



Since 1959

Atomically Precise Clusters

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Molecular materials with functions

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Atomically Precise Clusters of Noble Metals: Emerging Link between Atoms and Nanoparticles

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 Supporting Information

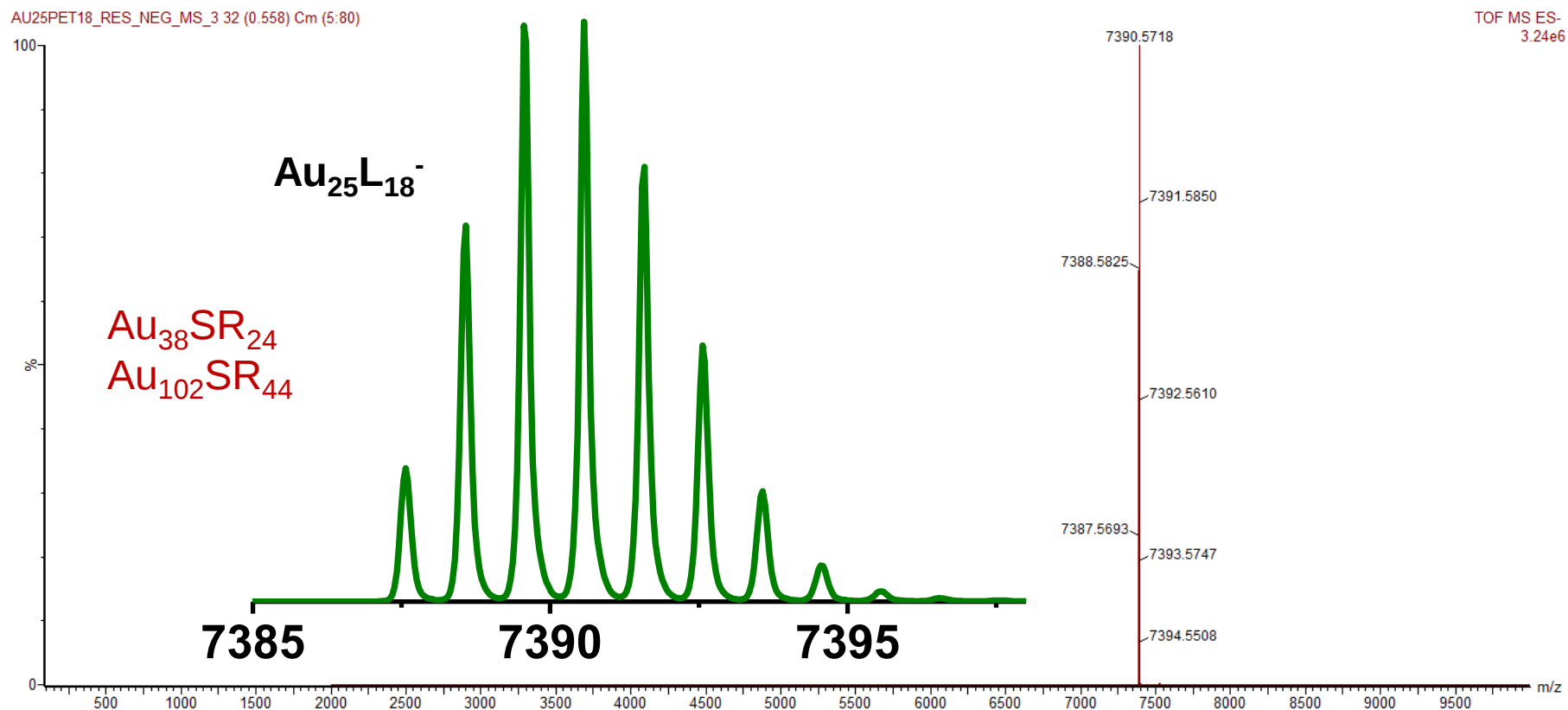
Citations: >2000

ABSTRACT: Atomically precise pieces of matter of nanometer dimensions composed of noble metals are new categories of materials with many unusual properties. Over 100 molecules of this kind with formulas such as $\text{Au}_{25}(\text{SR})_{18}$, $\text{Au}_{38}(\text{SR})_{24}$, and $\text{Au}_{102}(\text{SR})_{44}$ as well as $\text{Ag}_{25}(\text{SR})_{18}$, $\text{Ag}_{29}(\text{S}_2\text{R})_{12}$, and $\text{Ag}_{44}(\text{SR})_{30}$ (often with a few counterions to compensate charges) are known now. They can be made reproducibly with robust synthetic protocols, resulting in colored solutions, yielding powders or diffractable crystals. They are distinctly different from nanoparticles in their spectroscopic properties such as optical absorption and emission, showing well-defined features, just like molecules. They show isotopically resolved molecular ion peaks in mass spectra and provide diverse information when examined through multiple instrumental methods. Most important of these properties is luminescence, often in the visible–near-infrared window, useful in biological applications. Luminescence in the visible region, especially by clusters protected with proteins, with a large Stokes shift, has been used for various sensing applications, down to a few tens of molecules/ions, in air and water. Catalytic properties of clusters, especially oxidation of organic substrates, have been examined. Materials science of these systems presents numerous possibilities and is fast evolving. Computational insights have given reasons for their stability and unusual properties. The molecular nature of these materials is unequivocally manifested in a few recent studies such as intercluster reactions forming precise clusters. These systems manifest properties of the core, of the ligand shell, as well as that of the integrated system. They are better described as protected molecules or *aspicules*, where *aspis* means shield and *cules* refers to molecules, implying that they are “shielded molecules”. In order to understand their diverse properties, a nomenclature has been introduced with which it is possible to draw their structures with positional labels on paper, with some training. Research in this area is captured here, based on the publications available up to December 2016.

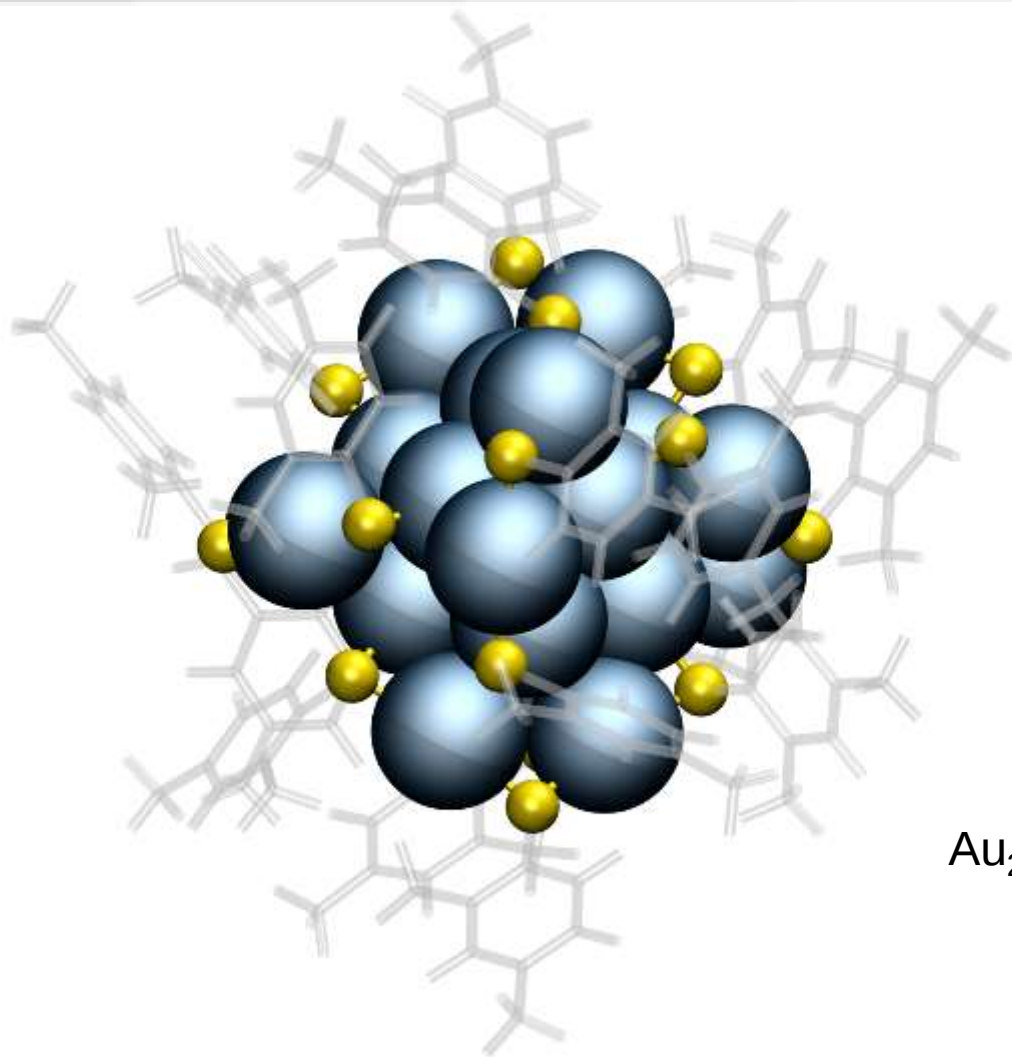


Also the pioneering work of R. W. Murray, Robert L. Whetten, Uzi Landman, Tatuya Tsukuda, Yuichi Negishi, Hannu Hakkinen, Rongchao Jin, Nanfeng Zheng, Terry Bigioni, Osman Bakr, Kornberg, Jianping Xie, C. M. Aikens, Thomas Buergi, Amala Dass, Ackerson, De-en Jiang, A. W. Castleman Jr., H. Schmidbauer, Robin Ras, Olli Ikkala

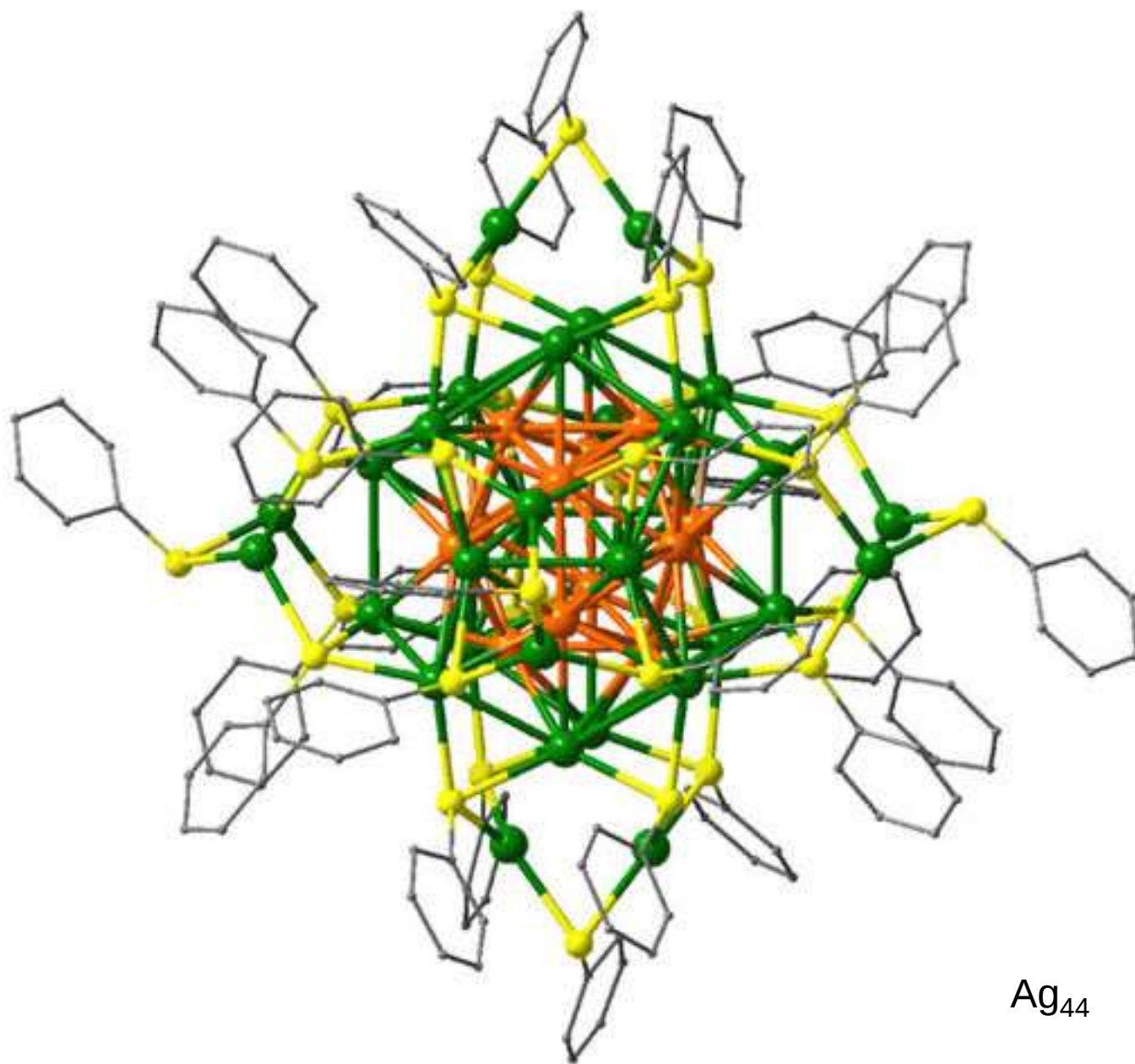
Molecular formula, Molecular weight



New molecules



$\text{Au}_{25}, \text{Ag}_{25}, \text{Ag}_{29}$

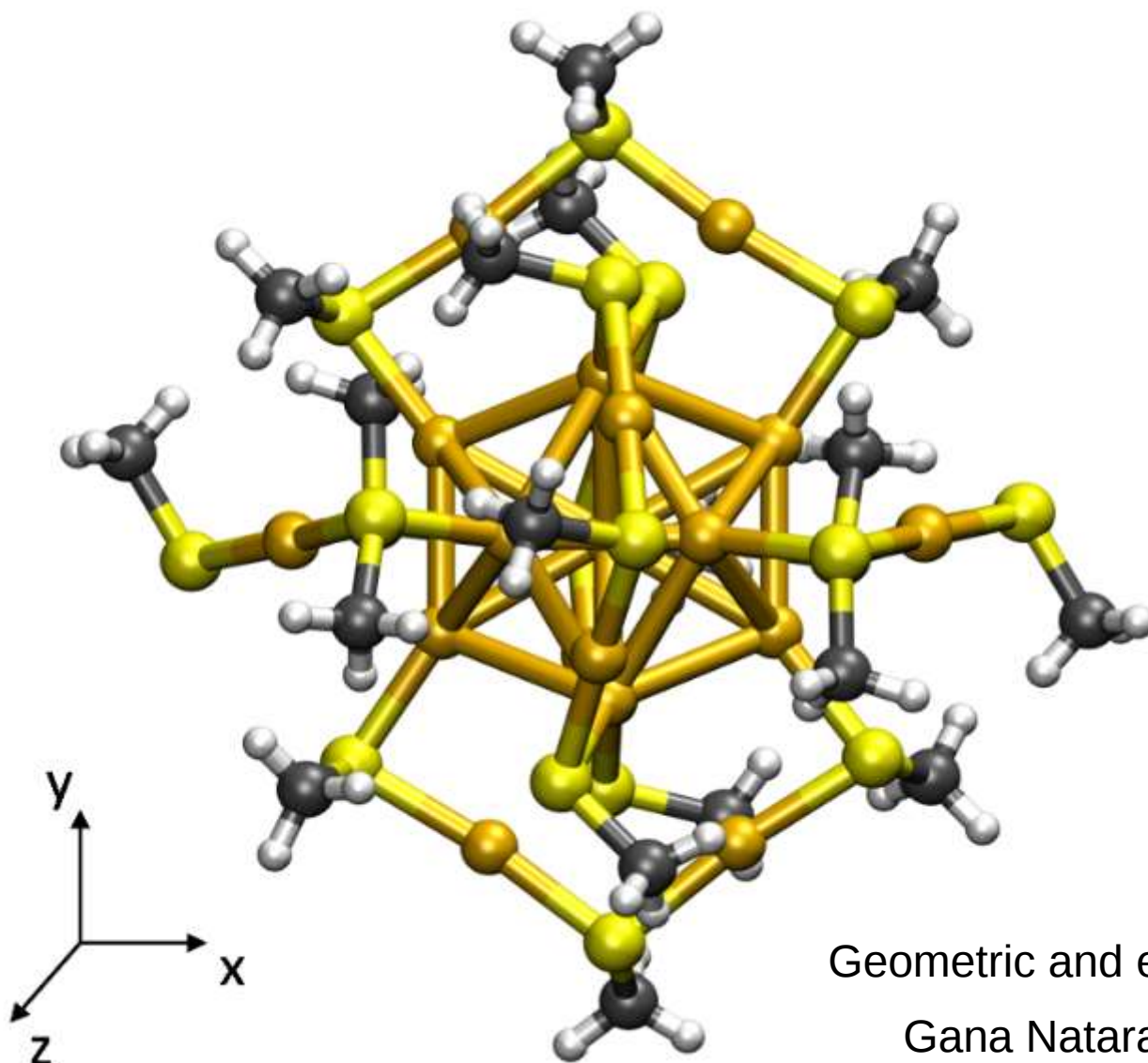


Nanfeng Zheng et al. *Nature Communications*, 2013
Terry Bigioni et al. *Nature* 2013

They make high quality crystals

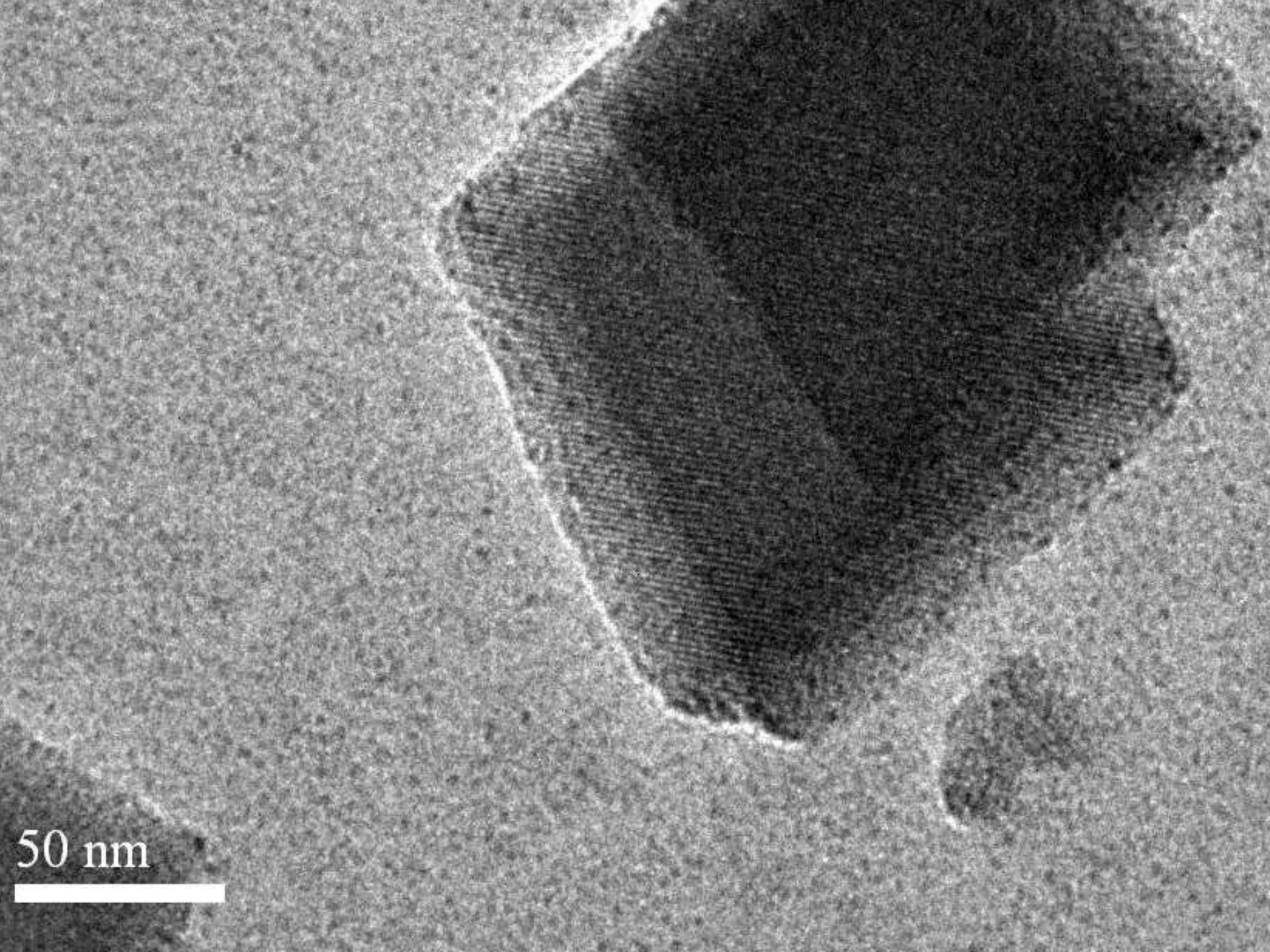


Molecular structure



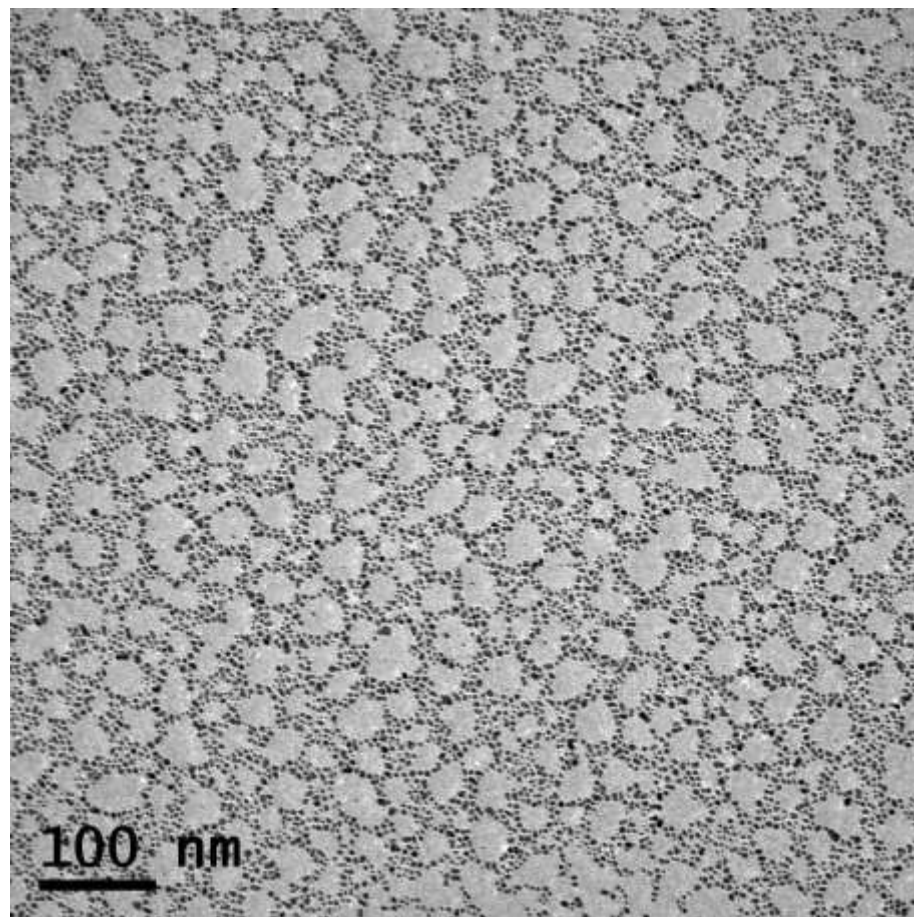
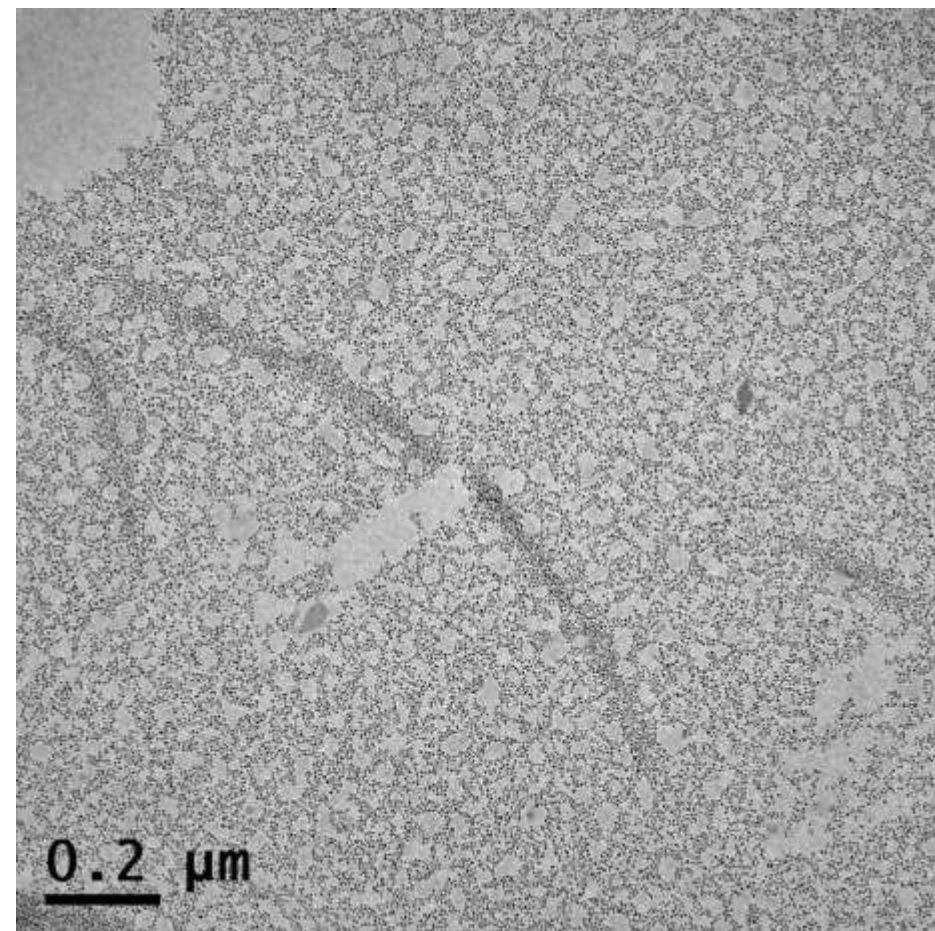
Geometric and electronic shells

