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Effects of aberration and advection on line transfer in plane parallel geometry

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Abstract. We have investigated the effects of aberration and advection on line formation in a plane-parallel medium. We have considered velocities of the order of v = 1000,2000,3000,4000,5000 km s^{-1} in a plane parallel medium in which the line centre optical depths are 500 and 1200. We consider a two-level atom approximation and find that the line source function (S_L) changes considerably depending on the optical depth, and S_L for $v = 0$ km s^{-1} differ from that at $v = 5000$ km s^{-1} by a factor of 10^3.

Key words: radiative transfer—aberration and advection—line transfer

The effects of large velocities of the order of $v/c \approx 0.1$ on the formation of spectral lines were investigated by Mihalas *et al.* (1976). They found that the terms containing v/c will produce effects of the order of about 6 to 7% only, while the terms containing mean thermal velocities (which arises out of the temperature of the gas) produce more changes in the line source functions. In an earlier paper (Peraiah 1987a) it was shown that the high velocities generate substantial changes in the radiation field of a medium moving with high velocities.

In that paper we consider monochromatic radiation field with coherent and istorpic scattering. We would like to investigate how these high velocities change the polychromatic radiation in a line.

The equation of line transfer in a plane parallel medium is written as (Castor 1972; Mihalas 1978; Peraiah 1987a, b)

$$(\mu + \beta)\frac{\partial I(z, \mu, x)}{\partial Z} + \mu(\mu^2 - 1)\frac{\partial \beta}{\partial Z}\frac{\partial I(z, \mu, x)}{\partial \mu} + 3\mu^2\frac{\partial \beta}{\partial Z} I(z, \mu, x)$$

$$= K_L[\beta' + \phi(x)][S(z, x) - I(z, \mu, x)]$$

$$+ \mu^2\frac{\partial v}{\partial z}\frac{\partial I(z, \mu)}{\partial x} - 3\mu^2\frac{\partial \beta}{\partial z} I(z, \mu, x), \quad \ldots(1)$$

where $I(z, \mu, x)$ is the specific intensity making an angle $\cos^{-1}\mu_0$ with the axis of symmetry along the Z direction. We have

$$\mu = \frac{\mu_0 + \beta}{1 - \mu\beta}, \qquad \ldots(2)$$

where $\beta = v/c$ (v is the velocity of the gas and c the velocity of light) and

$$x = \frac{\nu - \nu_0}{\Delta}, \quad \Delta = \frac{\nu_0}{c}\left(\frac{2kT}{m}\right)^{1/2}. \qquad \ldots(3)$$

The quantity K_L is the absorption coefficient at the line centre; β' the ratio of the absorption coefficients in the continuum and line centre; k the Boltzmann constant; and $\phi(x)$ the profile function. The source function $S(z, x)$ is given by

$$S(z, x) = \frac{\phi(x)}{\phi(x) + \beta'} S_L(z, x) + \frac{\beta'}{\phi(x) + \beta'} S_C(z, x), \qquad \ldots(4)$$

where S_L and S_C are the line and continuum source functions:

$$S_L(z, x) \frac{1 - \epsilon}{2} \int_{-\infty}^{+\infty} \int_{-1}^{+1} \phi(x) I(z, x, \mu) dx d\mu + \epsilon B(x), \qquad \ldots(5)$$

and

$$S_C(z, x) = \rho B(x), \qquad \ldots(6)$$

Here ϵ is the probability per scatter that a photon is thermalized by collisional de-excitation; $B(x)$ the Planck function; and ρ an arbitrary parameter which will be specified in advance.

