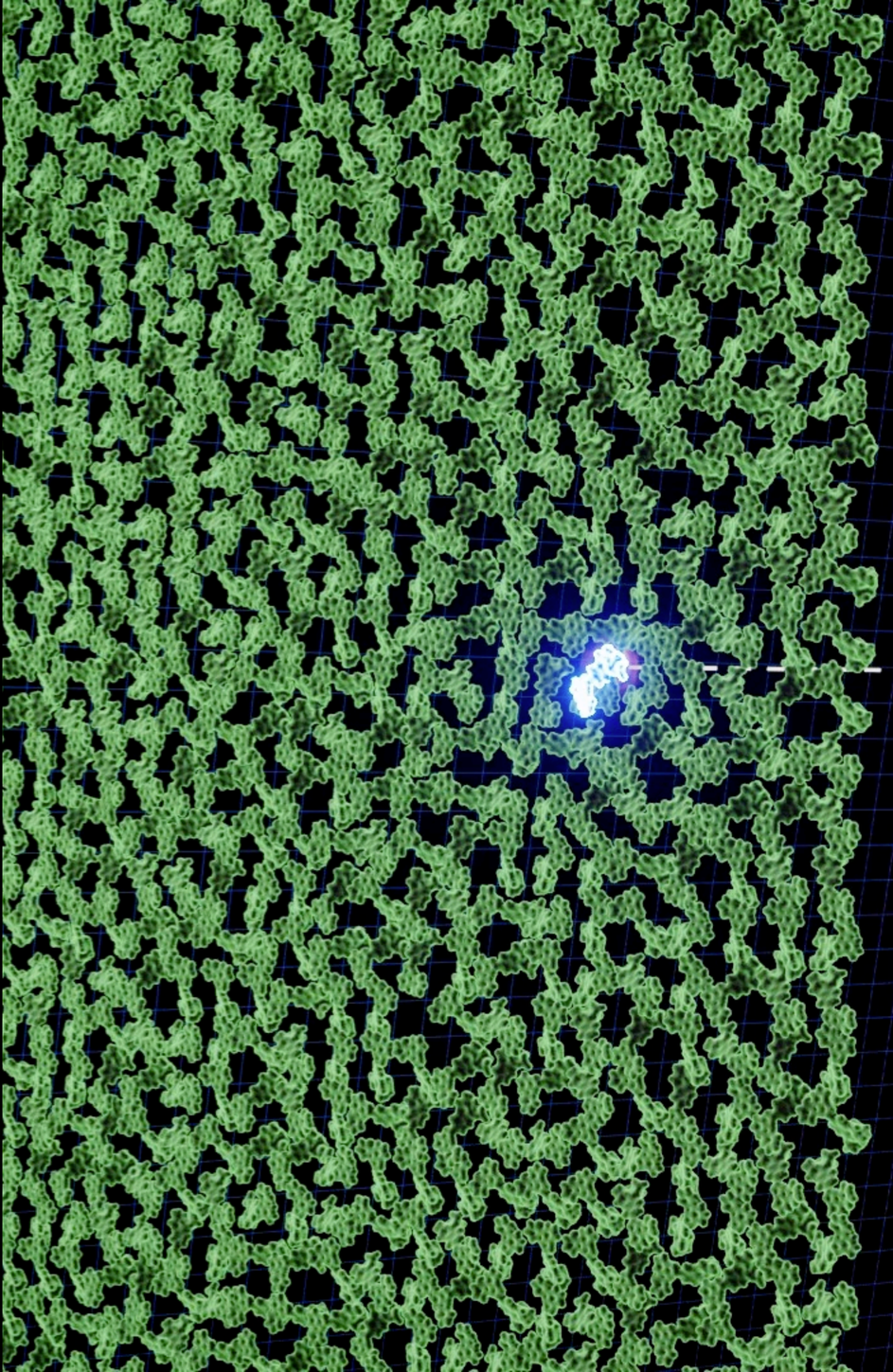
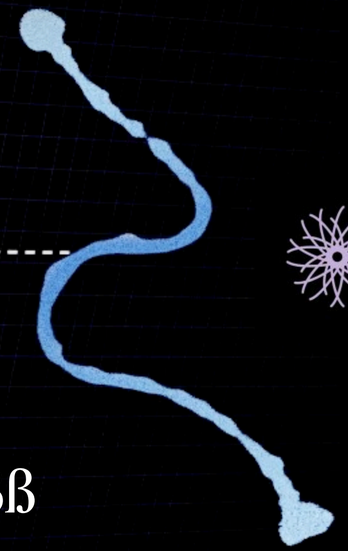
Barium capture and identification with molecular sensors





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ICHEP 2022
BOLOGNA

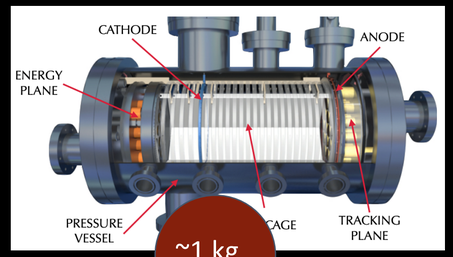
Towards a background-free 0νββ decay experiment

Pablo Herrero-Gómez on behalf of the next collaboration

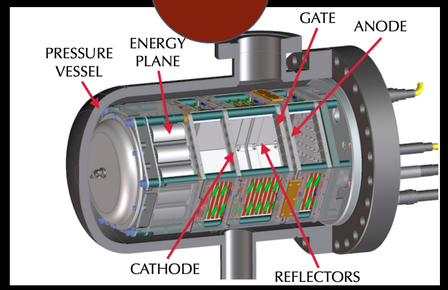
9th June 2022

The NEXT program

Prototypes
2010-2014
Demonstration of detector concept

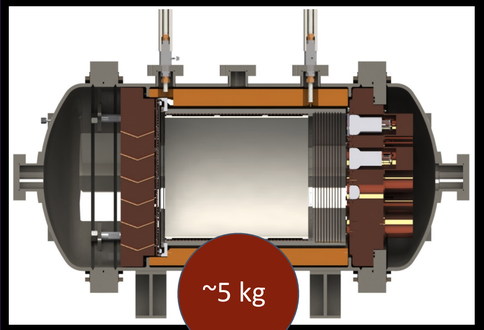


~1 kg



NEXT-White
2015-2021
Background model assessment

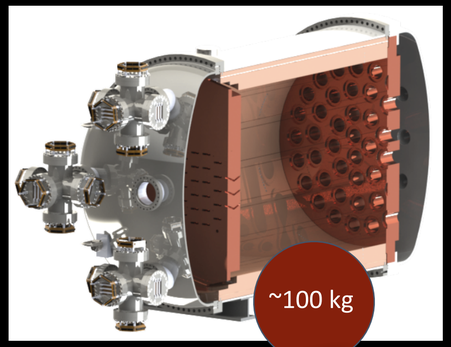
$2\nu\beta\beta$ measurement for ^{136}Xe



~5 kg

Talk by A. Redwine

NEXT-100
2022-2026
Neutrinoless double beta decay search in ^{136}Xe



~100 kg

Talk by H. Almazán

NEXT-HD
2027?
Neutrinoless double beta decay search through inverted neutrino mass ordering

NEXT-BOLD
Barium tagging for background-free experiment

1 Tonne

This talk

2009 2014 2015 2021 2022 2026 2027

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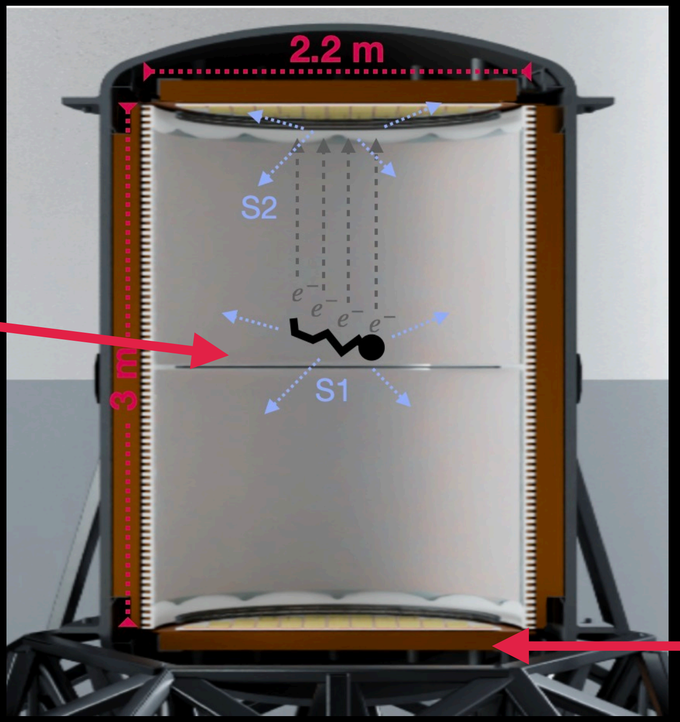
NEXT at the Ton Scale

- **Baseline concept:**
  - Symmetric TPC with central cathode



Cathode

Pressure vessel

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NEXT at the Ton Scale

- **Baseline concept:**
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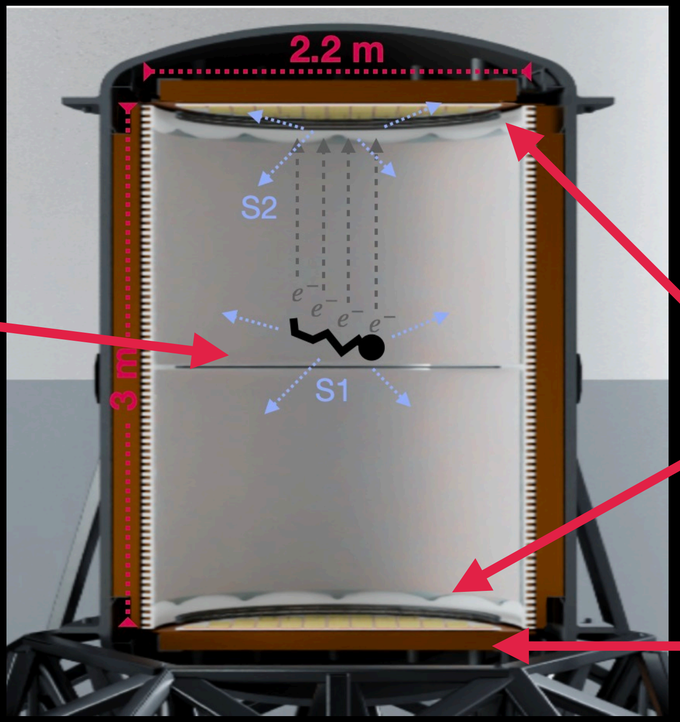
  - Dense SiPM plane readout



NEXT at the Ton Scale

- **Baseline concept:**
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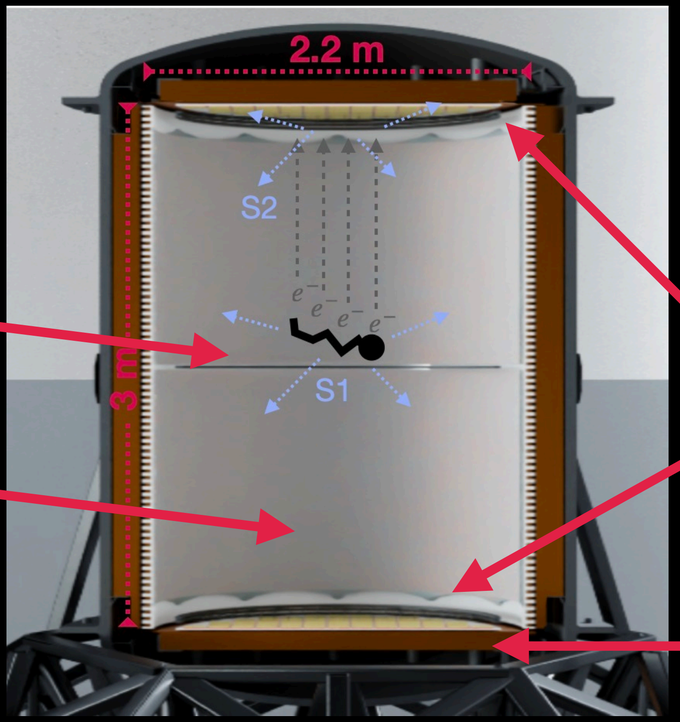
  - Optical fibers around barrel for energy measurement



NEXT at the Ton Scale

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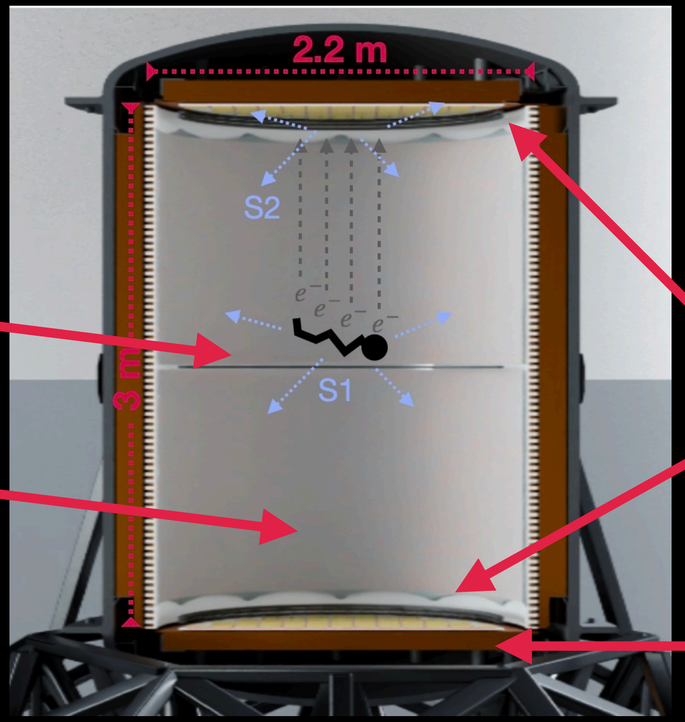
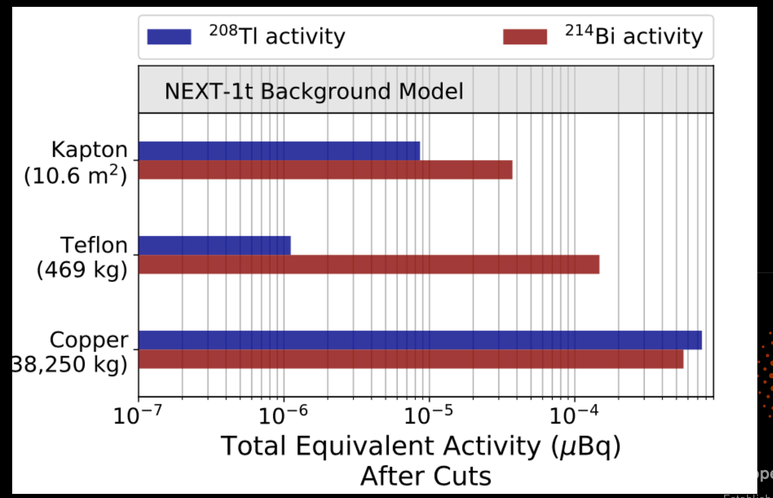
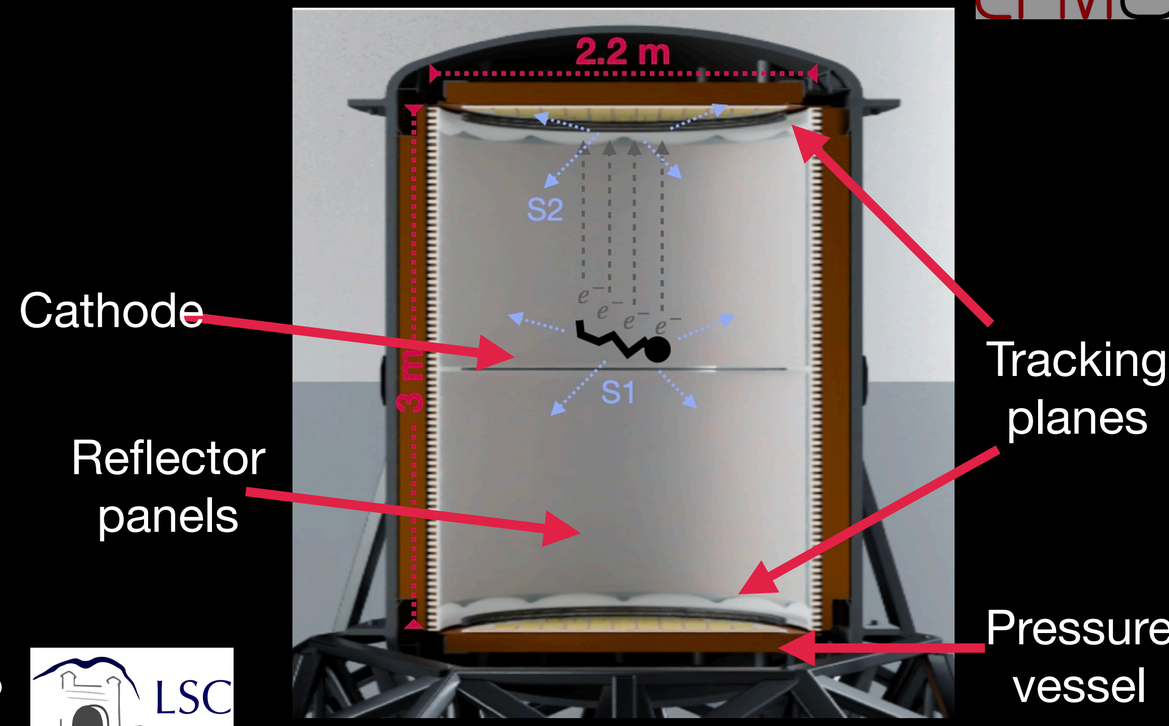
  - Estimated background 0.09 to 0.27 ct [ton yr ROI]$^{-1}$



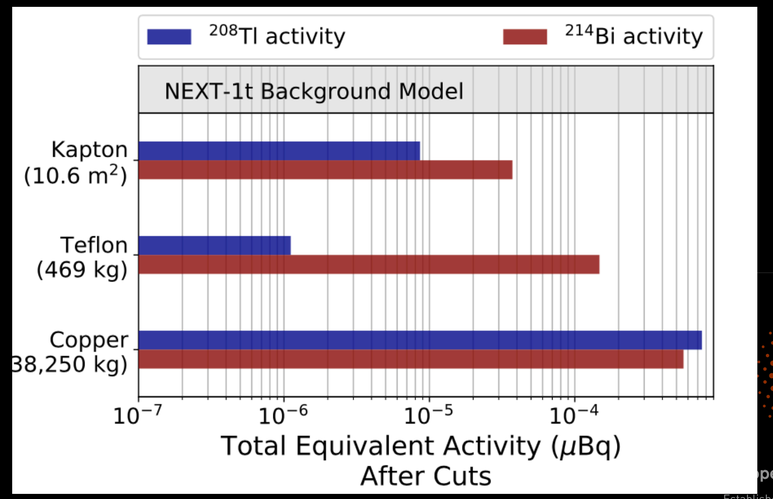


NEXT at the Ton Scale

- **Baseline concept:**
  - Symmetric TPC with central cathode
  - Dense SiPM plane readout
  - Optical fibers around barrel for energy measurement
  - Estimated background 0.09 to 0.27 ct [ton yr ROI]$^{-1}$
- Ongoing advanced readout R&D:
  - High speed cameras for optical tracking
  - Metalenses for enhanced VUV light collection
  - Low radioactivity MCP-PMTs for energy plane



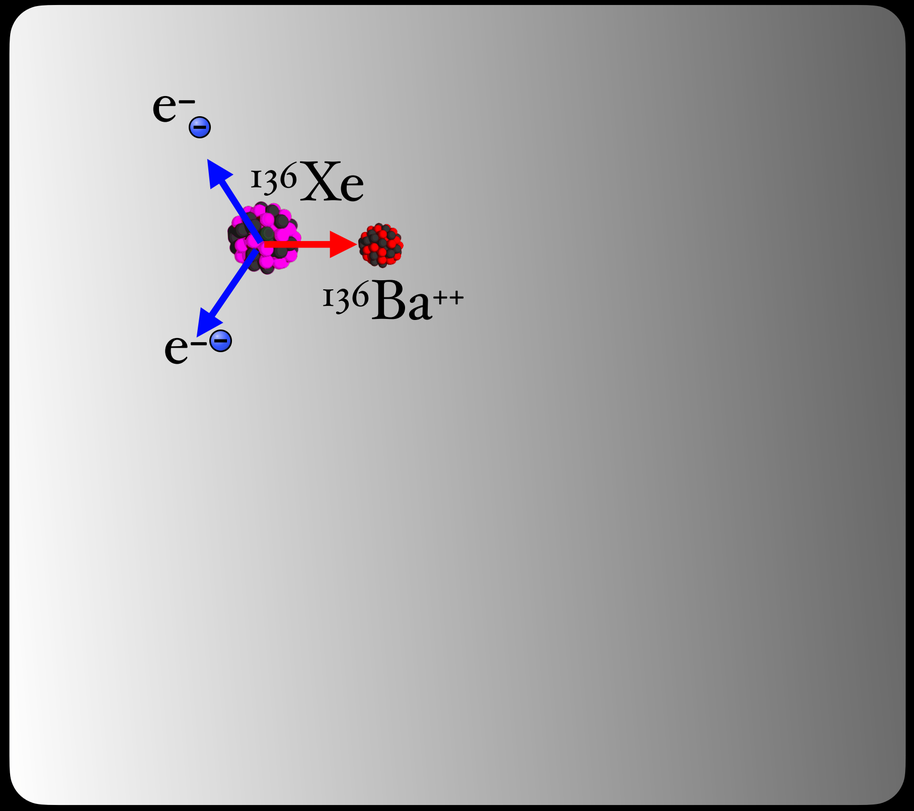
- Multi-module system with first module at Laboratorio Subterráneo de Canfranc
- Siting of subsequent modules TBD (likely a deeper site).
- Expected sensitivity >10^{27} yr to cover inverted ordering
- Use of gas additives (eg, ^{4}He) to reduce diffusion
- Potential for ^{3}He doping to reduce cosmogenic ^{137}Xe backgrounds



NEXT with Barium Tagging

Single molecule fluorescent imaging employed to detect Ba^{2+} produced in double beta decay.

J.Phys.Conf.Ser. 650 (2015) 1, 012002; JINST 11 (2016) 12, P12011;
Phys. Rev. Lett. 120 (2018) 13, 132504.



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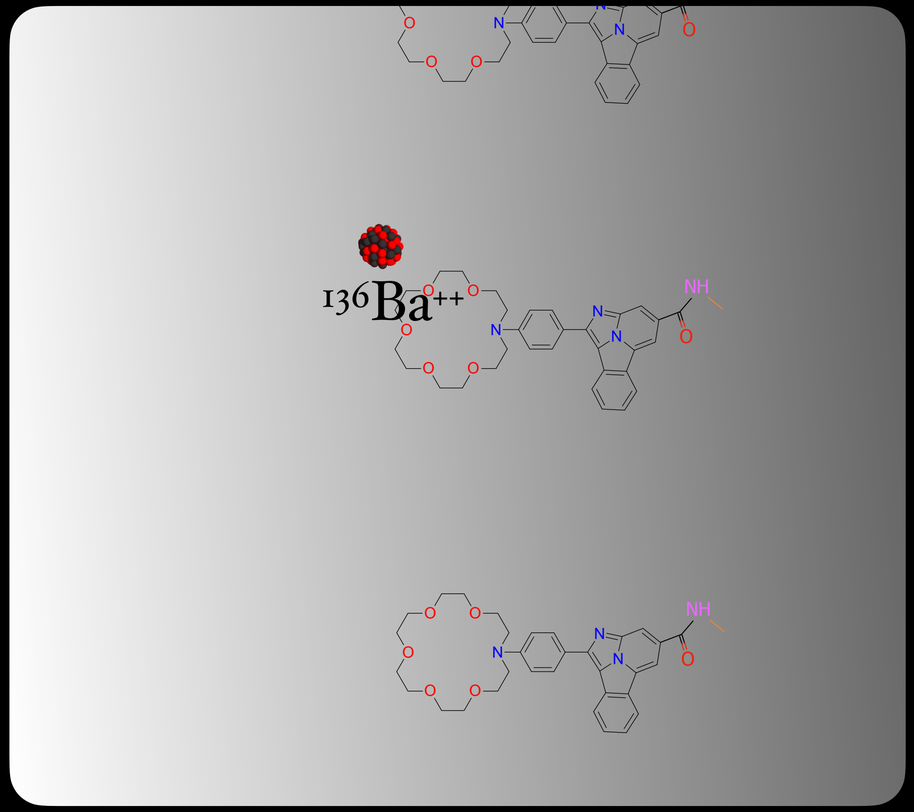

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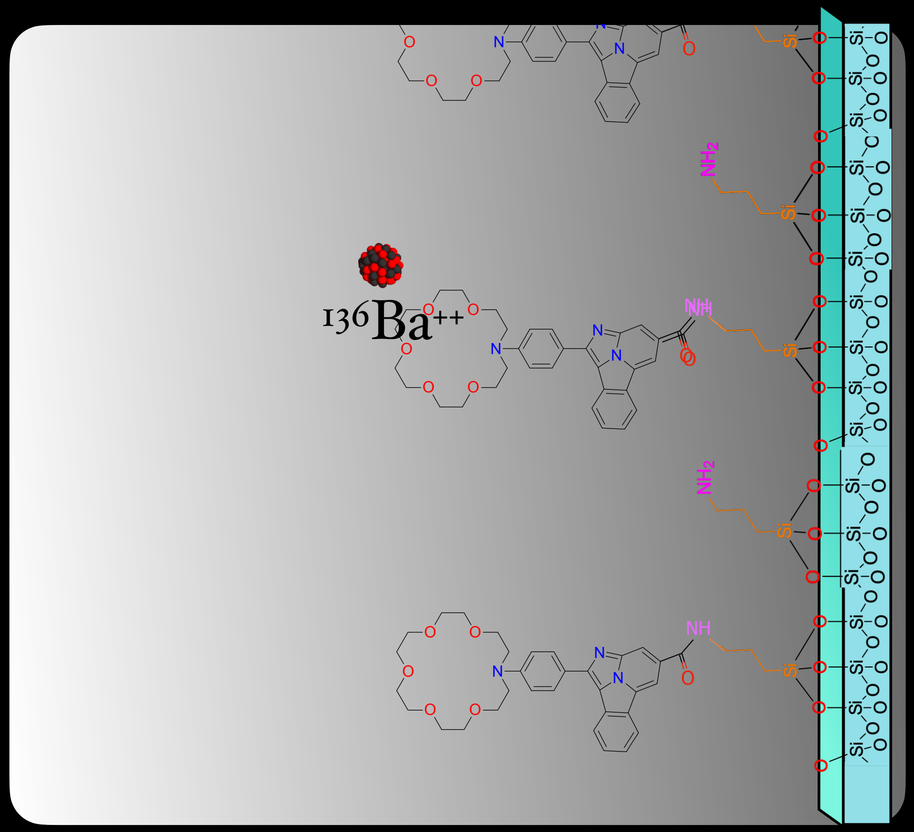

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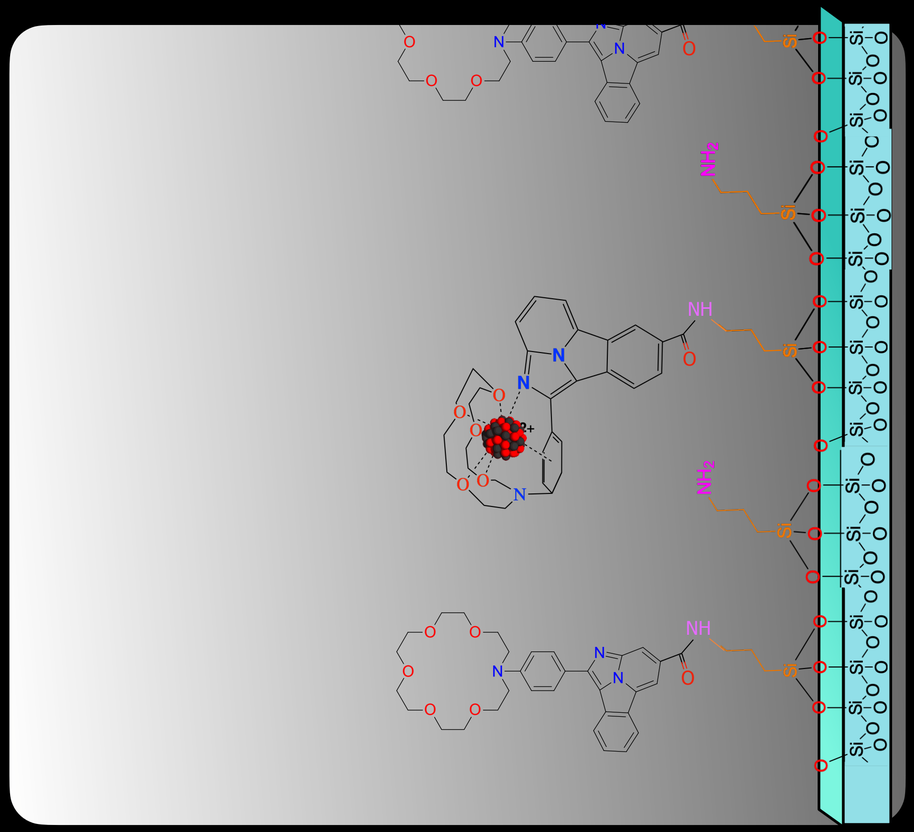
  - ❖ RF Carpets arXiv:2109.05902



