



Towards livermorium chemistry: Atom-at-a-time gas chromatography studies with polonium

Katharina Hermainski for the JGU-GSI-HIM-CTU-ÚJF-UiO collaboration



Collaboration partners

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Pushing the heavy element chemistry frontier

1 IA																		18 VIIIA																																			
Radioelements																		SHE studied chemically																		Focus of future studies																	
1																	2																	18																			
1																	2																	18																			
H																	He																	He																			
Hydrogen																	Helium																	Helium																			
3	4																10																																				
Li	Be																Ne																																				
Lithium	Beryllium																Neon																																				
11	12																18																																				
Na	Mg																Ar																																				
Sodium	Magnesium																Argon																																				
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K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr																																				
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37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54																																				
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Rubidium	Strontium	Yttrium	Zirconium	Niobium	Molybdenum	Technetium	Ruthenium	Rhodium	Palladium	Silver	Cadmium	Indium	Tin	Antimony	Tellurium	Iodine	Xenon																																				
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Caesium	Barium	Lanthanides	Hafnium	Tantalum	Tungsten	Rhenium	Osmium	Iridium	Platinum	Gold	Mercury	Thallium	Lead	Bismuth	Polonium	Astatine	Radon																																				
87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118																																				
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Francium	Radium	Actinides	Rutherfordium	Dubnium	Seaborgium	Bohrium	Hassium	Mtnerium	Darmstadtium	Roentgenium	Copernicium	Nihonium	Flerovium	Moscovium	Livermorium	Tennessee	Oganesson																																				

*Lanthanides	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
	Lanthanum	Cerium	Praseodymium	Neodymium	Promethium	Samarium	Europium	Gadolinium	Terbium	Dysprosium	Holmium	Erbium	Thulium	Ytterbium	Lutetium
**Actinides	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
	Actinium	Thorium	Protactinium	Uranium	Neptunium	Plutonium	Americium	Curium	Berkelium	Californium	Einsteinium	Fermium	Mendelevium	Nobelium	Lawrencium

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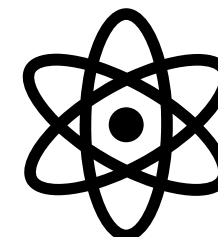
Mc and Nh recently studied chemically

Studying heavier SHE requires...



...Technical developments

➤ Unicell



...Studying the chemistry of homologues

➤ Polonium

A. Yakushev et al., *Front. Chem.* **2024**, *12*, 1474820.

What is known about polonium?

A periodic table highlighting the chalcogen group (S, Se, Te, Po) and a trend arrow pointing down, indicating increasing metallic character.

14	15	16	17	18
Si	P	S	Cl	Ar
32	33	34	35	36
Ge	As	Se	Br	Kr
50	51	52	53	54
Sn	Sb	Te	I	Xe
82	83	84	85	86
Pb	Bi	Po	At	Rn
114	115	116	117	118
Fl	Mc	Lv	Ts	Og

Increasing metallic character

Similar compounds as lighter homologues

Oxides

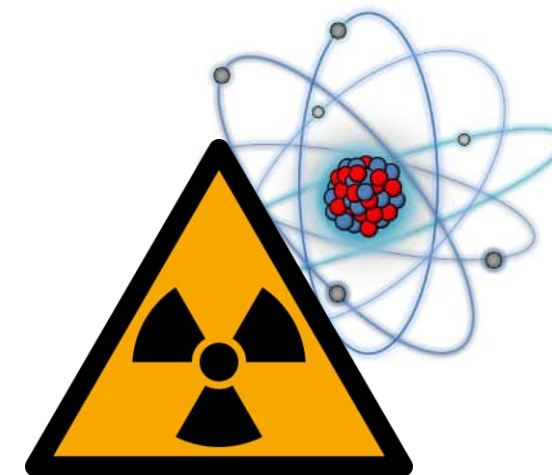


Oxoacids



Halogenides, interchalcogenides, polonides...

Most stable oxidation state: +IV



Highly radiotoxic

What is known about polonium?

Thermochromatography experiments on metals show strong adsorption of polonium to metal surfaces

$$-\Delta H_{\text{ads}}^{\text{Au}}(\text{Po}) = (250 \pm 7) \text{ kJ/mol}$$

E. A. Maugeri et al., *Radiochim. Acta.* **2016**, 104, 757-767

Similar reactivity of polonium and livermorium predicted in fully relativistic quantumchemical calculations

V. Pershina, M. Iliáš, *Mol. Phys.* **2025**, 123, 2573831

A. Ryzhkov et al., *Phys. Chem. Chem. Phys.* **2023**, 25, 15362



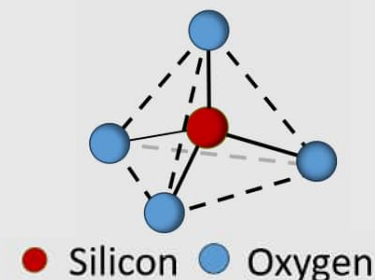
Experiments with polonium and livermorium on metal surfaces demand high temperatures

