THE 'MOMENTUM PROBLEM' OF WOLF-RAYET STARS: CAN IT BE EXPLAINED BY THE MULTIPLE SCATTERING MECHANISM?

U. SPRINGMANN and J. PULS
Institut für Astronomie und Astrophysik der Universität München, Scheinerstraße 1, D-81679 München, B.R. Deutschland

Abstract. The possibility of driving the dense winds of Wolf-Rayet stars via multiple scattering of photons in resonance lines is examined. For the case of many overlapping lines it is found that the diffuse radiation arising from the multiple scattering process leads to a radiative acceleration $g_{\rm rad}$ even larger than the commonly used ***unattenuated flux models*** where each line is assumed to interact separately with the unattenuated photospheric flux. The radial dependence of $g_{\rm rad}$ in the outer parts of the wind is now weaker than r^{-2}, which in turn leads to a steeper rise in the velocity field.

Key words: Radiative transfer – scattering – stars: mass loss – stars: Wolf-Rayet

1. The 'momentum problem' of WR stars

In contrast to OB-star winds, WR winds exhibit large values of the *wind performance number* η (ratio of wind momentum flux to photon momentum flux) $\eta = (\dot{M} v_\infty)/(L_*/c) \simeq 1 \ldots 160$ (*e.g.*, Hamann *et al.* 1993). Any theory that regards radiation pressure as the main accelerating mechanism of WR winds has to explain this unexpectedly high performance. Since *single scattering* of photons leads to $\eta < 1$, WR winds can only be driven radiatively by a very efficient *multiple scattering mechanism.* Recently Lucy & Abbott (1993) showed that a highly stratified ionization structure leads to an effective "photon trapping" which then yields high η-values (≈ 10). Evidence for such an ionization structure comes from observations (Schulte-Ladbeck *et al.* 1993) and from wind models (Hamann *et al.* 1994). However, Lucy & Abbott used a prespecified velocity field of the form $v(r) = v_\infty(1 - R_*/r)$ which is dynamically inconsistent with the computed radiative forces arising from the multiple scattering processes. In the present work we explore the potential of multiple scattering for driving a WR-wind together with an attempt at establishing a consistent velocity law.

2. The multiple scattering radiative acceleration

To investigate the influence of multiple scattering on the wind dynamics we first used a simple model: In addition to the usual standard assumptions (time independent, spherically symmetric wind structure), we assumed a power law opacity distribution of lines ($\mathrm{d}N_{\rm lines}(\kappa) \propto \kappa^{\alpha-2}\mathrm{d}\kappa$) and a logarithmic frequency distribution ($\mathrm{d}N_{\rm lines}(\nu) \propto \mathrm{d}\log\nu$). The resulting multiple

K. A. van der Hucht and P. M. Williams (eds.), Wolf-Rayet Stars: Binaries, Colliding Winds, Evolution, 170–171.

https://doi.org/10.1017/S0074180900201903 Published online by Cambridge University Press

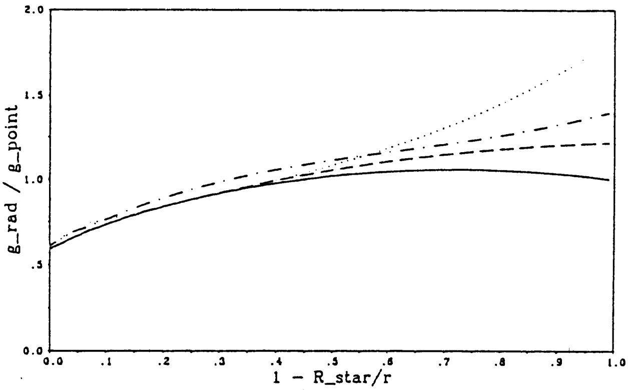

Fig. 1. **The ratio $g_{\rm rad}/g_{\rm point}$ for different line densities and a line opacity distribution $\alpha = 0.7$: $n_{\rm L} = 1, 10, 20$ (dashed, dash-dotted and dotted curve, respectively). For comparison the finite cone angle correction factor (*cf.* PPK) is also shown (fully drawn).**

scattering acceleration $g_{\rm rad}$ (determined from Monte Carlo simulations) is compared to $g_{\rm point}$ (all photons are strictly radial in direction, each line interacts with unattenuated flux from the stellar core). The result shows that multiple scattering can be very effective in driving the wind and that there is 'excess driving' at large radii compared to the standard $g_{\rm point}$. This finding fits well the observation of Koenigsberger (1990). For a WN5 model star with the same parameters as in Lucy & Abbott (1993) and a velocity field of the form $v(r) \propto \{\ln(r/R_*)\}^{1/2}$ we obtain highly consistent results. For such a velocity law, the energy balance is much better fulfilled than for the commonly adopted β-velocity law (see Springmann 1994). We conclude that high performance numbers can in principle be explained by multiple scattering if a large number of lines is present in the wind.

Acknowledgements

This work was supported by the *Deutsche Forschungsgemeinschaft* under grant Pu 117/1-2.

References

Hamann W.-R., Koesterke L., Wessolowski U. 1993, *A&A* **274**, 397
Hamann W.-R., Wessolowski U., Koesterke L. 1994, *A&A* **281**, 184
Koenigsberger G. 1990, *A&A* **135**, 282
Lucy L.B., Abbott D.C. 1993, *ApJ* **405**, 738 (LA)
Pauldrach A.W.A., Puls J., Kudritzki R.-P. 1986, *A&A* **164**, 86 (PPK)
Schulte-Ladbeck R.E., Davis K., Eenens P., Williams P.M. 1993, *BAAS* **25**, 1459
Springmann U. 1994, *A&A* in press

https://doi.org/10.1017/S0074180900201903 Published online by Cambridge University Press