Unification of Strongly Magnetized Neutron Stars with regard to X-ray emission from hot spots

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X-ray Isolated Neutron Star (XINS)

- Radio-quiet, thermally emitting neutron stars
- Nearby objects (< 500 pc)
- Show only single temperature blackbody emission
  ⇒ Key objects for ***M-R*** relation; "***Perfect NS***"
- $L_x \sim 10^{30} – 10^{32}$ erg s^{-1}
- $T \sim 10^6$ K: observed in soft X-ray band
- $B \sim 10^{13}$ G: strongly magnetized
- Only 7 objects are known; "The Magnificent Seven" or "Seven Samurai"

RX **J0420**.0-5022 (kT = **43** eV)
RX **J0720**.4-3125 (**102** eV)
RX **J0806**.4-4123 (**90** eV)
RBS1223 (**88** eV)
RX **J1605**.3+3249 (**105** eV)
RX J1856.5-3754 (**63** eV)
RBS1774 (**105** eV)

Discovery of the "keV-excess" in J1856

Spectral fitting with known BB model (w/ optical comp.) ⇨ **Well fitted below 0.8 keV**

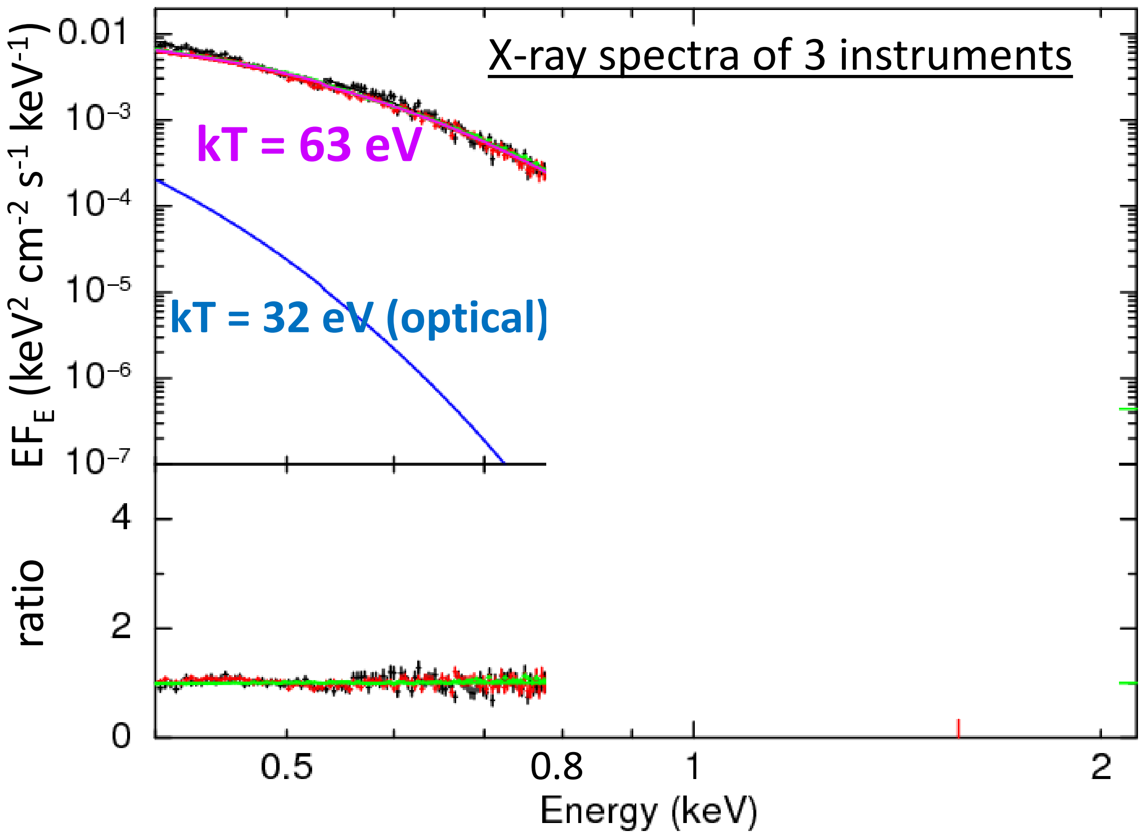
Suzaku

XIS1
Exposure: 450.4 ks
χ^2_r = 1.86 for 230 dof

XIS0+3
Exposure: 450.4 ks
χ^2_r = 1.41 for 239 dof

XMM-Newton

EPIC-pn
Exposure: 392.7 ks
χ^2_r = 3.06 for 147 dof



Discovery of the “keV-excess” in J1856

Spectral fitting with known BB model (w/ optical comp.) ⇒ Significant excess around 1 keV

Suzaku

XIS1
Exposure: 450.4 ks
χ^2_r = 1.86 for 230 dof

XIS0+3
Exposure: 450.4 ks
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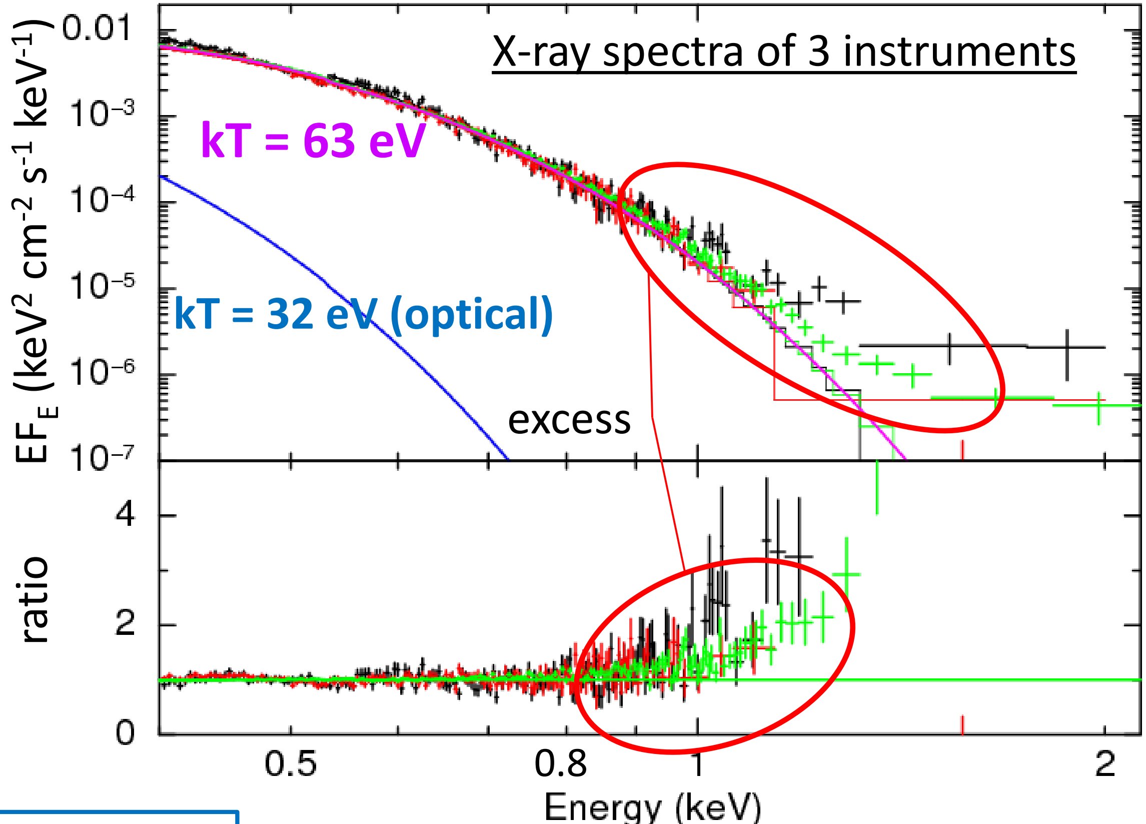


This doesn’t originate to artifacts (e.g. BG, pile-up)

