Astrophys Space Sci (2010) 329: 159–161
DOI 10.1007/s10509-010-0402-2

ORIGINAL ARTICLE

Multicomponent stellar wind from hot subdwarfs stars

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Received: 30 October 2009 / Accepted: 4 May 2010 / Published online: 10 July 2010

Abstract Stellar wind from hot subdwarf stars is mainly accelerated by the interaction of ultraviolet photospheric radiation with metals, mainly oxygen. Absorbing ions share momentum through Coulombic collisions with the remaining passive part of the plasma (namely protons). We found that in the case of the winds from hot subdwarfs, interactions could be so small that they stop the momentum transfer between the passive bulk of plasma and absorbing ions. As a result wind decouples at a certain point.

Keywords Stellar wind · Hot subdwarfs · Decoupling

1 Introduction

Stellar wind from hot luminous stars is mainly accelerated by the interaction of ultraviolet photospheric radiation with the resonance lines of ions, such as C, N, O, Fe. This interaction is described by the radiative acceleration. With assumption of one-component flow and point source, calculation of radiative acceleration was greatly simplified by CAK theory. The line force is parametrized by three constants only, k, α and δ acting on the whole plasma.

The approximation of one-component flow used by the CAK theory is acceptable for most cases of stellar winds from O stars and some B stars. But in reality the radiation is acting on absorbing ions and electrons only, and those particles share momentum through Coulombic collisions with the remaining passive part of the plasma (namely protons).

For thick winds usual one-component description lead to the same result, namely mass loss rate $\dot{M}$ and terminal velocity v_∞, as the multi-component description. But for the thin winds the result is different. Due to the low density, Coulombic collisions are not sufficient, so they stop transfer the momentum from absorbing ions to the passive plasma and decoupling of the components may occur.

This scenario for thin winds can be very important for hot white dwarfs, sdB and HgMn stars. It can help explain difference between derived metal abundances from spectral analyses and expected from equilibirum between gravitational settling and radiative levitation for stars with similar parameters (Unglaub 2008). Decoupling effect can disrupt chemically homogenous wind and blow up quickly only metal species from the wind.

2 Hydrodynamical description

We start with time-dependent forms of relevant hydrodynamics equations for a multi-component radiatively driven flow. We restrict ourselves to standard assumptions of 1D spherically symmetric outflow and to two components only, namely absorbing ions and passive plasma (protons). We also neglect the effect of macroscopic magnetic and electric fields and assume plasma quasi-neutrality. Acting forces on absorbing ions are gravity, dynamical friction, pressure gradient, and radiation, while on passive plasma they are only gravity, pressure gradient, and dynamical friction.

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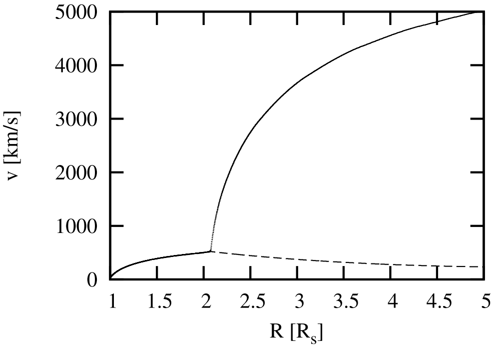

Fig. 1 Final wind-velocity laws for model of hot subdwarf after 100 flow time units. Absorbing ions are marked by *red color*, passive plasma by *green color*. Distance is measured in units of stellar radii

Continuity equations for both components are of the form

$$\begin{aligned}\frac{\partial \rho_p}{\partial t}+\frac{1}{r^2}\frac{\partial(r^2\rho_p v_p)}{\partial r}&=0\\ \frac{\partial \rho_i}{\partial t}+\frac{1}{r^2}\frac{\partial(r^2\rho_i v_i)}{\partial r}&=0\end{aligned}\tag{1}$$

Index p stands for passive plasma and index i stands for absorbing ions. Similarly, the equations of motion

$$\begin{aligned}\frac{\partial v_p}{\partial t}+v_p\frac{\partial v_p}{\partial t}&=-\frac{1}{\rho_p}\frac{\partial p_p}{\partial r}+\frac{R_{pi}}{\rho_p}-g_{eff}\\ \frac{\partial v_i}{\partial t}+v_i\frac{\partial v_i}{\partial t}&=-\frac{1}{\rho_i}\frac{\partial p_i}{\partial r}+g_i^{rad}-\frac{R_{pi}}{\rho_i}-g_{eff}\end{aligned}\tag{2}$$

where g_{eff} means effective gravity. Radiative acceleration take the form

$$g_i^{rad}(r)=\frac{(\eta\sigma_e)^{1-\alpha}}{4\pi v_{th}^{\alpha}}\frac{L_*}{r^2}k\left(\frac{1}{\rho_i}\frac{\partial v_i}{\partial r}\right)^{\alpha}f_{ion}f_{fin}\tag{3}$$

This is similar to CAK form, but because now acting on absorbing ions only, we must use scaling parameters η (see more in Krtička and Kubát (2000)). Instead of using energy equations we use isothermal assumption for both components.

