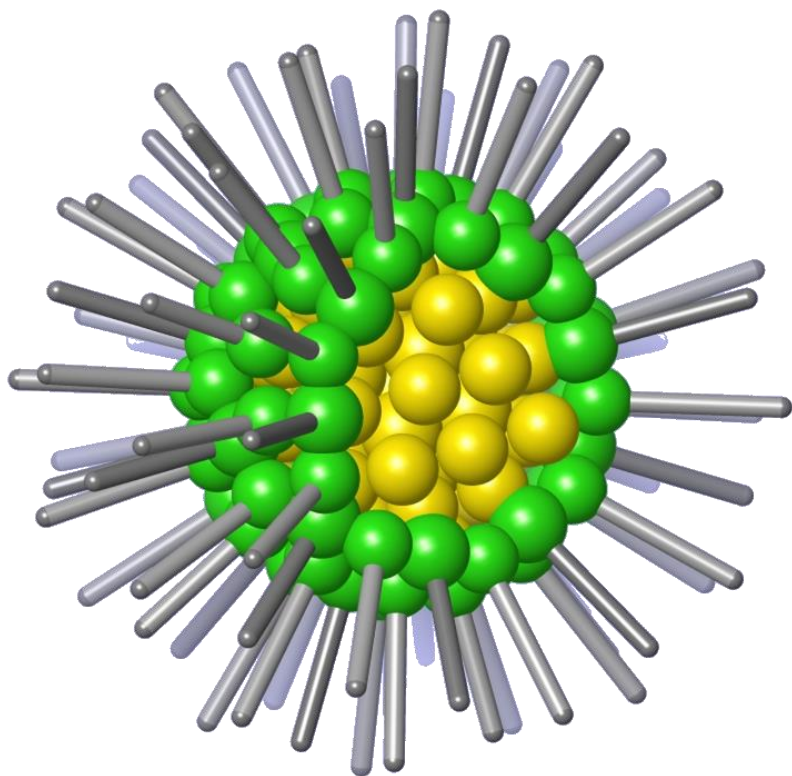


Affordable point-of-use drinking water purification using nanomaterials



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University of Alberta, July 3, 2014

Lab to market

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Partner agencies

Founder
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Associate Editor
ACS
Sustainable
Chemistry & Engineering

Distinguished Professor
South African Research Chair Initiative (SARChI)

Government of India
Department of Science and Technology
State Governments
West Bengal, Bihar, Uttar Pradesh

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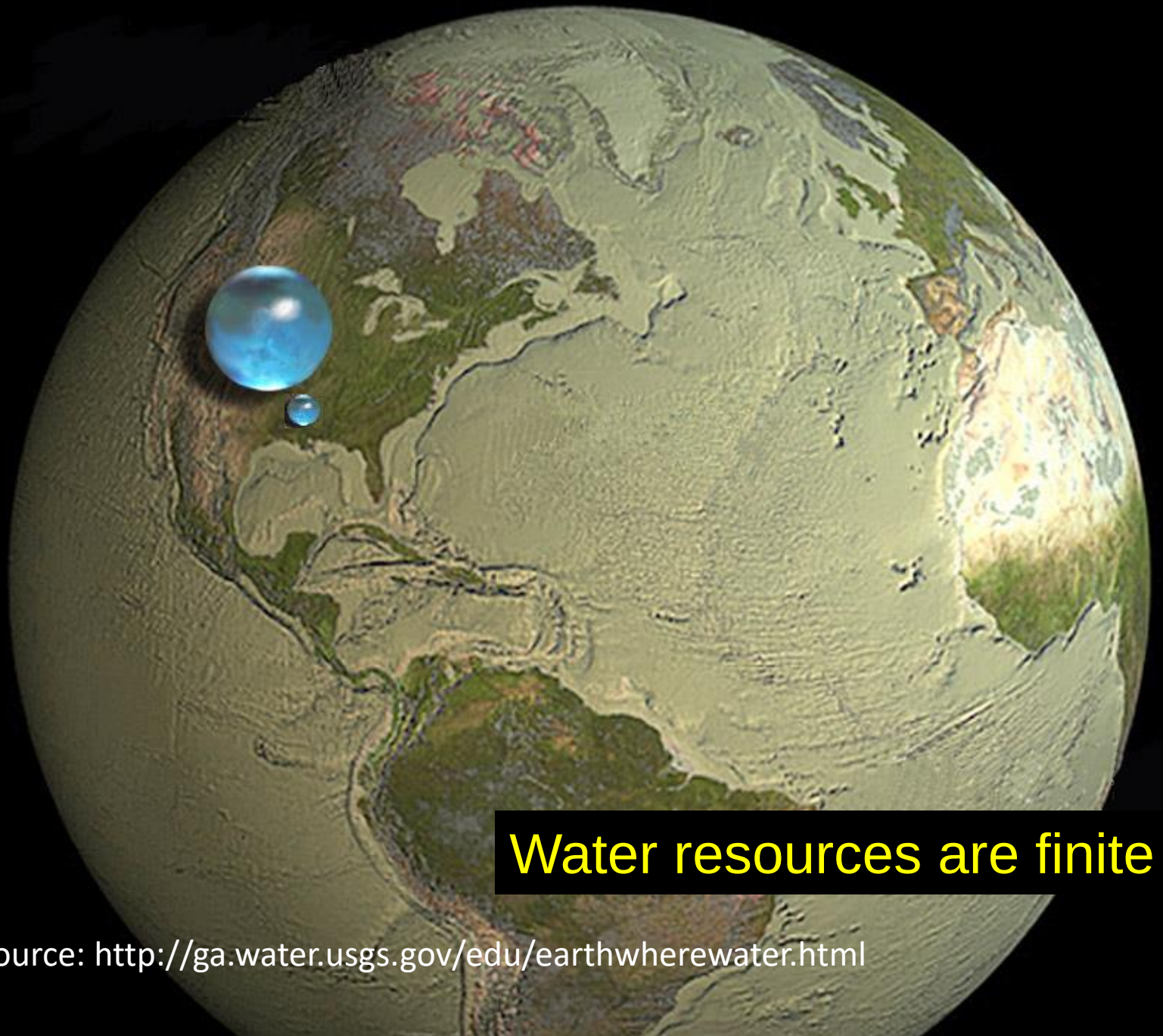
Academic zone

IIT Madras, Chennai, Tamil Nadu India

Residential zone

Research Park

Hostel zone

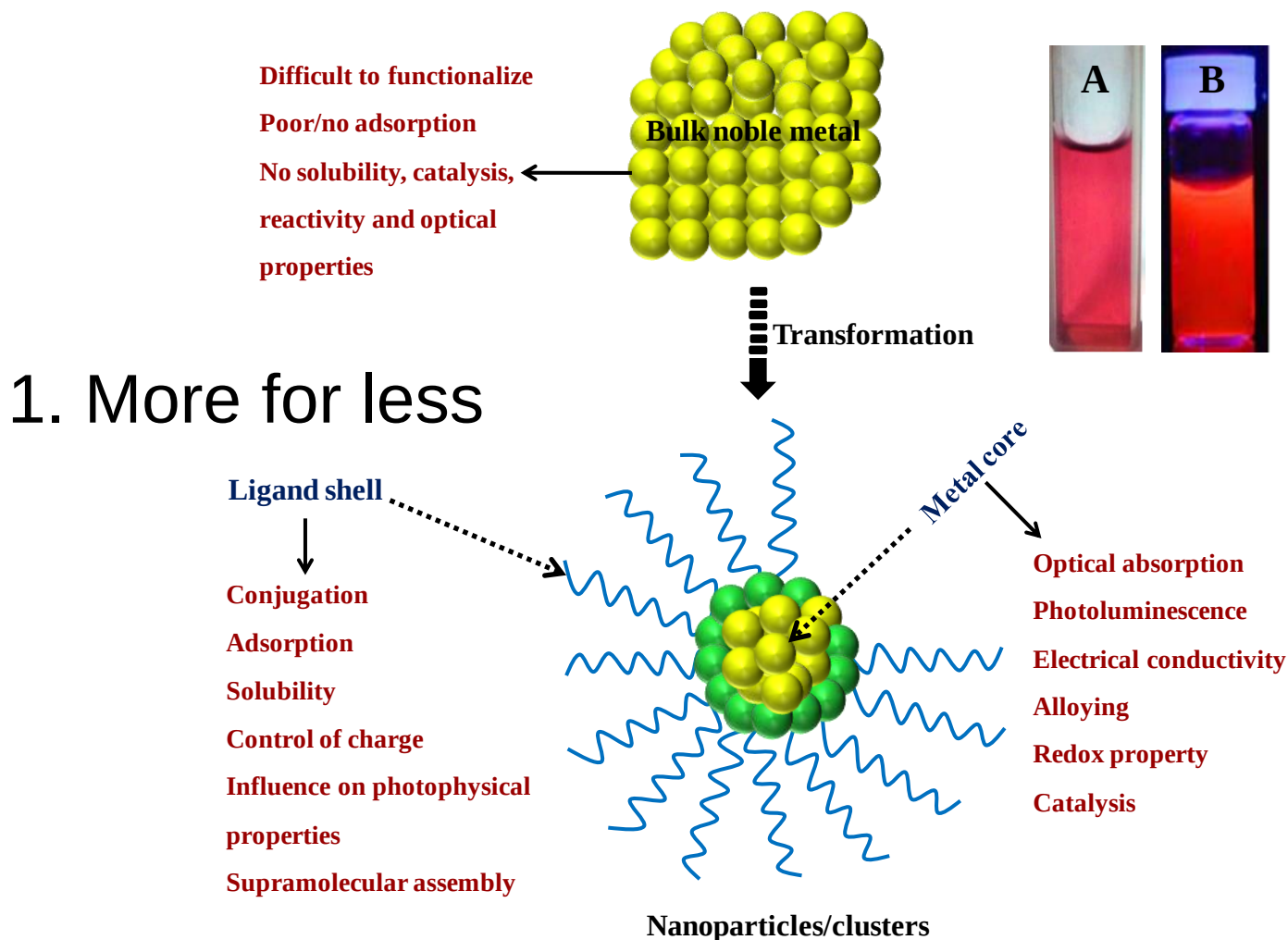


Water resources are finite

Source: <http://ga.water.usgs.gov/edu/earthwherewater.html>

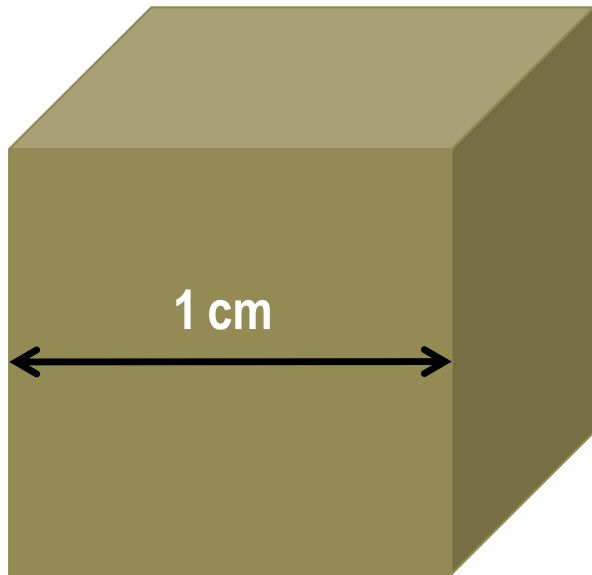
Why nanotechnology?

10^{-9}



1. More for less

Variation in properties originating from ligand shell and metal core as bulk noble metals transform to nanoparticles/clusters. Sizes are not to scale. New properties such as color and photoluminescence arise in such size regime. Photographs of Au@citrate nanoparticles (inset A) showing intense absorption of visible light and Au@SG (SG corresponds to glutathione thiolate) clusters (inset B) showing intense photoluminescence upon ultraviolet irradiation (from the author's work).

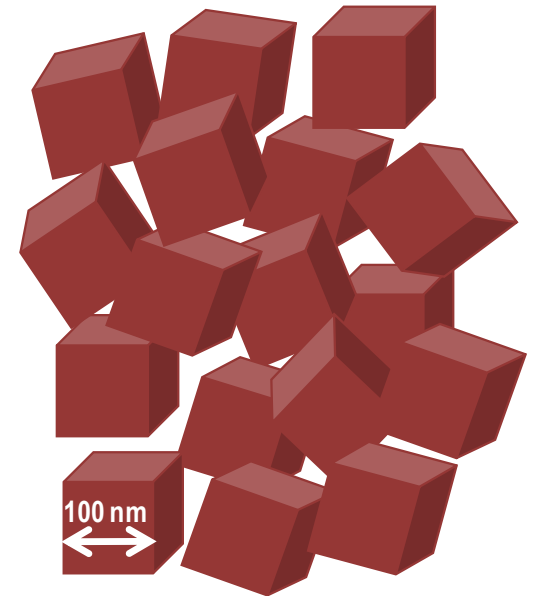


Bulk noble metal

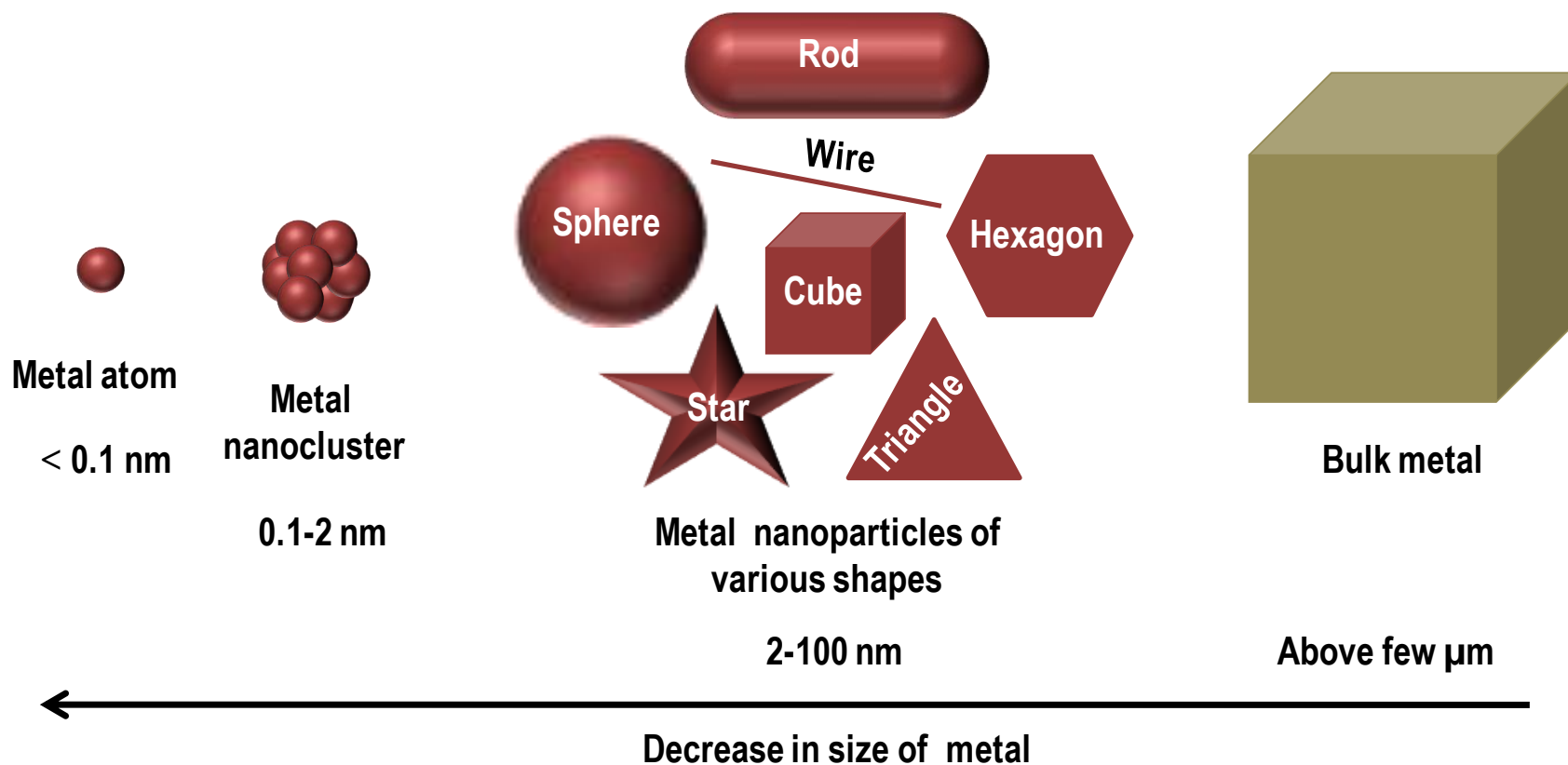
Reduction of size



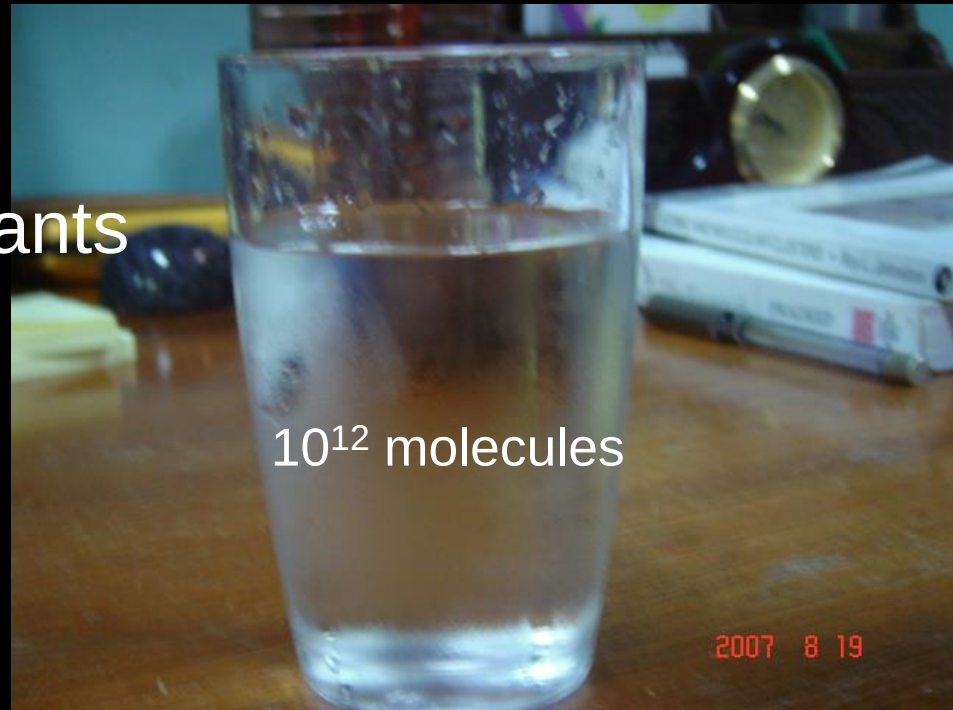
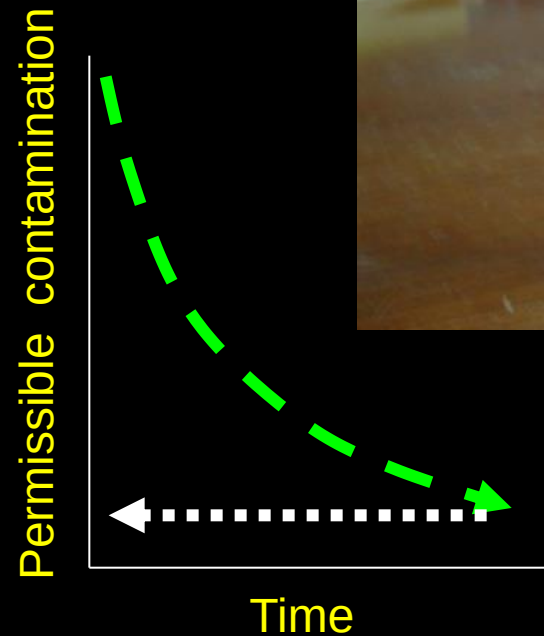
**Surface area
increases by 10^5**



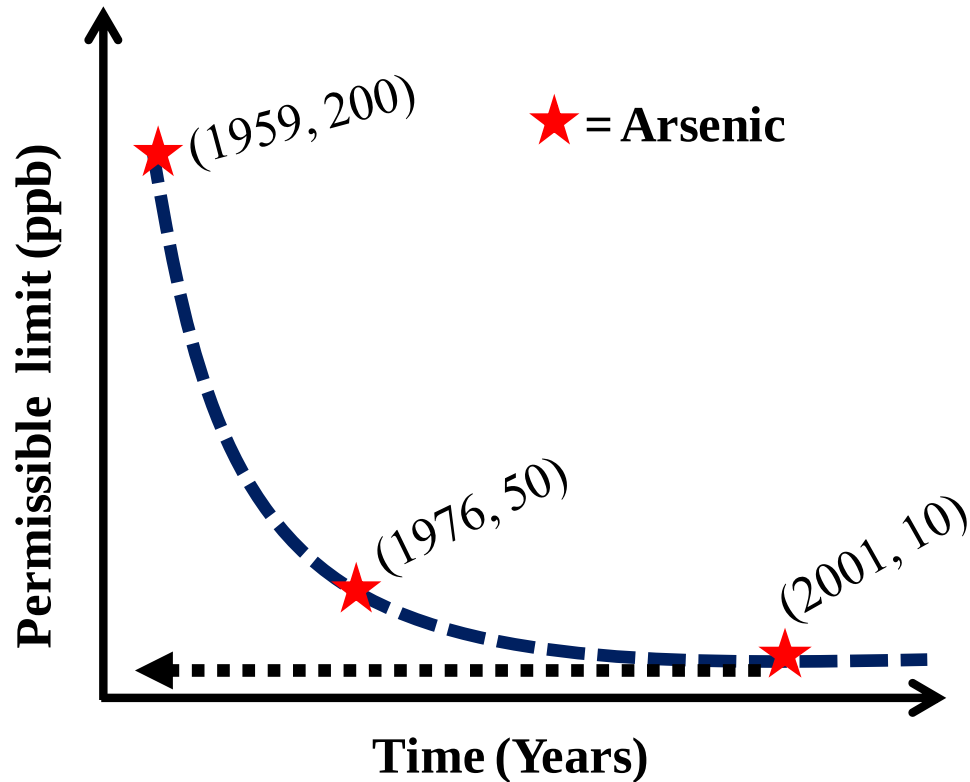
Noble metal of smaller size



2. Limits of contaminants

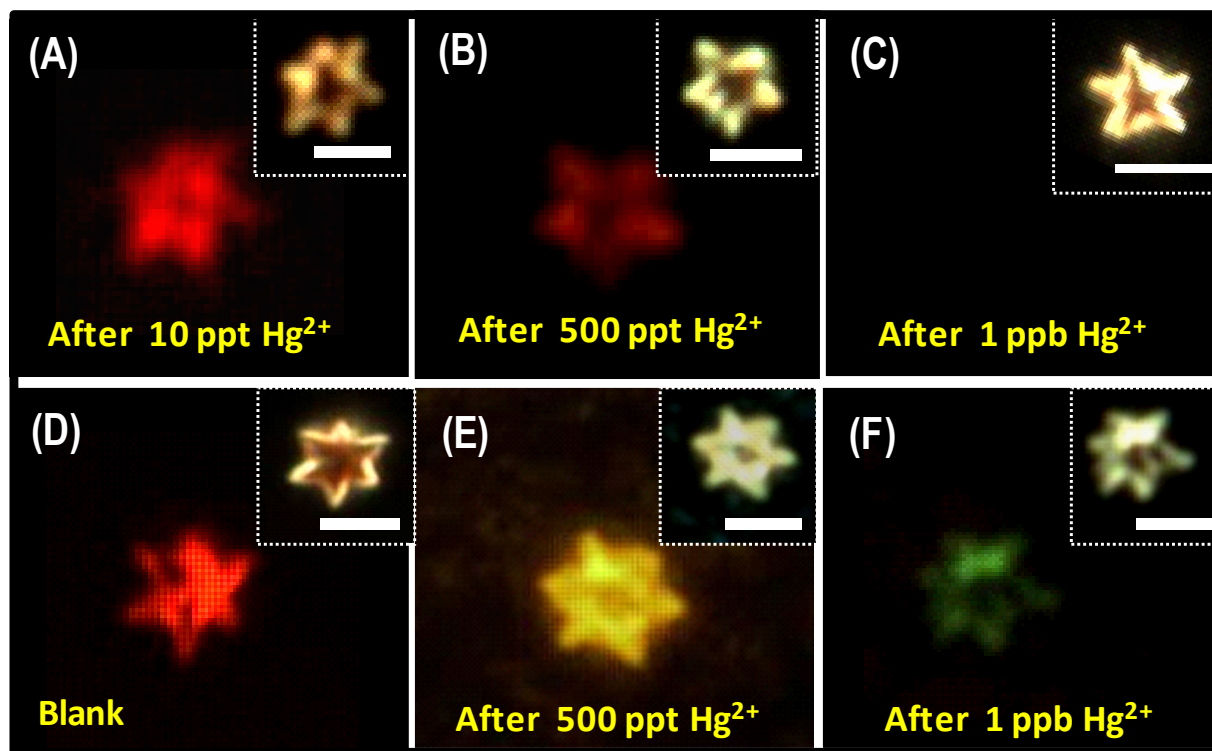


Permissible contamination reaches limits of detection



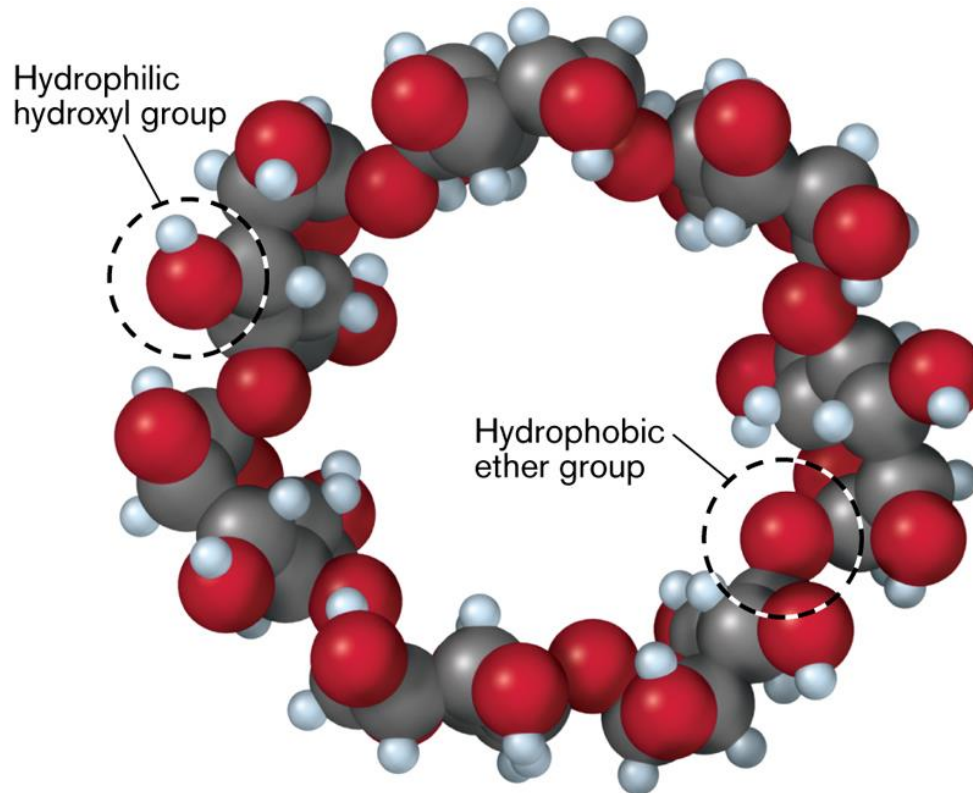
Decrease in the permissible limit of arsenic in drinking water, according to US EPA, with time. The graph indicates a general trend.

3. Can we reach limits?



(A)–(C) Dark field fluorescence images of $\text{Au@SiO}_2\text{@Ag}_{15}$ MFs showing the gradual disappearance of luminescence with increasing Hg^{2+} . (D)–(F) Fluorescence images showing variation in color during the addition of Hg^{2+} of different concentrations to $\text{Au@SiO}_2\text{-FITC@Ag}_{15}$ MFs. Insets in all images show the corresponding optical images of the MFs; scale bars are 3 μm .

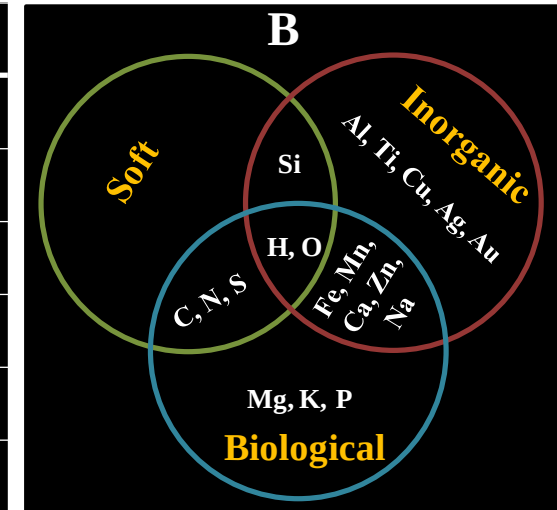
Cavities, channels, imprints, assemblies, fibres,



Materials in water – A simple view

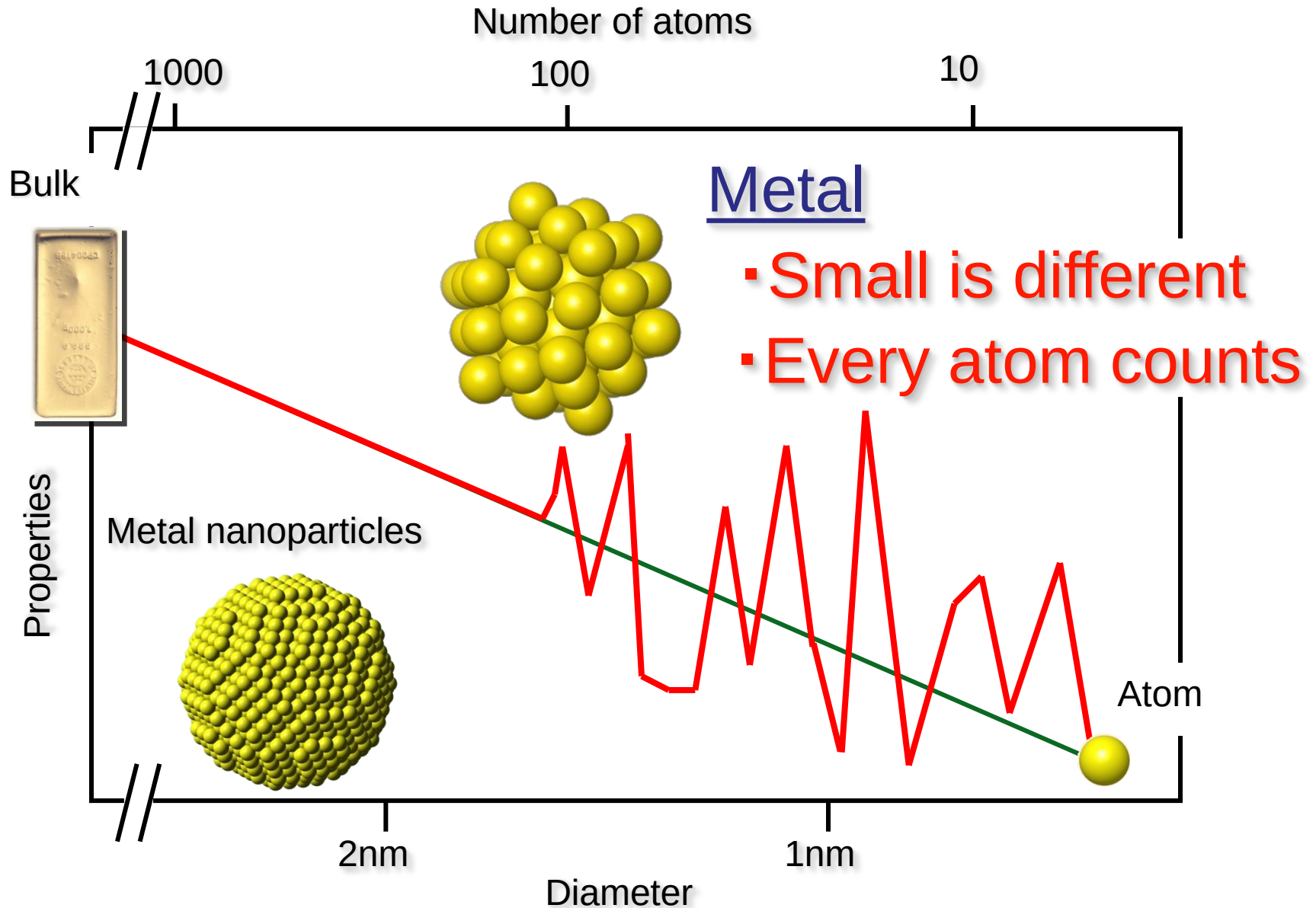
A

H 0.1	Be																	He
Na 2.8	Mg 2.0																	Ne
K 2.6	Ca 3.6	Ti 0.4				Mn 0.1		Fe 5.0										Ar
																		Kr
																		Xe
																		Rn



(A) Periodic table of elements and those used for water purification (highlighted). Abundances (in wt %)² of the highlighted elements in earth's crust are also mentioned. Note: The highlighted elements are not exactly in their original positions of the periodic table for clarity. (B) Elements that can be grouped to create diverse materials used for water purification.

Metal Clusters



Magic clusters

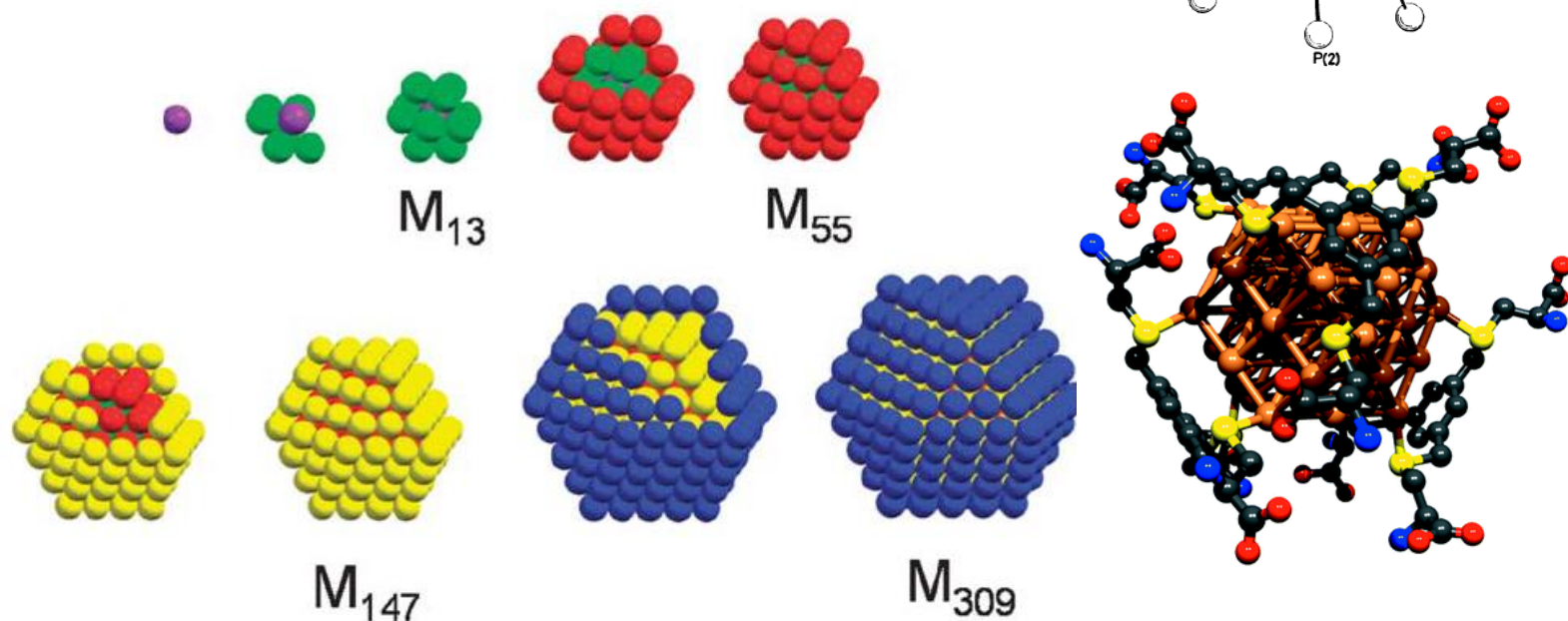
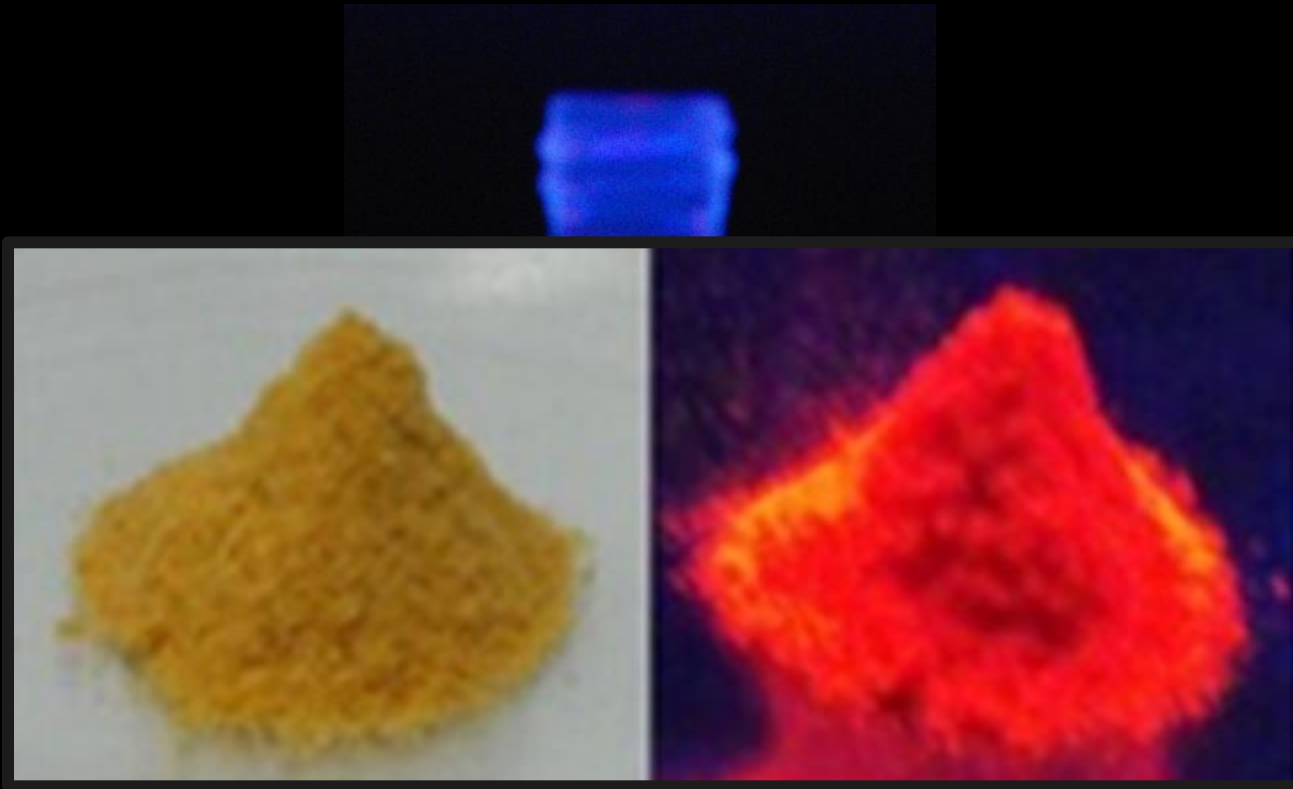
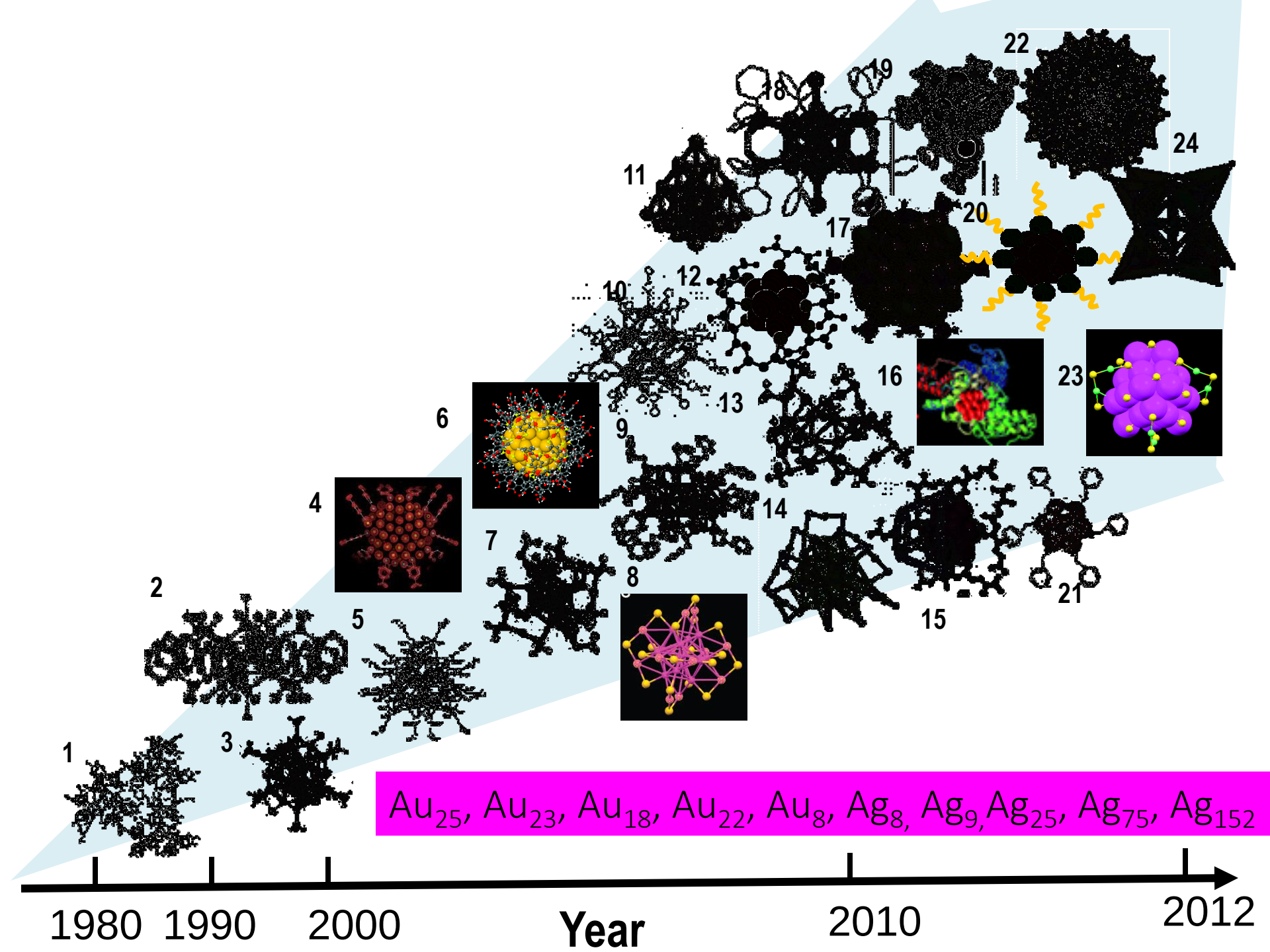


Fig. 1 Organization of full-shell clusters: a first single atom (purple) is surrounded by 12 others (green) to give a one-shell cluster M_{13} . 42 atoms (red) can be densely packed on the 12 green atoms ending with the M_{55} two-shell cluster, followed by 92 atoms (yellow) and 162 atoms (blue) to give M_{147} and M_{309} , respectively.