Lower temperatures needed on quartz (SiO_2) surfaces

Quartz is the suitable material for future chemical studies of livermorium

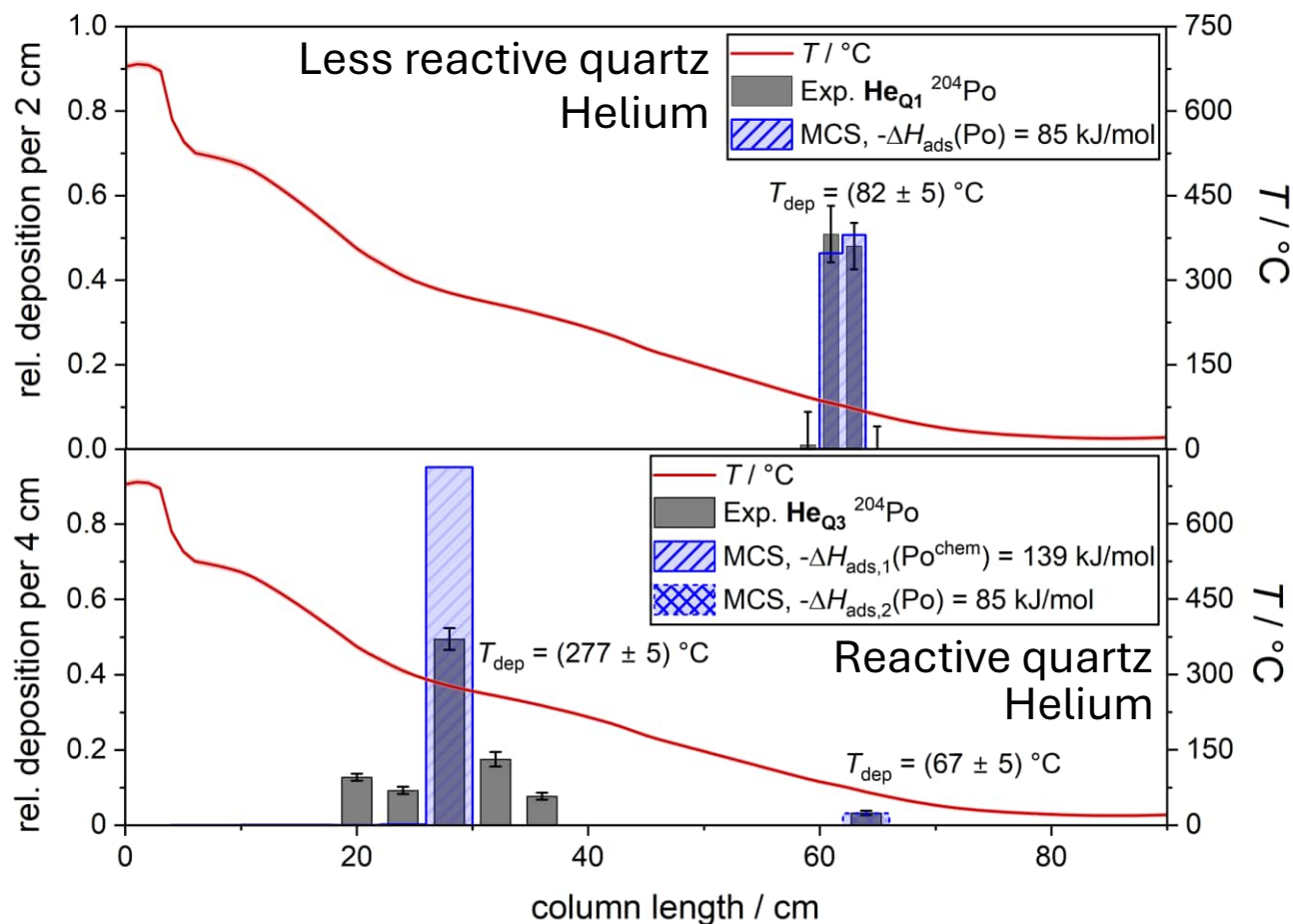
However only one published, detailed adsorption study of polonium on quartz

