The multiple personalities of cosmic dust

Stéphanie Cazaux

Groningen, The Netherlands

Nederlandse Organisatie voor Wetenschappelijk Onderzoek

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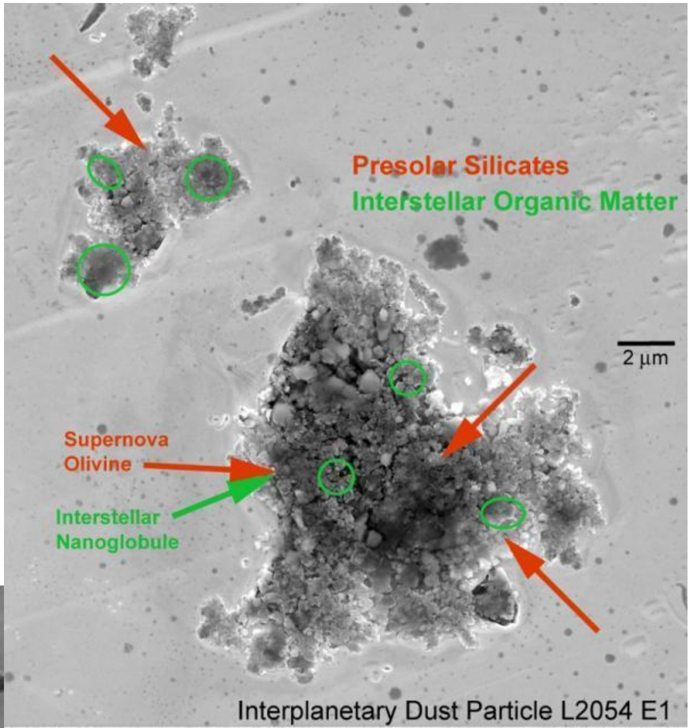
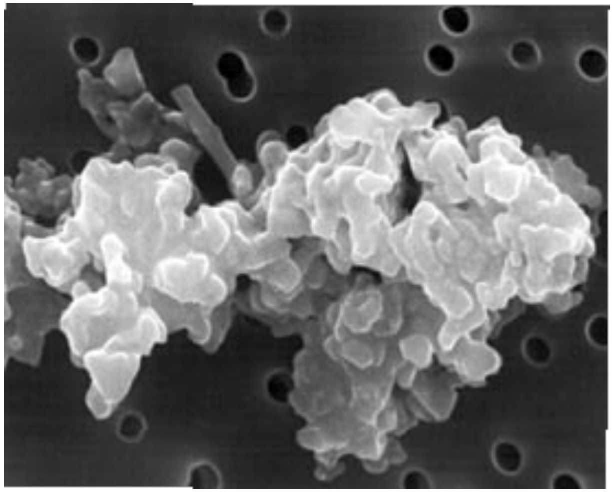
Outline

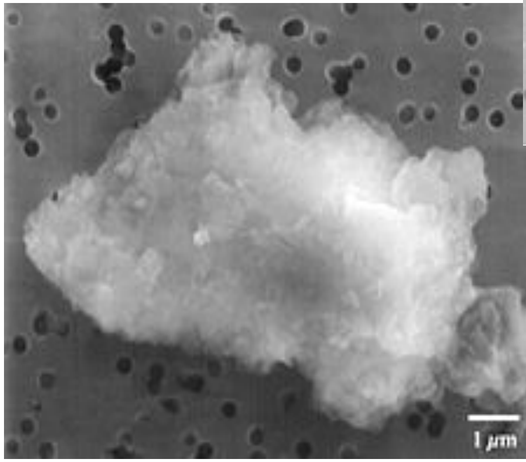
- Introduction: Cosmic dust
- The multiple personalities of cosmic dust: catalyst VS reservoir
  - Dust as catalyst: from H_2 to water
  - Dust as reservoir: from water to ices → deuterium used → our oceans
- Dust and star formation
- Summary and Conclusions

Interstellar dust grains

- upper atmosphere (aircraft)
- Falling on earth (40 tons /day)
- Emission/absorption

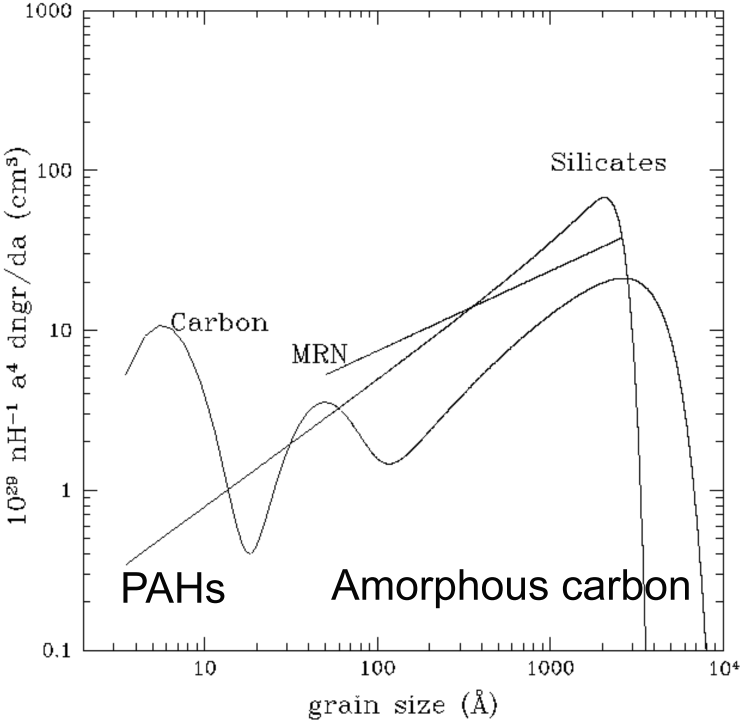






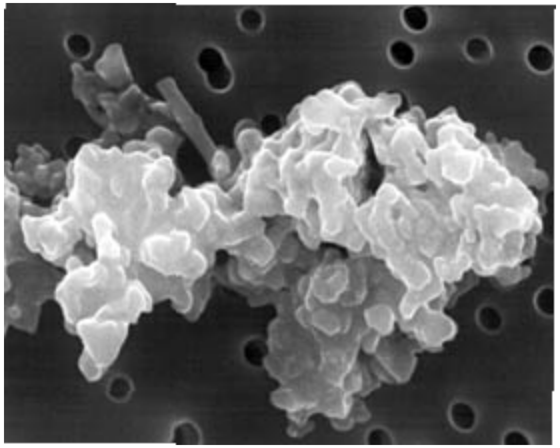
Interstellar dust grains

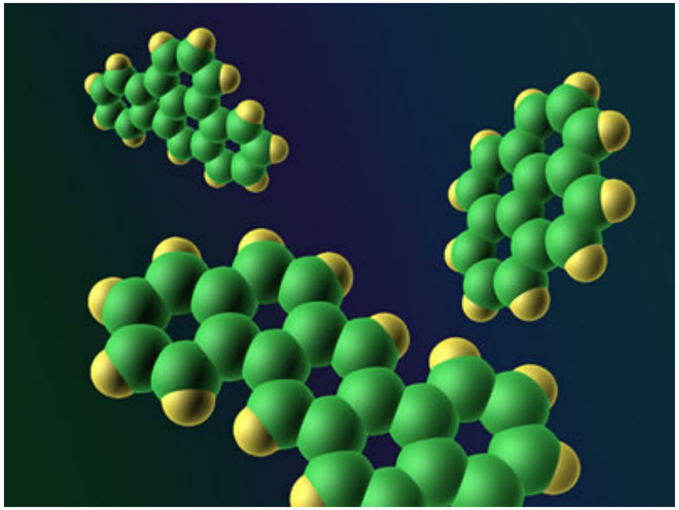
Grain size distribution

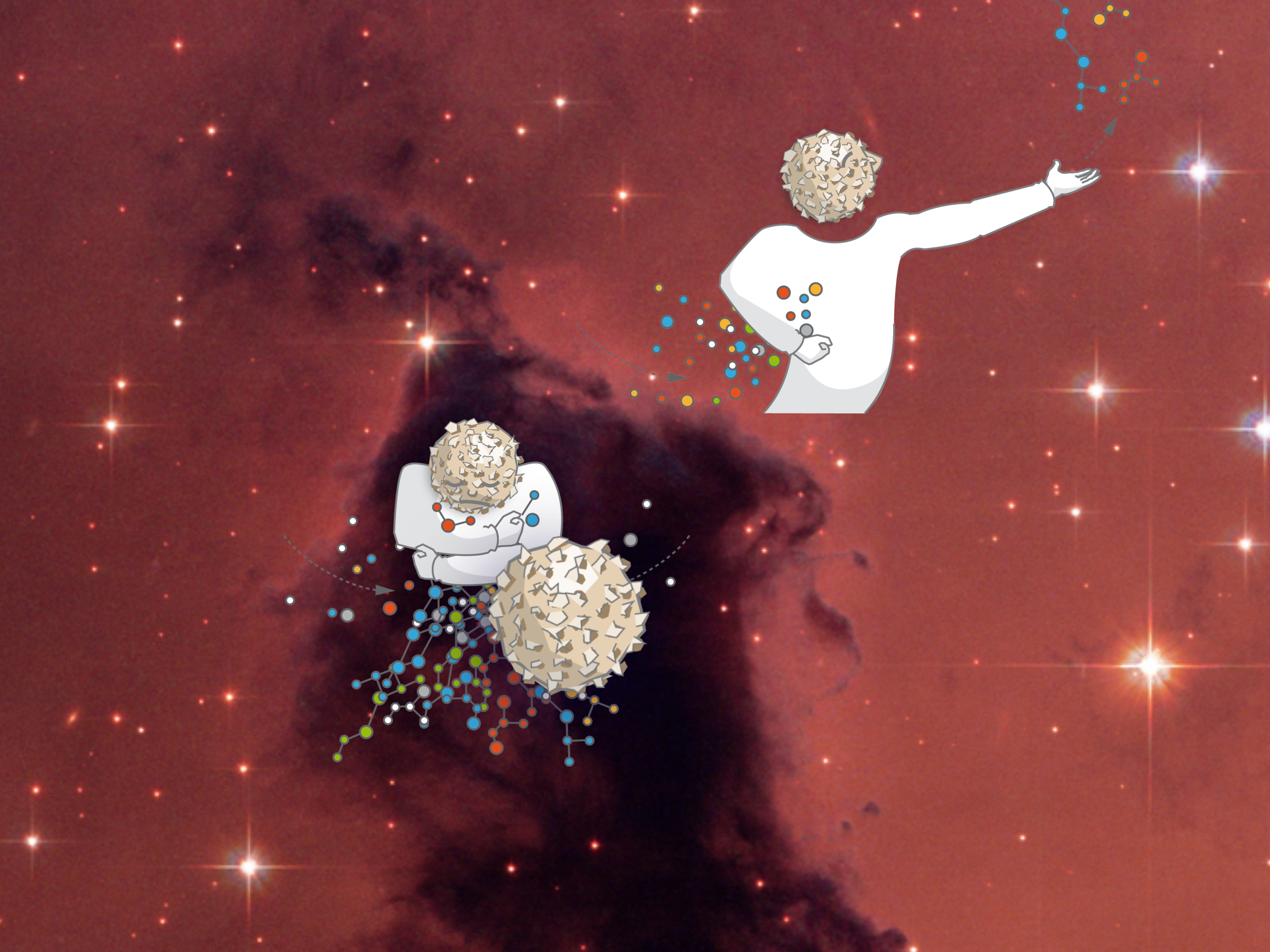


Weingartner & Draine 2001
Mathis, Rumpl & Nordsieck 1977

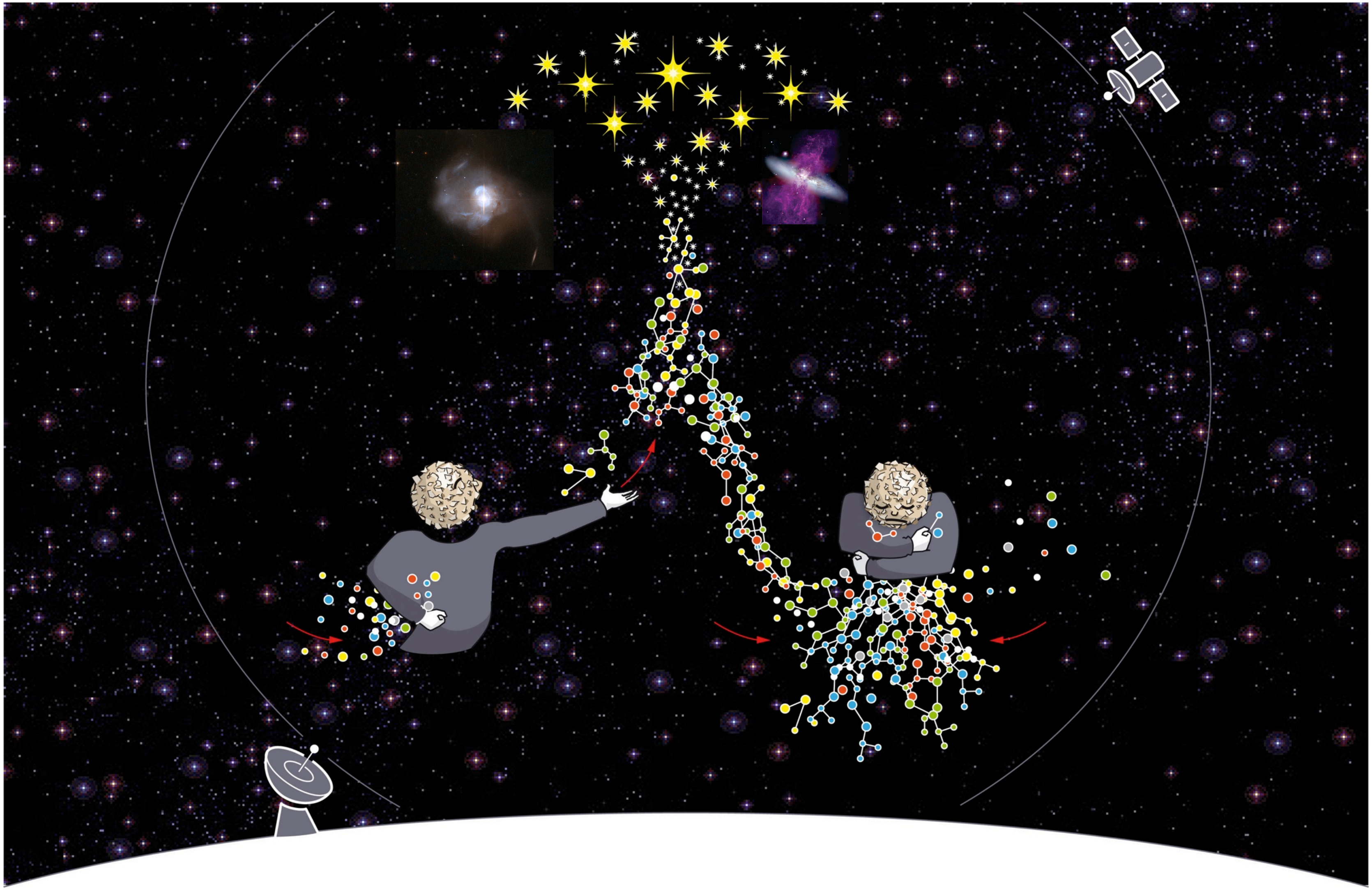
DUST= Silicates, Amorphous carbon, PAHs
PAHs = 50% of surface available for chemistry







The interplay between dust, ice and gas



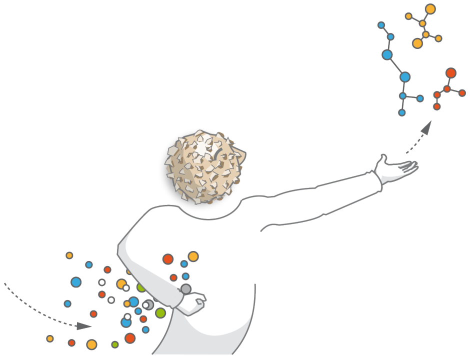
The multiple personalities of cosmic dust

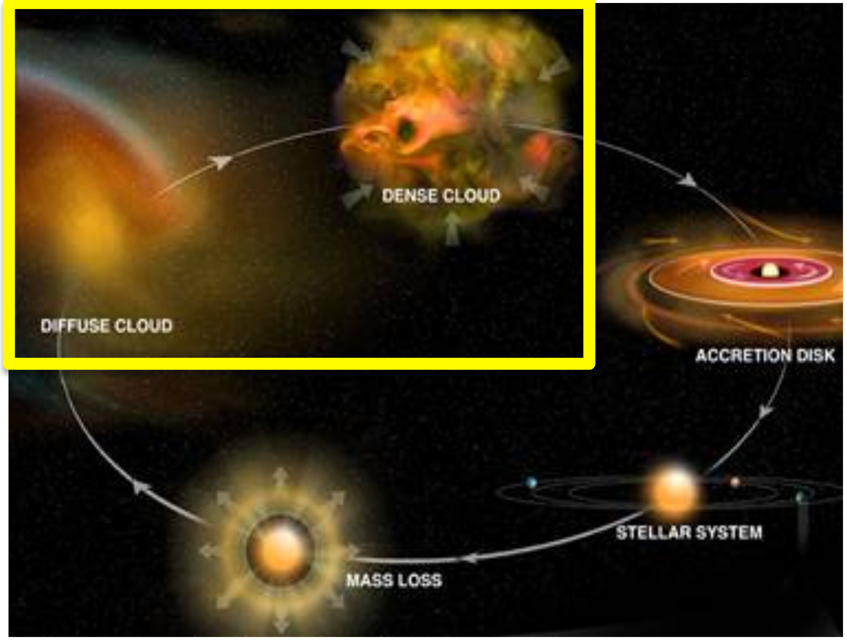
Star form in clouds made of gas + dust

Catalyst:

Enrich gas

H_2 ,H_2O, O_2, H_2O_2

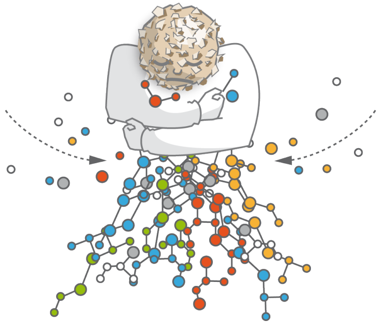




Reservoir:

Stealing gas

Ices formation

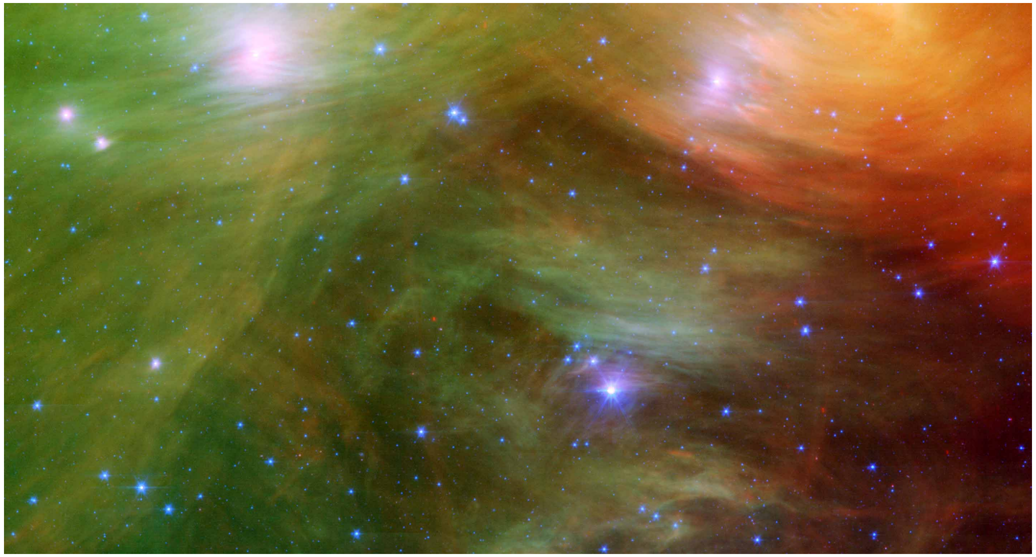


Dust as **catalyst** → simple process to form simple species?

Dust as **reservoir** → composition and complexity of ices?

Dust **catalyst/reservoir** impacts gas composition → star formation?

Dust as Catalyst: Molecular hydrogen



Diffuse cloud
H atomic

$H \rightarrow H_2$

Molecular cloud
H molecular

Dust as Catalyst: Molecular hydrogen

H_2 is the most abundant molecule of the Universe

$$H + e^- \rightarrow H^- + h\nu$$

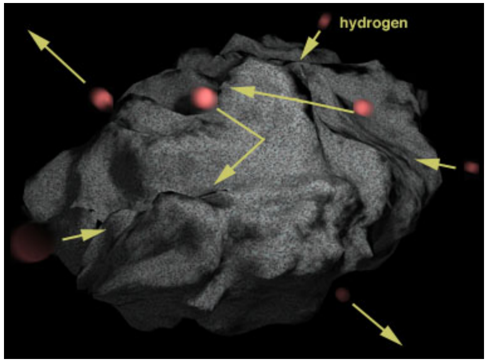
$$H^- + H \rightarrow H_2 + e^-$$

This reaction is not efficient to explain the abundances of H_2 in the Milky Way → dust

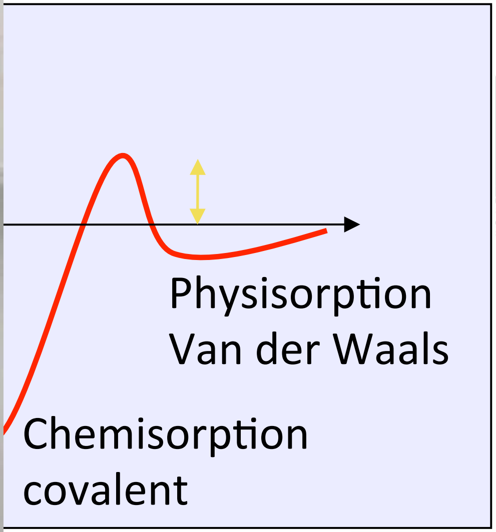
Gould & Salpeter 1963, APJ, 138, 408

H_2 forms on dust particles if small amount of dust is present (10^{-3})

Cazaux & Spaans 2004, APJ, 611, 40



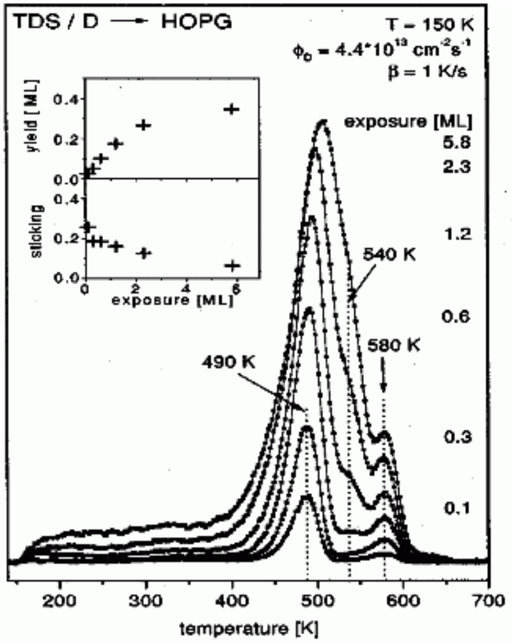
Formation of H_2 on dust



Physisorption
Van der Waals

Chemisorption
covalent

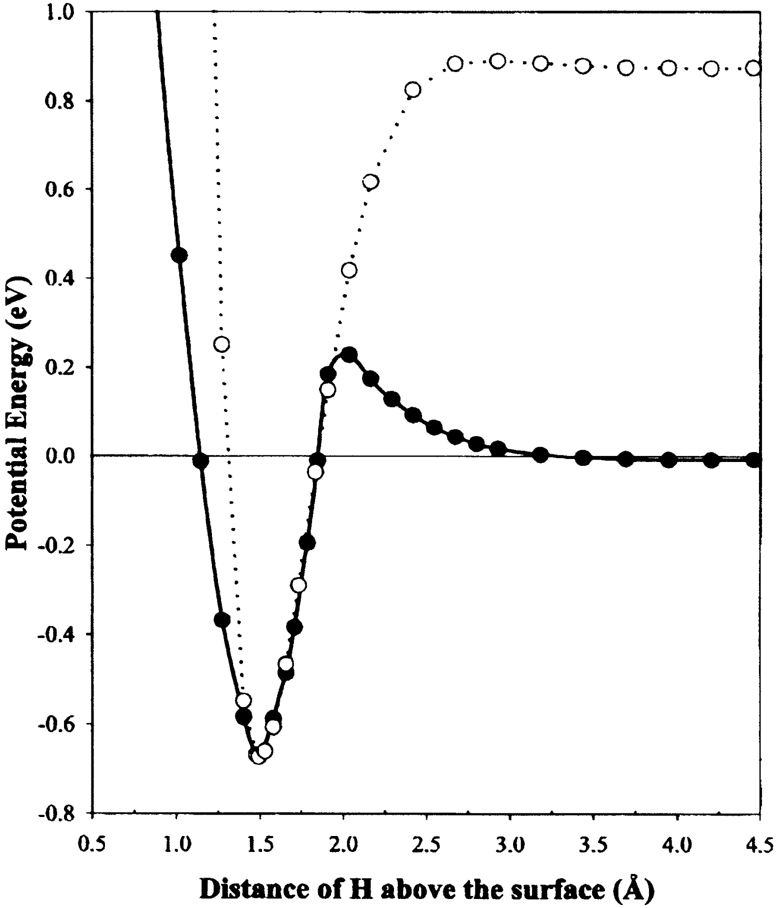
Graphite

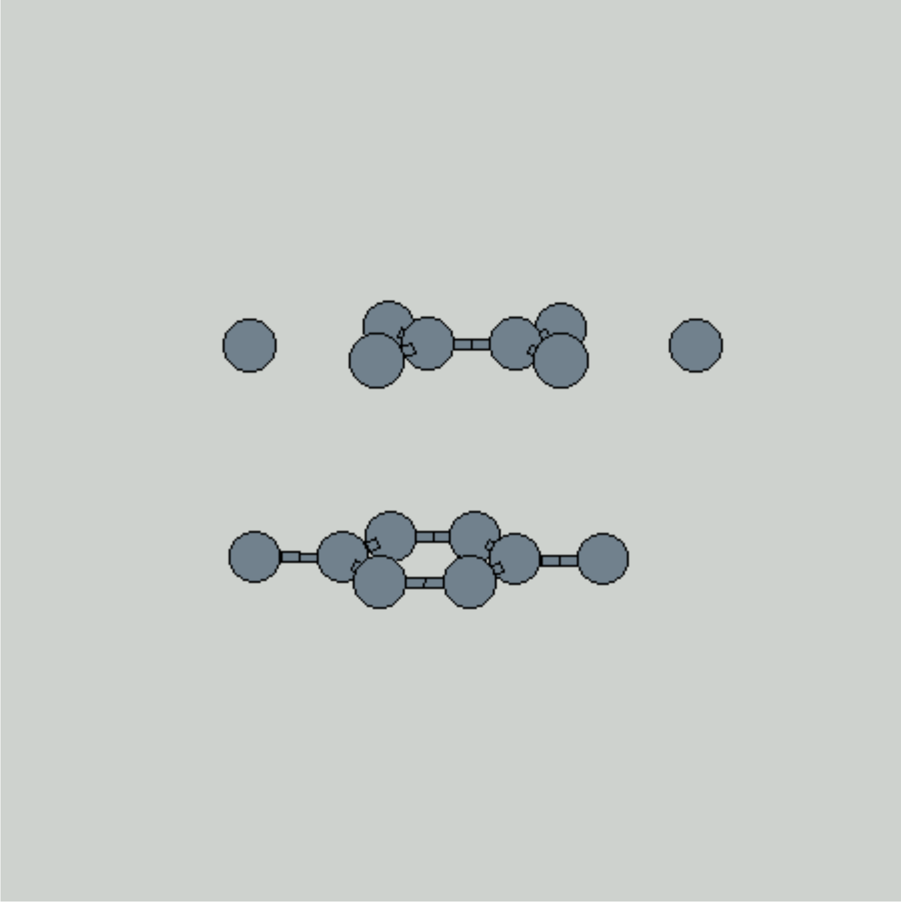


Zecho et al. 2002

Model H_2 formation on dust
interaction H/surface: **weak** OR **strong** → H_2 forms for wide range of T dust

Formation of H_2 on dust: Interaction H/surface





Sha et al, Surface 2002

Formation of H_2 on dust

Formation of H_2

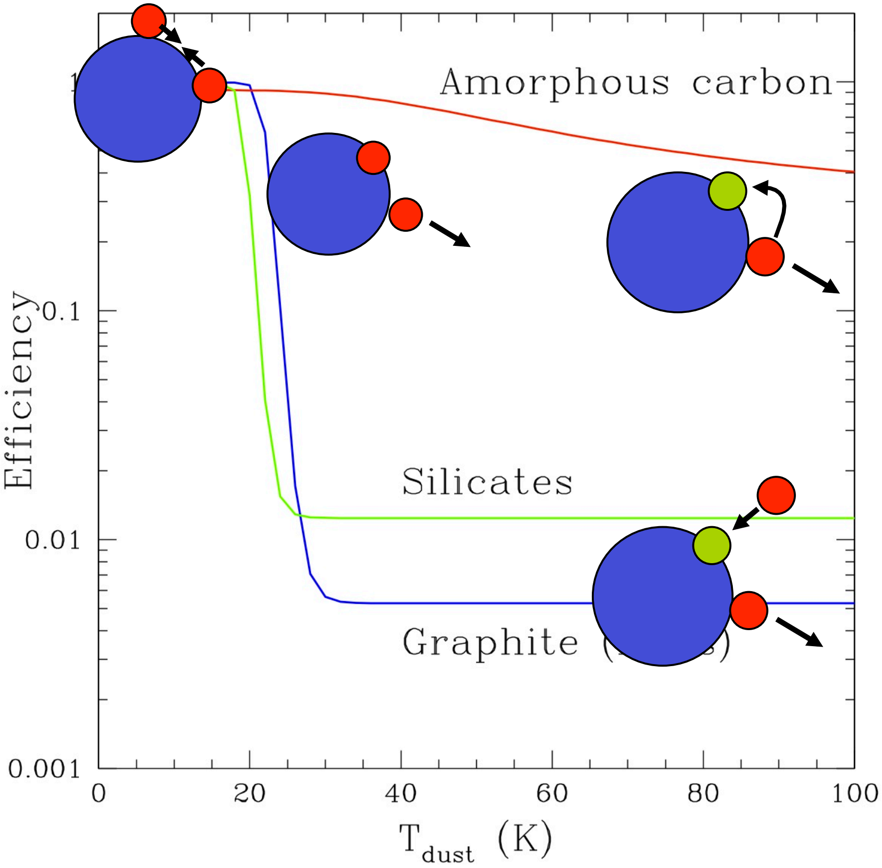
physisorbed atoms @ low T_{dust}
chemisorbed atoms @ high T_{dust}

H_2 forms for a wide range a T_{dust}

Drop in efficiencies at

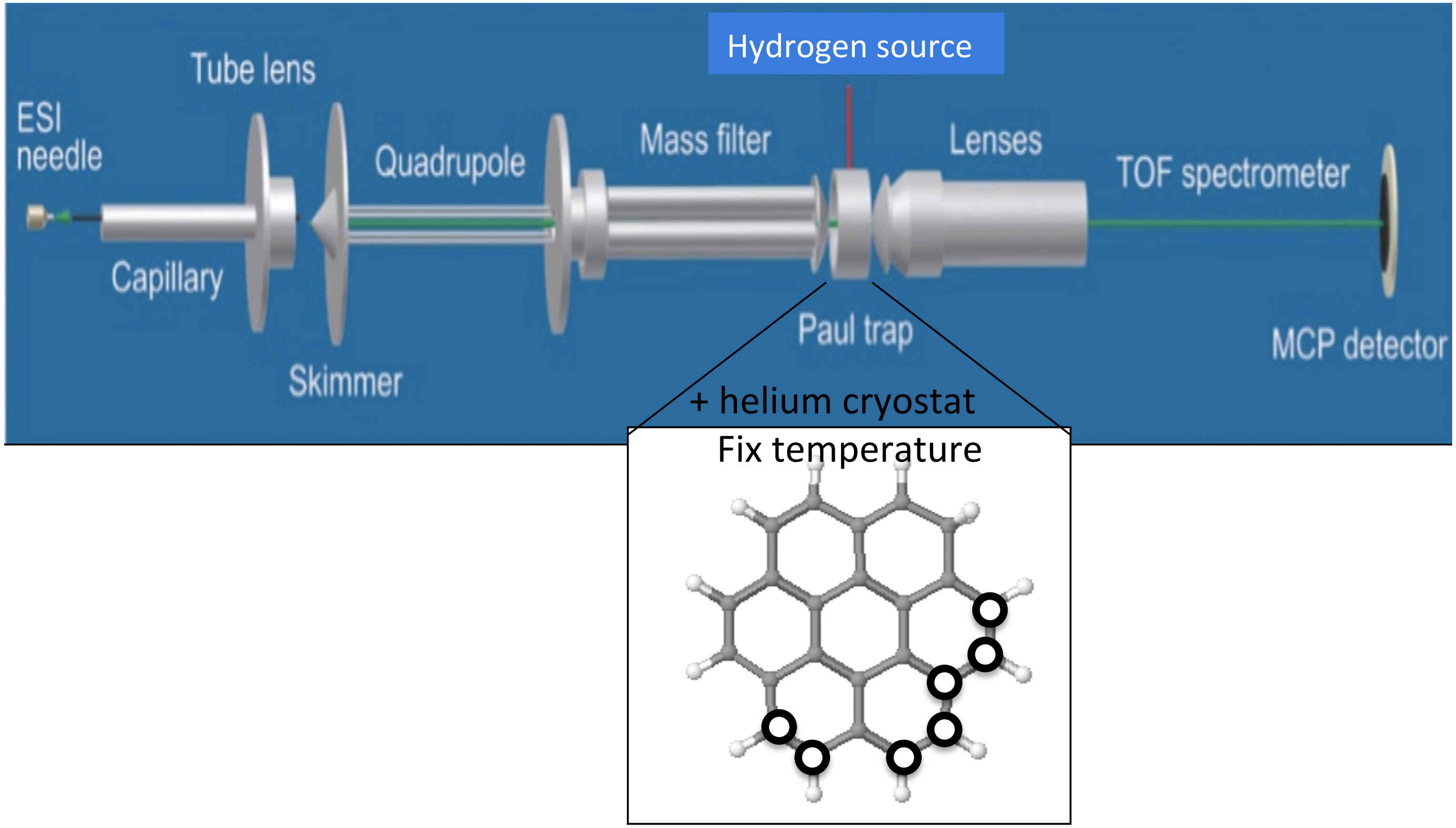
$T_{dust} > 20K$

H_2 formation on PAHs?



