THE PHYSICS AND CHEMISTRY

Alexey Potapov
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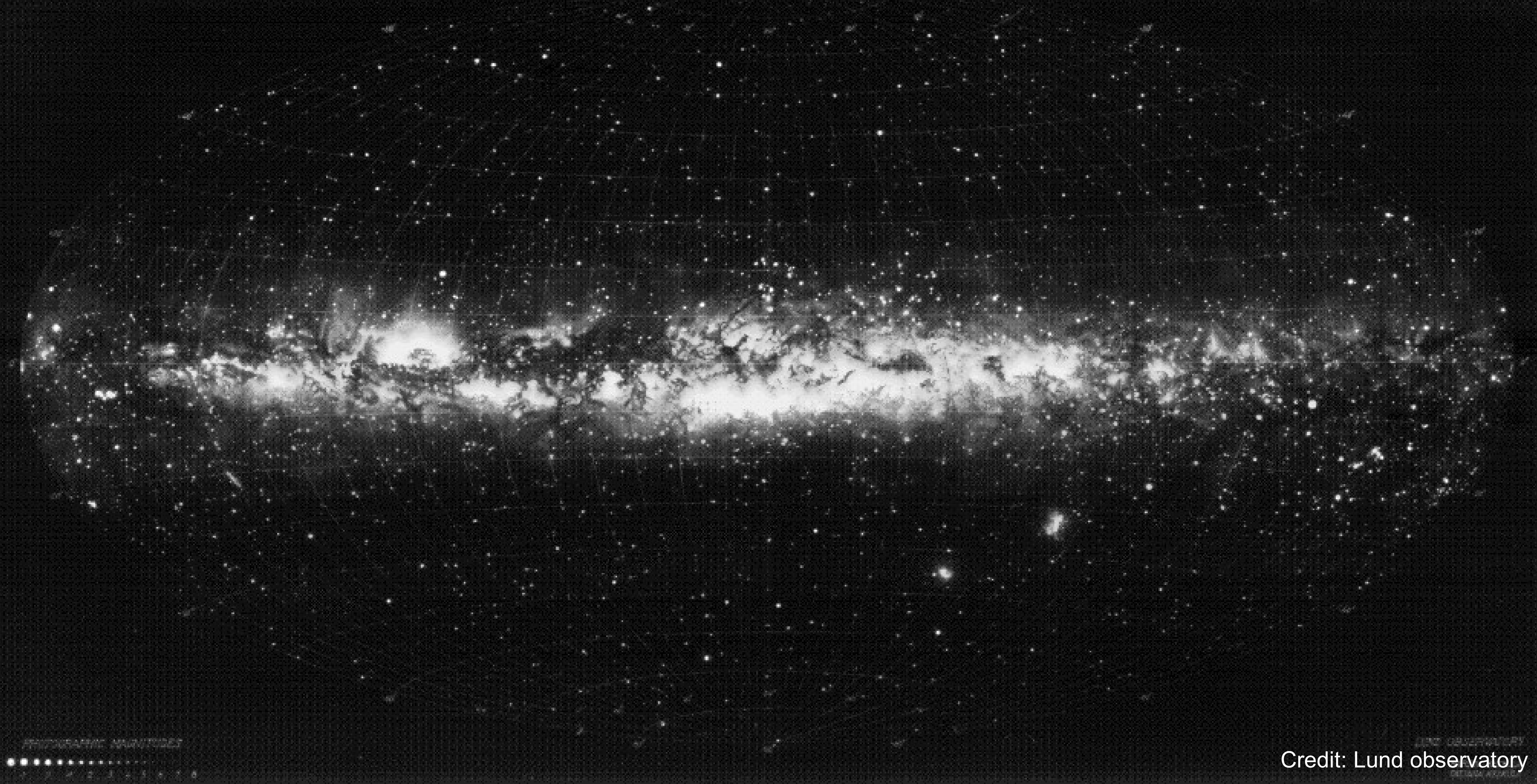
ON THE SURFACE OF COSMIC DUST GRAINS

The whole sky (by eyes)



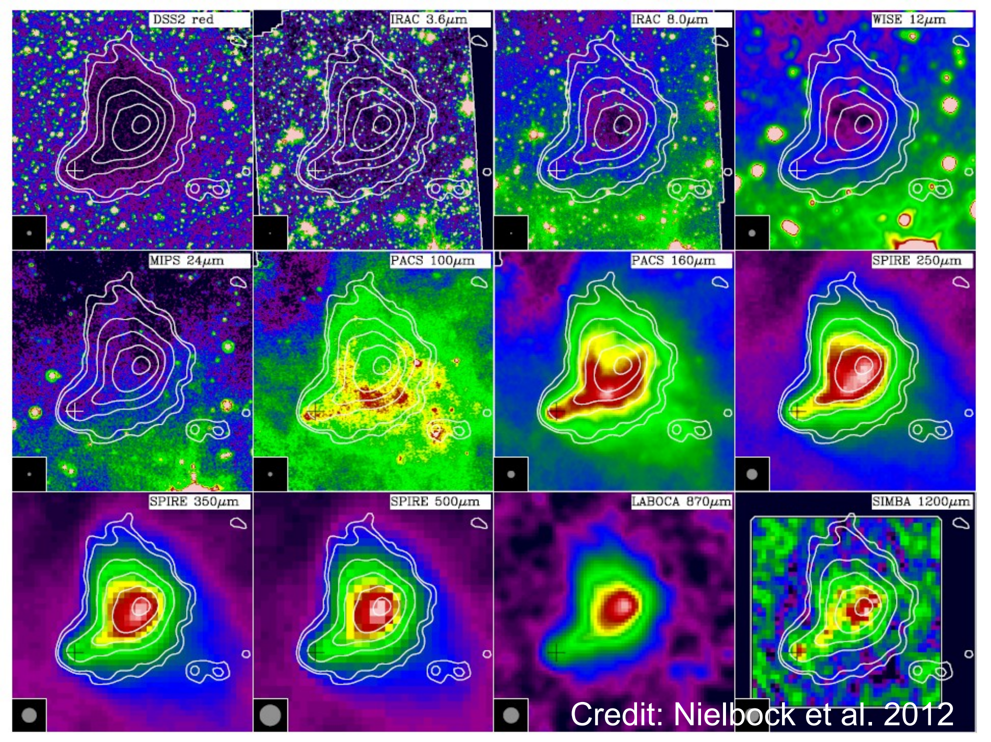
Credit: Lund observatory

The whole sky (by eyes)

“a lot of stars and black holes” (Jules Verne)

