Correlation study of spectral parameters of NS-HMXBs with *Suzaku*

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NS-HMXBs: A brief introduction

- Since magnetic field, B $\gtrsim 10^{12}$ G, the accreted material channels along these magnetic field lines leading to the formation of accretion columns.
- Inflowing material is directed towards the the magnetic poles of the neutron star where two hot spots are formed.
- The gravitational potential energy of the inflowing material is first converted into kinetic energy and then released as X-rays
- If the rotation axis and the magnetic axis of the neutron star are not completely aligned, the X-ray emission from the source appear pulsed to any distant observer.

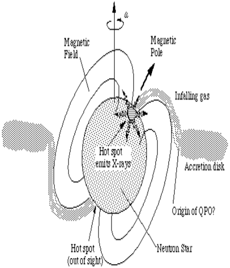

Image Courtesy: https://heasarc.gsfc.nasa.gov/

X-ray spectra of HMXBs

- Spectral shape usually interpreted in terms of Comptonization of the seed photons produced in the thermal mould of the neutron star accretion column by free electrons in the accreting material. Spectral cutoff energies are thus expected to be proportional to the electron temperature.
- How steeply the spectra fall off is given by folding energy.

$$\mathrm{HIGHECUT}(E) = A\ E^{-\Gamma} \times \begin{cases} 1 & (E \leq E_{\mathrm{cut}}) \\ \mathrm{e}^{-(E-E_{\mathrm{cut}})/E_{\mathrm{fold}}} & (E > E_{\mathrm{cut}}) \end{cases} \tag{1}$$

- Direct measure of magnetic field is possible through cyclotron absorption feature produced by resonant scattering of X-ray photons by electrons quantized in Landau levels (because of an intense magnetic field).
- Emission line features; K_{α} line give information about density of matter surrounding the X-ray source.

Correlation study of spectral parameters of NS-HMXBs with Suzaku

Broadband Spectroscopy (0.8-70 keV) of 39 XRBs (including classical HMXBs, 4 LMXBs with high magnetic fields and SFXTs; 17 sources display CRSF) using *Suzaku*

Same spectral model used - Power law modified by high energy cutoff (used bbody, partial covering model, gaussian and CYCLABS where needed)

Correlation study of spectral parameters with each other and with luminosity

X-ray spectra and the spectral fitting

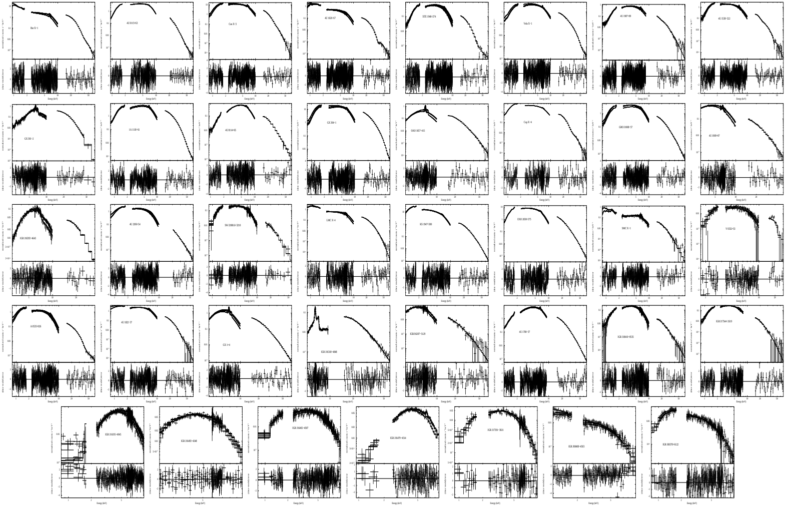

Figure : Spectra of all considered sources together with residuals from the best fits

Plan of my talk

- Present the correlation among different parameters first in the hard X-rays and then the soft X-rays.
- Compare the correlation study with the relationships already known in literature.

