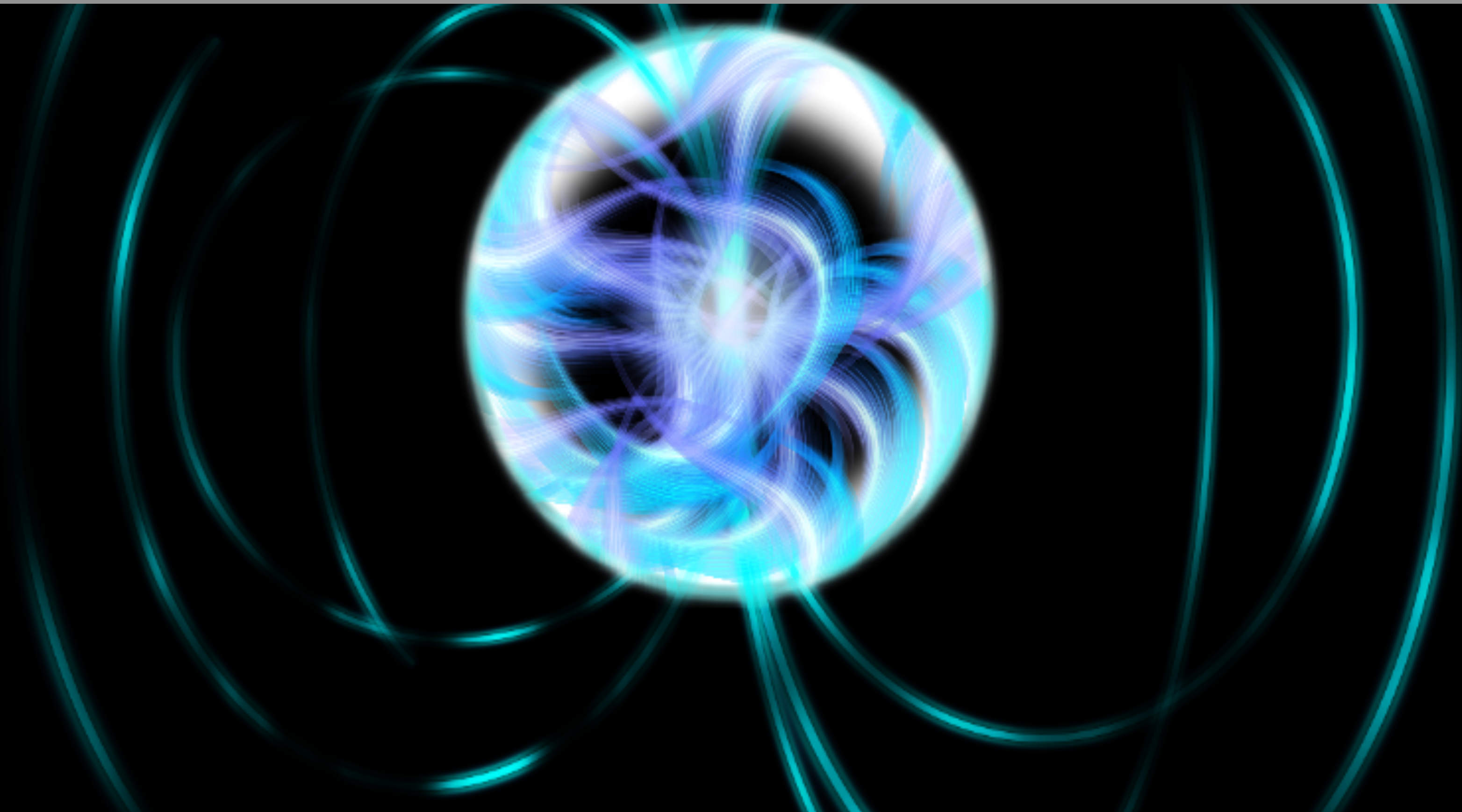
The Astro-H view of highly magnetic neutron stars: magnetars & Co.

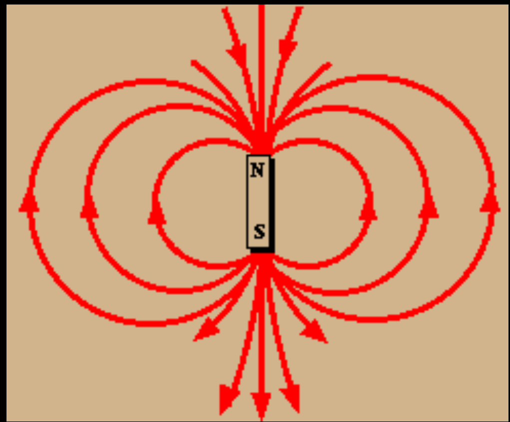


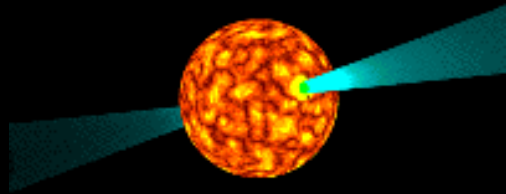
Daniela Hadasch & Nanda Rea

CSIC-IEEC, Barcelona, Spain

How do we define the B-field?

Rotating dipole

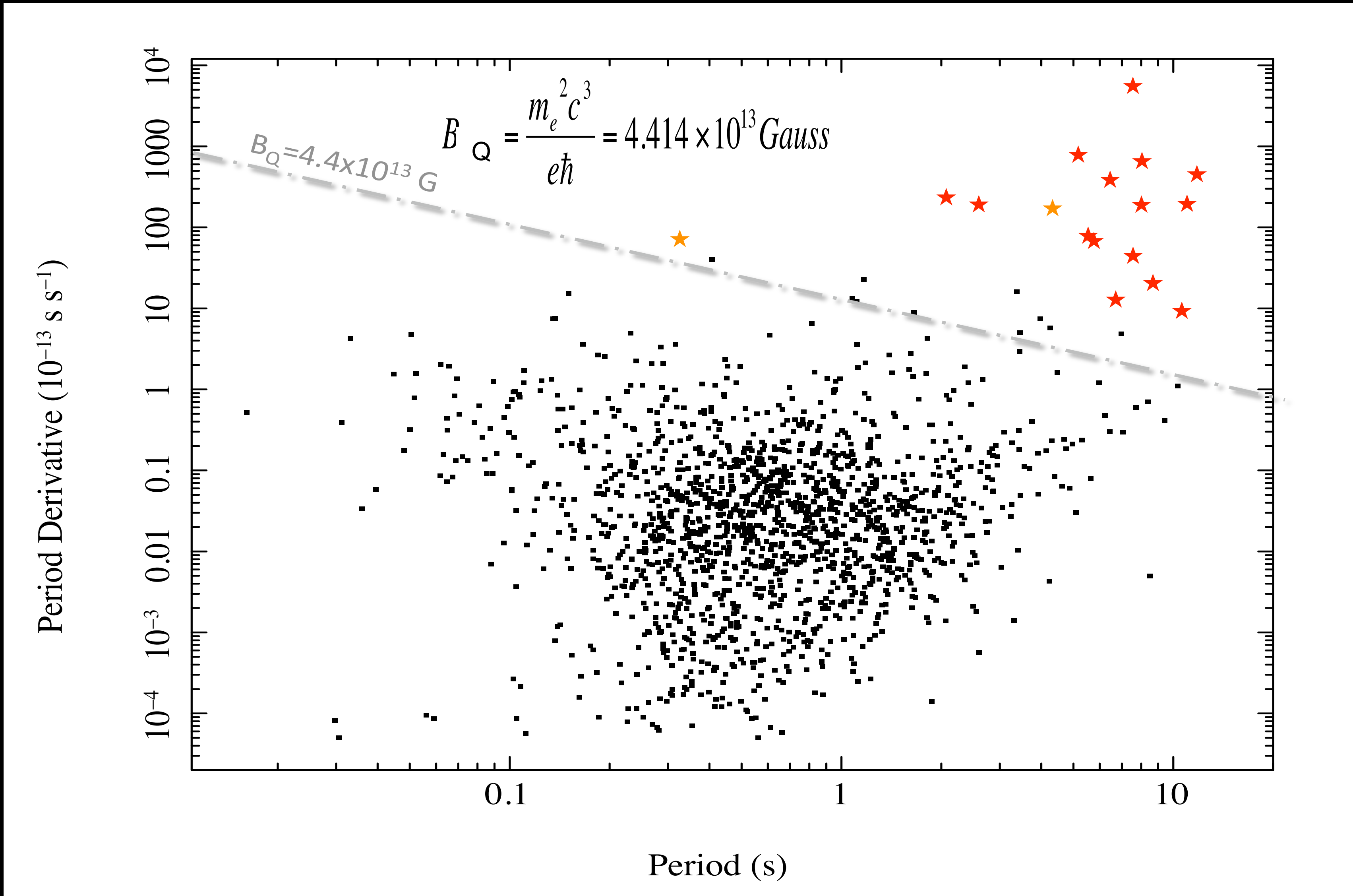




$$\dot{E}_{rot} = -\frac{2}{3c^3}|\ddot{m}|^2 = -\frac{2B^2R^6\Omega^4\sin^2\alpha}{3c^3}$$

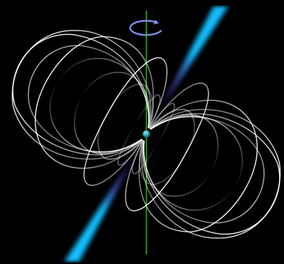
$$P\dot{P} = \left(\frac{8\pi^2 R_{ns}{}^6}{3c^3 I}\right) B_0{}^2 \sin^2\alpha$$

How do we define the B-field?



