Hunt for Molecules
F. Combes, F. Casoli, E. Falgarone, L. Pagani (eds)

EXTRAGALACTIC MOLECULAR HYDROGEN

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Abstract. Absorption line observations in the far-UV with FUSE have allowed to detect molecular hydrogen in the diffuse interstellar medium in front of several stars in both Magellanic Clouds and in front of the star cluster NGC 604 in the nearby spiral M 33. Upper limits have been obtained for a number of blue compact dwarf galaxies. The observed H_2/HI ratios are smaller than in our Galaxy, due to the higher UV radiation field and the lower abundance of dust. We also give a short discussion of the abundances of heavy elements in the neutral medium in front of NGC 604, as derived from observations with FUSE.

1 Introduction

Observations of absorption lines offer the best way to determine accurate abundances of molecules in the interstellar medium. Such observations were first made in the near-UV for Galactic CH, CH^+ and CN, then in the far-UV for H_2 (Carruthers 1970; Spitzer & Cochran 1973). In radio, and especially at millimeter wavelengths, OH, H_2CO, HCO^+, HCN (Encrenaz et al. 1980), CO and many other molecules have been detected in absorption in our Galaxy and in external galaxies (Liszt & Lucas 2004 and references herein). However, apart for a few observations of redshifted H_2 in Broad

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Absorption Line systems in front of quasars, far-UV observations of H_2 in external galaxies had to await the launch of the Far Ultra Violet Explorer (FUSE) in 1999

2 H_2 in the diffuse interstellar medium of the Magellanic Clouds

A comprehensive study with FUSE of H_2 lines in front of hot stars in the Magellanic Clouds is due to Tumlinson *et al.* (2002). These stars suffer little reddening (E(B-V) $\leq$ 0.27), so that the observed H_2 belongs to the diffuse interstellar medium. CO line observations show that there are dense molecular clouds in the Magellanic Clouds, but the stars behind or inside these clouds are too reddened to be observed with FUSE. The FUSE observations are summarized in Fig.1, in which the logarithm of the molecular fraction $f_{H_2} = H_2/H_{total}$ ratio is plotted as a function of reddening, with a comparison to Copernicus observations of stars in the Galactic disk. This comparison shows that f_{H_2} is smaller in the Magellanic Clouds, respectively 0.010 for the SMC and 0.012 for the LMC, compared with 0.095 for the Galactic disk. In particular, there is a sharp drop of f_{H_2} at low reddening. This could be explained by a reduced formation rate of H_2 on grains due to a lower abundance of metals, hence of grains, and to an enhanced photodissociation rate due to a higher far-UV radiation field in the Clouds.

3 FUSE observations of H_2 in other galaxies

Within a broad collaboration, we are conducting a program with FUSE whose principal aim is to see if the abundances of heavy elements differ in extragalactic HII regions and in the surrounding neutral medium. We first observed several blue compact galaxies (IZw 18, Mrk 59, IZw 36; others observed SBS 0335-052 and NGC 625): although absorption lines are seen in front of the hot stars of the ionizing cluster, no extragalactic H_2 could been detected in any of these galaxies.

However a positive detection has been achieved for the neutral medium in front of the cluster of ionizing stars in NGC 604, the brightest HII region of the nearby galaxy M 33 (Lebouteiller *et al.* 2006): Fig.2, We find a column density of logN(H_2) = 16.86±0.30 mol. cm^{-2}. This is only a tiny fraction (1.3 10^{-4}) of the total hydrogen since logN(HI) = 20.75±0.30 at. cm^{-2}. The excitation diagram of H_2 (Fig.3) shows as usual a thermal part

