Extra line-broadening in O-type stars

N. Markova[1], H. Markov[1], J. Puls[2], S. Simón-Díaz[4,5], A. Herrero[4,5]
[1] Institute of Astronomy and NAO, BG-1784 Sofia, Bulgaria
nmarkova@astro.bas.bg, hmarkov@astro.bas.bg
[2] Universitäts-Sternwarte, Scheinerstrasse 1, D-81679 München, Germany
uh101aw@usm.uni-muenchen.de
[3] Instituto de Astrofísica de Canarias, E38200 La Laguna, Tenerife, Spain.
[4] Departamento de Astrofísica, Universidad de La Laguna,
E-38205 La Laguna, Tenerife, Spain
ssimon@iac.es, ahd@iac.es
(Accepted on 18.10.2011)

Abstract. Using original data and incorporating similar data from previous studies we investigated the effect of extra line-broadening in the atmosphere of Galactic O-stars. Our results suggest that if not taken into account, the extra broadening can lead to significant overestimation of the measured $v \sin i$. The effect is not large (less than 30 km s^{-1}), and does not seem to depend on the luminosity class. In addition, our results suggest that the extra line-broadening is coupled with the rotation although the latter does not seem to be the only parameter which determines the value of the extra broadening.
Key words: stars: atmospheres; stars: early-type; stars: rotation; stars: oscillations

Ефекти на допълнително разширяване на линиите в спектрите на О-звездите

Н.Маркова, Х.Марков, Й. Пулс, С. Симон-Диаз А. Хереро

Използвайки оригинални данни и данни от предишни изследвания, ние сме изследвали ефектите на разширяване на линиите в спектрите на О-звездите от нашата Галактика, предизвикани от процеси различни от звездното въртене. Нашите резултати показват, че ако не бъдат правилно отчетени, тези ефекти могат да доведат до значително завишаване на оценките за скоростите на въртене определени от наблюденията. Голе-мината на допълнителното разширяване зависи от скоростта на въртене, но може да се допусне влияние от страна и на други физически параметри, например ефективна температура. Ефектът не е голям (под 30 km s^{-1}) и не са намерени данни за зависимост на големината на допълнителното разширяване от класа светимост.

1 Introduction

It has been known for a long time that the absorption line spectra of Galactic OB supergiants are likely subject to a significant amount of extra line-broadening in addition to stellar rotation (Conti & Ebbets [1977]; Penny [1996]; Howarth et al. [1997]). Extra line-broadening was initially suggested to be caused by a photospheric velocity field with a length scale longer than the mean free path of the photons, and subsequently referred to as "macroturbulence". However, this interpretation was questioned by more recent results which revealed that interpreted in terms of surface turbulent motion, the extra broadening would require presence of highly supersonic speeds in photospheric regions that is difficult to interprete. An althernative explanation in terms of stellar pulsation was suggested by Lucy [1976], and additionally worked out by Aerts et al. [2009]. For the case of B supergiants, observational evidence in support of this hypothesis has been recently reported by Simón-Díaz et al. [2010]. Although the origin of the extra line-broadening is so far unknown, its presence in the atmospheres of OB stars is important and deserves special attention because it may have important implications for our knowledge about the physics of these objects (Markova et al. [2011]).

While the properties of the extra broadening in B-type stars seem well established (Dufton et al. [2006]; Hunter et al. [2008], [2009]; Markova & Puls [2008]; Lefever et al. [2010]; Fraser et al. [2010]; Simón-Díaz et al. [2010], Simón-Díaz [2011]), our knowledge about this phenomenon in the case of O-stars is so far very limited (Simón-Díaz & Herrero [2007]; Simón-Díaz et al. [2011]. Motivated by this situation, a project to investigate the properties of rotational and extra line-broadening in the spectra of Galactic O-type stars has been initiated in close collaboration with investigators from the IAC, Spain and the LMU Munich, Germany.

In this contribution first results originating from the analysis of a limited sample of 33 *single* O-type stars are presented. Detailed information about this analysis will appear in a forecoming paper (Markova et al. [2011]).

2 Measurements and first results

For 23 of the sample stars, own estimates of the rotational and extra line-broadening have been derived using new observations obtained with the FEROS spectrograph (Kaufer et al. [1999]) at the ESO/MPG 2.2 m telescope in La Silla. For the rest, similar estimates from the studies of Najarro et al. [2010] and Simón-Díaz et al. [2010] were adopted. Since the three datasets have been derived applying same methodology and using spectra of similar quality, we consider them consistent within the error.