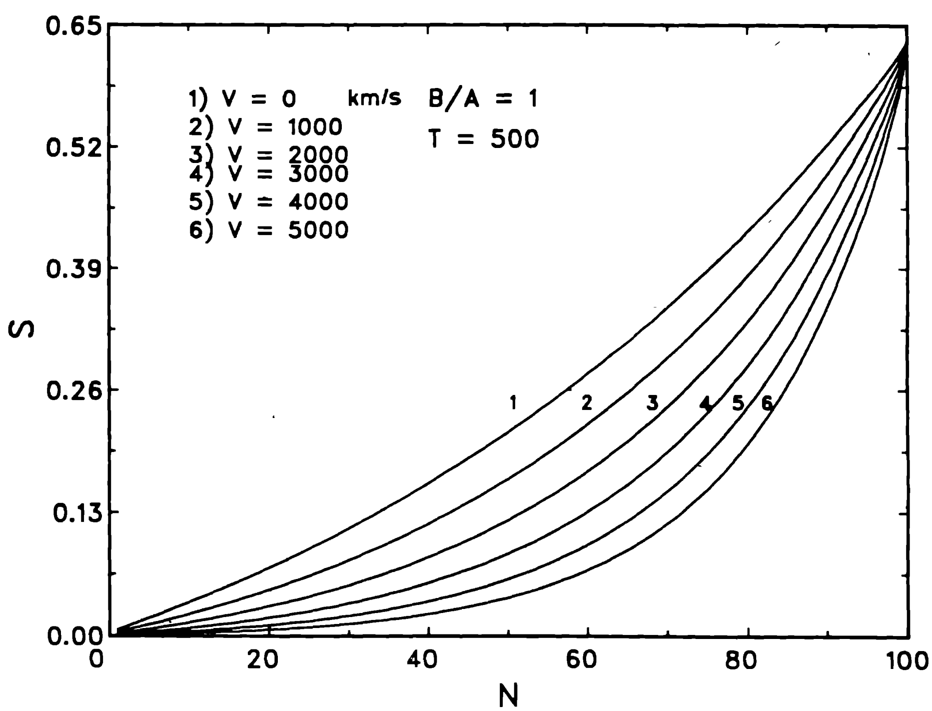

Figure 1. The line source functions are plotted against the shell numbers.

Equation (1) is solved using the technique described in Peraiah (1987a, b). The main aim of this paper is to show that the radiation field in a purely scattering medium is substantially modified by the aberration and advection terms due to large velocities in an expanding plane parallel medium. We shall show that severe deviations exist in the line source function given in equation (5). We set $\epsilon = 0$ and $\beta = 0$. We have sloved the equation with the following boundary conditions:

$$I^{-}(\tau = \tau_{max}, \ \mu_j) = 1$$

$$I^{+}(\tau = 0, \ \mu_j) = 0 \quad \ldots (7)$$

$$v(\tau = \tau_{max}) = 0$$

$$v(\tau = 0) = V, \quad \ldots (8)$$

where $v = 0, 1000, 2000, 3000, 4000, 5000 \ \mathrm{km \ s^{-1}}$ in different cases (see figures 1 and 2). We set $B/A = 1$ for plane parallel layers and the line centre optical depth $T = \tau_{max} = 500$ and 1200.

We have divided the medium into N shells each of equal optical thickness and plotted the source function S versus N in figure 1 for $T = 5000$ and for different velocities. Although the source functions corresponding to different v's do not change at $N = 1$ ($\tau = 0$, the emergent side) they change considerably inside the medium. Large velocities produce considerable amount of dilution of radiation field inside the medium. If the line centre optial depth is increased further to $T = 1200$, (see figure 2) the differences in the radiation field are enhanced considerably.

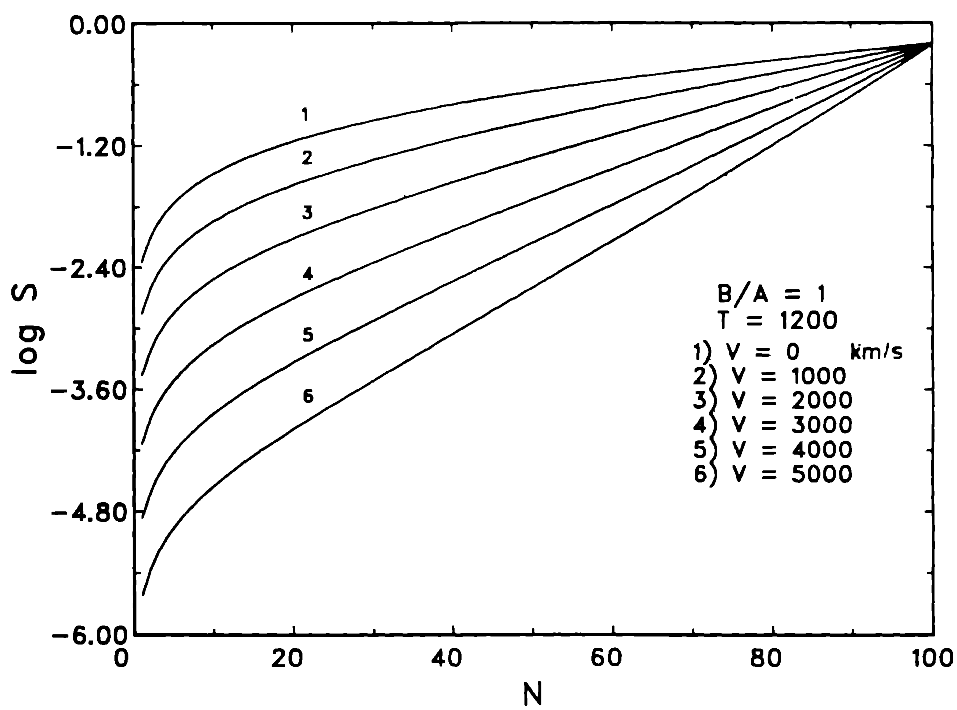

Figure 2. The line source functions are plotted against the shell numbers.

We have shown that in a scattering medium, the large velocities of expansion in the near relativistic range produce noticeable changes in the radiation field of several orders of magnitude.

References

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