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On the relation between the carriers of diffuse interstellar bands and simple molecular species

G.A. Galazutdinov, [1] J. Krełowski, [2] F.A. Musaev [1] and I.F. Bikmaev, [3]
[1] *Special Astrophysical Observatory, Nizhnij Arkhyz 357147, Russia*
E-mail: gala@sao.ru
E-mail: faig@sao.ru
[2] *Institute of Astronomy, Nicholas Copernicus University, Chopina 12/18, Pl-87-100 Toruń, Poland*
E-mail: jacek@astri.uni.torun.pl
[3] *Kazan State University, Kazan 420023, Russia*
E-mail: bikmaev@astro.ksu.ras.ru

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ABSTRACT

The interstellar clouds composed mostly of neutral hydrogen (HI clouds) show evident differences in the pattern of interstellar absorptions: the shapes of the extinction curves, the strengths of the diffuse interstellar bands and in the intensities of the features originating in simple molecular species. It is well–known that the ratio of the two prominent diffuse bands (5780 and 5797) varies strongly from cloud to cloud; our data suggest that this phenomenon is related to the intensities of the absorption features of interstellar molecules such as CH^+ or CH. However, the intensity ratio of the diffuse bands can change gradually, suggesting a "smooth" variations of the carrier abundances, while the strength ratios of molecular features and the colour excesses change rather stepwise when the diffuse band ratio reach a certain value.

Key words: interstellar medium–extinction–molecules

1 INTRODUCTION

Since the observations of Beals (1936), it is commonly accepted that the interstellar medium is not homogeneous, but contains many separate clouds. Their presence was revealed by the Doppler components, observed in the high resolution profiles of strong interstellar absorption lines, such as NaI D_1 and D_2 or CaII H and K along the sightlines towards distant, reddened OB stars. The first extraatmospheric survey of the interstellar extinction curves in spectra of bright stars (Bless & Savage (1972)) revealed evident differences between the extinction properties of interstellar clouds. About a decade ago Krełowski & Walker (1987), Josafatsson & Snow (1987) and Krełowski & Westerlund (1988) demonstrated that the strength ratios of the diffuse interstellar bands (DIBs) may vary from cloud to cloud which the fact proves that the relative abundances of DIB carriers inside individual clouds may be quite different. The most striking example of this phenomenon is that of the two neighbour diffuse bands centered around 5780 and 5797 Å. The effect is seen especially well in the spectra of nearby stars, apparently observed through single, absorbing clouds – Krełowski & Westerlund (1988). Observing distant objects we naturally deal with some ill–defined averages over some unknown number of different individual clouds.

Recently it's been shown that the DIB intensity ratios vary from cloud to cloud together with the relative strengths (measured in relation to E_{B-V}) of spectral features of simple molecules, such as CN or CH – Krełowski & al. (1992). The molecules apparently exist only in certain types of interstellar clouds – Krełowski & Sneden (1995). However, the existing sample of the objects in which the molecular features have been observed is still very scarce which makes the conclusions quite uncertain.

It is a very basic problem to find out whether the interstellar clouds can be classified into only a few spectral types or can form a continuous sequence. The answer requires a numerous sample of spectra of nearby stars in which the Doppler splitting is not observed in the profiles of sodium or calcium lines. If the strength ratio of the prominent DIBs 5780 and 5797 varies inside such a sample we have to consider this as the effect of the differing conditions inside individual clouds. The present paper aims at finding an answer to the question: do the relative intensities of the features of simple molecular species grow monotonically together with the 5780/5797 ratio or they do change rather stepwise due to e.g. some phase transition?

The idea of relating the behaviour of the DIBs to the physical parameters of the surrounding environment is important nd one of the most promising ways to obtain information on the nature of the DIB carriers which are com-

