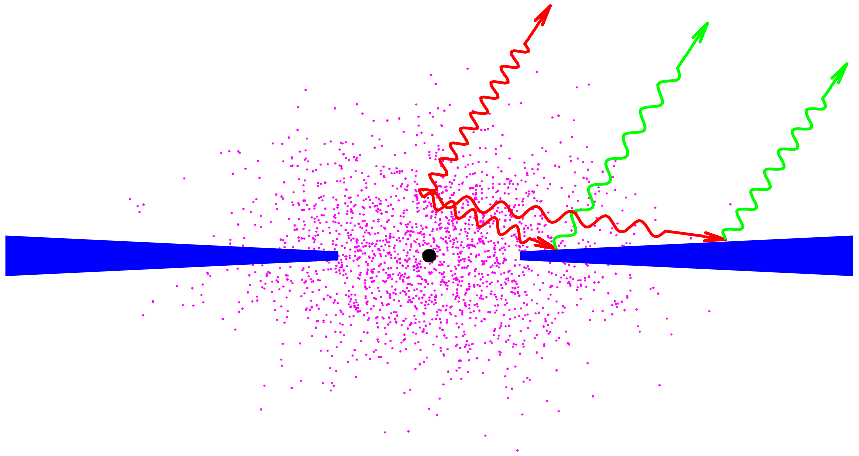
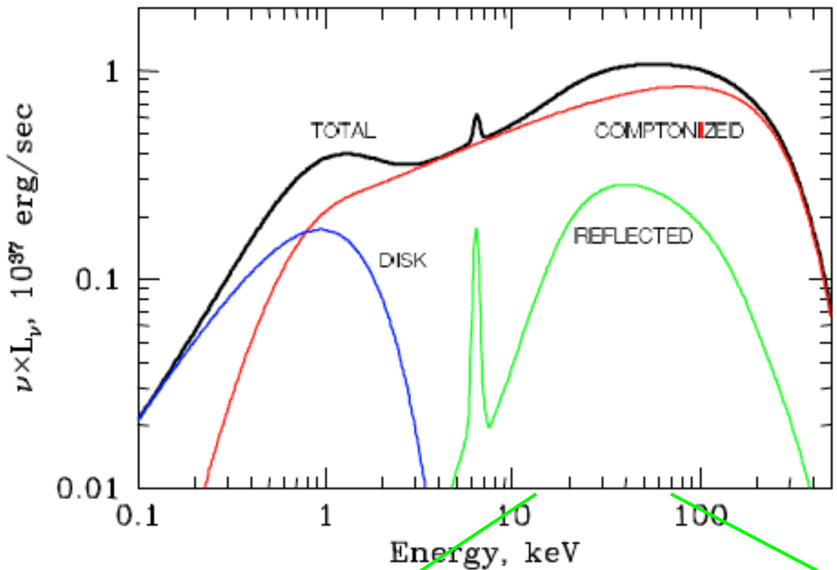
Reflected emission

contains important information about **geometry** of the accretion flow

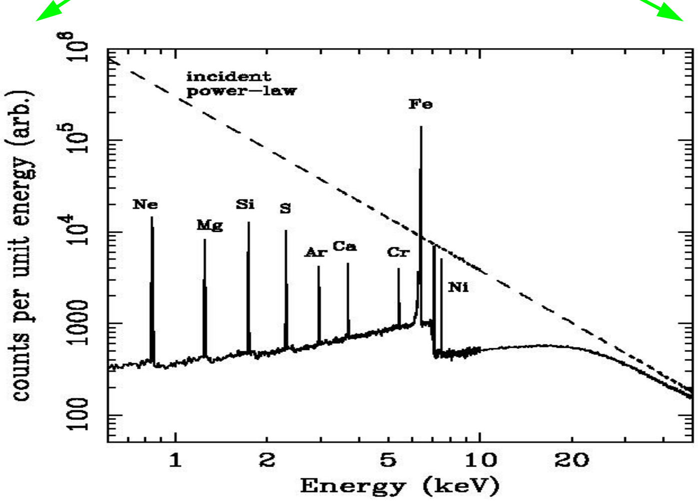


Reflected emission. Theory



Basko, Sunyaev & Titarchuk, 1974;