Cutoff energy versus luminosity

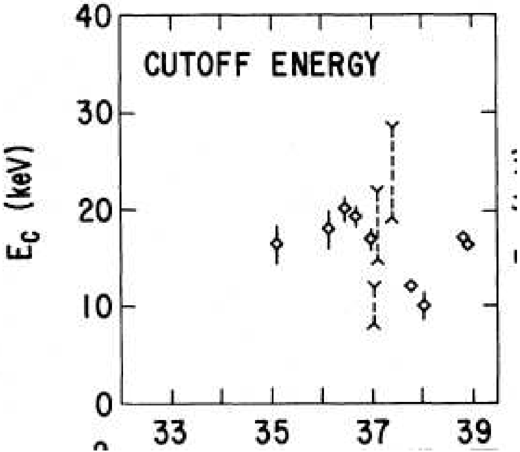

Figure : Cut-off energies versus luminosity, Figure adapted from White et. al 1983

- Lack of correlation between cutoff energy and luminosity (White et. al 1983).
- Low luminosity systems in their sample do exhibit a somewhat less sharp cutoffs (White et. al 1983).

Cutoff energy versus luminosity

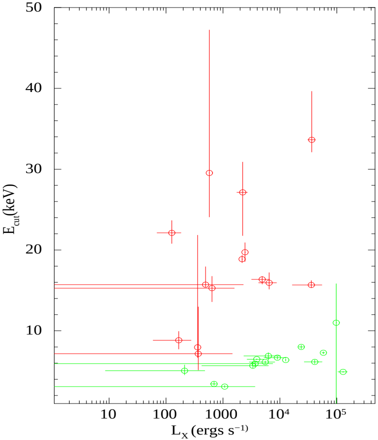

Figure : Cut-off energies versus luminosity, HMXBs divided into two classes (red and green)

For one group (red), it increases as mass accretion rate increase. For other group (green), cutoff energy remain almost unchanged with luminosity..WHY?

The sources in upper branch are: Her X-1, Cen X-3, 4U 1626-67, Vela X-1, 4U 1907+09, 4U 1538-522, GX 301-2, Cep X-4, IGR J16393-4643, SW J2000.6+3210, V0332+54, IGRJ16318-4848, IGRJ16207-5129 and IGR J17544-2619

The sources in lower branch are: 4U 0115+63, XTE 1946+274, 1A 1118-61, 4U 0114+65, GX 304-1, OAO 1657-415, 4U 1700-37, GRO J1008-57, 4U 1909+07, 4U 2206+54, KS 1947+300, EXO 2030+375, SMC X-1, 4U 1822-37 and IGR J18410-0535

- Not on the basis of the nature of it's companion star (Be XRBs or supergiants).
- Not also on the basis of accretion scheme (pure wind or disc type)
- Is it the beaming pattern then?

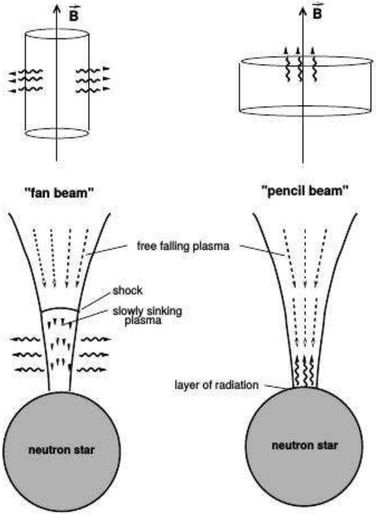

Figure : Pencil beam and fan beam formation. Figure adapted from Schonherr et. al 2008

...neither on the pattern of the pulse profiles!

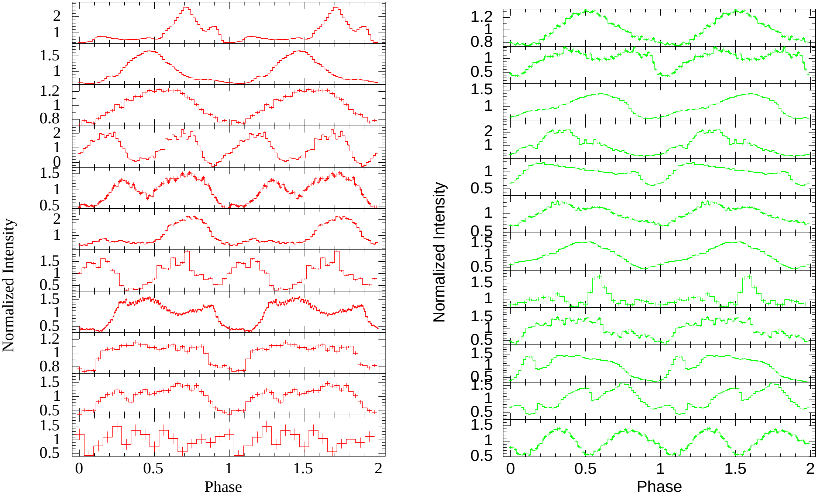

Figure : Red and green groups not differentiated on the basis of the beaming pattern; pencil (single peak) or fan beam (double peak) of pulse profiles.

