Suzaku View of Magnetars

1. Short History/Review of Magnetars
2. *Suzaku* Broadband X-ray Spectra
3. ToO Observations by *Suzaku*

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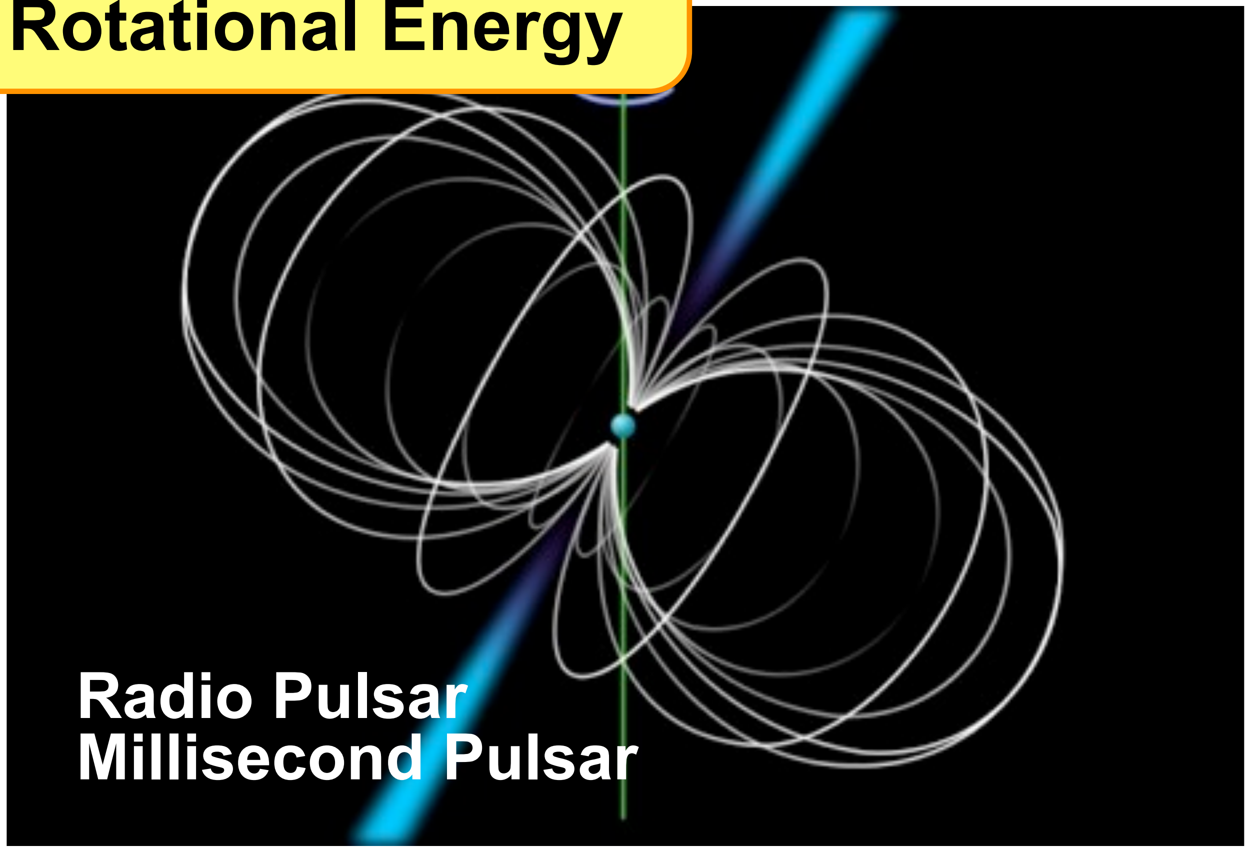
Suzaku Magnetar Key Project

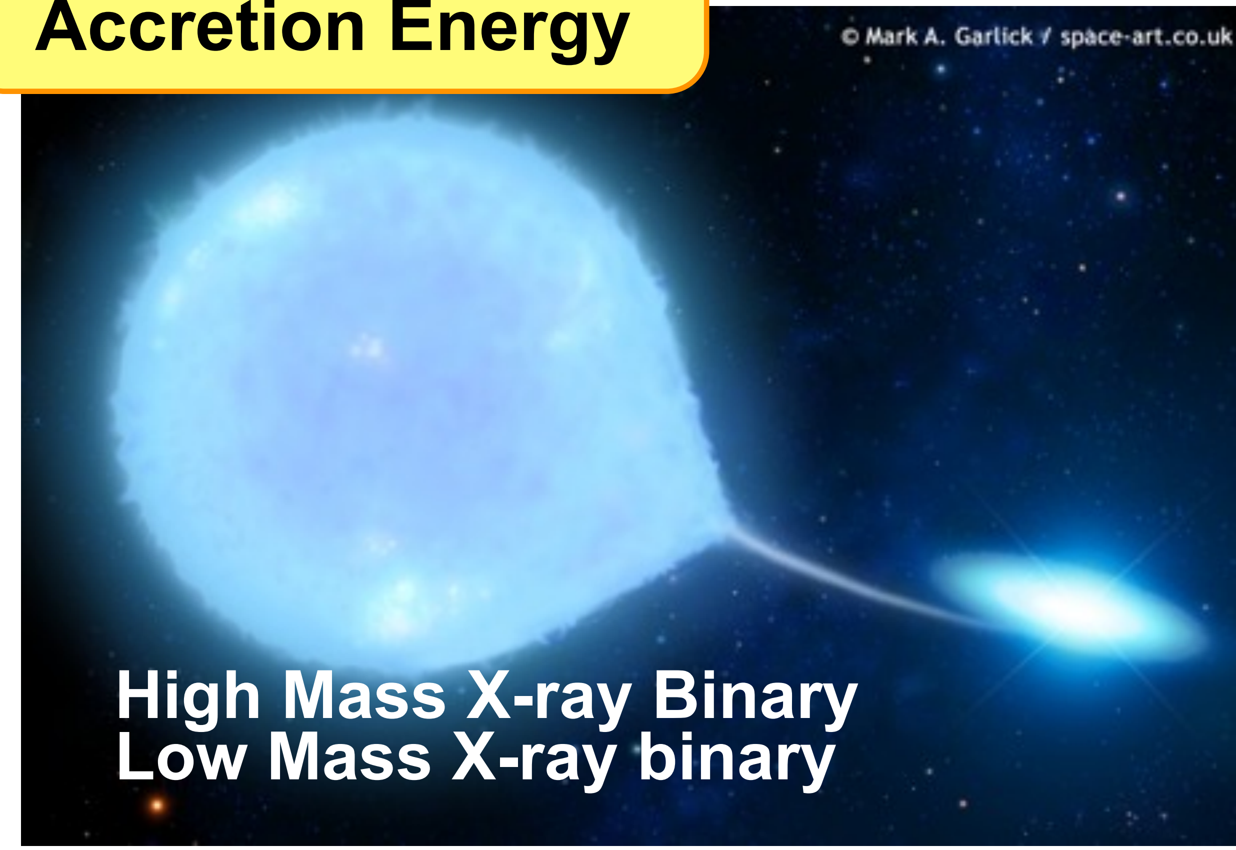
"Current Understanding and Future Study of Magnetars: Research Strategy in the ASTRO-H era"

Variety of Neutron Star; Energy Source

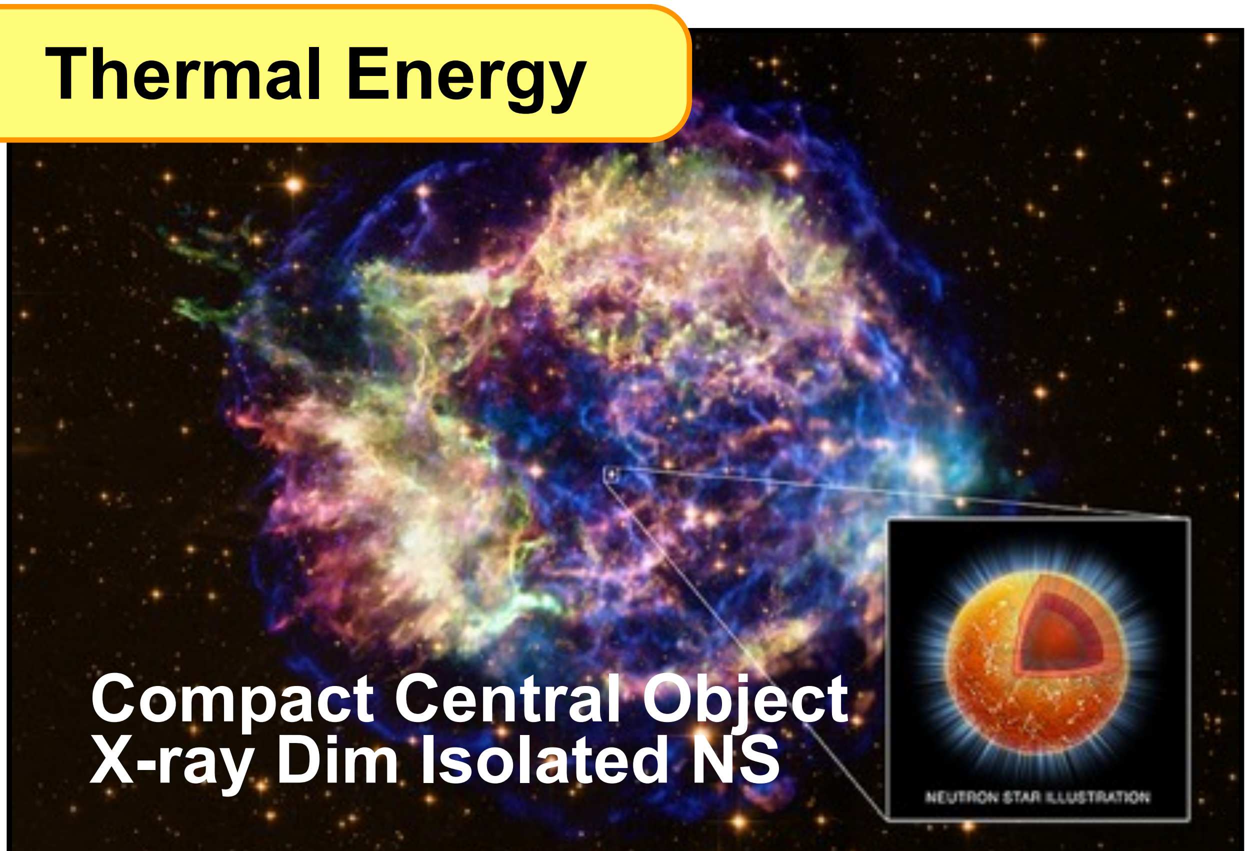
Rotational Energy



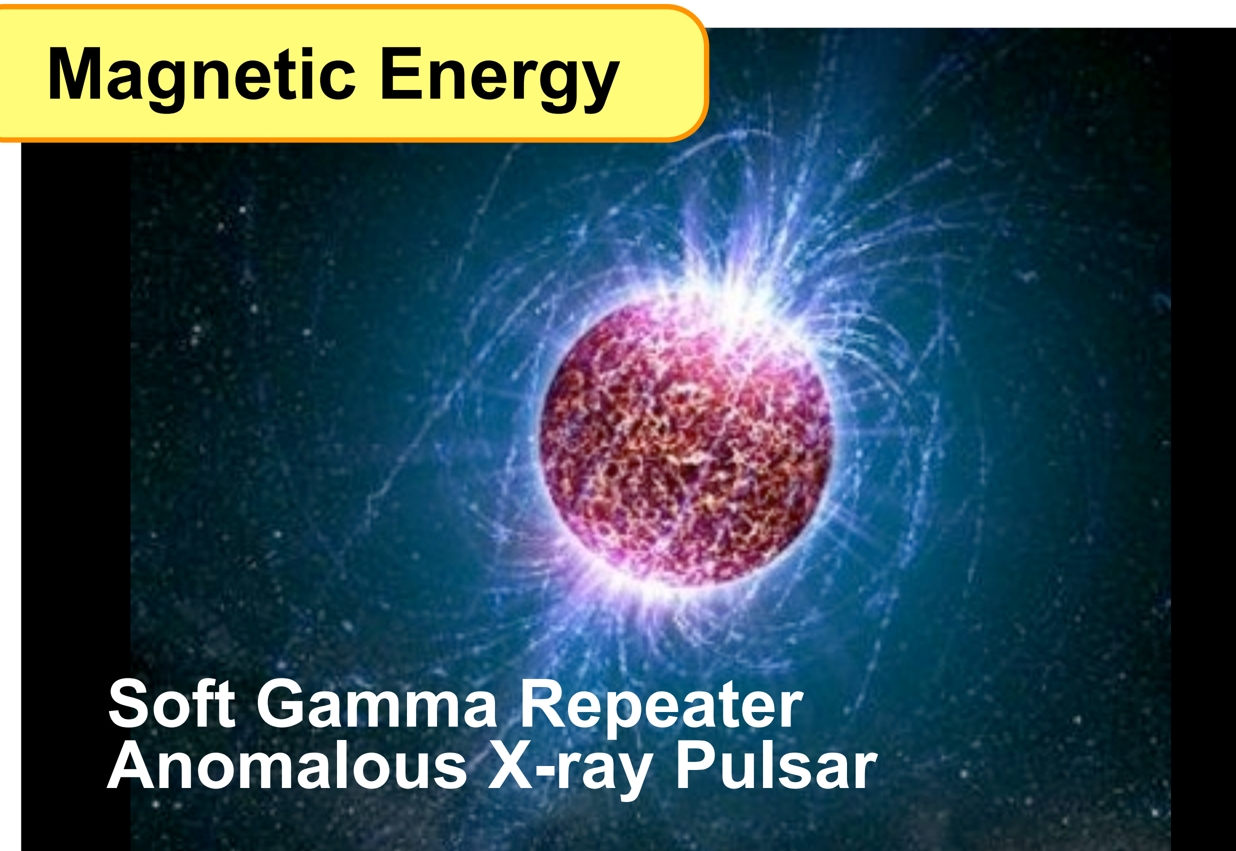
Accretion Energy



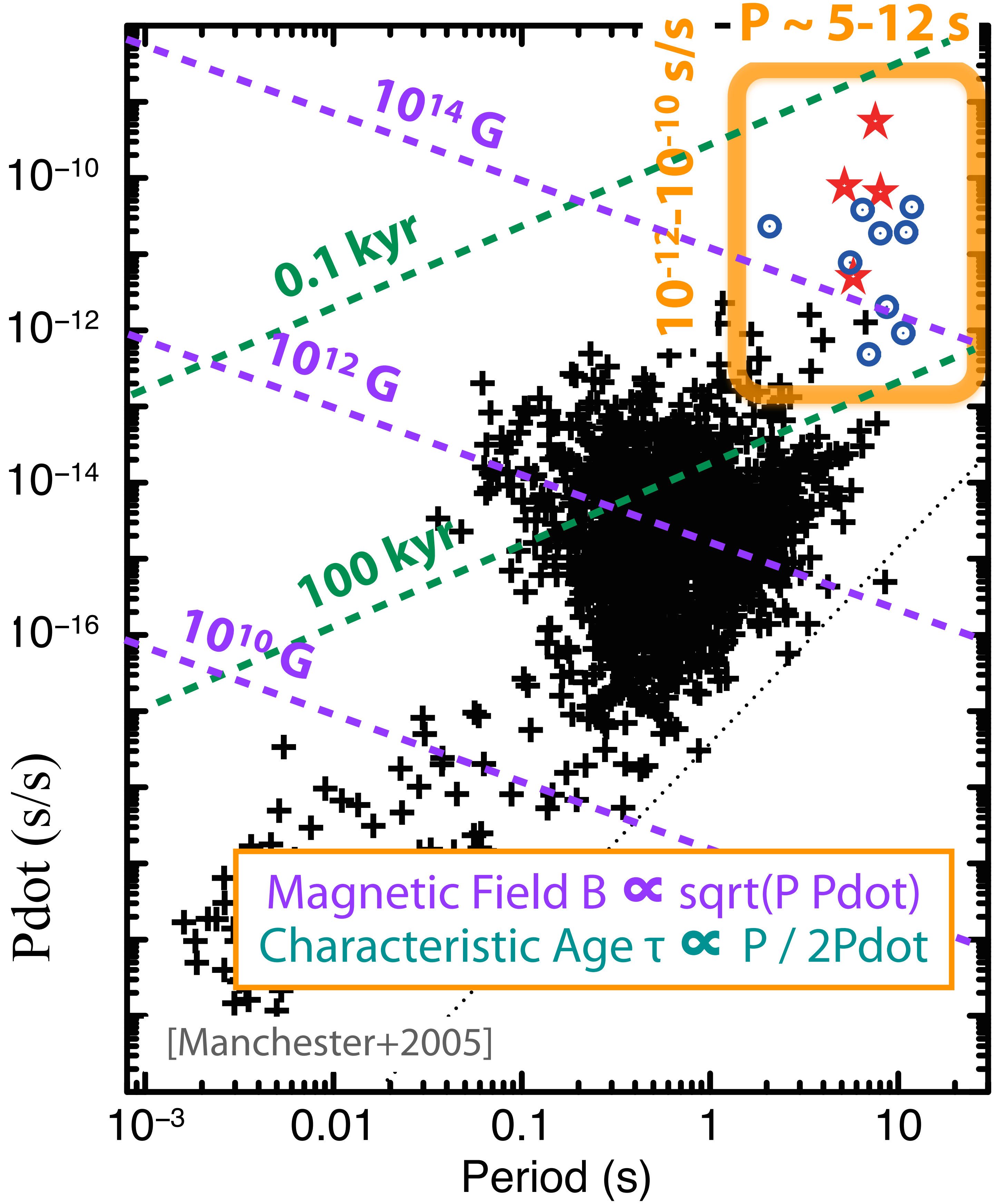
Thermal Energy



Magnetic Energy

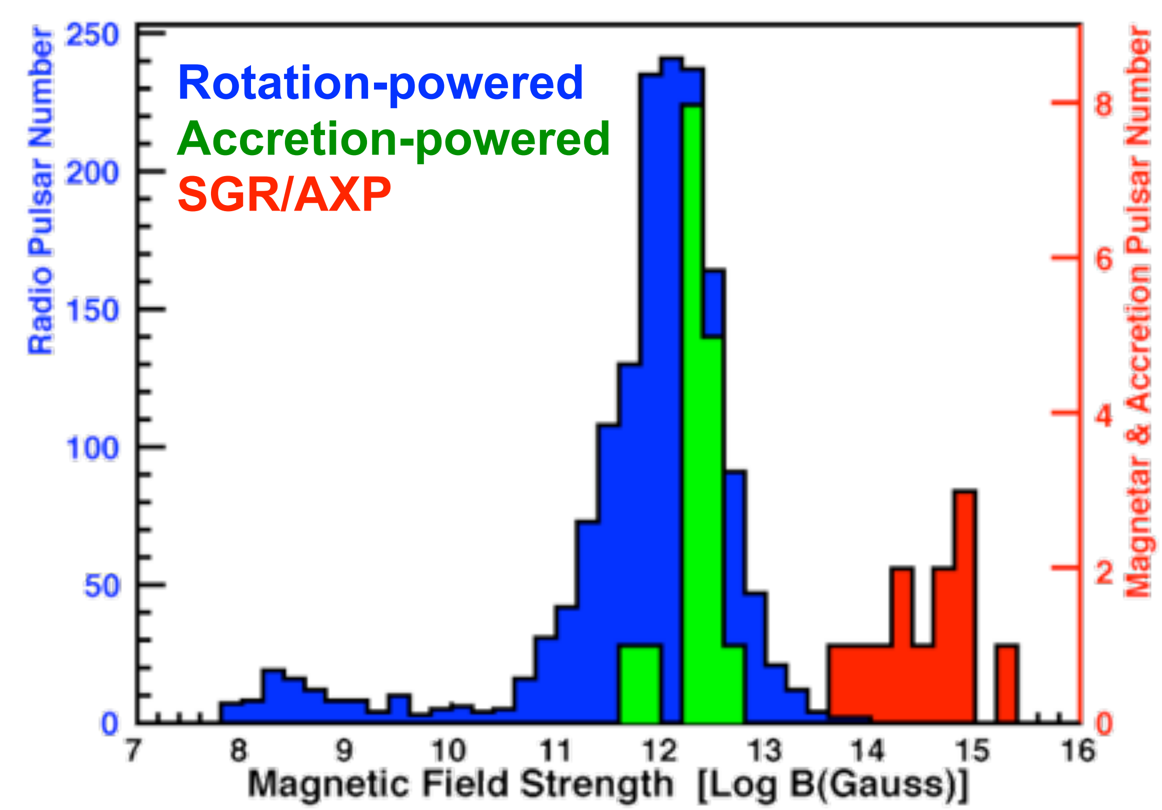


Magnetar Class



- Soft Gamma Repeater
- Anomalous X-ray Pulsar

- Strong Field (B > 1E+14 G)
- Young (τ < 100 kyr)
- Lx ~ 1e+35 erg/s

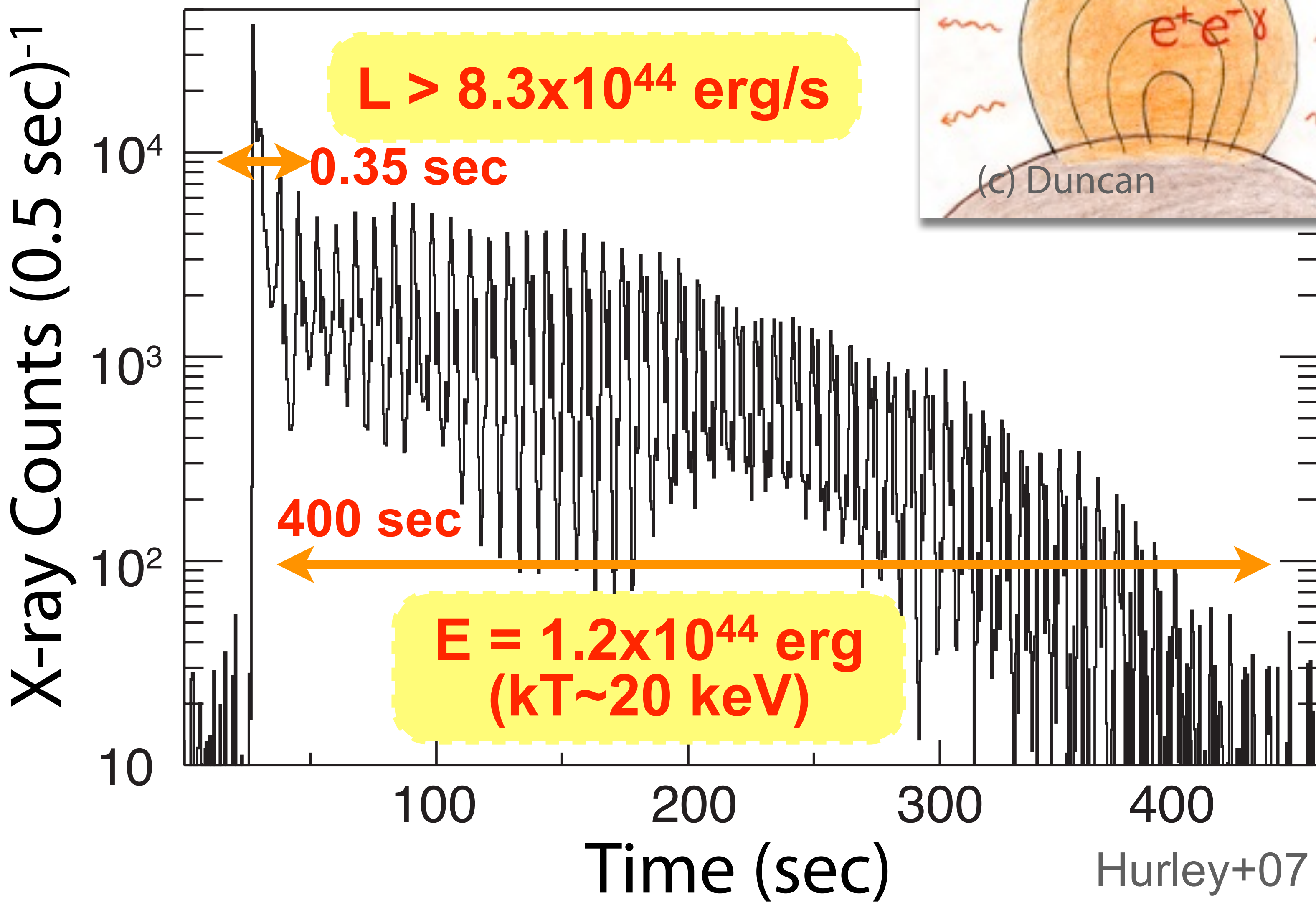


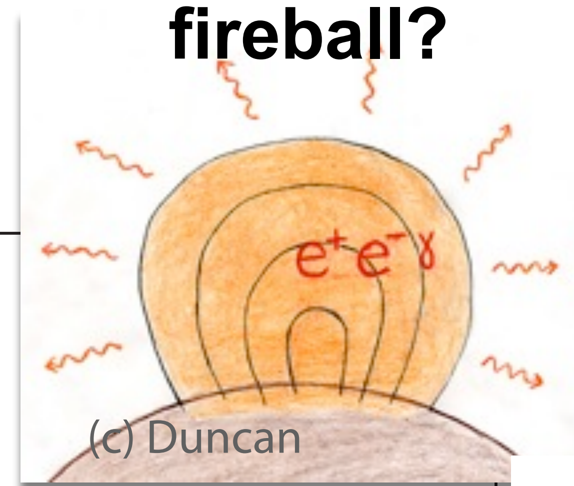
Ultra-strongly Magnetized NS?

