Magnetars: SGRs and AXPs

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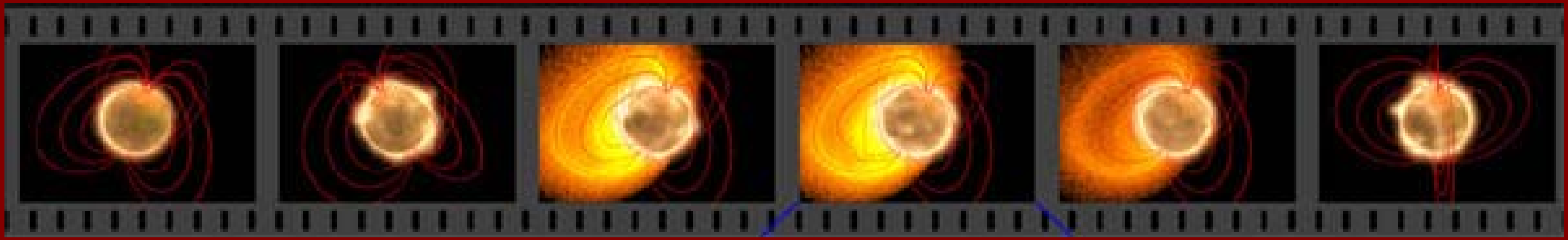
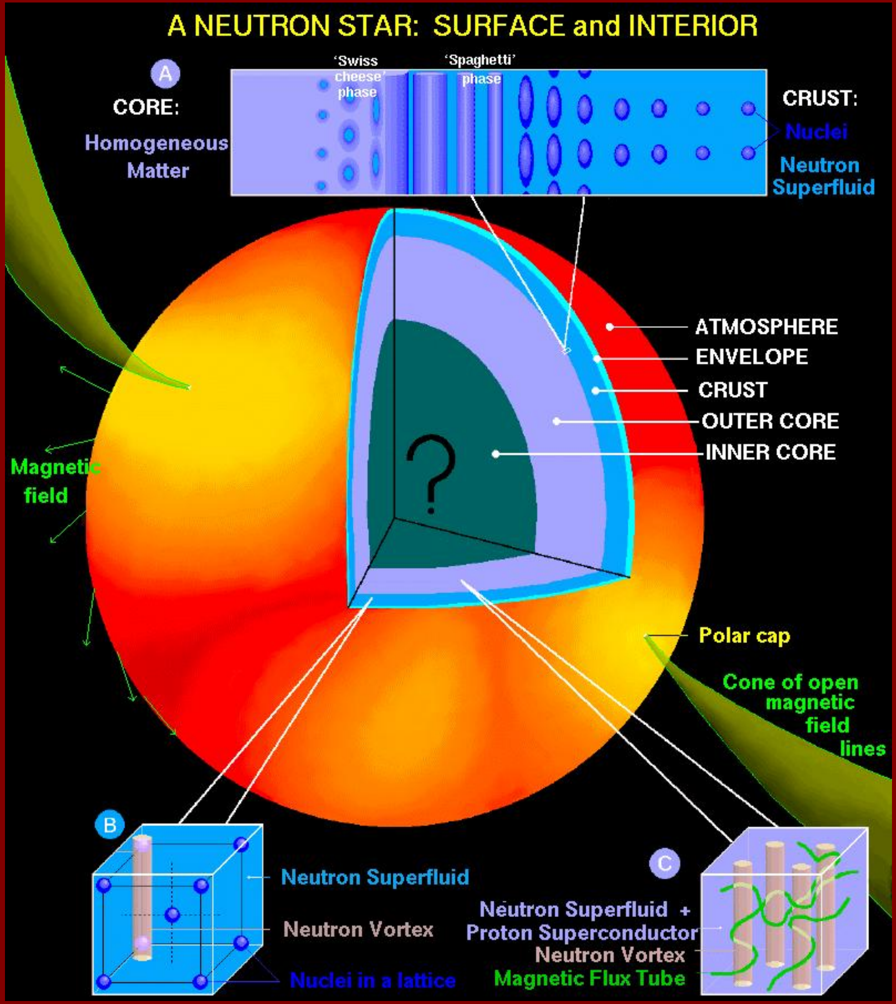


Neutron stars



(by Dany Page)

Mass ~1-2 solar masses
Radius ~10-15 km

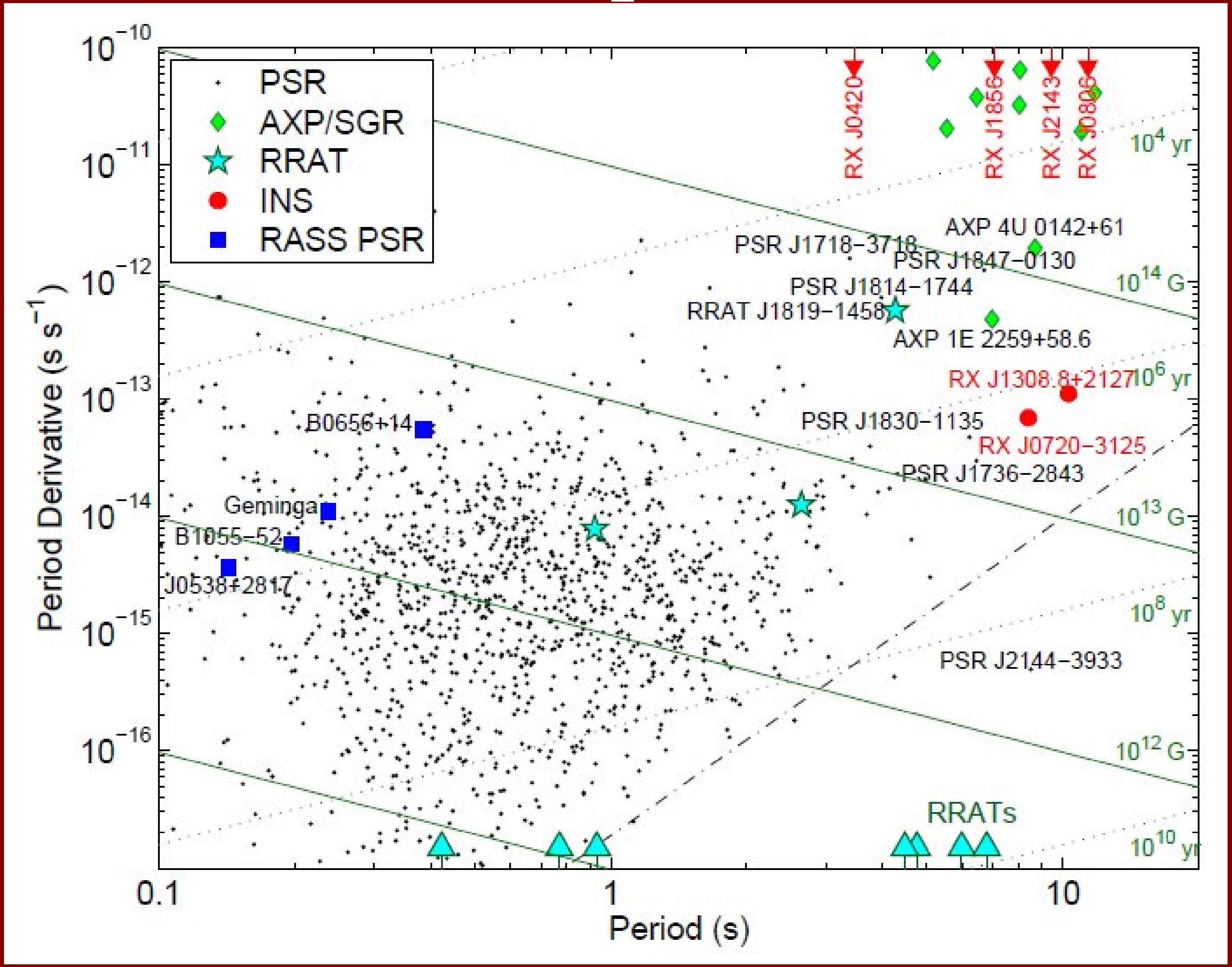
Observed as:

- Radio pulsars
- Accreting in binaries
- Compact central X-ray sources in supernova remnants.
- Anomalous X-ray pulsars
- Soft gamma repeaters
- The Magnificent Seven
- Transient radio sources (RRATs)
- Gamma-ray pulsars

See reviews:

- physics/0503245 - general
- astro-ph/0609066 – types of young
- arXiv: 0804.0250 - magnetars

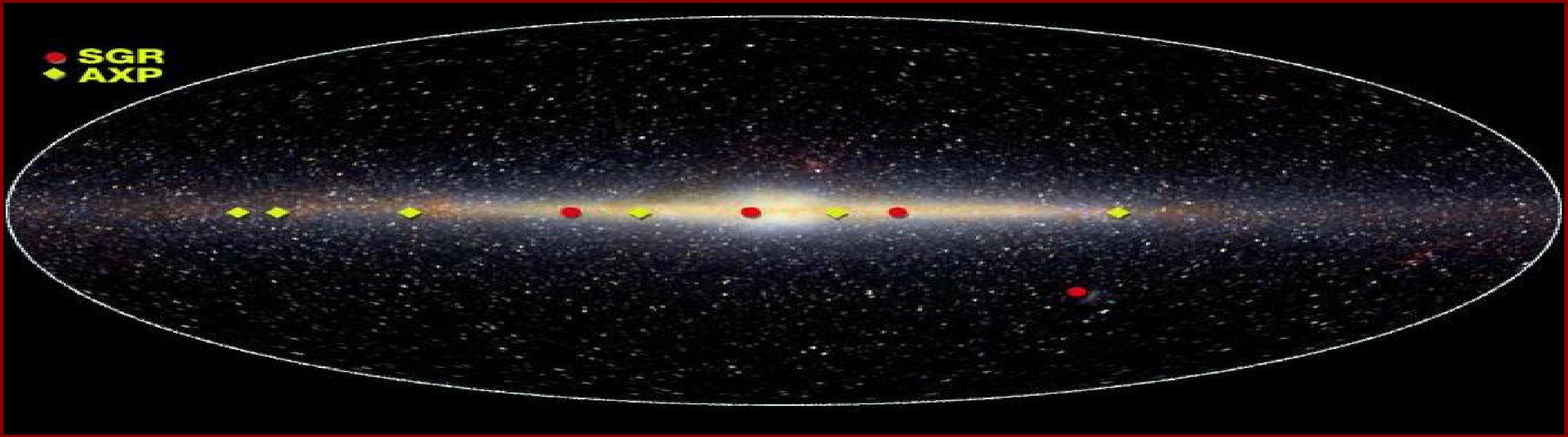
All NSs in one plot



Kaplan arXiv: 0801.1143

Magnetars in the Galaxy

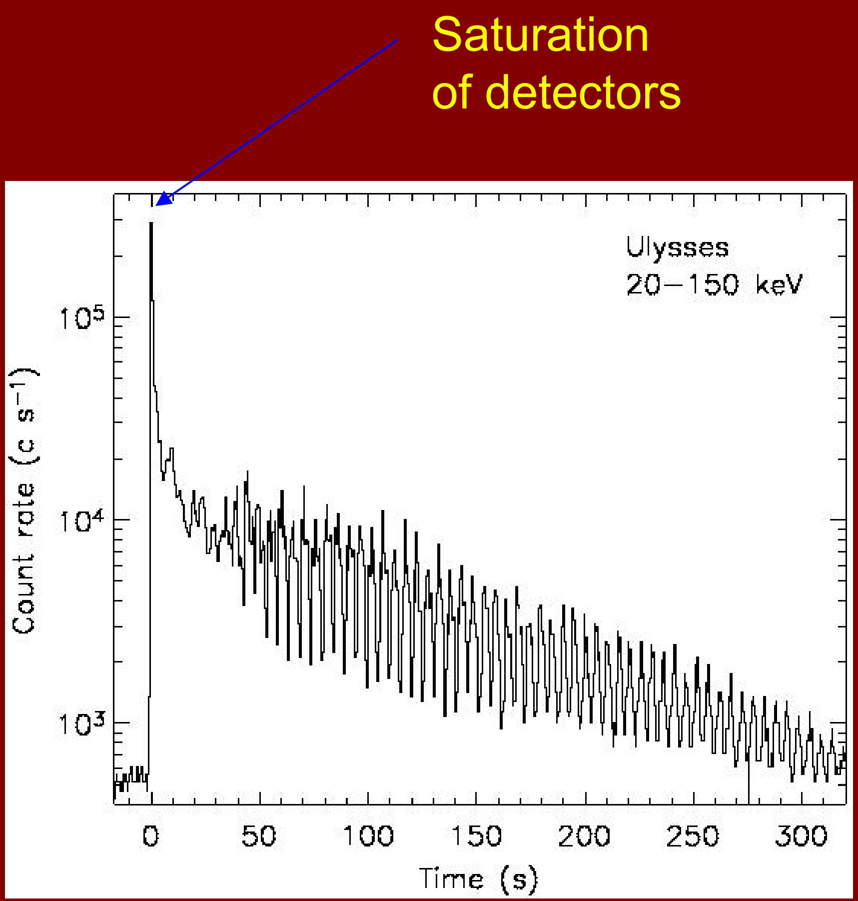
- 7 SGRs, 11 AXPs, plus candidates (3+3), plus radio pulsars with high magnetic fields…
- Young objects (about 10^4 year).
- At least about 10% of all NSs (or more, as transient magnetars can be abundant).