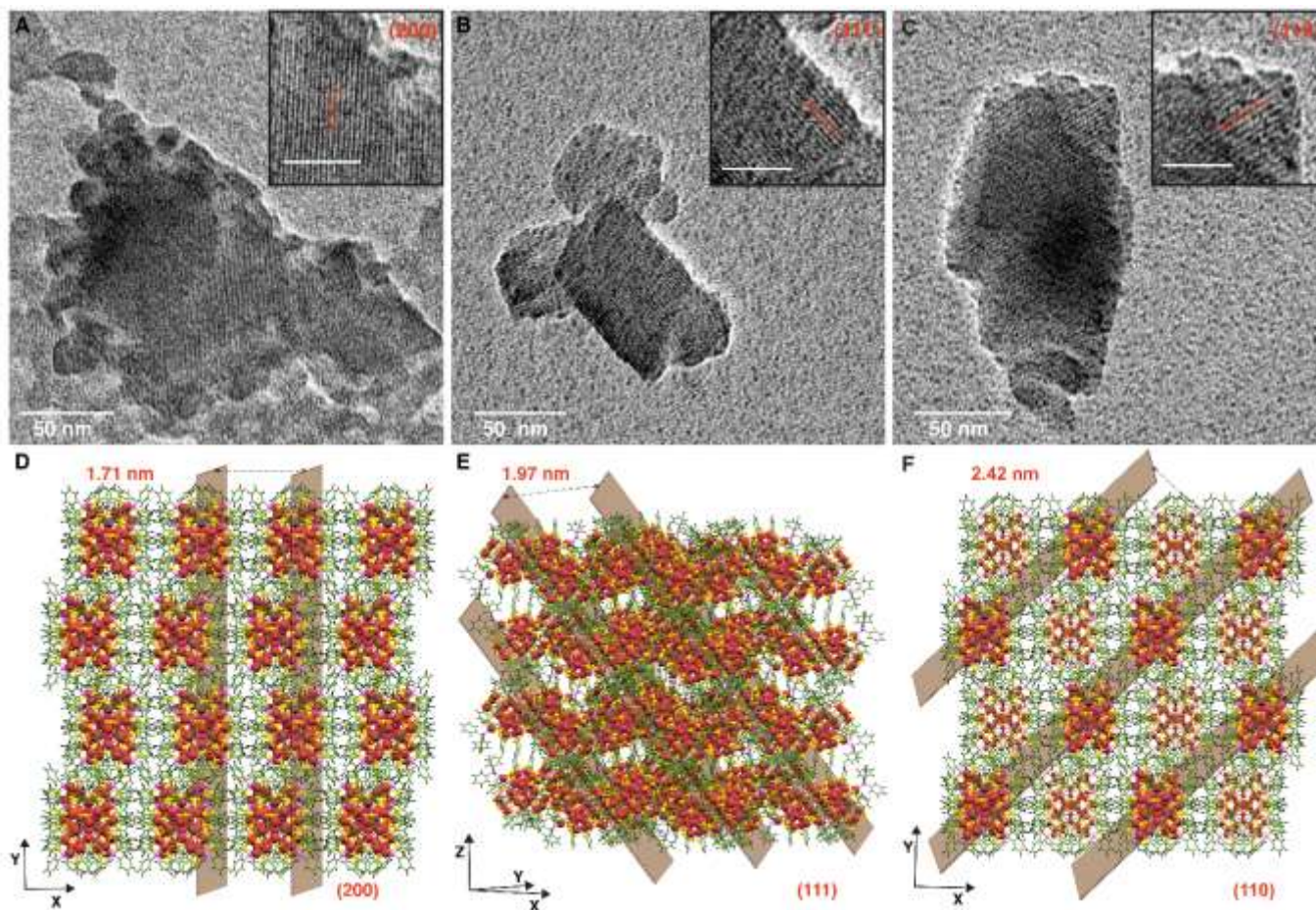
Gana Natarajan



50 nm

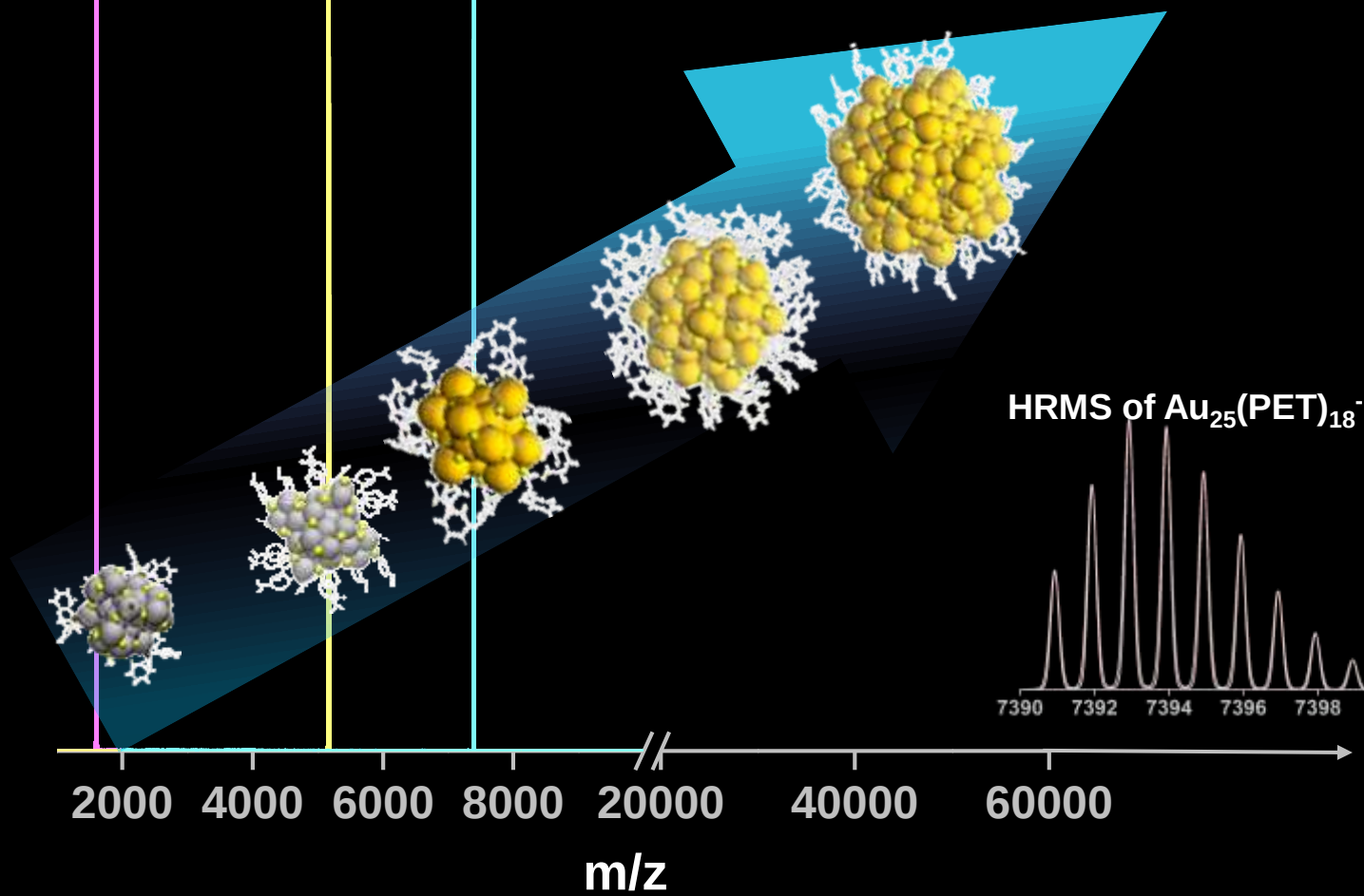
TEM images of Au₂₅ and Au₁₄₄





Ananthu Mahendranath et al. Chem.Comm.2021

$\text{Ag}_{29}(\text{BDT})_{12}^{3-}$ $\text{Ag}_{25}(\text{DMBT})_{18}^{-}$ $\text{Au}_{25}(\text{PET})_{18}^{-}$



Molecular materials

ACCOUNTS

of chemical research

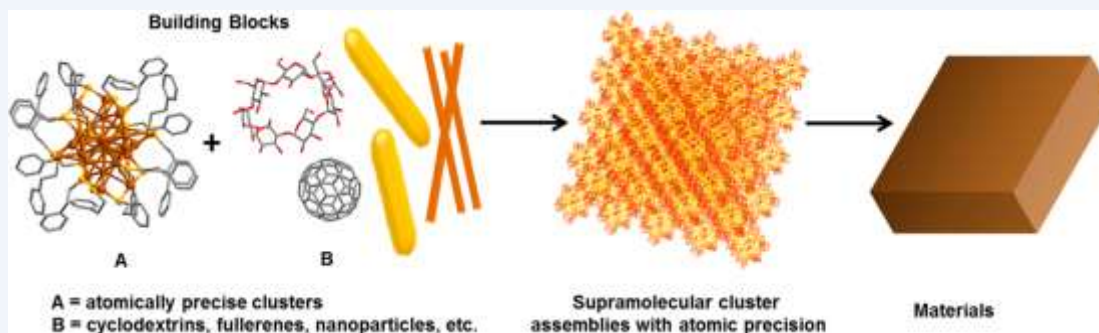
Article

pubs.acs.org/accounts

Approaching Materials with Atomic Precision Using Supramolecular Cluster Assemblies

Papri Chakraborty, Abhijit Nag, Amrita Chakraborty, and Thalappil Pradeep*

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



Molecules and their properties

Chemical formula	H ₂ O
Molecular weight	18.0148
Critical temperature	373.91°C
Critical pressure	22.05 MPa
Critical density	315.0 kg/m ³
Triple point temperature	0.01°C
Triple point pressure	615.066 Pa
Normal boiling point	100.0°C
Normal freezing point	0.0°C
Density of ice at normal melting point	918.0 kg/m ³
Maximum density, 3.98°C	999.973 kg/m ³
Viscosity, 25°C	0.889 mN s/m ²
Surface tension, 25°C	72 mN/m
Heat Capacity, 25°C	4.1796 kJ/kg.K
Enthalpy of vaporisation, 100°C	2,257.7 kJ/kg
Enthalpy of fusion, 0°C	333.8 kJ/kg
Velocity of sound, 0°C	1.403 km/s
Dielectric constant, 25°C	78.40
Electrical conductivity, 25°C	8 µS/m
Refractive index, 25°C	1.333
Liquid compressibility, 10°C	480. × 10 ⁻¹² m ² /N
Coefficient of thermal expansion, 25°C	256.32 × 10 ⁻⁶ K ⁻¹
Thermal Conductivity, 25°C	0.608 W/m.K

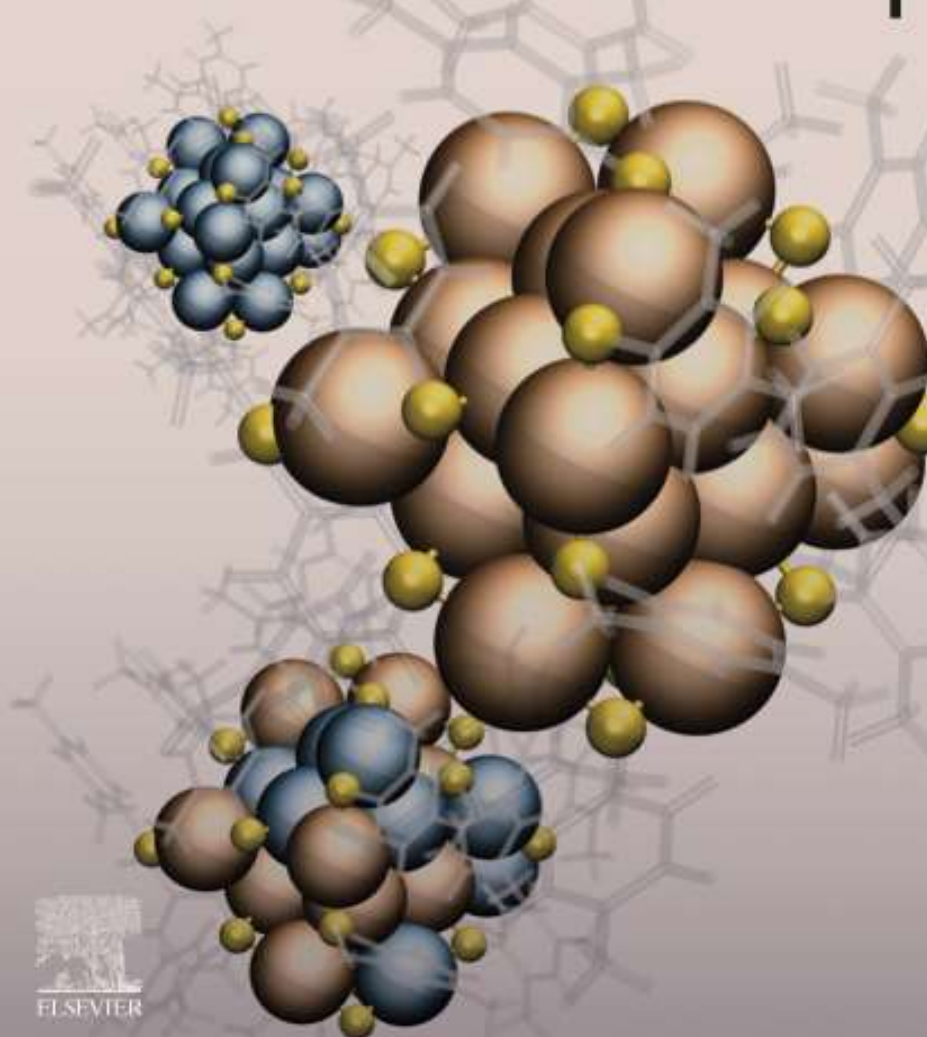
Molecular formula
Molecular weight
Molecular structure
Molecular absorption and emission
Molecular reactions
Molecular assembly
Molecular co-crystals

Phases - phase transitions
Physical properties
Electrical, magnetic
Mechanical properties
Electrochemical properties

Future?

Edited by
Thalappil Pradeep

ATOMICALLY PRECISE METAL NANOCCLUSERS



Molecular reactions



Reactions on clusters
Reactions between clusters

Inter-cluster reactions



Article

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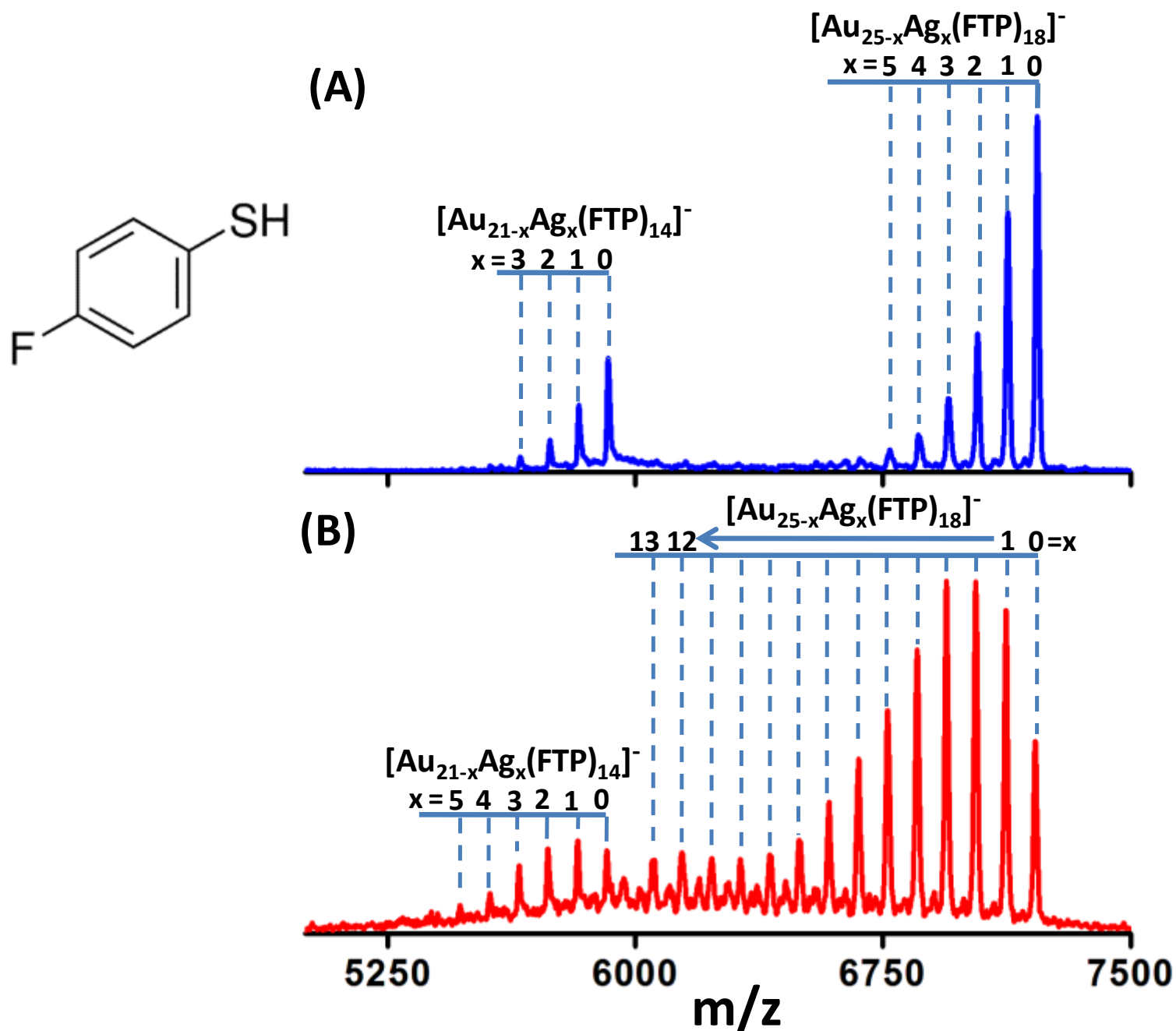
Intercluster Reactions between $\text{Au}_{25}(\text{SR})_{18}$ and $\text{Ag}_{44}(\text{SR})_{30}$

K. R. Krishnadas, Atanu Ghosh, Ananya Baksi, Indranath Chakraborty,[†] Ganapati Natarajan, and Thalappil Pradeep*

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

 Supporting Information





Energies for the substitution reaction of (A) Au in $\text{Ag}_{44}(\text{SR})_{30}$, (B) Ag in $\text{Au}_{25}(\text{SR})_{18}$ and (C) the overall reaction energies (in eV) as a function of their positions in product clusters, $\text{Au}_x\text{Ag}_{44-x}(\text{SR})_{30}$ and $\text{Au}_{25-x}\text{Ag}_x(\text{SR})_{18}$ for $x=1$

(A) Location of Au in $\text{Au}_x\text{Ag}_{44-x}(\text{SR})_{30}$ $\Delta E/\text{eV}$

Icosahedron (I)	-0.72
Dodecahedron: cube vertex (D_{cv})	-0.14
Dodecahedron: cube face (D_{cf})	-0.32
Staples (S)	-0.48

(B) Location of Ag in $\text{Au}_{25-x}\text{Ag}_x(\text{SR})_{18}$ $\Delta E/\text{eV}$

Central atom (C)	+0.71
Icosahedron (I)	+0.23
Staples (S)	+0.44

(C) Locations of Au in $\text{Au}_x\text{Ag}_{44-x}(\text{SR})_{30}$

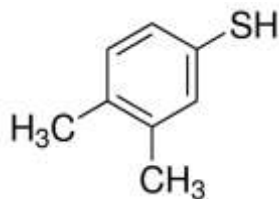
Location of Ag in $\text{Au}_{25-x}\text{Ag}_x(\text{SR})_{18}$	I	D_{cv}	D_{cf}	S
C	-0.015	+0.564	+0.388	+0.226
I	-0.486	+0.093	-0.083	-0.245
S	-0.276	+0.303	+0.127	-0.035

