Low frequency QPOs and Variable Broad Iron line from LMC X-1

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Collaborators

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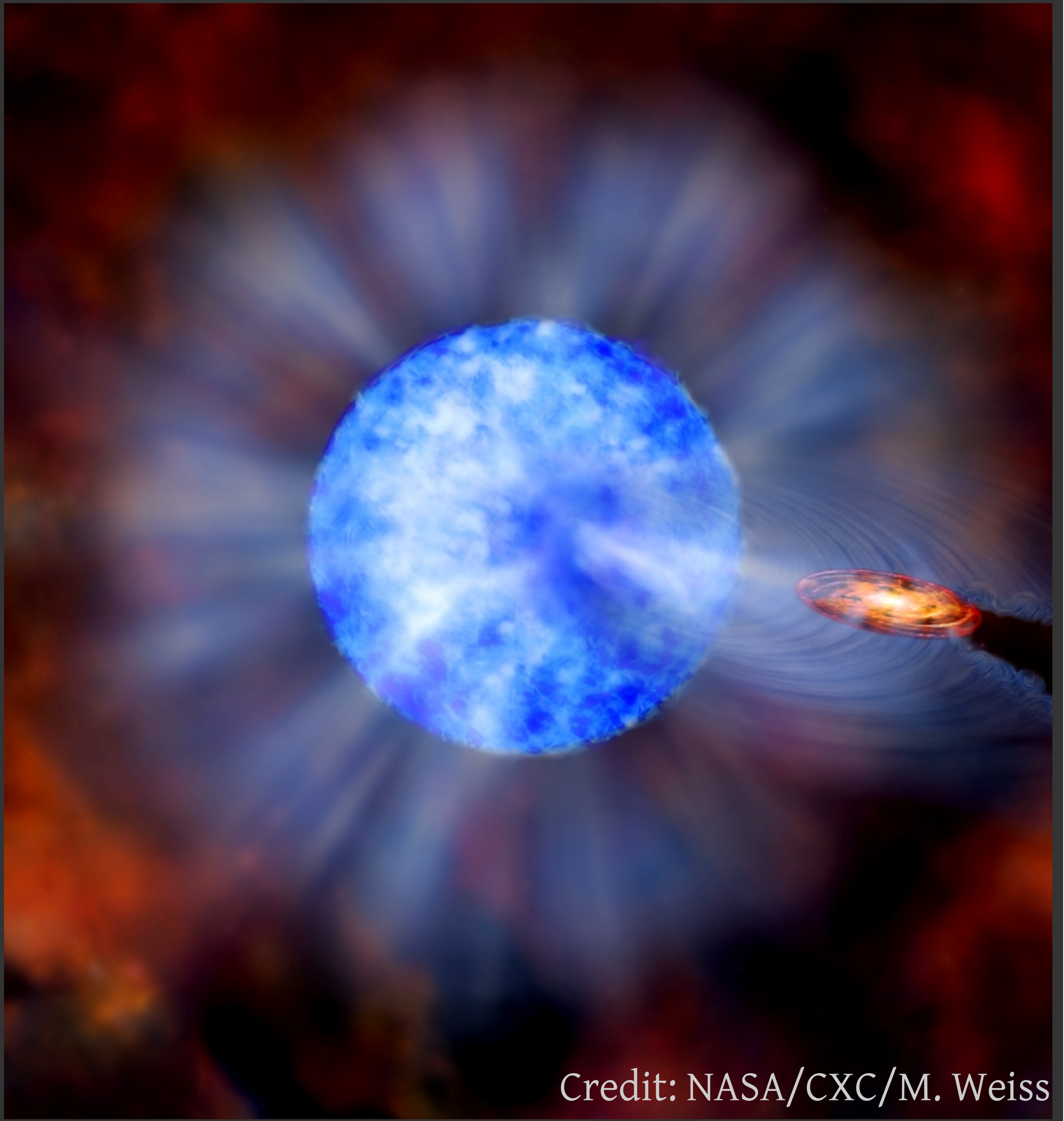
LMC X-1 : Persistent BH XRB

- $10M_\odot$ BH primary & $32M_\odot$ O7 secondary, period ~ 3.9 days, incli. ~ 36.4 deg
- Companion 5Myr past ZAMS, fills ~90% of its Roche lobe (Orosz et al. 2010)
- Wind accretion, L_X/L_{Edd} ~ 16% (Gou et al. 2009)
- 7% modulation in X-ray flux (RXTE/ASM), Thomson scattering in the stellar wind (Orosz et al. 2010)



