# Emission Model(s) of Magnetars

Silvia Zane, MSSL, UCL
on behalf of a large team of co-authors

*"Current Understanding and Future Studies of Magnetars: Research Strategy in the Astro-H era."*

*A celebration in honour of Prof Noriaki Shibazaki*

Tokyo, Japan, 1th Sept 2012

- SGRs/AXPs as "magnetars", the most extreme compact objects
- Multiband emission mechanisms – from Radio-IR to X-rays

# Congratulations to Prof Noriaki Shibazaki

- X-ray bursts, X-ray transients, Soft X-ray sources
- Pulsars, low mass binaries, Galactic buldge sources
- QPOs
- SNRs
- Theoretical studies
- Envelope oscillations
- Gamma ray lines
- NS evolution, interior and instabilities
- Accretion
- GRBs, jets
- Magnetars
- Suzaku
- … and lots and lots more!!

# MAGNETARs: the most extreme NSs

(Isolated) neutron stars where the main source of energy is the (super-strong) magnetic field

most observed NS have $B = 10^{9} - 10^{12}$ G and are powered by accretion, rotational energy, residual internal heat

$B \geq B_{QED} \approx 4.41 \times 10^{13}$ G : quantum effects important

In Magnetars: external field: $B = 10^{14} - 10^{15}$ G
internal field: $B > 10^{15}$ G

Low field magnetars: SGR0418+5279 and SGR1822 : still a quite large internal component, >50-100 times larger than Bdip

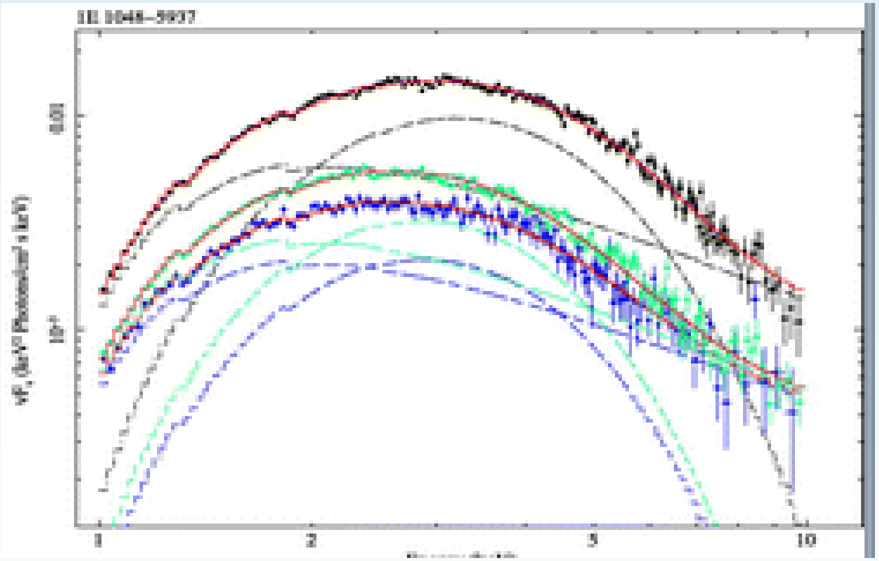
Duncan & Thompson 1992, ApJ 392, L9 ; Thompson & Duncan 1995, MNRAS 275, 255
Thompson et al. 2000, ApJ 543, 340; Thompson, Lyutikov & Kulkarni 2002, ApJ 574,332.

# AXPs/SGRs: magnetar candidates

| Source | P (s) | Pdot (s/s) | Hard-X | Short bursts | Outbursts | Association | Comm. |
|---|---|---|---|---|---|---|---|
| 1E 2259+586 | 6.978948446 (39) | 4.8 E-13 | yes | yes | yes | SNR CTB 109 | |
| 4U0142+61 | 8.68832973(8) | 2E-12 | yes | yes | yes | | |
| CXO J164710.2-455216 | 10.6107(1) | 9.2E-13 | no | yes | yes | Westerlund 1 | |
| CXOU J010043.1-721134 | 8.020392(9) | 1.9E-11 | no | no | no | | SMC |
| 1e 1048.1-5937 | 6.45207658(54) | (1-10)E-11 | no | yes | yes | GSH 288.3-0.5-2.8 | |
| XTE J1810-197 | 5.539425(16) | (0.8-2.2)E-11 | no | yes | yes | | Transient radio pulsar |
| 1E 1547.0-5408 | 2.06983302(4) | 2.3E-11 | yes | yes | yes | SNR G327.24-013? | Transient radio pulsars |
| 1RXS J170849.0-400910 | 10.9990355(6) | 2.4E-11 | yes | no | no | | |
| 1E 1841-045 | 11.7750542(1) | 4.1E-11 | yes | no | no | SNR Kes 73 | |
| AX J1845-0258 | 6.97127(28) | | no | no | yes | SNR G29.6+0.1 | candidate |
| SGR 1806-20 | 7.55592(5) | (0.8-10)E-10 | yes | Very active | yes | Massive star cluster | Giant Flare in 2004 |
| SGR 1900+14 | 5.16891778(21) | (5-14)E-11 | yes | Very active | no | | Giant Flare in 1998 |
| SGR 1627-41 | 2.594578(6) | 1.9E-11 | no | yes | yes | CBT 33 complex | |
| SGR 0526-66 | 8.0470(2) | 6.5E-11 | no | yes | | SNR N49 | LMC; Giant flare 1979 |
| SGR 0501+4516 | 5.7620699(4) | 6.7E-12 | yes | yes | yes | | |
| SGR 0418+5729 | 9.0783(1) | <6E-15 | no | yes | yes | | |
| SGR 1833-0832 | 7.5654091(8) | 7.4E-12 | no | yes | yes | | |
| SGR 1822.3-1606 | 8.43771977(4) | 2.54E-13 | | yes | | | |
| SGR1834.9-0846 | 2.4823018(1) | 7.96E-12 | | yes | | | SNRW41? |
| CXOU J171405.7-381031 | 3.82535(5) | 6.40E-11 | | | | | SNR CTB, 37B, HESS J1713-381 |
| PSR J1622-4950 | 4.3261(1) | 1.7E-11 | | | | | |

# Soft X-ray spectra

- 0.5 – 10 keV emission well represented by a blackbody plus a power law: WHY??
- Long term spectral evolution, with correlation among some parameters (as spectral hardening, luminosity, spin down rate…)
- Evolution of "transient" AXPs

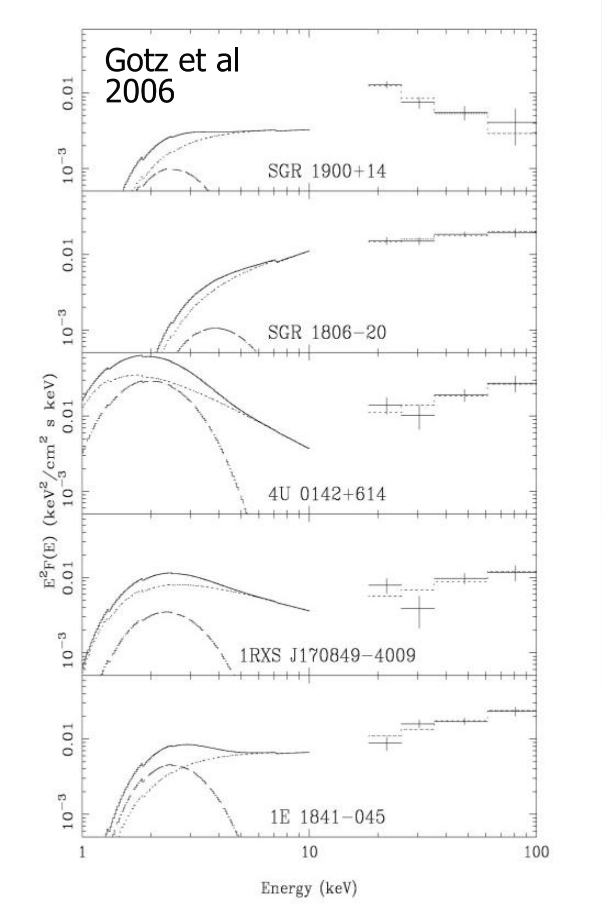



AXP 1E1048-5937; from Rea, SZ et al, 2008

- Black, blue, green are taken in 2007, 2005, 2003 (XMM-Newton)
- Red lines: total model, dashed lines: single BB and PL components

# Multiband Emission: hard X-rays

- INTEGRAL revealed substantial emission in the 20 -100 keV band from SGRs and AXPs
- Hard power law tails, $\Gamma \approx$ 1-3
- Hard Emission pulsed

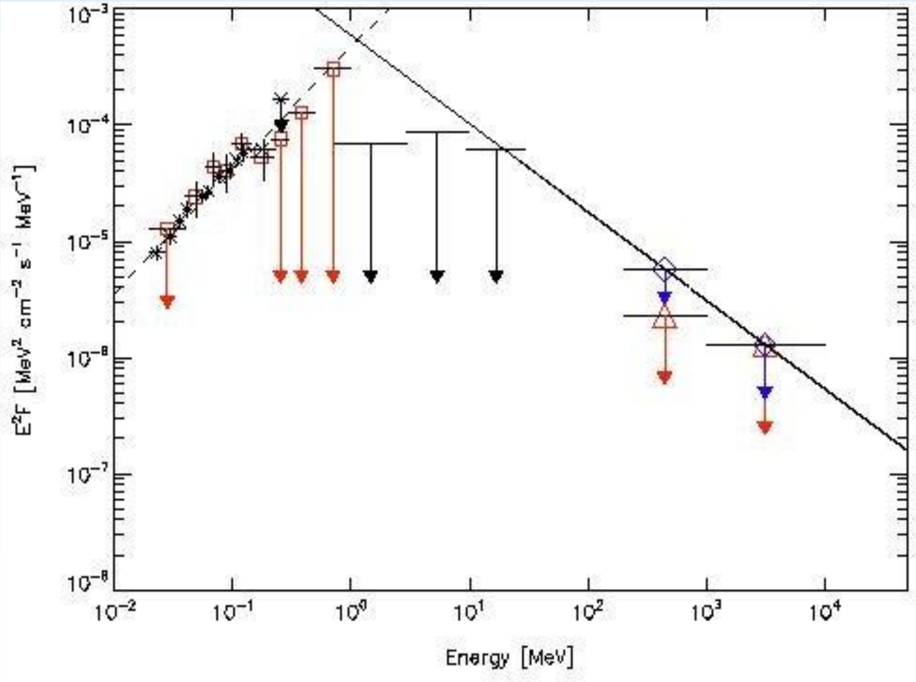


# Multiband Emission: hard X-rays

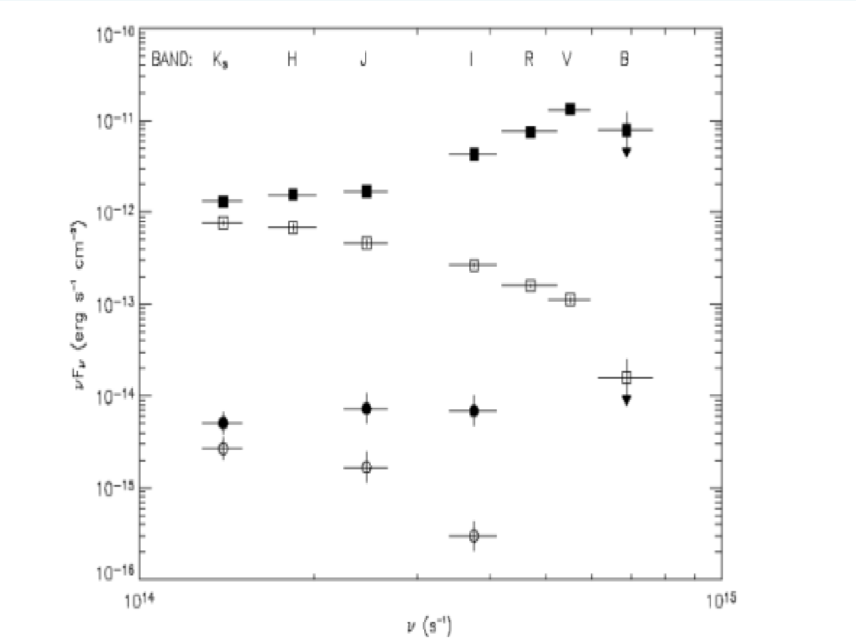
Sasamz Mus and Gogus 2011

Integral/Comptel/Fermi SED of 4U0142+61

Also, no detections so far from the Fermi-LAT team (ApJ, 2010)



