Unveiling the nature of the intriguing source X-Per : A deep view with Suzaku observation

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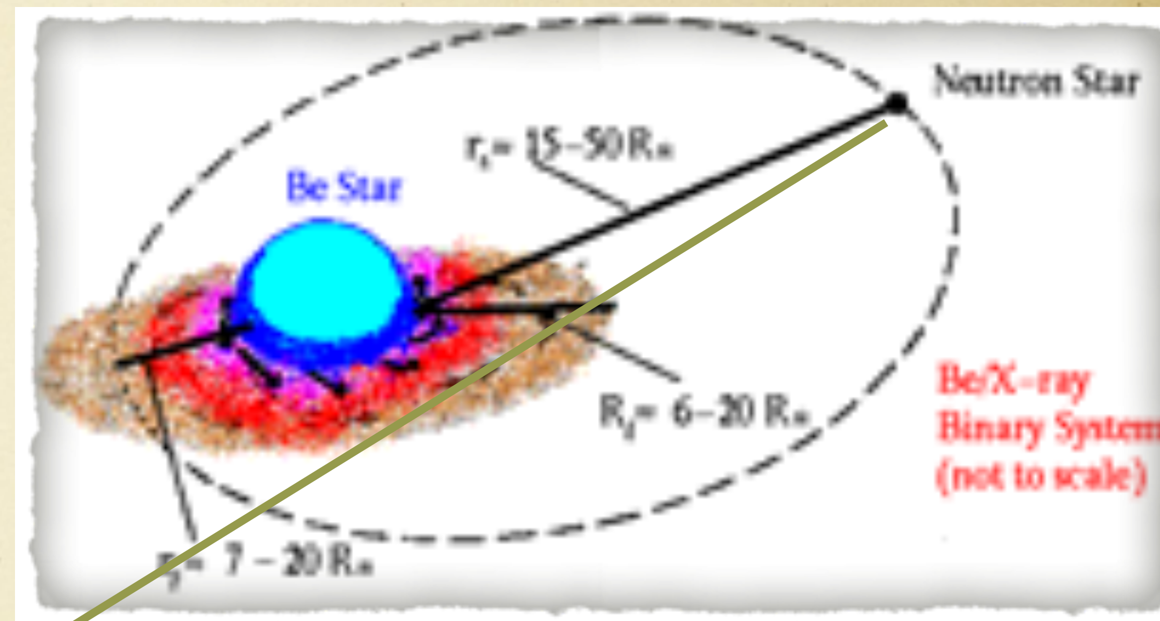
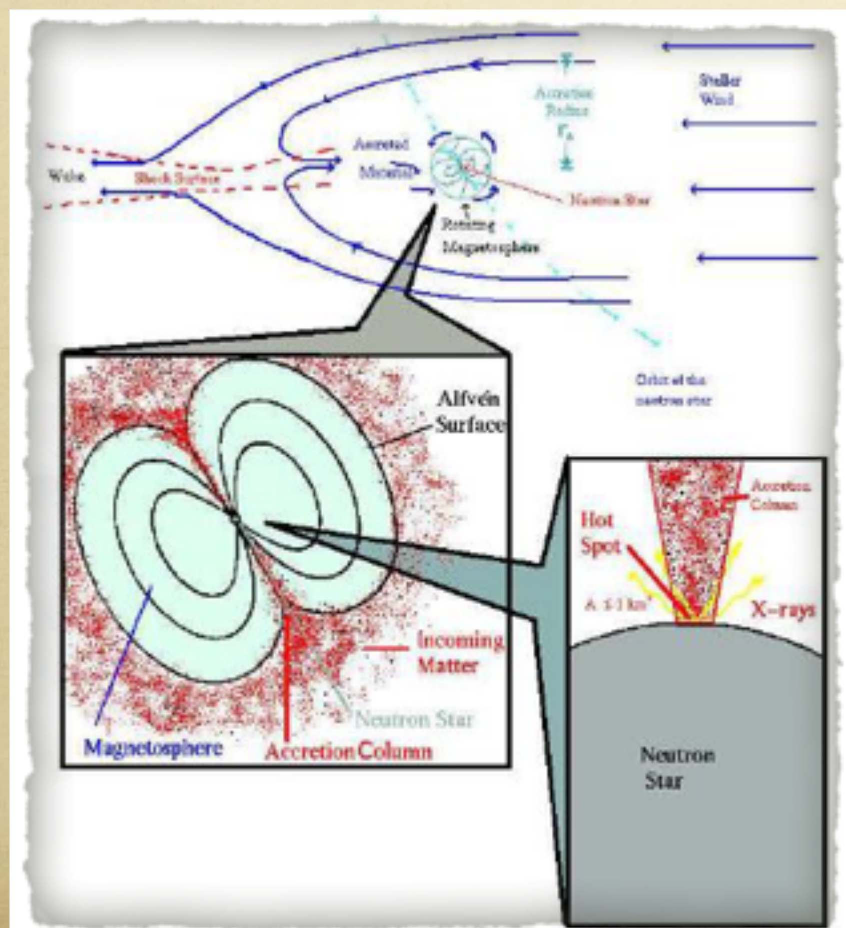
Accretion powered pulsars in Be X-ray binaries

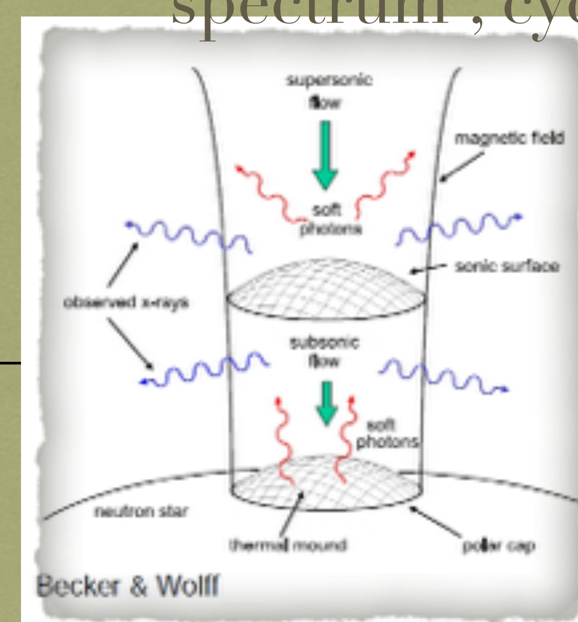
- Accretion from circumstellar disk of Be stars : Type I and Type II bursts

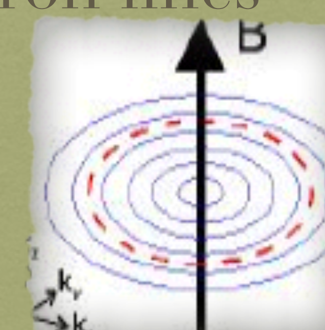
- Flow of matter dominated by magnetic field ~ 10^{12} G; formation of accretion column





Energy Spectrum: Comptonized spectrum , cyclotron lines





$$E_c \simeq \frac{\hbar e B}{m_e c} \simeq 11.6 \frac{B}{10^{12}\,\mathrm{G}}\,\mathrm{KeV}$$

Thermal + BMC Farinelli et al. 2012

4U 0352+309/X-Per: An unusual source in X-ray binary zoo

X-ray pulsar P ~ 837 s;
d=0.95±0.2 kpc (Tetling et al. 1998)

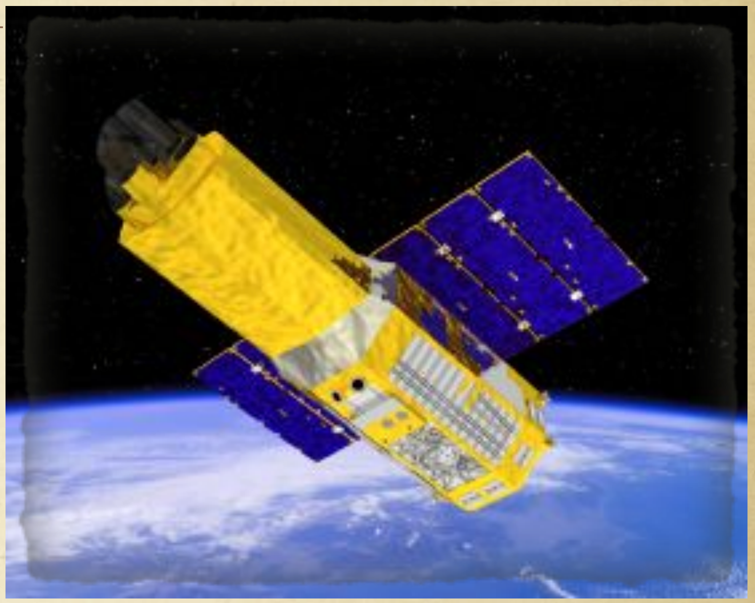
- Persistant Be X-ray pulsar; long (250 d) almost circular (e~0.11) orbit (Delgado-Marti et al. 2000) : NS does not pass through disc of Be star; No outbursts at periastron;
- Luminosity higher than other persistent Be systems ~ 10^{35} erg/s; accretion from slow dense wind of companion.
- Unusually hard spectrum ~ 100 keV -> 2 component model
- Presence of cyclotron line ~30 keV from RXTE (Coburn 2001) not confirmed from BeppoSAX (Di Salvo 1998) & Integral (Doroshenko 2012)

Deviation of X-ray spectrum from standard accretion powered pulsars: The nature of the unusually hard spectrum

- Thermal Comptonization vs BMC:high KTe/ bulk velocity
- Contradiction between spectral model of X-per
- Similarity of spectrum. with accreting magnetar 4U 2206+54. Slow dense wind (~ 150 km/s) requires B ~10^{14} G. Determination of B will help. CRSF ?

