Magnetars: new discoveries and synergies with multi-band facilities…the XMM view…

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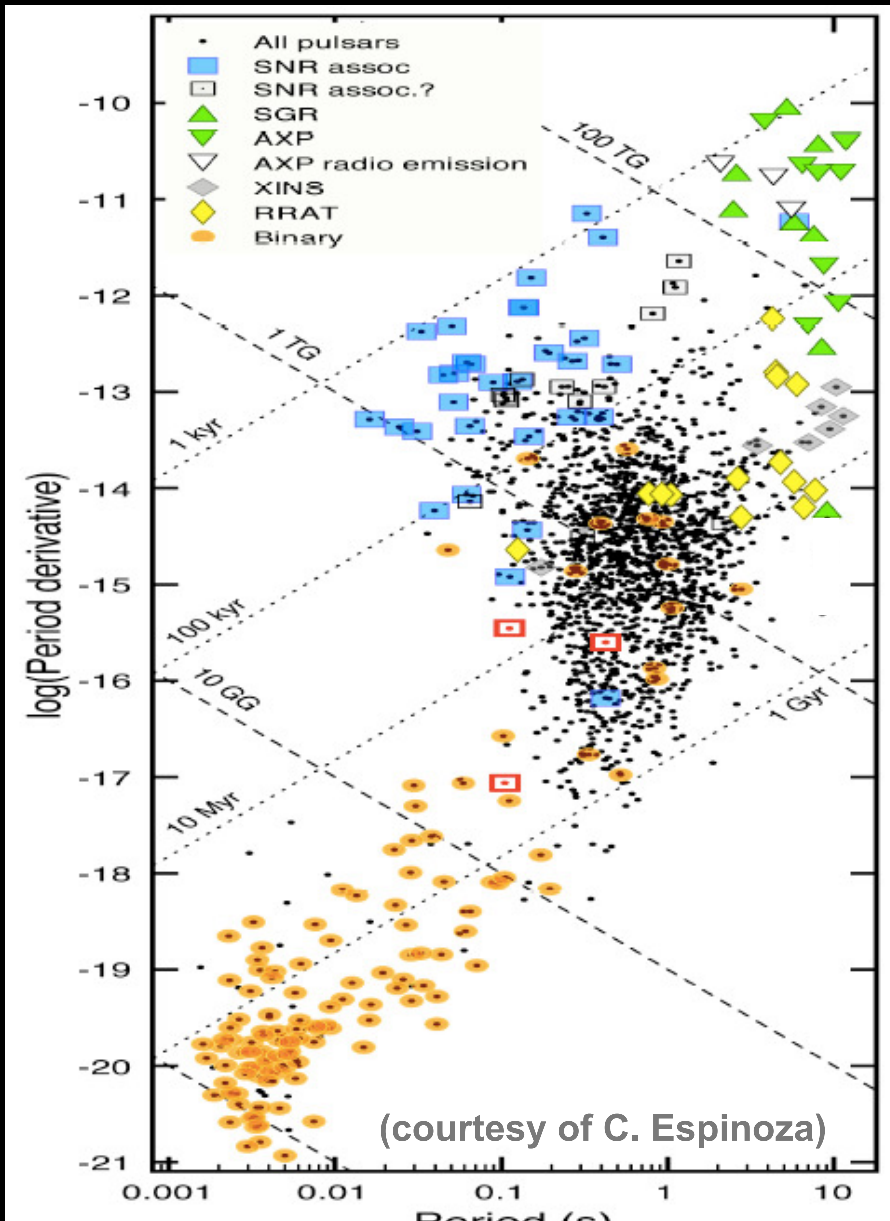
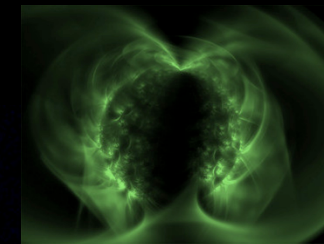
Universiteit van Amsterdam
cost
European Cooperation in Science and Technology
NWO
Netherlands Organisation for Scientific Research
Gobierno de España
Ministerio de Economía y Competitividad
CSIC
Consejo Superior de Investigaciones Científicas
IEEC

The pulsar zoo

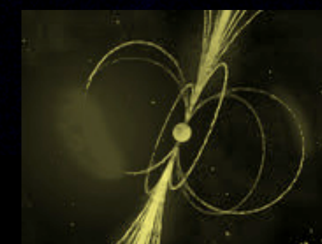


Magnetars: B-powered

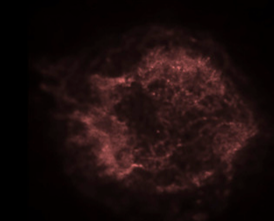


XDINS: kT-powered

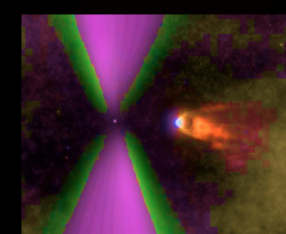
Pulsars and RRATs:
rotation-powered



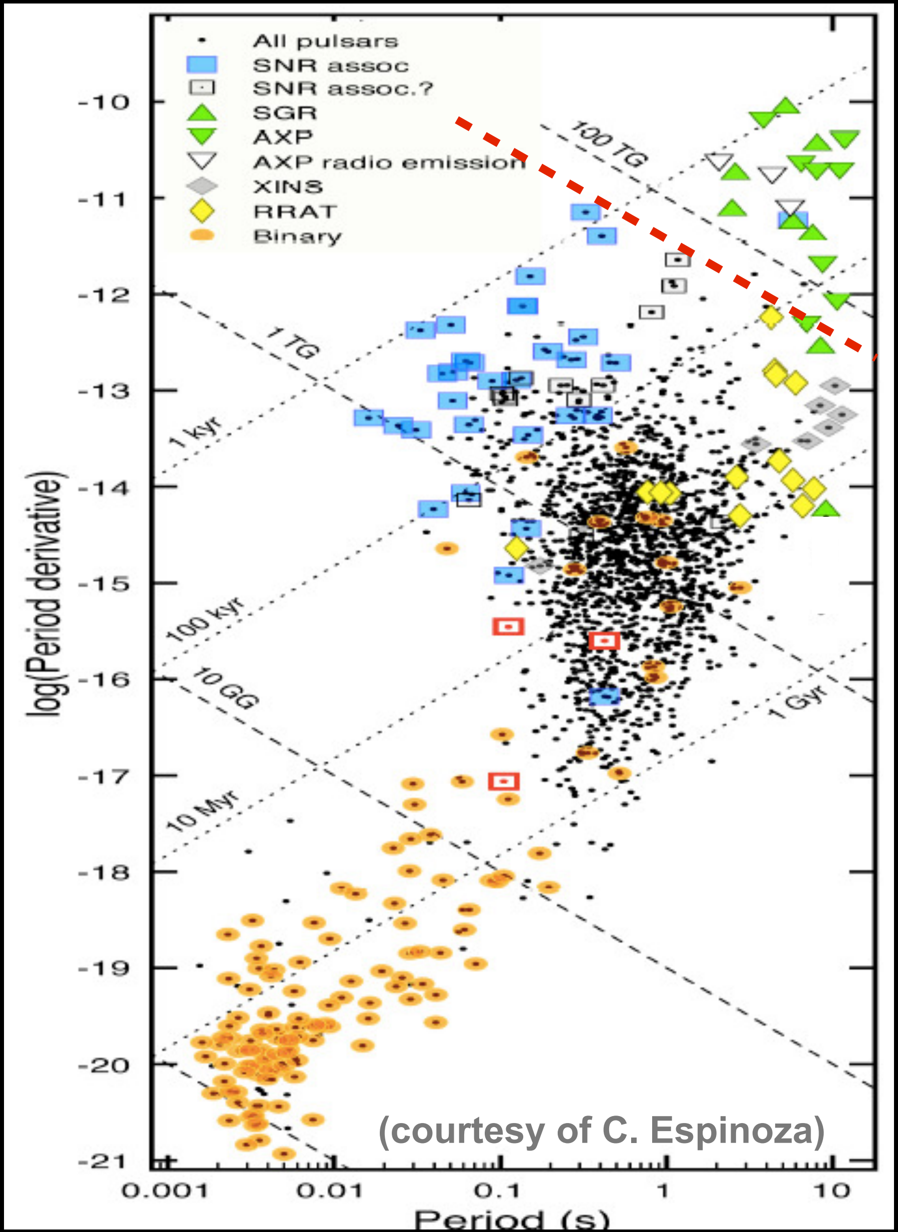
CCOs: kT-powered



Recycled binaries:
rotation-powered



The pulsar zoo: B-field estimates



$$\dot{E}_{rot} = I_{ns}\Omega_s\dot{\Omega}_s = -\frac{4\pi^2 I_{ns}\dot{P}_s}{P_s^3}$$

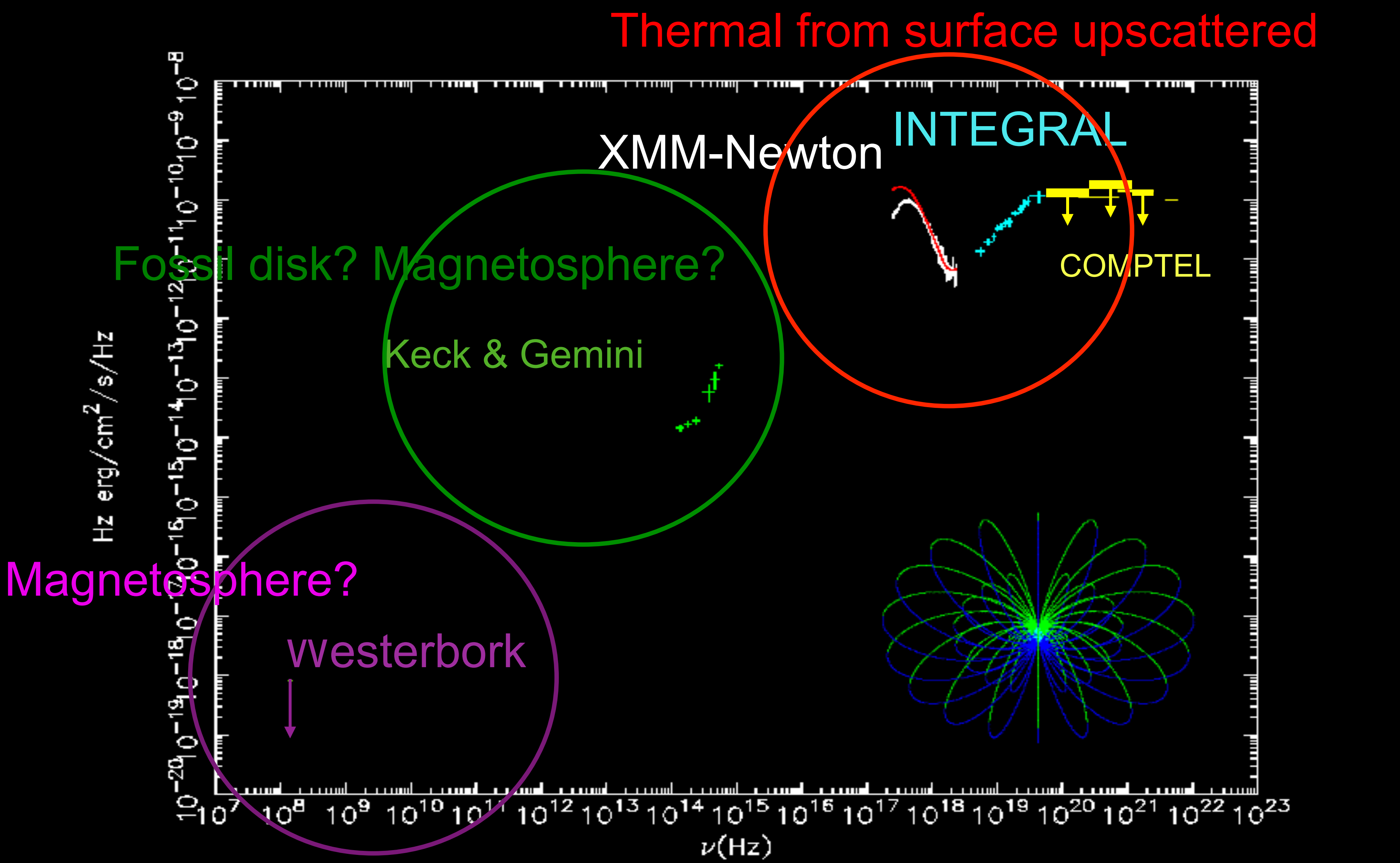
$$P_{dip-rad} = -\frac{2}{3c^3}|\ddot{\mu}_d|^2 = -\frac{2(B_d R_{ns}^3 \sin(1+\alpha))^2}{3c^3}\left(\frac{4\pi^2}{P_s^2}\right)^2$$

$$B_d \approx 3.2\times10^{19}\sqrt{P_s\dot{P}_s}\,Gauss$$

$$B_{critic} = \frac{m_e^2 c^3}{e\hbar} = 4.414\times10^{13}\,Gauss$$

Critical Electron Quantum B-field

Magnetar typical SED when quiet….