Soft Gamma Repeater (SGR)

Discovered by "Giant Flares" or recurrent burst activities. ~ 5 SGRs

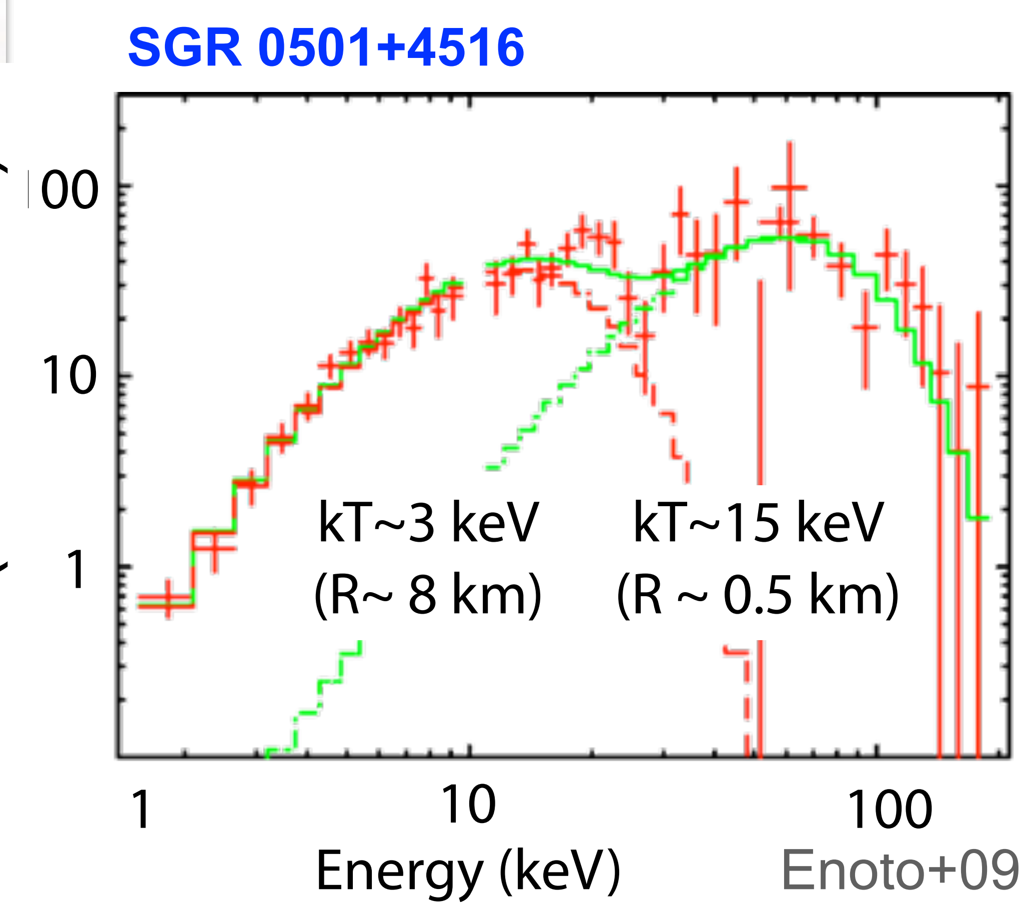
Giant Flare (3 events)





Short Bursts

a few hundred millisecond
empirically two Blackbody



- **Exceeding the Eddington Luminosity (~10^{38} erg/s) by ~6 orders of magnitudes**
- **B > 10^{14} G is required to confine a few dozen keV plasma for ~400 sec**

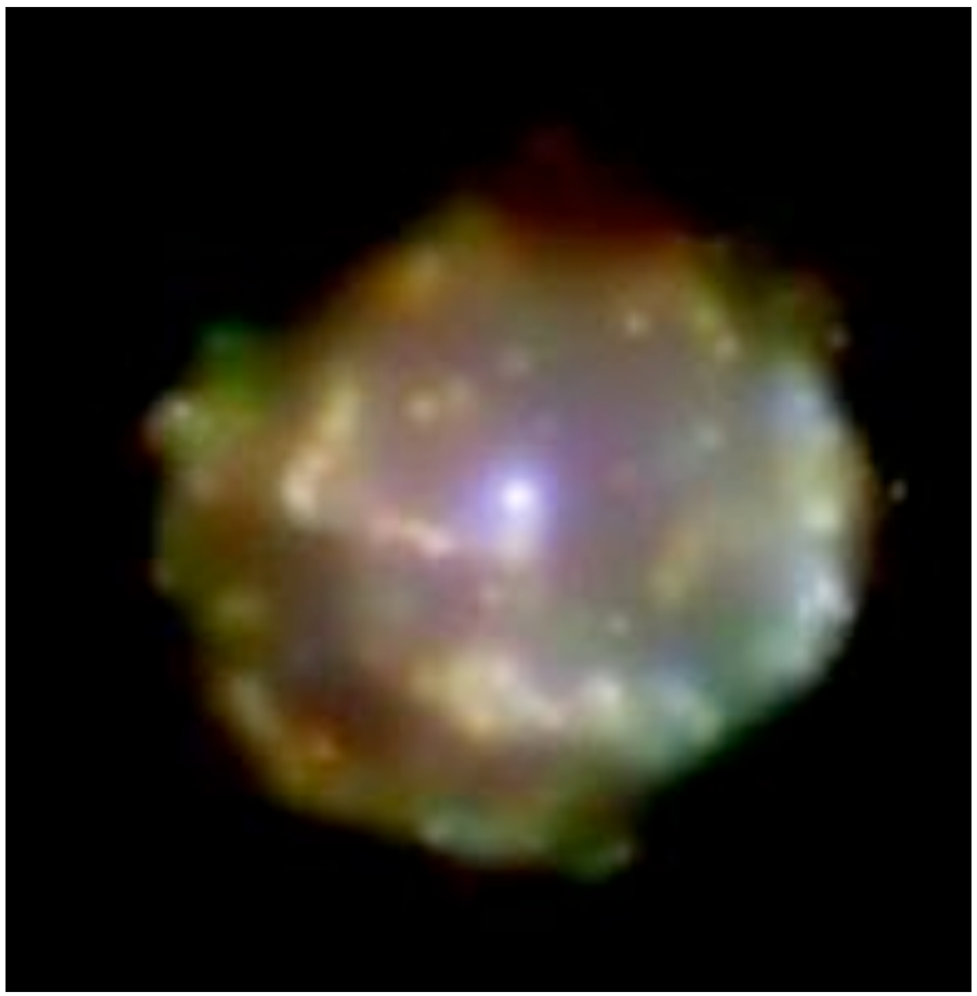
Anomalous X-ray Pulsar (AXP)

Discovered as pulsed bright persistent X-ray sources. ~15 AXPs

Associated with SNR

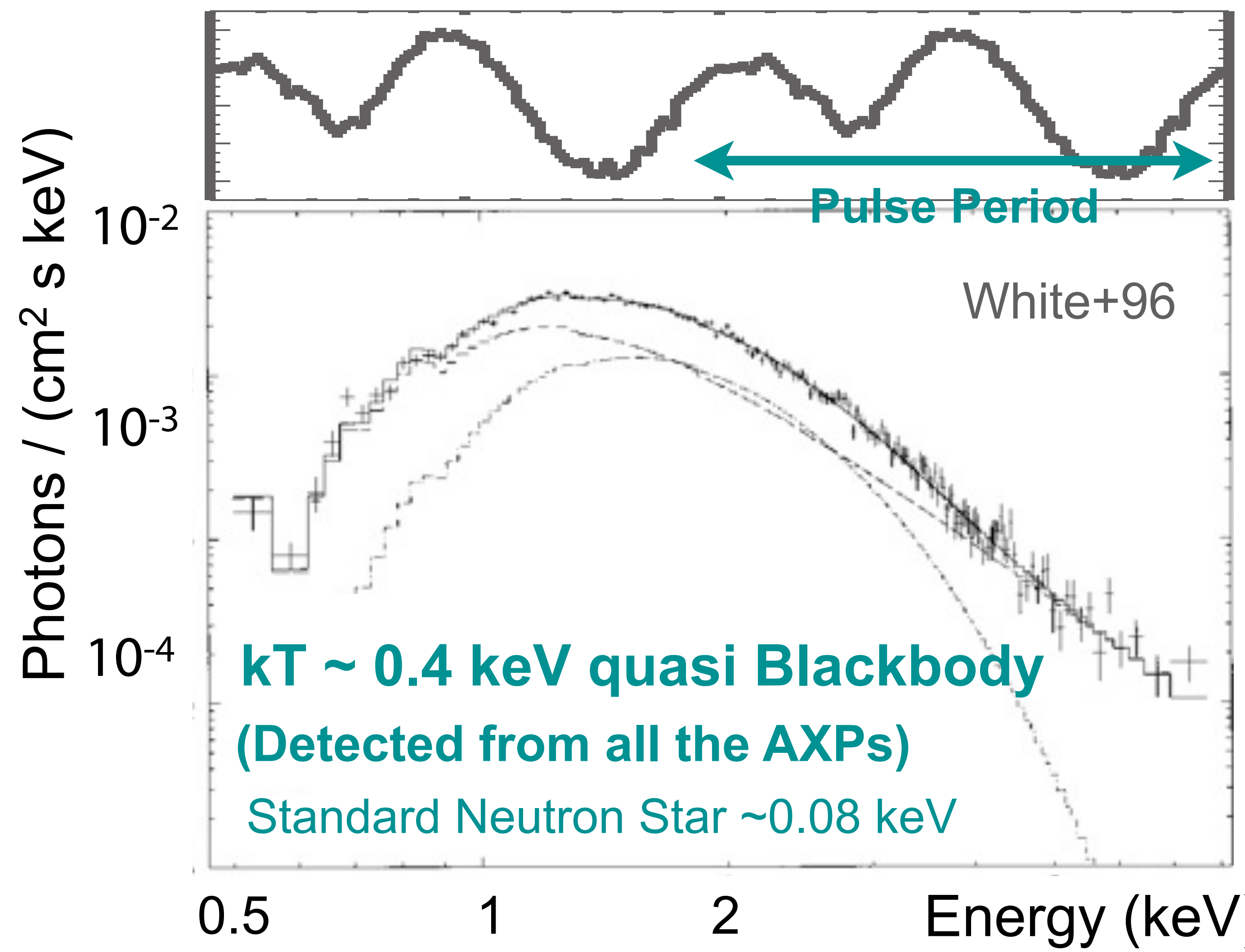
Persistent X-ray Emission

1E 1841-045 (SNR Kes73)



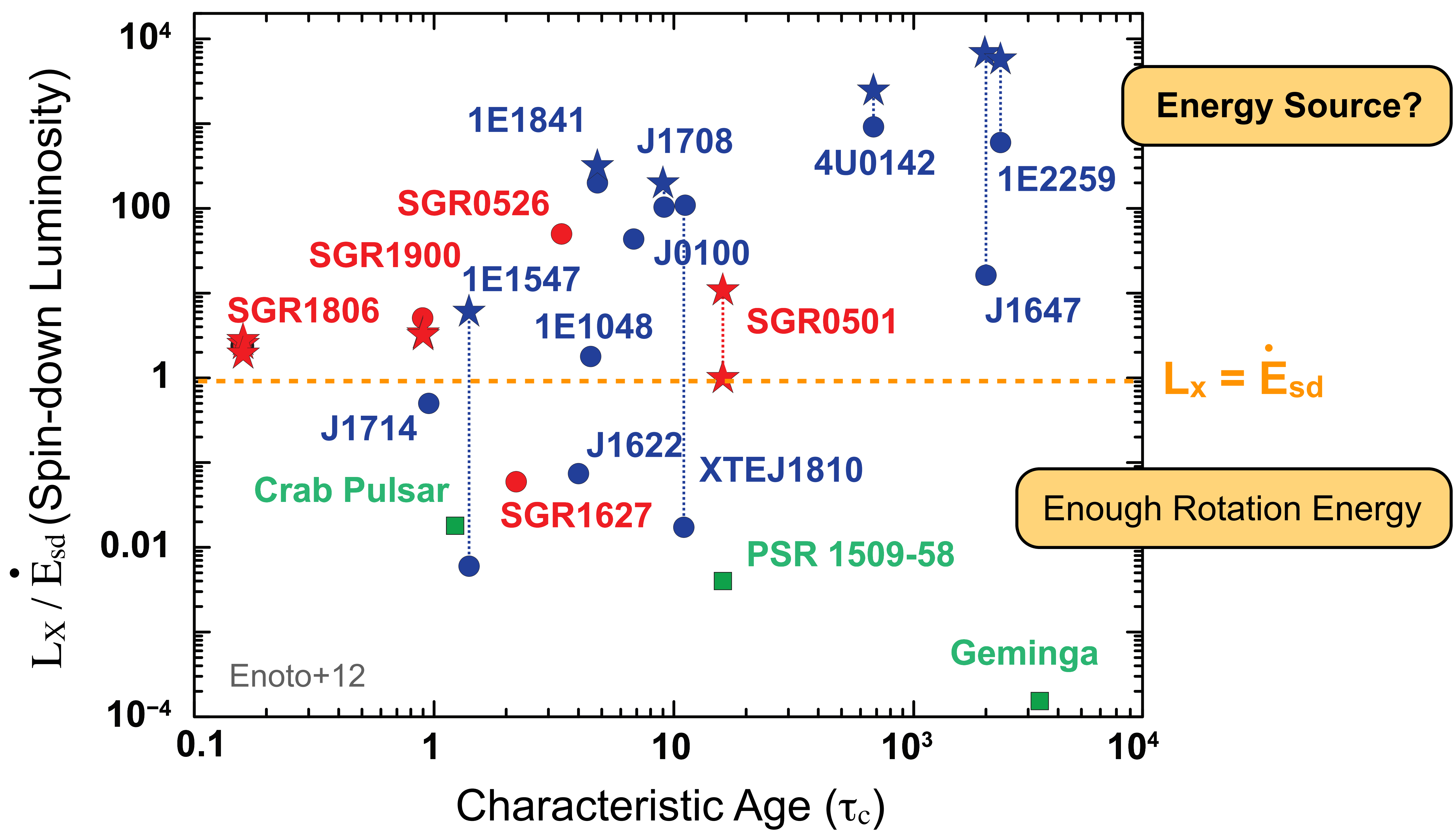
Chandra Image (c)CXO

4U 0142+61



- **Exceeding the Spin-down luminosity by ~2 orders of magnitudes (L_x >> L_{sd})**
- **Magnetic Energy => NS surface emission?**

Persistent X-ray Luminosity of SGR/AXP



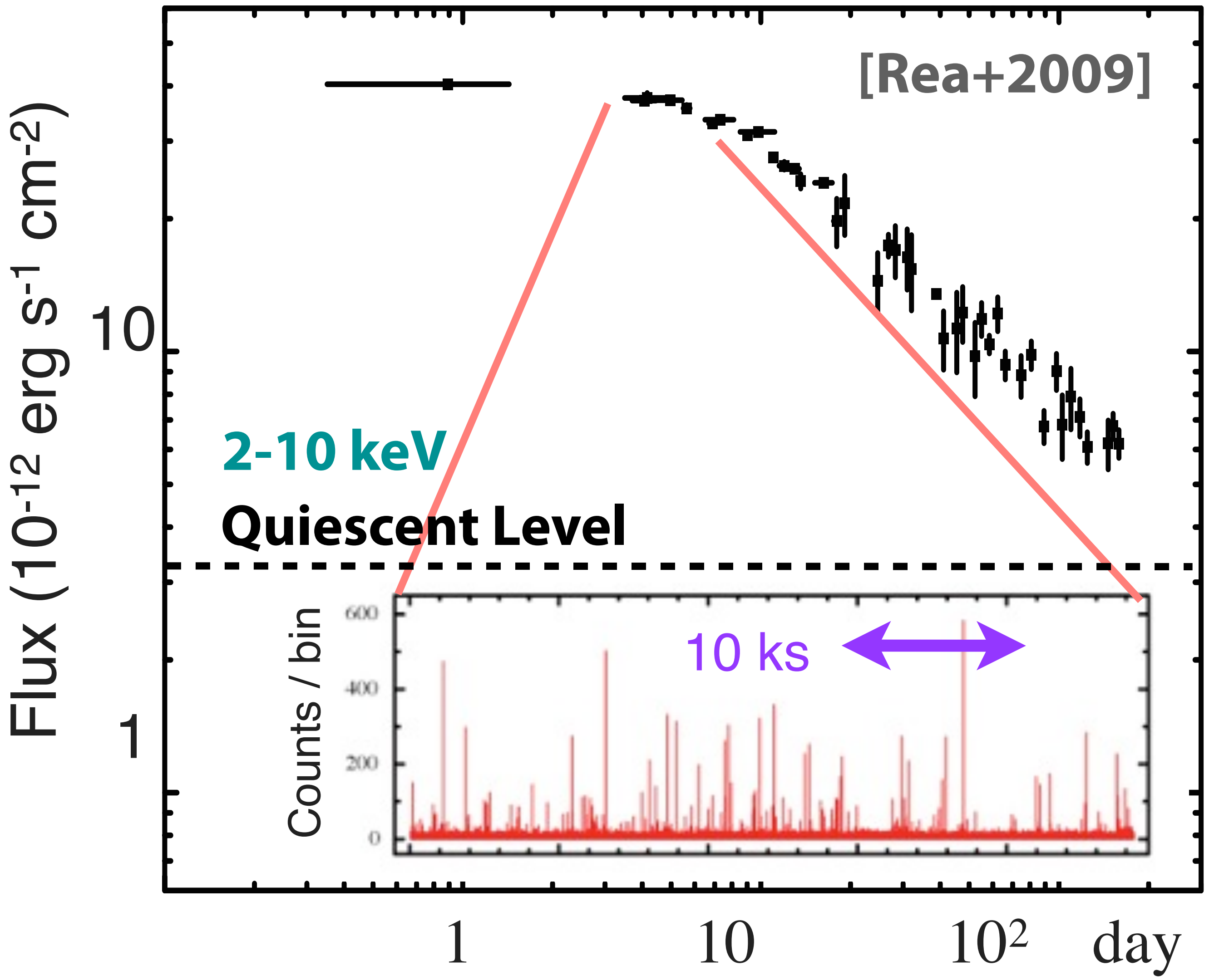
L_x >> Spin-down E_{sd}, no evidence for a binary companion (e.g., Kaspi+99)
Magnetars; Magnetically-powered Pulsars?

Recent Progress

Transient Magnetars

Outburst of persistent emission

SGR 0501+4516 (2008)



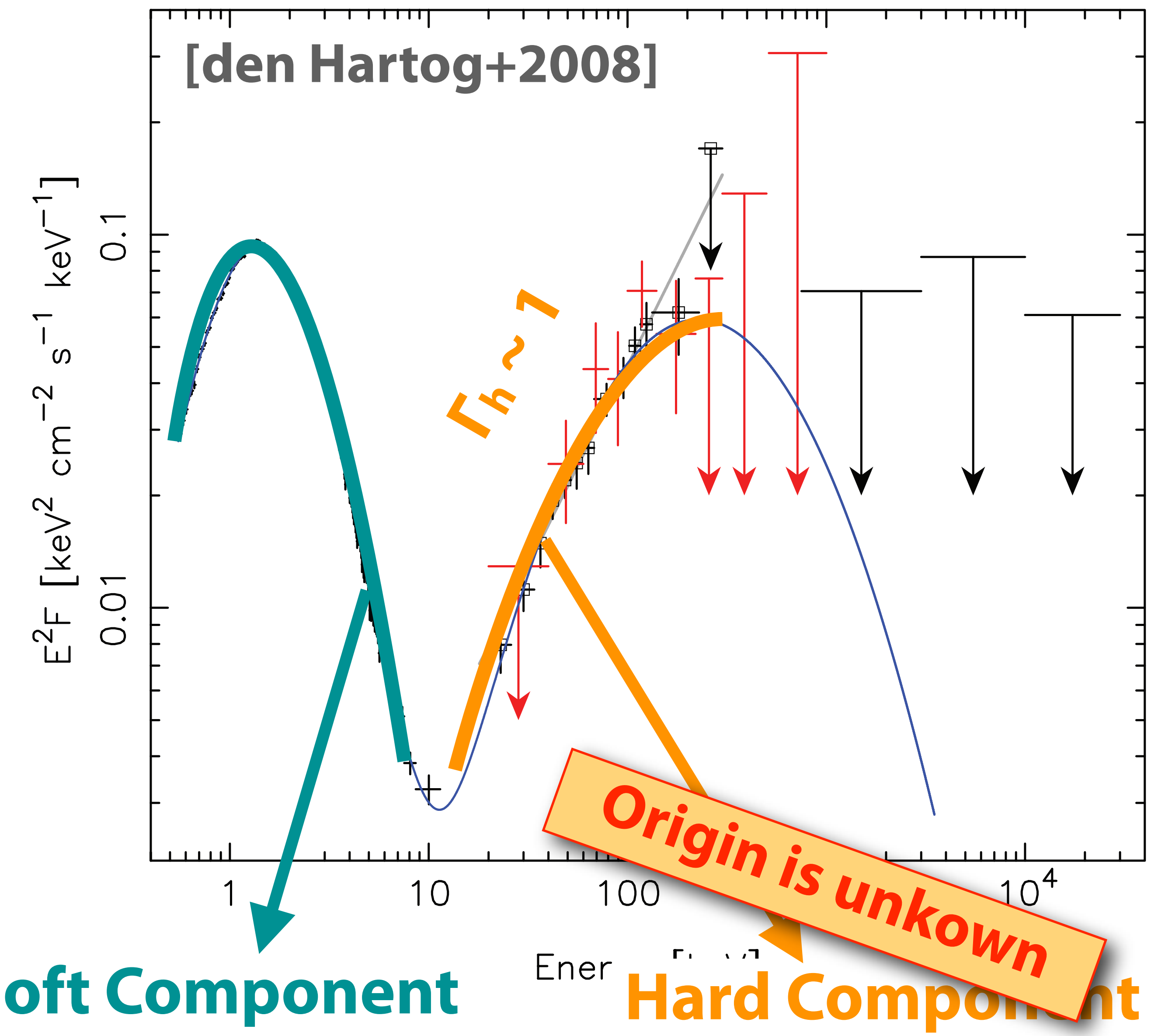
brighter by 1-2 orders of magnitude

Hard X-ray Component

discovered above 10 keV

[Kuiper+2006]

4U 0142+61 (XMM+INTEGRAL)



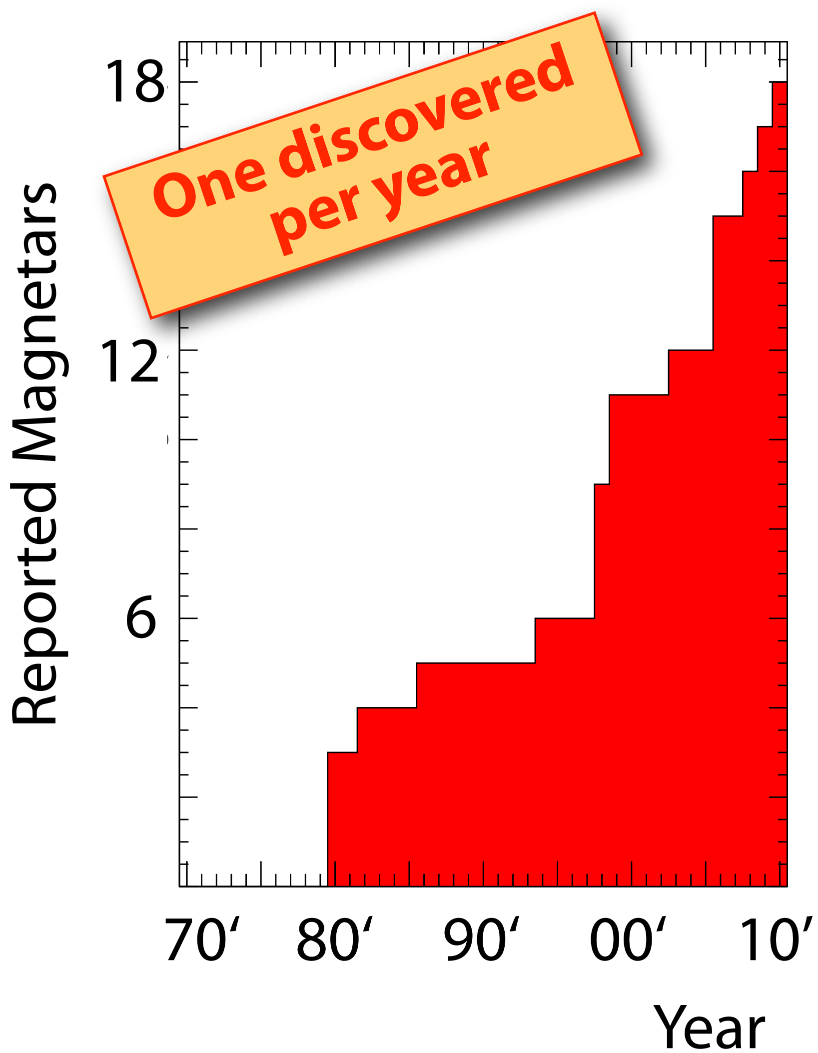
Challenge to provide a more unified characterization of Magnetars

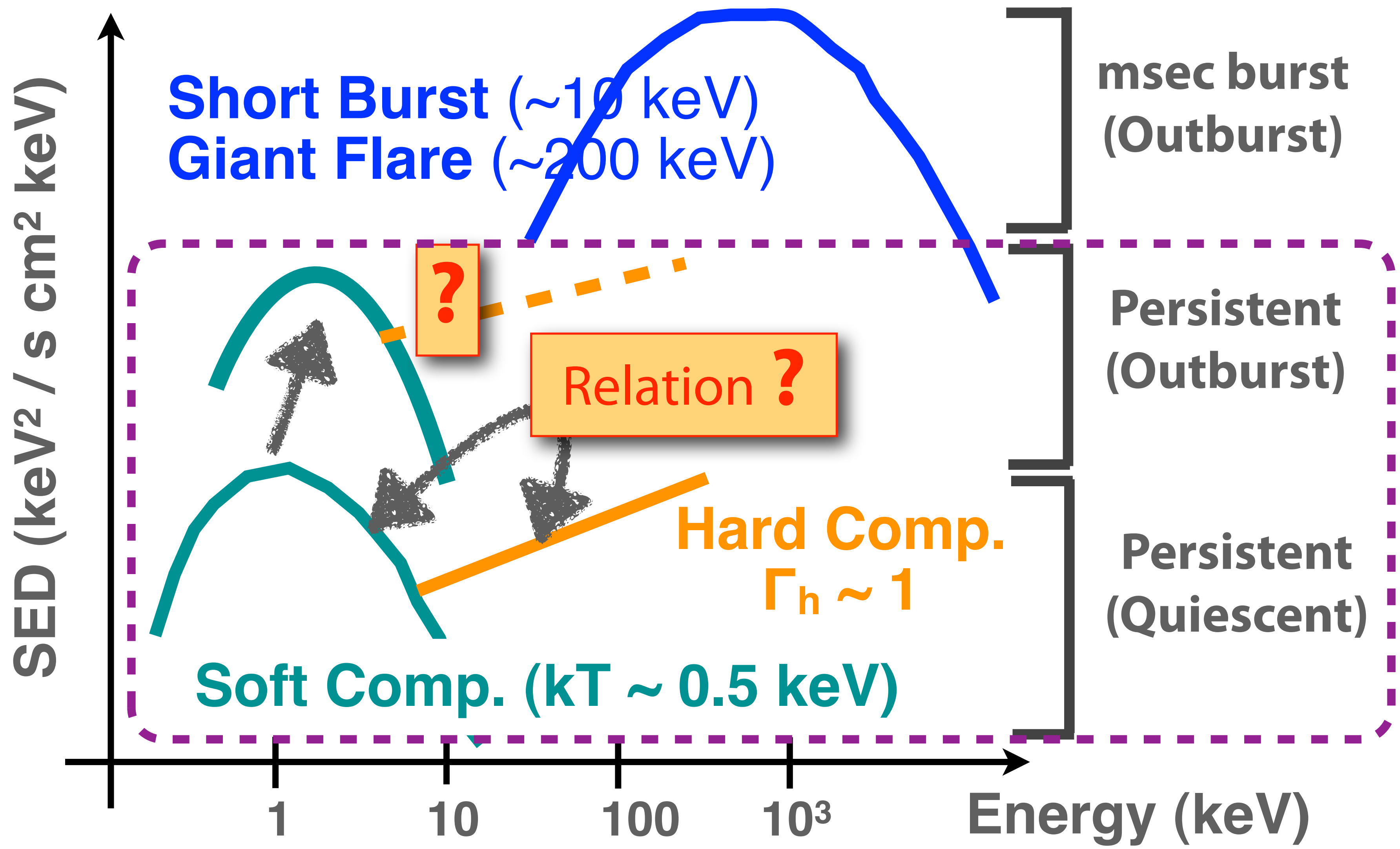
Question on Magnetars

"Do SGR and AXP have really the ultra-strong magnetic field (magnetars)?"

