New Insight into Magnetar Evolution and Concluding Remarks ～10 Current Issues with Magnetars (with personal prejudice and preference)～

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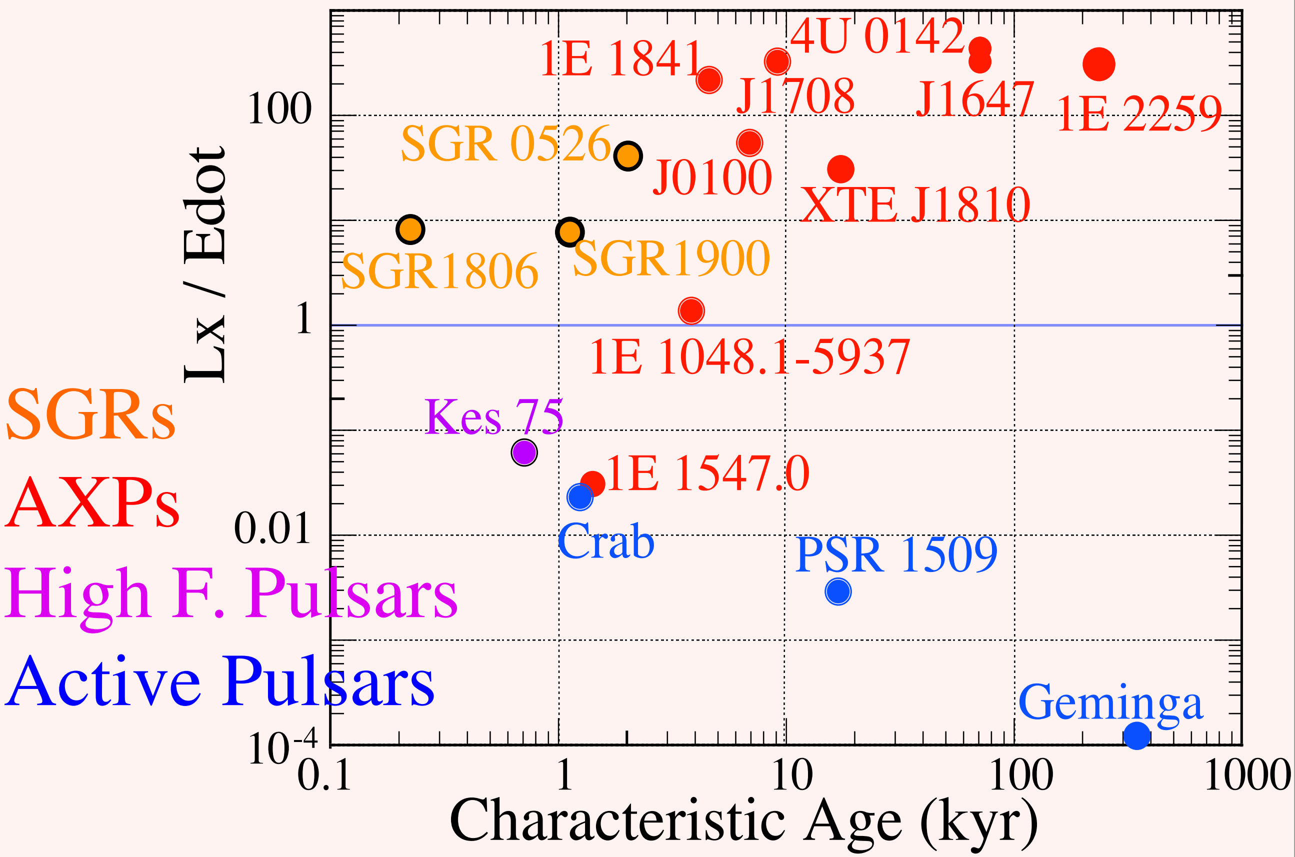
Congratulations, Shibazaki-san.
I am glad I have 29 joint co-authorships with you.

1. Are Magnetars Magnetically Powered?

Probably Yes

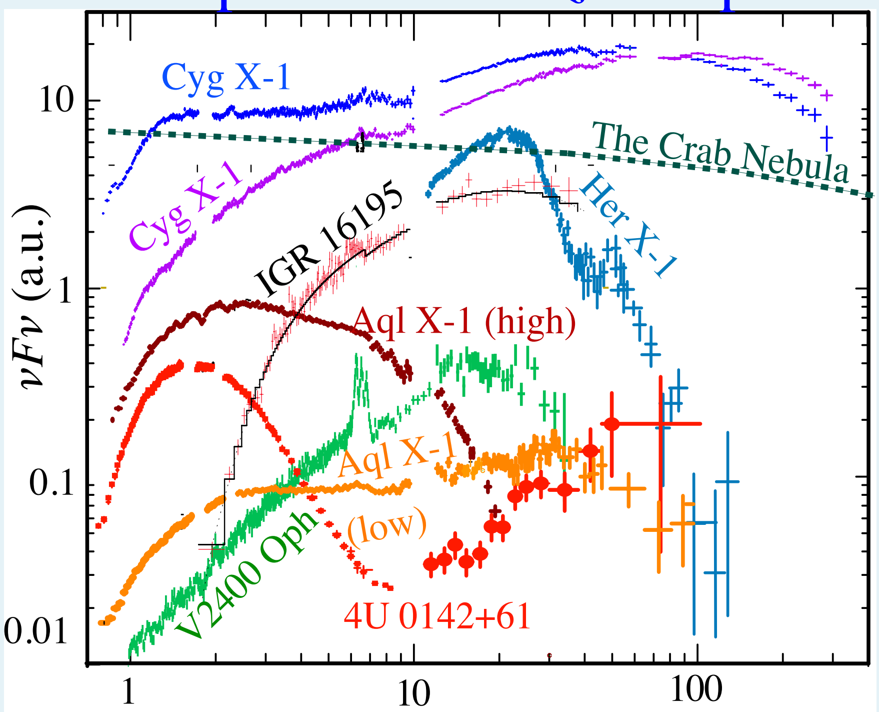
☆Evidence (1): their $L_x \gg$ their spin-down lum.



