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Mass-loss and multicomponent flow from central stars of planetary nebulae

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Abstract. We calculate multicomponent radiatively driven stellar wind models suitable for central stars of planetary nebulae. Some of these stellar winds may be adequately modelled using one-component models, however for some of them multicomponent models are necessary. We obtain a range of stellar parameters for different types of mass-loss.

1. Introduction

Hot star winds are accelerated mainly by absorption of radiation in resonance lines. This process can be divided into two steps:

1. transfer of light momentum to C, N, O, Fe, etc., by absorption of radiation, and by Thomson scattering to free electrons,
2. transfer of obtained momentum to predominant wind component (H, He).

Since the acceleration of different wind species may be different, their wind velocities may differ and so hot star winds have a multicomponent nature. For *high density* winds (e.g. of galactic O stars) this multicomponent nature does not influence the wind structure, however for *low density* winds multicomponent effects occur, for example frictional heating, decoupling of wind components, etc. (see Krtička & Kubát 2001). To estimate the importance of multicomponent effects for the winds of central stars of planetary nebulae we calculate multicomponent wind models for these stars.

2. Model assumptions

Basic assumptions of our models are the following:

- we assume a stationary spherically-symmetric flow,
- we solve the continuity, momentum and energy equations for each component of the flow, namely for absorbing ions, nonabsorbing ions (hydrogen and helium), and electrons (see Krtička & Kubát 2001),
- we assume solar chemical composition,
- line radiative force is calculated in the CAK approximation (Castor, Abbott & Klein 1975), we neglect wind instabilities and magnetic fields.

3. Multicomponent model equations

For each component a of the flow (i.e. accelerated ions, passive component (hydrogen and helium) and electrons) we solve continuity, momentum and energy equations in the form of

$$\frac{1}{r^2}\frac{\mathrm{d}}{\mathrm{d}r}\left(r^2\rho_a v_{ra}\right) = 0, \tag{1}$$

$$v_{ra}\frac{\mathrm{d}v_{ra}}{\mathrm{d}r} = g_a^{\mathrm{rad}} - g - \frac{1}{\rho_a}\frac{\mathrm{d}}{\mathrm{d}r}\left(a_a^2\rho_a\right) + \frac{q_a}{m_a}E + \sum_{b\neq a} g_{ab}^{\mathrm{fric}}, \tag{2}$$

$$\frac{3}{2}kv_{ra}\frac{\rho_a}{m_a}\frac{\mathrm{d}T_a}{\mathrm{d}r} + \frac{a_a^2\rho_a}{r^2}\frac{\mathrm{d}}{\mathrm{d}r}\left(r^2 v_{ra}\right) = Q_a^{\mathrm{rad}} + \sum_{b\neq a}\left(Q_{ab}^{\mathrm{ex}} + Q_{ab}^{\mathrm{fric}}\right), \tag{3}$$

where ρ_a is the density of a component a, v_{ra} is radial velocity, a_a is the isothermal sound speed, g_a^{rad} is the radiative acceleration either due to the line-transitions or due to the electron scattering, E is the electric polarisation field, g_{ab}^{fric} is the frictional acceleration, T_a is the temperature, Q_a^{rad} is the radiative heating/cooling term (calculated using electron thermal balance method, Kubát et al. 1999), Q_{ab}^{ex} is the heat exchange and Q_{ab}^{fric} is the frictional heating.

4. The frictional acceleration

The frictional acceleration g_{ab}^{fric} depends on the velocity difference via the Chandrasekhar function ($g_{ab}^{\mathrm{fric}} \sim G(x_{ab})$),

$$G(x_{ab}) = \frac{\Phi(x_{ab}) - x_{ab}\dfrac{\mathrm{d}\Phi(x_{ab})}{\mathrm{d}x_{ab}}}{2x_{ab}^2}, \tag{4}$$

where $\Phi(x_{ab})$ is the error-function and the relative velocity difference between wind components a and b is

$$x_{ab} = \frac{|v_{rb} - v_{ra}|}{\alpha_{ab}}. \tag{5}$$

For small relative velocity differences, $x_{ab} \lesssim 1$, the Chandrasekhar function $G(x_{ab})$ is increasing, the flow is stable in this case, however for larger velocity differences, $x_{ab} \gtrsim 1$, $G(x_{ab})$ is decreasing (see Fig.1). The latter behaviour enables *decoupling* of wind components, the flow is unstable for larger velocity differences (Owocki & Puls 2002, Krtička & Kubát 2002).

5. Examples of calculated wind models

Frictional heating is important if the velocity difference is comparable with averaged thermal speed, $x_{ab} \lesssim 1$. An example of frictionally heated wind model is given in Fig. 2.

If the relative velocity difference between wind components is higher than the averaged thermal speed, $x_{ab} \gtrsim 1$, *the wind components may decouple.* An example of model with hydrogen decoupling is given in Fig. 3.

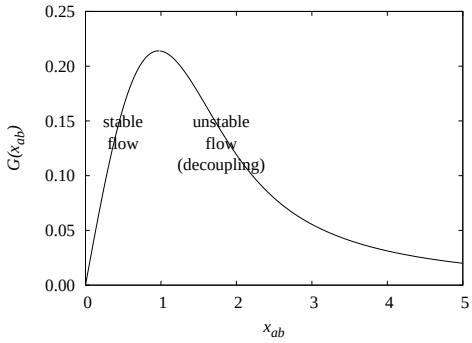

Figure 1. The run of Chandrasekhar function $G(x_{ab})$. The frictional acceleration is proportional to the Chandrasekhar function, $g_{ab}^{\rm fric} \sim G(x_{ab})$.

