CH^+ and $^{13}CH^+$ absorption lines in the direction of massive star forming regions

E. Falgarone[1], B. Godard[1,2], J. Cernicharo[3], M. De Luca[1], M. Gerin[1], T. Philipps[4], J. Black[5], D.C. Lis[4] & the PRISMAS team

[1]**Laboratoire de Radioastronomie**, École Normale Supérieure et Observatoire de Paris, Paris, France
[2]**Institut d'Astrophysique Spatiale**, Orsay, France
[3]**Centro de Astrobiología**, Madrid, Spain
[4]**Caltech, Cahill Center for Astronomy and Astrophysics**, Pasadena, USA
[5]**Onsala Space Observatory**, Onsala, Sweden

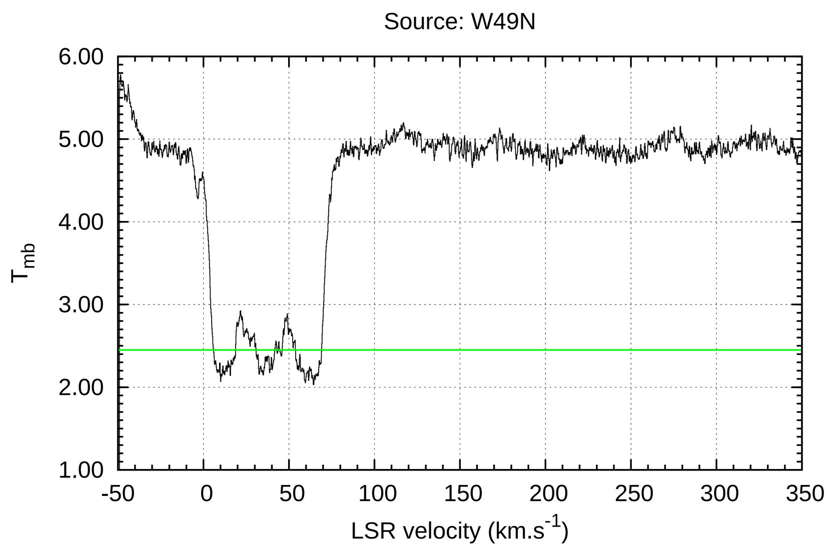
Abstract

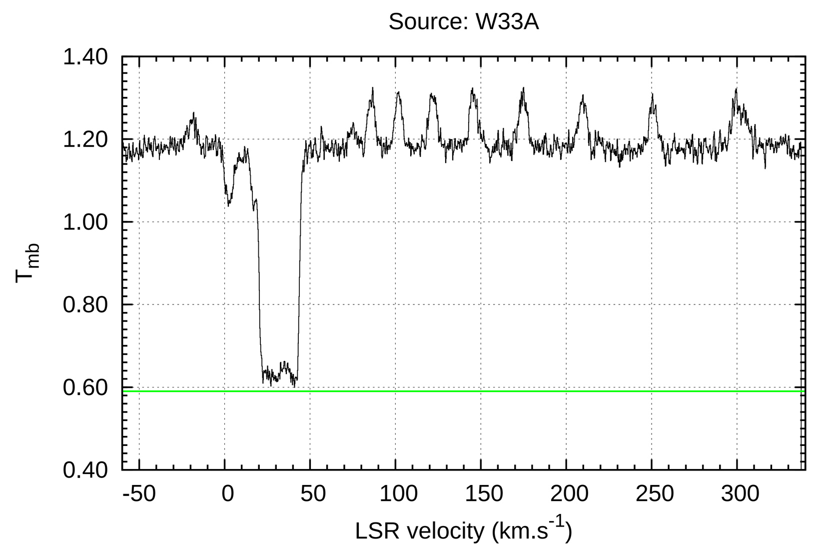
The study of small hydrides such as CH, CH^+, OH^+ and H_2O^+ is essential to understand the first steps of interstellar chemistry. In the framework of the Herschel-HIFI key project PRISMAS, we report the detection of CH^+ and $^{13}CH^+$ absorption lines in the direction of several remote star forming regions. The CH^+ lines are highly saturated. No emission line is detected in any of the three star-forming regions. The resulting CH^+ average abundances along W49N and W51 are found in excellent agreement with those derived from $^{13}CH^+$ CSO submillimeter observations [1] and are a few times larger than those inferred from visible observations of the local diffuse medium [2],[3],[4].

