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Isolated And Accreting Magnetars Viewed In Hard X-rays

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- Accreting magnetar candidates - superslow pulsation X-ray pulsars in HMXBs
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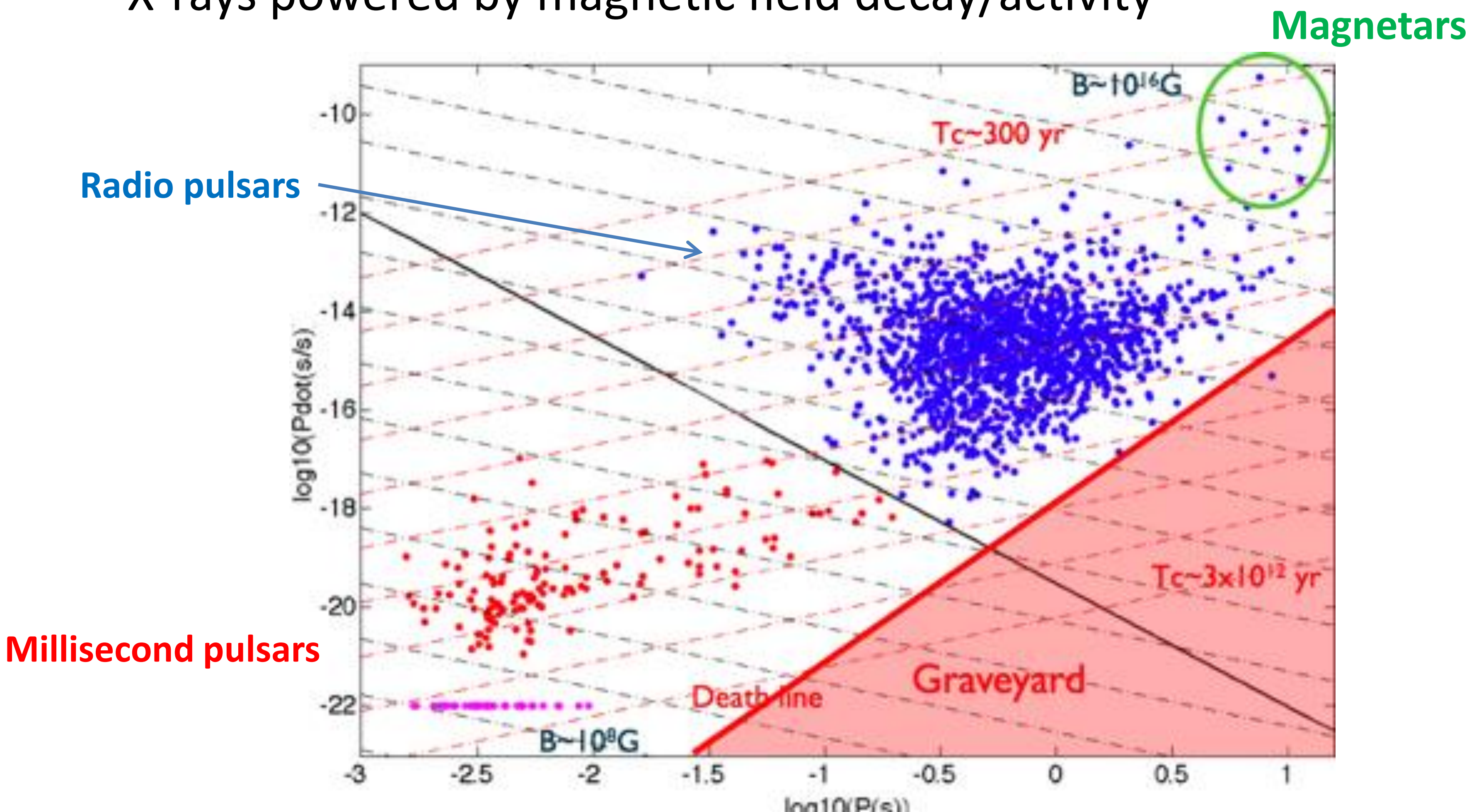
Isolated Magnetars

Pspin = 2 – 12 sec

high spin-down rate, Bs>10^{13} G, age≈10^4 yr

X-rays powered by magnetic field decay/activity



X-ray properties of magnetars

AXPs/SGRs:

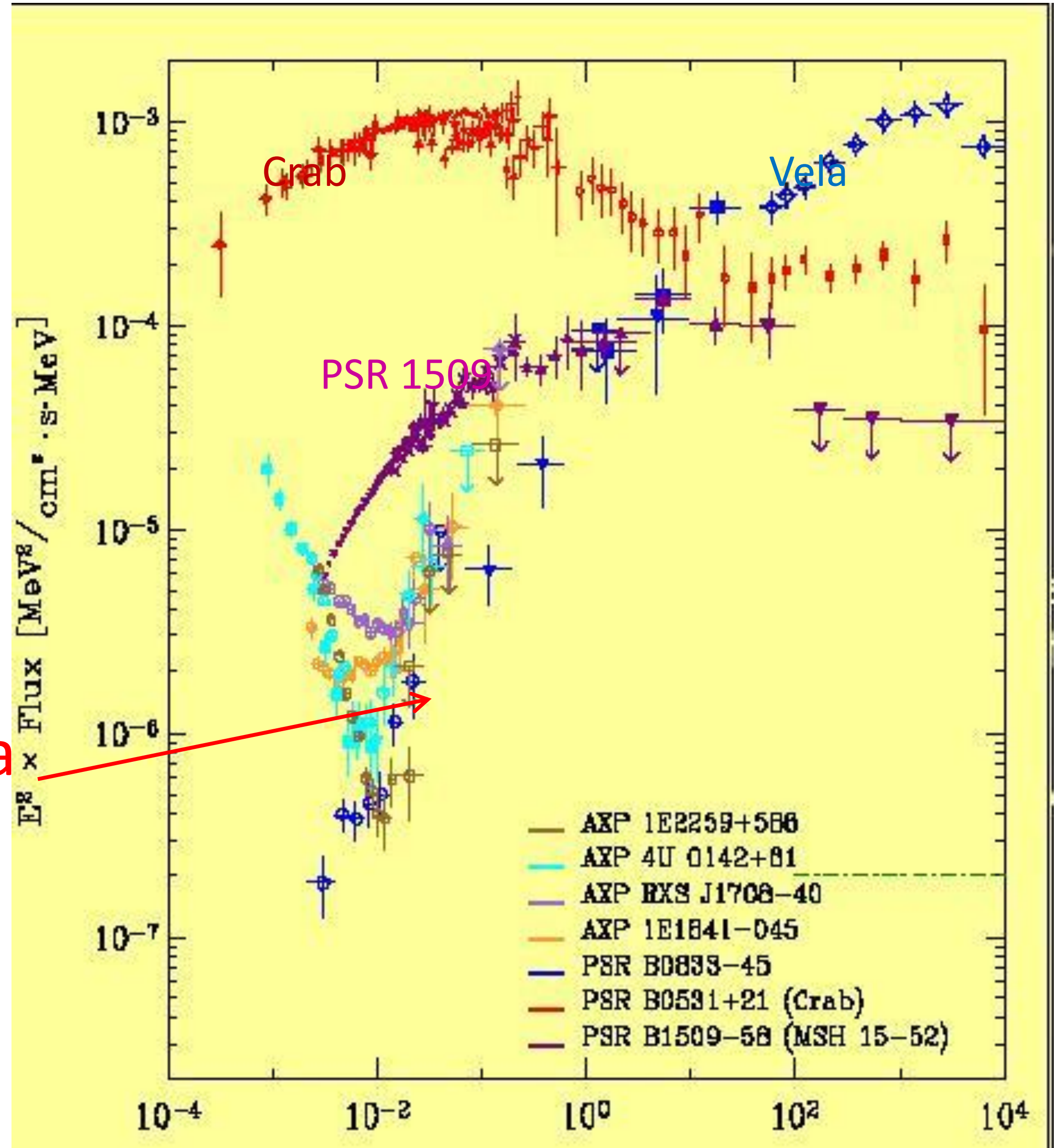
0.1 – 10 keV:
Thermal spectrum

>10 keV:
Non-thermal
Γ~ 0.5 – 1

Where is the high energy cutoff – important for the radiation models in magnetars

RXTE data

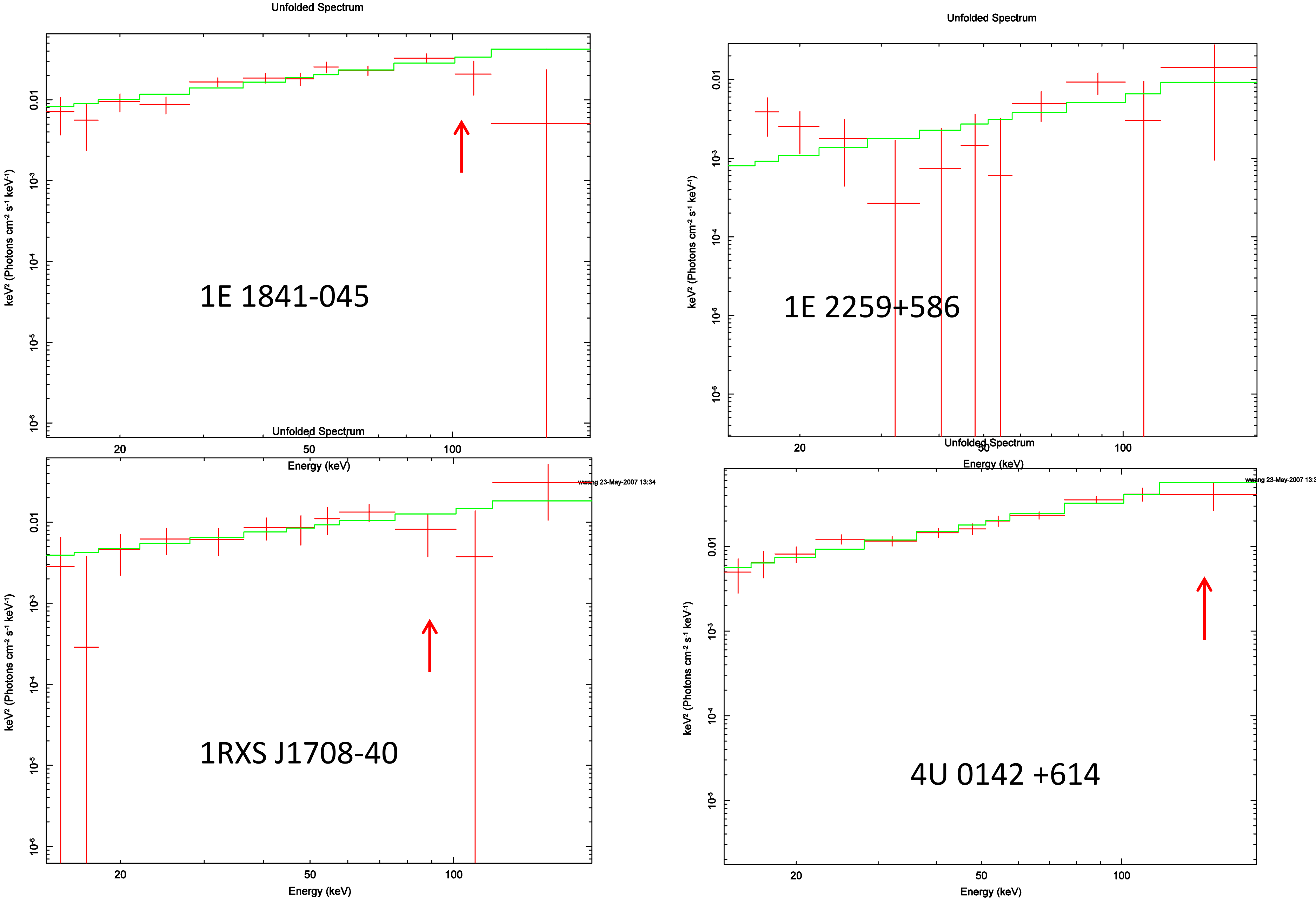
Kuiper 2006



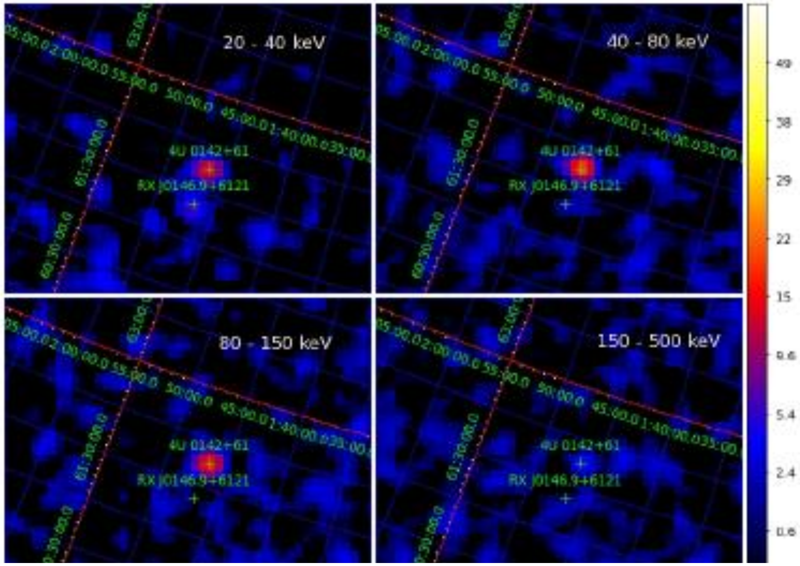
MeV

Swift/BAT data (Wang 2008)

