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High efficiency of soft X-ray radiation reprocessing in supersoft X-ray sources due to multiple scattering

V. Suleimanov[1,3], F. Meyer[2], and E. Meyer-Hofmeister[2]

[1] Department of Astronomy, Kazan State University, Kremlevskaya 18, Kazan 8, 420008, Russia
[2] Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Straße 1, 85740 Garching, Germany
[3] Kazan Branch of Isaac Newton Institute, Santiago, Chile

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Abstract. Detailed analysis of the lightcurve of CAL 87 clearly has shown that the high optical luminosity comes from the accretion disc rim and can only be explained by a severe thickening of the disc rim near the location where the accretion stream impinges. This area is irradiated by the X-rays where it faces the white dwarf. Only if the reprocessing rate of X-rays to optical light is high a luminosity as high as observed can be understood. But a recent detailed study of the soft X-ray radiation reprocessing in supersoft X-ray sources has shown that the efficiency is not high enough. We here propose a solution for this problem. As already discussed in the earlier lightcurve analysis the impact of the accretion stream at the outer disc rim produces a "spray", consisting of a large number of individual gas blobs imbedded in a surrounding corona. For the high mass flow rate this constitutes an optically thick vertically extended screen at the rim of the accretion disc. We analyse the optical properties of this irradiated spray and find that the multiple scattering between these gas blobs leads to an effective reprocessing of soft X-rays to optical light as required by the observations.

Key words. accretion, accretion disks – radiative transfer – scattering – stars: novae, cataclysmic variables – stars: circumstellar matter – X-rays: stars

1. Introduction

The recent progress in X-ray observations provides us with a wealth of X-ray spectra for a continuously increasing number of objects. A special class of objects are the supersoft X-ray sources, X-ray binaries with a very soft spectrum (most photons have an energy below 0.5 keV) and a very high luminosity (10^{37} to 10^{38} erg/s). These binaries are commonly understood as a white dwarf in a close orbit with a low-mass star where the mass flow towards the compact star forms an accretion disc. The very high accretion rate (10^{-7} $M_{\odot}$/yr) causes steady state burning on the white dwarf surface. The high accretion rate also is responsible for a thickening of the accretion disc rim as found to a lower amount also for the discs in low mass X-ray binaries (Milgrom 1978; Mason & Cordova 1982; White et al. 1995). A detailed analysis of the lightcurve of CAL 87 (Schandl et al. 1997) had already shown that the high optical luminosity can only be explained by a severe thickening of the disc rim where the accretion stream impinges. This area is irradiated by the X-rays where it faces the white dwarf. A high reprocessing rate of X-rays to optical light is needed to produce a luminosity as high as observed. A recent detailed study of the soft X-ray radiation reprocessing in supersoft X-ray sources (Suleimanov et al. 1999) has shown that the efficiency is not high enough. We now here discuss a new model. We suggest that due to the high mass flow rate a "spray" exists, a vertically extended area around the impact of the accretion stream at the outer disc rim. This area is filled with gas blobs. In the presented paper we discuss the optical properties of gas blobs and show how the light is reprocessed in such a spray.

In Sect. 2 we discuss the qualitative picture of the soft X-ray reprocessing during multiple scattering between gas blobs. In Sect. 3 the situation simplified to the radiation transfer in a flat cloud slab is considered. In Sect. 4 we desribe the application of the presented model to CAL 87 based on the lightcurve simulation of Schandl et al. (1997). A discussion and conclusions follow in Sects. 5 and 6.

2. Reprocessing of soft X-ray to optical radiation by multiple scattering between gas clouds

In previous work (Suleimanov et al. 1999) we showed that the reprocessing efficiency η is very small (0.05–0.1) if an accretion disc is irradiated by a soft X-ray flux ($E < 1$–2 keV). Due to the high opacity in this spectral band the soft X-rays cannot penetrate deeply into the disc atmosphere. As a result the soft

Send offprint requests to: V. Suleimanov,
e-mail: vals@ksu.ru

X-ray flux heats the upper atmospheric layers and is reradiated in the far UV spectral band. The temperature of deeper layers, where the optical disc radiation is formed, is increased only slightly. It is obvious that the same qualitative picture holds for an optically thick gas cloud with a temperature $T_c \sim 10^4$ K, irradiated by the soft X-ray flux. It means that the reprocessing efficiency A due to a single reradiation from the cloud irradiated by the soft X-rays is small too. But the efficiency η can be higher for a slab consisting of many separate gas clouds, irradiated by the soft X-rays.