Are two classes intrinsically the same class?

How the postulated strong magnetic field are dissipated and converted into the radiation?





Q. Hard component is common, even in outburst ?

Q. Is there any relation between the Soft & Hard Comp. ?

Suzaku Broadband X-ray Spectra

Magnetars in Japanese X-ray Astronomy

Tenma, Ginga

1. Particular spectral & timing feature of 1E 2259+584 Koyama et al., 1989, PASJ
   - Pdot ~ 6.2e-13 s/s, Cyclotron Resonance Feature ~7.2 keV?

Currently known a prototypical AXP

ASCA

2. ASCA, RXTE determination, P = 5.16 sec & Pdot = 1.1e-10 s/s of SGR 1900+14
   $\Rightarrow$ B ~ 2-8e+14 G
   Murakami et al., 1994 Nature, Kouveliotou et al., 1998 Nature, Murakami et al., 1999, ApJ

Magnetar Hypothesis

3. Glitch like behavior & Pulse profile change of 4U 0142+61
   Morii et al., ApJ, 2004

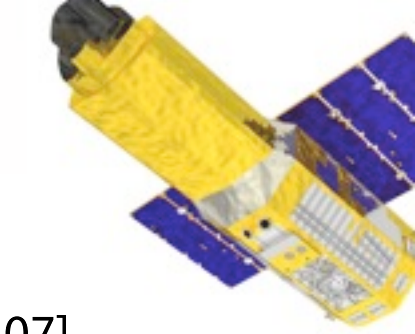
Currently known a prototypical AXP

HETE-2

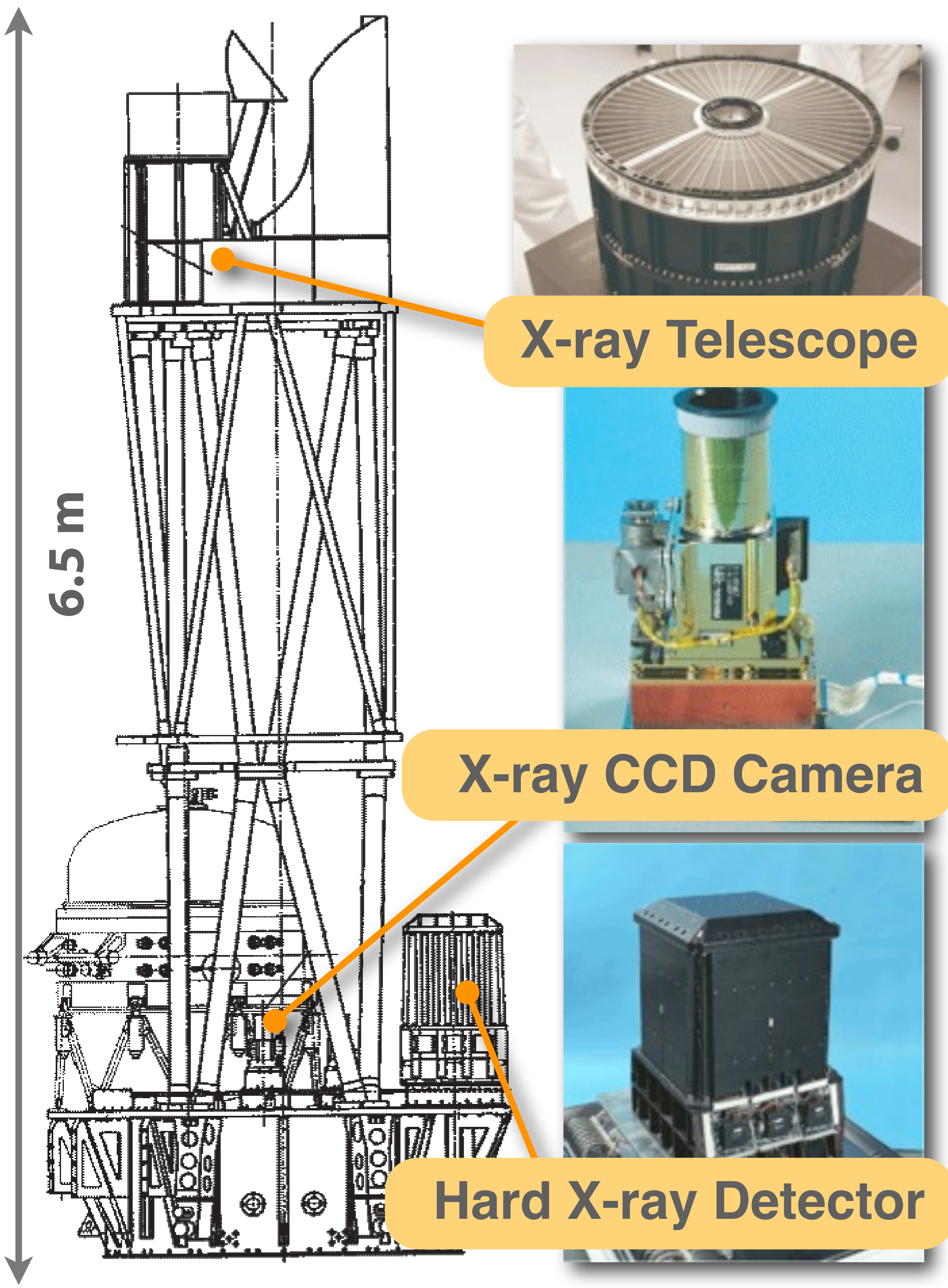
4. Spectral & timing analyses of short bursts from SGR 1806-20 & 1900+14
   $\Rightarrow$ Two blackbody spectral model (~4 keV & ~11 keV) Nakagawa et al., ApJ, 2007

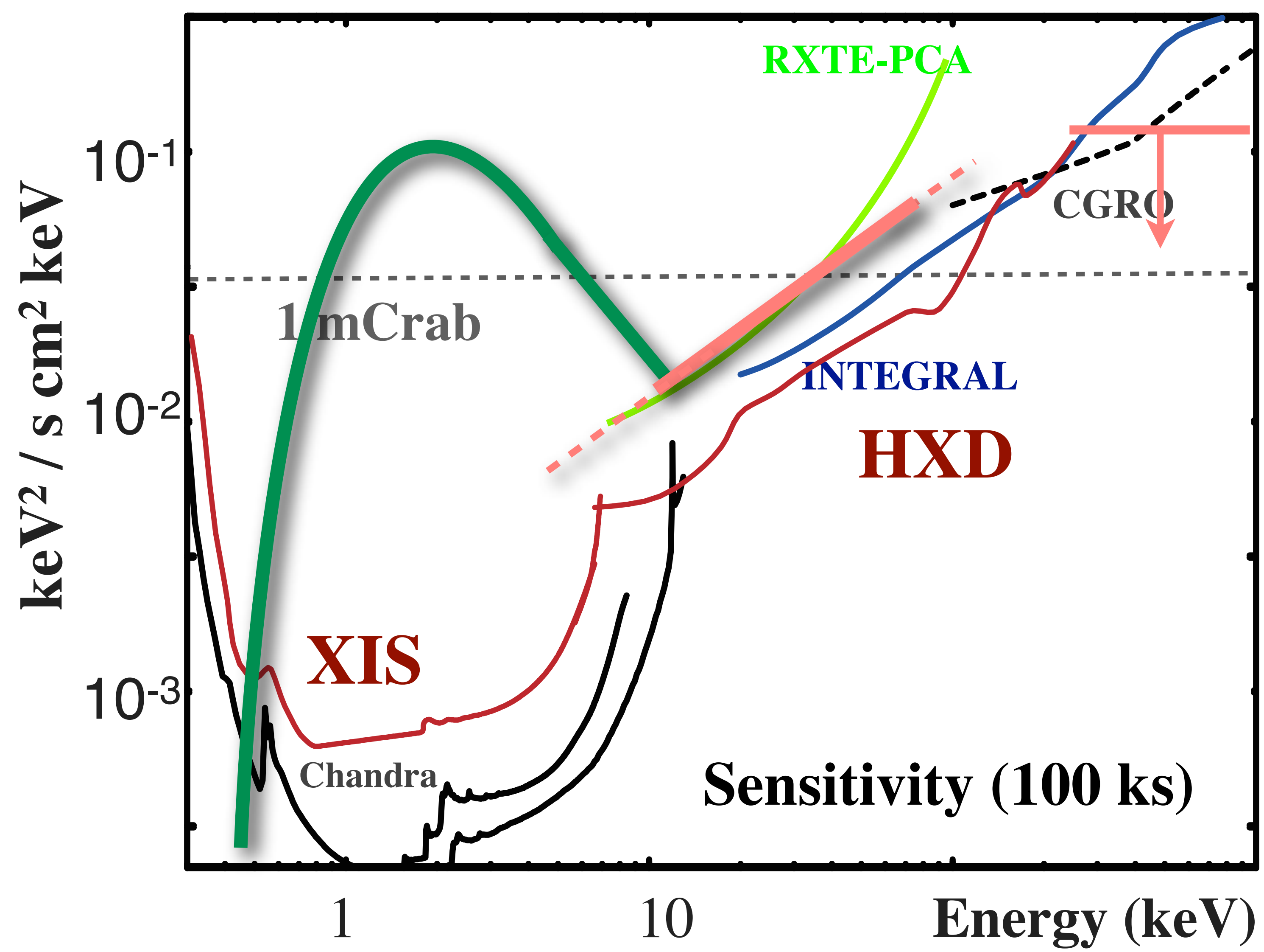
Understanding of short bursts

Suzaku Observatory



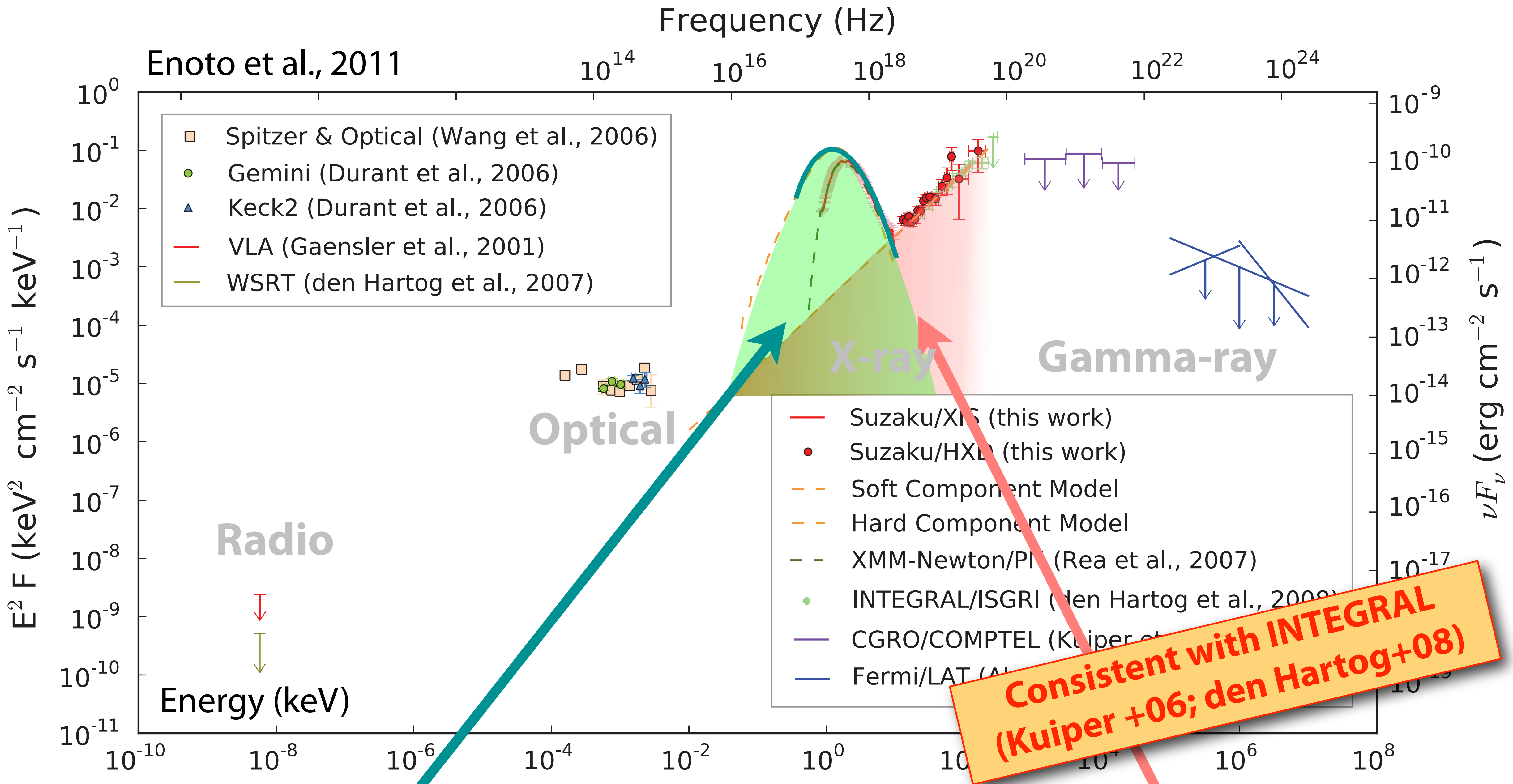
- Launched on 2005 July 10 [Mitsuda+07]
- Low background
- Wide energy band (0.2-600 keV)
- Suitable for low flux objects in hard X-rays





Both comp. can be observed simultaneously.

Persistent Emission: Typical AXP 4U 0142+61



Soft Component (0.2-10 keV)

- ~Blackbody (~0.3 keV)
- $L_{x(2\text{-}10\ \mathrm{keV})} = 10^{35}$ erg/s > $L_{sd} = 10^{32}$ erg/s
- NS Surface Emission

Hard Component (>~10 keV)

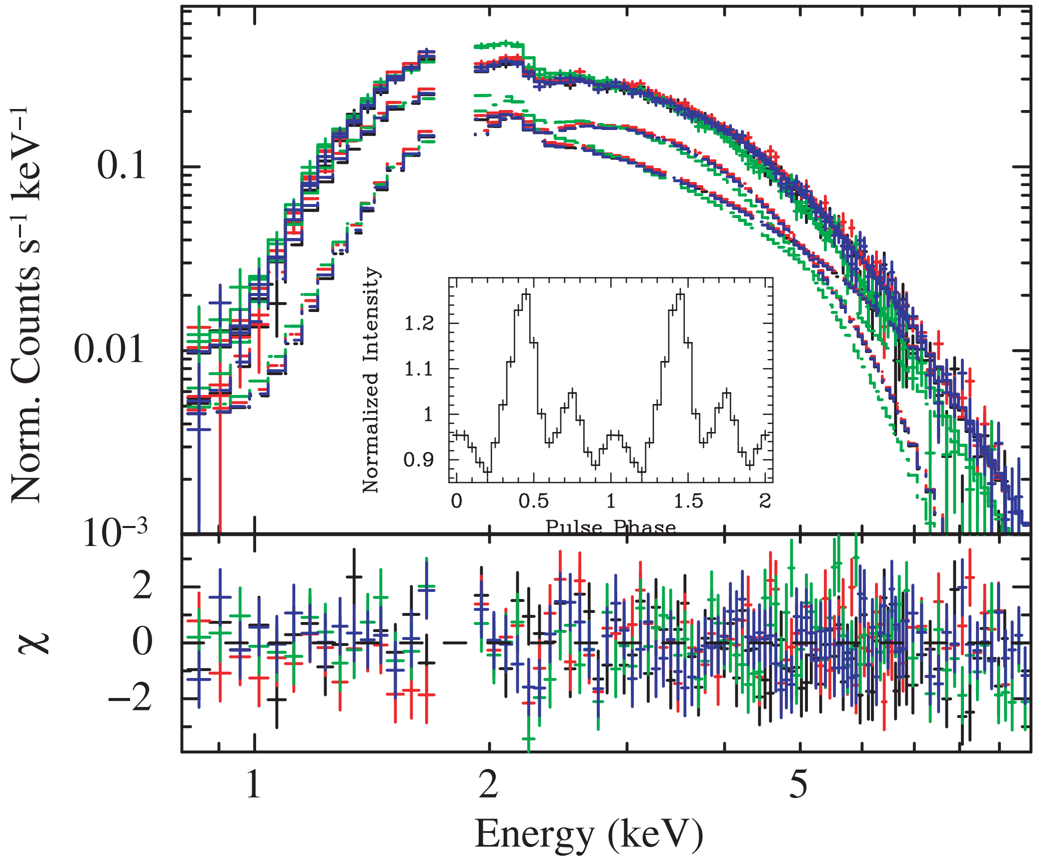
- PL (Γ~1) & Cutoff < 1 MeV (see also den Hartog+2008)
- $L_{x(10\text{-}70\ \mathrm{keV})} = 7\times10^{35}$ erg/s
- **Origin is unknown**

Early Results by Suzaku

CXOU J164710.2-455216

Naik et al., PASJ, 2008

ToO on 2006 September 23-24



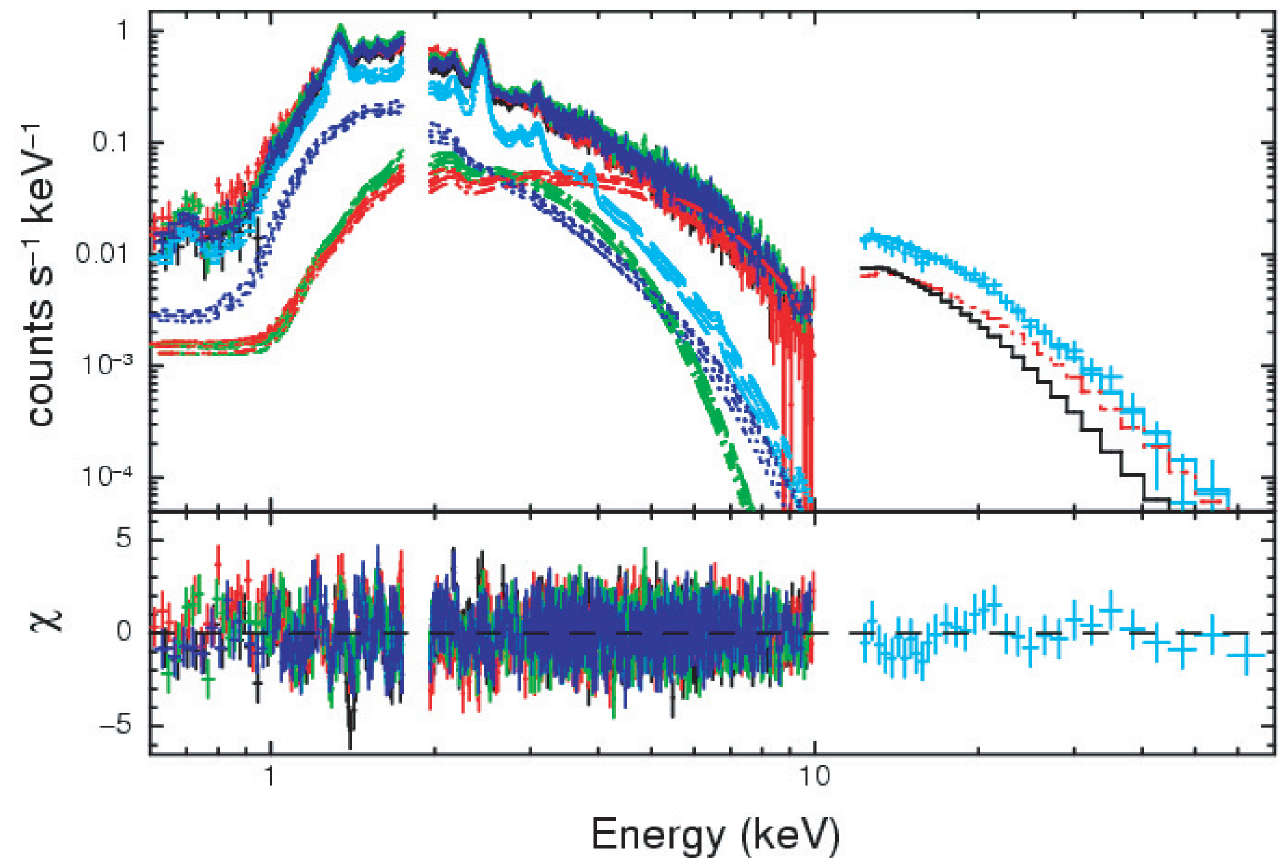
Three pulse peak profile of Soft Comp.

Hard comp. can not be studied due to contamination

AXP 1E 1841-045 (Kes 73)

Morii et al., PASJ, 2010

First broadband observation



Confirmed the hard comp. above 10 keV

BB (kT~0.5 keV)+PL(Γ~5.0)+PL(Γ~1.6)

SGR 1806-20 & SGR 1900+14

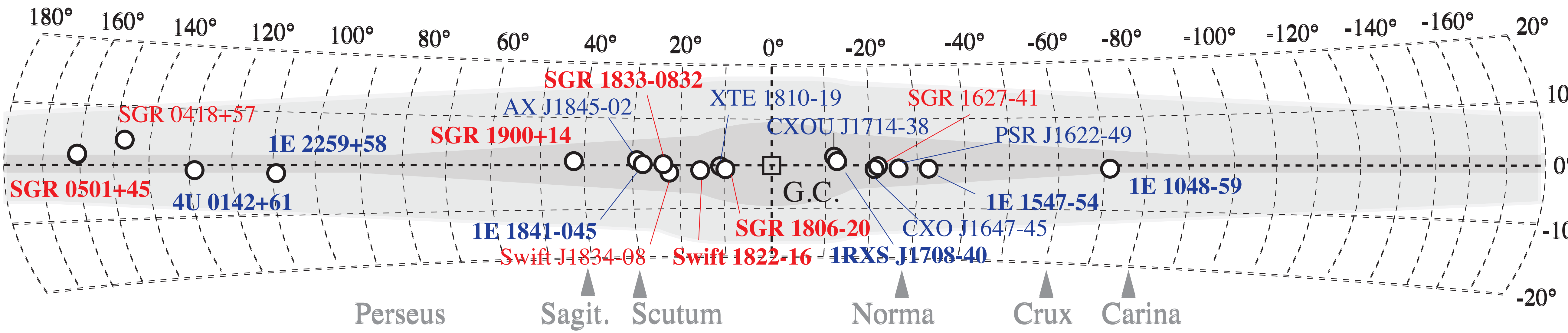
Nakagawa et al., PASJ, 2009

Hard X-rays were detected from SGR 1806-20

Also, some successful ToO observations
SGR 0501+4516 & 1E 1547.0-5408

⇒ **Magnetar Key Project**

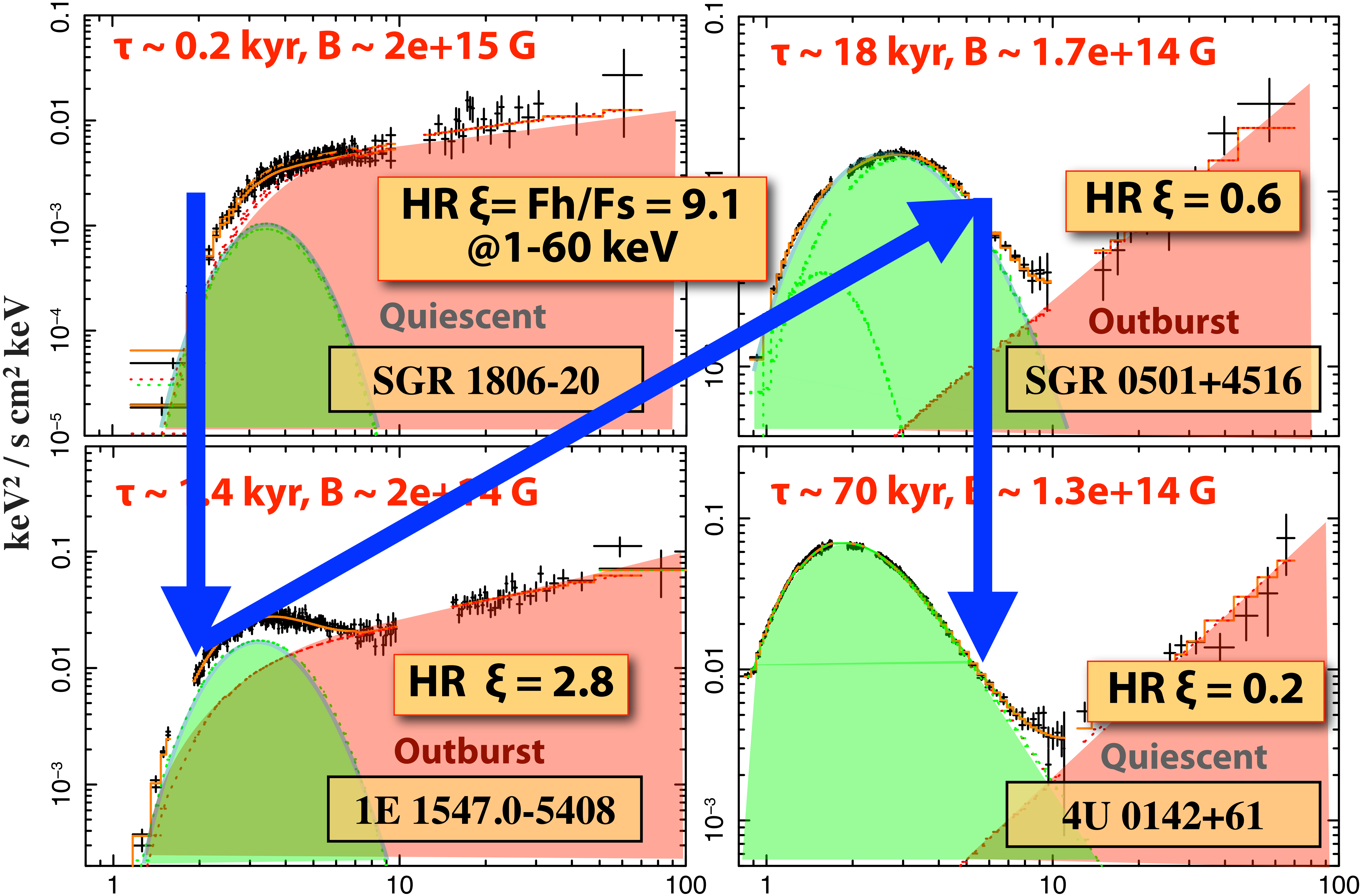
Suzaku Observations of Magnetars



1	SGR 1806-20	SGR	Esposito et al., A&A (2007) Nakagawa et al., PASJ (2009)
2	SGR 1900+14	SGR	
3	1E 1841-045	AXP	Morii et al., PASJ (2011)
4	CXO J1647-45	AXP: ToO in 2006	Naik et al., PASJ (2008)
5	1E 2259+586	AXP	Nakano et al., in prep
6	4U 0142+61	AXP	Enoto et al., PASJ (2011) Makishima et al., in prep
7	1RXS J1708-40	AXP	
8	SGR 0501+4516	Newly SGR (ToO in 2008)	Enoto et al., ApJL (2009) & ApJ (2010) Nakagawa et al., PASJ (2011)
9	1E 1547.0-5408	AXP (ToO in 2009)	Enoto et al., PASJ (2010) Yasuda in prep, Enoto submitted.
10	SGR 1833-0832	SGR (ToO in 2010)	Nishioka et al., in prep

