Aspects of X-ray data analysis for accreting compact objects: theory and results

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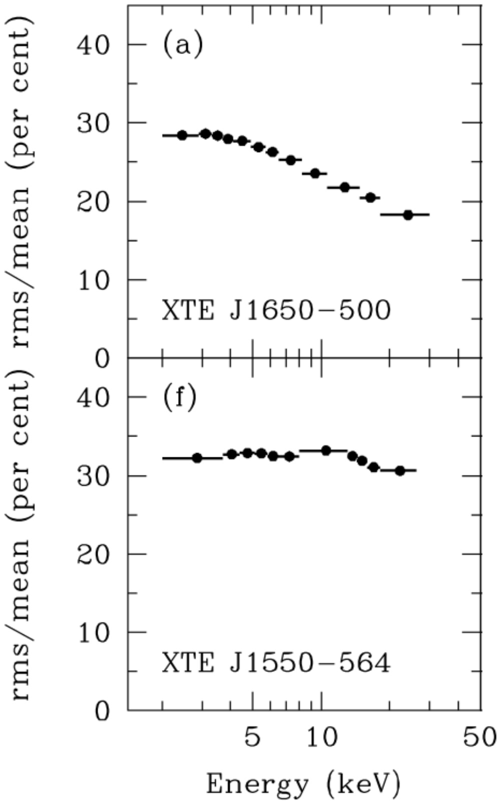
PhD lecture series, 2025, fall semester

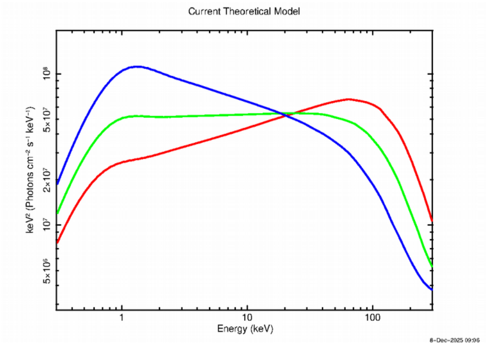
Previous lecture

Variability as a function of energy

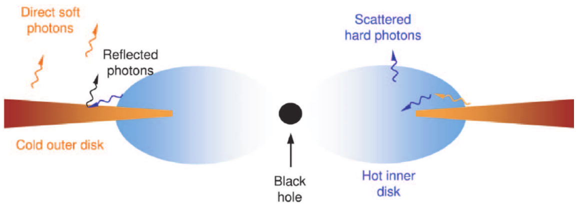


$$\mathrm{rms} = \frac{1}{x_m}\sqrt{\frac{1}{N}\sum_i^N (x_i - x_m)^2}$$

rms = 20-30%

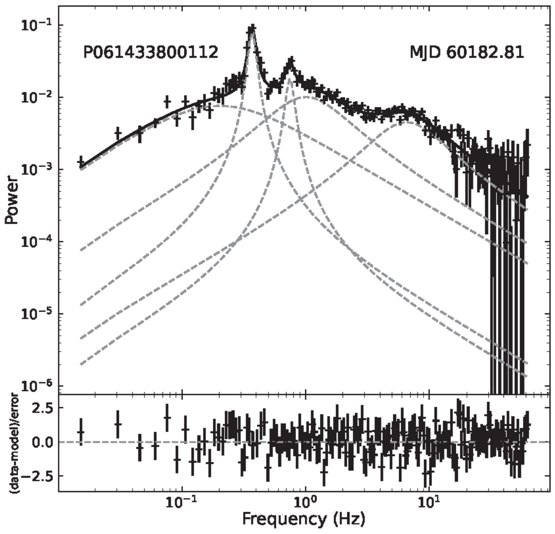


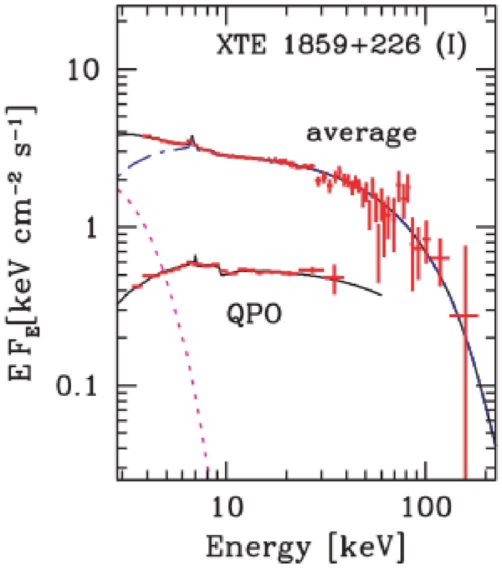
In hard state the variability is driven by changes in the soft photon flux