(see a recent review in arXiv:0804.0250)

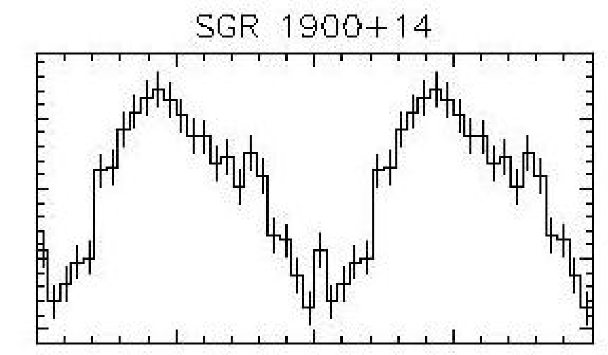
Soft Gamma Repeaters: main properties

- Energetic “Giant Flares” (GFs, L ≈ 10^{45}-10^{47} erg/s) detected from 3 (4?) sources
- No evidence for a binary companion, association with a SNR at least in one case
- Persistent X-ray emitters, L ≈ 10^{35} - 10^{36} erg/s
- Pulsations discovered both in GFs tails and persistent emission, P ≈ 5 -10 s
- Huge spindown rates, $\dot{P}/P \approx 10^{-10}$ ss^{-1}



SGRs: periods and giant flares

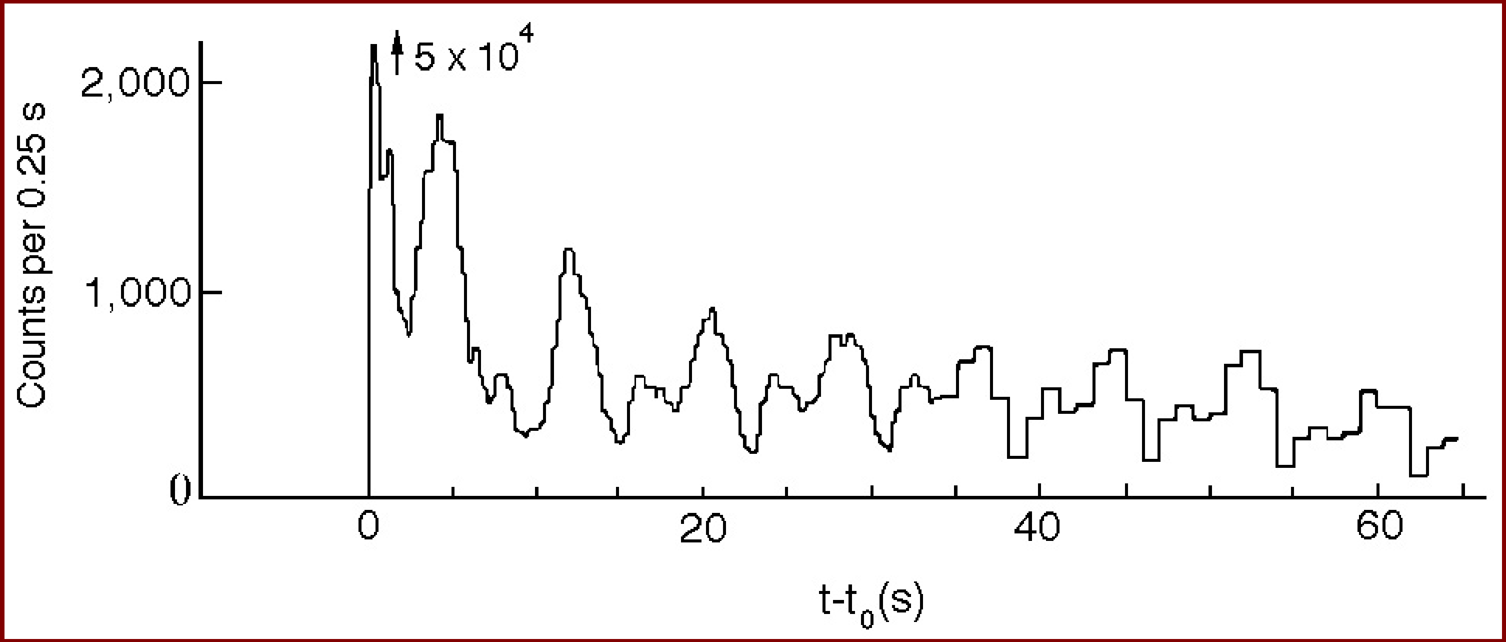
	P, s	Giant flares
▪ 0526-66	8.0	5 March 1979
▪ 1627-41	2.6	18 June 1998 (?)
▪ 1806-20	7.5	27 Dec 2004
▪ 1900+14	5.2	27 Aug 1998
▪ 0501+45	5.7	
▪ 2013+34?		
▪ 1801-23?		
▪ 0418+5729	9.1	
▪ 1833-0832	7.6	
▪ 1550-5418		



See the review in Woods, Thompson astro-ph/0406133 and Mereghetti arXiv: 0804.0250

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

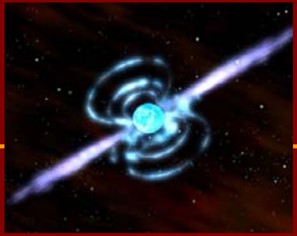


Mazets et al. 1979

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

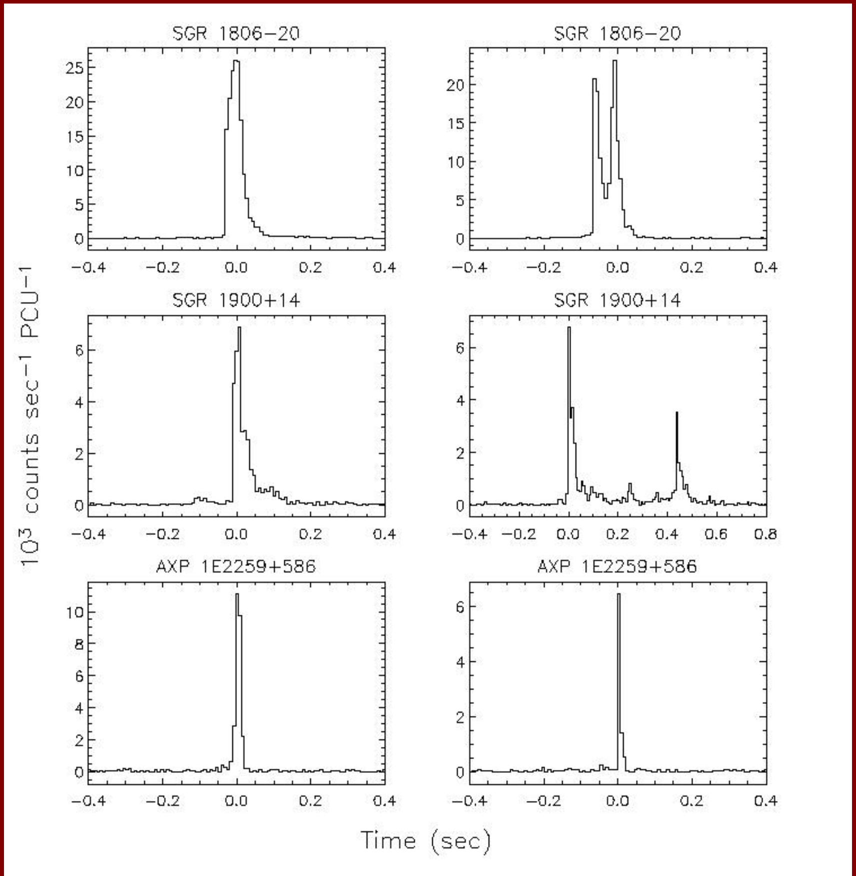
Power distribution is similar to the distribution of earthquakes in magnitude



See the review in Woods, Thompson astro-ph/0406133

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

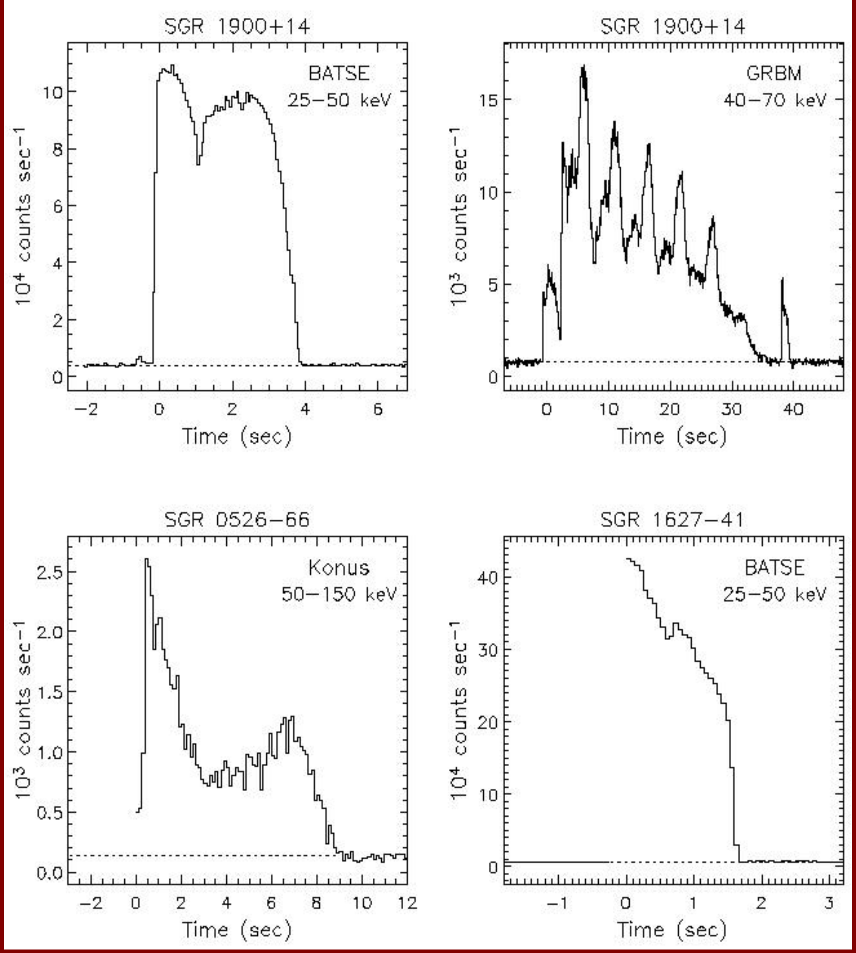


(from Woods, Thompson 2004)

Intermediate SGR bursts

Examples of intermediate bursts.

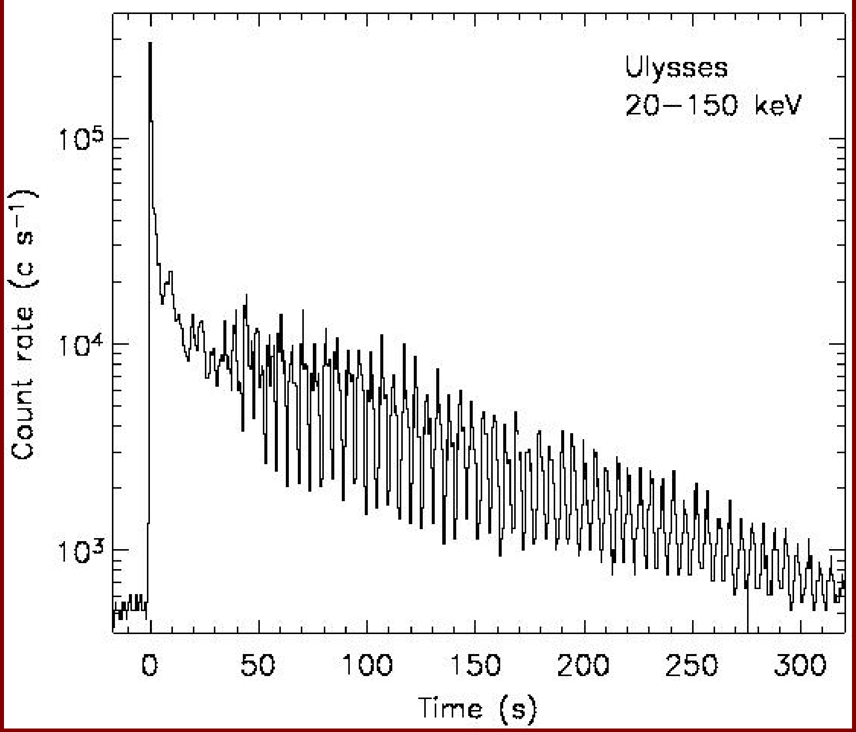
The forth (bottom right) is sometimes defined as a giant burst (for example by Mazets et al.).



(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

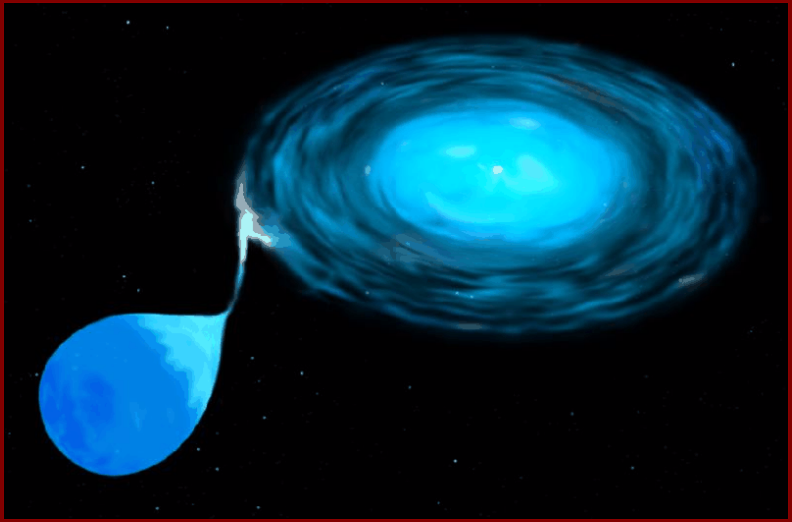


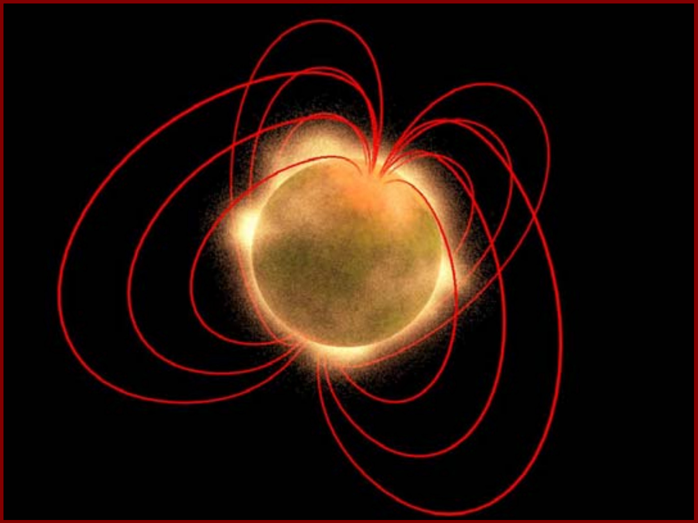
Hurley et al. 1999

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



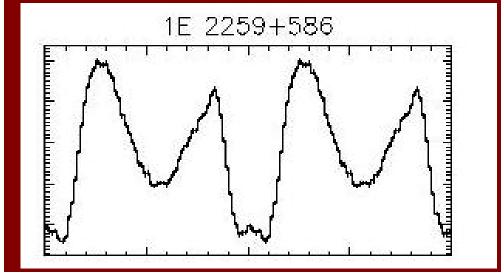


Anomalous X-ray Pulsars: main properties

- Eleven sources known:
  1E 1048.1-5937, 1E 2259+586, 4U 0142+614,
  1 RXS J170849-4009, 1E 1841-045,
  CXOU 010043-721134, AX J1845-0258,
  CXOU J164710-455216, XTE J1810-197,
  1E 1547.0-5408, AX J1818.8-1559 (+ PSR J1846-0258)
- 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, $\dot{P}/P \approx 10^{-11}$ ss^{-1}
- No evidence for a binary companion, association with a SNR in several cases

