SYNTHETIC SPECTRA FOR WN STARS

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ABSTRACT

A computer program is described which calculates the structure and the radiation field (including high resolution spectra) of spherically extended and moving atmospheres. Some preliminary results for models of WN stars ($L/L_\odot = 10^5$, $M/M_\odot = 10$, $T_{eff} = 30\,000$ K, and $\dot{M} = 3 \cdot 10^{-5}\ M_\odot y^{-1}$) are presented and discussed.

1. INTRODUCTION

The processes, which cause a star to show the Wolf-Rayet phenomenon, are not yet understood, although many different mechanisms have been proposed, see e.g. the papers of Cassinelli, Underhill and others in this volume. For testing the theoretical predictions it is therefore desirable to have semi-empirical models of the outer layers of the stars which fit the observed spectra as closely as possible. However, for the construction of model atmospheres for WR stars "classical" computer programs as e.g. the ATLAS program (Kurucz, 1979) are not appropriate, since it is necessary to take into account

a) the geometrical extension of the atmospheres
b) the high mass-loss rate which implies significant radial velocities down to photospheric layers
c) deviations from local thermodynamical equilibrium.

In the next chapter a program is described, which meets the desiderata a) and b) and which takes deviations from LTE into account approximately in the radiative transfer. In addition up to 2000 individual spectral lines can be incorporated in order to make direct comparisons with observed spectra possible.
In section 3 some preliminary results are given and discussed.

2. MODEL CONSTRUCTION

The model construction is based on the program which was used for the computation of geometrically extended spherical model atmospheres for red giants and super giants (Wehrse, 1981).

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In order to match the requirements mentioned it has been modified in the following respects:
(i) The pressure stratification is determined either by integrating the hydrostatic equation or by the continuity equation, when a velocity law v(r) and the mass loss rate $\dot{M}$ are given. It is also possible to switch from one assumption to the other at some specified optical depth (or radius).
(ii)The radiation field is determined by the observer's frame transfer equation

$$\mu \frac{\partial I}{\partial r} + \frac{1-\mu^2}{r} \frac{\partial I}{\partial \mu} = - \kappa I + (1 - \alpha) \kappa \int g I d\mu' + \alpha\kappa B \quad (1)$$

with

μ, μ' = cosine of the polar angle
ν = frequency
r = radial coordinate
$I \equiv I(r,\mu,\nu)$ = specific intensity
$\kappa \equiv \kappa(r,\mu,\nu)$ = extinction coefficient
$\alpha \equiv \alpha(r,\nu)$ = ratio of absorption to extinction coefficient
$g \equiv g(\mu,\mu')$ = phase function, here assumed to be constant i.e. we assume coherent isotropie scatterin
$B = B(r,\nu)$ = Kirchhoff-Planck-function

The extinction coefficient is given by the sum of the relevant continuum and line absorption as well as scattering coefficients. The bound-bound contributions depend on the direction via the Doppler effect, e.g.:

$$\kappa^{bb} = \Sigma_i \kappa_i^{bb}(r,\mu,\nu) = \Sigma_i \kappa_i^{bb} \; H\left(\Gamma_i, \nu\left(1 + \mu \frac{v(r)}{v_D(r)}\right)\right)$$

(H= profile function, v_D= Dopplervelocity, Γ_i= damping parameter)
Eq. 1 is solved as a first order equation in the framework of discrete space theory, comp. Peraiah and Grant (1973) and Wehrse (1981). The method is stable and accurate also in the presence of radial velocity fields. Since 4 angles per half-sphere and a Gaussian integration scheme for the μ coordinate are employed, the treatment in the observer's frame does not pose problems even for large velocities and/or velocity gradients.

It is possible to take into account up to 2000 individual lines. The frequency spacing can be adjusted to the resolution of observed spectra.
(iii) By means of the Newton-Raphson-method the temperature stratification T (r) can be determined for every given distribution

$$F^{tot}(r) = \int F_\nu(r)\, d\nu.$$

This allows to study the effects of the dissipation of non-radiative fluxes within the atmosphere.

3. RESULTS AND DISCUSSION

In this section we give preliminary results typical for WN stars:

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$L/L_\odot = 10^5$, $M/M_\odot = 10$, $T_{eff} = 30\,000$ K and $\dot{M} = 3 \cdot 10^{-5}\ M_\odot y^{-1}$
Additional parameters, which have to be varied independently, are the composition and the radial dependence of the velocity and the total flux.

Subsequently we will discuss a few general aspects of the models computed up to now.

For $F^{tot}(r) = \text{const.} = \sigma/\pi\ T_{eff}^4$ and small velocities the atmospheres are all compact. But in the outer layers electron scattering dominates strongly over absorption processes (implying a very loose coupling between matter and radiation field), so that when a relatively small amount of energy (of the order of a percent of the radiative flux) has been assumed to be released here, the atmosphere blows up and emission lines and extension effects become noticeable.

Changes in the abundances show up most directly in the strength of the corresponding emission lines which are generated in the outer parts of the atmosphere. However, since the lines are also the dominant cooling agents the relation between equivalent widths and abundances is very complicated.

In addition, variations in the helium to hydrogen abundance ratio lead to changes in the pressure of up to 0.5 dex in all layers. This is caused by the modifications of the ratio of free electrons to ions, of the mean molecular weight and of the continuous absorption coefficients. Further test calculations showed that by varying the velocity distribution all types of observed line profiles can be reproduced. It is therefore hoped that when for many lines the differences in the velocities and temperatures of the line forming layers are exploited it will be possible to obtain empirically reliable data for T (r) and v (r).

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DISCUSSION

Mendez: Did you try to apply this method to Of stars ?

Wehrse: I have not yet calculated Of model atmospheres in this way.

Hummer: Di I understand from your slide that you assume isotropic coherent scattering in the observers frame ? Do you account for continuous absorption and scattering ?

Wehrse: In my calculations I use $R = 1/4\pi\ \delta(v-v')$, but another phase function can equally be applied. Continuous absorption by the relevant ions (H, He^{o}, He^{+}, C^{o}, C^{+}, C^{++} ...) and electron scattering are taken into account.

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