Credit: Lund observatory

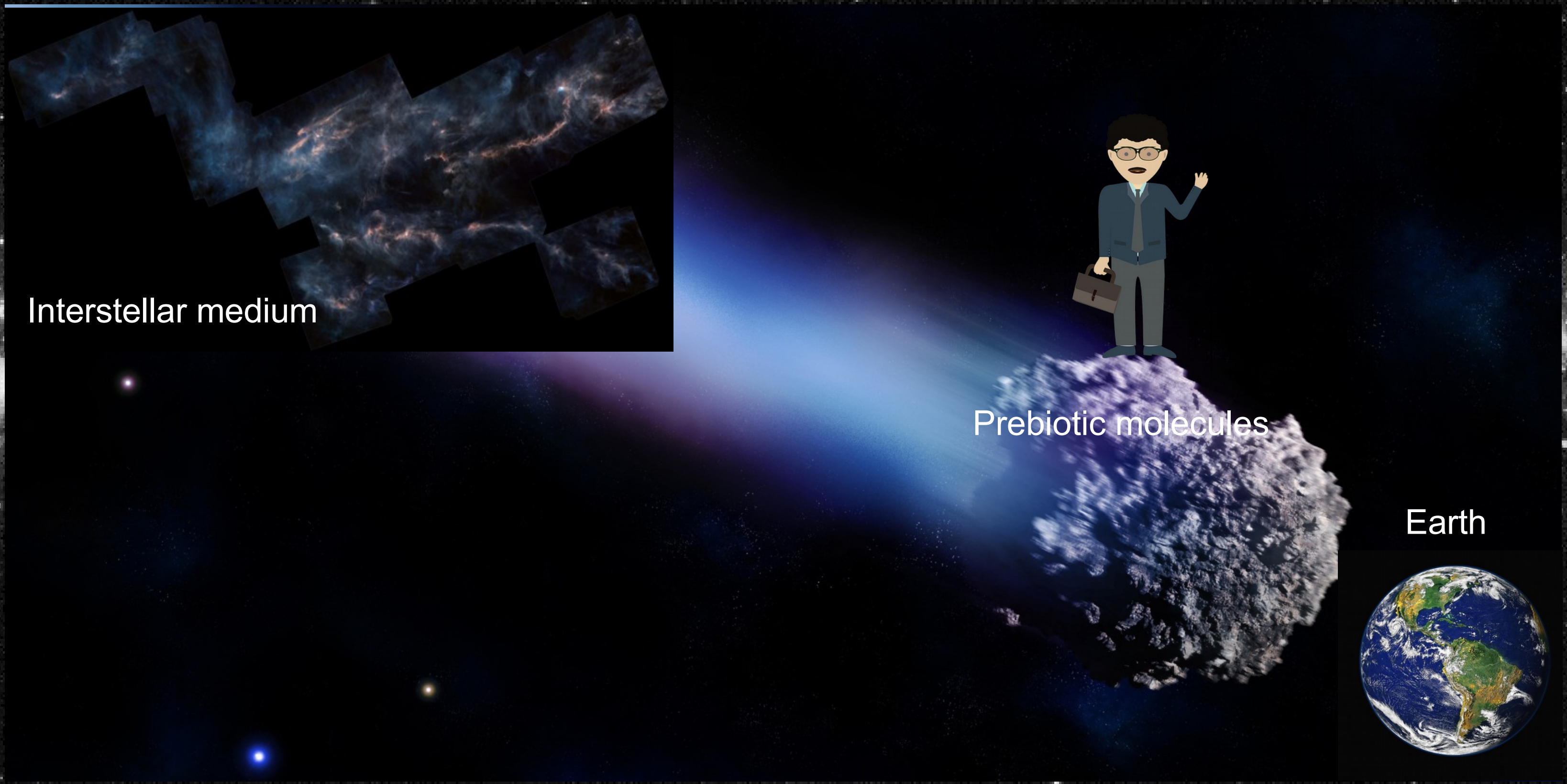
Molecular clouds



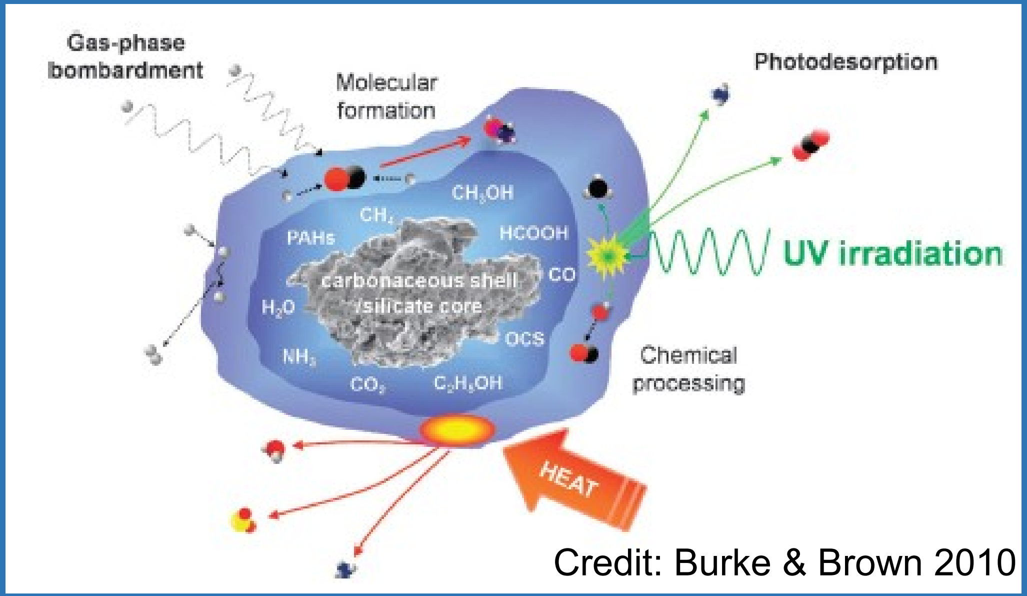
Credit: Nielbock et al. 2012

Credit: Lund observatory

Origin of life

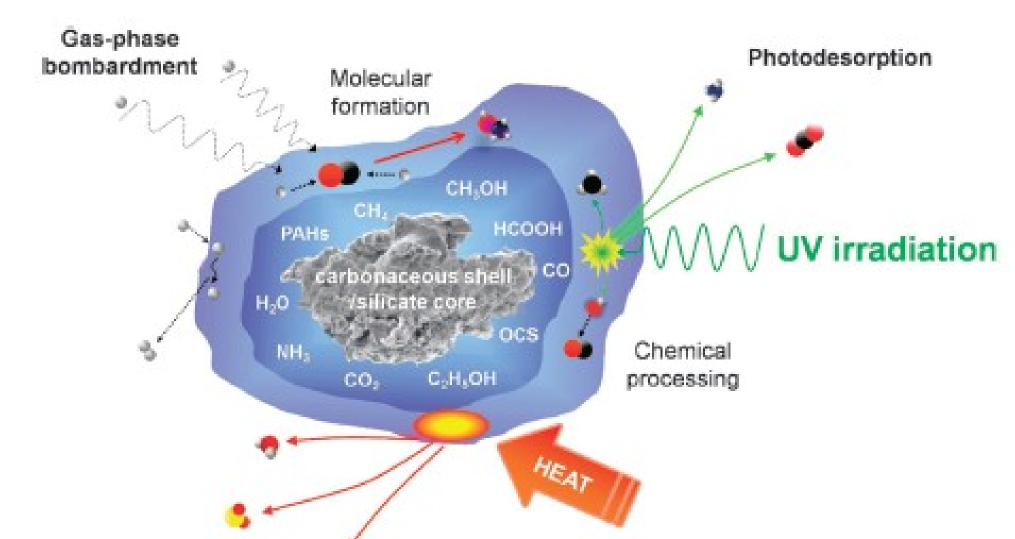


Structure of dust/ice grains

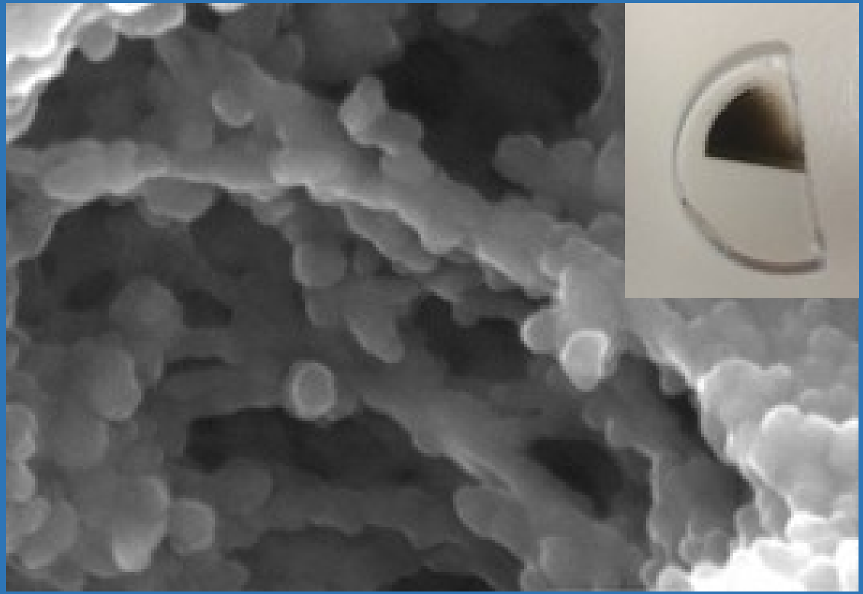


Credit: Burke & Brown 2010

Structure of dust/ice grains



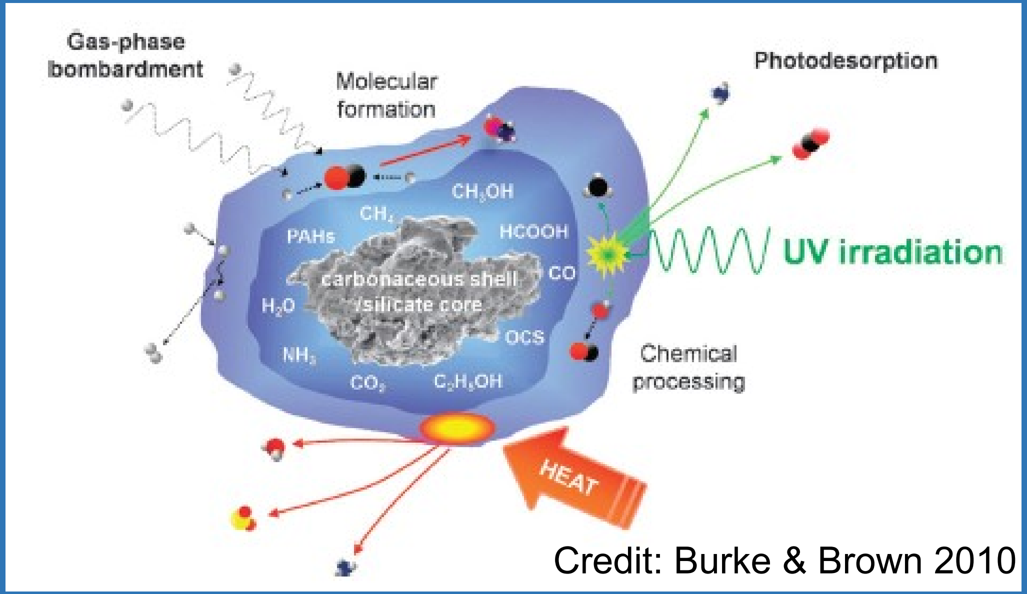
Credit: Burke & Brown 2010



HRTEM image of silicate grains (real surface area is unknown)
Inset: carbon grains on a KBr substrate (nominal surface area is 1 cm^2)

