The impact of dust on interstellar gas

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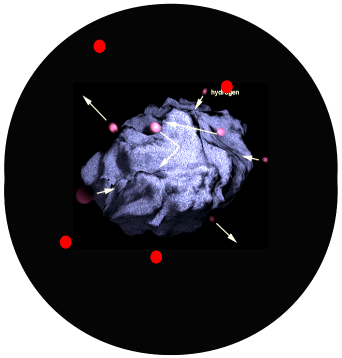
The low-metallicity ISM: chemistry, turbulence and magnetic fields

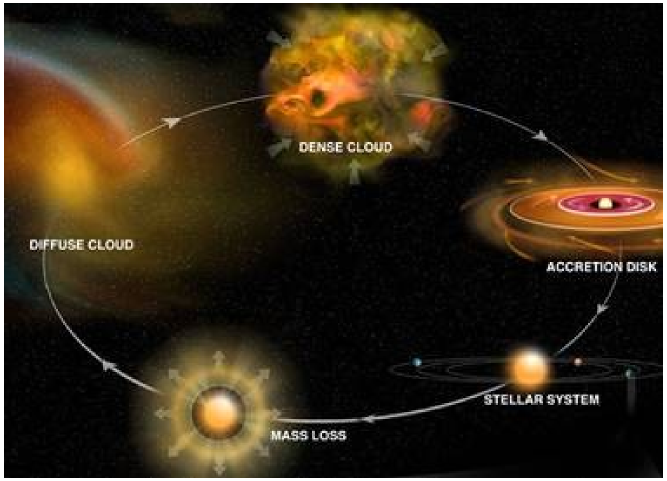
Overview

Star form in clouds made of gas + dust

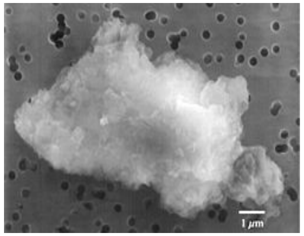
Catalyst: Enrich gas

H_2 , H_2O, O_2, H_2O_2





Reservoir:
Stealing the gas
Formation of ices



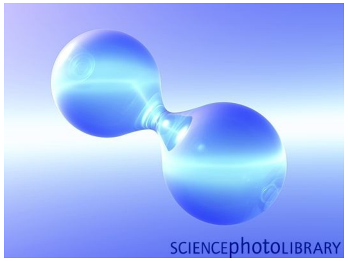
Impact of dust on the gas? Impact of dust on star formation?

Low metallicity? Traces of dust affect the chemistry?

Formation of H_2

Gas phase route:

$H^- + H \rightarrow H_2 + e^-$



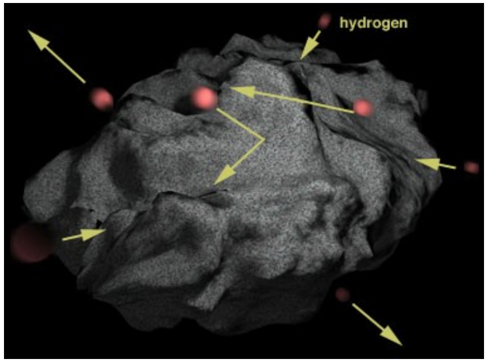
Grain surface route:

H_2 in MW **NOT** explained by gas phase reactions :

Grain *Gould & Salpeter 1963*

H_2 formation dust >> gas

Reaction exothermic → products gas

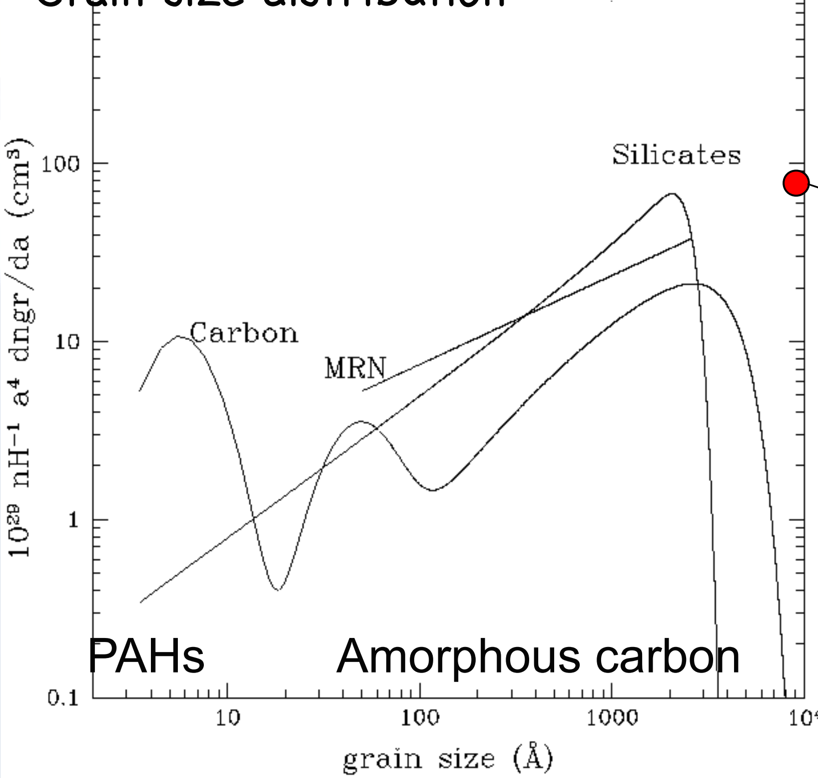


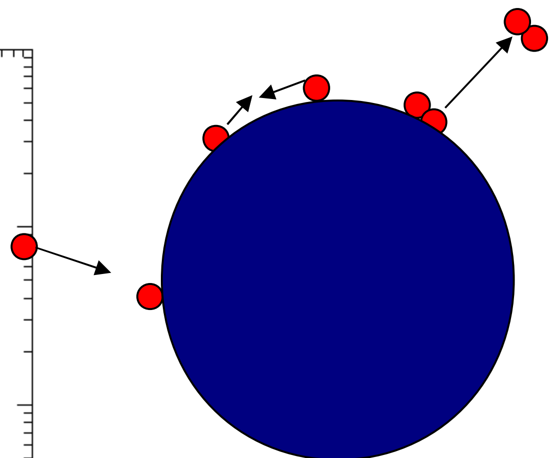
H_2 formation dust VS gas with metallicity?

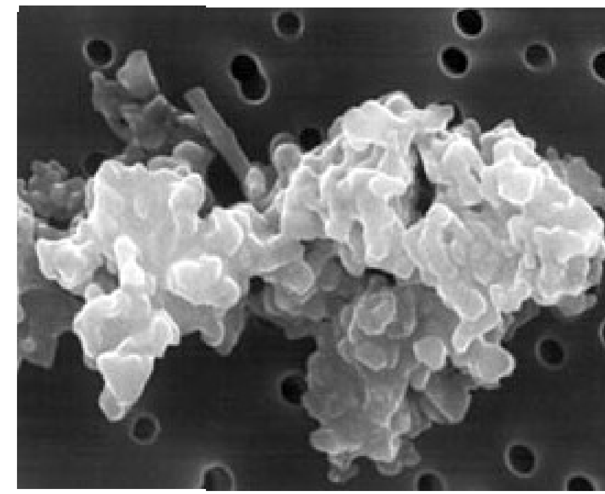
Are traces of dust enough to form H_2?