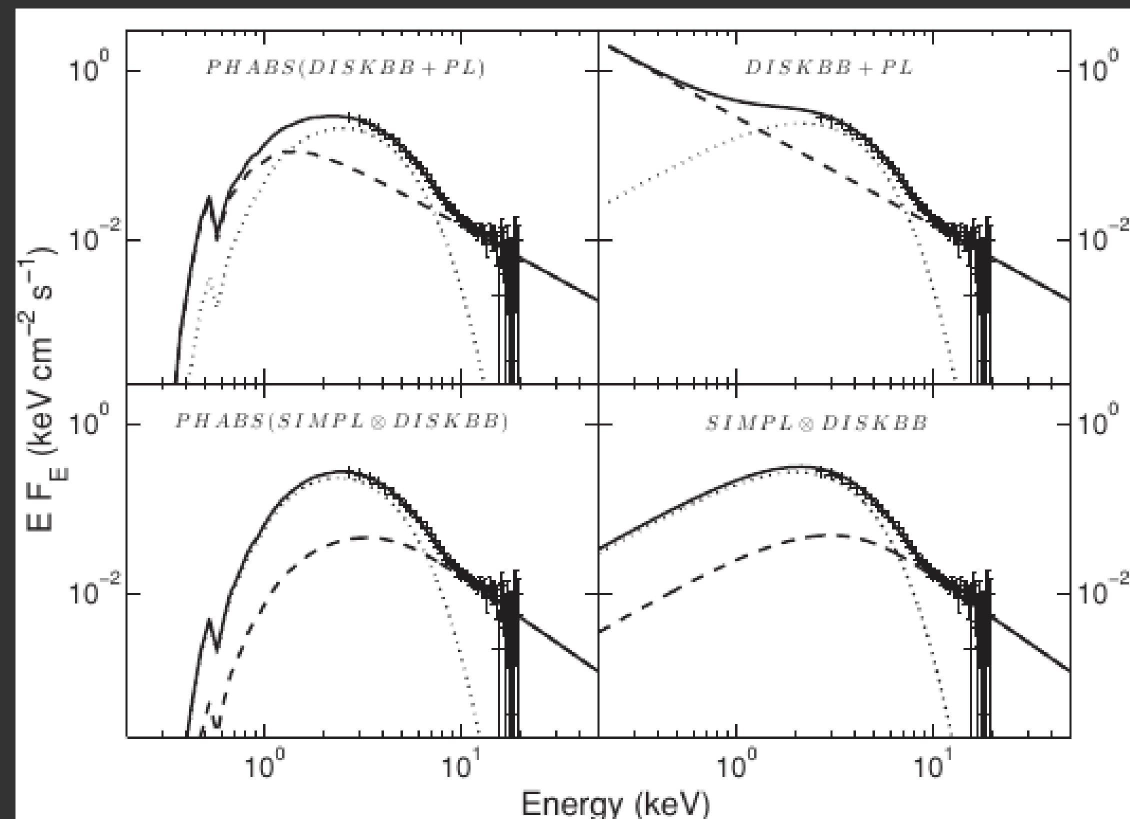
Credit: NASA/CXC/M. Weiss

LMC X-1 : X-ray Spectrum

- Almost all X-ray satellites have observed LMC X-1, very soft Spectrum, disk blackbody (kT_{in} ~ 0.9 keV) + steep power law tail (Γ~3).
- Always observed in the High/Soft state. Only one such BHB in MW and LMC/SMC!

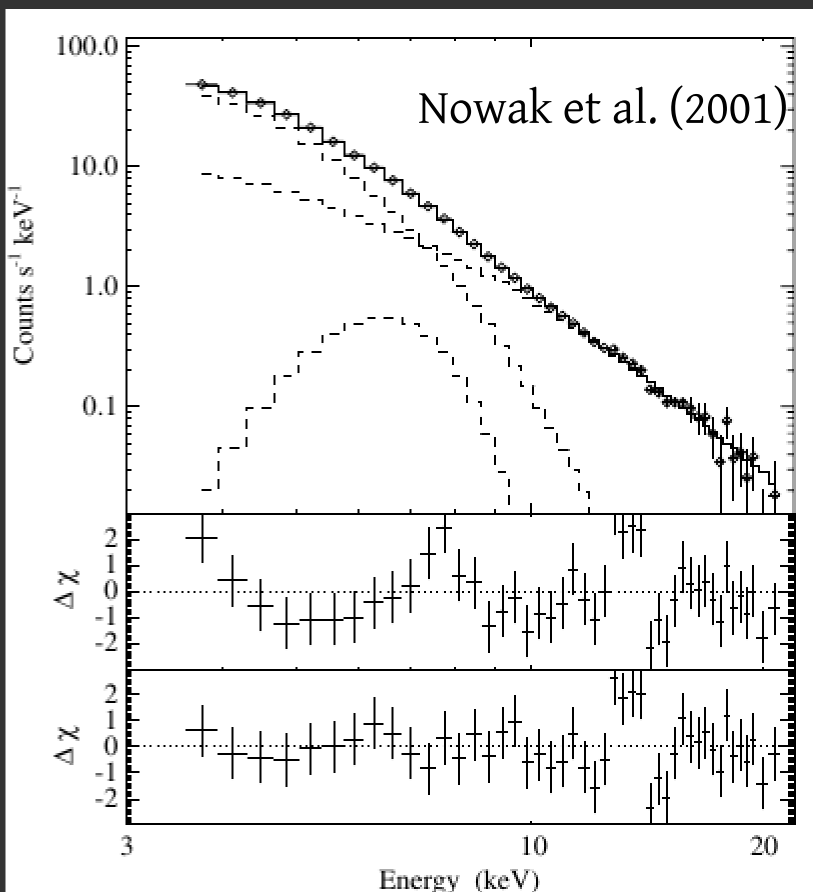
Nowak et al. (2001)

RXTE/PCA (Gou et al. 2009)



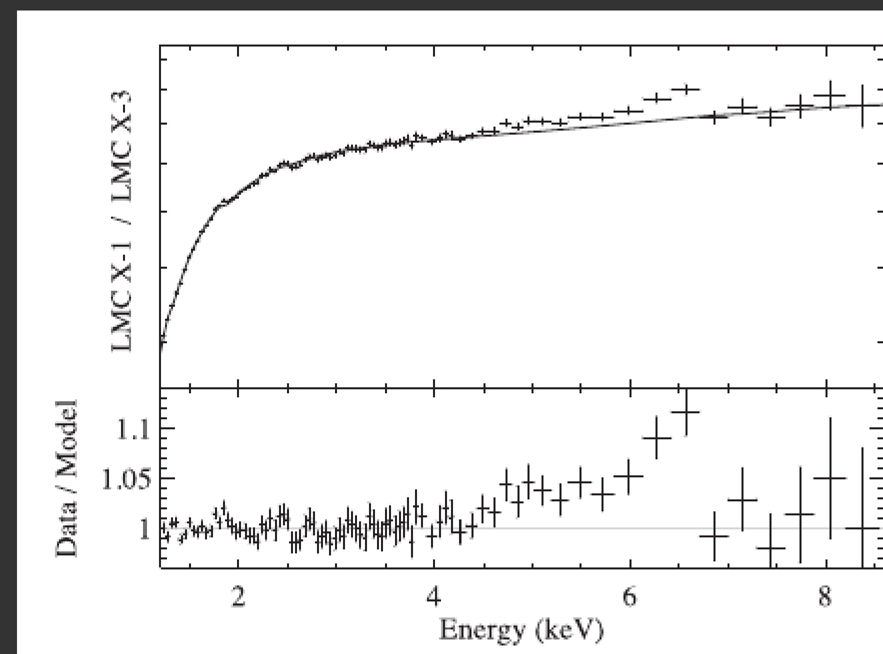
LMC X-1 : Broad iron line

- RXTE/PCA : broad iron line with σ ~ 1keV ?



