Hot high-gravity atmospheres as soft X-ray sources and the effect of hard X-ray irradiation

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Abstract. The expected soft X-ray emission from hot high gravity atmospheres is explored in a range of effective temperatures, gravities and chemical composition, assuming hydrostatic and radiative equilibrium and using LTE. The gravitational fields are applicable to magnetic CV's and supersoft X-ray sources. Irradiation of such atmospheres by a hard X-ray spectrum leads to a temperature inversion, which result in a decrease of absorption edges expected in non-illuminated atmospheres. Ionization stages are seen which are higher than expected on the basis of the effective temperture. Depending on the parameters, such as the irradiated flux and spectrum, some ionization edges and lines may be seen in emission.

1. Introduction

The spectrum of an optically thick soft X-ray source is often taken as blackbody emission. This is a fair approximation if the opacity as a function of photon energy is roughly constant. However, in the soft X-ray range the emission spectrum at certain temperatures and densities is dominated by a few ions, such as the helium and hydrogen-like ions of C, N and O. In such cases is the blackbody approximation insufficient, in particular when the observed spectrum is significantly limited by interstellar absorption such as the observed spectra of supersoft X-ray sources (Heise et al. 1994).

To investigate how soft X-ray emission varies with assumed physical parameters we have calculated in a standard way LTE plane-parallel atmospheres in hydrostatic and radiative equilibrium, ignoring most metal line opacities and metal line blanketing. An application to the spectra of supersoft X-ray sources is given by Heise et al. 1995.

In the case of accretion onto magnetic cataclysmic variables the atmospheric structure is modified by the presence of a hard X-ray source. Irradiation by hard X-rays was first considered by Williams et al. (1987). Van Teeseling et al. (1994) show that atmospheres irradiated by hard X-rays lead to a temperature inversion in the outer atmosphere. This feature was not noticed by Williams et al. Irradiated atmospheres have been applied to a high-resolution spectrum (Paerels et al. 1994) of AM Her. Results of non-illuminated atmosphere spectral fits to AM Her indicate that strong ionization edges are expected, but not observed. As shown by Van Teeseling et al. (1994), hard X-ray irradiation decrease the

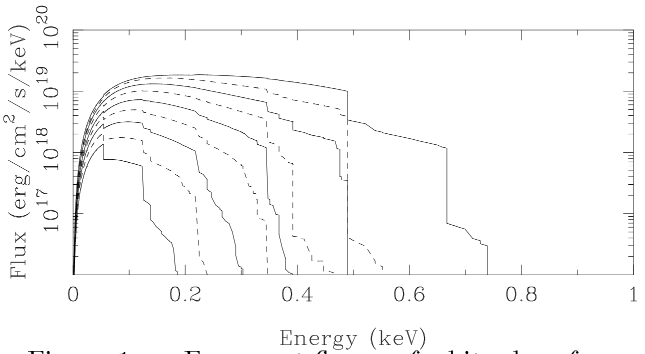

Figure 1. Emergent fluxes of white-dwarf LTE modelatmospheres for cosmic abundances show these to be predominantly soft X-ray sources. $\log g = 8$ and $T_{\mathit{eff}} = 2 \times 10^5$ to 6×10^5 K in steps of 0.5×10^5 K from bottom to top.

size of strong absorption edges and the observed soft X-ray spectrum of AM Her better fits spectra from irradiated atmospheres.

In this paper we give a preliminary account of the effects of hard X-ray irradiation. An exploration of parameter space (changing the spectral shape and incident hard X-ray flux) is presently being carried out.

2. Model atmospheres

The input parameters of the models are the effective temperature T_{eff}, the gravity g and chemical composition; the incident hard X-ray flux per cm^{-2} and spectral shape, taken to be thermal bremstrahlung of a temperature of 40 keV. The density in the more massive white dwarfs ($\log g \gtrsim 8$, $M \gtrsim 0.6 M_{\odot}$) is sufficiently high to assume that collisional ionizations dominate and that thermal equilibrium (LTE) determines the degree of ionizations and the atomic population levels.

For models close to the Eddington limit or strong irradiation non-LTE effects may play an important role, which are neglected in the present study. Non-LTE effects may result in further ionization of ions that form the dominant opacity source in the LTE approximation.

The opacities include free-free and bound-free absorption of the 15 most abundant elements. Ionization stages are complete up to 4 keV. The photoionization cross sections of the ground state for each ion of each individual subshell were calculated by Kaastra (1991) using the method described by Kallman & MacCray (1982). The models include compton heating in a way described by van Teeseling et al. (1994).