# Multiband Emission: Optical/IR



1E 0148.1−5937 (*circles*), 4U 0142+61 (*squares*)

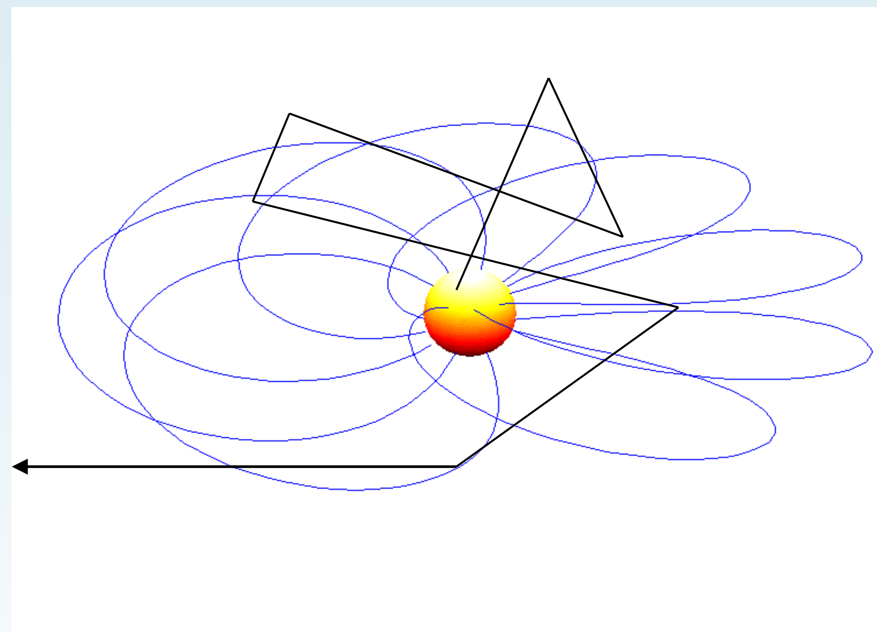
- Also, Optical/IR!
- Faint K~19-21 and sometimes variable IR conterparts
- Fossil disk or inner magnetosphere?

Durant and van Kerkwijk 2005

See also Daniela's talk

# Twisted magnetospheres

Twisted magnetospheres support large current flows ( >>>of the Goldreich-Julian current).



Thermal seed photons (i.e. from the star surface) travelling through the magnetosphere experience efficient resonant cyclotron scattering onto charged magnetospheric particles (e- and ions)

⇒ the thermal surface spectrum get distorted

⇒ typical PL tail.

**This can explain the BB+PL spectral shape observed <10keV.**

# A Monte Carlo Approach

(Nobili, Turolla, SZ 2008a,b)

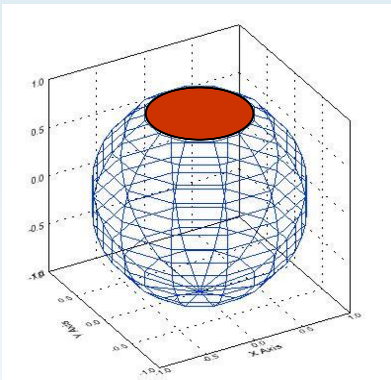
- Follow individually a large sample of photons, treating probabilistically their interactions with charged particles
- Can handle very general (3D) geometries
- Quite easy to code, fast
- Ideal for purely scattering media
- Monte Carlo techniques work well when $N_{scat} \approx 1$

Basic ingredients:

- Space and energy distribution of the scattering particles
- Same for the seed (primary) photons
- Scattering cross sections

# A Monte Carlo Approach

**Surface Emission**

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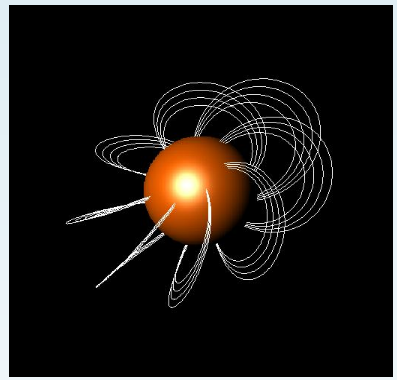
**Magnetosphere setting (twisted dipole)**



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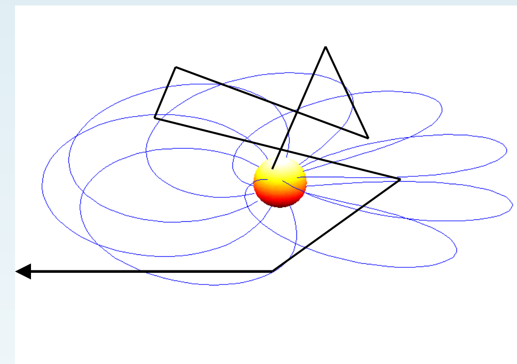
**Radiative transfer, Monte Carlo code**



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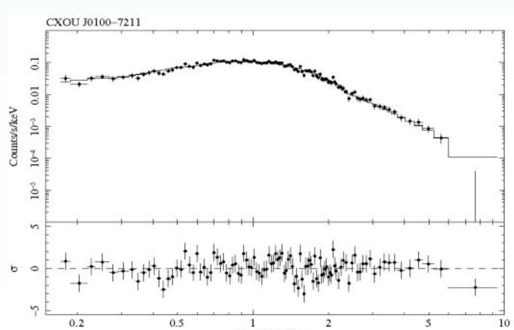
**Predicted spectra, lightcurves, polarization to be compared with X-ray data**




GOAL: probe the magnetospheric properties of the neutron star via spectral analysis of X-ray data

(Nobili, Turolla, SZ 2008a,b; SZ, Rea, Turolla & Nobili, 2009)

# Photon propagation in a magnetized medium

- Magnetized plasma is anisotropic and birefringent, radiative processes sensitive to polarization state
- Two normal modes of photon propagation: ordinary (O) and extraordinary (X) mode

# Thomson Scattering Magnetic Cross Sections

Completely differential cross sections at resonance (ERF)

$$\left.\frac{d\sigma}{d\Omega'}\right|_{O-O} = \frac{3\pi r_0 c}{8}\delta(\omega-\omega_c)\cos^2\theta\cos^2\theta' \qquad \left.\frac{d\sigma}{d\Omega'}\right|_{O-X} = \frac{3\pi r_0 c}{8}\delta(\omega-\omega_c)\cos^2\theta$$

$$\left.\frac{d\sigma}{d\Omega'}\right|_{X-X} = \frac{3\pi r_0 c}{8}\delta(\omega-\omega_c) \qquad \left.\frac{d\sigma}{d\Omega'}\right|_{X-O} = \frac{3\pi r_0 c}{8}\delta(\omega-\omega_c)\cos^2\theta'$$

$r_0 = e^2/mc^2$, $\omega_c = eB/mc$, $\theta, \theta'$ angles between photon direction and particle velocity before and after scattering

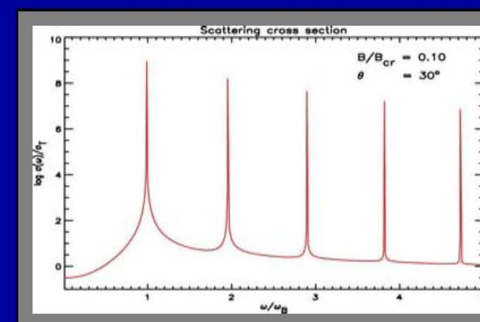
# Relativistic QED second order cross section (transition from the ground to an arbitrary state *ℓ*):

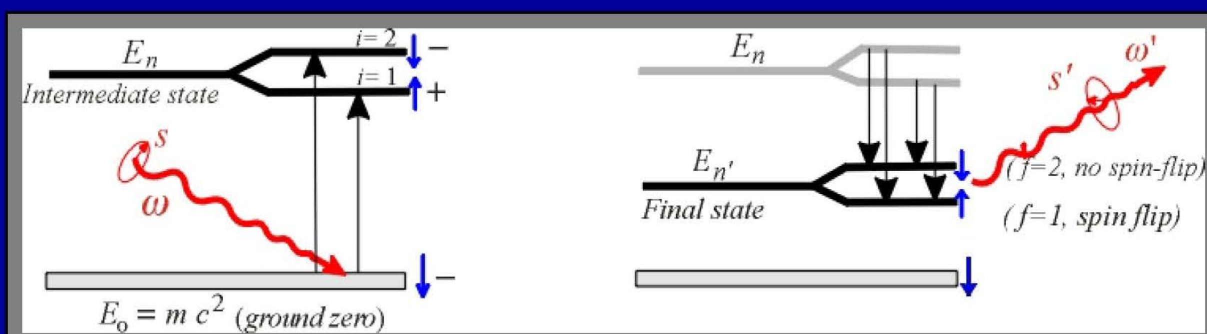
$$\left(\frac{\partial^2\sigma}{\partial\varphi'\partial\mu'}\right)_{s,f} = \frac{3\sigma_T}{16\pi}\frac{\omega'}{\omega}\frac{(2+\omega-\omega')e^{-(\omega^2\sin^2\theta+\omega'^2\sin\theta')/2B}}{(1+\omega-\omega'-\Delta\cos\theta')}\left|\sum_{n=0}^{\infty}\sum_{i=1}^{2}(F^{(1)}_{n,i,s,f}+F^{(2)}_{n,i,s,f})\right|^2$$

(*resonant terms*)

**F's are complicated *complex* functions that depend on**

- ***n*** - intermediate (virtual) Landau level
- ***i*** - electron spin of the intermediate excited state
- ***f*** - electron spin of the final state
- ***s, s'*** - initial and final photon polarization states



# XSPEC implementation:

- Build up a huge archive of models
- $B = 10^{14}$ G
- $\gamma_{bulk}-1 = 2^{[1/(1+Te]}/T_e$ ; then $T_e = T_e/2$

  (bulk kinetic energy = av. $E_{th}$ for a 1D Maxwellian; $T_e=kT_e/m_ec^2$)
- The resulting archive is a 22MB table with 4 model parameters:
  T, $\beta_{bulk}$, $\Delta\varphi$ + a normalization constant $\Rightarrow$ same number of degree of freedom as in the BB+PL model

Note: we also built up a second archive (300 MB table) with viewing angles effects included

For the viewing angle geometry we need to include two further dof, i.e. two angles which describe the disalignement between magnetic, spin axis and LOS ($0 \le \chi \le 180$ and $0 \le \xi \le 90$)

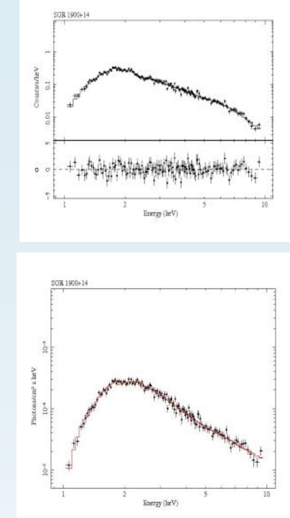
(Nobili, Turolla, SZ 2008a,b)

