Universal detection of high-temperature emission in X-ray Isolated Neutron Stars

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YONEYAMA et al. 2017 & 2019 + α

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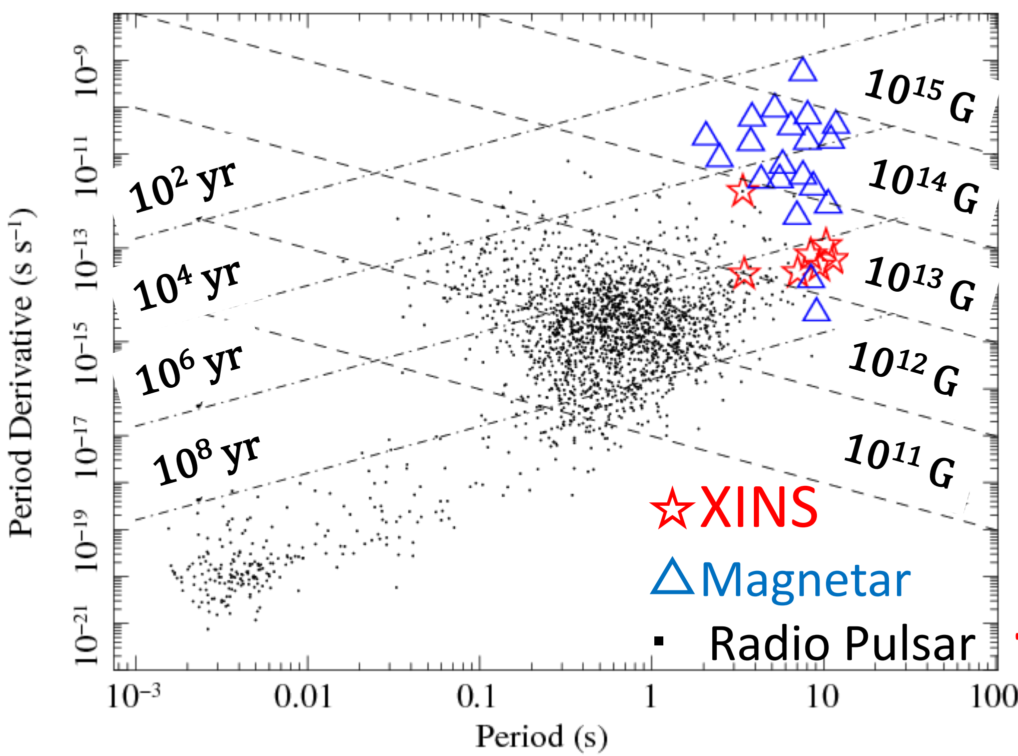
X-ray Isolated Neutron Star (XINS)

- Radio-quiet, thermally emitting neutron stars
- Nearby objects (< 500 pc)
- Only 7 objects are known; "The Magnificent Seven"
- Show only single temperature blackbody emission
- T ~ 10^6 K: observed in very soft X-ray band (< 2 keV)
- cooled, worn-out magnetars?



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)

The brightest; calibration source

Discovery of the “keV-excess” in J1856

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

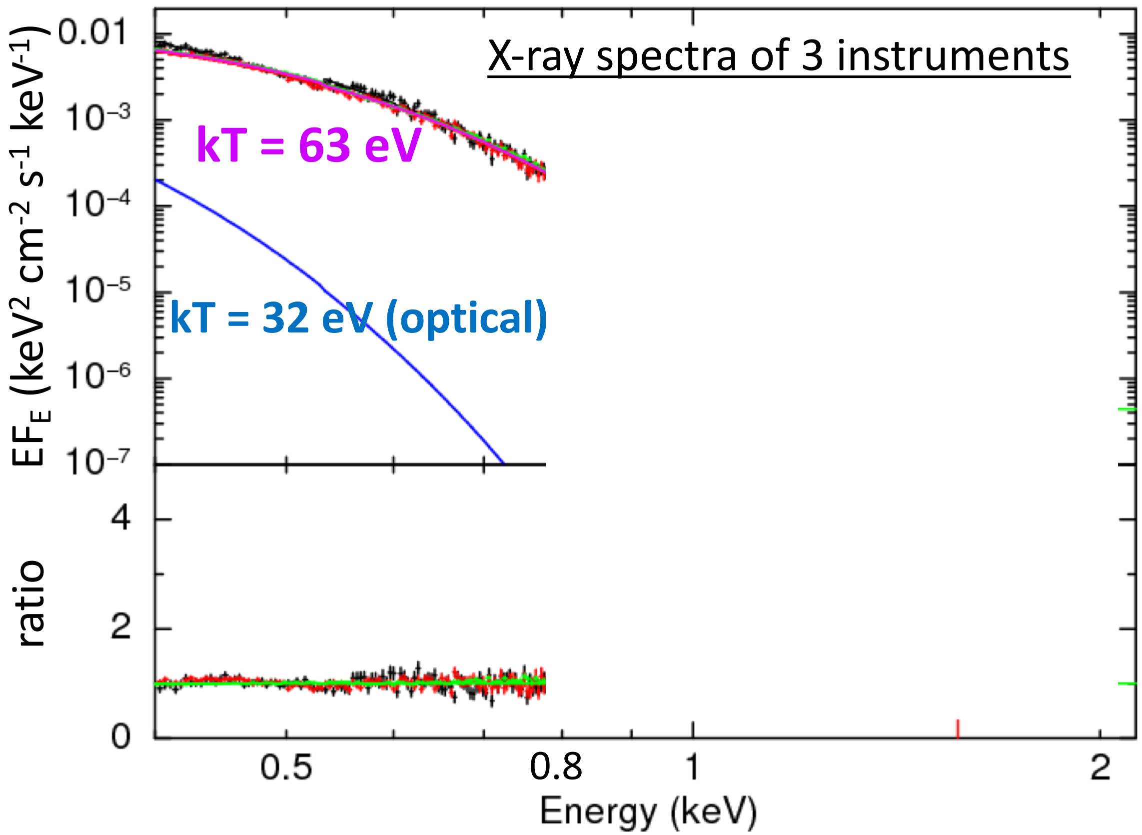
Suzaku

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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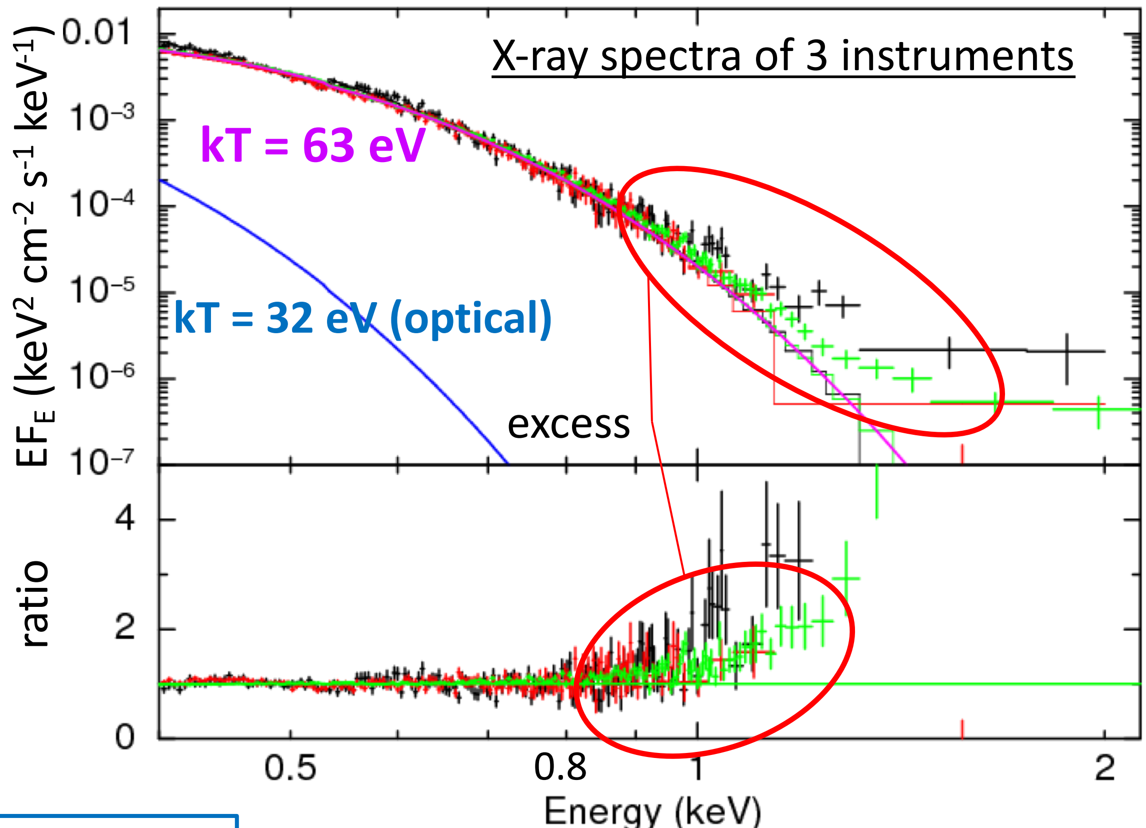