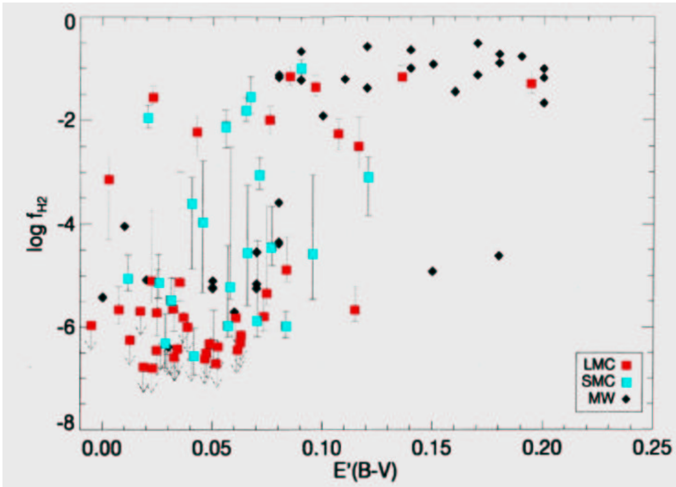

Fig. 1. Comparison of the FUSE LMC and SMC molecular fractions with the Copernicus sample of stars in the Galactic disk. The logarithm of the molecular fraction $f_{H_2} = H_2/H_{total}$ ratio is plotted as a function of the foreground-corrected color excess E'(B-V). From Tumlinson *et al.* (2002).

with temperature 112±10 K for J=1 and 2 and a higher excitation for J=3 and 4.

4 Heavy element abundances in front of NGC 604

While our result on the abundance of H_2 in front of NGC 604 only confirms what was known in the Magellanic Clouds, the FUSE spectrum also contains information on the abundances of several heavy elements. Reduction of the data by one of us (VL) using the profile-fitting procedure OWEN developed by Martin Lemoine and the FUSE french team at the Institut d'Astrophysique de Paris suggests that nitrogen, oxygen and argon are underabundant by one order of magnitude in the diffuse neutral medium in front of NGC 604 with respect to the abundances in the ionized gas of the HII region (Fig.4). However the abundance of ionized iron looks similar in the two media. Similar results have been obtained previously for several blue compact dwarf galaxies, for example IZw 36 (Lebouteiller *et al.*

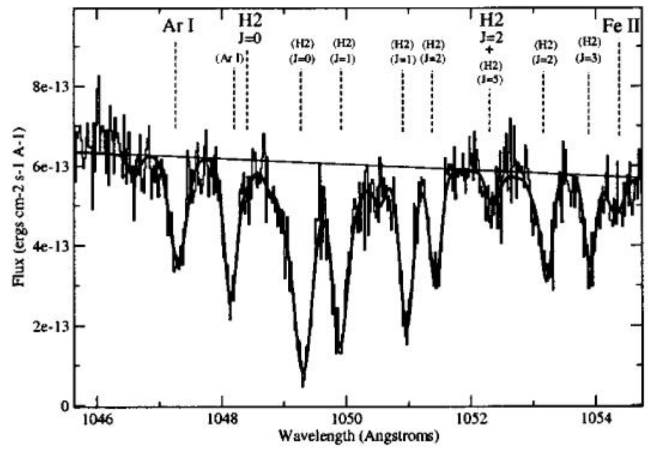

Fig. 2. Fragment of the FUSE spectrum of NGC 604 showing a number of Galactic H_2 lines and two H_2 lines from the diffuse interstellar medium in M 33 (labelled H_2). Two metal lines from M 33 are also visible.

2004), although with less certainty due to the lower signal-to-noise ratio in the FUSE spectra. A deeper analysis of the line saturation problems (Lebouteiller, 2005) shows that the only elements with reliable column density determinations in the neutral diffuse medium are ArI, FeII and PII: saturation makes the determination very uncertain for NI and OI. The underabundance of ArI by a factor 10 with respect to the ionized medium suggests a real underabundance of the element: it is difficult to imagine that there could be 10 times more ArII than ArI in the neutral medium, and argon cannot be much depleted on grains. The interpretation of the result for FeII - similar underabundances in the neutral and ionized gases - is far from obvious, because iron is known to be depleted on grains in both media; but if the overall abundance of iron is indeed smaller in the neutral medium, why should iron be more depleted in the ionized gas? As to phosphorus, its abundance is not accurately determined in the neutral gas, and not measured at all in the ionized one, so that a comparison is premature.