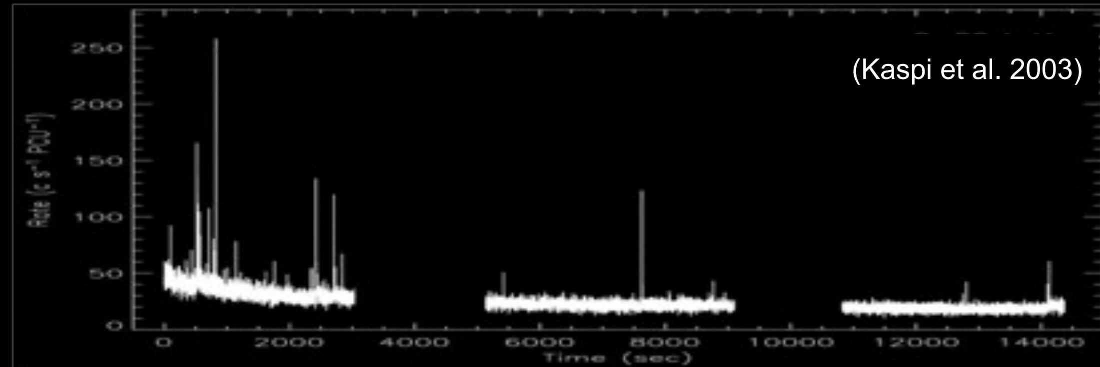


(Rea et al. 2007a, ApJ Letter)

Magnetar flaring activity (timescale: seconds/minutes)

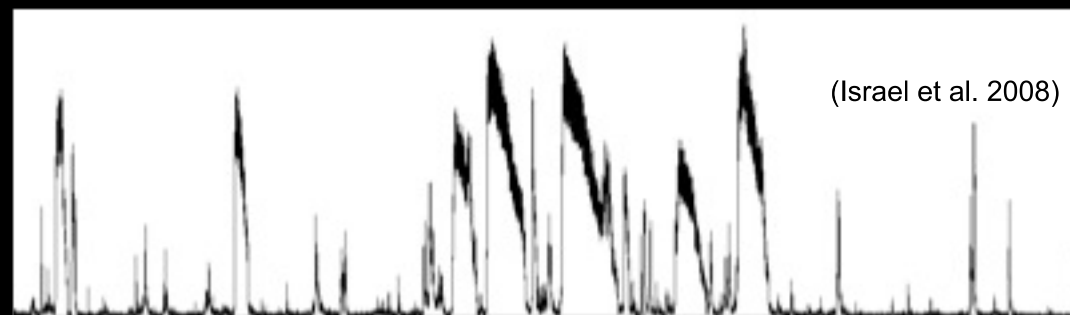
Short bursts

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



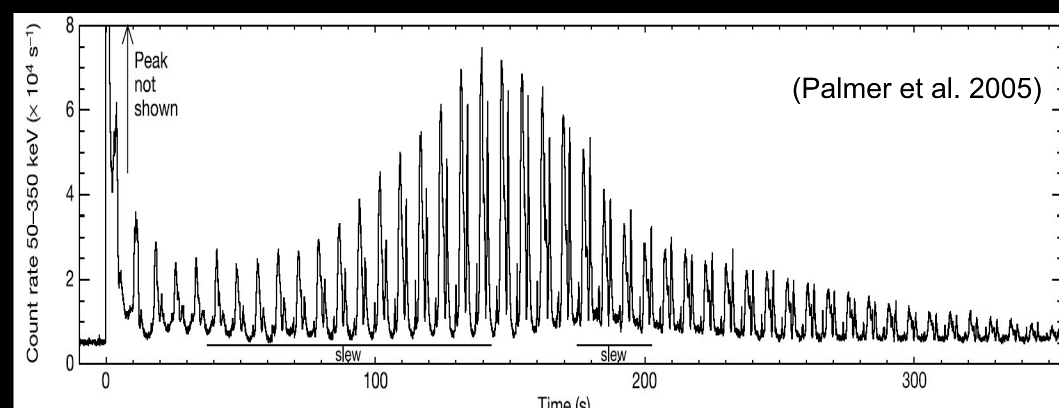
Intermediate bursts

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



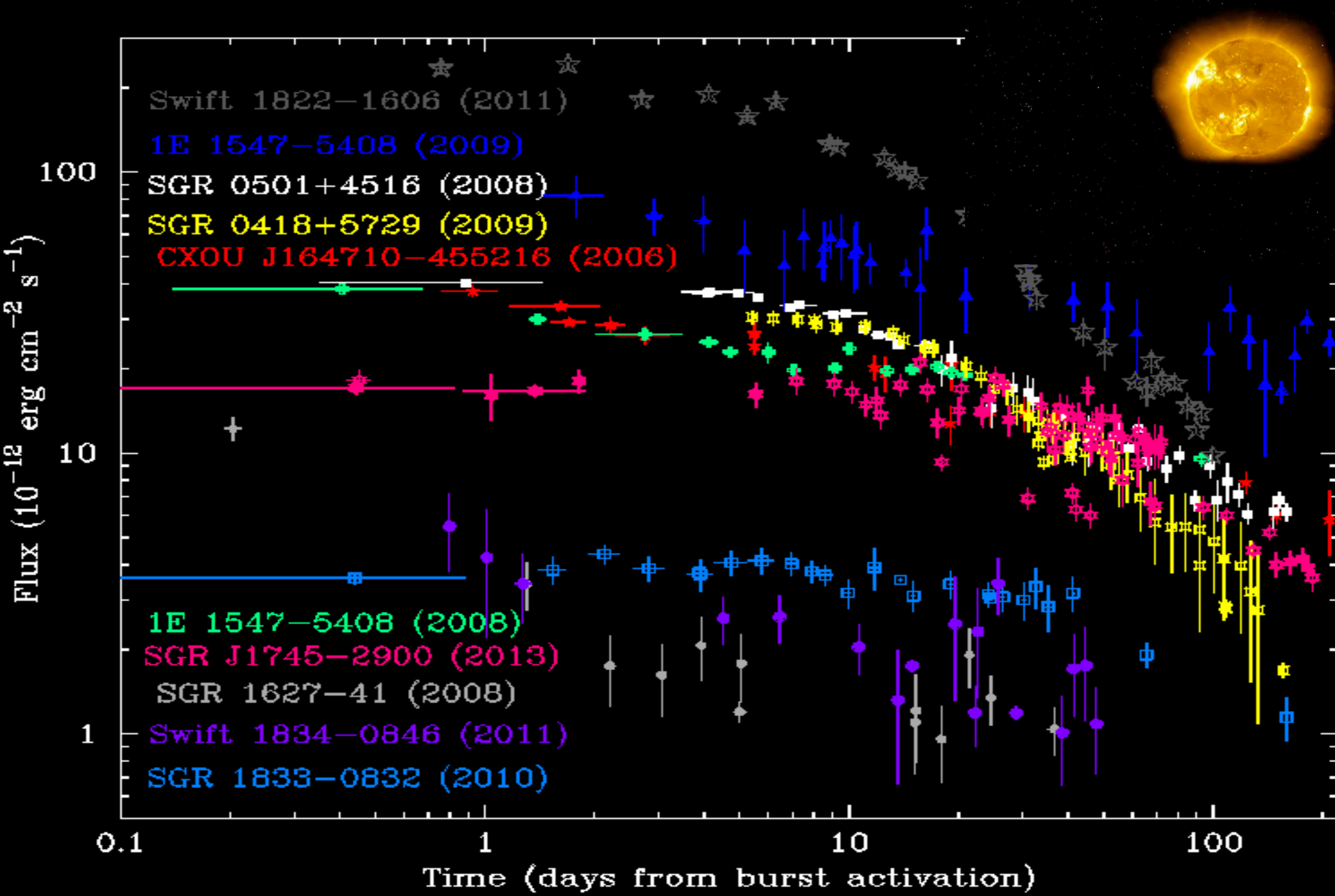
Giant Flares

- their output of high energy is exceeded only by blazars and GRBs
- peak energy > 3×10^{44} ergs/s
- <1 s initial peak with a hard spectrum which rapidly become softer in the burst tail that can last > 500s, showing the NS spin pulsations, and quasi periodic oscillations (QPOs)



