Outflow and apparent spin changes for high Eddington sources

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SEVENTH FRAMEWORK PROGRAMME

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Spin determination from the continuum fiting

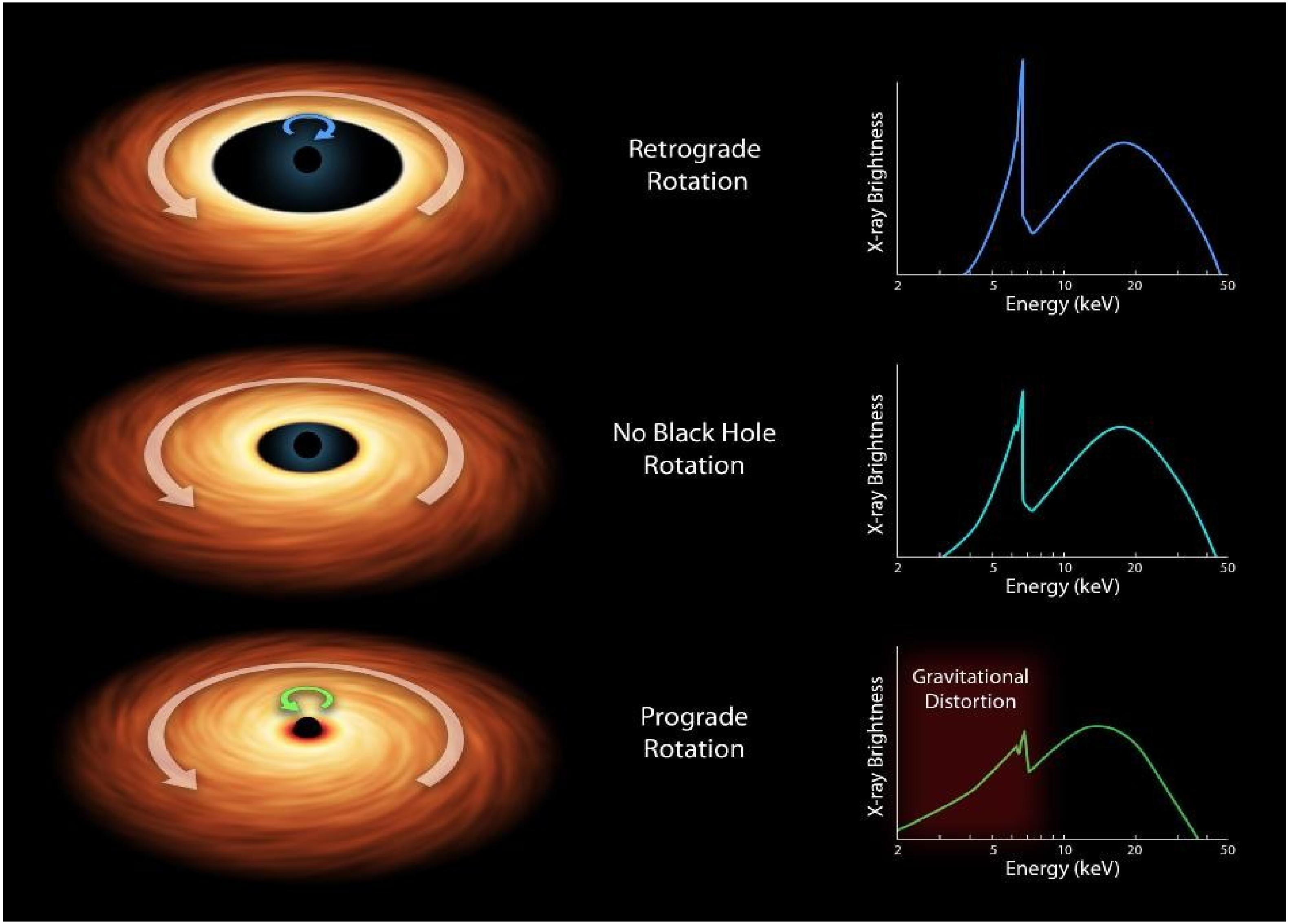


Image credit: NASA/JPL-Caltech

Problem

GRS 1915

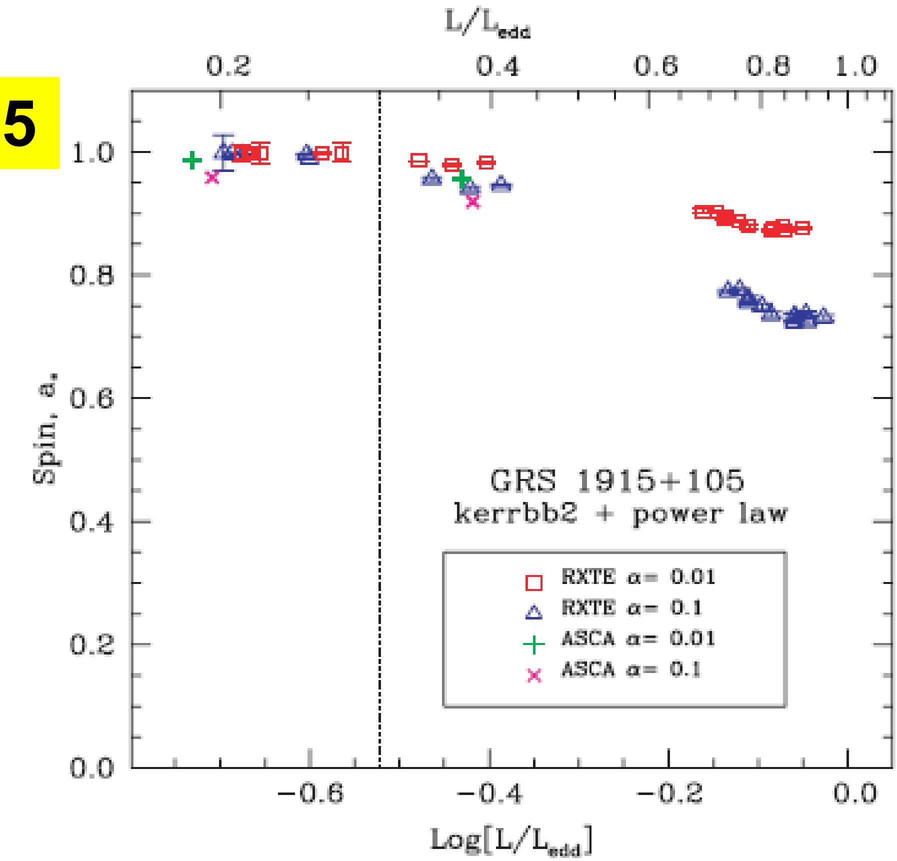


FIG. 7.—Spin parameter a_* vs. the Eddington-scaled luminosity L/L_{Edd} for all 22 *RXTE* and *ASCA* observations of GRS 1915 in the thermal state for two values of the viscosity parameter α. The tail emission is modeled as a simple PL. For reasons discussed in § 6.1 and the Appendix, the results are most trustworthy for $L/L_{Edd} \lesssim 0.3$; this limit is indicated here and below by the vertical dotted line. Data in this regime consistently give a very high estimate of the spin parameter of GRS 1915, $a_* \to 1$, independent of α or any other details.

Spin decreases with luminosity !