3 Dynamical friction

The passive plasma and absorbing ions interact via Coulomb collisions, which are described by a frictional force

$$R_{pi}=n_p n_i\frac{4\pi\ln\Lambda Z_p^2 Z_i^2 e^4}{k_B T}\frac{v_i-v_p}{|v_i-v_p|}G(x_{pi})\tag{4}$$

where n_p and n_i are the number densities of the passive plasma and absorbing ions, respectively, $\ln\Lambda$ is usual Coulomb logarithm, T is temperature and Z_p, Z_i are passive and ion plasma charges. Chandrasekhar function is given by

$$G(x_{pi})=\frac{\Phi(x_{pi})}{2x_{pi}^2}-\frac{\exp(-x_{pi}^2)}{x_{pi}\sqrt{\pi}}\tag{5}$$

with drift velocity (A_p, A_i are mean atomic mass of ions and passive plasma)

$$x_{pi}=\frac{|v_i-v_p|}{v_{th}\sqrt{1+A_i/A_p}}.\tag{6}$$

The rest are common constants, for more details please see Votruba et al. (2007).

4 Numerical scheme

First of all is necessary to mention, that inclusion of dynamical friction made calculation more difficult in compare with classical CAK calculation. It is because, now we have two different characteristic time scales, one correspond to the hydrodynamical processes (macroscopic) and second corresponds to the dynamical friction (microscopic). Fastest proces-dynamical friction trying to maintain local equilibrium. This class of the problem is called "stiff".

To solve the four hydrodynamic equations we use our developed hydrodynamics code for radiatively driven multicomponent flow. It employs a standard Euler scheme. Equations (1) and (2) are discretised using an operator-splitting, time-explicit, finite difference method on a staggered mesh. We calculate advection fluxes using van Leer's monotonic interpolation.

For calculation of frictional term we used implicit approach, instead of semi-explicit approach used in Votruba et al. (2007). The reason was that Chandrasekhar function is most important term for simulation of decoupling process. So we do not approximate Chandrasekhar function, but in every time steps we solve implicitly differential equation for drift velocity

$$\frac{dx_{pi}}{dt}=\mathcal{K}G(x_{pi}),\tag{7}$$

where

$$\mathcal{K}=\frac{(\rho_i+\rho_p)k_{pi}}{v_{th}A_iA_p m_p^2\sqrt{1+A_i/A_p}}\tag{8}$$

is constant in the given time step. This leads to the nonlinear algebraic equation for unknown drift velocity x_{pi}, which must be solved iteratively using Newton–Raphson method. Iteration is repeat until difference was smaller then choosen value. From known drift velocity, we can update momentum for both components.

Table 1 Stellar parameters

M [$M_\odot$]	R [$\odot$]	T [K]	k	α	δ
0.5	0.2	35 000	1.45	0.37	0.1

5 Model of the wind laws

As a star, representing hot subdwarfs star we use model see Table 1, with calculated CAK multipliers (see more details about the method of calculation (Krtička and Kubát 2004)). Absorbing ions are composed mainly from oxygen so we used value $A_\mathrm{i} = 16$ and ratio $Z_\mathrm{i}/Z_\mathrm{p} = 3.0$. Abundance of metals was approximated by $\eta = 0.01$.

Because we wanted to trigger strong decoupling instability we choosed for simulation very small Courant number of 0.05 to bring Courant time step somewhat closer to frictional time. As the initial condition we use CAK distribution of density and velocity. On both sides of domain boundary conditions are set according to the theory of characteristics.

6 Result

We find that metal ions decouple from the passive plasma and start to accelerate steeply at the decoupling radius, whereas the passive plasma starts to decelerate at this location (see Fig. 1). This stripping mechanism of metals from major part of plasma, can be useful for explanation, why we observe big difference in abundances. Because wind decouple behind the CAK point, the final mass loss rate $\dot{M} \approx 1.5 \times 10^{-11}$ solar masses wasn't too much influenced.

Moreover, because low density wind of the hot subdwarfs, we can expect not only decoupling effect but also generation of pulsating shells predicted by Porter and Skouza (1999). This will be our next focus of the work.

Also, we used in our simulation two major approximations, namely isothermal processes and two components composition only. Because isothermality is questionable due to frictional heating we will append full energy balance in our calculation.

Acknowledgement This work was supported by the grant CZ 205/09/P476.

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