Formation and Evolution of Porous Water Ices

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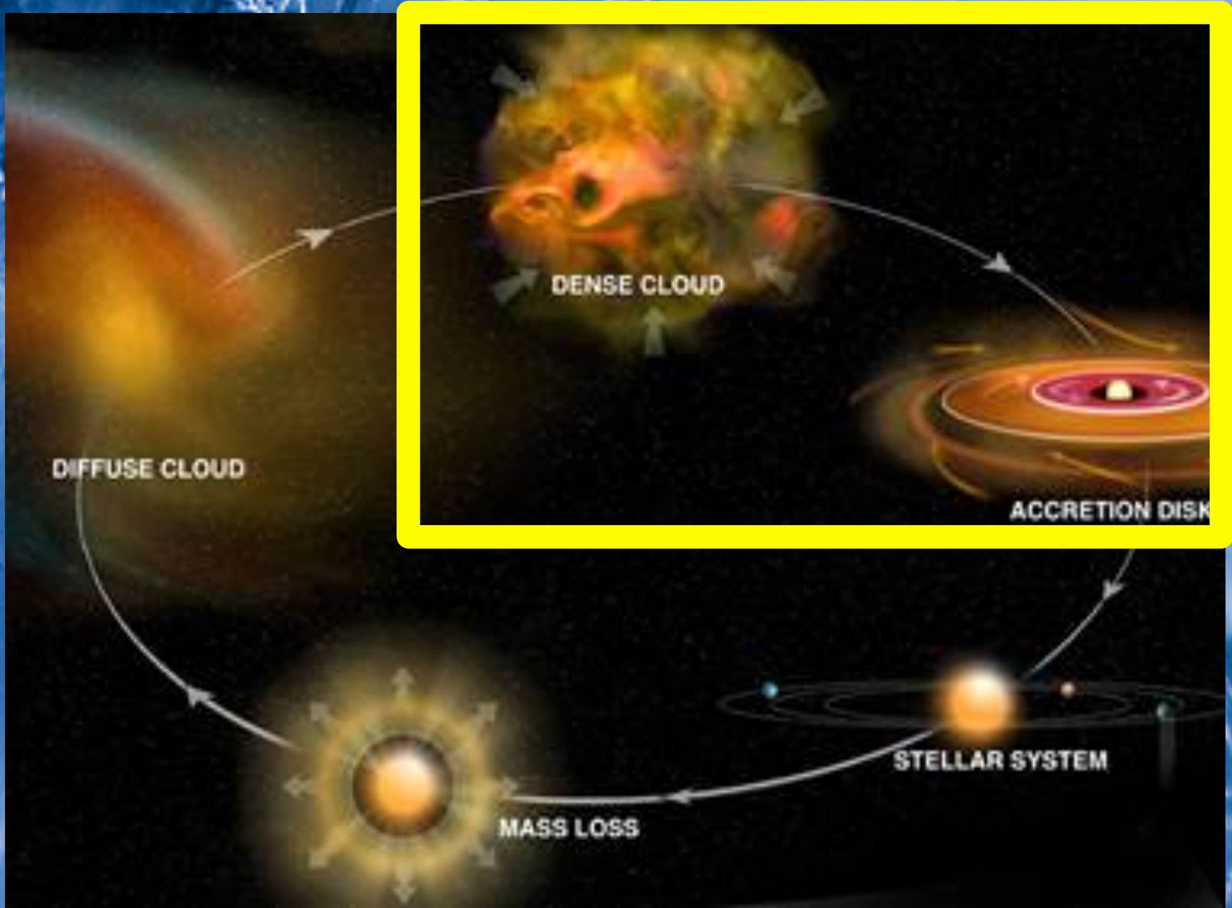
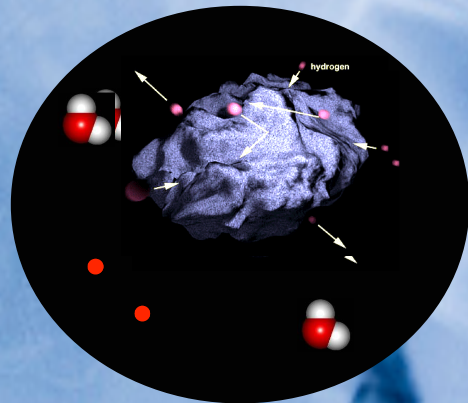
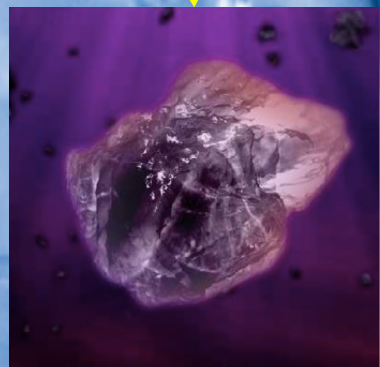
Formation and evolution of ices



