Sticking Coefficients of Astrochemically-Relevant Ices on Realistic Grains Analogues are Lower than Expected

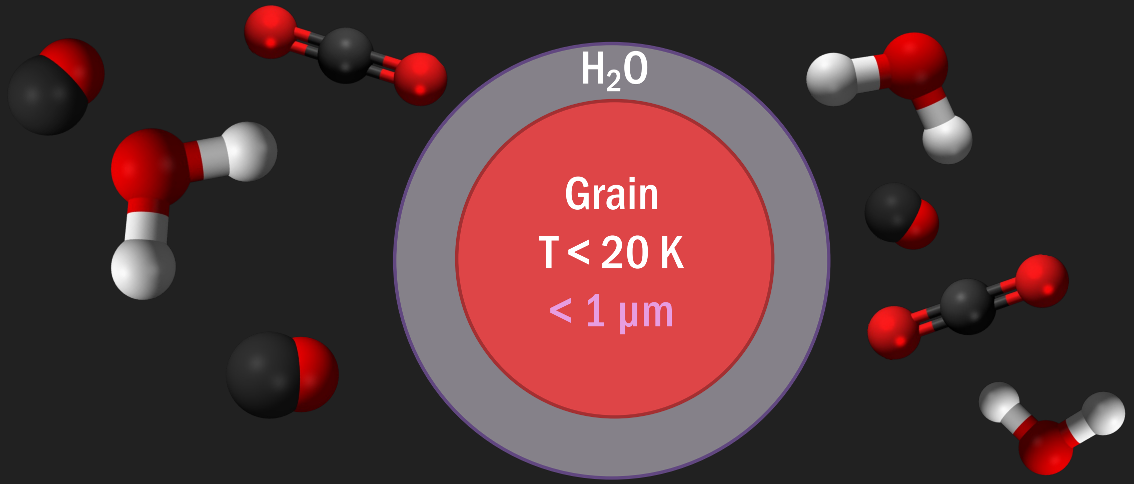
C. Stadler*[1], Ph. Parent[1], C. Laffon[1], Frederik Simonsen[2], Liv Hornkær[2]

[1]Aix Marseille Univ, CNRS, CINaM, Marseille, France

[2] Aarhus Univ, Center for Intertellar Catalysis, Aarhus Denmark

**caroline.stadler@univ-amu.fr*

Photo: NASA JWST



Accretion rate;

$$f_{\mathrm{acc,A}} = \boxed{S_{\mathrm{A}}} v_{\mathrm{A}} n_{\mathrm{grain}} \pi r_{\mathrm{grain}}^{2} n_{\mathrm{g}}(\mathrm{A})$$

S_A= Sticking coefficient of A

Number of adsorbed A / Number of available sites per surface unit

(10^{15} cm^{-2})

In astrochemistry, gas-grain interactions are modeled using S=1

nature astronomy

LETTERS

https://doi.org/10.1038/s41550-020-01288-7

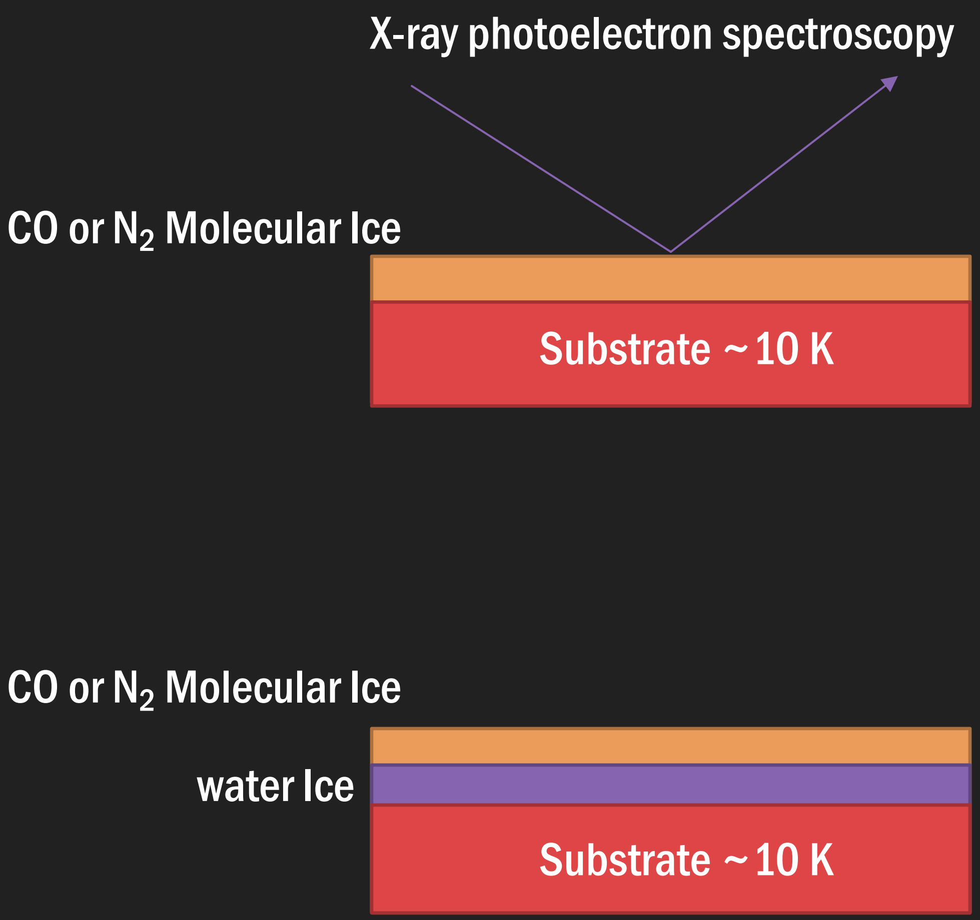
Check for updates

Laboratory-based sticking coefficients for ices on a variety of small-grain analogues

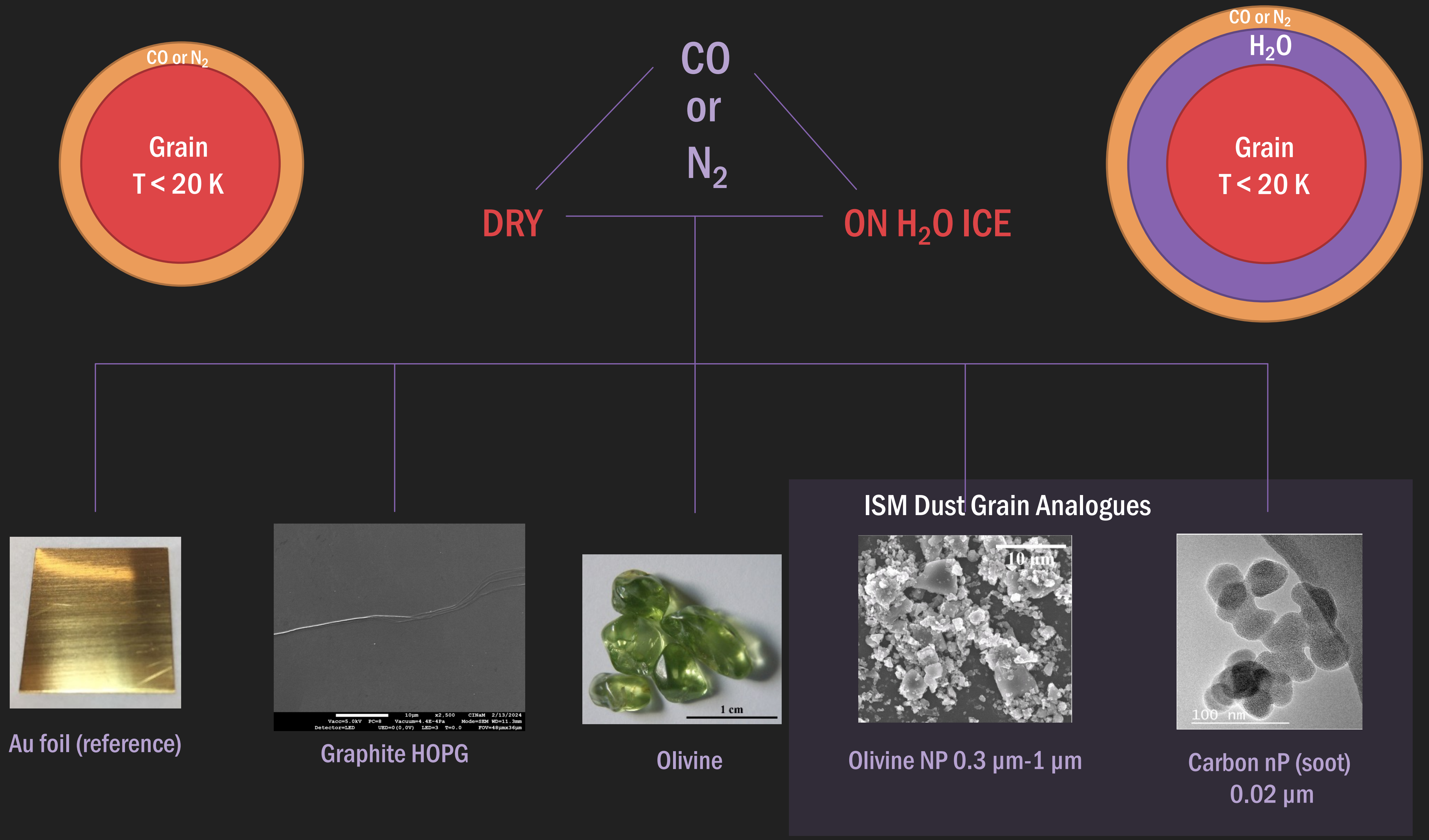
C. Laffon, D. Ferry, O. Grauby and P. Parent