E. A. Maugeri et al., *J. Nucl. Mater.* **2014**, 450, 292-298.

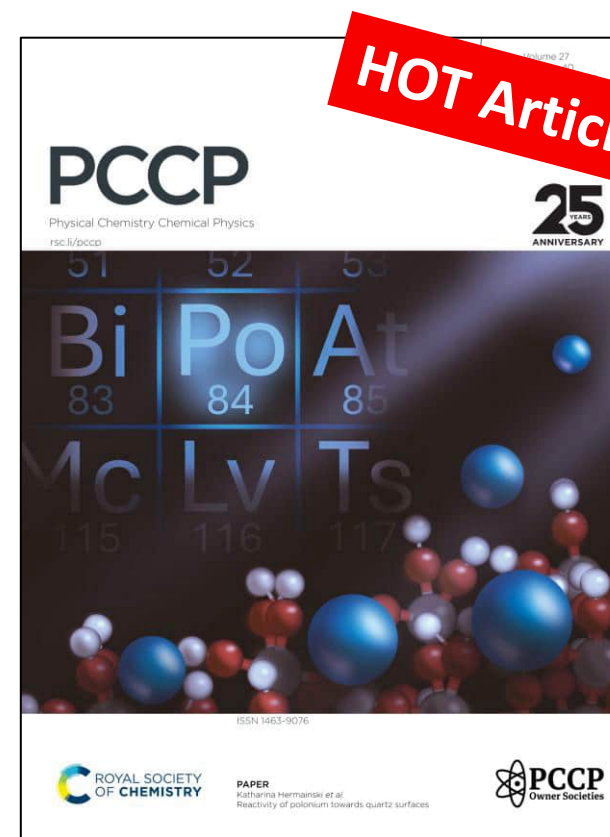


Unravelling the influence of the quartz surfaces

Status at TASCA 25: Influence of quartz surface hydroxlation on Po adsorption



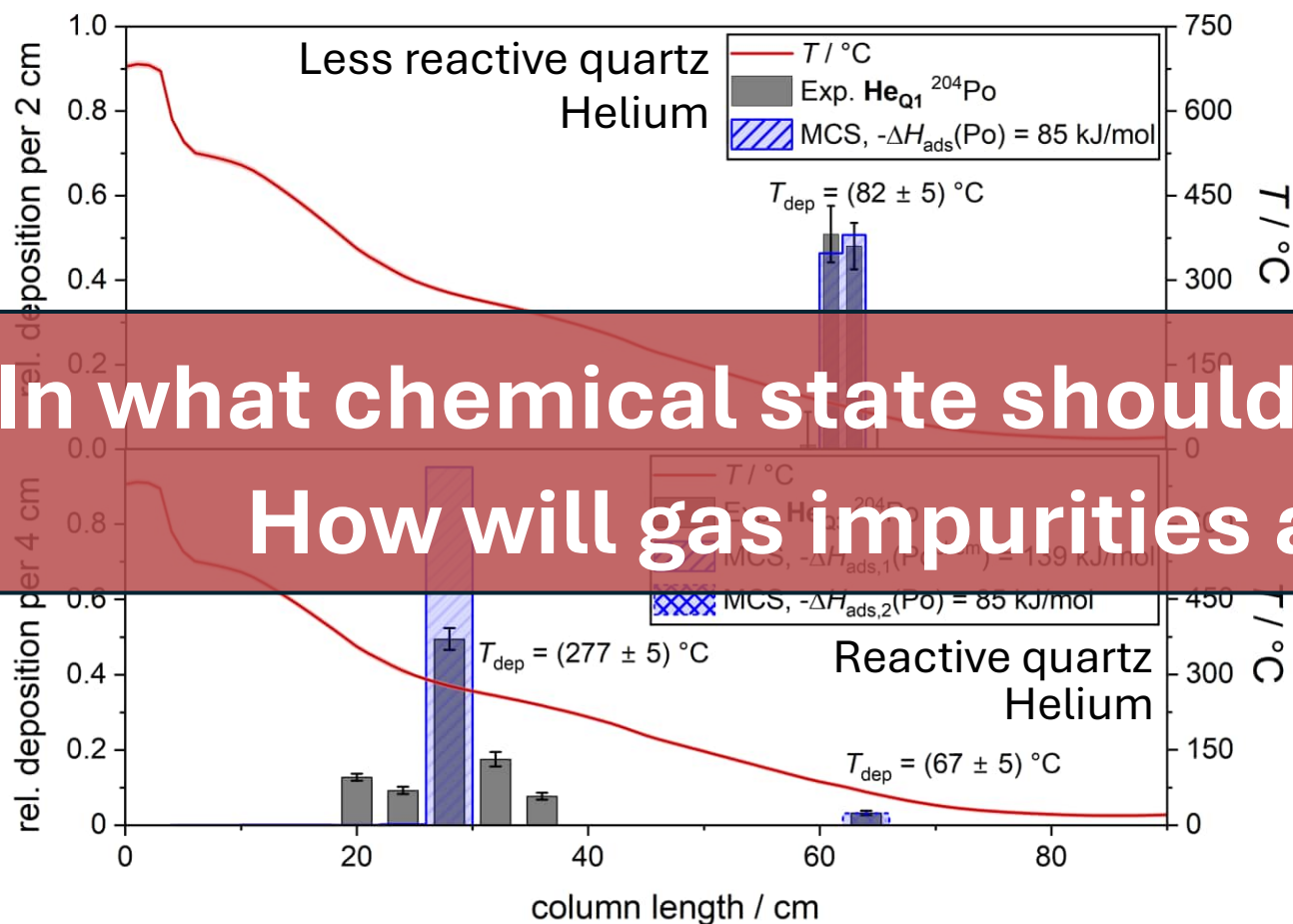
Results have been published:



K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2025**, 27, 21414-21423.

Unravelling the influence of the quartz surfaces

Status at TASCA 25: Influence of quartz surface hydroxylation on Po adsorption



Results have been published:



In what chemical state should livermorium be studied?
How will gas impurities affect the experiment?

K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2025**, 27, 21414-21423.

Studying Po at the atom-at-a-time regime



Experiments conducted at the Nuclear Physics Institute CAS in Husinec-Řež

Po 204 3.519 h e α 5.377 γ 884, 270 1016...	Po 205 1.74 h e, β ⁺ 1.5, 1.7... γ 872, 1001, 850 837... α 5.22, α → g	Po 206 8.8 d e γ 1032, 511 286, 807... e ⁻ , g	Po 207 2.79 s 5.80 h IT 268 109, e ⁻ γ 815 301..., e ⁻	Po 208 2.898 a α 5.112... e γ (292, 571...) g	Po 209 122.9 a α 4.833, 4.885... γ (751, 263) e ⁻ γ (896)
Bi 203 11.76 h e, β ⁺ 1.4, 2.2... γ 820, 825, 897 1848, 1034... g, m	Bi 204 11.22 h e γ 899, 375 984... g, m	Bi 205 14.91 d e, β ⁺ ... γ 1764, 703 988...	Bi 206 6.24 d e, β ⁺ ... γ 803, 881, 516 1719, 537...	Bi 207 31.55 a e, β ⁺ ... γ 570, 1064 1770...	Bi 208 3.68·10 ⁵ a e γ 2615
Pb 202 3.54 h 5.25·10 ⁴ a IT 787... γ 422 961... e, γ 490 460, 390...	Pb 203 6.21 s 51.92 h IT 825 γ 820, (5) e ⁻	Pb 204 66.93 m [0.00; 1.58] IT 912... γ 899 375... σ 0.703	Pb 205 1.70·10 ⁷ a e no γ σ ~5	Pb 206 [1.90; 86.73] σ 0.027	Pb 207 [0.35; 23.51] σ 0.647