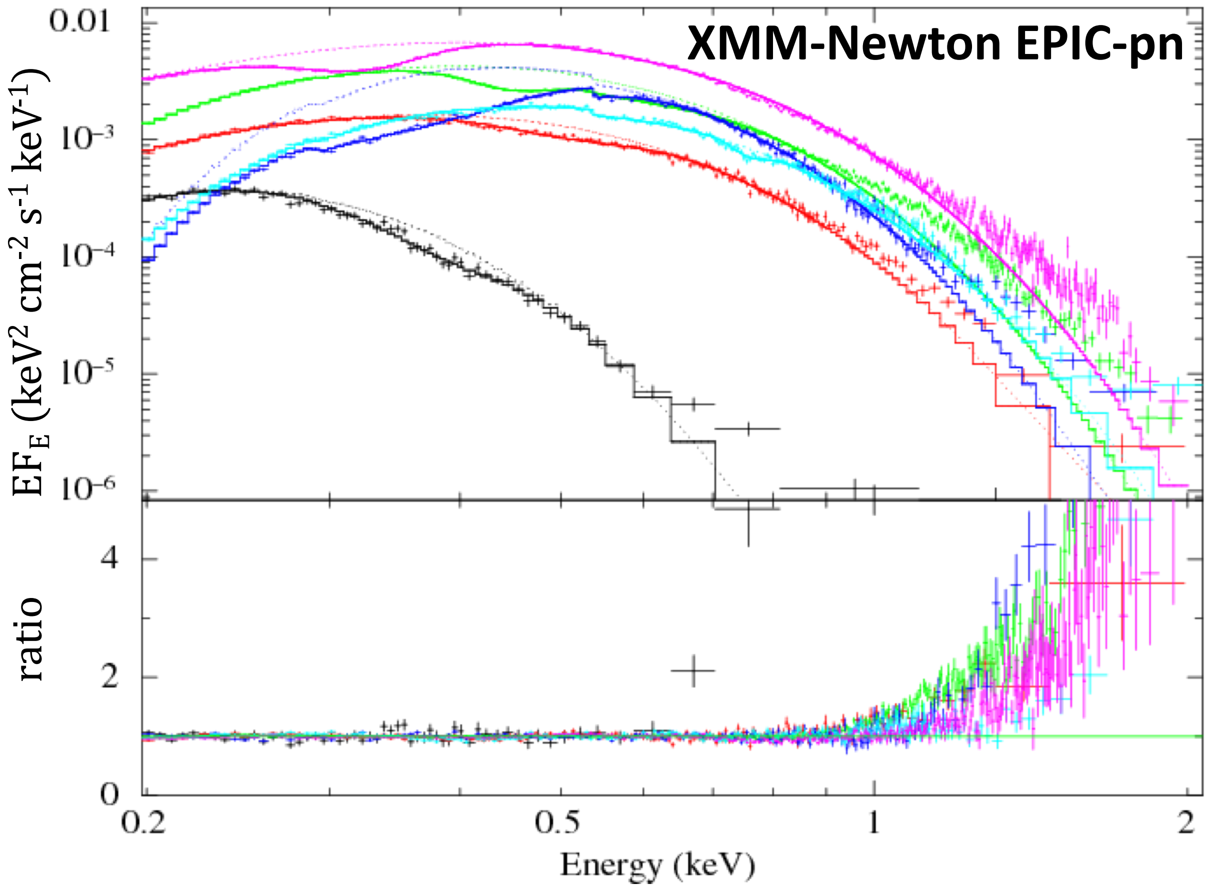
This doesn't originate to artifacts (e.g. BG, pile-up)
Yoneyama et al. 2017, PASJ

⇒ unknown component "**keV-excess**"

Search for the other 6 XINSs

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

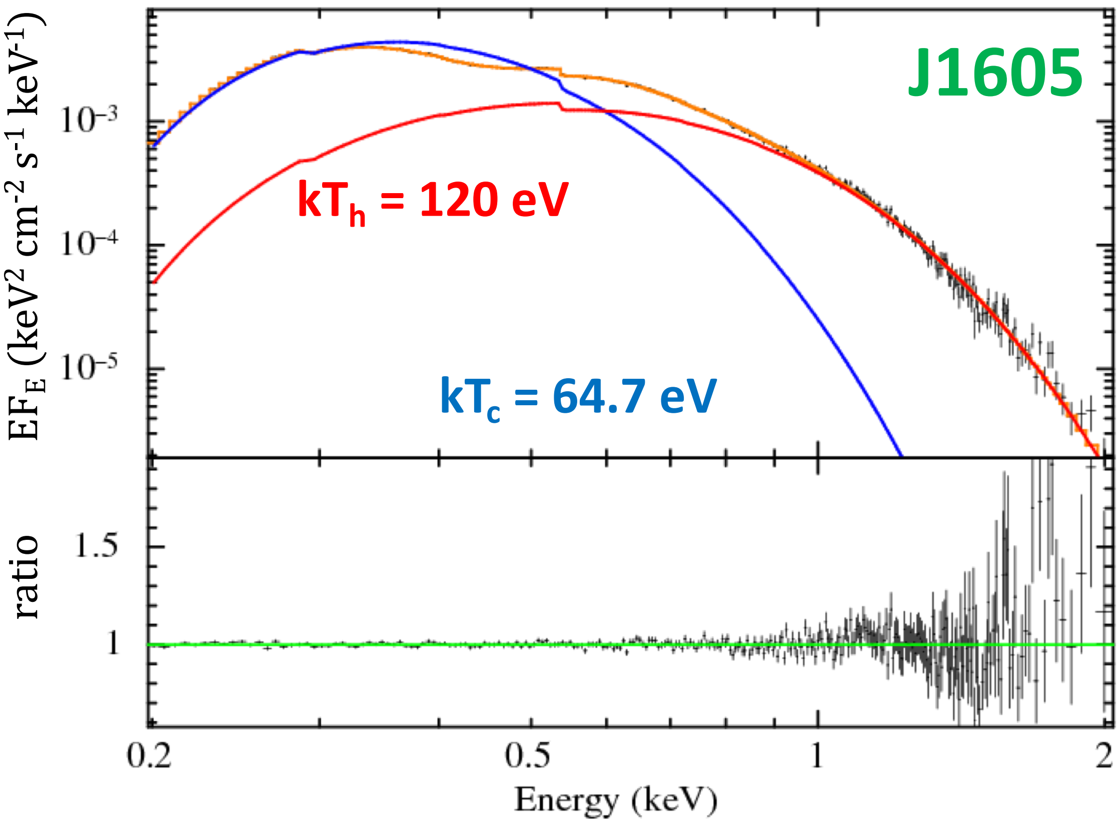
evaluation value : f_{ex} = (data - model)/model