This discussion should warn against a too rapid interpretation of the abundances derived from absorption lines in the far-UV. Fully reliable re-

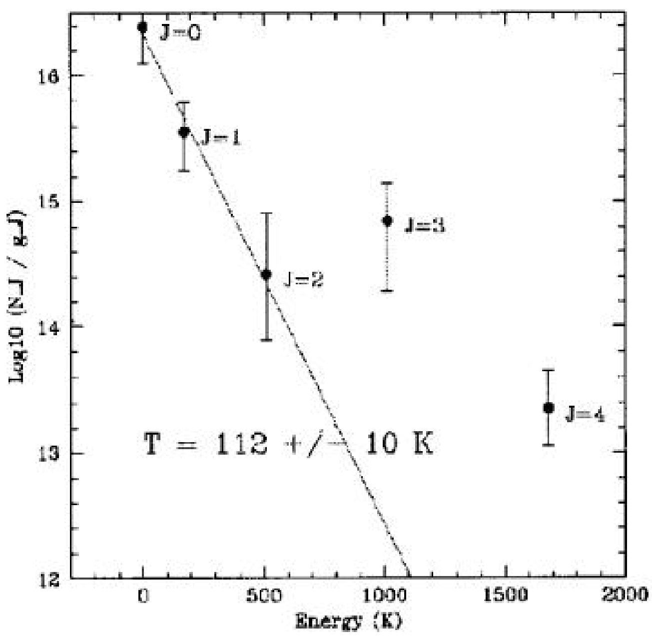

Fig. 3. Excitation diagram for the first 4 rotational levels of H_2 in the diffuse interstellar medium in M 33 in front of NGC 604. Column densities of the levels divided by the statistical weights are plotted against their excitation energies, in K. The rations of the J=1 and 2 to the J=0 levels yields a rotational temperature $T = 112 \pm 10$ K.

sults would require a high signal-to-noise ratio, and a better wavelength resolution than provided by FUSE for observations of extended targets like extragalactic HII regions. The first condition and to some extent the second one are met in observations of Magellanic Cloud stars, which should help to solve the present dilemna about possible abundance differences in the neutral diffuse gas and the HII regions in external galaxies.

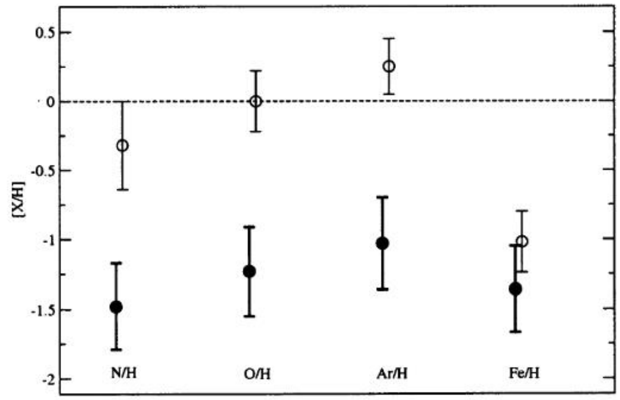

Fig. 4. Abundances of N, O, Ar and Fe with respect to the solar abundances, in the neutral diffuse gas in front of NGC 604 (full circles with error bars) and in the HII region NGC 604 itself (empty circles with error bars).

References

Carruthers, G.R. 1970, ApJ, 161, L81

Encrenaz, P.J., Combes, F., Lucas, R., Stark, A.A., Linke, R.A., & Wilson, R.W. 1980, A&A, 88, L1

Lebouteiller, V. (2005) Thèse, Université Paris VI

Lebouteiller, V., Kunth, D., Lequeux, J., Lecavelier des Étangs, A., Désert, J.-M., Hébrard, G., & Vidal-Madjar, A. (2004) A&A, 415, 55

Lebouteiller, V., Kunth, D., Lequeux, J., Aloisi, A., Désert, J.-M., Hébrard, G., Lecavelier des Étangs, A., & Vidal-Madjar, A. (2006) A&A, submitted

Liszt, H. & Lucas, R. 2004, A&A, 428, 445

Spitzer, L. Jr. & Cochran, W.D. 1973, ApJ, 186, L23

Tumlinson, J., Shull, J.M., Rachford, B.L. *et al.*, 2002, ApJ, 566, 867