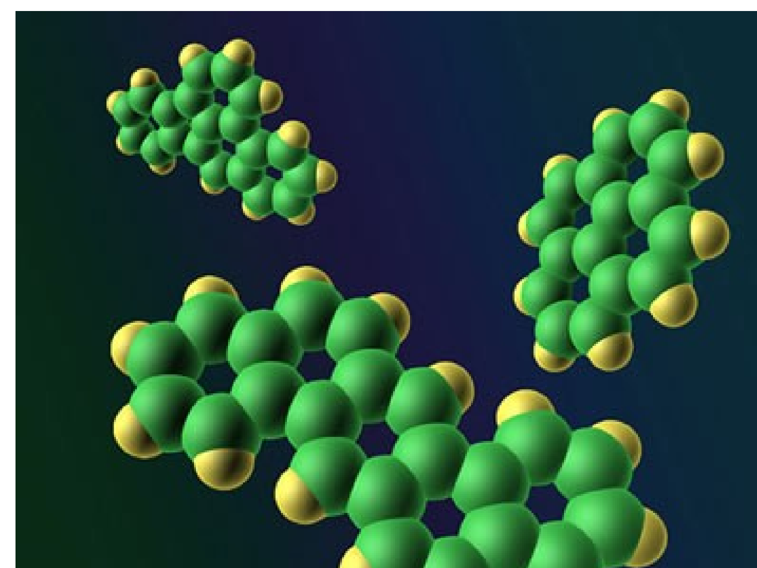
Interstellar dust grains

Grain size distribution









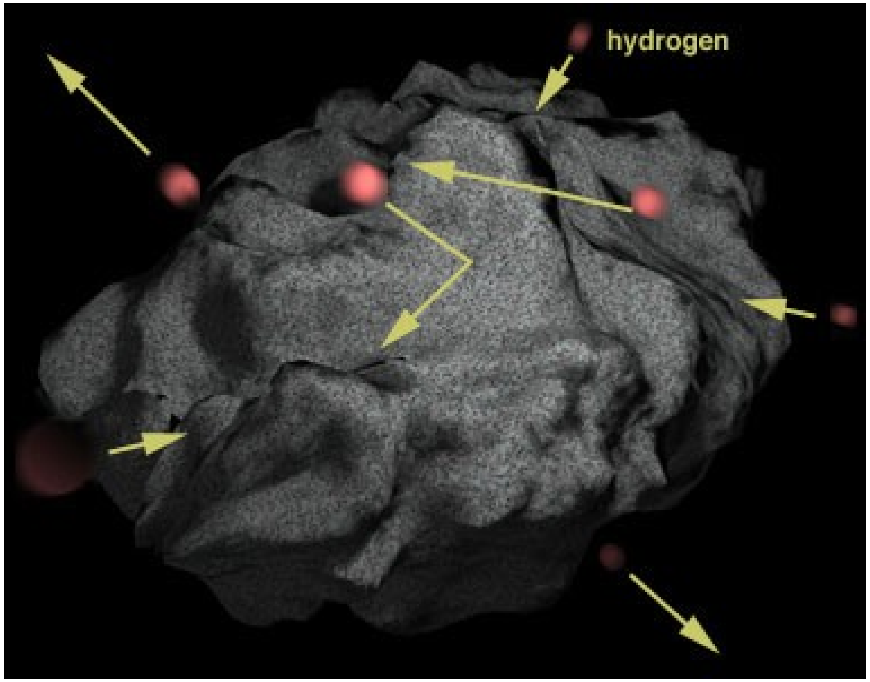
Weingartner & Draine 2001
Mathis, Rumpl & Nordsieck 1977

DUST= Silicates, Amorphous carbon, PAHs
PAHs = 50% of surface available for chemistry

Formation of H_2 on dust

1) Interactions atom/surface
   Experiments: TPD

   Ab-initio calculations



2) Mobility on the surface

Simulations → efficiency $\mathbf{H_2}$ formation

Early Universe. For which $Z_\odot$ dust boosts the formation of H_2?

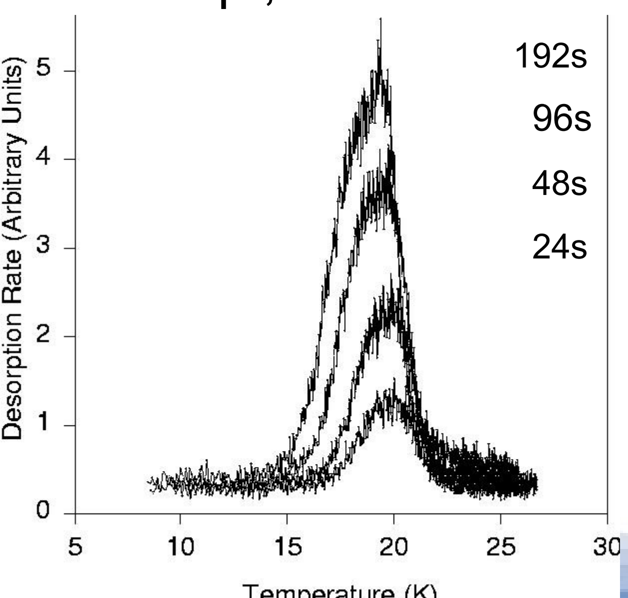
Interaction atom/surface: experiments

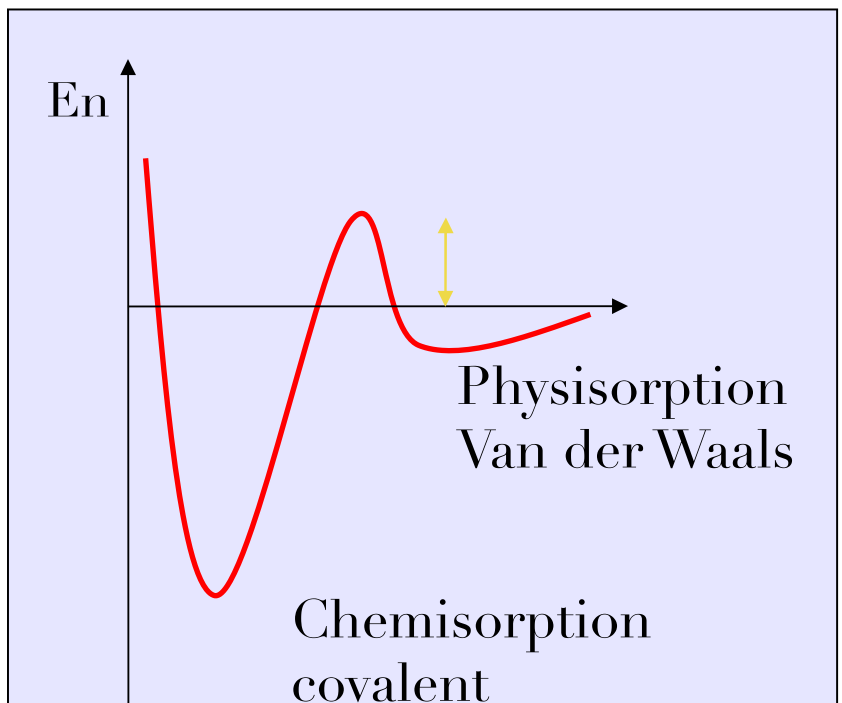
Experiments on graphite, amorphous carbon, silicates

Pirronello et al. 1997, 1999, Zecho et al. 2002, Perets et al. 2007, Vidali et al. 2007

