Observations of X-ray variability in Cygnus X-1

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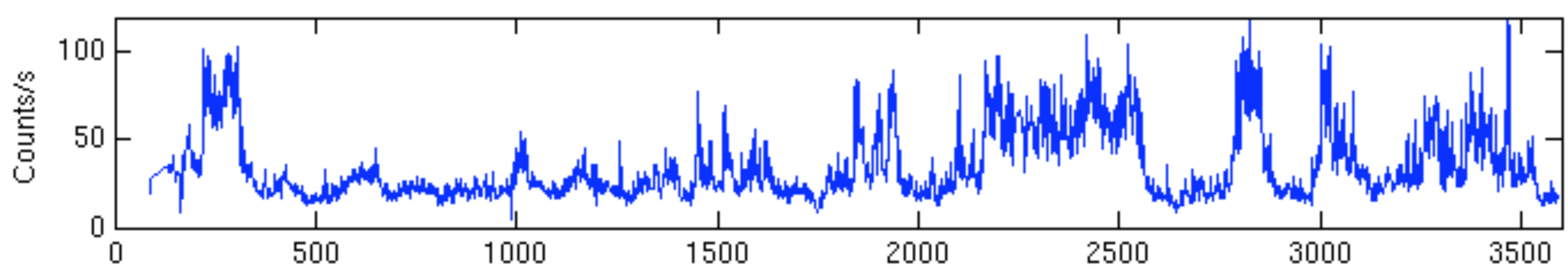
Outline

- Observed variability on short timescales
  - Systematic study of PDS
  - Support for disc truncation?
- The short term hardness flux correlation in the hard state – “mini-hysteresis” (work in progress!)
- Conclusions

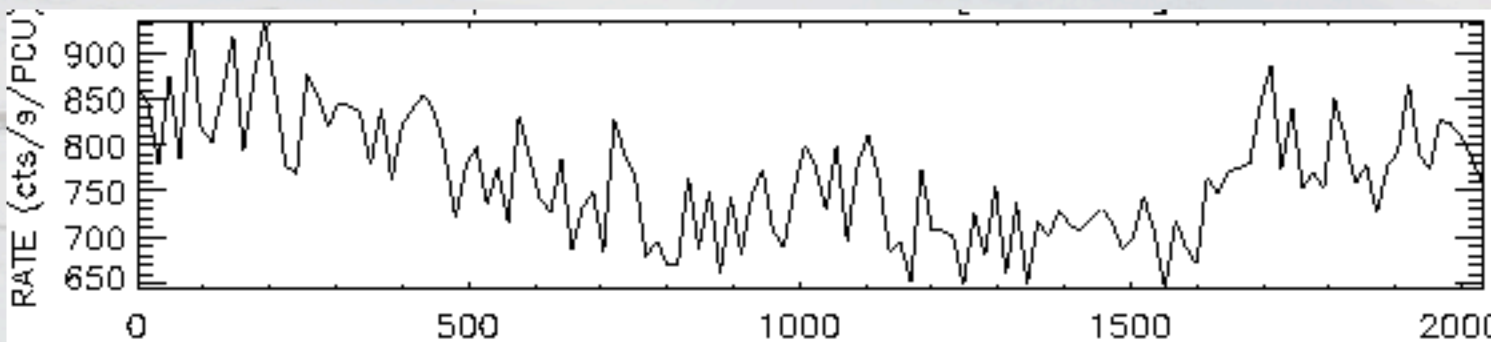
Variability on different timescales

ASM (1.3-12 keV) – days to years



Time (days)