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

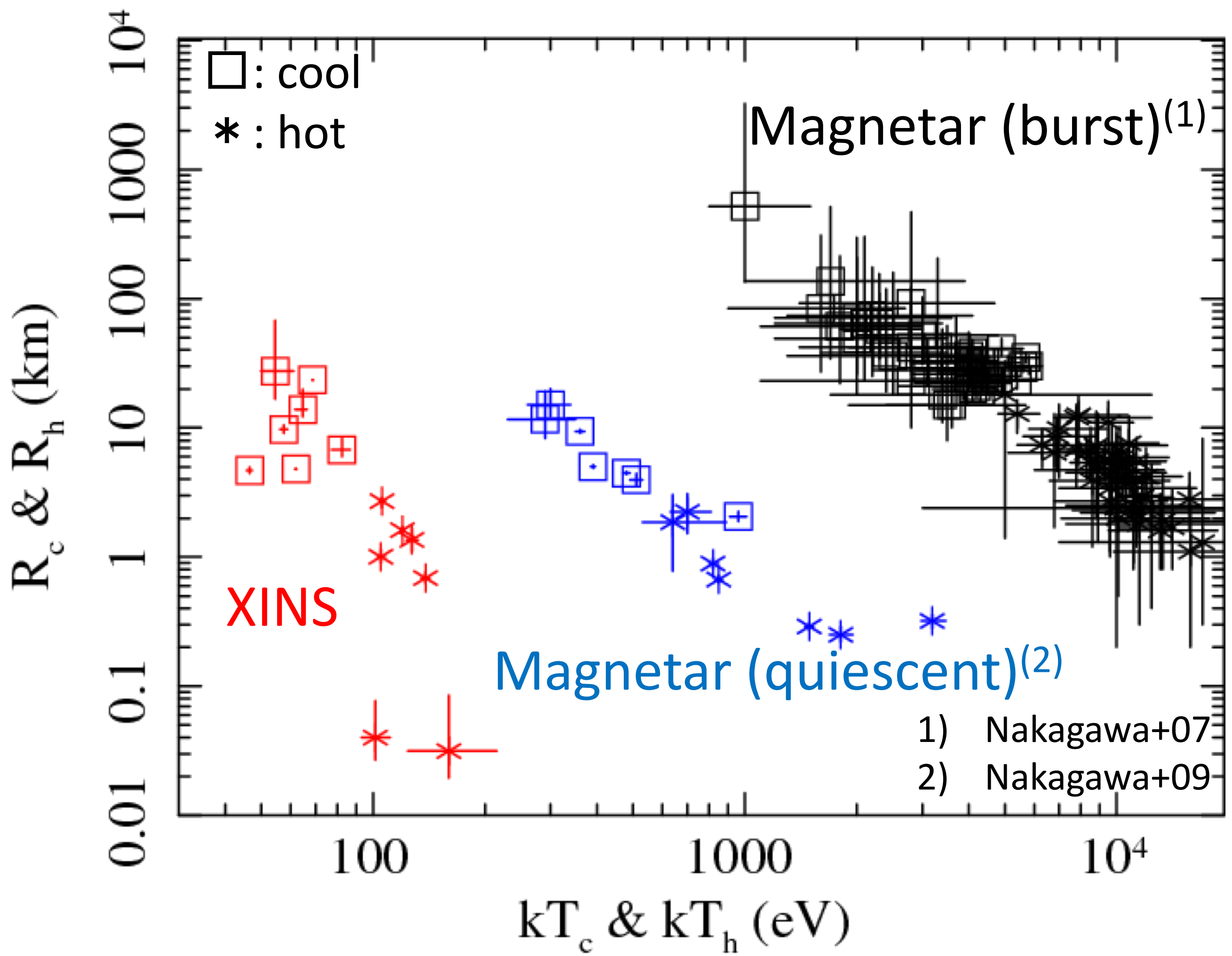
dual BB reproduces all the 7 XINSs

BB+powerlaw is acceptable for 3 sources

⇒ magnetars are also 2BB: worth comparing

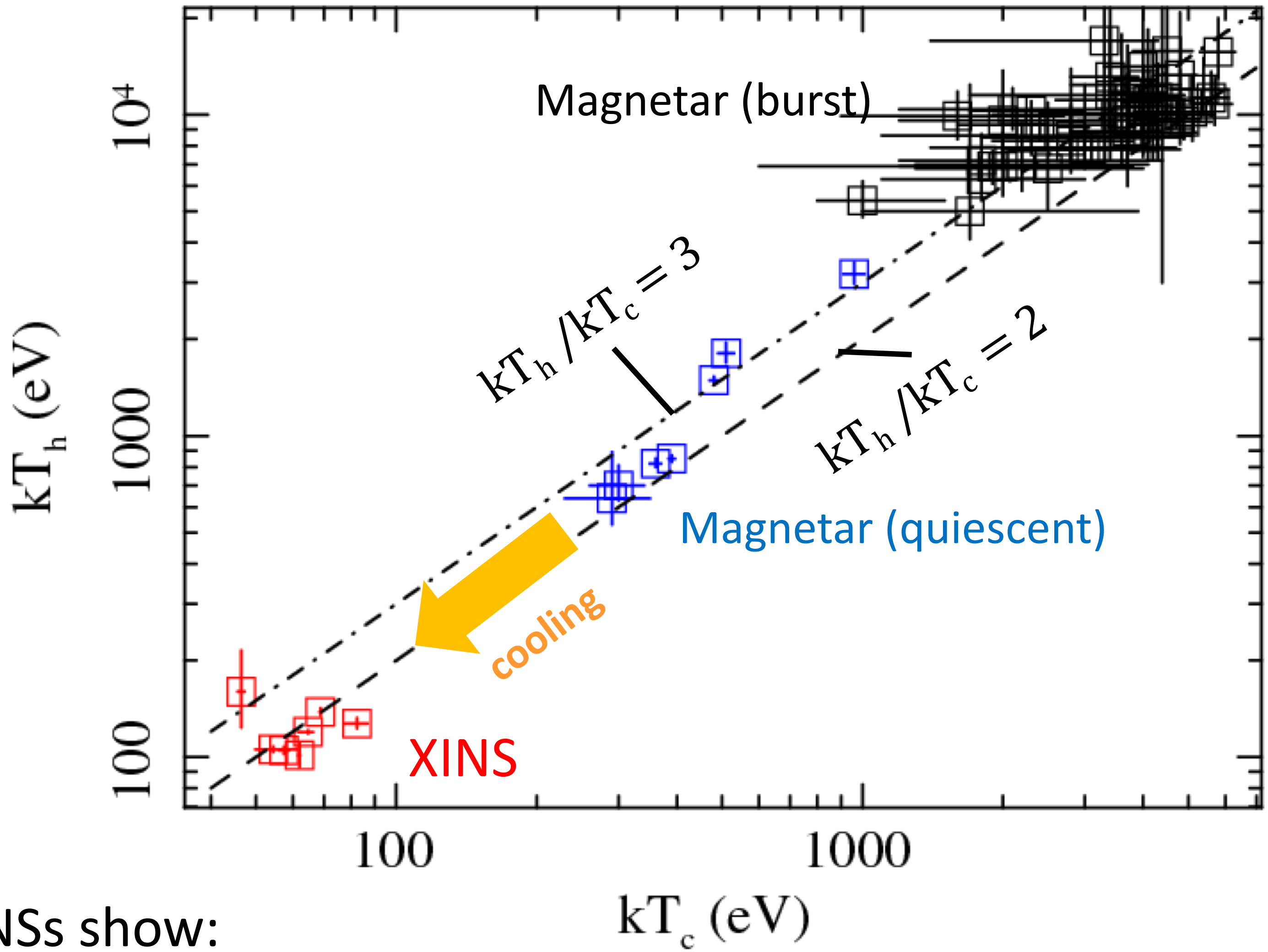
Yoneyama et al. 2019, PASJ

Comparison of XINS / Magnetar



similar radii, ~10 x different temperature ⇒ scaling relation

Cool component vs. Hot component



XINSs show:

- lower temperature
- similar ratio

⇒

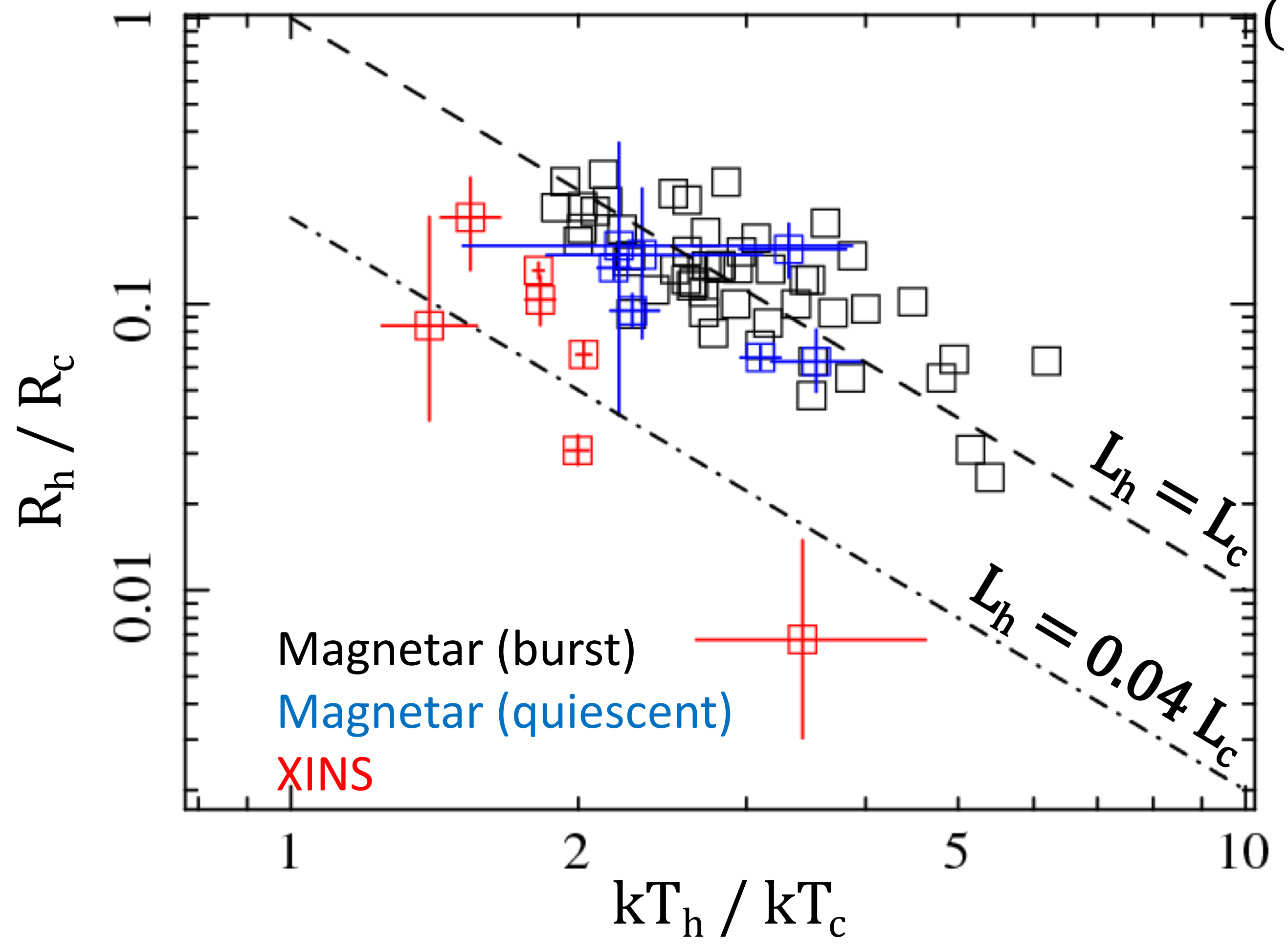
suggests the same origin

supports "Worn-out" hypothesis

Temp. ratio vs. Radius ratio

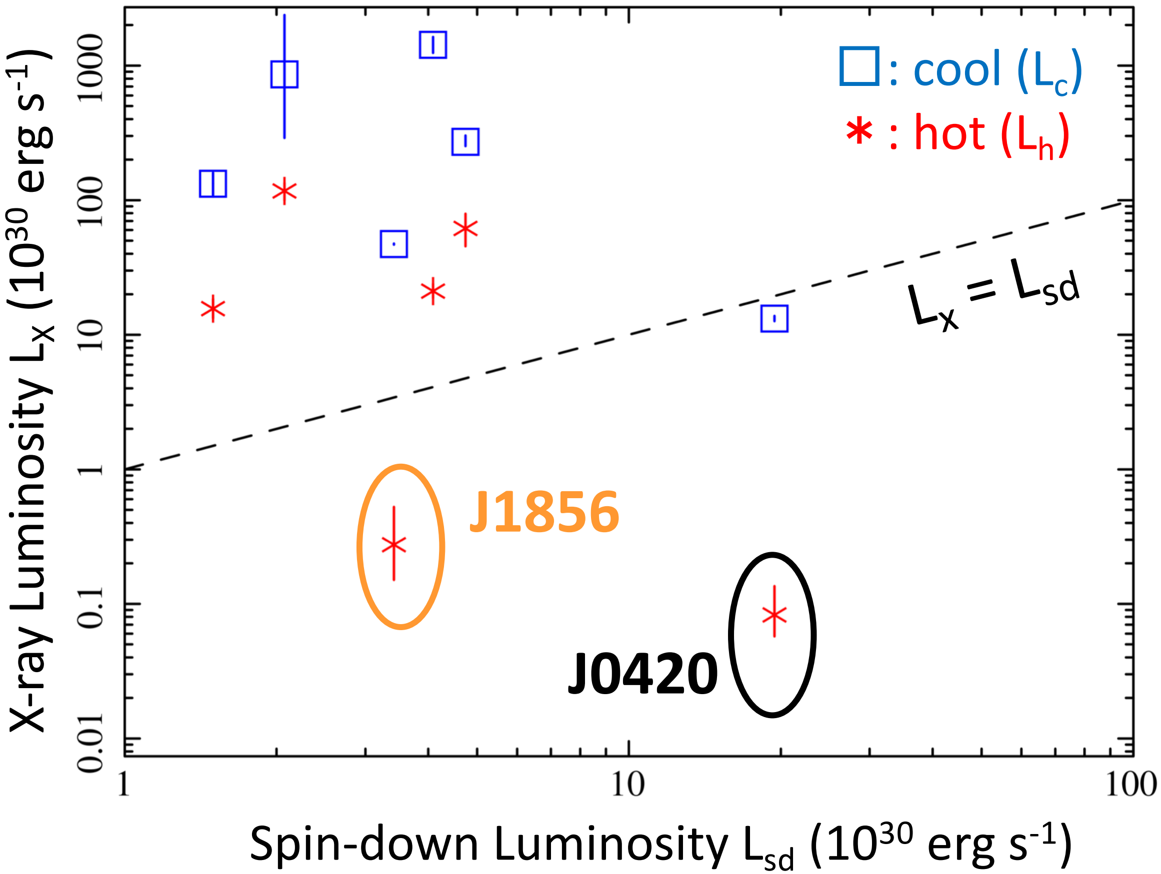
Magnetars: $L_h \sim L_c$ in both state (Nakagawa+09)

$(L = 4\pi R^2 T^4)$

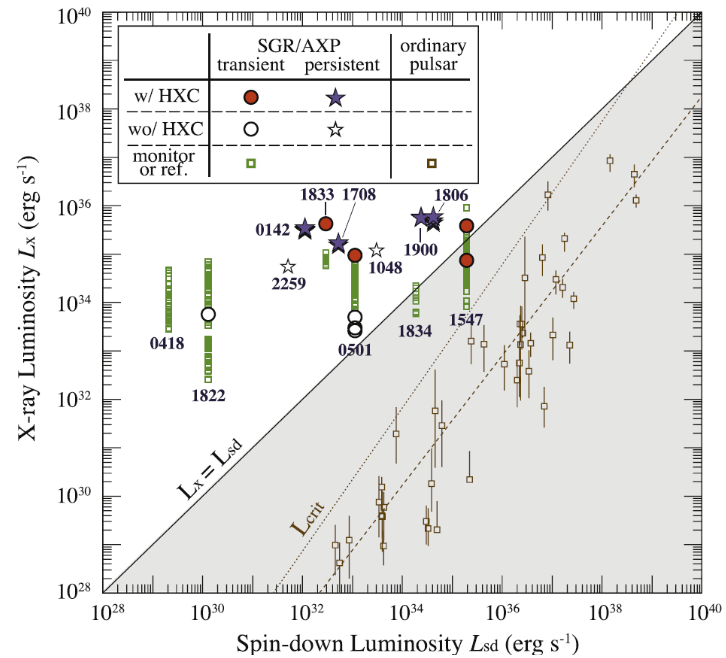


XINSs show $L_h < L_c \Rightarrow$ Thermal evolution

Comparing w/ spin-down Luminosity



c.f. Magnetar & Radio Pulsar (Enoto+17)



Hot component luminosity (L_h) is:

- consistent w/ spin-down for **J0420 and J1856** ⇒ ***Polar Cap?***
- inconsistent w/ spin-down for other 4 sources ⇒ other origin
- spin-down luminosity cannot be defined for J1605 (Pires+14, 19)

Physical view

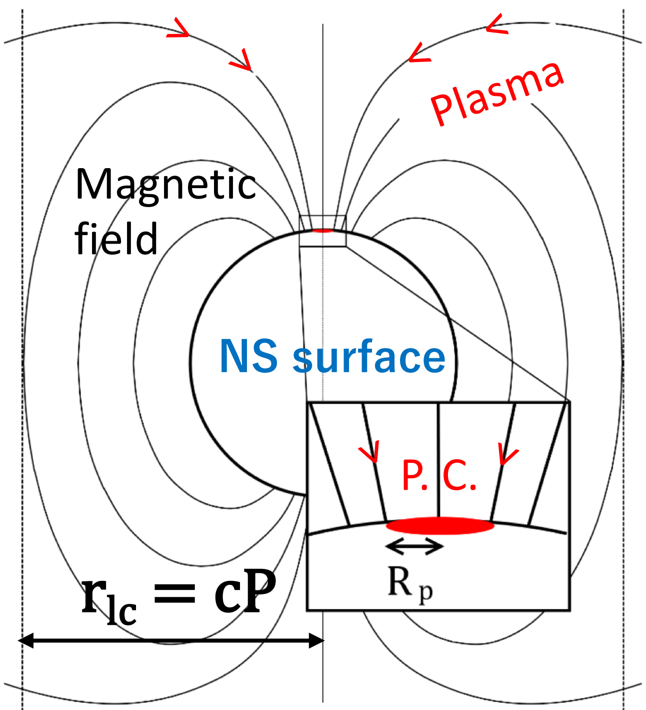
typical view:

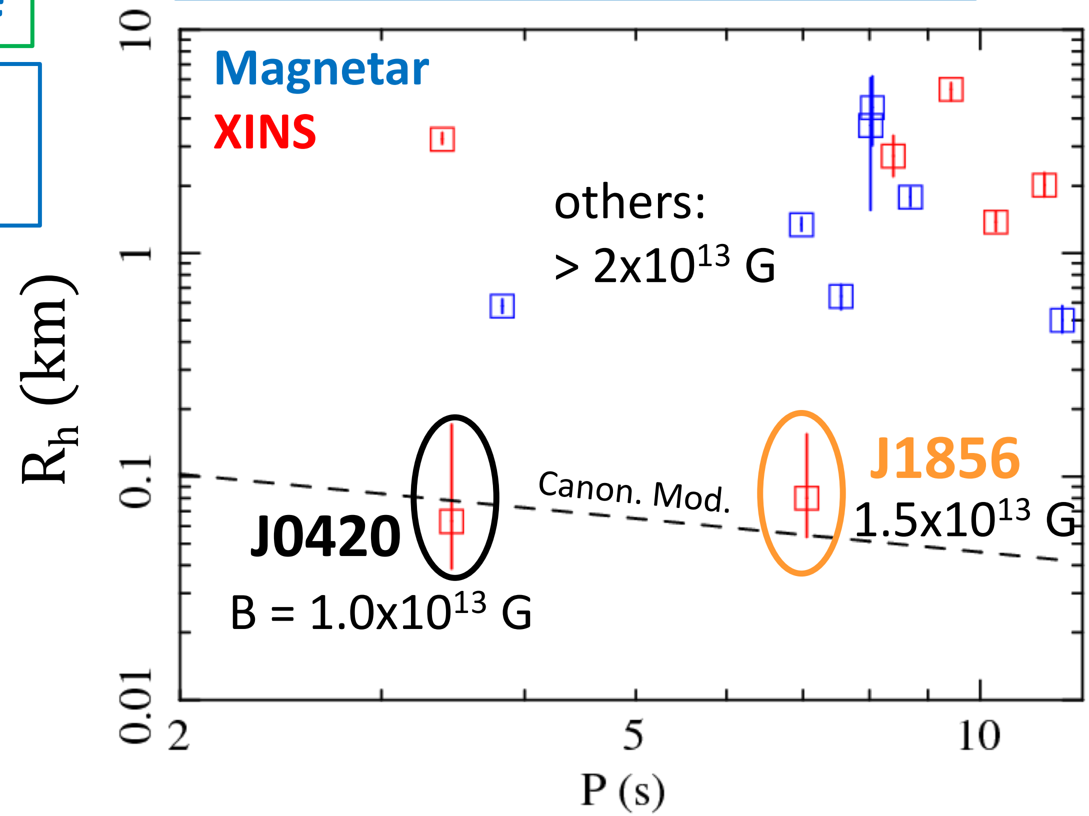
Hot: ***Polar Cap***
Cool: **Large area of surface**