Different classes of highly magnetic neutron stars

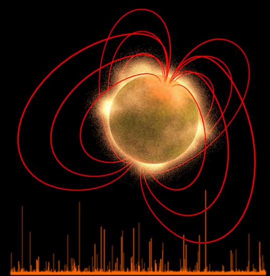
1- High-B pulsars: ~7 (over 2000)



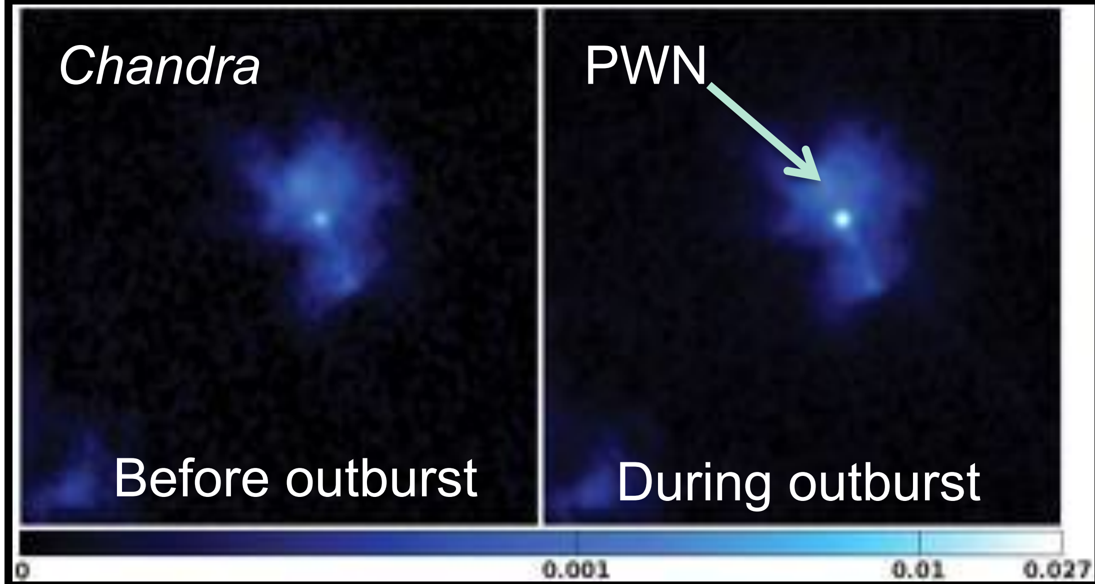
2- Thermally emitting neutron stars: ~9

3- Rotating radio transients (RRATs): ~1 (over 23)

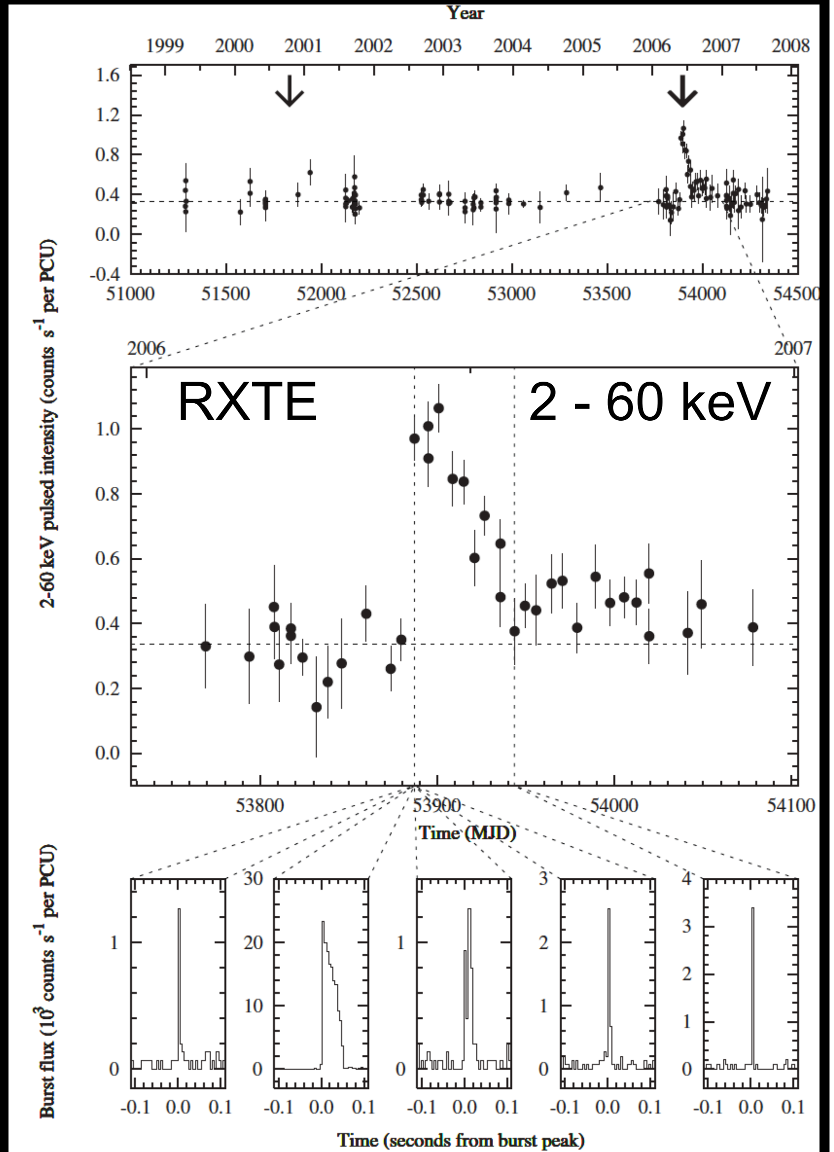
4- Magnetars: ~20



High B-field pulsars



- 7 sources only 4 of which are very faint **X-ray emitters**
- Periodicities in the arrival times between **0.3 -11 s**
- In 1 case there was evidence of magnetar like burst activity: **PSR J1846-0258**



Kumar & Safi-Harb 2008, ApJL
Gavriil et al. 2008, Science

High B-field pulsars: PSR J1846-0258

Why could it be a magnetar?

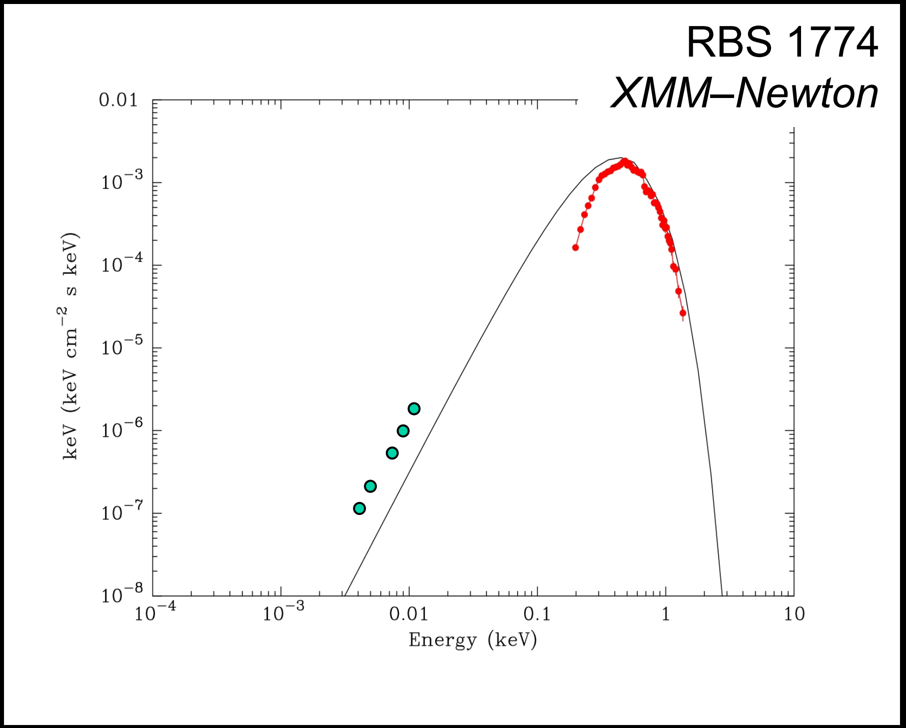
- largest dipolar magnetic field of known young rotation-powered pulsars: **4.9×10^{13} G**
- pulsars normally steady, this shows **large timing noise** and **magnetar like burst**: brightening by factor 6 between 2000-2006
- **spectrum softened**: change in B-field configuration or magnetar like burst
- **PWN spectrum changed** (not significantly…): injection of relativistic particles in PWN → enhancing brightness
- **unusually high X-ray efficiency and variability** → fraction of X-ray luminosity powered by magnetic energy (e.g. during burst)

Why not a magnetar?

- **X-ray luminosity did not exceed the pulsar's rotational energy power** → spin-down can energetically power the X-ray emission from the pulsar and its PWN

Thermally emitting neutron stars

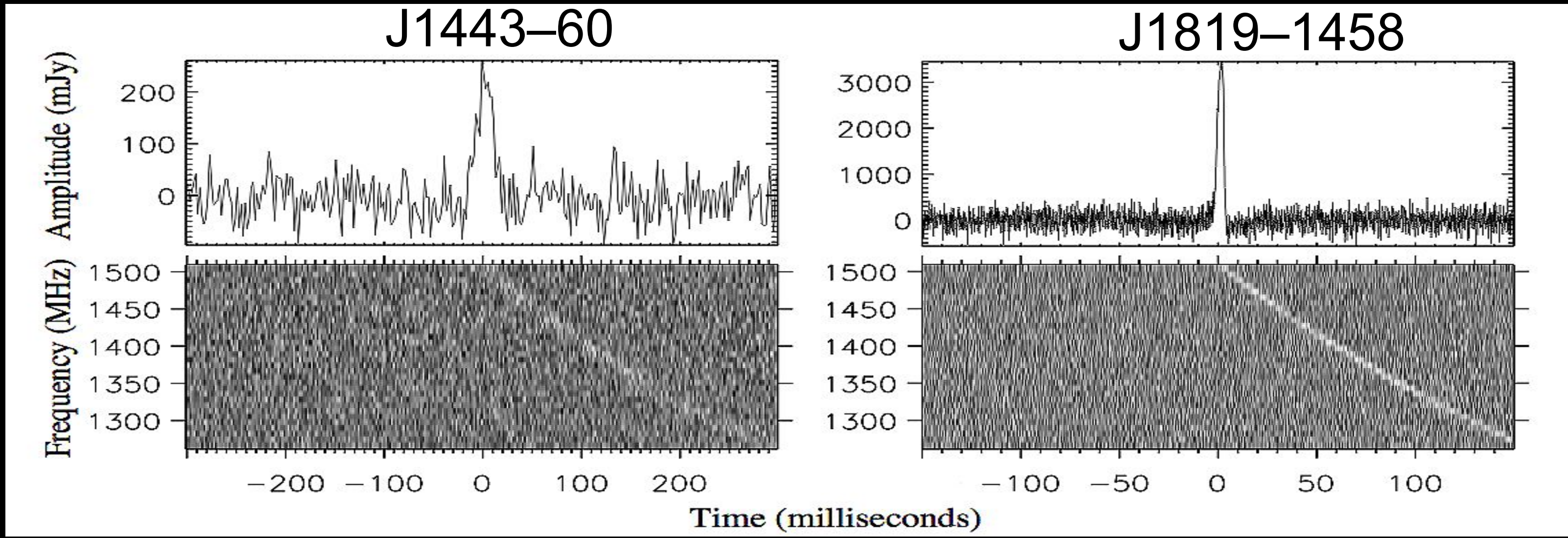
- 9 sources characterized by a **thermal spectrum plus an absorption spectral feature** (atmospheric or cyclotron)
- Periodicities in the arrival times between **4 -11 s** → **magnetar like**
- No radio pulsations (due to geometrical bias?): low luminosity at 1.4 GHz for RBS1774 wrt other pulsars
- Possible episodes of **glitches or precession**