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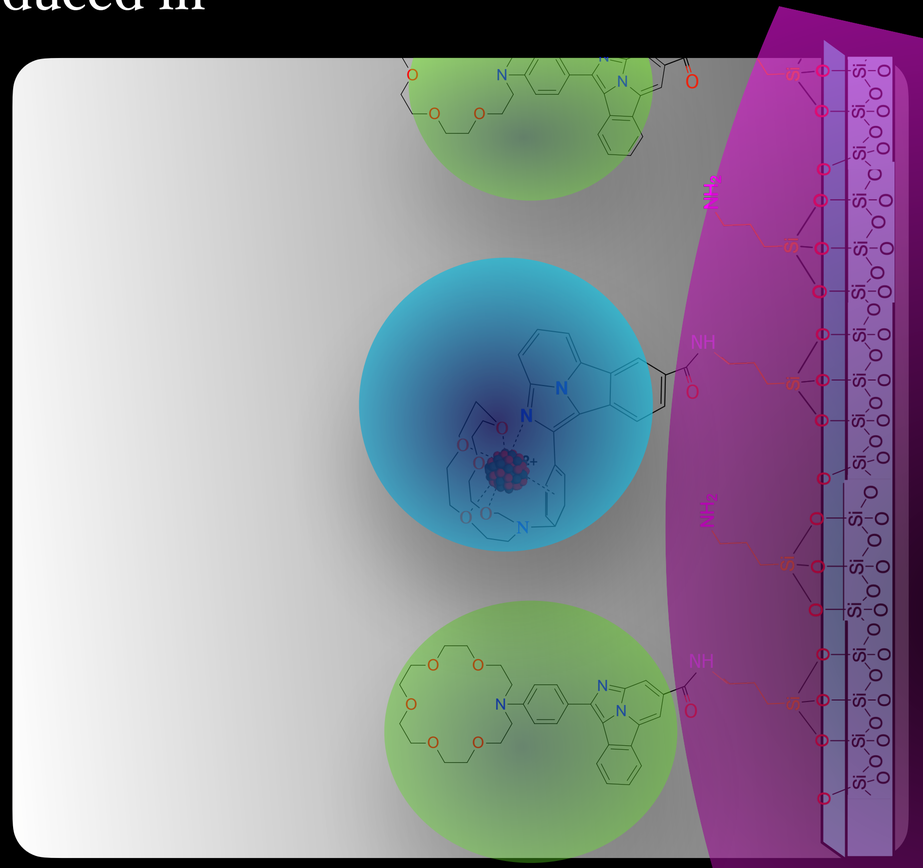
➡Prototyping: surface-science techniques



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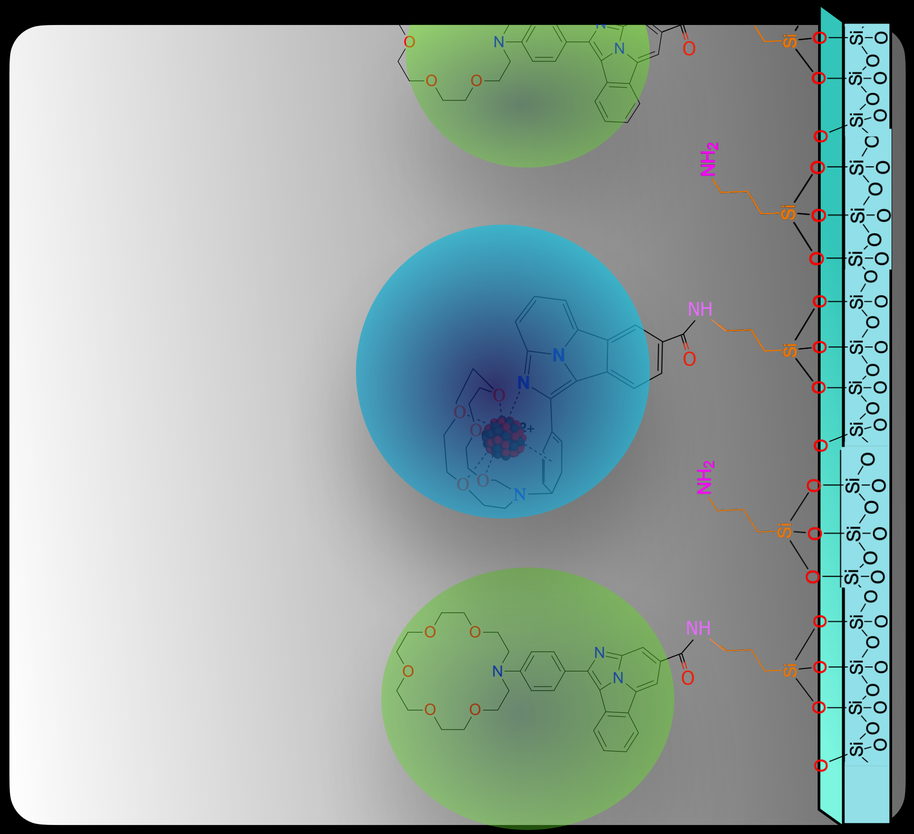

Realization of efficient, scalable barium tagging inHPXeGas could enable truly a background-free tonne-scale technology.

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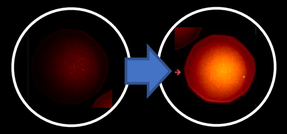
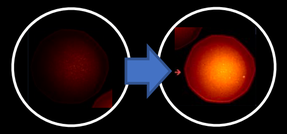
Chemosensors: 2 alternative approaches



Turn-on approach

Chemosensors: 2 alternative approaches



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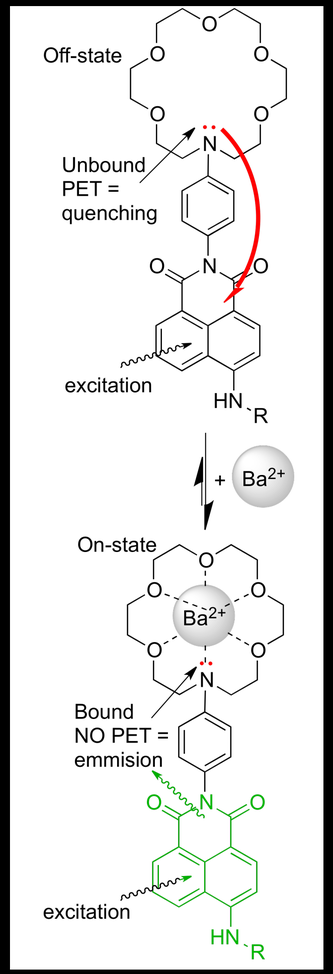

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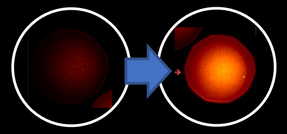

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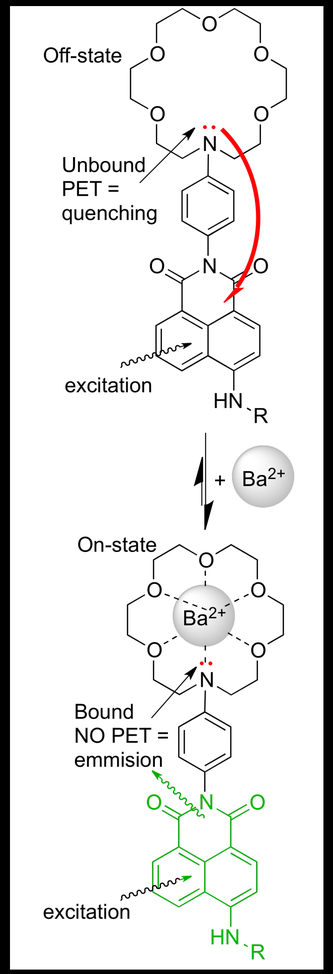

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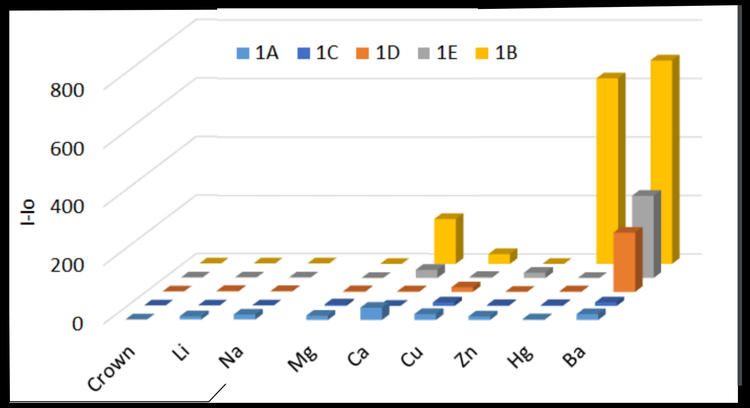

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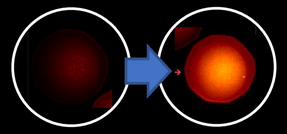

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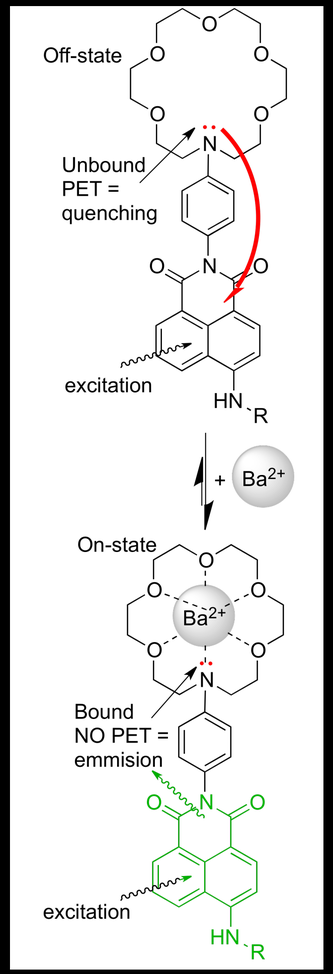

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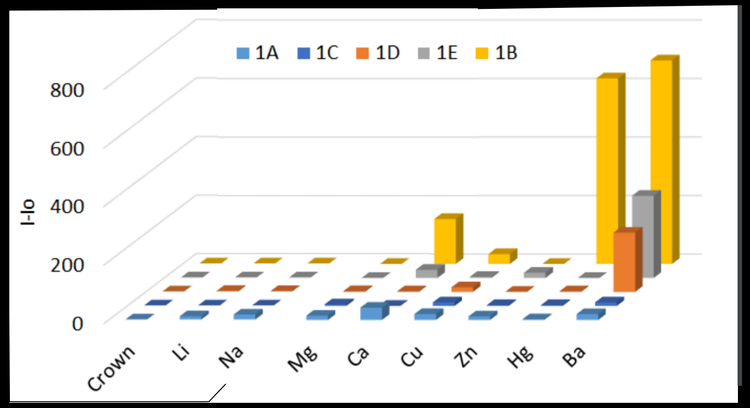
  Sci.Rep. 9 (2019) 1, 15097;



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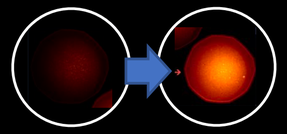

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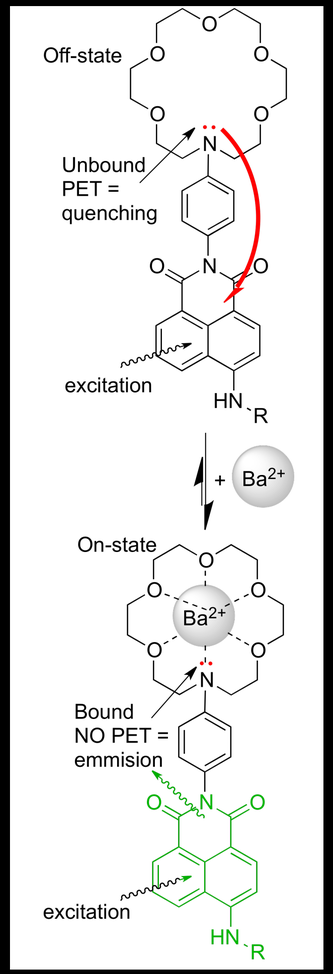

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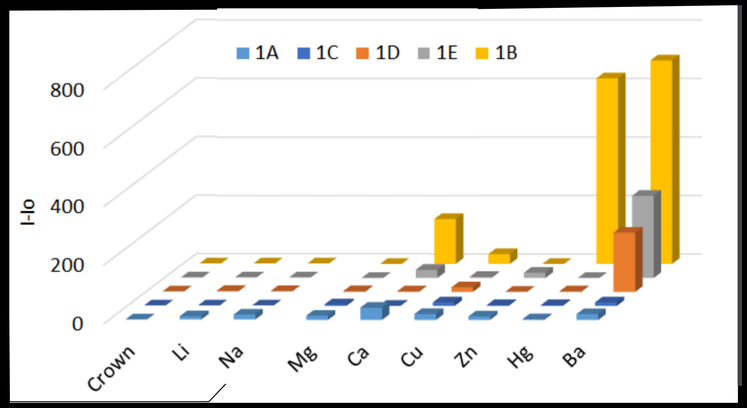
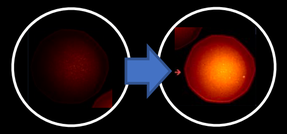


Bicolor approach

Chemosensors: 2 alternative approaches



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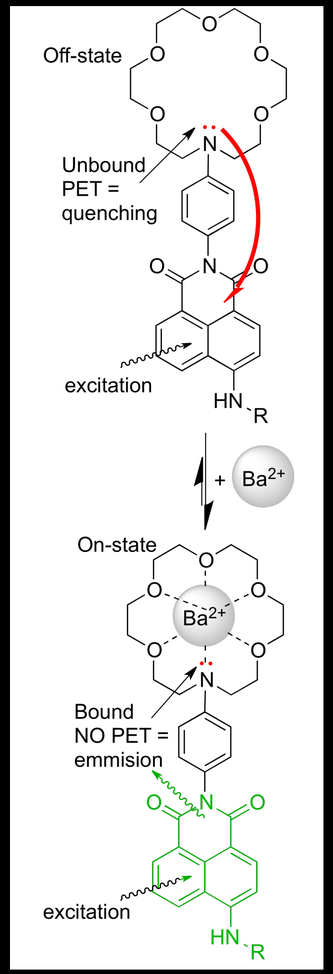

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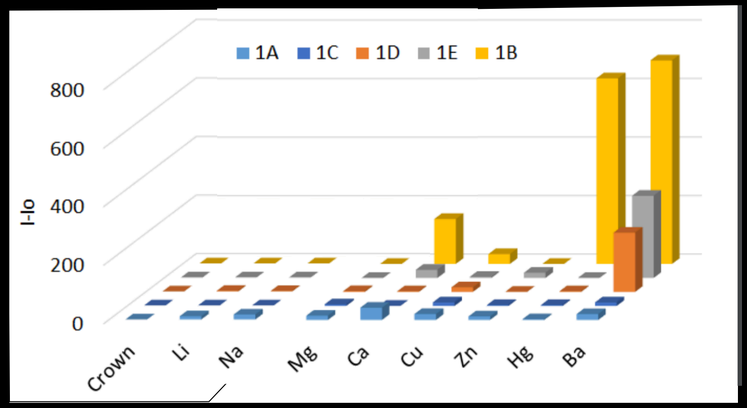
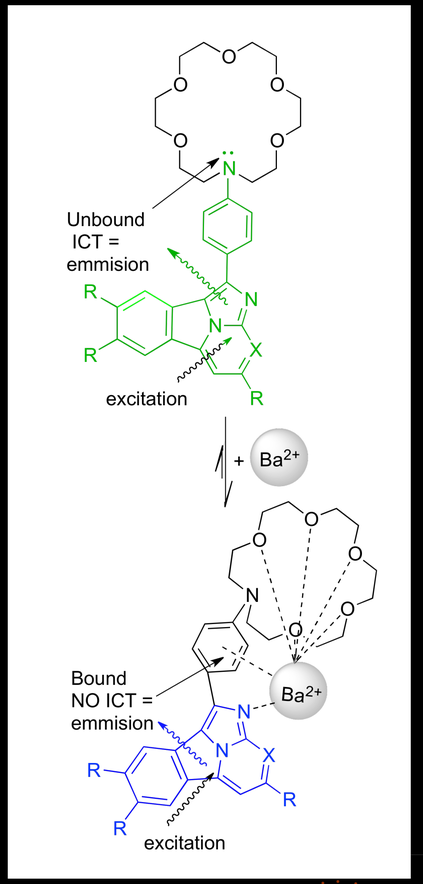


Bicolor approach

- Binding with Ba2+ ion produces a torsion in this molecule and thereby modifies the emission color.



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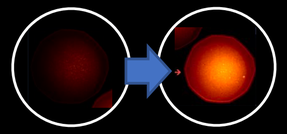
Chemosensors: 2 alternative approaches



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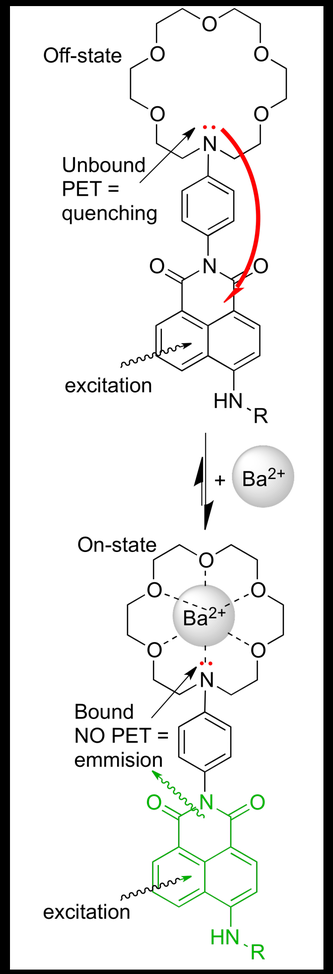

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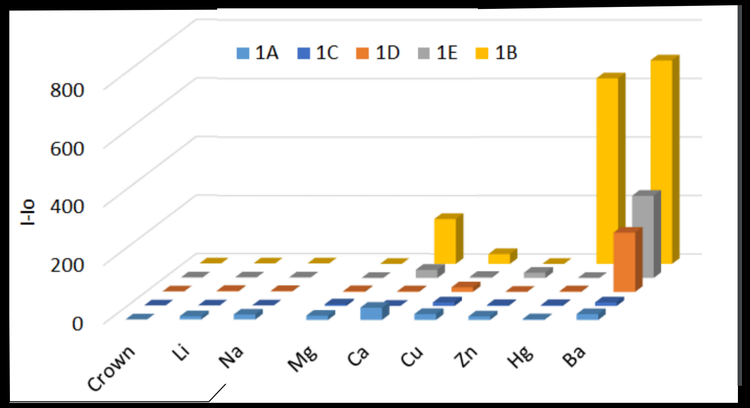

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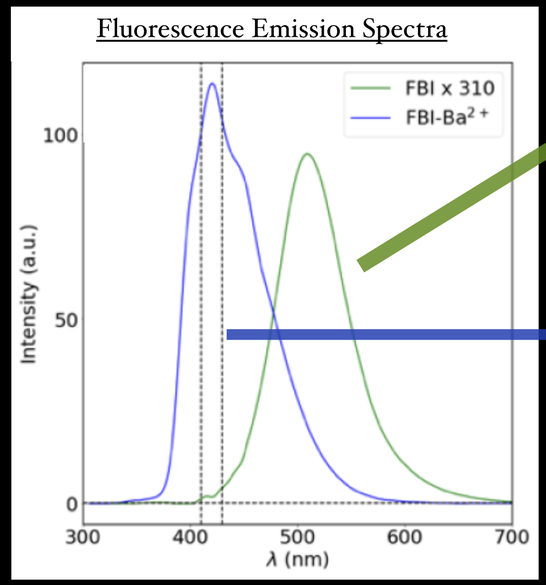
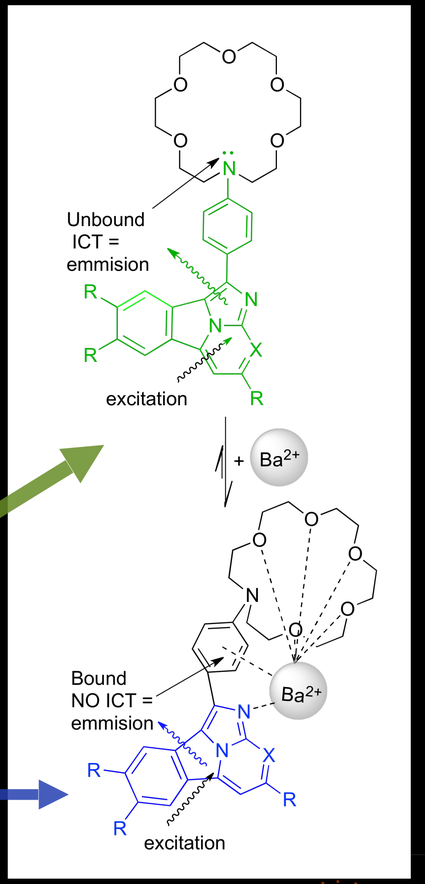
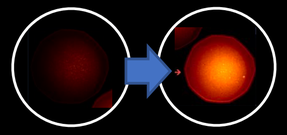
- The phenyl ring and a N-atom also interact with the ion.





Chemosensors: 2 alternative approaches



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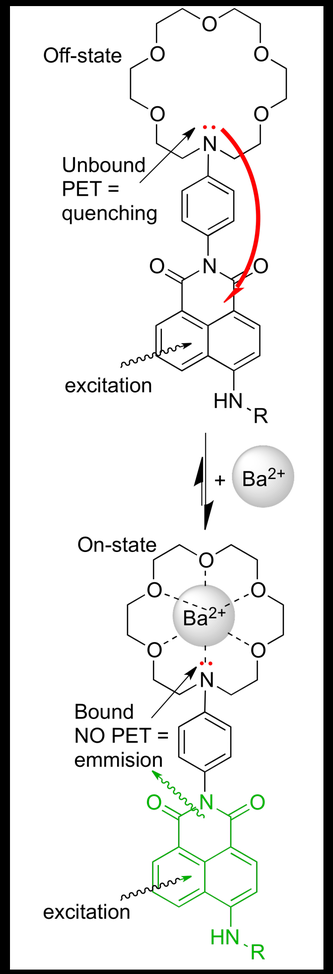

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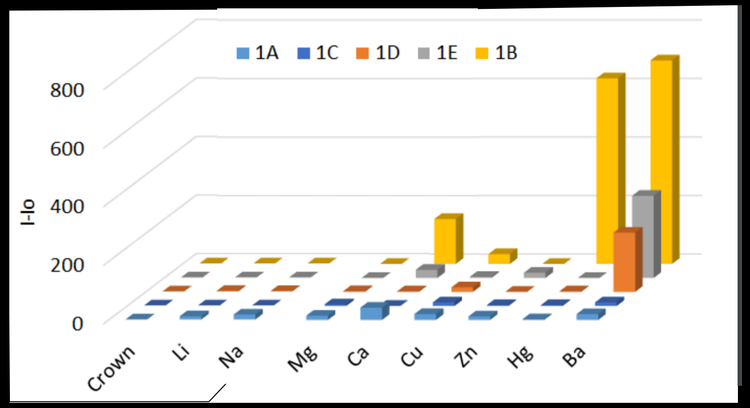

Bicolor approach

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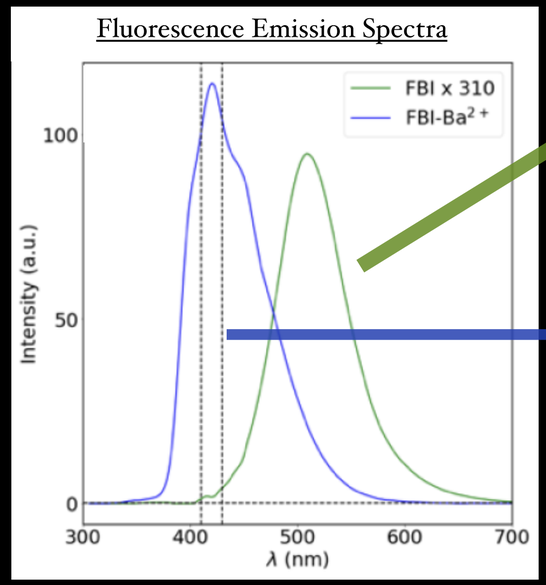
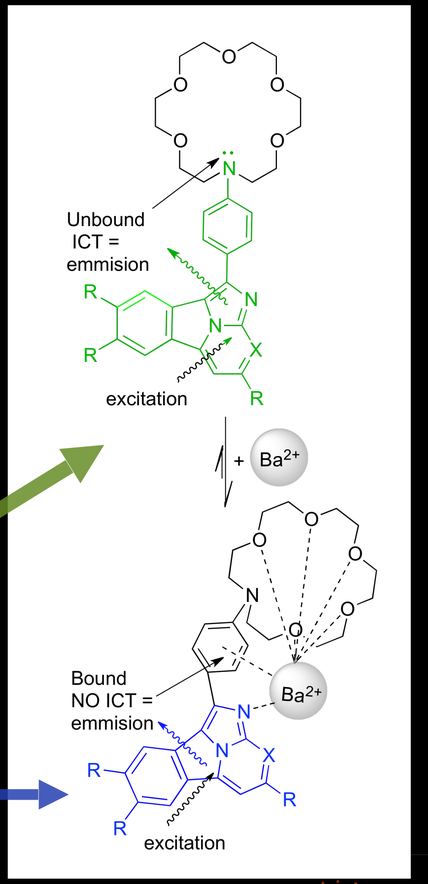
- The phenyl ring and a N-atom also interact with the ion.
- This shift is maintained in a dry environment (silica pellets)
  Nature 583 (2020) 7814, 48–54.
- Aim for larger color shift in future molecule generations





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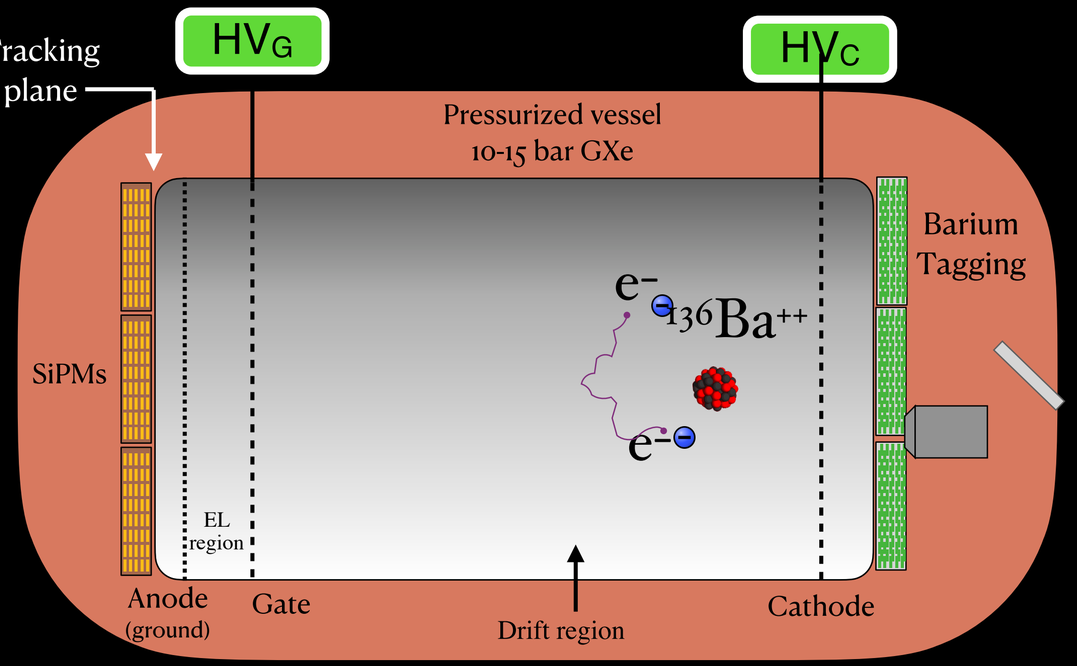
Barium Tagging: SABAT concept



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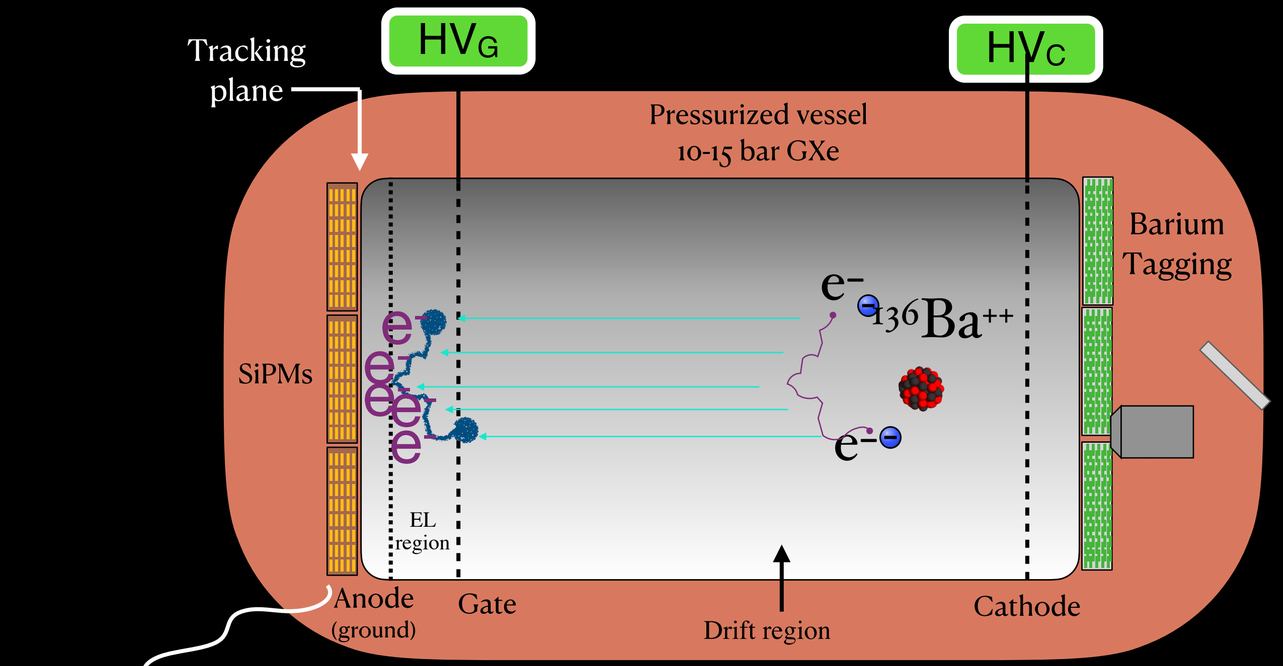

