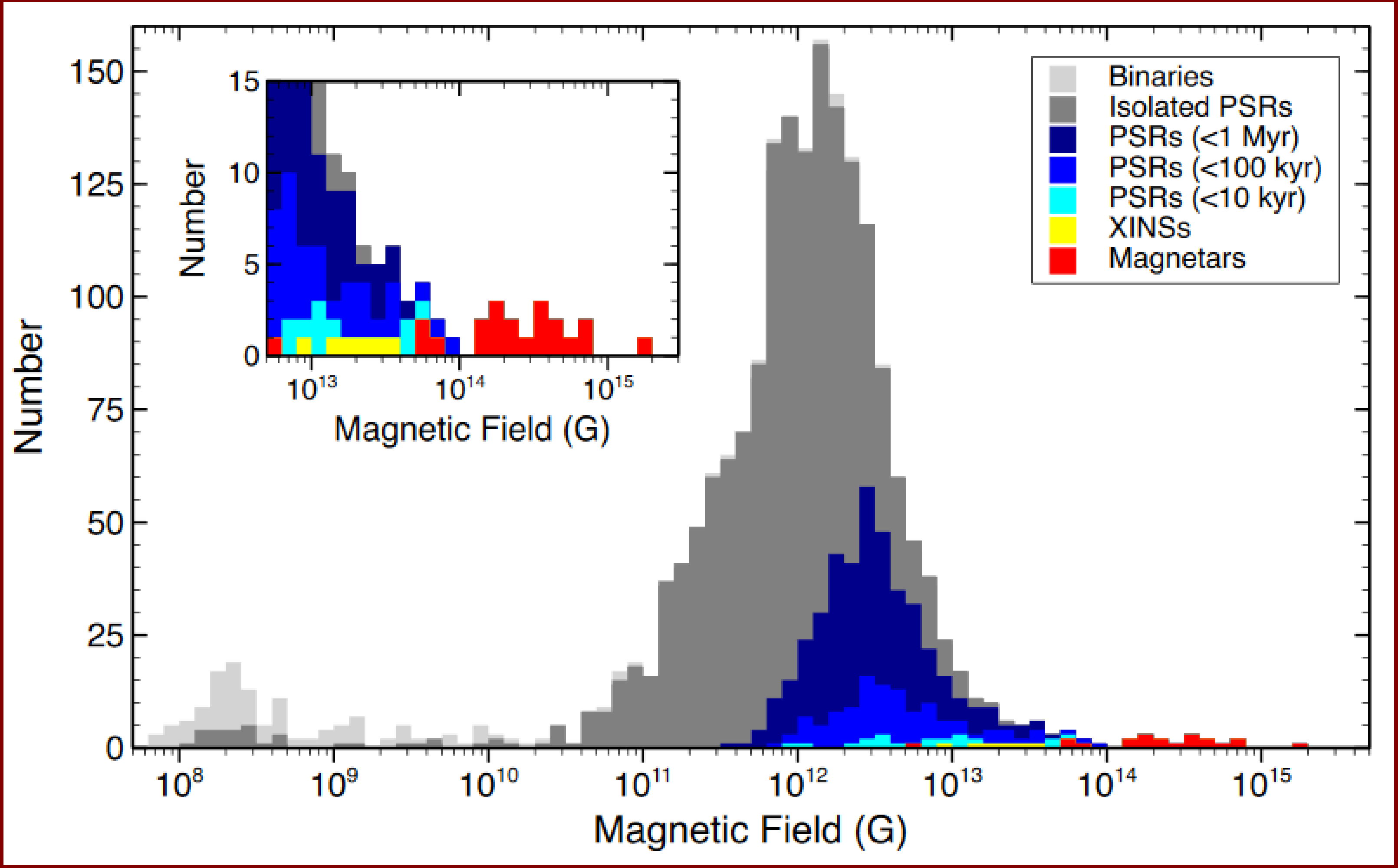
Magnetars: SGRs and AXPs

Magnetic field distribution



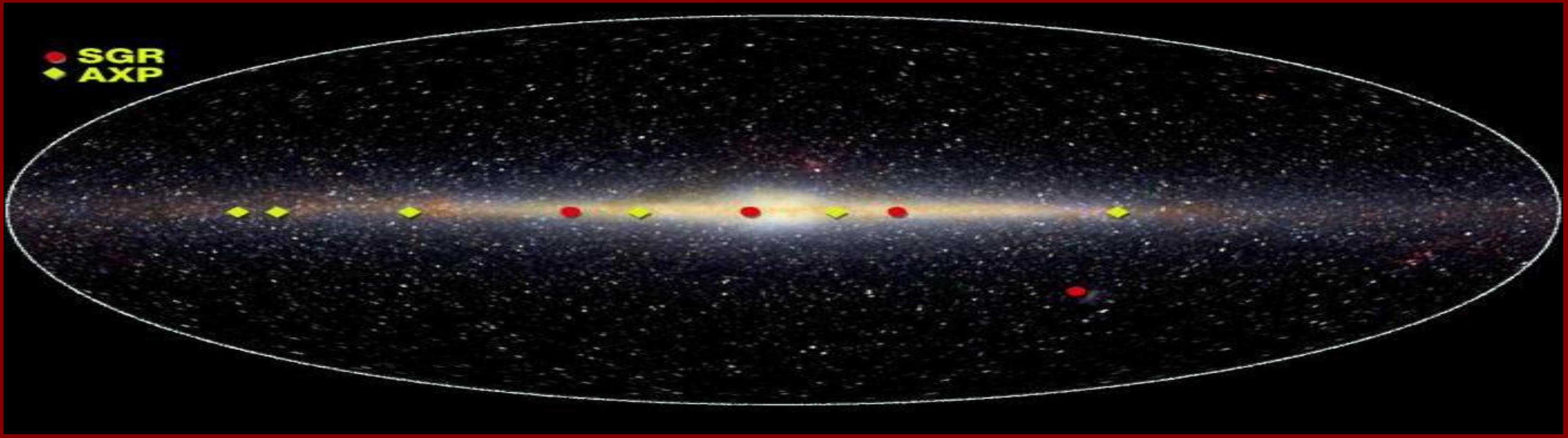
Fields from P-Pdot using magneto-dipole formula

1805.01680 (taken from Olausen, Kaspi 2014)

Magnetars in the Galaxy

- ~25 SGRs and AXPs, plus 6 candidates, plus radio pulsars with high magnetic fields (about them see arXiv: 1010.4592)…
- Young objects (about $10^{3\text{-}5}$ year).

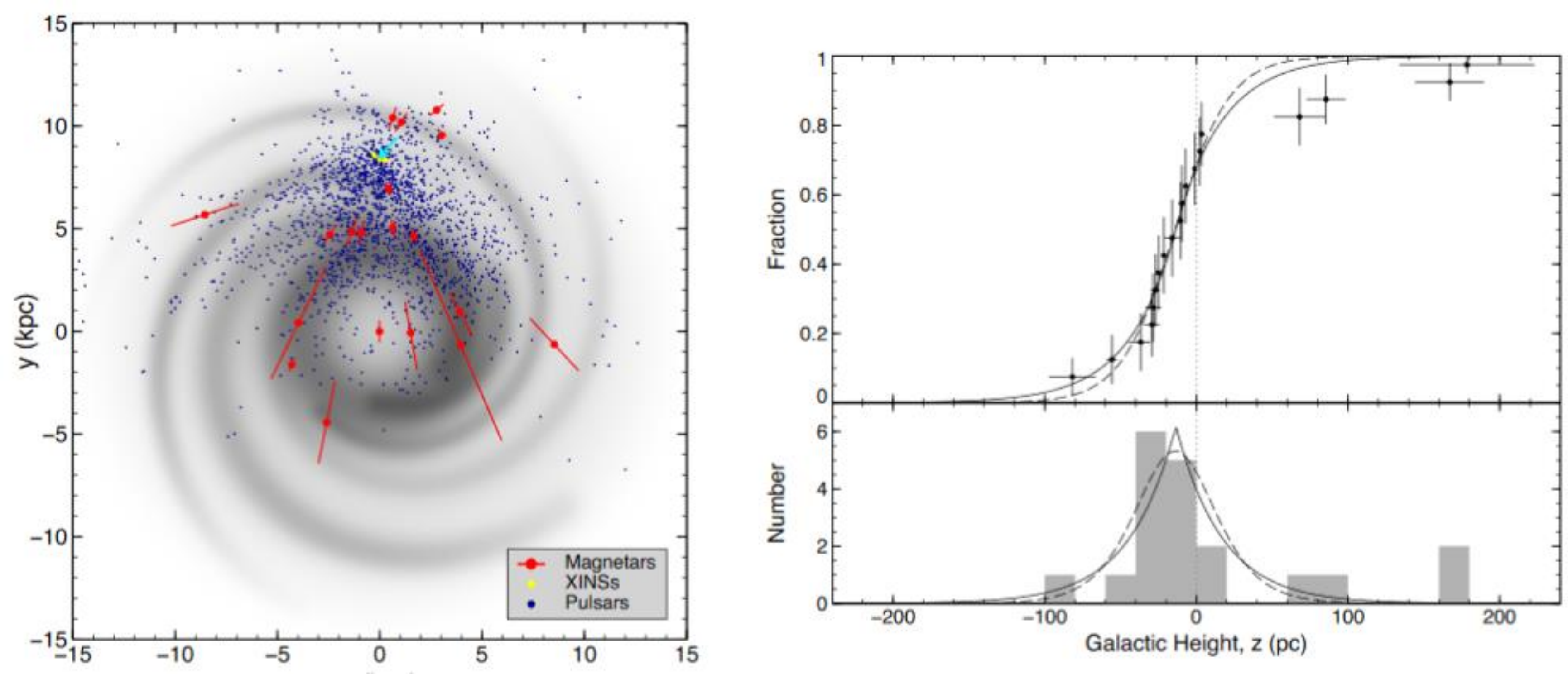
Catalogue: http://www.physics.mcgill.ca/~pulsar/magnetar/main.html



(see a review in arXiv:1503.06313 and the catalogue description in 1309.4167)

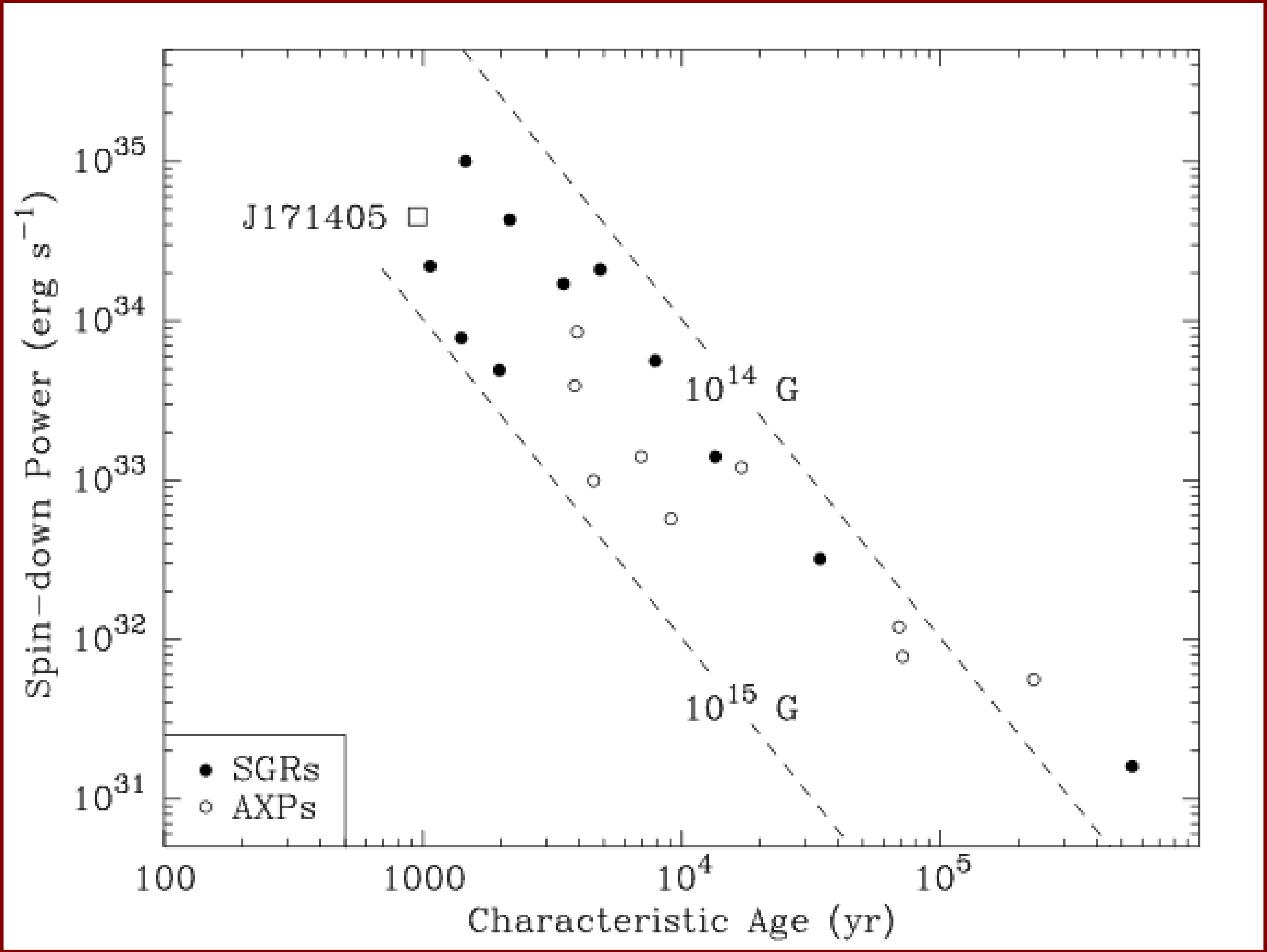
Spatial distribution

Scale height ~20 pc



The first parallax for magnetar XTE J1810−197
was measured due to radio observations, 2008.06438.

1703.00068



J171405
10^{14} G
10^{15} G
SGRs
AXPs
Spin−down Power (erg s^{-1})
Characteristic Age (yr)
10^{35}
10^{34}
10^{33}
10^{32}
10^{31}
100
1000
10^4
10^5

1907.13267

Birth rate of magnetars

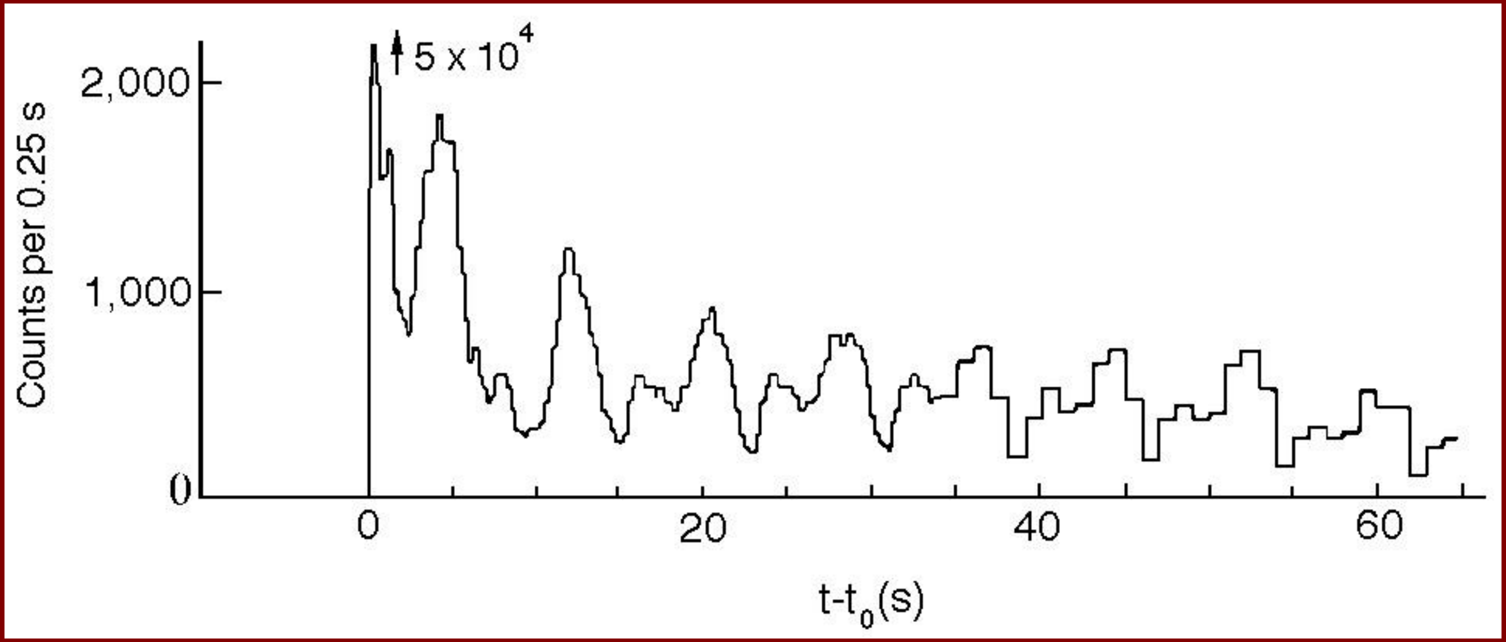
Fraction of magnetars among NSs is uncertain.

Typically, the value ~10% is quoted (e.g. 0910.2190).
This is supported observationally and theoretically.

Recent modeling favours somehow larger values: 1903.06718.
However, the result is model dependent.
In particular, it depends on the model of field decay.

