ON THE BEHAVIOR OF INTERSTELLAR *CO* AND *CN* MOLECULES IN INDIVIDUAL CLOUDS

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ABSTRACT

We discuss the behaviour of the absorption spectral features originating in interstellar biatomic, carbon bearing, molecules situated inside HI clouds; especially these of the CN and CO. They are seemingly related to the same physical properties of interstellar clouds which facilitate the formation or preservation of the carriers of some (narrow) unidentified diffuse interstellar bands (DIBs) and which apparently lead to the far-UV raise of the interstellar extinction curve, typically attributed to the presence of small, dust particles, in the intervening interstellar clouds. All the above mentioned features form the absorption spectra of individual clouds – apparently dependent on the physical parameters of these clouds (Krełowski et al. 1992). The recent review (Krełowski & Sneden, 1995) proposed a spectral classification of HI clouds. We present an investigation of the CN radical, observed only in some special clouds (in the CFHT spectra) together with the vacuum-UV spectral features of the CO molecule, well seen in the Hubble Space Telescope high resolution spectra, as well as in very numerous IUE high resolution ones. The behaviour of the spectral features of both molecules is proved to be surprisingly similar and related to that of diffuse interstellar bands.

Key words: interstellar medium; extinction; molecules; diffuse interstellar bands.

1. INTRODUCTION

The interstellar neutral clouds (HI clouds) produce a number of absorptions altering the continua of the stars observed through them (extinction, polarization) as well as many discrete features originating in atomic gas and/or simple molecules. These are accompanied by the unidentified features: the diffuse interstellar bands (DIBs) – the longest standing unsolved problem in all of spectroscopy. The last surveys (Jenniskens & Désert 1995; Krełowski, Sneden & Hiltgen 1995) added to the above list an enormeous number of very weak interstellar features, unidentified and most probably related to the well-known DIBs. The absorption spectra of HI clouds are thus very rich, which the fact proves that the physical processes inside them are very complex. All the above mentioned components of the spectra vary together, most probably reflecting changes in physical parameters of the clouds (Krełowski, Snow, Seab & Papaj 1992). It has been suggested recently that HI clouds can be divided into several types of different spectra (Sneden, Woszczyk & Krełowski 1992; Krełowski & Sneden, 1995). It is important to arrange the observed interstellar clouds of different spectral characteristics, into an evolutionary sequence. It is necessary to analyze lines-of-sight obscured by only one cloud to avoid a confusion caused by ill-defined averages. Only the spectra of individual clouds can be physically interpreted.

Table 1. Basic stellar data for targed stars

HD	Sp/L	V	B-V	E(B-V)
10516	B2 Ve	4.07	-0.04	0.19
24912	O7 e	4.04	+0.01	0.29
143275	B0.2 IV	2.30	-0.10	0.15
144217	B0.5 V	2.62	-0.07	0.17
147165	B0 III	2.89	+0.13	0.34
164353	B5 Ib	3.99	+0.02	0.06
167264	B0 Ia	5.38	+0.07	0.32
184915	B0.5 III	4.95	0.00	0.22
2905	B1 Iae	4.16	+0.14	0.33
23180	B1 III	3.82	+0.06	0.26
24398	B1 Iab	2.93	+0.10	0.31
27778	B3 V	6.36	+0.17	0.35
53367	B0 IV	6.94	+0.43	0.74
149757	O9 V	2.60	-0.02	0.26
179406	B3 V	5.34	+0.13	0.31
198478	B3 Ia	4.84	+0.41	0.53
206165	B2 Ib	4.73	+0.30	0.46
210839	O6 If	5.04	+0.25	0.57

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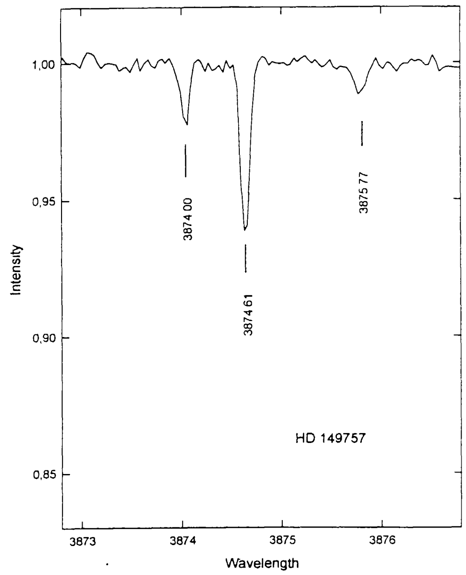

Figure 1. The CN molecule features in the spectrum of HD149757.

