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Ca II and CH$^+$ interstellar absorption observations in the direction of resolvable binary stars(*)

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Summary. — We report the initial results of a study to probe the small-scale structure in diffuse interstellar clouds by observing optical absorption lines of CH$^+$ at 4232 Å and Ca II K at 3933 Å towards both components in resolvable binary systems. The data analysis is still in progress. To date, 70% of the Ca II spectra have been analyzed for the 19 observed systems. For half of these, a difference in the line strength or in the number of calcium components is found. The sightlines have been selected so that the observing method provides a potential probe of the small-scale structure of the interstellar medium in the range 200-4000 AU.

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1. – Introduction

One of the most powerful means to study the diffuse and cool components of the interstellar medium (ISM) is provided by the optical observations of atomic and molecular absorption lines (Cowie and Songaila, 1986; van Dishoeck, 1990). In addition to the column densities of the observed elements, it is possible to get information on the velocity structure, density and inhomogeneity of the interstellar clouds where these species lie. However, the range of cloud sizes is still not well known and the extent to which the matter is clumped within individual clouds is very uncertain. In the past only a limited number of observations have been devoted to this subject.

A search of small-scale structure in the ISM has been carried out (Crovisier *et al.*, 1985; Kalberla *et al.*, 1985; Diamond *et al.*, 1989; Deshpande, 1992) by observing HI 21 cm absorption line in the few targets that are available (extragalactic radio sources as

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TABLE I. – *Observed binary systems.*

HD number	Right ascension	Declination (1950.0)	m_V (1950.0)	Spectral type	No. of Ca II K components	W_λ of Ca II K main component (mÅ)
HD24071	$03^{\rm h}\,46^{\rm m}\,44.7^{\rm s}$	−37°46′26″	5.42	A1V	5	8.7 ± 0.6
HD24072	$03^{\rm h}\,46^{\rm m}\,45.0^{\rm s}$	−37°46′20″	4.86	B9V	7	7.0 ± 0.8
HD32039	$04^{\rm h}\,57^{\rm m}\,54.7^{\rm s}$	+03°32′33″	7.03	B9Vn	...	...
HD32040	$04^{\rm h}\,57^{\rm m}\,56.1^{\rm s}$	+03°32′36″	6.66	B9Vn	...	...
HD34798	$05^{\rm h}\,17^{\rm m}\,05.8^{\rm s}$	−18°34′14″	6.39	B5IV	...	...
HD34797	$05^{\rm h}\,17^{\rm m}\,07.0^{\rm s}$	−18°33′37″	6.50	B8IV	...	...