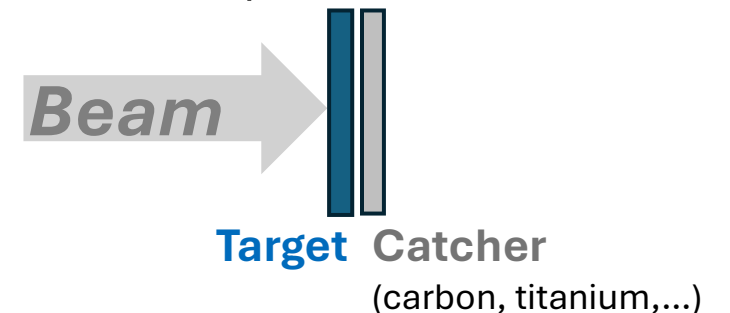
Target

Production in fusion reaction:
 $^{206}\text{Pb}(^3\text{He}, 4-5n)^{205,204}\text{Po}$

Beam energy: 48 MeV

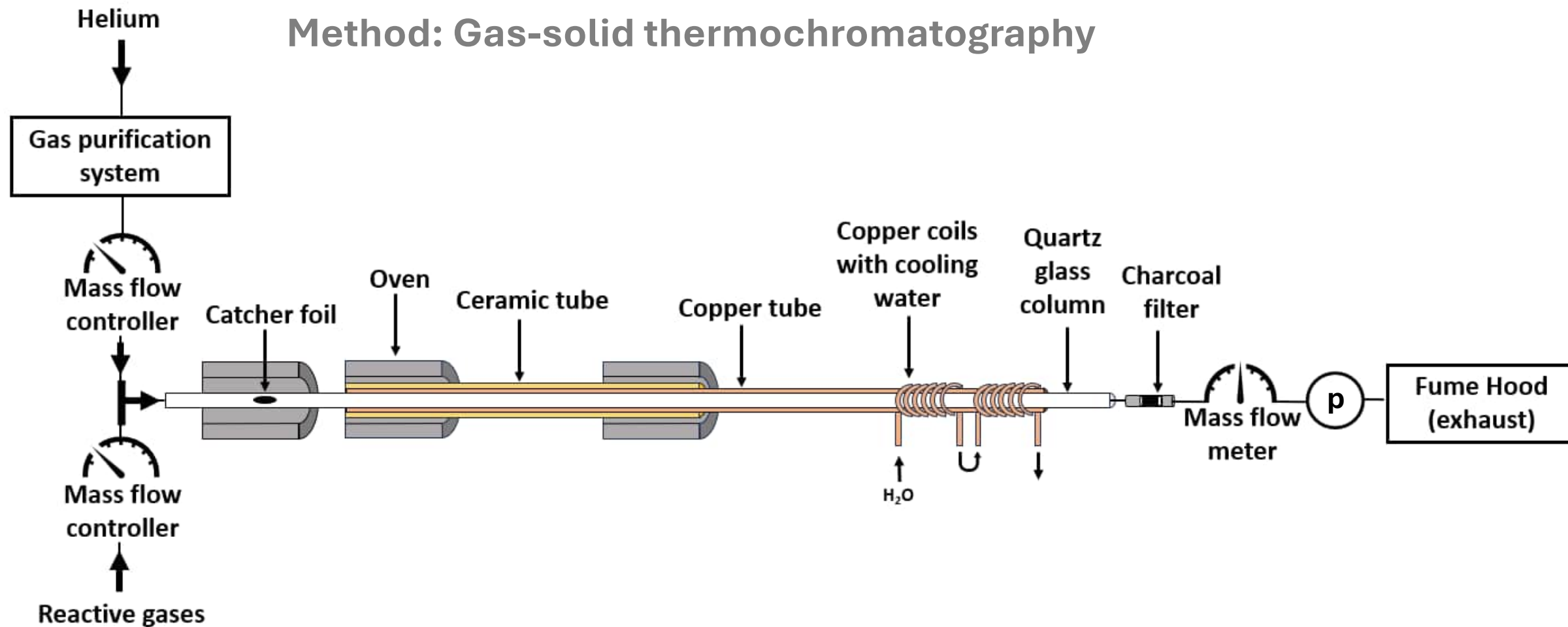
Beam current: 200 particle nA

Collection of produced activity
 in catcher foil (offline
 experiments)



Studying Po at the atom-at-a-time regime

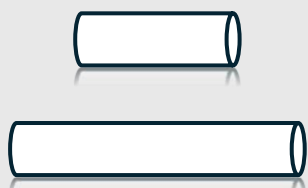
Method: Gas-solid thermochromatography



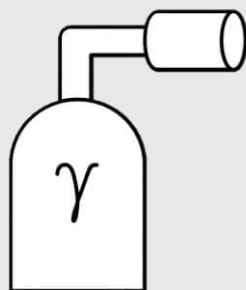
K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2025**, *27*, 21414-21423.

