X-ray reflection in a stellar-mass black hole binary system

R. R. Ross (*College of the Holy Cross*) & A. C. Fabian (*Institute of Astronomy*)

Abstract

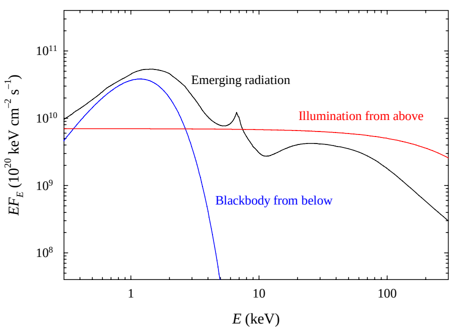
We extend our investigation of the reflection that can be expected from an accretion disc around a black hole of stellar mass. In addition to the variation in the strength and spectral shape of the illumination and the disc temperature, the density of the illuminated disc atmosphere is also allowed to vary. Thus the effective heating/ionization strength of the radiation emerging from the disc below varies, with important effects on the emergent X-ray spectrum.

Introduction

We have continued the work of Ross & Fabian (2007), calculating the X-ray reflection expected from an accretion disc in a black-hole binary system. The emerging spectrum differs markedly from reflection in an AGN because of the high temperature of the disc itself. With $kT_{\rm eff}$ ~ few × 0.1 keV, the thermal radiation from the disc contributes to the observed X-ray spectrum and to the ionization of metals in the illuminated surface layer.

Fig. 1 shows a sample reflection spectrum. Here the surface layer has hydrogen number density $n_{\rm H} = 10^{20}$ cm^{-3}. Blackbody radiation with $kT_{\rm BB} = 0.30$ keV enters the surface layer from below. The outer surface is illuminated by a cut-off power-law spectrum with photon index $\Gamma = 2$ and an *e*-folding energy of 300 keV for the high-energy exponential cut-off. The total illuminating flux, F_0, equals the total flux, $F_{\rm BB}$, in the blackbody entering from below. The blackbody radiation alone has ionization parameter $\xi_{\rm BB} = 4\pi F_{\rm BB}/n_{\rm H} = 1045$ erg·cm/s, which is high enough to make Fe XXV the dominant species of iron. All lighter elements are fully ionized. The illumination (with $\xi_0 = 4\pi F_0/n_{\rm H} = \xi_{\rm BB}$) causes iron to be ionized further, and Fe XXVI is the dominant ion for $\tau_{\rm T} < 0.5$. The emerging spectrum exhibits a strong, broad Kα emission feature which is a blend of Fe XXV (6.7 keV) and Fe XXVI (7.0 keV) lines.

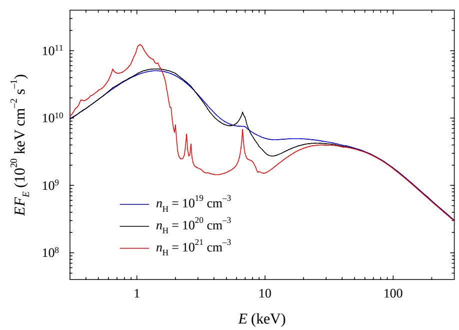
Fig 1: $n_{\rm H} = 10^{20}$ cm^{-3}, $kT_{\rm BB} = 0.30$ keV, $F_0/F_{\rm BB} = 1$ & $\Gamma = 2$



Results

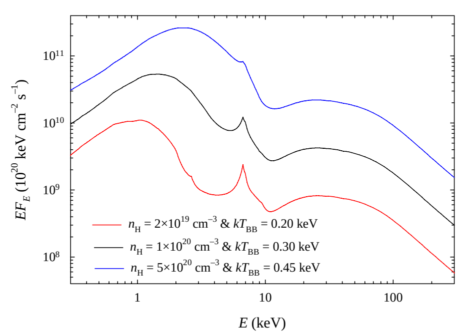
Although we have explored a broad range of parameter values, we shall only present results for the flux ratio $F_0/F_{\rm BB} = 1$ and photon index $\Gamma = 2$. For a fixed value of $kT_{\rm BB}$, changing the density changes the ionization of the heavy elements. Fig. 2 shows the result of changing the density in the previous model. With the density reduced to $n_{\rm H} = 10^{19}$ cm^{-3}, the ionization parameter is ten times higher, and iron is fully ionized within a deep surface layer ($\tau_{\rm T} < 3.5$). Only a very weak Fe XXVI Kα line is seen. If the density is raised to $n_{\rm H} = 10^{21}$ cm^{-3}, however, a strong, narrow iron Kα line at 6.7 keV results from the fact that Fe XXV dominates near the outer surface. The cooler, less highly ionized gas produces low-energy emission features, a sharp drop-off in the continuum around 2 keV, prominent Kα emission by S XV and S XVI around 2.5 keV, and a steeper (less smeared out) Fe K-edge.