HD35149	$05^{\rm h}\,20^{\rm m}\,12.2^{\rm s}$	+03°29′52″	5.00	B1V	...	...
HD35148	$05^{\rm h}\,20^{\rm m}\,13.0^{\rm s}$	+03°30′20″	7.18	B3V	...	...
HD36486	$05^{\rm h}\,29^{\rm m}\,27.0^{\rm s}$	−00°20′04″	2.24	O9.5	12	13.5 ± 0.4
HD36485	$05^{\rm h}\,29^{\rm m}\,27.0^{\rm s}$	−00°19′12″	6.85	B2V	12	42.7 ± 1.7
HD37043	$05^{\rm h}\,32^{\rm m}\,59.1^{\rm s}$	−05°56′28″	2.77	O9III	7	23.9 ± 0.7
HD37043B	$05^{\rm h}\,32^{\rm m}\,59.5^{\rm s}$	−05°56′35″	7.00	B7IV	7	21.2 ± 0.7
HD37742	$05^{\rm h}\,38^{\rm m}\,14.04^{\rm s}$	−01°58′02.97″	1.70	O9I	6	36.4 ± 0.2
HD37743	$05^{\rm h}\,38^{\rm m}\,14.00^{\rm s}$	−01°58′03.0″	4.21	B0III	6	22.3 ± 0.7
HD45725	$06^{\rm h}\,26^{\rm m}\,23.4^{\rm s}$	−06°59′58″	4.60	B3V	7	8.9 ± 0.4
HD45726	$06^{\rm h}\,26^{\rm m}\,23.9^{\rm s}$	−07°00′00″	5.40	B3	7	8.3 ± 0.5
HD59499	$07^{\rm h}\,26^{\rm m}\,55.9^{\rm s}$	−31°44′40″	6.39	B3V	4	56.2 ± 1.2
HD59500	$07^{\rm h}\,26^{\rm m}\,56.3^{\rm s}$	−31°44′34″	7.12	B4V	2	54.2 ± 0.7
HD61555	$07^{\rm h}\,36^{\rm m}\,46.3^{\rm s}$	−26°41′13″	4.50	B6V	no Ca II	...
HD61556	$07^{\rm h}\,36^{\rm m}\,46.8^{\rm s}$	−26°41′20″	4.62	B5IV	no Ca II	...
HD66005	$07^{\rm h}\,57^{\rm m}\,47.6^{\rm s}$	−49°50′21″	6.32	B2IV	...	...
HD66006	$07^{\rm h}\,57^{\rm m}\,48.7^{\rm s}$	−49°50′10″	6.34	B2IV	...	...
HD77002	$08^{\rm h}\,55^{\rm m}\,45.0^{\rm s}$	−59°02′08″	4.92	B2IV	2	11.9 ± 0.1
HD77002B	$08^{\rm h}\,55^{\rm m}\,50.2^{\rm s}$	−59°01′58″	6.87	B9.5V	2	8.9 ± 0.3
HD91356	$10^{\rm h}\,29^{\rm m}\,48.2^{\rm s}$	−44°48′43″	6.11	B4	5	13.3 ± 0.3
HD91355	$10^{\rm h}\,29^{\rm m}\,49.0^{\rm s}$	−44°48′32″	5.74	B9	7	18.4 ± 0.4
HD108248	$12^{\rm h}\,23^{\rm m}\,48.1^{\rm s}$	−62°49′19″	1.58	B0.5VI	2	9.7 ± 0.1
HD108249	$12^{\rm h}\,23^{\rm m}\,48.6^{\rm s}$	−62°49′20″	2.09	B1V	2	9.8 ± 0.1
HD144217	$16^{\rm h}\,02^{\rm m}\,31.5^{\rm s}$	−19°40′12″	2.62	B0.5V	3	31.1 ± 0.2
HD144218	$16^{\rm h}\,02^{\rm m}\,31.9^{\rm s}$	−19°40′00″	4.92	B2V	3	33.0 ± 0.2
HD145501	$16^{\rm h}\,09^{\rm m}\,04.0^{\rm s}$	−19°19′17″	6.30	B8V	2	38.9 ± 0.3
HD145502	$16^{\rm h}\,09^{\rm m}\,05.0^{\rm s}$	−19°19′56″	4.01	B2IV	2	55.2 ± 0.3
HD147933	$16^{\rm h}\,22^{\rm m}\,34.9^{\rm s}$	−23°20′01″	5.02	B2V	...	...
HD147934	$16^{\rm h}\,22^{\rm m}\,34.8^{\rm s}$	−23°19′58″	5.92	B2V	...	...
HD150135	$16^{\rm h}\,37^{\rm m}\,33.8^{\rm s}$	−48°40′03″	6.88	O6	...	...
HD150136	$16^{\rm h}\,37^{\rm m}\,35.1^{\rm s}$	−48°40′01″	5.66	O5	...	...
HD170740	$18^{\rm h}\,28^{\rm m}\,39.2^{\rm s}$	−10°49′55″	5.72	B2V	2	57.6 ± 0.3
HD170740B	$18^{\rm h}\,28^{\rm m}\,38.3^{\rm s}$	−10°49′57″	9.4	B9V	2	24.0 ± 6.0

