

Science with the Galactic O-Star Spectroscopic Survey (GOSSS):

The relationship between DIBs, ISM, and extinction

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ABSTRACT :

In this poster we show our preliminary analysis of DIBs (Diffuse Interstellar Bands) and other interstellar absorption lines with the purpose of understanding their origin and their relation with extinction. We use the biggest Galactic O-star blue-violet spectroscopic sample ever (GOSSS, see contribution by Maíz Apellániz). This sample allows a new insight on this topic because of the adequacy of O-star spectra, the sample number (700 and increasing, 400 used here), and their distribution in the MW disk. We confirm the high correlation coefficients between different DIBs and $E(B-V)$, though the detailed behavior of each case shows small differences. We also detect a moderately low correlation coefficient between Ca II $\lambda 3934$ (K) and $E(B-V)$ with a peculiar spatial distribution that we ascribe to the relationship between line saturation and velocity profiles for Ca II $\lambda 3934$.

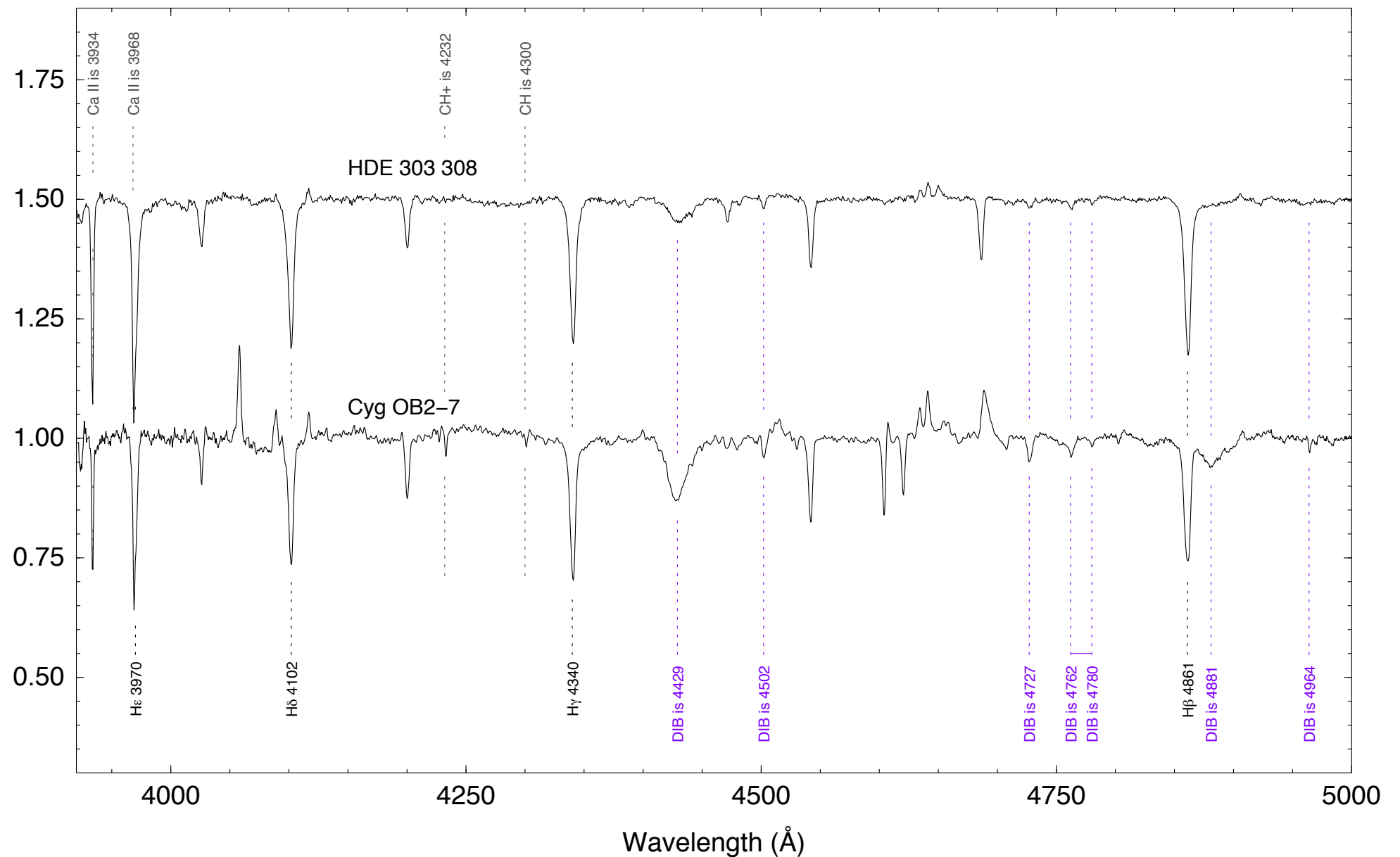
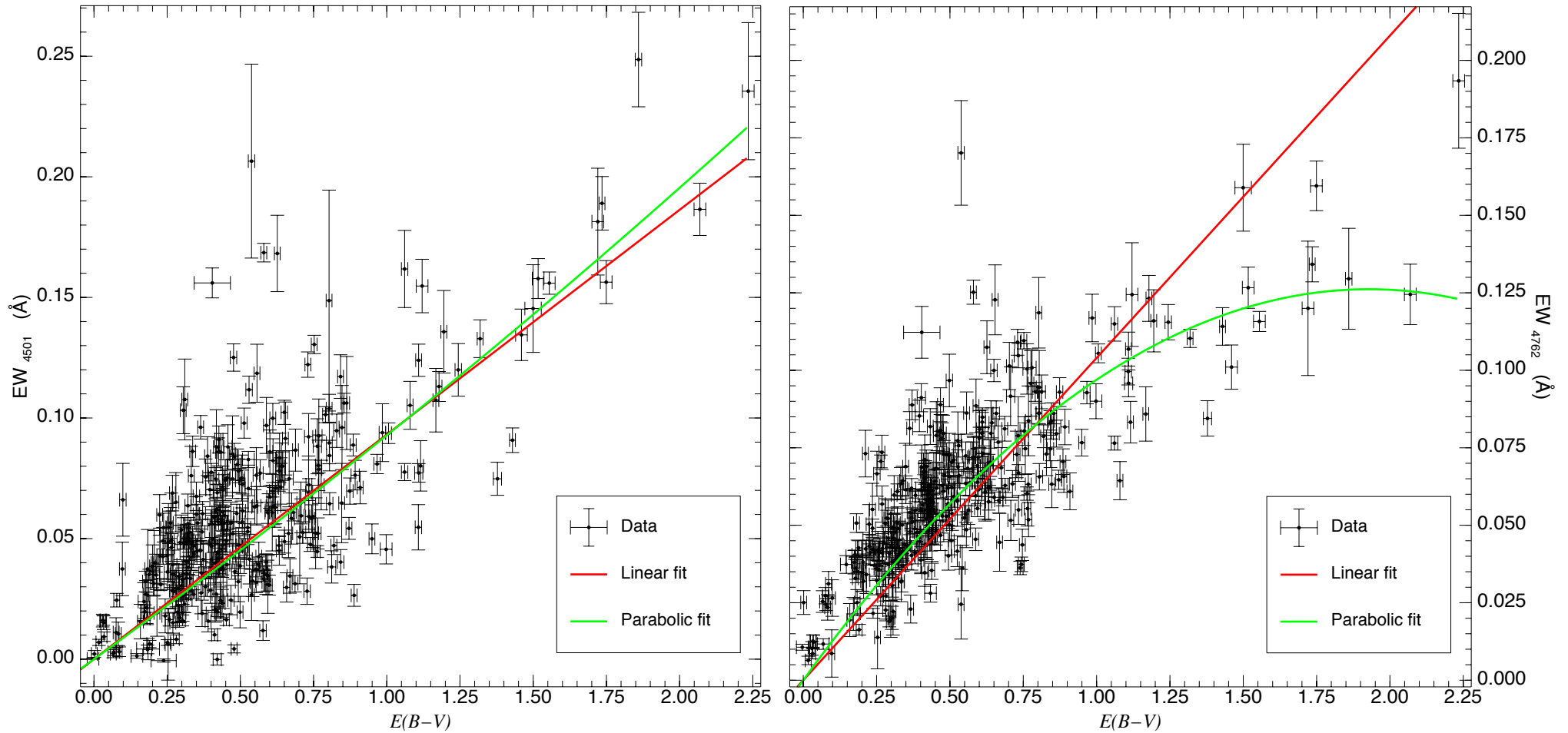
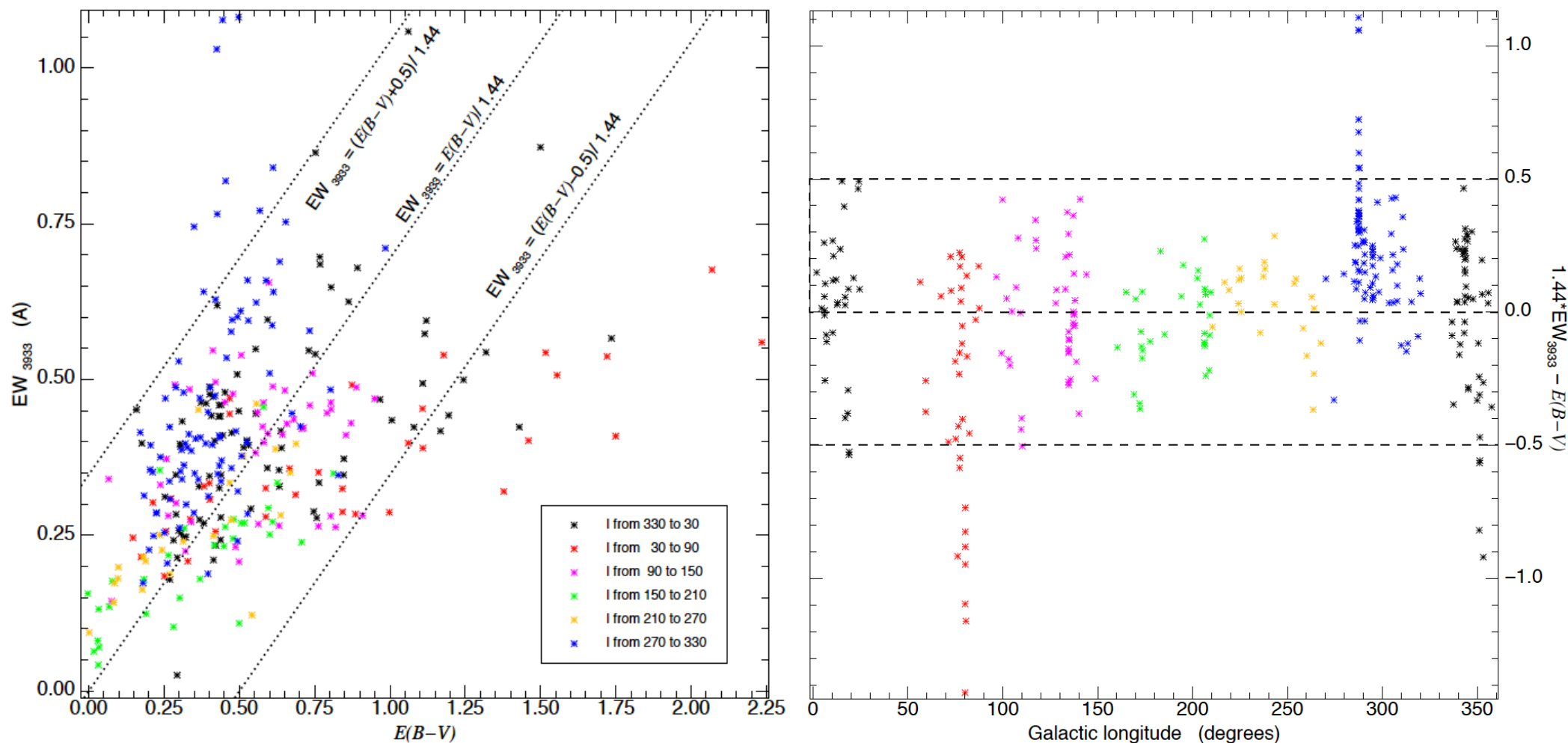