The projected rotational velocities, $v \sin i$, of all sample stars are estimated using the Fourier Transform (FT) method (viz. Gray [1976], see also Simón-Díaz et al. [2006], for a recent application to OB stars), which has been applied to the profiles of weak metal lines free of blends. The main adventage of the FT method is that it allows for the relative contributions of rotaion and other broadening mechanisms to be distinguished and separately evaluated.

To reveal if and to what extend the $v \sin i$ of the sample stars are influenced by the effect of extra broadening, the values originating from the FT approach, have been compared to similar data found in the literature which do not take into account extra broadening (mainly from Penny [1996] and Howarth et al. [1997], with individual data from Conti & Ebbets [1977]). For six sample stars without literature estimates, own $v \sin i$ - measuremens obtained by fitting observed profiles of strategic helium lines with synthetic ones, calculated with the FASTWIND code (Puls et al. [2005]) and additionally broadened to account for stellar rotation, have been used. From now on we will refer to these data as to "fake" projected rotational velocities, and will denote them as $v \sin i$ ("fake"). Although derived by means of different approaches, the adopted $v \sin i$ ("fake") were found to be consistent within the error (for more details see Markova et al. [2011]).

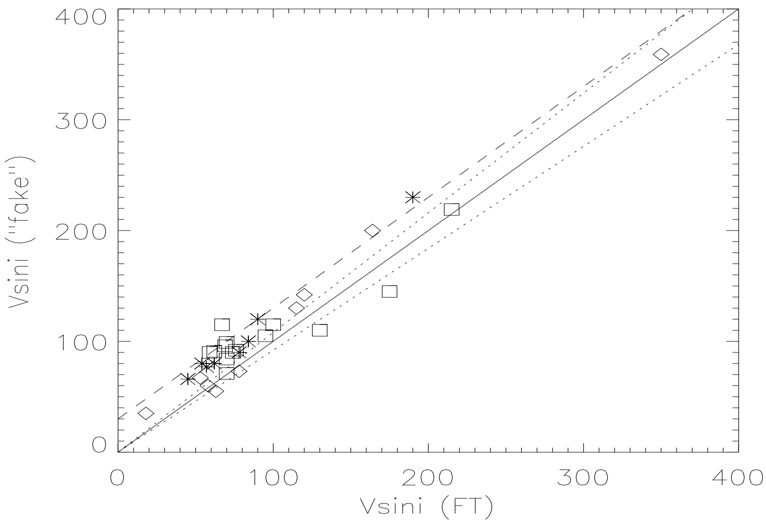

Fig. 1. Comparison of $v \sin i$ - estimates which do not take into account extra line-broadening, denoted as $v \sin i$ ("fake"), with similar estimates originating from the FT method, denoted as $v \sin i$ (FT). Symbols: squares - supergiants; asterisks - giants, diamonds - dwarfs. The one-to-one correspondence is marked with a solid line. Dotted lines limit the area corresponding to the 1σ uncertainty (± 8 %) adopted for the "fake" $v \sin i$. The 30 km s^{-1} difference between $v \sin i$ ("fake") and $v \sin i$ (FT) is marked with a dashed line.

The obtained results, illustrated in Fig. 1, show that for the majority of stars with low and intermediate projected rotational velocities ($v \sin i \leq$ 200 km/s), the FT values are smaller than the corresponding "fake" values. The differences are generally larger than the error budget of the "fake" $v \sin i$ (represented with dotted lines), and we ascribe them to the effect of extra line-broadening. In contrast to earlier expectation (see, e.g., Howarth et al. [1997]) but in agreement with Simón-Díaz et al. [2011], our results suggest that not only supergiants but also giants and dwarfs are affected by extra broadening.

For all sample stars, the magnitude of extra line-broadening, Θ_{RT}, has been determined applying the goodness of fit method. The procedure was as follows: for each star the $v \sin i$ was fixed at the value determined from the FT method, and by optimazing the agreement between observed and synthetic metal lines the contribution of the extra broadening was evaluated assuming a radial-tangential distribution of the magnitude of the velocity field (Simón-Díaz et al. [2010]).