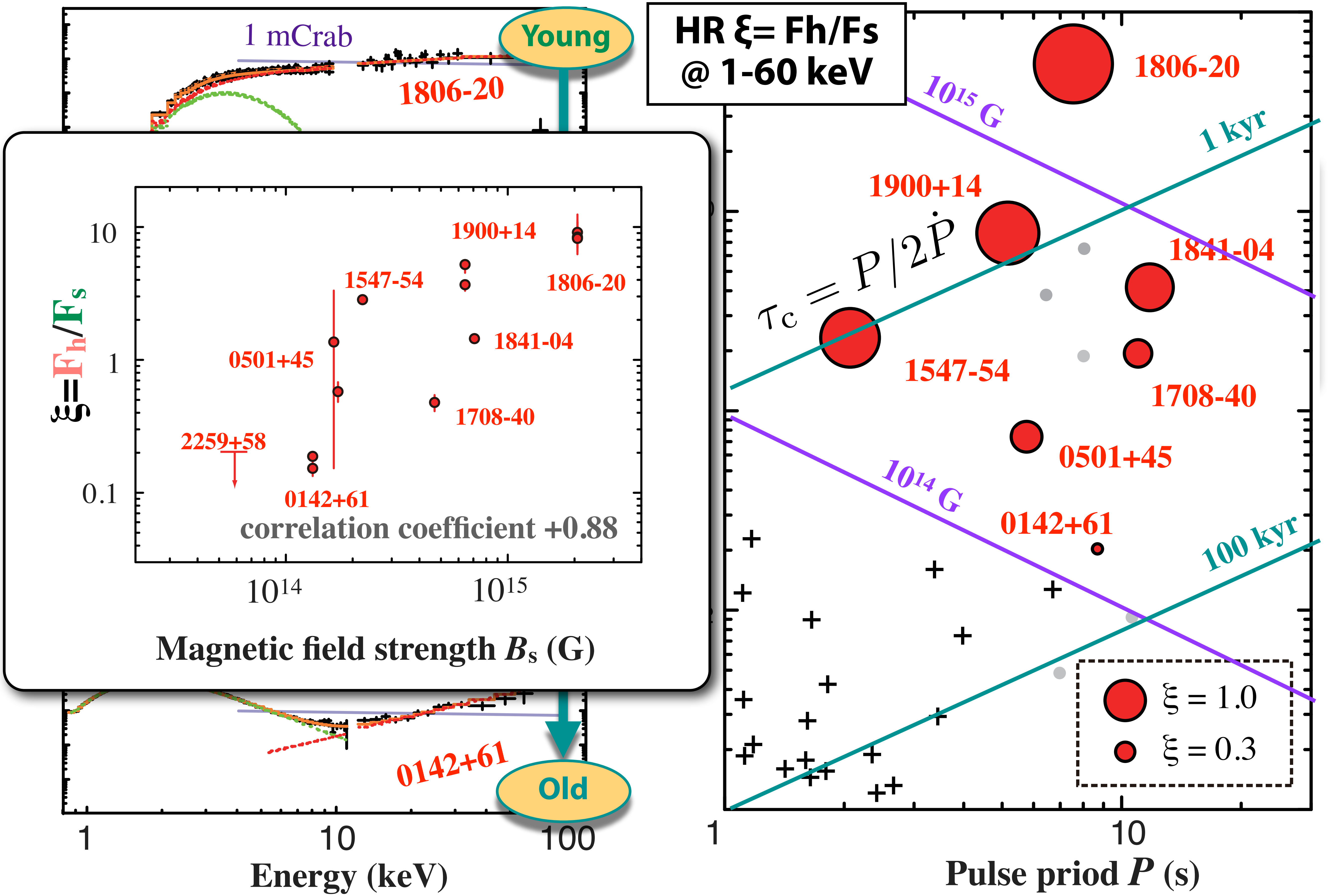
- Enoto et al., ApJL(2012) Comprehensive Analyses
- Takata et al., PASJ (submitted) Theoretical Approach

Examples of Suzaku Magnetar Spectra



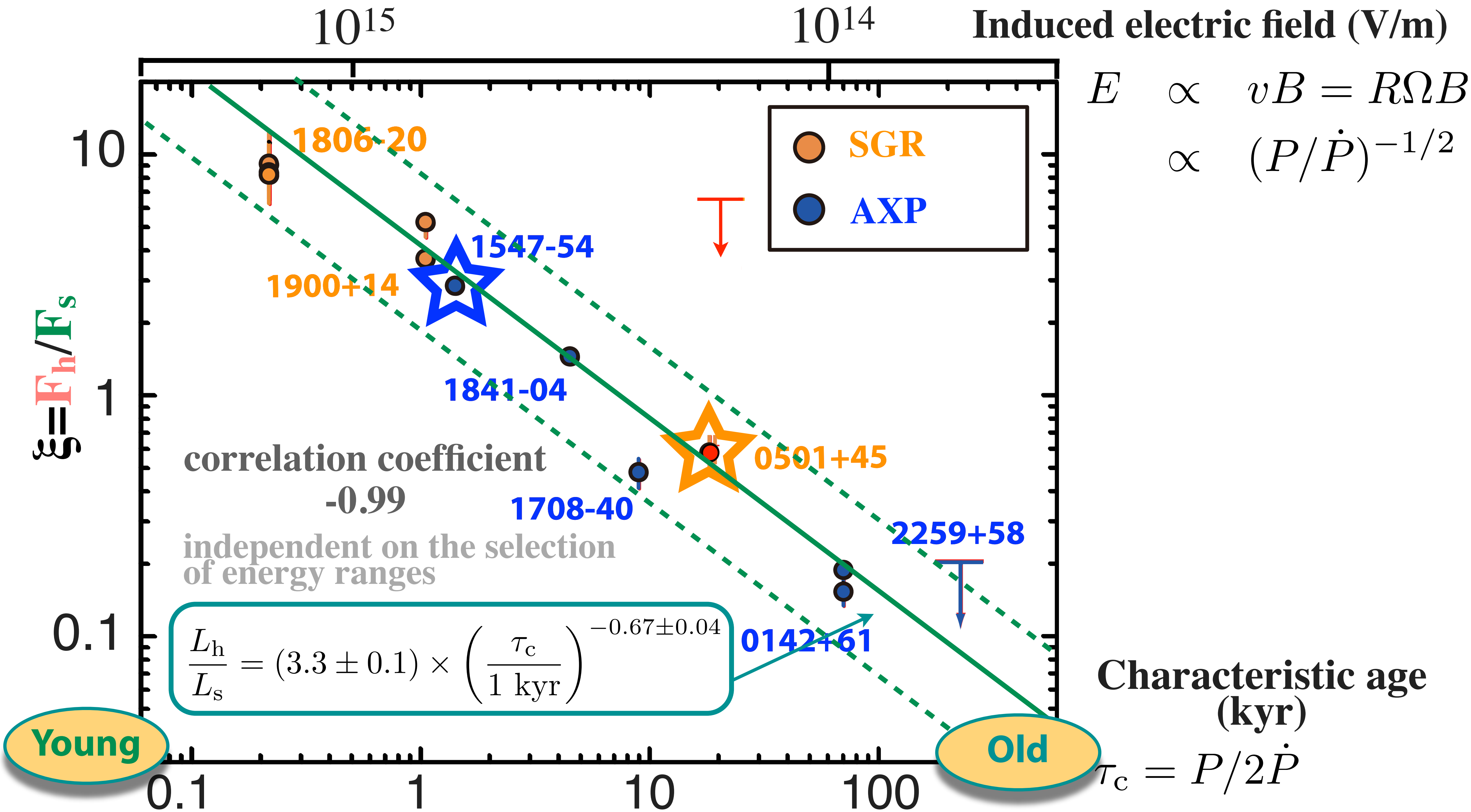
Enoto et al., ApJL (2010)

Wide-band spectra and P-Pdot diagram



Enoto et al., ApJL (2010)

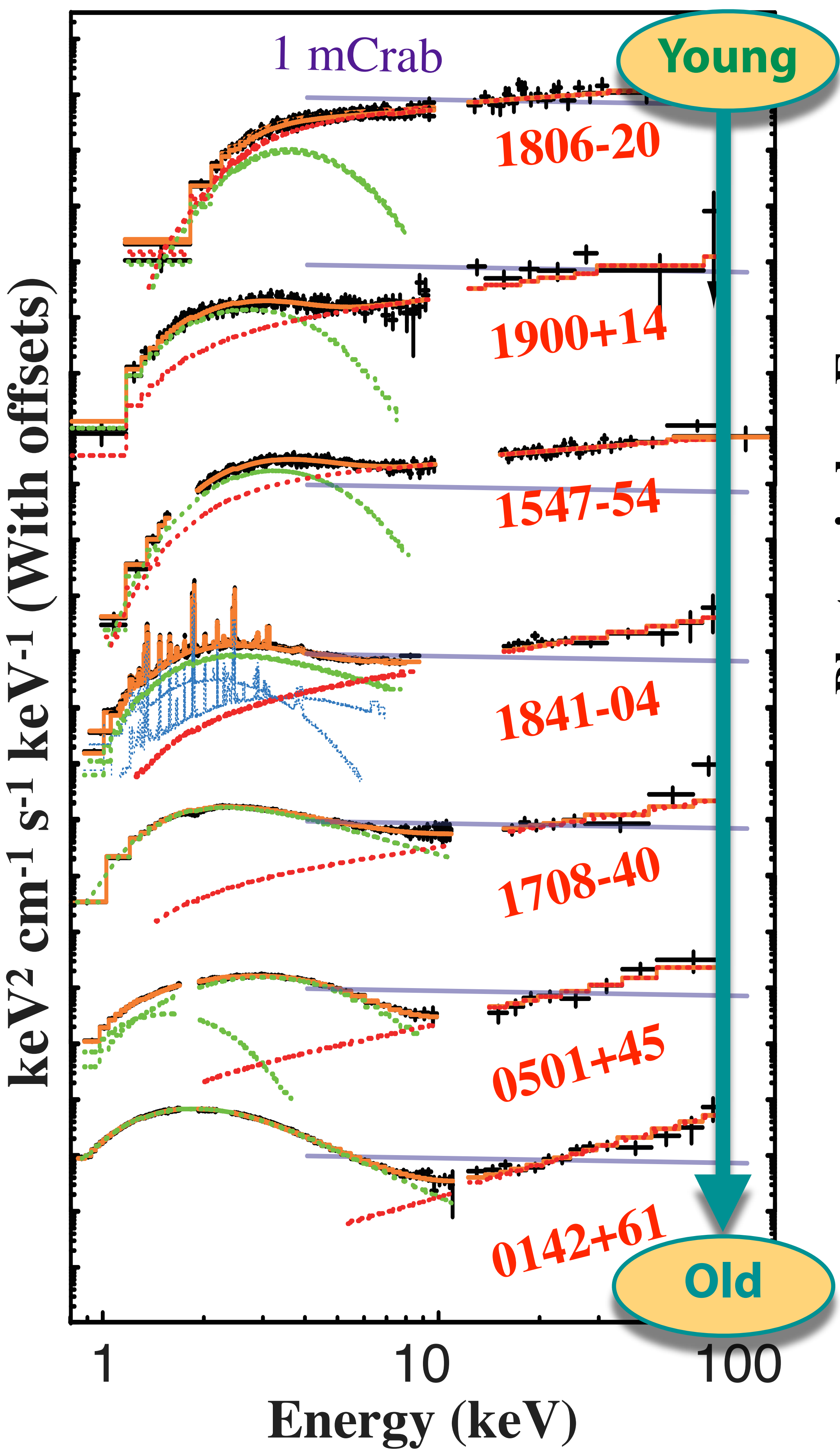
Hardness Ratio $\xi = F_h/F_s$ vs. τ_c

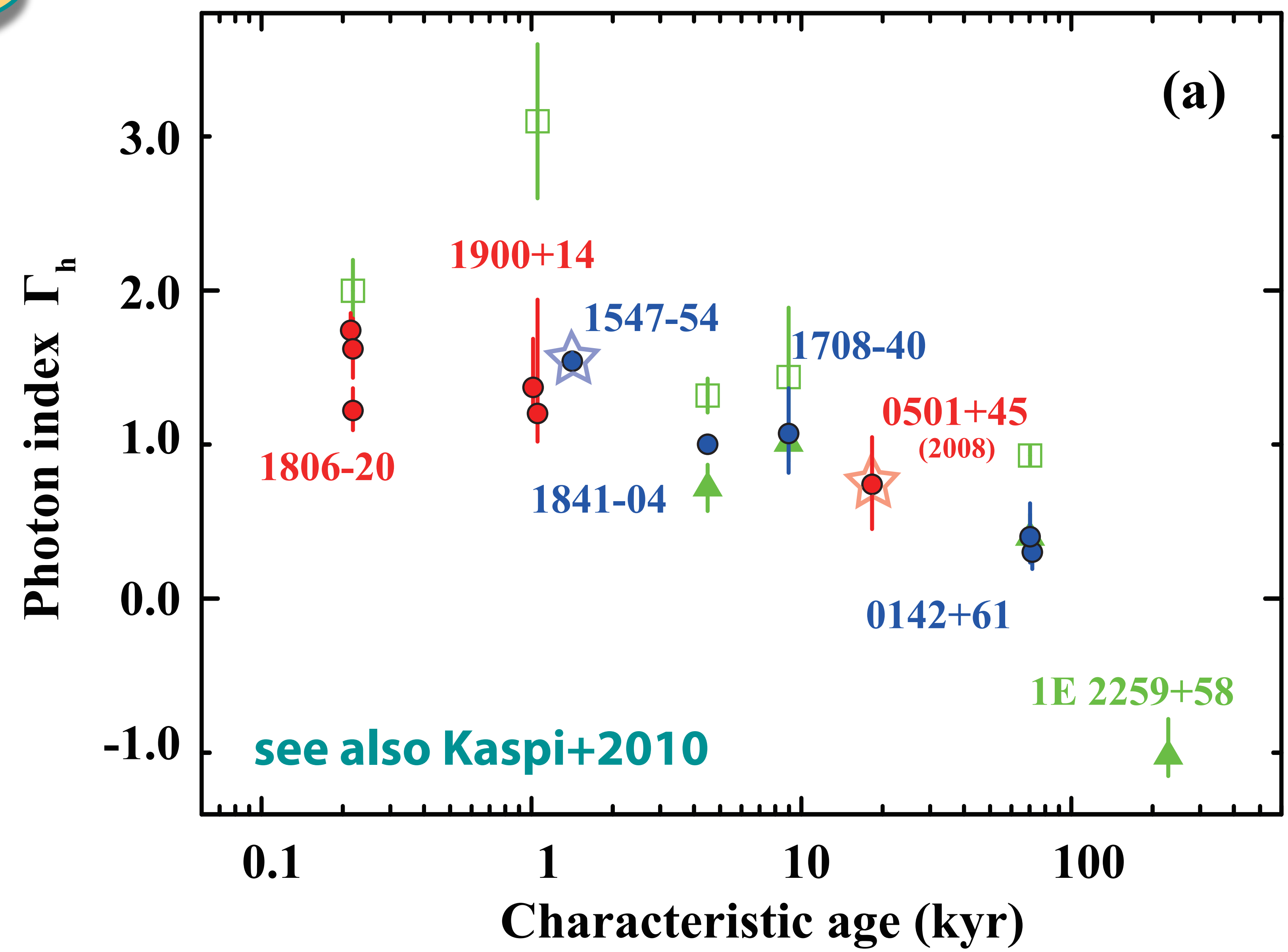


- Hardness ratio F_h/F_s is negatively correlated with the characteristic age τ_c.
- SGR & AXP are intrinsically the same kinds of object.
- Burst-active and quiescent states follow the same correlation ⇒ common mechanism.
- Interpreted as the relation to an induced electric field of the rotating magnetic field.

Enoto et al., ApJL (2010)

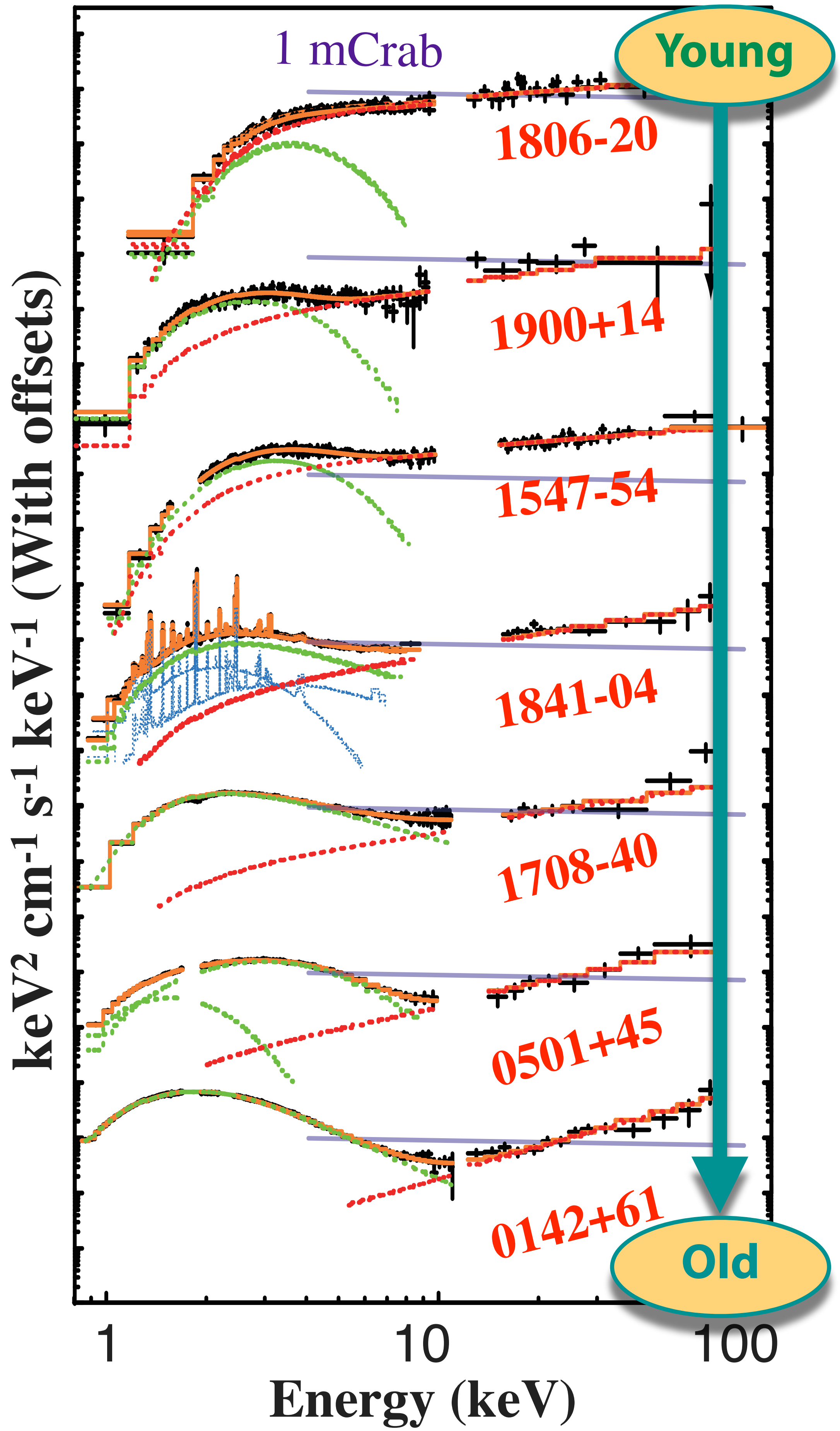
Hardening of the Hard Component

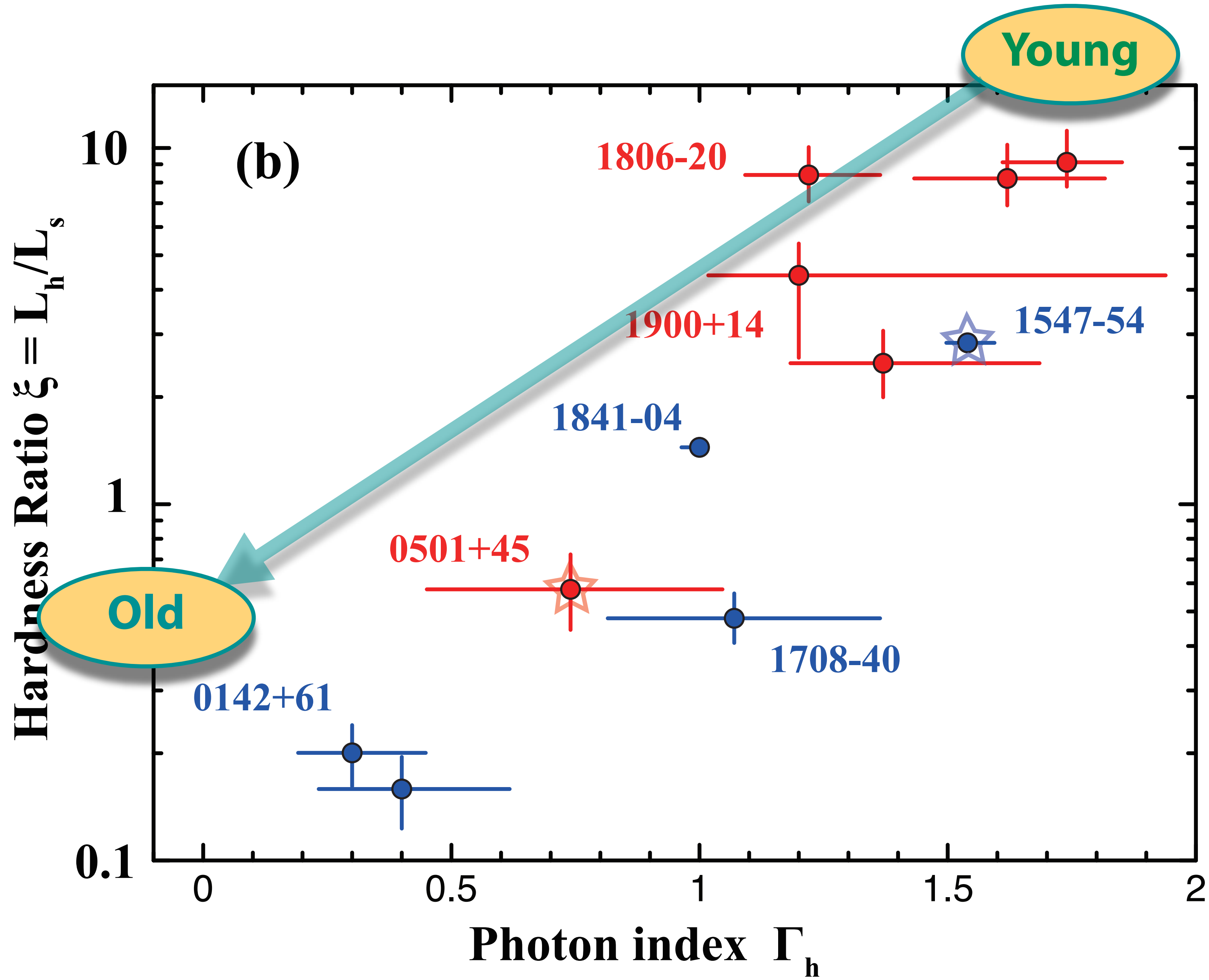




Enoto et al., ApJL (2010)

Hardening of the Hard Component





Toward the older magnetars,
Hard component becomes
- **harder**
- **weaker relative to the soft component**

Enoto et al., ApJL (2010)

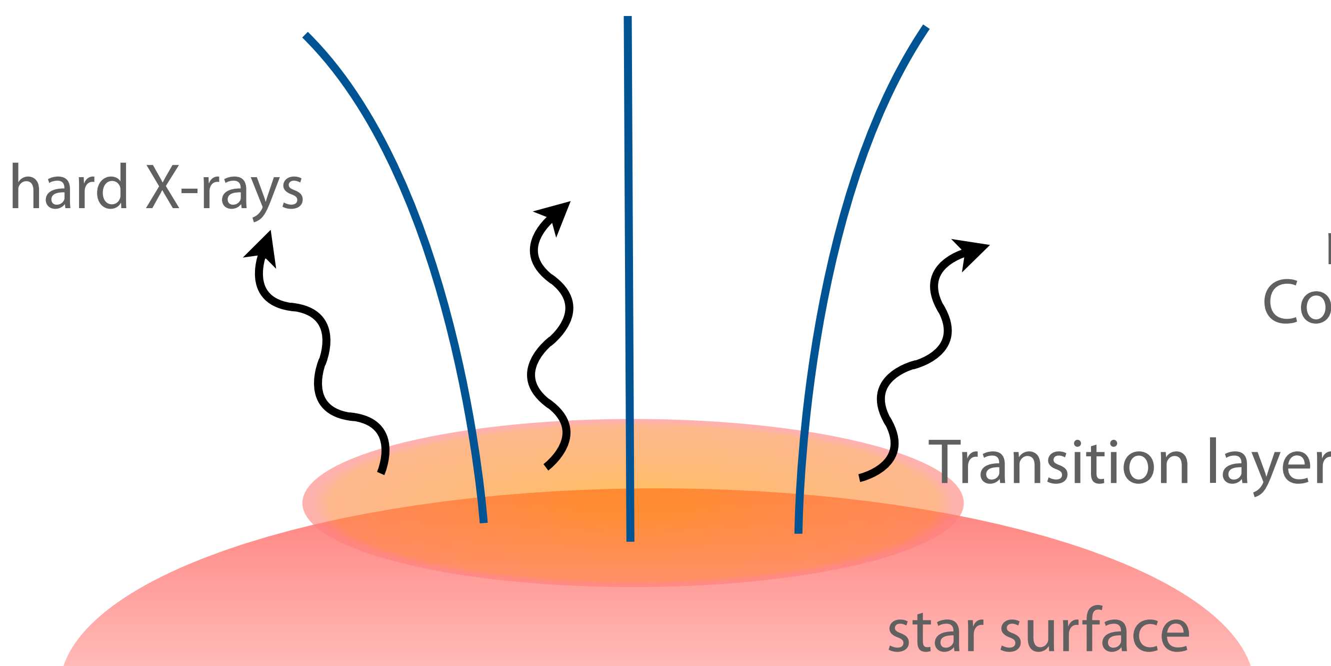
Emission Mechanism

a. Extremely flat Γ_h becomes harder toward sources with old τ_c.

b. $\xi = F_h/F_s$ is negatively/positively correlated with τ_c/B.