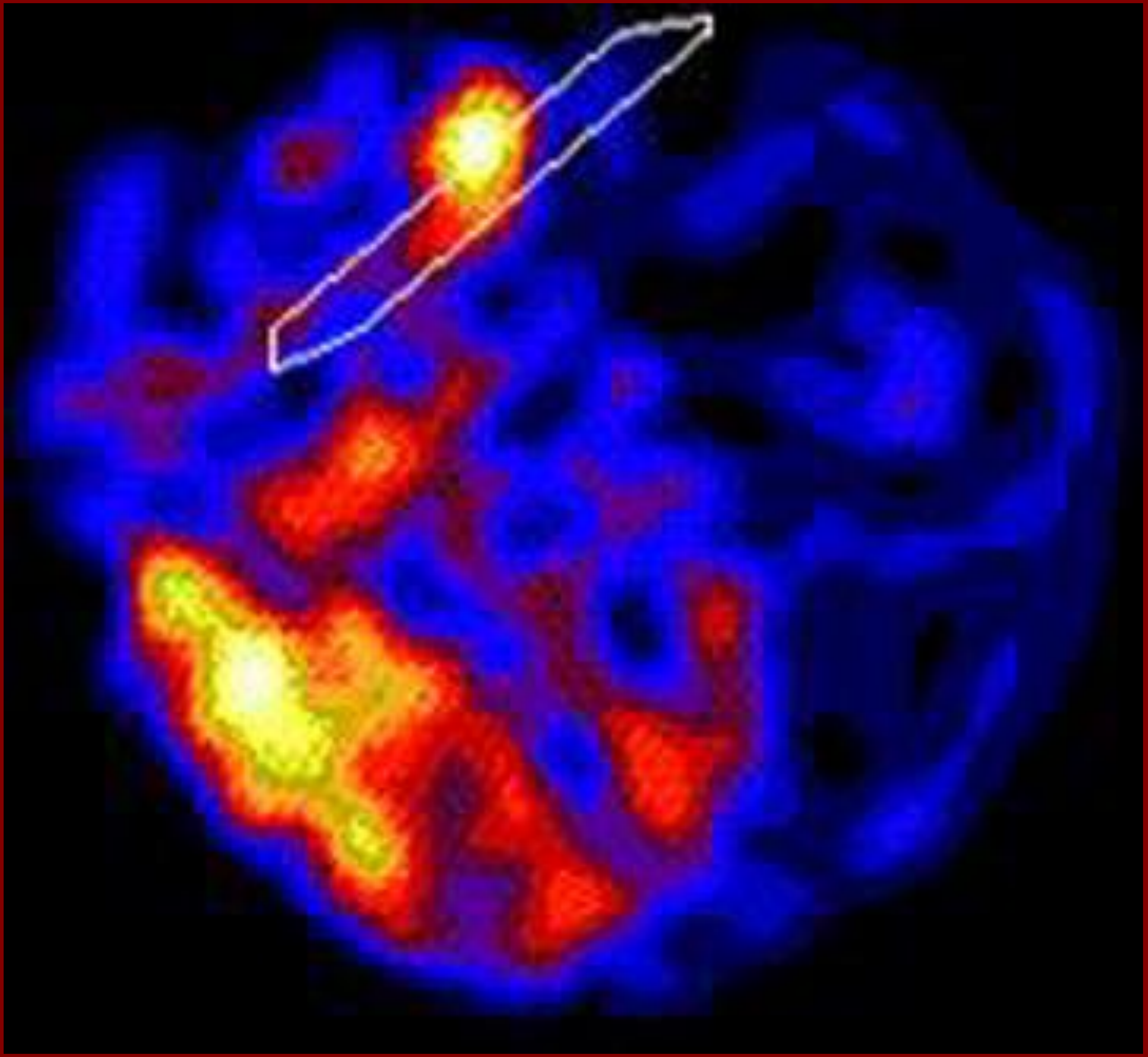
Historical notes

- 05 March 1979. The ”Konus” experiment & Co.
  Venera-11,12 (Mazets et al., Vedrenne et al.)
- Events in the LMC. SGR 0520-66.
- Fluence: about 10^{-3} erg/cm^2



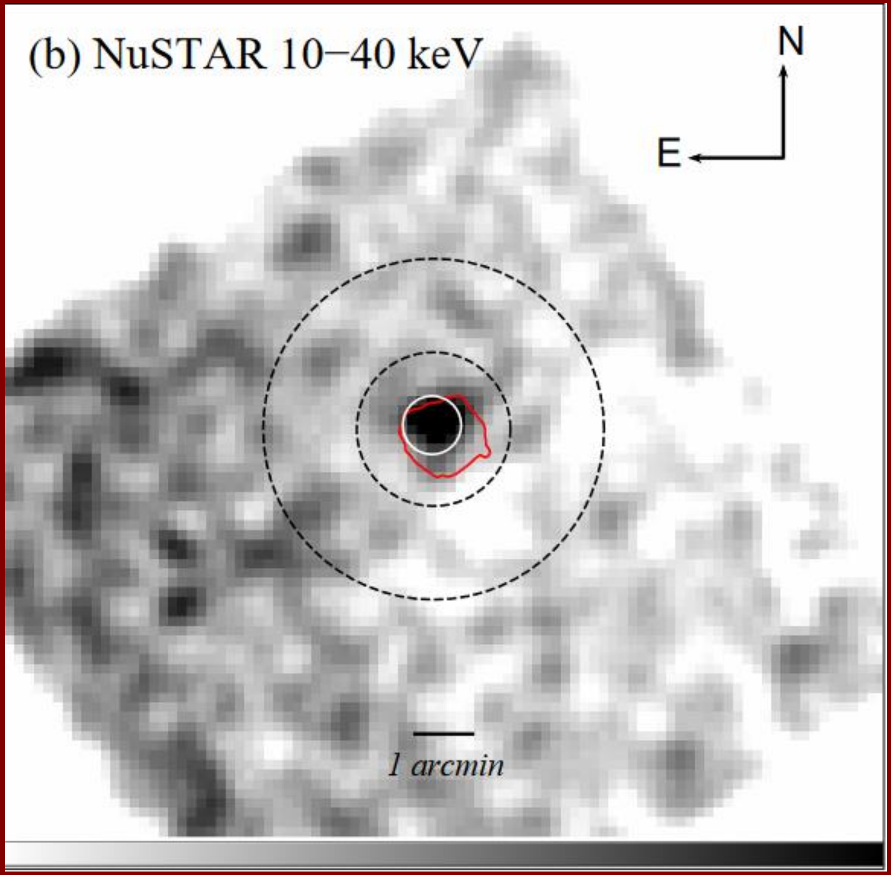
Mazets et al. 1979

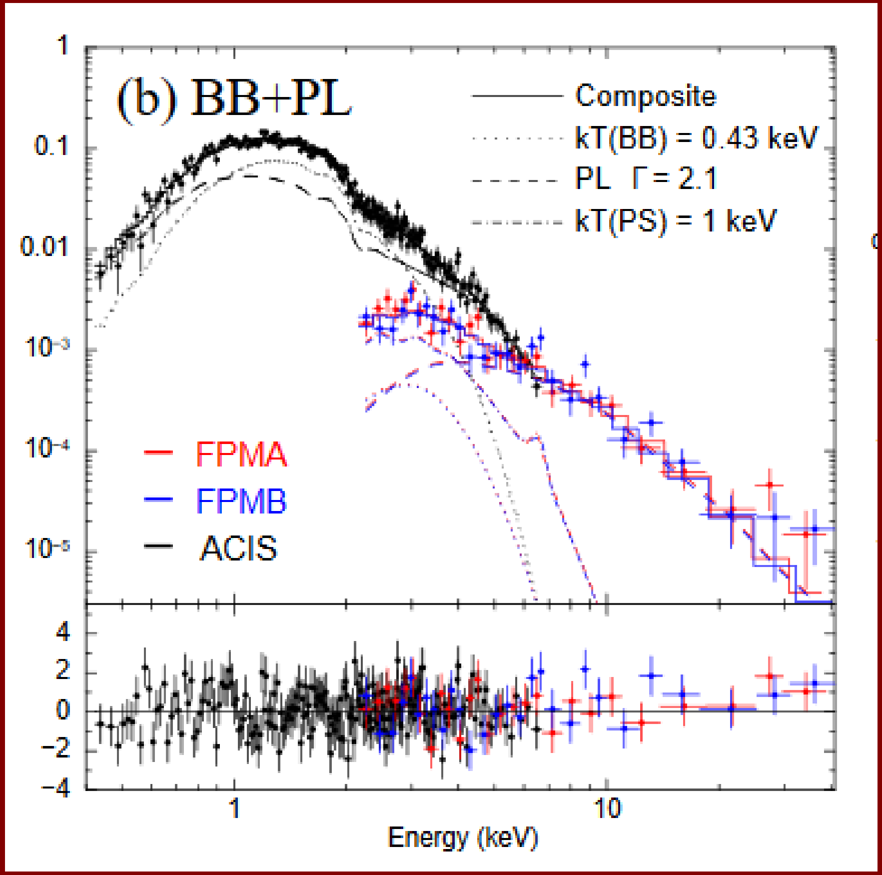
N49 – supernova remnant in the Large Magellanic cloud
(e.g. G. Vedrenne et al. 1979)



Magnetar on pension?

The source is not active since 1979.
Just in 2020 it was for the first time detected at E>10 keV in quiescence.



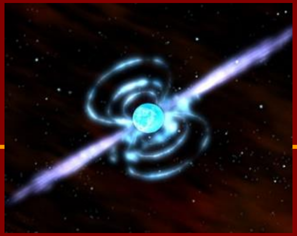


2003.11730

Main types of activity of SGRs

- Weak bursts. $L<10^{42}$ erg/s
- Intermediate. $L\sim10^{42}$–10^{43} erg/s
- Giant. $L<10^{45}$ erg/s
- Hyperflares. $L>10^{46}$ erg/s

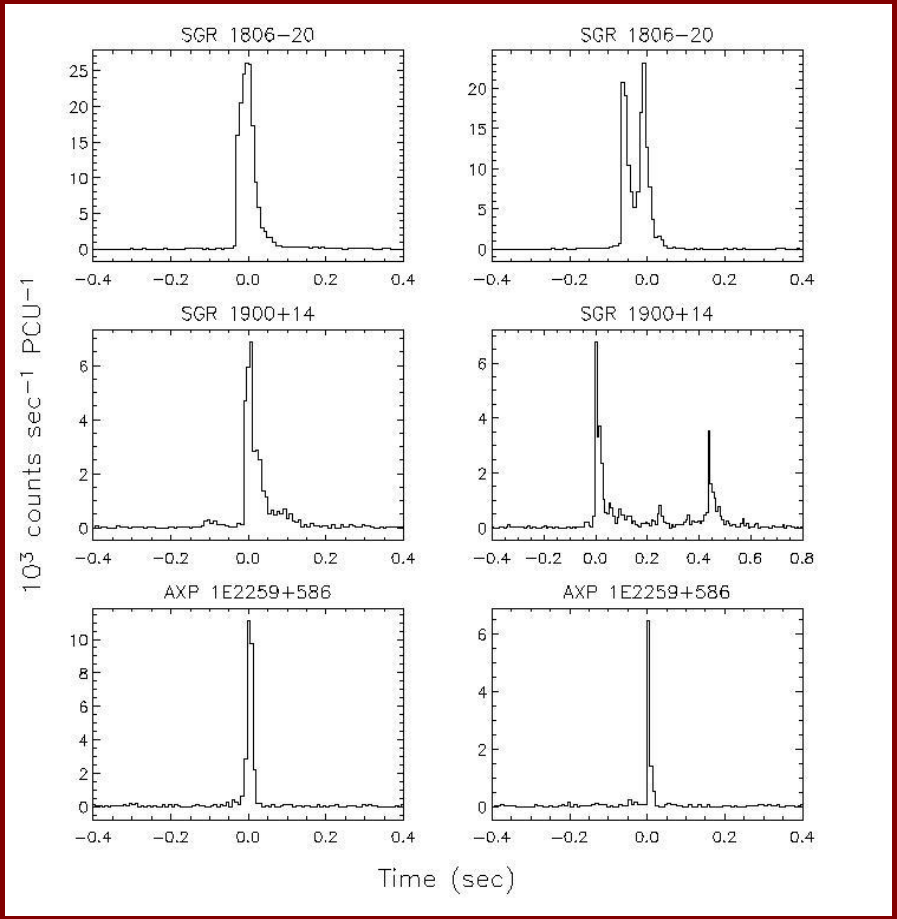
Power distribution is similar
to the distribution of earthquakes
in magnitude



See the review in
Rea, Esposito
1101.4472

Normal bursts of SGRs and AXPs

- Typical weak bursts of
  SGR 1806-29,
  SGR 1900+14 and of
  AXP 1E 2259+586
  detected by RXTE



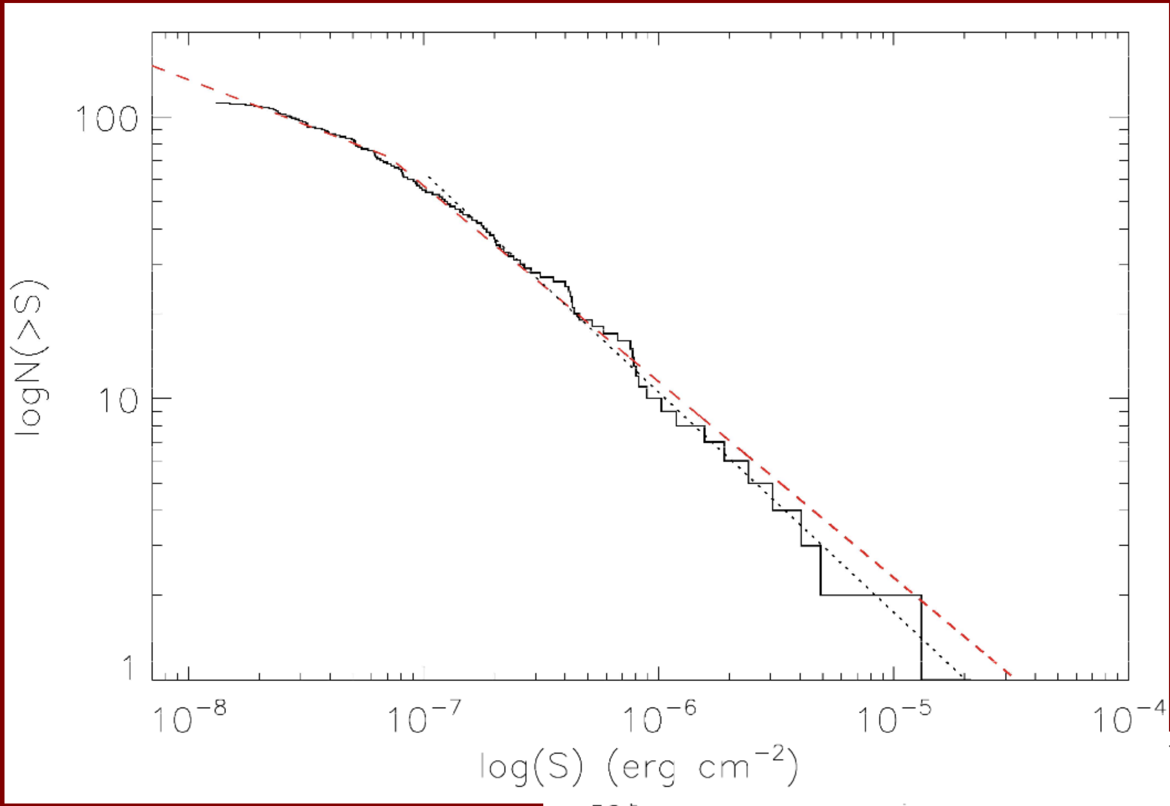
(from Woods, Thompson 2004)

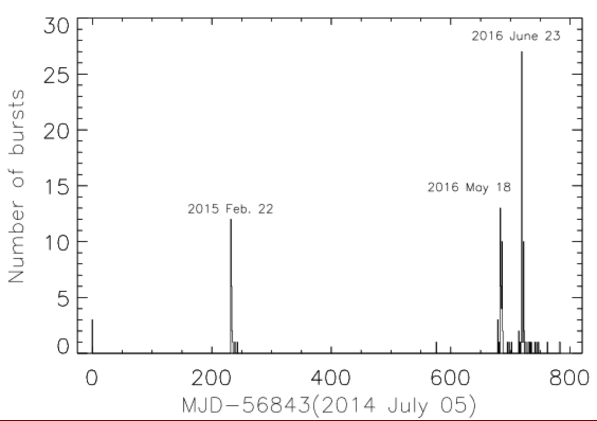
Outbursts

Individual flares often appear during period of activity. They are called *outbursts*.

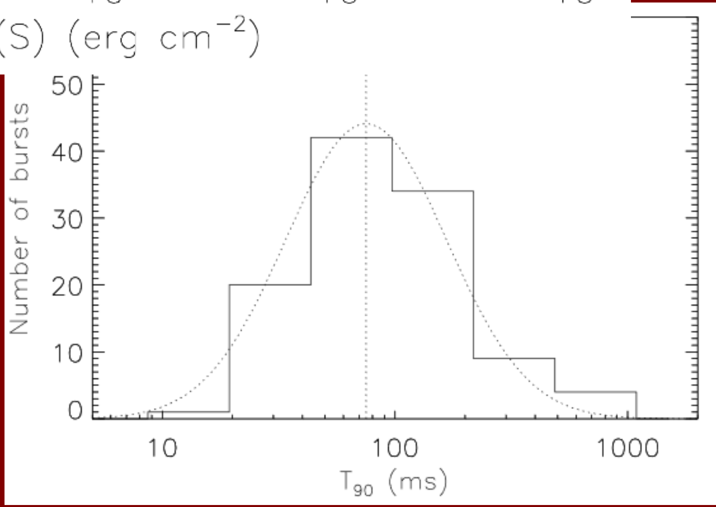
SGR J1935+2154 is the most recurring transient during last years.

127 bursts in 2-3 years. This amount allows detailed statistical studies.





See the review in Rea, Esposito 1101.4472

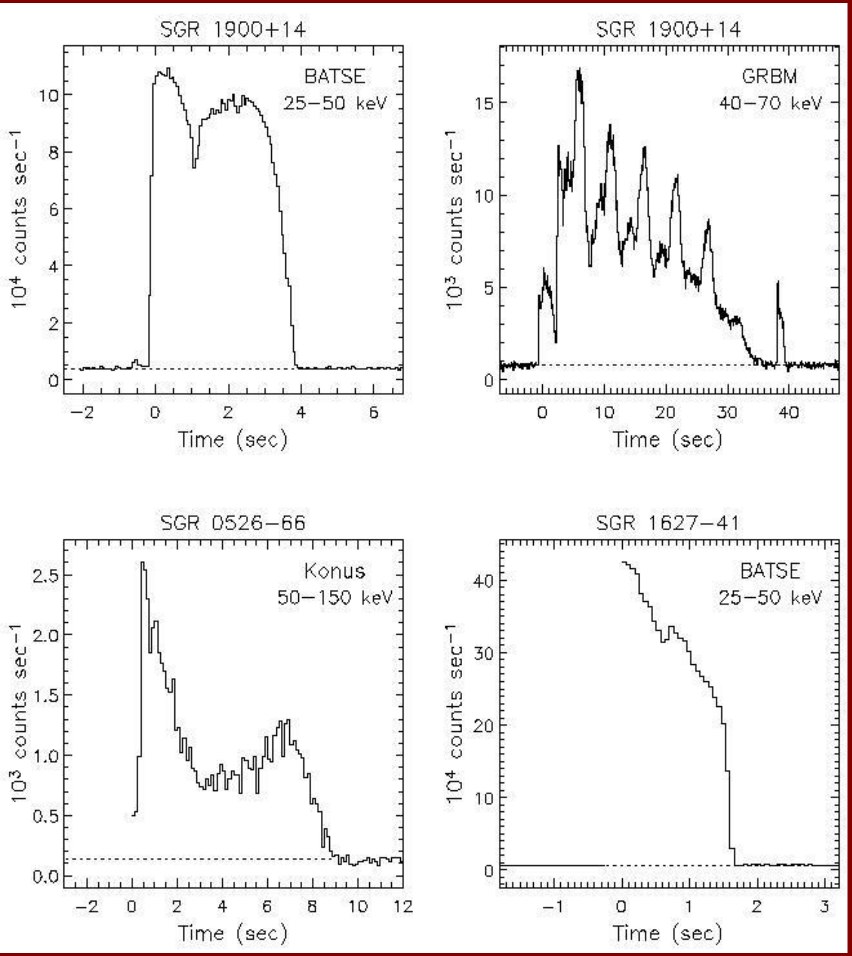


2003.10582

Intermediate SGR bursts

Examples of intermediate bursts.

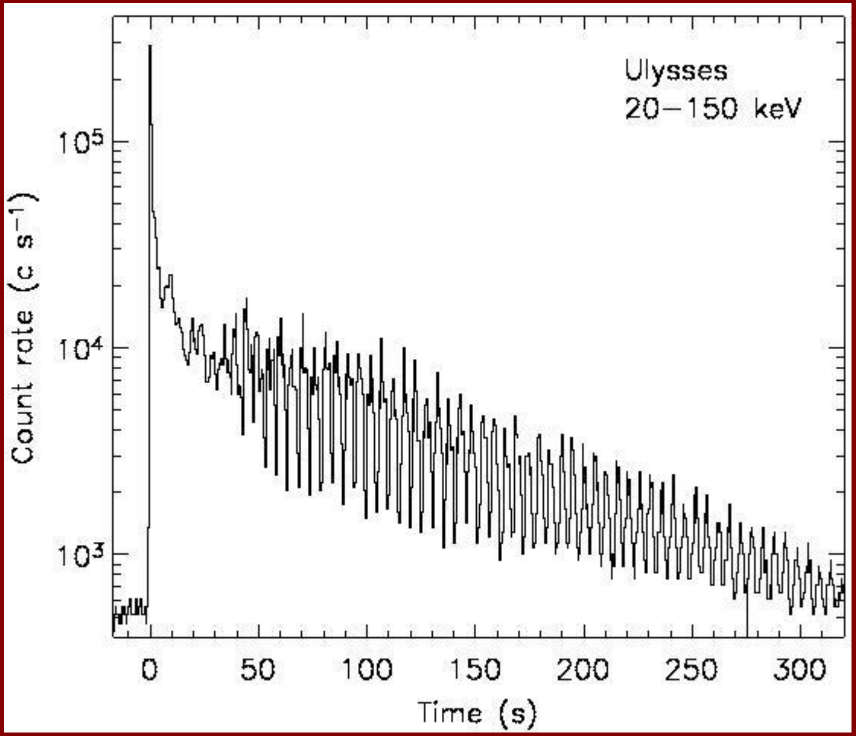
The forth (bottom right) is sometimes defined as a giant burst (for example by Mazets et al.).



