Off-states and X-ray reprocessing : Two flavours of X-ray binaries

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To be discussed ....

I. Are low intensity states in IGR J18027-2016 off-states? (with *Swift*)

II. X-ray reprocessing through X-ray eclipses

(With *XMM Newton*)

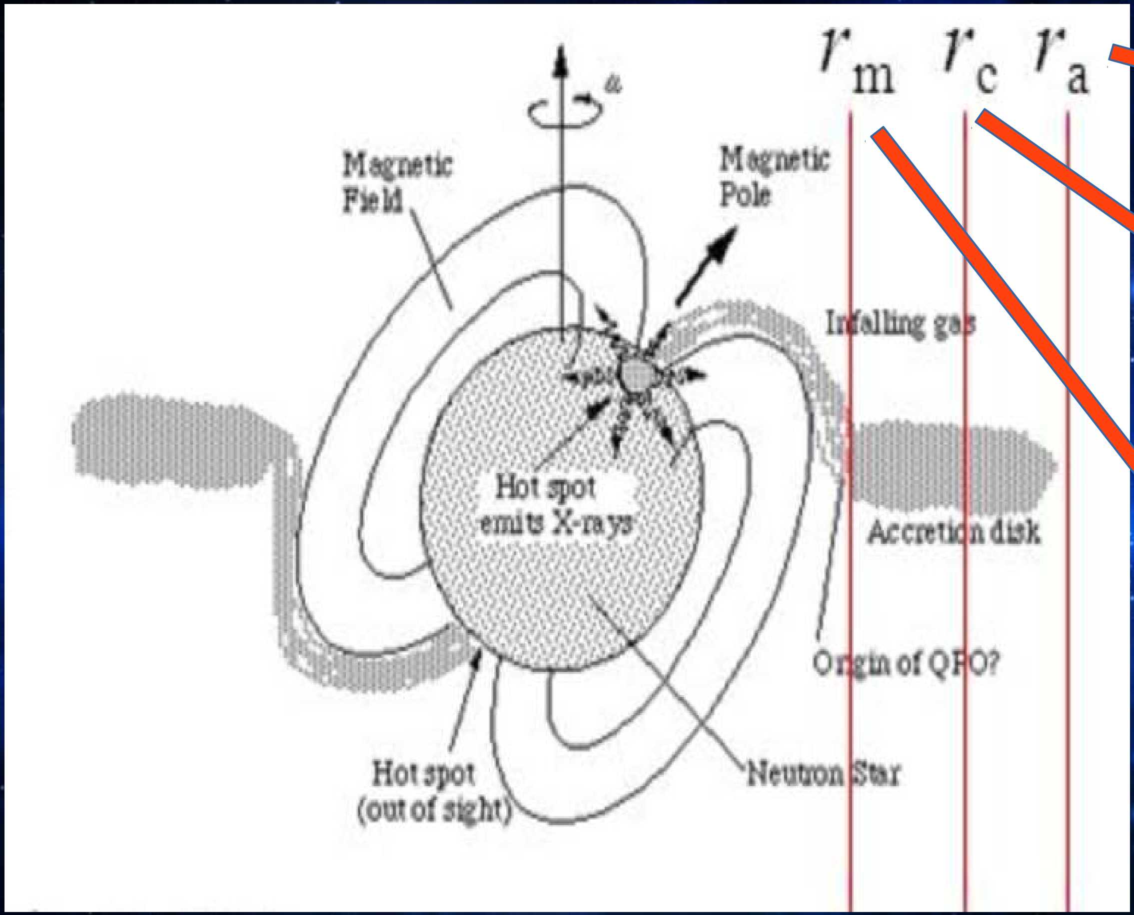
What are off-states ? & Causes?

Off states: Intensity falls near/below the detection sensitivity of the detecter

Possible Causes:

- Transition from accretion regime to inhibition regime or propeller regime (root cause : Variable wind density and/ velocity)
-
- Accretion from low density wind blobs
- Blocking of X-ray emission region by high density wind
- Unknown

The magnetic and centrifugal switches



Accretion radius

$$2GM_{NS}/v_w^2 = 3.7 \times 10^{10} v_8^{-2} \text{ cm}$$

Co-rotation radius

$$1.7 \times 10^{10} P_{s3}^{2/3}$$

Alfven radius

$$3.3 \times 10^{10} \dot{M}_{-6}^{-1/6} v_8^{-1/6} a_{10\,d}^{1/3} \mu_{33}^{1/3} \text{ cm}$$

I. $r_m > r_a$ | IA. $r_m > r_{co}$ | M | C | IB. $r_m < r_{co}$ | M | C

II. $r_m < r_a$ | IIA. $r_m > r_{co}$ | M | C | IIB. $r_m < r_{co}$ | M

IIBi. $P < P_{min}$ | C | IIBii. $P > P_{min}$ | C

Some familiar off-states

Off-states in GX 301-2

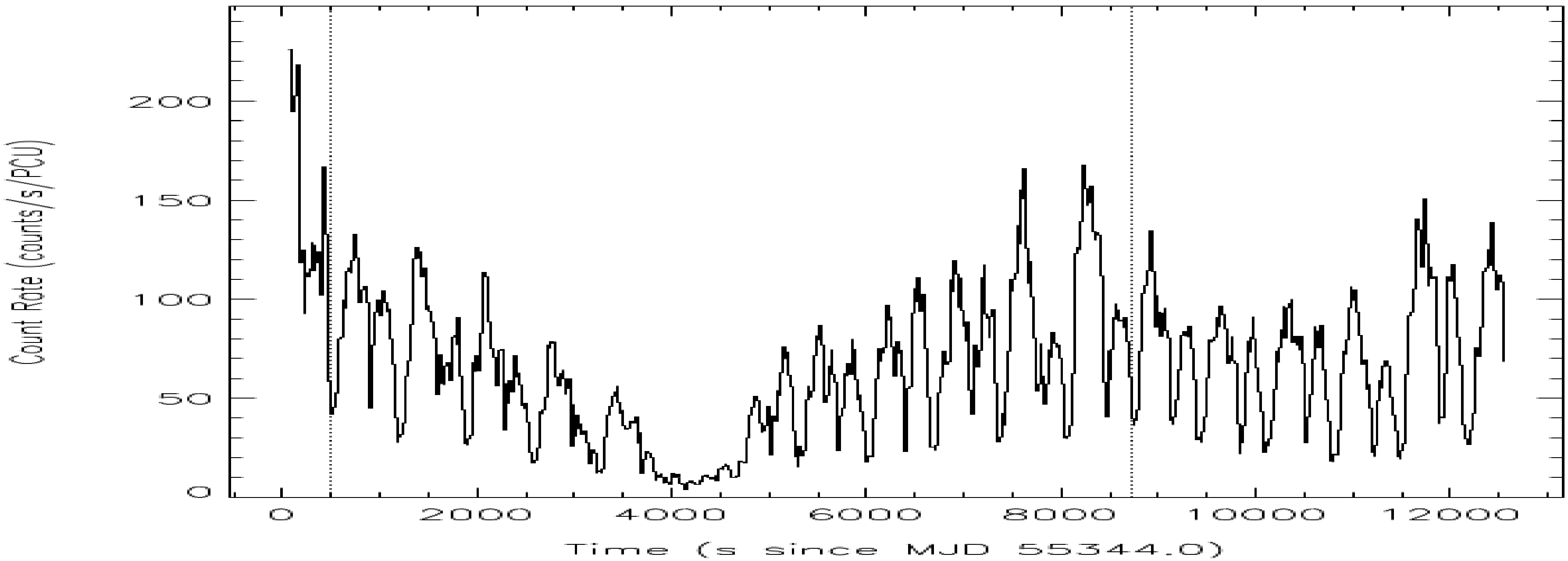


Fig. 1. Light curve of RXTE/PCA observations of GX 301−2 on 2010 May 28 (ObsID: 95354-03-03-00) in the 3−25 keV range. The vertical dotted lines indicate the time interval of detailed temporal and spectral investigations presented in Sect. 3.

RXTE/PCA lightcurve (GX 301-2) :
Gogus et al. 2010

Pulse profile : GX 301-2

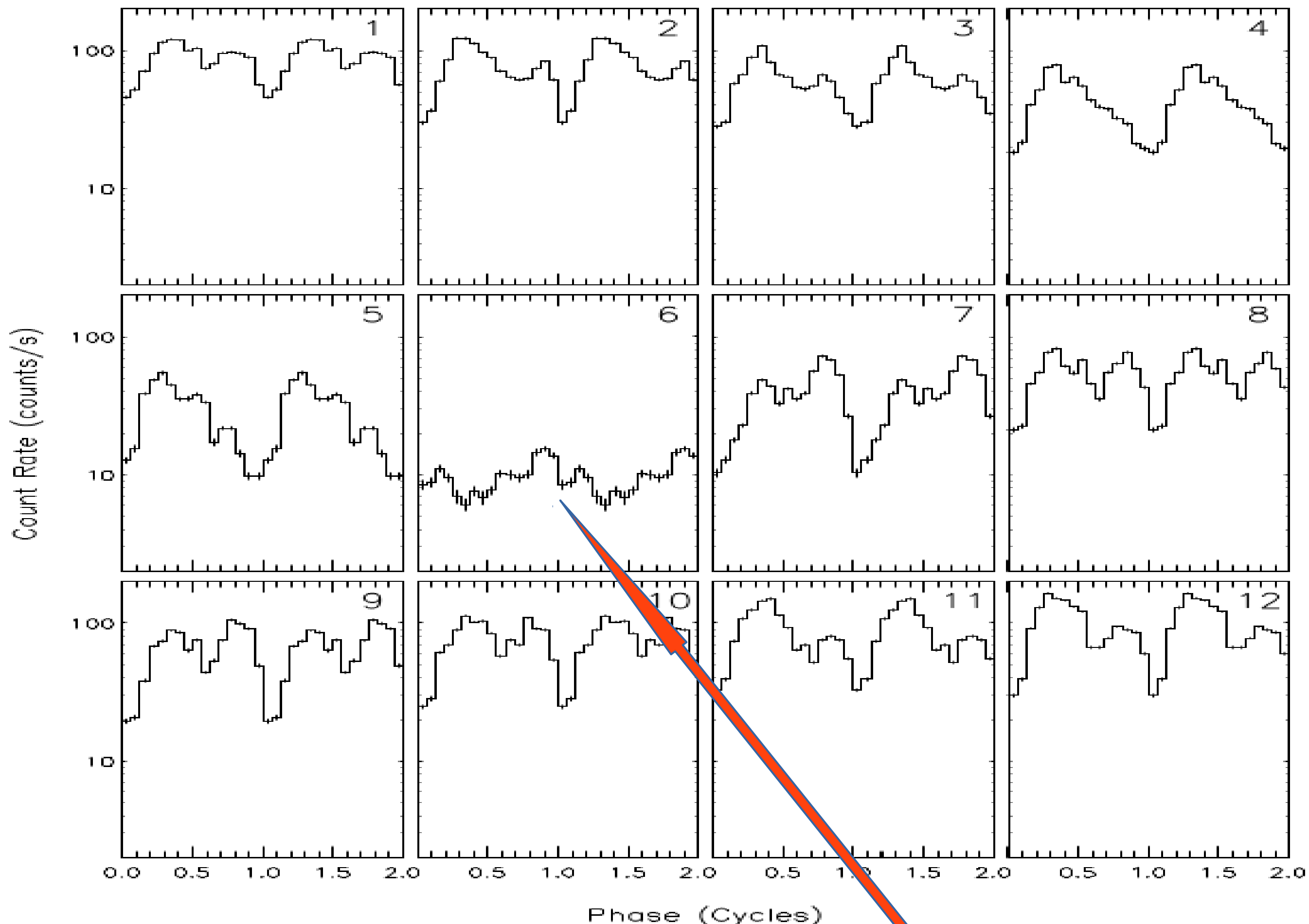


Fig. 2. Spin-phase light curves of GX 301−2 in the 3–25 keV band. Each individual plot is one spin cycle of the pulsar in a continuous time sequence within the time interval indicated in Fig. 1. The *Y* axes are on a logarithmic scale.

Pulsation ceases during off-states

Gogus et al. 2010

Variation of power-law photon index : GX 301-2

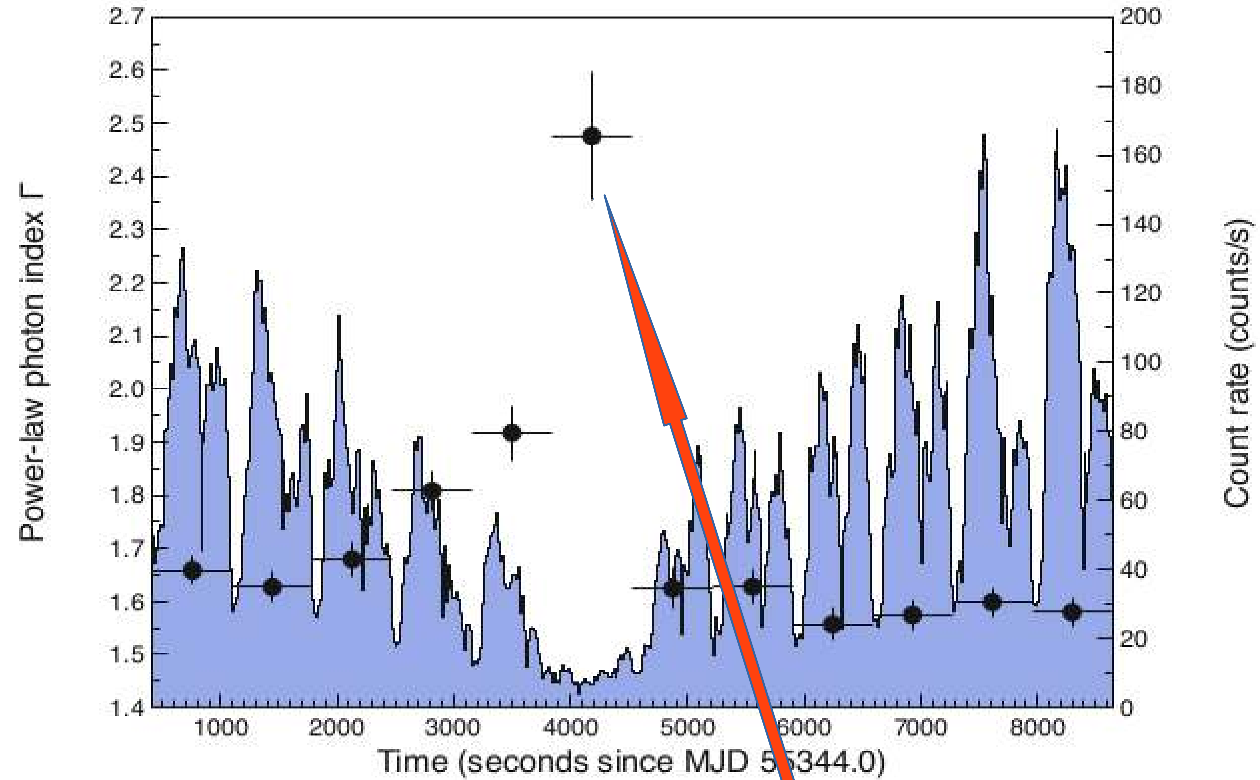


Fig. 4. Power-law indices obtained by spectral modeling (filled circles) and the background subtracted light curve of the source in the 3–25 keV range (blue histograms). The horizontal bars indicate one spin cycle (i.e., 686 s) over which each individual spectrum is extracted. The vertical bars are 1σ errors in power-law indices.