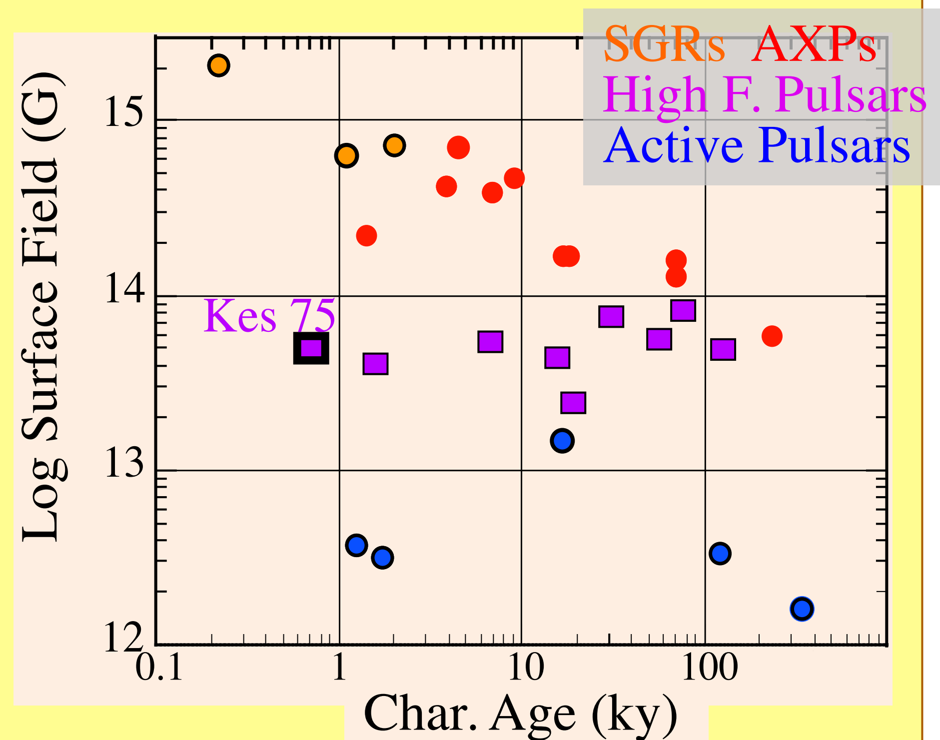
☆Evidence (2): Magnetars are more luminous than ordinary cooling NSs; internal heat is insufficient to explain their emission (Yakovlev)

☆ Evidence (3): absence of binary companion. Accretion from, e.g., a fall-back disk, would be unable to explain their characteristic two-comp. spectra.

A compilation of *Suzaku* spectra



☆Evidence (4): their dipole B (estimated from P and P-dot) decreases with their char. age.

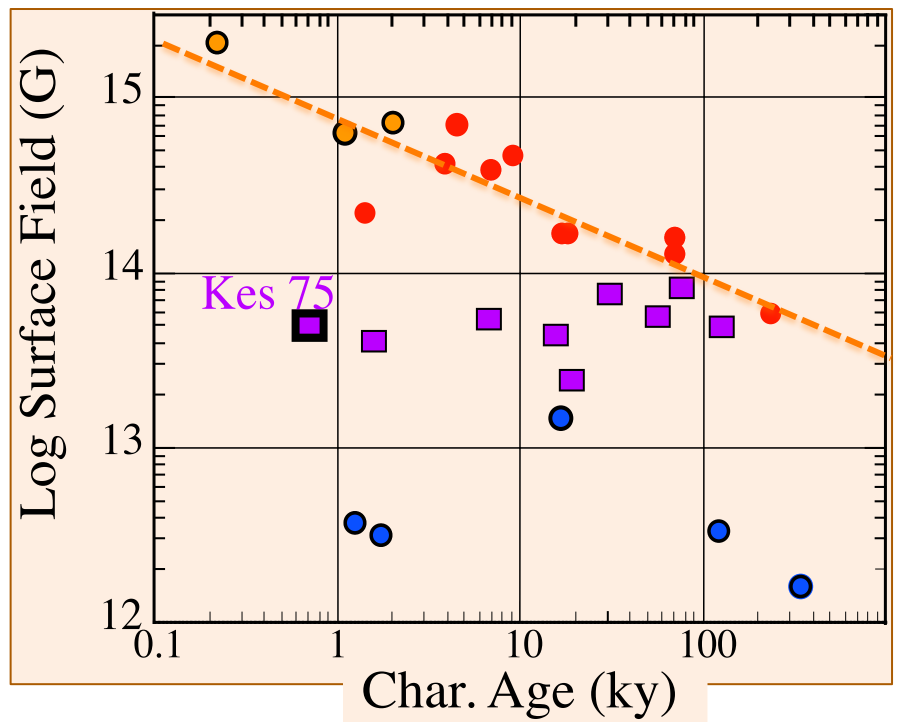


☆Evidence (5): mag. energy with B=$10^{14.5}$ G, liberated in 10 kyr, can sustain L_x~10^{35} erg/s.

2. How Old Are Magnetars?

Possibly much younger than considered so far

- Characteristic age $\tau_c \equiv P/2P$dot ; a good approx. of true age t_0 only when the braking index is n ~3, and B is constant.
- If $B \propto t^{-1/\alpha} \Rightarrow \tau_c \sim [\alpha/(\alpha-2)]\, t_0$; a significant over-estimate (Colpi+00; Nakano+11).
- Observation; $B \propto t^{-0.45} \Rightarrow$ $\alpha \sim 1/0.45 = 2.2 \Rightarrow \tau_c \sim 11 t_0$
- Magnetars can be much younger than their τ_c .



Magnetars are inferred to be extremely young objects, in agreement with their tight Galactic-plane concentration.

☆ Implications

- Magnetars are born as many as the B~10^{12} G NSs.
- Magnetars become quickly undetectable, because of their slow rotation and exhaustion of magnetic energy.
- Many aged magnetars lurk in the Milky Way.

☆ Supporting evidence

- Mangetar-like objects lurking among ordinary pulsars (Hadasch).
- Many new magnetars with low dipole-B being discovered (Zane).

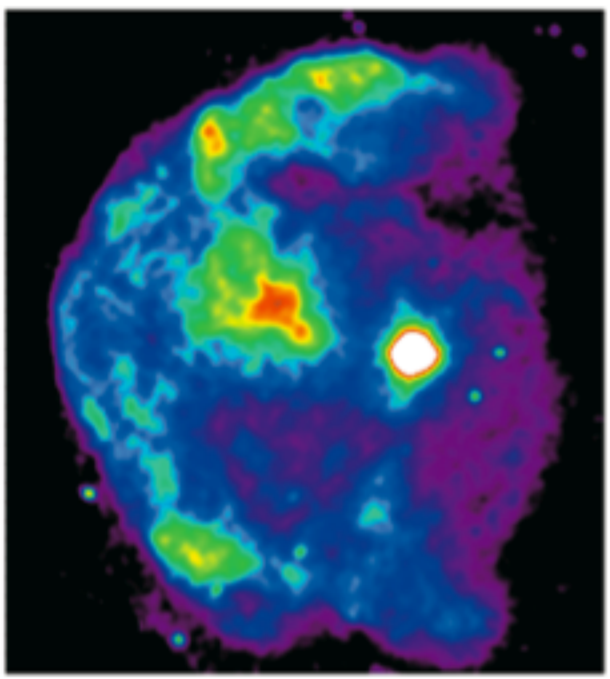
☆ Search for the predicted aged magnetars