Spectral index versus luminosity

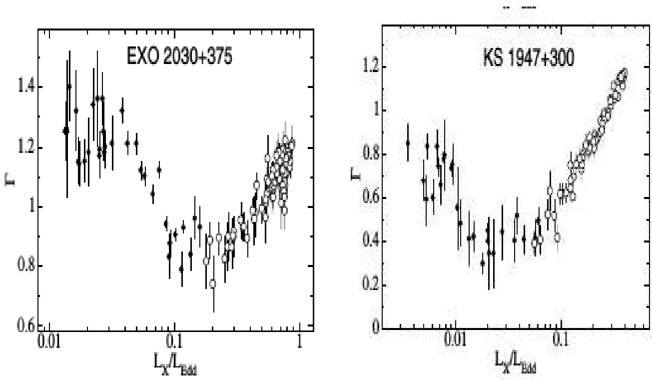

Figure : Spectral index versus luminosity for two Be-XRBs; Figure adapted from Reig et. al 2011

- γ and L_X anticorrelate with the X-ray flux during the low X-ray intensity states
- γ and L_X correlate during the high intensity states
- Different accretion regimes.

Spectral index versus luminosity

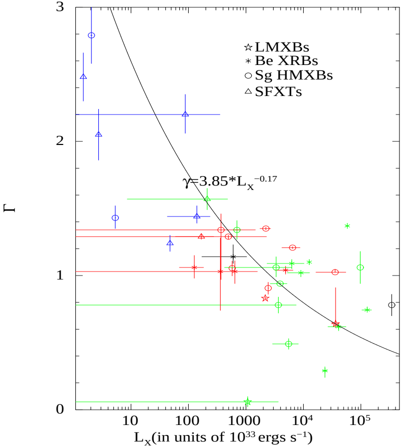

Figure : Spectral index versus luminosity; with the increase in luminosity, spectra becomes hard.

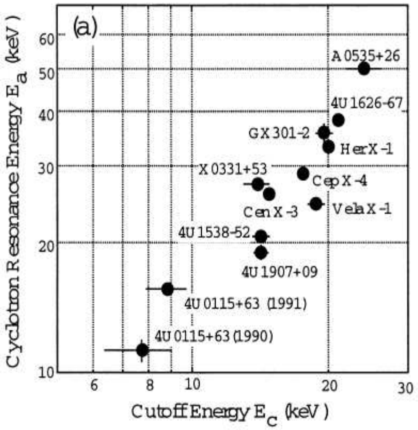

Figure : Cutoff energy versus cyclotron line energy; Figure adapted from Makashima et. al 1999

- $E_{cut} \propto E_C$; High-energy break in the spectrum is caused by the cyclotron resonance (Tanaka 1986; Makishima et. al 1999)

How does the magnetic field influence spectrum?

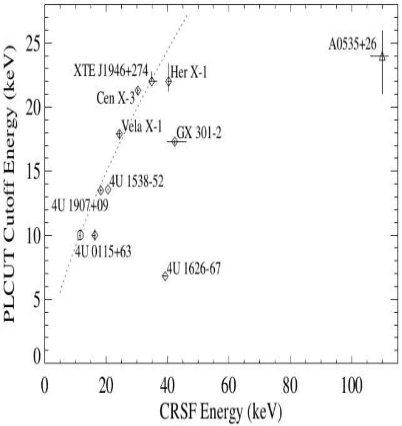

Figure : Cutoff energy versus cyclotron line energy; Figure adapted from Coburn et. al 2002

- $E_{cut} \propto E_C^{0.7}$; Thermal effect could also be contributing to the spectral break (Makishima et. al 1999; Coburn et al 2002)

How does the magnetic field influence spectrum?

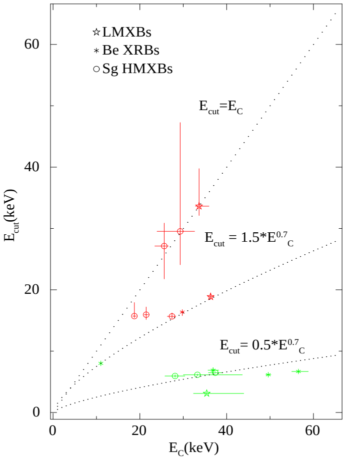

Figure : Cut-off energy versus cyclotron line energy.