Increase of power-law photon index during off-states
Gogus et al. 2010

Nature of the off-states in GX 301-2

- Gradual reduction and disappearance of pulsation ----> Possibly X-ray emitting regions are blocked by wind material
- Spectral hardening not observed during dips ----> Emiiting regions can not be blocked by wind material
- GX 301-2 has rapid spin up history (Koh et al. 1997) ----> Infalling material can be expelled via the propeller effect.
- Cessation of pulsation for 1 spin cycle only ----> The off-states can not be due to propeller effect

These Off-states could be due to decrease and brief Cessation of matter flowing into magnetic poles

Off-states in Vela x-1

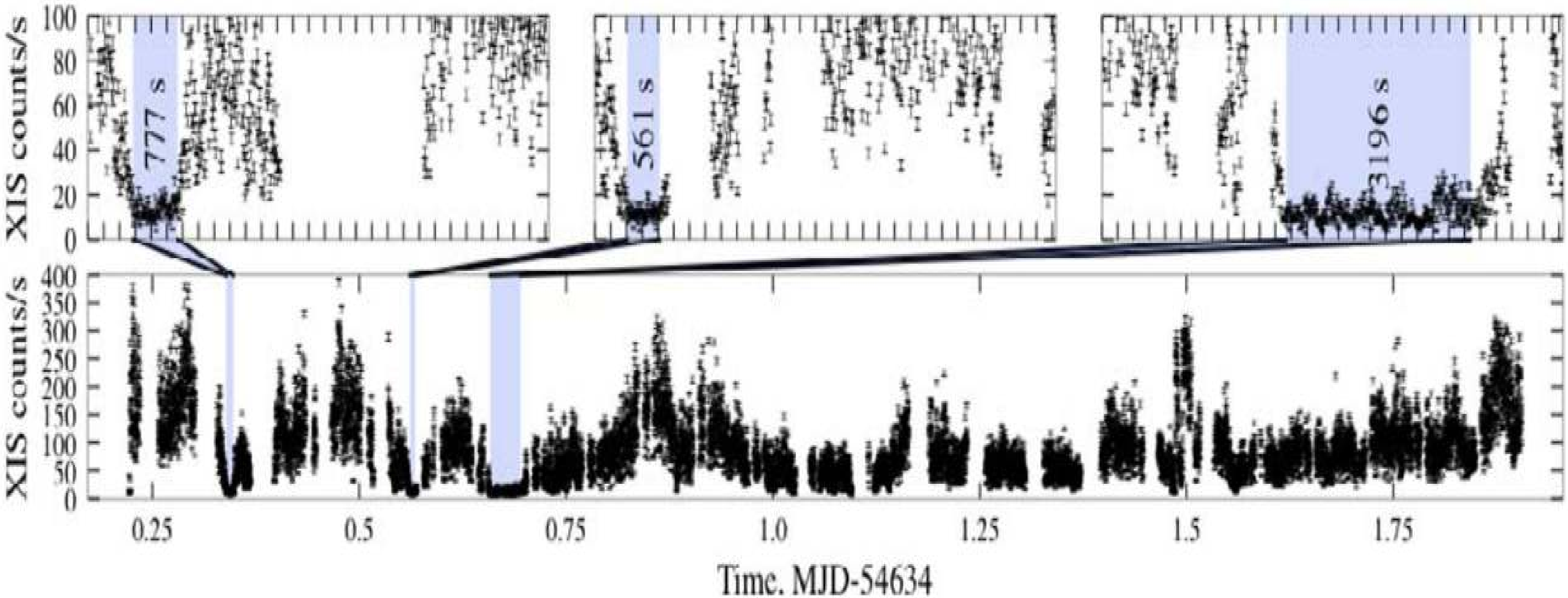


Fig. 1. Observation-long lightcurve in the 0.4–12 keV energy range using data from all XIS units is shown in the *bottom panel*. The *upper panels* show close-up views of the three detected off-states. Here, the time axis is ticked every pulse period.

Suzaku XIS lightcurve (Vela x-1):
Doroshenko et al. 2011

Vela x-1 with Suzaku

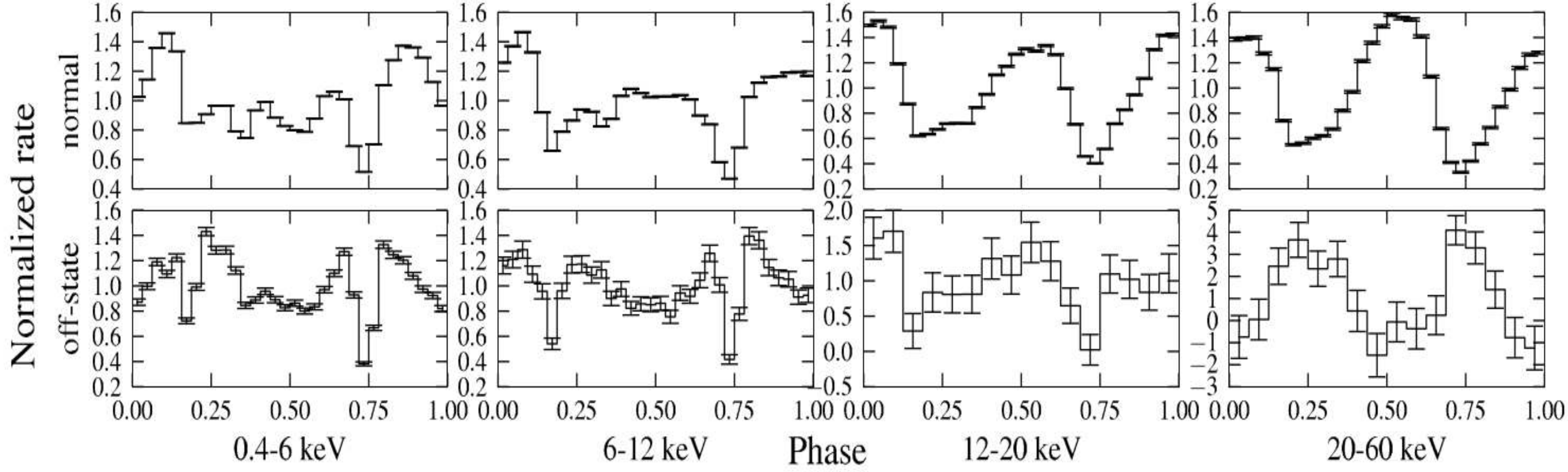


Fig. 2. Pulse profiles in four different energy ranges are shown for the normal (*upper panels*) and the "off-state" (*bottom panels*).

Pulse profile (Vela x-1: On & off states) :
Doroshenko et al. 2011

Nature Off-states in Vela x-1

- Pulsation during off-states ----> Emission is powered by accretion
- Short timescale of the state transition ----> Off-states can not be due to sudden drop of wind density/velocity
- Absence of emission lines ----> Off-states are not due to eclipse

These Off-states mut have some magnetospheric origin

Off-states in OAO 1657-415

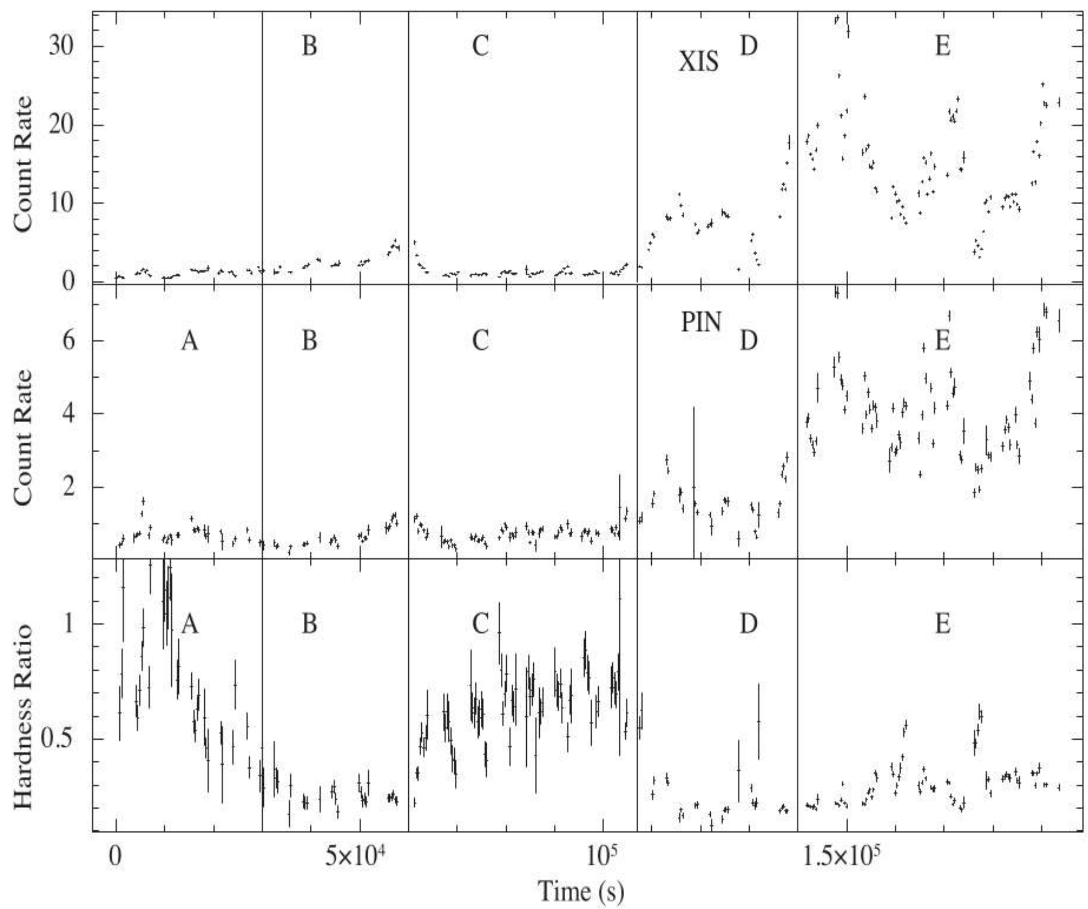


Figure 1. Background-subtracted light curves of OAO 1657−415 with a binning of 10 times the pulsar period (369 s). The upper and middle panels represent the XIS and PIN data, respectively. The lower panel represents the hardness ratio. The zero in time corresponds to MJD 55830.4 in this figure and the Figs 8 and 9.

Suzaku XIS & PIN lightcurve (OAO 1657-415):
Pradhan et al. 2015

Variability in OAO 1657-415

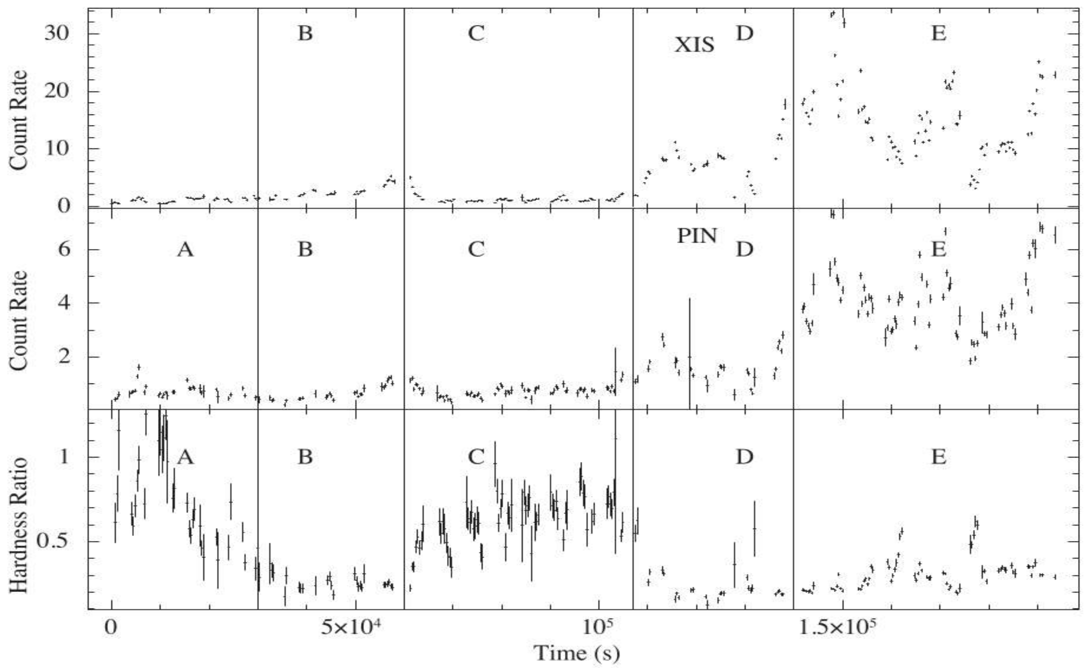


Figure 1. Background-subtracted light curves of OAO 1657−415 with a binning of 10 times the pulsar period (369 s). The upper and middle panels represent the XIS and PIN data, respectively. The lower panel represents the hardness ratio. The zero in time corresponds to MJD 55830.4 in this figure and the Figs 8 and 9.

A: large hardness ratio with large N_H and moderate equivalent width

B: hardness ratio is low with low N_H and low equivalent width

C: hardness ratio is high with very large N_H and large equivalent width

D: same as B
E: same as B, but flux higher by a factor of ~6

Nature of the Off-state in OAO 1657-415

- large increase in hardness ratio, N_H and equivalent width (In segment C) ----> The neutron star is passing through a dense clump of matter

The Off-state is mostly due to the absorption of source emission by dense wind clump

Few low intensity states : Off states ???

