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Diffuse interstellar bands in RAVE Survey spectra*

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ABSTRACT

We have used spectra of hot stars from the RAVE Survey in order to investigate the visibility and properties of five diffuse interstellar bands previously reported in the literature. The RAVE spectroscopic survey for Galactic structure and kinematics records CCD spectra covering the 8400-8800 Å wavelength region at 7500 resolving power. The spectra are obtained with the UK Schmidt at the AAO, equipped with the 6dF multi-fiber positioner. The DIB at 8620.4 Å is by far the strongest and cleanest of all DIBs occurring within the RAVE wavelength range, with no interference by underlying absorption stellar lines in hot stars. It correlates so tightly with reddening that it turns out to be a reliable tool to measure it, following the relation $E_{B-V} = 2.72(\pm 0.03) \times E.W.(\text{Å})$, valid throughout the general interstellar medium of our Galaxy. The presence of a DIB at 8648 Å is confirmed. Its intensity appears unrelated to reddening, in agreement with scanty and preliminary reports available in the literature, and its measurability is strongly compromised by severe blending with underlying stellar HeI doublet at 8649 Å. The two weak DIBS at 8531 and 8572 Å do not appear real and should actually be blends of underlying stellar lines. The very weak DIB at 8439 Å cannot be resolved within the profile of the much stronger underlying hydrogen Paschen 18 stellar line.

Key words. ISM: general – ISM: lines and bands – Surveys

1. Introduction

Diffuse interstellar bands (DIBs) were first discovered by Heger (1922) as stable lines that did not follow the orbital motion seen in spectroscopic binaries. The first systematic studies began only with Merrill (1934, 1936), who noted similarities (occurrence, intensity and velocity) and differences (far wider and with diffuse edges) with respect to atomic interstellar lines. A few years later the first interstellar molecule (CH) was identified by means of absorption lines at 4300.3 Å by Swings and Rosenfeld (1937). Since then, much progress has been recorded in understanding the absorption spectra of interstellar ions and molecules, while the origin of DIBs is still mysterious after almost a century after their discovery (Sarre 2006). The census of major DIBs in the optical region seems quite complete now, at least for those away from strong telluric absorption bands and stellar lines. A compilation maintained by Jenniskens (2007) lists 281 DIBs over the wavelength range from 3980 to 9632 Å. DIBs are also observed in external galaxies (e.g. in the SMC by Cox et al. 2007b; in the LMC by Cox et al. 2006; in NGC 1448 by Sollerman et al. 2005; in M31 by Cordiner et al. 2008), in starbust complexes (Heckman and Lehnert 2000) and damped Ly-α systems (Jukkarinen et al. 2004, York et al. 2006, Ellison et al. 2008)

The carriers of DIBs are still unknown. Some DIBs tend to show an appreciable correlation with reddening, even if others do not (e.g. Sanner et al. 1978, Krelowski et al. 1999), and this led to the hypothesis that they were produced on or in the interstellar dust grains. However, lack of polarization in DIB profiles (Cox et al. 2007a) argues

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* Table 1 is available electronic only