Figure 1 : Sample blue-violet spectra for two GOSSS O stars. The interstellar lines and DIB bands studied here as well as some other relevant lines and bands are indicated. Note the high EW of the Ca II K line and the moderate EW of the DIBs in HDE 303 308 (in Carina) and compare it with the high EW of the DIBs and moderate EW of the Ca II K line in Cyg OB2-7 (in Cygnus).



Figures 2 (left) and 3 (right): Equivalent line widths plotted against color excess for the two DIB bands centered near 4501 Å (Fig. 2) and 4762 Å (Fig. 3). We also show the linear and parabolic fits performed. The better fit by a parabola for the 4762 Å DIB band behavior is possibly due to the skin effect (DIBs originating in the diffuse ISM and in the outer layers of molecular clouds).



Figures 4 (Left) and 5 (right): Behavior of the Ca II $\lambda 3934$ (K) interstellar absorption as a function of $E(B-V)$ and Galactic longitude for the GOSSS sample. Note the different behavior in the direction of, on the one hand, Carina (blue), and on the other hand, Cygnus (red points) and, to some extent, Sagittarius (black). The 1.44 value is the slope of the linear fit performed.

	3933 Ca II	4232 CH+	4501 DIB	4726 DIB	4762 DIB	4780 DIB	4964 DIB	<i>E(B-V)</i>
3933 Ca II		0.387 0.924	0.548 0.980	0.604 0.990	0.651 0.986	0.610 0.938	0.529 0.951	0.452 0.997
4232 CH+	0.387 0.924		0.655 0.965	0.711 0.972	0.672 0.964	0.554 0.943	0.615 0.938	0.758 0.953
4501 DIB	0.548 0.980	0.655 0.965		0.859 0.990	0.861 0.986	0.803 0.962	0.717 0.961	0.727 0.986
4726 DIB	0.604 0.990	0.711 0.972	0.859 0.990		0.871 0.990	0.827 0.969	0.824 0.973	0.902 0.995
4762 DIB	0.651 0.986	0.672 0.964	0.861 0.986	0.871 0.990		0.826 0.940	0.721 0.946	0.807 0.991
4780 DIB	0.610 0.938	0.554 0.943	0.803 0.962	0.827 0.969	0.826 0.940		0.688 0.905	0.807 0.965
4964 DIB	0.529 0.951	0.615 0.938	0.717 0.961	0.824 0.973	0.721 0.946	0.688 0.905		0.735 0.963
<i>E(B-V)</i>	0.452 0.997	0.758 0.953	0.727 0.986	0.902 0.995	0.807 0.991	0.807 0.965	0.735 0.963	

Table 1: Correlation coefficients (top row in each cell) and noise-modified maximum correlation coefficients (bottom row) for the quantities in this work.

DATA DESCRIPTION AND PROCESSING

We used ~900 spectra corresponding to ~400 O stars (plus some B and WR stars) from the GOSSS survey (see contribution by Maíz Apellániz in this meeting) and reduced using the pipeline developed by one of us (see poster by Sota & Maíz Apellániz in this meeting). The spectra have high S/N (200 or better) and cover the 3900-5100 Å range with a spectral resolution $R \sim 2500$.

To measure the equivalent widths of the bands and lines of our study (Ca II $\lambda 3934$, CH+ $\lambda 4232$, and DIBs $\lambda\lambda 4501-4726-4762-4780-4964$ Å) we have used a visual IDL package based program written by one of us (Jesús Maíz Apellániz). The code allowed us to perform a fast and reliable analysis using both numerical integration and gaussian fits of each absorption line. Each fit was visually inspected and interactively adjusted to account for contamination by nearby lines, velocity shifts, and S/N effects. Some of the spectra were eliminated because of quality-control issues related to those effects.