- Candidates from *ASCA* Galactic plane survey
- Pilot survey with *Suzaku* AO7; soft BB spectrum, pulsations
- Hard tail search with *ASTRO-H*

3. How Are Magnetars Produced?

Core collapse Supernovae
- NSs
  - Magnetars
  - B~10^{12} G NS
  - CCOs (anti-magnetars)
- Black Holes

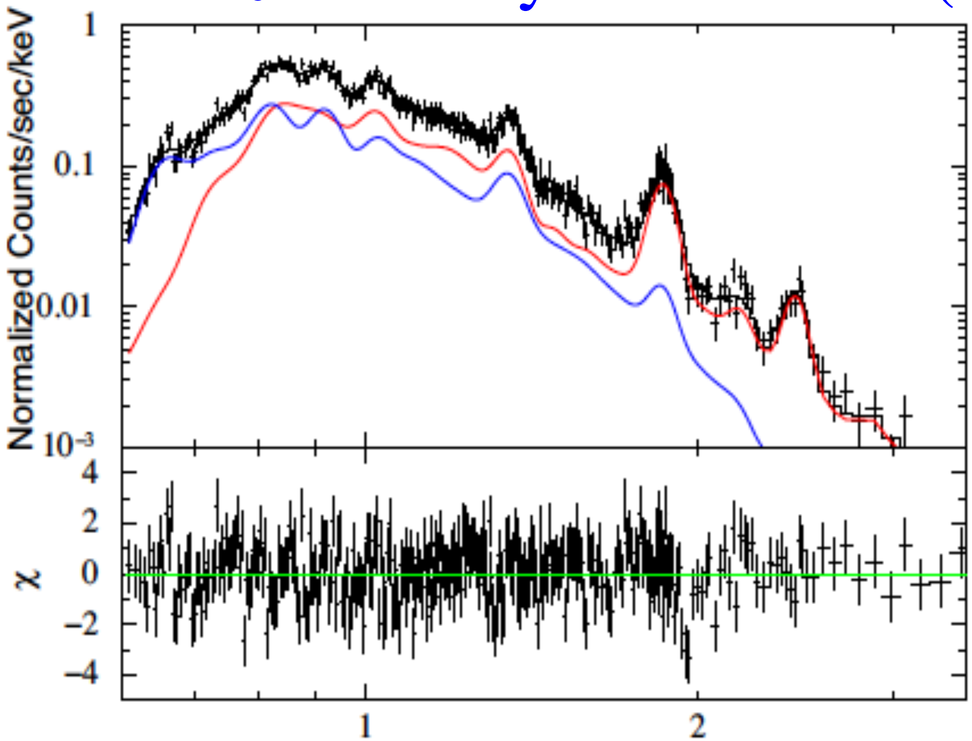
What causes this differentiation?



☆ X-ray diagnostics of SNRs hosing magnetars

ROSAT image of CTB109 (Sasaki +04), the SNR hosting the rather old magnetar X2259+586

☆*Suzaku* study of CTB109 (Nakano+11)



A typical SNII, without peculiarity:

- T_1=0.3 keV, T_2=0.6 keV
- Abundance patterns typical of SNeII
- Explosion energy (1.7-7)×10^{51} erg/s

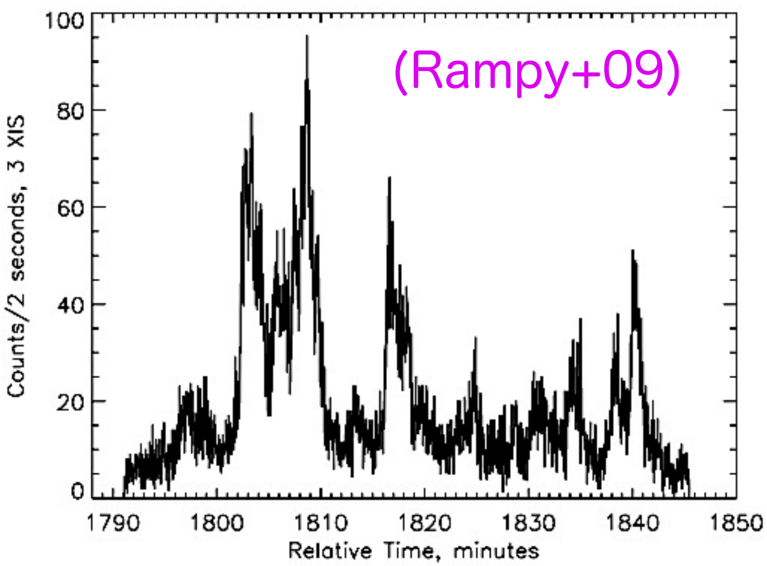
However, the estimated SNR age, ~20 kyr, is ≪ than τ_c=230 kyr of the central magnetar X2259+586. The age over-estimation of magnetars reconfirmed.

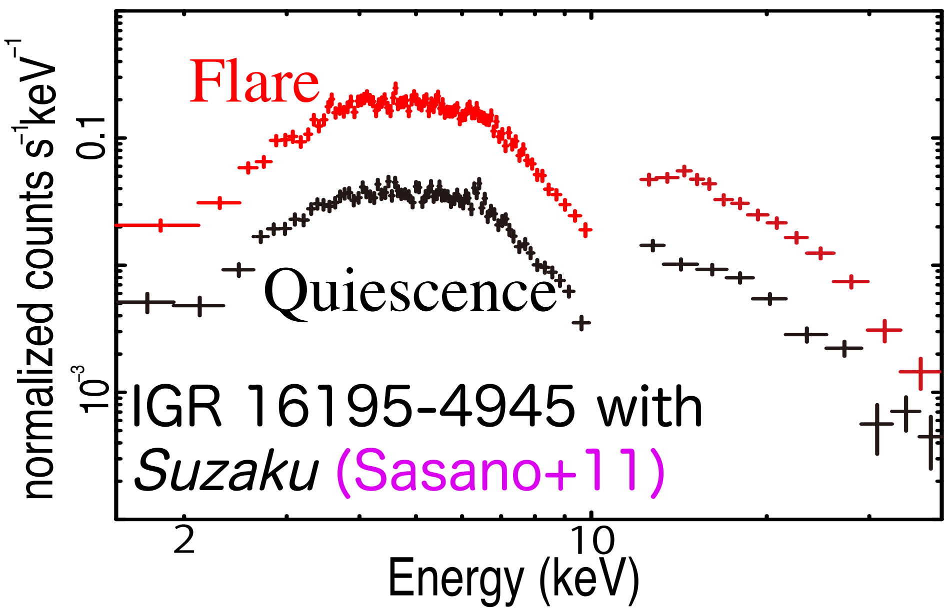
☆More detailed diagnostics to be conducted with the *ASTRO-H* microcalorimeter.

