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

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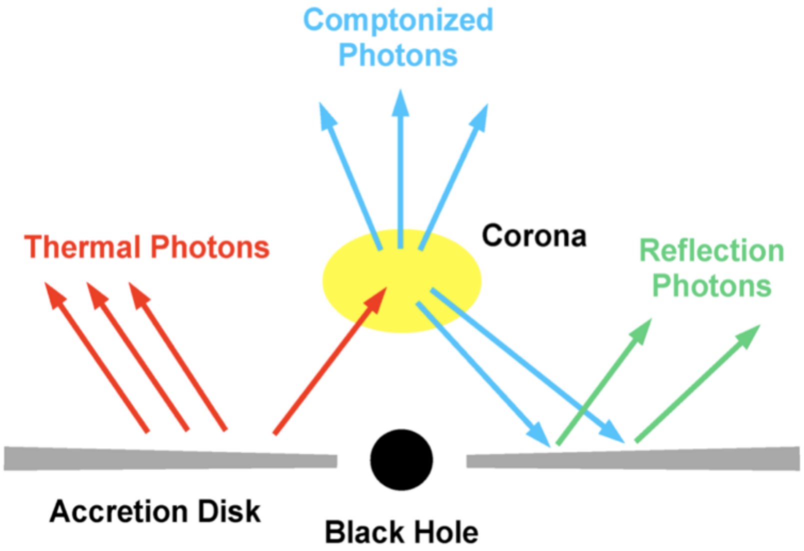
PhD lecture series, 2025, fall semester

# Lecture 3

# Overall geometry

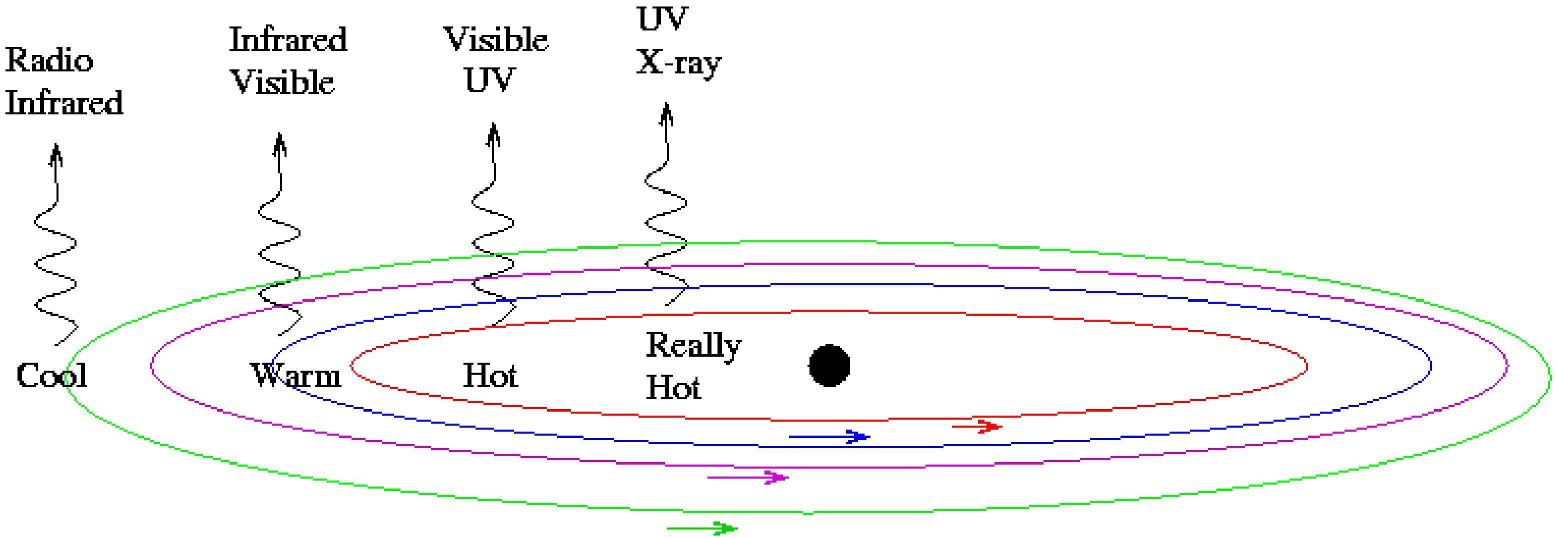
- Accretion disk around central black hole or neutron star.
- X-ray source:
  - Compact source
  - Extended corona
- Emission from the accretion disk
- Reflection/reprocessing by accretion disk