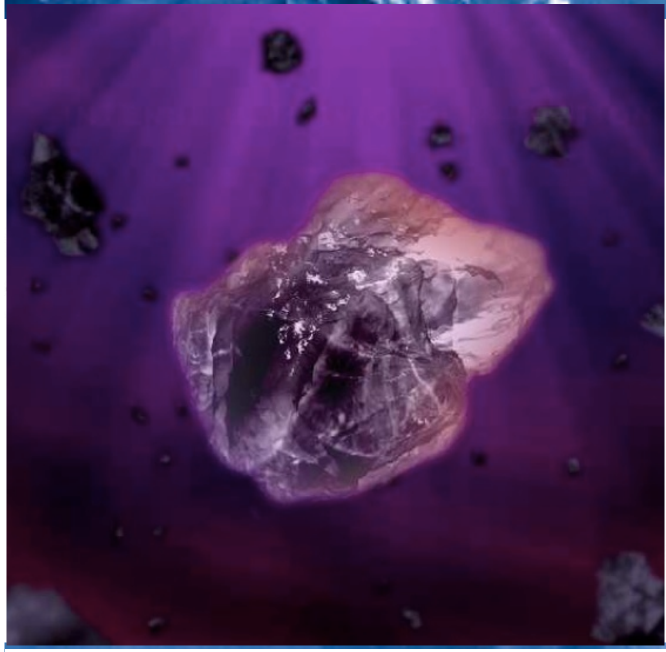




During this circle → ices form onto dust

- Solid: ice composition in absorption
- Gas phase: hot core/hot corino

Interstellar ices



Prestellar cores: CO depleted from gas

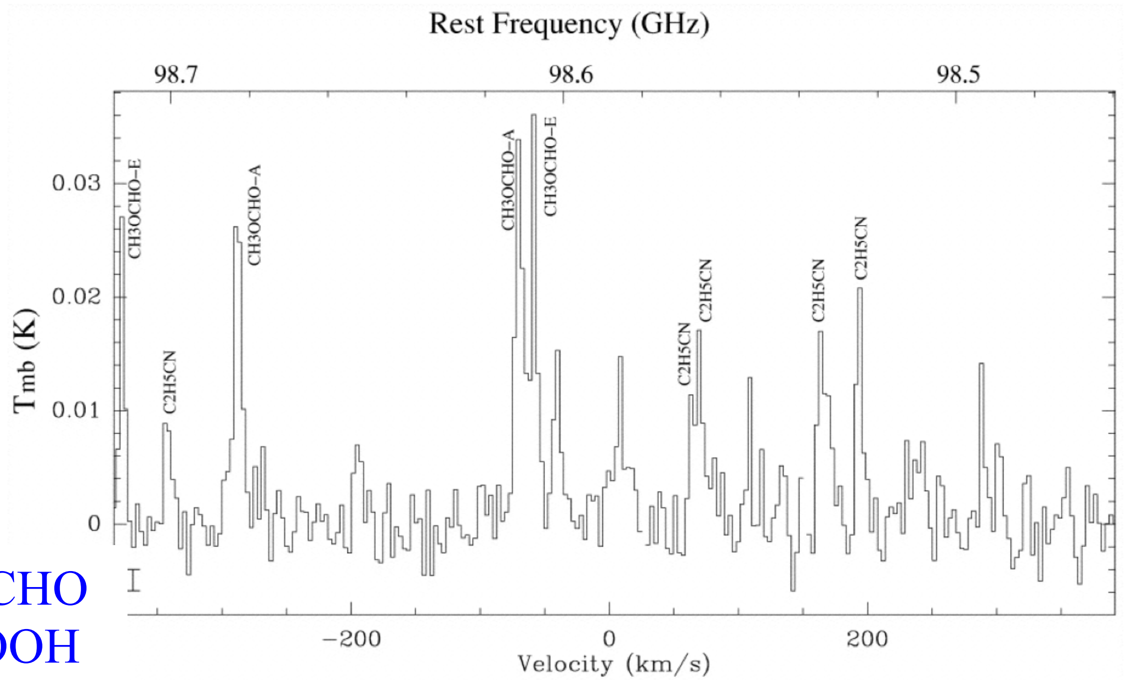
Bergin et al. 2002; Crapsi et al. 2004

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

Hot corino: complex molecules

Cazaux et al. 2003

Interstellar ices

- Responsible for unique and rich chemistry

- ice composition → chemical history

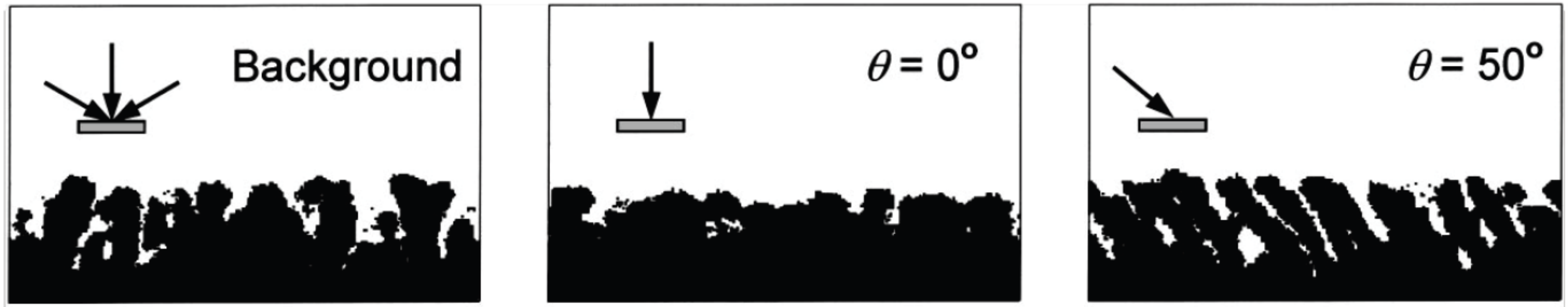
- ice structure → accretion, desorption, segregation, and local radiation fields.

Ices morphology

- Frost of water in dense clouds → amorphous water ice +trapped impurities *Tielens & Allamandola 1987*
- Theory→ amorphous and porous ices grown by a hit and stick mechanism *Cuppen & Herbst 2007*
- Laboratory → O+H = compact ices *Oba et al. 2009* but depend on the density of the gas *Garrod 2013*
- Ices porous in space? No observational evidence *Keane et al. 2001; Gibb et al. 2004*

Experiments

→ change of ice morphology under external influences: ion impact, VUV irradiation *Palumbo 2006; Raut et al. 2007*, H-atom bombardment, or **<u>during warming up</u>**

