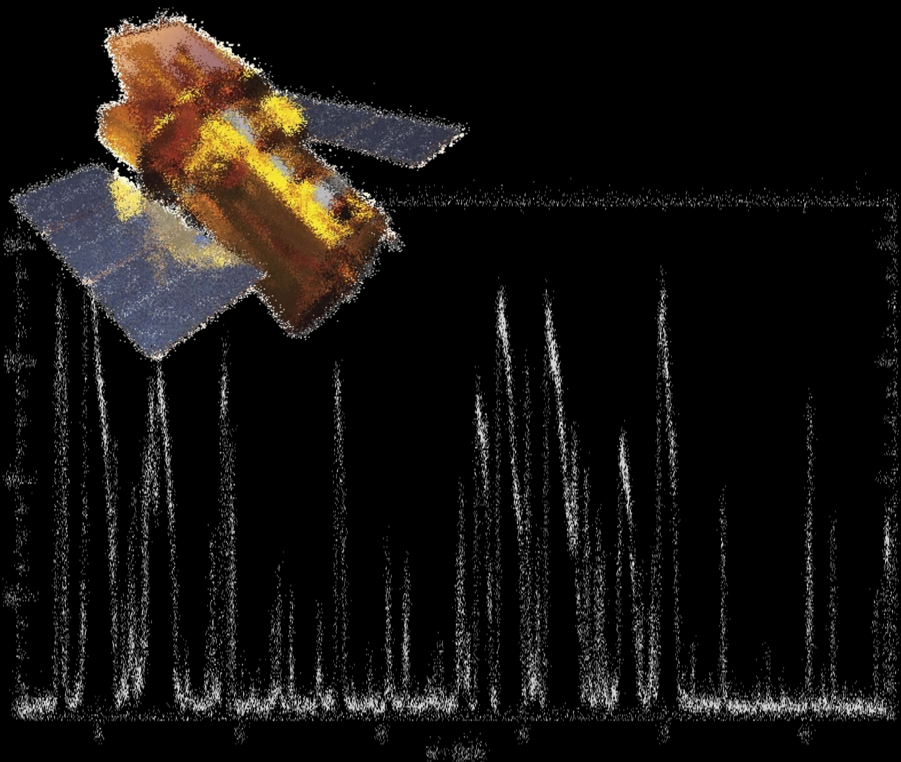
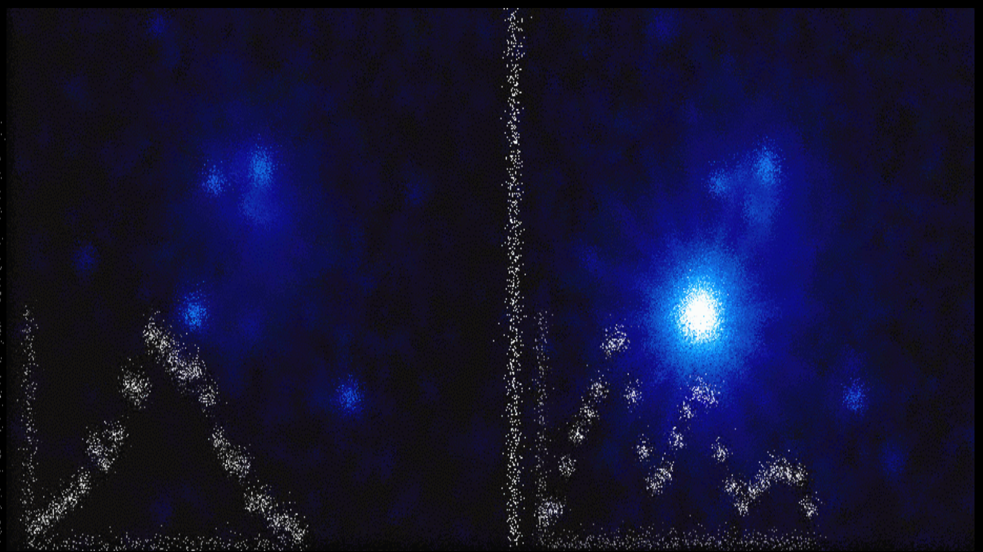
PROBING THE PHYSICS OF MAGNETARS





GIANLUCA ISRAEL (INAF – ROMA ASTRONOMICAL OBSERVATORY)

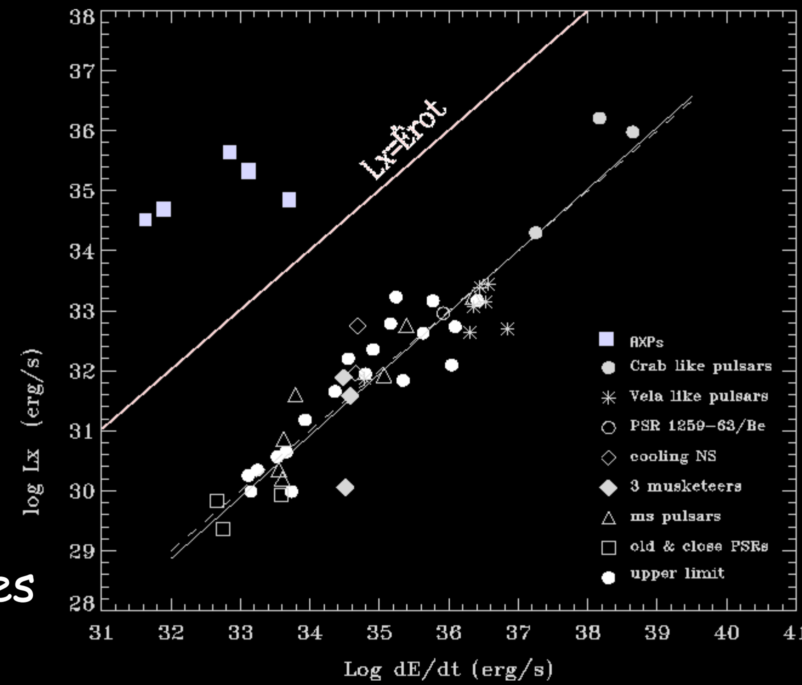
...and many many many others

WHY MAGNETARS ?

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



In analogy with isolated rotation-powered NS

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

10^{14-15} Gauss → MAGNEtic sTARS

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 !

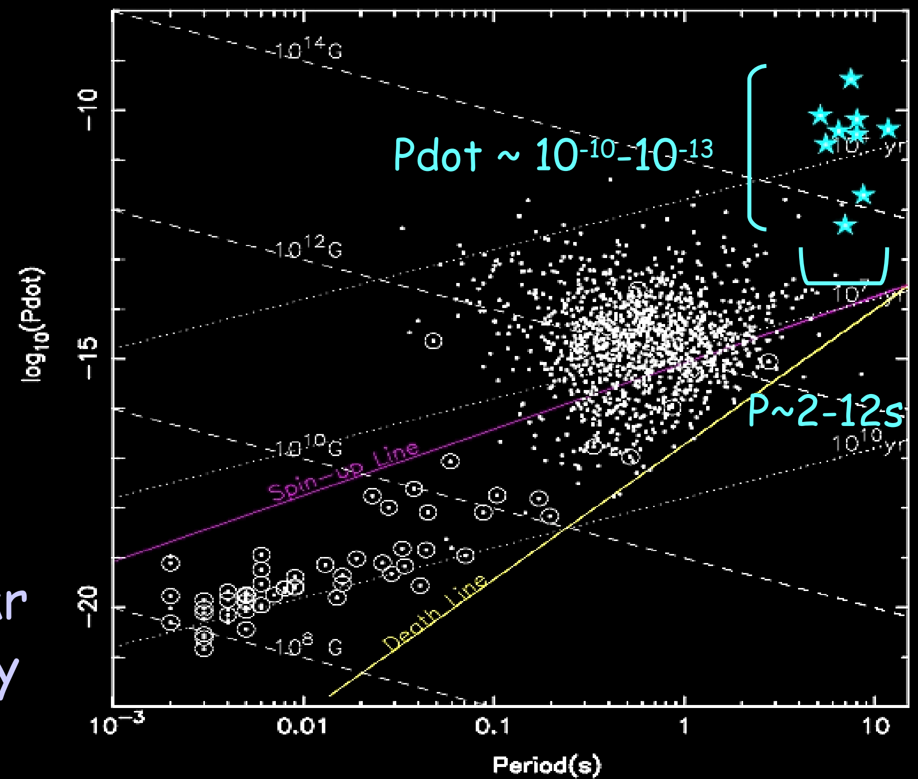
TWO (?) CLASSES OF MAGNETARS (HISTORICALLY)

Soft Gamma-ray Repeaters

- o Discovered in 1979 as sources of hard X-ray bursts and giant flares
- o 6 confirmed SGRs

