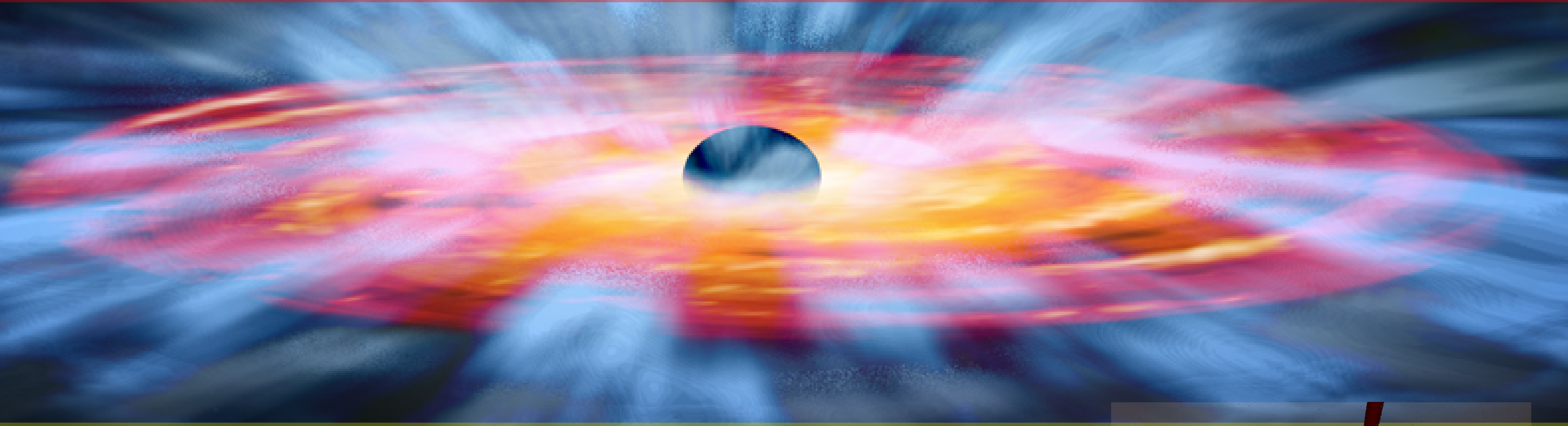
Very Fast X-ray Spectral Variability in Cygnus X-1



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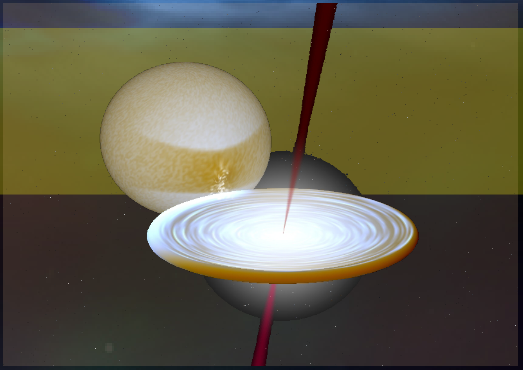
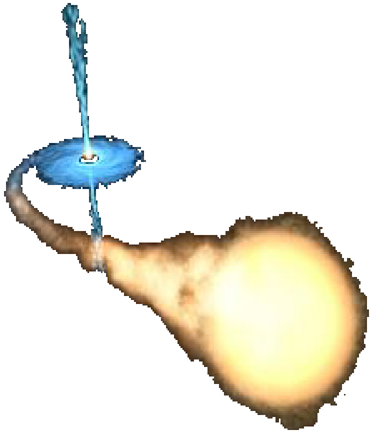
3rd April 2013



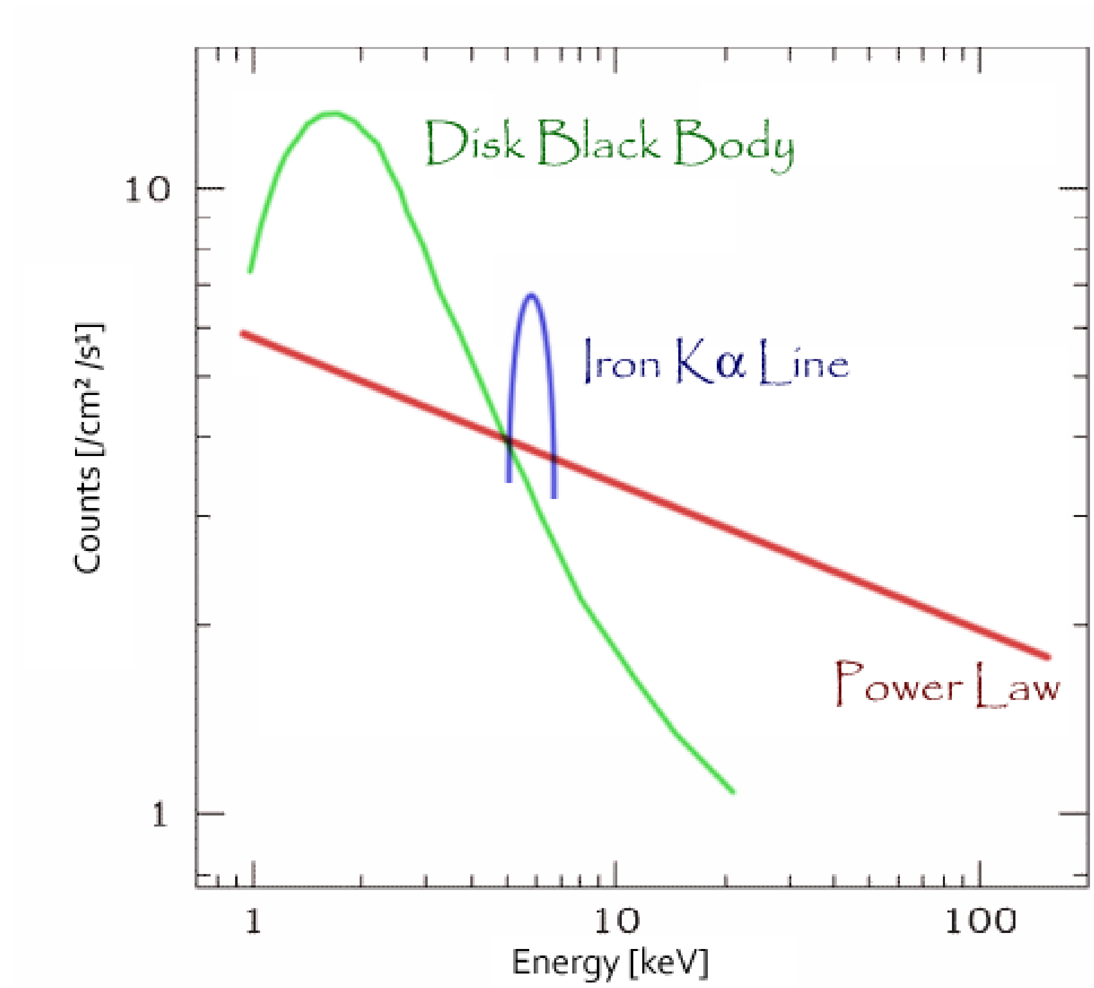
We apply a novel, but simple, analysis technique to rapid variability of Cygnus X-1, to investigate the relationship between the slope of the power law spectral component (Γ) and the count rate of the source.

