Astron. Astrophys. 184, L5–L6 (1987)

ASTRONOMY AND ASTROPHYSICS



*Letter to the Editor*

# Detection of interstellar CH and $CH^+$ towards SN 1987a*

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Received July 16, accepted July 28, 1987

Summary. We report the detection of interstellar CH and $CH^+$ towards supernova 1987a. For both of these molecules, one component is detected at a heliocentric velocity of about 280 km/s, corresponding to material inside the LMC. Some implications of our results with regards to the $H_2$-to-dust ratio are briefly discussed.

Keywords: SN 1987a, Interstellar medium, Magellanic Clouds, Abundances

## 1. INTRODUCTION

Supernova 1987a, which was discovered on February 24, provides a very bright light source for the study of the interstellar medium in the LMC at high resolution and high signal-to-noise ratio. It allows, among other possibilities, to detect very weak features which are beyond the reach of present-day capabilities when the much fainter "normal" stars are the only light sources available. Among such weak features are the visible and near-ultraviolet lines of CH, $CH^+$ and CN. In this Letter, we report the detection of interstellar CH and $CH^+$ lines in the spectrum of SN1987a, at a velocity corresponding to material inside the LMC. The observations and results are presented in Sect. 2, while some first implications of these results are discussed in Sect. 3.

## 2. OBSERVATIONS AND RESULTS

The observations were carried out at the European Southern Observatory (La Silla, Chile), with the Coude Echelle Spectrometer (CES) fed by the 1.4 m Coude Auxiliary Telescope. The detector was a high resolution RCA CCD (type SID 503, 640 x 1024 pixels, 15 x 15 μm each). The spectra were centered around the CH line at 4300 Å and the $CH^+$ line at 4232 Å. Each spectral region was observed on three different nights, with slightly different wavelength settings in order to minimize the effects of pixel-to-pixel variations and of the interference fringes in the silicate substratum. The wavelength calibration was provided by a thorium lamp, giving an accuracy of 0.2 km/s internally and 1 km/s externally. The resolving power, as determined from the thorium lines, was 85000 and 65000 for the CH and $CH^+$ spectra, respectively, corresponding to 3.5 and 4.5 km/s (FWHM). The spectra were reduced with the IHAP facility and subsequently co-added. The total exposure time was 5 h for CH and 5 h 15 for $CH^+$, resulting in signal-to-noise ratios of 680 and 550, respectively.

The final spectra, in a common heliocentric velocity scale, are presented in Fig. 1 after 3-points filtering. One LMC component is clearly present in both spectra, at a velocity of about 280 km/s. Its measured equivalent width and heliocentic velocity are listed in Table 1, along with the deduced column densities and the adopted molecular parameters (laboratory wavelengths and oscillator strengths). In addition, two other components might be present in the CH spectrum, just at the limit of detectability. The first of these (at 24 km/s) coincides with a component detected in the calcium spectra (Magain, 1987) while the second one, at 264 km/s, has no calcium counterpart and is probably not real. The feature between 10 and 40 km/s in the $CH^+$ spectrum is probably due to an imperfect correction of the interference fringes. With a detection limit of some 0.2 mÅ, one single line is thus detected in each spectrum. Its heliocentric velocity (≈ 279 km/s) corresponds to the strongest feature seen in the Ca I and Ca II spectra (Magain, 1987), as well as in the Na I and K I spectra (Vidal-Madjar et al., 1987) and in most species detected in the IUE spectra of de Boer et al. (1987).