We denote by A the fraction of incoming soft X-ray/far UV flux that is reradiated in the optical spectral band due to reradiation at a single cloud. By η we denote the fraction of incoming soft X-ray/far UV flux that is reradiated in the optical spectral band due to reradiation from an accretion disc or a cloud slab. We use the term "soft X-ray" for the spectral band with photon energy 0.1–1 keV and "far UV" for the spectral band with photon energy 0.015–0.1 keV.

The opacity of a plasma with $T \approx 10^4$ K is high in the far UV band. If an optically thick cloud is irradiated by a far UV flux this flux cannot penetrate deeply into the cloud. The far UV flux heats the upper cloud layers and is reradiated in the same far UV spectral band. The temperature of deeper layers, where the cloud optical radiation is formed, is increased only slightly. Therefore, the reprocessing efficiency A for the far UV flux to the optical band is expected to be small for reradiation at a single cloud. Thus reprocessing efficiencies in the soft X-ray and far UV band should be very similar, and thus below we will consider a common soft X-ray/far UV band.

In the stationary case all flux impacting on a cloud must be reradiated. As the electron scattering cross section in a cloud with $T \approx 10^4$ K is small compared to the absorption cross section we may assume that the incoming soft X-ray/far UV flux is fully absorbed, heats the upper cloud layers, and then is reradiated. We refer to this process as reflection. But the reradiated flux is not a black body radiation with a single temperature. The part reradiated in the far UV band has higher radiation temperature then the part reradiated in the optical band.

For a single reflection from a gas cloud, the main part, $(1 - A)F_x$, of the absorbed soft X-ray flux F_x is reradiated in the far UV band, only a small part, AF_x, is reradiated in the optical band. As mentioned above A, the reprocessing efficiency for single reflection, is around 0.05–0.1. Therefore, a reflection from a cloud can be considered as a kind of scattering. But this is a not scattering of a photon in the sense of an elementary physical process. It is only sutable description of the process of flux reflection from one cloud, which makes it simpler to describe the radiation transfer through a slab of clouds. If reflected from a slab consisting of many individual clouds radiation can have many such "scatterings" between clouds before it exits from the slab again, resulting in a reprocessing efficiency that is higher than A. In the next section we show that this efficiency η can reach up to 0.5 (with $A = 0.1$) in the most favourable case.

The optical light curve of the supersoft X-ray source CAL 87 was modelled by Schandl et al. (1997) with the assumption of $\eta = 0.5$. They showed that the outer parts of the accretion disc must be extended in z-direction. This extended

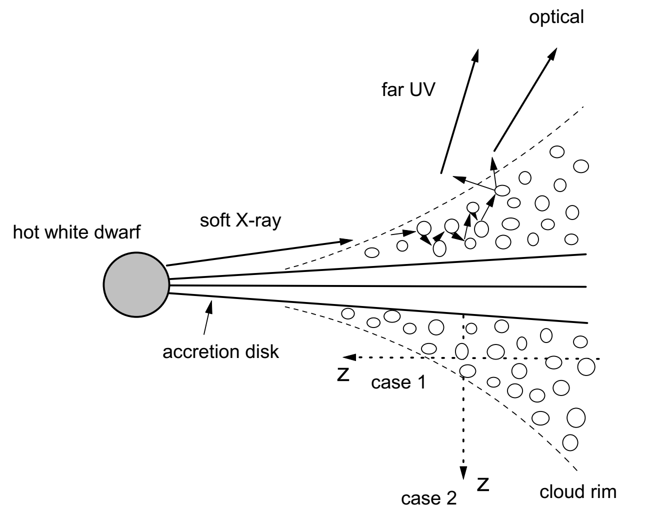

Fig. 1. The qualitative picture of the cloud rim above an accretion disc in supersoft X-ray sources.

