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The impact of iron group elements on the ionization structure of WC star atmospheres: WR 111

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Abstract. non-LTE iron blanketed model atmospheres are calculated with the new Potsdam code for expanding atmospheres. A blanketed model for the early-type WC star WR 111 is compared to its unblanketed counterpart. The resulting effects on the ionization and temperature stratification and on the dynamics of the WR wind are discussed.

1. Model atmospheres

The non-LTE model atmospheres are calculated under standard assumptions (see e.g. Hamann *et al.* these proceedings) including wind inhomogeneities ('clumping', see Hamann & Koesterke 1998) and line blanketing of iron group elements. In contrast to former program versions the radiation transport is now calculated over the whole spectrum ($\sim 10^5$ frequency points) under consideration of the complete opacity and coherent electron scattering in an approach similar to Hillier & Miller (1998).

For the inclusion of line blanketing we take advantage of the super level concept which is implemented analogous to Dreizler & Werner (1993). Using this method the iron group data of Kurucz (1991) are represented by about 10 super levels per ionization stage. The super levels are treated in non-LTE, so the ionization stratification of these elements is reproduced correctly. In the radiation transport the transitions between super levels are calculated explicitly by the application of complex cross sections which account for about 10^7 line transitions. This is necessary because in expanding atmospheres the radiation field couples in frequency by Doppler shifts. So all opacities must be treated at their proper place by a sufficient number of frequency points, and no sampling or re-ordering techniques can be applied. Additionally, the radiative acceleration $a_{\rm rad} = \frac{1}{\rho\, c} \int_0^\infty \kappa_\nu \mathcal{F}_\nu \, \mathrm{d}\nu$ can be calculated directly from the radiation transport.

For the WC model presented in this work model atoms of He, C, and O (210 levels) plus 48 super levels for the iron group (ionization stages III to X) are applied. The synthetic spectrum fits to the early-type WC star WR 111. Although a convincing spectral fit is obtained, only qualitative conclusions can be drawn from these calculations due to the preliminary state of the current program version (neglect of dielectronic recombination, hydrogenic ionization cross sections for iron group elements).

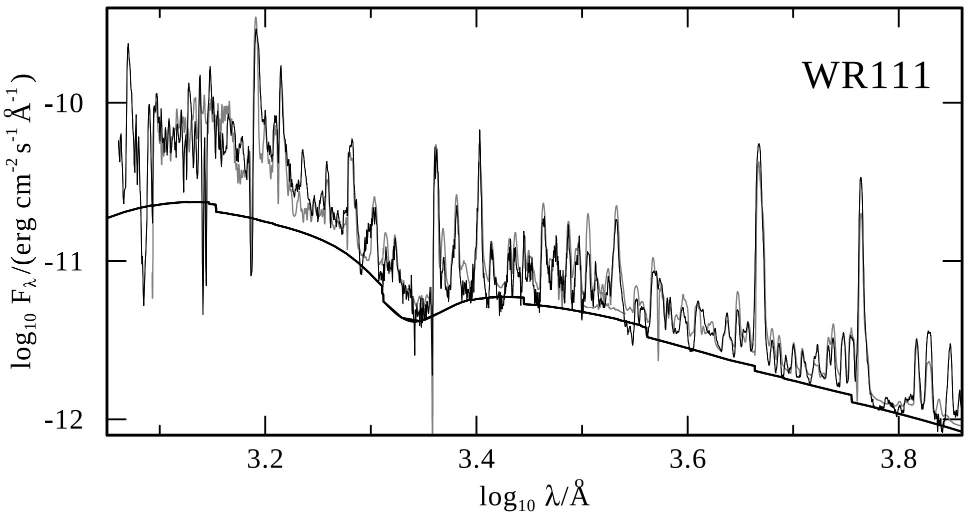

Figure 1. The comparison of the calculated (grey) and observed Spectrum (black) to a pure continuum calculation illustrates the influence of the large number of iron transitions below 2000Å on the apparent continuum.