Cazaux & Tielens 2002; 2004

Formation of H_2 on PAHs



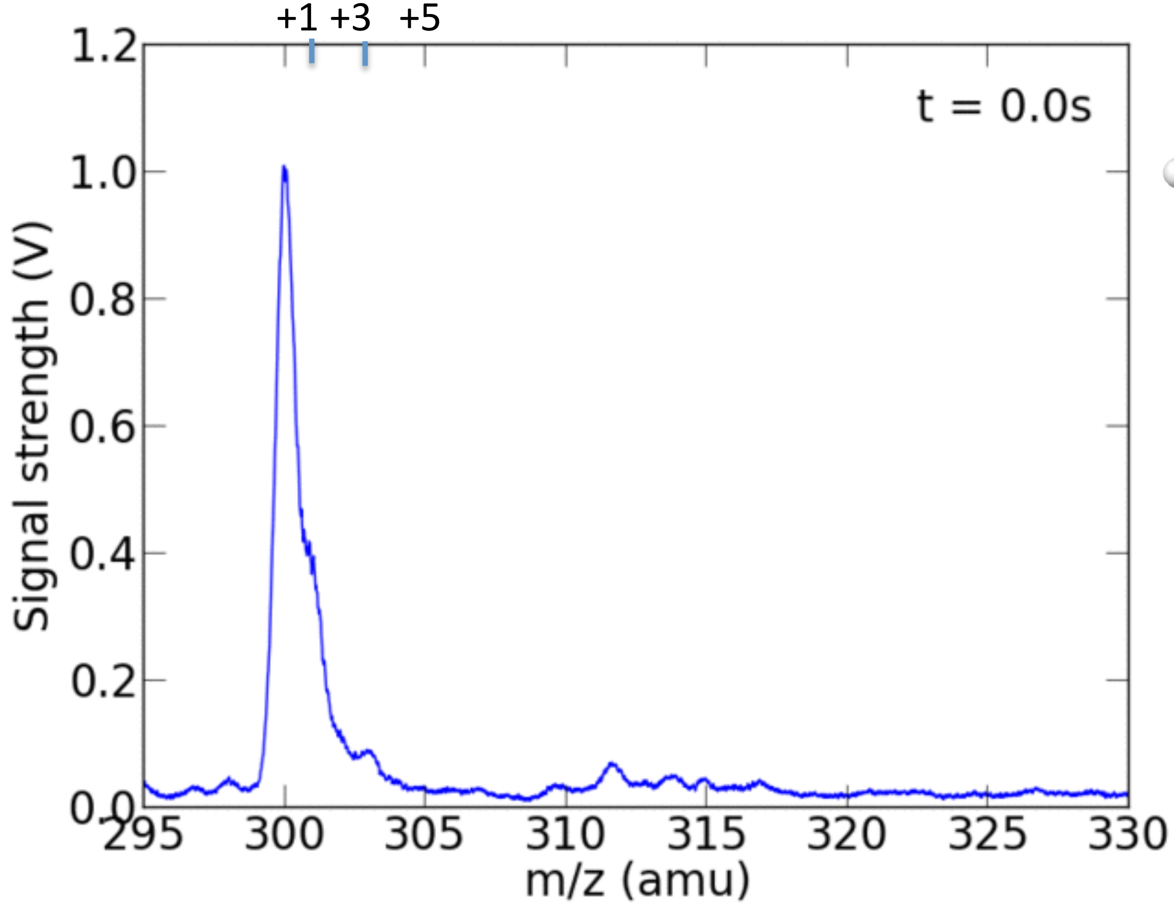
Hydrogen source

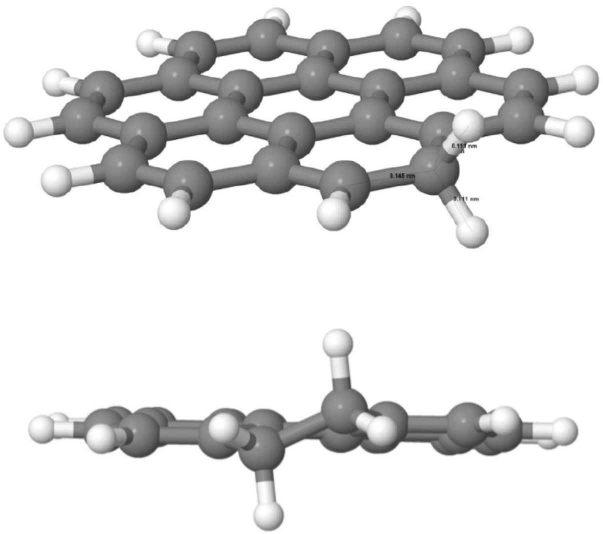
+ helium cryostat

Fix temperature

Boschman, L., Reitsma, G., Cazaux, S., Schlathoelter, T., Hoekstra, R., Spaans, M.
Zernike Institute for Advanced materials in Groningen

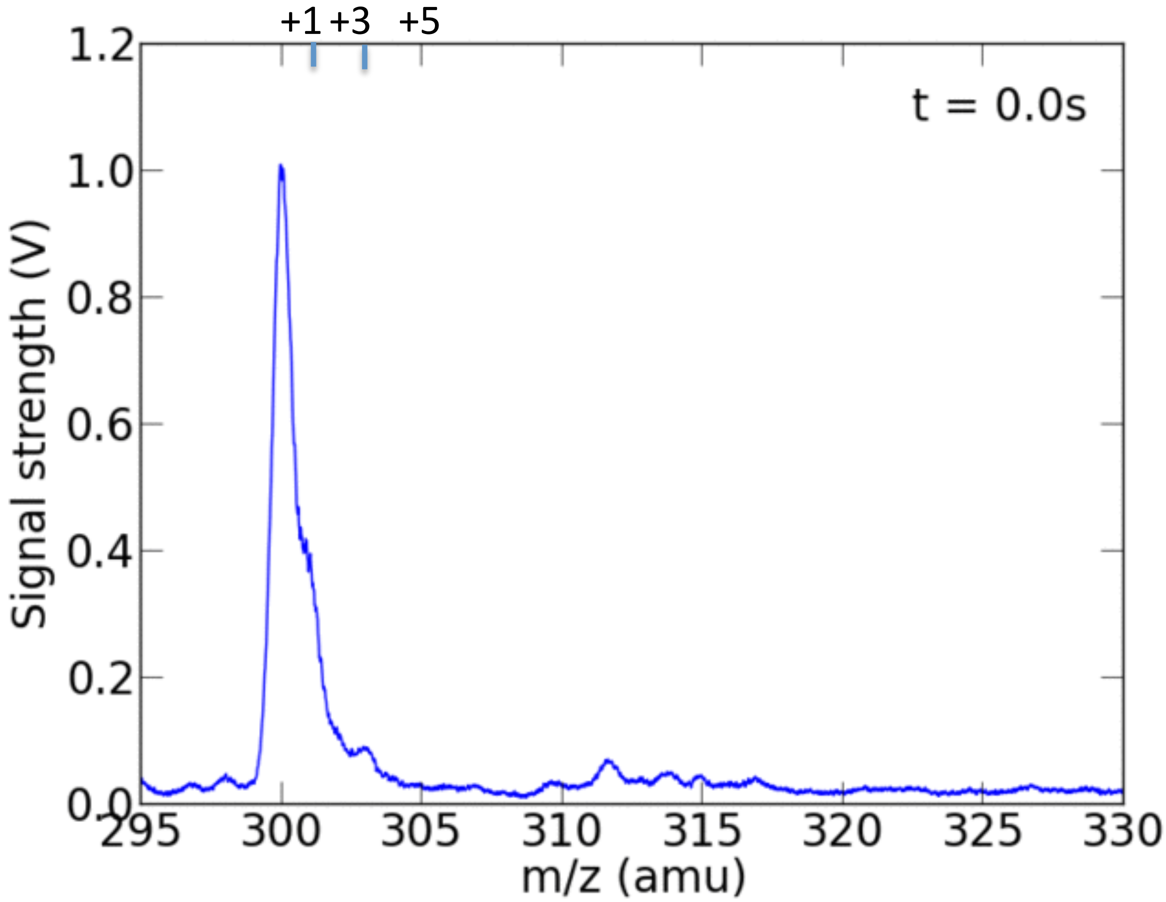
Formation of H_2 on PAHs

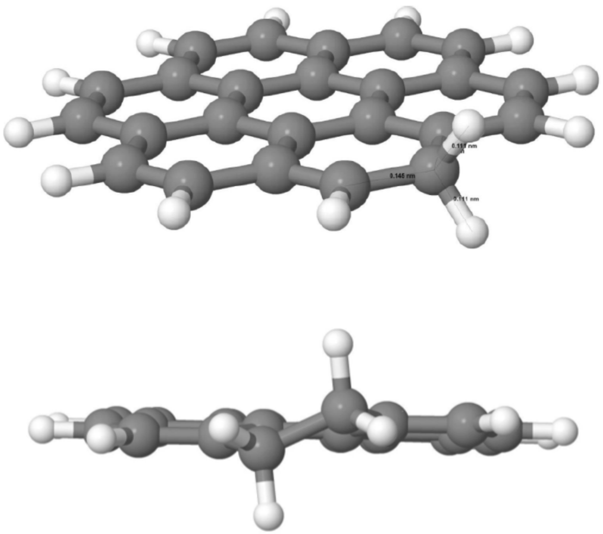




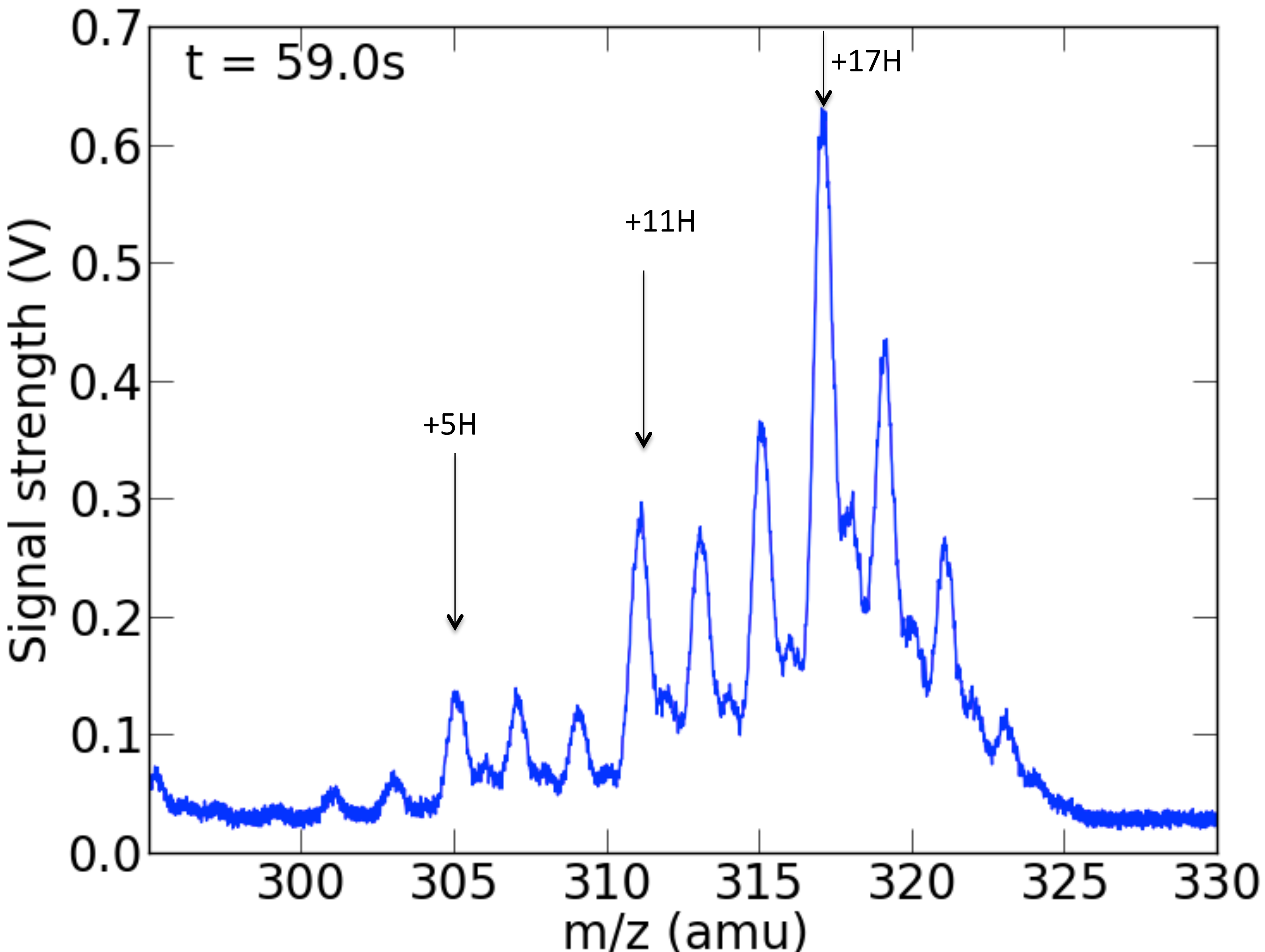
Boschman, L. et al. 2012

Formation of H_2 on PAHs

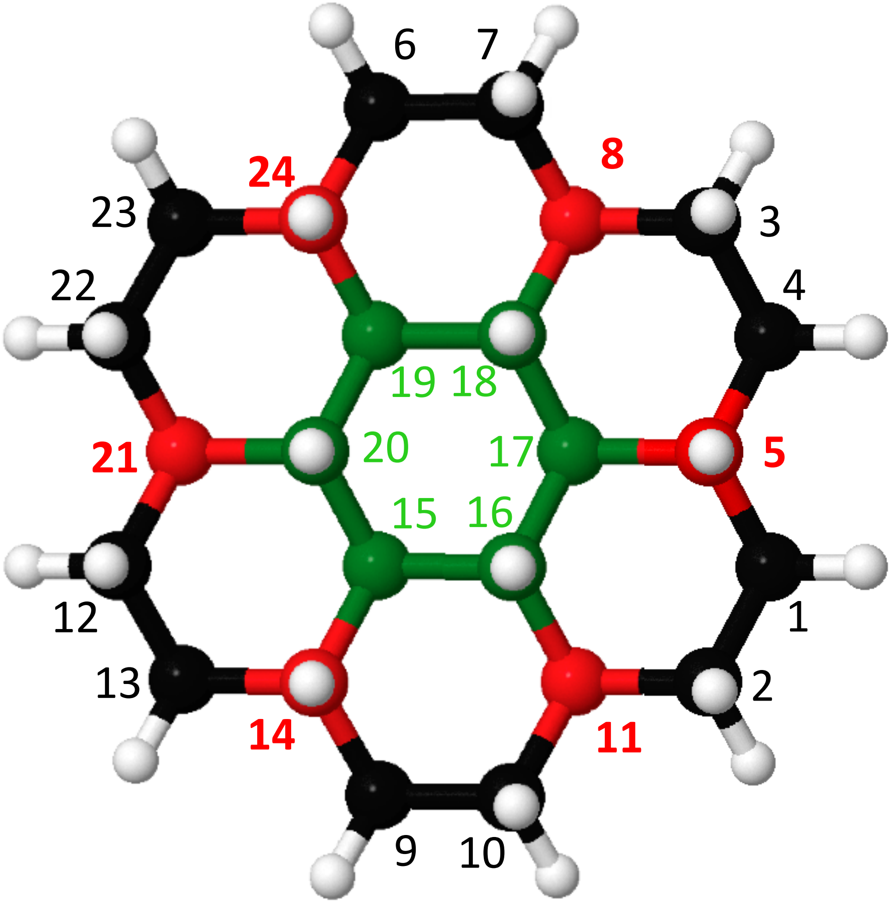




Boschman, L. et al. 2012


t = 59.0s
+17H
+11H
+5H
Signal strength (V)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
300
305
310
315
320
325
330
m/z (amu)