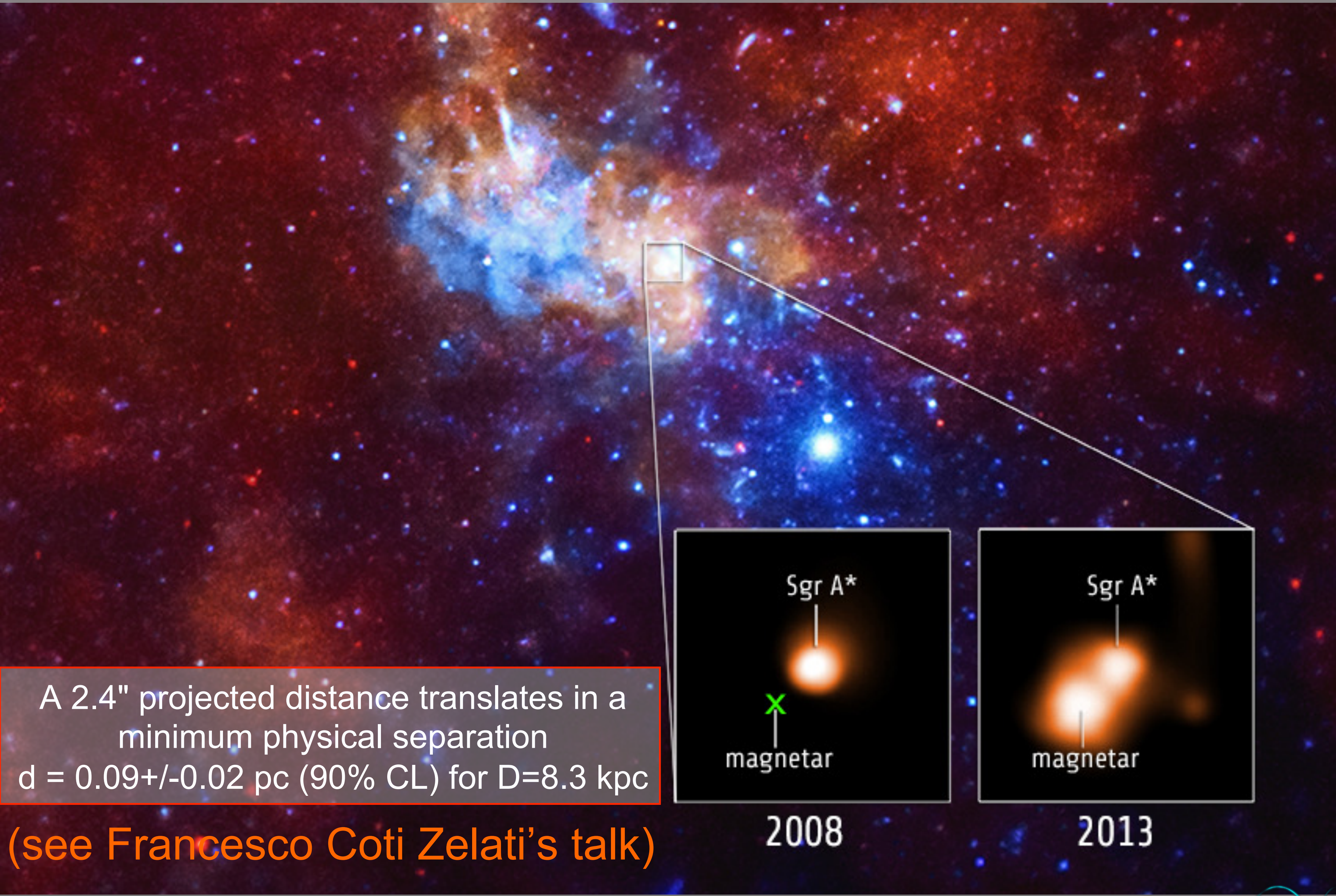
(Mereghetti 2008, Rea & Esposito 2011 for a review)

Magnetar outbursts (timescale: months/years)



(updated from Rea & Esposito 2011)

The Galactic Center magnetar: SGR 1745-2900



A 2.4" projected distance translates in a minimum physical separation
d = 0.09+/-0.02 pc (90% CL) for D=8.3 kpc

(see Francesco Coti Zelati's talk)

(Mori et al. 2013; Kennea et al. 2013; Rea et al. 2013; Kaspi et al. 2014; Coti Zelati et al. 2015)

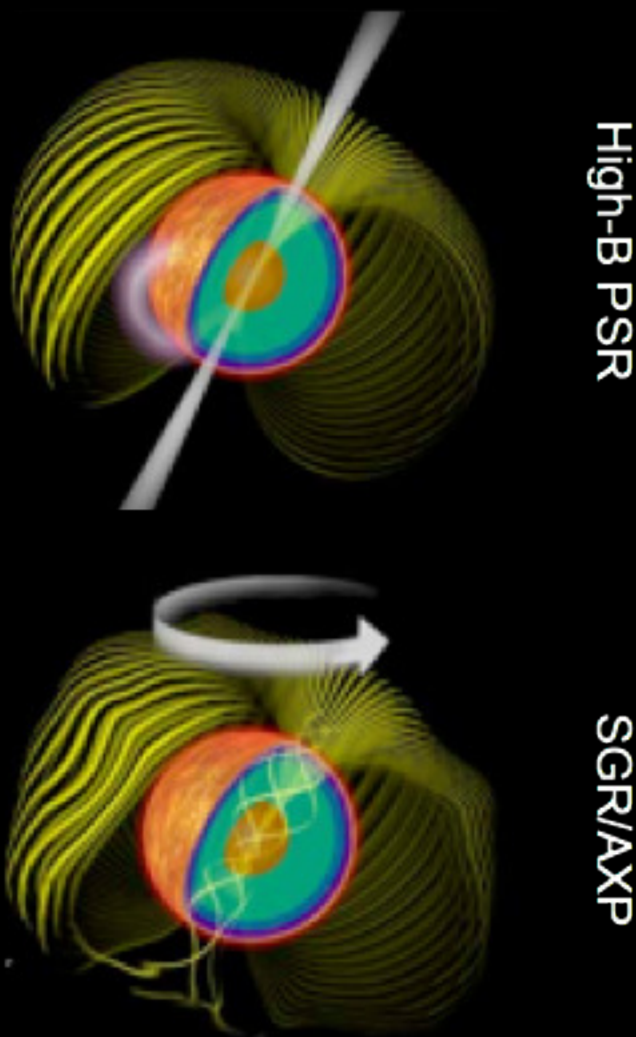
EEC

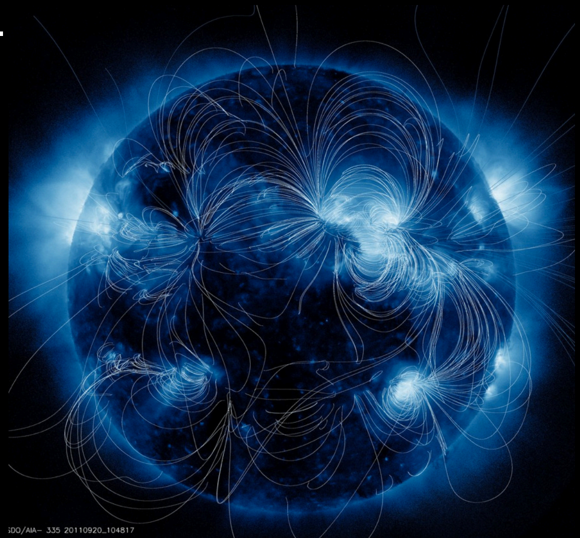
Magnetar theory in a nutshell

- 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...

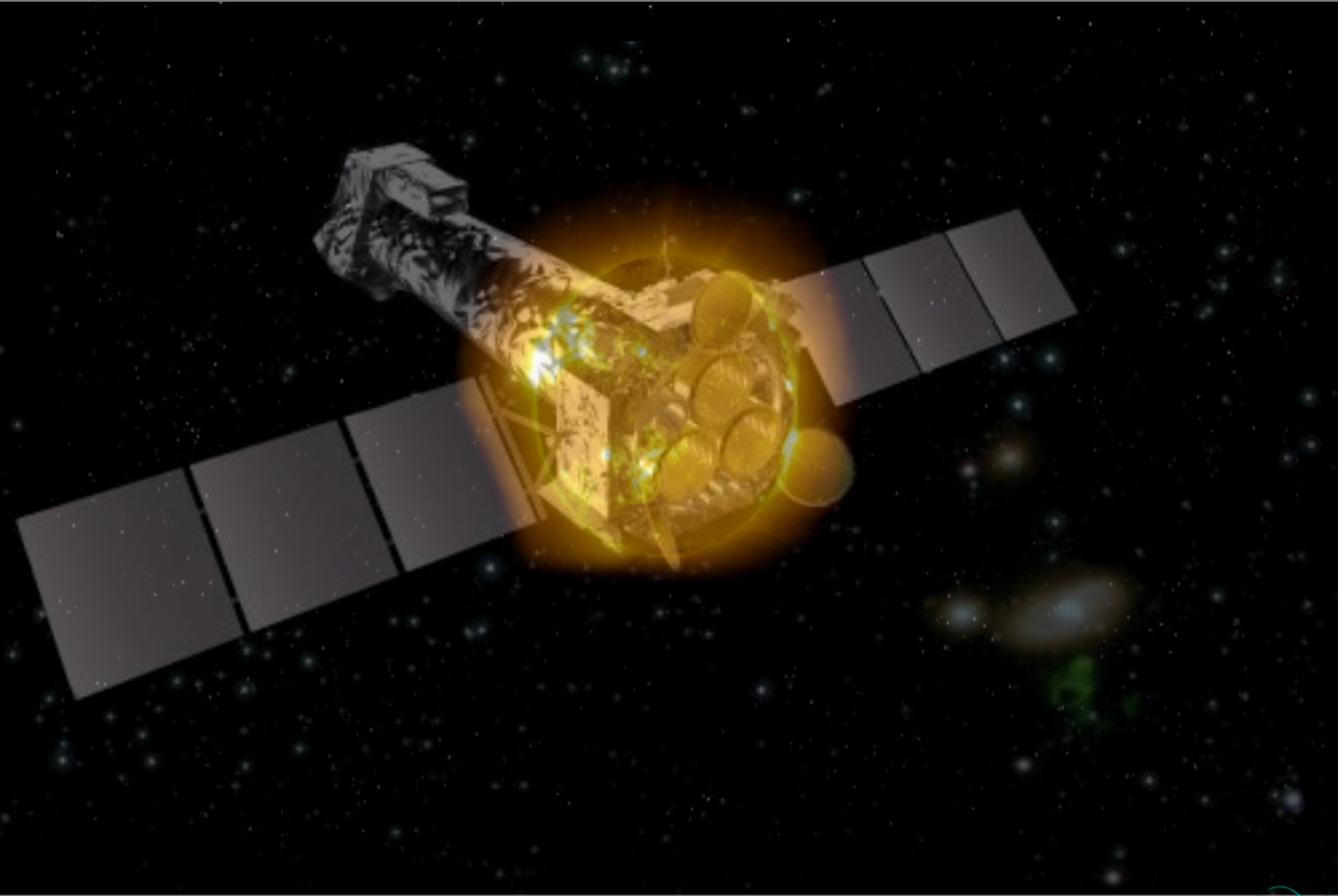
- Magnetar magnetospheres are filled by charged particles trapped in the twisted field lines, interacting with the surface thermal emission through resonant cyclotron scattering.





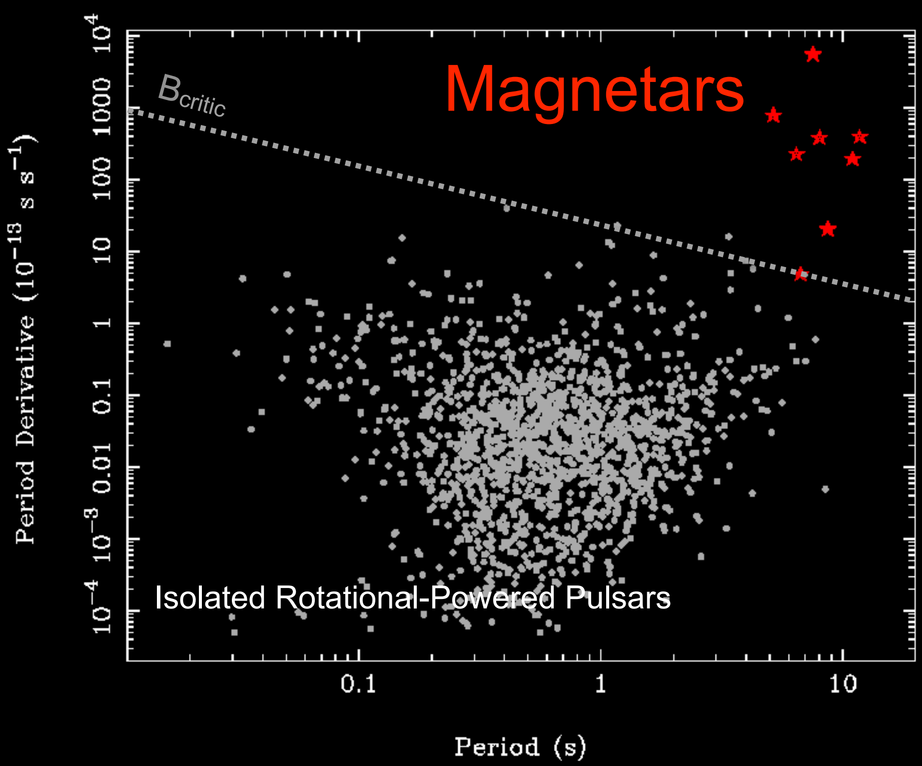
(Thompson & Duncan 1993; Thompson, Lyutikov & Kulkarni 2002; Fernandez & Thompson 2008; Nobili, Turolla & Zane 2008a,b)