Ag₂₅-Au₂₅ experiments

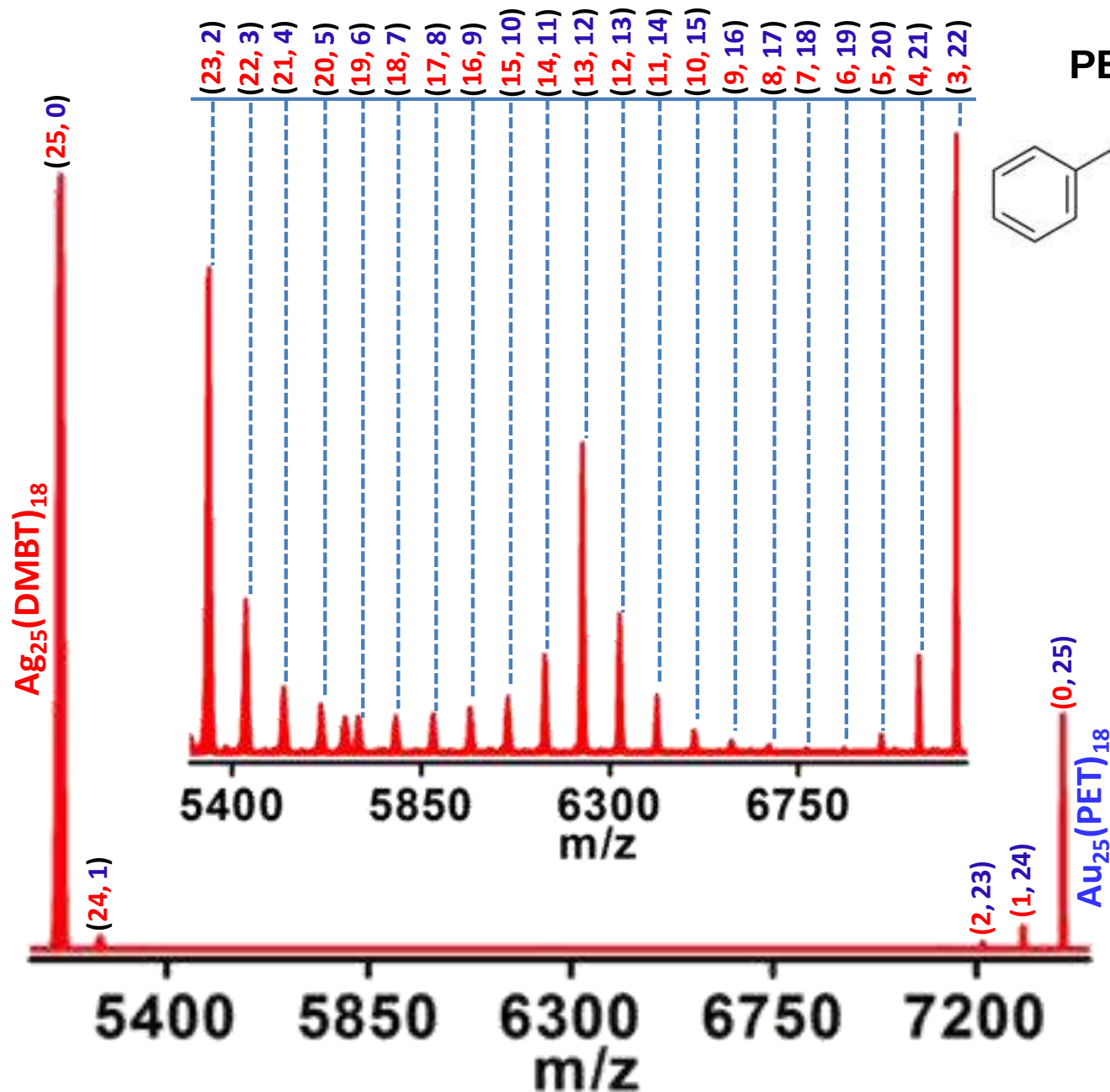
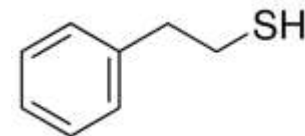
K. R. Krishnadas et al. *Nature Commun.* 2016

Reaction between $\text{Au}_{25}(\text{PET})_{18}$ and $\text{Ag}_{25}(\text{DMBT})_{18}$

DMBT

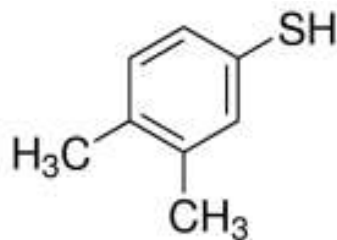


PET

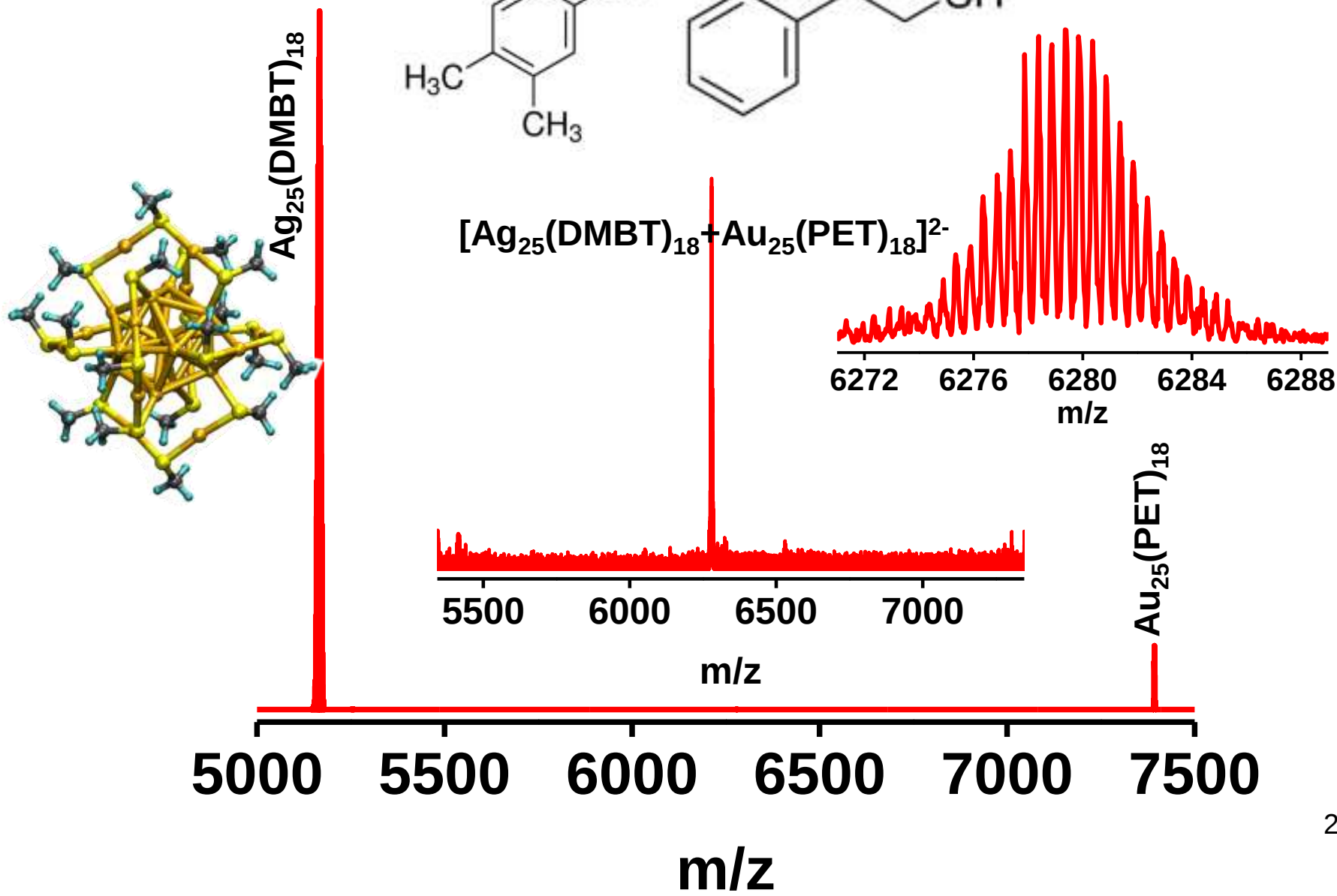
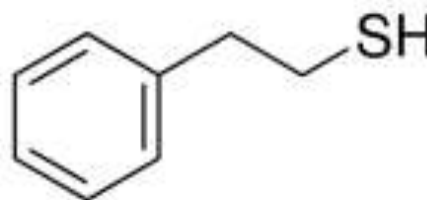




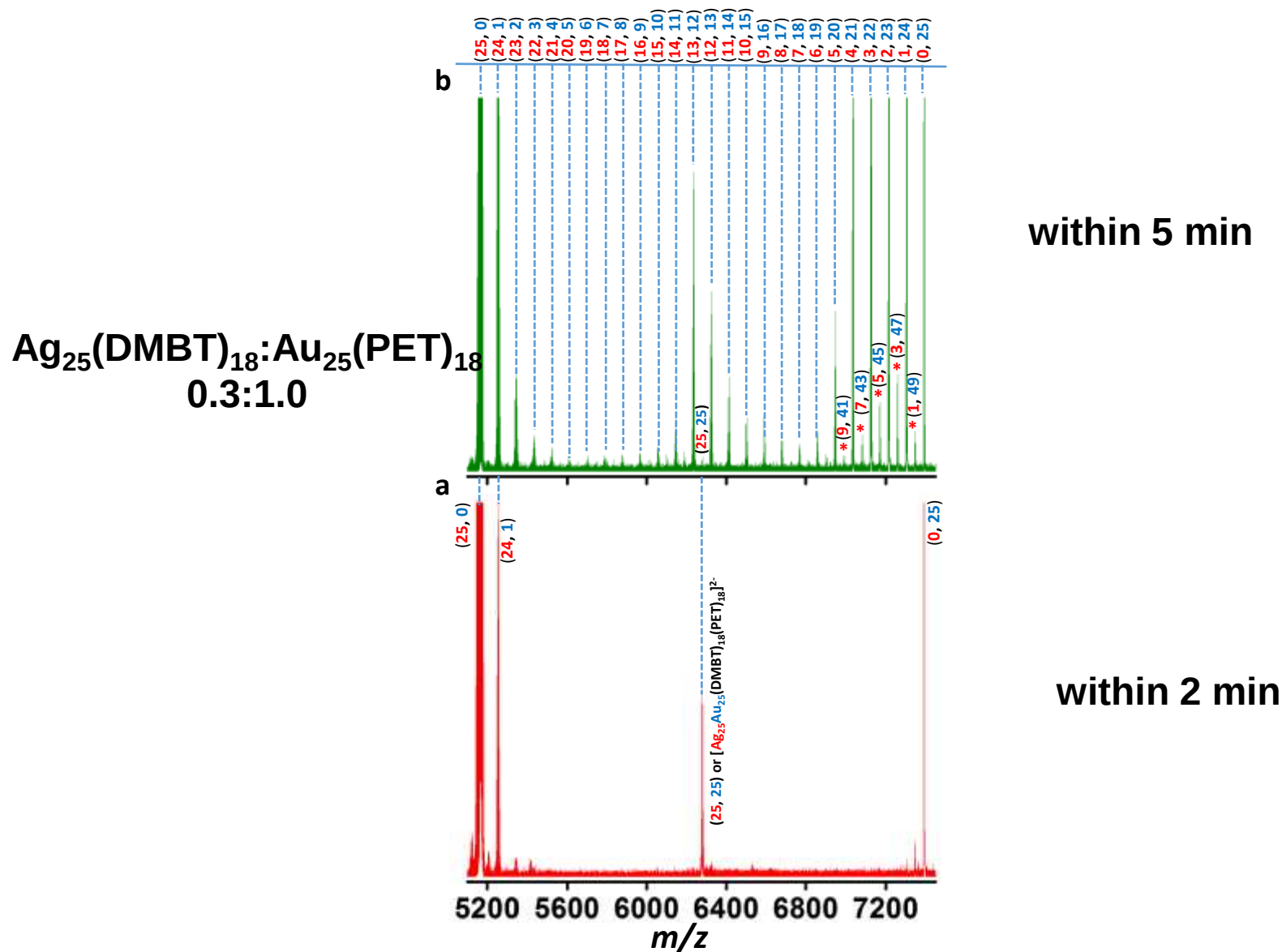
DMBT



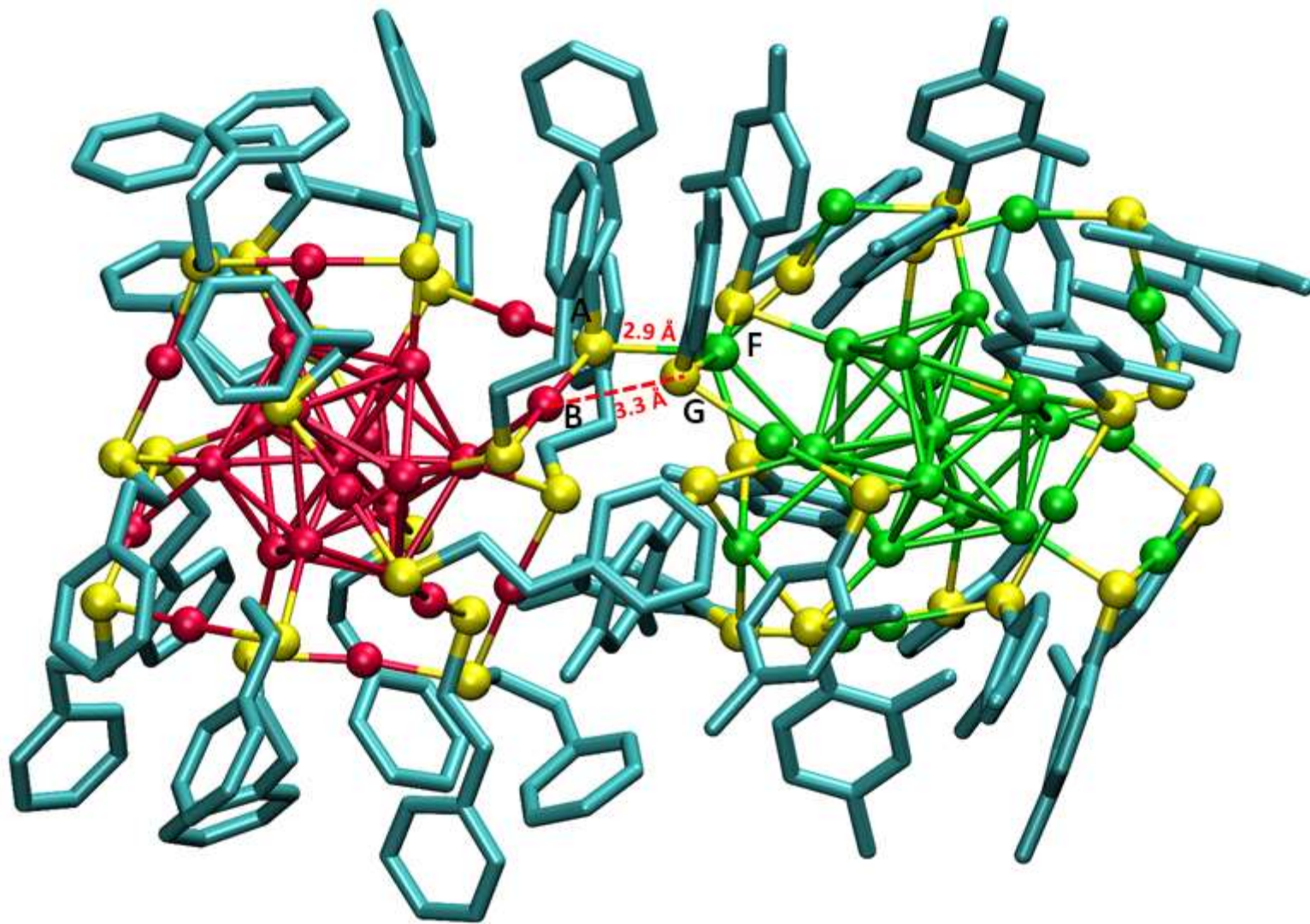
PET

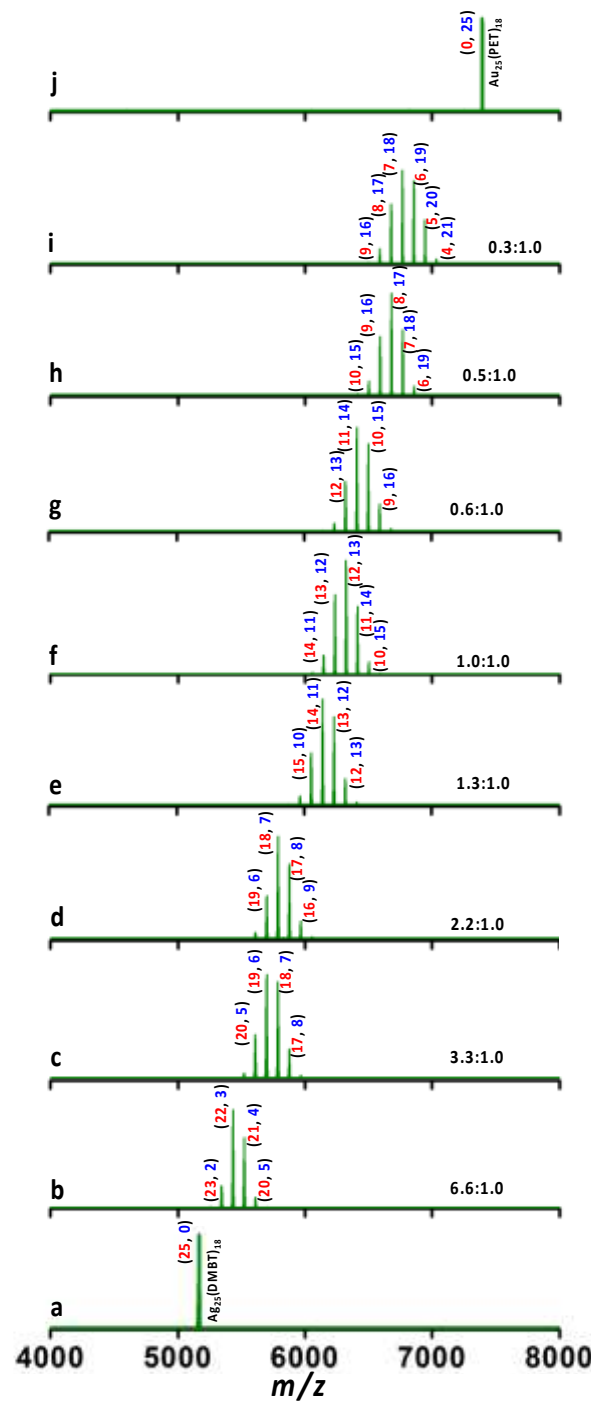


Evolution of alloy clusters from the dianionic adduct, $[\text{Ag}_{25}\text{Au}_{25}(\text{DMBT})_{18}(\text{PET})_{18}]^{2-}$



Optimized structure of $[\text{Ag}_{25}\text{Au}_{25}(\text{DMBT})_{18}(\text{PET})_{18}]^{2-}$

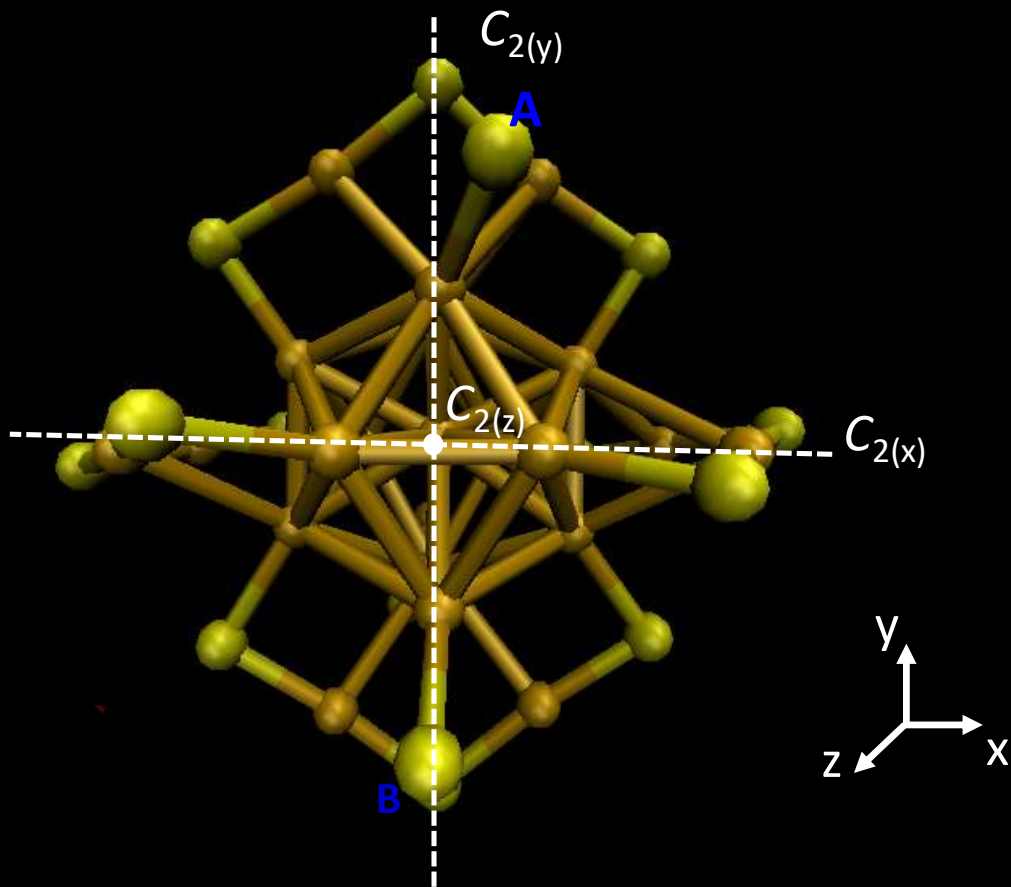




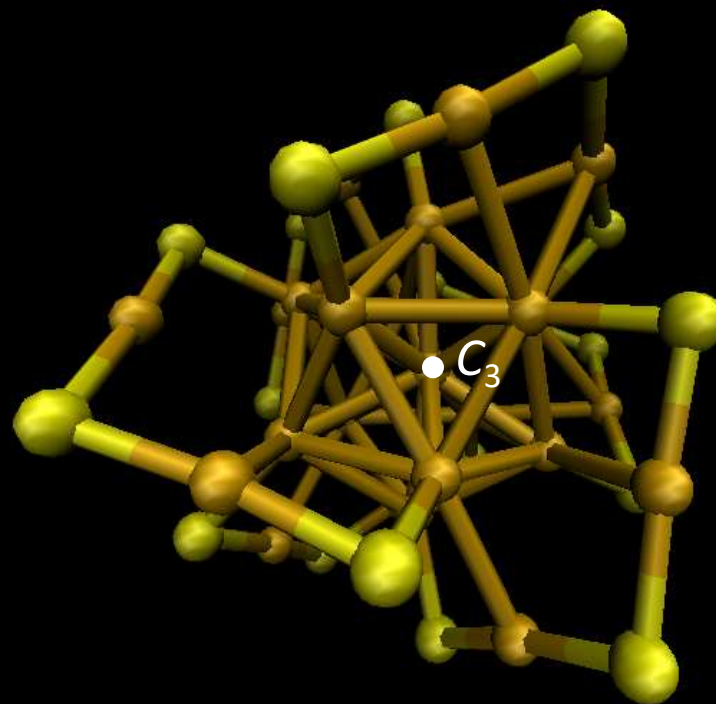
How do we comprehend this?