Studying Po at the atom-at-a-time regime

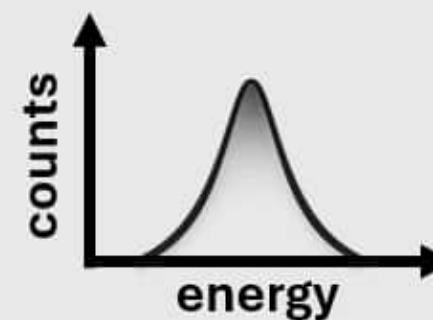
Detection of polonium in the column



Column cut
in 2 or 4 cm
pieces

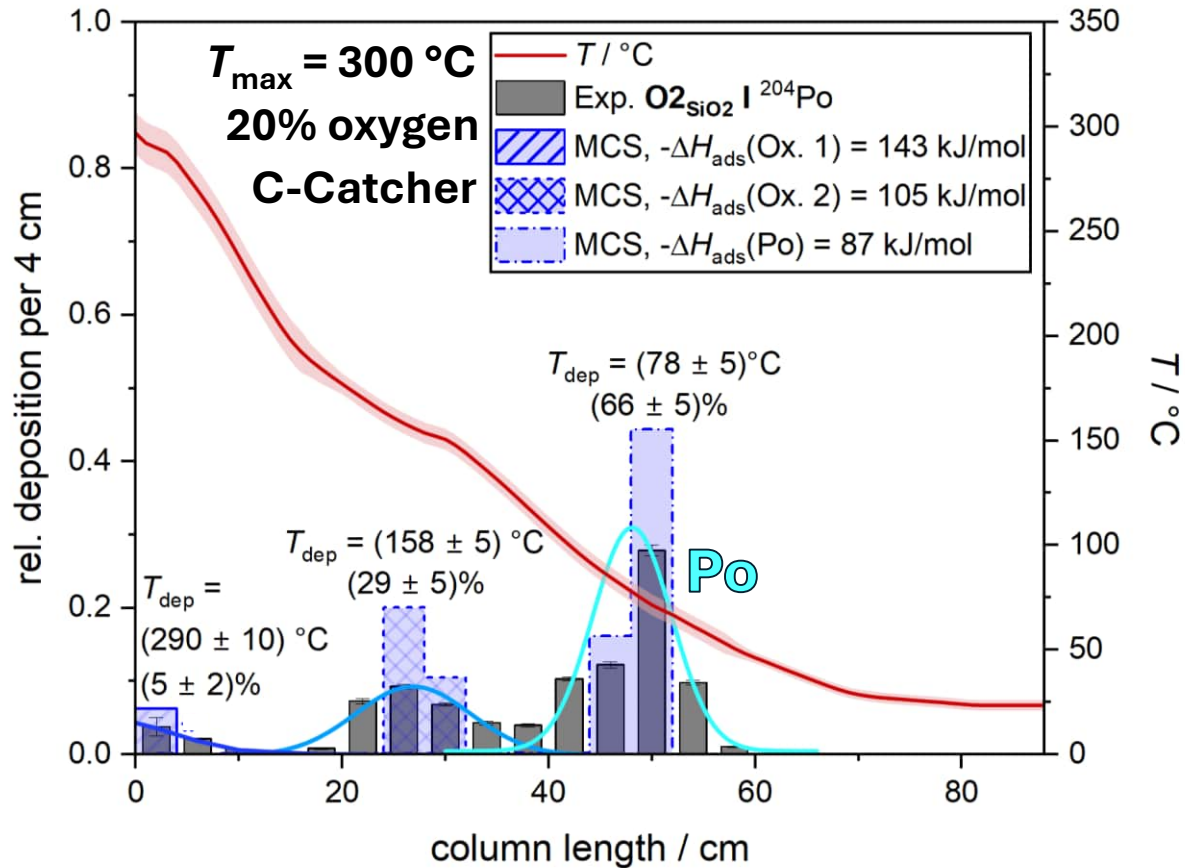


γ -Spectra of
individual
column pieces
measured

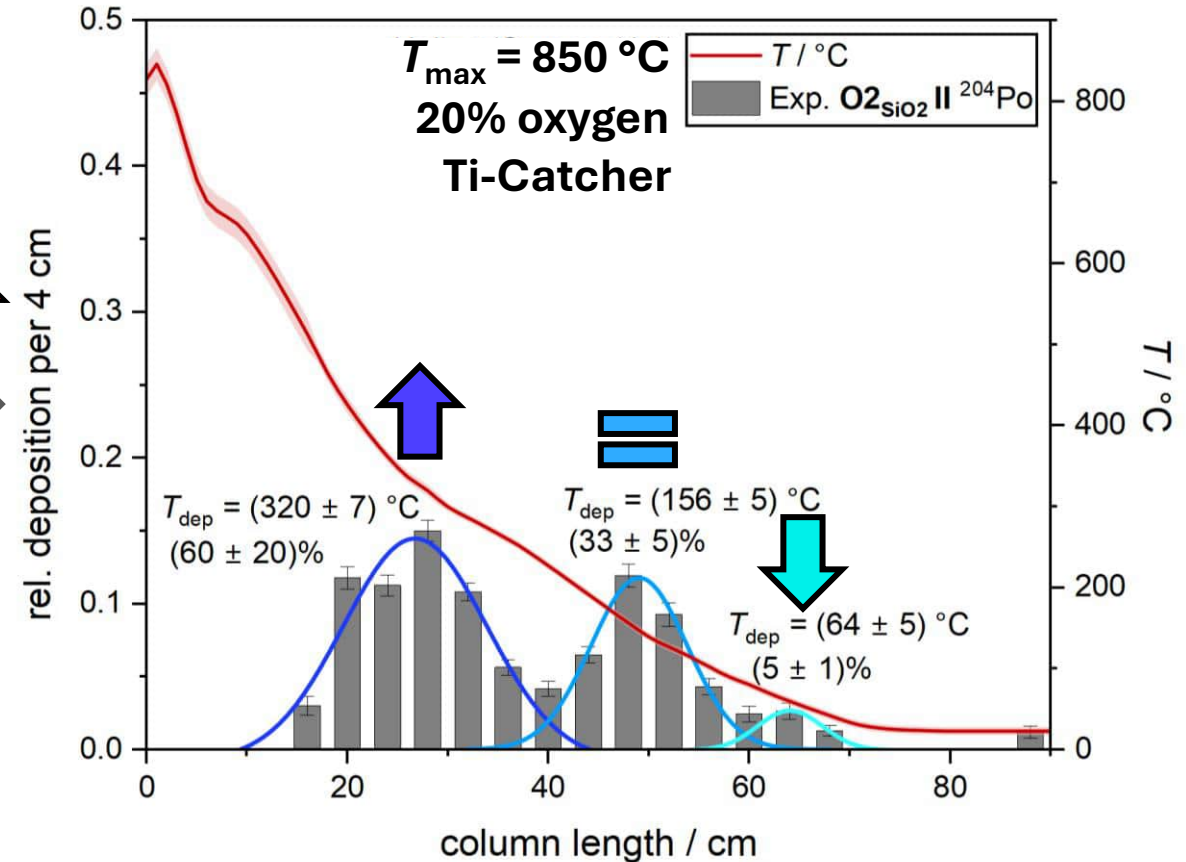


Polonium γ -peaks integrated and
baseline- and decay-corrected
Corrected integrals were normalized to
total polonium activity