Amorphous Carbon

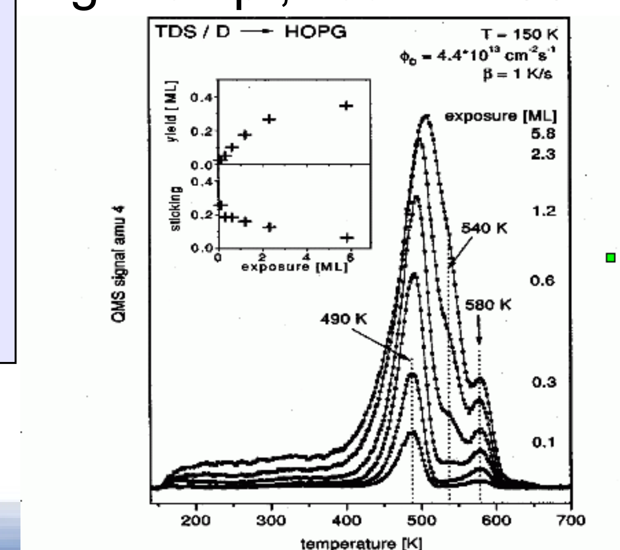
Low temp., Tsurf = 5 K



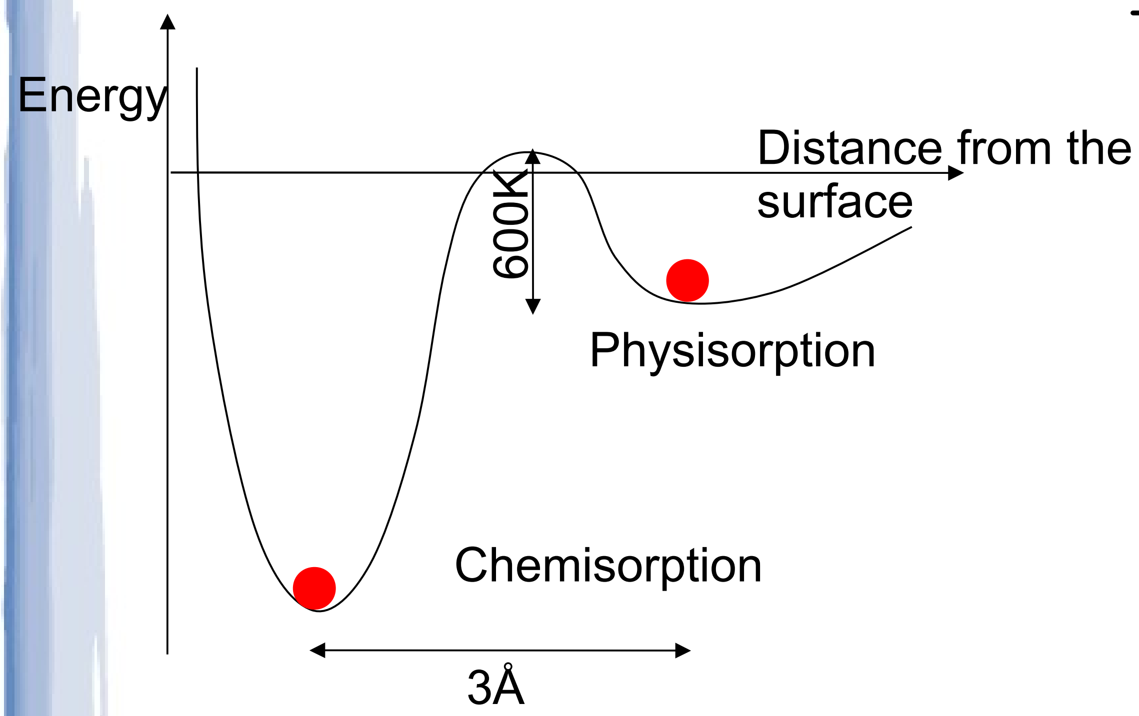


Graphite

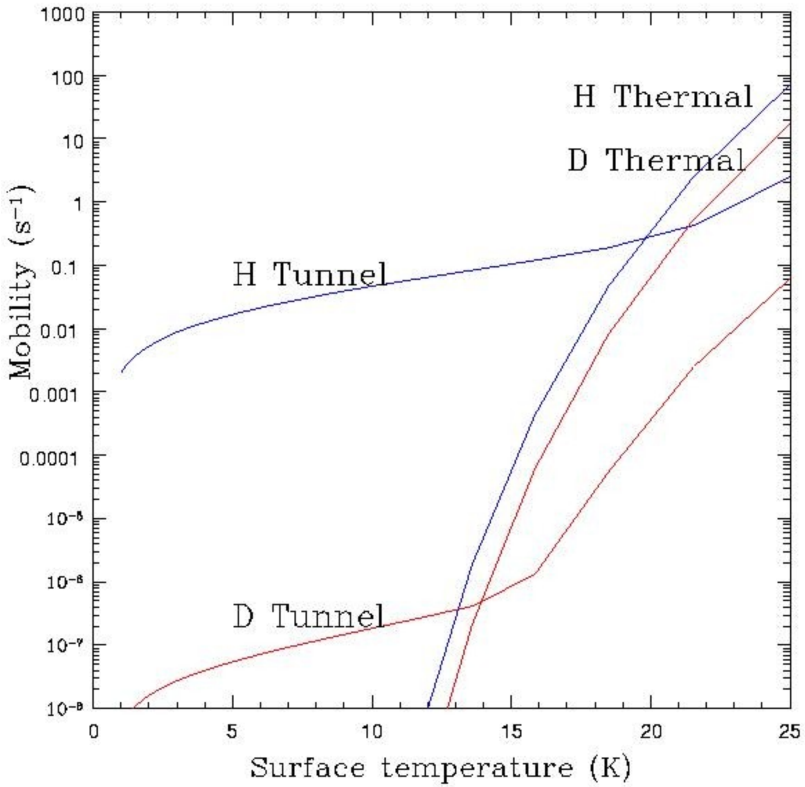
High temp., Tsurf = 150 K



Model:
Interaction and mobility

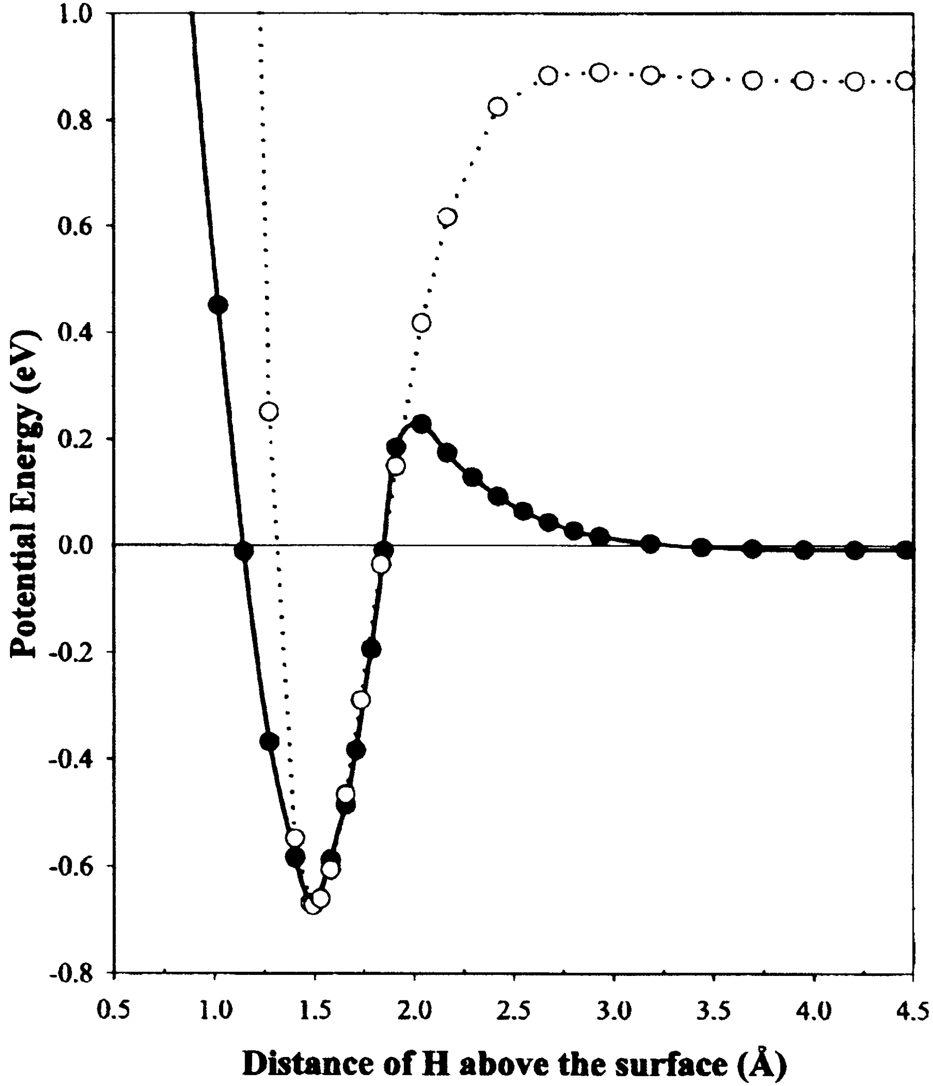


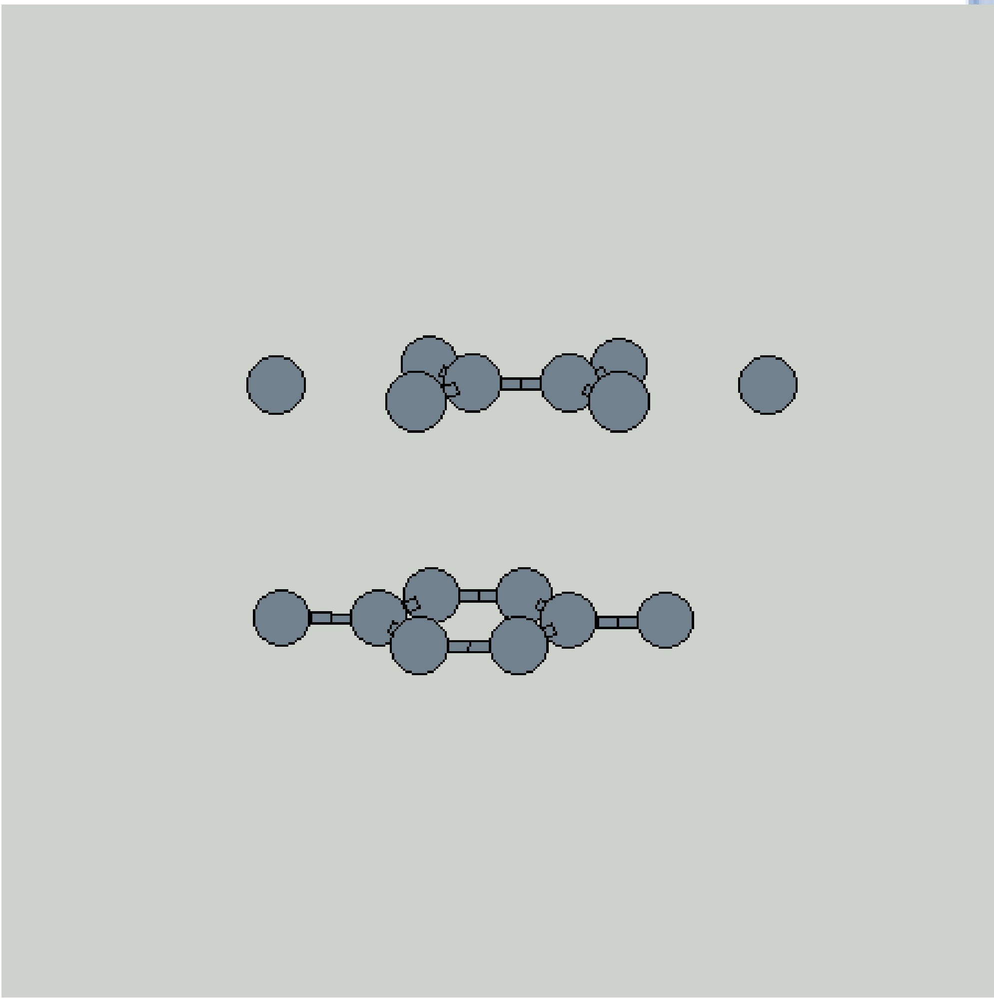
Transmission coefficient of the barriers
→ mobility of H and D atoms



- Physisorption + chemisorption
- tunnel + thermal hopping

Interaction atom/surface: Density functional theory (DFT)