(Rea et al. 2007b, MNRAS; van Kerkwijk & Kaplan 2007, Ap&SS)

Close (~500pc), **old neutron stars**, on the final phase of their cooling. Hotter than normal pulsars probably because of their **high B-fields** (~10^{13} G).

Rotating radio transients (RRATs)



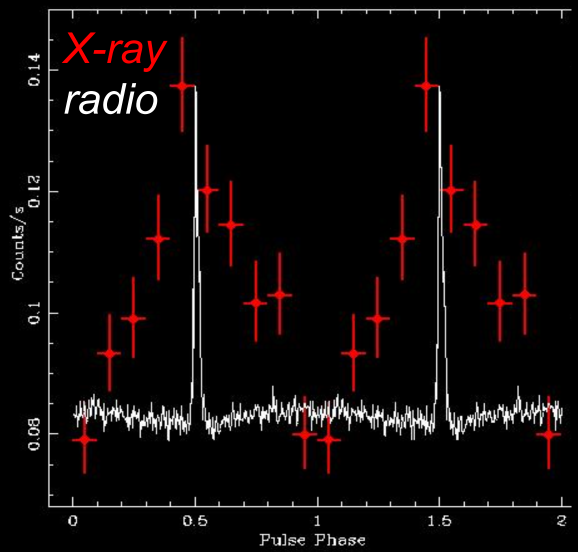
(McLaughlin et al. 2006, Nature)

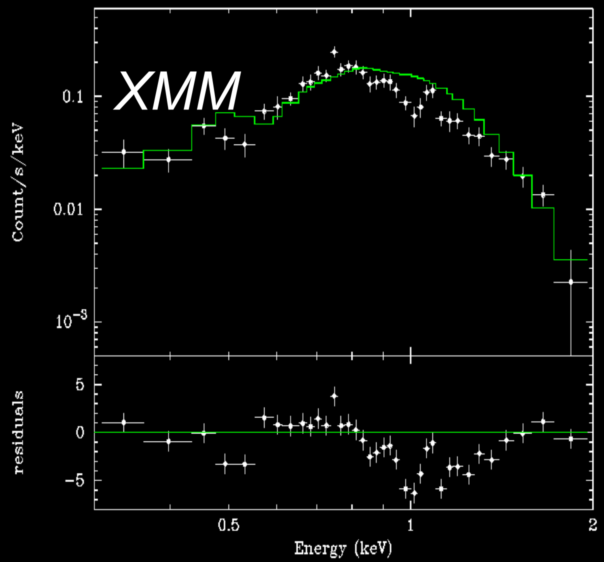
- 23 sources characterized by dispersed **radio bursts** between 2-30 ms
- The average time intervals between bursts is **4 min - 3 hour**
- Periodicities in the arrival times of bursts between **0.4 -7 s**

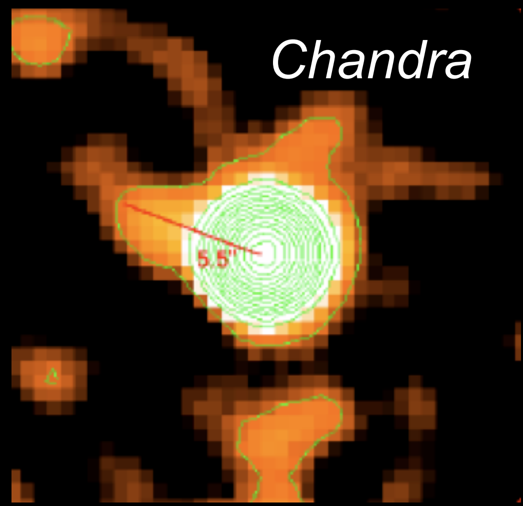
→ **Rotating neutron stars**

The most prolific burster (7 min of burst rate) and the most magnetic one (B~7×10^{13} G), RRAT J1819-1458, is also an X-ray emitter!

Rotating radio transients (RRATs): RRAT 1819-1458





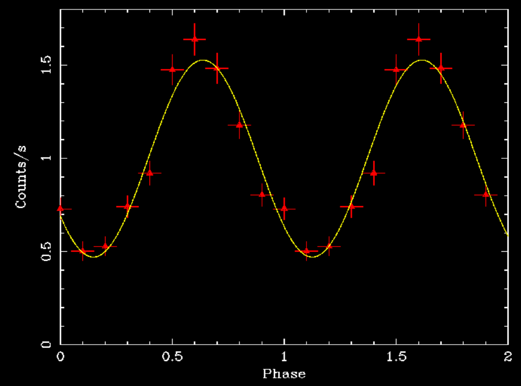


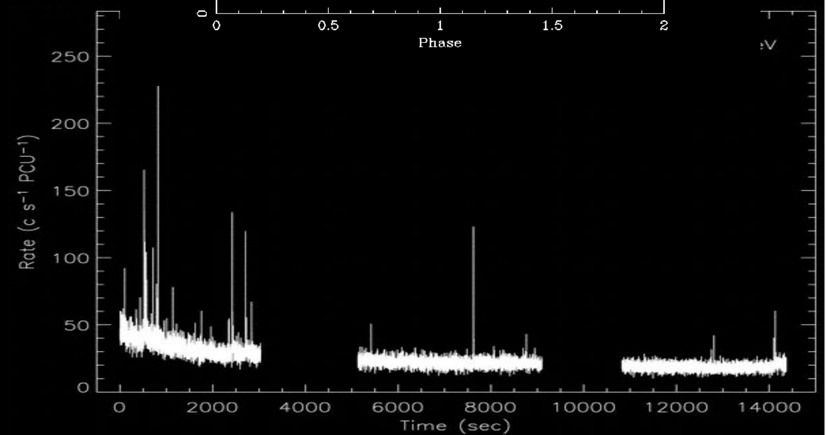
(McLaughlin, Rea, et al. 2007, ApJ; Rea et al. 2009, ApJL, Rea et al. 2010, MNRAS)

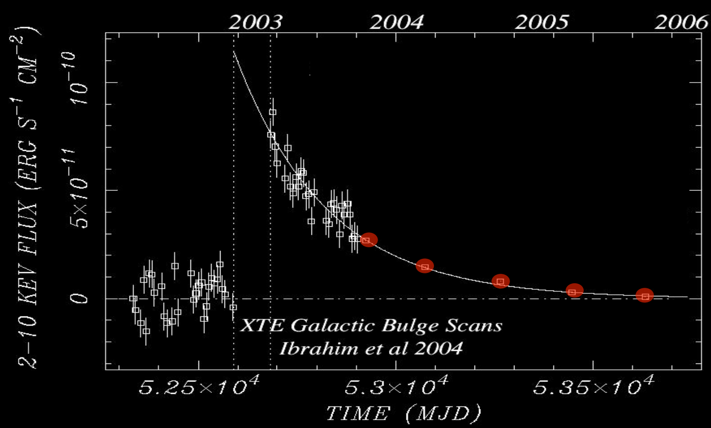
- Recently discovered to be also a strong **X-ray pulsar**.
- **Broad spectral features** in its X-ray spectrum around 1keV.
- Surrounded by a **possible magnetic-powered wind nebula**.
- Low spin-down energy loss → rather high X-ray efficiency for PWN X-ray emission → need of an **additional source of energy** such as the high magnetic energy of this source

Magnetars: SGRs and AXPs

- bright X-ray pulsars
  $L_x \sim 10^{33}$-10^{36} erg/s
- rotating with periods of **2-12s**
- glitches and neutron stars quakes
- **bursts** on many timescales
  (ms to 100s)
- **transient outbursts** (X-ray flux change of a factor of 10-1000)