(from Woods, Thompson 2004)

Giant flare of the SGR 1900+14 (27 August 1998)

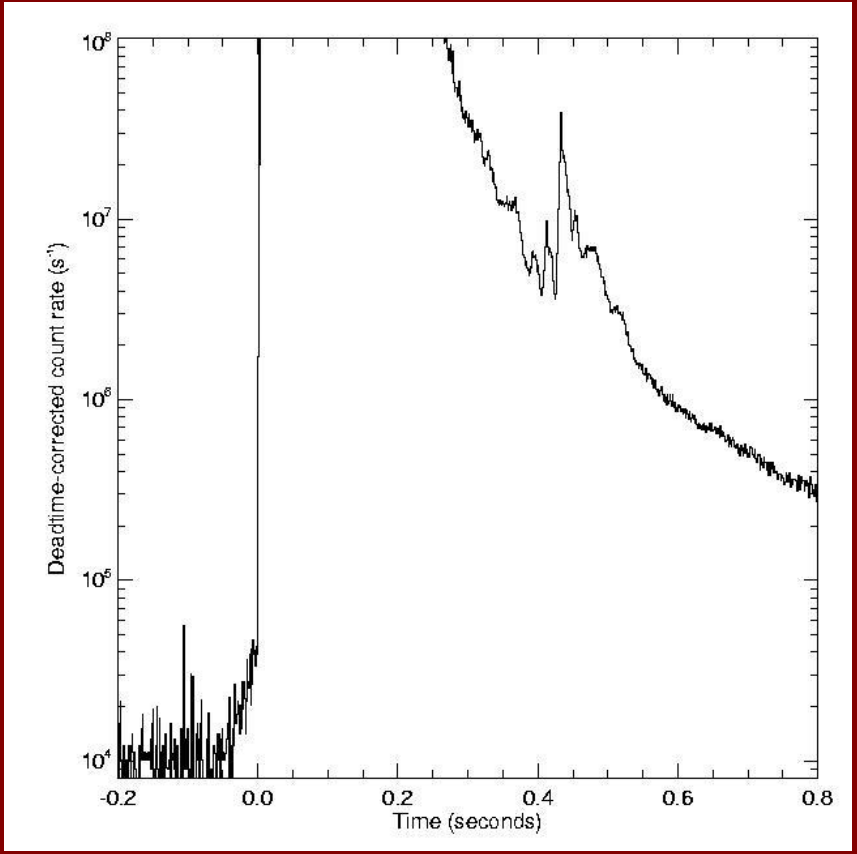
- Ulysses observations (figure from Hurley et al.)
- Initial spike 0.35 s
- P=5.16 s
- L>3 10^{44} erg/s
- $E_{TOTAL}>10^{44}$ erg



Hurley et al. 1999

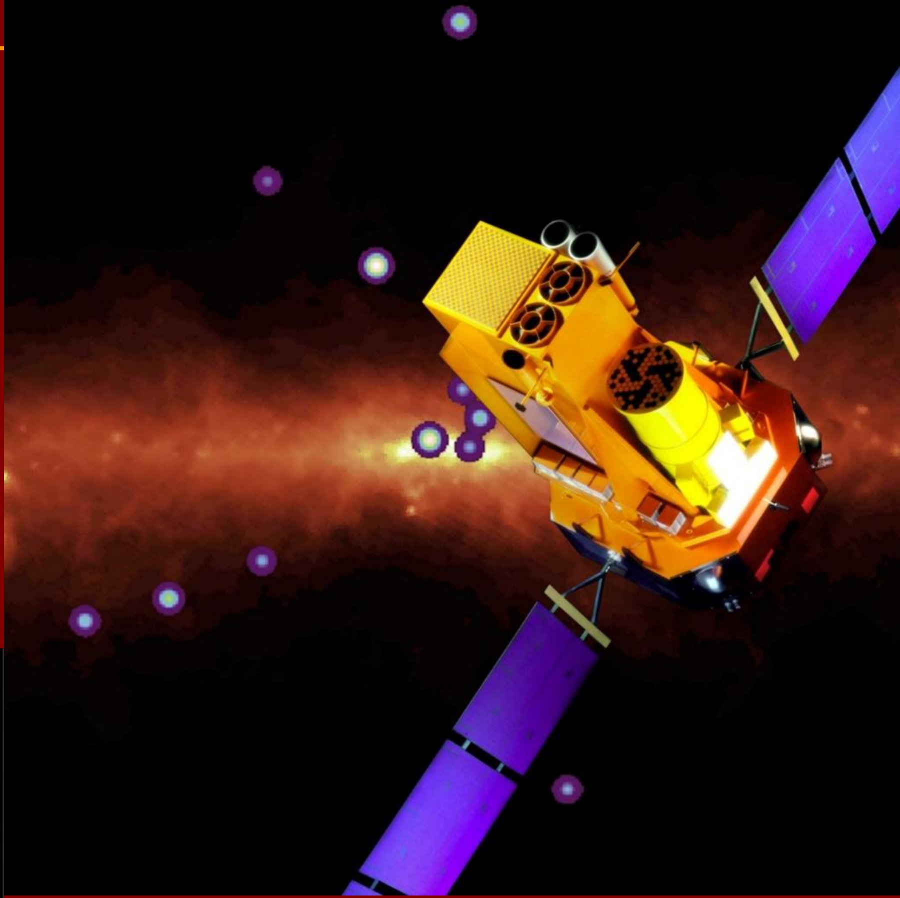
Hyperflare of SGR 1806-20

- 27 December 2004 A giant flare from SGR 1806-20 was detected by many satellites: Swift, RHESSI, Konus-Wind, Coronas-F, Integral, HEND, …
- 100 times brighter than any other!



Palmer et al.
astro-ph/0503030

C O R O N A S - F

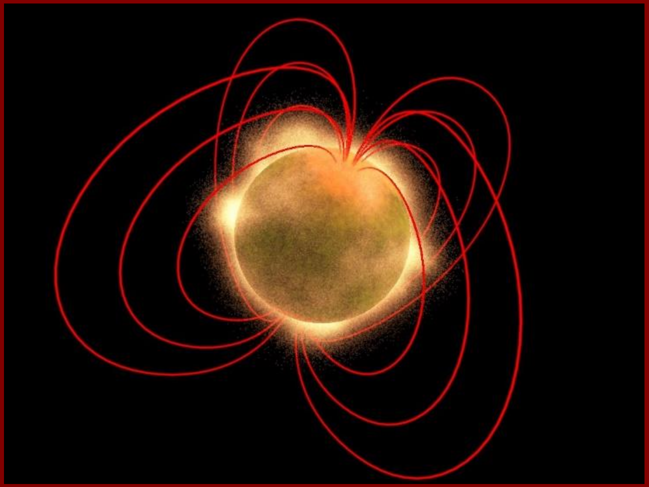


Integral

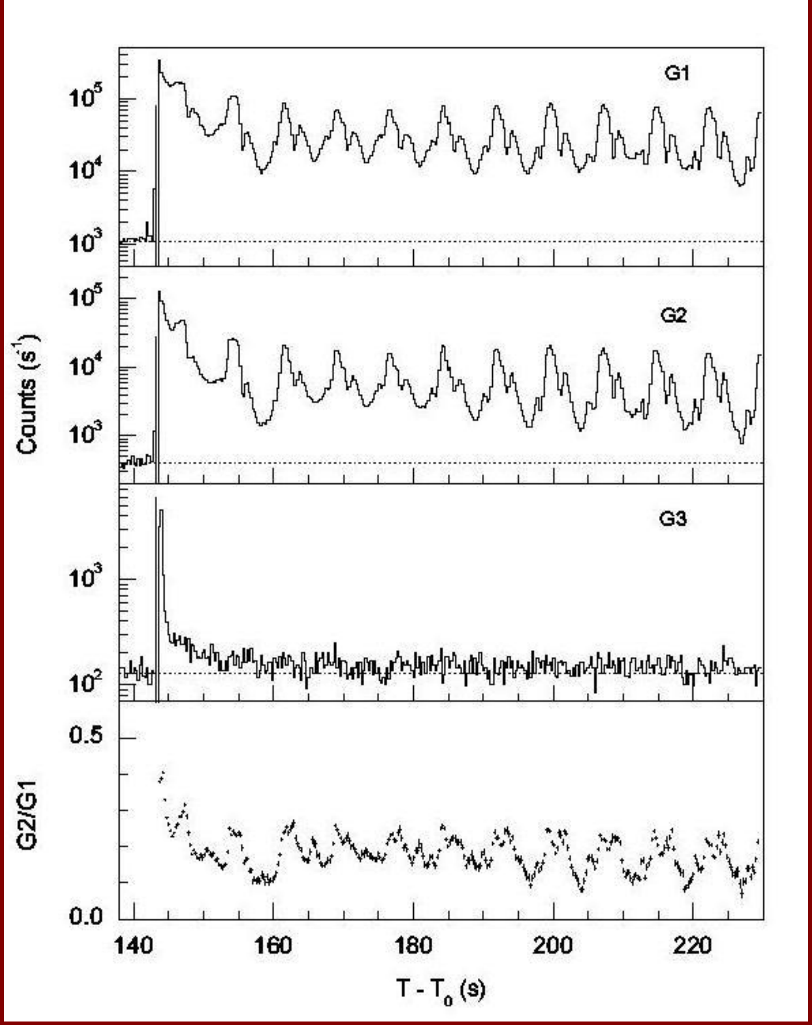
RHESSI

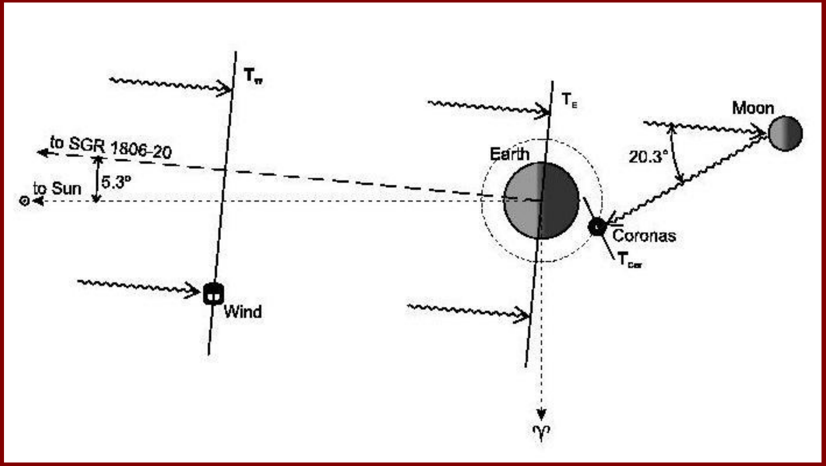
27 Dec 2004:
Giant flare of the SGR 1806-20

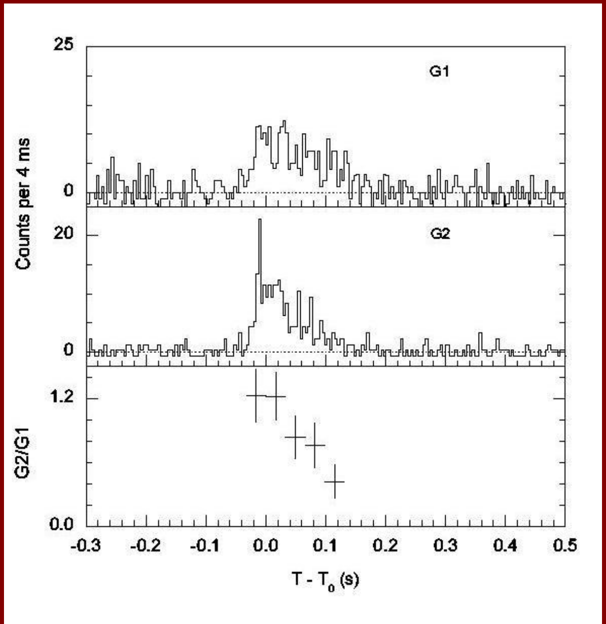
- Spike 0.2 s
- Fluence 1 erg/cm^2
- E(spike)=3.5 10^{46} erg
- L(spike)=1.8 10^{47} erg/s
- Long «tail» (400 s)
- P=7.65 s
- E(tail) 1.6 10^{44} erg
- Distance 15 kpc – see the latest data in arXiv: 1103.0006



Konus observations

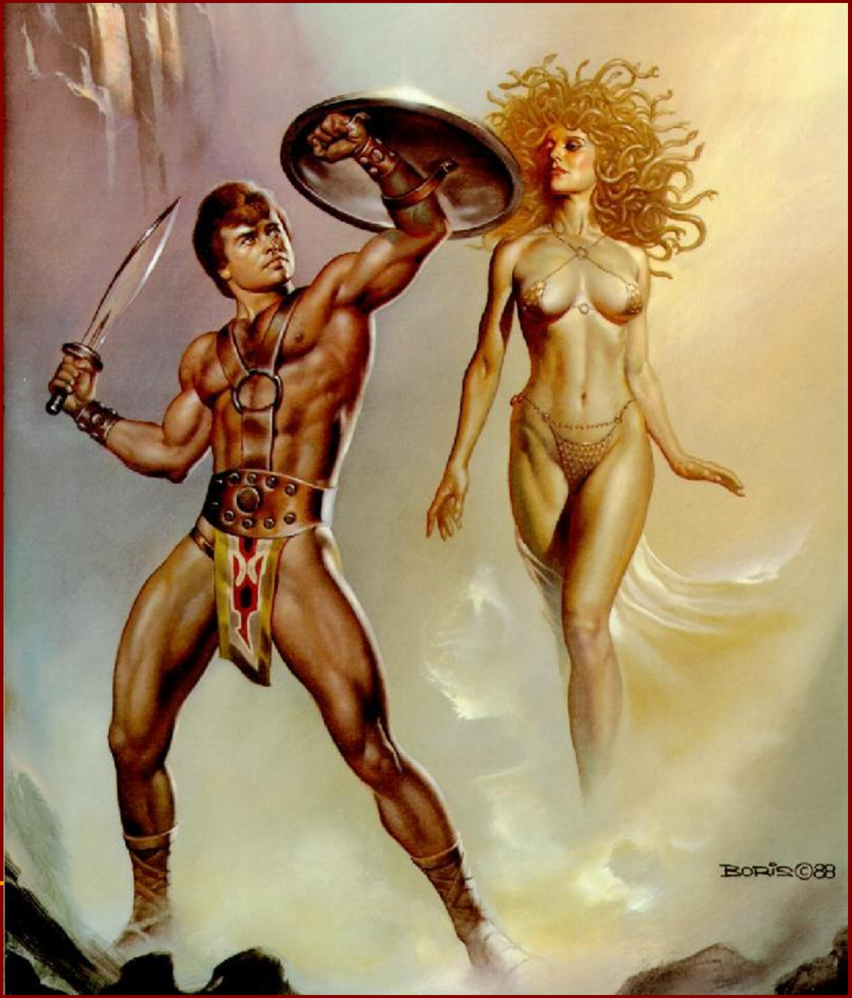






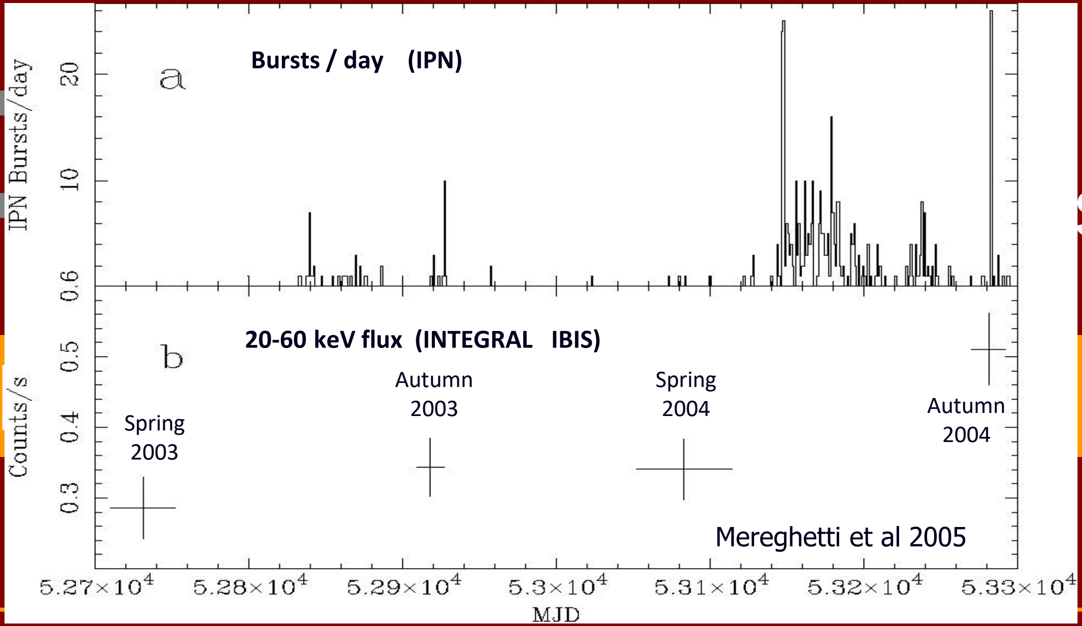
Mazets et al. 2005

The myth about Medusa



SGR 1806-20 - I

SGR 1806-20 displayed a gradual increase in the level of activity during 2003-2004 (Woods et al 2004; Mereghetti et al 2005)