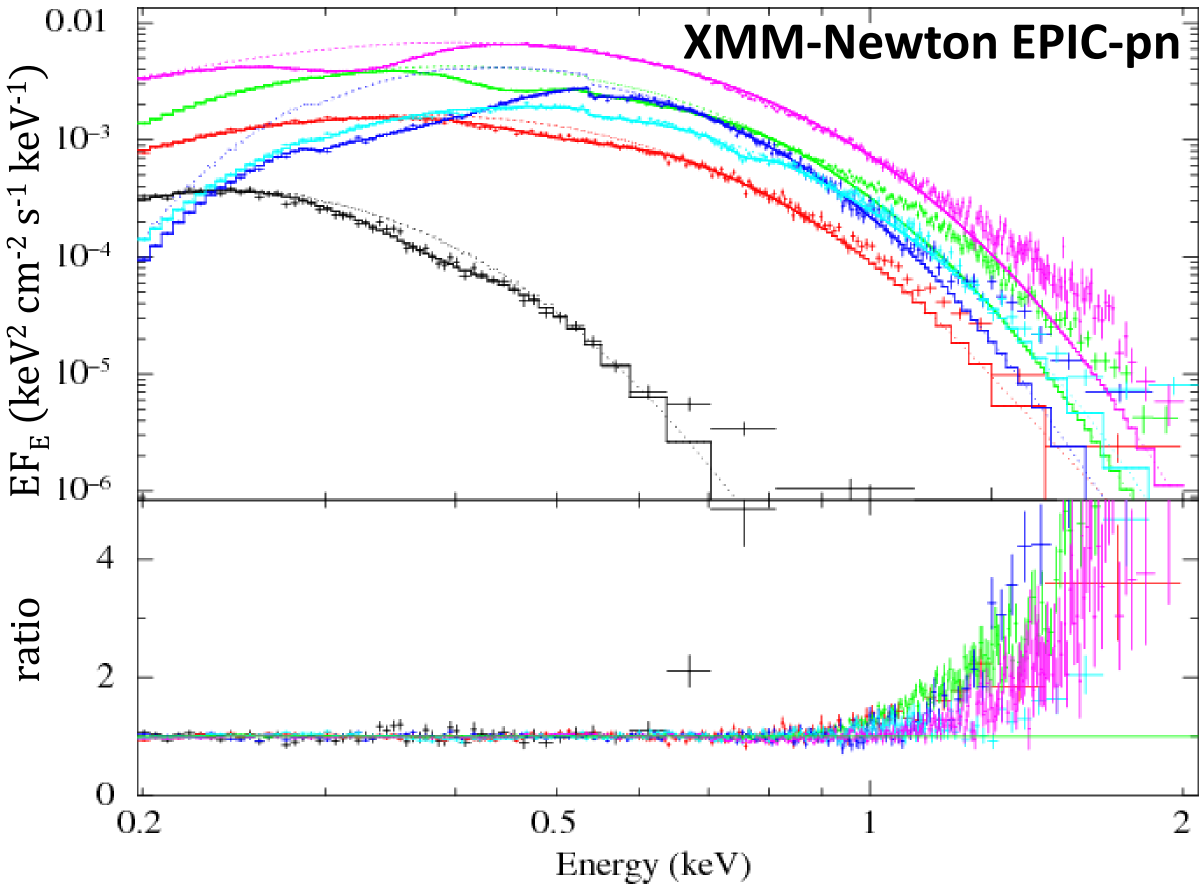
Yoneyama et al. 2017, PASJ

⇒ unknown component “**keV-excess**”

Search for the other 6 XINSs

fitting with known single BB model
⇒ **All the 6 sources show the keV-excess**

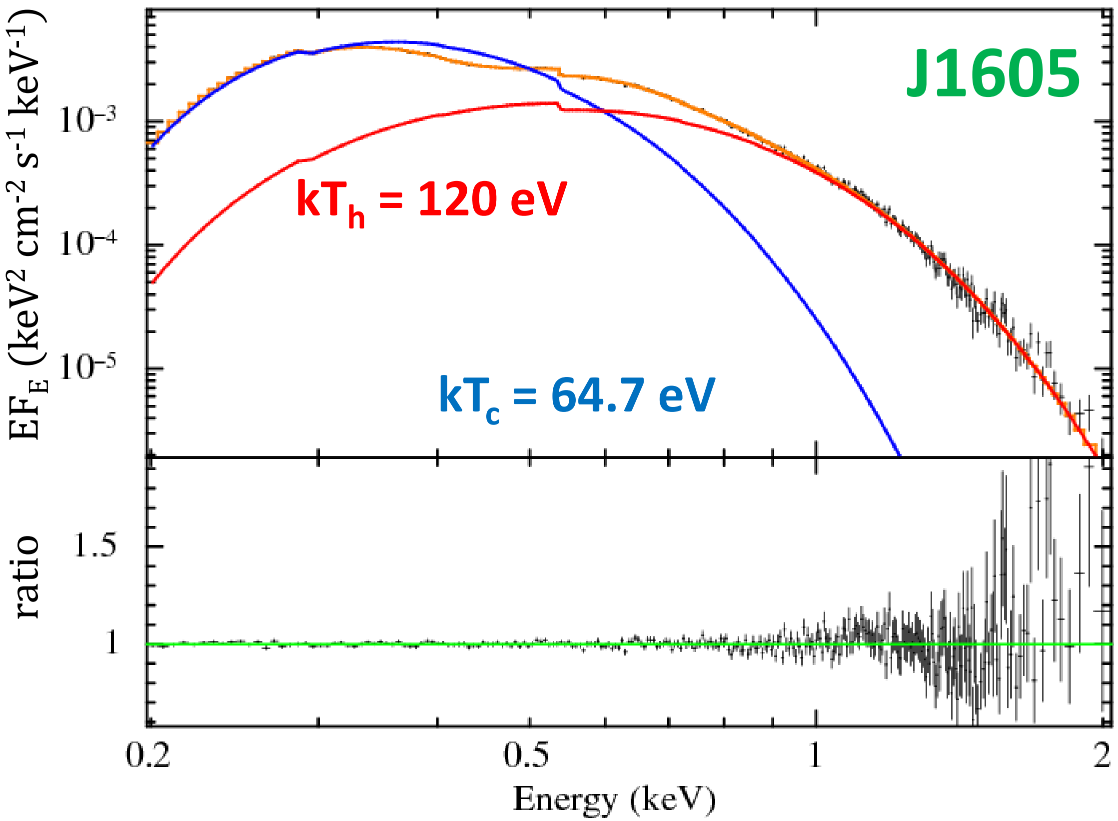
evaluation value : f_{ex} = (data - model)/model



Target	kT [eV]	f_{ex} [%]	band [keV]
J0420	42.8	85±15	0.6 – 1.0
J0720	102.2	33±7	1.3 – 1.7
J0806	89.6	90±12	1.2 – 1.6
RBS1223	88.4	70±5	1.2 – 1.6
J1605	105.0	139±4	1.3 – 1.7
RBS1774	104.6	44±7	1.3 – 1.7
J1856	63	16±2	0.8 – 1.2

keV-excess is universal for XINSs!