The obtained results are illustrated in Fig. 2, and show that:

i) all stars, even those for which the $v \sin i$ (FT) are found to be similar or larger than the corresponding $v \sin i$ ("fake"), give evidence of significant extra line-broadening. This finding, if confirmed by means of a

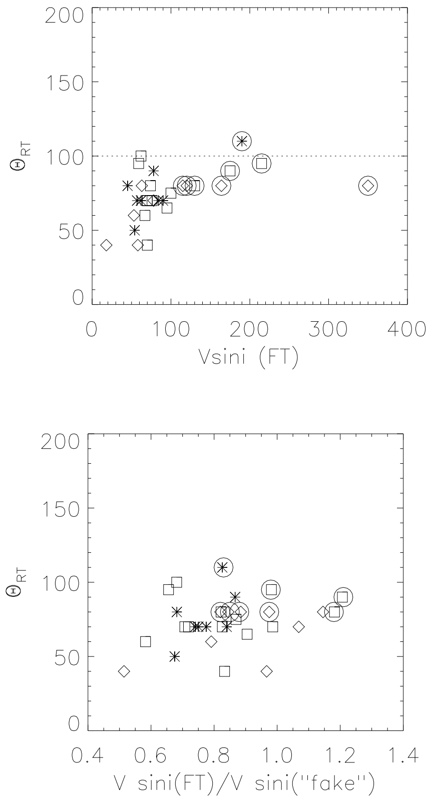

Fig. 2. The magnitude of extra line-broadening (in km s^{-1}) as a function of $v \sin i$ (FT) (left panel), and of the ratio of $v \sin i$ (FT) to $v \sin i$ ("fake") (right panel).

more elaborate analysis might imply that the effect of rotation and extra line-broadening is not a simple convolution of the two contribution.

ii) for the slow rotators ($v \sin i \leq 100$ km s^{-1}) large spread in the Θ_{RT} at same $v \sin i$ (FT) is observed suggesting presence of third parameters effects (e.g., dependence on effective temperature, stellar inclination, etc.); for the faster rotating stars, on the other hand, an increasing trend of Θ_{RT} with $v \sin i$ (FT) with a saturation at about 100 km s^{-1} seems to present.

iii) no evidence of a dependence of Θ_{RT} on the luminosity class was found: within the corresponding error, the mean Θ_{RT} values derived by averaging the data within the subsamples of the supergiants, giants and dwarfs are practically same and equal 76±15 km s^{-1}, 76±15 km s^{-1}, and 71±16 km s^{-1}, respectively.

3 Conclusions

Our results suggest that extra line-broadening, if not taken into account, can significantly affect the measured $v \sin i$ of O-type stars leading to somewhat larger values. The effect is not large: for the majority of stars the differences do not exceed 30 km s^{-1}, and does not seem to depend on the luminosity class: dwarfs, giants and supergiants seem to be equally affected. In addition, our results suggest that in O-stars the rotational and the extra line-broadenings are coupled in some way although the former does not seem to be the only parameter which determines the value of Θ_{RT}. Also, we found that the effect of rotation and extra broadening may not be a simple convolution of the two contributions. However, note that all these results must be qualified by stressing the relatively small sample of stars and the unknown value of sini i.

4 Acknowledgements

NM and HM acknowledge the financial supported of the Bulgarian NSF (grant DO02-85).

References

Aerts, C., Pults, J., Godart, M. et al., 2009, A&A, 508, 409
Conti, P. S., Ebets, D. 1977, ApJ, 213, 438
Dufton, P.L., Smartt, S.J., Lee, J.K et al. 2006, A&A 457, 265
Howarth, I., Siebert, K., Hussain, G., et al. 1997, MNRAS, 284, 265
Hunter, I., Lennon, D.J., Dufton, P.L. et al. 2008, A&A 479, 514
Hunter, I., Lennon, D.J., Dufton, P.L. et al. 2009,A&A 504, 211
Fraser, M., Dufton, P.L., Hunter, I. et al. 2010, MNRAS
Gray, D. E. 1976, *The observations and analysis of stellar photosphere* (1st ed., New York: Wiley)
Kaufer, A., Stahl, O., Tubbesing, S, 1999, Msngr 95, 8
Lefever, K., Puls, J., Morel, T. et al. 2010, A&A 515, 74
Lucy, L. B., 1976, ApJ 206, 499
Markova, N., Puls, J. 2008, A&A 478, 823
Markova, N., Puls, J., S. Simón-Díaz et al. 2011, A&A, submitted
Najarro, F., Hanson, M., Puls, J., 2011, A&A, arXiv 1108.5752, in press
Penny, L. R. 1996, ApJ, 463, 737
Puls, J., Urbaneja, M.A., Venero, R. et al. 2005, A&A 435, 669
Simón-Díaz, S., 2011, BSRSL, 80, 86
Simón-Díaz, S., Herrero, A. 2007, A&A 468, 1063
Simón-Díaz, S., Herrero, A., Esteban, C. et al. 2006, A&A, 448, 351
Simón-Díaz, S., Herrero, A., Uytterhoeven, C. et al. 2010, ApJ 720, 174
Simón-Díaz, S., Castro, N., Garcia, M., et al. 2011, BSRSL, 80, 514