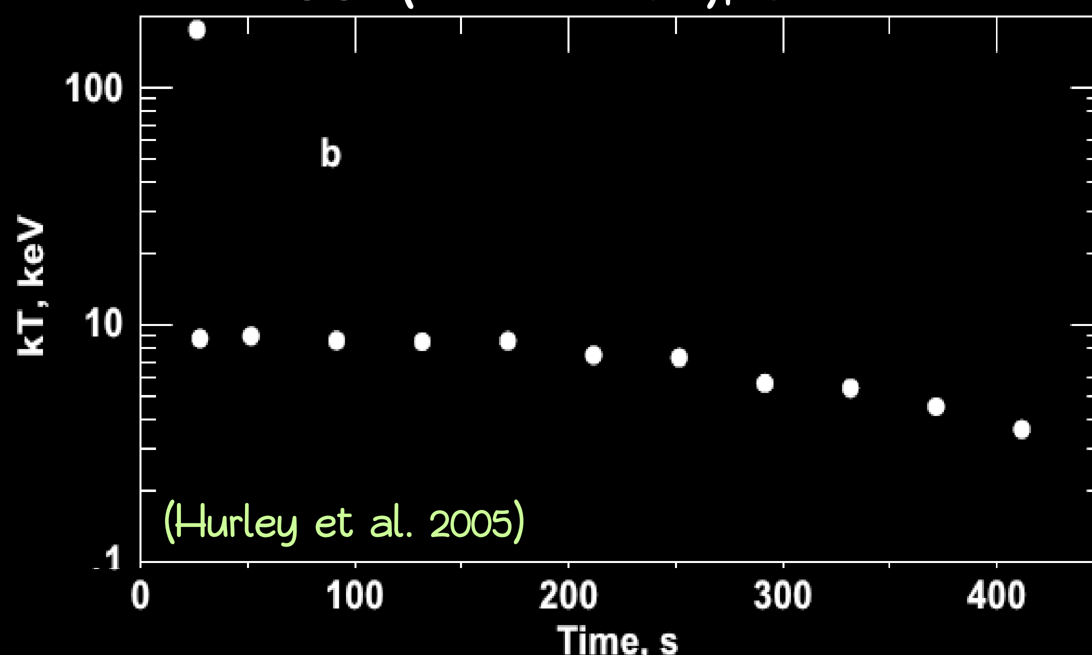
IFs VS GFs

The GF tail have temperature very similar to the hard one observed in IFs.
Similar physics behind
GF peak behaves differently

HETE-II (6-200keV); IF



RHESSI (20-1500 keV); GF



THE PROPOSED/QUALITATIVE SCENARIO

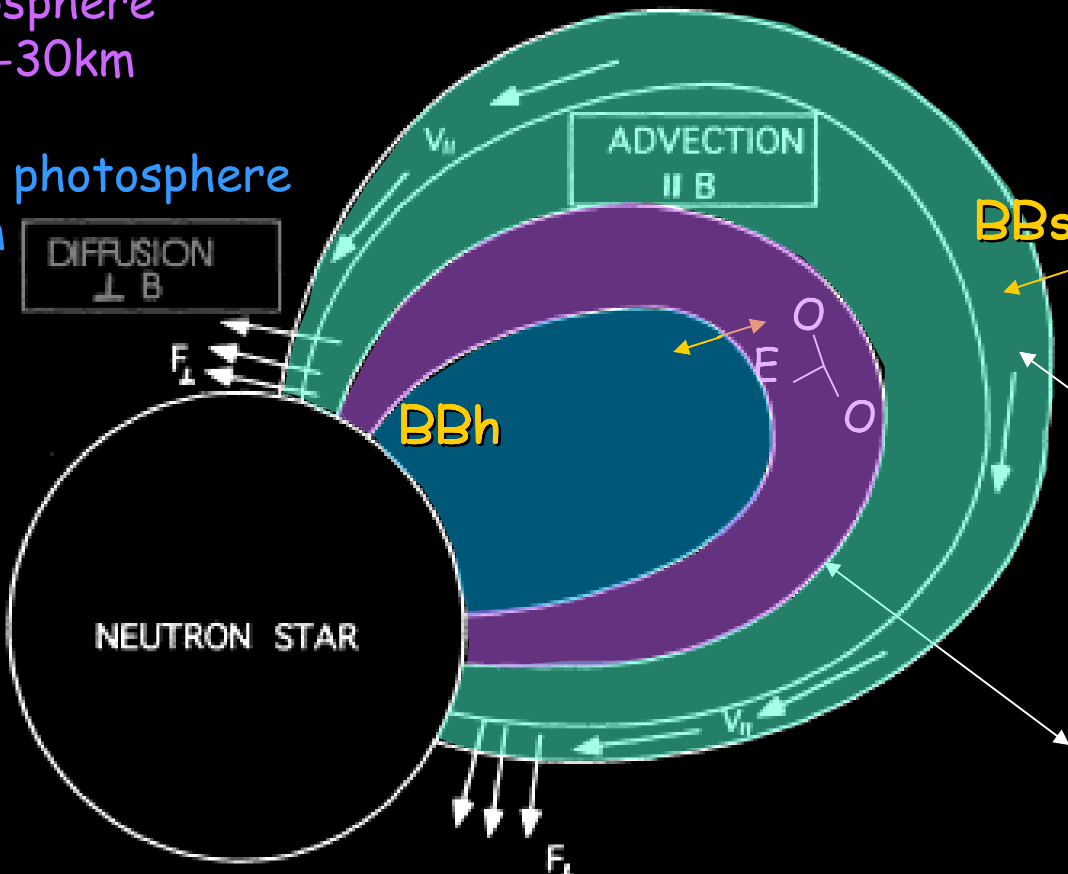
A possible interpretation: different way with which E- and O-mode polarised photons propagate into the magnetosphere; scattering cross section of E-mode may be reduced by B and the scattering photosphere is smaller (~R NS).

O-mode γ photosphere
R~100km

E-O-mode γ splitting photosphere
R~25-30km

E-mode γ photosphere
R~15km

The R~25km corresponding to the max radius of the BBh and the min of the BBs identifies a critical surface at which B=Bcrit (QED).



$O\text{-}e^{-}\text{-}e^{+}$

$B<B_{QED}=4.4\times10^{13}$ G

SGR1900 BAT spectra: implications

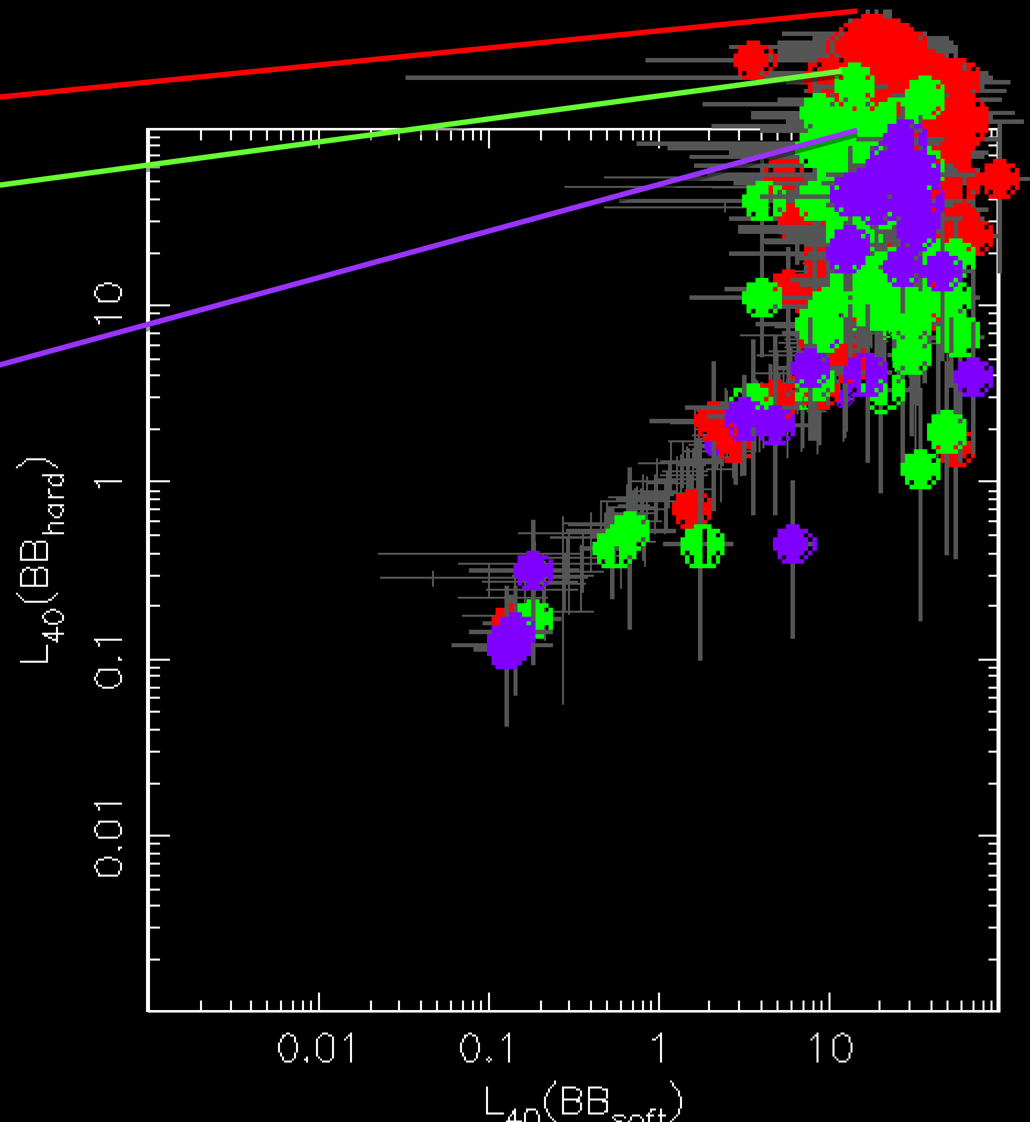
If correct (function of B) $L_{Edd,B}$ should be different for each burst (occurring at different NS surface regions)