Spectral fitting including the keV-excess



Target	kT_c [eV]	kT_h [eV]	χ^2_r / dof
J0420	46.5	160	1.2 / 85
J0720	82.4	127	1.3 / 354
J0806	57.5	105	1.0 / 194
RBS1223	68.7	138	1.1 / 229
J1605	64.7	120	1.0 / 282
J1856	62.0	101	1.2 / 206
RBS1774	54.5	106	1.1 / 218

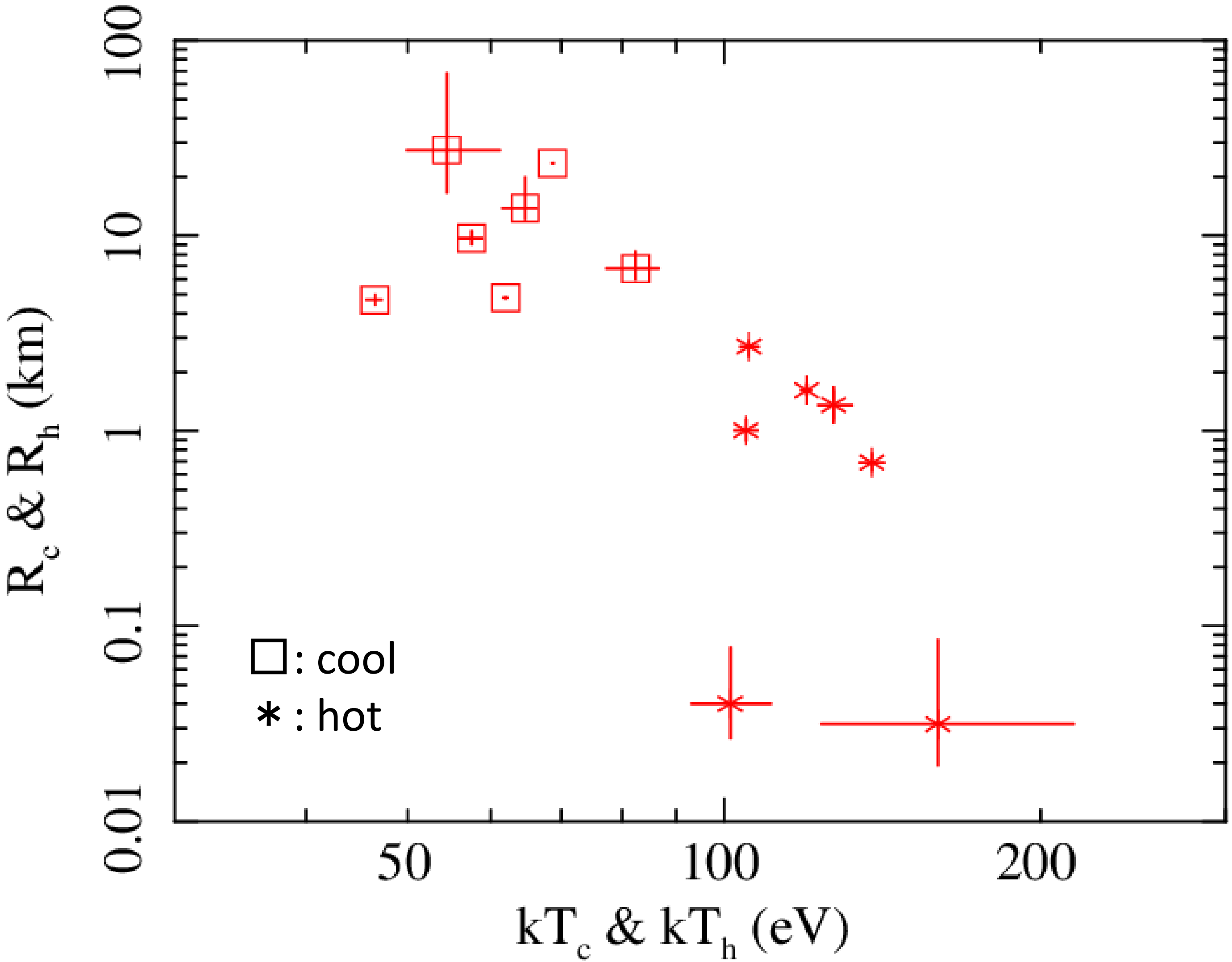
Target	kT [eV]	Γ	χ^2_r / dof
J0420	46.1	3.7	1.2 / 85
J0806	93.0	6.6	1.0 / 194
J1856	62.0	7.1	1.2 / 206

