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

Piotr Życki

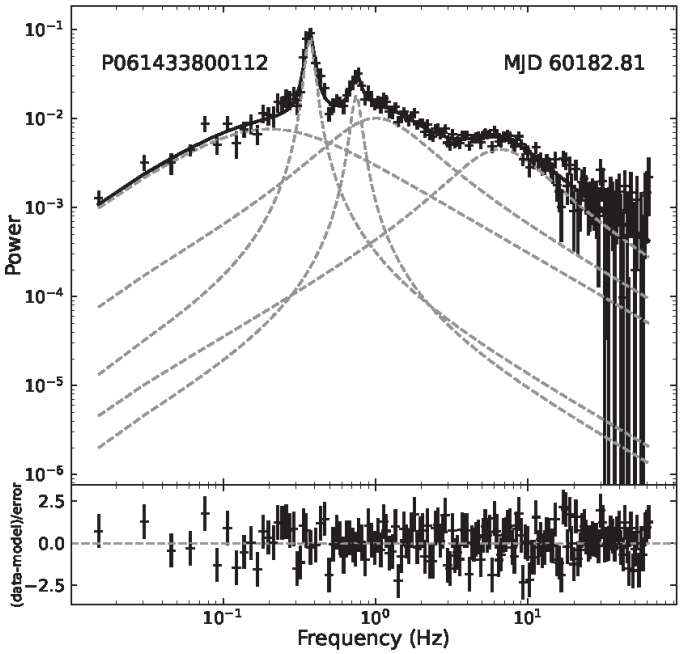
Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences

Lecture 10, 8.01.2026

PhD lecture series, 2025/26, fall semester

Previous lecture

Fourier-resolved spectroscopy



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

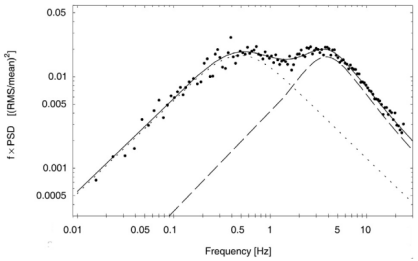
Integrate
over a narrow range of frequency,
or
over a component of PSD

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

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

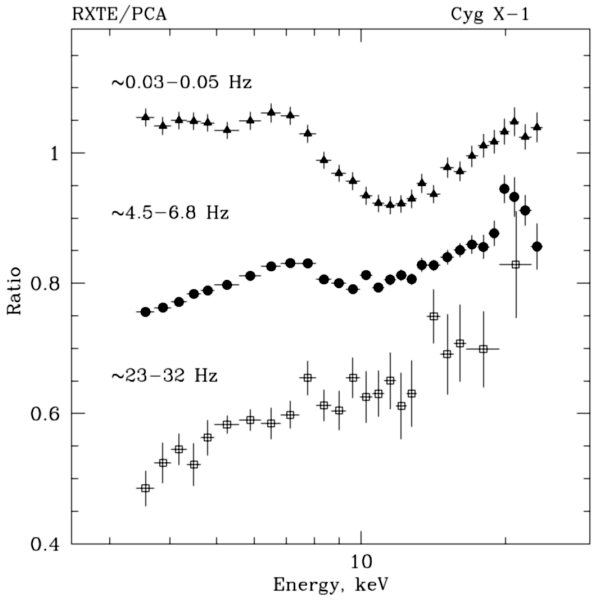
Previous lecture

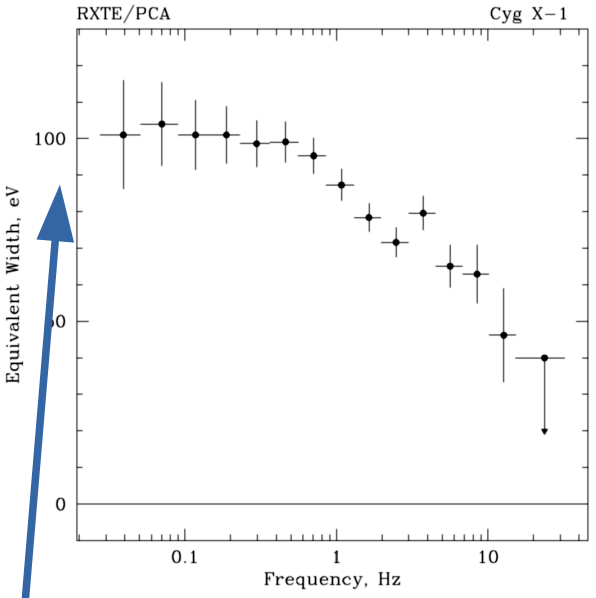
The case of regular PSD (no QPO), **Cyg X-1 in hard state**