We have extracted and fitted ~2 million RXTE spectra, all of which are between 16 and 100 ms in length, and cross-correlated Γ with the source counts.

All observations are taken from the RXTE archive and date from between 1996 and 1998. During this time, Cygnus X-1 underwent a major soft-state outburst.

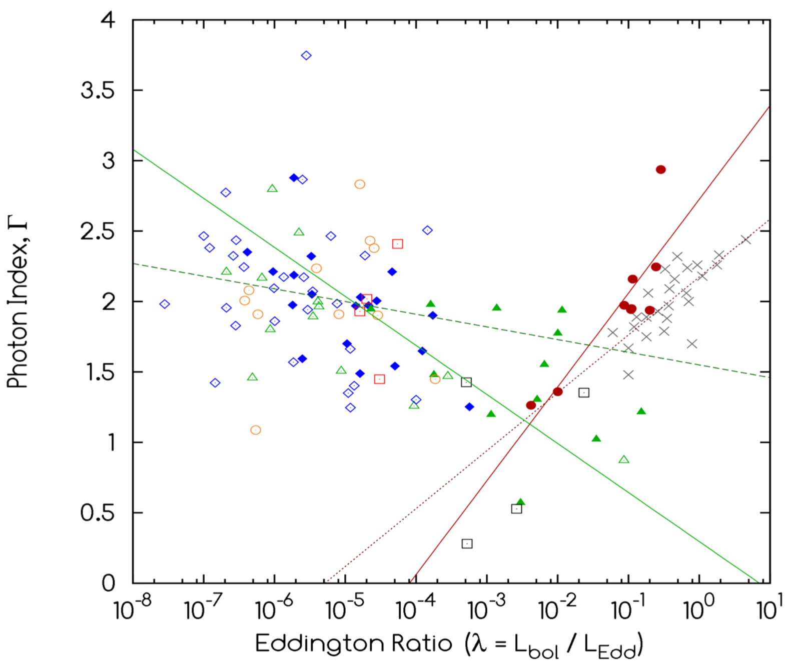


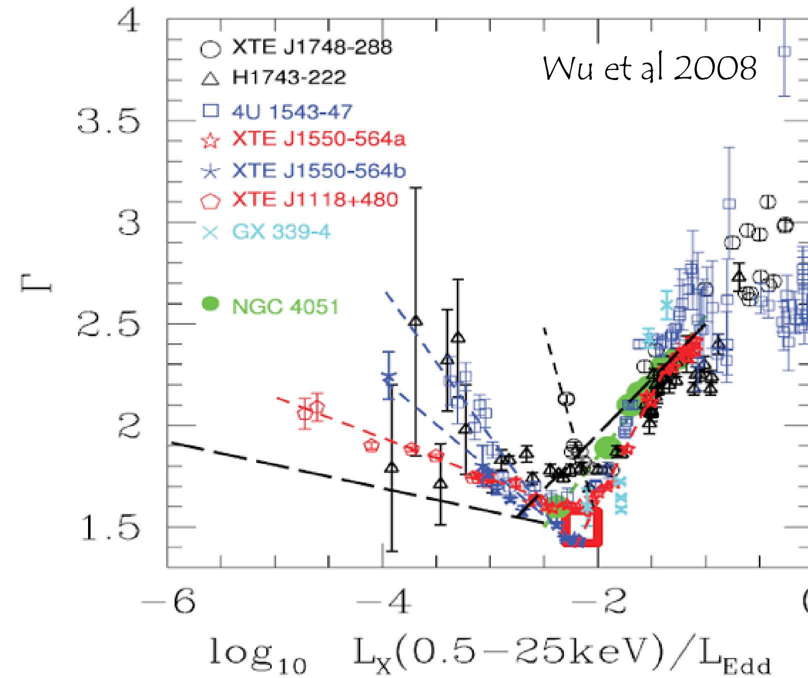
Fitting the Spectra



- Initially fit a model to whole observation, consisting of a power-law, iron line and, if required, a disk black body component.
- When fitting shorter time-scale spectra, all components remain fixed except for the power law photon index and normalisation.
- Method relies upon the assumption that the power-law shows stronger variability on short time-scales than the other components.