Shibhu, Habeeb, Uday, Kamalesh, Lourdu, Ammu, Ananya, Indranath, Atanu,....



New Protocols for the Synthesis of Stable Ag and Au Nanocluster Molecules

T. Udayabhaskararao and T. Pradeep*

DST Unit of Nanoscience (DST UNS), Thematic Unit of Excellence (TUE), Department of Chemistry, Indian Institute of Technology Madras, Chennai 600 036, India

ABSTRACT: “Catching” metals in the nonmetallic form in solution, as they grow to bulk, is one of the most exciting areas of contemporary materials research. A new kind of stabilization to catch the nonmetallic form of noble metals with small thiols has evolved as an exciting area of synthesis during the past decade. Gold clusters stay in the frontline of this research, yielding new “molecules” composed of a few to several hundreds of atoms. By taking guidelines from gold cluster research, various new protocols for silver nanoclusters were developed. In this Perspective, we highlight the recent advances on the synthesis of atomically precise silver, gold, and their alloy clusters with a special emphasis on silver. As a result of intense efforts of the recent past, clusters such as $\text{Ag}_{7,8}(\text{SR})_{7,8}$, $\text{Ag}_7(-\text{S}-\text{R}-\text{S}-)_4$, $\text{Ag}_9(\text{SR})_7$, $\text{Ag}_{32}(\text{SR})_{19}$, $\text{Ag}_{44}(\text{SR})_{30}$, $\text{Ag}_{140}(\text{SR})_{53}$, $\text{Ag}_{280}(\text{SR})_{140}$ and $\text{Ag}_{152}(\text{SR})_{60}$ (SR and S–R–S refer to thiolate and dithiolate ligands, respectively) were added to the literature. Moreover, “silver-covered” and “gold-covered” alloy clusters have also been synthesized. Early reports of the crystallization of such clusters are available. Several of these clusters are shown to act as sensors, catalysts, and pesticide degradation agents, which suggests that these materials may find applications in daily life in the foreseeable future.



Slow reduction

Diverse methods of synthesis

Udayabhaskararao et al. J. Am. Chem. Soc. **2010**, 132, 16304

Indranath et al. Nano Lett. **2012**, 12, 5861

Anindya et al. J. Nanoparticle Res. (In Press)

Udayabhaskararao et al. J. Phys. Chem. C **2012** (Revision)

Udayabhaskararao et al. J. Nanoparticle Res. **2013** (Preparation)

Indranath et al. J. Haz. Mater. **2012**, 211-212, 396

Aditi and T. Pradeep J. Phys. Chem. C **2012**, 116, 14057

Remya et al. J. Phys. Chem. C, **2012**, 116, 26019

Inside gels

Indranath et al. Chem. Commun. **2012**, 48, 859

Dhanalakshmi et al. Chem. Commun. **2012**, 48, 6788

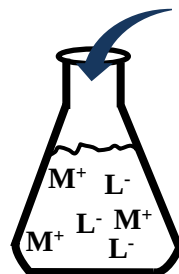
Shibu and T. Pradeep, Chem. Mater. **2011**, 23, 989

Shibu et al. J. Phys. Chem C **2008** 112, 12168

Shibu et al. ACS Appl. Mater. Interfaces, **2009**, 1, 2199

Habeeb et al. Nano Res. **2008**, 1, 333

Solid state route



Habeeb et al. Chem. Eur. J. **2009**, 15, 10110

Udayabhaskararao et al. Angew. Chem. Int. Ed. **2010**, 49, 392

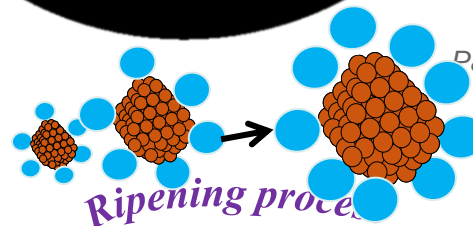
Mrudula et al. J. Mater. Chem. **2009**, 19, 4335

Interfacial etching

New methods to create noble metal clusters

Clusters -
where each atom
is important

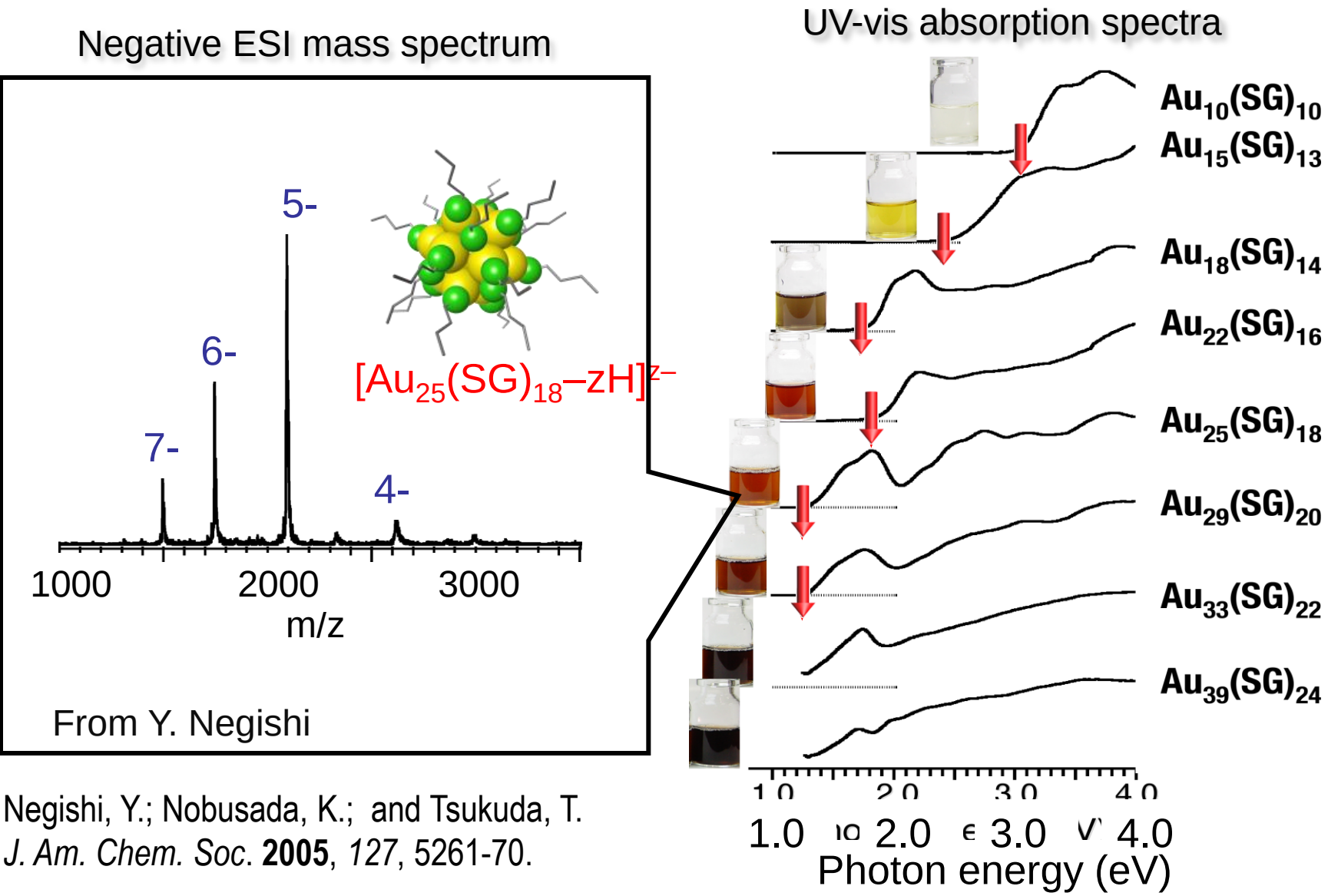
Size focusing



Part. Part. Syst. Char. (2013)

T. Udayabhaskararao and T. Pradeep, J. Phys. Chem. Lett. **4** (2013) 1553–1564

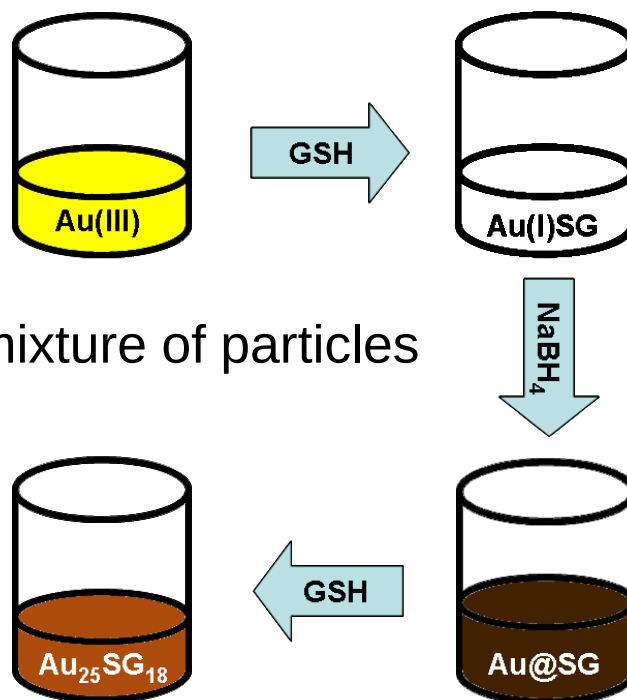
Systematic Isolation of Glutathione-Protected Gold clusters



Negishi, Y.; Nobusada, K.; and Tsukuda, T.
J. Am. Chem. Soc. **2005**, 127, 5261-70.

$\text{Au}_{25}\text{SG}_{18}$

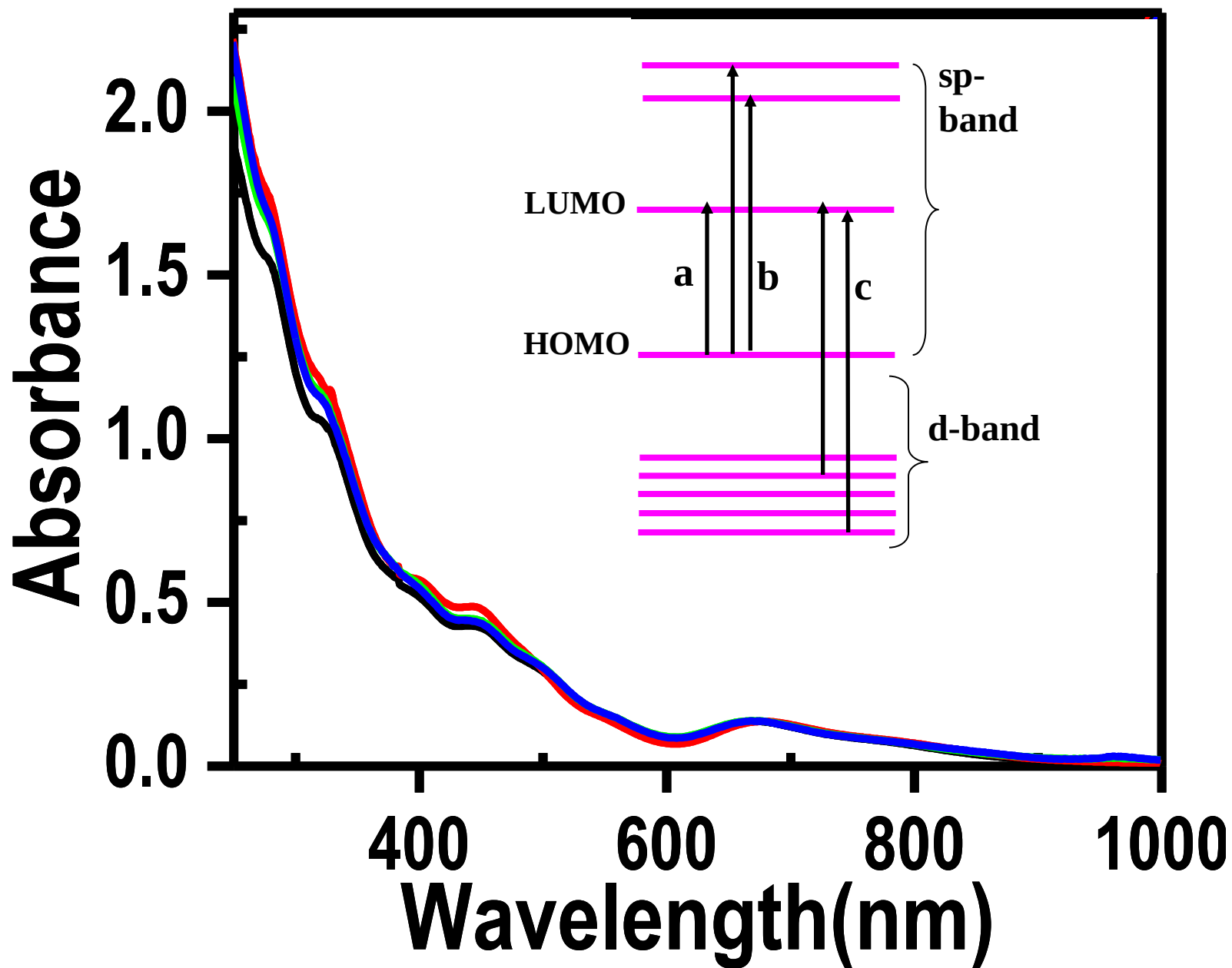
Synthesis: Au_{25} clusters can be preferentially populated by dissociative excitation of larger precursors



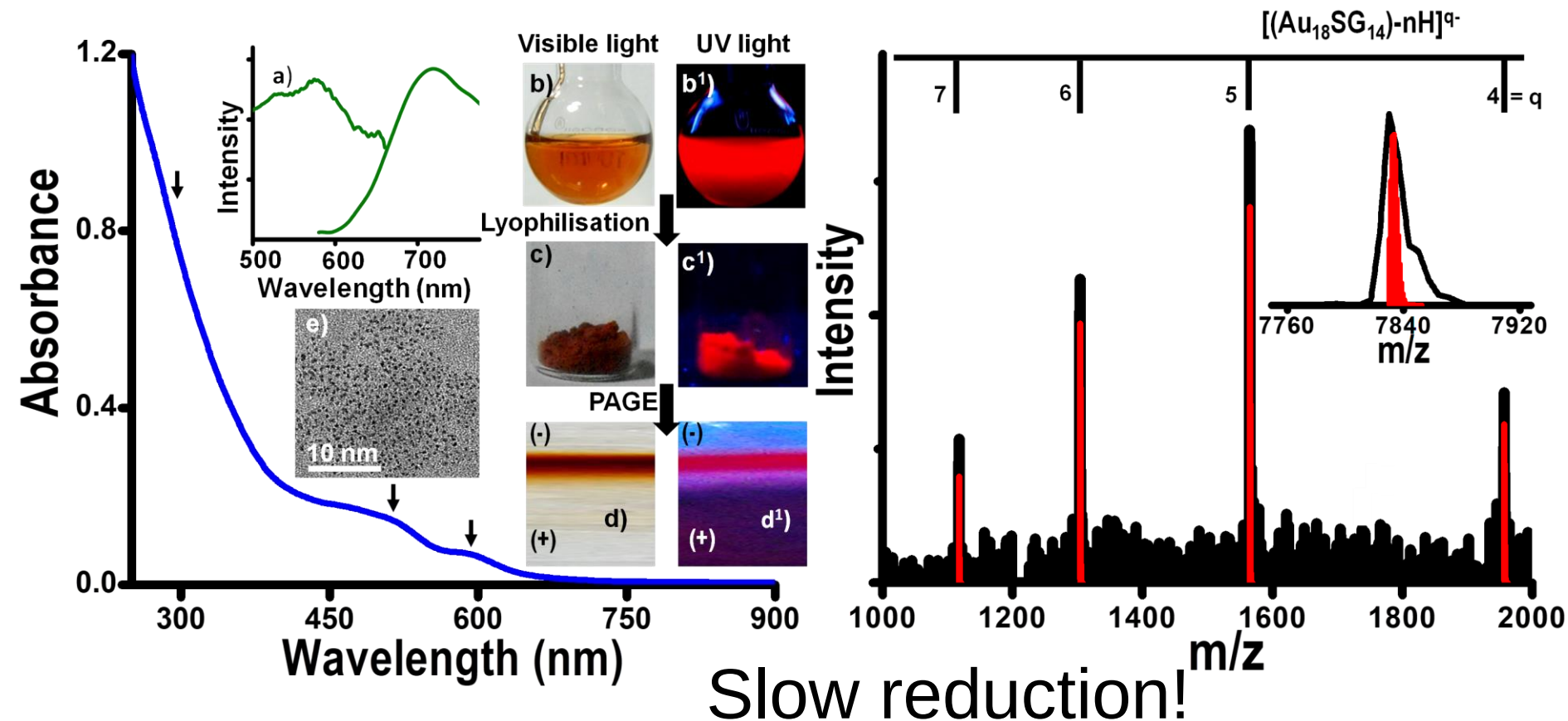
Direct synthesis from mixture of particles



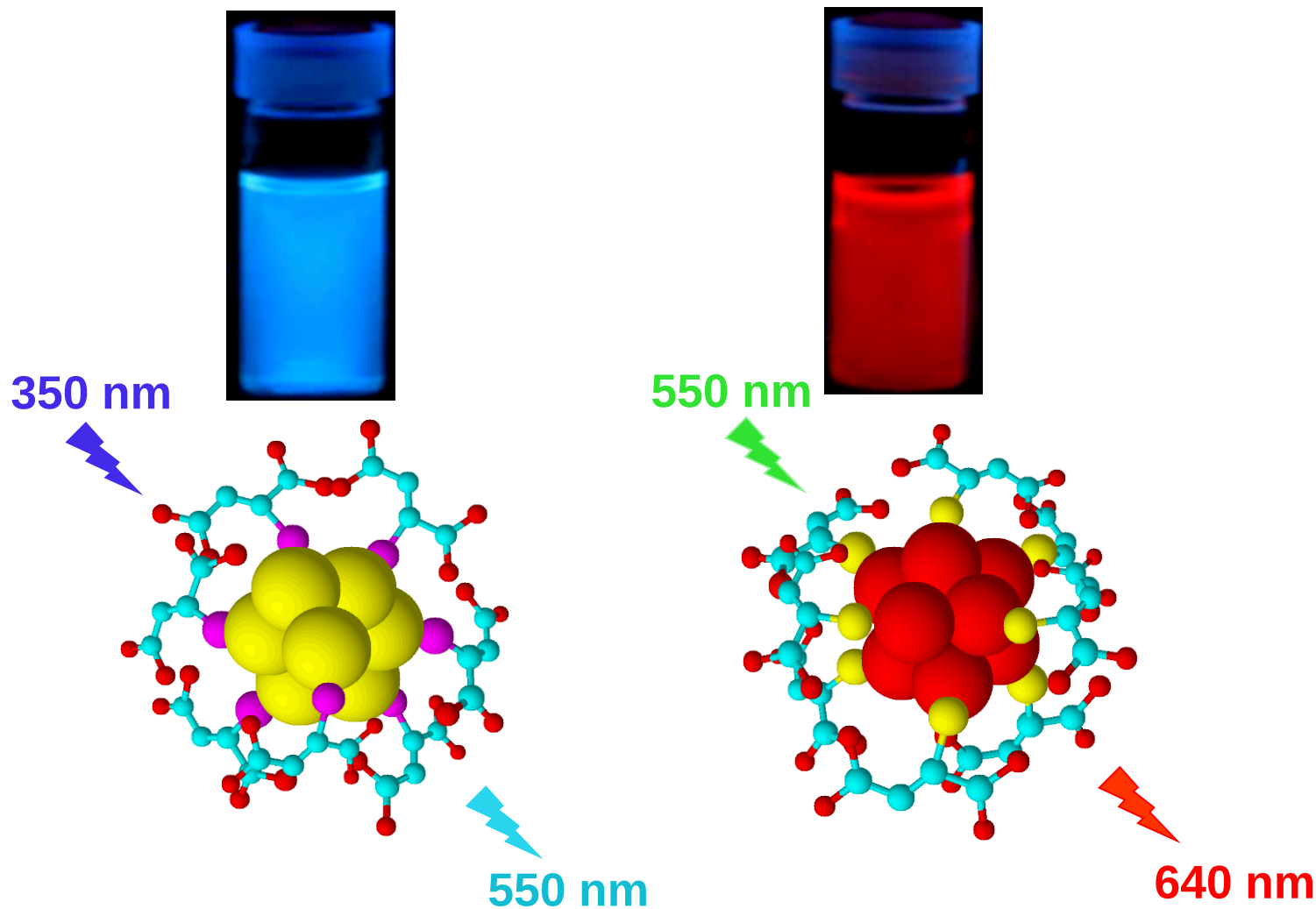
Scheme showing the synthesis of $\text{Au}_{25}\text{SG}_{18}$ clusters



One step methods - $\text{Au}_{18}\text{SG}_{14}$



Silver clusters - interfacial etching



TUB Rao and T Pradeep, *Angew. Chem. Int. Ed.* 49 (2010) 3925-3929(2010).

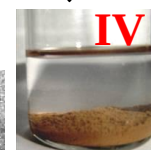
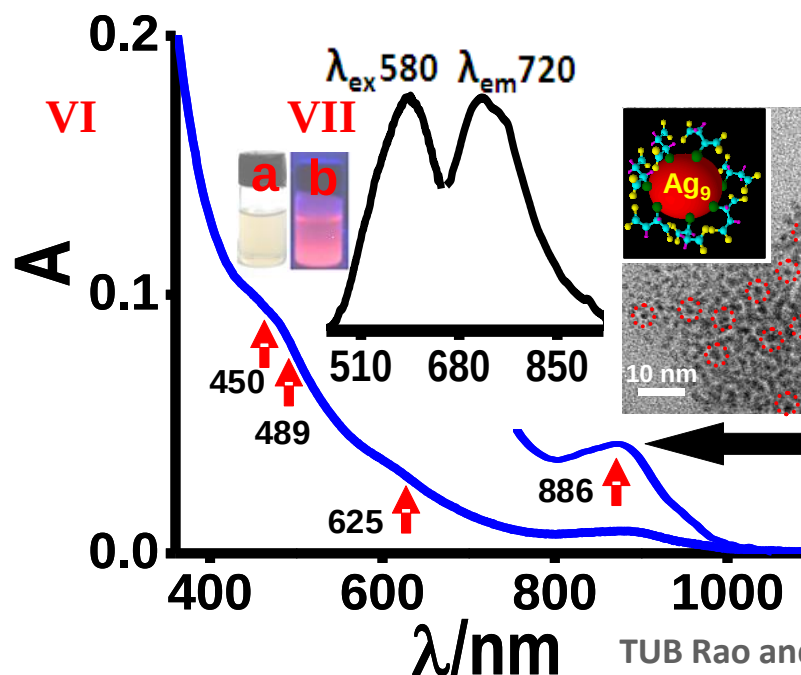
Ag₉MSA₇ - solid state synthesis



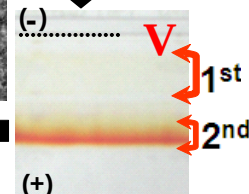
AgNO₃ + H₂MSA
(Initially both are colorless)

Became orange color

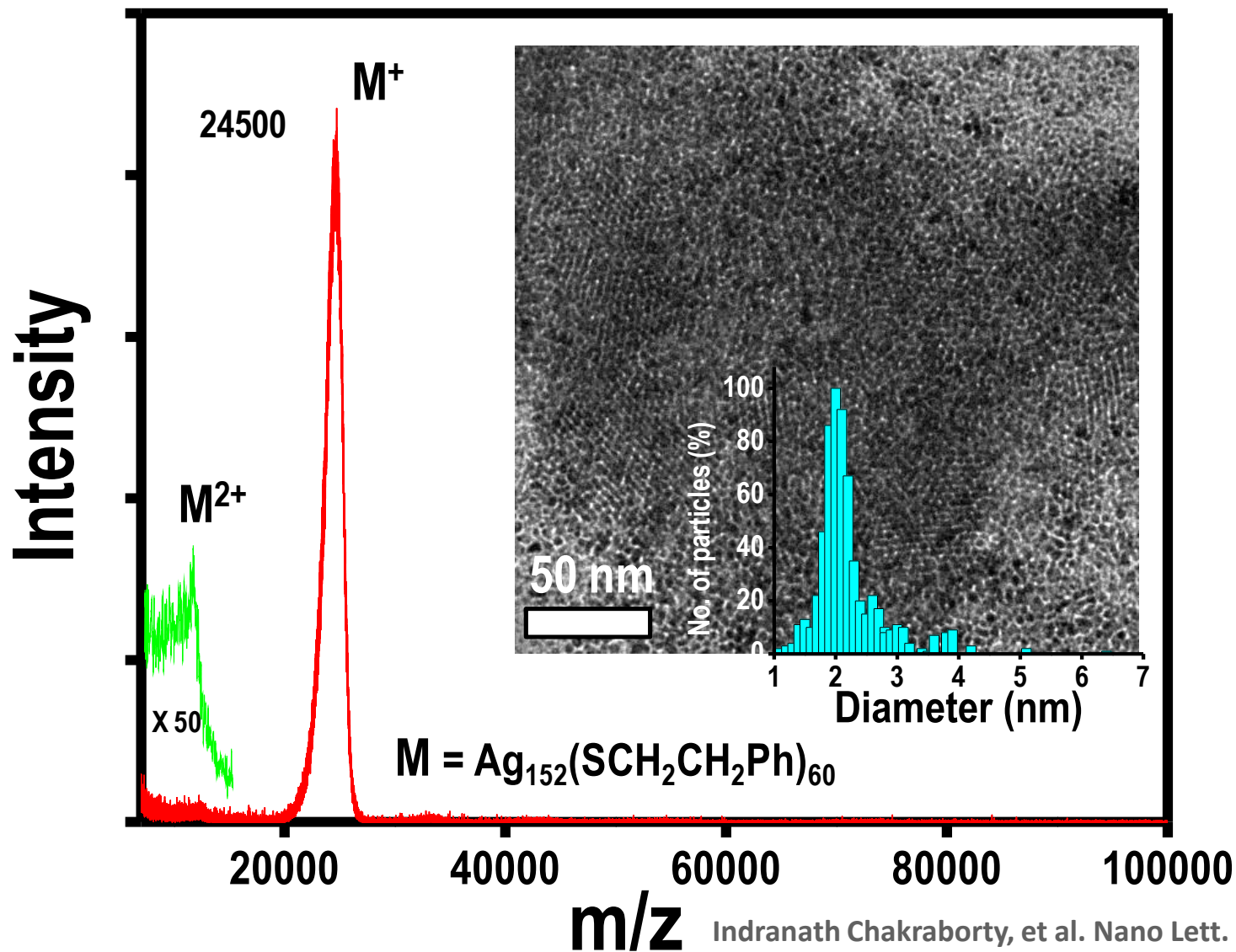
Water +
[Ethanol
(excess)]

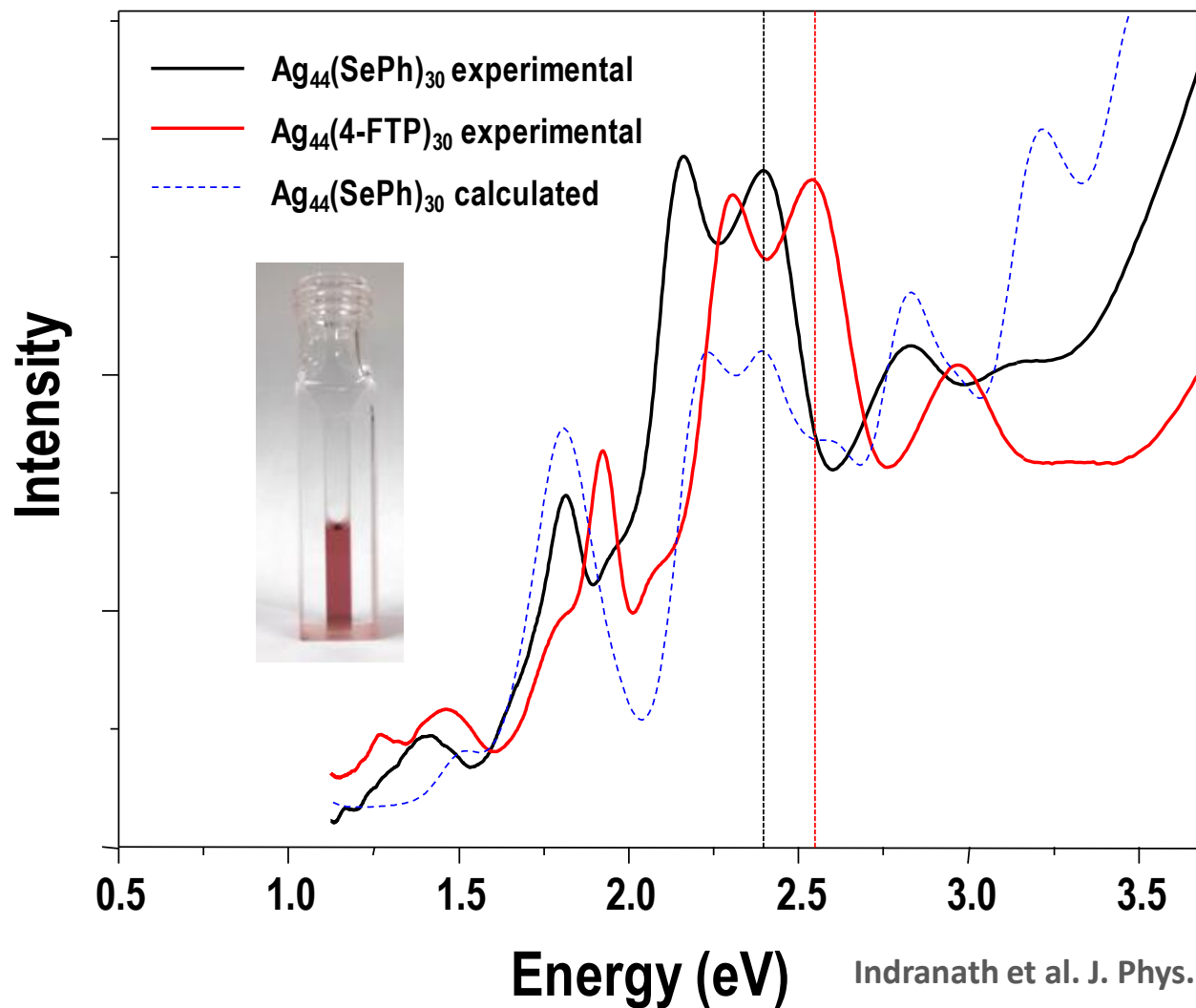


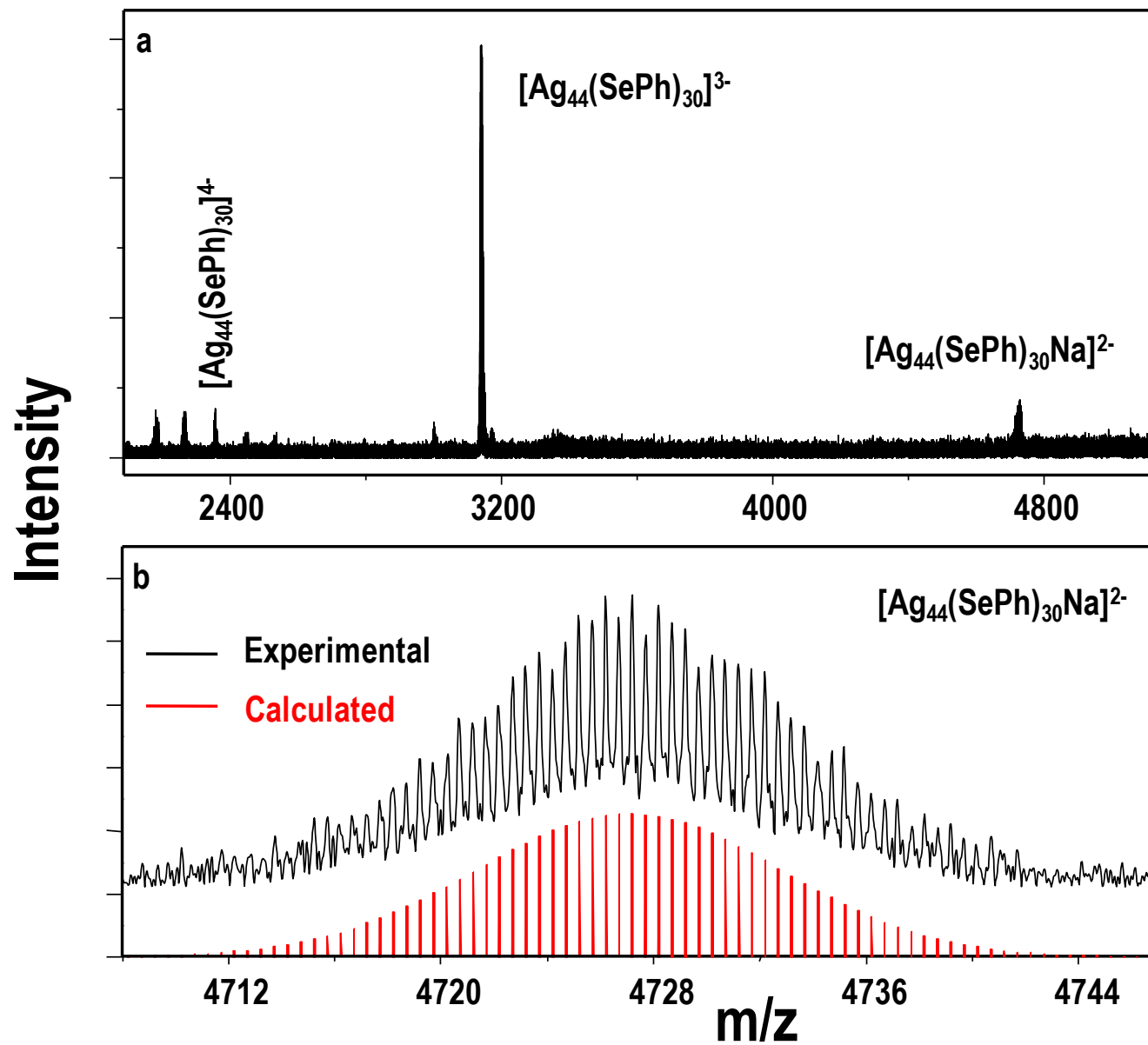
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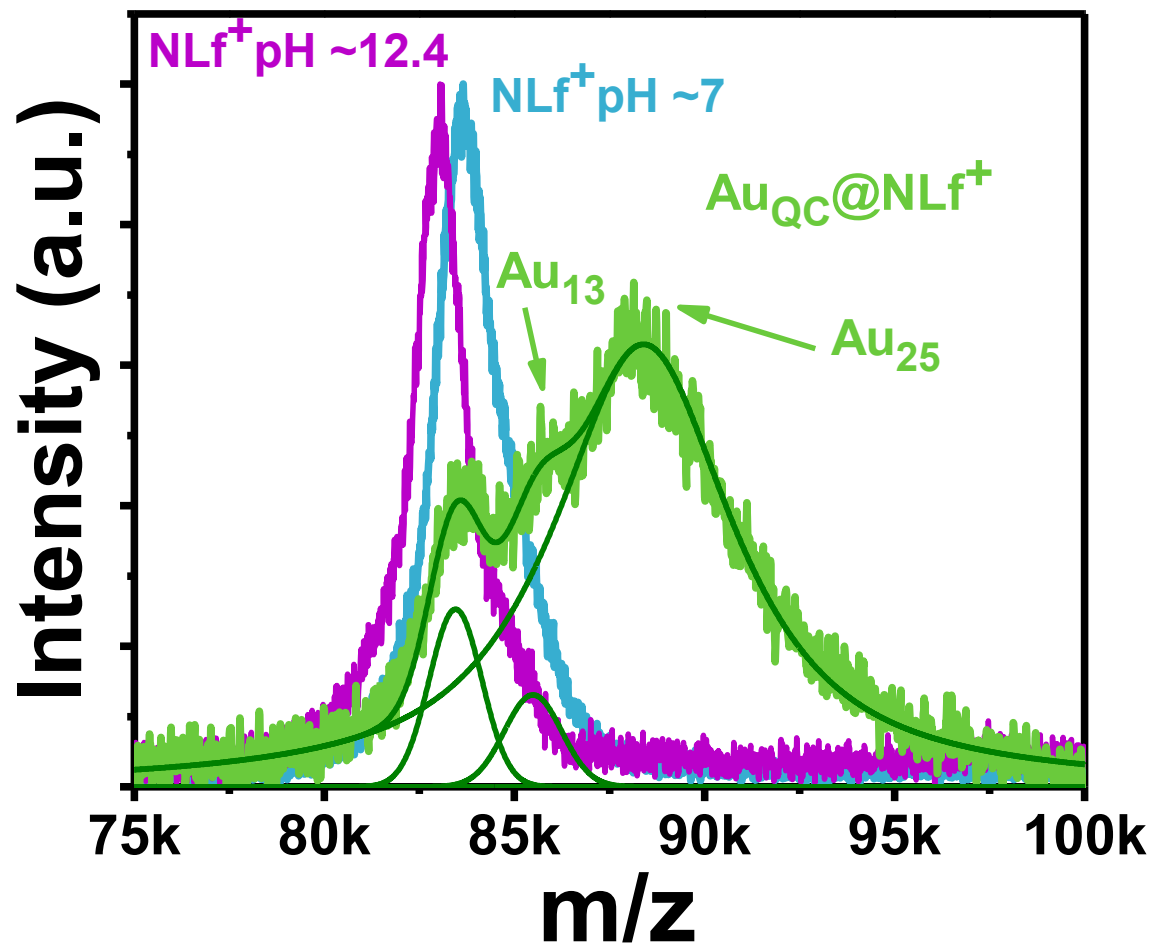
$\text{Ag}_{152}\text{PET}_{60}$