The color excesses $E(B-V)$ were derived from [a] the photometry in the Galactic O-Star Catalog (Maíz Apellániz et al. 2004, Sota et al. 2008), [b] the temperature-spectral type relationships in Martins et al. (2005), and [c] the magnitudes as a function of temperature and luminosity class in the latest version of CHORIZOS (Maíz Apellániz 2004).

All the equivalent widths were correlated with each other and with the color excess (Table 1). We performed for each pair linear and parabolic fits. For the linear fits we calculated the maximum possible correlation coefficient for two perfectly correlated variables affected by random noise (the value is close to but not exactly 1.0).

RESULTS

DIBs are one of the older questions without answer in astronomy. More than 300 bands have been discovered in nearly a century. The currently favored carriers are carbon-based, but their specific nature is still highly debated (Herbig 1995, Galazutdinov et al. 2000, Kaźmierczak et al. 2010).

As we knew from previous literature results, DIBs are tightly correlated with extinction, but also with a considerable dispersion and differences for each band. This has been once again verified in this study. Other important corroboration is the variability of the correlation coefficients, indicating that DIBs are likely to originate in a family of carriers instead of a single one (Table 1).

It is believed that DIB carriers are present in diffuse clouds or the surface of dense ones as opposed to dense cores. This could be the reason of the better fit by a parabola in Fig. 3 and is known as the skin effect: at high extinctions the EW of some DIBs depends on color excess more weakly than at low extinctions. On the other hand, some DIBs do not show the effect in our data (Fig. 2).

The relationship of the Ca II $\lambda 3934$ line with extinction (Figs. 4 and 5) shows an interesting behavior. For low values of $E(B-V)$, the EW of the line is approximately proportional to the reddening. At intermediate values, however, two branches form, one with large $E(B-V)$ and intermediate $EW(3934)$ and another one with intermediate $E(B-V)$ and large $EW(3934)$. Furthermore, the two branches are distinguished as regions in the sky, with the first one concentrated in Cygnus (with most stars being Cyg OB2 members) and, to some extent, Sagittarius, and the second one in Carina. The most plausible explanation is the existence of cloud velocity structure (unresolved in our spectra). Ca II $\lambda 3934$ can saturate in moderately dense clouds, so the behavior of its equivalent width depends not only on the amount of material present but also on whether it is distributed in one or more clouds of different velocities. Figs. 4 and 5 are consistent with Ca II being concentrated in a single cloud in the direction of Cygnus and in several in the direction of Carina. Such velocity distribution has been extensively studied for the case of the Carina Nebula Association (Walborn et al. 2007 and references therein), where multiple velocity components are indeed present and caused by the kinetic energy input from the massive stars there. On the other hand, Cygnus OB2 is closer to us than the Carina Nebula and has no associated H II region, so the absorbing Ca II cloud is likely to be a single and relatively unperturbed foreground object.

FUTURE

Our future plans include:

1. Increase the sample of observed stars.
2. Analyze the rest of the DIB lines in the blue-violet spectra.
3. Obtain spectra in the rest of the visible spectrum to observe more DIBs.
4. Use high-resolution spectra to study the velocity structure of the Ca II λ 3934 line and weak DIBs.
5. Use CHORIZOS to derive $E(4405-5495)$ and R_{5495} , the monochromatic equivalents to $E(B-V)$ and R_V , respectively, and study their correlation with the measured equivalent widths.

REFERENCES

- Galazutdinov, G. A. et al. (2000), *PASP* **112**, 771
- Herbig, G. H. (1995), *ARA&A* **33**, 19
- Kaźmierczak, M. et al. (2010), *MNRAS* **408**, 1590
- Maíz Apellániz, J. (2004), *PASP* **116**, 859
- Maíz Apellániz, J., Walborn N. R., Galué, H. Á., & Wei, L. H. (2004), *ApJS* **151**, 103
- Martins, F., Schaerer, D., & Hillier, D. J. (2005), *A&A* **436**, 1049
- Sota, A. Maíz Apellániz, J., Walborn N. R., & Shida, R. Y. (2008), *RMxAA (serie de conferencias)* **33**, 56
- Walborn, N. R. et al. (2007), *PASP* **119**, 156