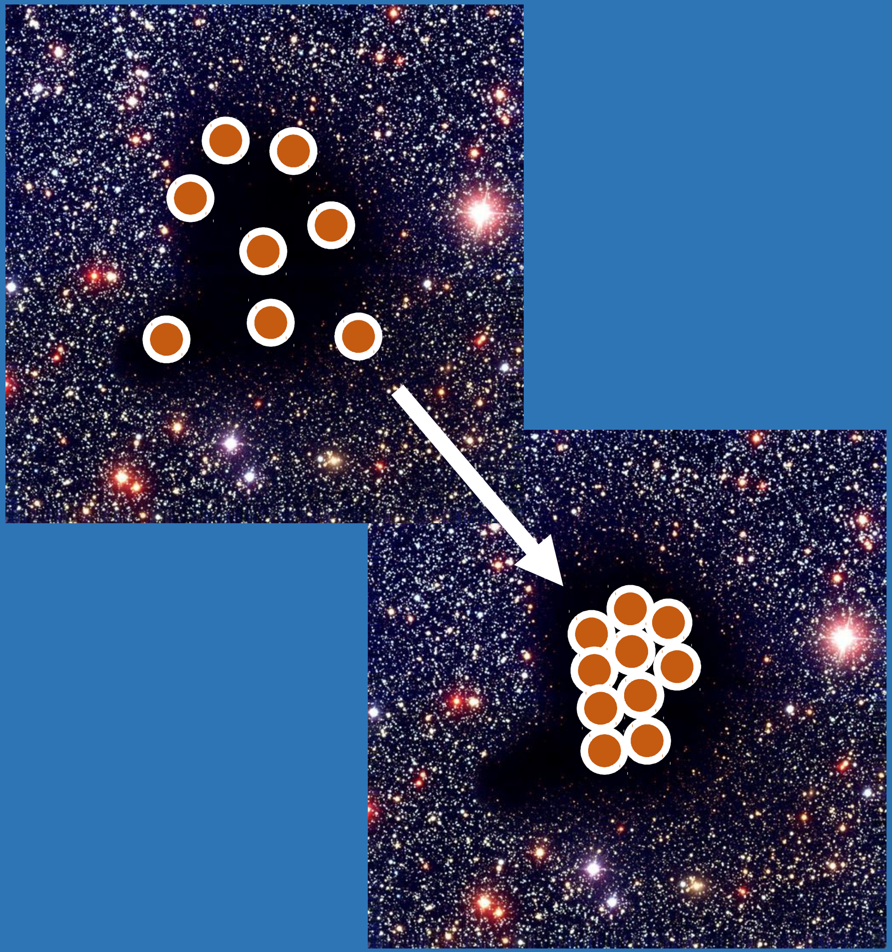
High porosity
Large surface

Structure of dust/ice grains

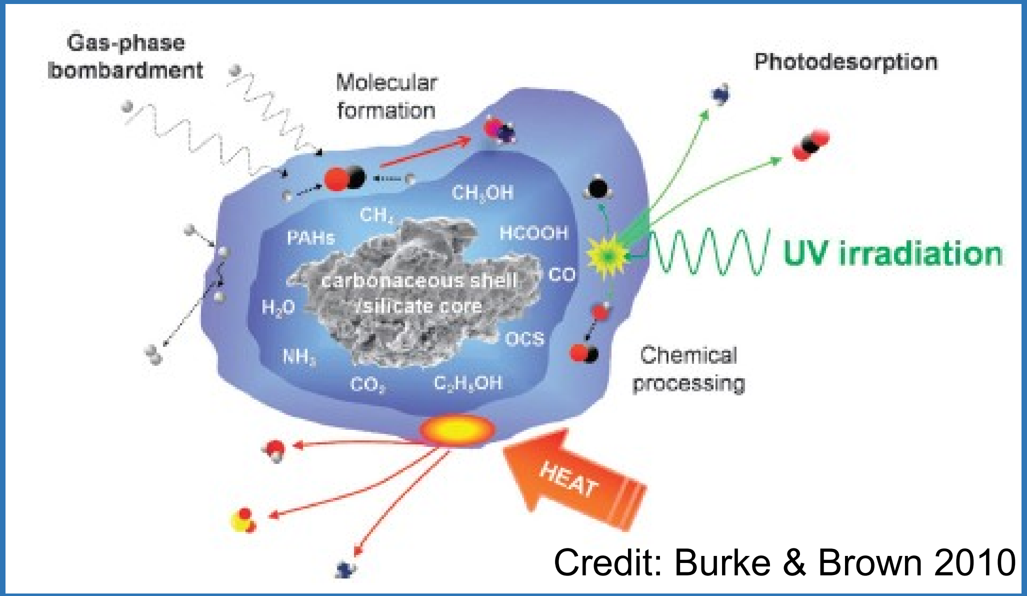


Credit: Burke & Brown 2010

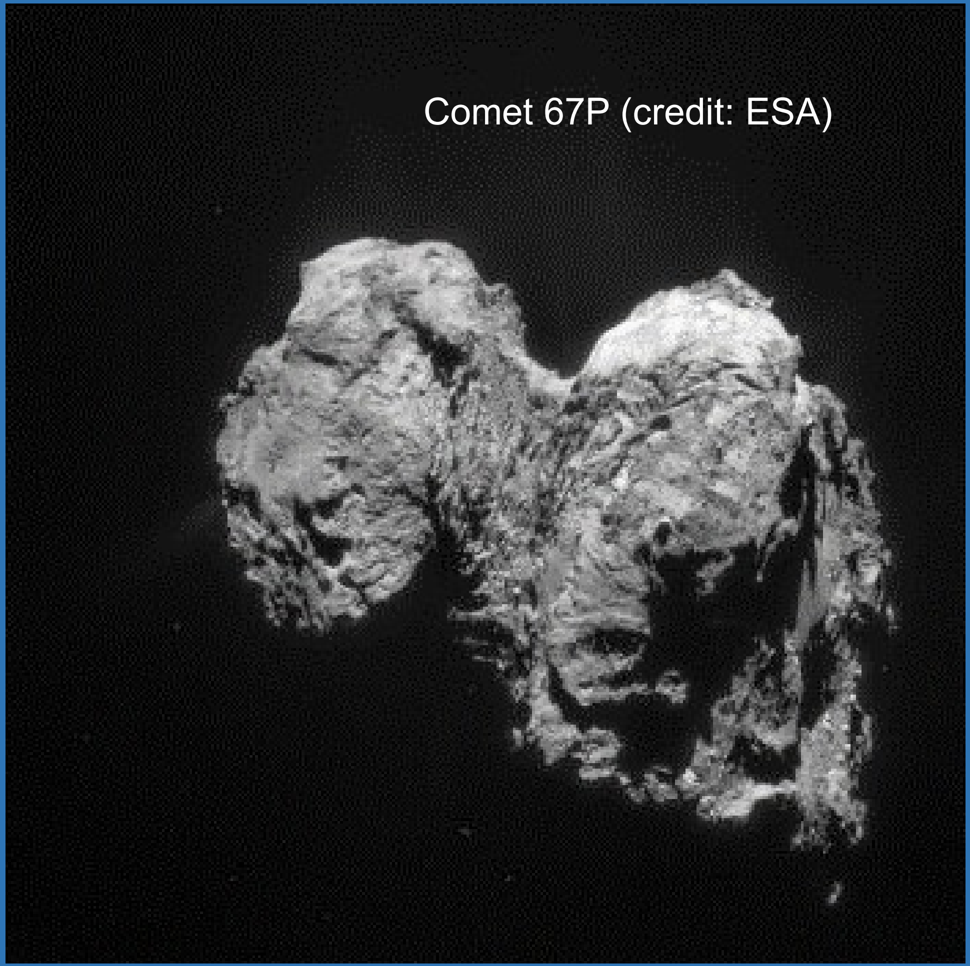
Cold condensation of dust in dense clouds



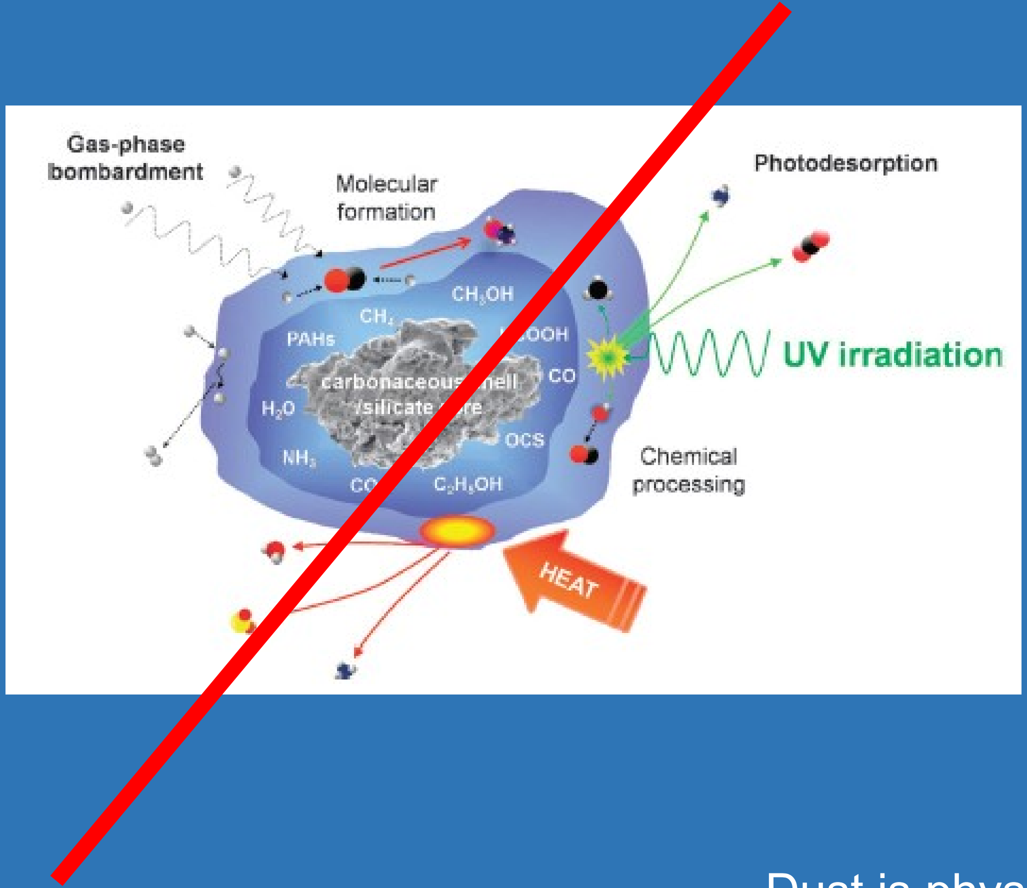
Structure of dust/ice grains



Credit: Burke & Brown 2010

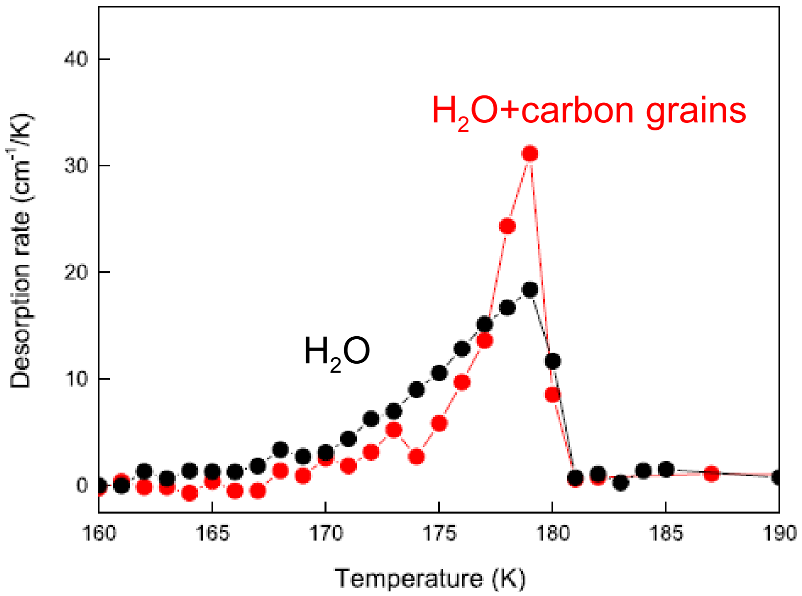

Comet 67P (credit: ESA)