L_{max}~ 7 10^{41} erg/s

L_{max}~ 5 10^{41} erg/s

L_{max}~ 3.5 10^{41} erg/s

A RATIO OF 2 IN L_{MAX} CORRESPONDS TO A FACTOR OF 3.2 IN B

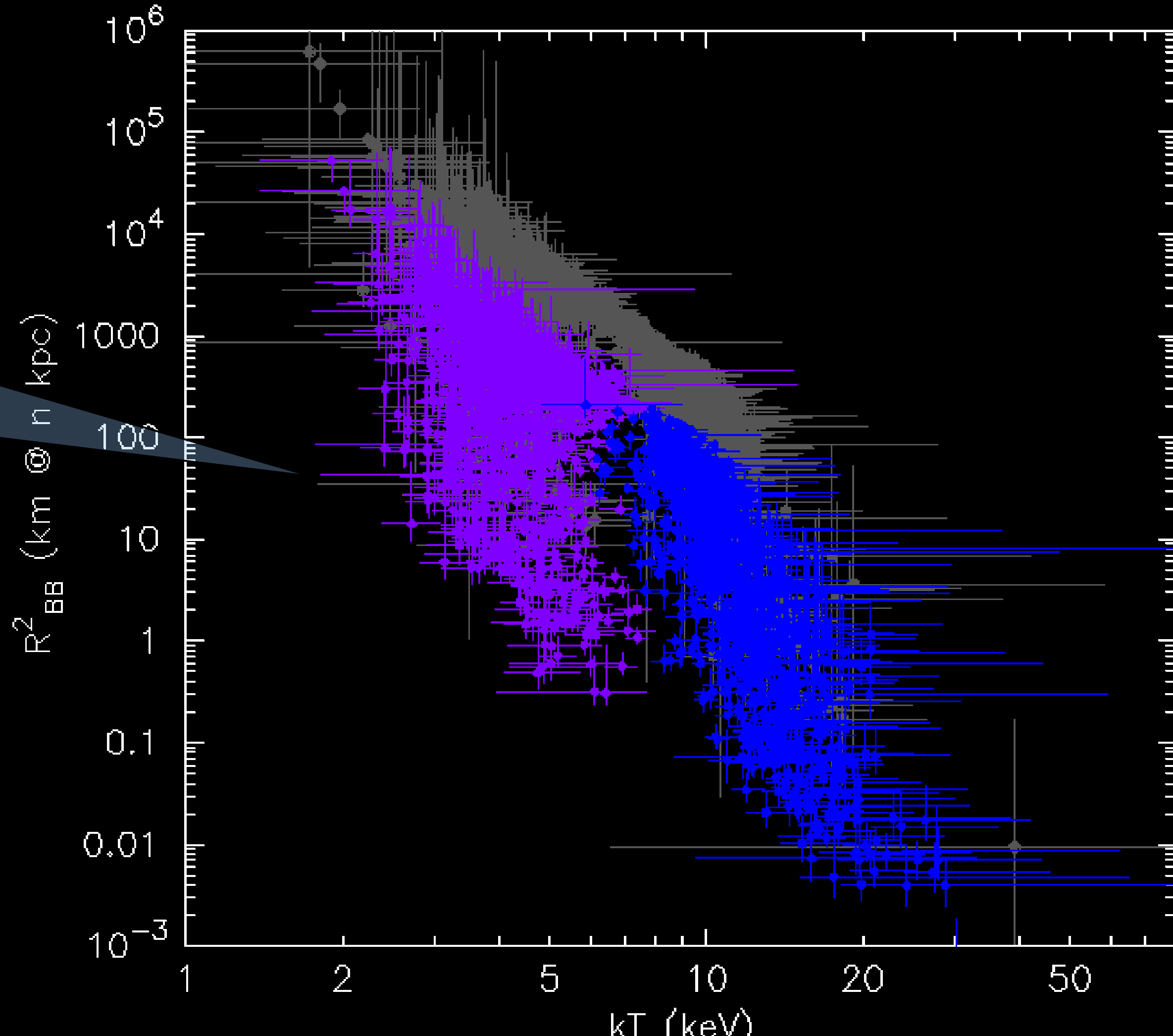


1E1547.0-5408 BAT SPECTRA (KT VS R²)

~1800 spectra fitted in a way similar to that of SGR1900+14 . About 1300 spectra were selected after fitting (with smaller uncertainties)

Very similar results and behavior to those of SGR1900!

Data are normalized to know distance (and it accounts for the shift in R²)



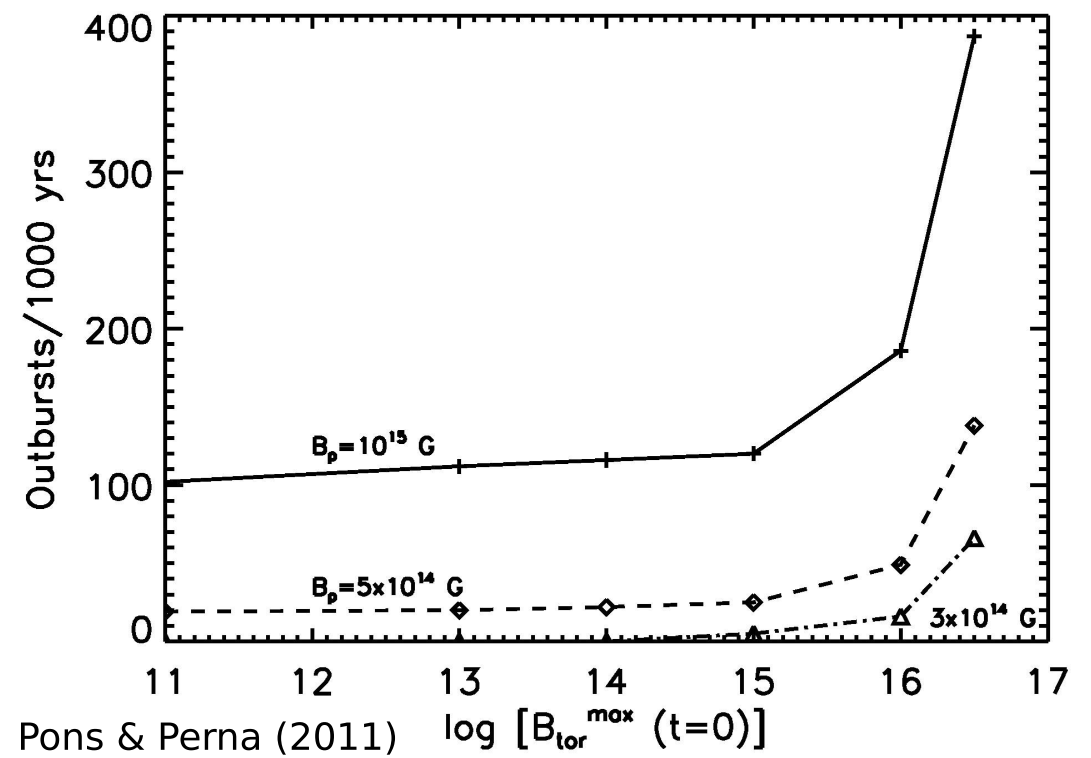
(GLI+ 2010; Vetere et al. 2010)

Calculation of magnetic stresses acting on the NS crust at different times (Perna & Pons 2011; Pons & Perna 2011)

Bursts/outbursts expected if $B_{p,0}$ > 3-4x10^{14} G

Activity strongly enhanced when $B_{tor,0} > B_{p,0}$

A large toroidal field is needed to crack the crust in (relatively) low-field sources



Pons & Perna (2011)

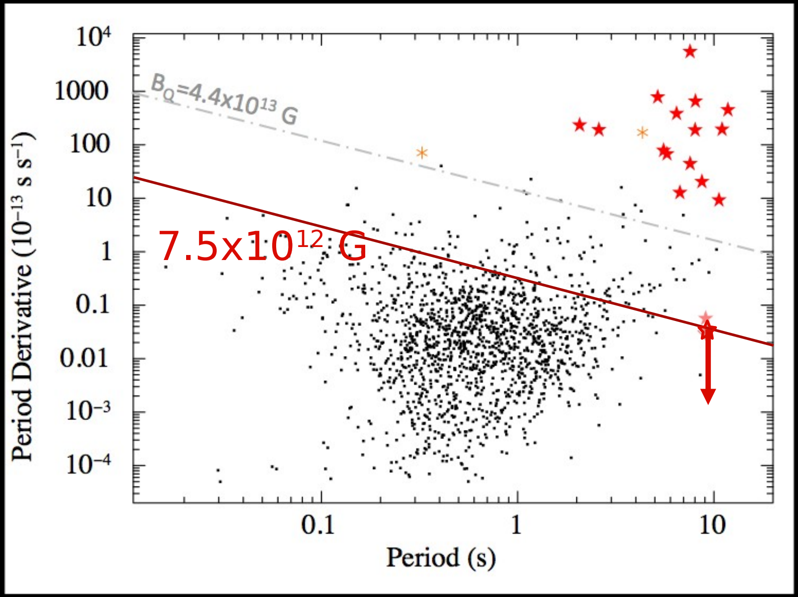
HOW MANY HIDDEN MAGNETARS CAN WE EXPECT?