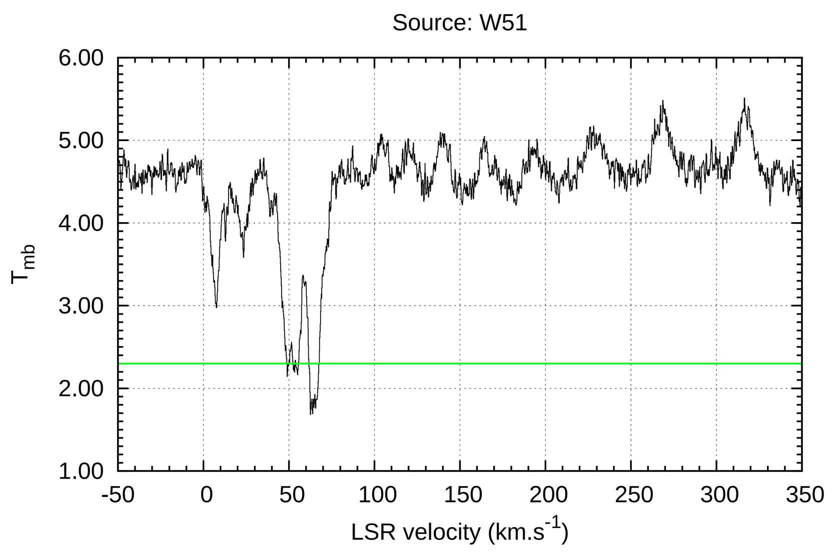
The average observed abundances still exceed by orders of magnitude those predicted by a UV-dominated steady-state chemistry because large endo-energetic barriers (several thousands Kelvin) have to be overcome in the cold gas. It has been proposed [6] that supersonic turbulence pervading the medium is a possible energy reservoir. We show that the predictions of the TDR (Turbulent Dissipation Regions) model, in which dissipation of turbulent energy in magnetized structures locally triggers a specific warm chemistry compare well with observations.

I HIFI observations of CH^+ (0-1) and $^{13}CH^+$ (0-1)