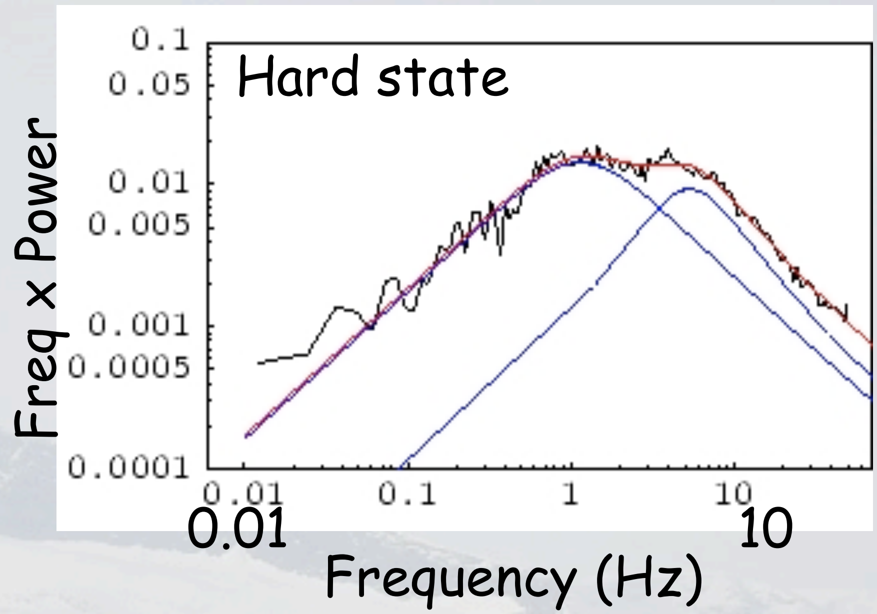
PCA – submillisecond to ~1hr

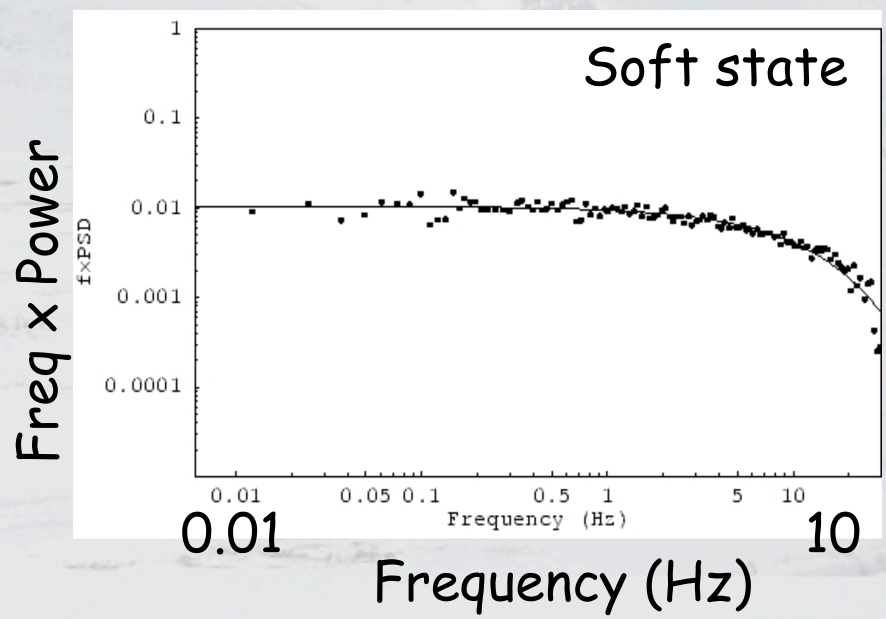


Time (s)

Temporal behavior of Cyg X-1

- Big differences between states
- QPO/break features in the hard state but not in the soft state.
- Power spectrum is variable on short timescales.





Study of Cyg X-1

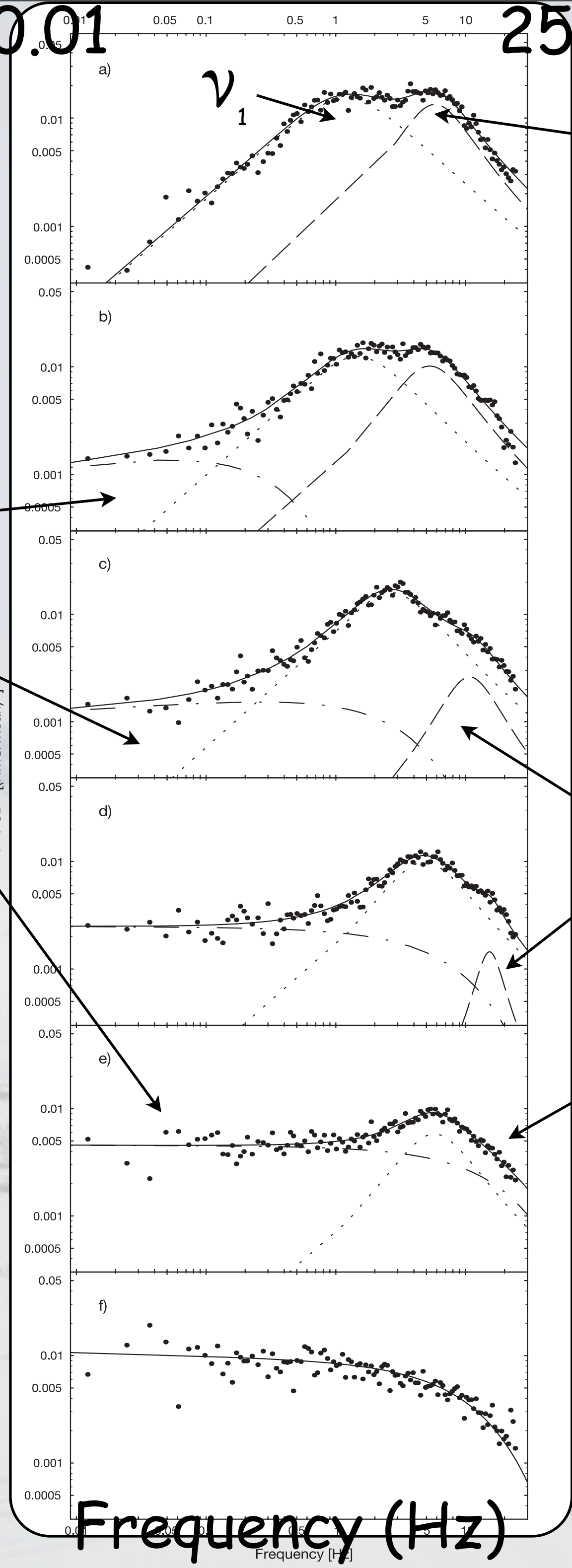
- Analyzed all available RXTE archival data, creating ~2000 PDS in the 0.01-25 Hz range (2-9 keV).
- Previous studies (Nowak 2000, Pottschmidt et al. 2004) used Lorentzians to fit the PDS – does not work in soft state, so we added a cut-off power-law.
- These three components enough to fit the PDS in our frequency range for ALL states.

