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Correlations between diffuse interstellar bands and atomic lines

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ABSTRACT

We present and discuss correlations between strengths of the well-known, strong interstellar atomic lines of K I and Ca II, and four selected, strong unidentified diffuse interstellar bands (DIBs): 5780, 5797, 5850 and 6614. In order to analyse a homogeneous sample of echelle high-resolution spectra it has been chosen to use measurements from Terskol Observatory in Northern Caucasus plus a selected number of higher resolution observations performed using other instruments. We demonstrate that the strength of certain DIBs correlate well with neutral potassium lines and to a much lower degree with ionized calcium lines. This fact suggests that the degree of irradiation of a cloud with UV photons, capable to ionize interstellar atoms, plays a crucial role in the formation/maintenance of certain molecular species: possible carriers of DIBs.

Key words: ISM: clouds – ISM: lines and bands.

1 INTRODUCTION

Diffuse interstellar bands (DIBs), since their discovery by Heger (1921), remain unidentified despite numerous efforts (for a review see Herbig 1995). Practically all possible inhabitants of dark interstellar clouds, ranging from the negative hydrogen ion to dust grains, have already been proposed as their potential carriers. Currently, the most often presented hypotheses connect these puzzling spectral structures with different kinds of complex interstellar molecules, most likely carbon-bearing species (for a review see Fulara & Krełowski 2000). This may allow to interpret their observed variety of appearance and their ubiquity in the interstellar spectra.

Generally, polar molecules based on carbon skeletons are considered as likely carriers of diffuse bands. Their emissions resulting from rotational transitions have already been observed using radio-astronomical techniques. However, their laboratory, gas-phase spectra, obtained with the so-called Cavity Ring Down (CRD) method, do not match any of the known DIBs (Motylewski et al. 2000). Nevertheless, observed DIB profiles, compared to laboratory ones of molecular features (e.g. NC_4N^+) suggest that many of them can be carried by such molecules, although unidentified yet (Schulz, King & Glinski 2000). It is, nevertheless, interesting that the species creating the strongest, microwave emission lines observed in the interstellar medium, are apparently not those that carry diffuse bands. Perhaps some of the latter originate in certain molecules that, despite their high abundances, do not cause microwave emissions?

Species without a dipole moment are thus very attractive candidates; they cannot be observed using the radio-astronomical techniques as a result of the lack of rotational transitions. Bare carbon chains were proposed as DIB carriers many years ago (Douglas 1977) but until very recently even the spectra of very short chains have not been known from laboratory gas-phase experiments. The recent observational determinations of the abundances of C_3, C_4 and C_5 species (Galazutdinov et al. 2002; Maier, Walker & Bohlender 2002) lead to the conclusion that one can hardly expect high enough abundances of longer chains: possible candidates to be the DIB carriers. Another molecules without dipole moment, polycyclic aromatic hydrocarbons (PAHs) can also very likely be the species in which DIBs do originate (Van der Zwet & Allamandola 1985; Léger & d 'Hendecourt 1985) but the existing comparisons between observational data and the spectra obtained in gas-phase experiments have not led to very optimistic conclusions (Salama et al. 1999).

As indicated many years ago (Krełowski & Westerlund 1988), intensity ratios of different DIBs may seriously differ from cloud to cloud. It is to be emphasized that only if carriers of any two interstellar spectral features react in the same way to variations of physical parameters, their intensities may behave in unison. If some molecule (DIB carrier) has, for example, two transitions corresponding to two bands, then their intensity ratio may not be constant in different environments. Each transition reacts to ambient physical parameters in its own way and thus we cannot expect constant ratio of features revealing different transitions even of the same carrier along different lines of sight. This makes the task of DIB identification even more difficult. Nevertheless, one can expect some pairs of interstellar spectral features correlating to a very high degree: their observations may shed some light on the formation of DIBs.

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A search for such pairs requires a statistically meaningful sample of reddened targets. The sample should include heavily reddened objects as the general correlation of all interstellar features with the reddening allows to extend the range of observed intensities of all features under consideration. The recently collected data base of echelle spectra of bright, reddened stars (using the echelle spectra acquired with the aid of the 2-m telescope of the Terskol Observatory in Norhtern Caucasus) allows to search for such correlations. The existing sample of observed objects allows to select a statistically meaningful set of spectra in which different interstellar features, identified and unidentified, are observed.

As already suggested by Krełowski et al. (1992), the intensities of other spectral features of interstellar origin (atomic and molecular ones) are very likely to change in unison with at least some of the DIBs. This fact may facilitate a determination of physical conditions, which make possible the formation of the DIB carriers.

This paper presents an analysis of mutual relations between interstellar atomic lines and selected DIBs. The latter remain unidentified but we believe that a determination of their relations to well-identified spectral lines may shed some light on the conditions that facilitate formation or preservation of diffuse band carriers and will allow to suggest to laboratory groups to measure some of the possible parameters that may characterize conceivable potential DIB carriers.

2 THE OBSERVATIONAL DATA

We used spectra with a resolution $R \equiv \lambda/\Delta\lambda$ of 45 000 acquired with the aid of the coudé echelle spectrometer (Musaev et al. 1999) fed by the 2-m telescope of the observatory on top of the peak Terskol (Northern Caucasus) to determine equivalent widths (EWs) of four DIBs (5780, 5797, 5850 and 6614) and two strong interstellar atomic lines (Ca II K line at 3933 Å and K I line at 7698 Å). The selected objects are sufficiently bright to allow recording of high S/N spectra.

The applied echelle spectrometer allows to cover in one exposure the range ~3500 to ~10 100 Å, divided into 92 orders, with the resolution $R = 45\,000$. The achieved resolution allows precise measurements of wavelengths and intensities of interstellar features. We applied a CCD camera, manufactured by Wright Instruments (UK) and equipped with 1242 × 1152 matrix (pixel size 22.5 μm × 22.5 μm), which allows to record the whole above mentioned range in one exposure.

The spectral range, covered in every exposure, contains in all cases the interstellar K (Ca II) line (near 3933 Å) as well as the feature (near 7698 Å) of neutral potassium (K I), which, as demonstrated by Galazutdinov & Galazutdinova (2004), shares the radial velocity with several diffuse bands in contrast to, for example, the Ca II K line. The above mentioned paper raised the problem of spatial correlations between carriers of different interstellar features. If the identified ones are supposed to facilitate deciphering the physical conditions that lead to the formation of the unidentified ones, we at least should be convinced that features of both kinds occupy the same places in the interstellar medium.