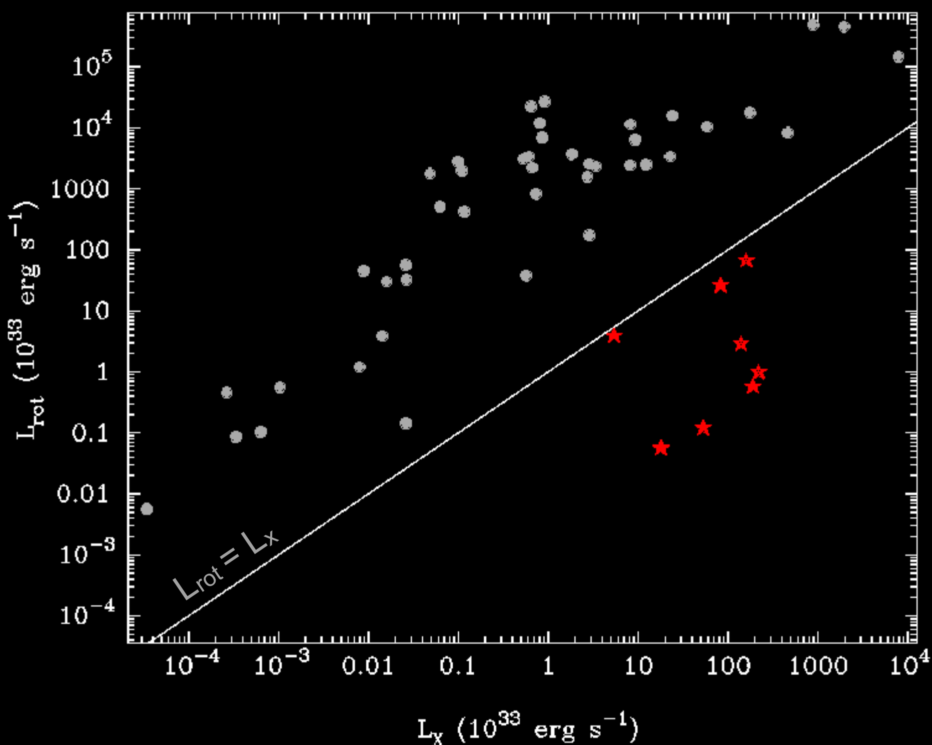
The XMM-Newton magnetar revolution



Magnetars: about a decade ago…

- Magnetic fields > B critical ~4.4×10^{13} Gauss
- X-ray luminosities exceed rotational power
- Stable soft X-ray pulsars with P~5-10s and Lx~10^{34-35} erg/s
- Radio quiet X-ray pulsars





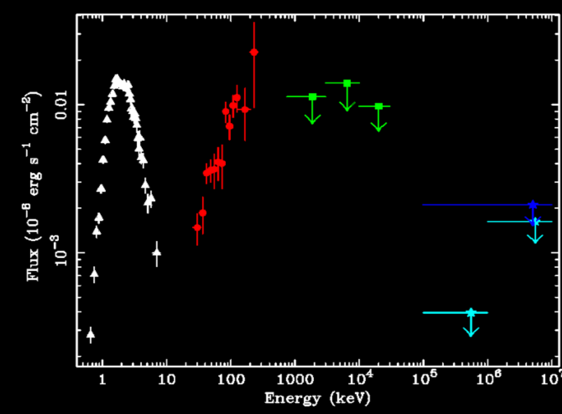
Magnetars: now…

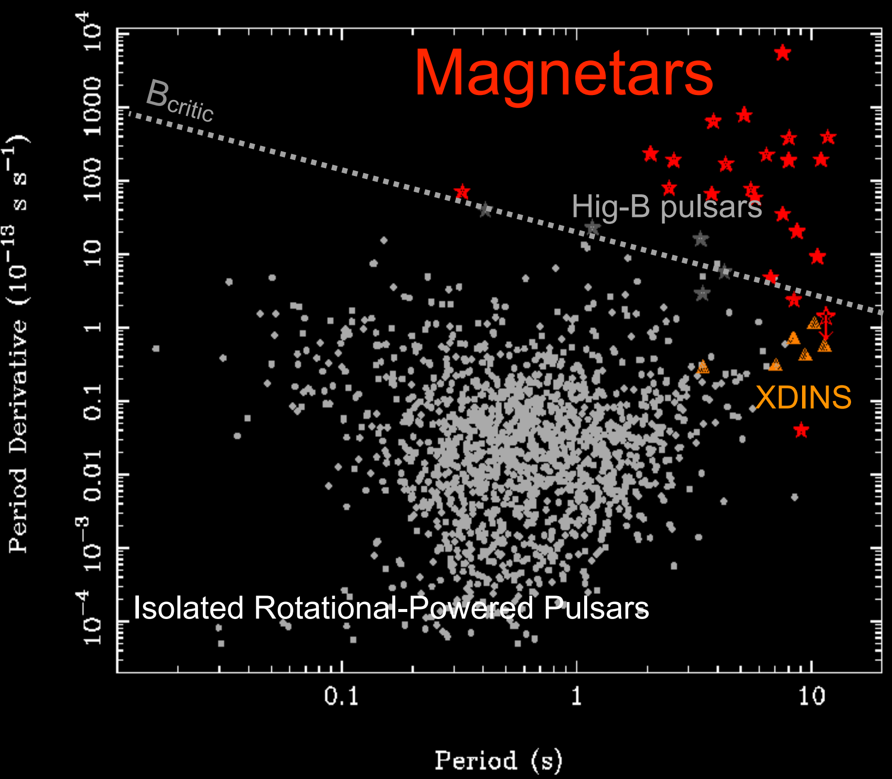
- Magnetic fields NOT always > B critical ~4.4×10^{13} Gauss

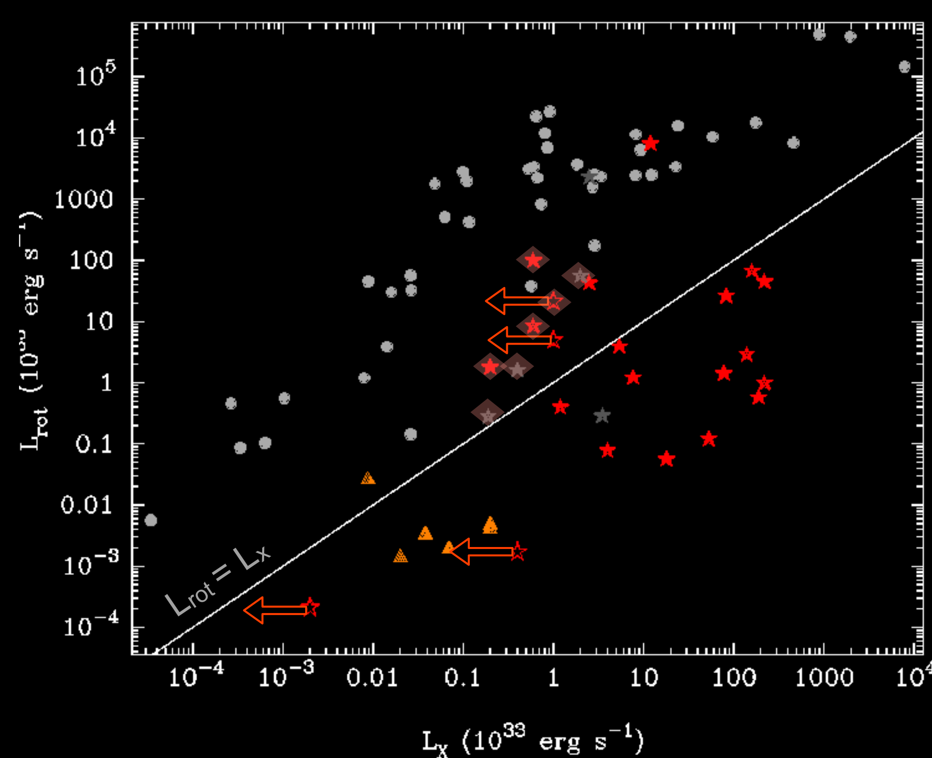
- X-ray luminosities does NOT always exceed rot. power

- NOT stable soft and hard X-ray pulsars (P~0.3-10s and Lx~10^{30-35} erg/s)

- NOT radio quiet, but radio on during transient events







Limiting magnetic field defining a magnetar?

A decade ago…

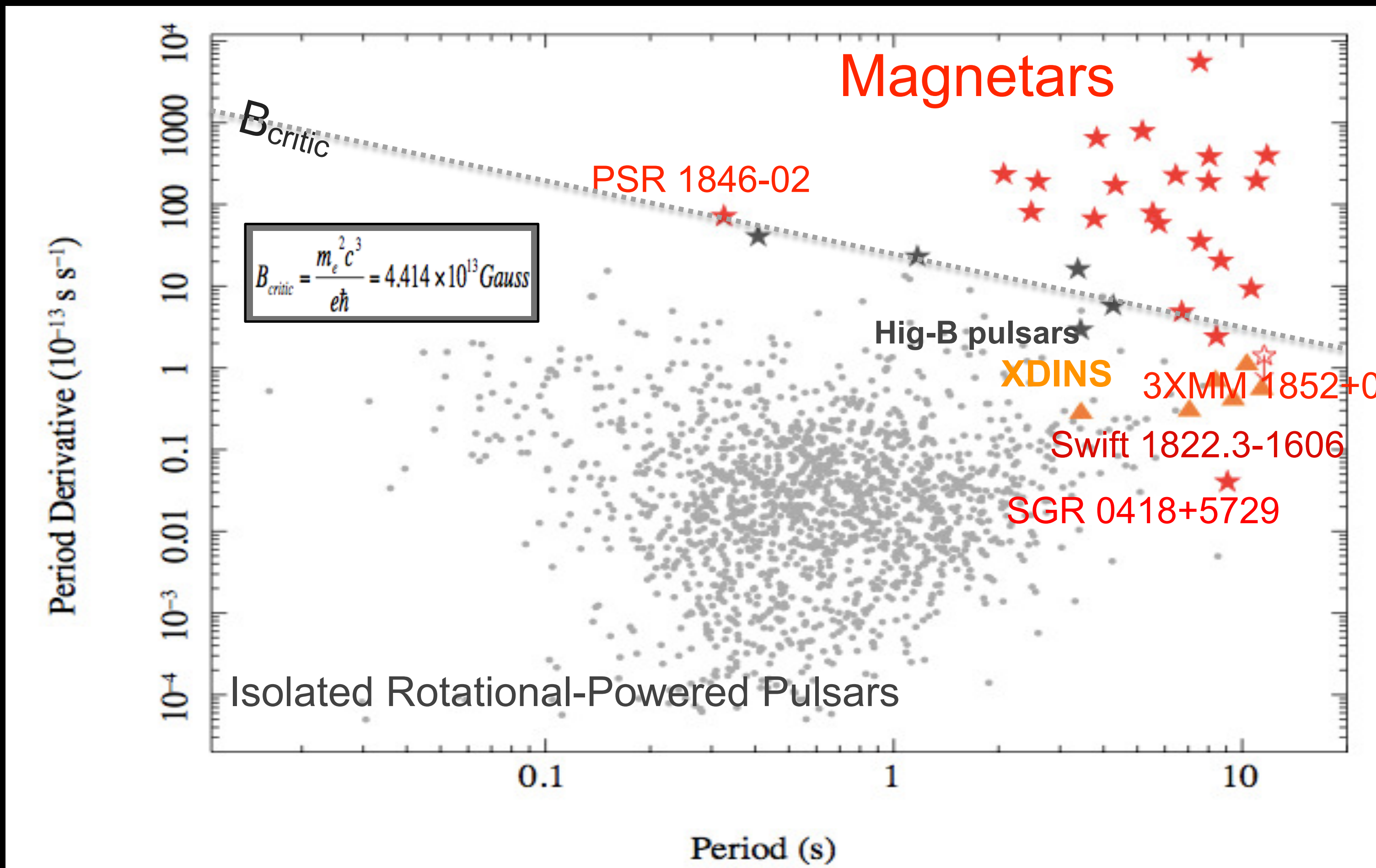
- Magnetic fields > B critical ~4.4×10^{13} Gauss

Limiting magnetic field defining a magnetar?

