Recent *Suzaku* Studies of the X-ray Emission from Magnetars

Teruaki Enoto (KIPAC/Stanford)

On behalf of *Suzaku* Magnetar Key Project

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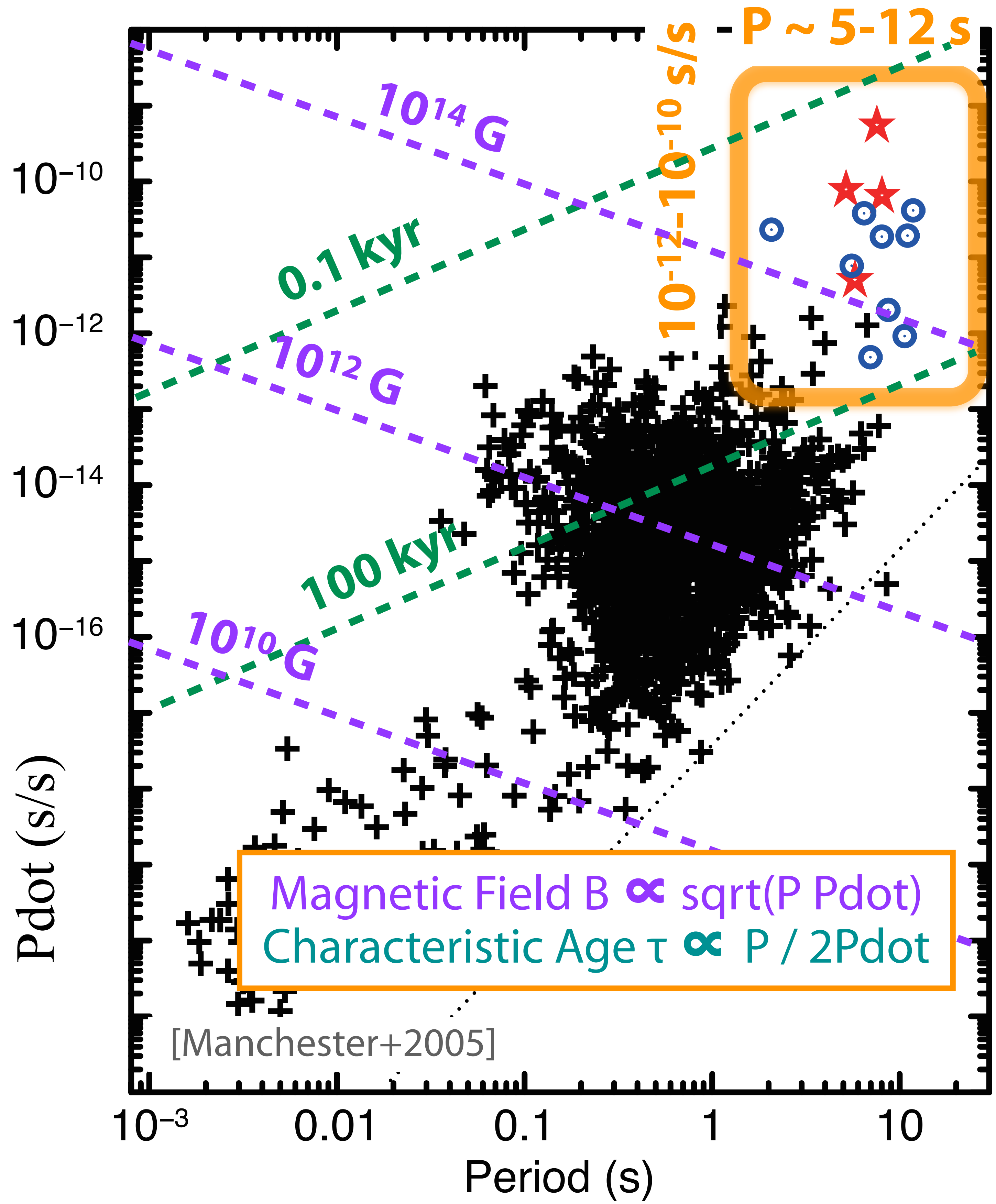
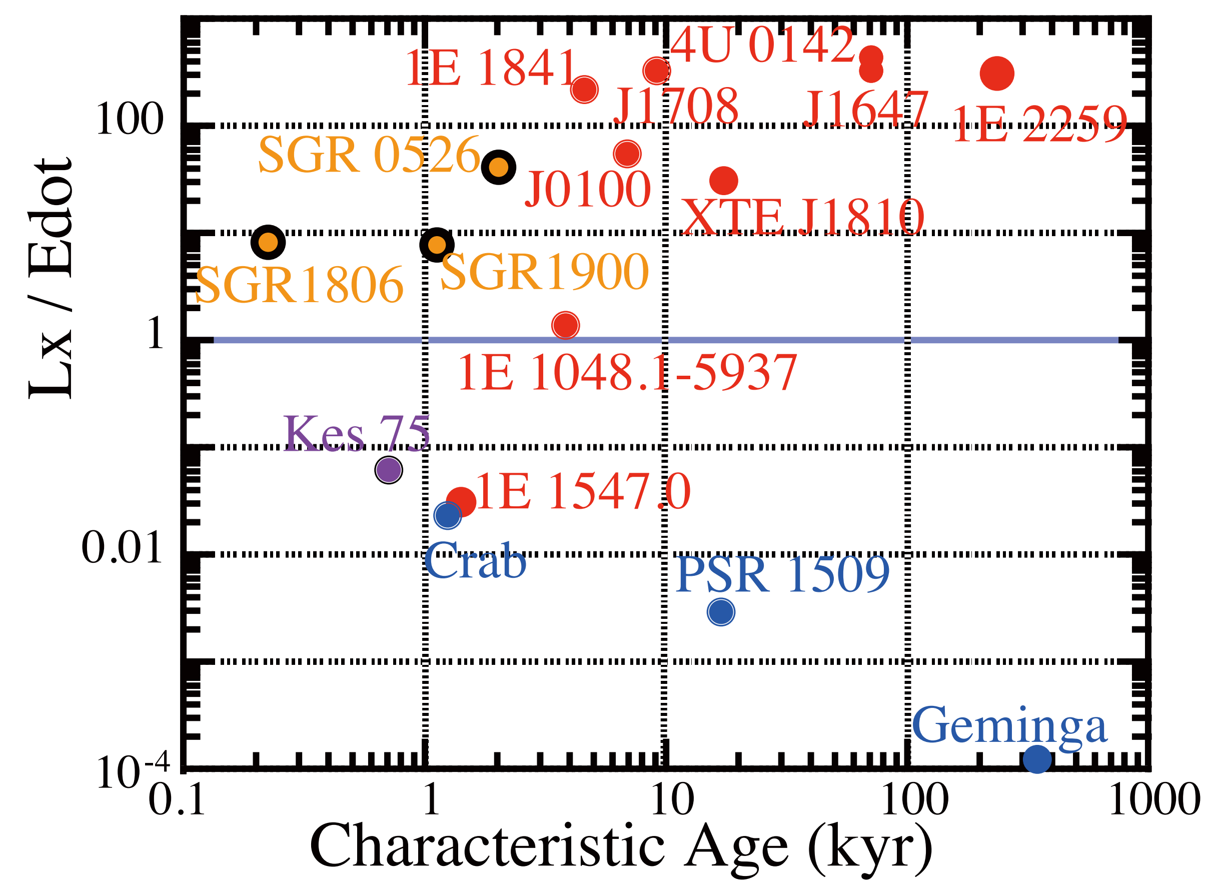
July 20, 2011, Suzaku 2011, Exploring the X-ray Universe: Suzaku and Beyond @ KIPAC/SLAC

Magnetar Class



- **Soft Gamma Repeater**
- **Anomalous X-ray Pulsar**

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

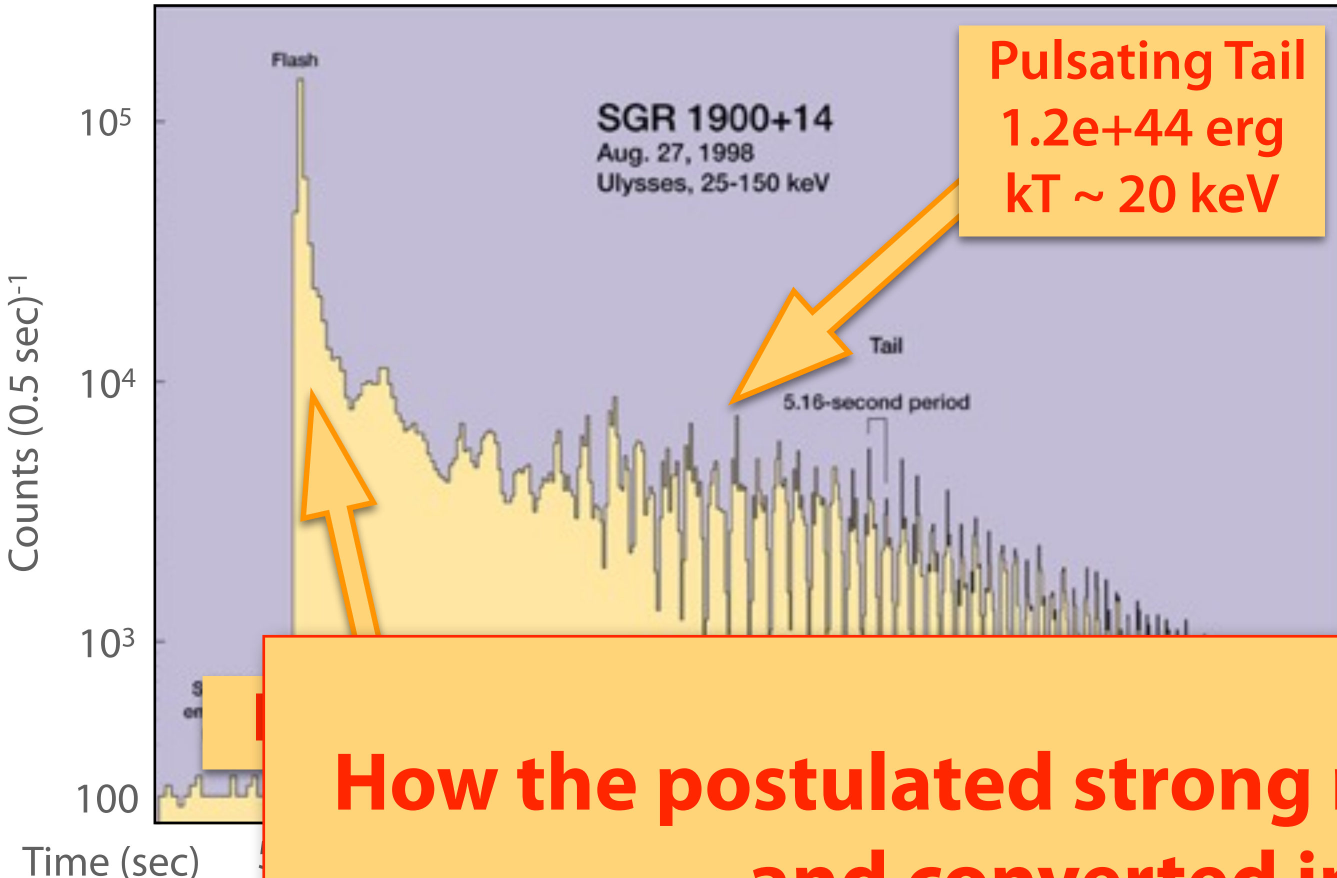


Magnetic-powered Pulsars ?

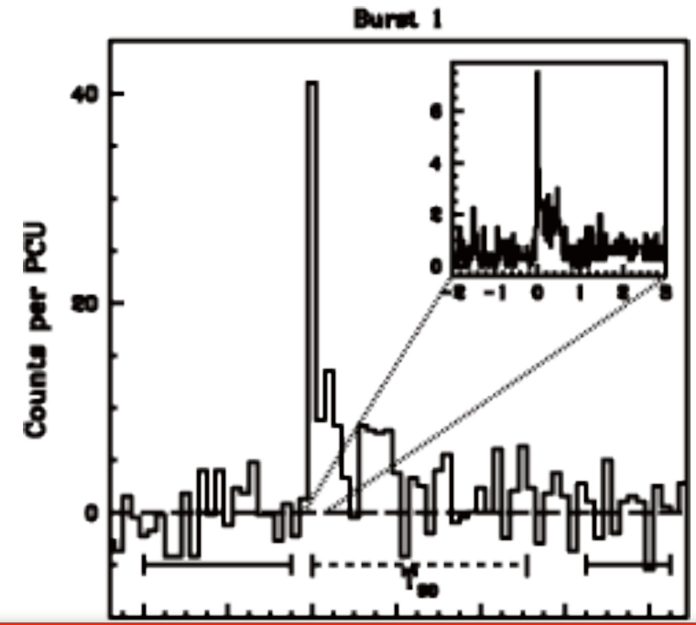
Activity & Energetics of Magnetars

"Giant Flares" (from three Soft Gamma Repeater)

Pulsating Tail
1.2e+44 erg
kT ~ 20 keV



"Short Bursts"

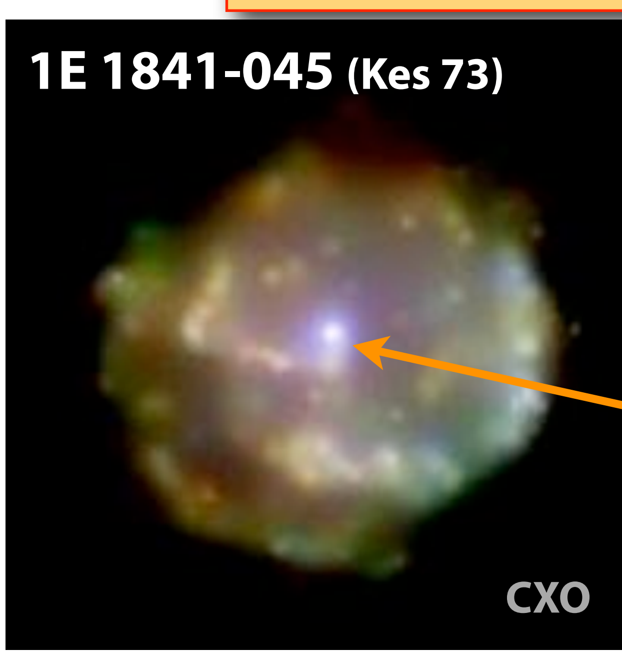


1E1048.1-5937
(Gavriil+2002)

erg/s

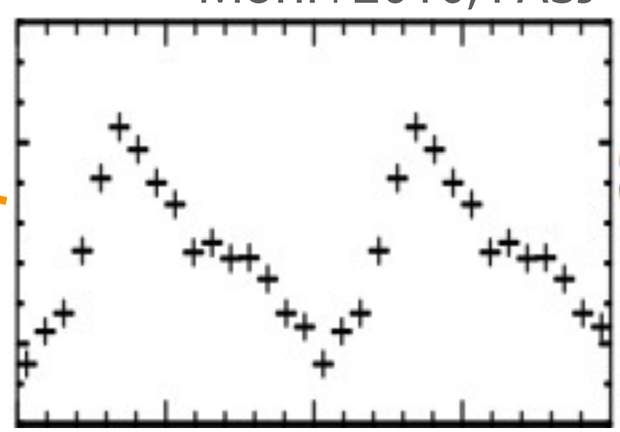
How the postulated strong magnetic field are dissipated and converted into the radiation?

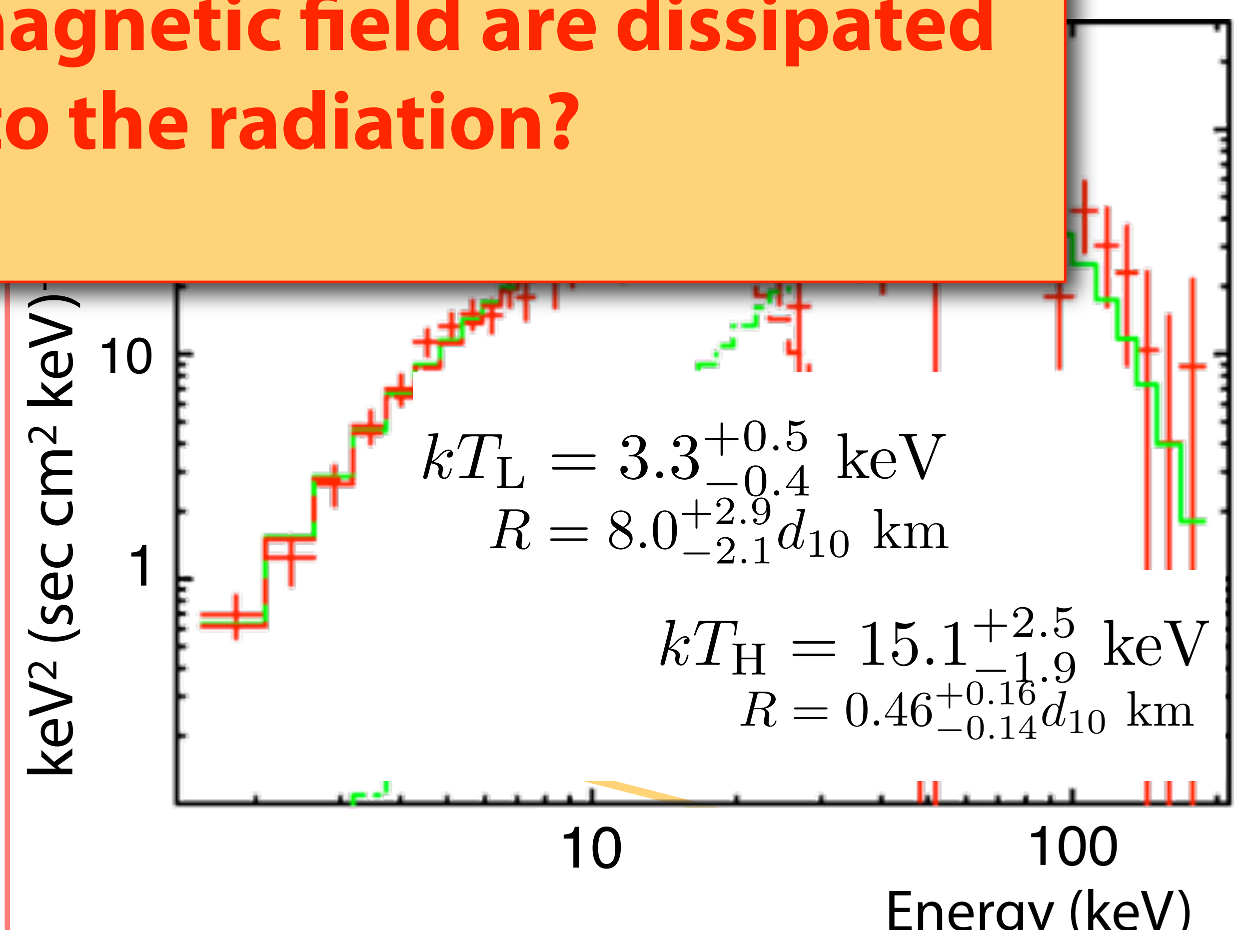
"Persis



Lx ~ 1e+34--1e+35 erg/s

Morii+2010, PASJ





$kT_{\rm L} = 3.3^{+0.5}_{-0.4}$ keV
$R = 8.0^{+2.9}_{-2.1} d_{10}$ km

$kT_{\rm H} = 15.1^{+2.5}_{-1.9}$ keV
$R = 0.46^{+0.16}_{-0.14} d_{10}$ km

Suzaku Observations of Magnetars

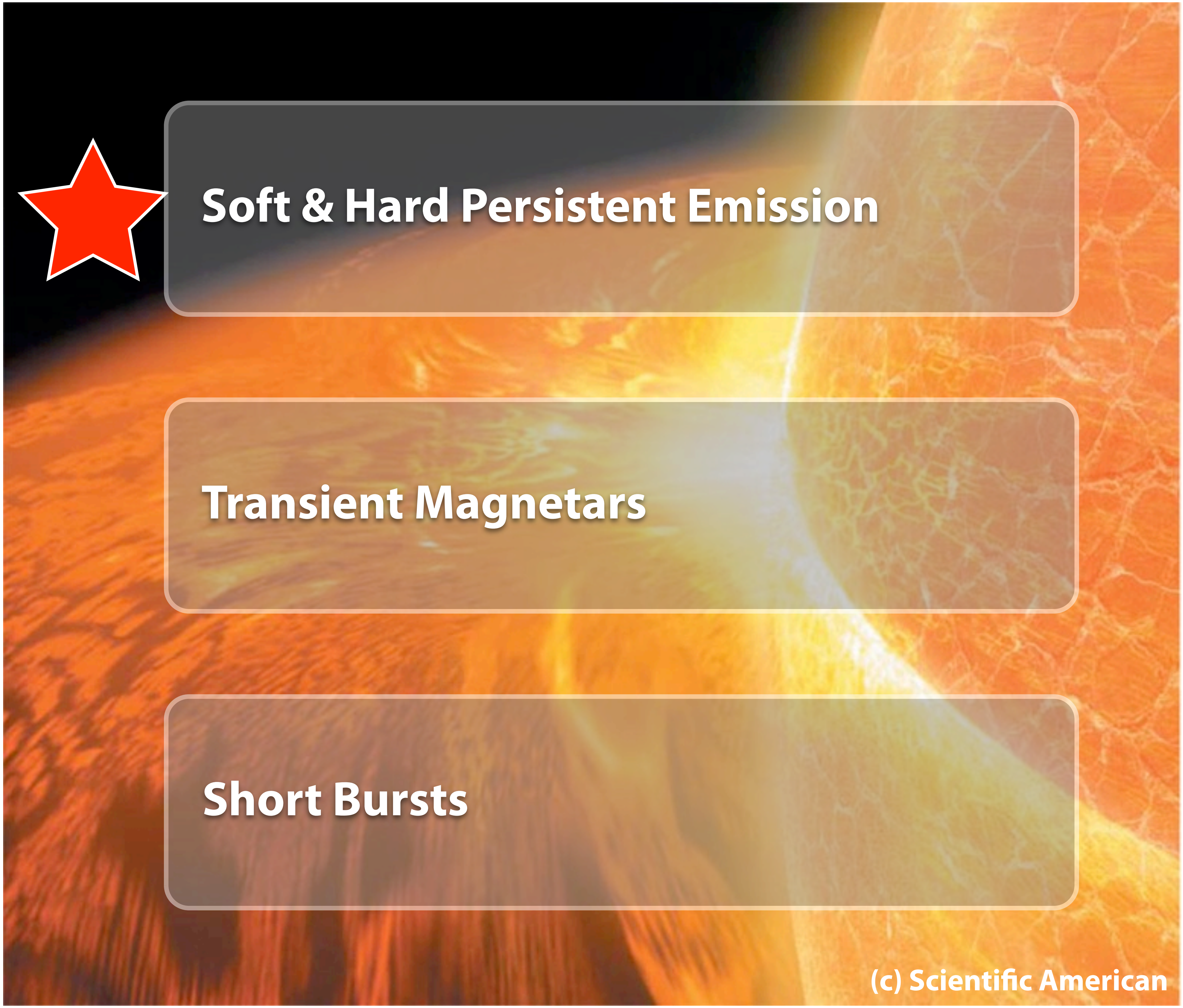
Magnetar on the Galactic Plane

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)
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 et al. in prep
10	SGR 1833-0832	SGR (ToO in 2010)	Nishioka et al., in prep

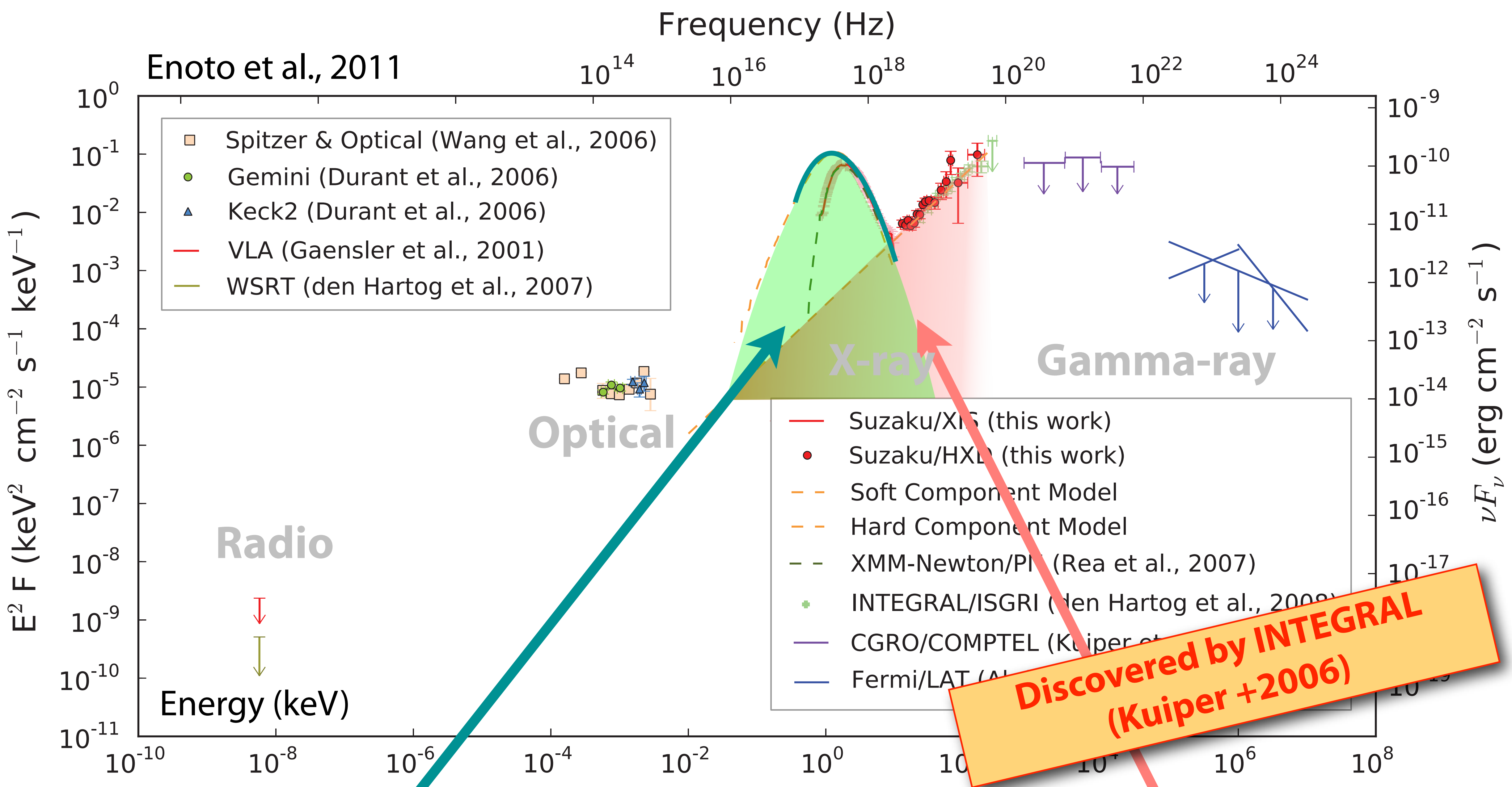
- Enoto et al., ApJL(2011) Comprehensive Analyses
- Takata et al., ApJ (submitted) Theoretical Approach