Anomalous X-ray Pulsars

- o Identified in the 90's as a peculiar class of soft and persistent X-ray pulsar with no signs of binary companions
- o 9 confirmed AXPs



- o Spin periods: 2 - 12 s
- o Period derivatives: 10^{-10}-10^{-13} ss^{-1}
- o Short (~100ms) X/γ bursts / Glitches
- o Rare Giant Flares (>10^{47} ergs; minutes)
- o Associated with SNRs (2) and massive open clusters (3) with M turn-off of 30-40Msolar and b<0.5 → ~10^4-10^5 yr

(See review: Mereghetti 2008, A&A Rev. 15, 225)

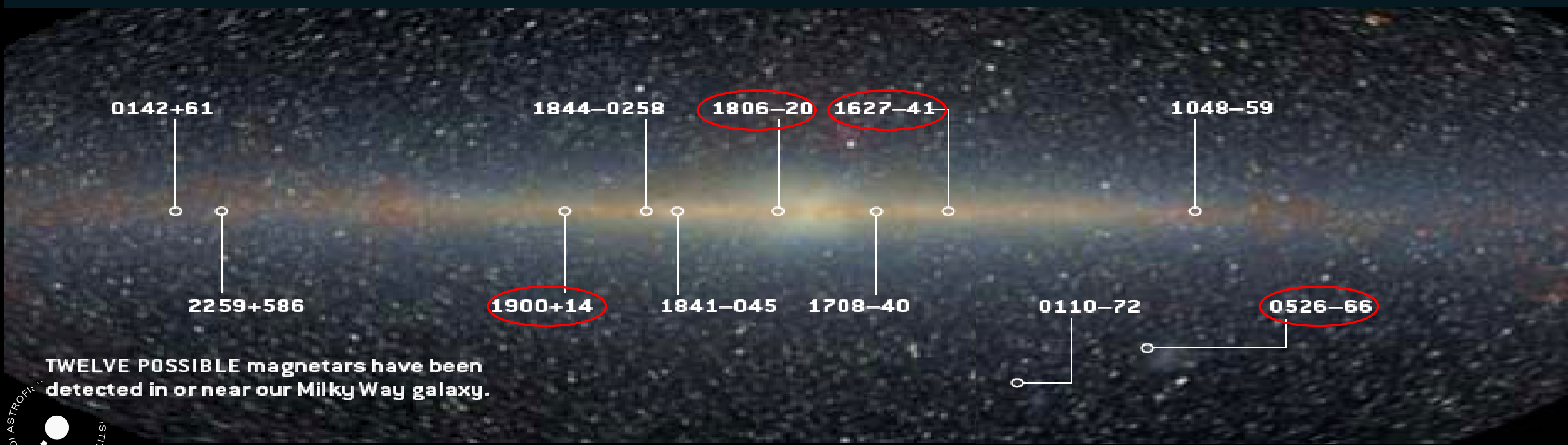
AXPs ≈ SGRs ?

Are the observational differences only introduced by observational selection effects? In this case these sources belong to the same class of objects:

in AXPs the quiescent, pulsating emission was discovered first in the X-ray band.

SGRs were discovered through their bursts in γ-ray

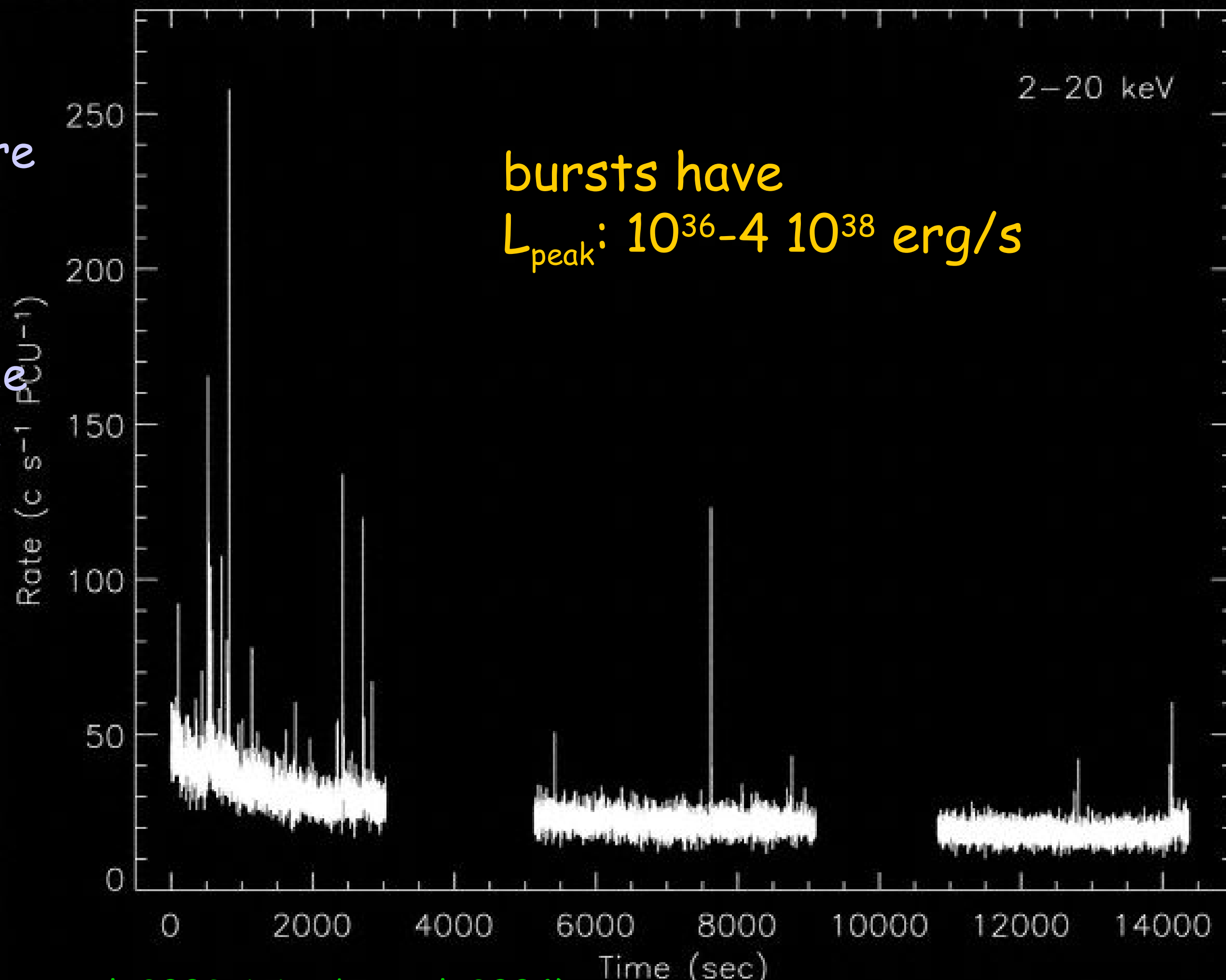
Temporal evolution ? However P and Pdot similar



1E2259 +586: THE MISSING LINK

~ 80 short bursts (Lx~ 10^{36}-10^{38} erg/s) detected in June 2002 (RXTE). Enhanced persistent emission (1-yr long) . A large glitch was detected too.

During the latest years several similar events were detected (mainly form Swift) from virtually all the AXPs making weaker and weaker the difference between SGRs and AXPs .