Structure of dust/ice grains



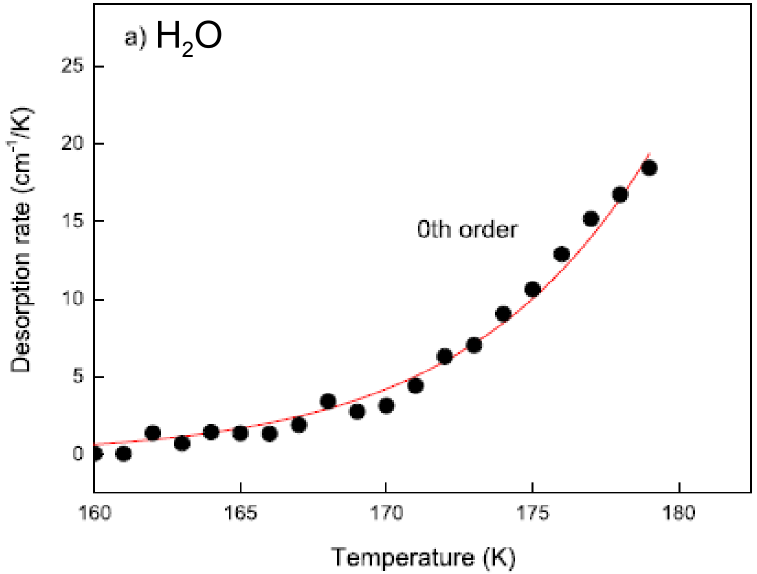
Dust is physically mixed with ice!

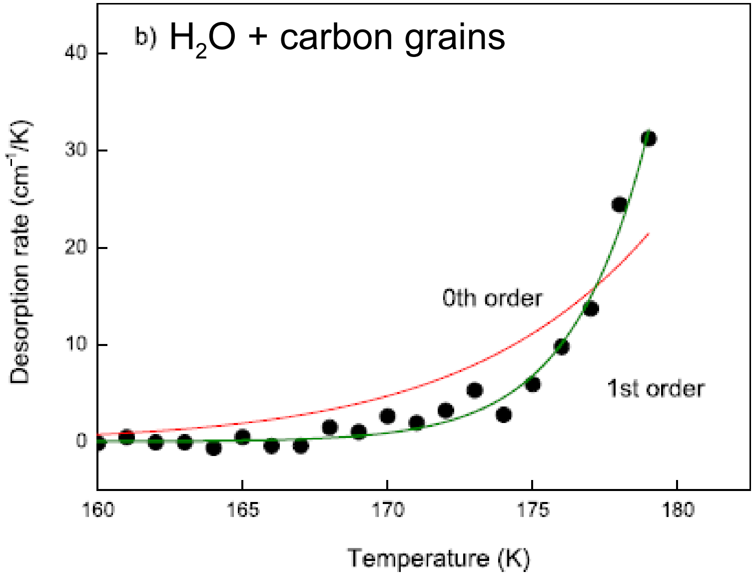
Thermal desorption of H_2O ice



$$dA/dT = v_0 \cdot 1/b \cdot N^i e^{-E/RT}$$

A – integrated band intensity
T – temperature
v_0 – pre-exponential factor = 10^{12}
b – heating rate = 1 K/min
N – number of molecules
~~i – desorption order~~
E – desorption energy





Potapov A. et al., *ApJ*, 2018, 865, 58

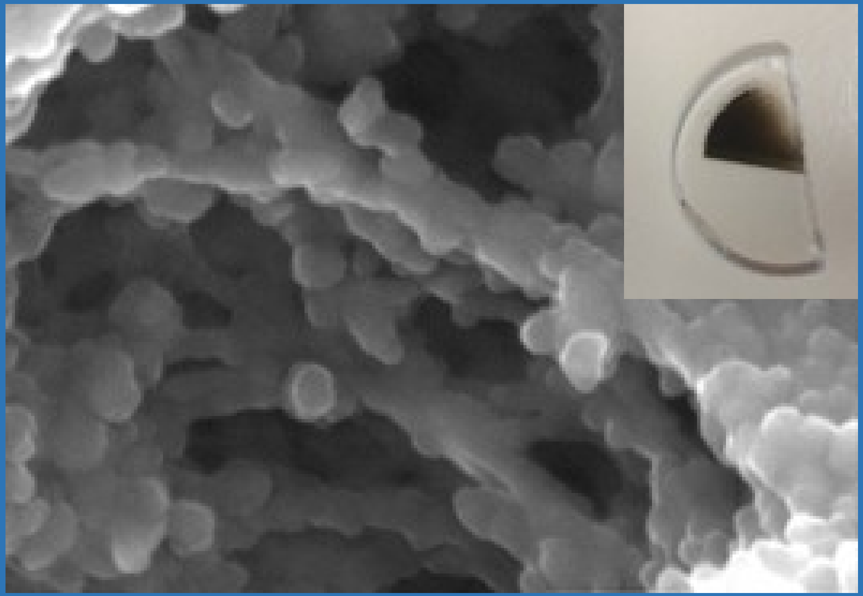
Thermal desorption of H_2O ice

H_2O (130 nm, 400 ML):
desorption order = 0 – multilayer desorption

H_2O (130 nm, 400 ML) + carbon grains:
desorption order = 1 – monolayer desorption

Correction factor of 400!

<u>Ice coverage of dust grains in the ISM:</u>
10^{18} molecule cm^{-2} – 1000 ML / 400 = 2.5 ML

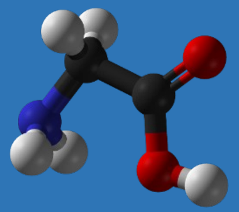


HRTEM image of silicate grains (real surface area is unknown)
Inset: carbon grains on a KBr substrate (nominal surface area is 1 cm^2)

Cosmic dust grains

Huge number of studies

from simple molecules to amino acids



Role of dust grains in the chemistry on their surfaces

- Direct participation of functional groups and atoms in surface reactions

Threefold catalytic effect

- A place where molecules can rapidly diffuse and react
- A third body to dissipate the energy released in exothermic bond formations
- Lowering the activation barriers of reactions

Direct participation of dust

A handful of studies

CO_2 in H_2O ice covering hydrogenated carbon grains by ion irradiation (Mennella et al., 2004)

CO and CO_2 in H_2O ice covering hydrogenated carbon grains by UV irradiation (Mennella et al., 2006)

CO_2 in O_2 ice covering atomic carbon foils by UV irradiation (Fulvio et al., 2012)

CO_2 in H_2O ice covering atomic carbon foils by proton irradiation (Raut et al., 2012)

CO and CO_2 in H_2O ice covering hydrogenated carbon grains by proton irradiation (Sabri et al., 2015)

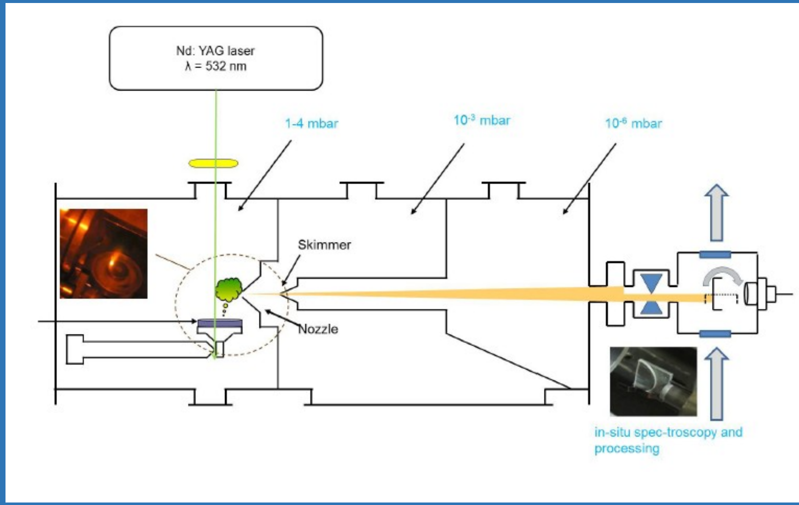
CO and CO_2 in H_2O ice covering graphite films by UV irradiation (Shi et al., 2015)