Our reduction of the echelle spectra was made using the DECH code (Galazutdinov 1992). This program allows to perform all standard procedures of CCD spectra processing and analysing. For wavelength calibration, we used either the solar spectrum or the spectrum of Procyon, which provided at least 15–20 points in each spectral order. The laboratory wavelengths are taken from the tables of solar spectra (Pierce & Breckinridge 1973). The wavelength scale was constructed on the basis of a global polynomial of the form, described in detail in the paper of Galazutdinov et al. (2000). The final solution uses typically 1500 lines and the rms residual error between the fit and the position of the lines is usually ⩽0.003 Å.

We have also added some additional objects observed using other instruments (McDonald Observatory echelle spectrograph, higher resolution Terskol spectra), which demonstrate good agreement between EWs of the same lines measured in spectra from different instruments.

3 RESULTS

The measurements of the EWs of the atomic lines are reasonably straightforward. Selecting the objects we restricted our sample to the targets where, at least while using the resolution of $R = 45\,000$, one can hardly find any Doppler splitting in these narrow atomic features. In such cases, the only source of errors is the uncertain continuum level from both sides of a line. This may alter the measured EWs but this error is relatively small as the lines of Ca II and K I are typically quite strong and deep and always very narrow. The high depth facilitates also the determination of the integration borders as the profile sides are very steep in such cases. In the lack of Doppler splitting, the profiles of atomic interstellar lines are simply single Gaussians and thus their EWs can be measured by means of fitting Gauss curves to their profiles. The measurements were performed in all cases using both techniques: direct integration and Gaussian fit. In all considered cases, both measurements coincide within the estimated errors. We have not measured EWs of sodium D doublet as the latter are usually saturated and thus only the column density, calculated using quite uncertain methods, could be used to correlate the strengths of these features with those of the DIBs.

Measurements of DIB EWs are more difficult. Their intrinsic profiles are usually not just simple Gaussians. Thus a precise determination of a DIB profile, before performing final measurements of its EWs, is necessary. Any method of determining DIB integration limits suffers some uncertainties. Moreover, these spectral features are often blended with some other neighbouring ones (Herbig 1975). An attempt to separate any two blended features may be successful if their profiles widths differ considerably. However, one cannot exclude the possibility that some DIBs of similar widths and depths are blended as well.

We have selected four strong DIBs for this investigation: 5780, 5797, 5850 and 6614. Out of the set of strong unidentified interstellar features, the 6196 DIB was not selected as it correlates perfectly with 6614 (Moutou et al. 1999) and the conclusions inferred for the latter hold also for the former. The next 6203 DIB is blended with both 6177 and 6205 broad DIBs, which makes its EW uncertain anyway. The 6270 feature is very likely contaminated with two neighbour stellar lines, while the strong 6284 DIB is situated close to the band head of the telluric O_2 feature. Also the profile of 6993 DIB is contaminated with telluric lines and can be separated from the contaminations only in very high resolution spectra.

The 5780 diffuse band is always observed on the background of the much broader 5778 feature (Herbig 1975). Because of the difference of widths the separation of the two features is relatively easy (Fig. 1). The intrinsic profile of the DIB slightly differs from a single Gaussian (Westerlund & Krełowski 1989). As it is rather broad, we should not expect any detectable Doppler splitting in the objects belonging to our sample, i.e. where such splitting is not detectable in much narrower profiles of atomic lines. Some errors may come from the choice of considering the continuum as a straight line above the feature; in fact, the continuum can be a bit curvilinear, which may cause our measured values to be a bit exaggerated. However, the shape of the above mentioned curve remains unknown;

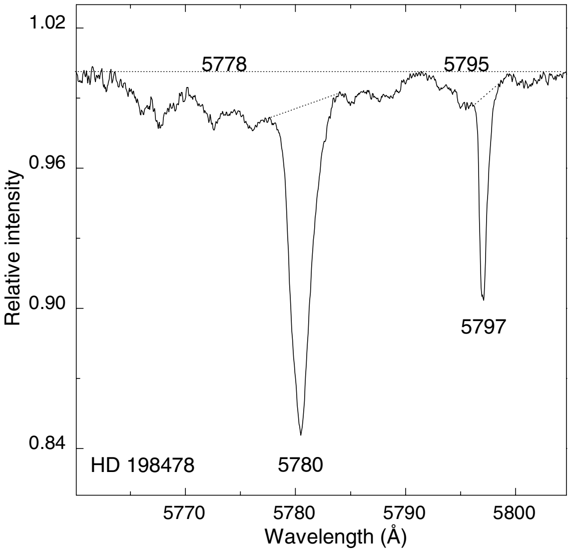

Figure 1. The first discovered DIBs 5780 and 5797 superimposed on the background of broader features centered around 5778 and 5795, respectively. The segments of straight lines represent the continuum used for measurements.

also we attempted at setting the continuum in the same way for every object. Other errors may result from the possible presence of weak DIBs (clearly present inside the 5778 profile) also inside the 5780 DIB. A separation of such contaminations seems not to be possible.

The well-known 5797 DIB is usually observed on the background of the much broader 5795 DIB, being apparently of different origin (Krełowski, Schmidt & Snow 1997). Also in this case the separation of both features may be difficult. A recent paper by Thorburn et al. (2003) presents the measurements of either 5797 alone or a blend 5795/5797 together (Fig. 2). Generally speaking a possible impact of neighbouring stellar and/or interstellar lines should be carefully taken into account while measuring DIB EWs. For example, the DIB EWs given by Sonnentrucker et al. (1997) differ in many cases by a factor of 2 or more from our measurements based on averages from different data sources. Such a difference (non-systematic!) must not follow simply measurement inaccuracies; it must be caused by uncertain integration limits and continuum levels. In this project we have consequently restricted our measurements to the 5797 DIB only, as done also, for example, in the paper by Herbig (1993). Our EWs perfectly correlate with the latter. The continuum level above the feature was set as a straight line, which in fact may lead to small errors, especially while the 5795 DIB is strong. However, the choice of a curve as a bottom of the latter must be considered as uncertain and thus we consequently apply a straight line segment. Measurements of the 5797 EW may be difficult in spectra of O stars, especially rapidly rotating ones, as the C IV 5801-Å line blends in such cases with the DIB. The uncertainties caused by this effect are difficult to estimate properly.

The 5850 DIB is situated at the edge of a much broader 5844 DIB (Krełowski et al. 1997). Fig. 3 demonstrates the shape of profile that has been used to measure the EW in every case. It is relatively easy to separate both features. However, the band is not as strong as any of the two described above and thus its measured EWs are more sensitive to the S/N ratio of the collected spectra.