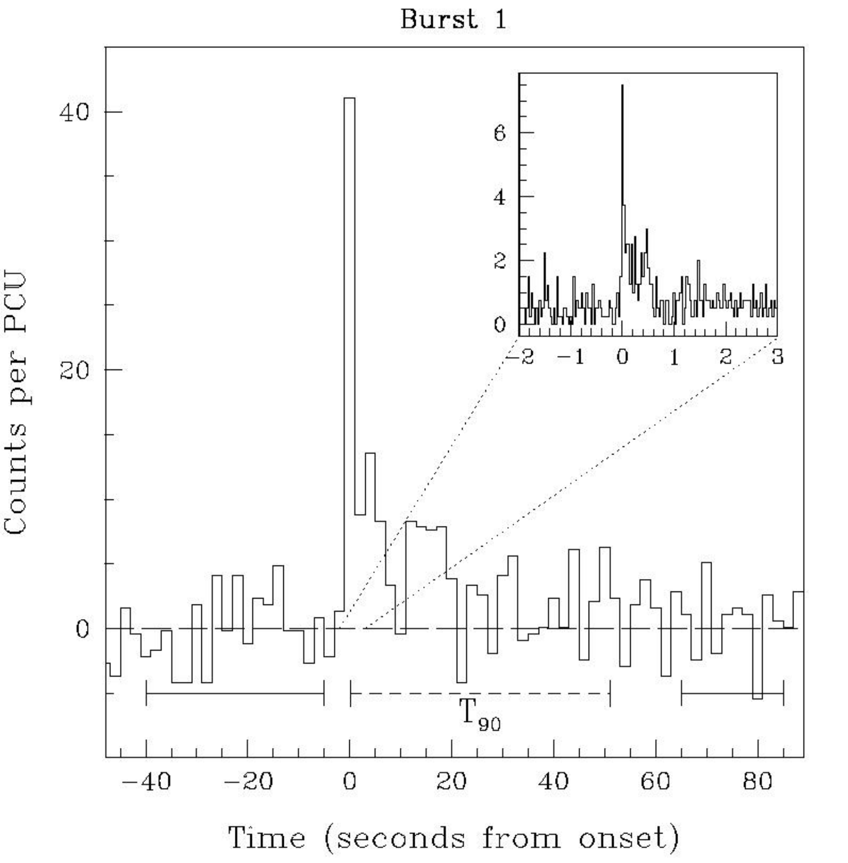
Known AXPs

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
1E 2259+586	7.0



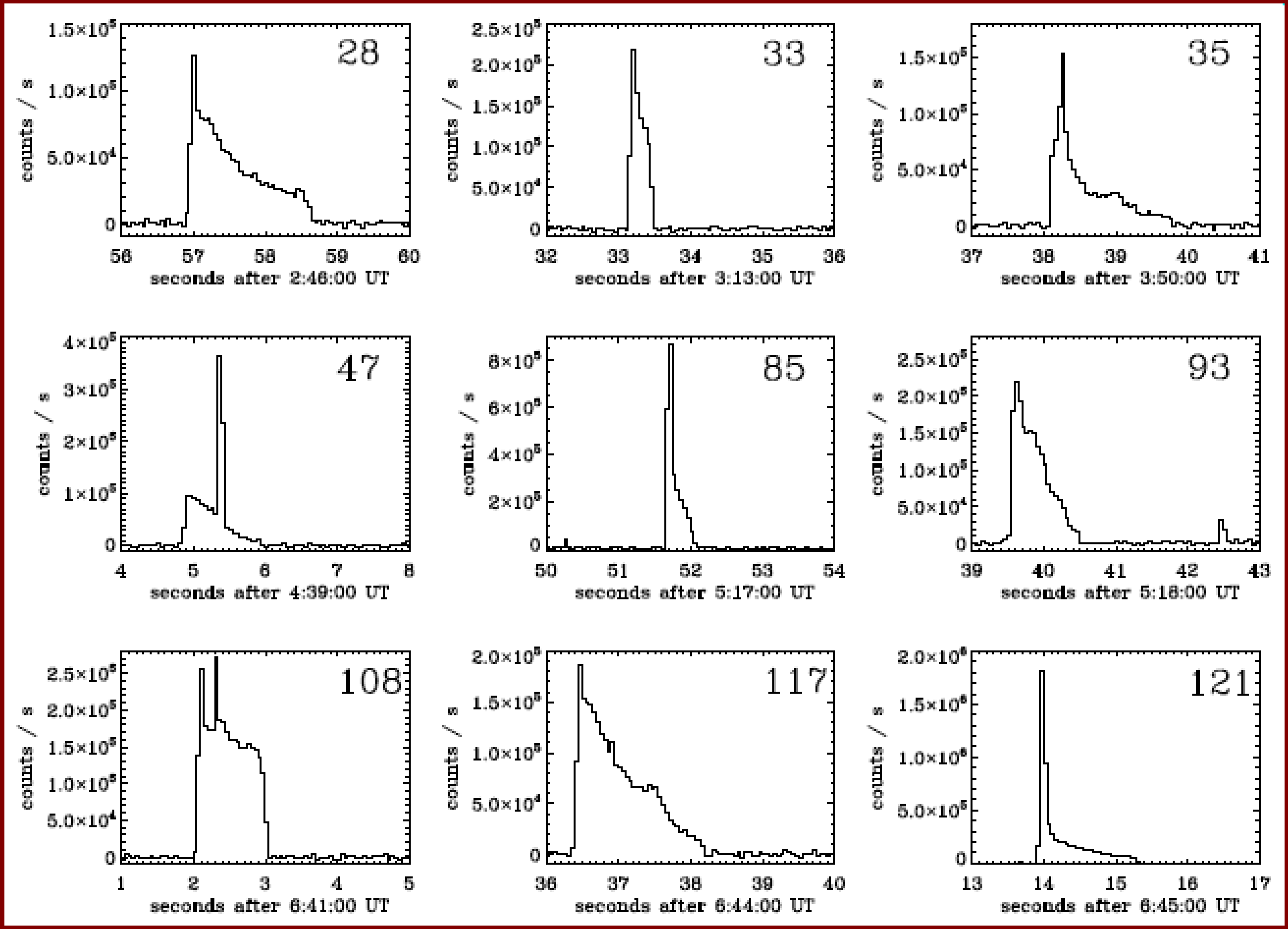
Are SGRs and AXPs brothers?

- Bursts of AXPs
  (from 6 now)
- Spectral properties
- Quiescent periods of SGRs (0525-66 since 1983)



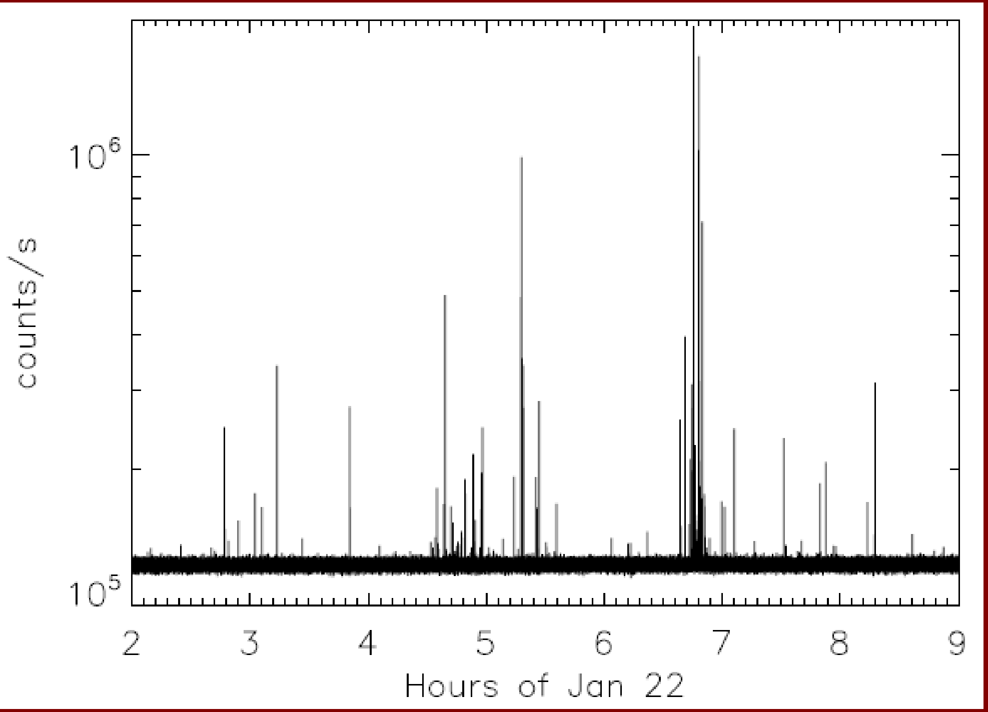
Gavriil et al. 2002

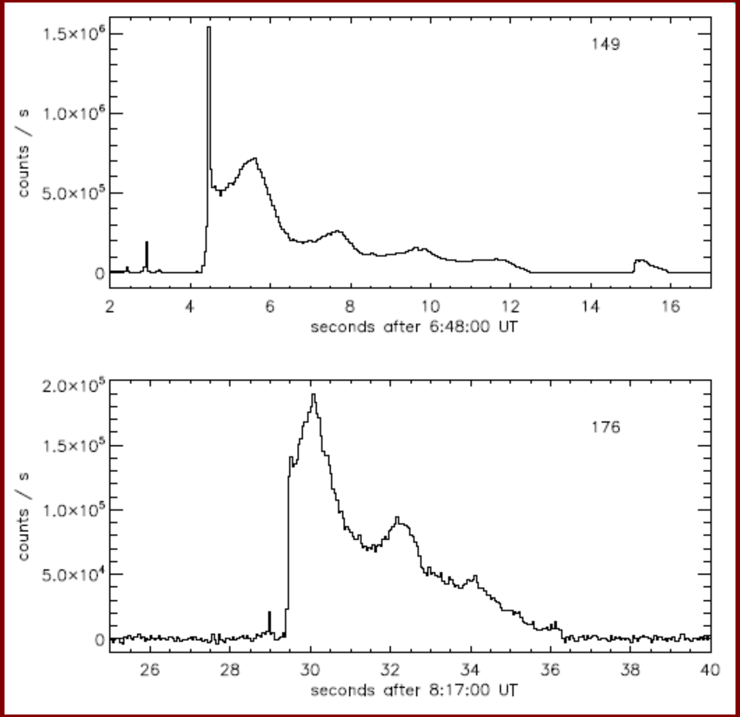
Bursts of the AXP 1E1547.0-5408



0903.1974

Bursts of the AXP 1E1547.0-5408





Some bursts have pulsating tails with spin period.

0903.1974

A Tale of Two Populations ?

SGRs: bursting X/γ-ray sources

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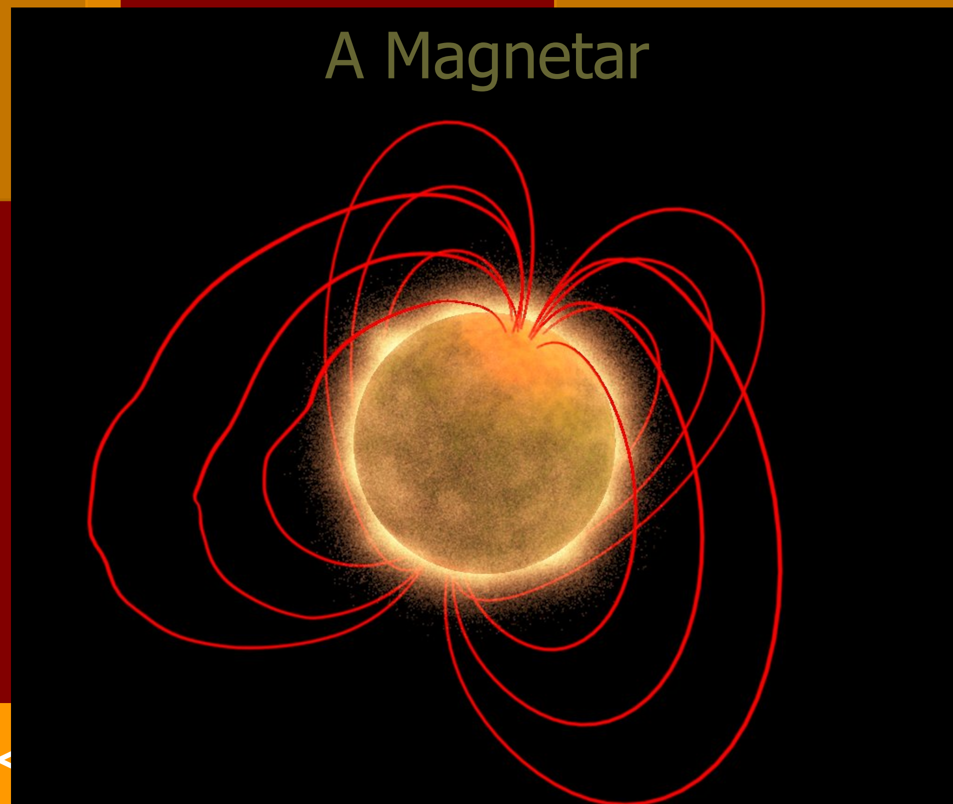

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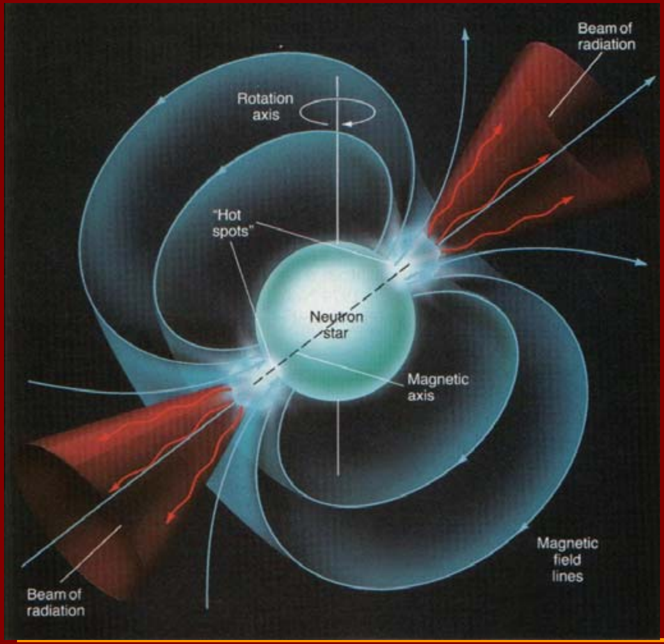
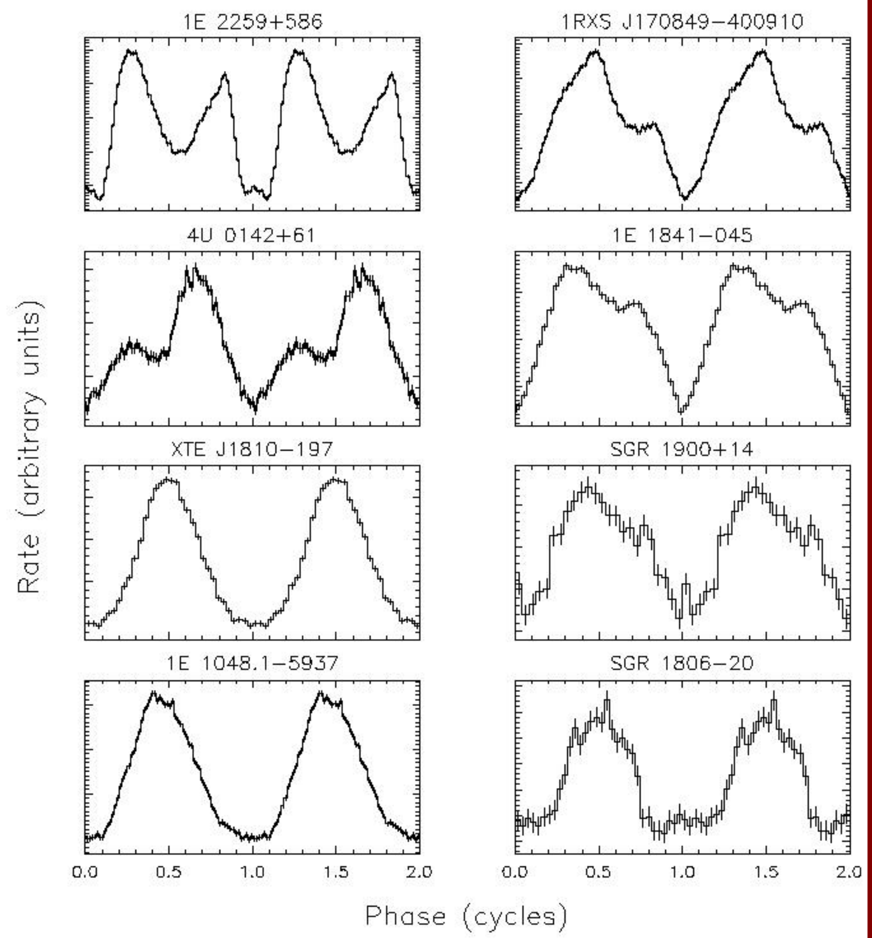
Pulsed X-ray emission: a neutron star