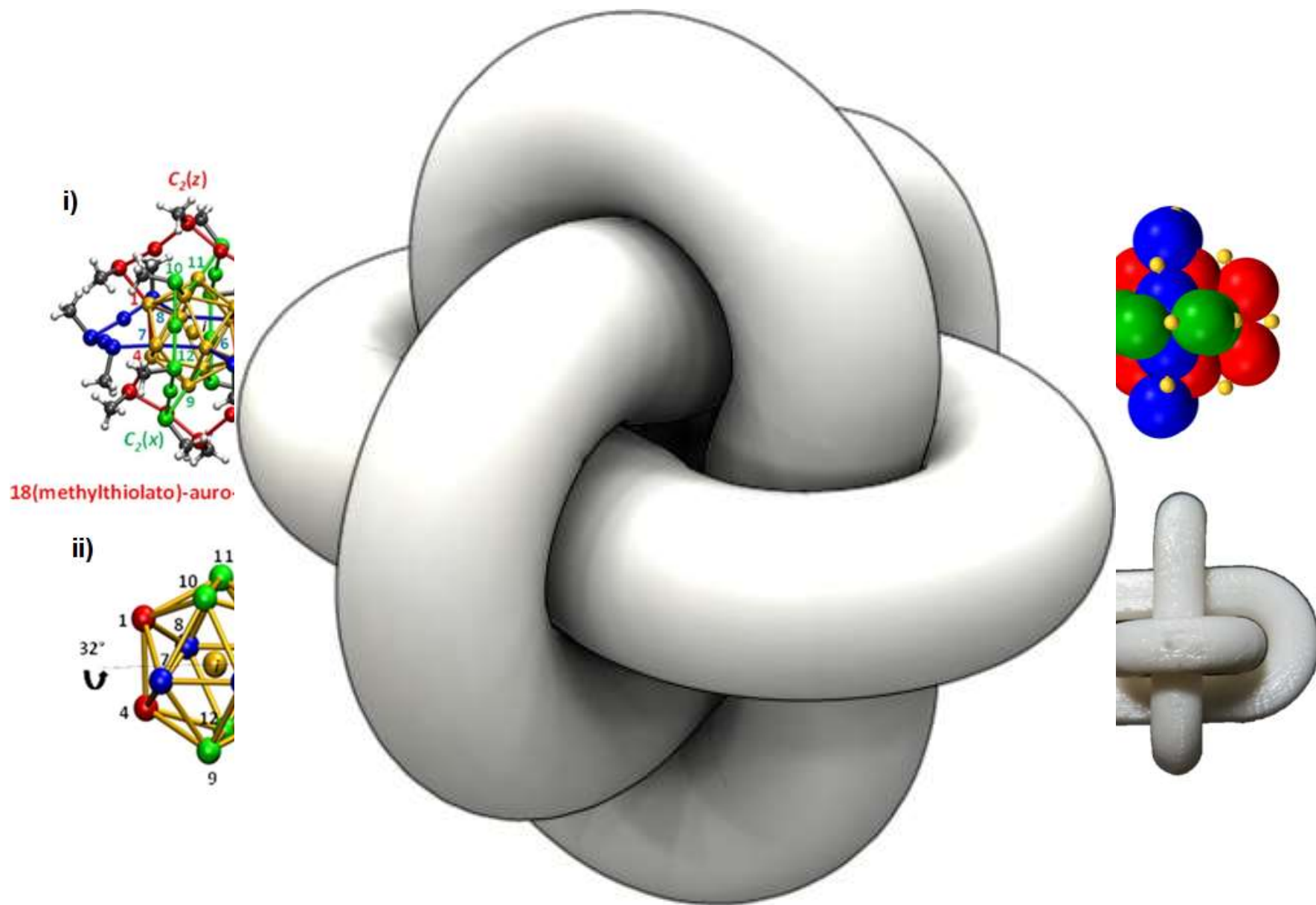
Nomenclature

1) Edge projection



2) Face Projection





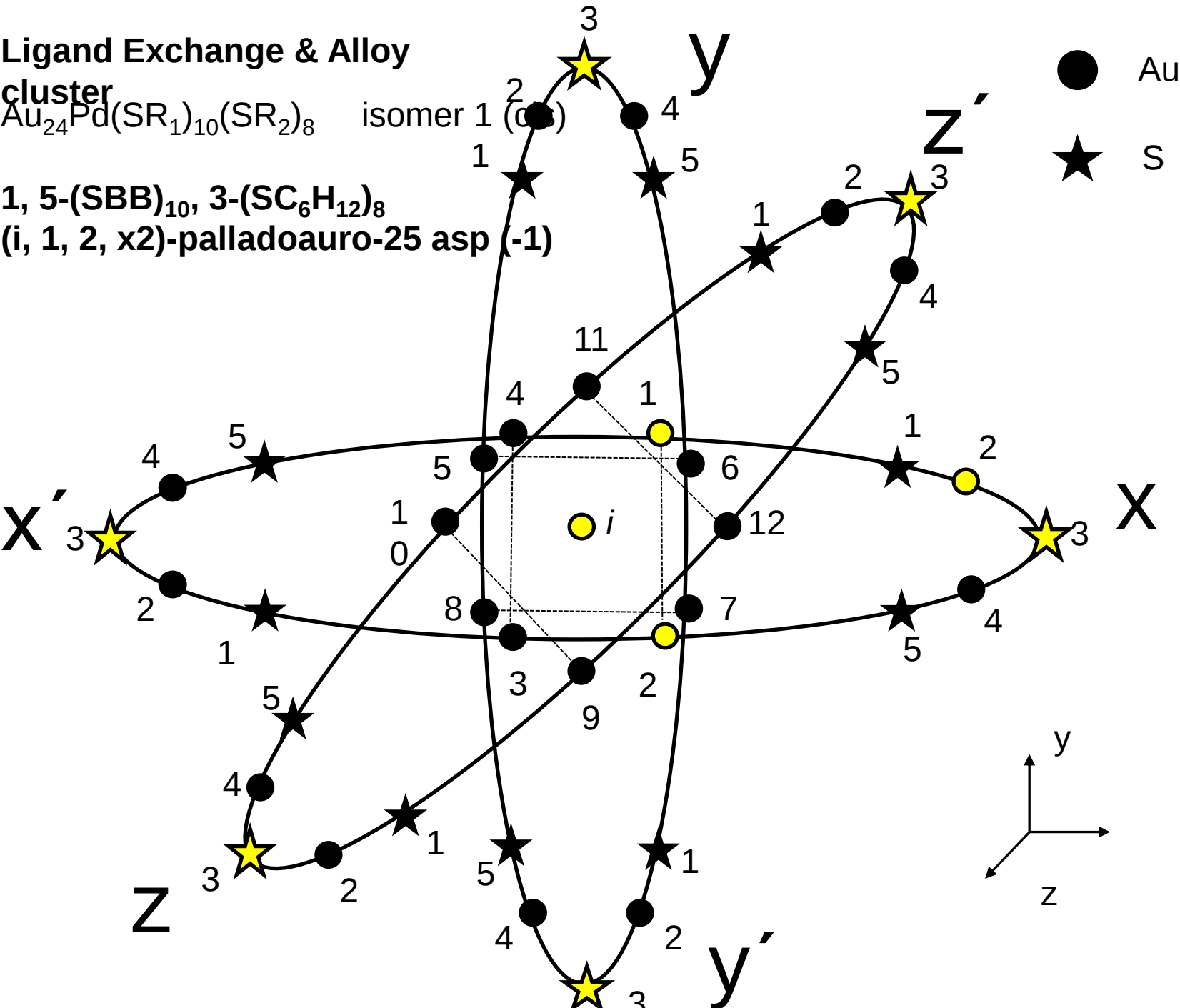
Aspicules

(D1-3,D2-3)-di(2-phenylethylthiolato),16(methylthiolato)-auro-25 aspicule(1-)
(D1-3,D2-3)-(PET)₂,(SMe)₁₆-auro-25 aspicule(1-)

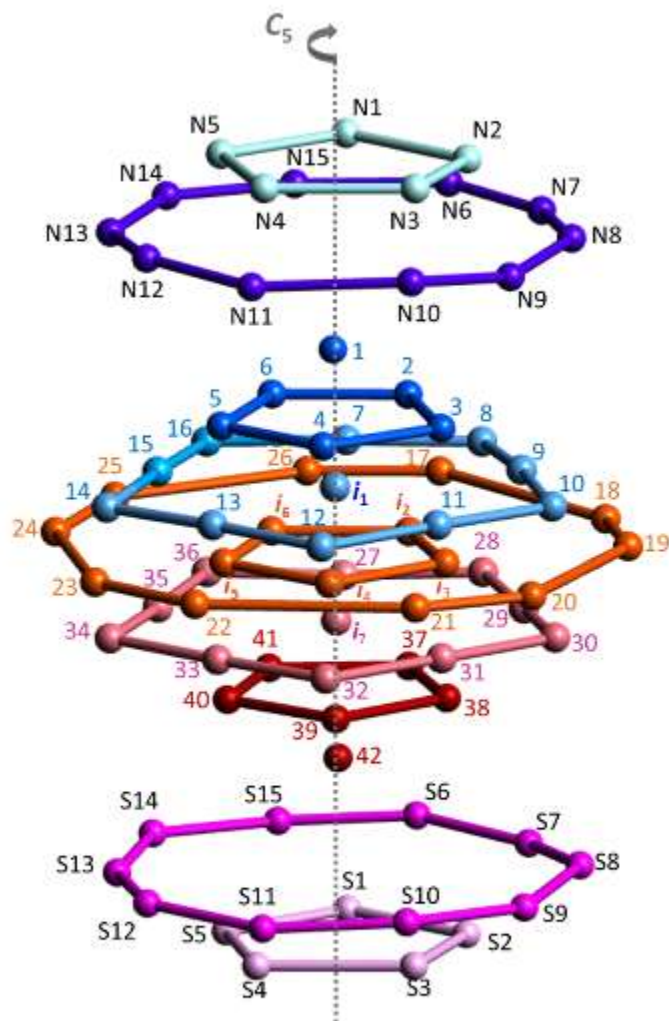
Ligand Exchange & Alloy cluster

$\text{Au}_{24}\text{Pd}(\text{SR}_1)_{10}(\text{SR}_2)_8$ isomer 1 (c)

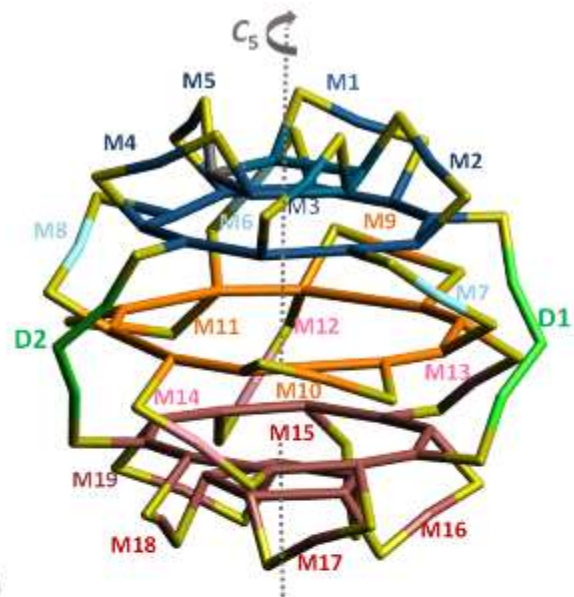
1, 5-(SBB)₁₀, 3-(SC₆H₁₂)₈
(i, 1, 2, x2)-palladoauro-25 asp (-1)



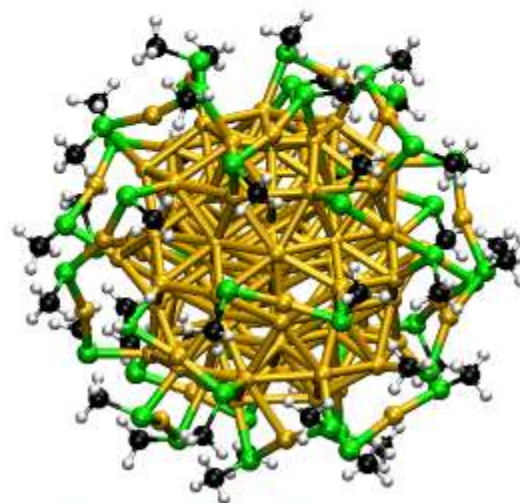
(A)



(B)



(C)



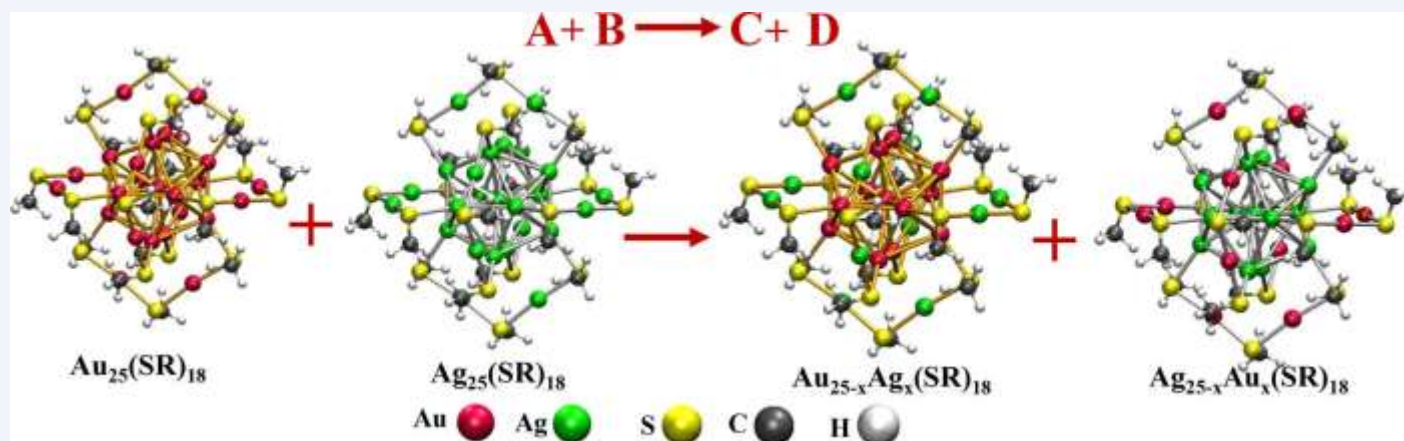
R-44(methylthiolato)-auro-102 aspicule(0)

R-(SMe)₄₄-auro-102 aspicule(0) and L-(SMe)₄₄-auro-102 aspicule(0) ³¹

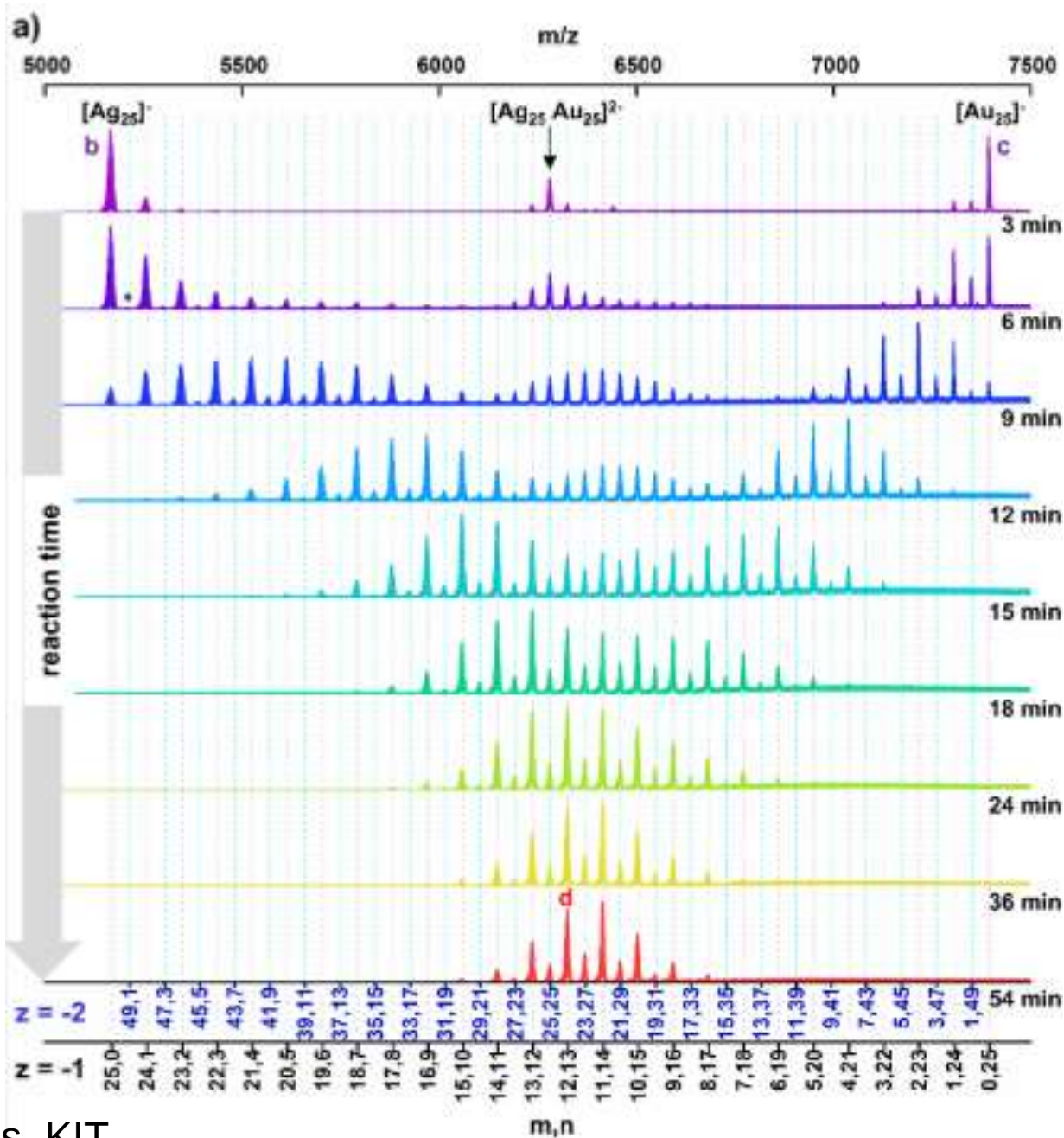
Interparticle Reactions: An Emerging Direction in Nanomaterials Chemistry

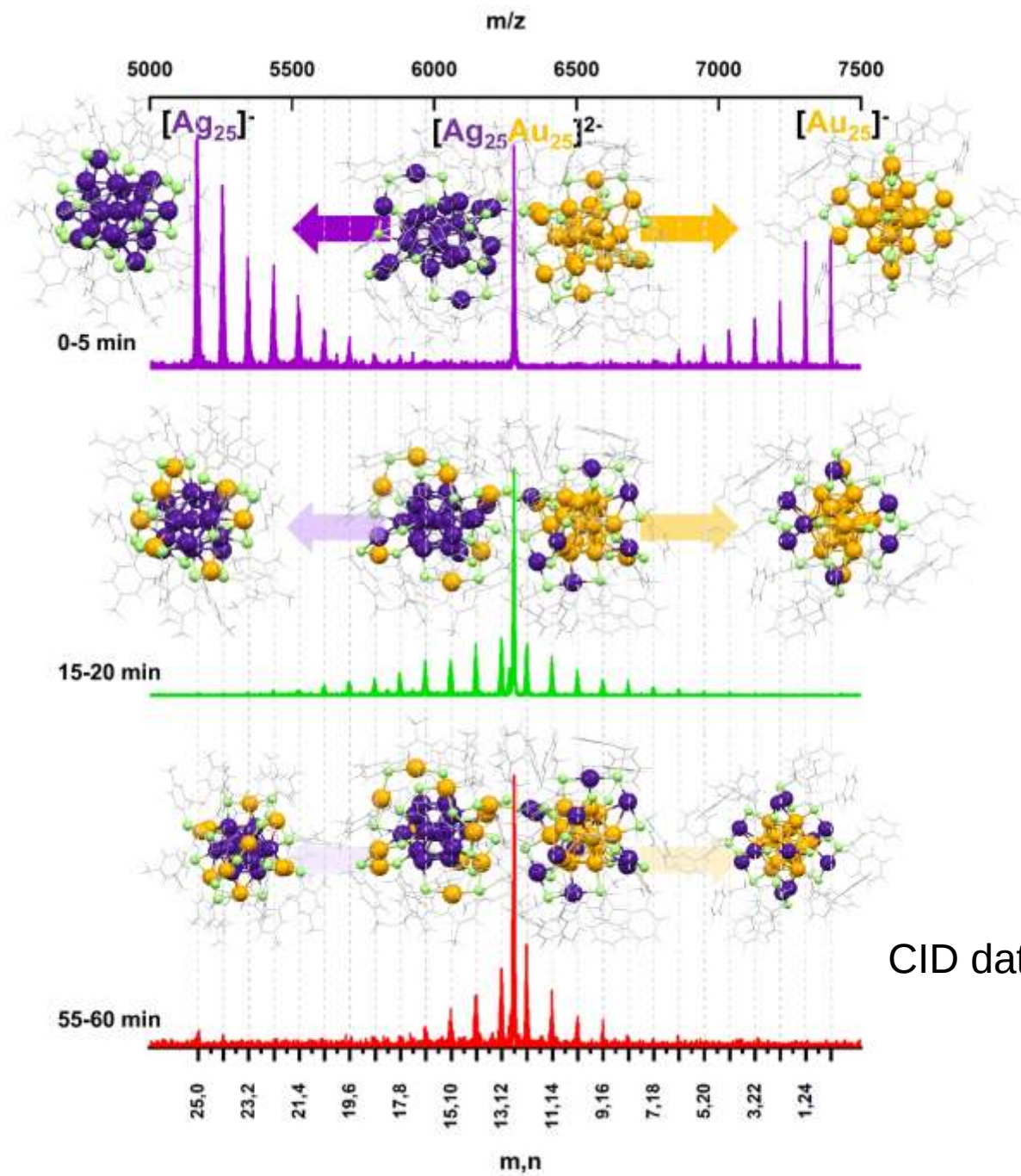
K. R. Krishnadas, Ananya Baksi,[†] Atanu Ghosh, Ganapati Natarajan, Anirban Som, and Thalappil Pradeep^{*ID}

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



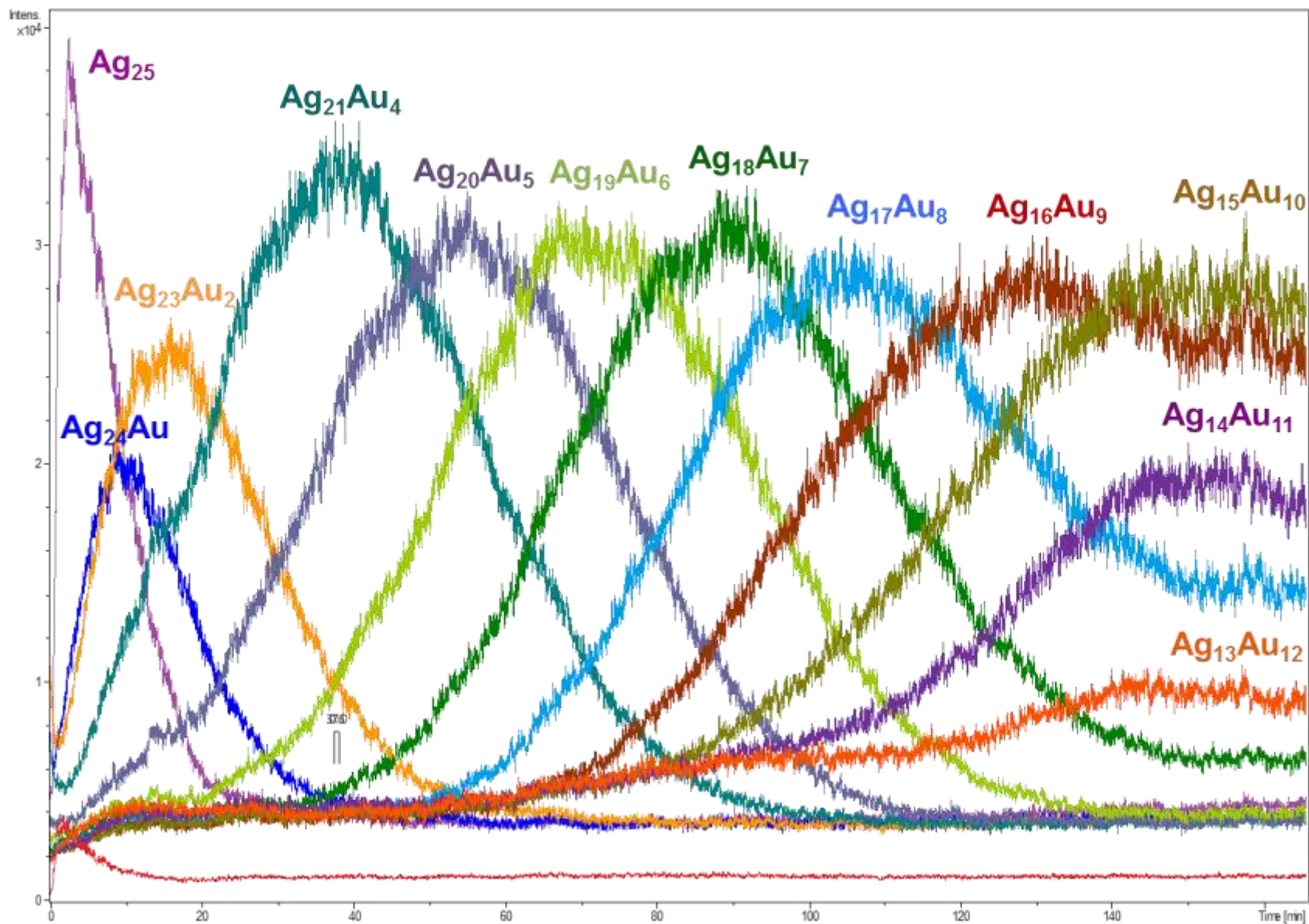
CONSPECTUS: Nanoparticles exhibit a rich variety in terms of structure, composition, and properties. However, reactions between them remain largely unexplored. In this *Account*, we discuss an emerging aspect of nanomaterials chemistry, namely, interparticle reactions in solution phase, similar to reactions between molecules, involving atomically precise noble metal clusters.