CO_2 and H_2O

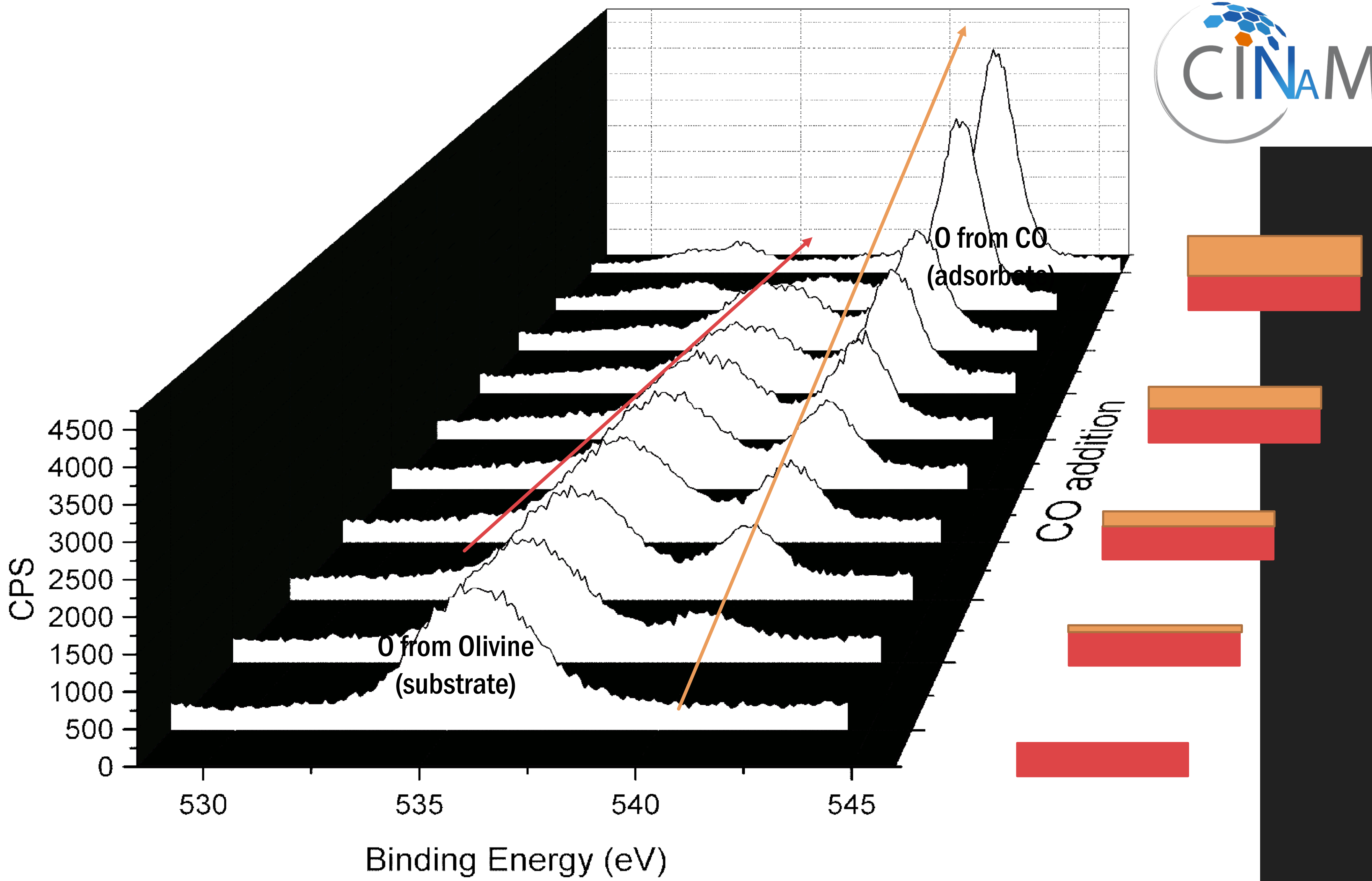
Nature Astronomy | VOL 5 | May 2021 | 445–450 |



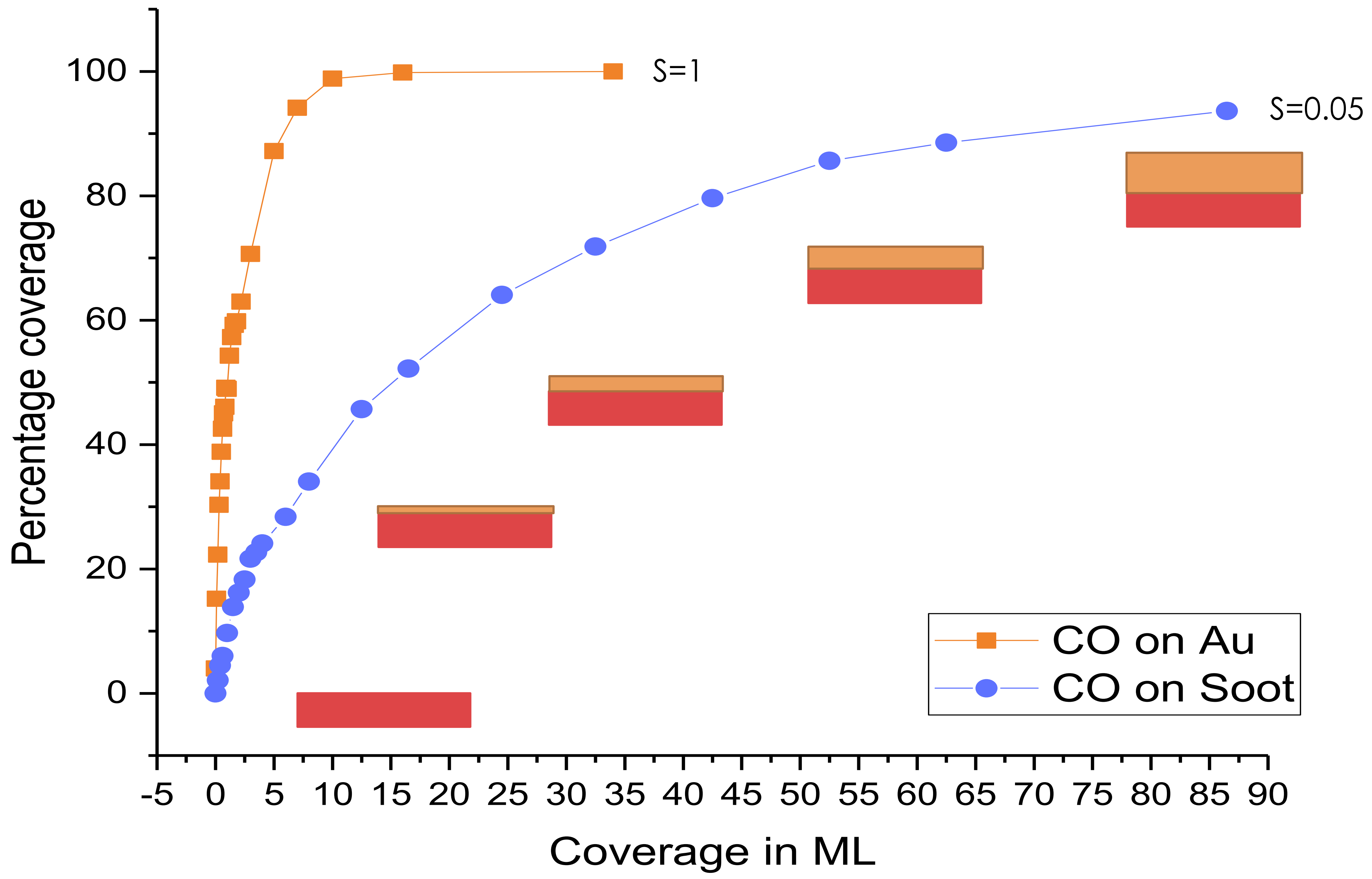
SUMO: CINaM, Marseille



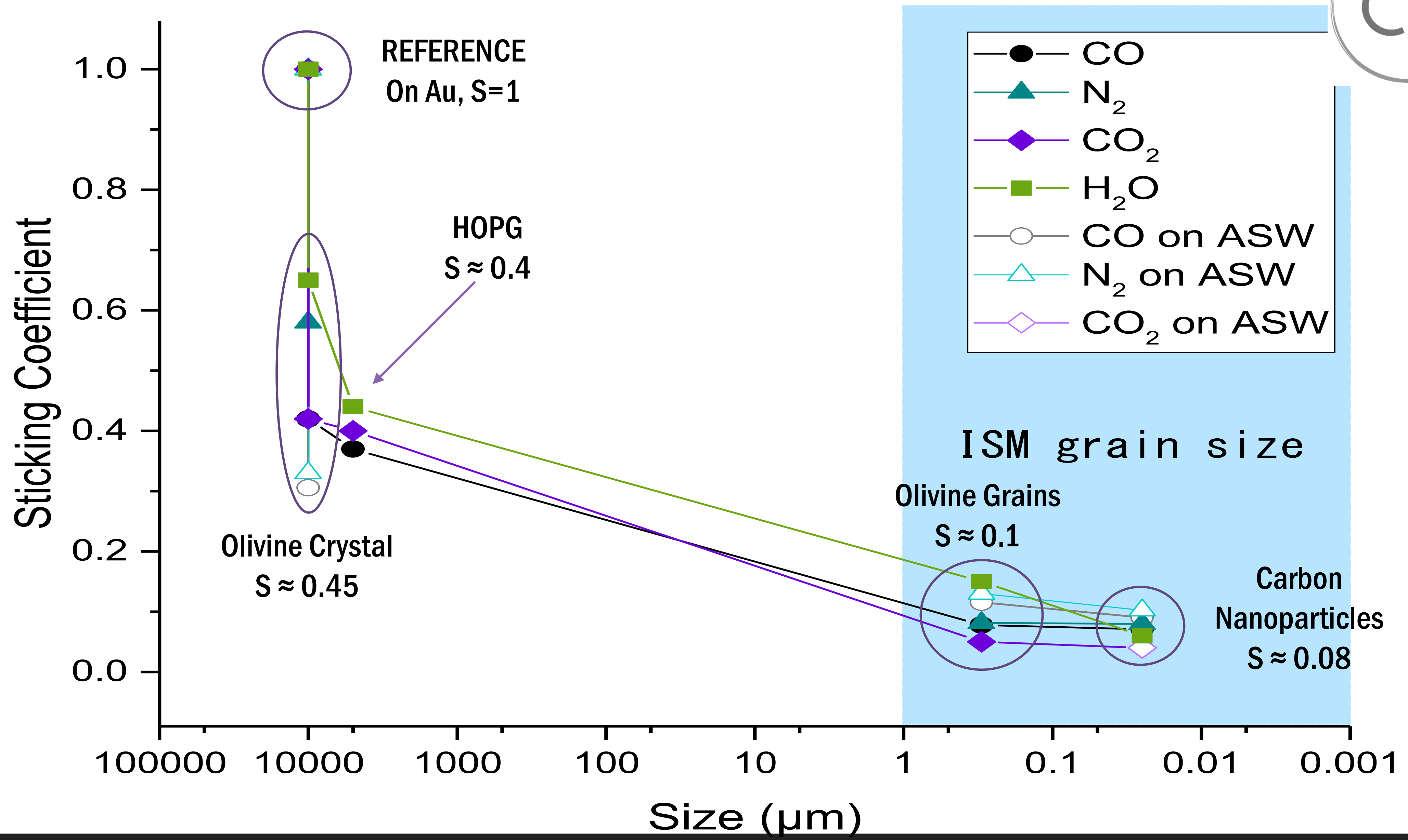
CO or N_2
Grain
T < 20 K
CO
or
N_2
DRY
ON H_2O ICE
CO or N_2
H_2O
Grain
T < 20 K
ISM Dust Grain Analogues
10 µm
1 cm
100 nm
Au foil (reference)
Graphite HOPG
Olivine
Olivine NP 0.3 µm-1 µm
Carbon nP (soot)
0.02 µm