A 10-15% of radio pulsars have B larger than that of SGR0418

A continuum of magnetar-like activity among pulsars given that B_Q is not crucial!

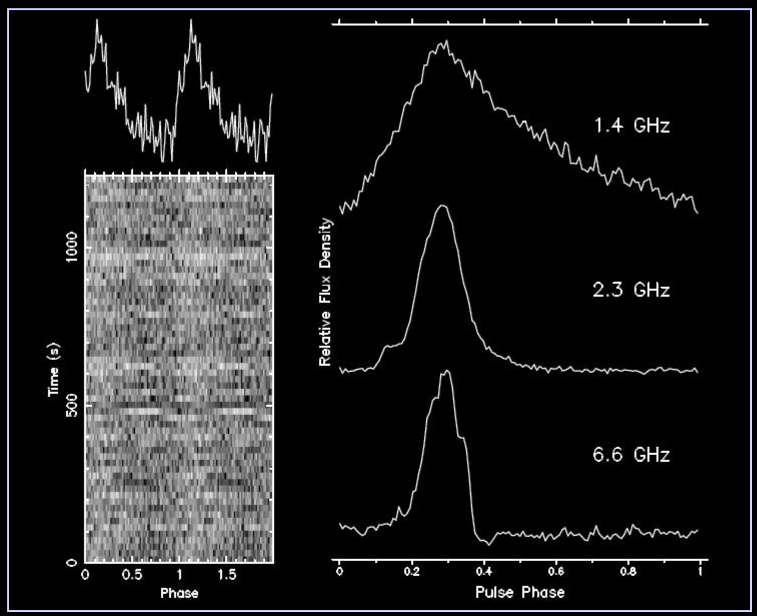
This revises the population of magnetars in our Galaxy.

Many more pulsars are expected to show magnetars-like activity.
A detailed population synthesis study is in progress…

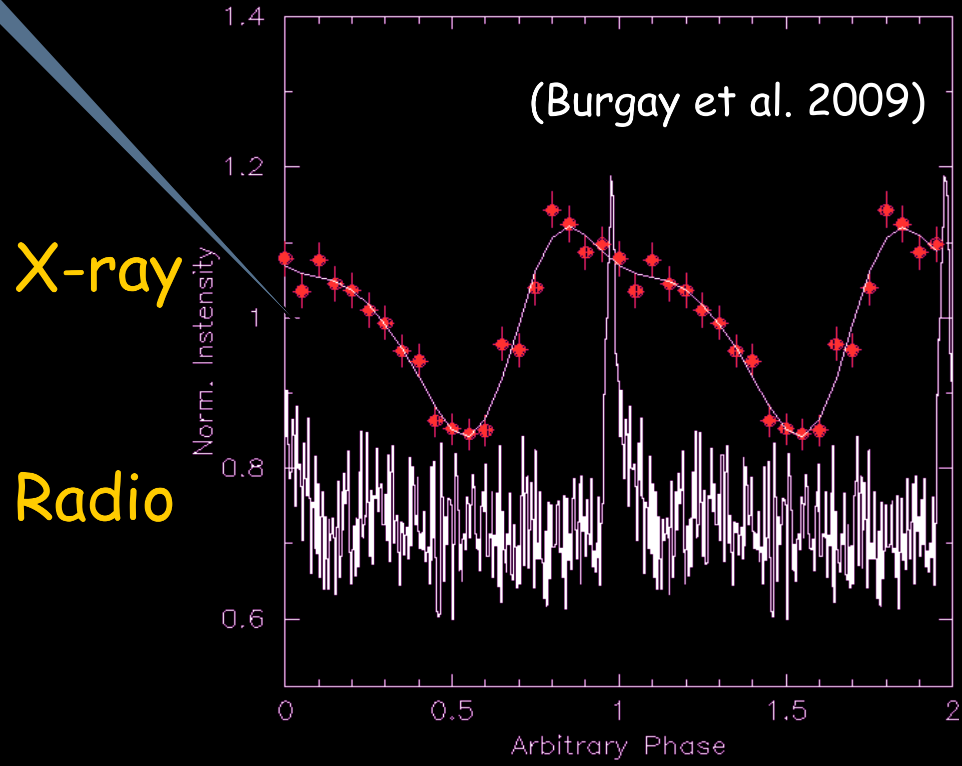


1E1547.0-5408: THE '09 RADIO SWITCH

Not detected on 22nd (Camilo et al. 09) and 23rd (Burgay et al. 09) Jan weak radio pulsations detected on 25th from Parkes in simultaneity with Chandra



2007 observations

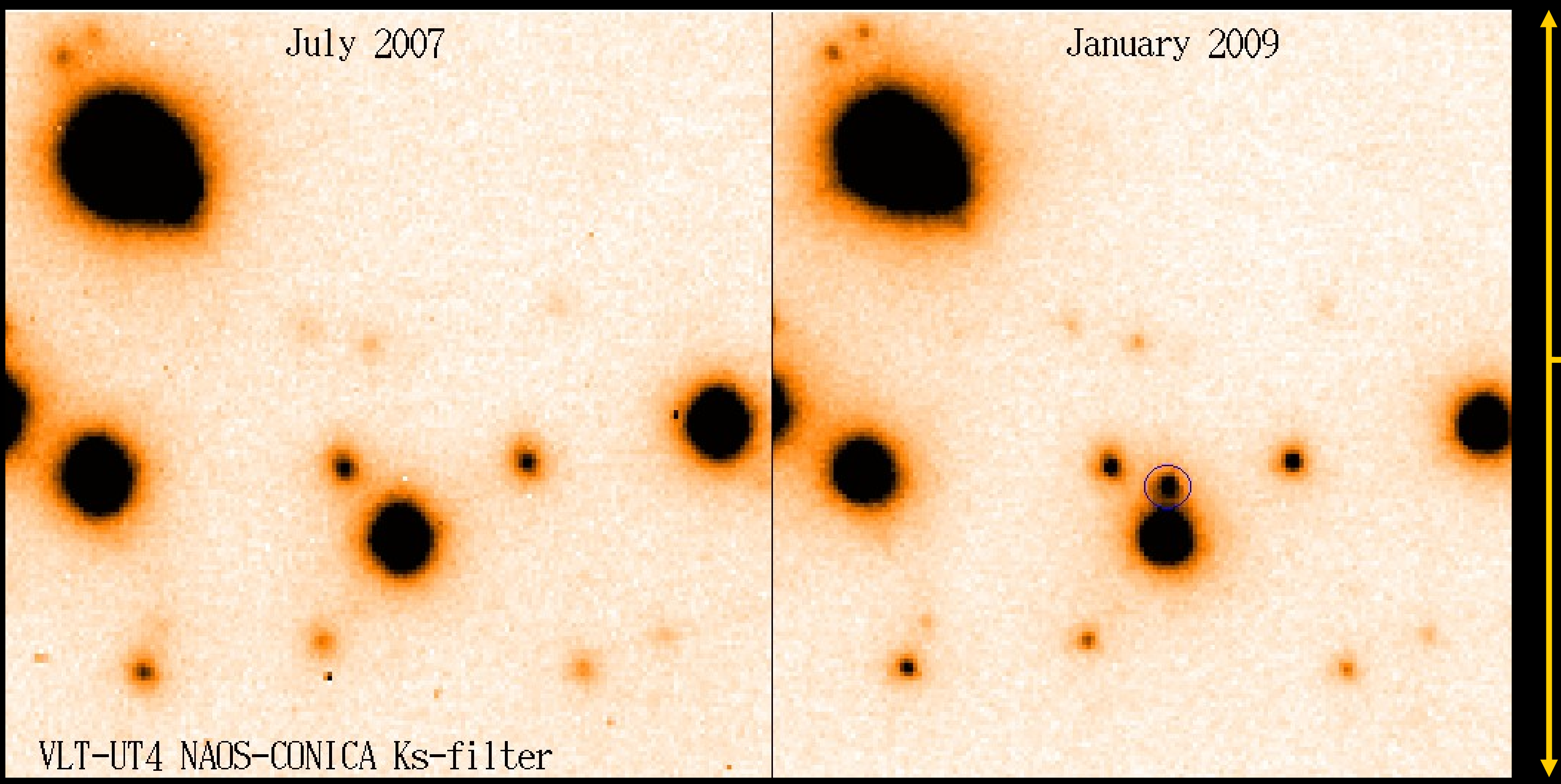


X-ray/radio alignement simila to XTEJ1810 and PSRJ1622

Radio variability not correlated to X-rays - no significant flux variations
In agreement with the idea that most of the X-rays originated deep in the crust after thermalization.... BUT