# Thermal emission from accretion disks

- Usual assumption: Keplerian rotation; locally blackbody radiation
- Radial dependance of temperature

$$F(r) \approx \frac{1}{r^3}$$



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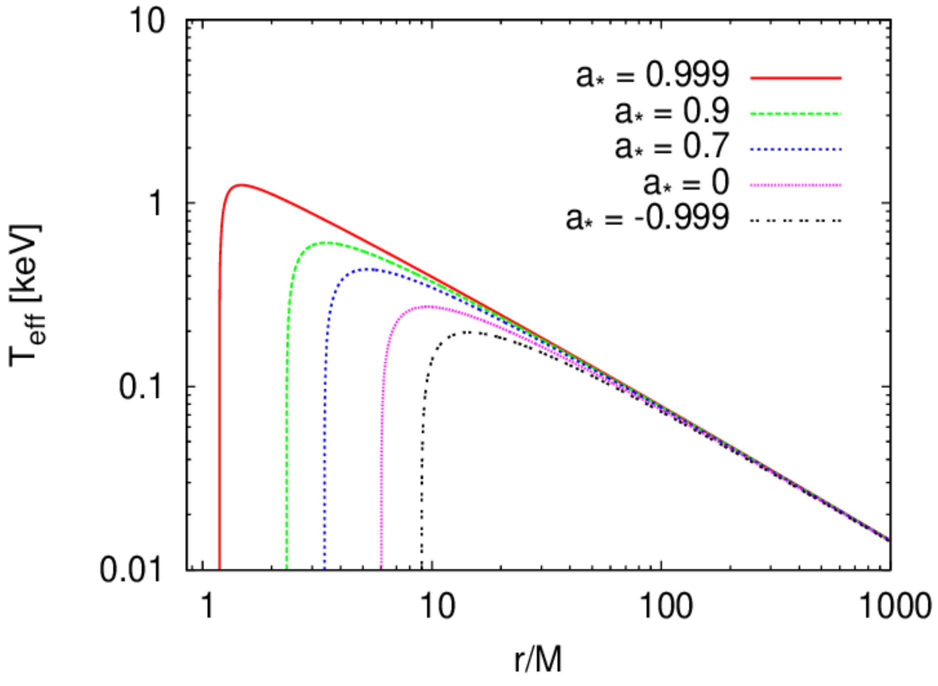


$$F(r) \approx \frac{1}{r^3}\left(1 - \sqrt{\frac{6}{r}}\right)$$ for a* = 0

50% of power released between 6 and 25 $R_g$

Bambi, Cosimo. (2024). Black hole X-ray spectra: notes on the relativistic calculations. 10.48550/arXiv.2408.12262.