4. Are There Magnetars in Binaries?

SFXTs (Supergiant Fast X-ray Transients) and Long-Period (>10^3 s) X-ray pulsars can be promising candidates (Bozzo+08; Sasano+11)

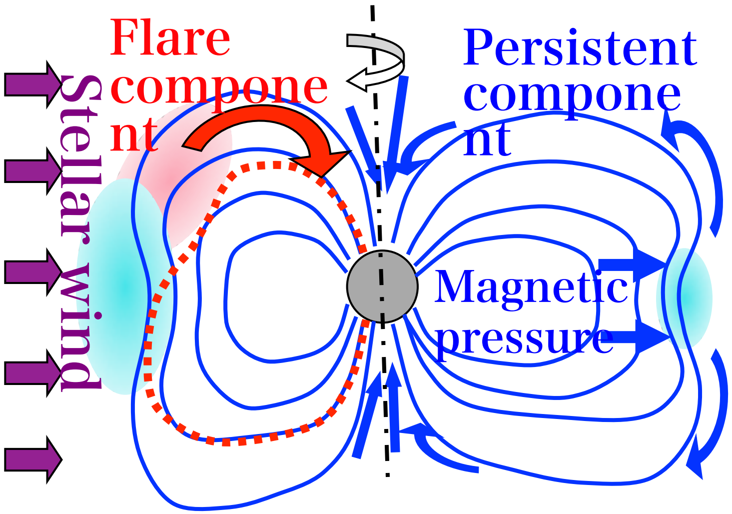
- Magnetar activity lasts < 10^5 yr, but what if they are in binaries?
- SFXTs, with super-G companion, show violent flares, low quiescent Lx (<10^{32} erg/s), and often long (>500s) pulse periods.
- A popular interpretation, invoking stellar-wind clumps, is unlikely because N_H does not necessarily increase during flares.

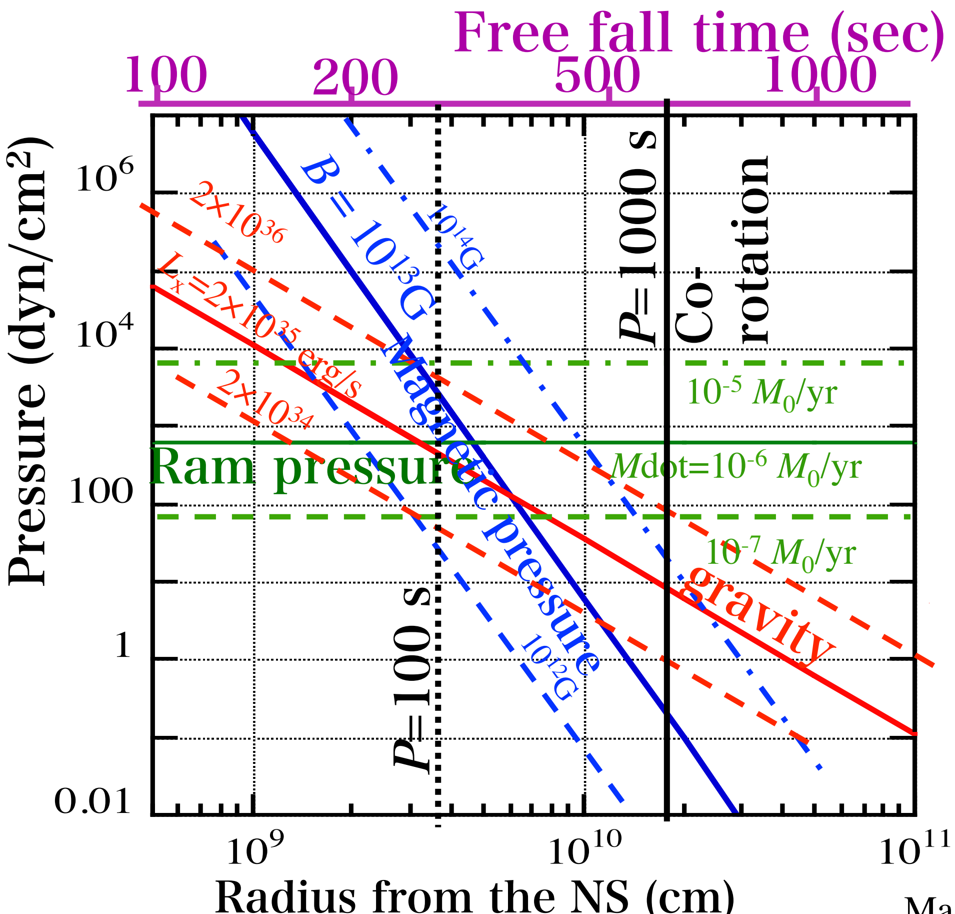




☆ Hypothesis (Sasano, Makishima+12):

- SFXTs contain magnetars.
- Co-rot. radius (r_c)∼Alfven radius (r_A).
- Mag. gating produces violent variations.
- If density ↓ ➔ $r_c < r_A$ ➔ accr. inhibition due to propeller effects (flip-flop)





☆ With *ASTRO-H*:

- Search for ECR features in 50-150 keV region.
- Pulse-phase dependent Doppler shifts in the Fe-K line energy ➔ estimates of $r_c \sim r_A$

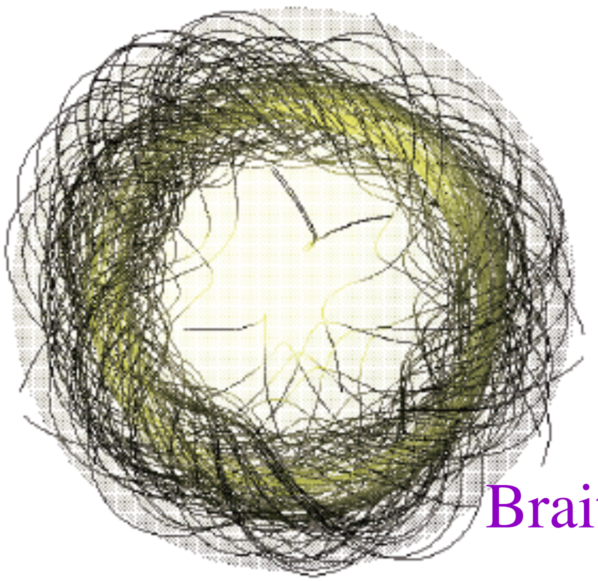
5. How is the Magnetic Energy Dissipated?