Reaction of polonium with oxygen

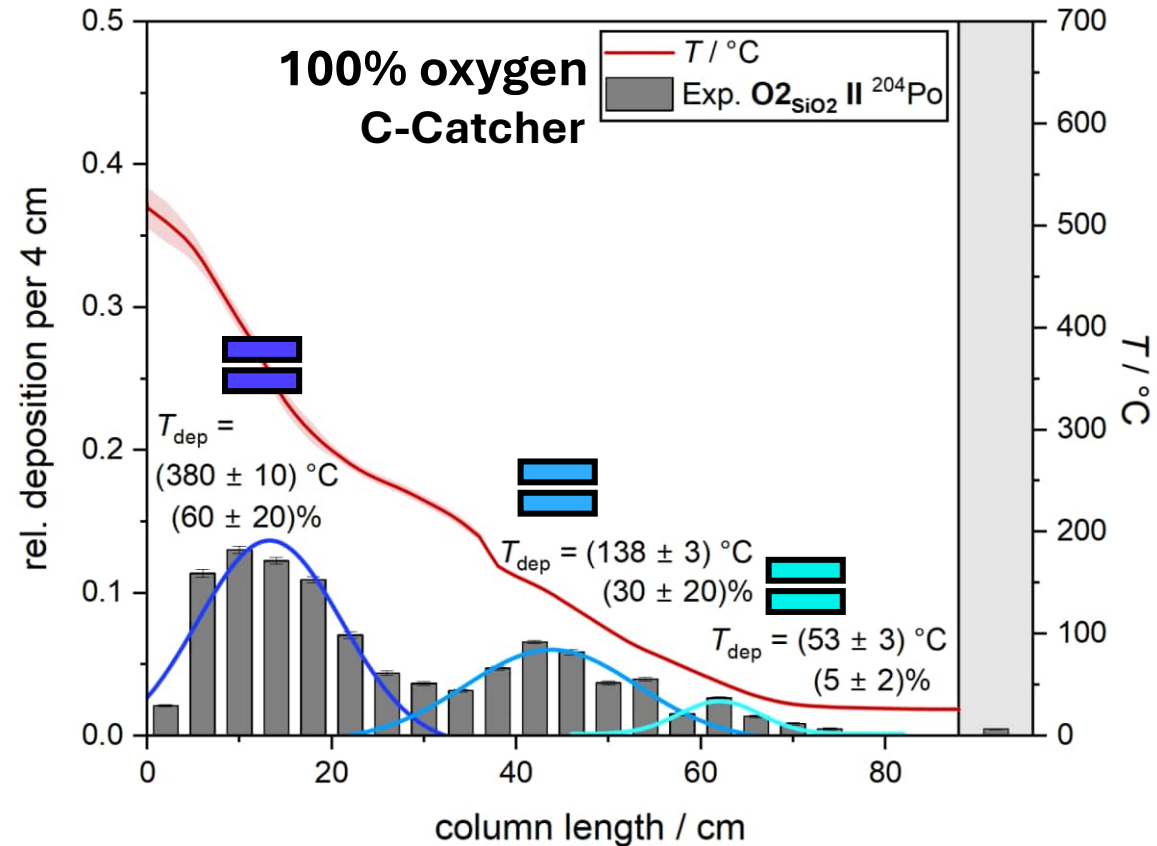
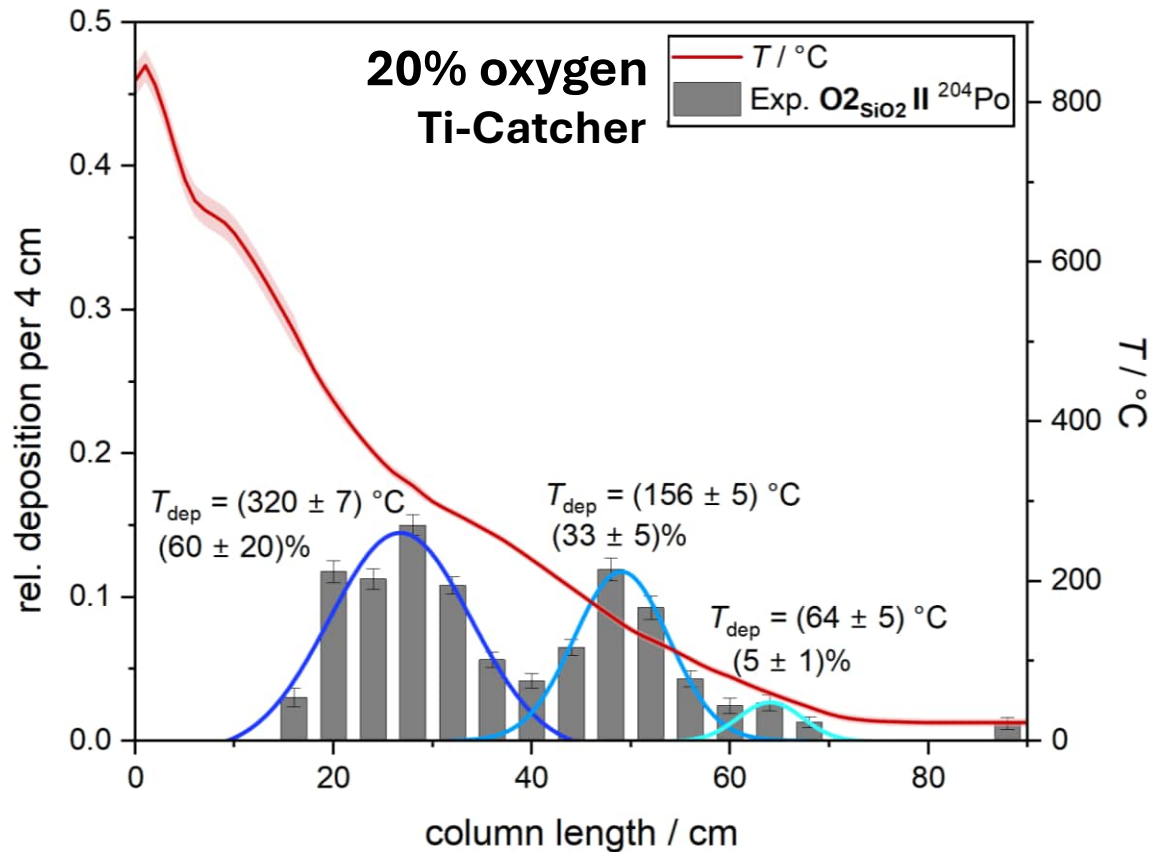