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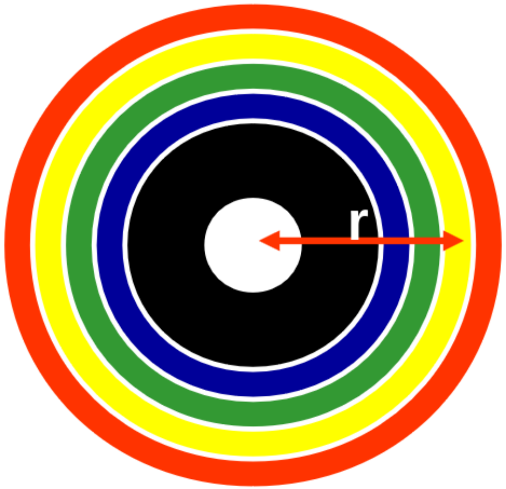
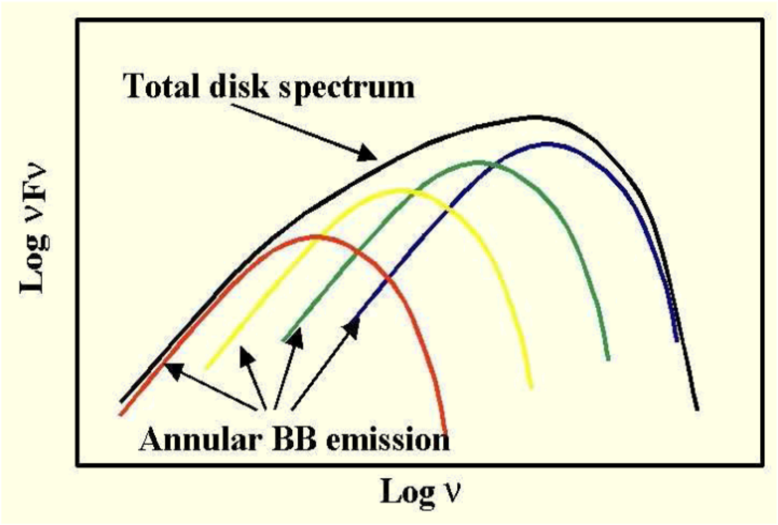
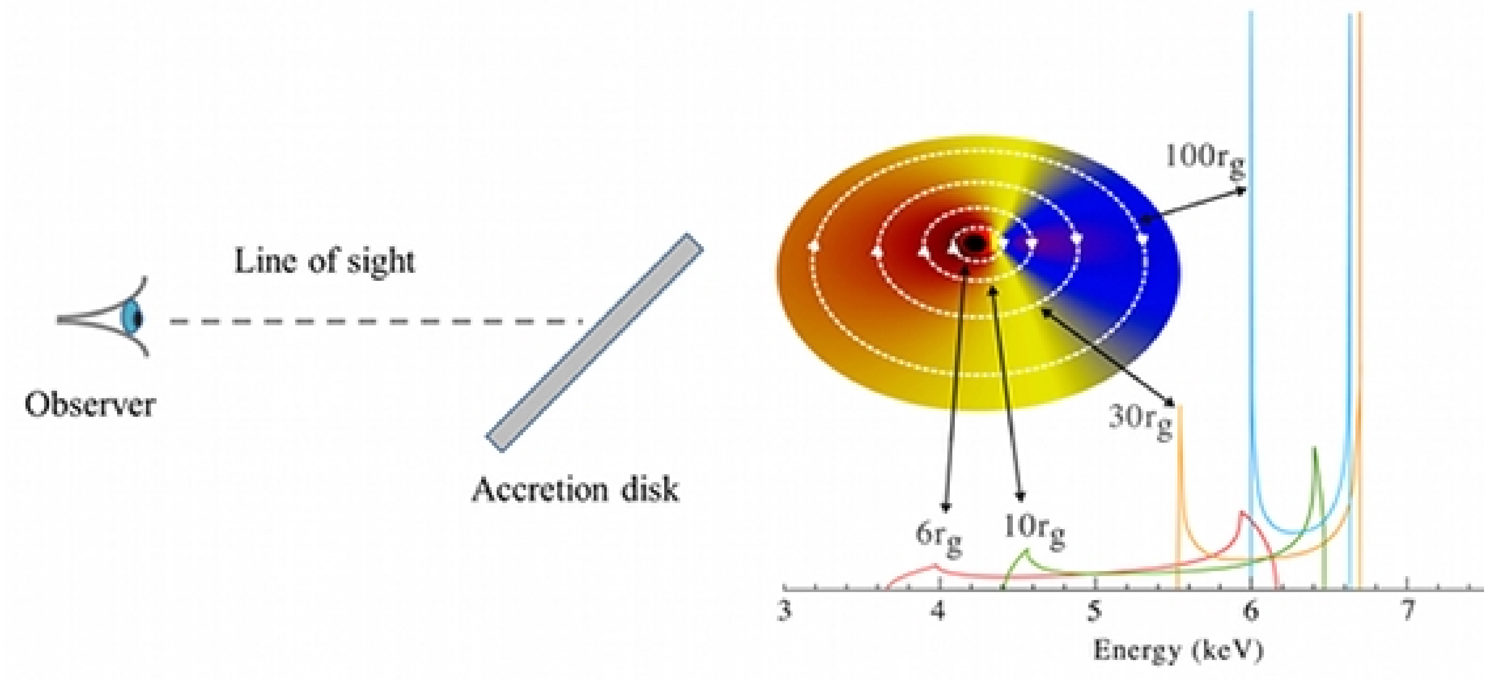



