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Unusually high rotational temperature of the CN radical* *(Research Note)*

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ABSTRACT

We analyse a high-resolution, high signal-to-noise spectrogram of the hot reddened star Trumpler 16 112 to find relationships between the physical parameters of the intervening interstellar medium (e.g., the rotational temperature of the CN radical) and the intensities of interstellar lines/bands. We report on the discovery of an interstellar cloud that shows an exceptionally high rotational temperature of CN (4.5 K) and unusually strong Ca I and Fe I interstellar lines. This rare CaFe-type cloud seemingly contains no diffuse band carriers.

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

1. Introduction

The rotational excitation of molecules with permanent dipolar momentum are believed to provide a possibility of direct and precise measurement of the cosmic microwave background (CMB) temperature. The most popular molecule for such purposes is CN. It has been used as a "thermometer" for many years (Smoot 2007). CN is most widely used and yields most precise results because the observations of its well-known band are made at optical wavelengths and use well developed technology. For cold, non-dense clouds, the contribution from sources other than the CMB tends to be quite small. However, there are lines of sight that show a temperature excess sufficiently exceeding the uncertainty of measurements, see e.g. Słyk et al. (2008), Palazzi et al. (1992).

The rare phenomena of CaFe-type clouds was previously reported by Bondar et al. (2007). In just a few known CaFe clouds no detectable molecular features (CH, CN) or diffuse interstellar bands are seen while lines of neutral 4227 Å Ca I and 3720 Å Fe I are unusually strong. In "normal" cases, the spectra of interstellar clouds show strong K I 7699 Å, Na I D1 and D 2, and Ca II H and K lines; the Fe I and Ca I ones are much weaker. The near-ultraviolet Na I doublet lines at ~3302 Å usually are also much stronger than those of Ca I and Fe I. Until now, these clouds are discovered only along sightlines toward hot, luminous objects with high rates of mass loss.

In this paper we report a unique target that shows both phenomena, i.e., high CMB-execess temperature and CaFe-type behaviour.

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2. Results and discussion

In Słyk et al. (2008) a very interesting object – Tr16 112 was mentioned. In the spectra of the target two distinct interstellar clouds separated by ~40 km s^{-1} are seen (Fig. 1). The blue component is quite peculiar. A very high rotational temperature of the CN radical (over 6 K) is reported towards it (Slyk et al. 2008). However, the temperature estimate is based on a modest quality spectrum and therefore uncertain. Moreover, the CN features look suspicious: the intensities of the $R(1)$ and $P(1)$ transitions were reported as very similar although the intensities were not high enough to suggest saturation of any transition.

This is why we re-observed this object in March 2009 using the UVES spectrograph fed with the Kueyen mirror of the VLT at Paranal. Below we present the spectra after shifting them to the rest wavelength velocity frame of the red component of the CH 4300 Å line. The result is quite interesting. Our new spectra suggest that one cloud or cloud system seen along the sightline towards Tr16 112 is of the CaFe type (Bondar et al. 2007) because its spectrum is dominated by CaI and FeI lines. The profile of the molecular feature, CH shows the opposite effect, i.e., its dominating component coincides in radial velocity with the weaker one of CaI or FeI (Fig. 1).

Both clouds (or cloud systems) contain molecular features, which makes it intriguing to find out whether they do contain the carriers of diffuse interstellar bands. We checked this for the narrow 6196 and 6379 DIBs. Beyond a doubt the DIB carriers are present only in one cloud system, the one that carries the dominating CH component. No signs of DIB components can be traced in the second system (Fig. 2).

The important question is whether the already reported CN B-X(0,0) band can be observed and how far the CN is related to CH. Figure 3 shows the comparison of the two molecular species. The result is quite astonishing. CN can be traced in both