*Canonical Model**) of polar cap:
$R_p = 0.145\ P^{-0.5}$

*) Goldreich & Jullian 69

⇒ Apply for XINS/magnetar





- Consistent for the 2 sources

⇒ may be **Polar cap emission**

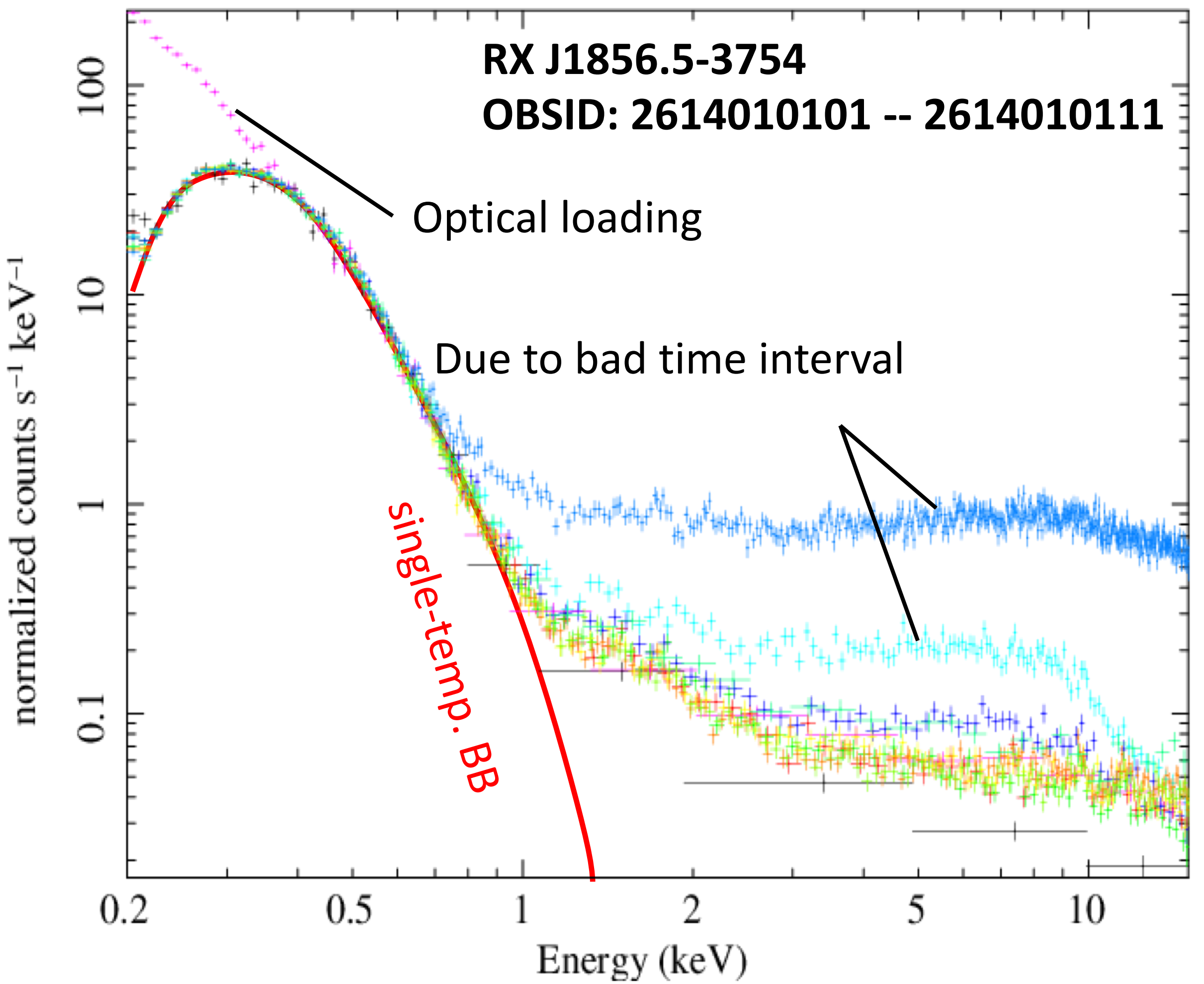
- Other 4 seem to be magnetar-like

⇒ Powered by decaying magnetic fields?

NICER data analysis: struggle with BG

Target: **J1856** (200 ks obs. is going on as GO cycle 1 program)

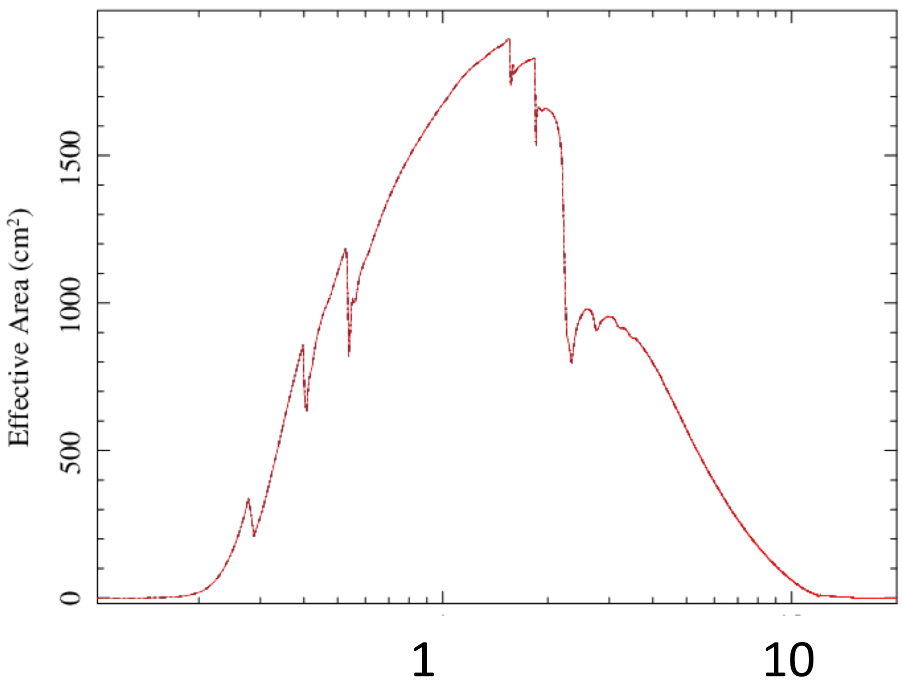
Spectra after standard screening (niXXXXXXXXXX_0mpu7_cl.evt.gz)



Advanced GTI selection for cleaned events

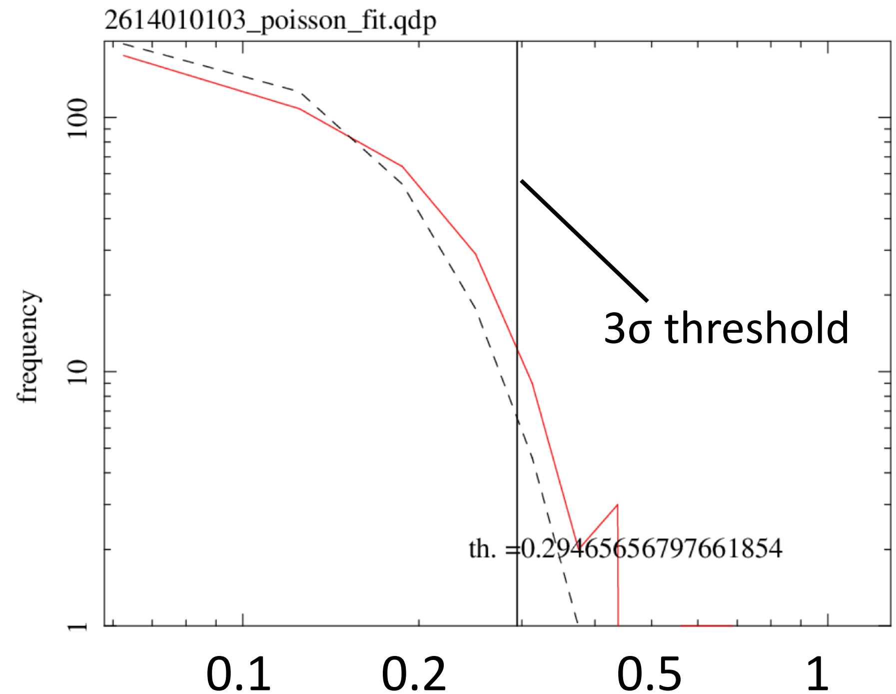
- XTI has no effective area in > 10 keV band
  ⇒ 12 – 15 keV light curve show NXB fluctuation
- Fitting count rate histogram w/ poissonian, select < 3σ time as GTI