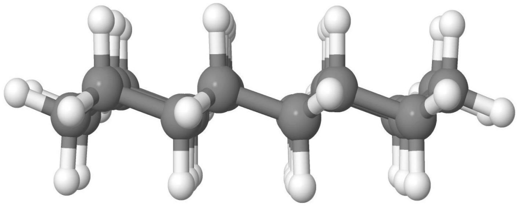
Formation of H_2 on PAHs

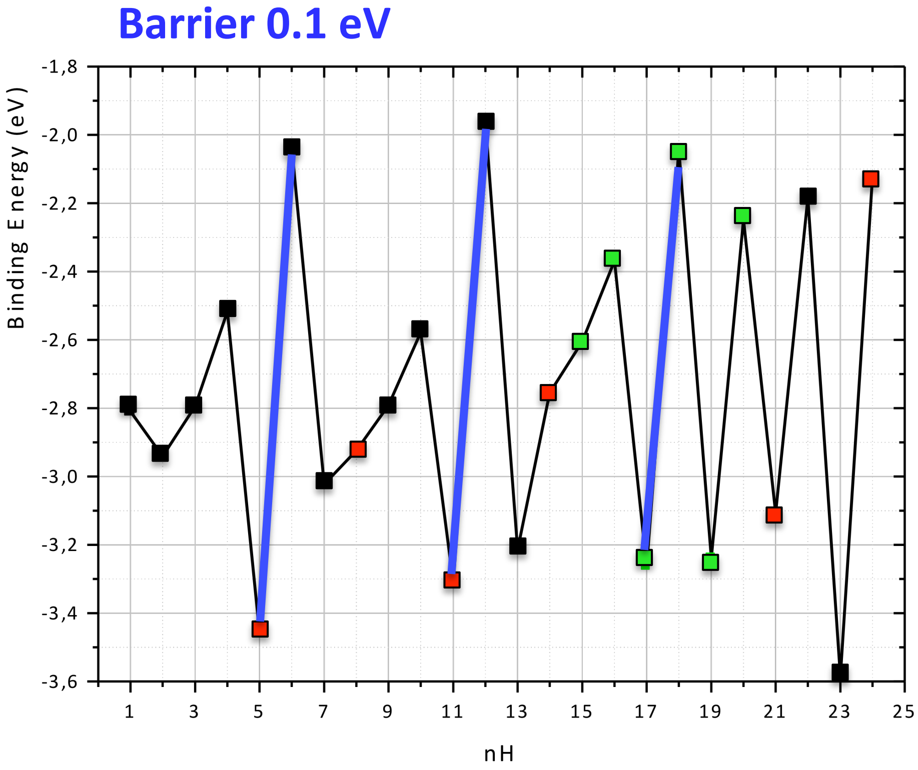


■ Outer edge

🟥 Inner Edge

🟩 Center





DFT calculations → Equilibrium geometries, binding energies and transition states

Formation of H_2 on PAHs

- Hydrogenation of coronene cations follow a definite sequence (from binding energies and attachment barriers)→ occurrence of stable states 5, 11 and 17 = Magic numbers

- For these stable closed-shell cations: further hydrogenation requires appreciable structural changes→ high barriers

- PAHs should be found in very hydrogenated state in ISM

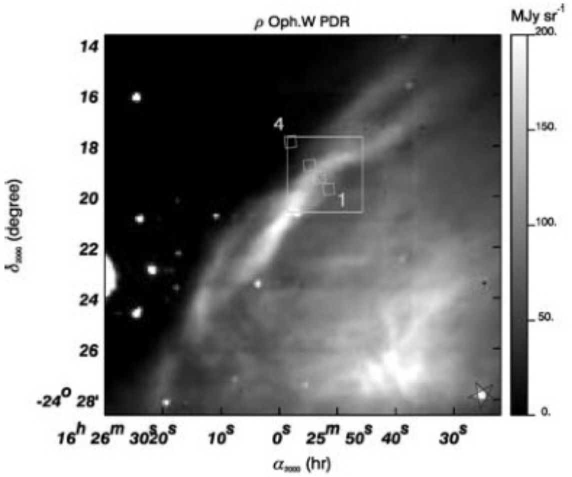
  H + PAHH → H_2 + PAH

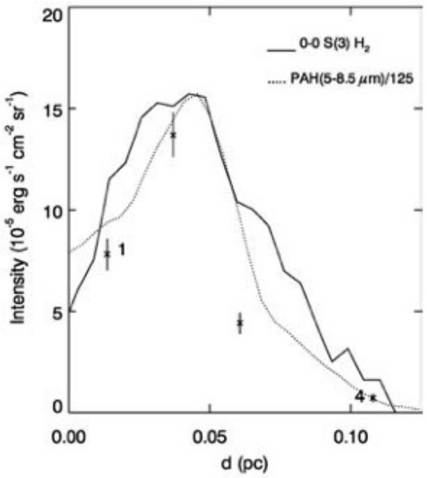
  H_2 increases with number of H

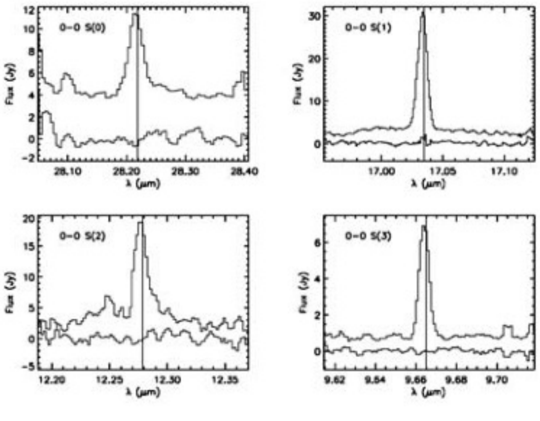
  UV + PAHH → H and H_2 loss

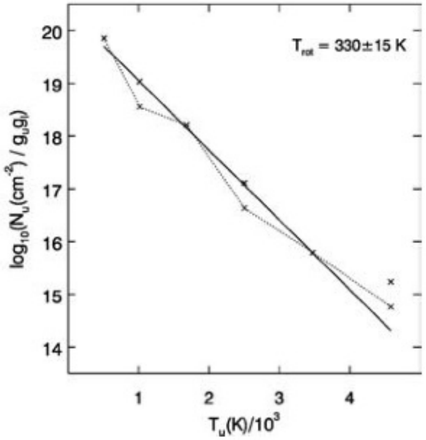
- H_2 formation in the ISM?

H_2 formation rate: Photo-dissociation Regions









□ ISO SWS

Rotational transitions of H_2

○ ISO LWS

□ ISOCAM- CVF

Spectro- imaging

Rotational transitions of H_2

Gas temperature

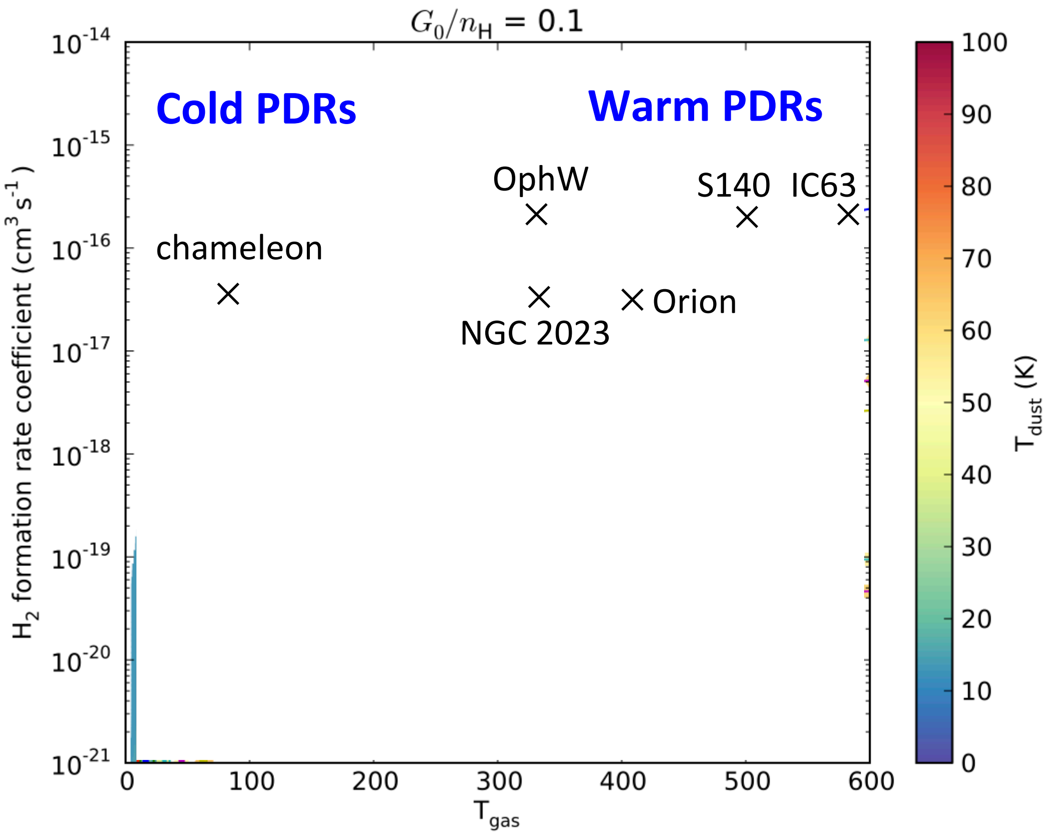
Photodissocation of H_2

Formation rate of H_2

Grain temperature

Abergel et al. 1996; Habart et al. 2003

Formation of H_2
PAHs VS dust



Boschman et al. A&A 2015

Observation of PDRs

Abergel et al. 1996

Habart et al. 2003

T_{dust}= 15 - 90K

T_{gas}= 60 - 620K

R(H_2)=3 10^{-17}-1.5 10^{-16} cm^3s^{-1}

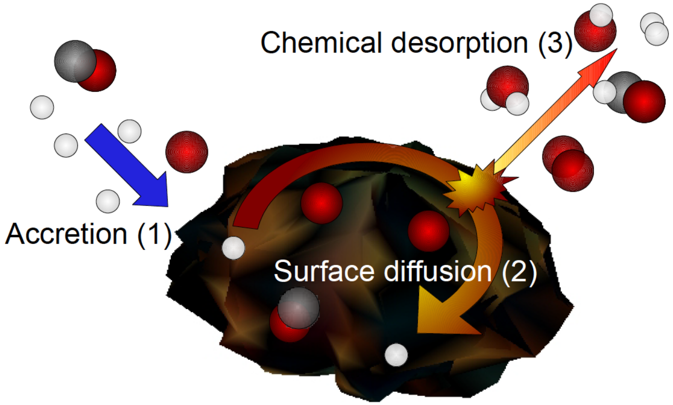
PDR model

Formation of H2

→Dust @ low Tgas

→PAHs @ high Tgas

Formation of molecules on dust



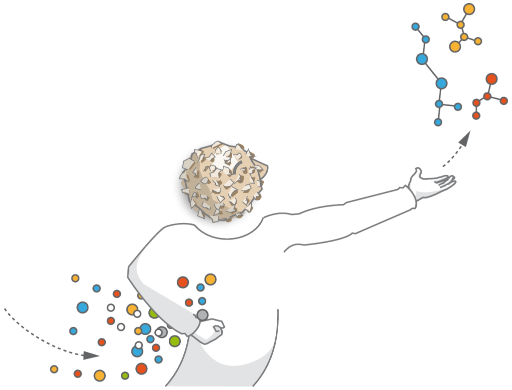
Some reactions on dust → gas

Experiments → formation of water surfaces

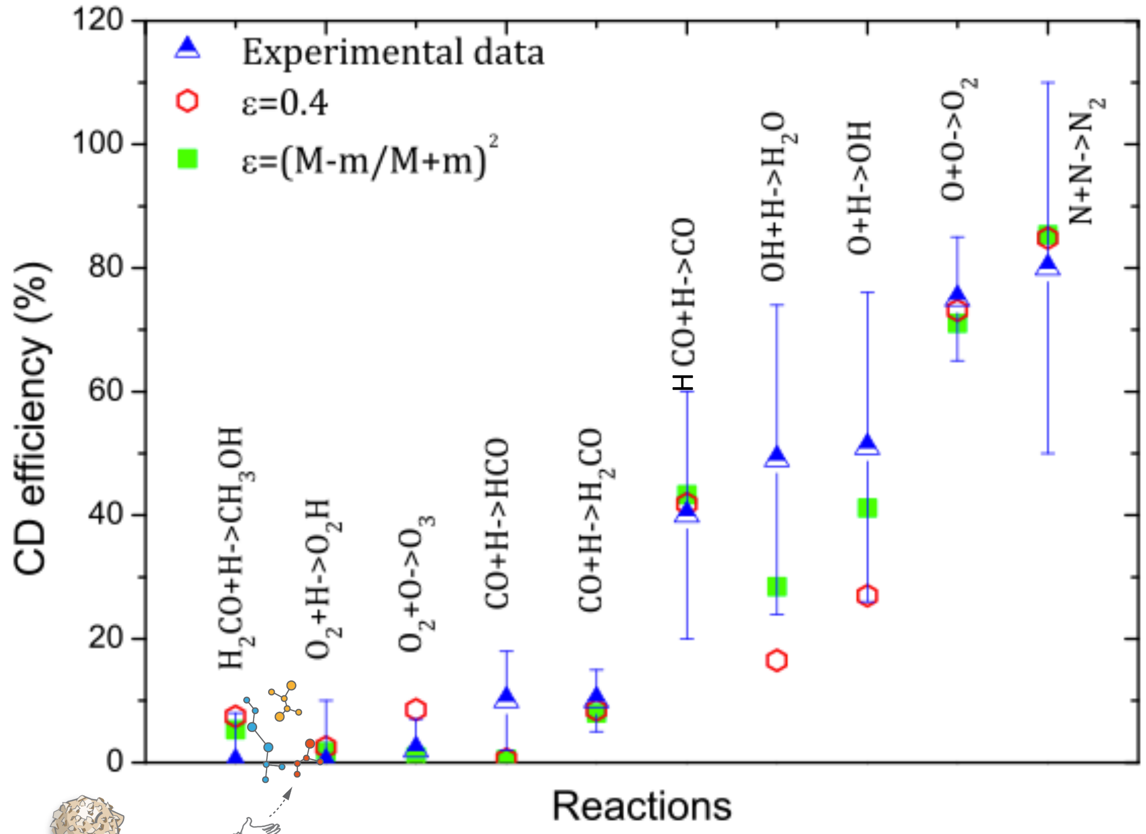
50 % of water forming on silicates is ejected in the gas upon formation

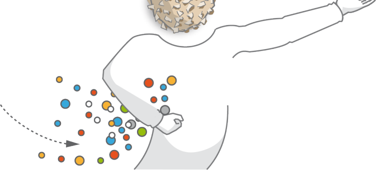
→ concerns many more reactions

Dulieu et al. 2012, Nature SR



Formation of molecules on dust





This process depends on:
- binding energy products
- degree of freedom of products
- mass relative /surface

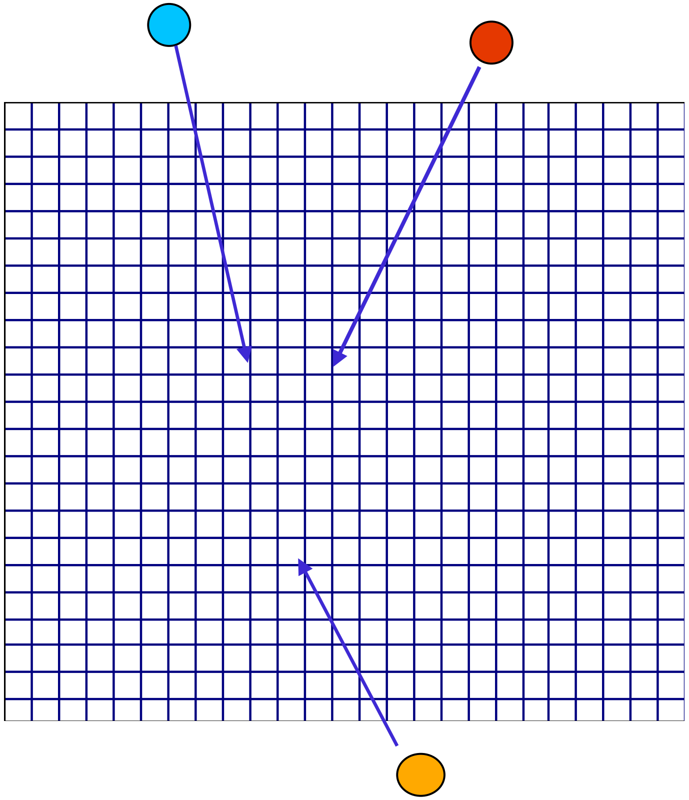
chemical desorption process → **Essential to quantify how dust impact the chemical composition of star forming regions.**

Cazaux, Minissale & Dulieu submitted

Formation of molecules on dust

Monte Carlo simulations

Grain surface = grid



H, D, O

nH=100 cm -3

1 H atom arrives every

→1000 sec (0.1µm)

→Day (100Å)