dual BB reproduces all the 7 XINSs

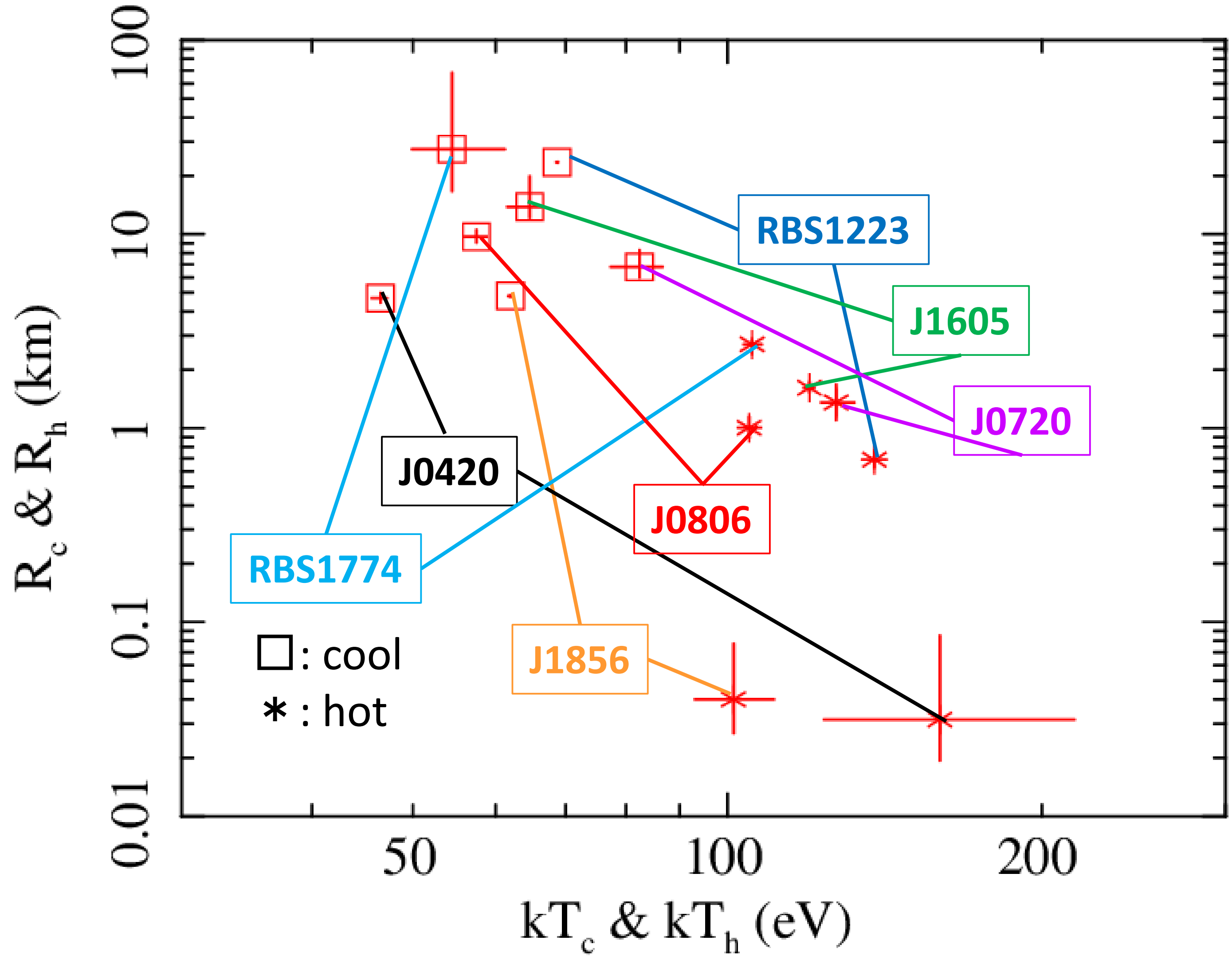
BB+powerlaw is acceptable for 3 sources

⇒ Focus on the **dual BB** model

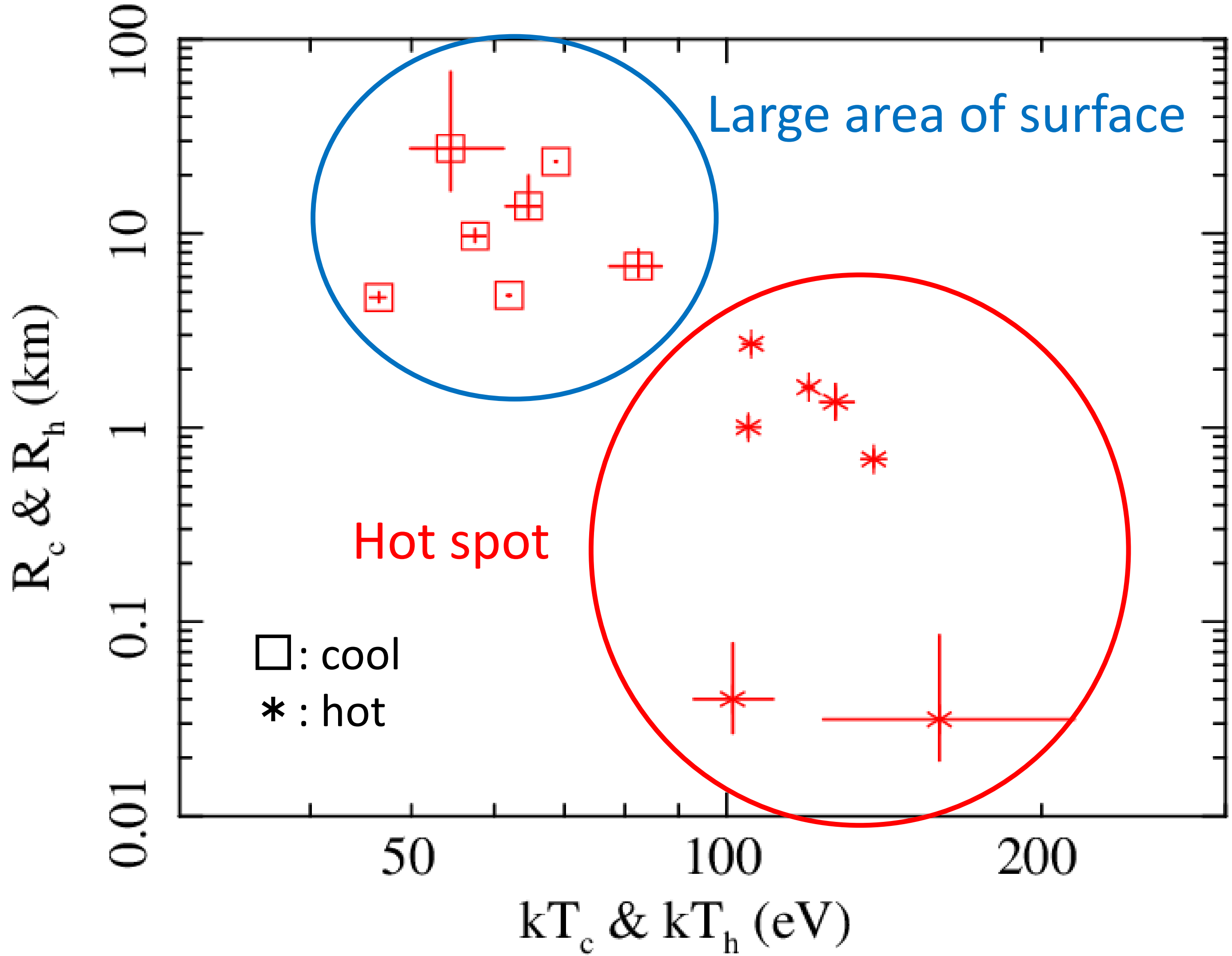
Temperature/Radius distribution



Temperature/Radius distribution



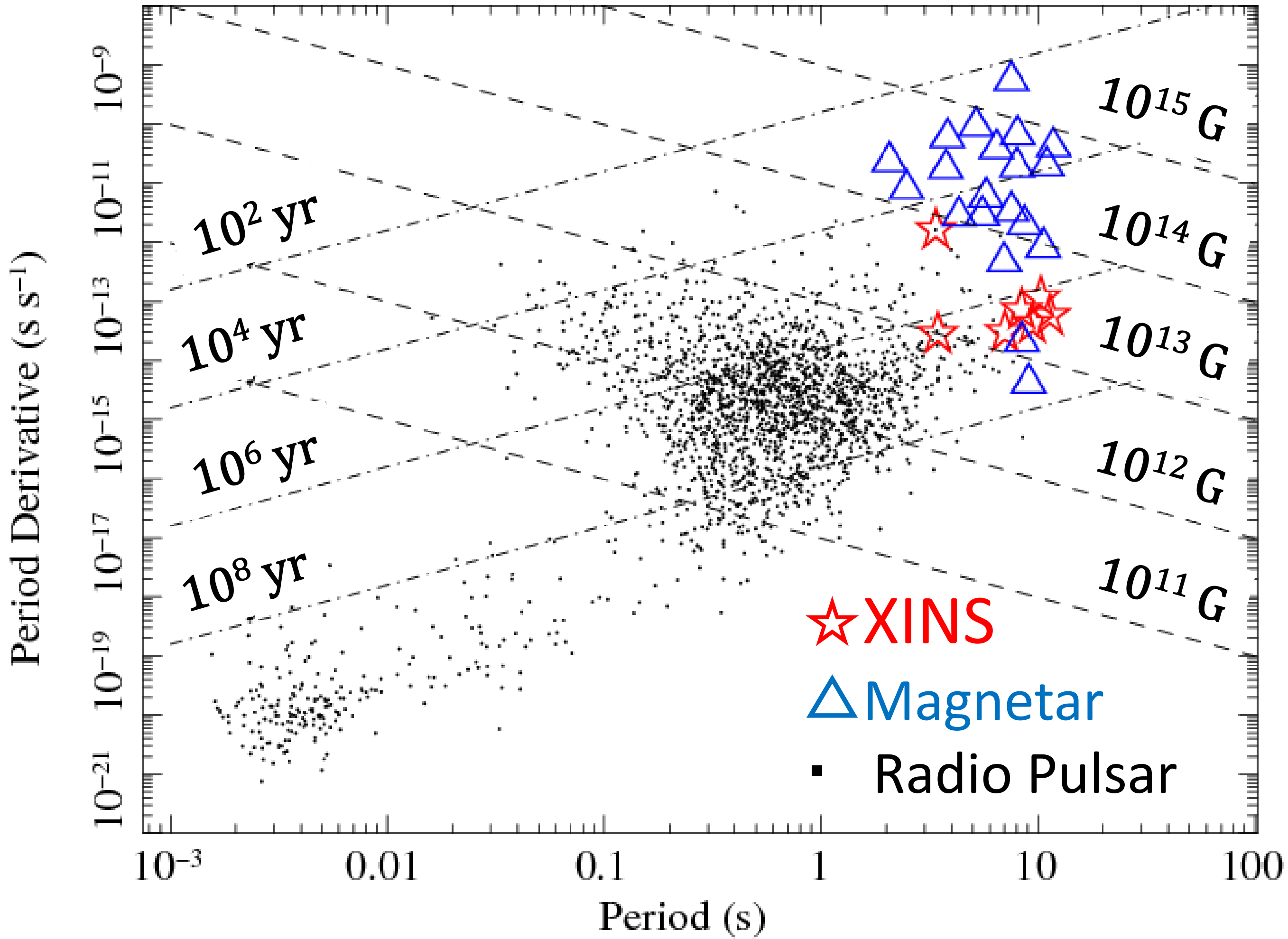
Temperature/Radius distribution



surface temperature distribution, **NOT ISOTHERMAL**
⇒ Take into account the keV-excess for ***M-R*** relation!