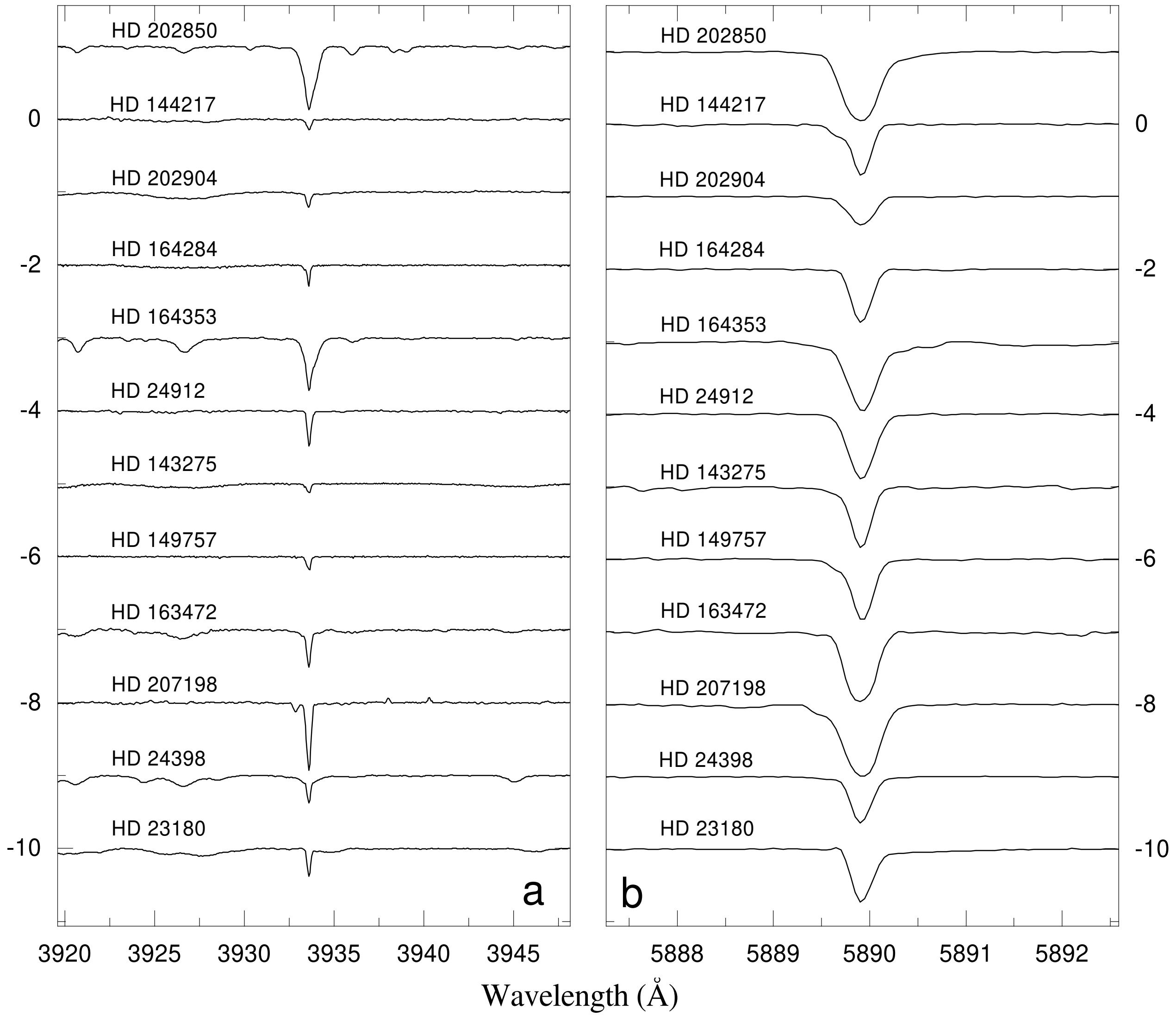

Figure 1. a. The profiles of the interstellar calcium K lines in the spectra of our program stars. **b.** The same as in the frame a, but for the interstellar sodium D_2 lines.

monly believed to be complex molecules. Molecular lines which do reflect some characteristics of the cloud are good tools to use.

2 THE OBSERVATIONAL RESULTS

2.1 The material

The observations have been conducted at the Russian Special Astrophysical Observatory, with the aid of the new coude echelle spectrometer fed with the SAO 1m telescope (Musaev (1993)). With the Wright Instruments CCD 1242x1152 matrix (pixel size 22.5μm x 22.5μm) the spectrometer covers in a single exposure the range ∼3500 Å – ∼9500 Å with the resolution R=40,000. Our observations concern mostly the bright stars which are most probably nearby objects, seen through individual clouds. We find the relatively small size telescope proper for this kind of project as the faint stars are most likely observed through several clouds. It is to be emphasized that such spectra contain all DIBs listed in the recent surveys of Jenniskens & Désert (1994) and Krełowski, Sneden & Hiltgen (1995) as well as atomic lines of CaI, CaII, NaI and KI and molecular features of CN, CH, CH^+ and C_2.