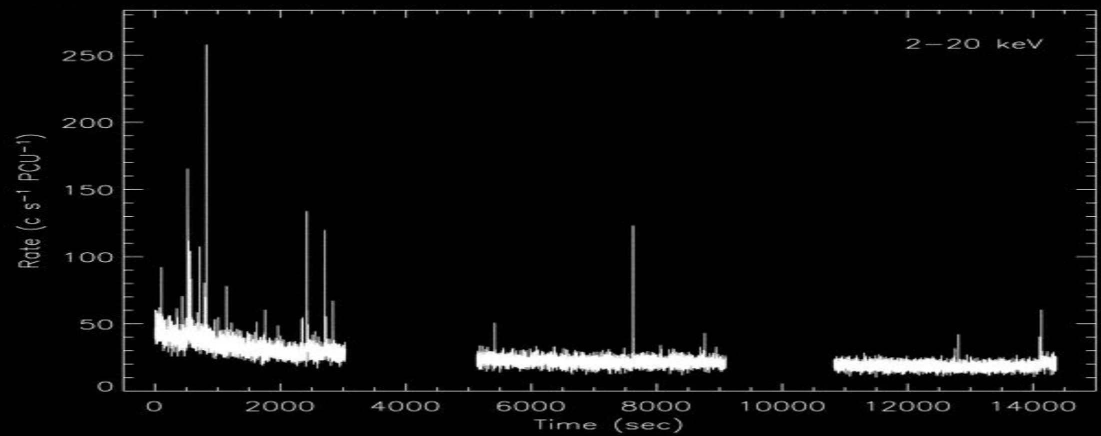




Magnetars: flaring episodes

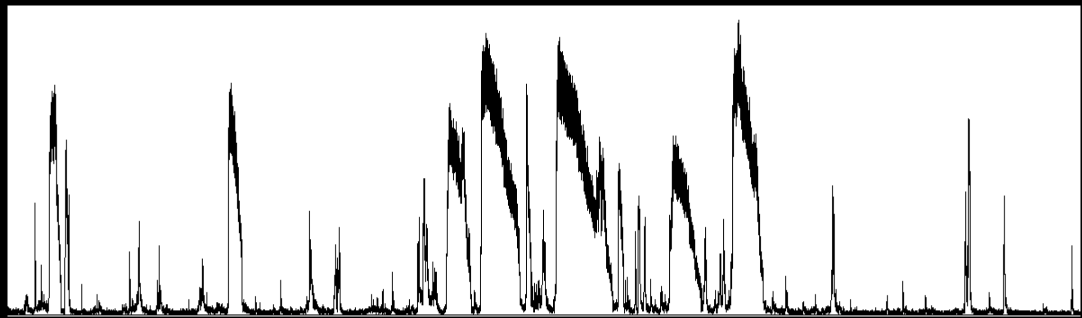
Short bursts

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



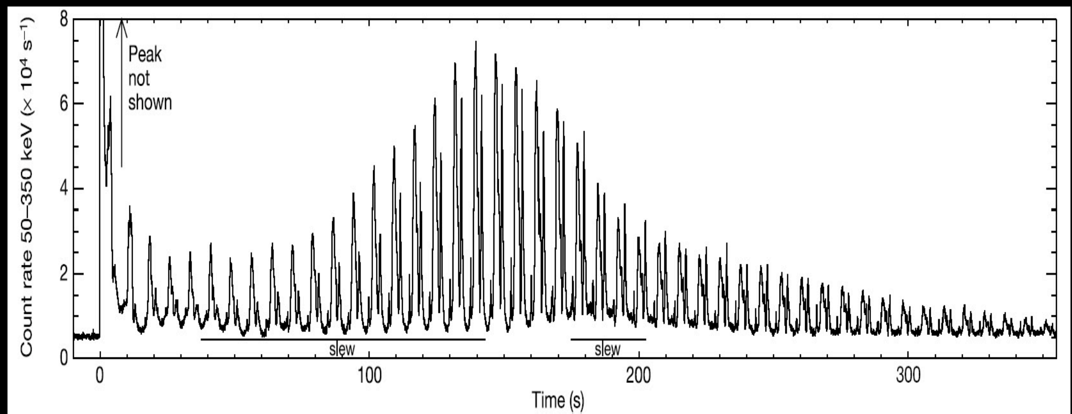
Intermediate bursts

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

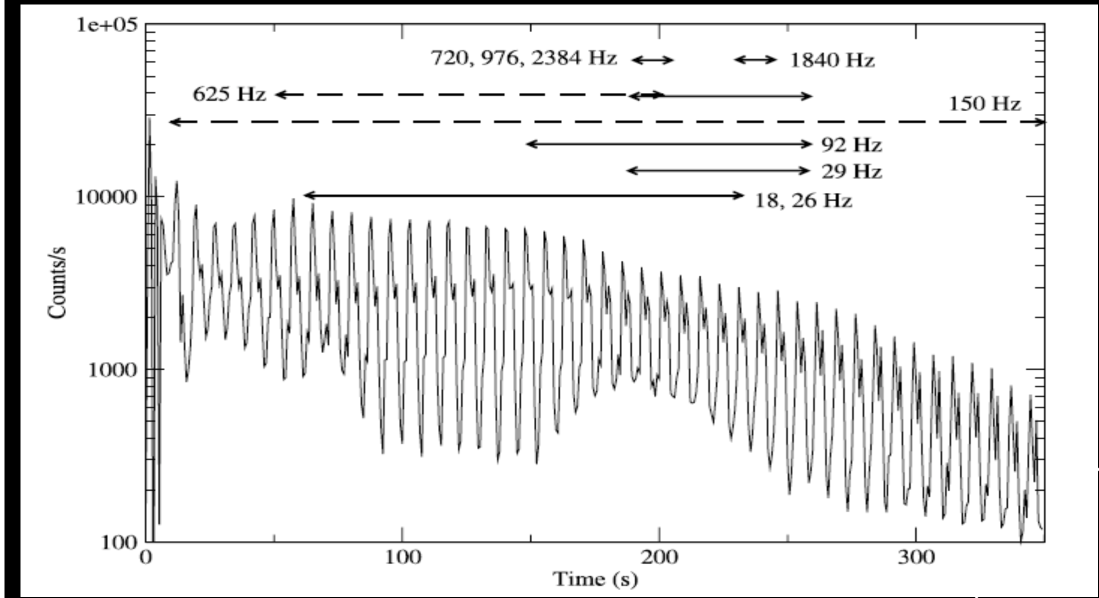


Giant Flares

- Output of high energy is exceeded only by blazars and GRBs
- peak energy > 3x10^{46} ergs/s
- burst tail can last >500s, showing the NS spin

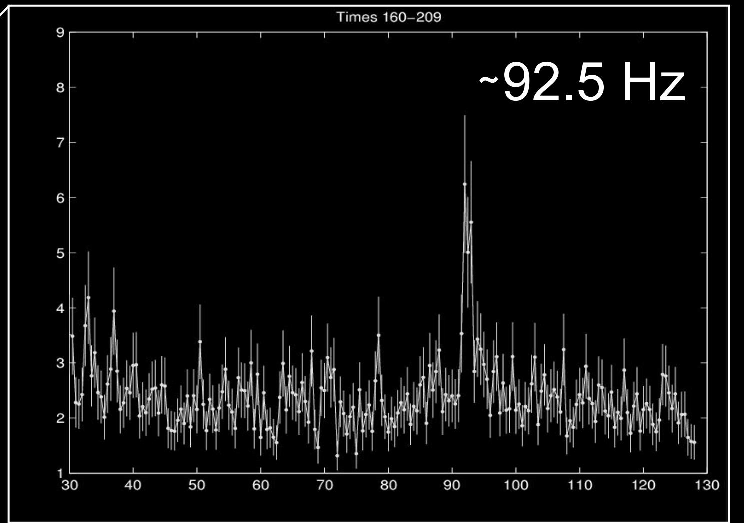


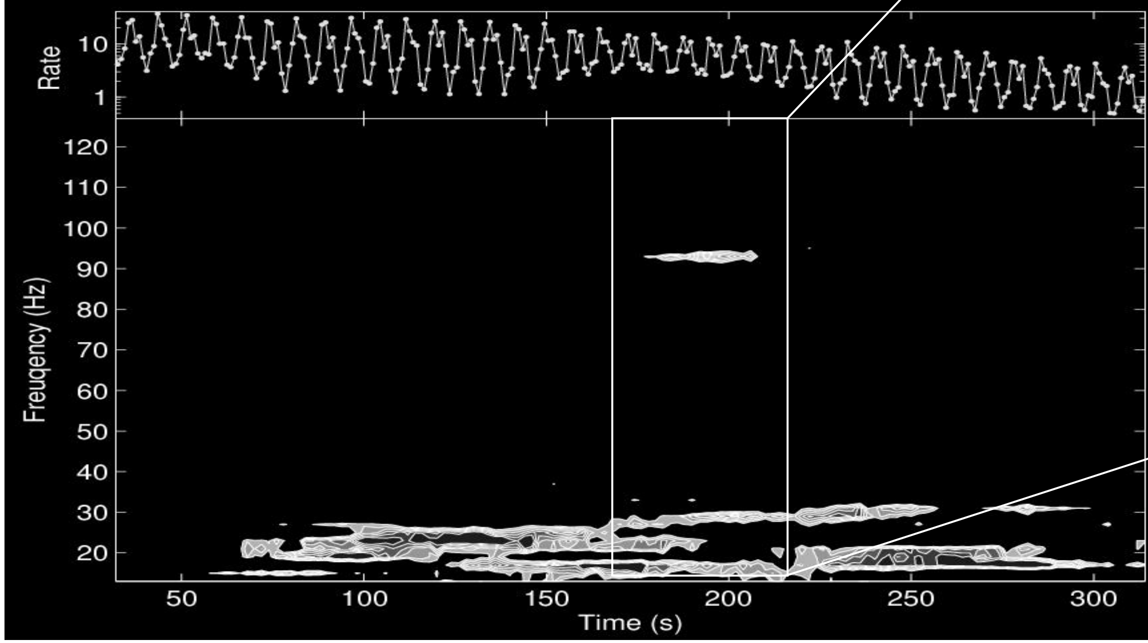
Magnetars: flaring episodes



Star-quakes on a neutron star!