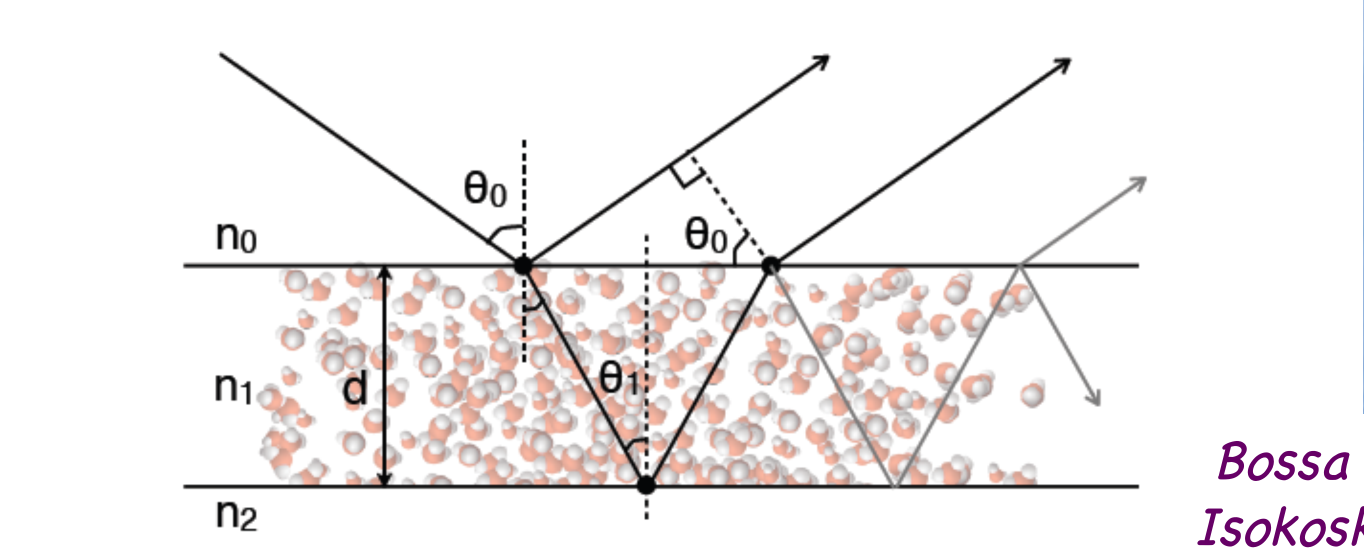


Ices created by deposition of water

Deposition sets porosity

Dohnálek et al. 2003

Experiments

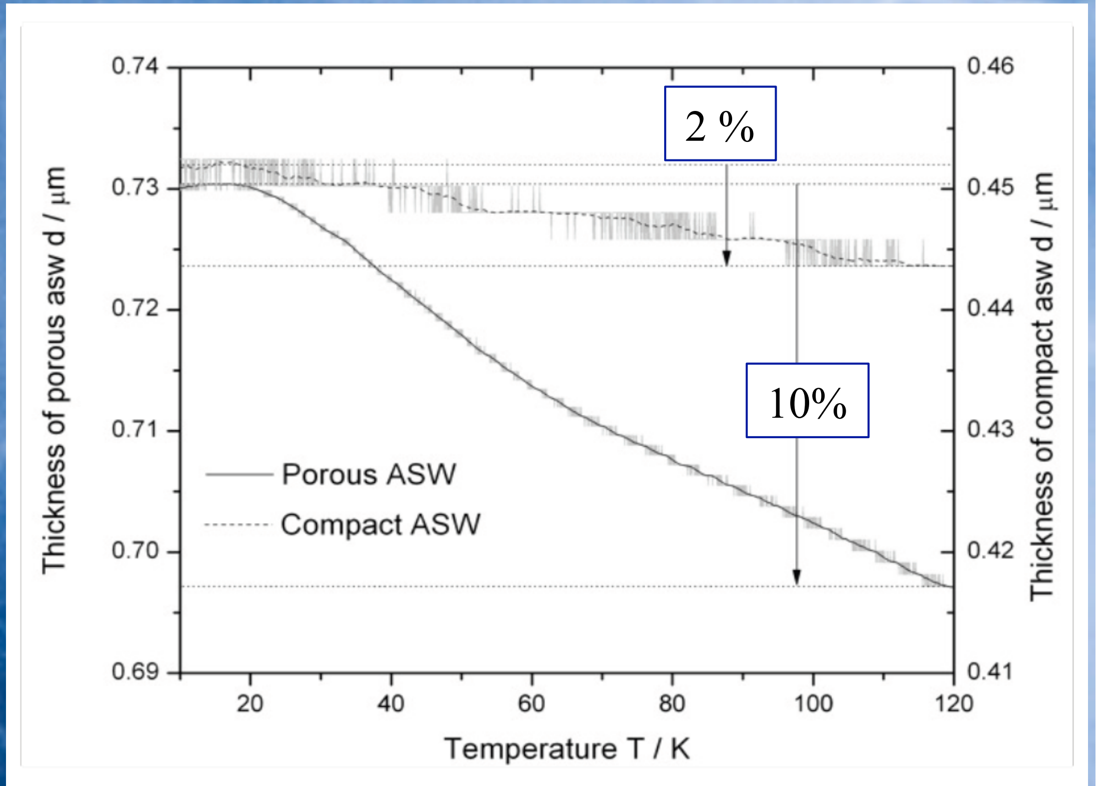


Bossa et al. 2012
Isokoski et al. 2014

- Leiden: Bossa, Isokoski, Linnartz, Tielens
- Optical interference technics (ice thickness)

Experiments

Exp. Show thickness decreases with T.
Density ≈ 0.61 g cm^{-3}
Porosity ≈ 32%

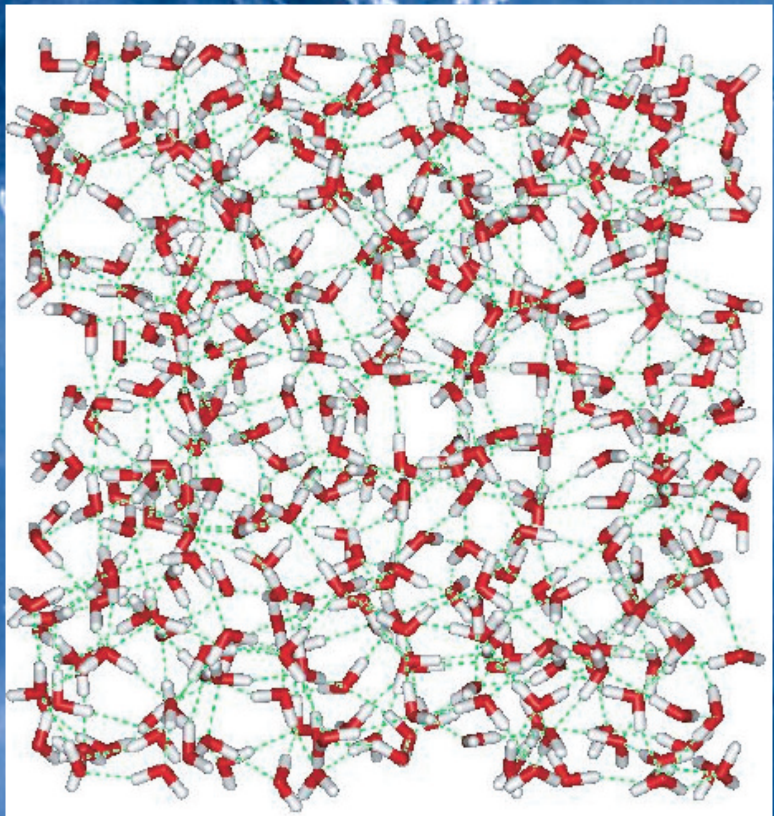


Bossa et al. 2012
Isokoski et al. 2014

What are the physical processes involved in the decrease of ice thickness?