outer rim is necessary to intercept a significant part of the hot white dwarf flux and to reprocess it into the optical band. In that work it was also shown that this rim can not be homogeneous and the suggestion was made that the rim consists of separate clouds, which can be a spray formed at the impact of the gas stream from the secondary star onto the disc. What we call "clouds" here are geometrically small cloudlets or gas blobs. The cloud radii should be much smaller than the disk radius in agreement with their formation on the scale of a two-stream-instability in the shear interaction. Thus, we suggest the following qualitative picture of the outer parts of the accretion disk in supersoft sources (see Fig. 1). Above the outer geometrically thin disk there is a slab of gas clouds embedded into a hot ($T \approx 5 \times 10^5$ K) intercloud medium. This geometrically thick slab intercepts a significant part from the soft X-ray radiation of the central source. This radiation is scattered many times between clouds inside the slab and finally reflected from the slab. We discuss the physical parameters of the clouds and the intercloud medium in Sect. 4. In a single scattering a small fraction (0.05–0.1) of the soft X-ray/far UV flux is reradiated in the optical band, but due to many scatterings before exit the final reprocessing efficiency increases by several times and can reach up to 0.5. This model can explain the high value of the soft X-ray reprocessing observed in some supersoft sources, such as CAL 83 and CAL 87.

3. Radiation transfer in the gas cloud slab

In this section we consider the radiation transfer in the cloud slab quantitatively. For simplicity we make the following approximations:

1) The cloud slab is plane, homogeneous, infinitely extended in the $x-y$ plane and has a finite geometrical thickness L in the z-direction (see Fig. 2). This means that the radiation transfer is in z-direction.

2) We consider radiation transfer in two spectral bands only. In band 1, that includes the soft X-ray and far UV bands, the

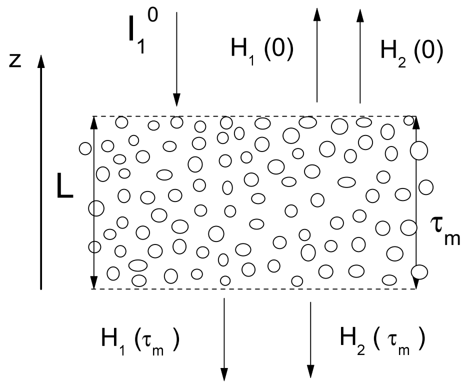

Fig. 2. The geometry of the radiation transfer in a cloud slab.

slab is illuminated from the outwards side. Band 2 includes the optical (visual and soft UV) band.

3) We treat the reradiation of the incoming flux by one cloud as a scattering. For single scattering the major part $(1-A)$ of the flux in band 1 is reradiated in the same band 1. The smaller part (A) of the flux in band 1 is reradiated in band 2. Incoming radiation in band 2 is fully reradiated in the same band 2. We define the scattering coefficient on clouds as

$$\chi_\mathrm{c} = \pi R_\mathrm{c}^2 N_\mathrm{c} \;\; \mathrm{cm}^{-1}, \tag{1}$$

where N_c is the cloud number density. The corresponding optical depth increment is:

$$\mathrm{d}\tau_\mathrm{c} = -\chi_\mathrm{c}\,\mathrm{d}z. \tag{2}$$

In this case the radiation transfer equation in the two bands can be written as:

$$\mu\frac{\mathrm{d}I_{1,2}}{\mathrm{d}z} = -(\chi_\mathrm{c}+\chi_\mathrm{e})I_{1,2} + \eta^\mathrm{c}_{1,2} + \eta^\mathrm{e}_{1,2}. \tag{3}$$

We take electron scattering in the intercloud medium into account, too, with the electron scattering coefficient χ_e:

$$\chi_\mathrm{e} = \sigma_\mathrm{T} N_\mathrm{e} \;\; \mathrm{cm}^{-1}. \tag{4}$$

Here N_e is the electron number density of the intercloud medium, $\eta^\mathrm{e}_{1,2}$ and $\eta^\mathrm{c}_{1,2}$ are the emissivities due to electron scattering and cloud scattering in the first and second spectral bands. One can rewrite Eq. (3) as follows:

$$\mu\frac{\mathrm{d}I_{1,2}}{\mathrm{d}\tau_\mathrm{c}} = (1+\alpha)I_{1,2} - S^\mathrm{c}_{1,2} - S^\mathrm{e}_{1,2}, \tag{5}$$

where $\alpha = \chi_\mathrm{e}/\chi_\mathrm{c}$, and $S^\mathrm{c}_{1,2}$, $S^\mathrm{e}_{1,2}$ are the cloud scattering and electron scattering source functions in both spectral bands.