Main Suzaku Topics on Magnetars

- Soft & Hard Persistent Emission
- Transient Magnetars
- Short Bursts



Persistent Emission: Typical AXP 4U 0142+61



Soft Component (0.2-10 keV)

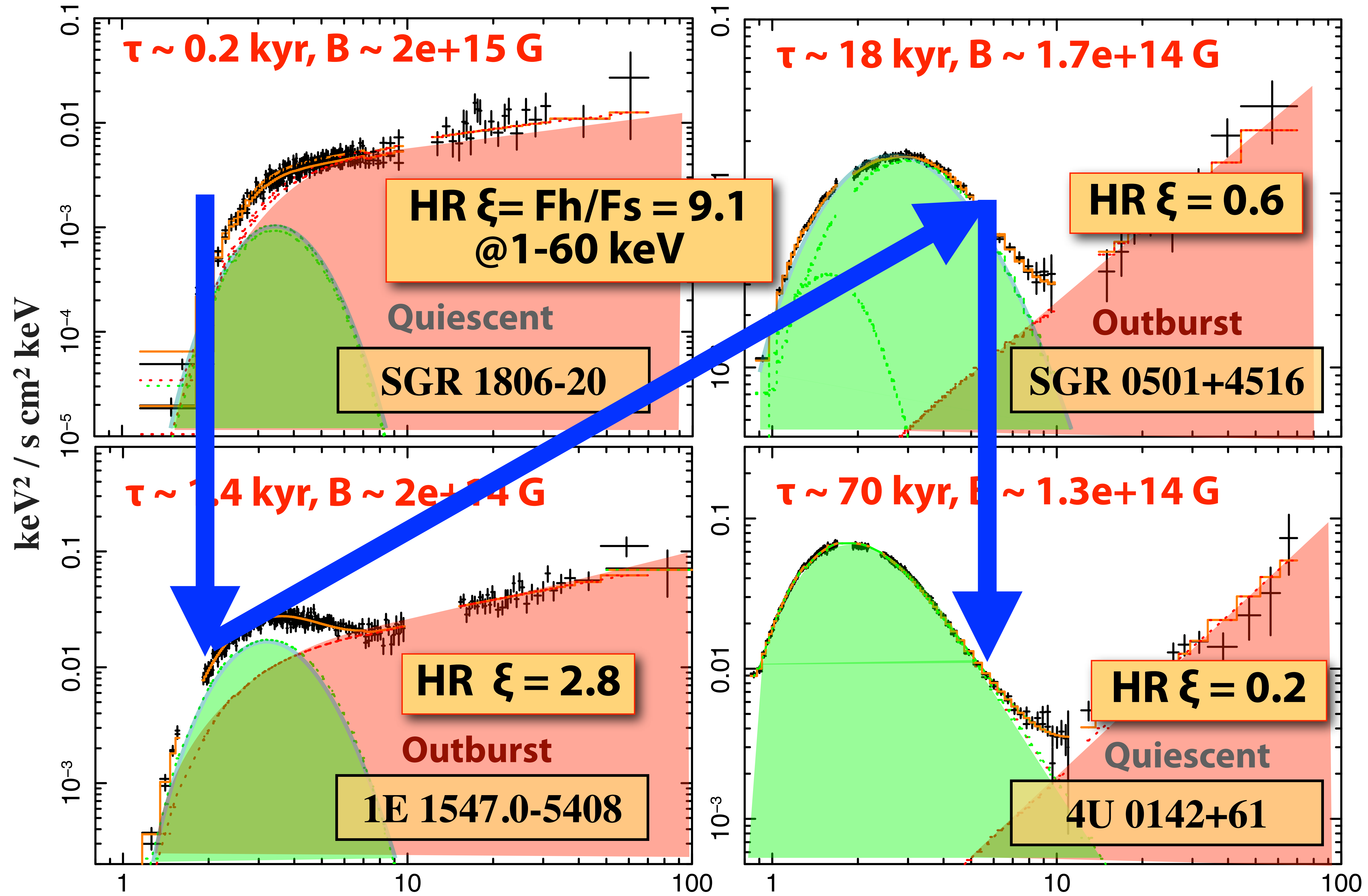
- ~Blackbody (~0.3 keV)
- $L_{x(2\text{-}10\ keV)} = 10^{35}$ erg/s > $L_{sd} = 10^{32}$ erg/s
- NS Surface Emission

Hard Component (>~10 keV)

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

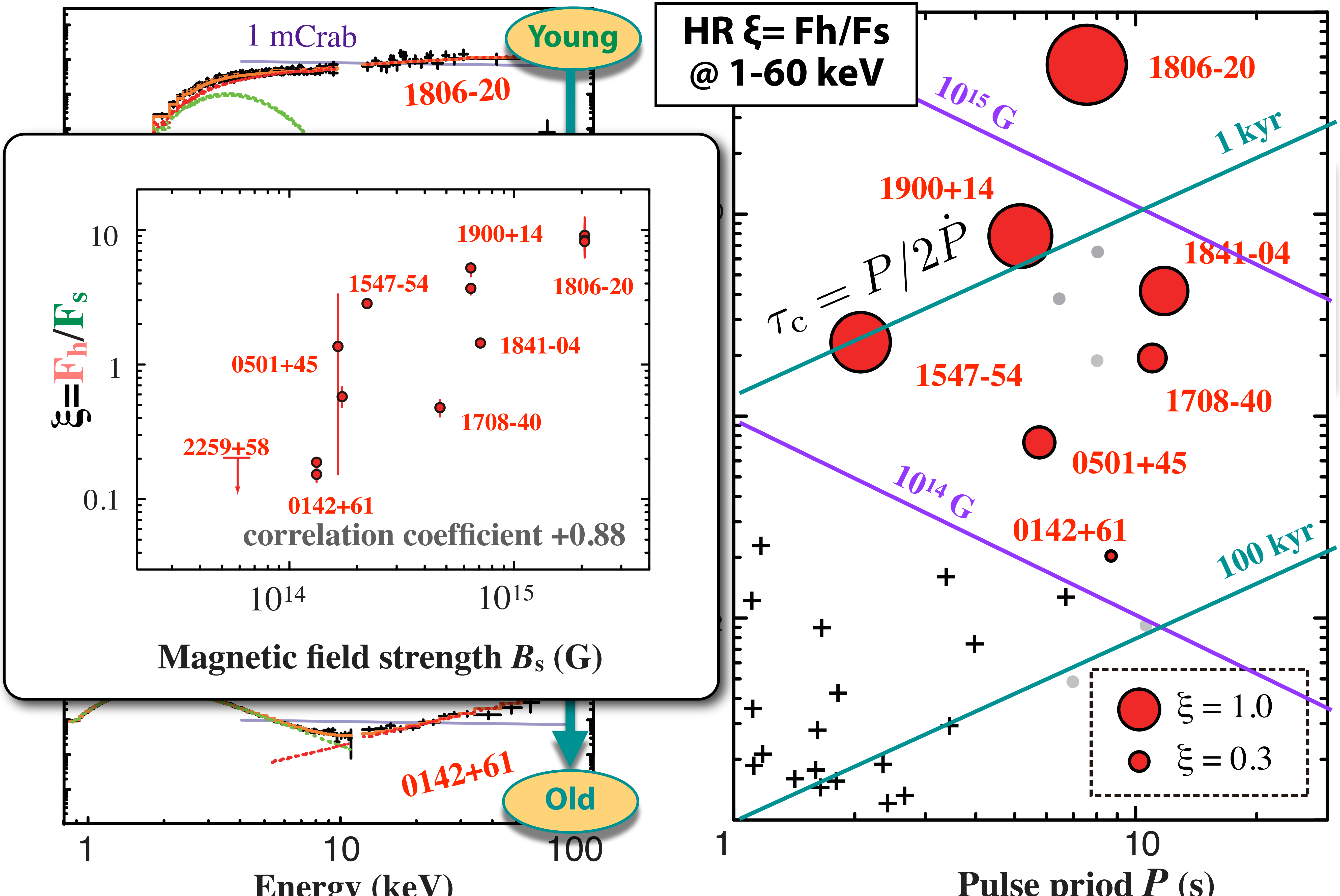
Challenge to provide a more unified characterization of magnetars.

Examples of Suzaku Magnetar Spectra



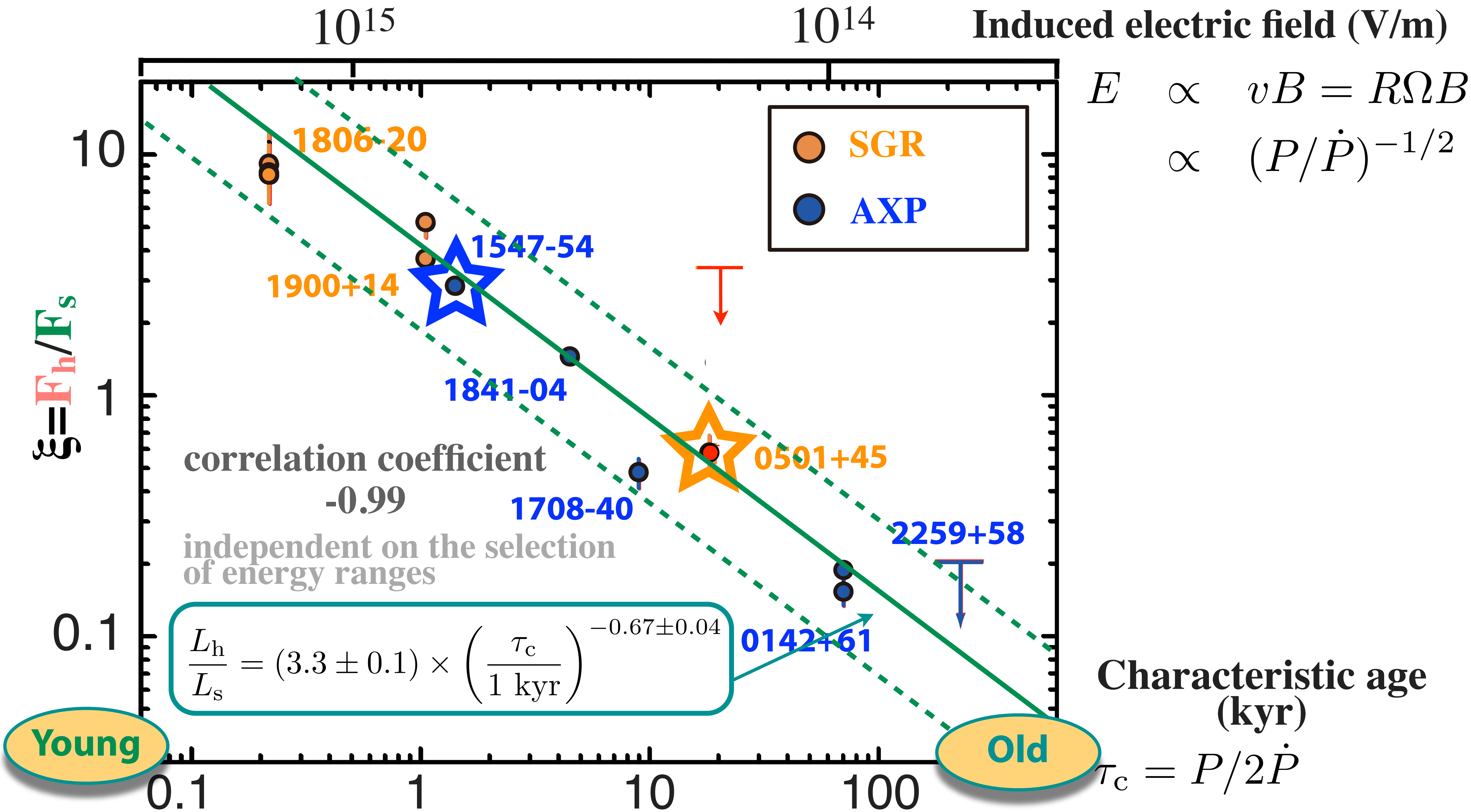
Enoto et al., ApJL (2010)

Wide-band spectra and P-Pdot diagram



Enoto et al., ApJL (2010)

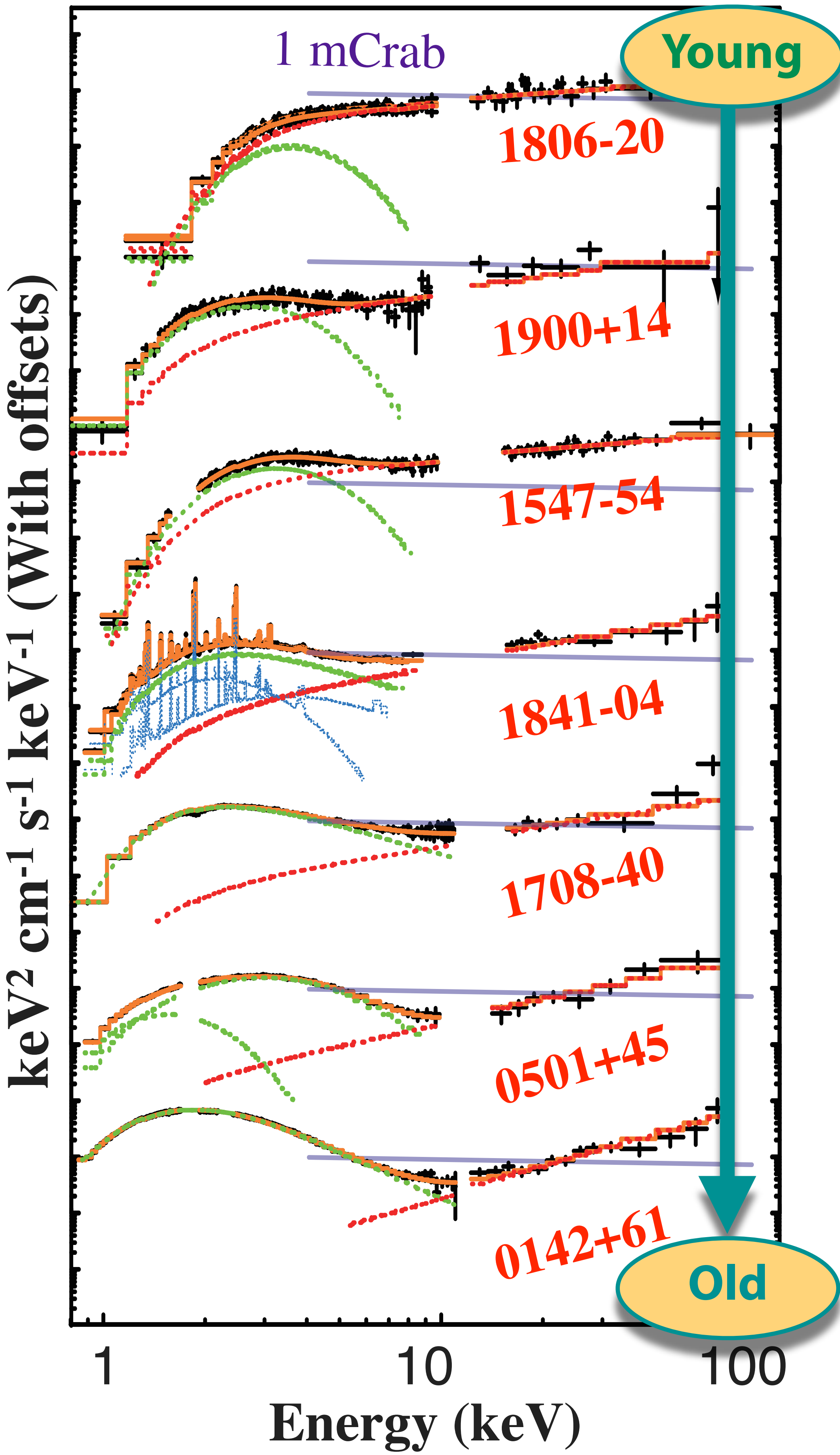
Hardness Ratio $\xi = F_h/F_s$ vs. τ_c

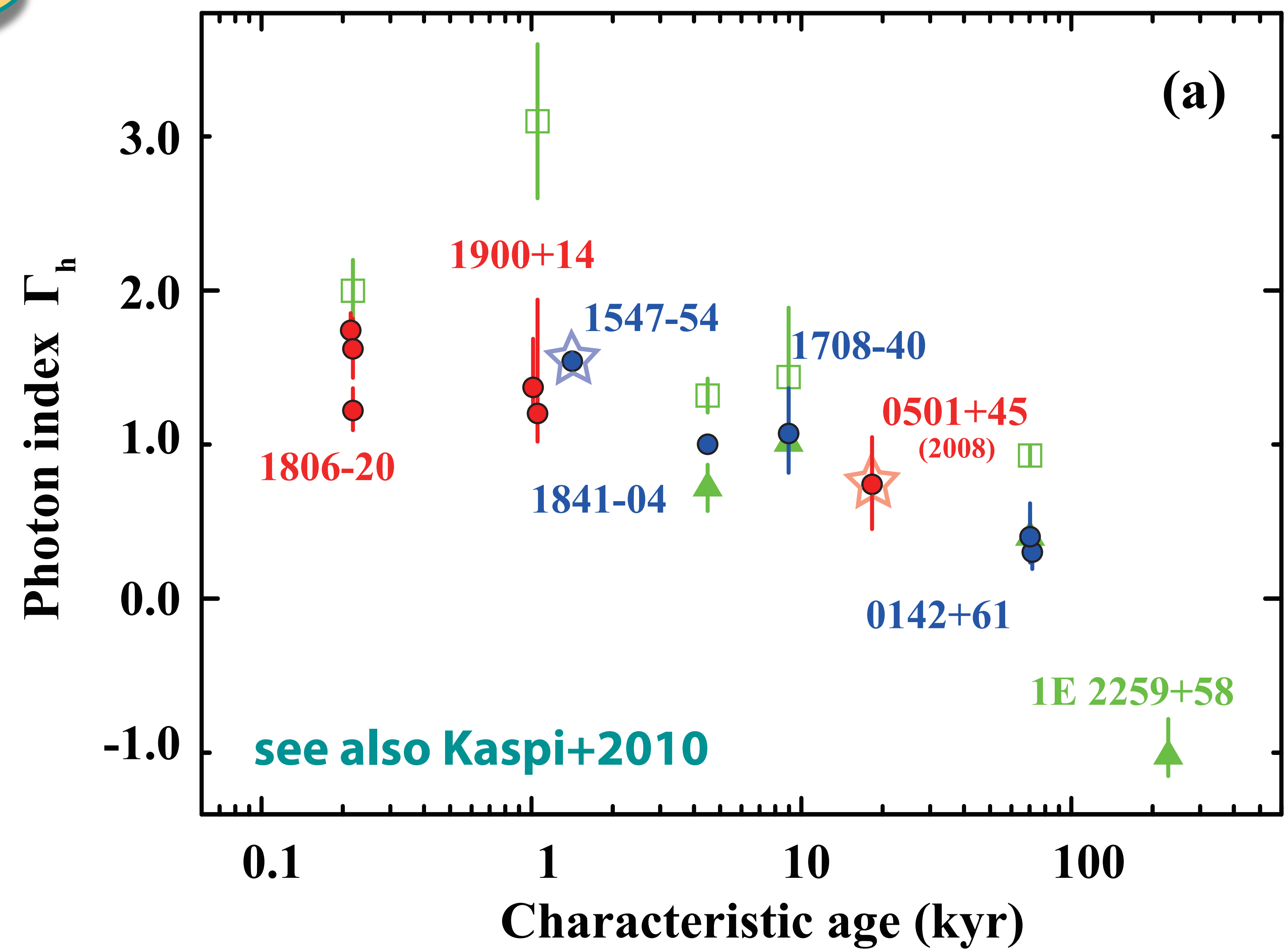


- Hardness ratio F_h/F_s is negatively correlated with the characteristic age τ_c.
- SGR & AXP are intrinsically the same kinds of object.
- Burst-active and quiescent states follow the same correlation ⇒ common mechanism.
- Interpreted as the relation to an induced electric field of the rotating magnetic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

Enoto et al., ApJL (2010)

Hardening of the Hard Component

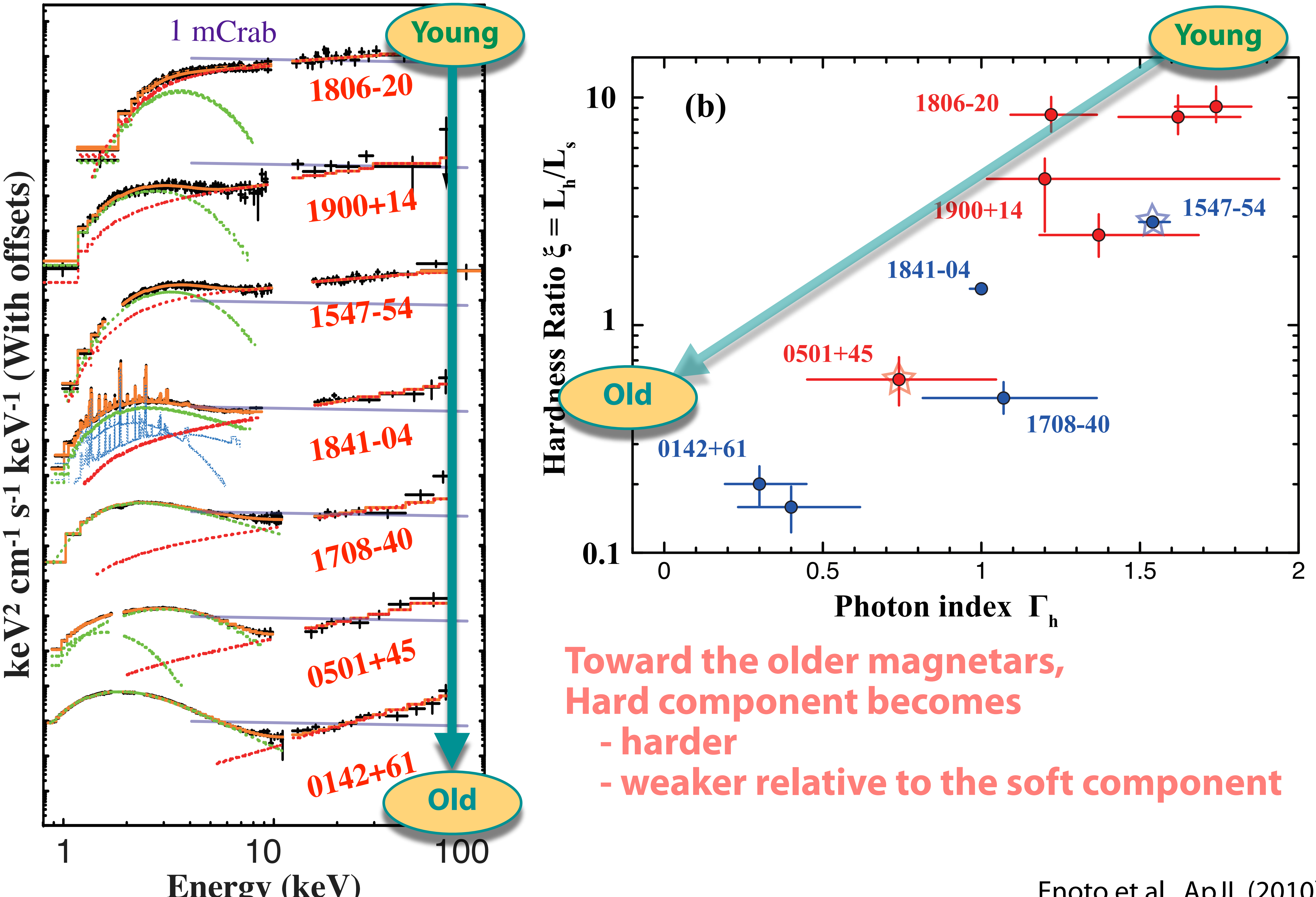




see also Kaspi+2010

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)

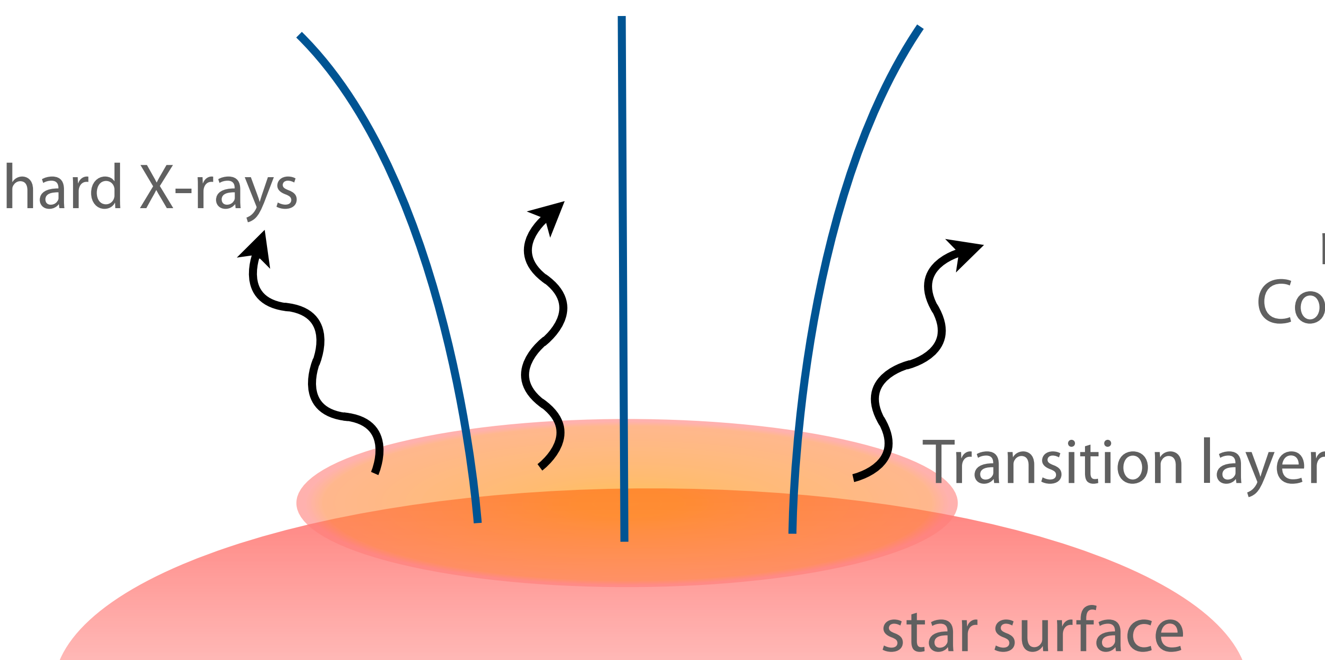
Emission Mechanism

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.