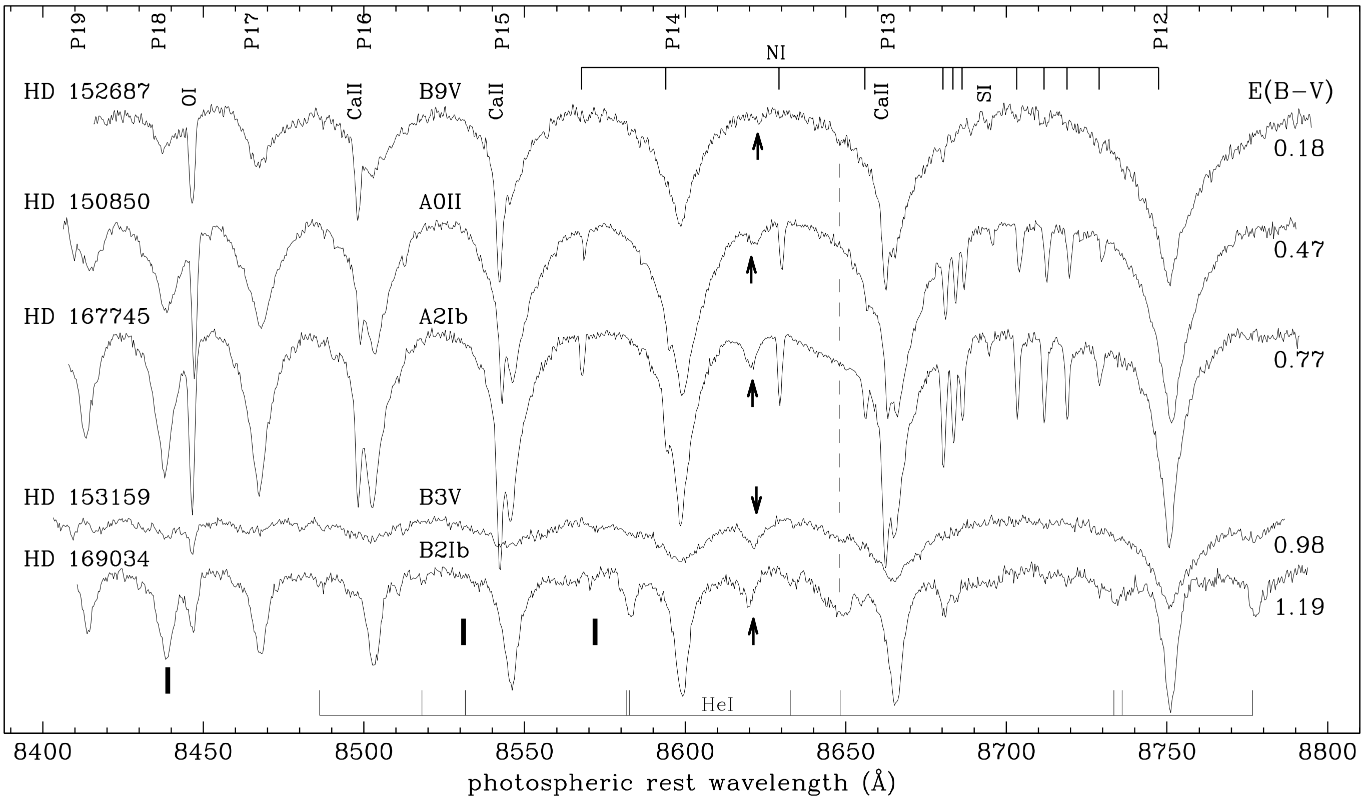

Fig. 1. A sample of RAVE spectra of early type HD stars ordered according to reddening. The strongest stellar lines are identified. The arrows point to DIB 8620, the thick vertical marks to DIBs 8439, 8531, 8572, and the dashed line to DIB 8648 Å.

against, and complex carbon-bearing molecules are generally considered as viable carriers (e.g. Fulara and Krelowski 2000), with fullerenes being subject of intensive laboratory studies (e.g. Herbig 1995, Leach 1995, Iglesias-Groth 2007). PAH (polycyclic aromatic hydrocarbons) have been frequently considered as promising carriers (van der Zwet and Allamandola 1985, Leger and Dhendecourt 1985), in particular for their success in explaining the unidentified infrared emission bands (UIR; Sarre et al. 1995). Laboratory studies suggest that only ionized and not neutral PAH could be viable carriers (e.g. Ruiterkamp et al. 2002, Halasinski et al. 2005), and this would agree with the observed insensitivity of DIB intensity to ambient electron density (Gnaciski et al. 2007). A search for correlations between different DIBs has been carried out as a criterion to guide possible identification (a strict correlation may imply a common carrier, whereas a lack of correlation indicates that different species are involved), but the degree of correlation cover the whole interval from good to very poor (e.g. Moutou et al. 1999). Finally, Holmlid (2008) has recently proposed a radically different mechanism for the formation of DIBs, namely doubly excited atoms embedded in the condensed phase named Rydberg matter.

The Radial Velocity Experiment (RAVE) is an ongoing spectroscopic survey of the whole southern sky at galactic latitudes $|b|\geq 25°$ for stars in the magnitude interval $9\leq I_{\rm C}\leq 12$, with spectra recorded over the 8400-8800 Å range at a resolving power around 7 500. The 150 fiber positioner 6dF is used at the UK Schmidt telescope of the Anglo-Australian Observatory. The main scientific driver of the project is the study of the stellar kinematics and metallicity of galactic populations away from the galactic plane (e.g. Smith et al. 2007, Seabroke et al. 2008, Veltz et al. 2008). RAVE begun operations in 2003 and has now reached the milestones of the first (Steinmetz et al. 2006) and second (Zwitter et al. 2008) data releases, with a current total of ∼250 000 stars already observed.

In this paper we investigate the detectability, measurability and properties of the DIBs known to occur within the RAVE wavelength interval. In this range there is no resonant line from ions sufficiently abundant in the interstellar medium to produce detectable features in high-resolution ground spectra. Weak C_2 interstellar lines due to the (2,0) band of the Phillips system are seen longword of hydrogen Paschen 12 and around HeI 8777 stellar lines (Gredel and Muench 1986) in highly reddened stars, the strongest ones occurring at 8751.5, 8753.8, 8761.0, 8763.6, 8773.1 and 8780.0 Å (Gredel et al. 2001).