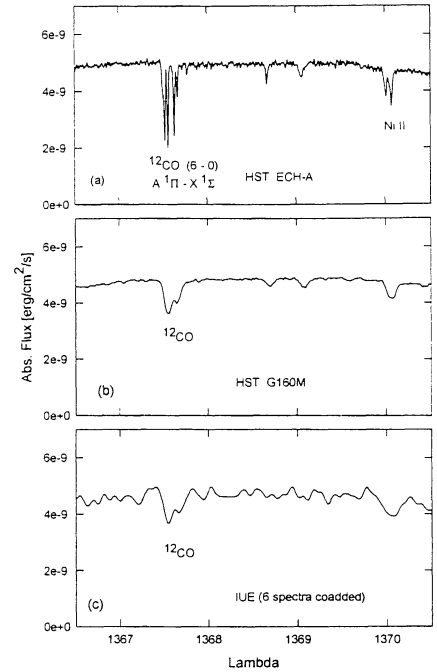

Figure 2. Interstellar $CO(6-0)$ band in the spectrum of HD149757. (a) high resolution (3.5 km/s) echelle spectrum from the HST $GHRS$, (b) middle resolution spectrum (G160M) from the HST $GHRS$, (c) high resolution SWP spectrum from the IUE.

The spectral range, available from the ground–based observatories, offers the possibility to observe the interstellar features of different origin: atomic lines, molecular features of CN, CH, CH^+, C_2, all possible DIBs and numerous weal interstellar features recently discovered.

The extraterrestrial ultraviolet, available from the orbiting observatories, allows to add to the above list several features of the two well–known molecules:

- the CO UV bands arising from the ground state $A^1\Pi - X^1\Sigma^+$,
- the H_2 molecule – the most abundant one, but difficult to be observed as its features are situated in far–UV range.

A lot of atomic resonant lines can be also observed from the orbit; their list is so long that we will not show it here. It is, however, interesting whether all the above mentioned features show the same Doppler structures inside their profiles along the same sightlines. Any observed difference can be very helpful in identifying the physical conditions inside individual clouds.

We attempt at finding a relation between the behaviour of the features originating in CO and CN molecules. The latter is a very interesting one: when discovered by Adams (1949) it was found only in 7 out of 300 observed spectra. In the paper of Krełowski et al. (1992) it's behaviour is demonstrated as strongly dependent on the shape of the interstellar extinction curve and the strength ratio of the major diffuse interstellar bands. Thus the CN features can be used as a classification criterion for the interstellar clouds. Possibly the CO molecule with it's rich far–UV spectrum can be used for the same purpose as the hard to measure in the existing spectra H_2 aggregate.

2. THE OBSERVATIONAL MATERIAL

The paper is based generally on the two sets of observed spectra. One of them have been acquired with the Canada–France–Hawaii Telescope (CFHT). The procedure for data acquisition and reduction using this system has already been described by Snow & Seab (1991). The spectra cover the yellow spectral range (5760–5905 Å) with a resolution of 40,000. In this range we observe two prominent diffuse bands near 5780 and 5797 Å as well as the weaker system of 5844/5850 Å described by Krełowski et al. (1993) and the two strong lines of the neutral sodium D_1 and D_2. Another spectral range covers the system of CN interstellar features: the lines at 3874.00, 3874.61 and 3875.77Å. The second line is the

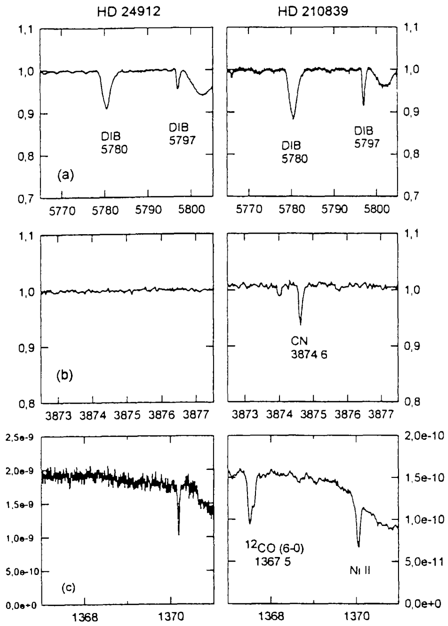

Figure 3. A comparison of the interstellar features in the spectra of HD 24912 ("sigma" type) and HD 210839 ("zeta" type); (a) the diffuse interstellar bands 5780 and 5797 Å, (b) the profiles of the CN 3874.6 Å, (c) the profiles of the CO $(6-0)$ *features in the HST spectra.*

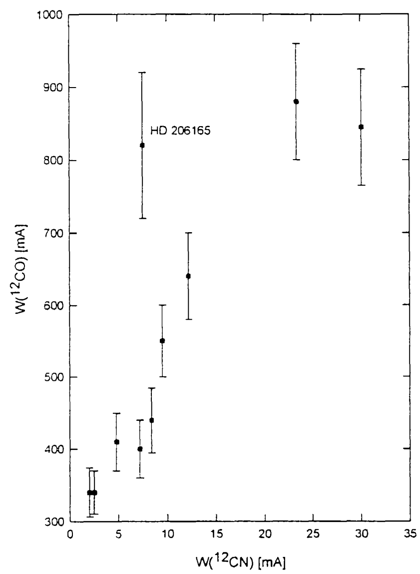

Figure 4. The correlation between the strengths of the CN and CO interstellar features.

strongest one. Fig. 1 presents the CN system in the spectrum of the well-known fast rotator ζOph (HD149757).