1. Observations



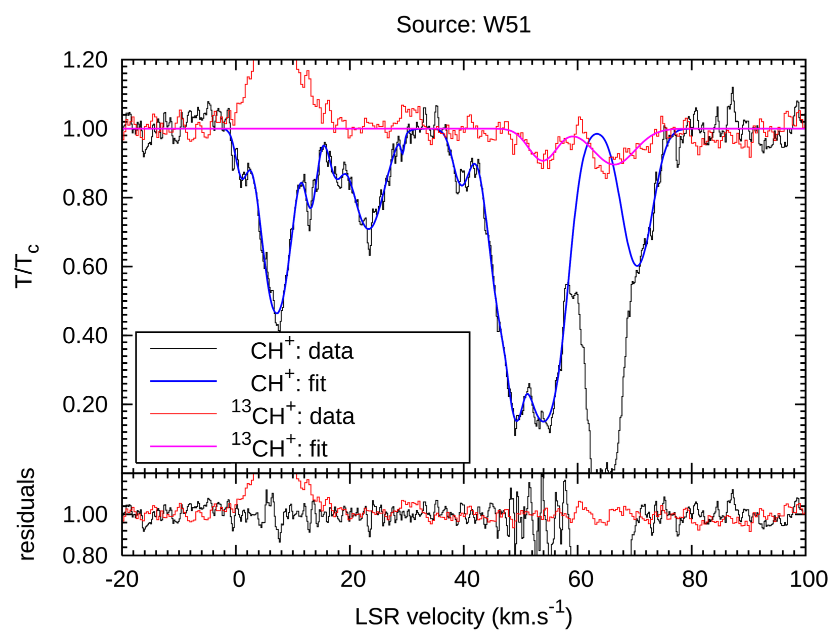


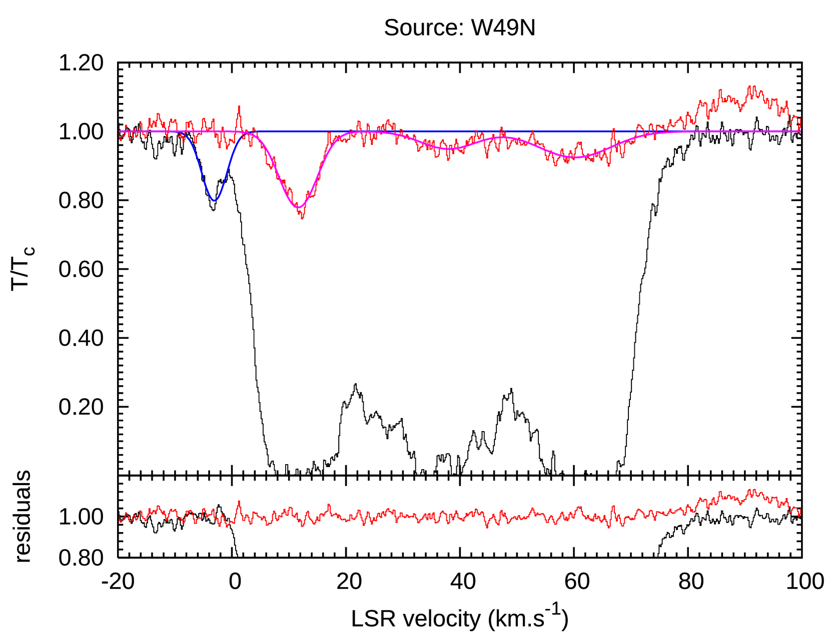


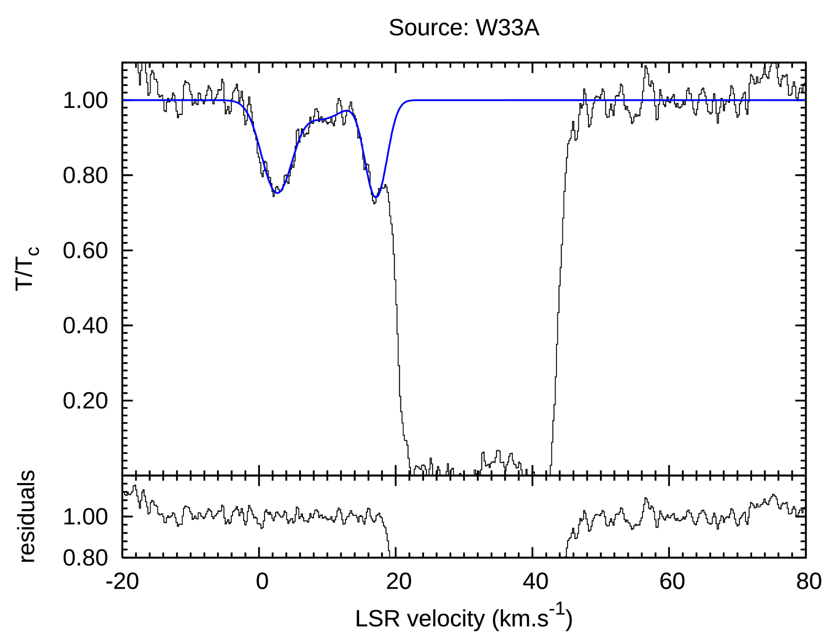
The above figures and the figure on the left show the CH^+ (0-1) HIFI absorption spectra displaying the different LO tunings used to disentangle lines from the upper and lower sidebands. In some cases, the saturated parts of the profiles fall below half the continuum level (green line), suggesting a gain sideband ratio different from unity. Note that no CH^+ (1-0) emission line is detected. The emission lines are from a different molecular species.