1E1547.0-5408's IR counterpart

Bright transient nIR object (Ks~18) 0.3" away from a bright nearby star.
Adaptive Optics have been used

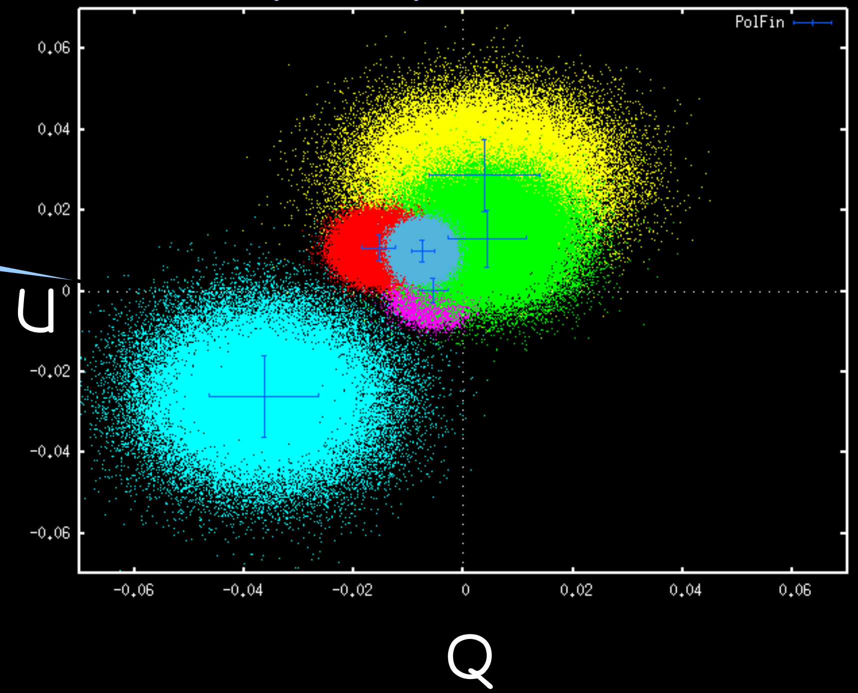


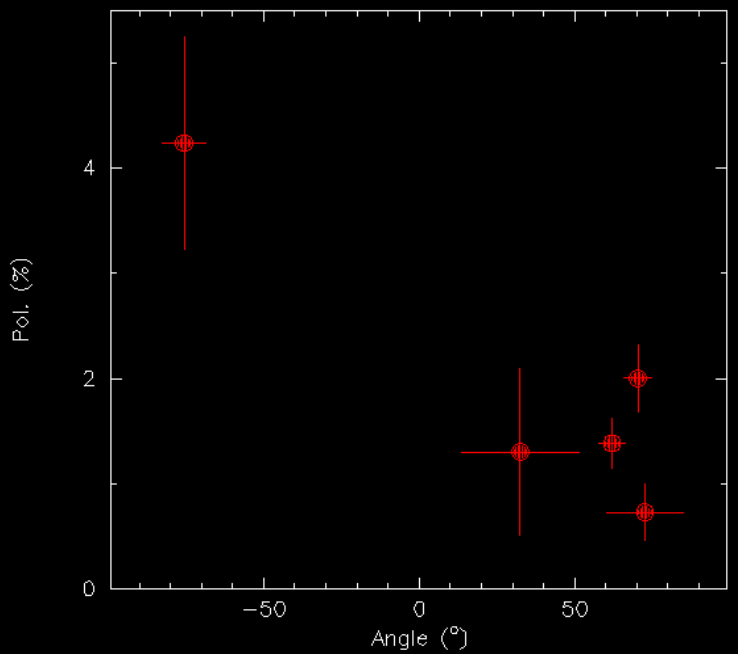
(I+ et al. 09; Mignani 10)

1E1547.0-5408'S IR COUNTERPART

Pol. Level ~4.2(0.9)% (4.5σ c.l.)

Is it ALL from the IR Transient (TIR)? ISM ?





If intrinsic to TIR - is ALL the pol. due to B ?
Compton scattering may result in a similar pol level.

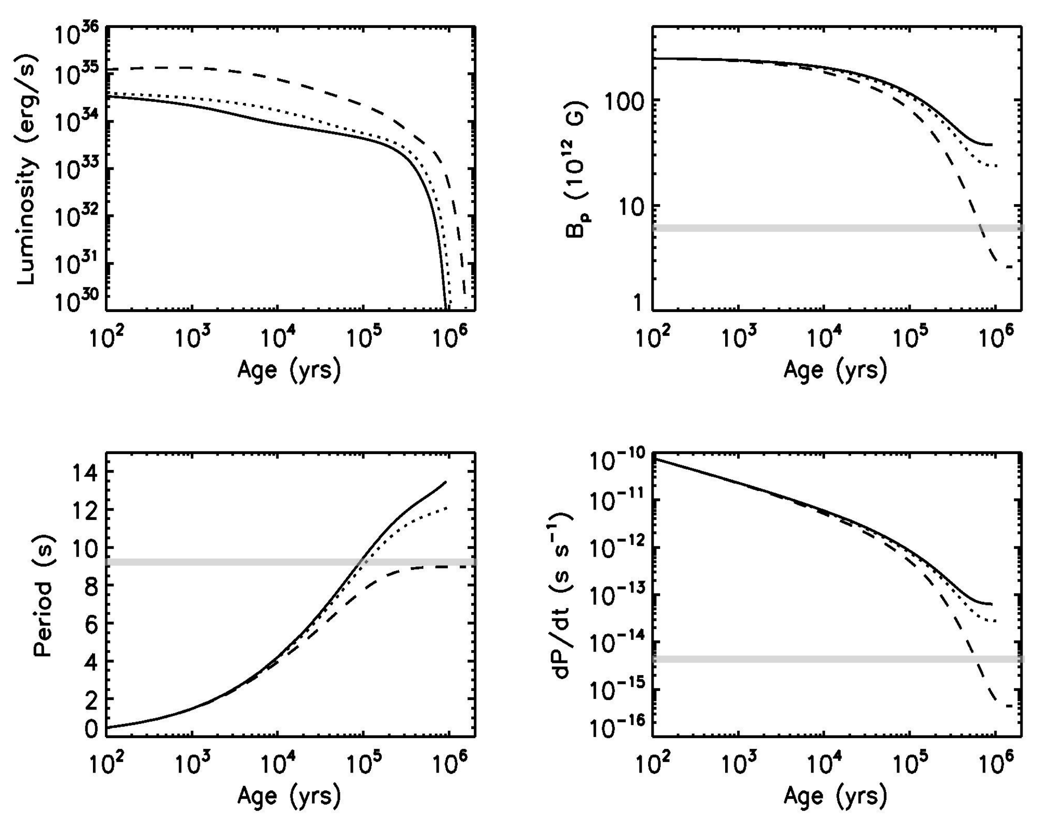
IR pol of 1E1547 similar to the optical pol measured in Crab and PSR0526 (~10-15%).