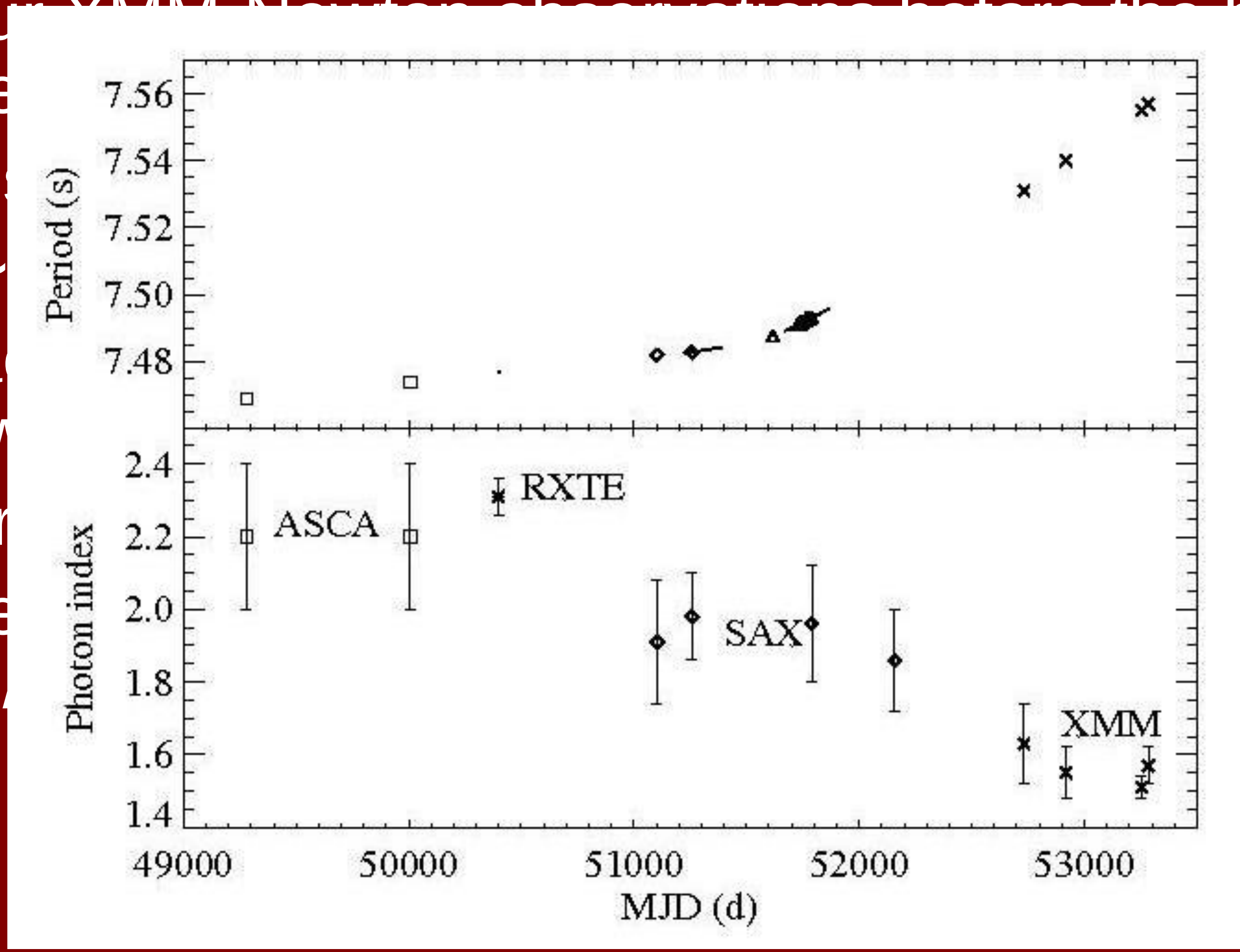


sity

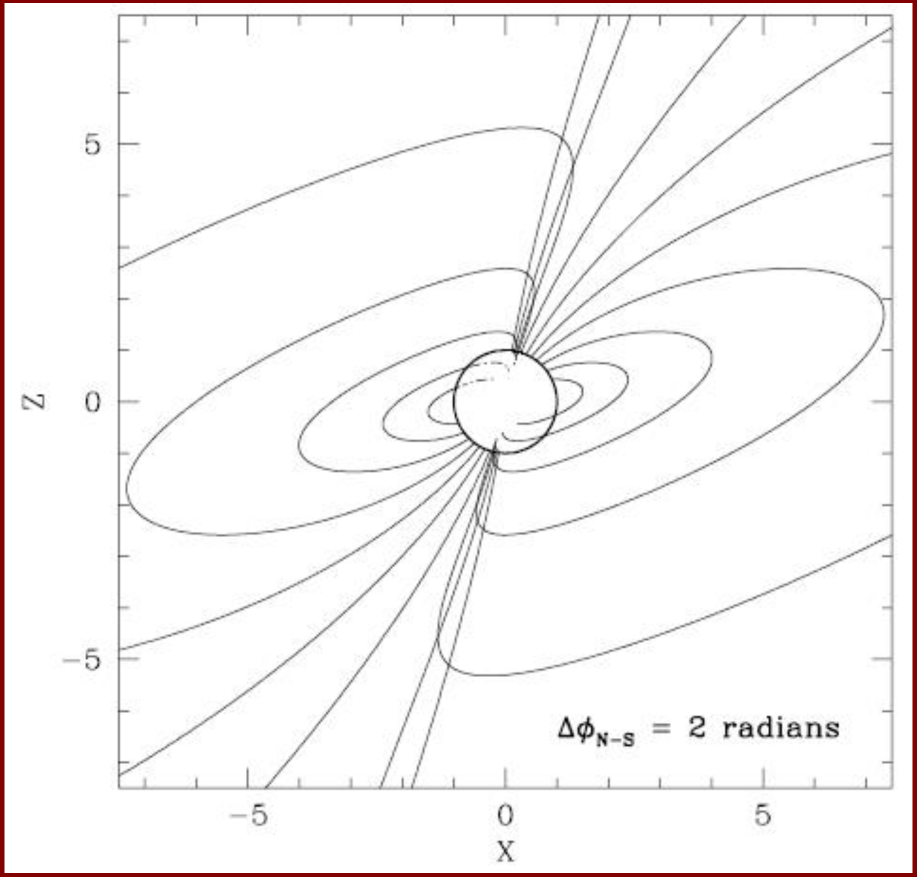
T

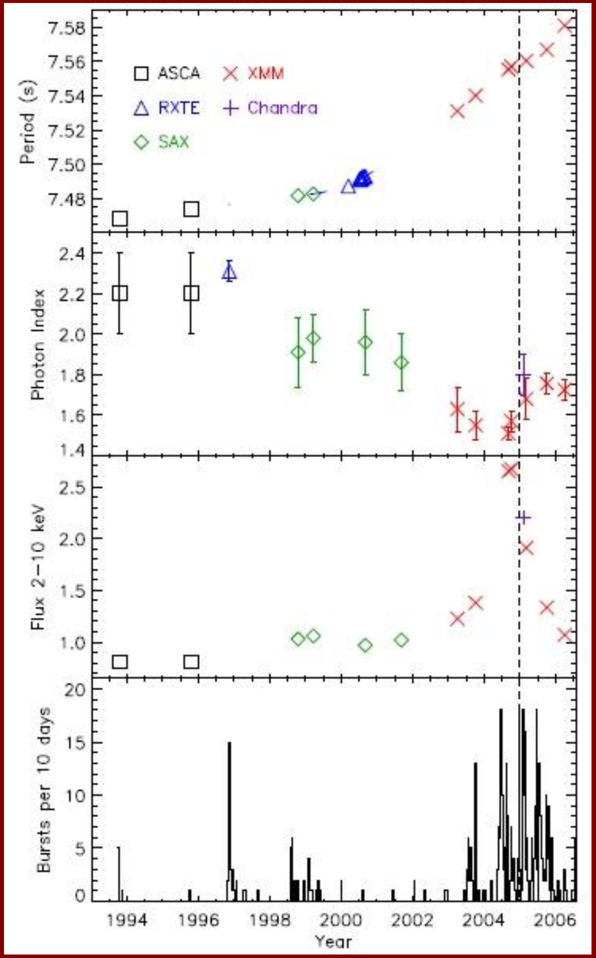
SGR 1806-20 - II

- Fou … urst
  (the … 2005)
- Puls … s
- Ṗ ~ … value
- Blac … rbed
  pow
- Har
- The … ~ 10^{36}
  erg/



Growing twist



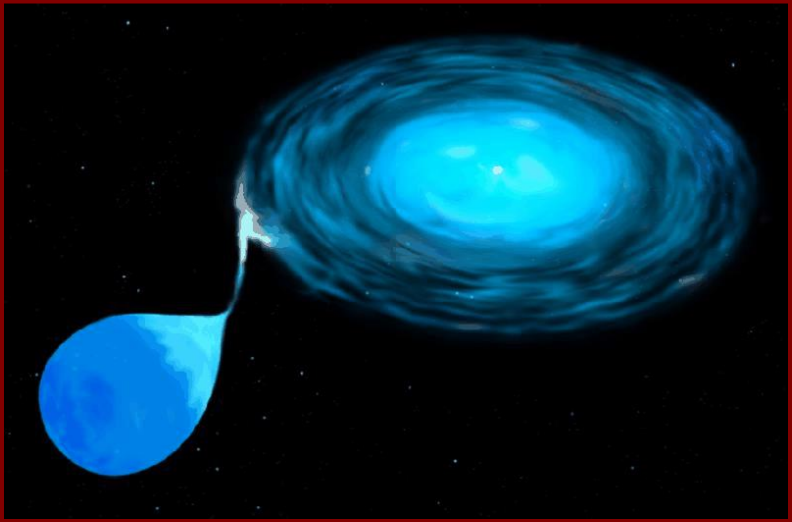


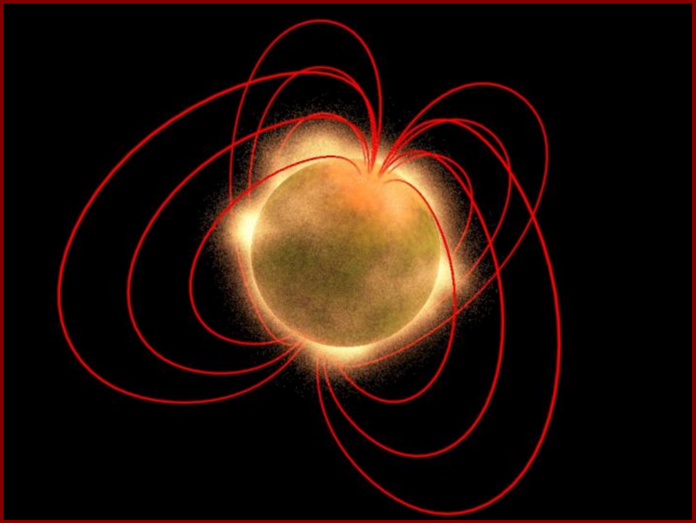
(images from Mereghetti arXiv: 0804.0250)

Anomalous X-ray pulsars

Identified as a separate group in 1995.
(Mereghetti, Stella 1995 Van Paradijs et al.1995)

- Similar periods (5-10 sec)
- Constant spin down
- Absence of optical companions
- Relatively weak luminosity
- Constant luminosity





Anomalous X-ray Pulsars: main properties

- About fourteen sources known:

  1E 1048.1-5937, 1E 2259+586, 4U 0142+614,

  1 RXS J170849-4009, 1E 1841-045, 3XMM J185246.6+003317,

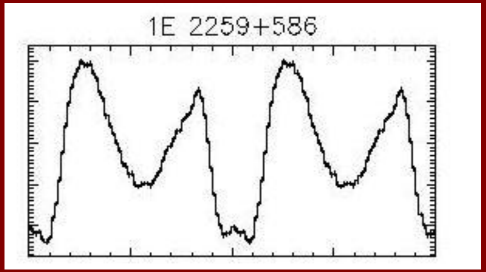
  CXOU 010043-721134, AX J1845-0258,

  CXOU J164710-455216, XTE J1810-197,

  1E 1547.0-5408, PSR J1622-4950, CXOU J171405.7-381031
- Persistent X-ray emitters, $L \approx 10^{34}$ -10^{35} erg/s
- Pulsations with $P \approx 2$ -10 s (0.33 sec for PSR 1846)
- Large spindown rates, $\dot{P}/P \approx 10^{-11}$ s^{-1}
- No evidence for a binary companion, association with a SNR in several cases

Known AXPs

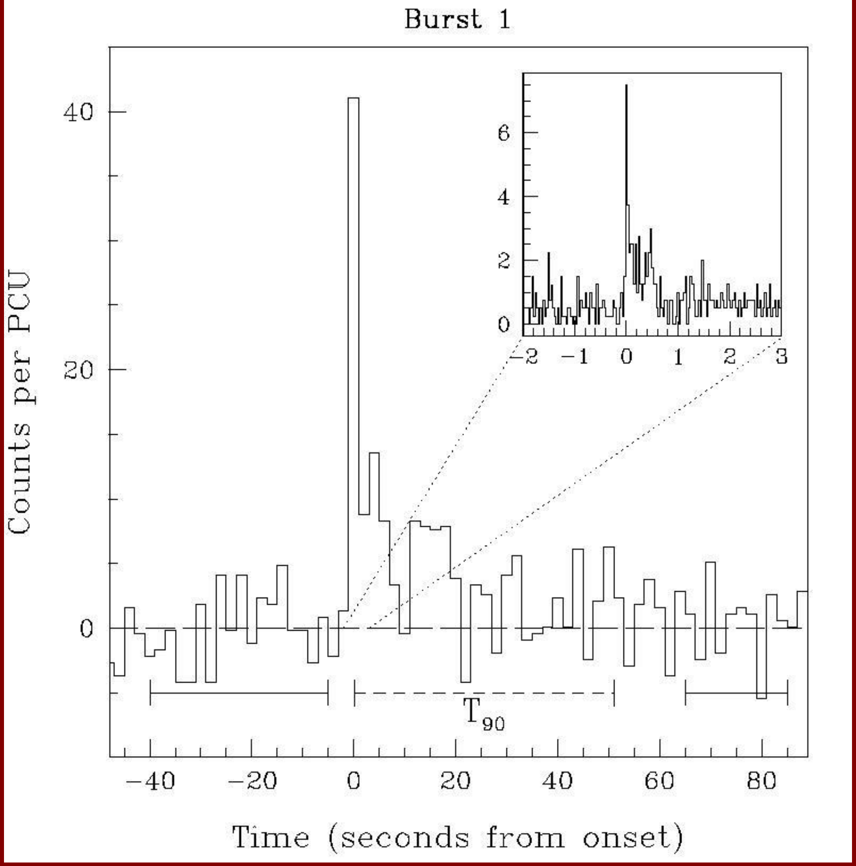
Sources	Periods, s
CXO 010043-7211	8.0
4U 0142+61	8.7
1E 1048.1-5937	6.4
1E 1547.0-5408	2.1
CXOU J164710-4552	10.6
1RXS J170849-40	11.0
XTE J1810-197	5.5
1E 1841-045	11.8
AX J1845-0258	7.0
PSR J1622-4950	4.3
CXOU J171405.7-381031	3.8
1E 2259+586	7.0



http://www.physics.mcgill.ca/~pulsar/magnetar/main.html

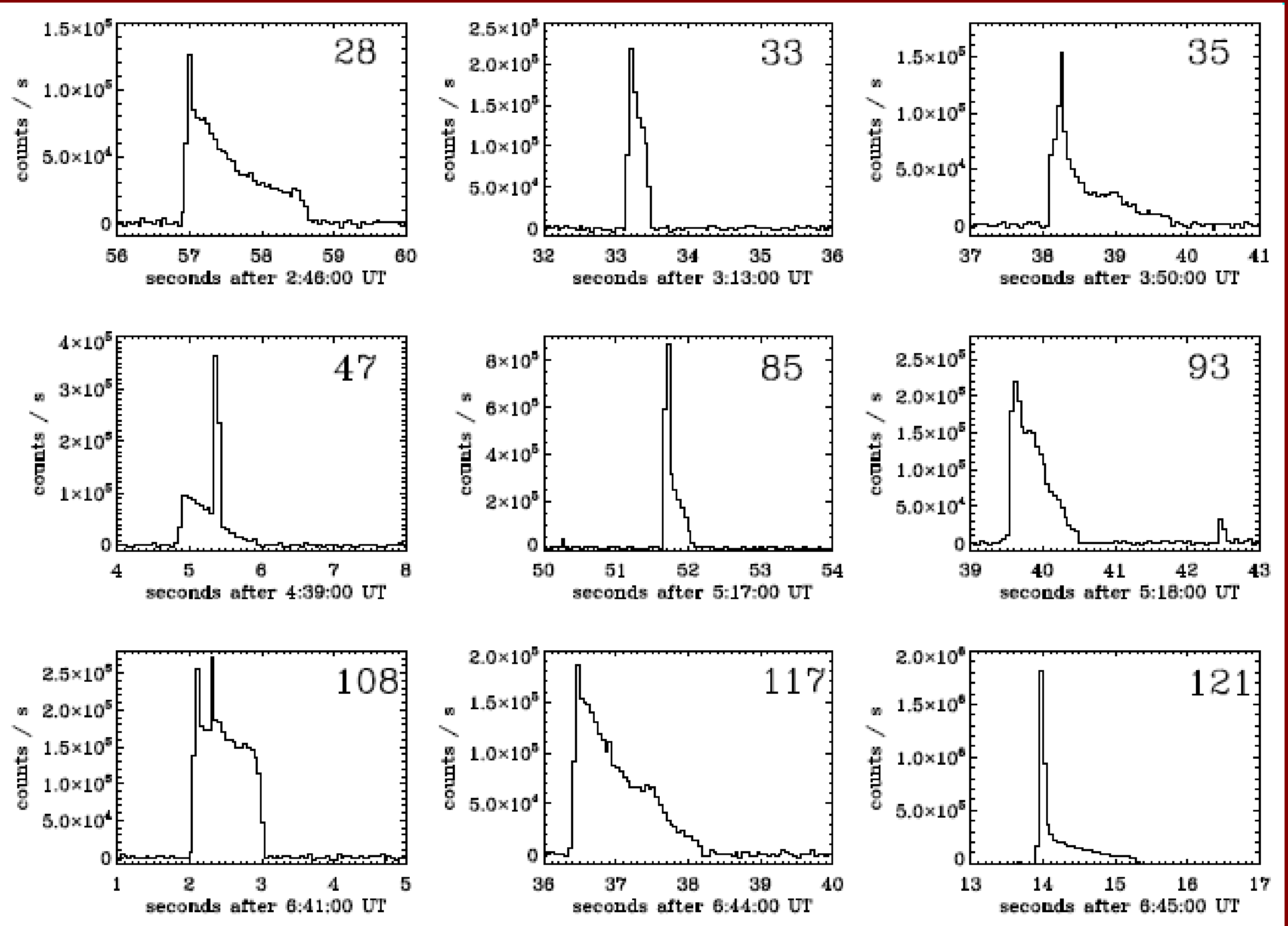
Are SGRs and AXPs brothers?

- Bursts of AXPs
  (more than half burst)
- Spectral properties
- Quiescent periods of SGRs (0525-66 since 1983)