➤ Two oxidized species involved.



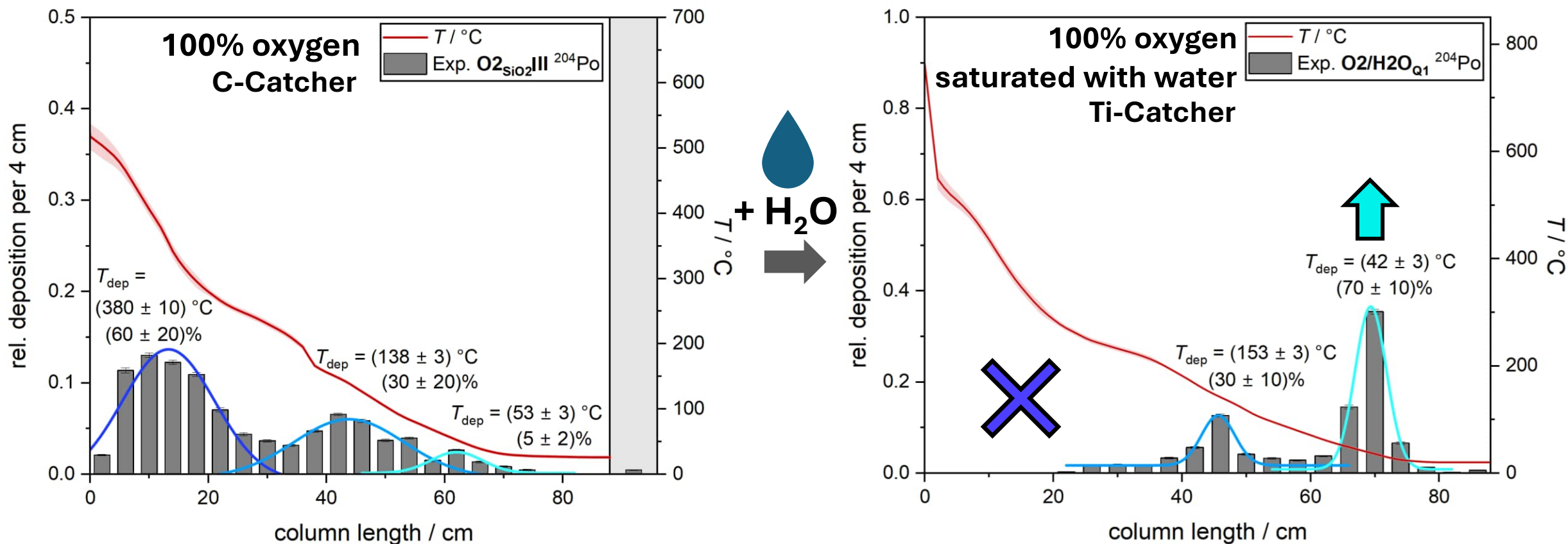
➤ Signs of chemical reaction!