2. Impact of iron group elements on the emergent flux distribution

As demonstrated in Fig. 1 a pseudo continuum is formed by a very large number of iron transitions below $\sim$ 2000Å (proposed by Koenigsberger & Auer 1985). With respect to unblanketed models a higher value for the extinction parameter is needed to fit the increased slope of the model continuum to the observation. The derived stellar luminosity is thus increased by the inclusion of line blanketing. The values of $L_\star = 10^{5.35} L_\odot$ and $E_{\mathrm{B-V}} = 0.29$ for the WR 111 model are in accordance with those obtained by Hillier & Miller (1999) who derived $L_\star = 10^{5.3} L_\odot$ and $E_{\mathrm{B-V}} = 0.30$ by means of their iron blanketed models.

3. Impact on the ionization stratification

In the following the blanketed model for WR 111 is compared to its unblanketed counterpart, which only differs with respect to its zero iron abundance. First of all the mean opacity is enlarged by the inclusion of iron opacities. This leads to an increase of the temperature slope in the optically thick part of the wind, and to an increased temperature of about 10% at the inner boundary. In the outer part of the envelope the recombination from He III to He II, from C IV to C III and from O IV to O III is considerably enhanced (Fig. 2). This effect occurs at the point of recombination from Fe VI to Fe V, where the iron line opacities dominate in the wavelength range above the optically thick He II continuum at 228 Å. Explanations for the enhanced recombination are on one hand shading effects on other ions (e.g. C III at 258 Å) and on the other hand interactions with the He II 303 Å resonance line (see Schmutz 1997). This line feeds the $n = 2$ level and thus supports the ionization of He II.