CID data of $[Au_{25}Ag_{25}]^{2-}$

Kinetics of the exchange (monitored on the Ag_{25} side)



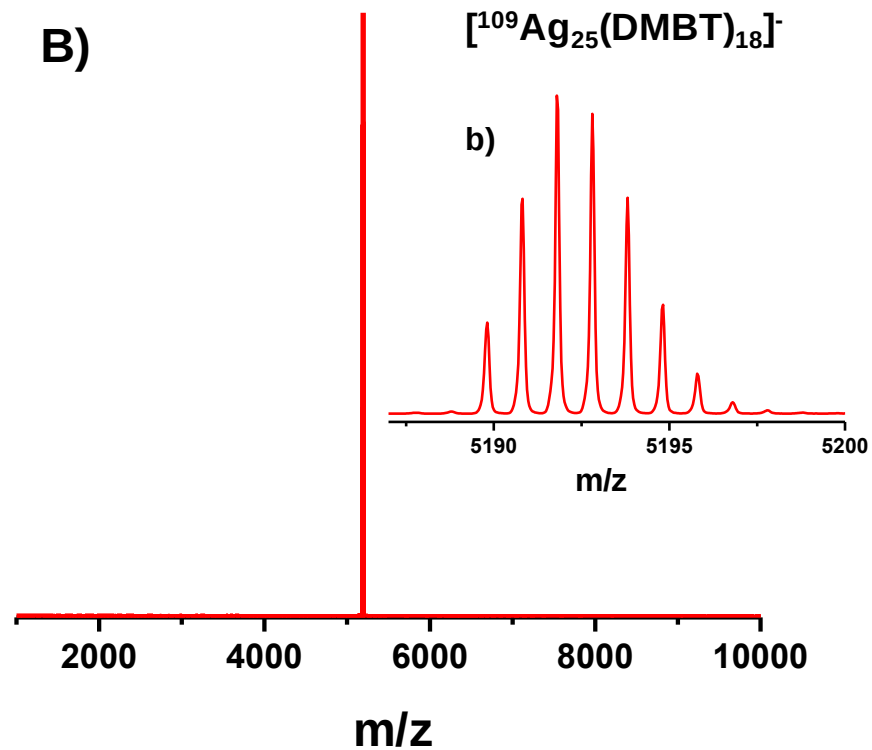
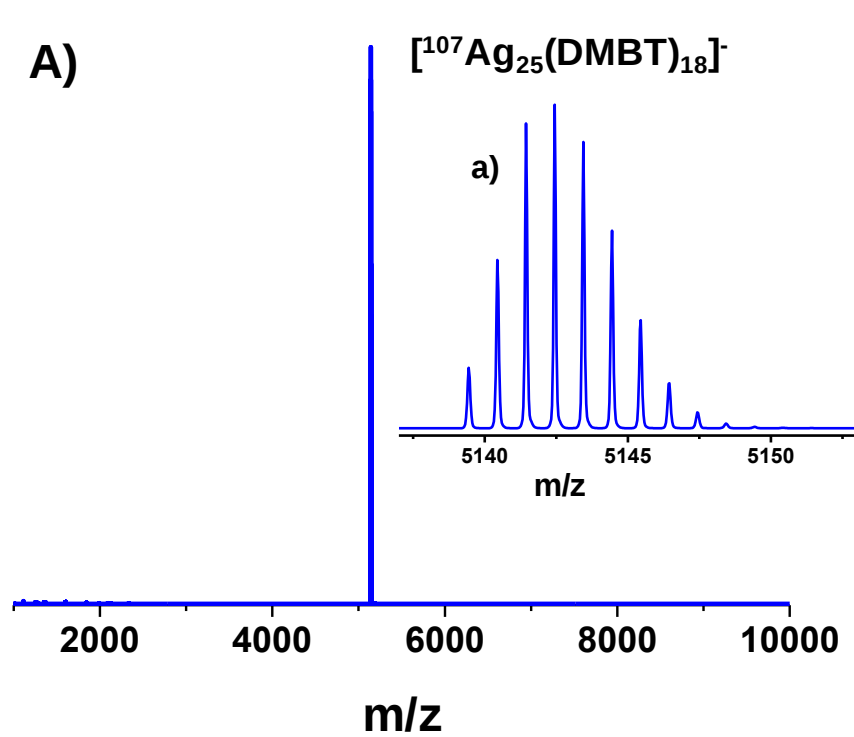
CONDENSED MATTER PHYSICS

Rapid isotopic exchange in nanoparticles

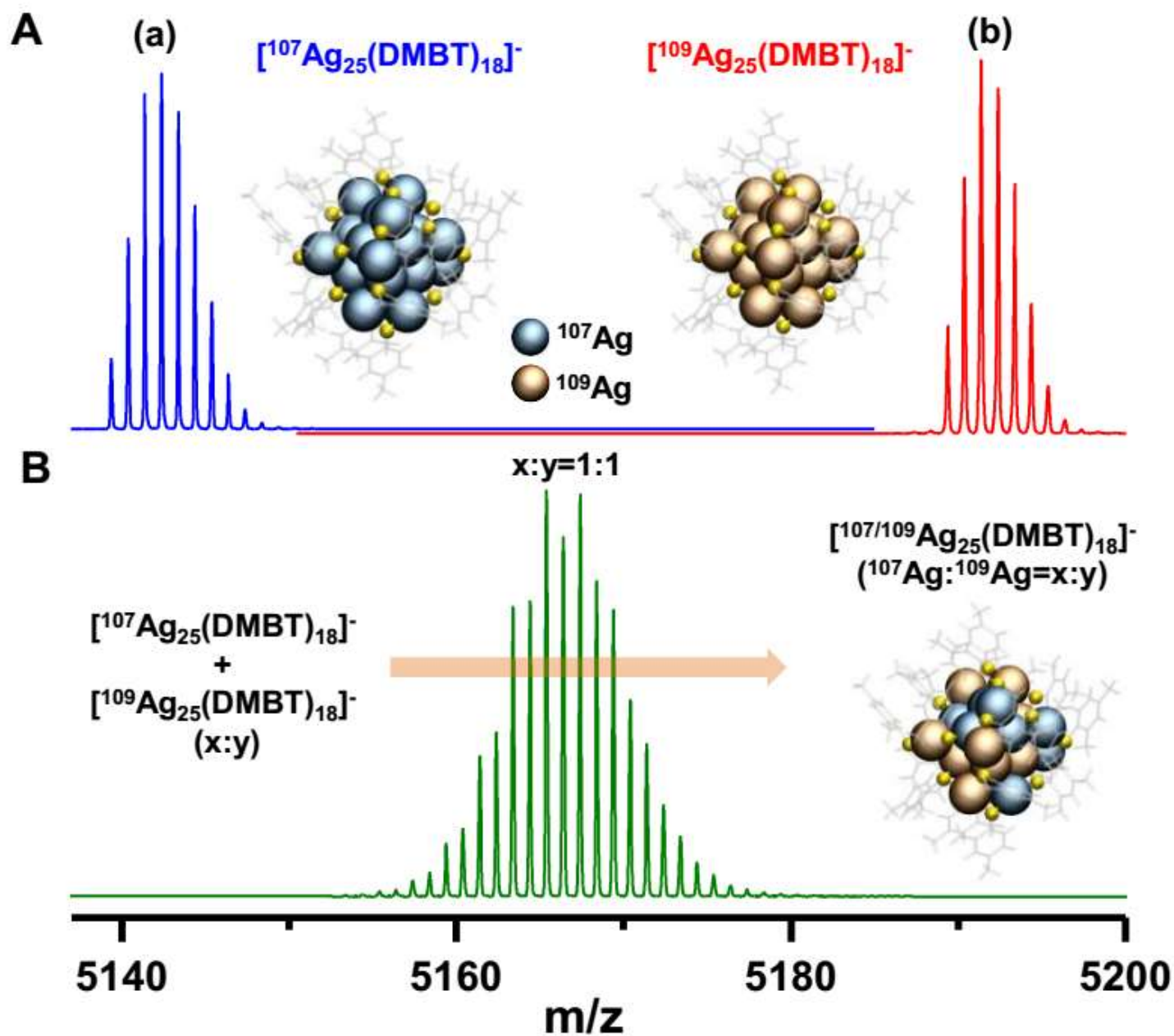
**Papri Chakraborty¹, Abhijit Nag¹, Ganapati Natarajan¹, Nayanika Bandyopadhyay¹,
Ganesan Paramasivam¹, Manoj Kumar Panwar¹, Jaydeb Chakrabarti², Thalappil Pradeep^{1*}**

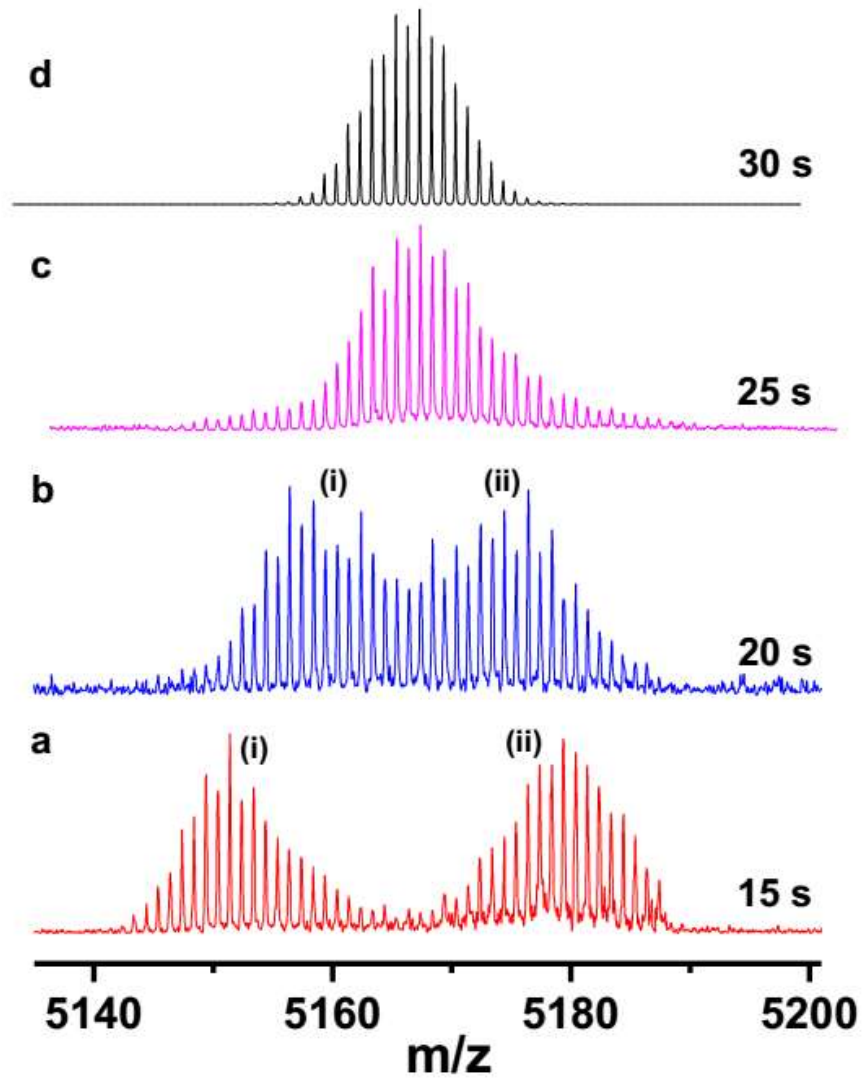
Rapid solution-state exchange dynamics in nanoscale pieces of matter is revealed, taking isotopically pure atomically precise clusters as examples. As two isotopically pure silver clusters made of ^{107}Ag and ^{109}Ag are mixed, an isotopically mixed cluster of the same entity results, similar to the formation of HDO, from H_2O and D_2O . This spontaneous process is driven by the entropy of mixing and involves events at multiple time scales.

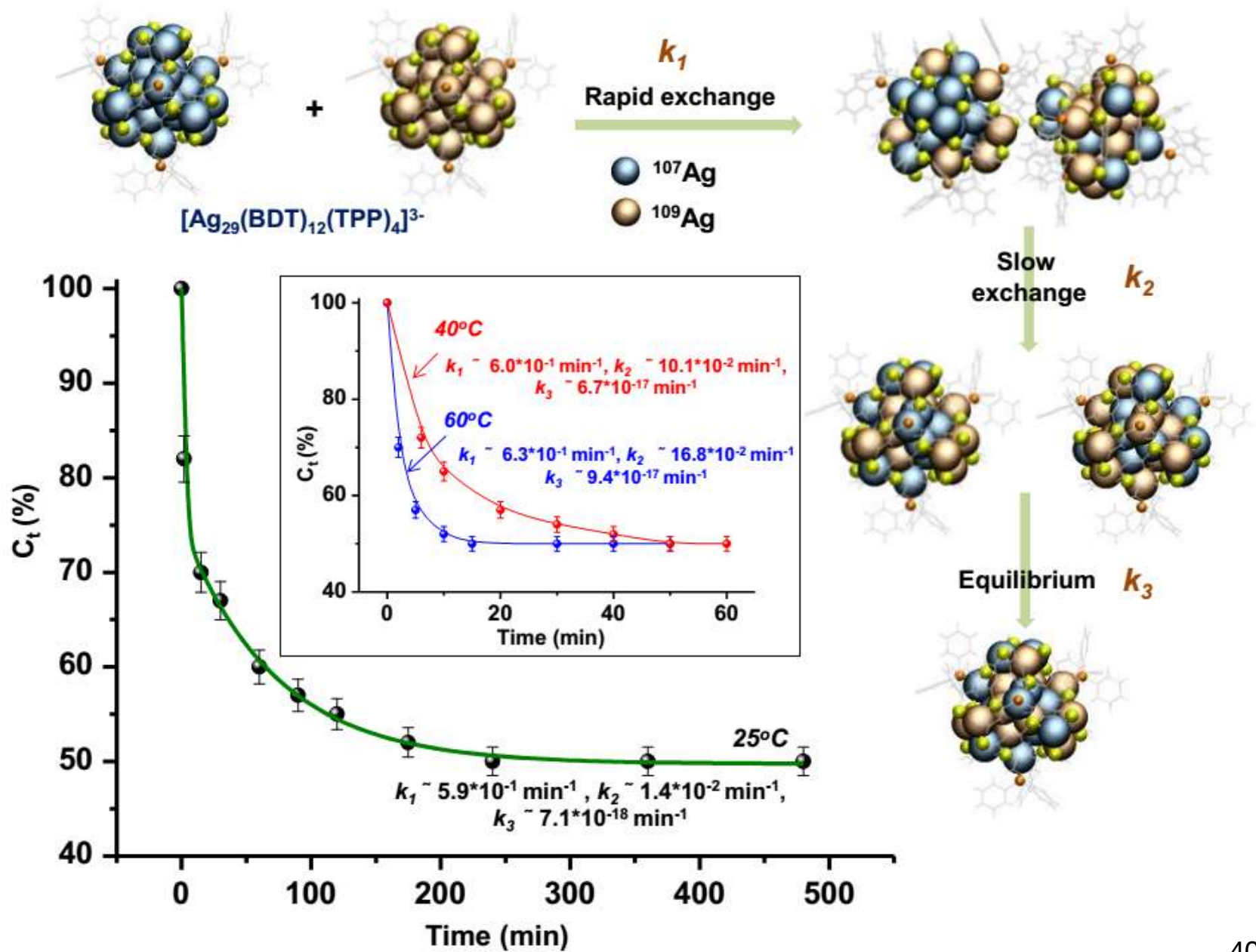
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ESI MS of **A)** $^{107}\text{Ag}_{25}(\text{DMBT})_{18}$ and **B)** $^{109}\text{Ag}_{25}(\text{DMBT})_{18}$. Insets shows the respective isotope patterns.

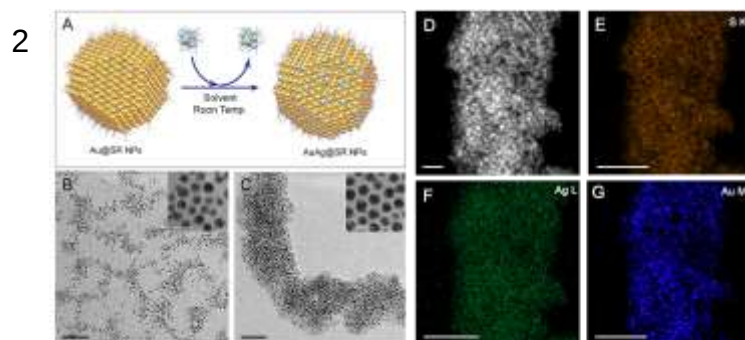
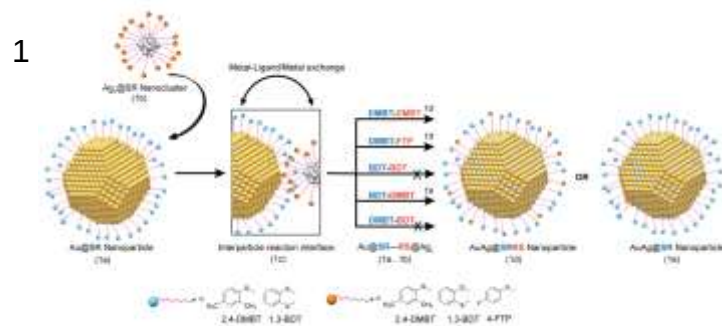




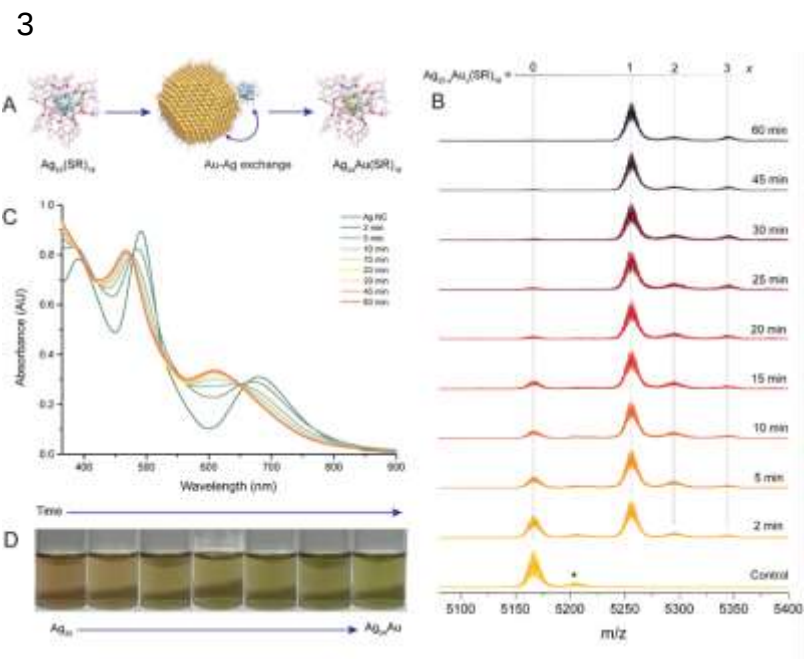


Can clusters react with nanoparticles?

Ag₂₅ with Au nanoparticles



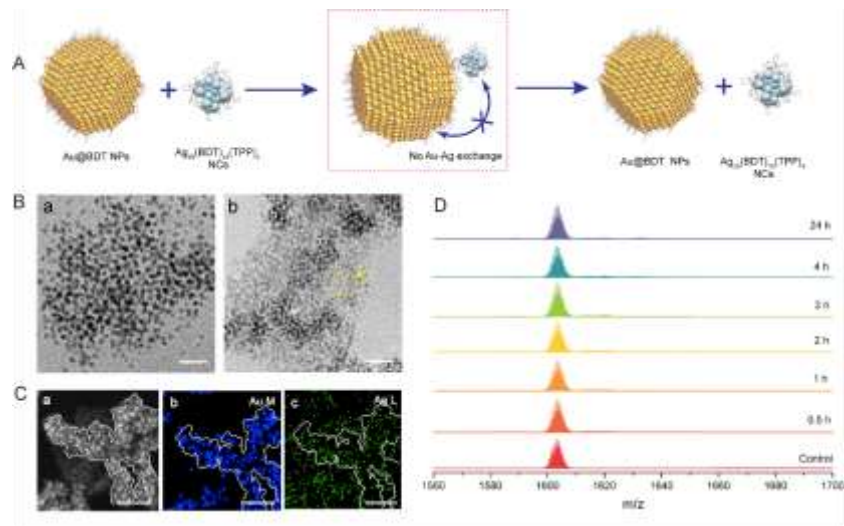
Scale bars: 50 nm (B-G) and 10 nm (insets of B and C).