PSD for different energies

Ratio to p.l. with Γ=1.8

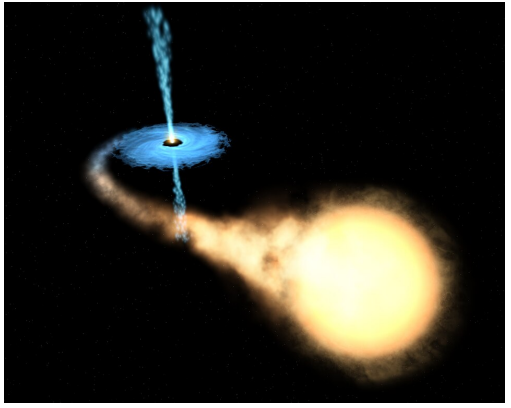




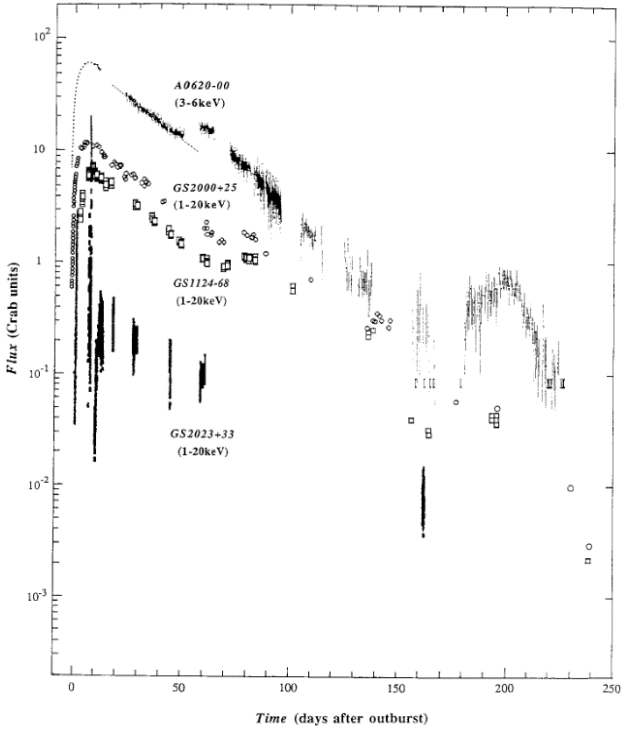
Equivalent width of the Kα line

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

Neutron star X-ray binaries



Soft x-ray transients

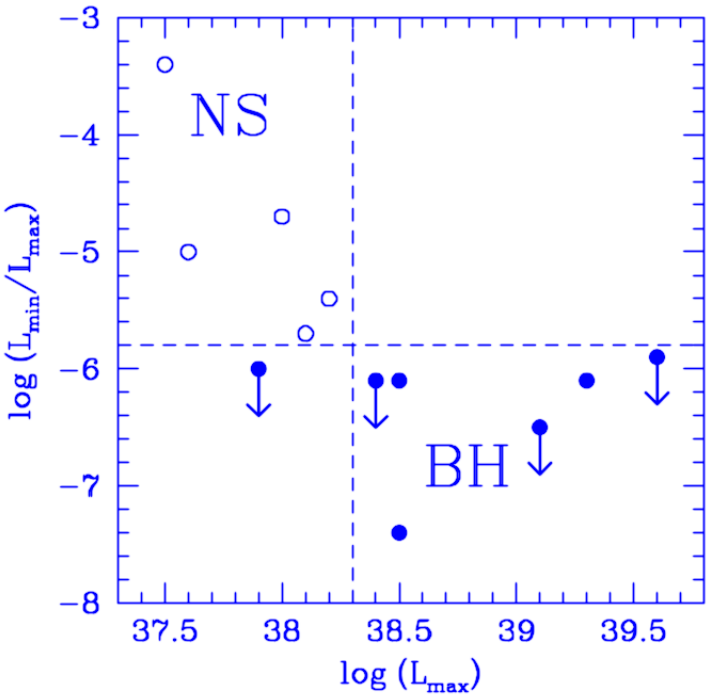


Black hole vs Neutron star transient sources

Soft x-ray transients

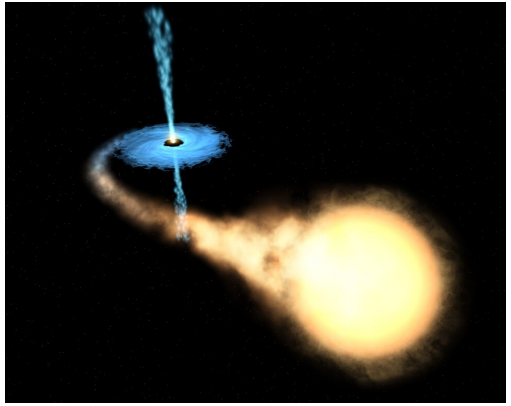
Black hole transients have a larger “swing” of luminosity between minimum and maximum during an outburst, meaning their minimum luminosities are lower than NS systems.

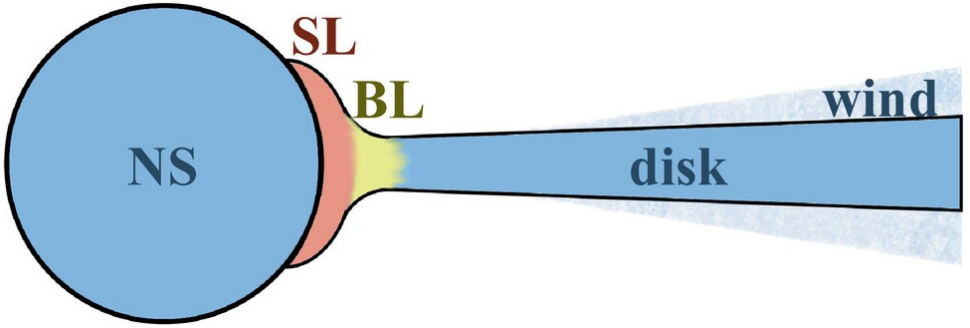
This is an evidence for the event horizon in black holes