2. Target selection

The flatter is the background stellar continuum, the easier and firmer is the detection and measure of a DIB. Only hot stars provide continua with a sufficiently small number of photospheric lines, and all DIB studies in the literature observed hot stars. Extensive checks with the Castelli and Munari (2001, hereafter CM01) synthetic spectral atlas, show that spectral types earlier than A7 have - irrespective of the luminosity class - flat background continua at the wavelengths of DIB 8620.4, the principal target of this paper. To be on the safe side by a fairly wide margin, we limited the target selection to A3 and hotter stars.

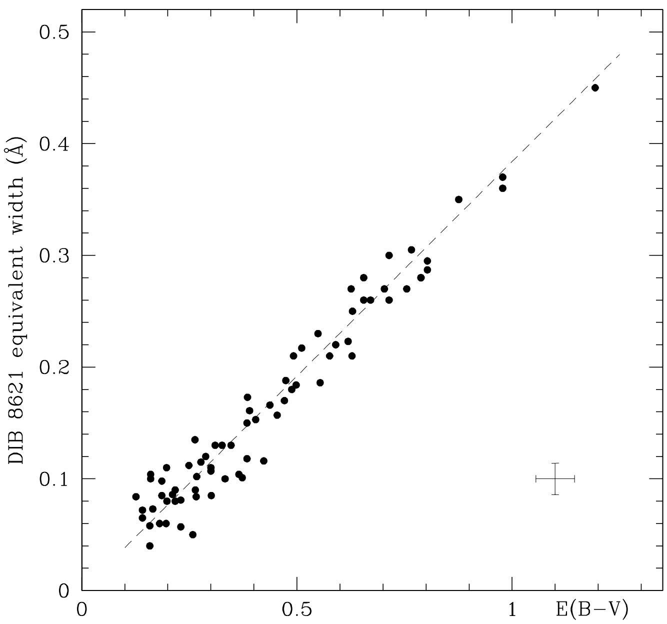

Fig. 2. The equivalent width of the diffuse interstellar band at 8620.4 Å as function of reddening. The dashed line represents Eq.(4) and the error bars are the average uncertainties of plotted points from Eq.(1) and (3).

DIBs generally increase their strength in pace with reddening, which is highest at the lowest galactic latitudes. For this reason, we selected for our analysis only HD stars observed by RAVE at $|b|\leq10°$ as part of calibration runs (normal survey observations are carried out at $|b|\geq25°$ where the reddening is generally negligible and therefore DIB signatures undetectable).

We limited the target selection to HD stars because (*i*) for all of them an accurate and homogeneous spectral classification has been provided by the Michigan Spectral Survey (Houk and Cowley 1975, Houk 1978, Houk 1982, Houk and Smith-Moore 1988, Houk and Swift 1999), (*ii*) intrinsic $B-V$ color is known for all spectral types and luminosity classes (Fitzgerald 1970), and (*iii*) accurate Tycho-2 $B_{\rm T}$ and $V_{\rm T}$ photometry is available for all targets. Together, they allow to derive a consistent value for the interstellar reddening affecting each target star.

Two further selection criteria were applied in order to enforce the highest possible quality of the results: we retained only the spectra (*a*) with S/N≥50 per pixel on the stellar continuum around DIB 8620, and (*b*) that do not show even the most feeble trace of residual fringing left over by the flat field division. The RAVE Survey CCD is a thinned, back-illuminated one, and as such it naturally presents fringing at the very red wavelengths of RAVE Survey observations. Flat fielding generally provides accurate fringing removal, but in some cases a weak and residual pattern survives (at a level ≤1% that does not affect the main RAVE Survey products: radial velocities and atmospheric parameters of observed stars).

The final target list after application of all above criteria count 68 targets observed by RAVE during the time interval 28 April 2004 to 21 October 2006, eight of them observed twice. They are listed in Table 1 (available electronic only).

3. DIBs over the RAVE wavelength interval

A DIB at 8439.4 Å was discovered by Galazutdinov et al. (2000). It is very sharp, and deeply blended with the Paschen 18 photospheric line. It is also intrinsically quite weak, being detectable only in high resolution and high S/N spectra of heavily reddened stars. RAVE spectra cannot reveal it.

A sharp DIB at 8530.7 Å was reported by Jenniskens and Desert (1994), but not confirmed by Galazutdinov et al. (2000). Its wavelength is coincident with the blend of 8528.967, 8529.025, and 8531.508 Å HeI photospheric absorption lines (cf CM01), compromising any clear detection. The DIB equivalent width reported by Jenniskens and Desert (1994) for four early type stars characterized by E_{B-V} ranging from 0.30 to 1.28, shows no clear trend with reddening and instead a better correlation with the intensity of HeI expected from the spectral type of the target star. Extrapolating Jenniskens and Desert (1994) data for HD 183143 reddened by E_{B-V}=1.28, an equivalent width of 0.065 Å could be expected for this DIB in the RAVE spectrum of HD 169034 in Fig. 1. This equivalent width is less than half that of the stellar HeI blend. If the DIB 8530.7 is real, which we doubt, RAVE spectra cannot disentangle it from the underlying and overwhelming HeI 8530 Å absorption blend.