The Relationship between Photon Index and Accretion Rate

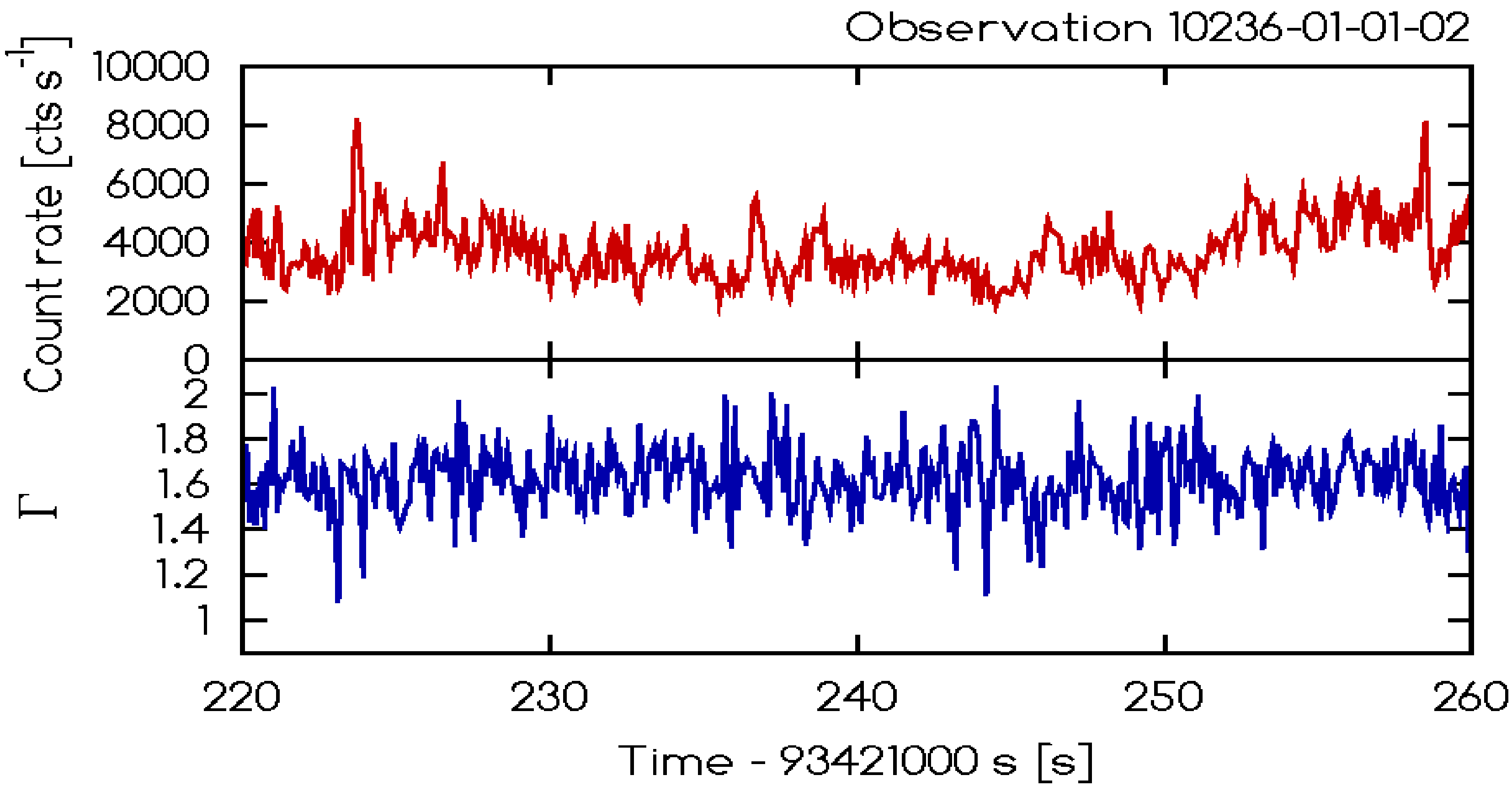




Previous studies show that Photon Index (Γ) is positively correlated with accretion rate (λ) above ~1% of the Edddington limit and anti-correlated with λ at lower accretion rates.

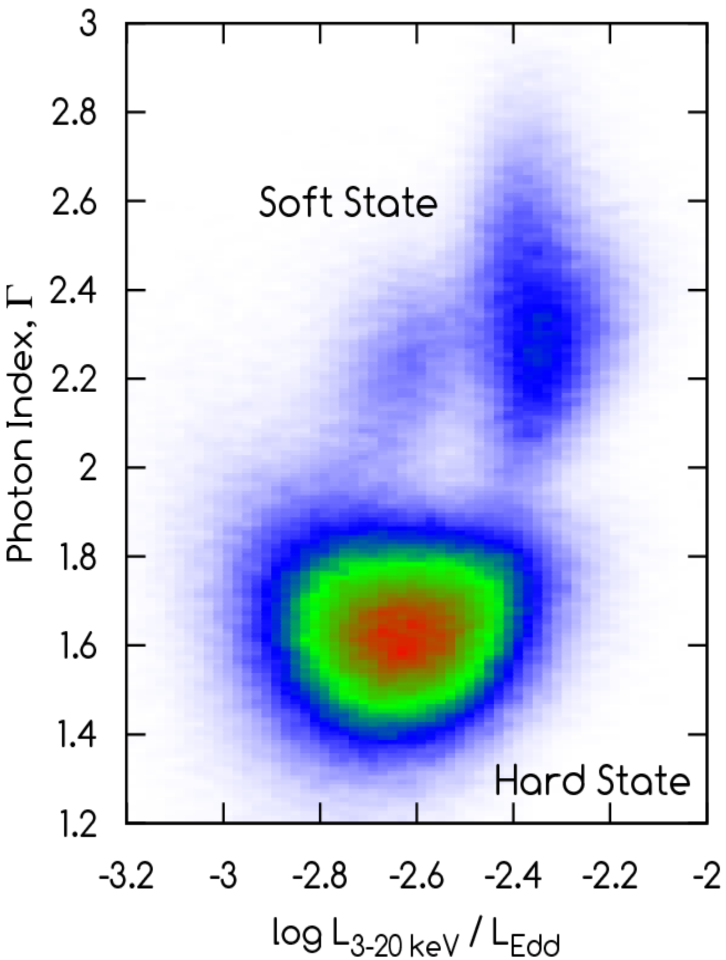
This is true for both X-ray binaries and AGN.

Time-resolved Spectroscopy of Cygnus X-1: The Results



Spectra extracted on ≤100 ms timescales to produce separate lightcurves of count rate and photon index (Γ).