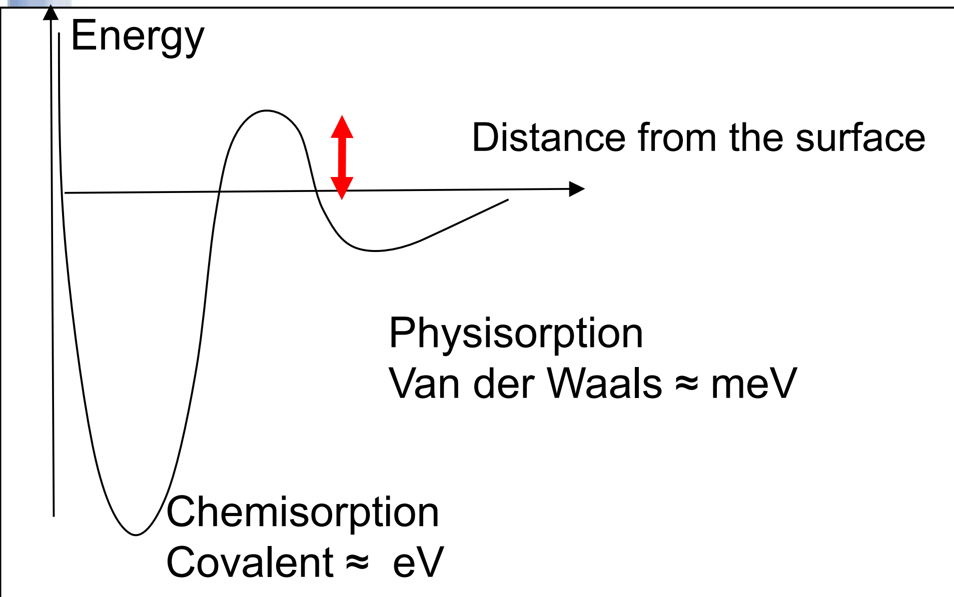




Eva Rauls

Sha et al, Surface Science 496, 318 (2002)

Interaction atom/surface: experiment



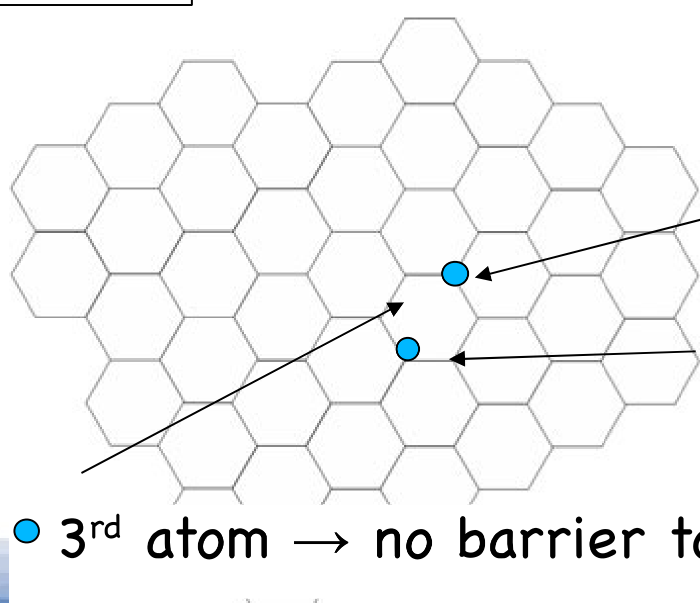
Graphite:

Chemisorption of H
C puckered out of the basal plane
associated with barrier ~ 0.2 eV.

Jeloaica & Sidis 1999

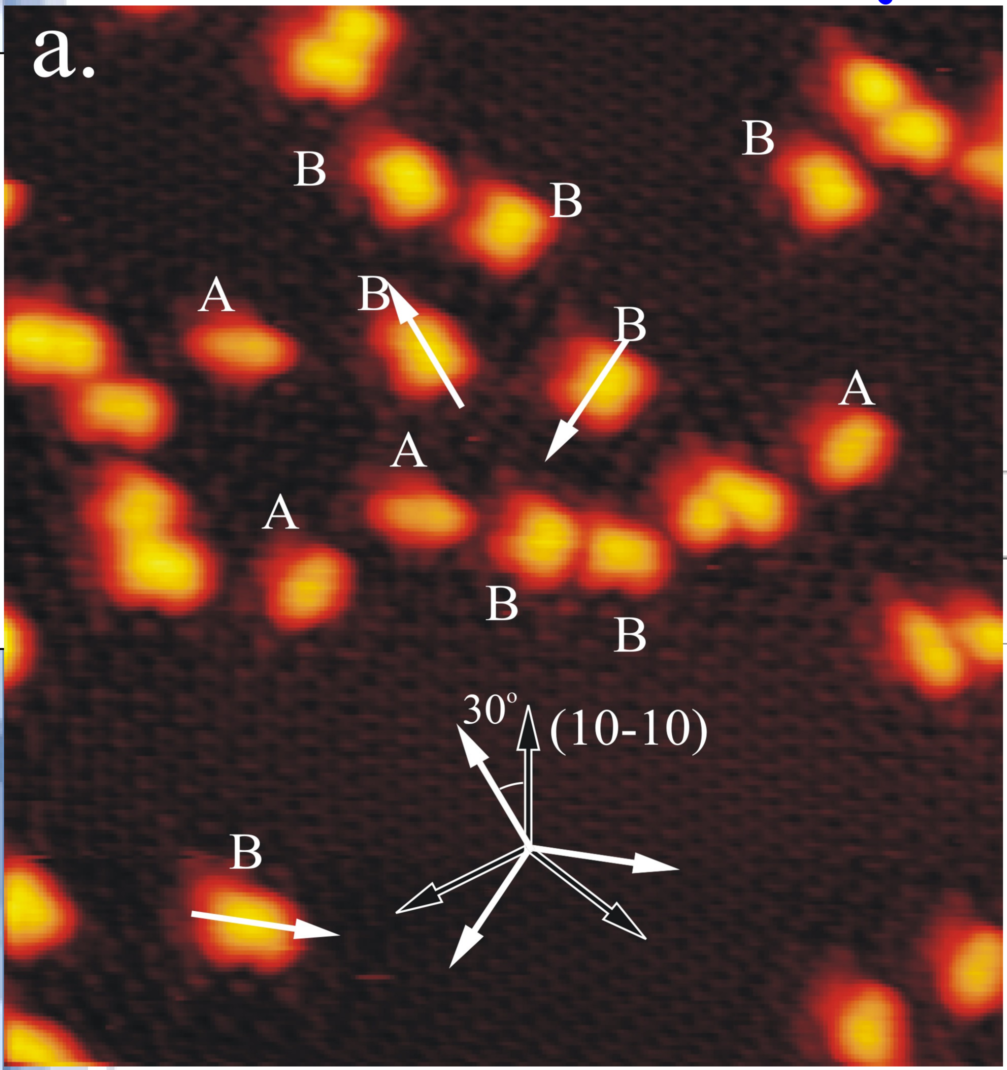
Sha & Jackson 2002

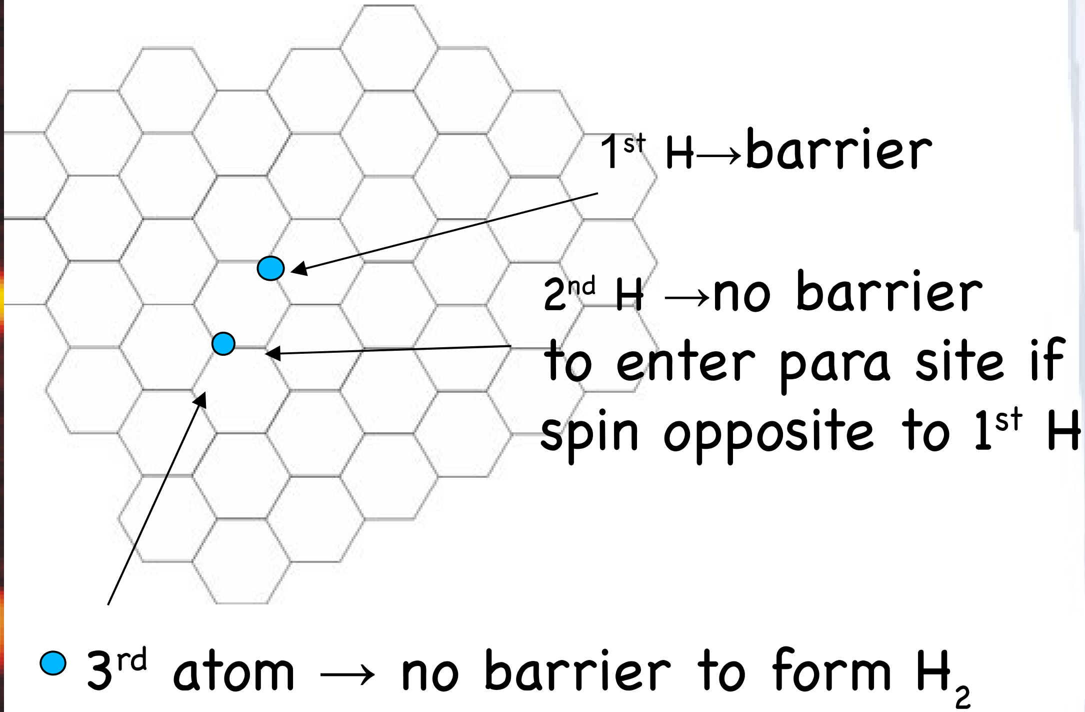
Recent studies:
Hoernekær et al. 2006
Rougeau et al. 2006
Bachellerie et al. 2007