R. Narayan et al., 1997

Neutron star X-ray binaries





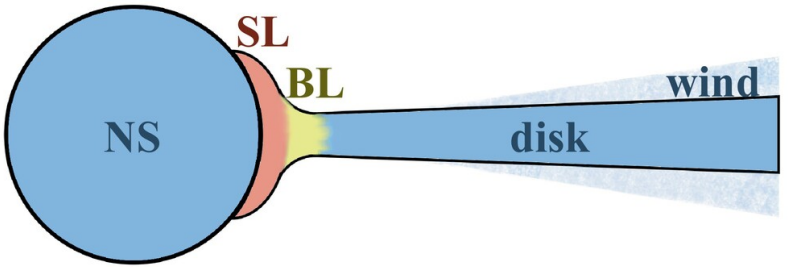
Bobrikova & Folsbrom, 2024

Neutron star X-ray binaries

$$E_p = -\frac{G M m}{r}$$

$$E_k = \frac{1}{2} m v^2 = \frac{1}{2} \frac{G M m}{r} = -\frac{1}{2} E_p$$

$$\Delta E = E_p + E_k - 0 = \frac{1}{2} E_p$$

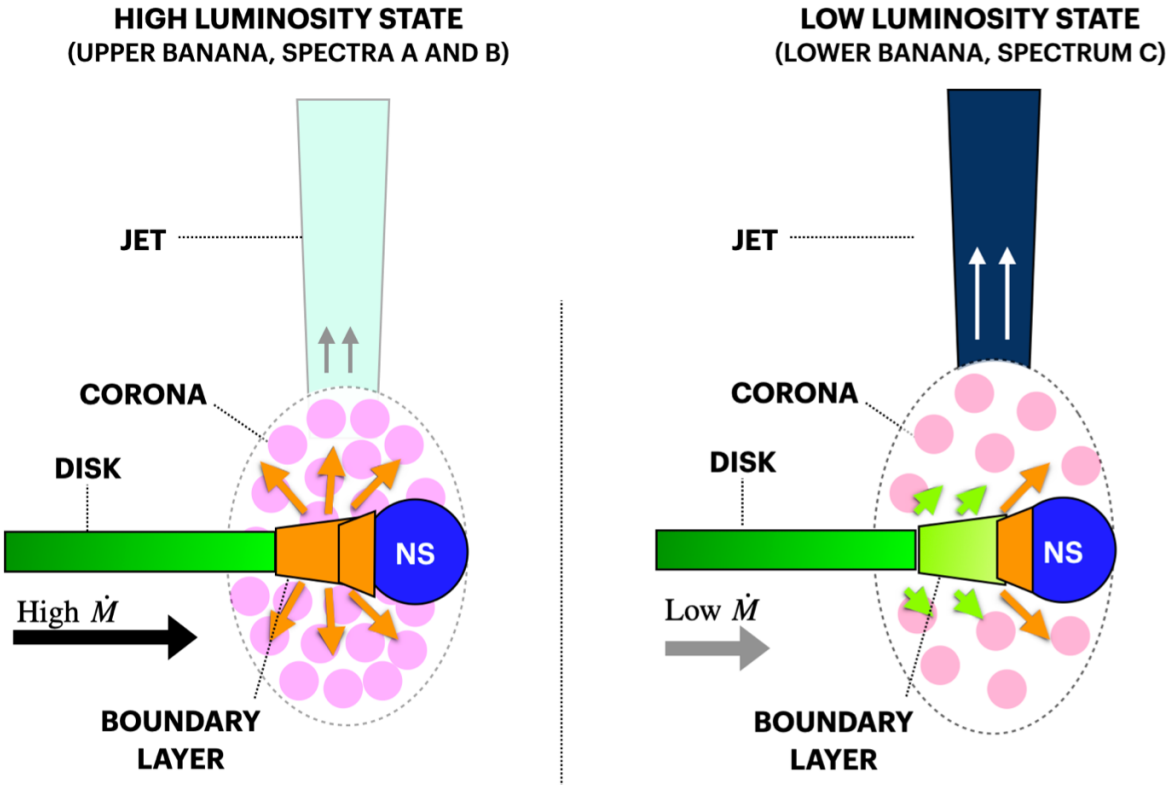


In NS systems the kinetic energy the gas has at the boundary layer will be dissipated there, while in BH systems it will swallowed by the BH.