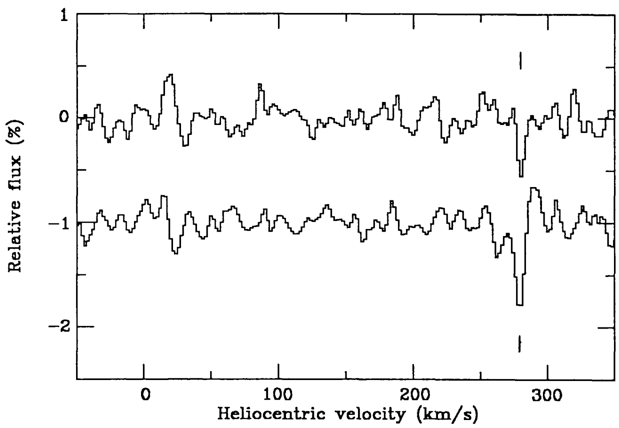


Fig. 1. Spectra of $CH^+$ (top) and CH (bottom) on a common heliocentric velocity scale. The ordinate refers to the $CH^+$ spectrum, while the CH spectrum is displaced vertically by 1%. The detected component is indicated by a vertical bar.

* Based on observations carried out at the European Southern Observatory (La Silla, Chile)

Table 1. Line data

| Species | λ(Å) | f | $V_{\odot}$(km/s) | W(mÅ) | N($10^{12}$ $cm^{-2}$) |
|---|---|---|---|---|---|
| CH | 4300.321 | 0.0057 | 278.8 | 0.9 | 1.1 |
| $CH^+$ | 4232.548 | 0.0055 | 279.7 | 0.4 | 0.5 |

## 3. DISCUSSION

Extensive surveys of interstellar CH and $CH^+$ in the solar neighbourhood have been published recently (Federman, 1982; Danks et al., 1984; Lambert and Danks, 1986). They have shown that the CH column density, N(CH), varies linearly with $N(H_2)$, which confirms the generally accepted view that CH is formed by a gas phase reaction network running in $H_2$. On the other hand, equilibrium chemistry in cool clouds fails to reproduce the observed $CH^+$ column densities by at least two orders of magnitude. Interstellar shock waves are generally advocated to solve this discrepancy. Elitzur and Watson (1978, 1980) have shown that $CH^+$ is efficiently produced in the hot gas immediately behind shock fronts if the latter have suitable velocities (≈ 5 to 15 km/s).

The very good correlation between CH and $H_2$ column densities, if extrapolated to the LMC, may provide a means of estimating the molecular hydrogen content in the line-of-sight to SN1987a. Since $H_2$ is, by far, the main molecular constituent of the interstellar medium, and one of the most difficult to detect directly, any estimate of its abundance is of considerable interest. From the linear relation between log N(CH) and log $N(H_2)$ found by Danks et al. (1984), and the CH column density reported in Table 1, we estimate log $N(H_2)$ ≈ 19.6 (±0.3) towards SN1987a, at a heliocentric velocity of 279 km/s, and much lower amounts of $H_2$ at other velocities. Another, independent, estimate of the $H_2$ column density is from the correlation between $N(H_2)$ and the interstellar reddening E(B-V) (Savage et al., 1977). With an estimated reddening of 0.2 mag towards SN1987a (West et al., 1987), we find, from Fig. 4 of Savage et al., log $N(H_2)$ ≈ 19.8 (±0.5). Since the reddening is due to interstellar dust, the good agreement between these two independent estimates of the $H_2$ column density indicates that the $H_2$-to-dust ratio should be roughly the same in the LMC and in the solar neighbourhood, which is not unexpected if $H_2$ is formed on the surface of dust grains (Duley and Williams, 1984; see also Israel et al.,1986, for a discussion of CO in relation to the gas-to-dust ratio in the LMC). This result is valid if the N(CH) - $N(H_2)$ relation can be extrapolated from the solar neighbourhood to the LMC. From the chemical reaction network (Federman, 1982), the density of CH, n(CH), is found to depend not only on $n(H_2)$, but also on $n(C^+)$. A different density of ionized carbon could thus change the relation between n(CH) and $n(H_2)$. Since the heavy elements are generally less abundant in the LMC than in the solar neighbourhood, if $n(C^+)$ scales with the overall C abundance, this means that we could slightly underestimate $N(H_2)$. However, our estimate of $N(H_2)$ from N(CH) is somewhat below the value deduced from E(B-V), so that it is very unlikely that this correction would worsen the agreement between these two estimates. In fact, it could even improve it.

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