↓

Formation of CO and CO_2

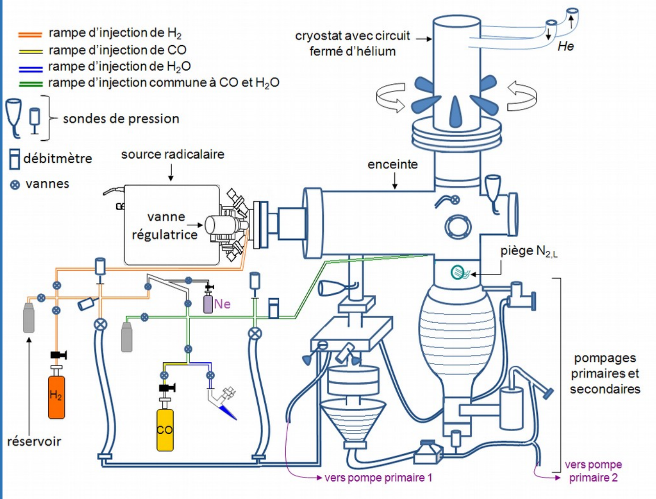
Direct participation of dust

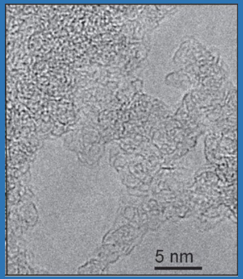
LabAstro, Jena



+

MONARIS, Paris





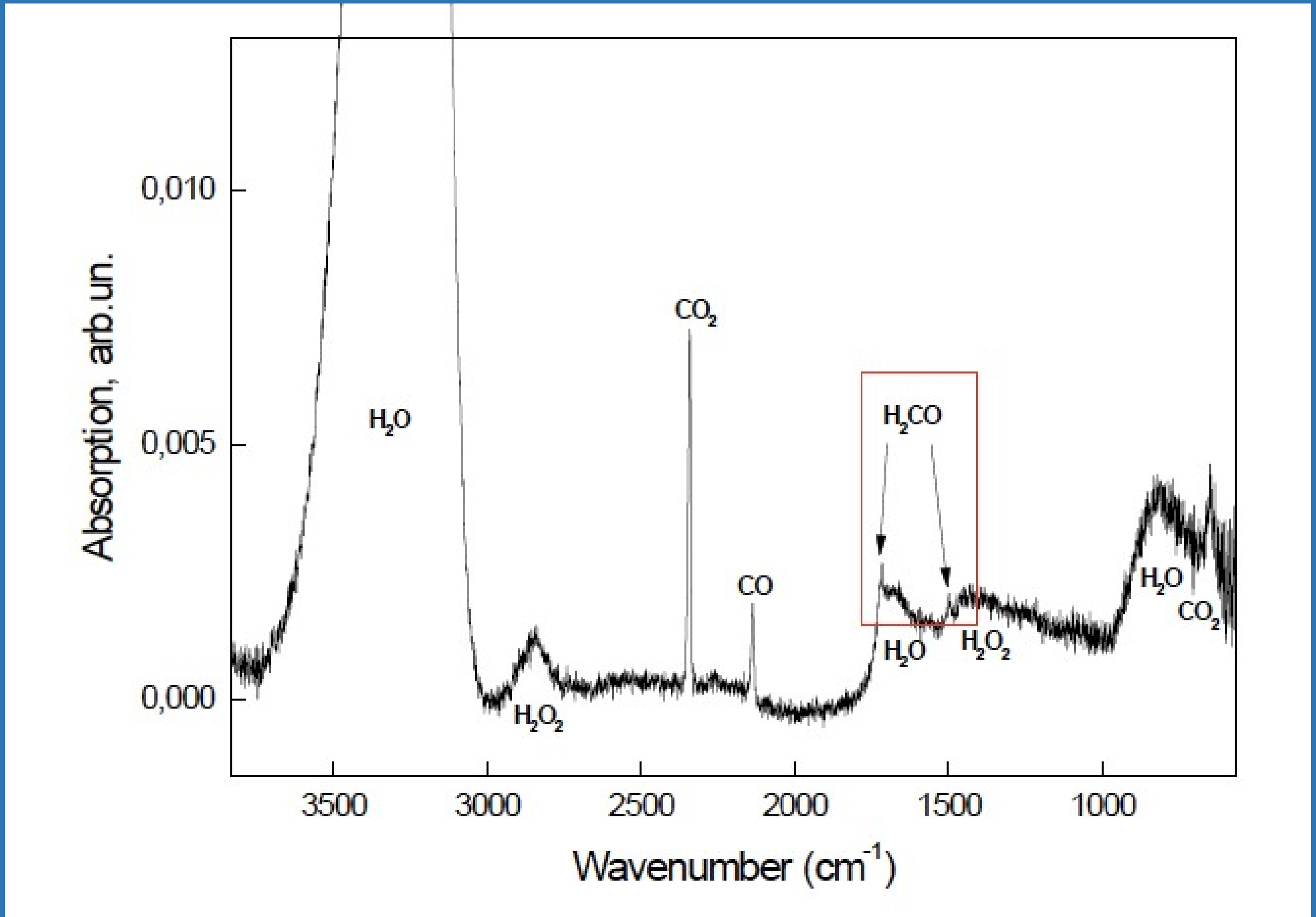
Amorphous hydrogenated fullerene-like carbon grains

Sample - fixed on a copper mirror at 10 K

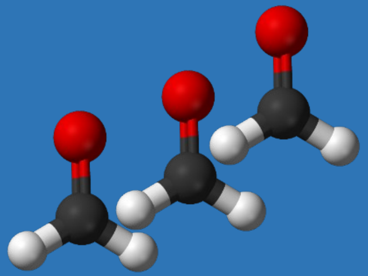
High vacuum chamber (10^{-9} mbar)

Bombardment – 30 minutes, 1.8×10^{20} atoms cm^{-2}

Direct participation of dust

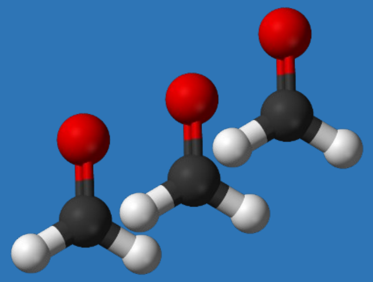


Difference IR spectrum before and after O/H bombardment of carbon grains



Direct participation of dust

A new route of molecules formation in the ISM:
grain surface processes



Potapov A., …, Krim L., *ApJ*, 2017, 846, 131

Catalytic effect of dust

Some studies

H_2 on crystalline silicate films (Pirronello et al., 1997)

H_2O on amorphous silicate films (Jing et al., 2011)

H_2O on amorphous silicate films (He and Vidali, 2014)

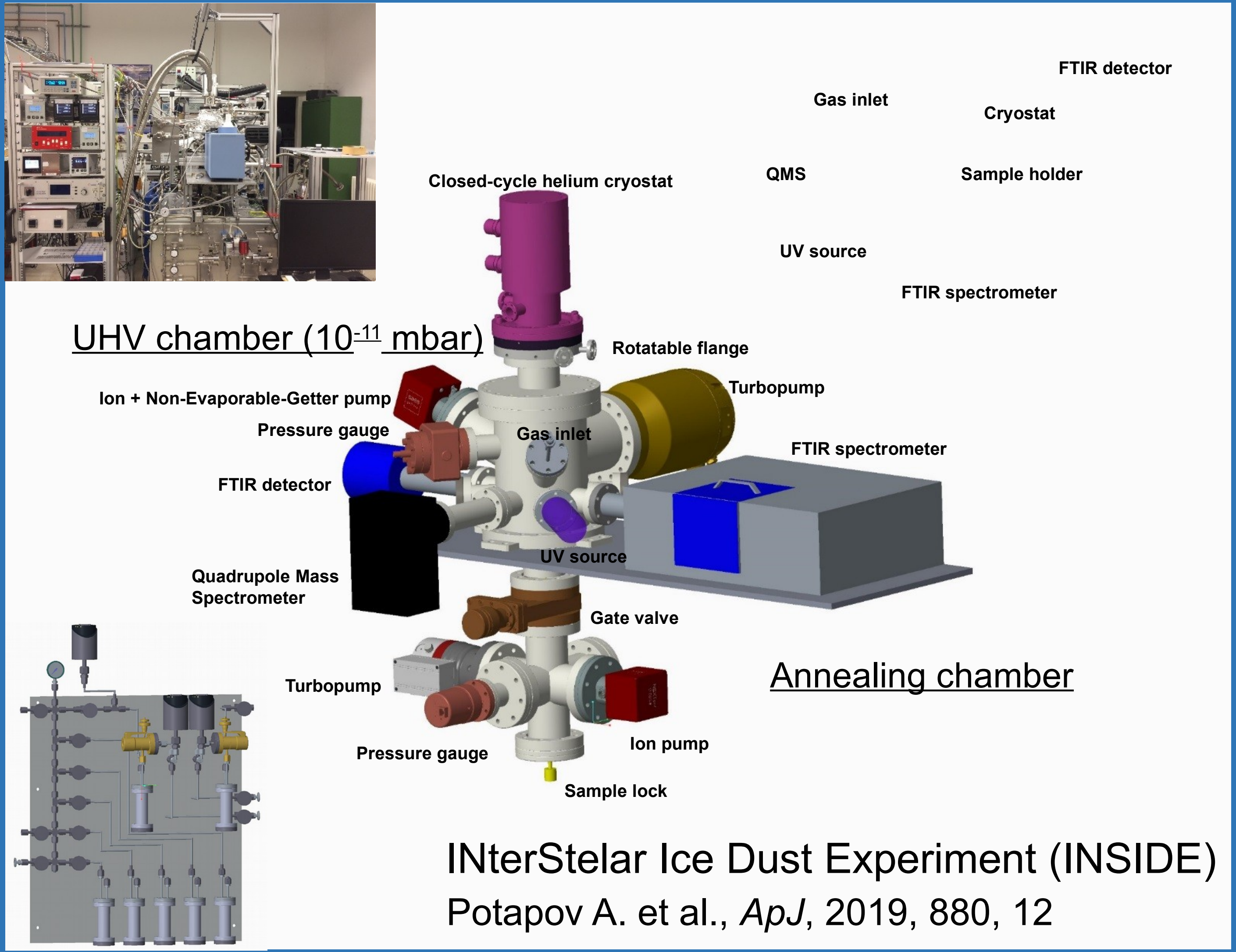
H_2 on amorphous silicate grains (Gavilan et al., 2014)