Pulse profiles of SGRs and AXPs



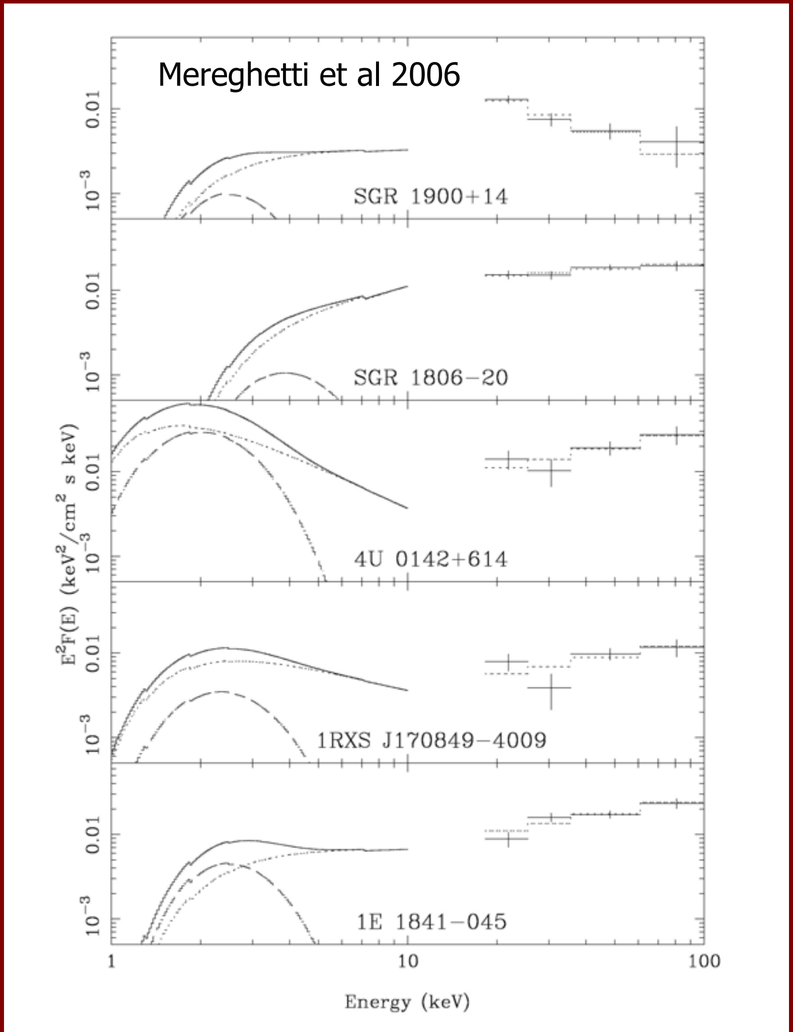


Hard X-ray Emission

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

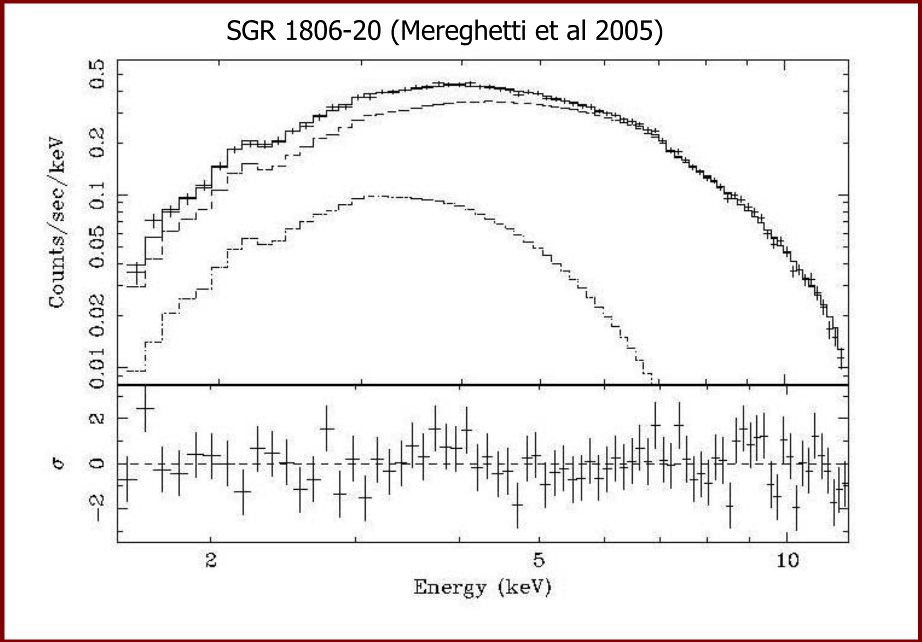
Hard power law tails with $\Gamma \approx 1\text{-}3$

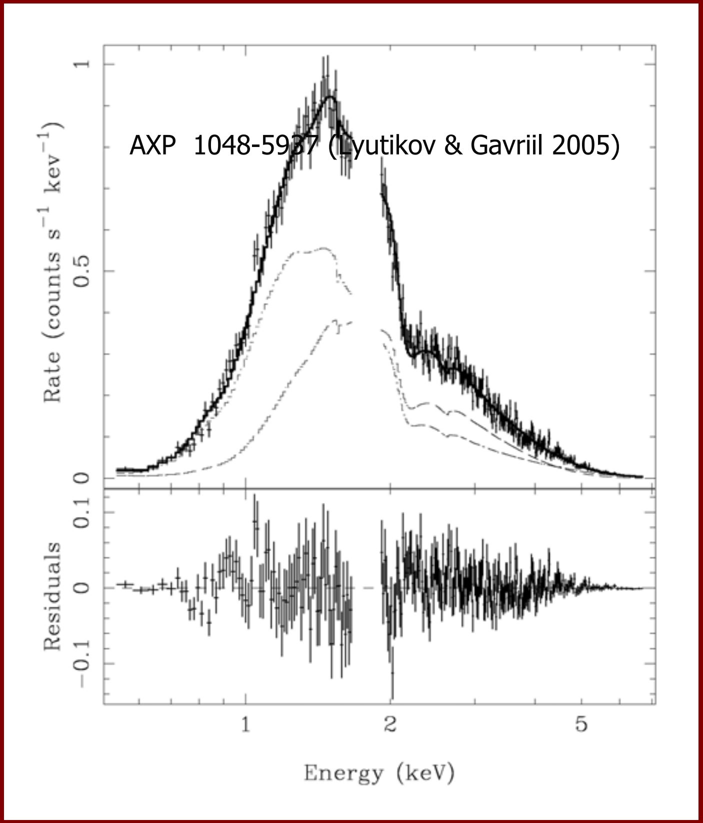
Hard emission pulse



SGRs and AXPs soft X-ray Spectra

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





SGRs and AXPs soft X-ray Spectra

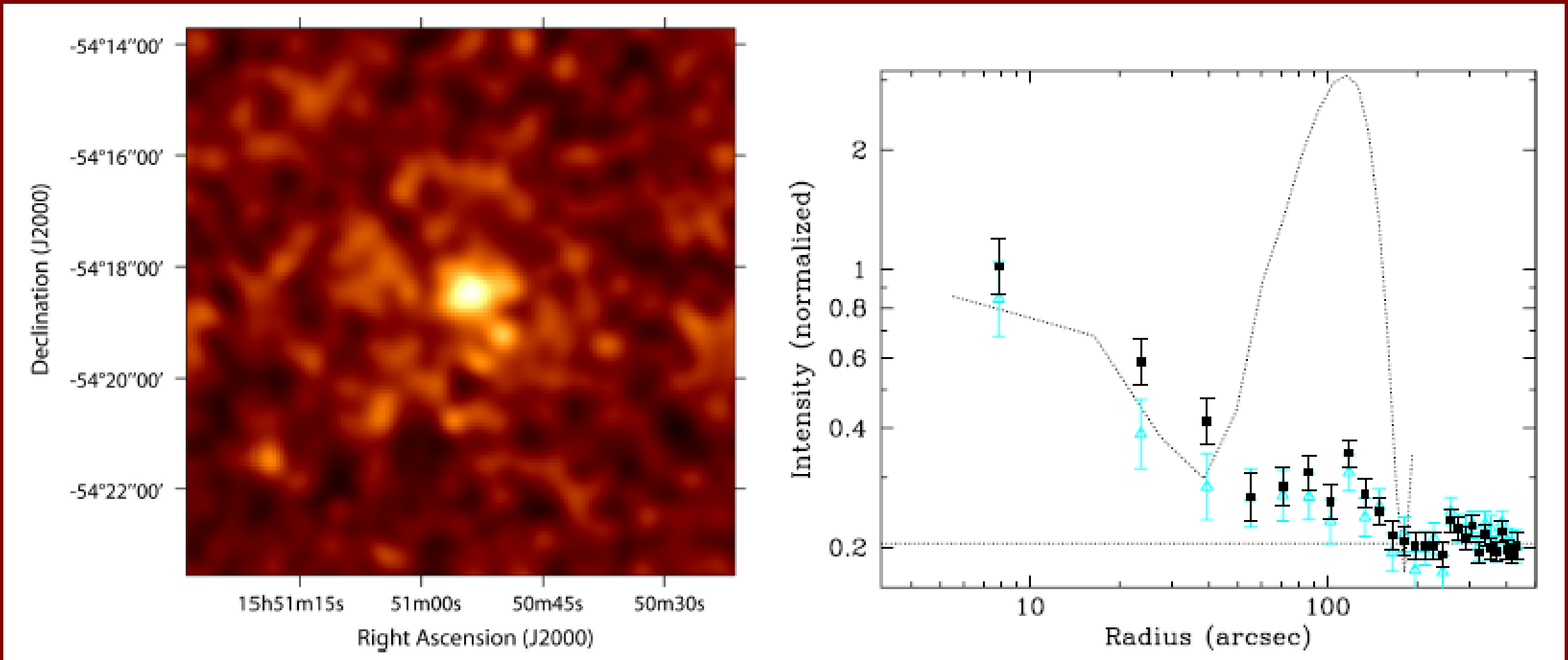
- kT_{BB} ~ 0.5 keV, does not change much in different sources
- Photon index $\Gamma \approx 1 - 4$,

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

  the non-thermal component

And what about AXPs and PSRs?

1E1547.0-5408 – the most rapidly rotating AXP (2.1 sec)
The highest rotation energy losses among SGRs and AXPs.
Bursting activity.



Pulsar wind nebulae around an AXP.

0909.3843

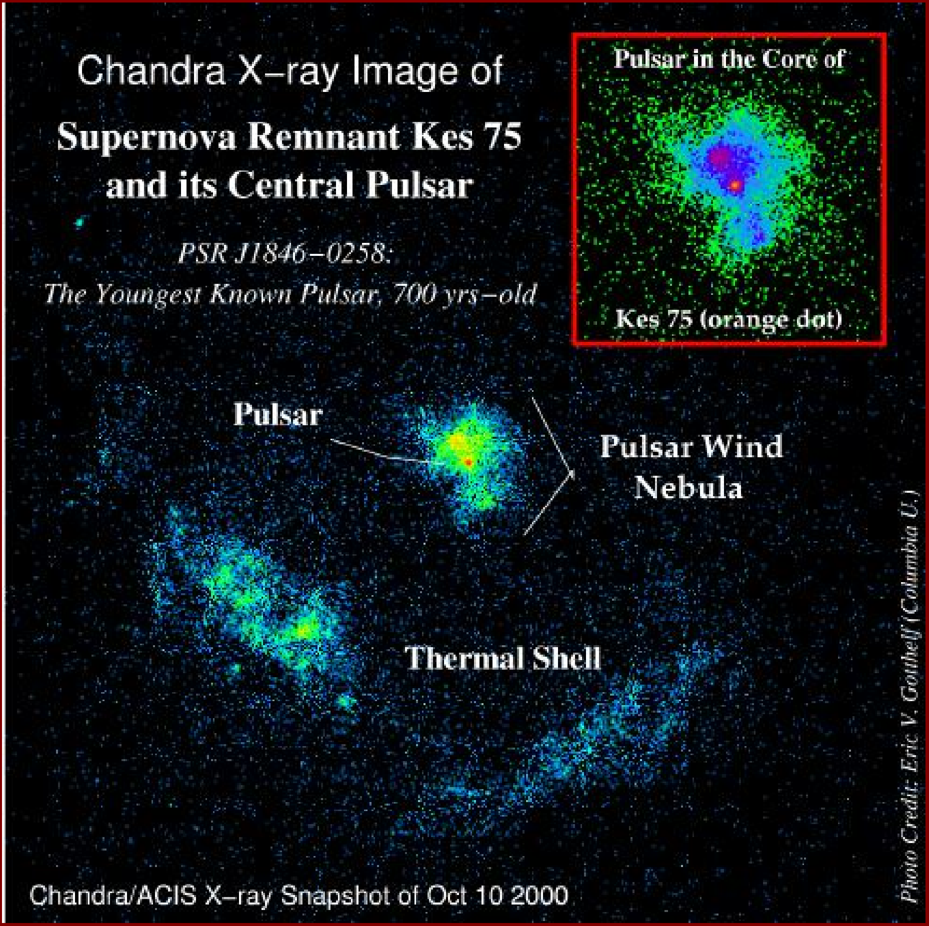
Transient radiopulsar

PSR J1846-0258
P=0.326 sec
B=5 10^{13} G

However,
no radio emission detected.
Due to beaming?