Show hints for high energy cutoff

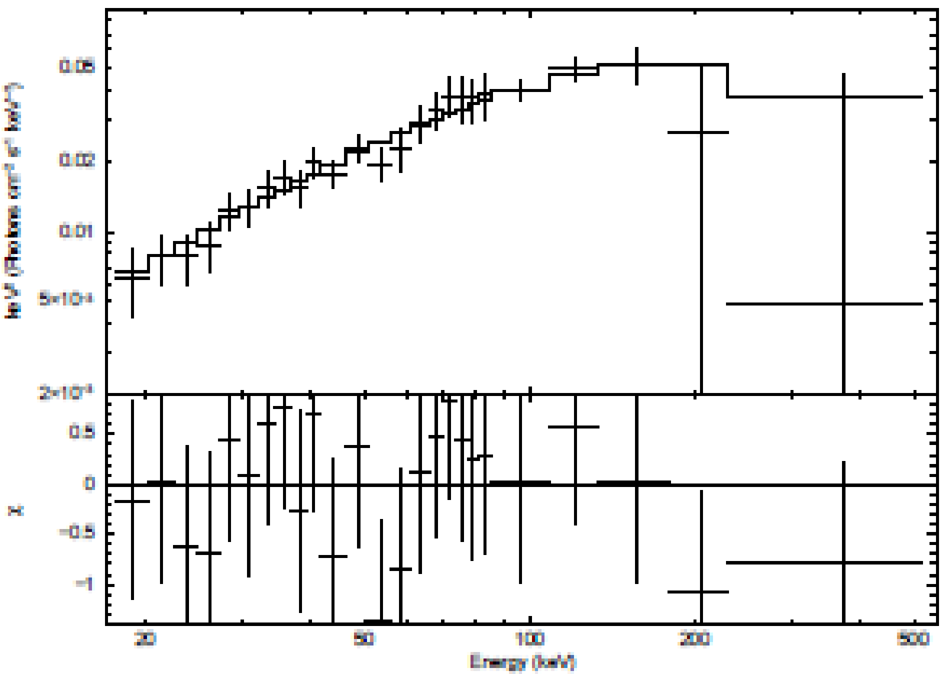


Recent results on 4U 0142+614 by INTEGRAL/IBIS



Wang et al. 2013

IBIS cannot detect 4U 0142 +61 above 150 keV, implying a high energy cutoff.



The average spectrum from 18 – 500 keV obtained by INTEGRAL observations from 2003 -2010.

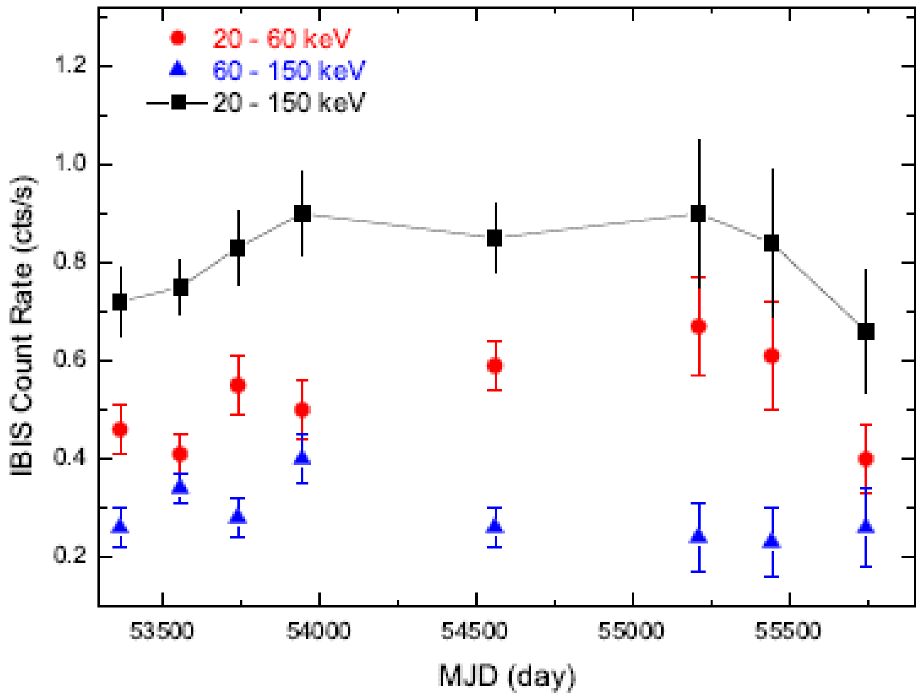
$\Gamma \approx 0.51 \pm 0.11$

$E_{cutoff} \approx 128.6 \pm 17.2$ keV

Flux 18-200 keV

1.3×10^{-10} erg cm^{-2} s^{-1}

Lx ~ 10^{35} erg/s (d=3kpc)



The total hard X-ray emission of 4U 0142+61 is stable from 2003 – 2012;
but spectral index varied from 0.4 – 1.6, cutoff from 110 – 250 keV

- cutoff energy at 130 keV, unconsistent with resonant inverse Compton scattering models with ultra-relativistic electrons (e.g., Baring & Harding 2007) which predict break around 1 MeV.
- the mildly relativistic electrons by persistent injections are required in the magnetar magnetosphere
- hard X-ray emission properties of 4U 0412+61 is still consistent with the accretion model, and the bulk and microscopic motions of electrons in the accreting flow should be mildly relativistic (Truemper et al. 2010, 2012)

Accreting Magnetars

- Neutron star high-mass X-ray binaries:

Corbet diagram

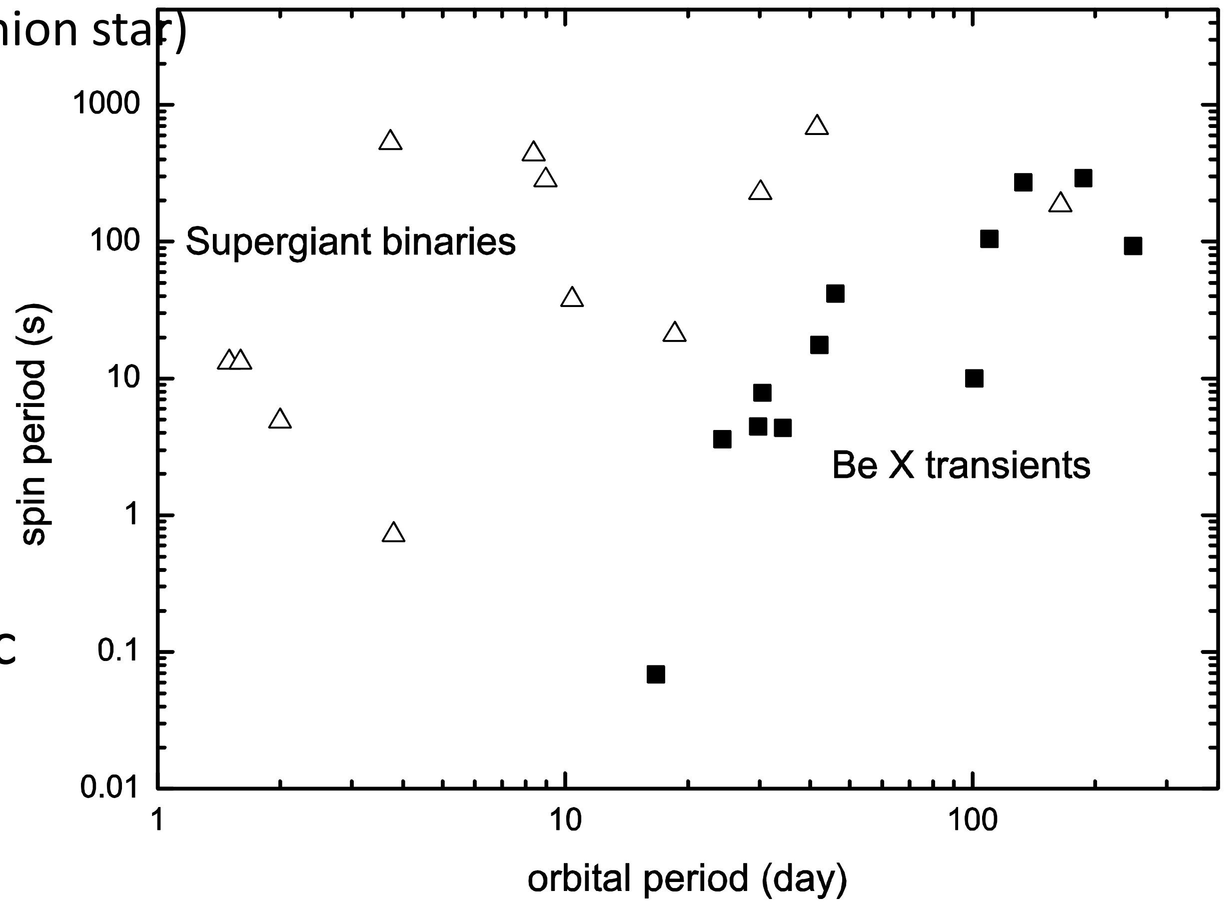
Be X-ray transient

(main-sequence companion star)

Supergiant binaries

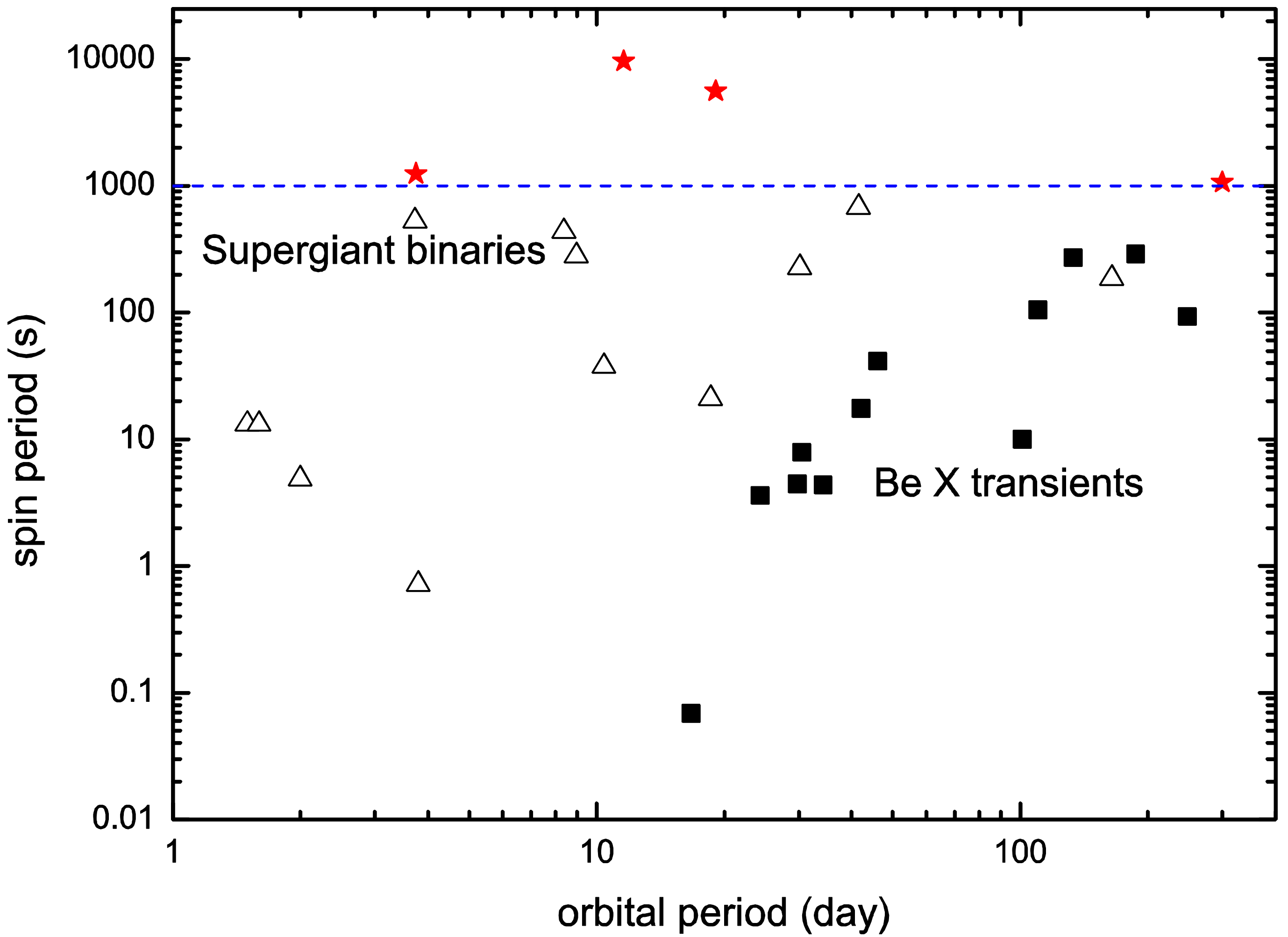
(supergiant companion)

Pspin ≈0.1 - 1000 sec



Recently some very slowly pulsation neutron stars are discovered in some binaries: P_{spin}>1000 s !

The P_{spin}- P_{orbit} diagram for Superslow X-ray pulsars in HMXBs



Why special for superslow pulsation X-ray pulsars

Origin of spin period in X-ray pulsars

Standard evolution of neutron star binaries:

a) ejector state: spin-down like radio pulsars;
b) propeller state: spin-down by interaction between magnetosphere and stellar winds;
c) accretor state: P_{spin} reaches a critical value; switch on as X-ray pulsars as observed.

$$P_{cr} \simeq 18\kappa^{3/2}\frac{M_{NS}}{1.4M_{\odot}}^{-5/7}[\frac{\mu}{10^{30}\mathrm{Gcm}^3}]^{6/7}[\frac{\dot{M}}{10^{15}\mathrm{gs}^{-1}}]^{-3/7}\mathrm{s},$$ (Pringle & Rees 1972 Ghosh & Lamb 1978)

The maximum spin period which can be reached in different observed conditions (magnetic field; accretion rate) :
from several seconds up to near 1000 s.

Then what channels produce the long spin period higher 1000 s ? It is a key question we need understand here.