Fitted model:
Kerbb2 = kerbb + bhspec

McClintock, Shafee & Narayan 2006

Attempts to solve the problem

LMC X-3

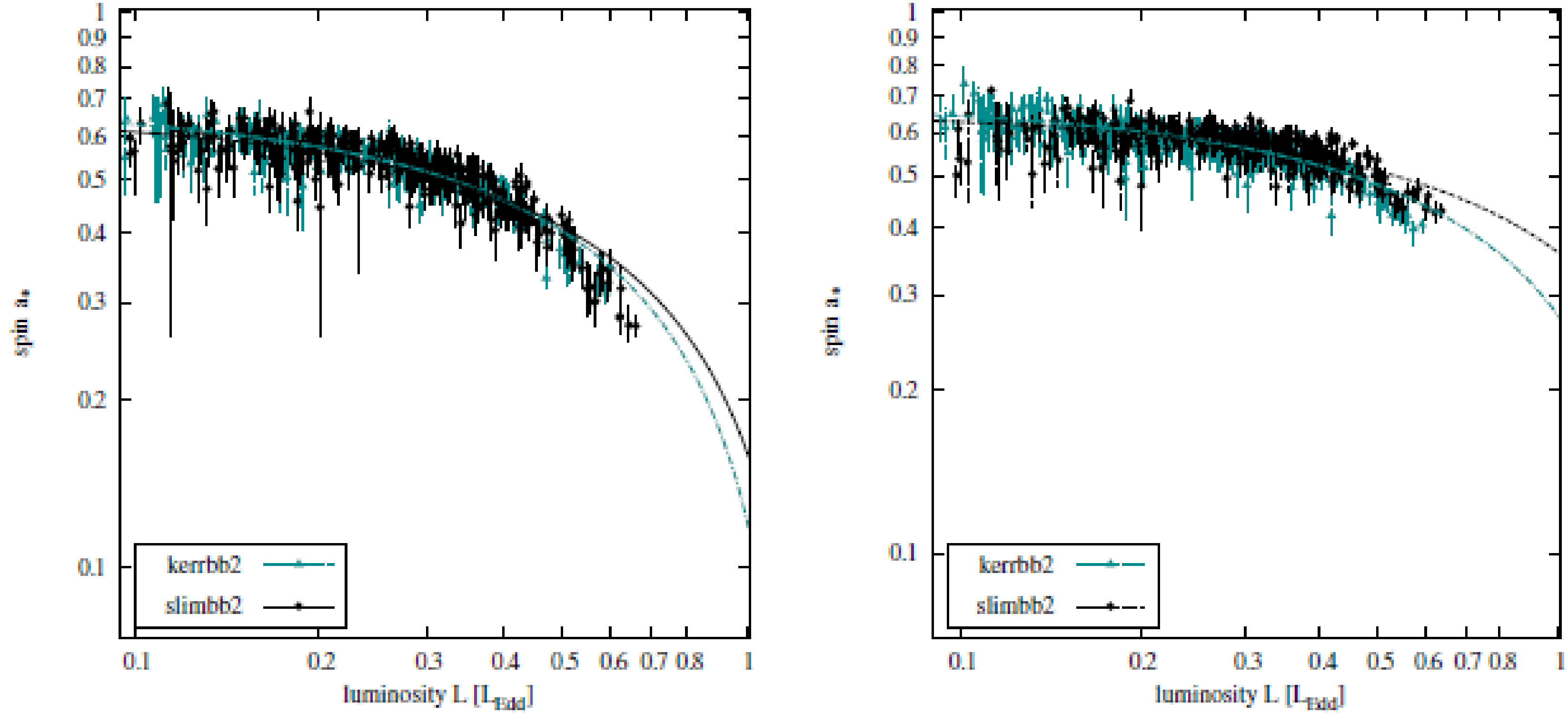


Fig. 3. Comparison between the disk models slimbb (black diamonds) and kerrbb2 (turquoise triangles) for viscosity parameters $\alpha = 0.1$ (*left*) and $\alpha = 0.01$ (*right*). The dashed and dot-dashed lines represent linear fits to the data. In all cases we assume LMC X-3 contains a 10 $M_\odot$ black hole, is located at a distance of 48.1 kpc and seen at an inclination of 66°.