- Suzaku clearly detected a relativistically broadened iron line

Steiner et al. (2012)



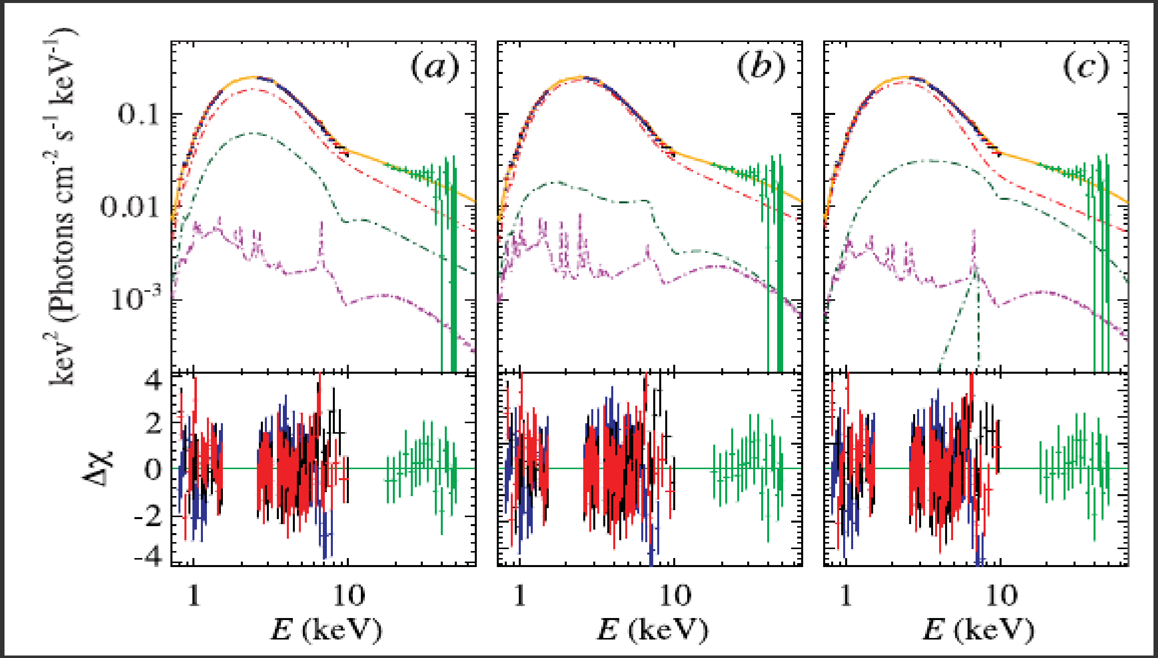
LMC X-1: BH Spin

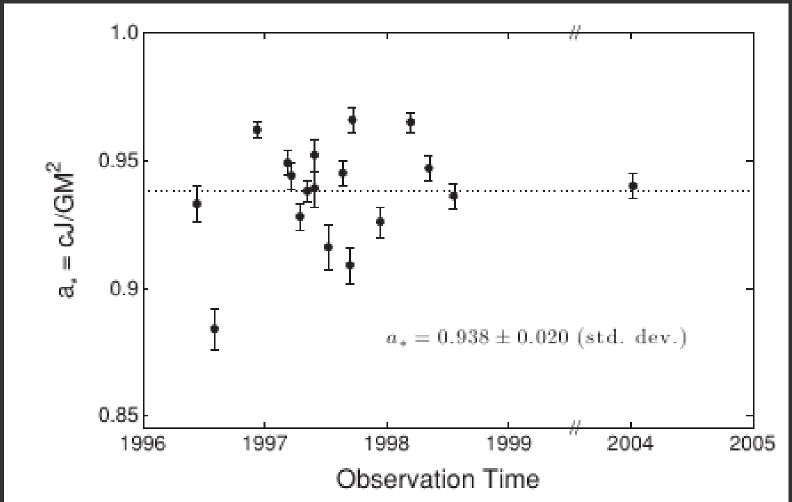
- Based on the detailed spectral modelling of the broad iron line & reflection, $a^*=0.97_{-0.25}^{+0.02}$

  (Steiner et al. 2012)

- Based on the continuum X-ray fitting of 18 RXTE/PCA spectra $a^*=0.92_{-0.07}^{+0.05}$

  (Gou et al. 2009)