George & Fabian 1991



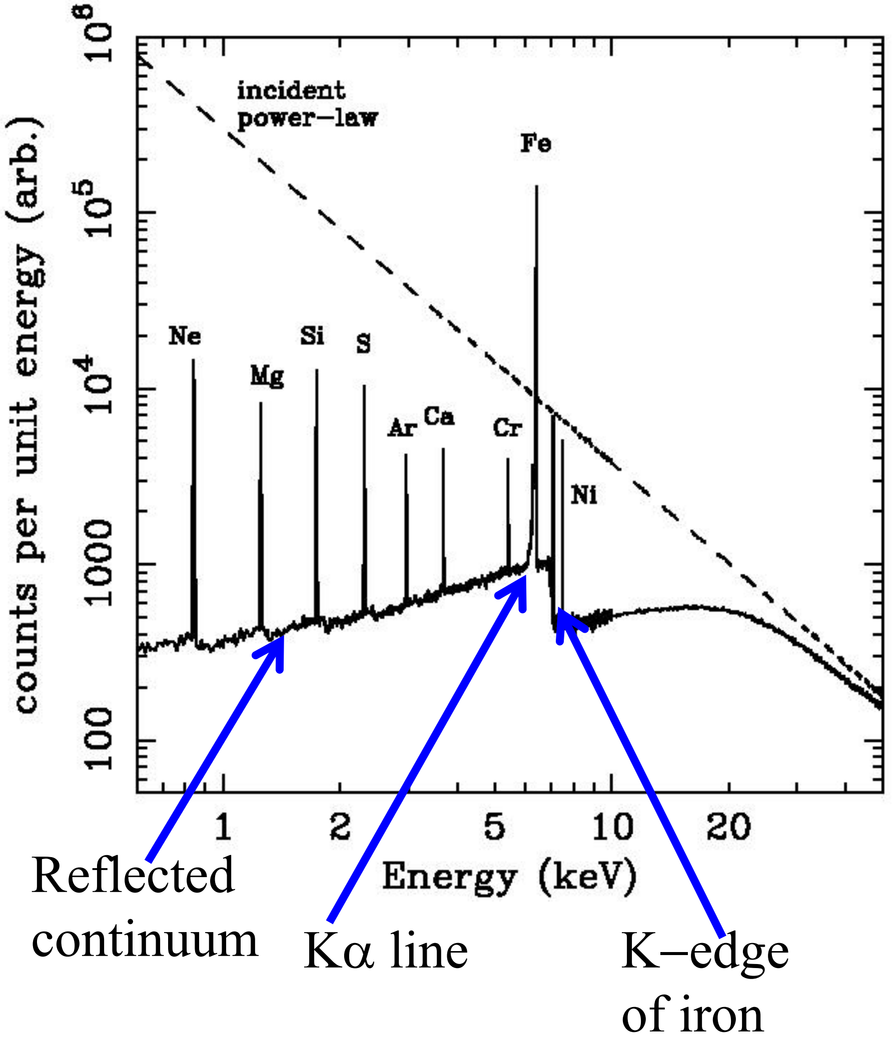
Reflected emission. Theory

- Compton scattering
  reflected continuum

- photoabsorption
  K-edges & fluorescent lines
  of metals

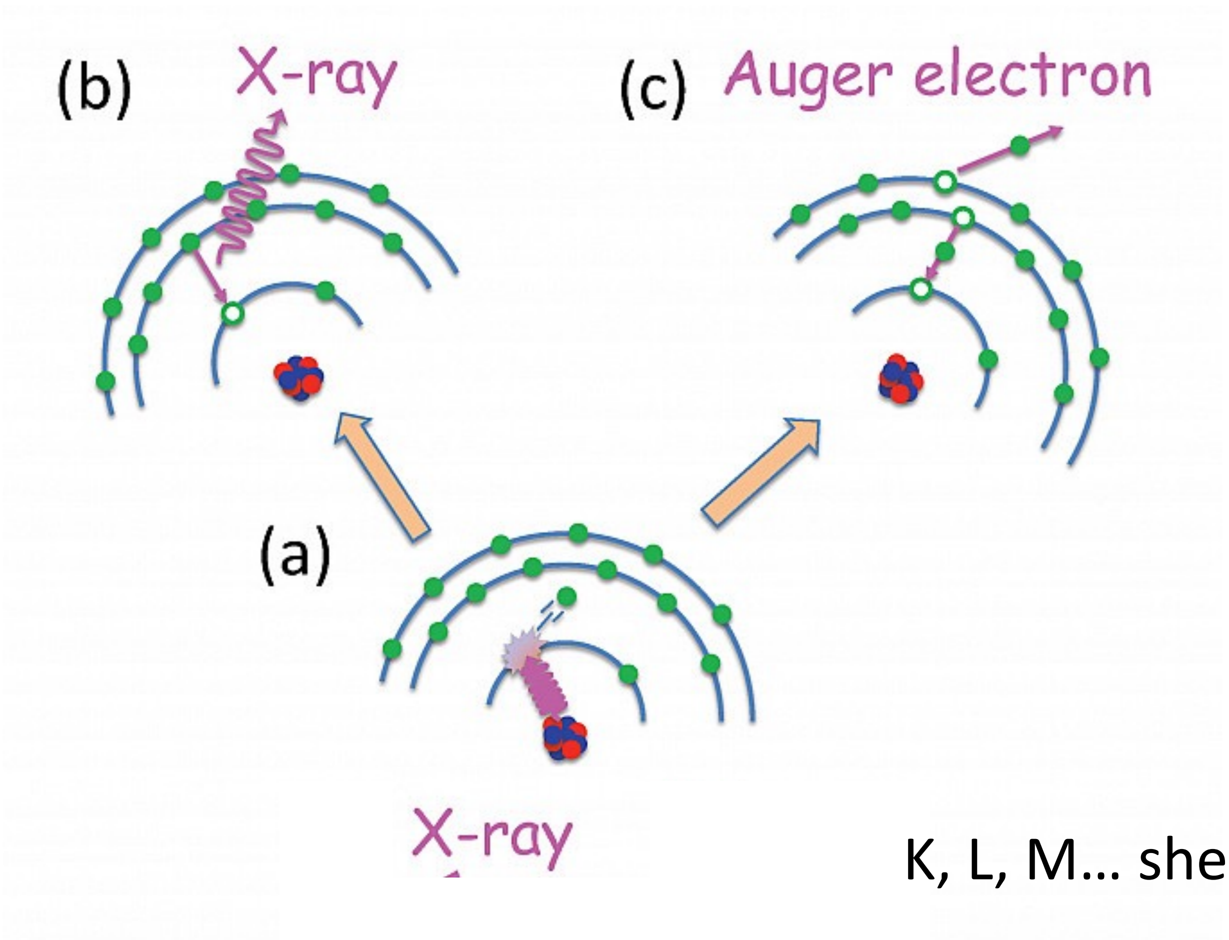
$$\boldsymbol{E \propto Z^2}$$

- **Iron K-shell features**



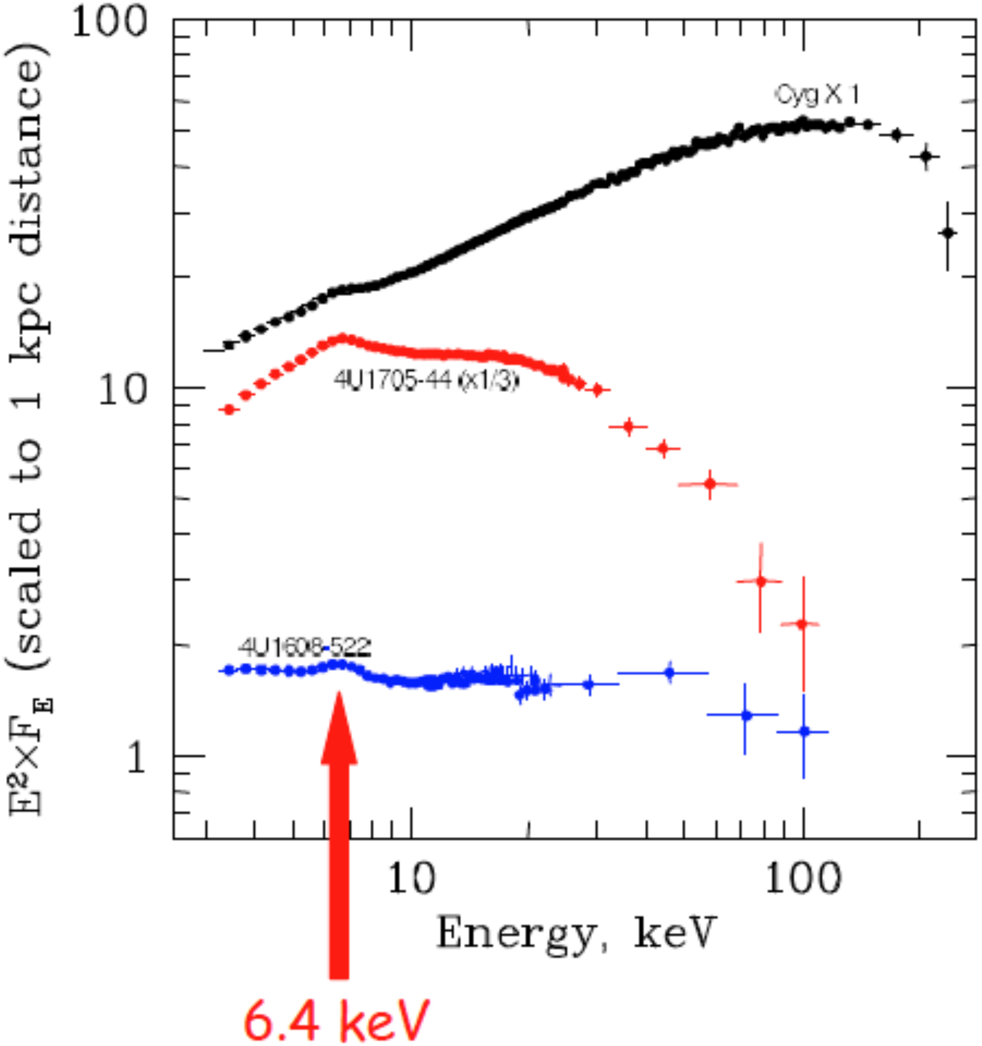
$\sigma_{ph-i} \approx \sigma_T$ at 8 keV

Fe Kα line



K, L, M… shells

Reflected emission: Observations



Reflection: Additional effects

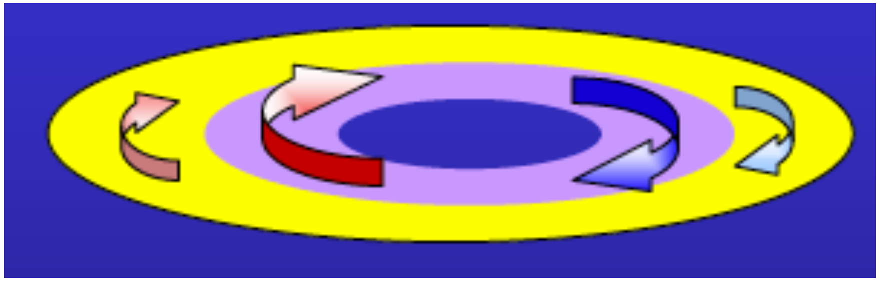
- Double-peak profile
- Doppler boosting (relativistic Keplerian motion in the disc causes Doppler frequency shift and relativistic aberration)

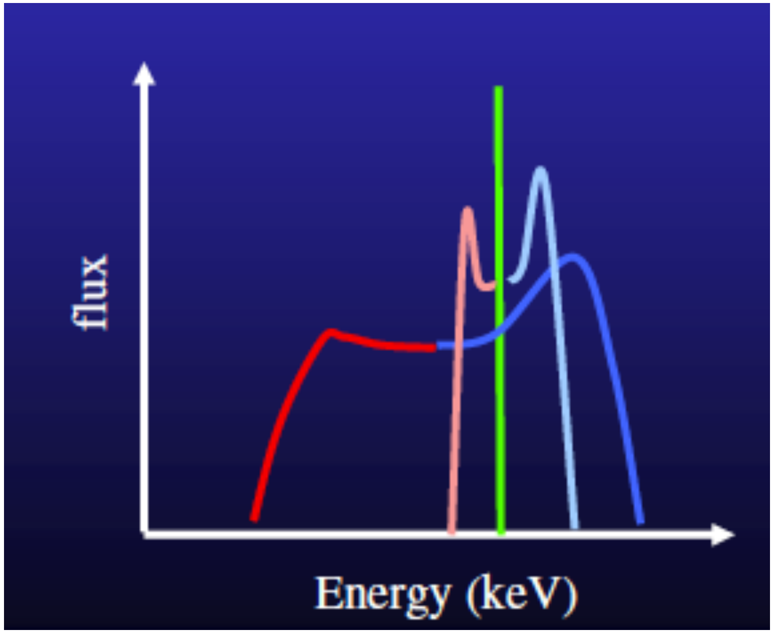
$$h\nu = \frac{h\nu'}{\gamma(1 - \frac{v}{c}\cos\theta\ )}$$