Hard X-ray properties of superslow pulsation X-ray pulsars

- Spin periods and evolution:

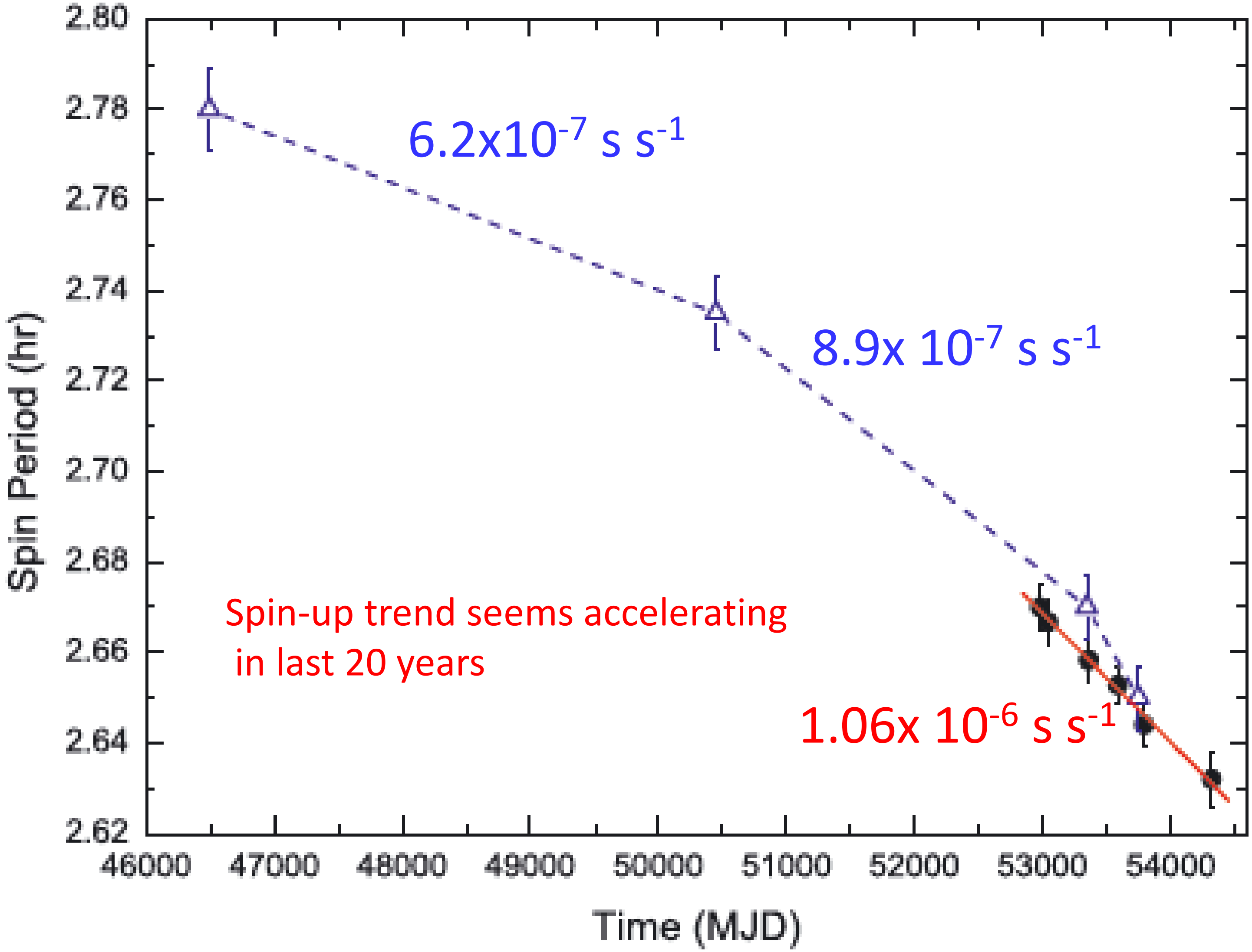
  2S 0114+65 : 9700 s

  4U 2206+54 : 5560 s

  SXP 1062 : 1062 s

More importantly, they undergo fast spin down/up trend.

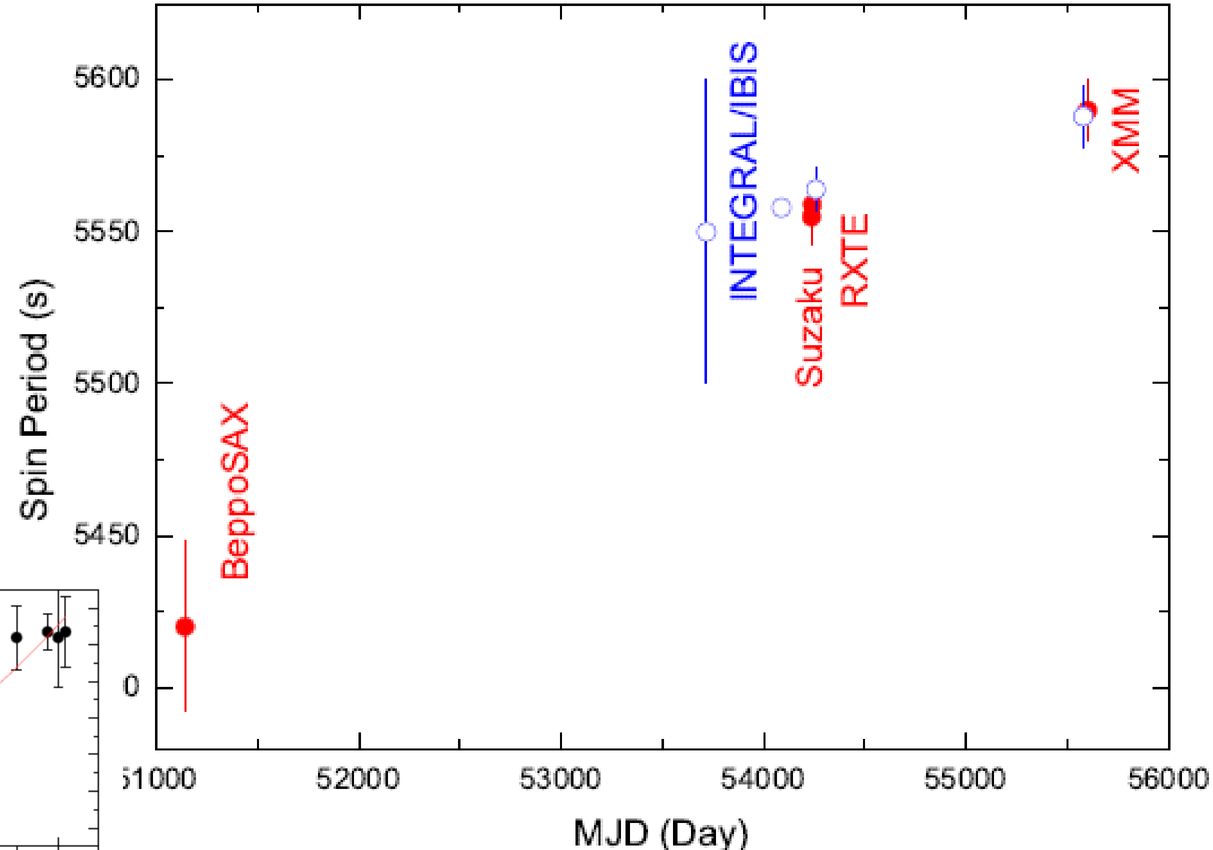
Spin-up trend of 2S 0114+65 from 1986 - 2008

