

Deuterium Chemistry in Starforming Regions

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Motivation

Deuterated molecules and in particular H_2D^+ are tracers for the unique chemistry of cold, dense environments like the very early stages of star formation. In addition to that, H_2D^+ is one of the few observable molecules that stays in the gas phase even at very low temperatures. Thus H_2D^+ observations can be used to probe the kinematical processes of the very inner region of protostellar cores. H_2D^+ in its ortho form has been detected in a few sources (see Fig. 1). We plan to observe the ground state transition of para- H_2D^+ at 1370 GHz using the CO N⁺ Deuterium Observations Receiver (CONDOR).

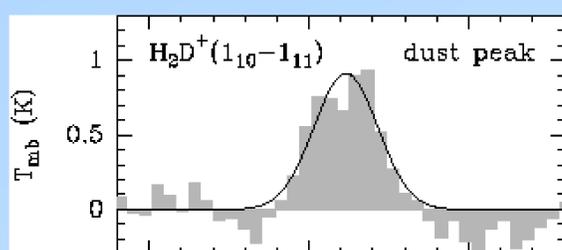
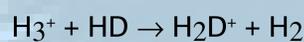


Fig. 1: Spectrum of ortho- H_2D^+ in L 1544, taken from Caselli et al. 2003.

Introduction

In recent years more and more deuterated species of molecules have been detected in space. Despite the low D/H ratio in the solar neighbourhood (10^{-5}), the relative abundance of these molecules, compared to their protonated counterparts, reaches values 0.1 to 1. At low temperatures, most deuterated molecules are formed via reactions with H_2D^+ . The $\text{H}_2\text{D}^+/\text{H}_3^+$ abundance therefore determines the fraction of deuterated molecules as a whole in these environments. Because of the mass dependence of the zero-point-energy and symmetry reasons the reaction



is endothermic by 220 K. From this follows that at low temperature (< 20 K) the H_2D^+ abundance is of the same order as that of H_3^+ .

A high H_2D^+ abundance is reached when CO, the main destroyer of H_2D^+ , is frozen out onto dust. Environments, that provide such condition are the early stages of star formation. In their dense, highly shielded protostellar cores and protostars temperatures below 10 K are reached.

Deuterium Chemistry

Due to the high activation energy of neutral-neutral reactions, ion-neutral reactions are the only ones taking place in cold, dense environments. H_3^+ and its isotopomers are the most abundant ions and thus play an important role in the chemistry.

Reaction with molecules containing heavier atoms, such as CO and N_2 , are of particular interest, since their daughter products N_2D^+ and DCO^+ are relatively easy to detect and are direct indicators for a high H_2D^+ abundance. Since nitrogen stays longer in the gas phase than CO, N_2D^+ is the best tracer for H_2D^+ . In the very inner part of star forming regions, however, only molecules consisting only of hydrogen and deuterium are gaseous.

Model

We developed a preliminary model, which calculates the equilibrium abundances of H_2D^+ and H_3^+ as a function of gas density and temperature. Furthermore the ortho/para- (o/p) ratio of H_2D^+ is computed. To simplify matters multiple deuterated isotopomers of H_3^+ (HD_2^+ and D_3^+) are neglected and CO is the only molecule included, which contains atoms heavier than helium.

The models show that once CO freezes out onto dust particles (at about 20 K) the H_2D^+ abundance increases dramatically. However the o/p ratio drops only initially because the lowest energetic level of ortho- H_2D^+ lies 86 K above that of para- H_2D^+ . At lower temperatures the o/p ratio rises due to chemical reactions, mainly collisions of H_2D^+ with H_2 (see contribution by Schlemmer).