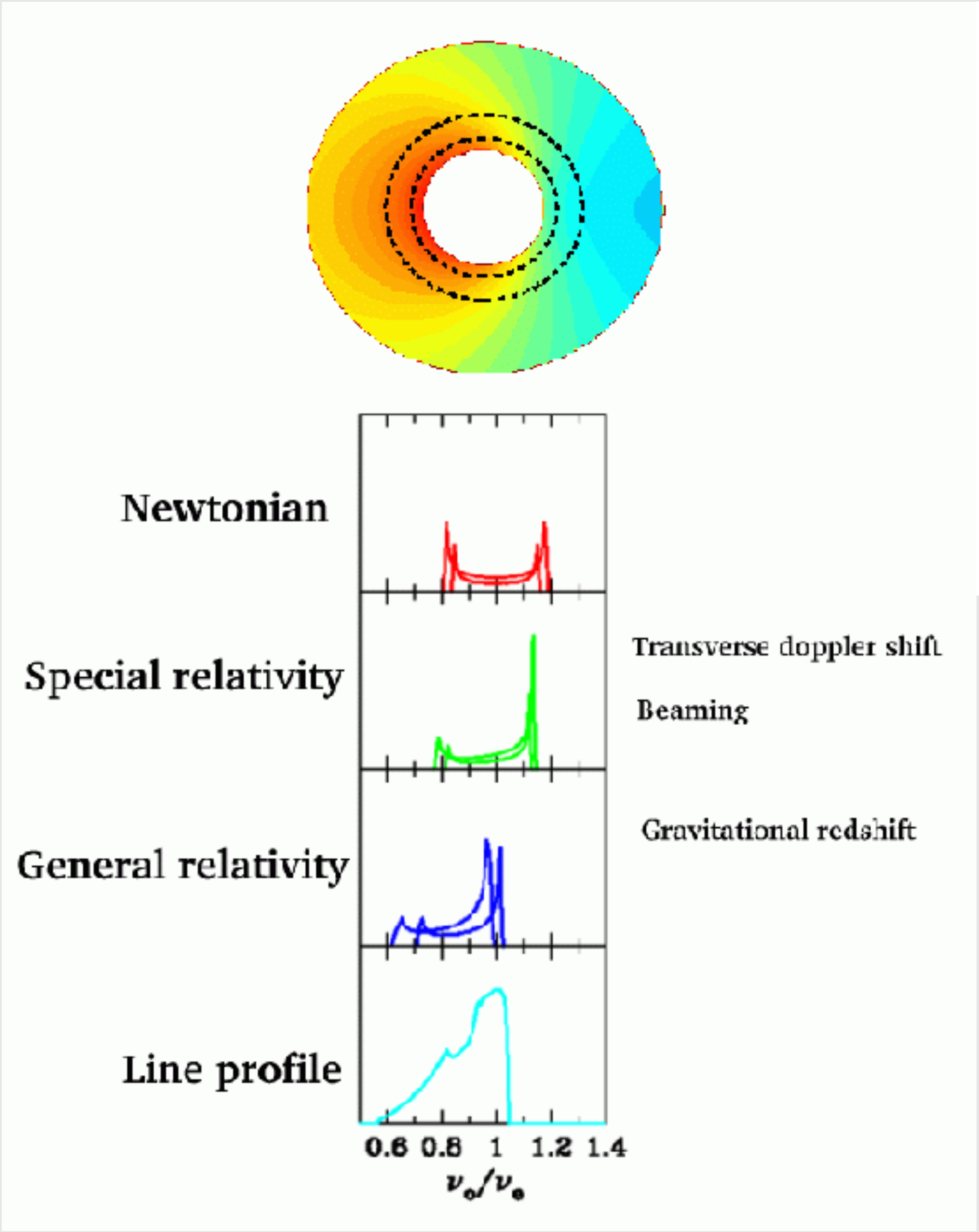
- Gravitational redshift and lensing

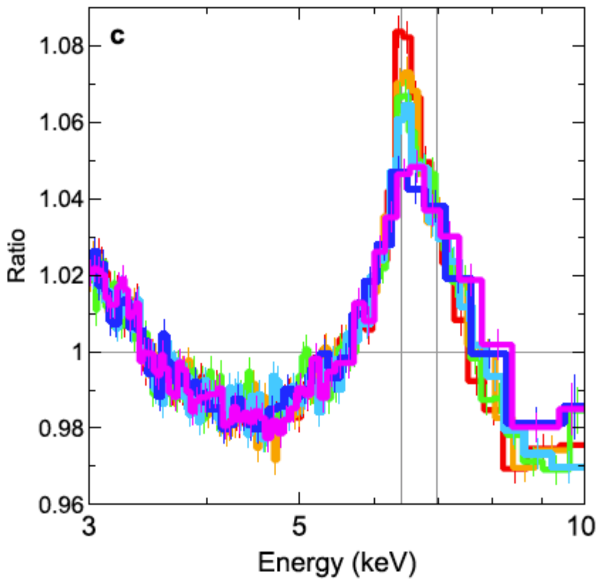
$$\frac{h\nu_\infty}{h\nu_e} = \sqrt{1 - \frac{R_S}{R_e}}$$

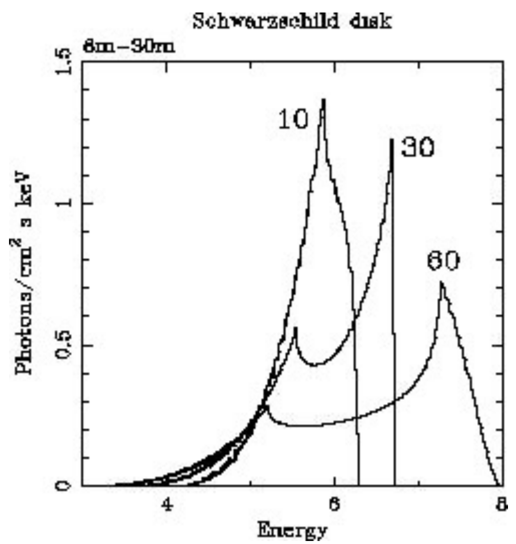
- Fe Kα line is broadened and skewed, its shape depends on R_{in}, which in turn depends on BH spin






Newtonian
Special relativity
Transverse doppler shift
Beaming
General relativity
Gravitational redshift
Line profile
0.6 0.8 1 1.2 1.4
ν_o/ν_e


c
Ratio
1.08
1.06
1.04
1.02
1
0.98
0.96
3
5
10
Energy (keV)

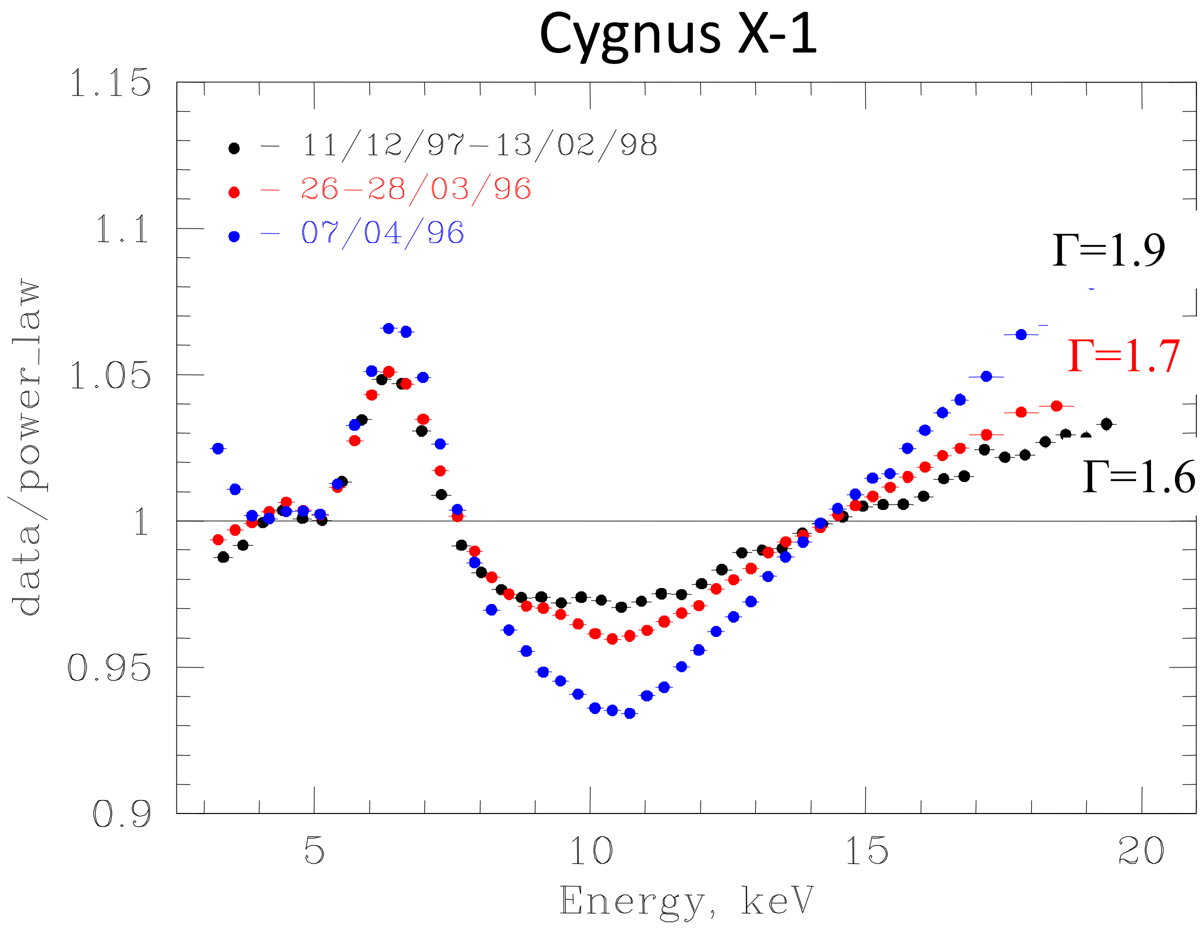

Schwarzschild disk
6m–30m
10
30
60
Photons/cm² s keV
Energy

Reflected emission. EW

- EW = equivalent width. It is the width of a rectangular spectral feature whose height is equal to the height of the continuum and whose area is equal to the integrated area of the spectral feature in a flux versus energy plot
- $EW = \int \frac{F_{line} - F_{cont}}{F_{cont}} dh\nu$ [eV]

- $EW_i \sim \sigma_i y_i n_i$ here σ_i is the cross-section, n_i is the abundance of species and y_i is the fluorescence yield (probability that a vacancy in the shell leads to a radiative transition, rather than Auger electron ejection)