CINaM
O from CO
(adsorbate)
O from Olivine
(substrate)
CO addition
CPS
0
500
1000
1500
2000
2500
3000
3500
4000
4500
530
535
540
545
Binding Energy (eV)



100
80
60
40
20
0
Percentage coverage
-5 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90
Coverage in ML
S=1
S=0.05
CO on Au
CO on Soot



REFERENCE
On Au, S=1
HOPG
S ≈ 0.4
Olivine Crystal
S ≈ 0.45
ISM grain size
Olivine Grains
S ≈ 0.1
Carbon
Nanoparticles
S ≈ 0.08
CO
N2
CO2
H2O
CO on ASW
N2 on ASW
CO2 on ASW
Sticking Coefficient
1.0
0.8
0.6
0.4
0.2
0.0
100000
10000
1000
100
10
1
0.1
0.01
0.001
Size (µm)

More info here

A&A, 689, A50 (2024)
https://doi.org/10.1051/0004-6361/202449167

Astronomy & Astrophysics

Experimental sticking coefficients of CO and N_2 on sub-micrometric cosmic grain analogs

C. Stadler, C. Laffon, and Ph. Parent

Aix Marseille Univ, CNRS, CINaM, Marseille, France
e-mail: caroline.stadler@univ-amu.fr; philippe.parent@univ-amu.fr

Received 5 January 2024 / Accepted 7 June 2024

Direct observation of ice nucleation events on individual atmospheric particles†

Cite this: *Phys. Chem. Chem. Phys.*, 2016, **18**, 29721

Bingbing Wang,‡*[a] Daniel A. Knopf,[b] Swarup China,[a] Bruce W. Arey,[a] Tristan H. Harder,[cd] Mary K. Gilles[c] and Alexander Laskin[a]

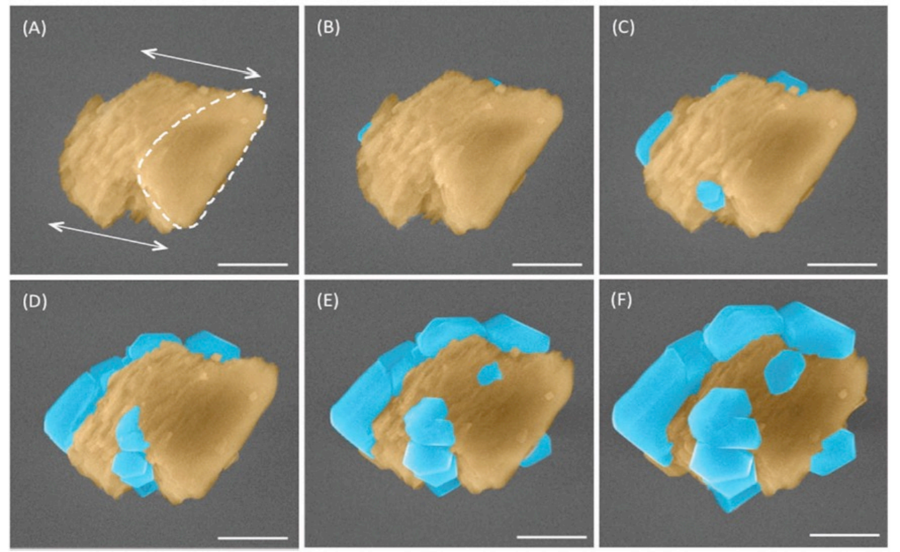


Fig. 7 Isothermal nucleation of ice on an individual kaolinite particle at 205.4 K. Ice formation is initiated at 124 Pa. False-colored images of kaolinite (brown) and ice crystals (blue) are shown for clarity. Dashed contour line shows the basal plane and arrows indicate direction of the stacked kaolinite platelets. Images show (A) prior to ice nucleation; (B) onset of ice formation, 124.2% RH_{ice}; (C–F) post ice nucleation event and growth of the ice crystals. ESEM images A–F were acquired sequentially, separated by 3 seconds. Scale bars are 5 μm.

Size Matters More Than Chemistry for Cloud-Nucleating Ability of Aerosol Particles

U. Dusek *et al.*

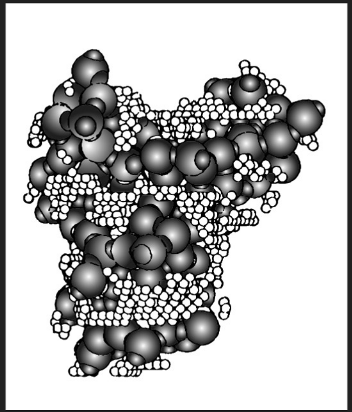
Science **312**, 1375 (2006);
DOI: 10.1126/science.1125261

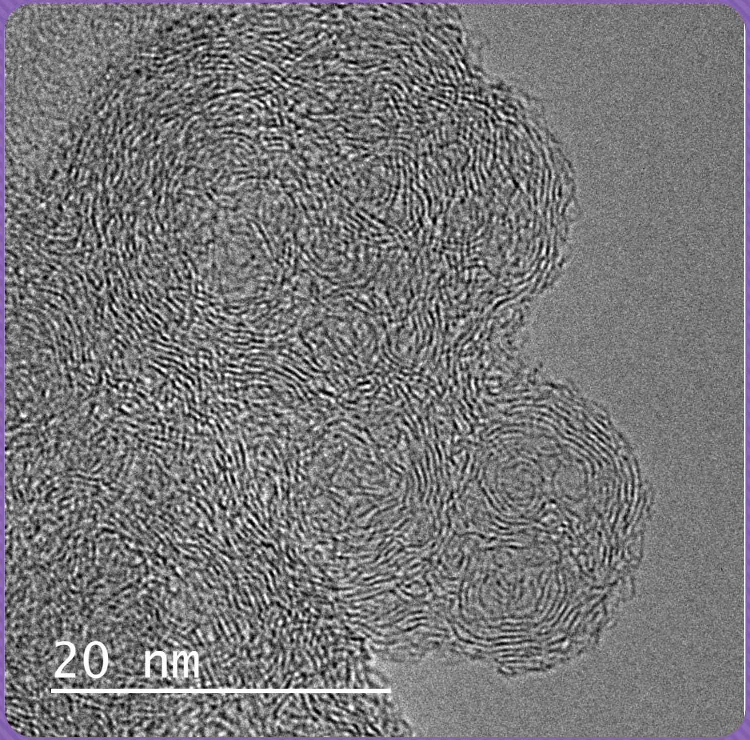
Eigenstates of a quantummechanical particle on a topologically disordered surface: H(D) atom physisorbed on an amorphous ice cluster (H2O)115

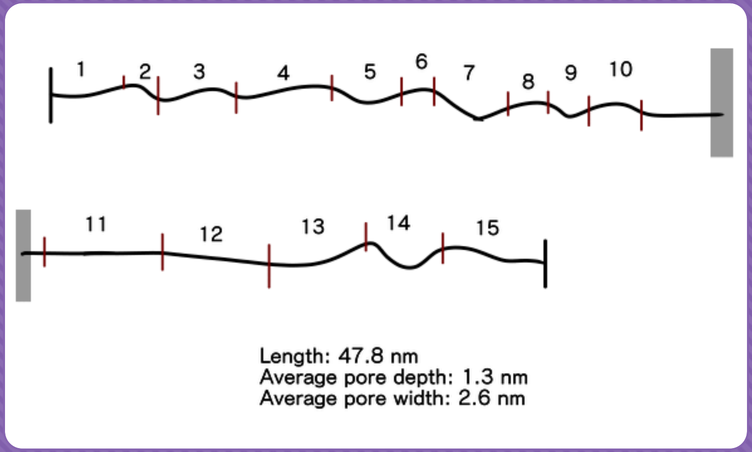
V. Buch and R. Czerminski

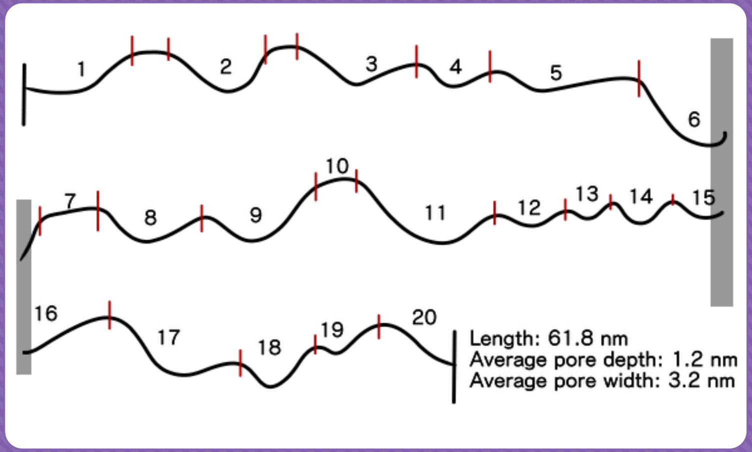
(Capillary condensation)

Citation: The Journal of Chemical Physics **95**, 6026 (1991); doi: 10.1063/1.461571