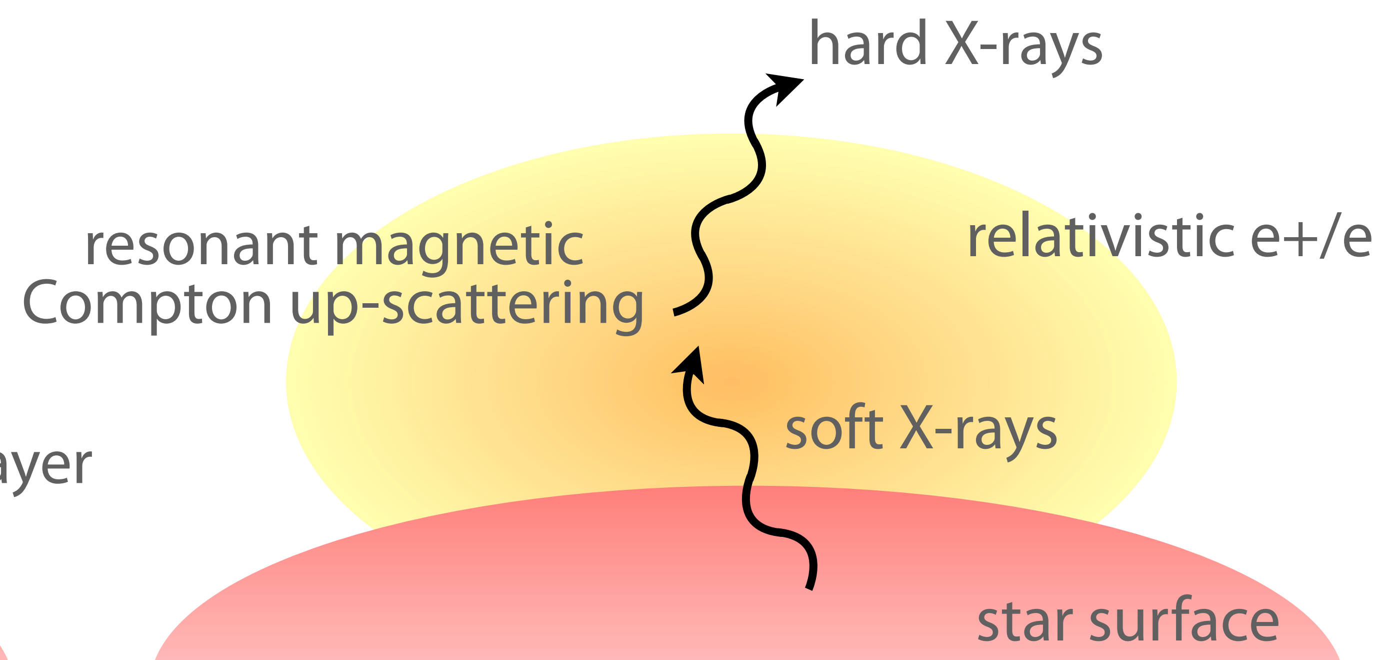
Thermal Bremsstrahlung ?

(Thompson & Beloborodov 2005)



Resonant Compton up-scattering?

(Baring & Harding 2007)



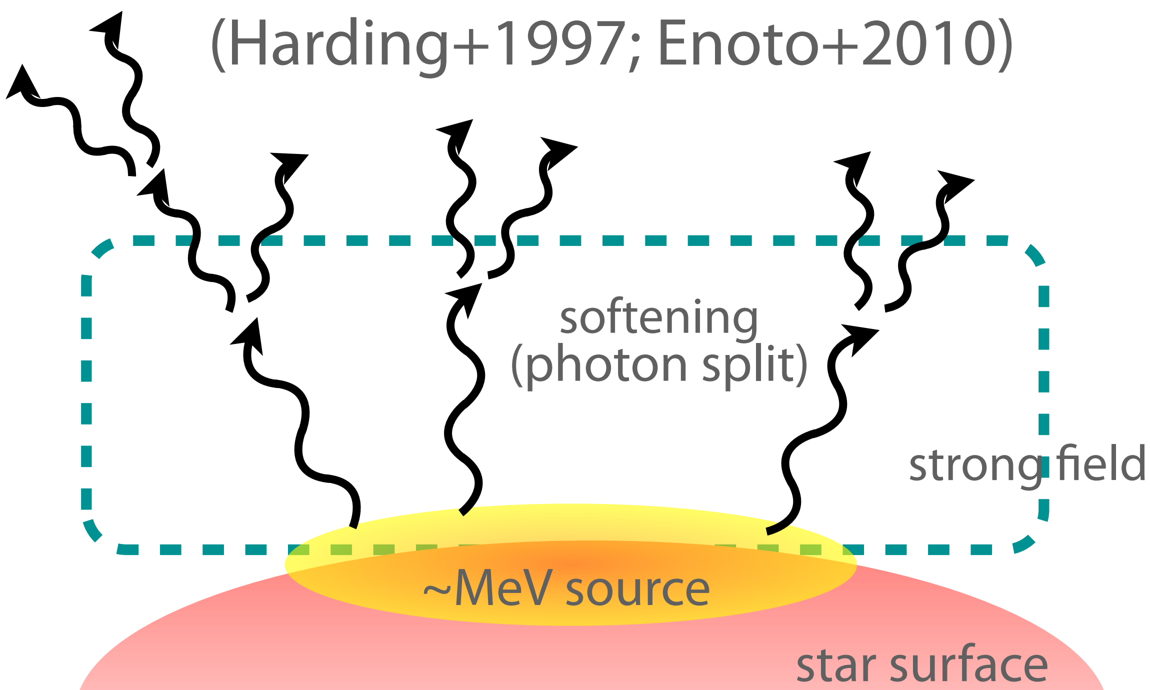
And also other models;
Heyl & Hernquist 2007
Trumper+2010

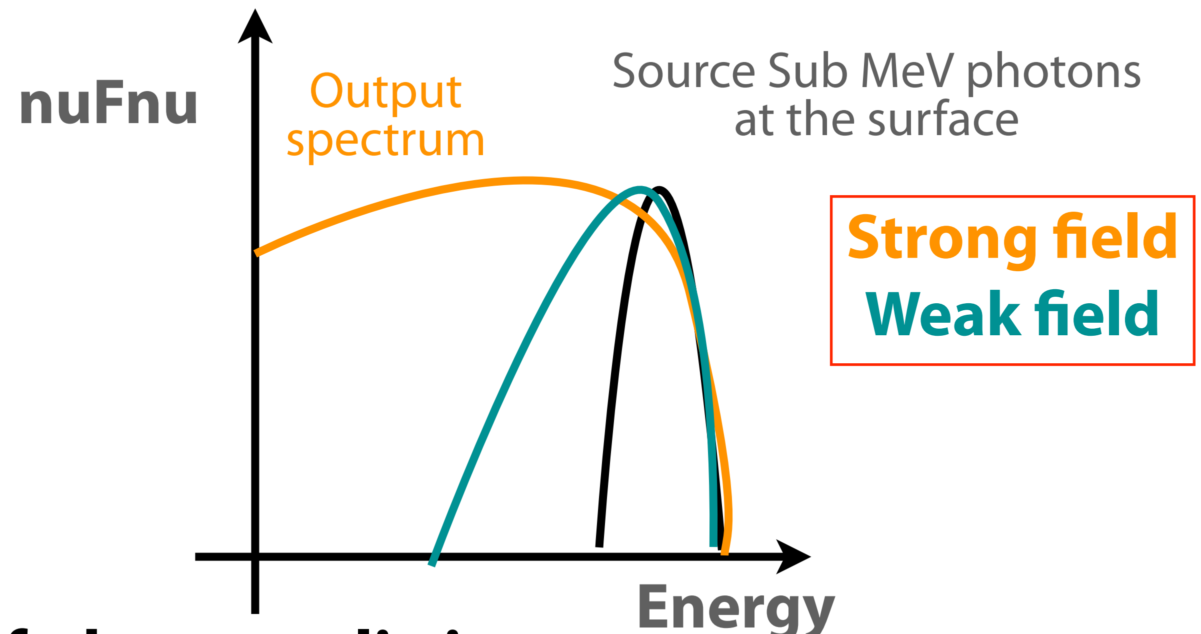
Down Cascade via "Photon Splittings"

Photon Splitting Effect?

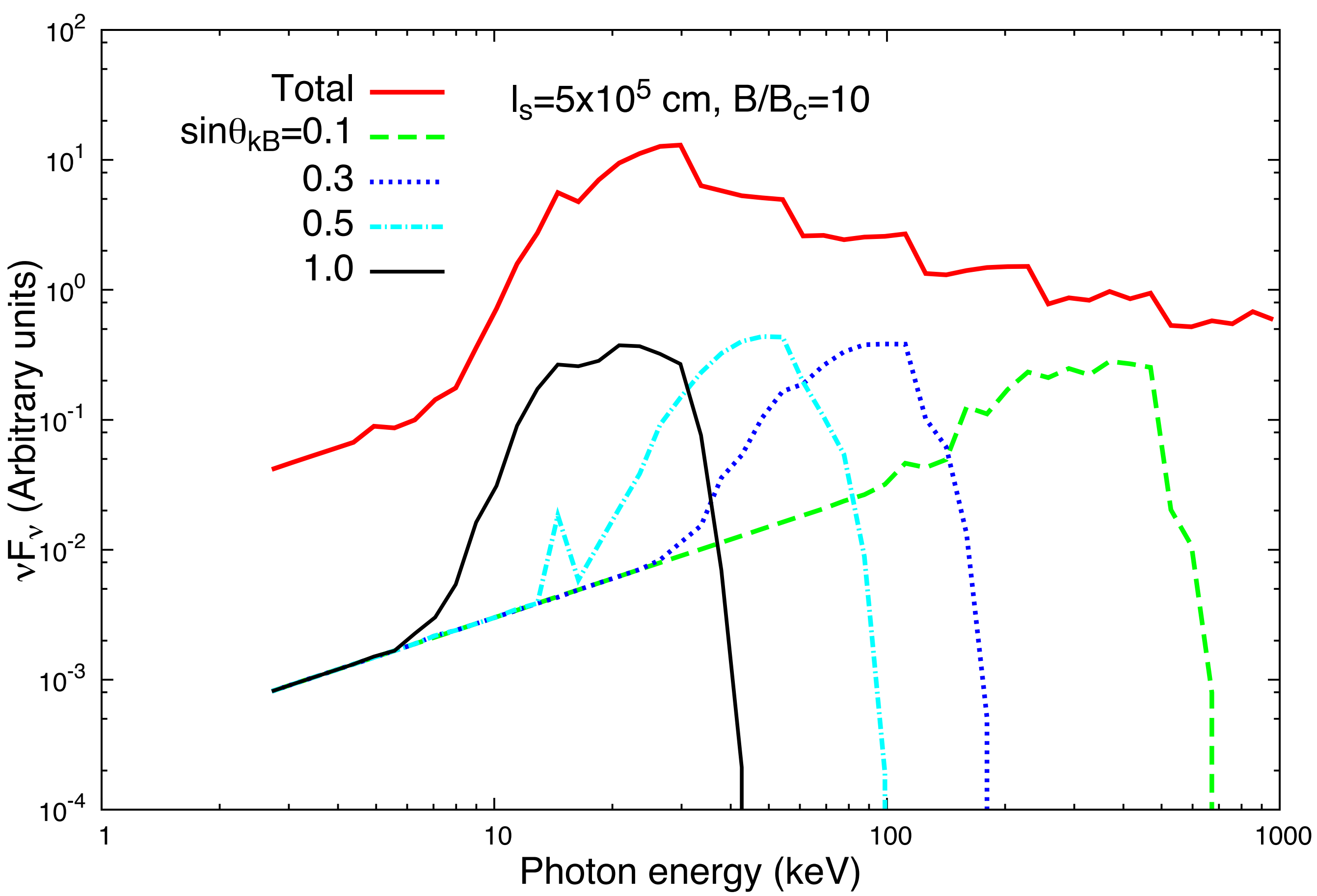
(Harding+1997; Enoto+2010)

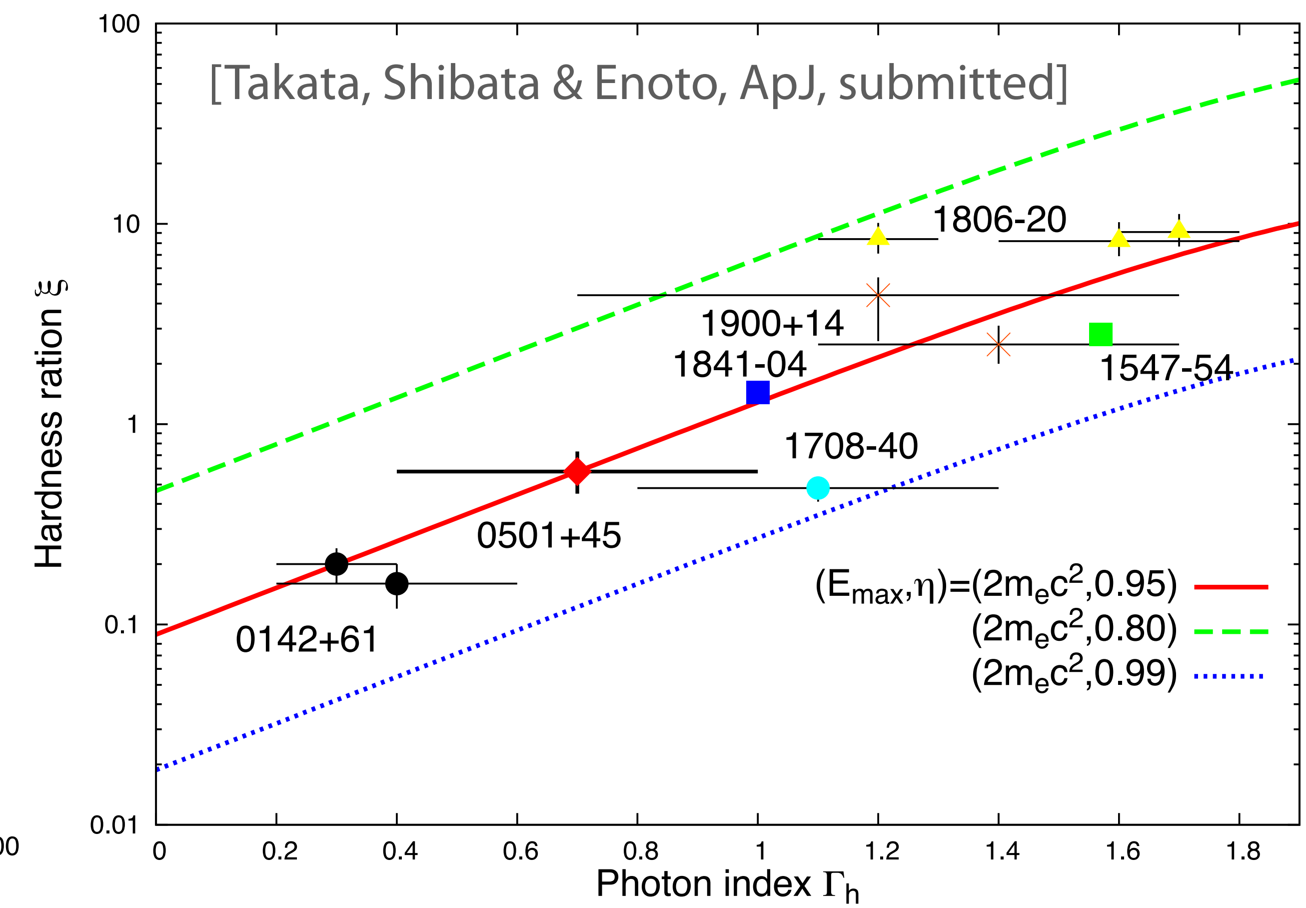
$$\hbar \frac{eB}{m_e c} = m_e c^2 \quad \Rightarrow \mathbf{B = 4.4e+13\ G}$$



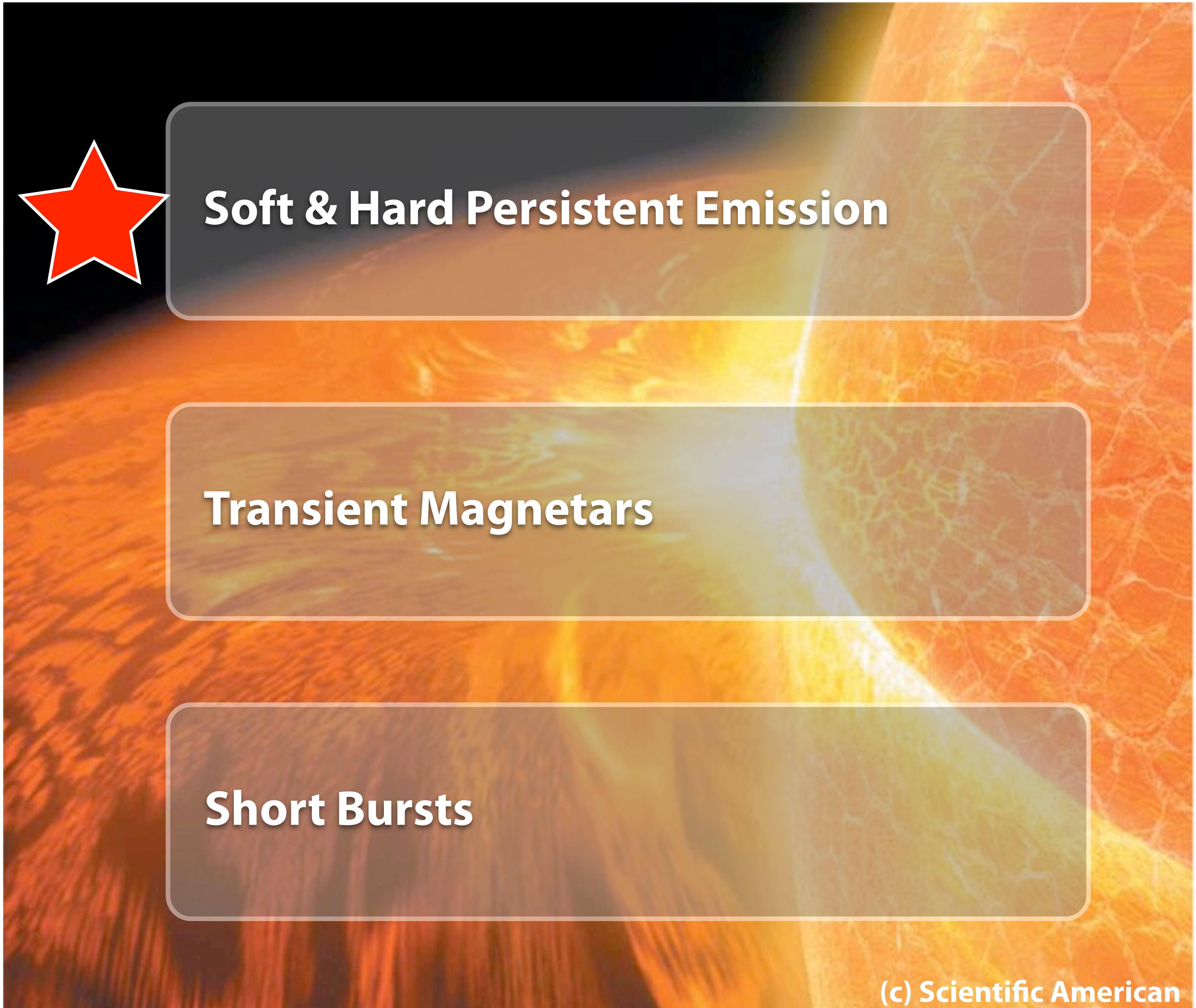


Theoretical Simulation of photon splittings



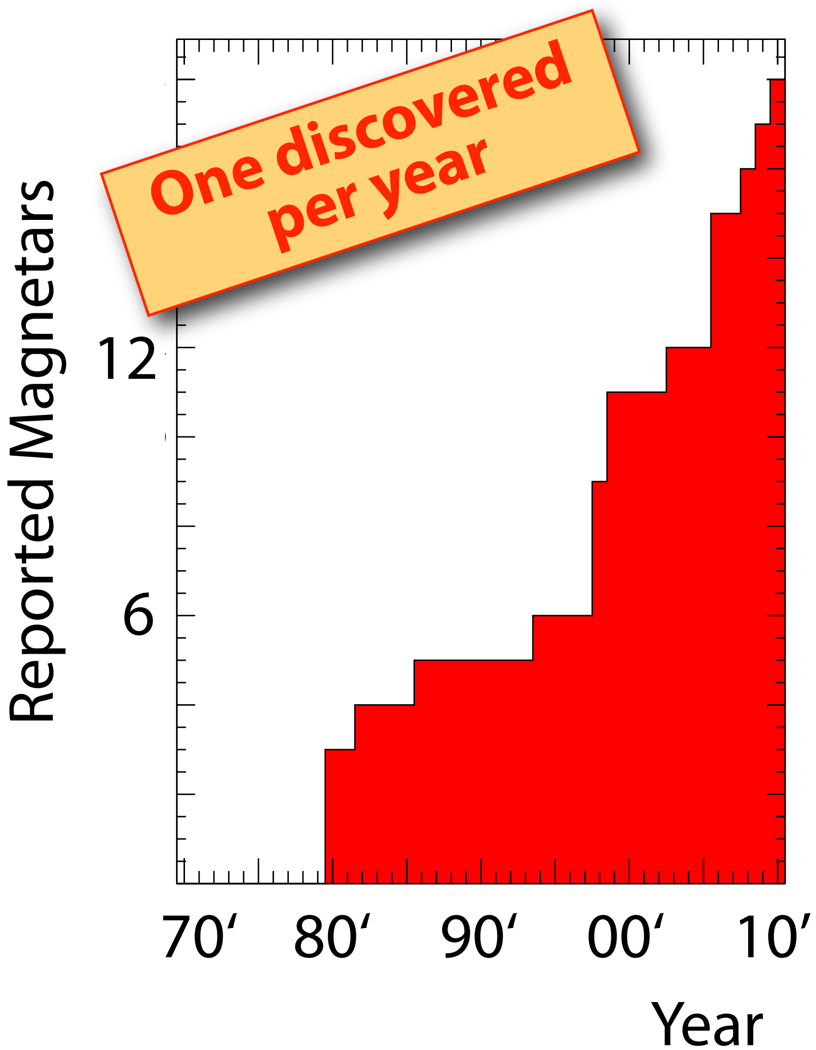


Main Suzaku Topics on Magnetars

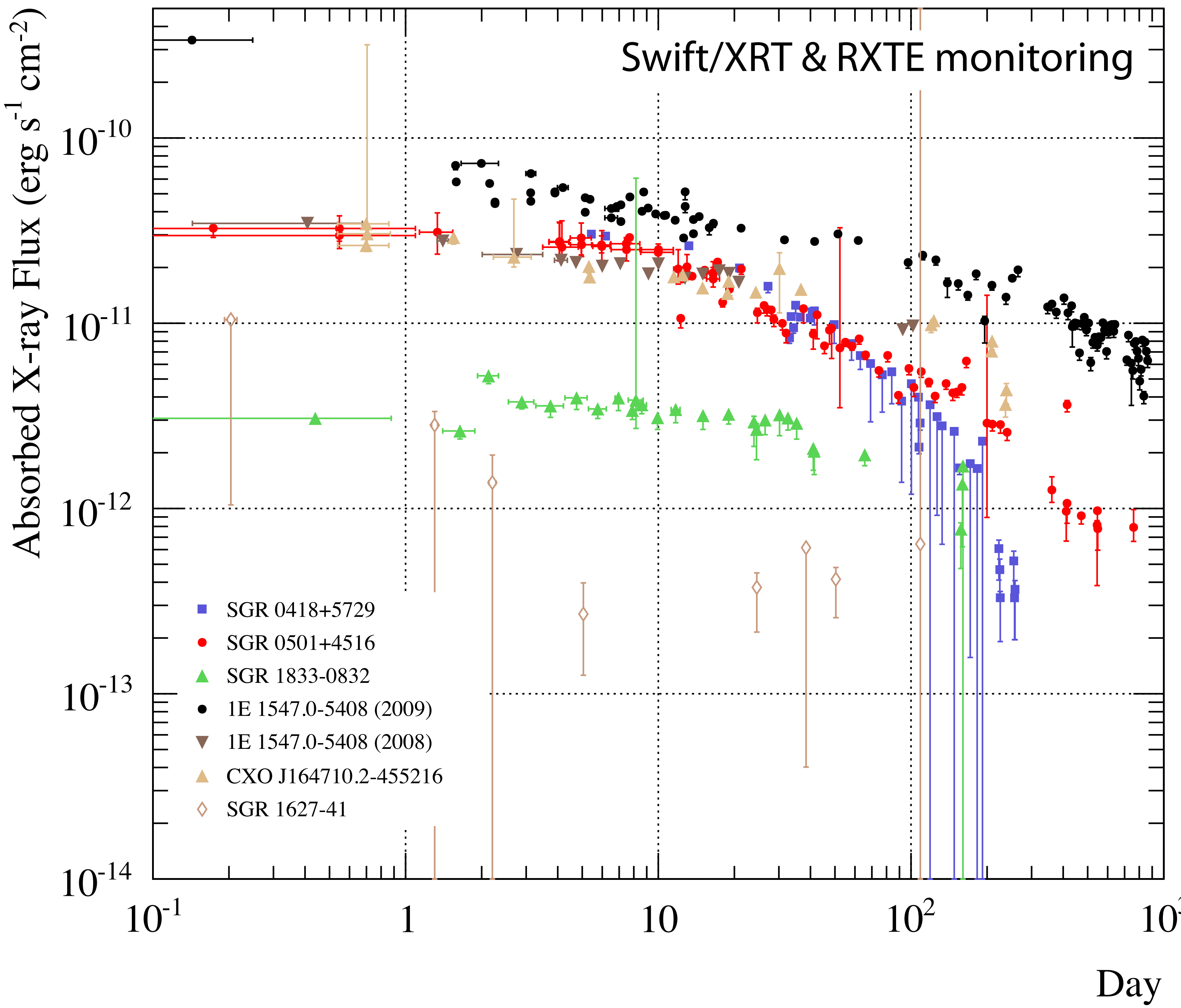


Recent Transient Magnetars

- Discovered through short bursts by Swift/BAT
- Outburst of persistent emission (brighter by 1-2 orders of magnitude)