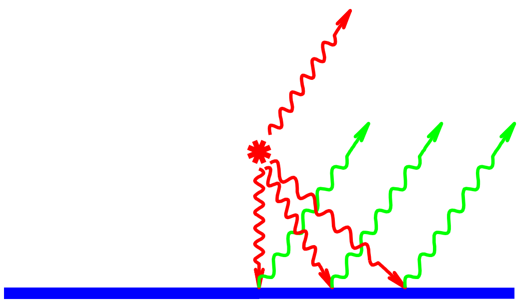
Reflected emission. EW and amplitude



Amplitude of reflection

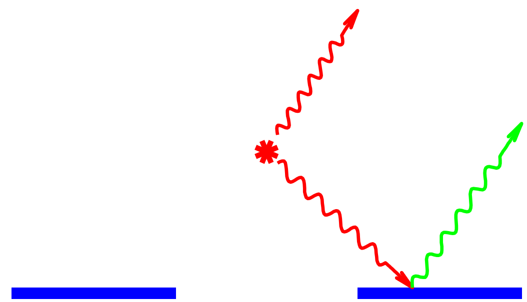
- Solid angle occupied by the reflector as viewed from X-ray source determines the strength of reflection continuum and iron line.

larger



$R = \Omega/2\pi = 1$

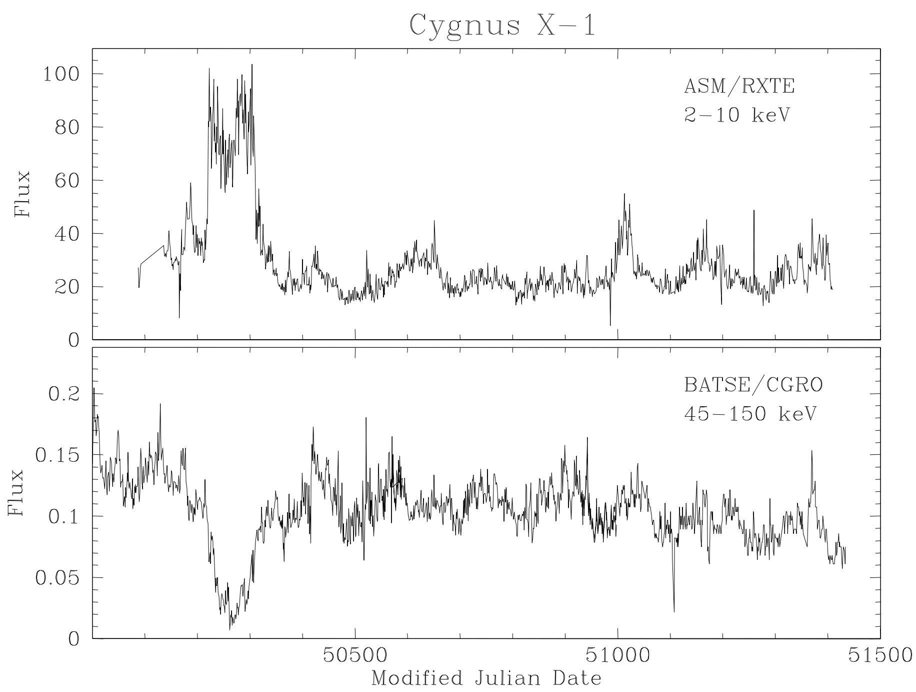
smaller

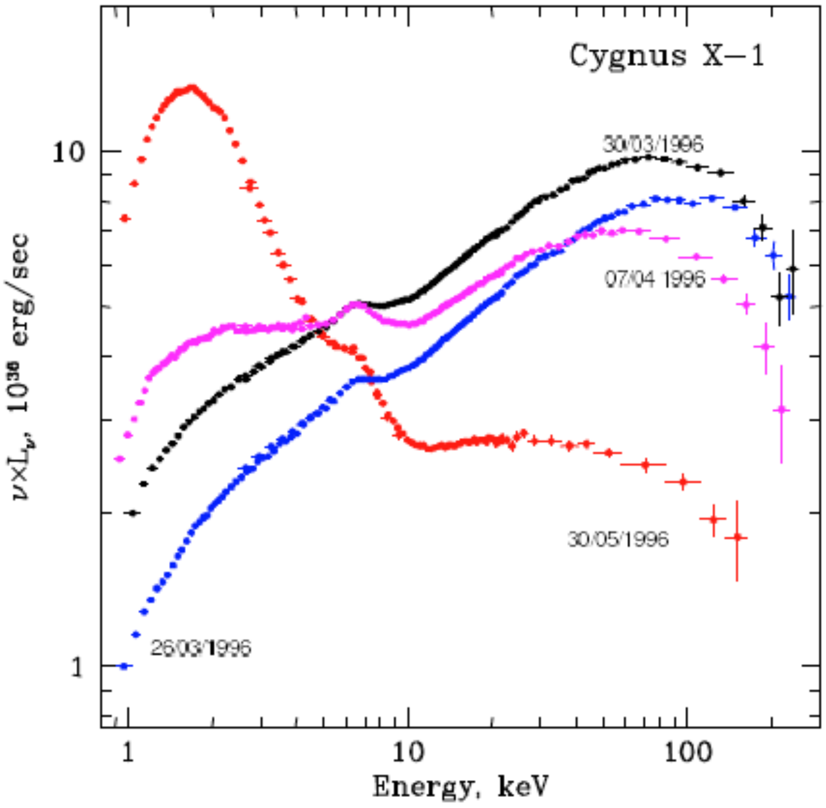


$R = \Omega/2\pi < 1$

Reflection scaling factor $R = \Omega/2\pi$

Spectral variability





Hard spectral state

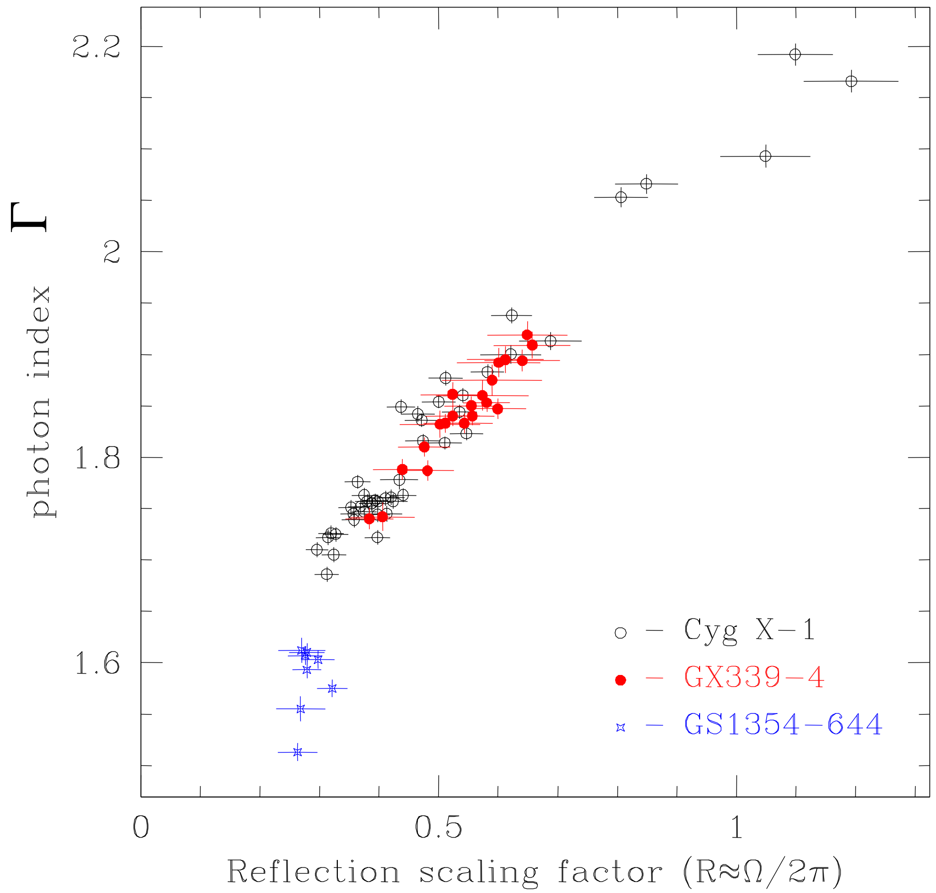
Data:

- Cyg X-1, GX339-4, GS1354-644
- 4U1608-52, Aql X-1, SAX J1808-36
- many RXTE observations, 3-30 keV

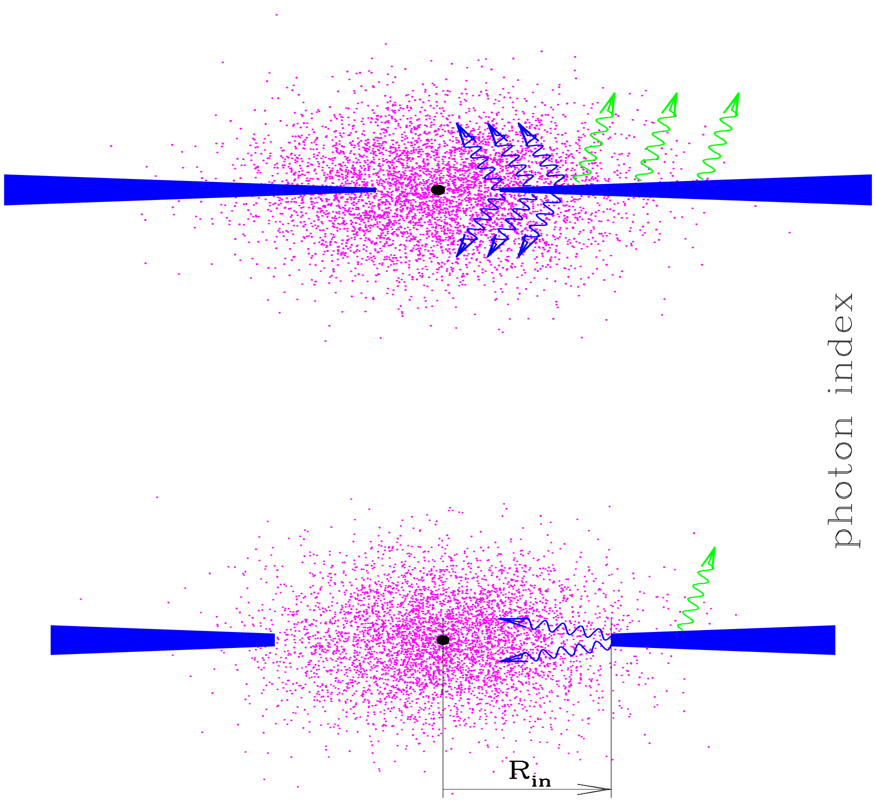
Measured parameters:

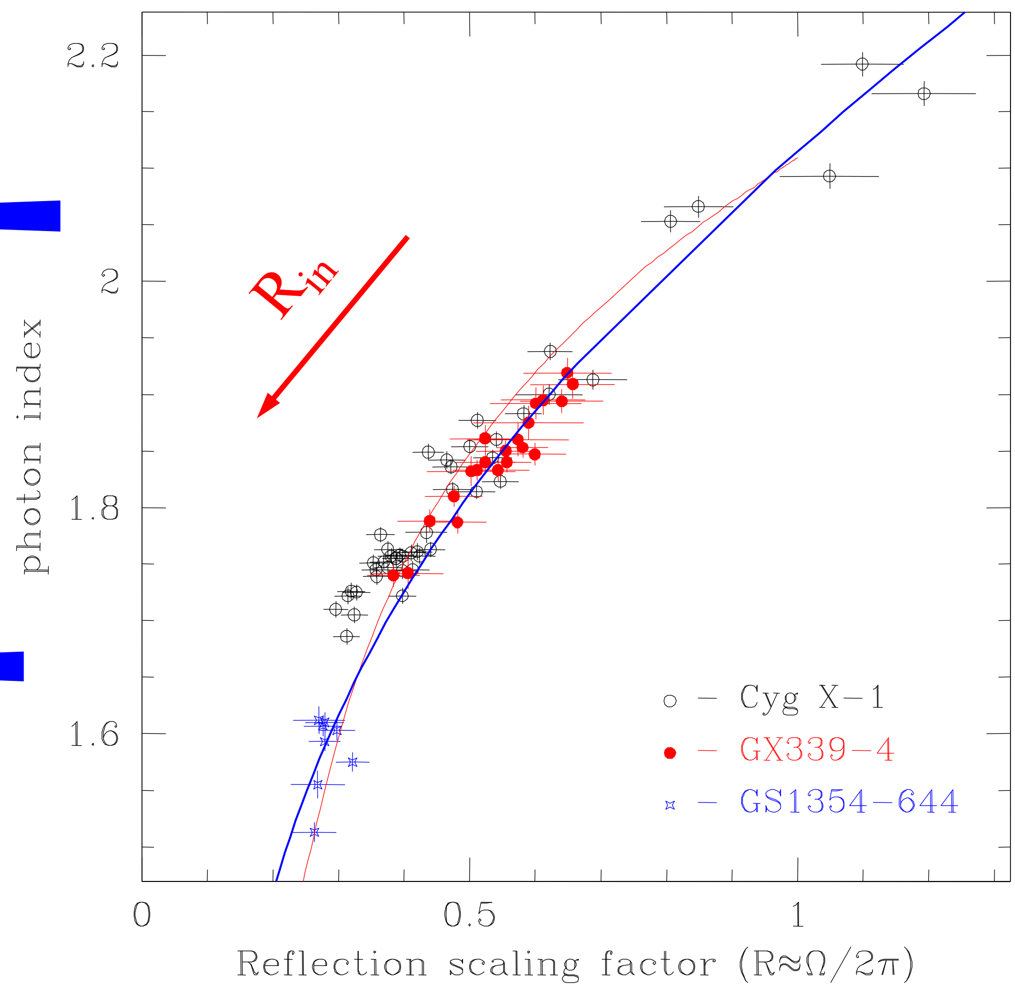
- spectral index of Comptonized emission
- strength of reflected component $(R=\Omega/2\pi)$
- Doppler broadening of 6.4 keV line
- characteristic frequencies of variability

Comptonization and reflection



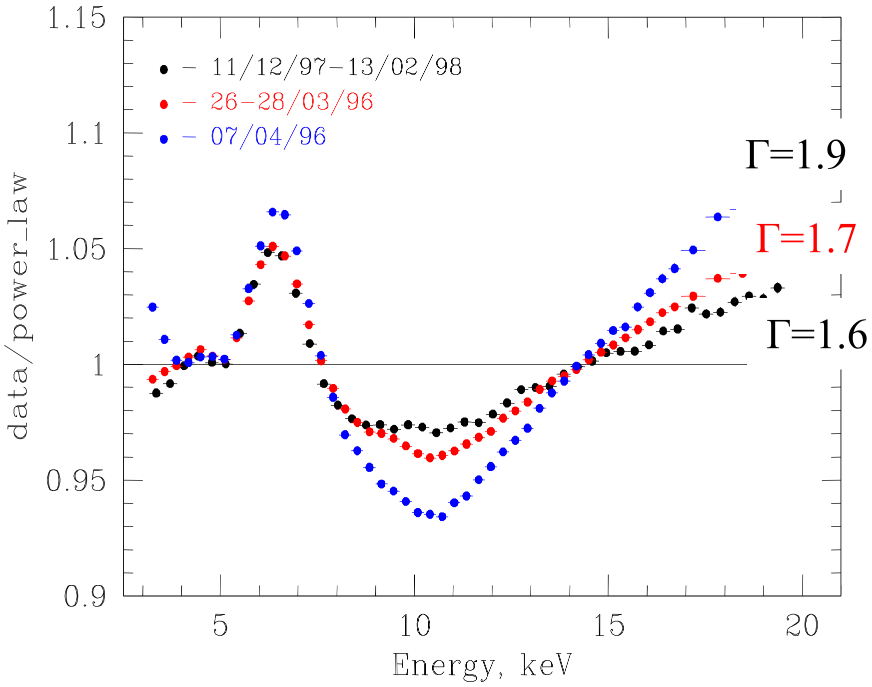
Comptonization & reflection in truncated disk picture