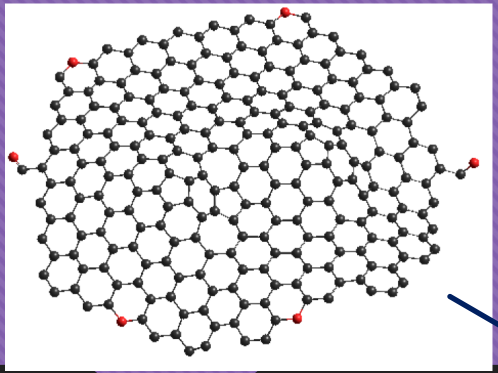


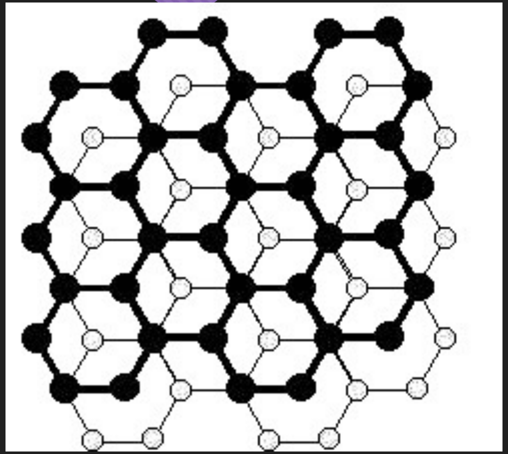


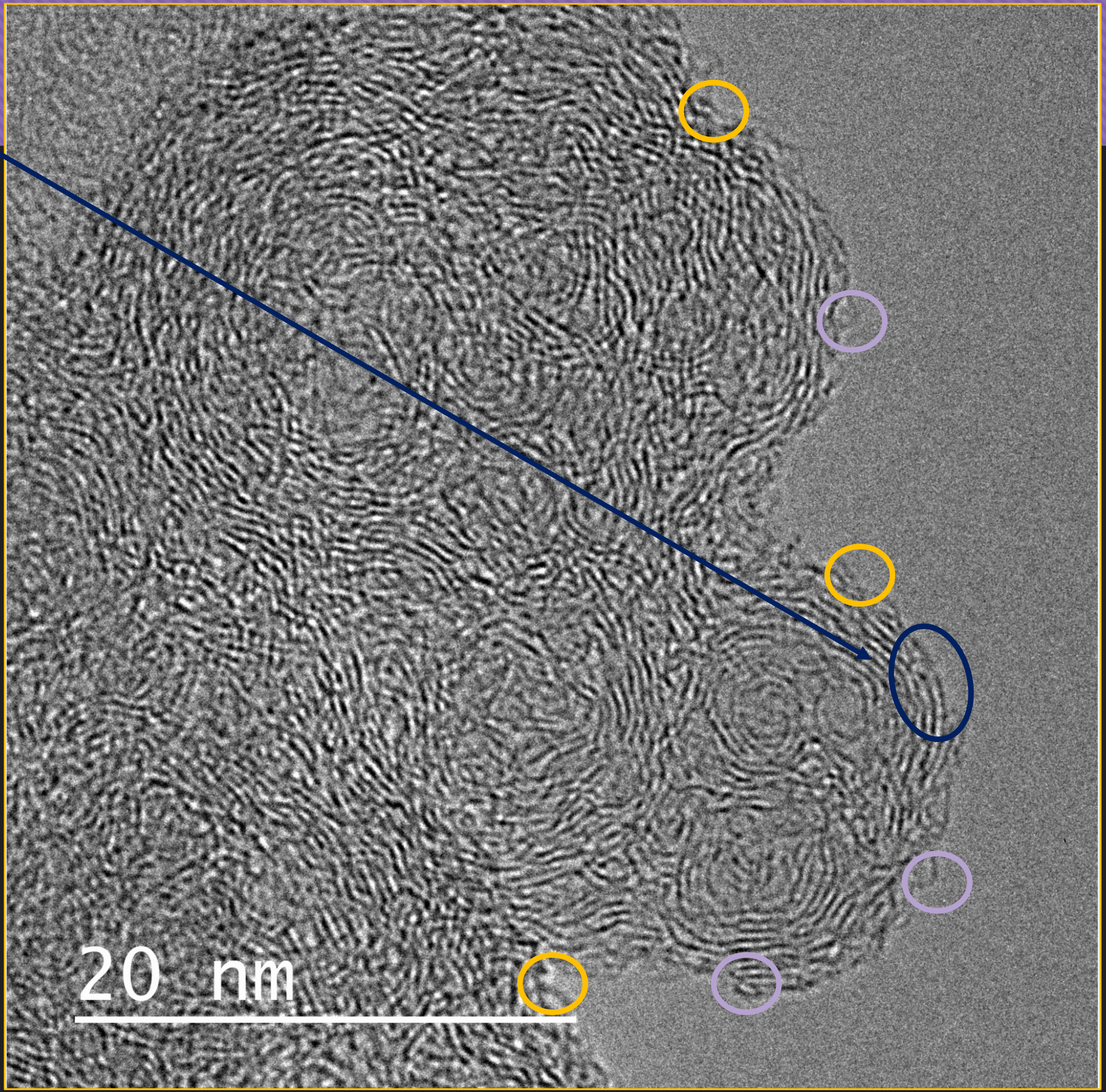


Contextualization – CO soot outlines

Dust Grain Analogue: Soot







LT-STM

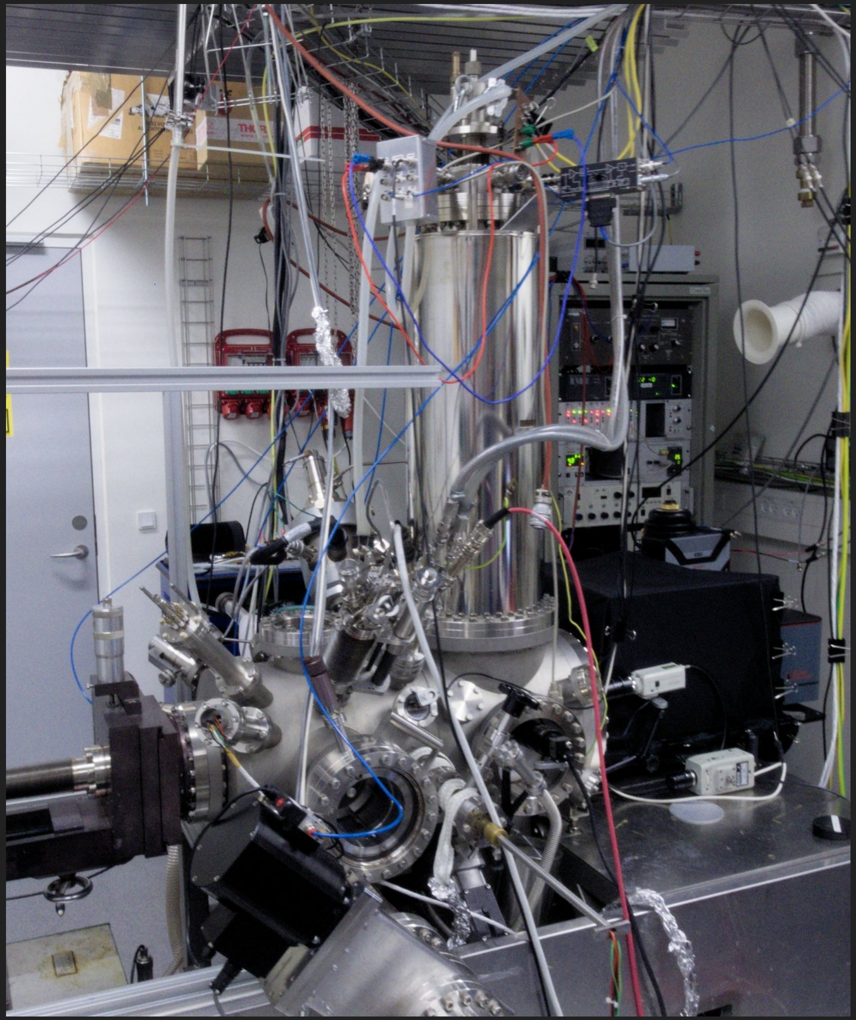
! Analysis still in progress for publication – No photos please