bursts have
L_{peak}: 10^{36}-4 10^{38} erg/s

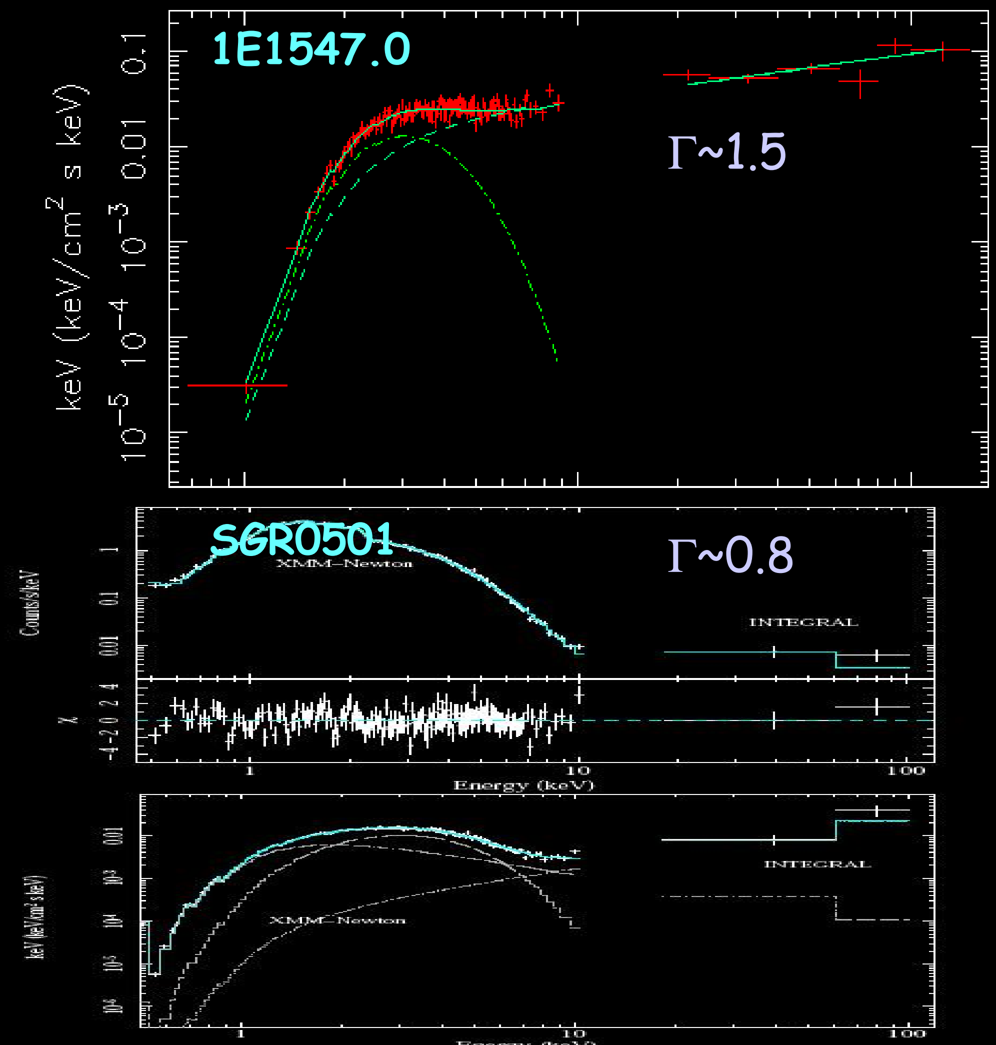
(Kaspi et al. 2003, Woods et al. 2004)

1E1547.0 AND SGR0501 BROAD BAND SPECTRA

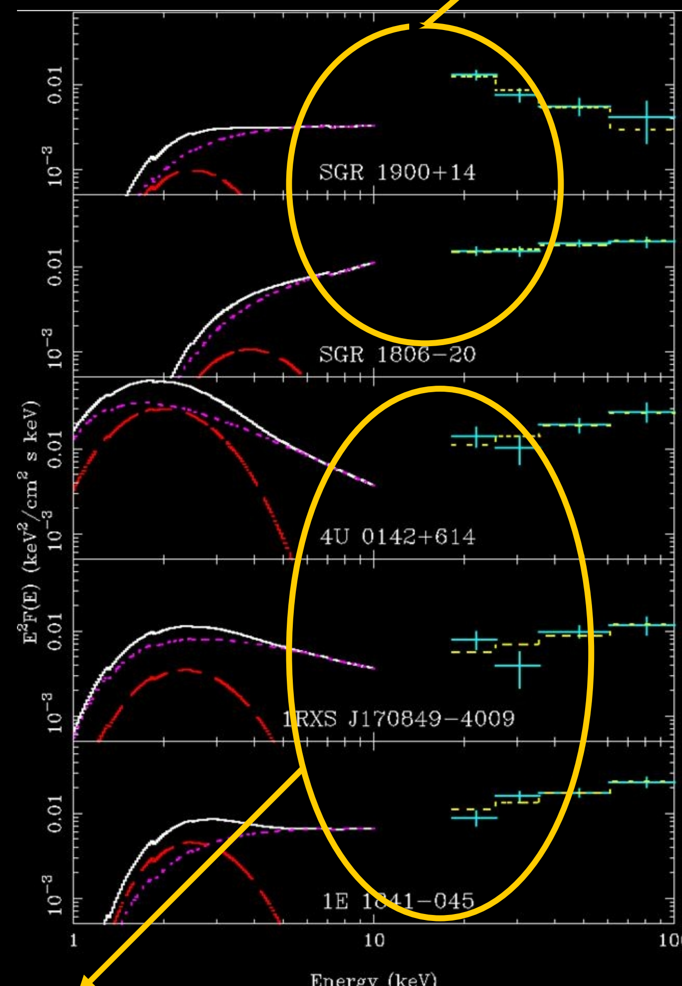
A continuum of spectral properties rather than two distinct " states"

- Same PL at Low and High E BUT BB dominates at Low E for 1E1547.0
- Two PLs for SGR0501(Rea et al. 2008; Israel et al. 2009b)

Chandra and XMM + INTEGRAL (simultaneous)



1PL



2PL

(Gotz et al. 2006, 2008)

THE CENSUS

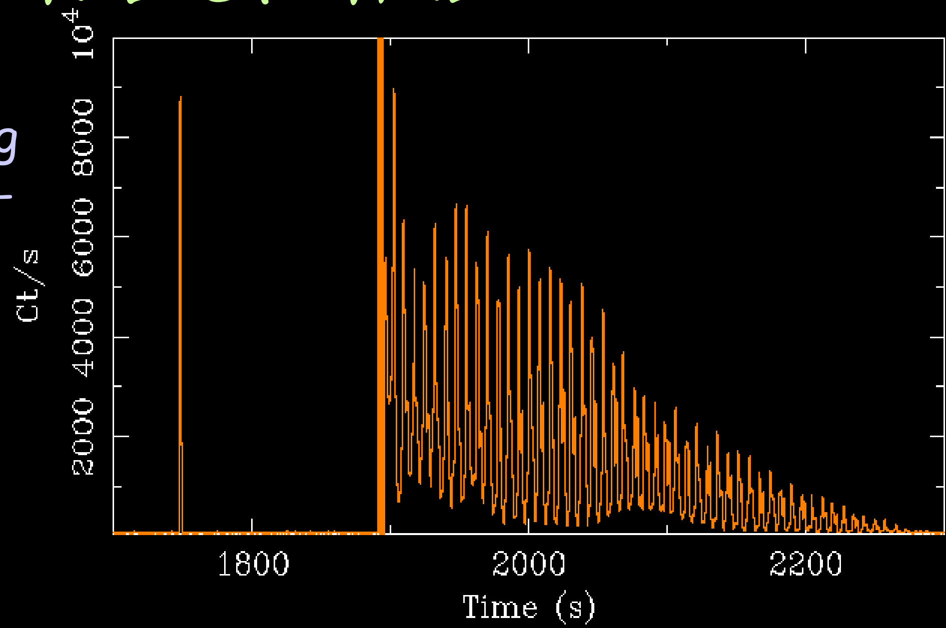
NAME	P (s)	dP / dt (10^{-11} s/s)	B (10^{14} G)	BURSTS	GIANT FLARES	GLITCHES
CXO J0100-72	8.0	1.9	4			
4U 0142+61	8.7	0.2	1.3	√		√
1E 1048-59	6.4	1 - 10	2.6 - 8.1	√		√
1E 1547-54	2.1	2.3	2.2	√		
CXO J647-45	10.6	0.09	1	√		√ ?
RXS 1708-40	11.0	2.4	5.2			√
XTE J1810-197	5.5	0.8 - 2.2	2.1 - 3.5	√		
1E 1841-045	11.8	4.1	7			√
AX J1845-02	7.0	--	--			
1E 2259+586	7.0	0.048	0.6	√		√
SGR 0414+57	**9.1**	**Not yet**	<0.6 !	√		√ ?
SGR 0501+45	**5.7**	**0.7**	**2**	√		√ ?
SGR 0526-66	8	6.5	5.7	√	√	
SGR 1627-41	2.6	1.9	2.2	√		
SGR 1806-20	7.6	8 - 80	8 - 25	√	√	
SGR 1900+14	5.2	5-14	5.1-8.6	√	√	√ ?