Time-resolved Spectroscopy of Cygnus X-1: The Results

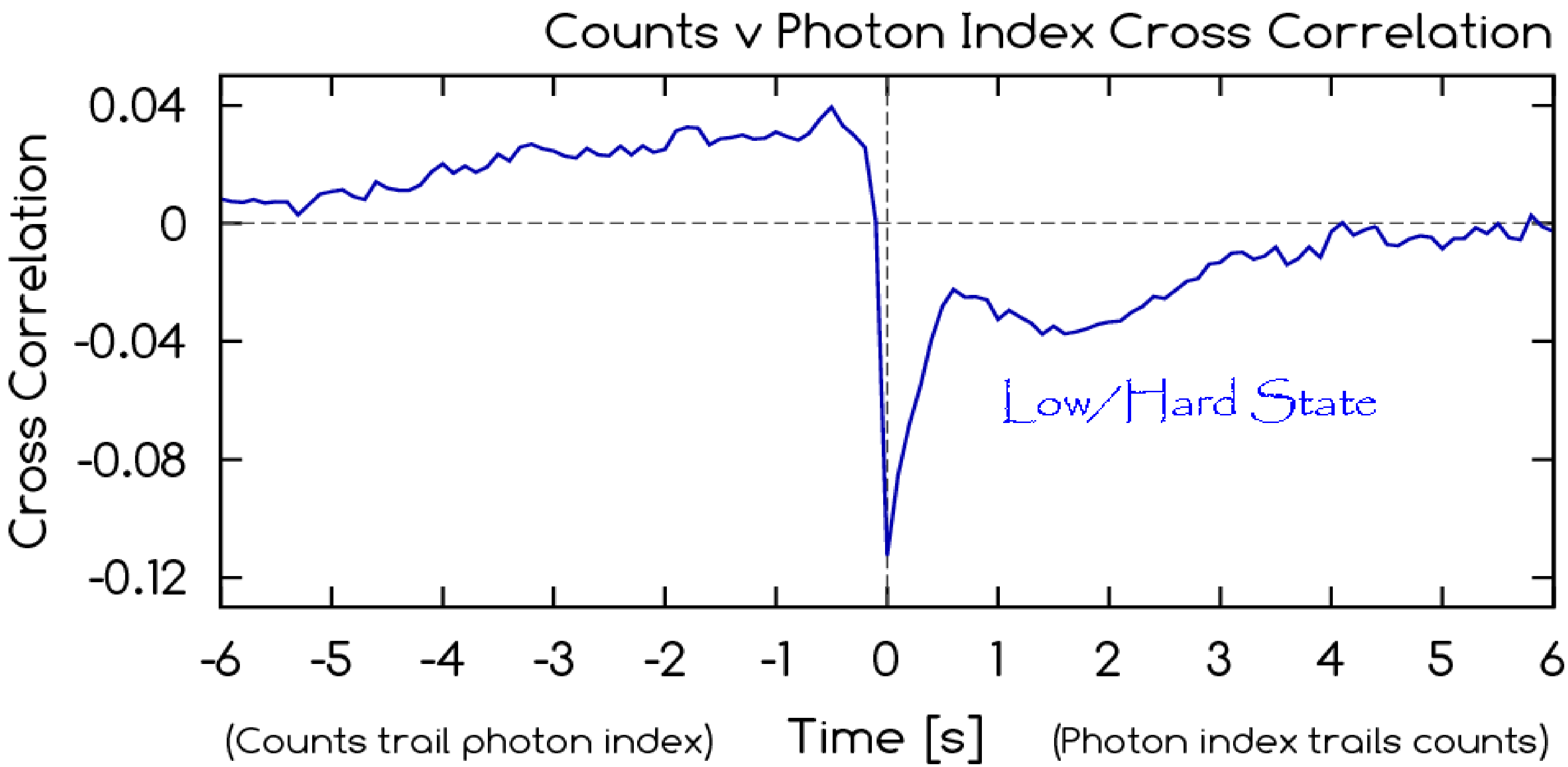


◊ The graph shows a density plot of approximately 500,000 spectral fits – each 100 ms in length – of Cygnus X-1 between 1996 and 1998.

◊ The hard and soft states are clearly distinguishable with a transition region (mostly observation 10238-01-04-00) bridging the gap.

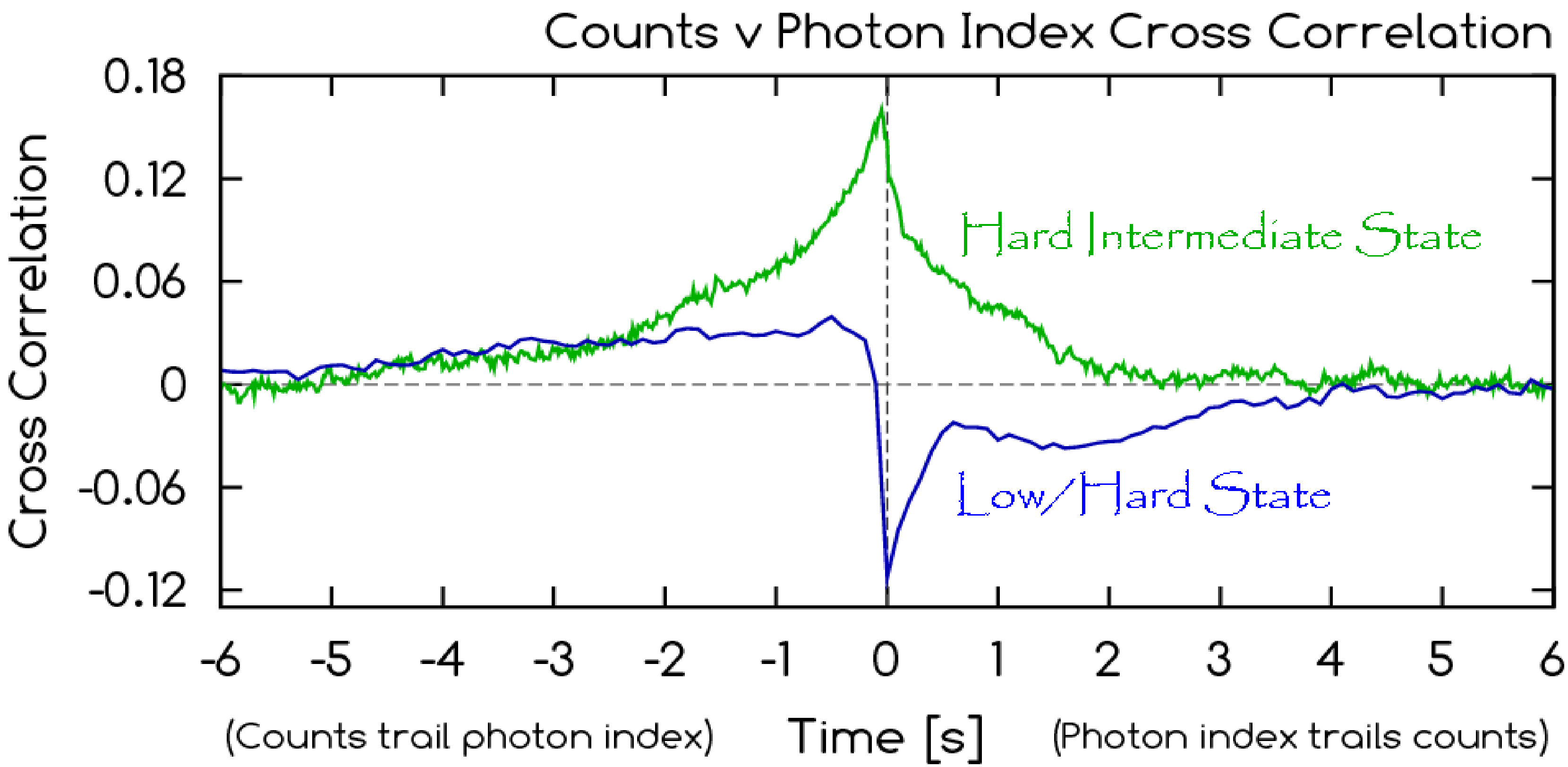
◊ The data are heavily affected by Poisson noise, which hides any correlation between the accretion rate and photon index.

