MASS-LOSS AND WIND MOMENTUM RATES OF HOT LUMINOUS STARS. THE EFFECTS OF WIND CLUMPING AND VARIABILITY IN GALACTIC O-TYPE STARS.

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1. Introduction

About six years ago a project to study wind variability of hot massive stars (HMS) in our Galaxy and in the Local group was initiated at the National Astronomical Observatory (NAO) of the Bulgarian Academy of Sciences. Almost since the onset of our investigation we have collaborated with Dr. Puls (University of Munich, Germany) and Dr. Scuderi (Catania Obs., Italy). In this talk I'm going to present results derived trough our HMS project and in particular those which refer to Galactic O-type stars.

Why is it important to study massive stars? First of all because these stars are the main engines of the cosmic evolution. In the present cosmos, they provide most of the metals and the energy. In the distant Universe they dominate the UV light from the young galaxies. The very first generation of these objects (very massive stars, Population III) might have been responsible for the re-ionization of the early Universe. At the endpoint of their evolution, massive stars suffer a gravitational collapse and explode as supernova (of type II or Ib,c). Eventually a Gamma-Ray-Burst emerges, the most energetic cosmic flash. Thus our knowledge about massive stars and their evolution is crucial for our understanding of the Universe as a whole.

On the other hand, studies of HOT massive stars (HMS) are particularly important because they may provide a unique opportunity to derive distances from purely spectroscopic tools. Indeed, the radiation driven wind theory predicts a simple relation between the "modified wind-momentum rate", $\mathbf{D_{mom}} = \boldsymbol{M}_{\mathbf{dot}}\, \mathbf{V_{inf}}\, \boldsymbol{R}_{\mathbf{star}}^{\mathbf{0.5}}$, and the stellar luminosity, L, in the form :

$$\log D_{mom} = \log D_0 + 1/\alpha\,(\log L/L_{\odot})$$

where M_{dot}, V_{inf} and R_{star}, are mass-loss rate, wind terminal velocity and stellar radius, respectively, and α is the power law exponent of the line strength distribution function. This relation is known as the Wind-momentum Luminosity Relationship (WLR) [1]. If properly calibrated - the coefficients of the WLR are expected to vary with spectral type and metallicity - the WLR can give very accurate distances (within 10%) out to the Virgo and Fornax clusters of galaxies [2].

2. Mass-loss rate estimates

To determine mass-loss rates the observed Hα profiles of 30 O-type stars have been fitted using the approximate method, developed by Puls et al. [3], which we modified to account for the effects of line-blocking and blanketing. Detailed information about the actual fit procedure can be found in [4] while in the following we will focus on the final results only.

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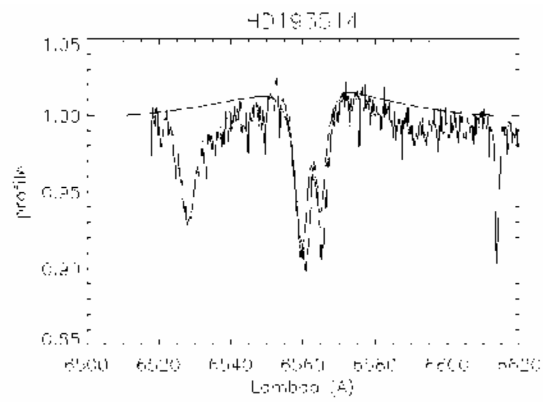

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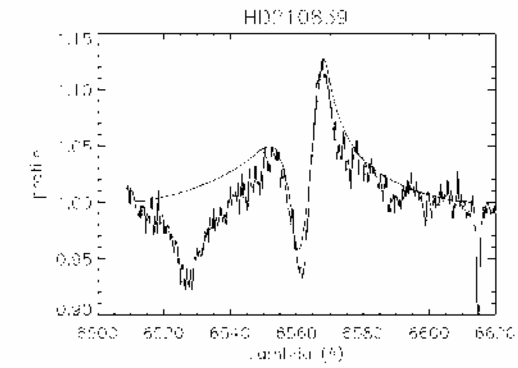