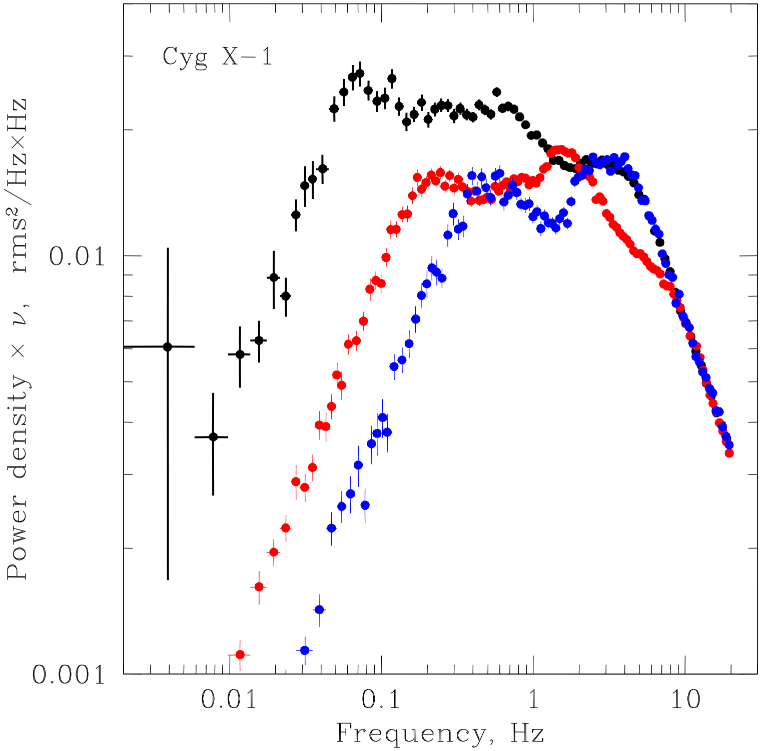


Reflection and noise

strength of reflection

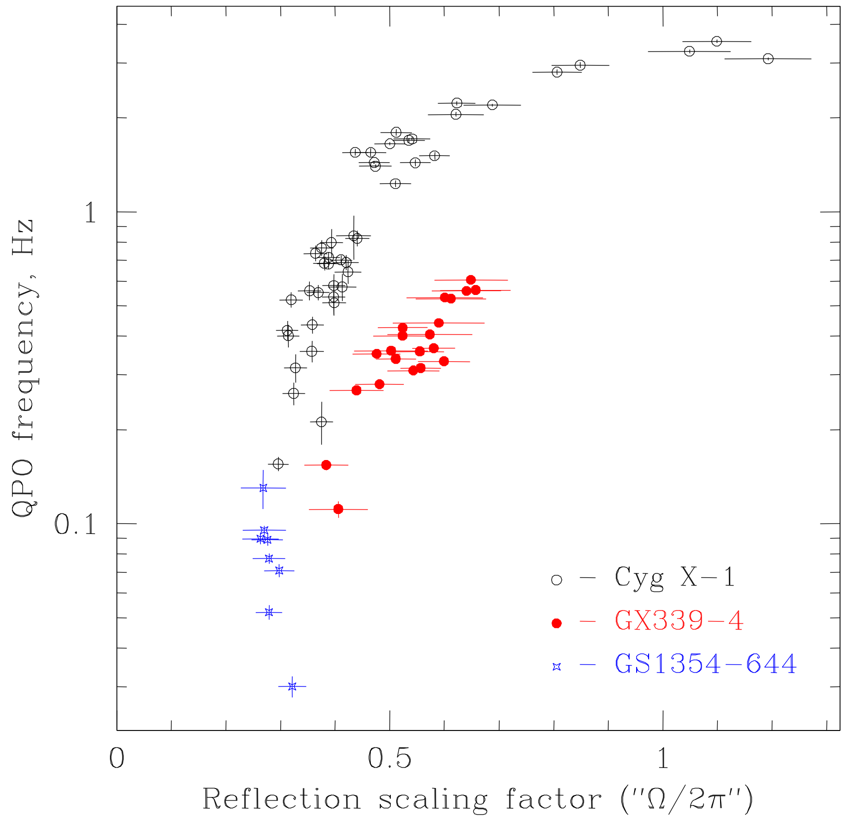


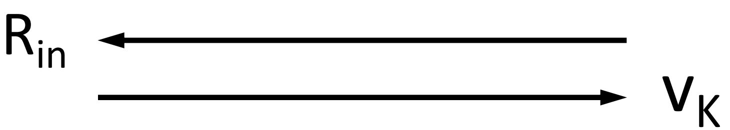
noise frequencies



QPO frequency

Time scales in the accretion flow are proportional to the Keplerian time scale

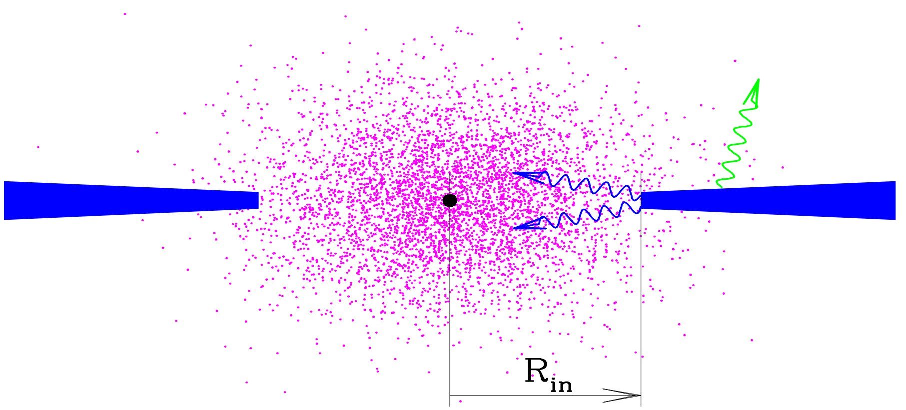


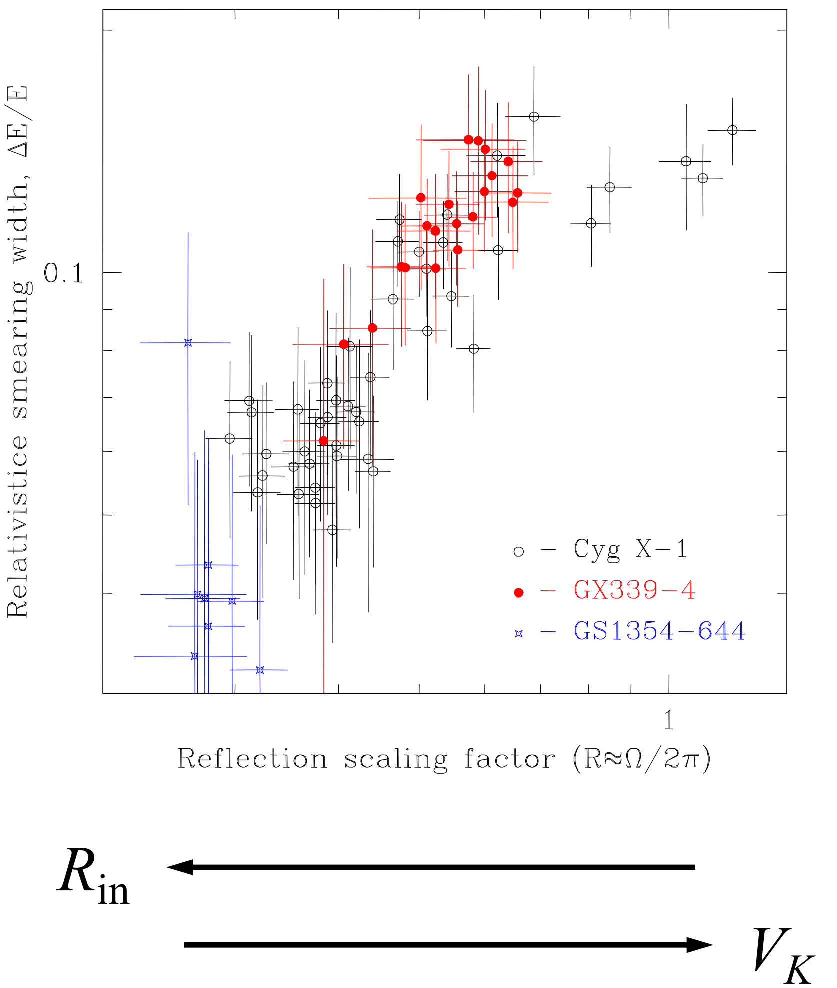


Doppler width of 6.4 keV line

- Doppler broadening

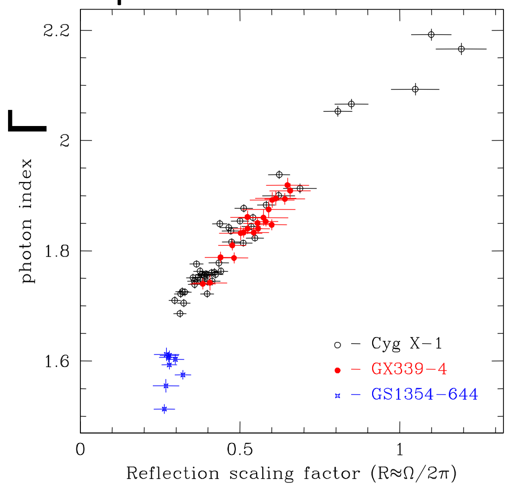
$$\frac{\Delta E}{E} \propto \frac{V_K}{c}$$