O/H=3 10^{-4}

D/H=2 10^{-5}

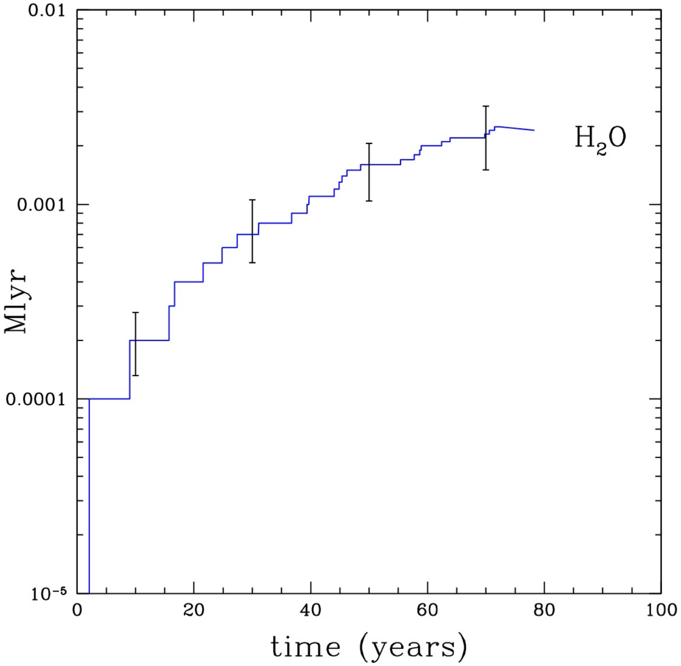
atom → random walk on surface

Diffuse clouds

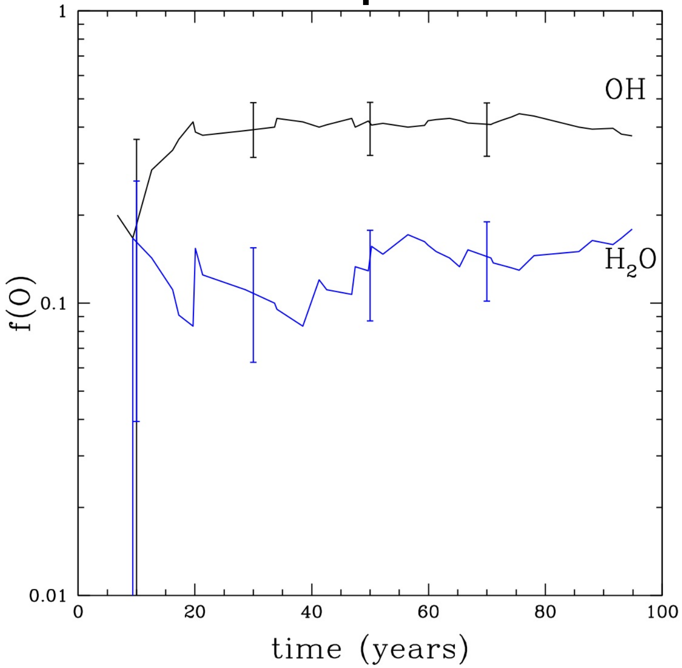
Diffuse clouds: H atomic

O+ H → OH
OH + H → H_2O

Grain surface



Gas phase



T_{dust}=18K
T_{gas}=100K
nH=100 cm^{-3}

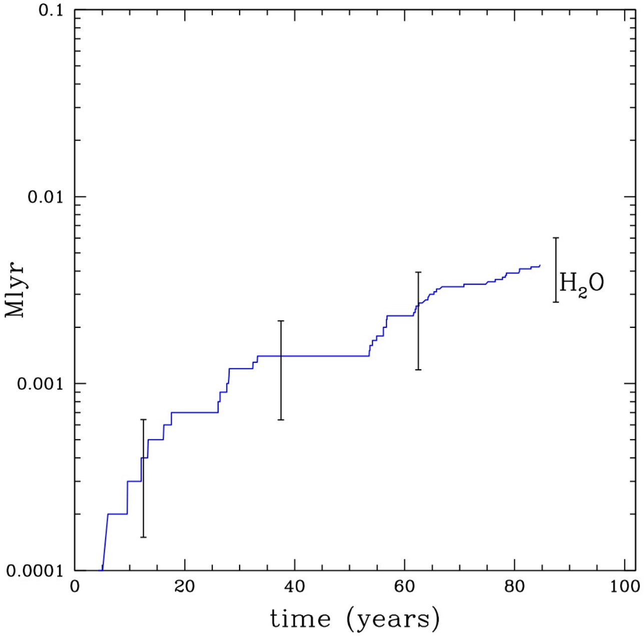
Cazaux, S., Cobut, V., Marseille, M., Spaans, M., & Caselli, P. 2010, A&A, 522, A74

Regions exposed to radiation

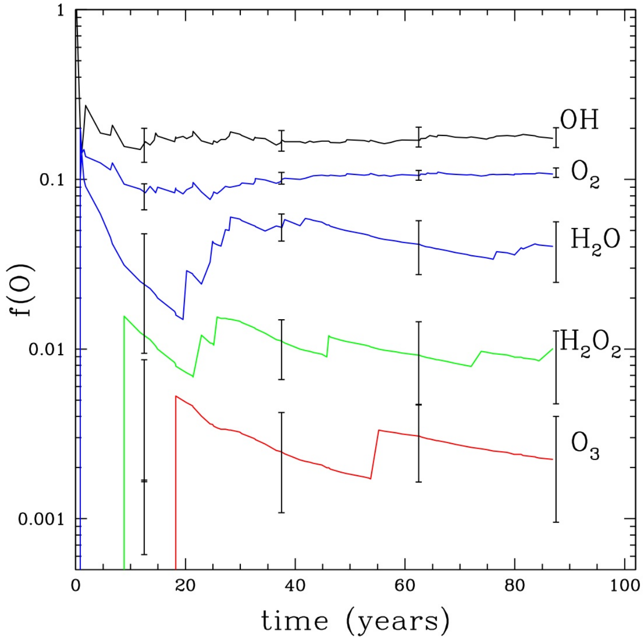
H molecular

H_2O forms with O_2 and O_3

Grain surface



Gas phase

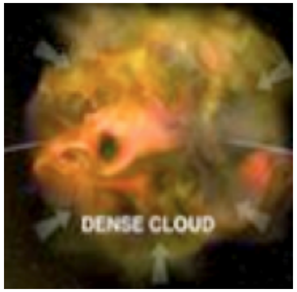


Tdust=30K
Tgas=30K
G0=10^3
Av=5
nH=1000 cm^{-3}

Formation of water on dust >> gas if Tdust<40K

Meijerink, Cazaux & Spaans 2011

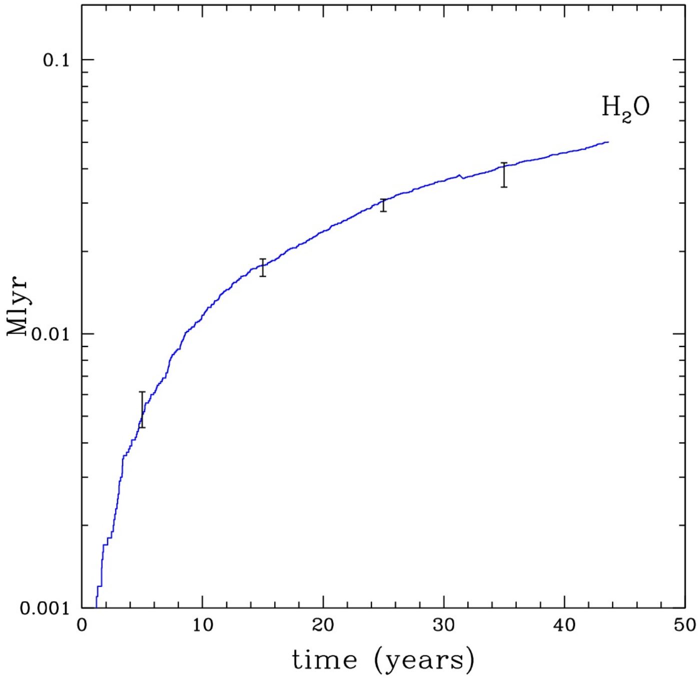
Dense clouds



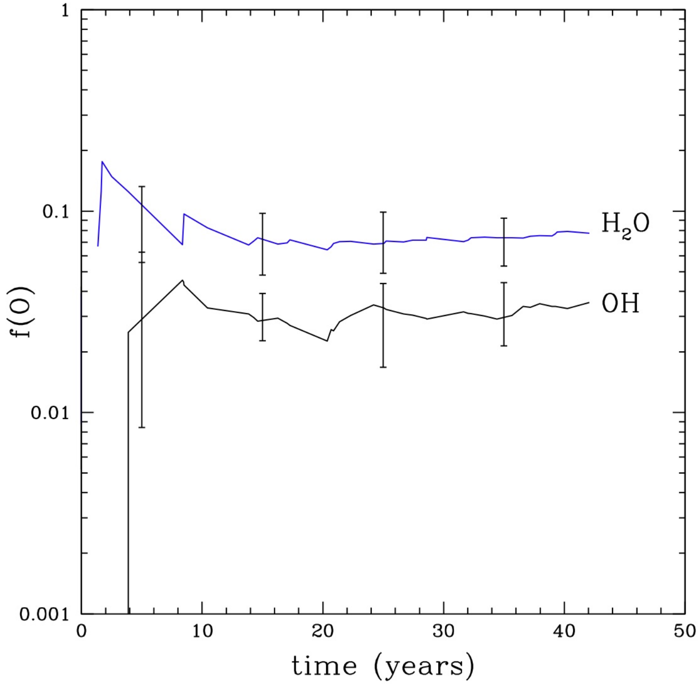
H molecular

$H_2 + O \rightarrow OH + H$

Grain surface



Gas phase



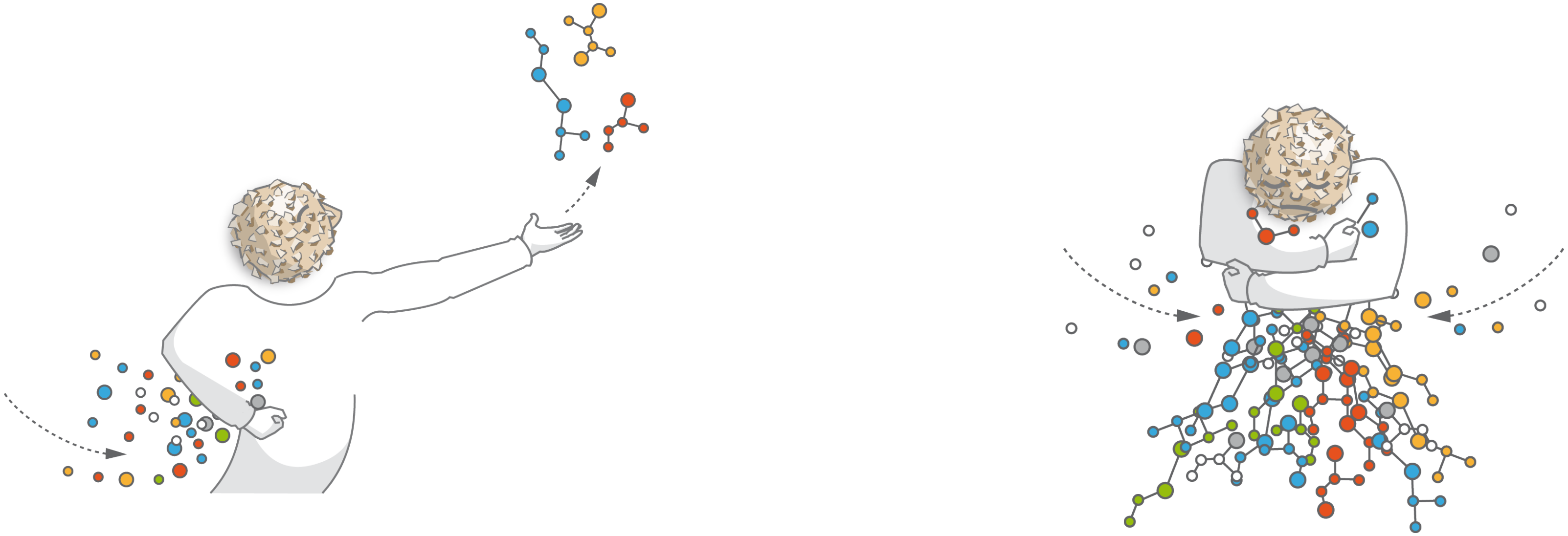
T_{dust}=12K
T_{gas}=20K
G_0=1
Av=5
nH=5000 cm^{-3}

From catalyst to reservoir

Chemistry on dust → impacts the gas

Different dust temperature imply different chemistry (hydrogenation VS oxygenation)

As the environment evolve: diffuse → molecular the personality of dust changes → reservoir



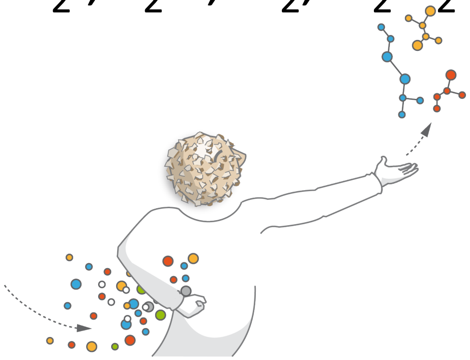
The multiple personalities of cosmic dust

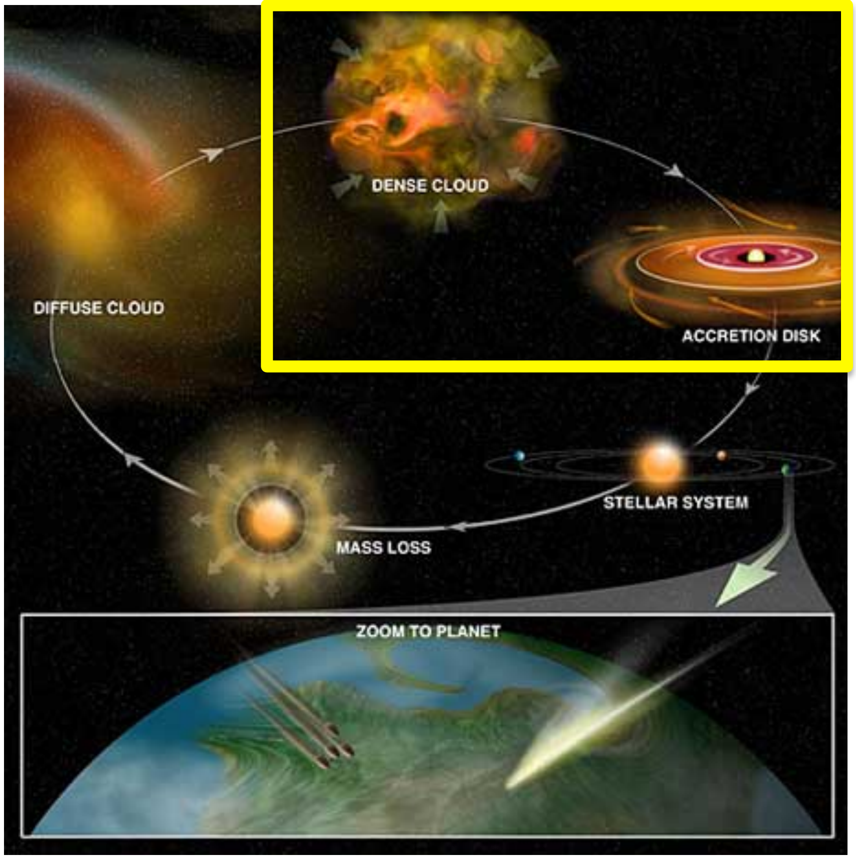
Star form in clouds made of gas + dust

Catalyst:

Enrich gas

H_2 ,H_2O, O_2, H_2O_2

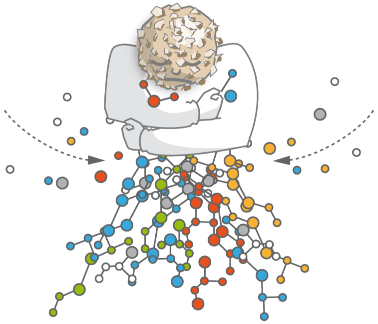




Reservoir:

Stealing gas

→ Ices



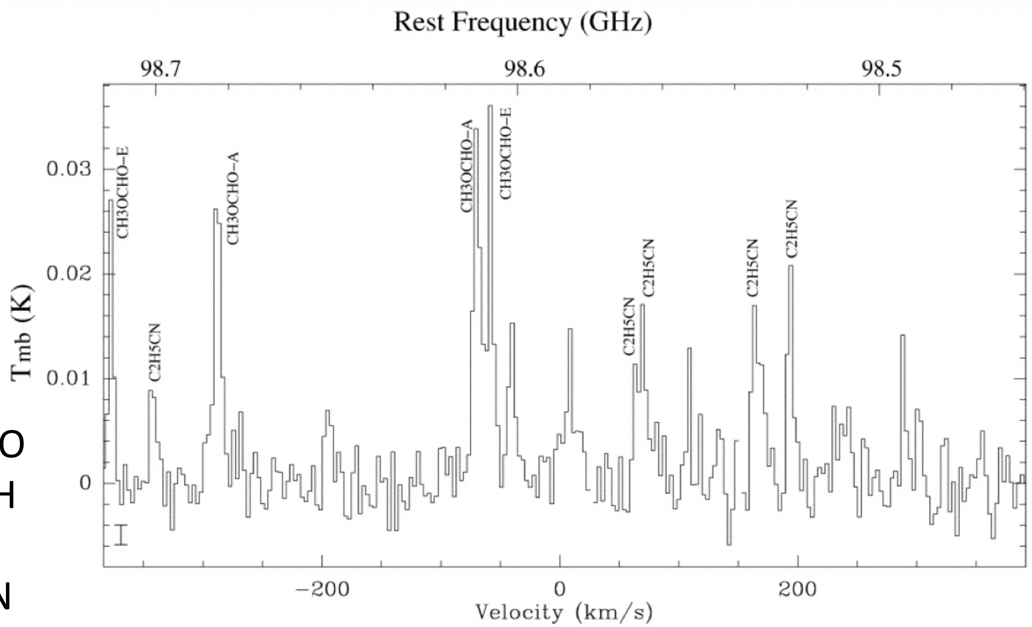
brought to planets → asteroids/comets

Dust as **reservoir** → composition and complexity of ices?