Coupled magnetic and therma
evolution (Pons, Miralles & Gepp
2009)

Standard cooling scenario (Pag
et al. 2004), toroidal+poloidal
crustal field, external dipole
M=1.4 $M_{▯}$, P_0 = 10 ms,

$B_{p,0} = 2.5\times10^{14}$ G,
$B_{pol,0} = 10\ B_{p,0}$, $B_{tor,0} = 0$ (▯) ,
4×10^{15} (···), 4×10^{16} G (- - -)

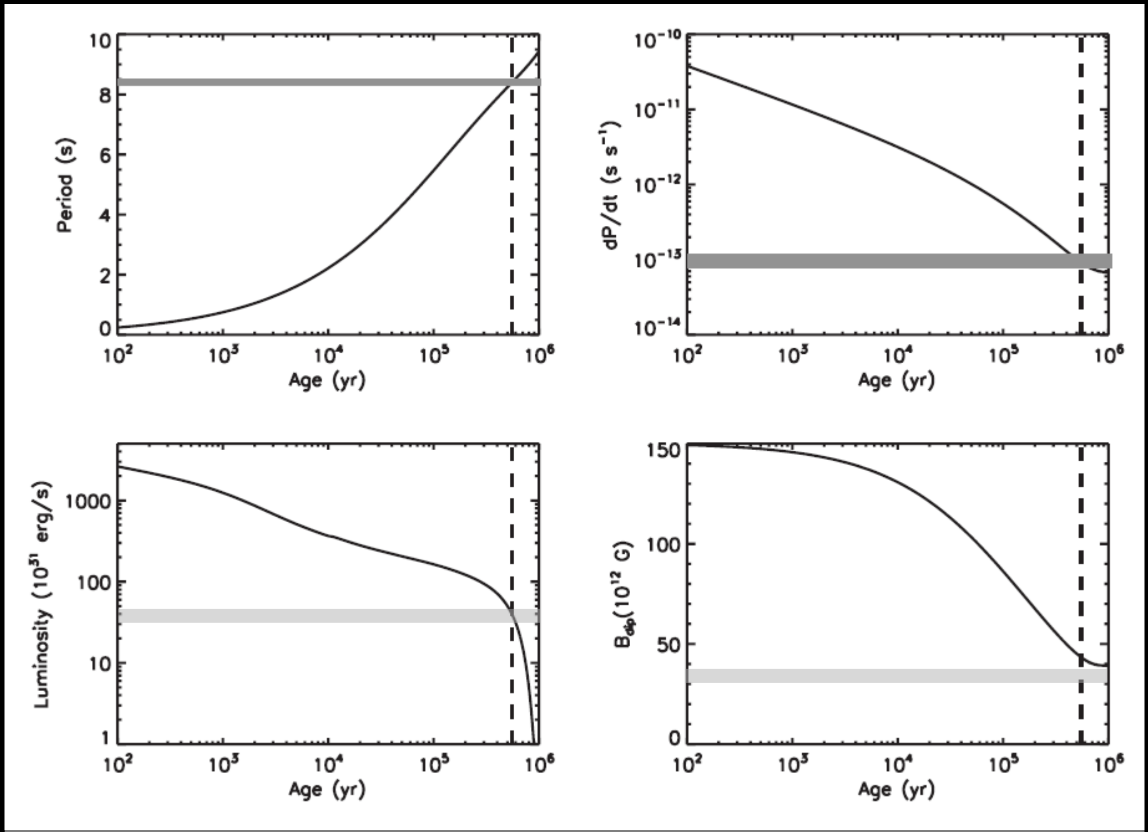
$P \sim 9$ s, $\dot{P} \sim 5\times10^{-15}$ s/s,
$B_p \sim 7\times10^{12}$ G, $L_X \sim 10^{31}$ erg/s
for an age ~ 1 Myr



SGR 0418 (Turolla et al. 2011)

$B_{p,0} = 1.5\mathrm{x}10^{14}$ G
$B_{tor,0} = 7\mathrm{x}10^{14}$ G

P ~ 8.5 s, $\dot{P}$ ~ $8\mathrm{x}10^{-15}$ s/s,
B_p ~ $3\mathrm{x}10^{13}$ G, L_X ~ $3\mathrm{x}10^{32}$ erg/s
for an age ~ 0.5 Myr



SGR 1822 (Rea et al. 2012)

TO TAKE HOME

TAXPs (and/or TSGRs) are, as expected, the largest fraction of the magnetar class.

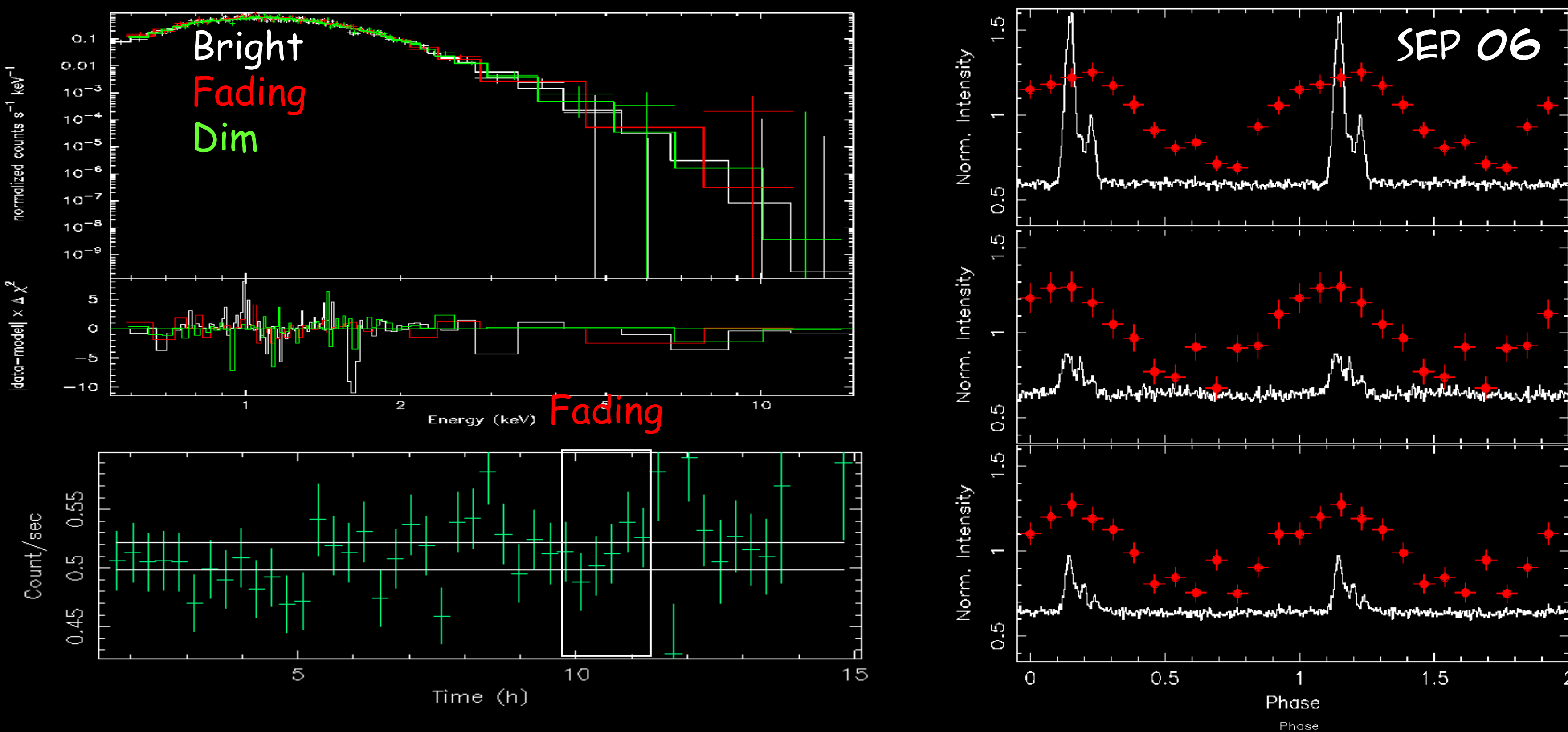
TAXP Outbursts seems to be a very powerful tool in the study the emission mechanism(s) from AXPs/SGRs.

- Low dipolar magnetic filed not the only ingredients for making a hol
  magnetar; identifying the parameter boundary for magnetar. Releva
  For demography and link with other NS classes.
- Development of new theoretical models including the physics of the
  matter/radiation interaction in strong MF.

The greatest part of these results have been obtained thanks to the complementary capabilities of small and large X-ray missions (Swift – RXTE - XMM – Chandra) and ground-based facilities (VLT, Parkes).
The importance of relying upon ToO multi-wavelength projects (simul observations)

- X-ray/radio pulse alignment, its stability,
- X-ray burst/radio pulsations link
- First measurement of IR polarization in a magnetar (not conclusive)

CONSTRAINTS FROM XTEJ1810-197 MW OBS.



X-ray/radio alignment : X-rays and radio are coming from the same portion of the NS

Radio variability not correlated to persistent X-rays - no significant flux variations

In agreement with the idea that most of the X-rays originated deep in the crust after thermalization Flux~const however Fr~0.01Fx.