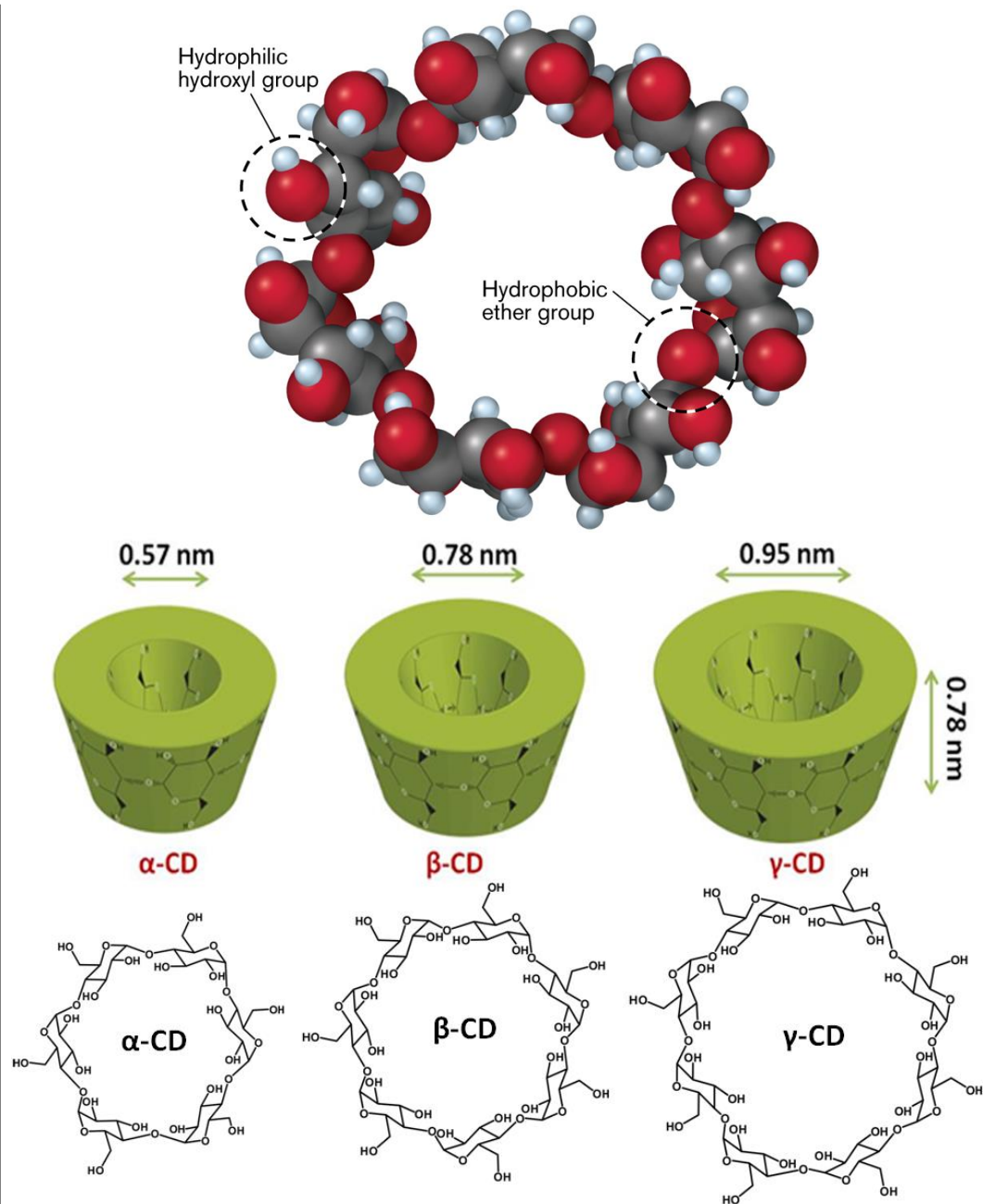
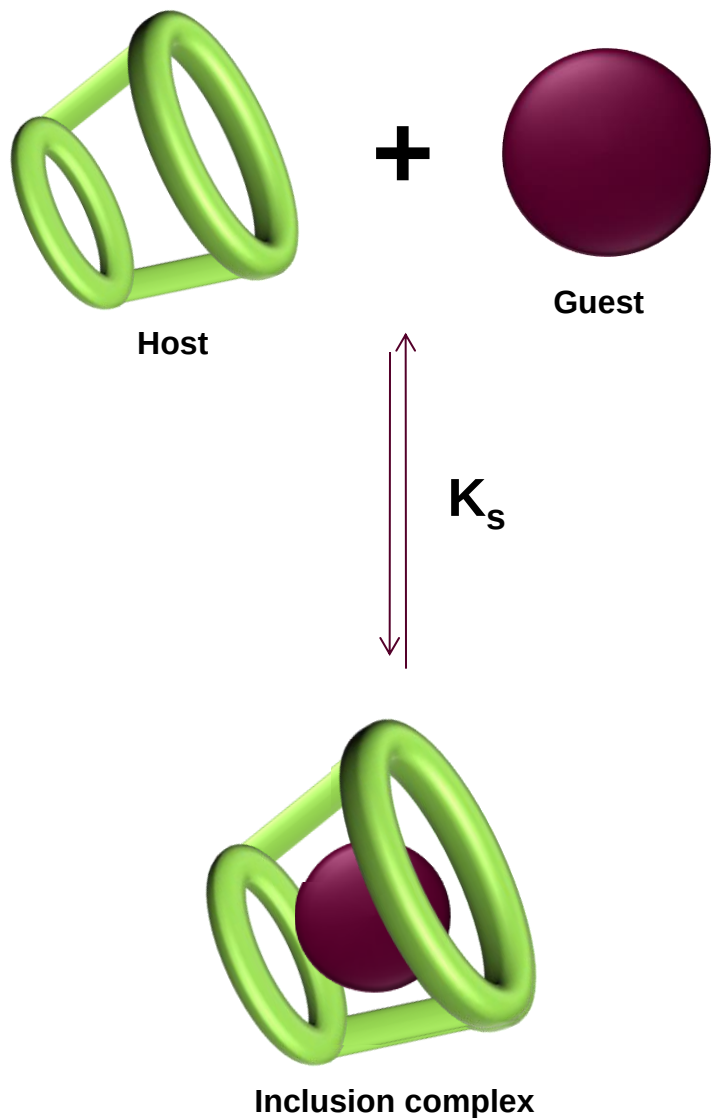
Cluster nucleation in proteins

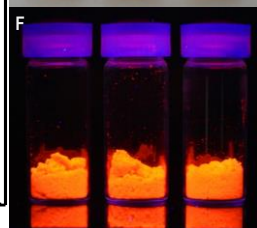
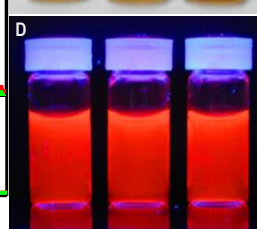
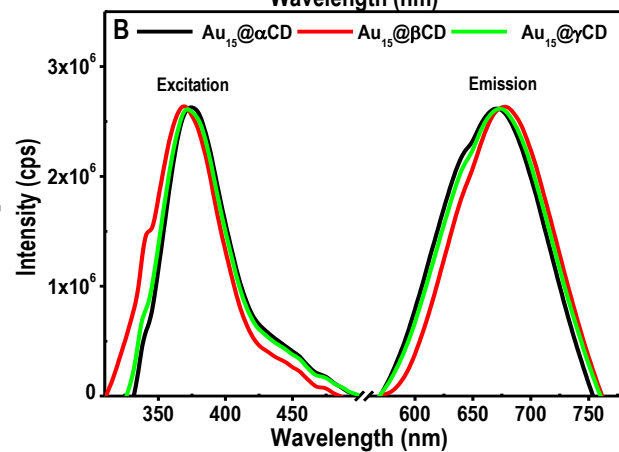
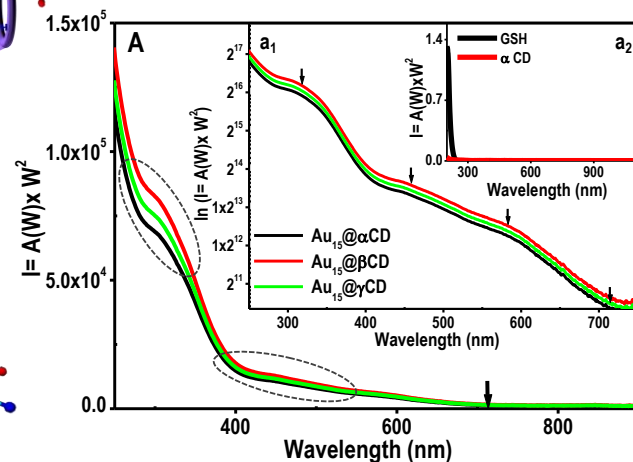
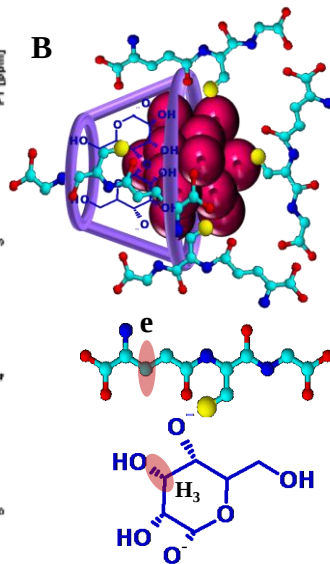
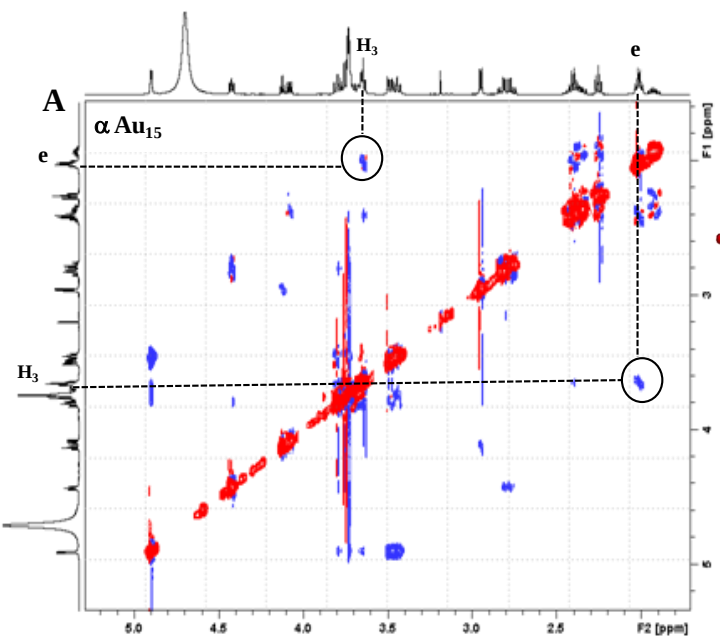
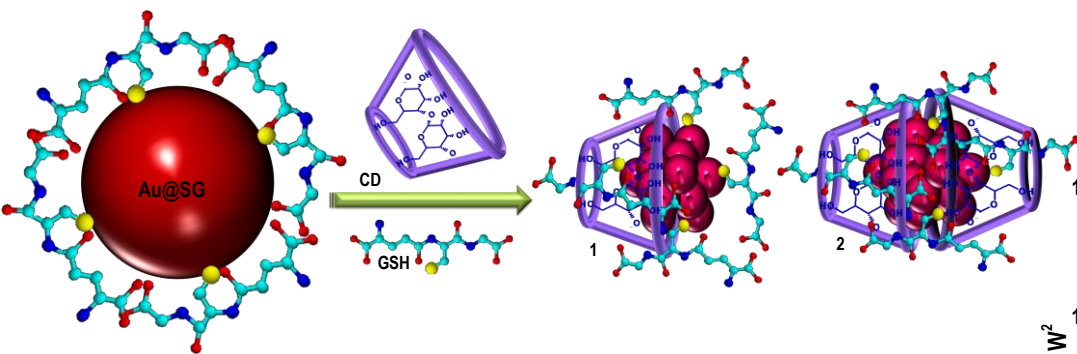


Kamalesh Choudhari et al. ACS Nano (2011)

Clusters in cavities

Cluster assemblies and host-guest complexes

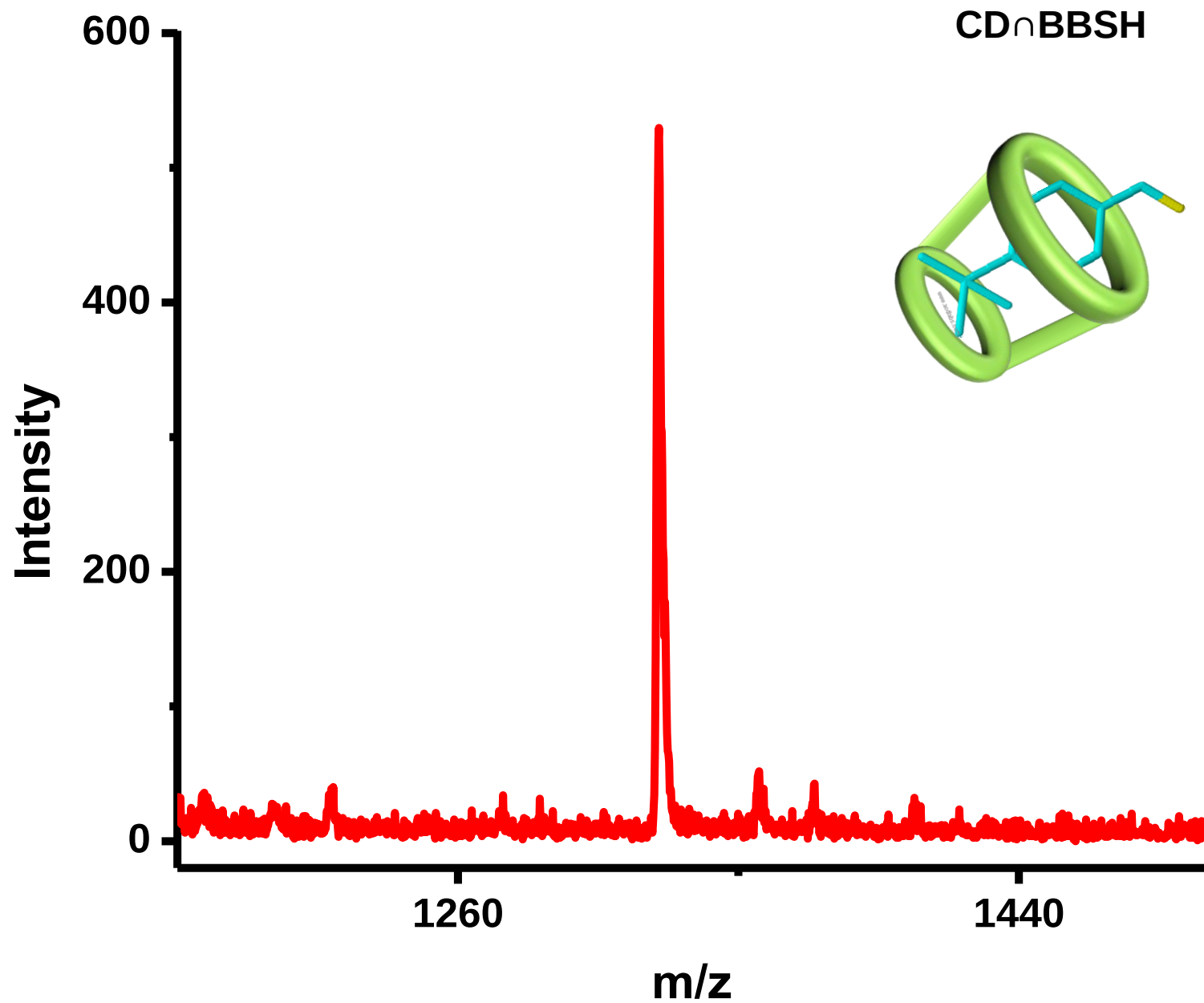




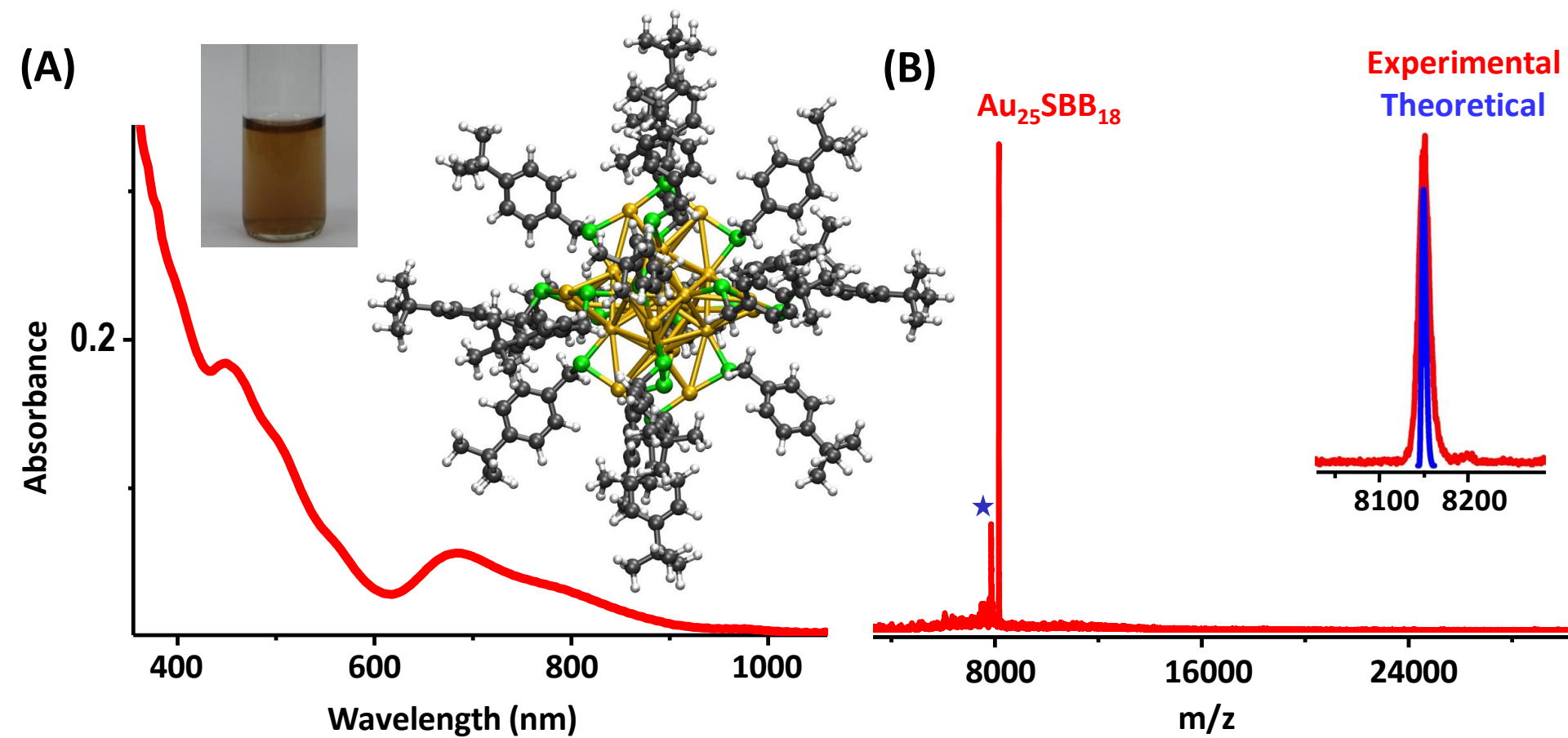
Indian patent, 4036/CHE/2010, filed on December 30, 2010.

E. S. Shibu and T. Pradeep, Chem. Mater. 23 (2011) 989–999.

Positive mode MALDI of BBSH $\cap$ CD complex

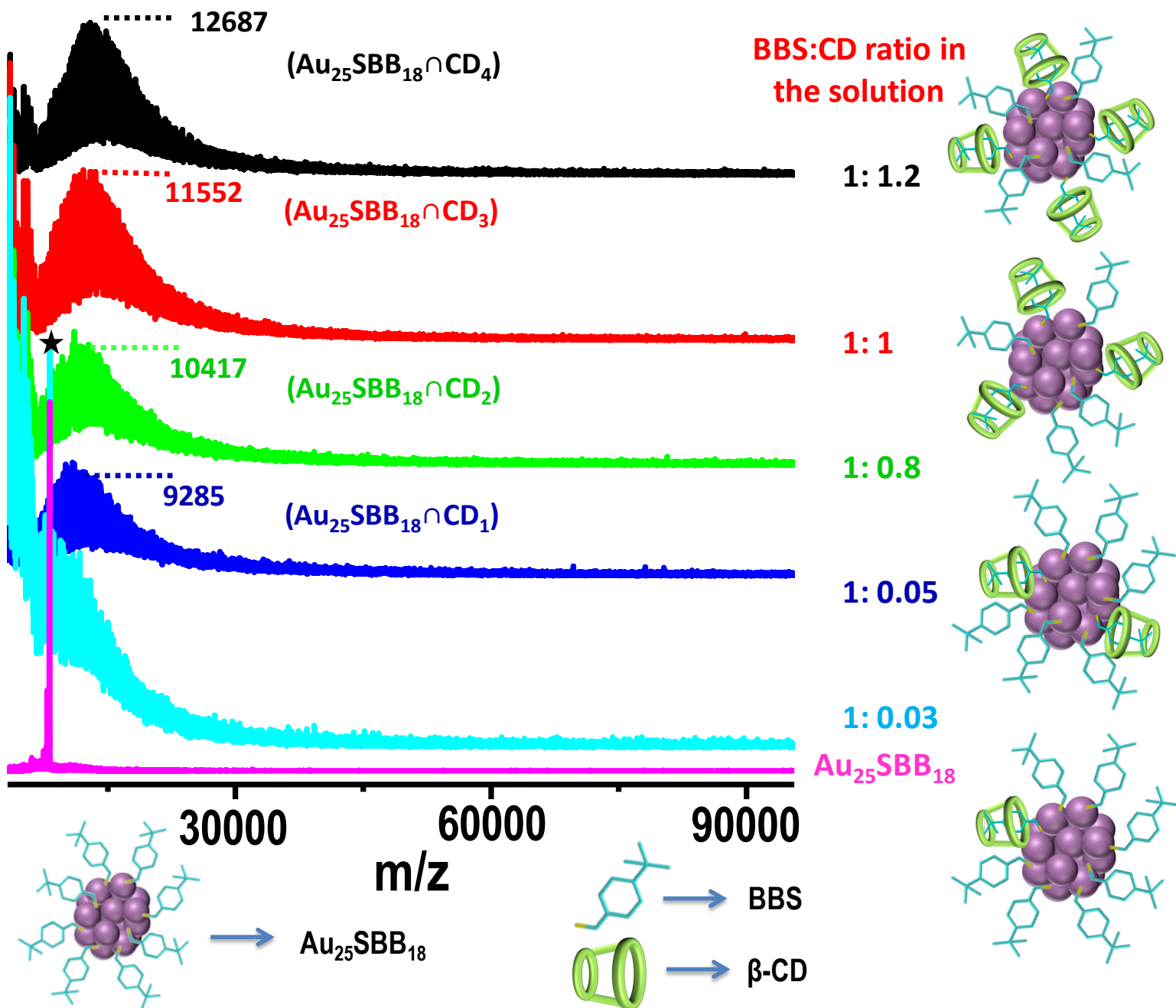


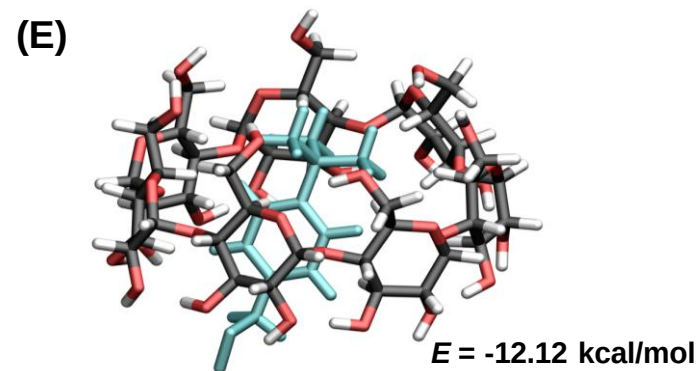
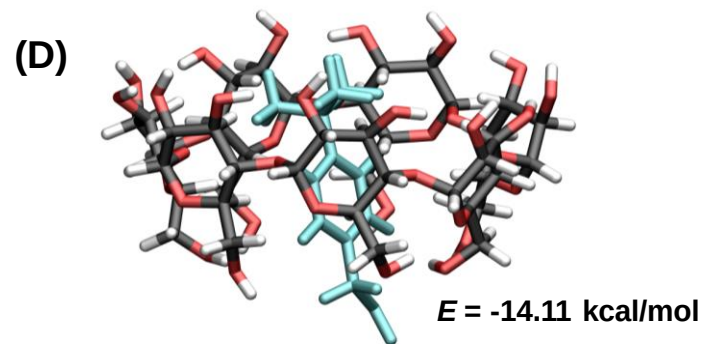
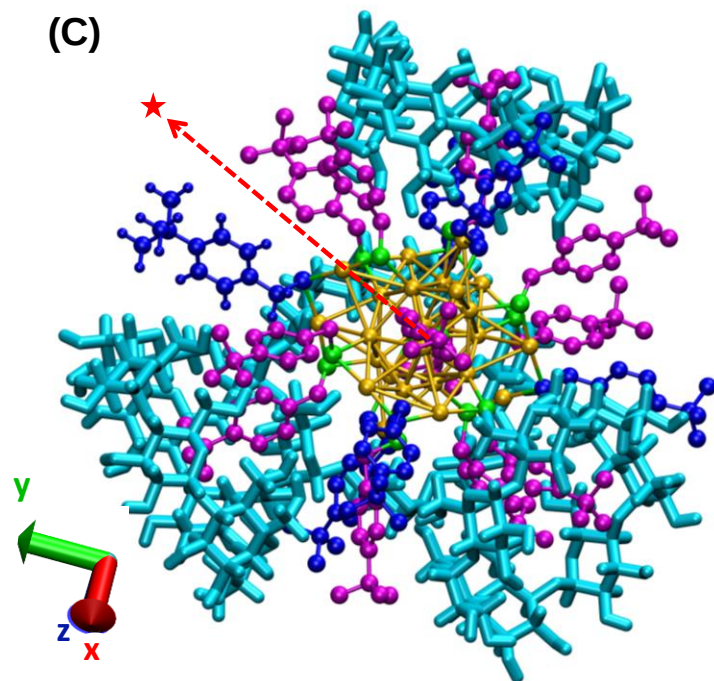
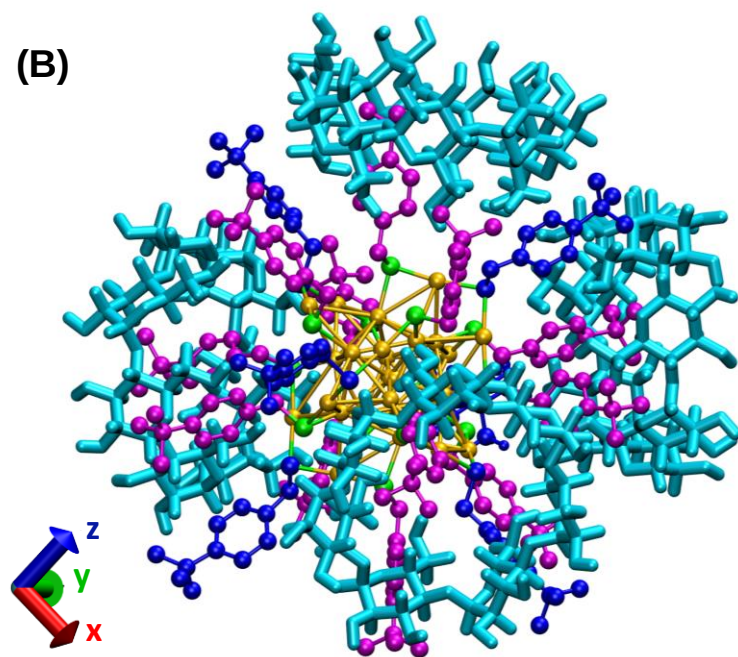
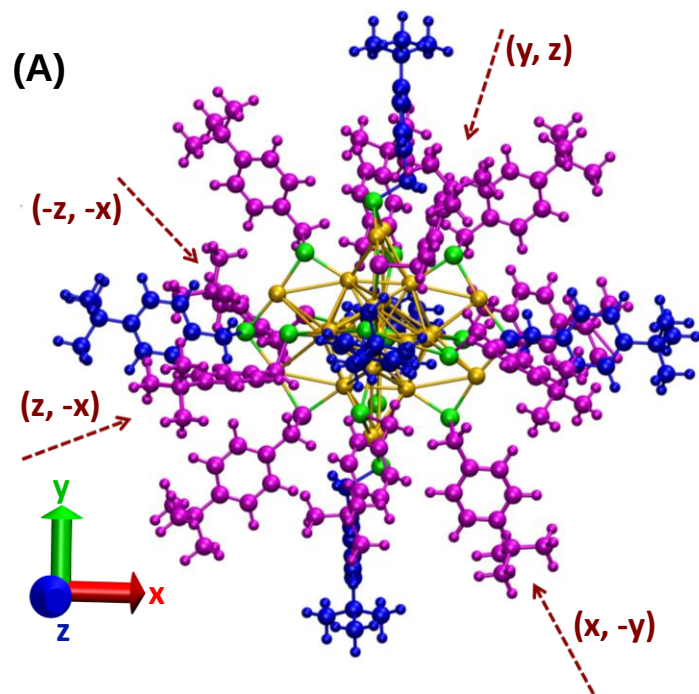
$\text{Au}_{25}\text{SBB}_{18}$

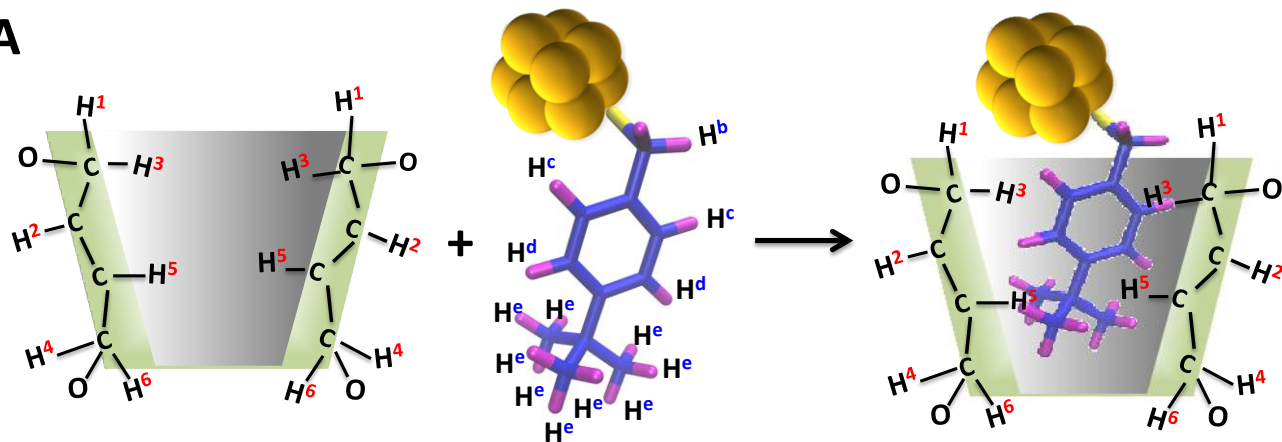
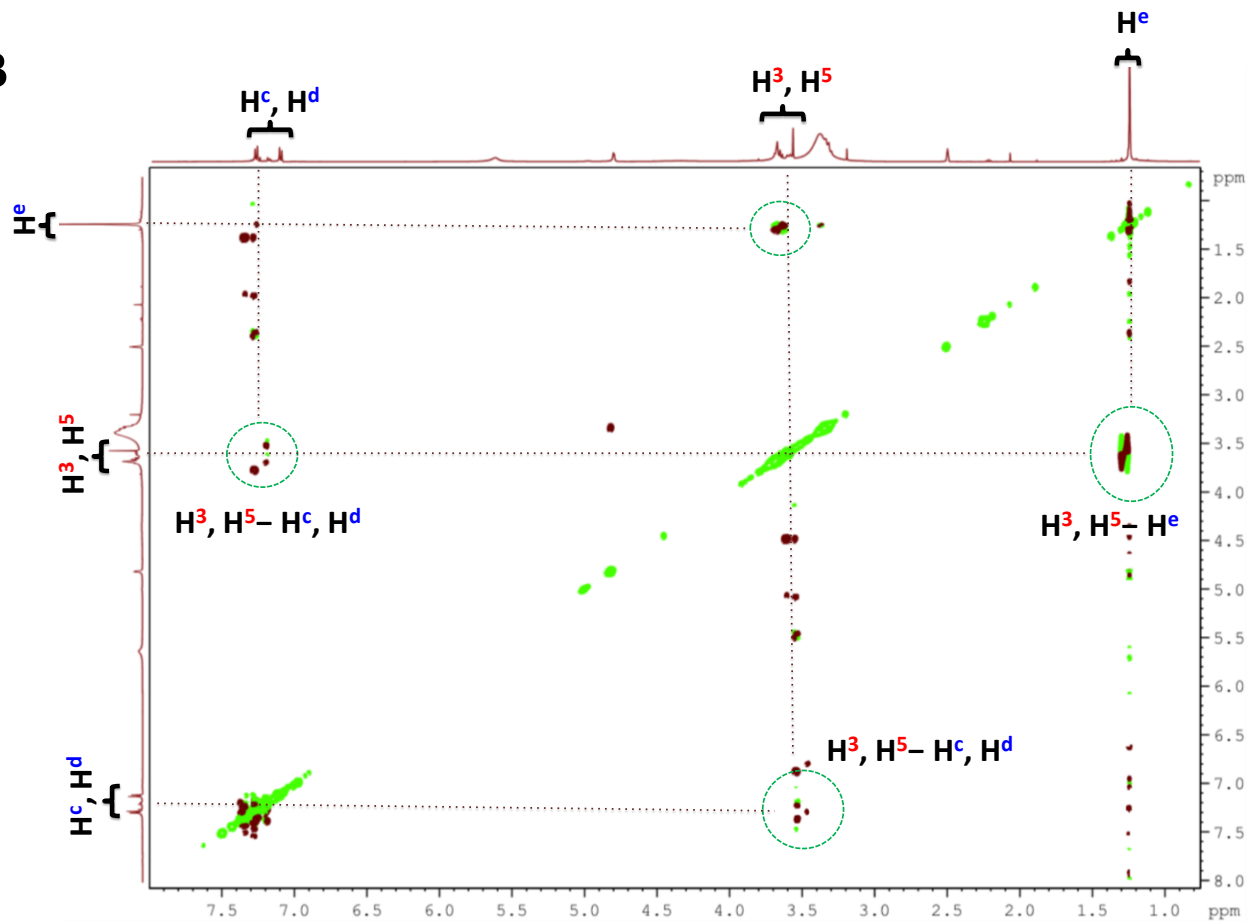


Ammu Mathew et al. ACS Nano 2014.

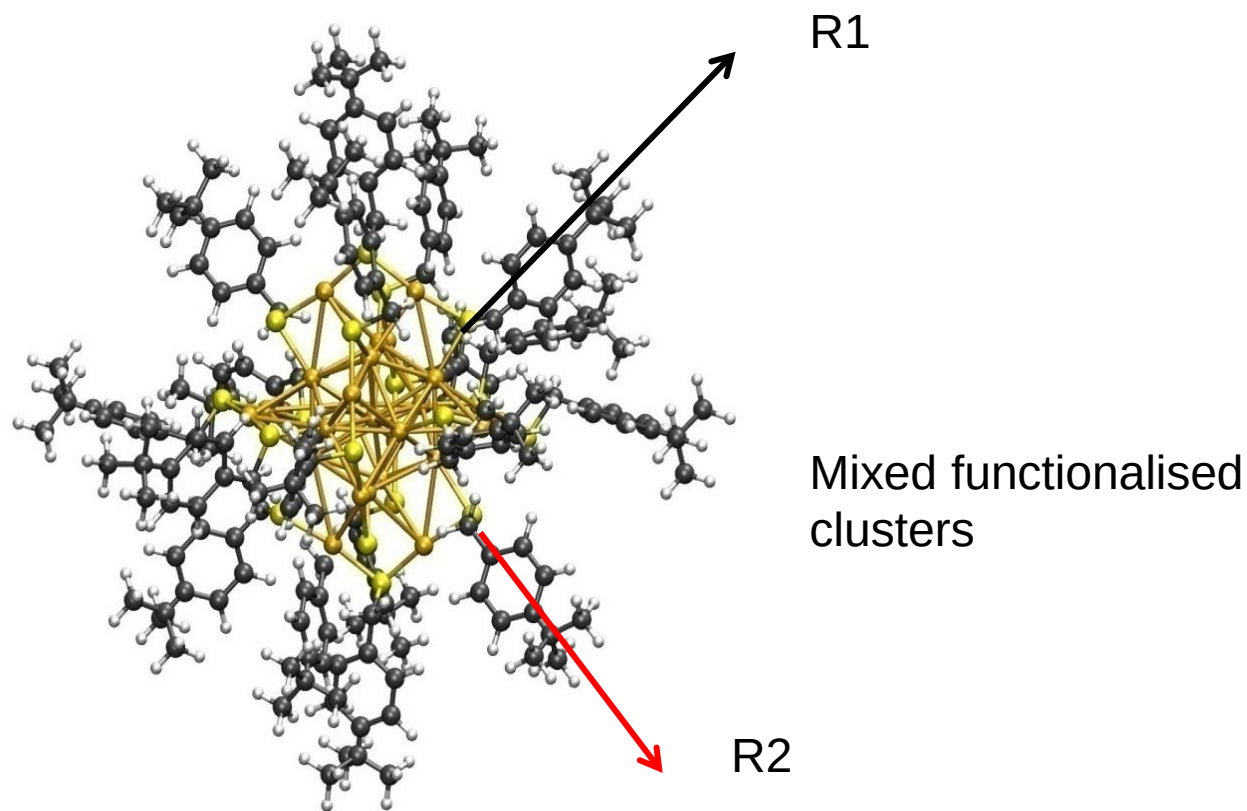
Au₂₅BBS₁₈⊂CD





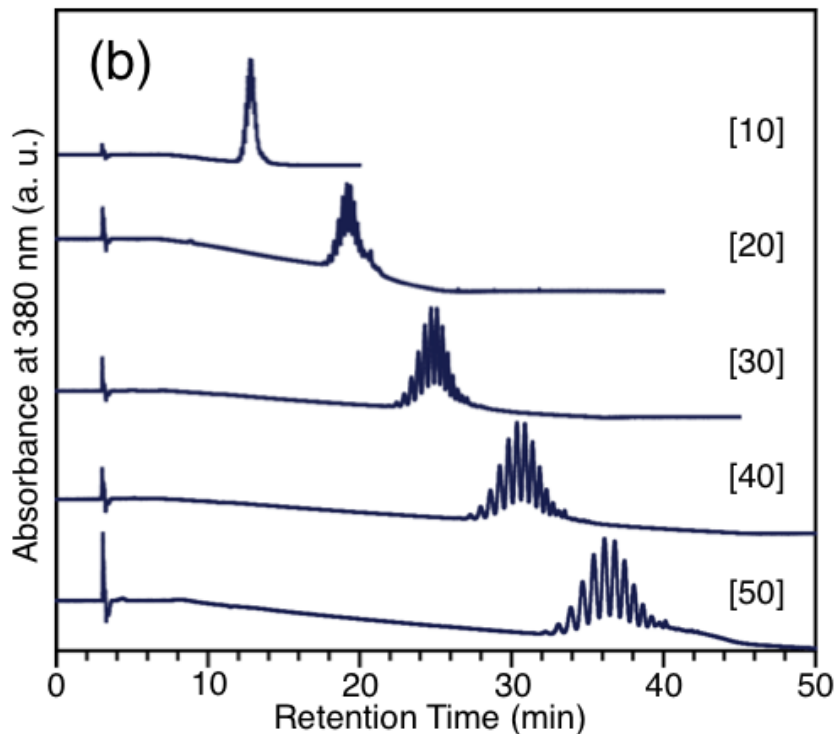
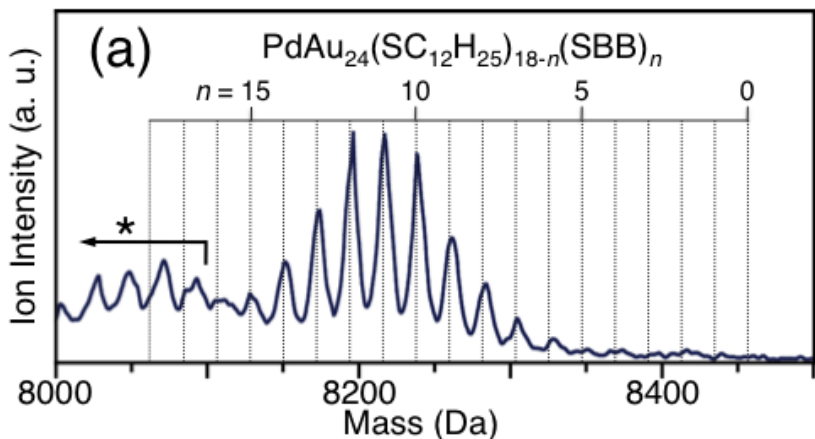
A**B**

Substitution chemistry of clusters

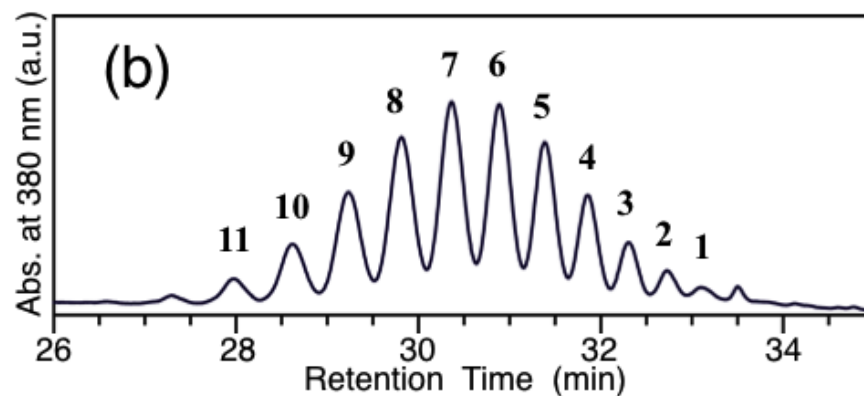
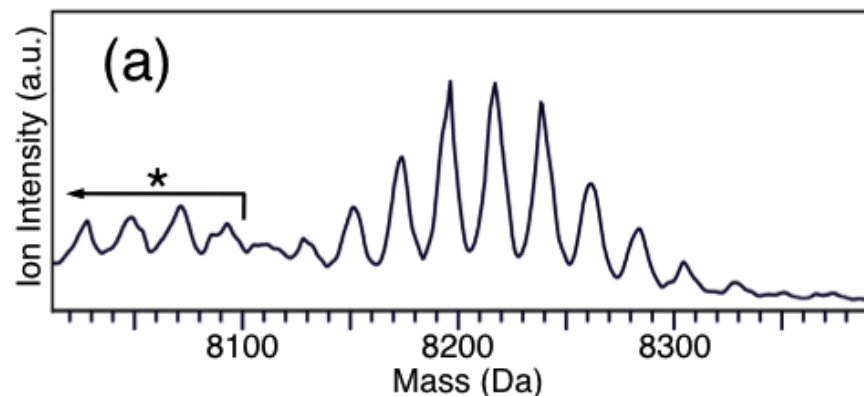


Yoshiki Niihori, Miku Matsuzaki, T. Pradeep and Yuichi Negishi, *J. Am. Chem. Soc.*, 135 (2013) 4946-4949