# XSPEC Implementation and fit of all magnetars spectra (<10 keV)

SZ, Rea, Turolla and Nobili MNRAS 2009

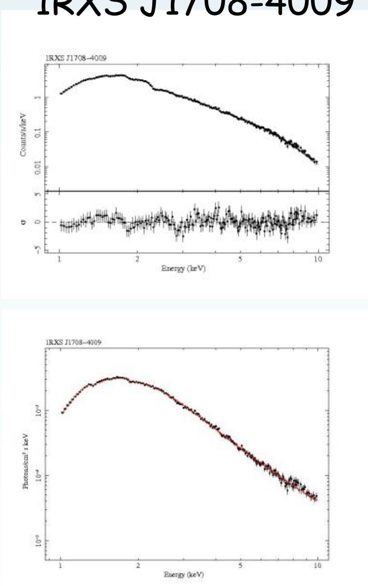
## fit with NTZ model only

SGR 1900+14



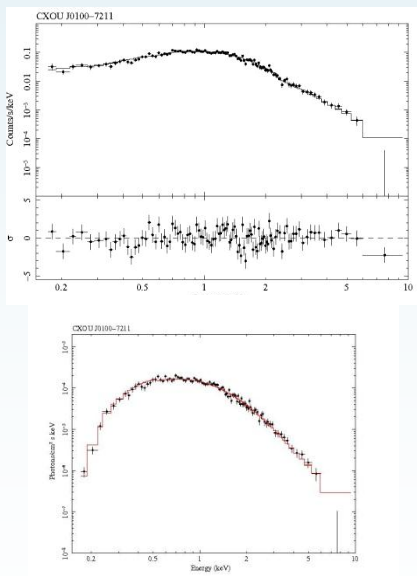
$\chi^2$= 0.99 (135)

1RXS J1708-4009



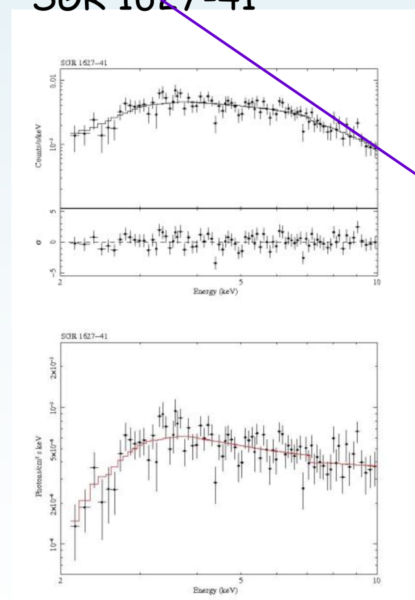
$\chi^2$= 0.97 (197)

CXOU J0100-7211



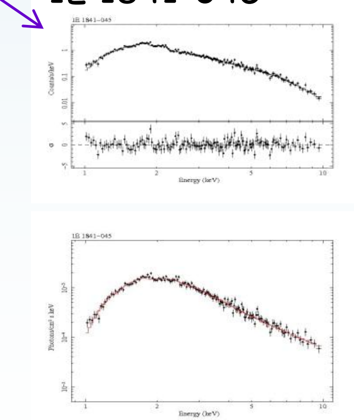
$\chi$2= 1.21 (101)

SGR 1627-41



$\chi$2= 1.16 (81)

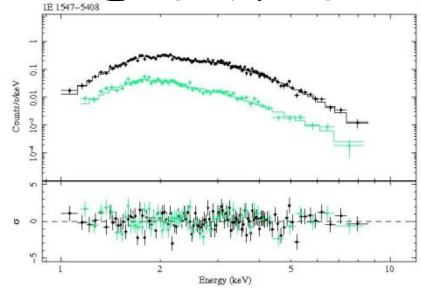
1E 1841-045



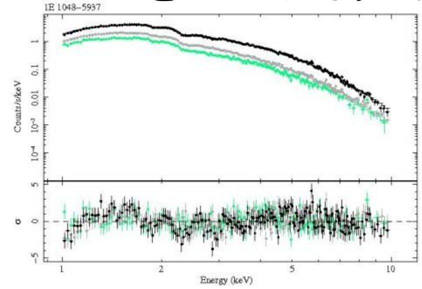
$\chi^2$= 1.04 (152)

# reproducing the source long-term evolution: fit with NTZ only

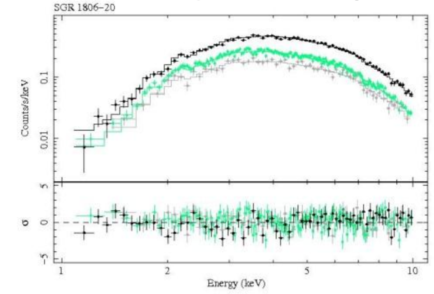
1E 1547.0-5408

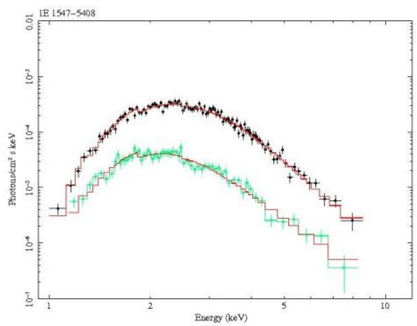


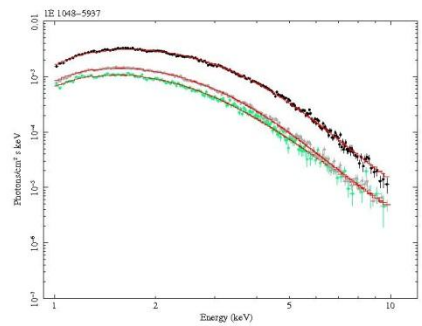

1E 1048-5937

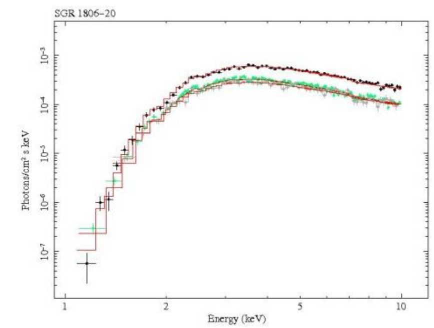



SGR 1806-20



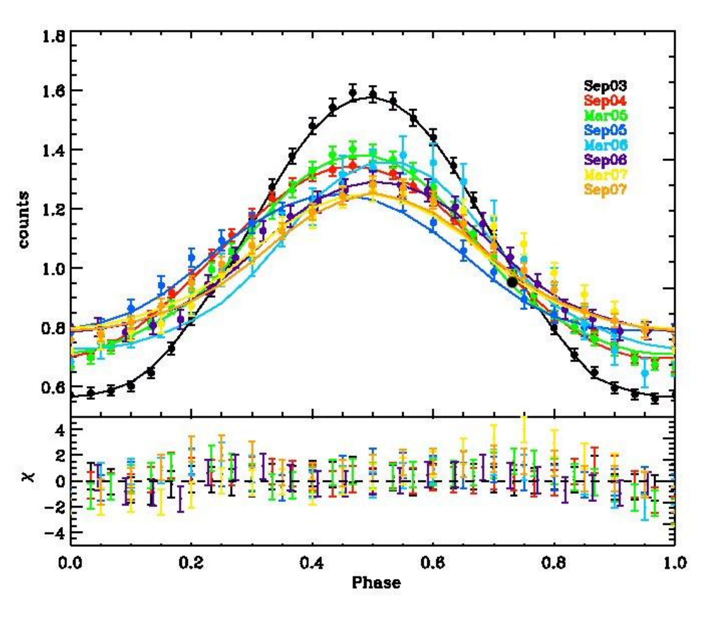

$\chi 2$= 1.11 (164)

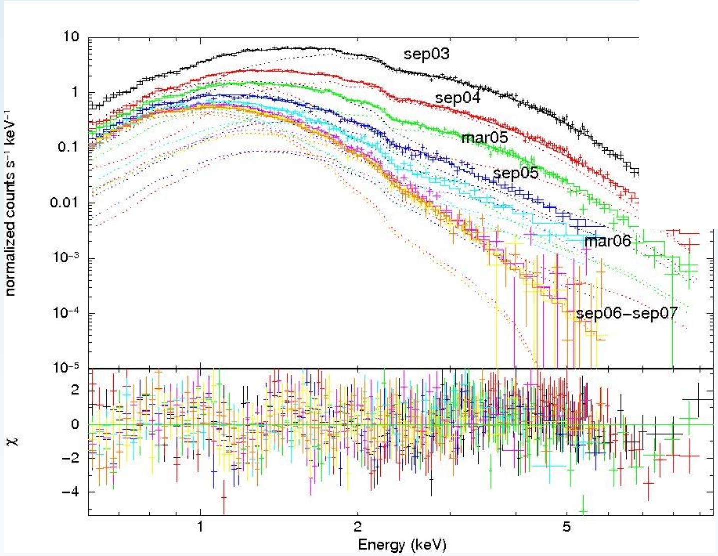
$\chi 2$= 1.22 (515)

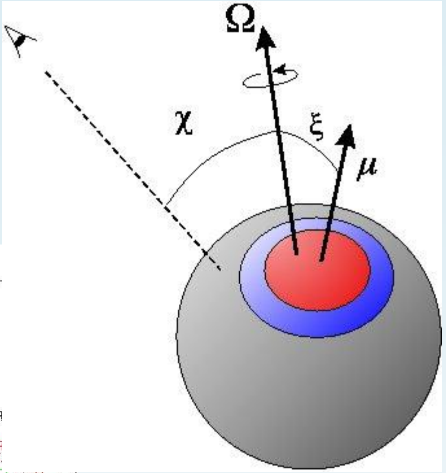
$\chi 2$= 0.98 (288)

# reproducing the Transient AXPS evolution

XTE J1810-197: 8 XMM observations between Sept 2003 and Sept 2007: coverage of the source during 4 years. Unique opportunity to understand the phenomenology of TAXPs.



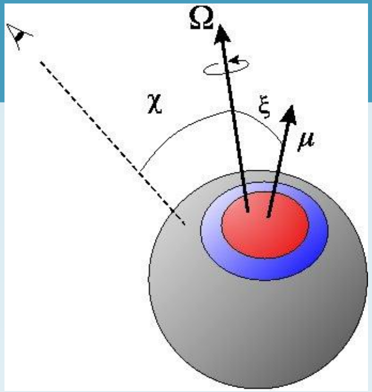



**+ similar for CXOU J164710.2-455261**

Albano, SZ et al, 2010

FIRST TIME A JOINT SPECTRAL/TIMING MODELLING WITH A MODEL BASED ON 3D SIMULATIONS!

# From TAXP XTE J1810-197, 3T thermal map:

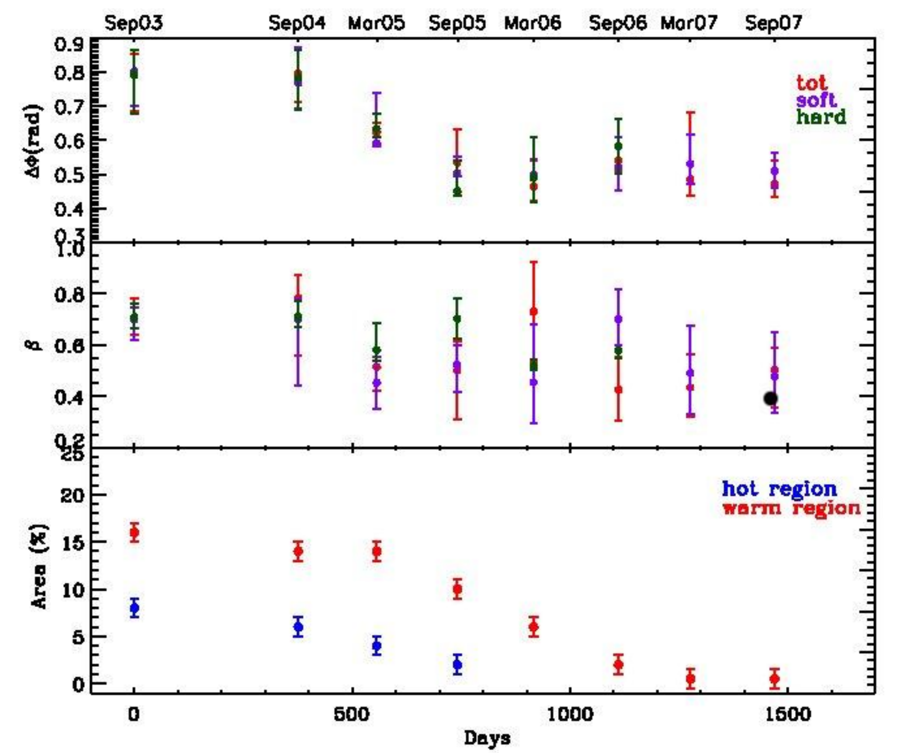



- Soon after the outburst
  ⇒ surface thermal map with 3 components: hot cap, surrounding warm corona, rest of the NS surface cooler

- Hot cap decreases in A and T indistinguishable from the corona ~March '06.