The 6614 DIB is one of the strongest unidentified interstellar features. It is apparently not blended with any broader interstellar band. The above facts facilitate its precise EW measurements. However, the band profile is variable, as demonstrated by Galazutdinov et al. (2002) and thus it is not certain whether the profile is not a blend of two features of similar strength and width. In all cases, we have measured the EWs of the whole feature as demonstrated in Fig. 4; the differences, found by Galazutdinov et al. (2002) in very high

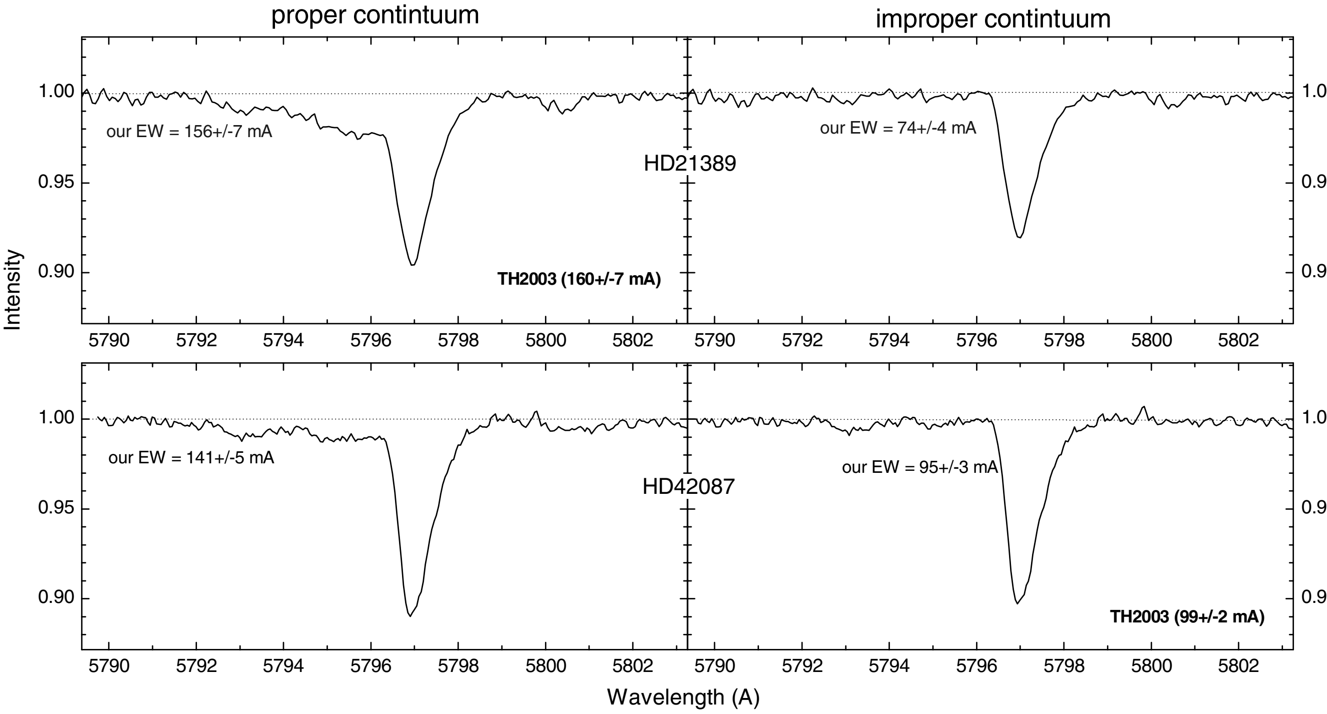

Figure 2. The uncertainties of DIB EW measurements originated in the lack of well-defined profiles in the recent measurements of Thorburn et al. (2003).

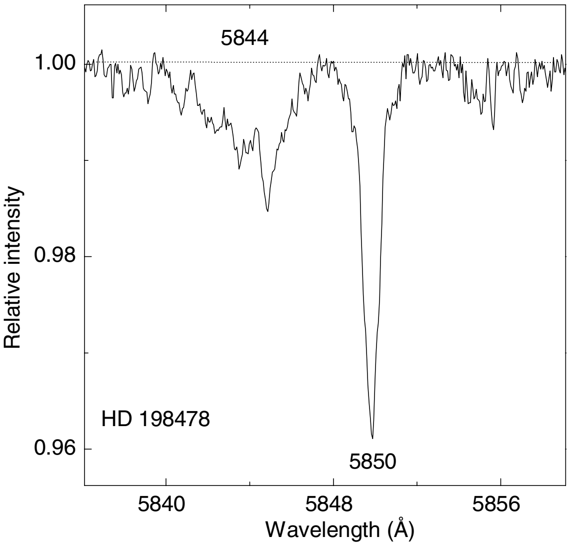

Figure 3. The profile of 5850 DIB used to measure its equivalent width (EW). The band seems to be completely separated from the broad, neighbouring 5844 one.

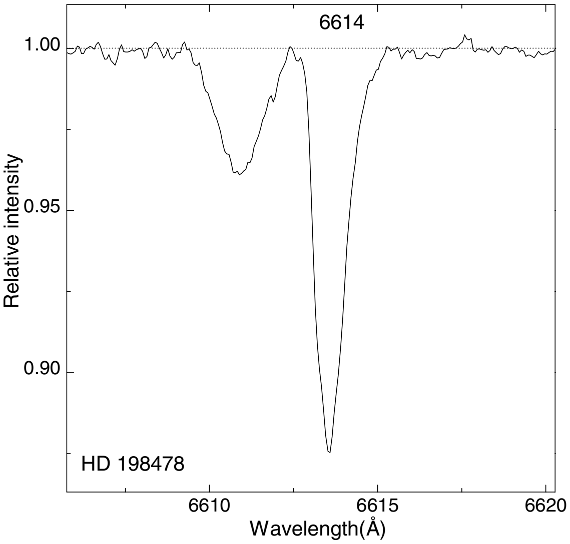

Figure 4. The applied profile of the 6614 strong DIB. The neighbouring stellar line may slightly lower the blue edge of the profile.

resolution spectra are not detectable in the applied $R = 45\,000$ resolution. The only source of possible errors is the stellar line from the blue side: in cases of rapid stellar rotation it may blend with the DIB, lowering its blue edge.