Link between XINS & Magnetar

- Magnetars are hotter (~ 1 keV), younger and stronger B than XINS

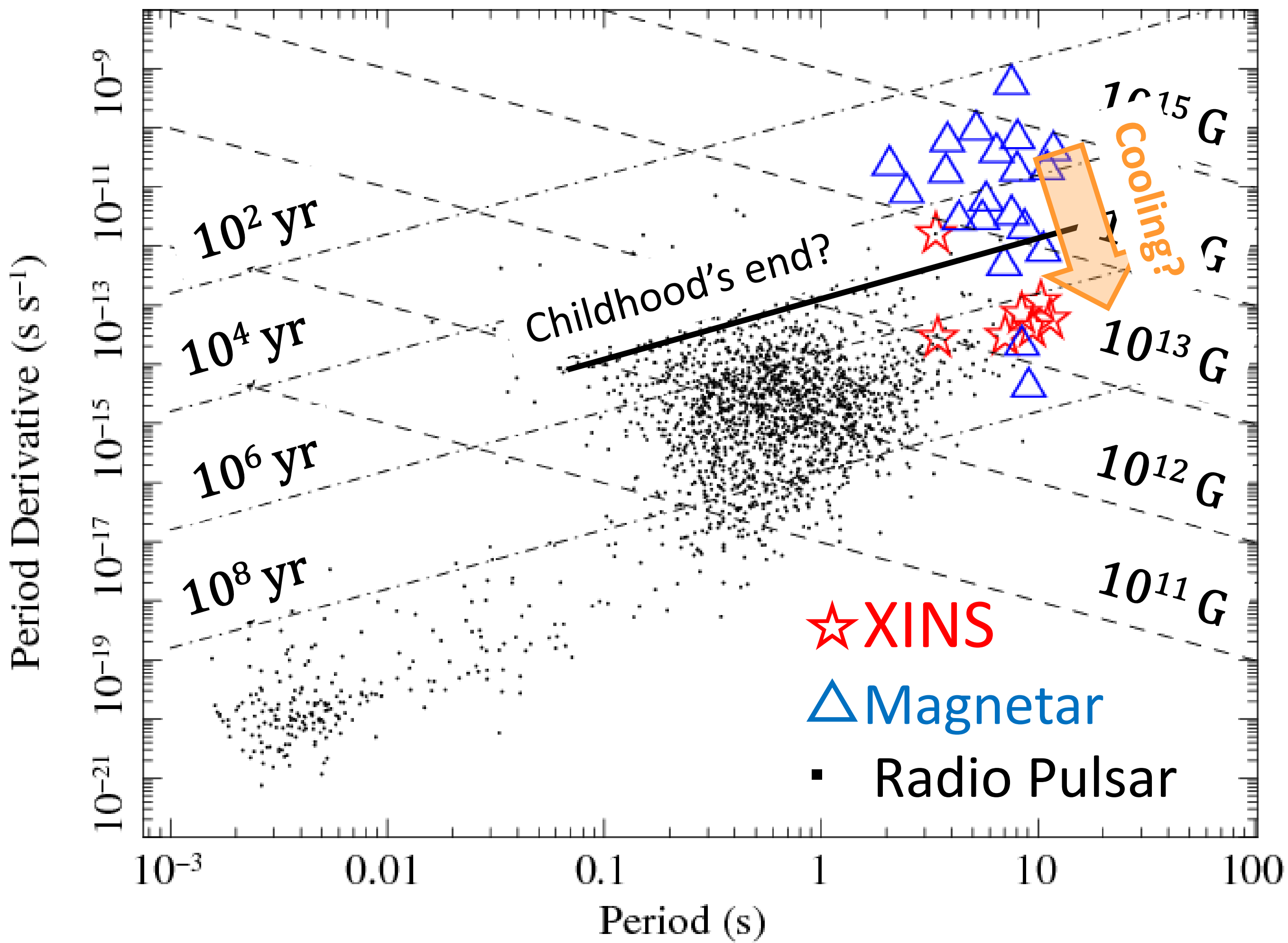


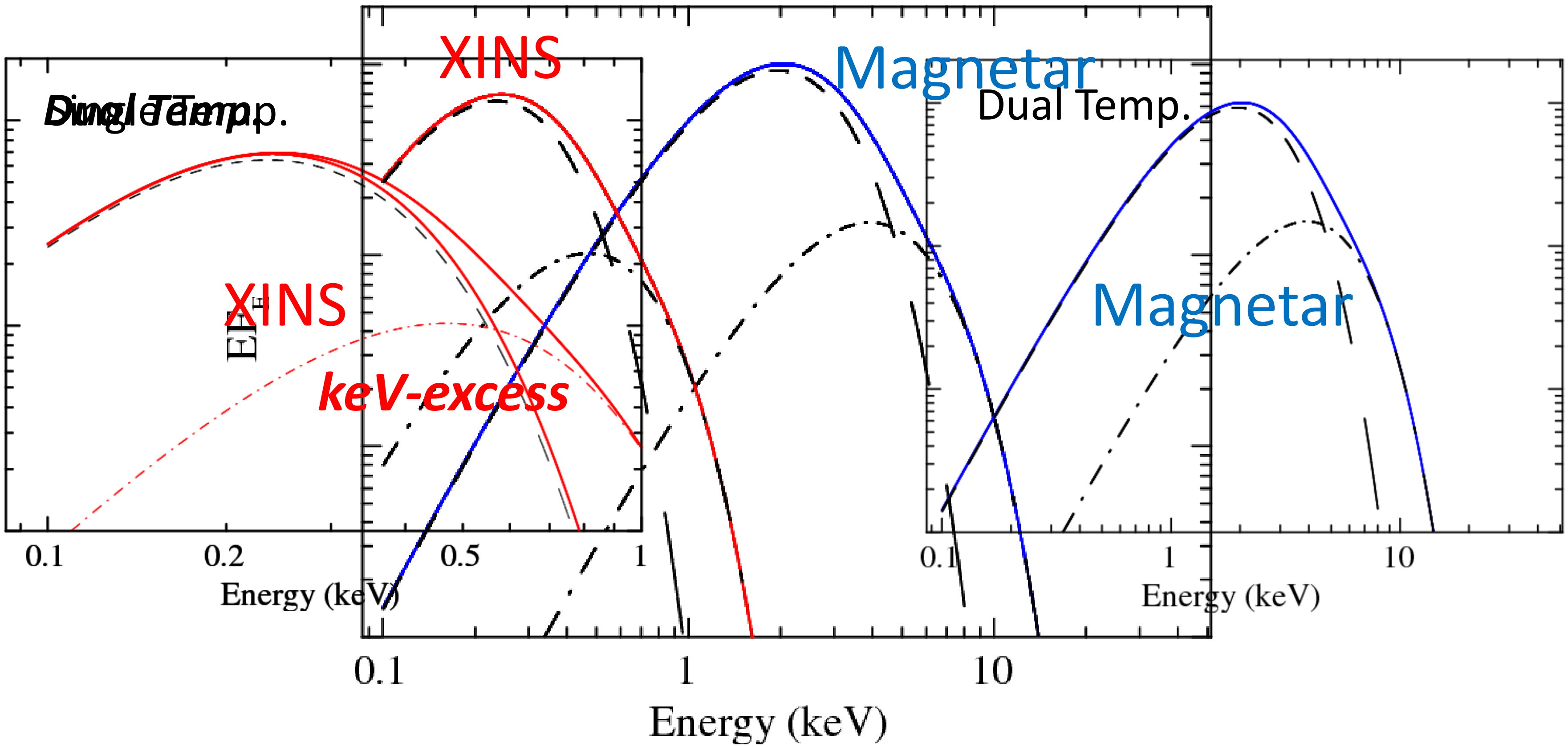
Link between XINS & Magnetar

- Magnetars are hotter (~ 1 keV), younger and stronger B than XINS

⇒ XINS may be old, "worn-out" Magnetar

- However, NO strong evidence has been reported!