Among all rotation powered PSRs it has the largest Edot. Smallest spindown age (884 yrs).

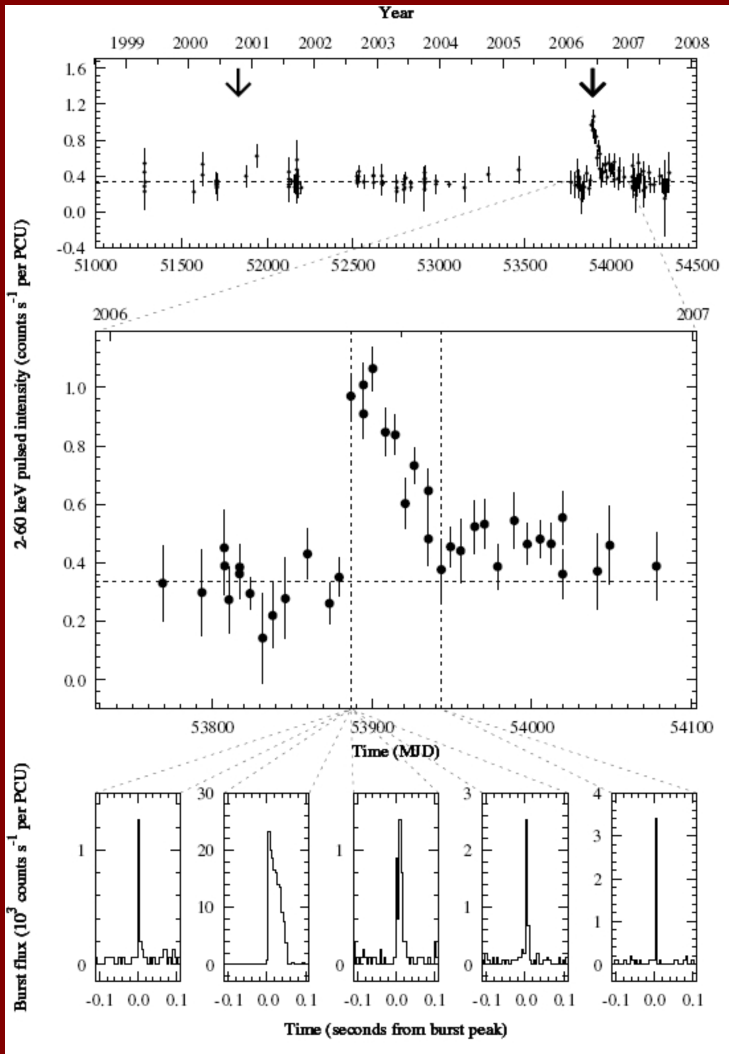
The pulsar increased
its luminosity in X-rays.
Increase of pulsed X-ray flux.
Magnetar-like X-ray bursts (RXTE).
Timing noise.



See additional info about this pulsar at the web-site http://hera.ph1.uni-koeln.de/~heintzma/SNR/SNR1_IV.htm

0802.1242, 0802.1704

Bursts from the transient PSR



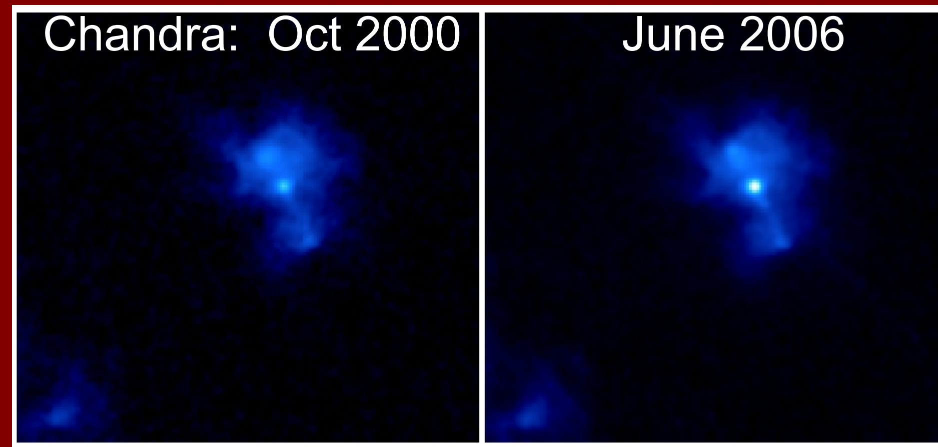


Table 1 PSR J1846−0258 Burst Temporal and Spectral Properties

	Burst 1	Burst 2	Burst 3	Burst 4	Burst 5
Temporal properties					
Burst day (MJD)	53886	53886	53886	53886	53943
Burst start time (fraction of day)	0.92113966(5)	0.93247134(1)	0.93908845(2)	0.94248467(5)	0.45543551(1)
Rise time, t_r (ms)	$4.2^{+3.5}_{-2.0}$	$1.1^{+0.9}_{-0.5}$	$1.90^{+1.7}_{-0.9}$	$4.1^{+3.1}_{-1.9}$	$0.9^{+2.2}_{-0.7}$
T_{90} (ms)	$71.8^{+38.0}_{-5.5}$	$42.9^{+0.3}_{-0.2}$	$137.0^{+11.4}_{-36.2}$	$33.4^{+29.1}_{-23.1}$	$65.3^{+0.7}_{-0.5}$
Phase (cycles)	-0.49(1)	-0.04(1)	-0.20(1)	-0.05(1)	-0.08(1)
Fluences and fluxes					
T_{90} Fluence (counts/PCU)	8.9±0.7	712.8±2.5	18.3±0.7	18.4±0.7	18.4±1.1
T_{90} Fluence (10^{-10} erg/cm^2)	4.1±2.4	289.9±13.1	6.6±2.5	5.8±1.7	5.3±2.0
Flux for 64 ms (10^{-10} erg/s/cm^2)	57±36	4533±227	99±41	97±31	79±32
Flux for t_r (10^{-10} erg/s/cm^2)	678±427	5783±885	810±385	828±284	2698±1193
Spectral properties					
Power-law index	0.89±0.58	1.05±.04	1.14±0.34	1.36±0.25	1.41±0.31
χ^2/DoF (DoF)	0.42 (1)	1.16 (55)	0.97 (3)	0.35 (2)	1.18 (2)

Gavriil et al. 0802.1704

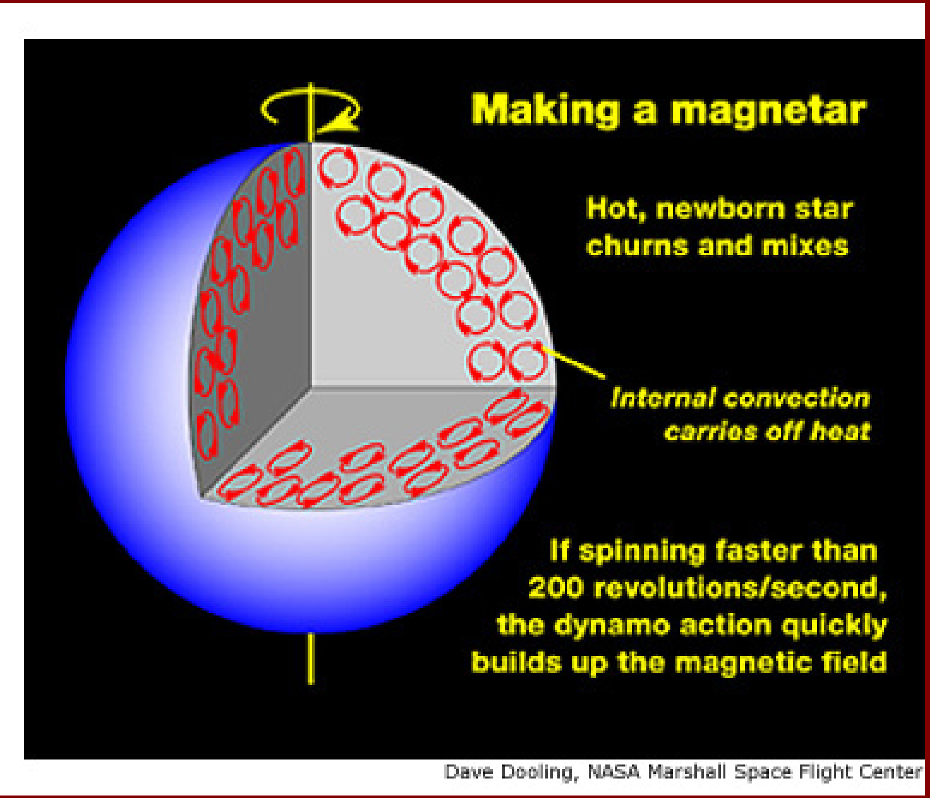
Generation of the magnetic field

The mechanism of the magnetic field generation is still unknown.

Turbulent dynamo

α-Ω dynamo (Duncan,Thompson)
α^2 dynamo (Bonanno et al.)
or their combination

In any case, initial rotation of a protoNS is the critical parameter.



Strong field via flux conservation

There are reasons to suspect that the magnetic fields of magnetars are not due to any kind of dynamo mechanism, but just due to flux conservation:

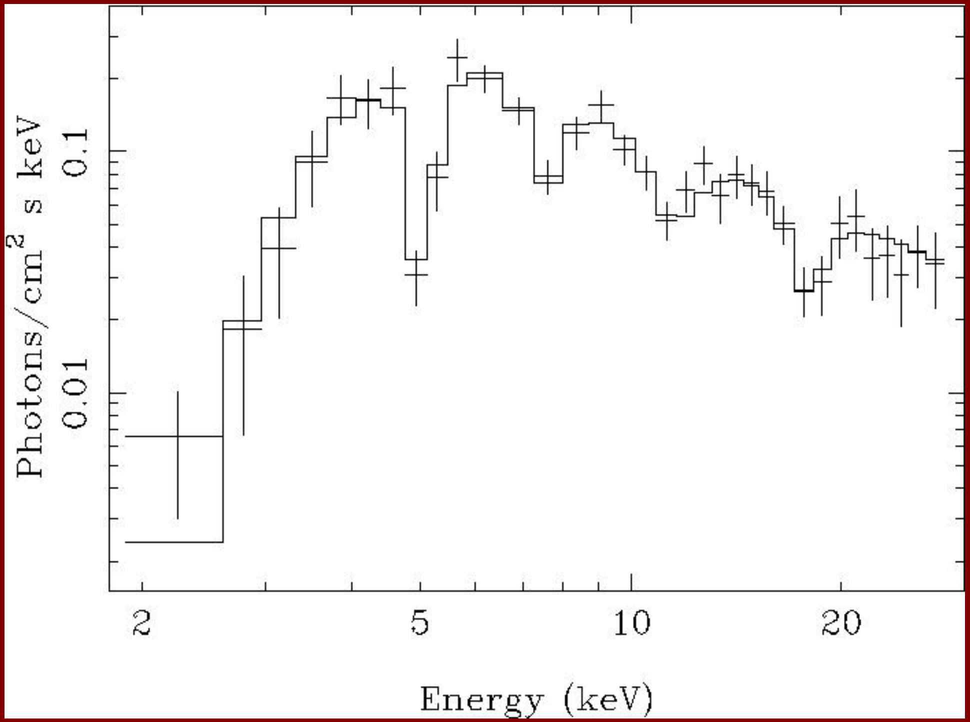
1. Study of SNRs with magnetars (Vink and Kuiper 2006). If there was a rapidly rotating magnetar then a huge energy release is inevitable. No traces of such energy injections are found.

2. There are few examples of massive stars with field strong enough to produce a magnetars due to flux conservation (Ferrario and Wickramasinghe 2006)

Still, these suggestions can be criticized (Spruit arXiv: 0711.3650)

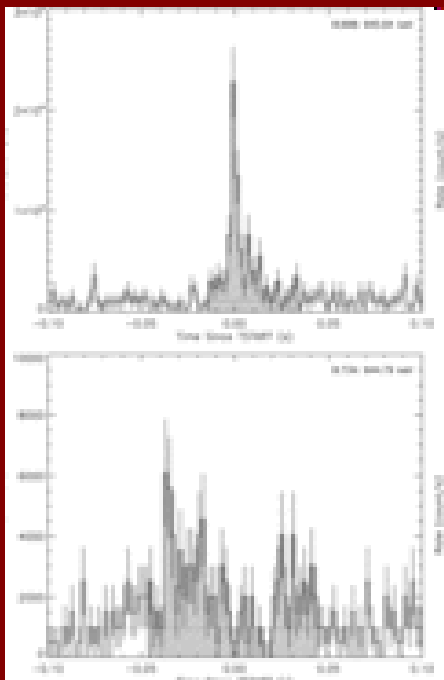
Magnetic field estimates

- Spin down
- Long spin periods
- Energy to support bursts
- Field to confine a fireball (tails)
- Duration of spikes (alfven waves)
- Direct measurements of magnetic field (cyclotron lines)



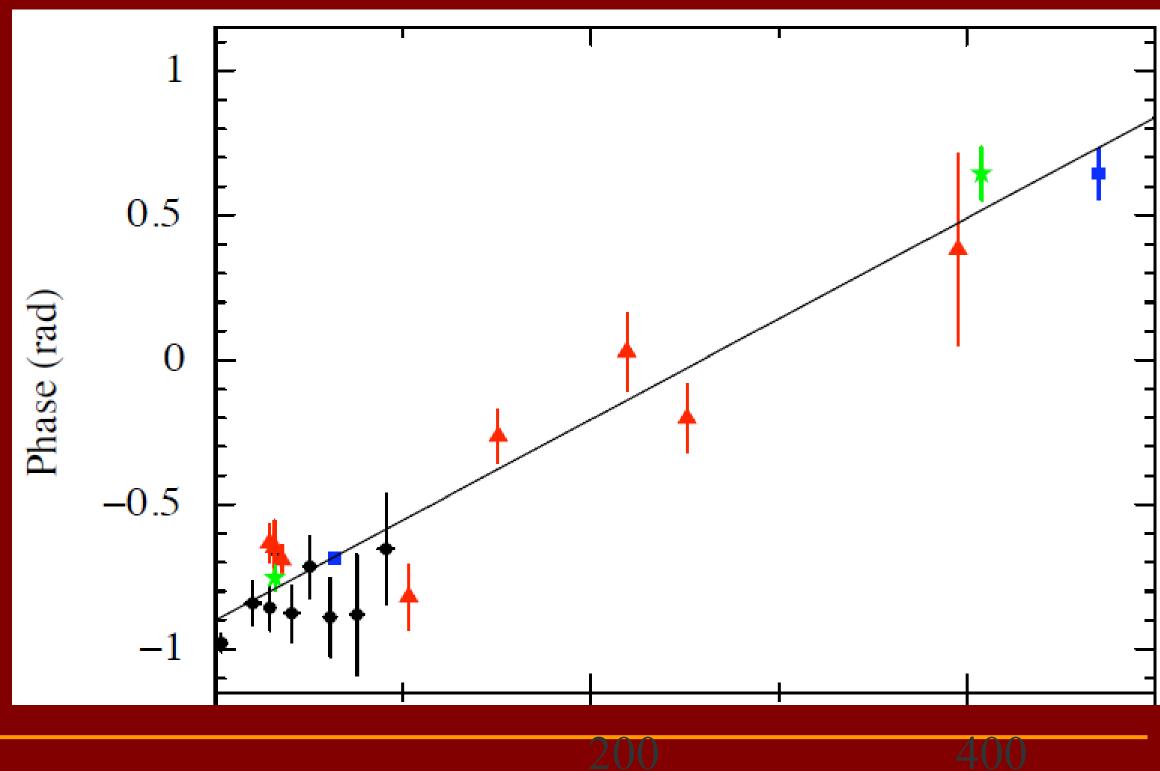
Ibrahim et al. 2002

Weak field magnetars



SGR 0418+5729
P=9.1 сек

Magnetic field is estimated from timing:
spin-down according to the magneto-dipole formula