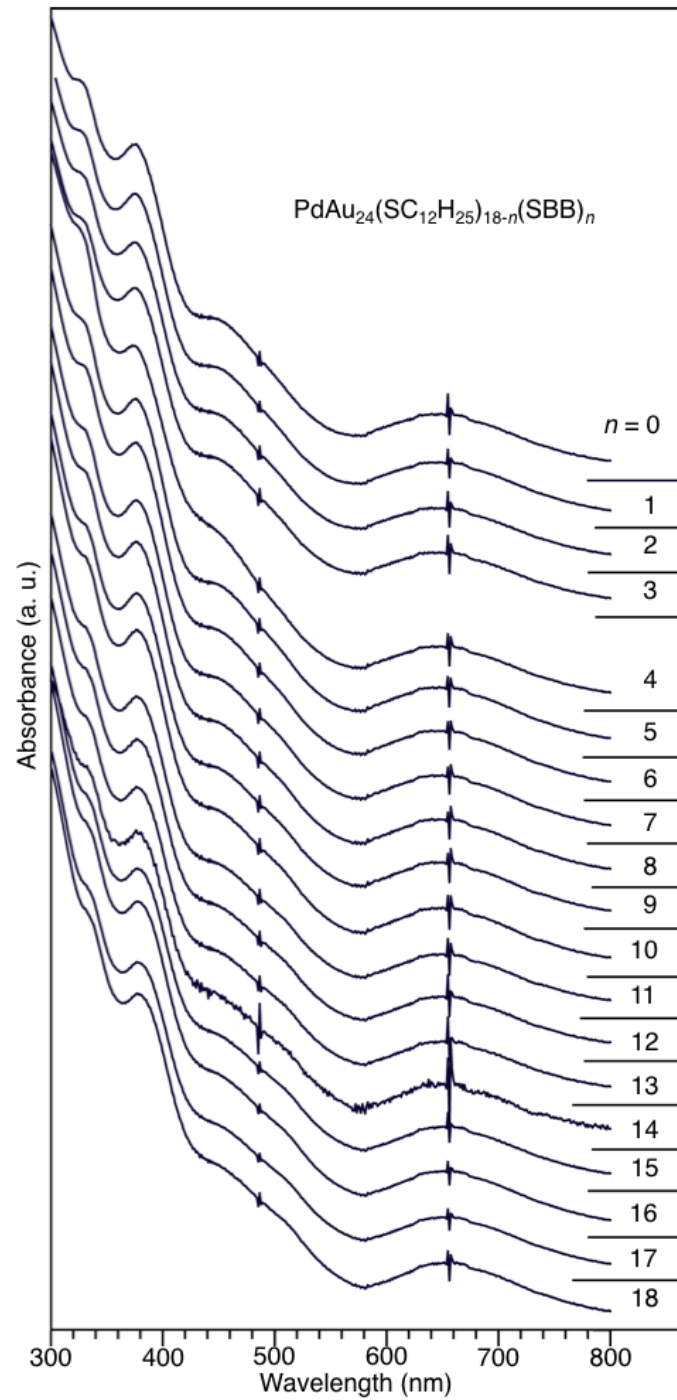
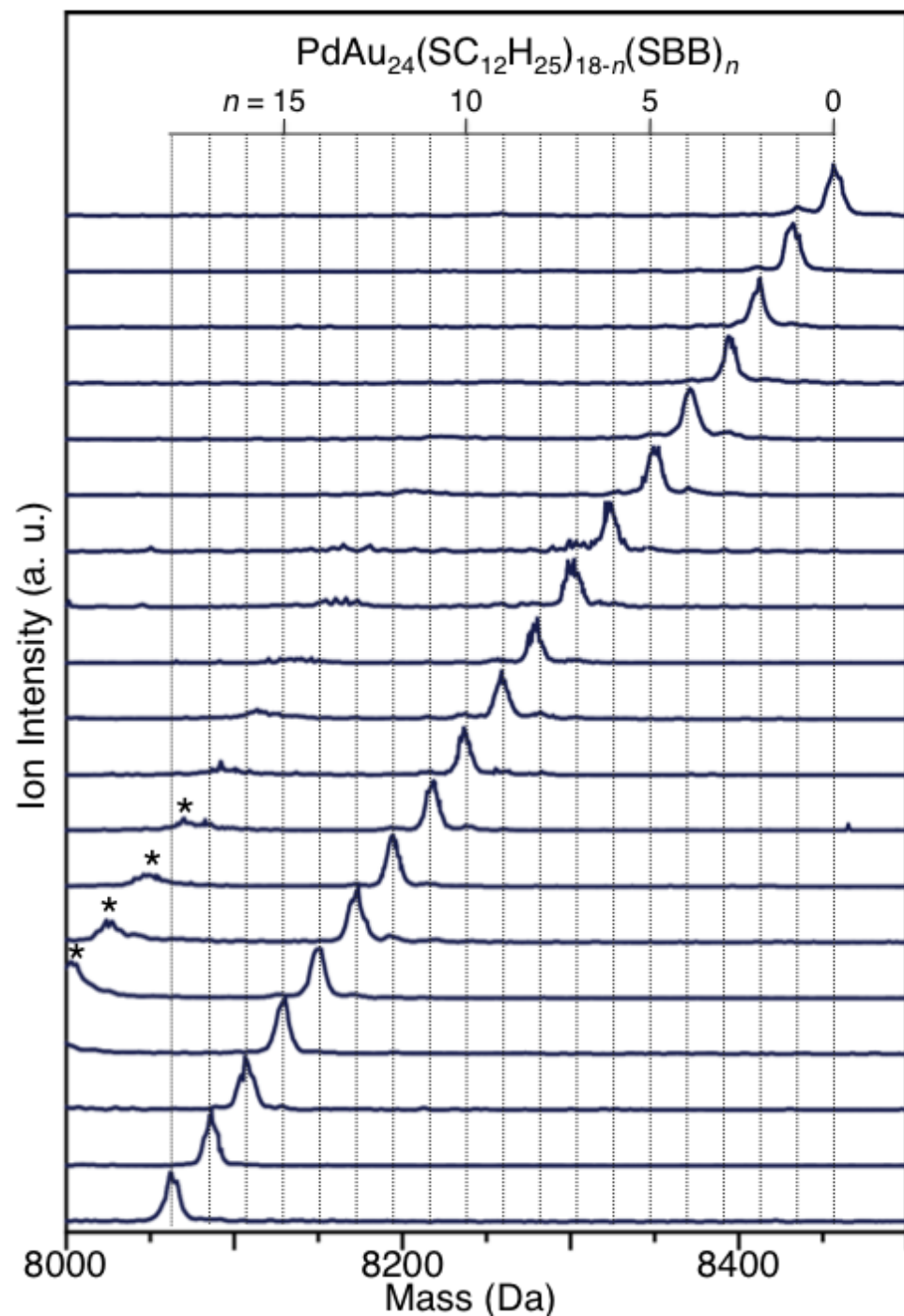
Separation of precise compositions of noble metal clusters protected with mixed ligands

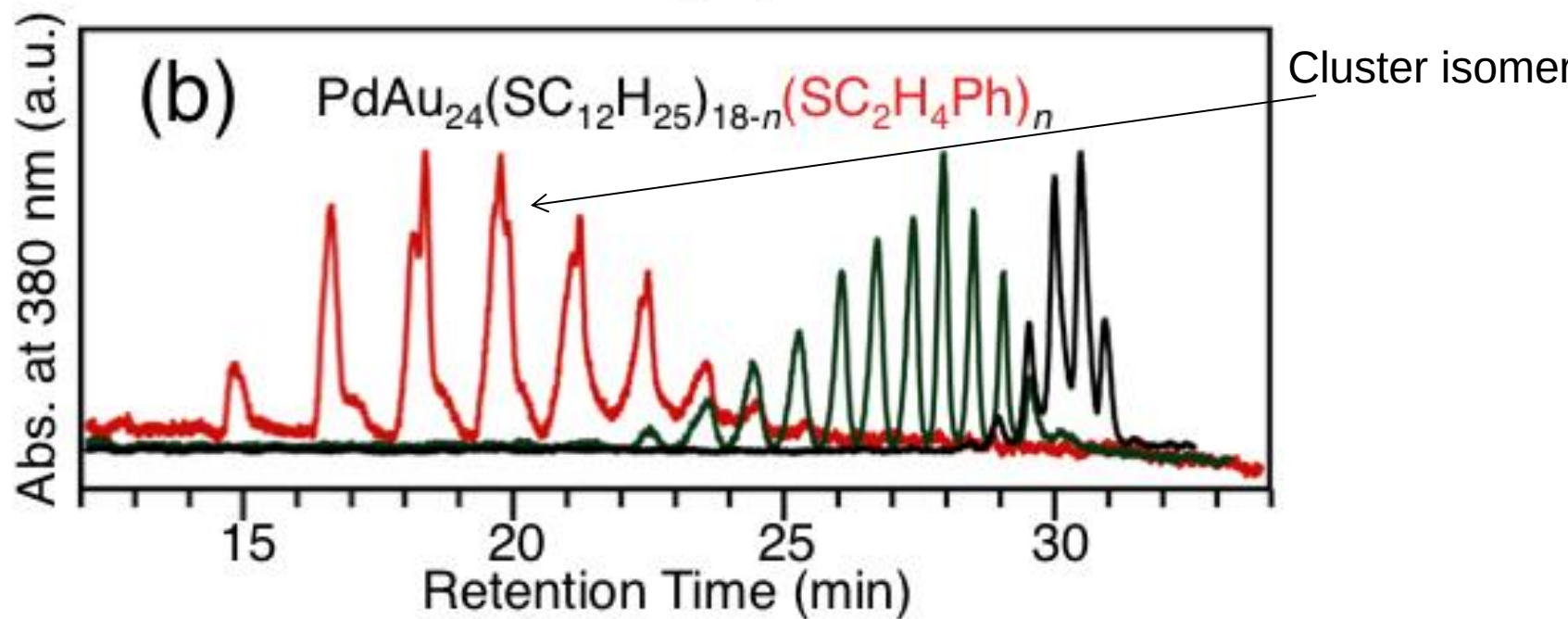
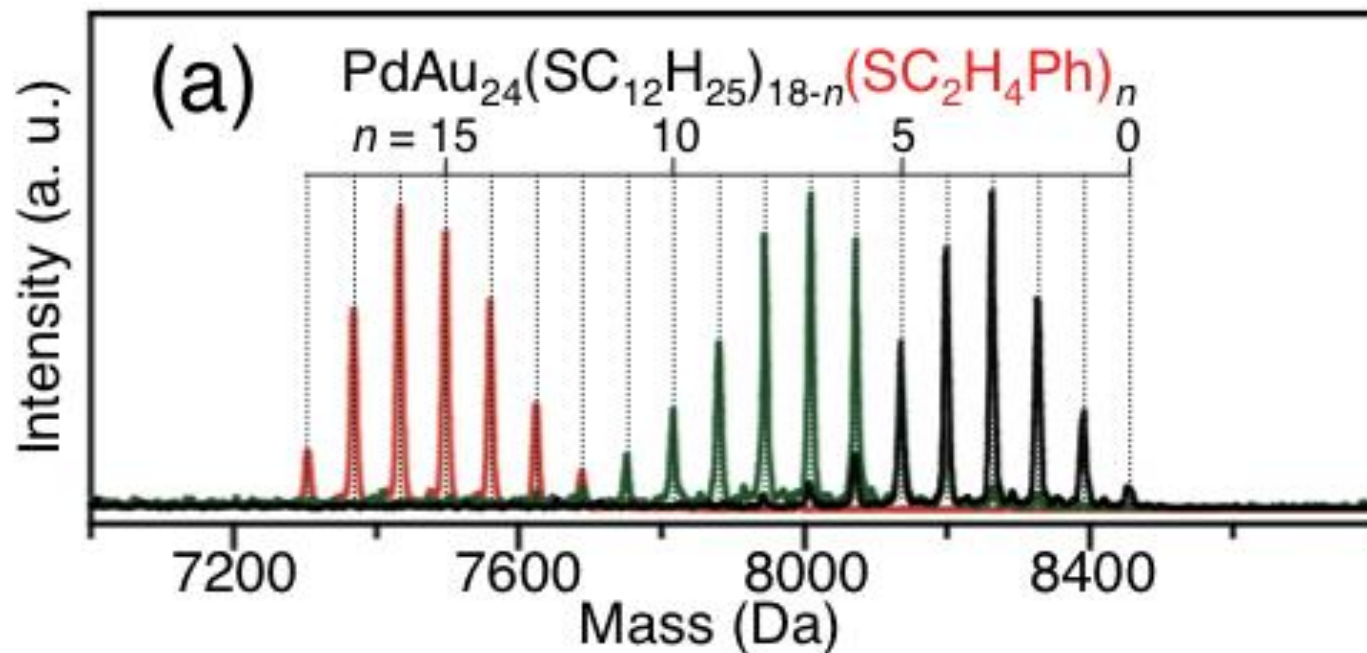


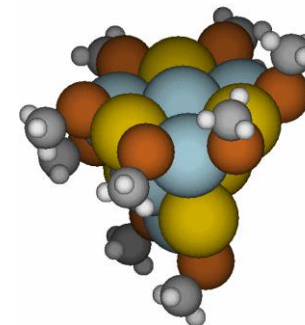
Ligand exchange chemistry –
Substitution chemistry



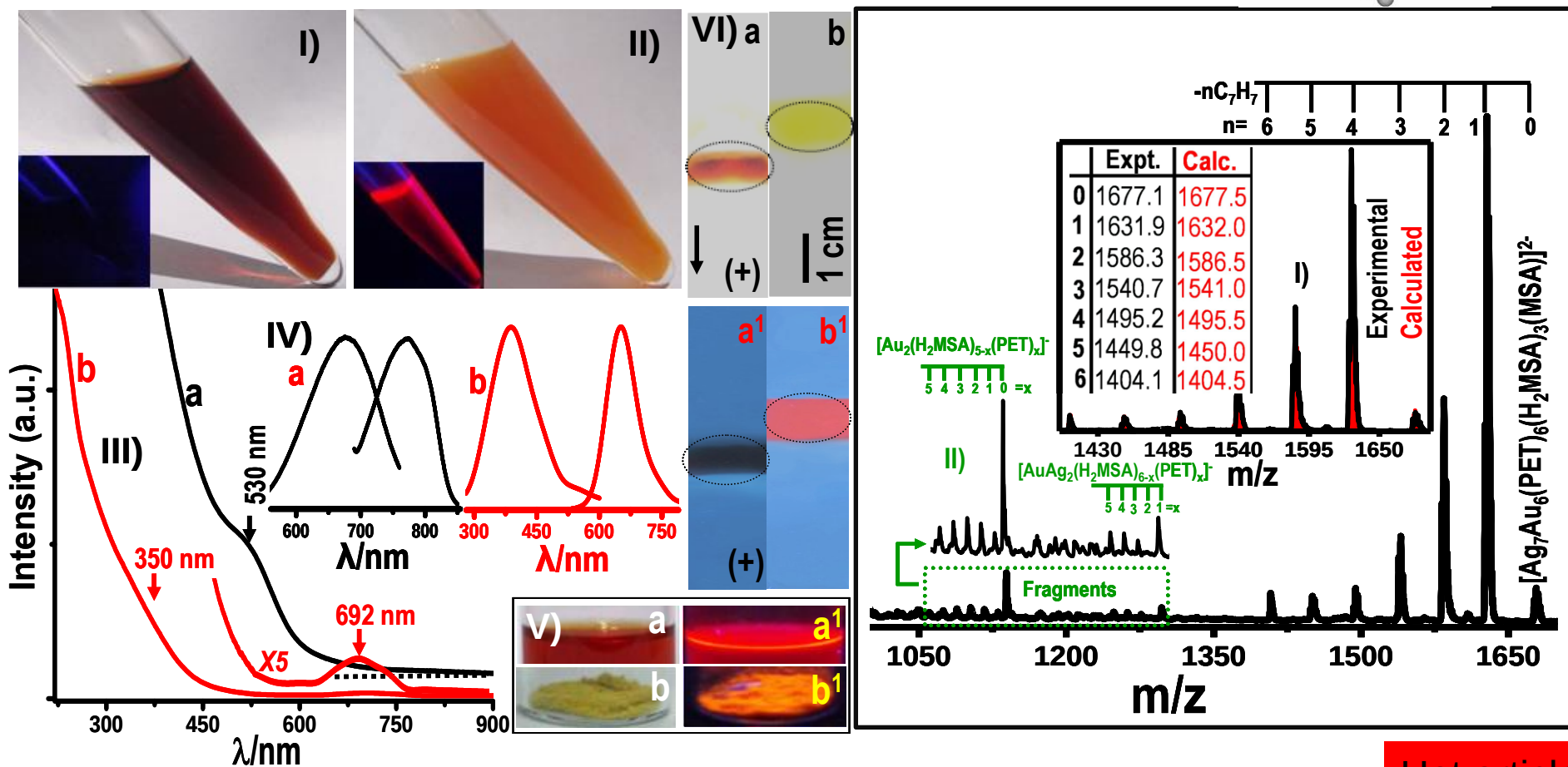
With Niihori and Negishi, Tokyo University of
Science



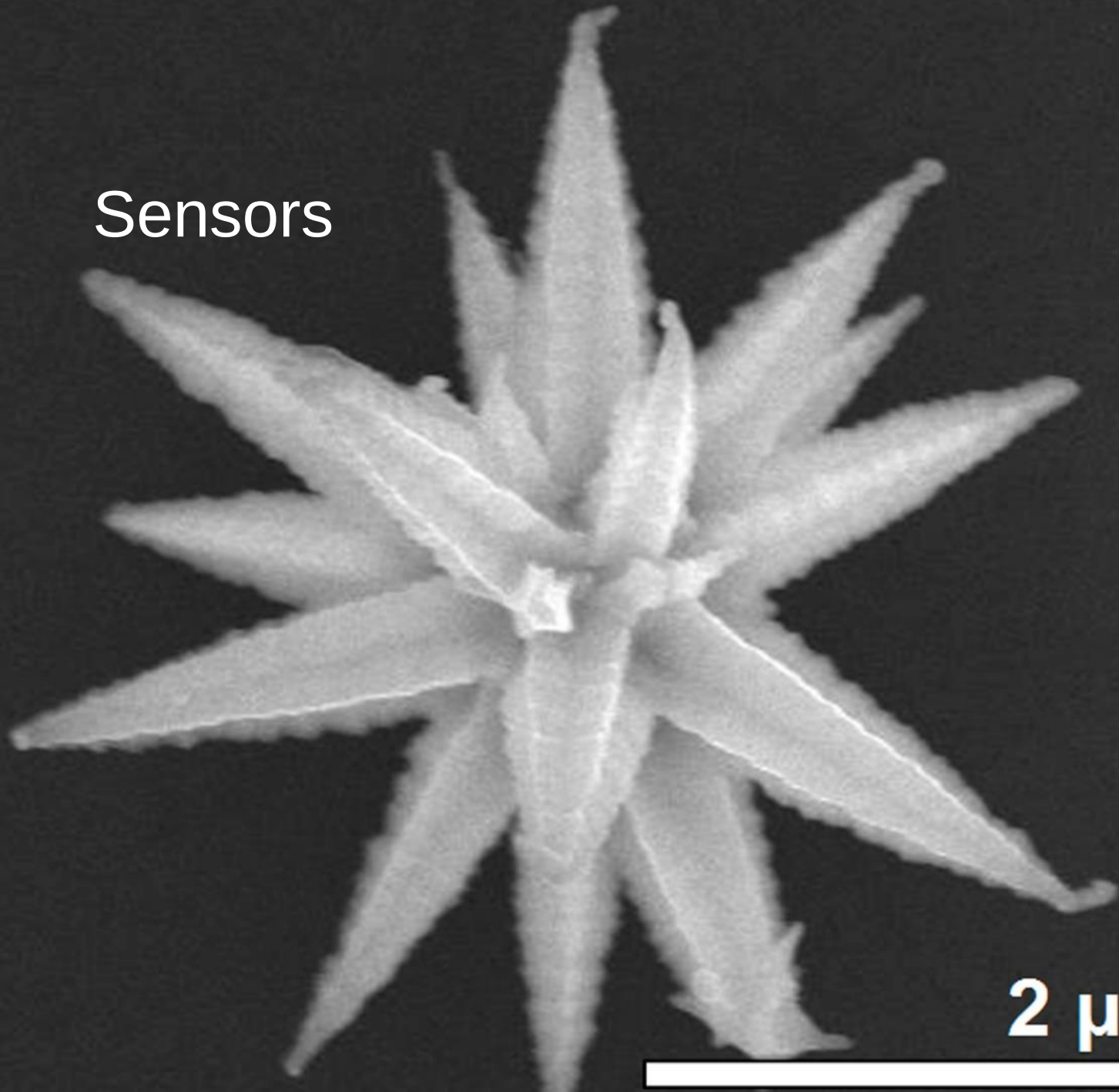




Ag₇Au₆ – 13 atom alloy cluster



Sensors

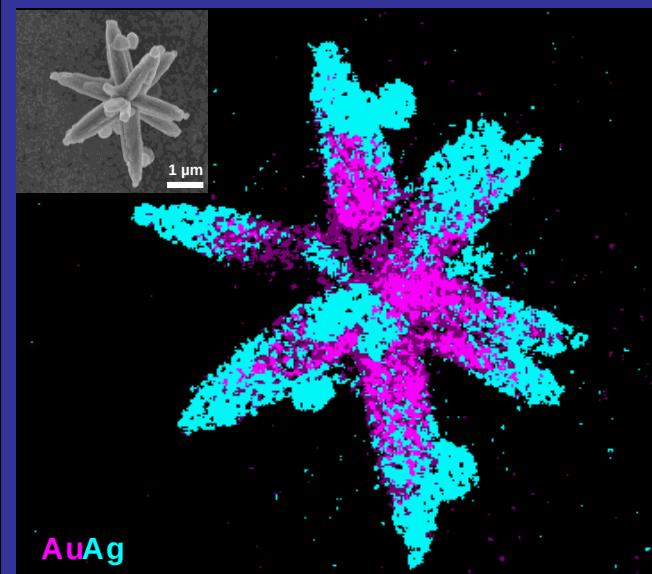


2 μm

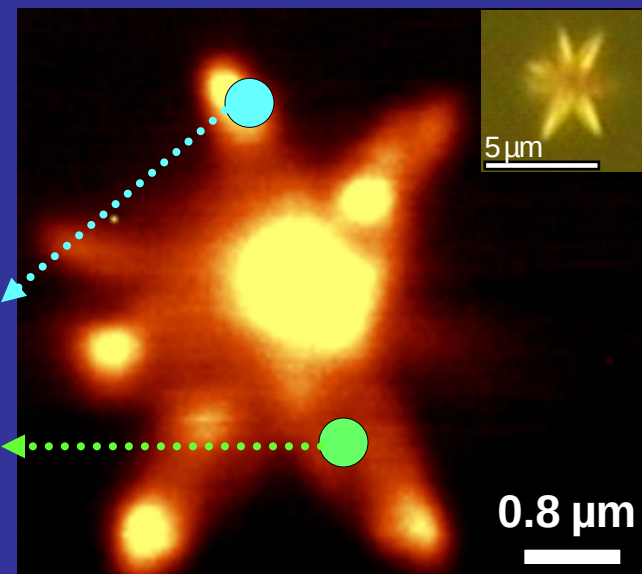
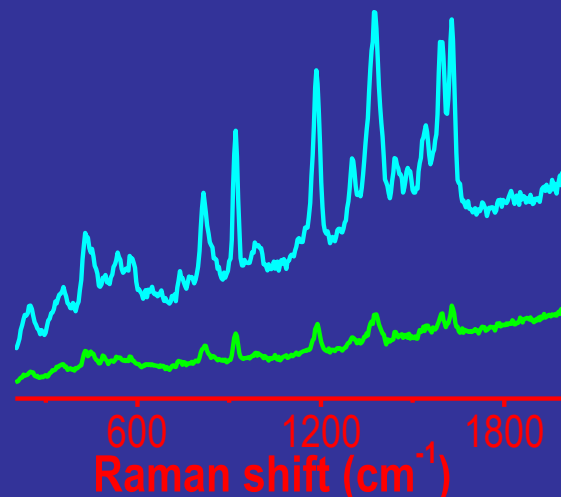


Region-specific SERS activity

Decreasing order of SERS activity $\rightarrow$ Au/Ag MFs > Au MFs > Au/Pt MFs



EDAX image of Au/Ag MF



Raman image of Au/Ag MF

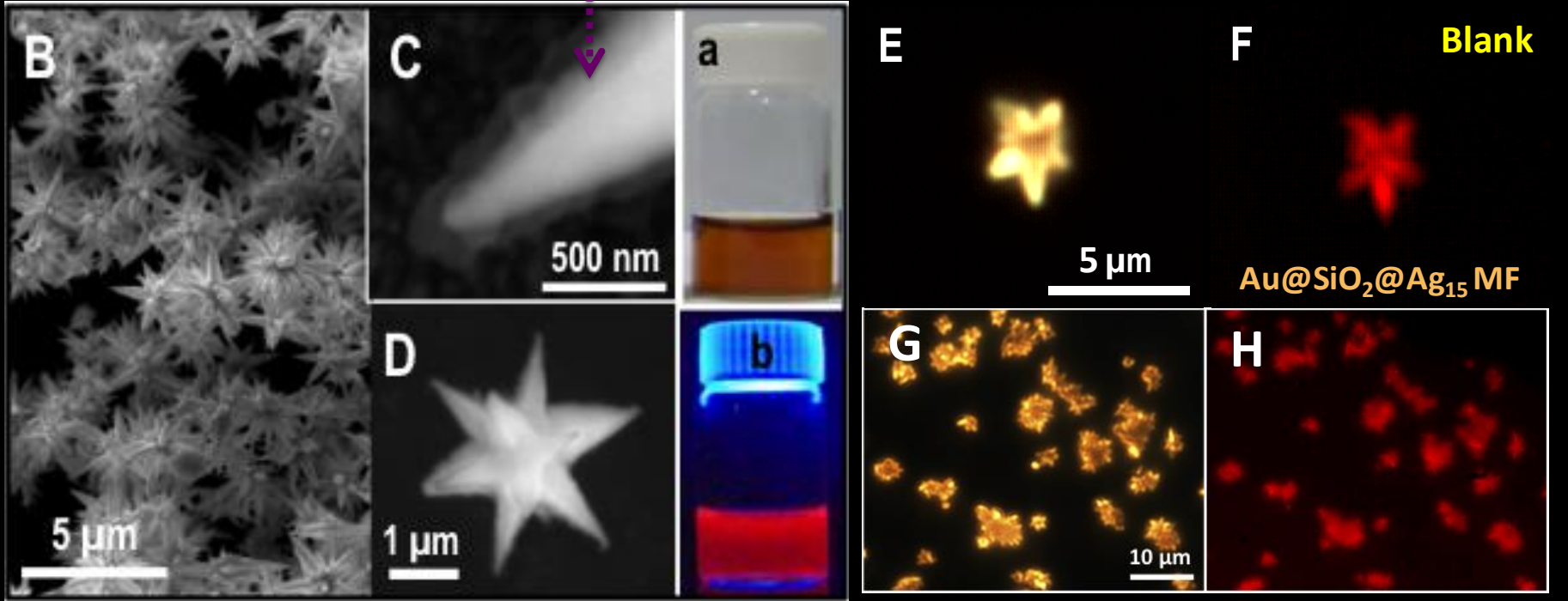
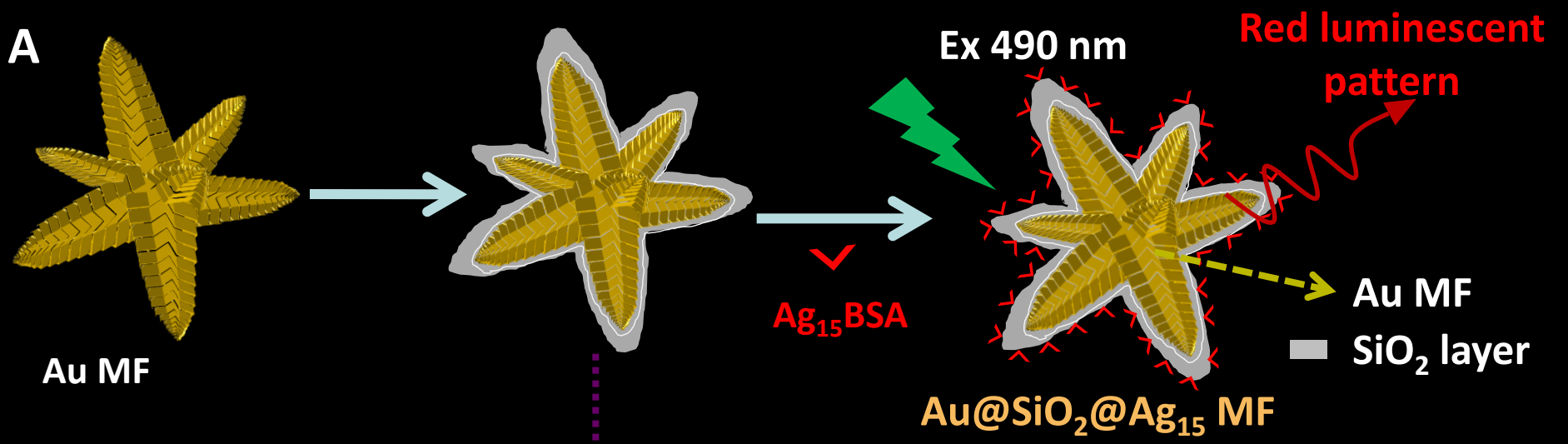
SERS intensity is higher at the tip compared to the body of the stem.

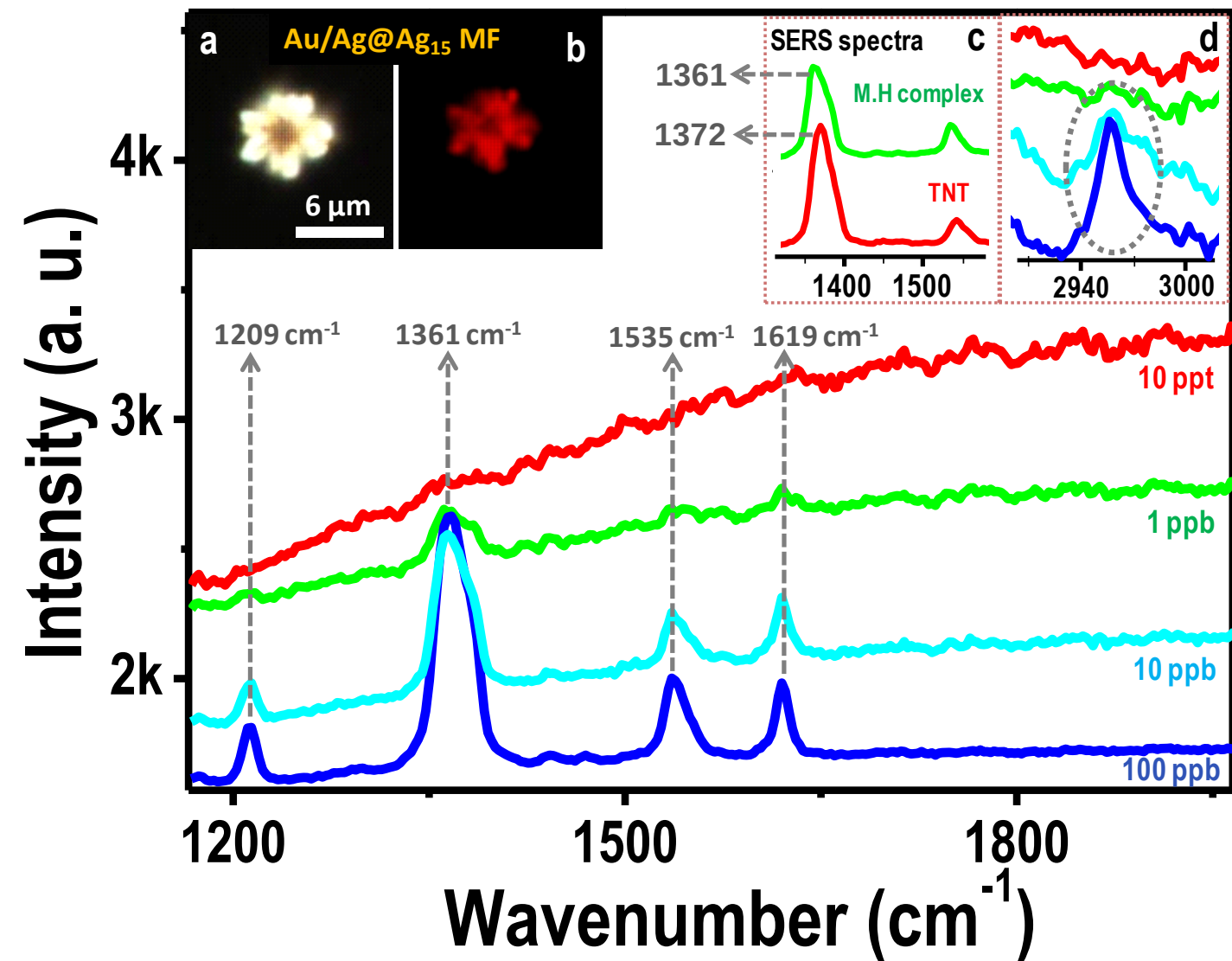
Au/Ag mesoflowers

- show high SERS activity than Au mesoflowers.
- show ten-fold increase in the SERS enhancement factor than Au mesoflowers.
- capable of detecting biomolecules and explosives at very low concentrations.

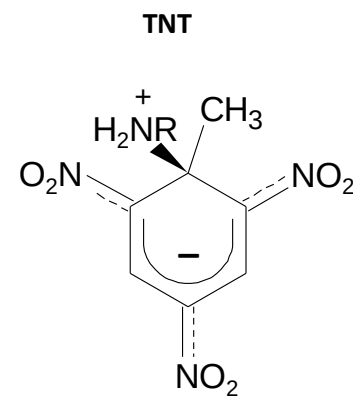
P. R. Sajanlal and T. Pradeep, *Langmuir*, 26 (2010) 8901- 8907.

Designing a sensor





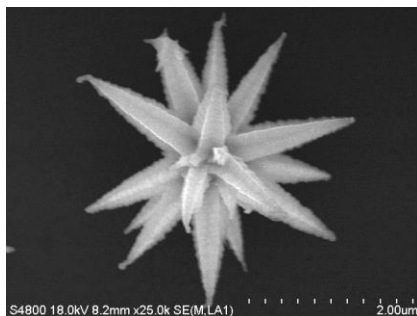
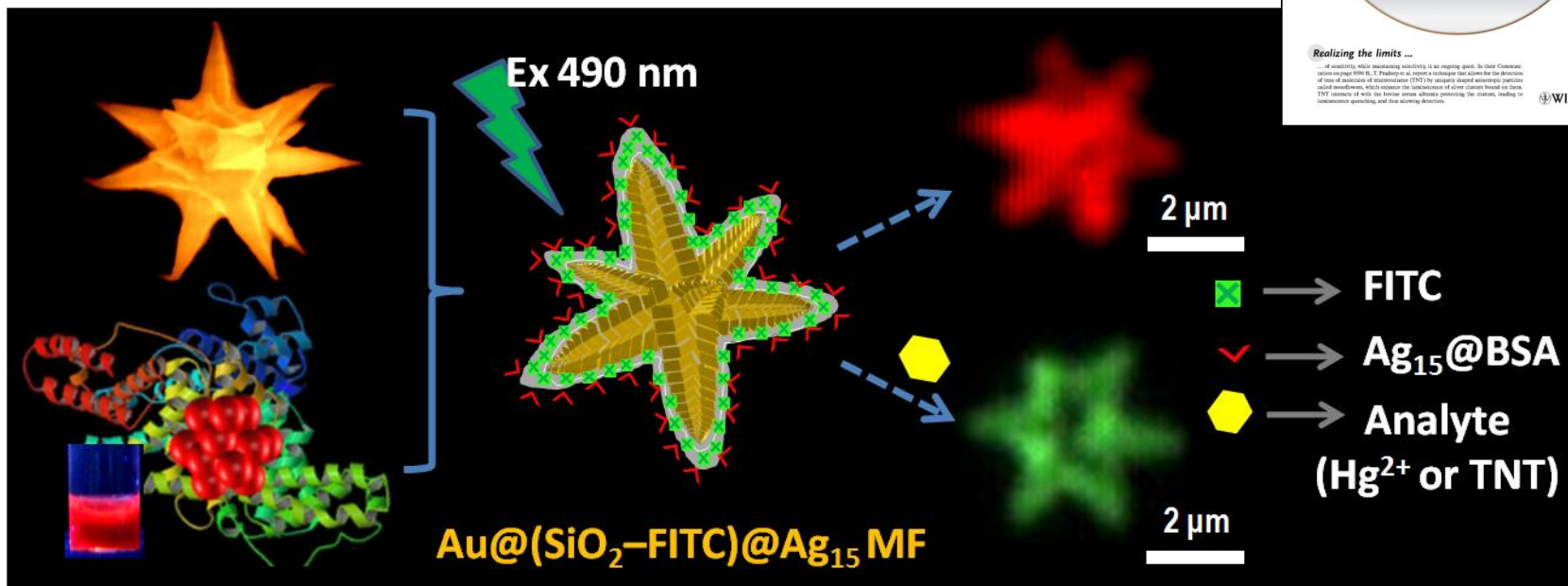
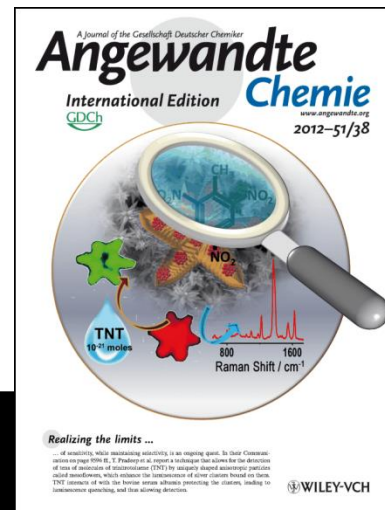
Meisenheimer complex



Meisenheimer complex is formed easily due to charge delocalization

Raman spectra showing the gradual evolution of TNT features as the concentration of TNT added to Au/Ag@Ag₁₅ MFs (a and b) increases. (c) Comparison of the symmetric and asymmetric NO₂ stretching bands in the SERS spectra of TNT before (black) and after Meisenheimer complex formation (gray). (d) The gradual appearance of a Raman band at 2960 cm⁻¹.