4) We take isotropic electron scattering, but we can not consider the cloud scattering as isotropic, since the clouds have a larger dimension than the light wavelength. Therefore, incoming flux is reflected mainly in the opposite direction, and the cloud scattering is described by a redistribution function that is unknown. We treat the radiation transfer in the two-stream approximation (Mihalas 1978; Suleimanov et al. 1999) for the directions $\mu_{1,2} = \pm 1/\sqrt{3}$, and introduce the anisotropy function β to take unisotropic scattering into consideration. This function describes the fraction of the radiation reflected in opposite direction to the source function. The source functions can be rewritten in this case as:

$$S_1^{\mathrm{c},\pm} = (1-A)(\beta I_1^\mp + (1-\beta)I_1^\pm) \tag{6}$$

$$S_2^{\mathrm{c},\pm} = A(\beta I_1^\mp + (1-\beta)I_1^\pm) + \beta I_2^\mp + (1-\beta)I_2^\pm \tag{7}$$

$$S_{1,2}^{\mathrm{e},\pm} = (I_{1,2}^\pm + I_{1,2}^\mp)/2. \tag{8}$$

The value of β ranges from 0.5 to 1. The cloud scattering is isotropic at $\beta = 0.5$, and at $\beta = 1$ the opposite directed radiation contributes to the source function.

In the framework of the above mentioned approximations the radiation field is described by 4 equations:

$$\pm\frac{1}{\sqrt{3}}\frac{\mathrm{d}I^\pm_{1,2}}{\mathrm{d}\tau} = (1+\alpha)I^\pm_{1,2} - S^{\mathrm{c},\pm}_{1,2} - \alpha S^{\mathrm{e},\pm}_{1,2}. \tag{9}$$

Here and below we do not write the index c at τ. Introducing the mean intensity:

$$J_{1,2} = \frac{1}{2}(I^+_{1,2} + I^-_{1,2}), \tag{10}$$

and the Eddington flux:

$$H_{1,2} = \frac{1}{2\sqrt{3}}(I^+_{1,2} - I^-_{1,2}), \tag{11}$$

we rewrite Eq. (9) in the form:

$$\frac{\mathrm{d}H_1}{\mathrm{d}\tau} = AJ_1 \tag{12}$$

$$\frac{\mathrm{d}J_1}{\mathrm{d}\tau} = 3(\alpha + A + 2\beta(1-A))H_1 \tag{13}$$

$$\frac{\mathrm{d}H_2}{\mathrm{d}\tau} = -AJ_1 \tag{14}$$

$$\frac{\mathrm{d}J_2}{\mathrm{d}\tau} = 3((\alpha+2\beta)H_2 + A(2\beta-1)H_1). \tag{15}$$

Solution of Eqs. (12)–(15) gives:

$$J_1 = C_1\exp(-b\tau) + C_2\exp(b\tau) \tag{16}$$

$$H_1 = \frac{d}{\sqrt{3}}(C_2\exp(b\tau) - C_1\exp(-b\tau)) \tag{17}$$

$$H_2 = C_3 - H_1 \tag{18}$$

$$J_2 = C_4 + 3(\alpha+2\beta)\tau C_3 - J_1 \tag{19}$$

where

$$b = (3A(\alpha + A + 2\beta(1-A)))^{1/2},$$

and

$$d = \left(\frac{A}{\alpha + A + 2\beta(1-A)}\right)^{1/2}.$$

The constants C_1, C_2, C_3, C_4 are obtained from the upper boundary condition at $\tau = 0$ and from the lower boundary condition at $\tau = \tau_\mathrm{m}$. We consider two cases for the lower boundary condition. In the first case there is no medium and source of radiation under a slab. This case corresponds to a radiation transfer through a cloud along the accretion disc rim. In the second case there is a homogeneous medium under the slab. This medium reprocesses the radiation from the first to the second band with the same efficiency as a cloud. The second case corresponds to radiation transfer through a slab above an accretion disc at a fixed disc radius.