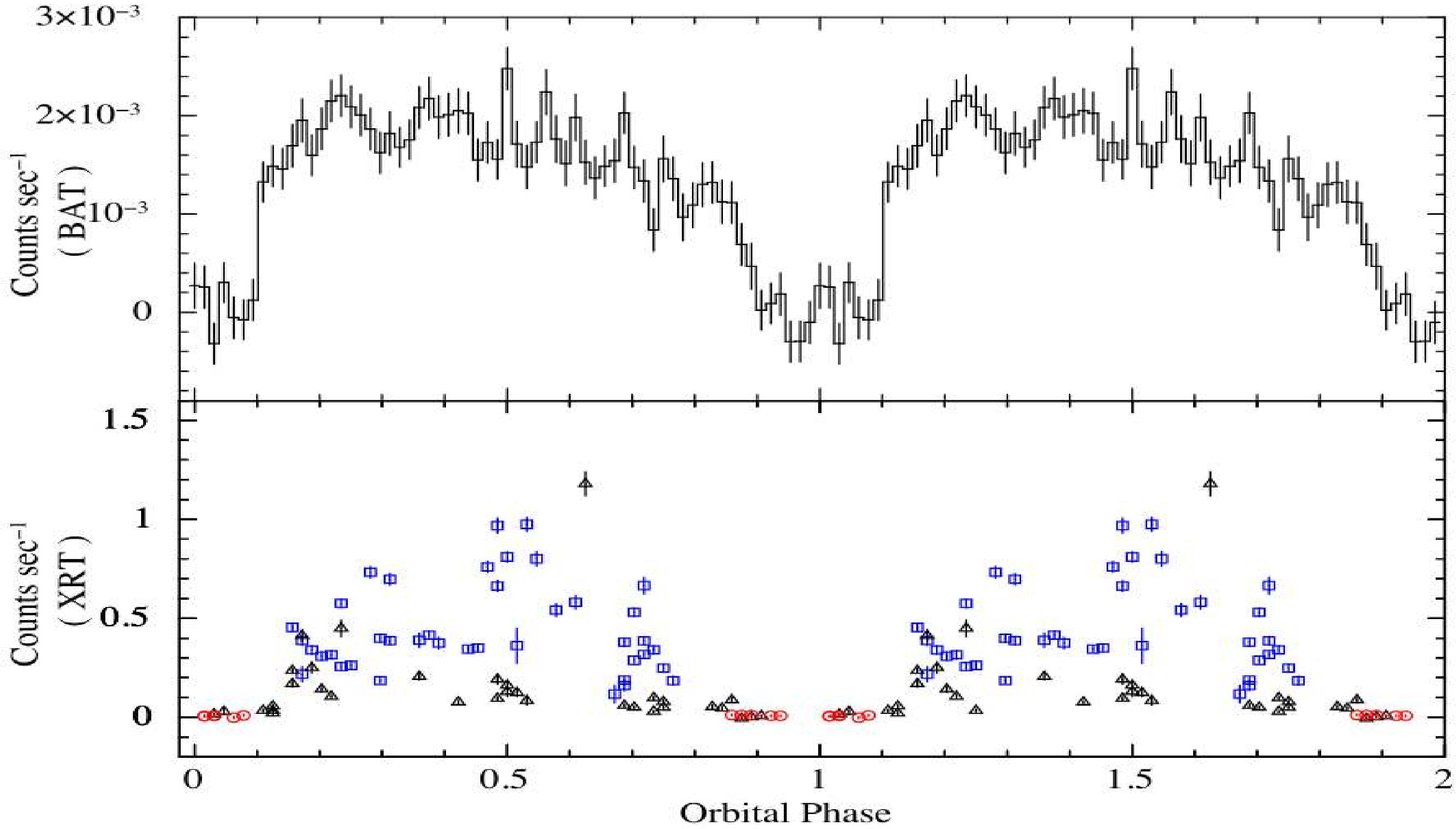


Figure 3. Top panel: orbital intensity profile of IGR J18027−2016 obtained by folding *Swift*-BAT light curve with orbital period of 394 843 s. Bottom panel: *Swift*-XRT light curves modulo same orbital period in three colours: pulsation detected where the number of source photons is greater than 600 – blue, number of source photons is less than 600 – black; faint – red.

Swift BAT & XRT lightcurveS (IGR J18027-2016):
Aftab et al. 2016

Variability in IGR J18027-2016

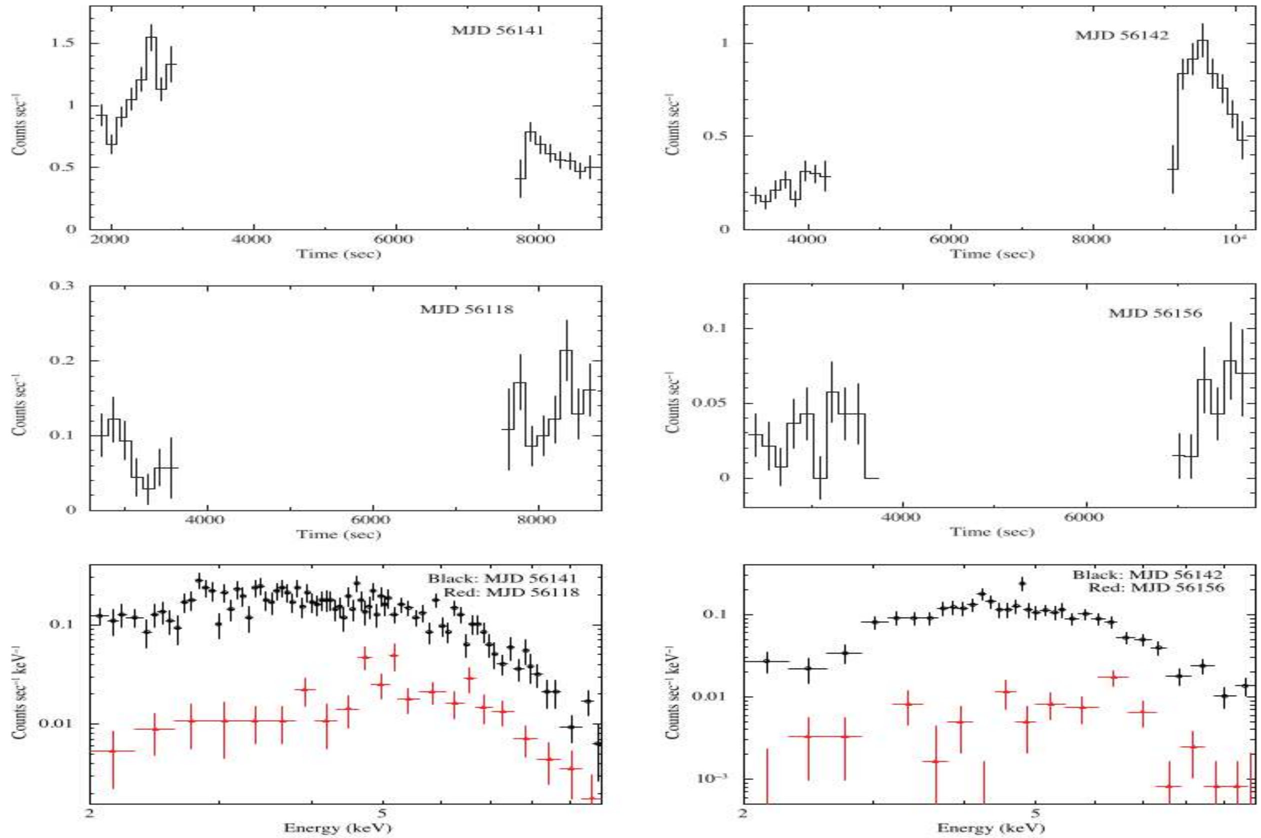


Figure 4. Left-hand panel: the top and middle panels show the light curves of two observations centred at orbital phase 0.48–0.52. In the top panel, the light curve of an observation (MJD 56141) shows a high count rate whereas the middle panel shows another observation (MJD 56118) in the same orbital phase range, having a low count rate. The lower panel is the plot of spectra of these two observations which bring out the fact that in the same orbital phase range, the X-ray intensities vary by a factor of ~10. Right-hand panel: same is shown for another set of observations (MJD 56142 and MJD 56156) centred at orbital phase range 0.69–0.75, but showing a large change in X-ray intensities.

Swift XRT lightcurves and spectra (IGR J18027-2016): Aftab et al. 2016

Variation in low energy absorption

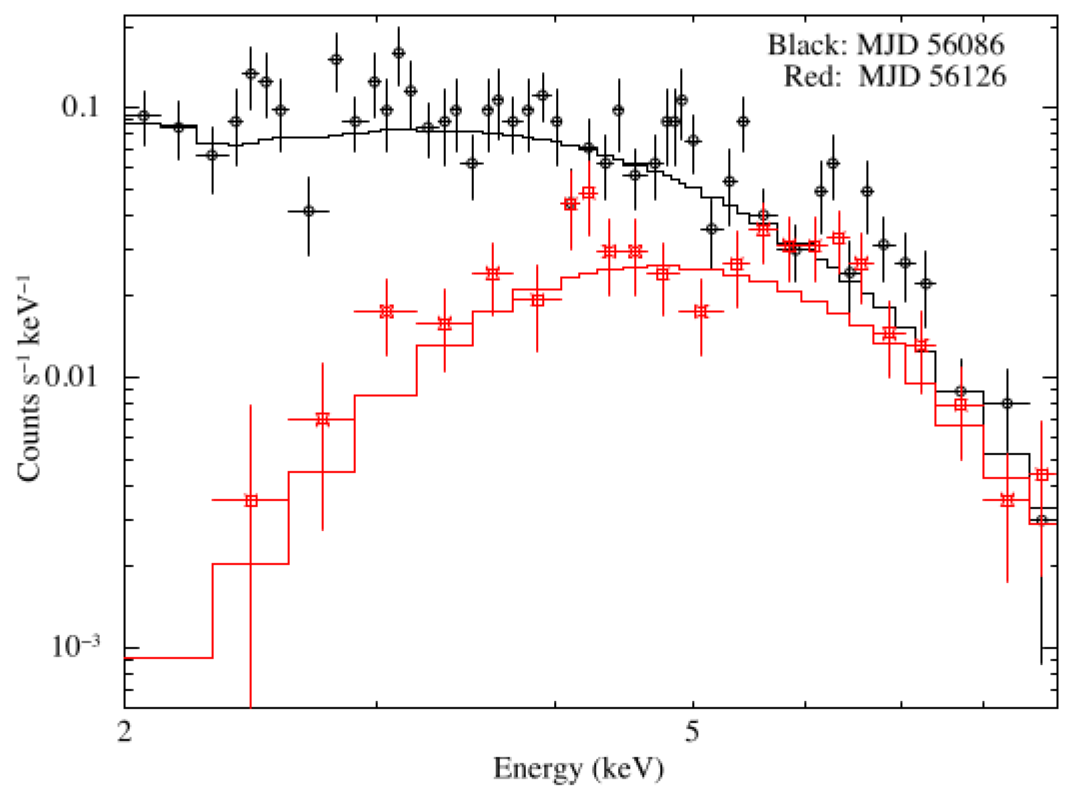


Figure 5. Spectra at MJD 56086 and 56126 are plotted together to show the variation in low-energy absorption.

Swift XRT spectra (IGR J18027-2016):
Aftab et al. 2016

Variation of spectral parameters

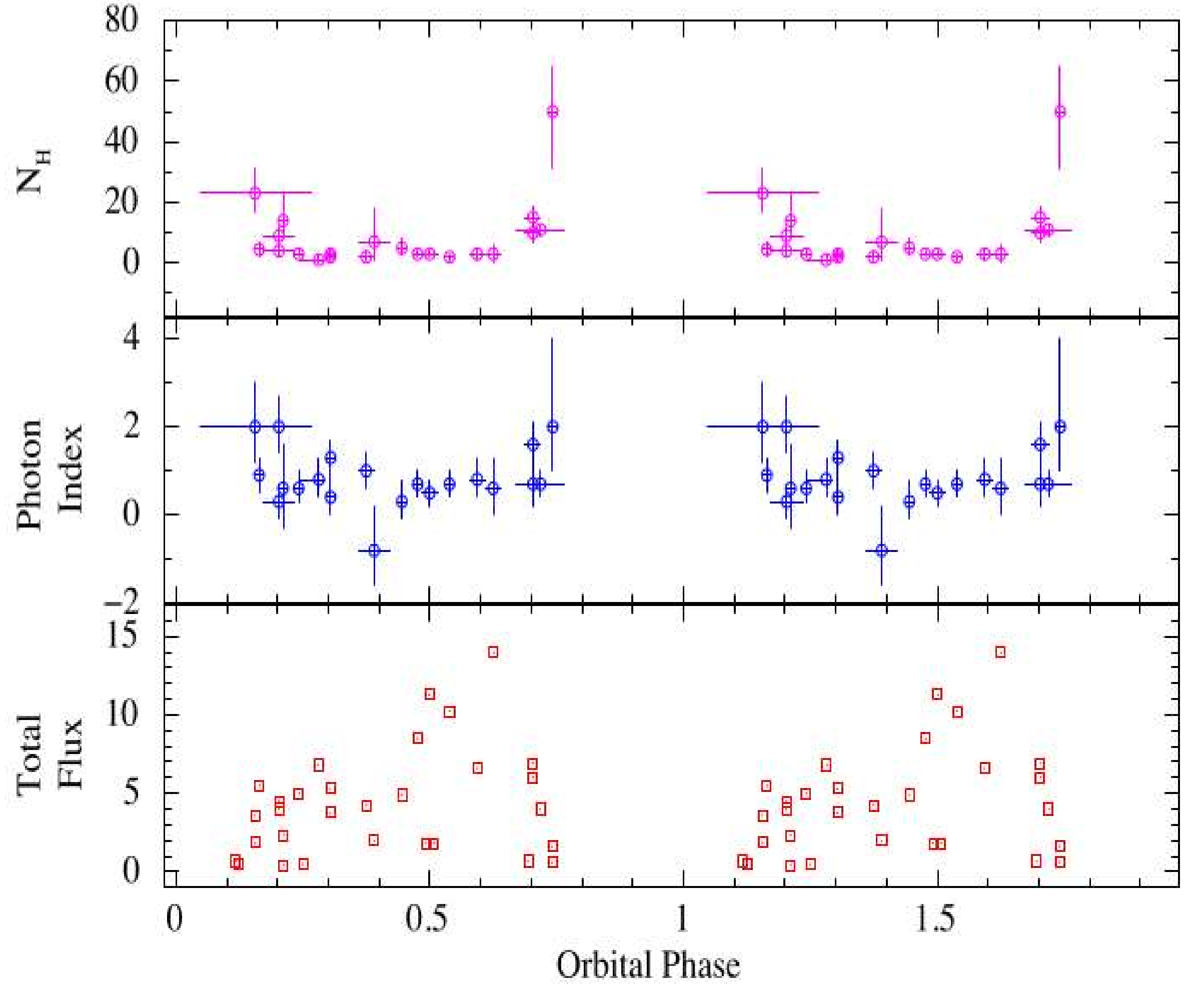


Figure 6. Variation of column density of hydrogen (N_H in units of 10^{22} cm^{-2}), photon index (Γ), total flux (F in the units of 10^{-11} erg cm^{-2} s^{-1}).

