Timing and Spectral studies of the Ultra-compact Binary **4U 1626-67**

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Motivation for this work

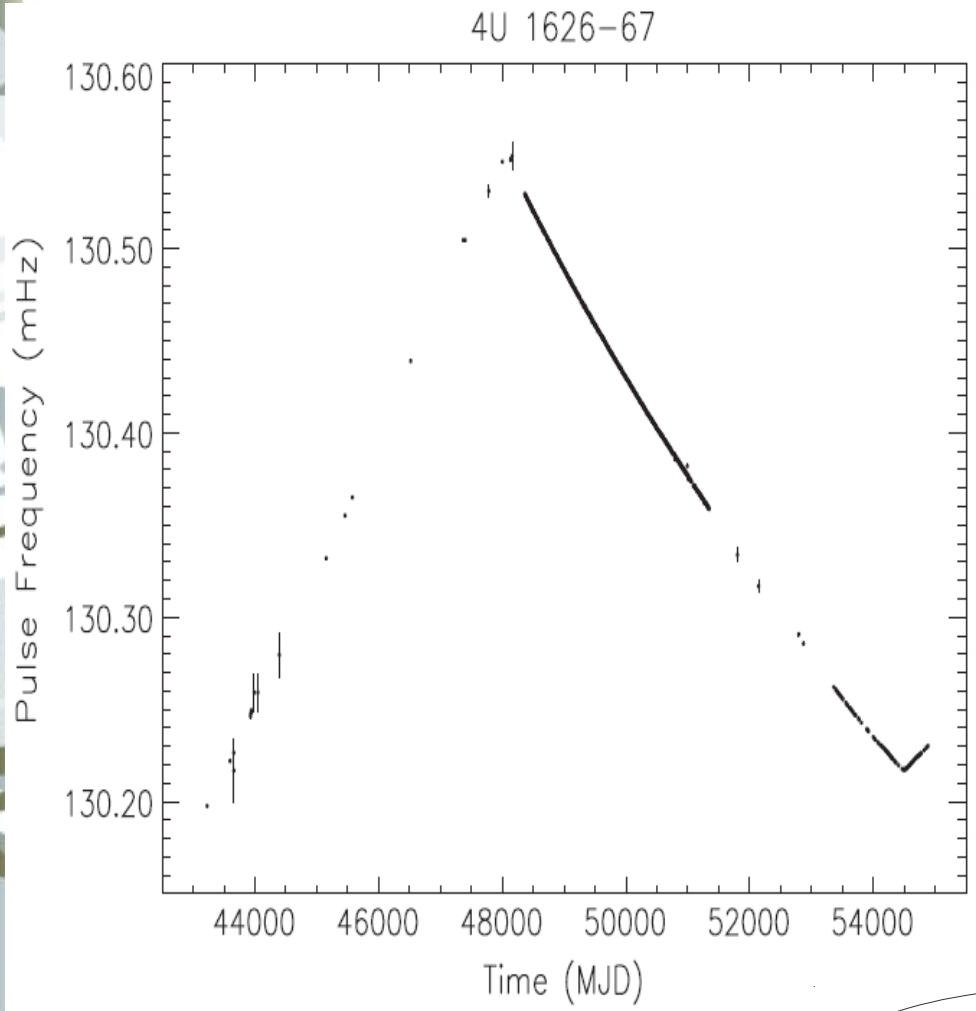
- **X-ray luminosity (mass accretion rate) is not the sole deciding factor in accretion torque.**
- **How the accretion disk couples to the magnetosphere is also important.**
- **Pulse phase dependence of emission line flux: evidence of warped disk.**

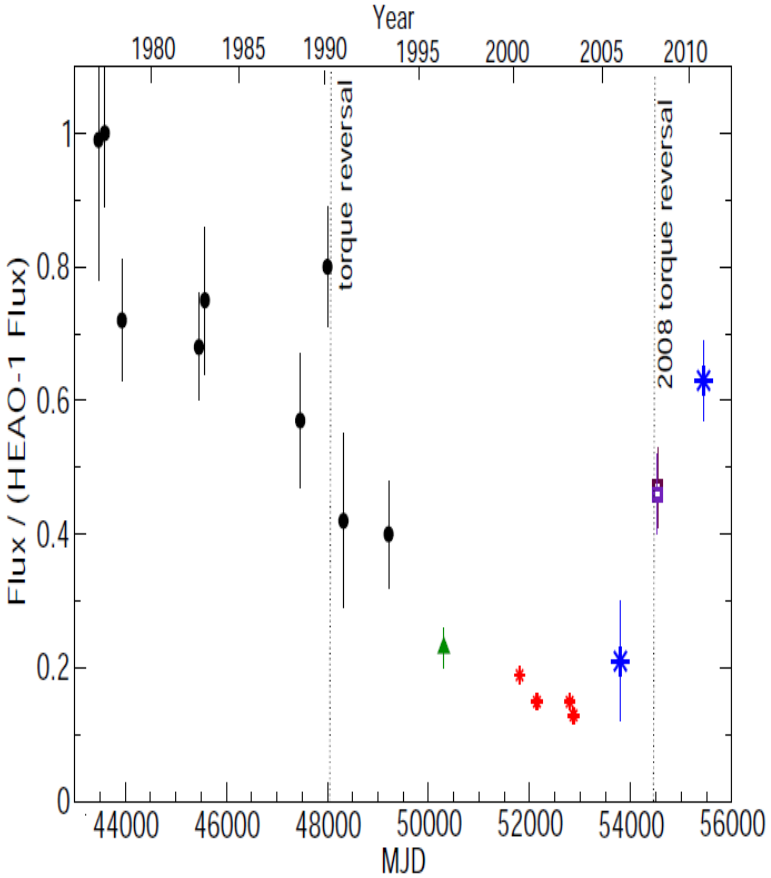
Relation between Torque & Luminosity

Frank King and Raine

$$\dot{\nu} \simeq 2.7 \times 10^{-12}\, m_1^{-3/7}\, R_6^{6/7}\, L_{37}^{6/7}\, \mu_{30}^{2/7}\, I_{45}^{-1}\, \mathrm{Hz\ s^{-1}}$$