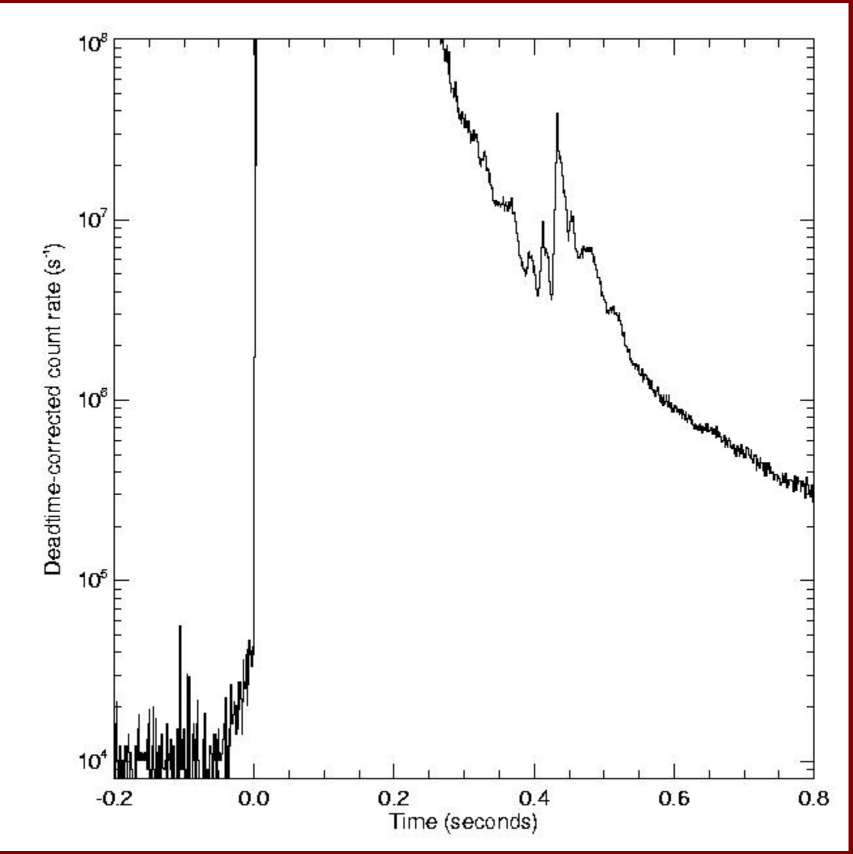
Straight line corresponds
to no spin-down

B<7.5 10^{12} Gs

arXiv: 1010.2781

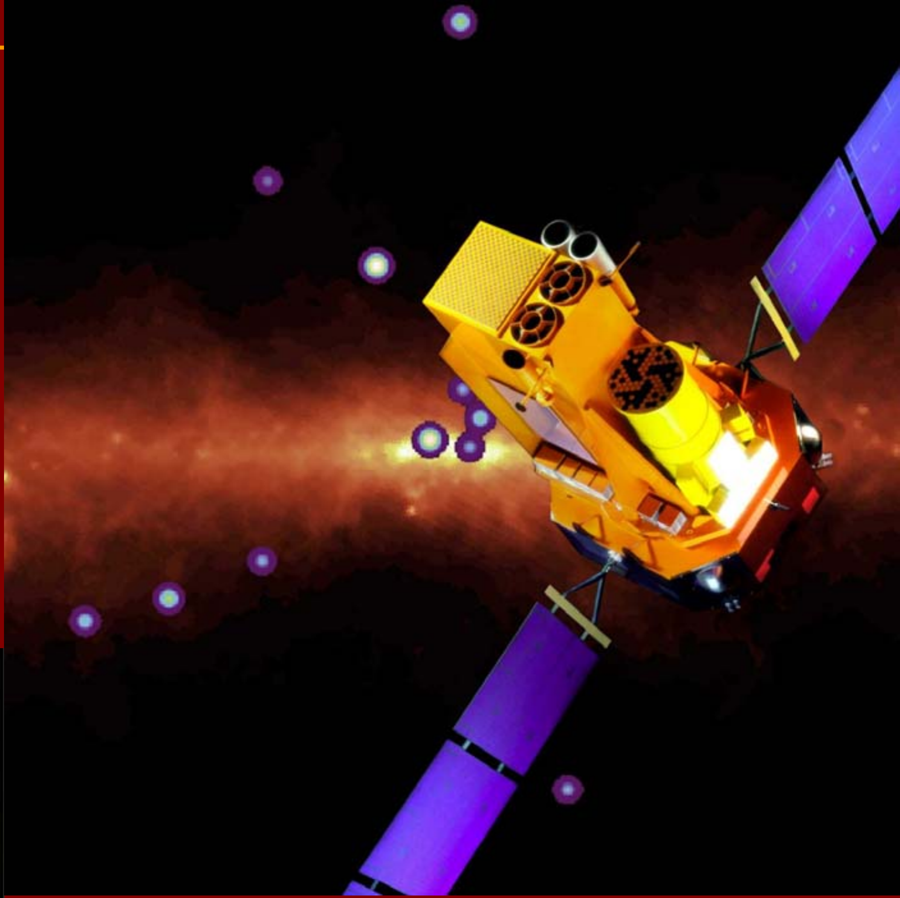
Hyperflare of SGR 1806-20

- 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

CORONAS-F

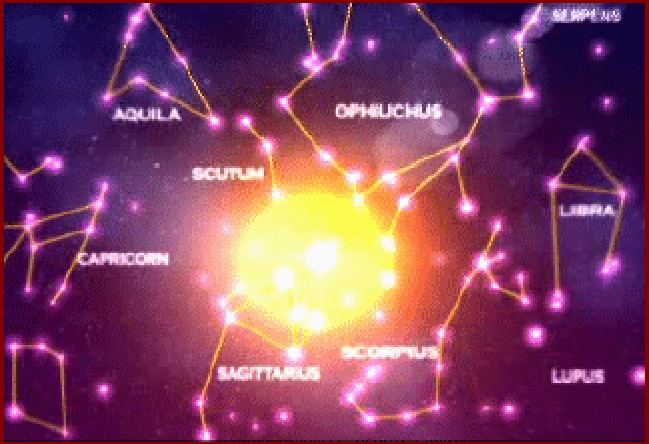


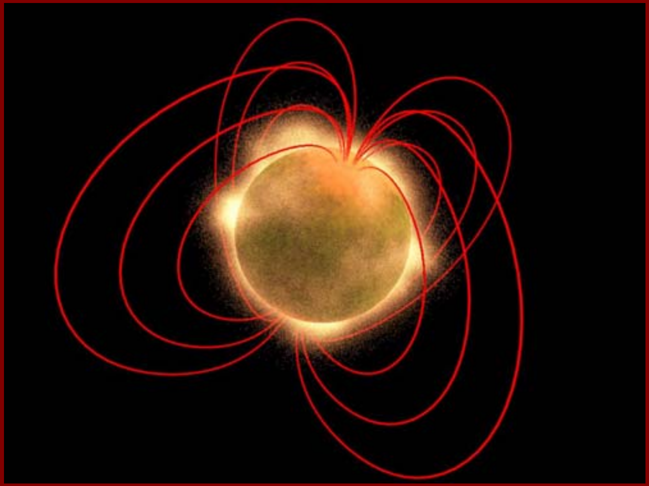
Integral

RHESSI

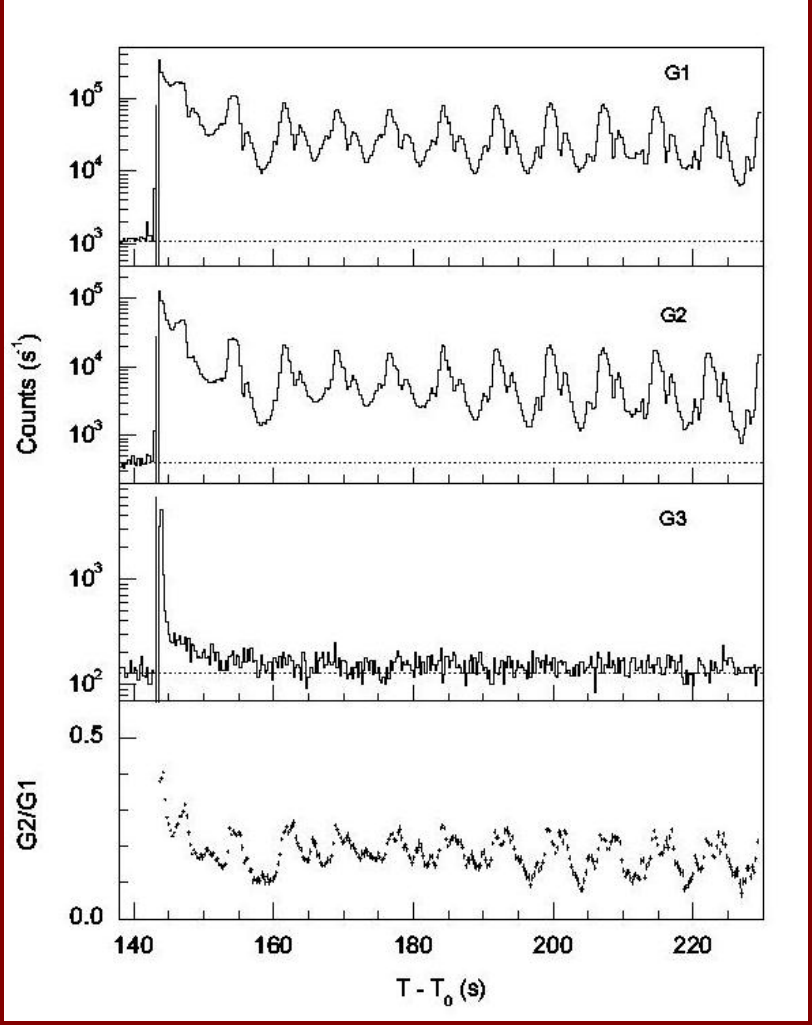
27 Dec 2004:
Giant flare of the SGR 1806-20

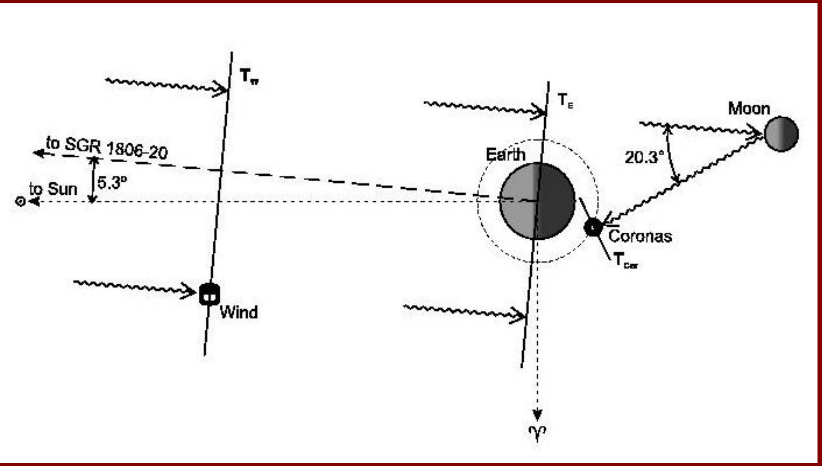
- Spike 0.2 s
- Fluence 1 erg/cm^2
- E(spike)=3.5 10^{46} erg
- L(spike)=1.8 10^{47} erg/s
- Long «tail» (400 s)
- P=7.65 s
- E(tail) 1.6 10^{44} erg
- Distance 15 kpc – but it is uncertain