Contradiction between previous results : RXTE, BeppoSAX Integral → **aim towards a broadband spectral model**

Suzaku: broadband sensitive mission from 0.2-600 keV

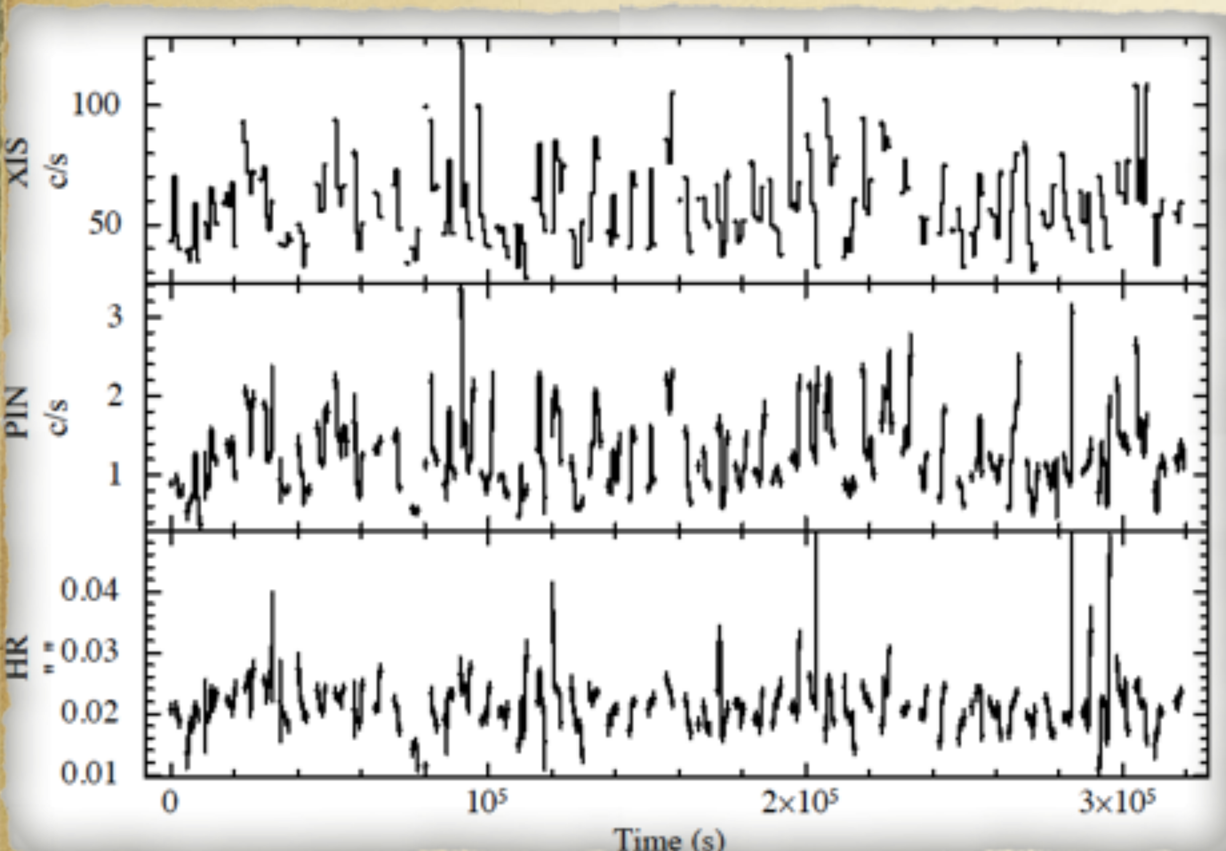


X-ray CCD at focal plane of Telescopes 0.2-12 keV

Hard X-ray detectors PIN & GSO 10-600 keV

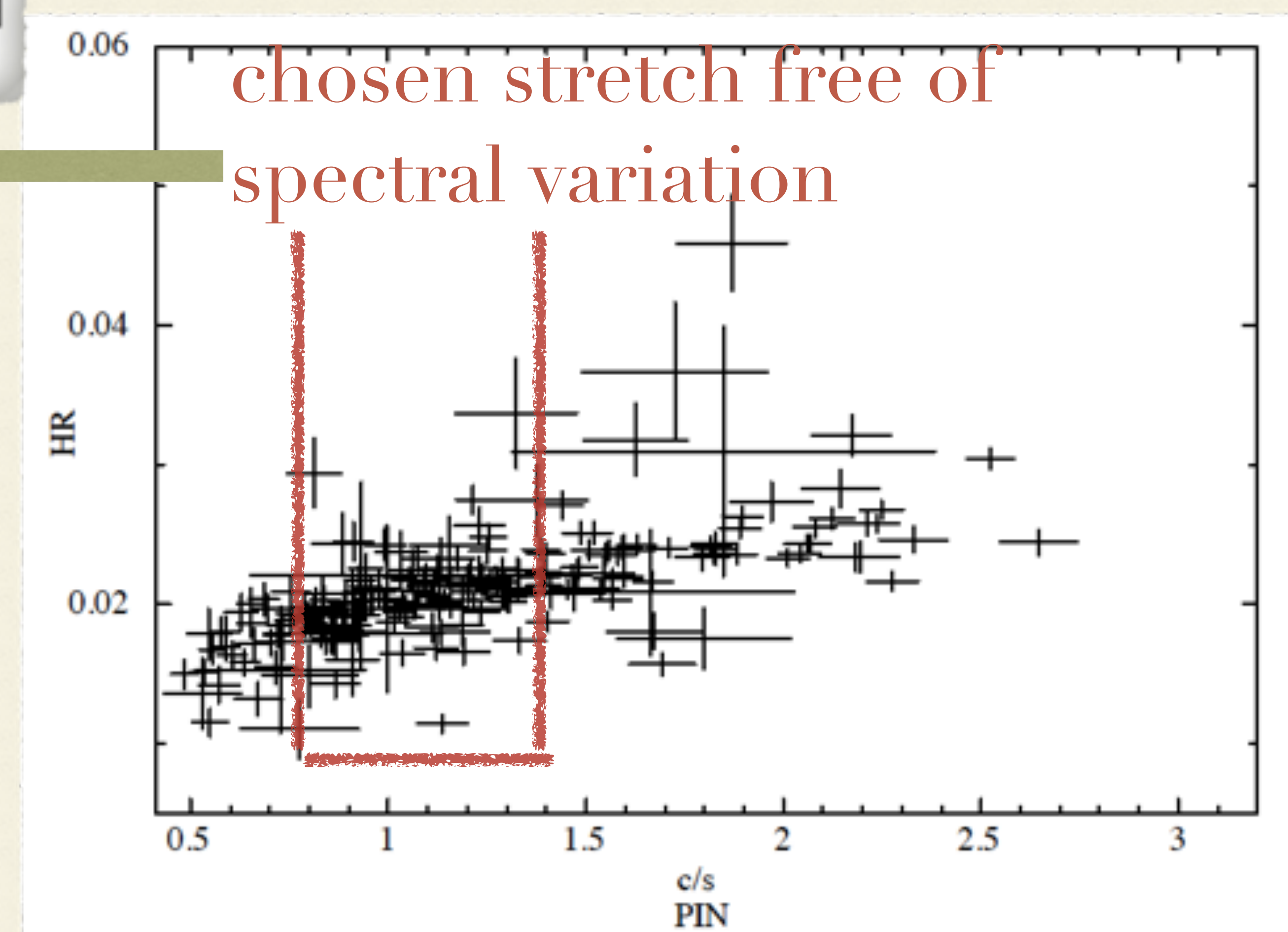
- Suzaku observation of the source 153 ks

Light curves: HR vs Intensity

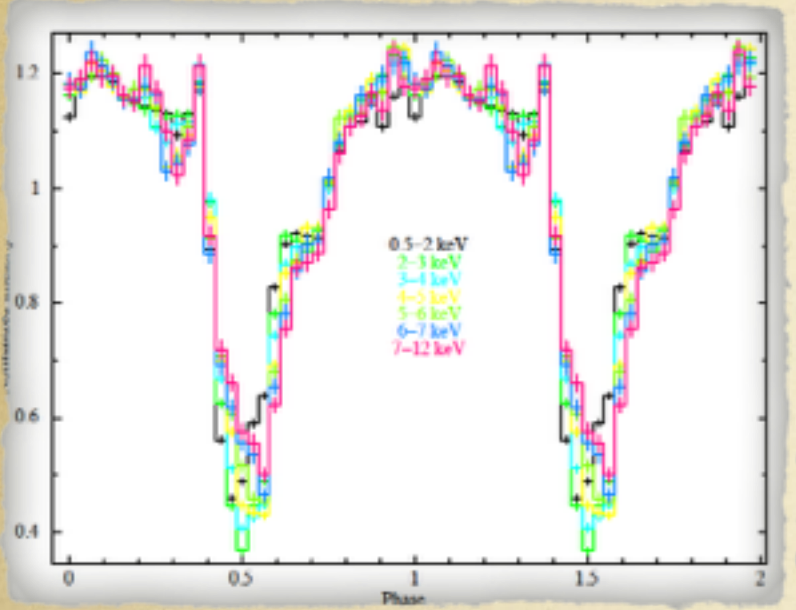


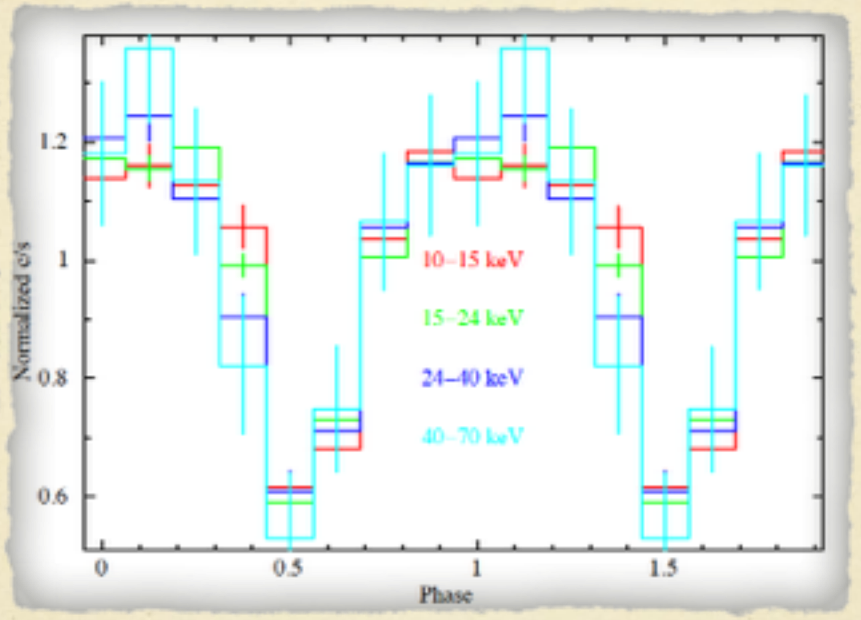
- Light curves in soft and hard X-ray bands for the entire stretch
- HR changes by a factor 2 with PIN count rate: spectral variations