Swift XRT (IGR J18027-2016):
Aftab et al. 2016

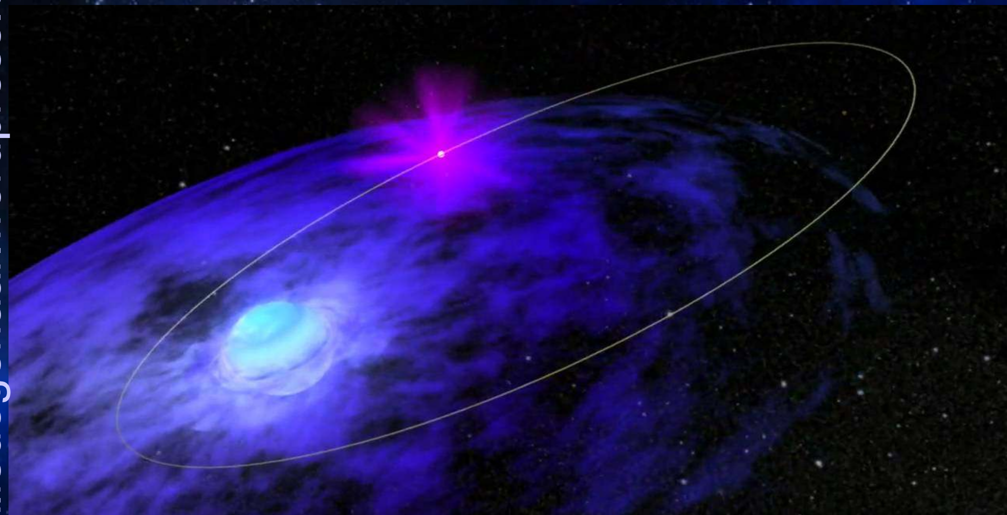
Causes of the low intensity states/off-states in IGR J18027-2016 are still unknown.

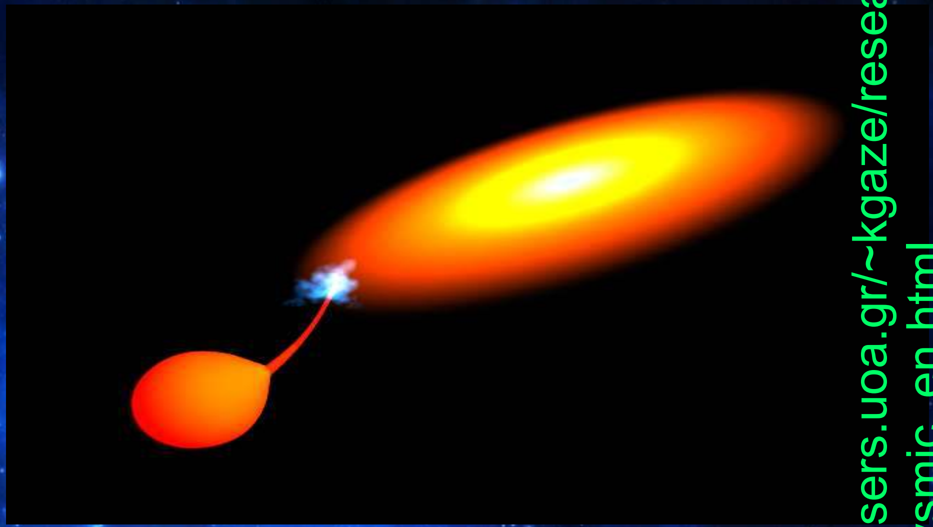
X-ray reprocessing through X-ray eclipses

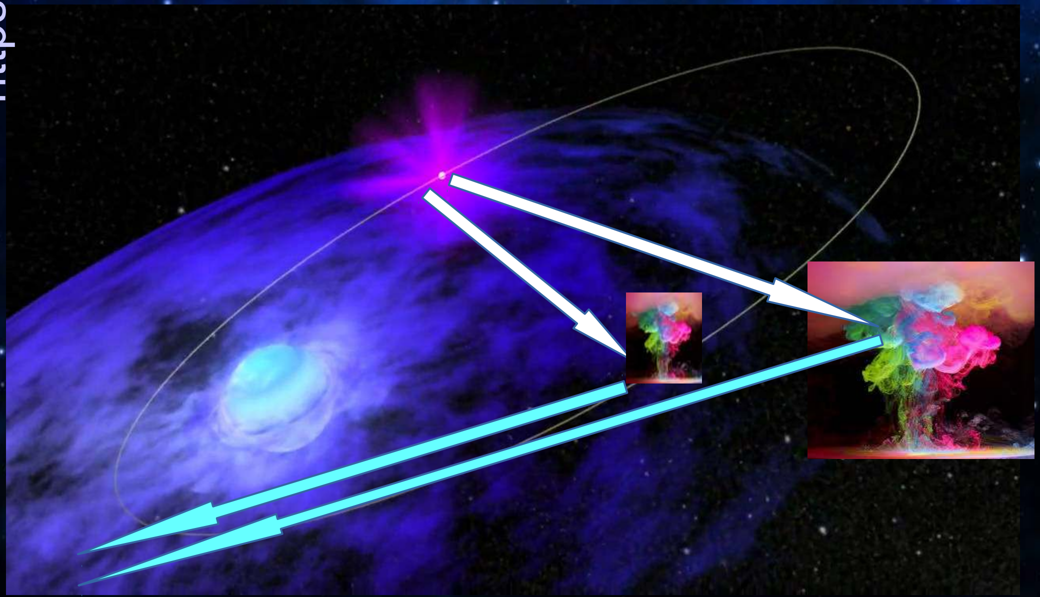
(With *XMM Newton*)

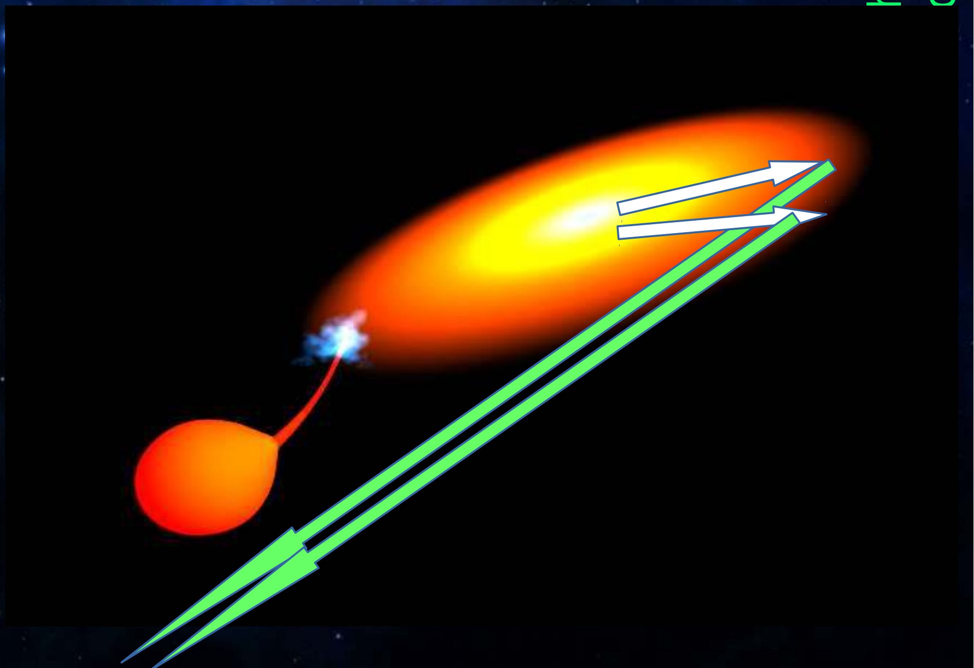

Eclipse does not hide … … … … … …
but reveals ……………………

X-ray eclipse and X-ray reprocessing





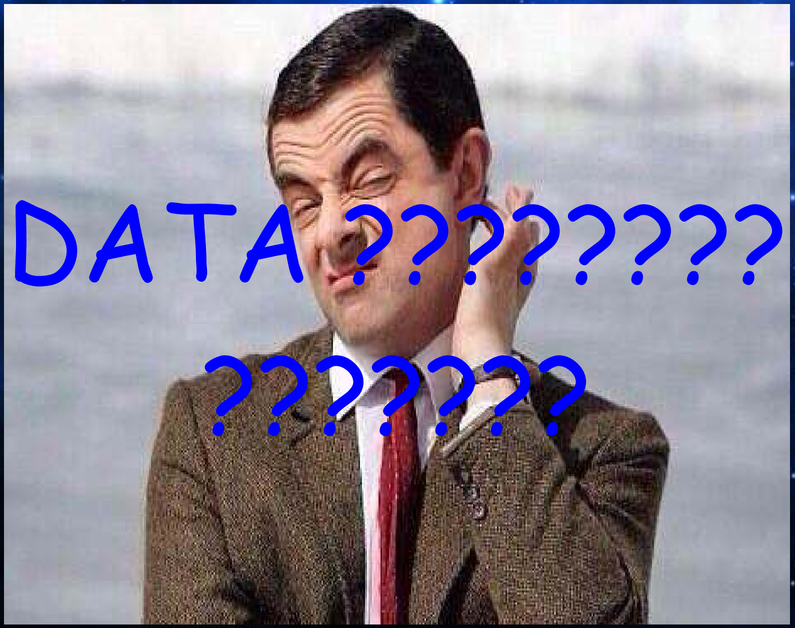




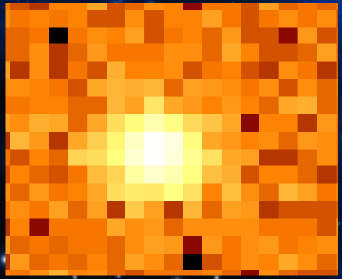
https://nathaliedegenaar.wordpress.com/

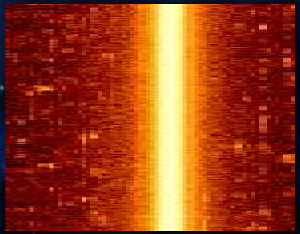
http://users.uoa.gr/~kgaze/research_cataclysmic_en.html

Now ……………



Found with *XMM Newton* EPIC pn .....





The Sources ....

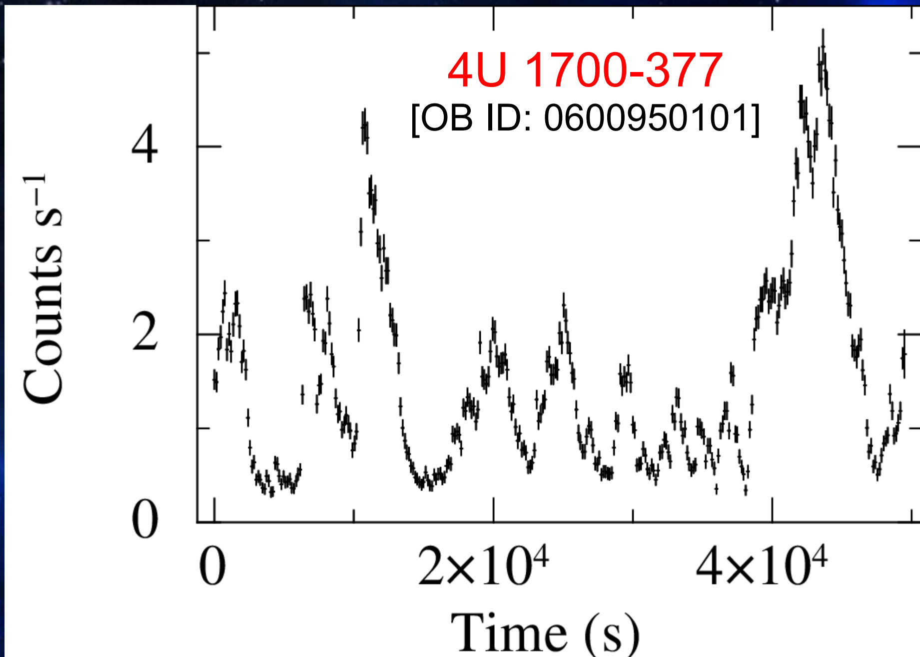
HMXBs

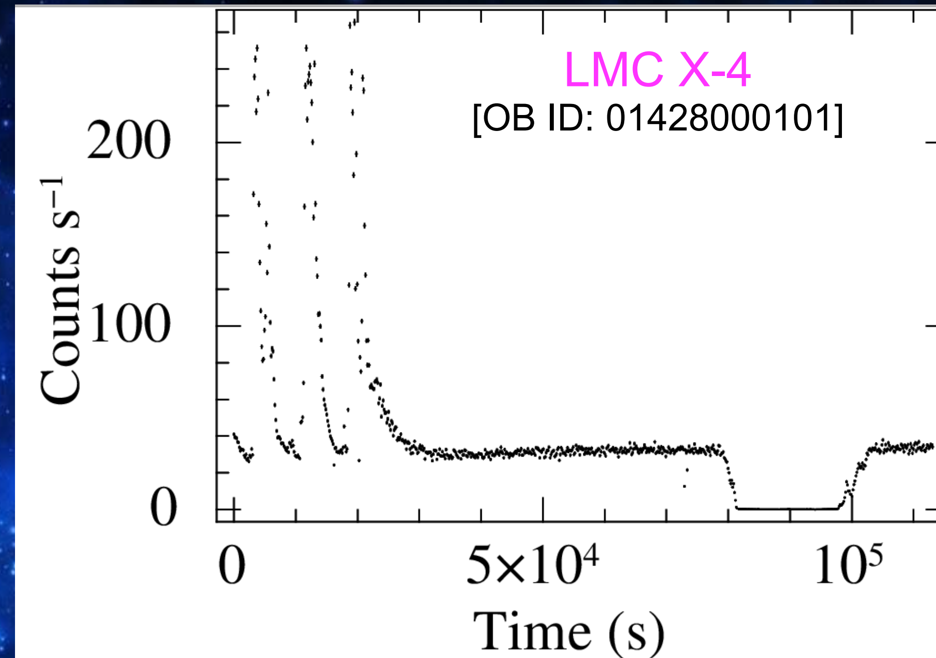
LMC X-4
Cen X-3
SMC X-1
4U 1538-522
4U 1700-377
IGR J18027-2016
IGR J16418-4532
IGR J16479-4514
IGR J17252-3616