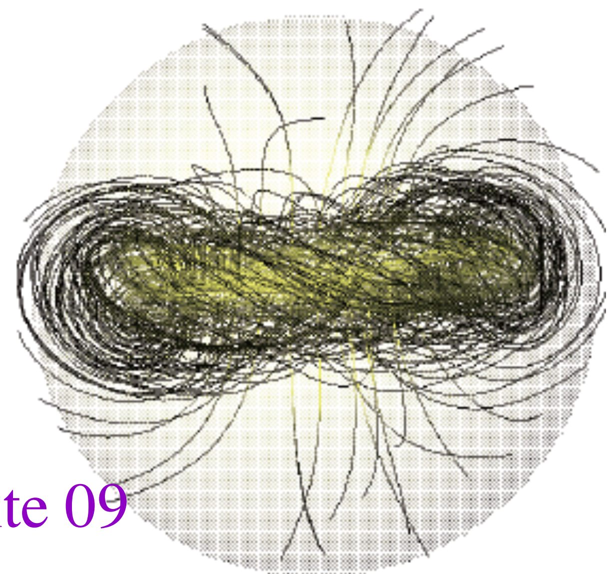
Still uncertain, but we already heard from Zane…

☆Need to understand basic MF configuration inside/outside the NS.

- Is the internal field configuration mainly toroidal or poloidal?
- Is the outer MF configuration mainly dipole or multipole?
- How large is the *B*-twist (how large is rot *B*) inside/outseide?
- Are the bursts triggered inside or outside the NS?

☆ Heat transport calculation is important (Yakovlev)





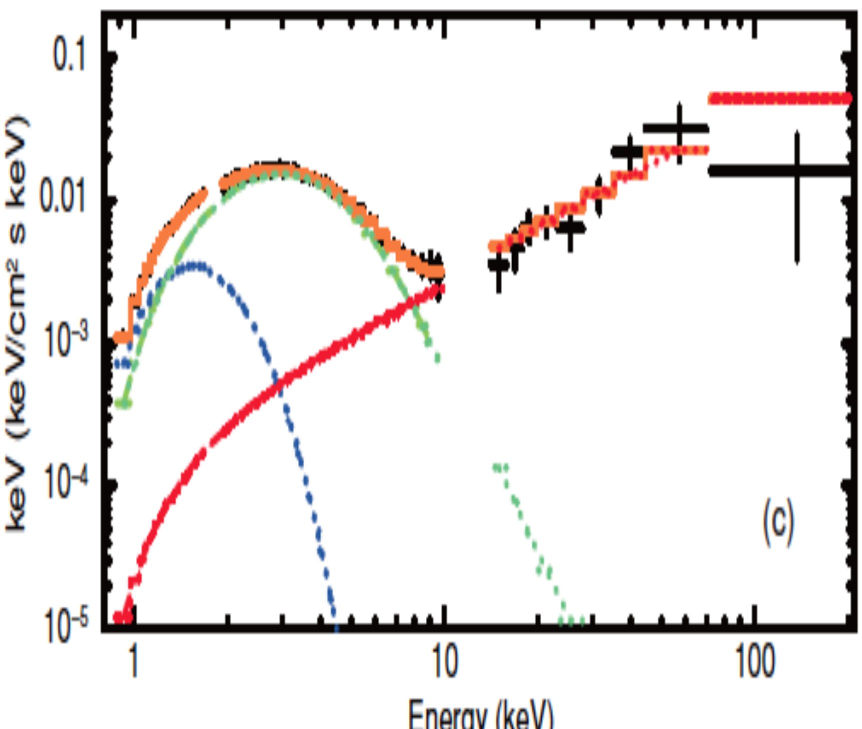
Braithwaite 09

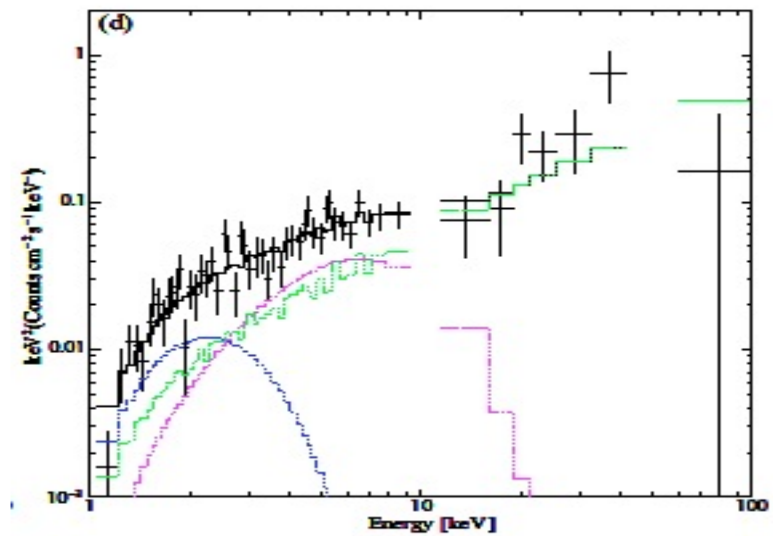
6. Do Microbursts Form Persistent Emission?

☆Conjecture: Persistent magnetar emission is formed by numerous μ-bursts (Thompson & Duncan 1996; Lyutikov 2003; Nakagawa 2007)

LogN-LogS relations are too uncertain to answer this Q, but the increased persistent emission during burst activity, as well as spectral similarities between burst and persistent spectra, suggest Yes

Persistent (left; Enoto+11) and stacked short-burst (right; Nakagawa+11) spectra of SGR0501+4516 observed with *Suzaku* during the 2008 activity. Both exhibit clear hard-tail emissoin.

