Comparison of relativistic iron line models I.

Fitting XMM-Newton data

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The analysis of the broad iron line profile in the X-ray spectra of active galactic nuclei and black hole X-ray binaries allows to constrain the spin parameter of the black hole. We compare the constraints on the spin value for two X-ray sources MCG-6-30-15 and GX 339-4 with a broad iron line using present relativistic line models in XSPEC — *laor* and *kyrline*. We investigate if the *laor* model still can be used for estimation of the spin with current data or if recently developed relativistic line models should be used instead.

Introduction

The galaxy MCG-6-30-15 has proven to be a very good source for testing different relativistic line models. The extremely skewed iron line has been revealed in X-ray spectra across all recent satellites. XMM-Newton observed MCG-6-30-15 for as long as 350ks during the summer 2001 (the revolutions 301,302,303) [3, 9]. The black hole binary GX 339-4 exhibited strong broadened line in 76ks observation in 2002 and also in two 138ks observations in the spring 2004 [5, 6, 7, 8]. Unfortunately, the data from the long 2004 observations suffer significantly from pile-up. Hence, we used the previous observation, which avoided the problems with pile-up by using the burst mode. The following analysis is done on pn data for both objects. In the case of MCG-6-30-15 the spectra of all three data sets were joined into one spectrum.

Data analysis

We reduced the data using SAS v.7.1.2 and followed the instructions of the previous analyses until grouping of the data bins. Instead of using *grppha* with 'group min' command we used *pharbn* script by M. Guainazzi which takes into account the energy resolution of the instrument. Next to the minimum number of counts per bin, we demand to oversample the instrumental resolution by a factor of 3. This different approach leads to a significant decrease of the total number of bins and to better statistics – more independent on the instrument properties. Consequently, the previous fits of GX 339-4 spectrum were not satisfying any more. We found a different fit, in which the line strength becomes much weaker. However, the spin value $a \approx 0.7$ enabled us to compare the *laor* model [4] with the *kyrline* model [2] for an intermediate value of the spin.

MCG-6-30-15

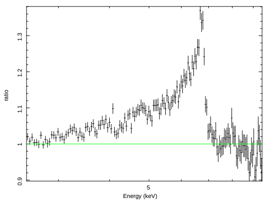

Fig. 1: Broad iron line for MCG-6-30-15.

observation: 2001/07/31-08/05
exposure time: 220ks
counts (2-10keV): 1.1×10^6cts
flux (2-10keV): $4{\times}10^{-11}$erg cm^{-2} s^{-1}
underlying model:
phabs*(po+zgauss$_{\rm em}$+zgauss$_{\rm abs}$)
$n_H = 0.041$cm^{-2}, $\Gamma = 1.9$, $E_{em} = 6.4$keV, $E_{abs} = 6.77$keV, $z = 0.008$

GX 339-4

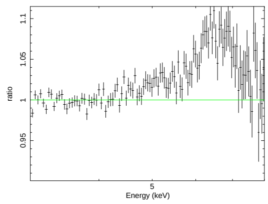

Fig. 3: Broad iron line for GX 339-4.

observation: 2002/09/29
exposure time: 2.25ks
counts (2-10keV): 1.0×10^7cts
flux (2-10keV): $9{\times}10^{-9}$erg cm^{-2} s^{-1}
underlying model:
phabs*(powerlaw+diskbb)
$n_H = 0.61$cm^{-2}, $\Gamma = 3.0$,
$kT = 0.87$keV

Table 1. Fit results for MCG-6-30-15 in 2.5-9.5keV

fit parameter	*kyrline*	*laor*	*kyrline**
a/M	0.94	0.96	0.90
i [deg]	26.7	26.8	24.7
E [keV]	6.67	6.66	6.7
q_1	4.9	4.7	4.6
q_2	2.84	2.87	2.81
r_b	5.5	5.1	5.5
χ^2/ν	175/148	174/148	179/148
EW [eV]	761	754	748

Results in tables 1. and 2.:

- the a/M value for *laor* was calculated from $R_{\rm in} = R_{\rm ms}$ (see Fig. 5)
- *Kyrline** considers limb brightening instead of limb darkening present in the other models.
- For MCG-6-30-15, the emissivity of the line is given by:
  $I \approx r^{-q_1}, \quad r < r_b$ and $I \approx r^{-q_2}, \quad r > r_b$
- For GX 339-4, the line parameters were fitted in 3-9keV, the value of energy was fixed at 6.97 keV and the inclination angle was assumed to be $i < 26°$

Table 2. Fit results for GX 339-4

fit parameter	*kyrline*	*laor*	*kyrline**
a/M	0.70	0.77	0.6
i [deg]	20	17	19
E [keV]	6.97	6.97	6.97
q_1	3.45	3.3	3.3
χ^2/ν	147/125	146/125	148/125
EW [eV]	175	199	164