Dust as reservoir: Interstellar ices

Prestellar cores: CO depleted from the gas *Bergin et al. 2002; Crapsi et al. 2004*

B68 IRAM 30m; *Bergin et al. 2002*
Extinction Av~27
$C^{18}O$ J=1-0



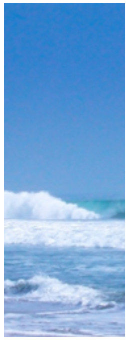
CH_3CHO
HCOOH
CH_3CN
C_2H_5CN
CH_3OCHO

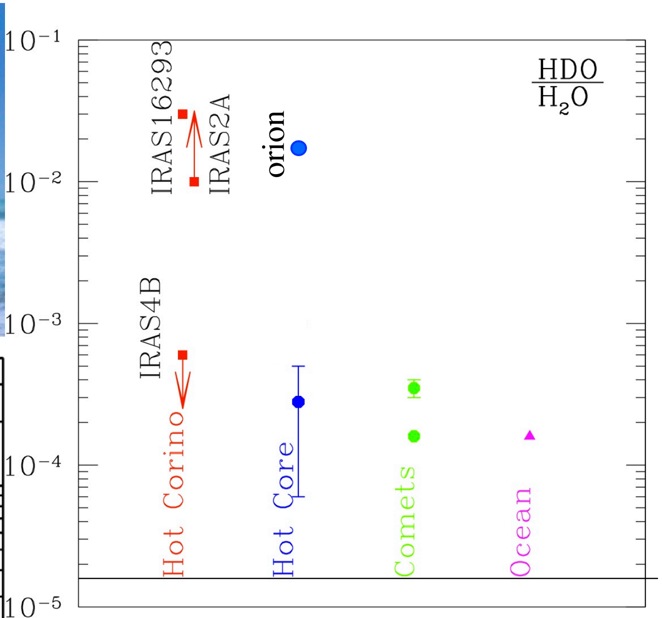
Cazaux et al. 2003

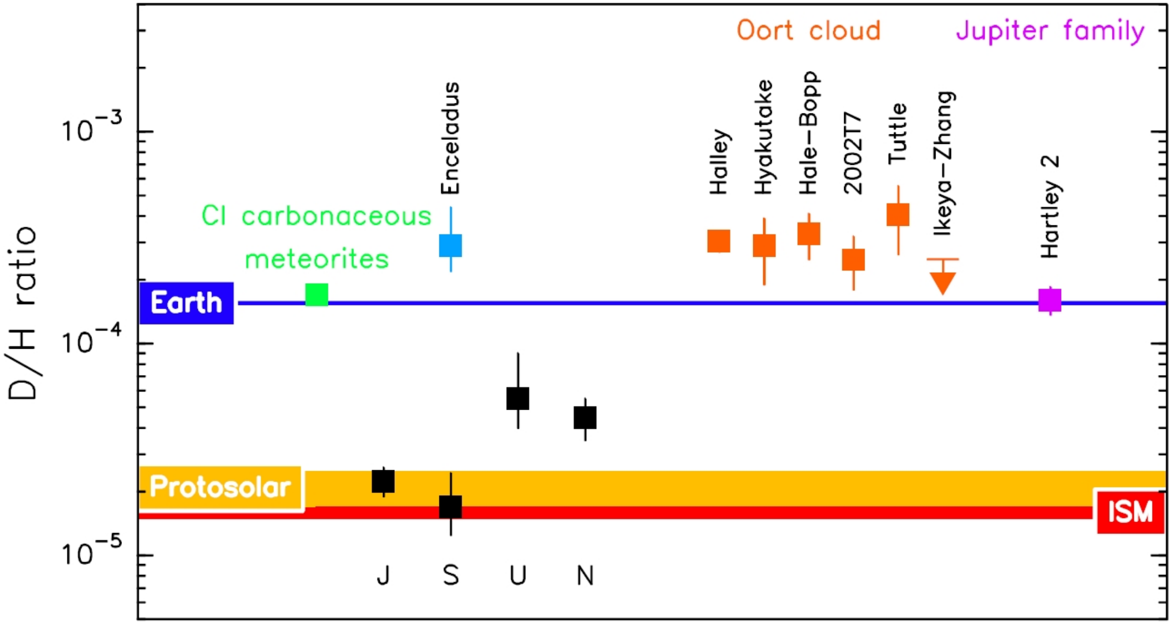
Interstellar ices

Heavy water HDO → origin of our oceans?

≠ HDO/H_2O in ≠ protostars?

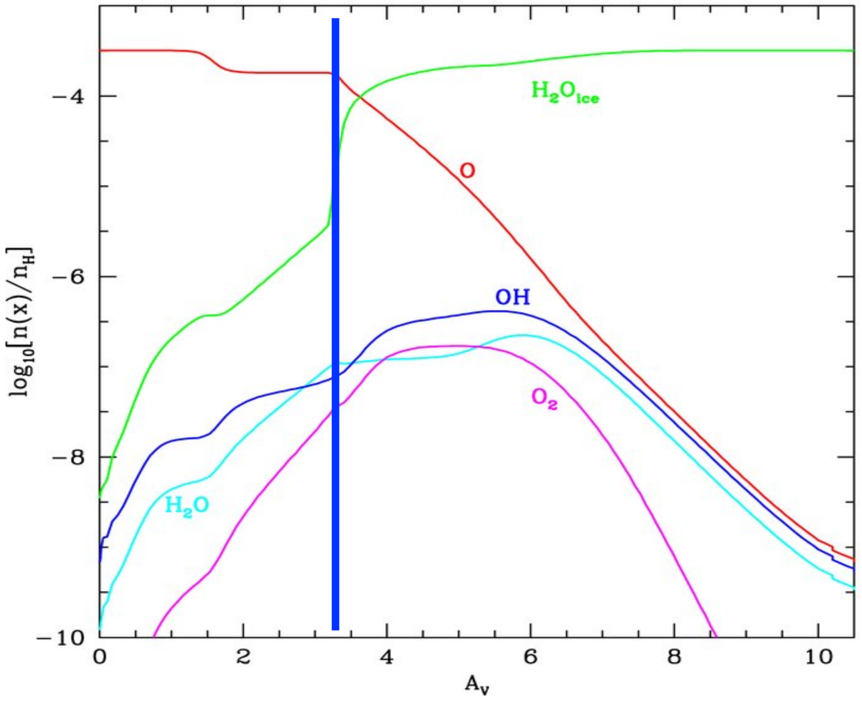


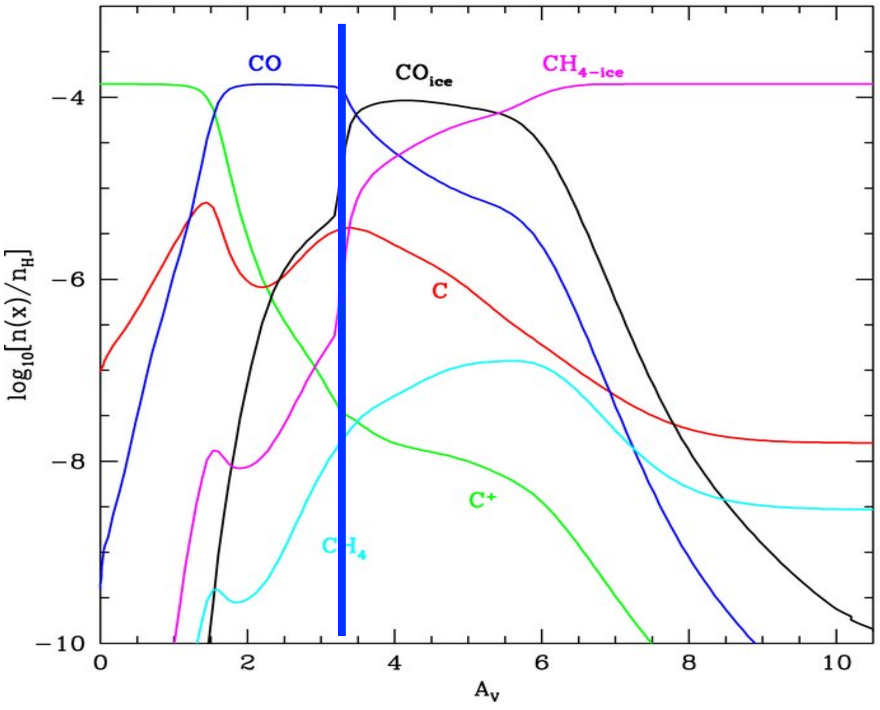




Hartogh et al. 2011, Nature, 478, 7368, 218

Formation of interstellar ices

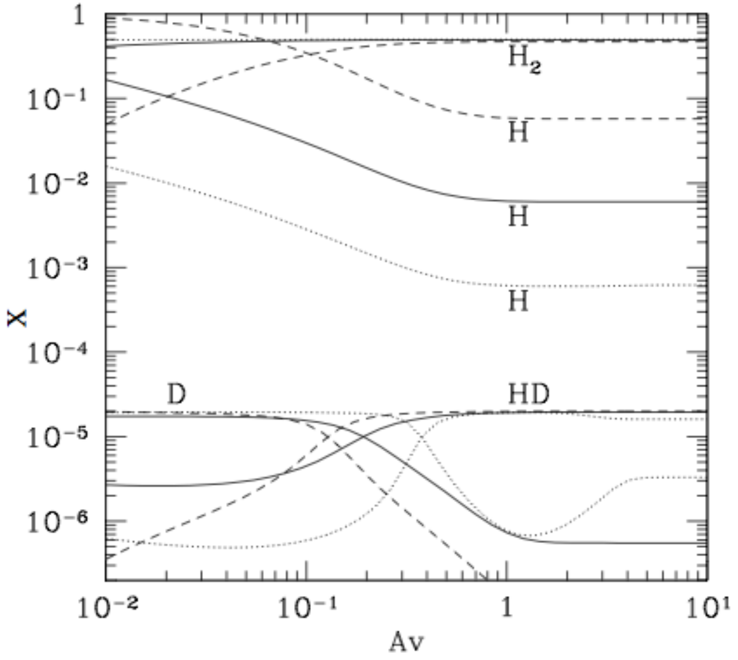


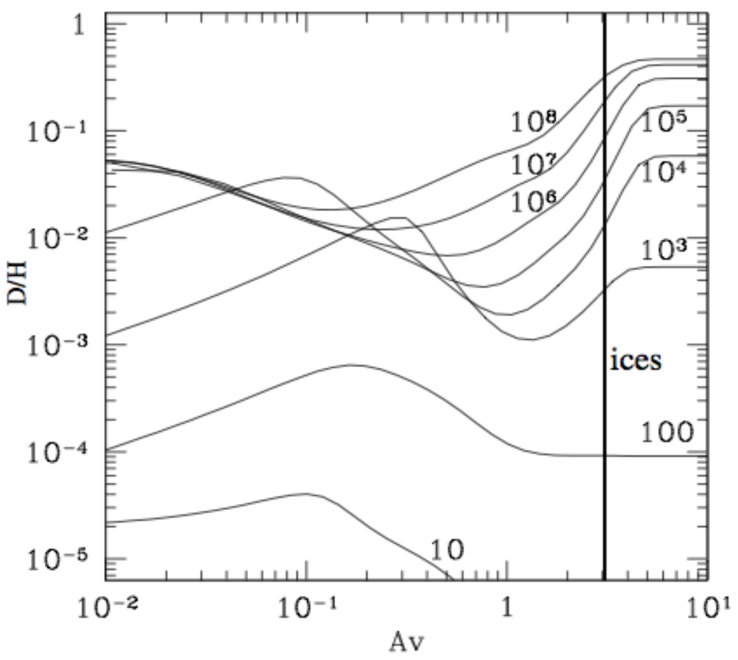


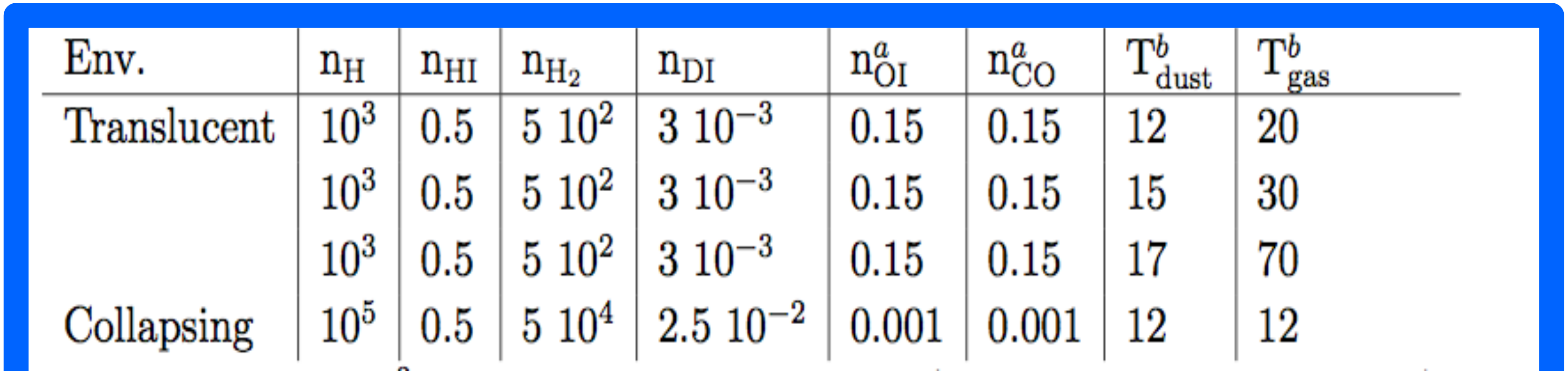
- CO and O both freeze out Av ~3

Hollenbach et al. 2008

Formation of the ices



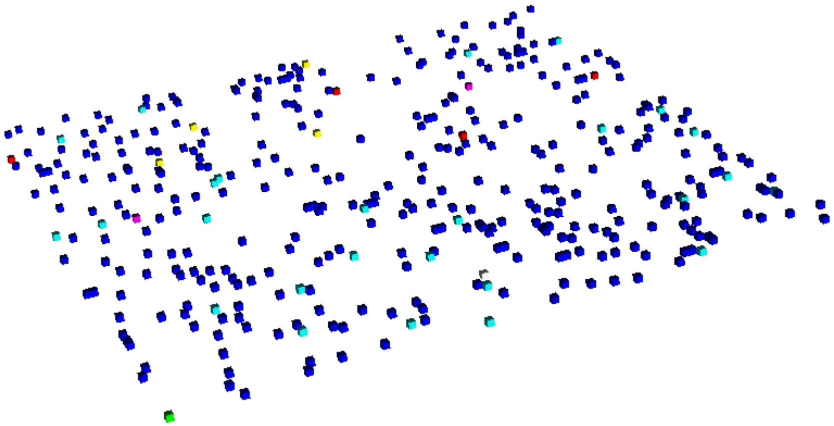




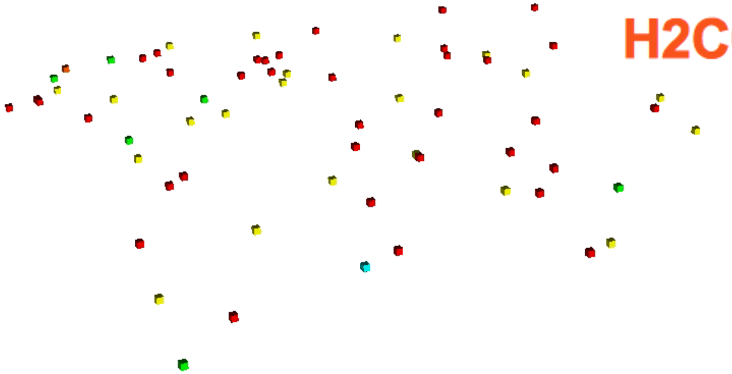
Env.	n_H	n_{HI}	n_{H_2}	n_{DI}	n^a_{OI}	n^a_{CO}	T^b_{dust}	T^b_{gas}
Translucent	10^3	0.5	5 10^2	3 10^{-3}	0.15	0.15	12	20
	10^3	0.5	5 10^2	3 10^{-3}	0.15	0.15	15	30
	10^3	0.5	5 10^2	3 10^{-3}	0.15	0.15	17	70
Collapsing	10^5	0.5	5 10^4	2.5 10^{-2}	0.001	0.001	12	12