eff. area of XTI



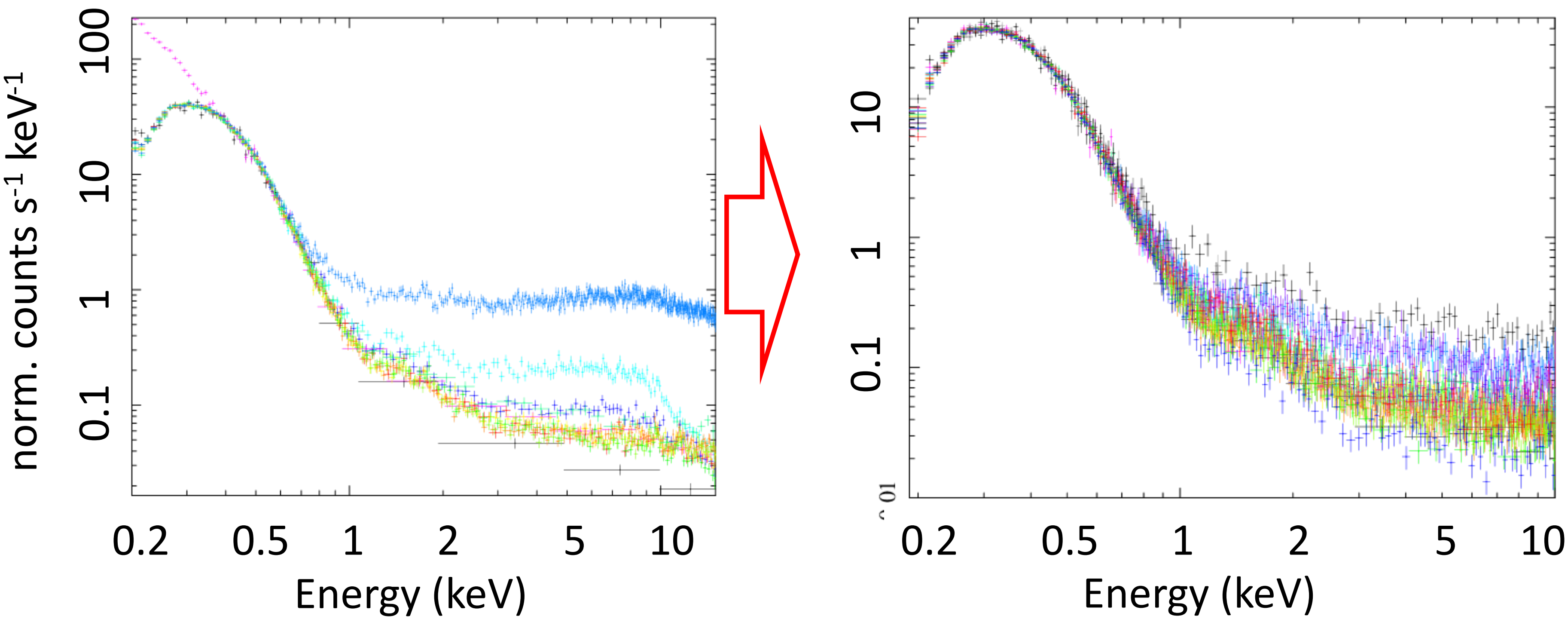
Energy (keV)

count rate histogram



count rate (/s)

Advanced GTI selection for cleaned events

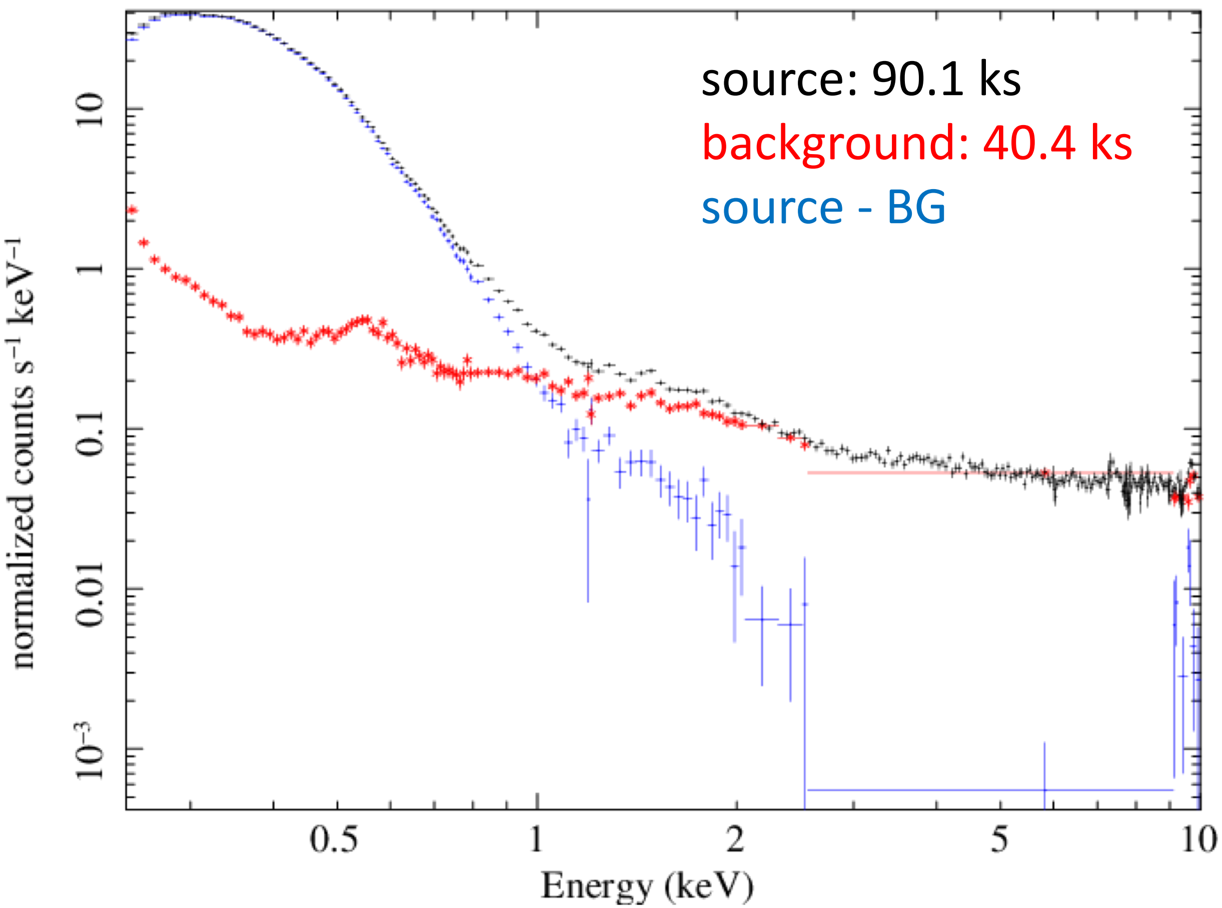


Net exposure: 101 ks ⇨ 90.2 ks

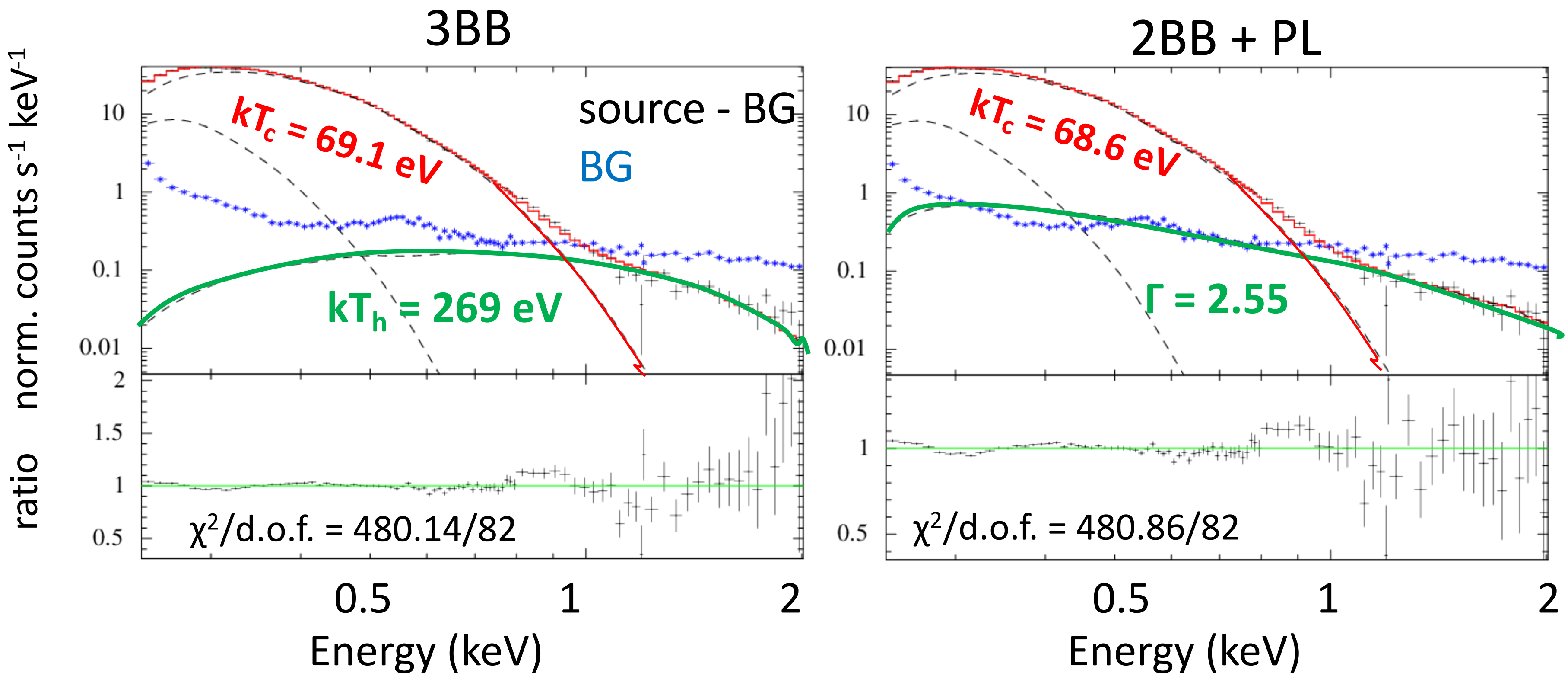
- Our method reduces ~ 10 % of effective exposure
- Fluctuation between obs. is reduced but not disappear