Paulami Bose, et al. Chem. Mat. 2024

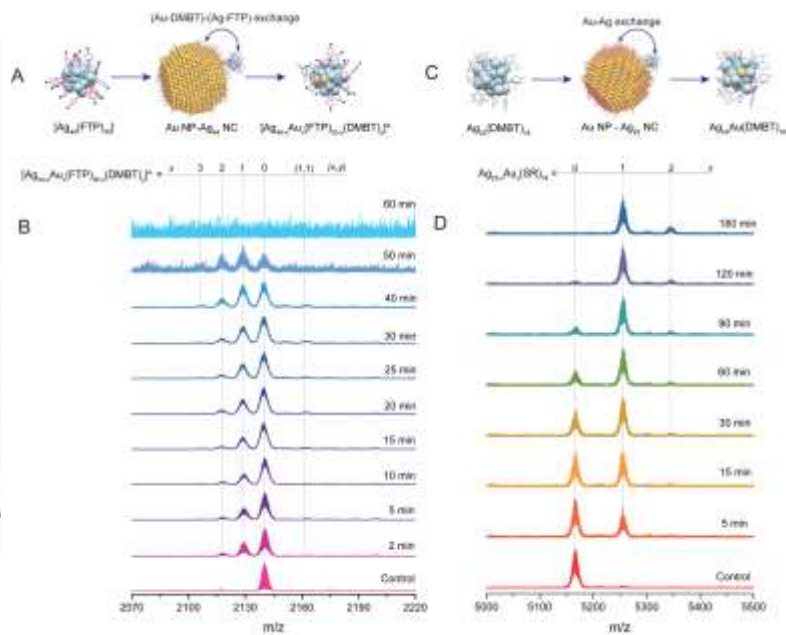
Interface controls the reaction

4

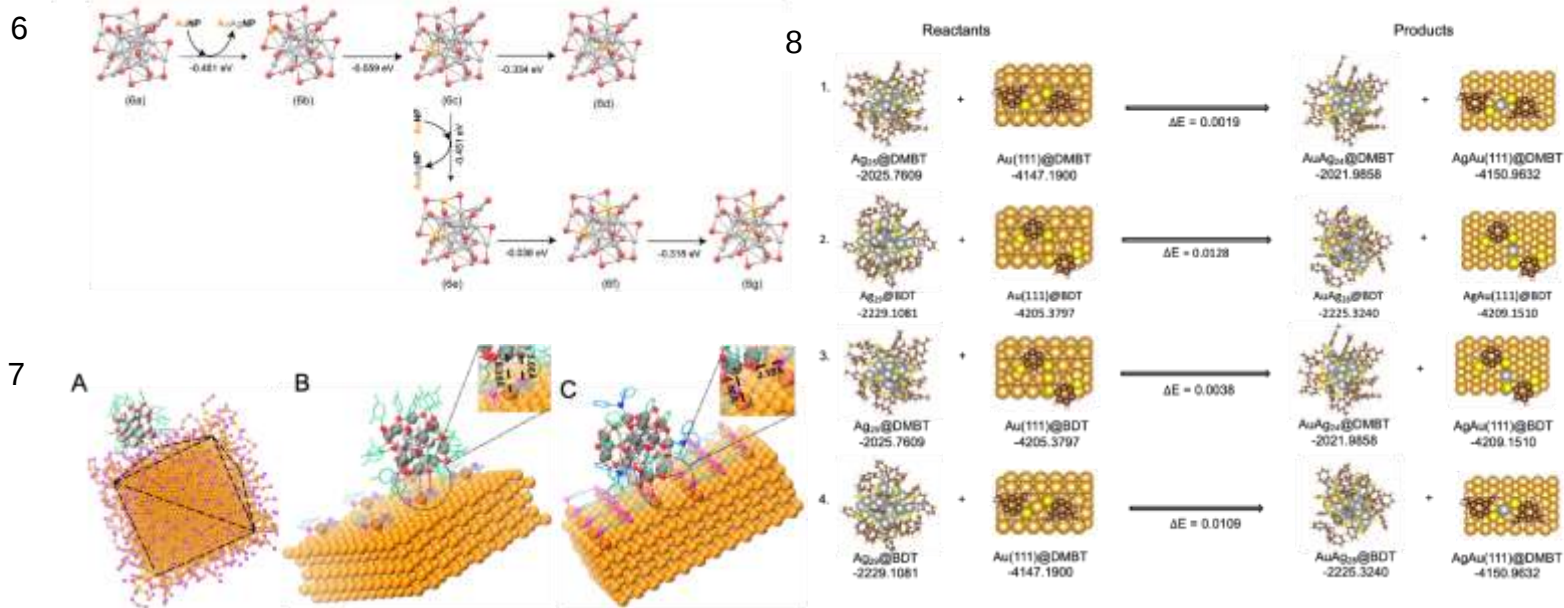


Scale bars: 20 nm

5



Computational insights



Reactions and new materials

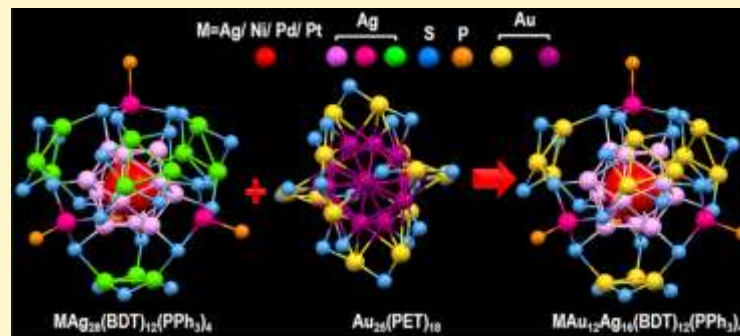
Intercluster Reactions Resulting in Silver-Rich Trimetallic Nanoclusters

Esma Khatun, Papri Chakraborty, Betsy Rachel Jacob, Ganesan Paramasivam, Mohammad Bodiuzzaman, Wakeel Ahmed Dar, and Thalappil Pradeep*[✉]

Department of Chemistry, DST Unit of Nanoscience (DST UNS) and Thematic Unit of Excellence (TUE), Indian Institute of Technology Madras, Chennai 600036, India

Supporting Information

ABSTRACT: Herein, we present an intercluster reaction leading to new trimetallic nanoclusters (NCs) using bimetallic and monometallic NCs as reactants. Dithiol protected bimetallic $\text{MAg}_{28}(\text{BDT})_{12}(\text{PPh}_3)_4$ (BDT = 1,3-benzenedithiol and M = Ni, Pd, or Pt) and monothiol protected $\text{Au}_{25}(\text{PET})_{18}$ (PET = 2-phenylethanethiol) were used as model NCs. A mixture of trimetallic $\text{MAu}_x\text{Ag}_{28-x}(\text{BDT})_{12}(\text{PPh}_3)_4$ ($x = 1-12$) and bimetallic $\text{Ag}_x\text{Au}_{25-x}(\text{PET})_{18}$ ($x = 1-7$) NCs were formed during the reaction as understood from time-dependent electrospray ionization mass spectrometry (ESI MS). Detailed studies of intercluster reaction between $\text{Ag}_{29}(\text{BDT})_{12}(\text{PPh}_3)_4$ and $\text{Au}_{25}(\text{PET})_{18}$ were also performed. Although both $\text{MAg}_{28}(\text{BDT})_{12}(\text{PPh}_3)_4$ (M = Ag, Ni, Pd, or Pt) and $\text{Au}_{25}(\text{PET})_{18}$ contain 13 atoms icosahedral core, only a maximum of 12 Au doped NCs were formed for the former as a



Reactions leading to co-crystals



Cite This: *ACS Nano* 2019, 13, 13365–13373

www.acsnano.org

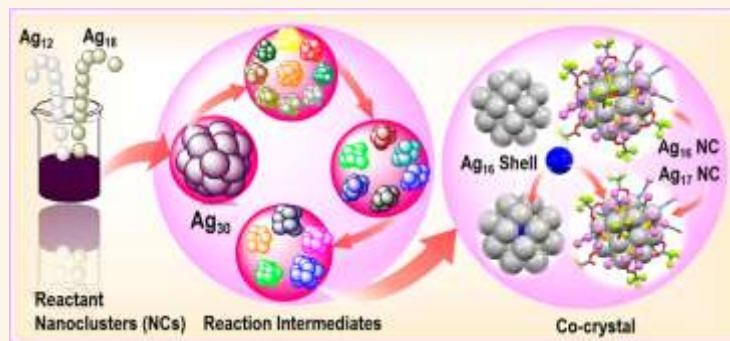
Interparticle Reactions between Silver Nanoclusters Leading to Product Cocystals by Selective Cocrystallization

Wakeel Ahmed Dar,[†] Mohammad Bodiuzzaman,[†] Debasmita Ghosh, Ganesan Paramasivam, Esma Khatun, Korath Shivan Sugi, and Thalappil Pradeep*[✉]

Department of Chemistry, DST Unit of Nanoscience and Thematic Unit of Excellence, Indian Institute of Technology Madras, Chennai 600036, India

Supporting Information

ABSTRACT: We present an example of an interparticle reaction between atomically precise nanoclusters (NCs) of the *same* metal, resulting in entirely different clusters. In detail, the clusters $[\text{Ag}_{12}(\text{TBT})_8(\text{TFA})_5(\text{CH}_3\text{CN})]^+$ (TBT = *tert*-butylthiolate, TFA = trifluoroacetate, CH_3CN = acetonitrile) and $[\text{Ag}_{18}(\text{TPP})_{10}\text{H}_{16}]^{2+}$ (TPP = triphenylphosphine) abbreviated as Ag_{12} and Ag_{18} , respectively, react leading to $[\text{Ag}_{16}(\text{TBT})_8(\text{TFA})_7(\text{CH}_3\text{CN})_3\text{Cl}]^+$ and $[\text{Ag}_{17}(\text{TBT})_8(\text{TFA})_7(\text{CH}_3\text{CN})_3\text{Cl}]^+$, abbreviated as Ag_{16} and Ag_{17} , respectively. The two product NCs crystallize together as both possess the same metal chalcogenolate



Supramolecular chemistry

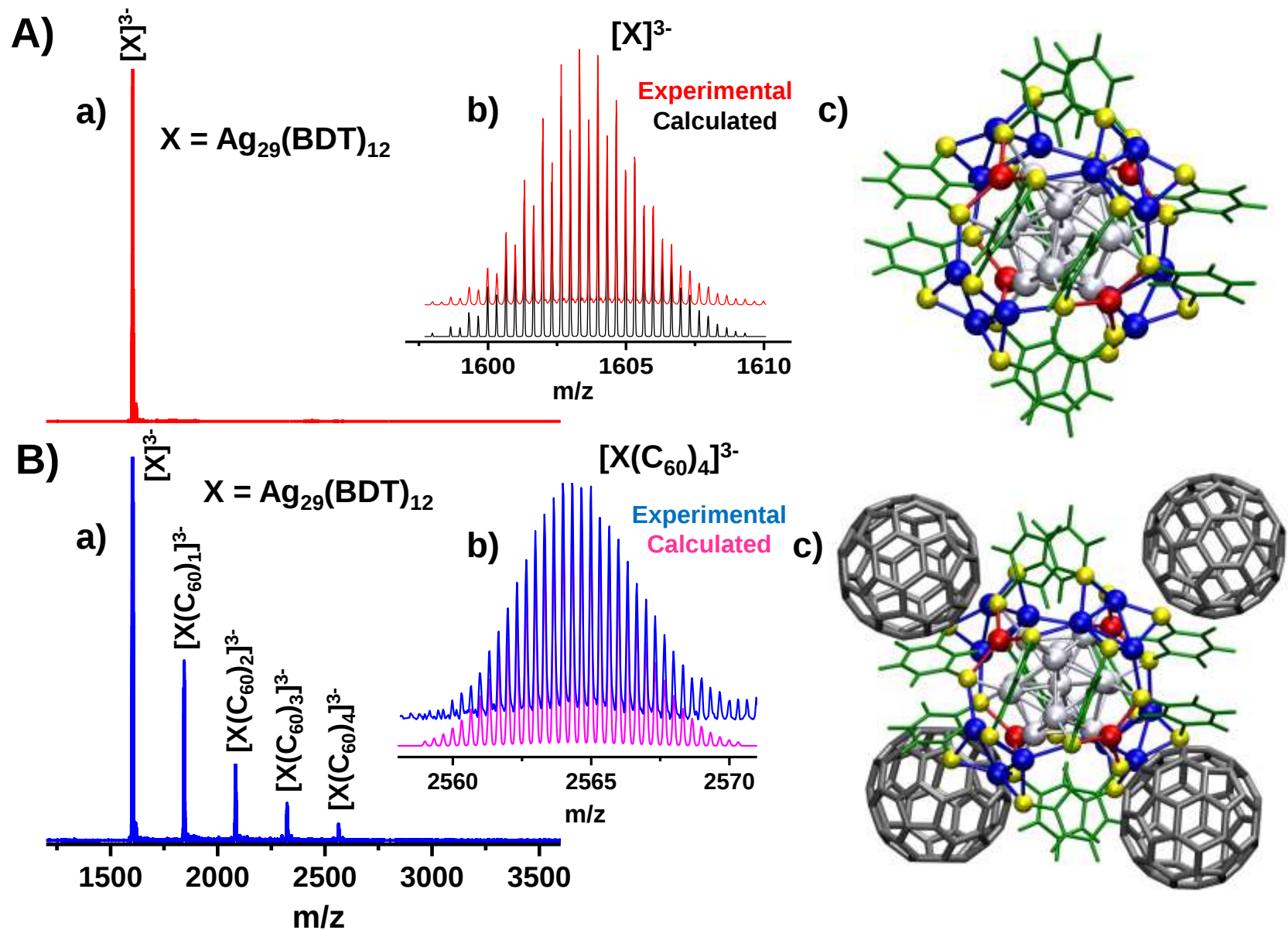
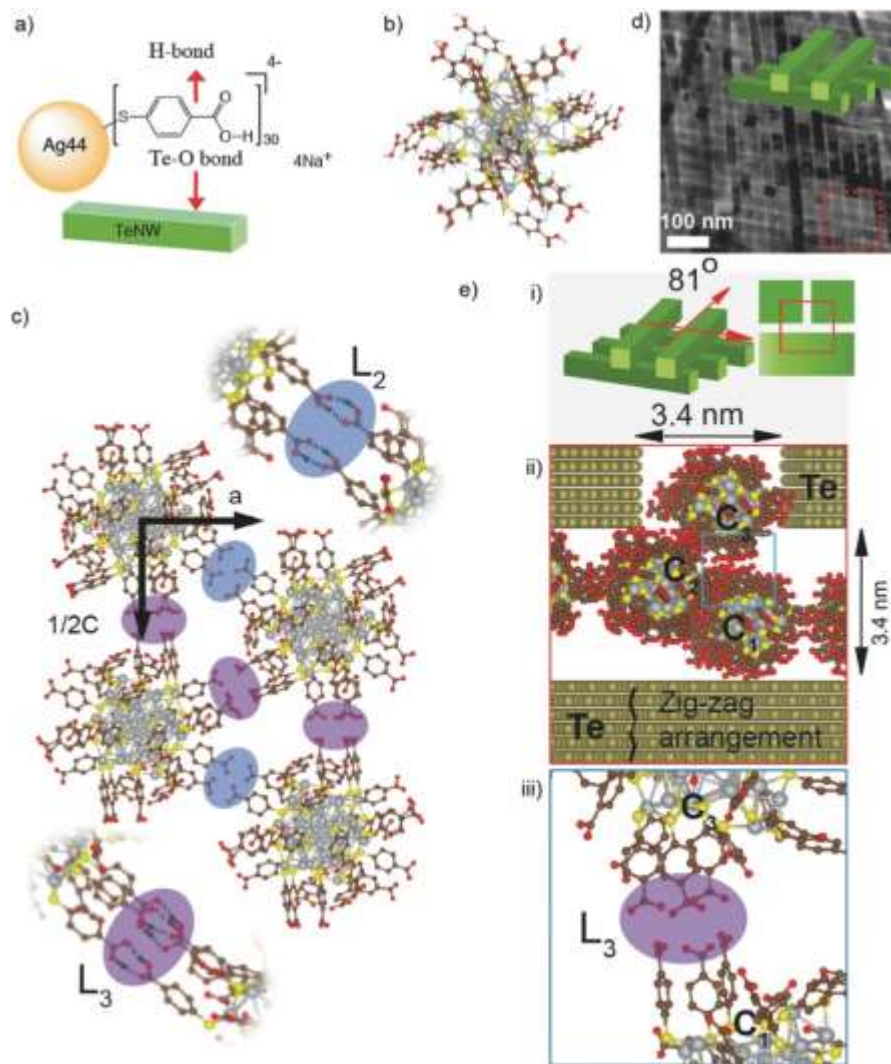
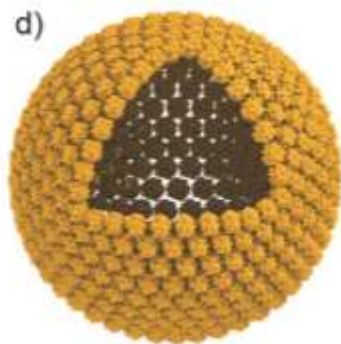
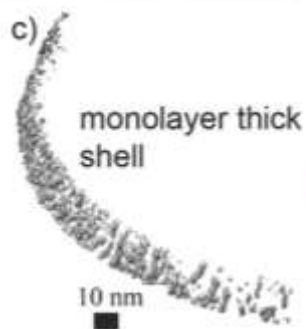
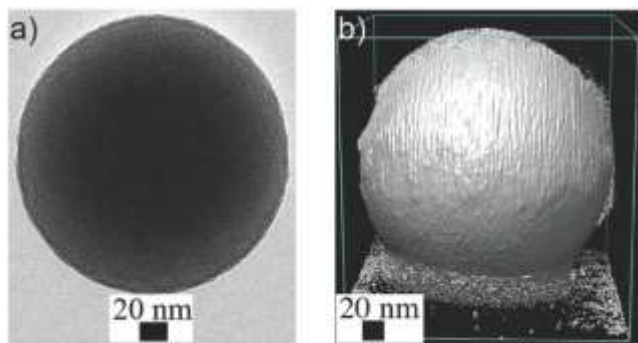
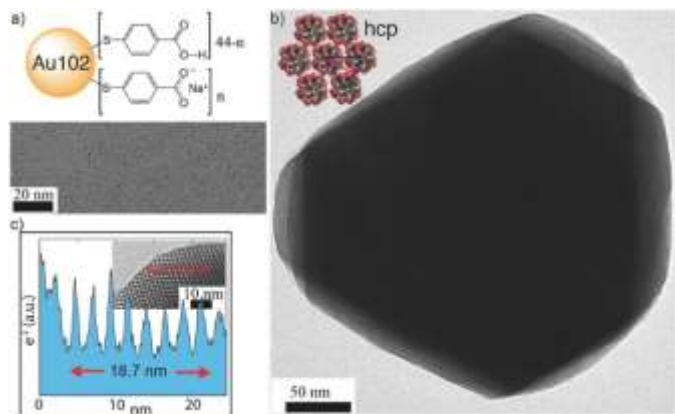


Figure 1. **A)** **(a)** Full range ESI MS, **(b)** experimental and calculated isotope patterns and **(c)** DFT optimized structure of $[Ag_{29}(BDT)_{12}]^{3-}$ cluster. **B)** **(a)** ESI MS of $[Ag_{29}(BDT)_{12}(C_{60})_n]^{3-}$ ($n=1-4$) complexes, **(b)** experimental and calculated isotope patterns of $[Ag_{29}(BDT)_{12}(C_{60})_4]^{3-}$ and **(c)** schematic of the possible structure of $[Ag_{29}(BDT)_{12}(C_{60})_4]^{3-}$.

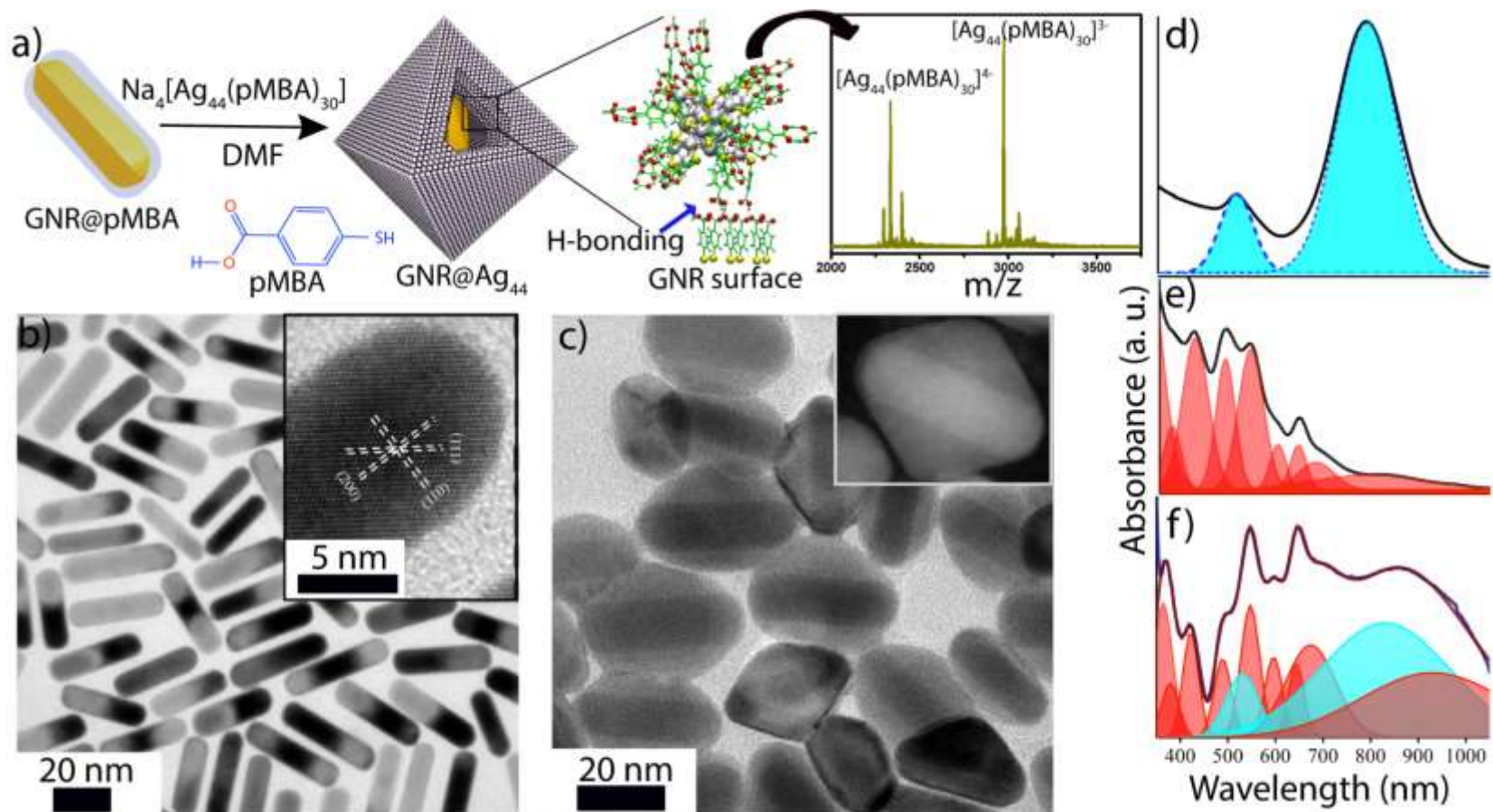
Assemblies and superstructures

Nanoclusters in colloidal assemblies



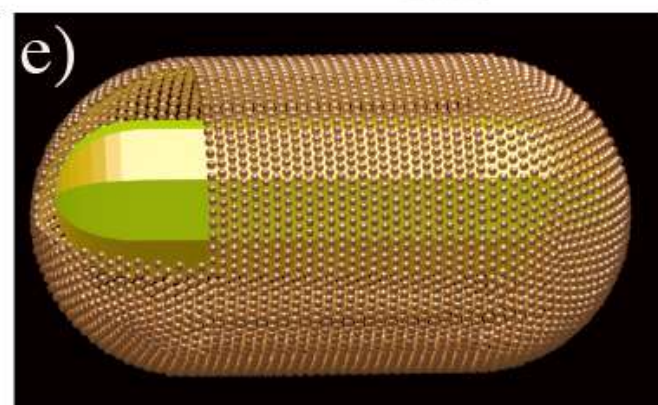
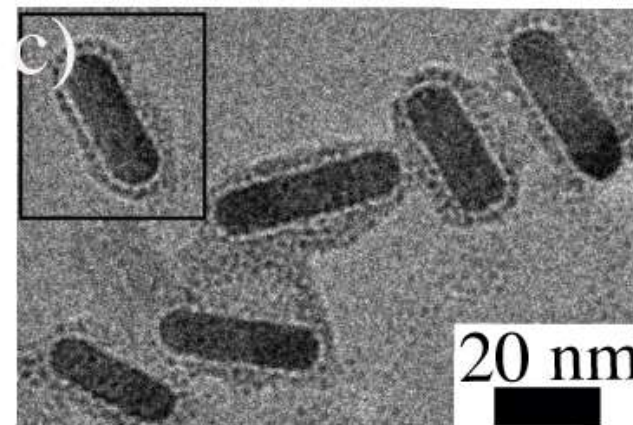
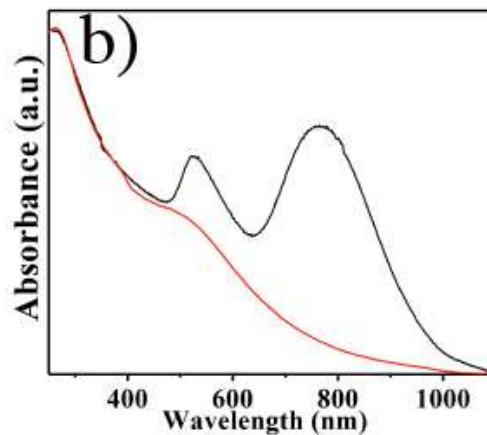
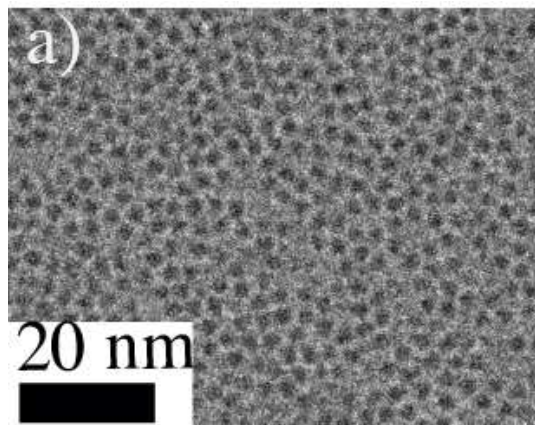
Som, A. et al., *Adv. Mater.* **2016**, 28, 2827–2833