- Warm corona shrinks at $T_w$~ 0.3 keV ~ const.
  Still visible in our last observation (Sept. '07), with a size down to 0.5% of the NS surface.

- Rest of the NS: T~ ROSAT (quiescent), during the entire evolution




- ΔΦ decreases (~0.8 rad to ~0.5 rad) during the first two years, then ~constant.

χ~148° ξ~23°

Albano, SZ et al, 2010

## (Good) Results:

- A self-consistent spectral and timing analysis, based on realistic modelling of resonant scattering, explain TAXPS outburst (a large number of datasets over a baseline of years). Similar strategy applied to TAXPs XTE J1810-197, CXOU J164710.2-455261 (Albano, SZ et al, 2010) and 1e1547 (Bernardini, SZ et al 2011)

- 3D model of resonant scattering of thermal, surface photons reproduces almost all AXPs and SGRs spectra below 10keV with no need of extra components and their long term evolution

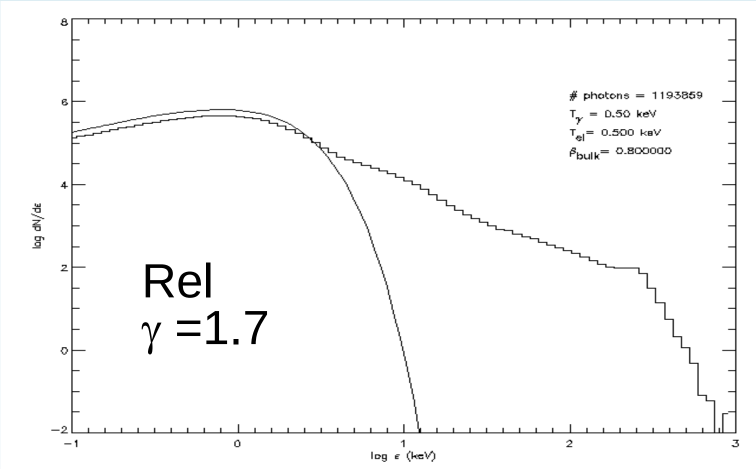
➔ Twisted magnetosphere model, within magnetar scenario, in general agreement with observations

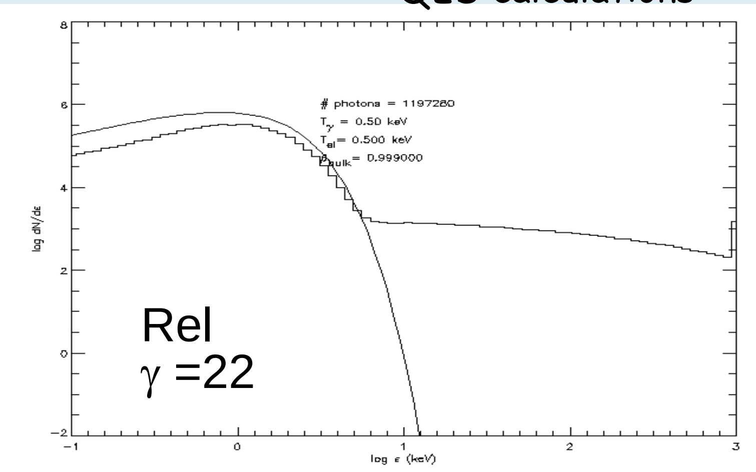
**Caveats:**

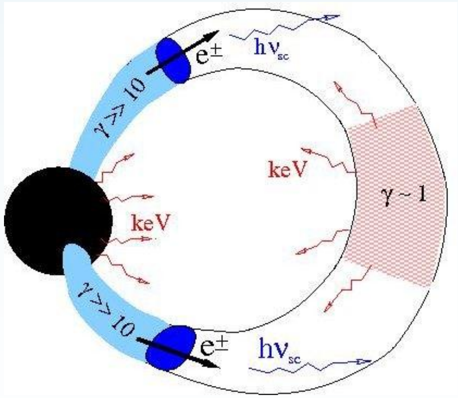
- Results support to a picture in which only a limited portion of the magnetosphere was affected by the twist (see also Beloborodov 2009)
- Future developments will require detailed spectral calculations in a magnetosphere with a localized twist which decays in time.
- Major source of uncertainty is the nature and energy distribution of scattering particles
- Charge velocity is a model parameter. Fits require mildly relativistic particles, $\gamma_e \sim 1$

# Hard X-ray: effects of velocity and B-field topology

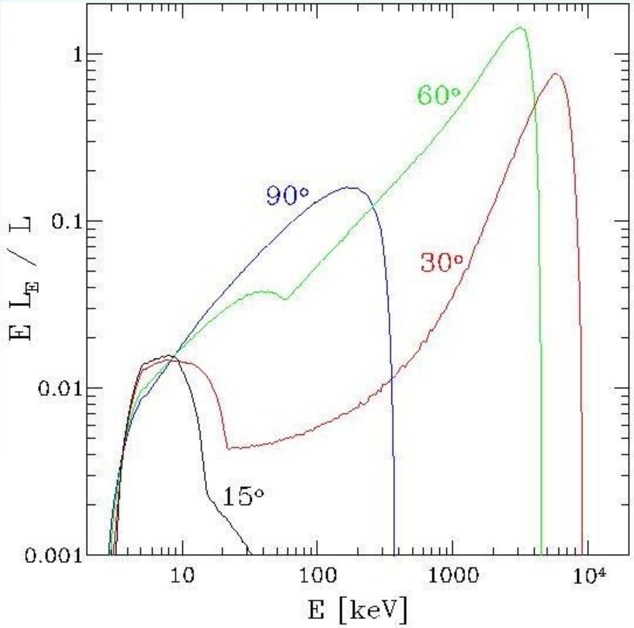
Nobili, Turolla and SZ, 2008.
QED calculations

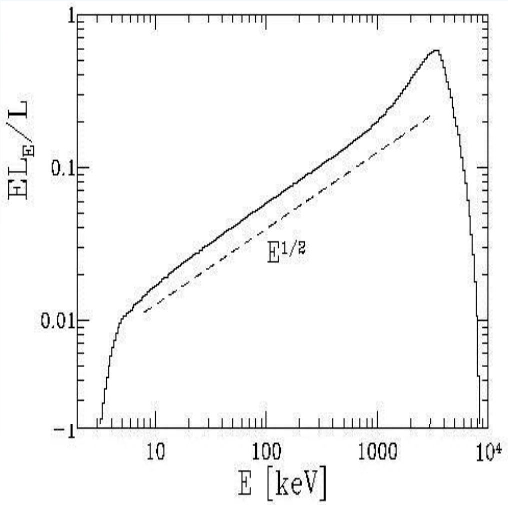


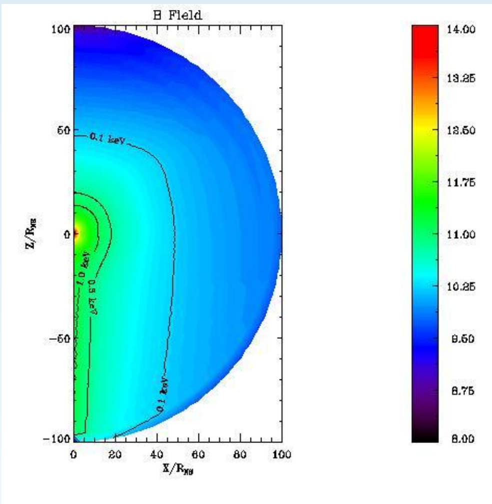



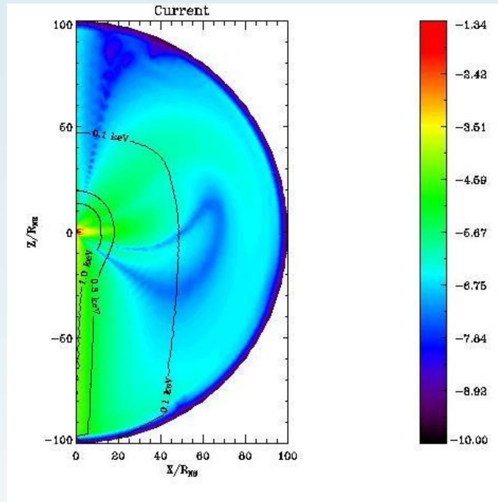

Beloborodov, 2012 (as submitted in astro-ph in Jan 2012)

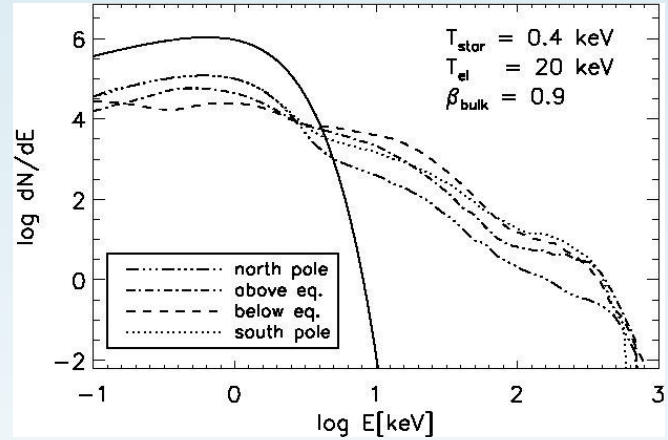


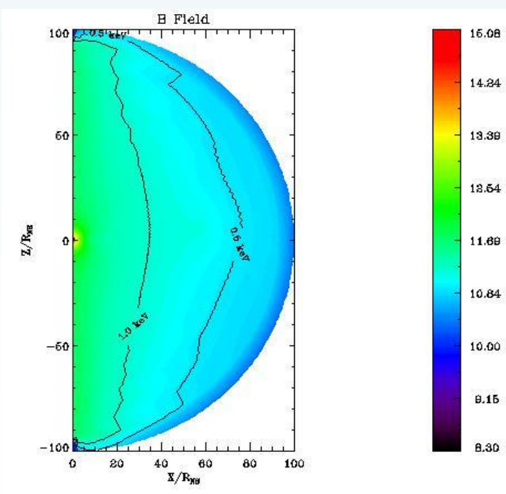



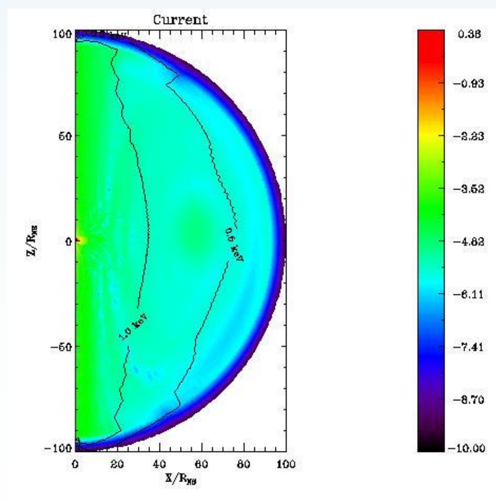
# Hard X-ray: effects of B-field topology