Canonical hard state PDS

Cut-off power law gradually moves into frequency range.

Such a component has been seen at lower frequencies in studies of long-term variability (e.g. Reig et al. 2002).

Canonical soft state PDS



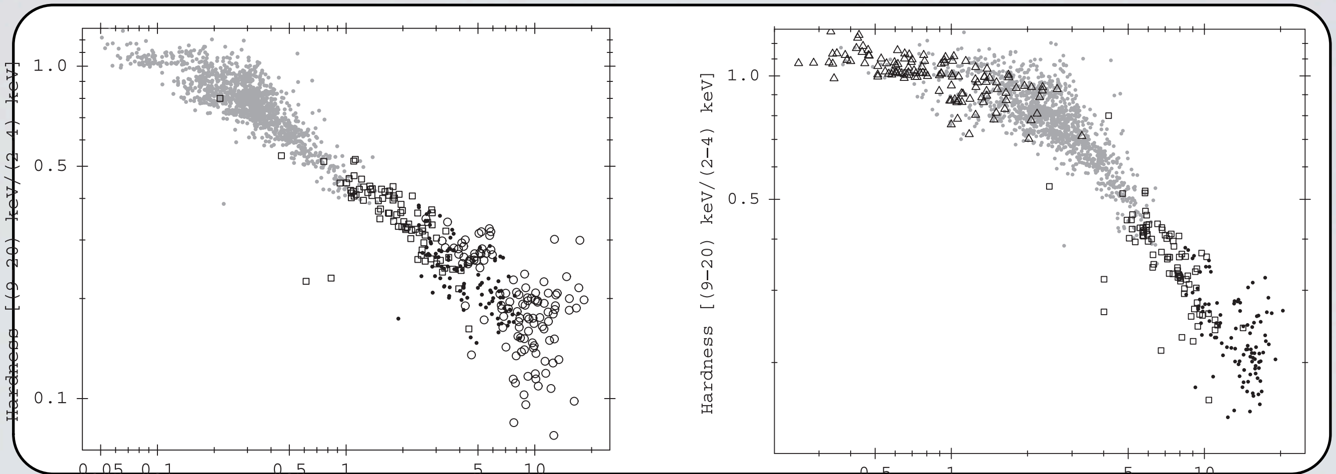
Lorentzians weaken and shift out of frequency range.

Still present in a large number of soft state (as defined by spectral index) observations.

Axelsson et al. (2005)

The peak frequencies of the two Lorentzian components

Hardness



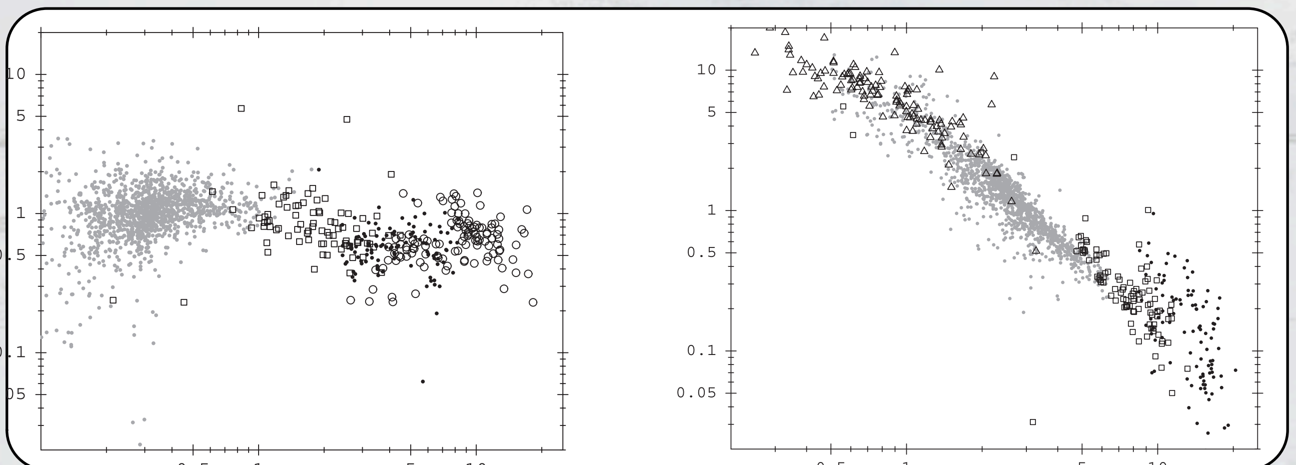
Γ~1.5

Γ~3

0.05 ν_1 (Hz) 10 0.1 ν_2 (Hz) 20

HR = (9-20 keV count rate)/(2-4 keV count rate)