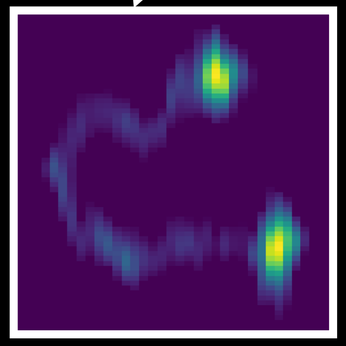

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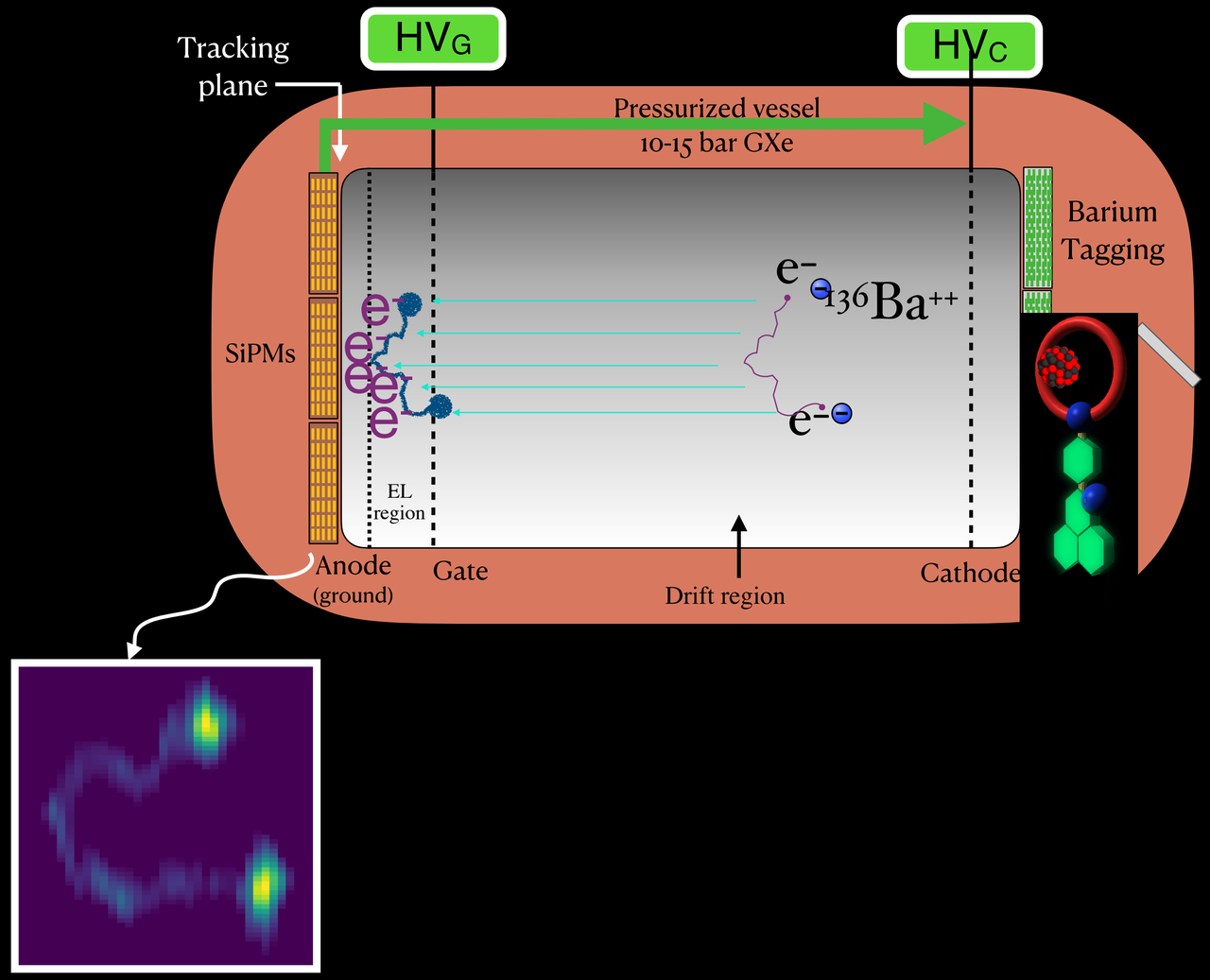

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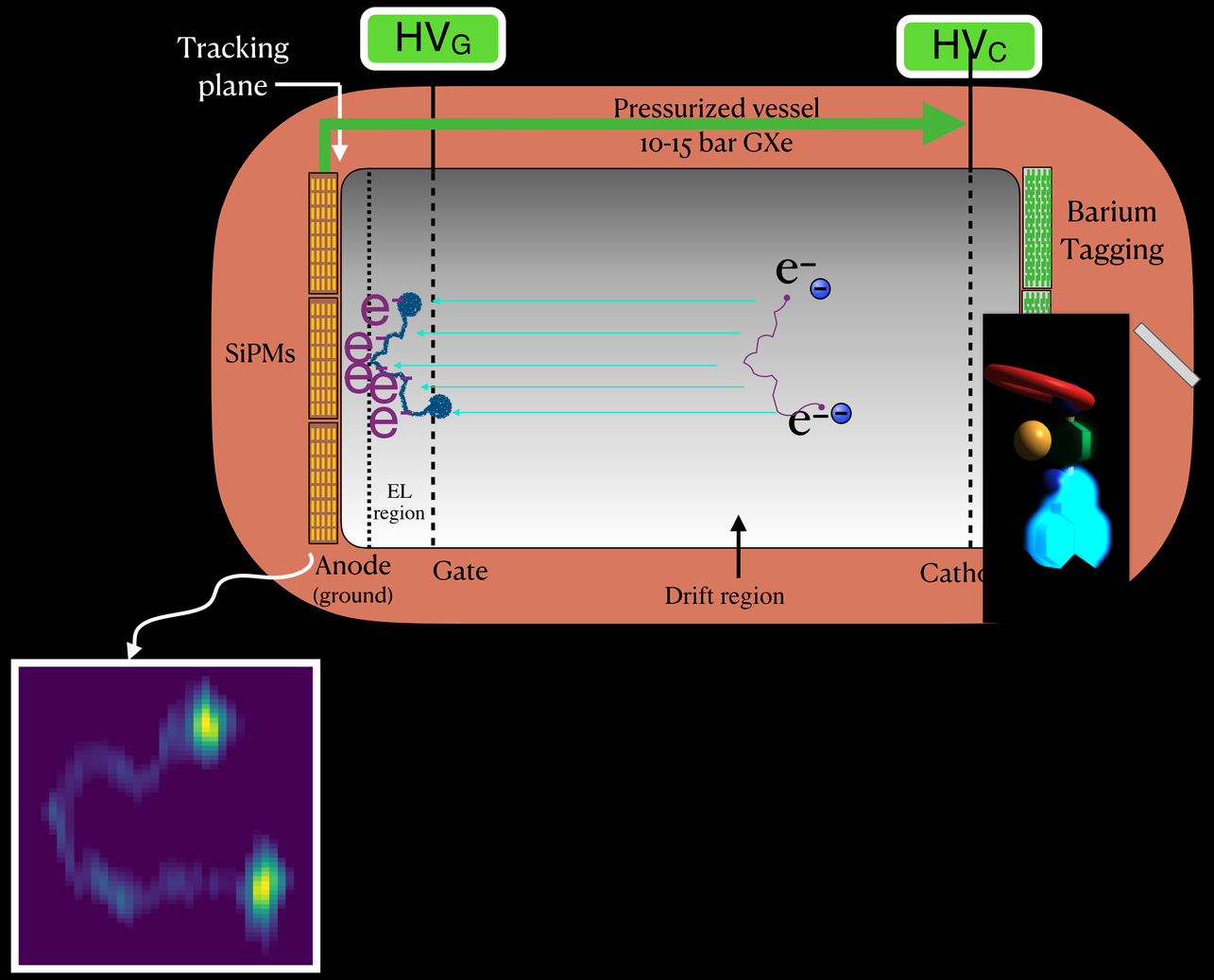

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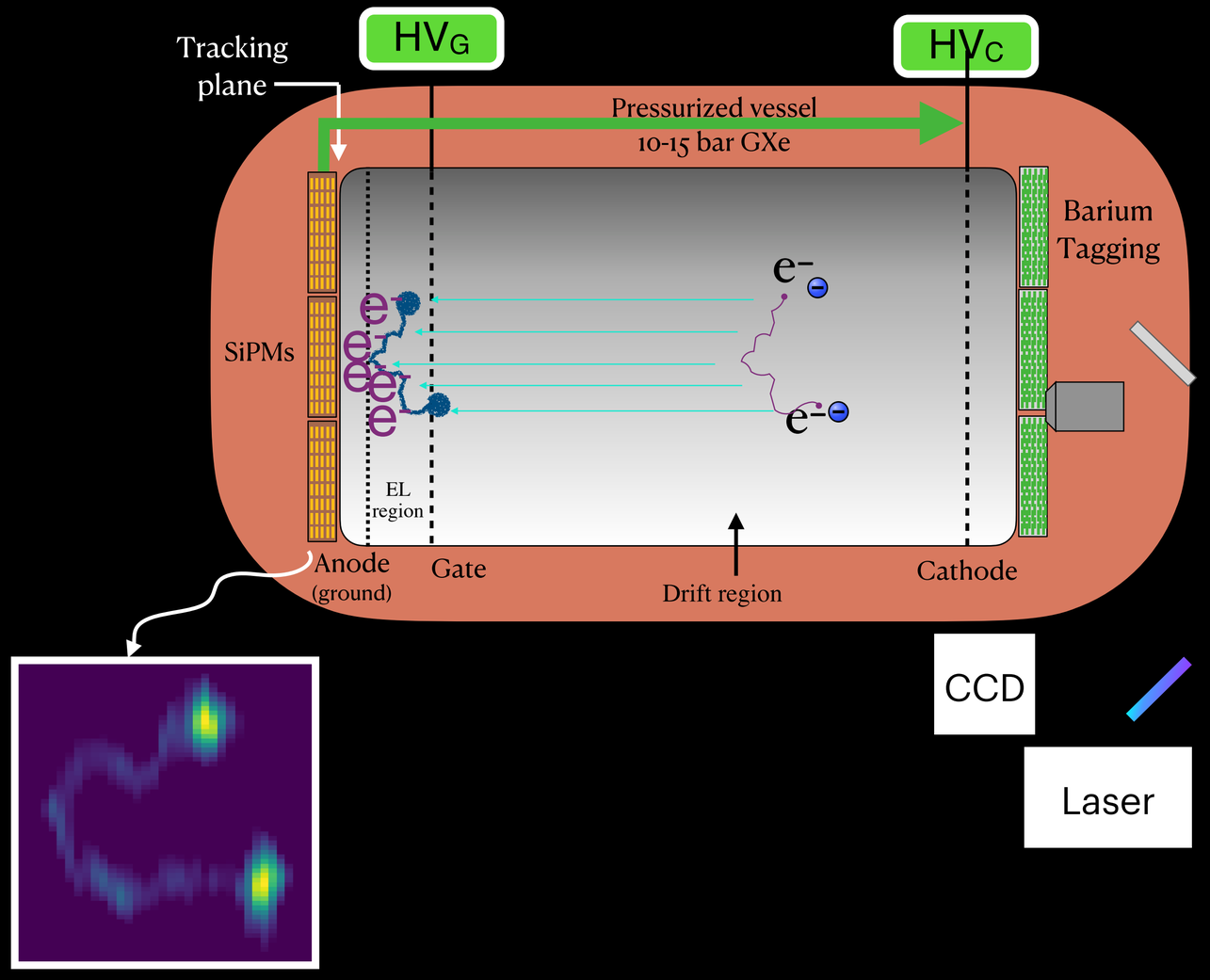

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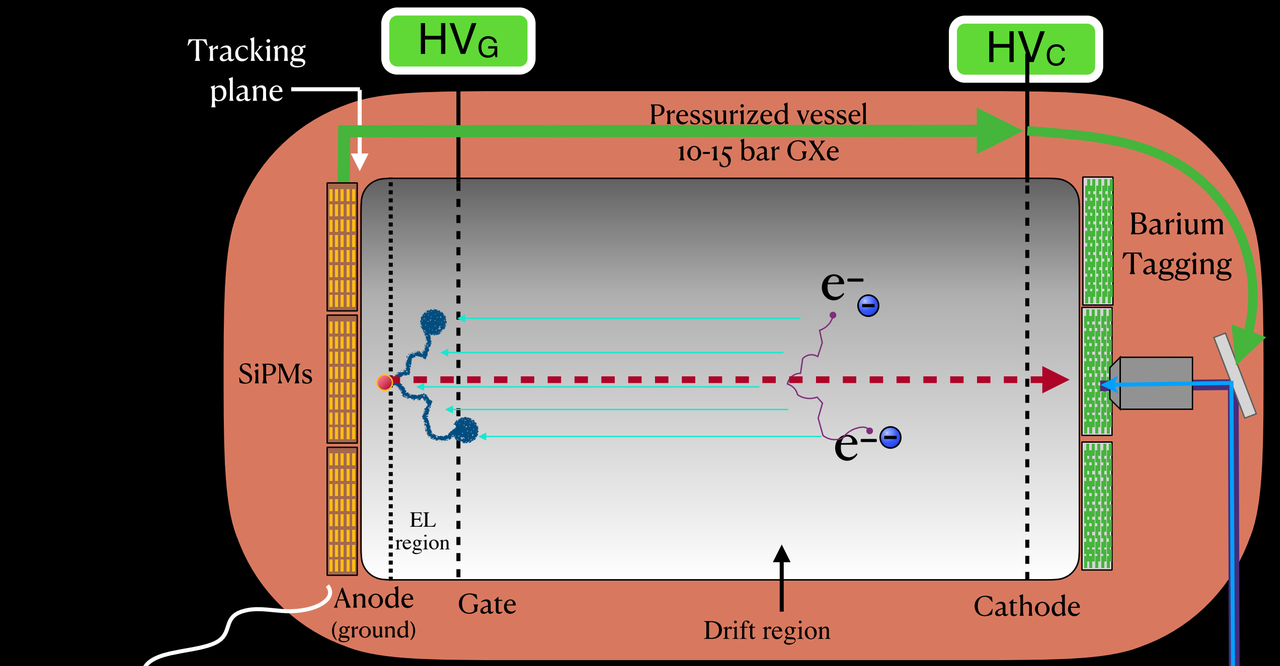

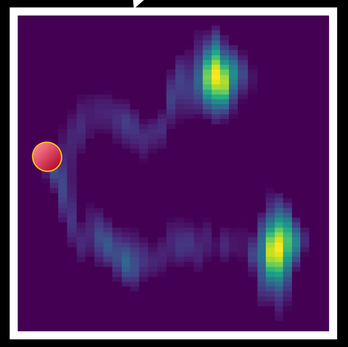

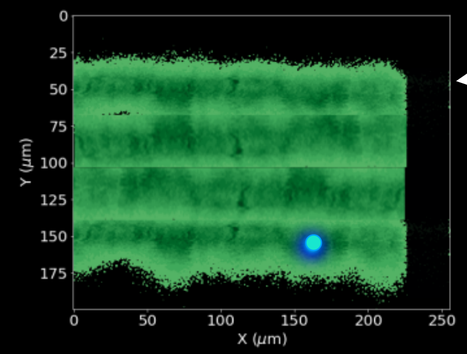

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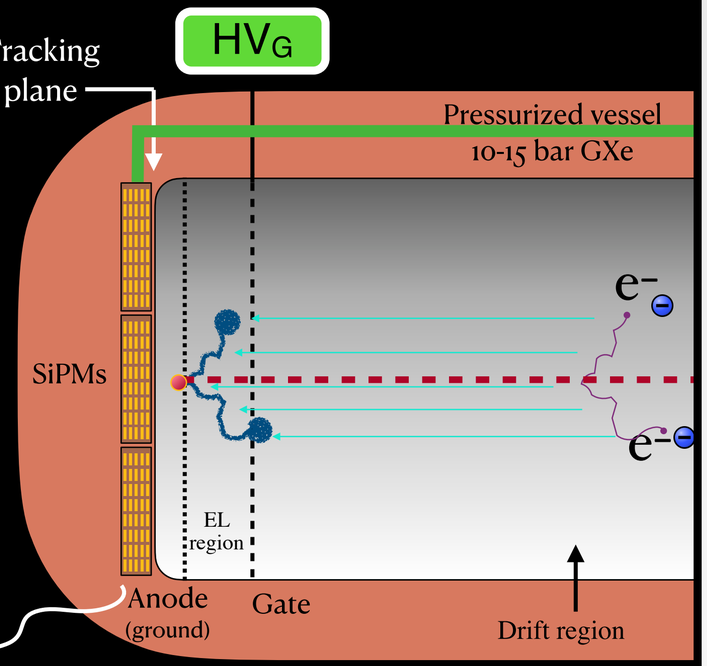

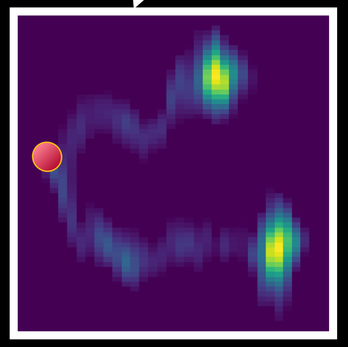

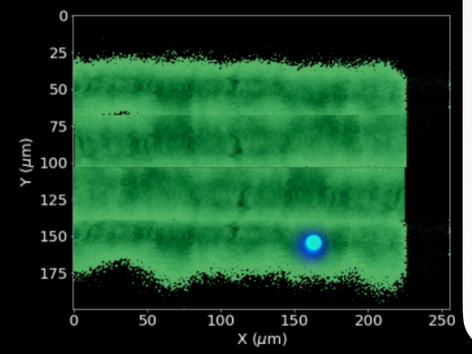

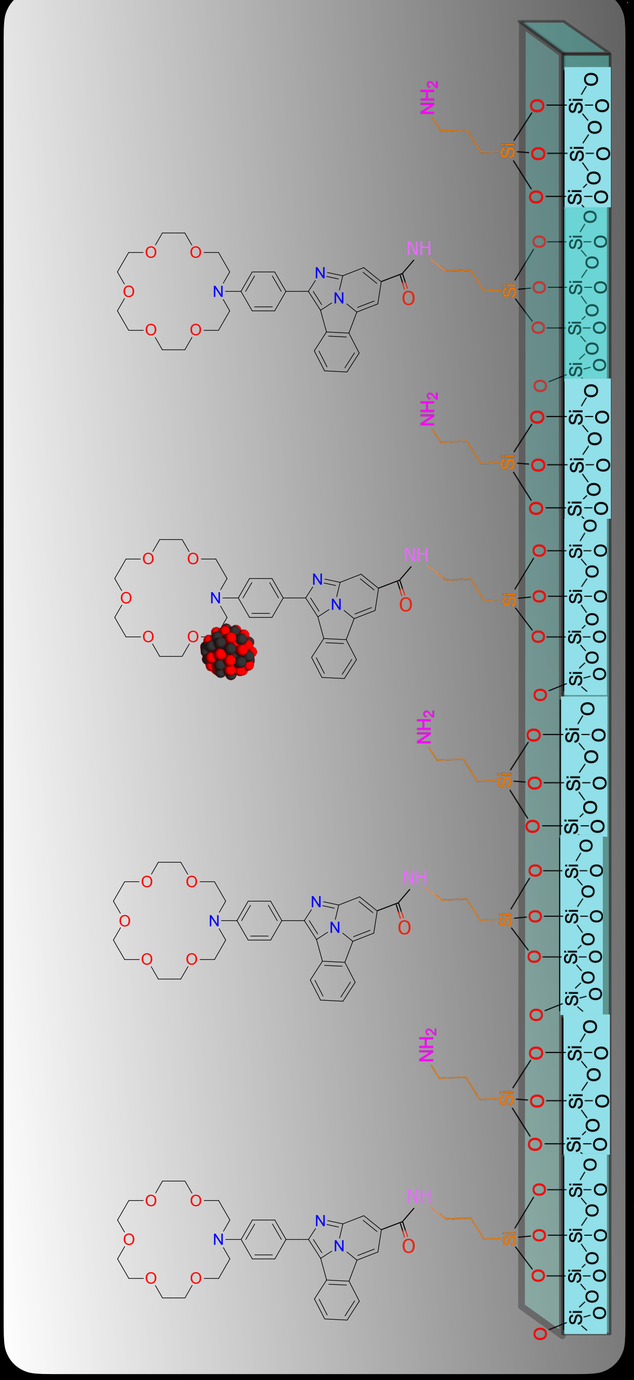

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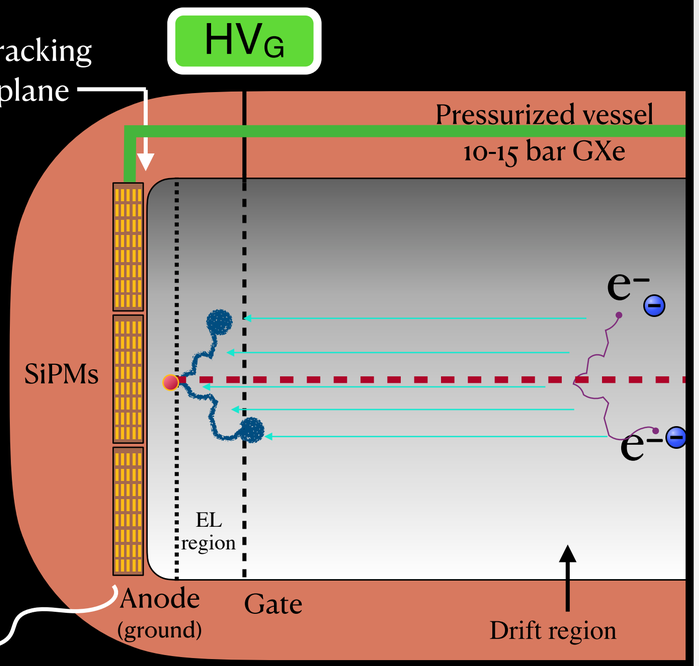

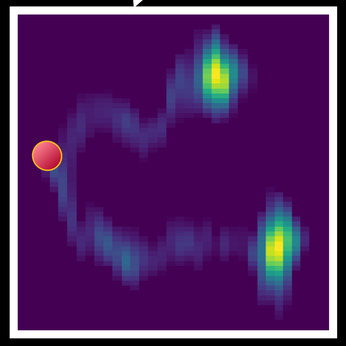

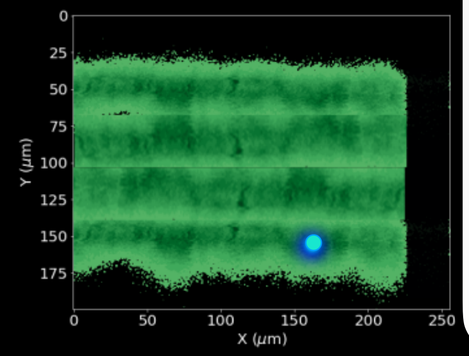

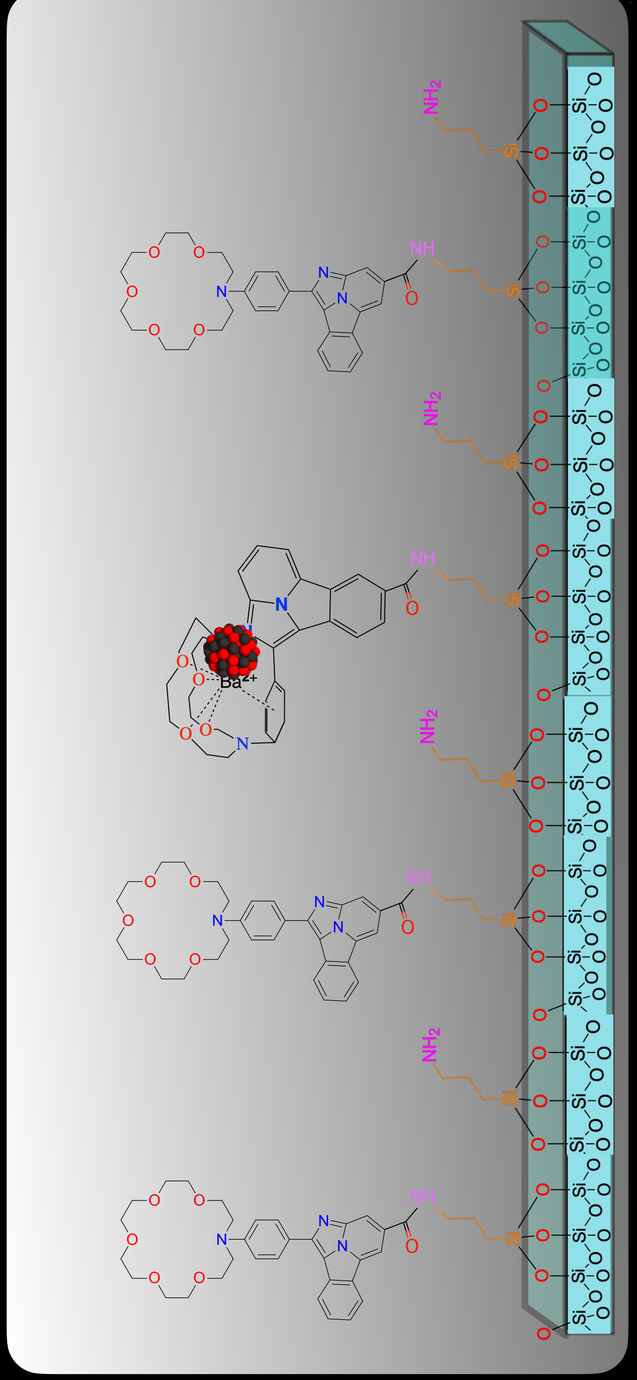

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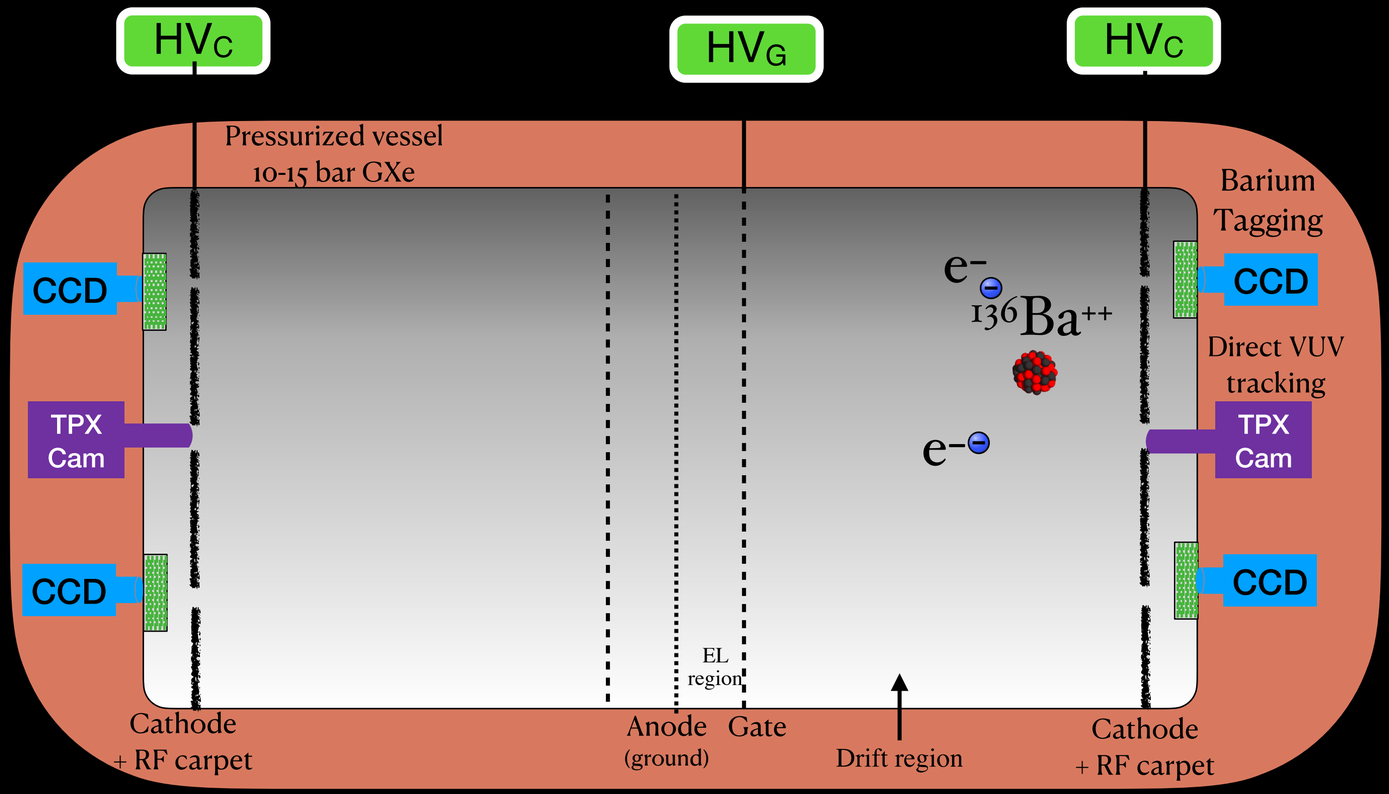
Barium Tagging: CRAB concept



