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Dicarbon molecule in the interstellar clouds†

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Abstract. We present high-resolution and high signal-to-noise spectroscopic observations of interstellar molecular lines of C_2 towards early-type stars. C_2 is particularly interesting because it is the simplest multicarbon molecule and its abundances give information on the chemistry of interstellar clouds, especially on the pathway of formation of (hydro)carbon chains and PAHs which may be considered as possible carriers of diffuse interstellar bands (DIBs). Homonuclear diatomic molecules have negligible dipol moments and hence radiative cooling of excited rotational levels may go only trough the slow quadrupole transitions (van Dishoeck & Black 1982). In C_2, pumped by galactic average interstellar field rotational levels are excited effectively much above the gas kinetic temperature and a rotational ladder of electronic transitions is usually observed from high rotational levels. Relations between abundances of the dicarbon and other simple interstellar molecules are considered as well.

Keywords. ISM: molecules, ISM: abundances

1. Introduction

The observational material consists of a set of high-quality echelle spectra (with resolution of 110,000 and signal-to-noise ratio above 200) from the high-resolution spectrograph UVES, acquired at the ESO Paranal Observatory (Bagnulo *et al.* 2003). Dicarbon is easily available observationally through its electron-vibration-rotation transitions from ground electronic level $X^1\Sigma_g^+$ to excited electronic levels $A^1\Pi_u$ (Phillips band) in optical and near-infrared range of the spectrum (6900–12000Å).

2. Results

We measured equivalent widths of (1-0) 10133-10262Å, (2-0) 8750-8849Å, (3-0) 7714-7793Å and in one case (HD 147889) also (4-0) 6909-6974Å bands of the C_2 Phillips system. The list of observed objects with some basic parameters is presented in Table 1. There are also determined total column densities of C_2 toward each star and excitation temperatures, which were extracted from the fit to the first four rotational levels ($J'' = 0, 2, 4, 6$).

In cases of optically thin clouds, i. e. for weak lines the column densities are derived from the relationship: $N_{\rm col}(J'') = 1.13{*}10^{17} EW/(f_{ij}{*}\lambda)$, where λ is the wavelength in [Å], f_{ij} is the absorption oscillator strength and EW equivalent widths in [mÅ]. Total column density is a sum of column densities determined from each low rotational level $N_{\rm col}(J'')$. Error of column densities depends on EW, which follows quality of spectrum: resolution and signal-to-noise ratio. Column density depends also on the oscillator strengths. We compare their theoretical values with our observations (to check their correctness), building relations between equivalent widths for transitions originated in each low rotational level, according to equation: $EW1/EW2 = f1/f2$. Observationally determined ratios of oscillator strengths are very similar to theoretical ones (from Bakker *et al.* 1997). Some

† Based on observations collected at the European Southern Observatory, Paranal, Chile

Table 1. Basic parameters of program stars and results for C_2 toward these objects

object	$T_{exc}[K]$	$N_{col}[10^{13}/cm^2]$	Sp/L	E(B-V)
HD 76341	66 ± 16	1.20 ± 0.2	O9Ib	0.49
HD 96917	66 ± 16	1.36 ± 0.4	O8.5Ib(f)	0.32
HD 97253	73 ± 68	1.27 ± 0.3	O5.5IIIf,cl,el	0.45
HD 115363	60 ± 1	4.01 ± 0.5	B1Ia	0.69
HD 136239	56 ± 11	3.66 ± 0.9	B1.5Ia v	0.94
HD 147933	63 ± 35	5.86 ± 0.3	B2.5V	0.45
HD 147889	73 ± 11	12.6 ± 0.8	B2V	1.07
HD 148184	67 ± 18	2.8 ± 0.3	B2Vn,el	0.52
HD 148379	81 ± 22	1.47 ± 0.2	B1.5Ia el	0.61
HD 151932	87 ± 12	1.57 ± 0.2	WN7A wr	0.35
HD 152003	76 ± 2	2.62 ± 0.6	O9.7Iab v	0.53
HD 152270	67 ± 27	2.56 ± 0.8	WC7 wr	0.53
HD 154368	53 ± 6	5.6 ± 0.7	O9.5Iab	0.78
HD 161056	80 ± 18	3.18 ± 0.5	B1.5V	0.60
HD 163800	59 ± 22	2.60 ± 0.6	O7IIIf	0.60
HD 168607	89 ± 10	1.35 ± 0.2	B9Iape	1.61
HD 168625	70 ± 24	1.32 ± 0.5	B6Iap	1.49
HD 169454	39 ± 3	5.80 ± 0.6	B1Iael	0.93
HD 179406	48 ± 9	4.60 ± 0.6	B3V	0.33
BD-14 5037a	53 ± 5	6.38 ± 0.6	B1.5Ia	1.59
BD-14 5037b	64 ± 4	4.26 ± 0.6		

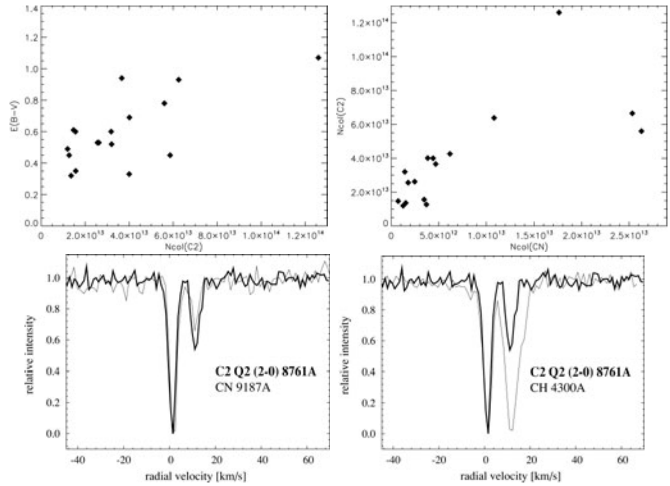

Figure 1. (a) [Top left] $N_{col}(C_2)$-E(B-V) (b) [Top right] N_{col}(CN)-$N_{col}(C_2)$ (c) [Bottom left] C_2-CN (d) [Bottom right] C_2-CH

departures likely follow errors in measuring C_2 lines. For the strongest lines, especially from (2-0) vibrational band, the relations evidently confirm theoretical expectations.

We measured dicarbon column densities toward above 20 stars. After that we tried to correlate C_2 abundance with those of other interstellar molecules (CN and CH) and with extinction (Figure 1a). Such relations may constrain chemical pathways which lead to the formation of these species.

Figure 1b shows relation between column densities of C_2 and CN. A majority of the considered objects suggest a tight correlation, but two points are considerably discrepant. These represent HD 169454 and HD 154368. Physico-chemical conditions in the intervening interstellar clouds (e.g., very low T_{exc}) likely vary considerably in these objects while compared to average conditions. Figures 1c and 1d compare Doppler-splitted profiles of molecular features in the spectrum of BD-14 5037. We compare lines profiles of C_2 (Q(2) 8761Å of (2-0) band) and CN (9187Å) which suggests that C_2 is spatially correlated with CN. Figure 1d compares C_2 and CH (4300Å) in the spectrum of BD-14 5037. CH does not share the profile shape with C_2.

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