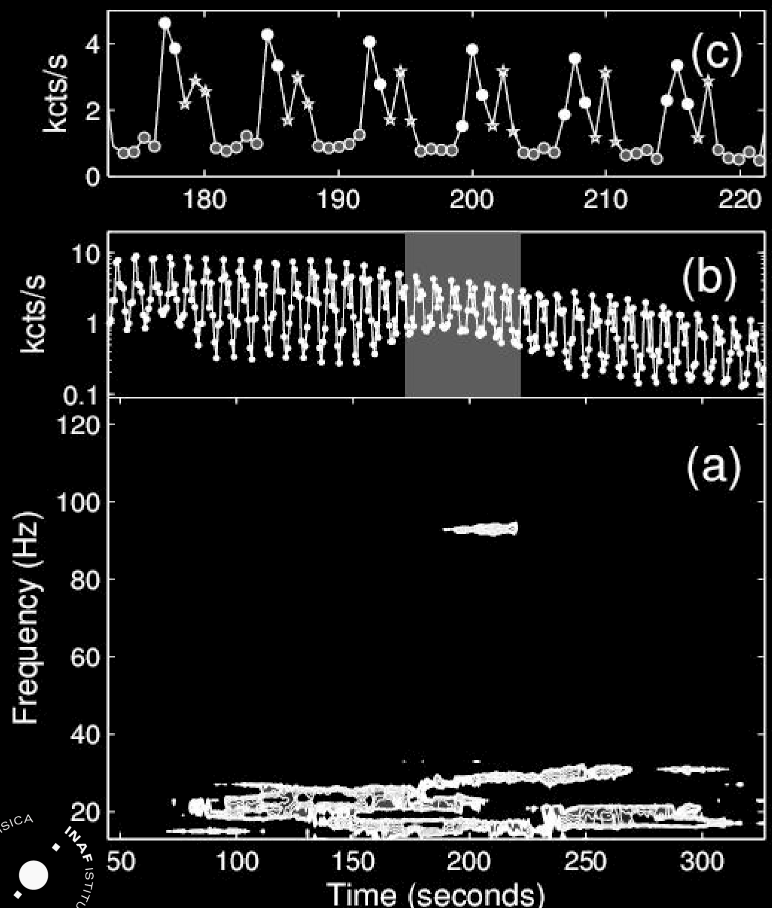
Outline

- Giant flare QPOs as an independent way for constraining the magnetic field
- Taking the radio and X-ray pulse of transient AXPs
- The study of SGR intermediate flares and their basic physics (trapped fireball)
- The recent cases of SGR0501 and 1E1547

SGR1806-20: QPOS IN THE 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 /cm² at Earth !!





Similar phenomenology and frequencies in the two sources during GFs

SGR1806-20: 18–30, 61, 92.5, 150–626-1840 Hz
SGR1900+14: 28.5, 52.5,84 and 155.5

Easily accounted for TOROIDAL GSOs (ℓ=2,4,7,13)
[ℓ=2,4,7,13 for SGR1900+14]

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

B AND THE CAVALLO-FABIAN-REES LIMIT

No direct way to infer B from obs. Several indirect ways. Many of then are model dependent.

The Cavallo-Fabian-Rees ΔL limit violation is independent from any assumption or models and allows to infer a B upper limit: $B \geq 4 \times 10^{15} G (10km/R_{ns})(0.1/\eta)^{1/2}$

$\Delta L/\Delta t = \eta\ 4\pi/3\ R^3\ n\ m_p\ c^2$

η=extr. efficiency

total energy released within Δt is related to the total mass within the source dimension R

$\Delta t > R/c(1+\tau_t)$

$\tau_t = \sigma_t nR$ (n baryon density)

Δt must exceed the time over which photons escape from the source

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

For QPOs (600-1800Hz) in SGR1806 the highest ΔL is $\Delta L/\Delta t = 2^{3/2}\ \pi\ L\ a_{rms}\ \nu_{QPO} \sim 10^{44}\ erg/s^2$

σ may differ from the Thomson cross section due to B. In the E mode (Meszaros 79) σ_t is σ reduced by a factor $\approx (\varepsilon B_q/(m_e c^2 B))^2$, thus we imposed

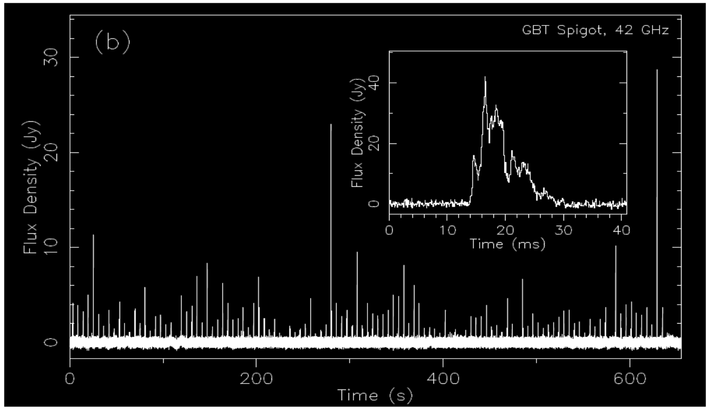
$(\varepsilon B_q/(m_e c^2 B))^2 < \eta/20$ which gives $B \geq 3\ Bq\ (0.1/\eta)^{1/2} \approx 10^{14}\ G$

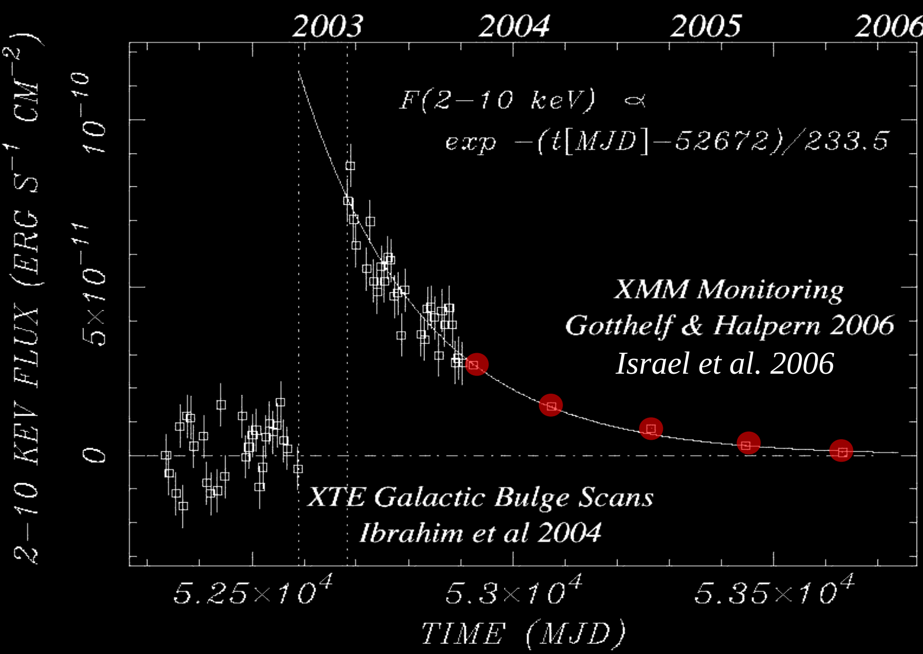
$\varepsilon \sim 14$keV from the BB component with kT~5keV and R~30km as measured in the ringing tail (Vietri et al. 2006)

From Outburst to Quiescence: XTEJ1810-197

The brightest radio (!!) pulsar in the sky for several months ! Transient emission

A new observational windows opened





$N_H = 1.05(5) \times 10^{22}$ cm^{-2}

kT = 0.67 +/- 0.01 keV

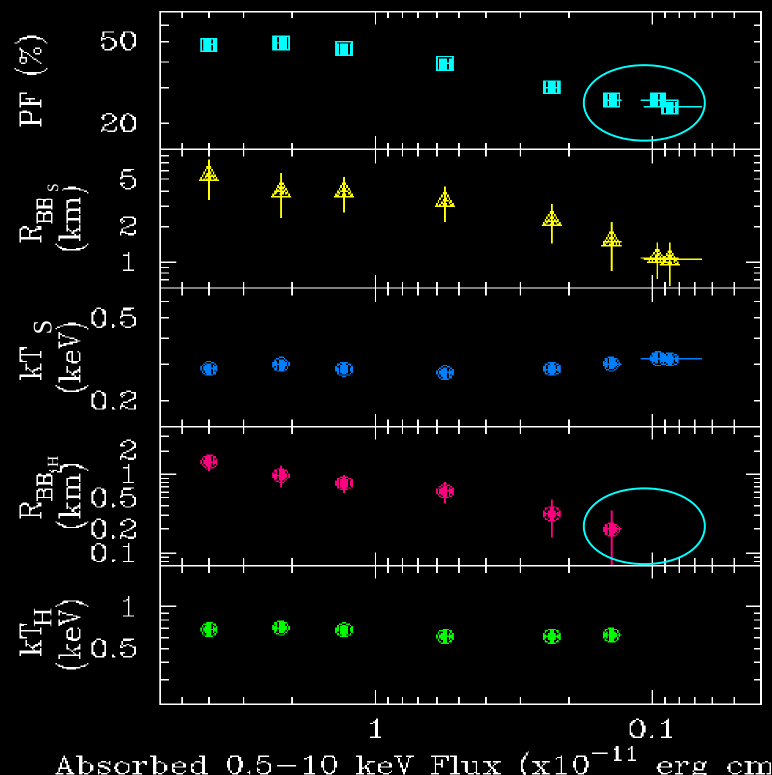
Γ = 3.7 +/- 0.2 (kT=0.3keV)