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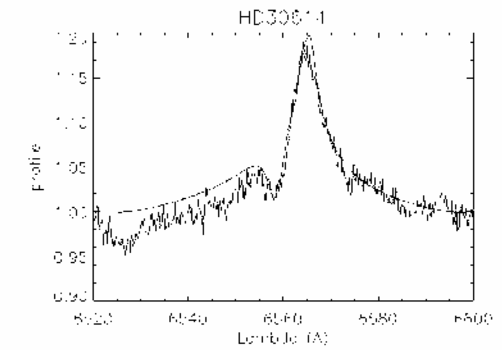

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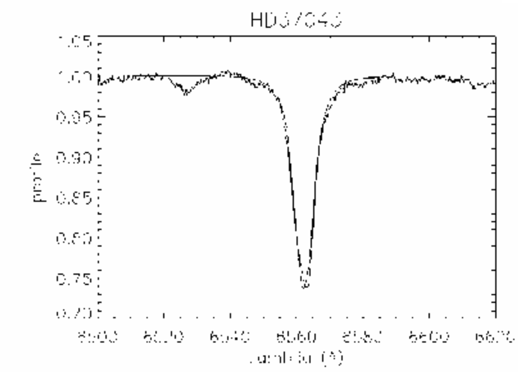

Fig. 1 Examples of differently shaped Hα profiles with the corresponding model fits.

In Fig. 1 typical examples of differently shaped Hα profiles together with the corresponding model fits are shown. Evidently, the agreement between observations and theoretical calculations is quite good and in particular does not depend on the strength of the wind. This finding however is somewhat leading away because and if mass-loss rate determinations, $\boldsymbol{M}_{\mathbf{dot}}$, are to be concerned one would find estimates of different accuracy for profiles in absorption (weaker winds) and in emission (stronger winds). The later result can be easily understood if one takes into account that in case of profiles in absorption the velocity exponent β cannot be constrained from the corresponding fit and thus makes $\boldsymbol{M}_{\mathbf{dot}}$ more uncertain [3,4].

3. Wind-momentum Luminosity Relationship for Galactic O-type stars

Having mass-loss rates of the target stars already determined one can calculate the corresponding wind momenta and subsequently to derive the WLR. The WLR for Galactic O-type stars is shown on Fig. 2. In order to improve the statistics and thus, to reduce the effect of uncertain distances [see 4], in addition to our data similar data from other investigations [5, 6] have been incorporated. The results illustrated in Fig. 2 clearly indicates that the WLR for luminosity class III/V objects strictly follows the theoretical predictions (dashed line) while the relation for the supergiants shows a vertical offset corresponding to an average factor of roughly 0.25 dex. This result is strikng because it contradicts the radiation-driven theory which predicts an unique relation (for all luminosity classes) instead.

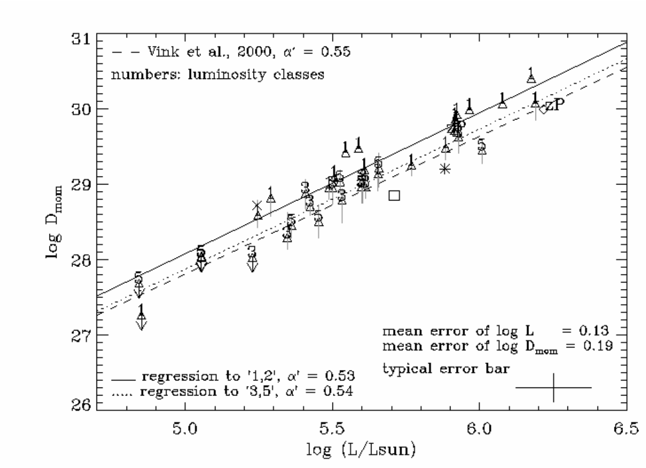

Fig. *2 WLR for Galactic O-type stars. Data from observations*.

4. WLR for Galactic O-type stars as a distant indicator.
The effects of spectral variability and wind clumping.

The possibility to use the WLR as a distant indicator is directly related to the accuracy of the derived $\boldsymbol{M}_{\mathbf{dot}}$ estimates. There are several physical processes that may effect and significantly modify the observed mass-loss rates, of which the most important are spectral variability and wind clumping.