Fitted model: slim disk + bhspec

Straub et al. 2011

Attempts to solve the problem

LMC X-3

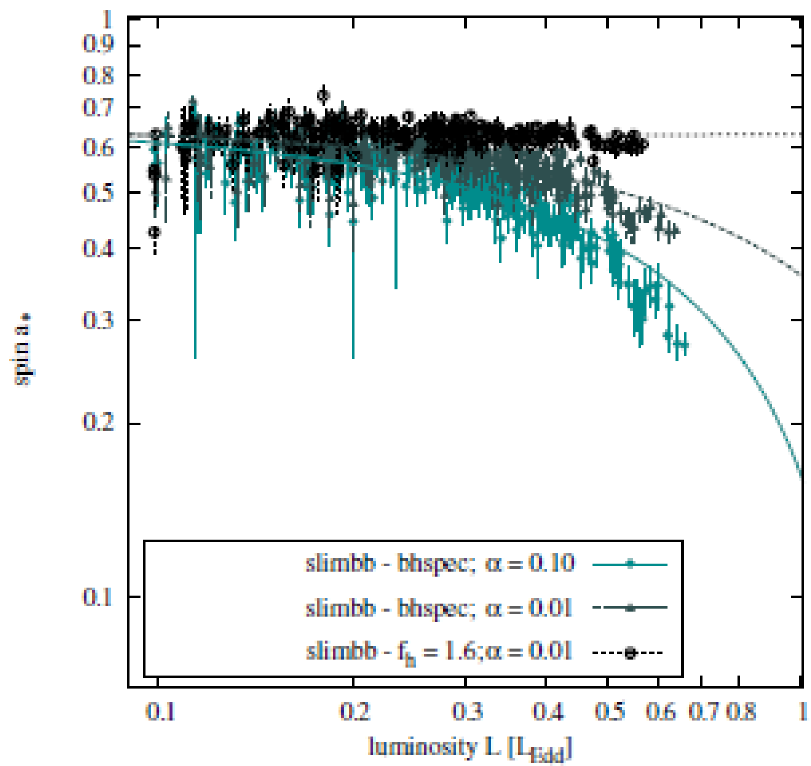


Fig. 4. Three spin estimations with `slimbb` assuming a 10 $M_\odot$ black hole in LMC X-3. Different alpha parameters and color correction treatments lead to a variety of trends with luminosity. The top two sets of fits have a low viscosity parameter, $\alpha = 0.01$. The upper of the two (black circles) represents a fit using a constant hardening factor. The middle pattern (gray triangles) shows a fit obtained using f_{hard} calculated with BHSPEC. The bottom points (turquoise diamonds) result from a high viscosity parameter, $\alpha = 0.1$, with BHSPEC hardening.

The best result is achieved when the complicated physics of the disk atmosphere is simply replaced with

f_h = const !

Straub et al. 2011

So what could have gone wrong?

- **Hardening factor is not well predicted by the disk atmosphere models (at least by BHSPEC)**

- **There is an outflow from the innermost parts of the disk**

We try to check outflow idea

Outflow description:

dot M = dot M_o exp(-x)

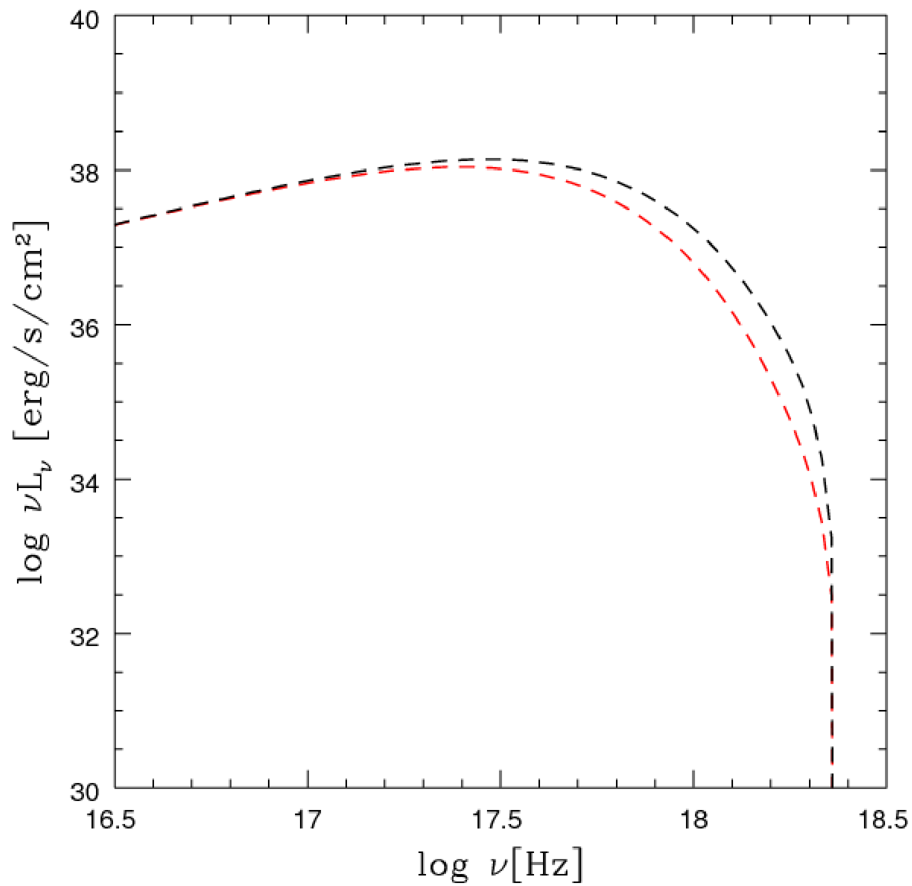
x = A/(r/r_ISCO - B)