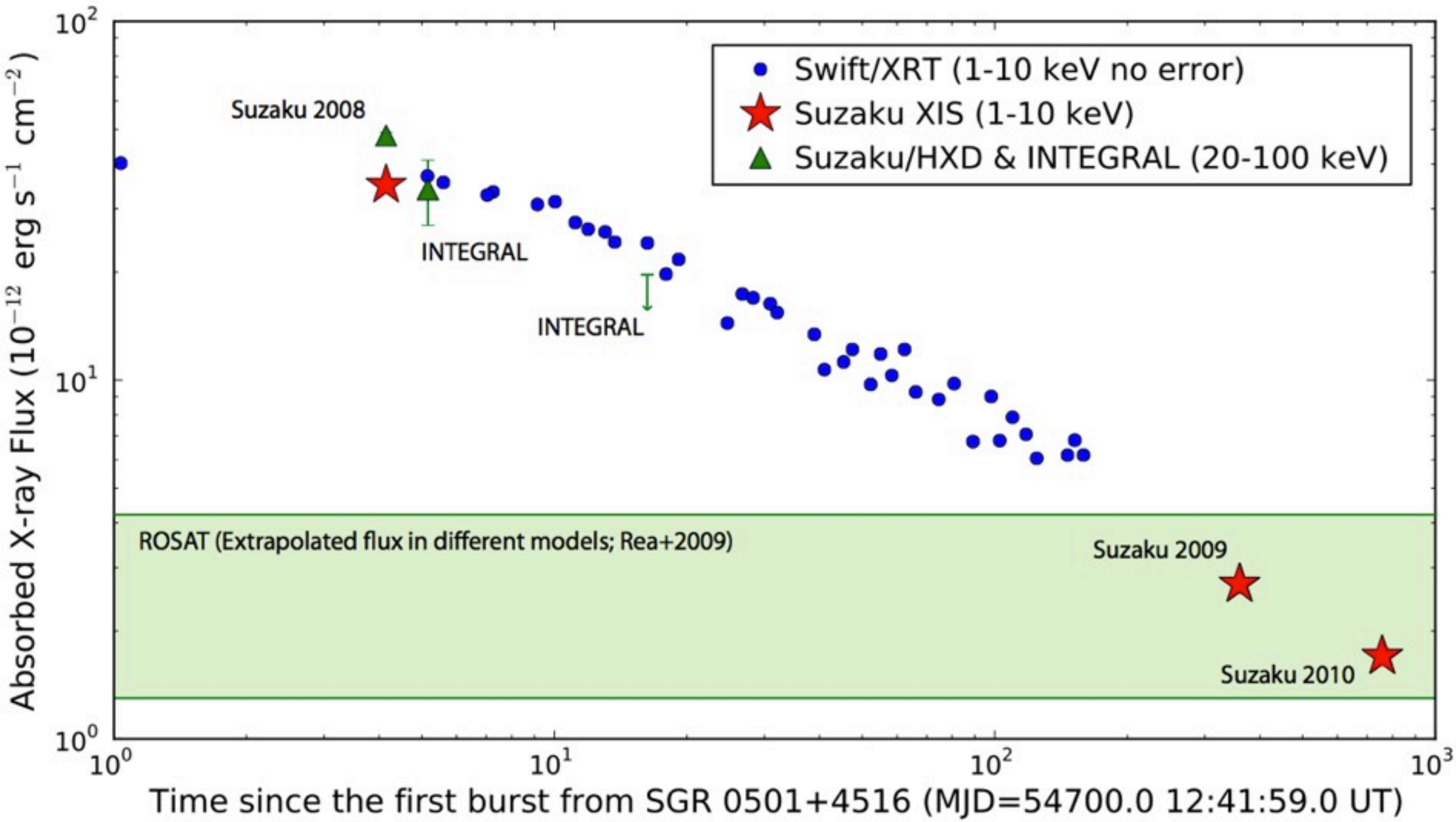


Soft Component (2-10 keV)



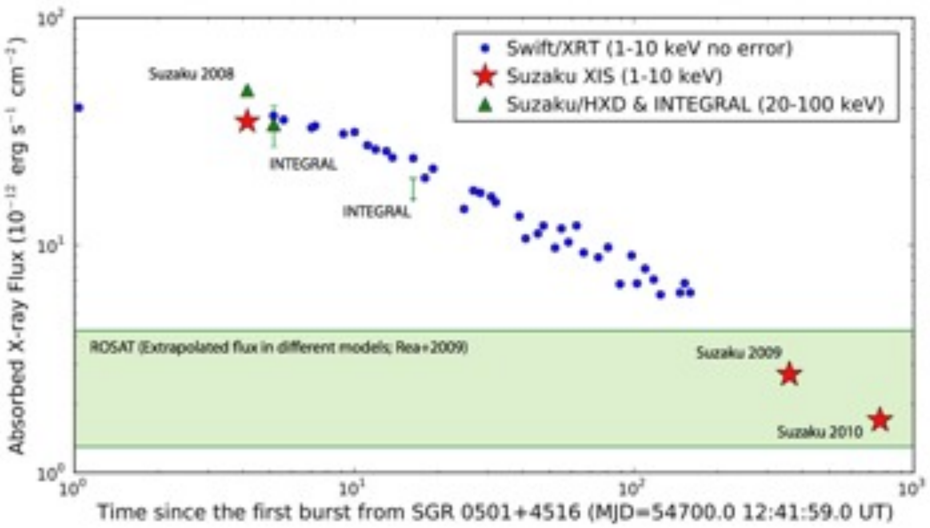
X-ray Decay (slope, initial phase) : "stellar interior" or "reconnection"

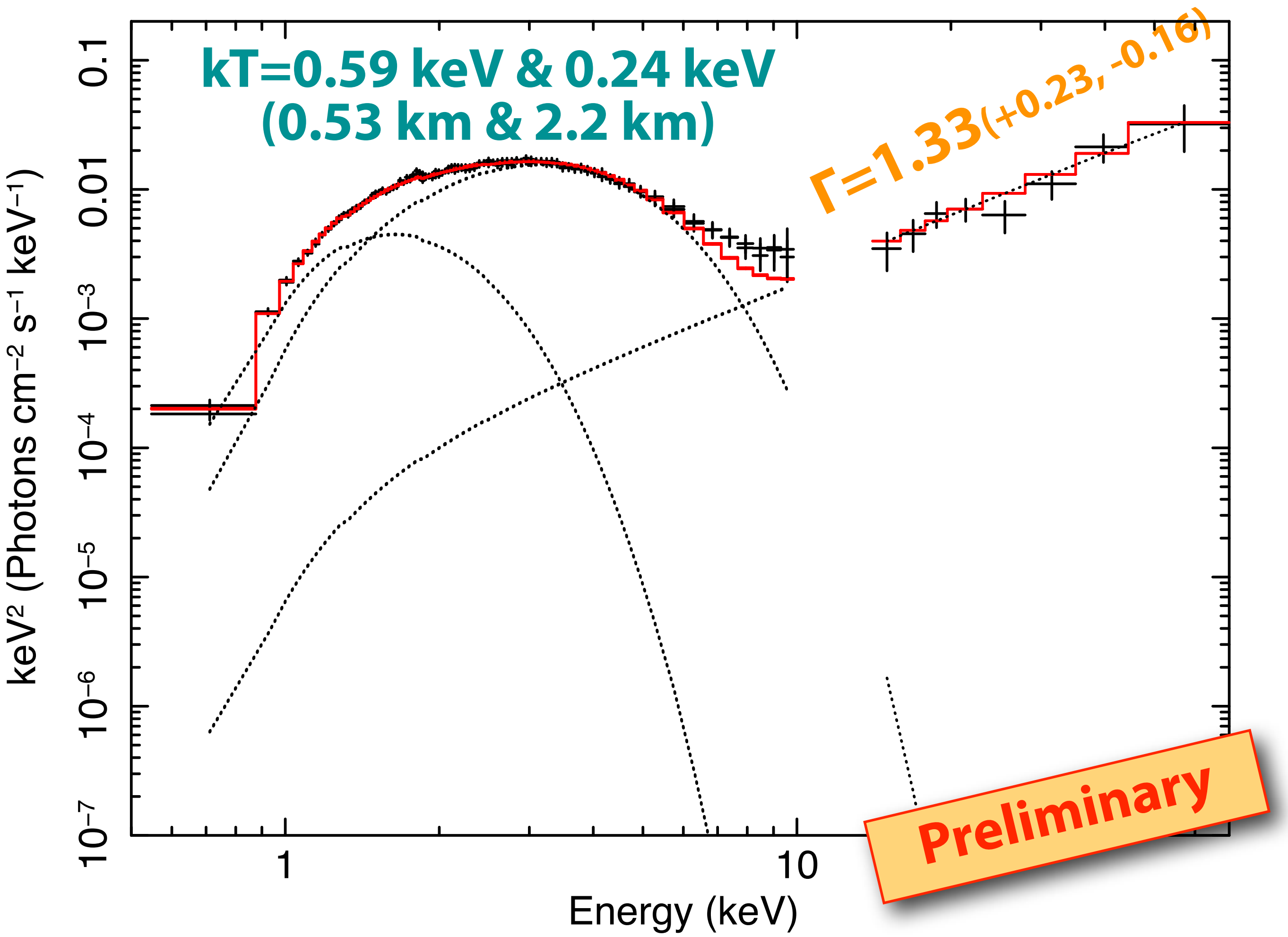
X-ray Decay SGR 0501+4516 & 1E 1547.0-5408



X-ray Decay SGR 0501+4516 & 1E 1547.0-5408

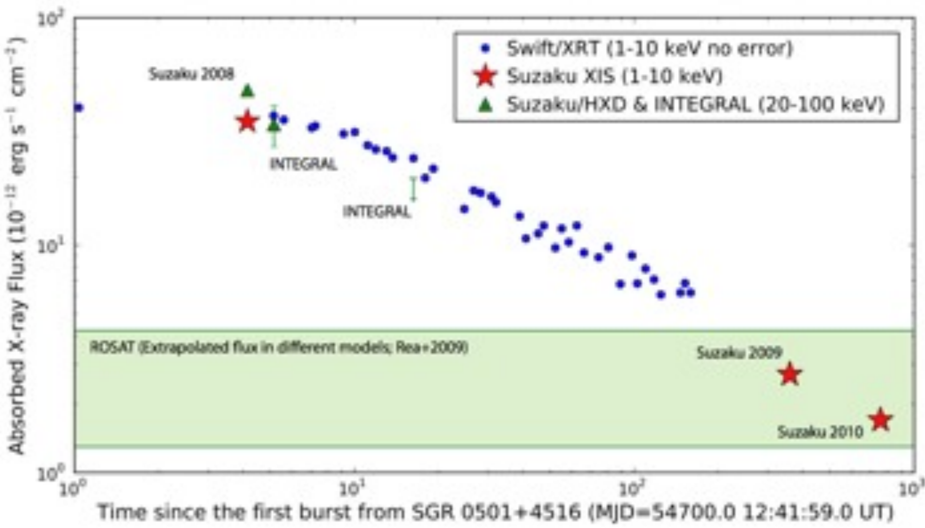
SGR 0501+4516

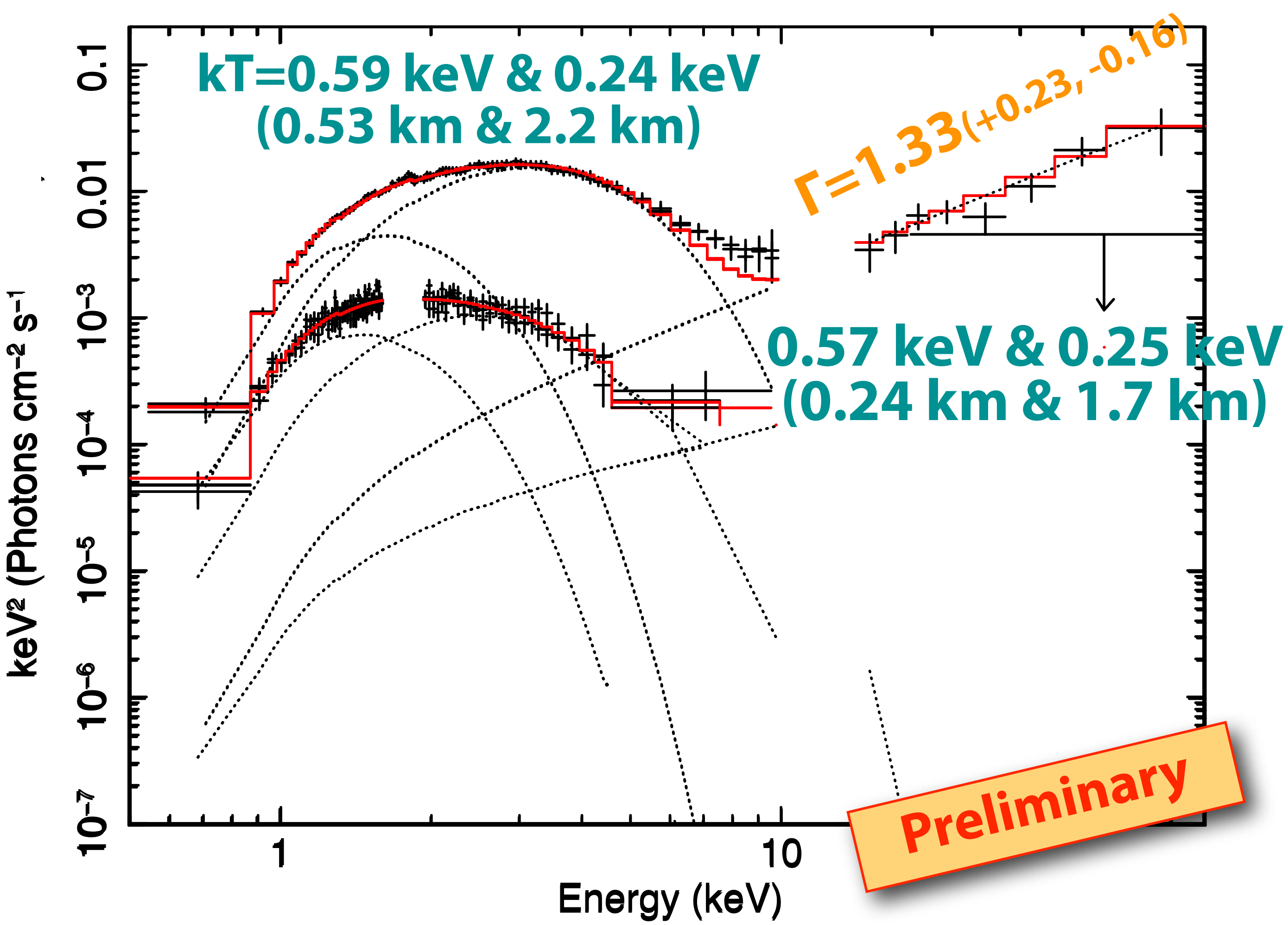




X-ray Decay SGR 0501+4516 & 1E 1547.0-5408

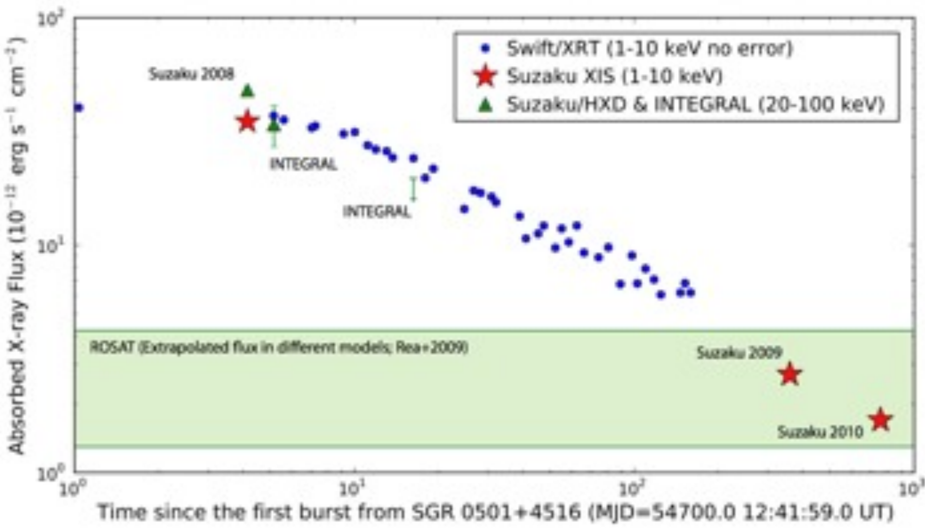
SGR 0501+4516

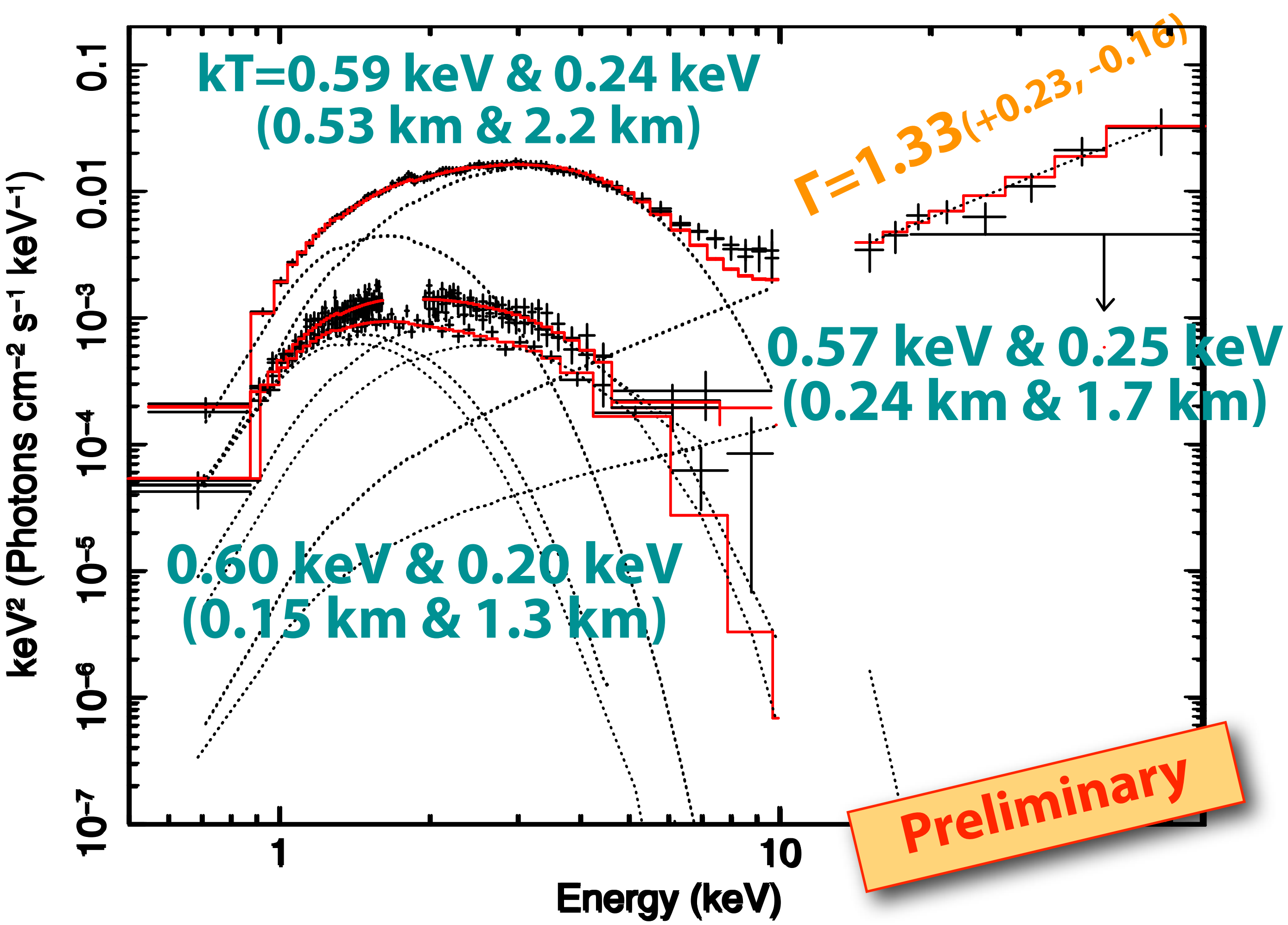




X-ray Decay SGR 0501+4516 & 1E 1547.0-5408

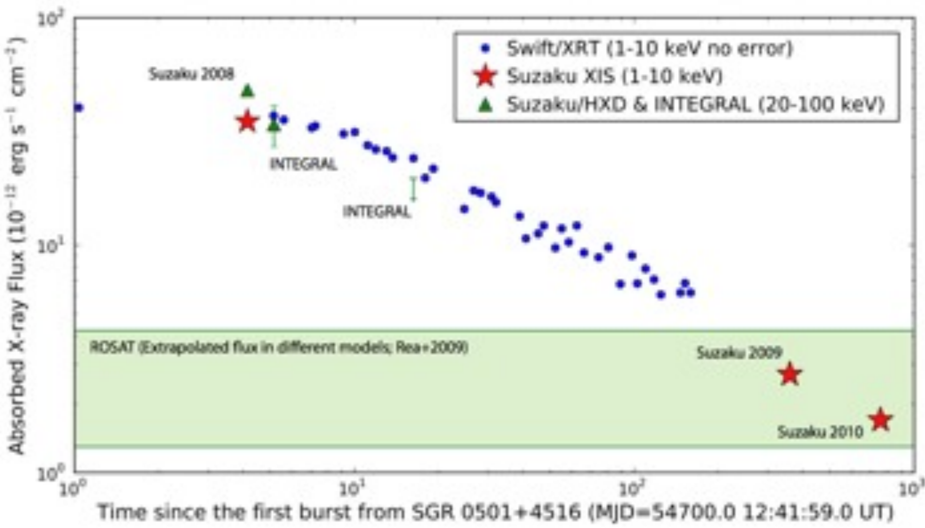
SGR 0501+4516

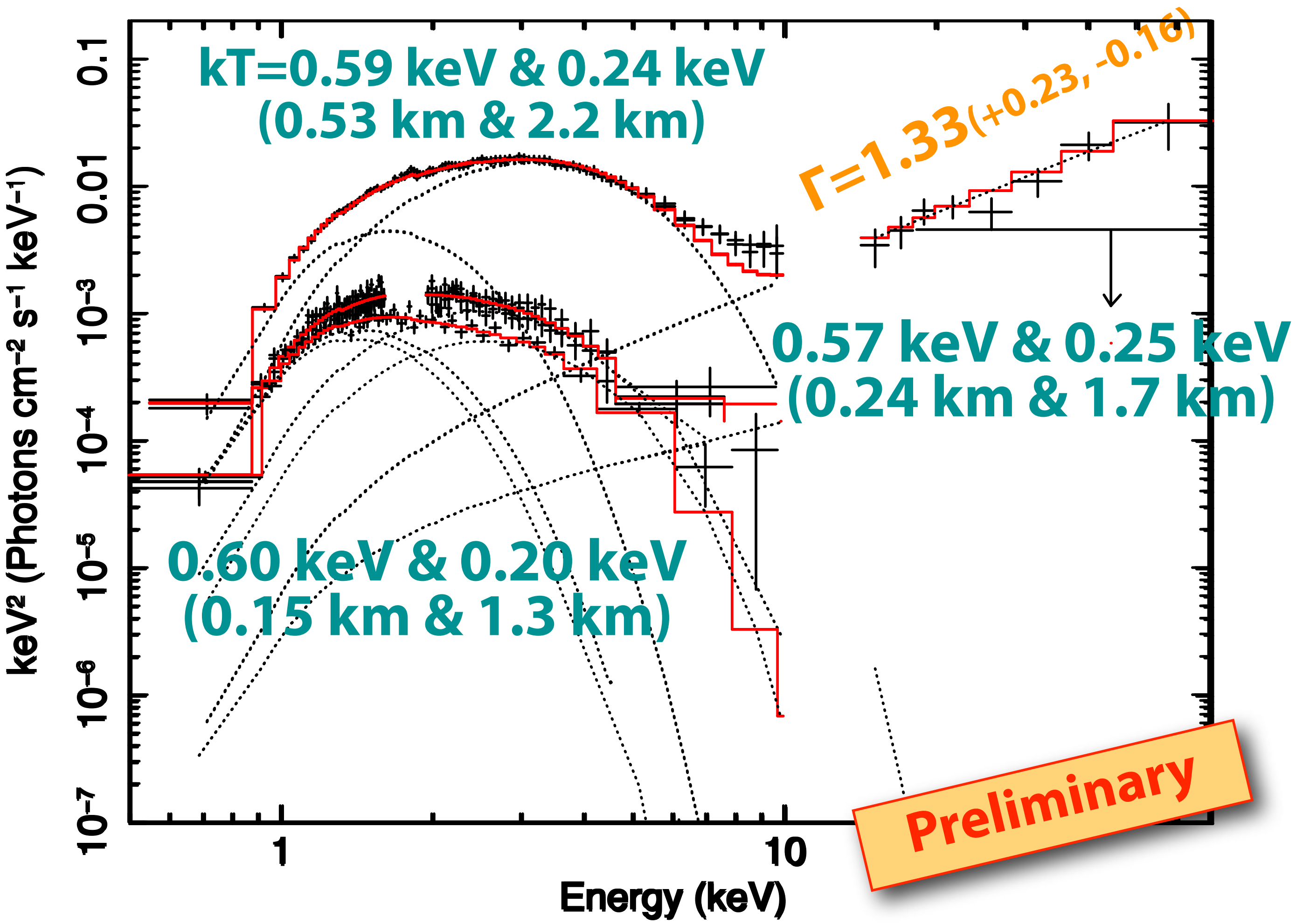




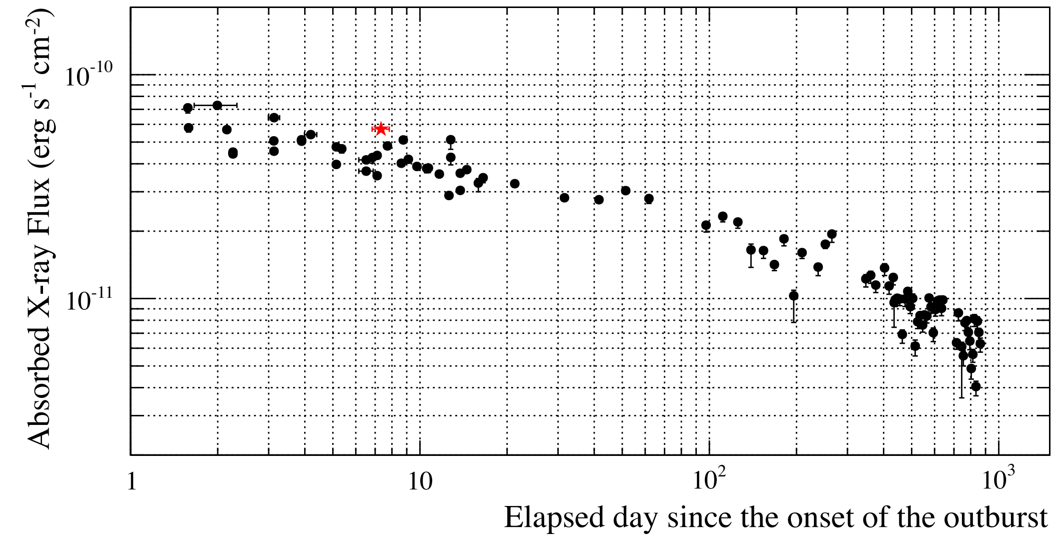
X-ray Decay SGR 0501+4516 & 1E 1547.0-5408