Sub-zeptomolar detection



Featured in:

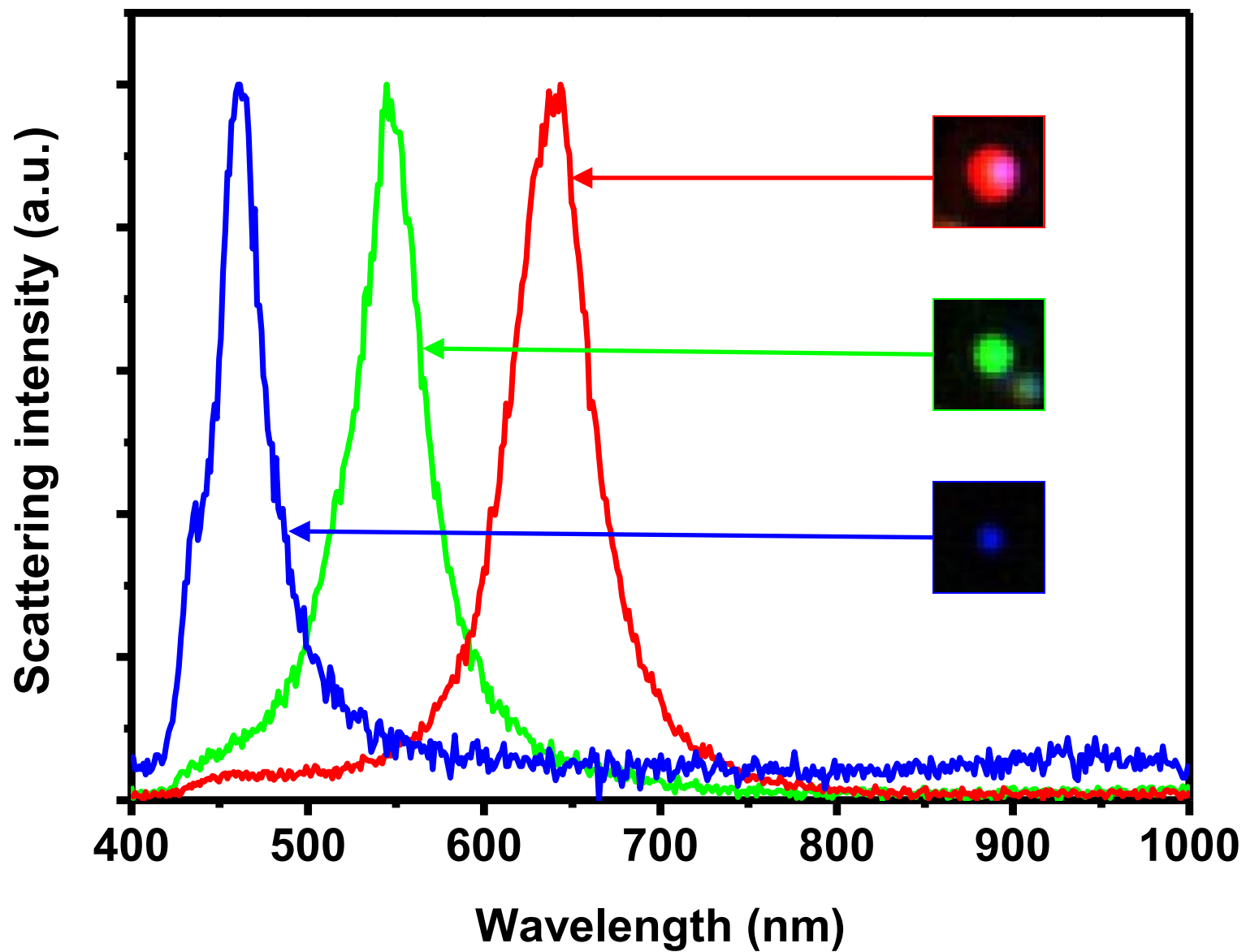
The Hindu, Telegraph, Times of India, etc.
C&E News
and many others

Ammu Mathew, et al. Angew. Chem. Int. Ed. 2012

Observing nanochemistry in real time



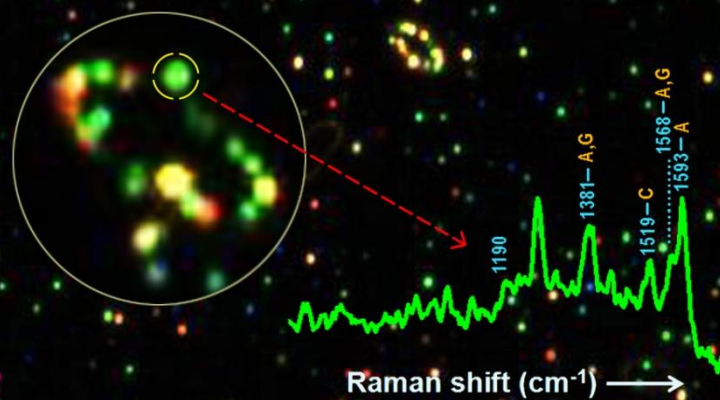
Mechanism of action

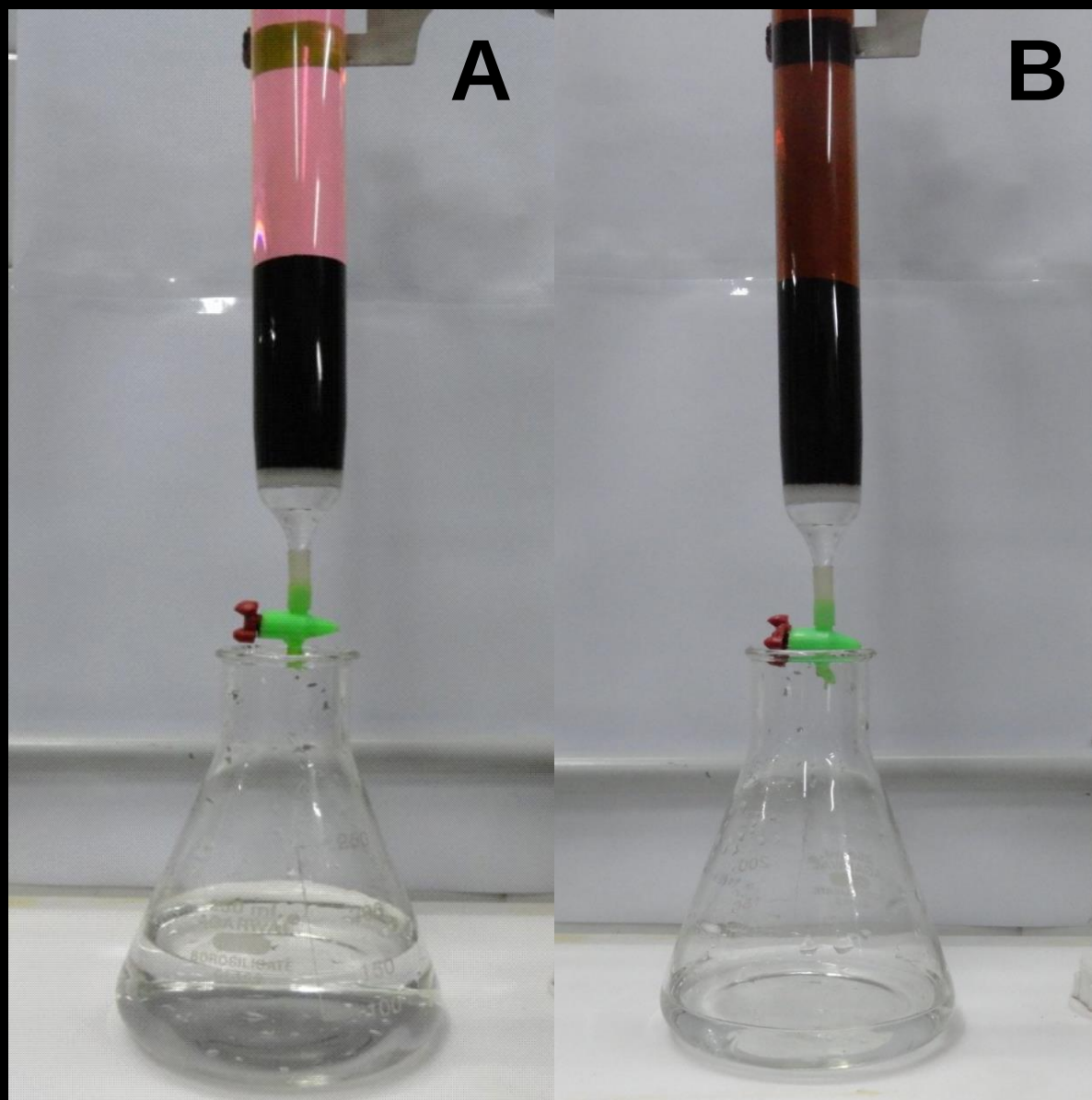


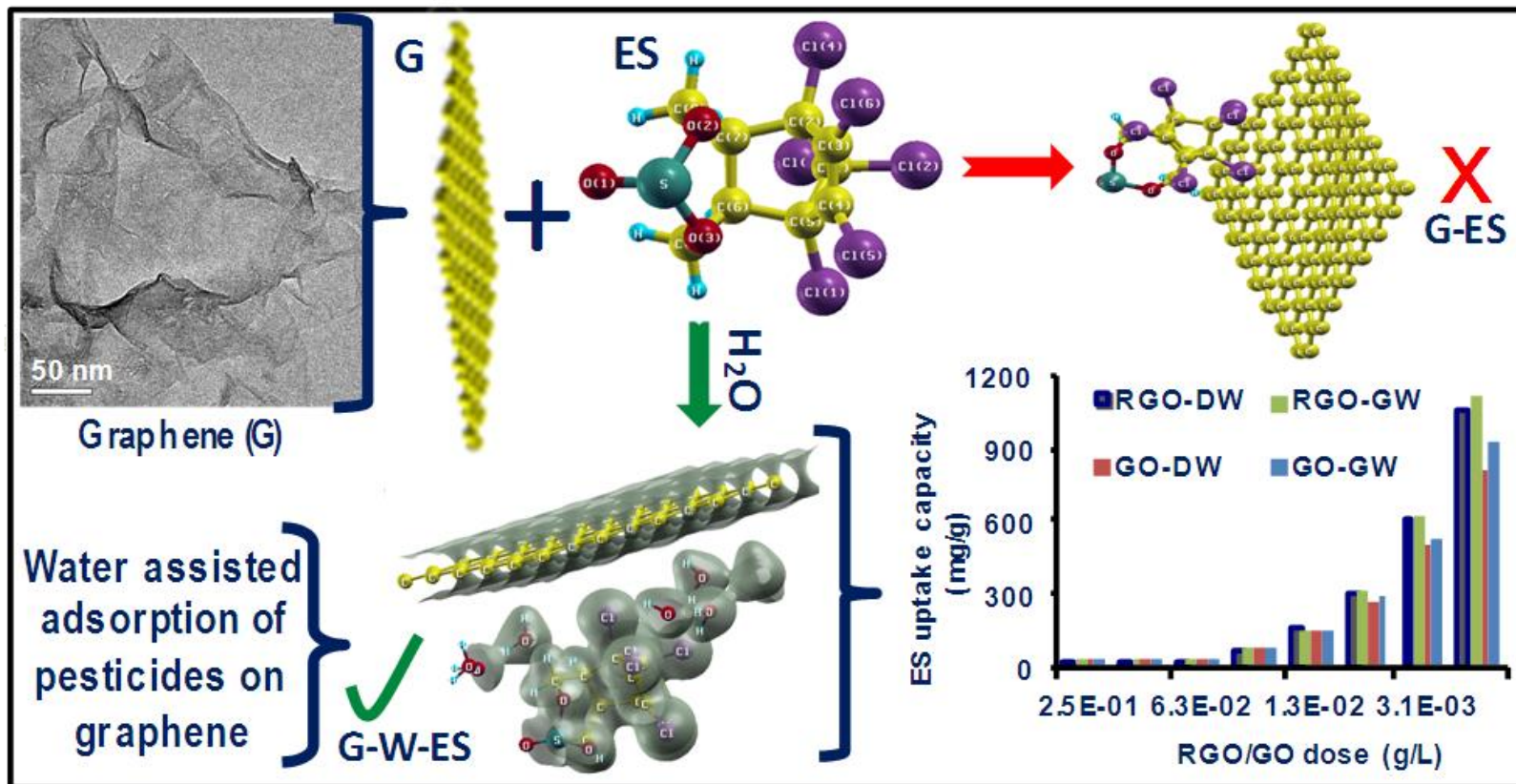
Probing the mechanism of
antibacterial activity of AgNPs

Particle

& Particle Systems Characterization







Graphene adsorbs pesticides more than its self weight!

Biopolymer- nanocomposi water purifica

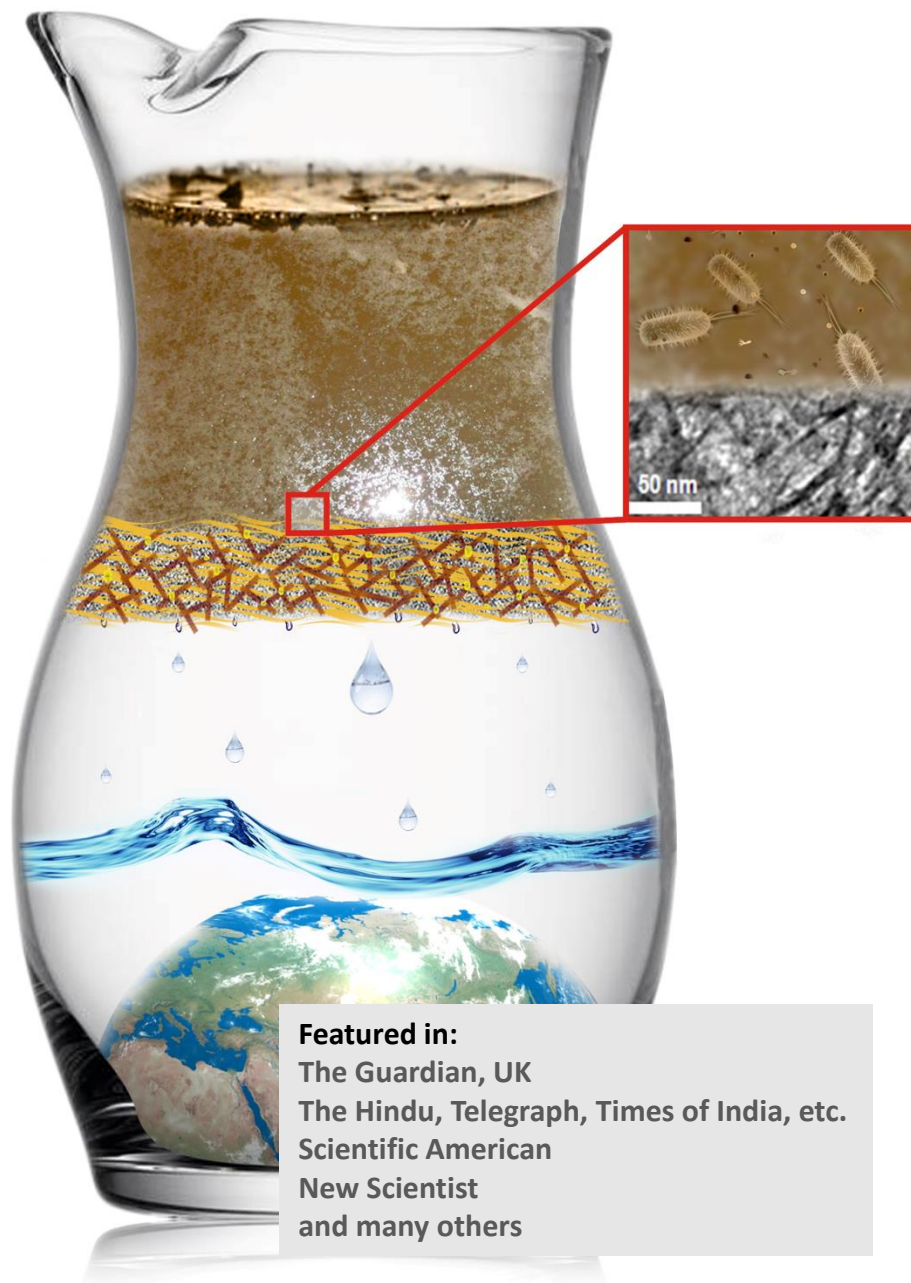
Mohan Udhaya Sankar¹, Sah
Kamalesh Chaudhari, and Th

Unit of Nanoscience and Thematic Ur

Edited by Eric Hoek, University of Cal

Creation of affordable materials f
water is one of the most promisin
drinking water for all. Combini
composites to scavenge toxic s
other contaminants along with
affordable, all-inclusive drinking
without electricity. The critical
synthesis of stable materials th
uously in the presence of cor
drinking water that deposit an
surfaces. Here we show that su
be synthesized in a simple and eff
out the use of electrical power.
sand-like properties, such as high
forms. These materials have bee
water purifier to deliver clean dri
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ambient temperature has wide
water purification.

hybrid | green | appropriate technolo



Featured in:

The Guardian, UK

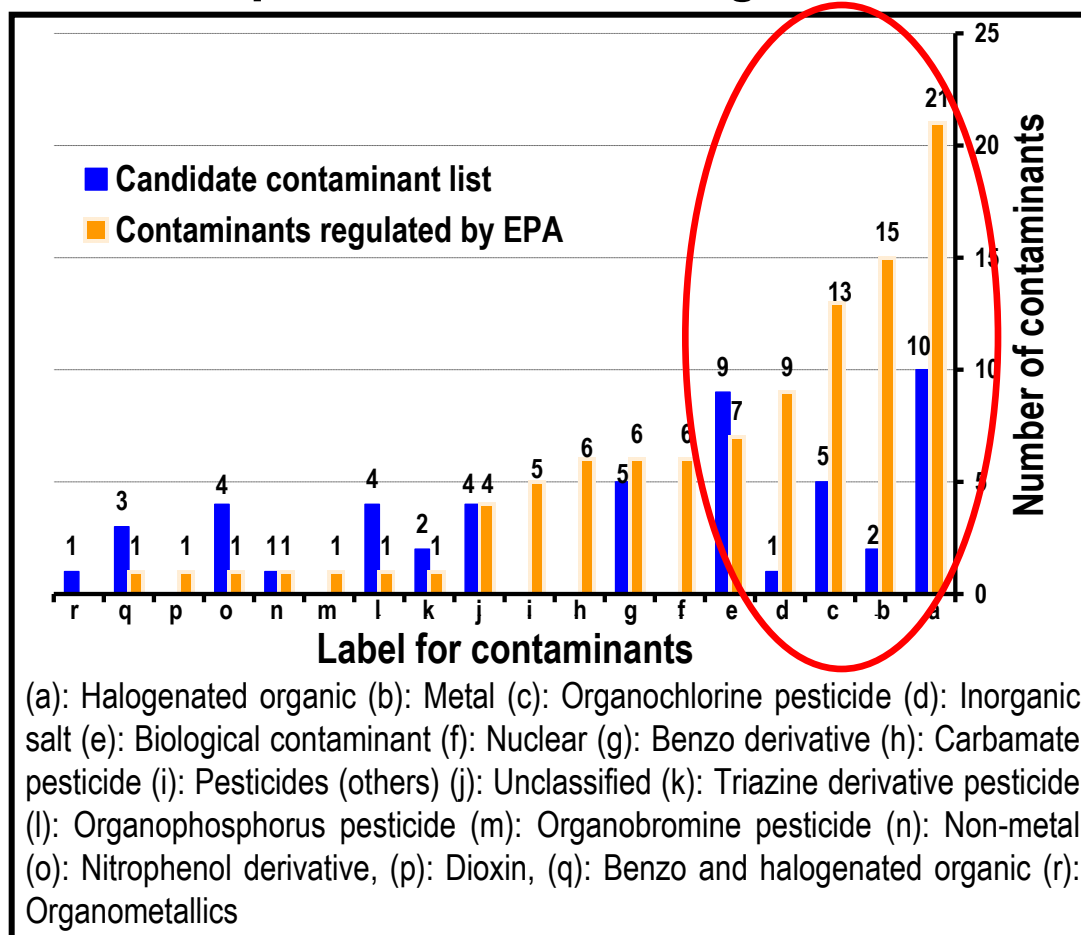
The Hindu, Telegraph, Times of India, etc.

Scientific American

New Scientist

and many others

Future of water purification: An enigma with some pointers



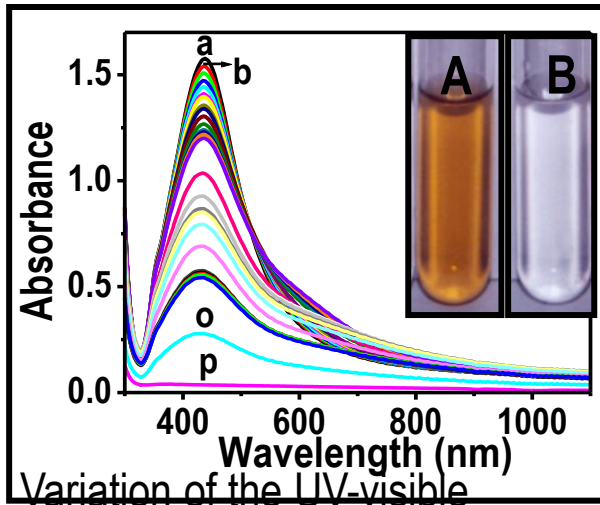
Category-wise distribution of contaminants regulated by USEPA and future contaminants

Noble metal nanoparticles for water purification: A critical review, T. Pradeep and Anshup, Invited critical review, Thin Solid Films, 517 (2009) 6441-6478 (DOI: 10.1016/j.tsf.2009.03.195).

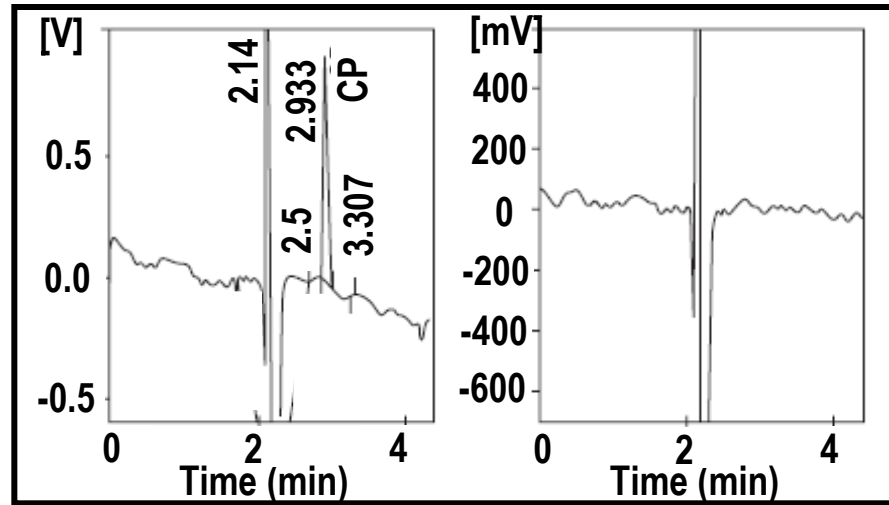
Noble metal nanoparticles: removal of pesticides from water

A.S. Nair, T. Pradeep, Curr. Sci. 84 (2003) 1560

A.S. Nair, R.T. Tom, V.R. Rajeev Kumar,
C. Subramaniam, T. Pradeep, Cosmos
3, (2007) 103



Variation of the UV-visible
absorption spectrum of silver
nanoparticles upon the addition
of CCl_4



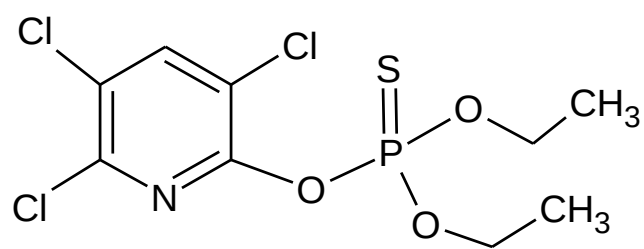
Gas chromatogram of chlorpyrifos solution (L) and after
treatment with silver nanoparticles (R)



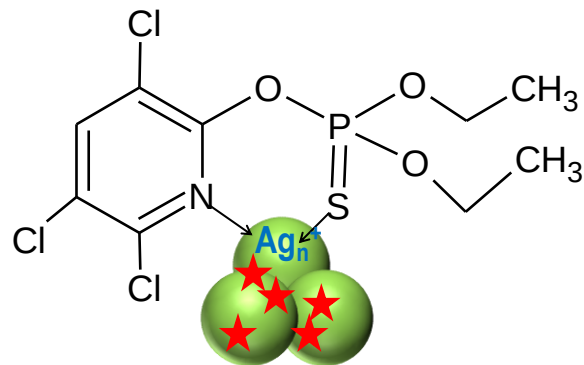
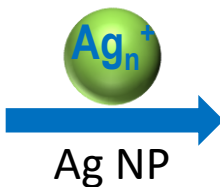
Indian patent 2006
PCT 2011 – US, Europe, Asia

June 2007

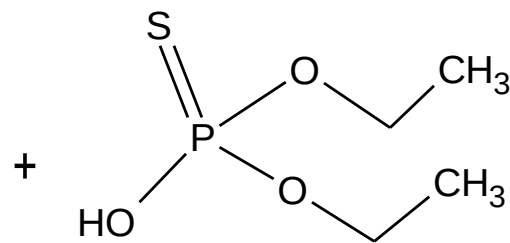
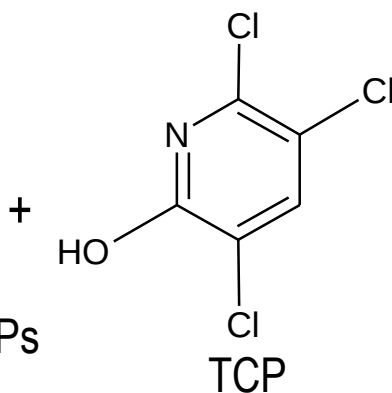
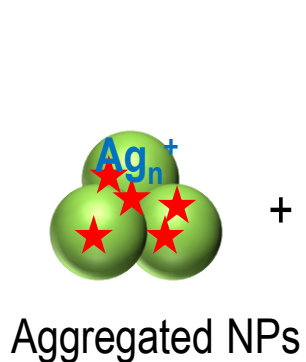
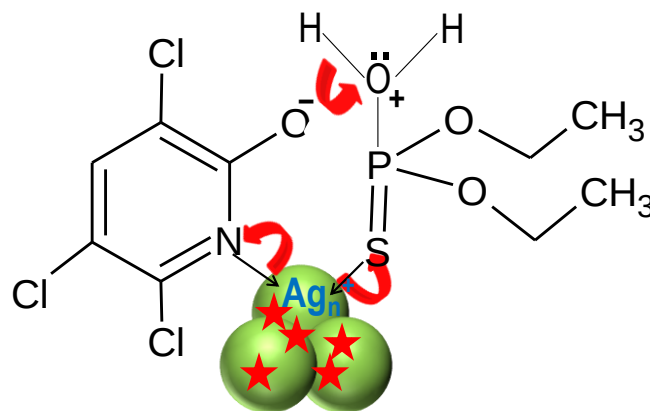
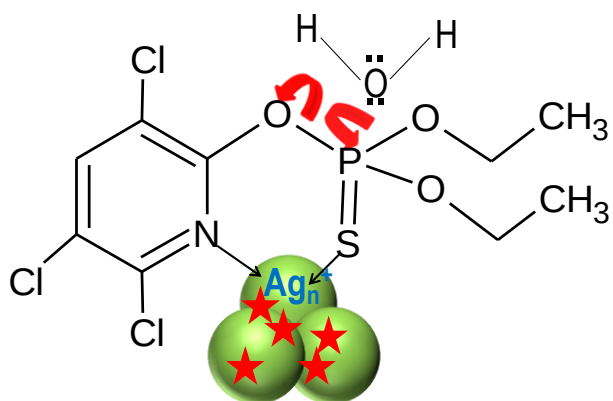
(L) Silver nanoparticles coated on activated alumina (R) Photograph of a pesticide filter device
using supported nanoparticles (WQA certified)



Chlorpyrifos^{*})



Surface complex



Diethylthiophosphate

World's first nanochemistry-based water purifier

RSC Advancing the
Chemical Sciences
Chemistry World

Pesticide filter debuts in India

20 April 2007

Killugudi Jayaraman/Bangalore, India

A domestic water filter that uses metal nanoparticles to remove dissolved pesticide residues is about to enter the Indian market. Its developers at the Indian Institute of Technology (IIT) in Chennai (formerly Madras) believe it is the first product of its kind in the world to be commercialised.

Mumbai-based Eureka Forbes Limited, a company that sells water purification systems, is collaborating with IIT and has tested the device in the field for over six months. Jayachandra Reddy, a technical consultant to the company, expects the first 1000 units to be sold door-to-door from late May.

'Our pesticide filter is an offshoot of basic research on the chemistry of nanoparticles,' Thalapathi Pradeep who led the team at IIT Chennai told *Chemistry World*. He and his student Sreekumar Nair discovered in 2003 that halocarbons such as carbon tetrachloride (CCl₄) completely break down into metal halides and amorphous carbon upon reaction with gold and silver nanoparticles¹.

Pradeep said this prompted them to extend their study to include organochlorine and organophosphorous pesticides, whose presence in water is posing a health risk in rural India. In research funded by the Department of Science and

Technology in New Delhi, his team found^{2,3} that gold and silver nanoparticles loaded on alumina were indeed able to completely remove endosulfan, malathion and chlorpyrifos - three pesticides that have been found at elevated levels in Indian water supplies.

Use and recycle

The mechanism of removal

Pradeep explained

environmental

filter and

pesticides

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A plant to make supported nanomaterials for water purification; with capacity of 4.5 tons per month, 2007

Chemistry world First ever nanotechnology product for clean water

1. Patents: A method of preparing purified water from water containing pesticides, **Indian patent 200767**
 2. Extraction of malathion and chlorpyrifos from drinking water by nanoparticles, **US 7,968,493** A method for decontaminating water containing pesticides, **EP 17,15,947**
- Product is marketed now by a Eureka Forbes Ltd.
Several new technologies are now available

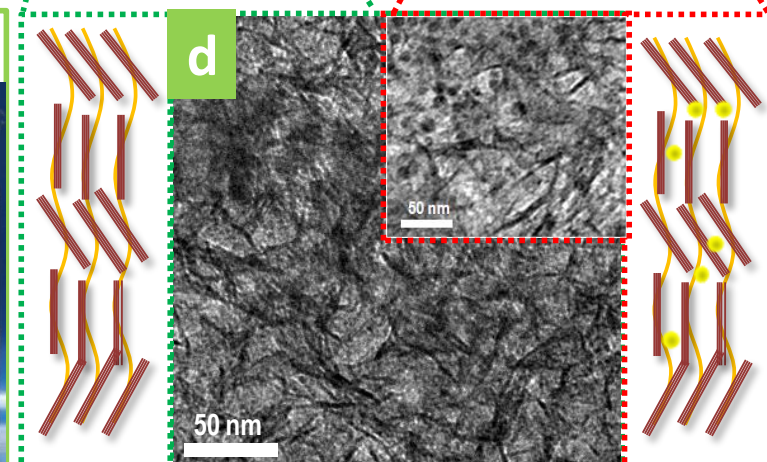
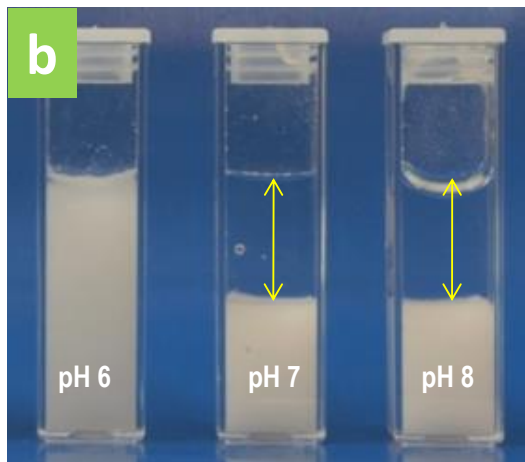
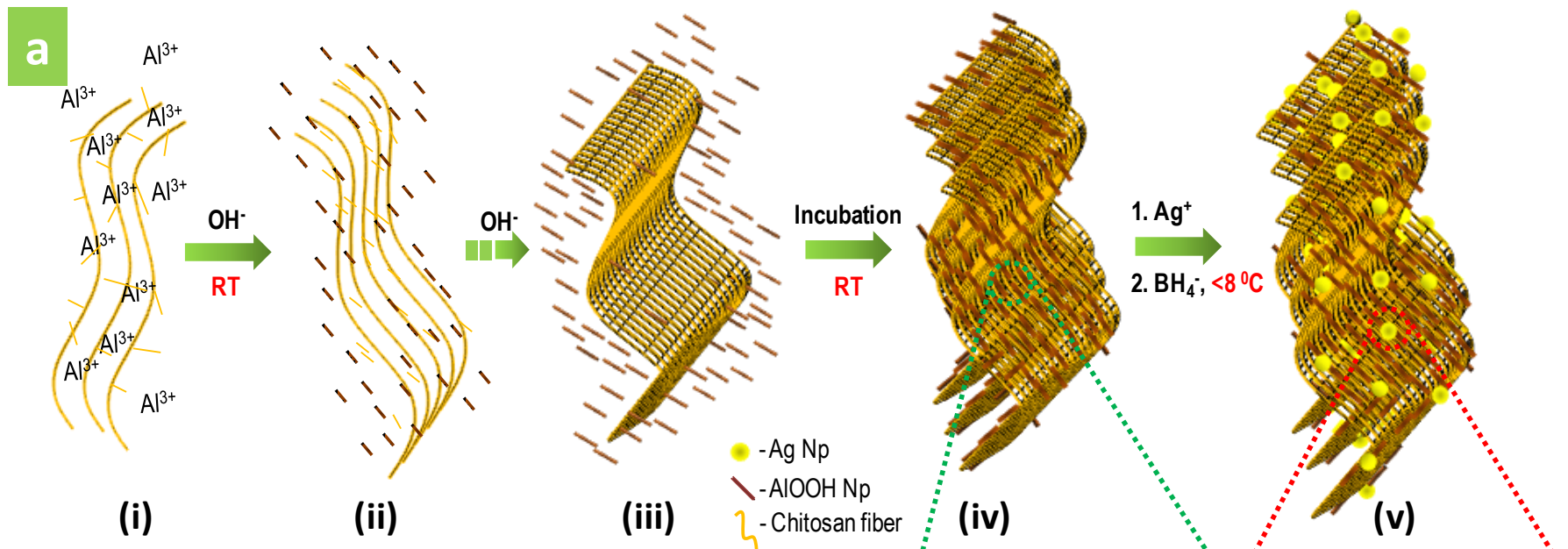


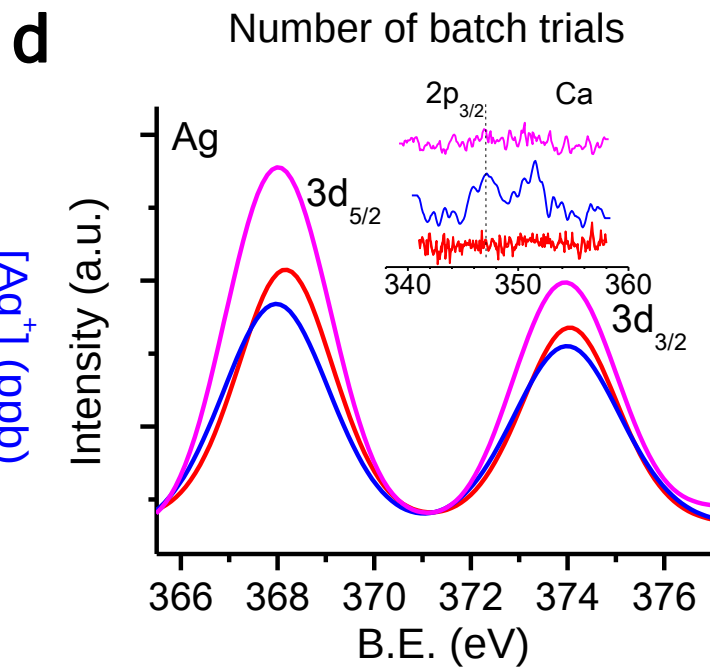
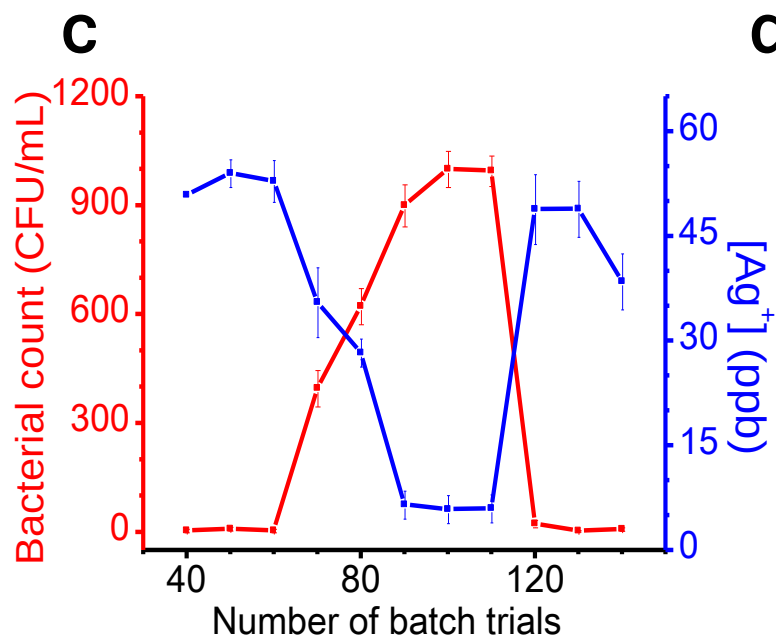
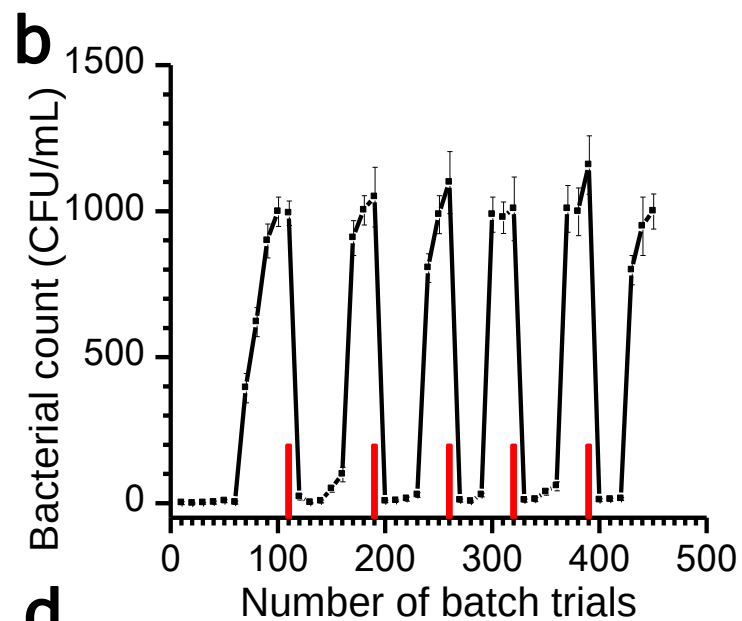
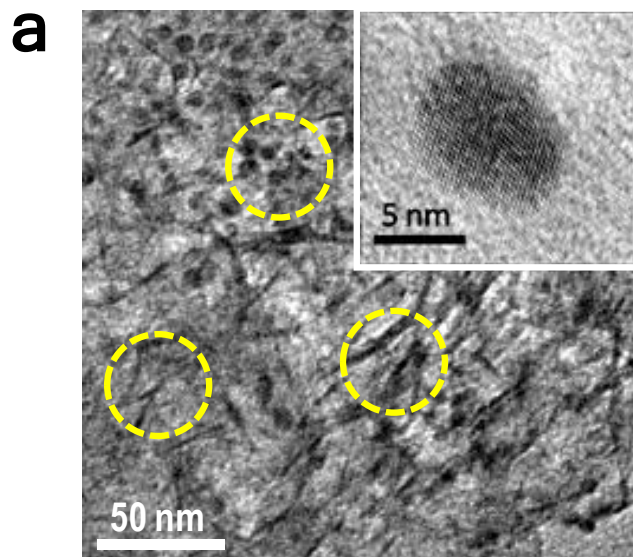
Affordable materials for water purification - Bioinspired

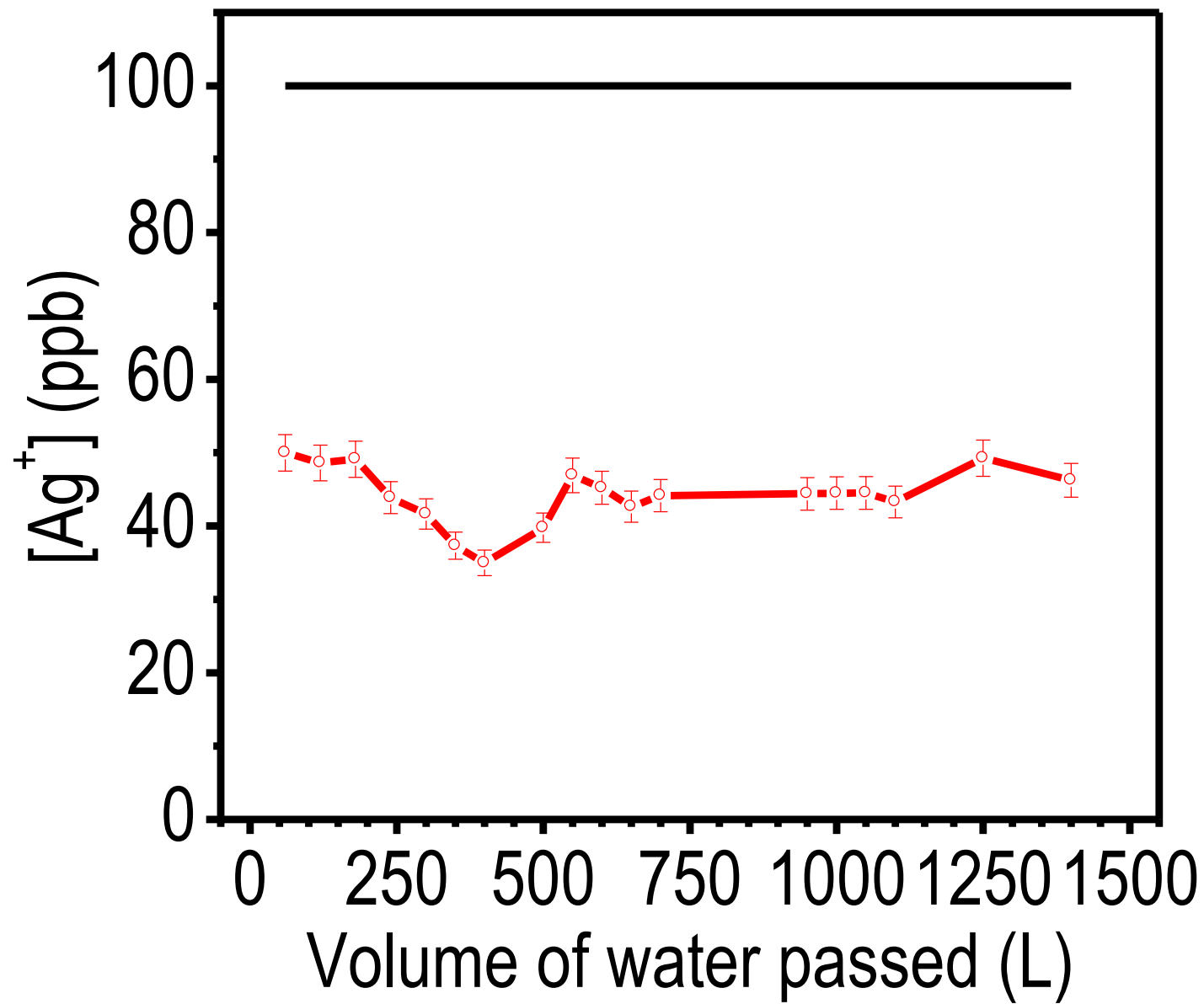
Water positive

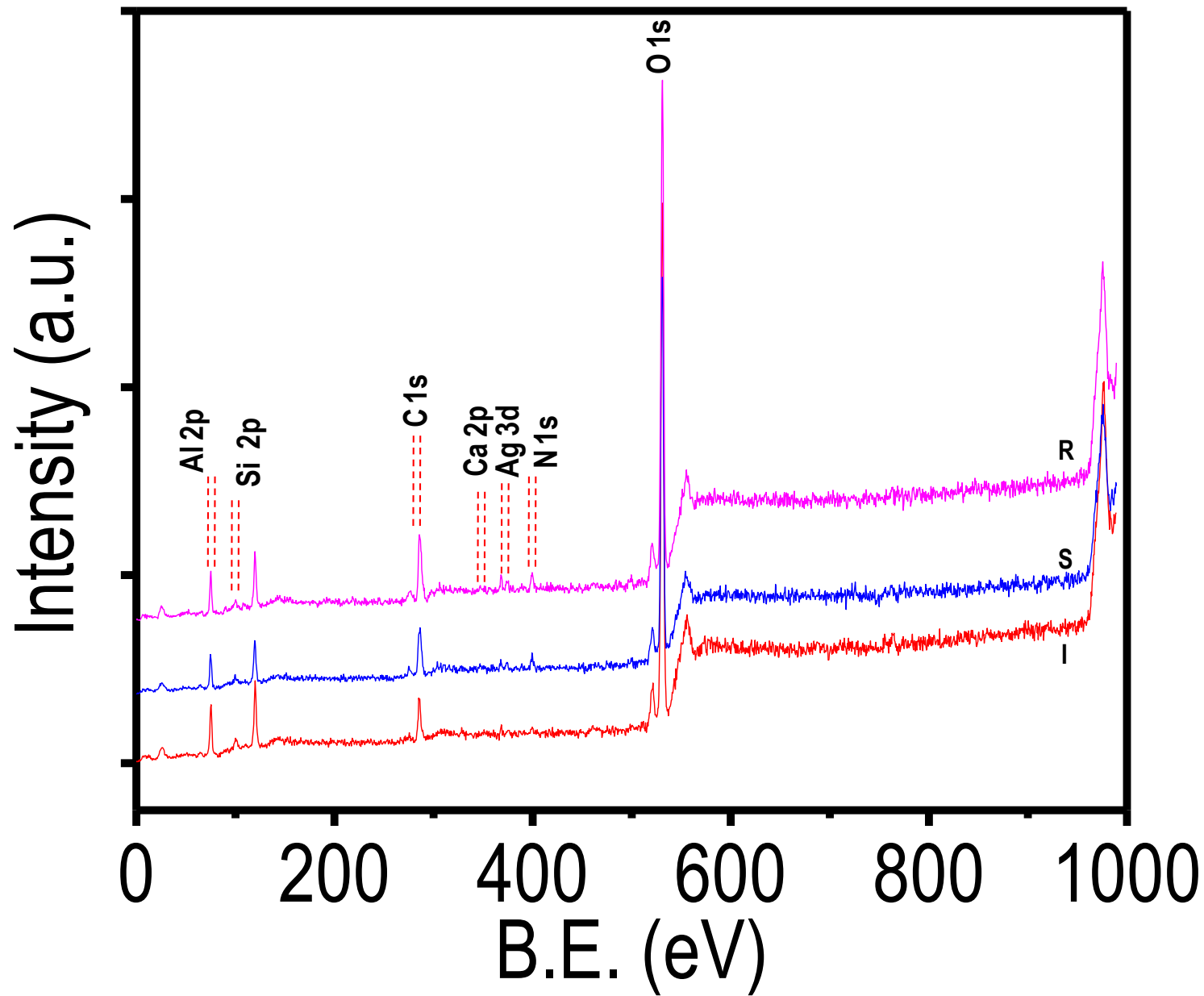
Water-based, room temperature, water stable