2. Data analysis

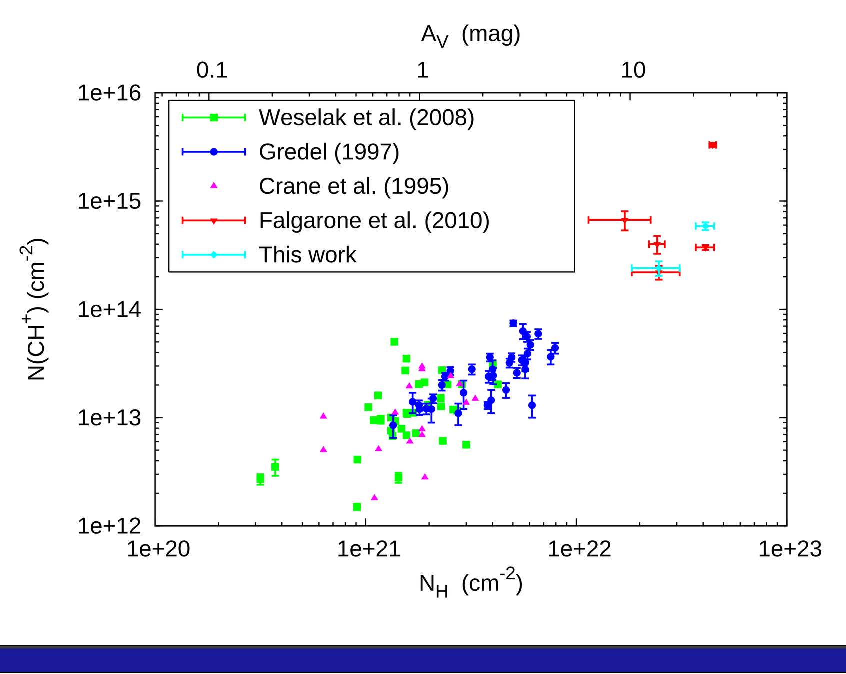
$^{12}CH^+$ and $^{13}CH^+$ are displayed for the rest frequencies $\nu = 835137.5$ and $\nu = 830214.0$ MHz respectively, [7],[8]. The non-saturated parts of the absorption profiles are decomposed into distinct velocity components. The opacity per component is inferred from a multi-Gaussian fitting procedure based on the Levenberg-Marquardt algorithm [9].