Previous lecture

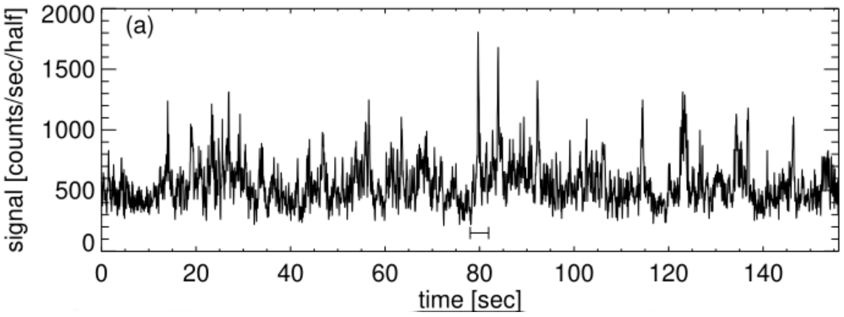
QPO: variability as a function of energy

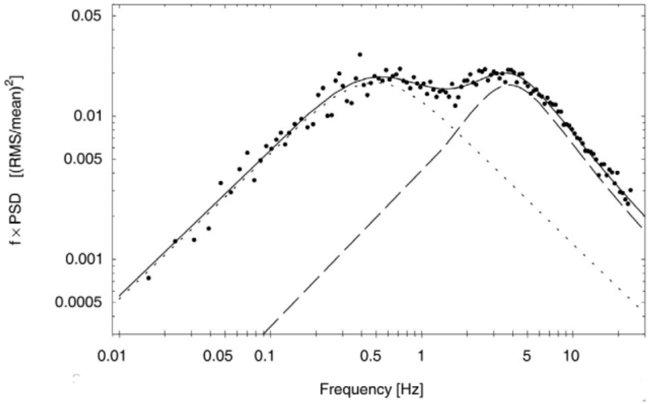




Fourier-resolved spectroscopy

Amplitude of variability: light curve vs power spectrum

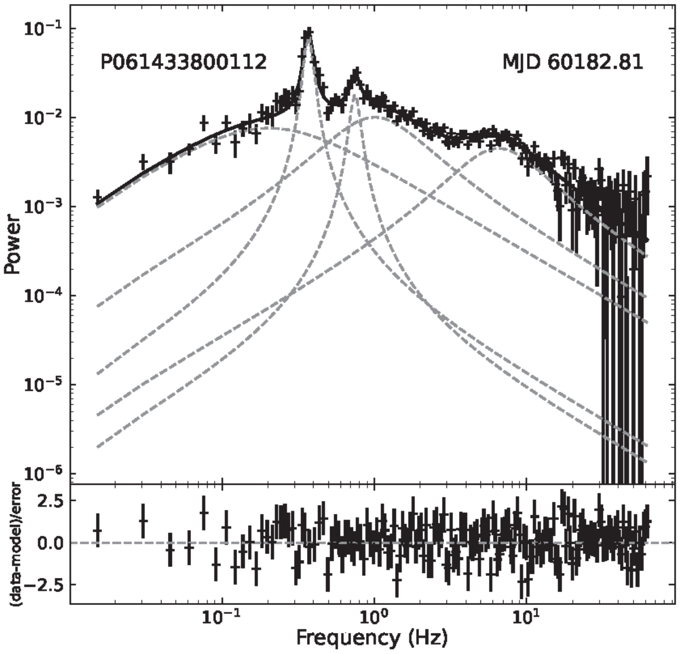




$$\mathrm{rms} = \frac{1}{x_m}\sqrt{\frac{1}{N}\sum_i^N (x_i - x_m)^2}$$

$$\mathrm{rms} = \frac{1}{x_m}\sqrt{\int_f P(f)\,df}$$

Fourier-resolved spectroscopy



$$\mathrm{rms}(f)=\frac{1}{x_m}\sqrt{\int_{\Delta f} P(f')df'}$$

Integrate
over a narrow range of frequency,
or
over a component of PSD

Do this for different energy channels, to produce spectrum as a function of Fourier f:

$$S(E;f)=\sqrt{\int_{\Delta f} P(f';E)df'}$$

How to understand Fourier-f resolved spectra?