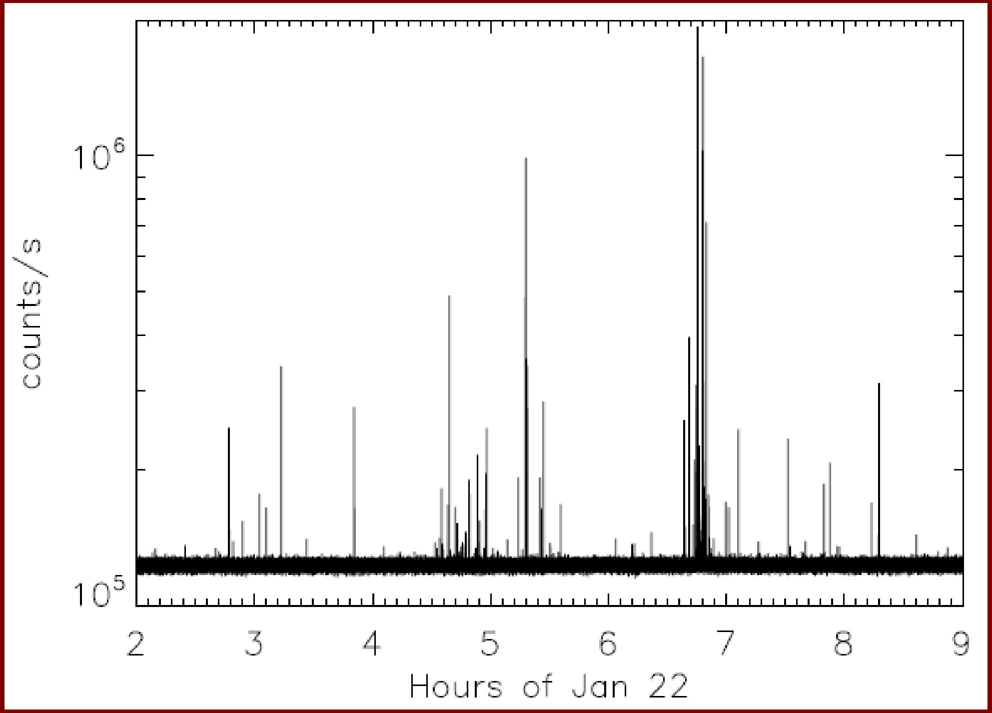
Gavriil et al. 2002

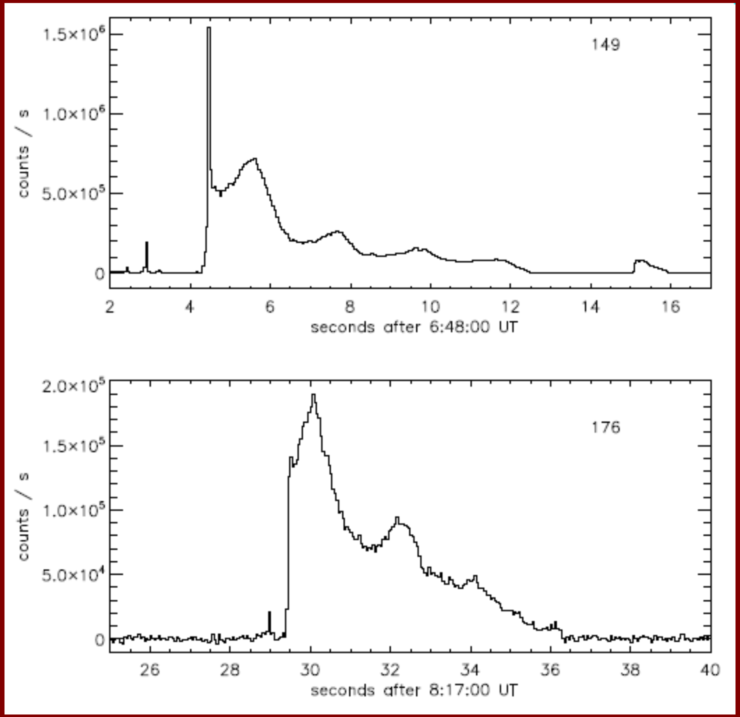
Bursts of the AXP 1E1547.0-5408



0903.1974

Bursts of the AXP 1E1547.0-5408

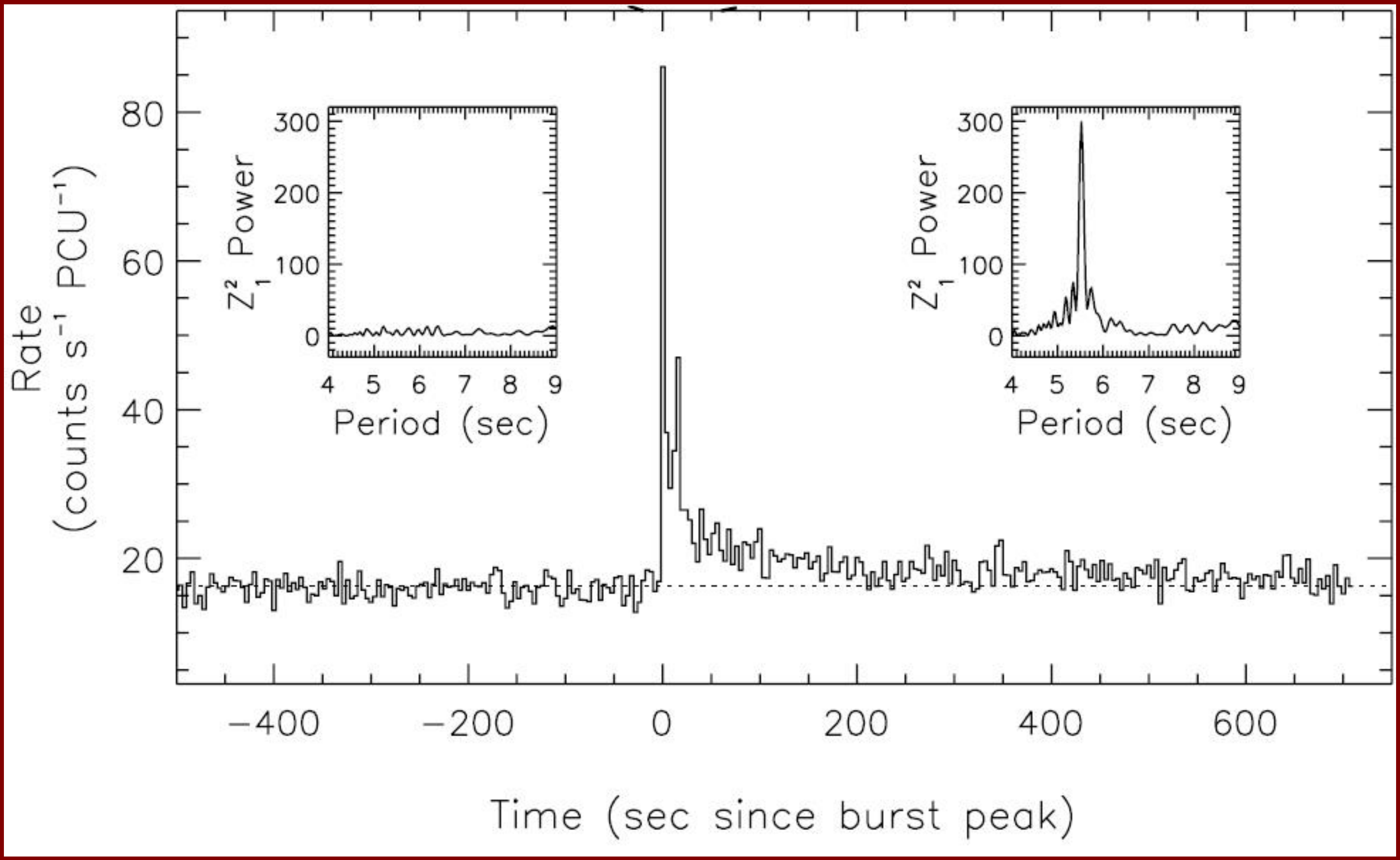




Some bursts have pulsating tails with spin period.

0903.1974

Unique AXP bursts?



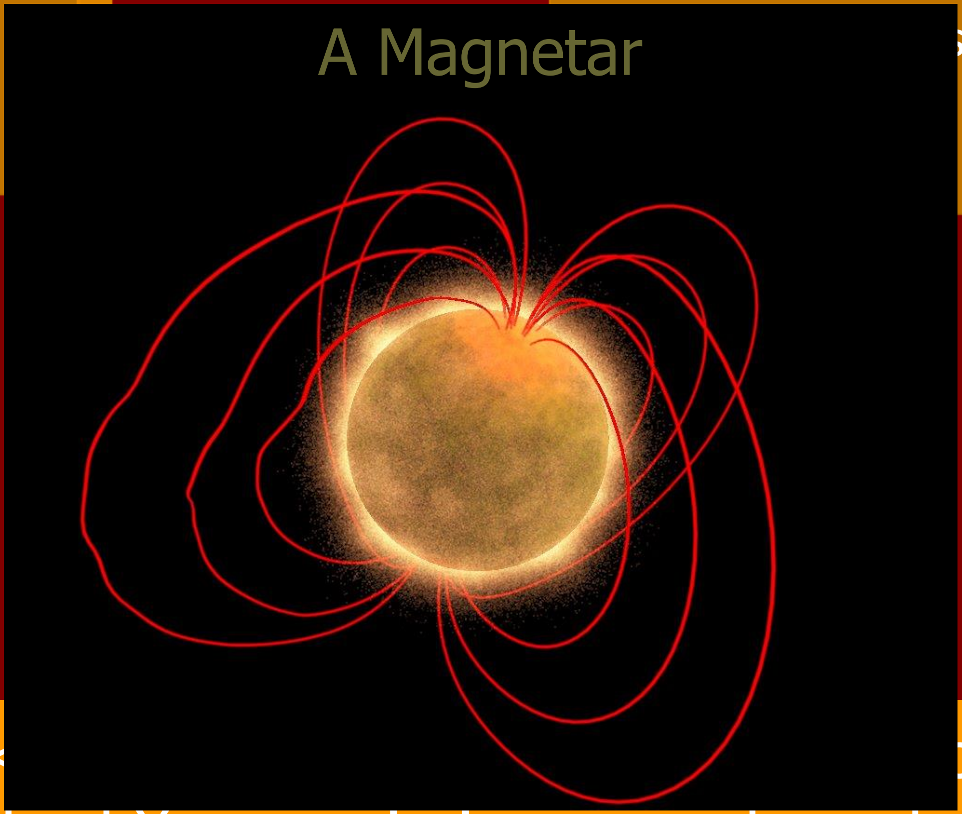
Bursts from AXP J1810-197. Note a long exponential tail with pulsations.

(Woods et al. 2005 astro-ph/ astro-ph/0505039)

A Tale of Two Populations ?

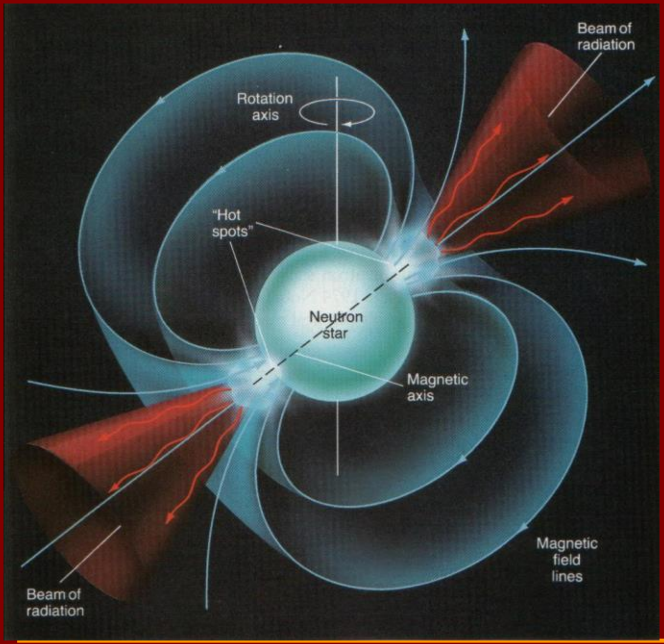
SGRs: bursting
X/γ-ray sources

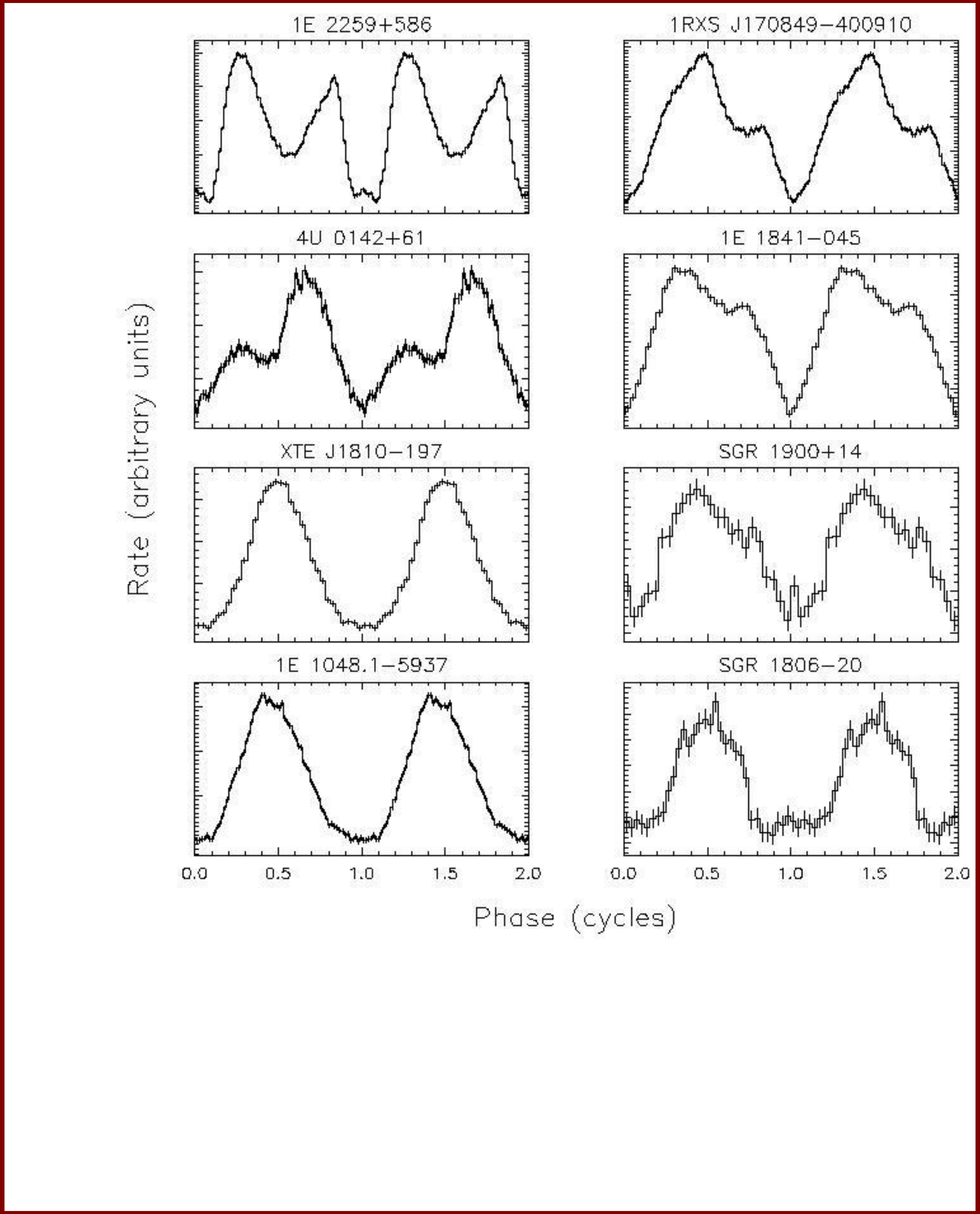
ss



R < ct
Pulsed X-ray emission: a neutron star

Pulse profiles of SGRs and AXPs



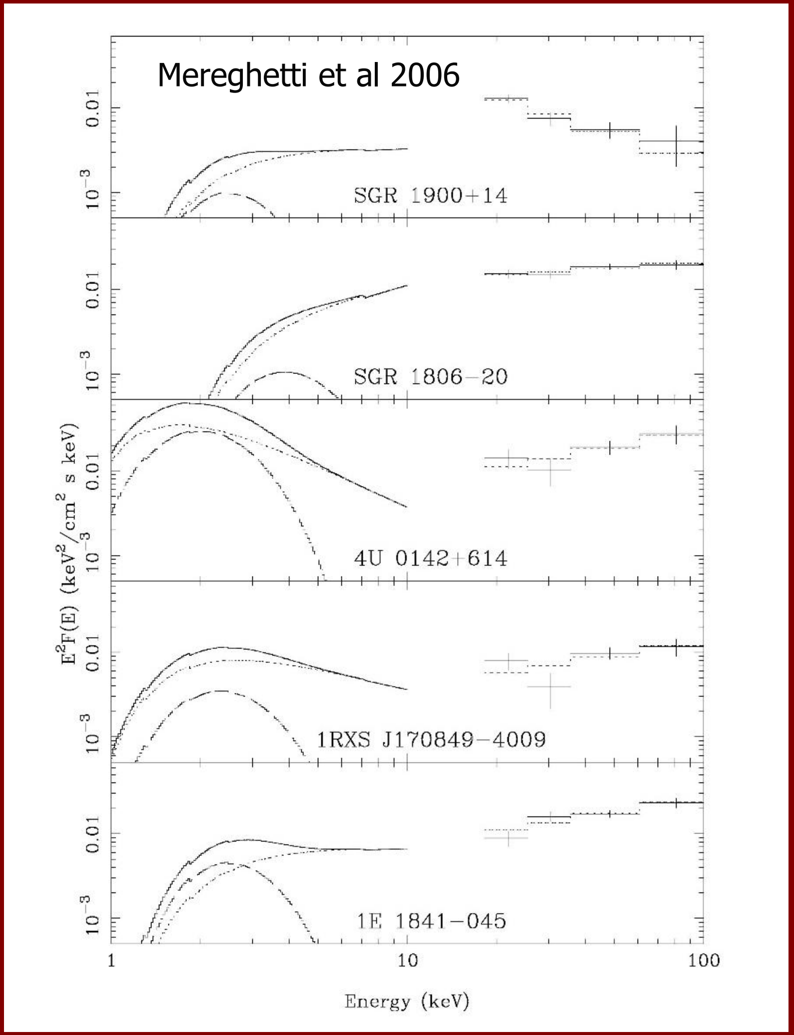


Hard X-ray Emission

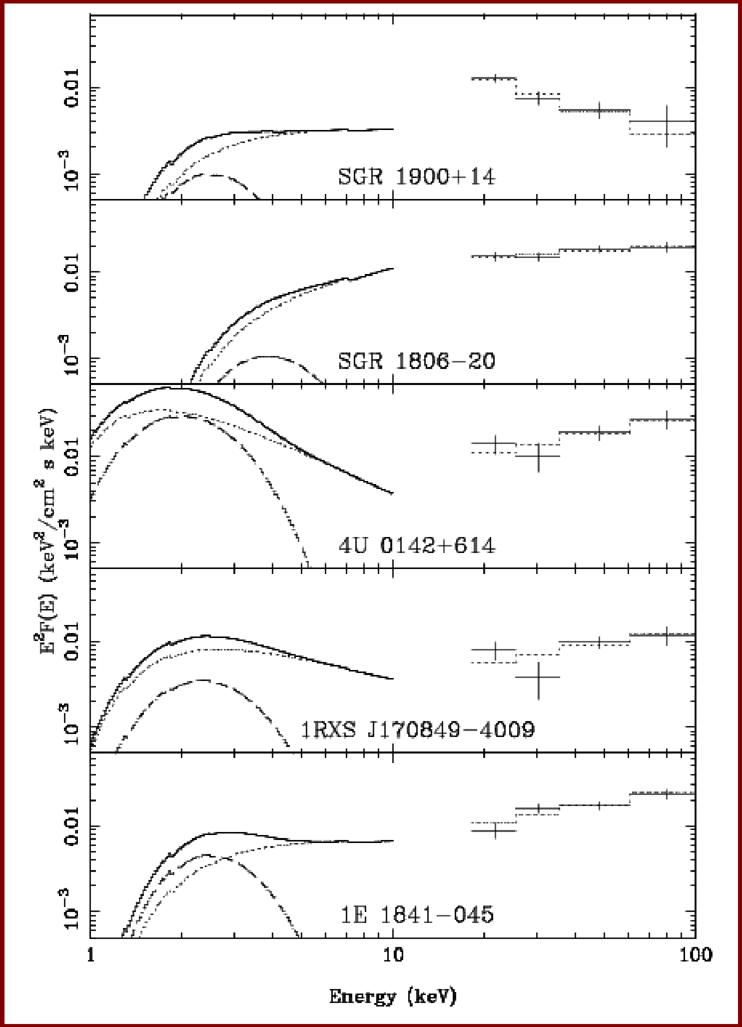
INTEGRAL revealed substantial emission in the 20 -100 keV band from SGRs and APXs

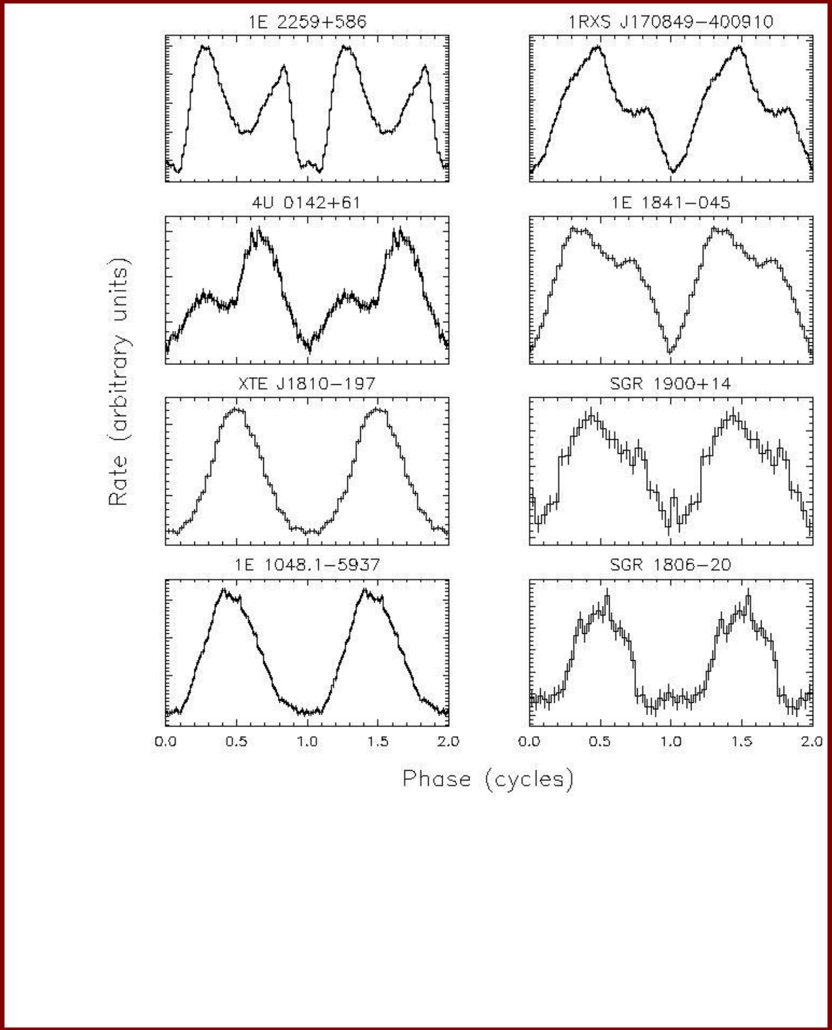
Hard power law tails with $\Gamma \approx 1\text{-}3$
(see 1712.09643 about spectral modeling)