SGR 0501+4516



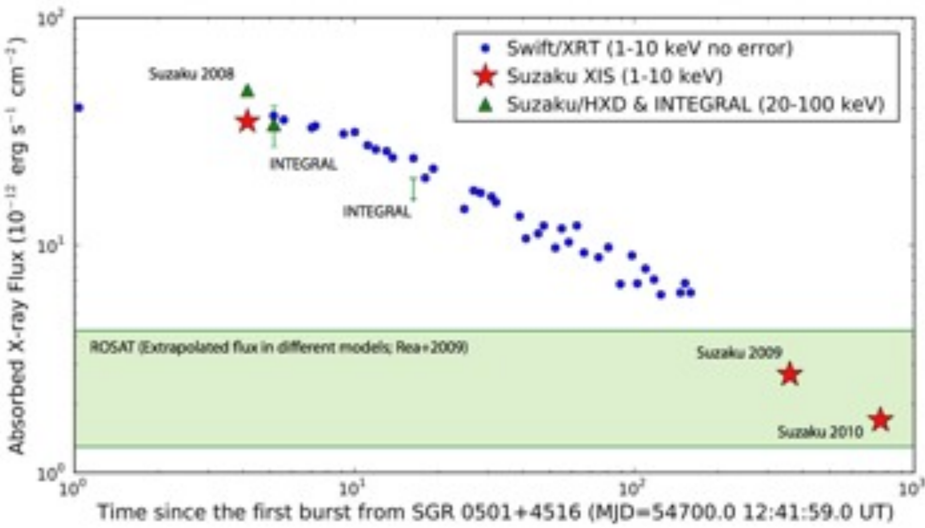


1E 1547.0-5408

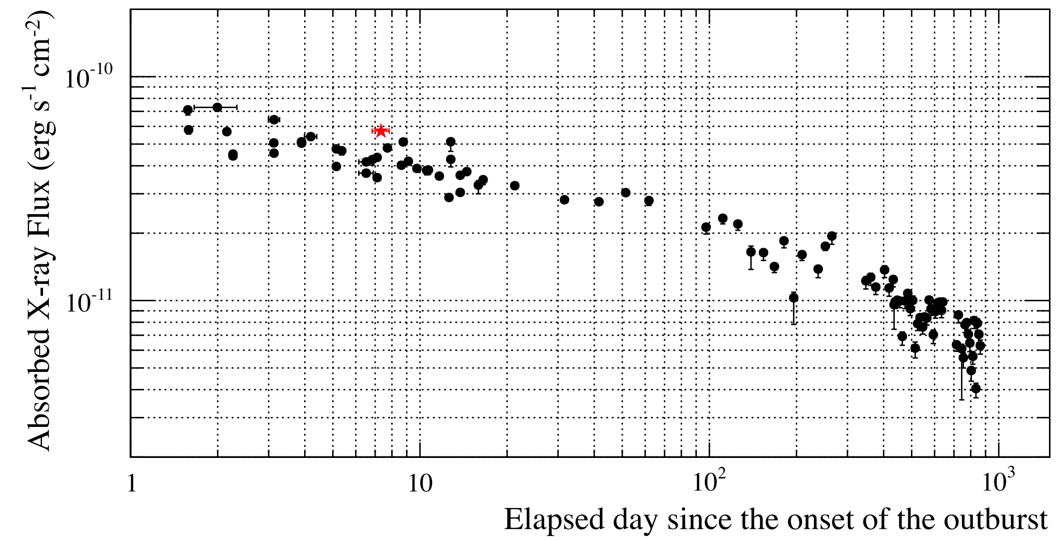


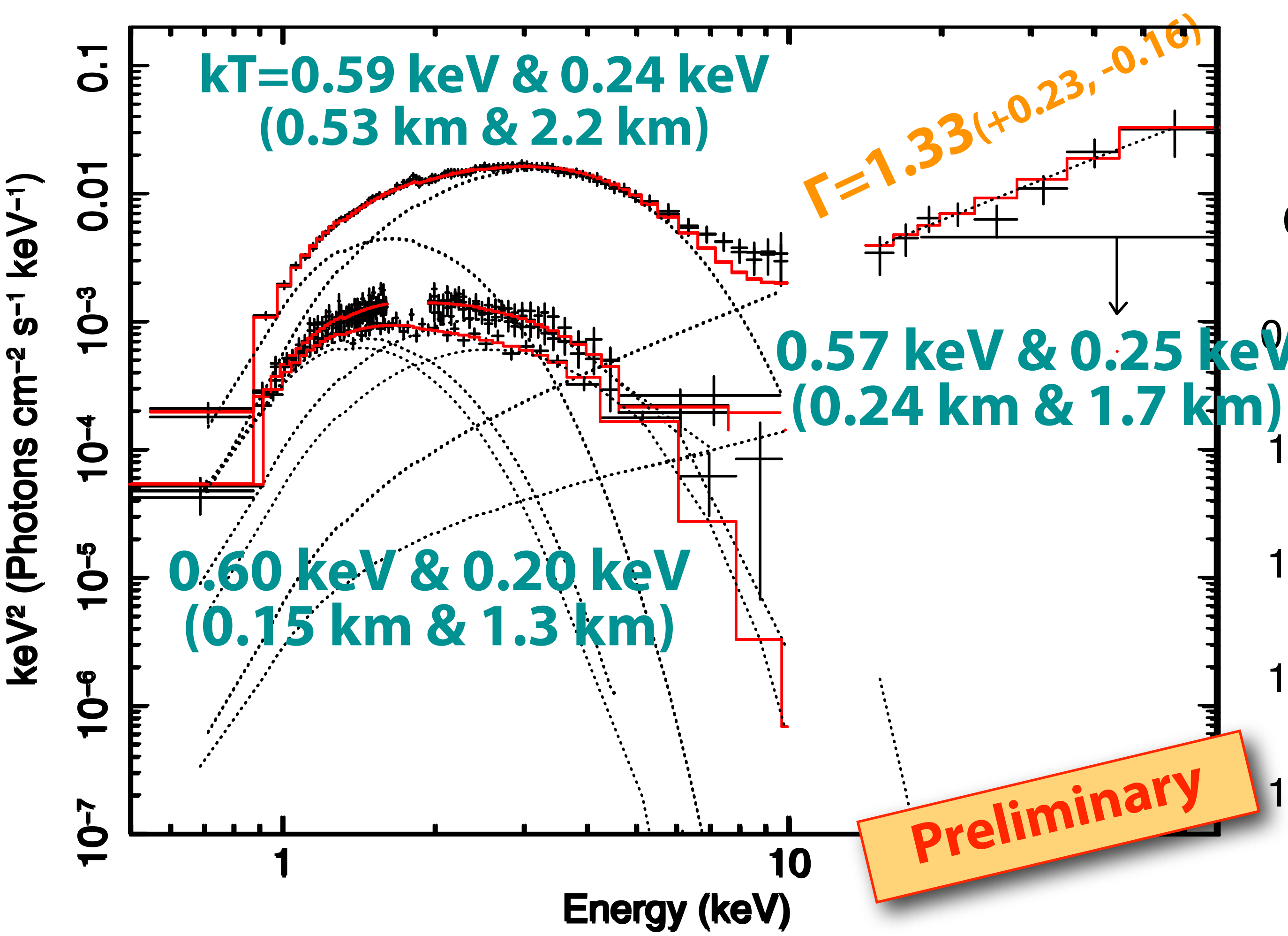
X-ray Decay SGR 0501+4516 & 1E 1547.0-5408

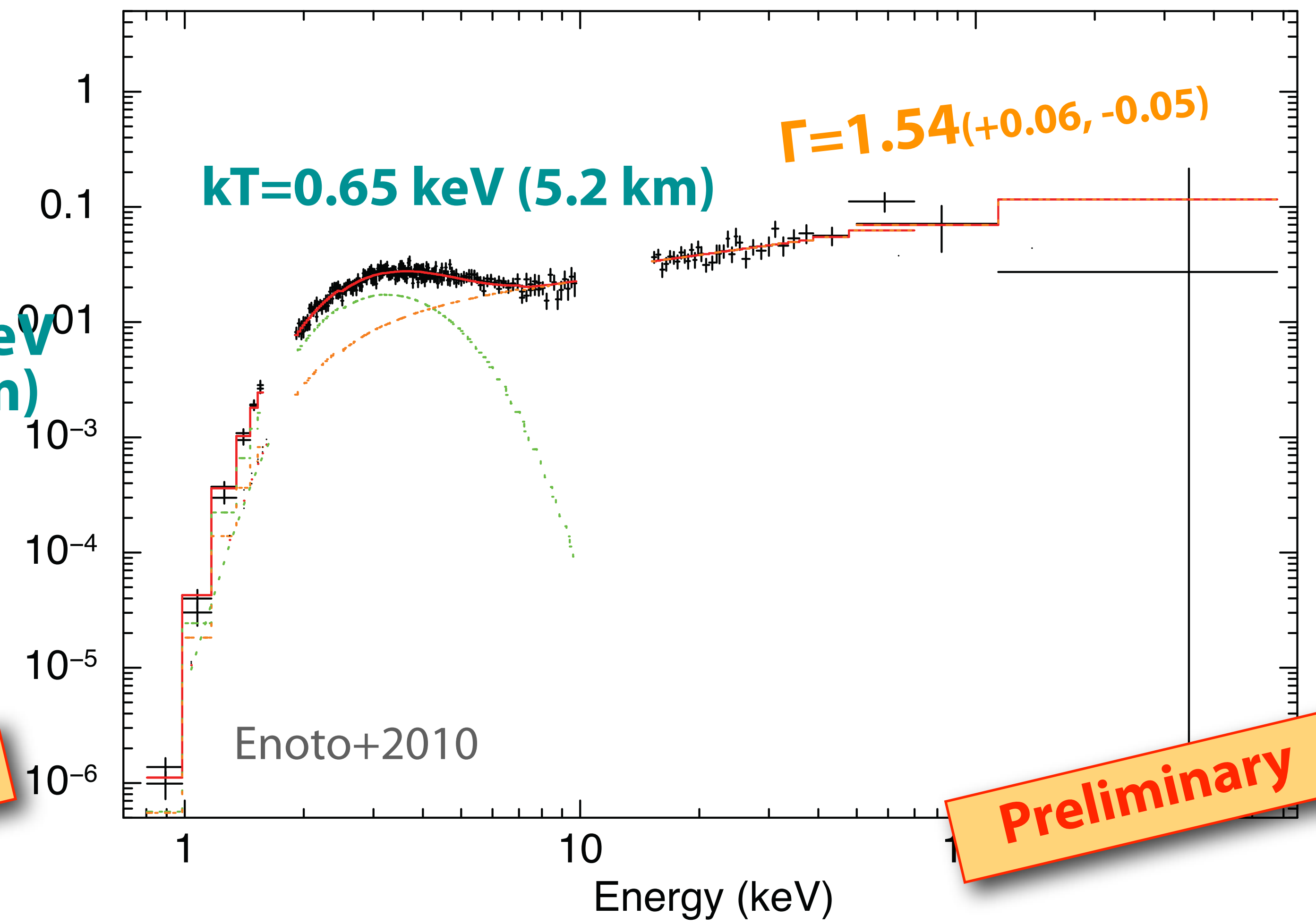
SGR 0501+4516



1E 1547.0-5408

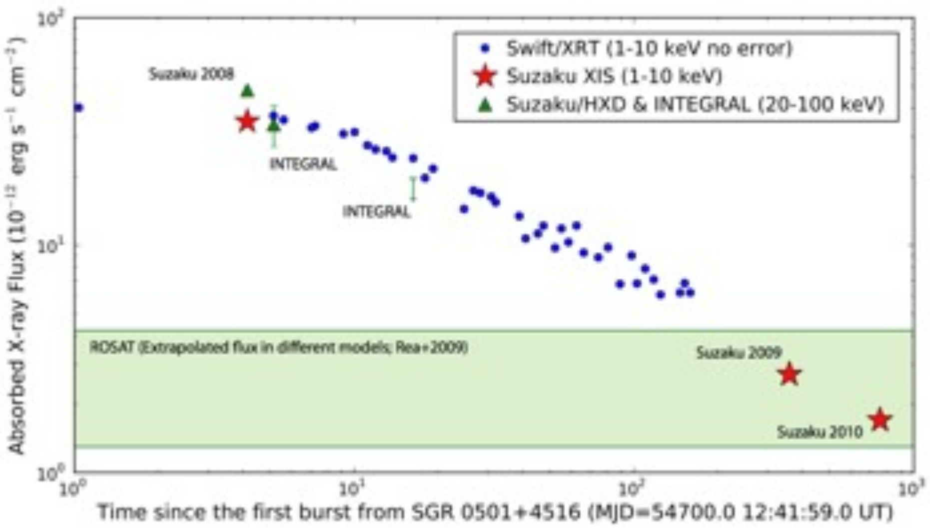




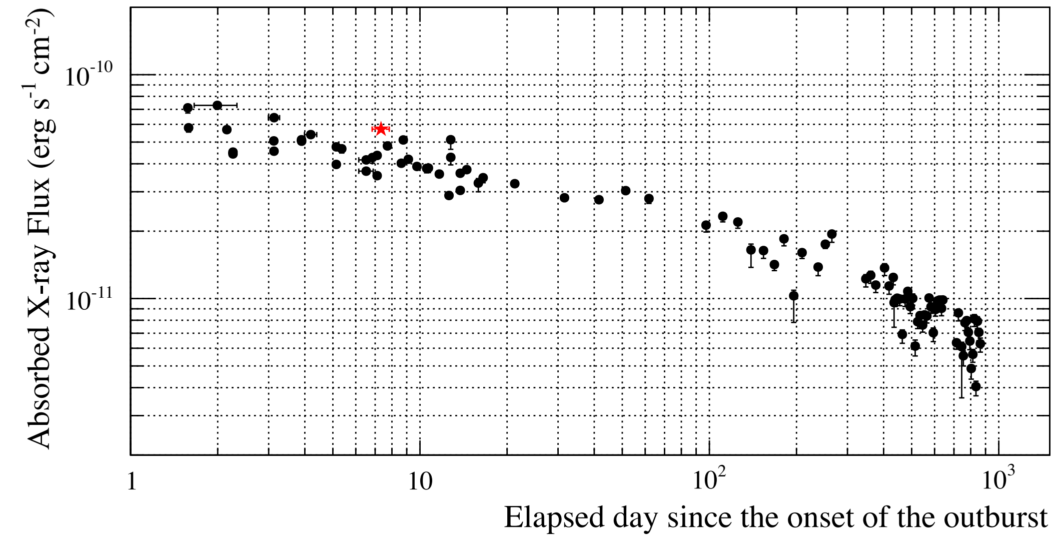


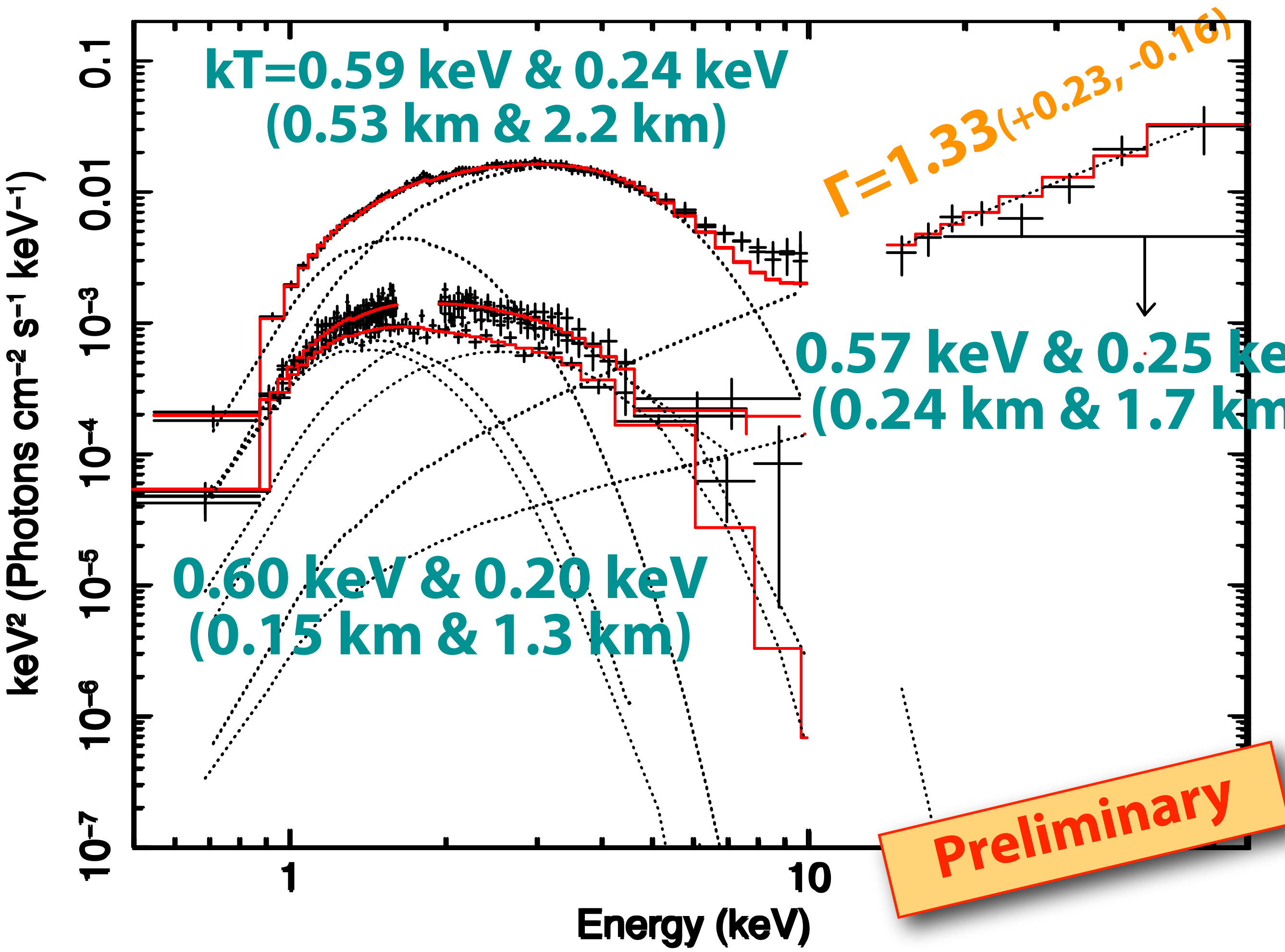
X-ray Decay SGR 0501+4516 & 1E 1547.0-5408

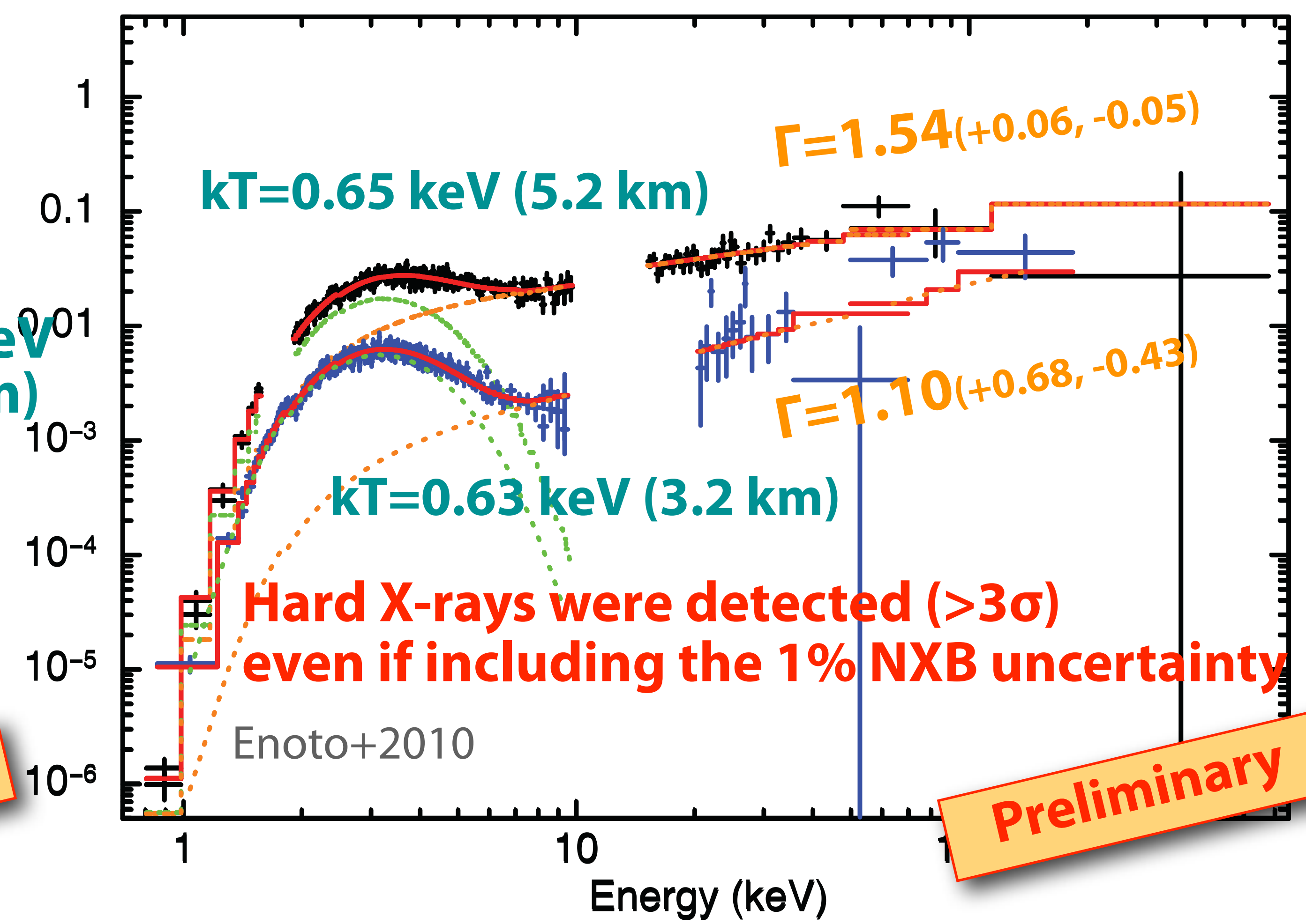
SGR 0501+4516



1E 1547.0-5408



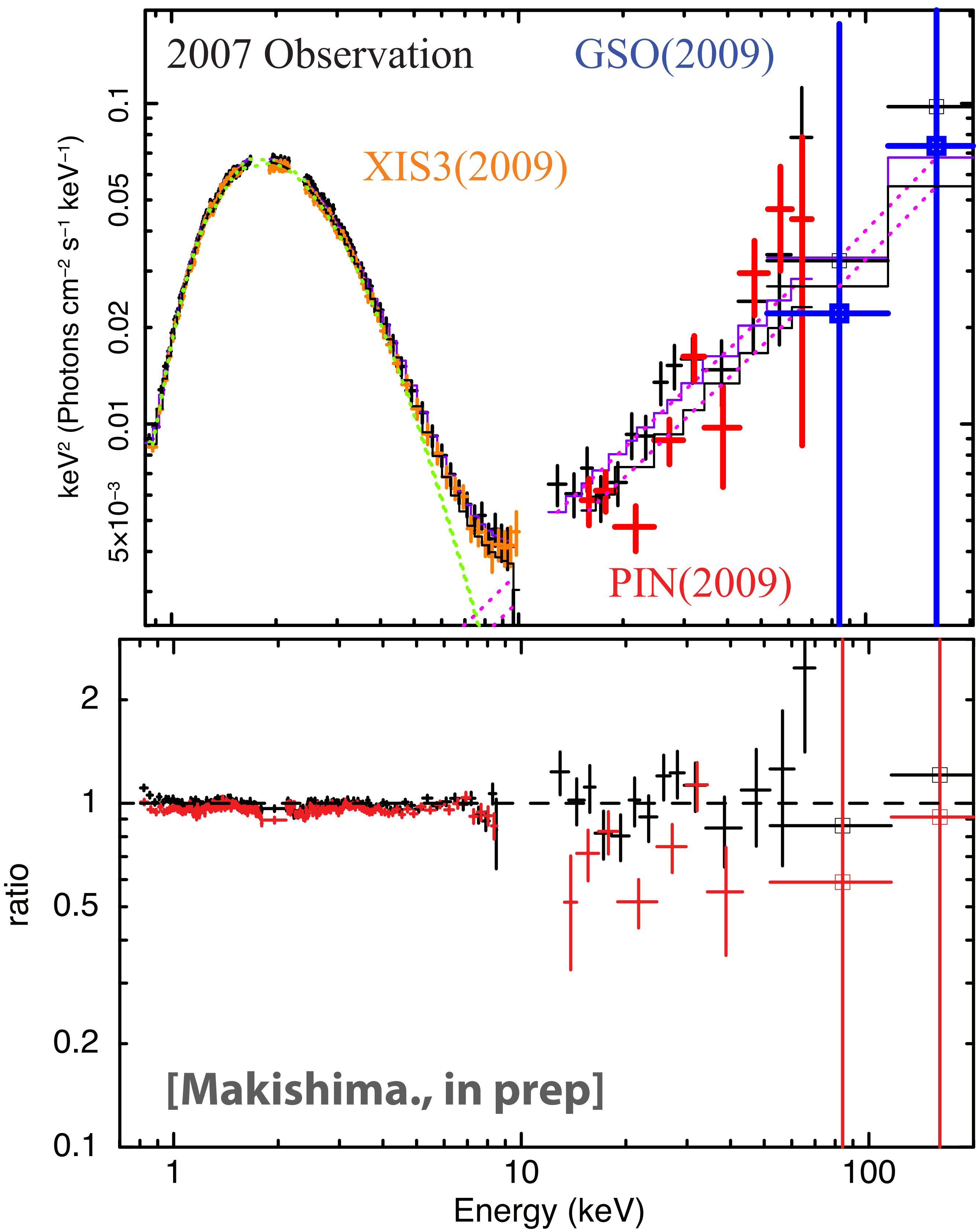




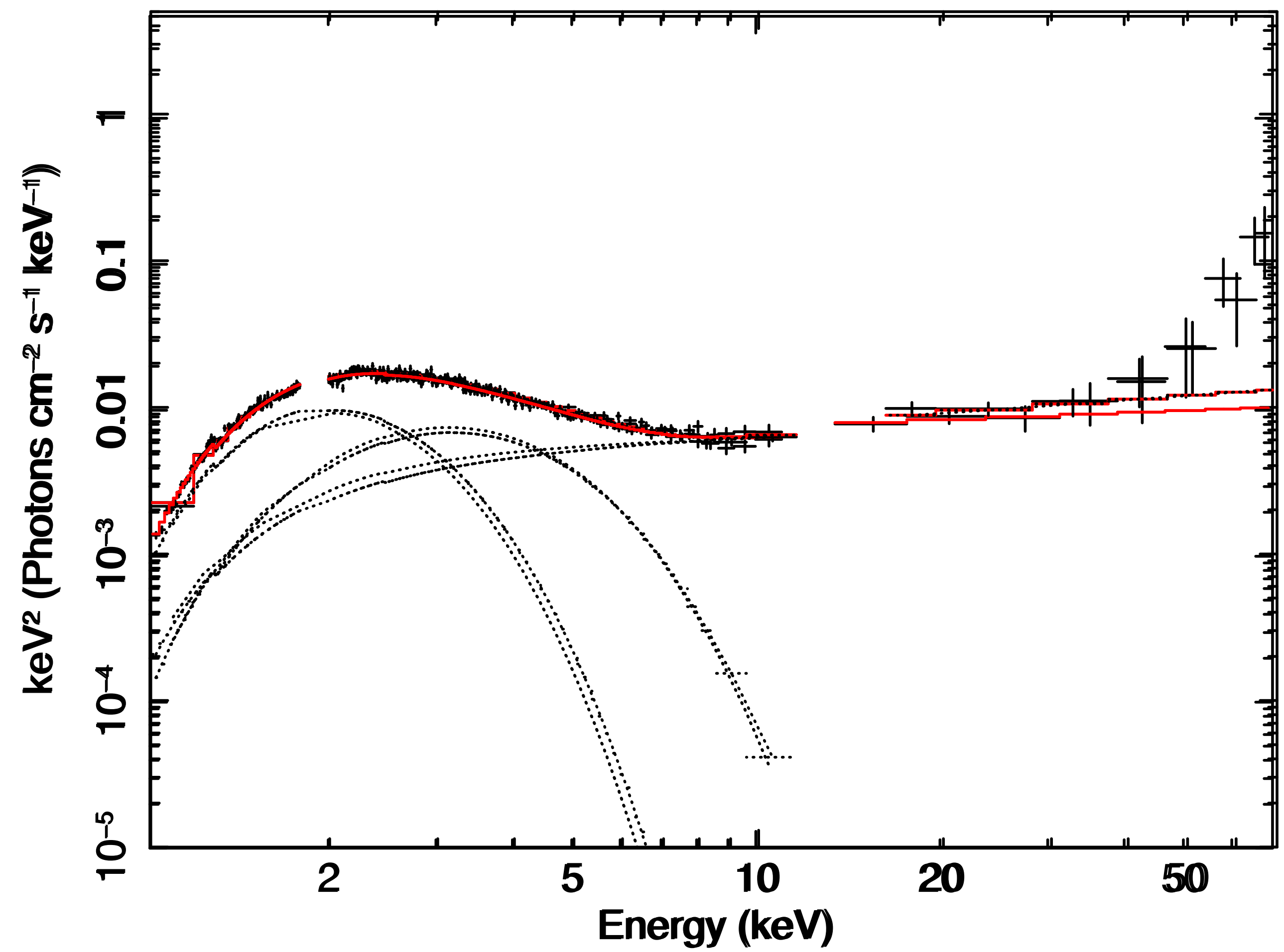
Spectral change in the soft/hard X-rays is a hot topic.