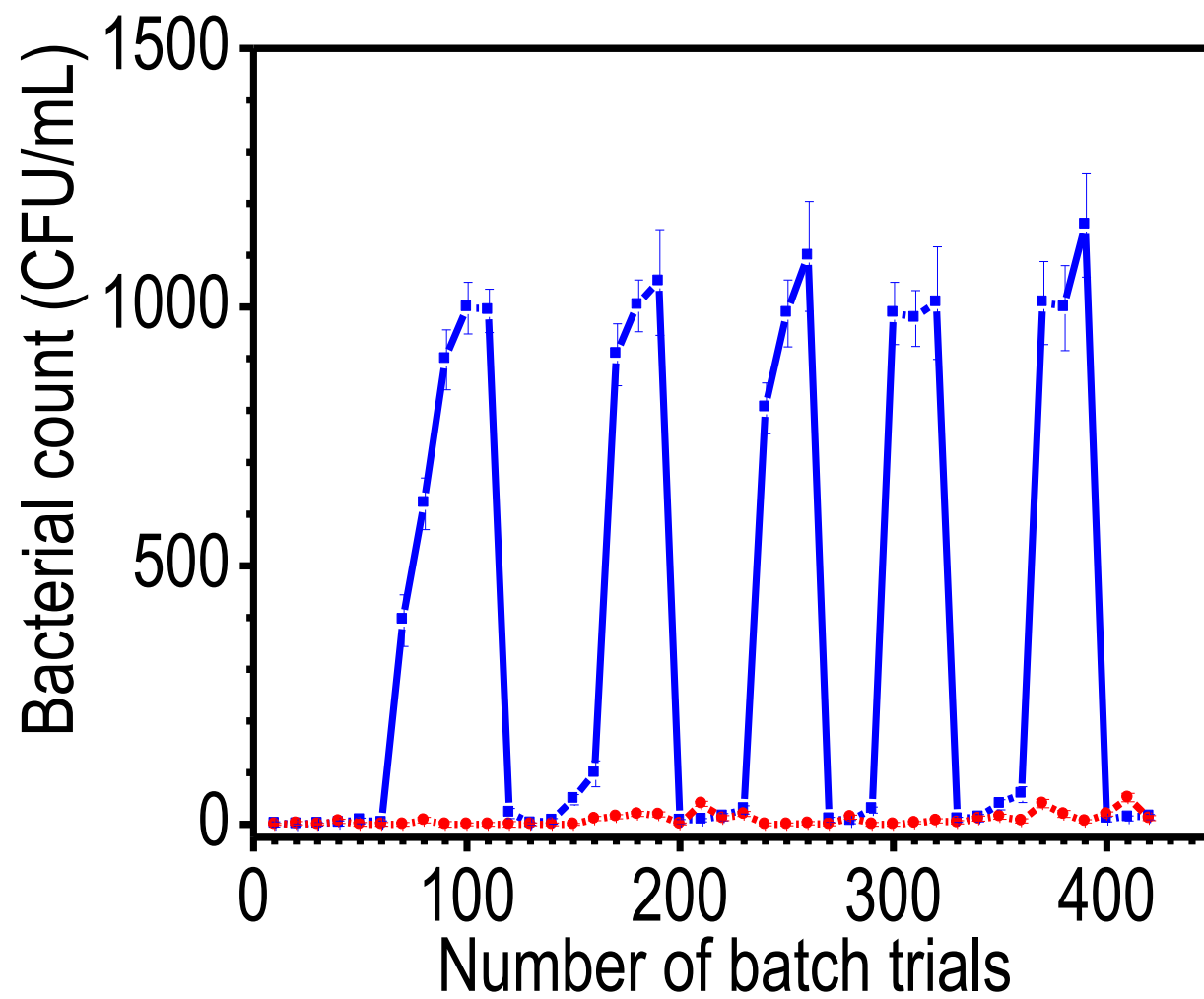
Green



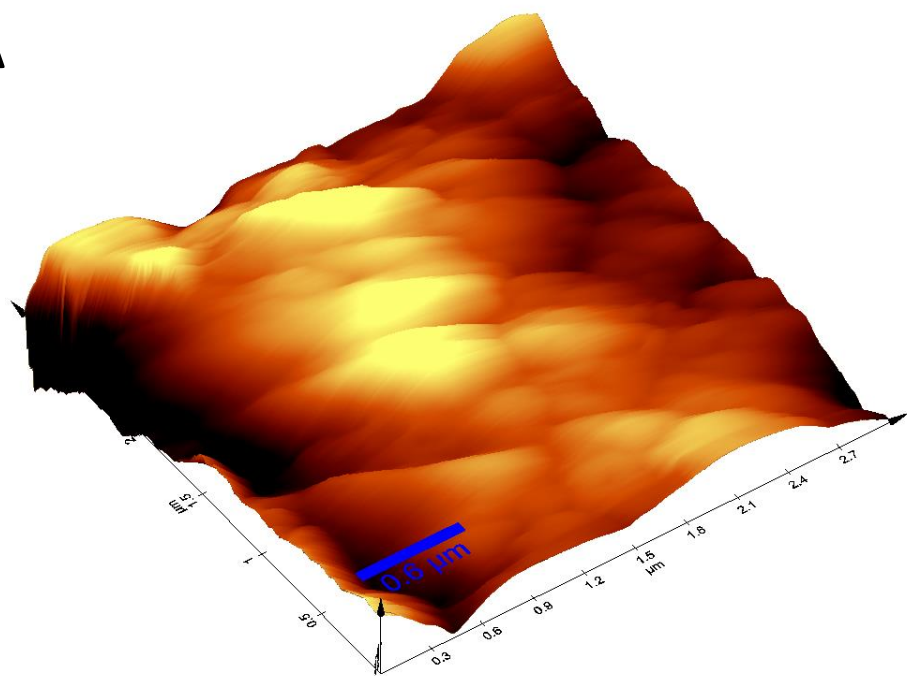








A

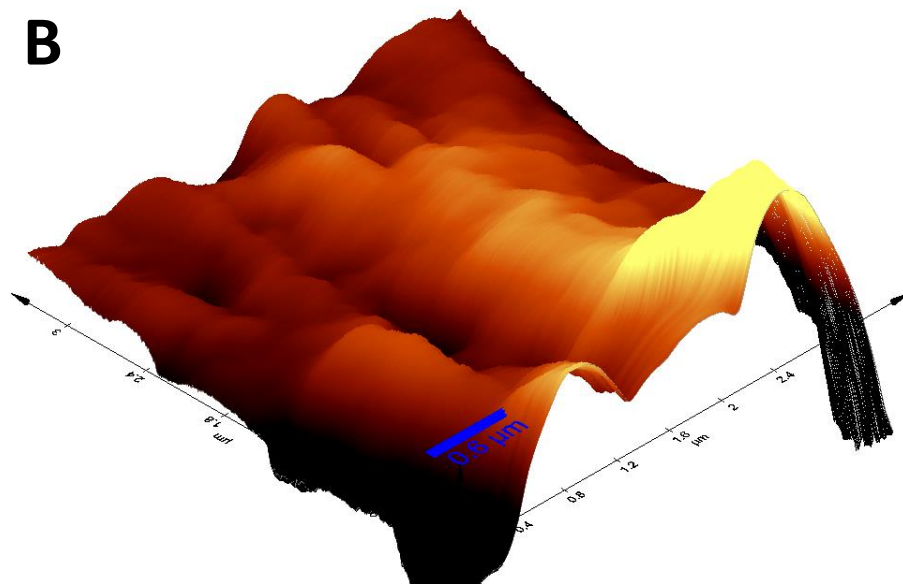


451.5 nm



0 nm

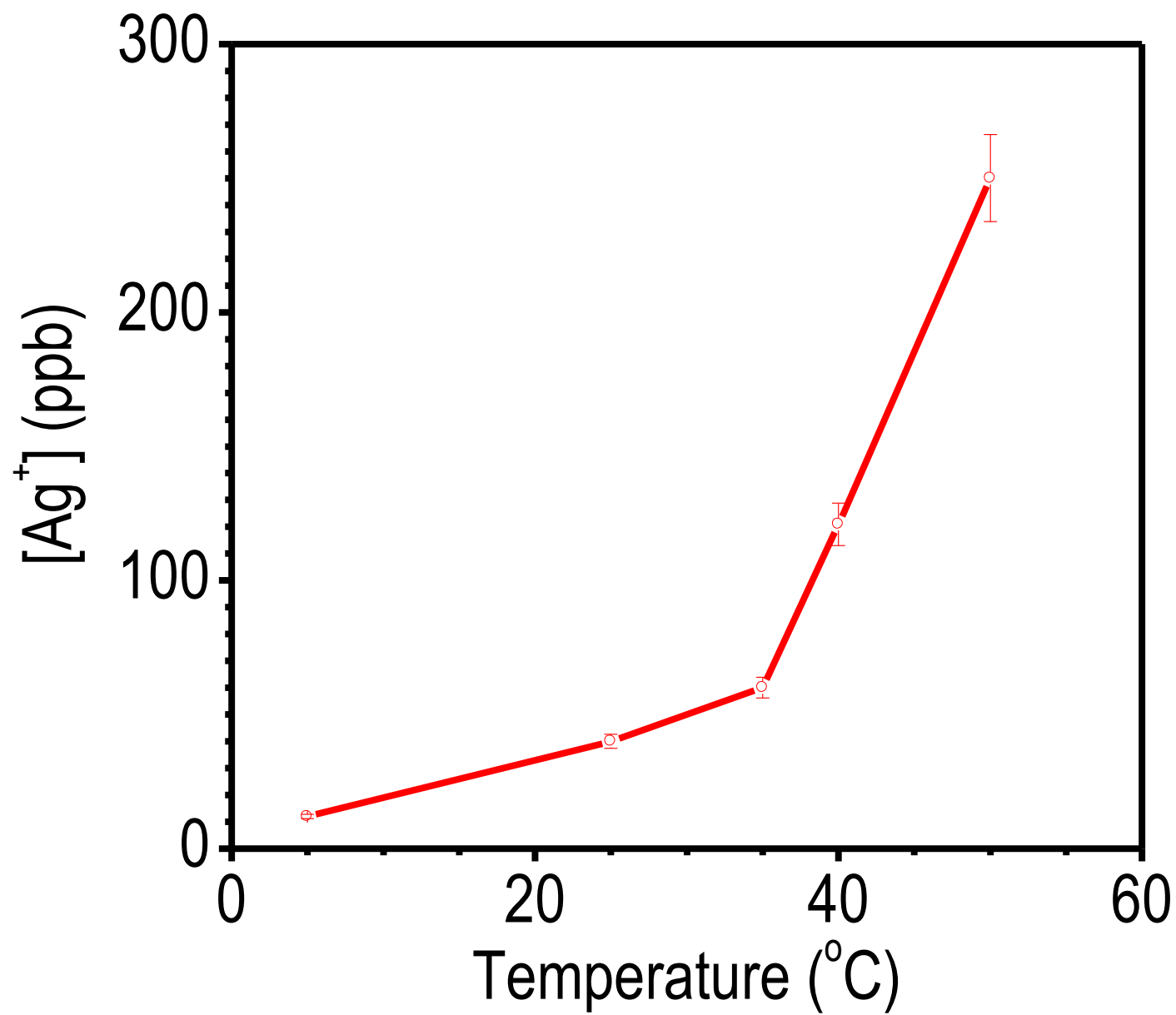
B

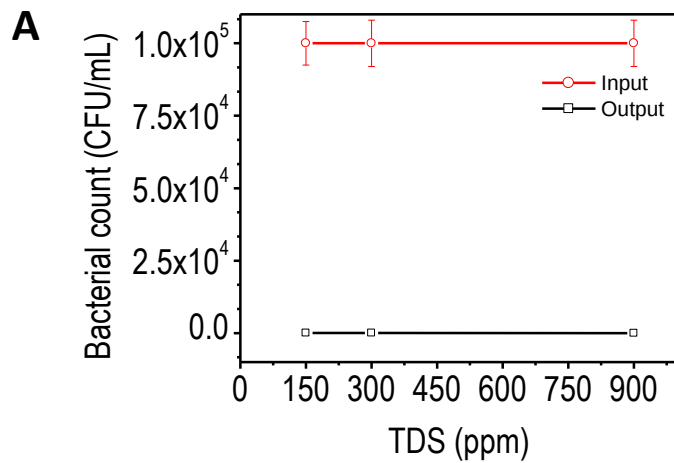


149.3 nm

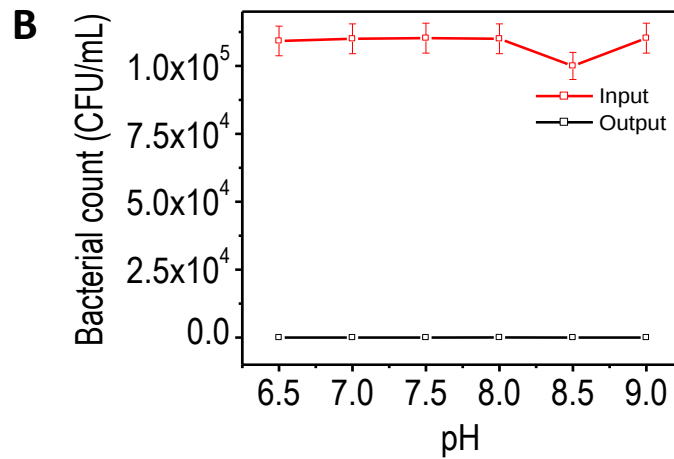


0 nm



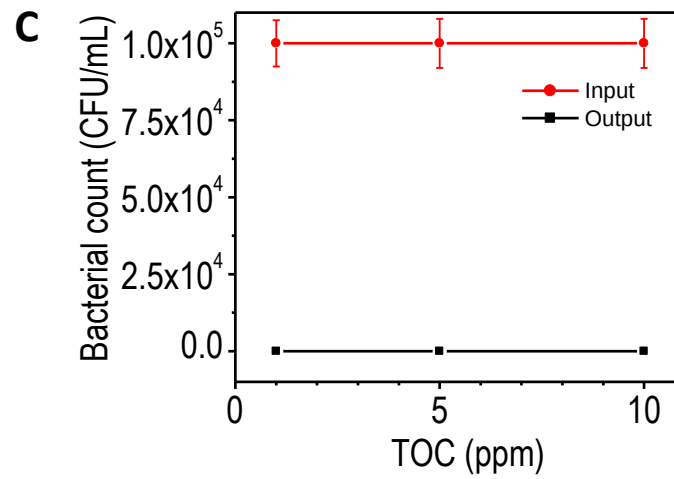


TDS



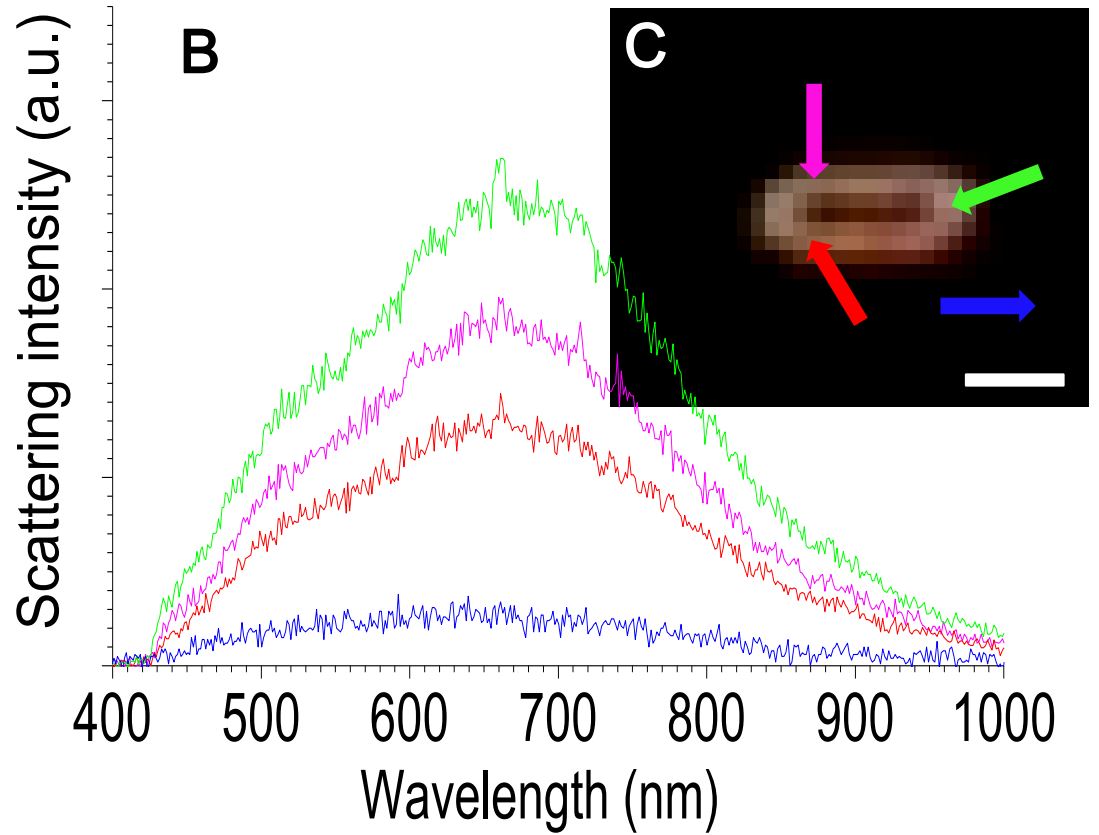
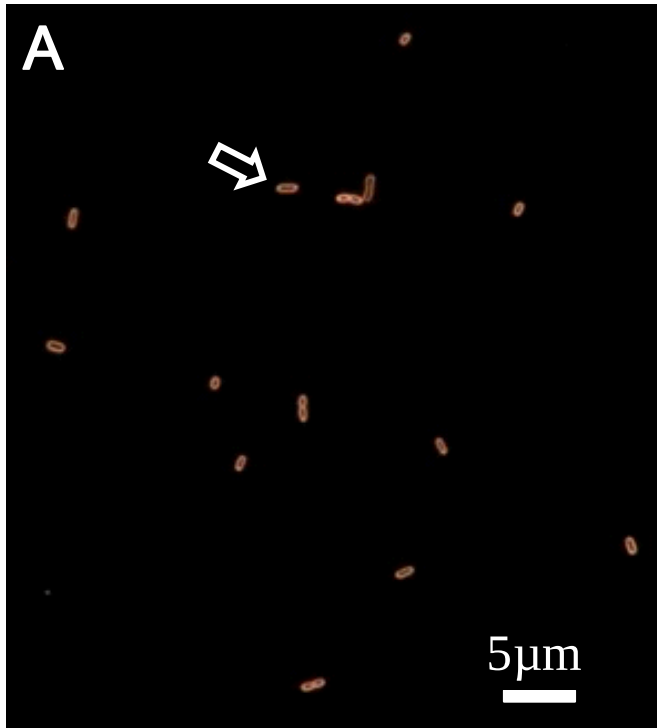
pH

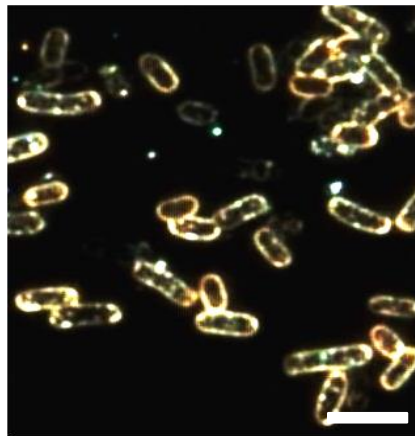
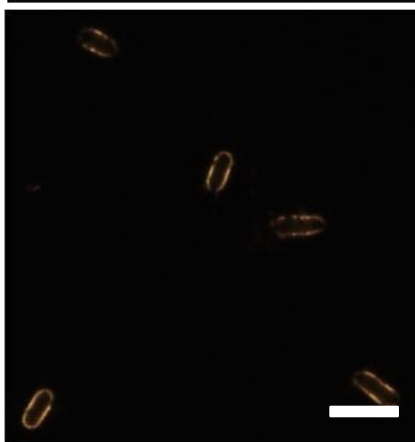
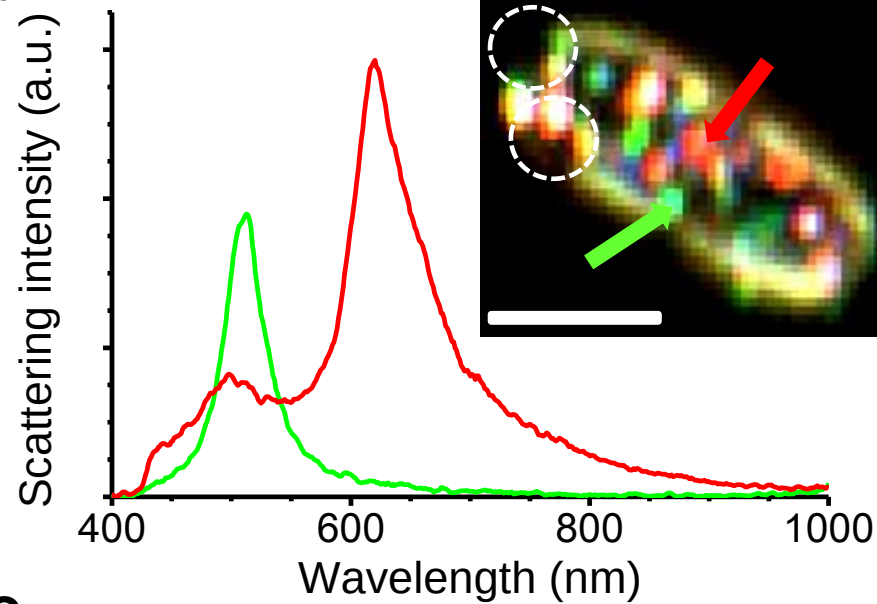
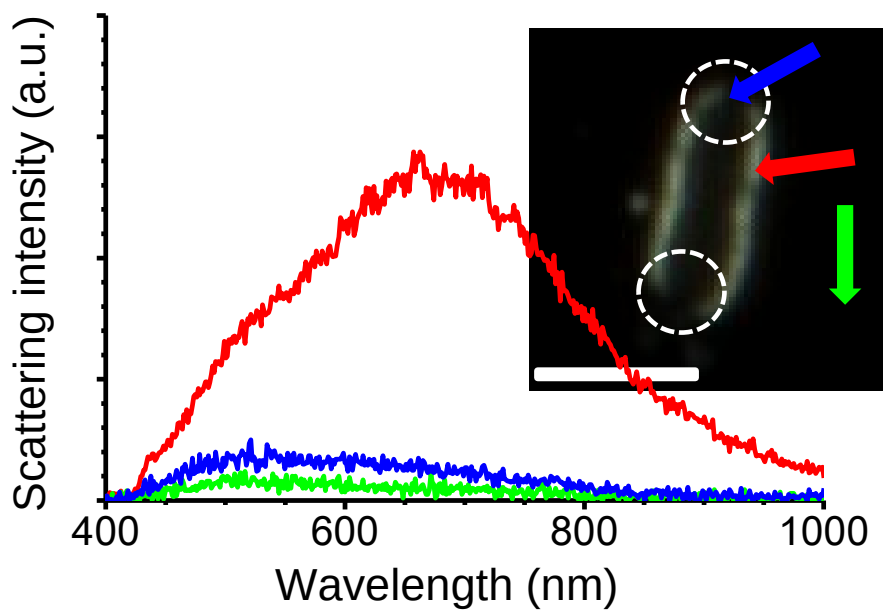
Real water experiments



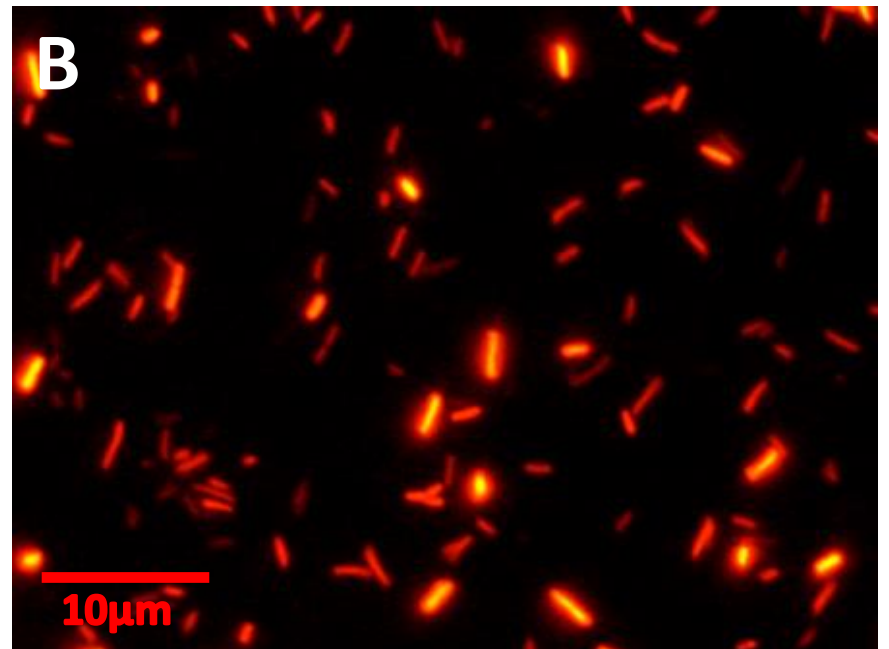
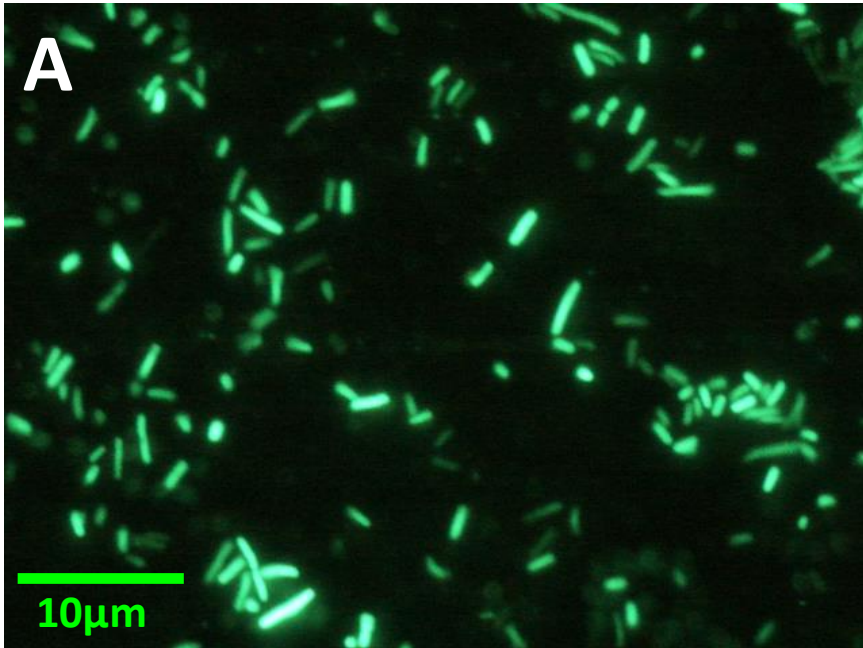
TOC – Humic acid

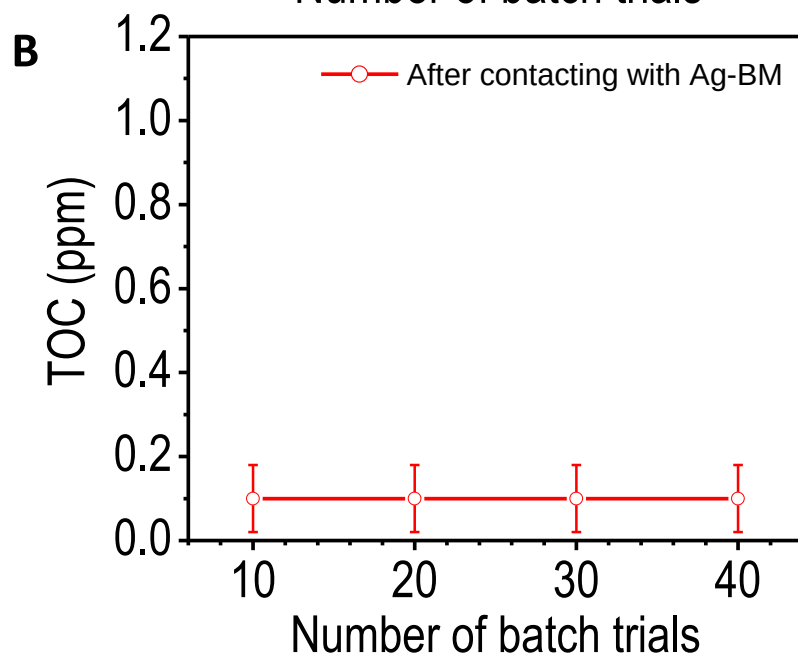
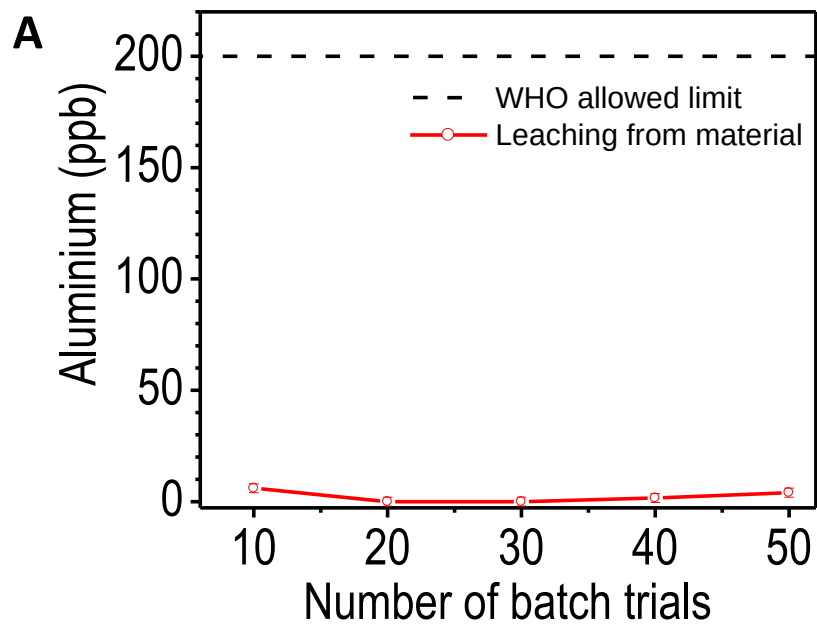
Nanotoxicity?



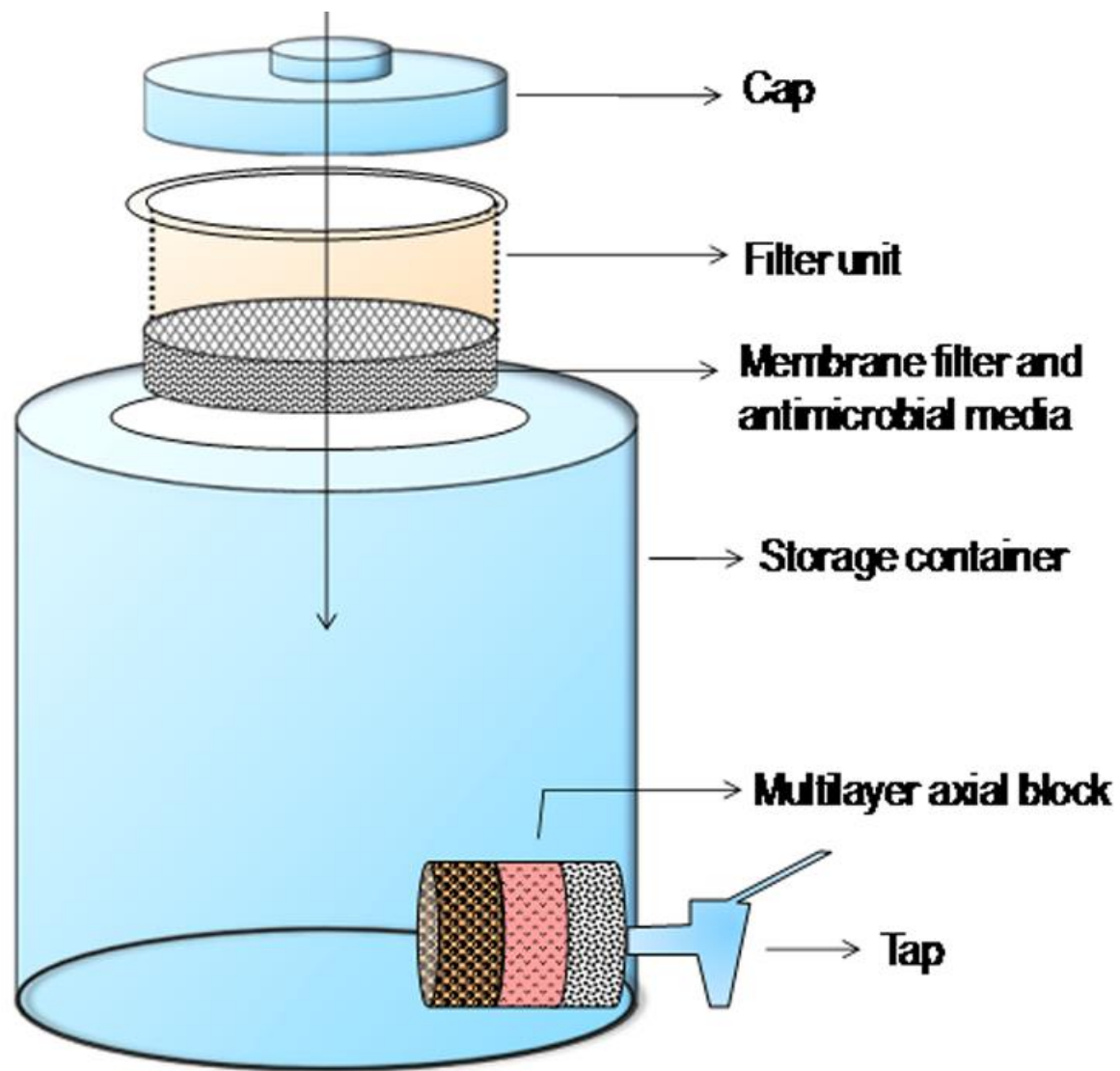
a**b****c****d****e**

Live/dead staining experiments





Leaching experiments



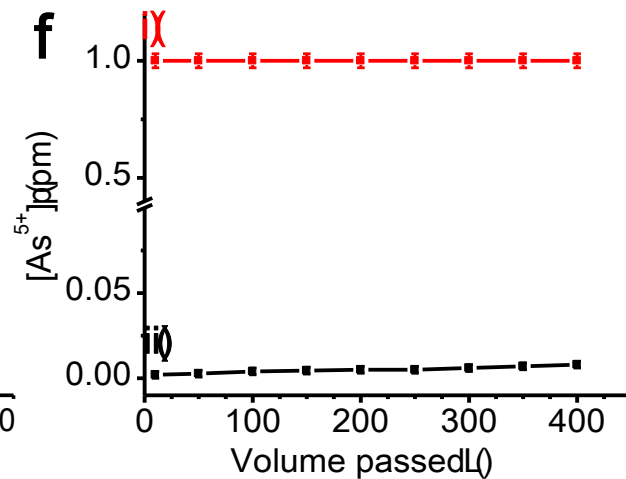
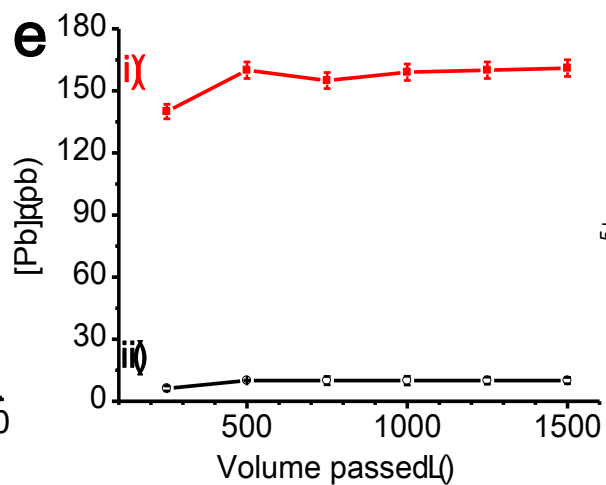
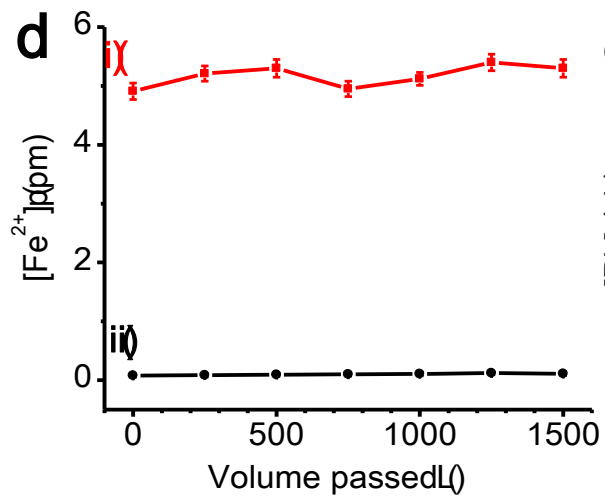
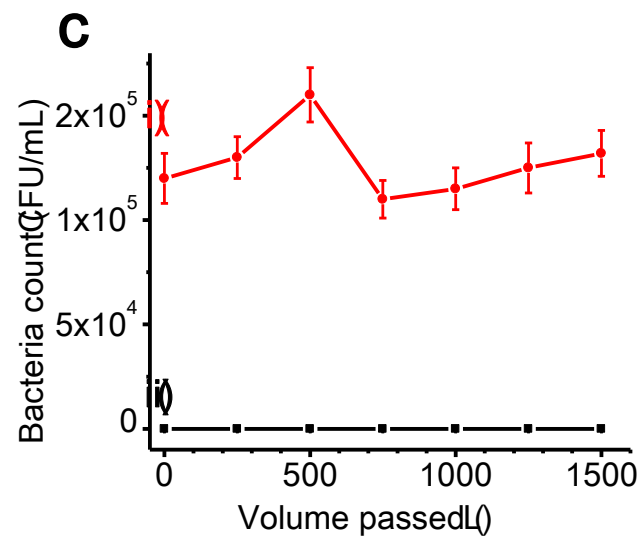
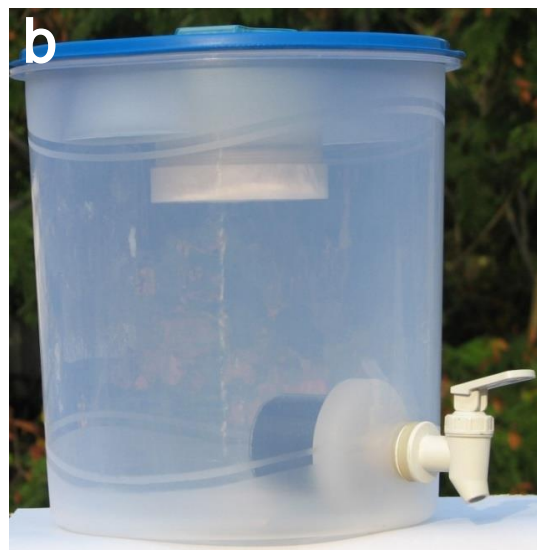
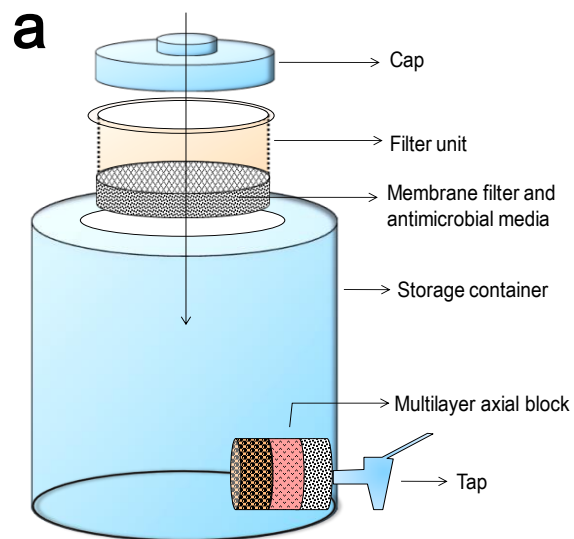
Physicochemical characteristics of influent natural drinking water

(Note: All parameters are expressed in mg L⁻¹, except for pH and conductivity)

ND-not detected

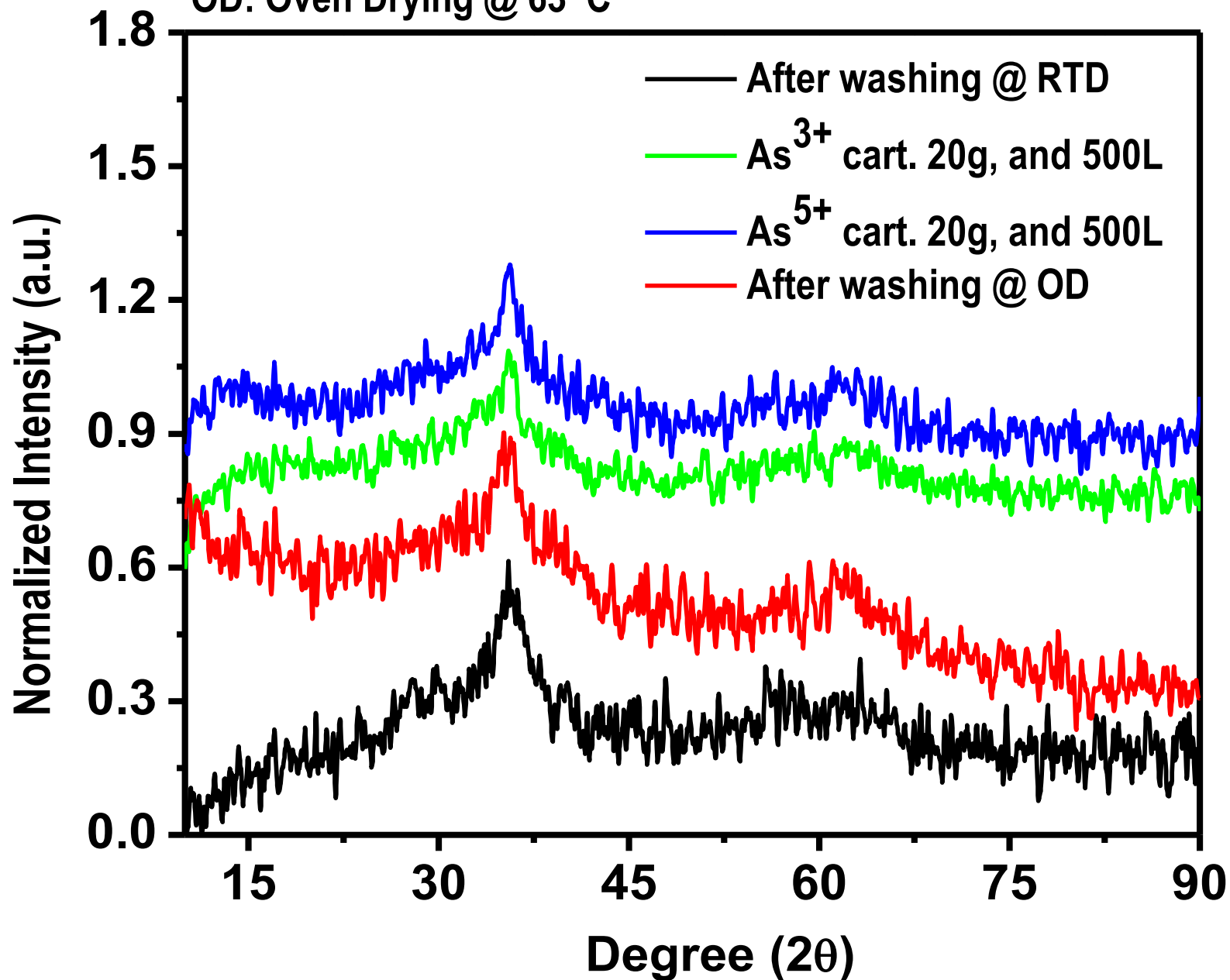
Natural drinking water (without treatment so that there is a residual bacterial count in it) was used for testing to ensure that that the material functions in the field.

