MULTI-LINE TRANSFER AND LINE BLANKETING IN A CLUMPY WOLF-RAYET WIND

D. SCHAERER
Geneva Observatory, CH-1290 Sauverny, Switzerland

Abstract. We present a Wolf-Rayet wind model including clumping, which is assumed to be due to full-scale supersonic compressible turbulence as suggested by Moffat & Robert (1994). It is shown that clumping leads to a larger transfer of radiative to mechanical luminosity, which corresponds to a momentum ratio of $(\dot{M}v_\infty)/(L/c) = 12$ for a typical WN5 star. We also show how clumping reduces the effects of line blanketing in spectral analyses.

Key words: stars: Wolf-Rayet – winds – mass loss

1. Introduction & calculations

Observations of Wolf-Rayet stars (WR) show evidence for clumpy structures in their winds (*e.g.,* Prinja *et al.* 1990; Robert 1991). A direct consequence from such substructures is that lower mean densities (*i.e.,* mass loss rates) can yield the same free-free or recombination line emission. In this work we study the effect of clumping on the dynamics of WR winds and on line blanketing. For a comparison and detailed analysis of a homogeneous model we refer to Lucy & Abbott (1993, hereafter LA).

Our treatment of clumping is based on the model of Moffat & Robert (1994), which assumes full-scale, compressible, supersonic turbulence to prevail. From the observed flux spectrum for emission-line substructures ($N(F_i) \propto F_i^\alpha$) we derive the density spectrum $\phi(\rho_i) = c\rho_i^{-(\alpha+2)}$ of the clumps. The constant c is obtained for a given mean ρ and temperature of the shell, provided α, the volume filling factor f, and γ the ratio of the minimum to maximum flux of the clumps are known. We take $\alpha = -2.4$ from Robert (1991), $f = 1$ (no density voids) and $\gamma = 0.03$. This implies that the density of the clumps scales over ≈ 1 order of magnitude and the mass loss rate would be reduced by a factor $m = 1.5$.

The density spectrum of the clumps is easily implemented in our Monte Carlo code (see Schaerer & Schmutz 1994ab, hereafter SSab). At the same time the mean density has to be reduced by the factor m in order to keep the same line emission as the homogenenous case.

For our calculations we choose the parameters of a "typical" WN5 star, WR6 from Hamann *et al.* (1993), *i.e.,* $T_\star = 71$ kK, $R_\star/\mathrm{R}_\odot = 2.7$, $\log\dot{M} = -4.1\ \mathrm{M}_\odot\mathrm{yr}^{-1}$, $v_\infty = 1700\ \mathrm{km}\,s^{-1}$, and $M/\mathrm{M}_\odot = 11.8$. For the metals we adopt the ionisation temperature from LA (with $\log T_R(\infty) = 4.35$).

K. A. van der Hucht and P. M. Williams (eds.), Wolf-Rayet Stars: Binaries, Colliding Winds, Evolution, 168–169.

2. Results & discussion

For the homogenenous wind we obtain a flux transfer rate of 4 % of the radiative luminosity to mechanical luminosity. This corresponds to $(\dot{M}v_\infty)/(L/c) = 10$, which is roughly one fourth of the observed value. The resulting UV spectrum is also close to LA.

With the adopted clumping a higher flux transfer rate of 4.4 % is achieved. This is due to the fact the number of interactions of the photons with matter is larger in the presence of clumps, since clumps with large density are preferred for $\alpha > -3$. For this case we obtain $(\dot{M}v_\infty)/(L/c) = 12$, which makes up ≈ 40 % of the (corrected) observed value. The main difference in the observable UV spectrum are stronger absorption features due to FeIV at $\lambda\lambda$ 1550-1700 Å. See LA for a discussion of the spectrum.

The importance of line blanketing in spectral analyses (see Schmutz 1994) is also affected by the presence of clumps. In general, blanketing effects will be *overestimated* in homogeneous models. As a consequence of clumping the relative number of electron to line scattering is increased. Therefore the effective mean scattering opacity *i.e.*, the blanketing (*cf.* SSb) is reduced, whereas conversely the absorptive mean opacity increases. The resulting blanketing is nevertheless still *larger* than what is obtained by simply reducing the density of a homogeneous model by the factor m.

In conclusion we have seen that clumping in WR winds can lead to a larger conversion of radiative to mechanical energy. We have also shown that clumping reduces the effect of line blanketing in spectral analyses. Treating multi line scattering with a simple clumping model we obtained for WR6 momentum ratios $(\dot{M}v_\infty)/(L/c)$, which exceed the single-scattering limit by a factor of 12. Although this value is closer to the observed one, this does not imply that WR mass loss rates can be explained by radiation pressure only, since a solution of the equation of momentum has not yet been achieved. It may well be that interior instabilities (Maeder 1985; *cf.* Bratschi, these proceedings) act in pushing up material, which will then be further accelerated by the processes modelled in this work.

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https://doi.org/10.1017/S0074180900201897 Published online by Cambridge University Press