3.1. The cloud slab seen along the accretion disc

In this case there is no incoming radiation at the lower boundary from below in both spectral bands: $I_1^+(\tau_m) = I_2^+(\tau_m) = 0$. At the upper boundary there is no incoming radiation in the second spectral band, $I_2^-(0) = 0$, but there is incoming radiation $I_1^-(0) = I_1^0$ in the first spectral band. This means that at the upper slab boundary there is the external irradiating flux $H_1^0 = -I_1^0/2\sqrt{3}$. These boundary conditions are expressed as:

$$J_1(0) - \sqrt{3}H_1(0) = I_1^0 \quad (20)$$

$$J_2(0) - \sqrt{3}H_2(0) = 0 \quad (21)$$

$$J_1(\tau_m) + \sqrt{3}H_1(\tau_m) = 0 \quad (22)$$

$$J_2(\tau_m) + \sqrt{3}H_2(\tau_m) = 0. \quad (23)$$

The constants obtained using these boundary conditions are:

$$C_1 = \frac{I_1^0}{1+d}\left(1 - \frac{1}{1-B}\right), \quad (24)$$

$$C_2 = \frac{I_1^0}{1-d} \cdot \frac{1}{1-B}, \quad (25)$$

$$C_3 = -\frac{I_1^0}{2\sqrt{3} + 3(\alpha + 2\beta)\tau_m}, \quad (26)$$

$$C_4 = I_1^0 + \sqrt{3}C_3, \quad (27)$$

where

$$B = \exp(2b\tau_m)\left(\frac{1+d}{1-d}\right)^2.$$

We consider 4 functions for describing the radiation emitted from the slab. The first one is the reprocessing efficiency from first to second band:

$$\eta = \frac{2\sqrt{3}H_2(0)}{I_1^0}. \quad (28)$$

The second one is the albedo of the cloud slab in the 1st spectral band:

$$\zeta = 1 + \frac{2\sqrt{3}H_1(0)}{I_1^0}. \quad (29)$$

The third and the fourth ones are the ratio of the flux coming out from the lower boundary in the second and in the first band, respectively, to the ingoing flux:

$$\eta_1 = \frac{2\sqrt{3}H_2(\tau_m)}{I_1^0}. \quad (30)$$

$$\zeta_1 = -\frac{2\sqrt{3}H_1(\tau_m)}{I_1^0}. \quad (31)$$

It is possible to consider two limiting cases:
1) The cloud slab is absent ($\tau_m = 0$). In this case there is no reflected flux in the second band, and the flux in the first band is equal to the incoming flux:

$$H_1(0) = -\frac{I_1^0}{2\sqrt{3}}.$$

2) The semi-infinite cloud slab ($\tau_m = \infty$). In this case $C_2 = C_3 = 0$, and the reprocessing efficiency is:

$$\eta = \frac{2d}{1+d}. \quad (32)$$

This is the maximum possible value at given A, α, and β.

We now consider the dependence of η, η_1, ζ and ζ_1 on the slab optical depth τ_m and on the parameters A, α and β. The dependence on τ_m at different values of A is shown in Fig. 3 for values $\alpha = 0.1$ and $\beta = 0.75$. As expected at small τ_m both reflected and transmitted slab fluxes in the second band are small, and in first band nearly all incoming flux is transmitted through the slab ($\zeta_1 \approx 1$). At $\tau_m \approx 1$ photons on average are scattered once on clouds and, therefore, $\eta \approx A$. The flux emitted in the second band from the backside of the slab is also maximal at $\tau_m \approx 1$–10. At the largest τ_m η grows up to its maximum possible value (Eq. (32)), and $\zeta = 1 - \eta$. This means that the rest part of the flux is reflected in the first band. The fraction ζ_1 of the transmitted radiation through the slab in the first band ζ_1 decreases exponentially with τ_m increasing, and η_1 decreases when τ_m increases. It is obvious that $H_1(\tau_m) \approx 0$ at large τ_m and therefore $H_2(\tau_m) \approx C_3(\tau_m)$. This gives:

$$\eta_1 = \left(1 + \frac{\sqrt{3}}{2}(\alpha + 2\beta)\tau_m\right)^{-1}. \quad (33)$$

Electron scattering decreases the reprocessing efficiency (see Fig. 4) (η and η_1 decrease when α increases). The electron scattering leads to reflection of the radiation without thermalization and if χ_e is larger than χ_c most of the irradiating flux is reflected back by intercloud electrons without significant scattering between clouds. This leads to decreasing η and η_1.

The functions η, η_1, ζ and ζ_1 depend only slightly on the coefficient of anisotropy β (Fig. 5). It is seen that in the case of isotropic scattering on the clouds ($\beta = 0.5$) the reprocessing efficiency is higher than in the case of unisotropic scattering ($\beta = 1$). In unisotropic scattering the radiation is reflected from clouds only backwards and penetrates less deeply into the cloudy slab and therefore undergos a smaller number of scatterings on clouds before escaping.