Sanner et al. (1978) listed an uncertain DIB at 8572 Å. It was dismissed as a photospheric stellar line by Jenniskens and Desert (1994) and was not detected by Galazutdinov et al. (2000). CM01 atlas shows the presence of a weak and diffuse blend of many photospheric absorption lines centered at the same wavelength as the supposed DIBs, confirming the proposed DIB as a spurious detection.

A moderately strong, broad and complex profile DIB, loosely centered at 8648.3 Å, was discovered by Sanner et al. (1978). It was later confirmed by Herbig and Leka (1991), Jenniskens and Desert (1994) and Wallerstein et al. (2007). Over the wavelength interval covered by the 8650 DIB there are two strong HeI photospheric absorption lines at 8648.258 and 8650.811 that appreciably confuse the picture (cf. CM01). RAVE spectra support the presence of a DIB at these wavelengths, whose intensity however does not correlate at all with reddening (as already noted by Sanner et al. 1978, their Fig. 4). In fact, in the RAVE spectra of Fig. 1, the 8648.3 DIB is clearly present at E_{B-V}=0.18, missing at E_{B-V}=0.47, prominent and broader at E_{B-V}=0.77, feeble or absent at E_{B-V}=0.98, and again strong at E_{B-V}=1.19. In the most reddened spectrum of Fig. 1 (HD 169034), the expected intensity of the interfering HeI blend at 8648.258, 8650.811 is equal to the intensity of the nearby HeI blend at 8581.856, 8582.670, which lead us to speculate that the equivalent width of the 8648.3 DIB in this spectrum should be ∼0.25 Å. A very close match is provided by Wallerstein et al.'s (2007) spectra for the stars HD 169454 and HD 183143 (their Fig. 1). Given the obvious interference by strong underlying stellar HeI and the lack of an appreciable correlation with reddening, we will not further discuss the 8648.3 DIB as seen in RAVE spectra.

4. The 8620 Å DIB

The strongest DIB over the RAVE wavelength range appears at 8620.4 Å. It was first discovered by Geary (1975), and then confirmed by all later investigators. Its tight correlation with reddening was discovered and discussed by Munari (2000, hereafter M00), and later confirmed by Wallerstein et al. (2007).

4.1. DIB measurement

The equivalent width and heliocentric wavelength of the 8620 DIB has been obtained on RAVE spectra by integrating - over the wavelength range of the DIB - the difference between the extrapolated underlying continuum and the observed spectrum affected by the DIB. The underlying continuum has been fitting with a 6^{th} order Lagrange polynomial between the Paschen 13 and 14 line centers. The results are reported in Table 1.

Eight of the sixty-eight program stars have a second RAVE spectrum satisfying the quality selection criteria outlined in Sect. 2. Four of them have been obtained with similar instrument set-ups (plate and fiber) on adjacent nights, while the other four were observed with different set-ups one year apart. The mean difference between the two measurements of the equivalent width in these eight pairs is:

$$\sigma(E.W.) \ = \ 0.014 \ \text{Å} \qquad (1)$$

which we consider to be representative of the mean accuracy of our DIB measurements.

The intrinsic DIB wavelength is reported as 8620.8 Å by Galazutdinov et al. (2000) from observations toward a single star (HD 23180), and as 8621.2 Å by Jenniskens and Desert (1994) from observations toward four stars. M00 gives 8620.4 Å from observations of 37 northern stars in the general Galactic anti-center direction, after correction for the velocity of interstellar atomic lines (NaI and KI). The RAVE program stars lies toward the Bulge and close to the Galactic center (see galactic coordinates in Table 1 and Fig. 3). Adopting the Brand and Blitz (1993) maps for the radial velocity of interstellar medium, the average velocity of the medium along the lines of sight to the program stars is essentially null. Therefore, the mean of heliocentric DIB wavelength in Table 1 represents also the intrinsic barycentric wavelength, whose average value is:

$$\lambda(DIB) \ = \ 8620.4 \ (\pm 0.1) \ \text{Å} \qquad (2)$$

4.2. Reddening of program stars

The reddening of the sixty-eight program stars was homogeneously derived from the Michigan spectral type of the HD stars, the corresponding intrinsic color $(B-V)_{\rm J}$ from Fitzgerald (1970), and observed the Tycho-2 $(B-V)_{\rm T}$ color ported to the Johnson system via Bessell (2000) transformations (cf Sect. 2). The reddening derived for the program stars is listed in Table 1 together with their spectrophotometric parallax derived adopting absolute M_V magnitudes from the Michigan Project[1]. The individual error sources contributing to the overall reddening error are: (*i*) the natural color width of a spectral sub-type (on the average 0.020 mag for O-A3 stars), (*ii*) the uncertainty in the spectral classification (if taken equivalent to one spectral subclass, it is also 0.020 mag), (*iii*) the error of Tycho-2 $(B-V)_{\rm T}$ color (on average 0.034 mag), (*iv*) the uncertainty of the color transformation from Tycho-2 to the Johnson system (unknown, and assumed to amount to a mere 0.010 mag). Considering them as independent quantities and adding them in quadrature, the mean value of the overall error budget of reddening determination is:

$$\sigma(E_{B-V}) \ = \ 0.045 \ \text{mag} \qquad (3)$$

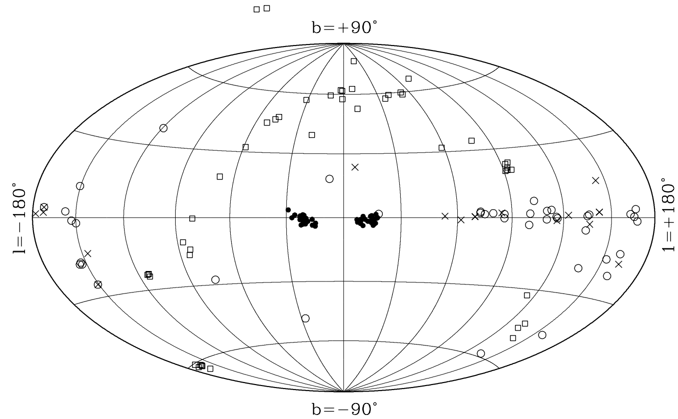

Fig. 3. Aitoff projection in galactic coordinates of the program stars (filled circles). Also plotted are the stars studied by Munari (2000, open circles), and those observed by Jenniskens and Desert (1994), Sanner et al. (1978, crosses) and Wallerstein et al. (2007, squares).

4.3. A tight relation between reddening and equivalent width

Figure 2 illustrates the relation between reddening and equivalent width of DIB 8620.4 for the seventy-six spectra of the sixty-eight program stars of Table 1. The relation is remarkably straight, with a least square fitting of:

$$E_{B-V} \ = \ 2.72 \ (\pm \ 0.03) \ \times \ E.W. \qquad (4)$$

where the E.W. is expressed in Å. The rms of the points is 0.020 Å in E.W. and 0.053 mag in E_{B-V}, which are only modestly larger than the typical measurement error in both axes as given by Eq.(1) and (3). This argues in favor of a very small *intrinsic* scatter of the points around Eq.(4), a remarkable property already preliminary focused upon by M00. The absence of significant cosmic scatter in the proportionality between reddening and equivalent width of the DID 8620 has two main implication: (*a*) the DIB carrier has an intimate partnership with the solid phase of the interstellar medium. A search and study of the polarization across the DIB profile would be worthwhile, and (*b*) the DIB 8620.4 can now be considered a viable tool to actually *measure* the amount of reddening and not simply to guess its presence.

The dispersion of the points along the mean relation in Fig. 2 is slightly larger at lower reddenings: the rms in E.W. of the points with E.W.$\leq$0.14 Å is 0.022 Å, and 0.016 Å for E.W.$\geq$0.14 Å. While the significance of this small difference is uncertain given the small number statistics, for sake of discussion it could be argued that some cosmic scatter - even if marginal - is actually present in the relation between reddening and intensity of the DIB 8620.4. In fact, a sharper relation at increasing E_{B-V} could simply mean than one starts to sample multiple clouds in the line-of-sight and thus any deviations between single clouds will be somewhat averaged out. Wallerstein et al. (2007) reported that stars

[1] http://www.astro.lsa.umich.edu/users/hdproj/mosaicinfo/absmag.html

seen through the ρ Oph molecular cloud show a DIB weaker than expected.

The proportionality relation found by M00 from 37 northern stars observed at high resolution and high S/N is $E_{B-V} = 2.69(\pm 0.03) \times E.W.$, which is essentially identical to Eq.(4). This is remarkable because the CCD adopted by M00 for his Echelle observations was a thick, front illuminated one without any fringing, and therefore ideal to aim for the highest accuracy. Fitting the data of the four stars observed by Jenniskens and Desert (1994) in high resolution with a Reticon detector gives $E_{B-V} = 2.77(\pm 0.1) \times E.W.$, and the 10 stars observed by Sanner et al. (1978) at low resolution again with a Reticon detector provides $E_{B-V} = 2.76(\pm 0.06) \times E.W.$ Finally, when the reddening of the target stars is homogeneously computed in the same way as done for this paper, also the Wallerstein et al. (2007) data support Eq.(4) above (G. Wallerstein, private communication).