Table 3. Flux in the broad line

	MCG-6-30-15	GX 339-4
net cts/s	3.59	592.1
model cts/s	3.59	592.5
line cts/s	0.20	5.1
line cts	$4.37.10^4$	$1.15.10^4$

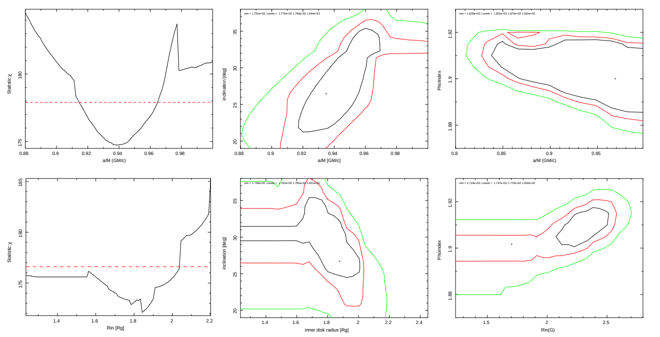

Fig. 2: The χ^2 statistics (left) and the confidence contours for the inclination angle (middle) and photon power-law index of the continuum (right) versus the spin parameter a/M (*kyrline*, top row) and R_{in} (*laor*, bottom row) for MCG-6-30-15. The black, red and green contours correspond to 1σ, 2σ and 3σ.

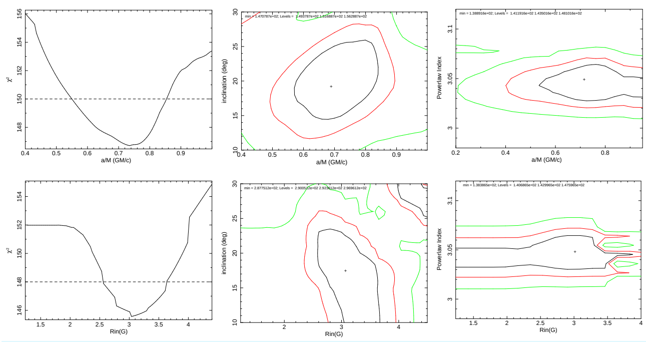

Fig. 4: The χ^2 statistics (left) and the confidence contours for the inclination angle (middle) and photon power-law index of the continuum (right) versus the spin parameter a/M (*kyrline*, top row) and R_{in} (*laor*, bottom row) for GX 339-4. The black, red and green contours correspond to 1σ, 2σ and 3σ.

Results

The main difference between *laor* and more recent relativistic line models like *kyrline* is in the determination of the spin value. The spin value is not fitted directly by the *laor* model. However, it can be estimated from the value of the inner radius of the disc, if we assume that the disc extends down to the marginally stable orbit (see Fig. 5). The tables 1. and 2. show that in the studied cases the *laor* model slightly overestimates the spin value. The value of the spin is bound to other parameters of the line (see contours spin vs. inclination angle) and also to the continuum parameters (see contours spin vs. powerlaw index). With the fixed continuum and with all other parameters of the line relaxed we get $a_{KY} = 0.88 - 1.0$ and $a_{laor} = 0.94 - 0.998$ for MCG-6-30-15, and $a_{KY} = 0.56 - 0.85$ and $a_{laor} = 0.65 - 0.86$ for GX 339-4.

We also tested how fast each model finished a steppar command on the spin value in the range $(0.89, 0.998)$. We find that the *laor* model was 10 times faster than the *kyrline* model. We also tried to compare the results with the *kerrdisk* model [1] which gives the same shape of the line as the *kyrline* model. However, we were not able to do it because the steppar command did not finish after 4 hours.

Conclusions

The *kyrline* model leads to a more well-defined minimum of χ^2 for the best fit value. The confidence contour plots for a/M versus other model parameters are much more regularly shaped. This indicates that the *kyrline* model has a smoother adjustment between the different points in the parameter space allowing for more reliable constraints on a/M. The *laor* model has a less accurate grid and is strictly limited to the extreme Kerr metric. It leads to the predictions of slightly higher values for the spin. However, the discrepancies between the *kyrline* and *laor* results are within the general uncertainties of the spin determination using the skewed line profile.

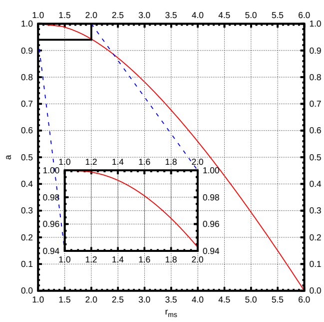

Fig. 5: Spin vs. marginally stable orbit relation.

References

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