SGR 1806-20: Hyperflare in 2004





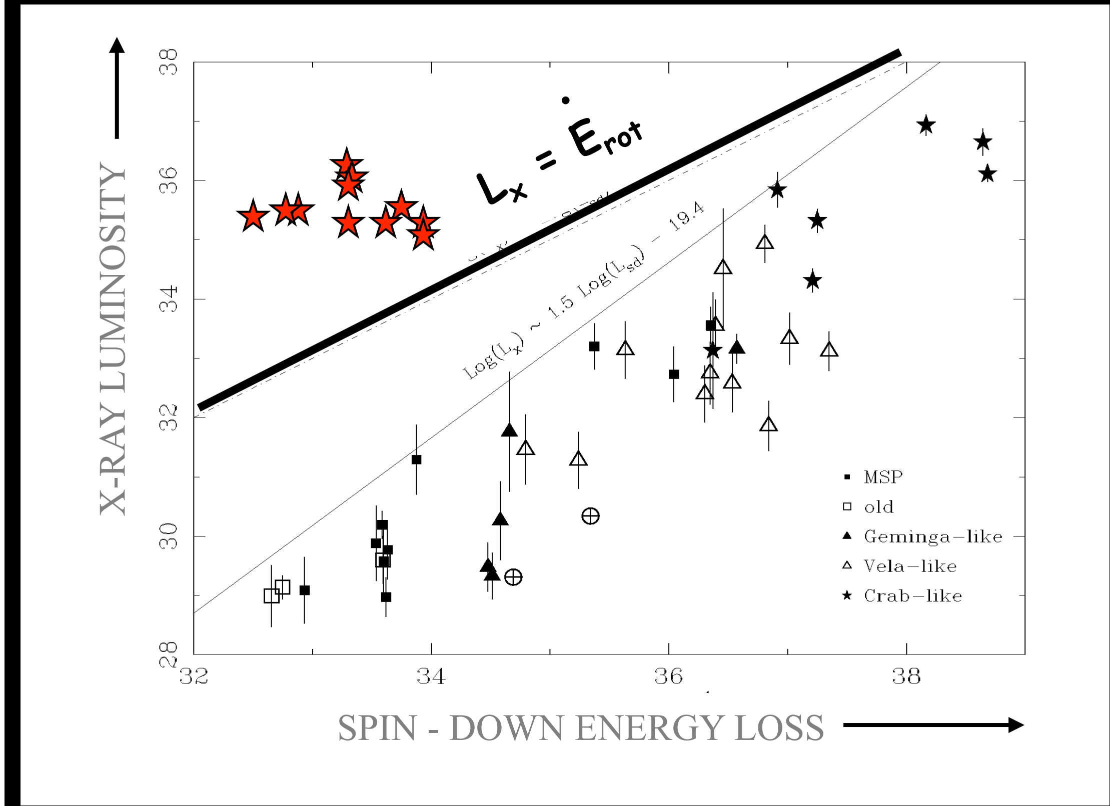
(Israel et al. 2005, Strohmayer & Watts 2005)

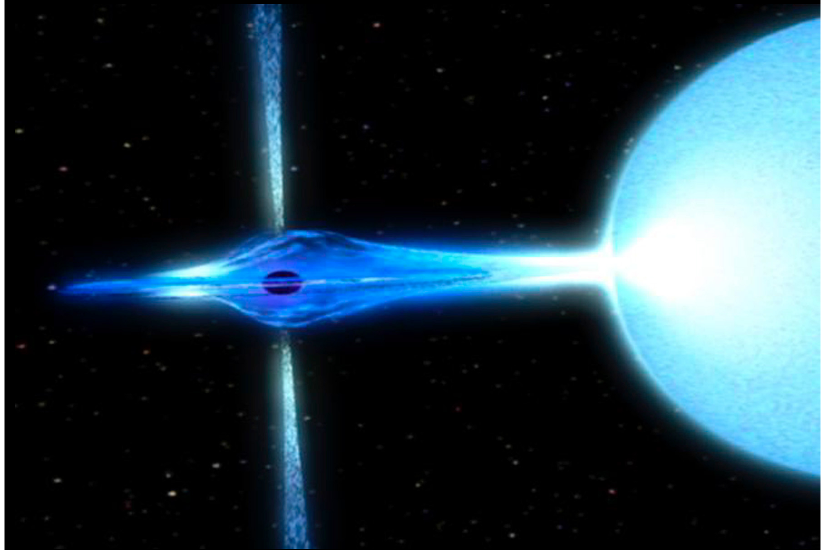
Magnetars: flaring episodes

SGR 1806-20: Hyperflare in Dec 2004

- Caused a strong perturbation in the Earth ionosphere and saturated the detectors on every high energy satellite
- A total energy of ~(3–10) x10^{46} ergs was released during the main ~0.2–0.5 s long spike at the beginning of the event.
- Seven days after the event, the source was observed and detected in the radio band for the first time
- Discover fast X-ray quasi-periodic oscillations (QPOs) at ~92.5 Hz associated with a relatively hard emission component that dominates the overall energy emission, about 170–220 s after the beginning of the flare
- Evidence of ~18 and ~30 Hz QPOs between 200 and 300 s from the onset of the hyperflare

Magnetars: Why magnetic energy?