Formation of ices

Physical/chemical conditions in the cloud where ices form



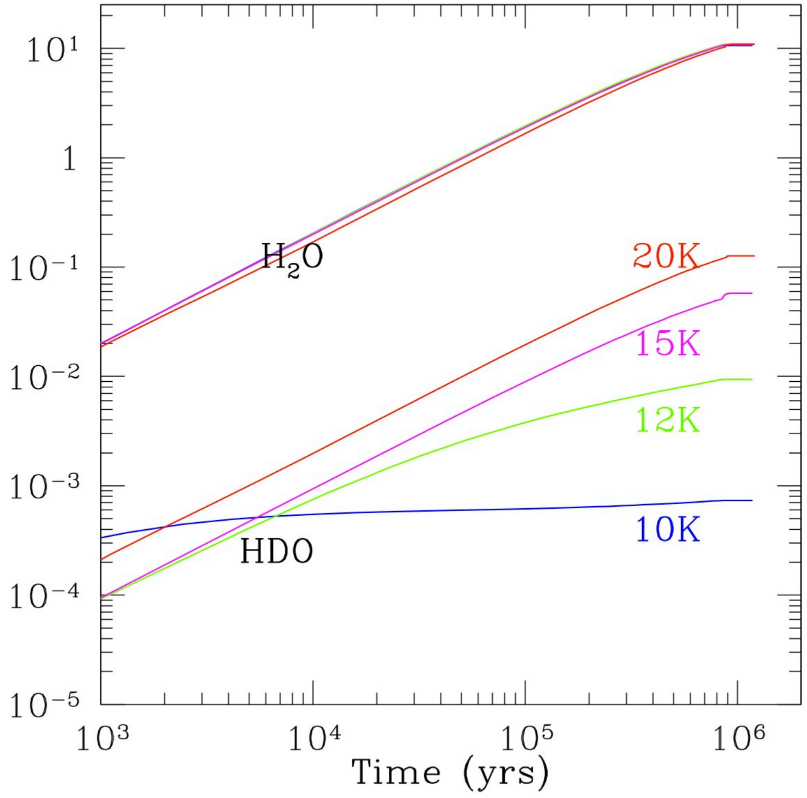
T_{dust}=12K



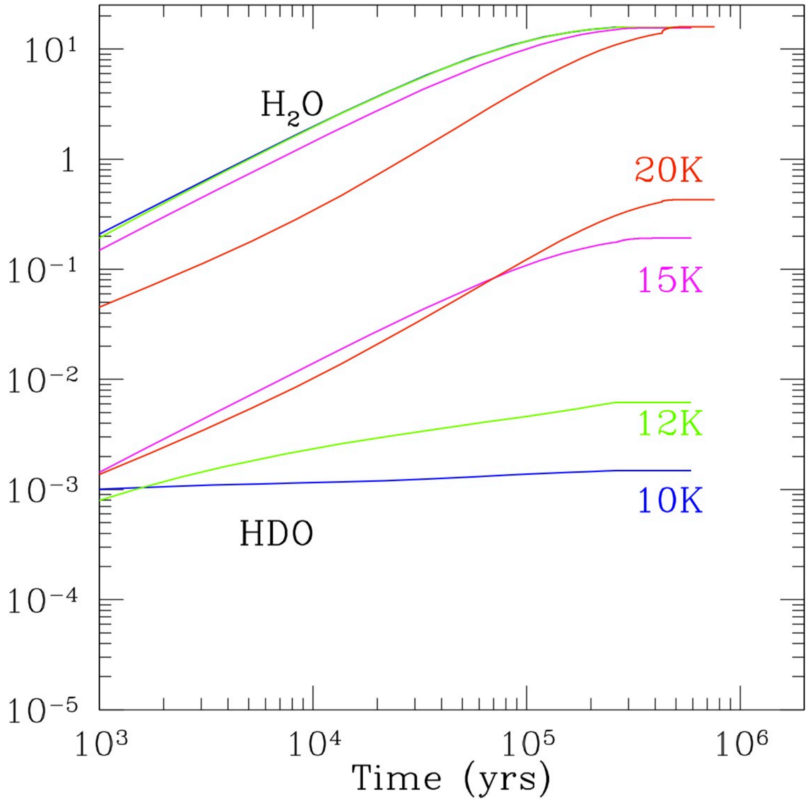
T_{dust}=17K

Dust temperature during formation ices → different chemistry

Formation of ices

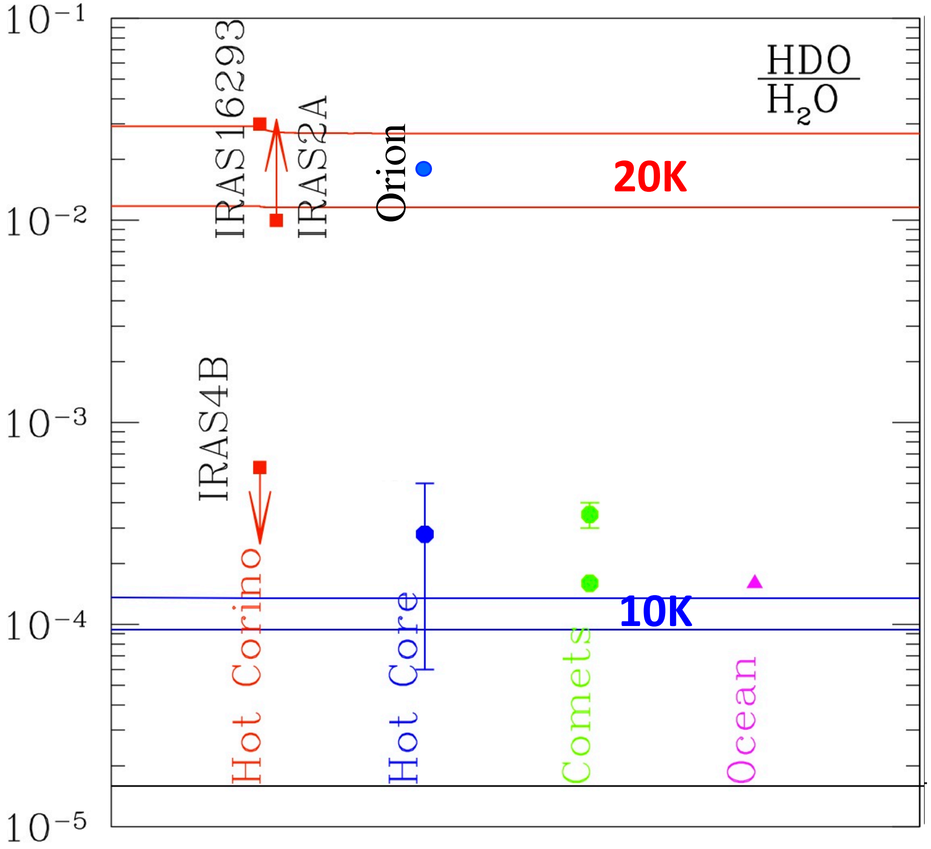


nH=10^3 cm $^{-3}$
D/H~ 10^{-3}



nH=10^4 cm $^{-3}$
D/H~ 10^{-2}

Comparison with observations



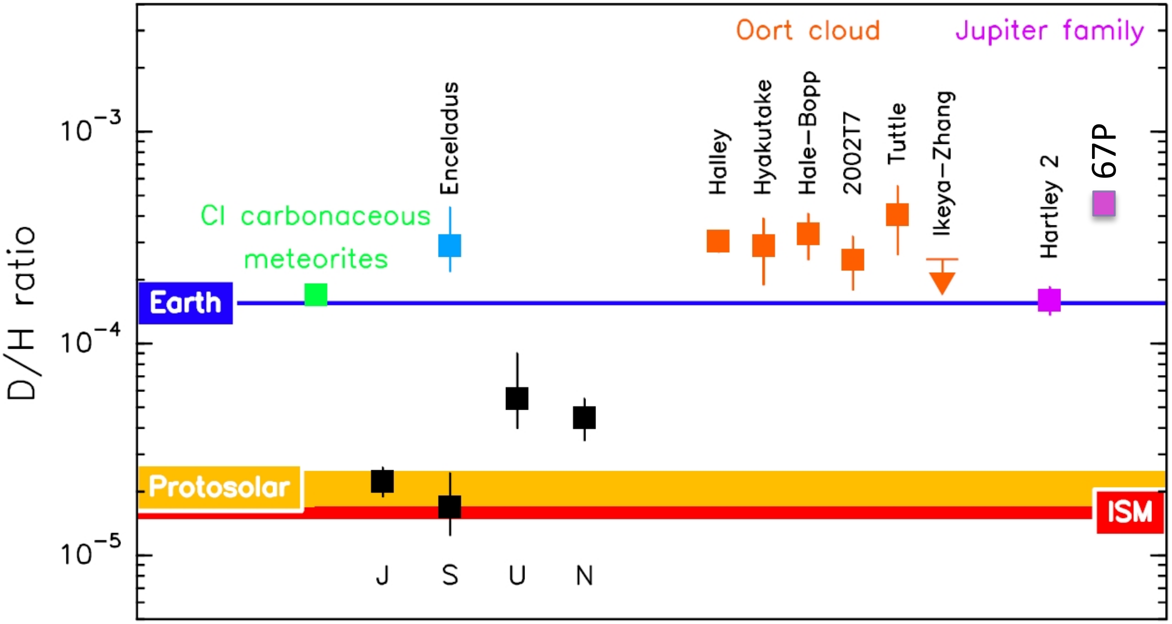
Deuteration of H_2O widely spread → relates physical conditions formation of ices

Studying formation of heavy water → clues on the origin of our Oceans / conditions of first phases SF

Interstellar ices

Heavy water HDO → origin of our oceans?

Our origin→ cold and dense



Hartogh et al. 2011, Nature, 478, 7368, 218

Results fro etta

67 P Jupiter family

HDO/H_2O = 5 1

Difference betw

ocean/co s/

asteroids?

- Isotopic exchanges during evaporation

CH3OD+H2O→ CH3OH + HDO

- ≠Evaporation

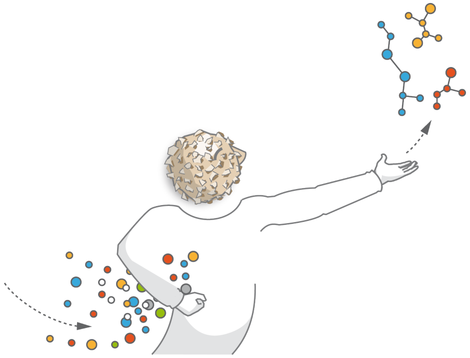
H_2O vs HDO

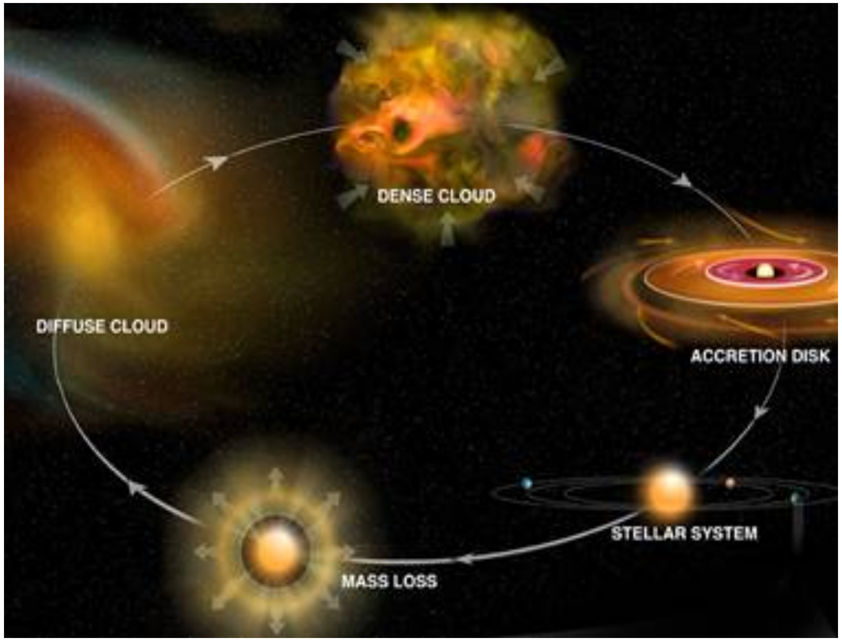
Dust and star formation

Star form in clouds made of gas + dust

Catalyst:

Enrich gas

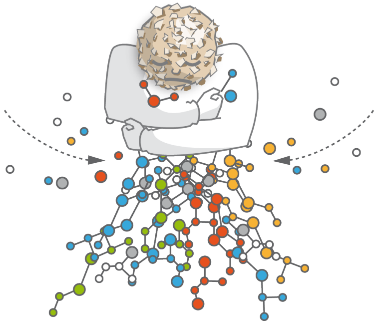




Reservoir:

Stealing gas

Ices formation



Dust **catalyst/reservoir** impacts gas composition → star formation?