Model: Kinetic monte carlo simulations

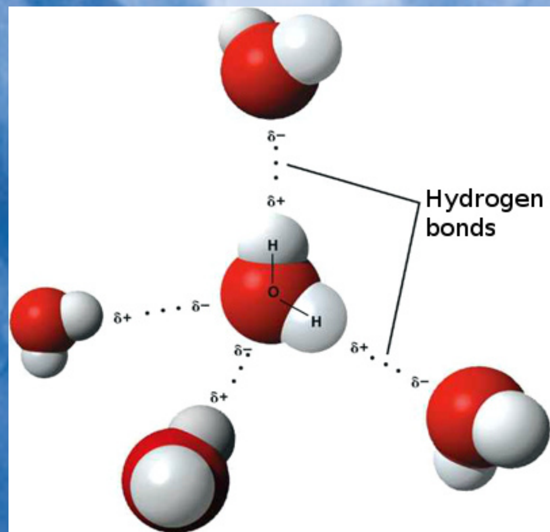
Model



Amorphous ice

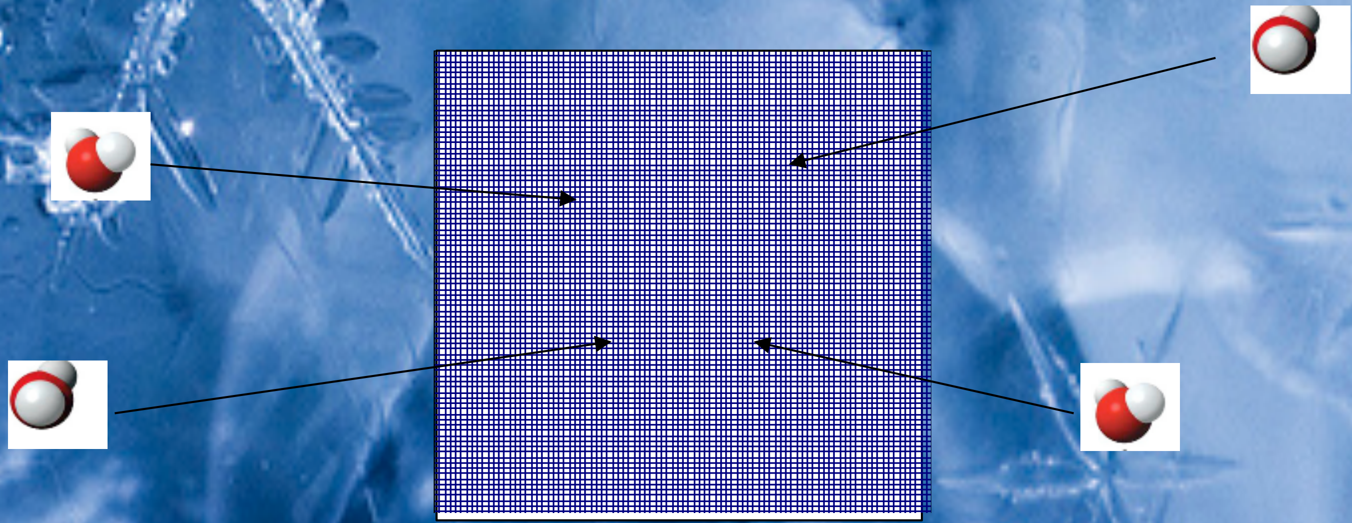
water molecules organized

Tetrahedron (4 neighbours)



Model

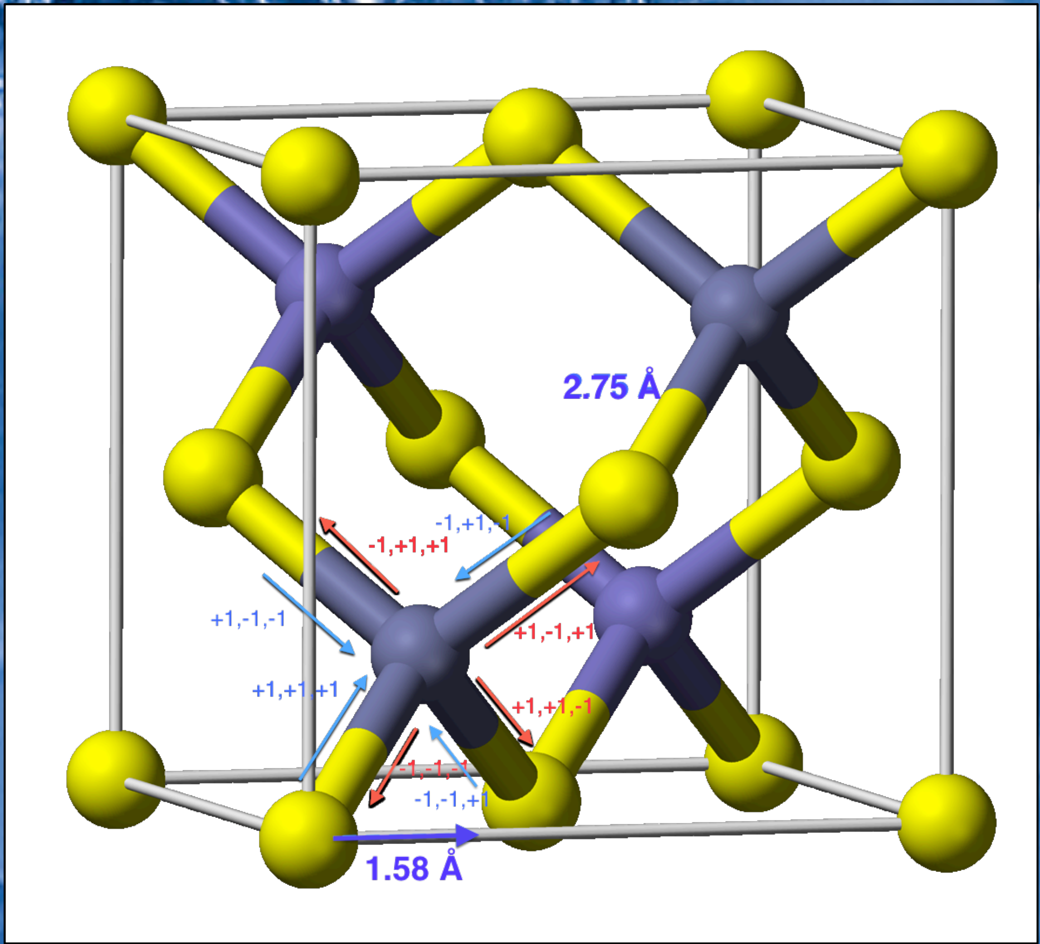
Kinetic monte carlo simulations:
hit and stick



Grid=surface

H_2O random
location and time

Model



Kinetic monte carlo simulations:

Position

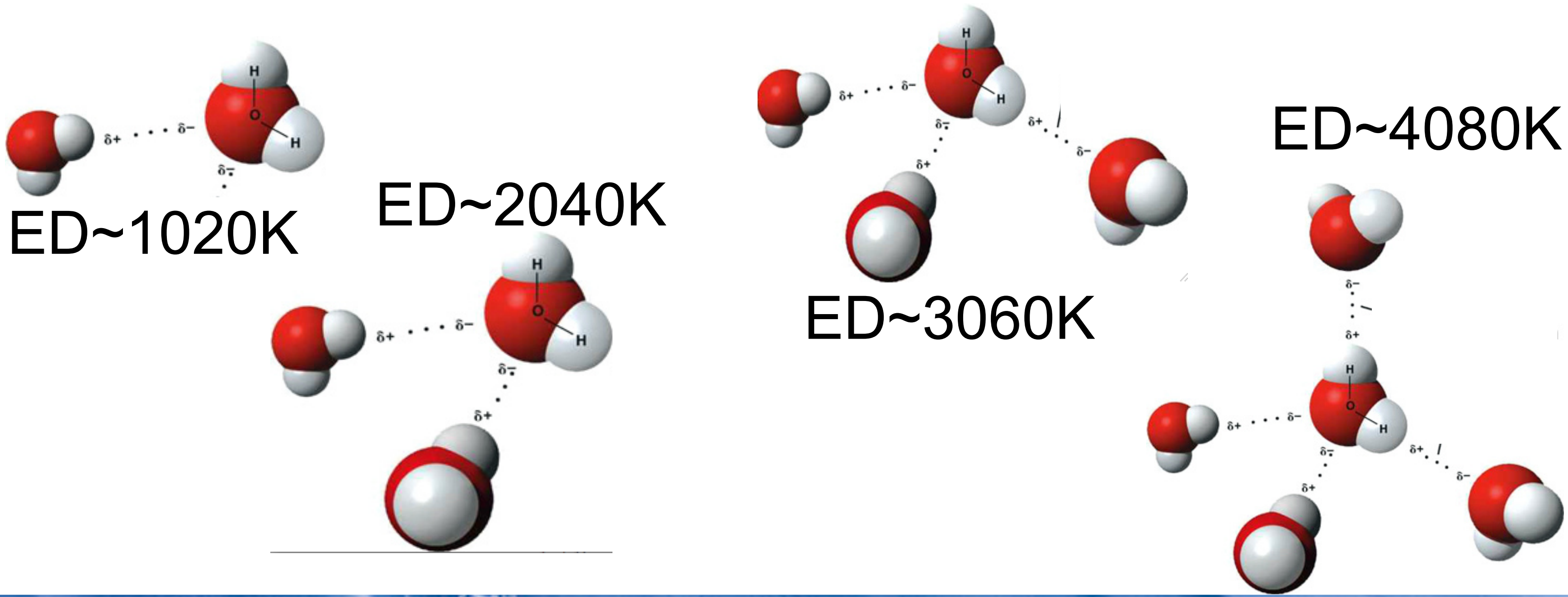
Mobility

Model

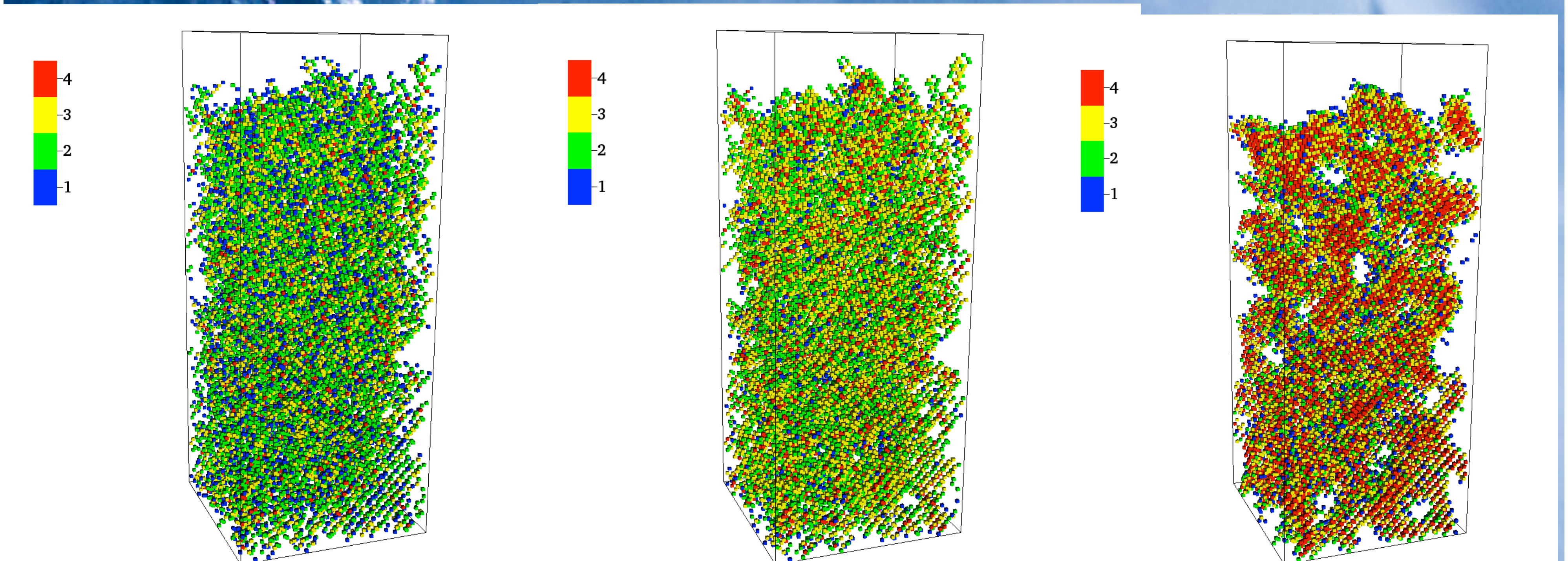
- Binding energy is ~ 0.22 eV per hydrogen bond and increases with numbers of neighbours