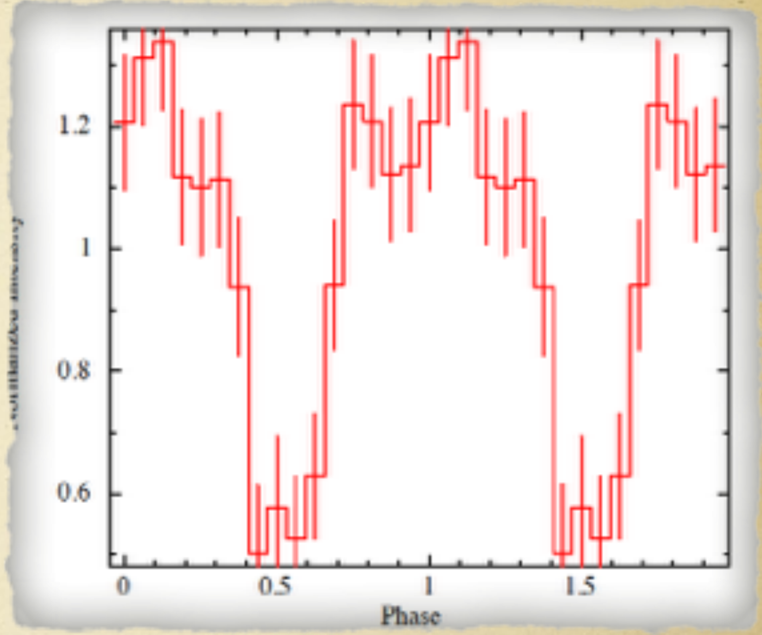
- Construct Average representative pulse profiles & energy spectrum



Pulse Profiles: Single Peaked; little energy dependence





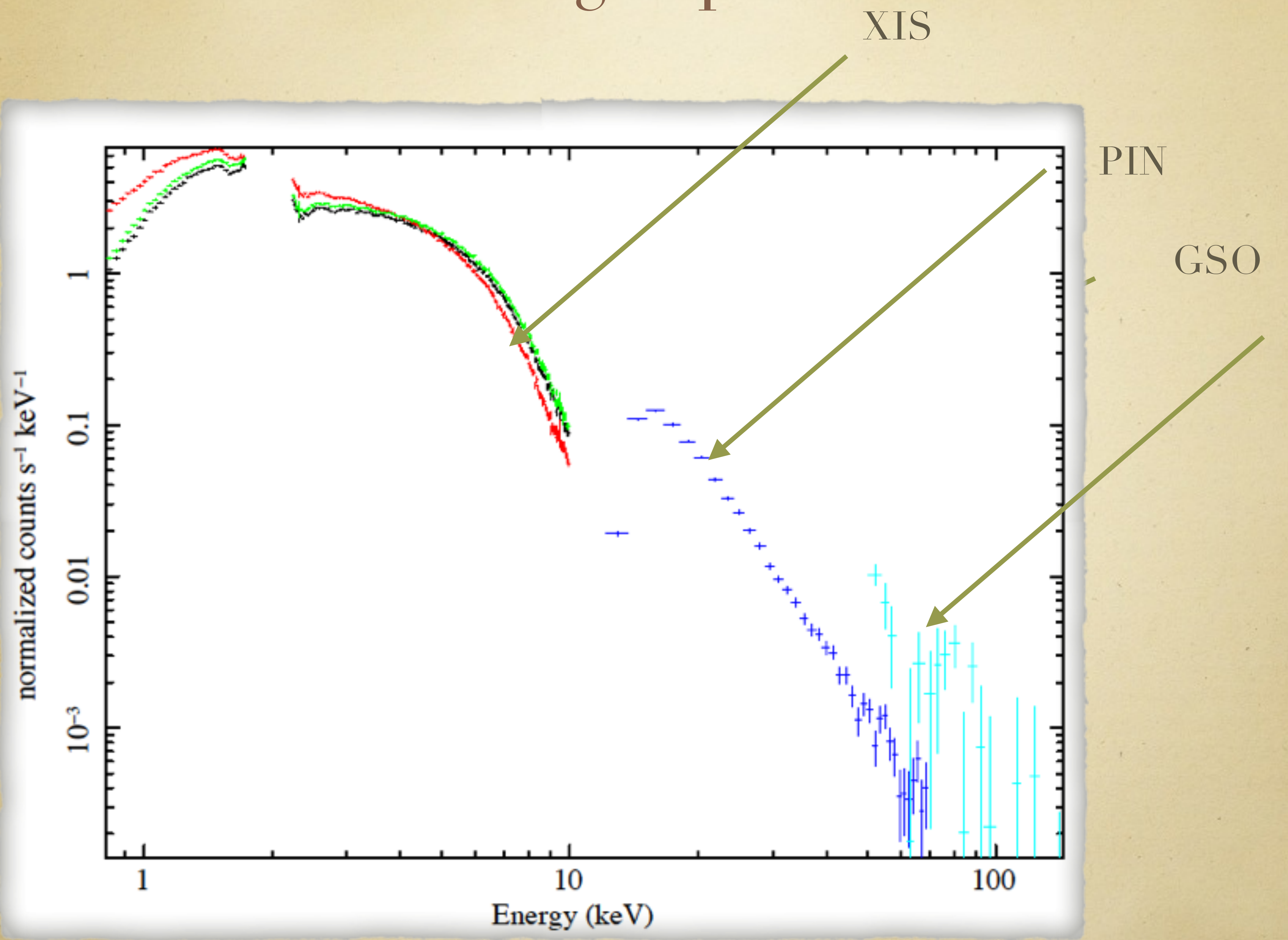


Low energy XIS pulse profile (0.5-10 keV)

High energy PIN pulse profile (10-70 keV)

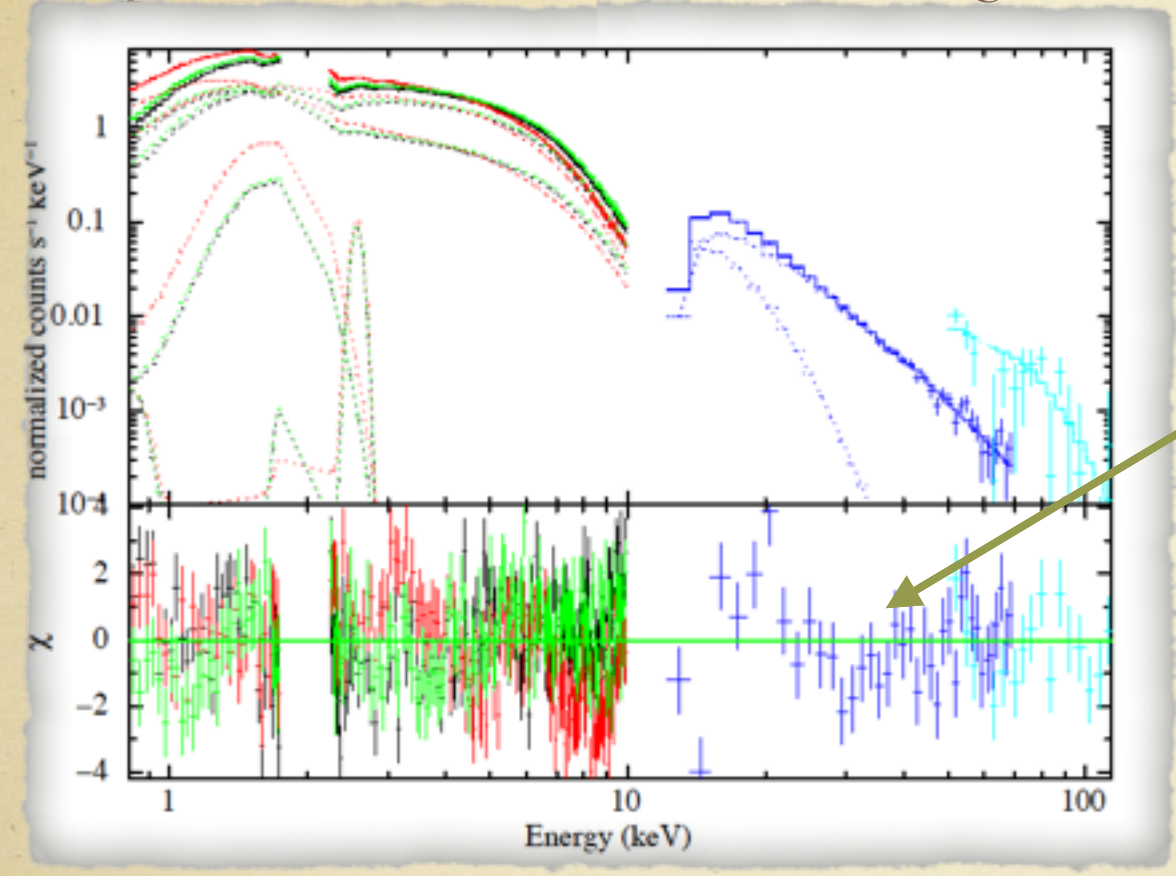
High energy GSO pulse profile (50-100 keV)