…

↓

Formation of H_2 and H_2O

Catalytic effect of dust



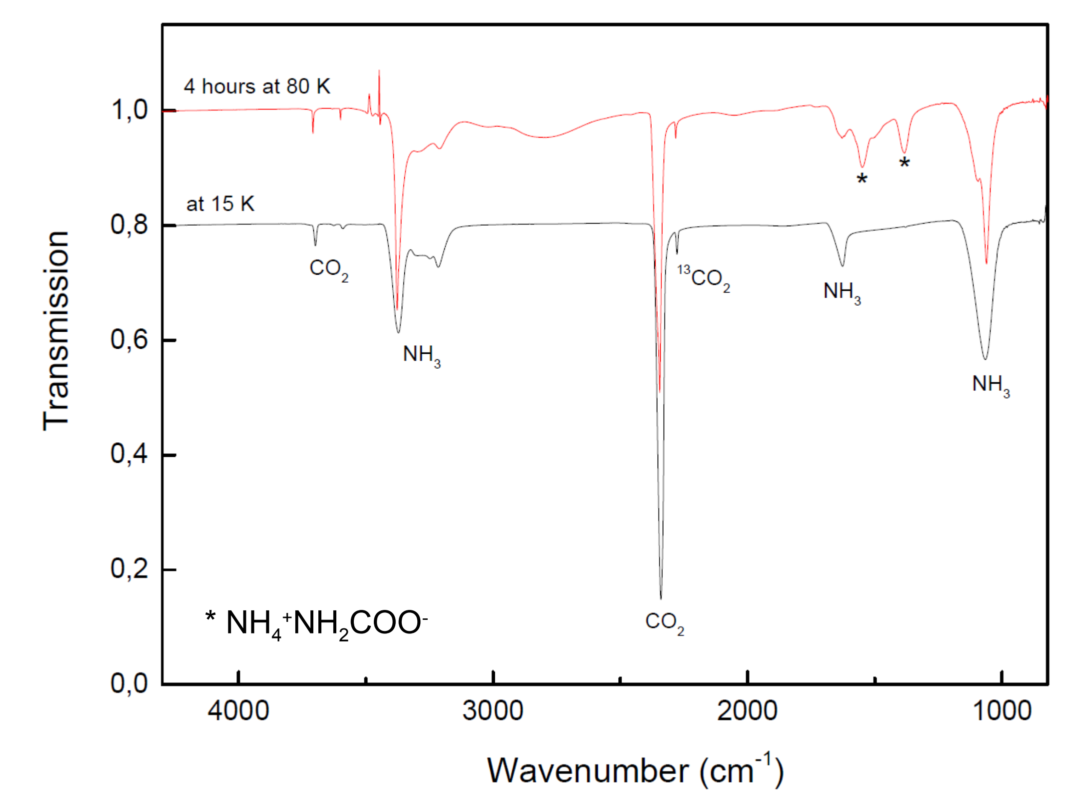
INterStelar Ice Dust Experiment (INSIDE)

Potapov A. et al., *ApJ*, 2019, 880, 12

$CO_2 + 2NH_3 \rightarrow NH_4^+NH_2COO^-$

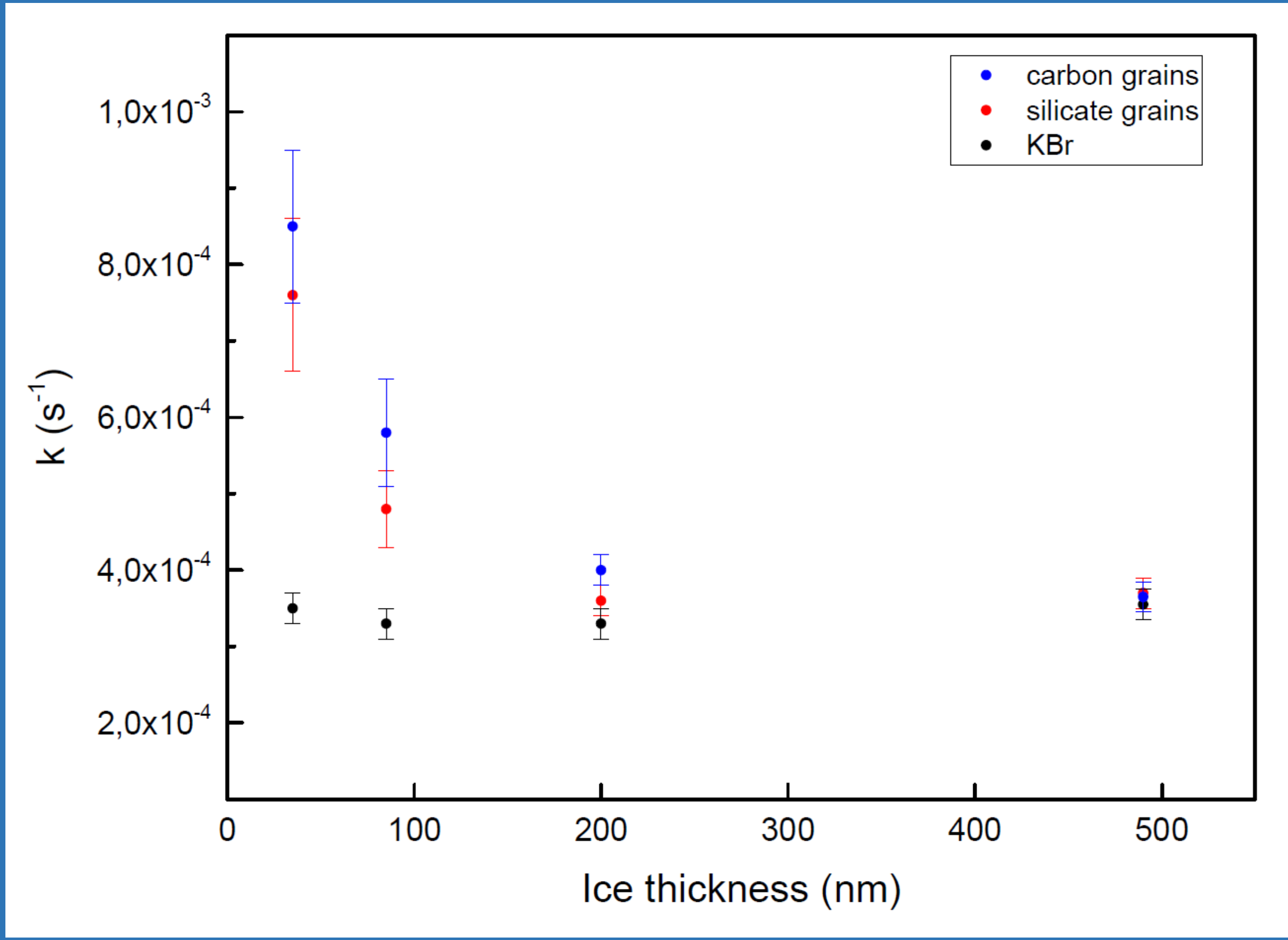
Catalytic effect of dust

IR spectra taken after the deposition of a NH_3:CO_2 4:1 mixture on carbon grains at 15 K and after 4 hours of the reaction at 80 K



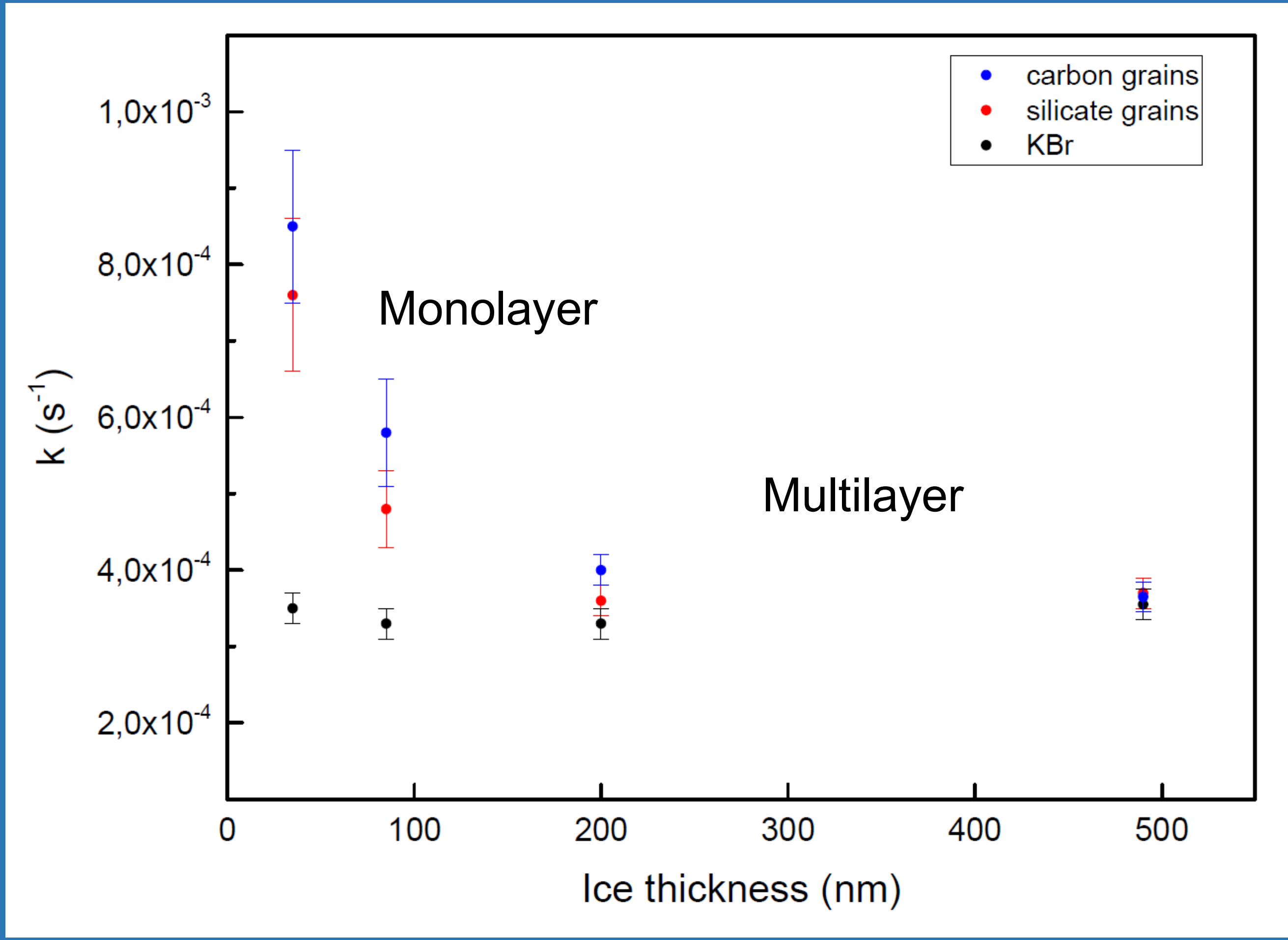
Time dependences of the $NH_4^+NH_2COO^-$ column density evolved from isothermal kinetic experiments at 80 K

