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On the nature of O Vz stars in 30 Doradus.

C. Sabín-Sanjulián[1,2], S. Simón-Díaz[1,2], A. Herrero[1,2], M. Garcia[1,2], and the VLT-FLAMES Tarantula Survey Collaboration

[1] Instituto de Astrofísica de Canarias, E-38200 La Laguna, Tenerife, Spain
[2] Departamento de Astrofísica, Universidad de La Laguna, E-38205 La Laguna, Tenerife, Spain

Abstract

O Vz stars are defined as those O-type stars displaying He II 4686 absorption line stronger than other He line in the blue spectral region. These stars have been hypothesized on spectroscopic grounds to be O-type stars on or close to the Zero-Age-Main-Sequence (ZAMS), also having weaker winds than normal O V stars. We have tested these hypothesis by performing a quantitative spectroscopic analysis of a sample of 37 O Vz (plus 49 O V stars used for comparison) discovered by the VLT-FLAMES Tarantula Survey (VFTS) in the 30 Doradus region within the Large Magellanic Cloud. To this aim, we have used the IACOB grid based tool, a fast, accurate and objective automatic tool to determine the stellar and wind parameters of large samples of O stars in a reasonable amount of time. A first inspection of the resulting physical properties of the O Vz stars in 30 Dor is presented here. The main outcome from our quantitative spectroscopic analysis is that O Vz stars in 30 Dor are not particularly closer to the ZAMS, nor necessarily have weaker winds when compared to normal O V stars in the same region.

1 Introduction: Massive stars and the O Vz phenomenon

Massive stars are powerful but scarce objects with initial masses higher than ~ 8 $M_\odot$ [6]. They have very short lifetimes and high luminosities. They lose matter by means of stellar winds, which, together with rotation, affect their evolution [7]. Due to their properties, they are crucial for the evolution of their host galaxies and the whole Universe, as they contribute to their chemical enrichment, are sources of powerful ionizing radiation, forming H II regions, and trigger new star formation episodes in their surroundings.

One of the open questions in the evolution of massive stars is the first stage of their lives. A typical high-mass protostar is formed in a molecular cloud within a very young H II region. It accumulates mass with an accretion timescale that could be larger than the contraction timescale if the star is very massive (see [1]). This fact would lead to a situation in which a high-mass star begins to burn hydrogen in its core while is still accreting material from the parental cloud. This object (a ZAMS star) would appear embedded and optically obscured in the molecular cloud. When the parental cloud is dissolved, it is easier to see the star in the optical range, but it is already evolved. Therefore, the ZAMS stage of very massive stars is very difficult to observe in the optical due to extinction (this problem could be avoided in near-infrared wavelengths [4]).

In the last decades, several observations of O V stars in the Milky Way and the Magellanic Clouds have opened a window to the study of O stars apparently near or on the ZAMS in optical ranges. [16] remarked the presence of O dwarfs in the Tr14 cluster (Carina Nebula) that showed higher He II 4686/He II 4541 absorption-line ratio than in normal dwarfs. This spectroscopic feature motivated the definition of a new luminosity subclass, the Vz, in which He II 4686 is deeper than He I 4471 and He II 4541. Several O Vz stars have been observed subsequently (viz. [8, 9, 17, 18, 10]). We also refer the reader to [19], where it is presented a compilation of all O Vz stars known by the date, located in the Galaxy and the Magellanic Clouds, forming a total of 25 objects. This number has been increased recently due to the discovery of ~ 50 O Vz stars by the VLT-FLAMES Tarantula Survey (VFTS)[1].

The O Vz phenomenon has been suggested to be an "inverse" Of effect, since He II 4686 shows less emission filling (due to wind) than in normal O V stars (see e.g. [15, 19] for further information). This type of stars has also been proposed to be on or very near the ZAMS and they are thought to have weaker winds than O V stars (see [19]).

In this work, we tested these hypothesis on a sample of 39 O Vz stars from VFTS. We also took a control sample of 47 O V stars. For the selection of samples, stars with detected radial variations (i. e. binaries) were discarded. We performed a quantitative spectroscopic analysis of these two samples. The importance of this study lies in the fact that it will be the largest sample of O Vz stars quantitatively analyzed up to date, which will also offer answers about the nature of O Vz stars and their differences (if any) to O V stars.

2 Methodology: quantitative analysis of O stars and the IACOB-GBAT

H, He I and He II lines are used to obtain gravity, effective temperature and helium abundance. The wings of H Balmer lines are affected by the Stark effect, so they are used to calculate gravity. On the other hand, the He I/He II ionization balance is used to obtain the effective temperature and helium abundance.