A decade ago

- Magnetic fields > B critical ~4.4x10^{13} Gauss

We now know there are low-field magnetars showing bursts and flares!



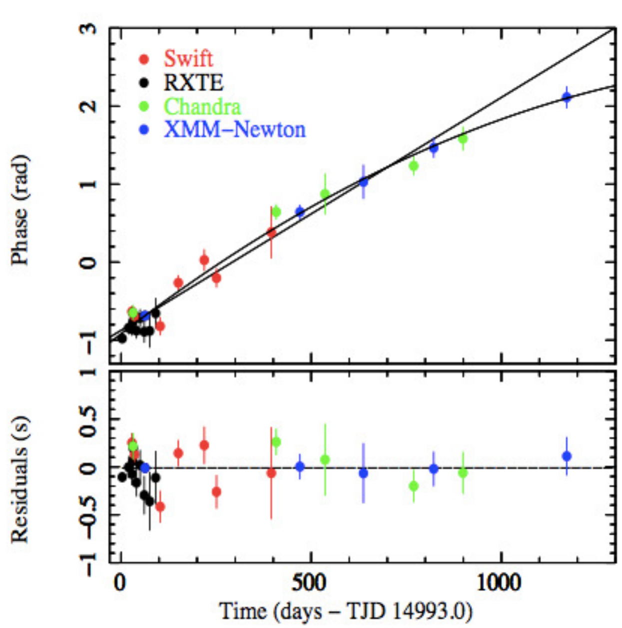
Low magnetic-field magnetars: we have three now!

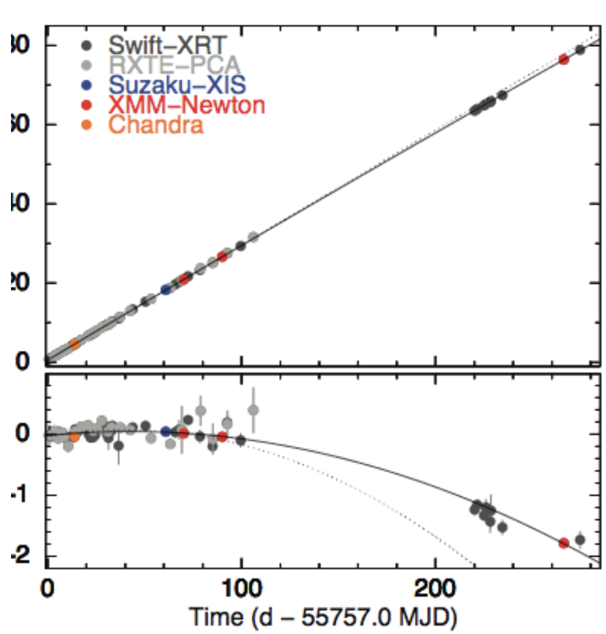
A multi-instrument result: XMM + Chandra key role

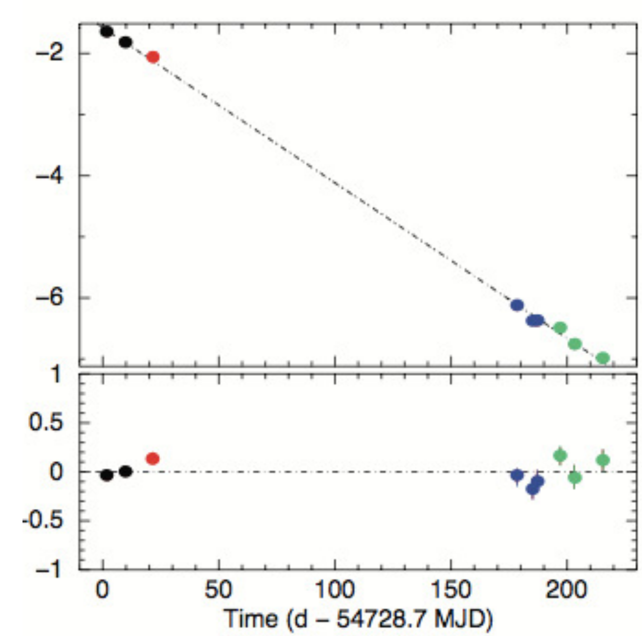
B = 6.2×10^{12} G

B = 2.3×10^{13} G

B < 4×10^{13} G







SGR 0418+5729

Esposito et al. 2010, MNRAS
Rea et al. 2010, Science
Rea et al. 2013, ApJ

Swift 1822-1606

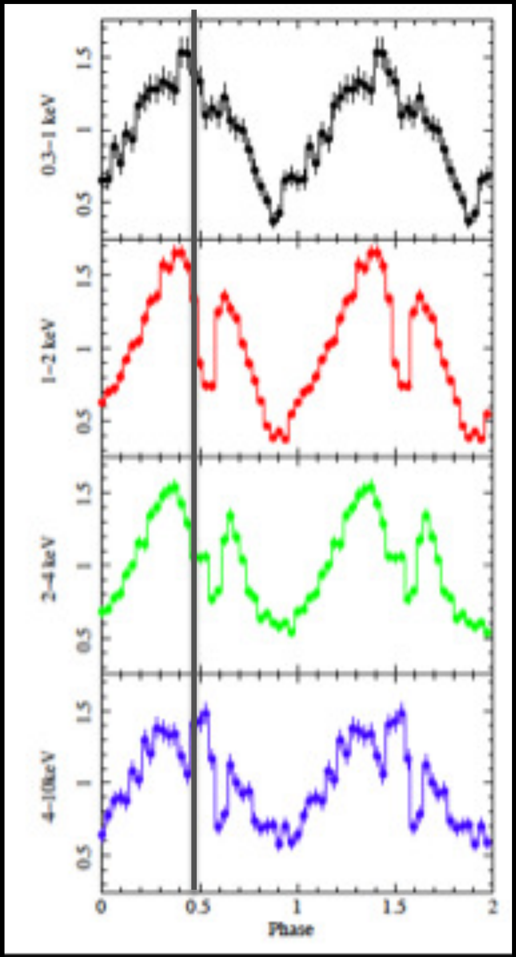
Rea et al. 2012, ApJ
Scholtz et al. 2012, ApJ

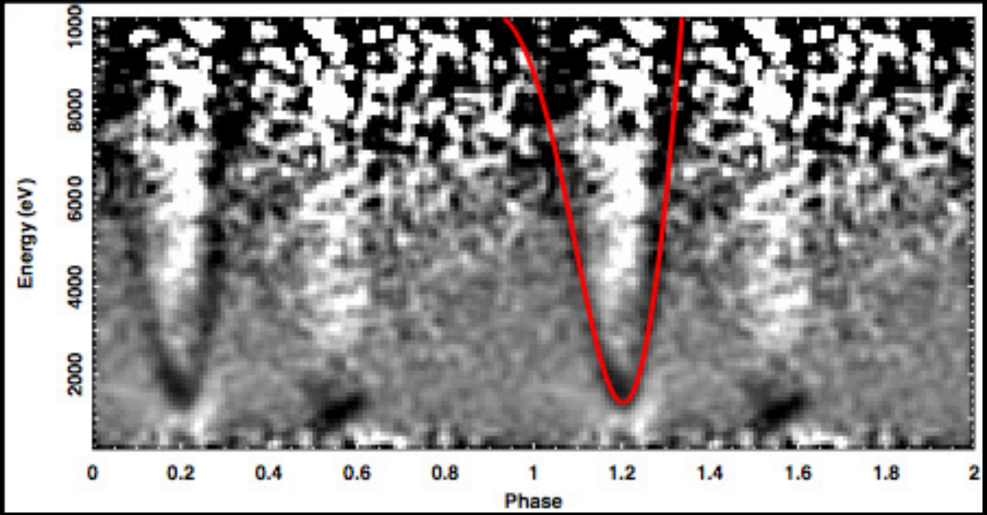
3XMM 1852+0033

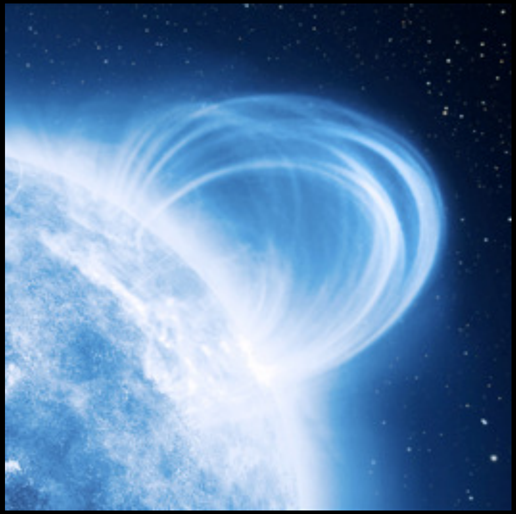
Rea et al. 2014, ApJL
Zou et al. 2014, ApJL

Low magnetic-field magnetars: proton cyclotron line?

An XMM stand alone result!







Different geometries can be envisaged, but the hypothesis of proton cyclotron resonant scattering in a magnetar loop is the most viable scenario.

$E_{cycl,p} = 0.6\ B_{14}$ keV

$\Rightarrow B \sim (2\text{-}20) \times 10^{14}$ G

(Esposito et al. 2010, MNRAS; Rea et al. 2012, ApJ; Tiengo et al. 2013, Nature)

Completeness of the magnetar population: stable or transient?