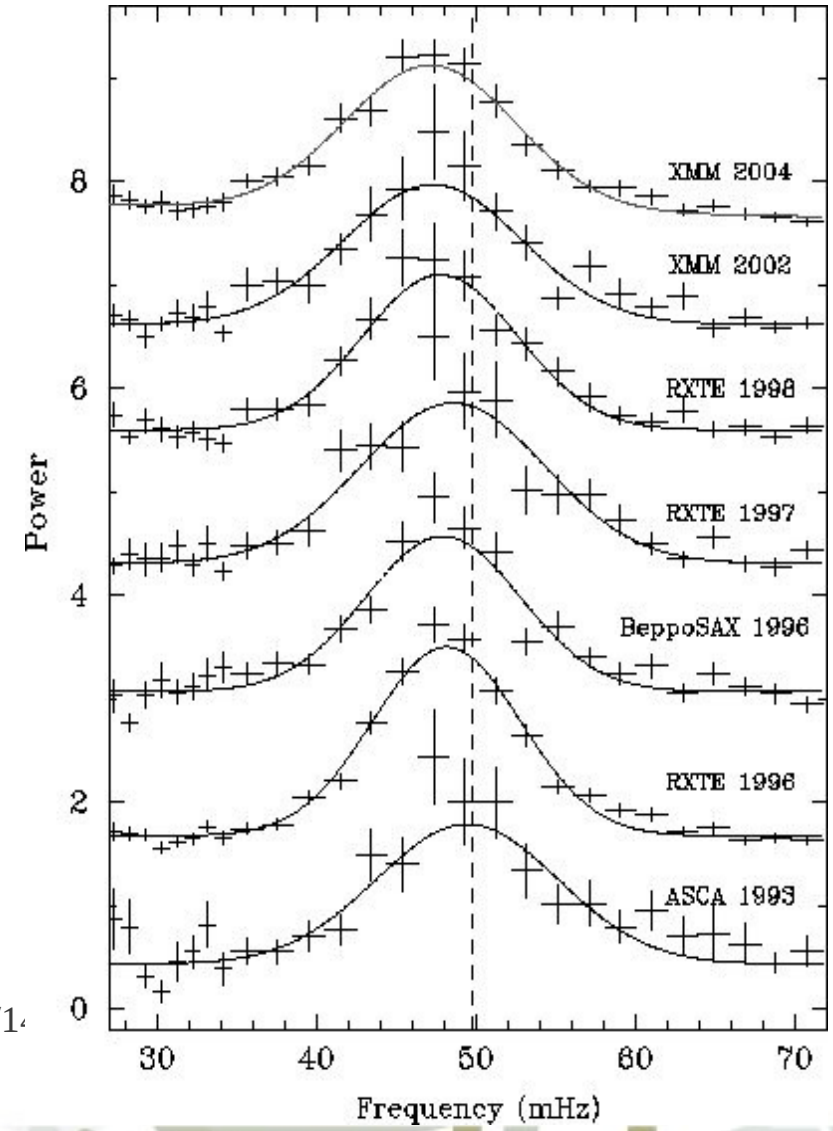
4U 1626-67 : Period and flux evolution

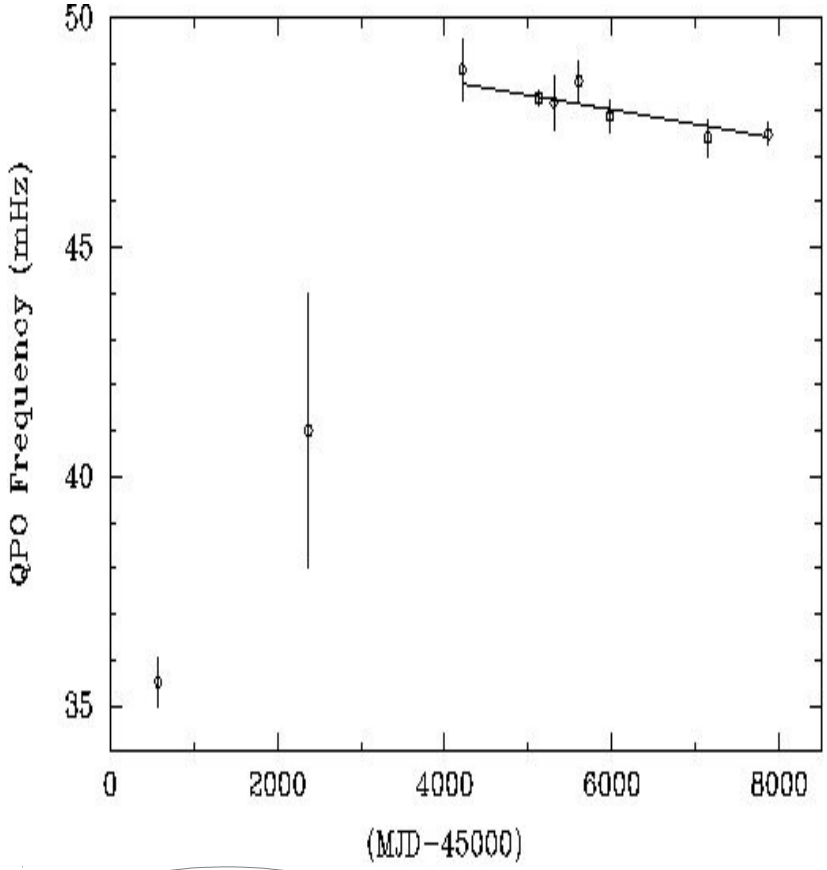




Camero. A. et al. (2012)