Compare to Quiescent X-ray Emission

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



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



Two Types?

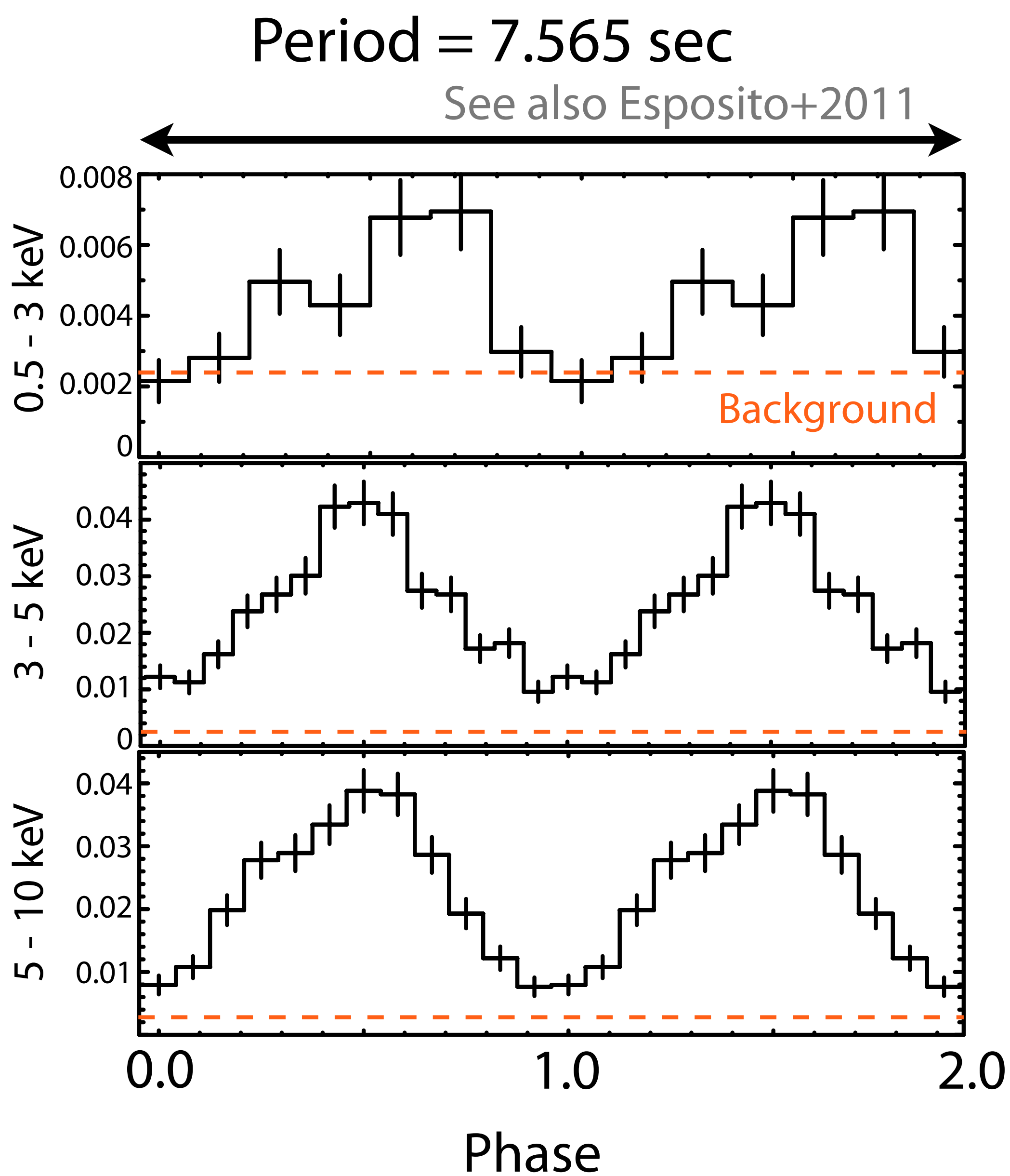
Persistently emitting magnetars (in quiescent) = stable?

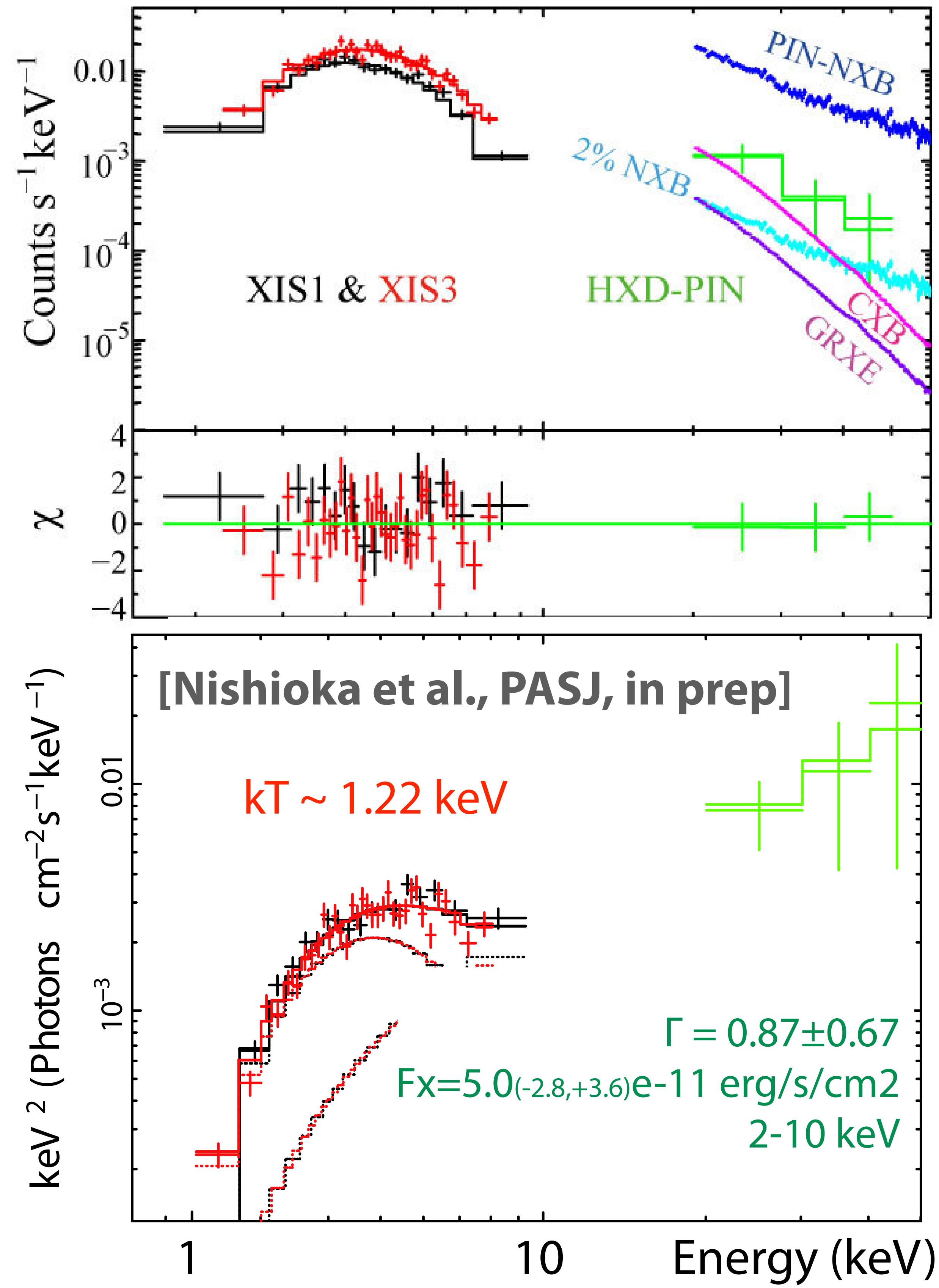
Transient Sources = decay at a month time-scale

New Magnetar: SGR 1833-0832

New magnetar discovered by Swift/BAT & RXTE on 2010 March 19

Suzaku ToO on 2010 March 27 (40 ks)





A sign of the hard X-rays (~2.4σ) in 15-50 keV

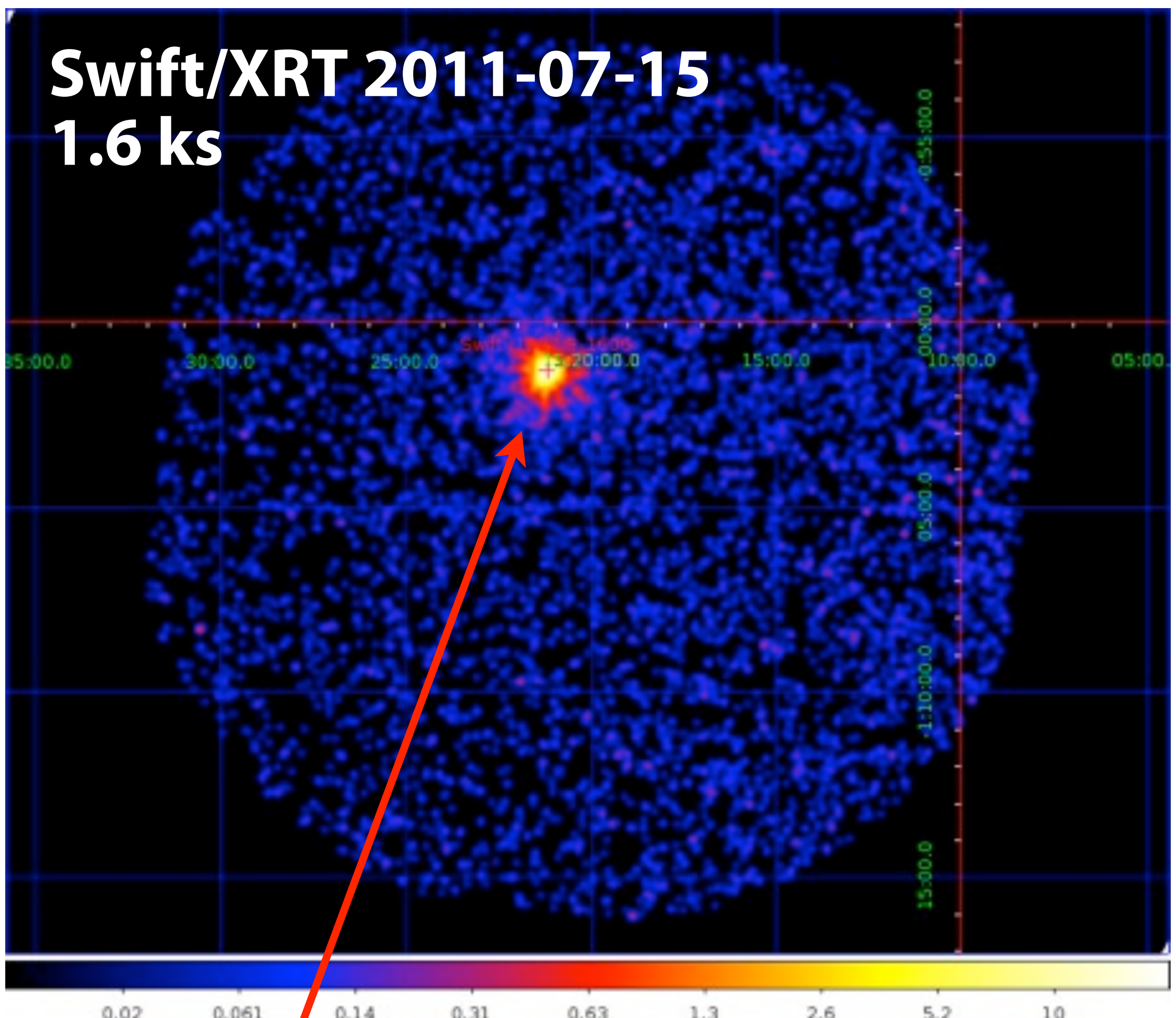
Unfortunately, Suzaku could not observed recent transients SGR J0418+5729 (Rea+2010, Science), but....

Possible New SGR?? Swift J1822.3-1606

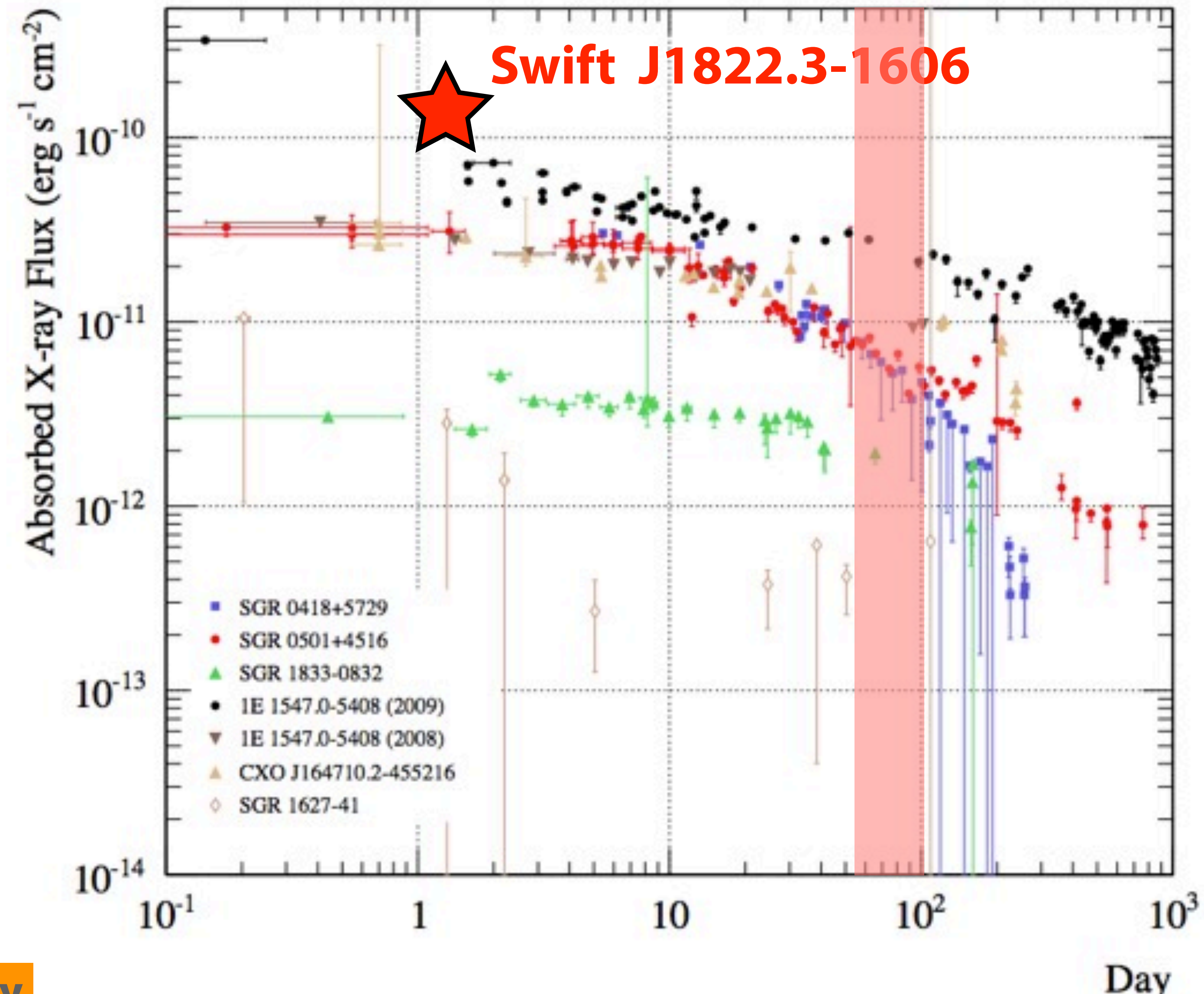
Discovery from a short burst by Swift/BAT (**2011-07-14 at 12:47:47.1 UTC**) [Atel #3488]

- Along the Galactic plane (l, b) = (15, -1.0)
- P ~ 8.43 sec [Atel #3491, #3489]
- Transient Behavior in X-rays

→ New Magnetar??



Suzaku Window (55-101 days after the onset)

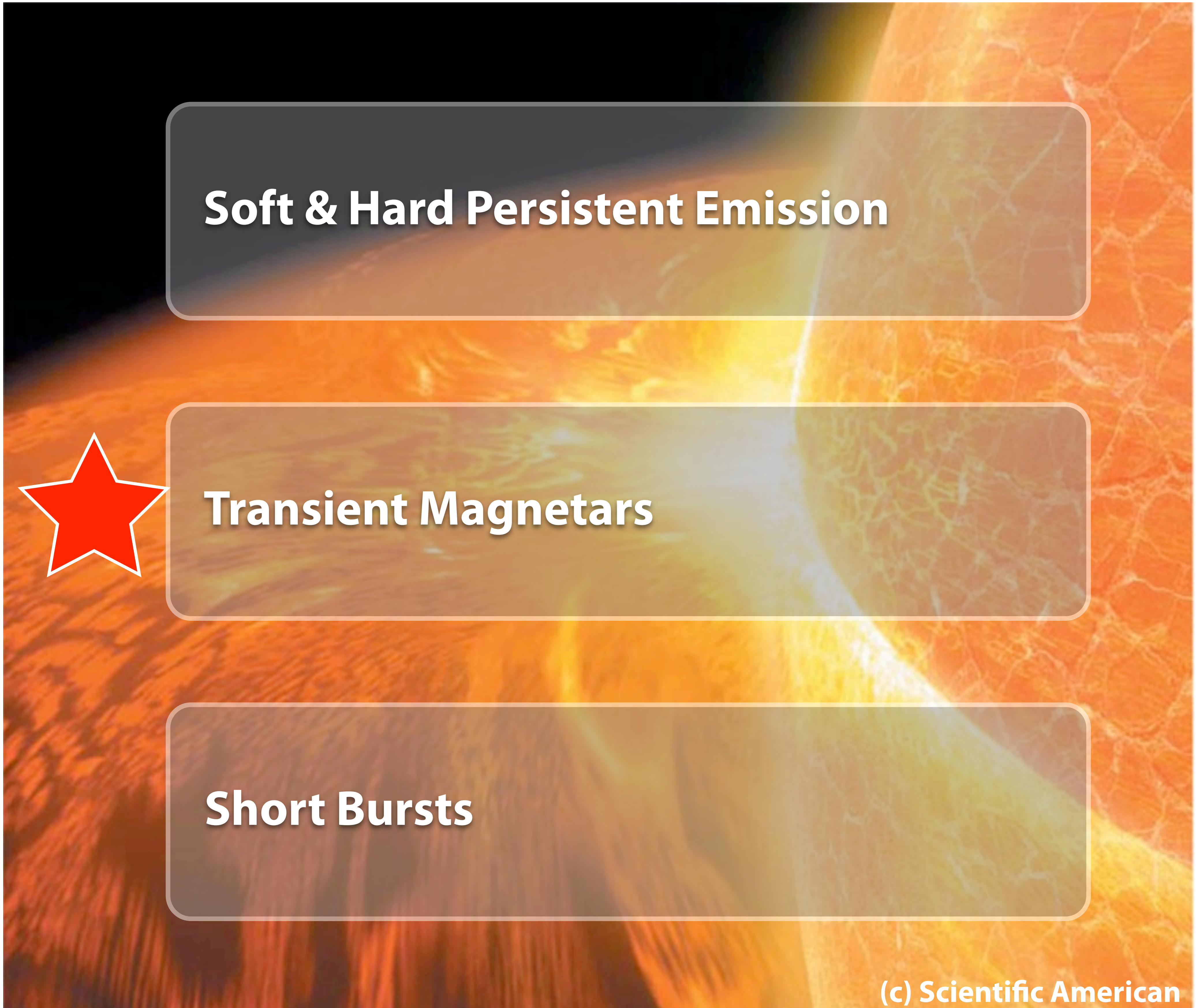


Blackbody Model Preliminary

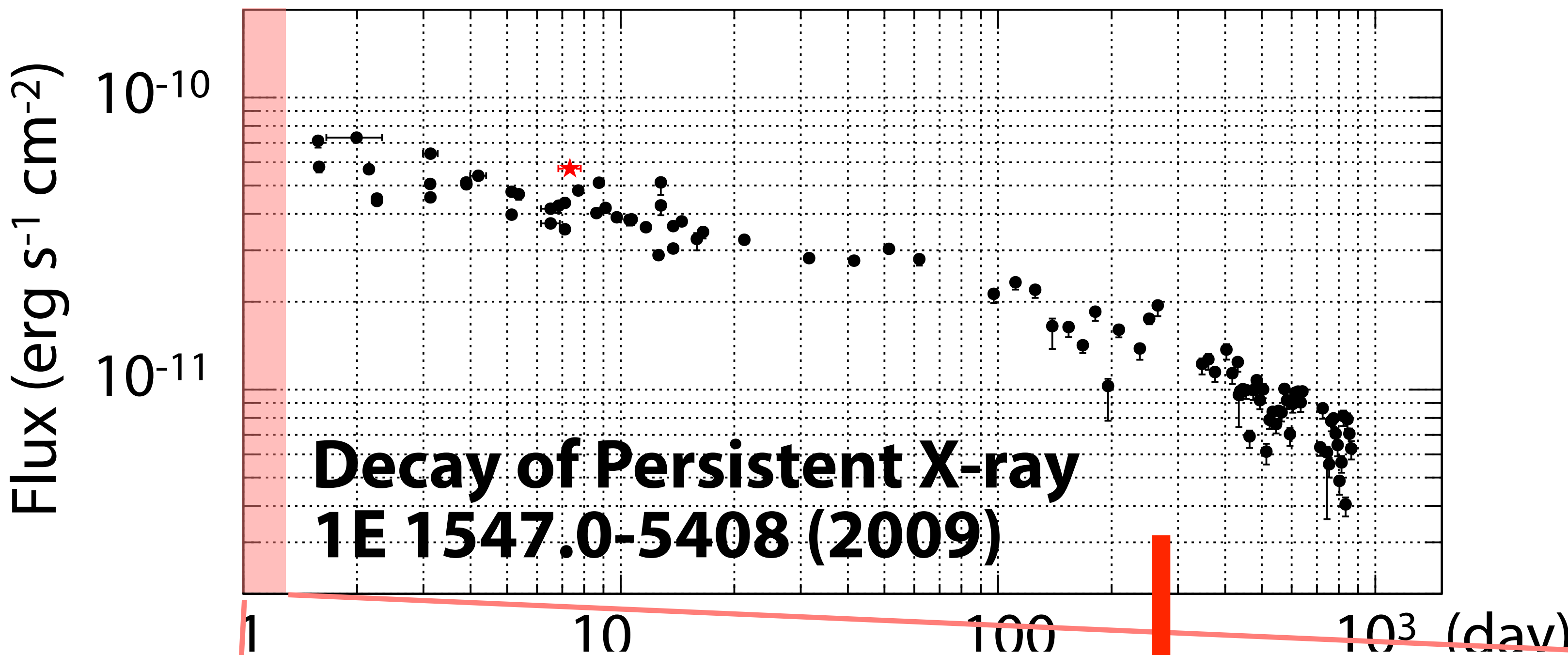
kT=0.81±0.01 keV, N_H=(1.4±0.3)e+21 cm^{-2}
F_X=(1.16±0.03)e-10 erg/s/cm^{-2} @2-10 keV

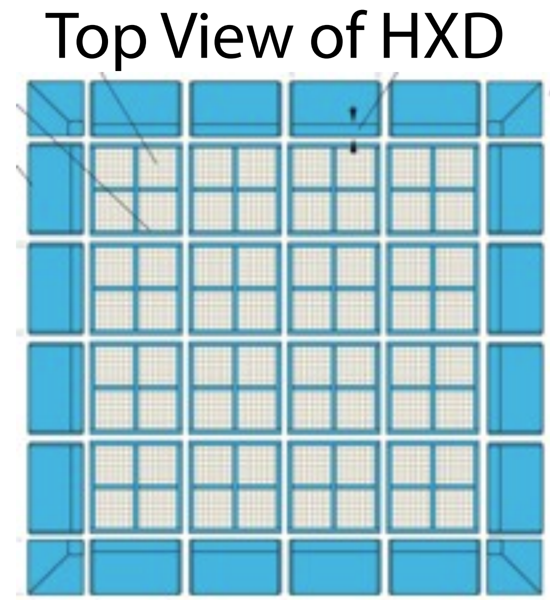
If this is a magnetar,
One of the brightest transient
hard X-rays may come from this source