SED courtesy of Gulab Dewangan, IUCAA, Pune (India)

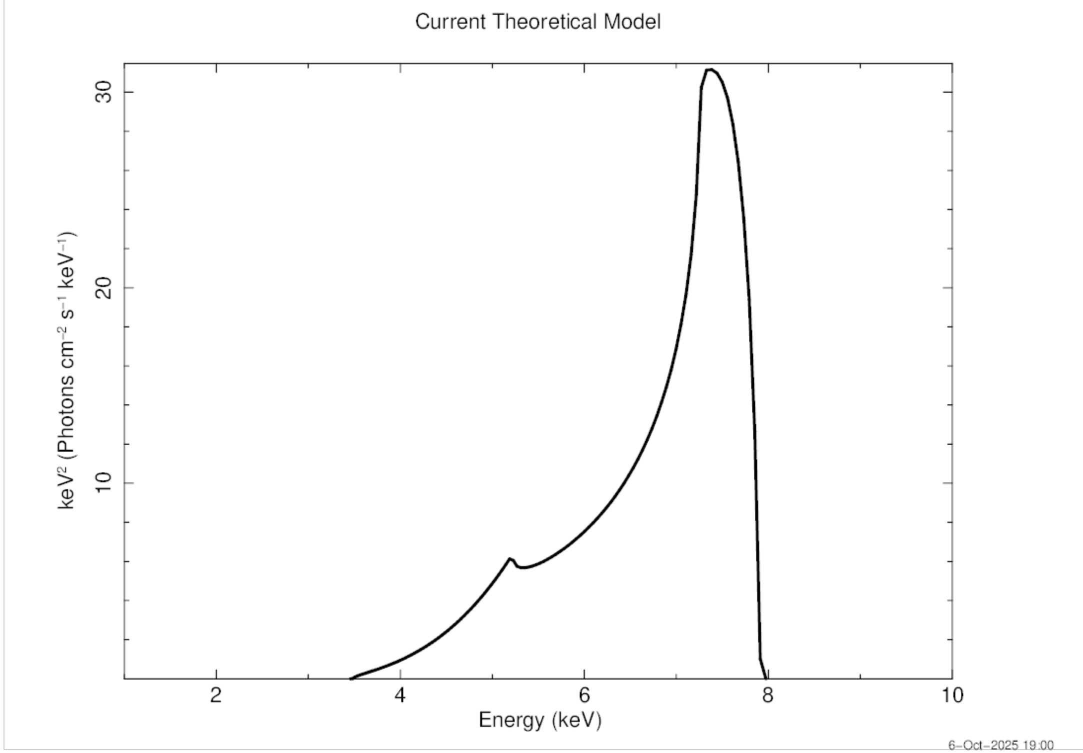
# Reflection from a relativistic accretion disk