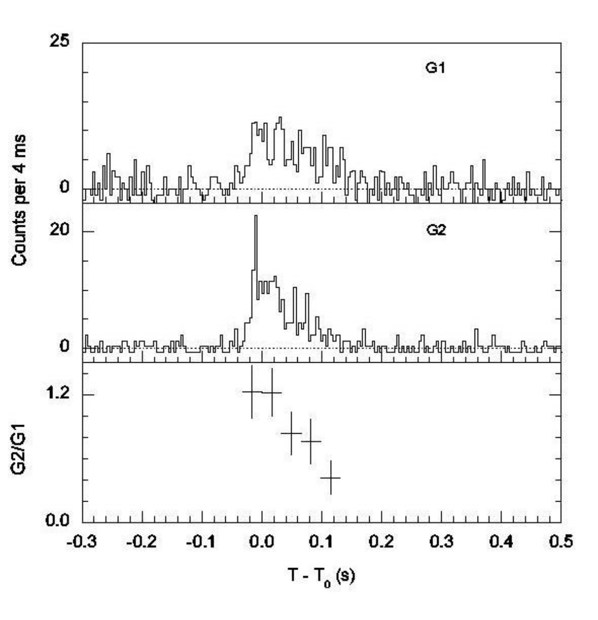




Konus observations



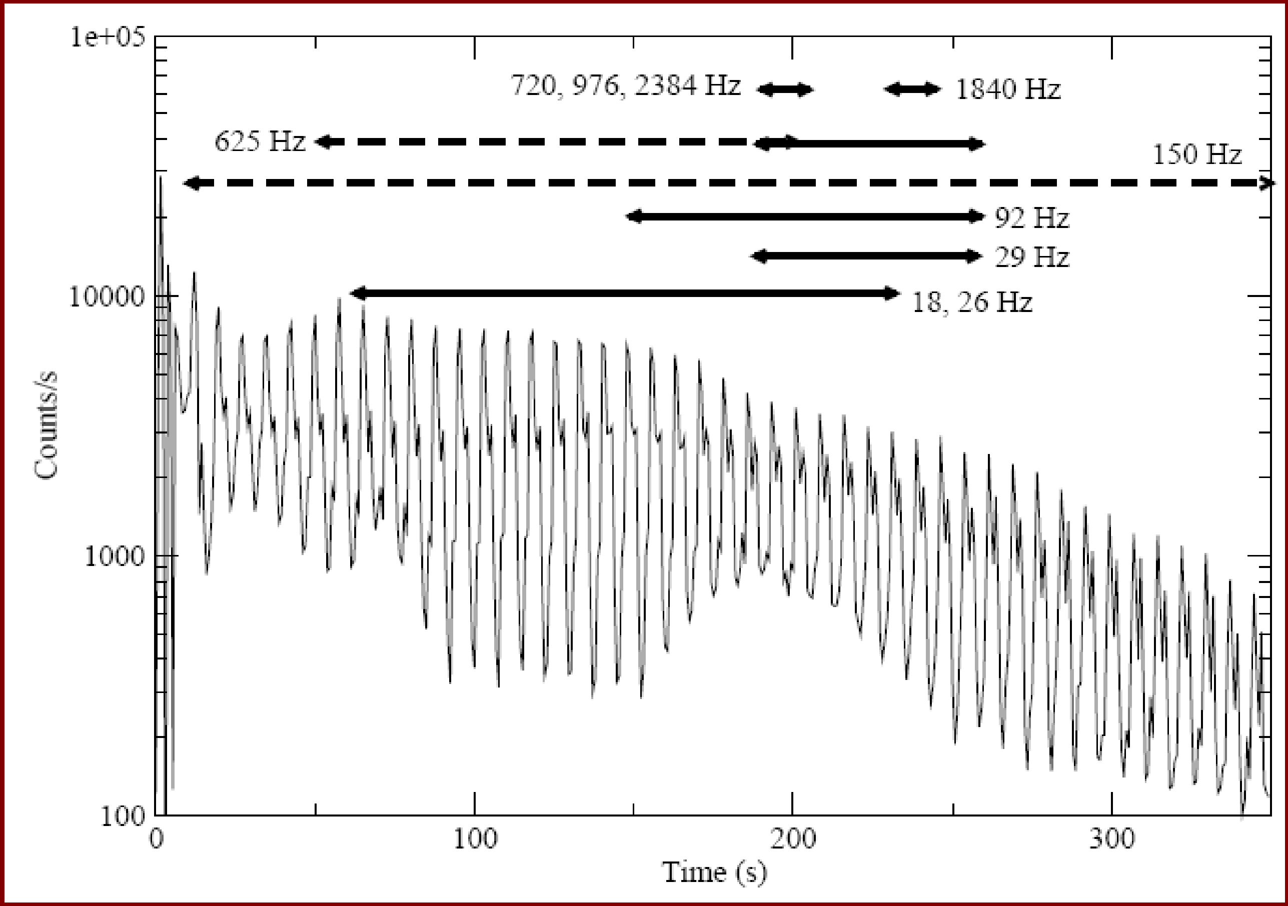




Mazets et al. 2005

QPO in tails of giant flares of SGRs

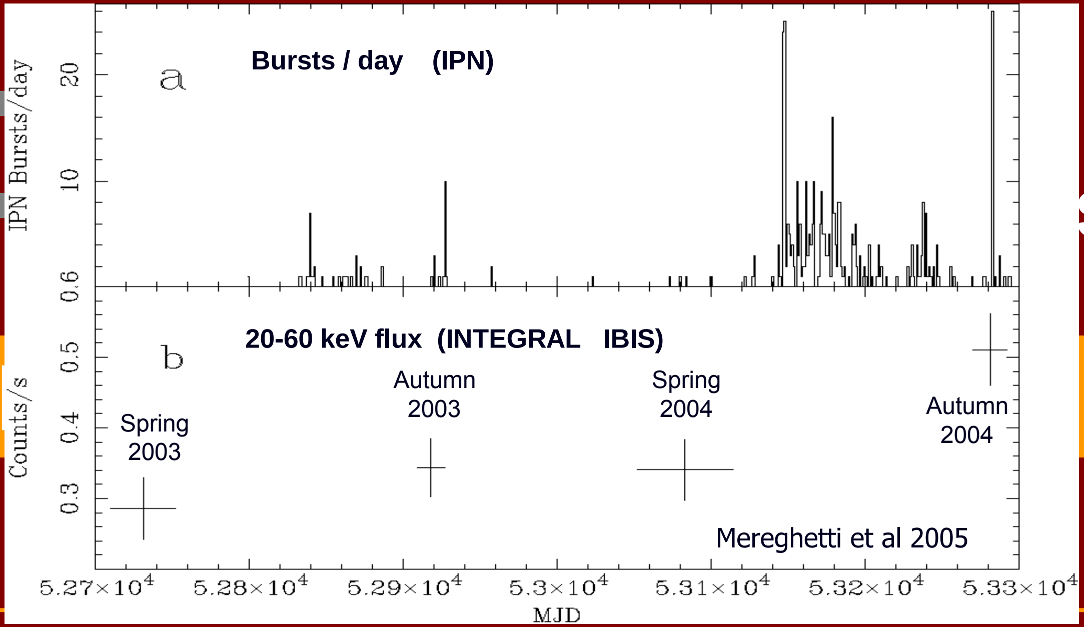
A kind of quasi periodic oscillations have been found in tail of two events (aug. 1998, dec. 2004). They are supposed to be torsional oscillations of NSs, however, it is not clear, yet.



(Israel et al. 2005 astro-ph/0505255,
Watts and Strohmayer 2005 astro-ph/0608463)

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)



SGR 1806-20 - II

- Fou[…]urst
  (the[…] 2005)
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- The[…] ~ 10^{36}
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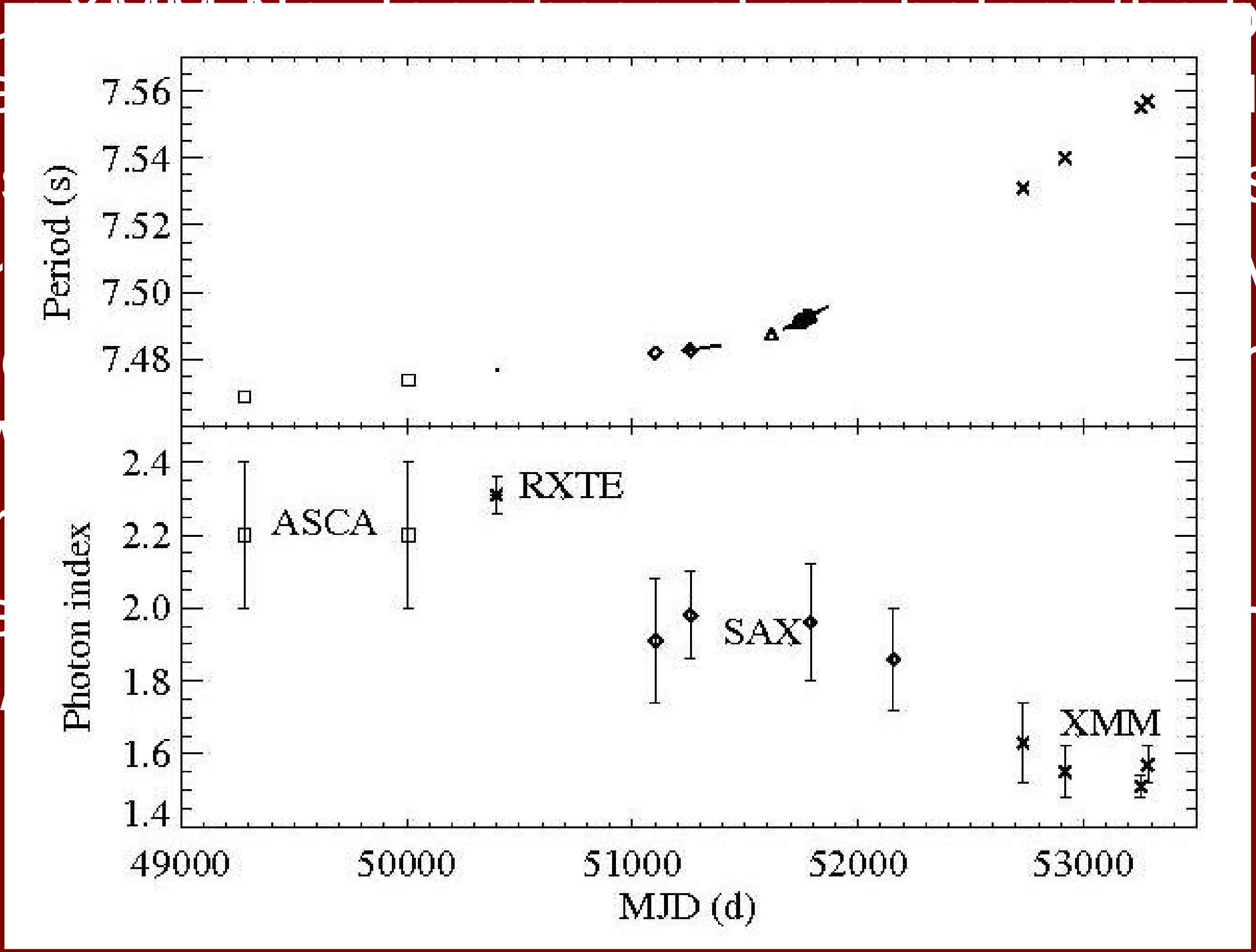
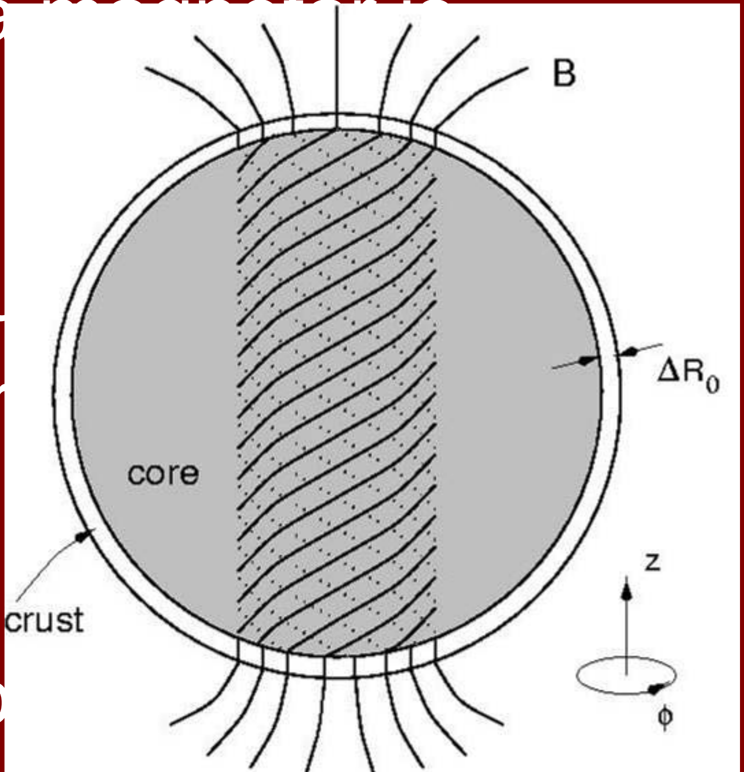


Twisted Magnetospheres – I

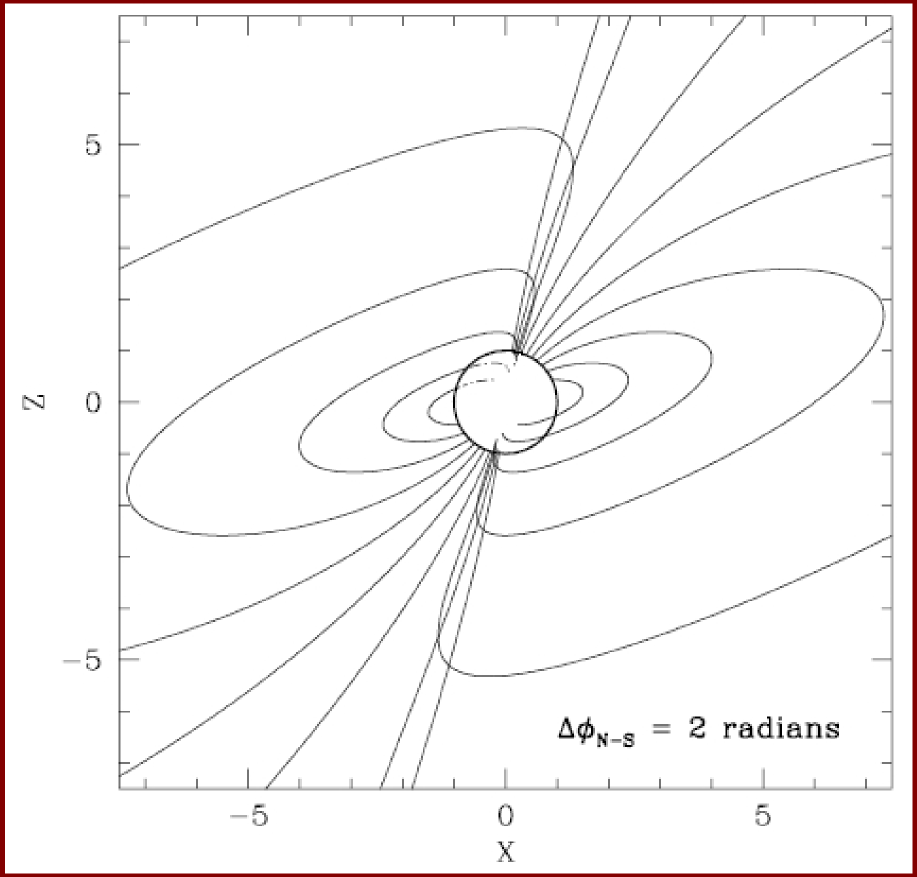
- The magnetic field inside a
  "wound up"
- The presence of a toroidal
  induces a rotation of the su
- The crust tensile strength r
- A gradual (quasi-plastic ?)
  crust
- The external field twists up