Main Suzaku Topics on Magnetars

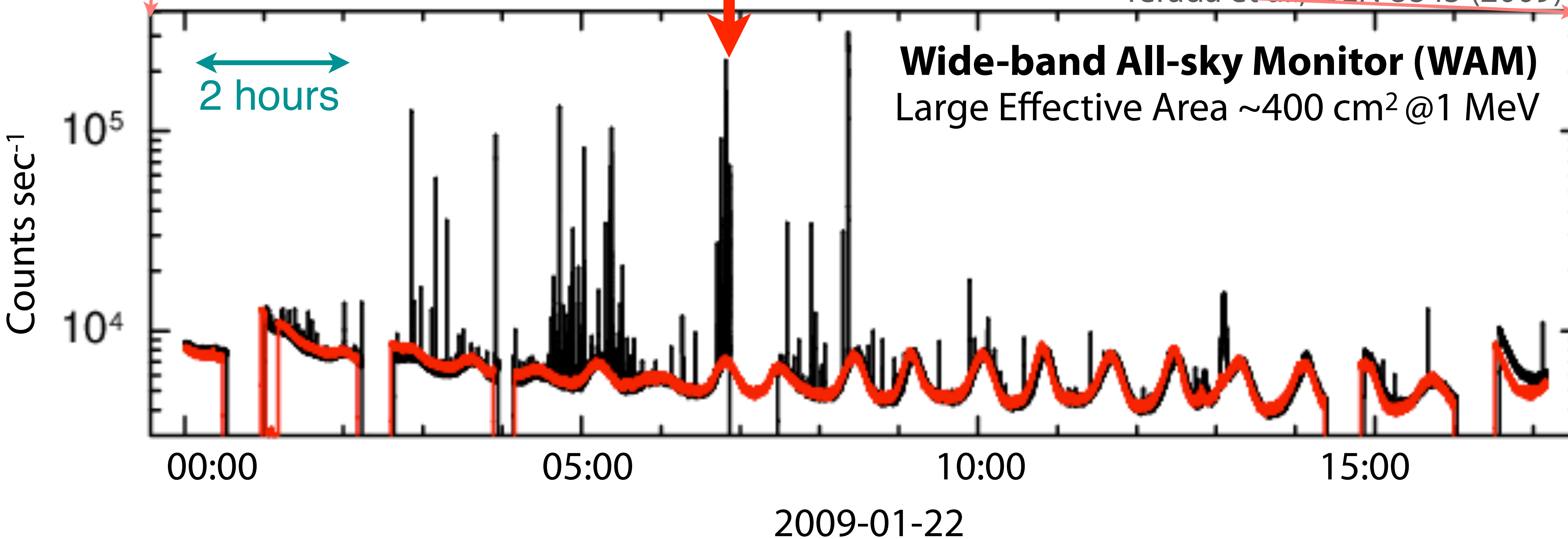


Early Burst forests from 1E 1547.0-5408



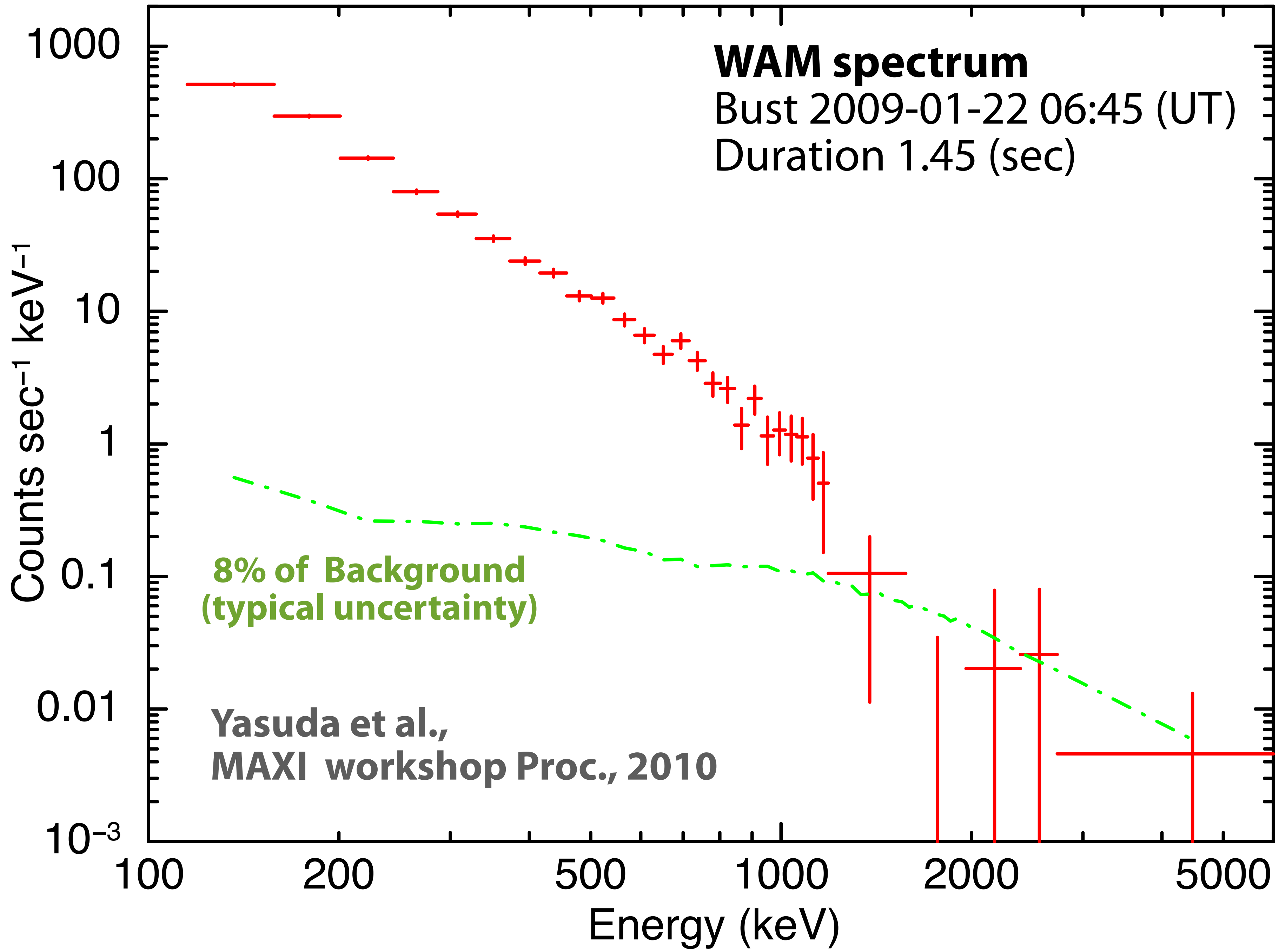


Terada et al., GCN 8845 (2009)



Suzaku WAM detected 250 bursts (>5.5 σ) during January 21 23:49-- 22 23:47 (UT)

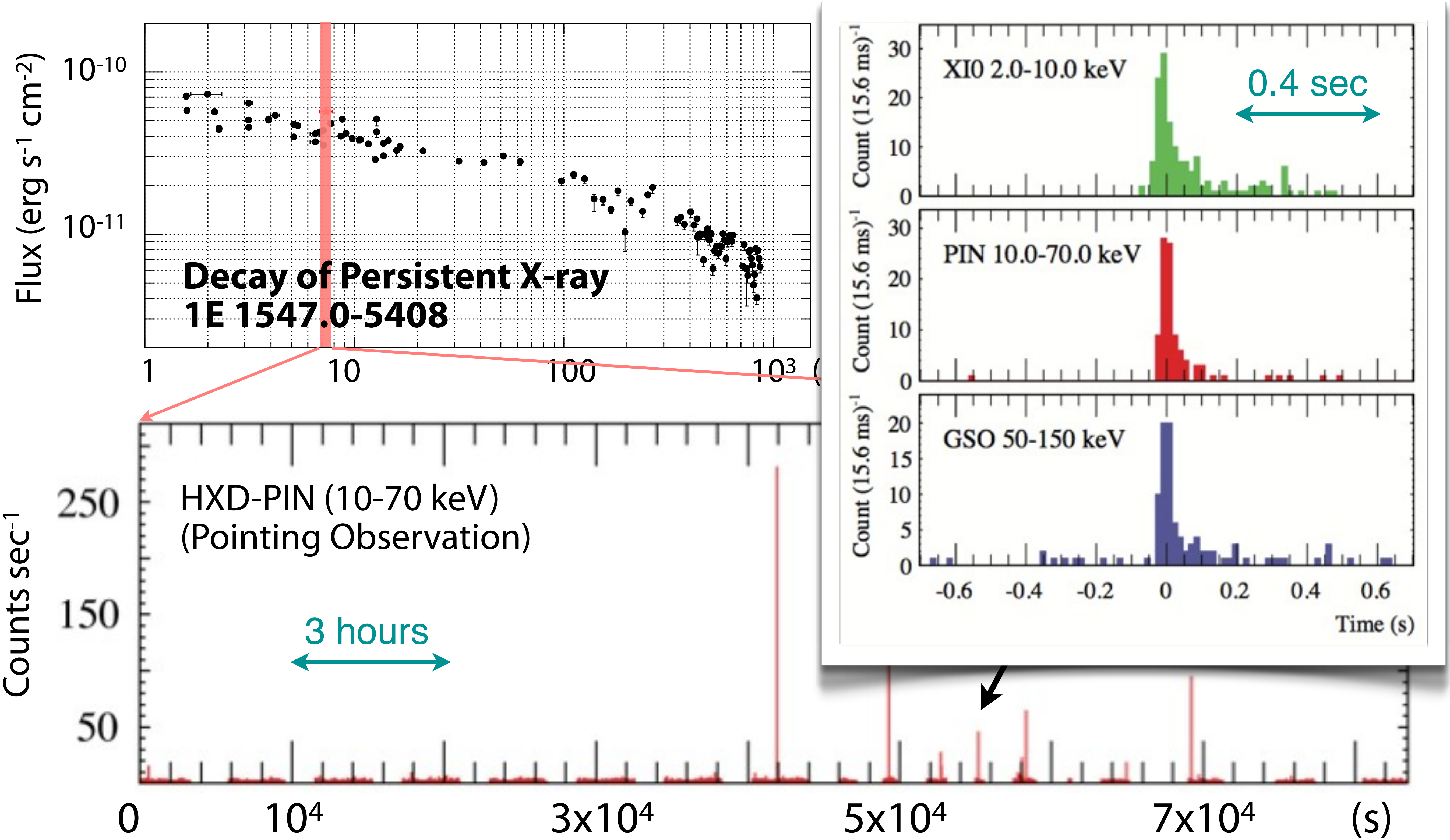
MeV Gamma Detection from Bursts



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

Short Bursts during the Pointing Observation

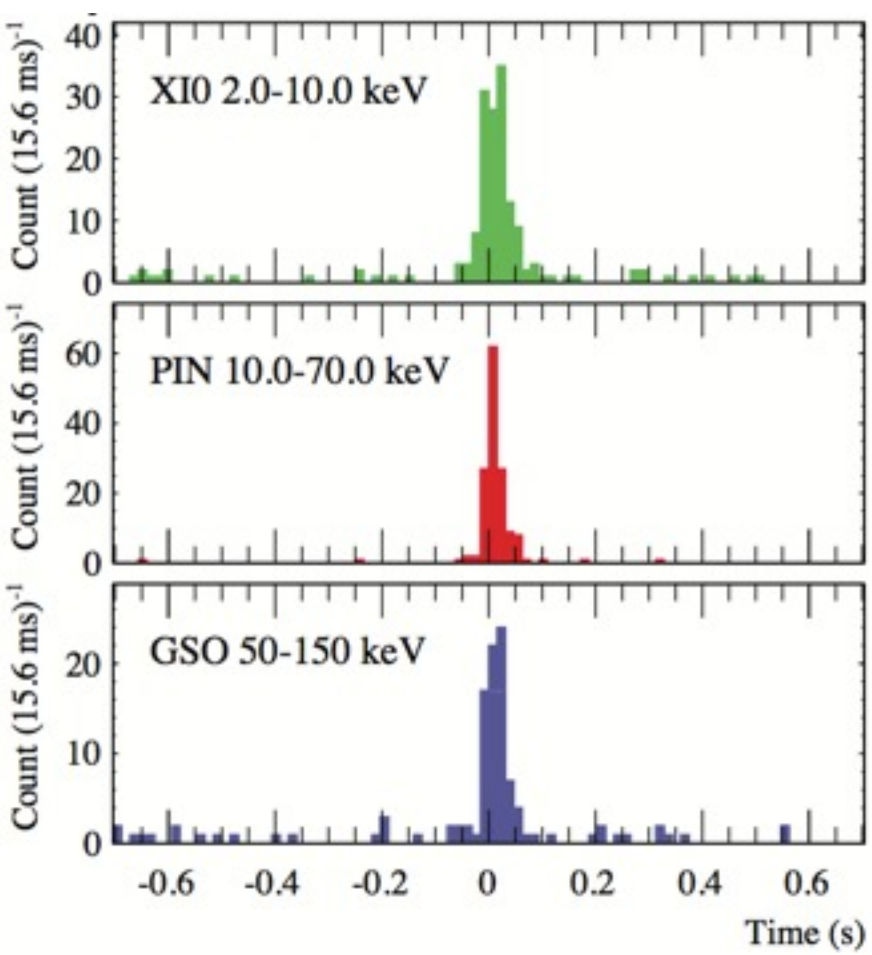


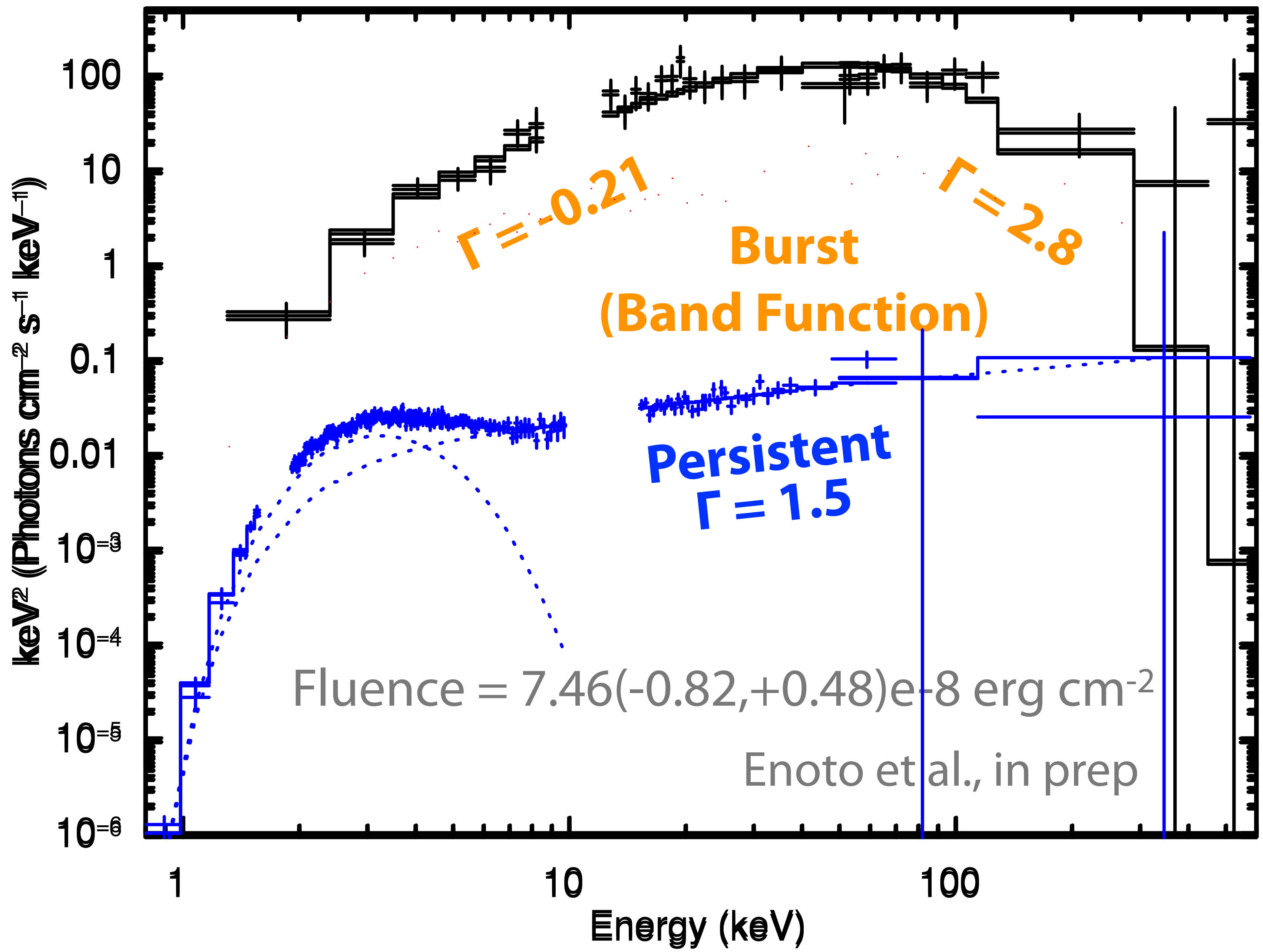
18 weak short bursts were identified with chance probabilities of $<10^{-5}$.

- X-ray fluences = 2×10^{-9} --10^{-7} erg cm^{-2} **(one of the weakest samples)**