Hard emission pulse



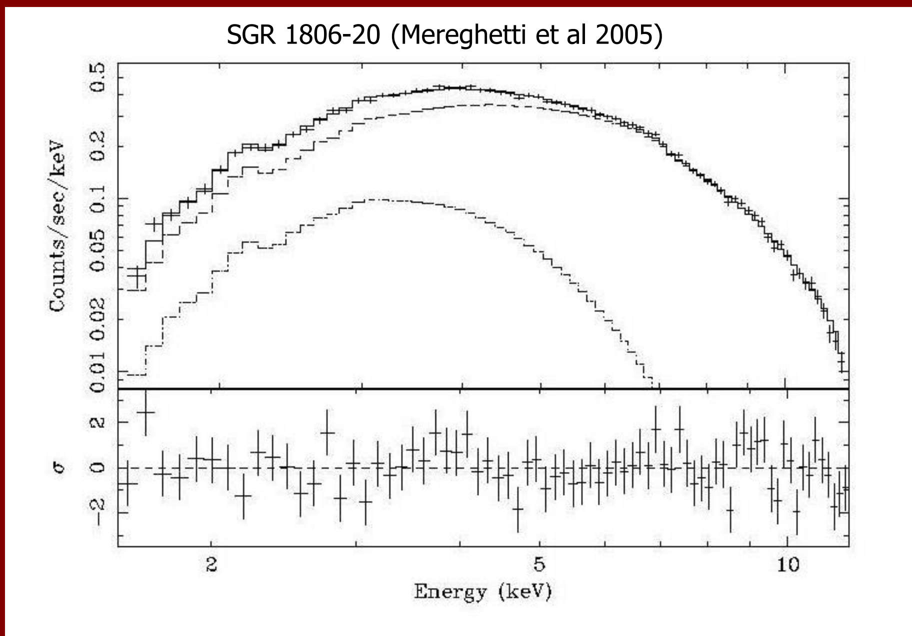
SGRs and AXPs

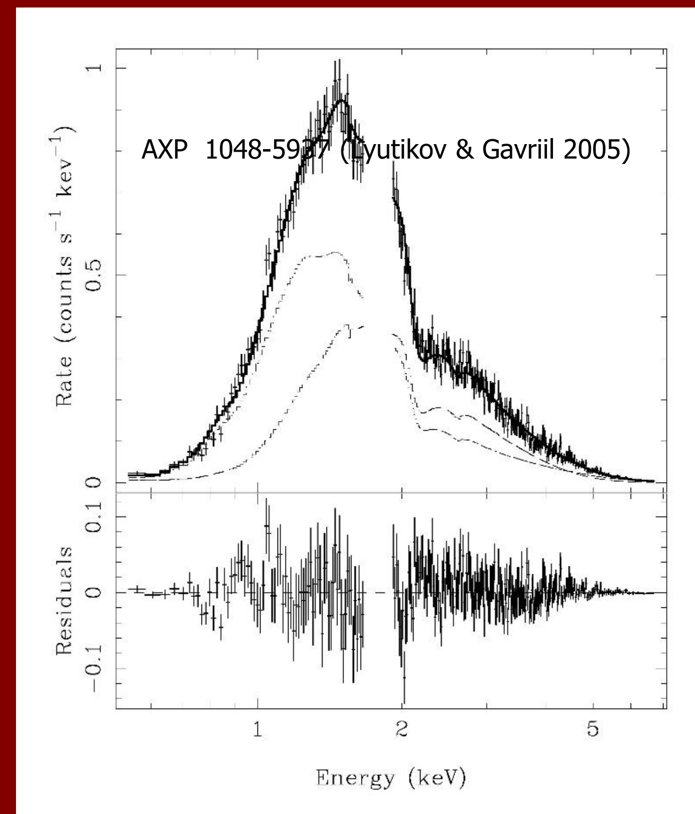




SGRs and AXPs soft X-ray Spectra

- 0.5 – 10 keV emission is well represented by a blackbody plus a power law





See also discussions in:
arXiv: 1001.3847, 1009.2810

SGRs and AXPs soft X-ray Spectra

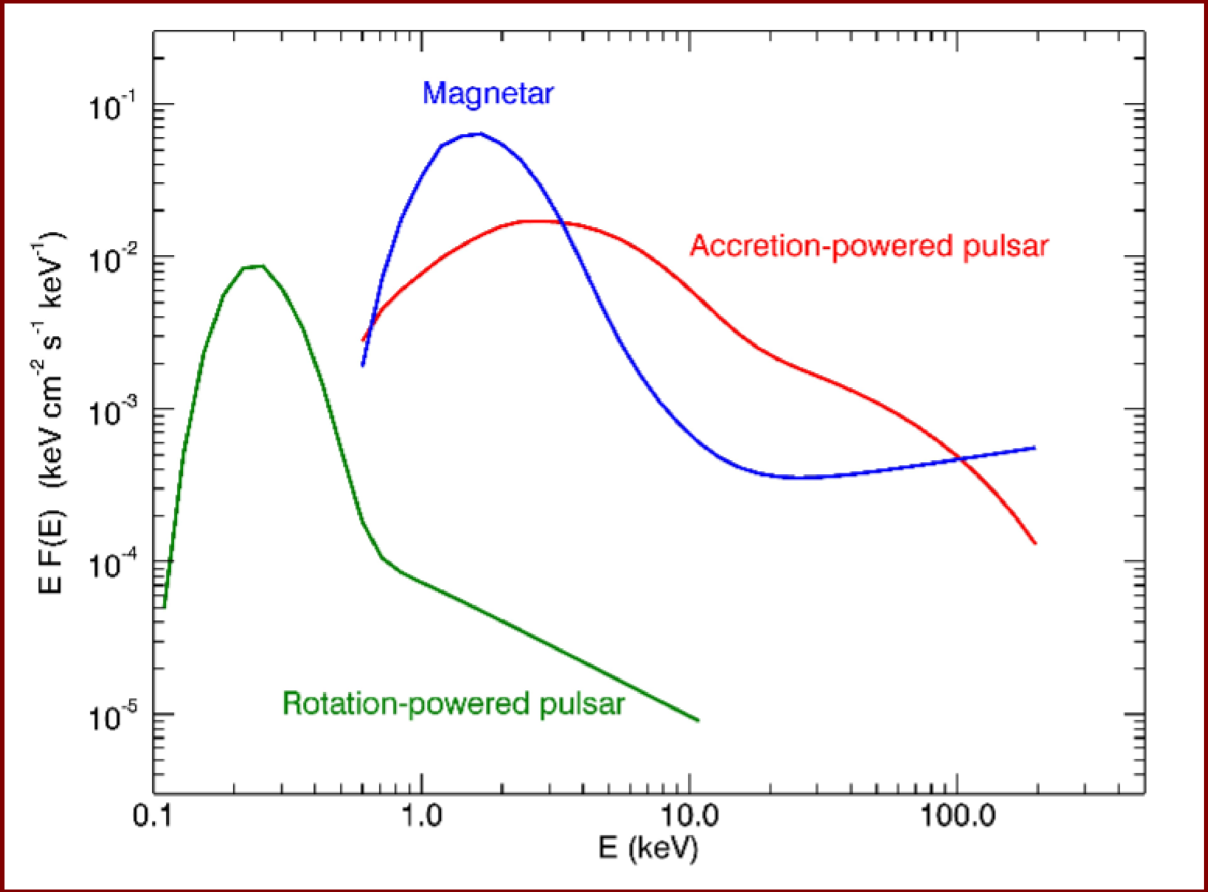
- kT_{BB} ~ 0.5 keV, does not change much in different sources
- Photon index $\Gamma \approx 1 - 4$,

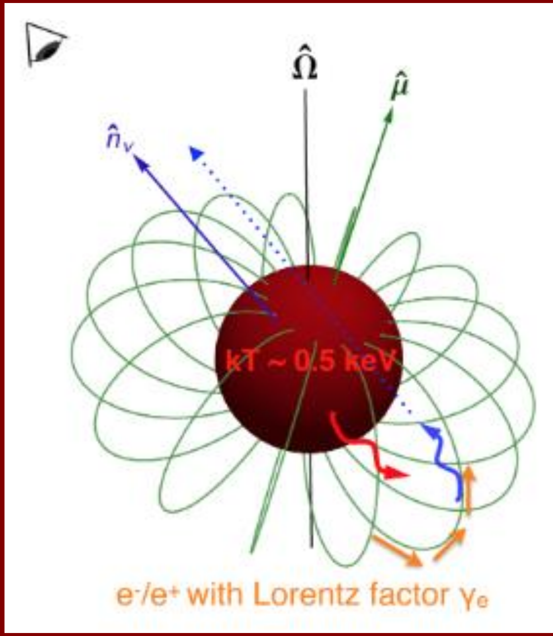
  AXPs tend to be softer
- SGRs and AXPs persistent emission is variable (months/years)
- Variability is mostly associated with

  the non-thermal component
- About polarization see 2001.07663

Magnetar spectra in comparison

1503.06313





1903.05648

Hard tails can be due to upscattering of thermal photons from the surface in the magnetosphere, see e.g. 2012.10815.

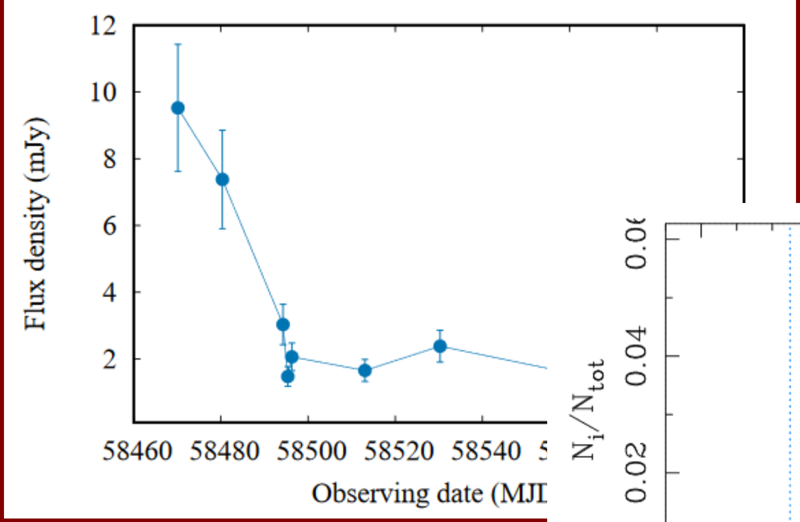
Magnetars can behave like radio pulsars

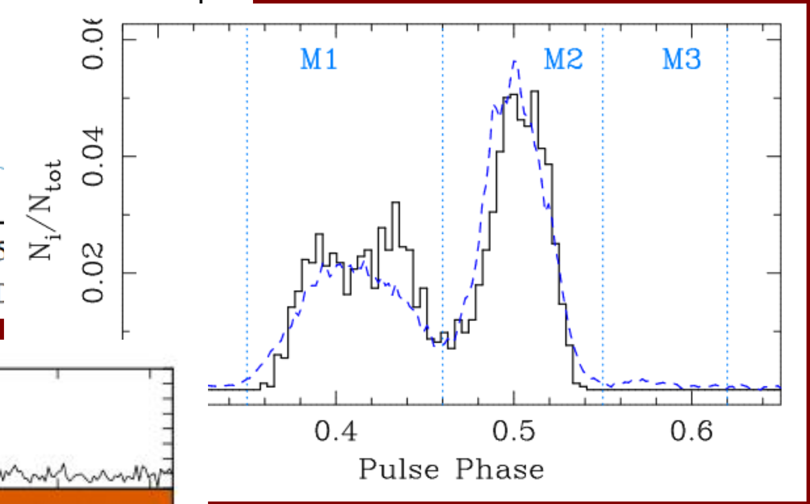
XTE J1810−197

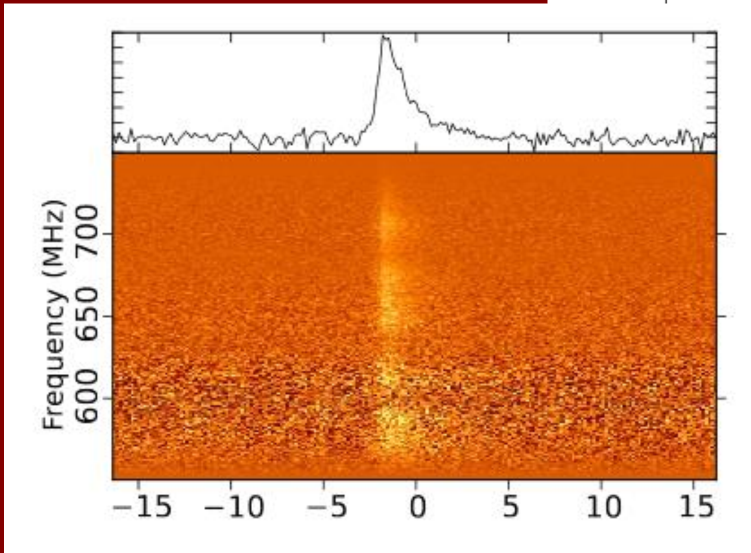
Was the first magnetar to show PSR-like radio emission.

Activity in radio is transient.

Shows short bursts which resemble FRBs (but are much weaker).







1908.04304

Young and fast magnetar with radio

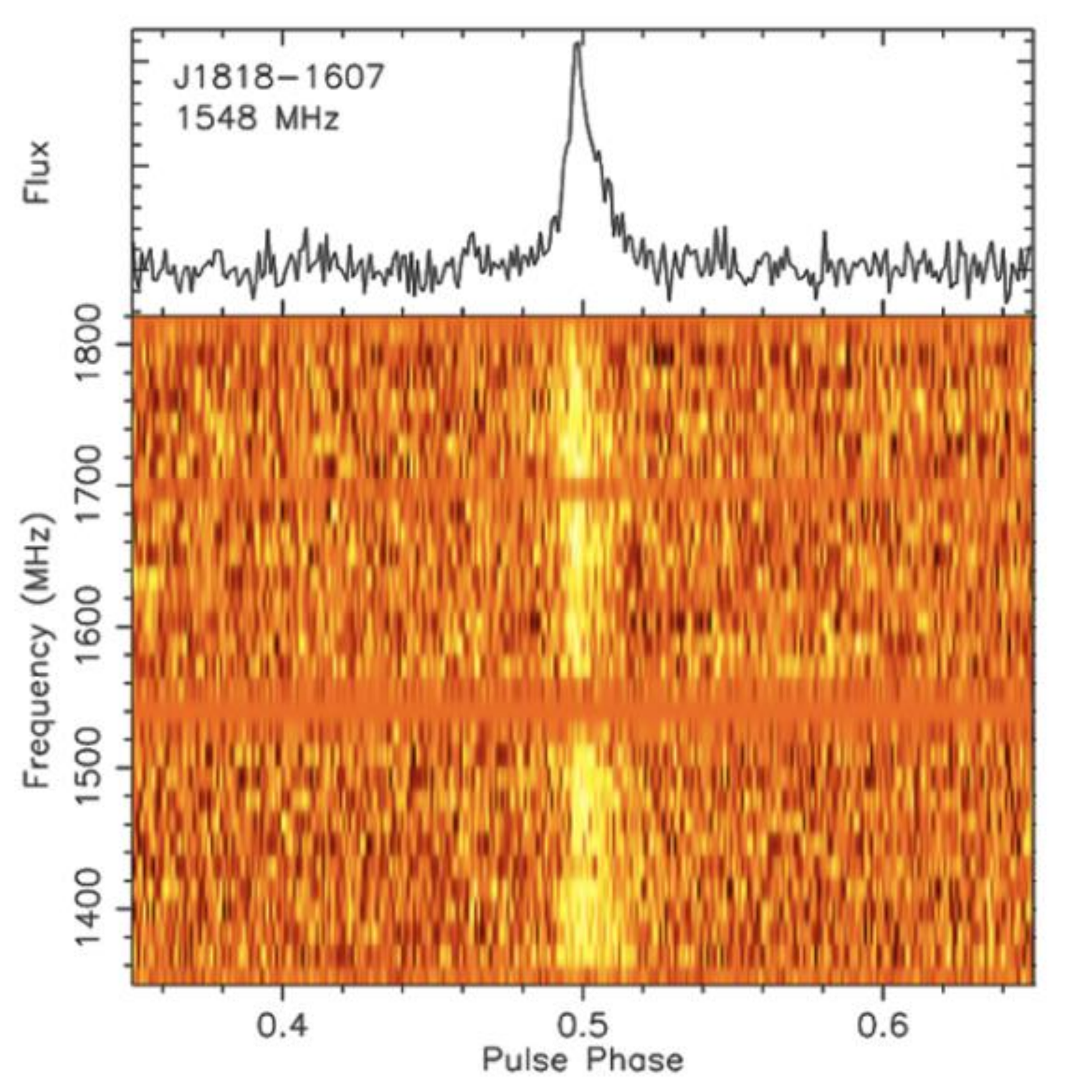
Swift J1818.0–1607
Discovered in March 2020.

Spin period 1.36 s.

Characteristic age 240 yrs.

Radio pulses.

Weak quiescent emission.



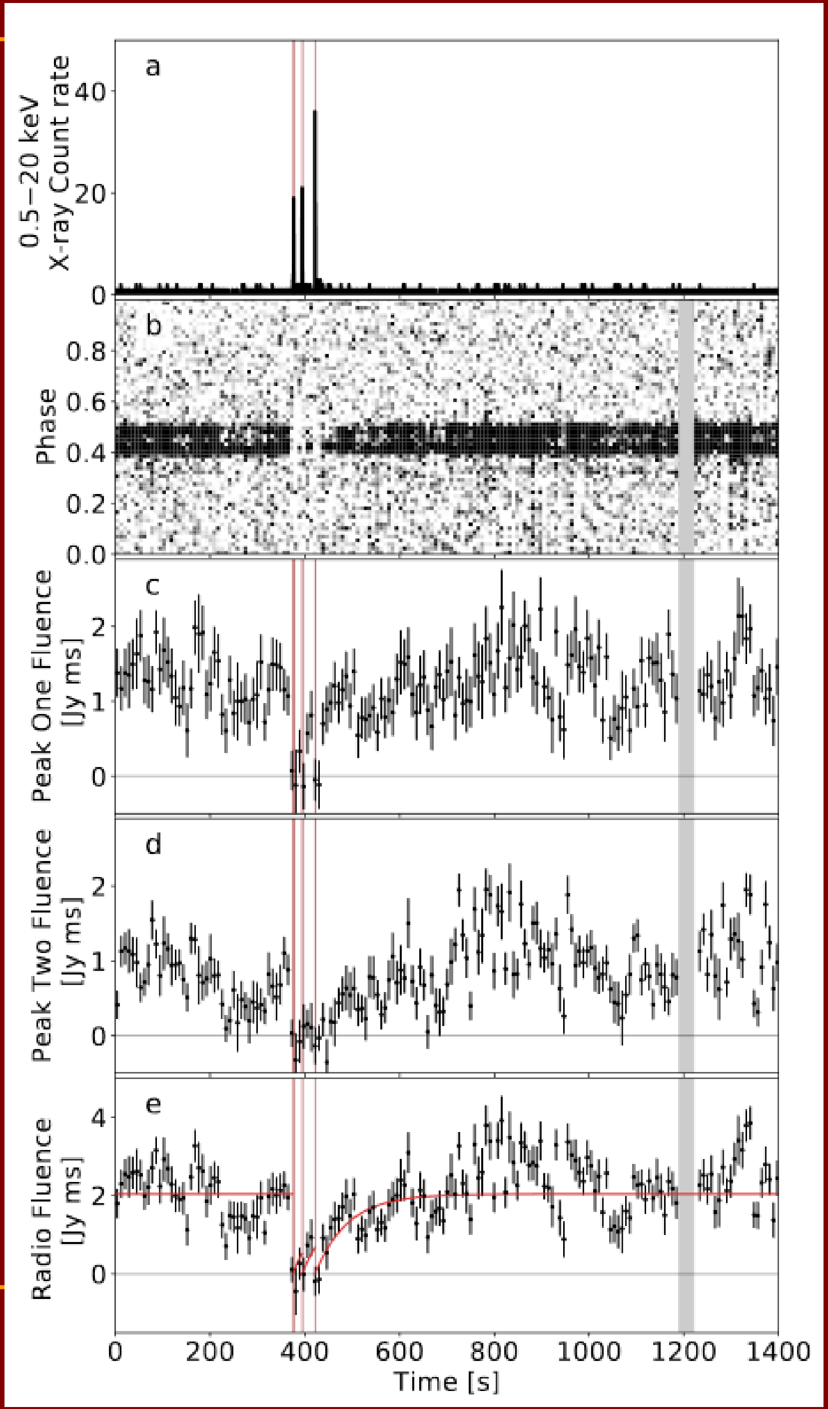
2004.04083

About first radio detection of this source see http://www.astronomerstelegram.org/?read=13577

Suppression of radio during bursts

PSR J1119−6127

The rotationally powered radio emission shuts off coincident with the occurrence of multiple X-ray bursts.