INTERCAT
Center for Interstellar Catalysis

With Liv Hornekær and Frederik Simonsen at Aarhus University

LHe temperatures – 4K

Added CO sequentially on HOPG



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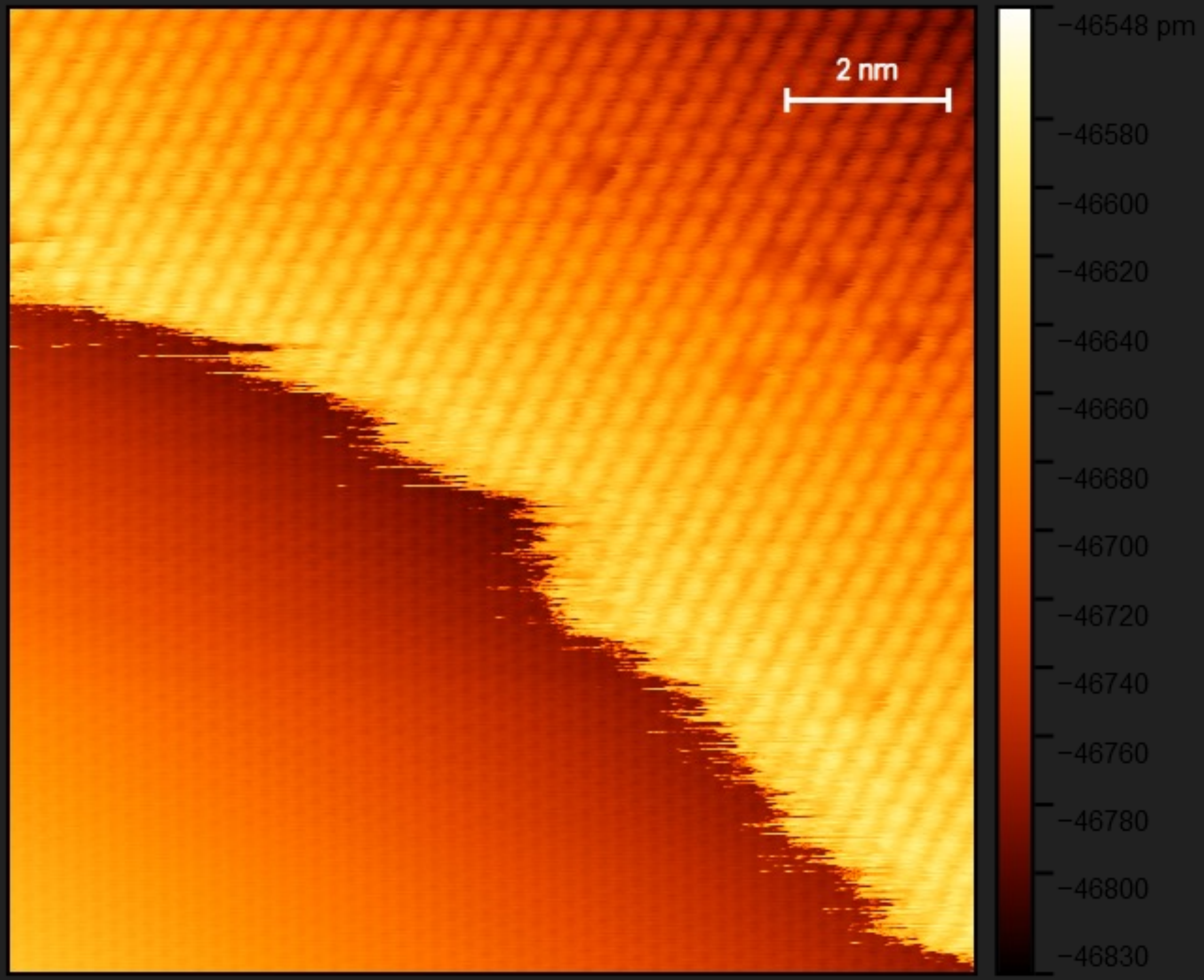
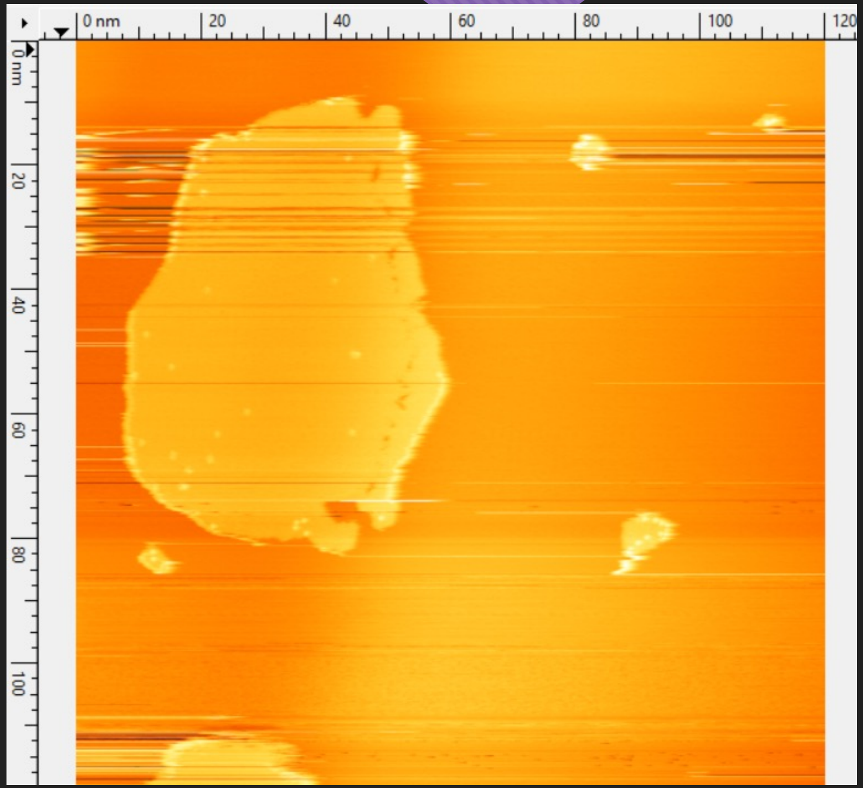