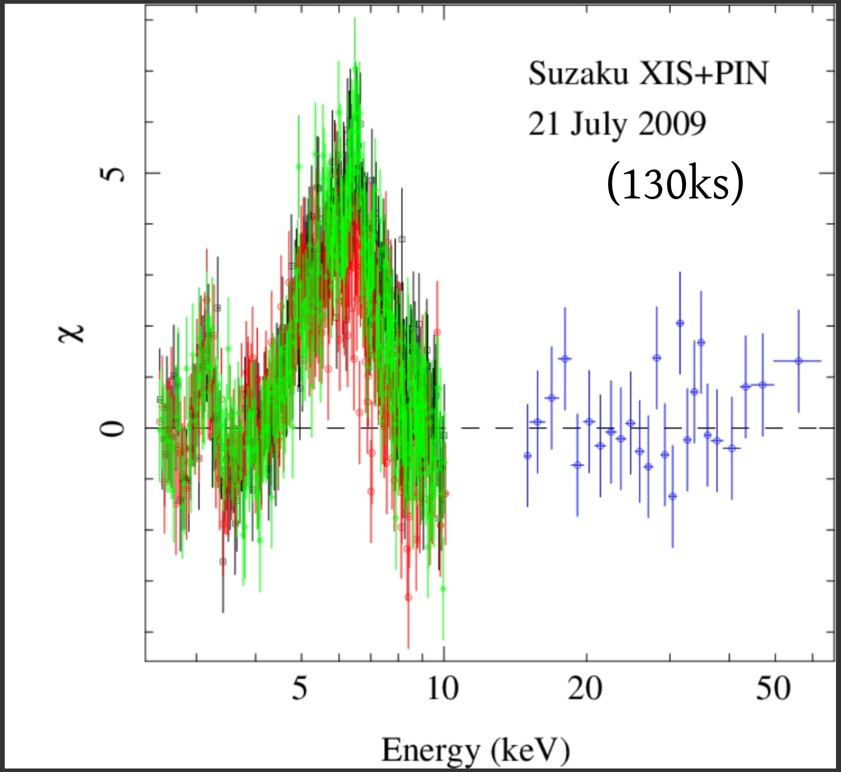


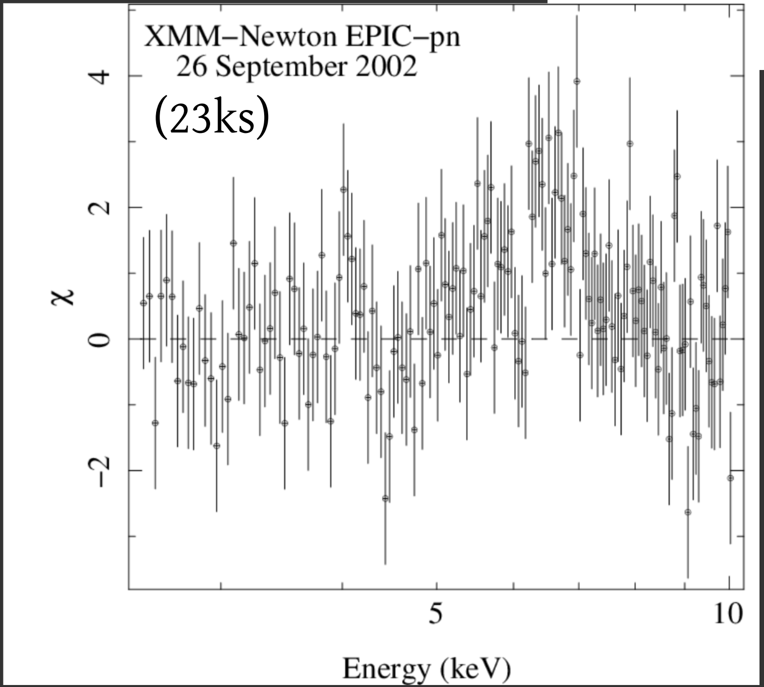


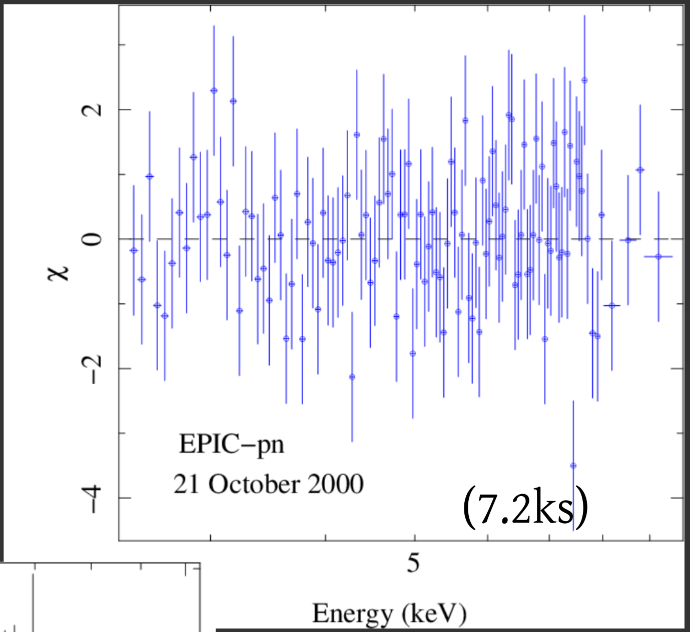
LMC X-1 : Variable broad iron line

- XMM-Newton & Suzaku observations
- Residuals from diskbb⊗simpl model, data in iron K band excluded in the fits