In Newtonian dynamics (above) the gas will emit the same amount of energy as the energy left. In relativistic calculations the amount of left energy is twice larger than the emitted. If the NS rotates the amount released is smaller.

So, the boundary layer/NS surface will emit a lot of energy!

Neutron star X-ray binaries

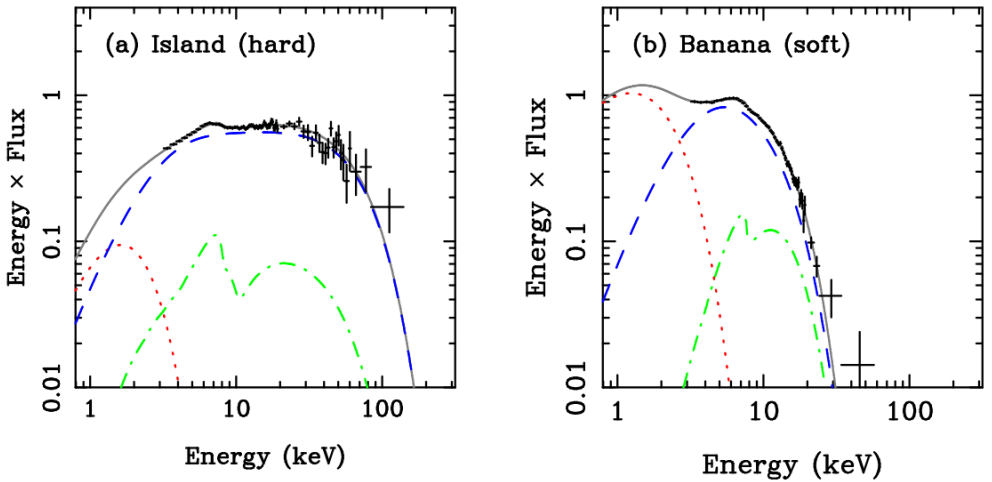


A. Marino, et al. 2023

X-ray spectra of NS XRB

Spectral components observed:

- Soft thermal component 1-2 keV
- Hard Comptonized tail,
  up to tens of keV
- Occasional reflection features



4U 1705–44

Done, Gierliński, Kubota, 20007

Two interpretations of the spectral model

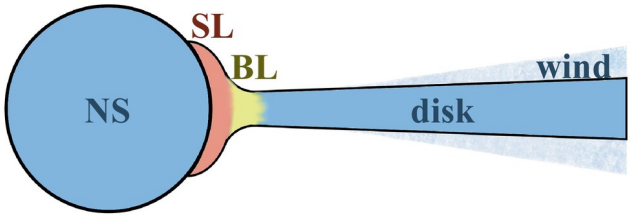
Eastern vs. Western model

Eastern model (Mitsuda et al. 1989):

- Disk blackbody emission from an accretion disk
- Comptonized emission from boundary layer

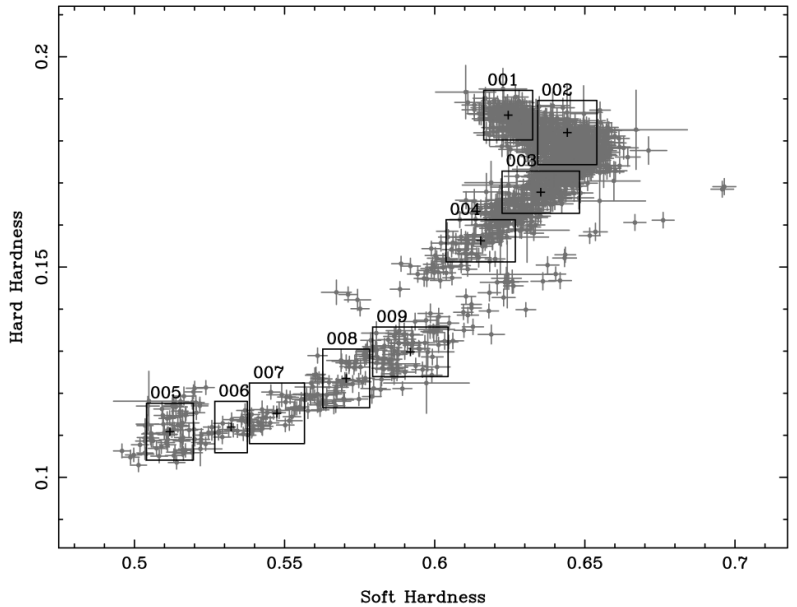
Western model (White et al. 1988):

- Blackbody emission from neutron star surface
- Comptonized emission from accretion disk