V=-2.12 V, I=64 pA

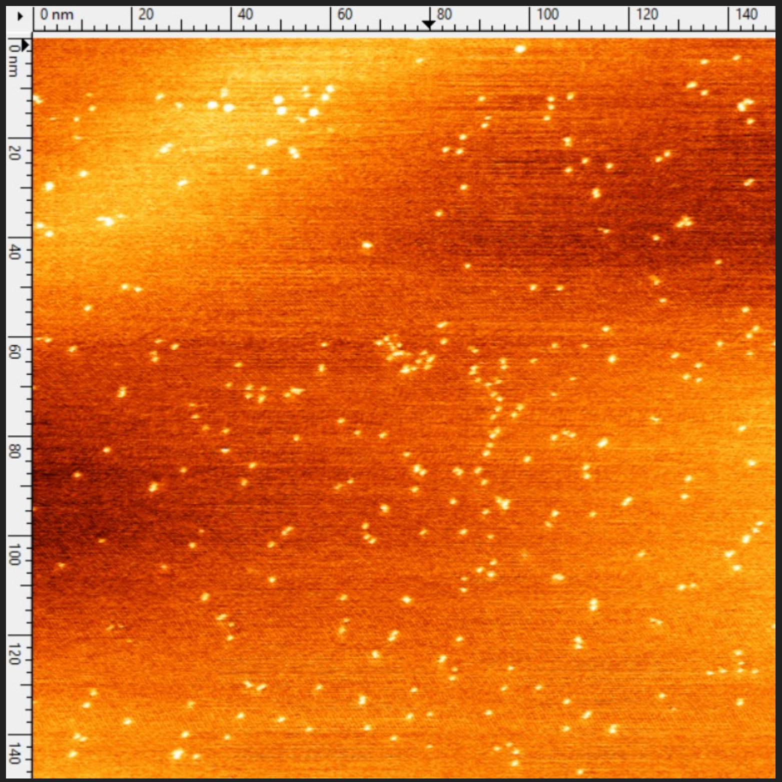
LT-STM – CO ices

! Analysis still in progress for publication – No photos please



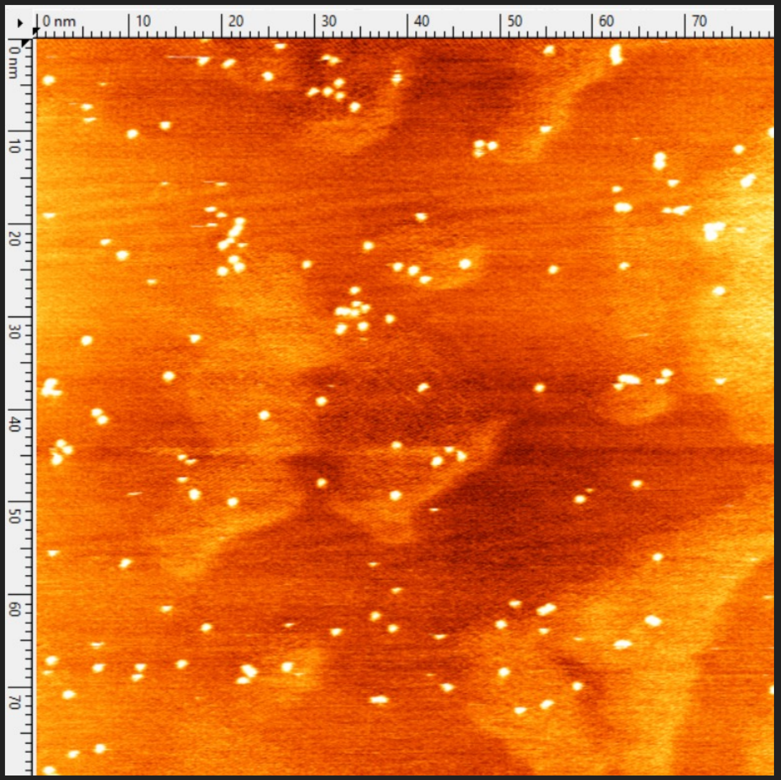
2.0V, 6.1E-12 A

ISLANDS



-2.2V, 5.5E-12 A

LAYERS

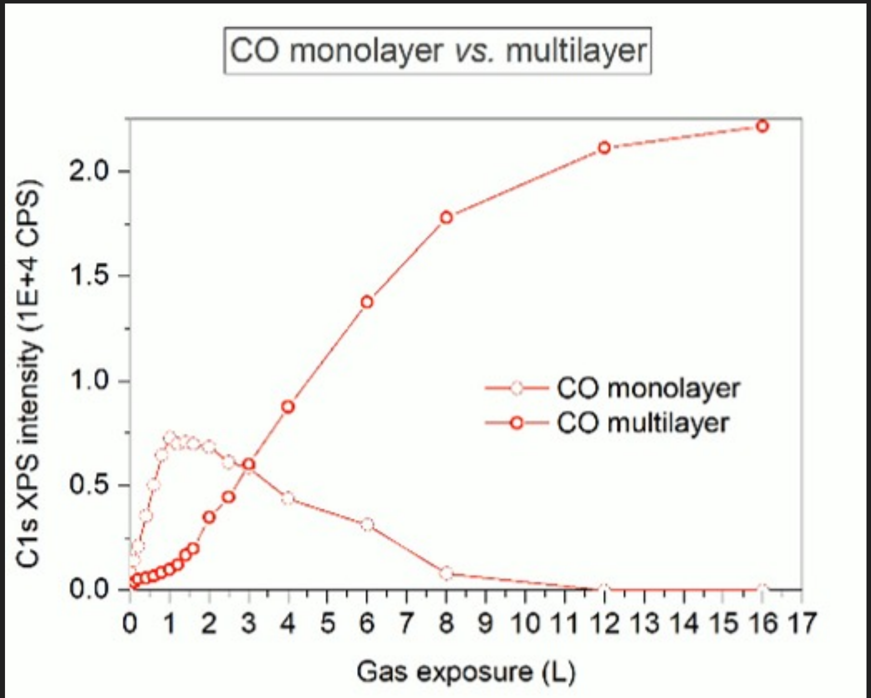


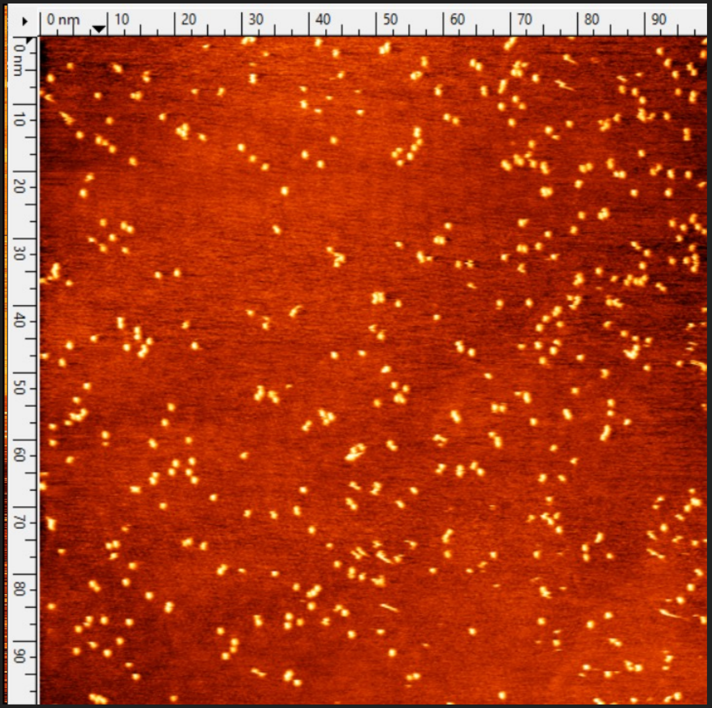
-2.3V, 1.0E-11 A

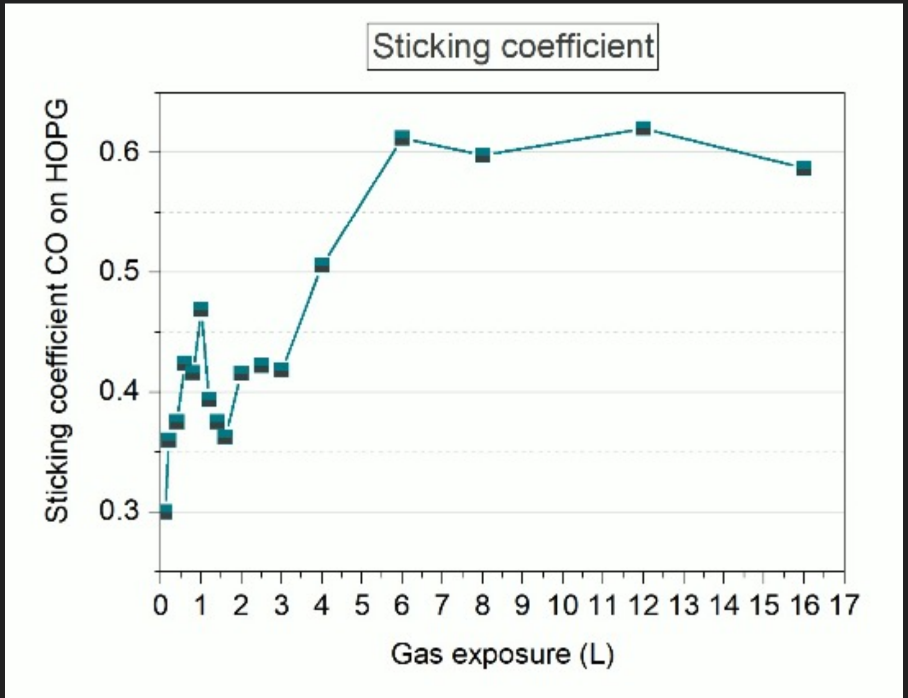
PACKING

XPS & LT-STM – details matter

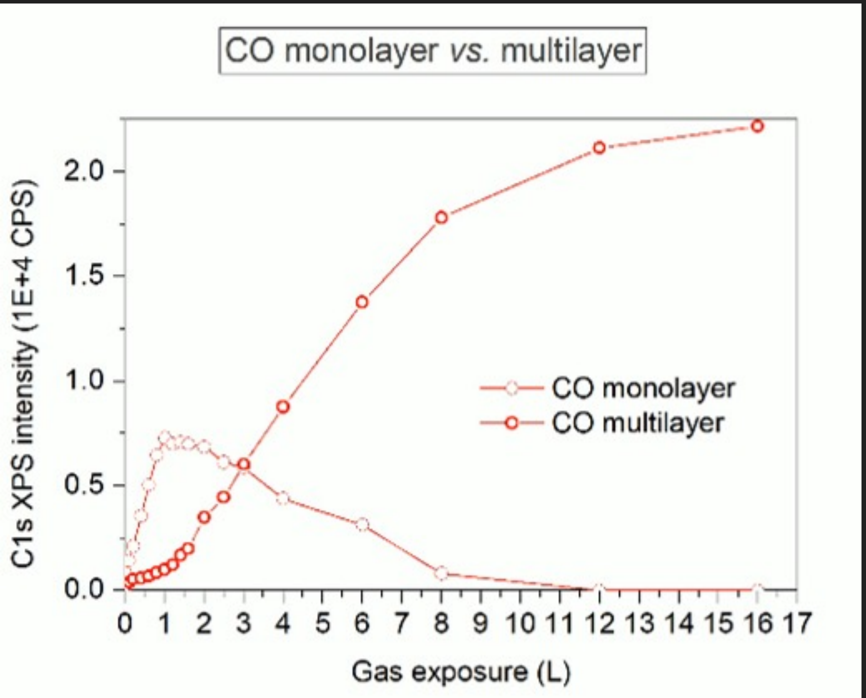
! Analysis still in progress for publication – No photos please

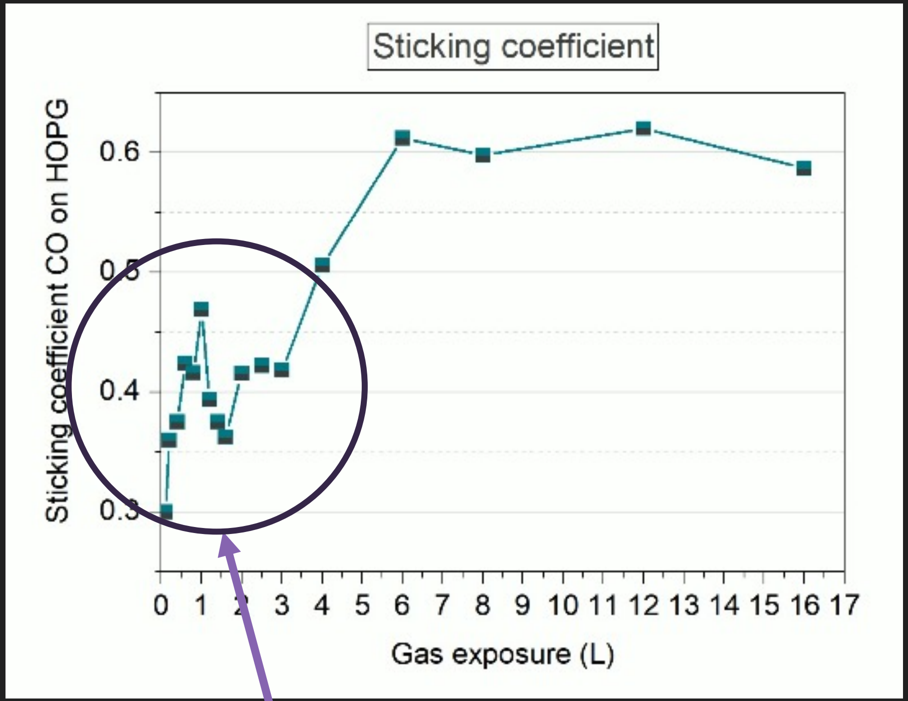




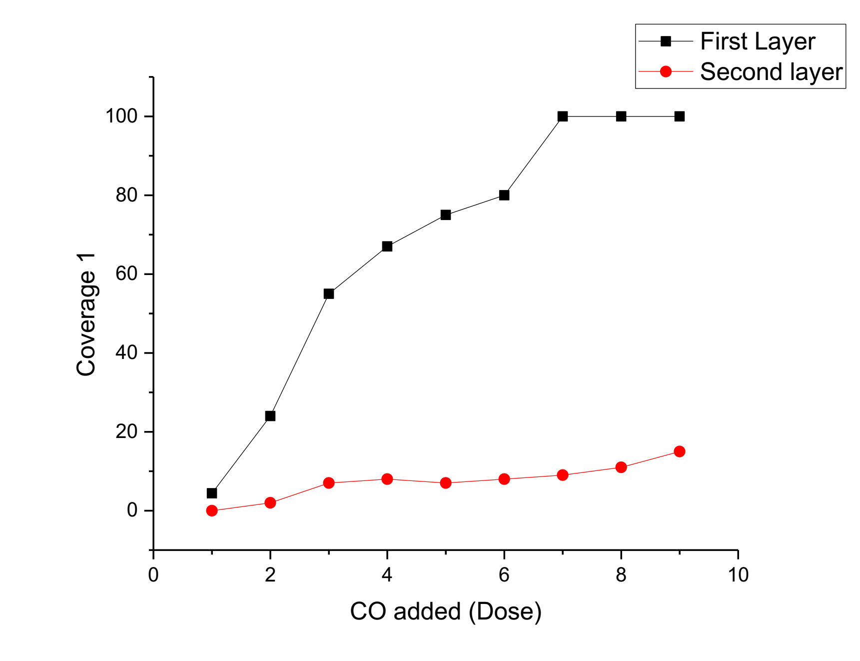


-2.6V, 1.4E-11 A

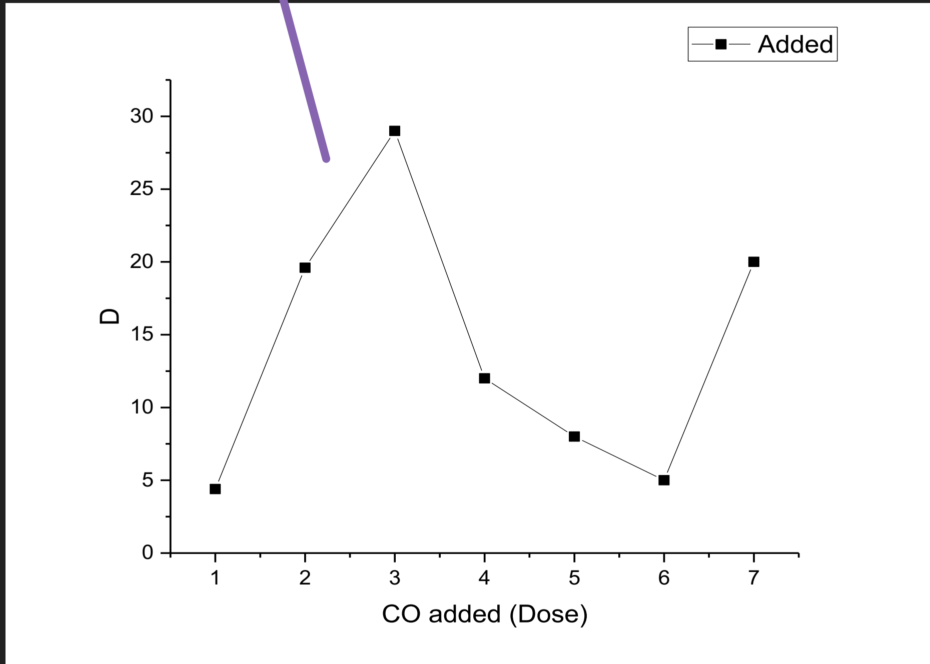

CO monolayer vs. multilayer
C1s XPS intensity (1E+4 CPS)
CO monolayer
CO multilayer
Gas exposure (L)