Our reduction of the echelle spectra was made using the DECH code (Galazutdinov (1992)). This program allows flatfield division, bias/background subtraction, one–dimensional spectrum extraction from the 2–dimensional images, correction for the diffuse light, spectrum addition, excision of cosmic ray features, etc. The DECH code also allows location of a fiducial continuum, measurements of the line equivalent widths, line positions and shifts, etc. The spectral range, covered in every exposure, contains strong and well–identified atomic interstellar lines. This allowed us to shift every spectrum to the rest wavelength standard for the observed clouds. The fact facilitates the detection of

Table 1. Basic stellar data

HD	Sp/L	V	B-V	E(B-V)
202904	B2 Vne	4.43	-0.11	0.13
24398	B1 Iab	2.93	+0.10	0.31
144217	B0.5 V	2.62	-0.07	0.17
164284	B2 Ve	4.64	-0.03	0.18
23180	B1 III	3.82	+0.06	0.26
149757	O9 V	2.60	-0.02	0.26
143275	B0.2 IV	2.30	-0.10	0.15
164353	B5 Ib	3.99	+0.02	0.06
24912	07 e	4.04	+0.01	0.29
202850	B9 Iab	4.23	+0.12	0.15
207198	09 IIe	5.95	+0.31	0.49
163472	B2 IV–V	5.82	0.09	0.30

weak or diffuse features, leaving no doubt where a possible, very weak feature should be situated in a spectrum.

The observational material is listed in Table 1. All the selected targets are bright and thus – nearby stars. Testing the possibilities of the spectrometer we found it especially useful for deriving profiles of very sharp lines such as atomic or molecular features. The sample contains objects characterized by very different strength ratios of the two prominent diffuse bands: 5780 and 5797 (see Fig. 2). It is of importance to search for a minimum number of easy–to–get spectral characteristics of interstellar clouds. We deliberately do not analyze here all possible DIBs – not all of them are easily accesible either due to their shalowness or to blending with another DIBs as well as due to stellar and telluric contaminations.

The profiles of the interstellar CaII K line are shown in Fig. 1a. This line seems to be much more sensitive to the varying conditions inside the interstellar clouds as its intensity, as well as the width, vary inside a much broader limit than e.g. the NaI lines. The good examples are the D_2 and K line profiles seen towards HD164353 and HD202850: these of the K line are much broader. We do not consider here the H line because of its blending with stellar lines which the fact always makes the profile determination difficult.

The profiles of the D_2 sodium line seen towards our targets are shown in Fig. 1b. As one can see the profiles are quite symmetrical, without evident Doppler splitting. They are, however, a bit broad which may be due either to some Doppler splitting, still not resolved in our spectrometer, or to a turbulence inside the intervening clouds. The papers of Hobbs (1974) and of Welty, Hobbs & Kulkarni (1994) present the very high resolution profiles of the sodium lines in several our targets: HD 144217, HD 143275, HD24398 and HD23180. In all of them it is difficult to find evident Doppler components.

2.2 The variable pattern of interstellar features

Fig.2 presents the range of the two major diffuse bands 5780 and 5797 Å observed in the spectra of our sample stars. The observed targets have been divided into three groups as indicated in the Table 2. The division is based on the apparently heavily variable strength ratio of the 5870 and 5797 bands as proposed by Krełowski & Sneden (1995). Two stars show the intermediate ratio of the two prominent DIBs. Let's emphasize that the high resolution profiles of the sodium lines towards one of them – HD 143275 – (Welty et al. (1994)) show almost no signs of the Doppler splitting and thus the intermediate ratio of the 5780/5797 DIBs is not the effect of mixing e.g. one "sigma" and one "zeta" cloud along this sightline.