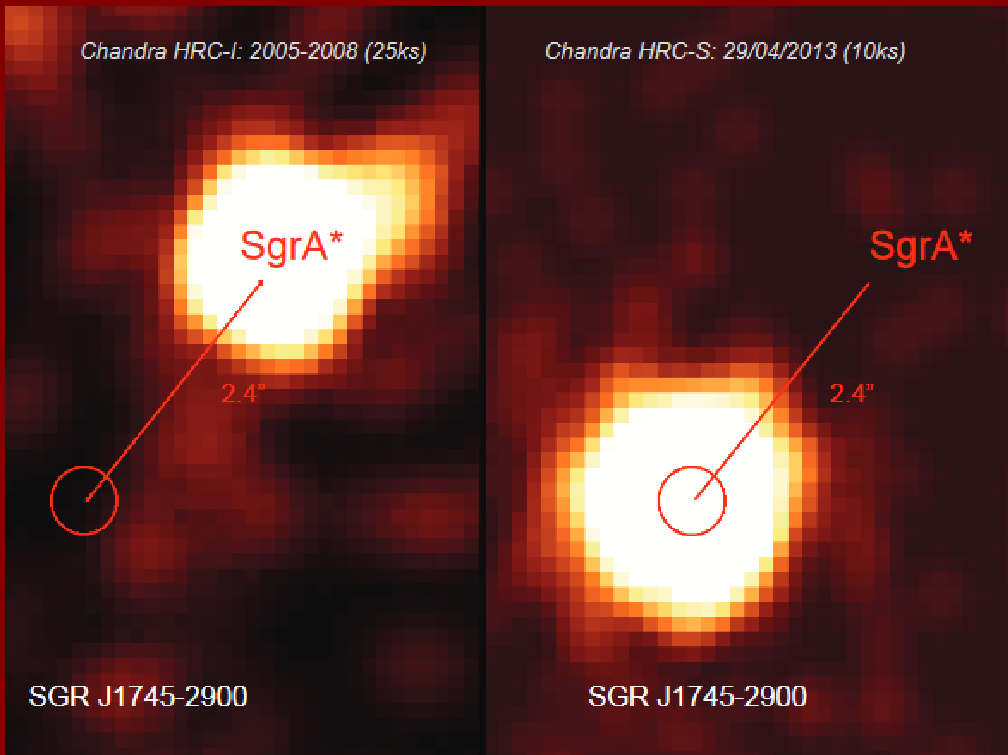


1710.03718

Galactic center magnetar

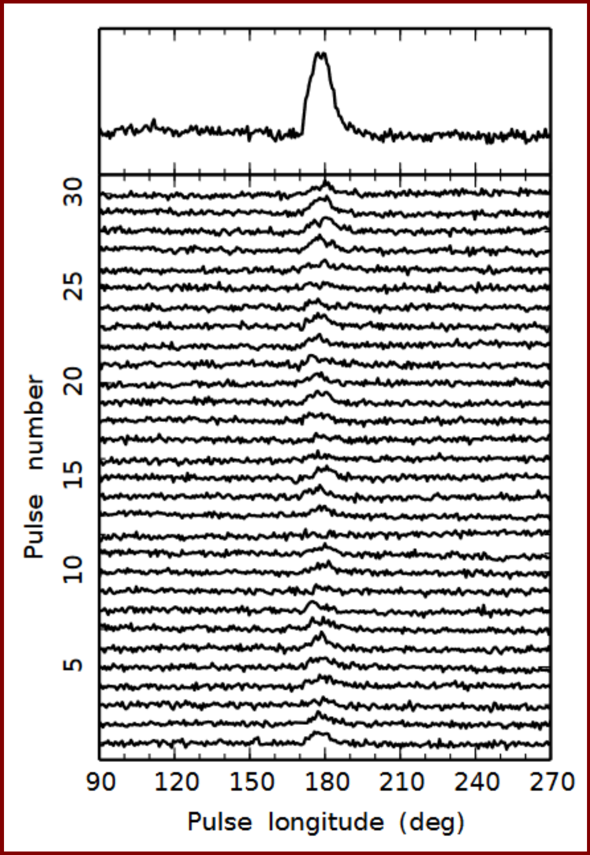
SGR/PSR J1745−2900

1307.6331



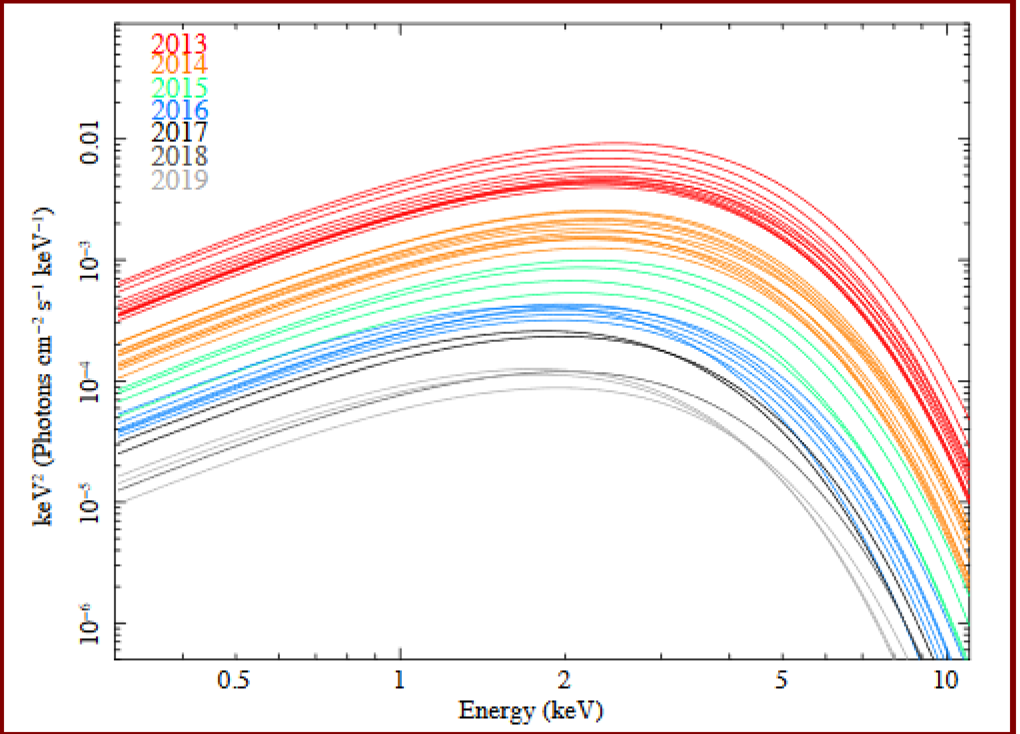
<1 pc from Sgr A*

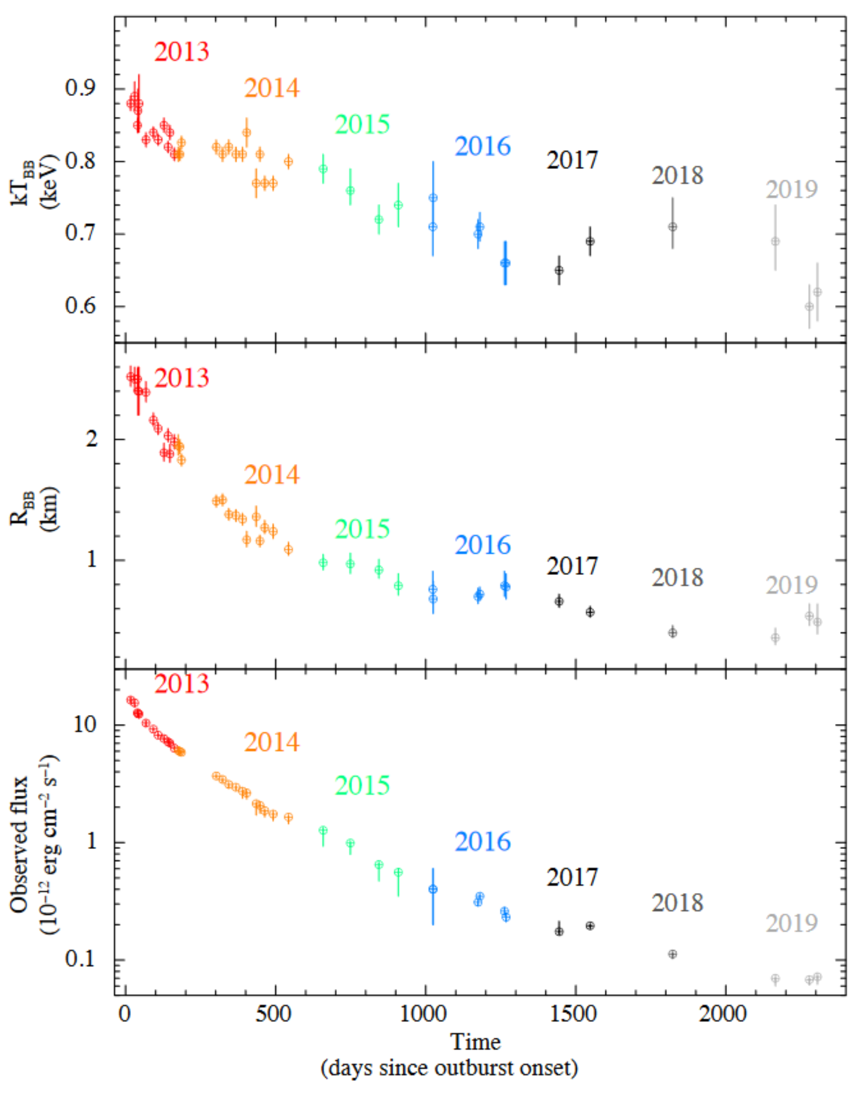
Radio pulsations detection in 2013
The largest dispersion measure and rotation measure among PSRs.



1802.07884

Evolution of the Galactic center magnetar after the outburst in 2013

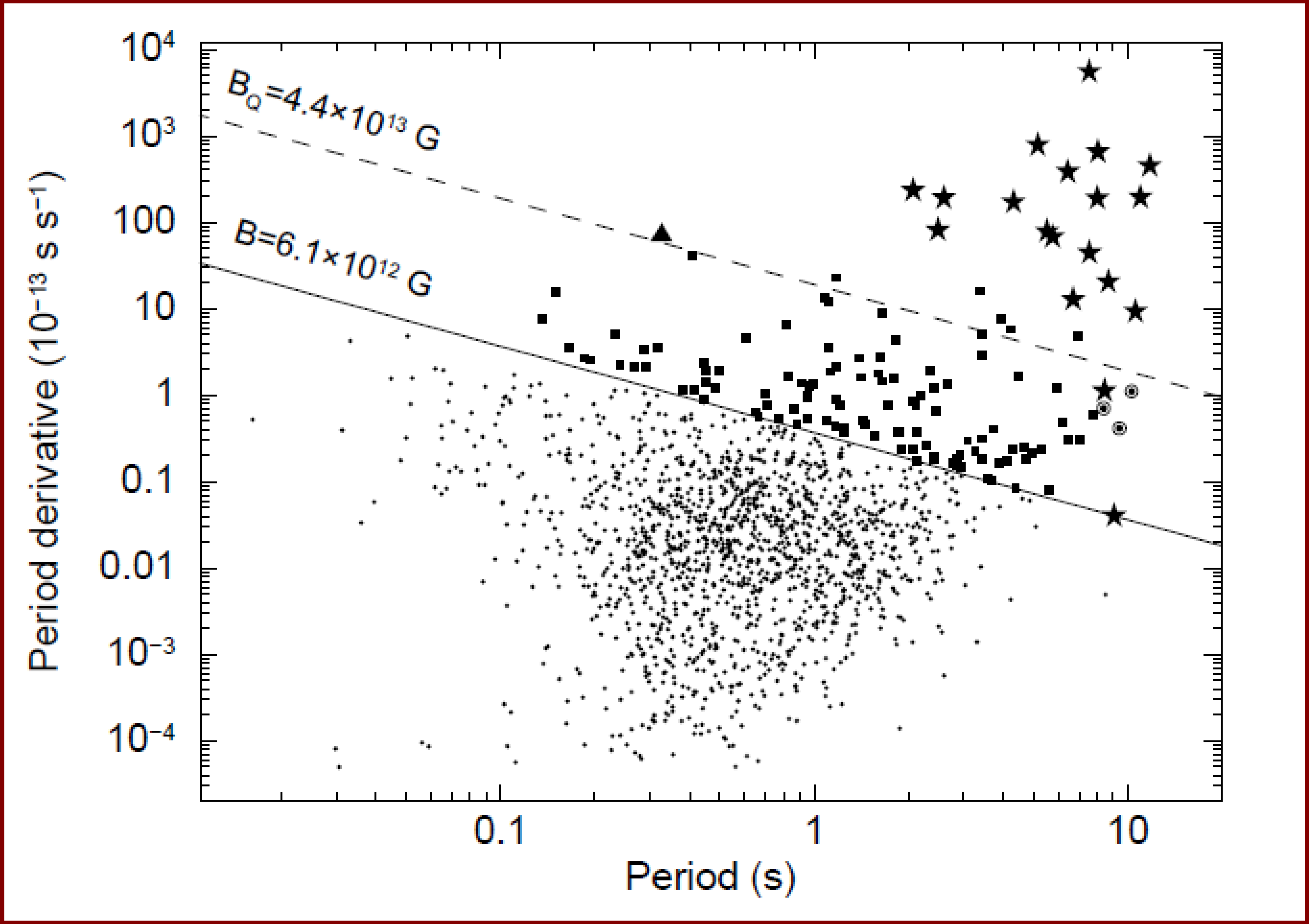




2003.07235

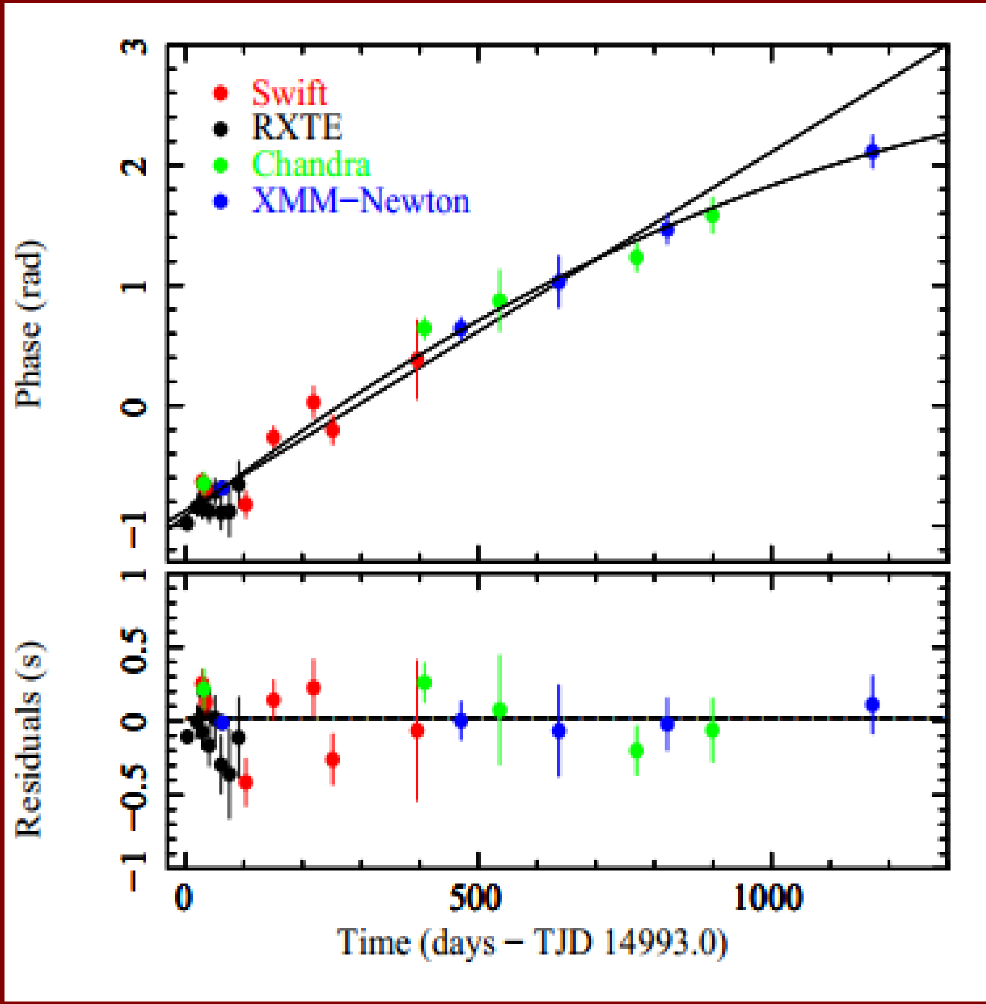
Low-field magnetars

SGR 0418+5729 and Swift J1822.3–160



See a review in [arXiv:1303.6052]

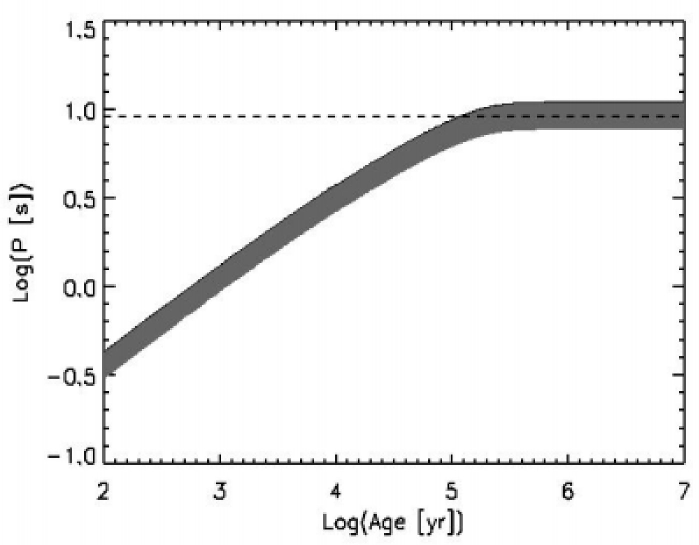
The first low-field magnetar



SGR 0418+5729

Only after ~3 years of observations it was possible to detect spin-down.

The dipolar field is ~6 10^{12} G.