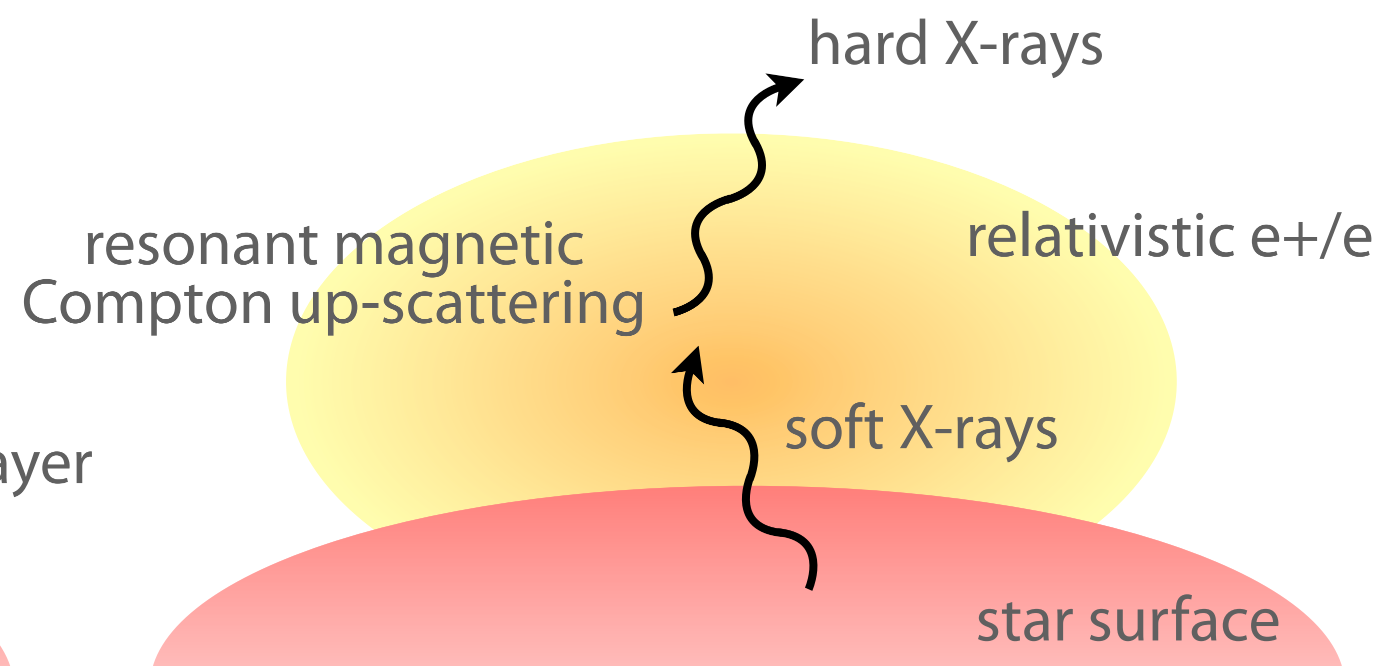
Thermal Bremsstrahlung ?

(Thompson & Beloborodov 2005)



Resonant Compton up-scattering?

(Baring & Harding 2007)



And also other models;

Heyl & Hernquist 2007

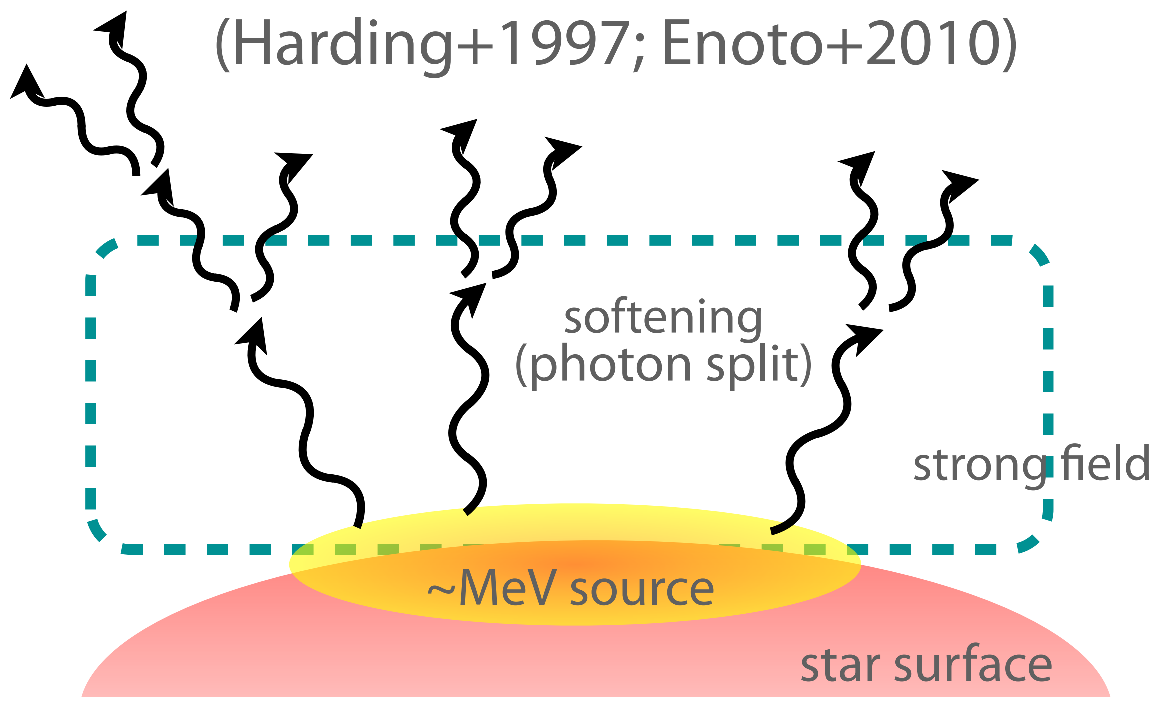
Trumper+2010

Kuiper+2006

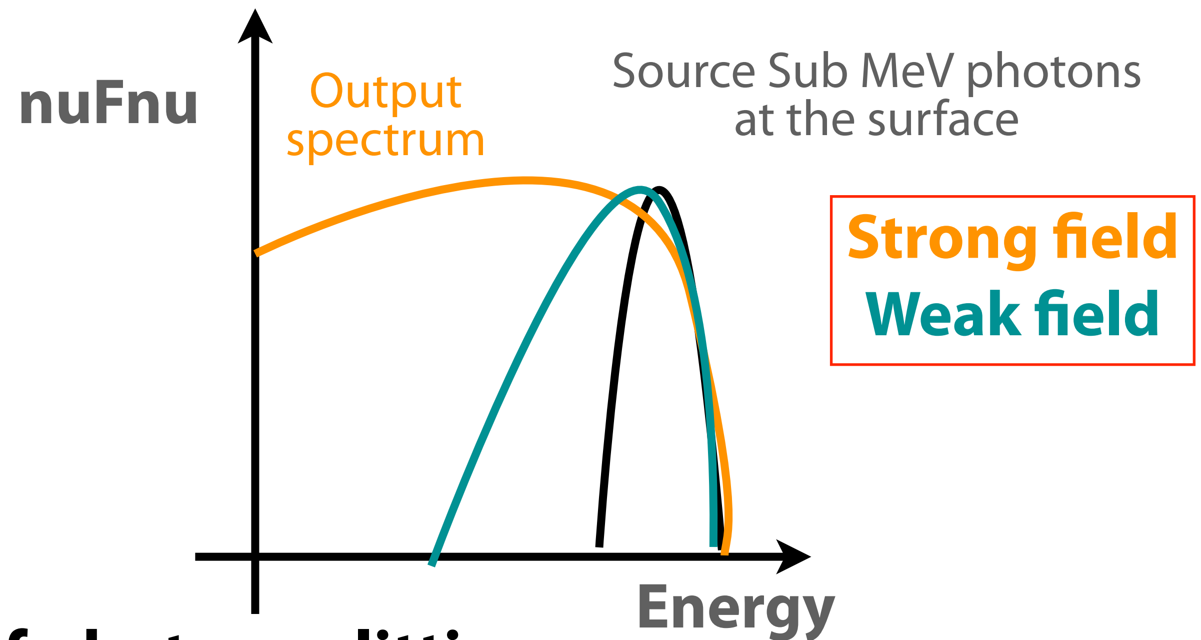
Down Cascade via “Photon Splittings”

Photon Splitting Effect?

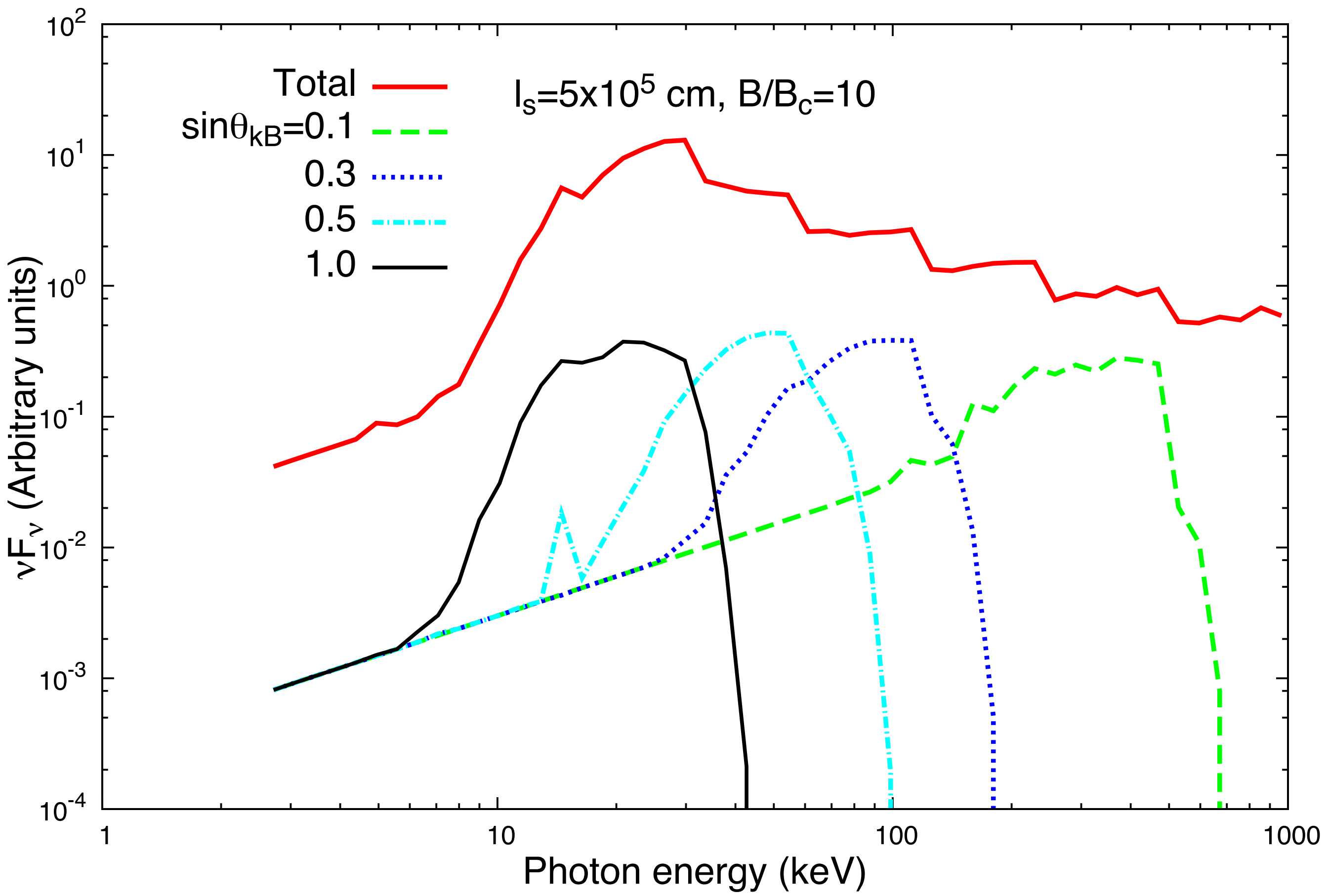
(Harding+1997; Enoto+2010)

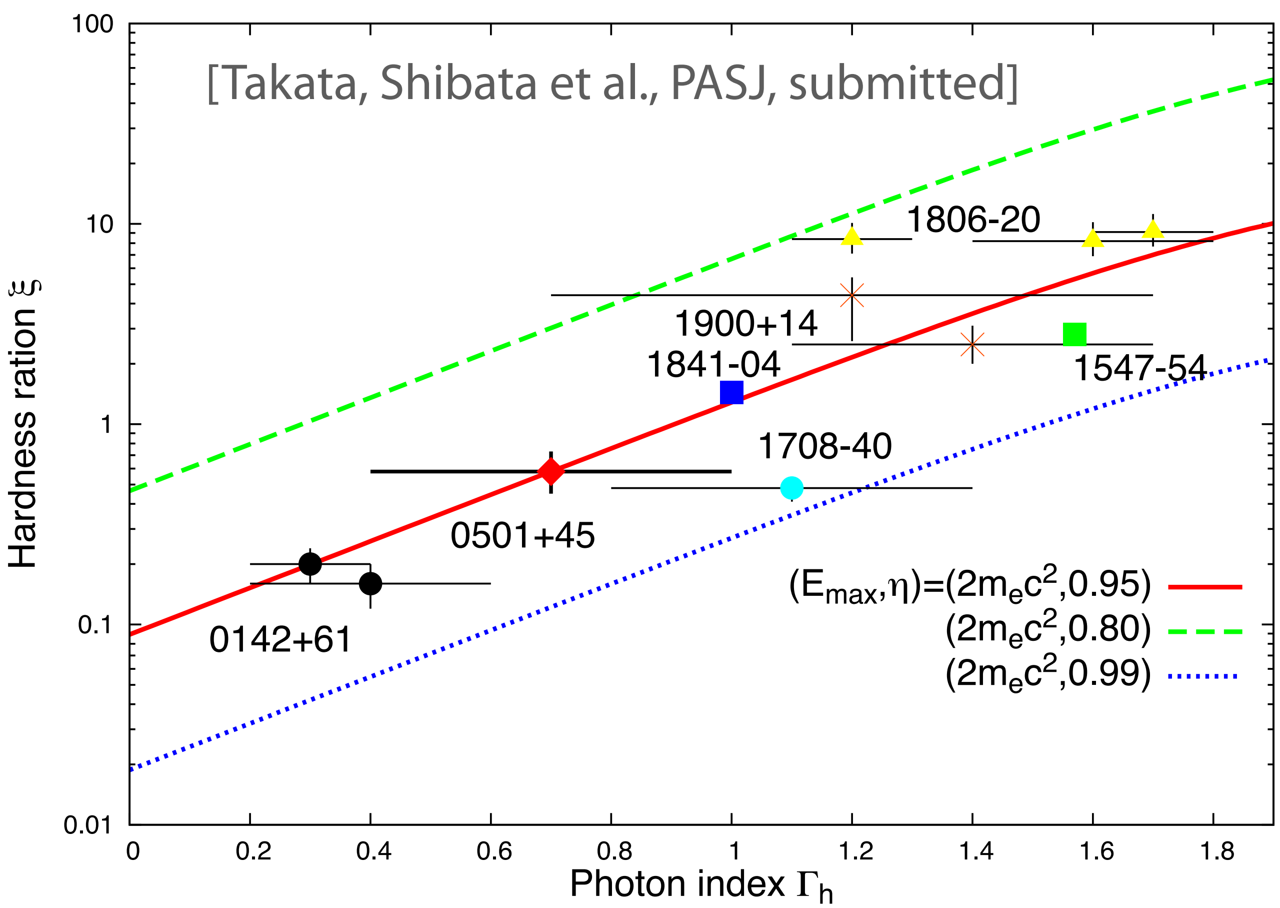


$$\hbar \frac{eB}{m_e c} = m_e c^2 \quad \Rightarrow \mathbf{B = 4.4e+13\ G}$$



Theoretical Simulation of photon splittings



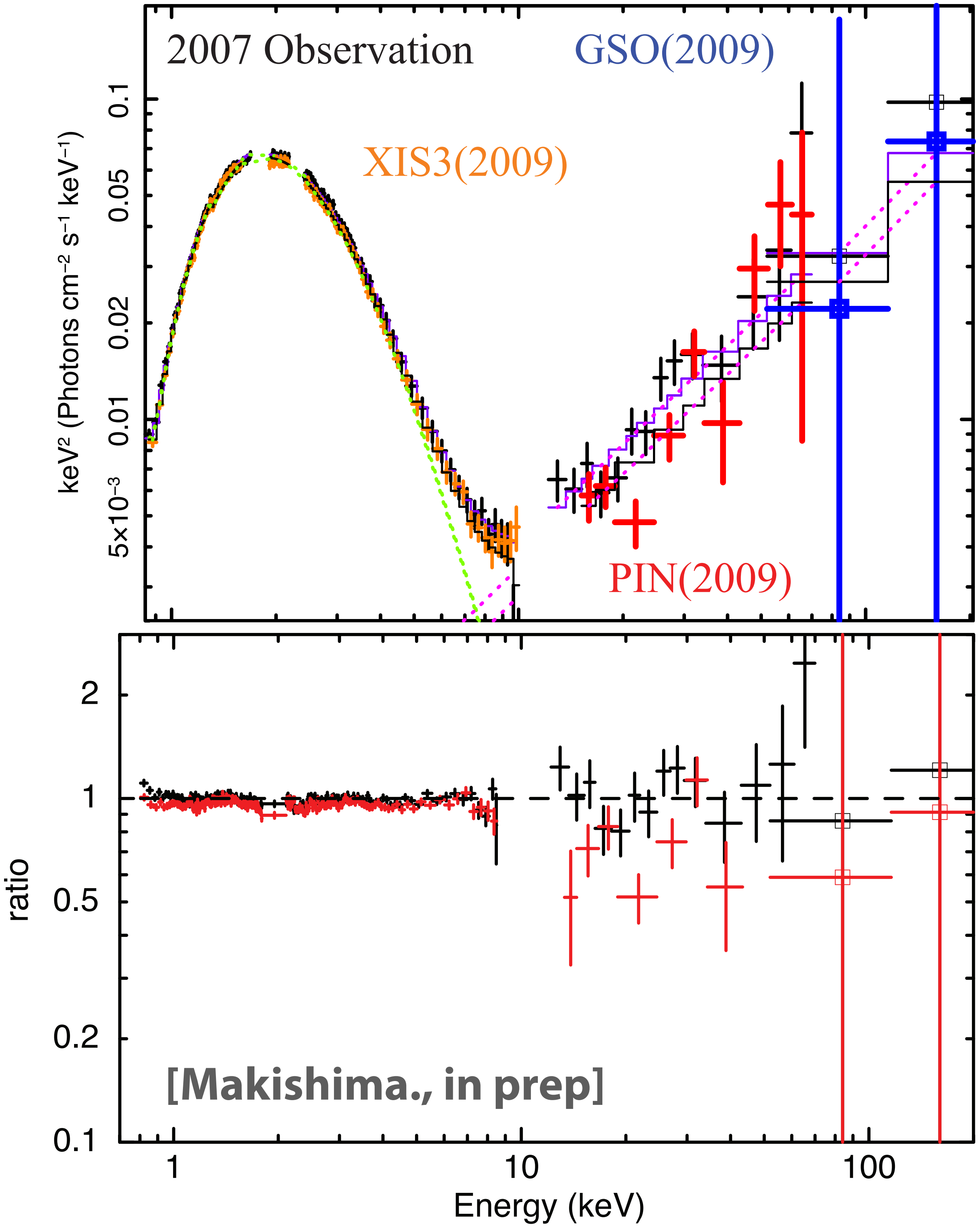


ToO Observations by *Suzaku*

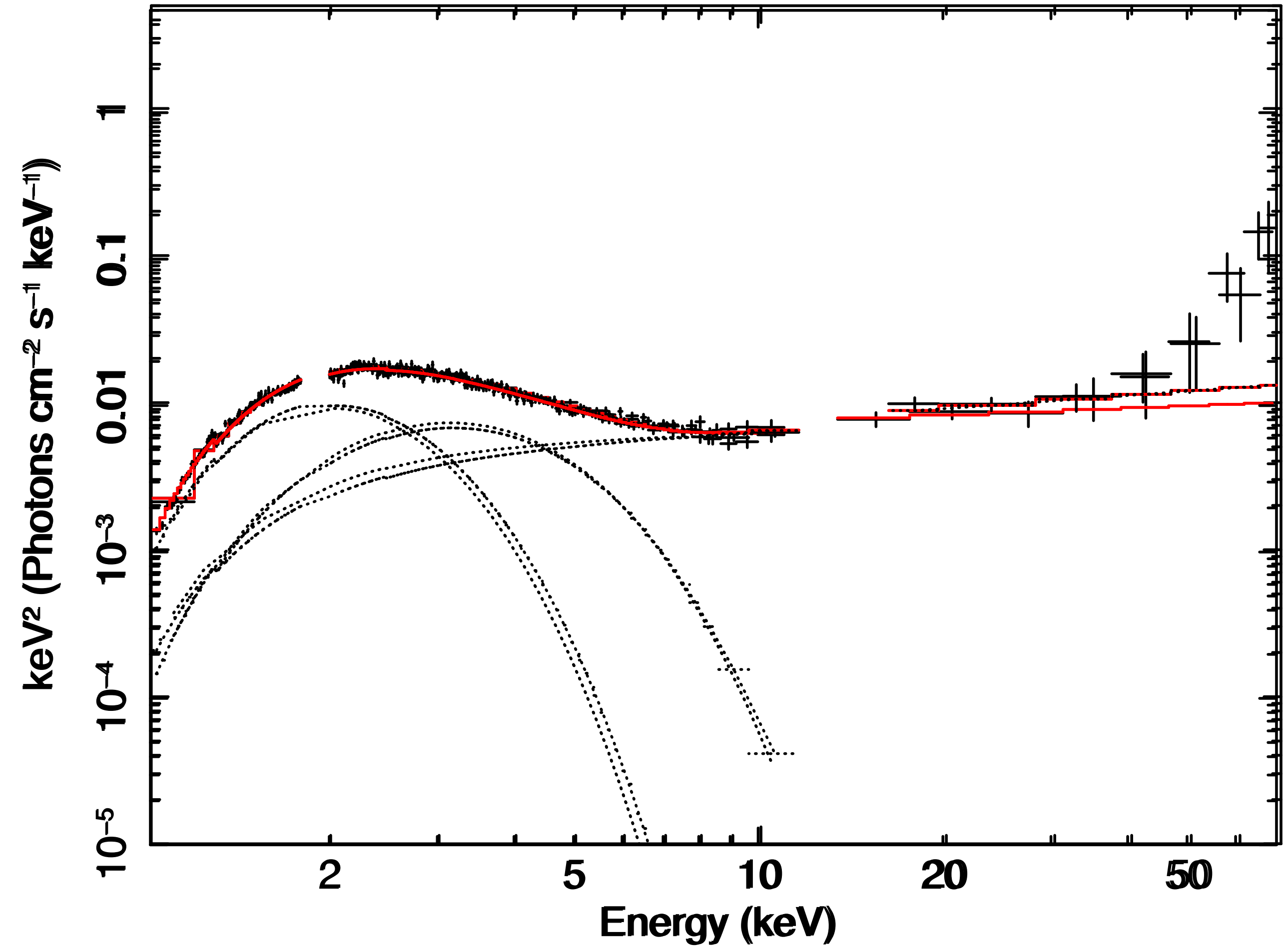
"Current Understanding and Future Study of Magnetars: Research Strategy in the ASTRO-H era"

Persistent Sources

4U 0142+61 (1st & 2nd Observations)



1RXS J1708-40 (1st & 2nd Observations)

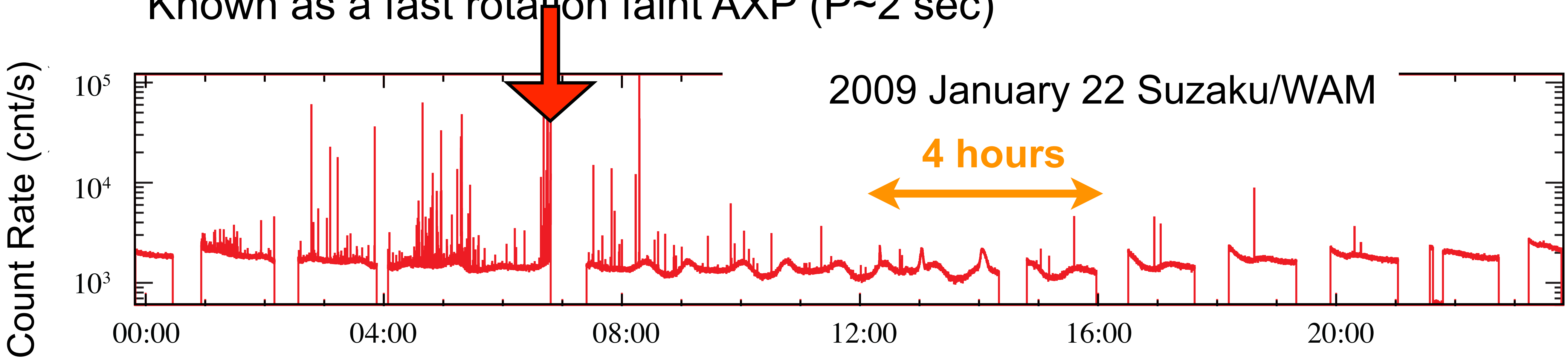


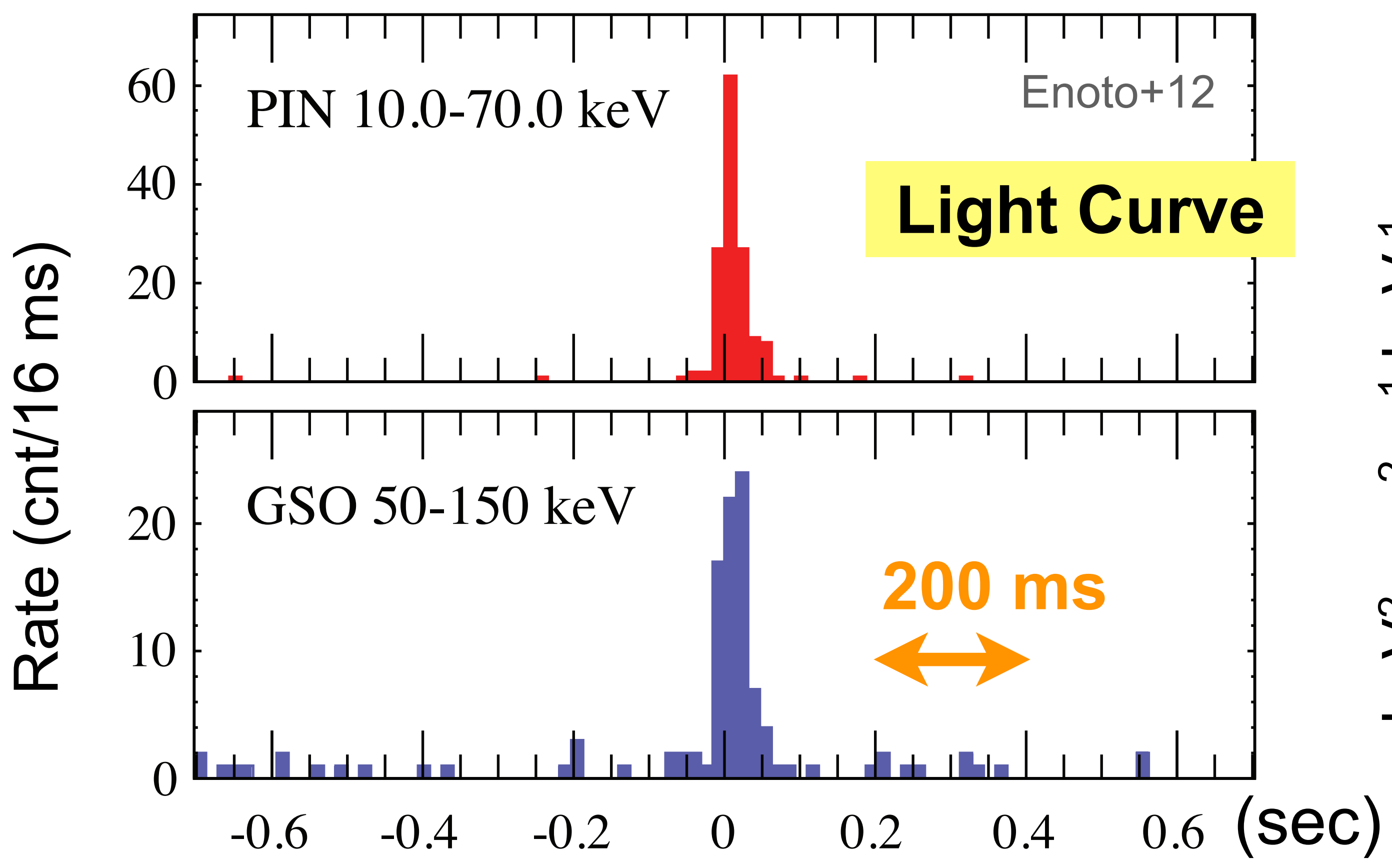
Soft/Hard Spectra of Persistent Source:
Stable within a few years
(see also den Hartog+2008, INTEGRAL)