ESA

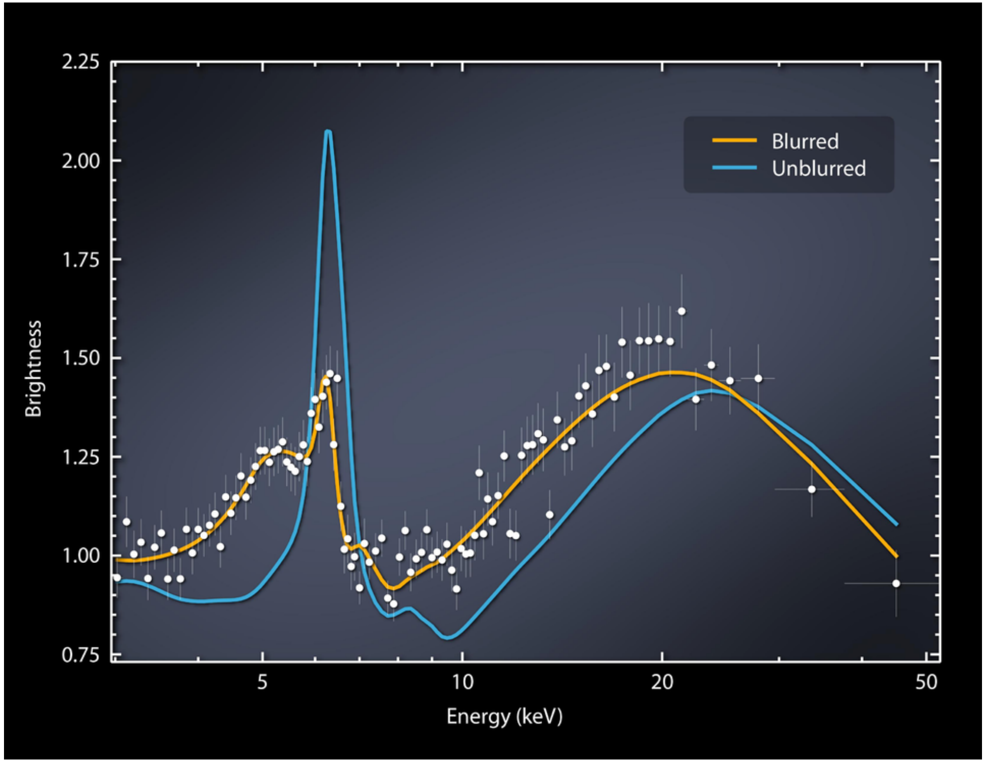
Doppler red- and blue-shift,
Doppler boost, gravitational redshift

# Reflection from a relativistic accretion disk




Fabian et al., 1989, MNRAS, 238, 729

# Effect on a spectrum

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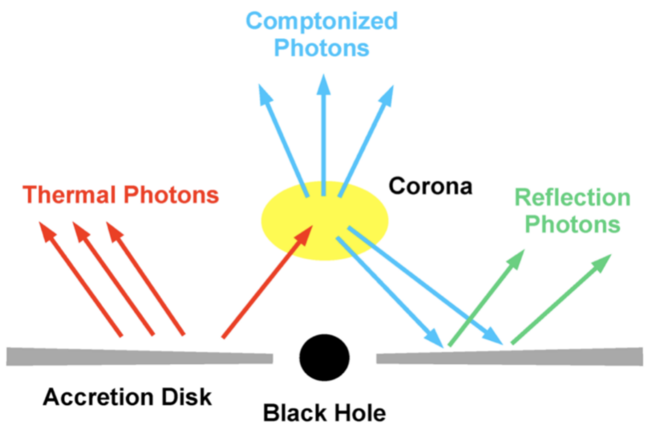
# Effect on a spectrum

Radial structure – at each radius (ring) a different input spectrum and relativistic effects

Applies to all spectral components emitted at a given radius, assuming the emitter rotates – applies to accretion disk thermal emission, hard X-ray emission, reflection component



# Short summary of spectral components

- Primary X-ray emission – (non)thermal Comptonization, $E$>1 keV, power law $N_E \sim E^{-\Gamma}$
  - Hard – spectral index $\Gamma<2$; goes **up** on $EF_E$ plot; most of the energy around 100 keV
  - Soft – spectral index $\Gamma>2$; goes **down** on $EF_E$ plot; most of the energy around 1 keV
- Reflection/reprocessing: spectral component peaking around 30 keV
- Accretion disk thermal emission: disk blackbody – composition of black body spectra from different radii. Blackbody emission: disk is optically thick (geometrically thin)
- Relativistic effects, broadening of spectral features

# Spectra of Cygnus X-1 in hard and soft state

High – mass X-ray binary, $M_{BH} \approx 20\ M_{\odot}$, $M_{C} \approx 30\ M_{\odot}$, $P_{orb} \approx 5.6$ day