Average spectrum



Average spectrum

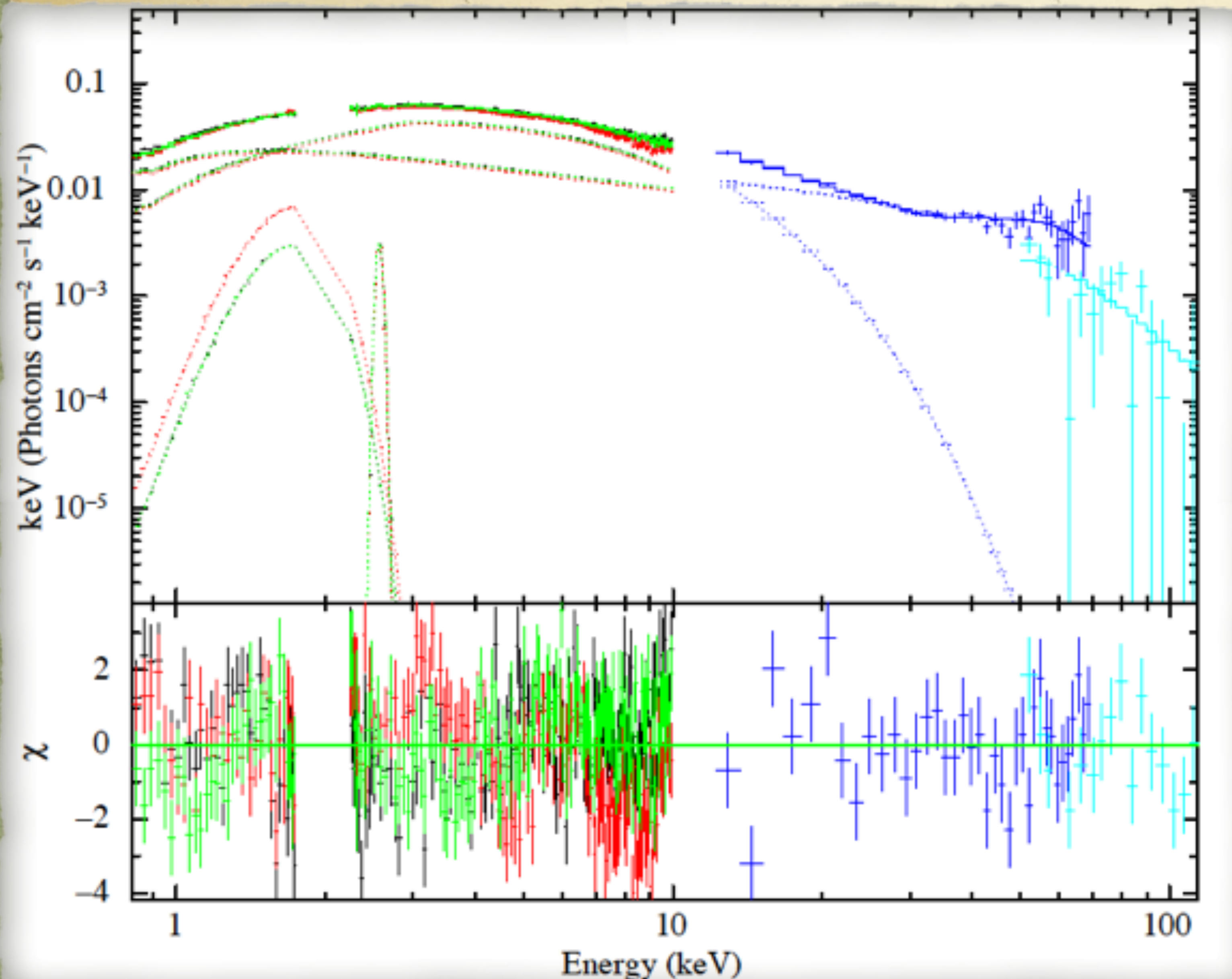
2 component model: low & high energy part fitted separately



Residual after continuum modeling

- Different spectral models: power laws with different exponential rollovers (Highecut, Newhcut, FDCUT); CompTT, Compmag
- Spectrum extends > 100 keV, tail like feature in PIN band exponential rollover constrained with the help of GSO
- Model chosen where the absorption feature/CRSF is best constrained