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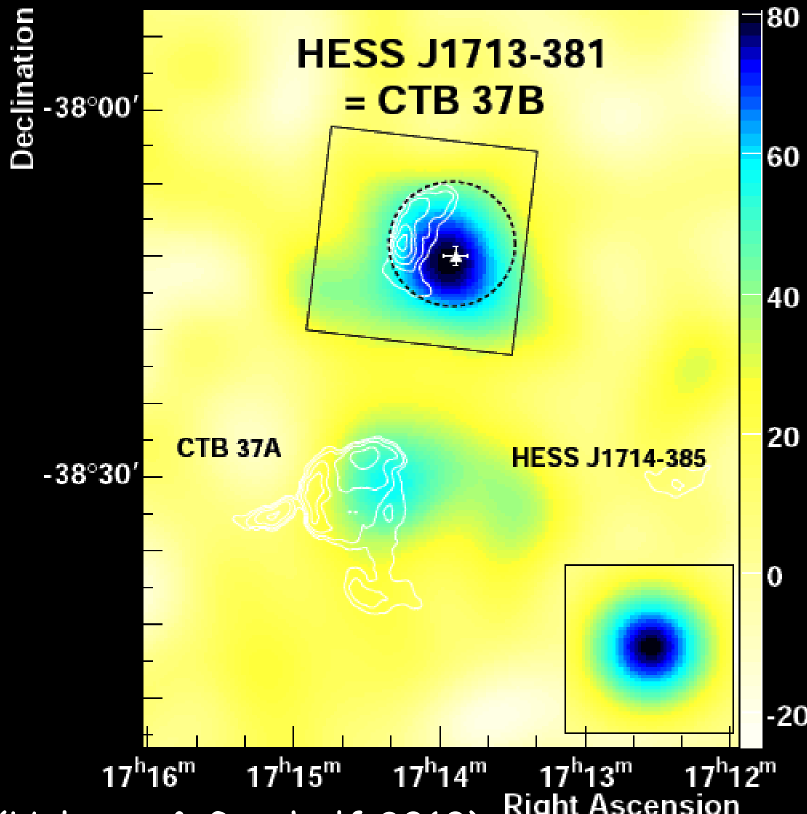
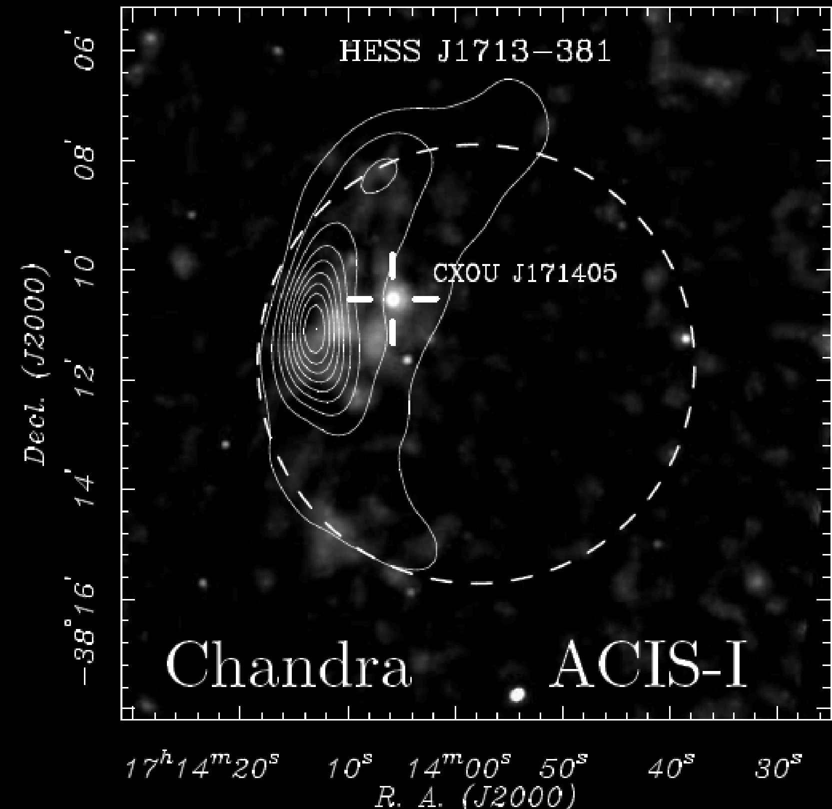
THE TEV/X-RAY EMISSION IN THE SNR CTB 37B

CTB 37B $\quad d \approx 8$ kpc $\quad$ Age $= 1600 - 4900$ yr



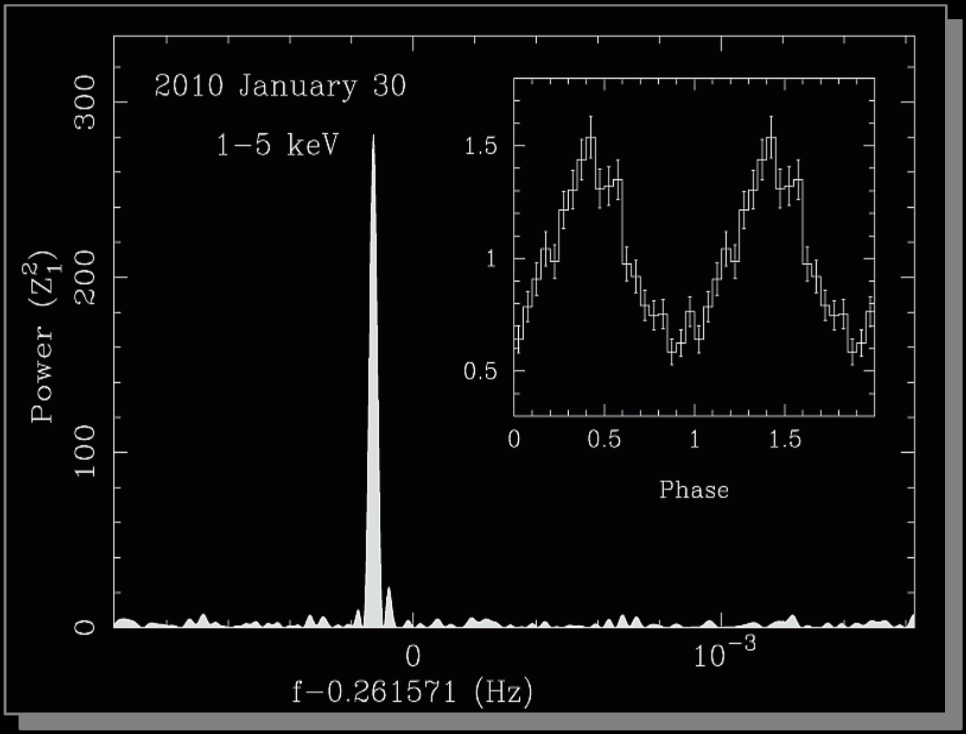


(Halpern & Gotthelf 2010)

THE ENERGETIC 3.82s PULSAR !!

Parameter	Value
R.A. (J2000)[a]	$17^h14^m05\overset{s}{.}74$
Decl. (J2000)[a]	$-38°10'30\overset{''}{.}9$
Epoch (MJD)	55,226.5
Spin period, P	3.824936(17) s
Period derivative, $\dot{P}$	$(5.88 \pm 0.08) \times 10^{-11}$
Range of dates (MJD)	54,856–55,227
Surface dipole magnetic field, B_s	4.8×10^{14} G
Spin-down power, $\dot{E}$	4.2×10^{34} erg s^{-1}
Characteristic age, τ_c	1030 yr

(Halpern & Gotthelf 2010)



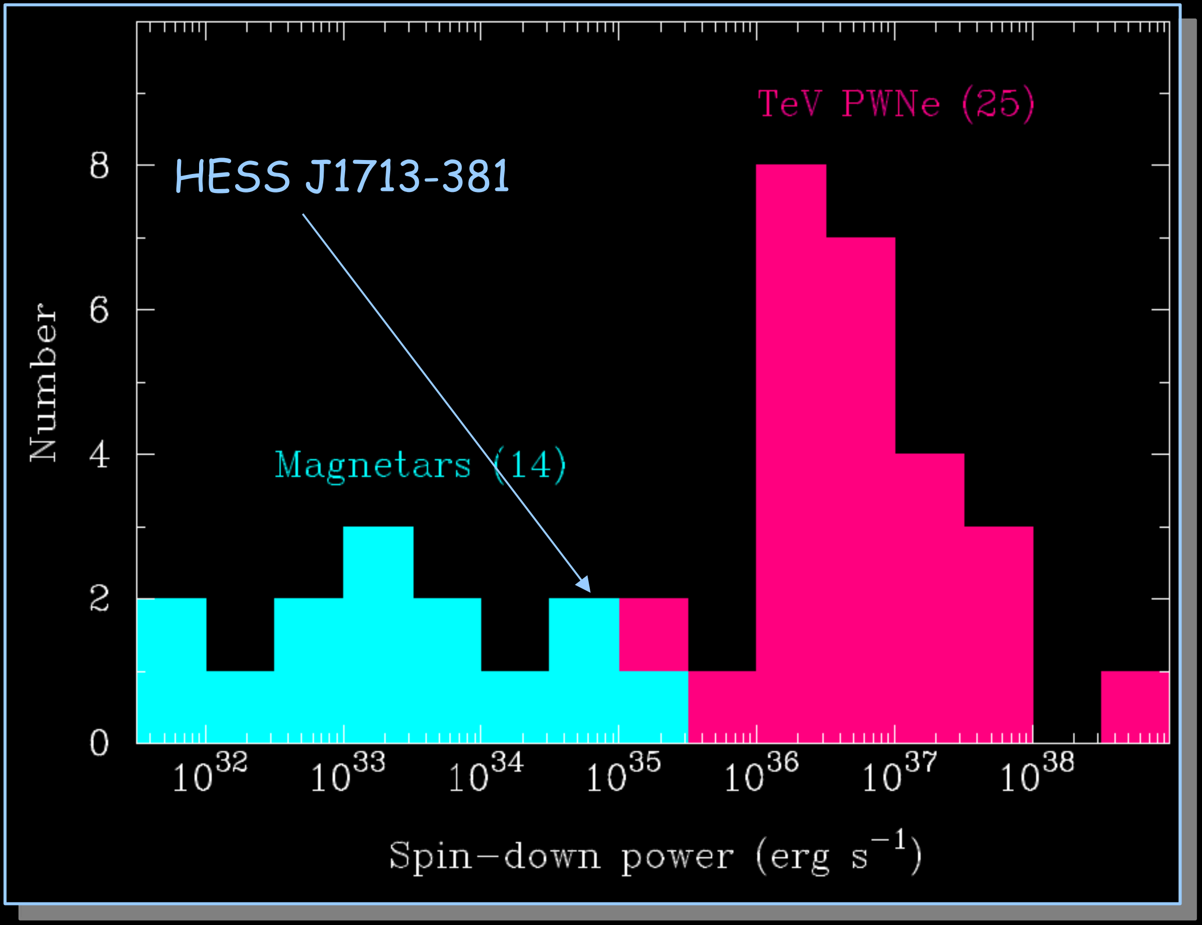
P, Pdot, Edot and τ_c makes HESS J1713-381 the first TeV-selected magnetar !!! Edot ~ Lγ