3rd atom → no barrier to form H_2

Interaction atom/surface: experiment



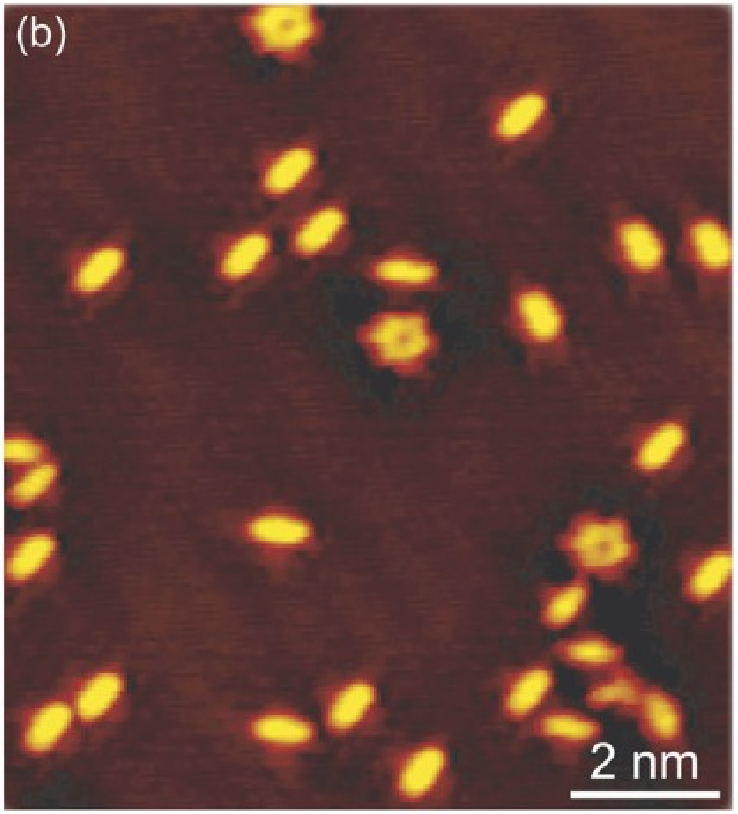


STM @ 170K

Hornekaer 2006

Interaction atom/surface: experiment

- 1 atom sticks → dust becomes catalyst → H_2 formation barrier-less



Atoms get grouped as
Dimers (2 atoms)
Trimers (3)
Hexamers (6)
Binding energy increases with number of atoms

Grain surface chemistry: Monte carlo simulations

Atoms arrive randomly from gas phase

$Flux = n_X v_X \sigma$ (s^{-1})

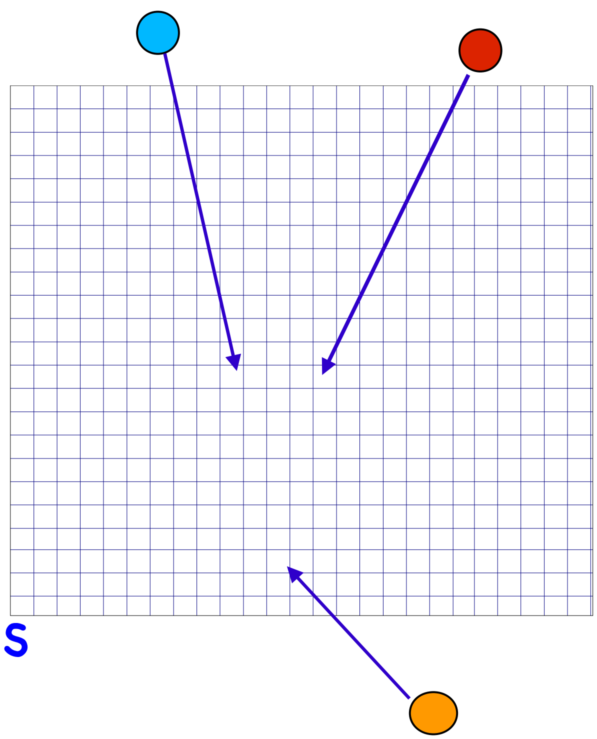
On the grid

random walk

UV + CR

Evaporation

Formation of molecules

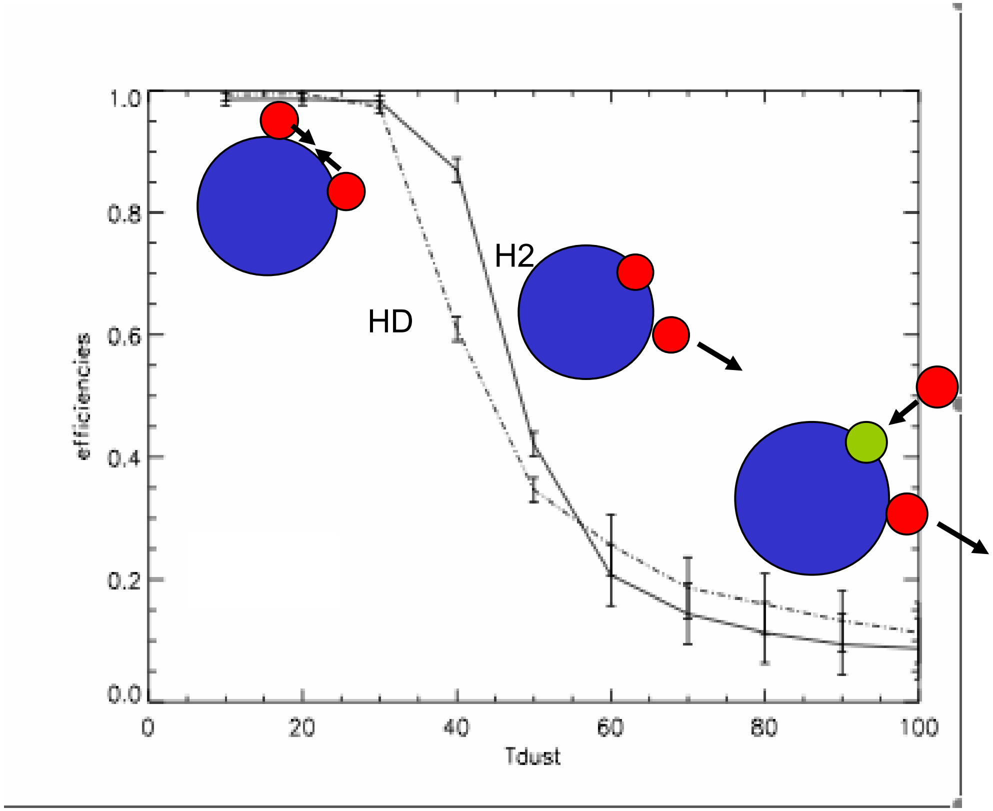


Grain surface = grid

Each point of the grid:

site atom/molecule

Formation of H_2 on dust



Formation of H_2 and HD

physisorbed atoms @ low T_{dust}

chemisorbed atoms @ high T_{dust}

clusters of atoms → H_2 and HD high T_{dust}

H_2 and HD in the early Universe

First stars cooled by H_2 → very massive ~100$M_\odot$

Stars cooled by HD few ~10$M_\odot$

Amount of coolant available → essential to star formation

H_2 and HD at low $Z_\odot$ **dust** VS **gas**?

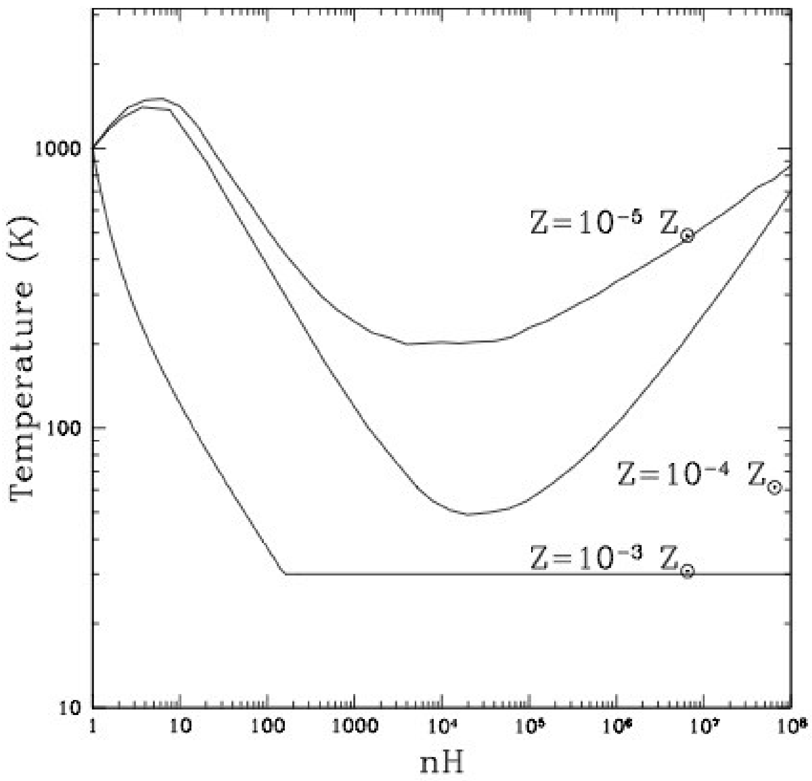
→ compute H_2 and HD formation during cloud collapse.