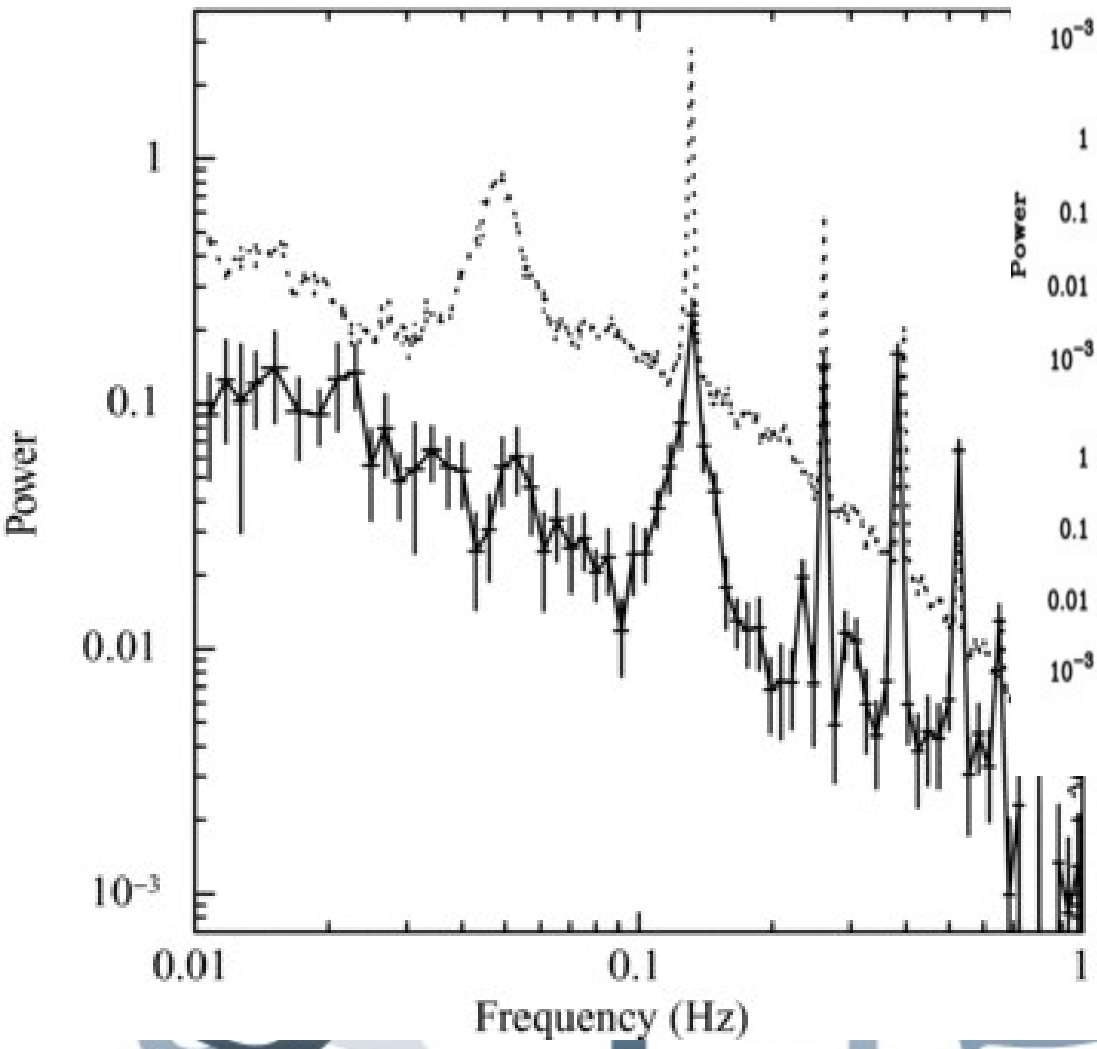
4U 1626-67 : QPO evolution

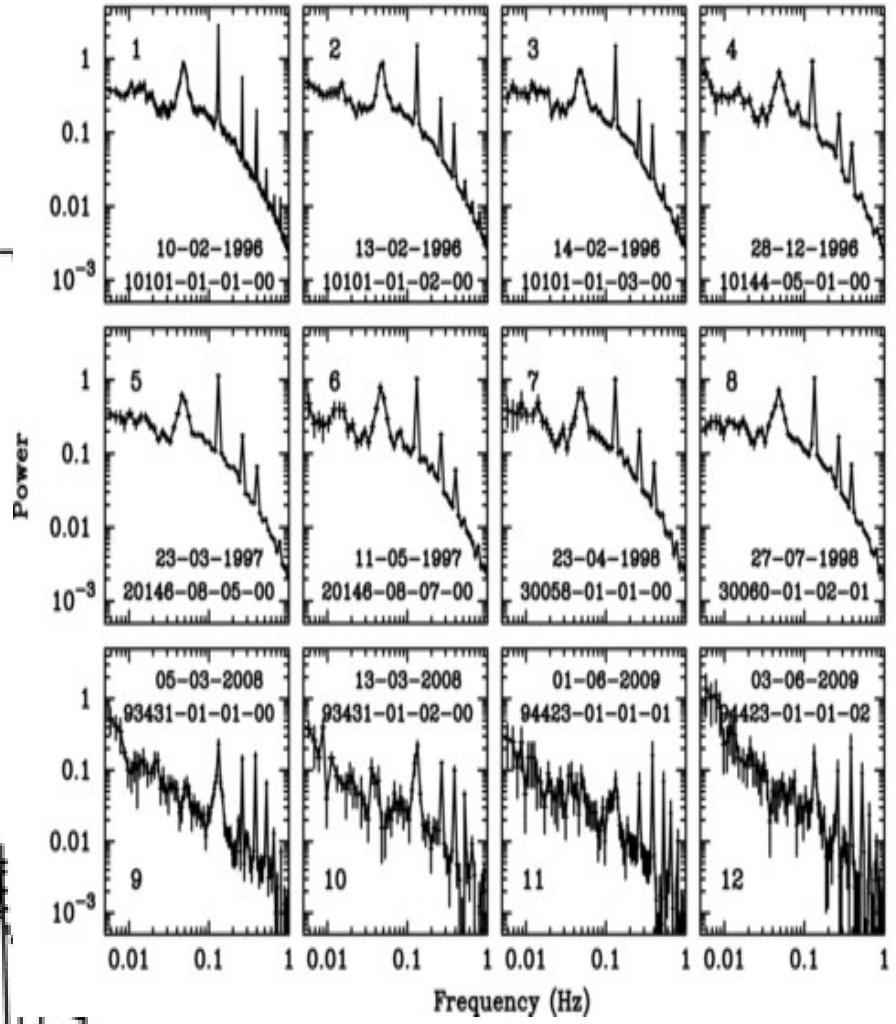




Kaur et al. 2008

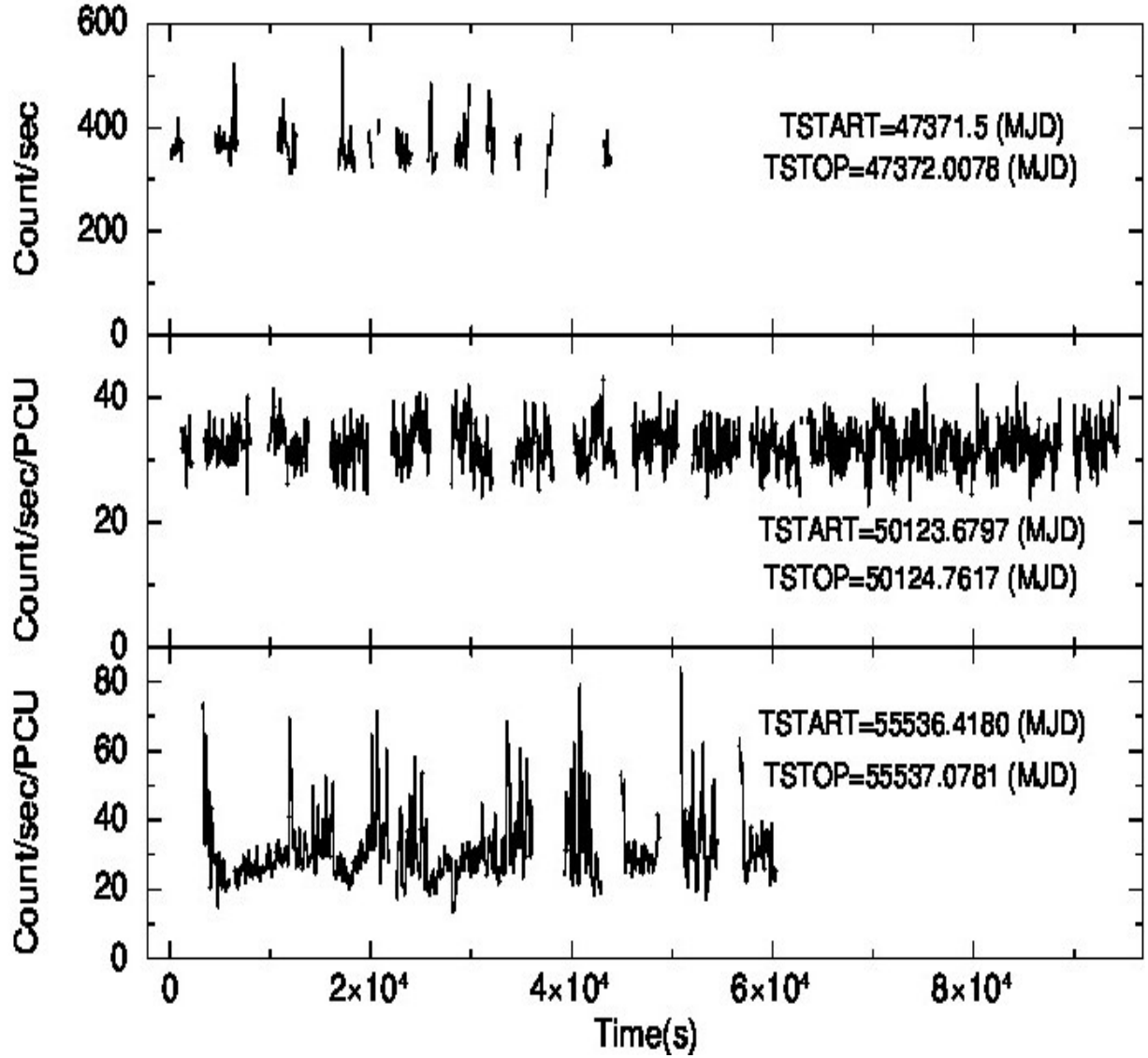
4U 1626-67: Power Spectrum





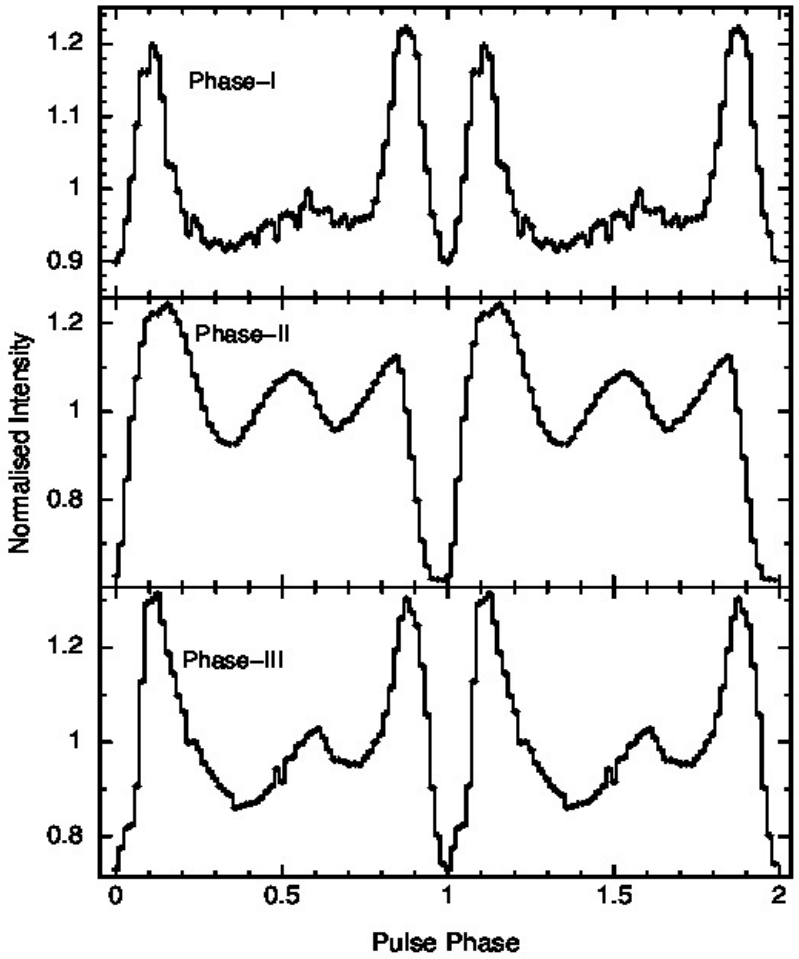
Jain et al. 2010

4U 1626-67: Light Curves



Beri et al. (2014)

Average Pulse Profiles



Remarkable difference in the Pulse Profile during spin-down phase (Phase-II).

Beri et al. (2014)

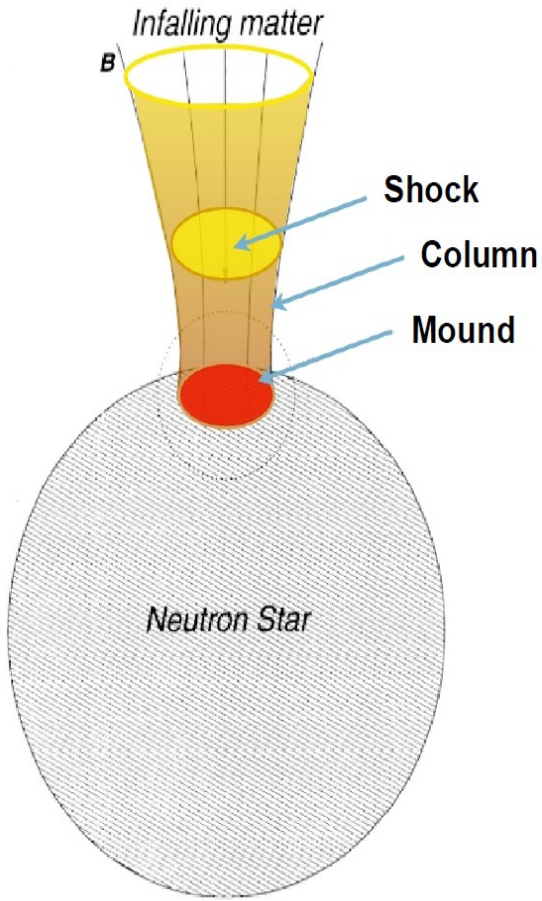
Pulse Profiles and Energy Dependence

The accreted material is threaded onto the magnetic field lines, energy is released as X-rays from the magnetic poles.

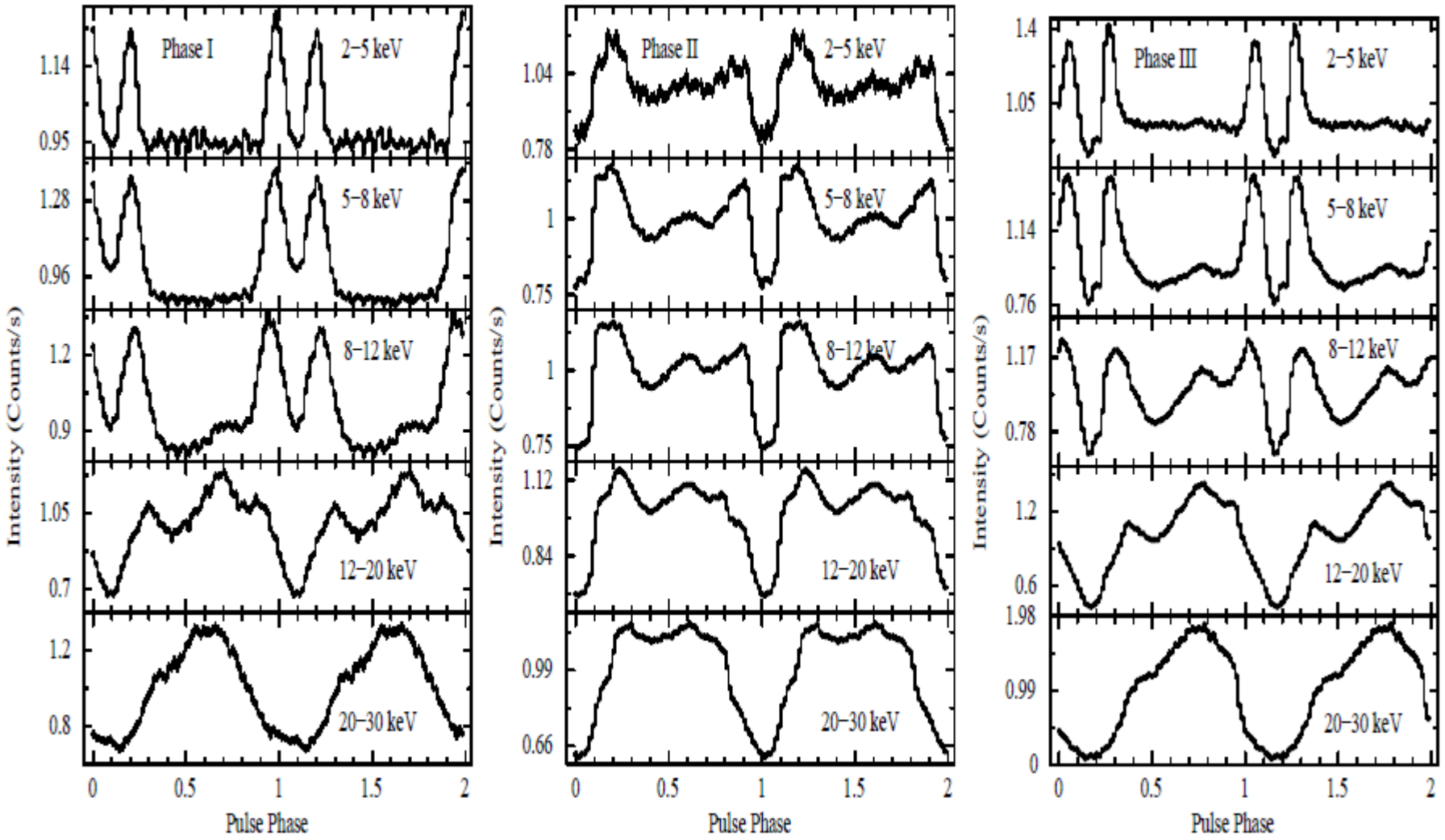
Shape of the pulse profile is modified by absorption & scattering & light bending.