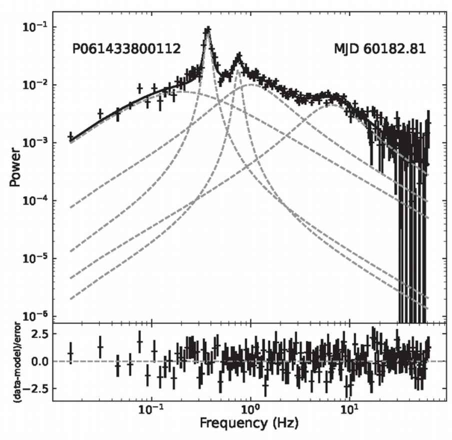
Imagine two component spectrum consisting of a variable black body and a constant power law.

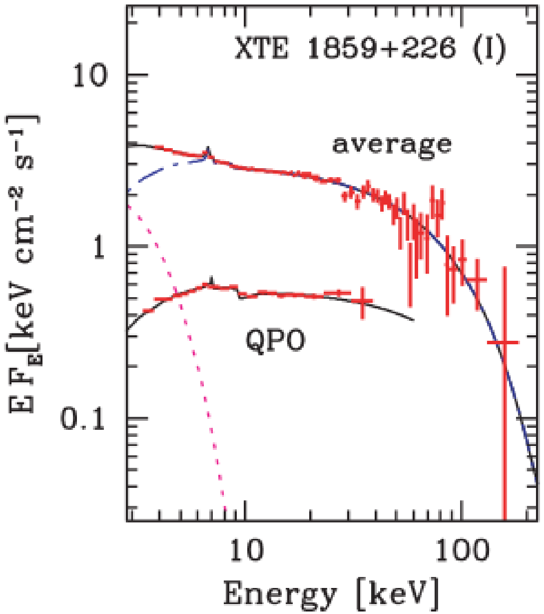
Apply a “filter” that passes through only the variable component: you see black body

Apply a “filter” that smears out the variable component: you see the constant power law