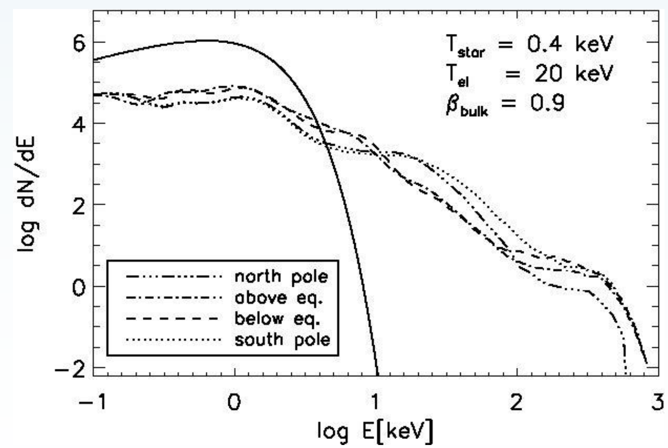


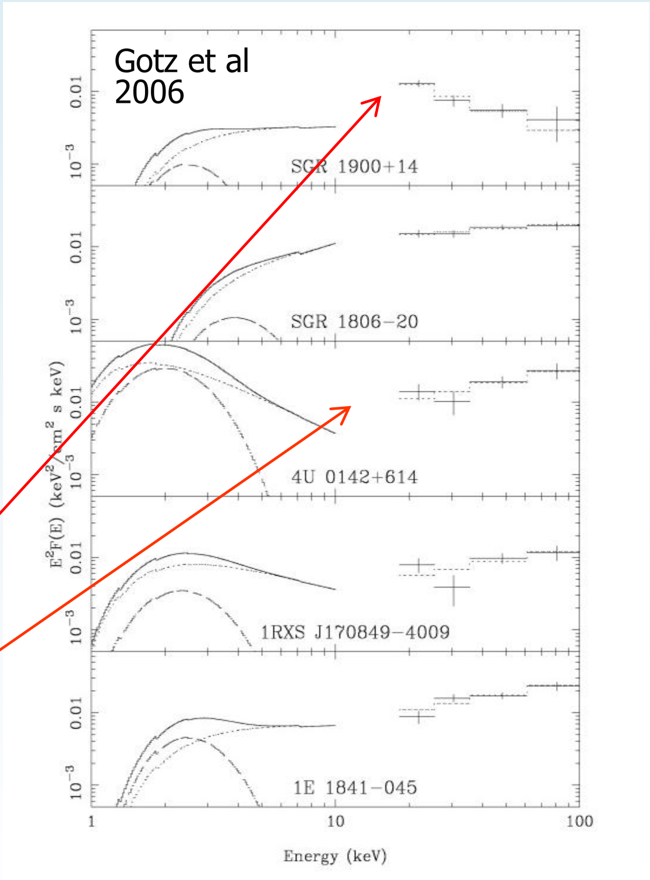




Vigano, SZ et al, 2012 Astro-ph 1111.4158

# Hard X-ray emission *is* expected:

- RCS onto the magnetospheric charges  or curvature emission produce LOT of hard X-ray emission (probably, in certain cases, too many to be compatible with Comptel and Fermi UL!)
- But the spectral details depend dramatically on v and B fields
- No quantitative prediction possible!




# Need to break the degeneracy..

- Coupled spectral and timing simulations
- More sensitive hard X-rays observations: PPS, detailed of the spectral turn-over soft/hard X-rays: Astro-H?

# IR Emission: the inner magnetospheric origin?

A thermal photon scatters where:

$$\gamma(1-\beta\cos\vartheta)\varepsilon = \varepsilon_B = m_e c^2 \frac{B}{B_Q}$$

Photon energy in the particle frame

Local cyclotron energy

$$\gamma = \gamma_{res} \sim \frac{m_e c^2}{\varepsilon}\frac{B}{B_Q}$$

1) $\lambda_{acc,res} << L$ e± can accelerate up to $\gamma_{res}$ before the end of the flux tube

2) $\lambda << \lambda_{acc,res}$ the mean free path for RCS is shorter than the acceleration length

If the moving charges are e± → $\frac{B}{B_Q} \geq 0.05$ $\frac{R}{R_{NS}} \leq 6$

$B / B_Q \geq 0.05$

# The Inner Magnetosphere

A region of intense pairs creation near the footpoints:

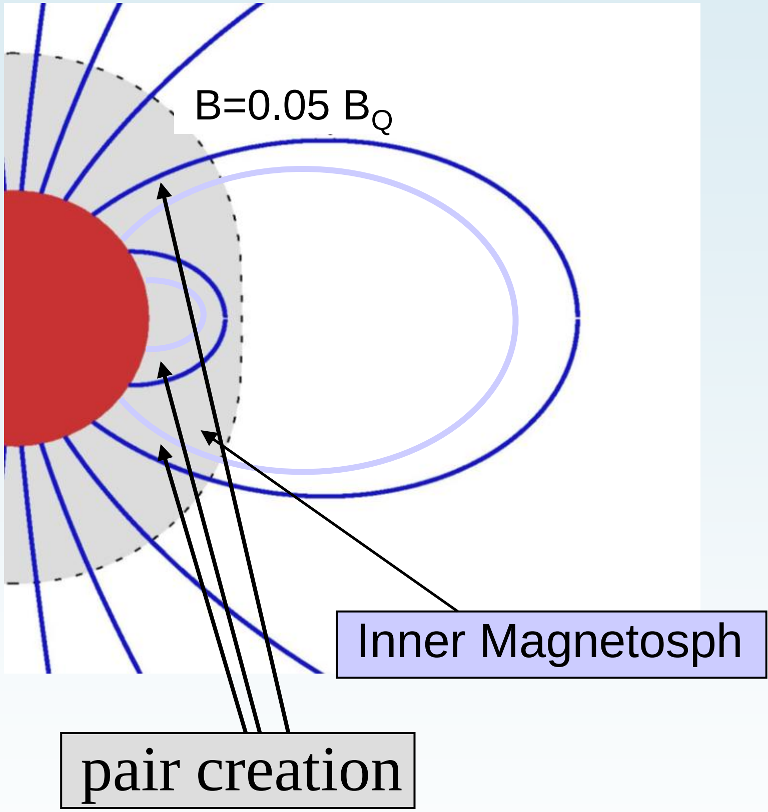
$$\gamma + B \rightarrow e^+ + e^- + B$$

$\Rightarrow \quad \varepsilon' \sim \gamma_{res}^2 \varepsilon / \left(1 + \gamma_{res} \varepsilon / m_e c^2\right) > 2 m_e c^2 / \sin\theta'$

$\Rightarrow \quad \alpha_{\pm} \geq 1 / R_{NS}$

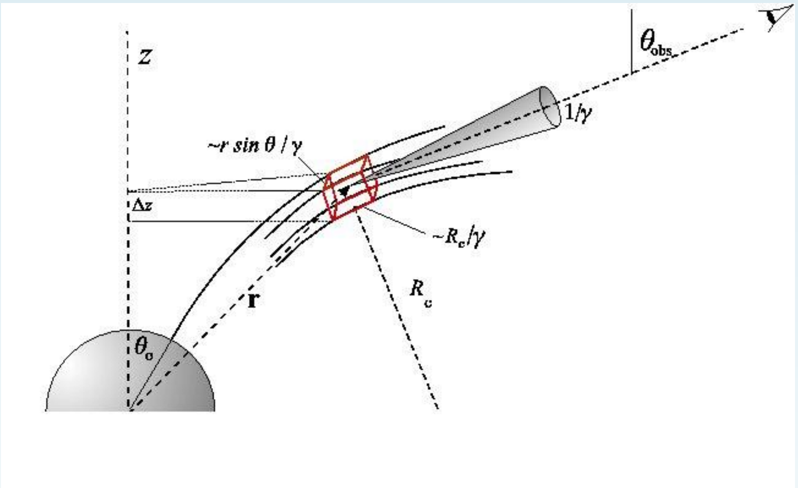
The second condition is verified in all this region for pairs created near threshold

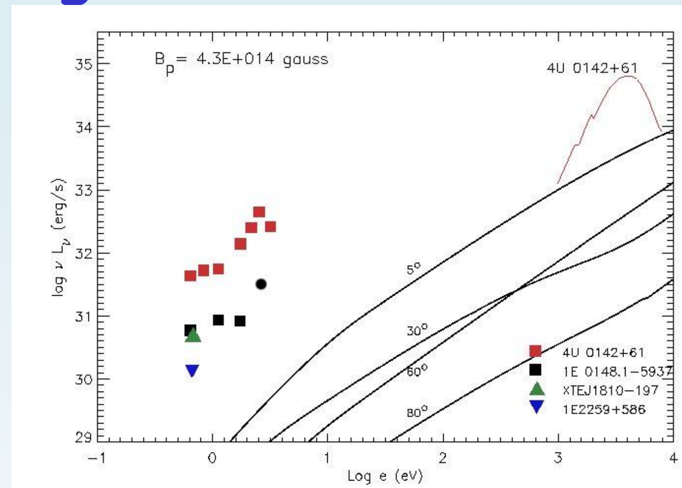
$\Rightarrow$ screening of the potential:
$e\Phi / m_e c^2 \approx \gamma_{res} \approx 500\ B/B_Q$




Charges undergo only few scatterings with thermal photons, but they loose most of their kinetic energy in each collision.
A steady situation is maintained against severe Compton losses because electrons/positrons are re-accelerated by the E-field before they can scatter again

# Spectrum of the curvature radiation emitted by the fast-moving charges



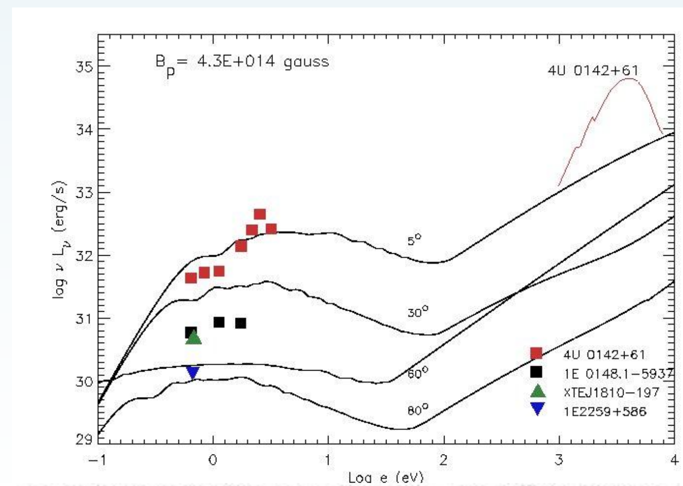




**Fig. 2** Model spectra for different values of $\theta_{obs}$ and $B_p = 4.3 \times 10^{14}$ G. The *XMM-Newton* X-ray spectrum of 1RXS J1708-4009 is from Rea et al. (2008; red solid line). The AXPs IR/optical data are from Duncan & van Kerkwijk 2005 (4U0142+614 and 1E1048-5937) and Mignani et al. 2007 (XTE J1810-197 and 1E 2259+586). The adopted distances for de-reddening are 5 kpc (4U 0142+614, 1RXS J1708-4009), 3 kpc (1E 1048-5937, 1E 2259+586), 4 kpc (XTE J1810-197), 8.5 kpc (1E 1841-045). *Left:* Spectra computed for incoherent curvature emission. *Right:* Same as in the left panel, but accounting for particle bunching.