Brill & Tippe 1967; Isaacs et al. 1999; Dartois et al. 2013

- Barrier for diffusion ED~nn*α*EB
- nn: number of neighbours and α ~0.4



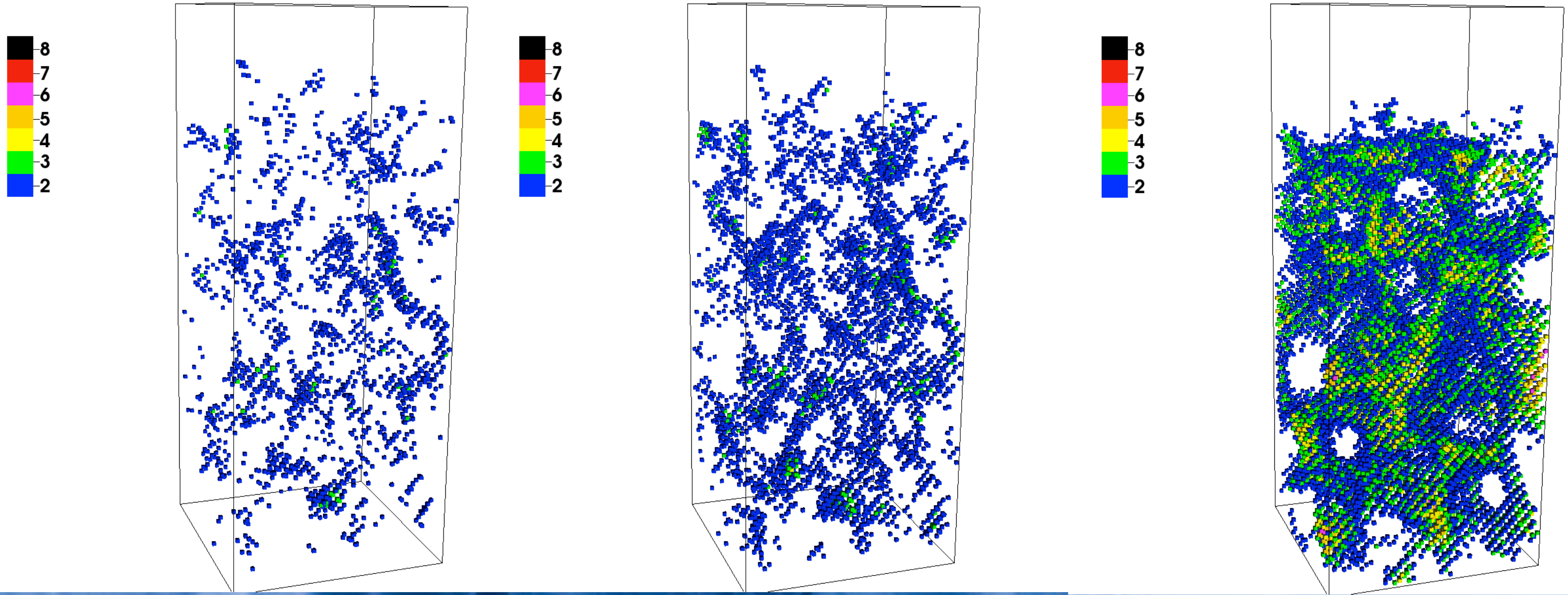
Ice morphology



T = 10 K   T = 60 K   T = 100 K

Cazaux et al. 2015

Ice porosity



T = 10 K

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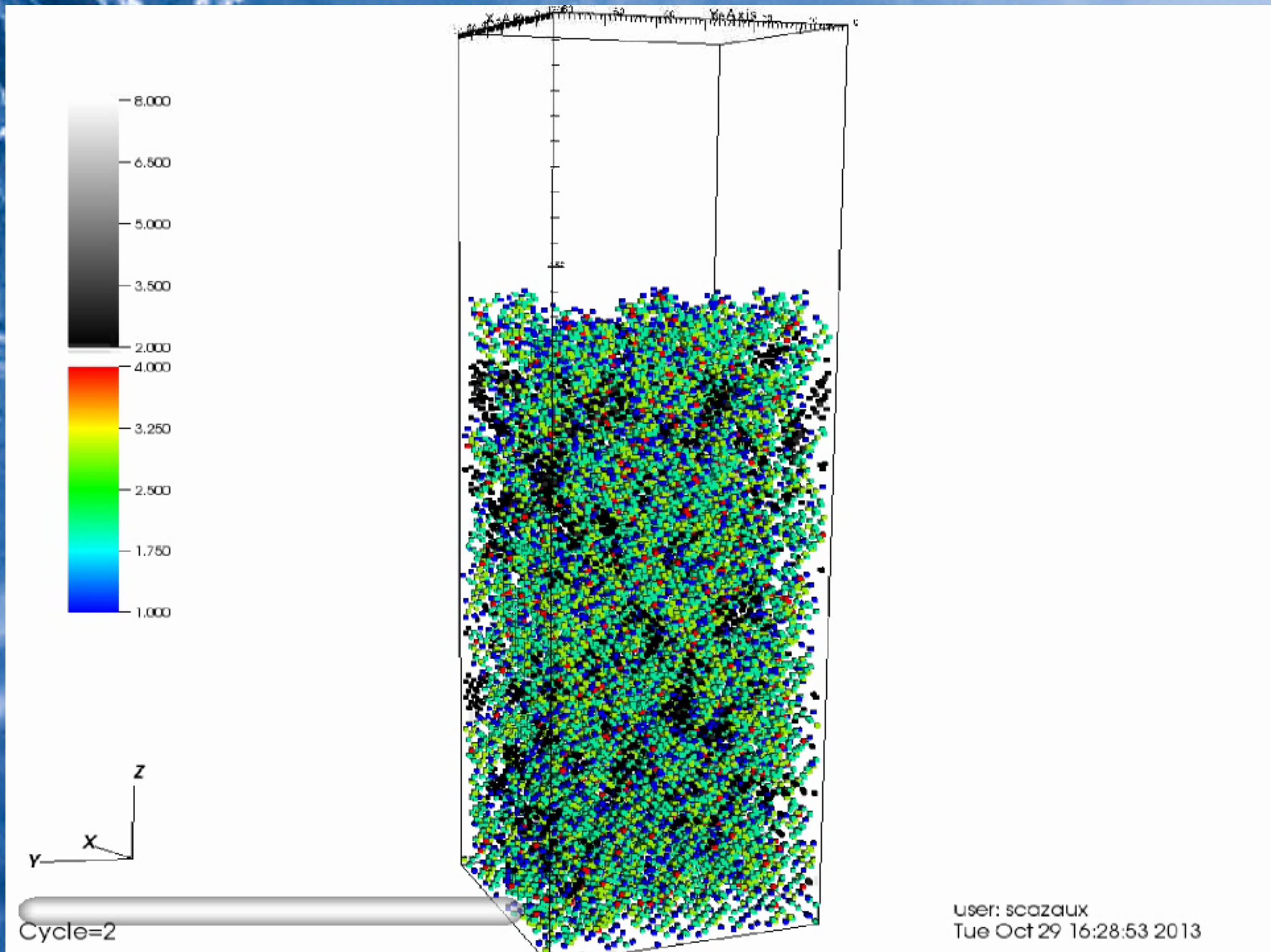
Cazaux et al. 2015