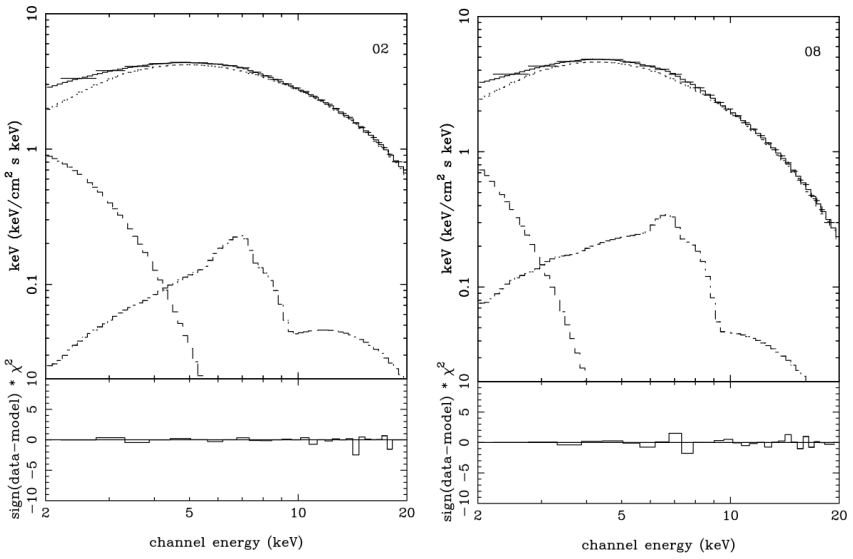
Eastern vs. Western model

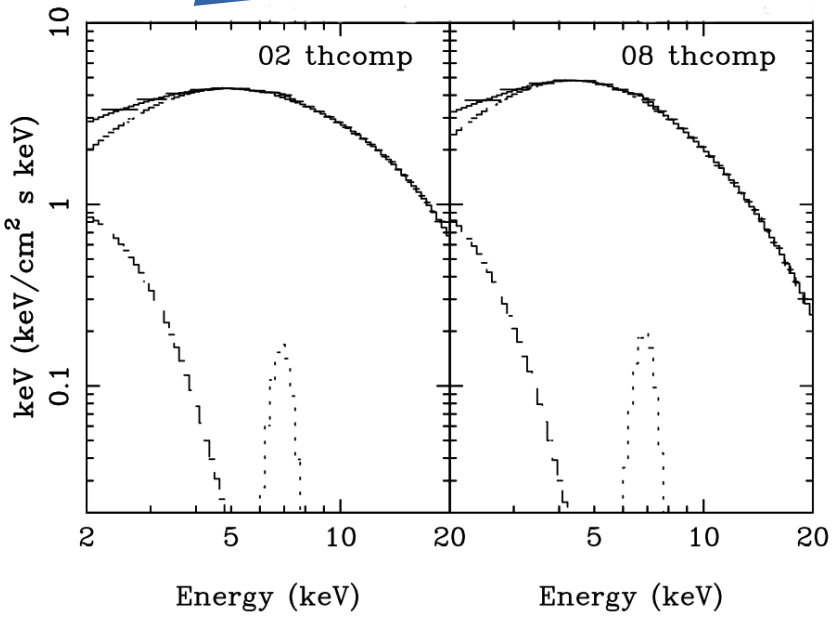
Cyg X-2



C. Done et al., 2002, MNRAS, 331, 453

Eastern vs. Western model for Cyg X-2





Disk blackbody + Comptonization

Blackbody + Comptonization

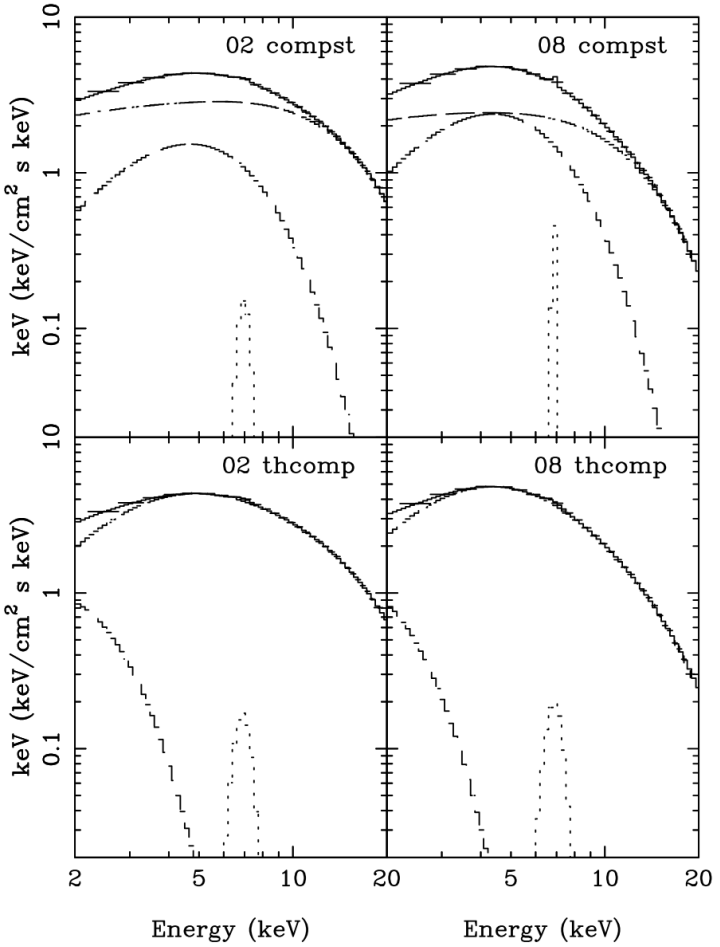
C. Done et al., 2002, MNRAS, 331, 453

Eastern vs. Western model for Cyg X-2

Western model.