Sticking coefficient
Sticking coefficient CO on HOPG
Gas exposure (L)

XPS


First Layer
Second layer
Coverage 1
CO added (Dose)

LT-STM


Added
D
CO added (Dose)

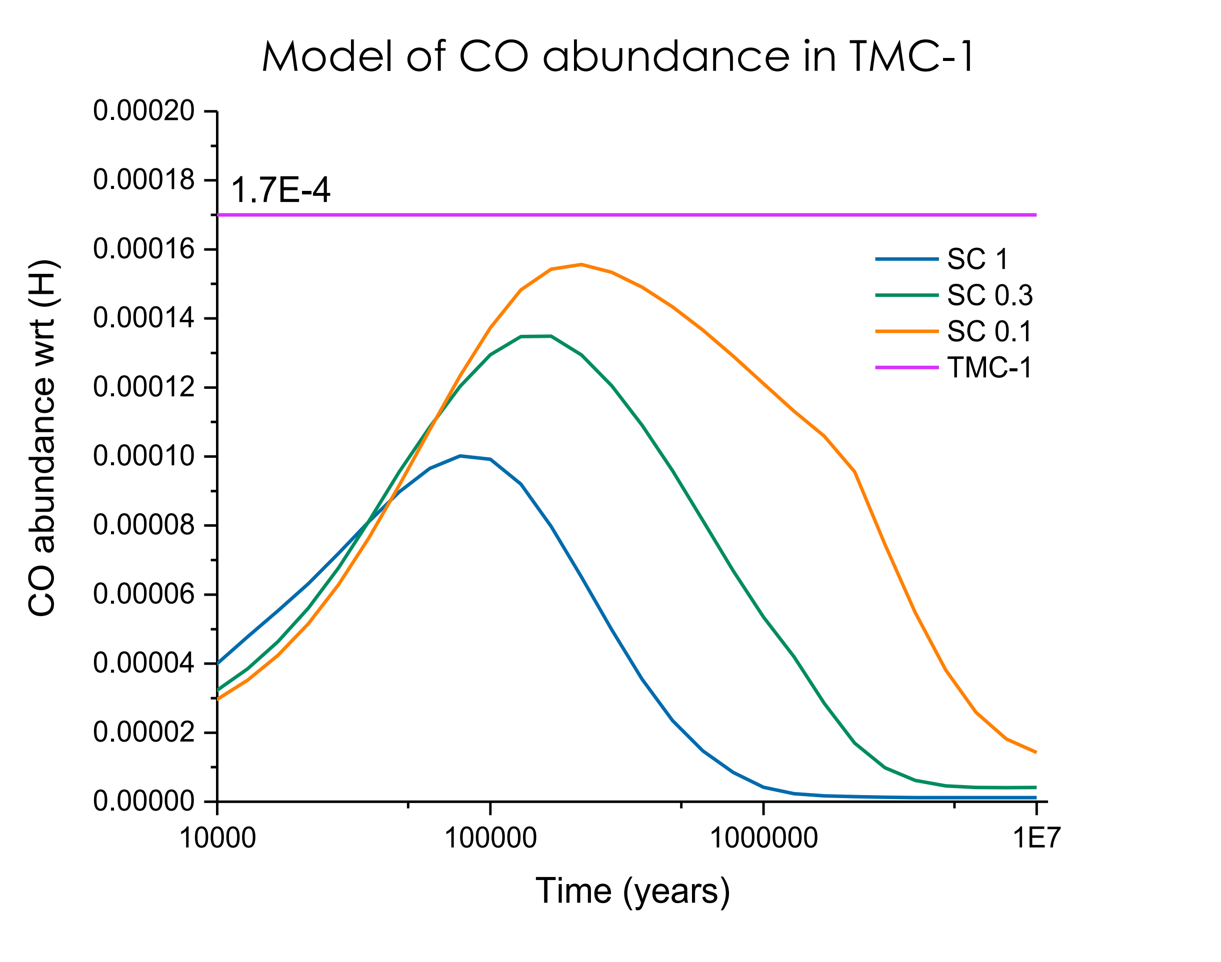
Astrophysical Implications – Nautilus 2.0

New collaboration with V. Wakelam & A. Taillard, LAB

Computational simulation

Putting the new sticking value into the computational astrochemistry model developed by V. Wakelam and Marcelino Agundez; Nautilus 2.0

First impressions were promising

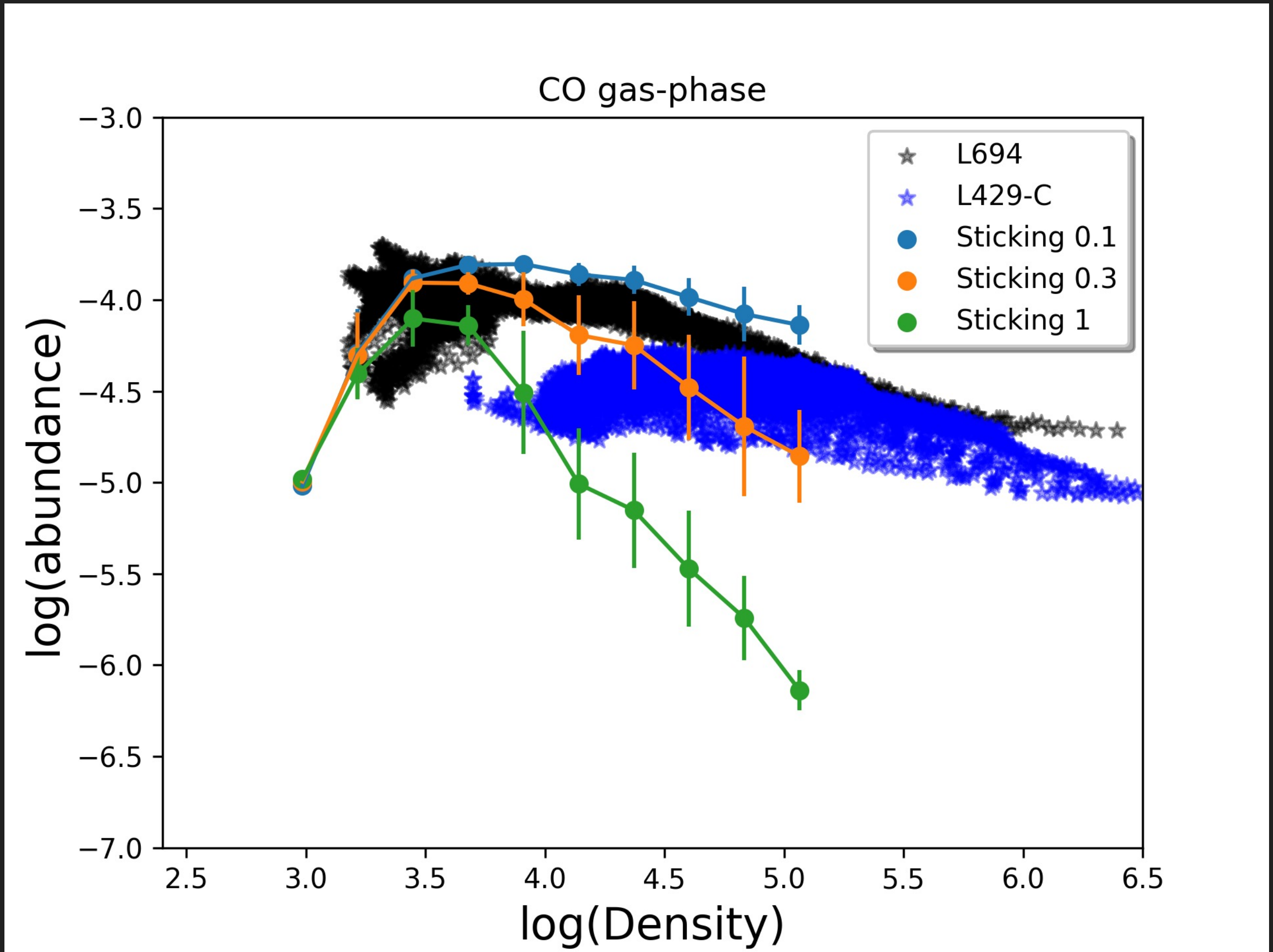


Astrophysical Implications – Nautilus 2.0

Hydrodynamic Simulation

A. Taillard & V. Wakelam

Paper in progress



Conclusions & Perspectives

Building from Laffon et al 2021: Accretion rates must be revisited: ISM grains condense far less gas than (previously) thought

- The sticking coefficient S for small molecules on interstellar medium is ≈ 0.1 (independent on factors such as the presence of water, the molecule being adsorbed), and not 1

- This itself has time-based astrophysical implications, resulting in it taking ~ 10 times longer for molecules to adsorb onto dust grains

- This was shown using **XPS** to be a physical effect, is still being analyzed in LT-STM and its importance has been highlighted with Nautilus 2.0

Thank you ☺

Supplementary Information – Specific surface area concern

The specific surface area increase was taken into account, and would be more consequential if the dosage wasn't enough to cover the surface.