Atomically precise nanocluster assemblies encapsulating plasmonic gold nanorods



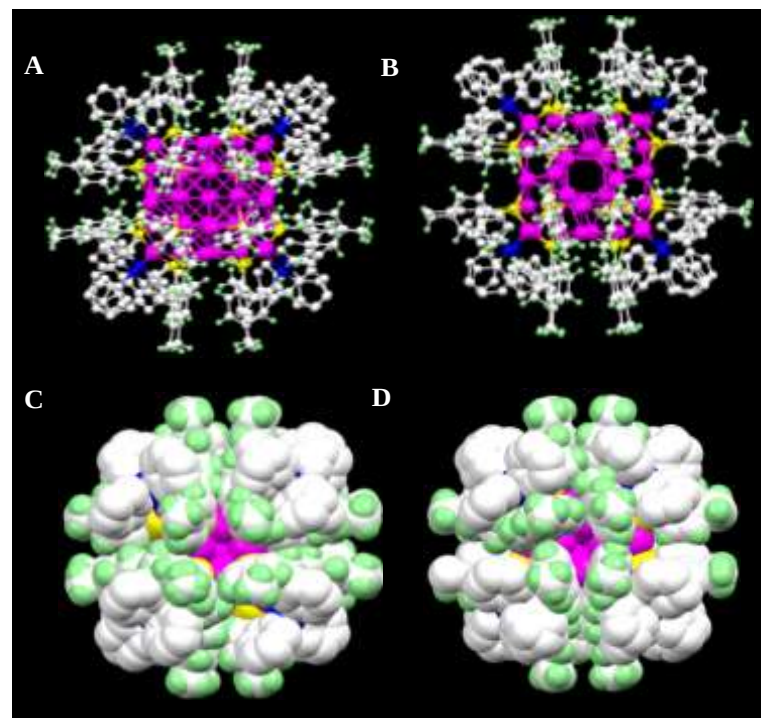
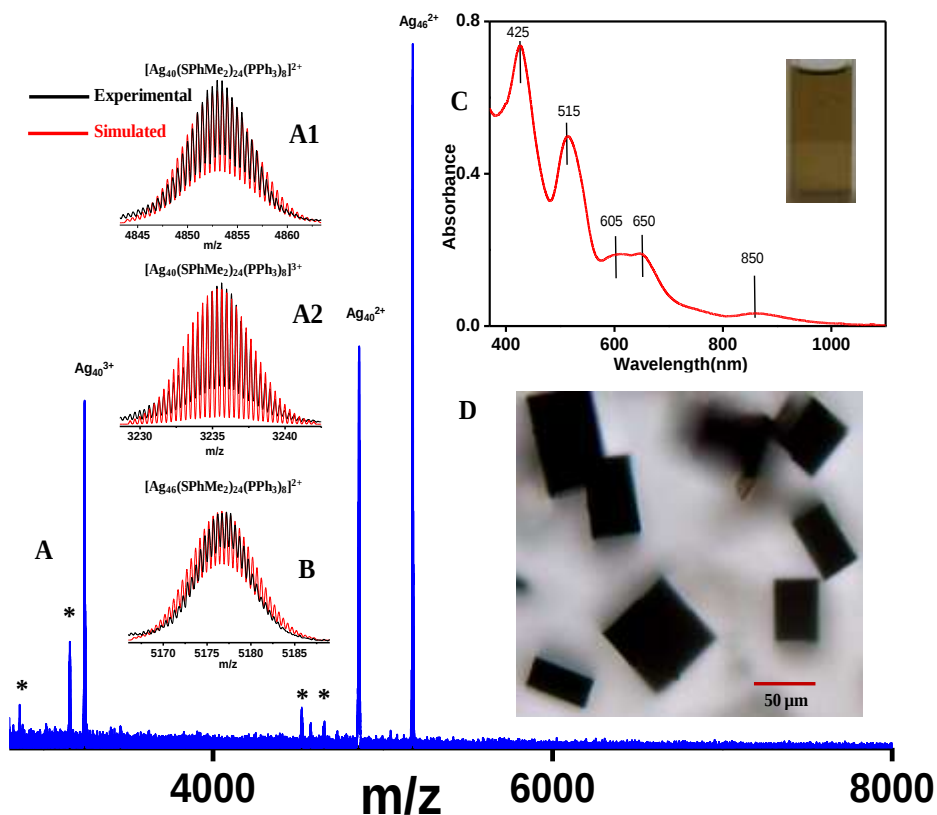
Chakraborty, A. et al., *Angew. Chem. Int. Ed.* **2018**, 57, 6522–6526.

Works for $\text{Au}_{250}(\text{pMBA})_n$ and aqueous solvent



Co-crystals

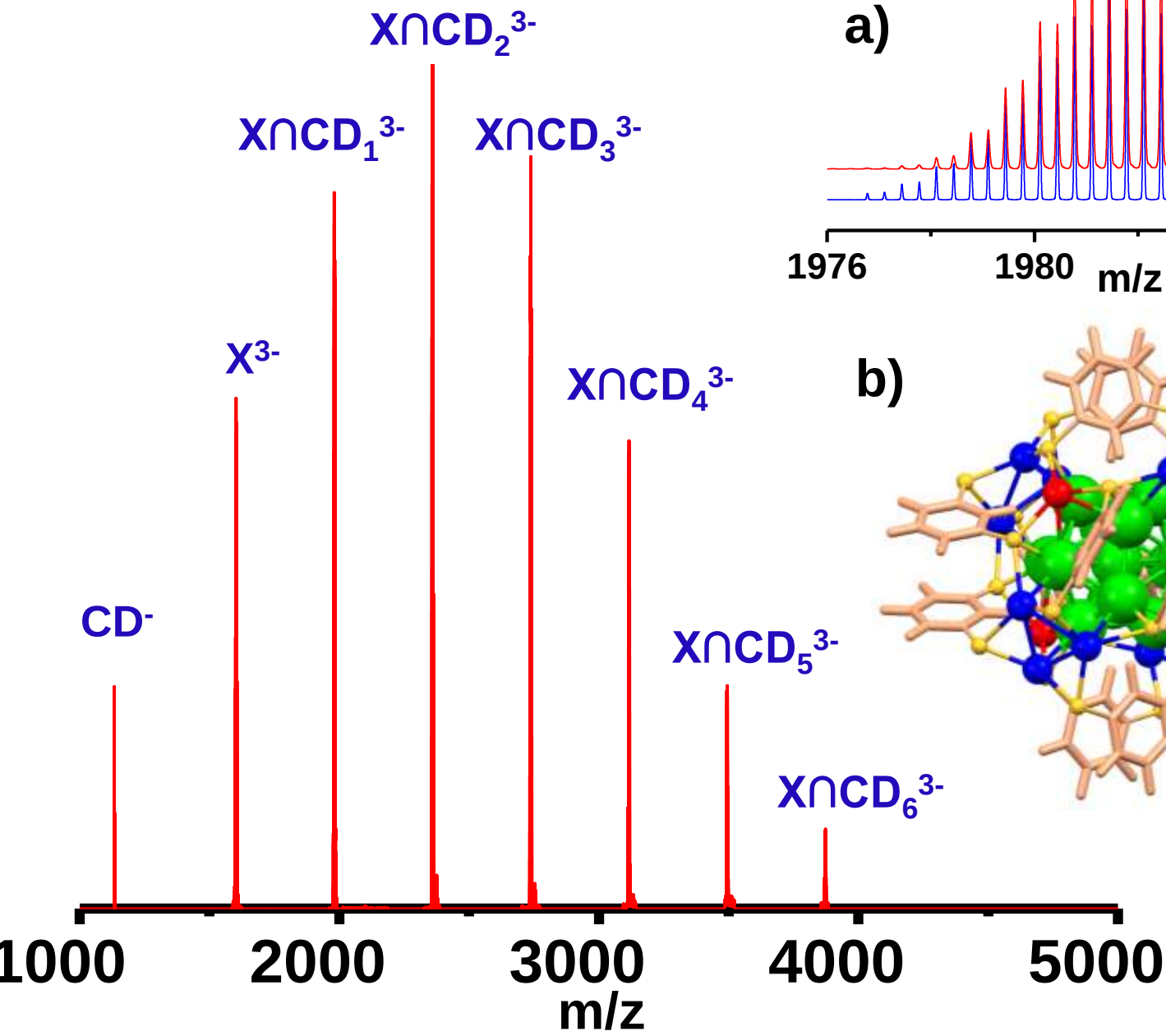
Ag_{40} and Ag_{46} with the same shell



M. Bodiuzzaman, et. al. *Angew. Chem. Int. Ed.* **2018**

Isomerism in supramolecular adducts

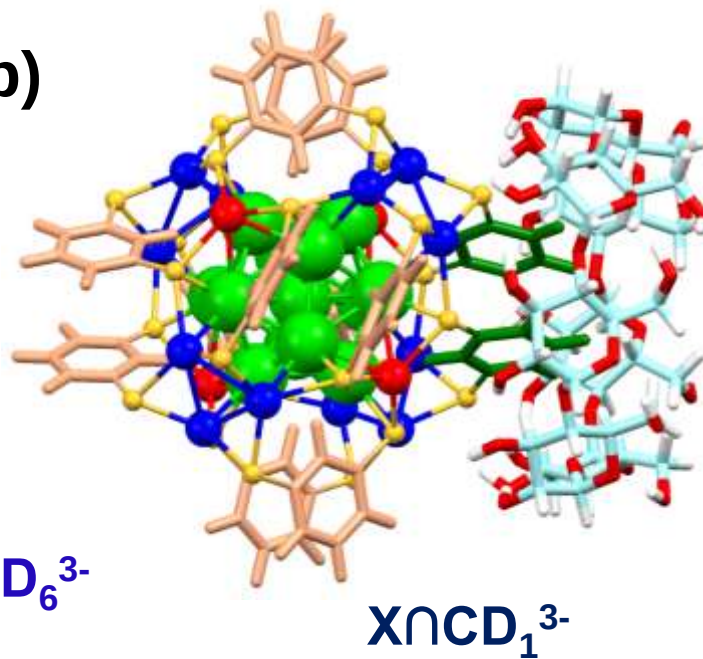
A)

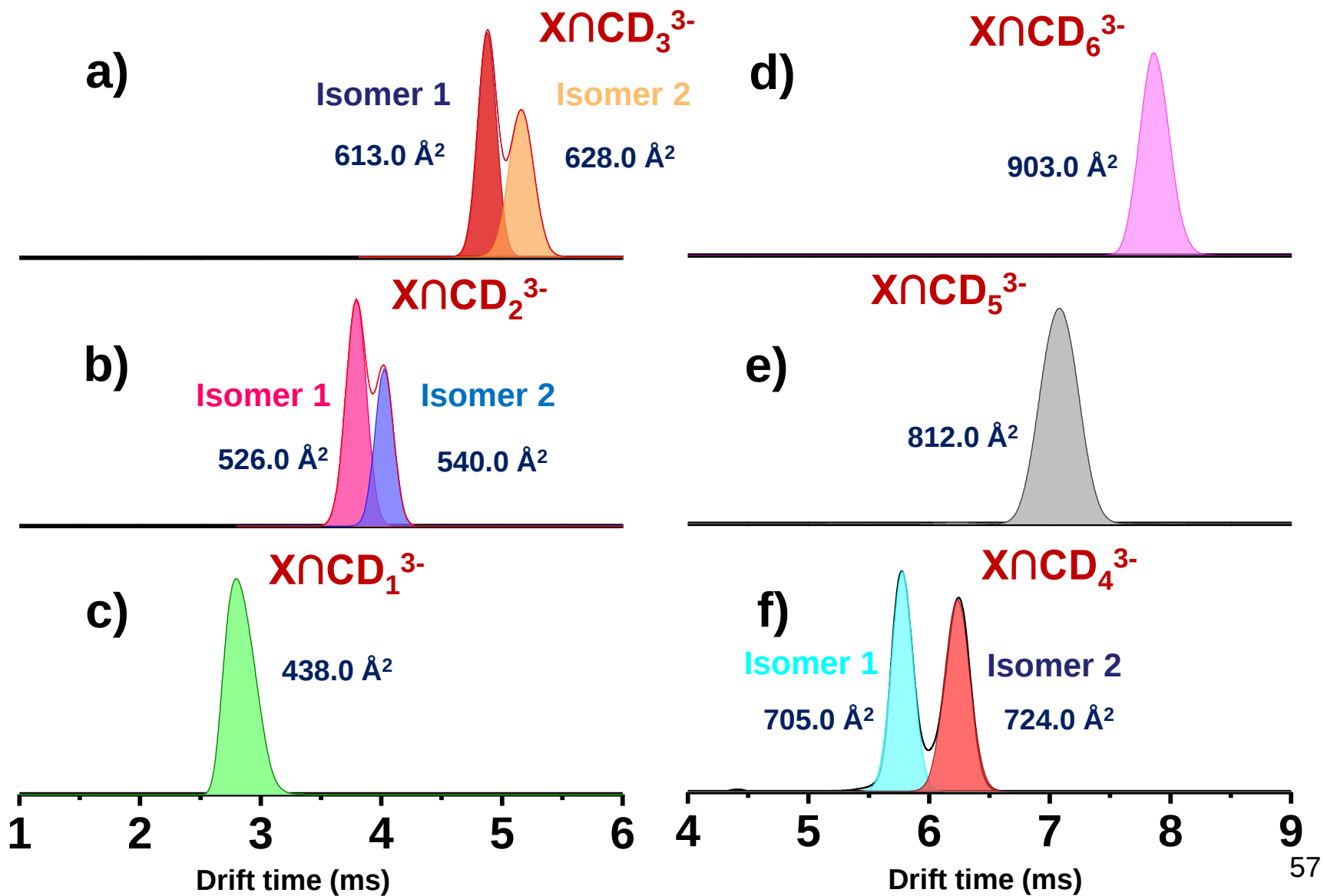
 $\text{Ag}_{29}\text{BDT}_{12} = \text{X}$ $\beta\text{-cyclodextrin} = \text{CD}$  XnCD_1^{3-}

a)

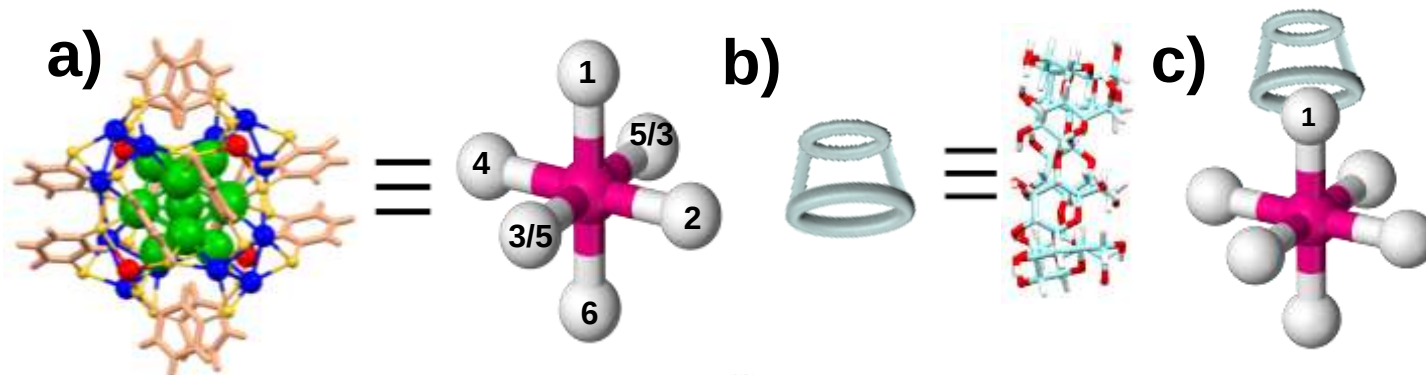
Calculated
Experimental1976 1980 1984 1988 m/z

b)

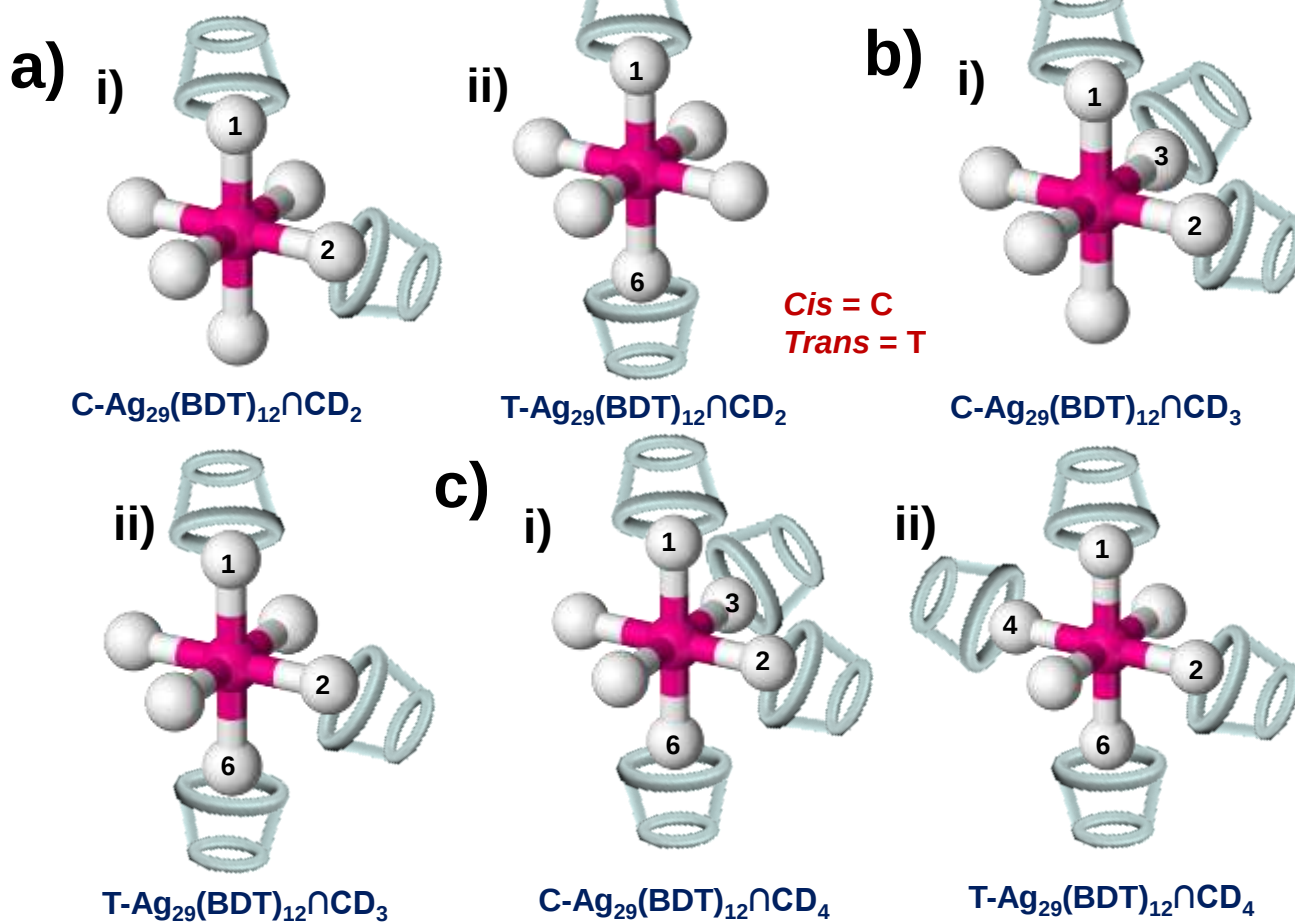




A)



B)



Where are they taking us to?

Biopolymer-reinforced synthetic granular nanocomposites for affordable point-of-use water purification

Mohan Udhaya Sankar¹, Sahaja Aigal¹, Shihabudheen M. Maliyekkal¹, Amrita Chaudhary, Anshup, Avula Anil Kumar, Kamalesh Chaudhari, and Thalappil Pradeep²

Unit of Nanoscience and Thematic Unit of Ex

Edited by Eric Hoek, University of California,

Creation of affordable materials for cons water is one of the most promising way drinking water for all. Combining the composites to scavenge toxic species other contaminants along with the ab affordable, all-inclusive drinking water without electricity. The critical proble synthesis of stable materials that can uously in the presence of complex s drinking water that deposit and caus surfaces. Here we show that such can be synthesized in a simple and effective out the use of electrical power. The na sand-like properties, such as higher shea forms. These materials have been used water purifier to deliver clean drinking ily. The ability to prepare nanostructu ambient temperature has wide releva water purification.

hybrid | green | appropriate technology | frugal science | developing world



Madras, Chennai 600 036, India

(received for review November 21, 2012)

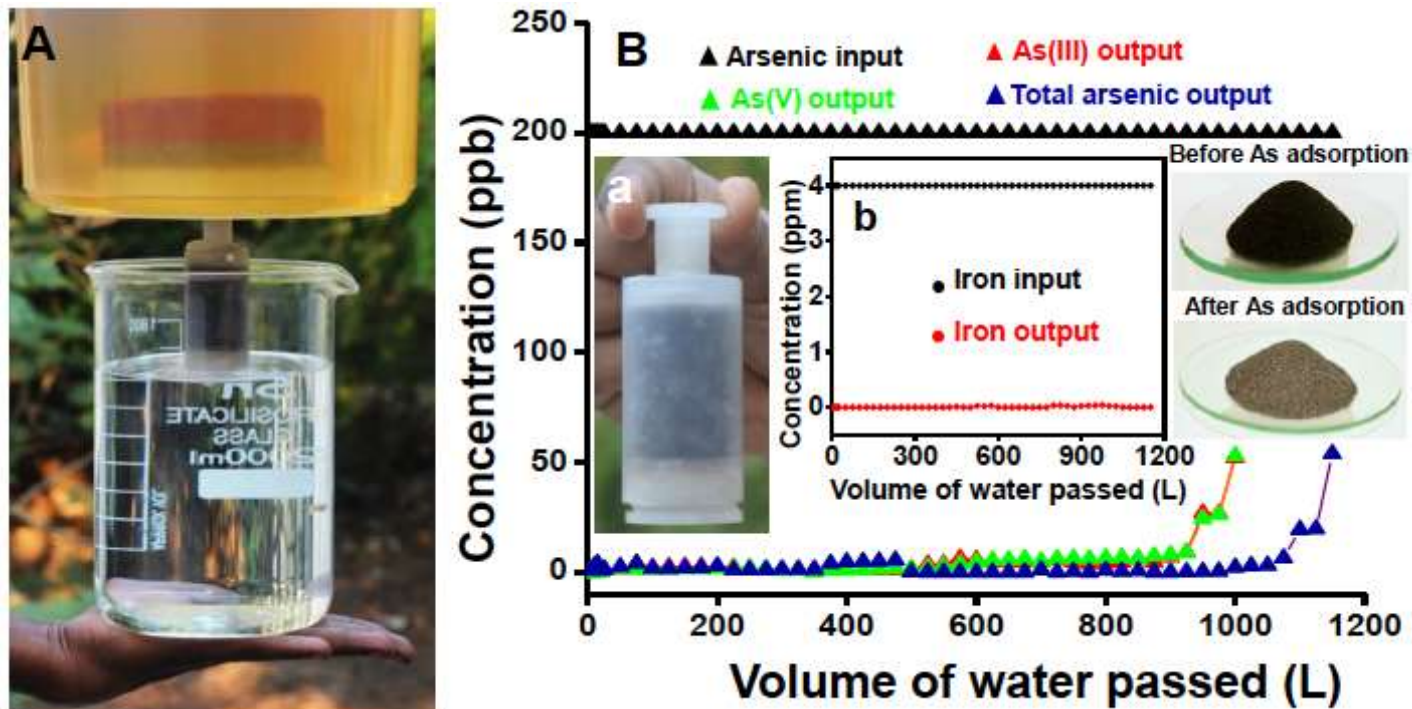
available; and (c) continued retention matrix is difficult.

ate a unique family of nanocrystalline n granular composite materials pre- ature through an aqueous route. The mposition is attributed to abundant -O on chitosan, which help in the crys- oxide and also ensure strong covalent : surface to the matrix. X-ray photo-) confirms that the composition is rich ps. Using hyperspectral imaging, the aching in the water was confirmed. to reactivate the silver nanoparticle al antimicrobial activity in drinking osites have been developed that can its in water. We demonstrate an af- device based on such composites de- and undergoing field trials in India, as :spread eradication of the waterborne