General trend of high energy pulses to have simpler shapes.

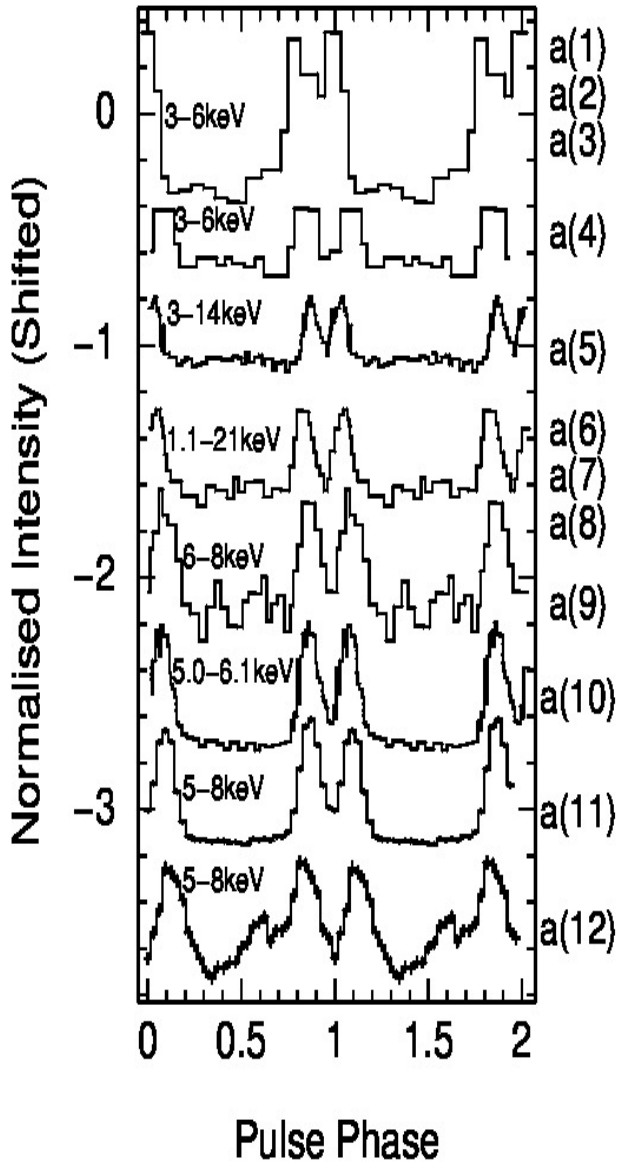
(White, Swank & Holt 1983; Bildsten et al. 1997).

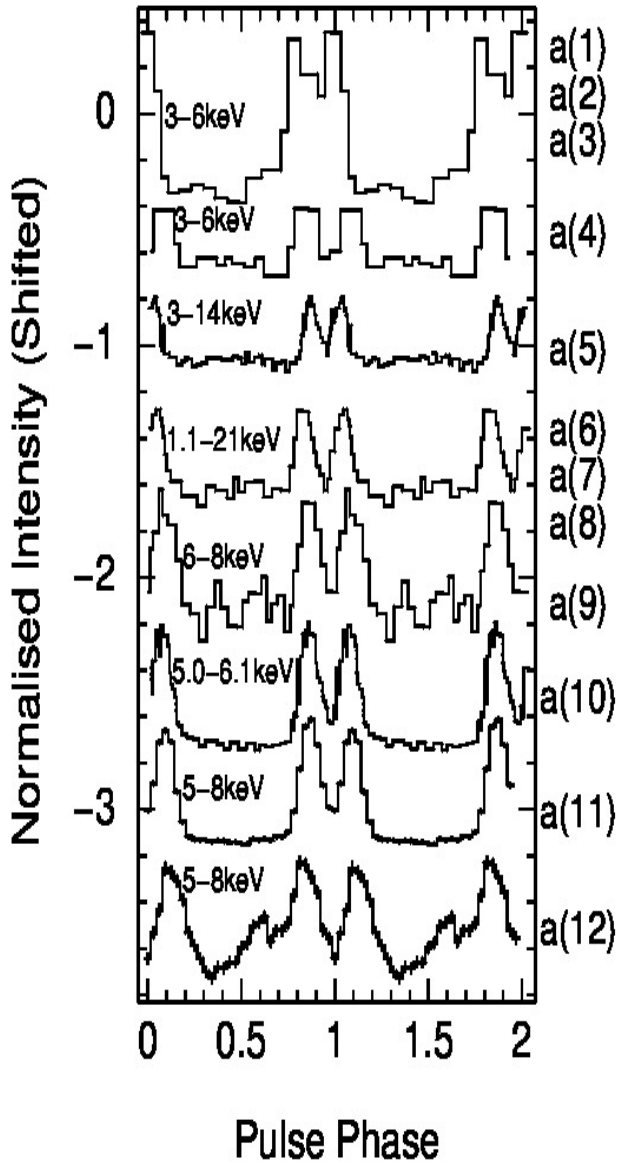


Energy Resolved Pulse Profiles



Phase-I	Phase-II	Phase-III
SAS-3	**ASCA-(GIS)**	**RXTE-(PCA)**
HEAO-1	**RXTE-(PCA)**	**RXTE-(PCA)**
HEAO-2	**BeppoSAX-(Mecs)**	**RXTE-(PCA)**
Tenma	**XMM-(PN)**	**RXTE-(PCA)**
Exosat	**Swift-(XRT)**	**RXTE-(PCA)**
Ginga	**Suzaku-(XIS)**	**RXTE-(PCA)**