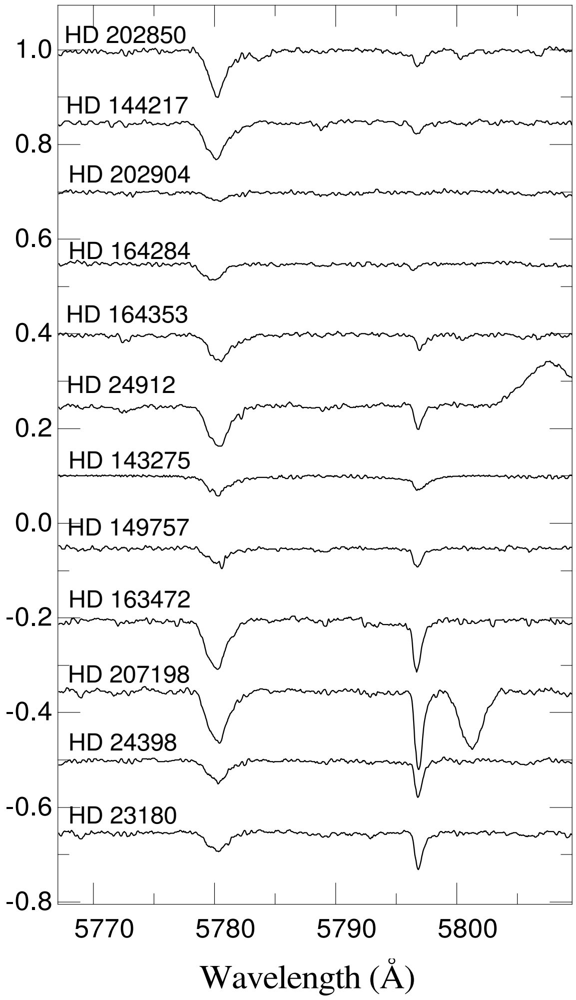

Figure 2. The diffuse interstellar bands observed in our program star spectra.

The moral coming from an analysis of the data depicted in Fig. 2 is clear: our sample contains a great variety of sightlines, intersecting very different environments. The latter are, however, most probably single interstellar clouds i.e. the object as homogeneous as possible. The observations of atomic and/or molecular features may facilitate the understanding of the physical conditions inside such clouds.

2.3 Atomic and molecular spectral features

We observe a gradual change of the DIB ratio inside our sample. This phenomenon can be interpreted as the effect of a gradual change of the physical properties of the absorbing matter inside interstellar clouds across the Sco OB2 association to which three of our targets (HD 144217, HD143275

