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A study of the ISM with large massive-star optical spectroscopic surveys

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Abstract

We are conducting a study on the imprint of the ISM on optical spectra based on two types of ongoing spectroscopic massive-star surveys: on the one hand, intermediate-resolution ($R = 2500$) green-blue spectra for ∼3000 stars obtained with the Galactic O Star Spectroscopic Survey (GOSSS). On the other hand, high-resolution ($R = 23\,000 - 65\,000$) optical spectra for 600 stars obtained from three different surveys, OWN, IACOB, and NoMaDS. The $R = 2500$ data allows us to reach a larger sample with an average larger extinction while the $R = 23\,000 - 65\,000$ sample provides access to more diffuse interstellar bands (DIBs) and allows for the resolution in velocity of some ISM features. For each spectrum we are measuring the equivalent widths, FWHMs, and central wavelengths of 10-40 DIBs and interstellar lines (e.g. Ca II H+K, Na I D1+D2) and, in the case of GOSSS, the existence of an H II region around the star. We have also derived from auxiliary data or compiled from the literature values for the reddening, extinction law, H I column density, parallax, and Hα emission. All of this constitutes the most complete collection ever of optical information on the ISM within 3 kpc of the Sun. We are analyzing the correlations between all of the collected quantities to discriminate between different possible origins of the DIBs.

1 Introduction

The last two decades have seen an explosion of ISM studies based on the IR-to-radio wavelength ranges, in good part due to large improvements in instrumentation and the number of dedicated telescopes at long wavelengths and the appearance of associated large-scale photometric and spectroscopic surveys. On the other hand, optical studies have mostly concentrated (with some notable exceptions such as [23]) in high-resolution analyses of small samples or specific regions. Somehow, the large-scale optical surveys of absorption lines, pioneered e.g. by [1] or [4] and which remained popular until the 1970s, have fallen out of fashion. This has happened despite the fact that some problems remain unsolved, such as the nature of the diffuse interstellar bands (DIBs), whose carrier remains unclear almost a century after their discovery. Here we present a project to do full-sky absorption-line surveys with larger samples, higher average extinctions, more modern instrumentation, and better S/N and complementary data than were possible in the mid-twentieth century. Most of the stars in our sample are of O spectral type for two reasons: their spectra are cleaner than most other stars (thus allowing to see the imprint of the ISM more easily) and their large luminosities allow us to probe to larger distances in the Galaxy.

2 Data

2.1 GOSSS spectroscopy

The Galactic O-Star Spectroscopic Survey (GOSSS; [11]) is a project that is obtaining green-blue, intermediate resolution ($R \sim 2500$) spectra for ~ 3000 early-type stars with the immediate goal of spectrally classifying all of the bright Galactic O stars. As of late 2012, we have observed ~ 1600 stars. GOSSS data are being obtained with four different telescopes in both hemispheres: the 1.5 m telescope at the Observatorio de Sierra Nevada (OSN), the 3.5 m telescope at Calar Alto Observatory (CAHA), the 4.2 m William Herschel Telescope (WHT) at the Observatorio del Roque de los Muchachos (ORM), and the 2.5 m du Pont telescope at Las Campanas Observatory (LCO). The first block of the survey was published as [16] and the second block will appear as Sota et al. (2013). GOSSS results on the spectral classification of O stars with C III $\lambda\lambda$4647-4650-4652 in emission have appeared as [22] and on rapidly rotating ON giants as [20].

GOSSS is a large-scale project with many goals, one of which is to study the imprint of the ISM on the observed spectra by measuring the absorption lines of atomic, molecular, and unknown (i.e. DIB) origin. Such studies have been traditionally carried out with high-resolution ($R > 10000$) echelle spectroscopy to (1) facilitate the detection of narrow, low equivalent width (EW) lines, (2) study the Doppler and intrinsic profiles of the lines, and (3) separate narrow ISM components from broad ones of stellar origin. However, intermediate-resolution spectra can also be used to study ISM lines of sufficient EW uncontaminated by stellar components. Furthermore, long-slit $R \sim 2500$ data has three advantages over higher-resolution echelle data: (1) the ability to reach targets of fainter magnitudes (with the same S/N and exposure time), (2) an easier way of measuring broad absorption structures (with echelle data it can be hard to measure the position of the continuum if the absorption structure spans a range comparable to an echelle order), and [3] the posibility of placing two (or more) targets on the slit, thus increasing the efficiency of the program.

2.2 High-resolution spectroscopy

As discussed in the previous subsection, high-resolution spectroscopy is required to study some of the effects that the ISM produces in the spectra of massive stars. For this project we are using four different high-resolution spectroscopic surveys of massive stars: OWN [2] is observing O and WN stars in the southern hemisphere using high-resolution spectrographs at La Silla, Las Campanas, Cerro Tololo (all of them in Chile), and CASLEO (Argentina). IACOB [14, 15] is observing northern O and B stars from La Palma (Spain). NoMaDS [10] is extending the magnitude coverage of IACOB to fainter objects using the Hobby-Eberly Telescope at McDonald Observatory (USA). Finally, CAFÉ-BEANS has just started to follow up on IACOB and NoMaDS obtaining multiple epochs to detect spectrocospic binaries and calculate their orbits using the 2.2 m telescope at Calar Alto (Spain). In total, we have observations of ~ 600 stars with spectral resolutions between 23 000 and 65 000. In all cases we reach down to 3900 Å but the red limit varies between different setups from 7200 Å to 10 000 Å. Some of the spectra have small gaps between orders or setups. The sample of stars observed at high resolution is nearly complete and has a lower mean extinction than the GOSSS sample.