Normalised Intensity (Shifted)
0
−1
−2
−3
3–6keV
3–6keV
3–14keV
1.1–21keV
6–8keV
5.0–6.1keV
5–8keV
5–8keV
a(1)
a(2)
a(3)
a(4)
a(5)
a(6)
a(7)
a(8)
a(9)
a(10)
a(11)
a(12)
0
0.5
1
1.5
2
Pulse Phase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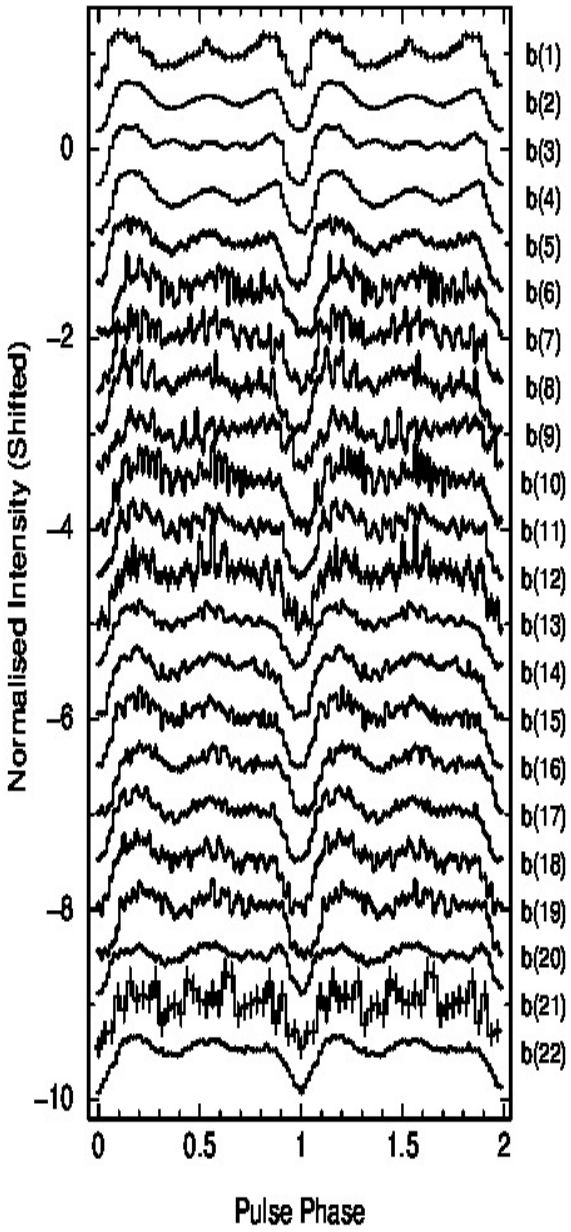
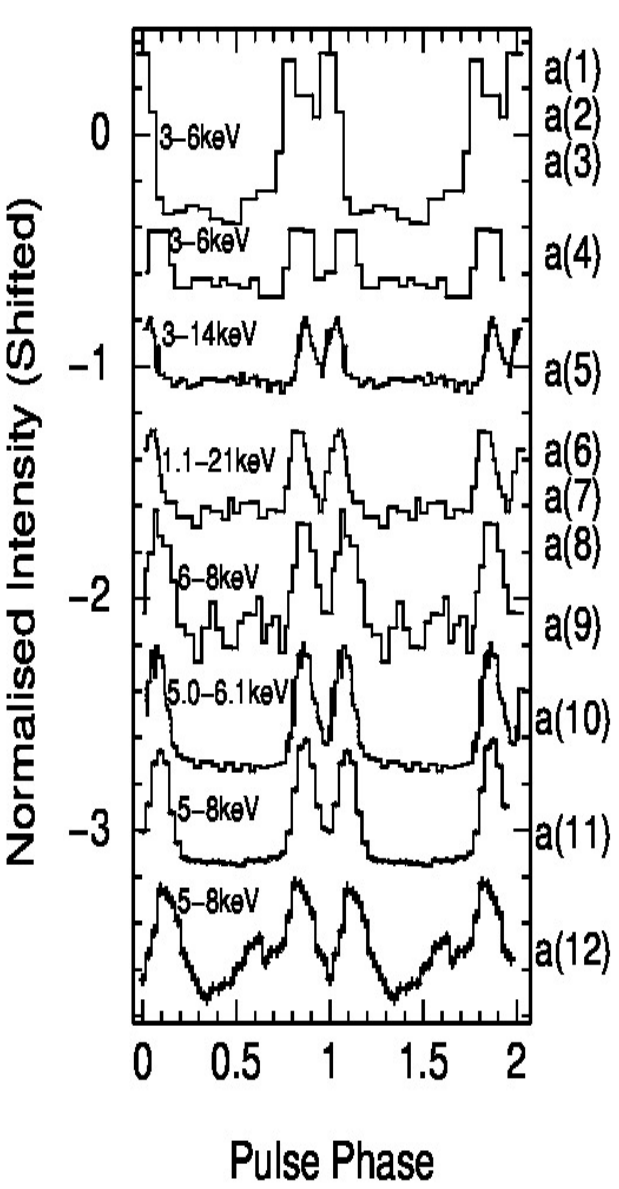
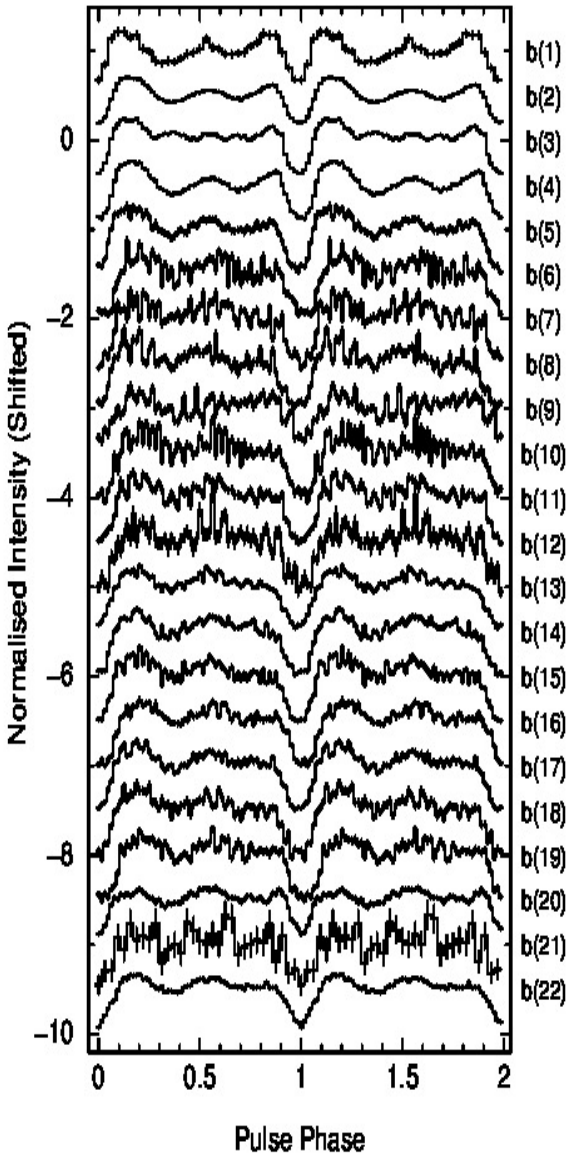
−1
−2
−3
3–6keV
3–6keV
3–14keV
1.1–21keV
6–8keV
5.0–6.1keV
5–8keV
5–8keV
a(1)
a(2)
a(3)
a(4)
a(5)
a(6)
a(7)
a(8)
a(9)
a(10)
a(11)
a(12)
0
0.5
1
1.5
2
Pulse Phase


Normalised Intensity (Shifted)
0
−2
−4
−6
−8
−10
b(1)
b(2)
b(3)
b(4)
b(5)
b(6)
b(7)
b(8)
b(9)
b(10)
b(11)
b(12)
b(13)
b(14)
b(15)
b(16)
b(17)
b(18)
b(19)
b(20)
b(21)
b(22)
0
0.5
1
1.5
2
Pulse Phase


Normalised Intensity (Shifted)
0
−1
−2
−3
3–6keV
3–6keV
3–14keV
1.1–21keV
6–8keV
5.0–6.1keV
5–8keV
5–8keV
a(1)
a(2)
a(3)
a(4)
a(5)
a(6)
a(7)
a(8)
a(9)
a(10)
a(11)
a(12)
0
0.5
1
1.5
2
Pulse Phase


Normalised Intensity (Shifted)
0
−2
−4
−6
−8
−10
b(1)
b(2)
b(3)
b(4)
b(5)
b(6)
b(7)
b(8)
b(9)
b(10)
b(11)
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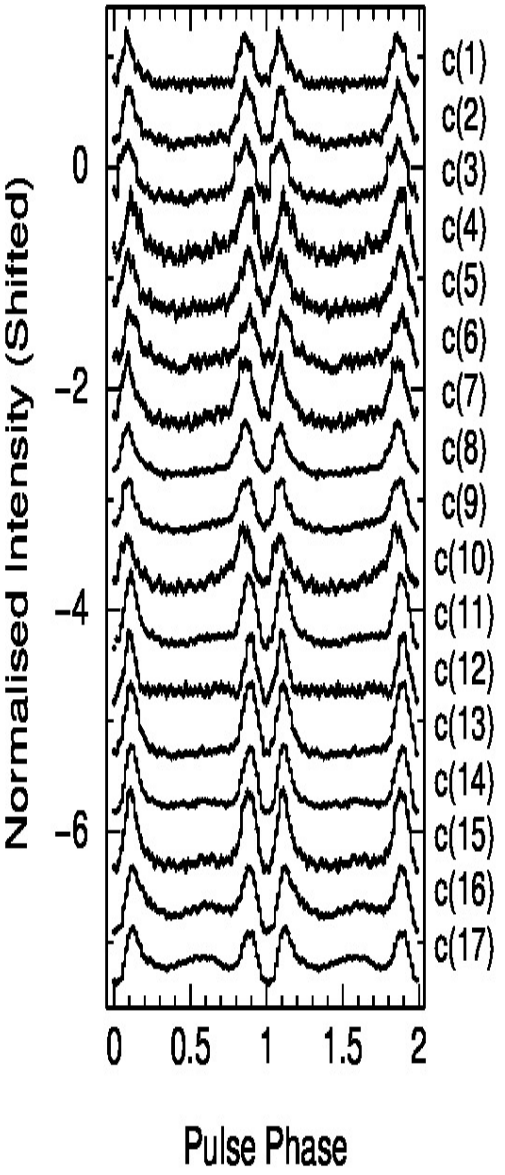
b(14)
b(15)
b(16)
b(17)
b(18)
b(19)
b(20)
b(21)
b(22)
0
0.5
1
1.5
2
Pulse Phase

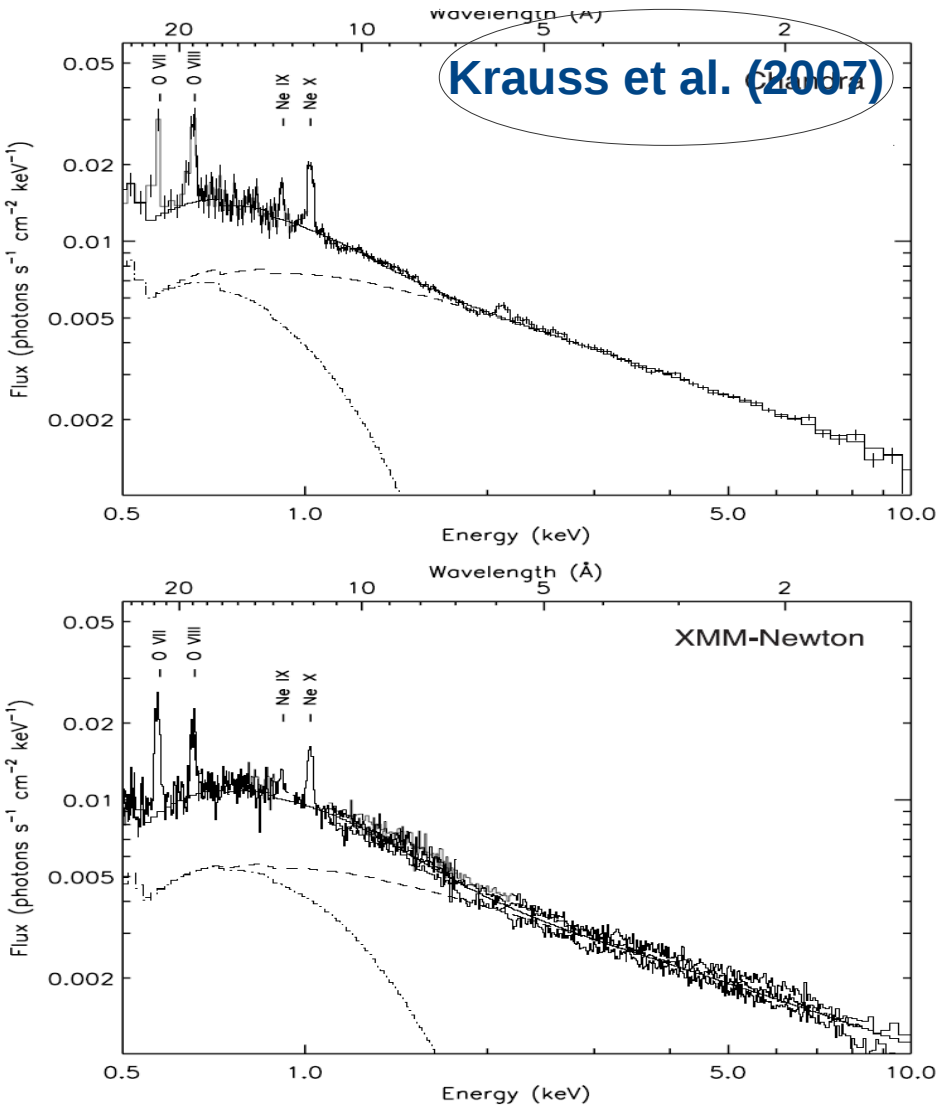

Normalised Intensity (Shifted)
0
−2
−4
−6
c(1)
c(2)
c(3)
c(4)
c(5)
c(6)
c(7)
c(8)
c(9)
c(10)
c(11)
c(12)
c(13)
c(14)
c(15)
c(16)
c(17)
0
0.5
1
1.5
2
Pulse Phase