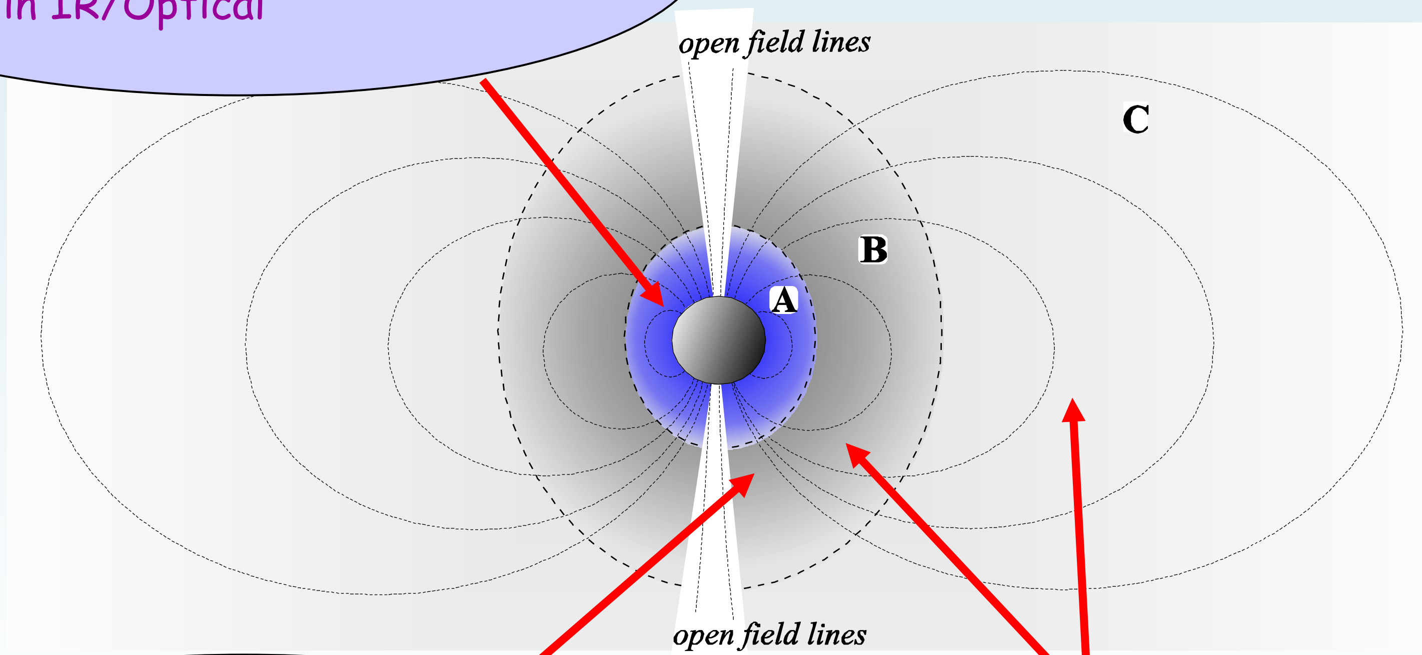
- IR/optical emission is coherent (bunching mechanism, two stream instability, electron positron/electron ion)
- N particles in a bunch of spatial scale l radiate as a single particle of charge Q=Ne
- amplification of radiated power by a factor N (Lesch 1998, Saggion 1975)
- $l \sim c/\nu_{pl}$

Zane, Nobili & Turolla,
Astro-ph 1008.1725 2011

# A POSSIBLE SCENARIO

Nobili, Turolla, SZ, 2011

A: e± pairs generated from high energy RCS photons.
$\gamma \approx 1000$
CR in IR/Optical




B: Mildly relativistic pairs slowed down to $\gamma \sim$ a few (Compton drag).
Soft X-ray spectra through RCS of surface thermal photons

B+C: $\gamma \sim 10^5$ or more.
CR or RCS up to the high energy band (100-1000 KeV) INTEGRAL ?

# Overall Picture & Future Developments:

robust

- Presence of an "intermediate" region populated by mildly relativis… s
  ⇒ RCS onto these charges may account for the soft X-ray spe…
- Curvature radiation from pairs with $\gamma$~1000 in the inner magnetos…ere provides enough energy reservoir to account for the optical/IR emission (if bunching is active)

Less solid

- Curvature and RCS radiation from external regions may account… e INTEGRAL emission – a breaking mechanism is necessary not t… e Comptel UL (compton losses, etc..)
- Possible correlation between IR/hard Xrays, although independent fluctuations are expected

open

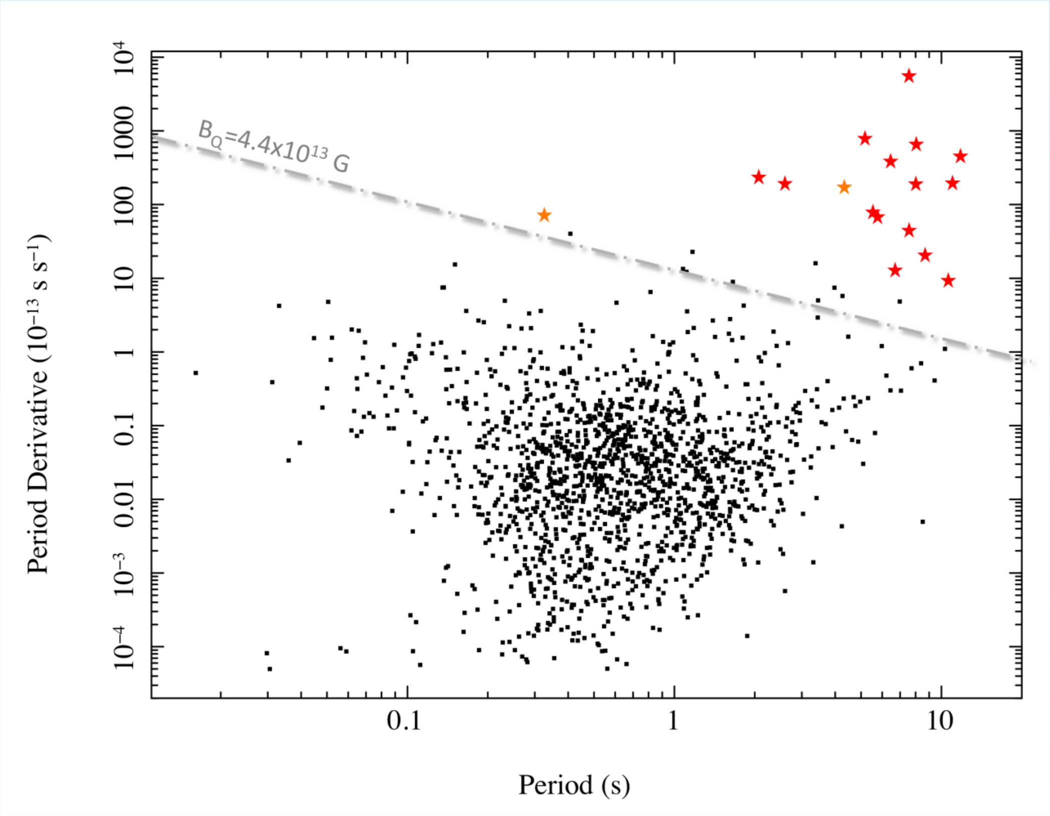
- The physical structure of the magnetosphere is still an open problem.
- Better model of the charge acceleration in the flux tubes / twist localized
- More physical modeling of the high E emission

# SGRs, AXPs and the Like: news?

"Magnetar activity" (bursts, outbursts, ...) detected so far only in high-B sources ($B_p$ > 5x10[13] G) : AXPs+SGRs (☆) and PSR J1846-0258, PSR J1622-4950 (☆)

The ATNF Catalogue lists 20 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



# SGR 0418+5729

- 2 bursts detected on 2009 June 05 with Fermi/GBM, spin period of 9.1 s with RXTE within days (van der Horst et al. 2010)
- All the features of a (transient) magnetar
  - Period derivative ?

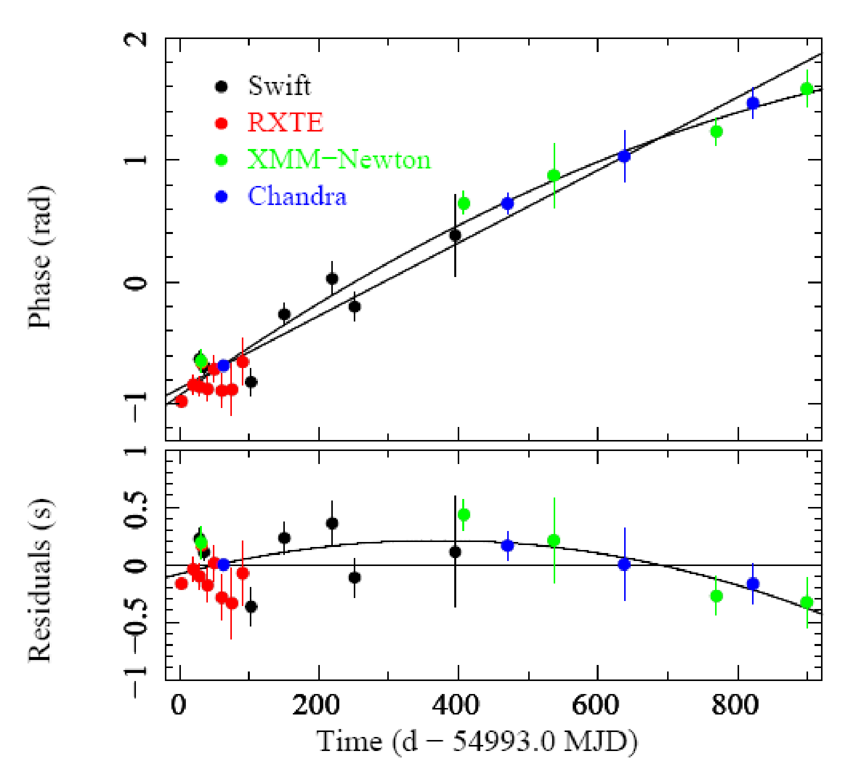
Monitoring now extends to ~ 900 d (as to mid 2012)

Positive detection of

$\dot{P} \sim 5.14\times10^{-15}$ s/s
$B_p = 7 \times 10^{12}$ G

(Rea et al. in preparation)

Previously reported upper limit
$B_p \sim 7.5\times10^{12}$ G (Rea et al. 2010)




See also Daniela's talk

# More Coming: SGR 1822-1606

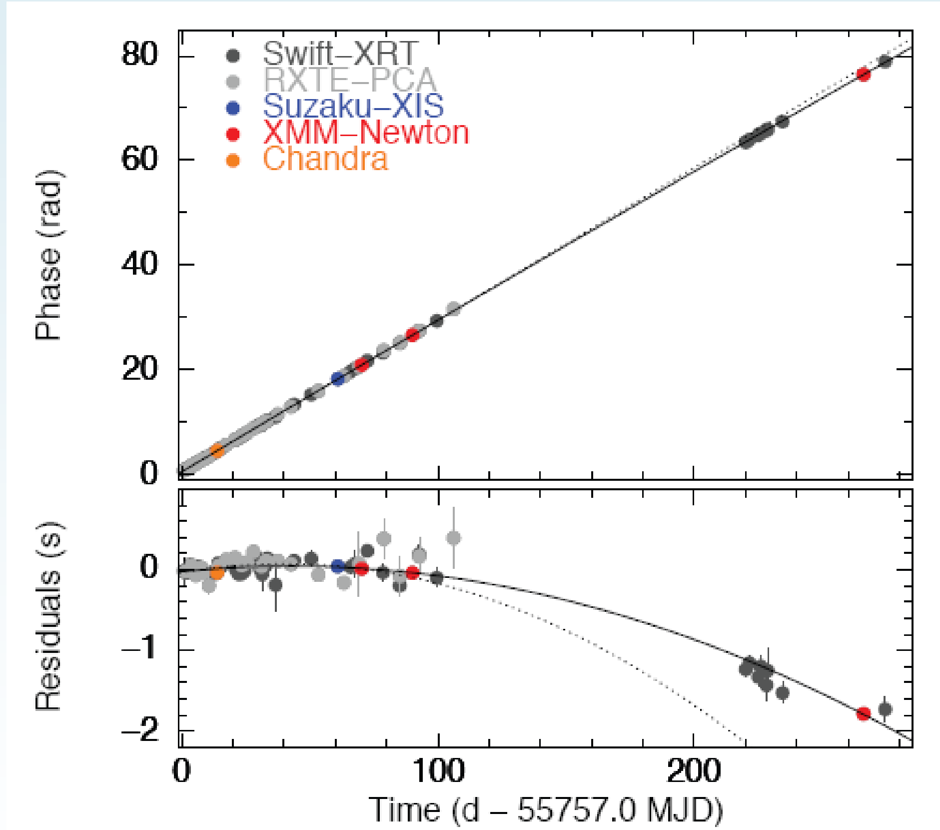
- Latest discovered magnetar, outburst in July 2011
- Monitored with Swift, RXTE, Suzaku, XMM-Newton and Chandra
- Quiescent source found in archival ROSAT pointings ($L_X \sim 4 \times 10^{32}$ erg/s)

$P = 8.44$ s
$\dot{P} = 8.3 \times 10^{-14}$ s/s

$B_p = 2.7 \times 10^{13}$ G (second weakest after SGR 0418)