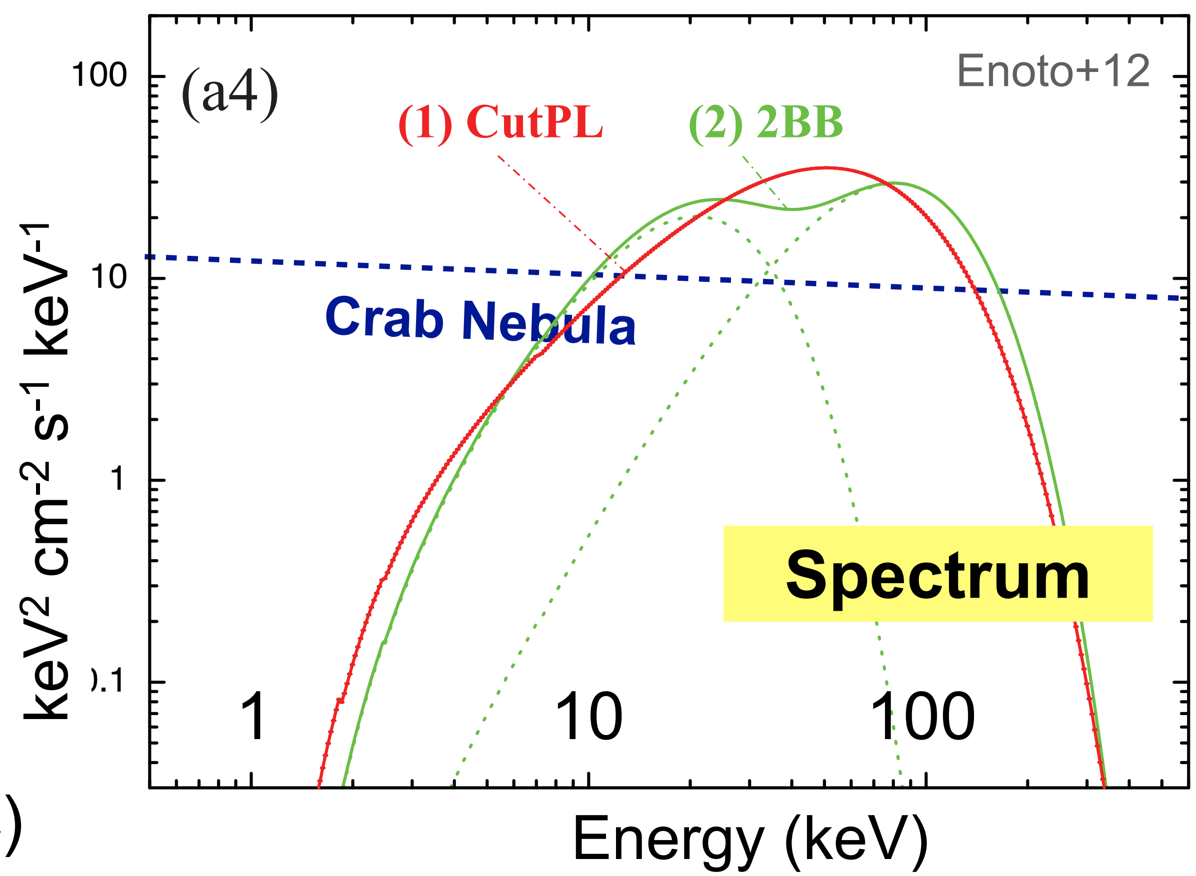
But,
Outburst of Transient Magnetars....

X-ray Outburst of AXP 1E 1547.0-5408 (1)

Known as a fast rotation faint AXP (P~2 sec)



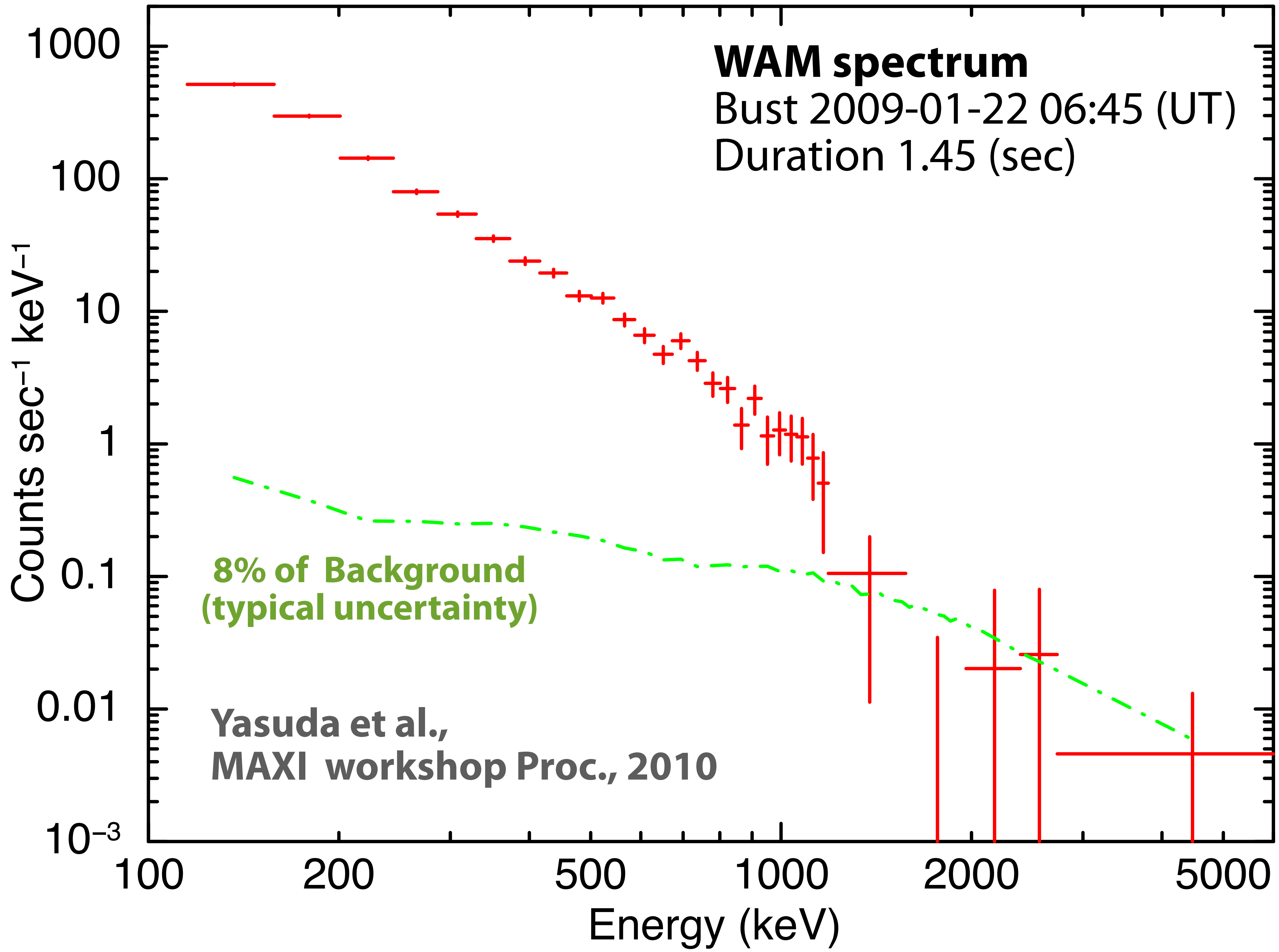




Feature1: Recurrent Bright Short Burst

Duration ~100-500 ms, (Empirically) Two blackbody spectrum (kT ~ 4, 11 keV)

MeV Gamma Detection from Bursts

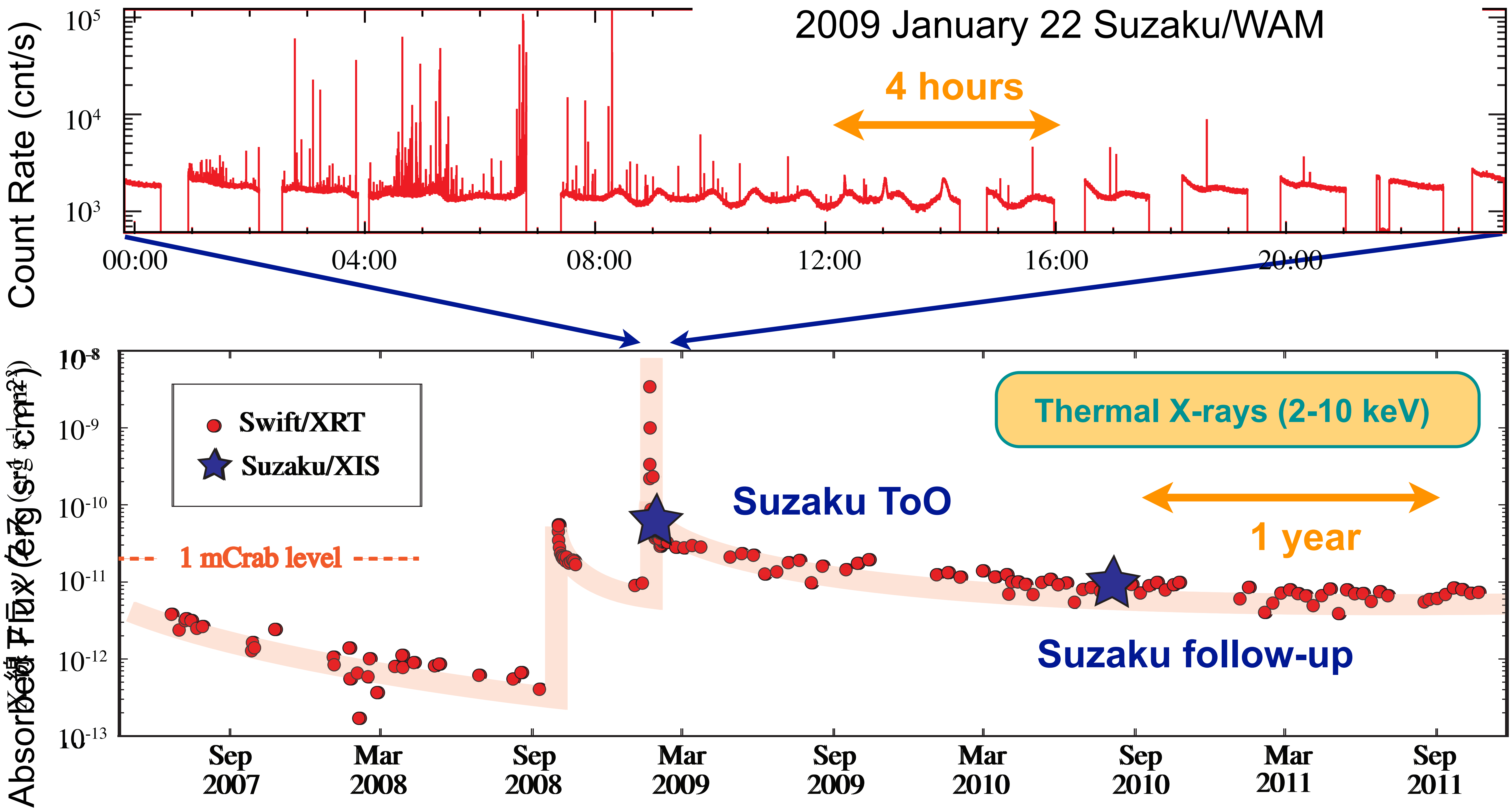


Gamma-ray Detection with 3.2 sigma level at least up to ~1 MeV !

- BB+PL : kT=9.7$_{(+21.6,\ -6.8)}$ keV & Γ=2.1$_{(+0.1,\ -0.2)}$ [Yasuda et al., in prep]
- No break of power-law in 200 keV to 1.2 MeV range

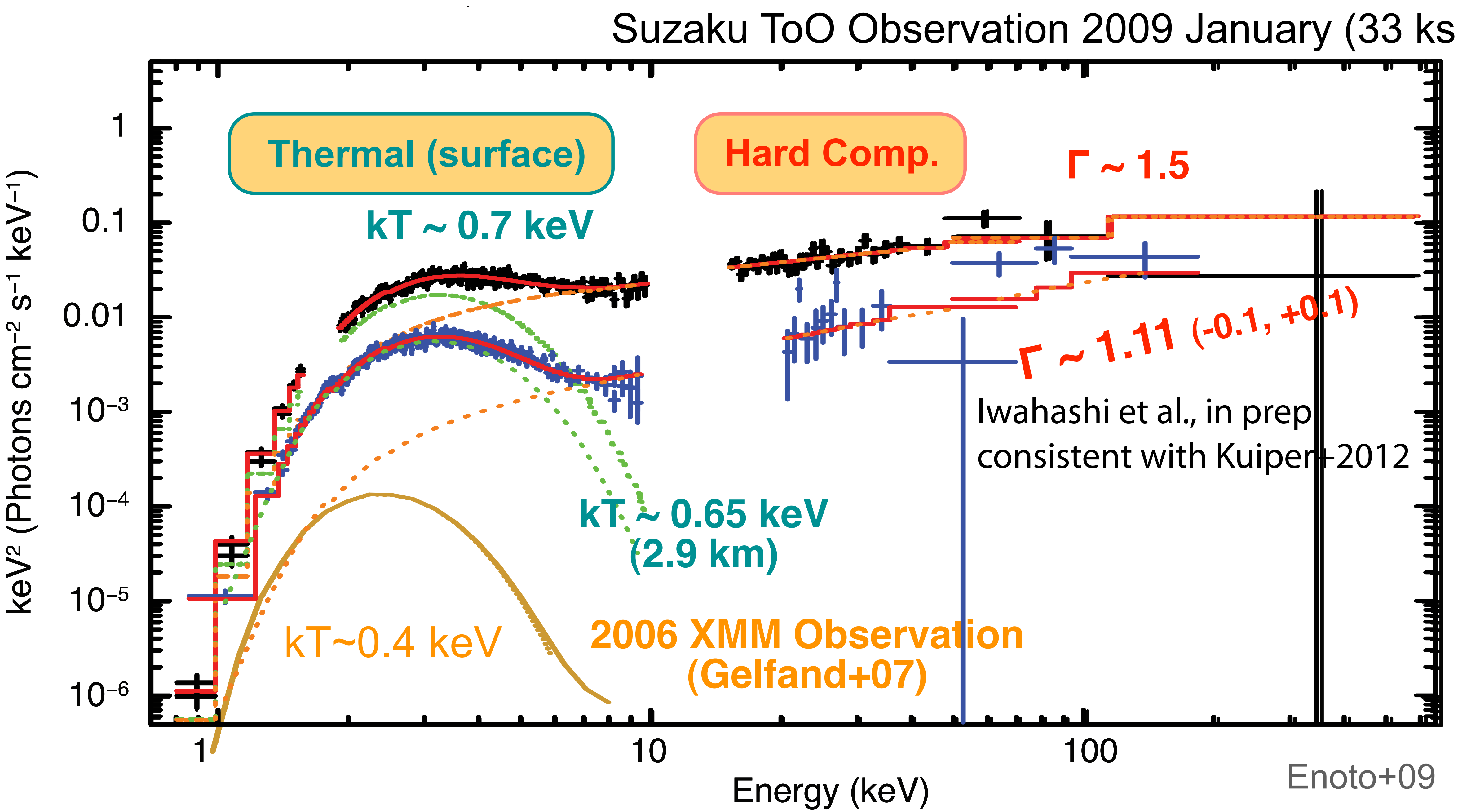
X-ray Outburst of AXP 1E 1547.0-5408 (2)

Known as a fast rotation faint AXP (P~2 sec)



Feature2: **Persistent X-ray becomes brighter by 2-3 orders of magnitude**

X-ray Outburst of AXP 1E 1547.0-5408 (3)

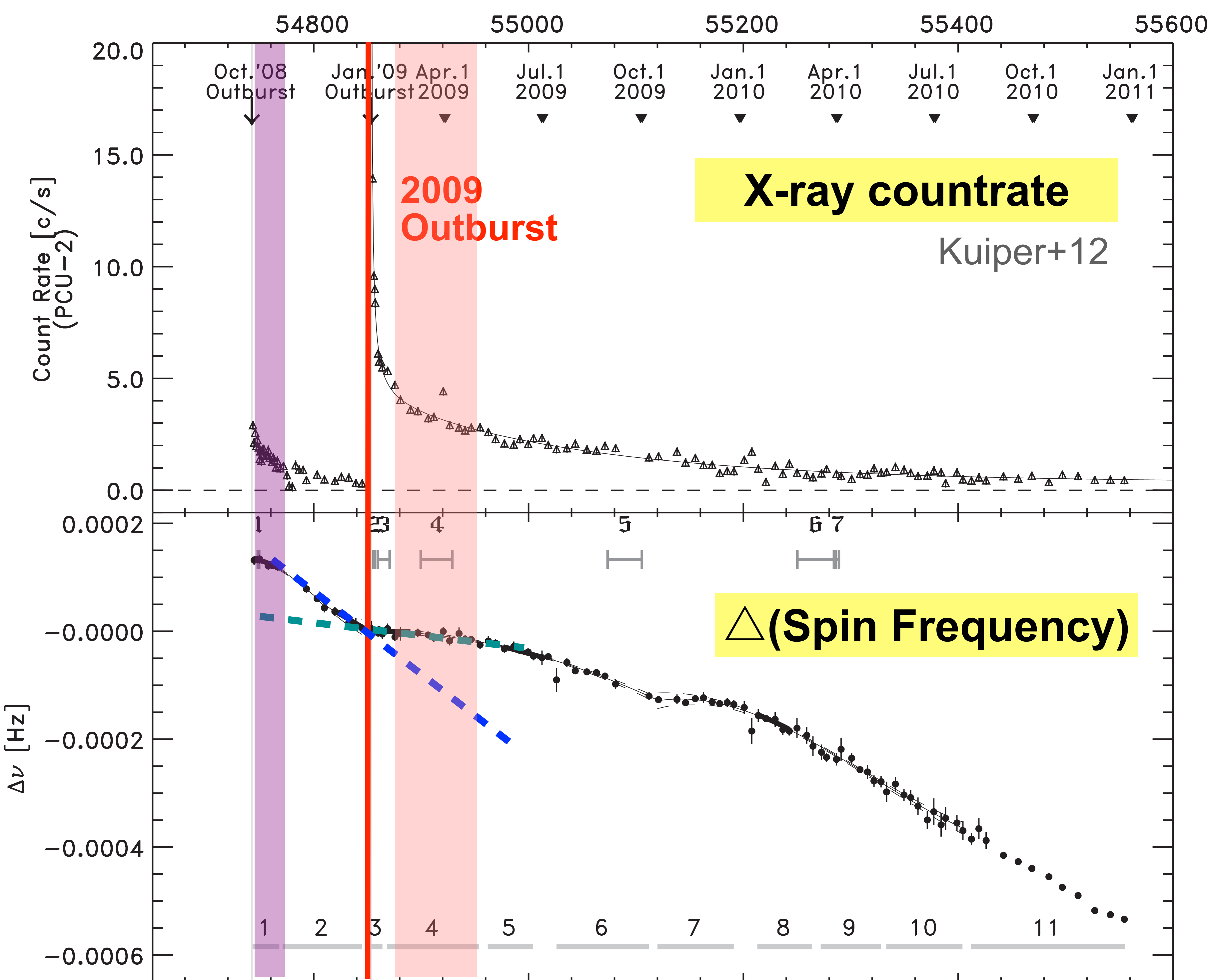


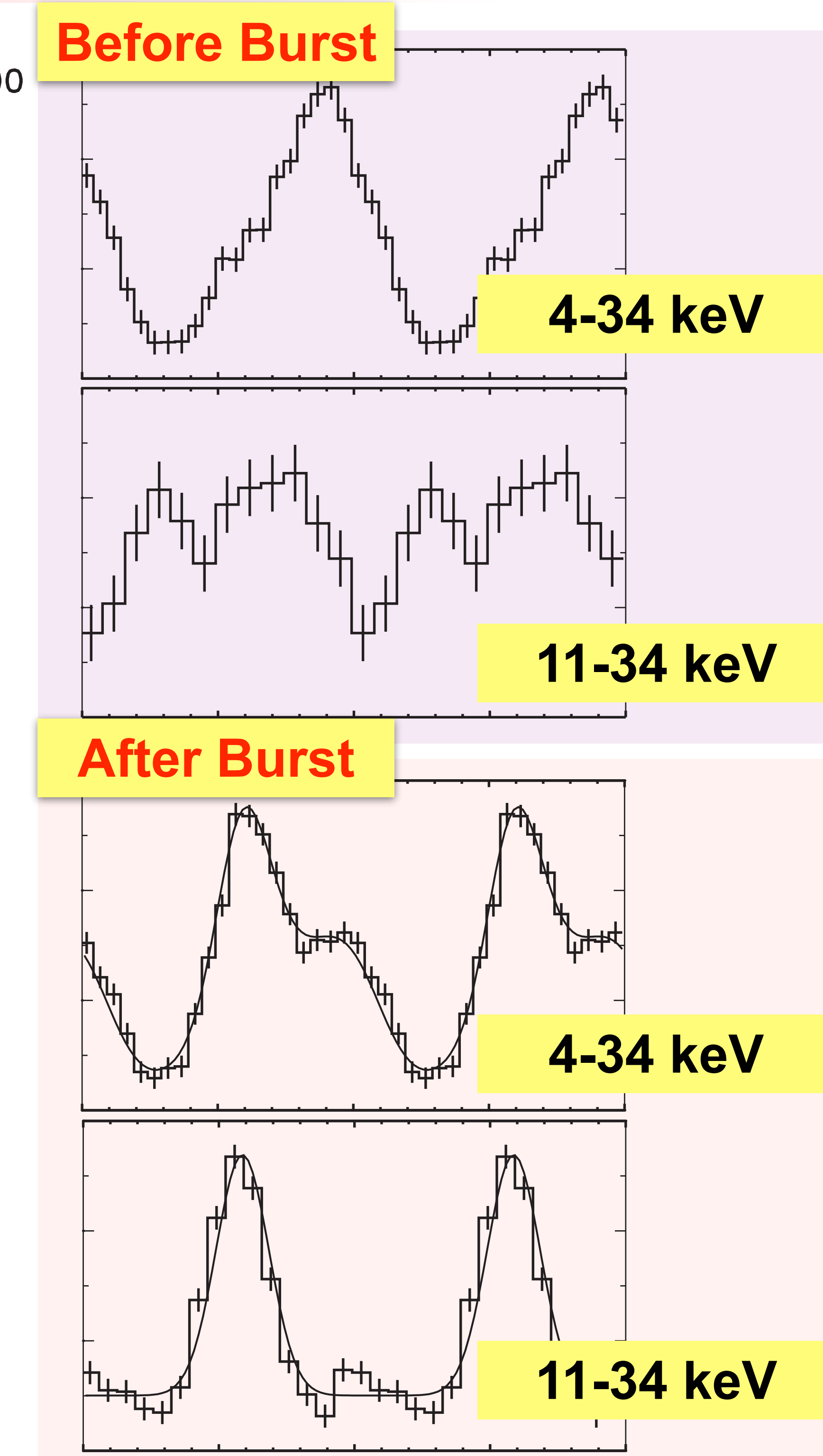
Hard X-rays were clearly detected during the magnetar outburst.
Follow-up observation confirmed the hard component one year after the outburst.

Feature2: Persistent X-ray becomes brighter by 2-3 orders of magnitude

Both components (soft thermal + hard X-rays) become brighter

X-ray Outburst of AXP 1E 1547.0-5408 (4)

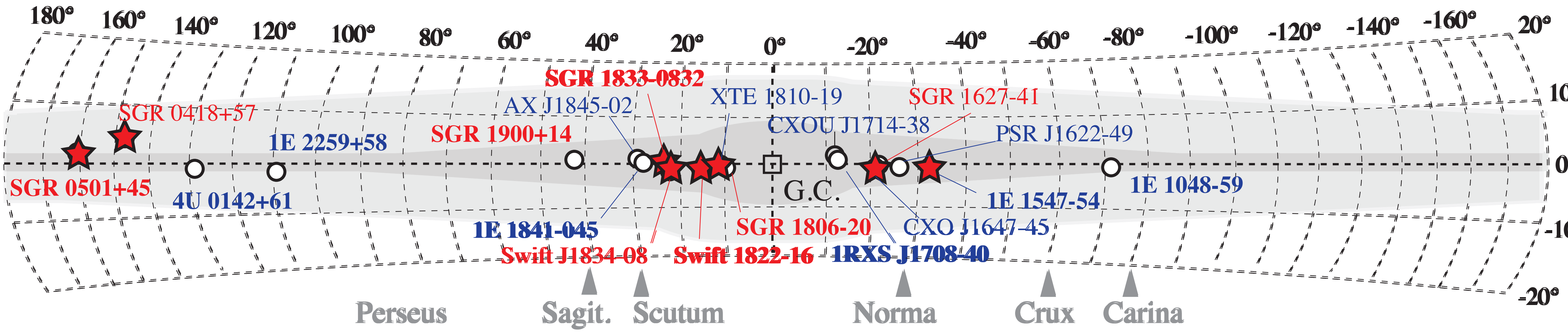




Feature3: A frequency derivative jump at the outburst ($\triangle\dot{\nu}/\nu = -0.69 \pm 0.07$)

Pulse profile change around the onset of the burst ⇒ Hot spot?