Our study and data from these other investigations cover about two hundreds different stars distributed over a great range of distances from the Sun and over a wide range Galactic longitudes, from the Galactic anti-center mapped by M00 to the Galactic center in this paper, as illustrated by Fig. 4. These stars have been observed with quite different techniques and instruments, and the equivalent width of the DIB measured with different approaches. Yet, they define one and the same proportional relation. We therefore propose that Eq.(4) can be safely adopted as a direct way to derive the reddening caused by the general interstellar medium.

In general terms, it could be argued that proportionality relation between reddening and DIB intensity could take the form $E_{B-V} = \alpha(l, b, d) \times E.W$, where α is allowed to vary as function of galactic coordinates and distance, reflecting local dis-homogeneities in the interstellar medium. The calibration of α requires observations of stars scattered through the whole Galaxy in a number which is orders of magnitudes larger than currently available. As noted by M00, only the forthcoming ESA's GAIA mission will be in a position to provide such a large dataset, both in the form of accurate distances and spectra covering the DIB 8620.4 in high resolution.

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Table 1. (available electronic only). Summary of basic information and DIB measurements for the program stars. *pl* is the RAVE fiber plate number (1 or 2), and *fiber* is the fiber number of the given plate (from 1 to 150). $\lambda_\odot$ is the measured heliocentric wavelength of the DIB and *e.w.* its equivalent width, both in Å. Photometric magnitudes are in the Johnson system.