Photon Index v Source Counts Cross Correlation Functions (Hard State)



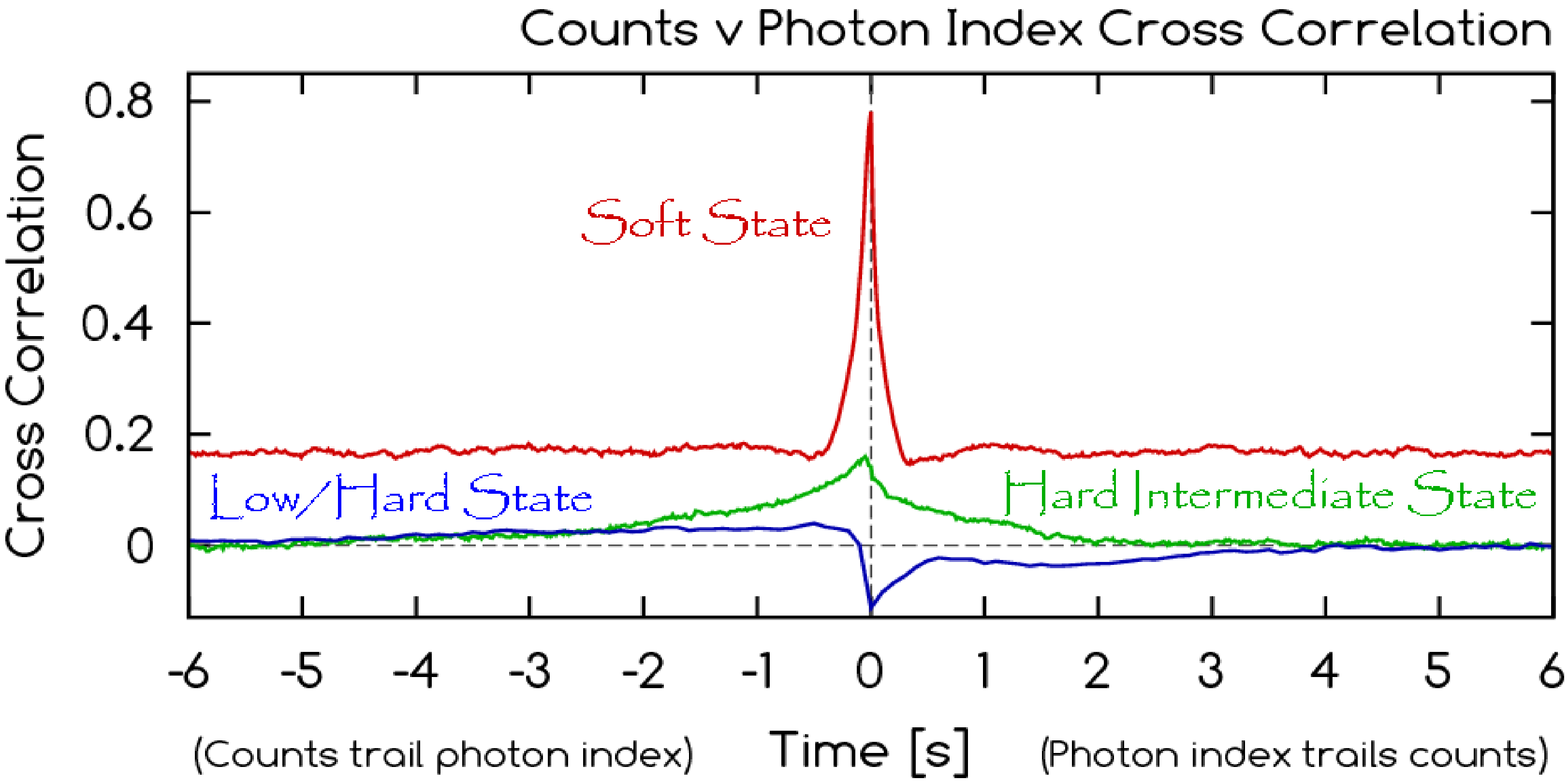
Low accretion rate hard-state observations.

Photon Index v Source Counts Cross Correlation Functions (Hard-Intermediate State)



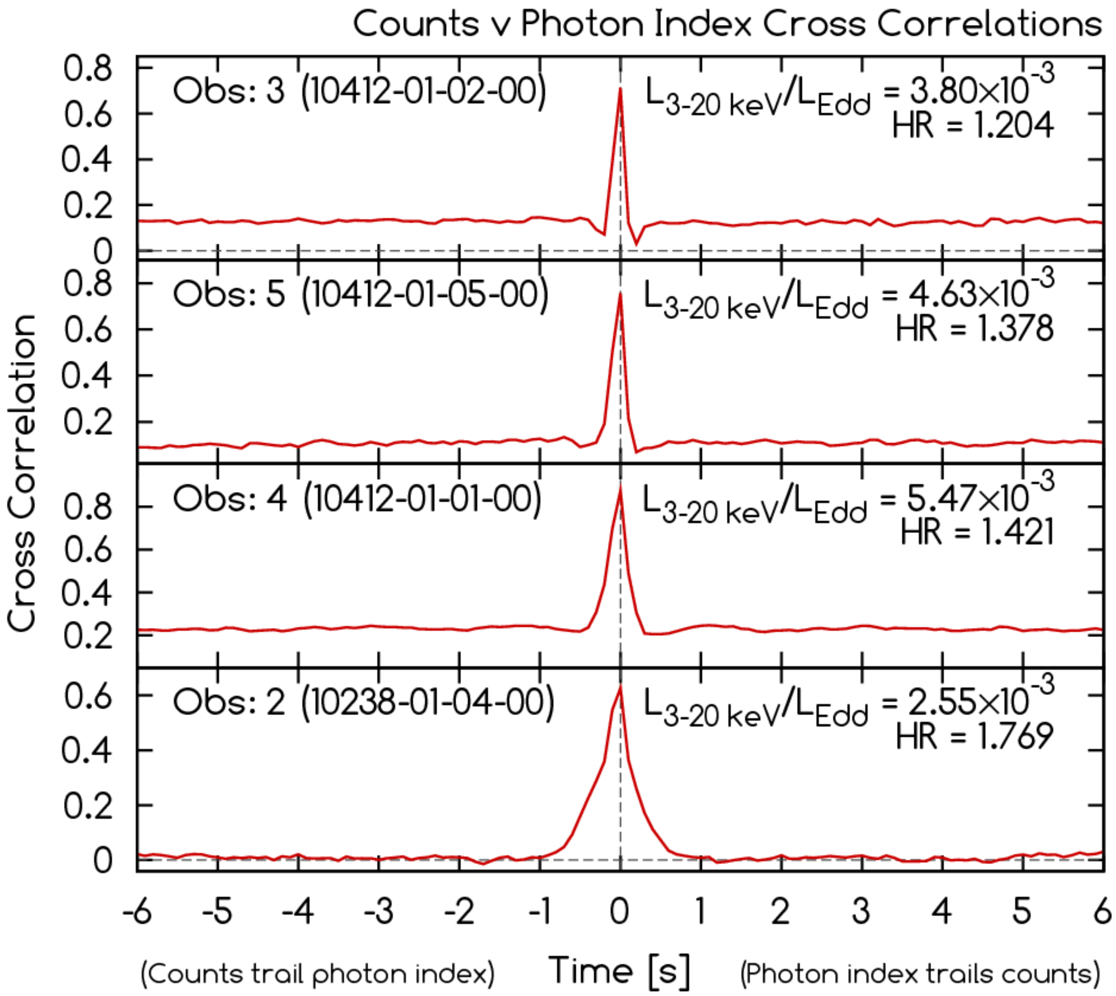
Hard state and hard-intermediate state observations.

