A Massive Star Odyssey, from Main Sequence to Supernova
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Interferometric and spectroscopic monitoring of emission lines: detection of CIRs in hot star winds

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Abstract. We present a theoretical study of hot star wind emissivity in the presence of hypothetical large scale wind structures. Contrary to previous investigations that have focused on the resulting P-Cygni profile variability, we investigate the impact on observable optical and near-infrared emission lines. Our working hypothesis assumes, that such extended wind over-densities are formed via a rotationaly modulated stellar mass loss rate, that gives rise to the so-called co-rotating interaction regions (CIR). Within this context, we find that the variability of emission lines traces an un-equivocal S-shape in the frequency-time space, *i.e.*, a spiraling pattern with positive *and* negative accelerations towards the line-of-sight over one stellar rotation period. Further, we demonstrate how lines forming at different heights can then be used to provide dynamical and geometrical constraints on the wind structures. Complementary to this spectroscopic approach, we also present theoretical expectations for forthcoming VLT-AMBER observations of a perturbed hot star outflow presenting such CIRs. The spectrally dispersed visibility and fringe phase output by the Differential Interferometry (DI) method show clearly-defined signatures of the presence of these CIRs. Extrapolating the adequacy of DI beyond the detection of CIRs, we speculate that this method provides very fruitful information on putative large scale structures in hot star environments.

1. Background, incentive and results

Targeting optical/near-infrared emission lines, we investigate the capabilities of spectroscopy and interferometry for the detection of large scale structures in hot star environments, so far mostly inferred from large amplitude ($\sim 10\,\%$) P-Cygni profile variability obtained with *IUE*.

Our theoretical study assumes that these large scale wind structures are associated with co-rotating interaction regions (CIR, Cranmer & Owocki 1996) induced by localised enhancements of brightness at the surface of a rotating star. We perform radiation hydrodynamics simulations with ZEUS-2D (Stone & Norman 1992) of such a system to derive the density/velocity structure of the outflow. The model stellar wind parameters correspond to the O4 I(n)f star

ζ Puppis, chosen to rotate in four days. Perturbation of the wind is done by means of two surface 'bright' spots ($\Delta\Phi = 20°$) that locally enhance the mass loss rate. Once a spot has rotated away, the radiation force goes back to its less-efficient state, so that previously lifted material stalls, advecting on a much longer time-scale than the wind's. This was a breakthrough, because this model permitted for the first time how one could obtain hot star wind variability operating on time-scales of days rather than hours. Note that the calculated velocity field is essentially *divergent*, *i.e.*, $\vec{\nabla} \times \vec{v} \approx \vec{0}$ so that the spiral pattern associated with the CIR does not in fact represent genuine streamlines.

Contrary to previous investigations that have focused on P-Cygni profiles, we investigate the impact on observable optical and near-infrared *emission lines.* Within the context of CIRs, we find that the variability of emission lines traces an un-equivocal S-shape in the frequency-time space, *i.e.*, a spiralling pattern with positive *and* negative accelerations towards the line-of-sight over one stellar rotation period. Further, lines forming at different heights vary with a phase-lag, that can be used to provide dynamical and geometrical constraints on wind structures. Using the ionization stratification of hot star winds should therefore represent an excellent opportunity to estimate the geometrical extent of large scale hot star wind structures.

Complementary to this spectroscopic approach, we also compute the theoretical expectations for VLT-AMBER interferometric observations (Petrov *et al.* 2000) of such a perturbed hot star outflow. For a *fixed* baseline (space-based interferometer), the spectrally dispersed visibility and fringe phase output by the Differential Interferometry (DI) method show strong variable signatures, over a rotation period, of the same nature as those determined from spectroscopy. In the realistic case of *changing* baseline (ground-based interferometer), DI remains a powerful tool, *albeit* complex, due to its high detection sensitivity for geometrical characterisation of large scale wind structures. For example, the fringe phase can follow the shift of the barycenter of wind emissivity on the plane of the sky and through the line, offering a much better insight into the geometry and dynamics of putative large scale structures than could be dreamed of by spectroscopic means.

Details of this study are given by Dessart & Chesneau (2002).

References

Cranmer, S.R., Owocki, S.P. 1996, ApJ 462, 469

Dessart, L., Chesneau, O. 2002, A&A 395, 209

Petrov, R., Malbet, F., Richichi, A., *et al.* 2000, in: P.J. Lena (ed.), *Interferometry in Optical Astronomy*, SPIE 4006, 68

Stone, J.M., Norman, M.J. 1992, ApJ 80, 753