	l_{gal}	b_{gal}	obs. date	field	pl	fiber	$\lambda_\odot$	e.w.	spectrum	$(B-V)_\circ$	$B-V$	V	M_V	E_{B-V}	d
HD 142062	330.9858	+03.5383	20040507	1607m49	1	042	8621.26	0.135	A1V	0.02	0.283	9.622	+1.30	0.26	0.3
HD 146461	332.9676	−00.1029	20040530	1607m49a	1	126	8621.55	0.084	A1III/IVs	0.01	0.276	8.858	+0.60	0.27	0.3
HD 146683	334.4530	+01.1731	20040530	1607m49a	1	102	8620.53	0.085	A1/A2V	0.04	0.206	8.434	+1.45	0.17	0.2
HD 146683	334.4530	+01.1731	20040530	1607m49b	1	102	8620.46	0.098	A1/A2V	0.04	0.206	8.434	+1.45	0.17	0.2
HD 148920	337.3820	+00.7937	20050428	1644m47	1	045	8620.56	0.065	B6V	−0.14	0.001	8.387	−0.70	0.14	0.5
HD 148920	337.3820	+00.7937	20050429	1644m47	1	045	8620.75	0.072	B6V	−0.14	0.001	8.387	−0.70	0.14	0.5
HD 148953	337.1032	+00.4645	20050428	1644m47	1	039	8619.68	0.153	A0IV/V	−0.02	0.384	10.058	+0.65	0.40	0.4
HD 149096	337.5089	+00.6436	20050428	1644m47	1	049	8620.69	0.112	B8III	−0.10	0.149	9.087	−1.00	0.25	0.7
HD 149278	337.8021	+00.6265	20050428	1644m47	1	048	8620.92	0.100	B5V	−0.16	0.000	9.181	−1.00	0.16	0.9
HD 149278	337.8021	+00.6265	20050429	1644m47	1	048	8620.69	0.104	B5V	−0.16	0.000	9.181	−1.00	0.16	0.9
HD 149341	338.1726	+00.9181	20040923	1646m47	1	056	8620.80	0.104	A0III	−0.03	0.335	10.137	+0.10	0.37	0.6
HD 149388	338.6584	+01.2974	20040923	1646m47	1	057	8620.53	0.073	B9IV	−0.07	0.095	8.994	−0.20	0.17	0.5
HD 149452	337.4654	+00.0330	20040923	1646m47	1	037	8620.98	0.287	O9V	−0.31	0.493	9.178	−4.70	0.80	1.9
HD 149452	337.4654	+00.0330	20050428	1644m47	1	035	8620.55	0.295	O9V	−0.31	0.493	9.178	−4.70	0.80	1.9
HD 149483	337.6560	+00.1727	20040428	1646m47	1	048	8619.27	0.086	B7Ib/II	−0.08	0.171	9.657	−4.80	0.25	5.4
HD 149494	337.8753	+00.3519	20040923	1646m47	1	052	8620.17	0.166	B3III/IV	−0.20	0.237	9.571	−2.80	0.44	1.6
HD 149899	339.2317	+01.0314	20040928	1646m47	1	066	8620.11	0.058	B8III/II	−0.10	0.058	8.227	−2.60	0.16	1.2
HD 149899	339.2317	+01.0314	20050429	1644m47	1	069	8620.32	0.040	B8III/II	−0.10	0.058	8.227	−2.60	0.16	1.2
HD 149966	338.6069	+00.3605	20050428	1644m47	1	064	8620.40	0.085	A2V	0.05	0.351	10.165	+1.60	0.30	0.3
HD 150006	337.1917	−00.9703	20040923	1646m47	1	019	8619.67	0.08	A0V	−0.01	0.188	8.712	+1.00	0.20	0.3
HD 150155	338.1419	−00.3153	20040923	1646m47	1	024	8620.46	0.13	B2/B3II	−0.19	0.120	9.471	−4.70	0.31	4.4
HD 150231	337.8064	−00.7271	20040923	1646m47	1	059	8619.93	0.107	B3V	−0.20	0.100	9.484	−1.70	0.30	1.1
HD 150400	338.7062	−00.2140	20040923	1646m47	1	093	8620.46	0.116	B8II	−0.10	0.323	9.322	−3.80	0.42	2.3
HD 150850	338.9943	−00.5926	20040923	1646m47	1	074	8620.72	0.170	A0II	0.00	0.471	8.367	−3.20	0.47	1.1
HD 151131	339.0357	−00.9666	20040923	1646m47	1	089	8619.54	0.173	B9Ib/II	−0.04	0.365	9.565	−4.55	0.41	3.7
HD 151475	338.8760	−01.5889	20040923	1646m47	1	119	8620.52	0.130	B2V	−0.24	0.107	8.061	−2.50	0.35	0.8
HD 151536	340.3561	−00.4079	20050428	1644m47	1	084	8619.73	0.184	B2II	−0.21	0.288	9.250	−4.80	0.50	3.2
HD 152184	337.7431	−03.4724	20040923	1646m47	1	142	8620.37	0.157	B8V	−0.11	0.344	9.368	+0.00	0.45	0.4
HD 152477	338.7360	−03.0264	20040923	1646m47	1	130	8620.65	0.28	B1Ib	−0.19	0.598	9.087	−5.70	0.79	2.9
HD 152477	338.7360	−03.0264	20050428	1644m47	1	126	8619.45	0.28	B1Ib	−0.19	0.598	9.087	−5.70	0.79	2.9
HD 152687	340.4282	−01.9319	20040923	1646m47	1	102	8620.47	0.06	B9V	−0.07	0.111	8.718	+0.50	0.18	0.3
HD 152799	340.6401	−01.9052	20040923	1646m47	1	101	8620.35	0.10	B2/B3III	−0.22	0.113	8.731	−3.35	0.33	1.6
HD 153052	341.2772	−01.7503	20040923	1646m47	1	098	8620.36	0.06	B9III	−0.06	0.136	9.771	−0.40	0.20	0.8
HD 153159	340.0195	−02.9046	20040923	1646m47	1	114	8619.94	0.36	B5Ib	−0.20	0.778	9.576	−5.70	0.98	2.8
HD 153159	340.0195	−02.9046	20050428	1644m47	1	113	8620.05	0.37	B5Ib	−0.20	0.778	9.576	−5.70	0.98	2.8
HD 153733	343.5662	−00.8275	20040924	1716m42	1	035	8619.87	0.11	A0III/IV	−0.03	0.167	9.705	+0.20	0.20	0.6