Ef_E spectrum of X-per from the best-fit model



Continuum parameters consistent with BeppoSAX

$\Gamma low=0.30\pm0.08$

$Ecut_{low}=2.94\pm0.04$

$Efold_{low}=3.57\pm0.20$

$\Gamma high=1.57\pm0.02$

$Ecut_{high}=57.9\pm10.0$

$Efold_{high}=23.6\pm15.0$

CRSF

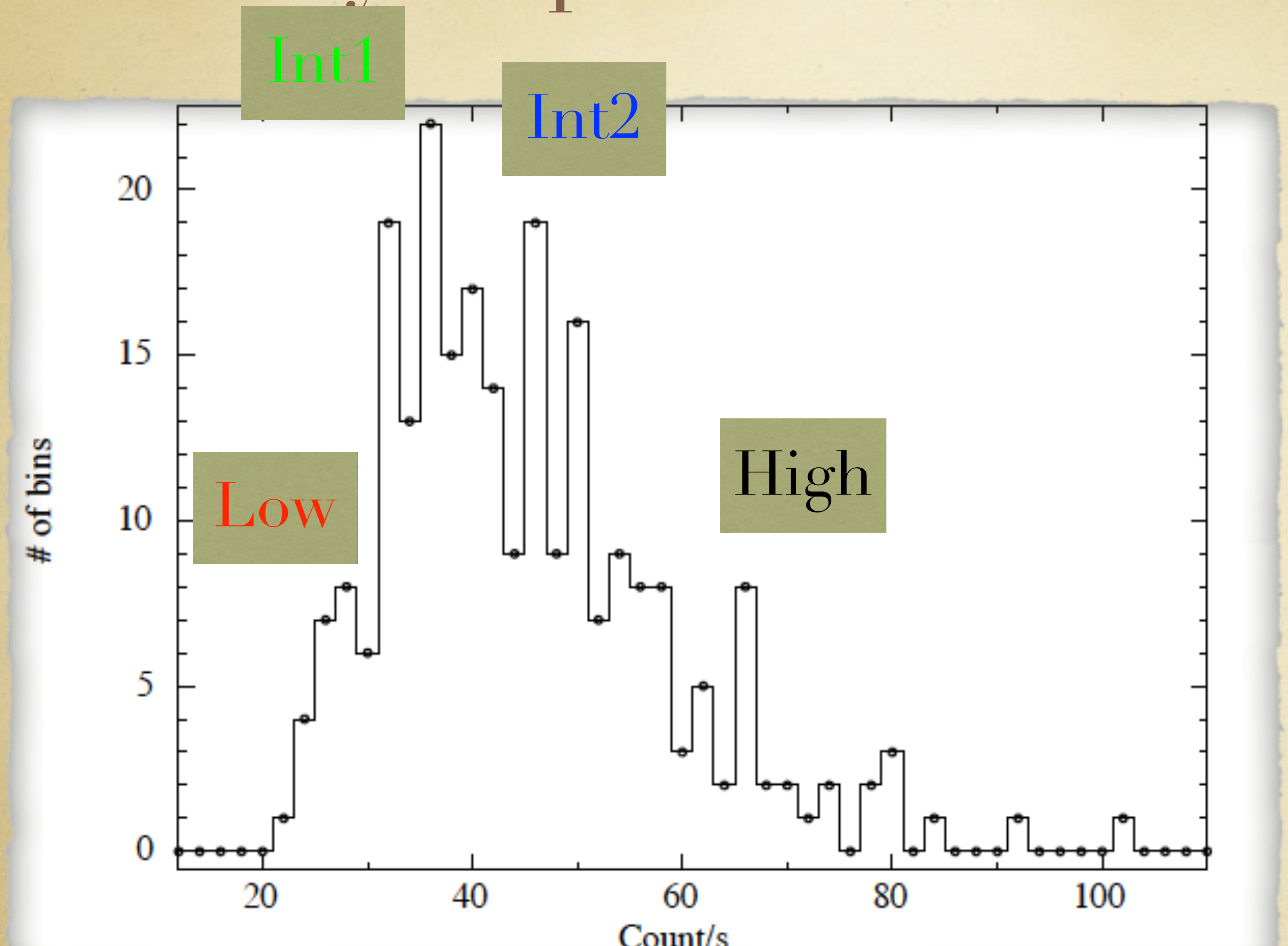
$E=31.3\pm2.1$

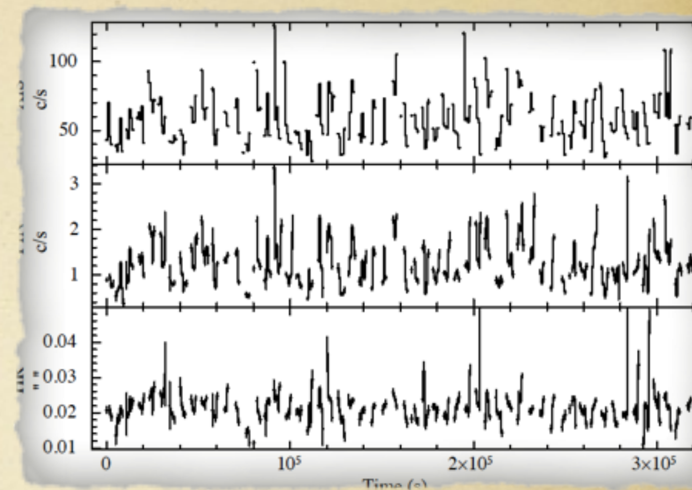
$D=0.20\pm0.08$

$W=6.6+3.0$

significance: run test PCI 0.5 %

Intensity Dependence: Count rate histogram