Hα and He II 4686 are the most affected lines (in the optical range) by the stellar wind, so we use them to characterize the wind properties. In our study, the wind is parameterized with the wind-strength Q parameter (see [6]), which is related to the mass-loss rate by means of Eq. 1:

[1] The VLT-FLAMES Tarantula Survey (P.I. C. Evans) is an ESO large programme (182.D-0222) that has obtained multi-epoch optical spectroscopy of over 800 massive stars in the 30 Doradus region of the Large Magellanic Cloud. See [3] for a detailed description of the observations and the main drivers of the programme.

$$Q = \frac{\dot{M}}{(R \cdot v_\infty)^{\frac{3}{2}}} \tag{1}$$

in which R is the stellar radius and v_∞ the terminal velocity. Given the large number of O stars in our sample, we decide to perform the quantitative spectroscopic analysis using the IACOB Grid-Based Automatic Tool (IACOB-GBAT, see [14]). This is a fast, accurate and objective tool to determine the stellar parameters of O-type stars in an automatized way. The tool is based on standard methods for the quantitative spectroscopic analysis of O stars (viz. [5, 12]) and is automatized using a line fitting chi-square algorithm.

A grid of about 190000 models calculated with the FASTWIND code [13, 11] is used for the quantitative analysis. Metallicity, projected rotational velocity, resolution and absolute magnitude (M_V) are fixed to run the automatic tool. In some cases there was nebular contamination affecting the H I and He I line profiles, so we clipped it for the analysis. The obtained parameters are effective temperature ($T_{\rm eff}$), gravity ($\log g$), helium abundance ($\epsilon\,$(He)) and the Q parameter.

3 Results

Once we obtained the stellar and wind parameters for the sample of 37 O Vz and 49 O V stars, the diagrams presented in Figs. 1 and 2 were used to investigate the physical properties of O Vz stars in 30 Dor and compare them with those of the normal O V stars. We mainly concentrated on three parameters: $T_{\rm eff}$, $\log g$ and $\log Q$.

First of all, Fig. 1 shows that the distribution in ages in O Vz and O V stars is very similar. All of the analyzed stars are located above the ZAMS, and all O Vz stars have ages higher than 1 Myr, reaching 3 and 4 Myrs in some cases. In second place, in Fig. 2 we see that the distributions of O Vz and O V stars according to wind-stregth Q paremeter are very similar. Both samples have weak winds as expected in dwarf O stars. Also, in Figs. 1 and 2 it is noticed that O Vz and O V stars show a similar distribution of gravities, which span from 3.6 to 4.2 dex. These results seem to point out that O Vz stars are not ZAMS O stars and do not have weaker winds than normal O V stars.

Interestingly, the distribution of effective temperatures in Figs. 1 and 2 indicates a remarkable difference between O Vz and O V stars. There seems to be four different regions in the diagram: region I (lower temperatures), in which O V stars dominate; region III, dominated by O V stars, and regions II and IV, where both O Vz and O V stars are found.

We are now performing a detailed study of the behaviour of the He lines involved in the O Vz phenomenon (He I 4471, He II 4541 and He II 4686) using FASTWIND synthetic spectra from the IACOB-GBAT grid. Preliminary results indicate that the observed distribution of O Vz and O V stars in 30 Dor can be explained as a natural phenomenon that appears with the continuous change in stellar parameters, particularly $T_{\rm eff}$ and wind-strength, in an environment of half solar metallicity. More details will be presented in a forthcoming paper (Sabín-Sanjulián et al., in prep.)