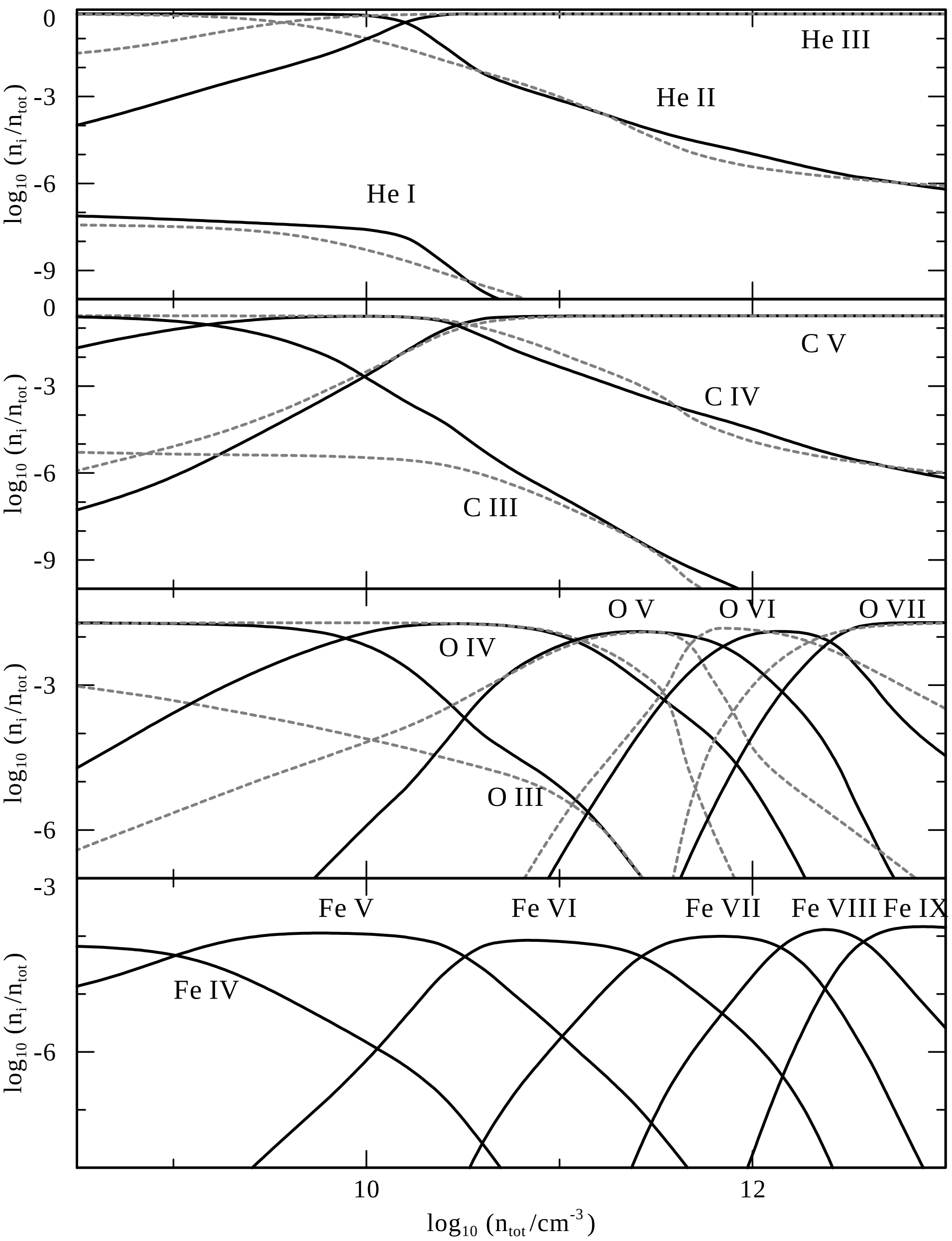

Figure 2. The populations of the ground states of the included ions are plotted versus the atomic density as a depth variable. The line blanketed model for WR 111 (solid line) is compared to its unblanketed counterpart (broken line). In the outer part of the envelope at the point of recombination from Fe VI to Fe V the blanketed model shows an enhanced recombination from He III to He II, from C IV to C III and from O IV to O III.

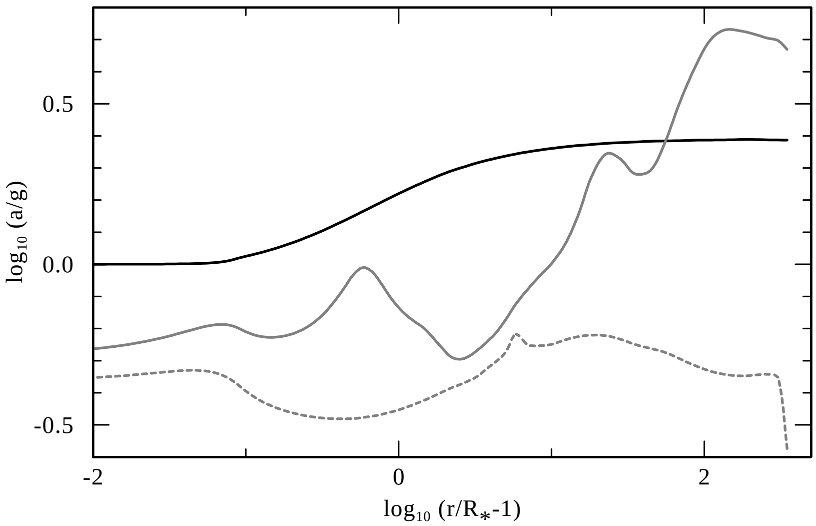

Figure 3. Comparison of the wind acceleration in units of the local gravity (black) to the computed radiative acceleration for the blanketed (grey) and the unblanketed model (grey, broken).

4. Effect on wind dynamics

Through the effect of clumping (density contrast $D = 10$ derived from the electron scattering wings) the derived wind efficiency $\eta = \dot{M} v_\infty / (L_\star/c)$ is lowered by a factor of $\sqrt{10}$ with respect to un-clumped models. In combination with the enhanced luminosity we obtain a value of $\eta = 11.8$ for the WR 111 model.

For an investigation of the amount of wind momentum provided by radiation pressure we compare in Fig. 3 the wind acceleration for the assumed velocity law to the calculated values for the radiative acceleration. In the outer part of the wind the values for the blanketed model are strongly enhanced with respect to the unblanketed one. The work $W_{\rm rad} = \dot{M} \int_{R_\star}^{\infty} a_{\rm rad}\, {\rm d}r$ performed by the radiation field per time interval corresponds to a fraction of 0.50 of the mechanical wind luminosity $L_{\rm wind} = \dot{M} \left(\frac{1}{2} v_\infty^2 + \frac{M_\star G}{R_\star} \right)$ in this model.

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