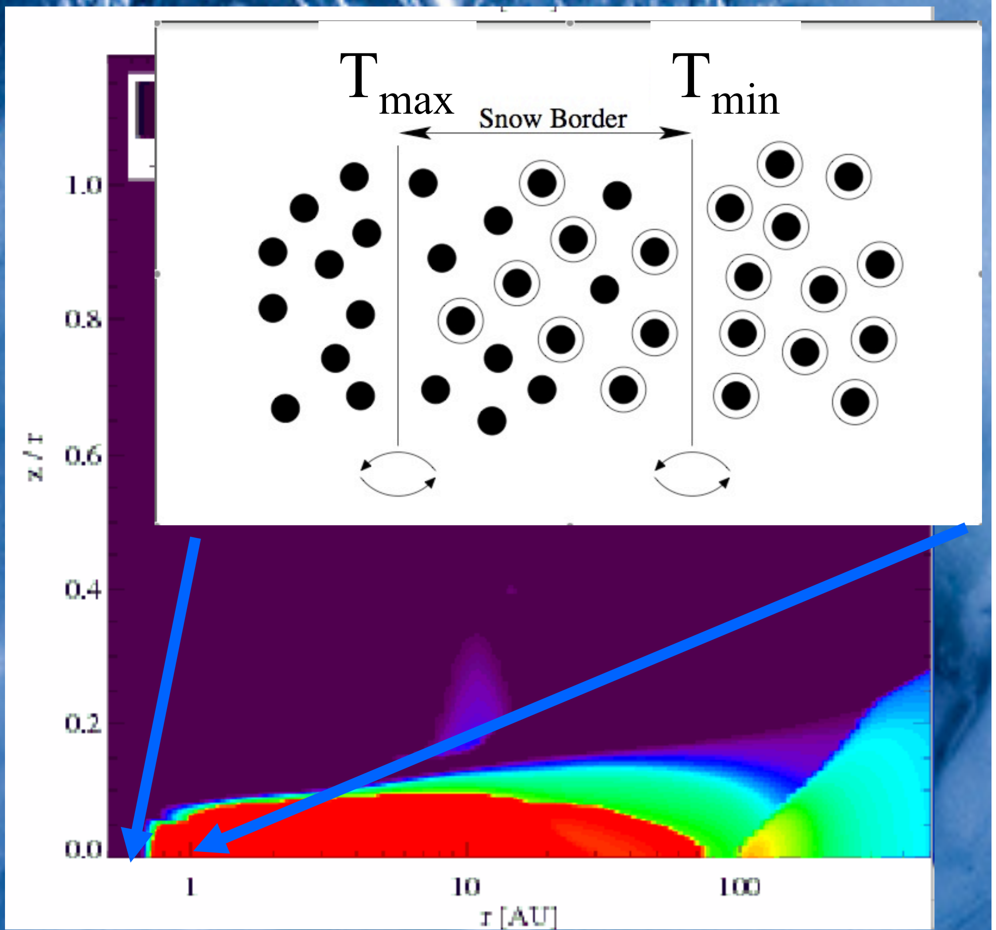
Evolution of water ice



Evolution of water ice

- We do not reproduce compaction with our Monte Carlo simulations (grid size)
- We find ices become more compact locally as T increases and pores grow
- Density ≈ 0.57 to 0.63 g cm^{-3}
  Exp ≈ 0.61 g cm^{-3}
- Porosity ≈ 30% - 40%
  Exp ≈ 32 %

Formation of water ice in disks



Woitke et al. 2009 T-Tauri disk

Water on carbon E ≈ 1400K

Lin et al. 2005 << **water/ water**

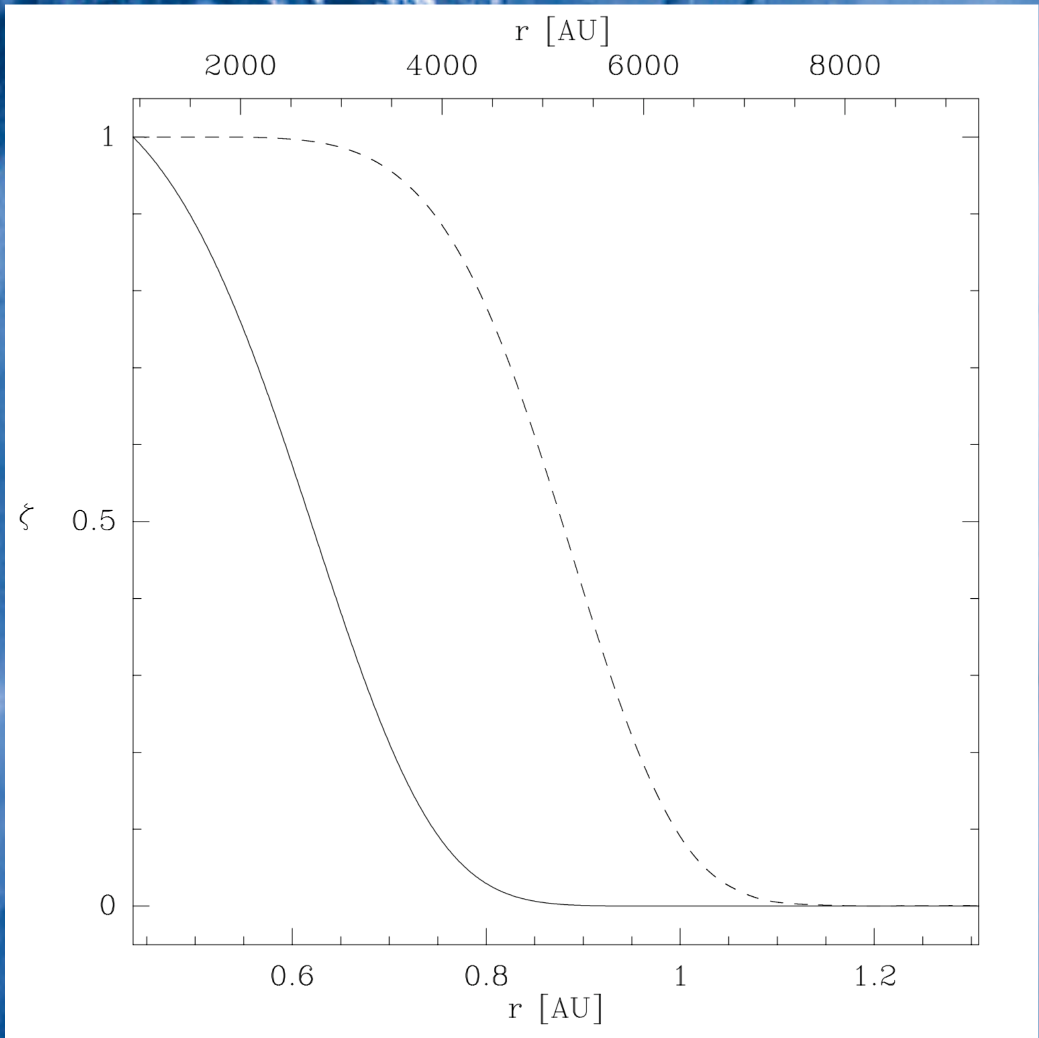
T first layer << T than ice

Evaporation and freeze-out do not occur at id T. *Papoular 2005*

→ impact snowline?