Measuring the selected DIBs, we have attempted to apply always the same profiles. This is of importance, especially while analysing spectra of heavily reddened (and thus faint) stars. They are likely to be of reasonably low S/N ratio, which may lead to some noise structures, contaminating the profiles. We have used the high S/N profiles, observed in nearby objects, to estimate the strengths of the DIBs in heavily reddened objects (Fig. 5). This can make the sample more uniform. However, if the profiles vary (physically) from object to object, the measurements may suffer some errors. The errors cannot, anyway, be estimated until high resolution spectra of the same targets are collected.

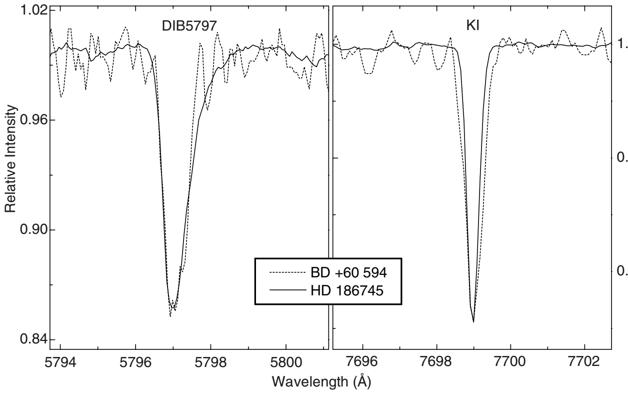

Figure 5. The interstellar features observed in two targets scaled to the same central depths. The K I line shows a small broadening towards BD +60 594, which may originate in the Doppler splitting. The EW of the 5797 DIB was measured in the rescaled spectrum of HD 186745 as the latter is of much better S/N ratio.

The results of our measurements are presented in Table 1. The listed errors have been evaluated solely on the basis of estimates of the S/N ratio, i.e. assuming a purely random noise in every spectrum. This is, however, only a conjecture: not a result of averaging several spectra from different sources. We have attempted thus to compare the same features in spectra taken with different instruments of different resolution. Fig. 6 compares the major DIBs: 5780 in the spectrum of HD 210839 and 5797 in the spectrum of HD 207198. Two resolutions are applied: in the case of 5780 the spectra are from the Canada–France–Hawaii Telescope (CFHT), equipped with the $R = 120\,000$ Gecko spectrometer and from the McDonald Observatory ($R = 60\,000$ Sandiford echelle); in the case of 5797 we compare the $R = 120\,000$ Terskol spectrum with that from McDonald. The differences between measurements evidently exceed the formally calculated errors. However, there is no doubt that the spectra from different instruments really coincide.

The multiple measurements are, however, restricted only to several bright stars. Generally they reasonably agree with those done using $R = 45\,000$, which supports the reliability of our conclusions, which are presented below. The comparisons seem to indicate that EWs of broad DIBs (like 5780 or 6284) can hardly be expected to coincide within less than 10 per cent if the data from different sources are compared. EWs of more narrow features, such as 5797 for example, may coincide inside approximately 5 per cent. Larger discrepancies may very likely indicate some systematic errors.

4 DISCUSSION

In order to make sure that our measurements of the K I EWs are correct, we have compared our values to those of Welty & Hobbs (2001) obtained in very high resolution spectra. Only a few targets are, however, common in both samples. The comparison is given in Fig. 7. Both sets of values correlate very tightly: the correlation coefficient exceeds 0.99. We have not been able to resolve some Doppler splitting in the observed profiles but the total EWs are apparently almost identical regardless of the resolution applied.

We attempted to find correlations between the EWs of the selected DIBs and of the considered atomic lines. Galazutdinov & Galazutdinova (2004) recalled the old result of Evans (1941) that the K line of Ca II seems to correlate reasonably well with distance to the observed stars. This result does not hold for the K I 7698 Å line.

Table 1. The equivalent width (EW) of two interstellar atomic lines and four diffuse bands as measured in the spectra of 35 reddened stars. The source of spectral type and photometric data is given in parentheses for each object.

Star	Sp/L	E(B−V)	K I	Ca II(K)	5797	5780	6614	5850
BD+60°594	O9V (Johnson & Hiltner 1956)	0.62	279	395	98	285	166	56
BD+40°4220	O7e (Hiltner & Johnson 1956)	1.97	266	121	190	725	276.5	90.5
BD+40°4227	O6e (Hiltner & Johnson 1956)	1.56	276	355	180	733.5	311.5	77
HD 15785	B1Iab (Morgan, Code & Whitford 1955)	0.76	203	510	162.5	374	222.5	58
HD 22951	B0.5 V (Murphy 1969)	0.22	51	112	35.2	99	40	22.5
HD 23060	B2Vp (Hiltner 1956)	0.32	80	92.5	35	156	88.5	19
HD 23180	B1 III (Johnson & Morgan 1953)	0.29	101.5	79.5	63	76	52.5	37.5
HD 23625	B2.5V (Crawford, Barnes & Golson 1971)	0.27	61.3	66	49	113.5	60	25
HD 24398	B1 Iab (Papaj, Krełowski & Wegner 1993)	0.34	75.5	57.5	58	94	58.5	20.5
HD 24534	O9.5pe (Lesh 1968)	0.56	117.6	139	58.6	84.1	53.5	29.5
HD 24912	O7.5Iab: (Conti & Leep 1974)	0.31	63.5	114	36	200	77.5	29
HD 40111	B1Ib (Lesh 1968)	0.12	23.7	162	25.7	136.7	36	11.5
HD 143275	B0.5IV (Hiltner, Garrison & Schild 1969)	0.13	31	34.5	13	74	25.5	7.5
HD 144217	B0.5V (Lesh 1968)	0.17	18.4	38	18.6	148.5	44.5	9.5
HD 148184	B2IVe (Buscombe 1969)	0.49	72	80	46.5	99	56	30
HD 149757	O9.5V (Morgan et al. 1955)	0.29	67.6	50	30.5	66.4	40.5	15.7
HD 164353	B5Ib (Murphy 1969)	0.14	38.7	112	28.5	98.7	47.5	10
HD 179406	B3V (Lesh 1968)	0.31	115.6	112	75.5	153.5	98	36
HD 184915	B0.5III (Buscombe 1969)	0.19	35.5	175.5	19.5	147.5	72	8
HD 186745	B8Ia (Morgan, Whitford & Code 1953)	0.96	253	166	222	465	288.5	93
HD 194279	B2Ia (Walborn 1971)	1.18	288	205	131	460	174	64
HD 195592	O9.5Ia (Morgan et al. 1955)	1.10	265	283	145	421	153.5	50
HD 203064	O8V (Conti & Leep 1974)	0.25	69.6	221	48.2	170	65	18
HD 203374	B0IVpe (Morgan et al. 1953)	0.56	150	274.5	71	144	79	20
HD 203938	B0.5IV (Hiltner 1956)	0.66	157.5	163	117	320	131	47
HD 204827	B0V (Morgan et al. 1953)	1.06	313	236	168	227	161.5	96.5
HD 206267	O6 (Conti & Leep 1974)	0.49	201	237	90	2232	117	45
HD 207198	O9Iab (Conti & Leep 1974)	0.56	249	259.5	140	237.5	119	71.5
HD 207538	B0V (Morgan et al. 1953)	0.59	222.5	226	156.5	227	159	67
HD 209481	O9V (Morgan et al. 1953)	0.35	77.5	272.5	57.5	148.5	85	21
HD 209975	O9.5Ib (Morgan & Roman 1950)	0.35	100	244	64.7	244.5	114	26.5
HD 210839	O6e (Conti & Leep 1974)	0.55	148	240	71	253	147	61
HD 213087	B0.5Ib (Morgan et al. 1955)	0.57	153.5	269	87	300	133.5	23
HD 217086	O7n (Garrison R. F., 1970)	0.92	258.5	279	154	532	215	51.5
HD 226868	B0Ib (Morgan et al. 1955)	1.03	265.5	392.5	148.5	392	155	58