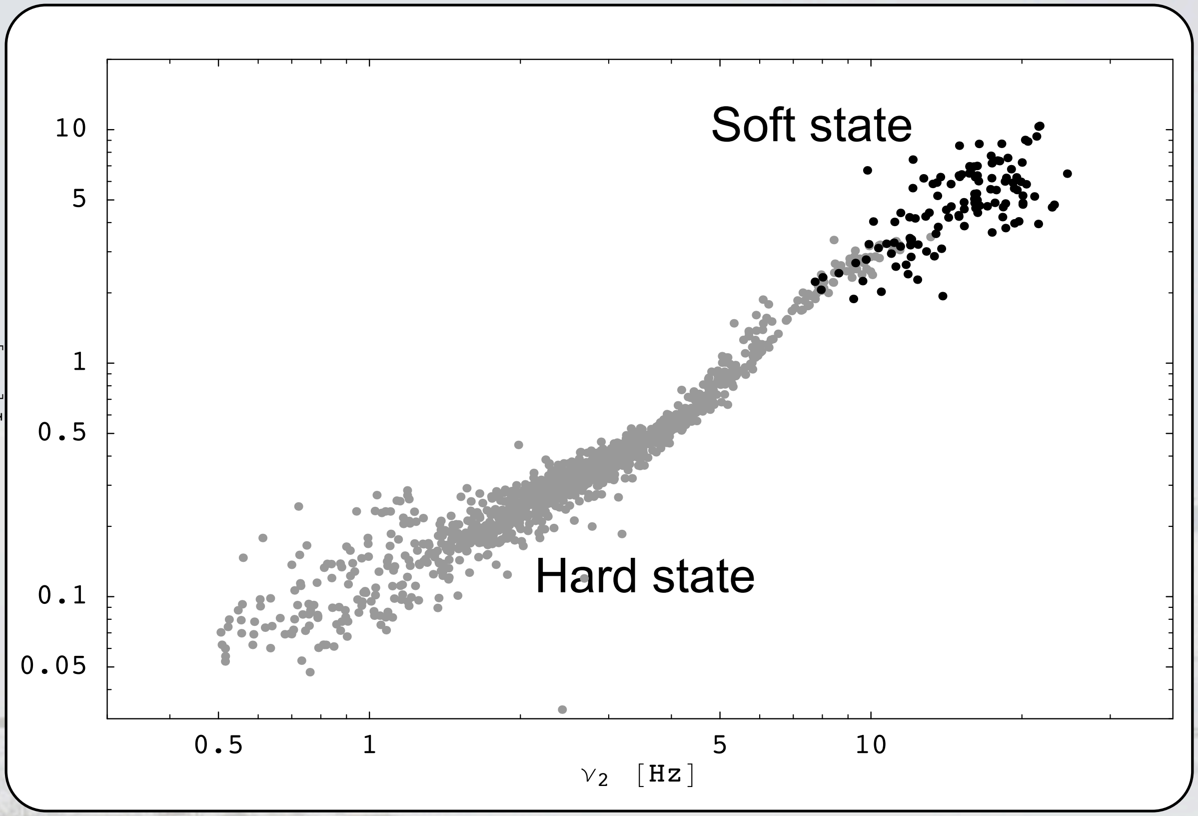
Width



0.05 ν_1 (Hz) 10 0.1 ν_2 (Hz) 20

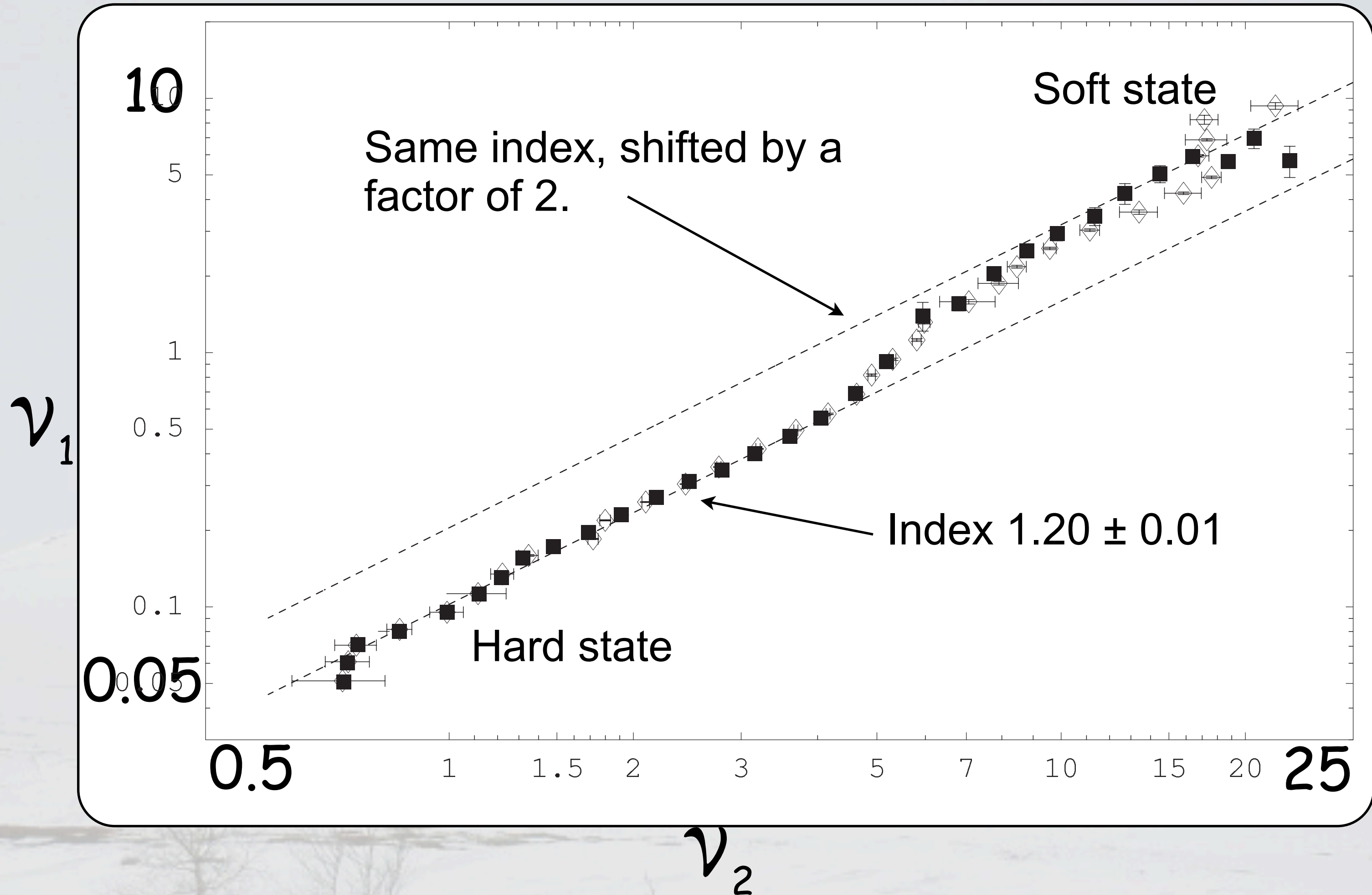
Figures from Axelsson et al. (2005)

Frequency correlation



ν_1

ν_2



Studying the relation between the two frequencies, we found that $\nu_2 \propto \nu_1^{1.2}$