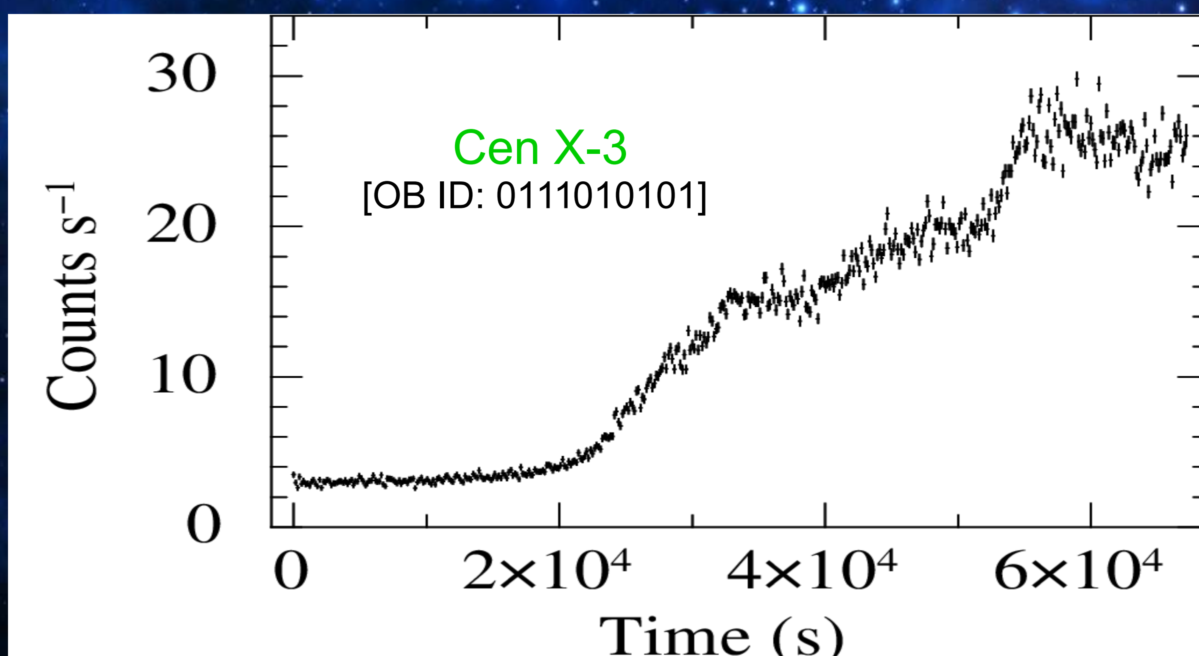
LMXBs

EXO 0748-676
MXB 1659-298
AXJ 1745.6-2901
XTE J1710-281

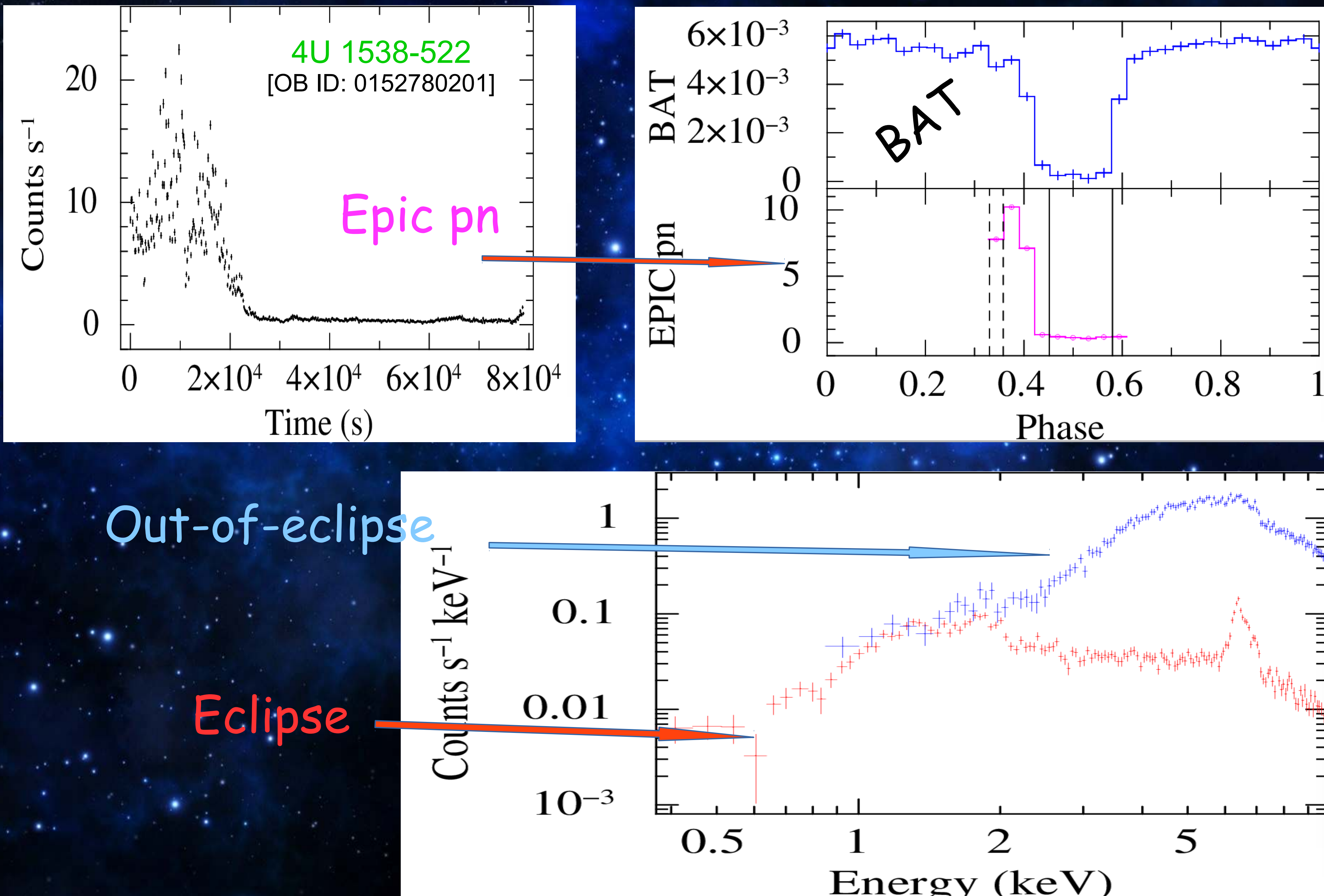
EPIC pn Lightcurves covering eclipses







Data Treatment !!



Fe Kα emission lines

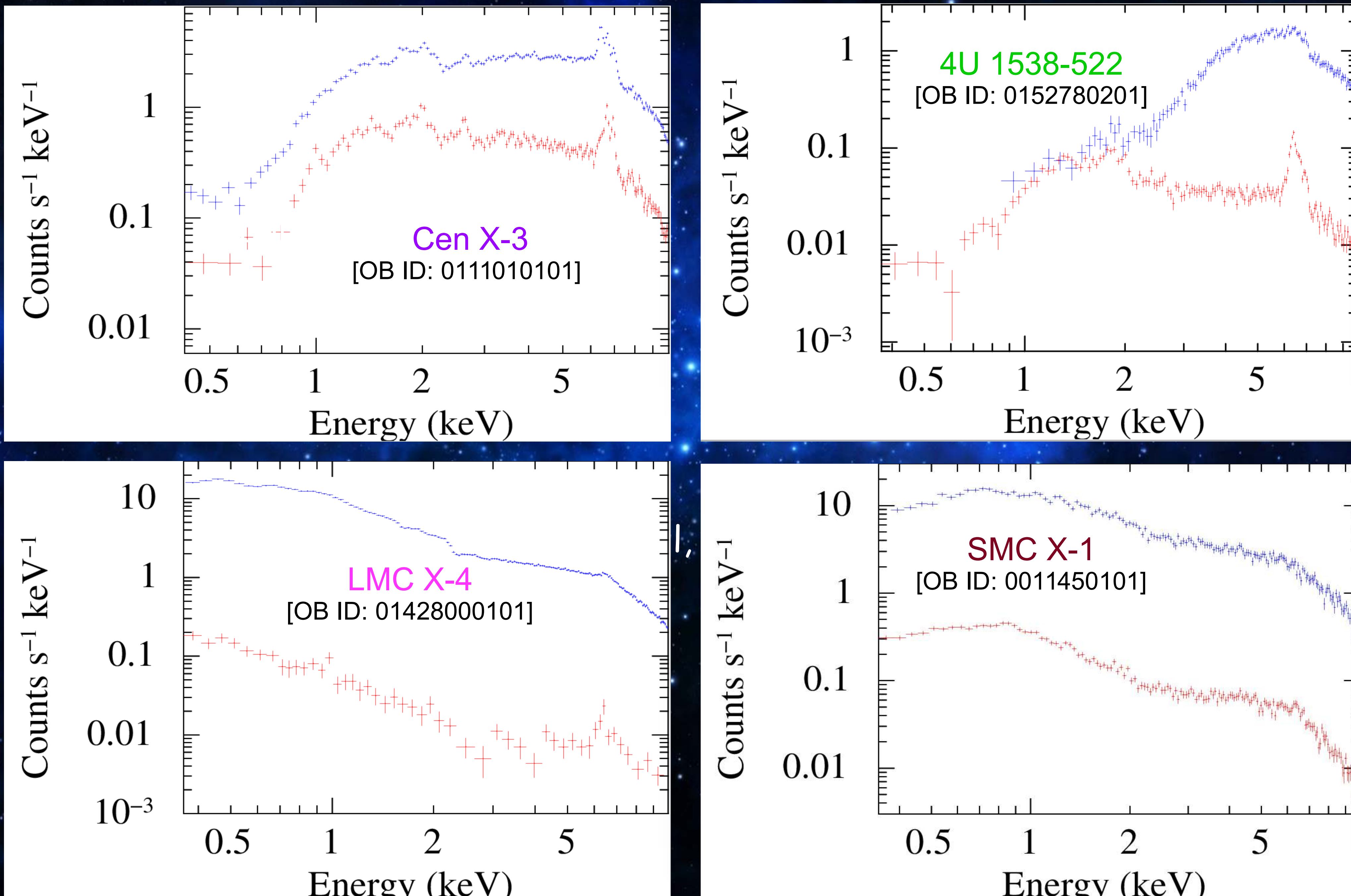
During eclipse: 12/13

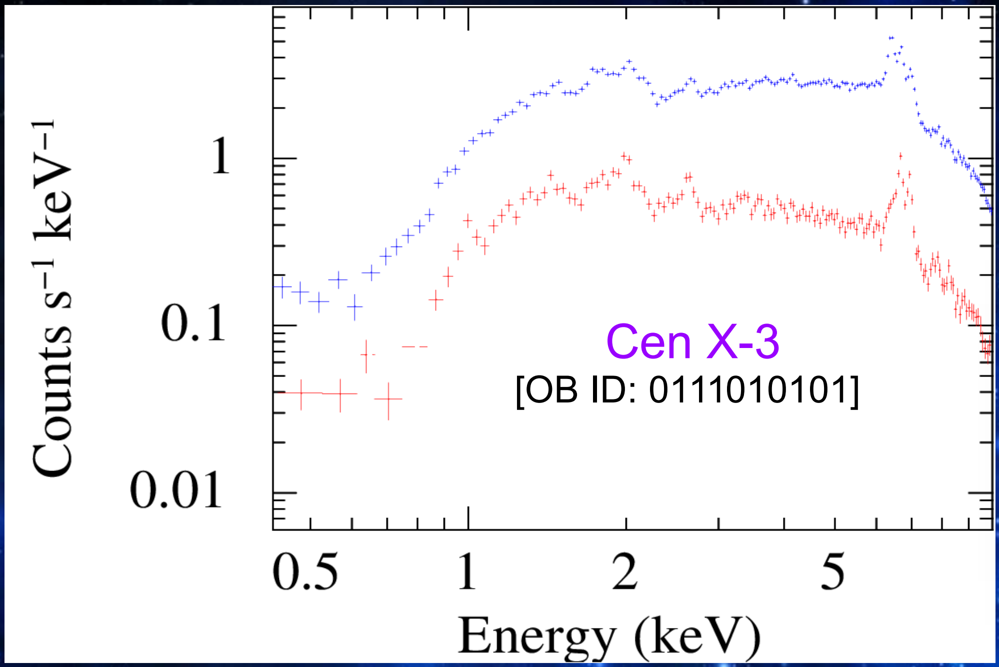
Cen X-3	(0111010101)
LMC X-4	(0142800101)
SMC X-1	(0011450101)
4U 1700-377	(0600950101)
4U 1700-377	(0083280401)
4U 1538-522	(0152780201)
IGR J 18027-2016	(0745060401)
IGR J 16479-4514	(0512180101)
IGR J 16418-4532	(0679810101)
IGR J 17252-3616	(0405640201)
IGR J 17252-3616	(0405640601)
IGR J 17252-3616	(0405641001)

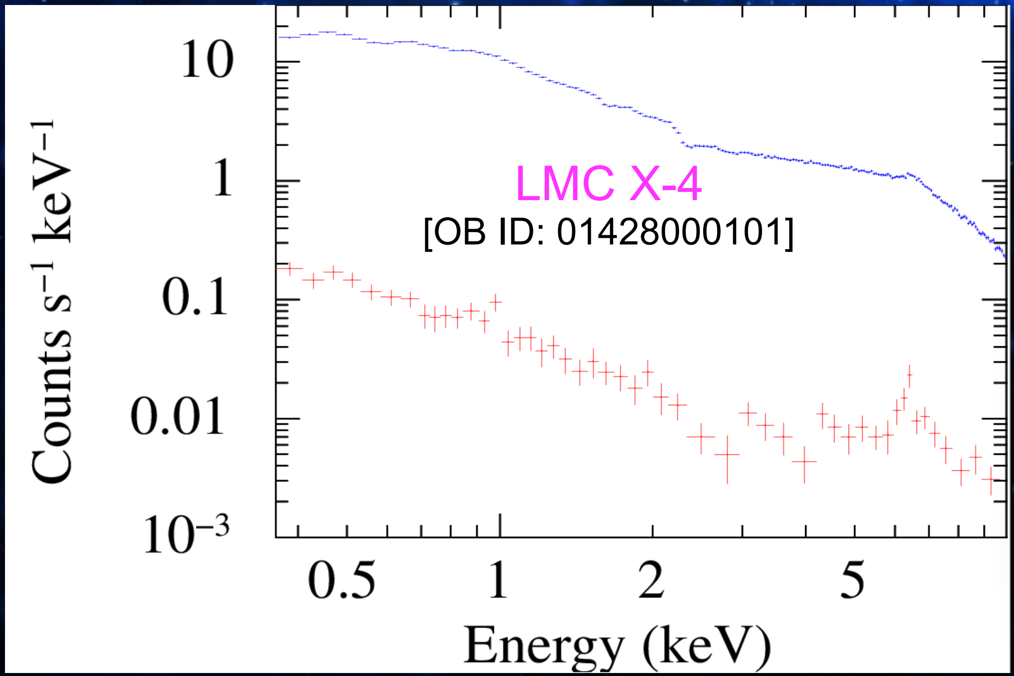
During out-of-eclipse: 5/7

Cen X-3	(0111010101)
LMC X-4	(0142800101)
LMC X-4	(0203500201)
4U 1700-377	(0083280401)
4U 1538-522	(0152780201)