Thus, very likely both lines are not formed in the same clouds. An analysis of correlations between both lines and DIBs may allow to infer a definite conclusion concerning the spatial correlation between DIB carriers and any of the two elements. The resulting correlation that we looked for, between the measured intensities of the selected DIBs and of those of two atomic lines $\lambda = 3933$ Å, the so called K line of Ca II and $\lambda \sim 7698$ Å of K I, is shown in Fig. 8.

Fig. 8 demonstrates the tight correlations of the selected DIBs with K I and the very poor with Ca II lines: this strongly suggests that the carriers of DIBs are closely spatially correlated with neutral potassium, i.e. situated in localized, probably relatively dense regions, while the ionized calcium is more evenly distributed in the interstellar medium. However, different DIBs do correlate with the K I line to a higher or lower degree.

Two out of the four DIBs, 5797 and 5850, apparently correlate very well with K I EWs. The correlation coefficient reaches 0.92 and 0.89 respectively, which must be considered as an exceptionally high value among possible pairs of interstellar lines or bands (Moutou et al. 1999). The observed scatter may easily follow uncertainties of measurements. It is, however, to be mentioned that towards one object, HD 186745, the measured strengths of both bands are extra high; the same effect, though weaker, can be seen in the case of 6614 but evidently not of 5780. This is not a result of measurement errors. The Terskol spectrum of HD 186745 is of high quality; moreover, we could compare the 5797 DIB also in the spectrum recorded by one of us (JK) using CFHT equipped with the Gecko spectrograph. The results coincide within 1 per cent of their value. In contrast, only low level correlations are observed between DIBs and ionized calcium lines.

The 6614 DIB is apparently not as tightly correlated with the EW(K I) as the two former DIBs. This must follow a different structure of its carrier. The conclusions concerning the 6614 DIB must be true also for the much narrower 6196 feature as they are mutually very well correlated. The 6614 DIB shows the best correlation with the Ca II K line strength. This may be of importance as the Ca II interstellar lines are correlated with distances to the observed stars (Galazutdinov & Galazutdinova 2004), which may be interpreted in terms of relatively homogeneous distribution of ionized calcium in the interstellar space. The same conclusion can be true to a certain extent in the case of the 6614 carrier. It is also to be emphasized that several heavily reddened objects show an unusual strength in

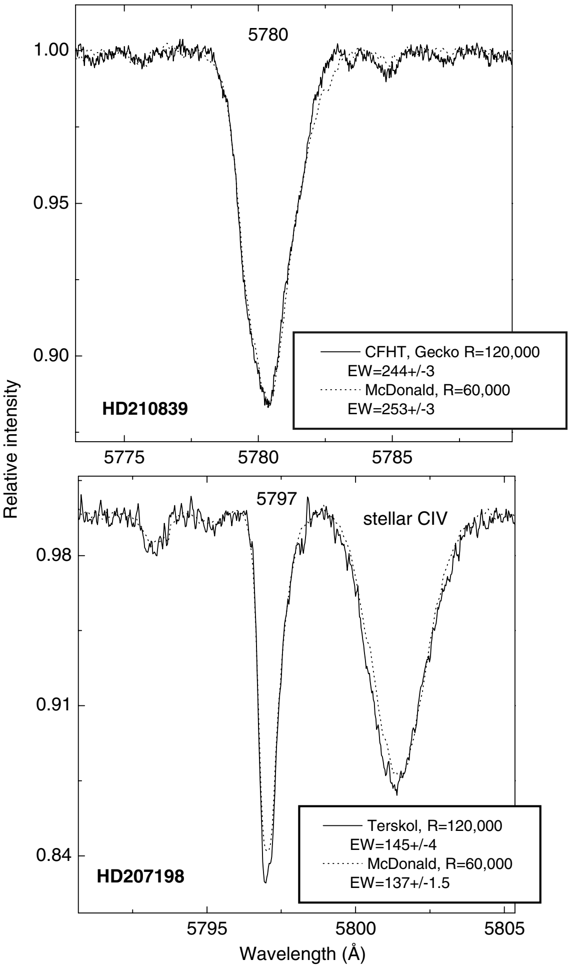

Figure 6. Profiles of diffuse interstellar bands (DIBs) obtained using different instruments compared together with their measured equivalent widths (EWs).

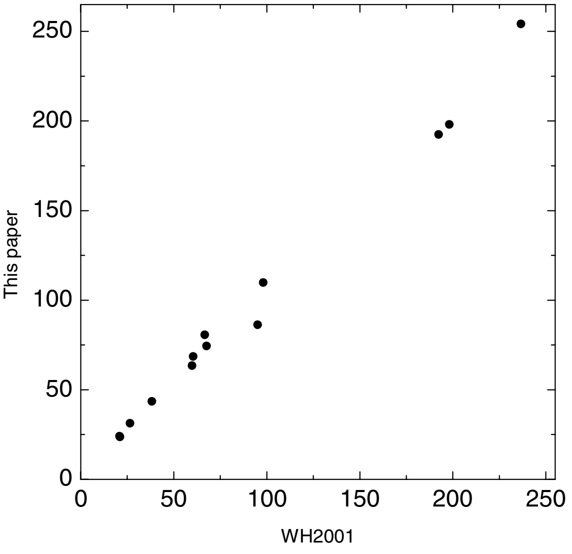

Figure 7. A relation between EWs measured in our spectra and those of Welty & Hobbs (2001).

comparison to that of K I. Among them are the two special targets (BD +40 4220 and BD +40 4227, see below): a fact that may suggest an important role of irradiation and/or ionization while the carrier of 6614 (and probably 6196) is formed.