Fourier-resolved spectroscopy

Quasi-periodic oscillations - again



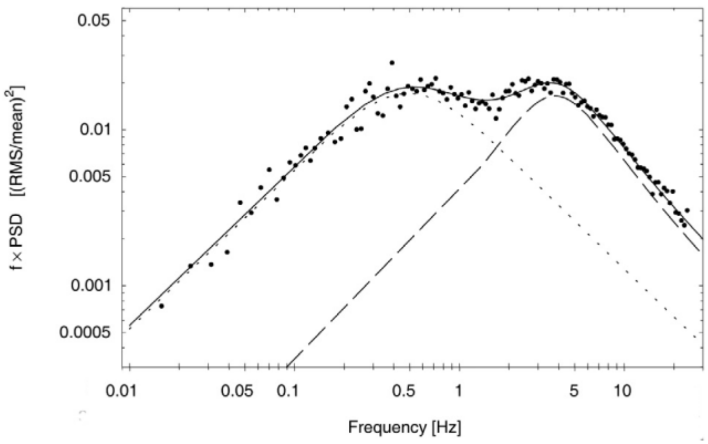


$$S(E;f)=\sqrt{\int_{\Delta f} P(f';E)\,df'}$$

This integration is over the Lorentzian component representing QPO

Fourier-resolved spectroscopy

Spectral properties as functions of Fourier frequency



1. Integrate over a small range of Fourier frequency

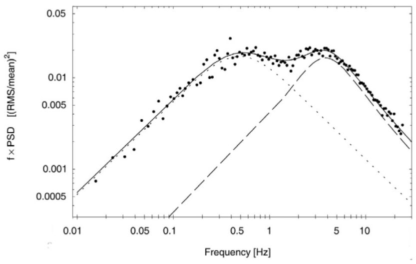
2. Do it for different energy channels

3. Produce:

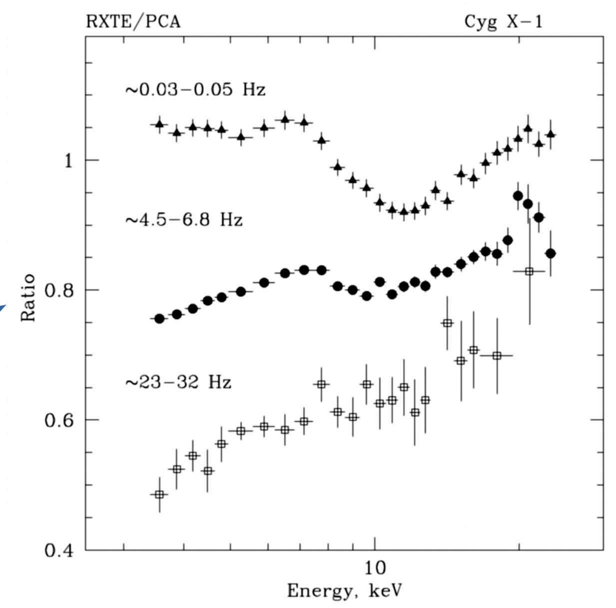
$$S(E;f)=\sqrt{\int_{\Delta f} P(f';E)\,df'}$$

Fourier-resolved spectroscopy

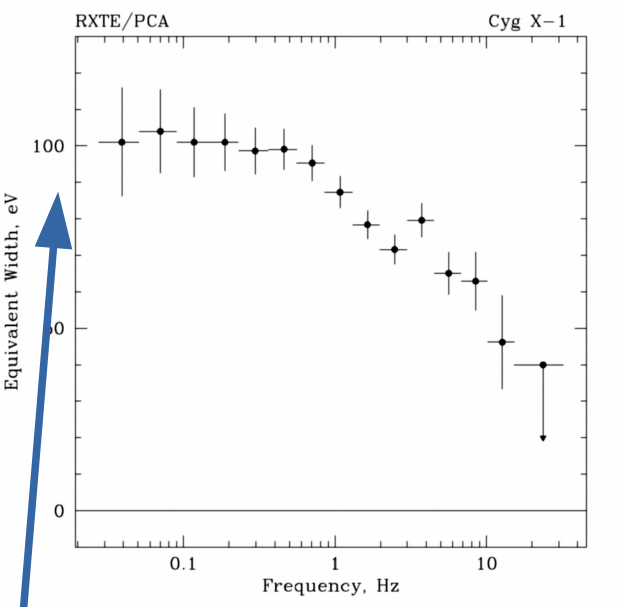
The case of regular PSD (no QPO), **Cyg X-1 in hard state**