4 types ofHMXB spectra (pn) : during and outside eclipse





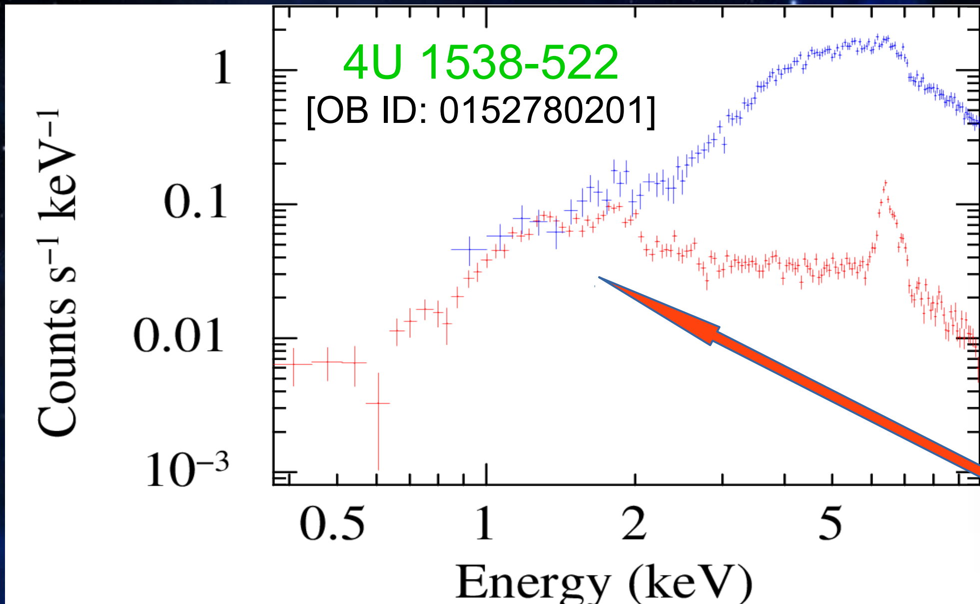


O-O-E: Strong Fe Kα line

E: Strong Fe Kα line

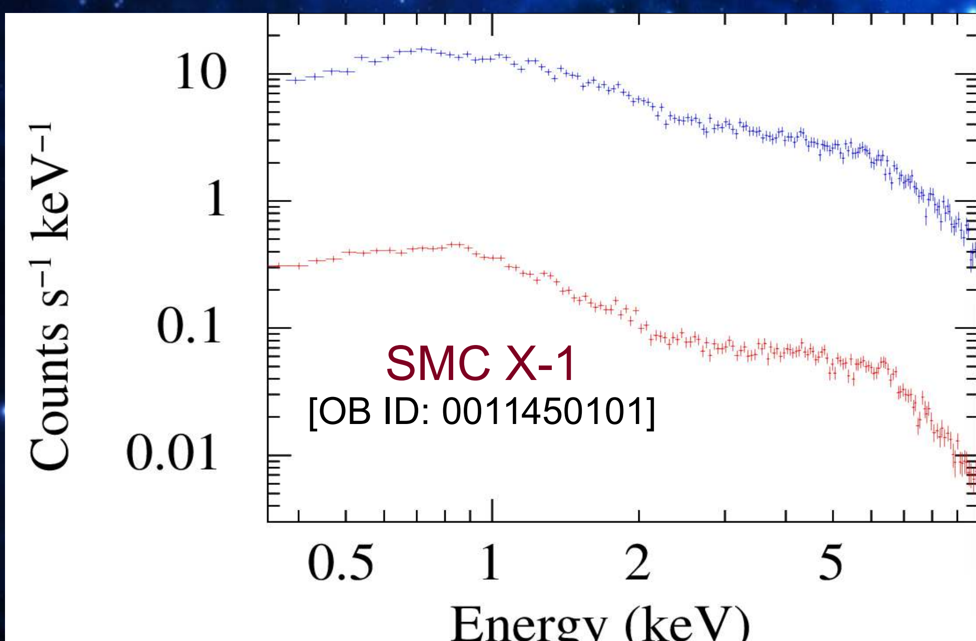
O-O-E: Weak Fe Kα line

E: Weak Fe Kα line



O-O-E: Weak Fe Kα line
E: Strong Fe Kα line

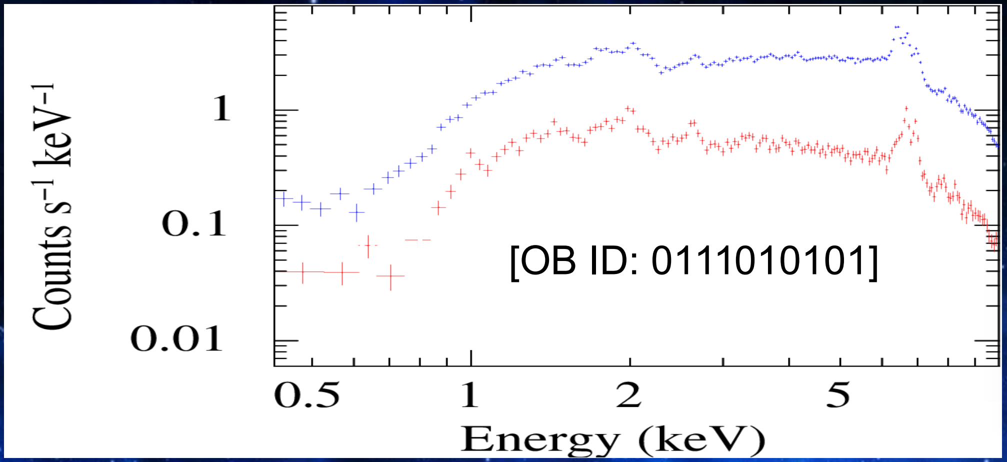
Below 2 keV
nearly same spectral shape

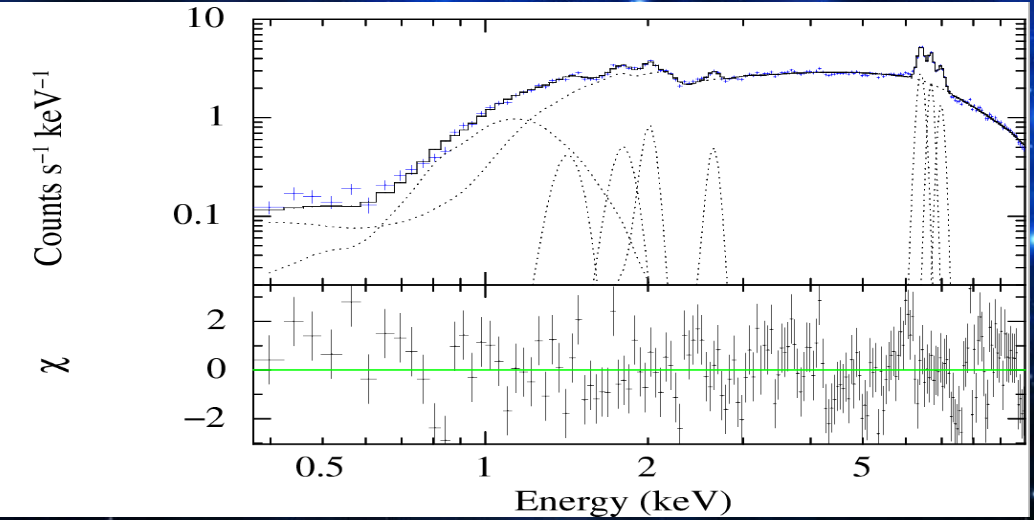


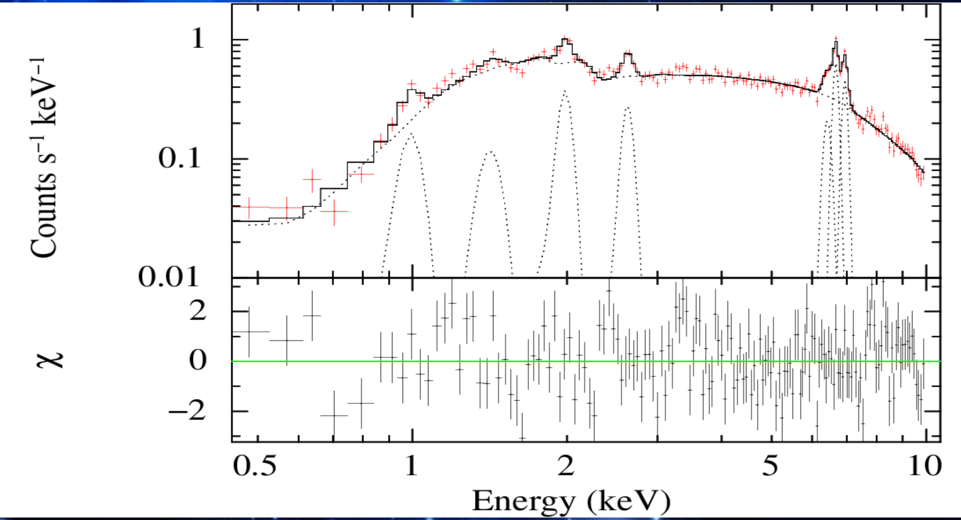
O-O-E: No Fe Kα line

E: Weak Fe Kα line

Cen X-3: Eclipse vs. Out-of-eclipse







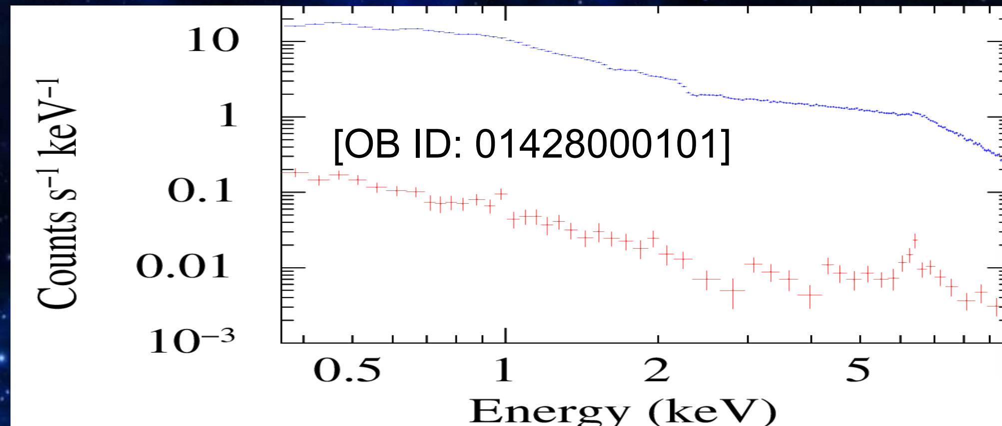
$\Gamma = 0.21$
Flux : 43.60 × 10^{-11} ergs cm^{-2} sec^{-1}
χ^2 (DOF)= 272.49 (150)

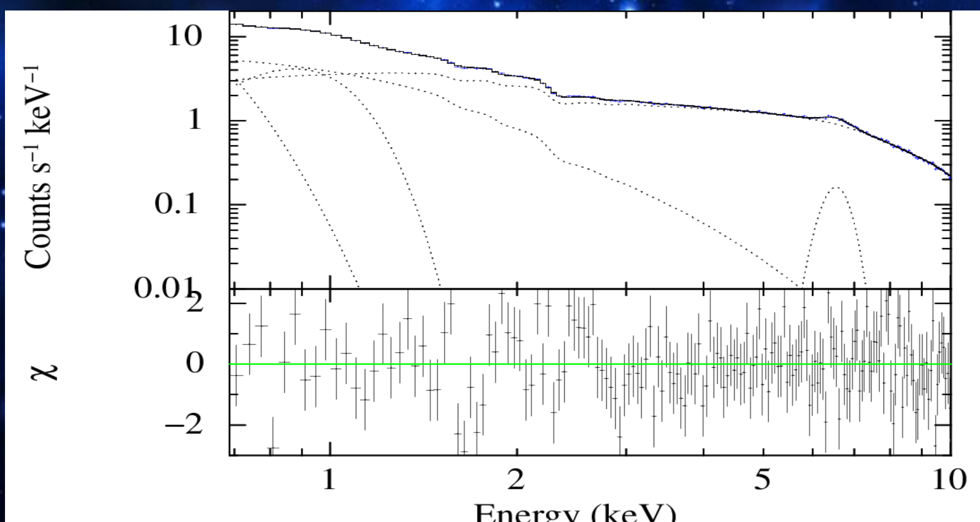
Fe Ka line flux = 17.25 × 10^{-4} photons cm^{-2} sec^{-1}
Eqv width: 229.73 eV

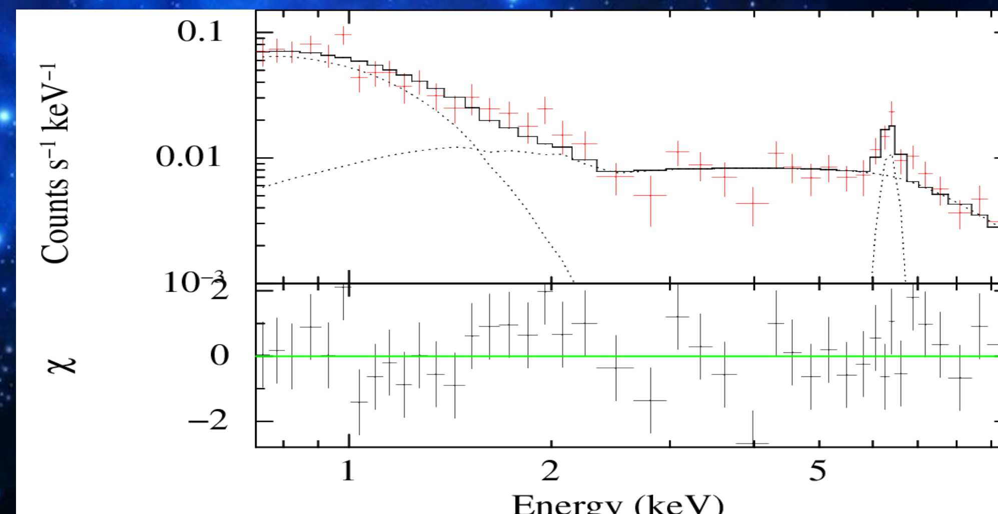
$\Gamma = 0.78$
Flux : 4.45 × 10^{-11} ergs cm^{-2} sec^{-1}
χ^2 (DOF)= 250.79 (130)