Background subtraction

- Merging all data of J1856
- Employing blank sky (RXTE-2) data as background, normalized in 3 – 8 keV
- BG subtracted spectrum has counts ***up to 2 keV***



Spectral fitting



- Residual (possibly) due to systematic error below 0.5 keV
- **Fitting parameters are inconsistent with previous result**

  (e.g. Yoneyama+19; kT_c = 62 eV, **kT_h = 101 eV or Γ = 7**)

⇒ BG subtraction could not be enough

Summary

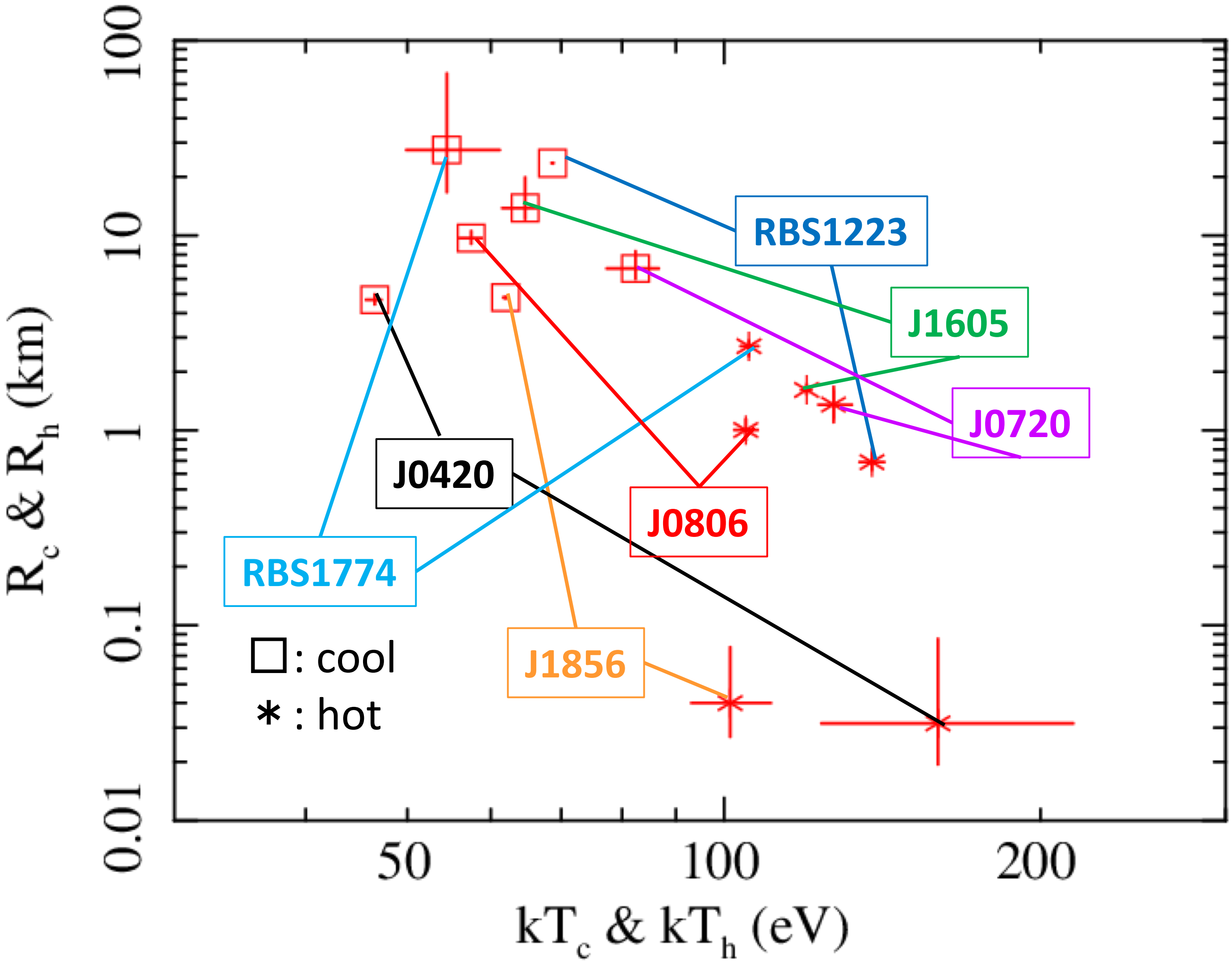
- XINSs have been considered to show single temperature blackbody emission
- We discovered the keV-excess in **all the 7 XINSs**
- **Dual BB model** (or BB+PL)reproduces the X-ray spectra
- Spectral shape are similar with Magnetars

  ⇒ suggesting the same origin

  supporting the "worn out" hypothesis
- Origin of the keV-excess could not be uniform
- For two of XINSs, canonical polar cap can explain
- If so, we will be able to determine M-R of an XINS
- NICER observation is now going on
- Background estimation is complicated and difficult