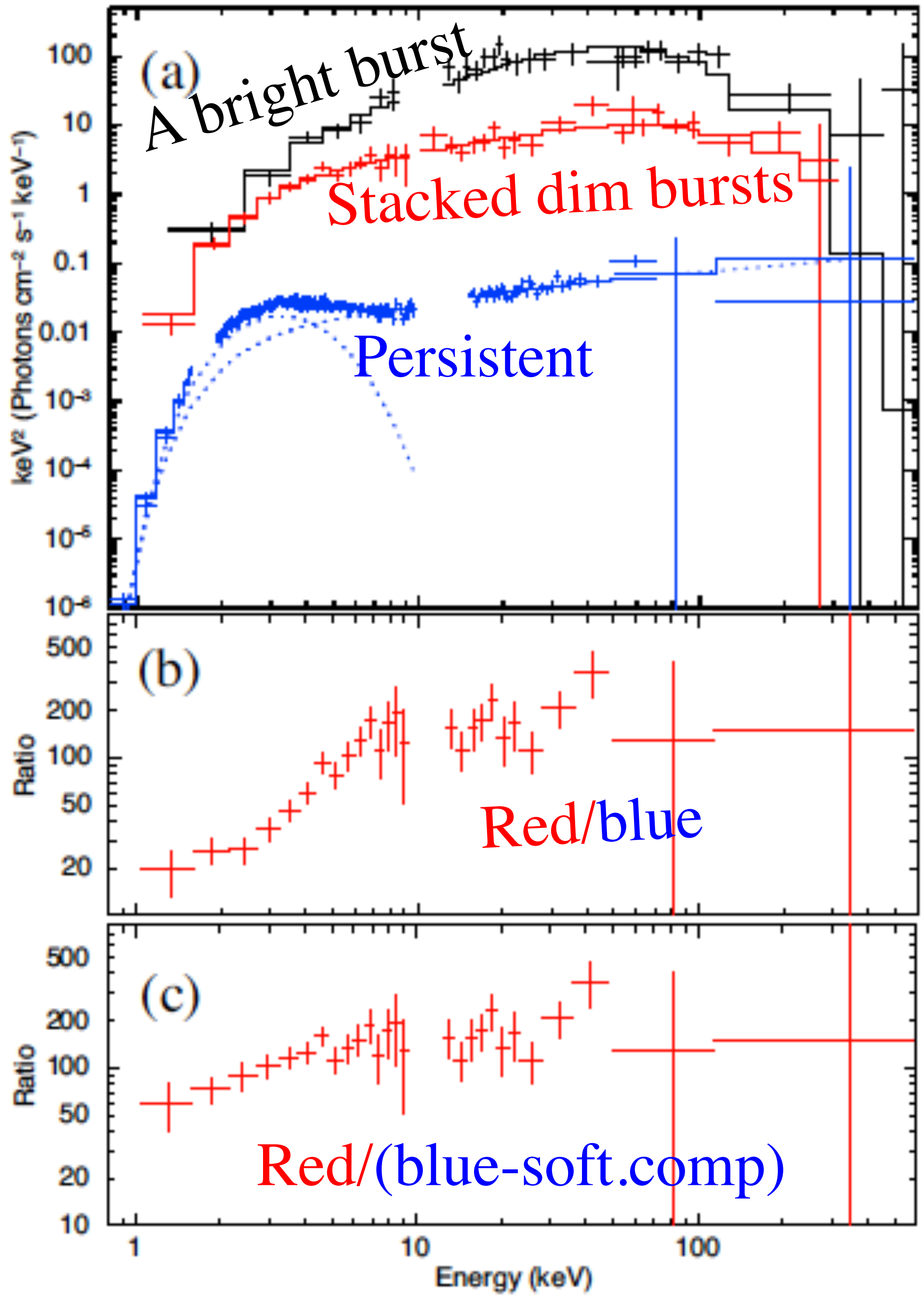




Three broad-band *Suzaku* spectra of 1E1547.0-5408 in its 2009 activity (Enoto+10, +12) all show similar shapes
➔ Possibly a common origin, involving sudden magnetic energy release.

☆ With *ASTRO-H*:

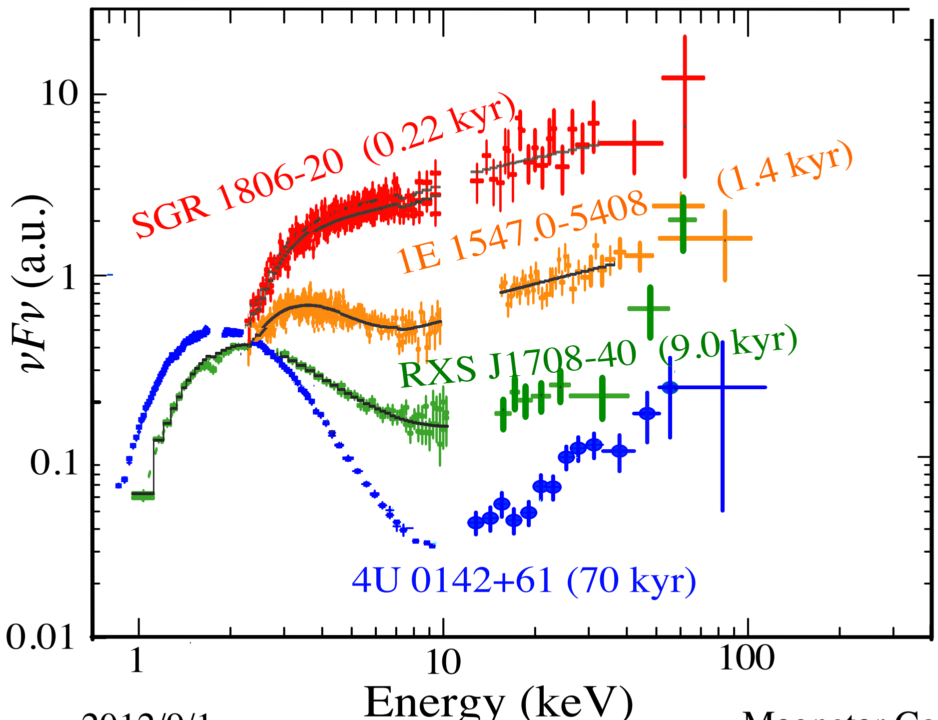
- Better comparison of wide-band spectra
- Studies of still weaker short bursts to better constrain Log*N*-Log*S*
- Variability study of the persistent HXC.