Alam, GCD+ 2014

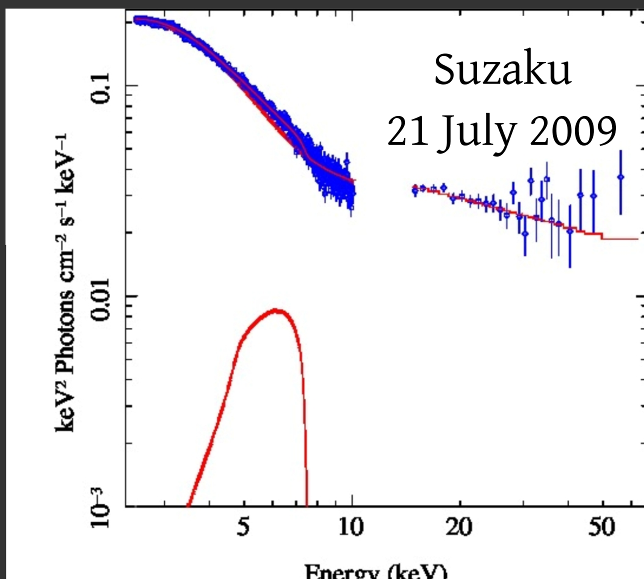


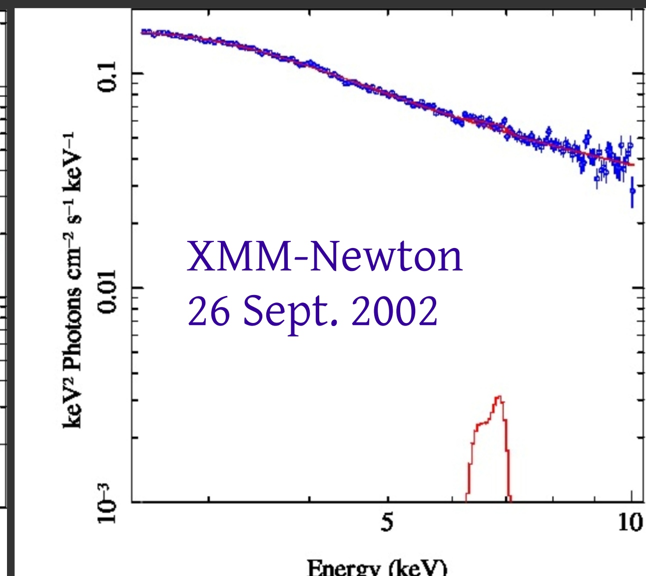


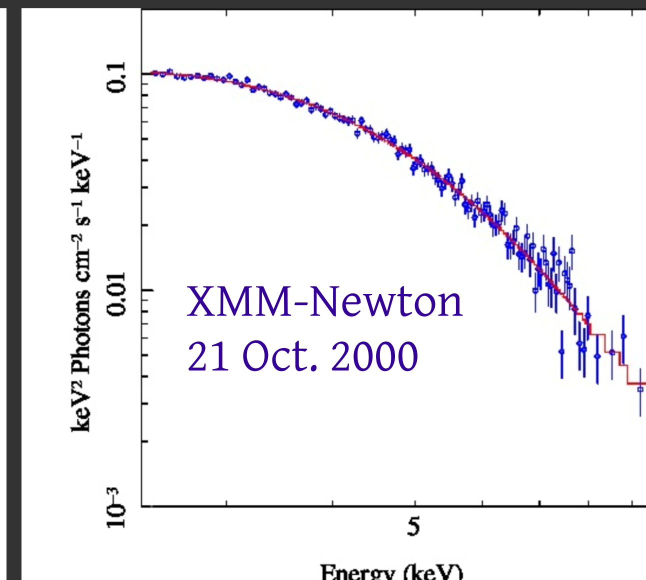


LMC X-1 : Variable broad iron line

Model : diskbb⊗simpl + LAOR







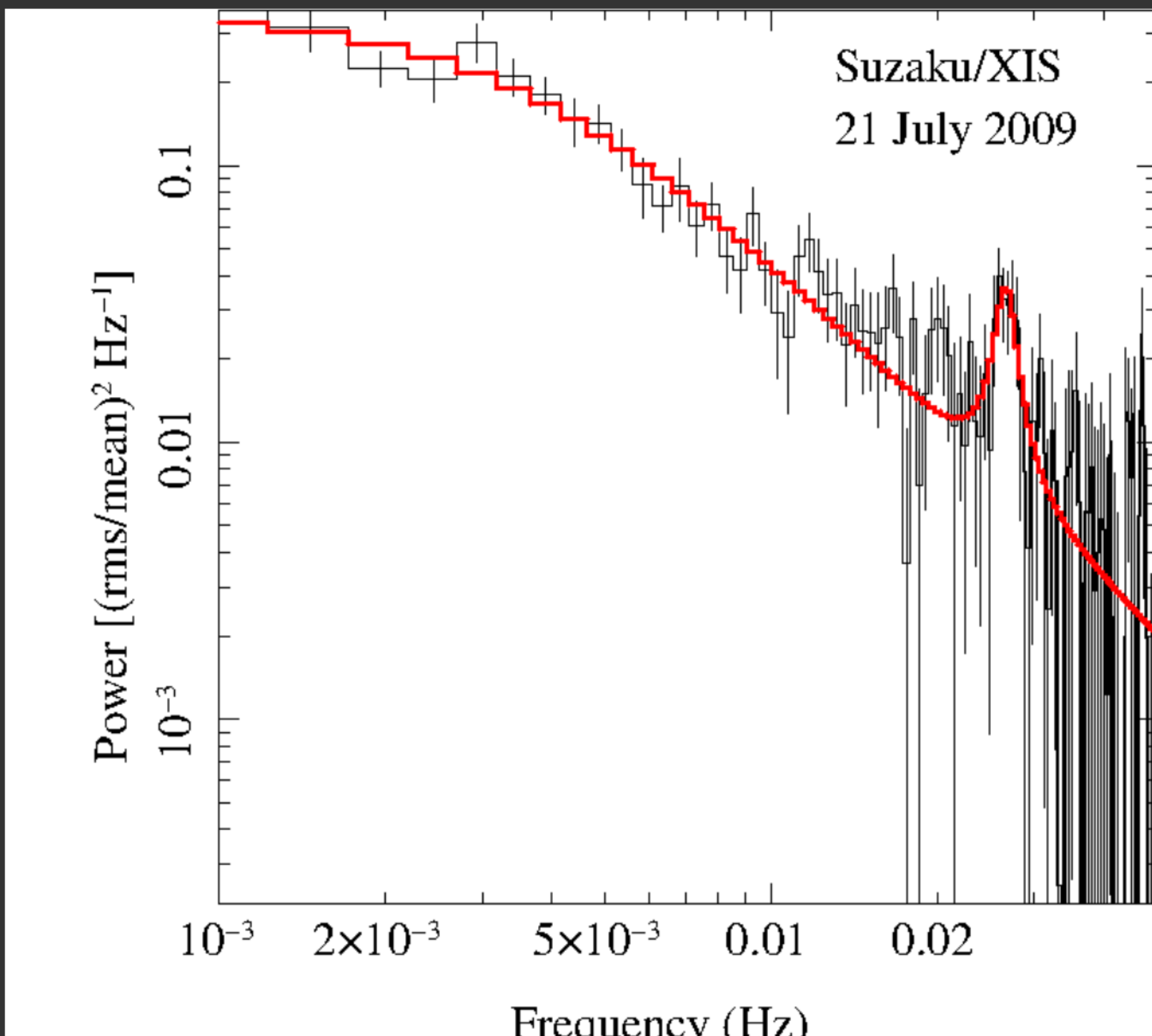
diskbb kT_{in}(keV)	$0.79^{+0.02}_{-0.01}$	0.65 ± 0.02	0.90 ± 0.03
simpl Γ	$2.45^{+0.04}_{-0.04}$	$2.91^{+0.04}_{-0.13}$	~ 3.3
f_{scr}	$0.138^{+0.004}_{-0.005}$	$0.35^{+0.02}_{-0.04}$	$0.026^{+0.014}_{-0.021}$
Laor E_{line}(keV)	$6.9^{+p}_{-0.02}$	$6.69^{+0.11}_{-0.10}$	–
r_{in}	$2.3^{+0.1}_{-0.1}$	64^{+113}_{-31}	–
q	$4.5^{+0.1}_{-0.1}$	3 (f)	–
f_{line} (ph cm^{-2} s^{-1})	$7.9^{+1.1}_{-1.0} \times 10^{-4}$	$4.6^{+1.7}_{-2.0} \times 10^{-5}$	–
disk frac. (2 – 20 keV)	~ 0.60	~ 0.35	~0.94

LMC X-1 : Variable Broad iron line

- Broad iron line – clearly detected only in the presence of strong PL tail
- Broad iron line stronger when inner disk temperature is higher (kT_{in}~0.8keV) and r_{in} is smaller (~2.3r_g) during the *Suzaku* observation.
- Strong PL illuminating the disk extending to innermost regions => Strong relativistic iron line