Different spectra, different emission mechanism

⇨

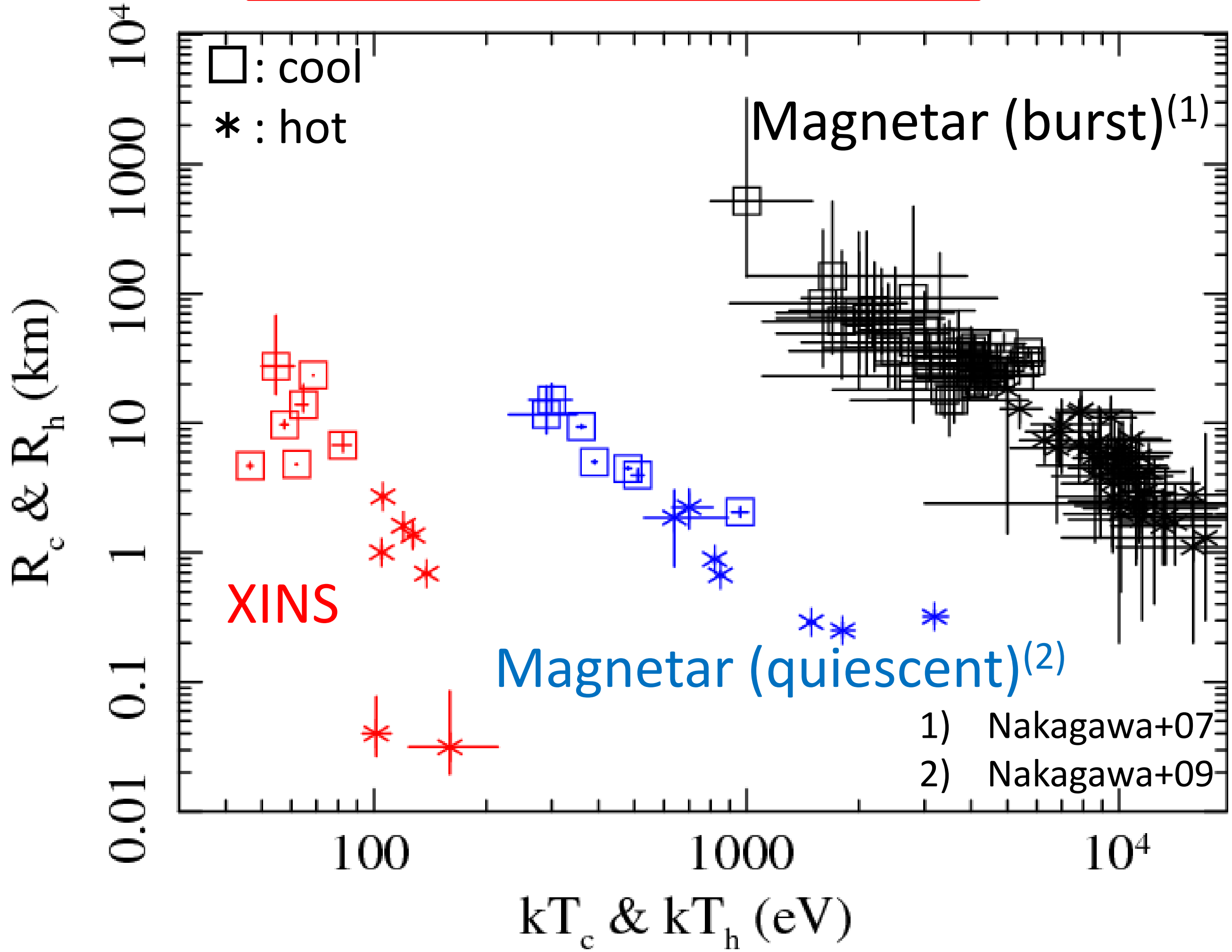
Discovery of the ***keV-excess***

Unification

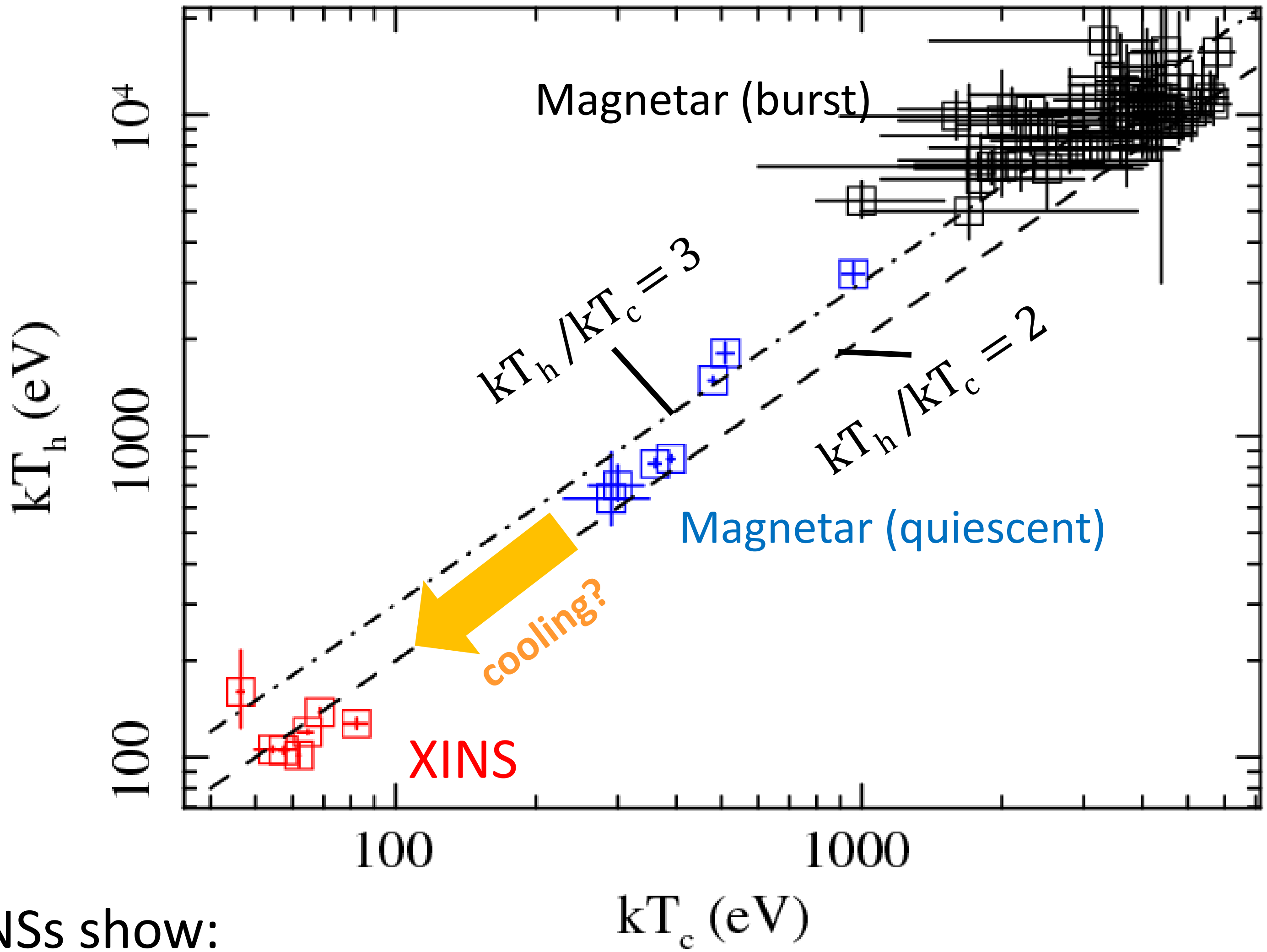
Comparison of XINS / Magnetar

characteristic parameters of XINS/Magnetar:

(kT_c, R_c) & (kT_h, R_h)