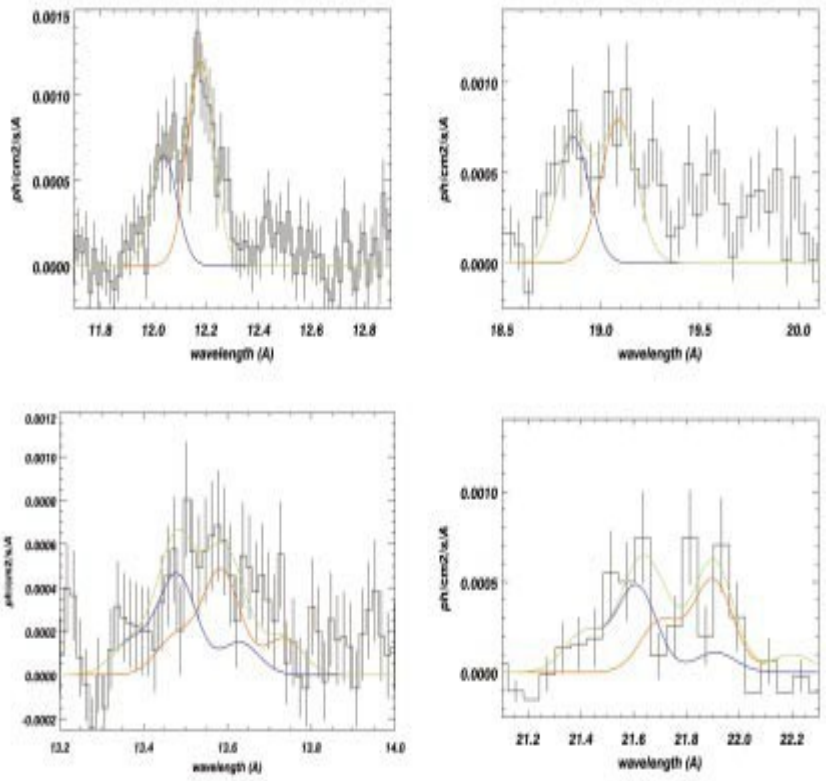
Conclusions from Timing Analysis of 4U 1626-67

- We established a clear correlation between the accretion torque acting on pulsar 4U 1626-67 and its pulse profile.
- Exception to the standard model of accretion torque.
- There may be a change in the accretion mode at the instances of torque reversal.

Beri. A*., Jain, Chetana; Paul, Biswajit; Raichur, Harsha, MNRAS, 2014; 439, 1940.

X-ray Spectrum

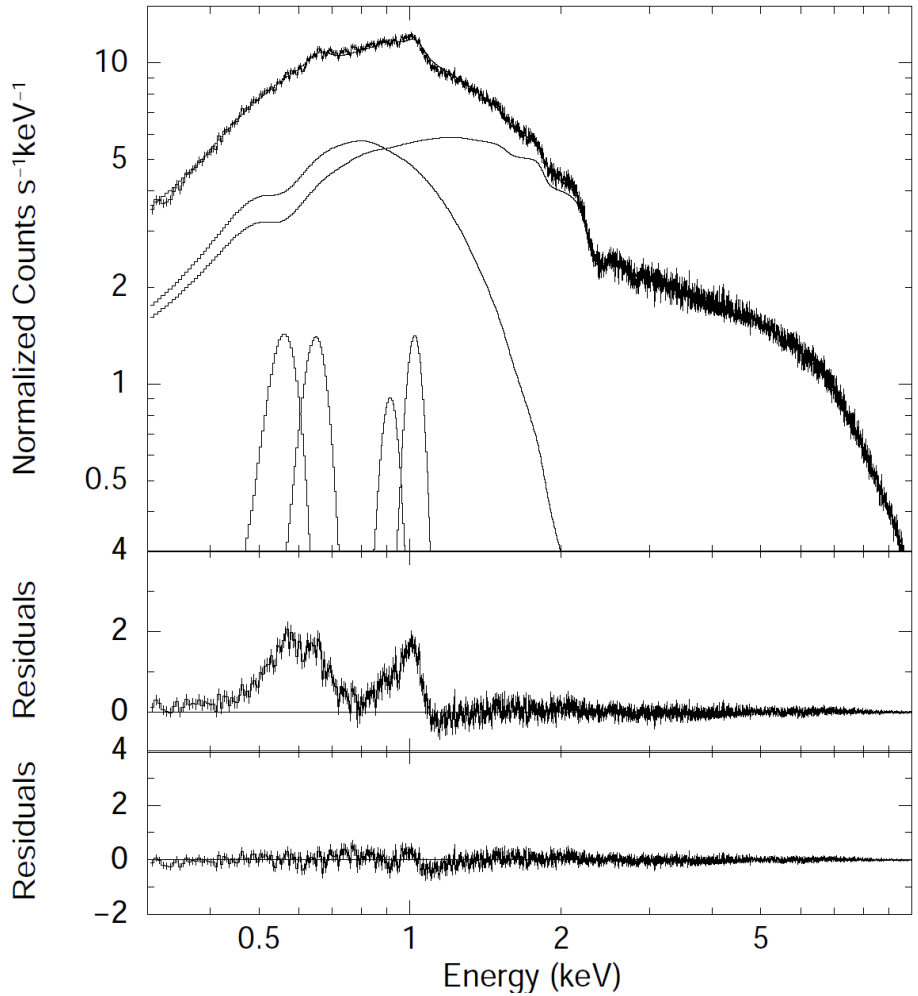




Schulz et al. 2001

Phase Averaged Spectrum : Epic (PN)

Beri et al.



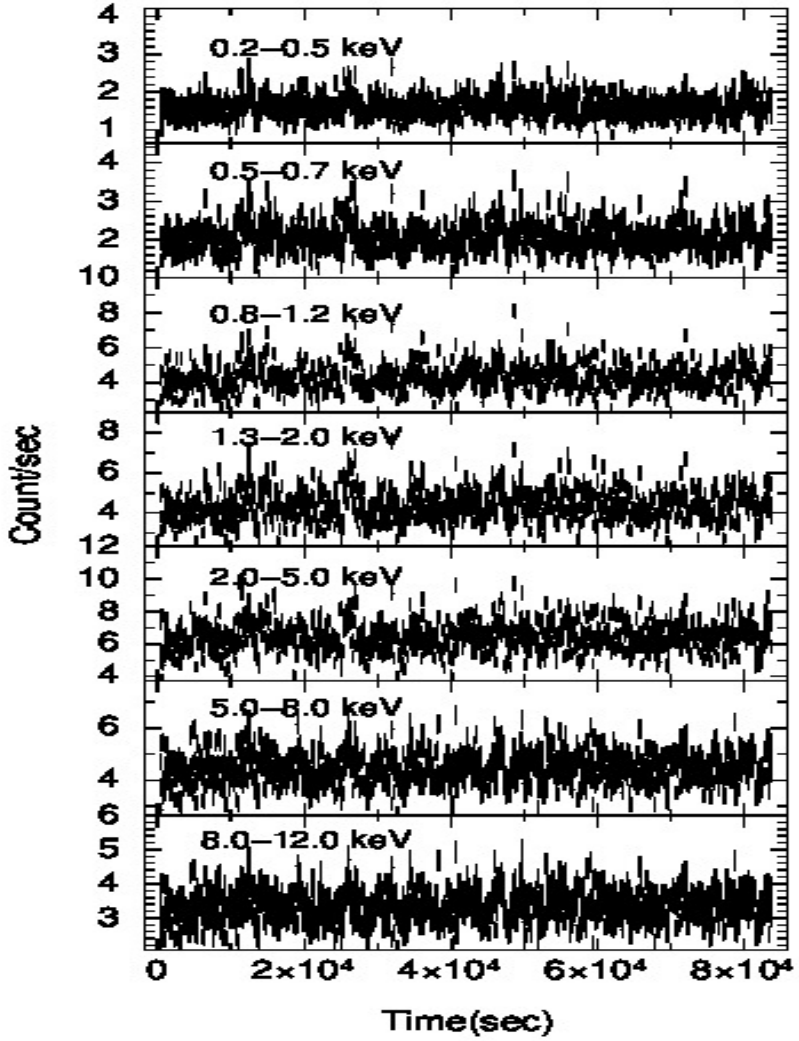
Parameter	Model Values
N_H (10^{22}atoms cm^{-2})	0.102 ± 0.001
PowIndex (Γ)	0.793 ± 0.003
N^a_{PL}	$0.00656 \pm .00004$
BBody (kT) keV	0.229 ± 0.001
N^b_{BB}	441.0 ± 17.9
LineFlux[c]	
O VII (0.568 keV)	6.4 ± 0.1
O VIII (0.653 keV)	3.7 ± 0.1
Ne IX (0.915 keV)	1.36 ± 0.09
Ne X (1.02 keV)	1.88 ± 0.07