A decade ago…

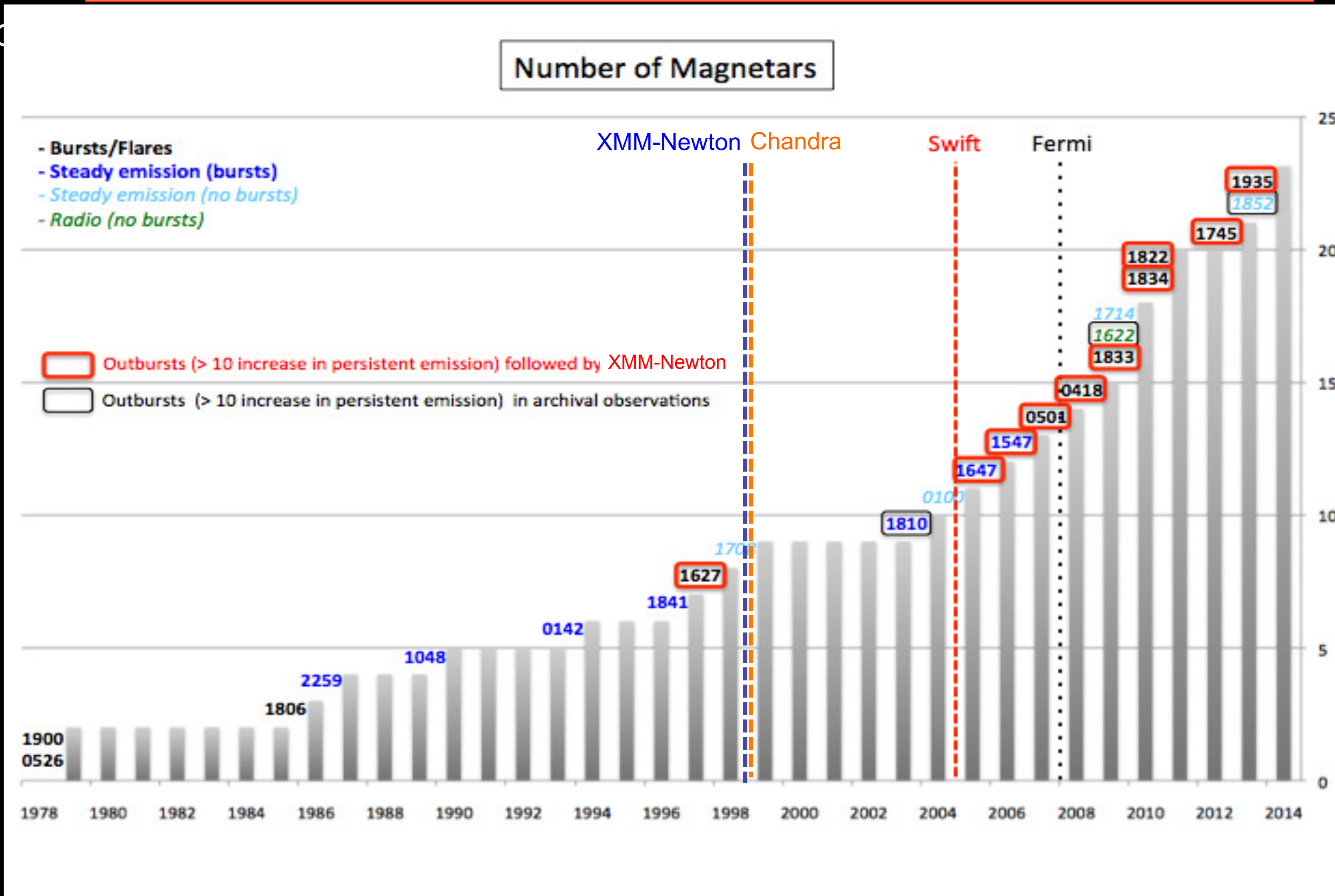
- Stable soft X-ray pulsars with P~5-10s and $L_x \sim 10^{34-35}$ erg/s

Completeness of the magnetar population: stable or transient?

A decade ago…

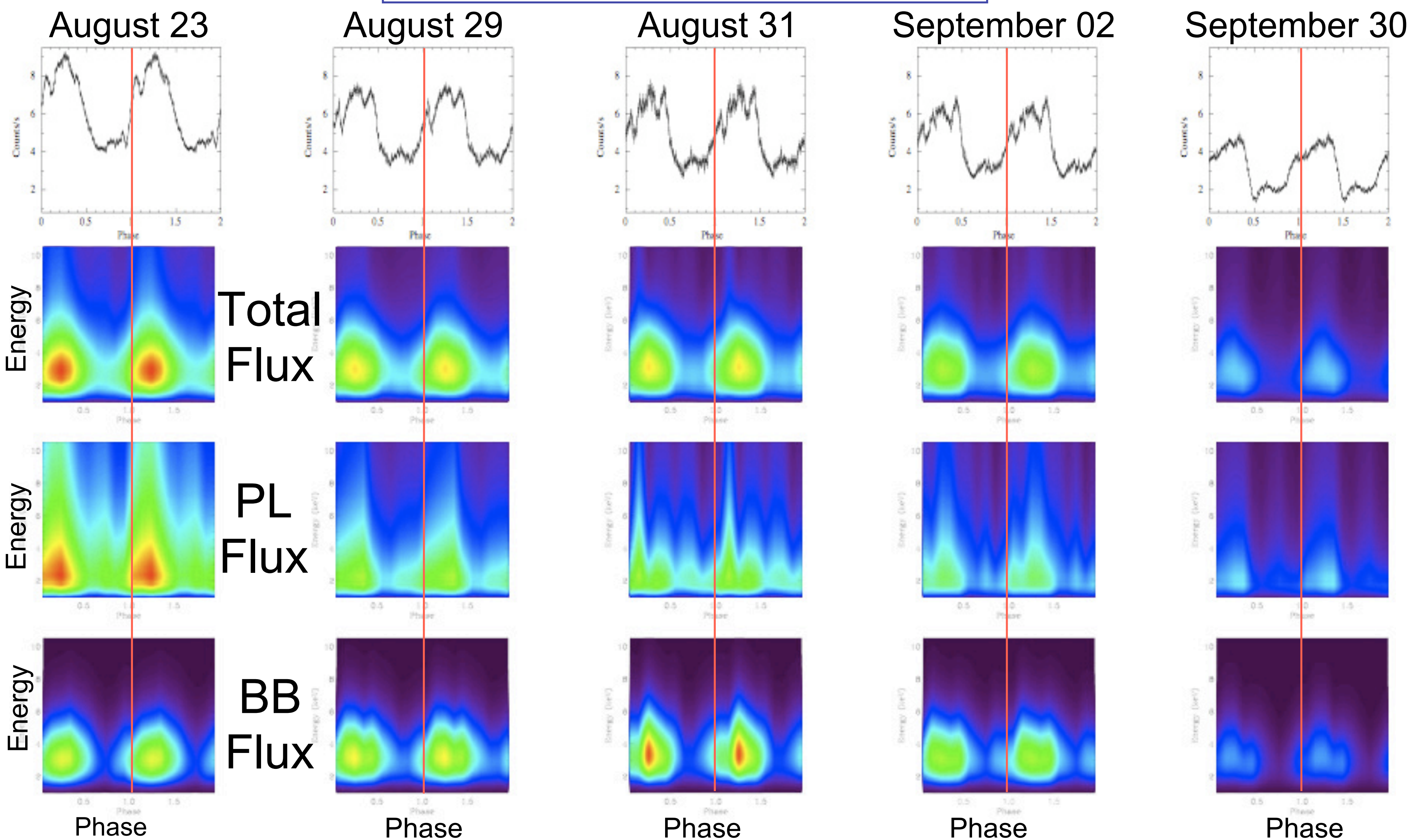
Magnetars are transient!

- Stab

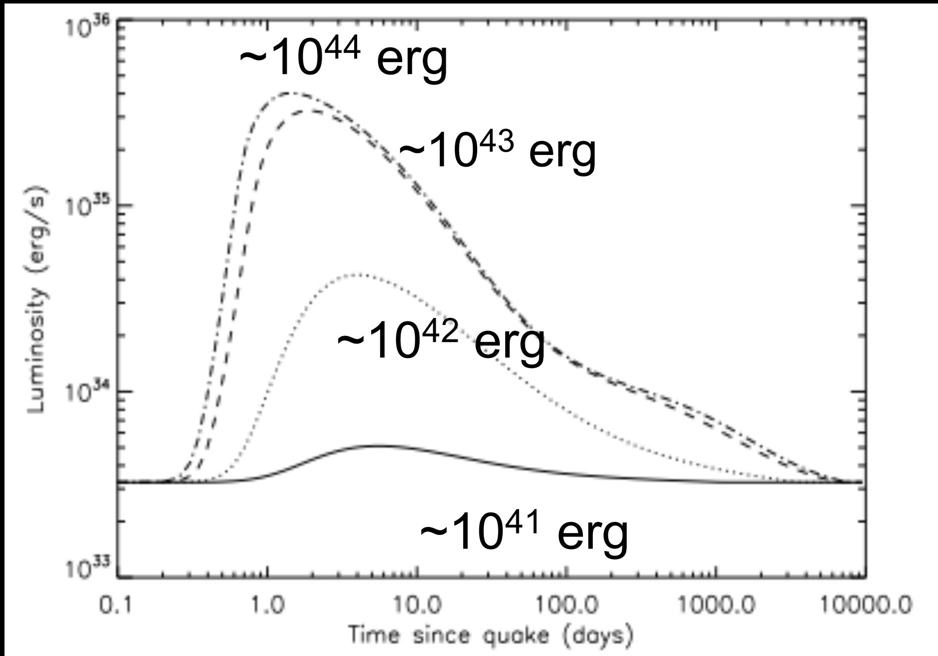


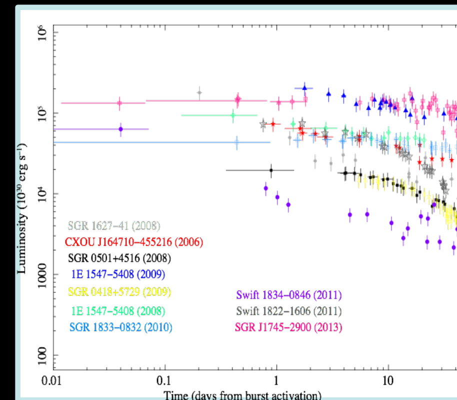
Transient magnetars: study crustal cooling

An XMM stand alone result!



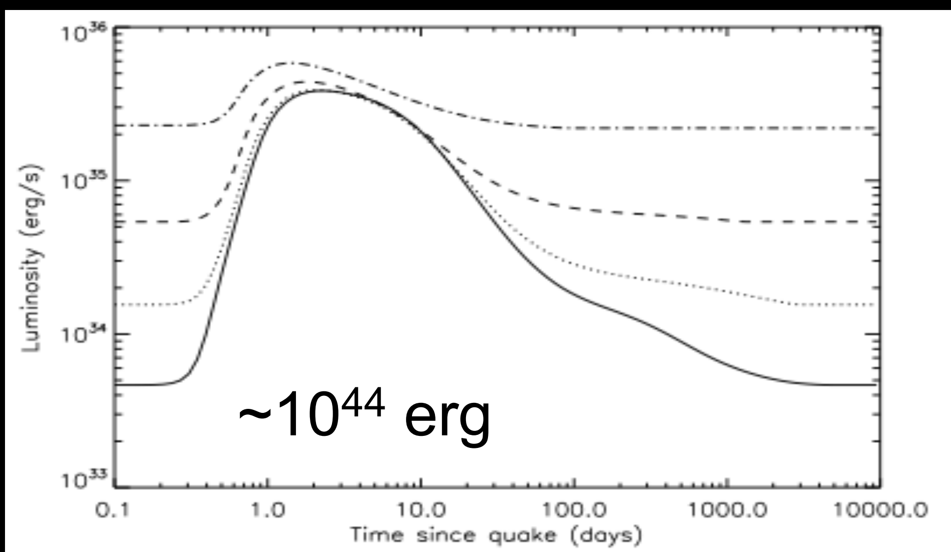
Transient magnetars: study crustal cooling

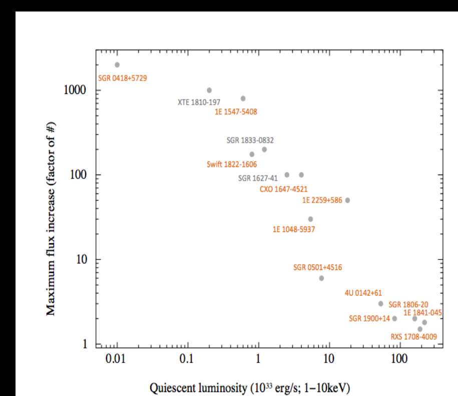




Varying the injected energy

Standard candles!