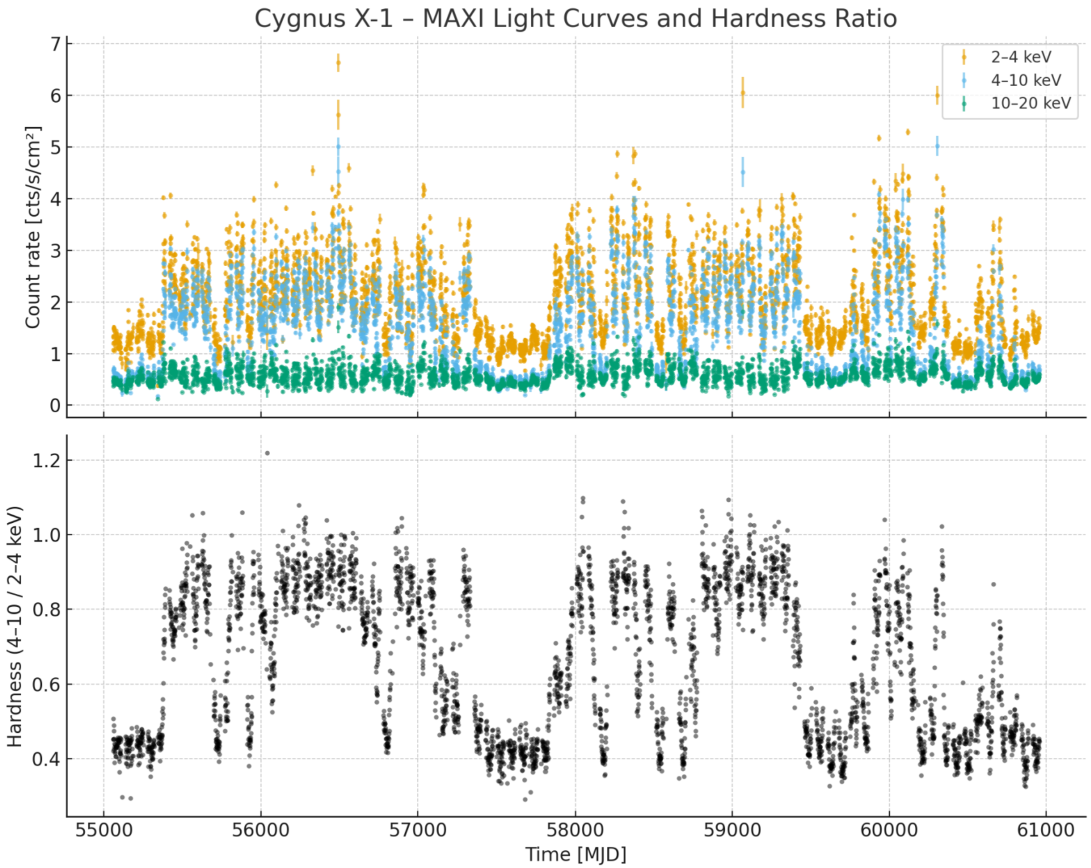
Discovered in 1964

In 1974 Stephen Hawking bet against Kip Thorne that Cyg X-1 is not a black hole. Admitted losing the bet in 1990.

One of the most observed BH sources

Shows a number of states, differing in spectral and temporal properties

# Cyg X-1 long term X-ray lightcurve




Changes of count rate and hardness ratios

# Spectra of Cygnus X-1 in the hard state

Hard X-ray component, well modelled by thermal Comptonization, with slope Γ≈1.6, kT≈100 keV

Reflection component present, with Fe Kα line at 6.4 keV.

Amplitude of the spectral component ≈ 0.3 of that expected in the simplest geometry.