Notes: Errors quoted are for the 68 % confidence range.
a → Powerlaw normalisation (N_{PL}) is in units of photons cm^{-2} s^{-1} keV^{-1} at 1 keV
b → Blackbody normalisation (N_{BB}) is in units of photons cm^{-2} s^{-1} keV^{-1}
c → Gaussian normalisation is in units of 10^{-4}photons cm^{-2} s^{-1}

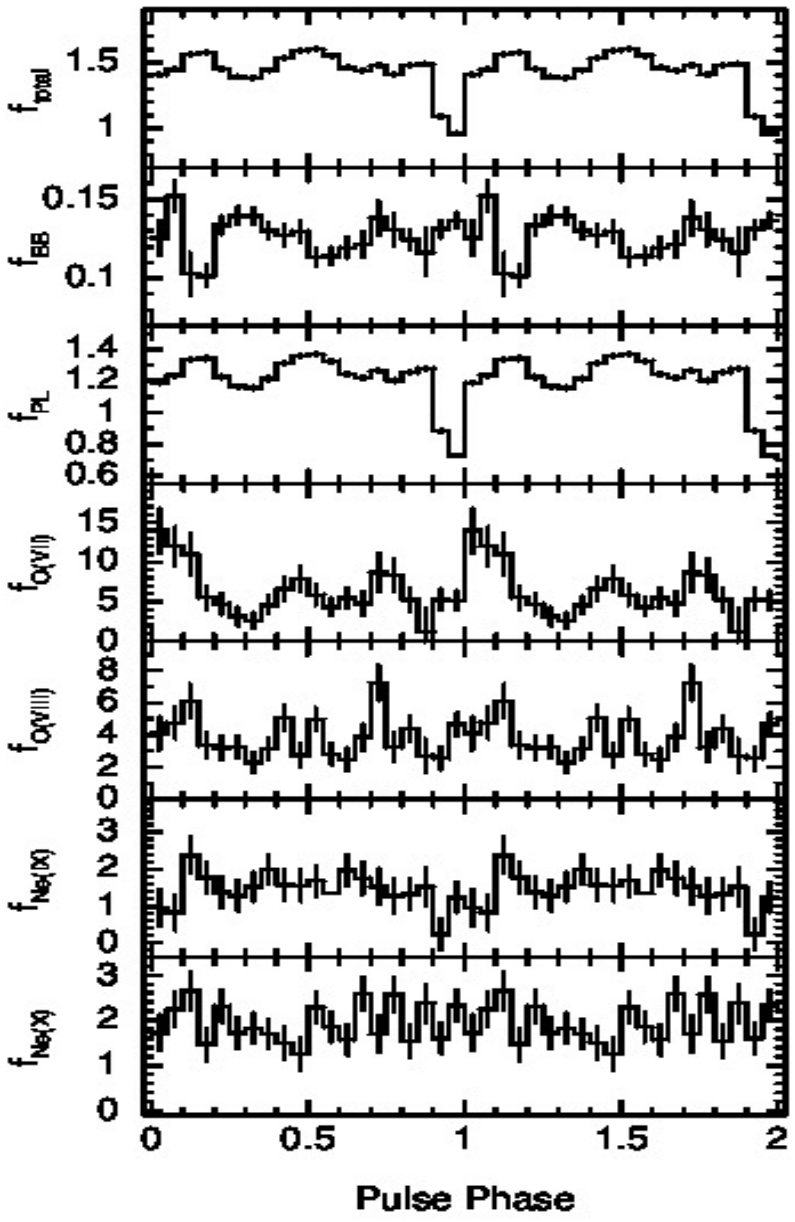
Beri et al. (submitted to MNRAS)

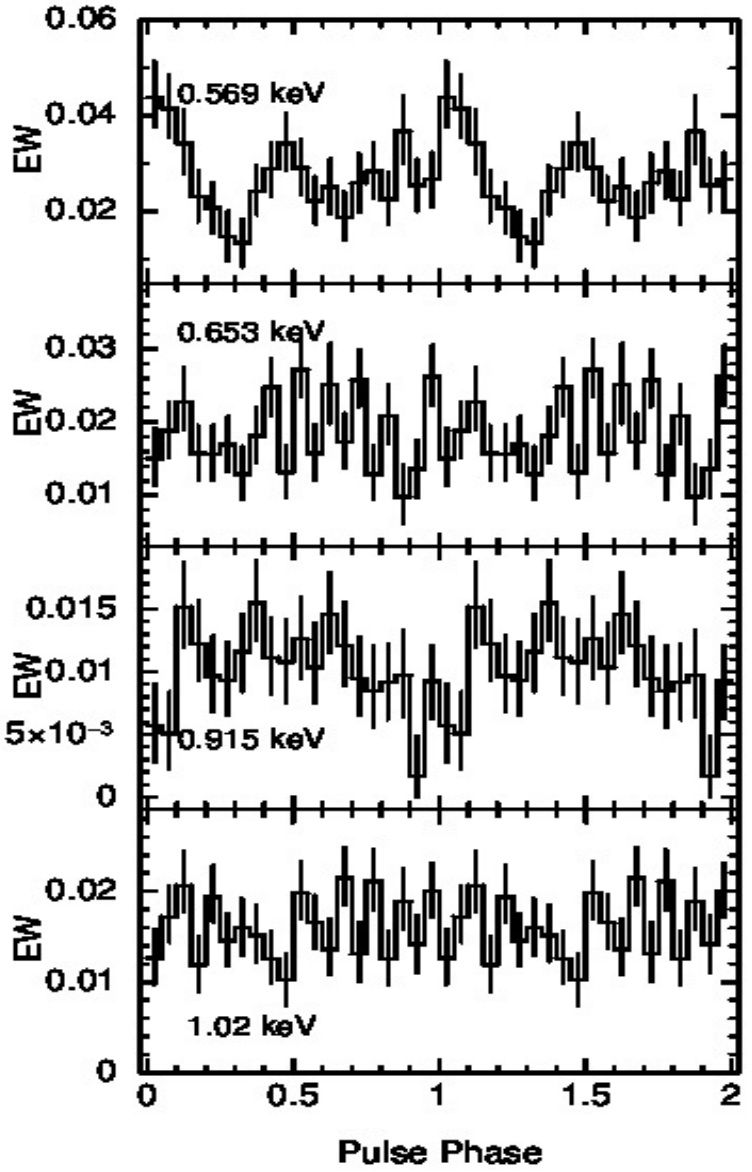
Pulse Phase Resolved Spectroscopy : A tool to probe the geometry of accreton disk

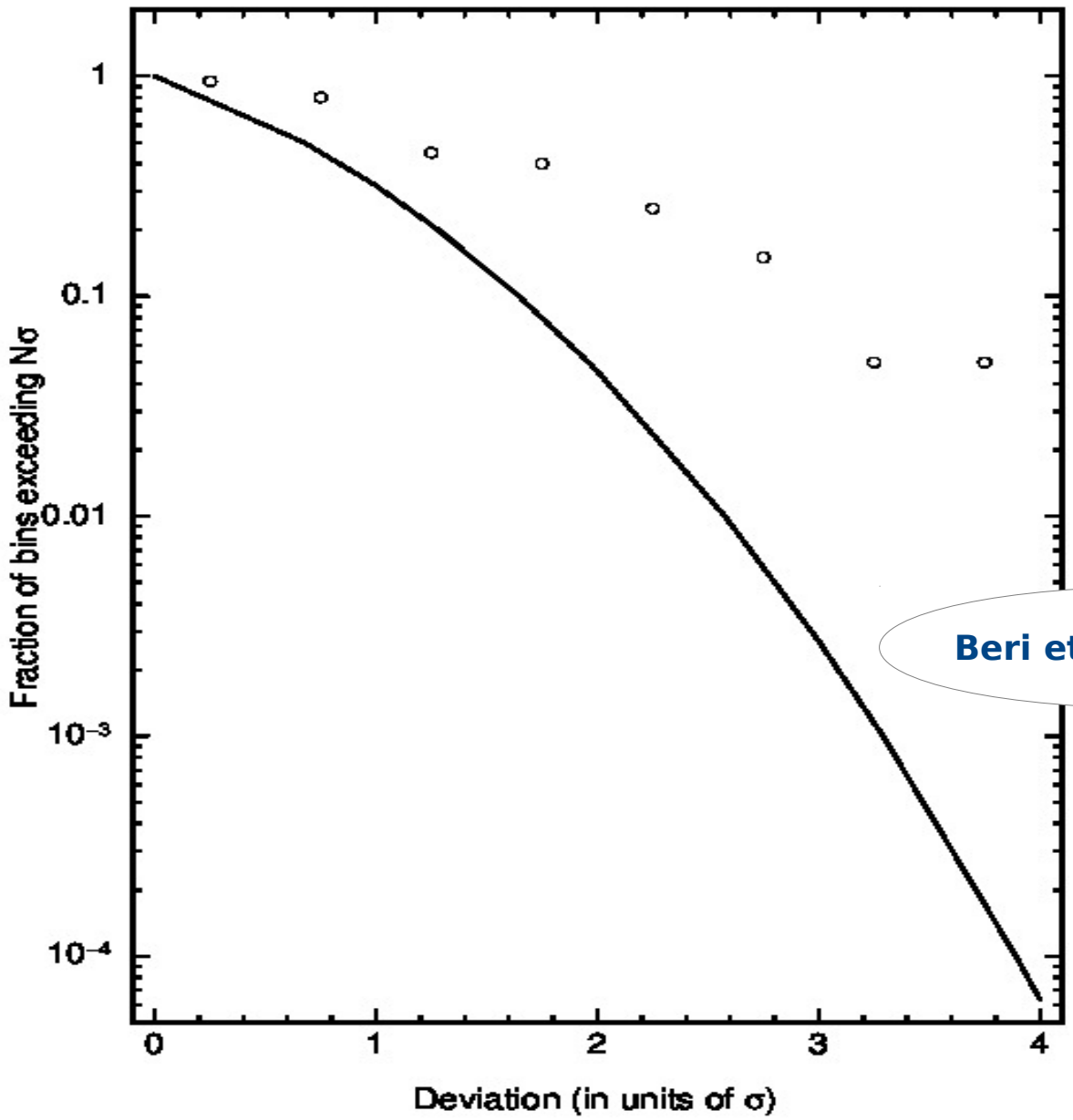
- To start with this, we extracted light curves in narrow energy bands.