The impact of dust on star formation

No coolant

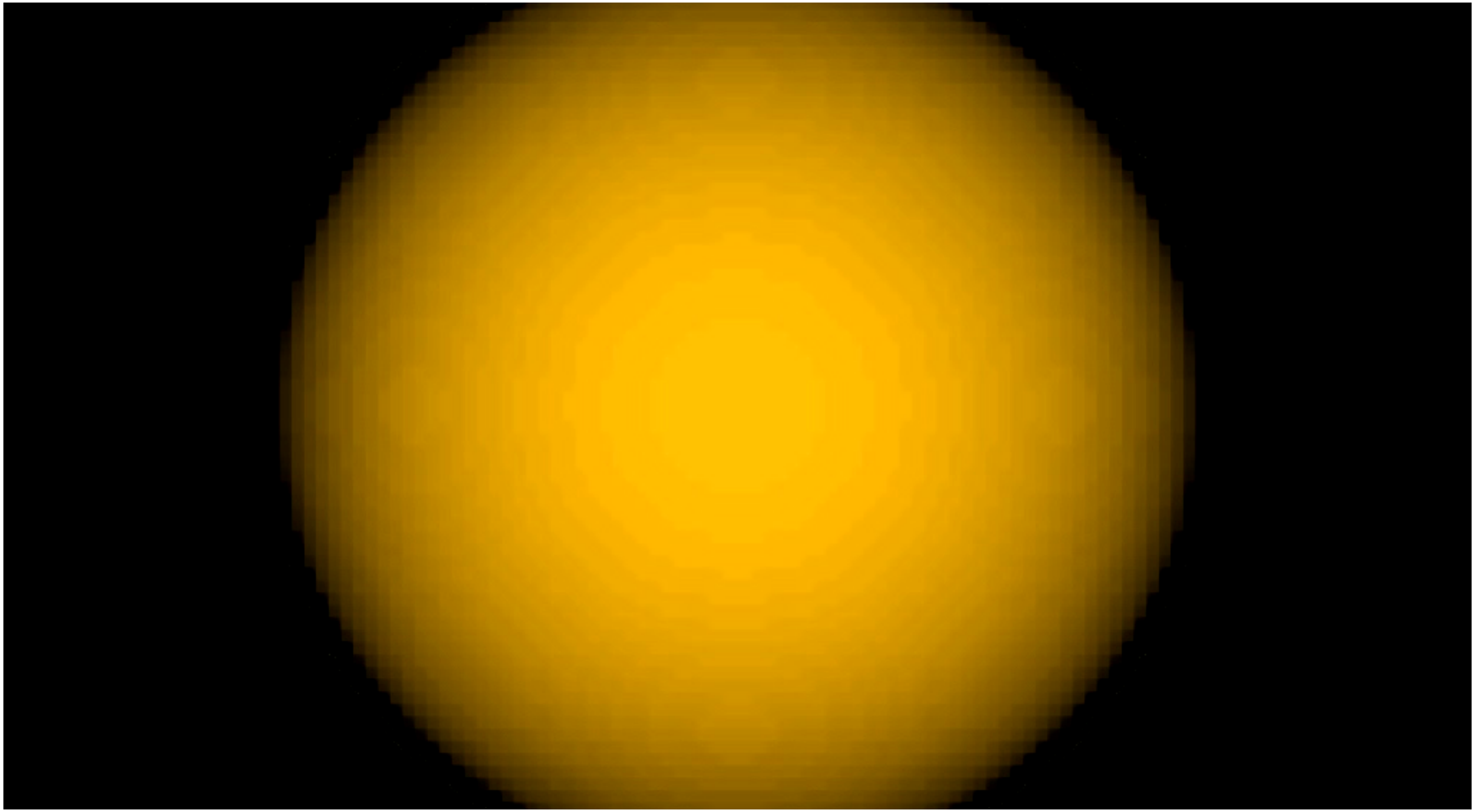
coolants

Molecular cloud evolution: Hydrodynamic code dust affects

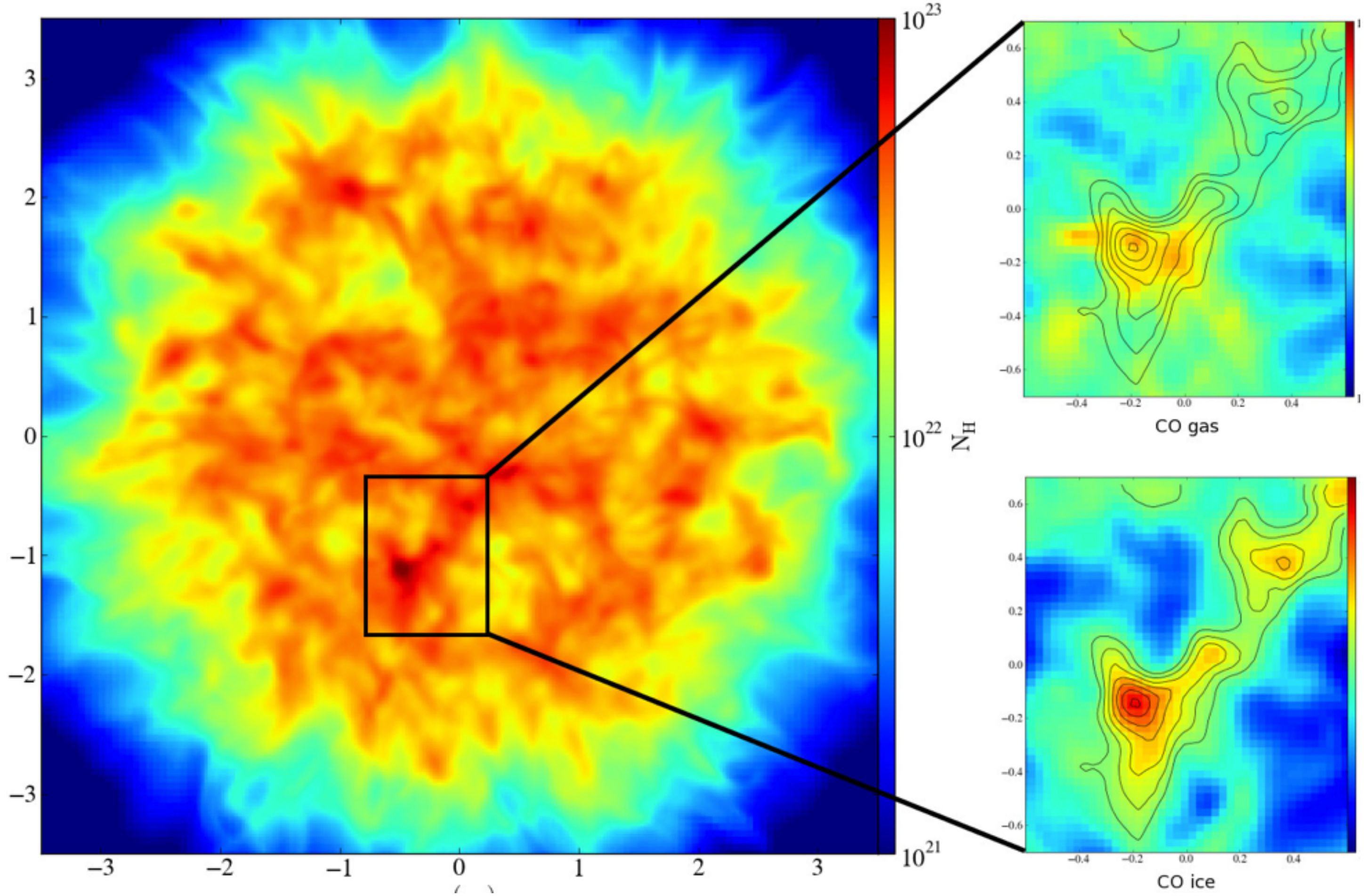
➔Cloud fragmentation

➔Star formation and final masses

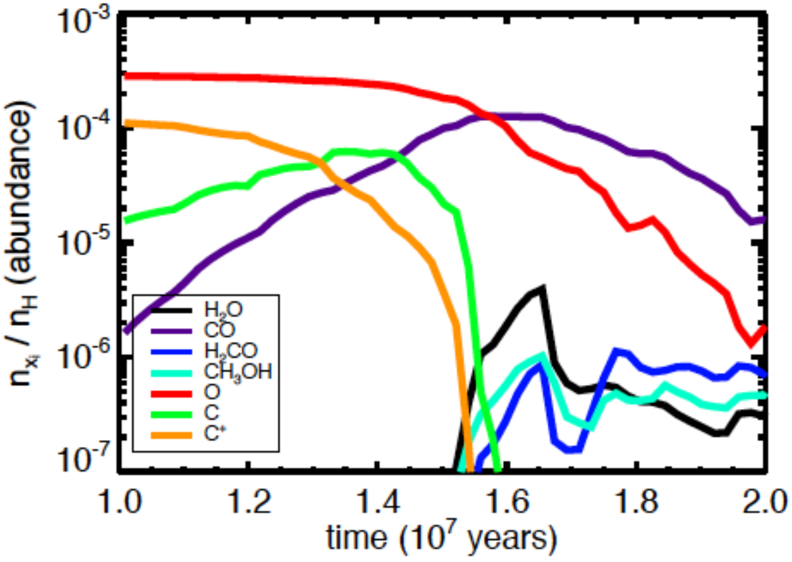
The impact of dust on star formation



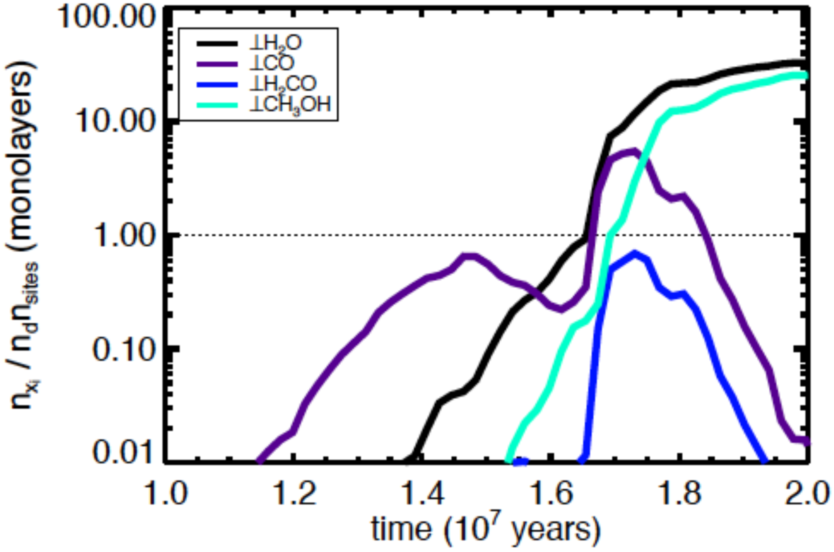
The impact of dust on star formation



Dust, ice and gas in star formation



Gas content



Ice content

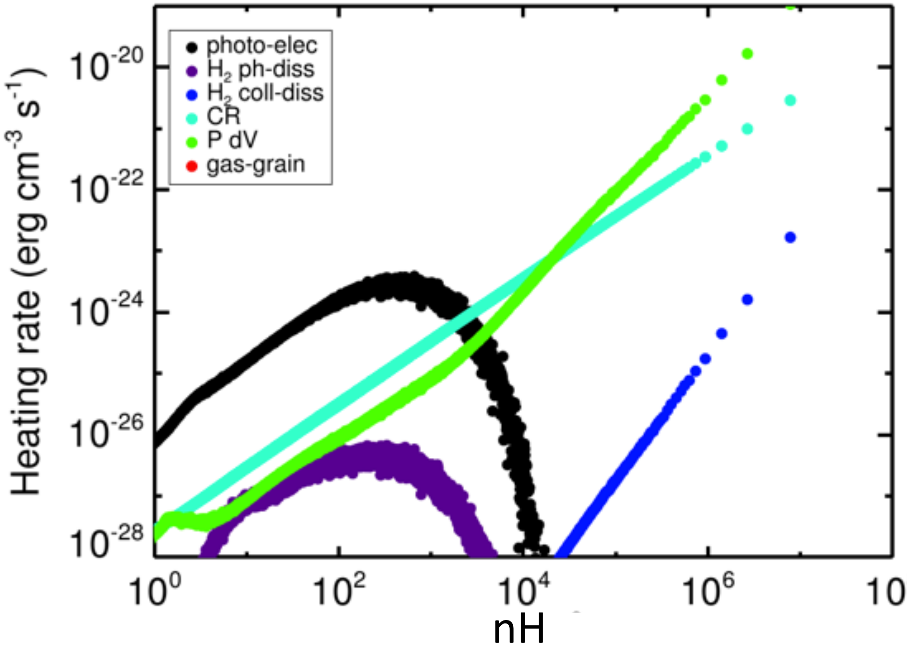
Hocuk & Cazaux 2014

- Follow formation/composition of ices with cloud evolution.
- Predict gas content during cloud evolution → observables
- During SF → CO freeze onto dust → less coolant in the gas

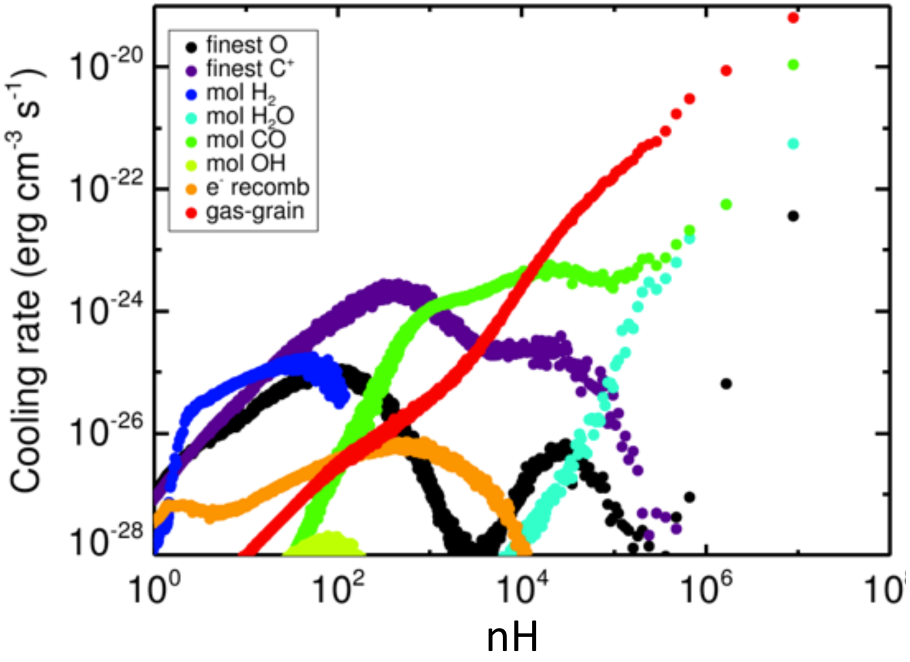
Dust, ice and gas in star formation

Cloud Evolution

Heating



Cooling

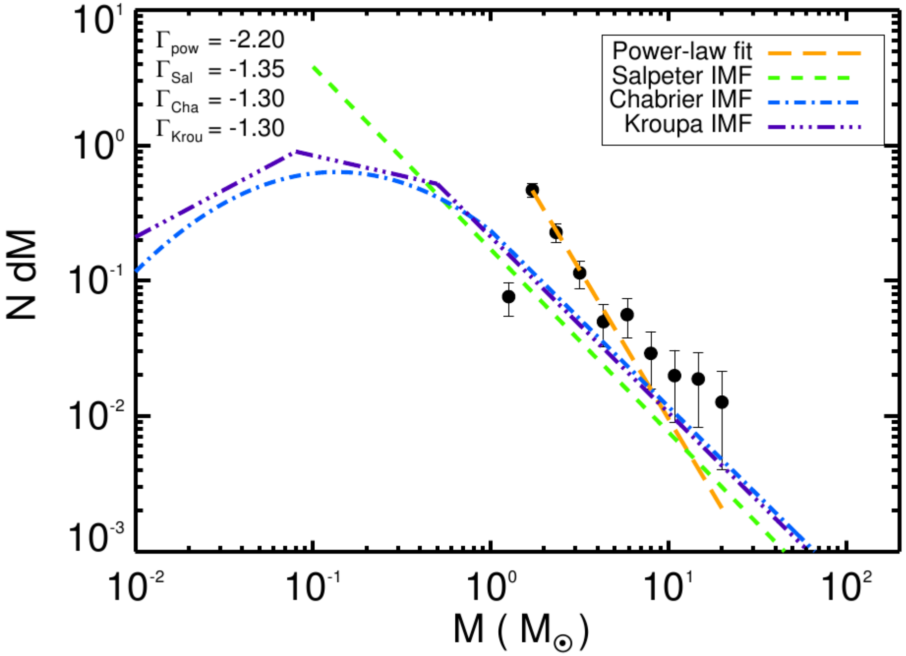


Hocuk Cazaux & Spaans 2012

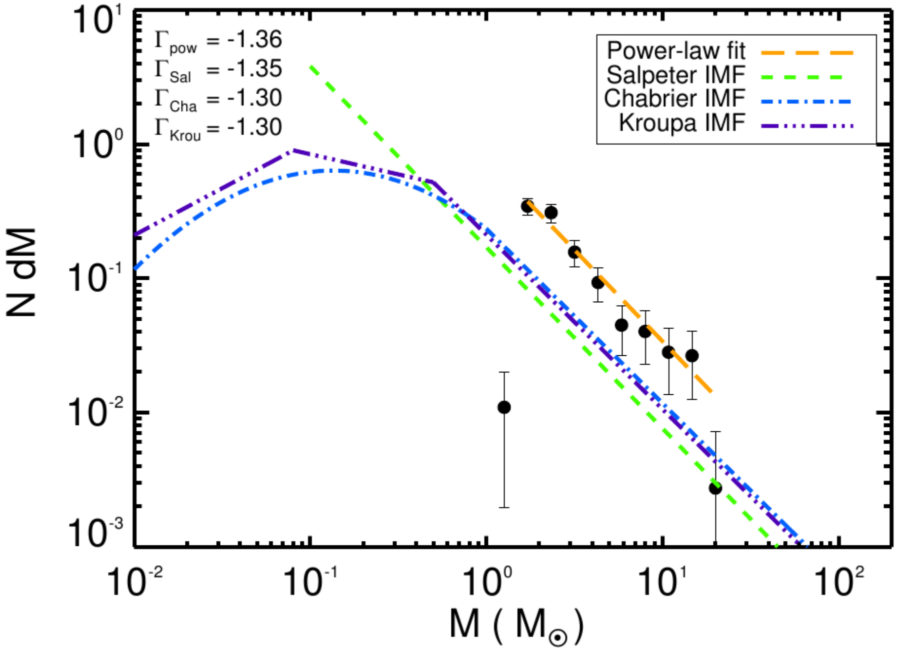
Dust, ice and gas in star formation

Initial mass function (mass distribution of stars).
Include sink particles to form stars
If dust is included → leads to IMF similar to Salpeter.
More simulations needed for lower masses.

Without interplay gas/dust

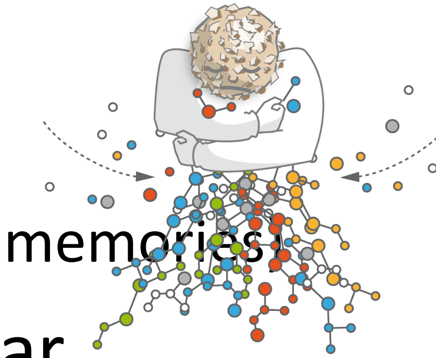


With interplay gas/dust

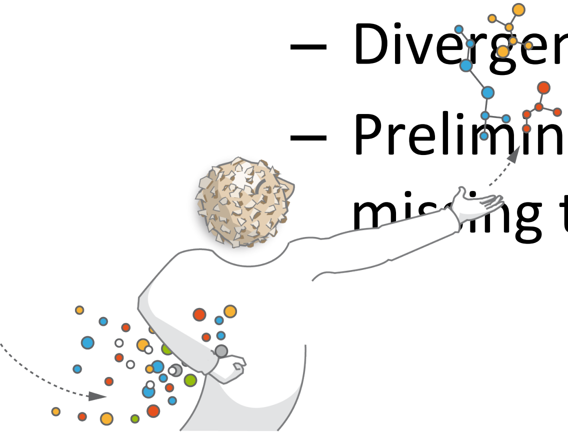


Conclusions

- Interplay between dust, ice and gas is essential to predict/interpret observations
  - Dust catalyst → enrich the gas
  - Dust reservoir → steals the gas → ices (our memories)

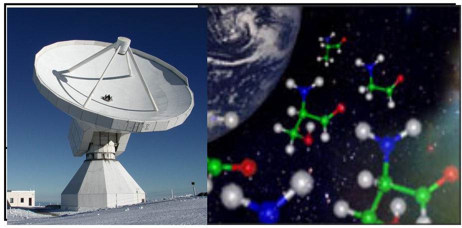


- Description of the ISM → crucial to star formation.
  - Divergences from a clouds with/without dust.
  - Preliminary results show that some coolants should be missing to reproduce the observed IMF.



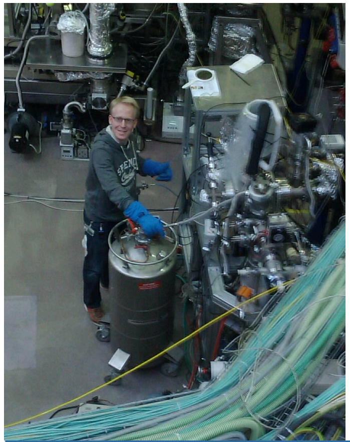
Interstellar dust:
The hidden protagonist

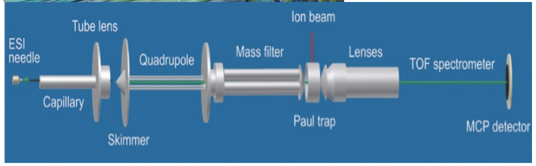
Observations



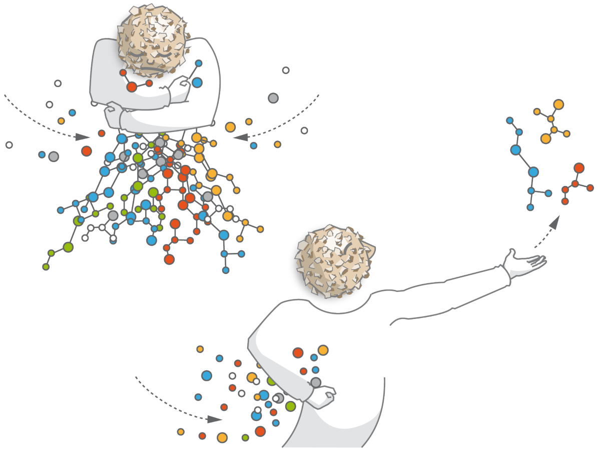
Gisela Banos Esplugues
Postdoc

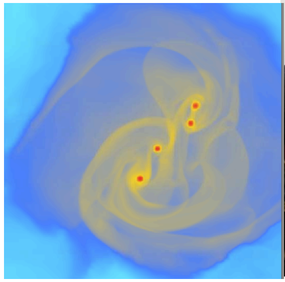
Leon Boschman
PHD



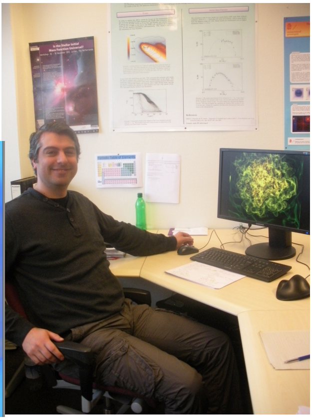


Experiment





Simulations



Seyit Hocuk
postdoc

Thank you