H_2 and HD in the early Universe

Cloud collapse with 1atom cm-3 @ z=10

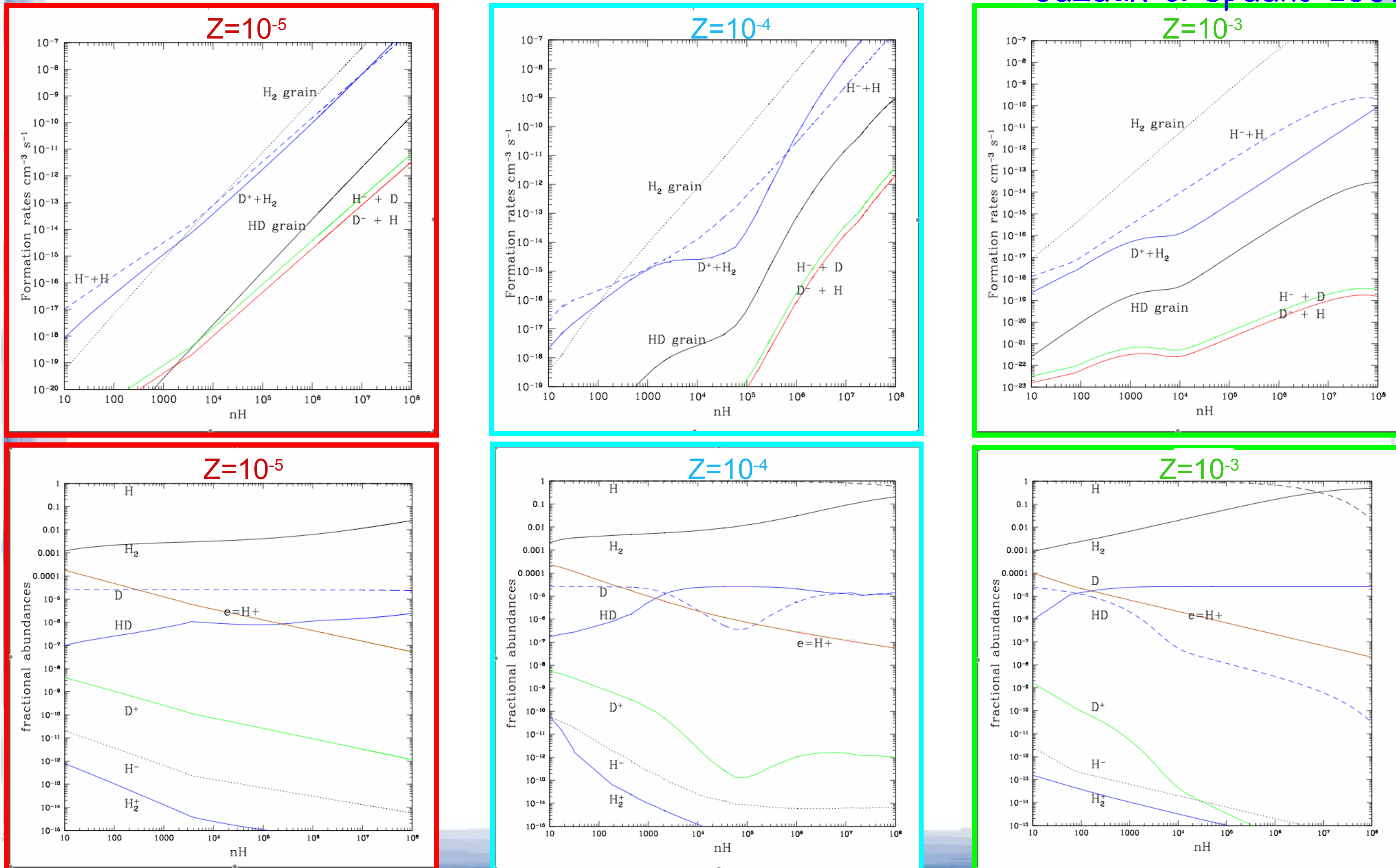
Temperatures profiles depend on

- Adiabatic heating
- Cooling by H2 and HD (when no metals, Glover & Abel 200
- Cooling by fine structure line: (Meijerink & Spaans 2005)



H_2 and HD in the early Universe

Cazaux & Spaans 2009



H_2 and HD in the early Universe: Conclusions

- Traces of dust → H_2 on dust grain most efficient route.

- H_2 produced → HD forms through $D^+ + H_2$ → Grain surface routes never dominate.

- Traces of dust boost H_2 which boost HD →
These coolants could impact star formation (Work in progress).

Formation of molecules on dust

Water is an important coolant of warm dense clouds (Neufeld 1995)

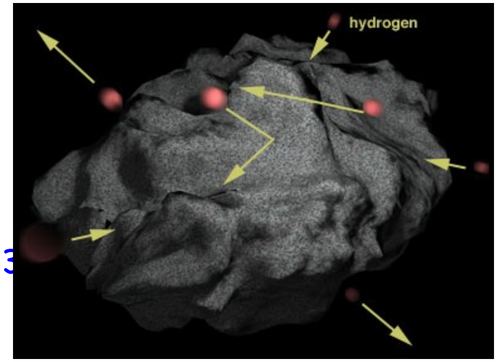
Observed by Hershel in XDR

H_2O forms → **gas**

- In warm environments H_2 + O
- Cold shielded cores H_3^+ / H_3O^+

→ **dust**

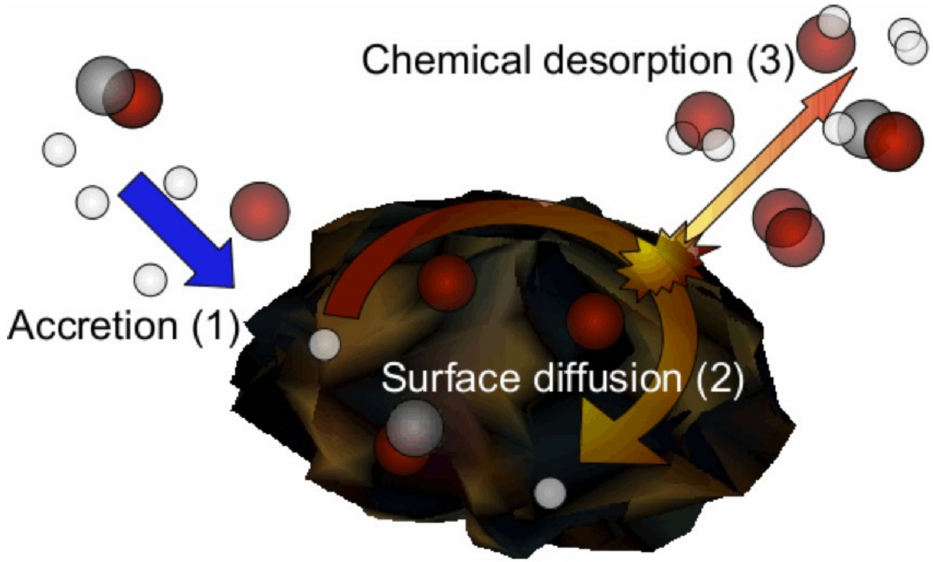
- Several routes involving O, O_2 and O_3



Formation of molecules on dust

Exothermic reaction → product released in gas.

$H + H \rightarrow H_2$	60 %
$H + O \rightarrow OH$	30 %
$OH + H \rightarrow H_2O$	90 %
$H_2 + O \rightarrow OH + H$	0 %
$H_2 + OH \rightarrow H_2O + H$	0 %
$O + O \rightarrow O_2$	60 %
$O + O_2 \rightarrow O_3$	50 %
$H + CO \rightarrow HCO$	80 %



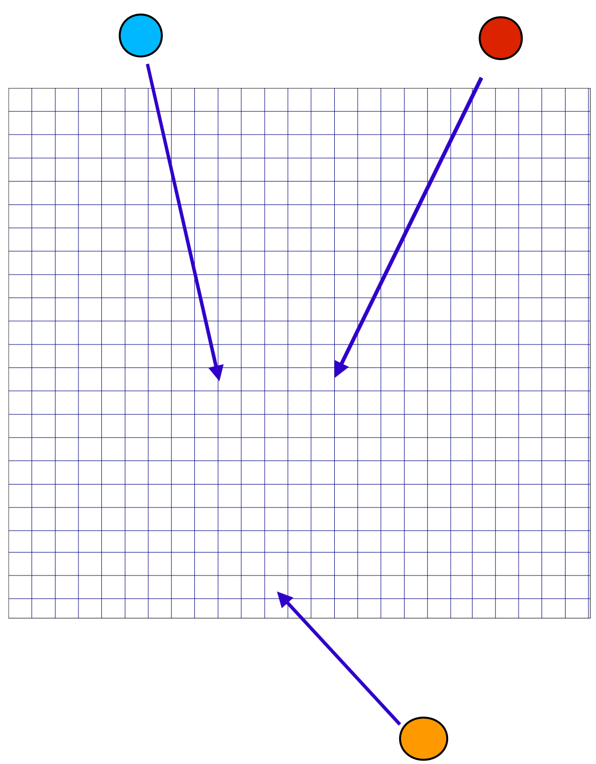
Derived from exp (Dulieu et al. 2012)