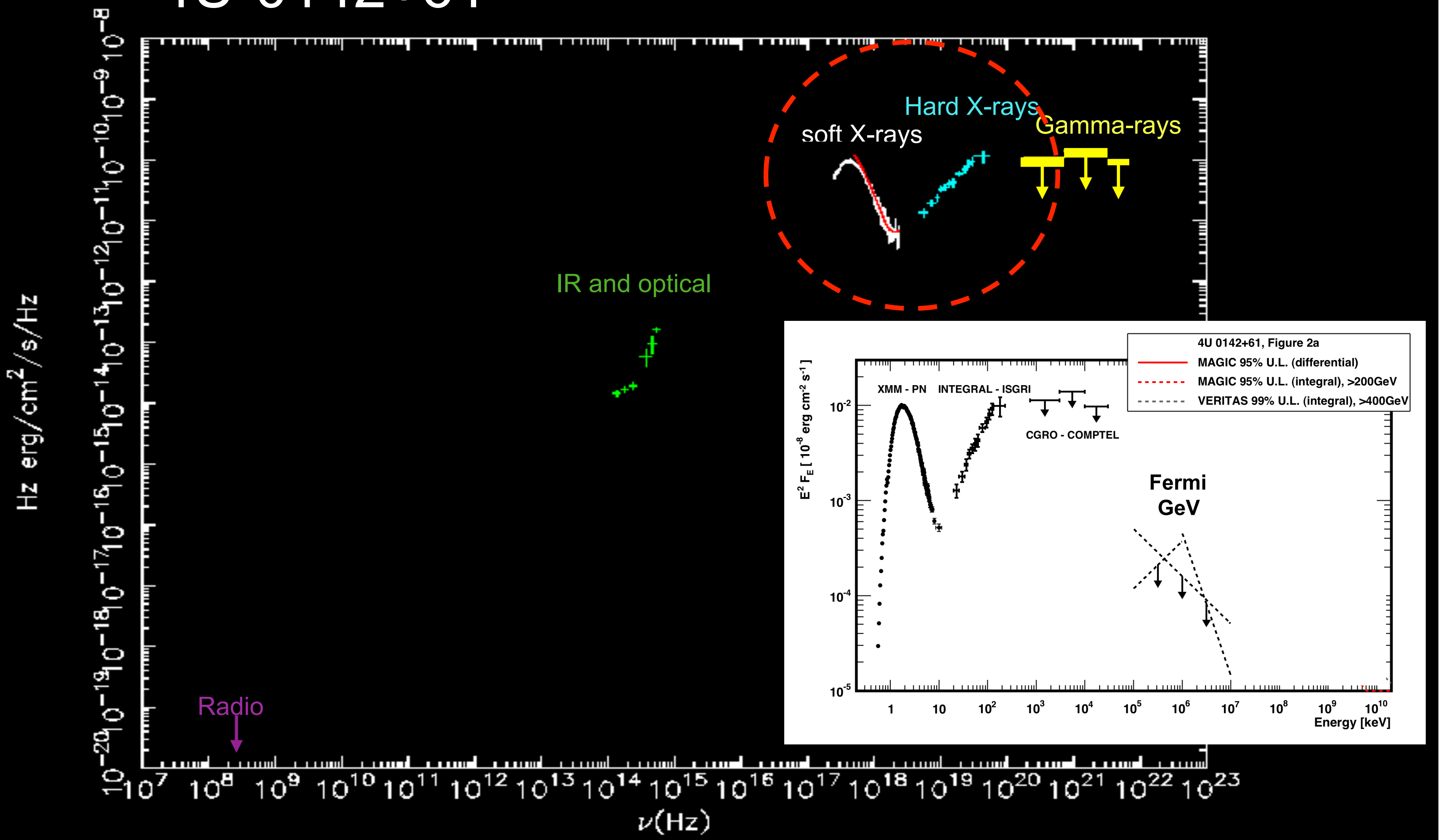
Low rotational power

No evidence for a companion star

Another energy resevoir was needed

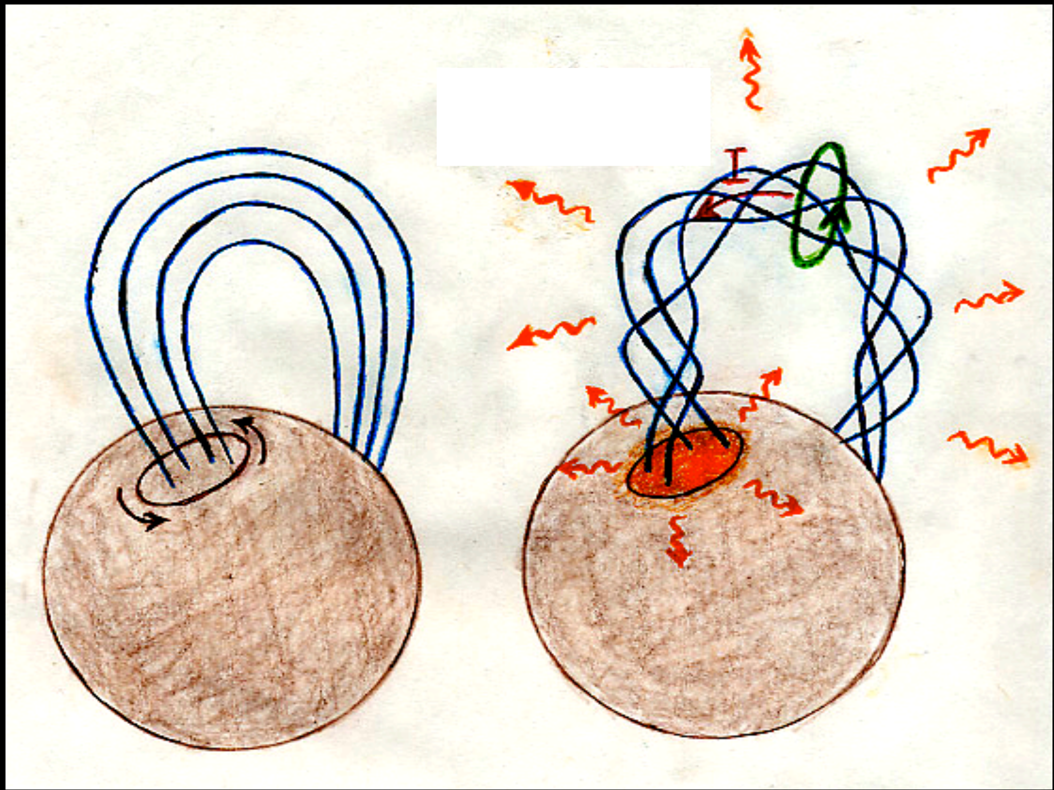
Magnetars: multiband emission

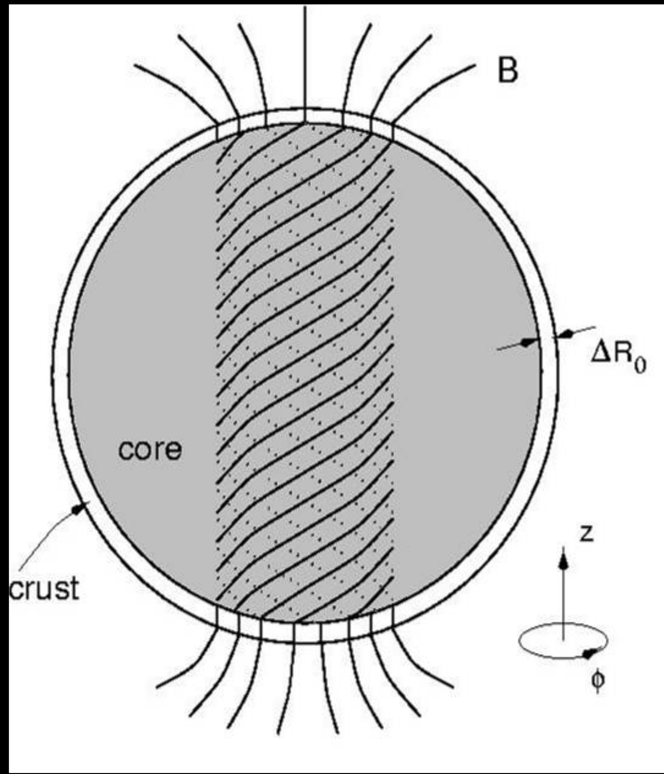
4U-0142+61



(Israel et al. 2004; Kuiper et al. 2004; Gotz et al. 2006; Rea et al. 2007a, ApJL; Fermi-LAT coll. 2010, ApJL; MAGIC coll. 2012, A&A, submitt.)

Magnetars vs normal radio pulsars



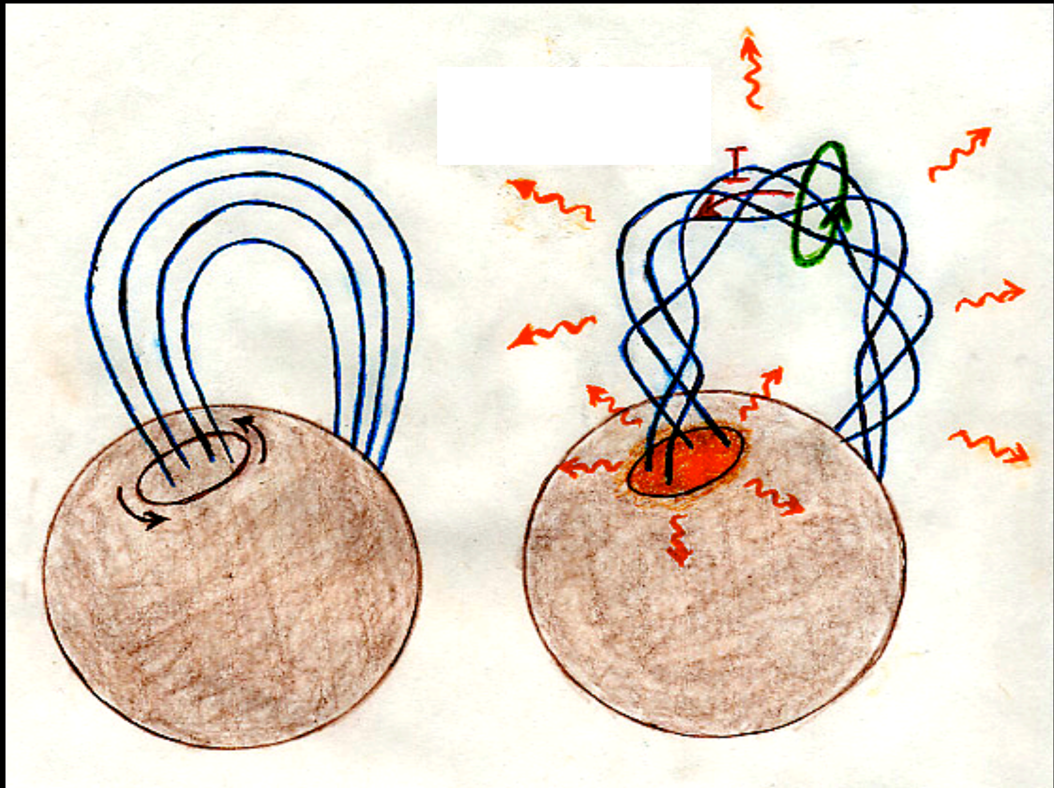


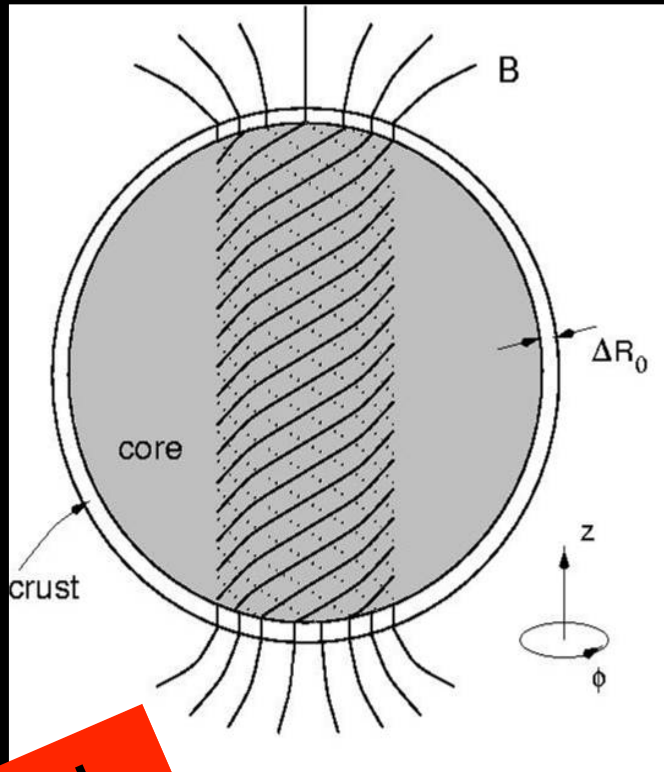
(Thompson & Duncan 1992; 1993; 1995;1996; Thompson, Lyutikov & Kulkarni 2002)

Magnetars were thought to differ from radio pulsars since their **internal magnetic field is twisted up** to ~10 times the external dipole.

At intervals, it can twist up the external field ⇒ **stresses** build up in the NS crust, crustal fractures, **large outbursts and flares**

Magnetars vs normal radio pulsars





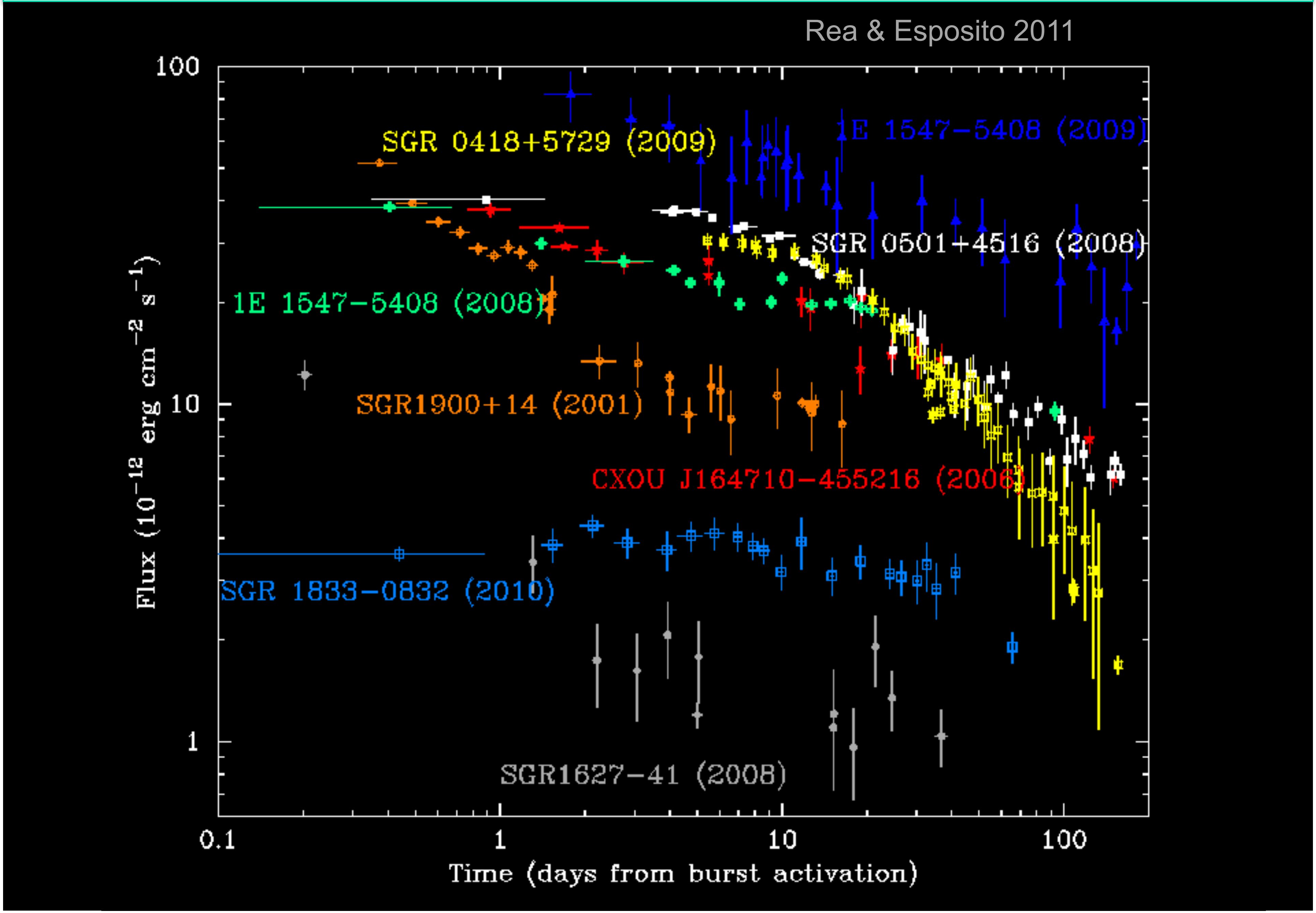
(Thompson & Duncan 1992; 1993; 1995;1996; Tho… Kulkarni 2002)

More next talk by S. Zane!