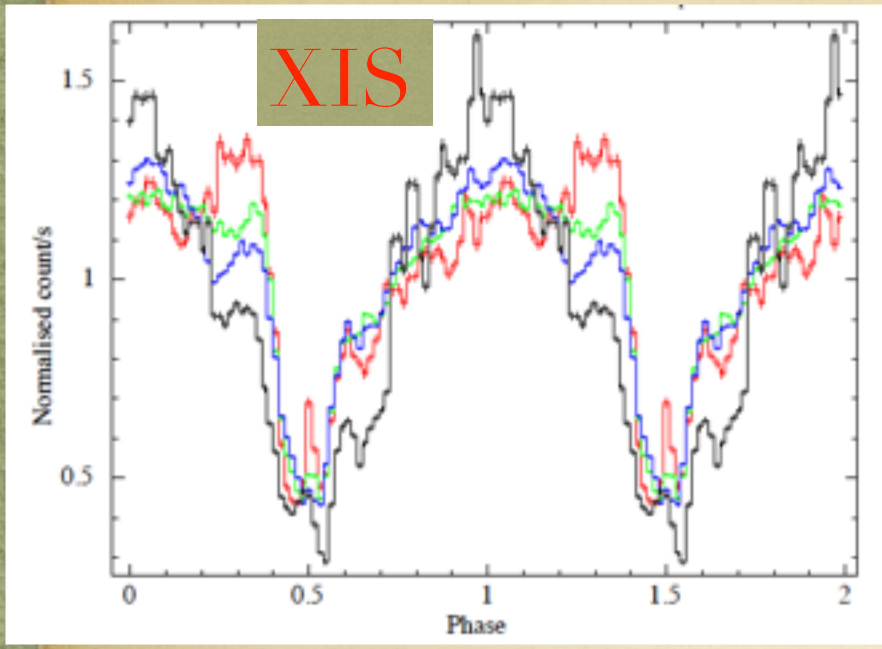


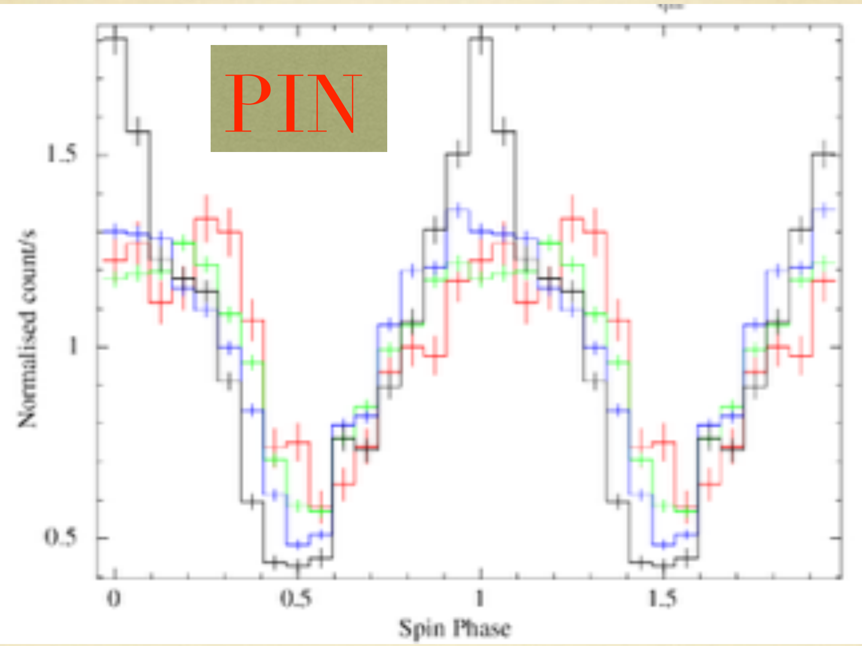


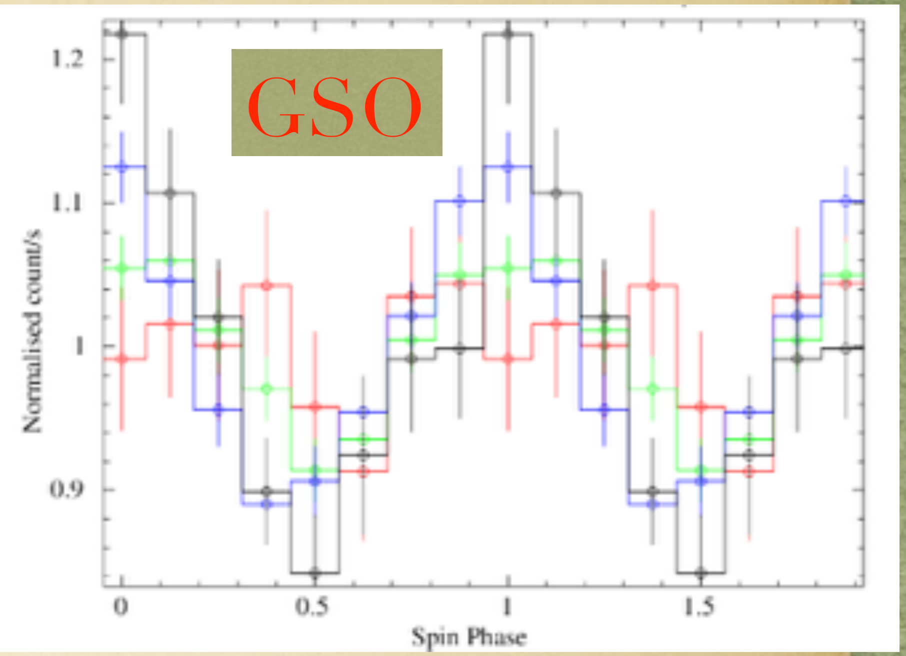
Low < 31 c/s	Int1 31-45 c/s	Int2 45-65 c/s	High > 65 c/s

- Indication/ of change of spectral state/accretion geometry

Pulse profiles: Intensity Dependence

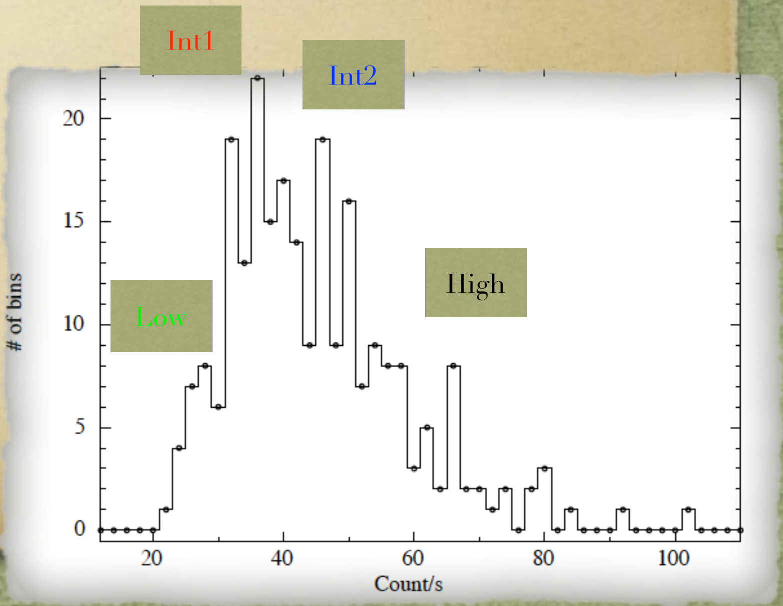




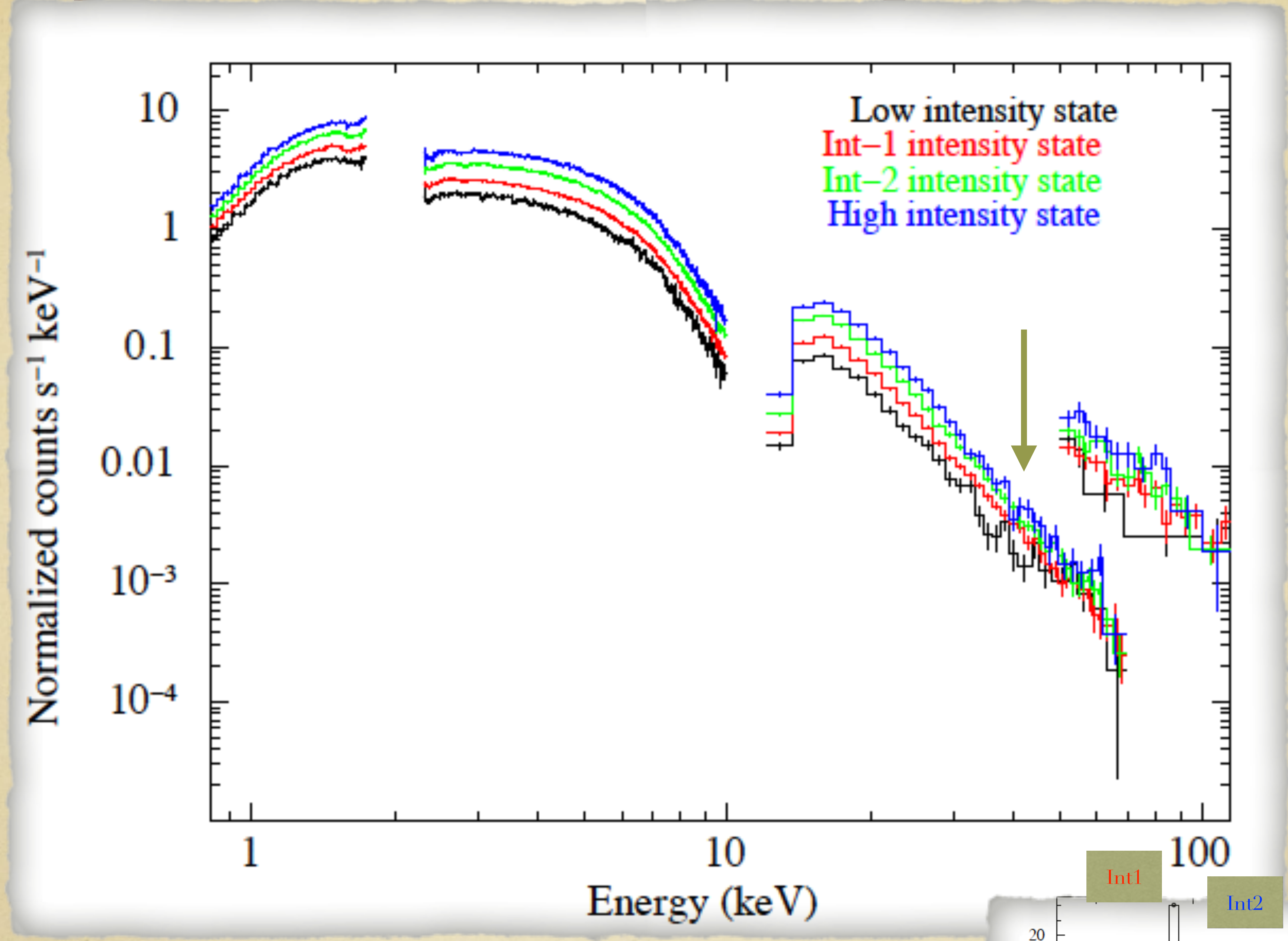


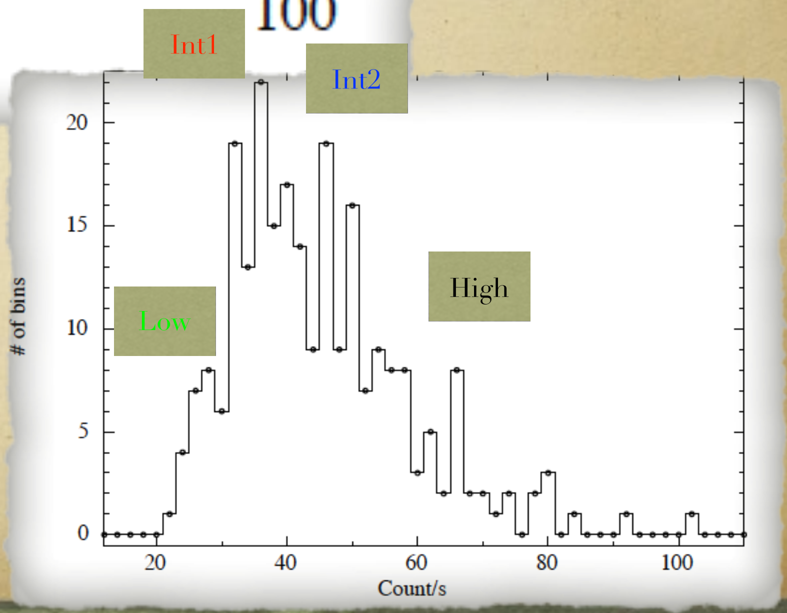
Low < 31 c/s | Int1 31-45 c/s | Int2 45-65 c/s | High > 65 c/s