where 0 < B < 1 and A is positive.

We did the excercise for the specific numbers:
A = 1.1, B = 0.15
and for the two values of the spin.

We do the exercise for a Novikov-Thorne model (no advection).

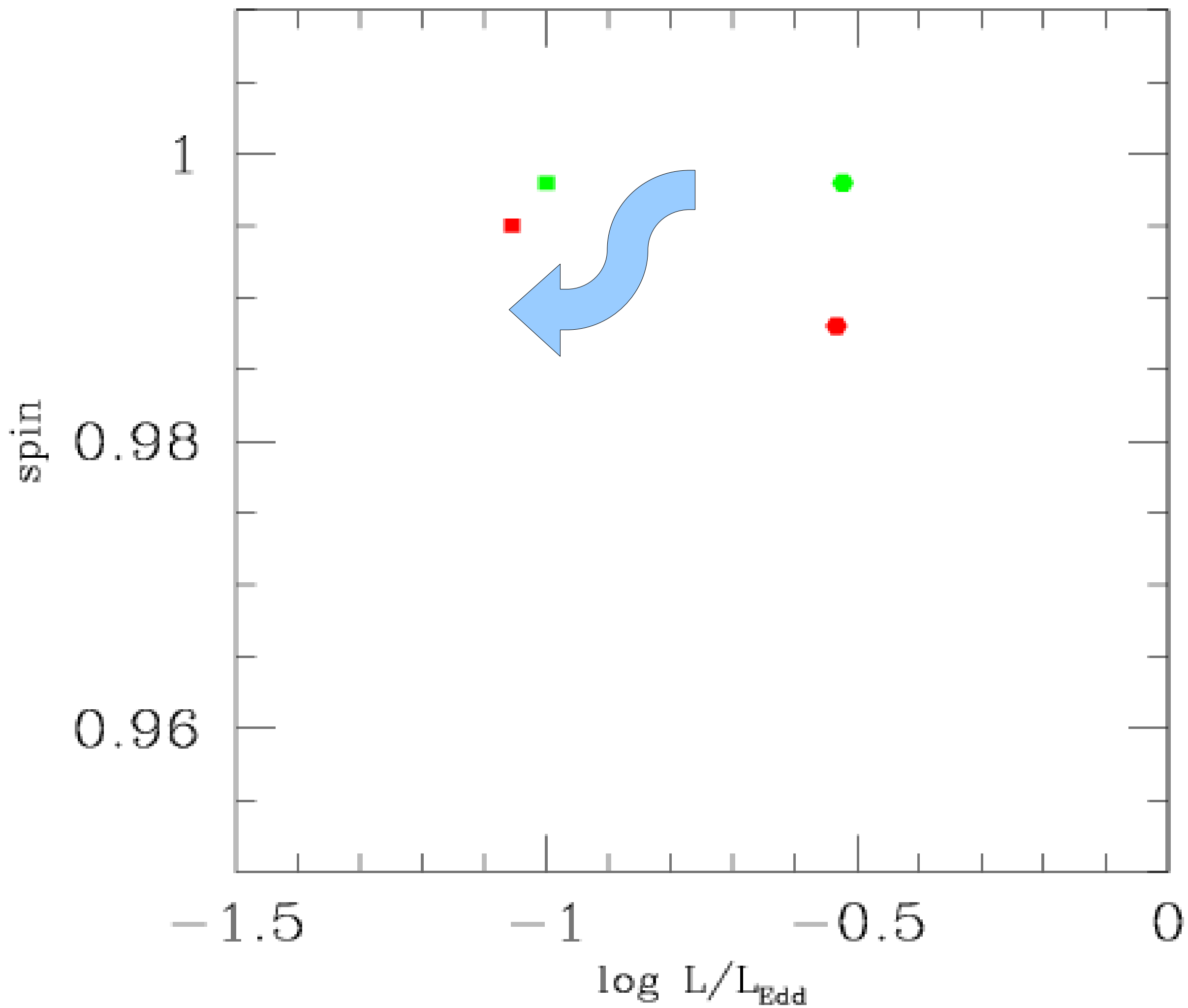
Outflow



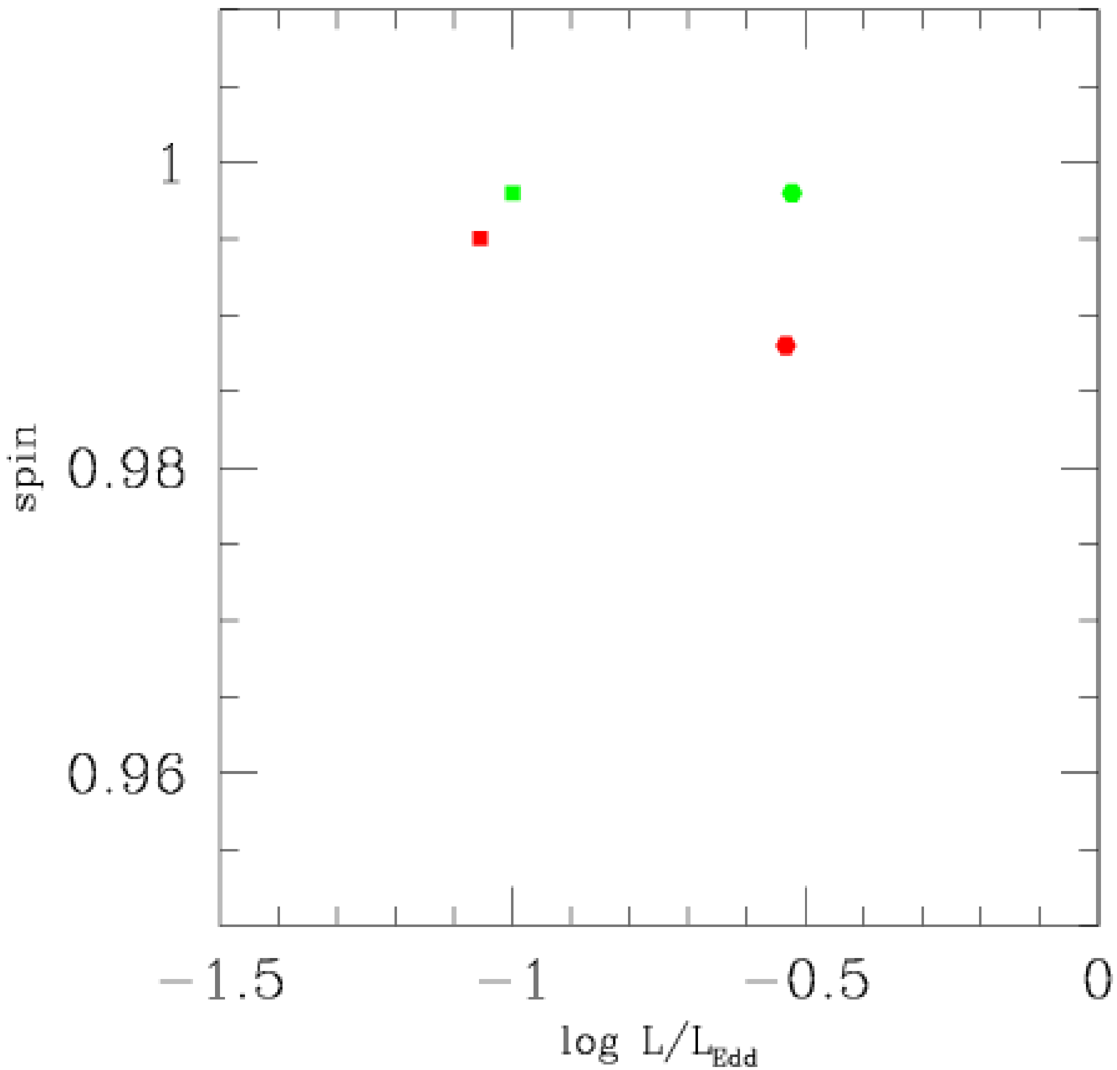
Outflow does not change the normalization at low frequencies but cuts-off the spectrum at high frequencies