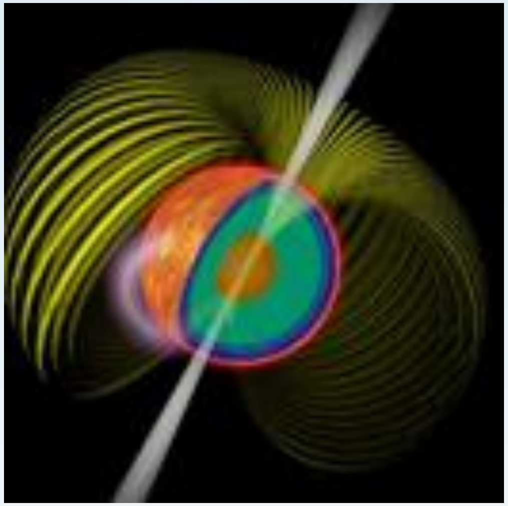
$\tau_c = 1.6$ Myr
(Rea et al 2012)

$\tau_c = 29.5$ Myr for SGR 0418

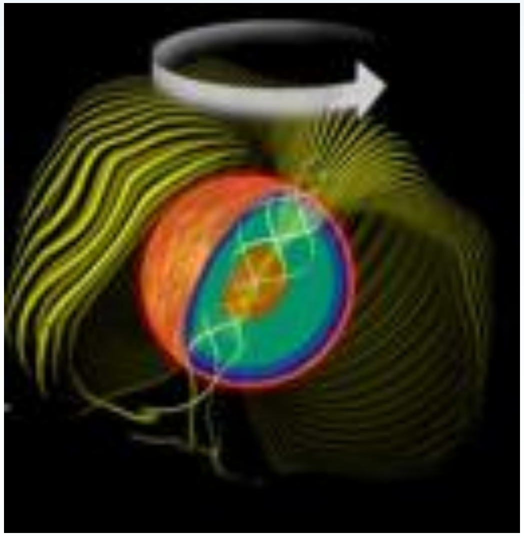


# A Magnetar at Work

- What really matters is the internal toroidal field $B_\varphi$
- A large $B_\varphi$ induces a rotation of the surface layers
- Deformation of the crust ⇨ fractures ⇨ bursts/twist of the external field



High-B PSR

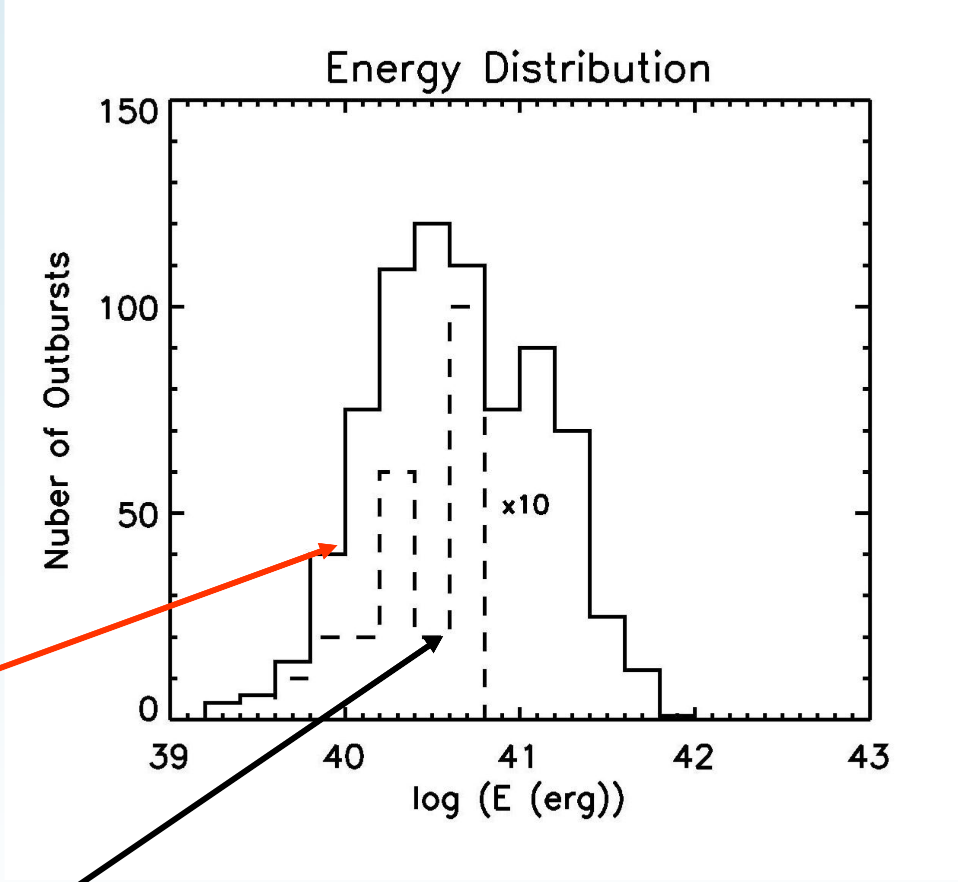


SGR/AXP

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

Max stress substained by the crust as in Chugunov B Horowitz 2010

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




$B_{tor,0} = 2.5 \times 10^{16}$ G
$B_{p,0} = 2.5 \times 10^{14}$ G

$B_{tor,0} = 8 \times 10^{14}$ G
$B_{p,0} = 1.6 \times 10^{14}$ G

Is a large $B_{tor}$ necessary associated with a large $B_p$?

Clear that a dipolar B is not enough to explain the variety in phenomenology: why some “high B” pulsars do not display bursts, while some “low field” SGRs do?

# Are "low-field" SGRs Old Magnetars ?

- Main issues (Turolla, SZ  et al. 2011)
  - Spectrum of the persistent emission (OK)
  - P, $\dot{P}$ and $B_p$ from magneto-rotational evolution
  - capacity of producing bursts
- Clues (Rea et al. 2010)
  - Large characteristic age (> 24 Myr)
  - Weak bursting activity (only 2 faint bursts)
  - Low dipole field ($B < 7.5 \times 10^{12}$ G)

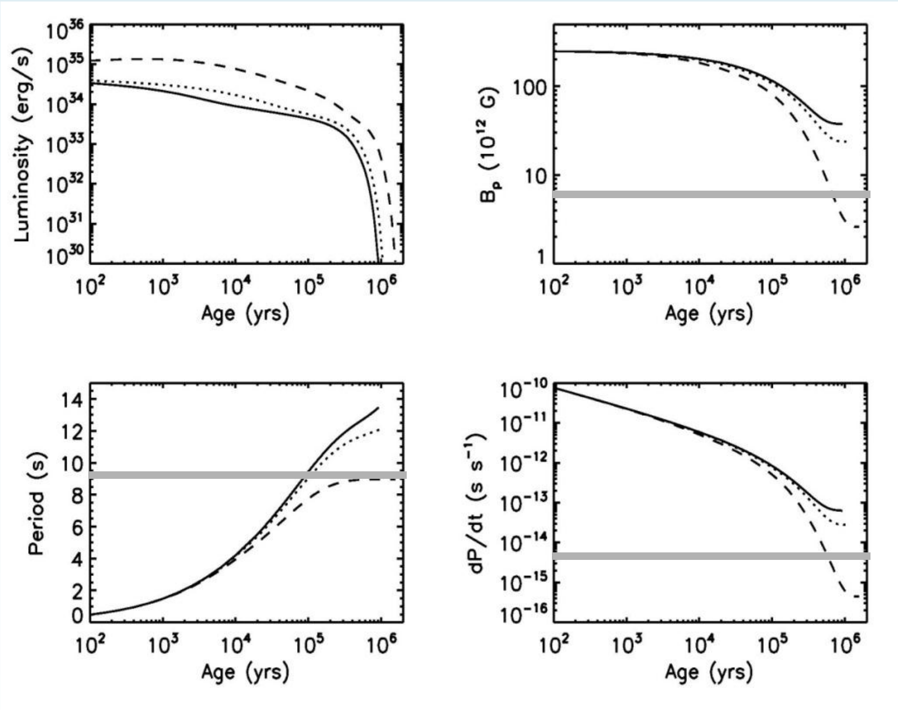
# Magneto-rotational Evolution

- Long term 2D simulations of magneto-thermal evolution of a NS
- Coupled magnetic and thermal evolution (Pons, Miralles & Geppert 2009)
- Hall drift ambipolar diffusion, OHM dissipation (mainly crustal processes)
- Standard cooling scenario (Page et al. 2004), toroidal+poloidal crustal field, external dipole

$M=1.4\ M_\odot, P_0 = 10$ ms,
$B_{p,0} = 2.5\times10^{14}$ G

$B_{tor,0} = 0$ (—) , $4\times10^{15}$ (···), $4\times10^{16}$ 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

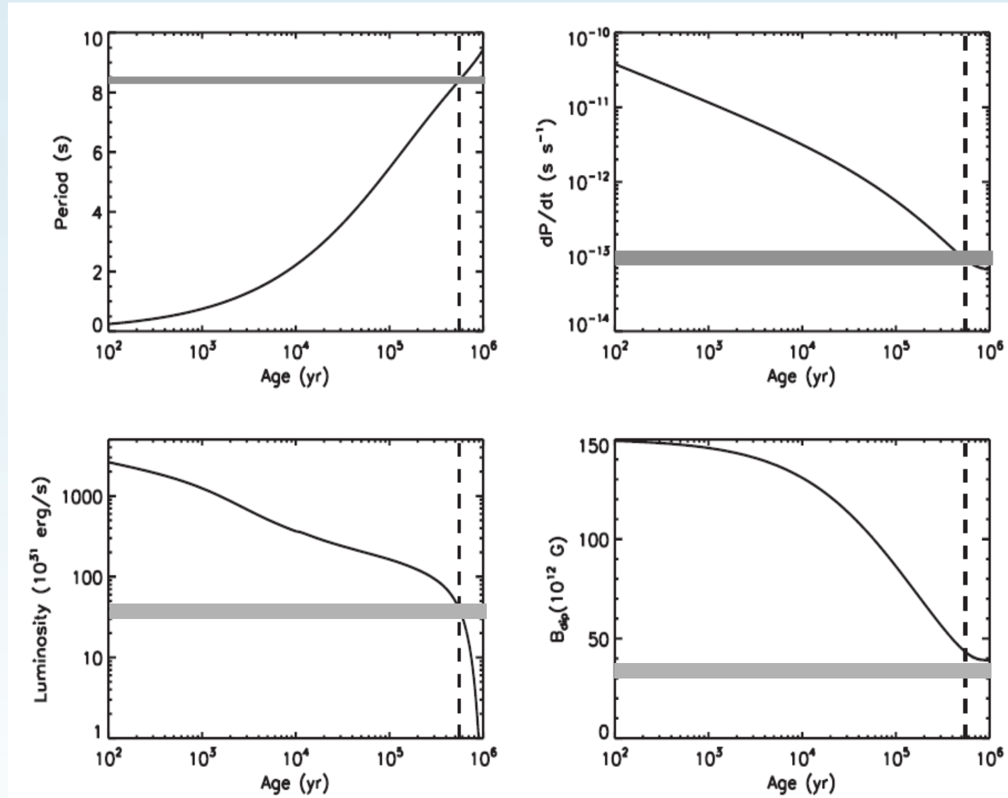



SGR 0418 (Turolla, SZ et al. 2011)

$B_{p,0} = 1.5\times10^{14}$ G
$B_{tor,0} = 7\times10^{14}$ G

$P \sim 8.5$ s, $\dot{P} \sim 8\times10^{-15}$ s/s,
$B_p \sim 3\times10^{13}$ G,
$L_X \sim 3\times10^{32}$ erg/s

for an age ~ 0.5 Myr




SGR 1822 (Rea, SZ et al. 2012)

# Wear and Tear

Crustal fractures possible also at late evolutionary phases (≈ $10^5$ – $10^6$ yr; Perna & Pons 2011)