Which mechanism is responsible for the TeV emission? SNR ?

THE TeV EMISSION FROM HESS J1713-381

TeV emission detected from PWNe powered by pulsars... not SNR.
HESS J1713-381 is a SNR not a PWNa.

Moreover:
- no magnetar shows a PWNa;
- all magnetars have Edot < few 10^{35} erg/s;
- mangetars are powered on close B lines;
- Maximum e^- energy limited to GeVs.



And so ?

IC FROM A "RELIC" PWNA ?

Current data do not allow to exclude a PWNa inside the SNR-shell.
If so, given that Edot ~ Lγ NOW, the scenario of a pulsar powered PWNa involves particles ejected in an earlier time when Edot was larger!
However, the magnetar model involves current in CLOSE B-field lines developing voltages not larger than 10^9 V.

What about the emission from the OPEN B-field lines ?

IT exists (magnetar theory predicts e^- <3GeV) since we observed transient pulsed radio emission from two magnetars !!

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If so, IC of these e^- might power the PWNa for 10^3/several 10^4 yr. It implies an initial P of < 0.14s

An electron that IC scatters a photon to E_γ(TeV) has synchrotron and inverse Compton liftimes:

$$t_s \approx \frac{4200\,\mathrm{yr}}{\sqrt{E_\gamma(\mathrm{TeV})}} \left(\frac{B}{10\,\mu\mathrm{G}}\right)^{-2}$$

$$t_{\mathrm{IC}} \approx \frac{8 \times 10^4\,\mathrm{yr}}{\sqrt{E_\gamma(\mathrm{TeV})}}$$

the latter for IC scattering on the microwave background.

Too B or not too B?

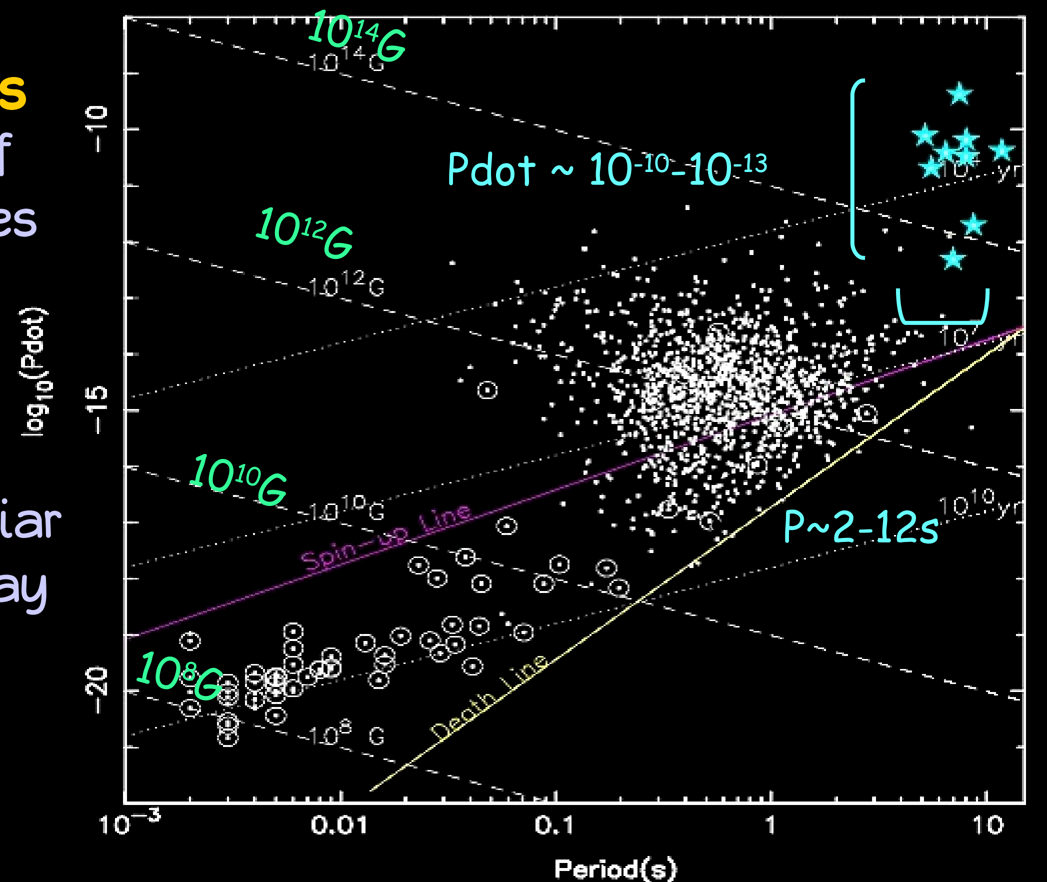
TWO CLASSES OF MAGNETARS (HISTORICALLY)

Soft Gamma-ray Repeaters

Discovered in 1979 as sources of hard X-ray bursts and giant flares

Anomalous X-ray Pulsars

Identified in the 90's as a peculiar class of soft and persistent X-ray pulsar with no signs of binary companions



AXPs = SGRs

- Persistent vs transient
- Associated with SNRs (4) and massive open clusters (3) with M turn-off of 30-40Msolar and b<0.5 ~10^4-10^5 yr

Current number is about 25 objects

OUTLINE

- Magnetar

- HE Flare/outburst phenomenology

- Low Pdot/B magnetar and implications

- Flares: magnetically confined fireball
  Standard candles ?

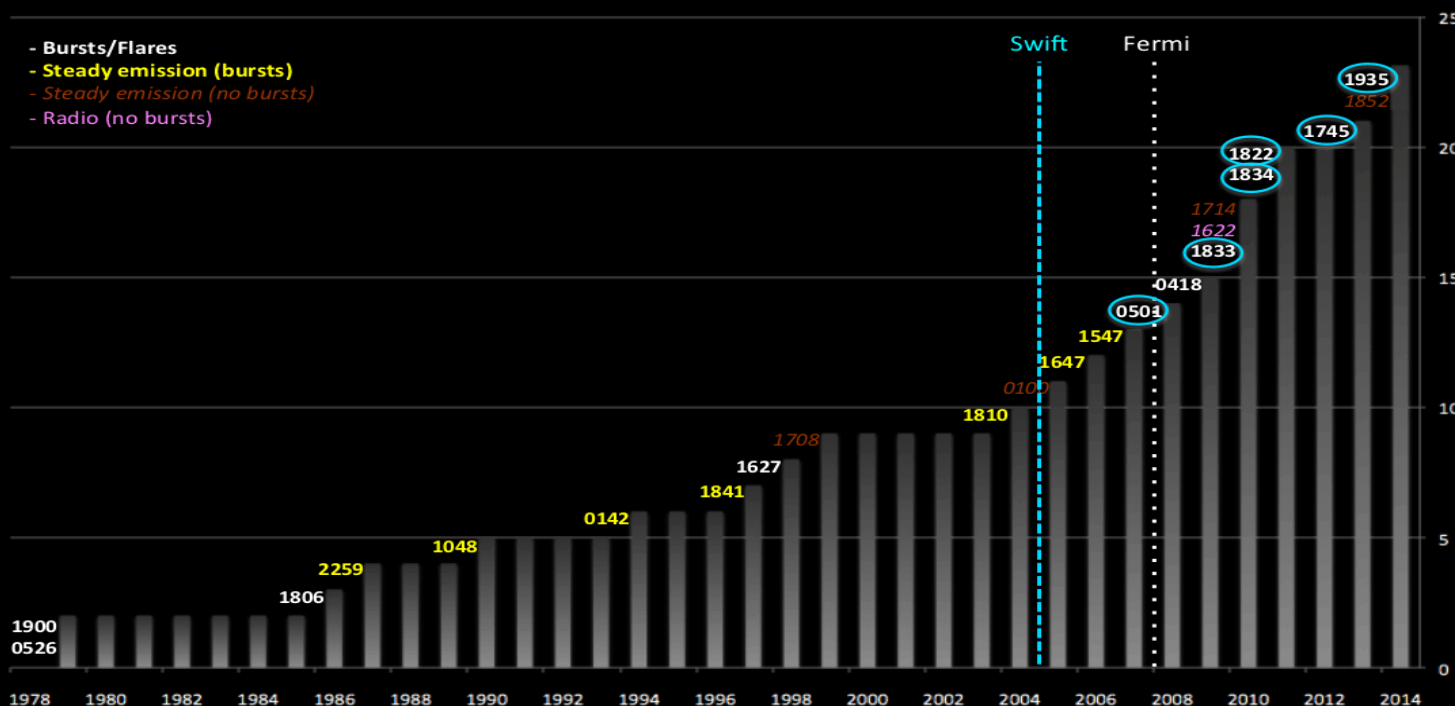
- Giant Flares
  What we learned (EOS, magnetic fields)