A Series of Discovery of New Magnetars



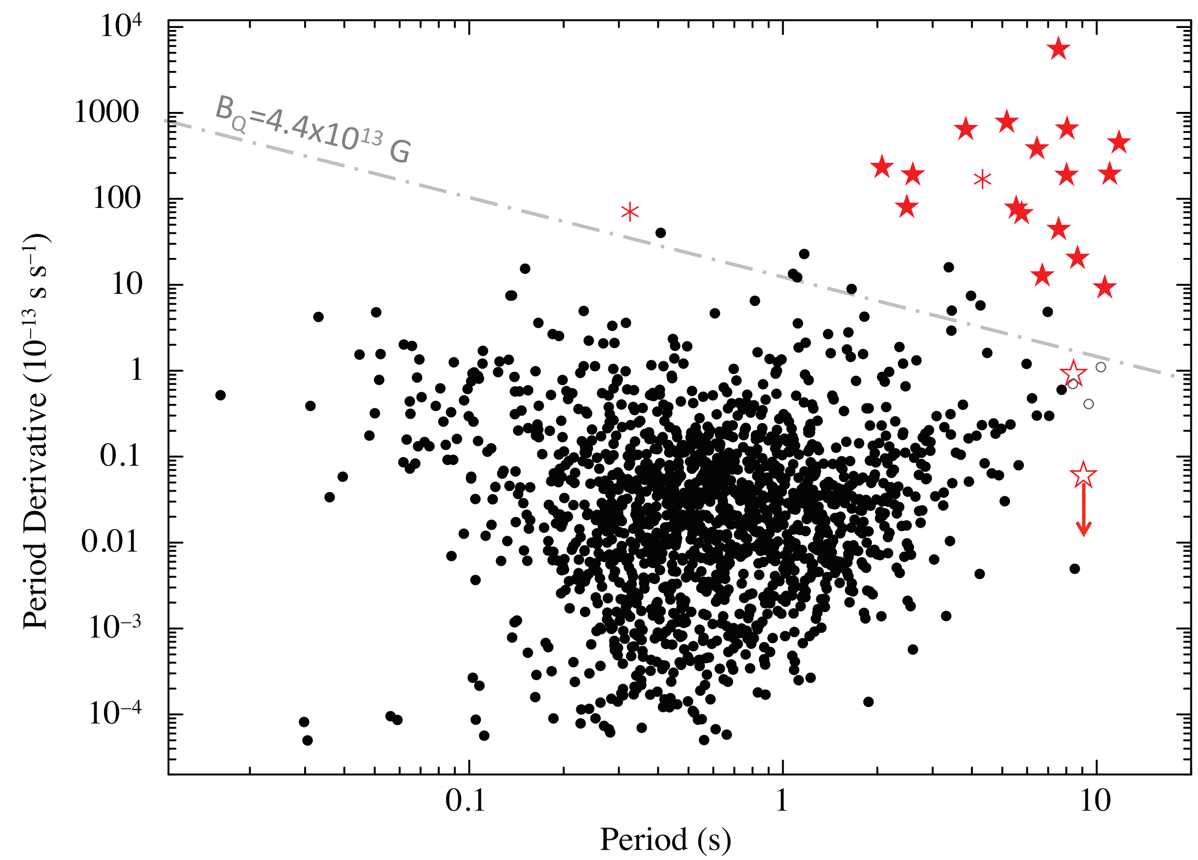
X-ray Outburst

1. Short bursts,
2. Persistent Outburst,
3. Jump of frequency (glitch)

New Discovery

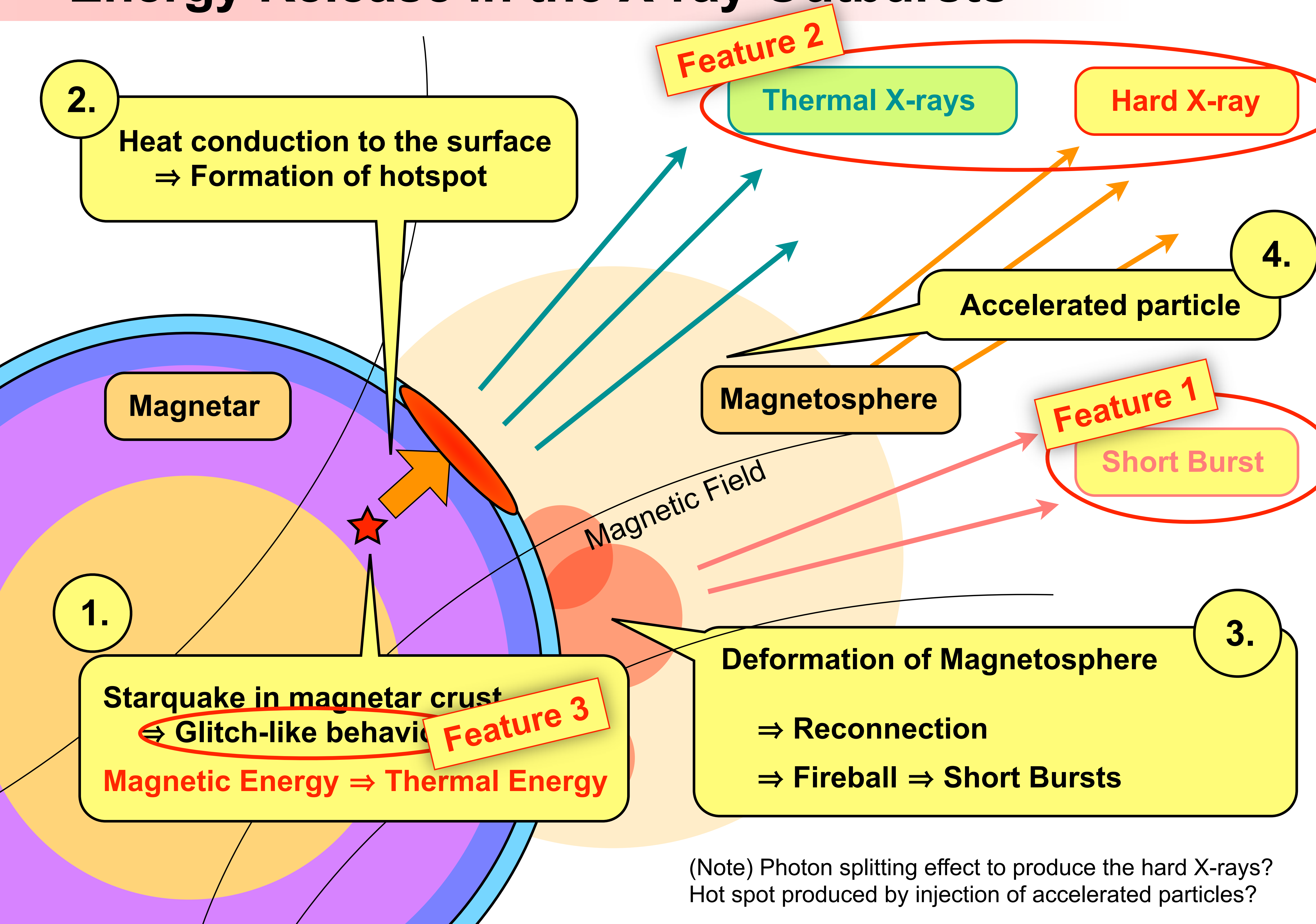
2006 CXOU J164710-455216
2008 SGR 0501+4516, SGR 1627-41, 1E 1547-5408
2009 1E 1547-5408, SGR 0418+5729
2010 SGR 1833-0832
2011 Swift J1822.3-1606, Swift J1834.9-0846

Rea+11



Population of magnetars seems to be much larger than we expected
(X-ray outburst is an essential process to release the magnetic energy)

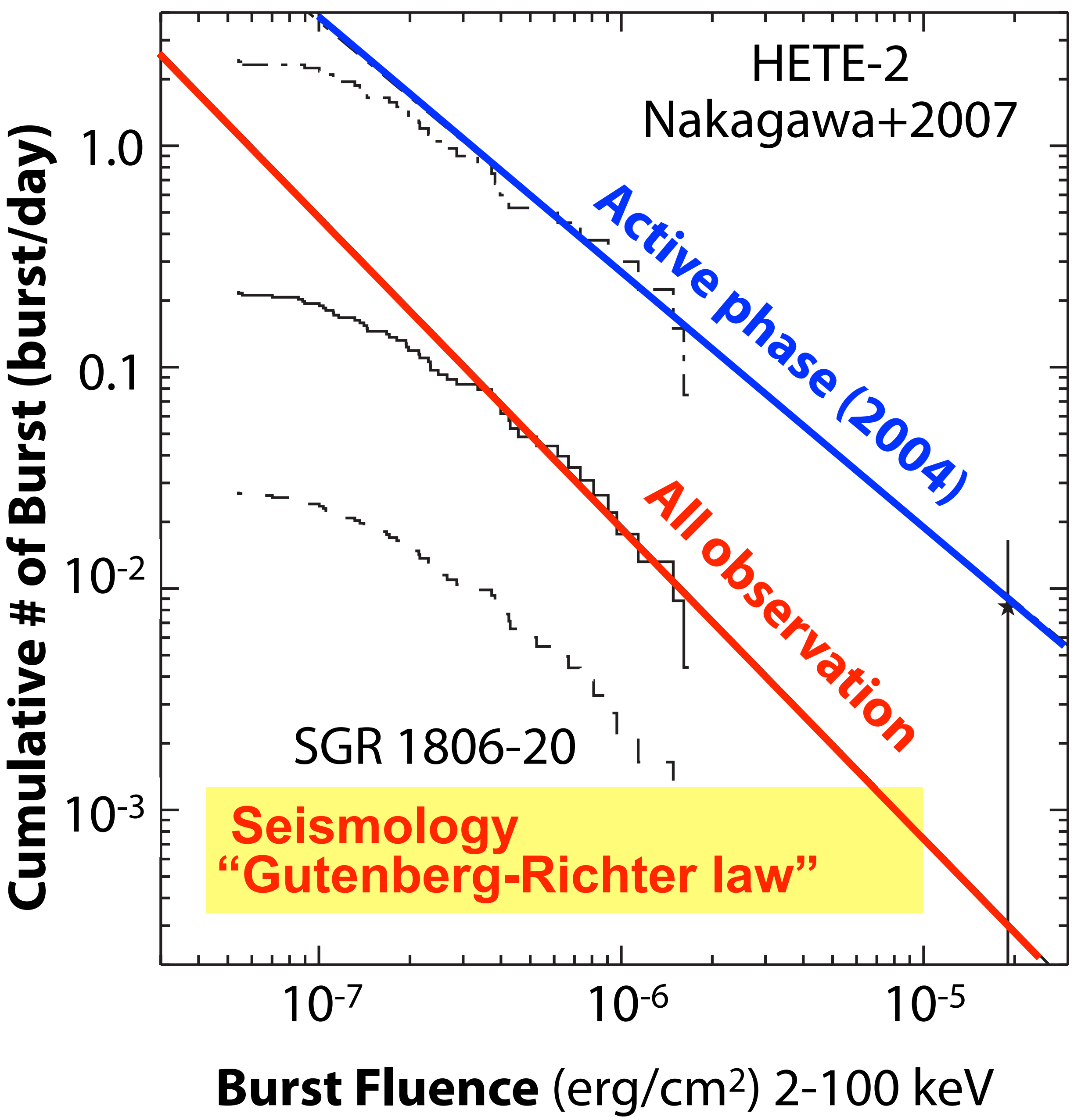
Energy Release in the X-ray Outbursts



(Note) Photon splitting effect to produce the hard X-rays?
Hot spot produced by injection of accelerated particles?

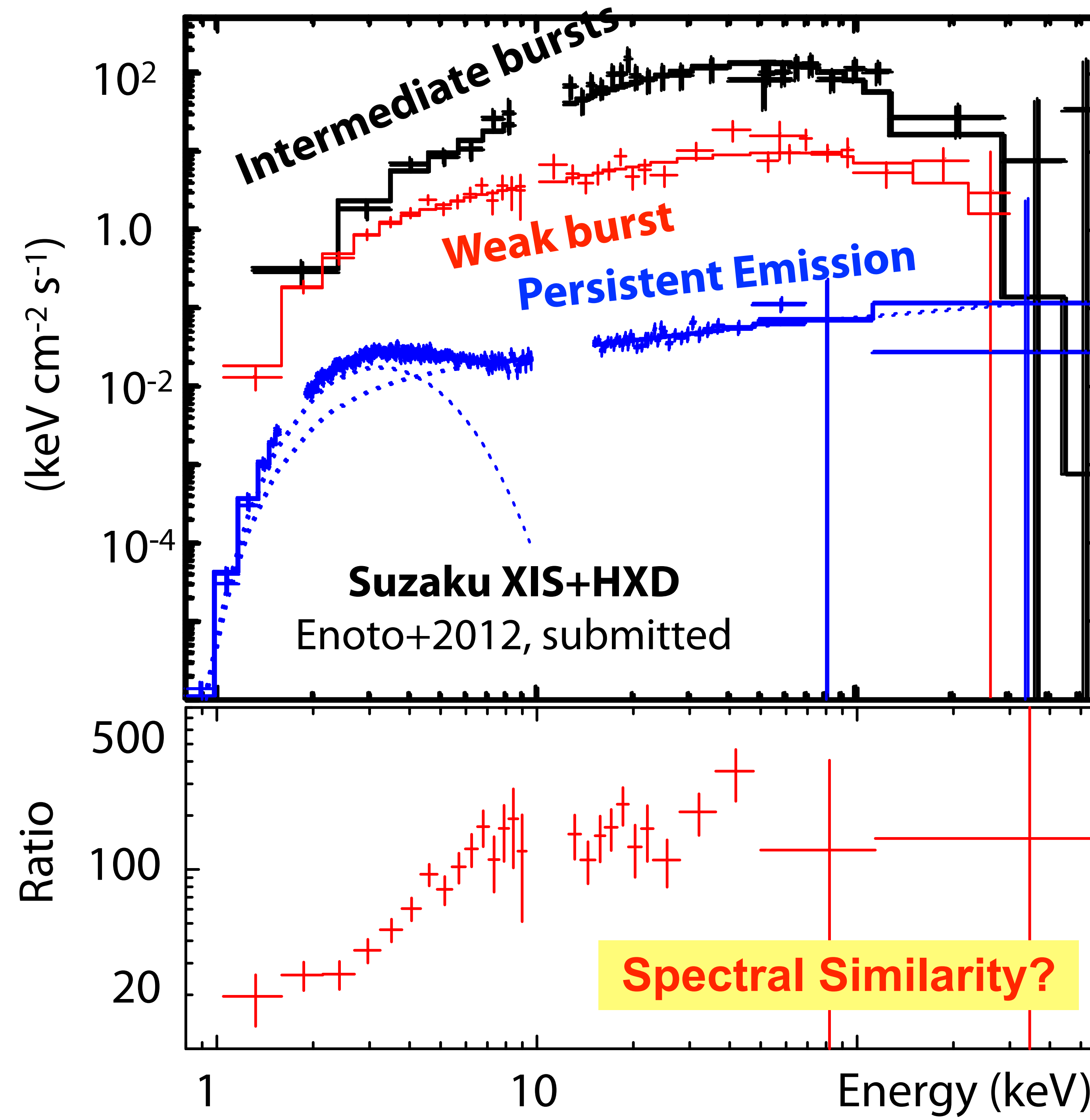
Persistent vs. Unresolved small short bursts

Number-intensity distribution



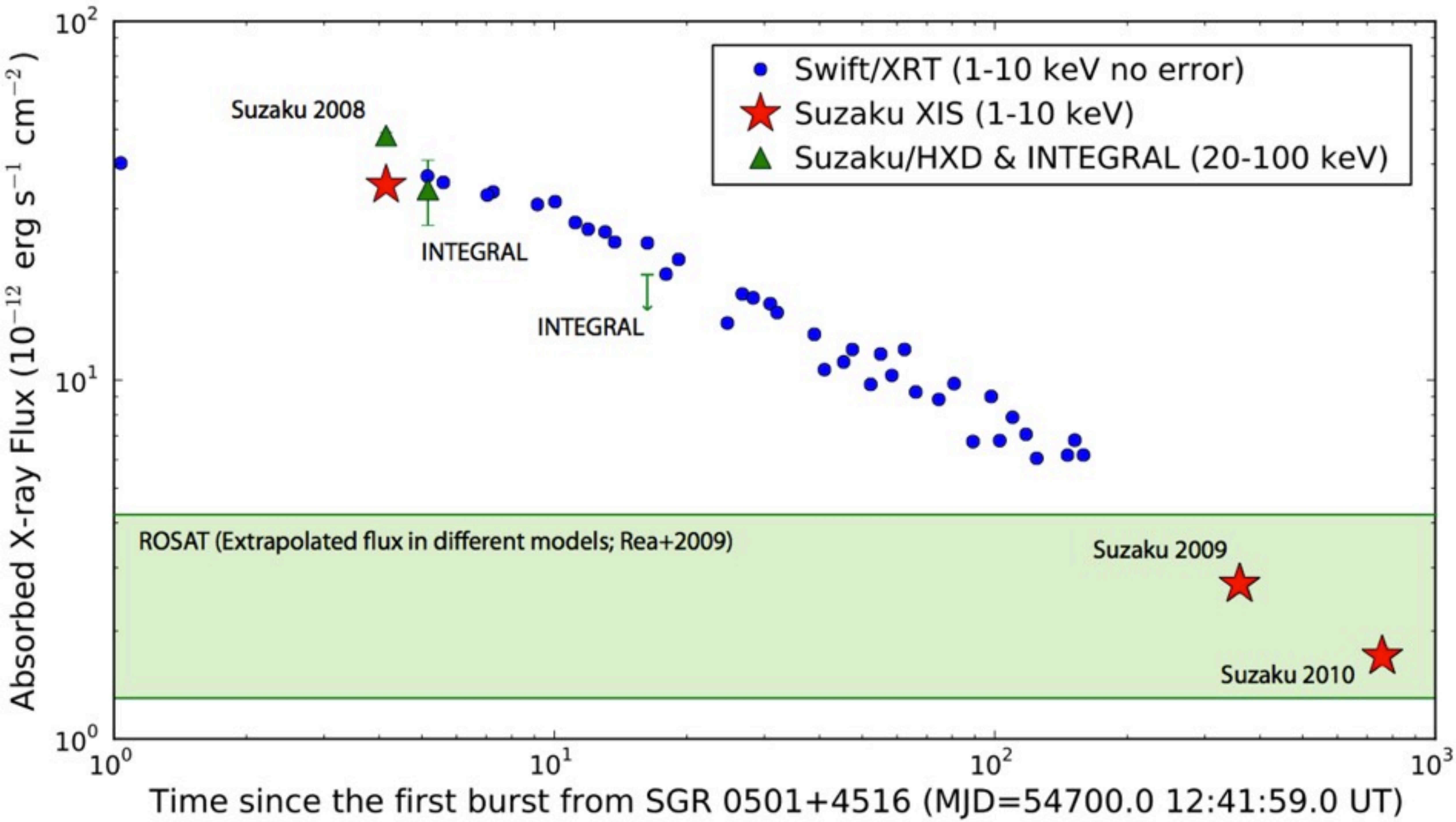
Unresolved small short bursts?

Spectral comparison (1E 1547.0-5408)



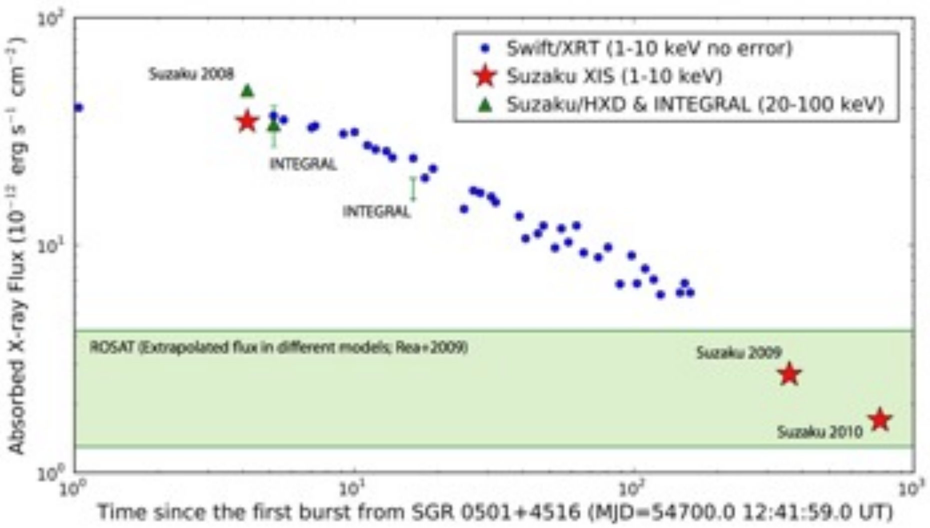
Cumulation of small short bursts can produce the persistent emission?