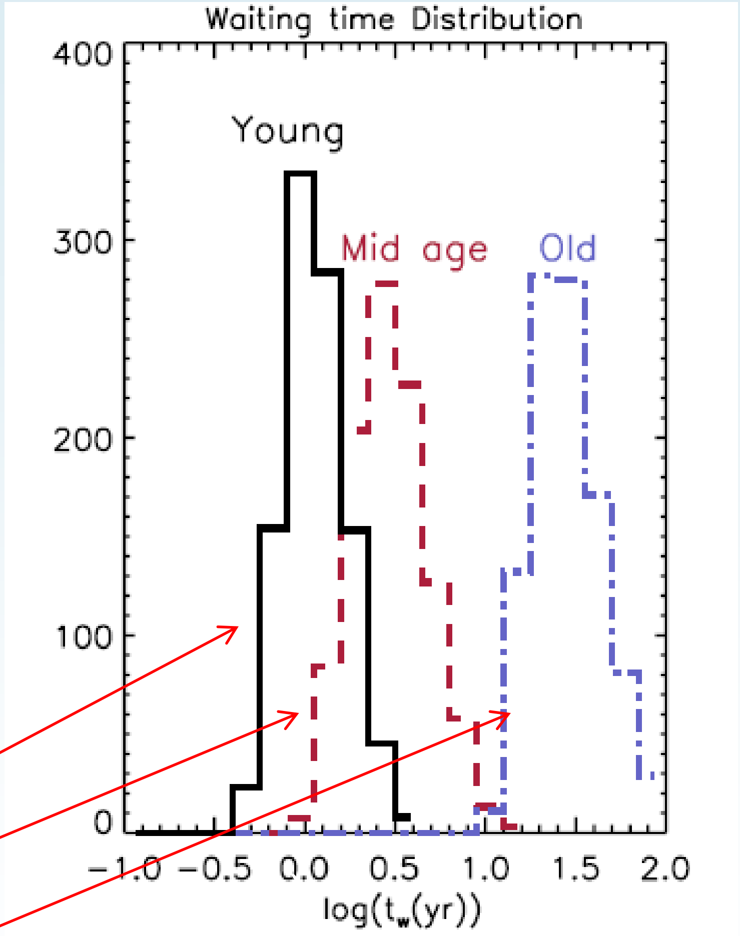
Burst energetics decreases and recurrence time increases as the NS ages

For $B_{p,0} = 2\times10^{14}$ G and $B_{tor,0} = 10^{15}$ G,
$\Rightarrow \Delta t \approx 10 - 100$ yr

Very close to what required for SGR 1822

Fiducial model for SGR 0418 has similar $B_{p,0}$ and larger $B_{tor,0}$ ⇨ comparable (at least) bursting properties

Young: 400-1600 yr (SGRs)
Mid age: 7-10 kyr (AXPs)
Old: 60-100 kyr (old AXPs)




(Perna and Pons 2011)

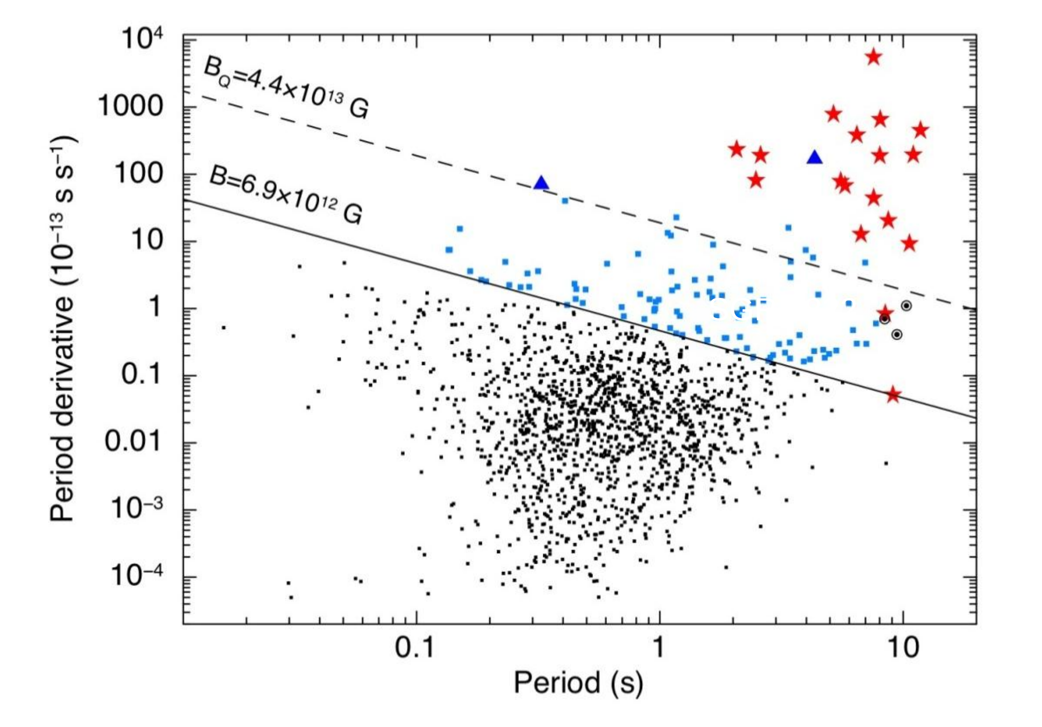
# Inferences

SGR 0418+5729 (and SGR 1822-1606) is a low-B source: more than 20% of known radio PSRs have a stronger $B_p$

Their properties compatible with aged magnetars ≈ 1 Myr old

A continuum of magnetar-like activity across the P-$\dot{P}$ diagram

No need for a super-critical field




See also Daniela's talk

# Tuning in to Magnetars

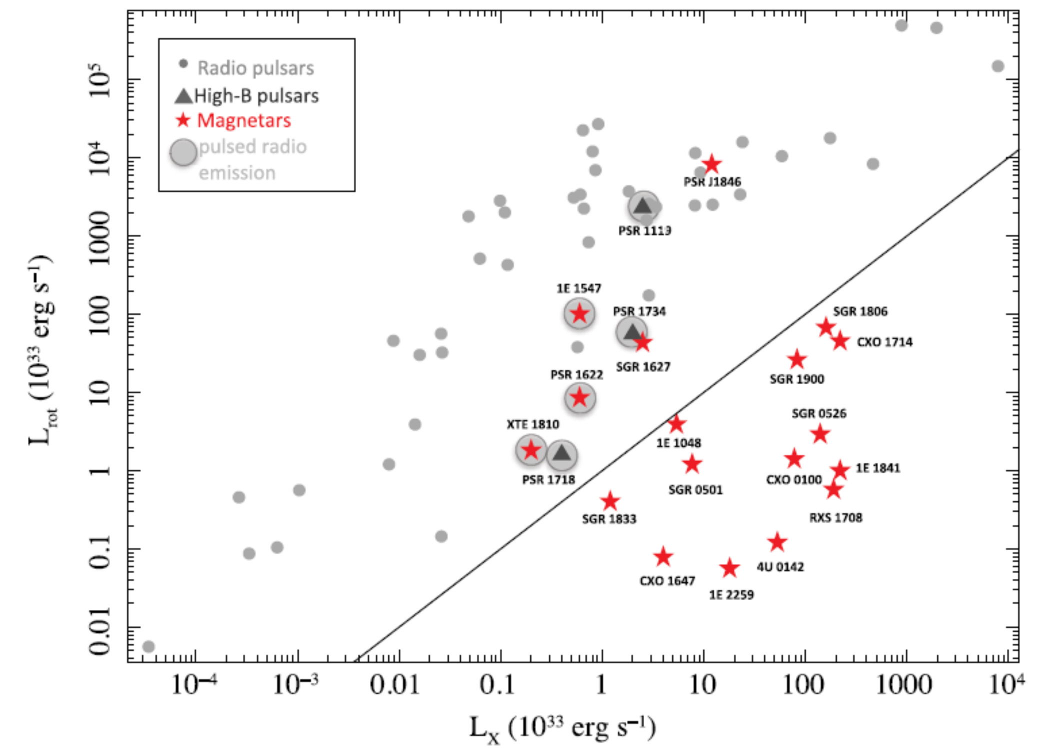
- "Canonical" SGRs/AXPs are radio silent and have $L_X/L_{rot} > 1$
- Radio PSRs with detected X-ray emission have $L_X/L_{rot} < 1$
- Ephemeral (pulsed) radio emission discovered from XTE J1810–197, 1E 1547–5408 and PSR 1622–4950 after outburst onset
- Magnetar radio emission quite different from PSRs (flat spectrum, variable pulse profiles, unsteady)

# Dr Pulsar and Mr Magnetar

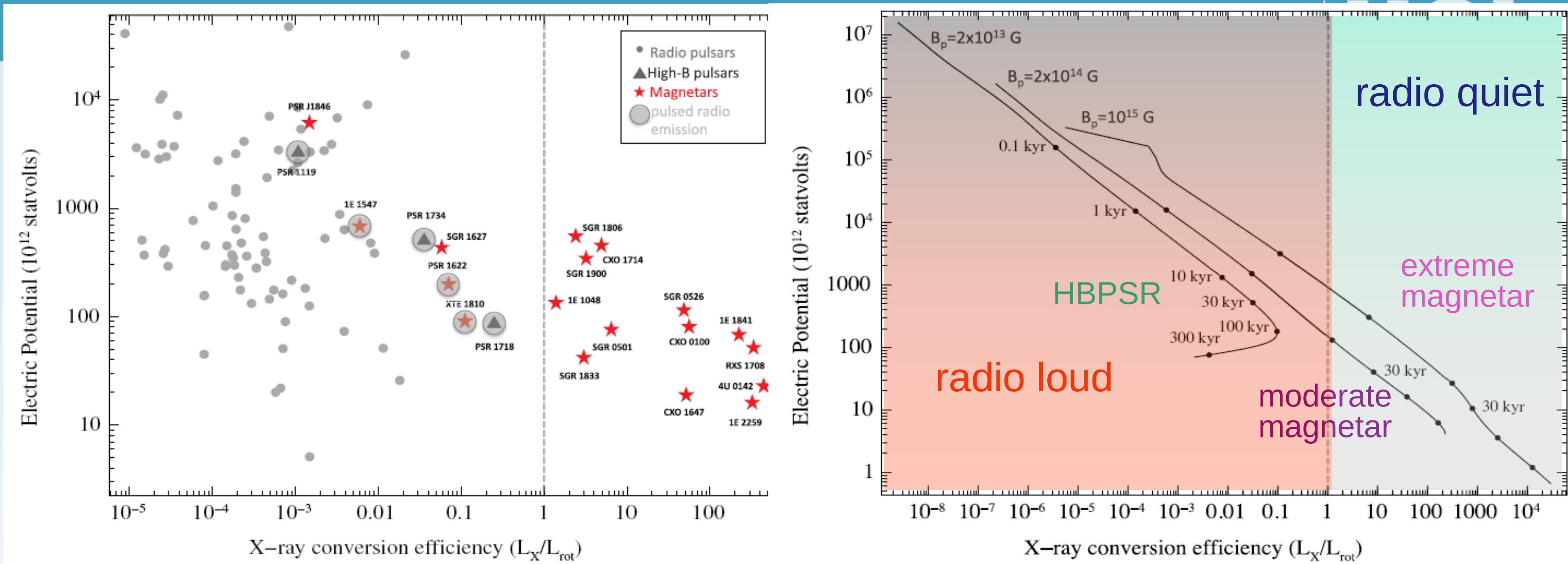
All radio-loud magnetars have $L_X/L_{rot} < 1$ in quiescence

The basic mechanism for radio emission possibly the same as in PSRs

Active only in sources with $L_X/L_{rot} < 1$ (could be persistent radio emitters too)




What is producing the different behaviors ?




Rea, Pons, Torres and Turolla (2012)

Potential drop, $\Delta V = 4.2\times10^{20}\,(\dot{P}/P^3)^{1/2}$ statvolt $\sim L_{rot}^{1/2}$
Radio: curvature from accelerated charge particles, extracted by the surface by the electrical voltage gap due to Bdip ⇒ e +/e- pair cascade

Magneto-thermal evolution

- HBPSR, $B_{p,0} = 2\times10^{13}$ G, $B_{tor,0} = 0$ G
- moderate magnetar, $B_{p,0} = 2\times10^{14}$ G, $B_{tor,0} = 2\times10^{14}$ G
- extreme magnetar, $B_{p,0} = 10^{15}$ G, $B_{tor,0} = 10^{16}$ G

HBPSRs always stay in the "radio-loud" zone (cooling before slowing down)
moderate magnetars exit in ≈ 10 kyr (slow down before cooling)
extreme magnetars exit in < 1 kyr (slow down even faster before cooling)

THANKS !