Photon Index v Source Counts Cross Correlation Functions (Soft State)



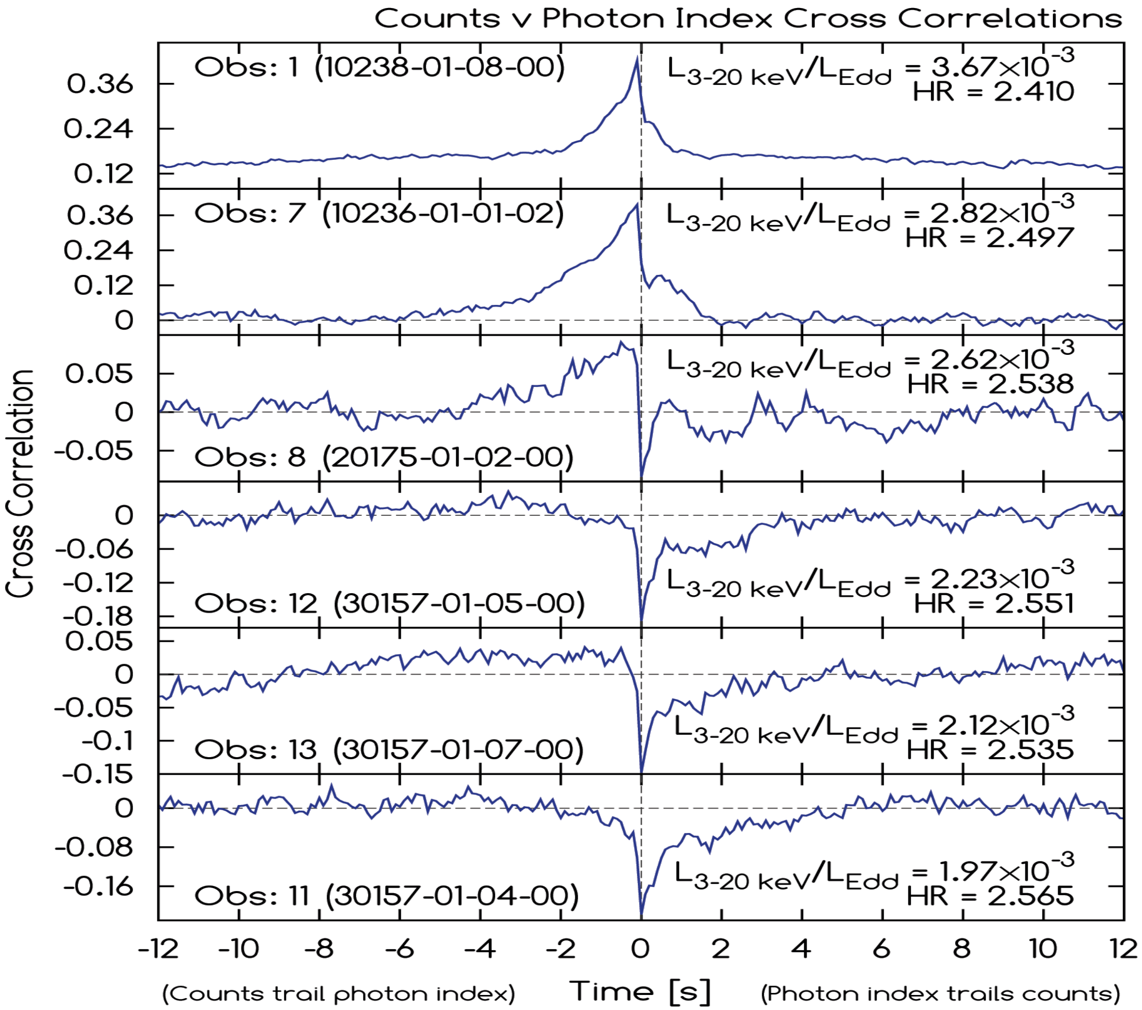
Low/hard state, hard-intermediate state and soft state observations.

Individual Observations (Soft State)