The need for proper spectral models used to model the data.

Upper panels used a physically incorrect model (common at that time), drawing wrong conclusions

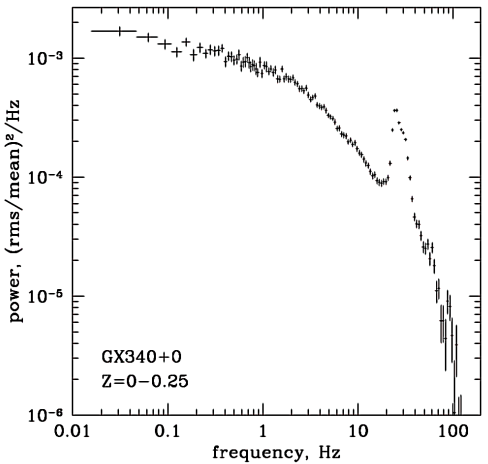


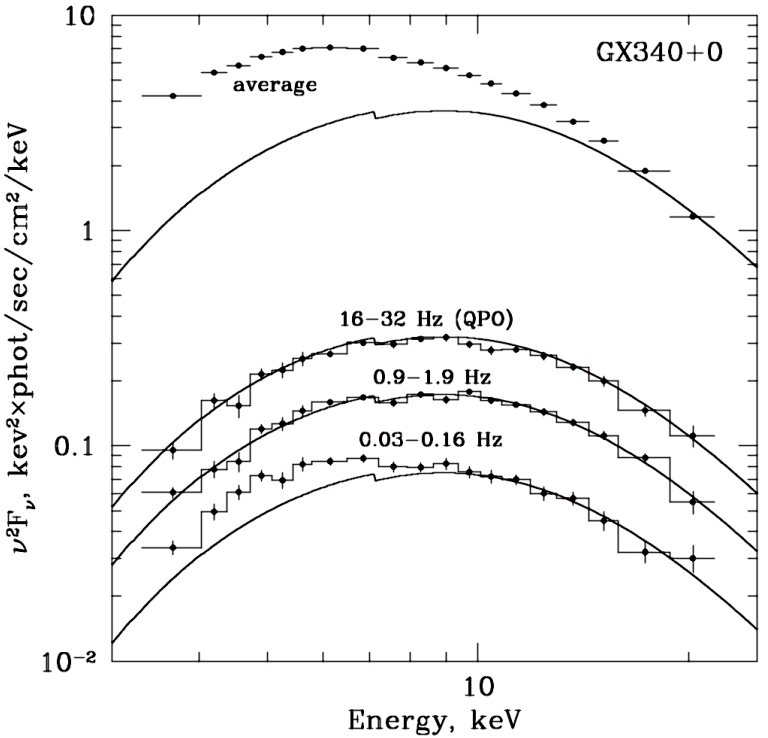
C. Done et al., 2002, MNRAS, 331, 453

What is the correct model?

Use variability!