LMC X-1 : X-ray Variability

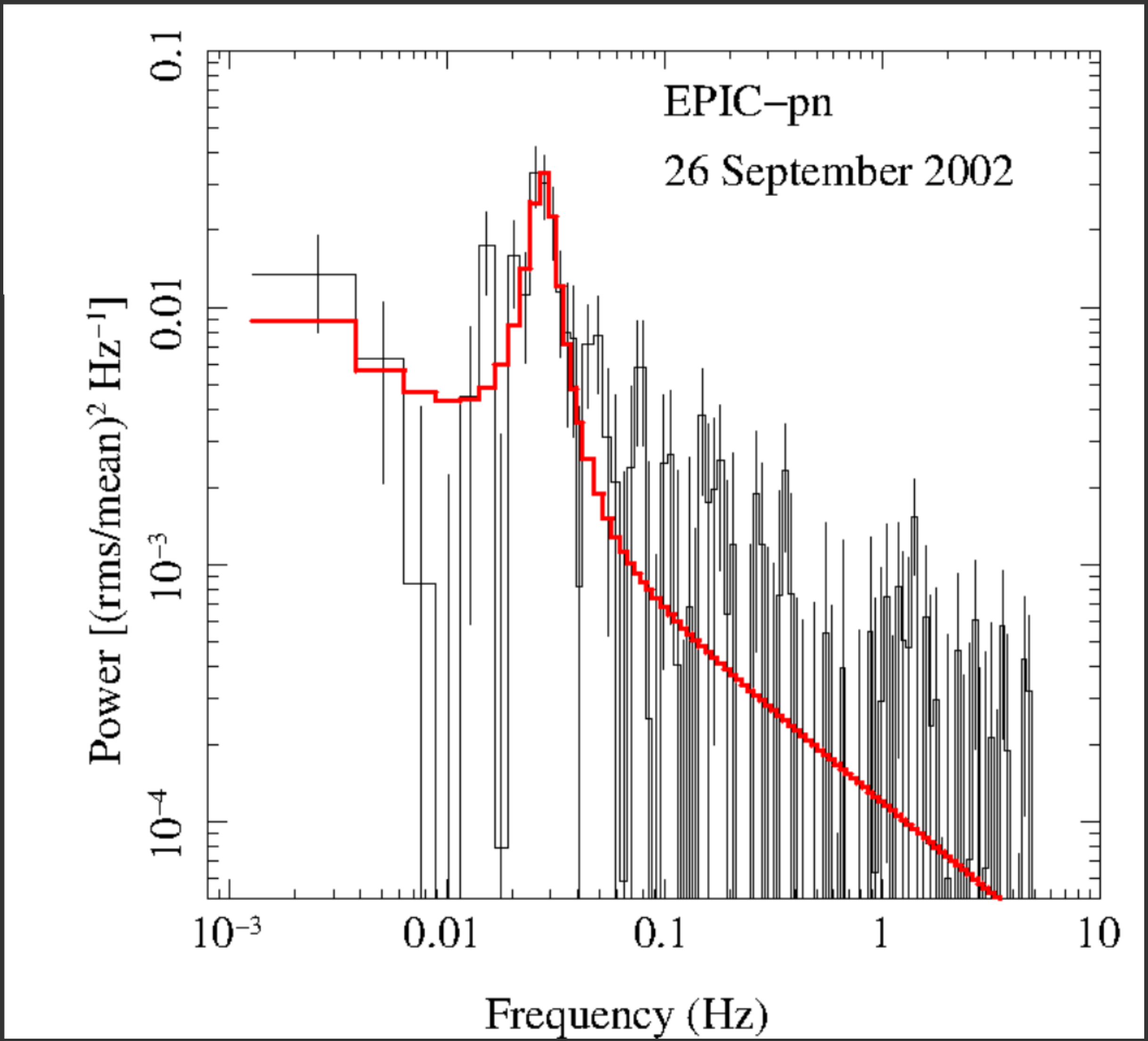
Suzaku (21 July 2009)



- ZFC + QPO
- ν_{QPO} ~ 26.5 mHz
- Q ~ 10
- Rms ~ 1.1%
- Significance ~ 8.9σ
- Disk fraction ~ 0.60

LMC X-1 : X-ray Variability

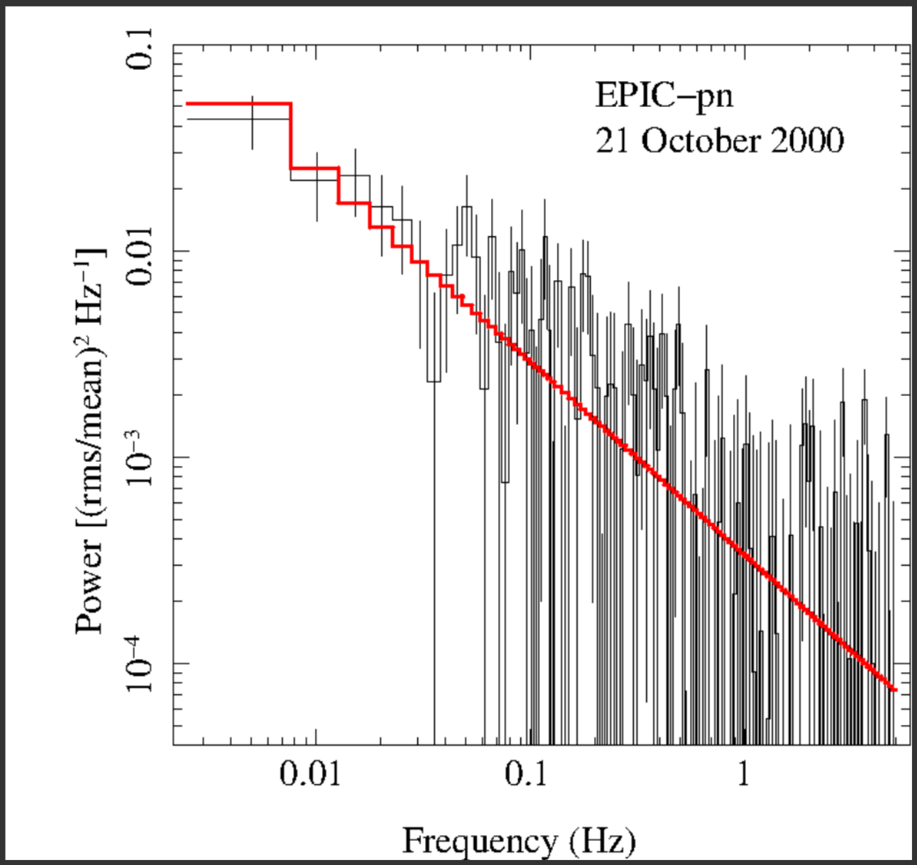
XMM-Newton (26 September 2002)