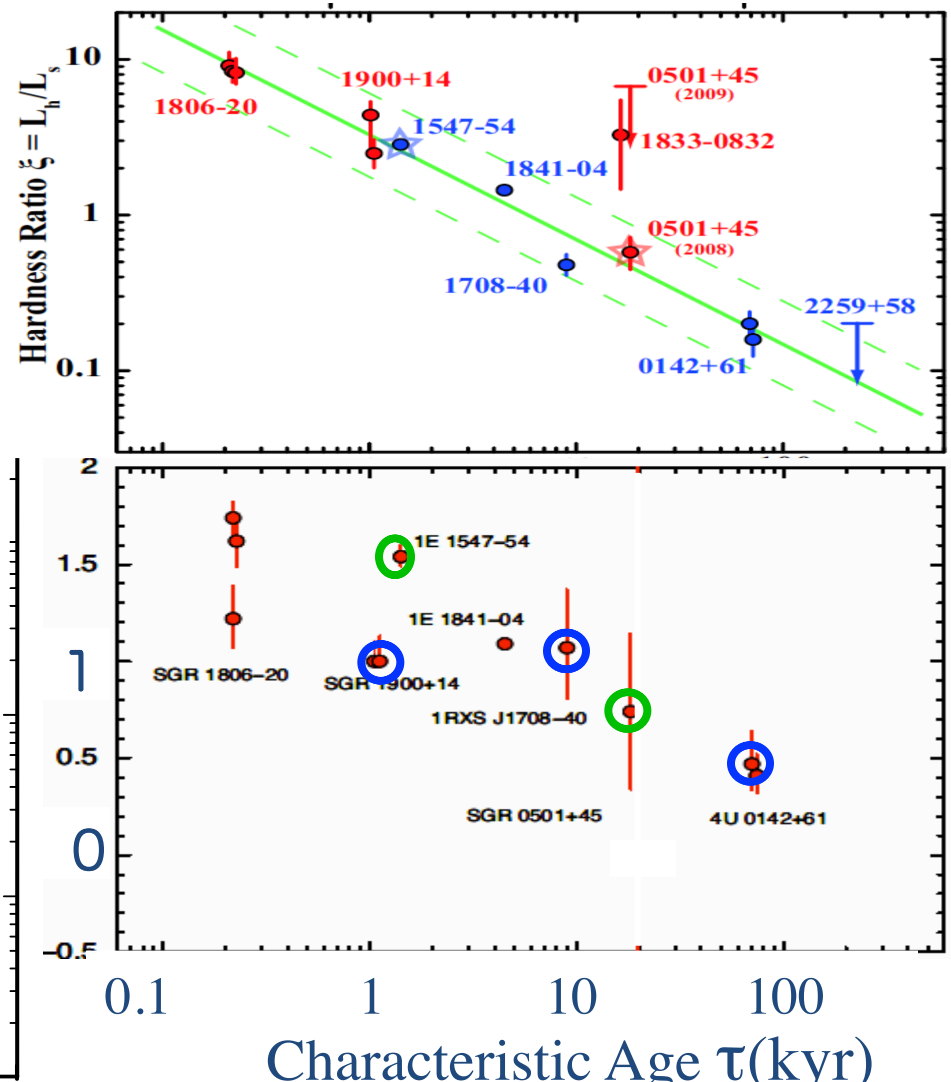


7. How is the Hard Component Emitted?

☆ *Suzaku* wide-band persistent spectra of magnetars (Enoto+10)

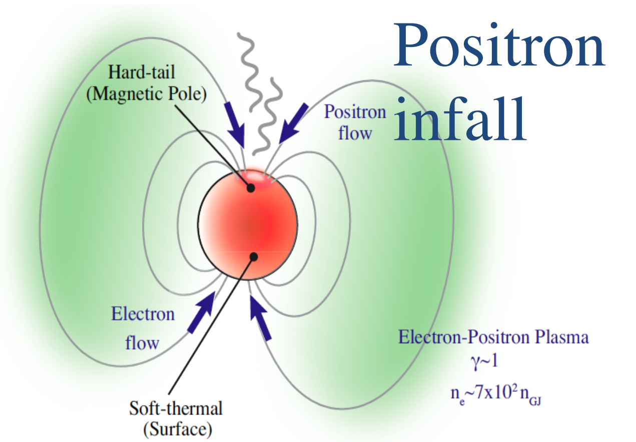
- Characteristic 2-comp. spectra, SXC + HXC (e.g., Kuiper+06).
- HXC is unusually hard; Γ= 0.5~ 1.5; no easy explanation.
- Older objects have lower HXC vs. SXC ratios but flatter Γ.





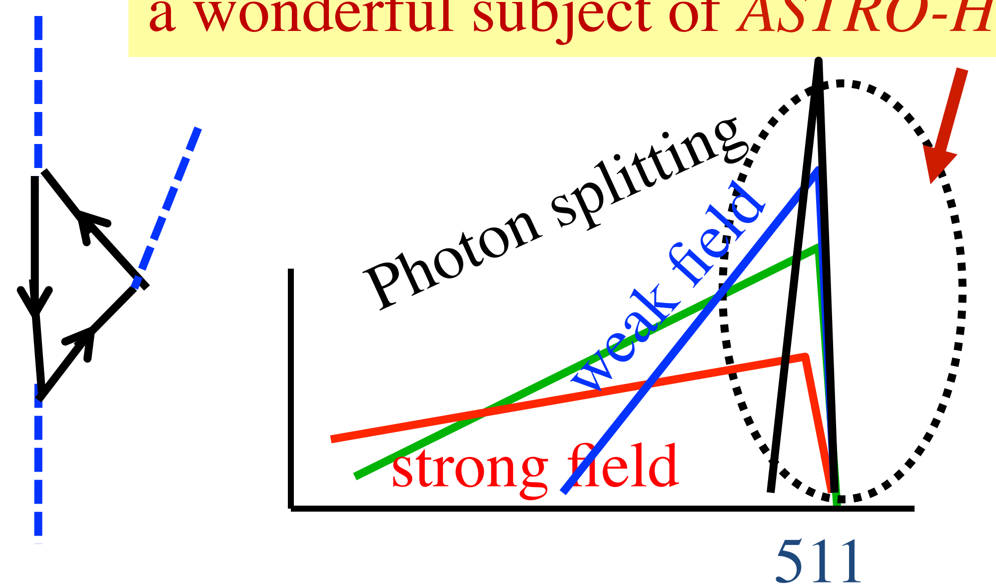
- HXC and SXC are emitted with similar angular patterns
  ∵) L_{hard}/L_{soft} is specified uniquely by τ_c with little scatter.
- Both components probably emitted from similar locations, NS surface or magnetosphere ∵) Similar pulse profiles.
- HXC has a high radiation efficiency ∵) some show $L_{hard} \gg L_{soft}$

e+e- pear production in magnetosphere ➔annihilation on the NS surface ➔ repeated "splitting" of the 511 keV photons in the MF