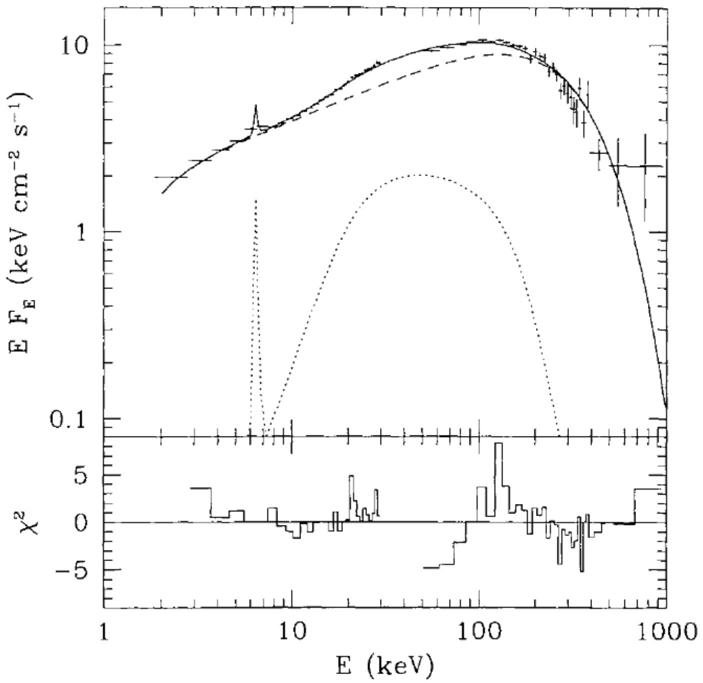
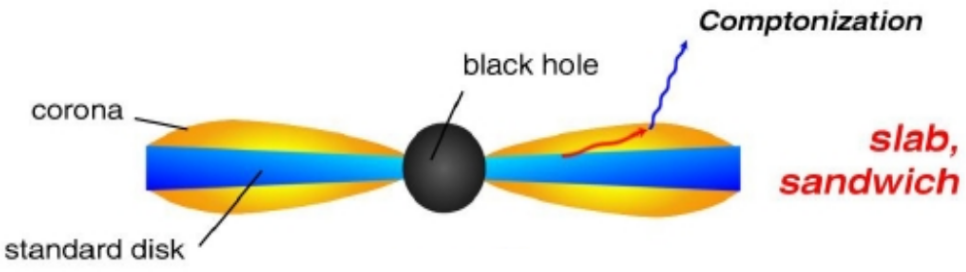


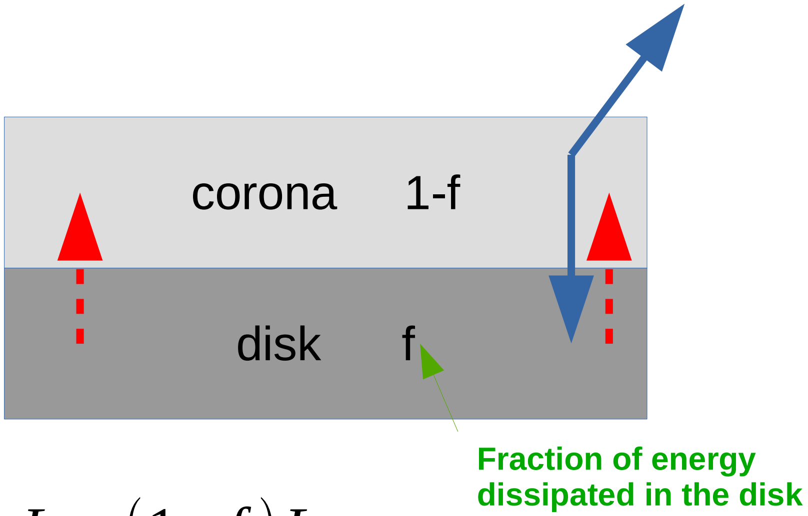

**Figure 3.** The isotropic one-temperature thermal Comptonization model fitted to the data set 2. The upper panel shows the data (crosses), the thermal Comptonization continuum (dashed curve) and the reflection component (dotted curve). The solid curve shows the sum. This model yields $\chi^2_\nu < 1$, but there is still a systematic residual pattern for the OSSE data (the lower panel).

© 1997 RAS, MNRAS **288**, 958–964

Gierliński et al.