Line blanketing and line opacities have only be considered for the H and He lines and some of the more important UV lines. The H line opacities are calculated using the interpolation formulae given by Kurucz (1970). The effect of overlapping of the higher series members is included by setting the opacity to its free-bound values at the series limit, beyond the Inglis-Teller limit. This way of treating the lines is adequate to evaluate the blanketing effect of the lines

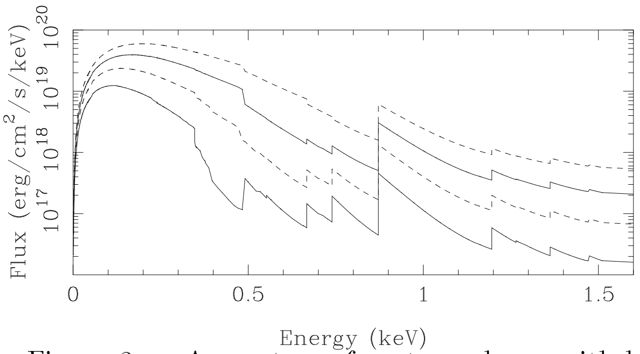

Figure 2. A spectrum for atmospheres with $\log g = 9$, $T_{eff} = 4, 5, 6$ and 7×10^5 K irradiated with the same amount of incident flux as the nett flux through the atmosphere, showing ionization edges of C, N, O and Ne in emission.

on the continuum; it does not yield accurate profiles. To study the effect of the temperature inversion in the UV-range of IUE, some of the more important UV lines (N-II, N-III, N-V, Si-II, Si-III, C-IV, He-II) have been included, with line profiles and damping constants given by Sahal-Bréchot et al. (1971).

3. Hot high-gravity atmospheres without irradiation

The emerging flux from a selection of the models using cosmic abundances is depicted in Fig. 1 for $\log g = 8$, corresponding to white dwarfs of mass $\sim 0.6 M_\odot$.

The models with $T_{eff} < 3.5 \times 10^5$ K have a flux in the soft X-ray range which is dominated by the cumulative effect of free-bound emissions of metals other than C, N and O. At $T_{eff} = 4 \times 10^5$ K and 4.5×10^5 K the soft X-ray flux is dominated by a strong continuum up to the C V ground state absorption edge at 0.39 keV. For $T_{eff} \sim 5.5 \times 10^5$ K C V is fully ionized and a continuum up to the C VI edge at 0.49 keV is seen. At still higher effective temperatures all of the carbon is ionized and the spectrum is dominated by N VI at 0.67 keV and O VII at 0.74 keV. In atmospheres of larger gravity the higher densities shift the ionization equilibrium in favor of lower ionization stages. The continua and absorption edges of C V, C VI, N VI and O VII therefore appear at higher temperatures. White-dwarf effective temperatures from fits therefor will depend on the assumed gravity and cannot be determined uniquely.

For all abundances the calculated models emit a large fraction of the bolometric luminosity in the soft X-ray range: they represent typical soft X-ray sources. In Fig. 1 and 2 of Heise et al. (1994) it is shown that they are more efficient soft X-ray emitters than blackbody spectra at the same temperature. The soft X-ray effficiency hardly changes when metal abundances are varied from 5% – 100% of cosmic abundances. The observed flux, however, is significantly reduced by interstellar absorption.

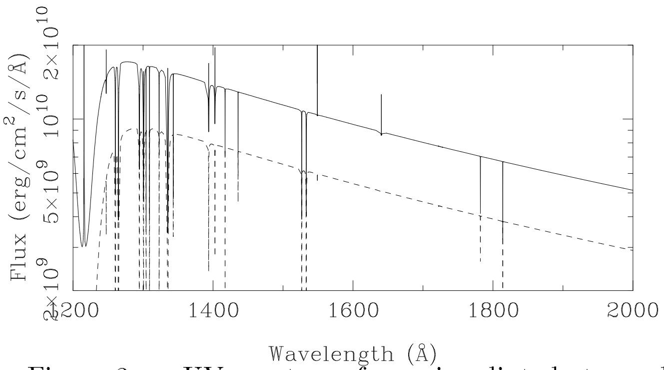

Figure 3. UV spectrum for an irradiated atmosphere (solid line) with $T_{eff} = 2 \times 10^4\,$K irradiated with the same incident hard X-ray flux (bremsstrahlung 10keV) as through the bottom, showing C-V (1550Å) and He-II (1640Å) in emission. For comparison a spectrum of a non-irradiated atmosphere of the same temperature (dotted line) is given.

4. Irradiation by hard X-rays

In addition to the effects of hard X-ray irradiation described by van Teeseling et al. (1994) we note that the temperature inversion may result in reversing some ionization edges in emission, while others stay in absorption. An example of such a spectrum is shown in Fig. 2. Lines in the X-ray range are not yet taken into account but will also appear in emission.

Depending on the depth of formation of UV lines, the temperature inversion may cause UV absorpion lines to be filled in with central emission, or to be entirely in emission. Just by way of example we show in Fig. 3 an atmosphere with $T_{eff} = 2 \times 10^4\,$K irradiated on top with a hard X-ray flux of the same amount as the nett flux through the atmosphere and witha bremsstrahlung spectrum of 10keV. Ly-α remains predominantly in absorption having a small central reversal. Si-II and Si-III lines remain in absorption, but C-V (at 1550Å) and He-II (at 1640Å) are in emission. These results, however, depend critically on the assumed incident spectrum and local hard X-ray flux. UV line emission in magnetic cataclysmic variables are usually ascribed to photoionization in the accretion stream, but it is possible that part of the UV line emission originates from a larger area in the photosphere.

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