Universal Detection of High-temperature Emission in X-ray Isolated Neutron Stars

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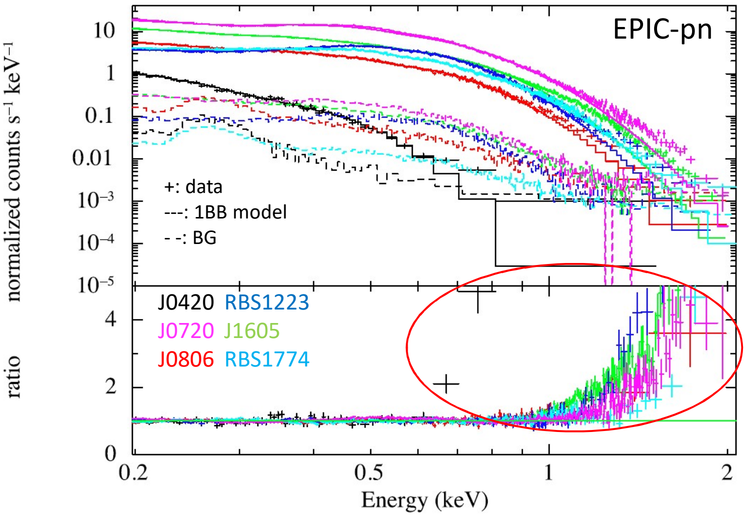
X-ray Isolated Neutron Stars (XINSs) are thermally emitting neutron stars. Their spectra have been reproduced with a single-temperature blackbody (1BB) model with the temperature of kT ~ 40 – 100 eV. From their pulsation, the age and magnetic field is estimated to be τ ~ 1 Myr and B ~ 10^13 G. On the basis of spectral and timing parametres, it have been often speculated that XINS are aged, cooled magnetars ("***worn-out***" hypothesis). Here we report that all 7 XINSs show a high-energy component in addition to the 1BB model, namely "***keV-excess***". Analyzing all the XMM-Newton data for the XINSs with the highest statistics ever achieved, we find that their X-ray spectra are all reproduced with a dual-temperature BB (2BB) model, similar to magnetars. The spectral parametres are also similar to those of magnetars. The remarkable similarity in the spectra between XINSs and magnetars suggests that the origins of their emissions are the same.

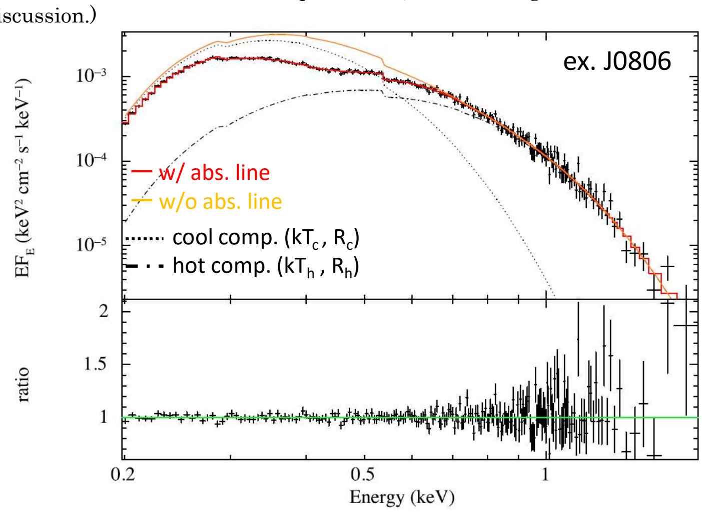
Discovery of the keV-excess

As previously reported, we first found the keV-excess, an excess emission over the 1BB model around 1 keV in the brightest XINS, RX J1856[1], integrating all the available data of XMM-Newton EPIC-pn data. We then search for the other 6 XINSs with the same way and find that all of them universally show the keV-excess. None of these can be explained by systematic errors.



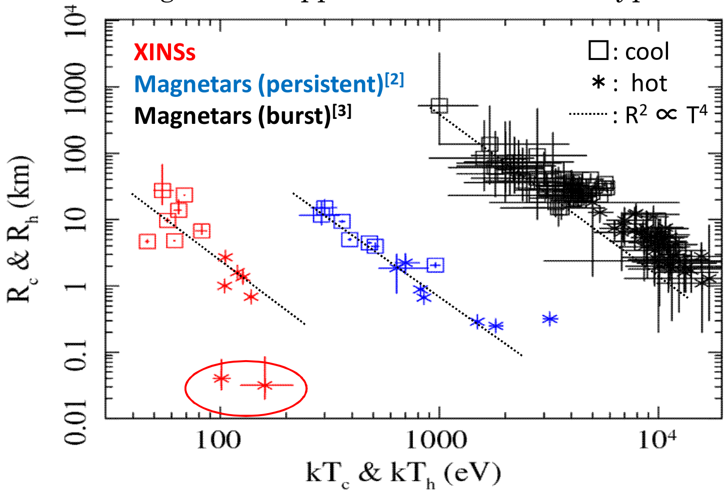
Spectral fitting with the keV-excess

We try to approximate the excess emission by fitting each X-ray spectrum of the XINSs, in addition to the 1BB model, with two separate models of another blackbody (2BB) and a power-law (BB+PL model). The 2BB model well reproduces all the sources, whereas the BB+PL model is acceptable only for 3 sources. (Both the models include an absorption line, whose origin is still under discussion.)



Comparison with magnetars

The soft X-ray spectra of the magnetars are also reproduced with the 2BB model. Comparing the XINSs and magnetars, we find that their spectral paramatres show remarkable similarity in temperature ratio (kT_h/kT_c ~ 2-3) and emission radii (R_c ~ 10 km and R_h ~ 1 km), although the temperatures are significantly different. These scaling relations suggest that they have the same origin and supports the "***worn-out***" hypothesis.



Discussion

- ***Origin of the hot component in XINSs***

While most of the sources show similar R_h, **two of the XINSs, J0420 and J1856 show significantly small radii** (○ in ↑), which can be explained with a polar cap heated by accretion of charged particles (seen in radio pulsar)[4]. They also have the weakest magnetic field and coolest surface among XINSs. Theoretical study of a surface temperature distribution for magnetized NSs[5] suggests that existence of a toroidal field produces larger hot spots and an extended cooler region. We then speculate that **five out seven XINSs have a toroidal magnetic field as magnetars**, while the coolest two stars do not. If so, the two will be elder XINSs. However, the characteristic age is not correlated with temperature, magnetic field and R_h.

- ***Future works***

We also analyse NICER data to obtain more statistics. For J1856, the keV-excess appears in some observation, however, background evaluation is not enough.

[1] Yoneyama et al. 2017, PASJ, 67, 50
[2] Nakagawa et al. 2009, PASJ, 61, 109
[3] Nakagawa et al. 2007, PASJ, 59, 653
[4] Goldreich & Julian 1969, ApJ, 157, 869
[5] Perna et al. 2013, MNRAS, 434, 2362