3.2. The cloud slab seen above the accretion disc

The reprocessing efficiency of the accretion disc is the same as for a cloud. In this case the lower boundary conditions are expressed:

$$d_1^2 J_1(\tau_m) + \sqrt{3}H_1(\tau_m) = 0, \quad (34)$$

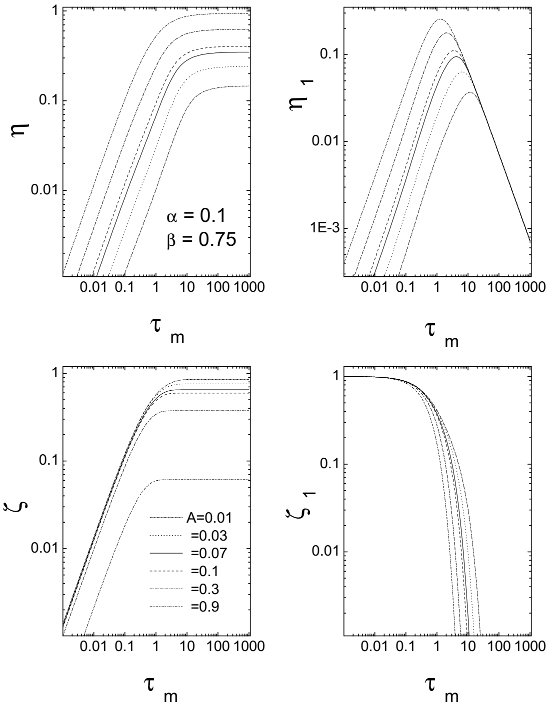

Fig. 3. The functions η, ζ, η_1, ζ_1 vs. a cloud slab optical depth τ_m at fixed $\alpha = 0.1$ and $\beta = 0.75$ and different values of A.

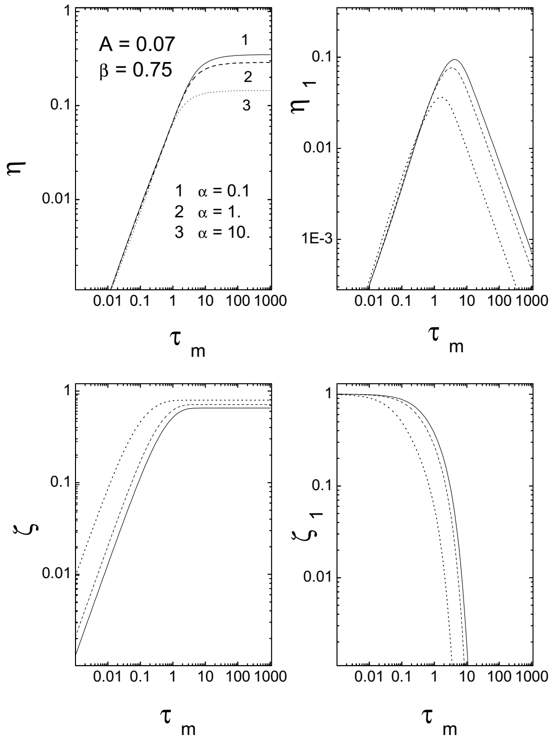

Fig. 4. The functions η, ζ, η_1, ζ_1 vs. a cloud slab optical depth τ_m at fixed $A = 0.07$ and $\beta = 0.75$ and different values of α.

$$H_2(\tau_m) + H_1(\tau_m) = 0, \tag{35}$$

where

$$d_1 = (A/(2 - A))^{1/2}. \tag{36}$$

Equation (35) leads to C_3=0, therefore $C_4 = I_1^0$.

The upper boundary conditions are the same as in the case considered before.

The constants C_1 and C_2 are:

$$C_1 = \frac{I_1^0}{1+d}\left(1 + \frac{1-d}{1+d}\cdot\frac{1}{B_1}\right) \tag{37}$$

$$C_2 = \frac{I_1^0}{1+d}\cdot\frac{1}{B_1} \tag{38}$$

where

$$B_1 = \frac{1-d}{1+d} - \exp(2b\tau_m)\left(\frac{d_1^2+d}{d_1^2-d}\right). \tag{39}$$

It is obvious that $\eta \approx A$ if a cloud slab is absent ($\tau_m = 0$) and η grows up to the value given by Eq. (32) if τ_m tends to ∞. One notes that η in the second case is greater than in the first case at all τ_m (Fig. 6). Radiation does not escape from the slab lower boundary, but returns to the slab due to reflection from the accretion disc. As a result the radiation emitted from the cloud slab has a larger number of scatterings between clouds before escaping.