PSD for different energies



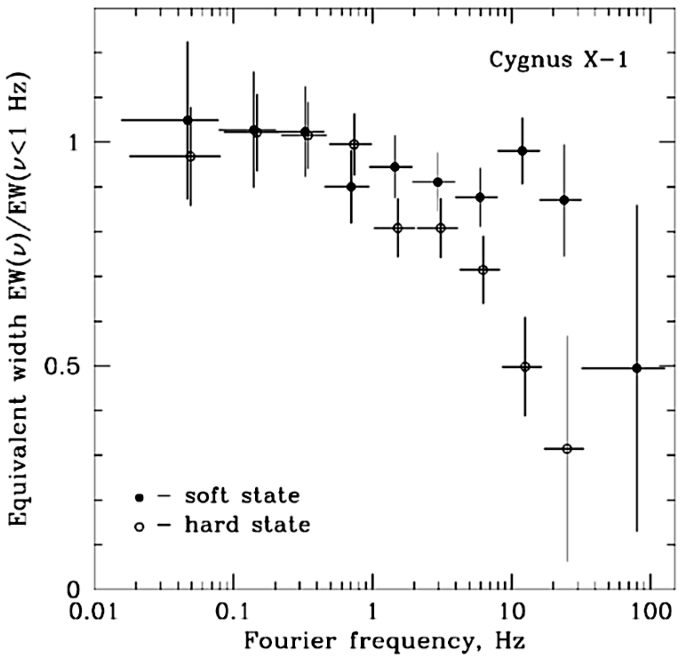
Ratio to p.l. with Γ=1.8

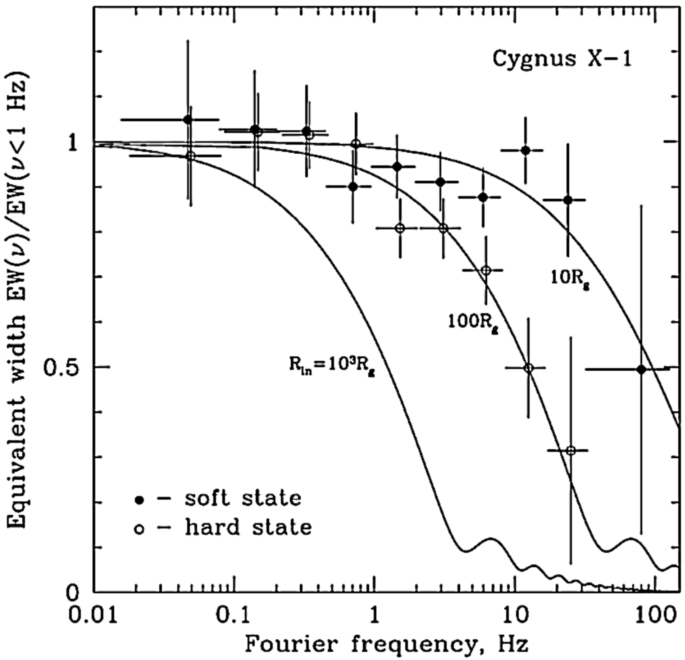


Equivalent width of the Kα line

Revnivtsev, Gilfanov, Churazov, 1999, A&A, 347, L23

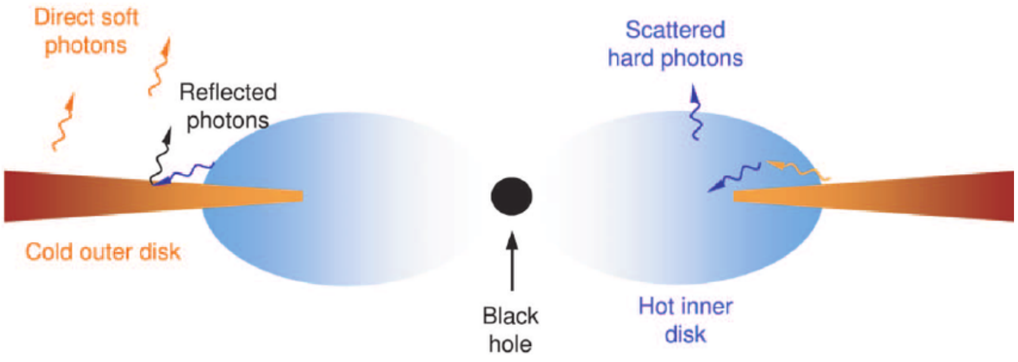
Cyg X-1 in soft state vs hard state

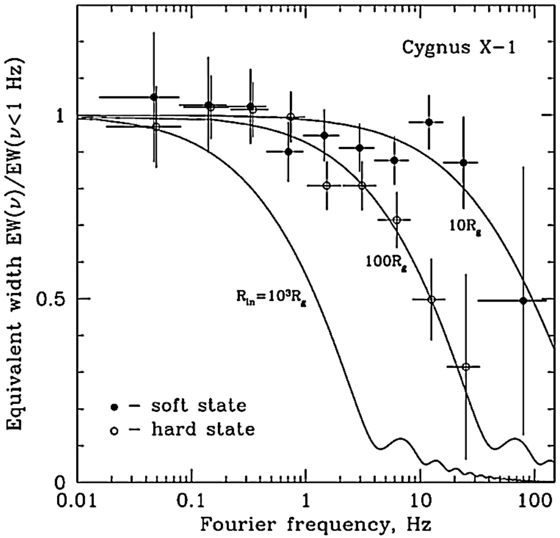




Gilfanov, Churazov, Revnivtsev, 2000, MNRAS, 316, 923

How to understand these results ?