Formation of molecules on dust: Monte carlo simulations

Atoms arrive randomly from gas phase

$\text{Flux}=n_X\, v_X\, \sigma\ (s^{-1})$

- On the grid
- random walk
- UV + CR
- Evaporation
- Formation of molecules



Grain surface = grid

Each point of the grid:

site atom/molecule

H_2, HD, D_2, OH, OD, O_2, H_2O, HDO, D_2O, O_3, HO_2, DO_2, H_2O_2, HDO_2, D_2O_2

Diffuse clouds

Diffuse clouds: H atomic

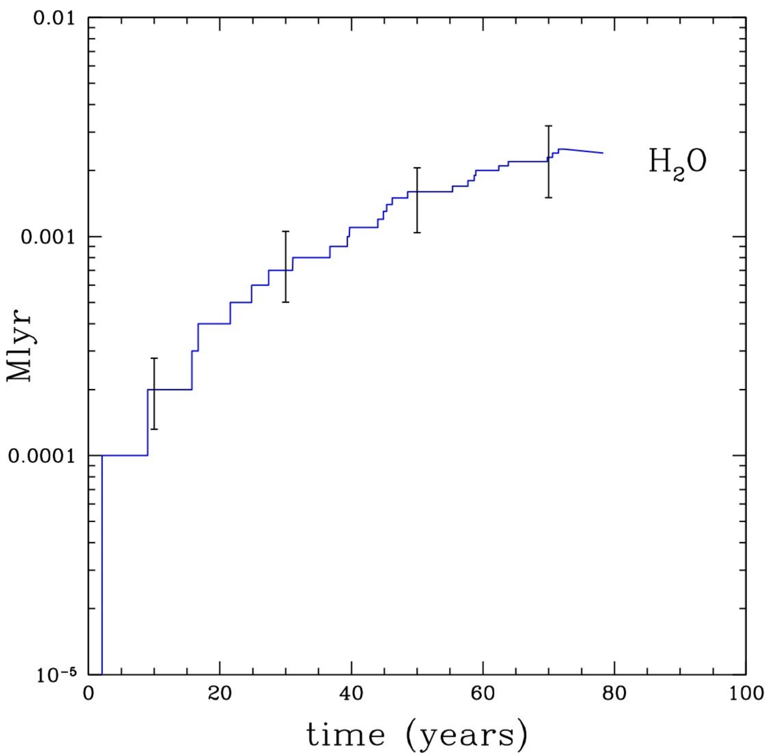
T_{dust}=18K, T_{gas}=100K

nH=100 cm^{-3}, O/H =3 10^{-4}, D/H=2 10^{-5}

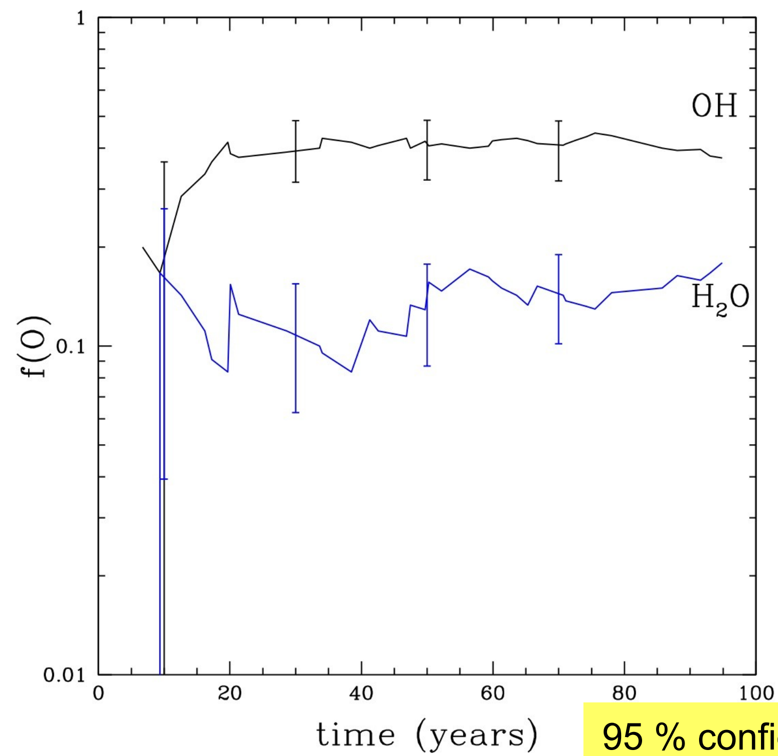
$O + H \rightarrow OH + H \rightarrow H_2O$

$O + H \xleftarrow{h} OH + H \xleftarrow{h} H_2O$

Grain surface



Gas phase



95 % confidence level

Photo-dissociation regions

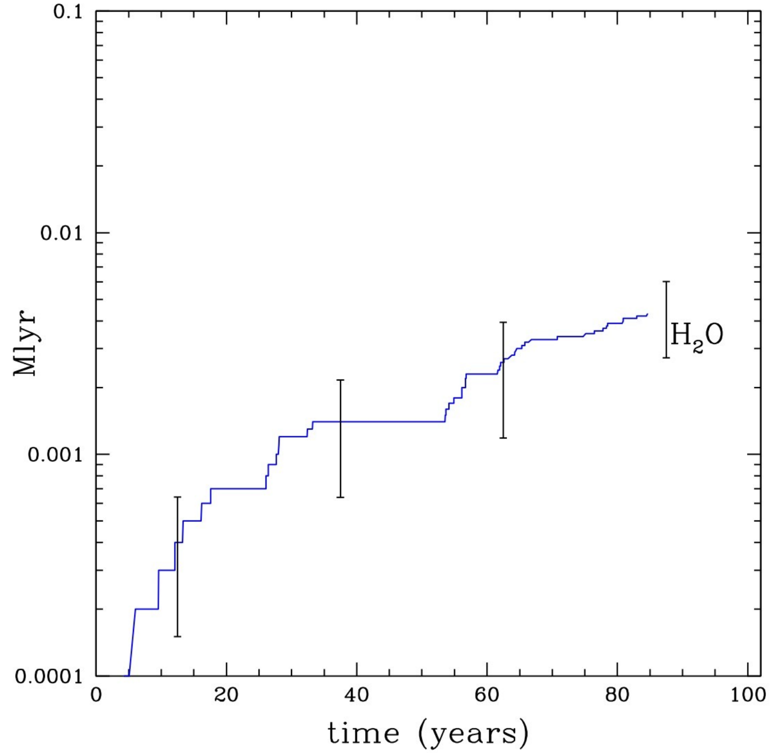
PDR: H molecular

T_{dust}=30K, T_{gas}=30K, $G_0=10^3$, Av=5

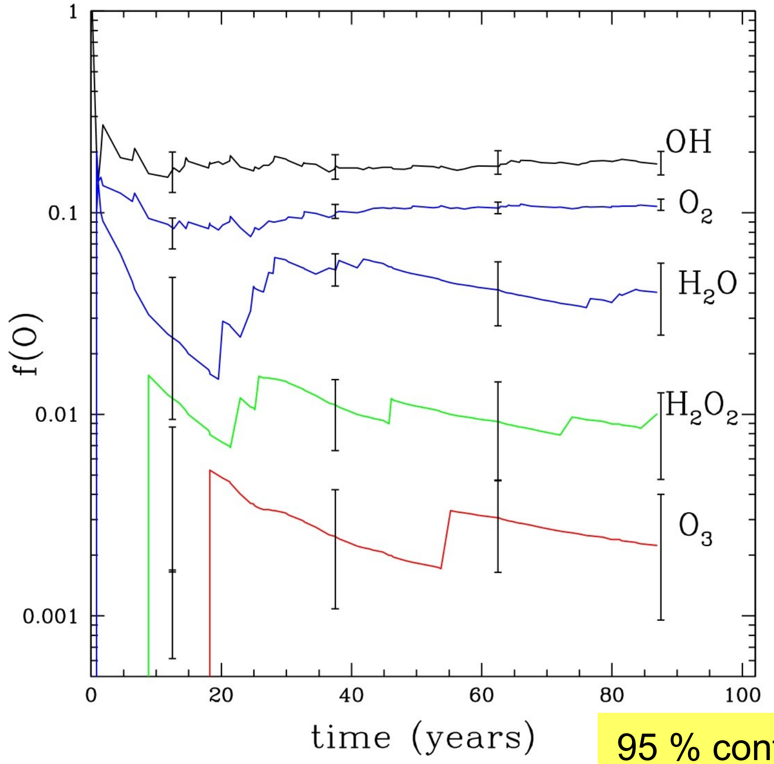
nH=1000 cm^{-3}, O/H =3 10^{-4}, D/H=2 10^{-5}

H_2O forms with O_2 and O_3

Grain surface



Gas phase



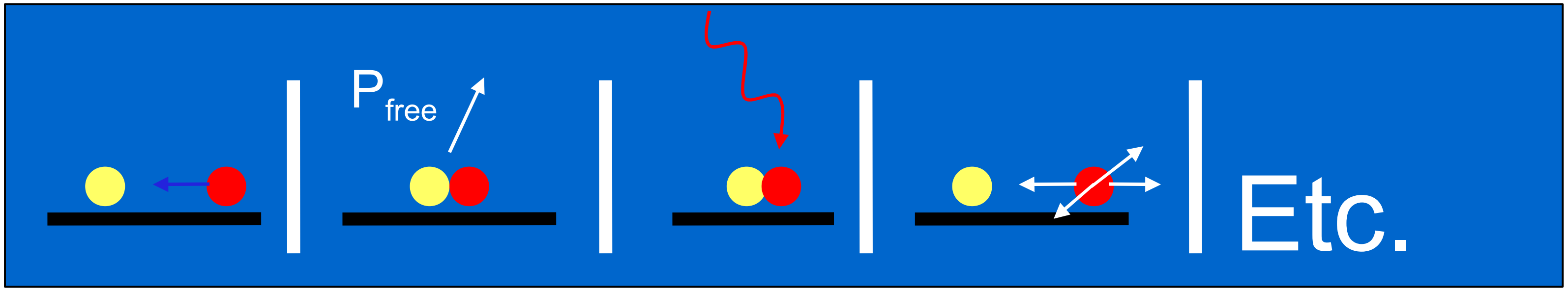
95 % confidence level

Formation of molecules on dust

Cold grains (~**10 K)** favours **hydrogenation**

Warmer grains (**30 K**) favours **oxygenation**

UV photons **dissociate** species that **recombine**. "dissociation-formation-dissociation" boost gas phase.



