



Laboratoire d'Étude du Rayonnement et de la Matière en Astrophysique

### De-excitation of molecular hydrogen upon formation on water ice at 10 K: implications for dense interstellar clouds

### **Emanuele Congiu**

post doc @ LERMA Observatoire de Paris – Université de Cergy-Pontoise



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#### Key role of molecular hydrogen formation/destruction reactions in the Universe



- Hydrogen = **90%** visible matter

- H + H + grain  $\rightarrow$  H<sub>2</sub> + 4.48 eV

The degree of excitation of nascent H<sub>2</sub> will have an impact on the chemistry of the ISM

#### Energy partition upon H<sub>2</sub> formation



Influence on the dynamics of the interstellar medium

## Dense clouds : « H<sub>2</sub> world »



H<sub>2</sub>O

H<sub>2</sub>O

OCN- H<sub>3</sub>O+

CO



CO

- Adsorbed H<sub>2</sub> on the grains
- Modify sticking (Amiaud et al 2007, JCP)
- Isotopic segregation (Dulieu et al 2005,CPL)
- Ortho/para segregation (Amiaud et al 2008, PRL)
- Impact on energetics ?

### **Experimental apparatus**

#### (FORMOLISM)



### Experimental apparatus (D- and H-atom beams)



## Experiment



UHV chamber

- 1 Amorphous Solid Water Ice substrate Porous (P-ASW) or Non Porous (NP-ASW)
- 2 **D-beam** (60 % D, 40 % D<sub>2</sub>)
- 3 Monitor (real time) the residual partial pressure of  $D_2$

#### All D<sub>2</sub> molecules

ionizing electron energy in the QMS: Excited-D2 molecules

ionizing electron

energy in the QMS:

**15 eV** 

<u>30 eV</u>

# Formation of D<sub>2</sub> upon D irradiation of non-porous ASW





- Behaviour of  $D_2$  and D is different: D+D  $\rightarrow$  Formation occurs
- Non dissociated part of the beam adsorbes on the surface and <u>time evolution follows molecular coverage</u>
- Adsorbed molecules enhance the recombination efficiency





- Excited molecules only initially
- Then production of molecules but little internal excitation
- De-excitation favoured by the already adsorbed molecules





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А:





**B**:





**C**:





### Excited molecules from non porous ice Role of already adsorbed molecules



- Adsorbed D<sub>2</sub> molecules on the ice surface: Enhance formation rate but...
- ...de-excite promptly the nascent molecules in regime of surface saturation
- → molecules adsorbed act as energy exchangers (Schutte et al. 1976, JCP)



- No steep increase of excited-D2 signal



Weak signal of excited molecules :

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Atoms are mobile at 10 K and penetrate the porous structure

- Molecules formed are re-captured by the porous structure: no significant internal energy and no kinetic energy (Hornekaer et al 2003)







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Although excited-D<sub>2</sub> molecules are formed on an icy surface:

- → conditions in dense clouds (high molecular coverage + possible porous nature of grain surfaces) cause that only a small fraction of newly formed molecules are released in the gas phase with significant internal energy
- •Explains why attempts of excited-H<sub>2</sub> detection in dark quiescent clouds were unsuccessful (Tiné et al. (2003): LDN1498, LDN1512; Lemaire & Field (2001): Barnard 68)
- ➔ Most formation energy is likely to be deposited into icy grains in H₂ dominated region, and perhaps not only on icy surfaces... (on silicates and carbonaceous materials too?)





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## **Collaborators (lab team)**

Prof. J.L. Lemaire Dr. François Dulieu Dr. Henda Chaabouni Elie Matar (PhD) Hakima Mokrane (PhD) Mourad Chehrouri (PhD) Mario Accolla (visiting PhD)



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#### Tuning the kinetic energy of the ionising electrons



#### Tuning the kinetic energy of the ionising electrons



# Abrupt decrease of the binding energy (H<sub>2</sub> & D<sub>2</sub>)



(fig. 5 & 6, Govers Mattera Scoles, J. Chem. Phys., 1980, 72, 5446)