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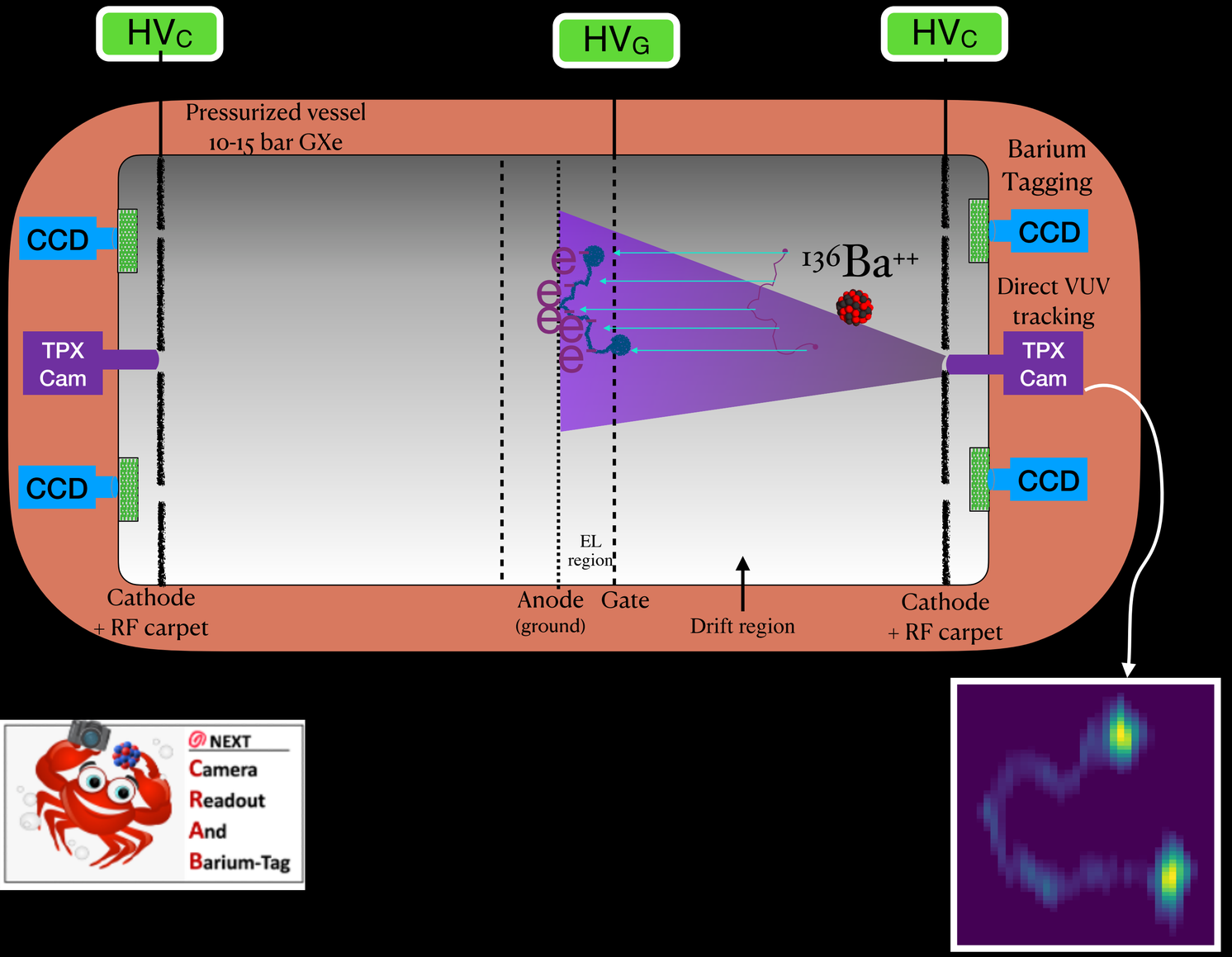

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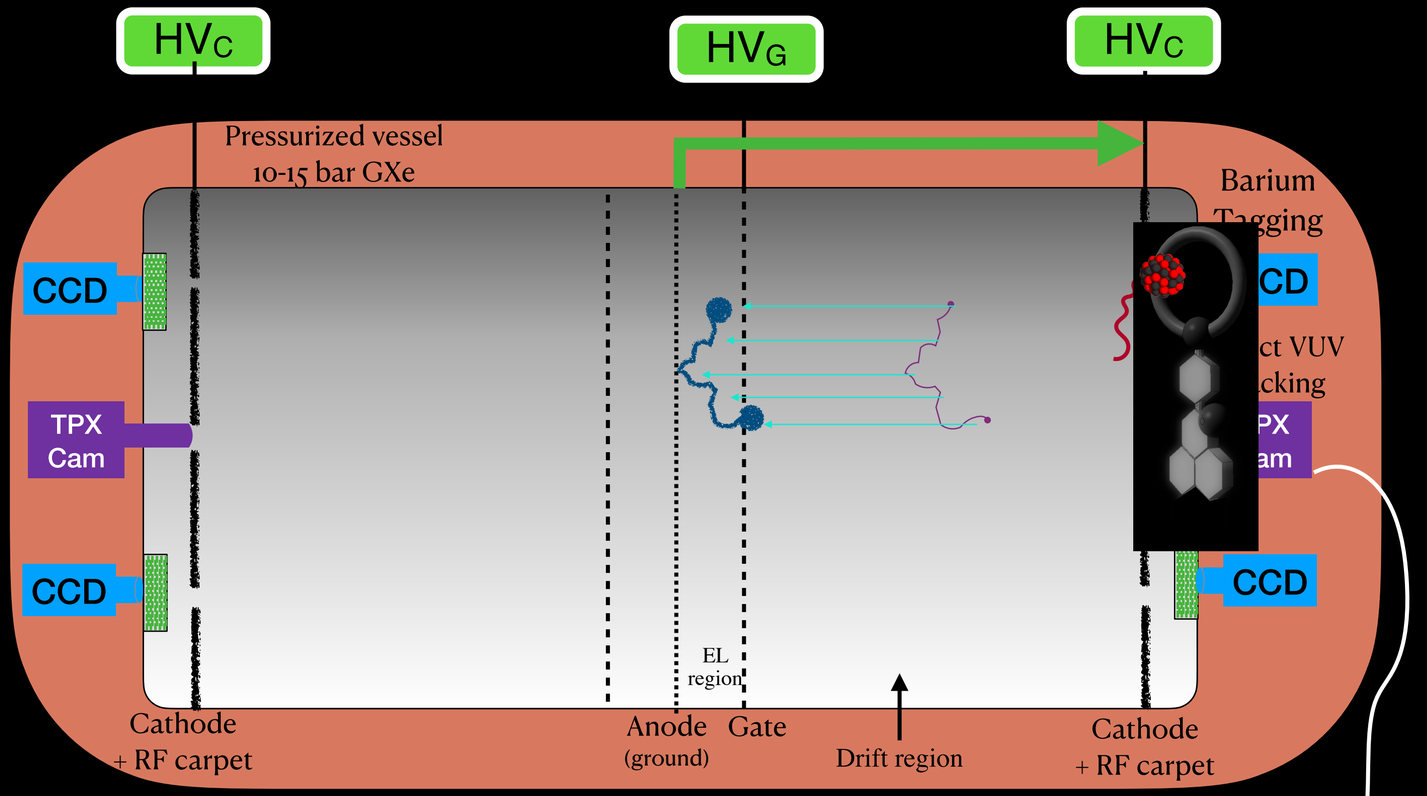
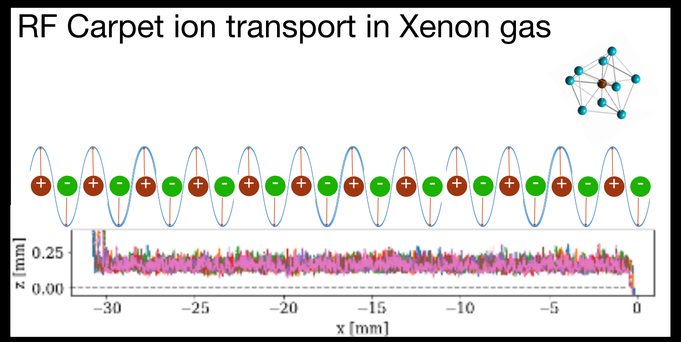
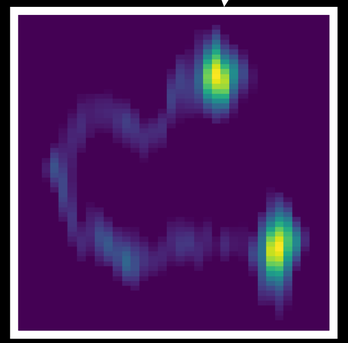




SIMION simulation



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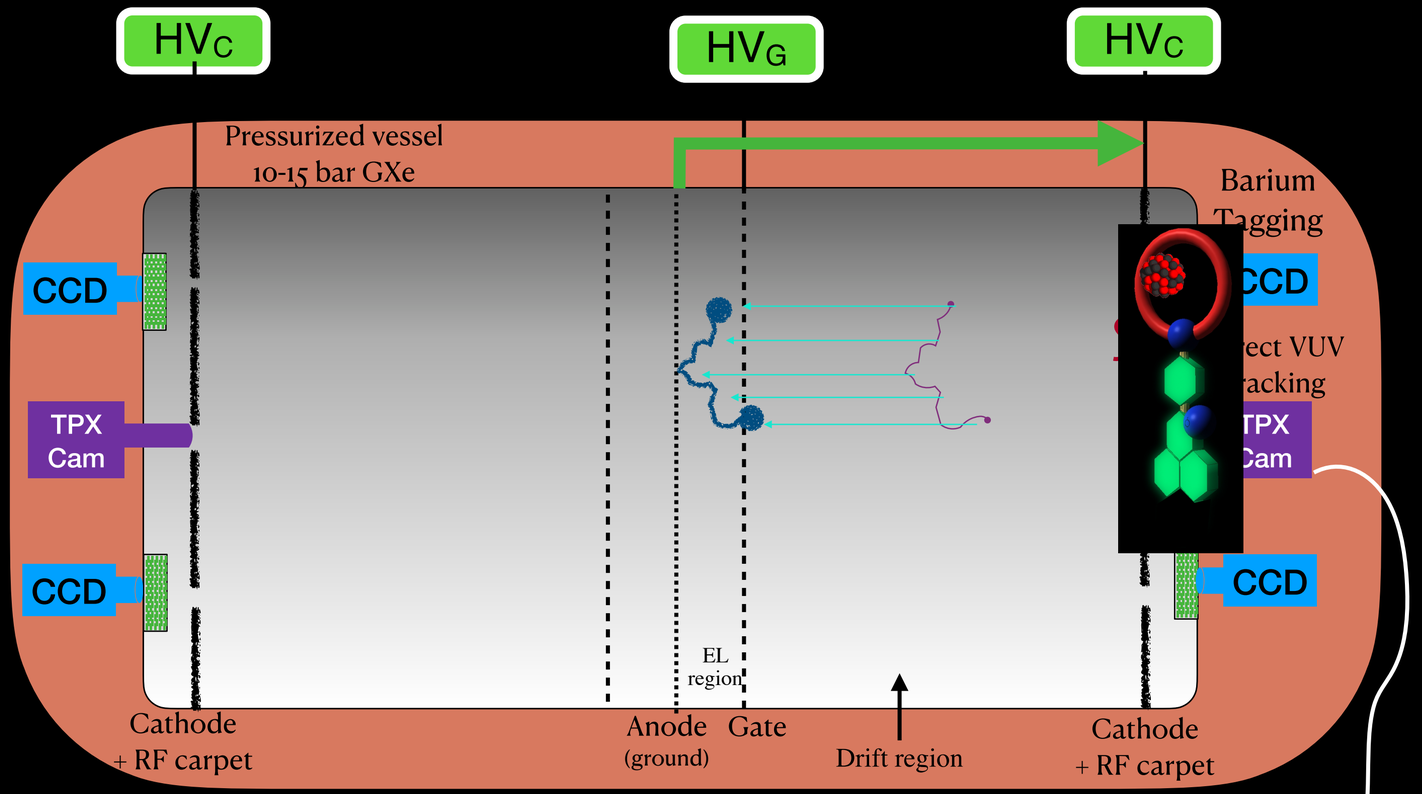

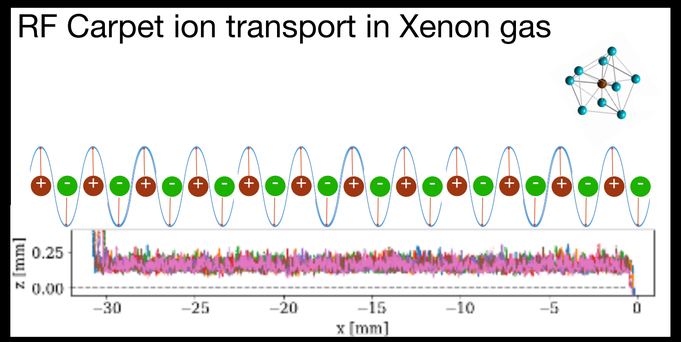

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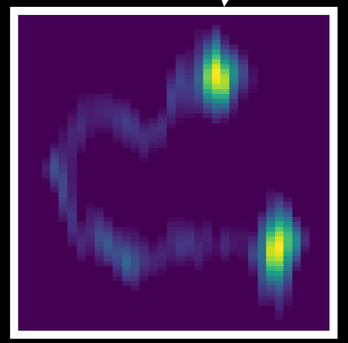

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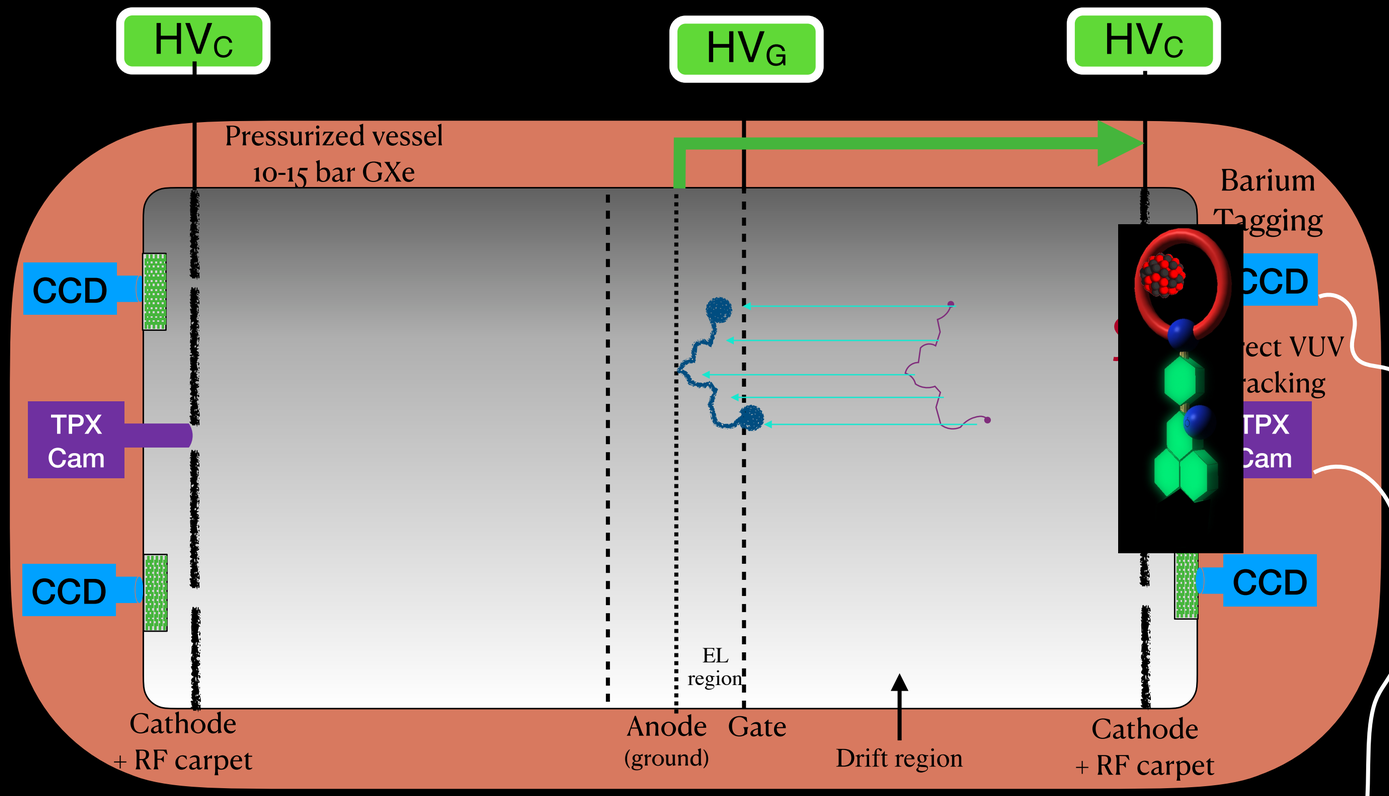

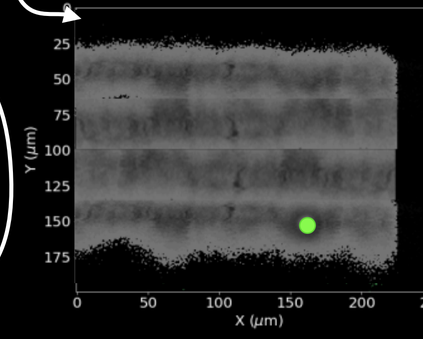

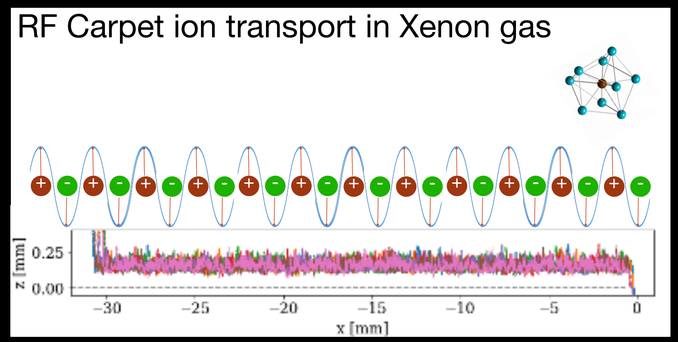

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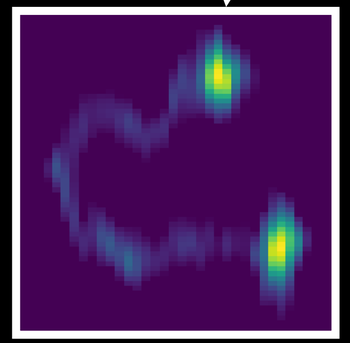

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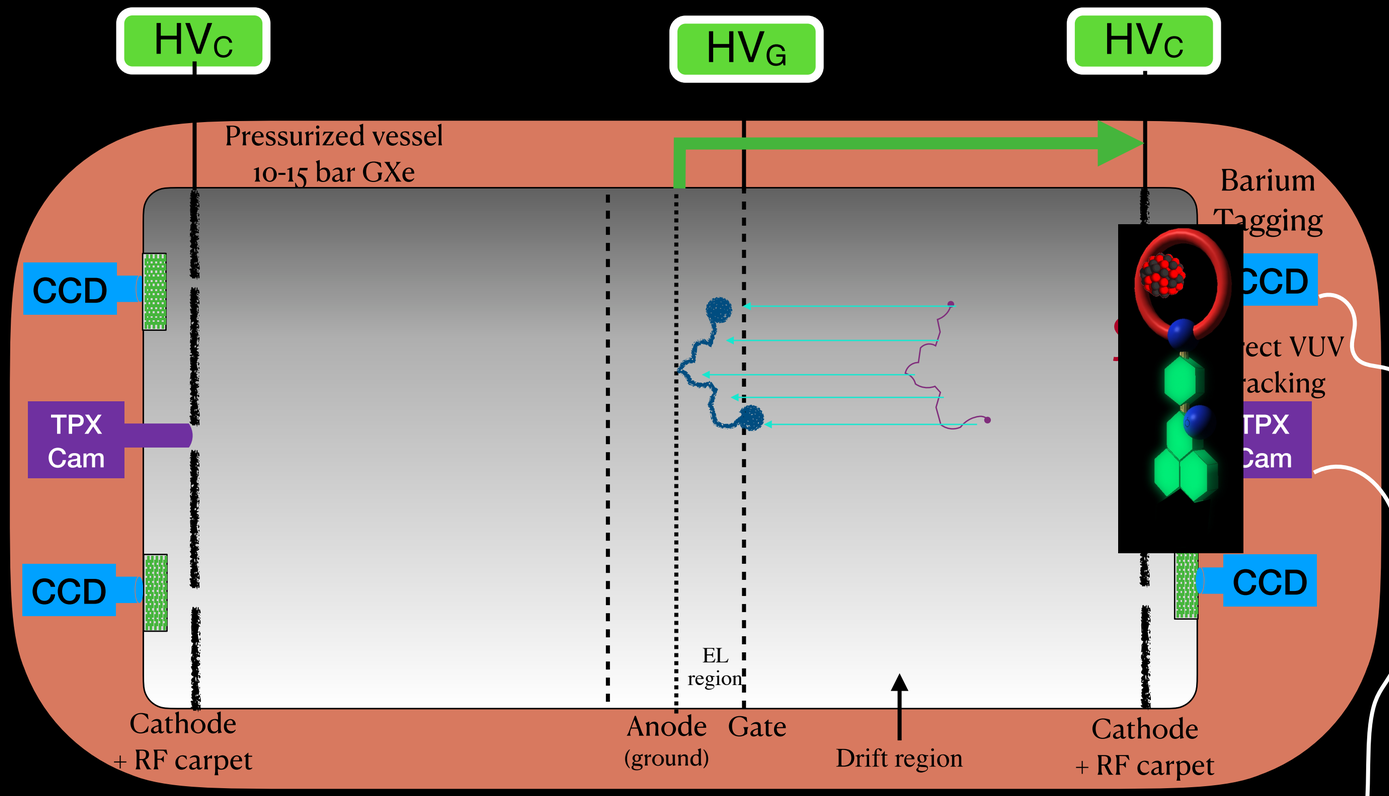
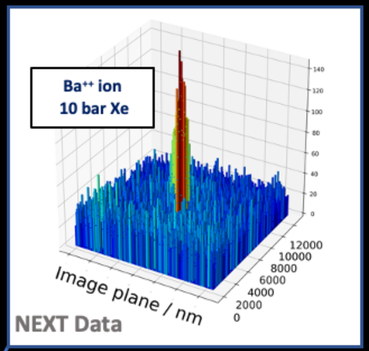
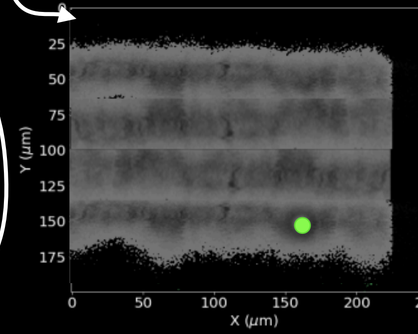
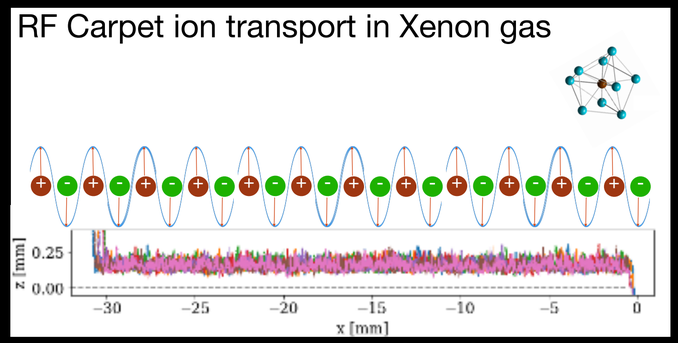


2. Single Ba^{2+} ion tagging w/SMFI







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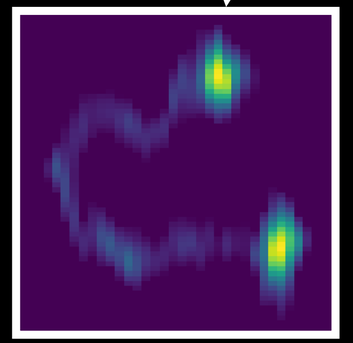

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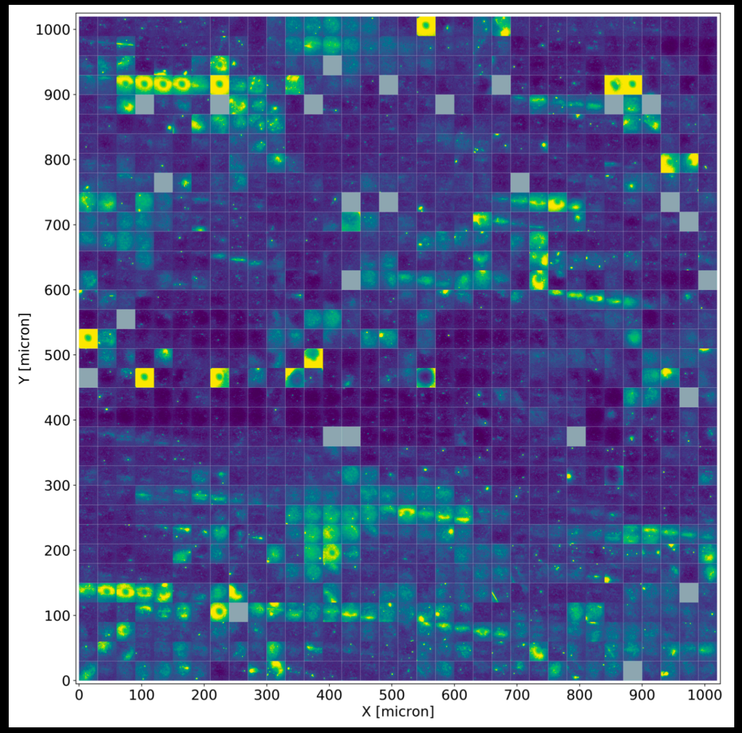
High pressure single molecule microscopy

- Single molecule microscopy over large surface within high pressure TPC volume is a technically challenging prospect.
- NEXT prototypes demonstrate mm2 area scan within high pressure xenon gas.