Parameters	Value
Total coliforms (CFU/mL)	1-2 x 10 ³
p H @25°C	7.8
Conductivity (μS/cm)	640.000
Fluoride	0.573
Chloride	86.340
Nitrate	1.837
Sulphate	32.410
Silicate	15.870
Lithium	ND
Sodium	53.740
Ammonium	ND
Potassium	2.330
Magnesium	14.340
Calcium	28.720

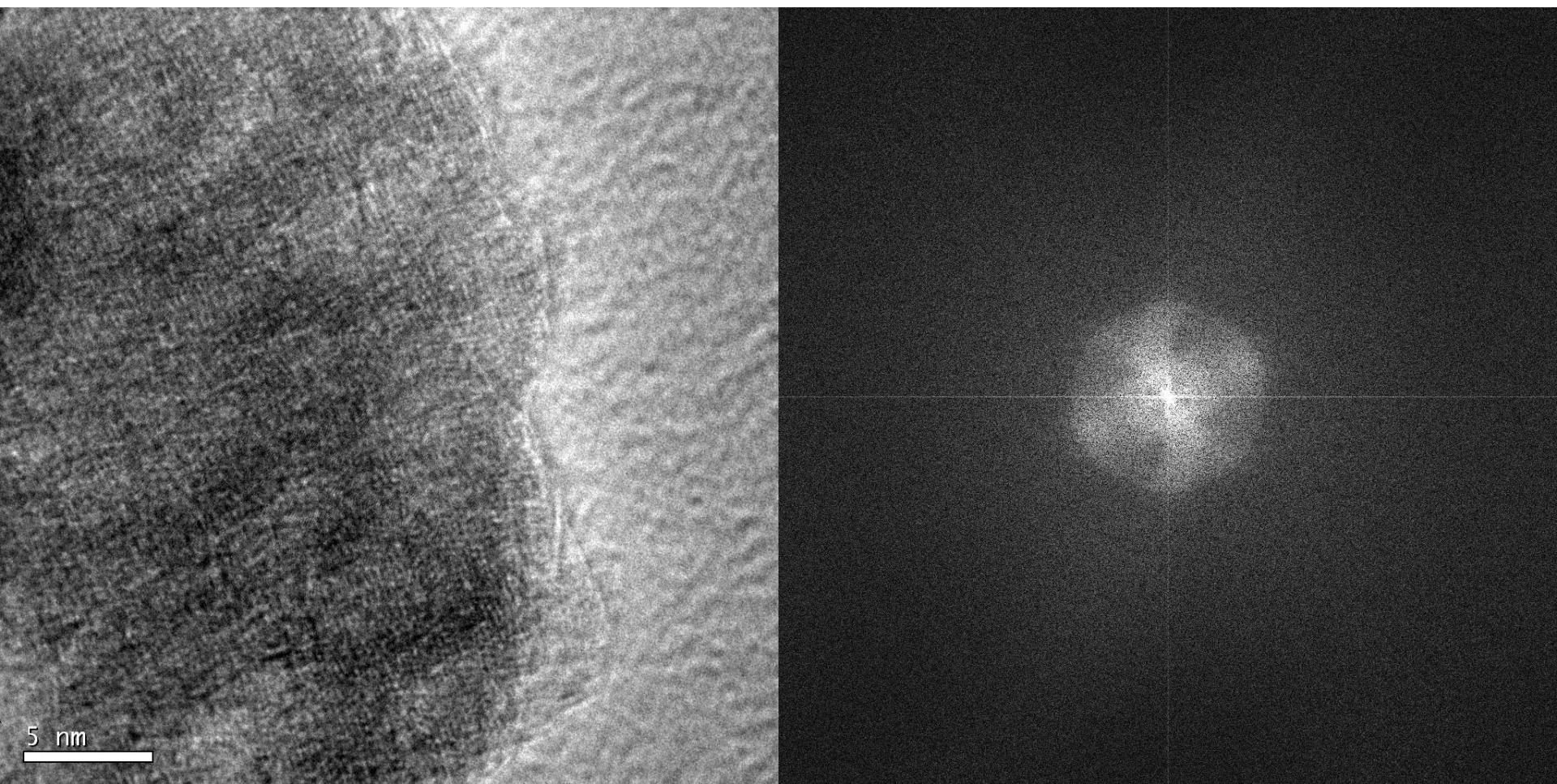


RTD: Room Temperature Drying

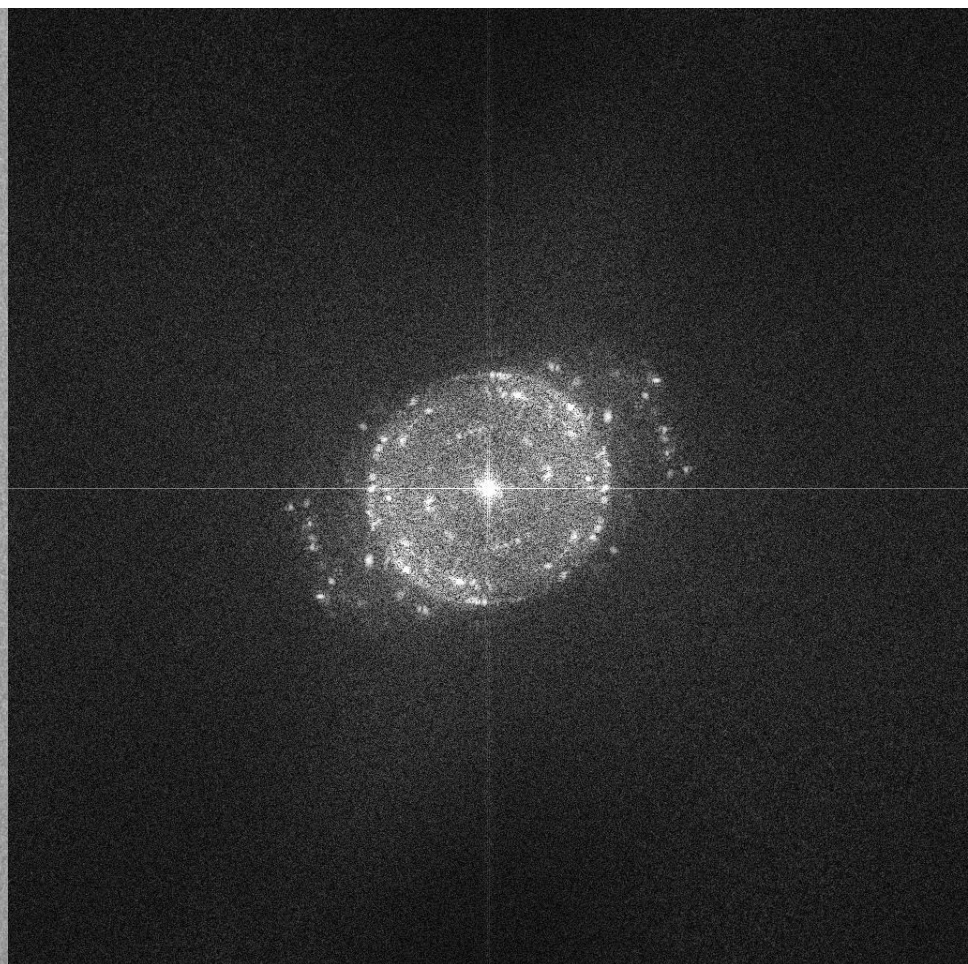
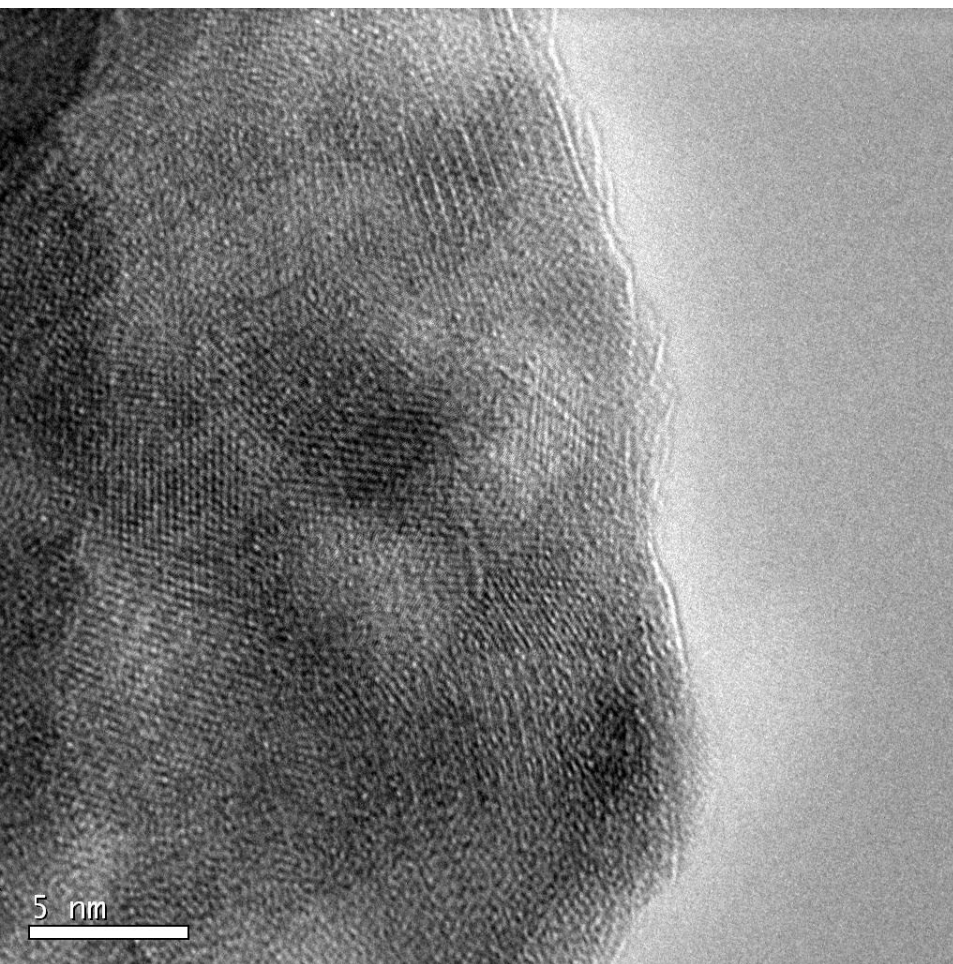
OD: Oven Drying @ 63⁰ C

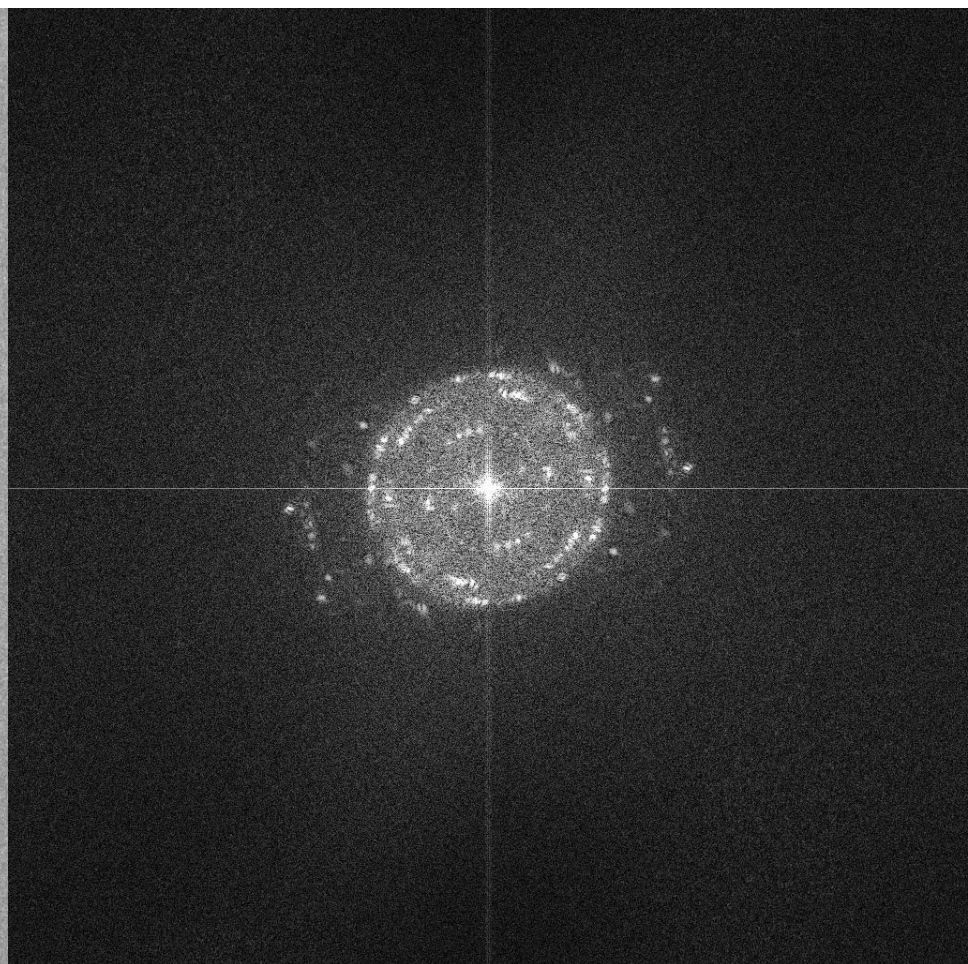
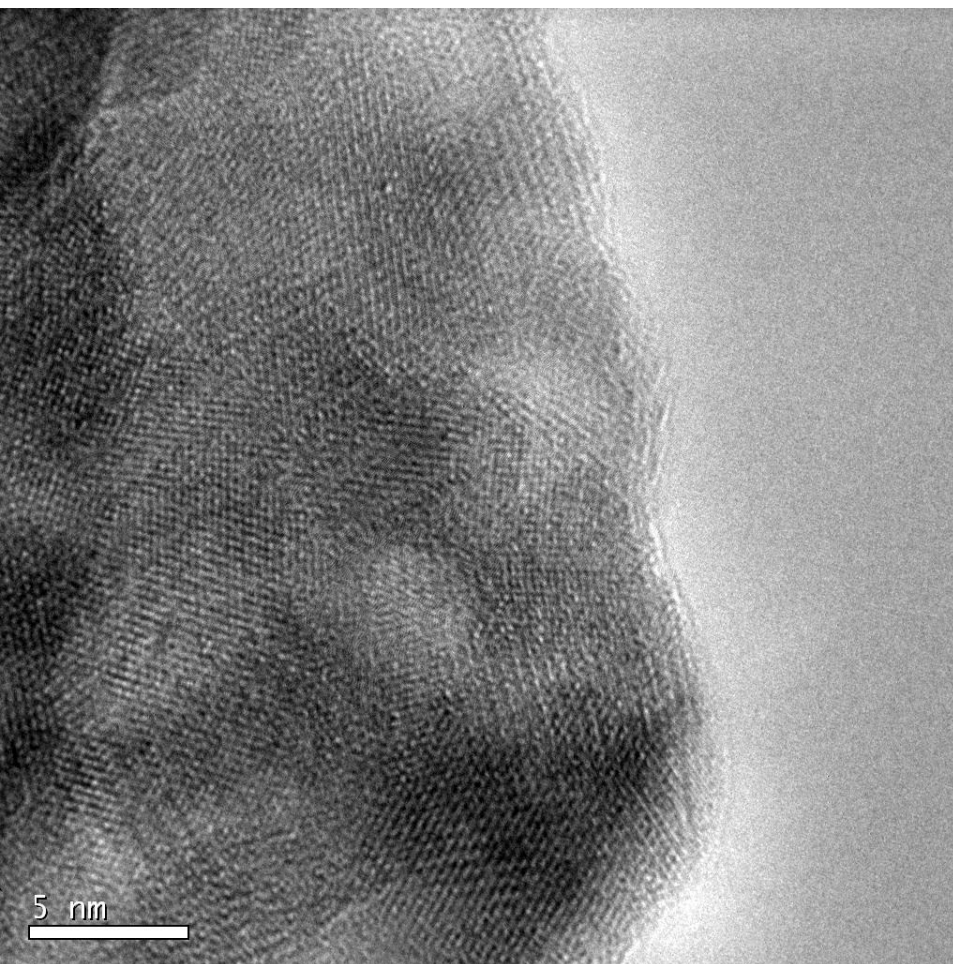


Metastable phase



Time dependent TEM





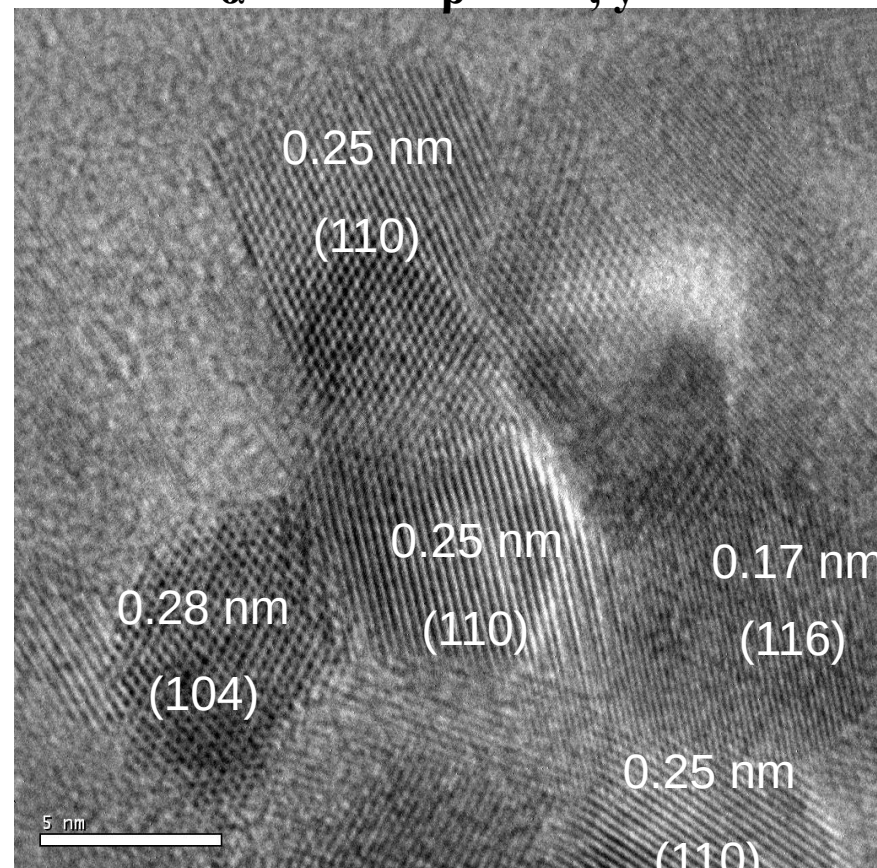
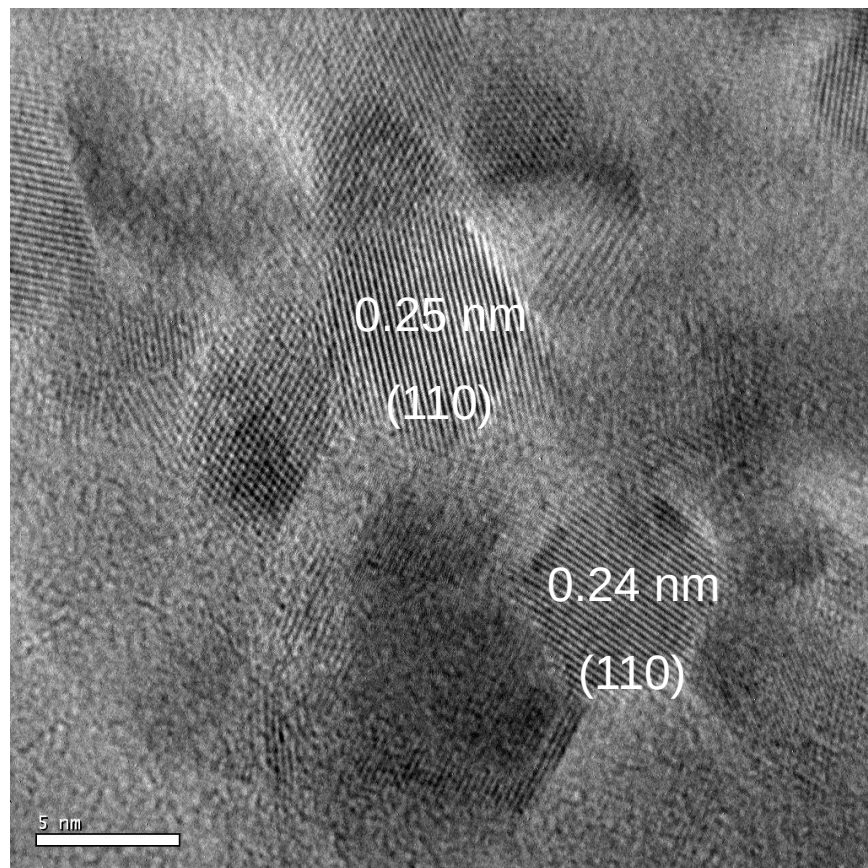
Ferrihydrite: 0.22 nm, 0.25 nm

HRTEM images of initial material

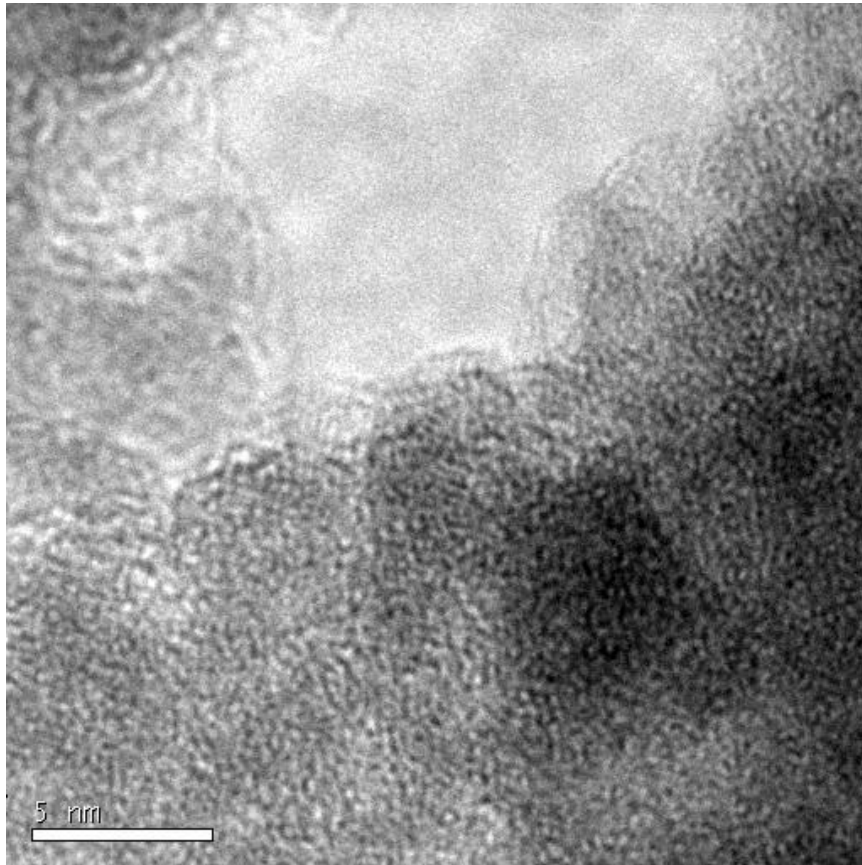
PCPDF No. 29-0712 (Hexagonal)

$a = 5.08$, $b =$, $c = 9.4$

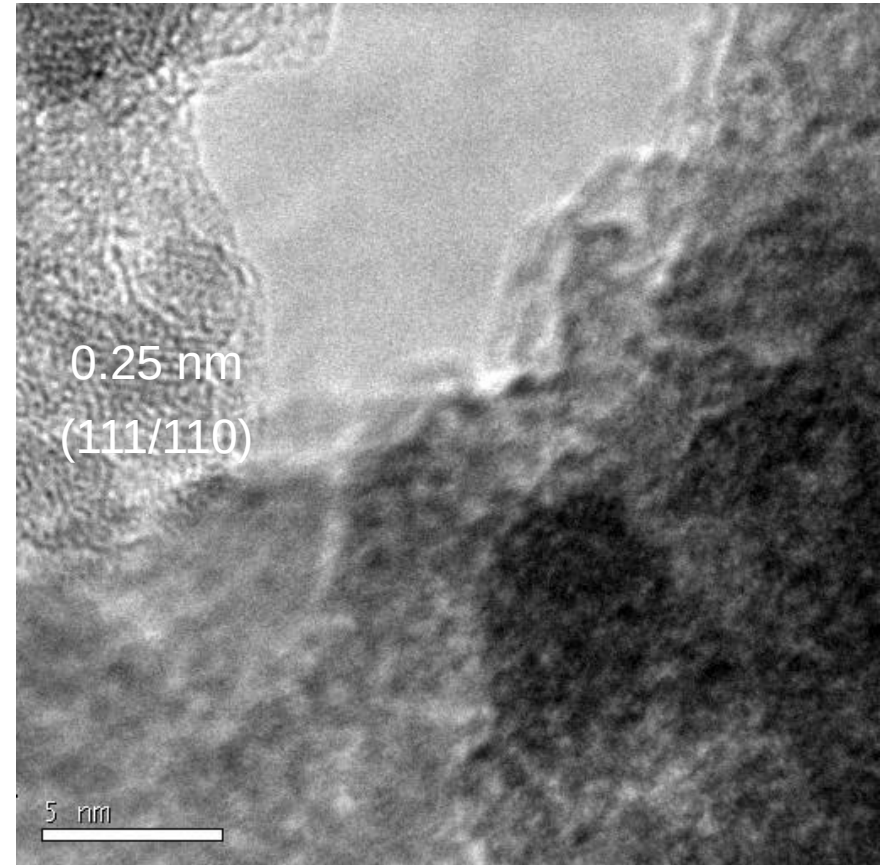
$\alpha =$ $\beta =$, $\gamma =$



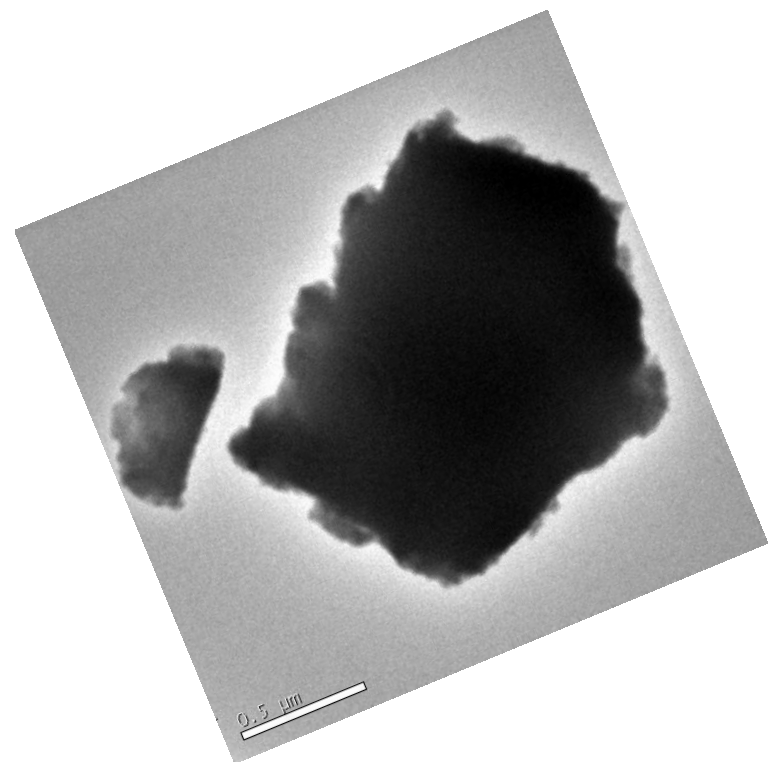
HRTEM images of As(V) adsorbed (or reacted) material [image from the same area at different depth of focus]



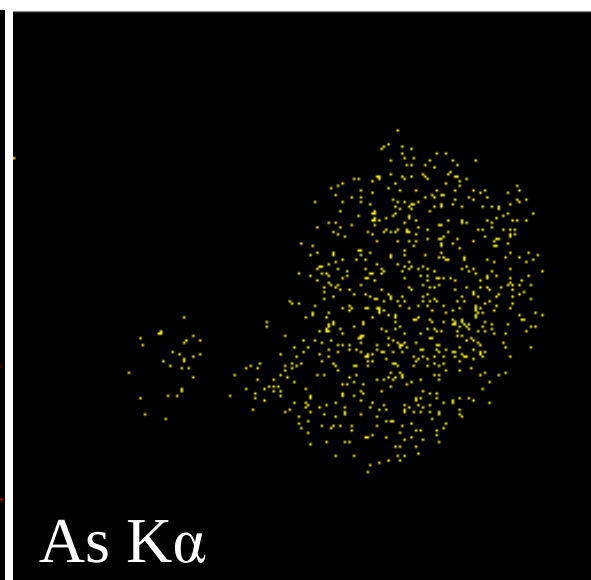
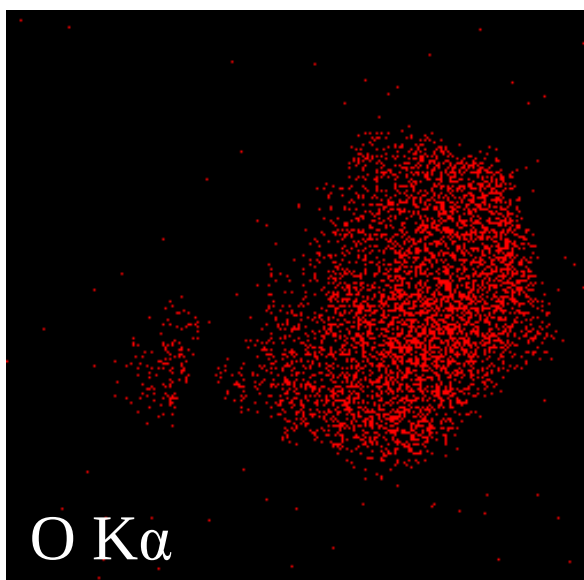
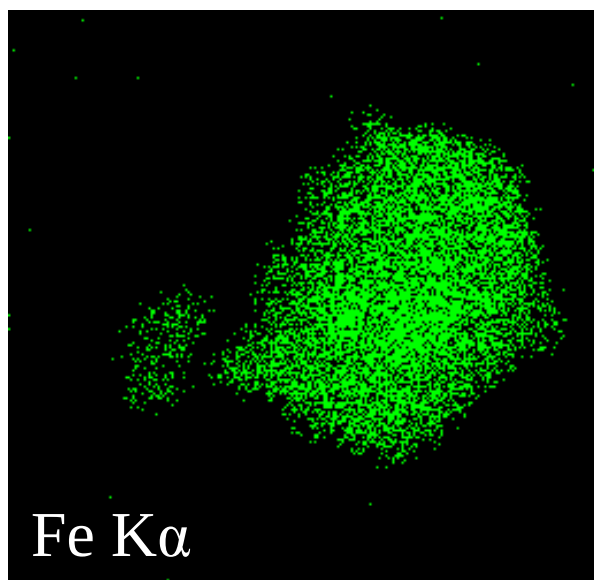
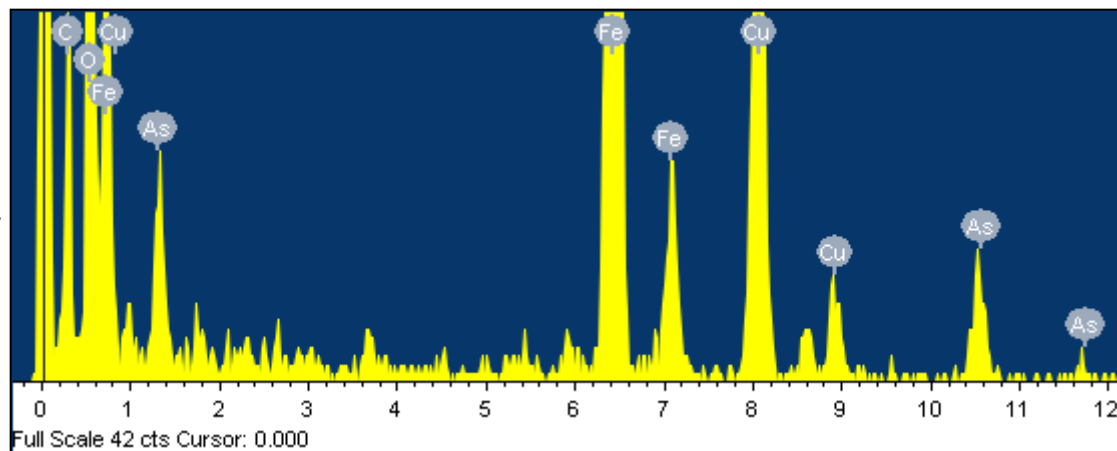
Goethite: α -FeOOH (0.25 nm)
PCPDF No. 81-0464 (Orthorhombic)
 $a = 4.604$, $b = 9.959$, $c = 3.023$
 $\alpha =$ $\beta =$, $\gamma =$



Ferrihydrite: 0.22 nm, 0.25 nm
PCPDF No. 29-0712 (Hexagonal)
 $a = 5.08$, $b =$, $c = 9.4$
 $\alpha =$ $\beta =$, $\gamma =$



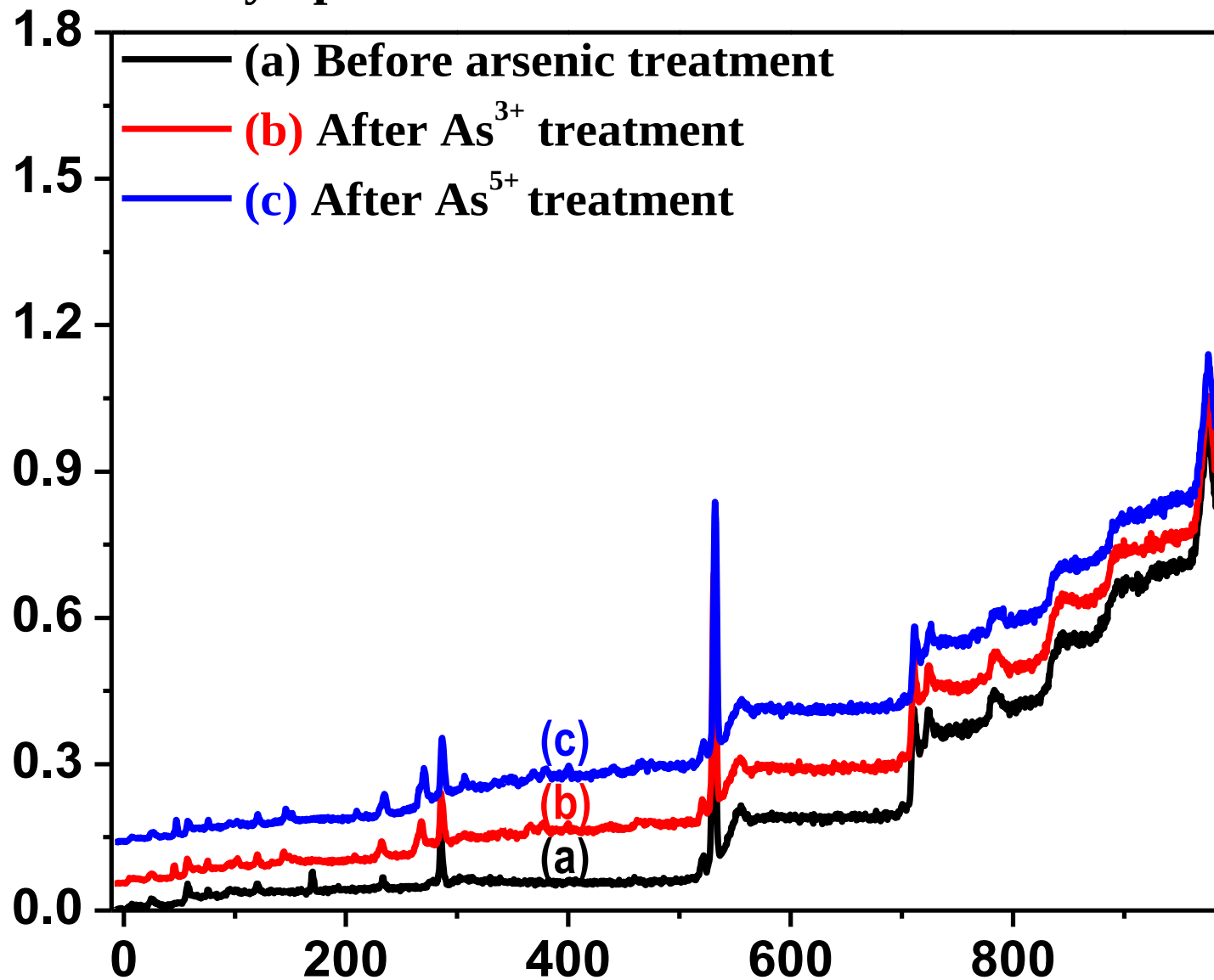
Element	Weight%	Atomic%
O K	32.84	63.62
Fe K	60.89	33.79
As K	6.27	2.59
Totals	100.00	100.00