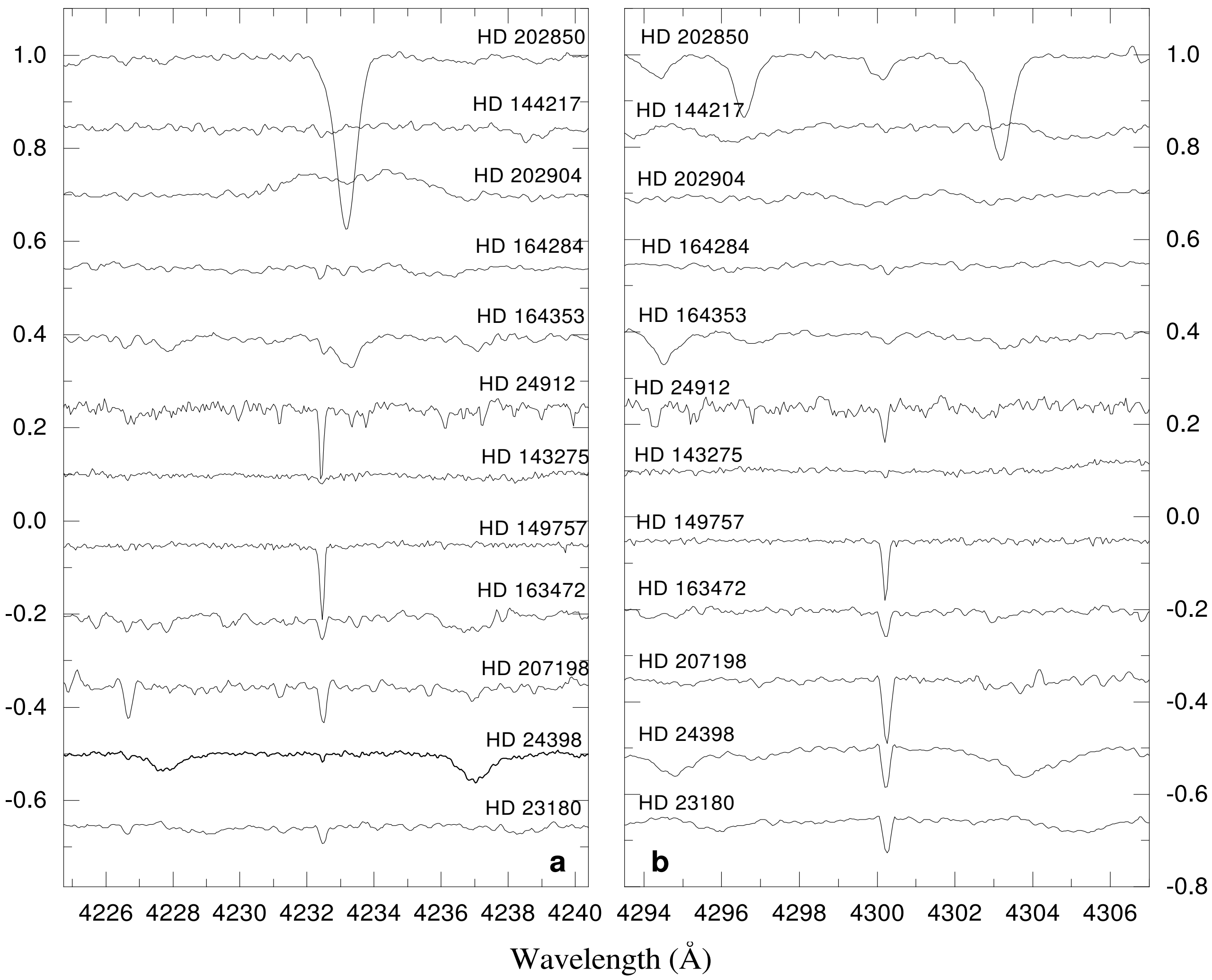

Figure 3. a. The molecular features of CH^+ observed in spectra of our program stars. The Ca I 4226 Å line is also detectable in several spectra. In the spectra of relatively cold stars HD 164353 and HD 202850 the molecular feature is blended with the stellar Fe II line. **b.** CH line observed in spectra of our targets. The emission type feature seen in HD 202904 is real. In the spectrum of HD 202850 CH feature is blended with the stellar Ti II line.

and HD149757) belong. The abundances of the DIB carriers apparently are very sensitive to e.g. their accretion onto grain surfaces, the irradiation of the clouds by nearby stars or some other phenomena.

The "zeta" type objects observed in Per OB2 association are known to have the spectra containing pretty strong lines of simple molecular species such as CN (Krełowski & al. (1992)). It is thus interesting to check the behaviour of molecular features in other similar targets and compare with another objects in which the DIB ratio suggests the "zeta" type cloud. If the "sigma" and "zeta" type objects always behave in the same fashion the conclusions of Krełowski & al. (1992), concerning the physical parameters of the interstellar clouds, can be considered as more general. It is a very interesting question whether the molecular spectrum changes rather gradually (as the 5780 and 5797 DIBs ratio) or stepwise (like the extinction curves) – see Krełowski & al. (1996).

The molecular features, observed in our targets, are shown in the Fig. 3. These features are typically very sharp. An inspection of the Figure proves that their intensities depend strongly on the observed ratio of the major DIBs. Apparently this ratio is a very powerful parameter, chracterizing the physical conditions inside HI clouds. Let's emphasize that this parameter can be found easily as neither 5780 nor 5797 are strongly contaminated with stellar or telluric lines.

3 DISCUSSION

Table 2 summarizes our measurements of the major DIB central depths as well as those of the features originating in simple molecular species. The lack of entries in this Table means that the respective features are below the level of detection.