Images taken in 10 bar Xe gas with external EMCCD camera and lasers

Scan surface is ~15cm into vessel volume



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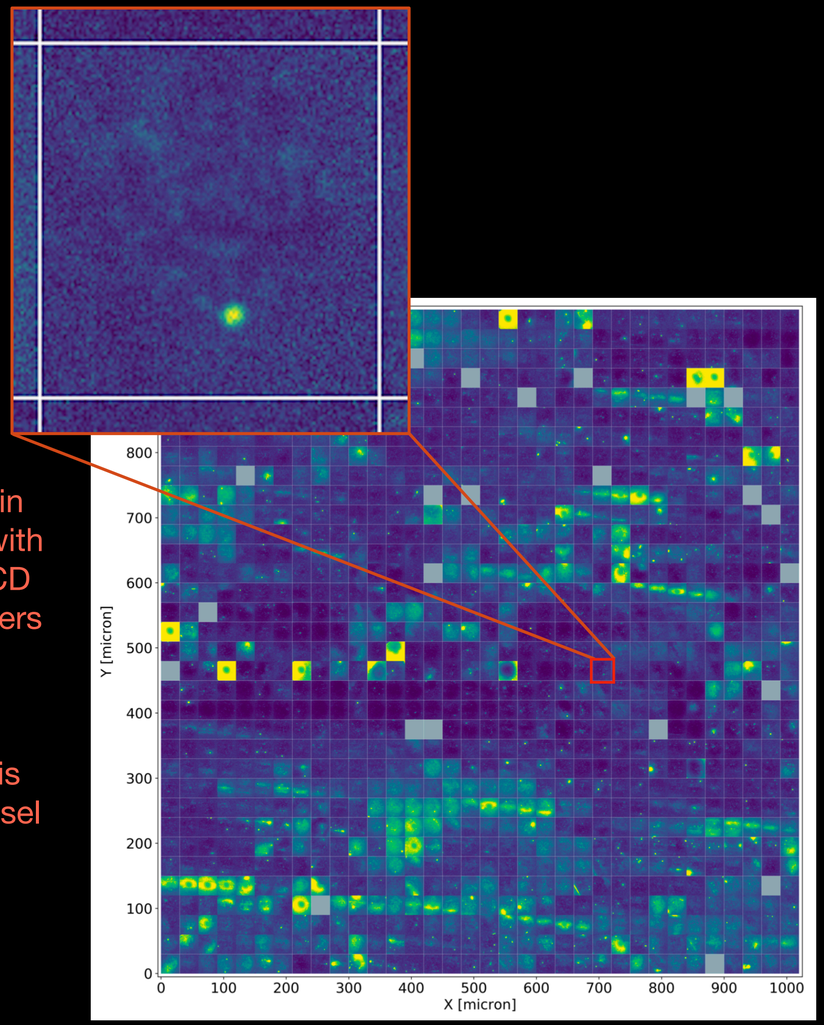

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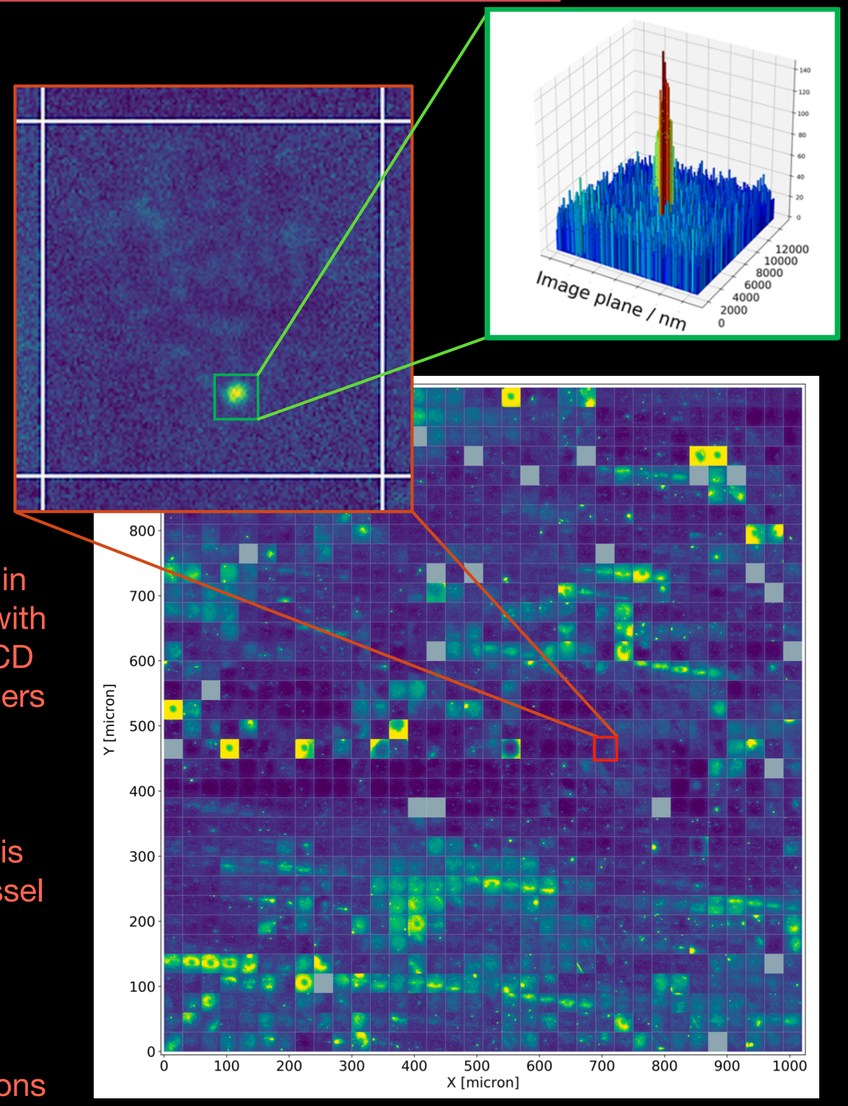

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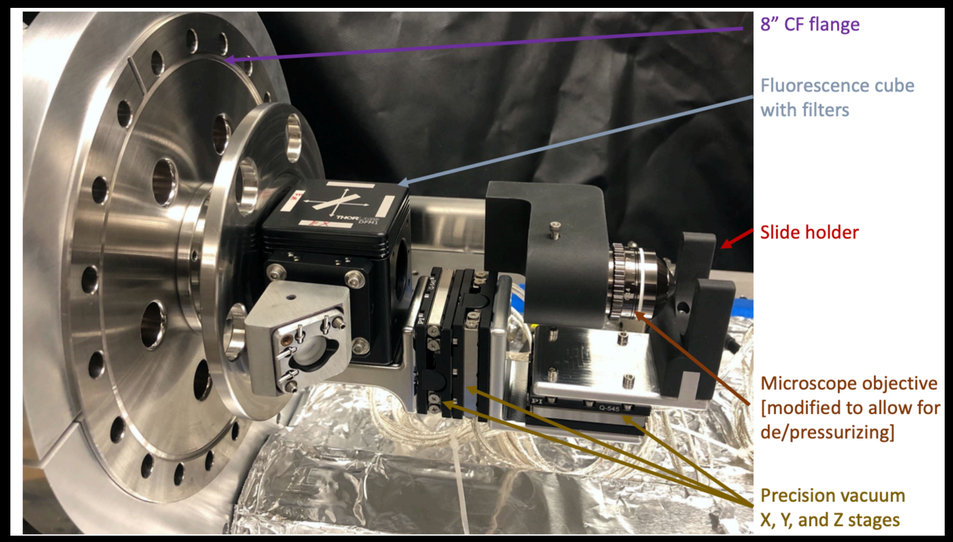
ACS Sens. (2021) 6, 1, 192−202; arXiv:2201.09099;
Sci.Rep. 9 (2019) 1, 15097



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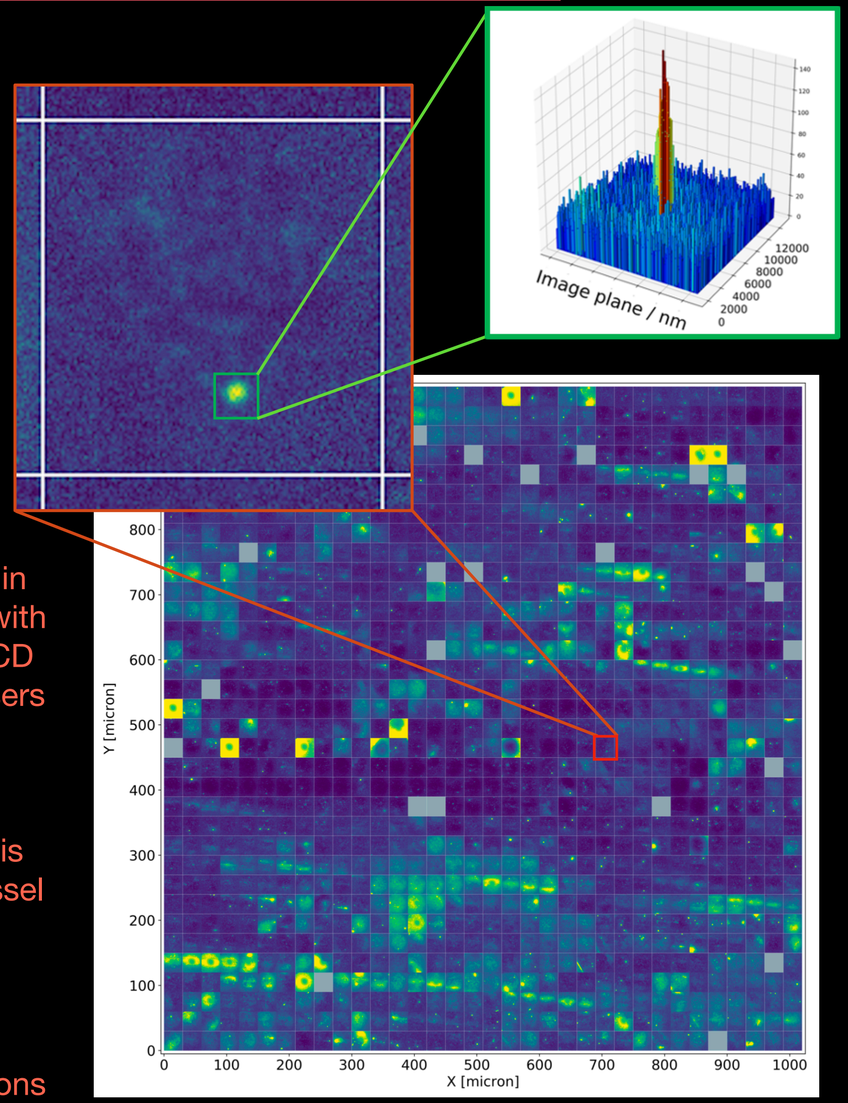

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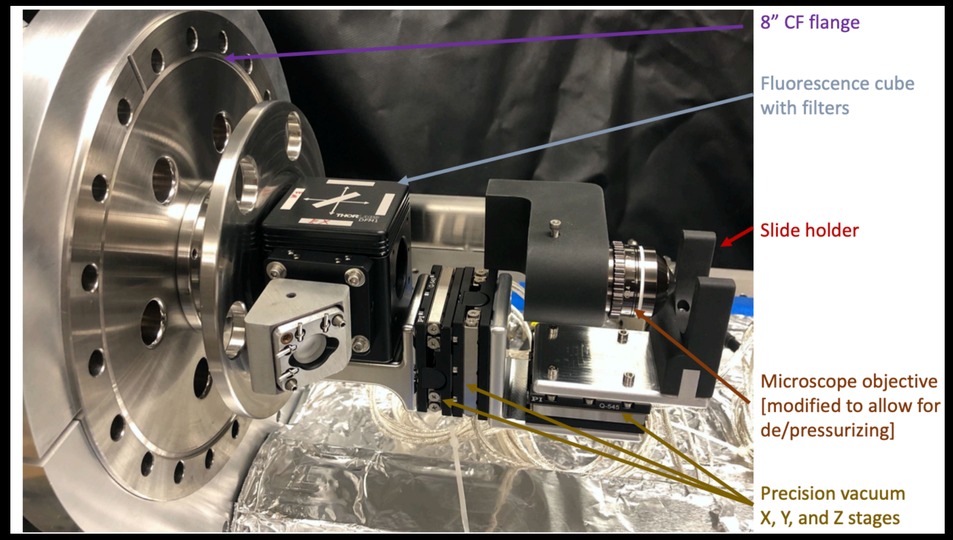

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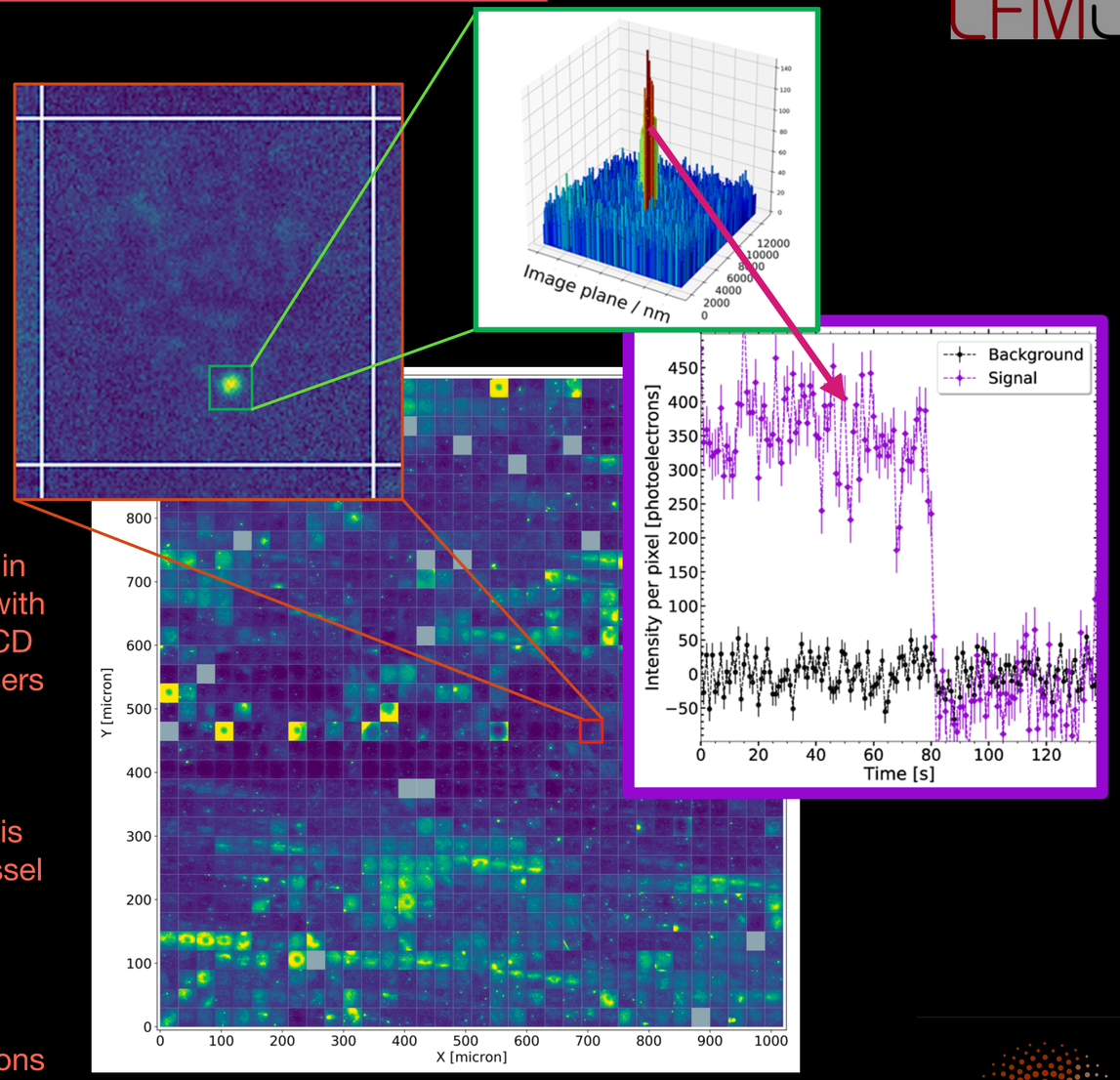

Dry single barium ion sensing demonstrated via single-step photobleach

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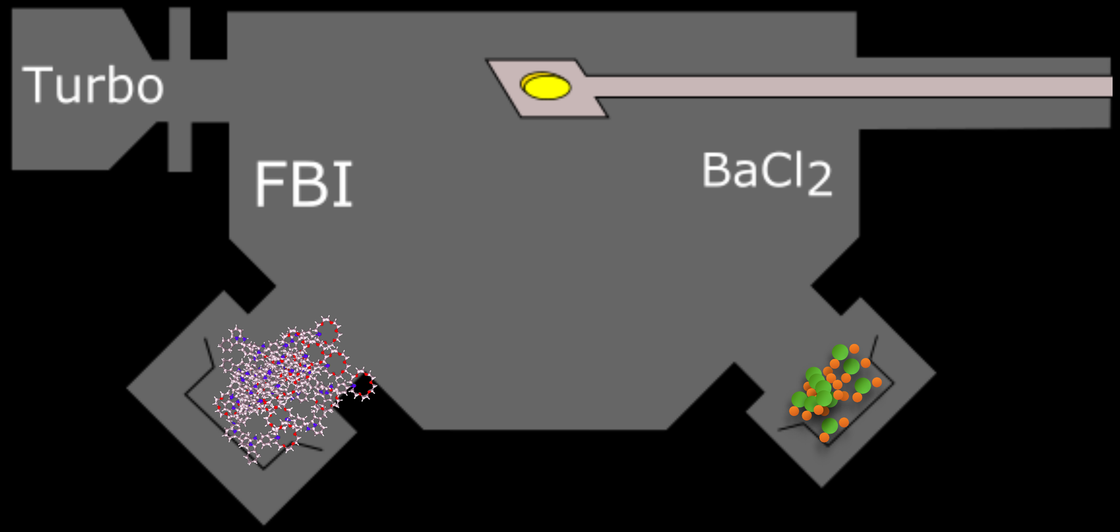
Molecular chelation by monolayer in UHV



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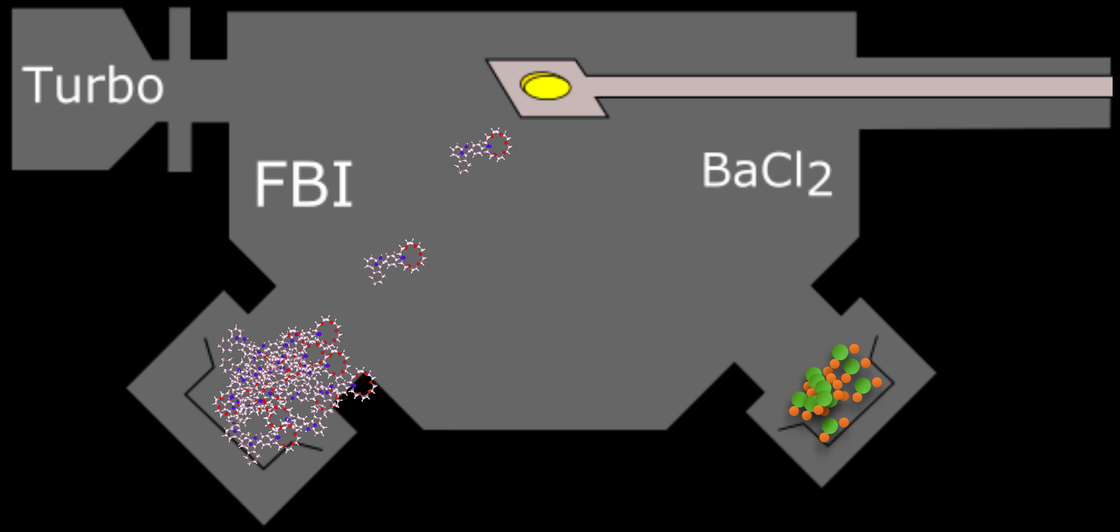

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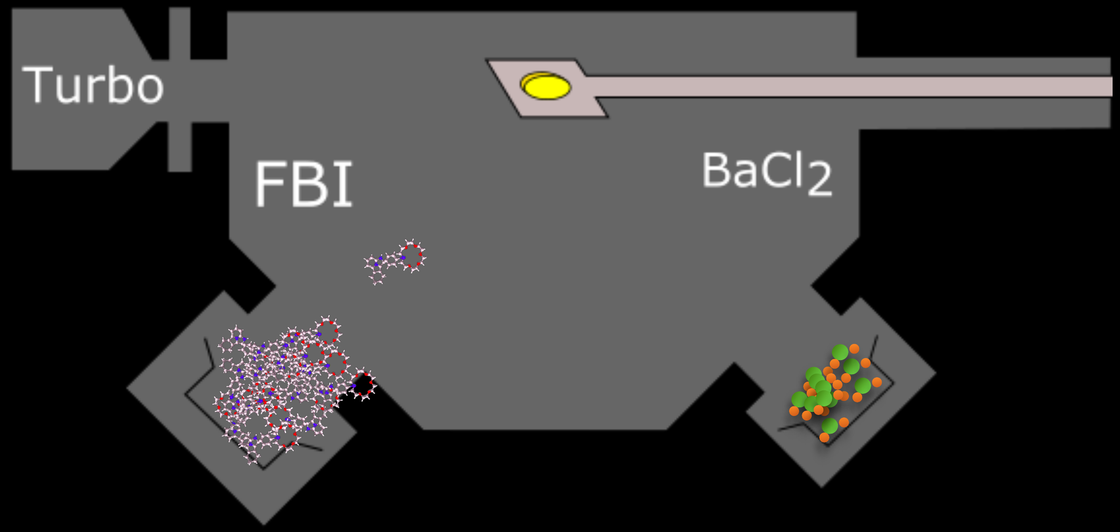

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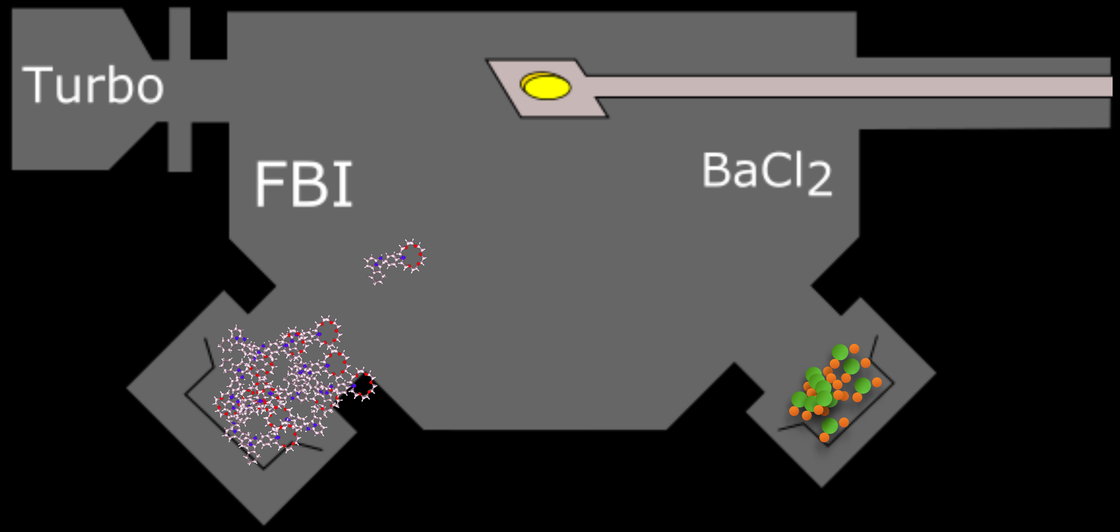
1. We performed further measurements evaporating FBI molecules and $BaCl_2$ on a Au (111) surface in UHV.



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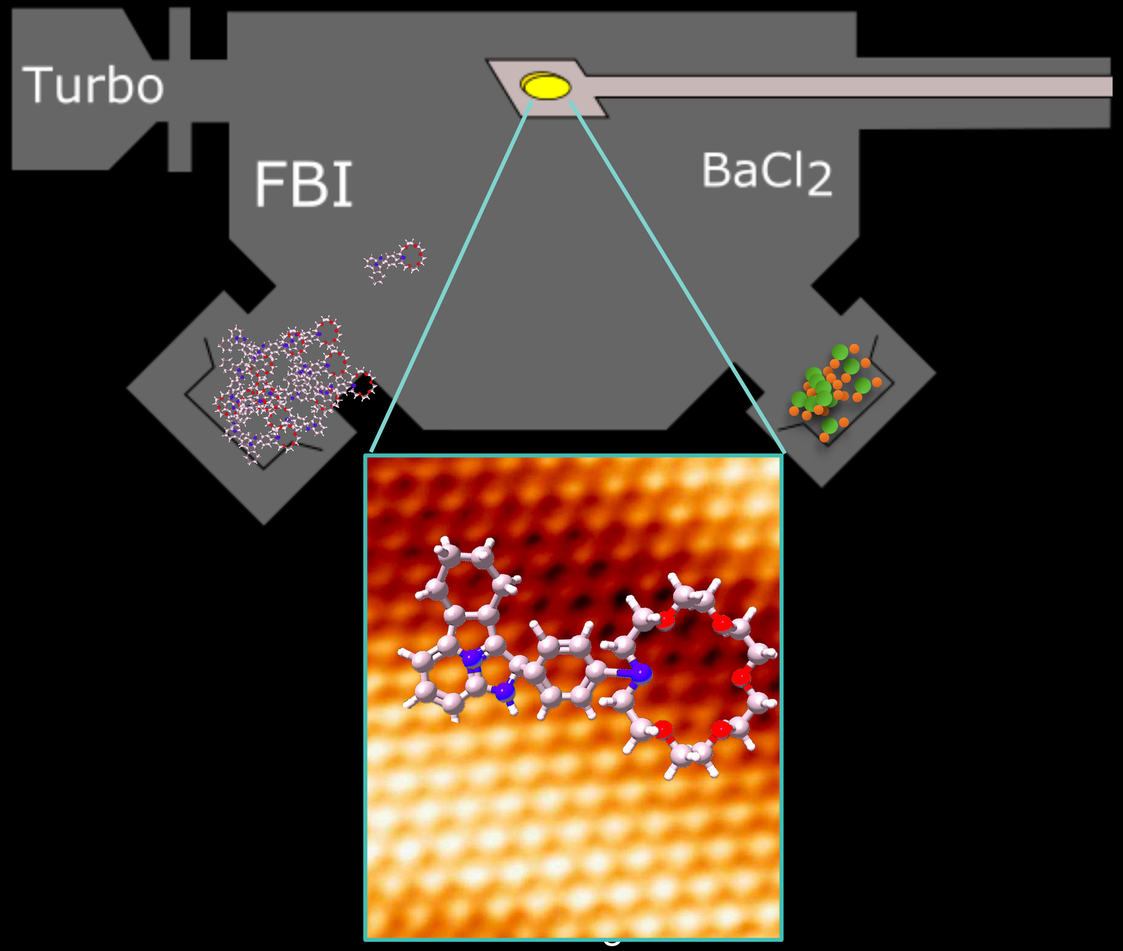

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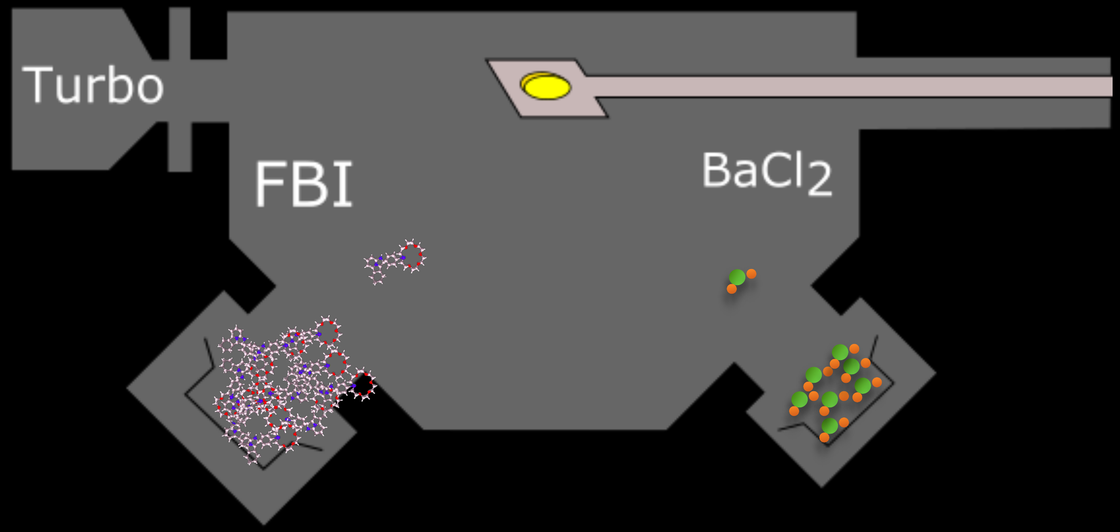

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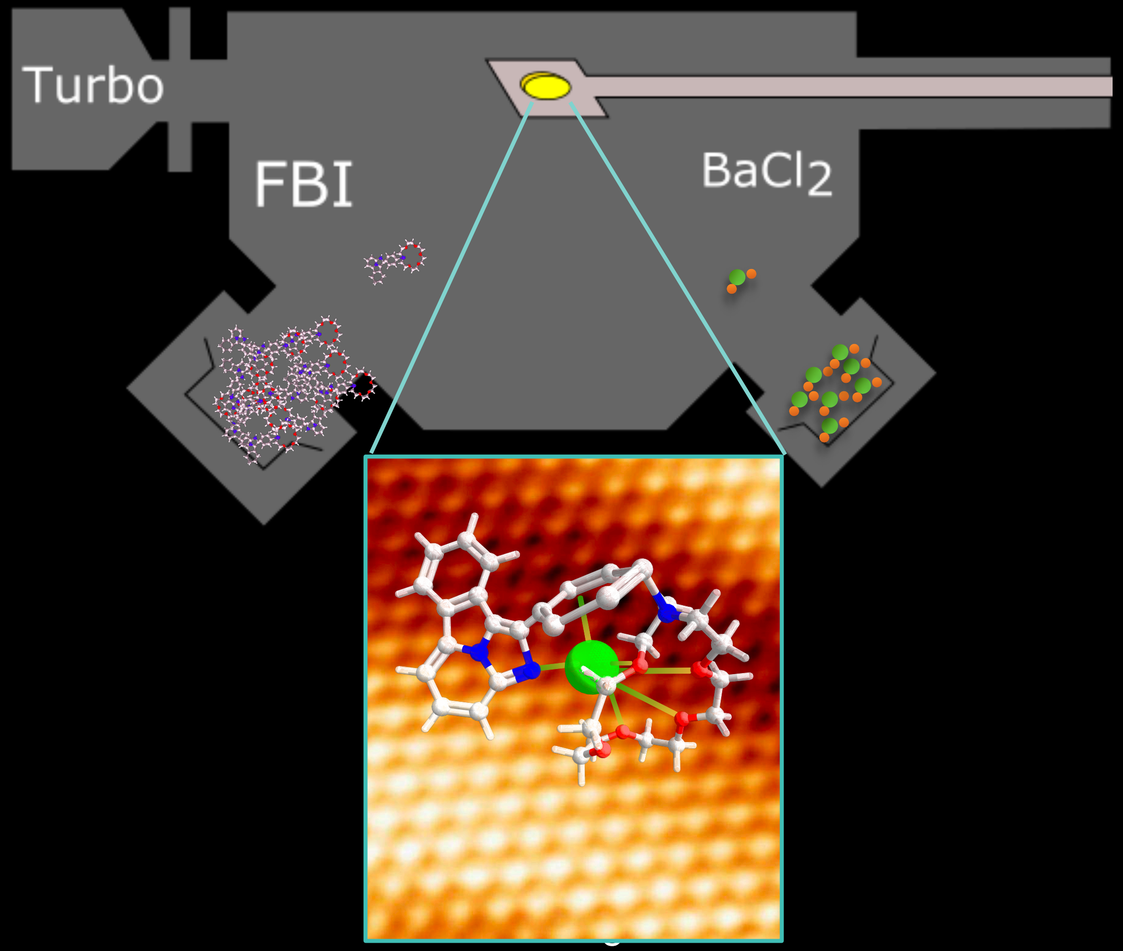