Pulse Phase Resolved Spectrum

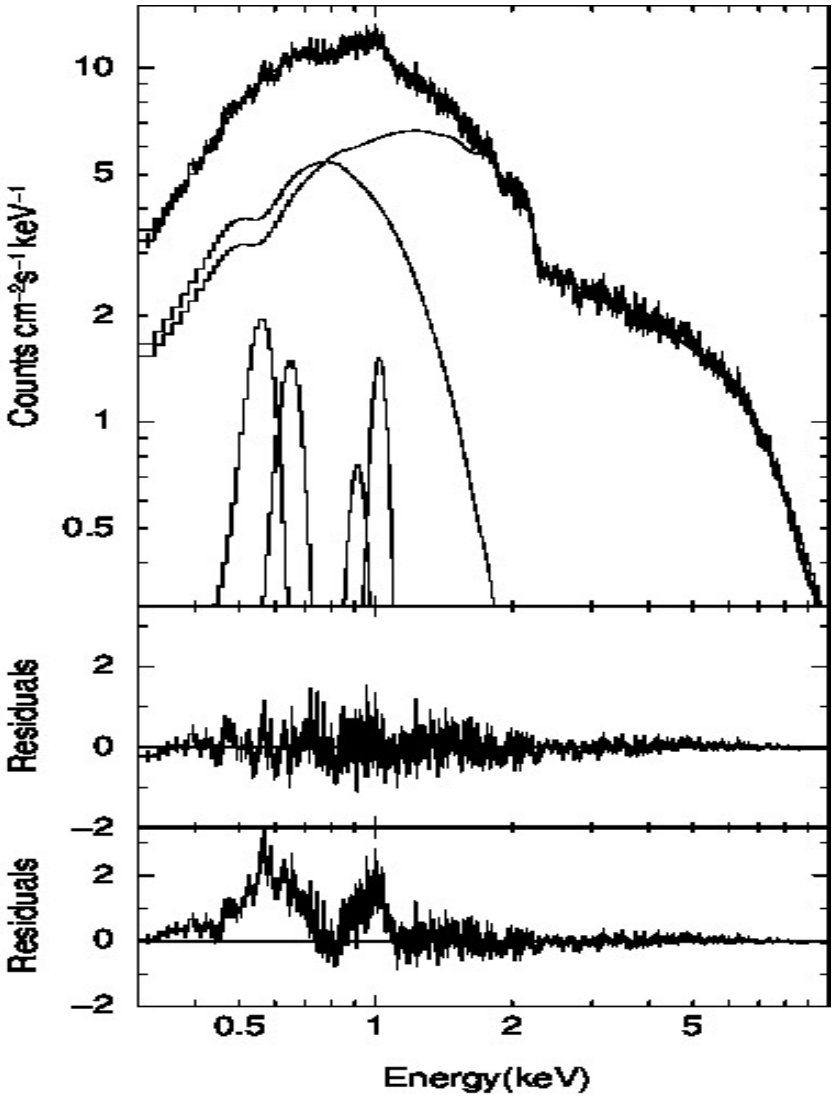


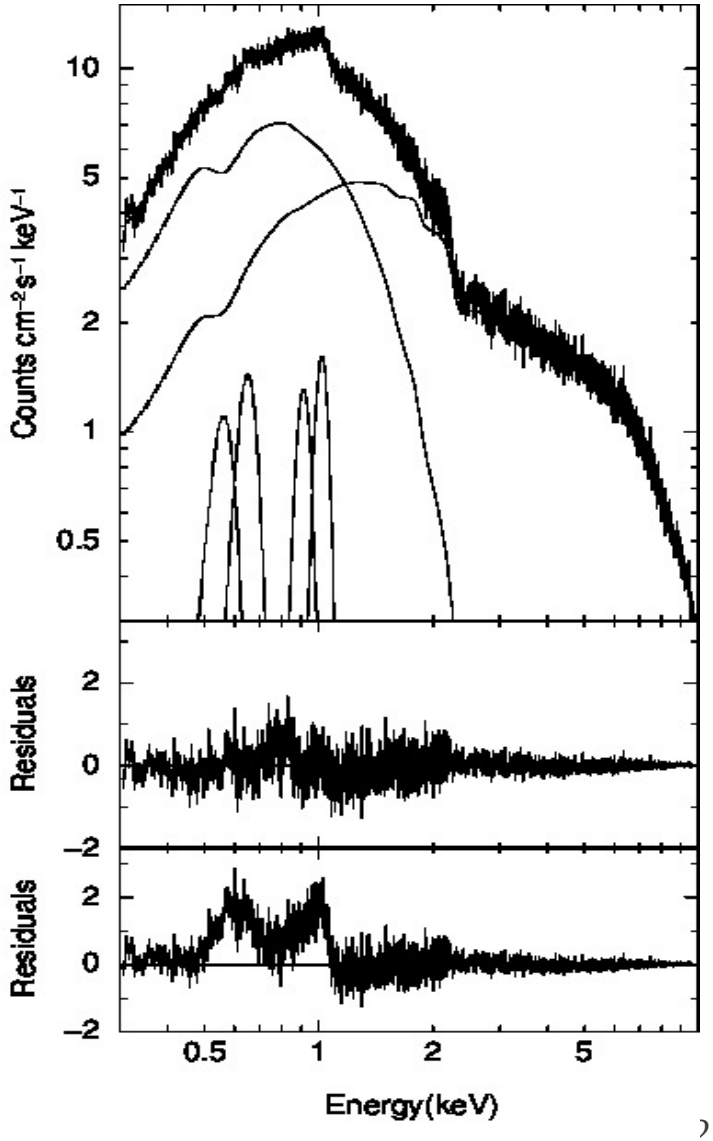




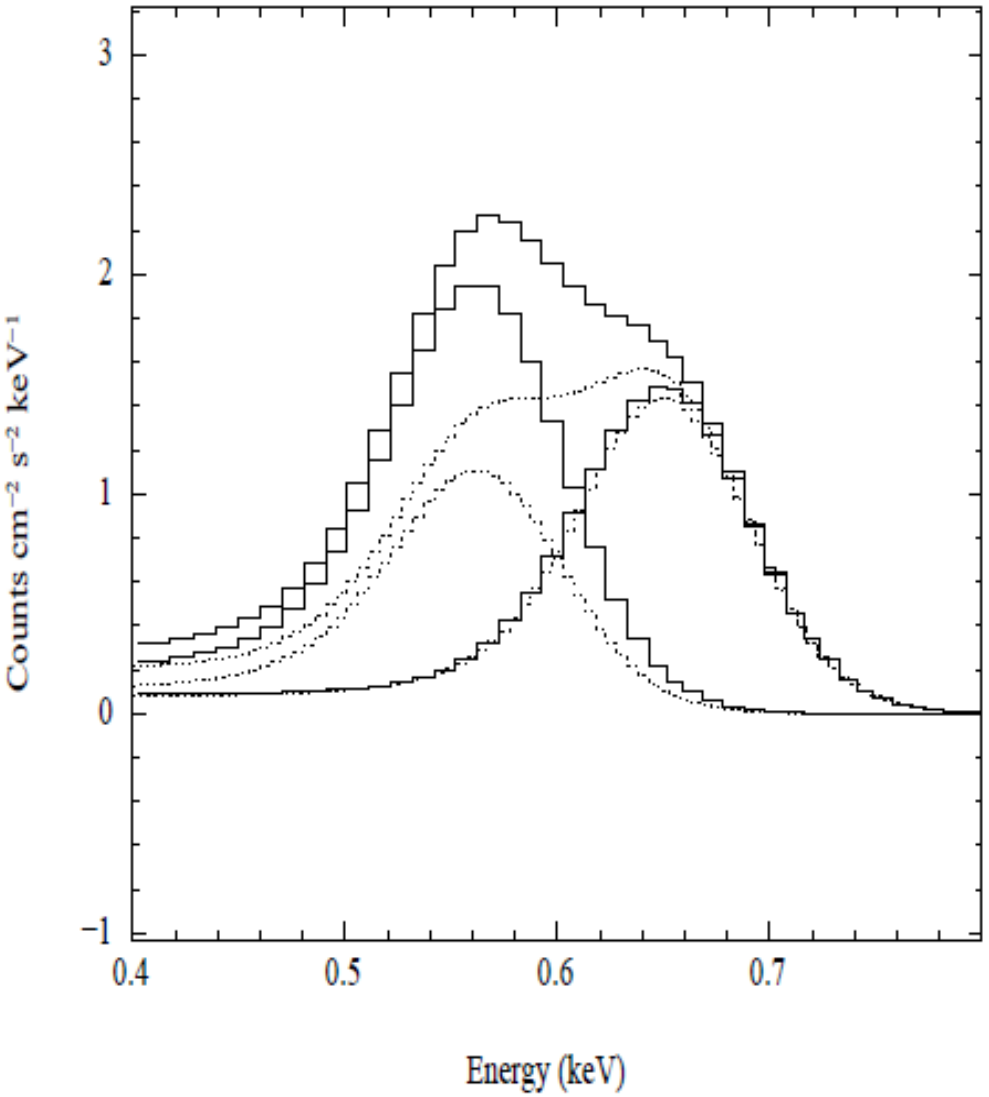
Beri et al. (submitted)

Pulse Phase Resolved Spectrum





Best fit fluxes of the two emission lines at 0.568 keV , 0.653 keV and their sum



- We found strong variation of O VII (0.569 keV) emission line.
- This provides an evidence for a warped accretion disk.
- Observation was in spin-down era , does warp change ? ? ?

Thank you