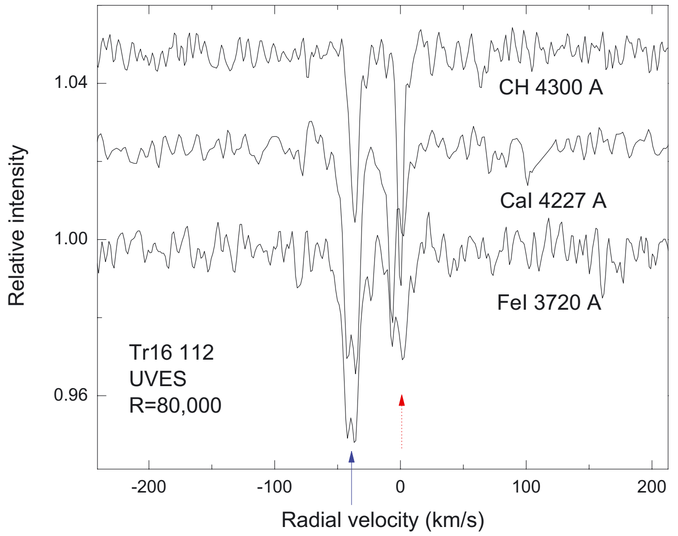

Fig. 1. Profiles of interstellar lines in the spectrum of Tr16 112. The spectra are shifted to the rest wavelength of the red CH component (marked with dotted arrow); neutral elements are more evident at $V_r = -40$ km s^{-1} (marked with solid arrow).

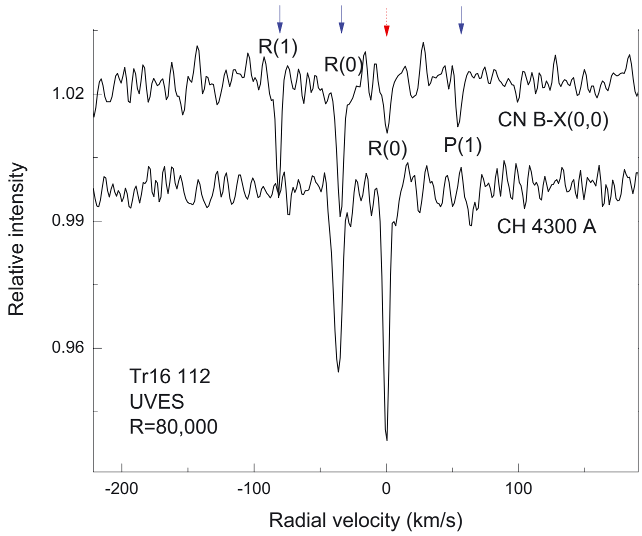

Fig. 3. Interstellar molecular bands compared in the spectrum of Tr16 112 in the radial velocity scale. CN dominates in the cloud where CH is weaker. The –40 km s^{-1} component is marked with solid arrows.

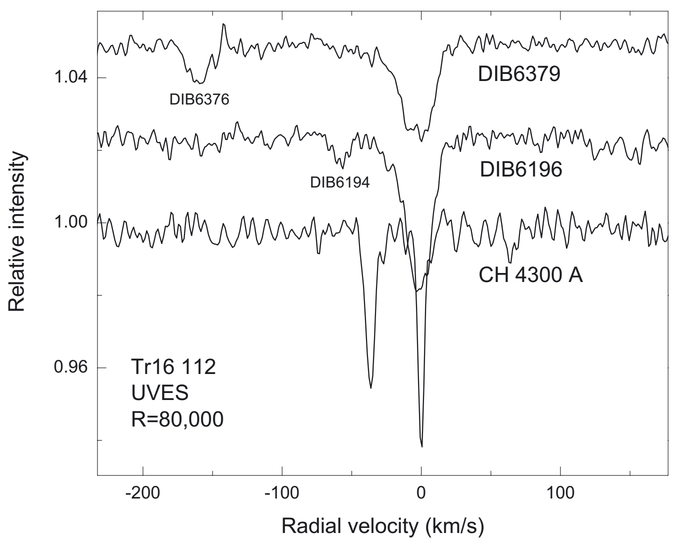

Fig. 2. Profiles of interstellar lines in the spectrum of Tr16 112 compared in radial velocity scale. No diffuse band components corresponding to the –40 km s^{-1} CN are visible.

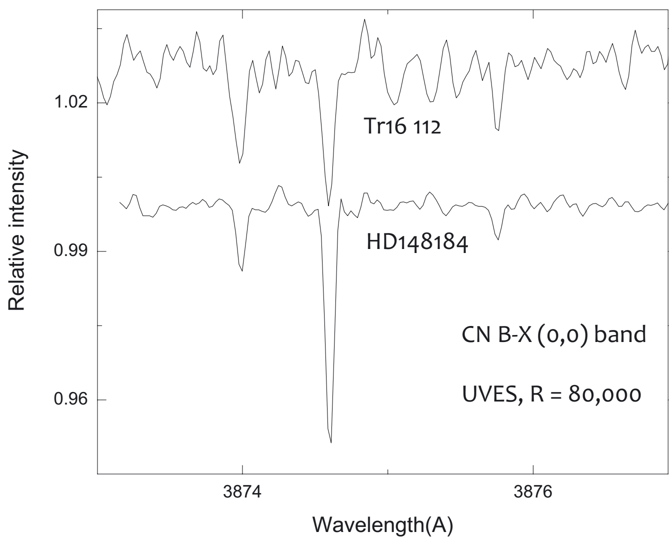

Fig. 4. Unsaturated CN band in two targets: in "normal" HD148184 and in Tr16 112 (–40 km s^{-1} CN component) shown together for clarity.