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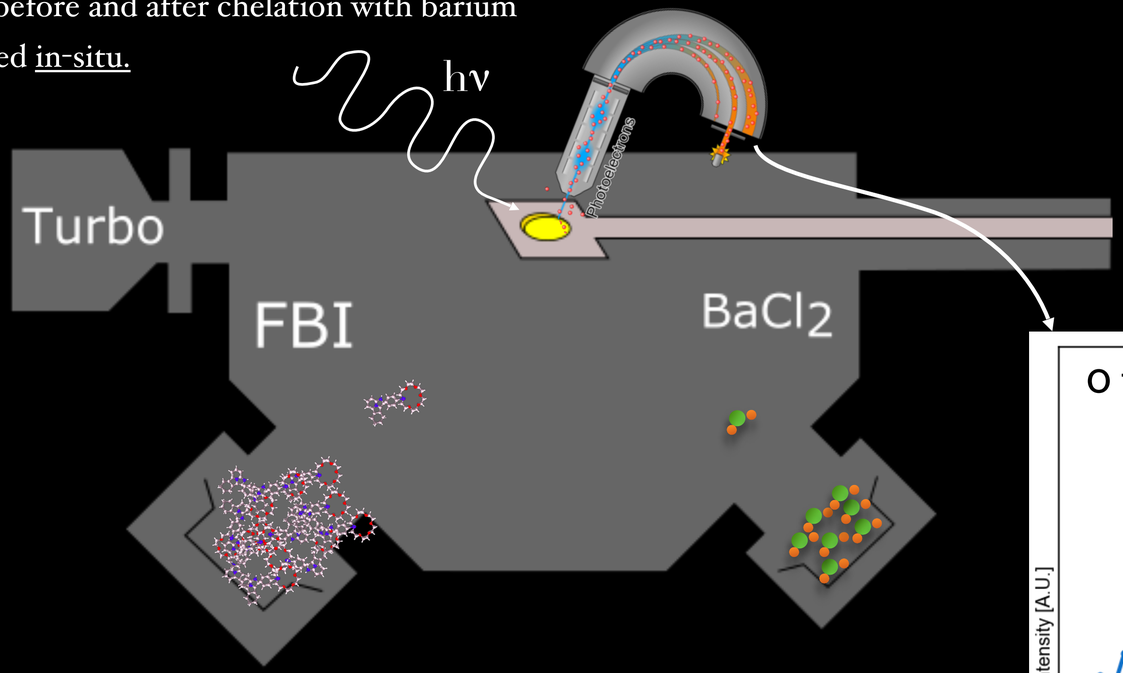

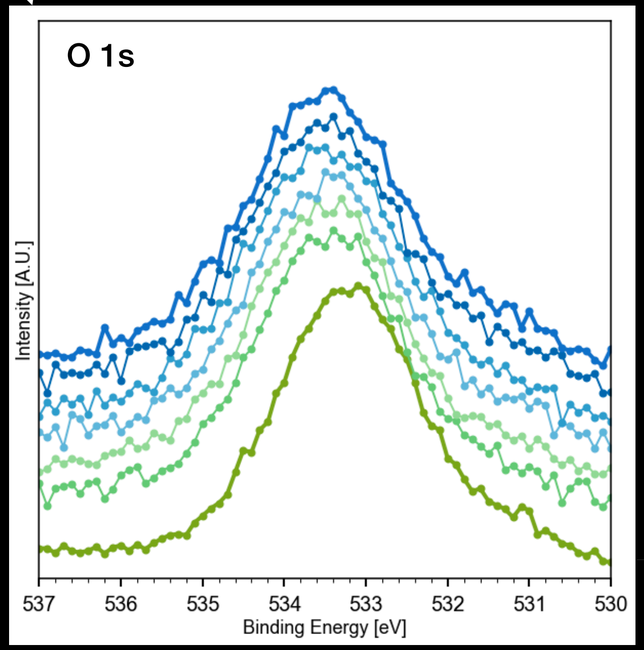

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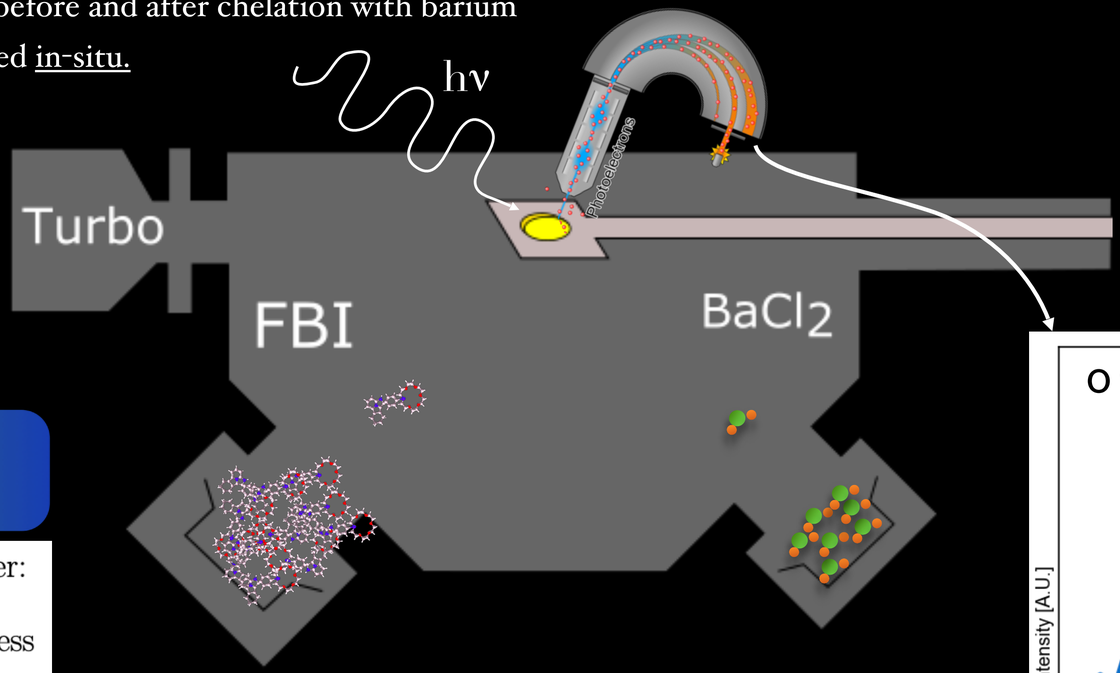

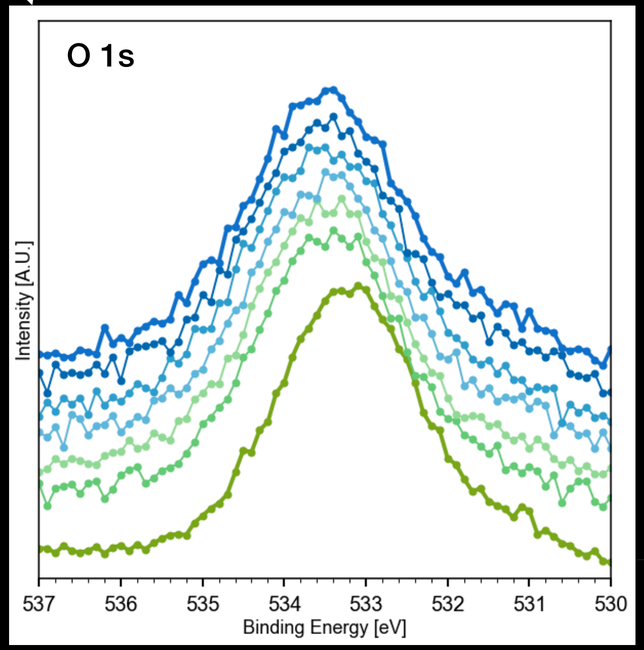

Paper in revision stage at Nature Comm.

Ba^{2+} ion trapping by organic submonolayer: towards an ultra-low background neutrinoless double beta decay detector

P. Herrero-Gómez[1,2], J.P. Calupitan[1], M. Ilyn[1], A. Berdonces-Layunta[1,2], T. Wang[1,2], D. G. de Oteyza[1,2], M. Corso[1,2], R. González-Moreno[2], I. Rivilla[2,3], B. Aparicio[4], A.I. Aranburu[5], Z. Freixa[3,5], F. Monrabal[2,3], F.P. Cossío[2,4], J.J. Gómez-Cadenas[2,3†], C. Rogero[1,2*] and NEXT collaboration.

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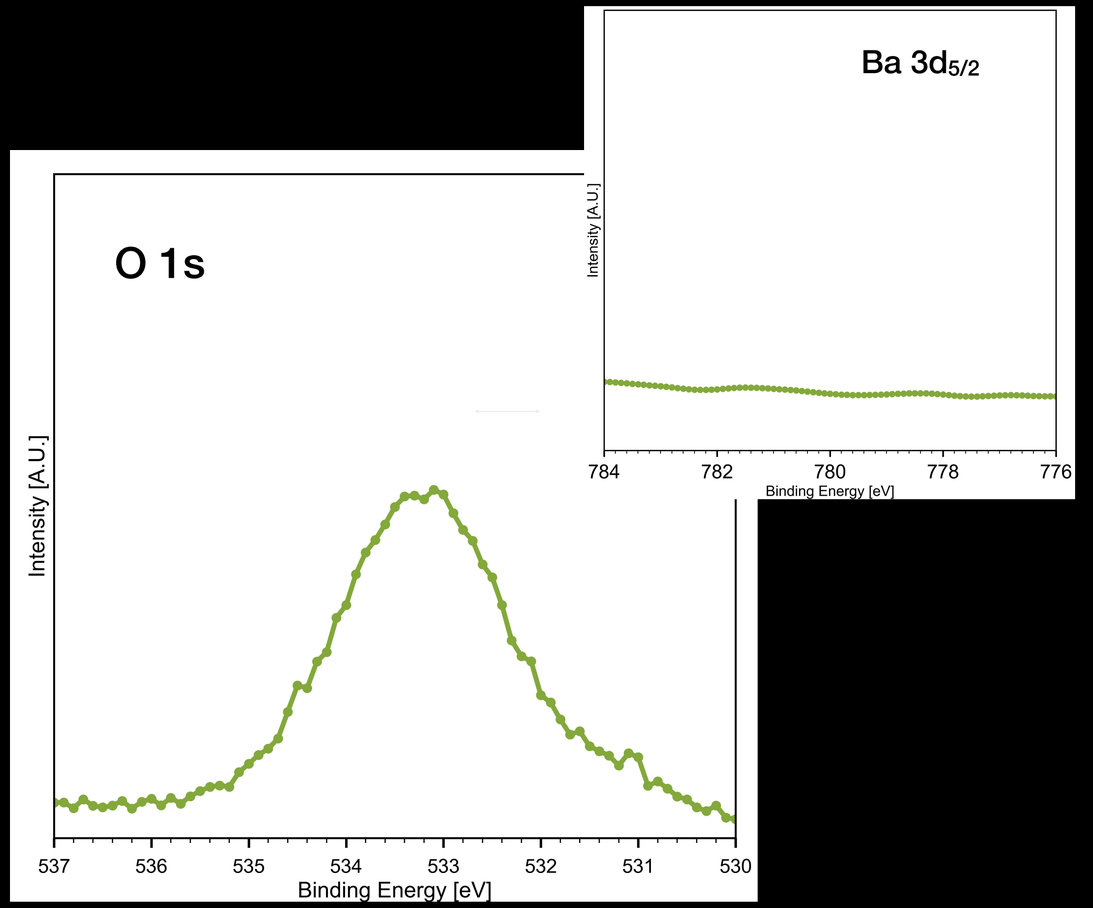
Chemical proof of barium trapping: XPS.

(X-ray Photoemission Spectroscopy)



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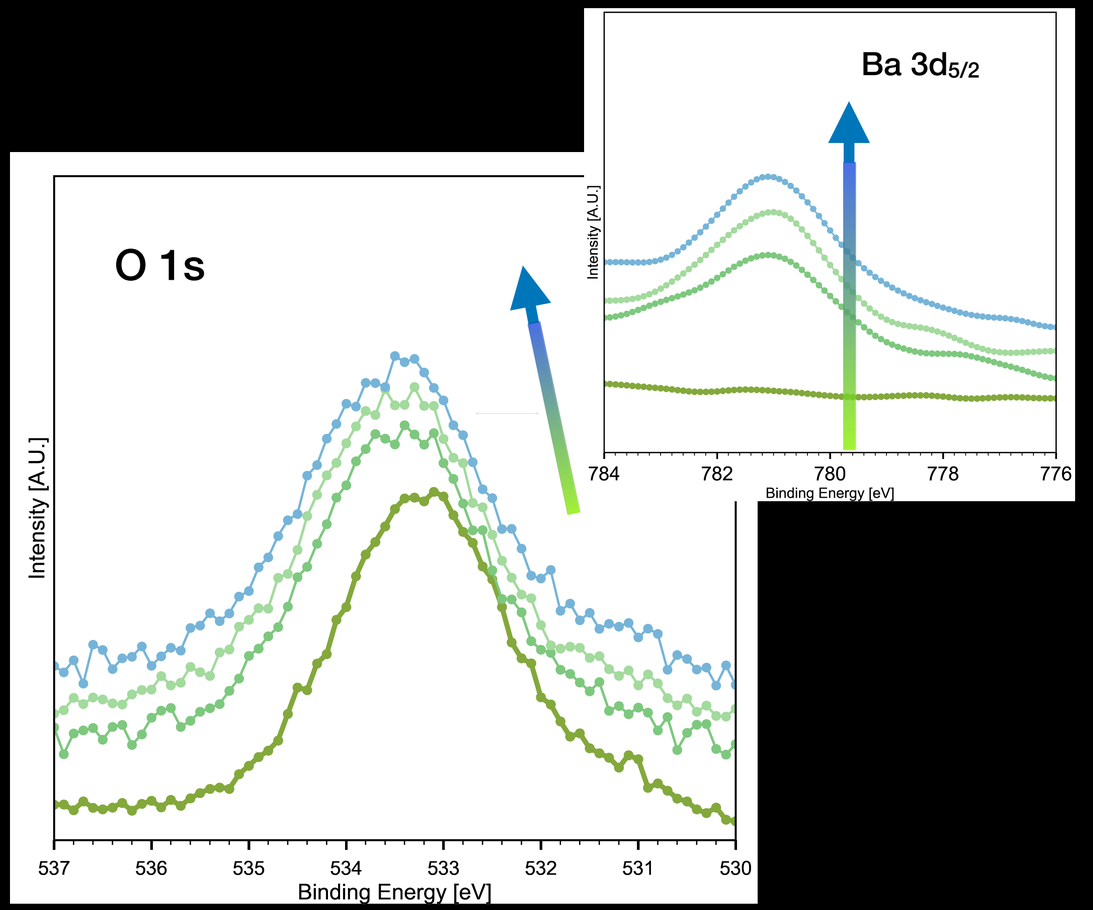

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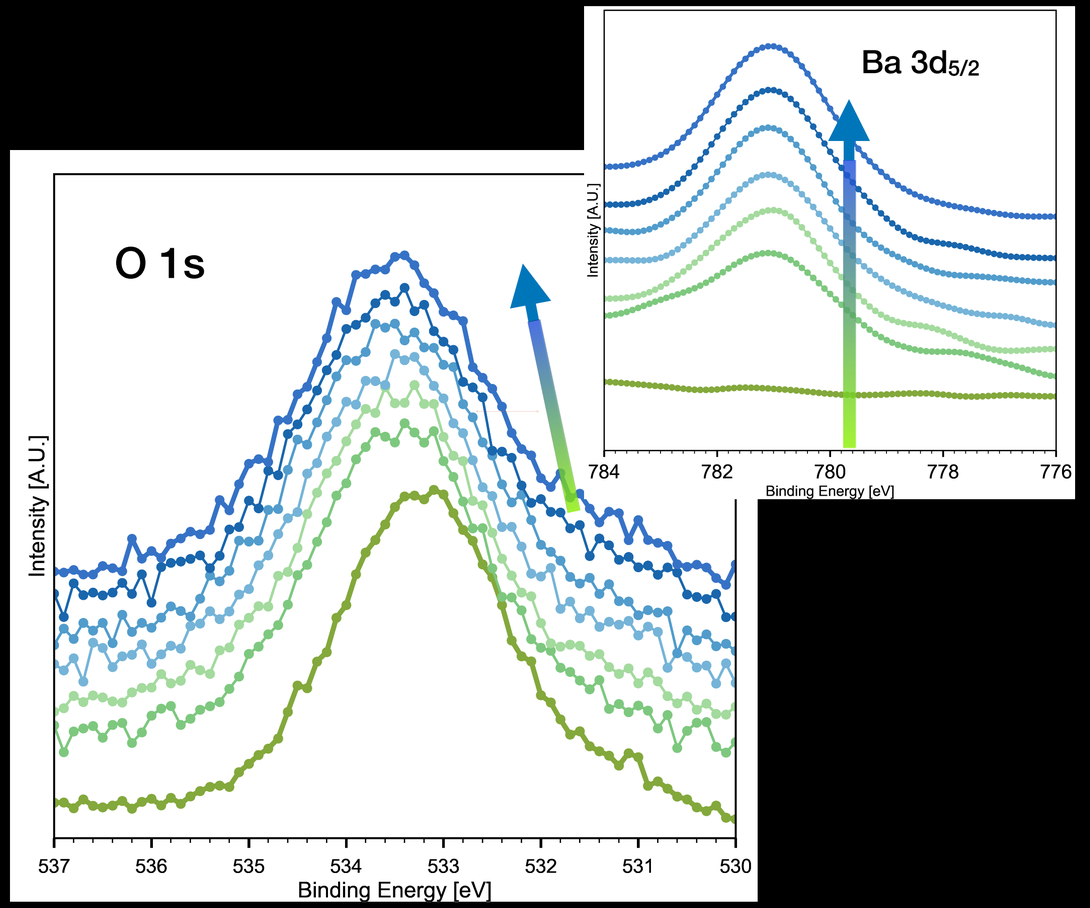

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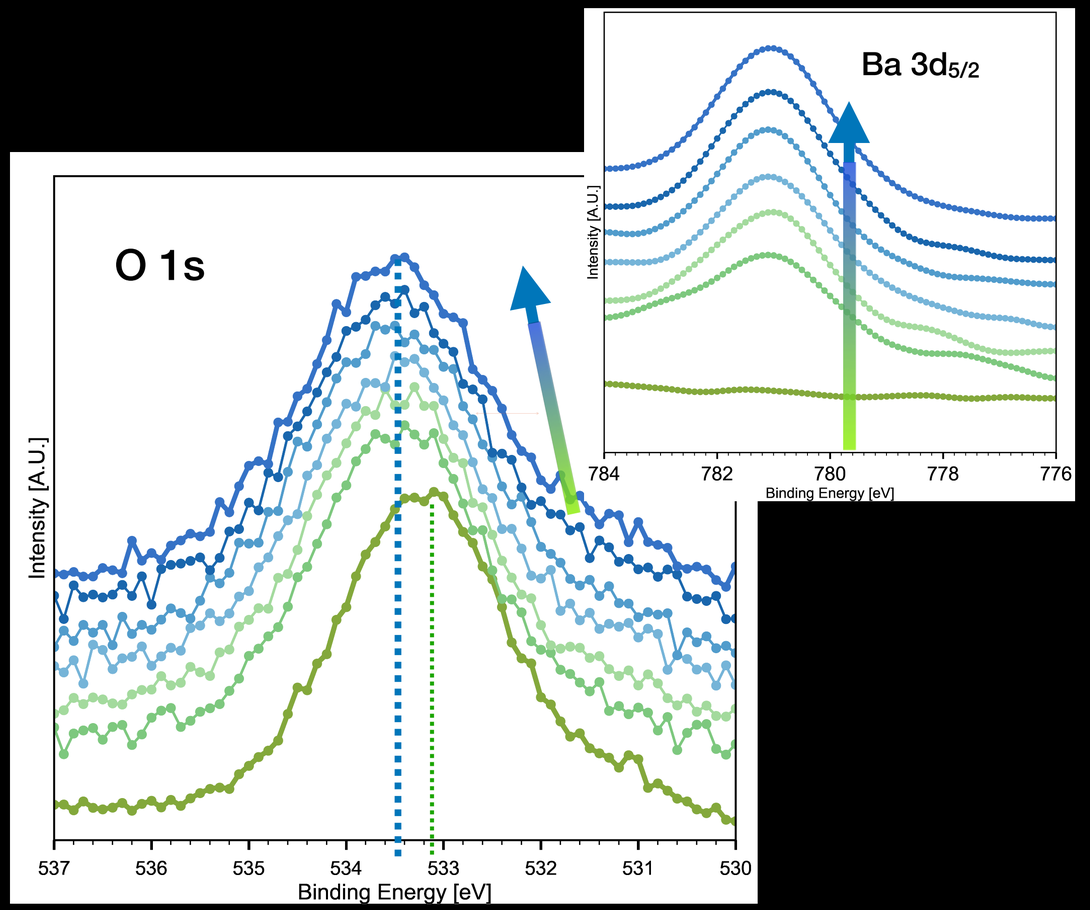

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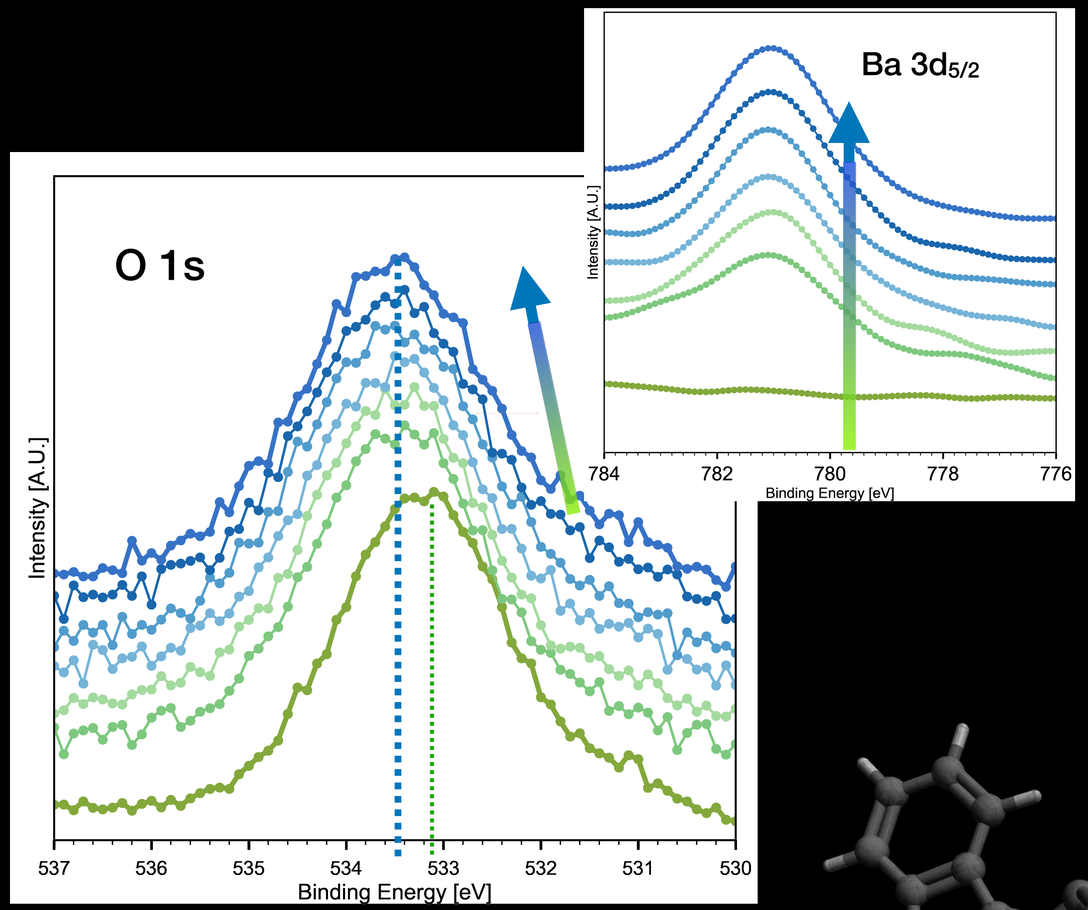

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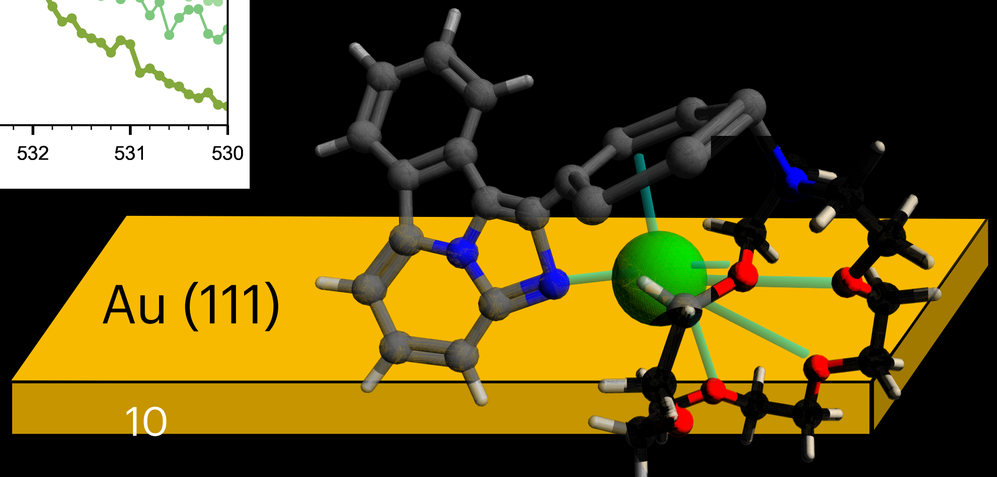

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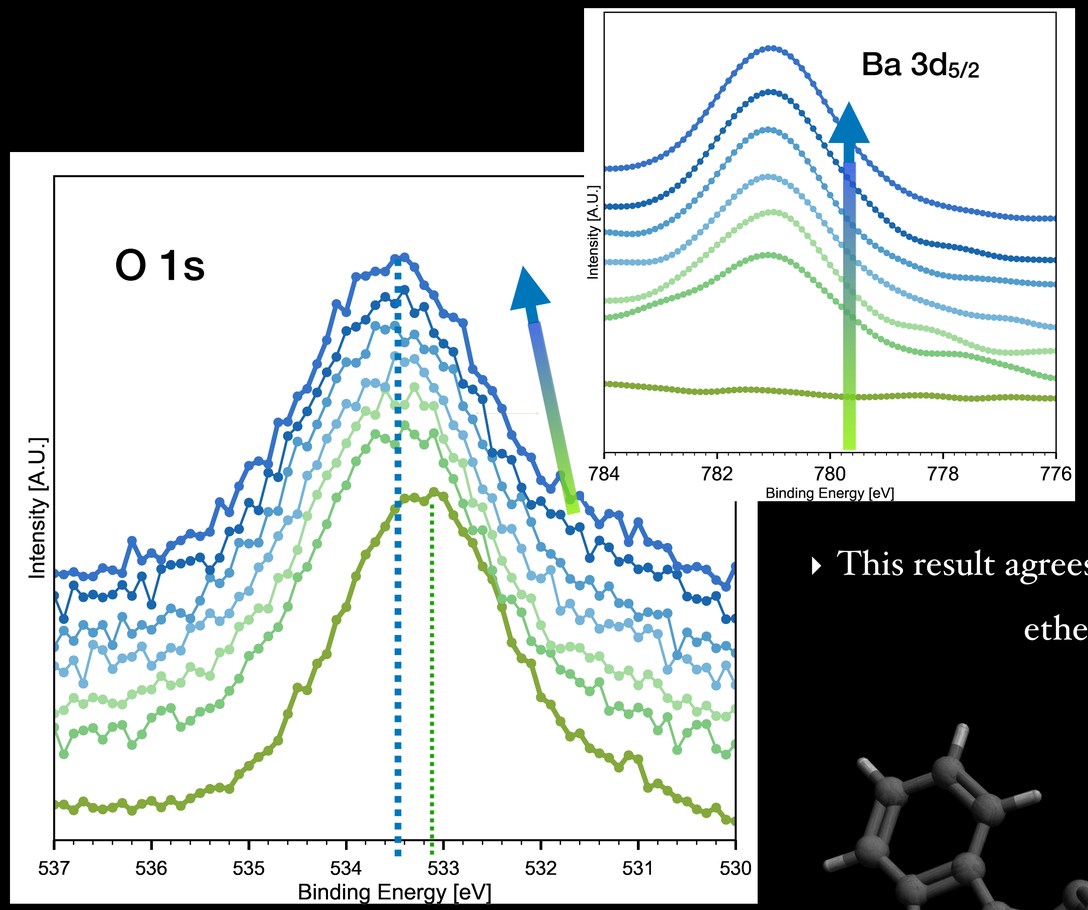