- The Future and next generation instumentations

NEW MAGNETARS

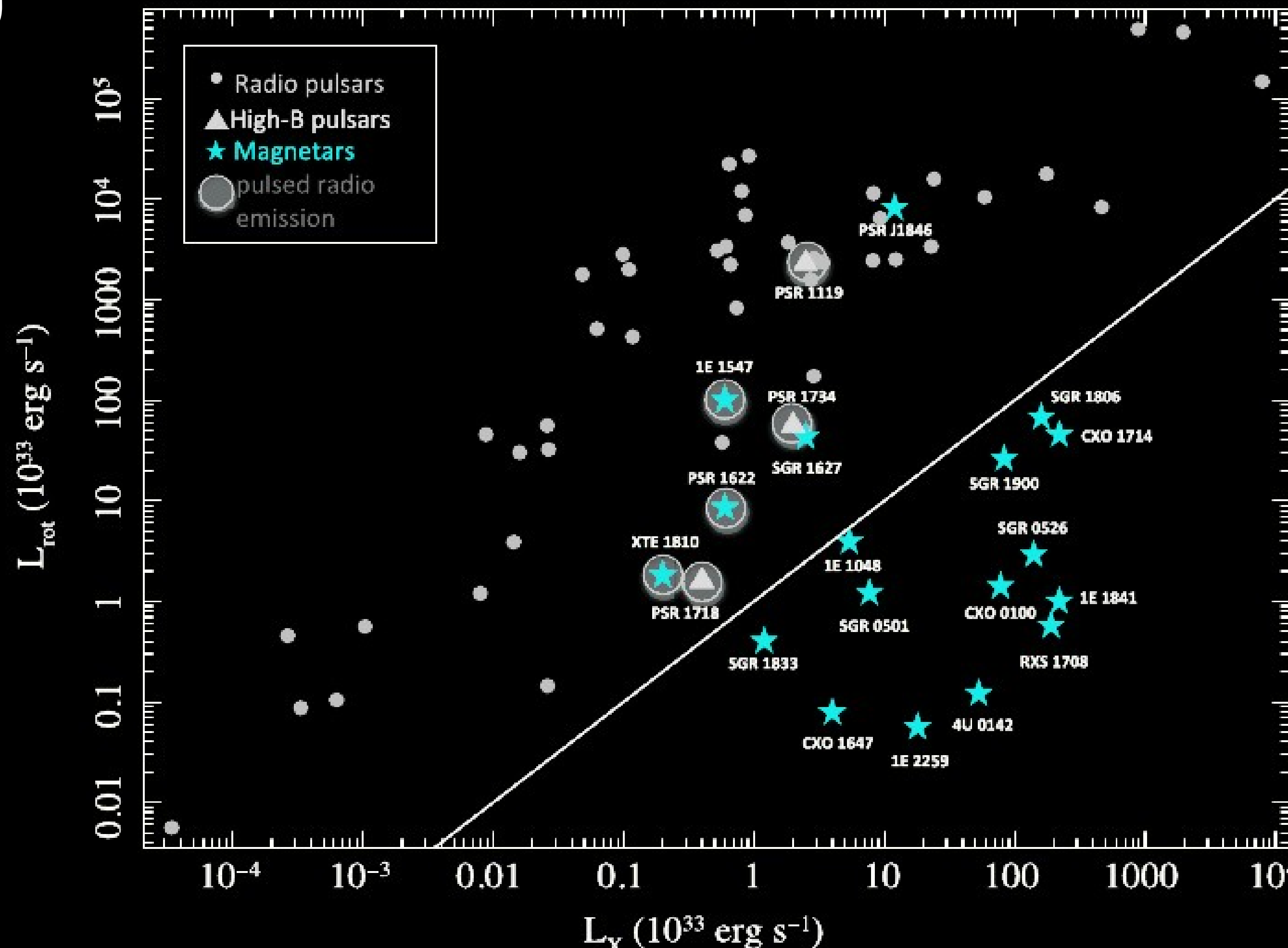
Mainly discovered through burst detection

6 out of 10 new magnetars dicovered by BAT in the latest 10yr
1 discovered by Fermi GBM
2 in soft X-rays
1 in radio



RADIO EMISSION

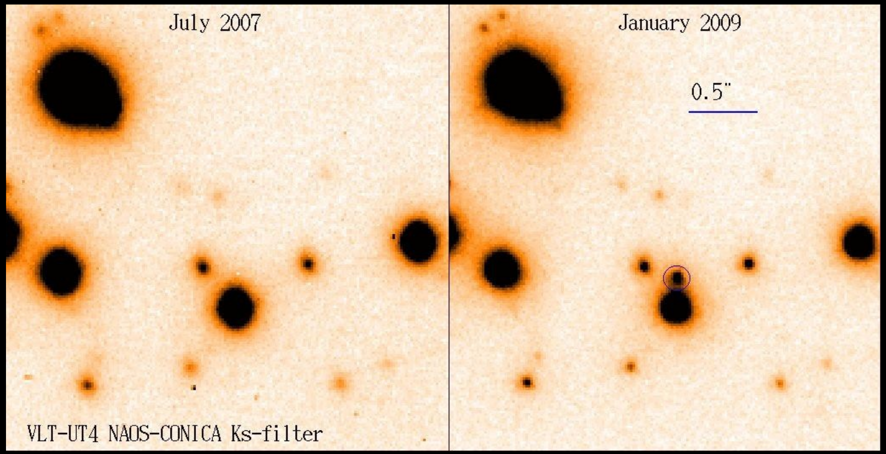
Magnetar can work as normal radio pulsar depending on the ratio between the quiescent X-ray emission and their rotational energy



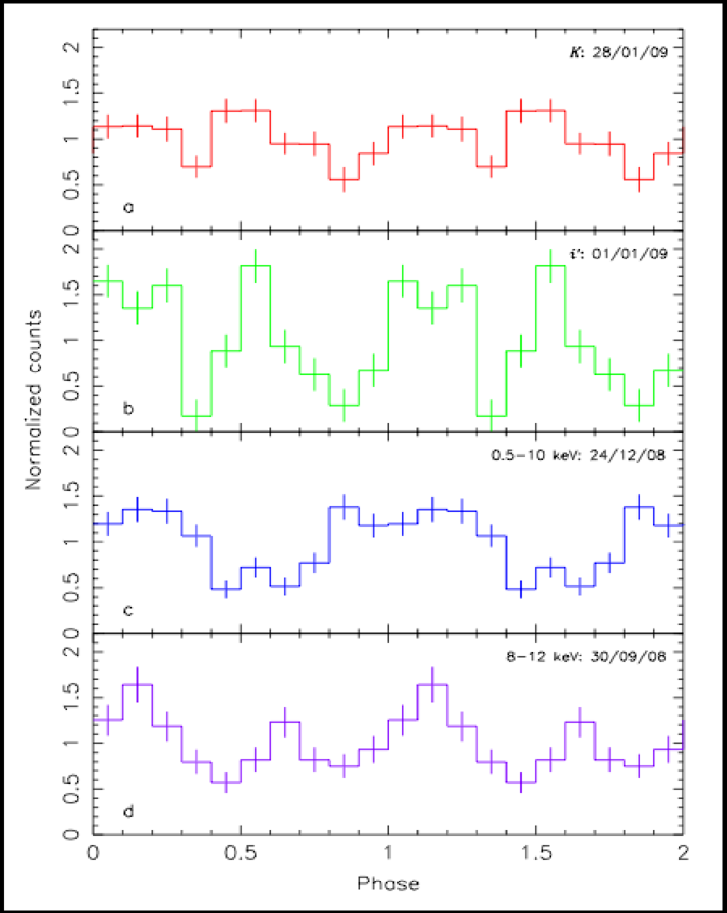
(Pons+ 2012)

MAGNETARS GENERAL PROPERTIES

- Faint infrared/optical emission (K>20)
- X-ray and infrared emissions decay together in transient magnetars! … IR pulses



(Israel et al. 2010)



(Dhillon et al. 2011)