The strengths of DIBs are apparently not as sensitive to physical conditions inside the interstellar clouds as those of the well–identified molecular features. A good illustration of this is the example of the two stars from the Sco

Table 2. Central depths (in %) of interstellar features. R – 5780/5797 strength ratio

HD	5780	5797	R	4232	4300
Sigma group					
202904	1.5	0.5	3.0	-	-
144217	9.0	3.0	3.0	2.5	2.0
164284	3.5	1.5	2.3	3.0	2.5
202850	10.0	2.5	4.0	-	-
164353	5.5	2.5	2.2	4.0	3.0
Intermediate group					
143275	3.0	2.0	1.5	2.0	1.5
24912	9.0	5.0	1.8	16.0	9.0
Zeta group					
149757	3.0	3.0	1.0	16.0	13.0
24398	5.0	8.0	0.6	2.0	8.5
23180	4.0	8.0	0.5	4.0	8.0
163472	10.0	10.0	1.0	5.5	6.0
207198	11.5	16.5	0.7	8.0	14.0

OB2 association: HD144217 and HD143275. They are close neighbours on the sphere and also their spectral types, luminosity classes apparent magnitudes and colour excesses are very similar. However, the strength ratio of 5780 and 5797 DIBs is twice as big in HD 144217 as in HD 143275. Both stars have been observed with the aid of the McDonald Observatory echelle spectrograph fed with the 2.1m telescope and the high resolution spectrograph at the CFH Telescope – the 5780/5797 ratio is the same in both cases. In both spectra the molecular features are barely detectable. On the other hand where the 5797 DIB becomes deeper than the broader neighbour 5780, the molecular features are always easily visible.

The varying ratios of the above listed features can be considered as related to some kind of evolution of the interstellar clouds, possibly caused by the irradiation of nearby, bright stars. It may be important that in most of our "zeta" targets the CH line is evidently stronger than that of CH^+, except in HD 149757, However, the latter star is apparently observed through two clouds (Savage (1992)). It is interesting that in the spectrum of another target: HD24912, which is also observed through two clouds (Crane, Lambert & Sheffer (1995)) the CH line is weaker than CH^+ as well as in HD 149757.

The uncertainty as to whether our targets are really obscured by only single clouds makes impossible a definite conclusion concerning the "Intermediate group" of Table 2. Most probably HD 143275 shines through a single, evolved cloud, but HD 24912 is seen through two different ones. This is probably why the molecular features in their spectra behave in completely different fashions. One can argue that HD 143275 is observed through a single cloud not only because of the shape of the interstellar atomic lines but also because it is the nearby object (one of the brightest reddened stars on the sky) and it seems very unlikely that two separate clouds can be seen along such a short sightline.

The main conclusion of the present paper is that the abundances of the diffuse band carriers apparently change much more gradually than those of the simple molecules. The DIB carriers can be abundant in both "sigma" and "zeta" type clouds – only their relative abundances are apparently different. The latter start changing earlier than those of simple molecular species. The growing 5797/5780 strength ratio does not result in an evident growth of the intensities of the molecular features until a certain point is reached. Perhaps the latter can be considered as a kind of a phase shift which takes place in the evolving interstellar clouds.

The major diffuse bands and the molecular features described above may be very useful as parameters of cloud evolution. It is much easier to measure them precisely than e.g. to determine reliably the extinction curve which depends strongly on the spectral classification and on proper choice of standard. It is certainly of importance to collect more spectra containig both DIBs and atomic/molecular features; they should allow to set the criteria of the spectral classification of interstellar clouds.

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REFERENCES

Beals C.S., 1936, MNRAS, 96, 661
Bless R.C., Savage, B.D., 1972, ApJ, 171, 293
Crane P., Lambert D.L., Sheffer Y., 1995, ApJS, 99, 107
Galazutdinov G.A., 1992, Preprint Spets. Astrof. Obs. Russian, No. 92
Hobbs L.M., 1974, ApJ, 191, 381
Josafatsson K., Snow T.P., 1987, ApJ, 319, 436
Jenniskens P., Désert F.-X., 1994, A&AS, 106, 39
Krełowski J., & Walker G.A.H., 1987, ApJ, 312, 860
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., Sneden C., Hiltgen, D., 1995, Planetary and Space Science, 43, 1195
Krełowski J., Sneden C., 1995, in Tielens A.G.G.M., Snow T.P., eds, The Diffuse Interstellar Bands, IAU Coll. 137, Kluwer, Dordrecht, p.13
Krełowski J., Megier A., Strobel A., 1996, ApJ, 308, 912
Musaev F.A., 1993, SovAL, 19, 776
Savage B.D., 1992, in Benvenuti P., Schreier E., eds, Science with the Hubble Space Telescope, ESO Conference and Workshop Proc. No. 44, p. 309
Welty D.E., Hobbs L.M., Kulkarni V.P., 1994, ApJ, 436, 152