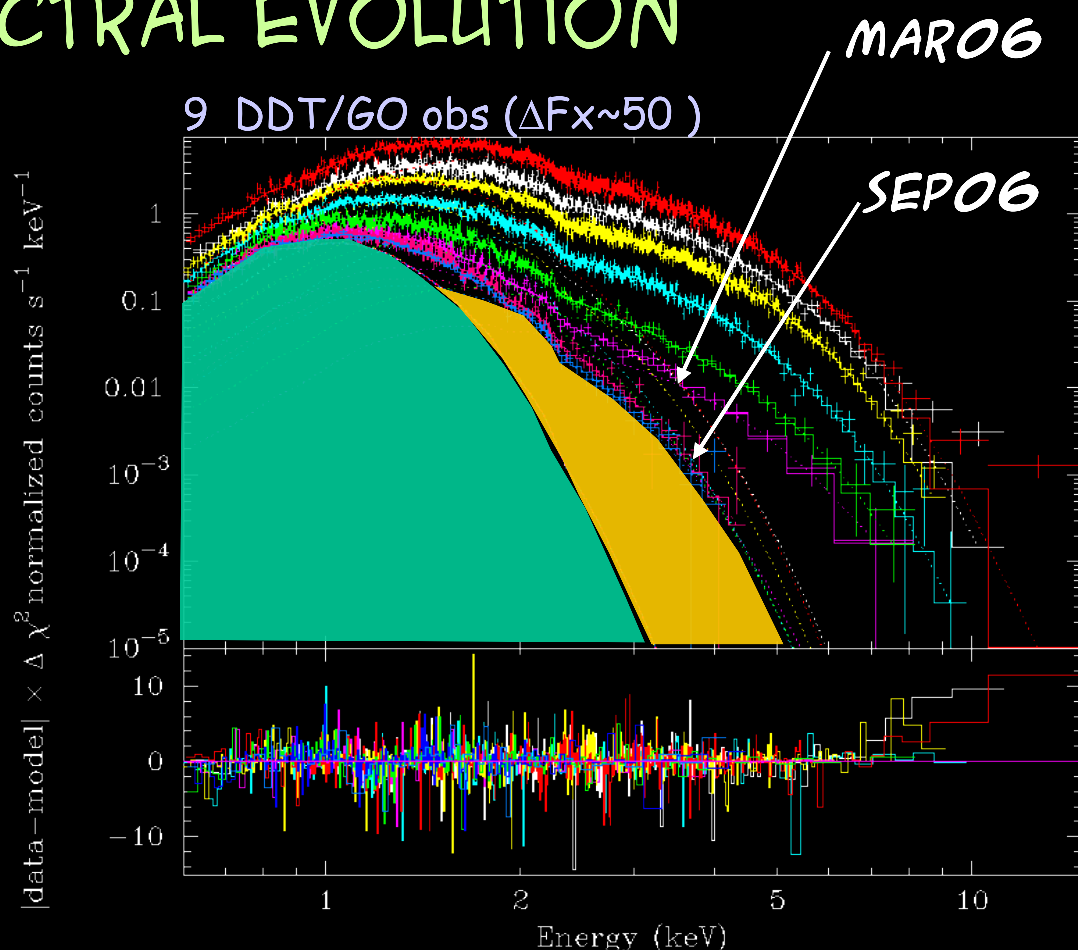
P=5.5s

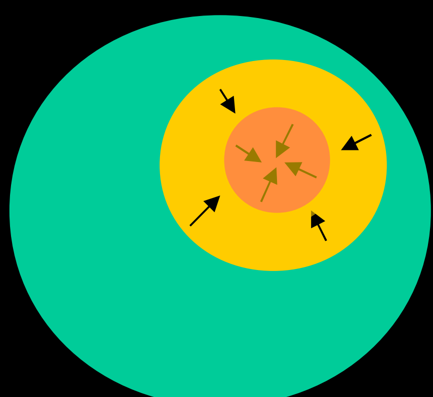
Pdot=2 10^{-11} s/s

PF=46(3)%

THE LONG-TERM SPECTRAL EVOLUTION







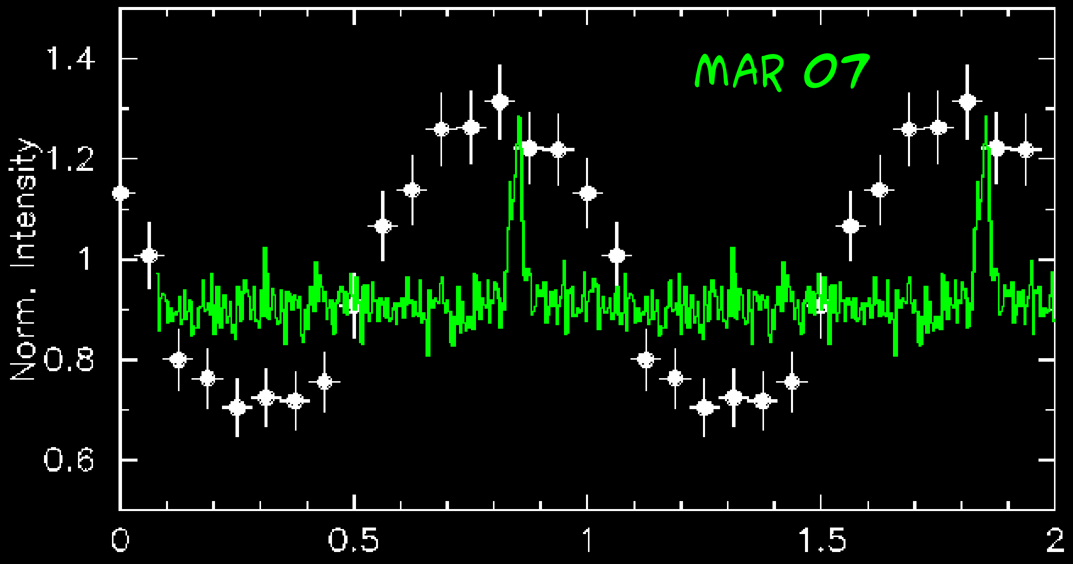
Hard BB disappeared between MAR and SEP 06 -> PF flattens

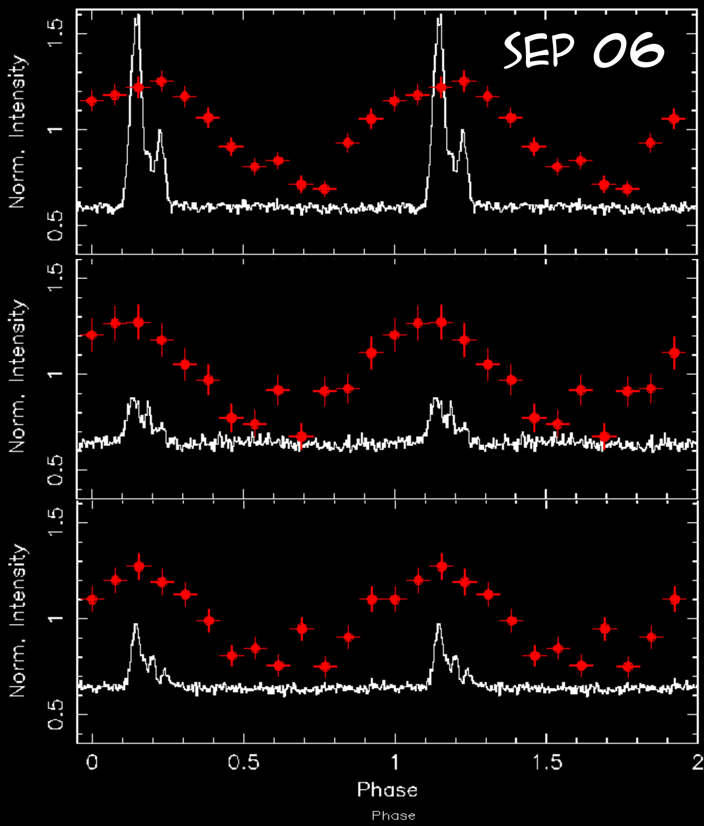
(Israel et al. 2008; Bernardini et al. 2009)

2BB -> 3BB Ftest gives p~10^{-12}

CONSTRAINTS FROM XTEJ1810-197 MW OBS.

No significant X-ray variability during the radio transitions. Flux~const however Fr~0.01Fx





Simultaneous detection of radio and X-ray pulsations is one of the strongest evidence against accretion being at work!