- Similar dependence independent of energy indicates change in beaming pattern — accretion geometry
- Higher intensity profiles more beamed
- To explore the spectra

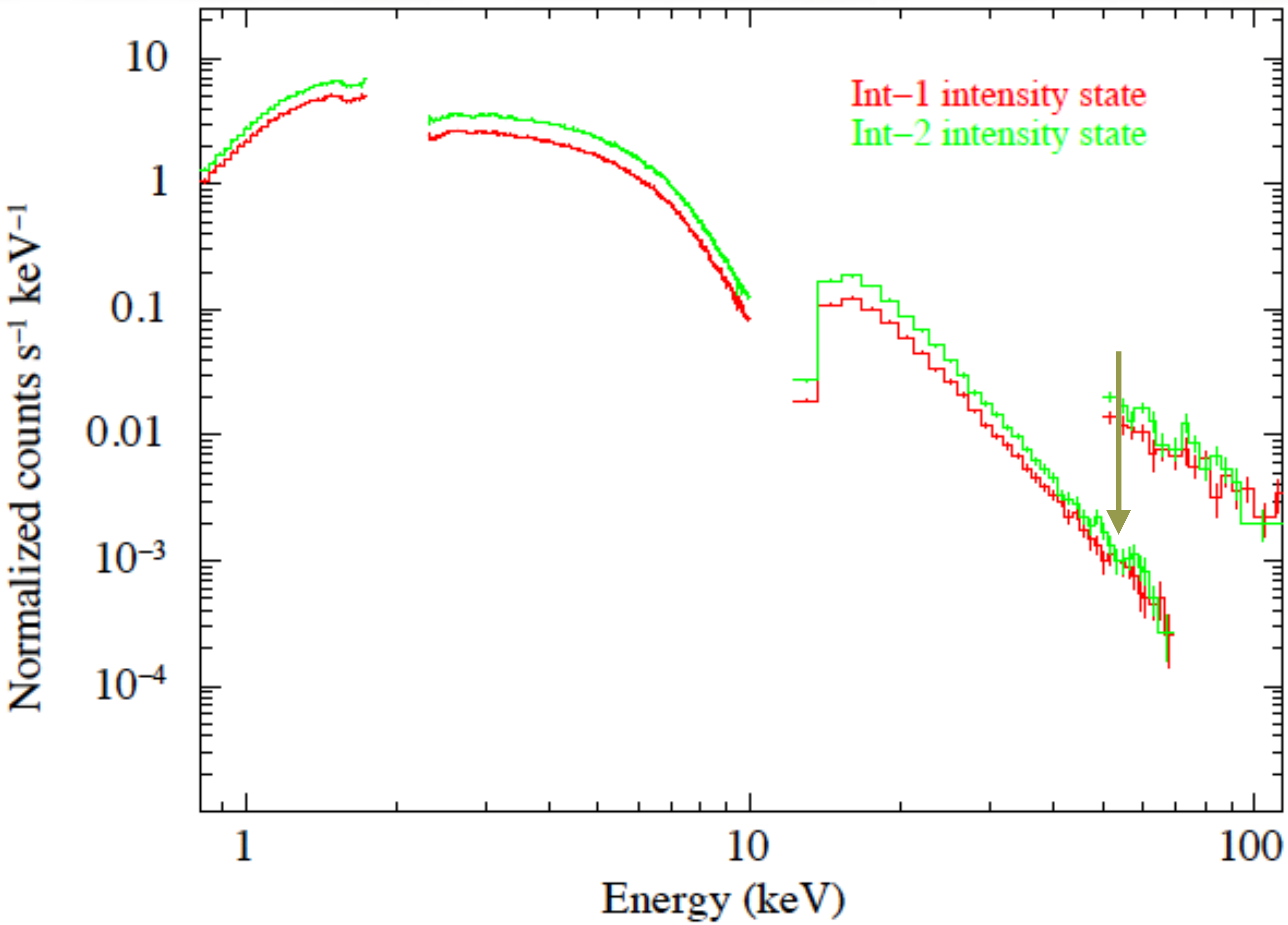


Spectra: Intensity Dependence

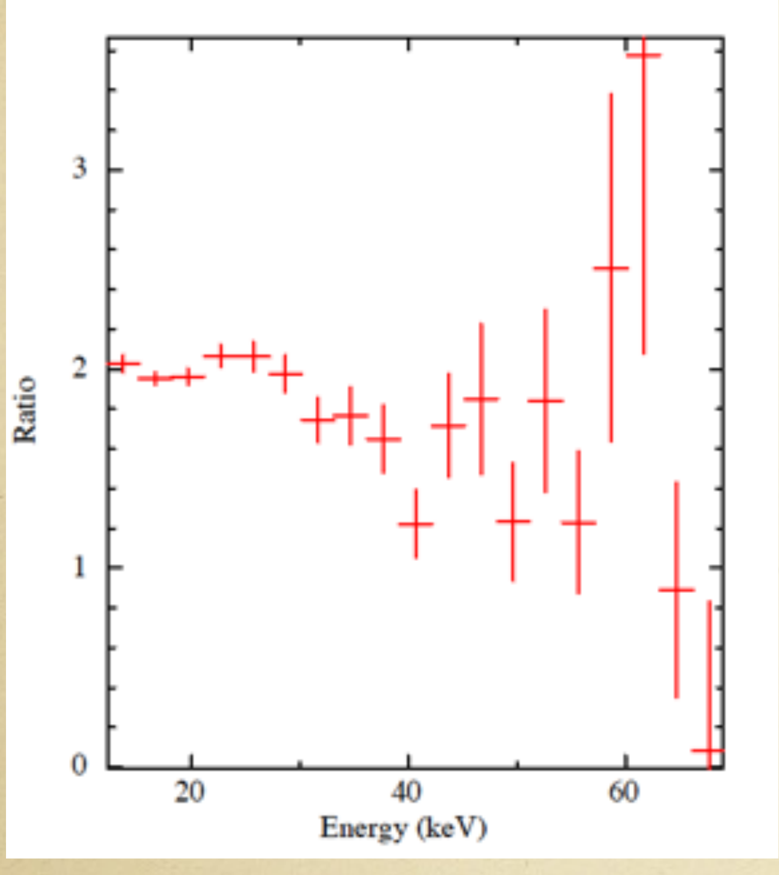




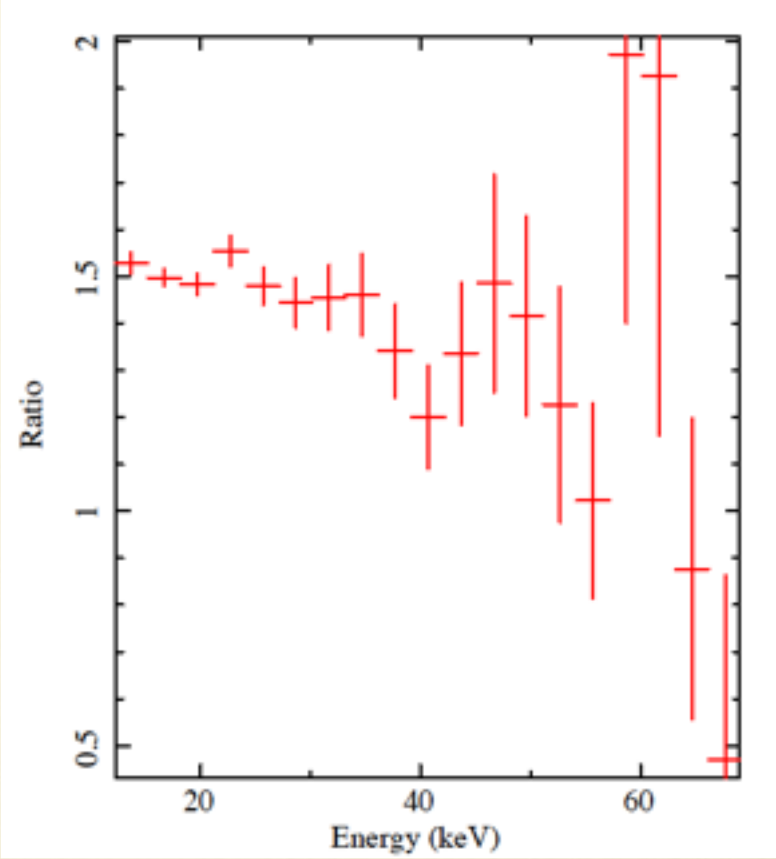
Closer look at Int2



Ratio of PIN spectrum at different intensity states



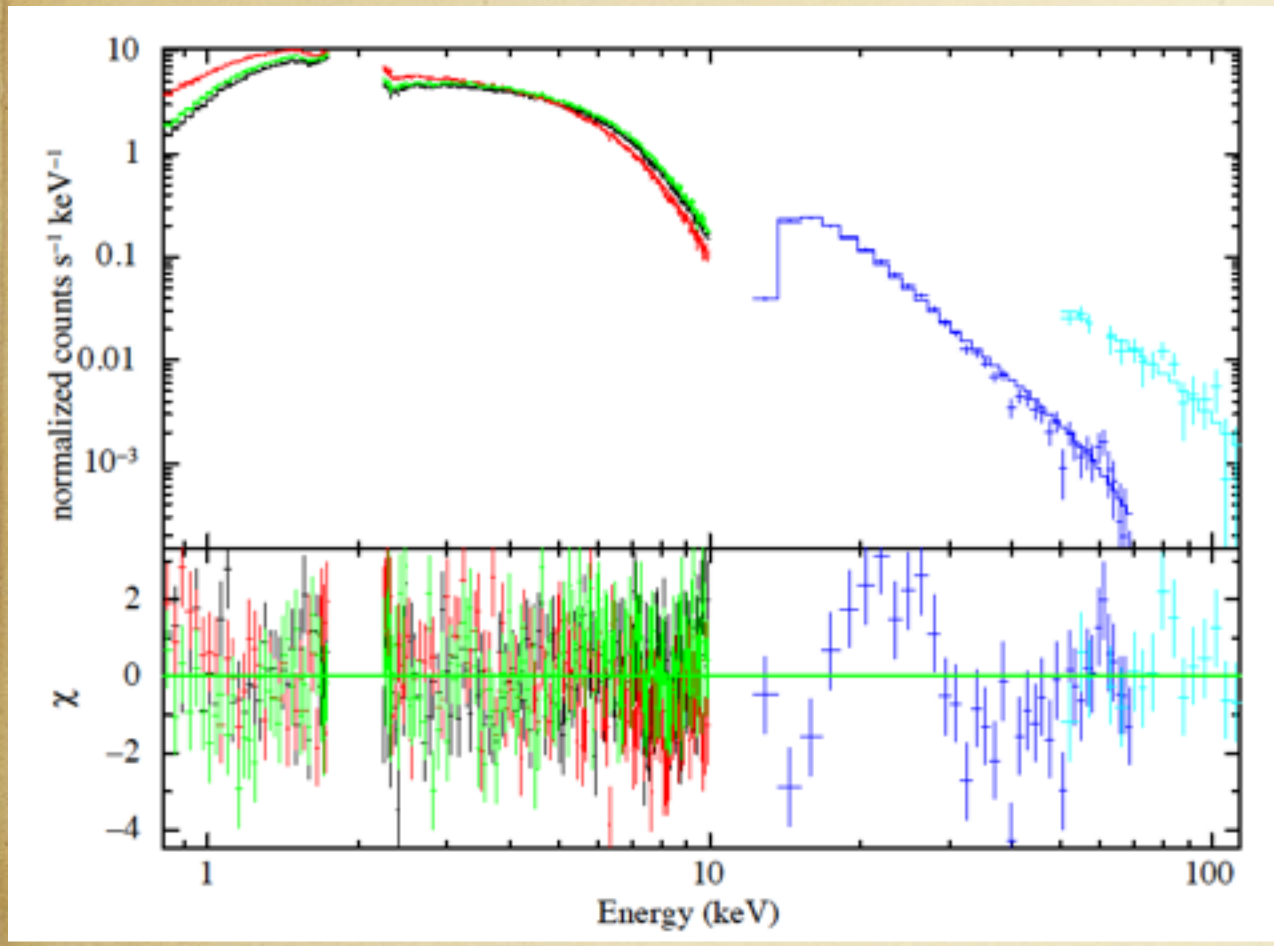
High to average



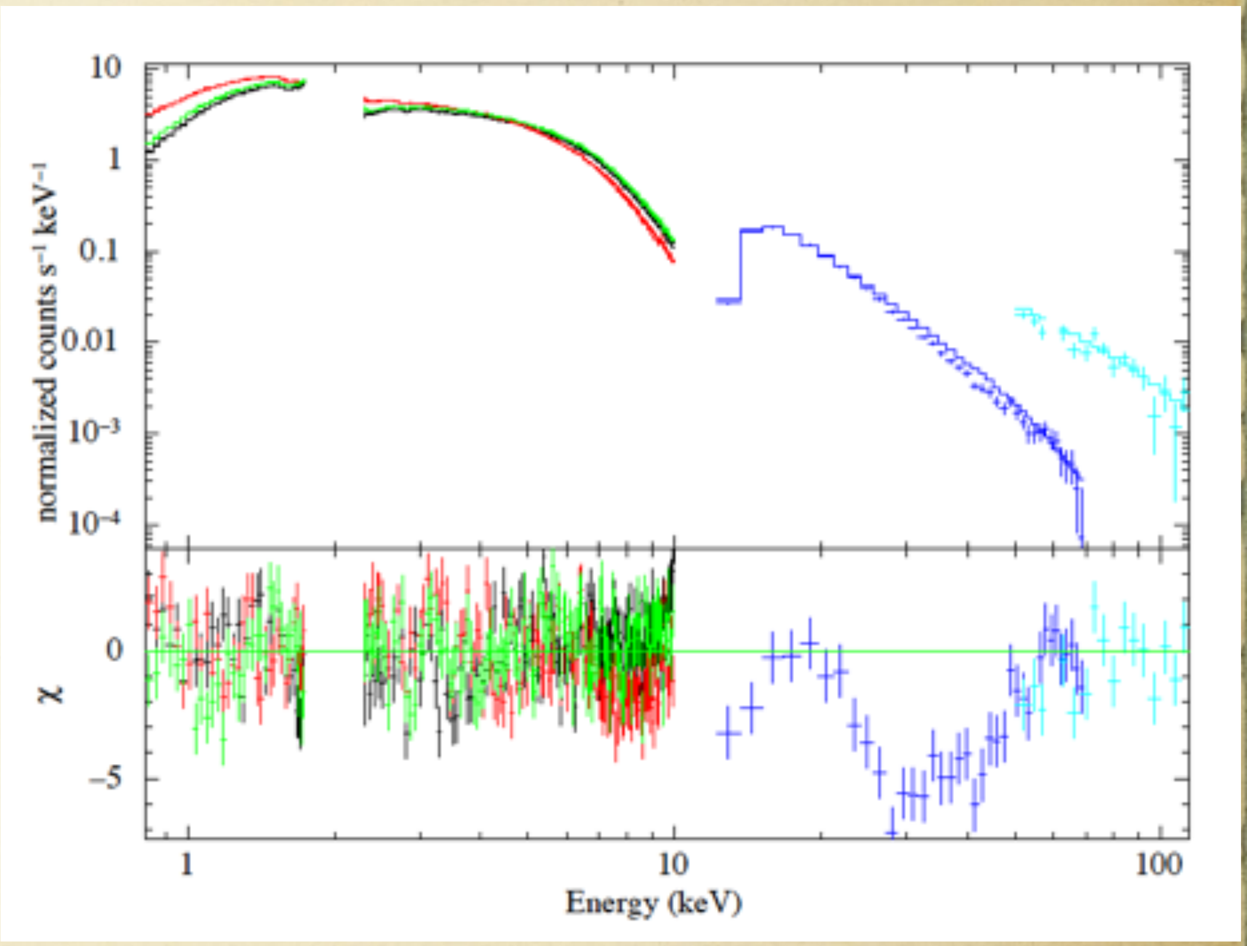
Int2 to average

- The shallow CRSF seen in average more prominently seen. Explore change in parameters

High state

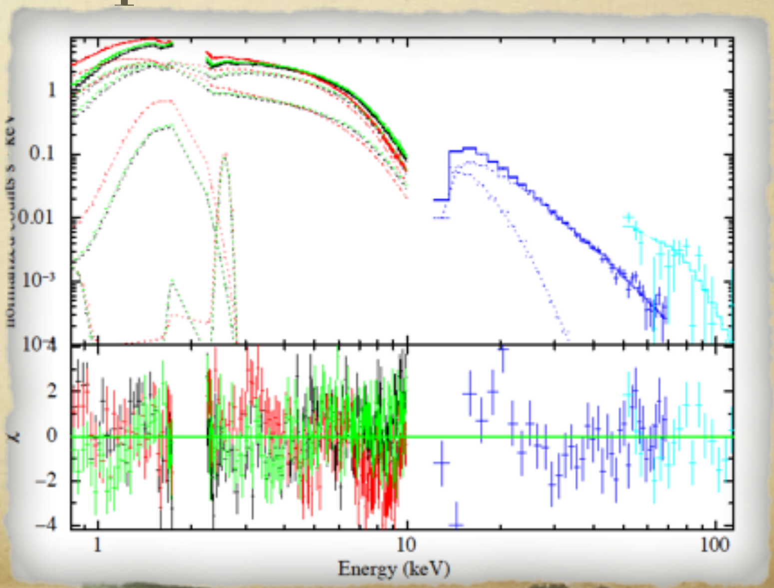


Int2 state



- Asymmetric line? with reg wings: requires 2 Gaussians

Average



Intensity resolved spectrum: Results

Parameter	High	Int2	Int1	Low
Γhigh	1.45±0.03	1.48±0.02	1.55±0.02	1.67±0.04
Ecrsf keV	38.1±1.8	38.5±1.5	31.5±2.0	33.4±6.1
Dcrsf	0.7±0.1	0.4±0.1	0.24±0.07	0.26±0.19