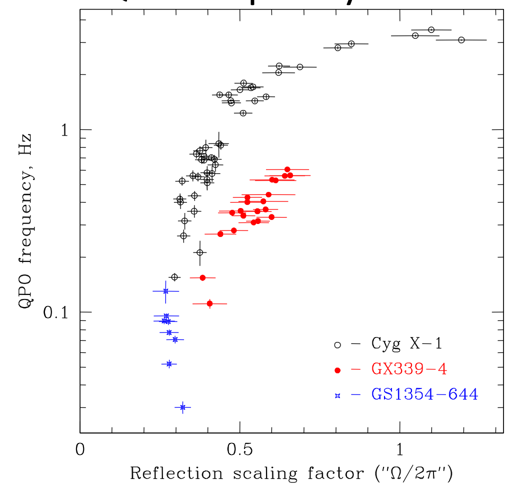


ONE parameter

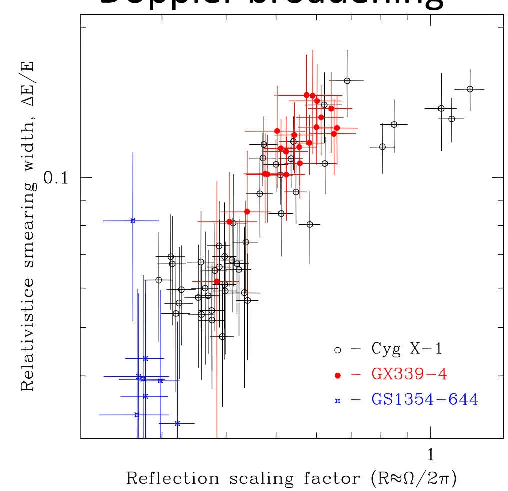
spectral index



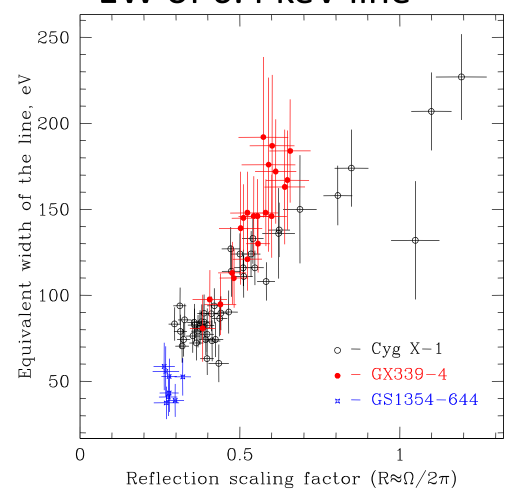
QPO frequency



Doppler broadening

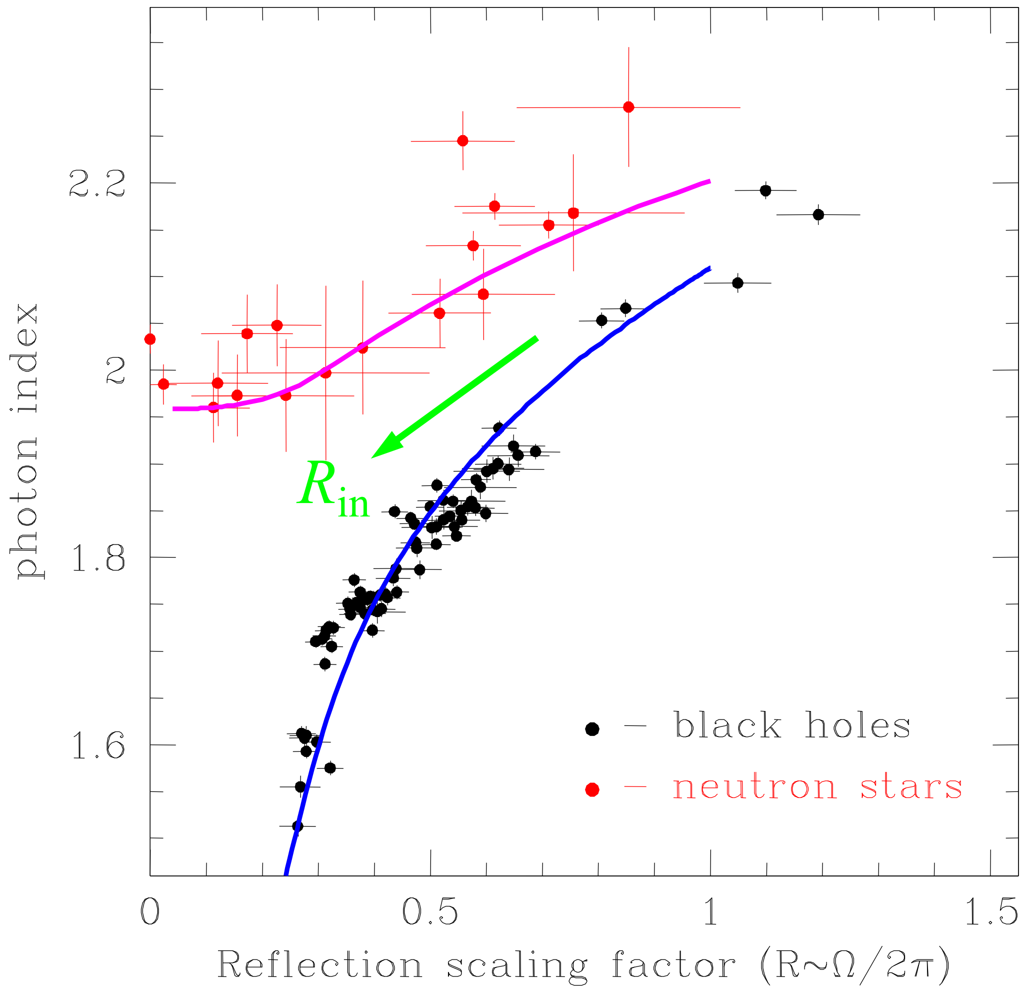


EW of 6.4 keV line



as a function of the strength of the reflected component

Comptonization & reflection
Black holes vs. neutron stars



Comptonization & reflection
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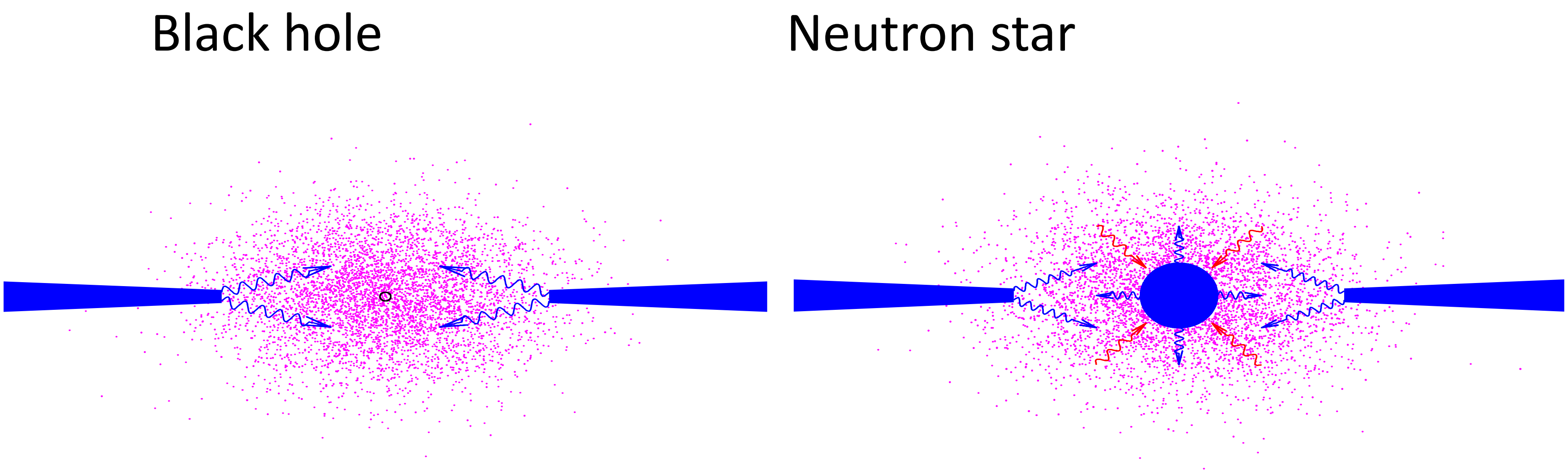
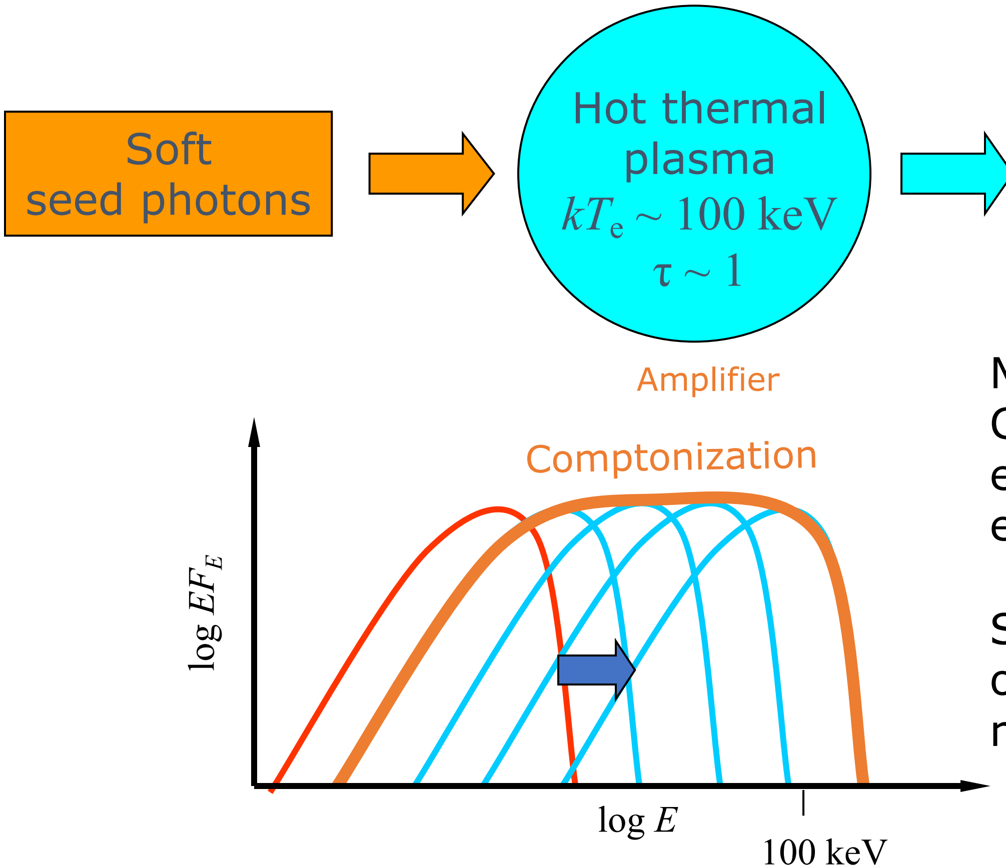


Photon index $\Gamma_{NS} > \Gamma_{BH}$ because of additional cooling of hot plasma by the emission from the NS surface

Hot thermal plasma – thermal Comptonization



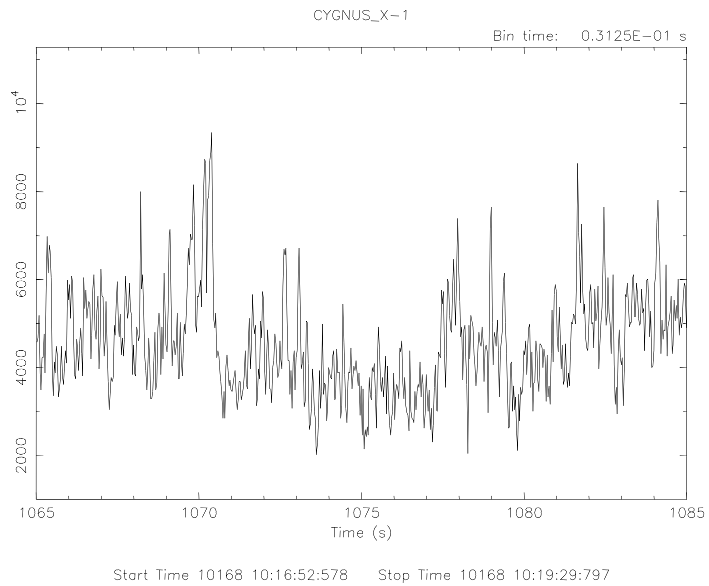
Multiple inverse Compton scattering: energy transfer from electrons to photons.