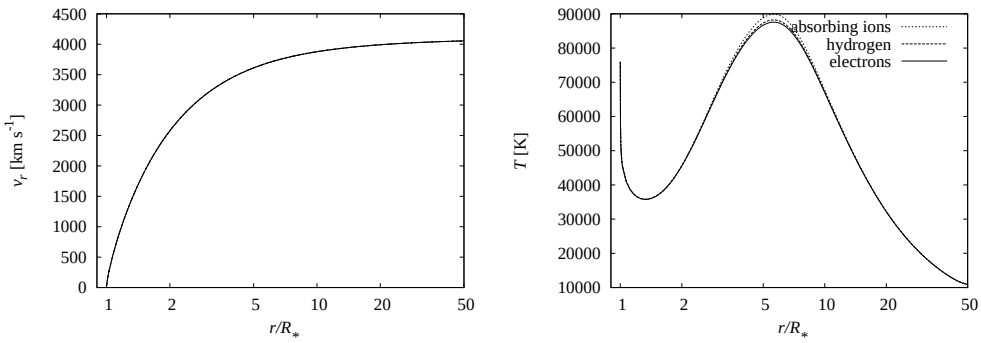

Figure 2. The stellar wind model of star with parameters $T_{\rm eff} = 100\,000\,{\rm K}$, $M = 0.6\,{\rm M}_\odot$ and $\log g = 6.46$ (CGS). Velocities of wind components are nearly equal in this case and the stellar wind is heated in the central parts of the model due to the frictional heating

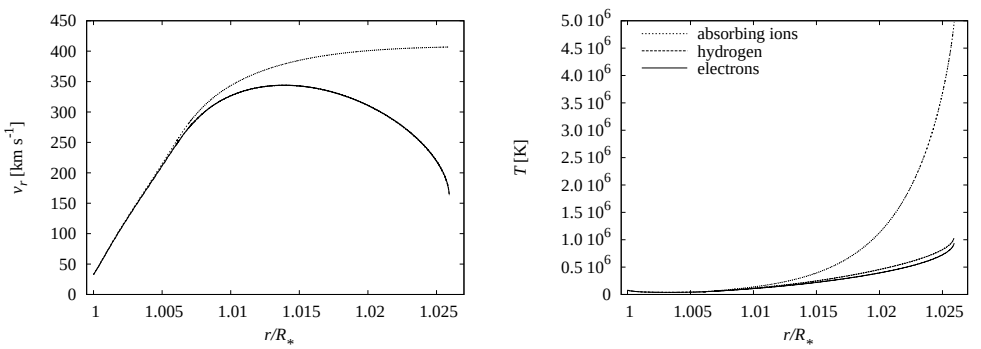

Figure 3. The stellar wind model of a white dwarf with parameters $T_{\rm eff} = 100\,000\,{\rm K}$, $M = 0.6\,{\rm M}_\odot$ and $\log g = 7.57$ (CGS). The absorbing component is not able to accelerate hydrogen any more, hydrogen may fall back onto the stellar surface or may create the circumstellar shells (Porter & Skouza 1999). The stellar wind is significantly frictionally heated in this case.

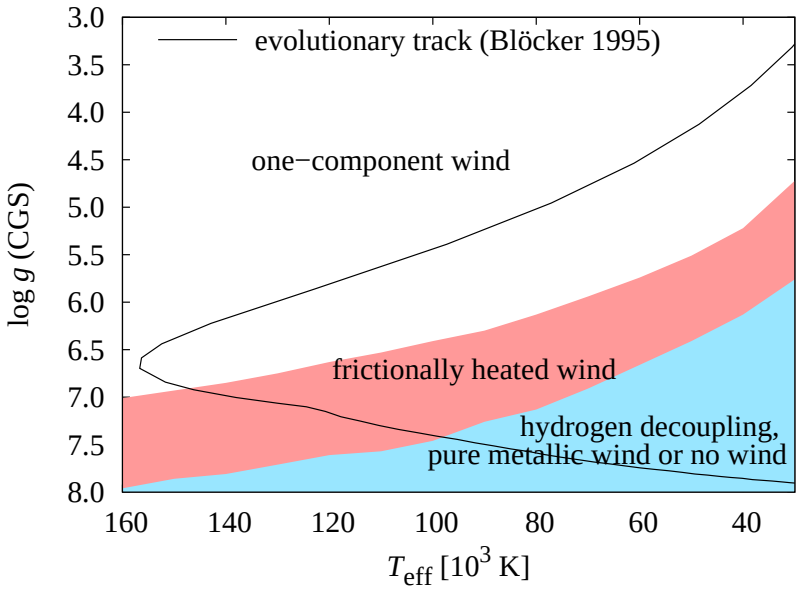

Figure 4. Regions in $T_{\rm eff}/\log g$ diagram with different kinds of stellar wind

6. Regions in $T_{\rm eff}/\log g$ diagram

Using our wind models, for stars with $M = 0.6\,{\rm M}_\odot$ we have derived regions in the $T_{\rm eff}/\log g$ diagram with different types of stellar winds (see Fig. 4). Corresponding evolutionary track by Blöcker (1995) of a post-AGB stage is also plotted in this figure. Apparently, in the course of the post-AGB evolution also the stellar wind evolves. At the initial stages the stellar wind can be regarded as a one-component. During the subsequent stellar cooling the stellar wind becomes frictionally heated and subsequently either hydrogen falls back onto the stellar surface or pure metallic wind exists. The coolest stars do not have any wind.

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