- Powerlaw + QPO
- ν_{QPO} ~ 28 mHz
- Q ~ 3.8
- Rms ~ 1.9%
- Significance ~ 5.9σ
- Disk fraction ~ 0.35

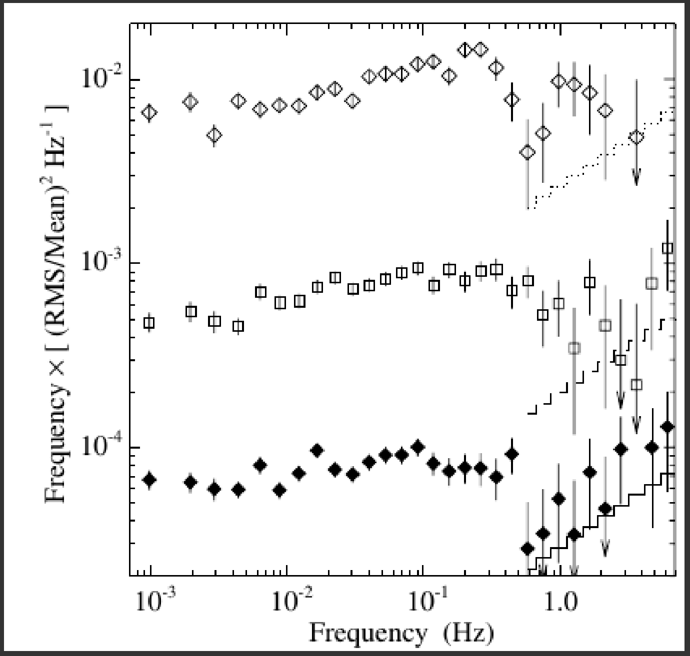
LMC X-1 : X-ray Variability

XMM-Newton (21 Oct. 2000)



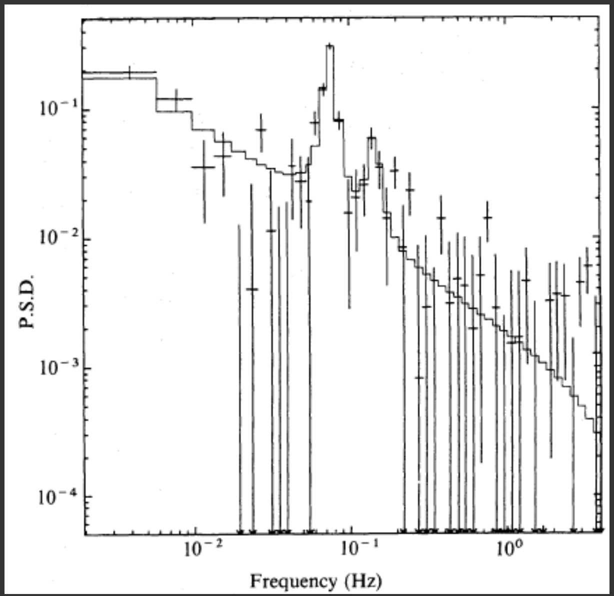
- Powerlaw PSD,
  90% upper limit on QPO rms ~ 1.1%
  disk fraction ~ 0.94
- PSD similar to RXTE measurement

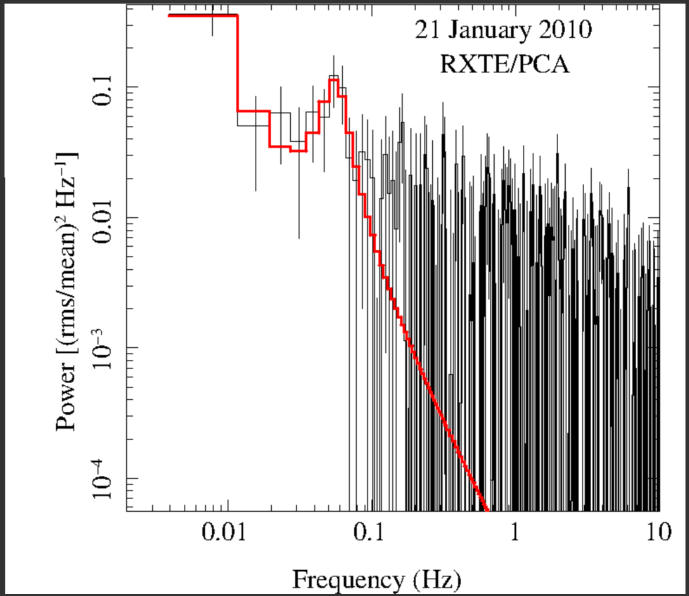
Nowak et al. 2001

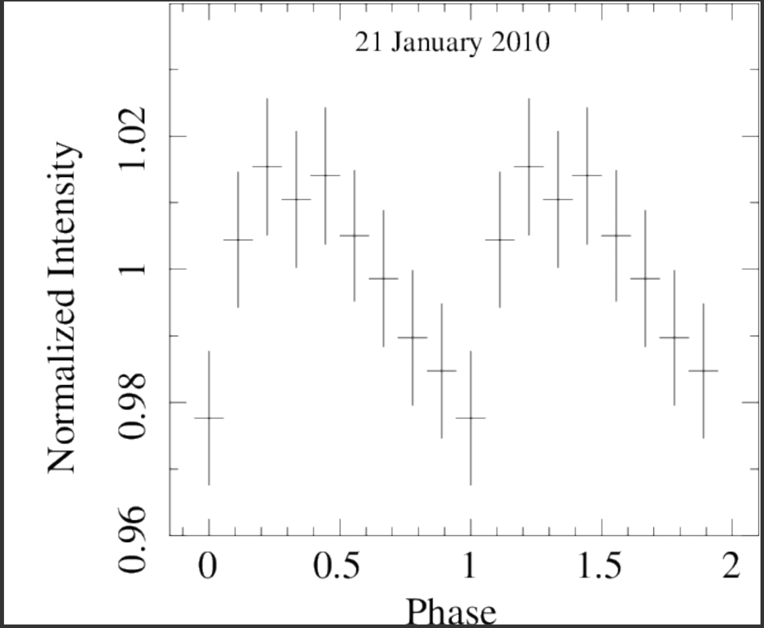


LMC X-1 : Low Frequency QPOs

- 75 & 140mHz QPOs detected earlier with Ginga in the presence of strong PL component.
  (Ebisawa et al. 1989)
- These QPOs were ruled out based on the non-detection by RXTE/PCA in the 1996 data.
  (Nowak et al. 2001)
- Jan 2010 RXTE/PCA data indicate the presence of LFQPOs in LMC X-1