- thermal velocity v_θ
- turbulent velocity v_t 0.1 km s^{-1} *Pietu et 2003 HH star*
- accretion velocity v_{acc} M ≈10^{-6} $M_\odot$ yr^{-1} *Hueso & Guillot 2005*

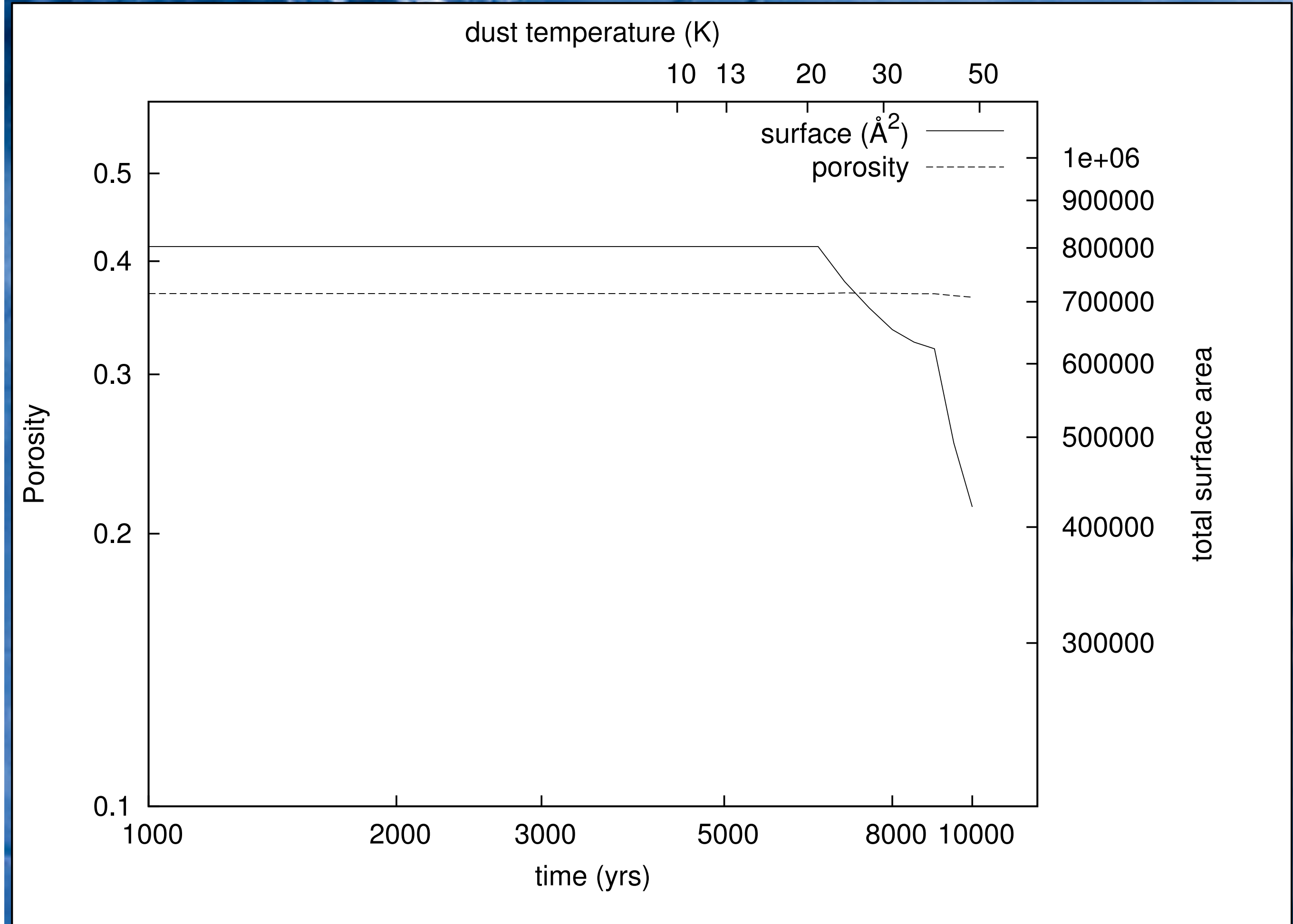
Formation of water ice in disks



- The snowline is actually a snow border (with a size of 0.4 AU).
- Impact on snowline locations
- planet formation → coagulation of a mixture bare-icy grains to form planets?

Marseille & Cazaux 2011

Evolution of water ice

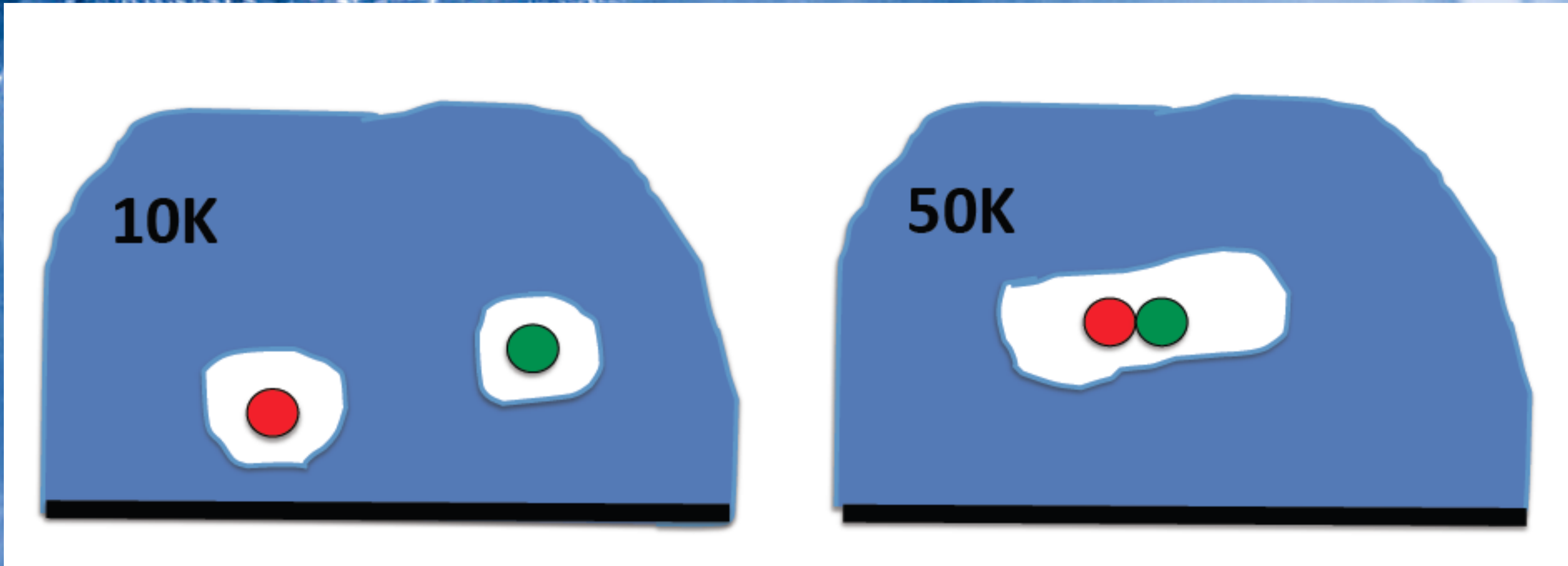


Star forming Temperature of gas and dust, initially at 10 K, reaches 200 K in 5 10^4 years

Garrod & Herbst 2006

At T ≈ 30 K, which corresponds to 8 10^3 years → restructuration

Pores boost reactivity?



New process to form molecules in space?

Conclusions

- Exp show → Porous ice become compact as T increases (10%)
- MC simulations show that ices become compact AND pores merge and grow.
- pore coalescence → new solid state process that may boost the formation of new molecules in space
- First layer of ice forms at lower T than evaporation → Snow border

Thank you

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