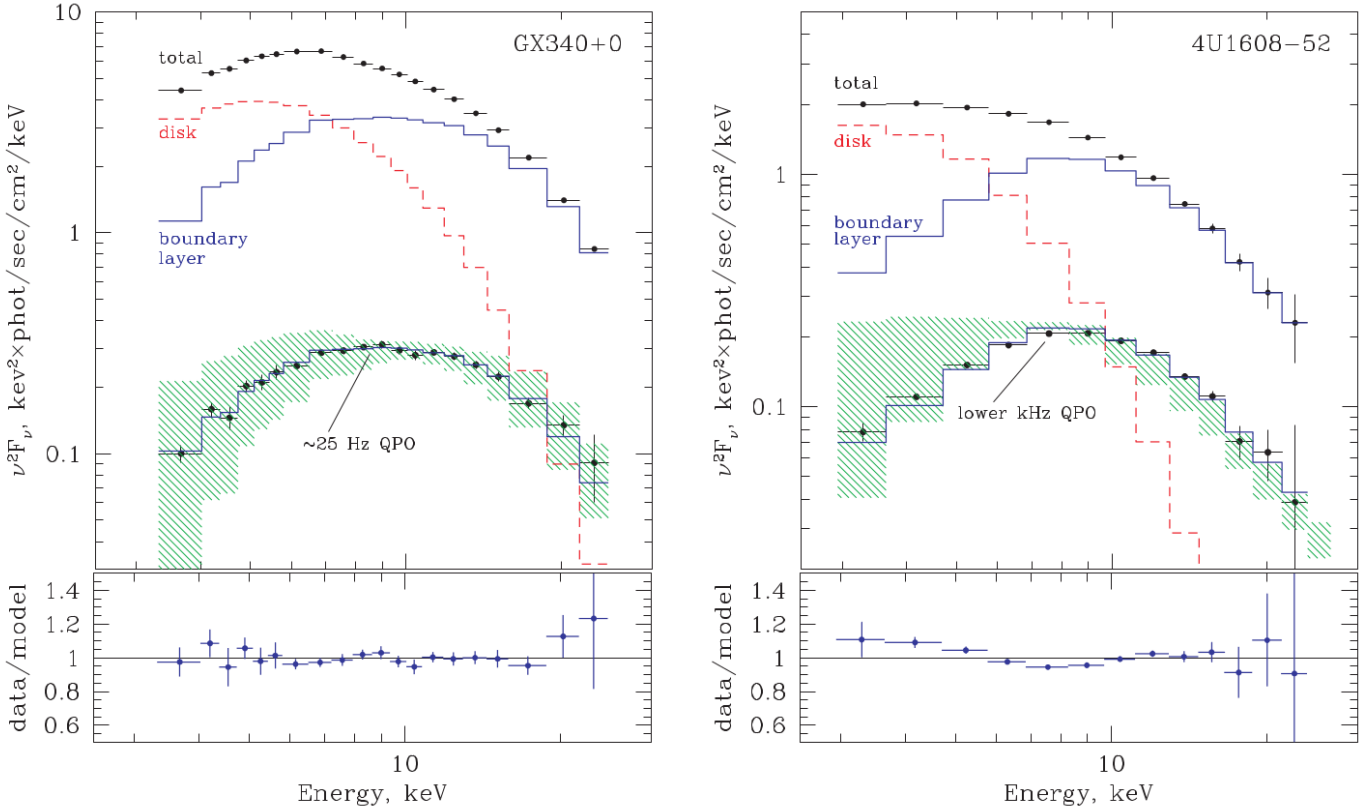
Fourier-frequency resolved spectra





Gilfanov et al., 2003, A&A, 410, 217

What is the correct model?



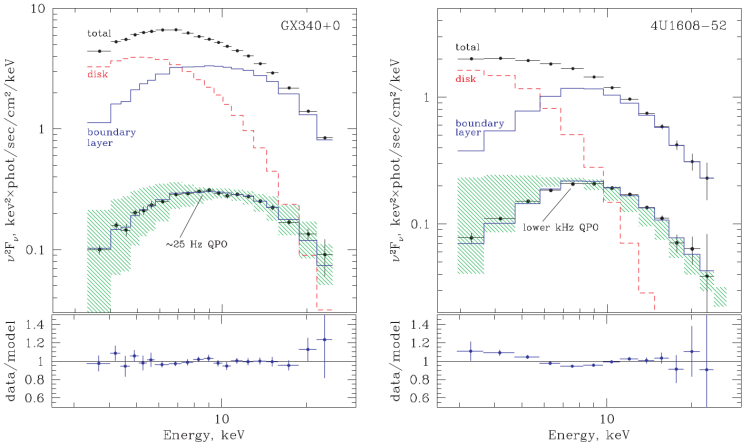
Gilfanov et al., 2003, A&A, 410, 217

What is the correct model?

The variable component has spectral shape of Comptonized emission.

Variability is expected from the boundary layer, not the disk.

So, the Comptonized emission comes from the boundary layer – this is the **Eastern** model



Gilfanov et al., 2003, A&A, 410, 217