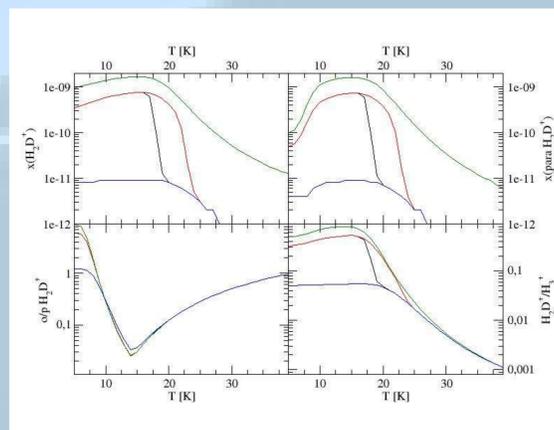


Fig. 2. The overall H_2D^+ abundance, para H_2D^+ abundance, the ortho/para- ratio of H_2D^+ and the $\text{H}_2\text{D}^+/\text{H}_3^+$ ratio are plotted as a function of temperature for four different chemical models. The H_2 density is 10^6 cm^{-3} in all four cases. The green line shows a model without any CO, whereas in another model CO was assumed to stay in gas phase (blue). The black and the red line represent models in which CO depletion was computed following Hasegawa & Herbst (1993) assuming an adsorption energy of 960 K and 1210 K, respectively.

Observations

Because observations of H_2D^+ are difficult due to poor atmospheric transmission and a shortage of receivers we observed several sources in N_2D^+ 3-2 (231.332 GHz) with the KOSMA 3m telescope, in February and March 2005.

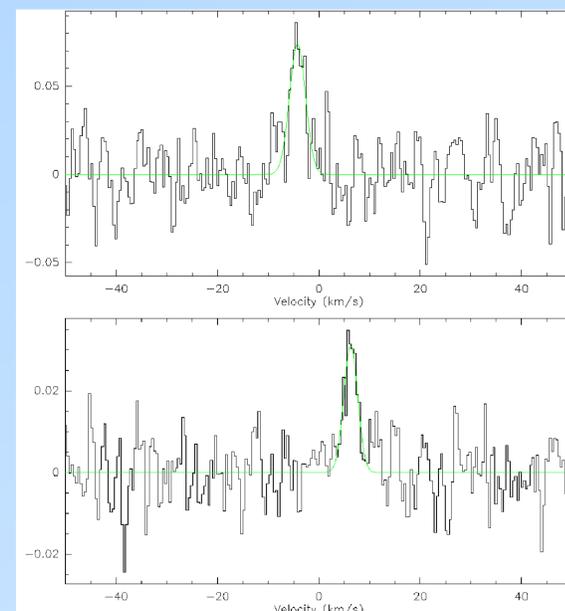


Fig. 3. N_2D^+ 3-2 spectra of the molecular ridge in the north of DR21 (upper panel) and the Class 0 protostar IRAS 03282+3035 (lower panel).

Both high mass- and low mass star forming regions are among these sources. The objects were selected because of their large N_2H^+ 1-0 emission and in the case of the high mass star forming regions because of their low $\text{CS}/\text{N}_2\text{H}^+$ ratio, indicating that molecules are frozen out onto dust. The brightest emission observed comes from the molecular ridge in the north of the high mass star forming region DR21. Additional N_2H^+ 3-2 (279.512 GHz) observations were carried out for this object. Due to the large beamsize ($2'$ at 230 GHz) the emission cannot be localized, but an average $\text{N}_2\text{D}^+/\text{N}_2\text{H}^+$ ratio of 0.1 ± 0.05 was measured, which corresponds to an $\text{H}_2\text{D}^+/\text{H}_3^+$ ratio of about 0.3.

The detection of N_2D^+ towards high mass star forming regions is of particular interest, because accelerated collapse, as suggested by Lintott et al. (2005), can not occur in sources where N_2D^+ had enough time to form.

Future Plans

We plan to observe the sources in which we detected N_2D^+ with larger telescope to obtain better spatial resolution. We are particularly interested in the ridge of DR21, where the source emitting N_2D^+ is completely unknown.

Furthermore we will observe the most promising objects in both ortho- and para- H_2D^+ . The H_2D^+ observation will allow us to trace the kinematics in cold cores as well as to test chemical models.

REFERENCES:

Caselli et al. 2003, A&A, 403, 37
 Hasegawa & Herbst 1993, MNRAS, 261, 83
 Lintott et al. 2005, ApJ, 620, 795