Spectral Comparison: Burst vs. Persistent

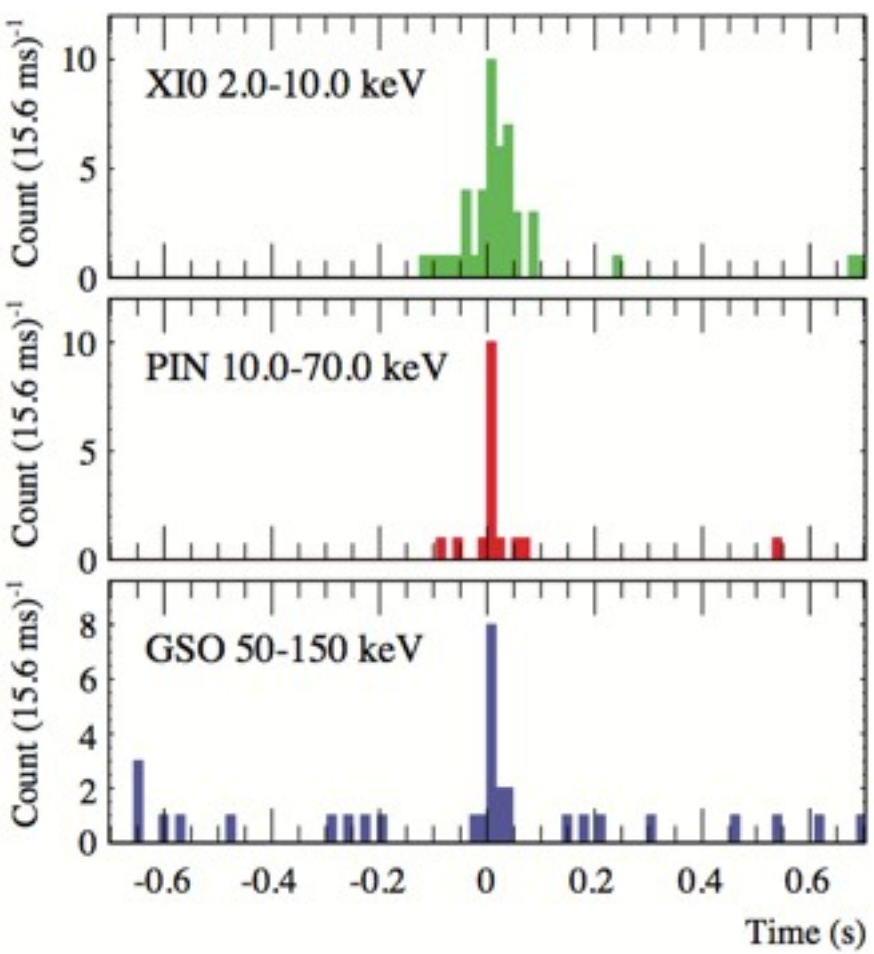
One Short Bursts

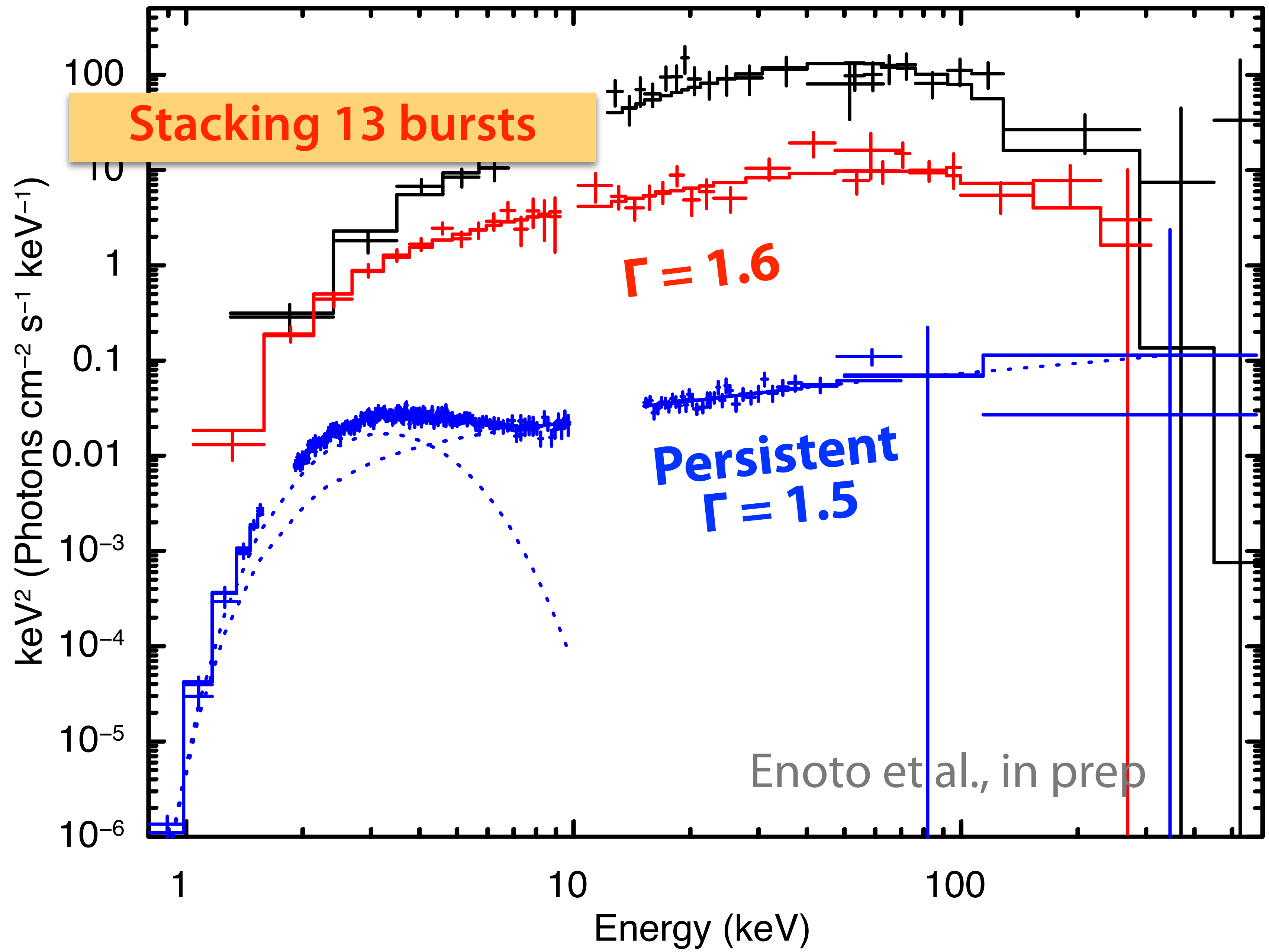




Spectral Comparison: Burst vs. Persistent

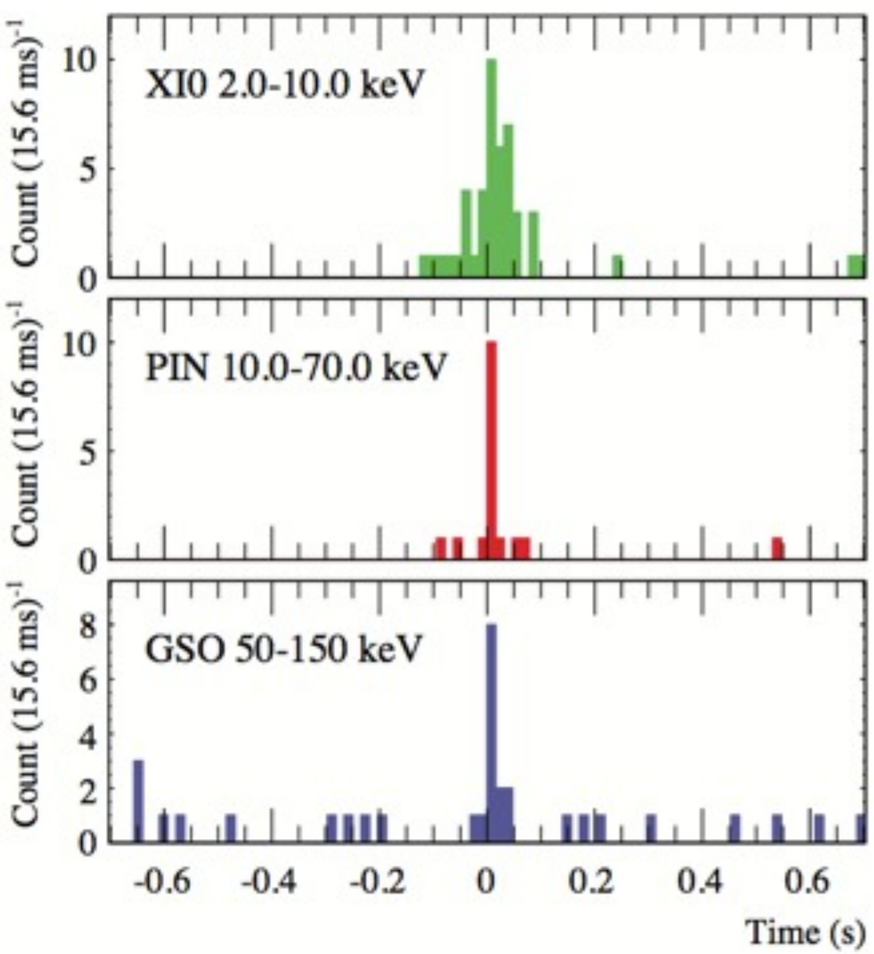
Weaker Bursts

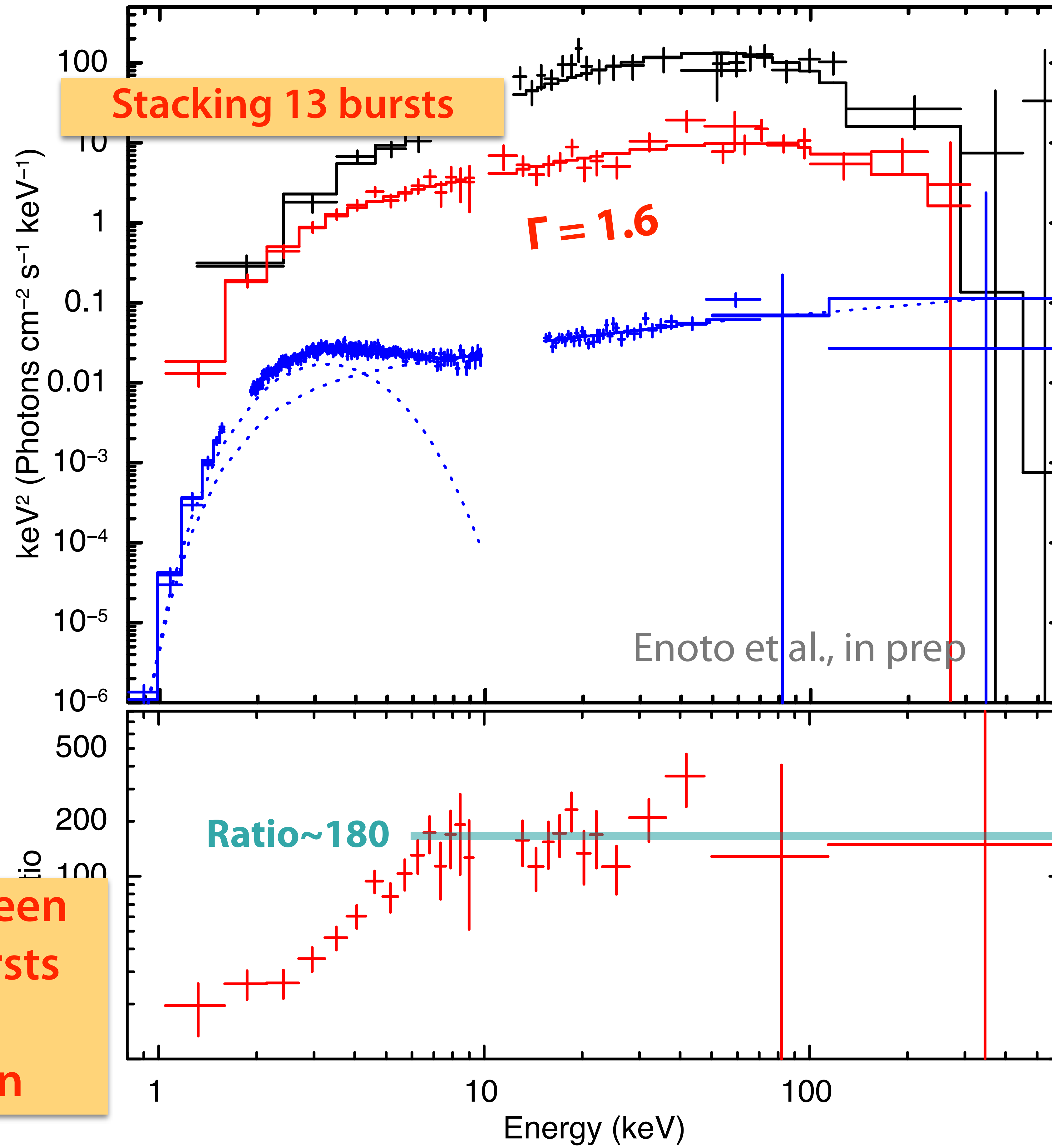




Spectral Comparison: Burst vs. Persistent

Weaker Bursts

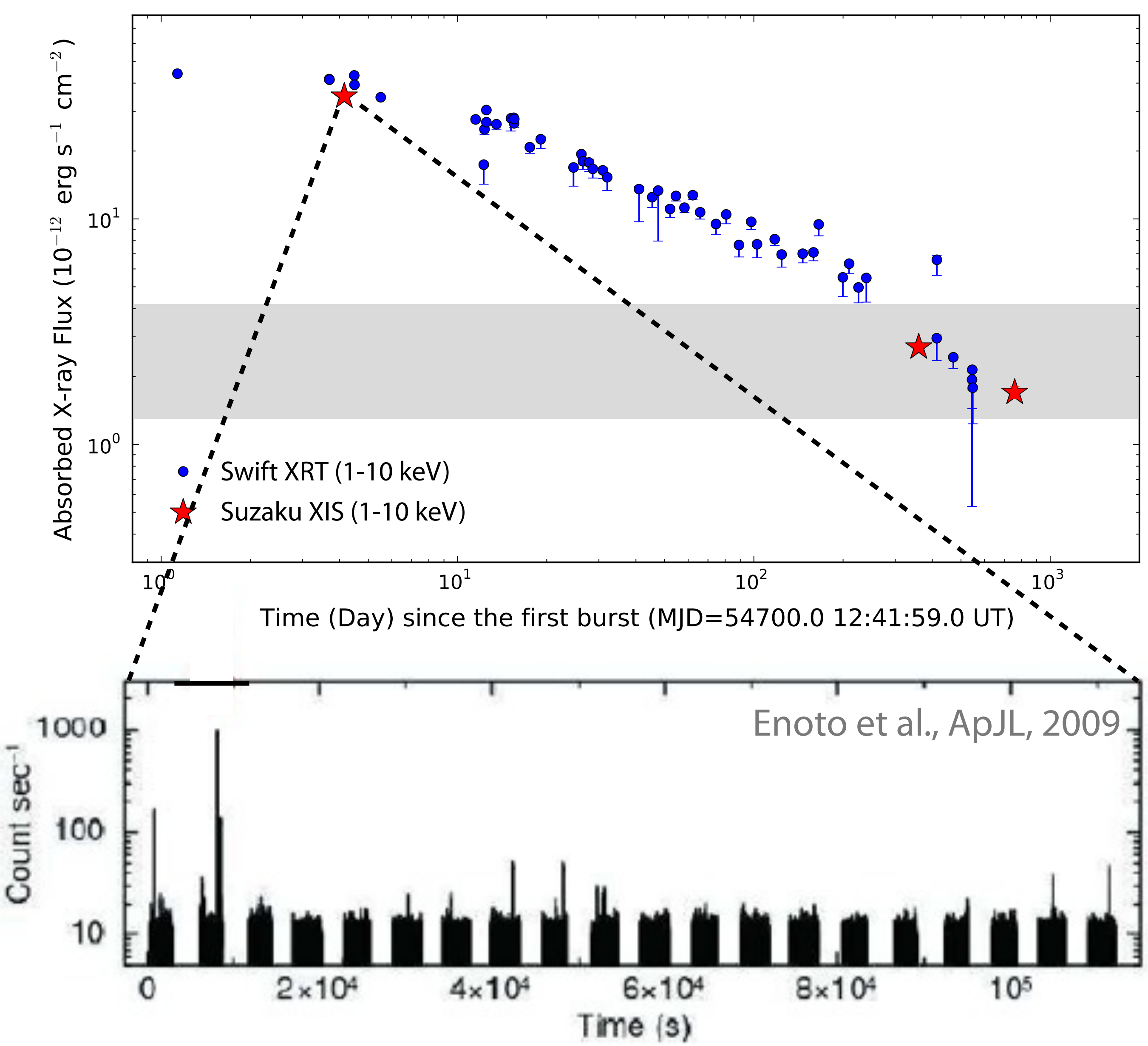


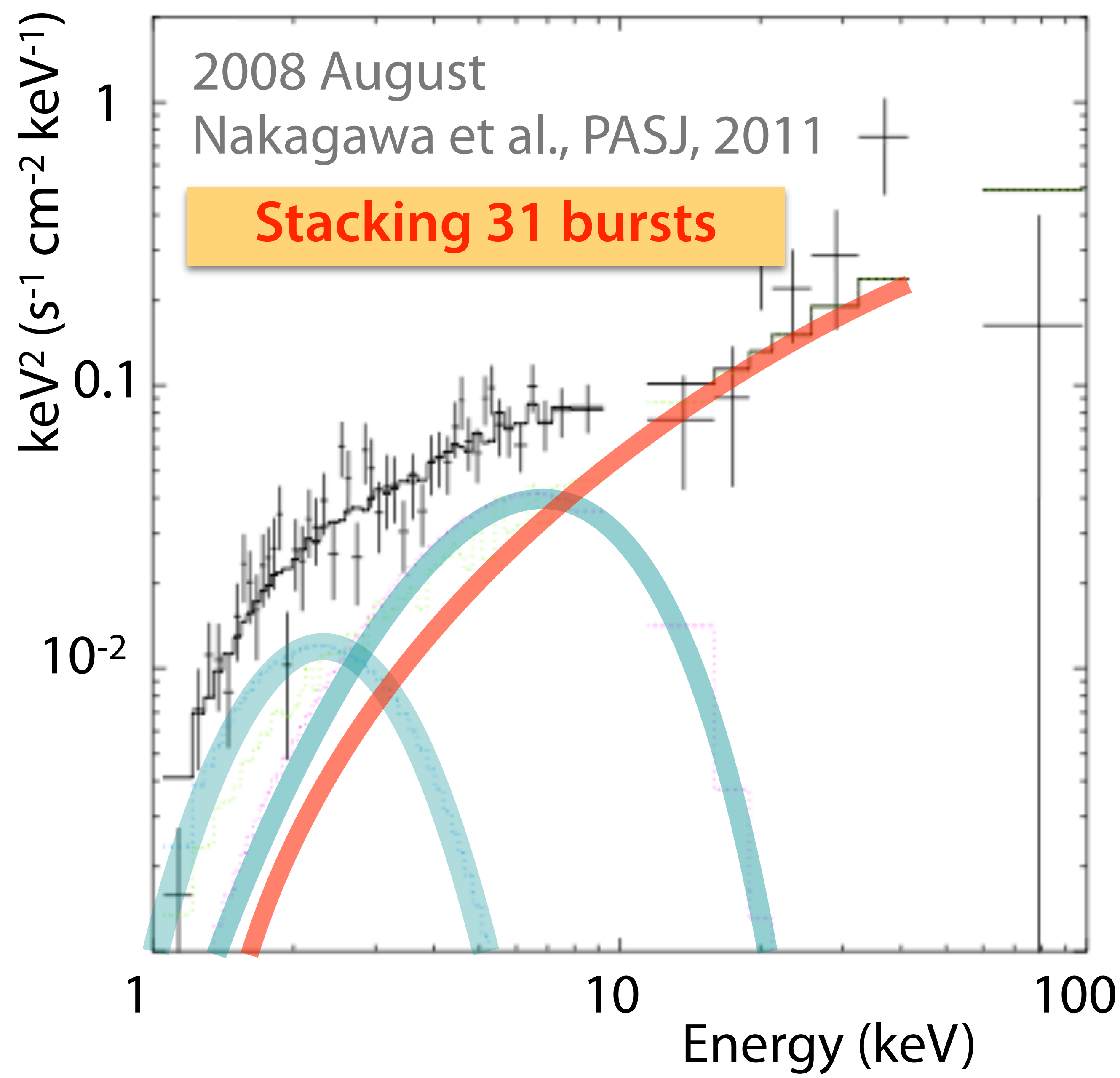


Spectral Similarity between the stacking weaker bursts and the persistent Emission

Short Bursts from SGR 0501+4516

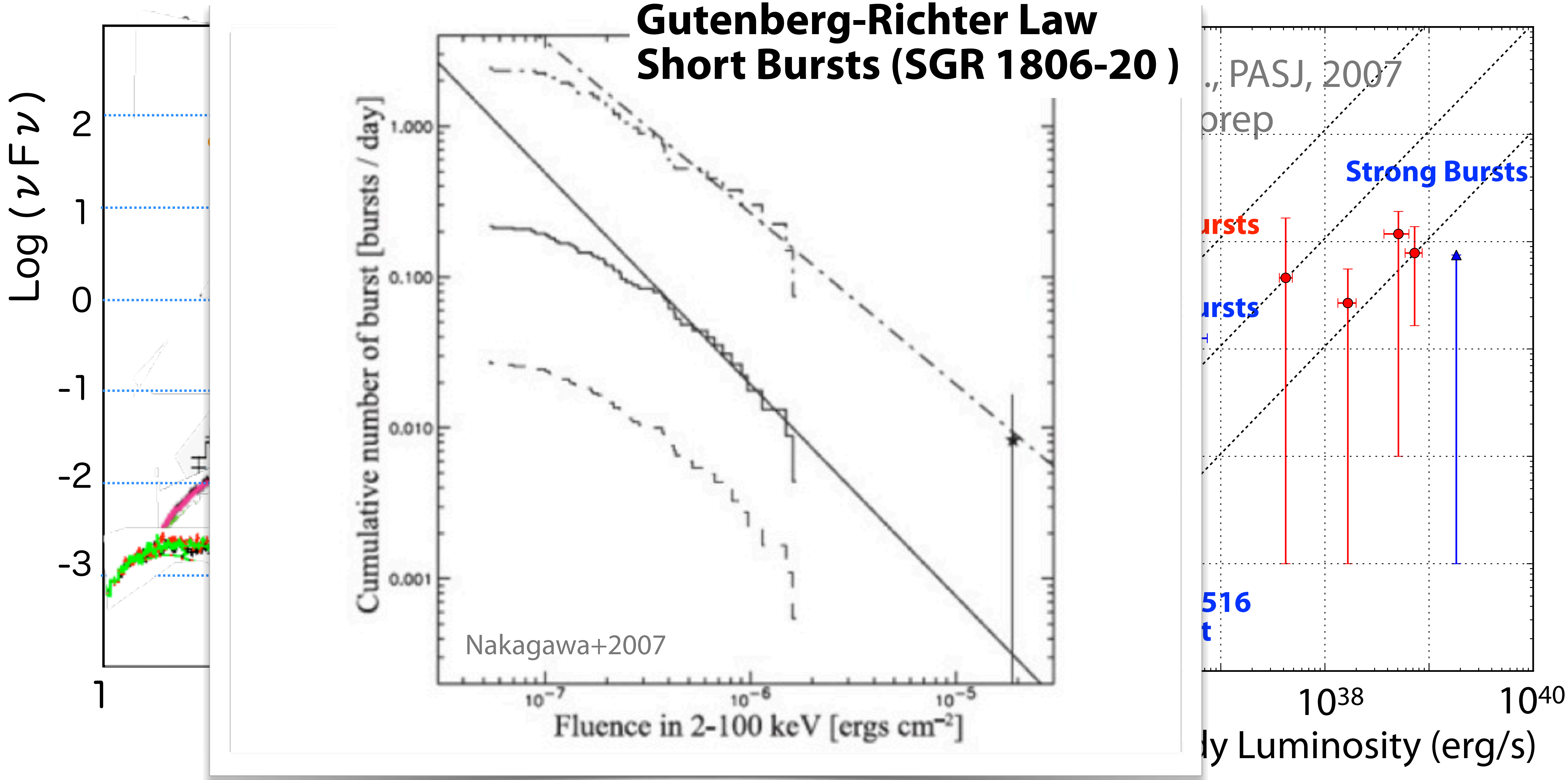
31 weak bursts were detected with an average fluence ~1×10^{-9} erg/cm^2 (Nakagawa+2011)





2BB+PL model : kT = 0.49 keV, kT = 1.7 keV, and Γ = 1.0

Short Bursts from SGR 0501+4516



Persistent X-ray emission may be an assembly of "micro-burst"?

Nakagawa et al., PASJ, 2007 (see also Lyutikov+2003)

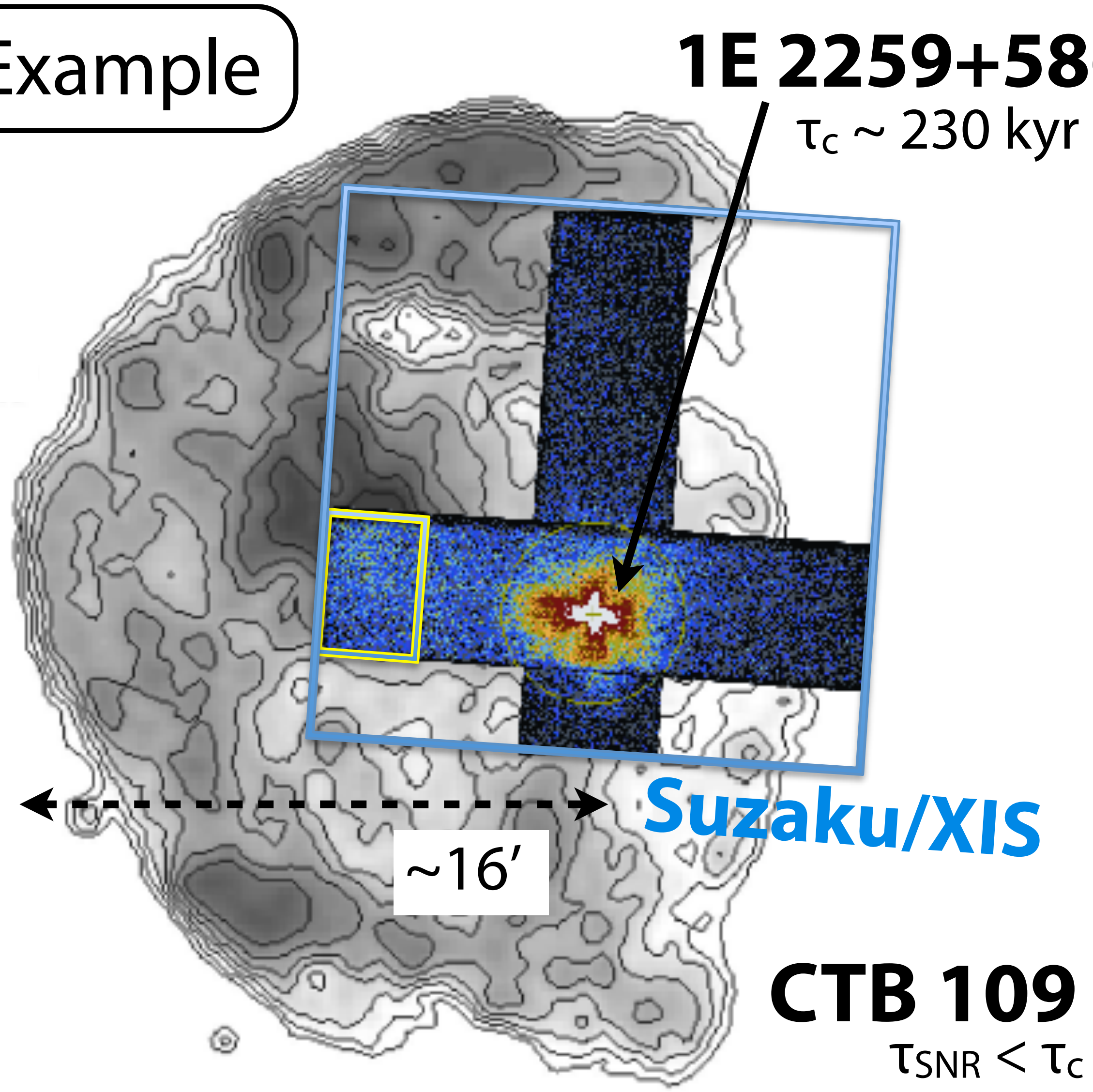
Unresolved "micro-bursts" can reach the persistent luminosity in a certain slope of the Gutenberg-Richter Law (1E 1547.0-5408).

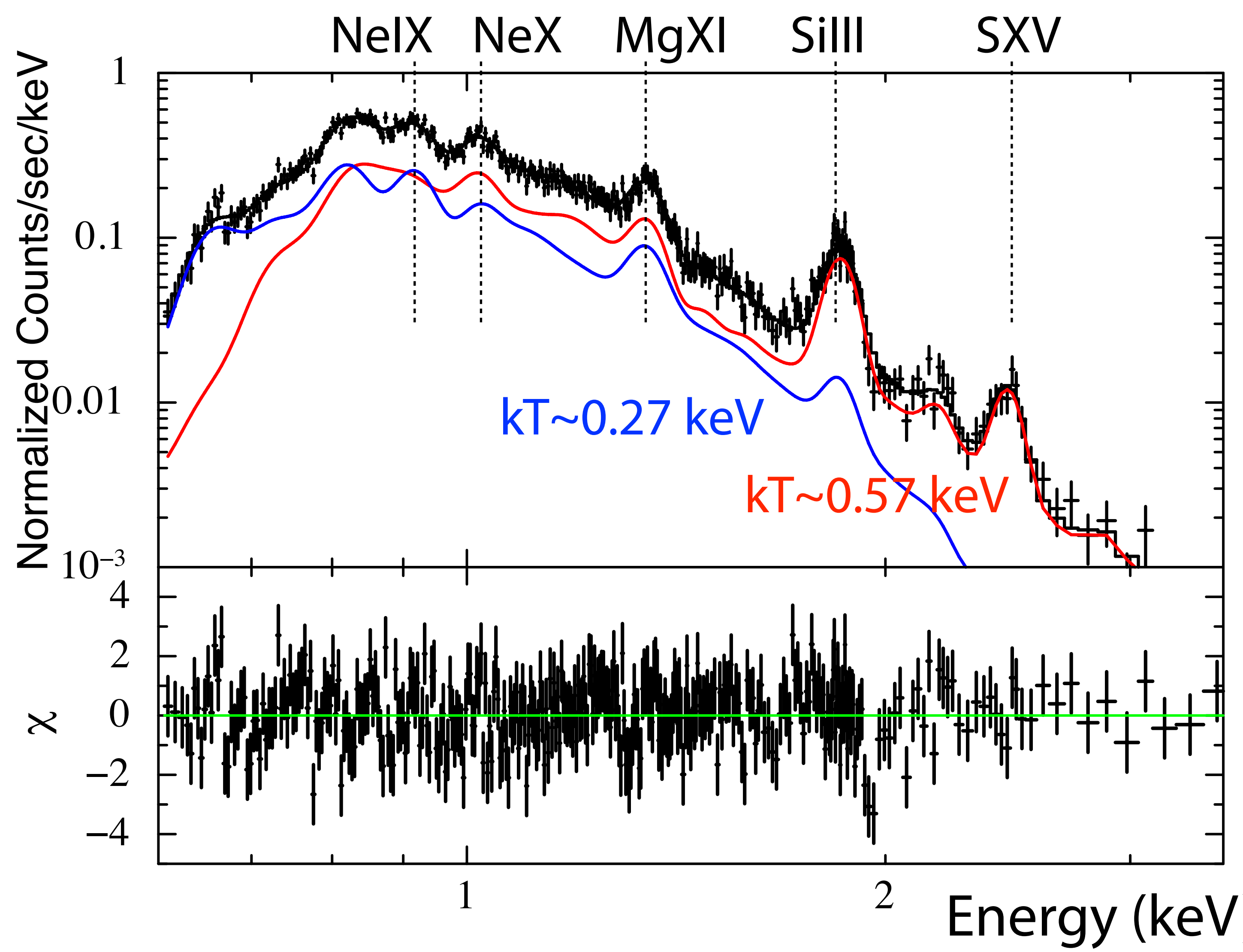
Enoto et al., in prep

Another Topic : SNR associated a magnetar

Environments of magnetars
- SNR/magnetar system is different from others?
- "Magnetar characteristic age" vs "SNR age"?

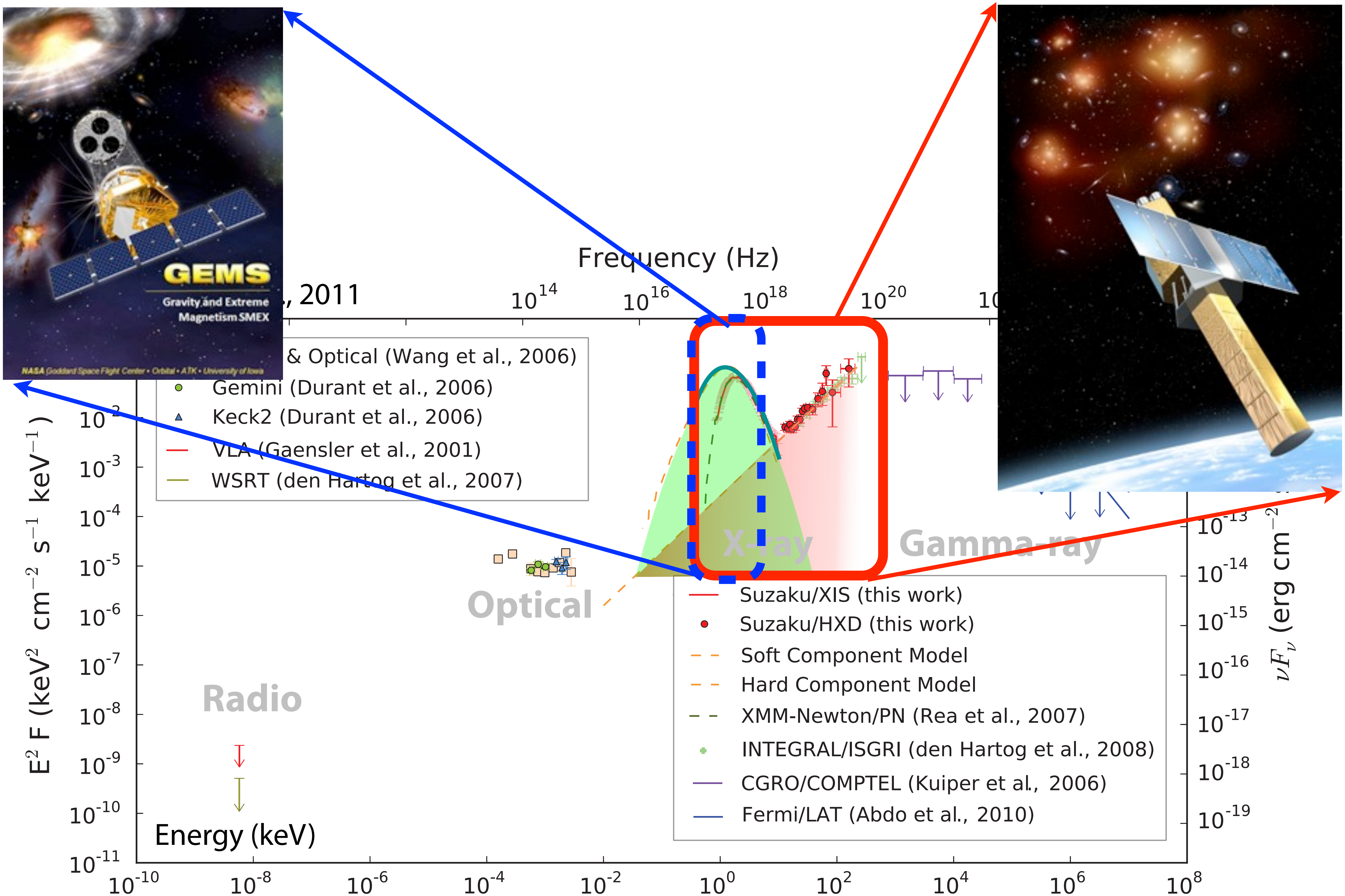
Example





Presentation by Nakano-san (tomorrow)

Beyond Suzaku: ASTRO-H & GEMS



Summary

1. **Soft & Hard X-rays from Magnetars**
   - The broadband hardness ratio ξ is correlated to the characteristic age τ_c and magnetic field B ($\xi \propto \tau_c^{-0.7}$, $\xi \propto B^{1.2}$).
   - The photon index of the hard X-rays becomes harder for sources with old characteristic ages (Γ_h ~ 1.8 to 0.4).
   - A study of the spectral trend is a nice target in ASTRO-H (NuStar) with discussions of the origin and cutoff of the Hard X-rays.
2. **Transient Magnetars**
   - The gradual X-ray decay (~1 year) of transient magnetars are appropriate targets of Suzaku, and have been monitored.
   - Simultaneous monitoring of the soft & hard X-rays will become important for understanding the dissipation of magnetic energy.
3. **Short Bursts**
   - High sensitivity of the HXD-PIN allowed us to detect weaker short burst events. The spectral similarity between the burst and persistent emission indicates a possible connection of their emission mechanism.
4. **Magnetar Environment, SNR (& PWN)**
   - The magnetar environments might be a clue to their stellar evolution.