Are there any models predicting this index?

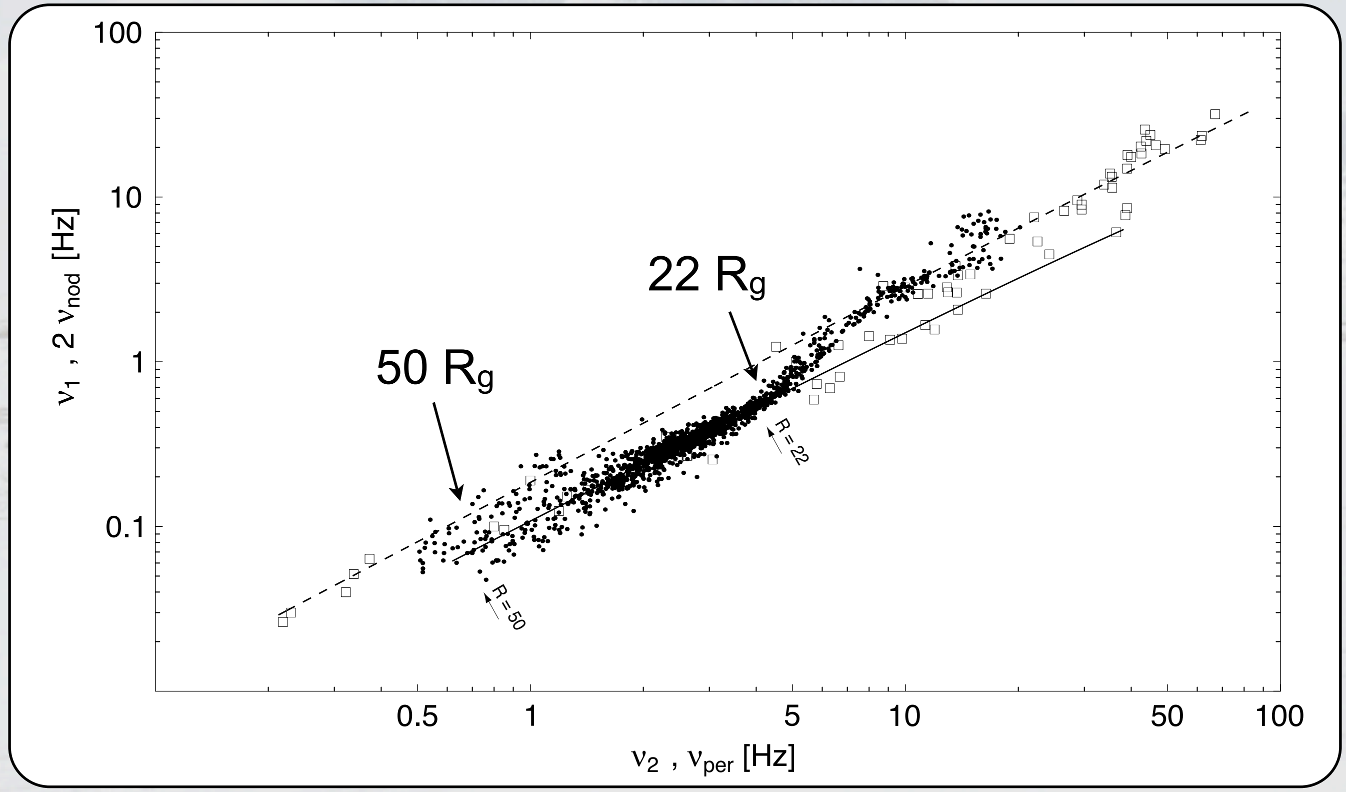
One suggestion is the relativistic precession model (RPM, Stella, Vietri & Morsink 1999). Frequencies are then the nodal and periastron precession frequencies:

$$\nu_{\rm nod} \propto a_* M^{1/5} \nu_{\rm per}^{6/5}$$

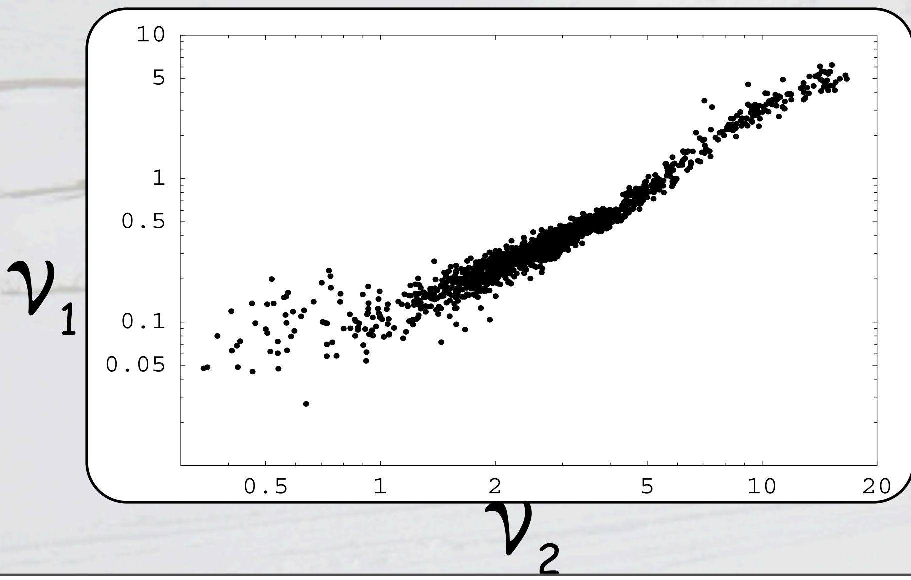
Frequencies vary with radius, so which one do we choose?

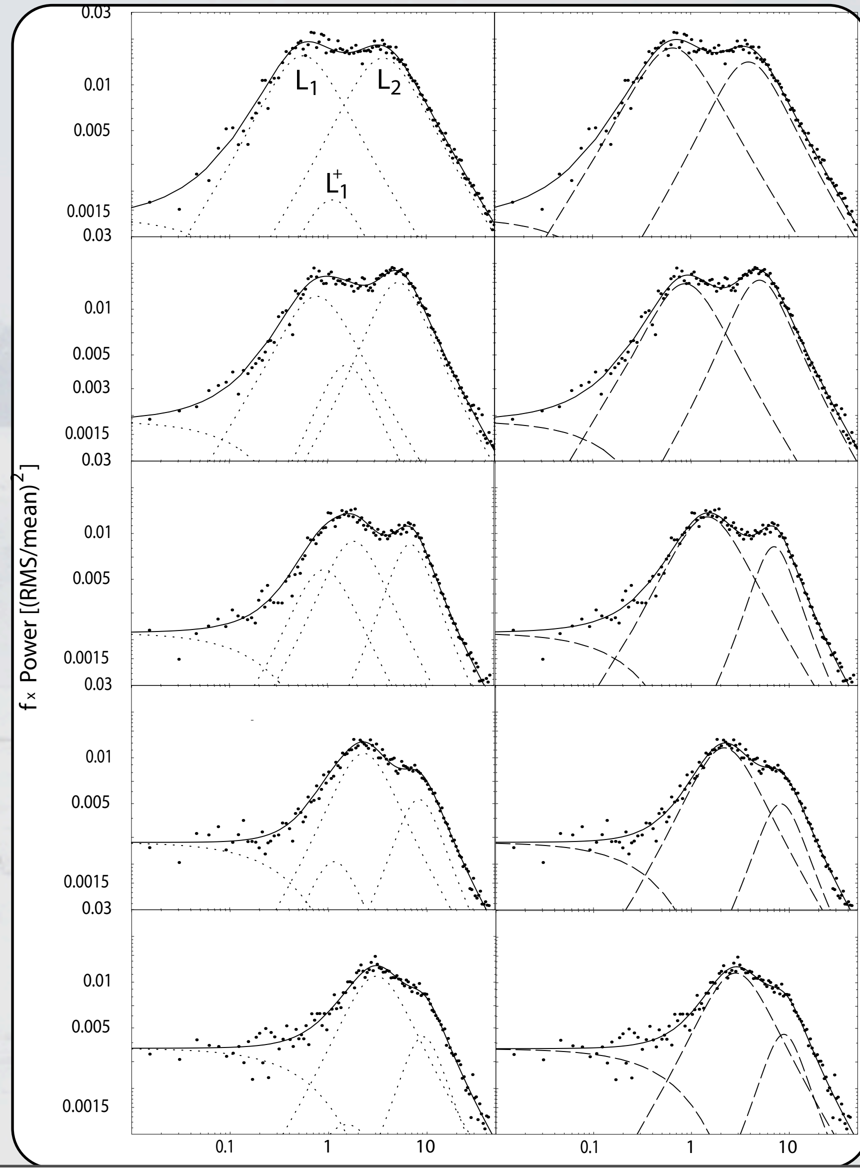
How about inner disc radius? Psaltis & Norman (2000) suggested that the transition between cool disc and hot flow could pick out these frequencies.