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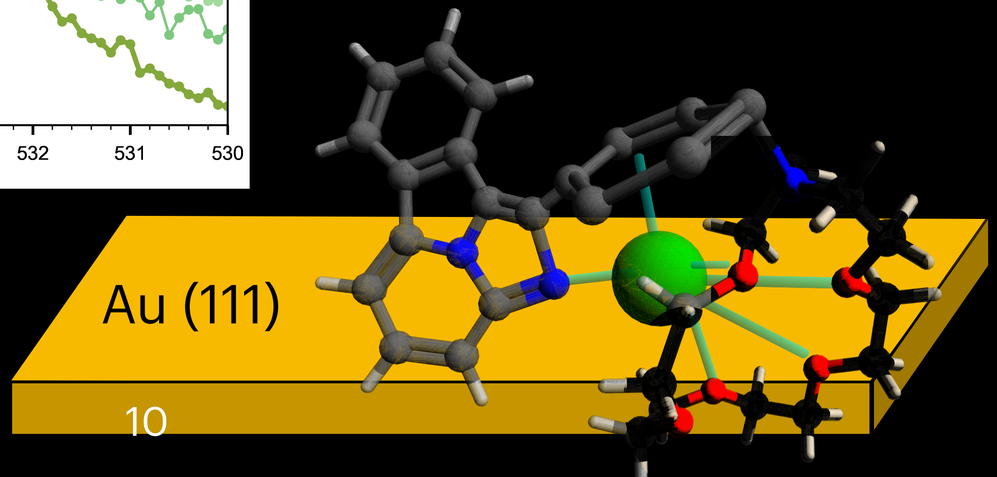

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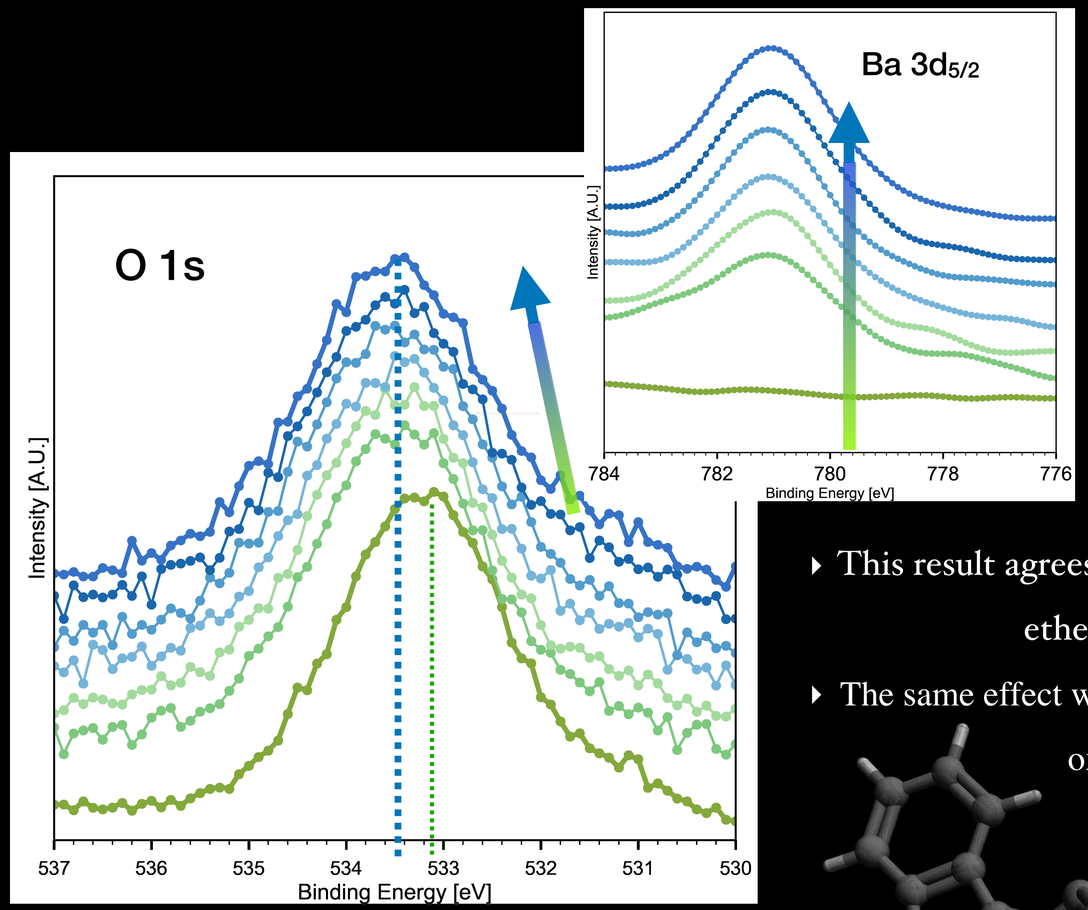

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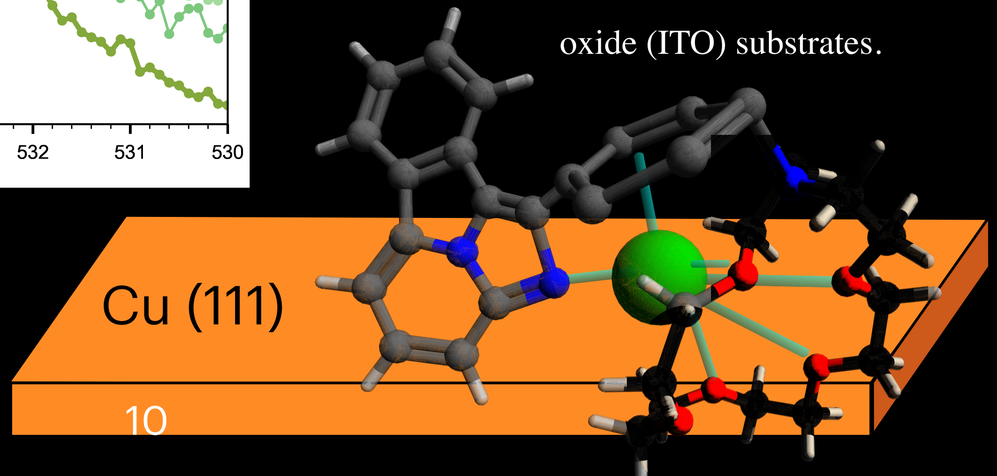

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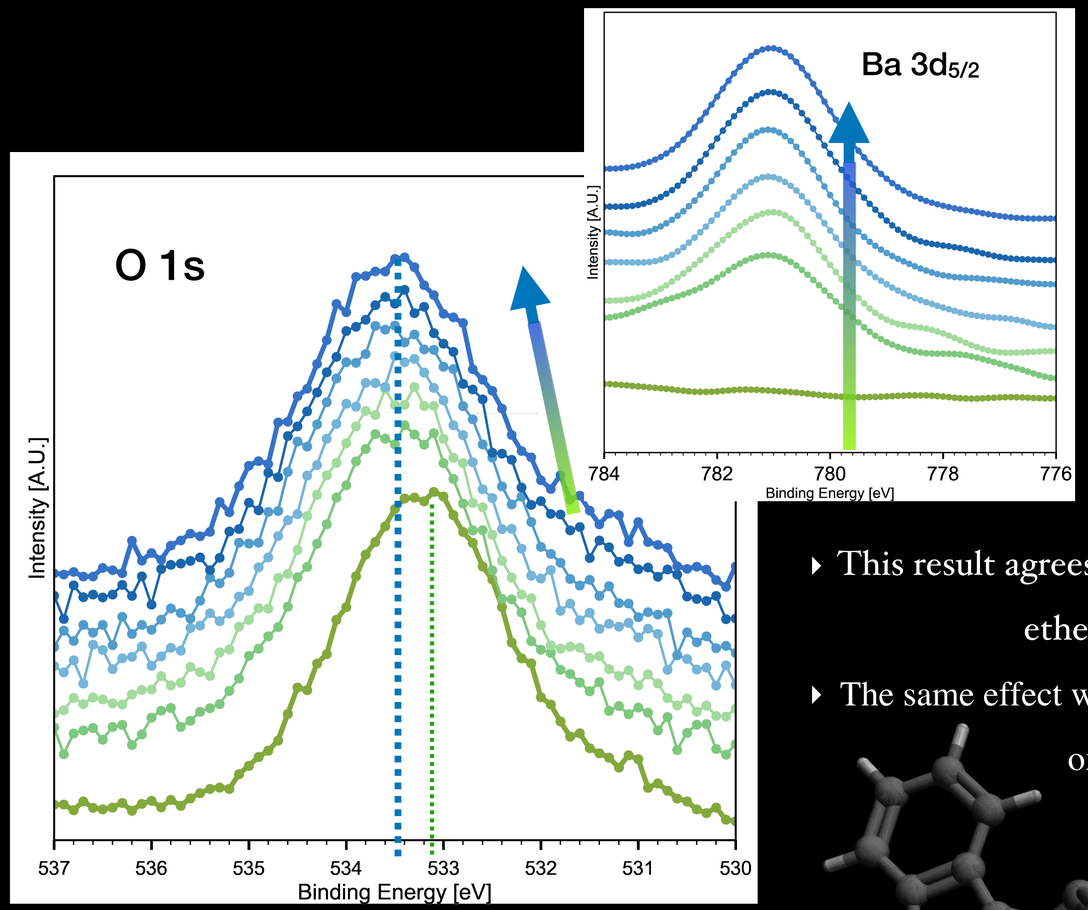

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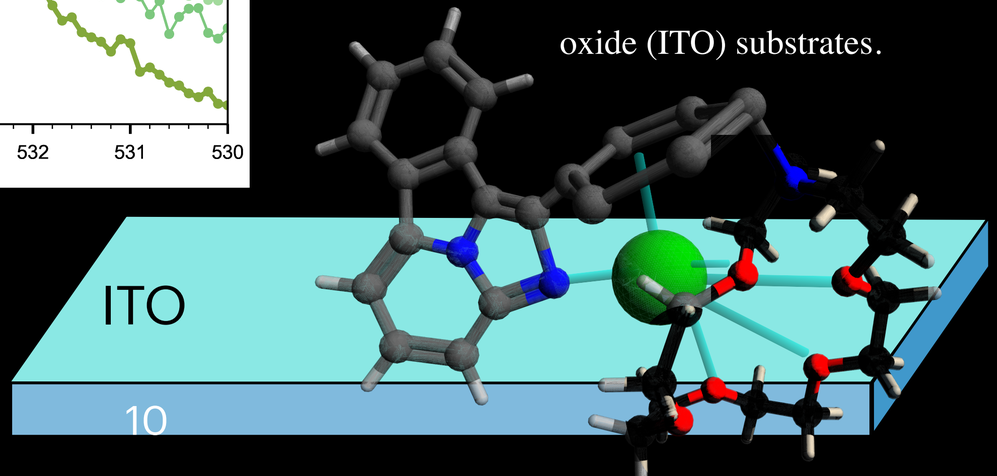

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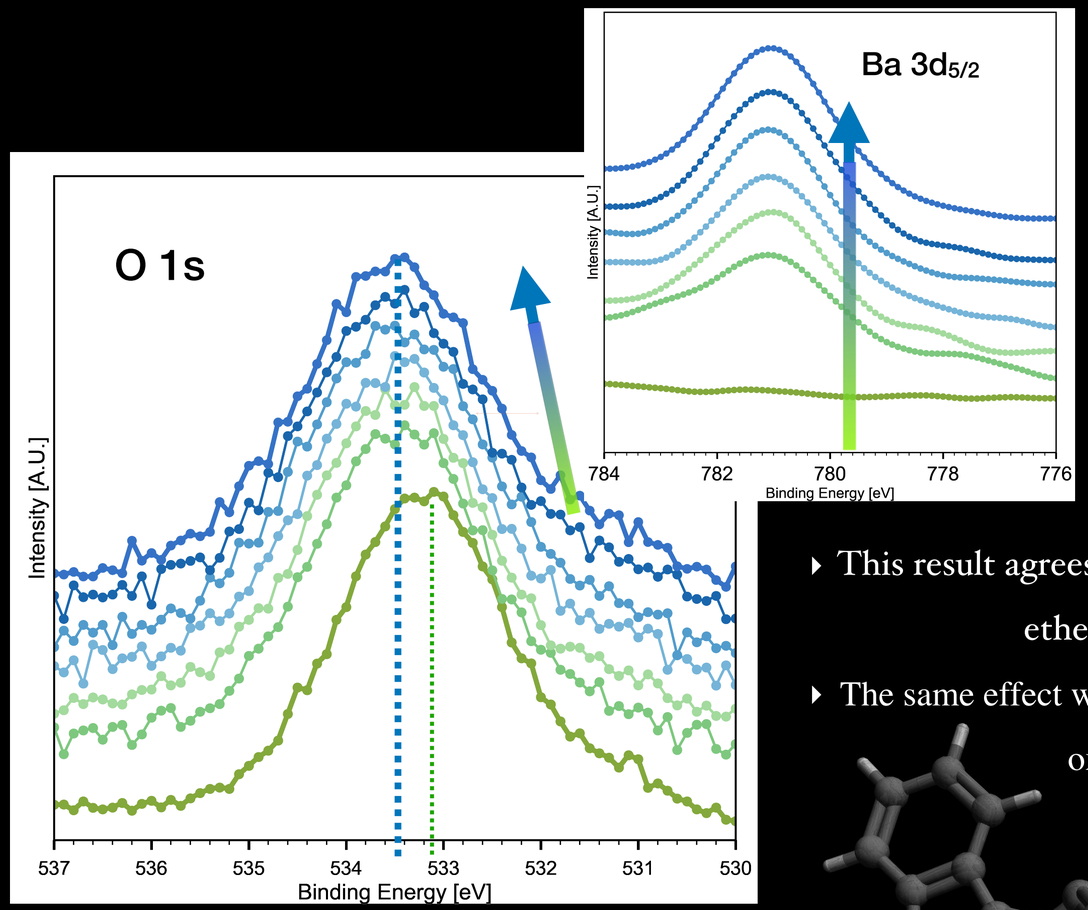

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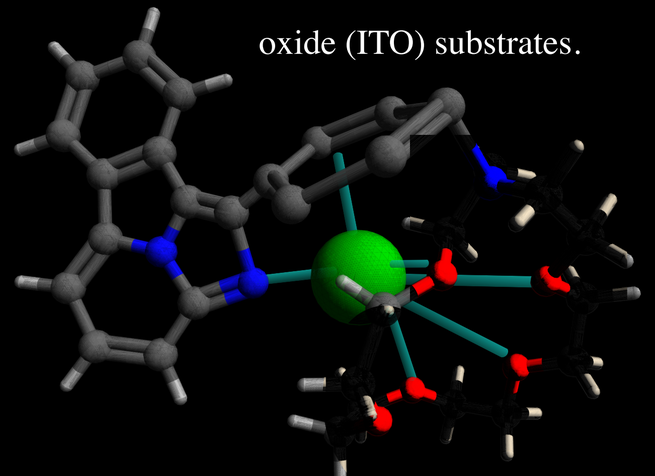

Chemical proof of Ba^{2+} chelation by fluorescent indicators in UHV

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Conformational change produced by chelation

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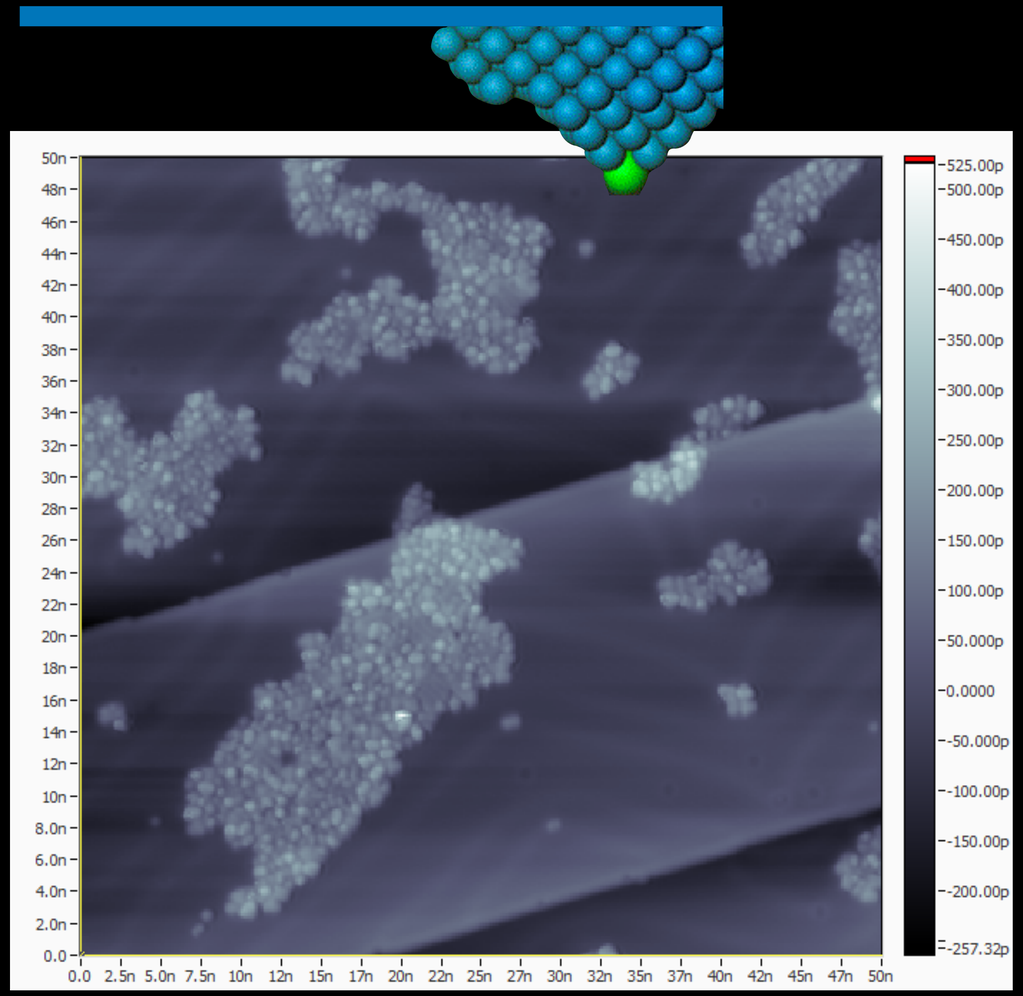

Model: Sub Monolayer sensor

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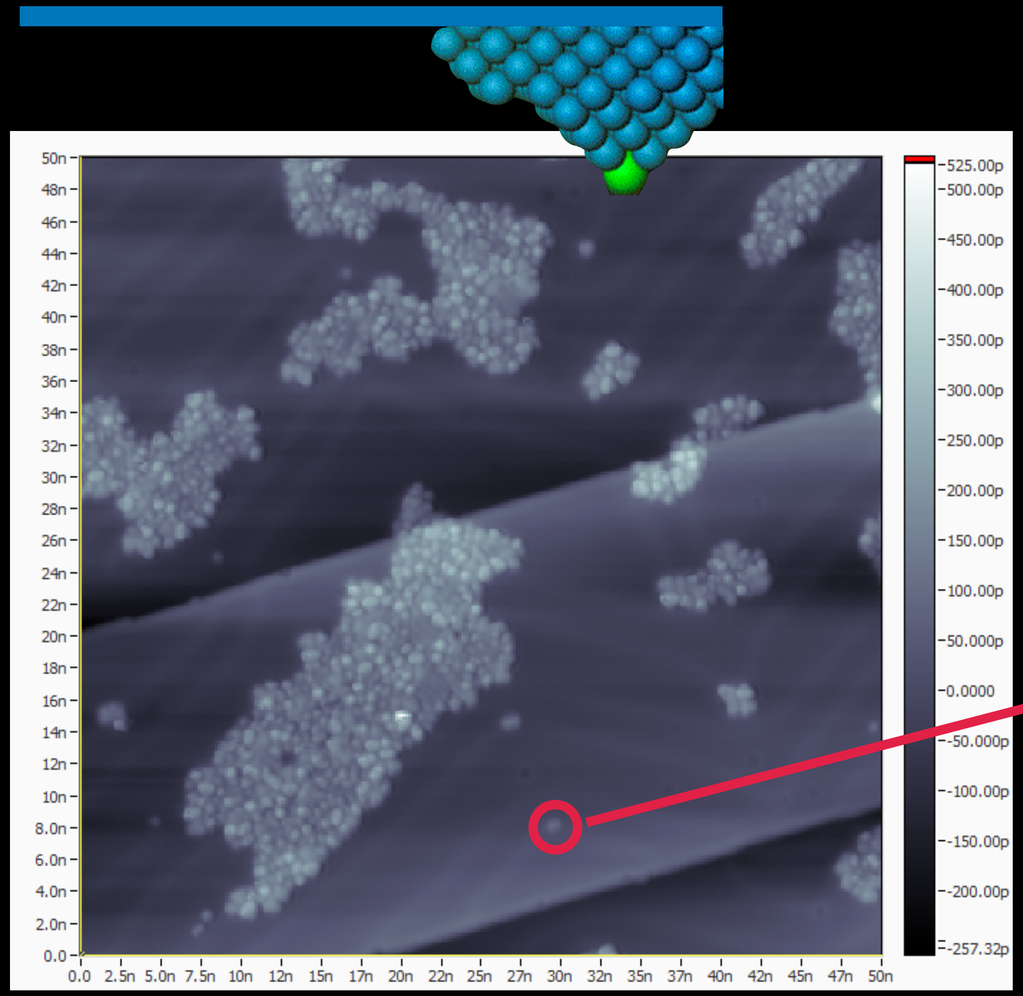

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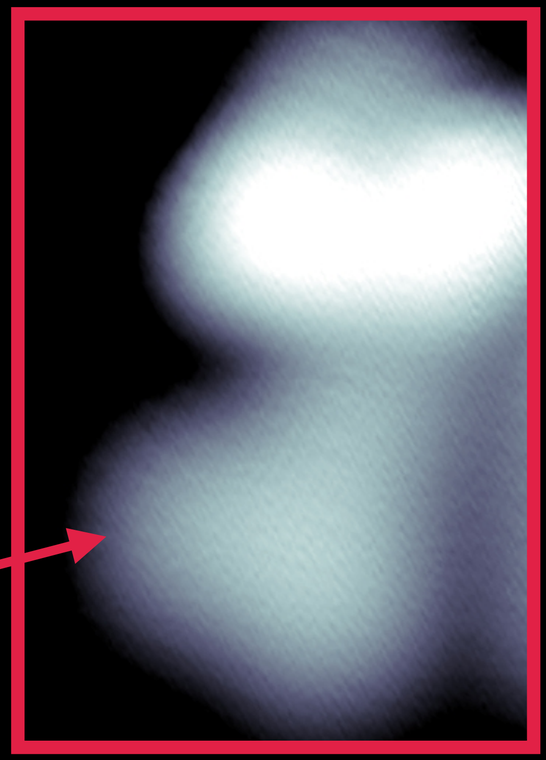

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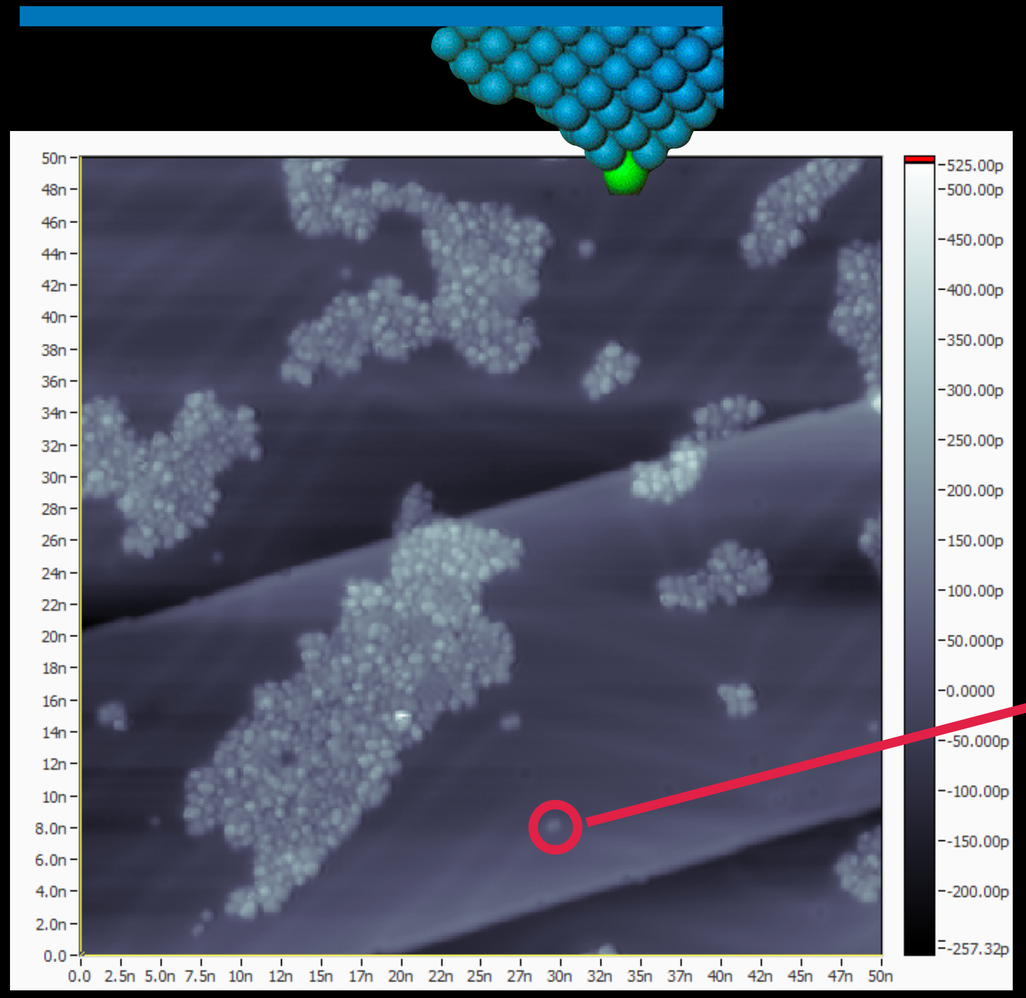

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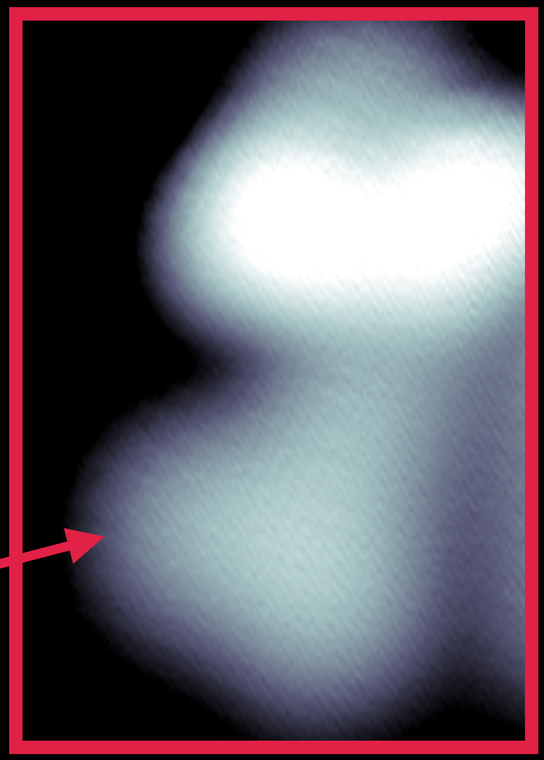

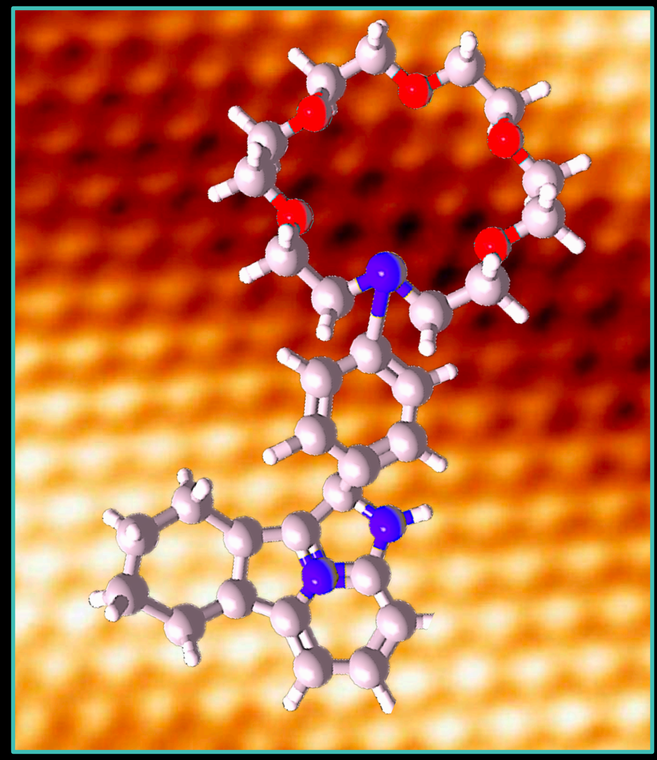

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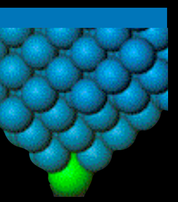

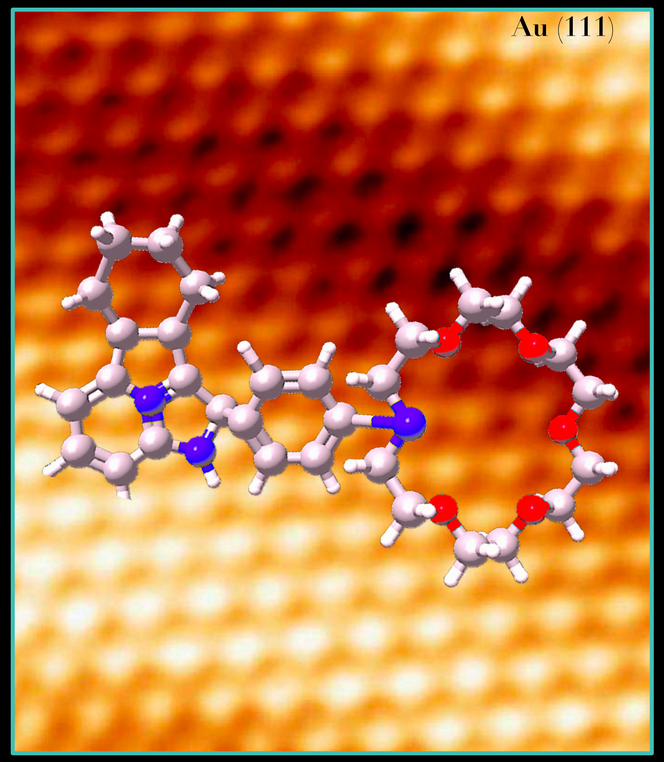

1.FBI molecules were deposited on Au (111) in sub-monolayer regime.