Catalytic effect of dust



Dependence of the reaction rate coefficients of the $CO_2 + 2NH_3 \longrightarrow NH_4^+NH_2COO^-$ reaction on the ice thickness for various surfaces

Catalytic effect of dust



Dependence of the reaction rate coefficients of the $CO_2 + 2NH_3 \rightarrow NH_4^+NH_2COO^-$ reaction on the ice thickness for various surfaces

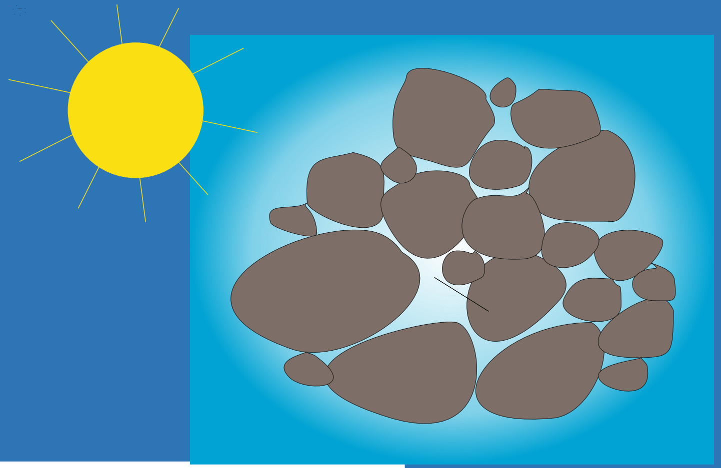
Potapov A., Theule P., et al., *ApJL*, 2019, 878, L20

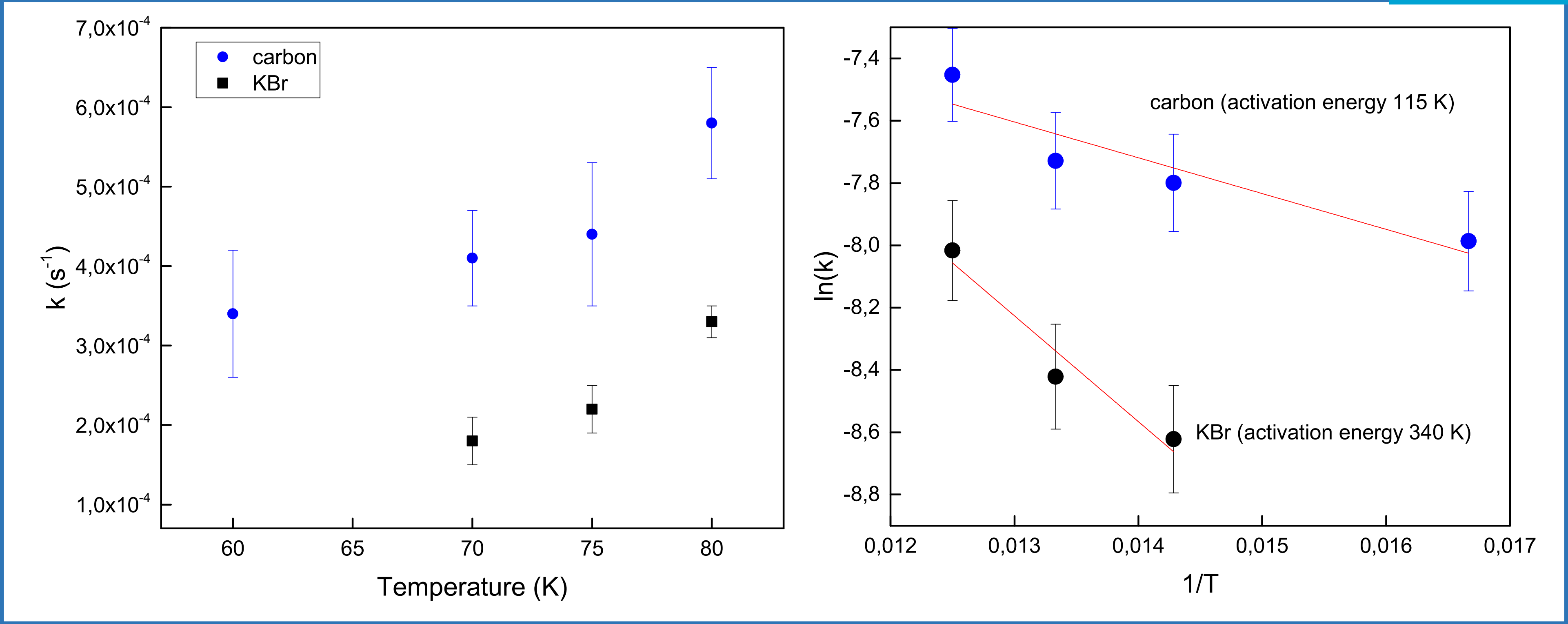
Catalytic effect of dust

- An increased diffusion rate of species
- A formation of an intermediate weakly bound CO_2–NH_3 complex that helps to overcome the reaction barrier
- Lowering of the activation barrier of the reaction

Catalytic effect of dust

- An increased diffusion rate of species?
- ~~A formation of an intermediate weakly bound CO_2–NH_3 complex that helps to overcome the reaction barrier~~
- Lowering of the activation barrier of the reaction