Small energy shift in one scattering, but many scatterings

$$\frac{\Delta E}{E} \sim \frac{E}{m_e c^2} \sim \frac{4kT_e}{m_e c^2}$$

Variability of reflected emission

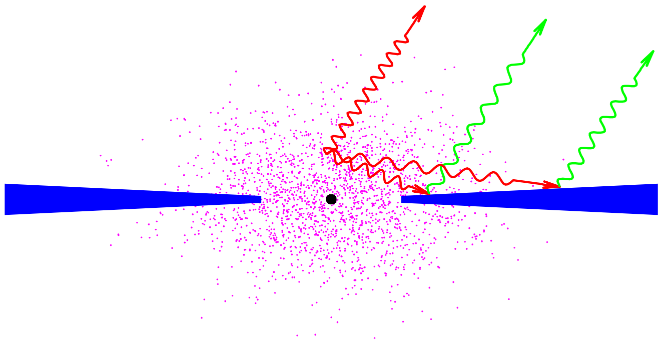
- primary emission:



- light crossing time

$$\Delta t \sim \frac{(10 \div 100) R_g}{c} \sim 1 \div 10 \text{ msec}$$

- reflected emission:
  - suppression of high frequencies
  - time delay



Time response of the disc

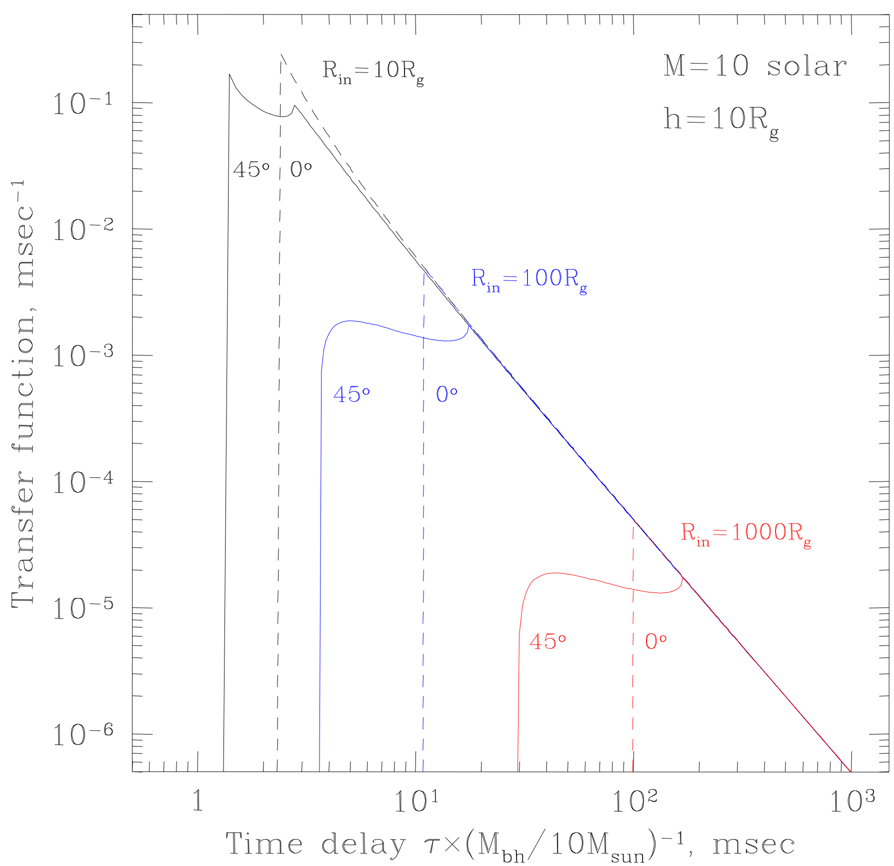
- in time domain:

$T(t)$ – transfer function of the disk = the reflected signal produced by a short $\delta(t)$ flash at some height above the disk center.

The reflected signal is the convolution of the intrinsic signal and transfer function $F_0(t)$

$$F_{refl}(t) = \int F_0(t-\tau)T(\tau)d\tau$$

Transfer function of the disk



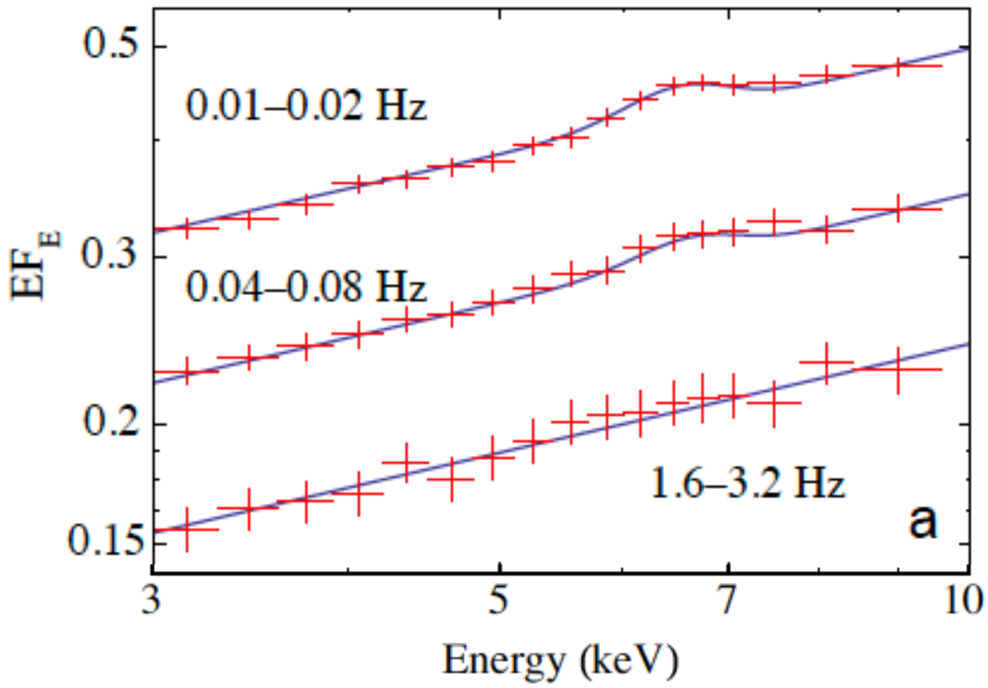
Variability of reflected emission: **soft** and **hard** state

The variability of the reflected component can be used to probe inner radius of the accretion disc

$$F_{\rm refl}(t) = \int_0^\infty F_0(t-\tau)T(\tau)\,{\rm d}\tau$$

$$\hat{F}_{\rm refl}(f) = \hat{F}_0(f) \times \hat{T}(f)$$

$$EW(f) \propto \frac{|\hat{F}_{\rm refl}(f)|}{|\hat{F}_0(f)|} = |\hat{T}(f)|$$



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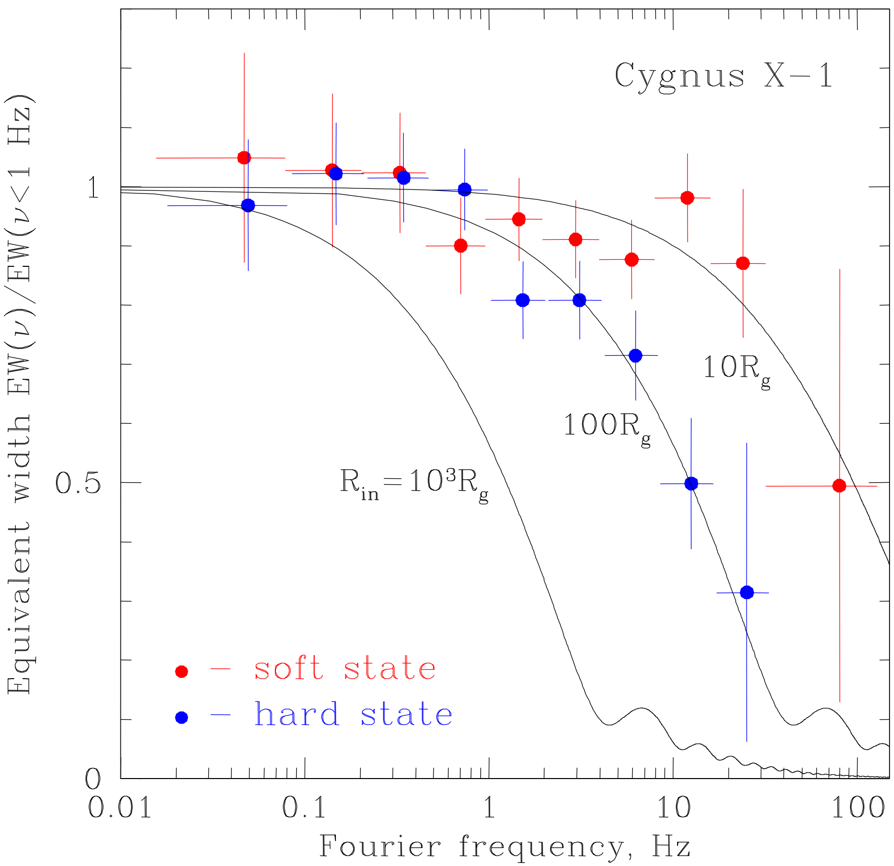

Revnivtsev et al. 1999, Gilfanov et al. 2001