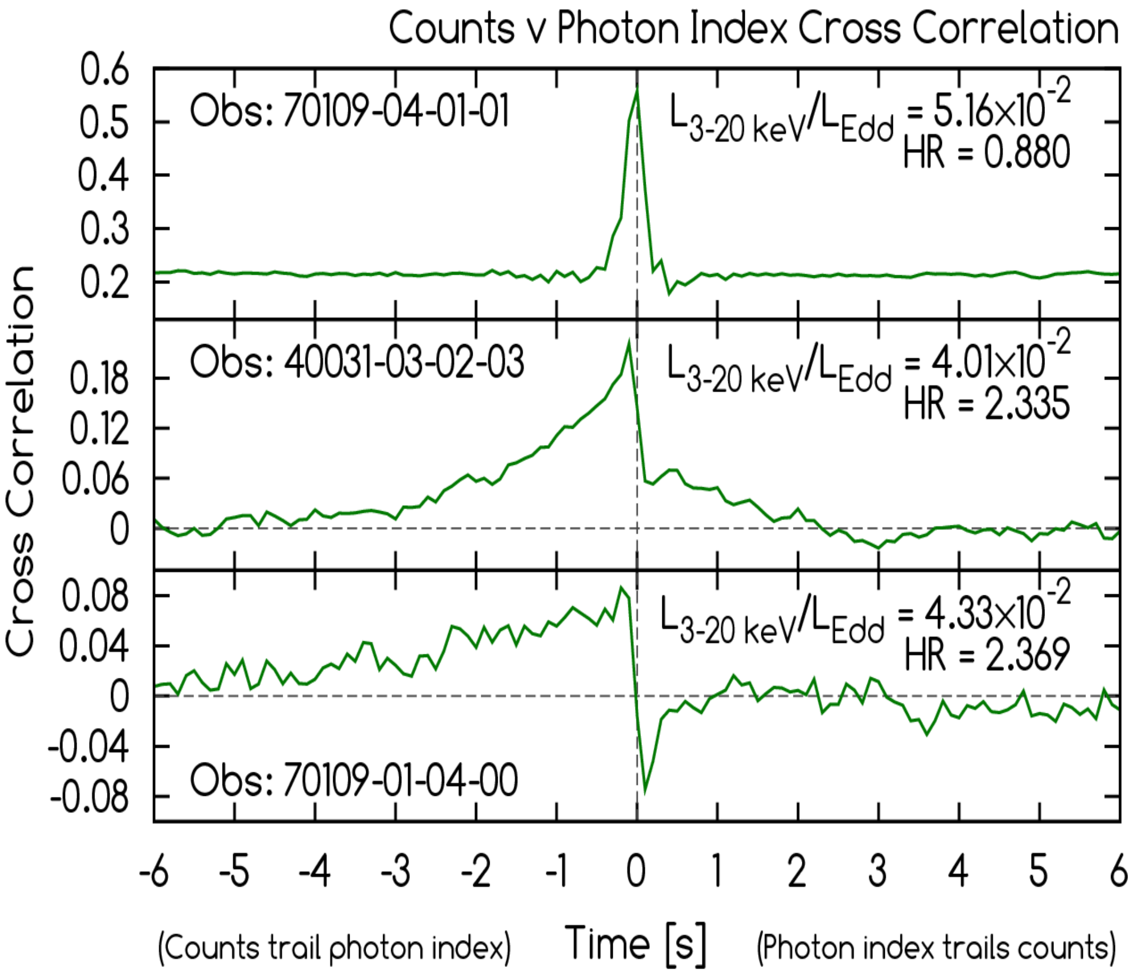
- Observations are sorted into order of hardness ratio (shown on the right-hand-side of each panel).
- Width of the peaks clearly increases with hardness ratio.
- Most of the CCFs show a much broader (~1 ks), weaker component which we associate with variability of the disk.

Individual Observations (Hard State)



- Hard state CCFs show weaker correlations than the soft states, and are less symmetric.
- The positive correlation in softer observations gives way to an anti-correlation in harder observations.
- Anti-correlation skewed to the right-hand-side.

Source Counts v Γ CCFs – Observations of GX 339-4



- A limited study of GX 339-4 shows similar behaviour to that seen in Cygnus X-1, namely a positive correlation which broadens in the harder states, a narrow anti-correlation which becomes stronger in the hardest observations and a degree of asymmetry which increases with hardness ratio.
- Observations all date from April/May 2002 as the source was rising to a soft state.

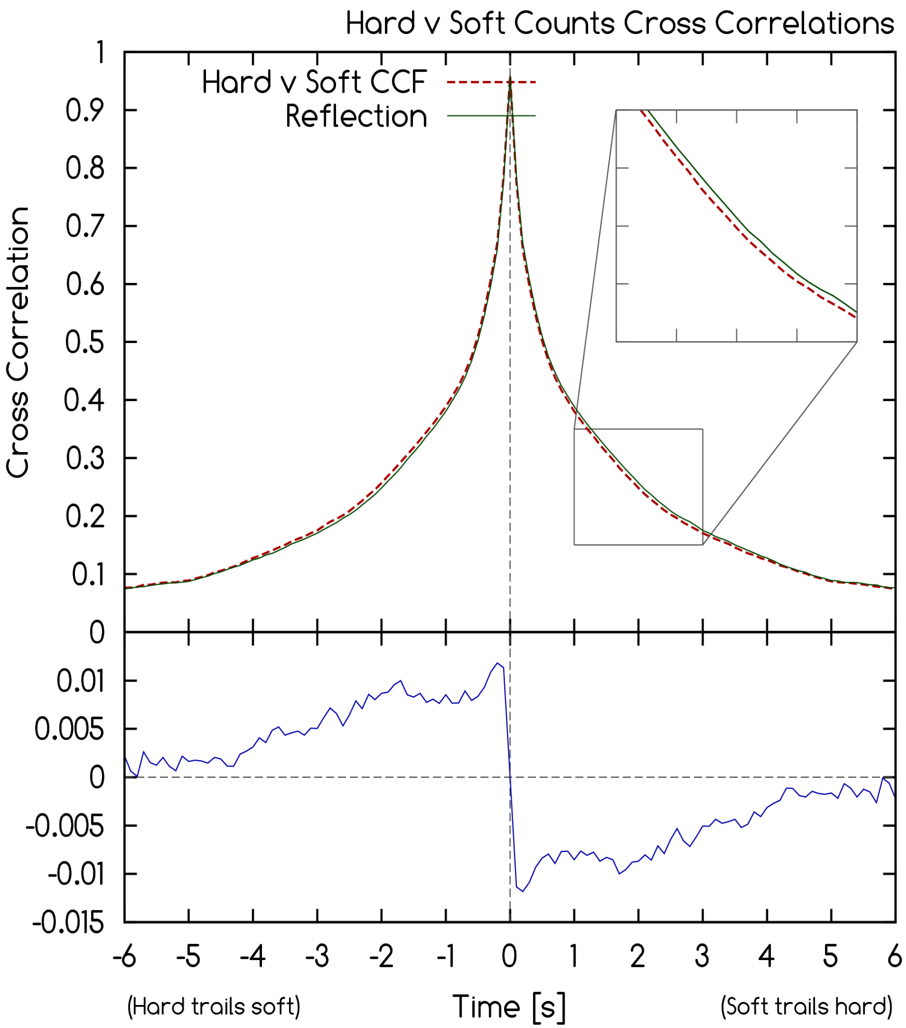
The Origin of the Positive and Negative Peaks

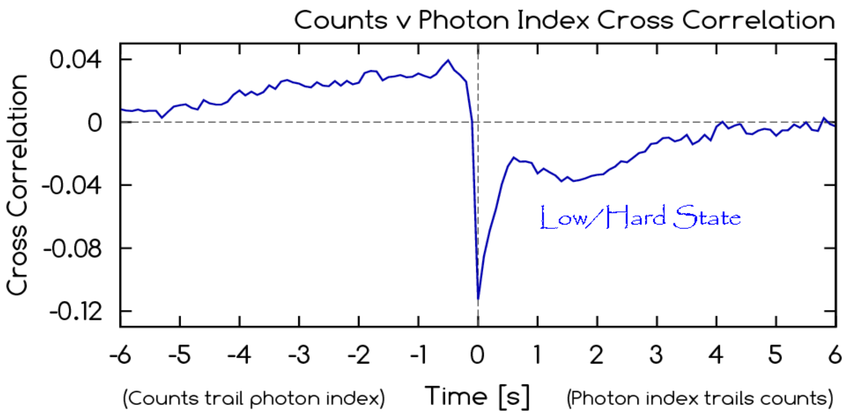
- CCFs show positive and/or negative peaks with widths less than ~10s at (or near) zero lag. The relative strength of these components depends upon the hardness ratio of the source at the time.