Reaction of polonium with oxygen



➤ Results are reproduced, no change with oxygen content in the gas phase

Reaction of polonium with oxygen and water



➤ Addition of water significantly effects proceeding chemical reaction.

Reaction of polonium with oxygen and water

Two possible explanations:

Volatility: $\text{PoO}_2 < \text{PoO} < \text{Po}$

Decomposition of formed oxide species due to *in situ* modification of the surface.

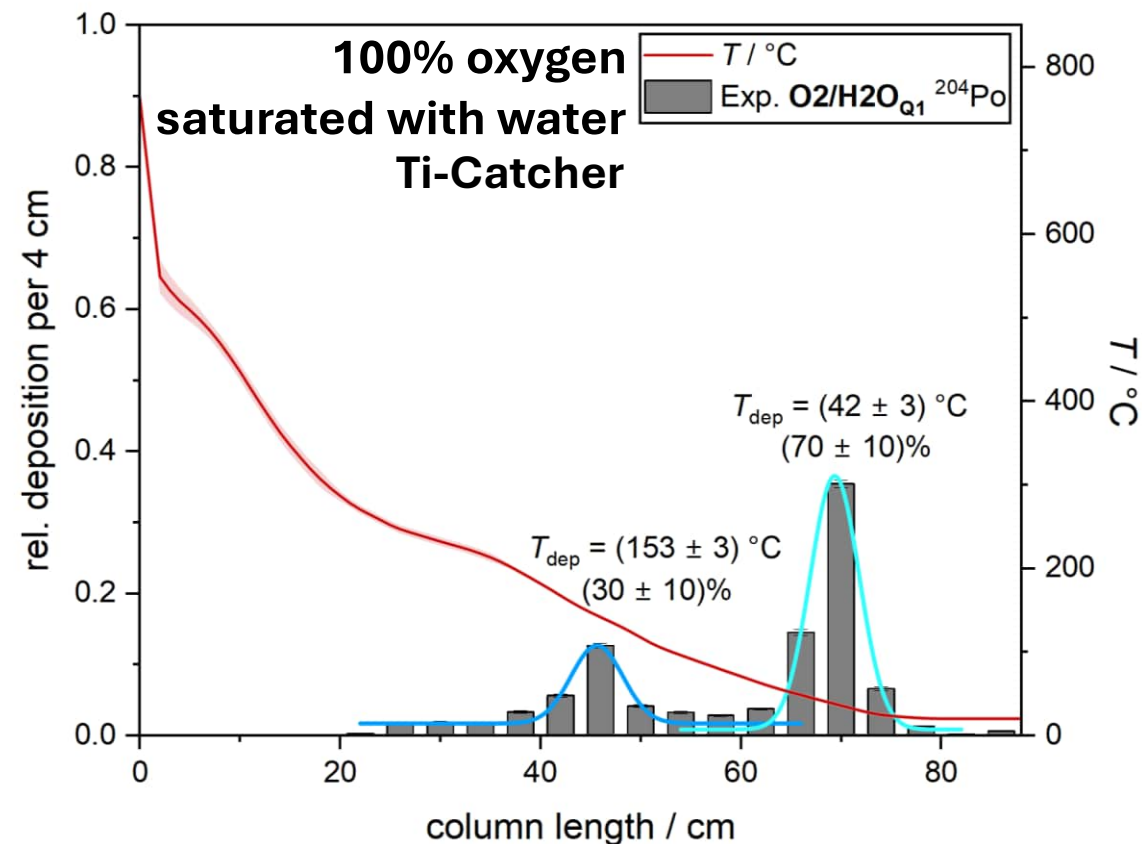
➤ In agreement with theory

Volatility: $\text{PoO}_2 < \text{Oxoacid} (\text{H}_2\text{PoO}_3) < \text{Po}$

Stepwise reaction: First formation of oxide, then reaction to the more volatile oxyhydroxide.

➤ In accordance with Te chemistry

➤ Oxidation of polonium in oxygen depends on the maximum temperature and the water content in the carrier gas.



Summary

- Two oxidized, less volatile species than elemental polonium are formed in oxygen atmosphere.
- The reaction was found to be dependent on the maximum temperature and the water content in the carrier gas.
- Results can be explained by decomposition of oxides or stepwise reaction with oxygen and water.

**Experiments suggest to study
livermorium in the elemental state**



K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2025**, 27, 21414-21423.

Results shown
today:

K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2026**, 28, 7617-7628.

Results presented
at TASCA 25,
published last year:



Acknowledgements

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