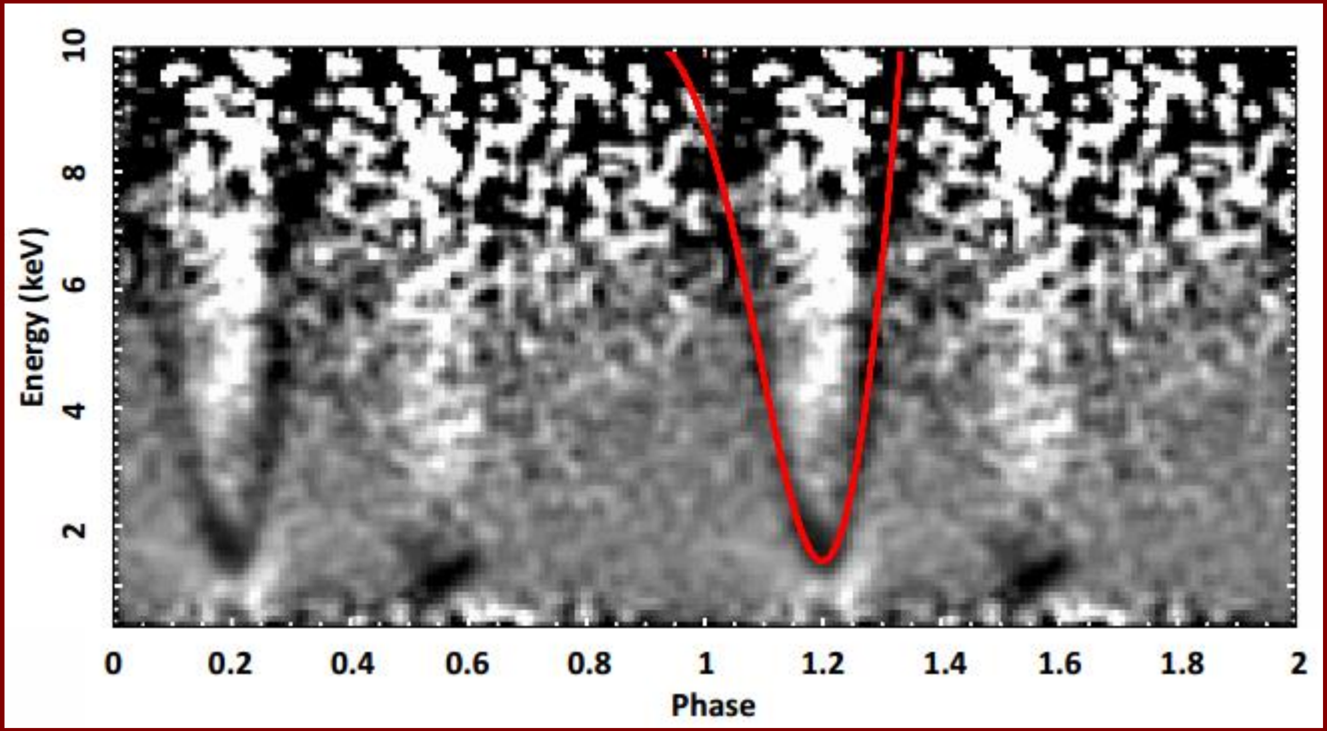


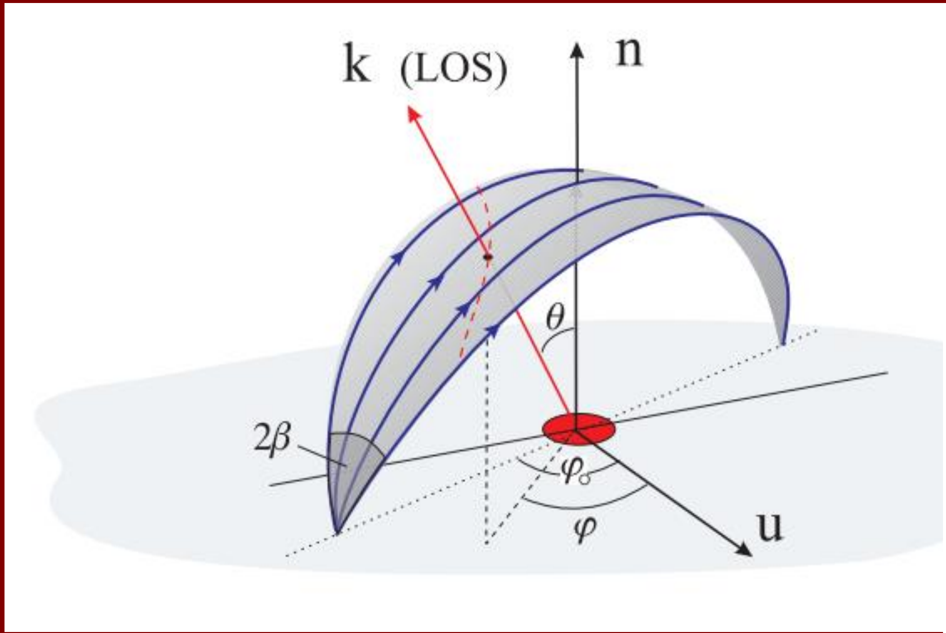
The dipolar field could decay, and activity is due to the toroidal field.

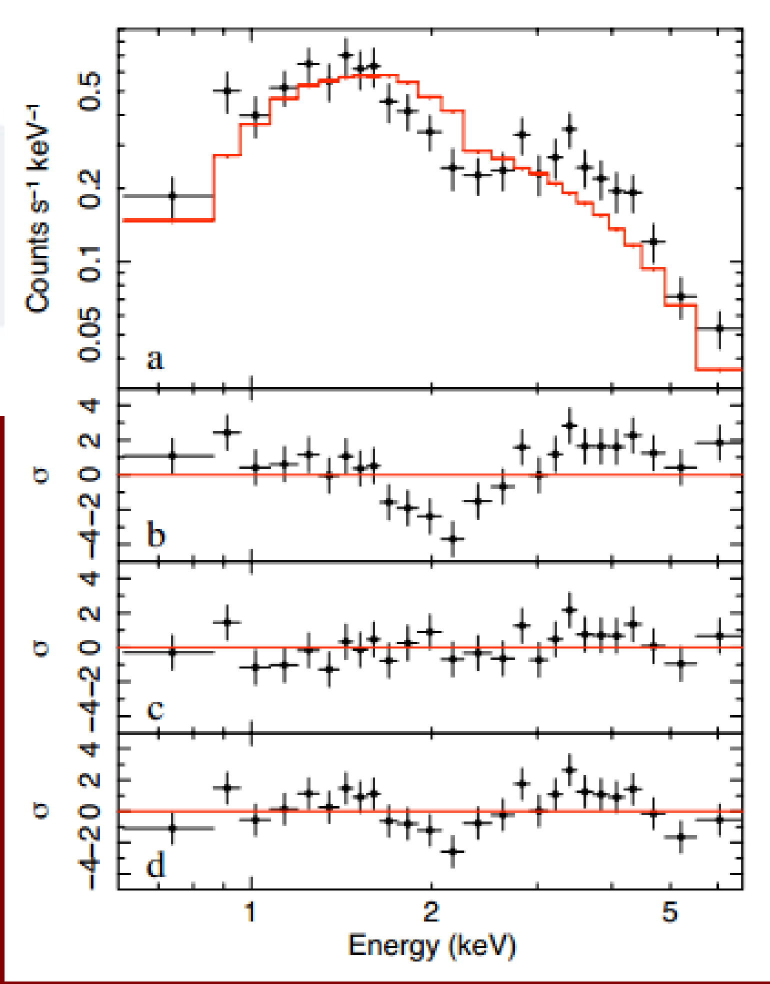
1303.5579

Large field (at last) … But multipoles!

XMM-Newton observations allowed to detect a spectral line which is variable with phase.
If the line is interpreted as a proton cyclotron line,
then the field in the absorbing region is $2\ 10^{14} – 10^{15}$ G

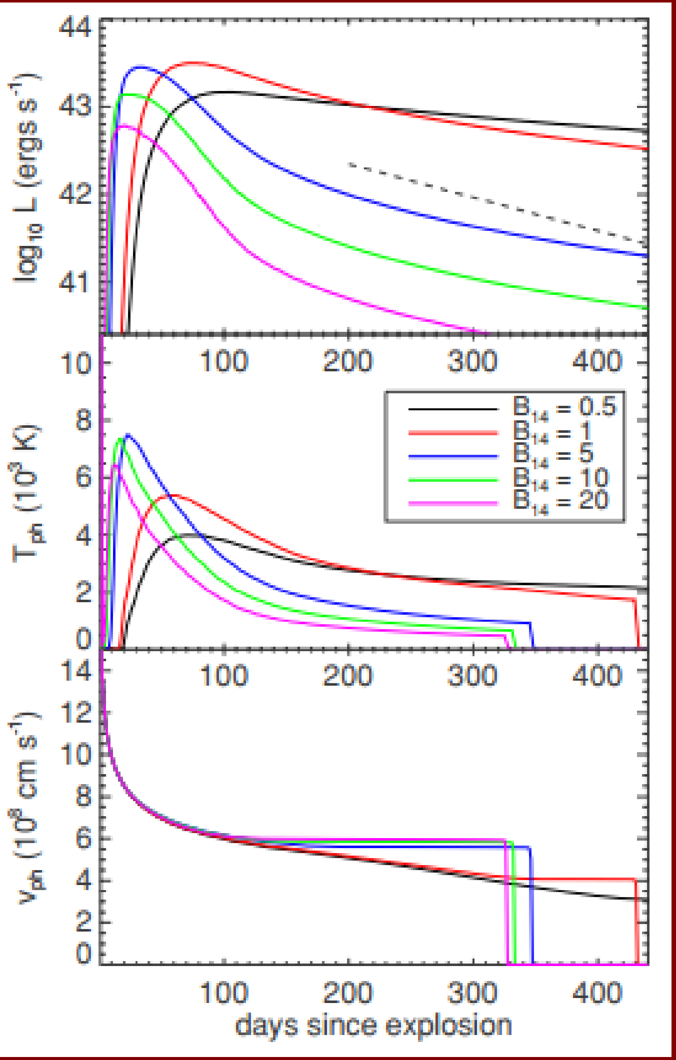




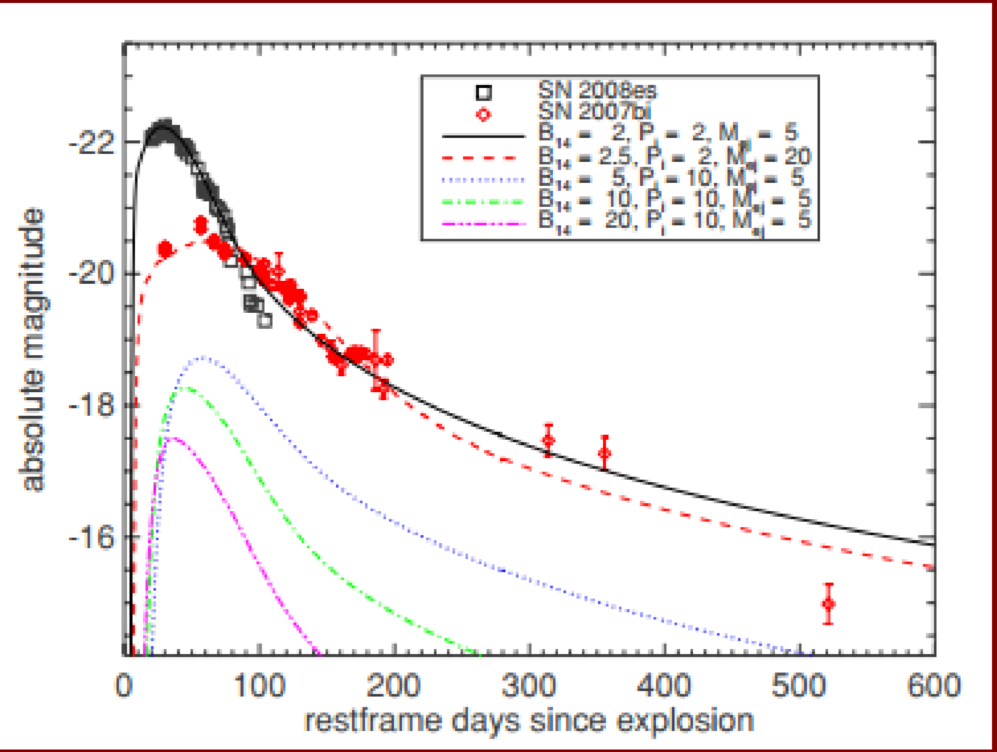


a. Spectrum for the phases 0.15-0.17 and the best-fit model (red) for the phase averaged spectrum
b. Residuals for this model
c. Residuals for the model with a line
d. Residuals for the BB+powel law model (no line)

Magnetars and supernovae

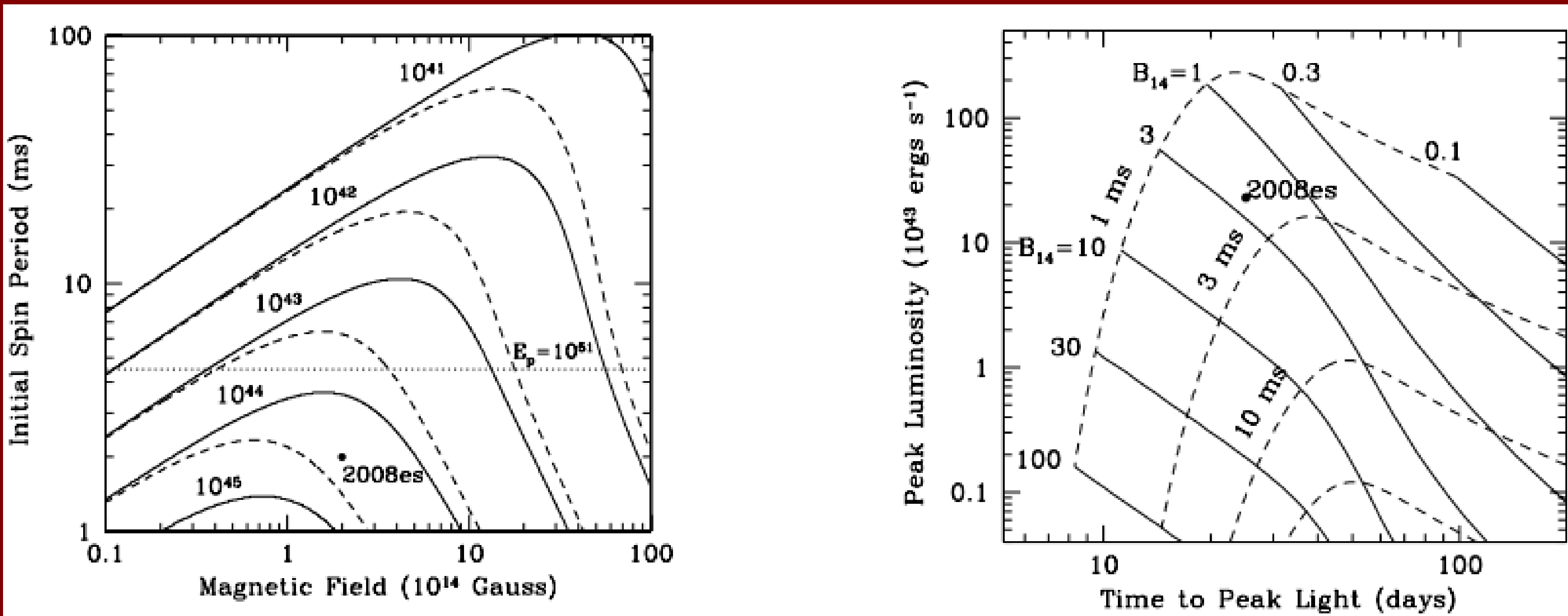


With large field and short spin a newborn NS can contribute a lot to the luminosity of a SN.



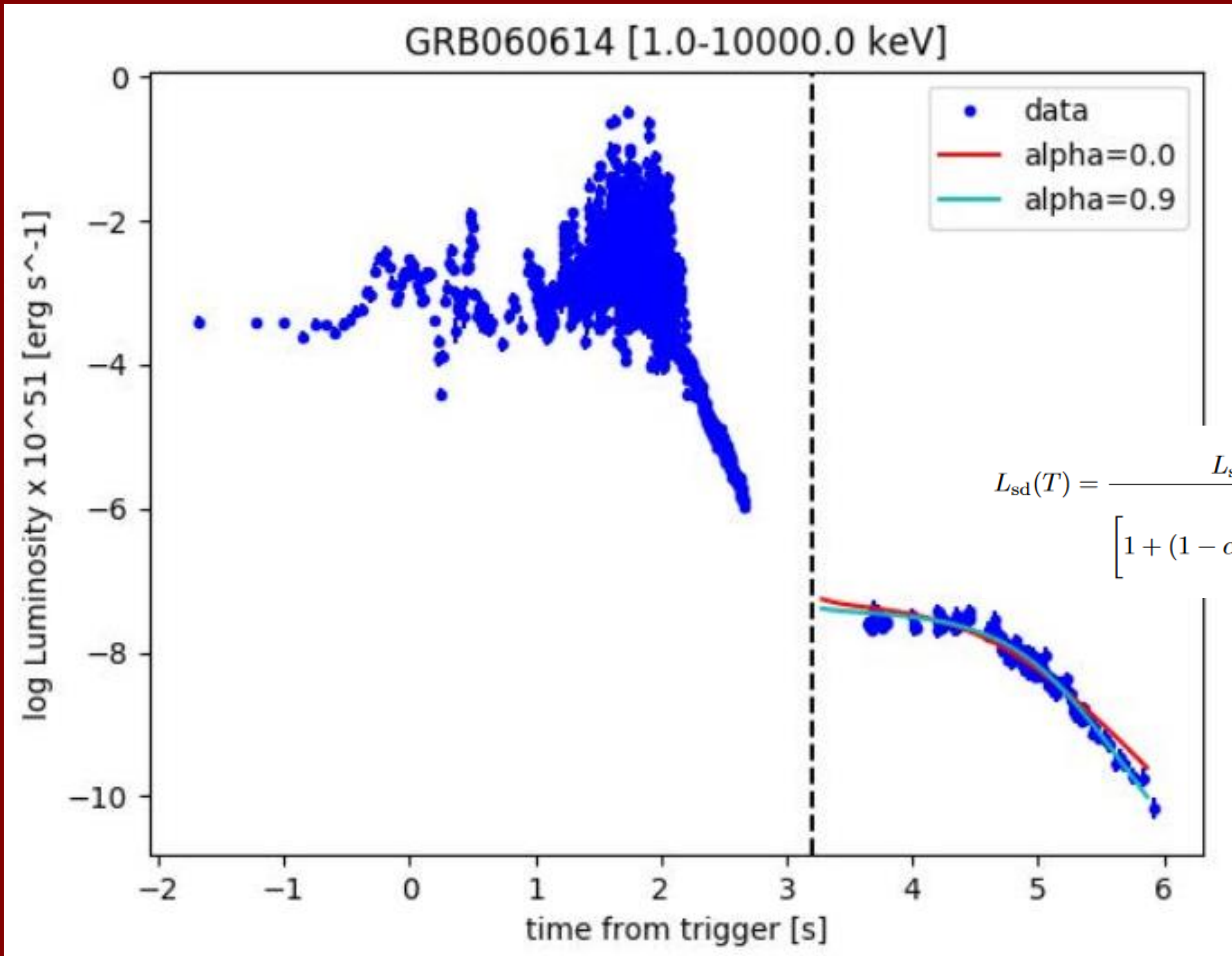
KASEN & BILDSTEN (2010)

Parameters needed



About young millisecond magnetars see also 1906.02610, and a review in 2103.10878.

Magnetars and GRBs



$$L_{\rm sd} = \frac{\mu^2}{c^3}\, \Omega^4 \left(1 + \sin^2\theta\right)$$

$$L_{\rm sd}^{\rm (N-I)} = L_{\rm sd}\left(\frac{\Omega}{\Omega_i}\right)^{-2\alpha}$$

$$n = 3 - 2\alpha.$$

$$L_{\rm sd}(T) = \frac{L_{\rm sd,i}}{\left[1+(1-\alpha)\,\frac{T}{\tau_i}\right]^{\frac{2-\alpha}{1-\alpha}}} = \frac{E_{\rm spin,i}}{\tau_i\left[1+(1-\alpha)\frac{T}{\tau_i}\right]^{\frac{2-\alpha}{1-\alpha}}},$$

1804.08652

Papers to read

- Woods, Thompson astro-ph/0406133 – old classical review
- Mereghetti arXiv: 0804.0250
- Rea, Esposito arXiv: 1101.4472 - outbursts
- Turolla, Esposito arXiv: 1303.6052 - Low-field magnetars
- Mereghetti et al. arXiv: 1503.06313
- Turolla, Zane, Watts arXiv: 1507.02924 – Big general review
- Beloborodov, Kaspi arXiv: 1703.00068
- Esposito et al. arXiv: 1803.05716
- Coti Zelati et al. arXiv: 1710.04671 – outbursts
- Gourgouliatos, Esposito 1805.01680 – magnetic fields
- Dall'Osso, Stella 2103.10878 - millisecond magnetars