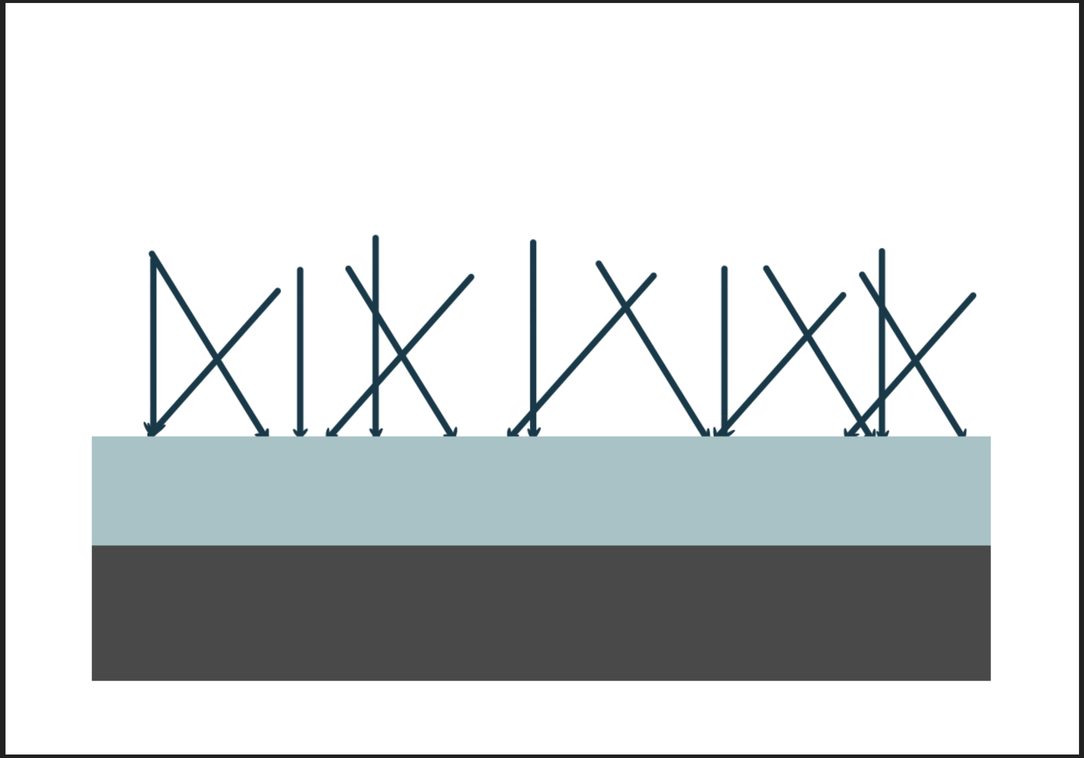
- Since we open a pump, the dosage is dynamic and large

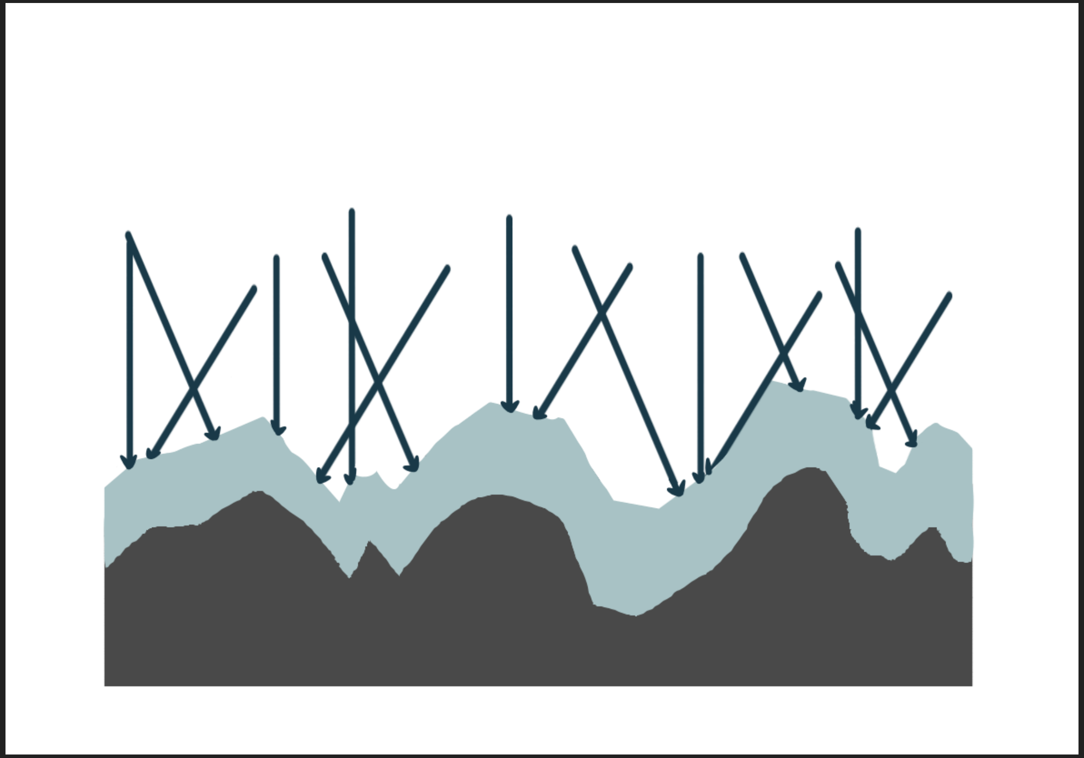
Eg, Steam on bathroom mirrors after a shower – a larger mirror will still be covered in condensed steam

- however, this may not be the case if the steam comes from one specific location
- **Isotropic** adsorption, so adsorption everywhere
- This also limits the effect of shadowing

It's not a monolayer over the whole surface, it's the chance that the molecule sticks

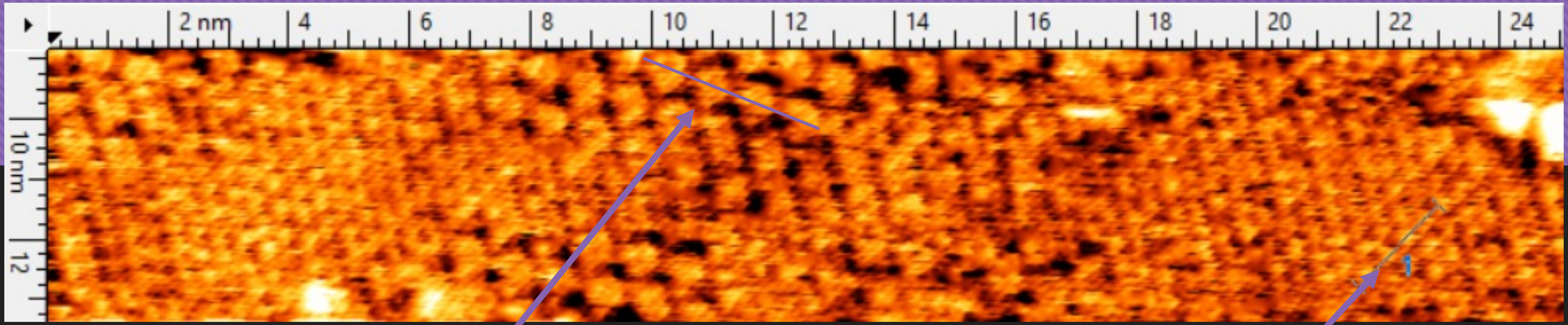
Flat vs Rugged covering

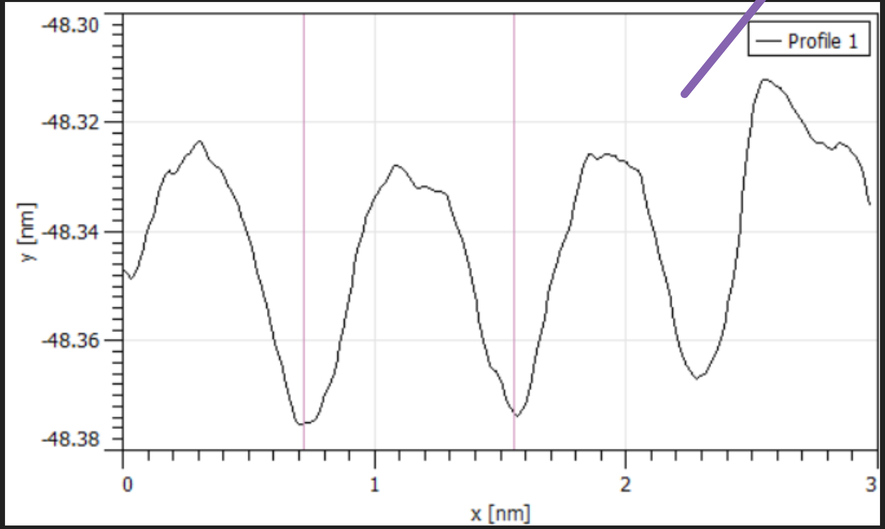


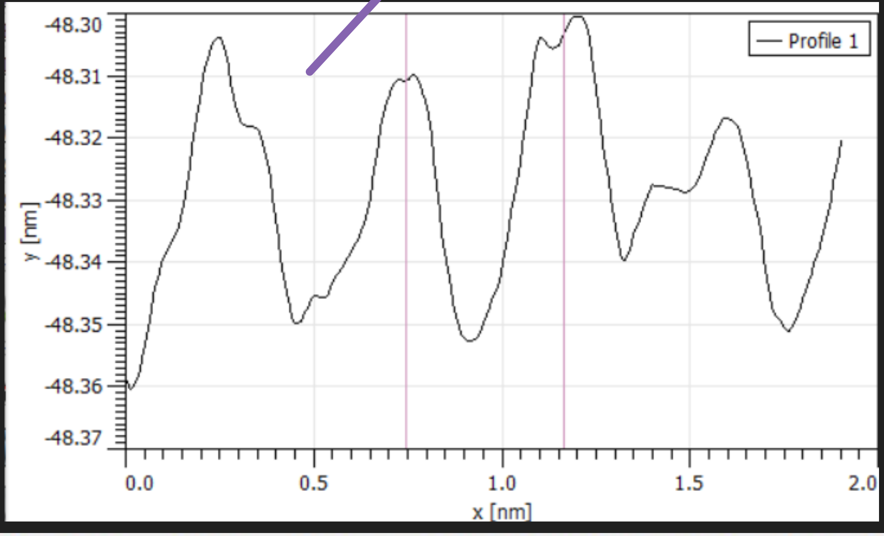


! Analysis still in progress for publication – No photos please

Patches are Packing Structure







Points	X [nm]	Y [pm]	Length [nm]	Height [pm]	Angle [deg]
	0.719	-48375.2			
	1.555	-48373.3	0.835	2.0	0.13

Points	X [nm]	Y [pm]	Length [nm]	Height [pm]	Angle [deg]
	0.745	-48310.86			
	1.165	-48303.42	0.420	7.43	1.01