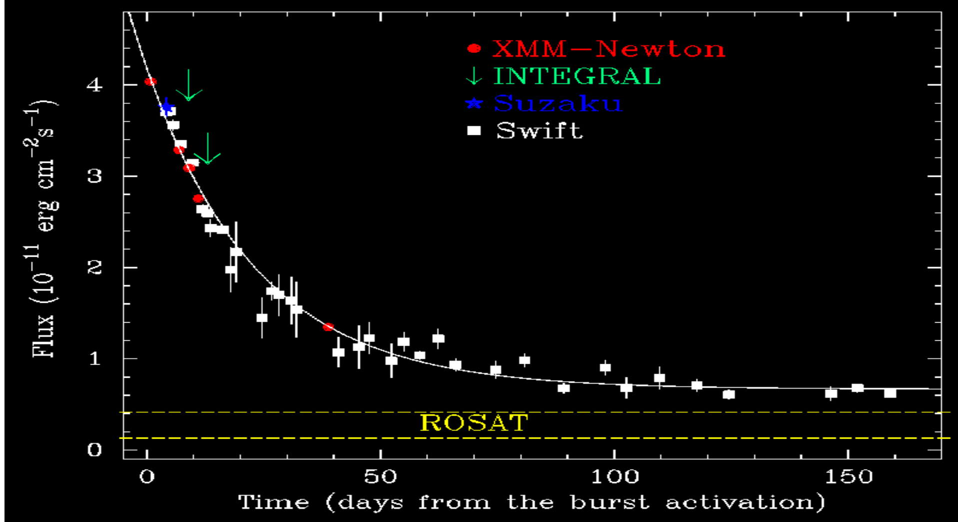
Magnetars were thought to diff… pulsars since their **internal magnetic field is twisted** … times the external dipole.

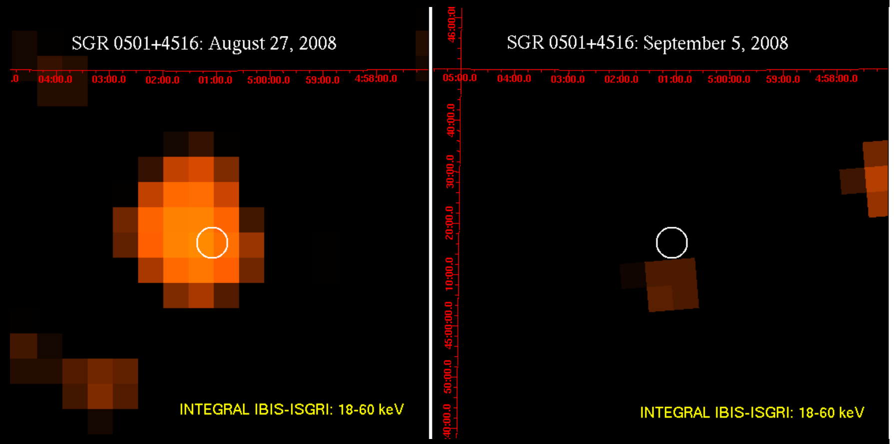
At intervals, it ca… the external field ⇒ **stresses** build up in the NS crust, crustal fract…es, **large outbursts and flares**

Magnetars: transient events



Magnetars: transient SGR0501+4516





First transient detection at hard X-rays!

- Cooling down differently depending on the rotation phase.
- Non-thermal emission decays faster than the thermal one.

→ became undetectable by INTEGRALsome time within 10 days after the on-set of the bursting activity

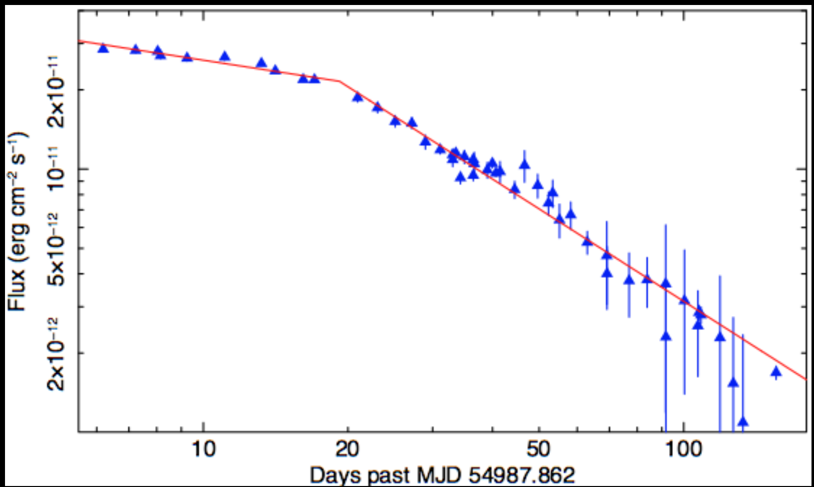
→ first detection of a variable hard X-ray component in a magnetar over such a short timescale.

(Rea et al. 2009, MNRAS)

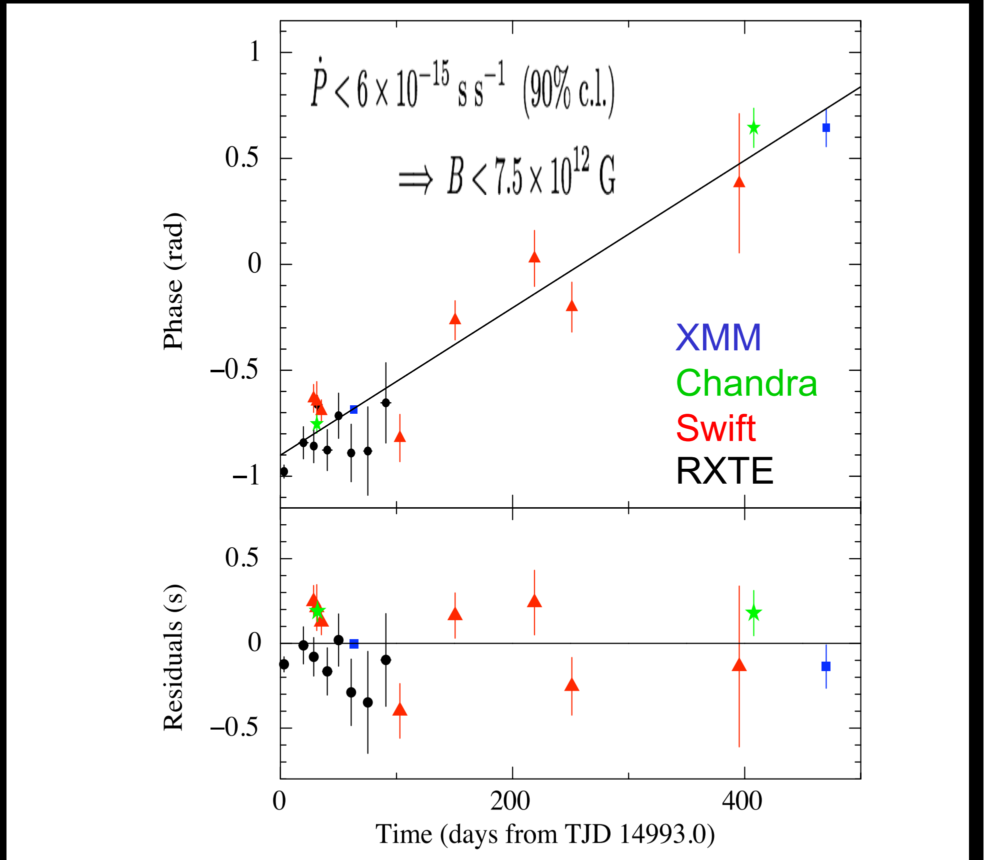
Many more magnetars are hidden in the pulsar population

Recently we have discovered the first low-B "magnetars".