We now take the spectrum with an assumed outflow and fit a simple Novikov-Thorne model **without outflow,** in the 2 – 10 keV band.

Outflow



Outflow



Outflow creates an illusion of a spin dropping with the luminosity

BUT

The effect requires significant amount of outflow

In our case

$\dot{M}_{outflow} = 0.7 \dot{M}_0$

Is this a problem?

Outflows from the central parts of the disk

$$\rho = \frac{\dot{M}_{\rm out}}{4\pi v b r^2}. \qquad (2)$$

The nature of the outflow depends on b. If $b \sim 1$ we can neglect scattering of photons from the sides of the outflow, while for $b \ll 1$ this process is dominant. For completeness we first briefly revisit the case $b \sim 1$ (cf. Pounds et al. 2003).

The electron scattering optical depth through the outflow, viewed from infinity down to radius R, is

$$\tau = \int_R^\infty \kappa\rho\, {\rm d}r = \frac{\kappa \dot{M}_{\rm out}}{4\pi v b R}. \qquad (3)$$

From equations (1) and (3) we get

$$\tau = \frac{1}{2\eta b}\frac{R_{\rm s}}{R}\frac{c}{v}\frac{\dot{M}_{\rm out}}{\dot{M}_{\rm Edd}}. \qquad (4)$$

Defining the photospheric radius $R_{\rm ph}$ as the point $\tau = 1$ gives

$$\frac{R_{\rm ph}}{R_{\rm s}} = \frac{1}{2\eta b}\frac{c}{v}\frac{\dot{M}_{\rm out}}{\dot{M}_{\rm Edd}} \simeq \frac{5}{b}\frac{c}{v}\frac{\dot{M}_{\rm out}}{\dot{M}_{\rm Edd}}, \qquad (5)$$

where we have taken $\eta \simeq 0.1$ at the last step. Since $\lesssim 1$ and $v/c < 1$ we see that $R_{\rm ph} > R_{\rm s}$ for any outflow rate $\dot{M}_{\rm out}$ of the order of $\dot{M}_{\rm Edd}$, that is, such outflows are Compton-thick.

King & Pounds 2003

The flow becomes Compton thick. Disk photons are upscattered and we do not see the disk!

Thus we should not use such a spectrum for spin measurement at all!

Collimated outflows

If instead $b \ll 1$, photons typically escape from the side of the outflow rather than making their way radially outwards through all of it. Almost all of the photons escape in this way within radial distance $r = R_\perp$ where the optical depth across the flow

$$\tau_\perp \simeq \kappa\rho(r)b^{1/2}r \qquad (6)$$

is of the order of unity. Thus

$$\frac{R_\perp}{R_s} = \frac{1}{2\eta b^{1/2}}\frac{c}{v}\frac{\dot{M}_{\rm out}}{\dot{M}_{\rm Edd}} \simeq \frac{5}{b^{1/2}}\frac{c}{v}\frac{\dot{M}_{\rm out}}{\dot{M}_{\rm Edd}}, \qquad (7)$$

and we again conclude that the outflow is Compton-thick for $\dot{M}_{\rm out} \sim \dot{M}_{\rm Edd}$.

But in this case at least the flow does not shield the disk and only a small fraction of photons gets upscattered...

This conclusion evidently implies that much of the emission from such objects will be thermalized and observed as a softer spectral component [see equation (18) below]. The observed harder X-rays

Why jest-like outflow should lead to considerable Comptonization ?

King & Pounds 2003

Summary

We can check broader parameter space for the model but the solution of the problem lies more likely in the hardening factor.