3. CH+ column densities

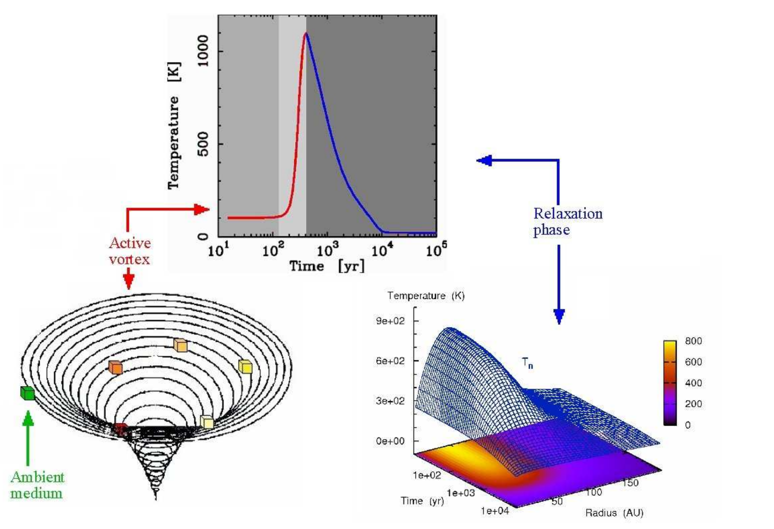


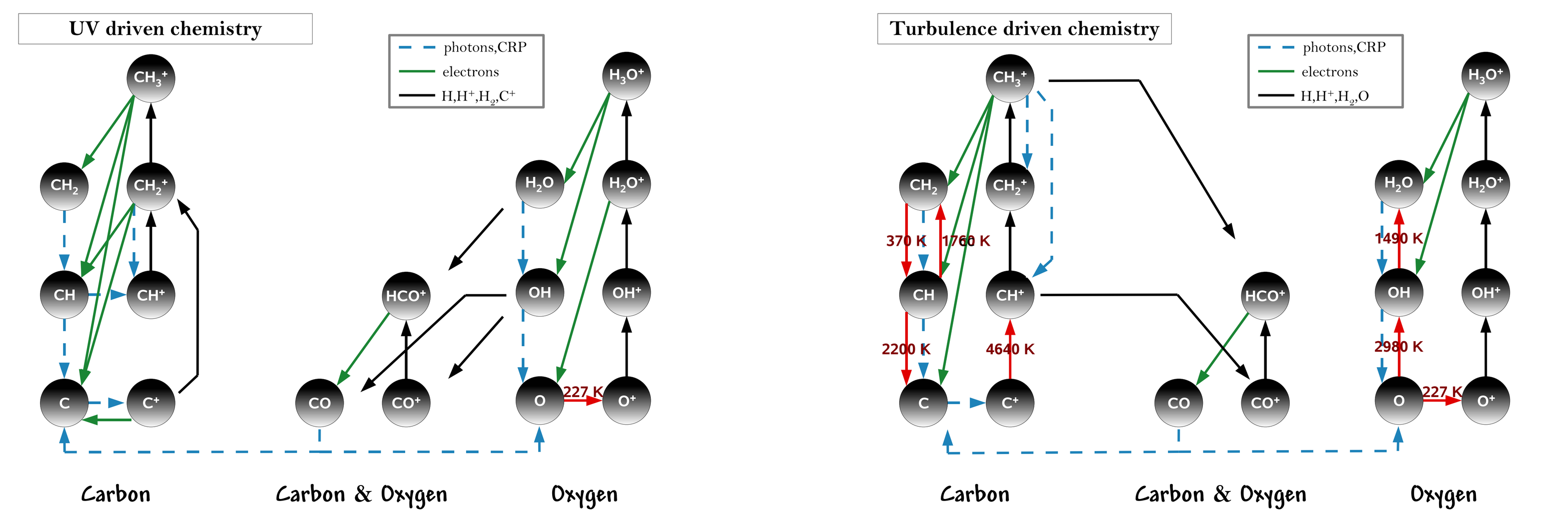
The CH^+ column densities inferred from the HIFI $^{13}CH^+$ lines are computed for an isotopic ratio of 50 and compared to other samples : CSO submillimeter data in red [1] and visible data from absorption lines towards nearby stars [2],[3],[4]. They are displayed versus to the total H column density on each line of sight, inferred from K extinction [5]. The scatter of the data points are large. However, the average CH^+ abundances are about 3 times larger among the inner Galaxy sources than in the Solar Neighborhood : $[CH^+]/[H] = (3 \pm 2) \times 10^{-8}$ and $(8 \pm 5) \times 10^{-9}$ respectively.

II Model of turbulent dissipation regions (TDR)

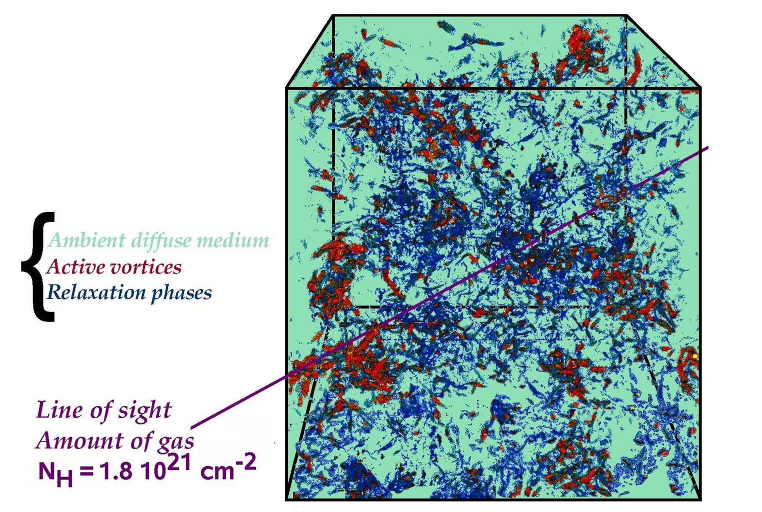
1. Chemical and thermal evolution of a magnetized vortex

The TDR code is a 1-D model in which the chemical and thermal evolutions of a turbulent dissipative burst followed by a long lasting relaxation period are computed (right panel). The induced heating terms are sufficient to trigger a warm chemistry, *i.e.* not only driven by the UV photons. The chemical network is fundamentally modified because many endothermicities and activation barriers are overcome (bottom panels). During both the dissipation and relaxation stages, the abundances of CH^+, HCO^+, OH, H_2O, CN and many others molecules rise from 2 to 5 orders of magnitude over the whole structure ($\sim 10^2$ AU).