Fe Ka line flux = 0.88 × 10^{-4} photons cm^{-2} sec^{-1}
Eqv width: 102.40 eV

LMC X-4: Eclipse vs. Out-of-eclipse







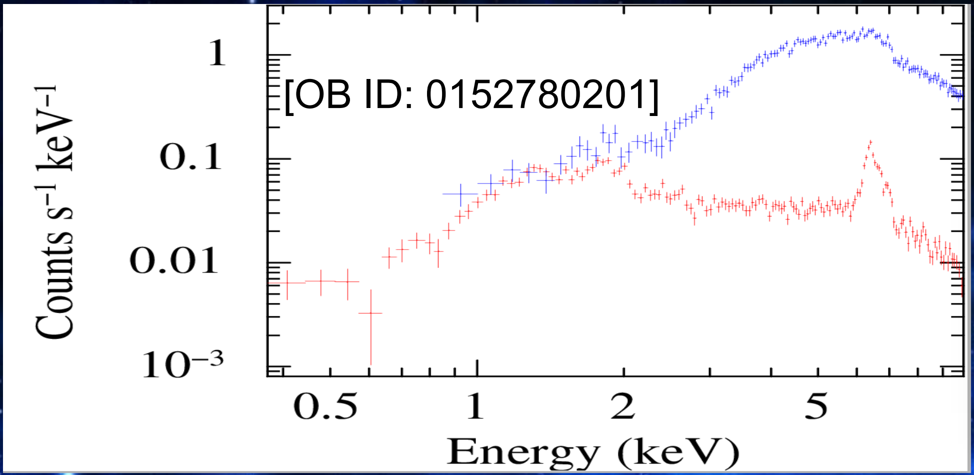
$\Gamma = 0.58$
Flux : 34.49×10^{-11}
ergs cm^{-2} sec^{-1}
χ^2 (DOF)= 192.40 (157)

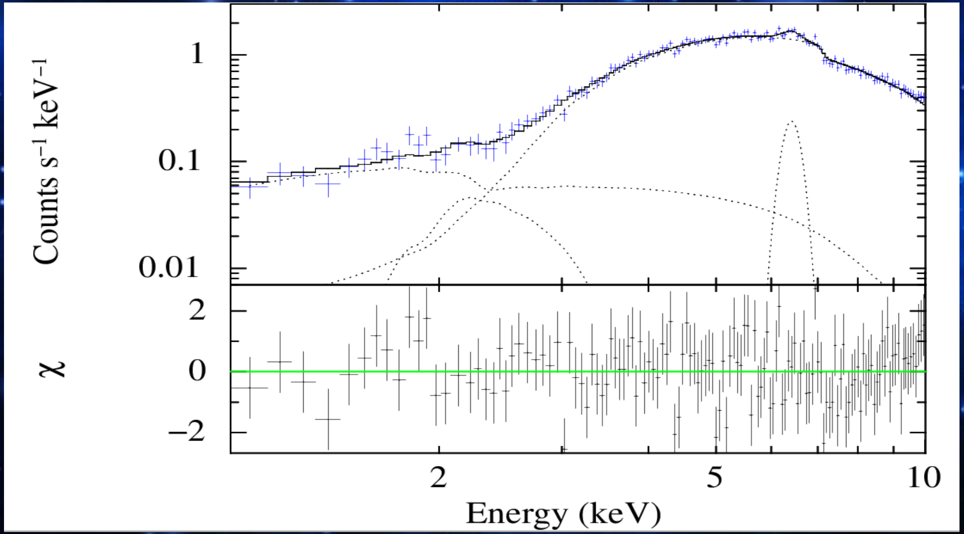
Fe Ka line flux = 3.6×10^{-4}
photons cm^{-2} sec^{-1}
Eqv width: 147.81 eV

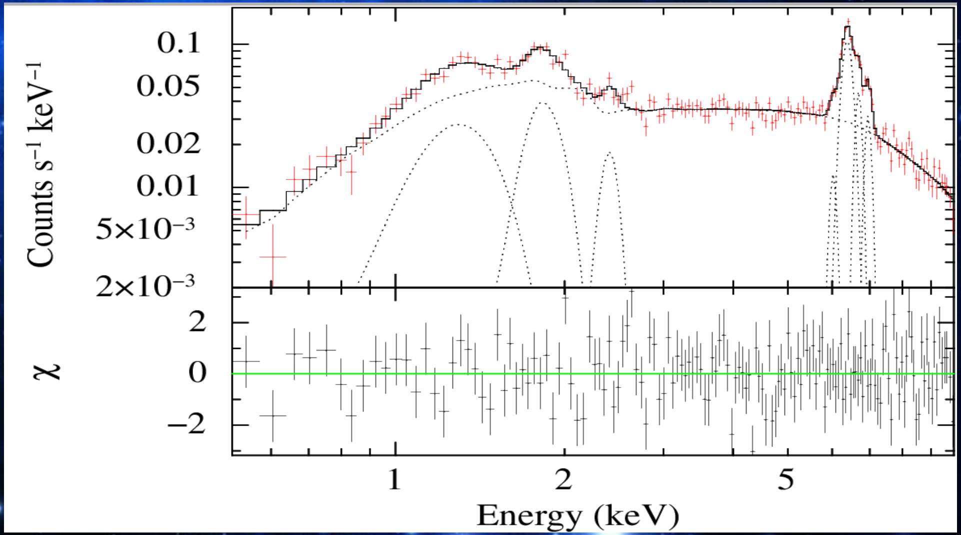
$\Gamma = 0.11$
Flux : 0.11×10^{-11}
ergs cm^{-2} sec^{-1}
χ^2 (DOF)= 38.09 (35)

Fe Ka line flux = 0.08×10^{-4}
photons cm^{-2} sec^{-1}
Eqv width: 663.33 eV

4U 1538-522: Eclipse vs. Out-of-eclipse







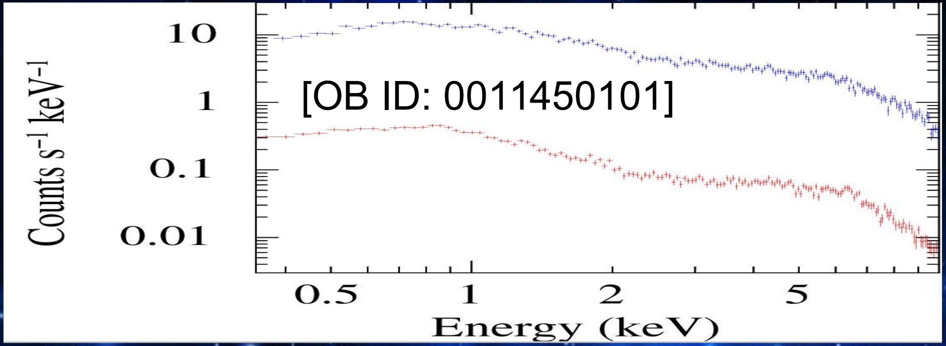
$\Gamma = 0.73$
Flux : 13.93×10^{-11}
ergs cm^{-2} sec^{-1}
χ^2 (DOF)= 125.59 (125)

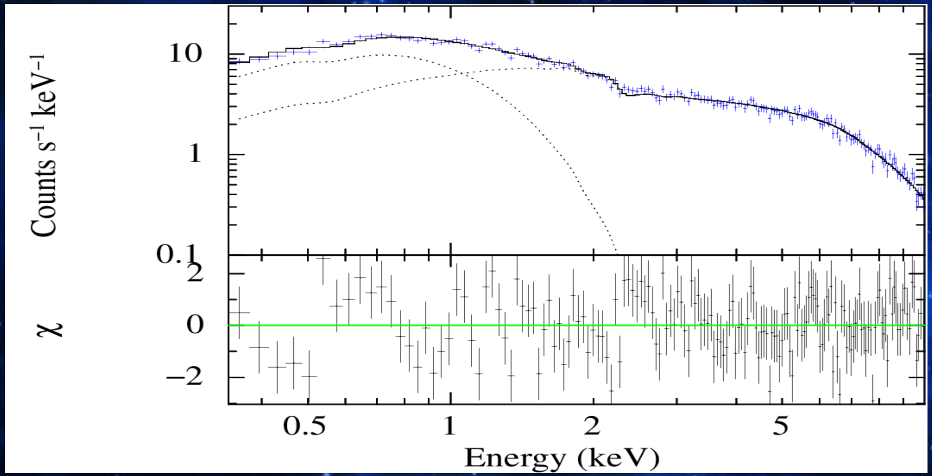
$\Gamma = 0.22$
Flux : 0.46×10^{-11}
ergs cm^{-2} sec^{-1}
χ^2 (DOF)= 178.19 (128)

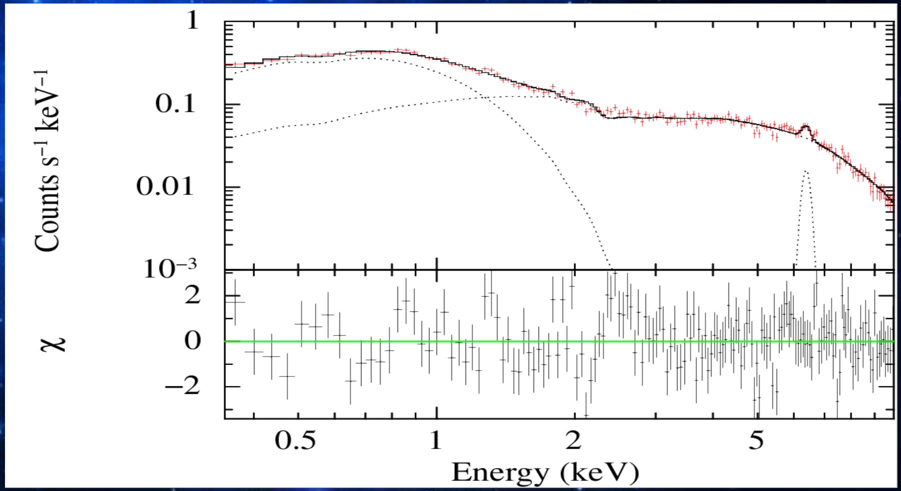
Fe Kα line flux = 2.43×10^{-4}
photons cm^{-2} sec^{-1}
Eqv width: 78.51 eV

Fe Kα line flux = 0.57×10^{-4}
photons cm^{-2} sec^{-1}
Eqv width: 792.38 eV

SMC X-1: Eclipse vs. Out-of-eclipse







$\Gamma = 0.20$
Flux : 39.84×10^{-11} ergs cm^{-2} sec^{-1}
χ^2 (DOF)= 198.21 (156)

$\Gamma = 0.20$
Flux : 0.52×10^{-11} ergs cm^{-2} sec^{-1}
χ^2 (DOF)= 194.10 (147)

Fe Kα line flux = 0.08×10^{-4} photons cm^{-2} sec^{-1}
Eqv width: 136.75 eV

Fe Kα emission: Eclipse vs Out-of-eclipse

Flux Ratio: O-O-E/E (8-313)
(Min: 4U1700-377, 20-02-2001, Max: LMC X-4, 09-09-2003)

Eclipse

Largest EqW: 2675.58 eV
IGR J17252-3616 (0405640201)

Smallest EqW: 102.40 eV
Cen X-3 (0111010101)

Largest Fe Kα emission flux:

8.79×10^{-4} photons cm^{-2} sec^{-1}
4U 1700-377 (0083280401)

Smallest Fe Kα emission flux:

0.07×10^{-4} photons cm^{-2} sec^{-1}
IGR J16418-4532 (0679810101)

Out-of-eclipse

Largest EqW: 229.73 eV
Cen X-3 (0111010101)

Smallest EqW: 78.51 eV
4U 1538-522 (0152780201)

Largest Fe Kα emission flux:

26.07×10^{-4} photons cm^{-2} sec^{-1}
4U 1700-377 (0083280401)

Smallest Fe Kα emission flux:

1.53×10^{-4} photons cm^{-2} sec^{-1}
LMC X-4 (0203500201)

Fe XXV, Fe XXVI emission lines

Eclipse:

Cen X-3 (0111010101): Fe XXV, Fe XXVI

LMC X-4 (0203500201): Fe XXV

4U 1700-377 (0600950101): Fe XXV, Fe XXVI

4U 1538-522 (0152780201): Fe XXV, Fe XXVI

IGR J17252-3616 (0405640201): Fe XXVI

Out-of-Eclipse:

Cen X-3 (0111010101): Fe XXV, Fe XXVI

Cen X-3: Fe Kα, Fe XXV, Fe XXVI emission lines

Eclipse

Emission flux:
× 10^{-4} photons cm^{-2} sec^{-1}

Fe Kα :	0.88
Fe XXV:	2.13
Fe XXVI:	1.66

EqW: eV

Fe Kα:	102.40
Fe XXV:	243.48
Fe XXVI:	208.29

Out-of-eclipse

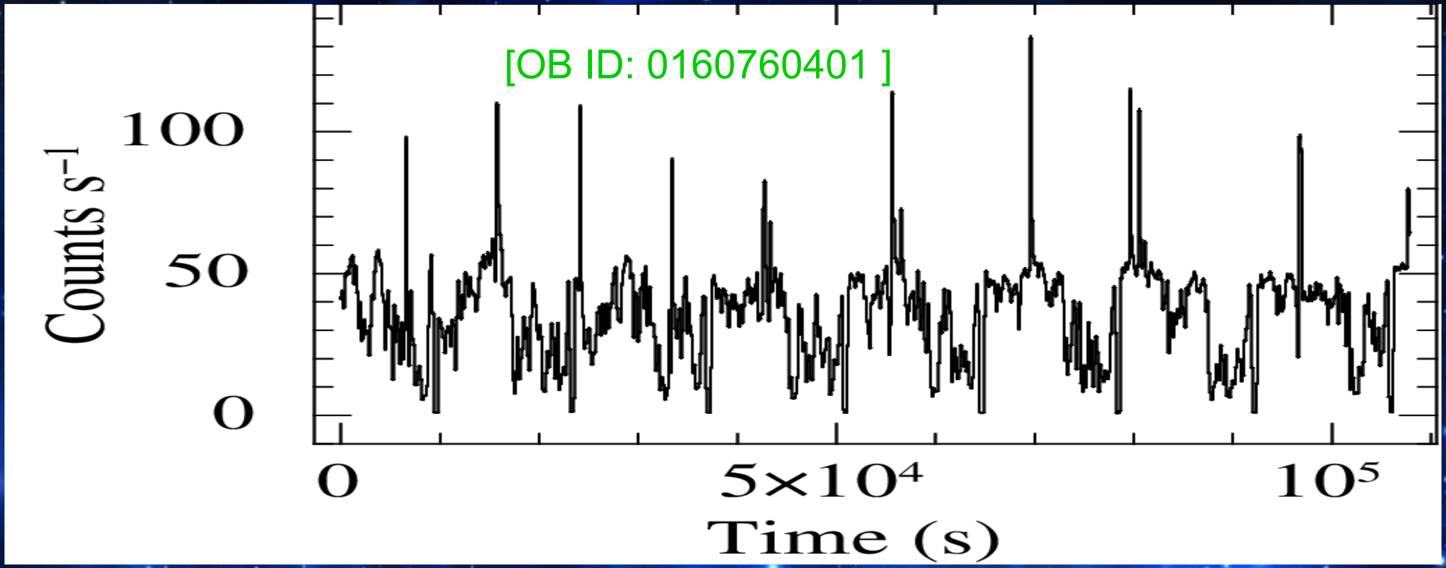
Emission flux:
× 10^{-4} photons cm^{-2} sec^{-1}