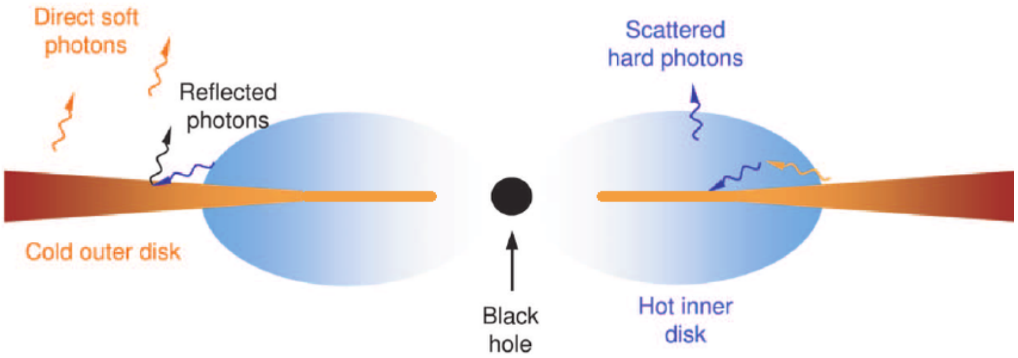


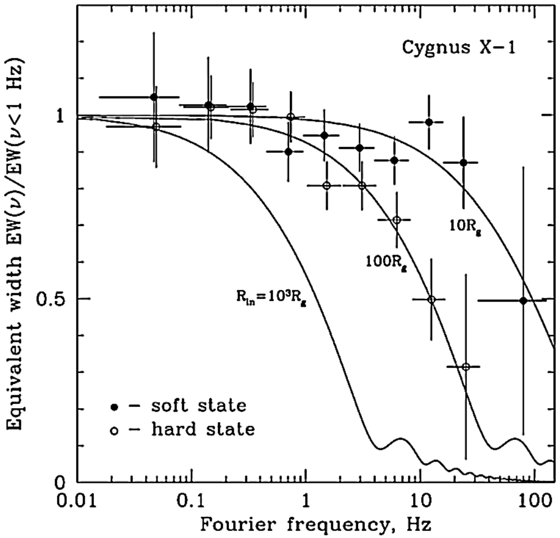
Timescale of variability (~1/*f*) maps the radial distance from the center: far away – slow; close by – fast.

Fast variability originates closer to the black hole than the slow variability. **Hard state: (1) The spectra produced closer to the black hole are harder, because of the lack of soft photons. (2) Little reflection at small radii.**

Gilfanov, Churazov, Revnivtsev, 2000, MNRAS, 316, 923

How to understand these results ?