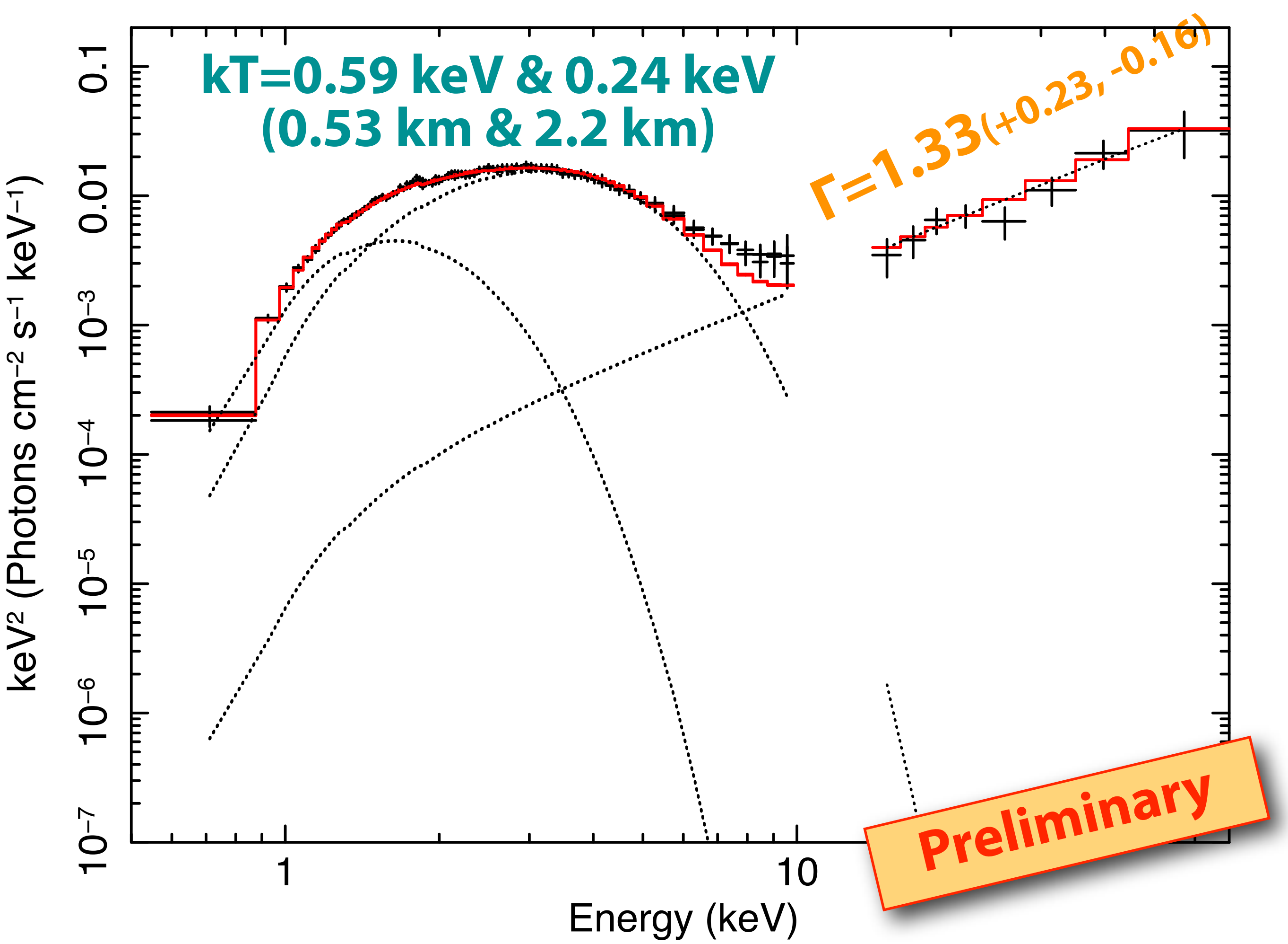
Hard X-rays During the X-ray Outbursts



Hard X-rays During the X-ray Outbursts

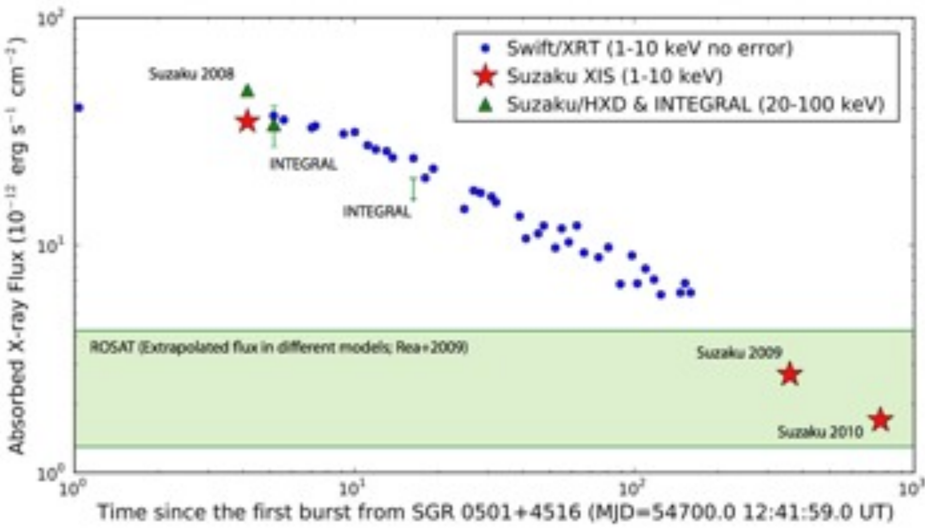
SGR 0501+4516

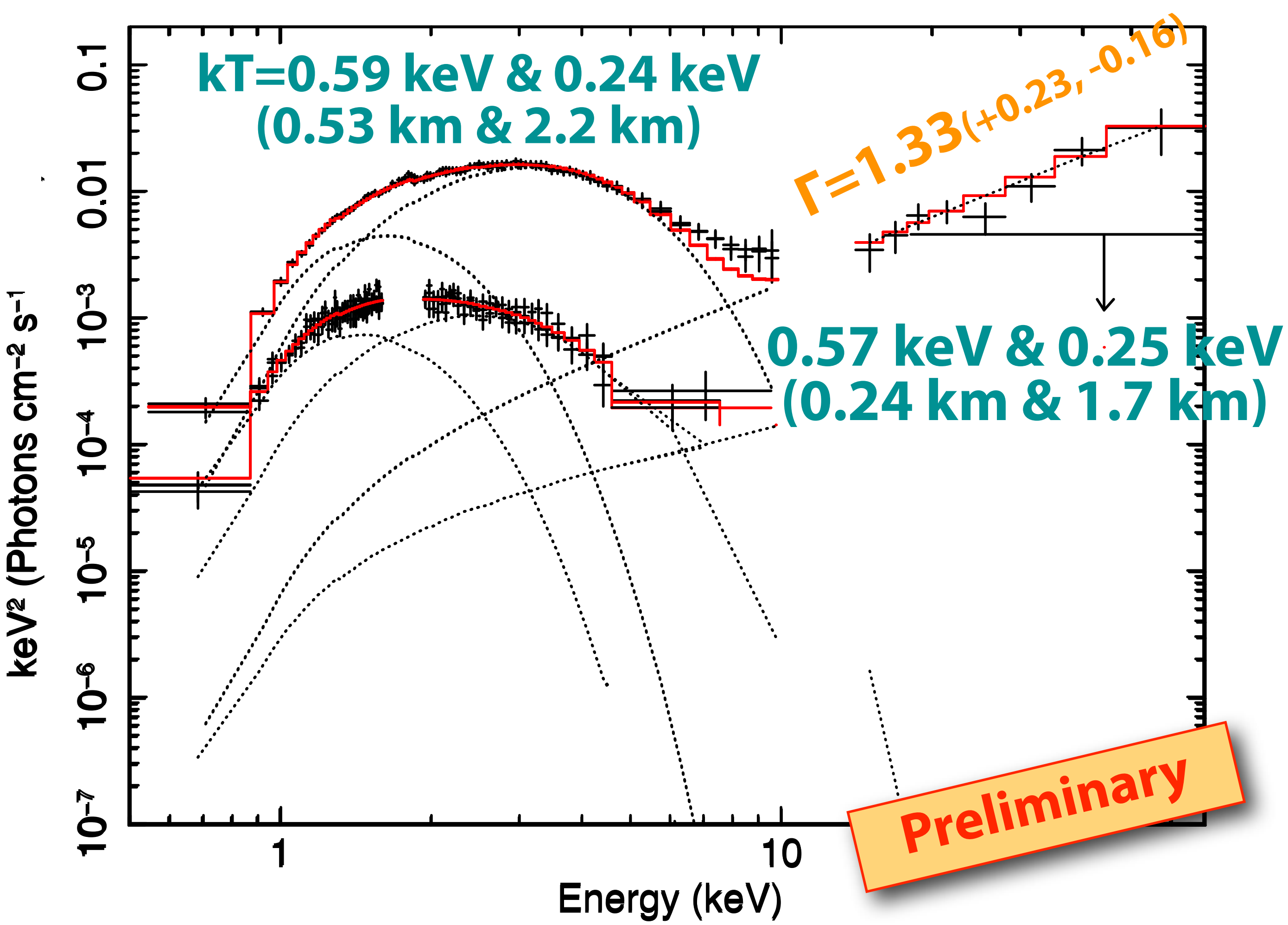




Hard X-rays During the X-ray Outbursts

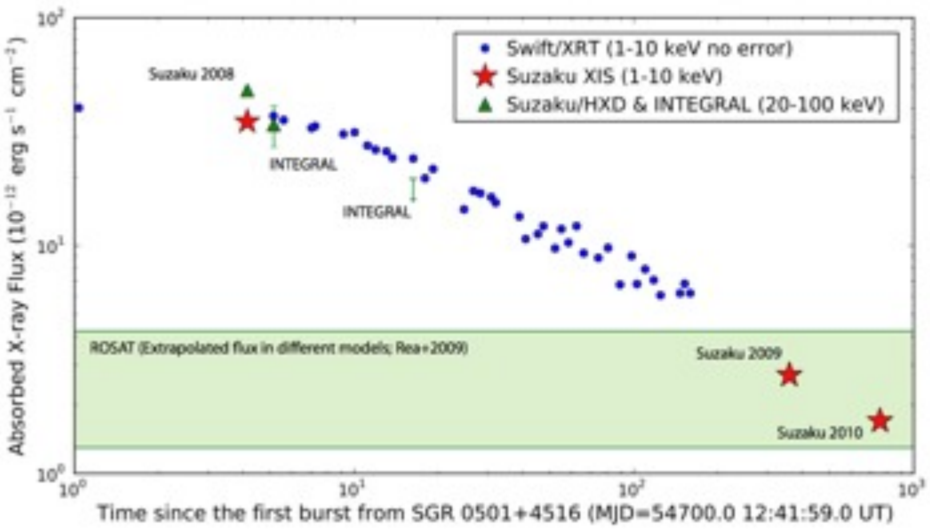
SGR 0501+4516

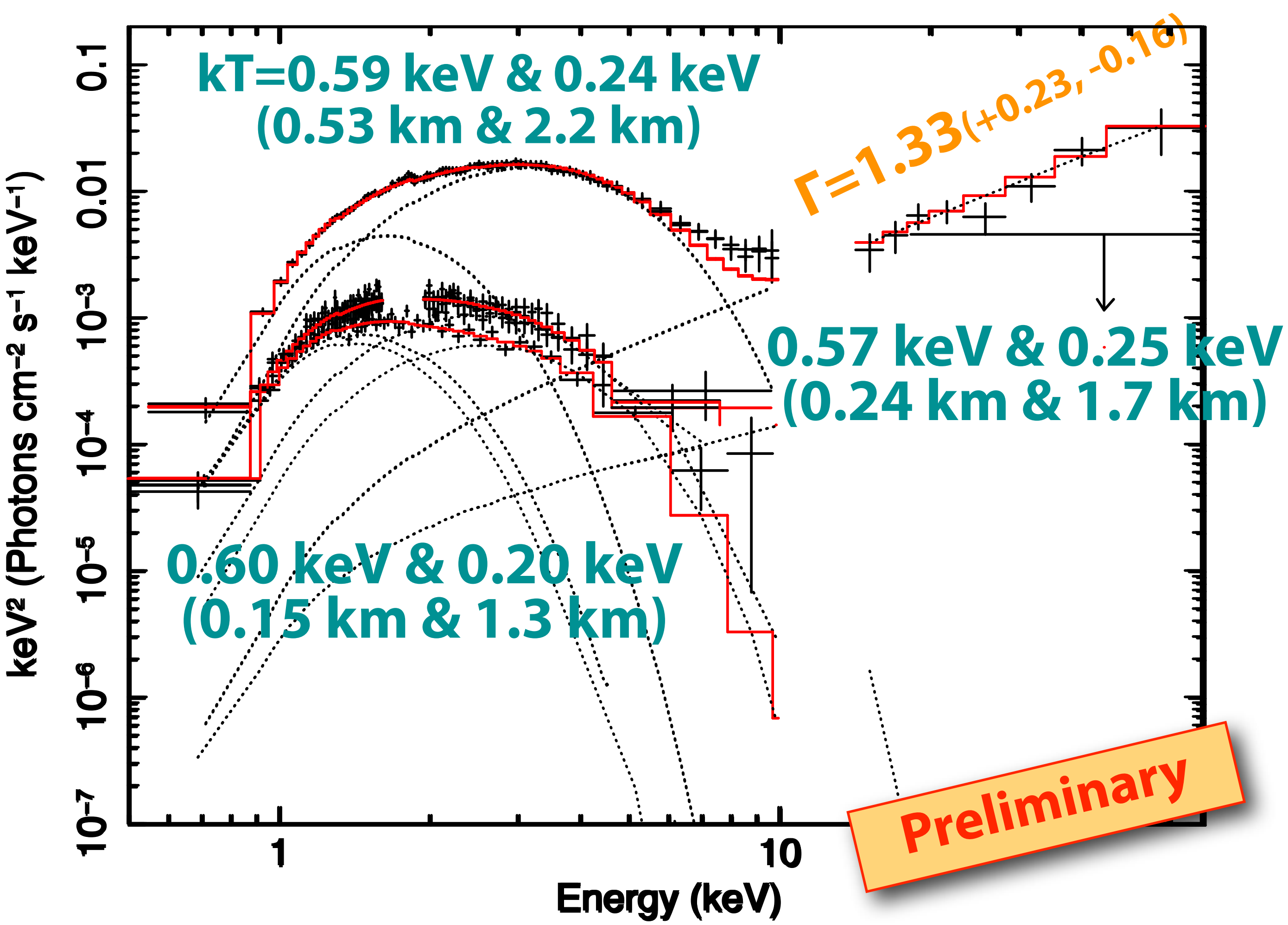




Hard X-rays During the X-ray Outbursts

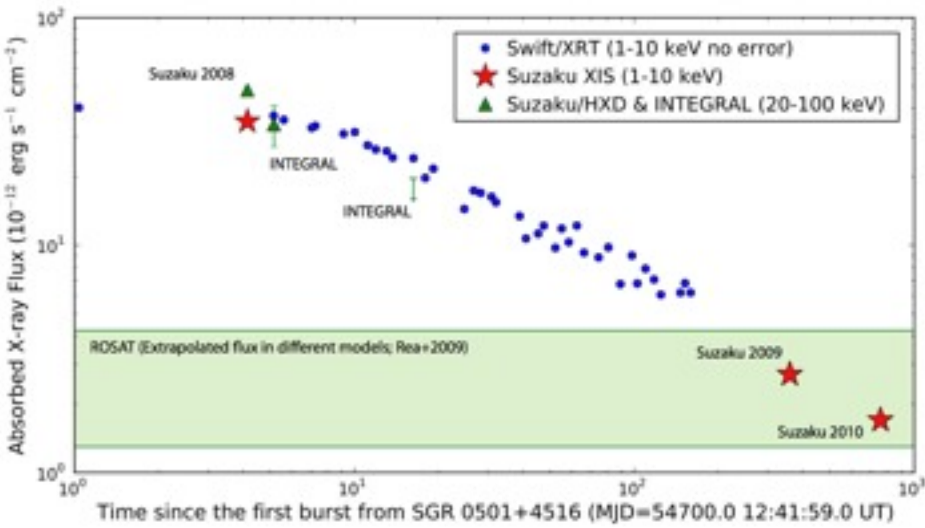
SGR 0501+4516

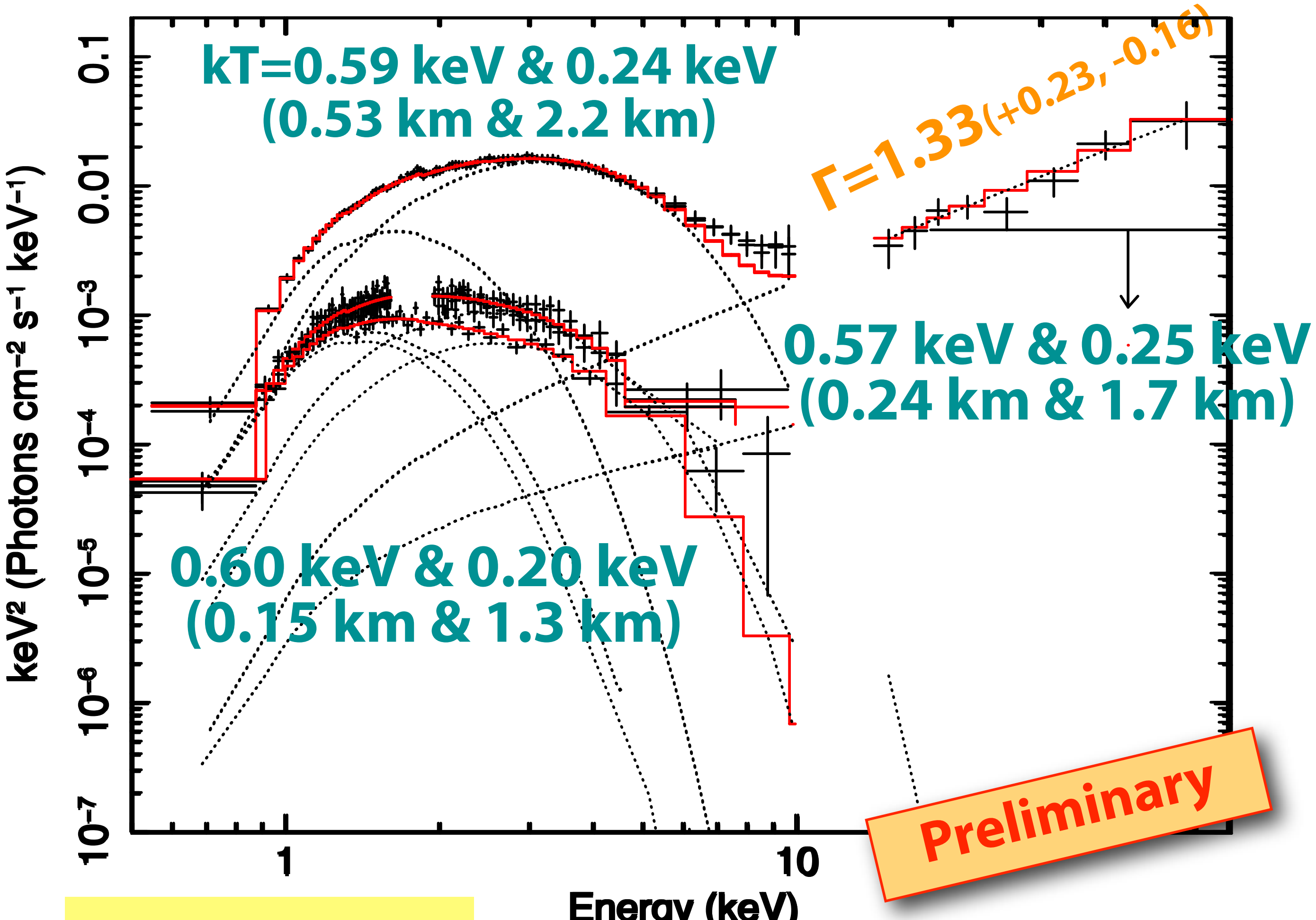




Hard X-rays During the X-ray Outbursts

SGR 0501+4516

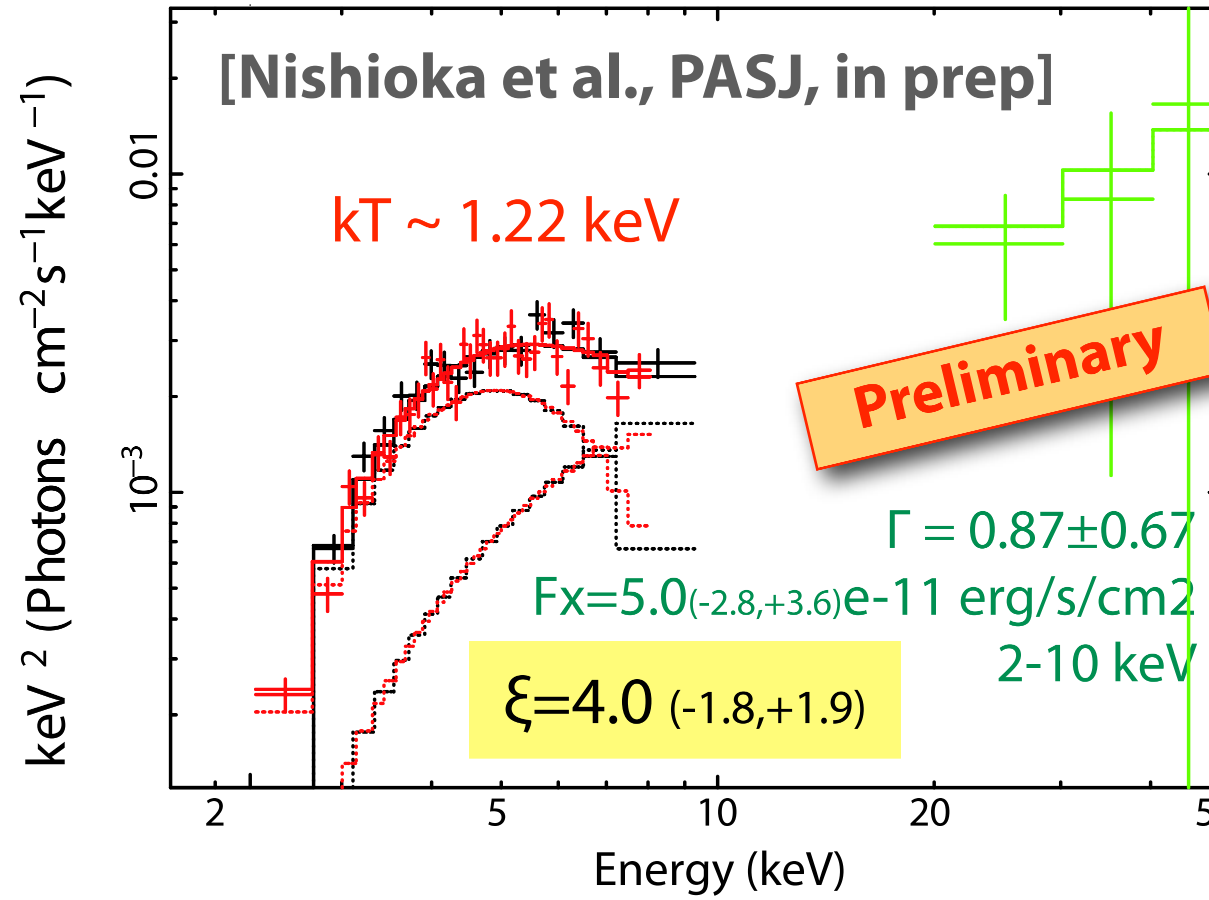




ξ<6.7

SGR 1833-0832

Suzaku ToO on 2010 March 27 (40 ks)



SGR J0418+5729

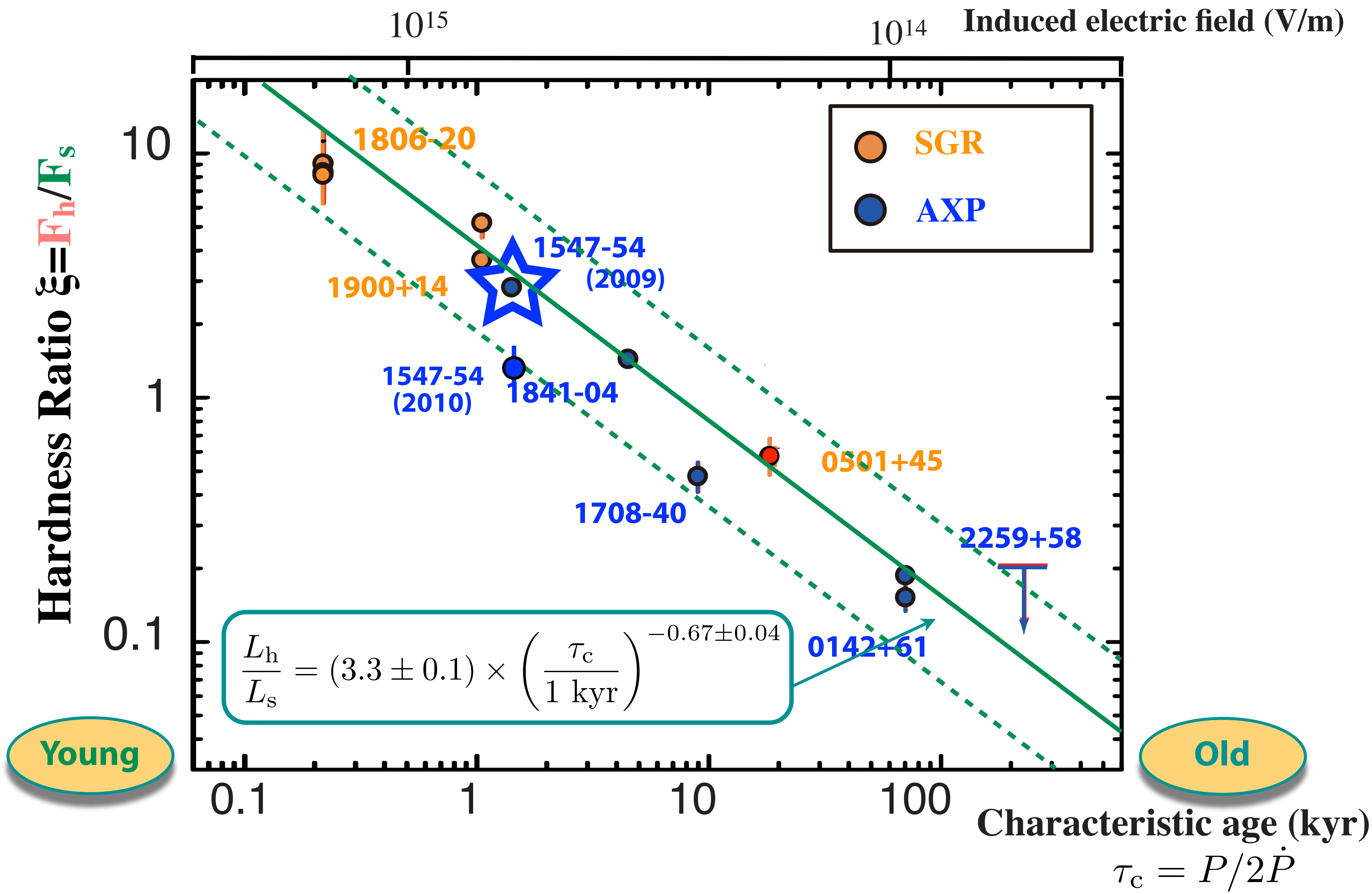
(e.g., Rea+2010)

Unfortunately, Suzaku could not observed this.

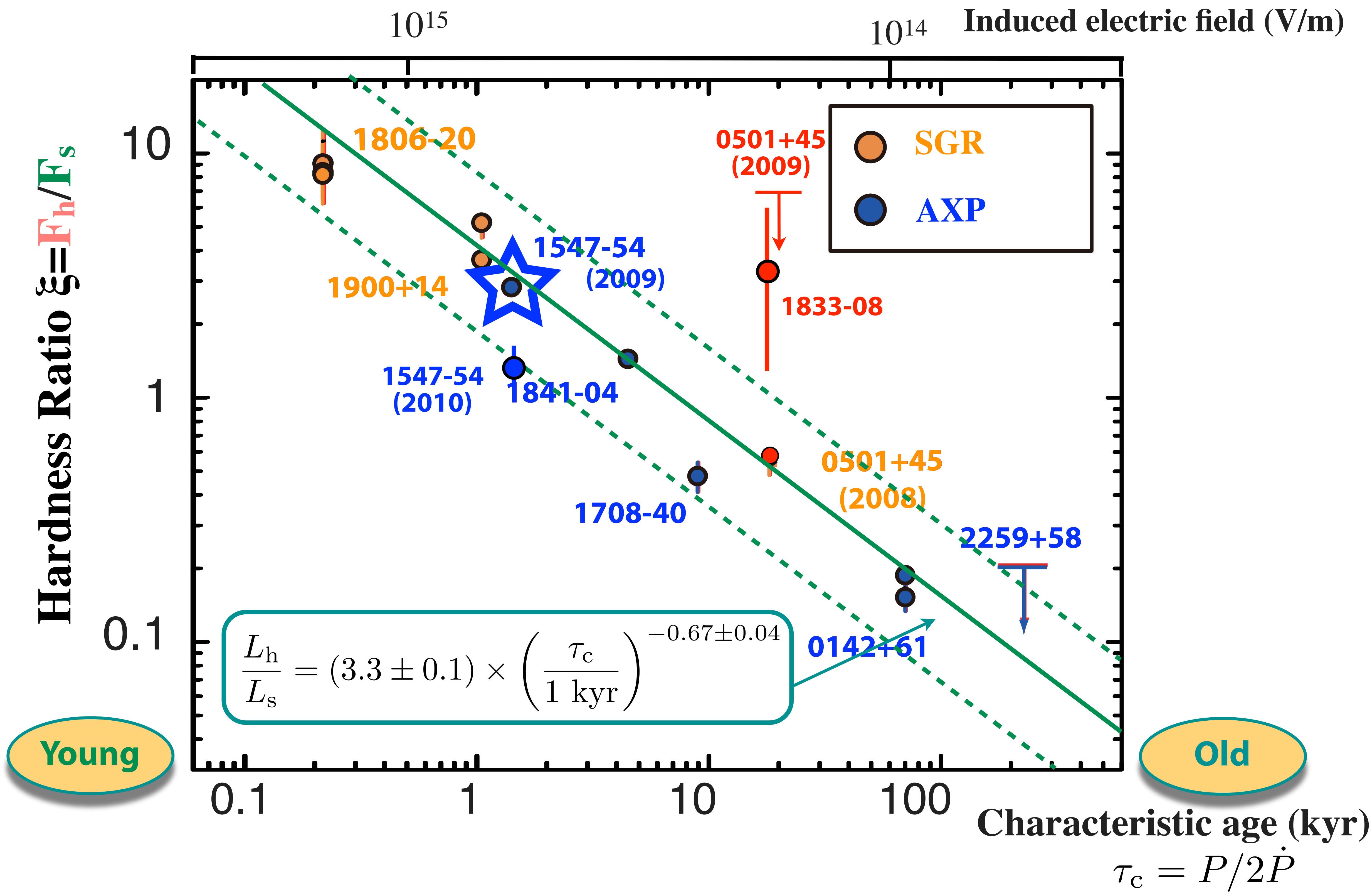
Swift J1822.3-1606

Discovered on 2011 July,
Suzaku analyses are ongoing.

Hard X-rays During the X-ray Outbursts



Hard X-rays During the X-ray Outbursts



Most of persistent/transient sources follow the relation,
the behavior of transient sources in their outburst could be interesting topic to be studied.

Summary

- There is growing evidence that SGR and AXP are magnetars, but observational confirmations are still required to resolve their true nature, a release mechanism of magnetic energy, and the physics in the strong field.

- *Suzaku* confirmed the hard X-rays from most of magnetars. The broadband X-ray study suggested the spectral evolution related with magnetar's characteristic age and magnetic field.

- The X-ray outbursts of transient magnetars could be a key to understand their release of the stored magnetic energy. *Suzaku* detected the enhanced hard X-rays during the outburst states, as well as the soft thermal X-rays.

There will be a great progress using ASTRO-H (launched in 2014)