Fig 2: $kT_{\rm BB} = 0.30$ keV, $F_0/F_{\rm BB} = 1$ & $\Gamma = 2$



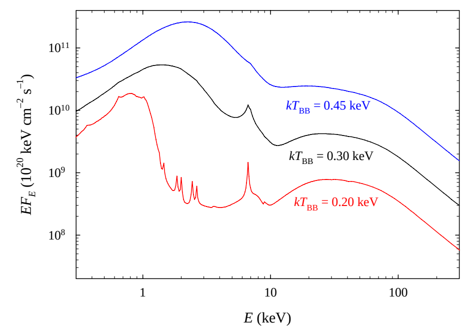
Changing the value of the blackbody temperature, $T_{\rm BB}$, affects the emerging spectrum in a complicated way. For one thing, it changes the value of the ionization parameter by changing $F_{\rm BB}$. However, it also changes the overall shape of the continuum. A harder blackbody spectrum has more ionizing power than a softer one, even for the same value of ξ. This is illustrated in Fig. 3, which shows models with $n_{\rm H}$ and $kT_{\rm BB}$ adjusted so that all three models have the same ionization parameters as the model shown in Fig. 1. Although the values $kT_{\rm BB} = 0.45$ keV and $n_{\rm H} = 5\times10^{20}$ cm^{-3} give the same ionization parameter, iron is now more highly ionized. Fe XXVI dominates for $\tau_{\rm T} < 1.0$. The weaker line emission and the stronger continuum combine to produce a smaller apparent Fe Kα feature. Meanwhile, the lower values $kT_{\rm BB} = 0.20$ keV and $n_{\rm H} = 2\times10^{19}$ cm^{-3} result in a less highly ionized surface layer. Fe XXVI only dominates for $\tau_{\rm T} < 0.2$, and sulfur is no longer fully ionized for $\tau_{\rm T} > 3.4$. A very strong Fe XXV Kα line rises up from a diminished continuum, and a weak S XVI Kα line is also visible.

Fig 3: $F_0/F_{\rm BB} = 1$ & $\Gamma = 2$



The importance of the $kT_{\rm BB}$ value can be seen by considering models with fixed density. Fig. 4 shows results with $n_{\rm H}$ fixed at 10^{20} cm^{-3}. For $kT_{\rm BB} = 0.45$ keV , the combination of an ionization parameter five times larger (than for 0.30 keV) and a harder continuum keeps iron fully ionized for $\tau_{\rm T} < 2.7$. The Fe Kα line can barely be seen in the emerging spectrum. Reducing the $kT_{\rm BB}$ value to 0.20 keV only makes the ionization parameter five time smaller (than for 0.30 keV), but it produces the least ionized surface layer presented here. Iron is less ionized than Fe XXV for $\tau_{\rm T} > 0.3$, and magnesium, silicon and sulfur are not fully ionized near the surface. There is a sharp drop-off in the emerging continuum just above 1 keV, and Kα emission lines due to Mg XII, Si XIII–XIV, and S XV–XVI can be seen in addition to the Fe XXV line.

Fig 4: $n_{\rm H} = 10^{20}$ cm^{-3}, $F_0/F_{\rm BB} = 1$ & $\Gamma = 2$



Conclusion

We see that by varying $n_{\rm H}$ and $kT_{\rm BB}$, a broad range of spectral shapes and features can be produced in the emerging spectrum when the accretion disc is illuminated by a power-law X-ray spectrum. Of course, adding variations in the parameters $F_0/F_{\rm BB}$ and Γ broadens the range of spectra even further (see Ross & Fabian 2007).

The emerging spectra shown here are calculated in the local rest frame of the illuminated disc surface. Gravitational redshift and the relativistic Doppler effect smear out and skew the spectra as viewed from Earth. Relativistically-blurred four-parameter reflection models have been applied to data from GX 339-4 recently (Reis et al. 2008). Additional black-hole binary sources are currently under study.

References

Reis R.C., Fabian A.C., Ross R.R., Miniutti G., Miller J.M., Reynolds C., 2008, MNRAS, in press

Ross R.R., Fabian A.C., 2007, MNRAS, 381, 1697