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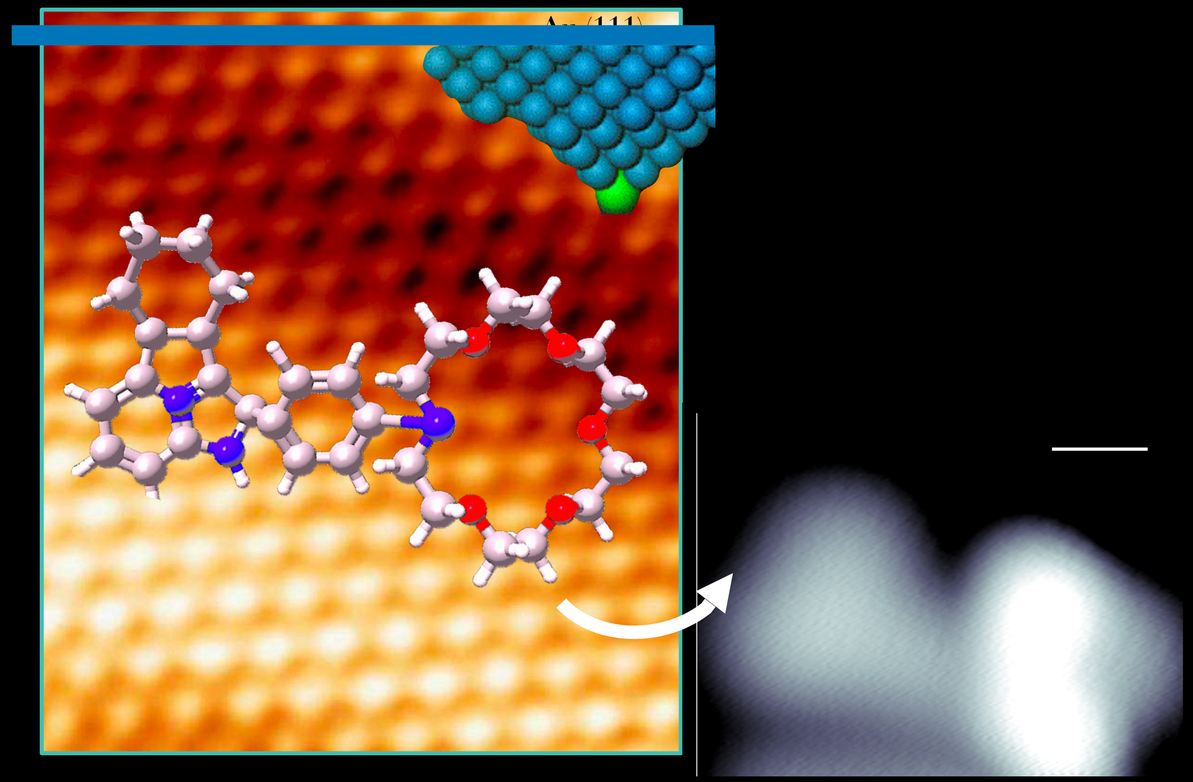

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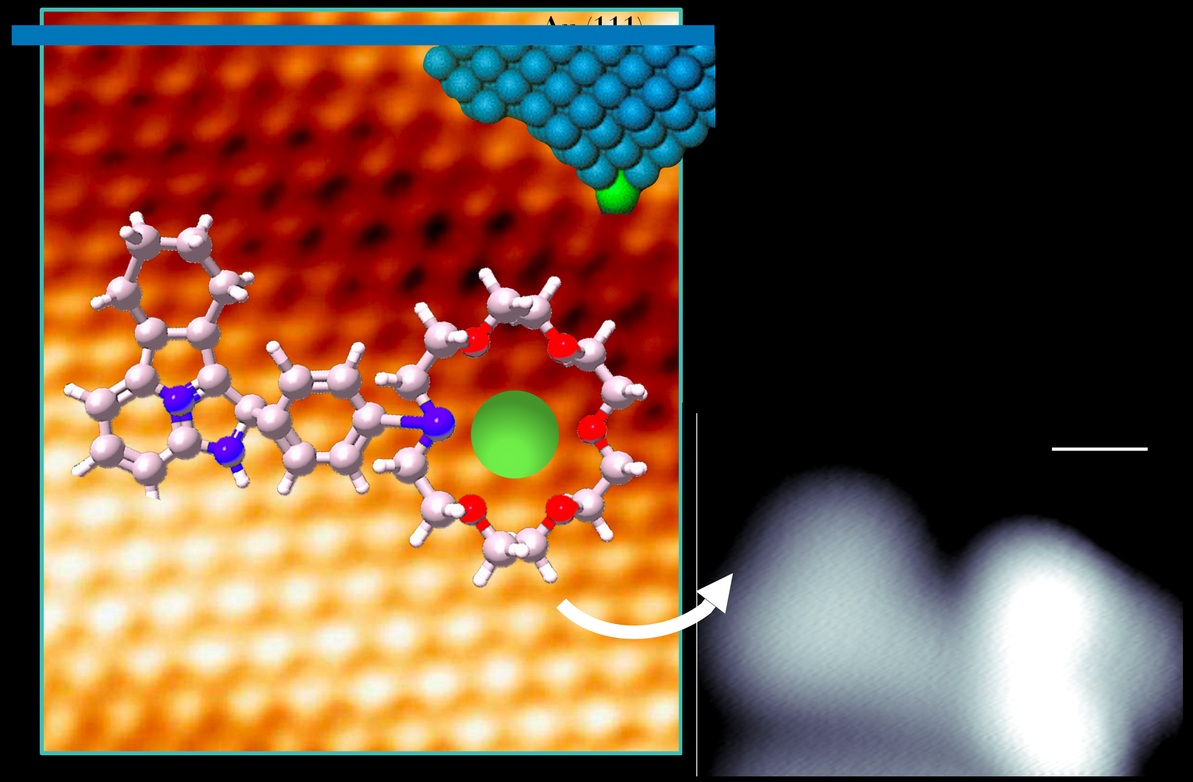

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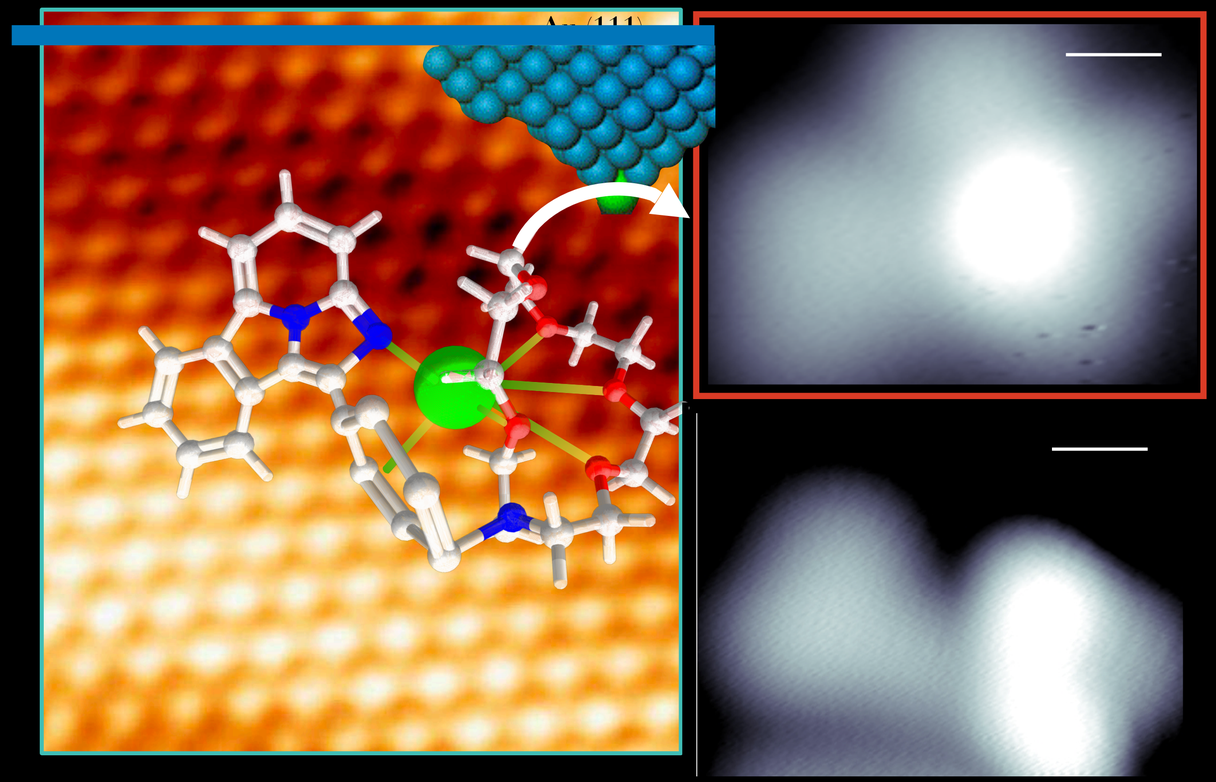

First unambiguous proof of Ba^{2+} chelation by fluorescent indicators in UHV

1.FBI molecules were deposited on Au (111) in sub-monolayer regime.

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4. Clear topological change is visible, indicating coordination with the ion.

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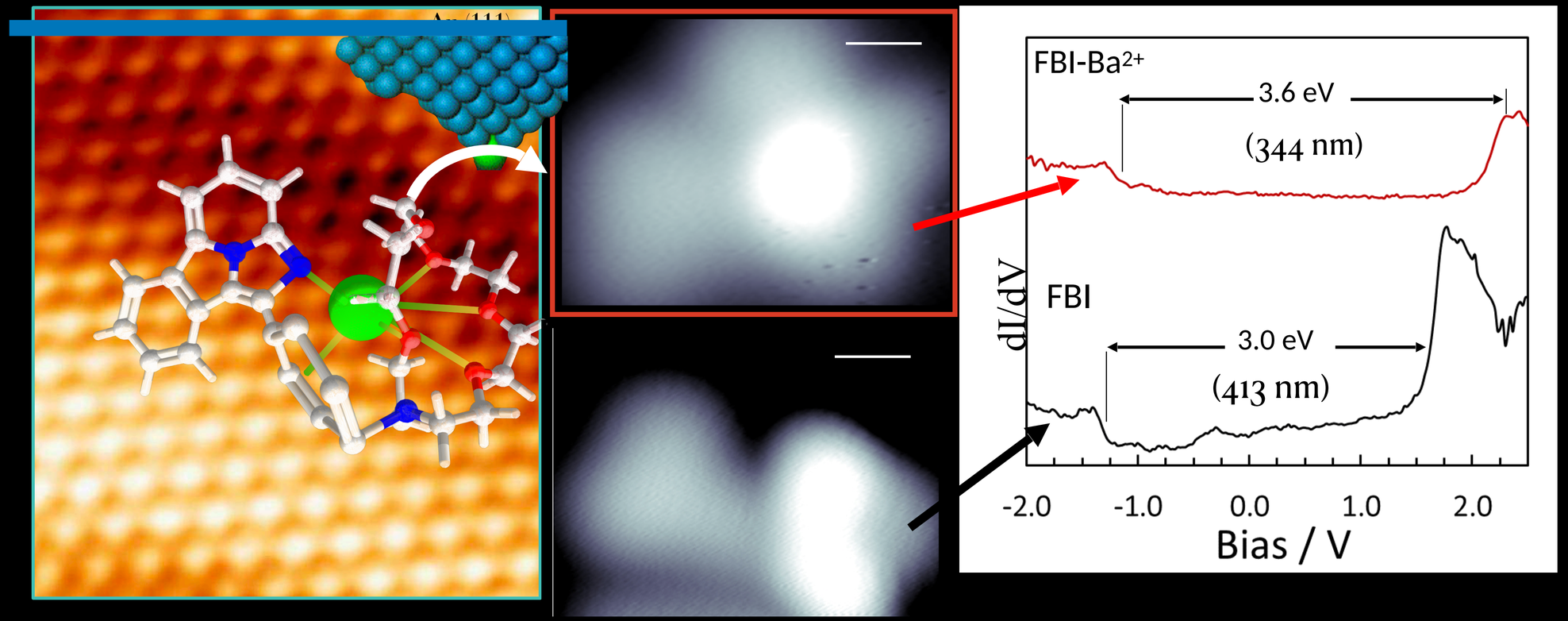

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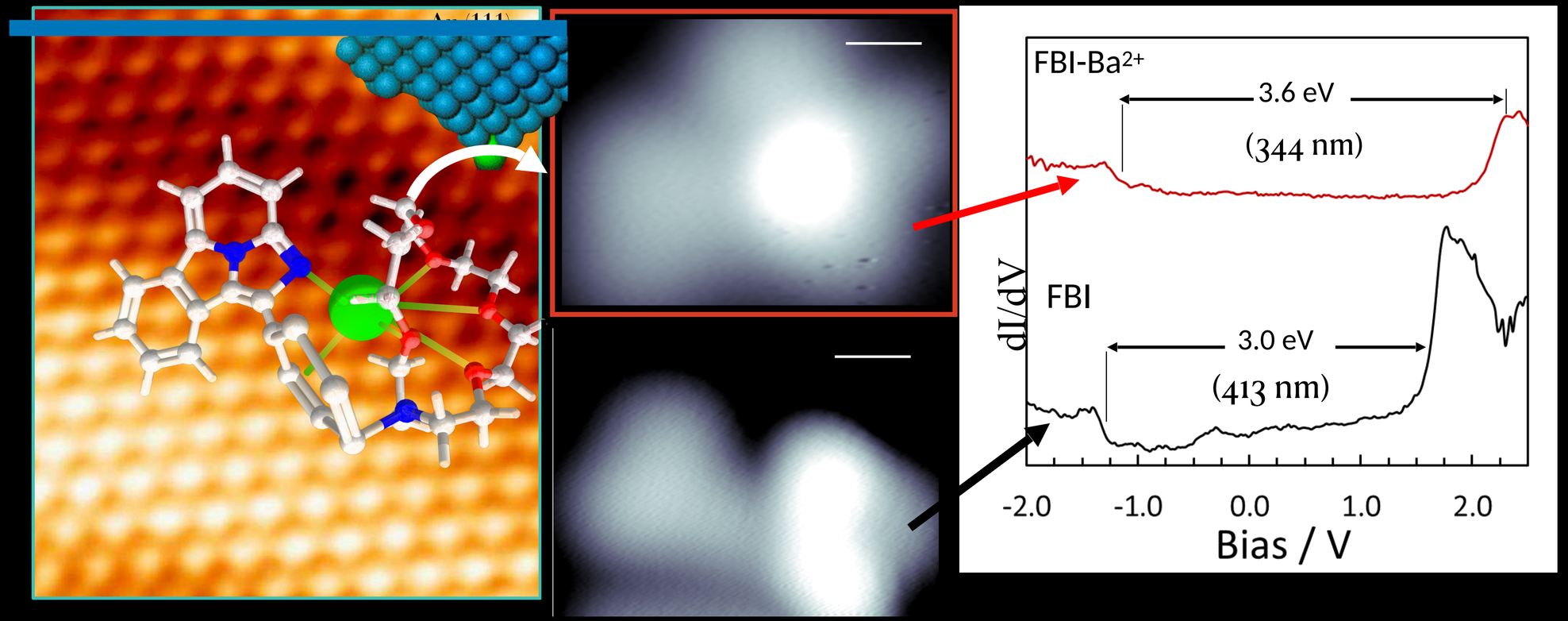

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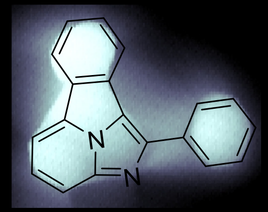
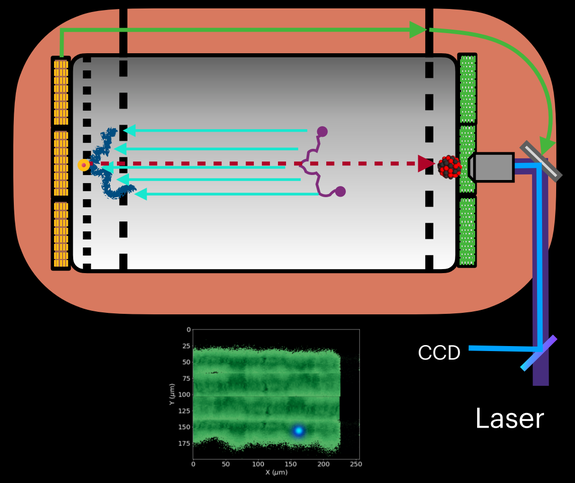
6.High resolution images of the fluorophore moiety were recorded as well.



Conclusions

- NEXT has developed dry-phase fluorescent sensors tuned to bind efficiently and selectively to Ba^{++}



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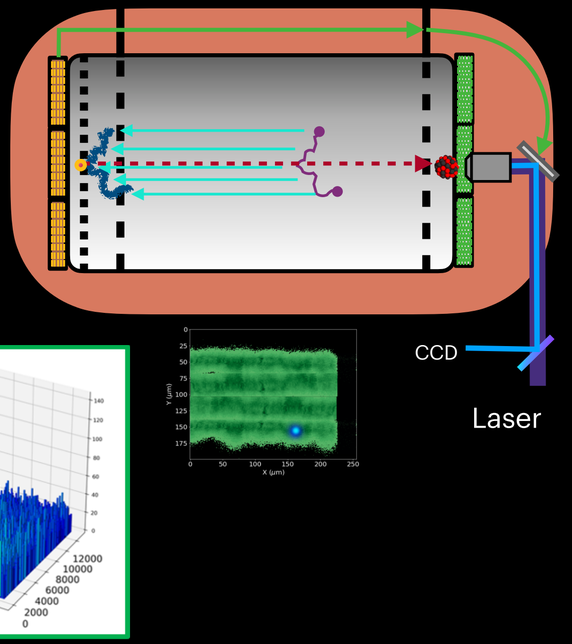

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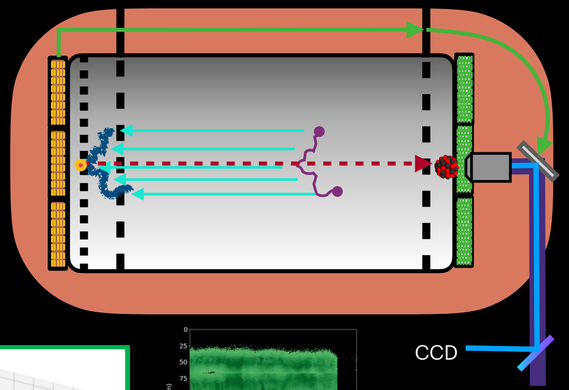
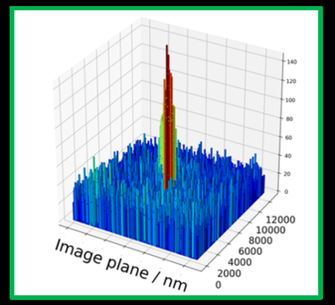
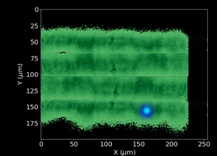
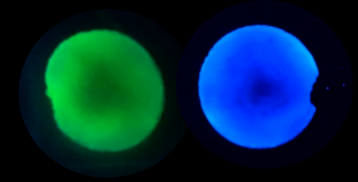
- This work: deposition of controlled molecular samples (up to the level of 1 ML) in metallic surfaces. Chelation takes place in vacuum with Ba^{++}.









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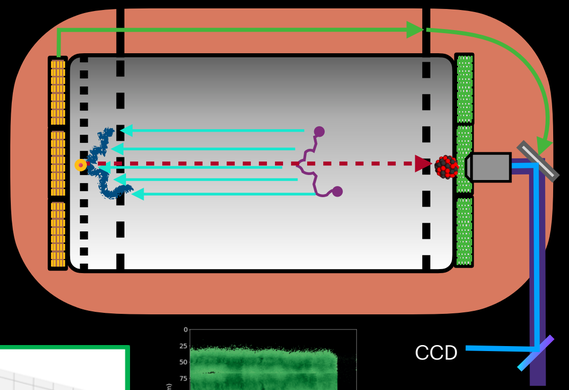
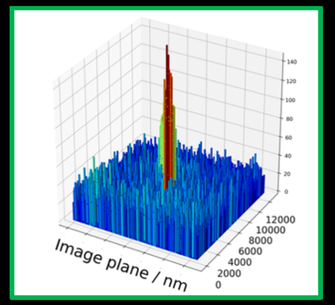
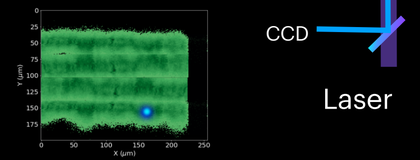
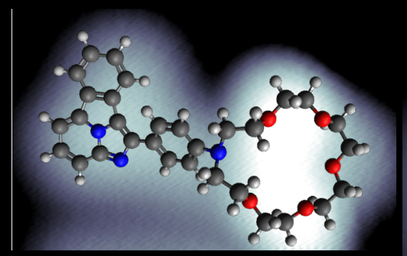
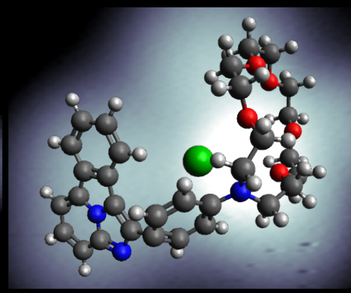
- The characteristic conformational change upon chelation with Ba^{++} was confirmed with STM-STS and is consistent with theoretical calculation (paper in preparation).











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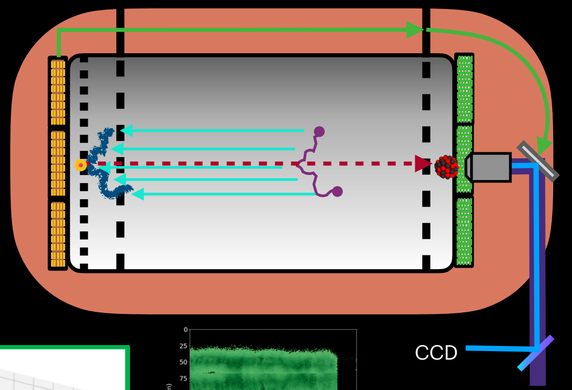
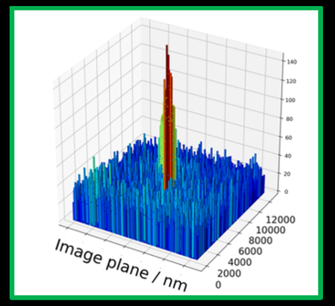
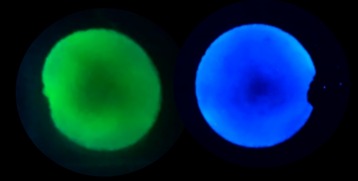
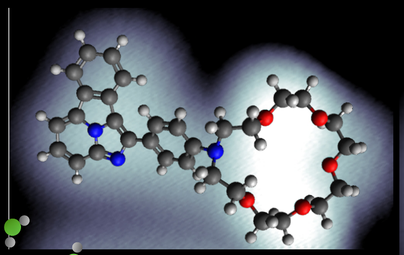
Conclusions

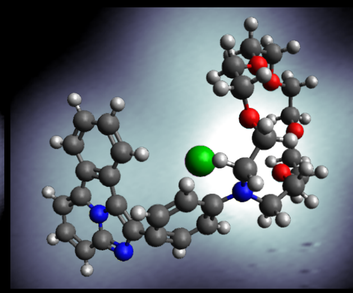
- NEXT has developed dry-phase fluorescent sensors tuned to bind efficiently and selectively to Ba^{++}
- High-Pressure Single Molecule microscopy is also being developed.
- This work: deposition of controlled molecular samples (up to the level of 1 ML) in metallic surfaces. Chelation takes place in vacuum with Ba^{++}.
- The characteristic conformational change upon chelation with Ba^{++} was confirmed with STM-STS and is consistent with theoretical calculation (paper in preparation).
- Realization of efficient, scalable barium tagging could enable a truly background-free technology!

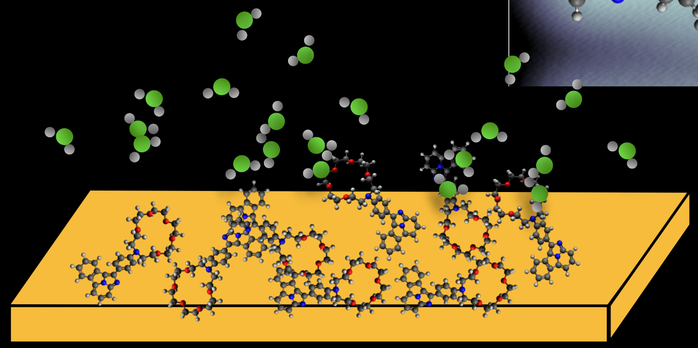












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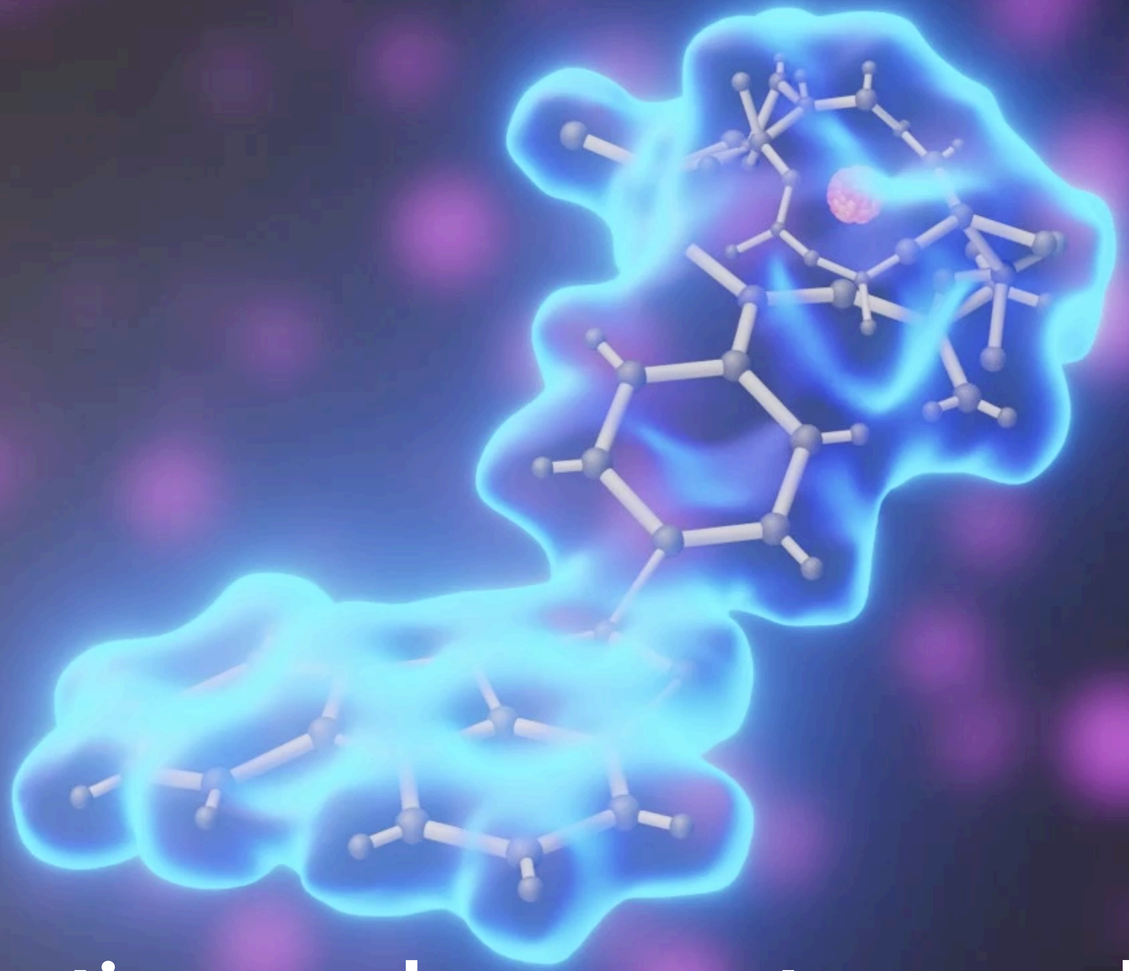
Thank you!



Questions and comments are welcome