Species released in gas → photo-dissociated.
Boost VS photo-dissociation?

Star formation

How does dust (and metallicity) impact SF?

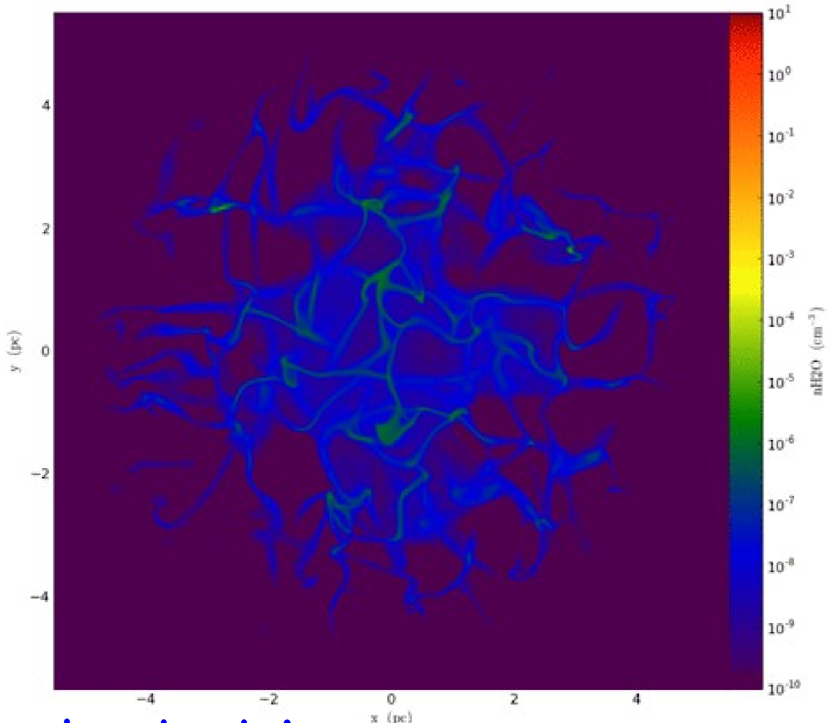
MHD simulations: Flash

gas phase + dust chemistry

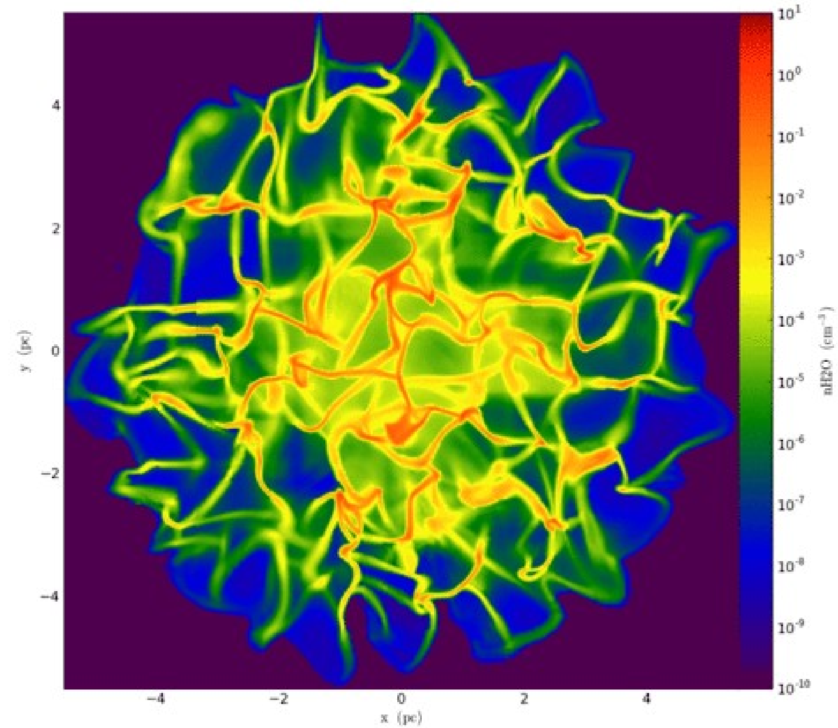
Star formation

Initial cloud conditions: 10^3 cm^{-3}
Isothermal: Tgas =Tdust=20K
10 chemical species
Gas phase: 40 reactions
Dust: H_2 and H_2O

gas only



gas + dust

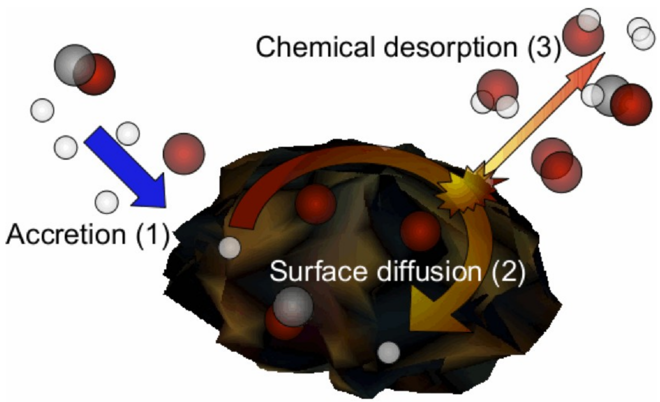


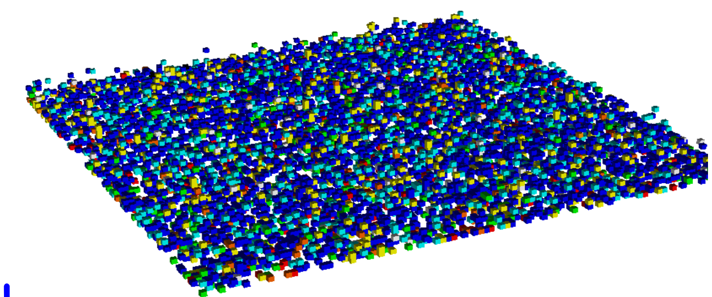
Hocuk et al in prep.

Star formation

Include cooling and heating mechanisms

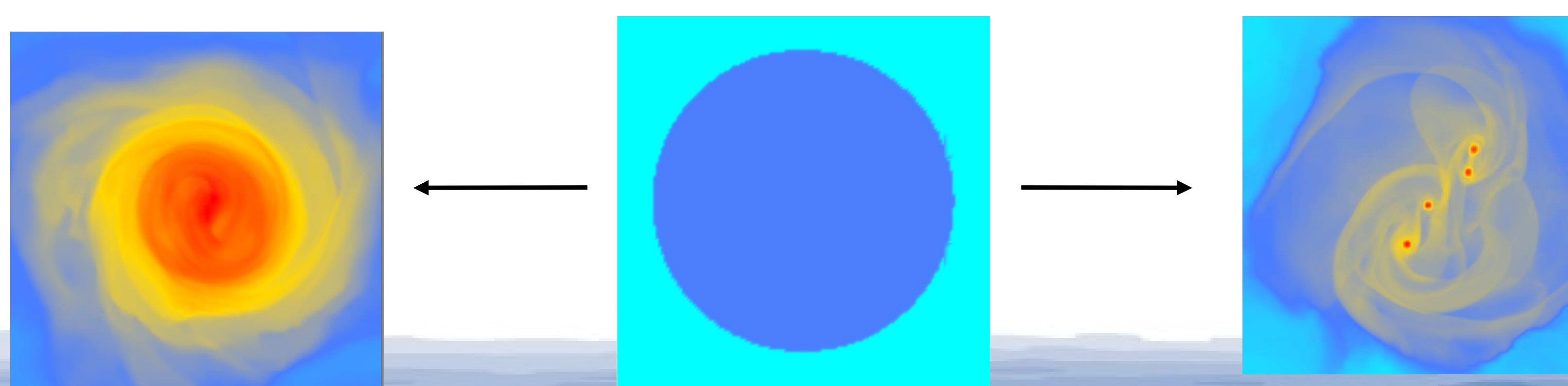
Extend the chemical network (dust + gas)





Fragmentation of Molecular cloud

Dust impact fragmentation/ SF efficiency and IMF.



Summary and Conclusions

H_2 formation on dust involves:

H weakly bound to the surface.

H strongly bound to the surface and making pairs (or groups).

Traces of dust (10^{-5} $Z_\odot$) are enough to form H_2.

H_2 forms on dust → boost HD through $D^+ + H_2$

Other molecules forming on dust → release in the gas if exothermic reactions → direct impact on the gas (coolants).

Hydrodynamic simulations + dust / gas chemistry + cooling → Star formation varies with $Z_\odot$ (scales with dust).