LMC X-1 : Origin of milli-Hz QPOs

- ~27mHz QPOs from LMC X-1 in High/Soft state
- Not related to the Keplerian frequency at the inner edge of the disk
- Global disk oscillations due to interaction between the BH and accretion disk (Titarchuk & Osherovich 2000).

$$\nu_0 \approx 2 \left(\frac{R_{in}}{3R_S}\right)^{-\frac{8}{15}} \left(\frac{M_{BH}}{M_\odot}\right)^{-\frac{8}{15}} \left(\frac{P_{orb}}{3hr}\right)^{-\frac{7}{15}} \left(\frac{R_{adj}}{R_{in}}\right)^{-0.3} \mathrm{Hz}$$

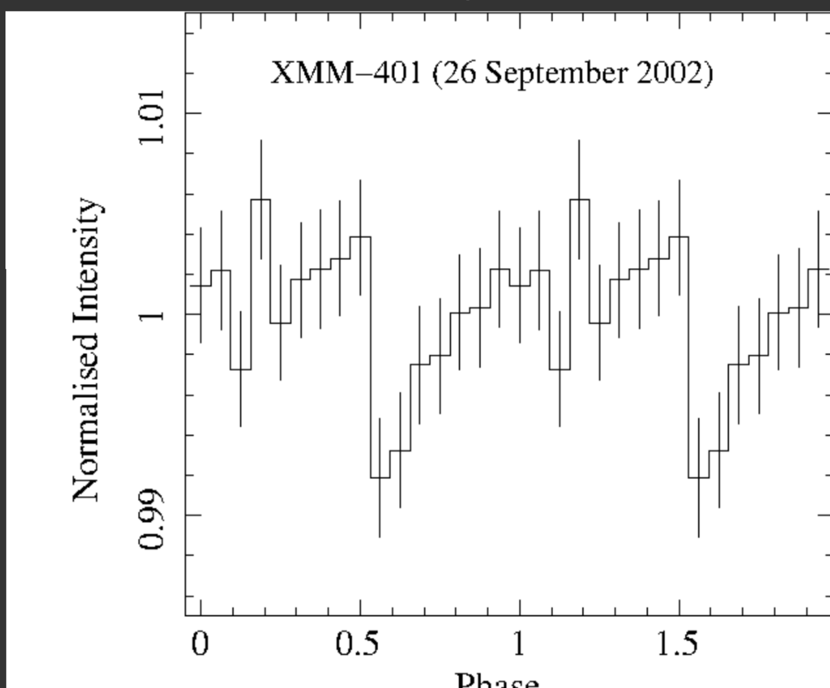
Disk oscillation frequency $\nu_0 \approx 0.15$Hz for LMC X-1.

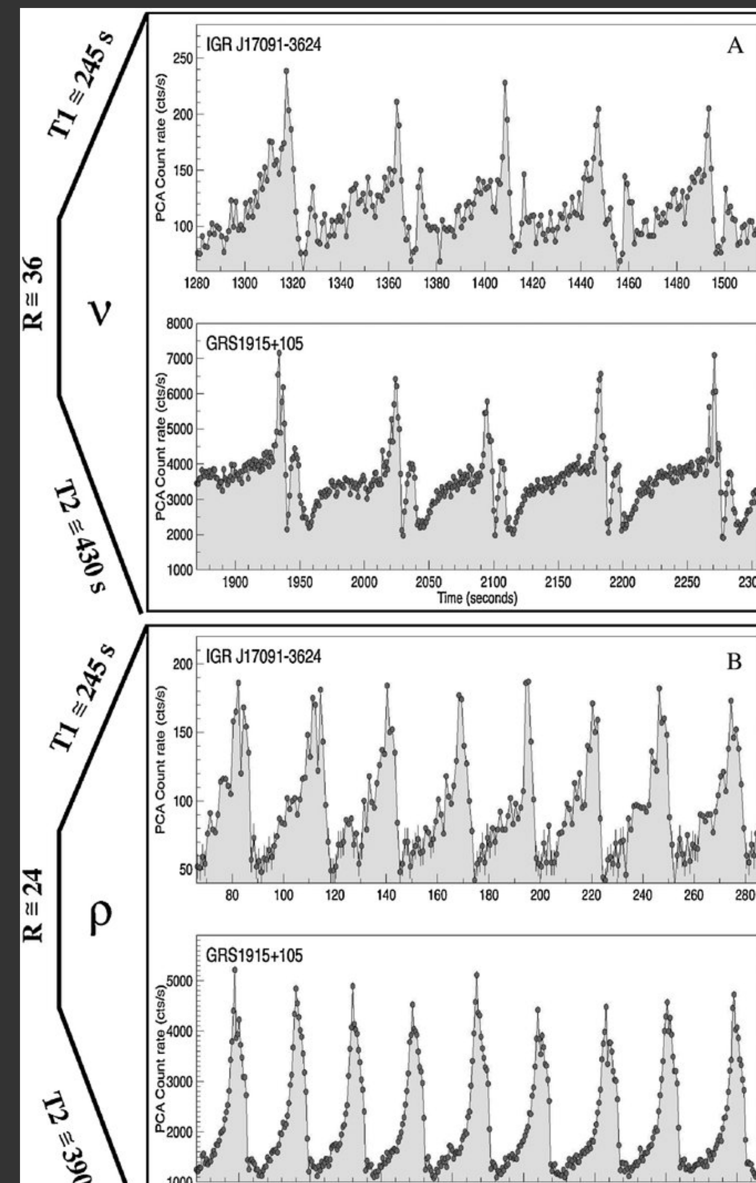
Too high!

LMC X-1 : Origin of milli-Hz QPOs

- Heart-beat QPOs (similar to mHz QPOs from GRS1915+105 & IGR J17091-3624) (Altamirano et al. 2011)

QPO phase-folded lightcurve of LMC X-1





Unlikely to be the heart-beat oscillations

Conclusions

- Discovery of mHz QPOs from a persistent BHB LMC X-1 in the high/soft state
- Detection of variable broad iron line from LMC X-1
- Presence of the QPO and broad iron line both depend on the strong PL component
- The very low frequency QPOs from LMC X-1 unlikely to be the heart-beat oscillations or due to global disk oscillations.
- ASTROSAT will perform detailed study of these QPOs.