Wolf-Rayet Phenomena in Massive Stars and Starburst Galaxies
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Inhomogeneous winds: the nature of emission-line profile variations in Wolf-Rayet spectra

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Abstract.
We present the results of simulations which show that stochastic line-profile variations (LPVs) of Wolf-Rayet emission lines can be reproduced with an inhomogeneous wind model, in which line-emission arises from a large number of discrete wind emission elements (DWEEs). A comparison between simulations and LPVs from 9 WR stars provides useful information about the nature of the inhomogeneous and dynamical structure of the wind. Although the detailed spatial/fractal structure of the inhomogeneous wind is poorly constrained by analysis of LPVs, simulations suggest the wind to be highly fragmented, being composed of at least 10^4 DWEEs in the line-emission region. Analysis of LPV patterns reaveal DWEEs to be associated with large fluctuations in the velocity field. These fluctuations are locally anisotropic; the velocity dispersions of DWEEs are systematically larger in the radial direction ($\sigma_{v_r} \approx 200\,\mathrm{km\,s^{-1}}$) than in the transverse direction ($\sigma_{v_\theta} \approx 50\,\mathrm{km\,s^{-1}}$). LPV patterns also yield estimates of the wind acceleration, which can be used to test hypotheses about the wind velocity-law.

1. Summary of poster display

We have analyzed nine time-series of high-resolution spectra obtained in 1988-1989 at *CFHT* and *ESO* for nine Wolf-Rayet stars of various subtypes (*cf.* Robert 1994). For the WC stars, C III $\lambda\,5696$ was observed, whereas He II $\lambda\,5412$ was monitored for the WN stars. All stars display line-profile variations (LPVs) on timescales of hours. Assuming LPVs to be the consequence of wind clumping, we used a simple *phenomenological* model to simulate LPVs from an inhomogeneous wind. We represent the line-emission as arising from a large number of Discrete Wind Emission Elements (DWEEs). One DWEE propagates radially with increasing velocity v, and at a projection angle θ. It shows up in the spectrum as a moving discrete emission feature at line-of-sight velocity $\xi = v\cos\theta$. The motion, basic physical properties, and statistical distribution of these DWEEs are described *in velocity space* by a simple set of model equations and parameters.

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We present a simulated spectral time-serie showing LPVs, and show how model parameters affect the resulting LPV patterns.

2. Conclusions

Line Profile Variations (LPVs) in Wolf-Rayet emission-lines are consistent with the hypothesis of an inhomogeneous wind. LPVs can be reproduced by assuming the line-emission to arise from a large number of DWEEs. Though the total number and statistical distribution in flux of DWEEs affect the intensity of line fluctuations, it has little effect on apparent LPV-patterns. The detailed spatial/fractal geometry of the inhomogeneous wind structure is therefore only weakly constrained by LPV-patterns. However, at least $N_e \approx 10^4$ discrete elements must be used in simulations to reproduce observed variability levels.

LPVs provide information on kinematics of the wind and wind fluctuations. Velocity dispersion associated with local wind perturbations are large and apparently anisotropic. Dispersion in the radial direction is usually $\sigma_{v_r} \approx 200\,\mathrm{km\,s^{-1}}$ and dispersion in the transverse direction is $\sigma_{v_\theta} \approx 50\,\mathrm{km\,s^{-1}}$. The only exception is WR 134 where σ_{v_r} and σ_{v_θ} are at least twice as large (see below). The anisotropic behavior is consistent with hydrodynamical shocks generated from instabilities in a line-driven wind (Rybicki, Owocki & Castor 1990). LPV patterns also provide information on the wind acceleration rate. Data are found to be consistent with a β-law with $20 < \beta R_* \mathrm{R}_\odot{}^{-1} < 80$. The duration (characteristic lifetime) of LPV features is consistent with the time needed for one discrete wind element to cross the line-emission region (transit time). The only exception is WR 134, where the characteristic lifetime of LPVs is found to be inconsistent with this picture.

LPVs in WR 134 appear to be inconsistent with our model of radially propagating wind inhomogeneities. Incidentally, this star was known for having recurrent LPV patterns (McCandliss *et al.* 1994; see also Morel *et al.* 1997), and should therefore be considered as having a peculiar LPV behavior.

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