2.3 Literature data

Here we list some of the sources for the complementary data used for this project:

- Spectral types are obtained from the GOSSS project itself [11].
- Photometry has been compiled from the Galactic O-Star Catalog, http://gosc.iaa.es [12, 17].
- [5] provides a modern compilation of interstellar column densities.
- A number of sources [9, 7, 8, 24] are used for existing information on DIBs.
- The new reduction of the Hipparcos data [18] is used for the parallaxes.

3 First results

We have started the study by measuring the EWs for 12 DIBs and three additional ISM lines for the O stars in our current GOSSS sample using an interactive custom-made IDL procedure. Each individual measurement has been done first automatically and then inspected manually in order to tweak the positions of the fitted regions and background positions. This needs to be done because of the varying velocity shifts between the star and the intervening ISM, the different nearby stellar lines present for different spectral subtypes, and the need to establish a detection threshold as a function of S/N. In most cases the EW has been obtained by numerical integration with a comparison value obtained by gaussian fitting in order to check for discrepancies. For some broad DIBs (e.g. DIB λ4428) it has been necessary to subtract from the profile overimposed stellar lines and in others (e.g. DIB λ4881) the EW has been measured by fitting a Lorentzian profile due to the presence of a neraby strong contaminating stellar line. We have also checked that the measured central wavelength and FWHM yield consistent results.

We show in Figs. 1 and 2 the 2-D histograms for the EWs of DIB λ4428 and Ca II λ3934 with the color excess $E(B-J)$. As it can be seen, DIB λ4428 is highly (but not completely)

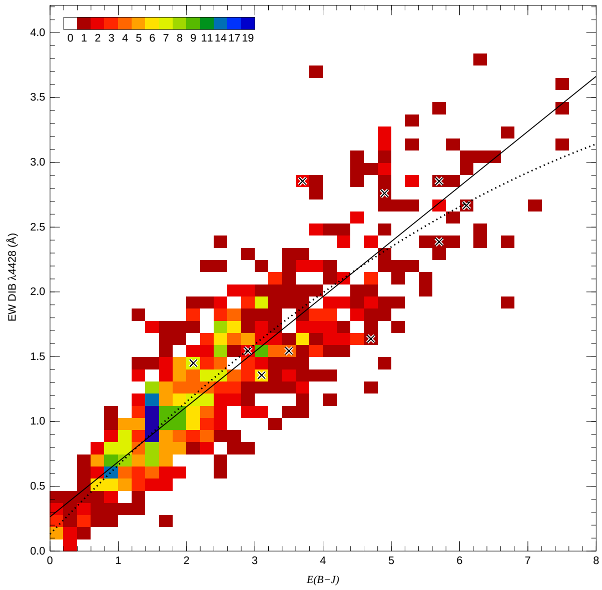

Figure 1: 2-D histogram of $E(B-J)$ against the EW of DIB λ4428. The size of the vertical cell is set to the average uncertainty in the EW. Cells marked with an X have at least one point with large EW uncertainty. The continuous and dashed lines are first- and second-order polynomial fits, respectively.

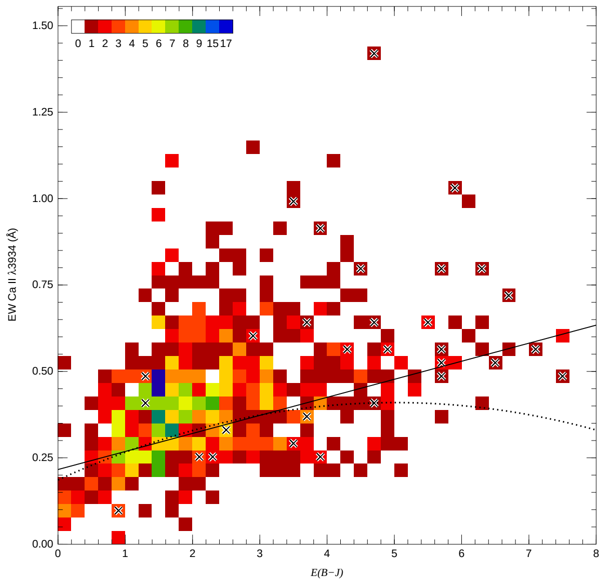

Figure 2: Same as Fig. 1 for the EW of Ca II λ3934.

correlated with $E(B-J)$, a known result for DIBs and here extended to a larger, more extinguished (on average) sample. On the other hand, Ca II λ3934 is poorly correlated with $E(B-J)$: indeed, it is possible to find stars with twice the EW of other targets that are three or four times more extinguished. The reason for the different behavior can be explained as follows: the DIB carriers are thought to be associated and well mixed with the diffuse ISM (e.g. [6]), which is responsible for most of the extinction for our sample, and even the most intense DIB λ4428 is optically thin in our sample. Hence, DIB λ4428 is well correlated with $E(B-J)$. On the other hand, Ca II λ3934 has a more uniform distribution than dust in the Galactic disk [13, 23], leading to more uniform column densities as a function of distance than dust. Also, Ca II λ3934 saturates easily and this makes its EW strongly dependent on the kinematics of the gas: a dispersion in cloud velocities helps increase the measured EW. Indeed, most points with EW Ca II $\lambda3934 > 0.75$ Å in Fig. 2 are located in the Carina nebula, an object with extremely complex gas kinematics (typical lines of sight have 23 to 26 identified components, [19, 21]).

We have recently acquired new GOSSS spectra (not included in Figs. 1 and 2) that significantly increase the number of stars with $E(B-J) > 4$. Our goal is to publish a paper during 2013 with the results derived from GOSSS spectroscopy. That paper will be followed by another one with the high-resolution data.

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