continuum background are necessary or pulsar observations). Significant variations in profiles on scales above 40 000 AU and below 25 AU were measured.

More recently, evidence for structures on a scale of ≈ 0.1 pc has been obtained from observations of closely spaced stars in the LMC (Molaro *et al.*, 1989) and two globular clusters (Langer *et al.*, 1990).

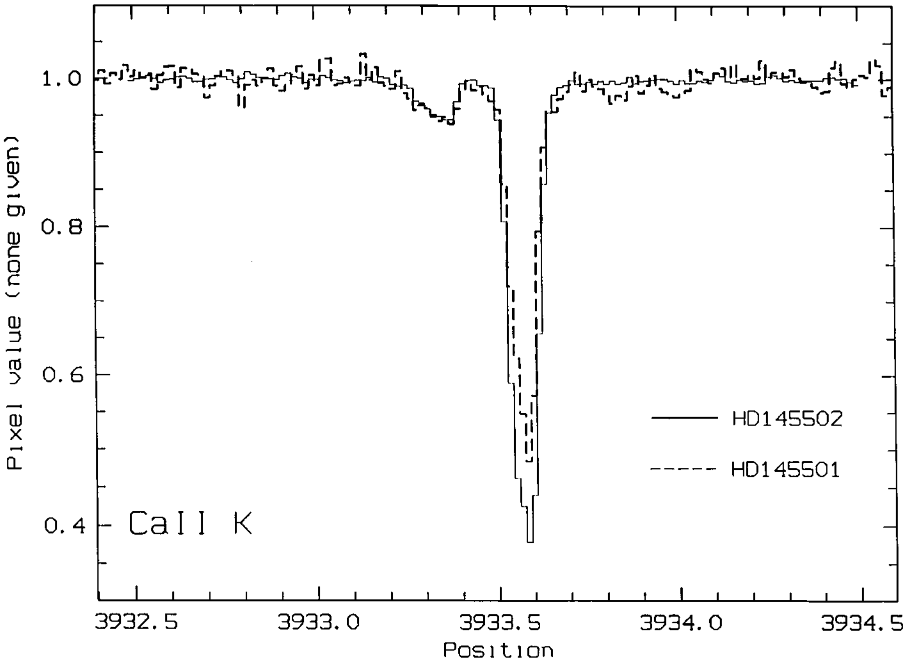

Fig. 1. – Ca II K interstellar absorption lines towards the two stars HD145501 and HD145501. The difference in the strength between the main component line in the two spectra is greater than 20%.

One of the major problems in using distant backgrounds (extragalactic radio sources, globulars, LMC) is the large uncertainty in the distance of the intervening clouds and hence the impossibility of determining the real scale length of any apparent structure.

A technique to avoid this problem is to perform high-resolution observations of interstellar absorption lines towards both components of binary systems and to look for line strength differences in the spectra. Using this method, Meyer (1990) reports only one case, out of the 6 studied, in which the differences in the strength of the measured lines towards the two stars are greater than 50% resulting in an ISM structure on a scale of 2800 AU.

Our project is directed towards enlarging the sample of the observed resolvable binary stars in order to determine if the existence of small-scale structure (in the range 200–4000 AU (0.001–0.02 pc)) in the interstellar medium is more the exception than the rule or vice versa. In the following sections we give details on the observations and we present the *very* preliminary results.

2. – Observations and data analysis

The high-resolution spectra were obtained at the 1.4 m Coudè Auxiliary Telescope of ESO on La Silla during two observing runs: in 1993 June, performed in remote mode from Garching and in 1993 December, *in loco*. The adopted configuration, CCD plus long blue camera, provided a resolution of about 115 000 at the studied wavelengths.

The sight lines were selected on the basis of the following constraints:
1) both components are O or B stars: hot stars are preferred for their high ionization level

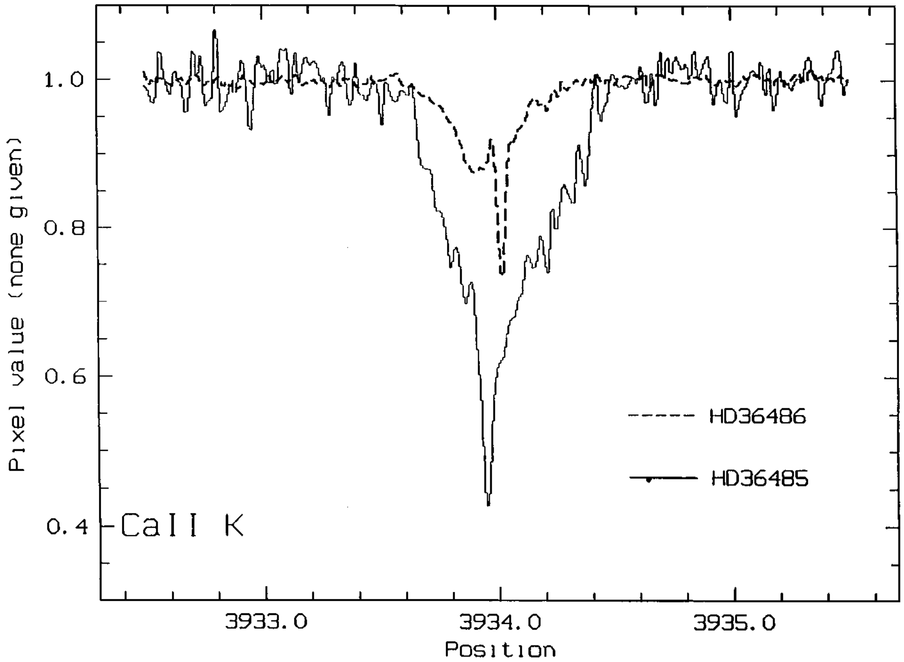

Fig. 2. – Ca II *K* interstellar absorption lines towards the two stars HD36485 and HD36486. This latter star migth show in its spectrum a stellar calcium feature, but the contamination by the stellar component would not compensate the strong difference observed in the two spectra.

so that the stellar continuum is almost flat;

2) separation between the two components and distance of the stars providing a check on ISM structure on scale less than 4000 AU;

3) stars for which a detection of interstellar absorption features already existed (this was generally true for only one of the two components).

Data reduction was performed using the MIDAS system following the standard procedure. For each image we subtracted the bias level, divided by the nightly flat field and removed the cosmic rays. The spectra extraction was performed summing only on the rows with higher S/N. Stellar spectra were wavelength-calibrated using comparison spectra of a thorium/argon calibration lamp obtained during each night of the observing runs.