If interpretation is correct we can accurately track the inner edge of the accretion disc.



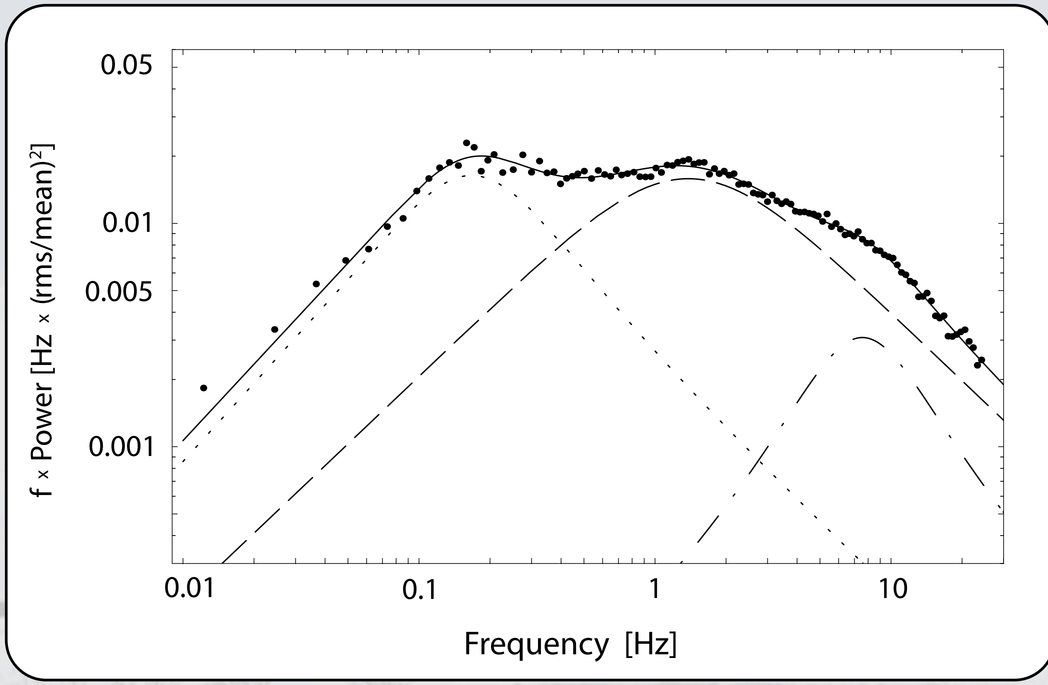
- Is the change during the transition due to a shift to a harmonic, i.e., $\nu_{1,soft}=2\nu_{1,hard}$?
  - A gradual shift will not be detectable in the PDS but can explain the results observed in the frequency relation.





