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STRUCTURED STELLAR WINDS

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RESUMEN

Existen diversas evidencias indirectas de que los vientos impulsados por radiación emitidos por estrellas calientes (tipo O y Wolf-Rayet) no son homogéneos. Se discute el aglomeramiento como un factor que afecta los espectros integrados, y por consiguiente el diagnóstico sobre la pérdida de masa. Se propone la interferometría como herramienta para alcanzar la resolución necesaria para analizar la estructura interna de estos vientos estelares.

ABSTRACT

There are various, but indirect evidences that the radiation-driven winds from hot stars (O-type and Wolf-Rayet) are not homogeneous. Clumping is discussed as an example that affects the integrated spectra, and thus the mass-loss diagnostics. To resolve structured winds, interferometers might be the currently best tools.

Key Words: stars: early-type — stars: mass loss — stars: winds, outflows — stars: Wolf-Rayet

1. STELLAR WINDS - INTRODUCTION

Observational indications for structured stellar winds are found from line profile variations such as discrete absorption components (Prinja & Howarth 1988, DACs) in O star spectra and discrete wind emission elements (DWEEs) in Wolf-Rayet (WR) star spectra (Moffat et al. 1988; Lepine & Moffat 1999). They are thought to be connected with co-rotating interactive regions embedded within the stellar wind. In WR spectra, emission line wings from Thomson scattering by free electrons in the stellar wind show a weakness that can only be reproduced by stellar model atmospheres if small-scale wind inhomogeneity, i.e. "clumping", is taken into account.

2. MODELS

Currently, a few codes exist for modeling the expanding atmospheres of stellar winds from O and WR stars, e.g. CMFGEN (Hillier & Miller 1998) and PoWR (Hamann & Gräfener 2004). Assumed is a spherically symmetric, stationary and homogeneous configuration of the wind. The low densities and high radiative fields require a full non-LTE treatment that solves the radiative transfer equations simultaneously with the rate equations for the population numbers of the atomic levels. Statistical equilibrium and energy conservation provide the constraints in this scheme. Wind inhomogeneities can be accounted for in the PoWR models in two concepts that will be described briefly.

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2.1. *Micro-Clumping*

Compared to the homogeneous "smooth" wind scenario the same amount of wind matter is "condensed" into clumps. These clumps have an increased density compared to the smooth wind case by a factor $D = \rho_{\rm clump}/\rho_{\rm smooth}$, i.e. the "clumping factor". This factor can also be understood in terms of a volume filling factor $f_{\rm V} = D^{-1}$, when assuming that the volume between the clumps is void. First approaches are made to model winds with a low-density component as inter-clump medium (Zsargó et al. 2008). For simplicity, the clumping factor is often assumed to be constant, but there are observational indications for a radial dependence $D(r)$ (Puls et al. 2006; Liermann & Hamann 2008).

For the micro-clumping scenario it is strictly assumed that the clumps are optically thin. The effect of micro-clumping in synthetic spectra leads to an improved fit of the observed electron scattering wings of strong emission lines. Adequate clumping factors were found in the range $D = 4$ to 10 for the Galactic WR stars. The empirical mass-loss rates derived from fitting recombination lines scale with the clumping factor as $\dot{M} \sim D^{-1/2}$, and are therefore reduced by micro-clumping.

2.2. *Macro-Clumping*

In the case of macro-clumping we assume more realistic clumps, allowing them to have any optical depth and even to be optically thick for certain wavelengths. Still the clumps have a uniform density enhancement $D(r)$. Their distribution within the stellar atmosphere is statistical with an average clump separation (for details see Feldmeier et al. 2003;

Owocki et al. 2004; Oskinova et al. 2004). Macro-clumping effectively reduces the opacity. For example the P V resonance line in the UV can be fitted with higher mass-loss rates. The reported discrepancies (Bouret et al. 2005) between mass-loss rates derived from recombination lines and from the P V resonance doublet can be solved by macro-clumping (Oskinova et al. 2007).

3. GALACTIC WR STARS & VLTI

About 47 single Galactic WN stars are visible from the Southern hemisphere, and thus can be observed with ESO-VLTI. The fundamental stellar parameters of these stars were determined by modeling the UV and optical spectra with the PoWR code (Hamann et al. 2006). However, WR stars do not show a sharp stellar disk due to the expanding atmosphere. A "stellar radius" R_* is defined in the models at a Rosseland optical depth of 20, resembling the size of the hydrostatic core of the star. Far the largest angular stellar diameter of 3 mas was found for WR 105, while the other stars are below 1 mas. Thus most of the stars lie a priori below the VLTI-AMBER resolution limit, assuming the 130 m baseline in the near-IR J-band. However, in the near-IR continuum the stars appear a few times larger than R_*, and emission lines even arise further out in the wind up to $10\,R_*$. Wind emission regions might therefore be resolved in visibilities.

The Galactic WC star γ^2 Vel, a WC+O binary system, is the interferometrically best studied WR star, being very close and very bright. The stars themselves are not resolved but the orbit is determined and the wind-wind collision zone (WWCZ) between the companions is detected with VLTI (Millour et al. 2007). This demonstrates the capabilities of interferometric instruments to resolve large scale wind asymmetries, e.g. oblate winds, disk and WWCZs. However, it seems hardly possible to detect clumps within the wind region since the clump size is at maximum of the order of the stellar radius (Oskinova, priv. communication) and the brightness ratio decreases over the separation squared. From the assumed statistical distribution of the clumps in the wind it even seems unrealistic to detect photocenter variations as they might smear out. A possible way might be to observe at shorter wavelengths and/or to use longer baselines. The Australian SUSI operates at visual wavelengths and baselines up to 640m, and the North American CHARA Array covers the near-IR with baselines up to 330 m (for the northern WR stars).

However, the interferometric resolving power is still significantly limited by the enormous optical paths and the small through-put to the detector, which allows to observe only the brightest targets so far. Typical H-band magnitudes for Galactic WR stars are fainter than 6th magnitude, while the VLTI limiting magnitudes are 5 and 6 mag in the H- and K-band, respectively. The faintness of the WR stars is thus a major drawback in using the current interferometers.

So far, the best way to analyze structured stellar winds is the polarization signal arising from the electron scattering in the wind. For a smooth wind the net continuum polarization is zero and thus variablity is attributed to clumpy structures in the winds (e.g. Robert et al. 1989). Already slight deviations from a spherical wind cause detectable polarization and the observed timescales of its variability can help to constrain the scenario of few but massive clumps versus many but small clumps in the wind (Davies et al. 2007).

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