The next step in the data analysis was the determination of the column densities of each detected line. Spectral line profiles were modelled using the MIDAS context CLOUD were column densities are computed by using Voigt profile model.

For most of the stars the observed profile shows more than one component for both Ca II *K* and CH^+. The minimum number of components necessary to reproduce the data has been adopted in the analysis. Due to the spectral resolution we have in our spectra, it is not possible to resolve components separated by less than 1–2 km sec^{-1}.

3. – Results and discussion

Table I lists the observed binary systems and, for spectra analysed to date, the number of Ca II *K* components detected in each spectrum and the equivalent width measured for

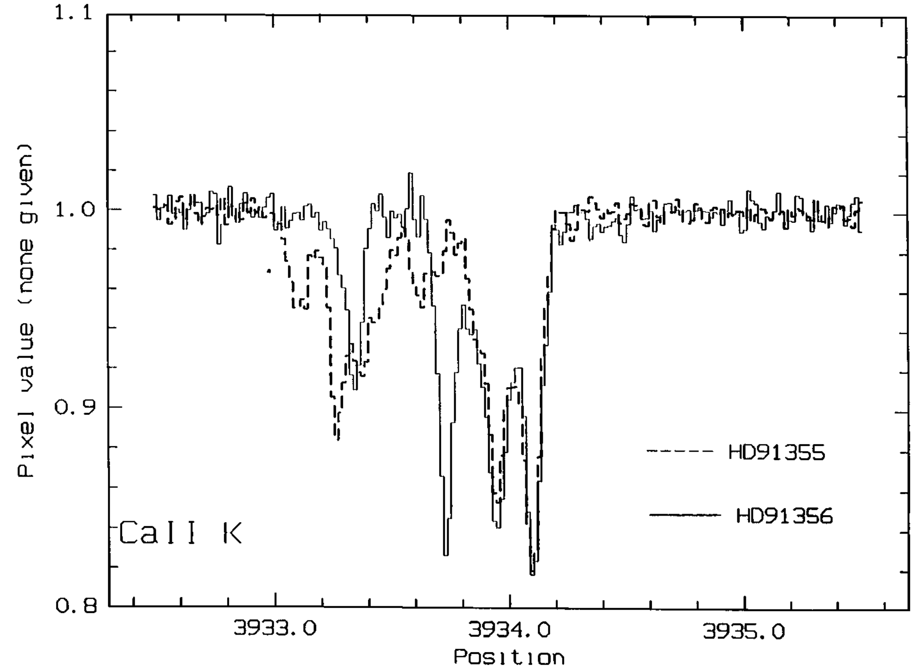

Fig. 3. – Ca II *K* interstellar absorption lines towards the two stars HD91355 and HD91356. In this case in addition to the difference in strength of the observed features, the two spectra show also a different number of calcium components.

the main component. The uncertainties associated to the equivalent width reflect both the statistical and the continuum placement errors.

The figures show some examples of the detected differences.

Figure 1 shows the Ca II *K* interstellar absorption line towards both components of μ *Sco* system (HD145501, HD145502). The high-resolution observations indicate a multi-component profile with a line strength difference ($> 20\%$) concetrated in the main component.

Figure 2 shows the Ca II *K* absorption line towards the two stars HD36486 and HD36485. The latter is a B2V star so there might be a contribution to the line due to the stellar calcium which show up in star of this spectral type, but even if this is the case it could not account for the strong difference between the two profiles. Moreover, it seems that the main interstellar component do not coincide in velocity.

Figure 3 shows a case in which the spectra of the two stars HD91355 and HD91356 differ in the number of components. This means that the clouds dimensions would be even smaller than the separation of the star.

50% of the analysed systems (at the Ca II wavelength) show differences in the line strength or in the number of components. Since data analysis is still in progress, we cannot establish if the presence of small-scale (< 4000 AU) structure in the diffuse interstellar medium is the rule or the exception.

Moreover, additional observations towards some of the stars in our sample are necessary to obtain a comparable signal-to-noise ratio in the two spectra. This will give us more confidence in the reliability of any detected difference in the interstellar features of the observed sightlines, even if the S/N does not seem to be a limit in the cases reported in the figures.

IRAS and CO maps, when available, in the observed direction of our sample will also be used in conjunction with the optical study. The complete set of observations will increase the possibility to understand any detected difference in the measured column densities or number of components.

It is clear that the sample of lines of sight has to be as large as possible (the number of suitable binary systems that can give us information on the small scale is limited) in order to establish a more complete range of sizes and to try to understand any possible correlation between any of the species parameters, like linewidth or column density, and the derived size of the clouds.

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