SGR 0418+5729



The X-ray outburst discovered in June 2009 (Esposito et al. 2010, MNRAS)

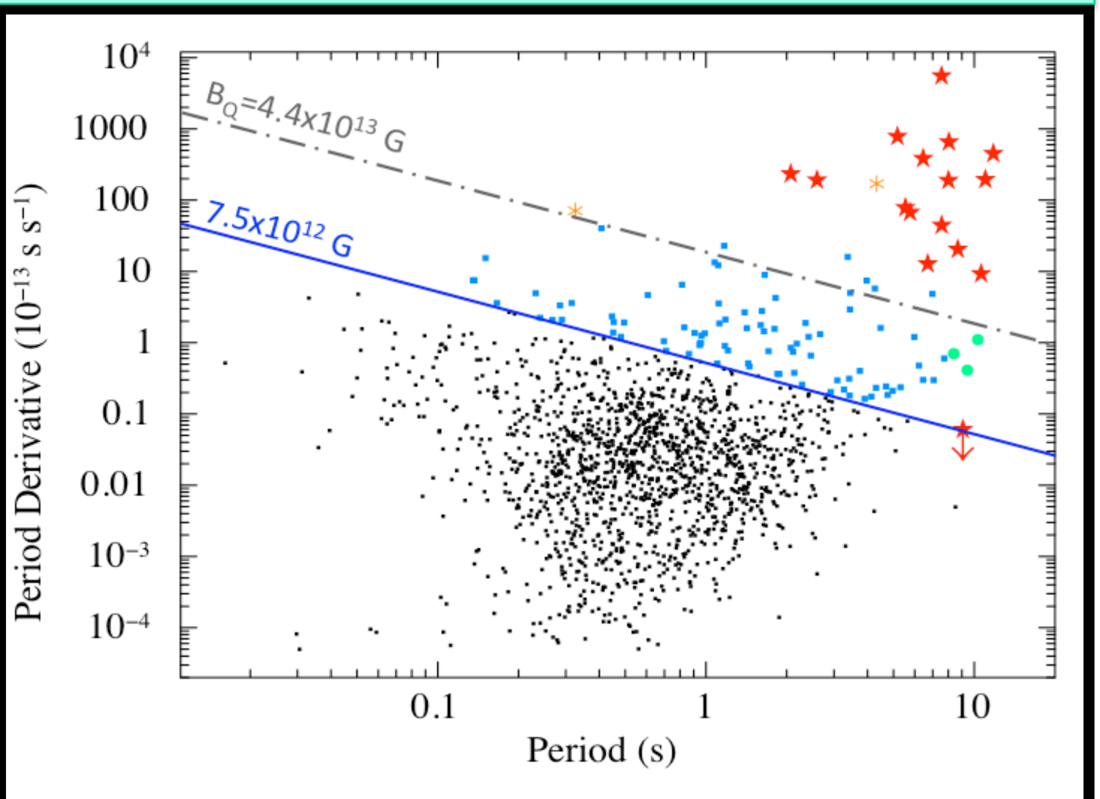


(Rea et al. 2010, Science)

No detection of period derivative in first 160 days after outburst onset
→ upper limit on the period derivative

Many more magnetars are hidden in the pulsar population

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



Before

→10% of the pulsar population was expected to be magnetars.

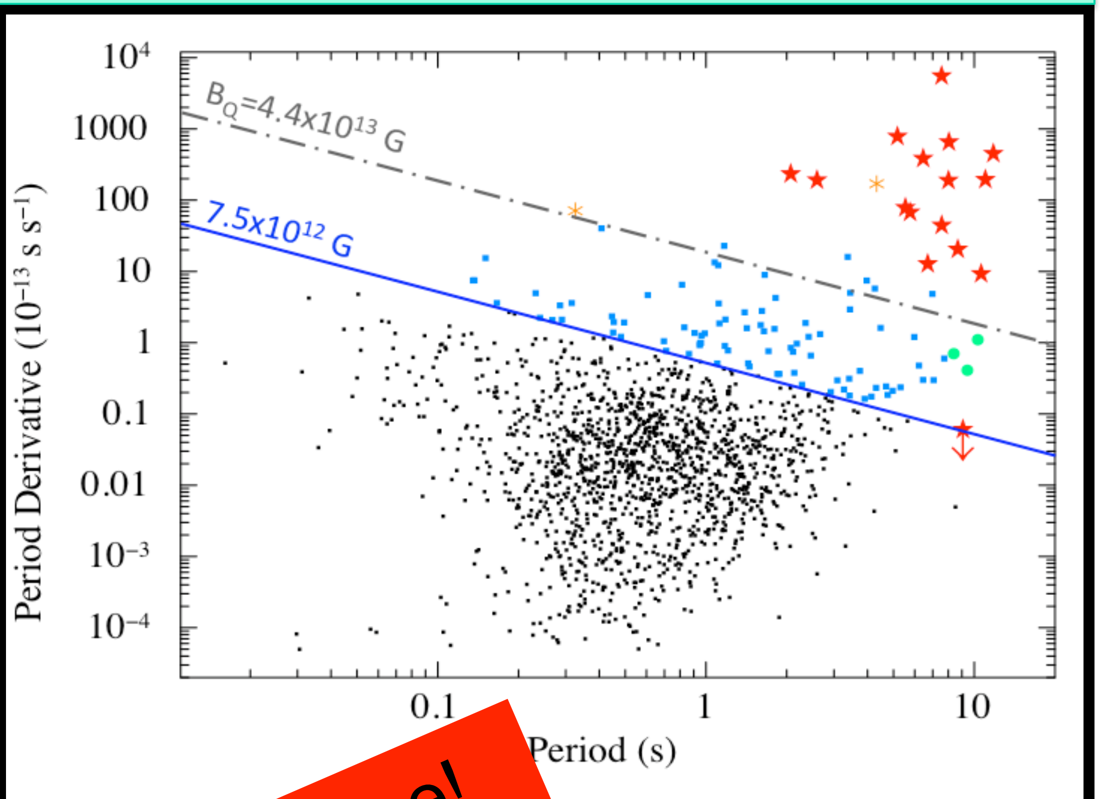
Now

→ more than 50% ?!

(Rea et al. 2010, Science)

Many more magnetars are hidden in the pulsar population

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

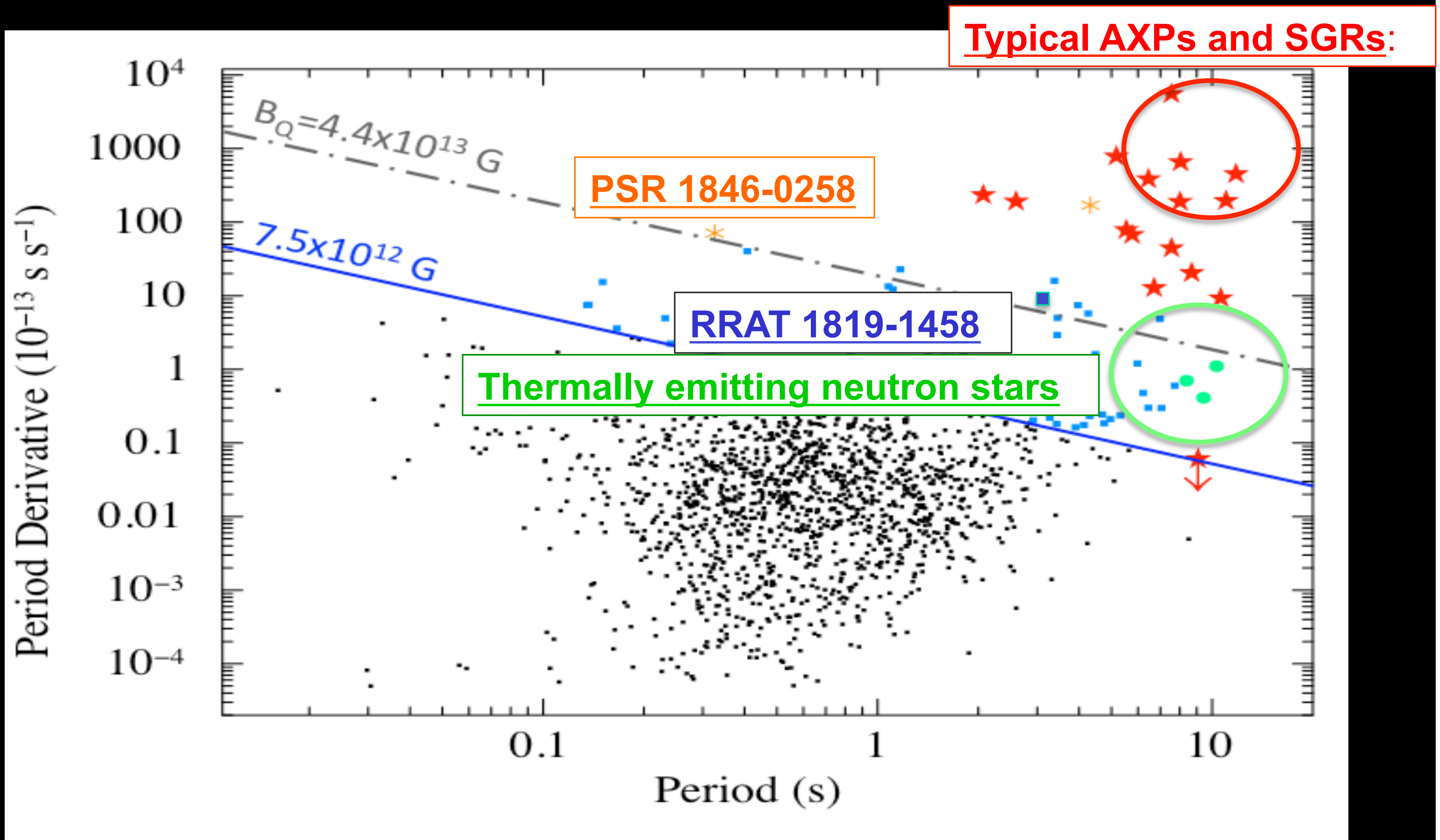


Before
→10% of the pulsar pop… …was expected to be magnetars.
Now
→ more than 5…

More next talk by S. Zane!

(Rea et al. 2010, Science)

Where are we with studying strongly magnetic neutron stars?



Conclusions

Astro-H will be crucial for the study of the strongly magnetic neutron stars.

1. Deep observations at hard X-ray will shed light on the resonant cyclotron scattering process in the relativistic regime, in particular thanks to the **wide band spectral modelling**.

2. The **spectral calorimeter** throughput will be crucial for the study of the spectral lines observed in the thermally emitting neutron stars and RRAT 1819-1458.

3. The discovery of low-B field magnetars show that many apparently normal pulsars will turn on as magnetars anytime hence the **fast pointing** (a day or so) will be a strong requirement at that aim.

4. **High time resolution** in a possibly high telemetry mode is also important to study the neutron star quake during magnetars' flares.

Thank you!

Arigatō!

有り難う