Survey Spectrum

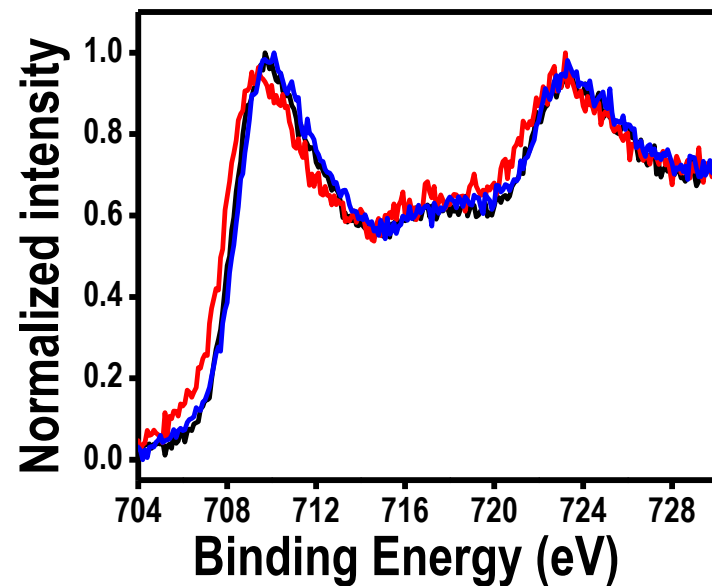
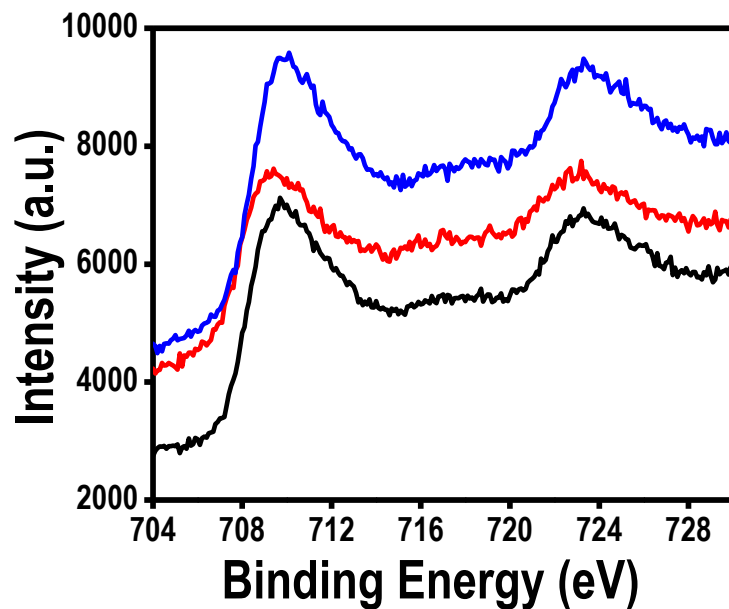
Arsenic Material

Normalized Intensity

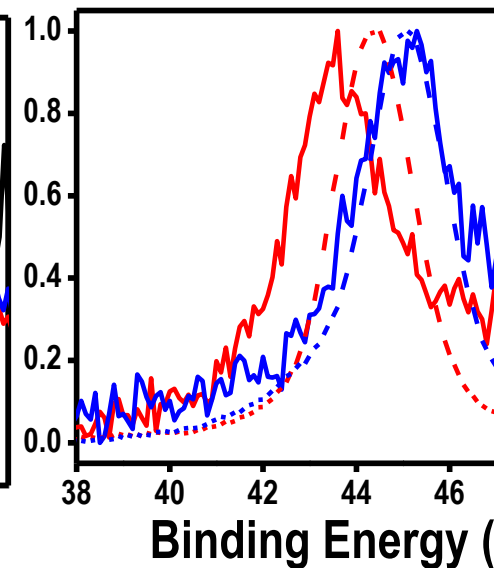
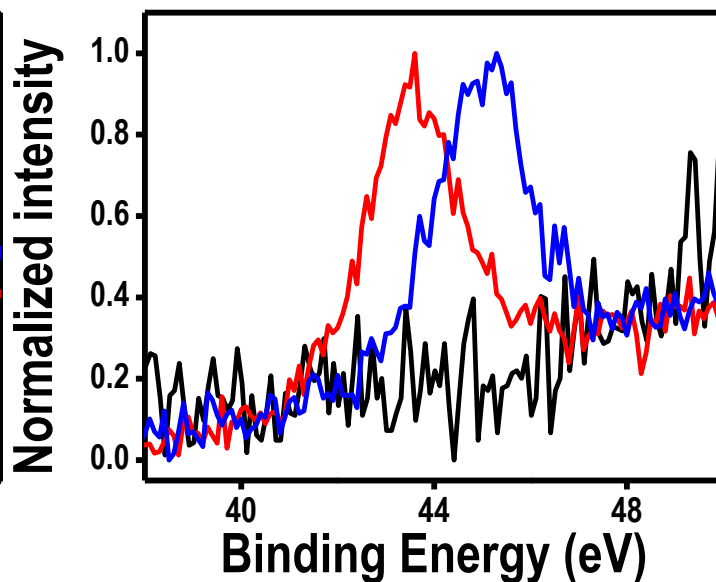
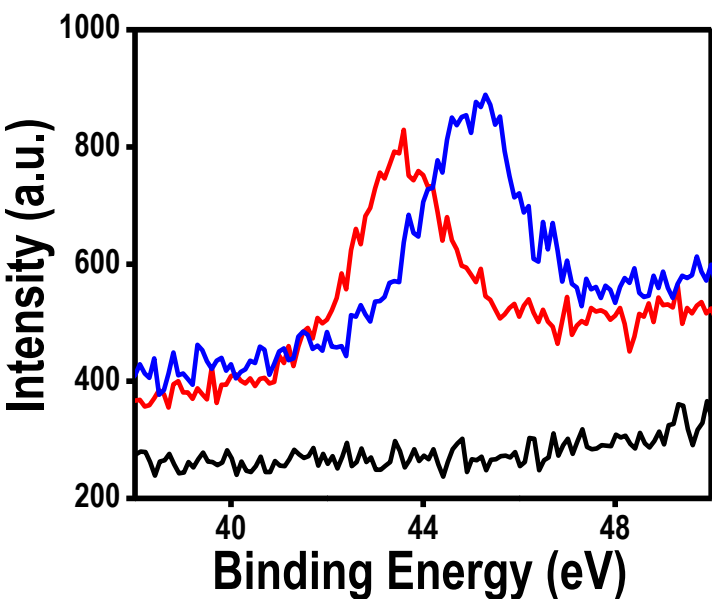


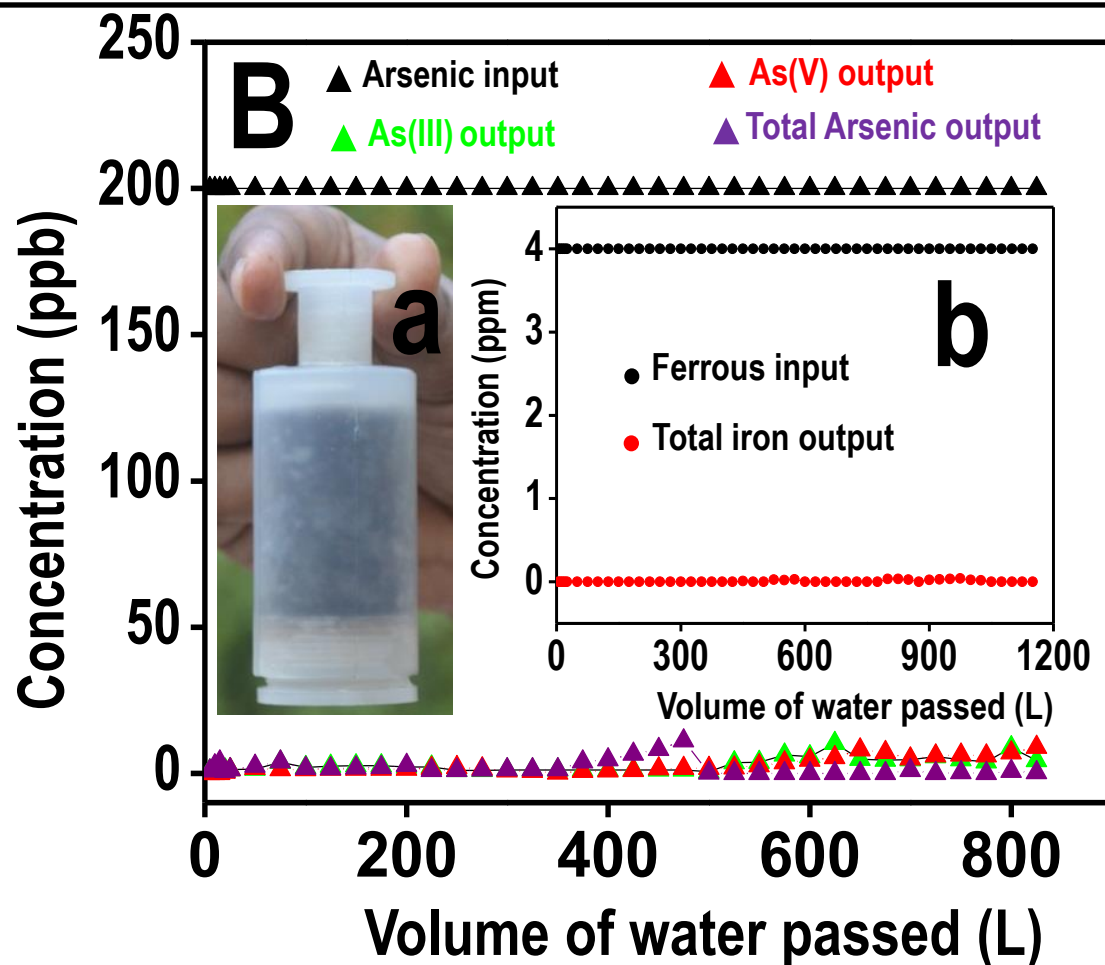
Binding Energy (eV)

Iron 2p



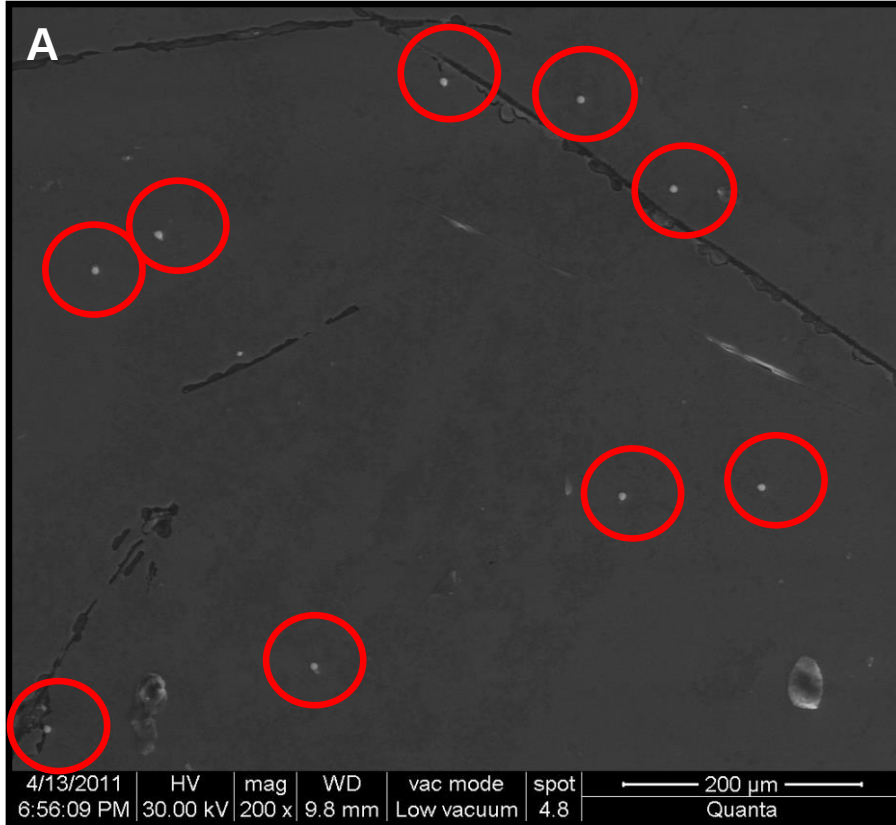
Arsenic 3d_{5/2}





A simple set-up which has been used for arsenic testing study: arsenic containing water is turned into arsenic free clean drinking water using a simple cartridge having the arsenic adsorbent (A), and a cartridge having about 20 g of the adsorbent (a). Arsenic experiment which was conducted using a 60 g cartridge, under natural water conditions (B), and the ferrous experiment which was conducted with combination of arsenic experiment (b).

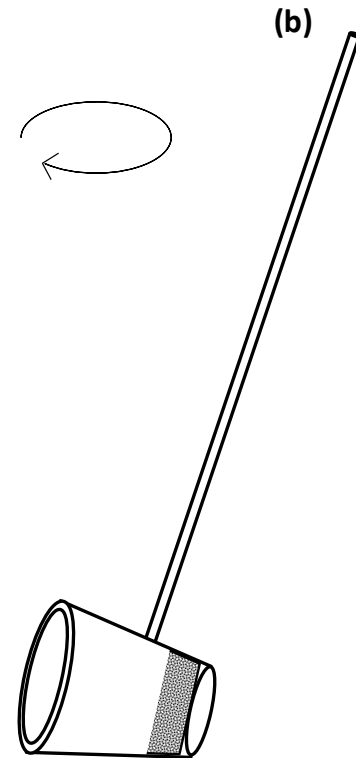
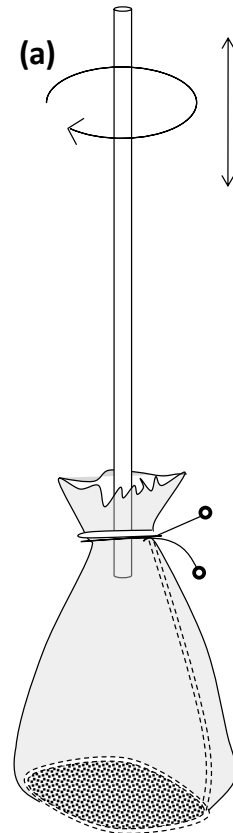
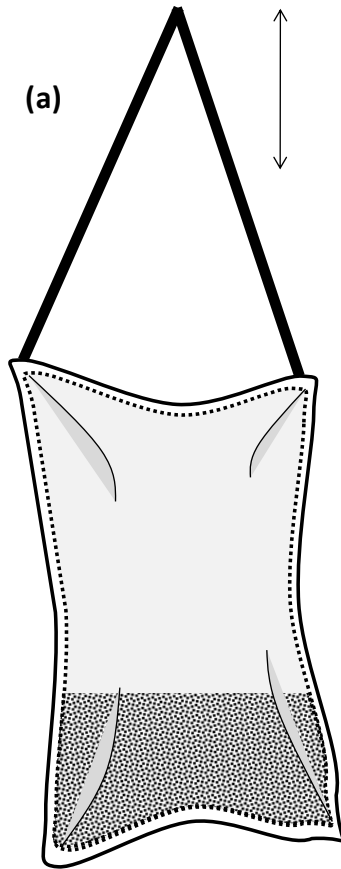
Cyst removal



Performance summary

		NSF norms	NSF Standard	InnoNano's Product
Functional Parameters	Sand & Sediment	Turbidity: 11 NTU to <0.5 NTU	NSF/ANSI 53	√
	Chlorine	2 ppm to <0.5 ppm	NSF/ANSI 42	√
	Bacteria	105 CFU/ml to absent	NSF/ANSI 55	√
	Virus	10 ³ PFU/ml to absent	NSF/ANSI 55	√
	Cyst	50000/ml to <2/ml	NSF/ANSI 53	√
	Pesticides	Chloroform: 300 ppb to <15 ppb	NSF/ANSI 53	√
	Iron	2 ppm to <0.2 ppm		√
	Lead	150 ppb to 10 ppb	NSF/ANSI 53	√
	Arsenic	300 ppb to 10 ppb	NSF/ANSI 53	√
	Mercury	6 ppb to 2 ppb	NSF/ANSI 53	√
	TDS	Not applicable		X
	Nitrate	Not applicable		X

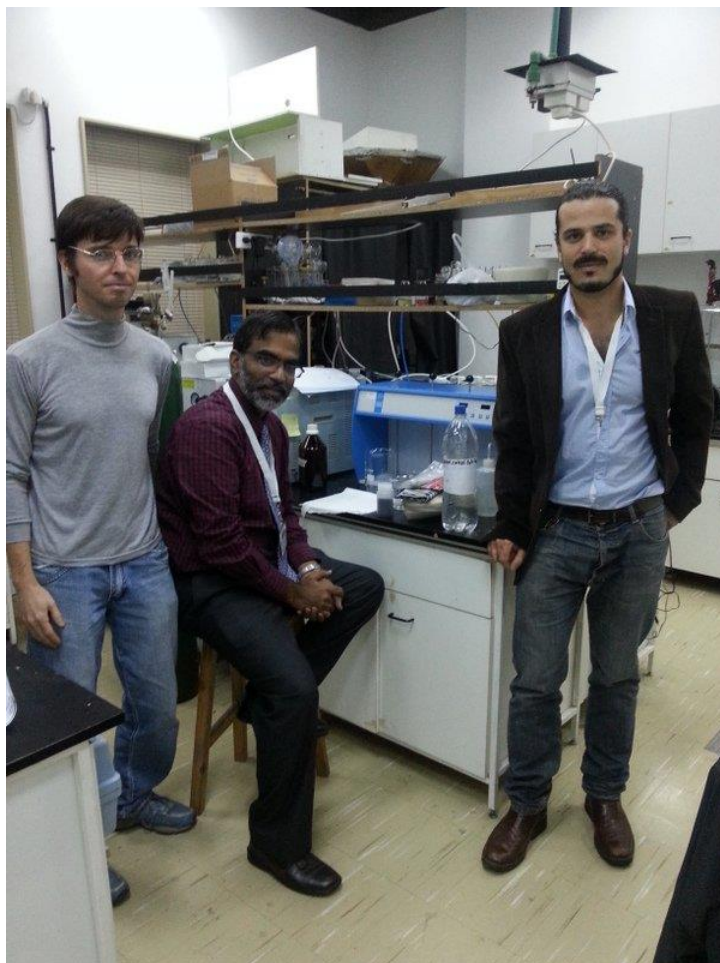
Implementing technologies





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DOI: 10.1002/anie.201311053



Mass Spectrometry Very Important Paper

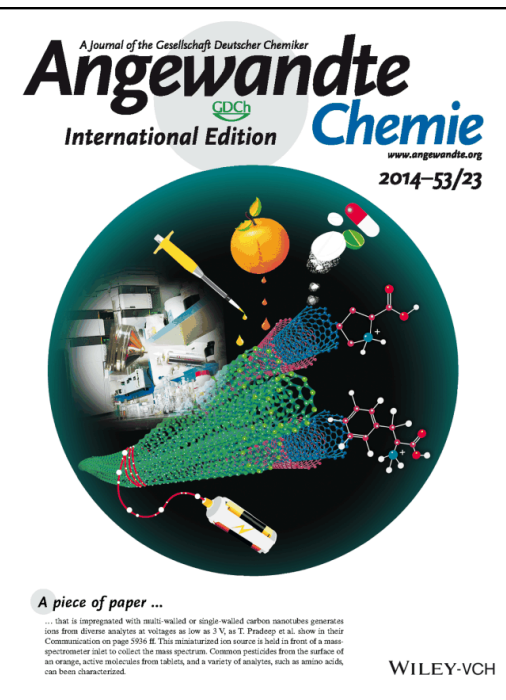
Molecular Ionization from Carbon Nanotube Paper**

Rahul Narayanan, Depanjan Sarkar, R. Graham Cooks, and Thalappil Pradeep*

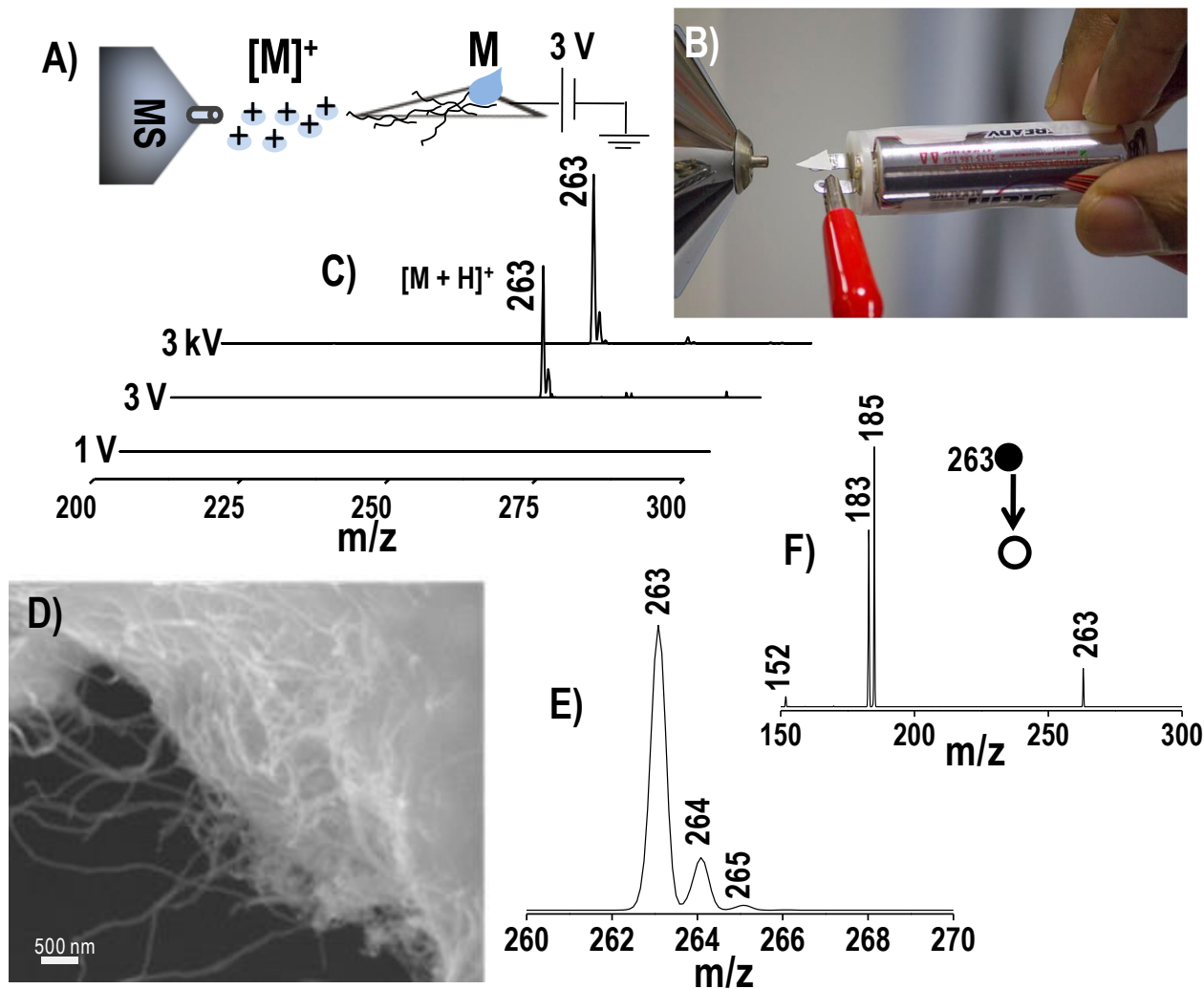
Dedicated to Professor C. N. R. Rao on the occasion of his 80th birthday.

Abstract: Ambient ionization is achieved by spraying from a carbon nanotube (CNT)-impregnated paper surface under the influence of small voltages (≥ 3 V). Organic molecules give simple high-quality mass spectra without fragmentation in the positive or negative ion modes. Conventional field ionization is ruled out, and it appears that field emission of microdroplets occurs. Microscopic examination of the CNT paper confirms that the nanoscale features at the paper surface are responsible for the high electric fields. Raman spectra imply substantial current flows in the nanotubes. The performance of this analytical method was demonstrated for a range of volatile and nonvolatile compounds and a variety of matrices.

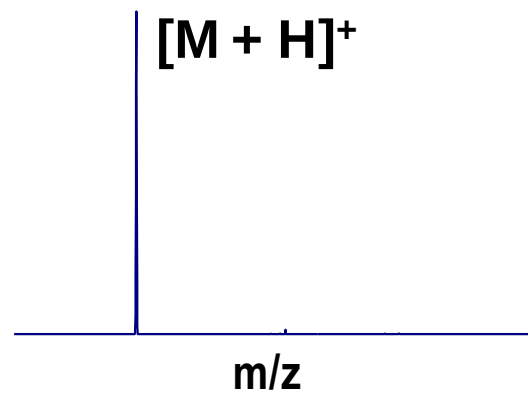
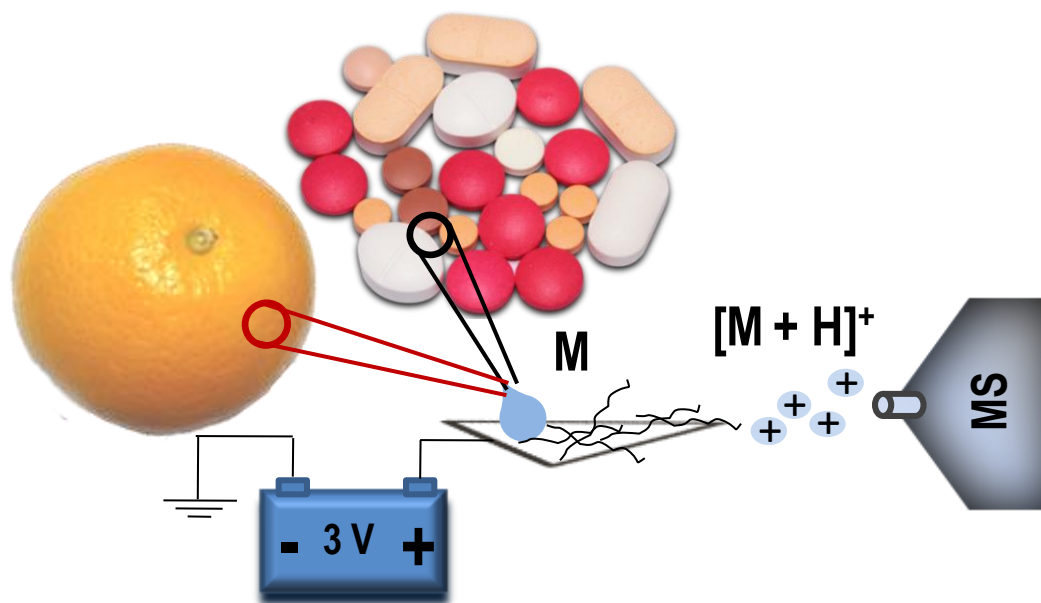
over the past decade. Herein, we report ionization achieved from a substrate of carbon nanotubes (CNTs) at a potential as low as 3 V, in which the high electric fields at the CNT protrusions are responsible for the ionization, which appears to occur by microdroplets.^[8] With this “nanodroplet” ionization, small organic analytes, which are applied as solutions, are detectable in small amounts, whereas salts yield both positive and negative ions, whereas a high voltage (HV) is not required.



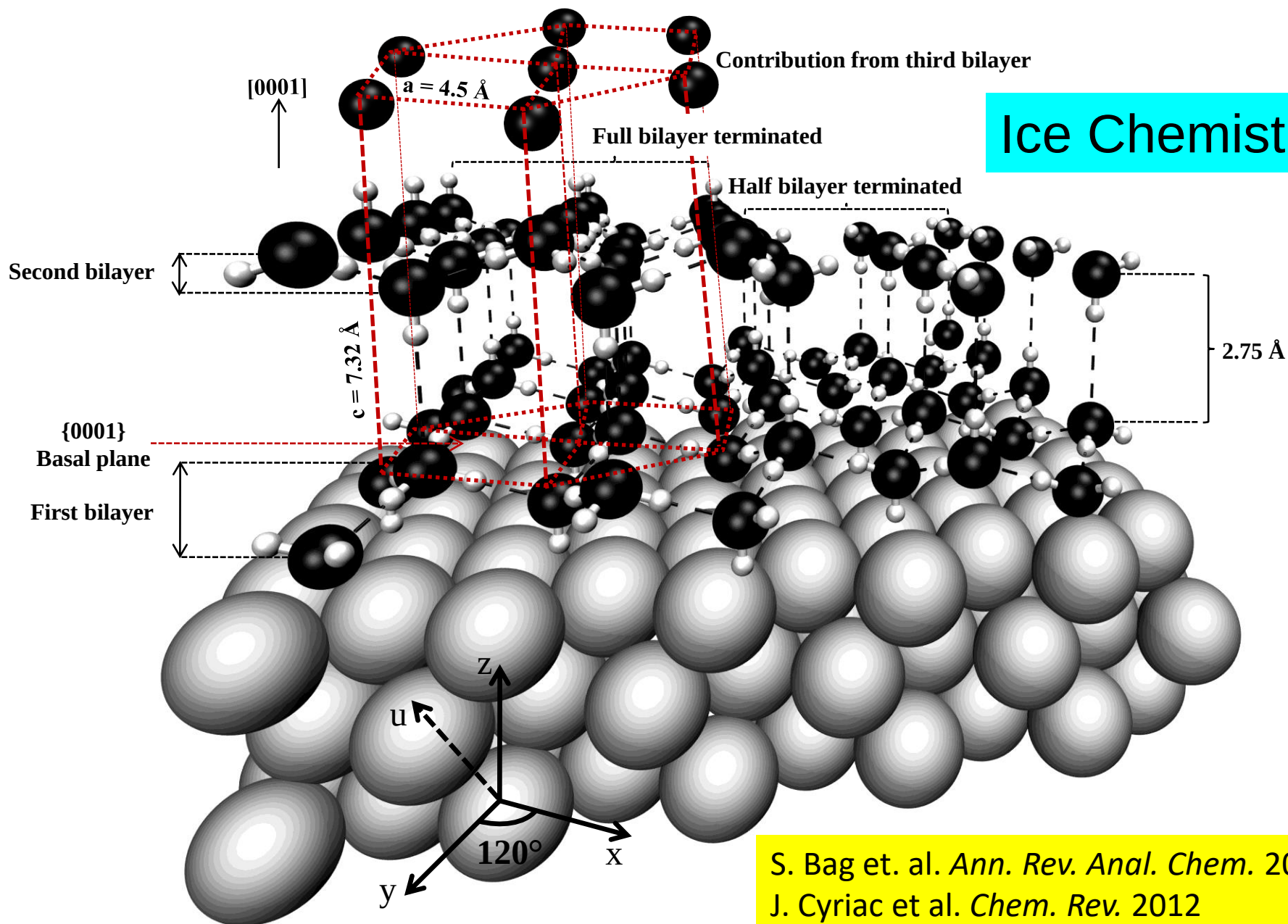
WILEY-VCH



A) Schematic diagram of ionization from CNT paper, B) Optical photograph of the ionization source C) mass spectrum of triphenylphosphine (M) at 3 kV, 3 V and 1 V from wet CNT paper, D) FE-SEM image of CNT-coated paper, E) isotope distribution of the protonated molecule at 3 V and F) product ion MS^2 of m/z 263.

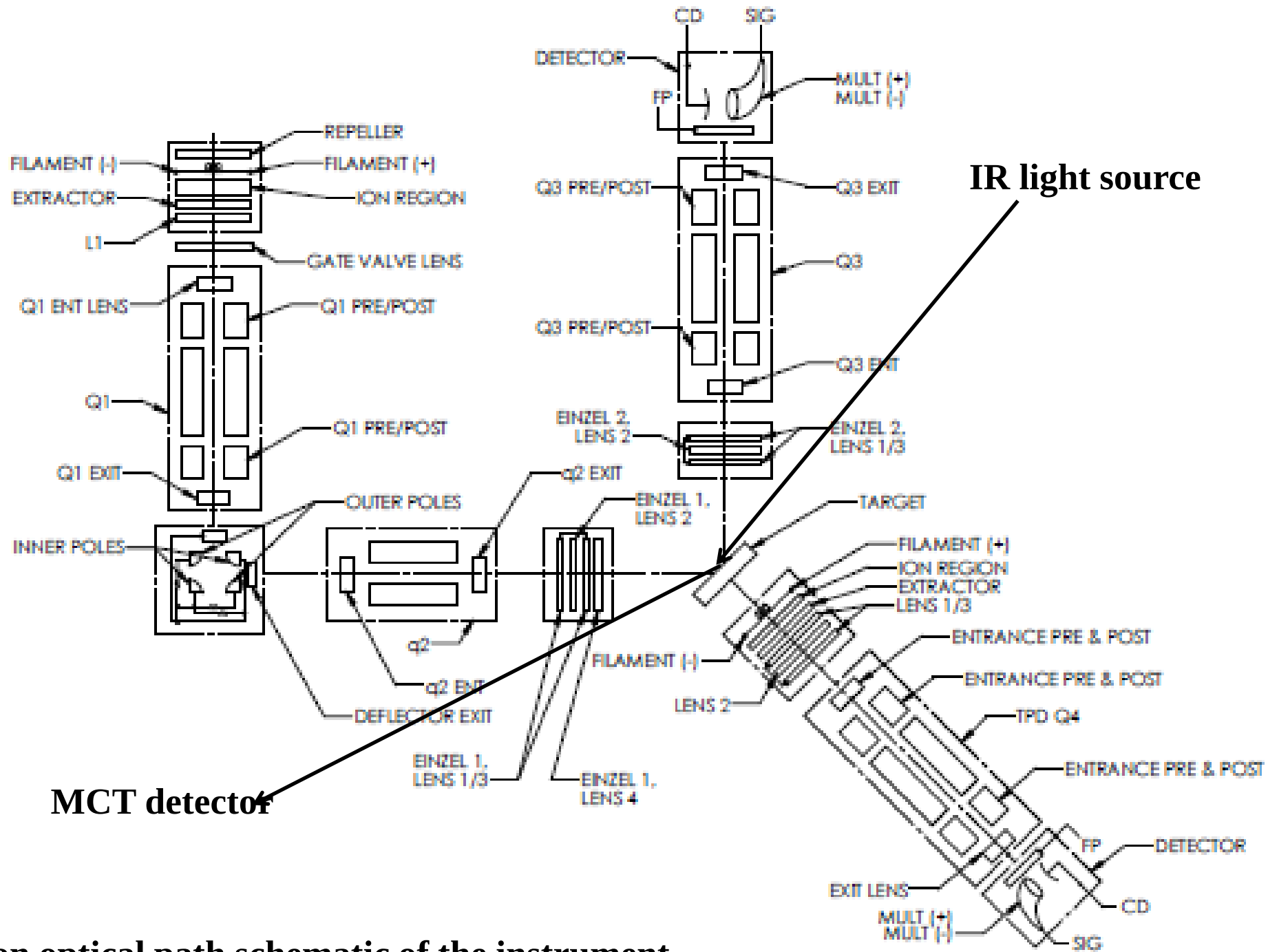


Ice Chemistry



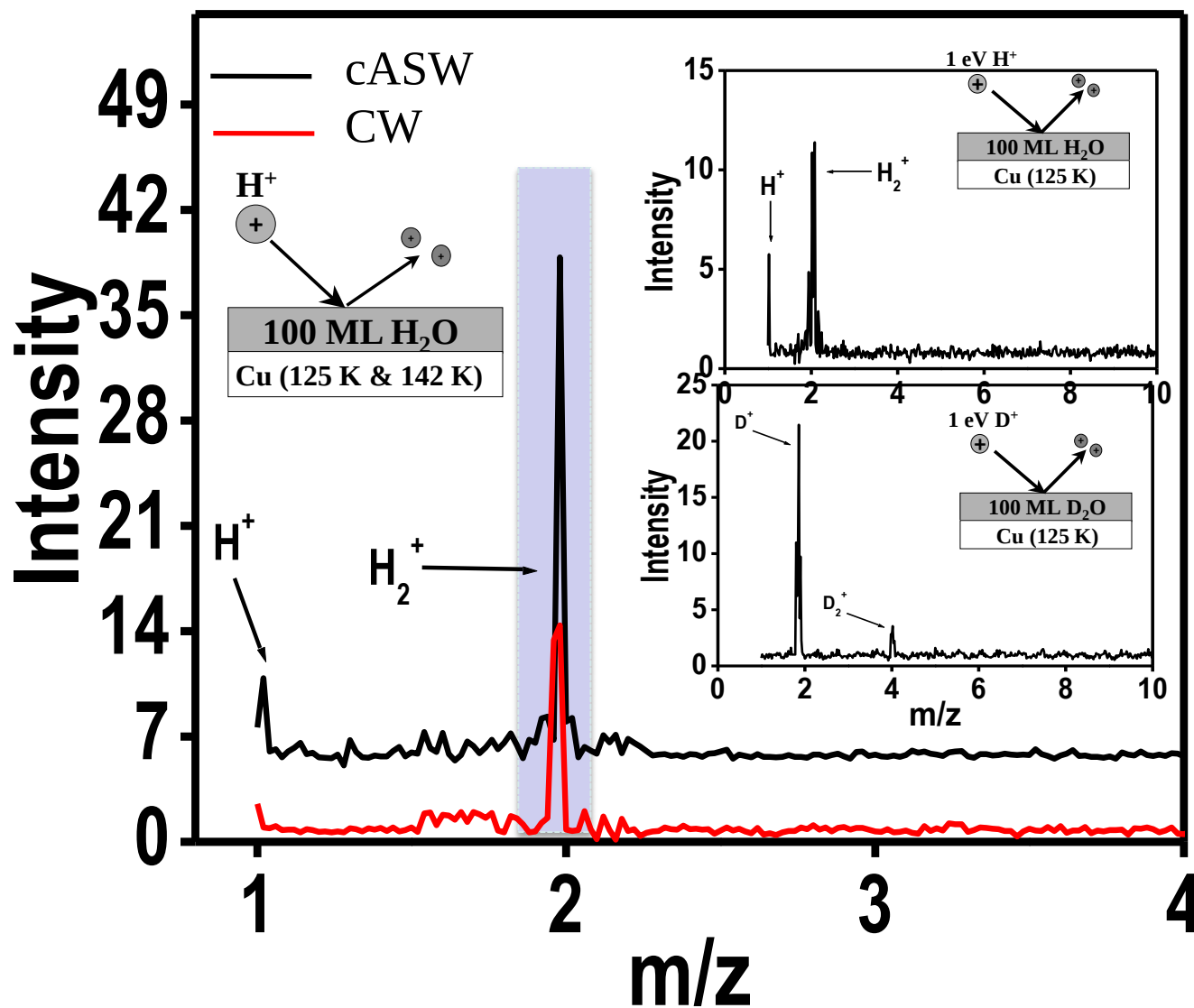
S. Bag et. al. *Ann. Rev. Anal. Chem.* 2013
J. Cyriac et al. *Chem. Rev.* 2012

A perspective view of 1h ice growth on a Ru(0001) substrate. The grey balls indicate the Ru atoms, the black balls represent the oxygen atoms and the white balls stands for the hydrogen atoms. Hydrogen bonds in the ice structure are shown by black dotted line in between the water molecules. The epitaxial growth of ice is shown.



Ion optical path schematic of the instrument





Mass spectrum upon the bombardment of 1 and 2 eV H^+ on amorphous ice (cASW) & crystalline ice (CW)







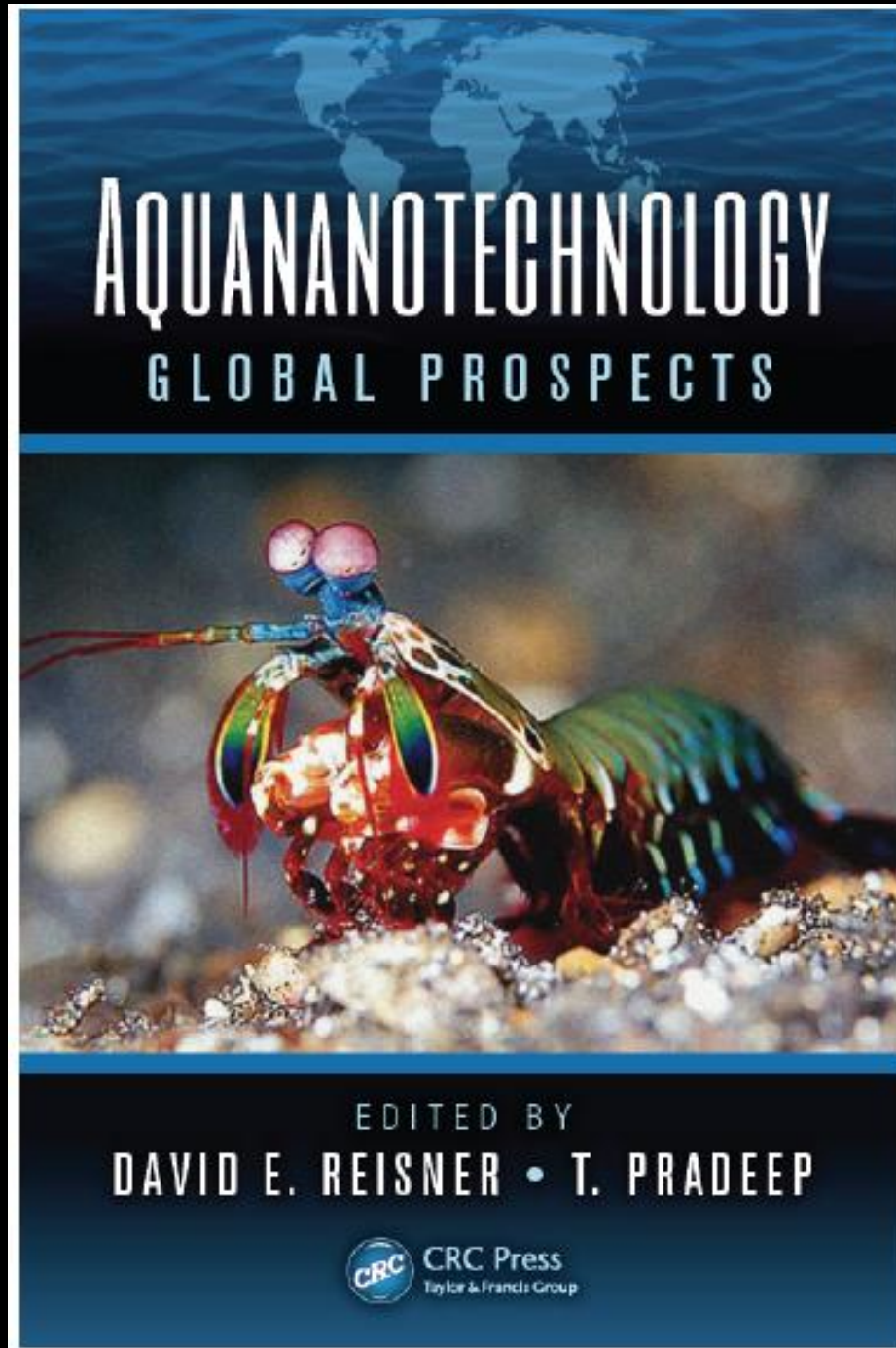






DST Nano Mission

New Book



On water, let us unite!

Samir Pal, Uzi Landman, Rob Whetten, Y. Negishi, Hannu Hakkinen, Robin Ras,...

Thank you