4. Physical parameters of the clouds and the intercloud medium for accretion discs in SSS

There are several costraints on the clouds and the intercloud medium. In the following we describe how the physical parameters are connected to the properties of the matter in the spray, the disc, to the spray geometry, the accretion rate and the radiation from the white dwarf.

(1) The mass flow rate in the spray has to be less than or equal to that coming from the secondary star. Here the cross section of the spray enters and the Kepler velocity. The modeling of Schandl et al. (1997) for CAL 87 gives an example.

(2) For our suggestion of multiple scattering it is necessary that scattering at clouds occurs more often than scattering in the intercloud medium. This is a constraint on filling factor and cloud size for efficient reprocessing.

(3) The temperature difference between the inner irradiated side and the cooler outer side of the spray allows to estimate the optical depth of the cloud slab τ_m.

(4) From the value of τ_m the scattering coefficient on the clouds $\chi_c = \tau_m L$ (L slab thickness) follows and that from the cloud radius $R_c = \frac{3}{4} f/\chi_c$ with the filling factor f of clouds in the spray. Assuming a value for f the density ρ_c in the cloud follows from the total amount of gas flowing through the spray.

(5) From a given cloud temperature and ρ_c the optical depth in the cloud τ_c follows. The value for τ_c should be large, >1, becomes large if the opacity κ_c is large enough. This is a constraint for ρ_c. This can be reached more easily for a small filling factor.

(6) An important constraint is that the clouds remain confined in the intercloud medium. The pressure in the clouds is

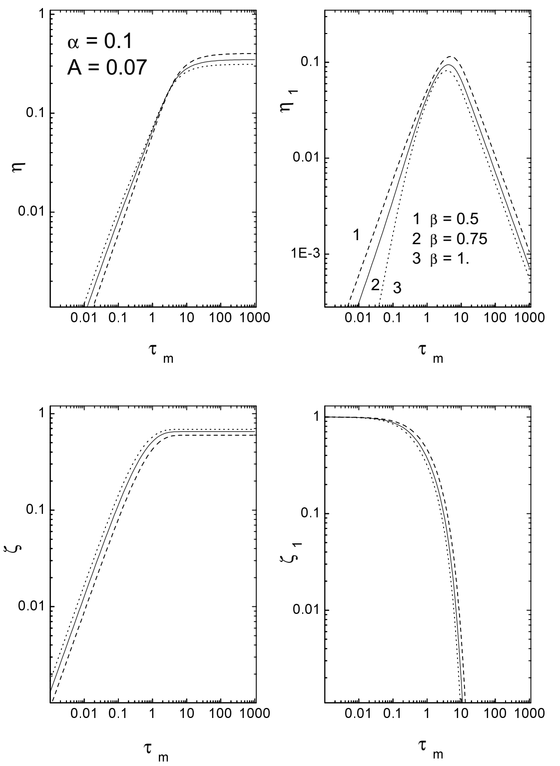

Fig. 5. The functions η, ζ, η_1, ζ_1 vs. a cloud slab optical depth $\tau_{\rm m}$ at fixed $\alpha = 0.1$ and $A = 0.07$ and different values of β.