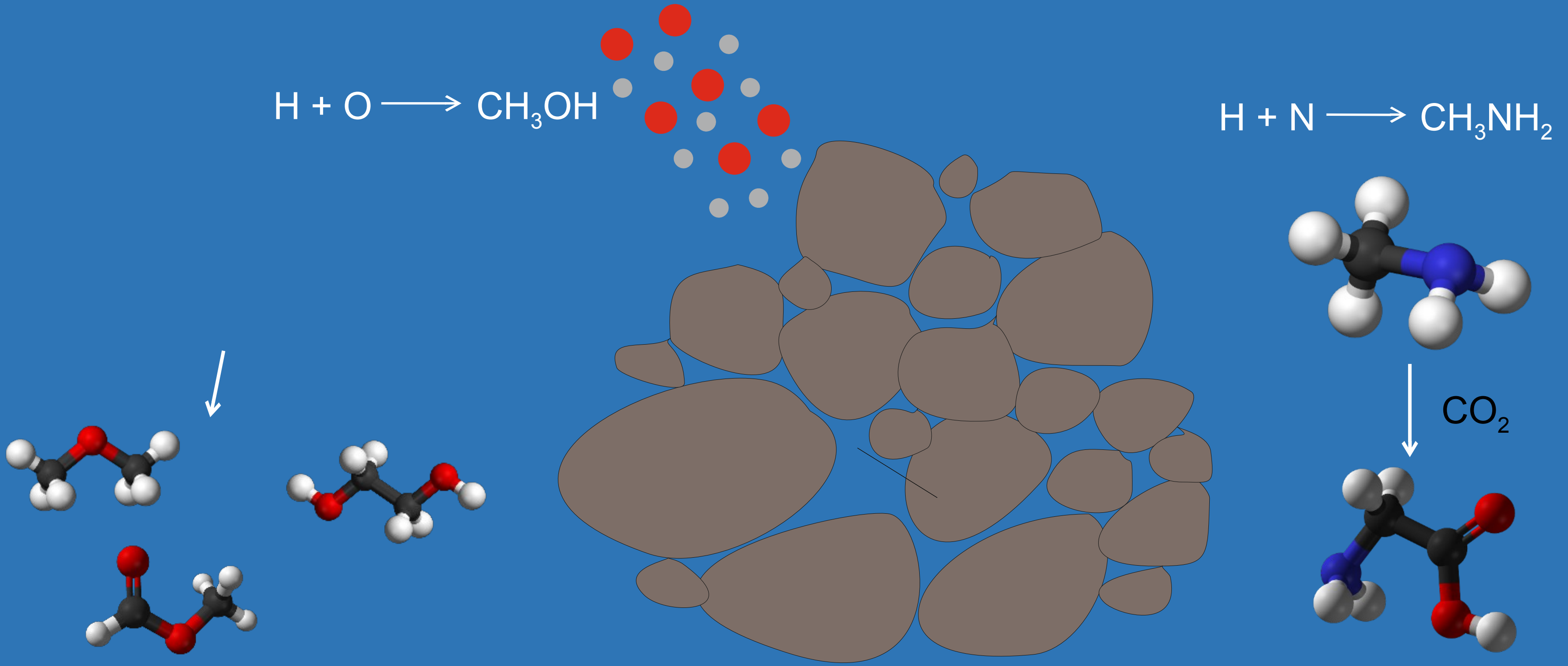




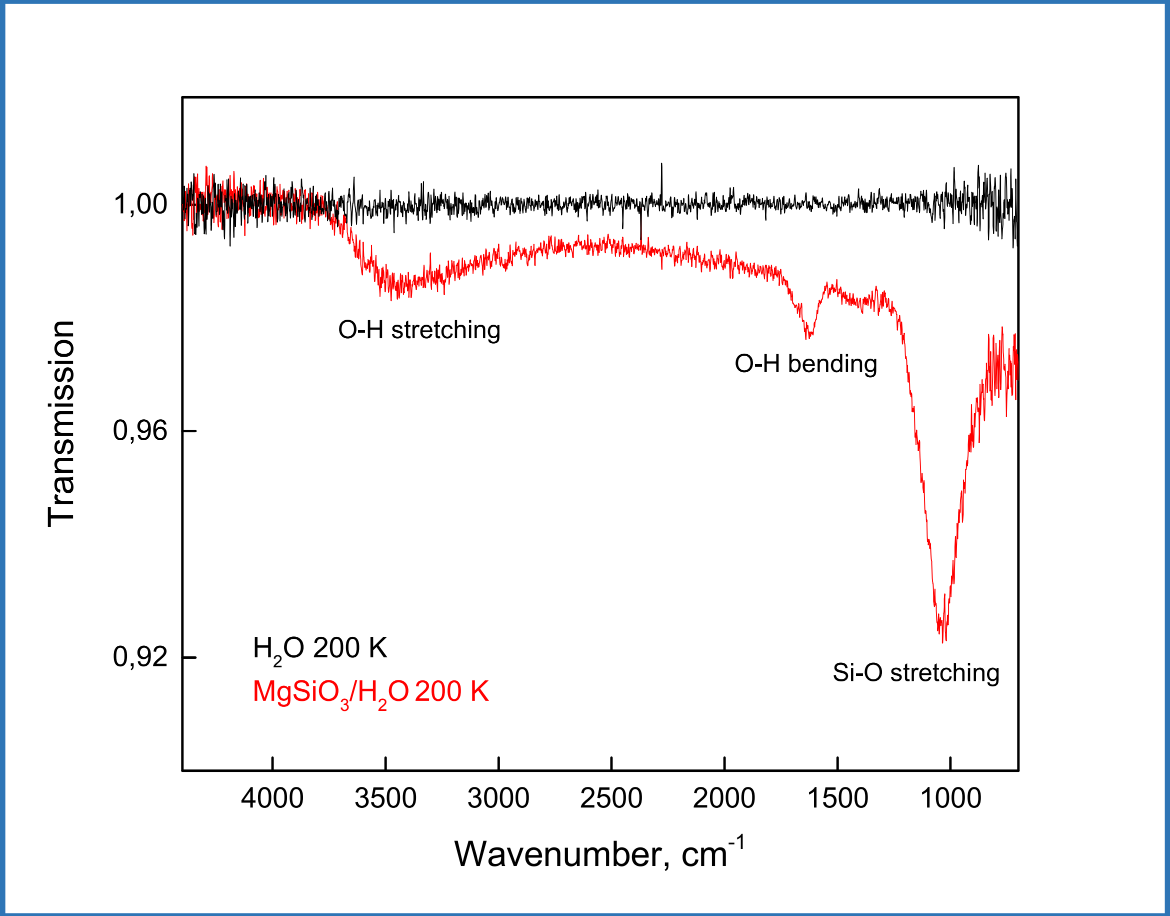
Potapov A. et al., to be submitted

Role of dust grains in the chemistry on their surfaces

Hydrogenation reactions (as a good example)



Trapping of water in silicates



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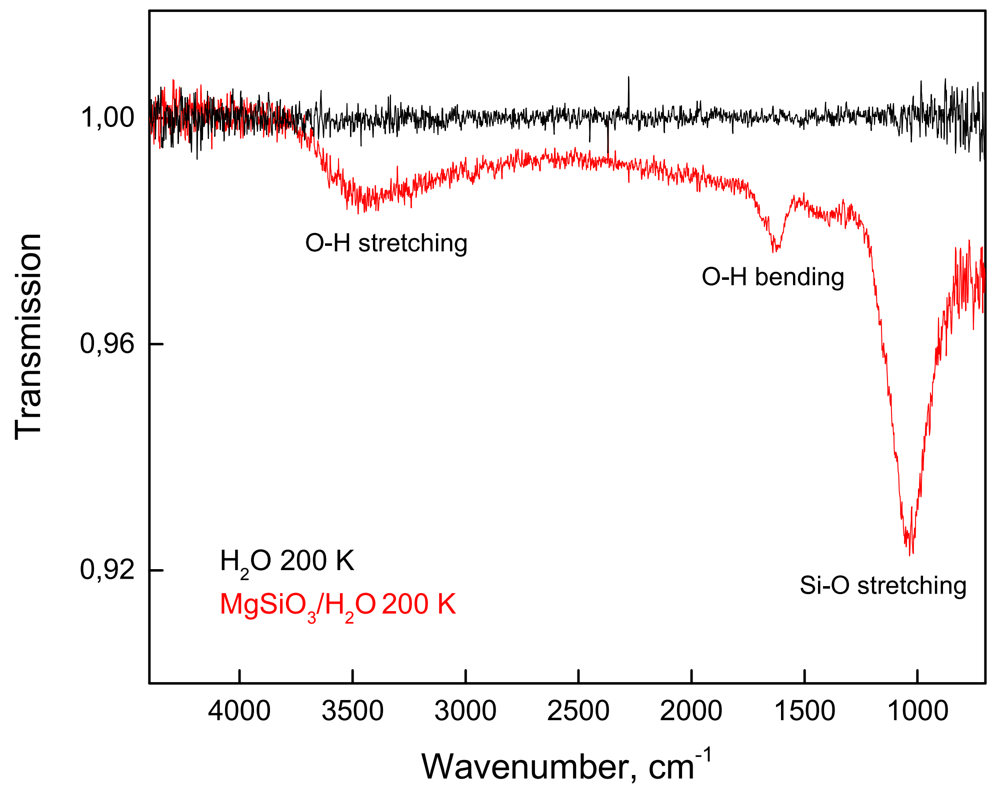
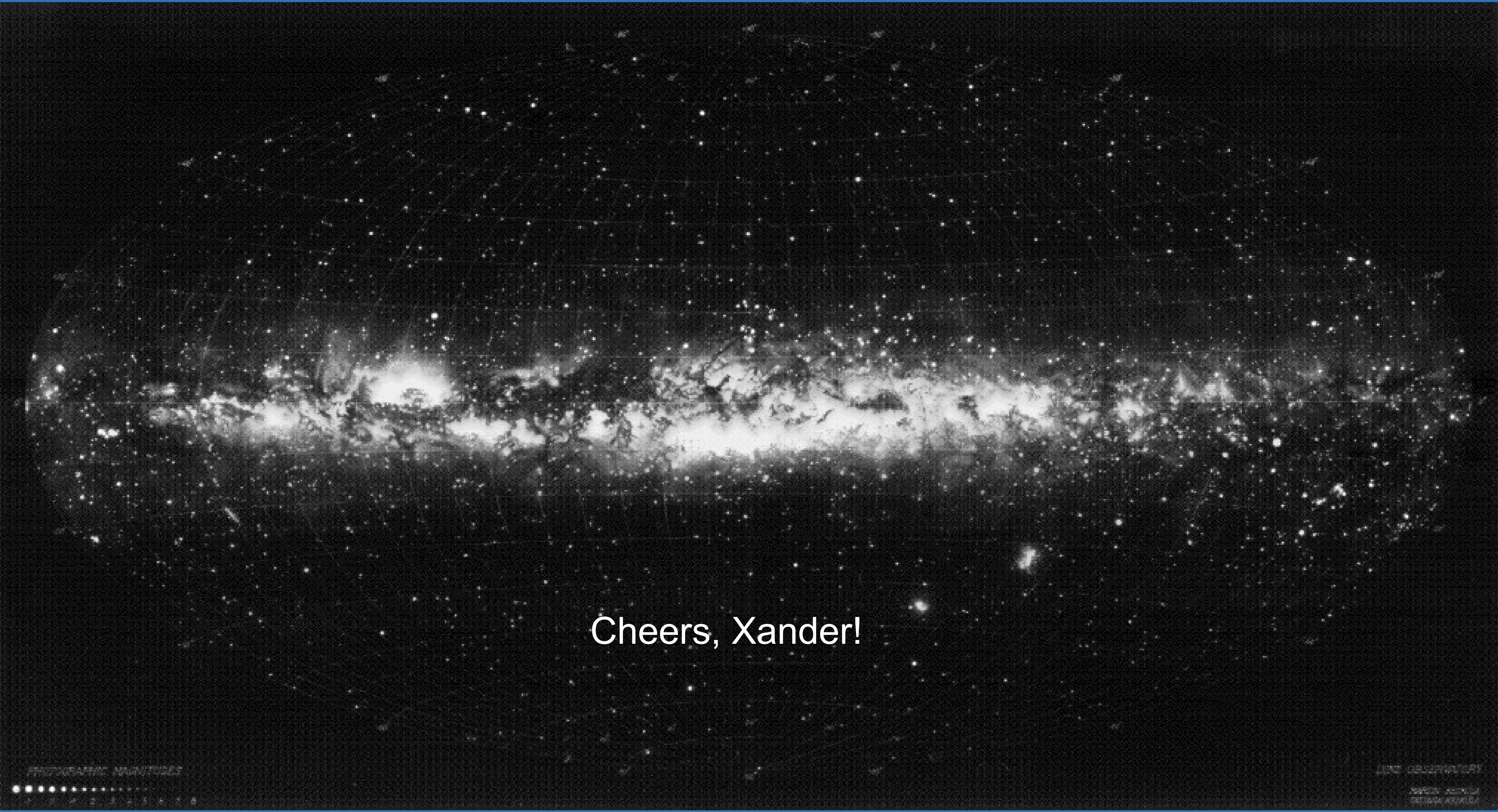


Potapov A. et al., *ApJ*, 2018, 861, 84 and *to be submitted*

Trapping of water in silicates

Trapped water can survive the transition from cold star-forming regions to protoplanetary disks and stay in silicates in the terrestrial planet zone



Cheers, Xander!