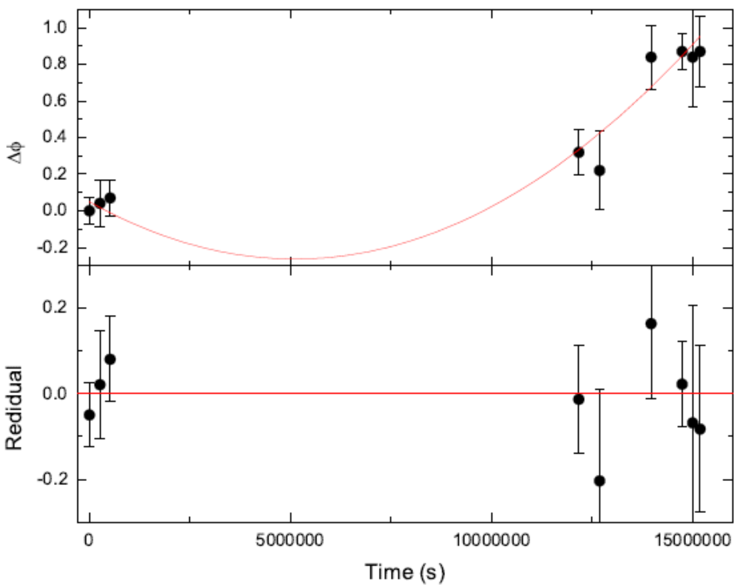


Wang 2011

Spin-down trend of 4U 2206+54 in last 20 years

Average Spin–down rate of $5x10^{-7}$ s s^{-1}



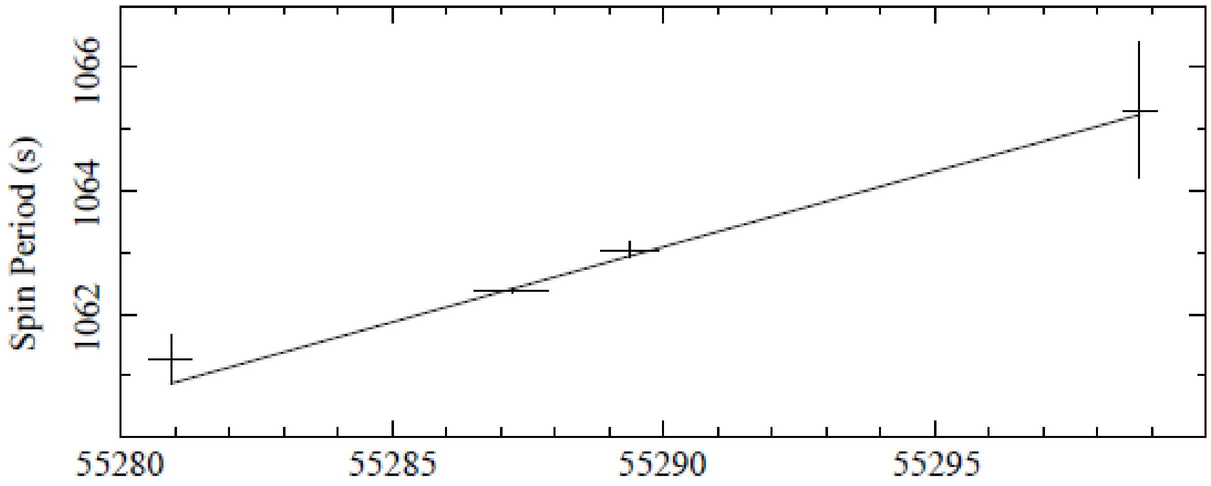


Phase-shift method finds the spin-down behavior in half year in 4U 2206+54 (2006 May - Dec): \dot P ~ $(6\pm 2)x10^{-7}$ s s^{-1}

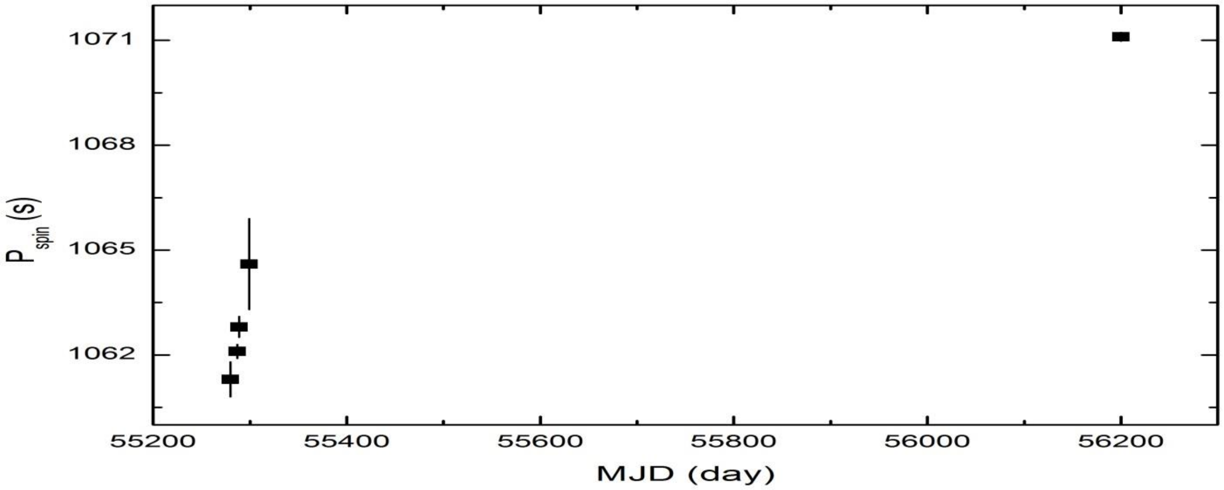
Wang 2012,2013; Reig et al. 2012

Be X transient SXP 1062

- Located in the Small Magellanic Cloud, associated with a SNR (2-4x10^4 yr)
- A large spin-down rate of 3x10^{-6} s/s during an outburst in 2010.



Haberl et al. 2012



From 2010-2012 average rate: ~ 10^{-7} s/s

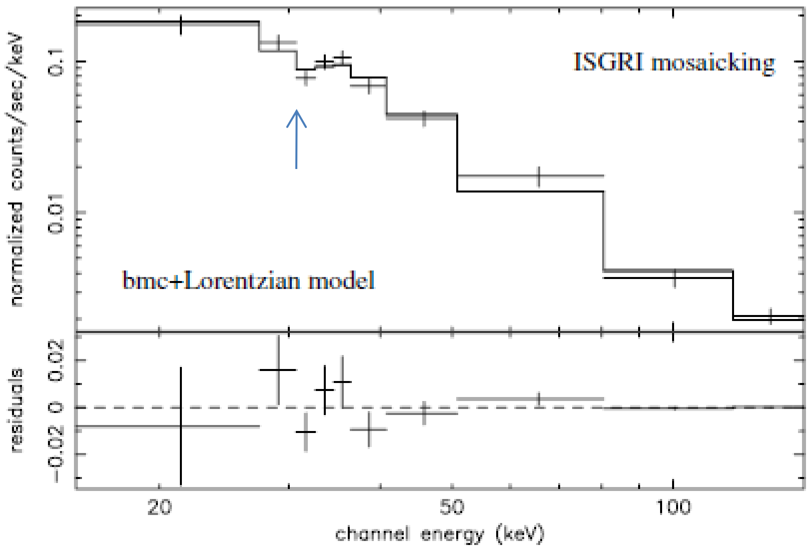
Sturn et al. 2013

Possible cyclotron resonance absorption features in 4U 2206+54

- The features were reported by INTEGRAL/IBIS:

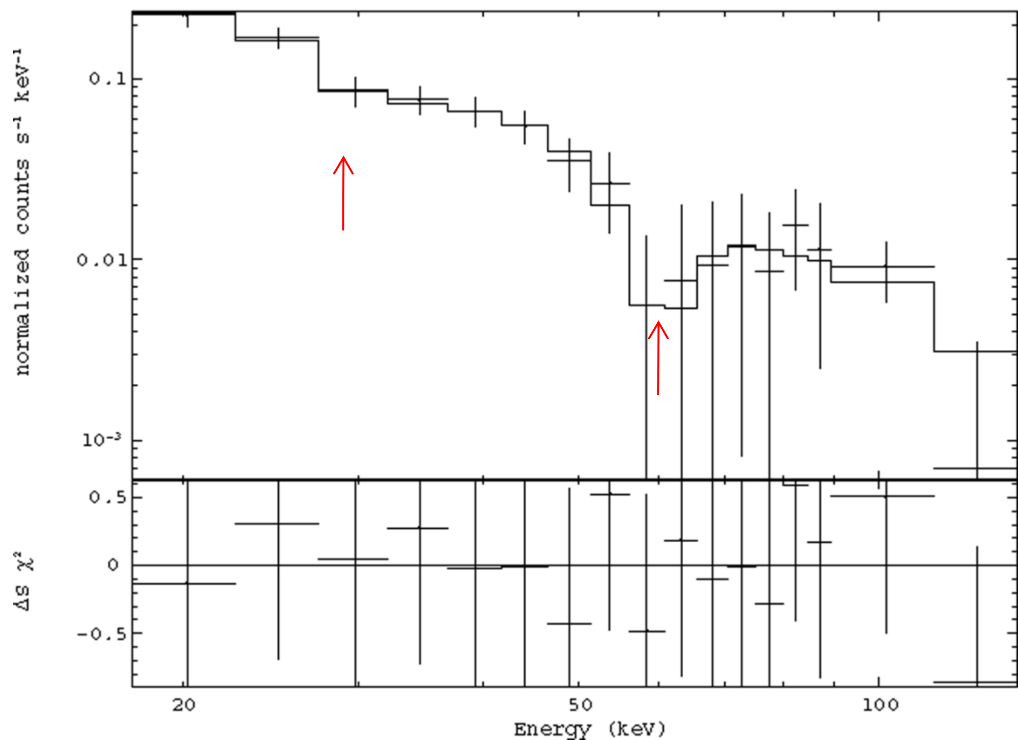
fundamental line around 30 keV

first harmonic at ~ 60 keV



Blay et al. 2005

Wang 2009

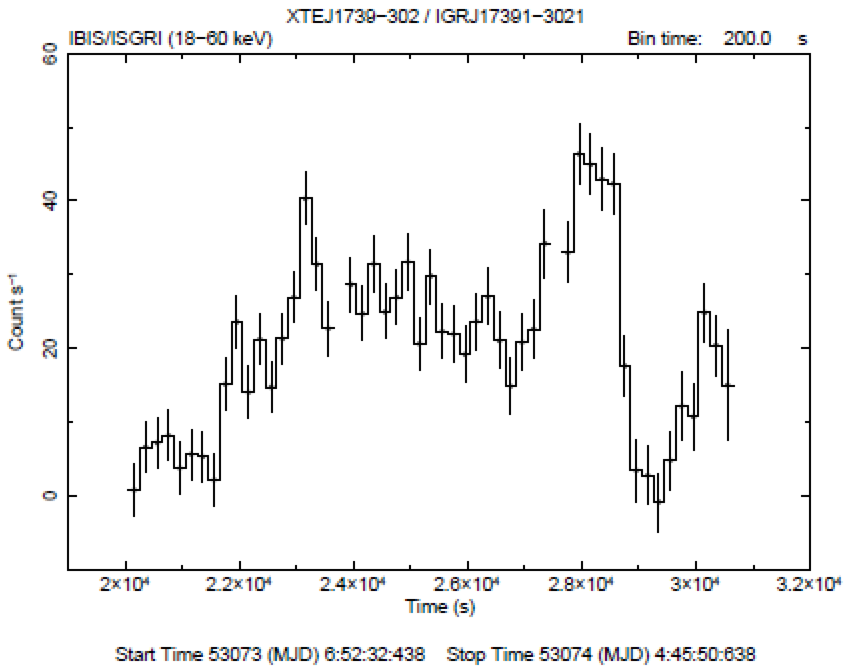


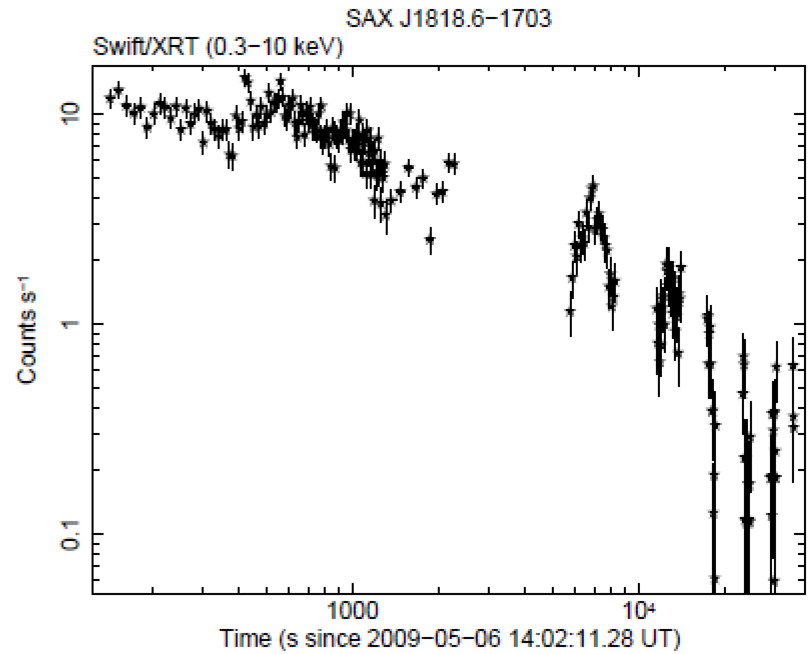
Assuming the electron absorption case :
$B_s=3.3\times10^{12}$ G

Other possible candidates of accreting magnetars

Supergiant Fast X-ray Transients

- Generally high mass X-ray binaries divided into two classes -
  Be X-ray transients: main-sequence companion, transients
  supergiant X-ray binaries: supergiant companion, persistent X-ray emissions.
- Supergiant fast X-ray transients (SFXTs) discovered by INTEGRAL now are a new subclass of HMXBs
- SFXTs: outburst states $L_x \sim 10^{36}$-10^{37} erg/s ; time scale 10^{3-4} s
  quiescent states: $L_x \sim 10^{32}$ erg/s
- Some SFXTs have show X-ray pulsations – they should be neutron star binaries (30 – 1200 s)
- Some SFXTs – a black hole cannot be excluded





The nature and physical mechanisms of SFXTs are debated.