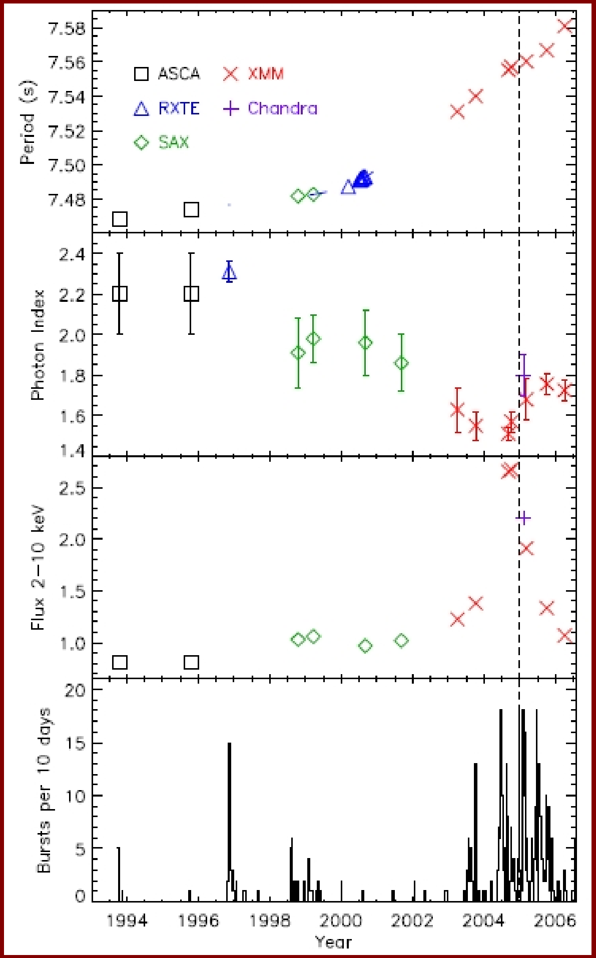
  (Thompson, Lyutikov & Kulkarni 2002



Thompson & Duncan 2001

Growing twist

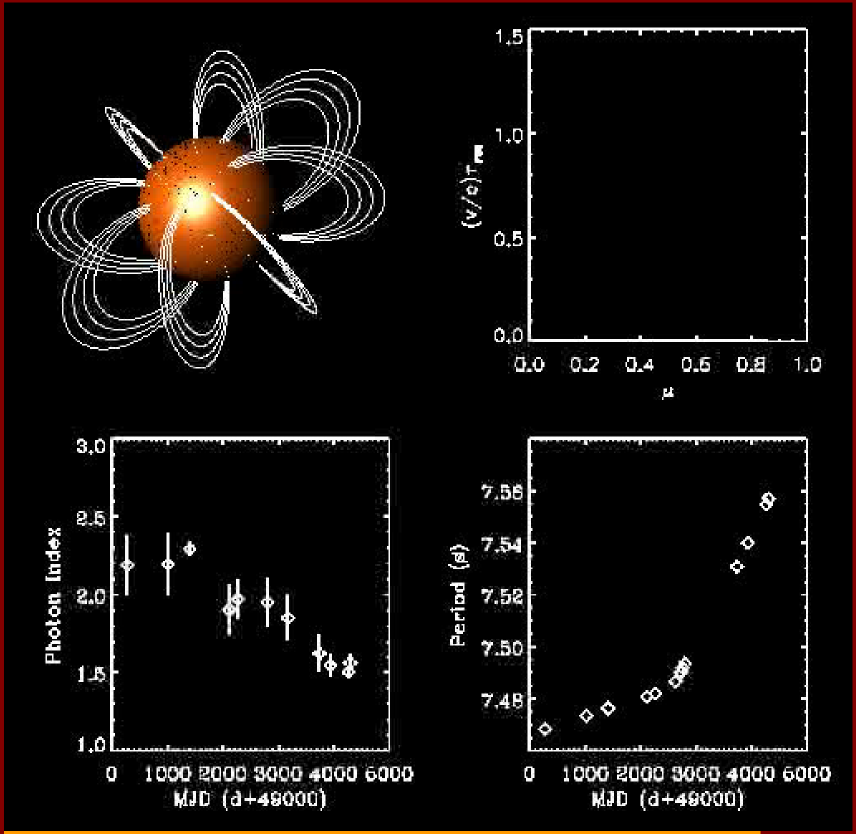




(images from Mereghetti arXiv: 0804.0250)

A Growing Twist in SGR 1806-20 ?

- Evidence for spectral hardening AND enhanced spin-down
- Γ-Pdot and Γ-L correlations
- Growth of bursting activity
- Possible presence of proton cyclotron line only during bursts



All these features are consistent with an increasingly twisted magnetosphere

Twisted magnetospheres

- Twisted magnetosphere model, within magnetar scenario, in general agreement with observations
- Resonant scattering of thermal, surface photons produces spectra with right properties
- Many issues need to be investigated further
  - Twist of more general external fields
  - Detailed models for magnetospheric currents
  - More accurate treatment of cross section including QED effects and electron recoil (in progress)
  - 10-100 keV tails: up-scattering by (ultra)relativistic ($e^{\pm}$) particles ?
  - Create an archive to fit model spectra to observations (in progress)

Thompson, Lyutikov, Kulkarni astro-ph/0110677
Beloborodov arXiv: 1008.4388

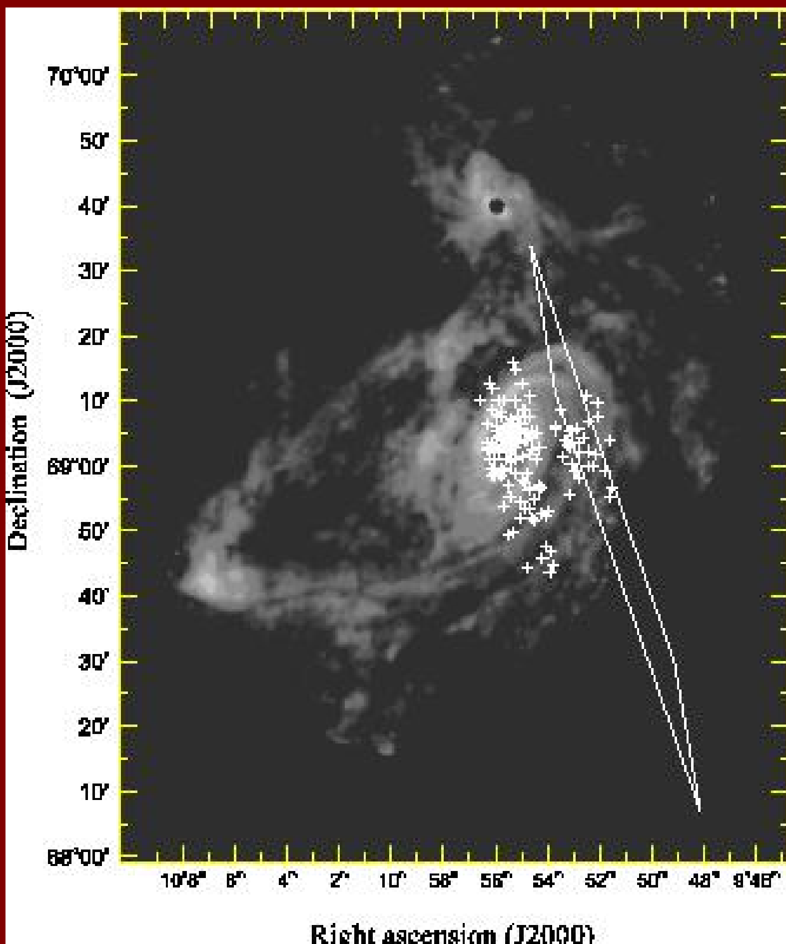
Extragalactic giant flares

Initial enthusiasm that most of short GRBs can be explained as giant flares of extraG SGRs disappeared.

At the moment, we have a definite deficit of extraG SGR bursts, especially in the direction of Virgo cluster (Popov, Stern 2006; Lazzatti et al. 2006).

However, there are several good candidates.

Extragalactic SGRs



It was suggested long ago (Mazets et al. 1982) that present-day detectors could alredy detect giant flares from extragalactic magnetars.

However, all searches in, for example, BATSE database did not provide clear candidates (Lazzati et al. 2006, Popov & Stern 2006, etc.).

Finally, recently several good candidates have been proposed by different groups (Mazets et al., Frederiks et al., Golenetskii et al., Ofek et al, Crider ....).

[D. Frederiks et al. astro-ph/0609544]

What is special about magnetars?

Link with massive stars

There are reasons to suspect that magnetars are connected to massive stars (astro-ph/0611589).

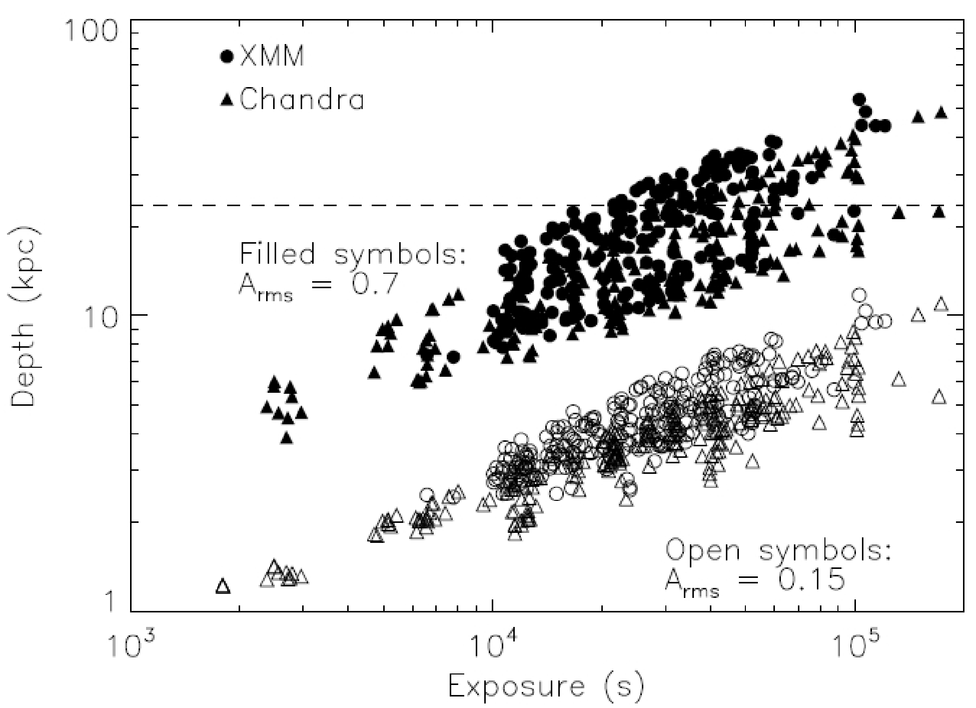
Link to binary stars

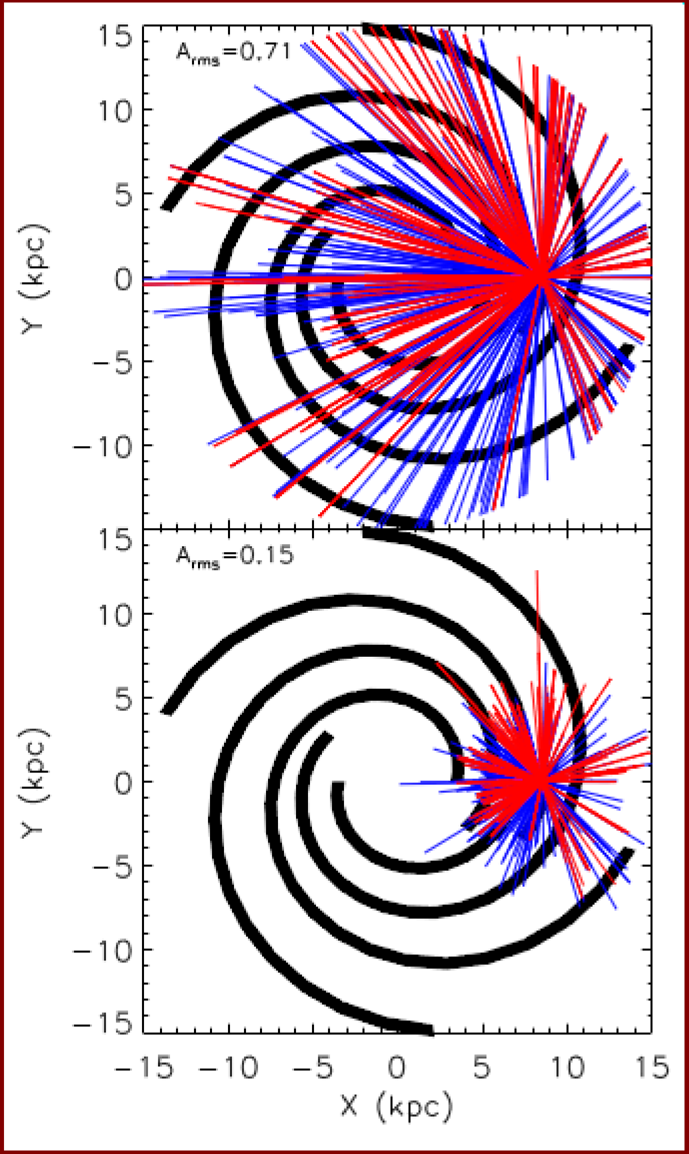
There is a hypothesis that magnetars are formed in close binary systems (0905.3238, astro-ph/0505406).

The question is still on the list.

AXP in Westerlund 1 most probably has a very massive progenitor >40 Msolar.

How many magnetars?





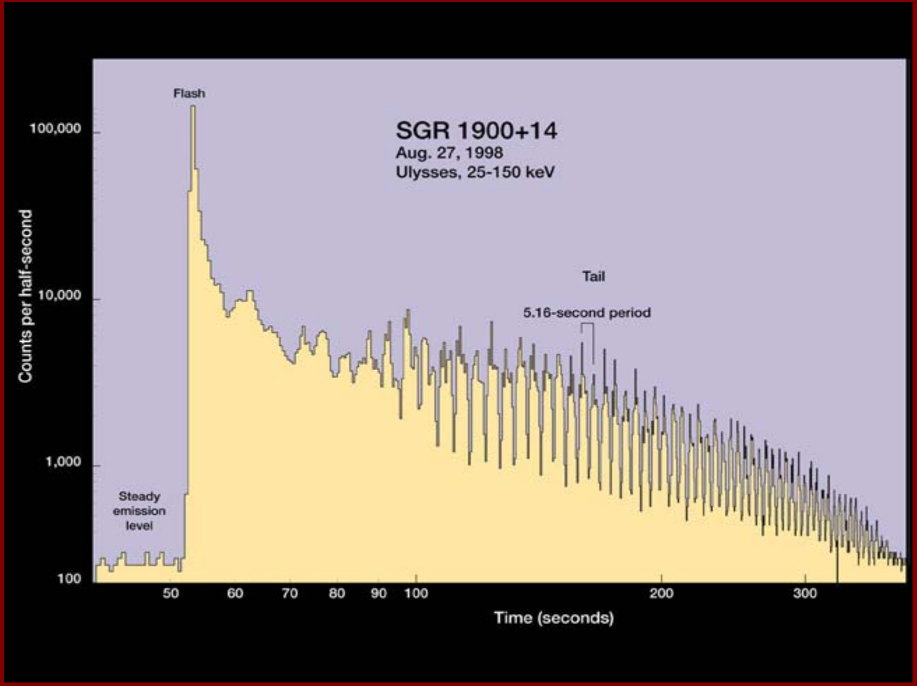
<540 barely-detectable (L=3 10^{33} A_{rms}=15%)

59^{+92}_{-32} easily detectable (L=10^{35} A_{rms}=70%)

Muno et al. arXiv: 0711.0988

Conclusions

- Two classes of magnetars: SGRs and AXPs
- Similar properties (but no giant flare in AXPs, yet?)
- Hyperflares (27 Dec 2004)
- Transient magnetars
- About 10% of newborn NSs
- Links to PSRs (and others?)
- Twisted magnetospheres



Papers to read

- Mereghetti arXiv: 0804.0250
- Woods, Thompson astro-ph/0406133
- Beloborodov arXiv: 1008.4388