(Enoto+10, Shibata+11)

cutoff expected above 511 keV
a wonderful subject of *ASTRO-H*



8. *Why the Soft Comp. has Two T's? (Nakagawa)*

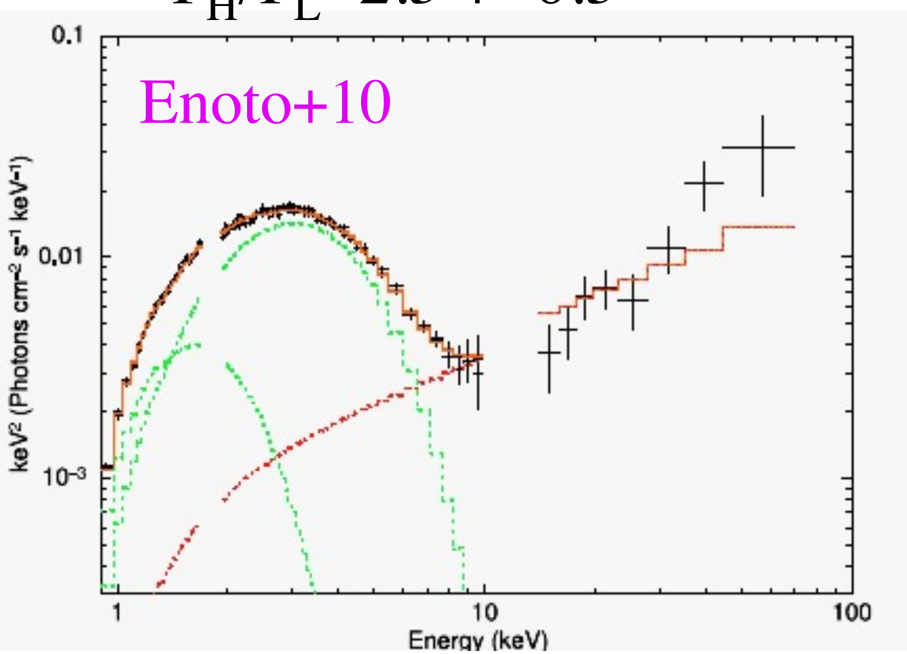
☆ *Suzaku* spectra of SGR 0501+4516

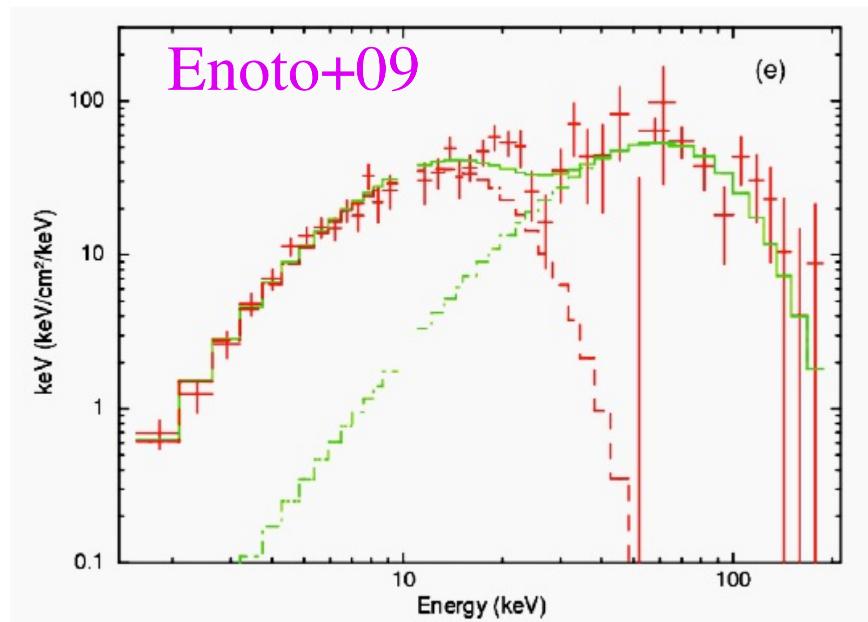
SXC of the persistent emission

T_L=0.25 ± 0.03 keV
T_H=0.57 ± 0.03 keV
T_H/T_L=2.3 +- 0.3

A strong short burst

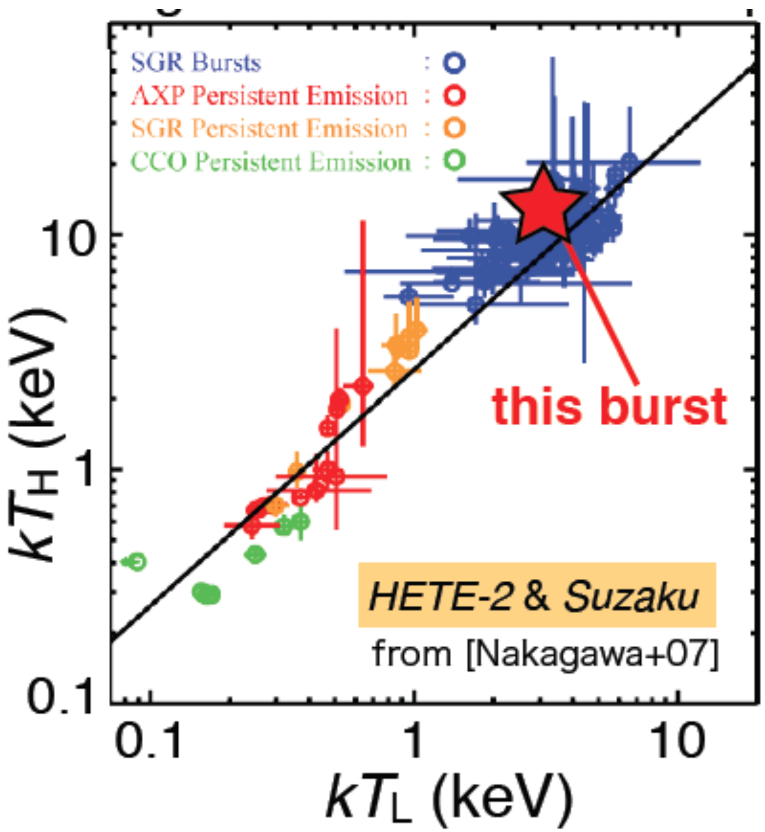
T_L=3.3 ± 0.5 keV
T_H=15.1 ± 2.5 keV
T_H/T_L=4.6 ±1.0





At least a few possibilities..

The two temperatures are in good proportion to each other (Nakagawa+07)



1. The 2T property is an artifact caused by deviations from a pure blackbody spectrum.

   1a. Effects of Compton scattering in the magnetosphere (Zane).

   1b. Is the “blackbody” spectrum still valid when the emitting/absorbing electrons can move along 1-Dim?

2. The 2T results represent real effects, e.g., different photospheres between O-mode and X-mode photons (double refraction; 複屈折)➔ polarization measurements essential

9. *Do Magnetars really have $B>B_c$?*

☆ Primary evidence

- MF strengths estimated from *P* and *P*dot

☆ Circumferential evidence for very strong MF

- Tight clustering of their pulse periods (2—11 sec)
- Sporadic emission of bursts, often with super-Eddigton L_x
- Very unusual 2-component X-ray spectra
- …

☆ Decisive evidence

- Detection of proton cyclotron resonance features
- Any firm evidence for QED effects..

10. How are the Magnetic Fields Held ?

☆ Some electric currents (protons and/or electrons)?

☆Nuclear ferromagnetism due to neutron's spin alignment (Makishma+99; Tasumi)?

☆More sophisticated idea – pion-condensed domain walls (Hashimoto+12) ?