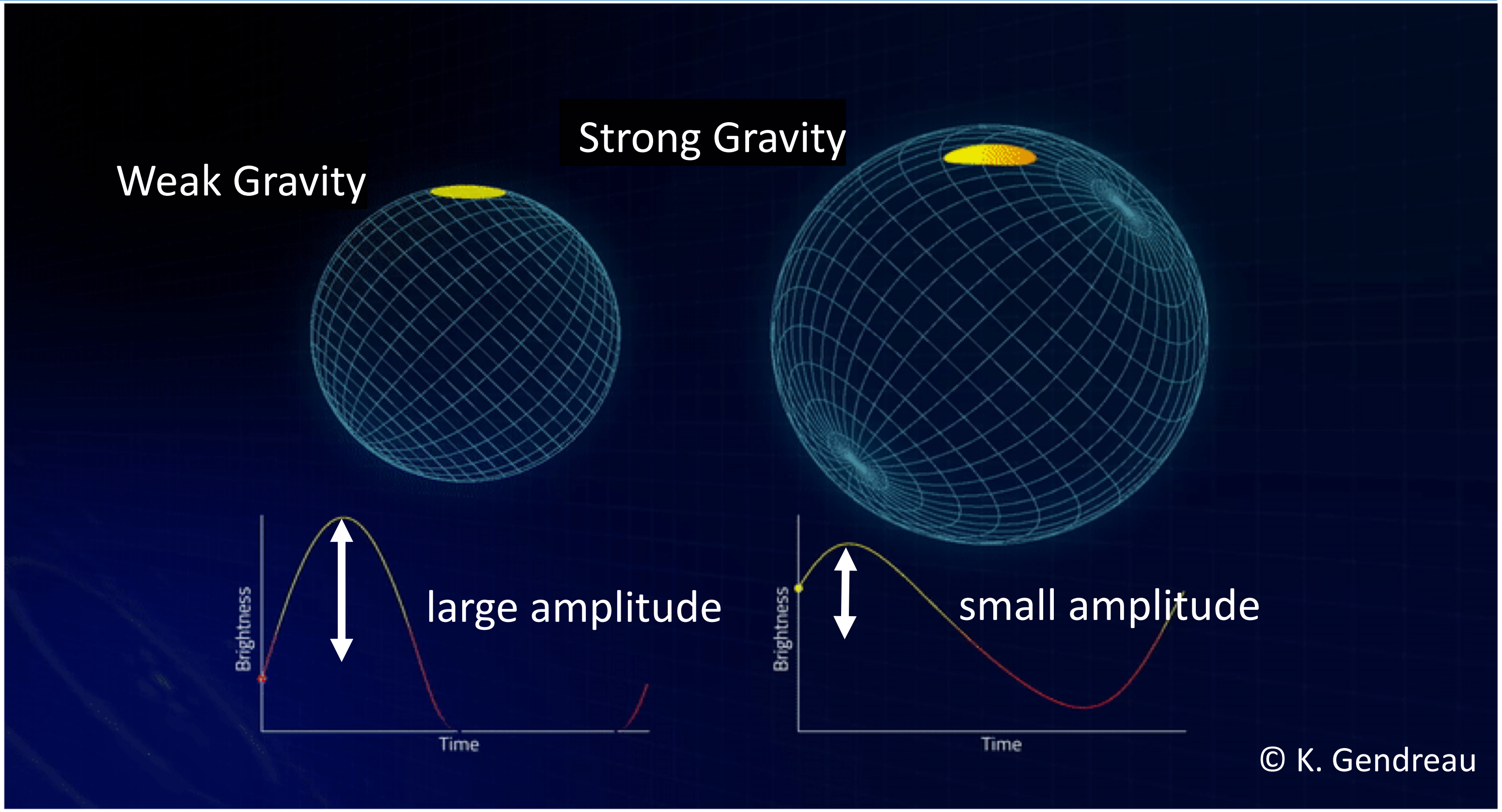
back up

Temperature/Radius distribution



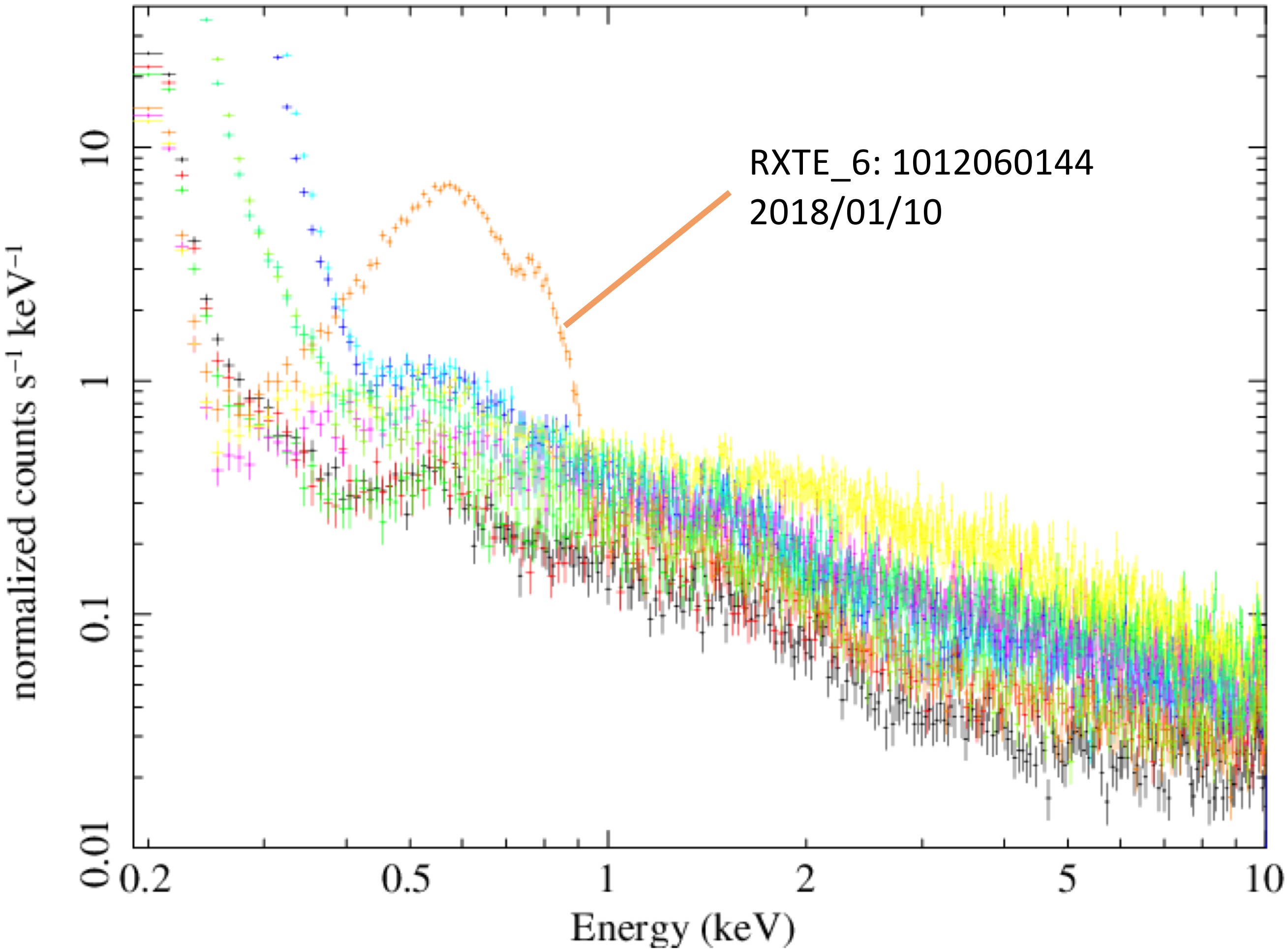
Possibility of determining M-R

Assuming the keV-excess (hot component) is from polar caps, we can determine M-R of XINS using the ***light-bending effect***

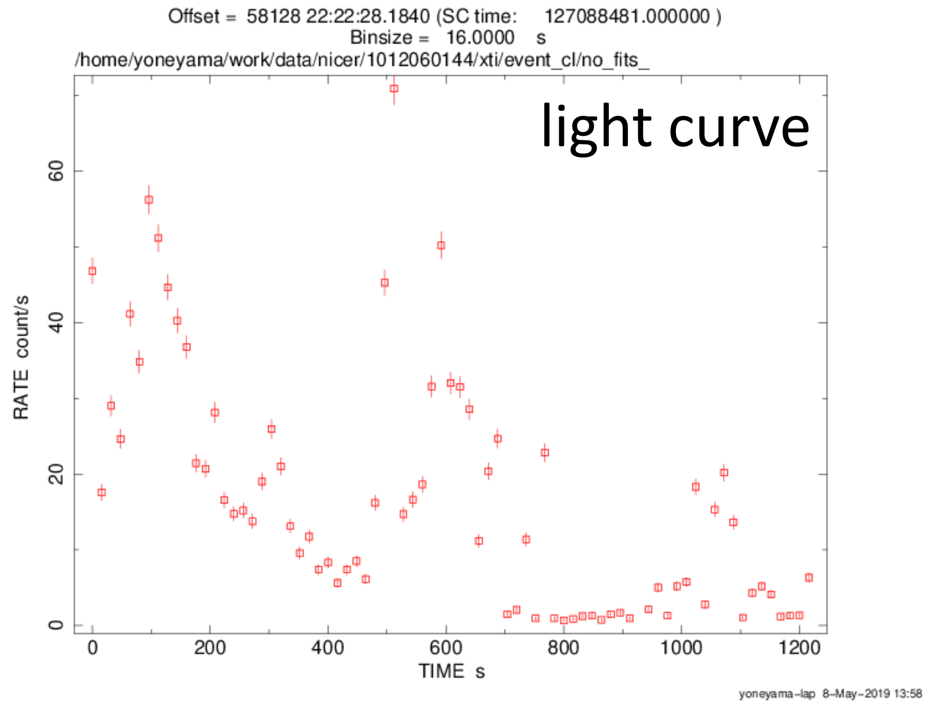


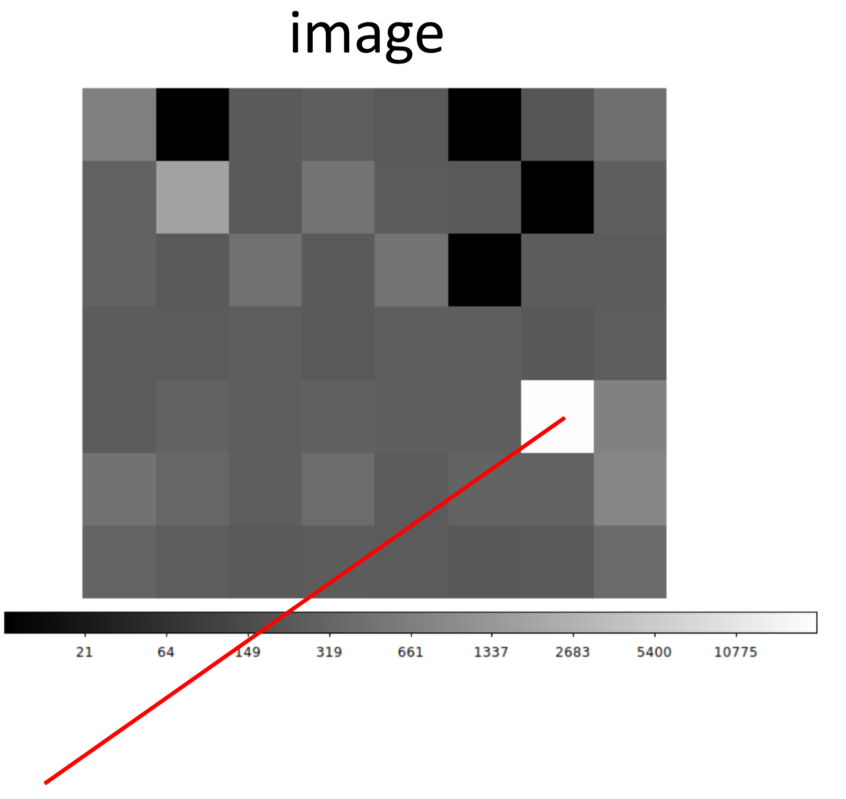
- ***NICER*** have sufficiently large area and timing resolution
- Target: **J1856** (200 ks obs. is going on as GO cycle 1 program)

BGD spectra (RXTE-[2, 5, 6]) w/ the same procedure



Unusual feature in 1012060144





- NXB flare in 1 module