cloud systems but it is much stronger in the CaFe cloud! Our measurements are given in Table 1 together with those from Słyk et al. The large difference is seen for the EWs of $P(1)$ band measured in our recent and the Słyk et al. (2008) spectra. However, the data of Słyk et al. (2008) are of a much lower quality. Indeed, the resolving power is almost twice as high in our recent data and show a similar difference in the signal-to-noise ratio.

The EWs of individual transitions in this dominating CN band are $R(0) = 2.96$ mÅ, $R(1) = 1.75$ mÅ and $P(1) = 0.82$ mÅ. In this high SNR spectrum the ratio of $R(1)$ to $P(1)$ apparently resembles exactly that of their oscillator strengths, i.e., 2, which proves the lack of saturation. On the other hand the ratio of $R(0)$ to $R(1)$ in the dominating cloud is very unusual -1.69 ± 0.33 instead of 3.70 (the value expected when the features are not saturated and $T_{\rm rot} = 2.725$ K), which leads to the ratio of $R(0)$ to $R(1)$, abundances being 1.13 ± 0.55 instead of 2.463, which is characteristic for the CMBR temperature. The rotationally excited level is almost as populated as the ground

Table 1. Observed targets and equivalent width (in mÅ) of CN transitions in the $v \sim -40$ km s^{-1} (except the most right column – see Fig. 3) component compared with the data from Slyk et al. (2008).

	HD 148184		Tr16 112		
	B2Vne $E(B-V) = 0.48$		O6V $E(B-V) = 0.62$		
	UVES	Słyk et al.	UVES	Słyk et al.	UVES ($v \sim 0$)
$R(1)$	1.00 ± 0.10	1.62 ± 0.20	1.75 ± 0.22	2.45 ± 0.60	–
$R(0)$	3.66 ± 0.11	3.75 ± 0.20	2.96 ± 0.33	3.00 ± 0.50	1.25 ± 0.65
$P(1)$	0.55 ± 0.10	0.77 ± 0.40	0.82 ± 0.18	2.04 ± 0.60	–

one. In "normal" circumstances the population of the excited level should be about 40% of that of the ground level. These populations lead to the rotational temperature equal to 4.5 K. It is the highest observed CN rotational temperature; in this object the result is certain because the CN features are too weak to be saturated (Słyk et al. 2008). On the other hand, the quality of spectrum makes the measurements precise.

The next figure (Fig. 4) compares the B-X (0,0) CN band in Tr16 112 with the same band in the UVES spectrum of

HD 148184. The strengths of individual transitions in the latter case are below the threshold of saturation according to Słyk et al. (2008). The comparison proves the evident difference of the populations of the ground level and the first rotational one in both cases. In HD 148184 we observe a fairly typical case, i.e., the equivalent widths of the measured features are: $R(0) = 3.66$ mÅ and $R(1) = 1.00$ mÅ. The $R(0)/R(1)$ ratio is thus 3.66 – nearly identical to that expected if the excitation is caused by the cosmic background radiation only. Apparently the physical conditions in one of the clouds that obscure Tr16 112 facilitate the rotational excitation of this molecule.

It is a very clear evidence that the rotational temperature of CN may be higher than that of the cosmic background radiation. However, the observed object is very unusual – it is unique in the fairly large sample of Słyk et al. (2008). Let us summarize our conclusions:

- we found a very special interstellar cloud whose spectrum is dominated by FeI, CaI and CN absorption features (other metals, NaI and KI behave similar to FeI and CaI, i.e., the same Doppler components dominate in their profiles
- the cloud is characterized by a very high rotational temperature of CN; the precision of the UVES spectrum clearly proves that this temperature in individual clouds may be considerably higher than that of the cosmic background radiation
- the specific cloud does not contain carriers of narrow diffuse interstellar bands; the latter are seemingly related instead to CH.

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References

Bondar, A., Kozak, M., Gnaciński, P., et al. 2007, MNRAS, 378, 893
Palazzi, E., Mandolesi, N., & Crane, F. 1992, ApJ, 398, 53
Słyk, K., Bondar, A. V., Galazutdinov, G. A., & Krełowski, J. 2008, MNRAS, 390, 1733
Smoot, G. F. 2007, Rev. Mod. Phys., 79, 1349