# Comptonization – the amplification factor




$\Gamma \approx \frac{7}{3} A^{-1/6}$ Beloborodov, 1999

For $A$=2 the photon index Γ≈2.05

**In this geometry Γ can never be smaller than 2**

**A hard spectrum is not possible!**

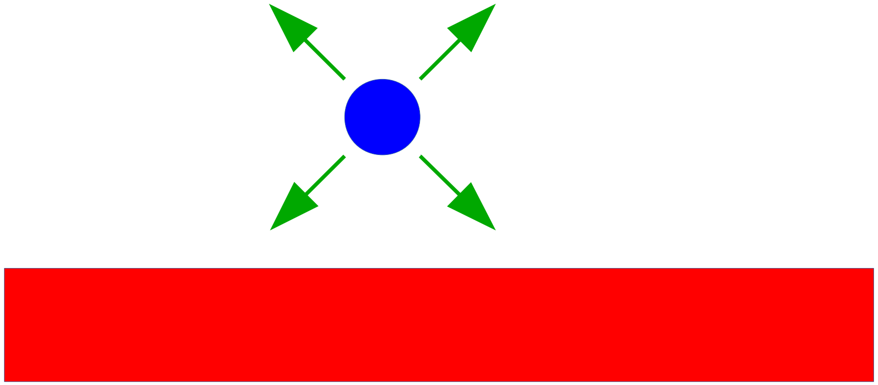
$$L_h = (1-f) L_{tot}$$

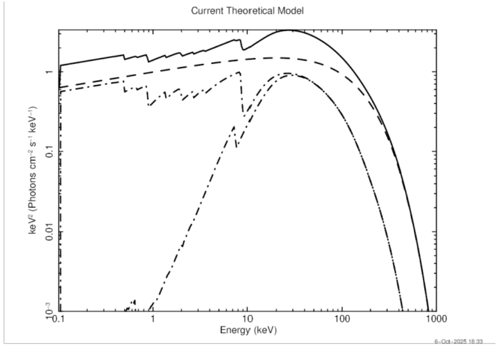
$$L_s = f\, L_{tot} + 0.5 * (1-f) L_{tot}$$

$A = \frac{L_h}{L_s}$ – amplification:

F. Haardt, L. Maraschi, 1991, ApJ, 380, L51

# Reflected component






From the point-of-view of the X-ray source, half of the sky is covered by the reflector.

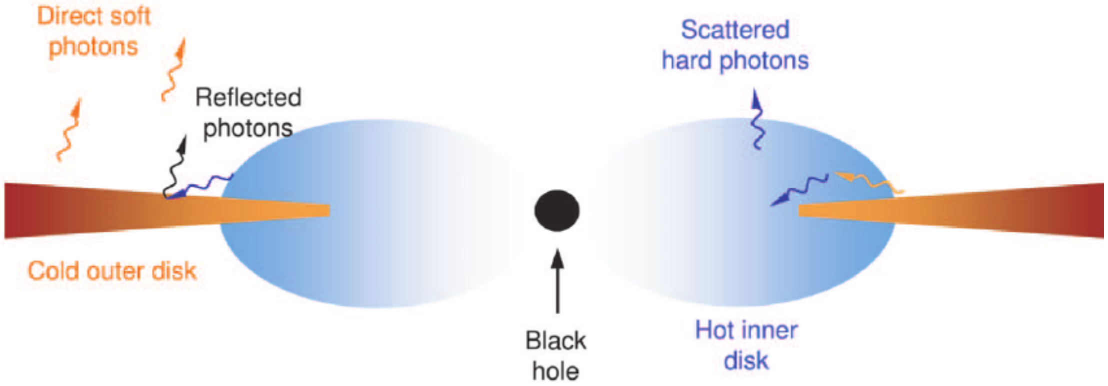
Reflection amplitude $R = \frac{\Omega}{2\pi}$ (also need to assume that the emission is isotropic)

Then, *R*, as determined from the fit to the data, provides information about the geometry.

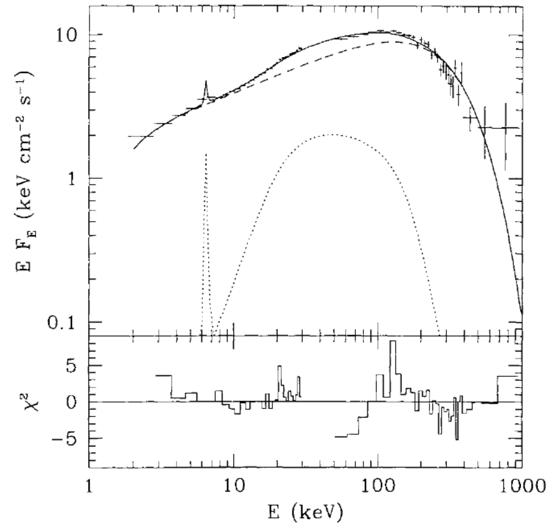
# Spectra of Cygnus X-1 in the hard state

„Photon-starved plasma” - cannot be a simple slab disk-corona geometry

Low amplitude of reflection, R=0.3, confirms the above




**Inner hot accretion flow model**

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 Gierliński et al.