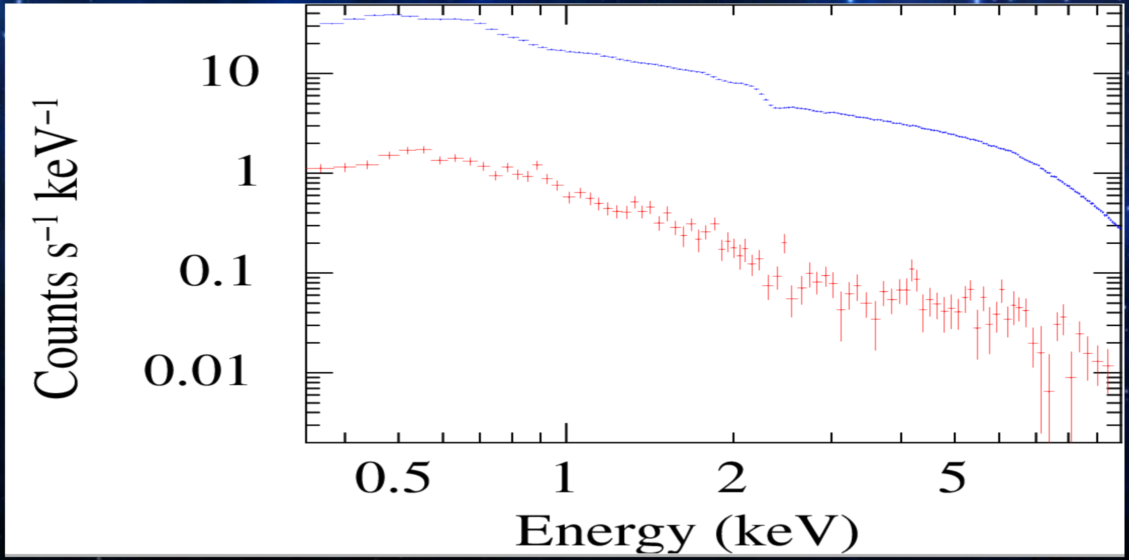
Fe Kα :	17.25
Fe XXV:	11.65
Fe XXVI:	8.75

EqW: eV

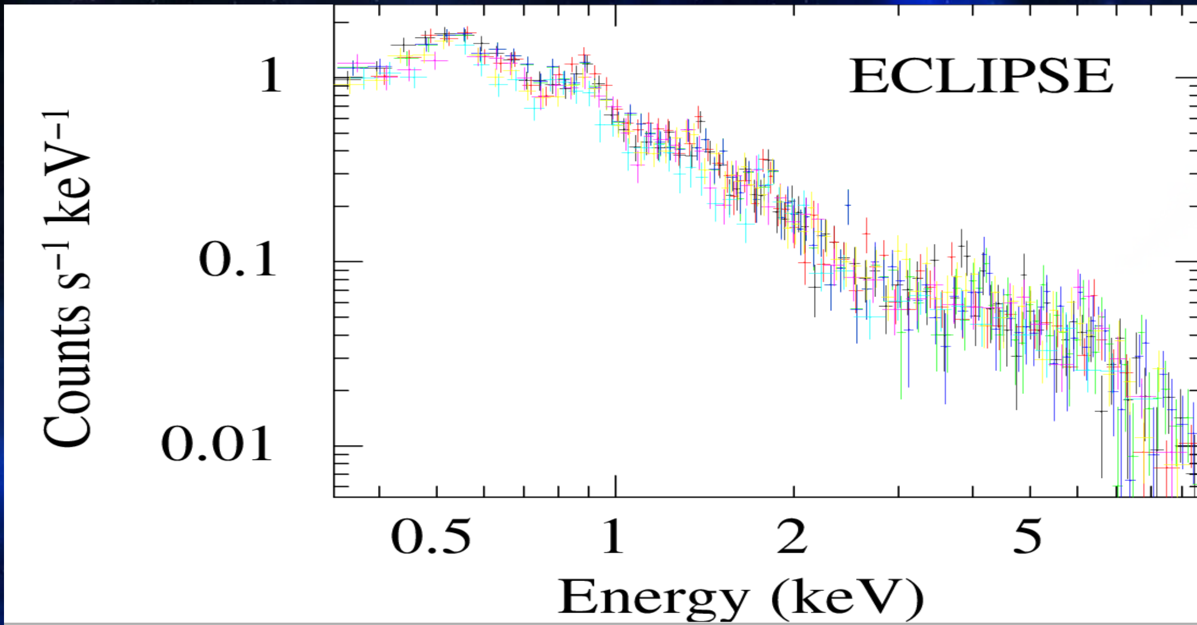
Fe Kα:	229.73
Fe XXV:	133.44
Fe XXVI:	125.56

LMXB: EXO 0748-676



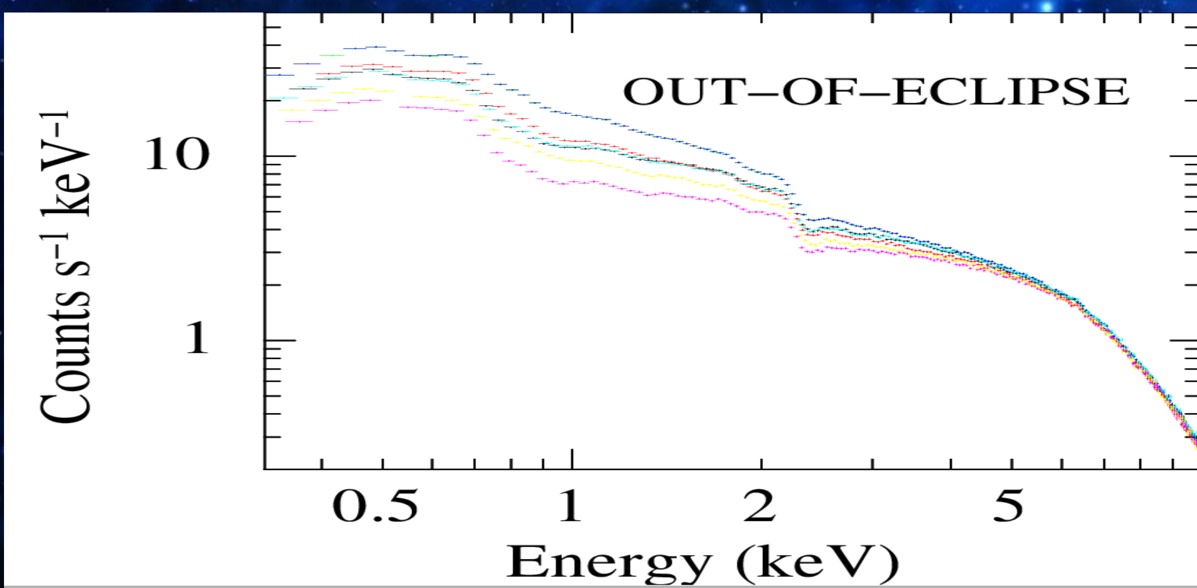


EXO 0748-676: 7 EPIC pn observations



Intesity in the 7 Observations overlaps

Nearly same emission property of the source

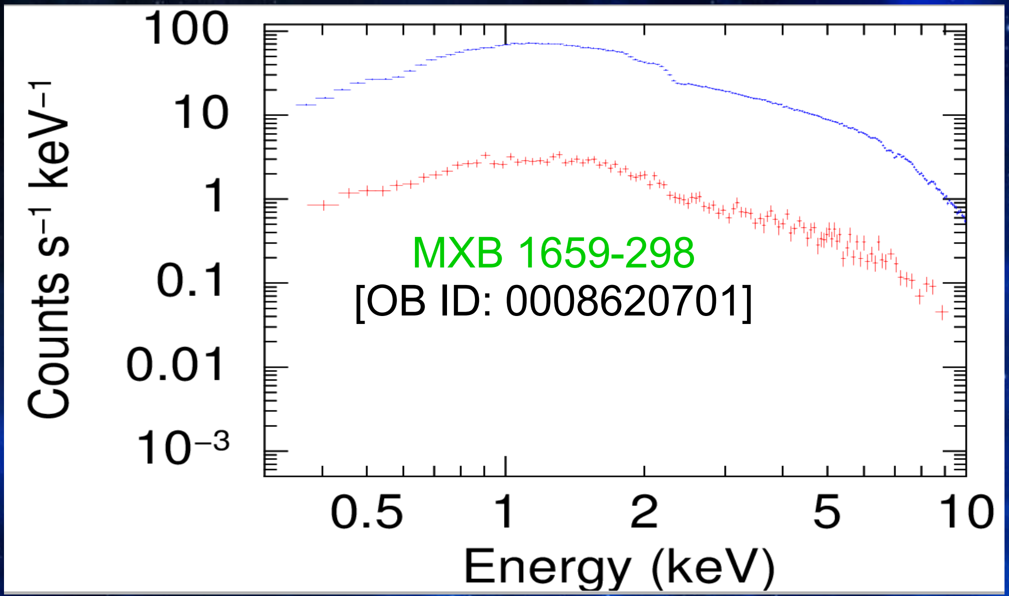


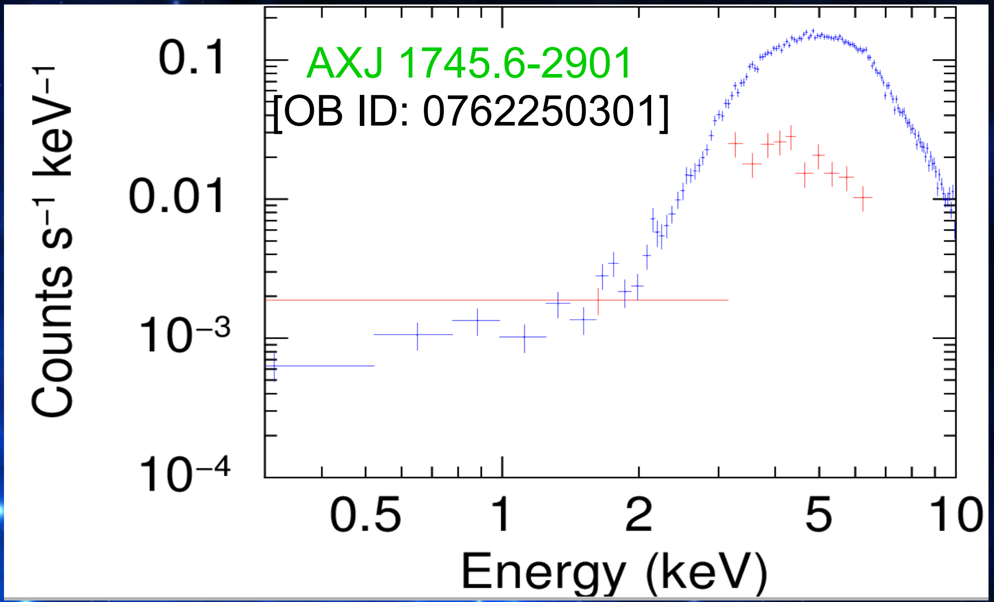
Below 5 keV Intesity varies, above 5 keV overlaps

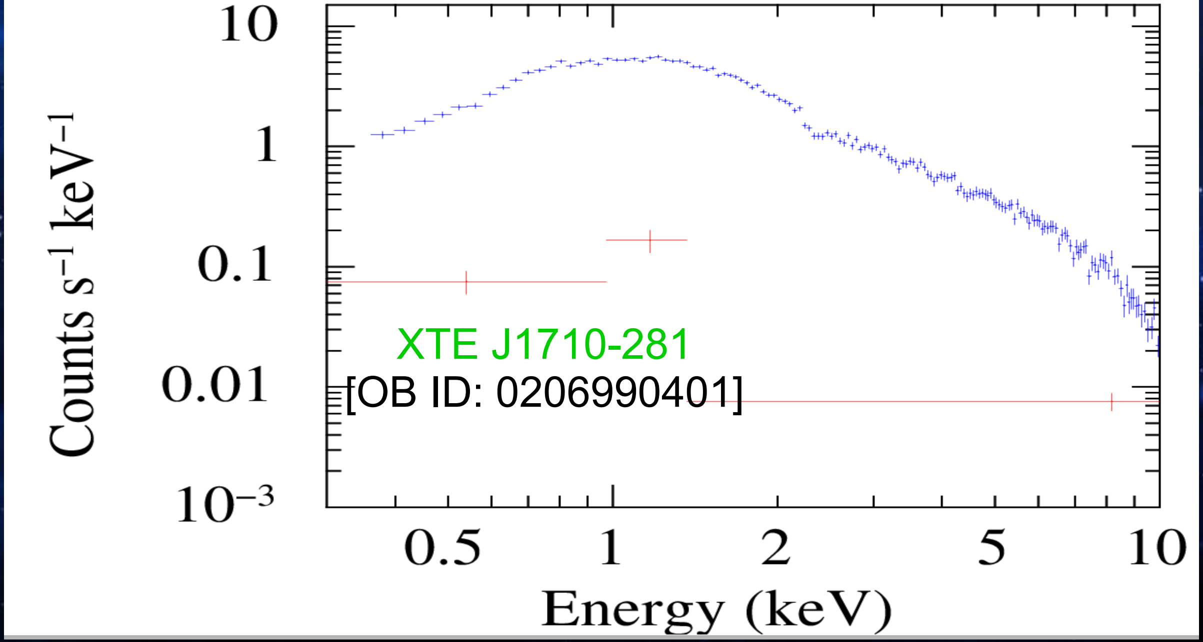
Nearly same harder X-ray reprocessing property

variable soft energy reprocessing property of the accretion disc

LMXB spectra (pn) : during and outside eclipse







Summary

Low intensity states may/may not be off-states

Most of the HMXB environment is rich in neutral Fe atom: except SMC X-1

Cen X-3: Most of the neutral/less ionized Fe atoms are along or around the line of sight and highly ionized Fe atoms are far away

4U 1538-522: Origin of the soft X-rays are far away from the NS

LMXB EXO 0748-676: The part of the disc absorbing low energy X-rays varies over 2 months, source emission properties are nearly same

LMXB XTE J1710-281: very small accretion disc


Thanks a lot .....
To the Designer of the beautiful cosmos and to all of you.