2. Modelling of a random line of sight across the diffuse ISM



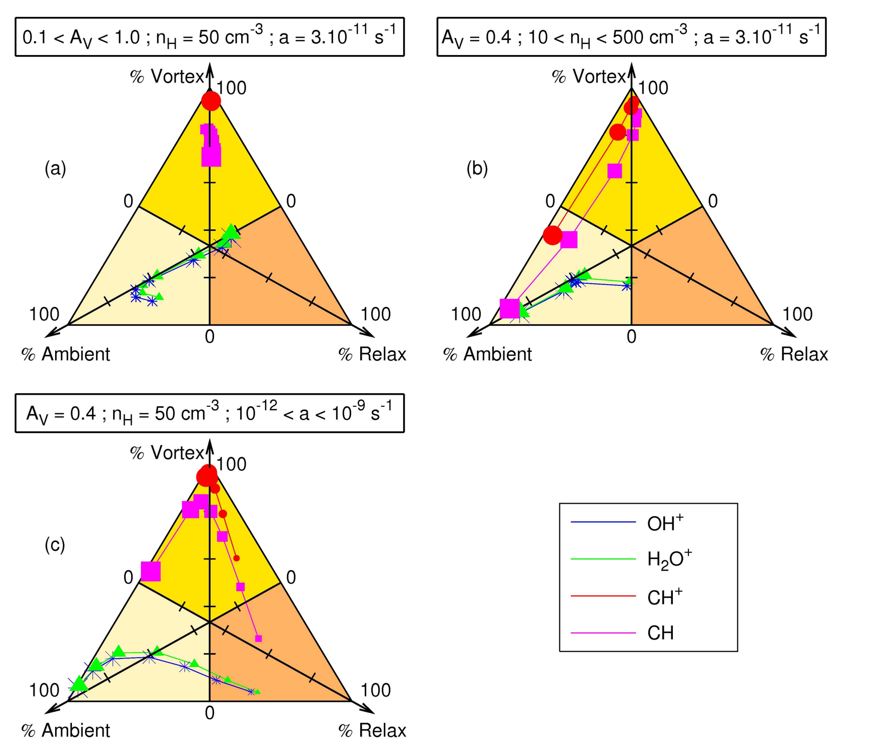
A random line of sight intercepts three kinds of diffuse gas (left panel) : (1) the ambient medium (with a filling factor larger than 90 %) in which the chemistry is driven by the UV radiation field, (2) the active vortices where the chemistry is enhanced by the dissipation of turbulent energy, and (3) the relaxation stages where the gas previously heated and enriched cools down to its original state. The total number of active vortices is fixed by the average turbulent transfer rate ε in the cascade.

III TDR model predictions

The average CH^+ abundance depends on the density and the UV-illumination conditions of the gas in which the bursts occur. For $10 < n_H < 500$ cm^{-3} and $0.2 < A_V < 1.0$, it scales as

$$\frac{N(CH^+)}{N_H} \sim 1.9 \times 10^{-9} \frac{\varepsilon}{2 \times 10^{-25}\mathrm{erg.cm^{-3}.s^{-1}}} \left(\frac{n_H}{50\mathrm{cm^{-3}}}\right)^{-2.33} \left(\frac{A_V}{0.4}\right)^{-1} \qquad (1)$$

for $\chi = 1$ (in units of the Draine's UV interstellar radiation field). Depending on the parameters, the fraction of CH^+ formed in the active stages varies between 40 % and 100 % (bottom panels).



Thefigures on the left illustrate the influence of the UV-shielding (top left), gas density (top right) and turbulent rate of strain a (bottom left) on the chemistry of 4 species. They display the relative contribution of each phase (ambient medium, active or relaxation phase of the dissipation burst) to the abundance of a given molecule. The symbols increase as the parameter increases in each triangle.

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