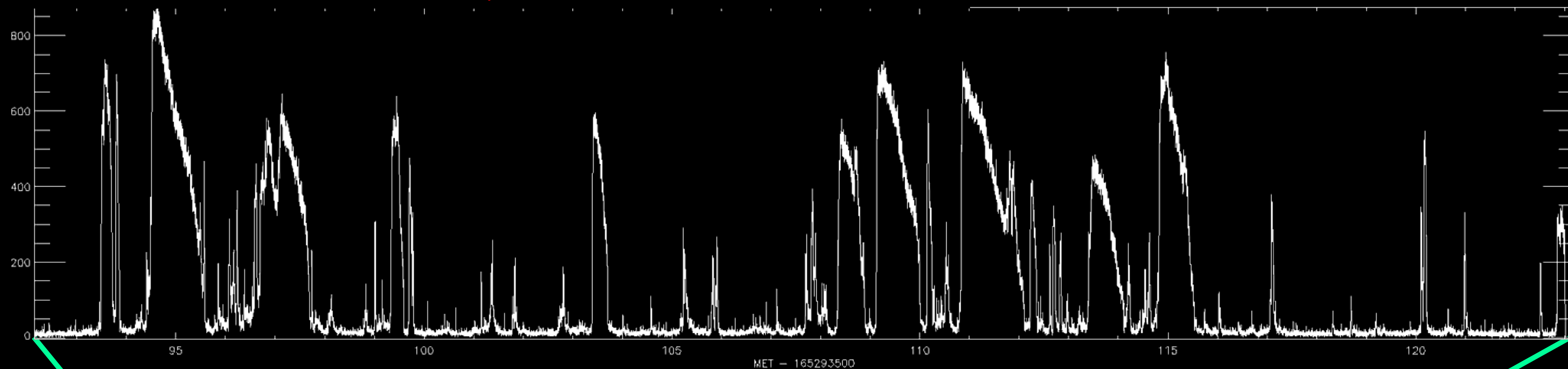
X-ray/radio alignment → X-rays and radio are coming from the same portion of the NS. A larger X-ray duty cycle indicates a larger emitting area for X-rays.

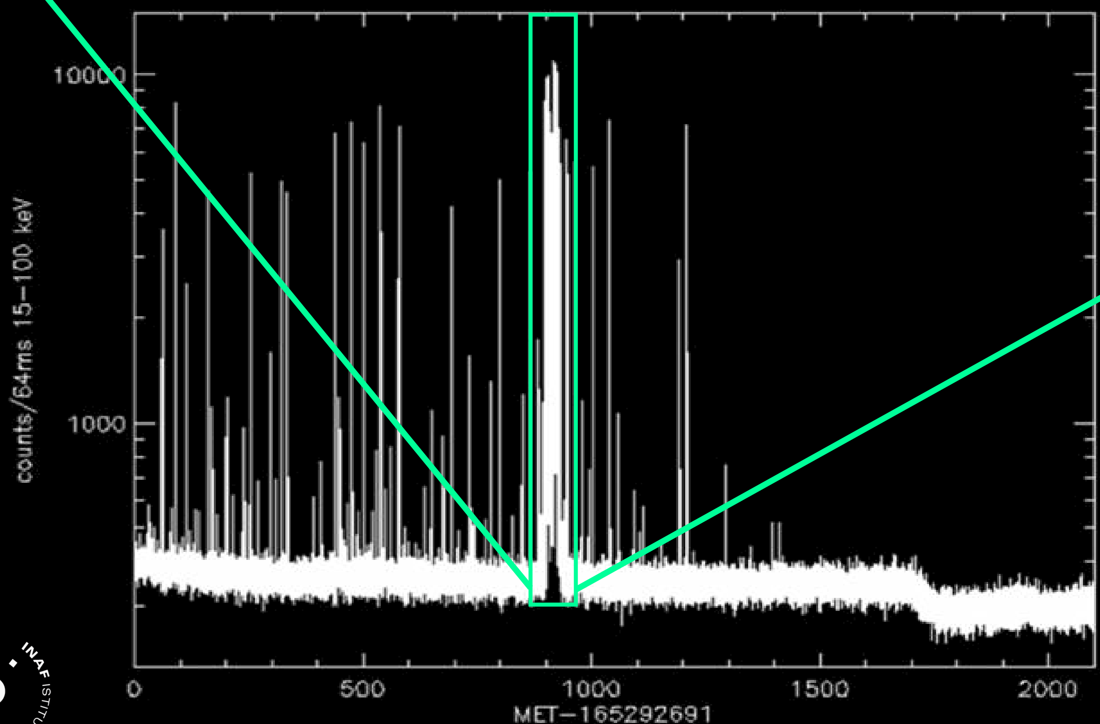
Radio variability not correlated to X-rays - no significant flux variations

In agreement with the idea that most of the X-rays originated deep in the crust after thermalization.

THE 2006 BURST FOREST

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 (one of the more energetic events recorded ever after the 1998 giant flare)

Time resolved spectroscopy Resulted in 729 spectra with an average # of photons of 4000 and Δt in the 8ms-400ms range

THE '06 BURST FOREST: SPECTROSCOPY

Different simple models considered in analogy with previous work done by Feroci et al. (2004), Olive et al. (2004) and Nakagawa et al. (2007).
[Bremss not able to fit the low energy part; 2BB better choice]

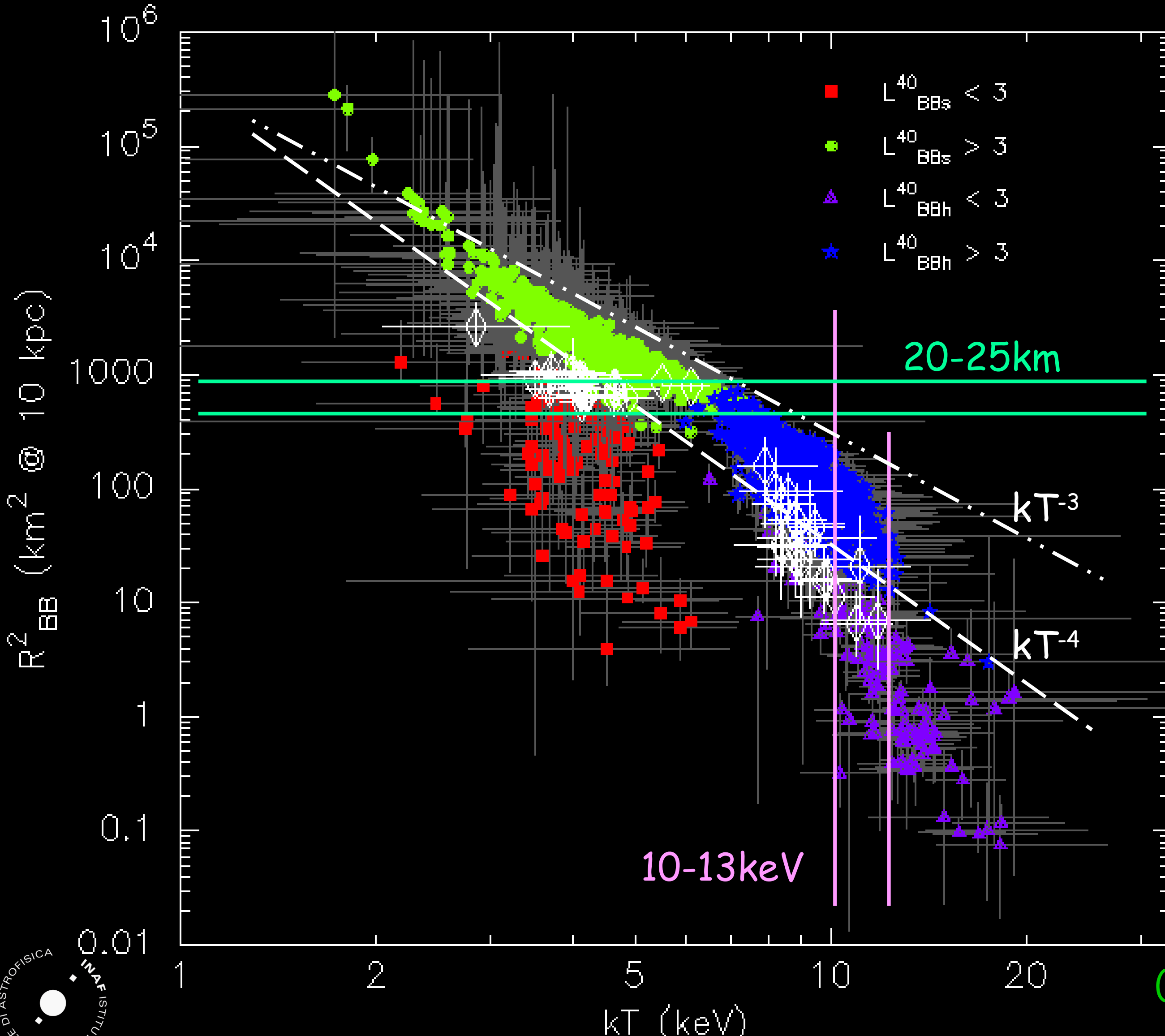
Fits carried out on BAT (on short timescales; 729 spectra; 10-150keV) and BAT+XRT (burst average; 8 spectra; 2-150keV) data.

