Analyzing Relativistic Effects around Black Holes: XMM observations of Cygnus X-1

Thomas Dauser¹, Refiz Duro¹, Jörn Wilms³, K. Pottschmidt², M. A. Nowak³, S. Fritz¹,⁴, E. Kendziorra⁴, M. G. F. Kirsch⁵, C. S. Reynolds⁶, R. Stauber⁷

¹ECAP, ²CRESST/UMBC/NASA/GSFC, ³MIT, ⁴AT, ⁵ESA-ESEC, ⁶UMD

eMail: thomas.dauser@sternwarte.uni-erlangen.de

We investigate the relativistic effects around black holes by spectral analysis of Modified Timing Mode observations of Cygnus X-1 with XMM-Newton. Simultaneous RXTE observations revealed the existence of a coronal, relativistically smeared reflection component. In both cases the light color indicates the intrinsic broadening of the intrinsic emission line.

Abstract

For the analysis we use simultaneous XMM-Newton and RXTE observations of Cygnus X-1. EPIC-pn data are shown in blue, PCA data in red, and HETE in orange.

Jet Base vs. Corona Geometry

Fitting showed that the data is equally well described if we assume that the photons irradiating the accretion disk originate from the base of a jet. Although some continuum parameters are slightly different, both models describe the data very well. As can be seen in the above figure, the shape of the smeared reflection does not change much and hence a slightly different power law index and norm can compensate for the changes. Therefore, we conclude that emission from a low jet base ($\sim r_c$) can not be distinguished from the canonical model ($\sim r_{\text{in}}$) in the case of Cygnus X-1. This degeneracy is likely to be caused by the high ionization of the accretion disk, which results in a large Compton broadening of the intrinsic emission line.

The Full Model

Fitting showed that the data is equally well described if we assume that the photons irradiating the accretion disk originate from the base of a jet. Although some continuum parameters are slightly different, both models describe the data very well. As can be seen in the above figure, the shape of the smeared reflection does not change much and hence a slightly different power law index and norm can compensate for the changes. Therefore, we conclude that emission from a low jet base ($\sim r_c$) can not be distinguished from the canonical model ($\sim r_{\text{in}}$) in the case of Cygnus X-1. This degeneracy is likely to be caused by the high ionization of the accretion disk, which results in a large Compton broadening of the intrinsic emission line.

Cygnus X-1 is therefore plausibly close to maximally rotating.

Acknowledgments & References

This work was partly supported by the European Community under contract ITN215212 “Black Hole Universe” and by the Bundesministerium für Wirtschaft und Technologie under Deutsches Zentrum für Luft- und Raumfahrt grants 50OR0901 and 50OR0912. This paper is based on observations obtained with XMM-Newton, an ESA science mission with instruments and contributions directly funded by ESA member states and NASA. We thank M. D. Davis Troja for useful discussions on the CTE effects, M. Harke for the Chandra extraction, and J. E. Davis for developing the slxfig module used for plotting all figures.

Fritz S., 2000, Observation, IAS

Image: ESA

Figure 1 (Duro et al., 2011): XMM-Newton and RXTE light curve of Cygnus X-1 on 2004 November 20 and 21. EPIC-pn data are shown in blue, PCA data in red, and HETE in orange.

Figure 2 (Duro et al., 2011): a. Unbaked XMM-Newton and RXTE data and best fit model components. Green line: reflection continuum in the frame of the disk (note the strong Compton broadening: the “jet” above 10 keV is due to the numerical resolution of the reflection model). Purple line: relativistically smeared reflection component. b. Measured count rate spectra. c. Residuals of the best fit for the relativistic convolution to the data. d. Best fit residuals including relativistic convolution.

Figure 4 (Duro et al., 2011): y: significance contours for the corona geometry, based on $\Delta \chi^2 = 2.30, 4.61,$ and 9.2. Two minima are apparent, one indicating a low spin black hole at an unusually large $\alpha$, and one indicating an almost maximally spinning black hole consistent with a thin accretion disk ($\alpha = 0$).

Most-best-fit parameters are consistent between all three fits. Letting the emissivity free in the coronal model yields unphysically high values at low spin of the black hole. Given that most physical scenarios for very steep emissivity profiles such as strongly torqued accretion disks (Agol & Krolik, 2000) also require high $\gamma$, the high spin solution is preferred on physical grounds. This argument is strengthened by the fits in the lamp post geometry, which also lead to high $\alpha$. Moreover, the solution of a rapidly spinning black hole is consistent with spin measurements from the accretion disk continuum (Gou et al., 2011).