Varying initial quiescent luminosity

All magnetars are transient!

(Pons & Rea 2012)

A unified scenario for different neutron star classes

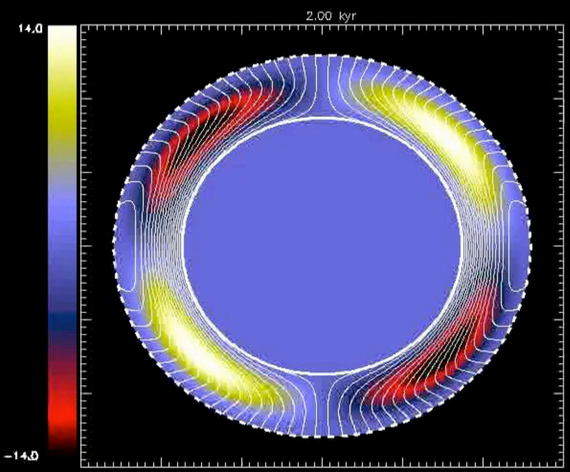
Magnetic properties at birth, and age, drive the different neutron star classes

Relatively Magnetic Pulsar

Intial conditions:

$B_{dip} \sim 10^{13}$ G (white lines)

$B_{int} \sim 10^{14}$ G (colors)

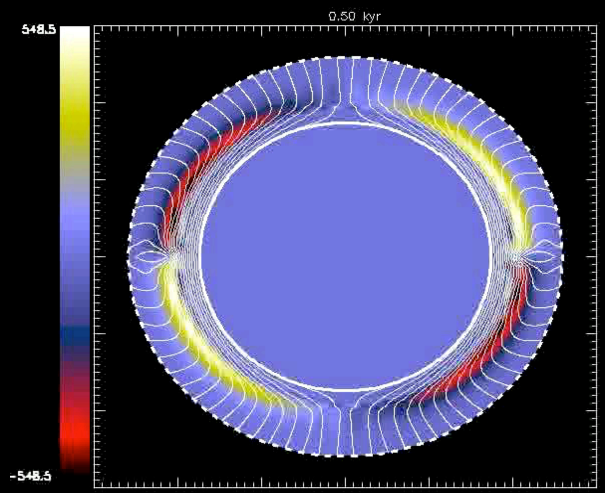


Very Magnetic Pulsar

Initial conditions:

$B_{dip} \sim 10^{14}$ G (white lines)

$B_{int} \sim 10^{15}$ G (colors)

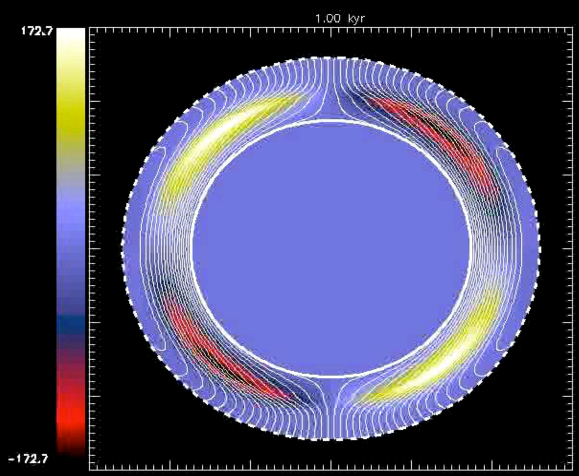


Extremely Magnetic Pulsar

Intial conditions:

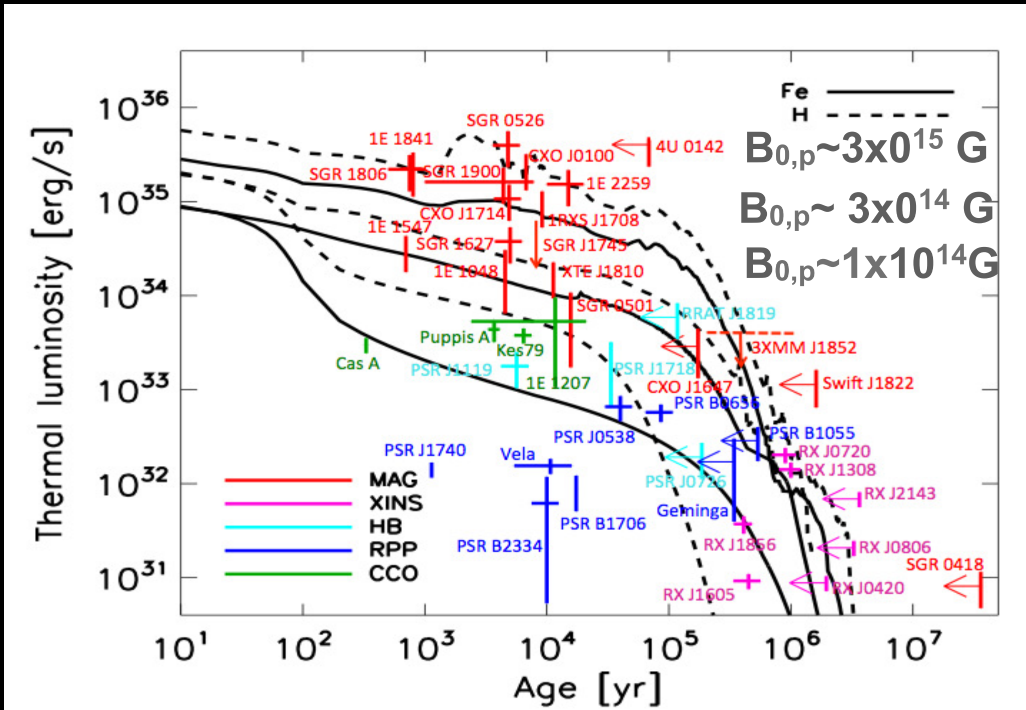
$B_{dip} \sim 10^{15}$ G (white lines)

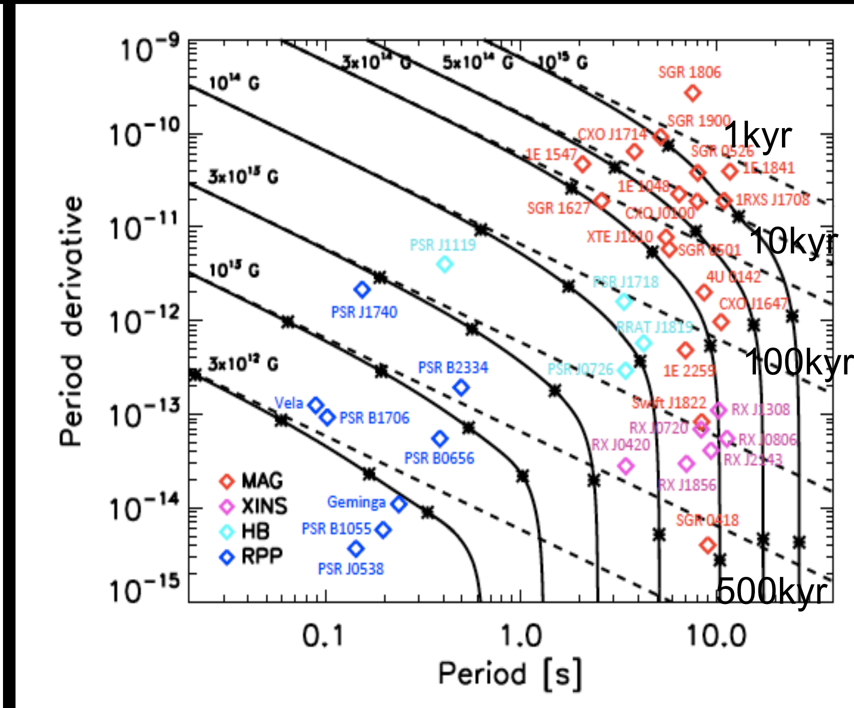
$B_{int} \sim 10^{16}$ G (colors)

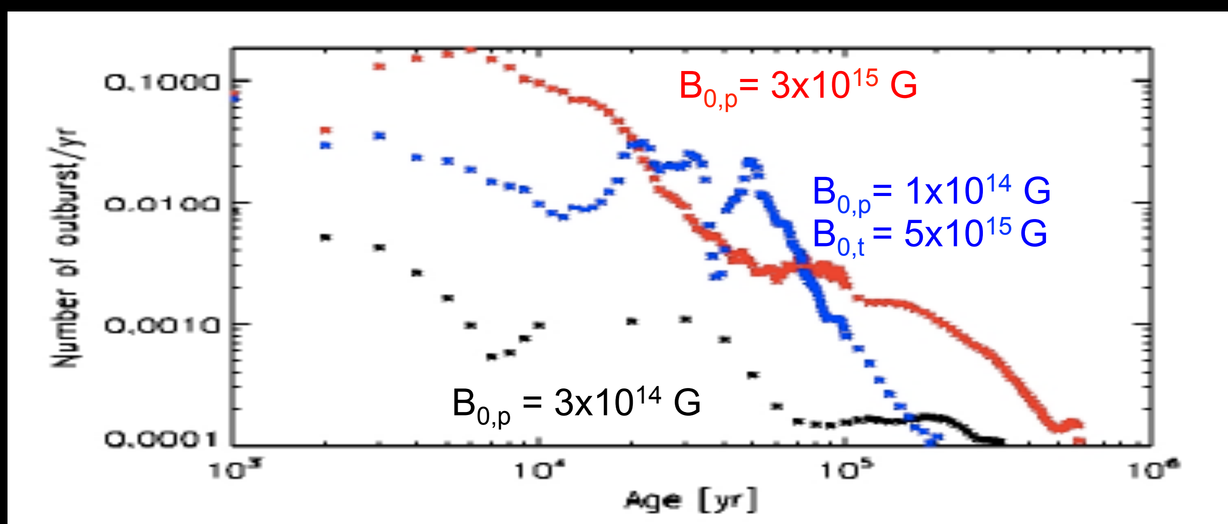


(Vigano', Rea, Pons, Perna, Aguilera & Miralles 2013; Elfritz et al. 2016 in prep)

A unified scenario for different neutron star classes







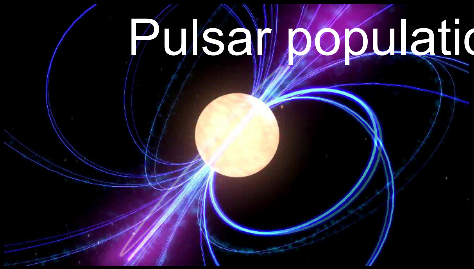
(Vigano', Rea, Pons, Perna, Aguilera & Miralles 2013; Elfritz et al. 2016 in prep)

ICE-IEEC

Magnetars… are starting to show up everywhere…

Coalescence of compact binaries

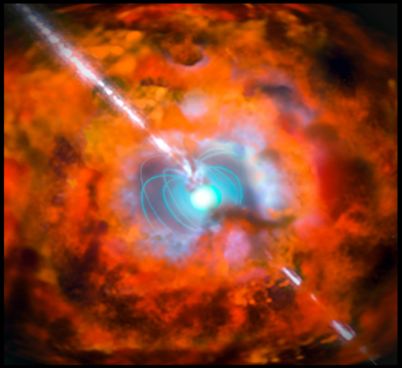
Pulsar population



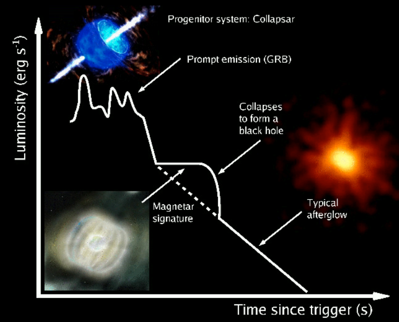
FRBs

?