The 5780 DIB is poorly correlated with K I, which in fact seems to be in agreement with the heavily variable ratio of 5780/5797 DIBs (Krełowski & Westerlund 1988). The DIB is exceptionally strong in cases of the so-called σ-type objects (Krełowski & Sneden 1995), where the K I line is usually quite weak. Perhaps the carrier of the 5780 DIB is an ionized molecule and thus the feature becomes strong in UV irradiated environments where potassium is ionized and its lines weak (Fig. 9). The band does not seem to be related to the Ca II features and thus we should expect its carrier to be localized in heavily irradiated but rather compact clouds: most likely inside the newly born OB stellar associations, like Sco OB2 where the archetype of the σ-type cloud (in front of σ Sco) is observed. This could be supported by the special case of the two discrepant objects in Fig. 8. The extra-strong 5780 is observed towards two stars: BD +40 4220 and BD +40 4227. Both objects clearly belong to the same association: they are also very hot and bright objects, which may lead to a very strong irradiation of the intervening clouds, providing they belong to the same association, which is very likely.

In the case of DIBs that show a strong correlation with the K I line, it is conceivable that their carriers may be relatively easily destroyed by not very energetic photons. It looks like a necessary condition that the unidentified carriers of such DIBs could be formed and/or preserved in the same environment, which facilitates the presence of neutral potassium. Assuming that the resonance line at 7698 Å of K I is not detectable only when potassium is ionized by the UV field that penetrates the region, the observed correlation with some DIBs might be a result of the rather close vicinity of some relevant energy values of the DIB carriers with the ionization potential of potassium. To be more specific, we can imagine that the correlation among certain DIBs and the observed K I line means that the carriers of the spectral features are destroyed in a similar way by the same UV field. This may mean that the 5797 DIB carrier has an ionization potential close to 4.341 eV, so that it can be ionized in a similar way as K I is, or that the carrier has the strength of at least one of its bonds close to the same K I ionization potential value, so that it can be dissociated or that a group can be detached by the UV field. Another possibility, if the carrier of the well correlated DIBs is a negatively charged ion, is that the neutral species has an electron affinity close to the K I ionization potential. In such a case, the same UV field can ionize potassium and detach the electron from the negatively charged ion, which is the DIB carrier, at a similar rate.

Our results are consistent with the fact that the vast interstellar space may be quite uniformly filled with the ionized calcium (as can be deduced by the correlation of the strength of its lines with the distance of the illuminating star), while the interstellar molecules, as well as for example neutral potassium, populate instead very localized and rather denser clouds. The above conclusion is illustrated in Fig. 10 where we demonstrate that the Ca II K interstellar line may contain strong Doppler components being not related to any similar structures in other atomic lines (K I or Na I), molecular lines (CH 4300 Å) or two selected DIBs. The conclusion is hard to infer in the case of broad DIBs, like 5780, because of their intrinsic width. This DIB, as well as 6284 and perhaps 6614, may be caused by, for example, ionized molecules, which require some UV irradiation to become the carriers. They may become relatively strong in clouds