Many early type stars have already been observed with the IUE satellite; a few of them have been observed also in high resolution with HST. The quality of the IUE high resolution spectra is usually not very high. However, having some experience gained from the HST high resolution spectra we can trace the molecular features in the IUE spectra as well. This allows to make use of the extensive archive of the IUE spectra. Observed interstellar CO features are of a series of UV bands in the fourth positive system arising from the ground state $A^1\Pi - X^1\Sigma^+$. Some of them are strongly blended with stellar features which makes their measurements unrealiable. Only the easily traceable oscillation bands: (6-0) 1367.6 Å, (4-0) 1419.0 Å, (3-0) 1447.4 Å, (2-0) 1477.6 Å, (1-0) 1509.7 Å, have been measured and discussed in this paper. The first of them, taken from the HD 149757 observations with both HST and IUE is shown in Fig. 2.

The targets, selected for this project are the stars observed both with the CFHT and IUE telescopes. For some of our targets also the high resolution HST spectra are available. The targets are listed in Table 1.

3. RESULTS

Our targets have been divided into two groups: one similar to the "sigma" type cloud proposed by Krełowski & Sneden (1995) and the other one, resembling the "zeta" type. As shown in Fig. 3(c), comparing the HST spectra of the two stars: HD24912 and HD210839 , the intensity of the CO features changes dramatically from type to type. The same has already been reported by Krełowski et al. (1992) for the CN molecule.

Table 2.contains the equivalent widths of the major diffuse interstellar bands (5780 and 5797 Å) in the spectra of all our programme stars. It is clearly seen that some of them are typical "sigma" objects with the 5780 feature much stronger than the neighbour 5797 one. Others, with the 5780 feature not much stronger than the 5797 clearly belong to the "zeta" type. The CN and CO features are seen only in the "zeta" type objects. In "sigma" type clouds they are not only weak – they are below the level of detection.

It is impossible to measure the CO features in IUE spectra with a high precision. However, we have constructed the measure of the "total" CO strength. It is the sum of the equivalent widths of the five, mentioned in Chapter 2, CO oscilation bands. Assuming that the errors are random we can believe that this measure is quite precise. Fig. 4 relates the strengths of the CN and CO features. It is evident that their correlation is tight.

Table 2. Equivalent widths of measured interstellar features (in mÅ.)

HD	W(5780) mÅ	W(5797) mÅ	W(5780)/W(5797)	W(CN) mÅ	W(CO) mÅ	log[(N HI)/(N H_2)]
10516	68.4	10.0	6.8	0.0	0.0	1.46
24912	190.0	33.5	5.7	0.0	0.0	0.57
143275	78.6	13.7	5.7	0.0	0.0	1.60
144217	159.1	13.8	11.5	—	0.0	1.20
147165	284.4	31.0	9.2	0.0	0.0	1.59
164353	107.0	25.0	4.3	0.0	0.0	0.74
167264	222.5	81.9	2.7	0.0	0.0	0.86
184915	151.3	22.9	6.6	1.7	0.0	0.57
2905	281.6	66.6	4.3	2.0	340	0.93
23180	80.3	62.0	1.3	4.8	410	0.21
24398	99.1	55.7	1.8	8.4	440	0.12
27778	82.0	33.5	2.5	30.1	845	0.6
53367	—	—	—	23.4	880	—
149757	70.1	28.3	2.5	7.2	390	0.04
179406	156.9	66.9	2.4	12.2	639	—
198478	300.6	71.5	4.2	2.5	340	—
206165	206.3	73.9	2.8	7.5	820	—
210839	246.6	67.4	3.7	9.5	550	0.12

The H_2 column densities towards our target stars have also been analysed. The existing data (presented in Table 2.) were published by Savage et al. (1977) and by Jenkins et al. (1986). As we can see, the N(H I)/N(H_2) ratio is generally greater for "sigma" type clouds then for "zeta" one.

4. DISCUSSION

It seems evident that the abundances of the simple, carbon-bearing molecules: CN and CO are very sensitive to physical conditions inside interstellar clouds. The abundances can be high either due to some perfect protection mechanism, shielding the molecules against the energetic, far–UV photons or due to some conditions which efficiently facilitate their formation.

It is to be emphasized that the strongly differing populations of simple molecules are observed in the presence of very different shape of the interstellar extinction curve. The molecules are abundant where the fine grains (believed to be bare silicates), responsible for the far–UV rise of the extinction are abundant. Such grains shield the cloud interior – the far–UV photons are much less likely to penetrate it. On the other hand the molecules can also be formed on grain surfaces, leaving them pretty easily as any gain of energy (photon, collision) rises the grain temperature substantially.

It is a very interesting question – why the two such different molecules: the free radical CN and the stable and strongly bonded one – CO behave in the same fashion. A more extensive project involving many reddened stars of different extinction curve shapes is clearly necessary.

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