The uncertainty in both mass-loss and wind-momentum rates caused by wind variability turnes out to be rather insignificant [8]. This result seems somewhat astonishing, especially in those cases when drastic changes in the Hα profile shape have been observed. Note, however, that for not too low wind densities small changes in thus $\boldsymbol{M}_{\mathbf{dot}}$ give rise to large changes both in the profile shape and the equivalent width [3]. In fig. 3 the WLR for Galactic O-supergiants are shown. Vertical lines represent the error in the wind momenta introduced by wind variability. Obviously, wind variability can only increase the local scatter without changing the concept of the WLR. This result is in full agreement with an investigation by Kudritzki [9] who reported 0.15 dex as an error in the wind momentum rates of one A-supergiant caused by wind variability.

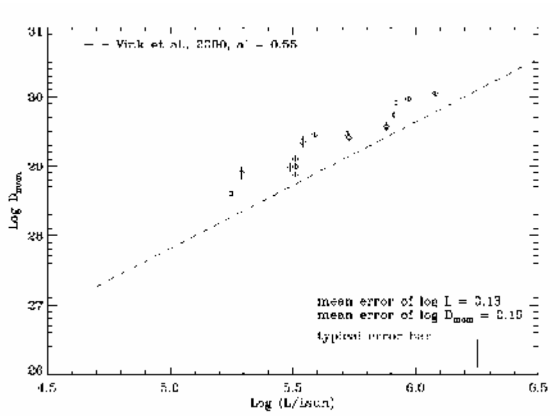

Fig. 3 WLR for Galactic O-supergiants. Vertical lines represent the error introduced by wind variability.

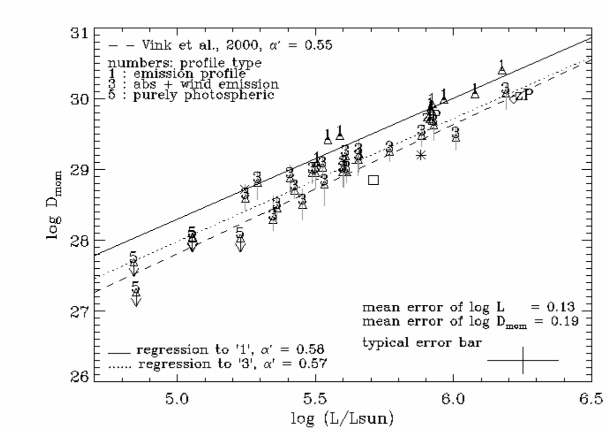

Fig. 4 WLR for Galactic O-type stars but with regression in dependence of profile type.

On the other hand, it turned out that wind clumping might be responsible for the established disagreement between observations and theory. This possibility seems to be supported by the fact that the majority of stars with higher wind momenta show Hα in emission (see Fig. 4). Indeed, it may be that in objects with Hα in emission one can 'see' the effect of wind clumping (due to the larger contributing volume) which then mimics higher mass-loss rates (and thus wind momentum) then actually present. In objects with Hα in absorption, on the other hand, only contribution from the innermost (not clumped) wind are present and, thus ***M*** $_{\mathbf{dot}}$ is observed at its actual value.

5. Future perspectives

The possibility to use the WLR as an indicator of wind clumping in O-star winds is very exciting but needs to be proven independently. One way to check this possibility is to compare mass-loss rates derived from Hα, IR and radio fluxes. In case the wind is clumped and if the predictions of the hydro-dynamical simulations about the radial stratification of the clumping factor are correct – this factor is expected to be higher in
the inter-mediate part of the wind and should decrease inwards and outwards [7] - these estimates should differ significantly [4].

In order to investigate this point in detail we have started a multi-wavelength observational campaign to derived IR and radio-continuum fluxes for our Hα targets.
The observations in radio domain have been already complete and consist
of fluxes measured at 0.7, 2.0, 3.5 and 6 cm by means of VLA. Part of the targets
have been observed in the near IR domain (at JHKLM) at the Crimea Obs. While observations in the far IR domain (at 24, 70 and 160 μk) are planned for Spitzer observatory.

Acknowledgement
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