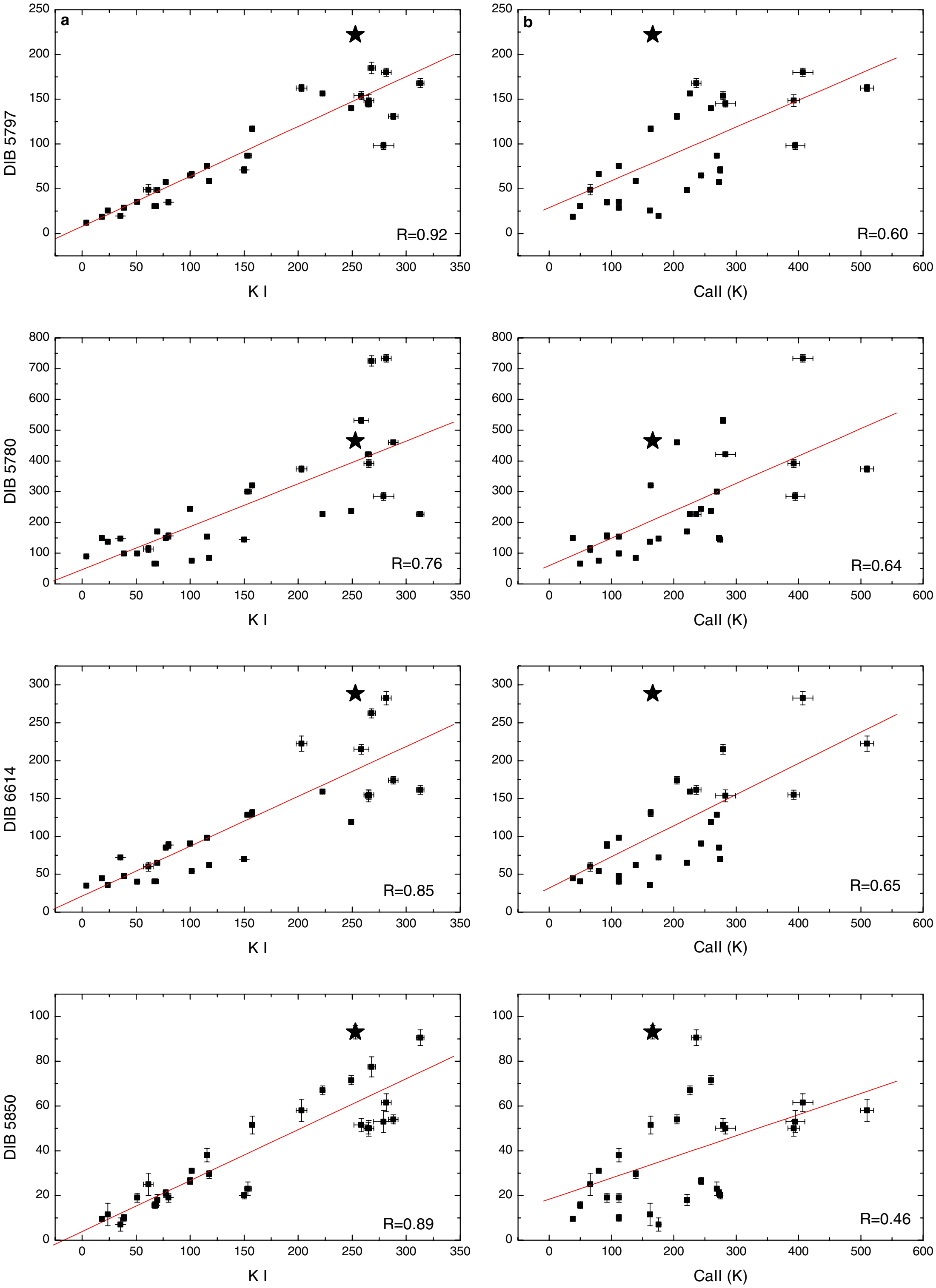

Figure 8. The correlations (correlation coefficients *R* are given in the left bottom part of each panel) between the two selected atomic lines of neutral potassium and ionized calcium and the selected DIBs. K I correlates very tightly with 5797 and 5850, while the correlation with 6614 and 5780 is much worse. Ca II does not correlate well with any of the DIBs. Star symbol denotes HD 186745.

situated in vicinity of hot, luminous stars (Fig. 9). It is, however, very difficult to infer this conclusion based on a statistically meaningful sample, as towards distant objects one must take into account the general growth of the Ca II line intensity with distance.

5 CONCLUSIONS

We have looked for the existence of possible correlations between the measured intensities of the selected DIBs and of those of two

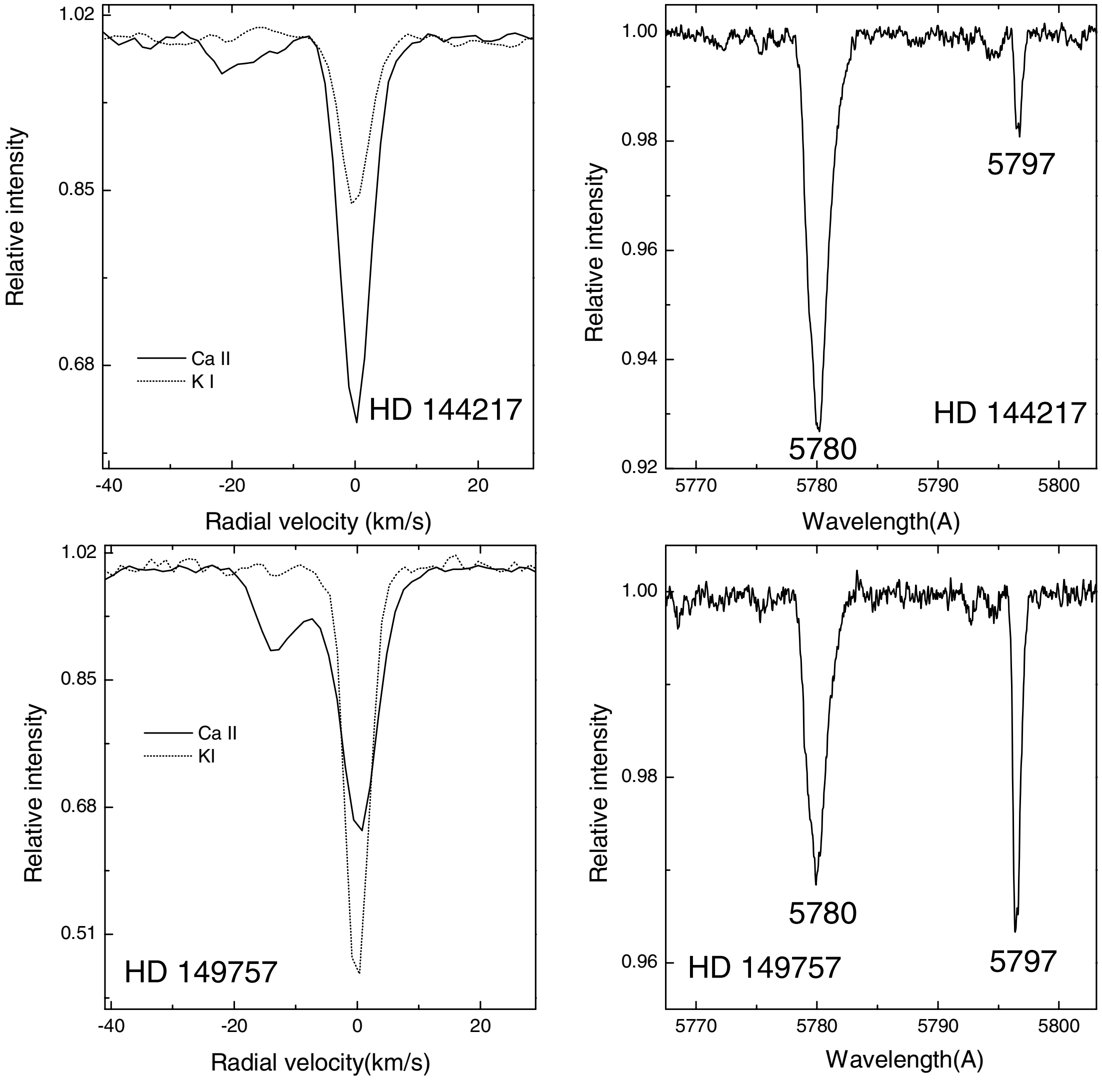

Figure 9. The ratios of atomic lines and DIBs varying in unison. HD 144217 is evidently of σ type, while HD 149757 is the archetype of the ζ one. Both objects belong to the same, nearby Sco OB2 association and thus the interstellar features very likely originate inside it.

atomic lines, $\lambda = 3933$ Å, the so called **K** line of Ca II, and $\lambda \sim 7698$ Å of K I. Correlation of certain DIBs with K I lines allowed us to deduce both the spatial correlation of their carriers and to a certain extent to obtain possible suggestions on some of the energies that are responsible for the existence and excitation of the carriers. On the basis of such deductions, we suggest to laboratory groups, whose work will be invaluable for the final goal of identifying the carriers of diffuse bands, to look for species that may have either the ionization potential or strength of one or more bonds or the electron affinity close to the value of the ionization potential of neutral potassium.