2BB and CompTT are, by far, the models which give the smallest reduced χ^2

Spectral Model	$<\chi^2_\nu>$ BAT+XRT[a]	σ	$<\chi^2_\nu>$ BAT	σ	Parameters (#)
Bremss	4.84	1.17	1.71	1.95	2
DiskBB	2.91	0.84	1.17	0.51	2
CompST	2.41	0.16	1.08	0.42	3
CutoffPL	1.36	0.07	1.07	0.23	3
Bremss+BB	1.33	0.25	1.06	0.28	4
CompTT	0.88	0.07	0.99	0.17	4
BB+BB	0.88	0.08	1.01	0.16	4
Bremss[b]	...	...	0.91	0.11	2

THE KT – R^2 PLANE

Sharp edge / saturation present for the brightest part of the bursts



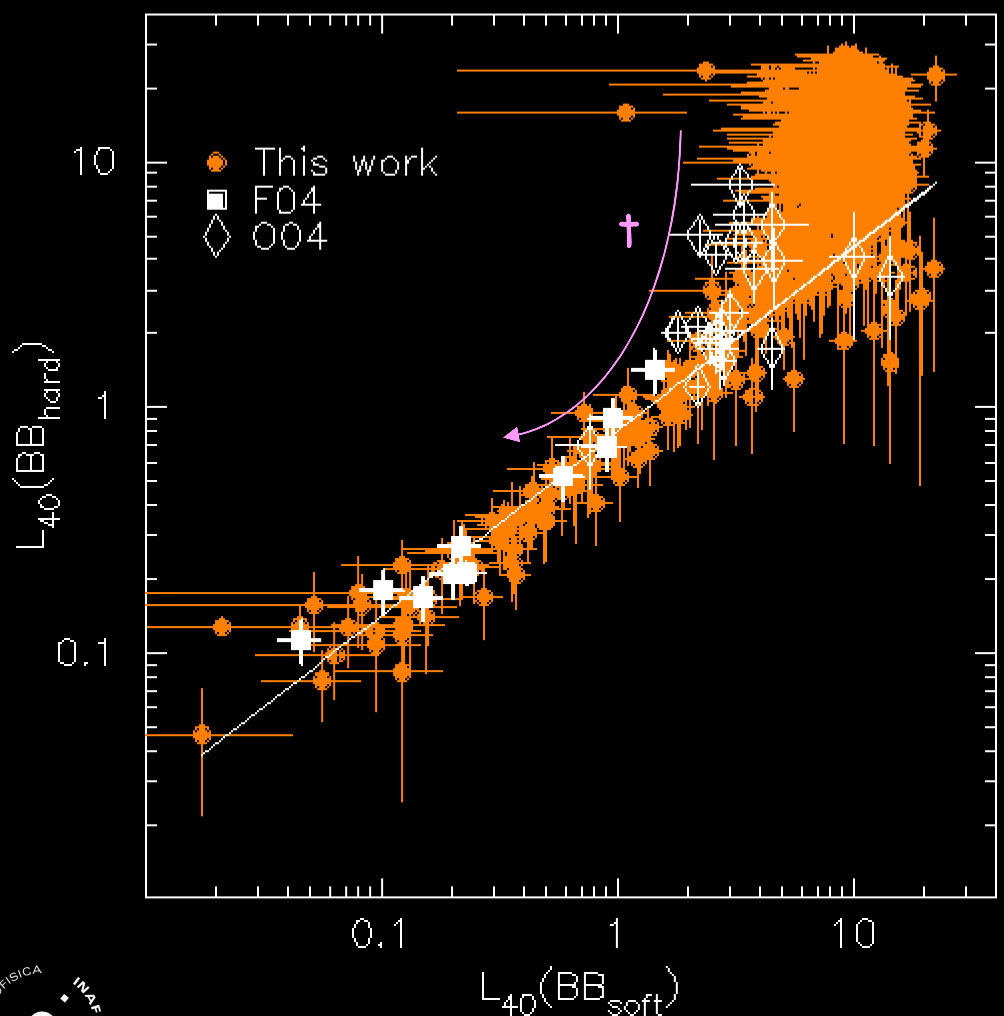
The 2BB distributions identify a natural separation surface at 20-25km

A sort of turn/cut-off is present for the BBh around 10-13keV and 5-15km

The locus identified by the relation R^2kT^3=c can be regarded as constant number of emitted γ per unit time (R^2kT^4=c identifies a constant L)

(Israel et al. 2008)

2BB: L_{SOFT} VS L_{HARD}



BBs and BBh Luminosities correlate below 3×10^{40} erg/s (iso-L). Above such value only LBBh evolves.

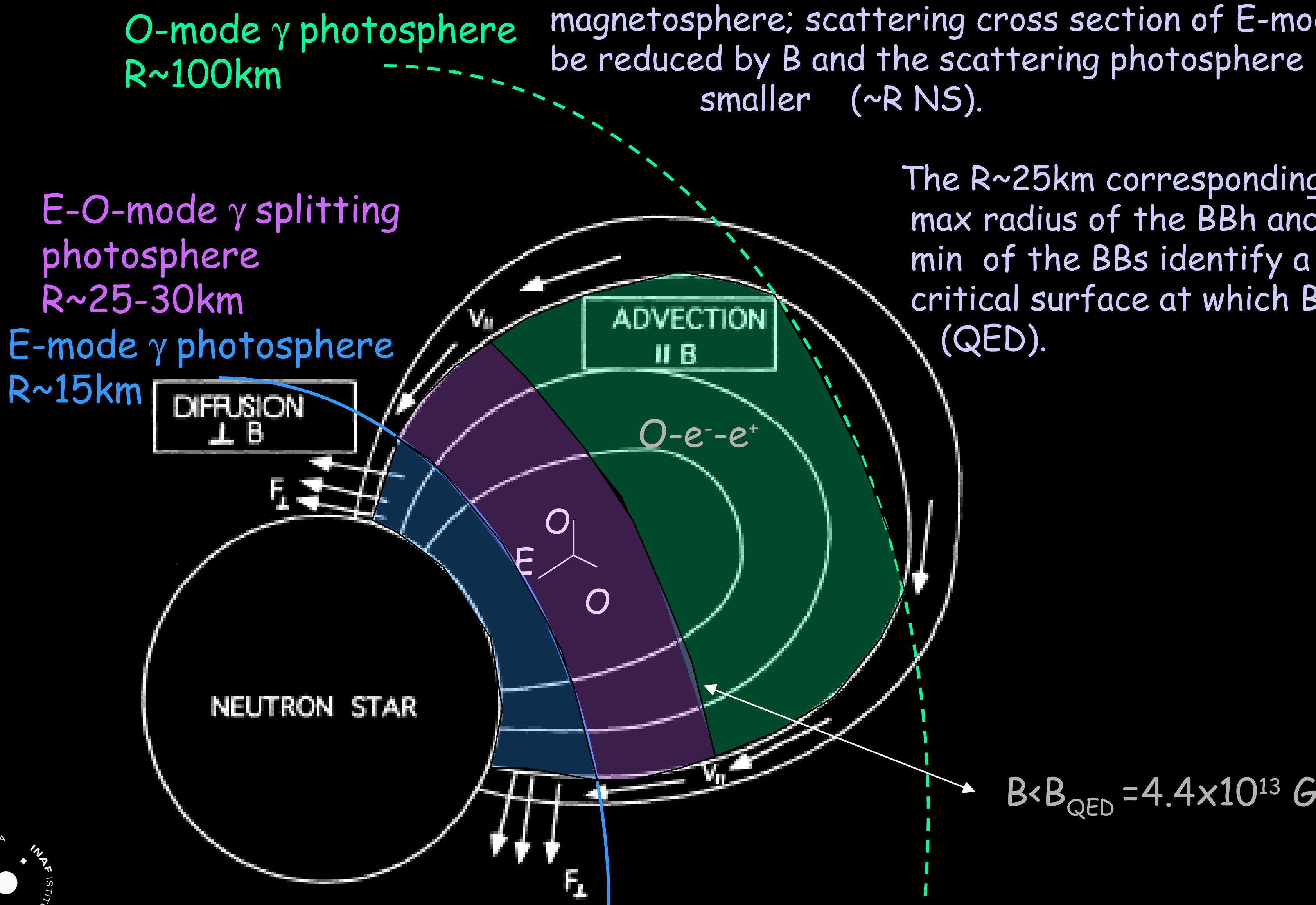
Max LBBh is ~3×10^{41} erg/s at 10keV and 15km = magnetic Eddington luminosity (Paczynsky 1992) for B of 8e14 G [similar to that inferred form P and Pdot].