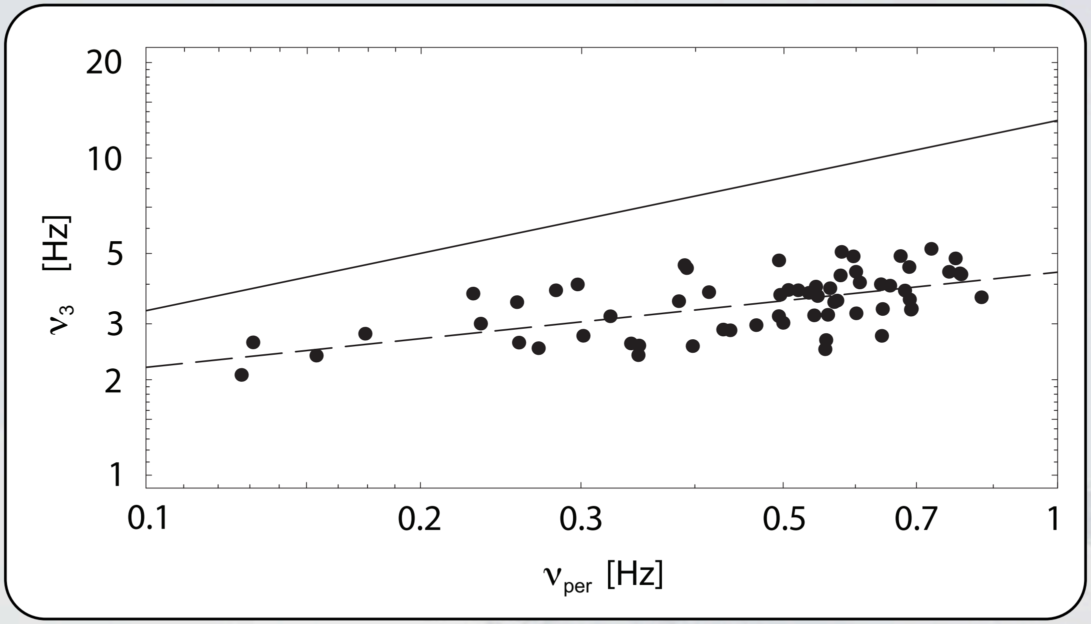
Not quite done yet...

Some of our hard state PDS show signs of an additional Lorentzian component.



Previous studies (e.g., Pottschmidt et al. 2004; Nowak 2000) have reported several Lorentzian components. We see it in only a small fraction of our hard state cases. This is probably due to our frequency window (0.01-25 Hz).

No obvious candidate for this frequency in the RPM (any ideas?).

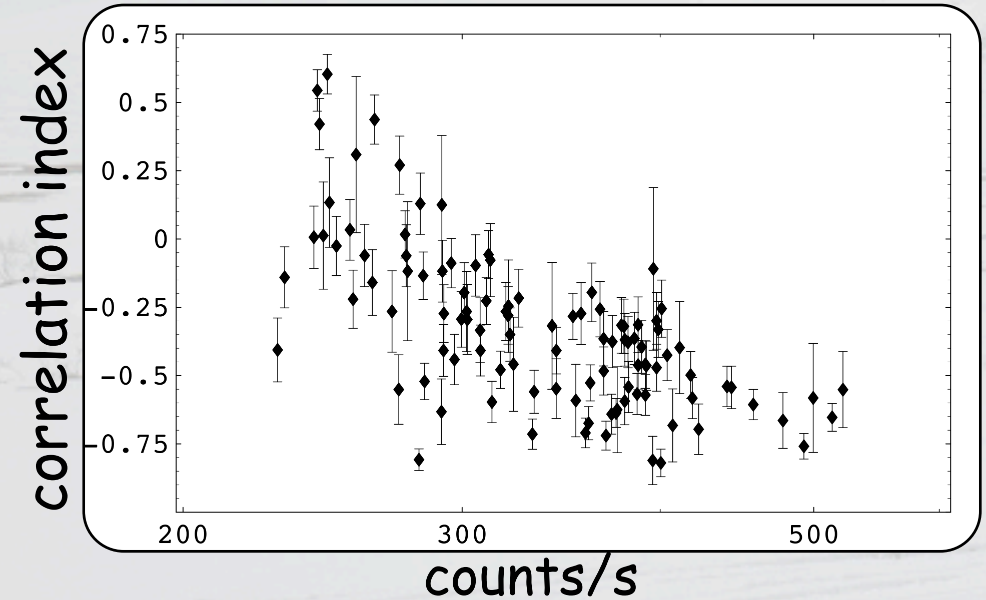


Appears to scale as square root of Keplerian frequency.

The observations where three Lorentzian components are seen in our window are also the ones with the highest hardness ratio and the lowest flux – the "hard edge".

We also looked at the hardness flux correlation within these observations. In the hard state there is an overall negative correlation (e.g. Zdziarski et al 2002), but...

Each point corresponds to an observation of ~30 mins.



As Cyg X-1 goes to the hard edge, this correlation weakens on short timescales (<1 hr)

On longer timescales, the correlation remains negative.

(Axelsson et al., submitted)

If we believe that changes in hardness (spectral shape) are a result of the inner disc radius responding to changes in the accretion rate, and that these changes occur on the viscous timescale at this radius, then the vanishing correlation on short timescales may be a sign that the disc does not have time to reconfigure at these large radii (50 R_g).

Conclusions

- Few components enough to model the evolution of the PDS of Cyg X-1 in both hard and soft states.
- Frequencies shift in a way consistent with the truncated disc scenario.
- Disappearance of short-term hardness-flux correlation in hard edge may give information about viscous timescale in disc.


Thank you!