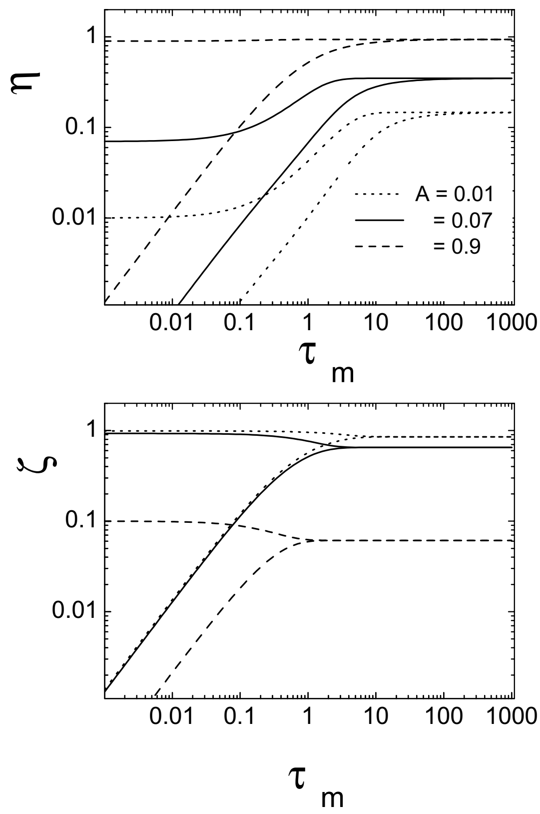

Fig. 6. The functions η and ζ vs. a cloud slab optical depth $\tau_{\rm m}$ at fixed $\alpha = 0.1$ and $\beta = 0.75$ and different values of A in the second case of the lower boundary conditions.

related to the values mentioned before in statement (4). For a given temperature ($\approx 5 \times 10^5$ K) in the intercloud medium pressure equilibrium requires a certain density. The resultant electron scattering coefficient $\chi_{\rm e}$ should then be smaller than $\chi_{\rm c}$ (statement (2)).

To study the physical parameters in the case of CAL 87 we took the values for white dwarf mass, accretion rate, luminosity and disc size from the light curve modeling of Schandl et al. (1997). We used a slab thickness of 2×10^{10} cm. For the temperature at the non-irradiated side of the spray we took 20 000 K. With these values we find a filling factor of about $\frac{1}{10}$ and the listed constraints are fulfilled.

5. Discussion

In the first paper (Suleimanov et al. 1999) we have shown that the reprocessing efficiency of the soft X-ray to the optical band due to irradiation is low, $A = 0.05-0.1$ for an accretion disc or a star surface.

The optical depth of the cloud slab in the supersoft X-ray source CAL 87 is large, documented by the small fraction of flux leaving the back side of the spray compared to the irradiated flux at the illuminated side. This means that the reprocessing efficiency in multiple scattering of soft X-ray and far UV flux between clouds can be close to the maximum possible value given by Eq. (32). In our example the electron scattering in the intercloud medium is small in comparison with the scattering on the clouds. Therefore, the reprocessing efficiency η can reach 0.3–0.5. This is sufficient to explain the large observed optical and UV fluxes in the classical supersoft X-ray sources CAL 83 and CAL 87 (Popham & DiStefano 1996).

It is obvious that the model considered here is very simple, but it reflects the main physical property of radiation transfer between clouds above an accretion disc in SSS. The model suggested here can be further developed by considering the radiation transfer in the cloud slab using numerical methods that allow to leave the two-stream approximation and to consider a more realistic redistribution function for scattering on clouds. Moreover, the height of the cloud slab can be comparable with the radial thickness, therefore and one may consider the two dimensional radiation transfer problem. Cloud properties can depend on the location in the slab, particularly, the cloud reprocessing efficiency A in the center of the slab can be different from the efficiency of a cloud near the slab boundary. One may consider this point, too.

6. Conclusions

We suggest that above the outer accretion disc in supersoft X-ray sources there is a spray of geometrically small clouds. In this layer cool clouds ($T_{\rm c}$ around 20 000 K) are embedded in a hot intercloud medium ($T_{\rm e} \approx 5\times10^5$ K). This rim structure is irradiated by the soft X-ray/far UV flux of a central hot white dwarf ($T_{\rm eff} \approx 5\times10^5$ K). We show that in multiple scattering between the clouds the reprocessing efficiency of soft X-ray to optical flux can increase significantly in comparison with the reprocessing efficiency in simple scattering on a cloud.

In the framework of a simple analytical model we obtain a solution of the radiation transfer problem in a plane slab of clouds irradiated by a soft X-ray flux. We treat the reradiation of the flux impinging on a cloud as a scattering. In single scattering a fraction A ($A \approx 0.05{-}0.1$) of soft X-ray or far UV flux is reprocessed to the optical/soft UV flux and the rest part $(1 - A)$ is reflected in the far UV spectral band. The radiation in optical/soft UV band is scattered in the same band. The radiation reflected from the slab has been scattered many times between clouds before escaping, and as a result the fraction of the optical/soft UV radiation in the reflected flux reaches 0.3–0.5. This explains the observed large optical and UV fluxes in some SSS by reradiation of the white dwarf soft X-ray radiation. This is the main conclusion of our work. The result establishes the spray as an important element in the physics of SSS.

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