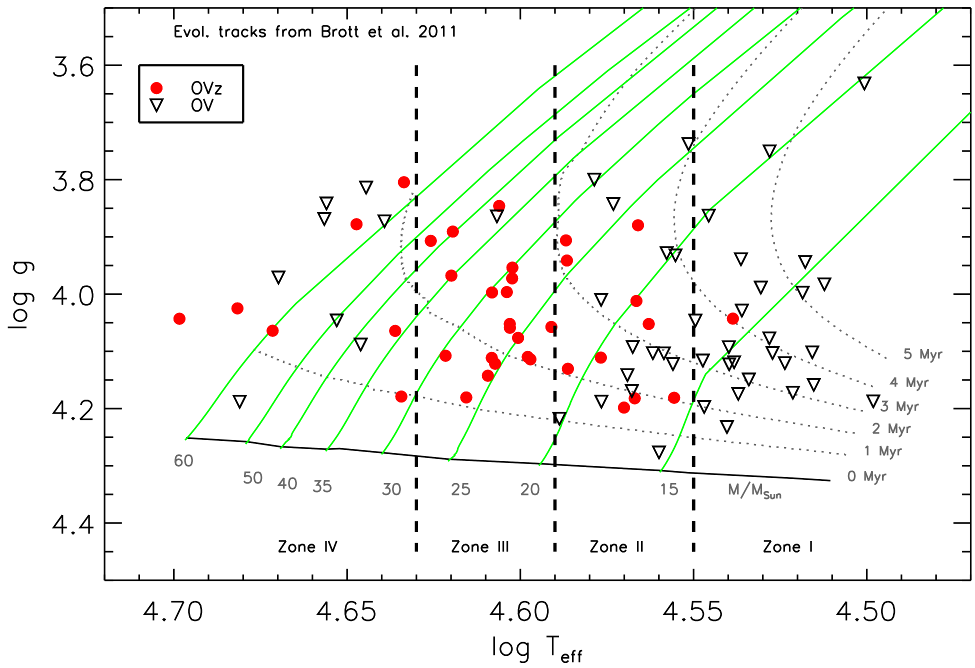

Figure 1: $\log g$ – $T_{\rm eff}$ diagram for the sample of O Vz and O V stars. Red dots correspond to O Vz stars and black triangles to O V stars. Evolutionary models (ZAMS in black and evolutionary tracks in green) and isochrones (grey dotted lines) are taken from [2], considering an initial rotational velocity of 171 km/s. Their corresponding initial masses and ages are indicated in grey.

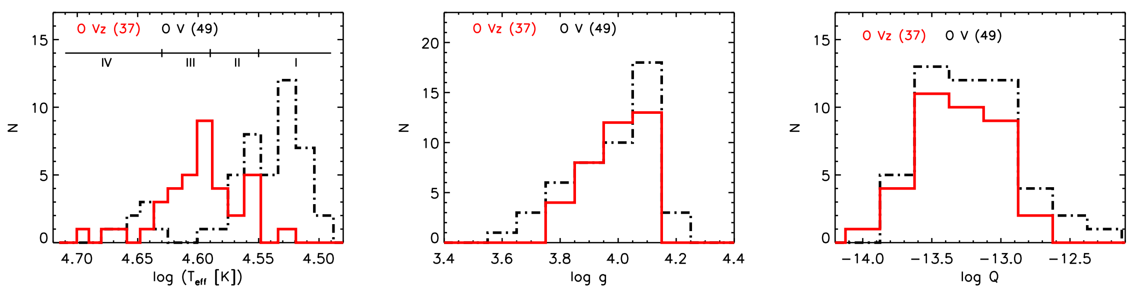

Figure 2: Distribution of stars according to efective temperature, gravity and wind strength. The black line corresponds to O V stars and the red one to O Vz stars. Also, four regions are indicated according to the different distributions in $T_{\rm eff}$.

4 Conclusions

We have performed a quantitative spectroscopic analysis of the largest and most homogeneous sample of O Vz stars up to date, consisting of 37 objects, and 49 O V stars for comparison, all of them located within 30 Doradus. We have used a fast and accurate automatic method, based on a grid of FASTWIND models to determine the stellar and wind parameters. A first inspection of the resulting physical properties of the O Vz stars ($T_{\rm eff}$, $\log g$, $\log Q$) points towards no remarkable differences compared to normal O V stars, contrary to what was previously hypothesized on spectroscopic grounds. In particular, we have found that O Vz stars are not particularly closer to the ZAMS. Also, these stars have neither higher gravities nor weaker winds. We have also found, by means of studies on FASTWIND models, a possible explanation of the O Vz phenomenon based on variations in effective temperature and wind-strength. This global picture, which seems to disagree with the hypothesis about the nature of O Vz stars based on empirical arguments, is now being further investigated by the detailed inspection of individual targets.

References

[1] Bernasconi P. A. & Maeder A. 1996, A&A, 307, 829

[2] Brott I., Evans, C.J., Hunter, I., et al. 2011, A&A, 530, A115

[3] Evans C. J., Taylor, W.D., Hénault-Brunet, V., et al. 2011, A&A, 530, A108

[4] Hanson M. M. 1998, ASPC, 131, 1

[5] Herrero A., Kudritzki R. P., Vilchez J. M., et al. 1992, A&A, 261, 209

[6] Kudritzki R.-P. & Puls J. 2000, ARA&A, 38, 613

[7] Maeder A. & Meynet G. 2000, ARA&A, 38, 143

[8] Morrell N. I., Walborn N. R., & Fitzpatrick E. L. 1991, PASP, 103, 1049

[9] Parker J. W., Garmany C. D., Massey P., & Walborn N. R. 1992, AJ, 103, 1205

[10] Parker J. W., Zaritsky D., Stecher T. P., et al. 2001, AJ, 121, 891

[11] Puls J., Urbaneja M. A., Venero R., et al. 2005, A&A, 435, 669

[12] Repolust T., Puls J., & Herrero A. 2004, A&A, 415, 349

[13] Santolaya-Rey A. E., Puls J., & Herrero A. 1997, A&A, 323, 488

[14] Simón-Díaz S., Castro N., Herrero A., et al. 2011, JPh Conference Series, 328, 012021

[15] Sota A., Maíz Apellániz J., et al. 2011, ApJS, 193, 24

[16] Walborn N. R. 1973, ApJ, 179, 517

[17] Walborn N. R. & Parker J. W., 1992, ApJ, 399, L87

[18] Walborn N. R. & Blades J. C., 1997, ApJS, 112, 457

[19] Walborn N. R. 2007, arXiv:astro-ph/0701573