Cyclotron line energy versus width

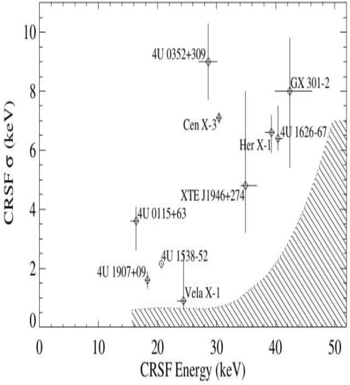

Figure : Cyclotron line energy versus width. Figure adapted from Coburn et. al 2002

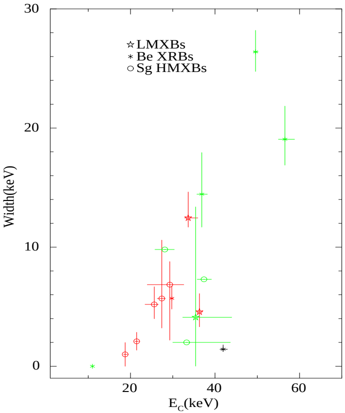

Figure : Cyclotron line energy versus width.

Cyclotron line energy versus width

$$W_{\mathrm{c}} \propto E_{\mathrm{C}} \sqrt{kT_{\mathrm{e}}}\, |\cos(\theta)| \tag{2}$$

(Mezoras et.al 1992)
Can be explained in terms of Doppler shifting, however small cos θ imply (Coburn et. al 2002) either

- Selection Effect?
- Preferred angle (between the magnetic field and the rotation, in response to accretion)?

Continuum flux and iron line flux; Valuable information about environs of neutron star.

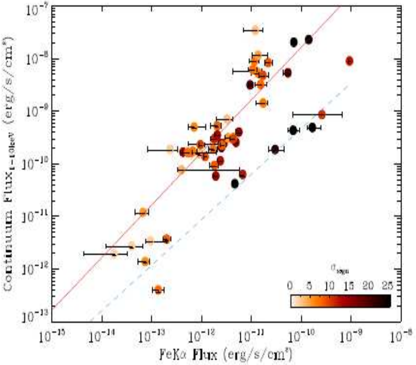

Figure : Continuum flux versus iron line flux, Figure adapted from Garcia et. al 2015

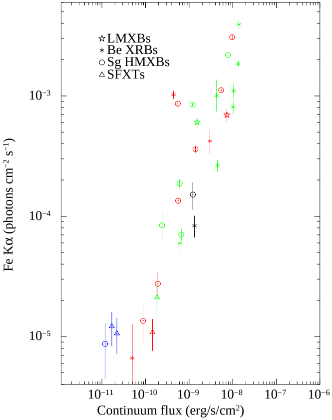

Figure : Continuum flux versus iron line flux from this work

N_H versus EQW

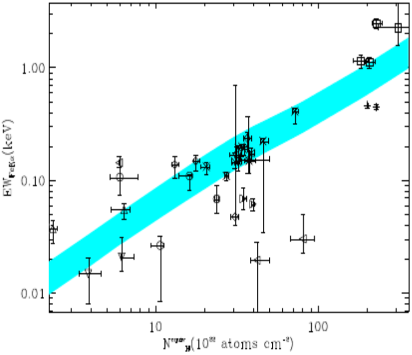

Figure : N_H versus equivalent width, Figure adapted from Garcia et. al 2015

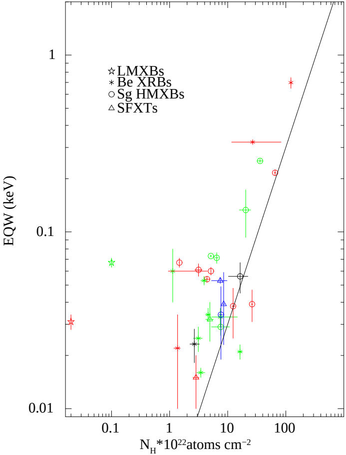

Figure : N_H versus equivalent width from this work

Conclusions

- Updated the previous correlation study, both in soft and hard X-rays, thanks to the broadband spectral capacity of *Suzaku*.
- Two different behaviour of XRBs in the variation of cutoff with luminosity unexplained so far!
- Magnetic field influences the spectrum differently for different 'class' of XRBs


thanks
Snowangel Blessings