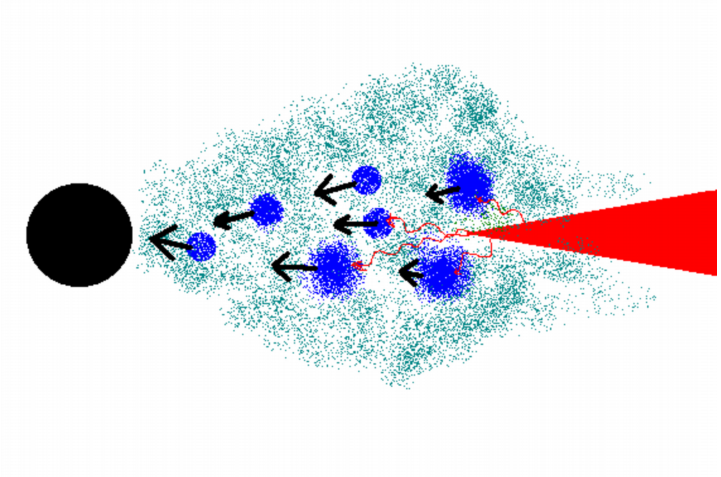


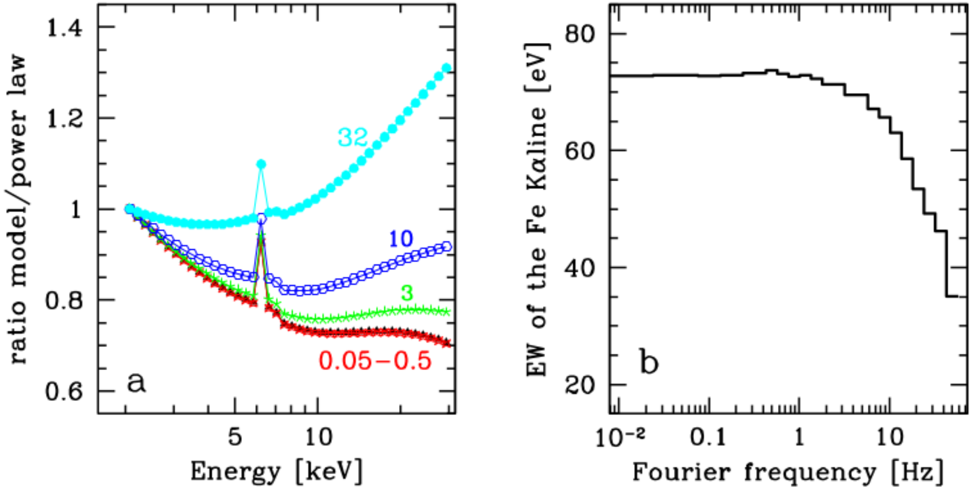
Soft state: the reflected spectra are produced also at small distances, hence at higher frequencies, so the EW remains large at high f.

Gilfanov, Churazov, Revnivtsev, 2000, MNRAS, 316, 923

How to understand these results ?

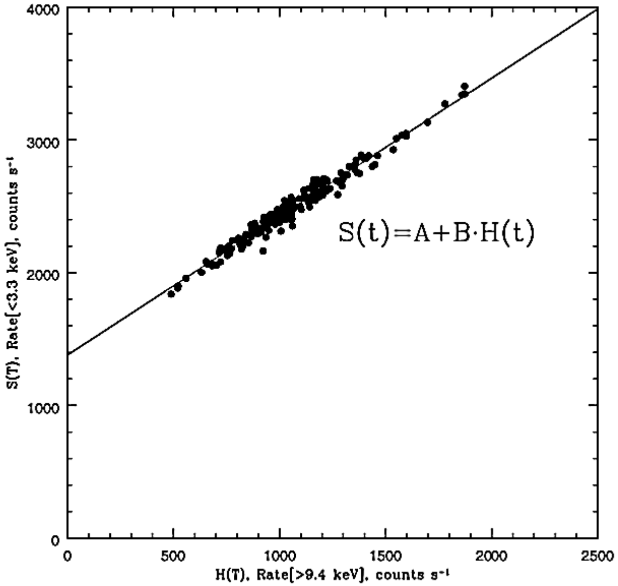
Propagating perturbations

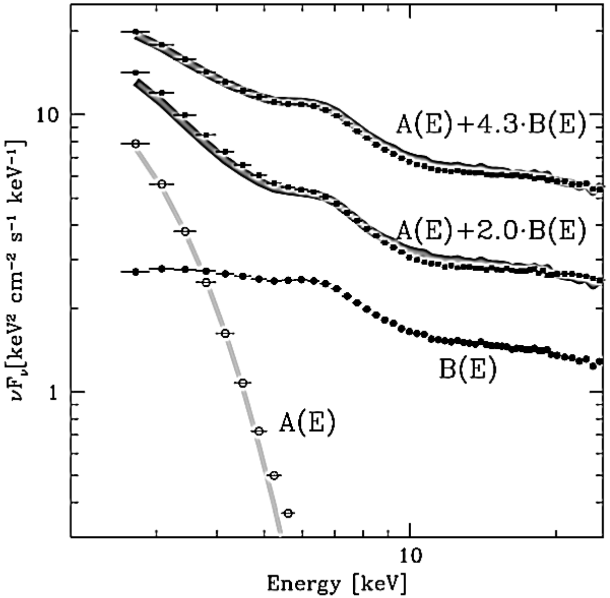




Życki, 2003, MNRAS, 340, 639

Cyg X-1 in soft state





The character of variability indicates that the disk is constant while the Comptonized emission varies.

Churazov, Gilfanov, Revnivtsev, 2001, MNRAS, 321, 759