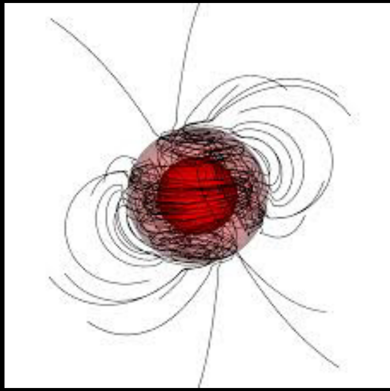
Super Luminous supernovae



Gamma Ray Bursts



Gravitational waves



ULXs

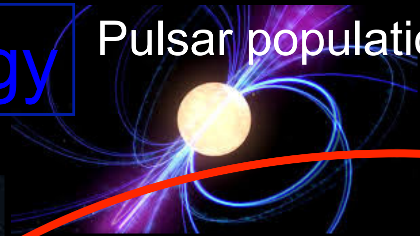
Super Giant Fast X-ray Transients

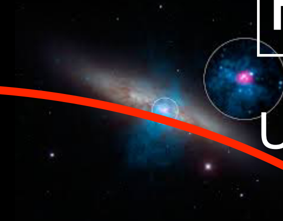
Which is the definition of magnetars?

Which is the definition of a magnetar?

Magnetic Energy

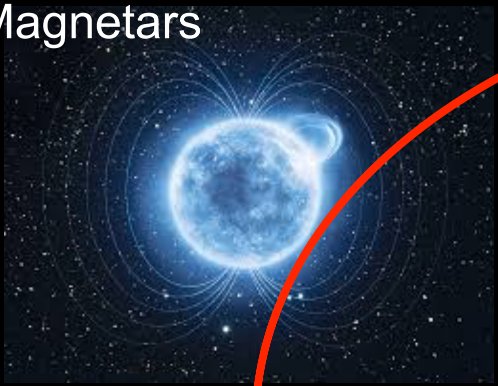
Pulsar population



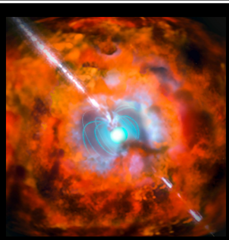


Rotational Energy

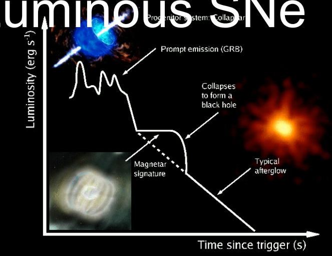
Magnetars



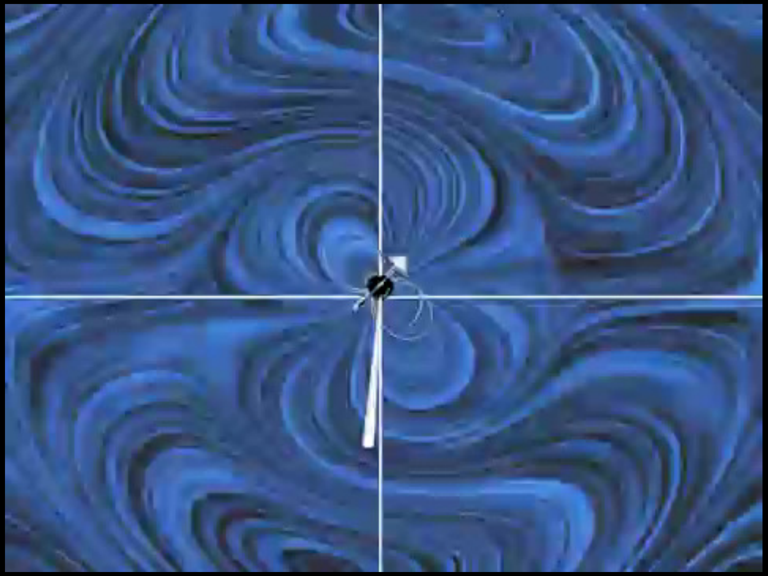
ULXs

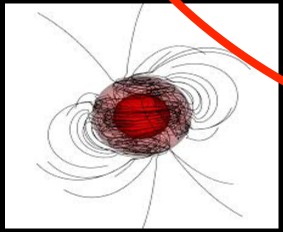


Super Luminous SNe



Gamma Ray Bursts





Gravitational waves

Gravitational Energy

Coalescence of compact binaries

Magnetar science with XMM-Newton + multiband facilities

Swift + Fermi/GBM + MAXI: trigger on new magnetar outbursts

XMM-Newton fast slew:

- Spin period and Pdot (characterizing the transient)
- Proton cyclotron lines
- Surface temperature at the beginning of the outburst

Chandra, NuStar, INTEGRAL:

- multi-X folow-up depending on visibility and preliminary spectral results

ESO, GTC, WHT, Hubble

- Triggered depending on distance and environment

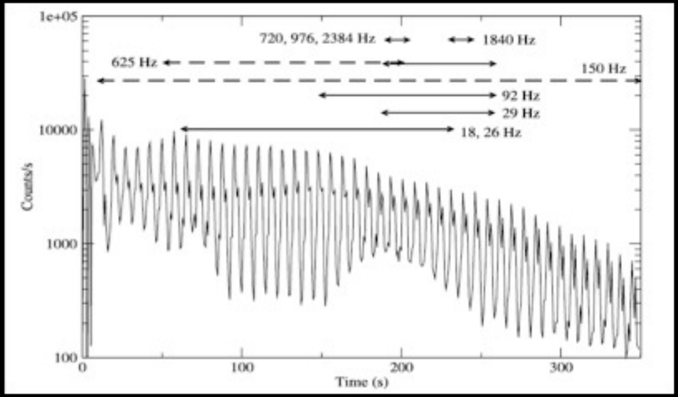
Parkes, GTB, Effelsberg, EVLA, ATCA

- Triggered depending on distance and environment

Fermi-LAT comes from free, MAGIC comes within the GRB program

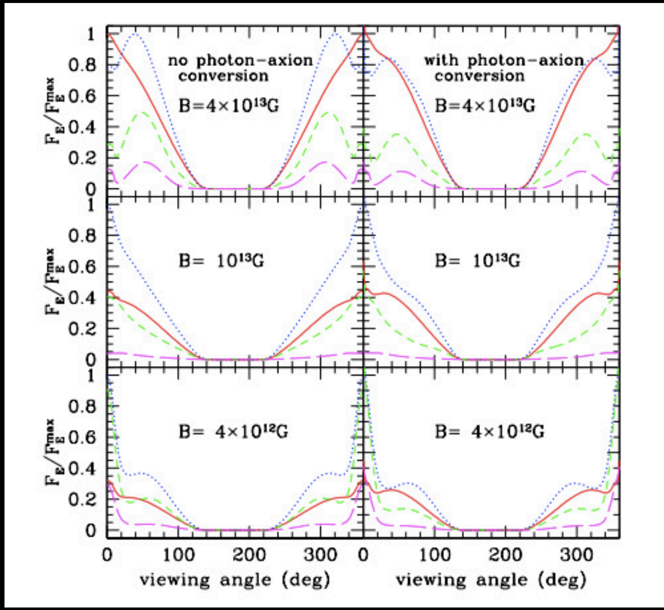
Future for XMM-Newton in the field…

- Get ready for the next Giant Flare…



Extremely difficult to set-up multi-band fast reaction, and simultaneous observations within ToO programs.

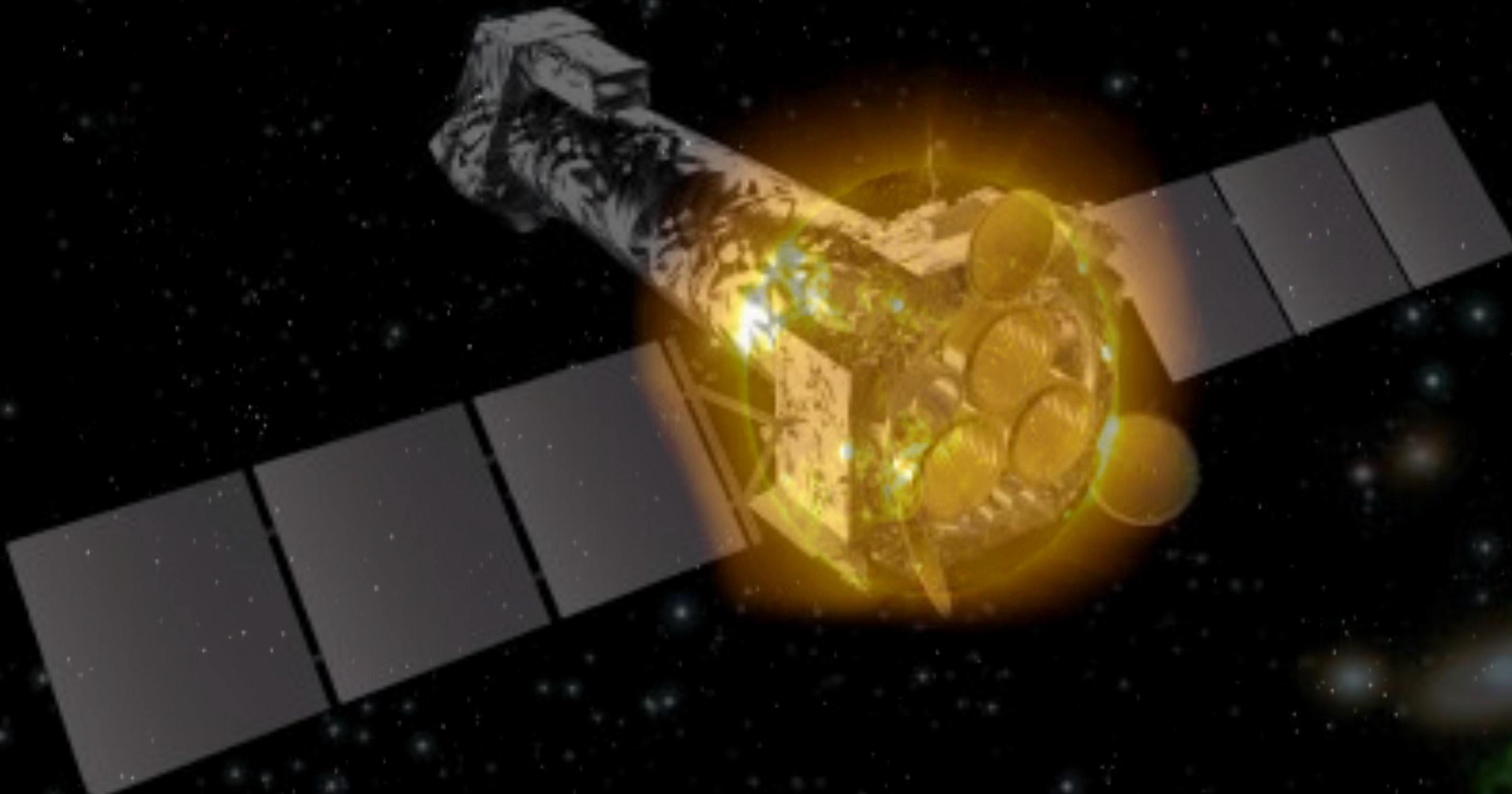
- Very deep (LP or VLP) observations of 10^{13} G objects in search for weak spectral lines, surface temperature maps, axions (?)…



Very difficult to get highly risky LP or VLP accepted…actually, impossible…

The XMM-Newton magnetar revolution….

…just started!



THANKS!!!