The general picture of the interstellar medium gets more complicated, which can make the troubles one meets while trying to create a self-consistent model of it at least understandable. Interstellar clouds are apparently not just compact and homogeneous objects. They consist likely of dense cores, which host most of interstellar molecules and dust grains and vast halos, which reveal their existence through Ca II absorptions. Some of the carriers of the unidentified DIBs may, to a certain extent, populate such halos, but a vast majority is concentrated in cores. Seemingly exact measurements of the K I current wavelength may allow precise determinations of the rest wavelengths of diffuse bands. Ca II is ill-advised as a source of the radial velocities leading to the rest wavelengths of DIBs. It remains unanswered how far the cloud cores are homogeneous, but this problem seems to be currently out of reach.

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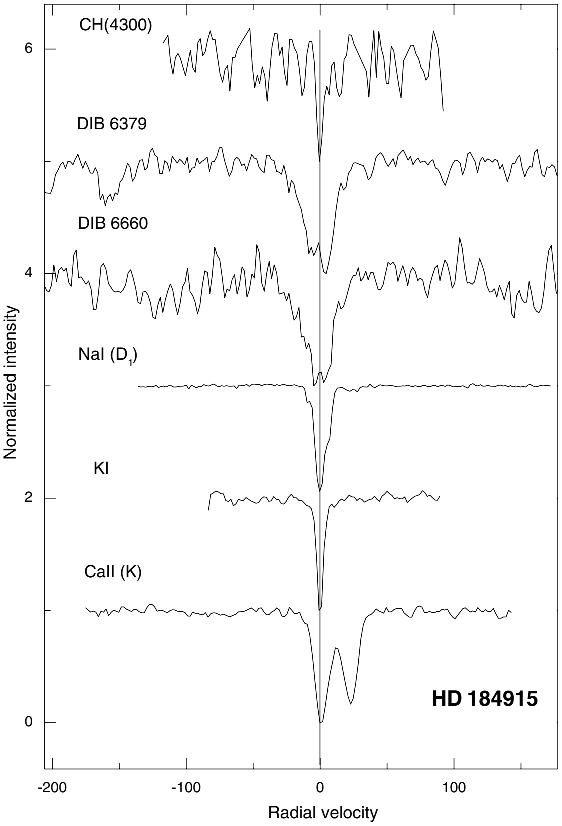

Figure 10. The example of the evident Doppler component of the Ca II K line not related to any similar structure in any other atomic or molecular line as well as DIB. All spectra have been shifted to the rest wavelength velocity frame using the K I line.

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REFERENCES

Buscombe W., 1969, MNRAS, 144, 31
Conti P. S., Leep E. M., 1974, ApJ, 193, 113
Crawford D. L., Barnes J. V., Golson J. C., 1971, AJ, 76, 1058
Douglas A. E., 1977, Nat, 269, 130
Evans J. W., 1941, ApJ, 93, 275
Fulara J., Krełowski J., 2000, New Astron. Rev., 44, 581
Galazutdinov G. A., 1992, Preprint Spets. Astrof. Obs., No. 92
Galazutdinov G. A., Galazutdinova O. A., 2004, ApJ(submitted)
Galazutdinov G. A., Krełowski J., Musaev F. A., Ehrenfreund P., Foing B. H., 2000, MNRAS, 317, 750
Galazutdinov G. A., Krełowski J., Musaev F. A., 2001, MNRAS, 377, 1063
Galazutdinov G. A., Pętlewski A., Musaev F., Moutou C., Curto G. Lo., Krełowski J., 2002, A&A, 395, 223
Garrison R. F., 1970, AJ, 75, 1001
Heger M. L., 1921, Lick Obs. Bull., 10, 146
Herbig G. H., 1975, ApJ, 196, 129
Herbig G. H., 1993, ApJ, 407, 142
Herbig G. H., 1995, ARA&A, 33, 19
Hiltner W. A., 1956, ApJS, 2, 389
Hiltner W. A., Johnson H. L., 1956, ApJ, 124, 367
Hiltner W. A., Garrison R. F., Schild R. E., 1969, ApJ, 157, 313
Johnson H. L., Hiltner W. A., 1956, ApJ, 123, 267
Johnson H. L., Morgan W. W., 1953, ApJ, 117, 313
Krełowski J., Sneden C., 1995, in Tielens A. G. G. M., Snow T. P., eds, Astrophysics and Space Science Library Vol. 202, The Diffuse Interstellar Bands, Kluwer Academic Publishers, Dordrecht, p. 13
Krełowski J., Westerlund B. E., 1988, A&A, 190, 339
Krełowski J., Snow T. P., Seab C. G., Papaj J., 1992, MNRAS, 258, 693
Krełowski J., Schmidt M. R., Snow T. P., 1997, PASP, 109, 1135
Léger A., d 'Hendecourt L. B., 1985, A&A, 146, 81
Lesh J. R., 1968, ApJS, 17, 371
Maier J. P., Walker G. A. H., Bohlender D. A., 2002, ApJ, 566, 332
Morgan W. W., Roman N. G., 1950, ApJ, 112, 362
Morgan W. W., Whitford A. E, Code A. D., 1953, ApJ, 118, 318
Morgan W. W., Code A. D., Whitford A. E, 1955, ApJS, 2, 41
Motylewski T. et al., 2000, ApJ, 531, 312
Moutou C., Krełowski J., d 'Hendecourt L., Jamroszczak J., 1999, A&A, 351, 680
Murphy R. E., 1969, AJ, 74, 1082
Musaev F. A., Galazutdinov G. A., Sergeev A. V., Karpov N. V., Podyachev Yu. V., 1999, Kinematika i Fizika Nebesnyh Tel, 15(3)
Papaj J., Krełowski J., Wegner W., 1993, A&A, 273, 575
Pierce A. K., Breckinridge J. B., 1973, KPNO preprint, 1063
Salama F., Galazutdinov G. A., Krełowski J., Allamandola L. J., Musaev F. A., 1999, ApJ, 526, 265
Schulz S. A., King J. E., Glinski R. J., 2000, MNRAS, 312, 769
Sonnentrucker P., Cami J., Ehrenfreund P., Foing B. H., 1997, A&A, 327, 1215
Thorburn J. A. et al., 2003, ApJ, 584, 339
Van der Zwet G. P., Allamandola L. J., 1985, ApJ, 146, 76
Walborn N. R., 1971, ApJS, 23, 257
Welty D. E., Hobbs L. M., 2001, ApJS, 133, 345
Westerlund B. E., Krełowski J., 1989, A&A, 218, 216