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

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

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).



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).

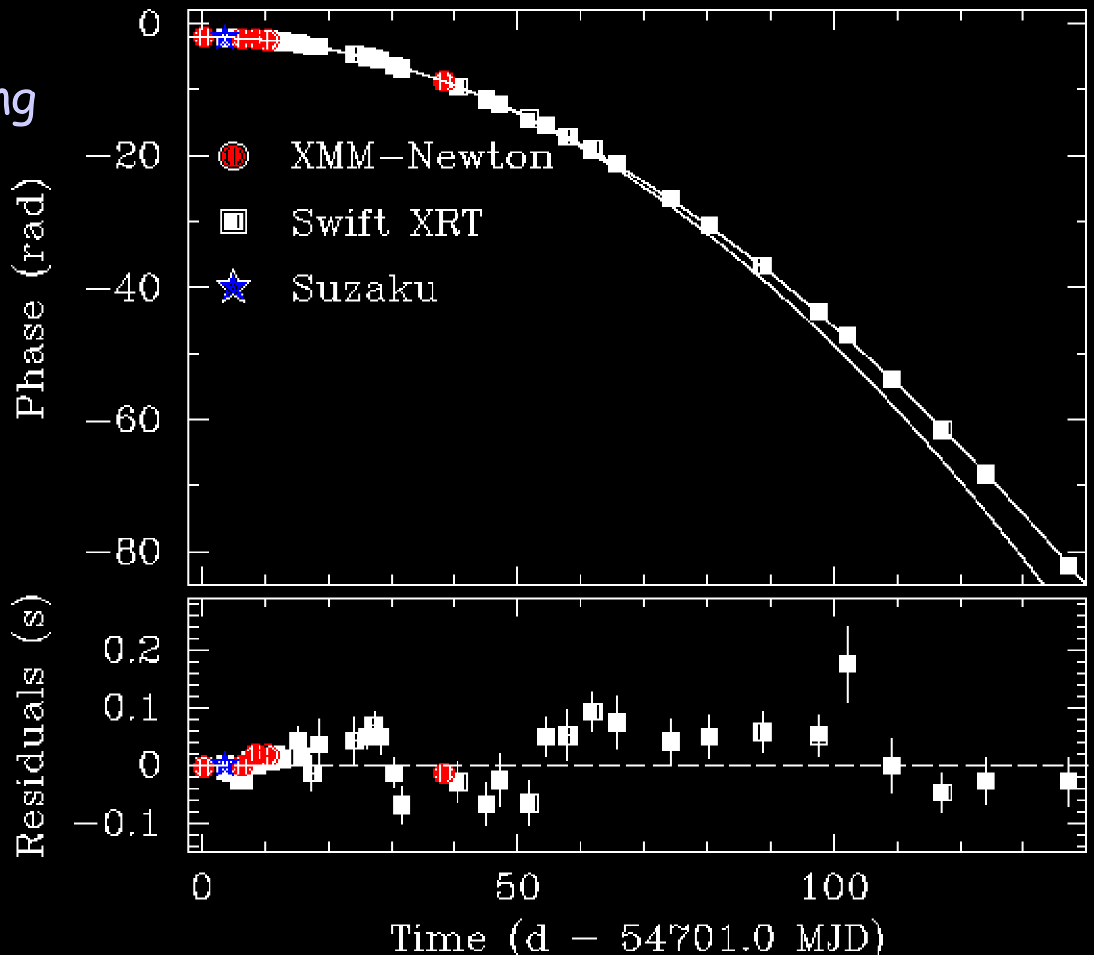
TAKING THE PULSE OF SGR0501+4516

P=5.7620690(1) s,

$\dot{P}$= 6.77(8) × 10^{-12} s s^{-1}

$\ddot{P}$= 1.9(4) × 10^{-19} s s^{-2} → decreasing spin-down

Consistent with a post-glitch (not observed!) recovery time of ~1yr



(Rea et al. 2009)

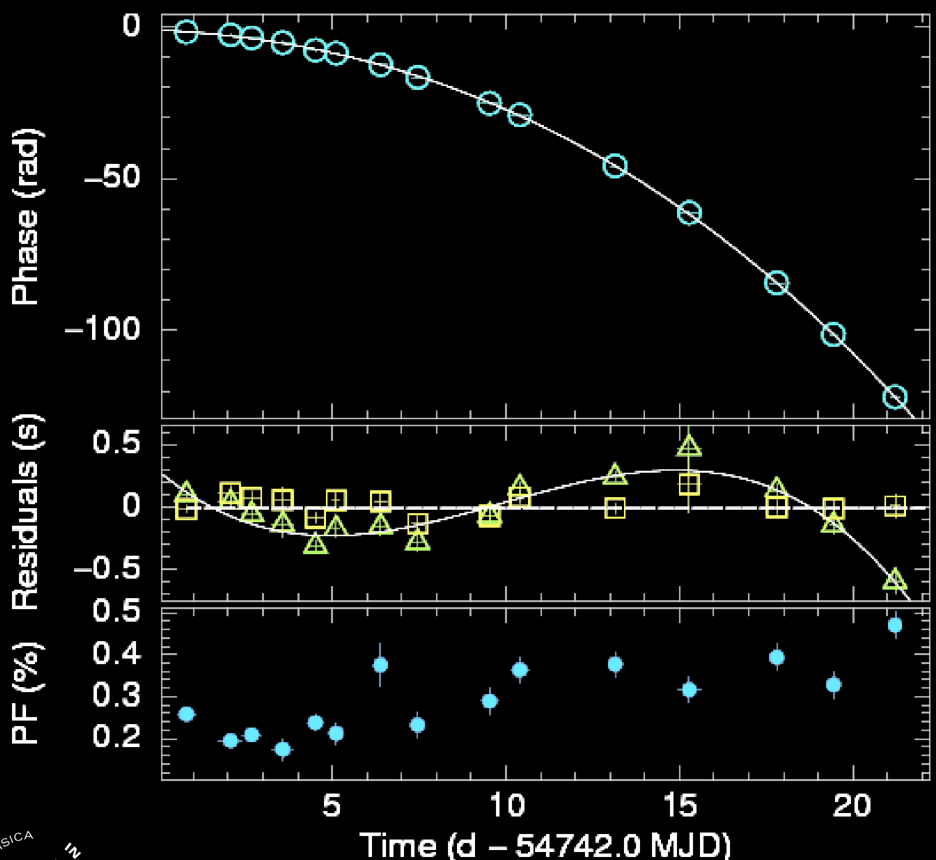
1E1547.0-5408 '08 $P - \dot{P} - \ddot{P}$ SOLUTION

$P=2.0713410(7)$ s,

$\dot{P}= 2.9(2) \times 10^{-11}$ s s^{-1}

$\ddot{P}= 2.4(4) \times 10^{-17}$ s s^{-2} → inc. spin-down

Oct. 2008



(Israel et al. 2009)

Implications (preliminary):

- standard scenario (radio pulsarlike) $\ddot{P}$ > or < 0 depending on whether $\dot{P}$post / $\dot{P}$sec < or > 1

- magnetar/twist scenario in disagreement unless the twist is implanted locally and it have not yet reached its maximum value (after that it decreases) …… to be confirmed in the future

For a review on glitches and Pdot see Dib et al. 2008

CONCLUSIONS…. NOT THAT CONCLUSIVE

Peculiar events (flares and outbursts) seems to be a very powerful tool in the study the emission mechanism(s) from AXPs/SGRs and their evolution.
Almost all AXPs/SGRs are Transient and emit flares !! At all wavelengths !!
The difference between AXPs and SGRs is small … if any.

QPOs discovered during the tail of the GFsand thought to be related to GSOs excited by a crack in the NS crust

- Toroidal modes may give info on the surface structures;
  Their comparison (n=0 / n=1) modes gives info on $\Delta R/R$
- Poloidal modes may give direct info on the magnetic field strength in the NS core.

The greatest part of these results have been obtained thanks to the complementary capabilities of small and large X-ray missions (Swift – XMM – Chandra). Fermi mission is detecting new Magnetars !
ToO and Multi-Wavelenght obs strategy has revealed to be a fundamental strategy

New, more physical spectral fits (to be) used (but model-dependent)……
Simultaneous timing and spectral fits are a powerful tool.