(1) SFXTs are wind-accretors. Some researchers thought the stellar wind is structured, and outbursts are produced by the accretion of the very dense wind clumps (in't Zand 2005, Walter & Zurita 2007, Ducci et al. 2009).

(2) SFXTs has a magnetar with a slow pulsation (1000s) which induces the variability (Bozzo et al. 2008).

Returning to the question:
what is physical origin for long spin period?

- Li & van den Heuvel (1999): born as a magnetar with B>10^{14} G, allow for the neutron star to spin down slower than 1000 s in Myrs, and field decays to 10^{12} G at present (difficulty in time scales)
- Ikhsanov (2007): a phase "subsonic propeller" between the transition from known supersonic propeller state to accretor state would allow for the long spin period :

$$P_{\rm br} \simeq 2000 \frac{M_{\rm NS}}{1.4 M_{\odot}}^{-4/21} [\frac{B_{\rm surf}}{0.3 B_{\rm cr}}]^{16/21} [\frac{\dot{M}}{10^{15} {\rm g s}^{-1}}]^{-5/7} {\rm s},$$

Applying the above formulae to the case of 4U 2206+54/2S 0114+65, one derives the magnetic field of ~ 10^{14} G!

Alternative approaches:

- Spin-down rate in accreting state in standard model

  $$\dot{P} \sim 2\pi B^2 R_{NS}^6 / (GMI)$$ (Lipunov 1992)

  for SXP 1062 , B= 3×10^{14} G

  for 4U 2206+54 , B= 5×10^{13} G

- Recently , a new theory of quasi-spherical accretion for X-ray pulsars is developed (Shakura et al. 2012):

  the magnetic field in wind-fed neutron star systems is given by

  $$B_{12} \sim 8.1\, \dot{M}_{16}^{1/3}\, V_{300}^{-11/3} \left(\frac{P_{1000}}{P_{orb\,300}} \right)^{11/12} \mathrm{G}.$$

  However, we still find the derived magnetic field of

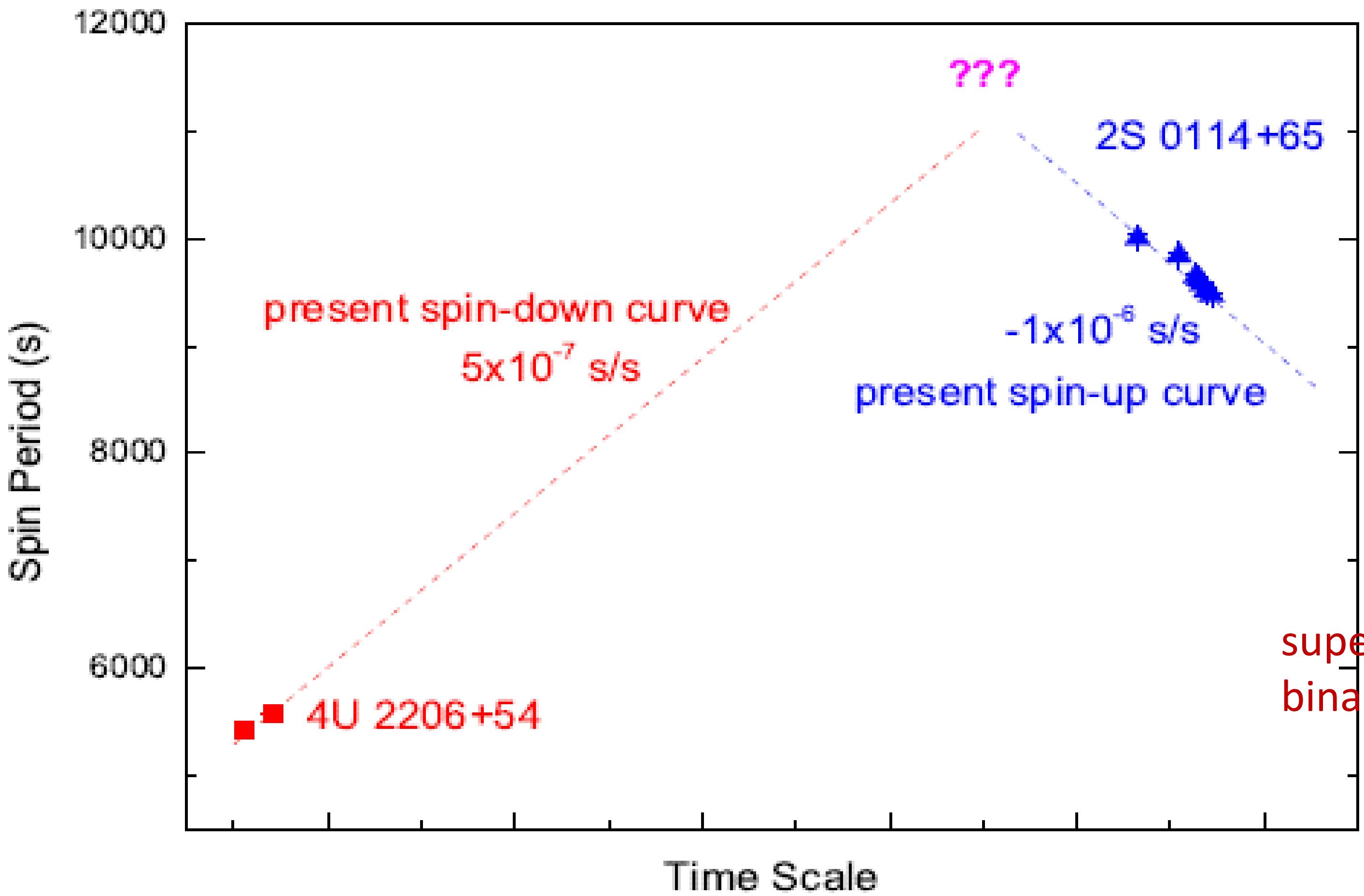
  2×10^{14} G for 4U 2206+54

  $>10^{14}$ G for SXP 1062

  These super-slow pulsation pulsars would be accreting magnetars!

Evolution scenario of accreting magnetars

- Possible evolution link in slow pulsation X-ray pulsars (accreting magnetars) – supergiant X-ray pulsars



supergiant X-ray binaries – SFXTs?

	Isolated magnetars	Accreting magnetars
Spin period	2 – 12 s	> 1000 s
Spin period derivative	10^{-12} – 10^{-10} s/s	10^{-7} – 10^{-6} s/s
Characteristic age	10^4 -10^5 yr	10^4 -10^6 yr
X-ray spectral properties	<10 keV : thermal kT~0.1-1keV >10 keV : non-thermal with Γ~ 0.5 – 1.5 Cutoff energy at 100-200 keV	Power-law plus a high energy cutoff (30 -100 keV): Γ~ 2.0 – 2.5
X-ray luminosity (1-100 keV)	10^{35} -10^{36} erg/s (Q) >10^{40} erg/s (B)	10^{34} -10^{37} erg/s
Energy power	Magnetic field decay/ activity ; accretion?	Wind-fed direct accretion

Thank you for your attention!

More detailed information, please send mail to

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