- The positive correlation in the soft states is consistent with Compton cooling of the corona by seed photons from the inner edge of an accretion disk. The width of the peak broadens as the source hardens, which, perhaps, could be due to truncation of the disk and/or expansion of the corona.

- We tentatively associate the narrow anti-correlation in the hard states with the self-Comptonisation of cyclo-synchrotron seed photons in the inner accretion flow.

The Soft-Hard Lag

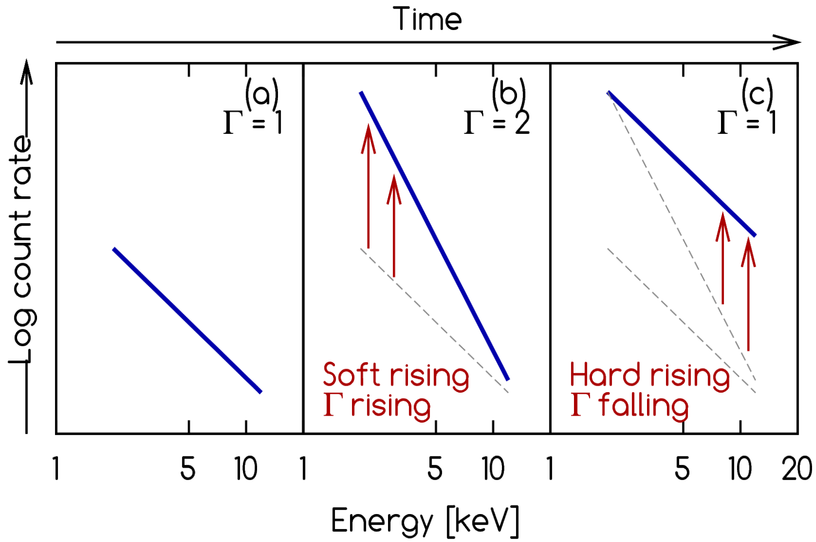


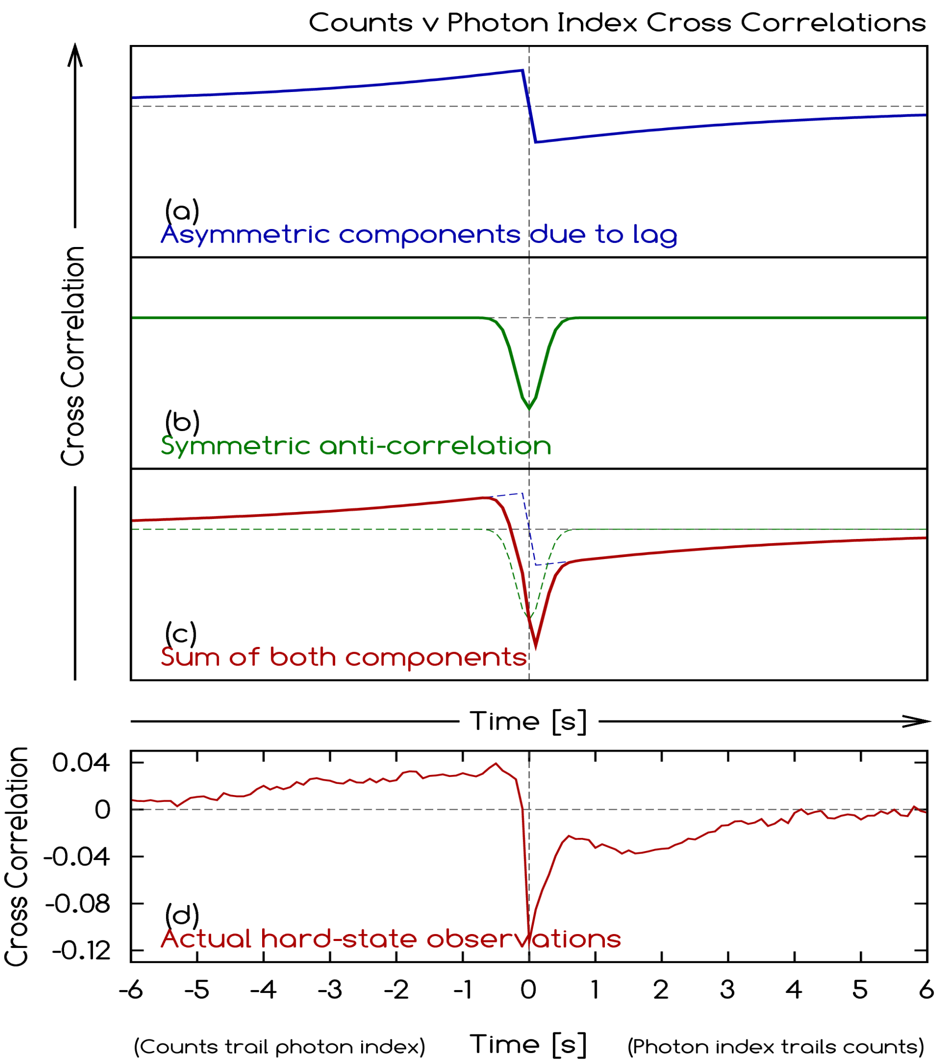


Left: CCF of hard count rate v soft count rate reveals a slight asymmetry.

Lag can be explained if there is a radial gradient in the energy or temperature of the Comptonising electrons, such that the higher energy electrons are mostly closer to the black hole than the lower energy electrons.

The Asymmetric Component





Above: A soft/hard lag causes Γ to initially rise, and then fall, as the count rate increases.

Right: This softening and hardening may be responsible for introducting the asymmetric component into the CCF.

Summary

CCFs of count rate versus photon index can be decomposed into three distinct components, the relative strength of which depends upon the hardness ratio:

- ◊ A positive correlation, peaking at zero lag which is strongest in the soft states and broadens as the hardness ratio increases. Probably caused by Compton-cooling of the corona by seed photons from the inner edge of the disk.

- ◊ A narrower negative correlation, also peaking at zero lag, which can only be seen in the hard state observations. Possibly caused by self-Comptonisation of cyclo-sychrotron emission in a hot accretion flow.

- ◊ An asymmetric component caused by small fluctuations in the fitted photon index due to changes in the hard flux lagging those in the soft flux.