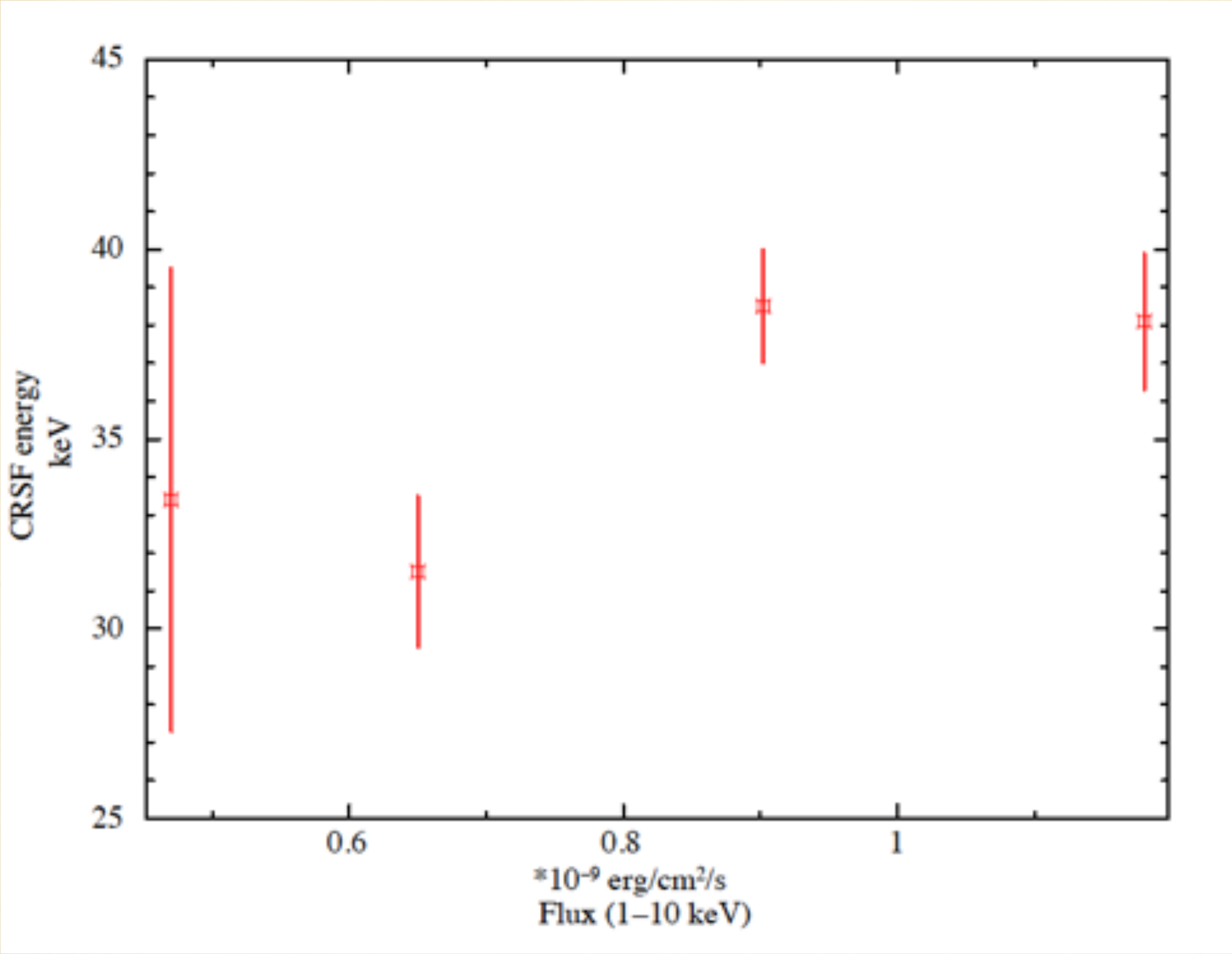
CRSF seen at high intensity states ?

BeppoSAX (1-10 keV):**1.7 $*10^{-10}$** erg/s

INTEGRAL (1-10 keV):2.1 **$*10^{-10}$** erg/s

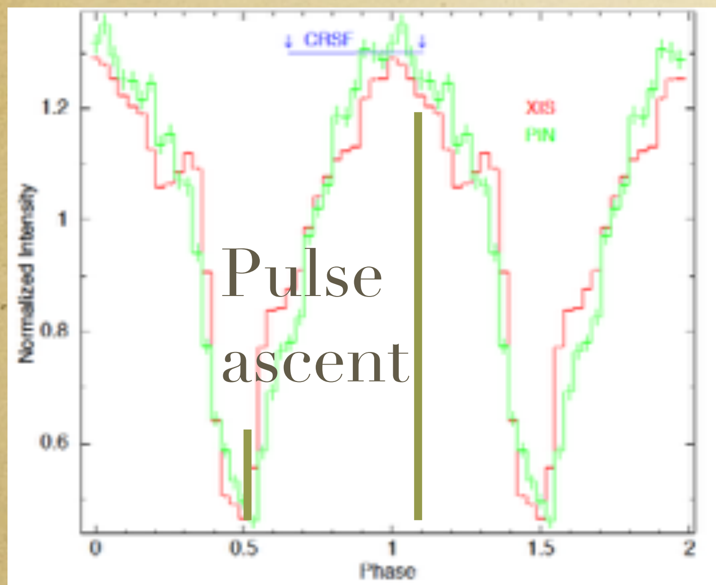
Suzaku (1-10 keV):**6.6 $*10^{-10}$ erg/s**

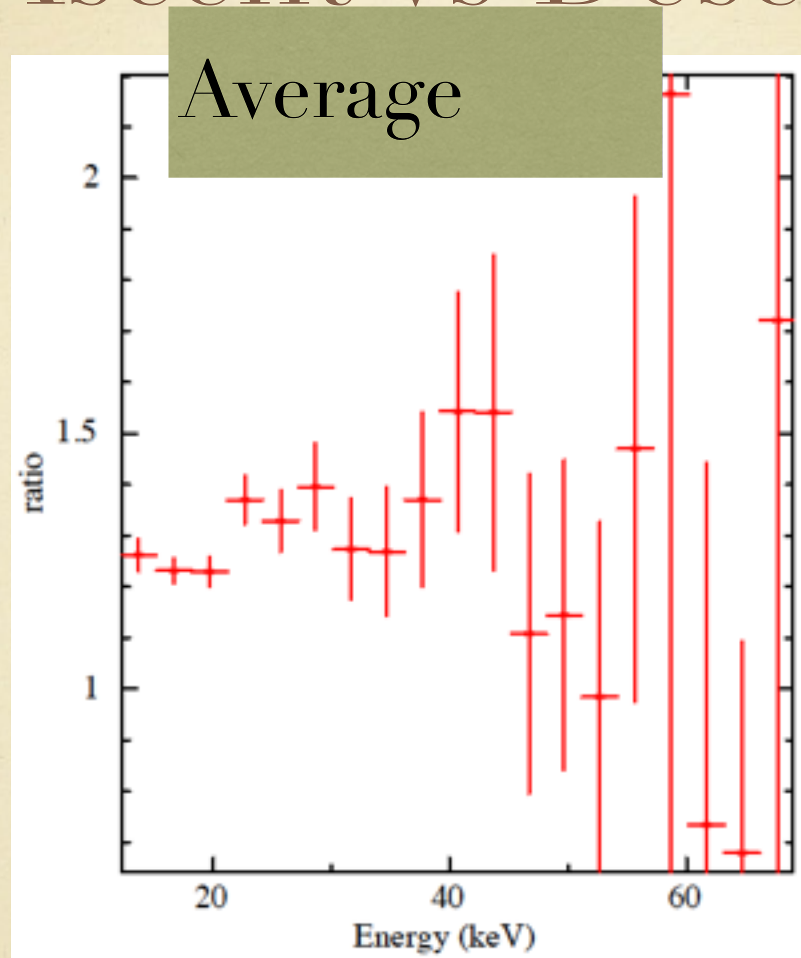
- Harder spectrum with more prominent CRSF at higher intensity (shifted to higher E)
- Change in accretion geometry, beam..direct look into poles at high intensity?

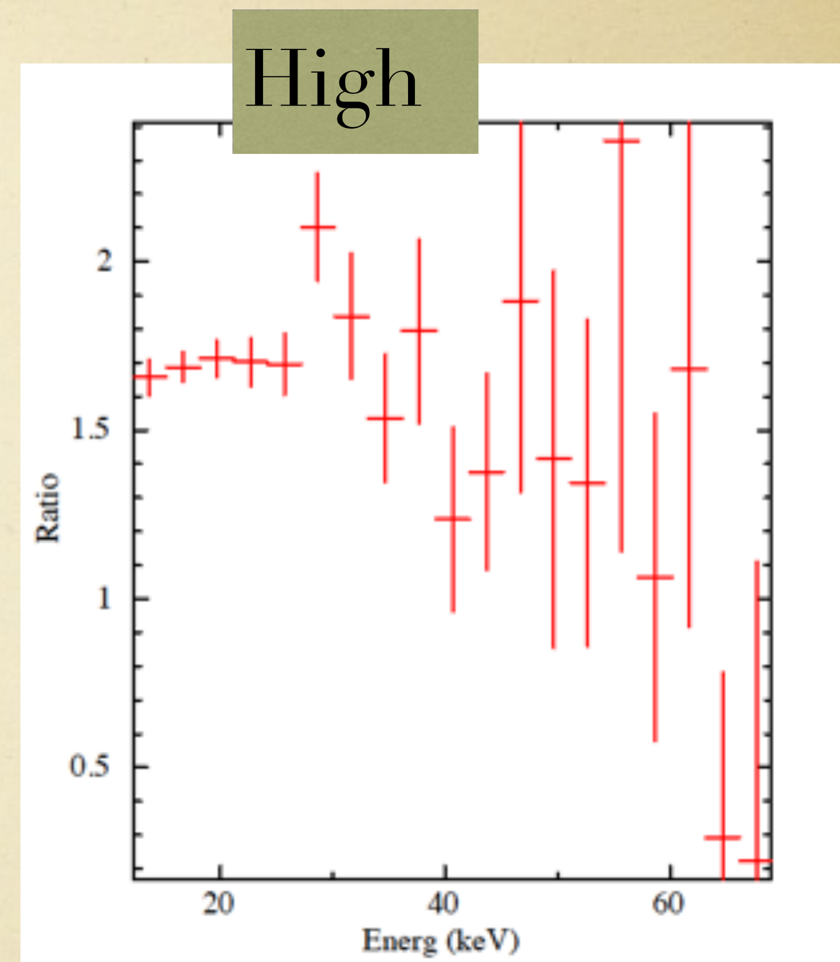


- Positive correlation of CRSF energy with Intensity
- Consistent with accretion in the sub-critical regime (Staubert et al. 2007, Klochkov et al 2012, Mushtukov et al. 2015). Lx 2 $*10^{35}$ erg/s

Looking for changes w.r.t pulse phase: Ascent vs Descent







- Average spectra: All parameters same except slightly deeper CRSF at pulse ascent.
- High Intensity: Spectra harder, CRSF deeper at pulse ascent.

SUMMARY

- Best constraint on the broadband spectral model of X-Per so far. Confirmed the CRSF at 30 keV; B ~ 3 x 10^{12} G
- Presence of intensity states: indication of changes in beaming geometry & accretion
- Narrower beam with harder spectrum & more prominent CRSF with increasing intensity
- Positive correlation of CRSF with intensity: consistent with models of accretion at sub-critical regime.