Cool component vs. Hot component



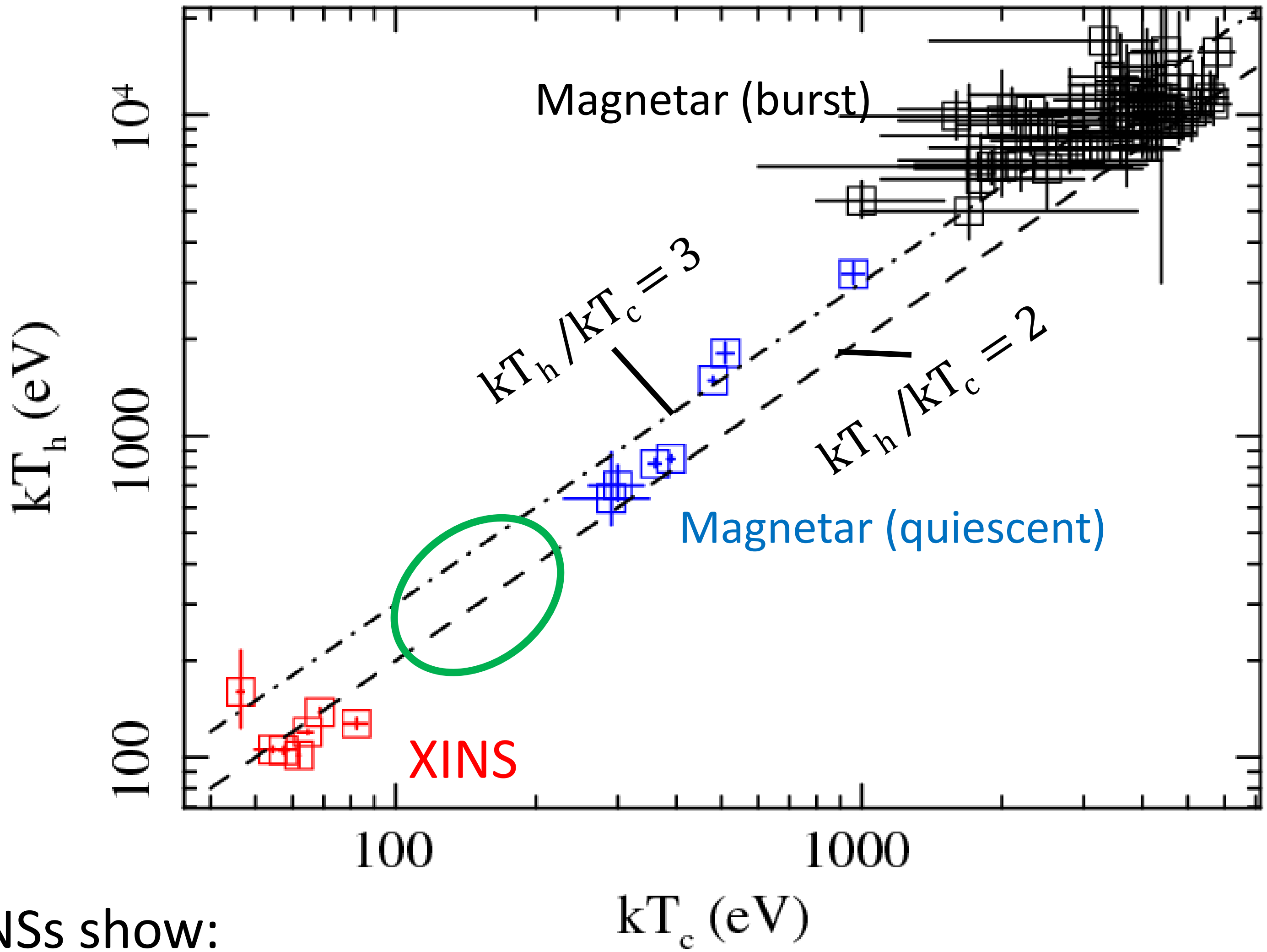
XINSs show:

- lower temperature
- similar ratio

⇒

suggests the same origin
supports "Worn-out" hypothesis

Cool component vs. Hot component



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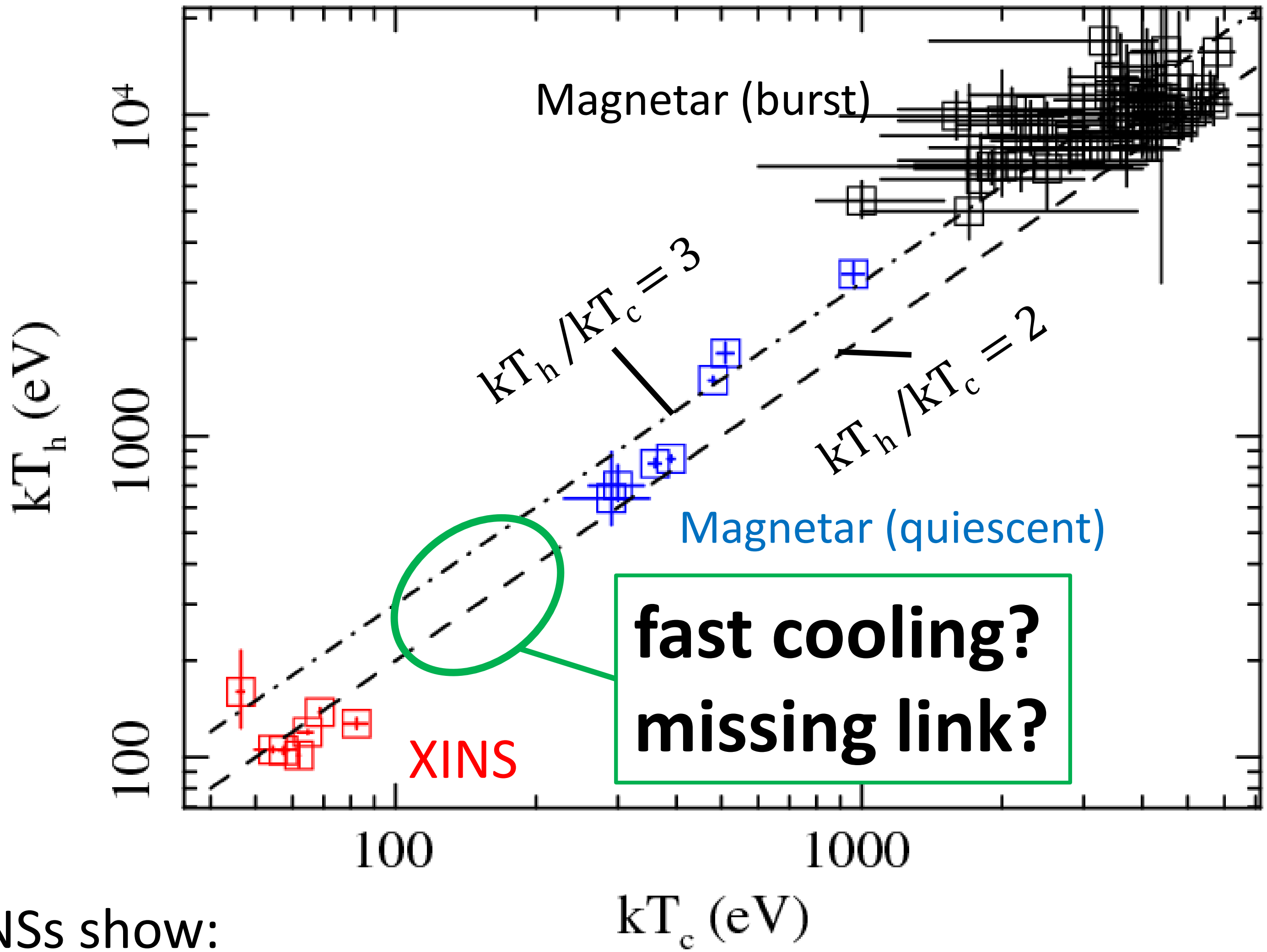

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- lower temperature
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suggests the same origin