HD 155707	343.6462	−03.5420	20040924	1716m42	1	001	8620.76	0.22	A3/5V	0.12	0.690	9.904	+1.95	0.57	0.2
HD 155913	345.2870	−02.6070	20050528	1716m42	1	137	8620.07	0.27	O5/O6	−0.32	0.435	8.300		0.76	
HD 156903	345.1283	−03.9903	20040924	1716m42	1	128	8620.51	0.057	A0III	−0.03	0.200	8.556	+0.10	0.23	0.4
HD 164971	006.8868	−00.9279	20061021	1813m21	1	018	8620.52	0.21	O	−0.31	0.266	9.434		0.58	
HD 165285	010.0898	+00.5289	20061021	1813m21	1	061	8620.02	0.27	O	−0.31	0.393	8.415		0.70	
HD 165689	008.3102	−01.0444	20061021	1813m21	1	027	8619.97	0.081	B2IV	−0.24	−0.010	8.078	−3.10	0.23	1.2
HD 165892	009.1729	−00.8113	20061021	1813m21	1	042	8620.36	0.223	B2II	−0.21	0.409	9.040	−4.80	0.62	2.4
HD 165997	010.4100	−00.2132	20061021	1813m21	1	066	8621.31	0.102	A1V	0.02	0.287	8.548	+1.30	0.27	0.2
HD 165998	009.0769	−00.9798	20061021	1813m21	1	048	8620.77	0.280	B9Ib	−0.06	0.595	8.485	−5.50	0.66	2.5
HD 166107	007.2160	−02.1634	20061021	1813m21	1	002	8620.90	0.12	B2Vn	−0.24	0.048	7.964	−2.50	0.29	0.8
HD 166167	009.3727	−01.0082	20061021	1813m21	1	064	8620.78	0.217	B9.5Iab/Ib	0.00	0.511	8.606	−5.95	0.51	3.9
HD 166787	011.0639	−00.8013	20061021	1813m21	1	075	8620.72	0.25	B0.5Ia	−0.22	0.409	8.265	−6.40	0.63	3.5
HD 166852	008.5074	−02.3235	20061021	1813m21	1	135	8620.27	0.18	O	−0.31	0.178	8.573		0.49	
HD 166963	013.9363	+00.5596	20040902	1820m18	2	064	8620.27	0.110	B2Ib	−0.16	0.140	9.926	−5.70	0.30	8.7
HD 166996	014.6202	+00.8993	20040925	1822m16	1	040	8620.76	0.21	B2Ib	−0.16	0.332	9.418	−5.70	0.49	5.2
HD 167201	008.7967	−02.6054	20061021	1813m21	1	116	8619.96	0.188	B7Ib	−0.04	0.434	9.233	−5.60	0.47	4.7
HD 167266	008.7040	−02.7322	20061021	1813m21	1	136	8619.35	0.084	A3IV	0.09	0.216	9.356	+1.20	0.13	0.4
HD 167451	016.8261	+01.5206	20040925	1822m16	1	066	8620.95	0.35	B1Ib	−0.19	0.686	8.289	−5.70	0.88	1.8
HD 167745	014.7878	+00.0405	20040925	1822m16	1	039	8620.79	0.305	A2Ib	0.05	0.816	9.399	−5.00	0.77	2.5
HD 168230	012.5852	−01.7346	20040902	1820m18	2	082	8620.10	0.26	B2Ib/II	−0.18	0.491	9.528	−5.25	0.67	3.5
HD 168302	015.0993	−00.4363	20040925	1822m16	1	054	8619.91	0.09	B4III	−0.18	0.084	9.314	−2.55	0.26	1.6
HD 168674	013.8800	−01.6459	20040925	1822m16	1	001	8620.01	0.21	B2Iab/Ib	−0.17	0.458	9.818	−6.00	0.63	5.9
HD 168678	010.0536	−03.7338	20061021	1813m21	1	117	8619.72	0.05	A2IV	0.06	0.318	8.034	+1.00	0.26	0.2
HD 168726	014.8355	−01.1767	20040902	1820m18	2	079	8620.58	0.08	B3III	−0.20	0.017	9.755	−3.10	0.22	2.7
HD 168765	014.1408	−01.6248	20040902	1820m18	2	083	8620.75	0.161	B3II	−0.17	0.220	9.380	−4.60	0.39	3.6
HD 168917	016.9136	−00.3128	20040925	1822m16	1	081	8620.29	0.26	B0/B0.5III/II	−0.30	0.355	8.456	−4.95	0.66	1.9
HD 169034	017.6553	−00.0693	20040925	1822m16	1	076	8620.25	0.45	B2Ia	−0.17	1.023	8.212	−6.80	1.19	1.8
HD 169084	017.3543	−00.2604	20040925	1822m16	1	079	8620.58	0.186	A1III	0.01	0.564	9.600	+0.50	0.55	0.3
HD 169419	014.4065	−02.3223	20040902	1820m18	2	095	8620.8	0.23	B2Ia/Iab	−0.17	0.379	9.402	−6.55	0.55	7.1
HD 169827	014.8328	−02.6184	20040925	1822m16	1	135	8620.14	0.09	B9.5II	−0.03	0.187	8.336	−3.40	0.22	1.6
HD 170083	016.0506	−02.2565	20040925	1822m16	1	116	8620.09	0.15	B5Ib	−0.09	0.294	9.211	−5.70	0.38	5.5
HD 170297	015.7067	−02.7202	20040925	1822m16	1	121	8620.68	0.118	A0III/IV	−0.03	0.354	9.857	+0.20	0.38	0.5
HD 170549	016.5854	−02.6498	20040925	1822m16	1	111	8619.54	0.101	A2II	0.05	0.423	8.313	−2.90	0.37	1.0
HD 170604	015.8792	−03.0970	20040925	1822m16	1	120	8620.58	0.115	B1Ib	−0.19	0.087	8.505	−5.70	0.28	4.7
HD 170797	015.3991	−03.6133	20040925	1822m16	1	126	8620.08	0.13	A0III	−0.03	0.296	9.631	+0.10	0.33	0.5
HD 328856	338.5558	−01.1339	20050428	1644m47	1	034	8620.69	0.30	O9.5III	−0.30	0.414	8.459	−5.50	0.71	2.2
HD 328856	338.5558	−01.1339	20050429	1644m47	1	034	8620.69	0.26	O9.5III	−0.30	0.414	8.459	−5.50	0.71	2.2
HD 329033	338.6091	−01.4120	20040923	1646m47	1	123	8620.77	0.27	B1III	−0.26	0.366	10.104	−4.40	0.63	3.3