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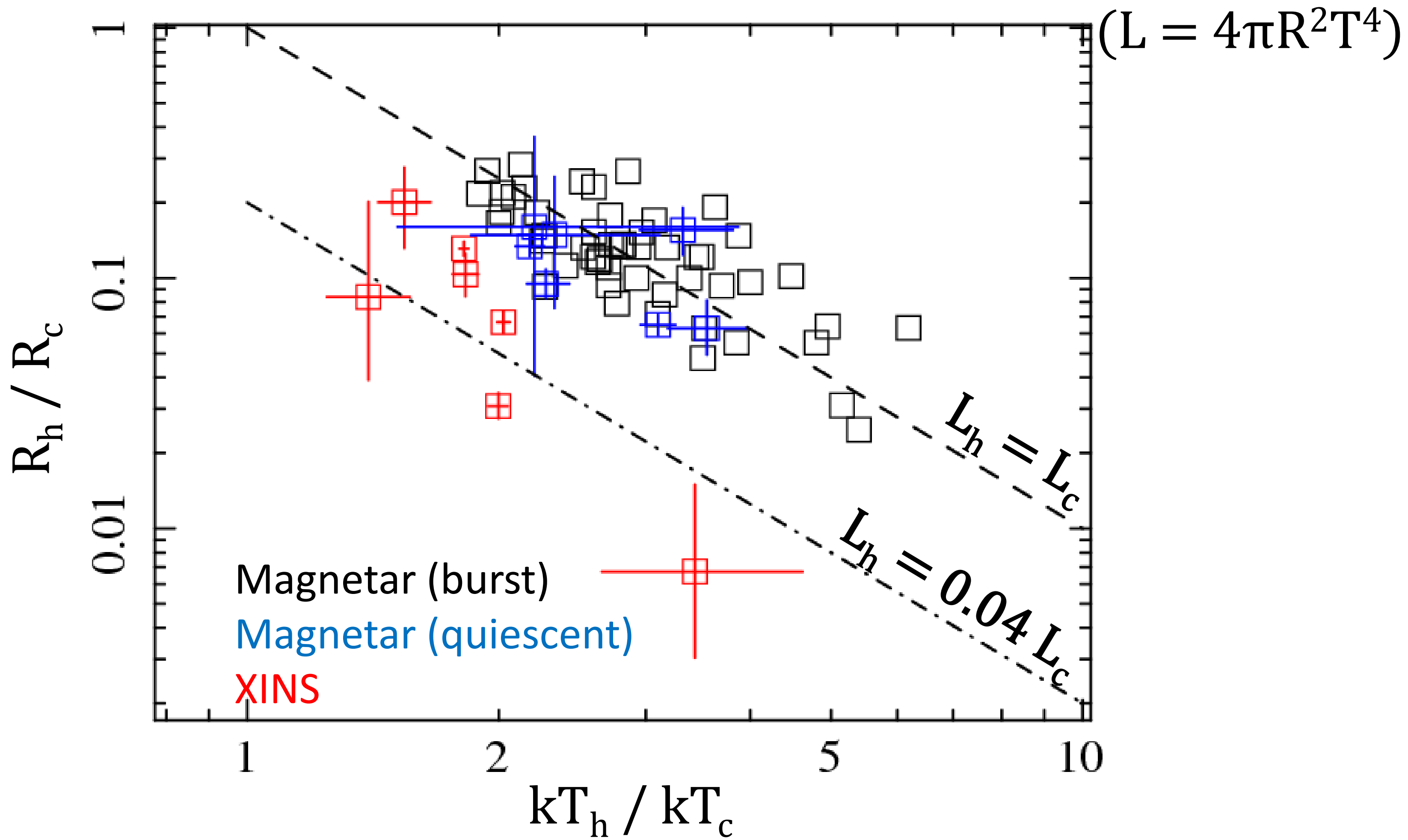
Temp. ratio vs. Radius ratio

Magnetars: $L_h \sim L_c$ in both state (Nakagawa+09)



XINSs show $L_h < L_c$ ⇒ Thermal evolution? (work in progress)

Summary

- XINSs have been considered to show single temperature blackbody emission
- We discovered the keV-excess in **all the 7 XINSs**
- **Dual BB model** reproduces the X-ray spectra
- XINSs are no longer "Perfect NS"
- Spectral shape are similar with Magnetars
  ⇒ suggesting the same origin
  supporting the "worn out" hypothesis
- Evolution from magnetar to XINS will be fast, or there will be missing object between them
- Luminosity ratio of the dual components may be a hint for thermal evolution

back up

Physical view

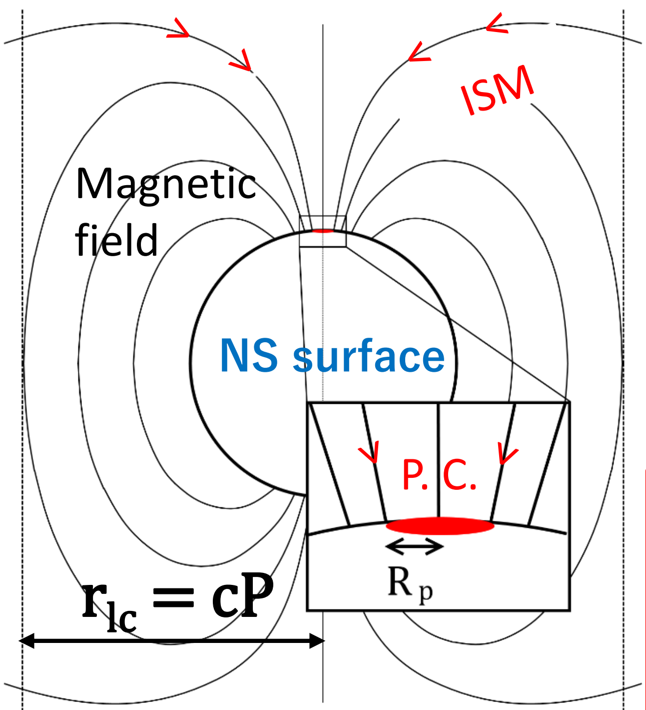
Normal view:

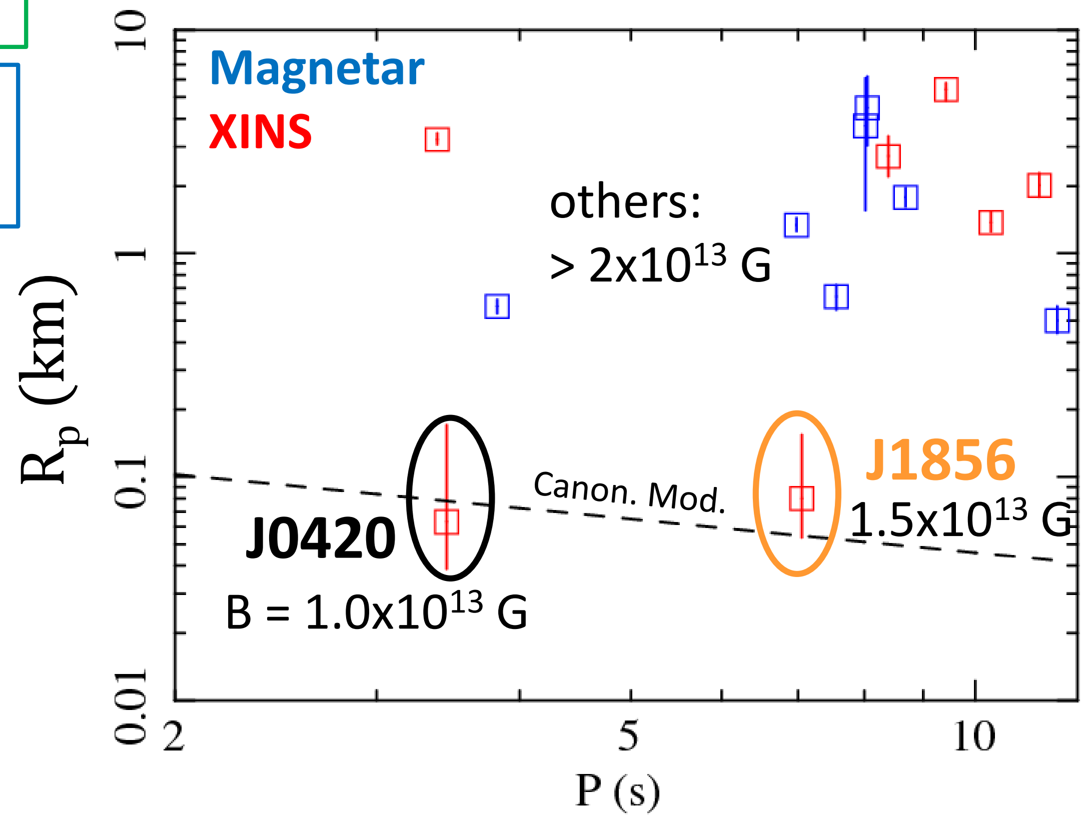
Hot: ***Polar Cap***
Cool: **Large area of surface**

Canonical Model[1] of polar cap:
$$R_p = 0.145\ P^{-0.5}$$

1) Goldreich+69

⇒ Apply for Magnetar/XINS





- Consistent for the weakest 2 sources
- Are they the oldest Magnetar/XINS ?

⇒ No (character. age)