Results and Discussion

M. Udhaya Sankar, et. al. *Proc. Natl. Acad. Sci.*, 110 (2013) 8459-8464.

Range of materials, their affordability and safety



A. Anil Kumar, et. al. *Adv. Mater.*, 29 (2016) 1604260.

Safety of spent media, TCLP

Clean water for everyone



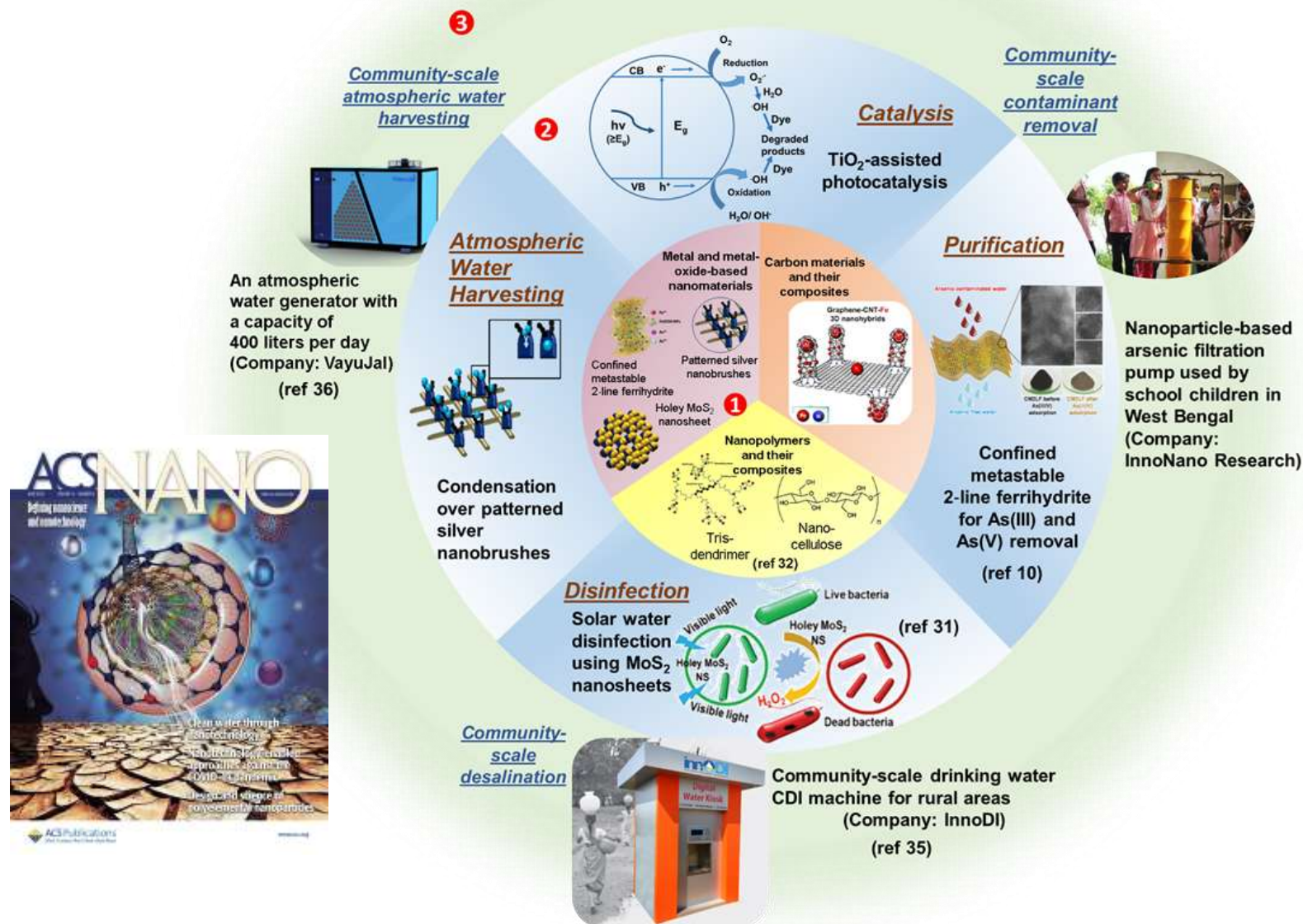
ACS Sustainable Chemistry & Engineering Editorial,
December 2016



We developed environmentally friendly water positive nanoscale materials for affordable, sustainable and rapid removal of arsenic from drinking water.

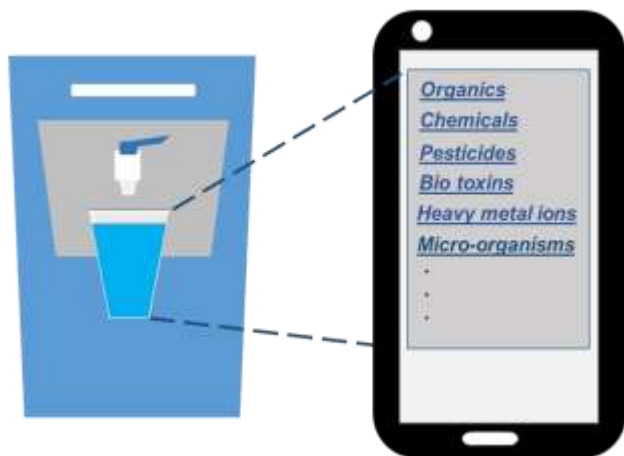
There are over 1700 community installations across the country, serving 1.3 million people with arsenic and iron-free water every day.

Evolution of materials to products



Smart water purifiers and big data

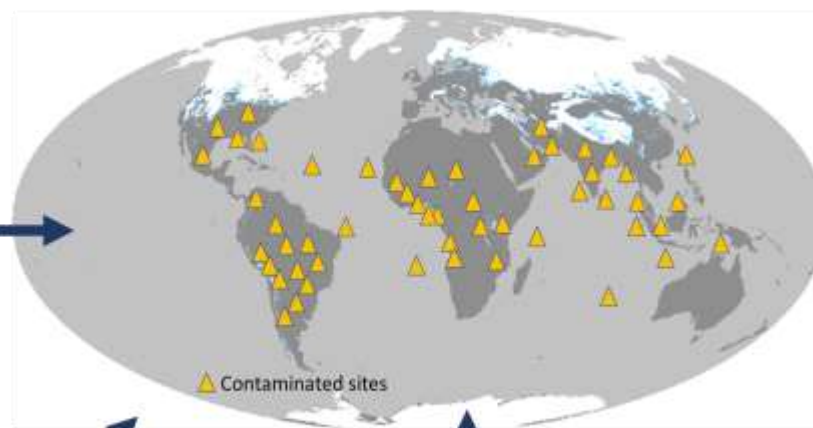
Smart Water Purifiers linked to IoT



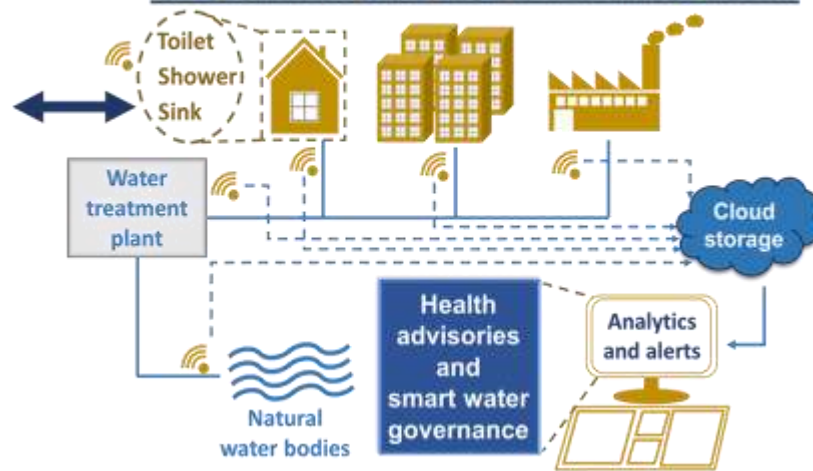
Cost-effective sensor accessory for point-of-use applications



Global Map of Water Health



IoT-enabled sensing for households and distribution networks



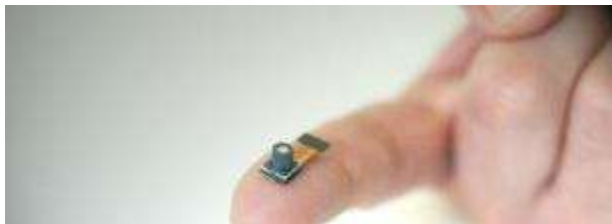
Sensors and new opportunities



Analog/Grating
Equipment
\$ 5~6 Billion (2017)
a few **100k units** (2017)



**Ultra compact Low Cost
Spectral Sensor Module**
~ **Billions units** (? 2027)

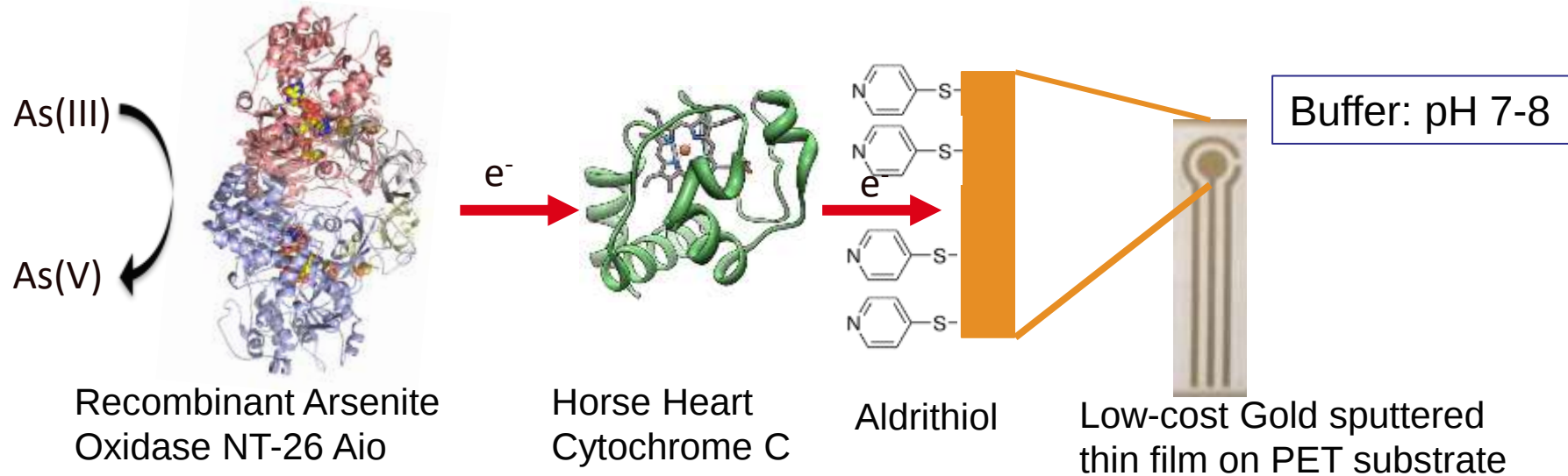


Water quality measurement – In the pipeline

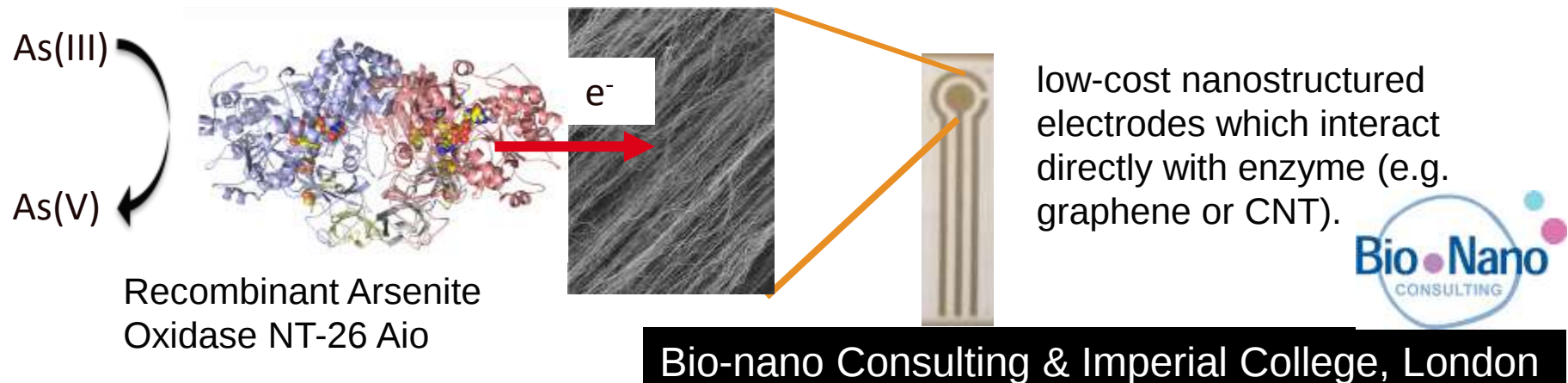
nano λ

Biosensor Design

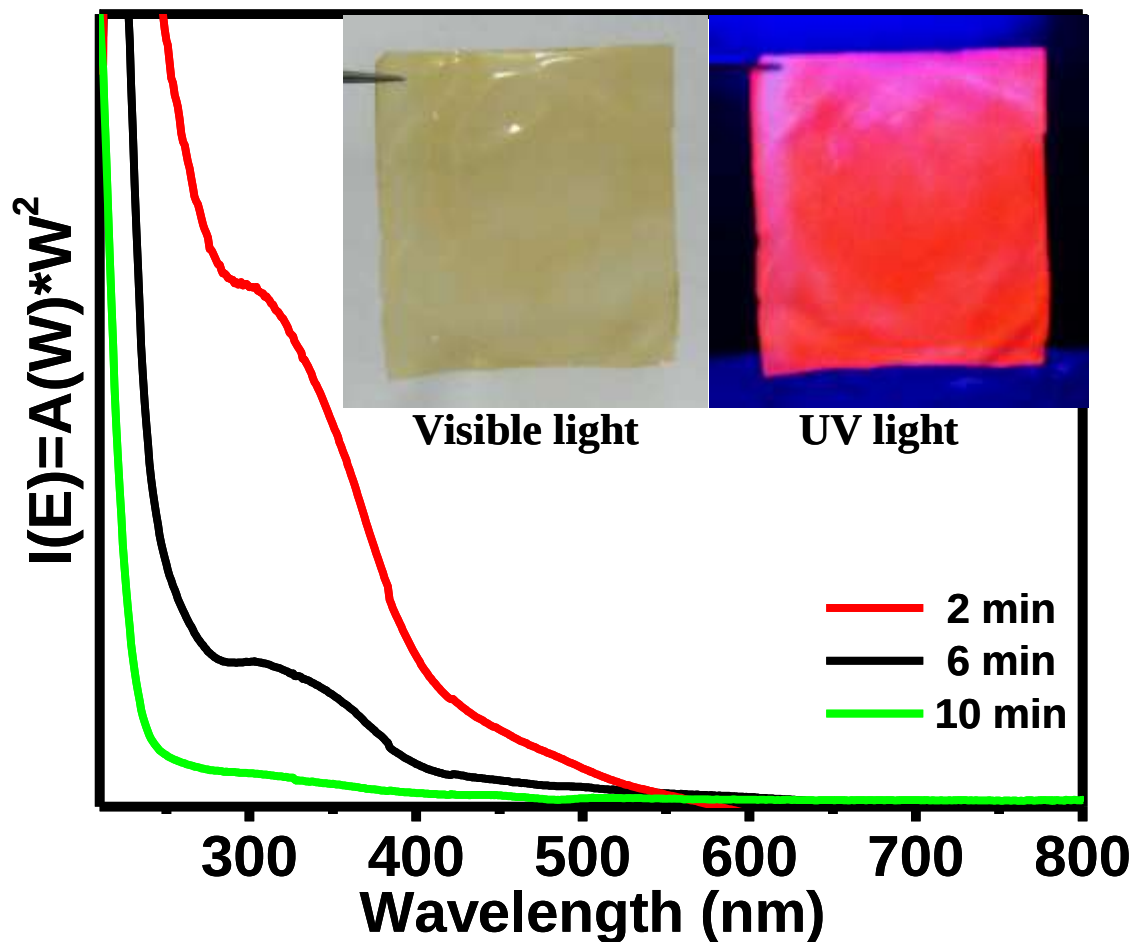
1st Generation Design (Mediated Electrochemistry)



2nd Generation Design (Direct Electron Transfer)

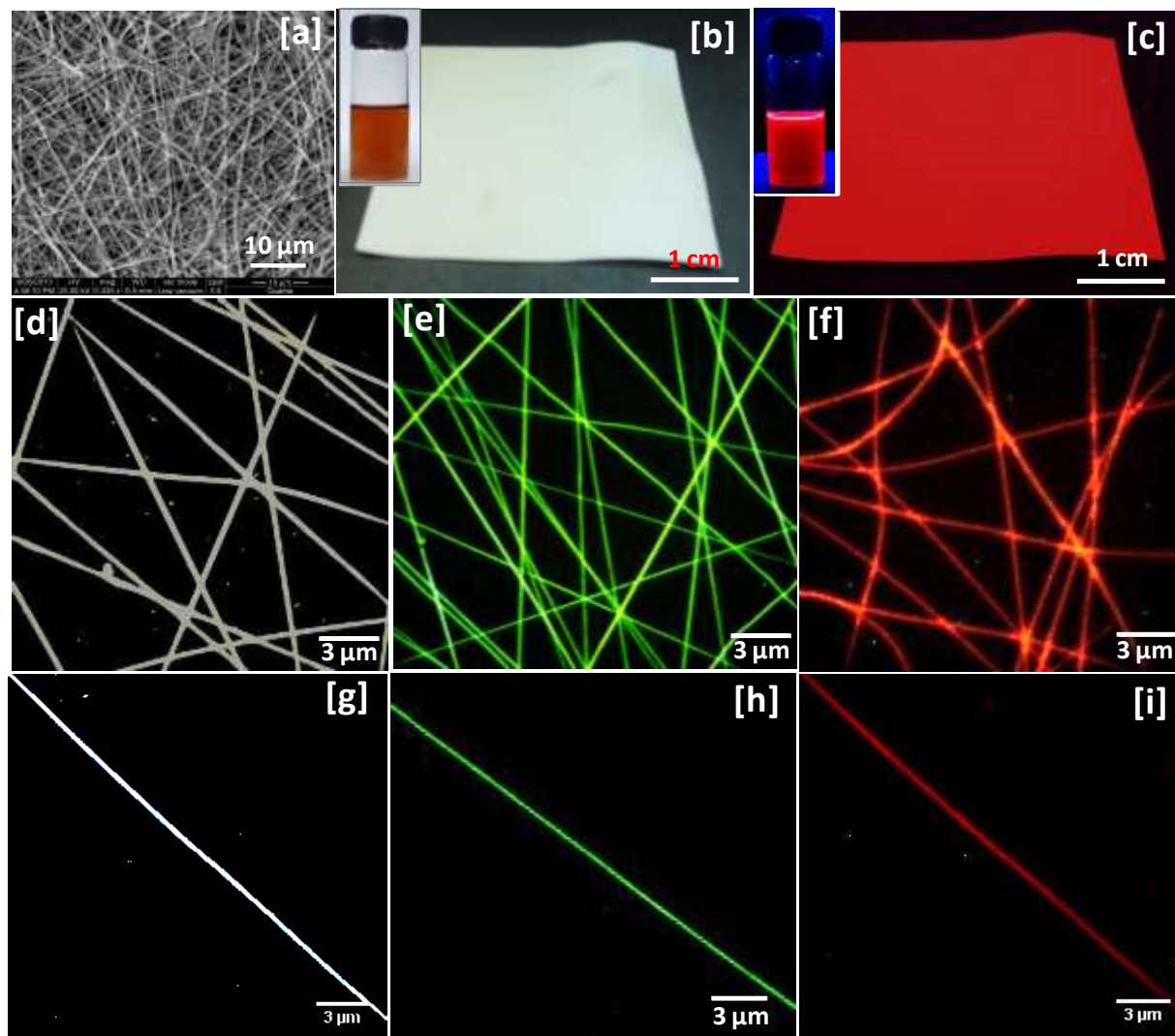


Cluster-based metal ion sensing

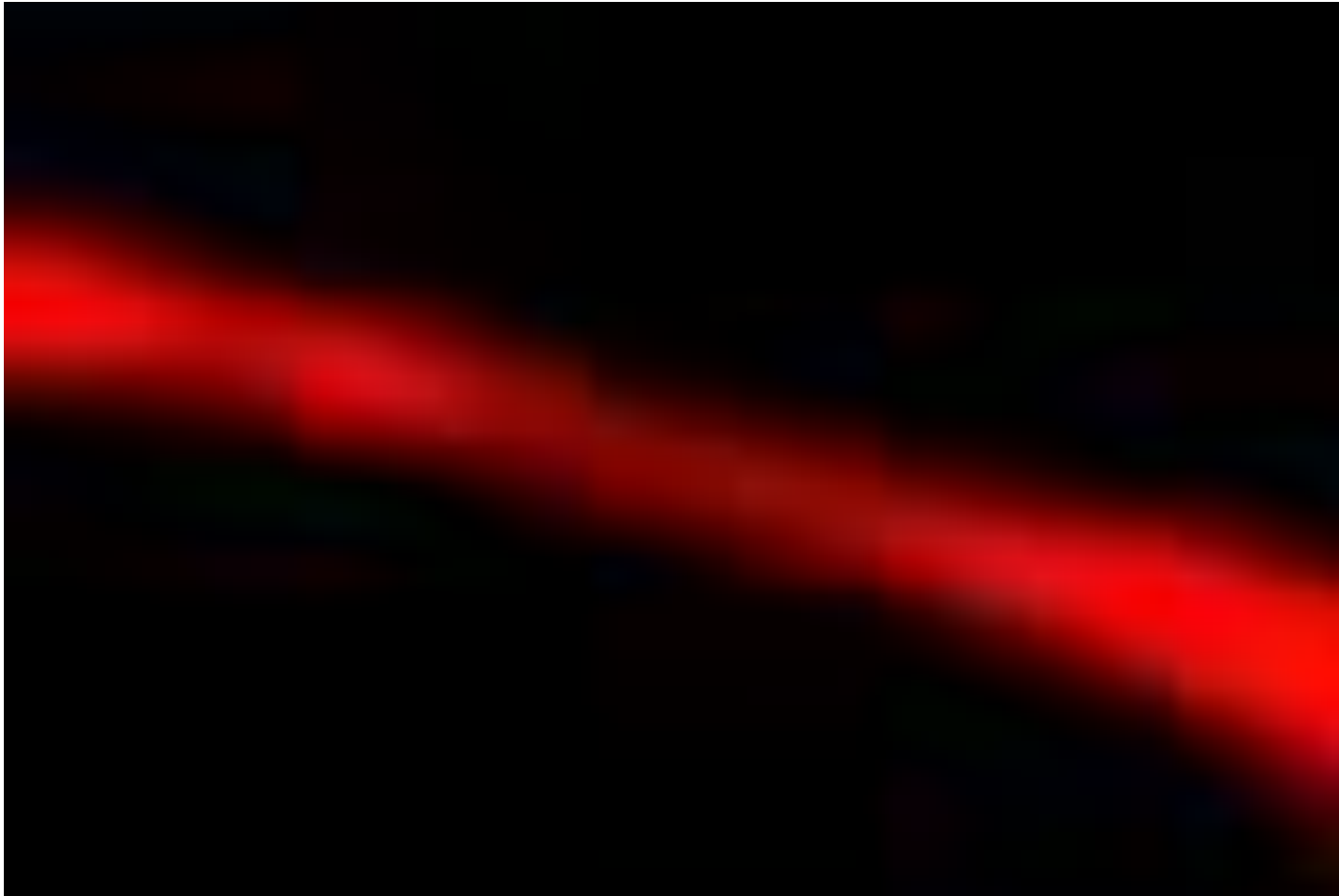


Decrease in the absorption of Au_{15} as a biofilm is dipped into the cluster solution. Inset: Free standing quantum cluster loaded film in visible light and UV light.

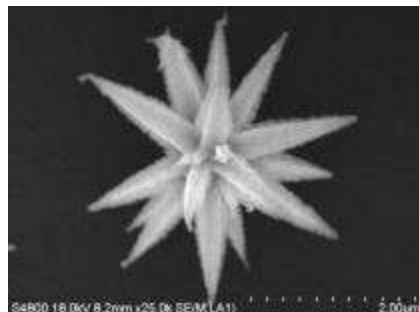
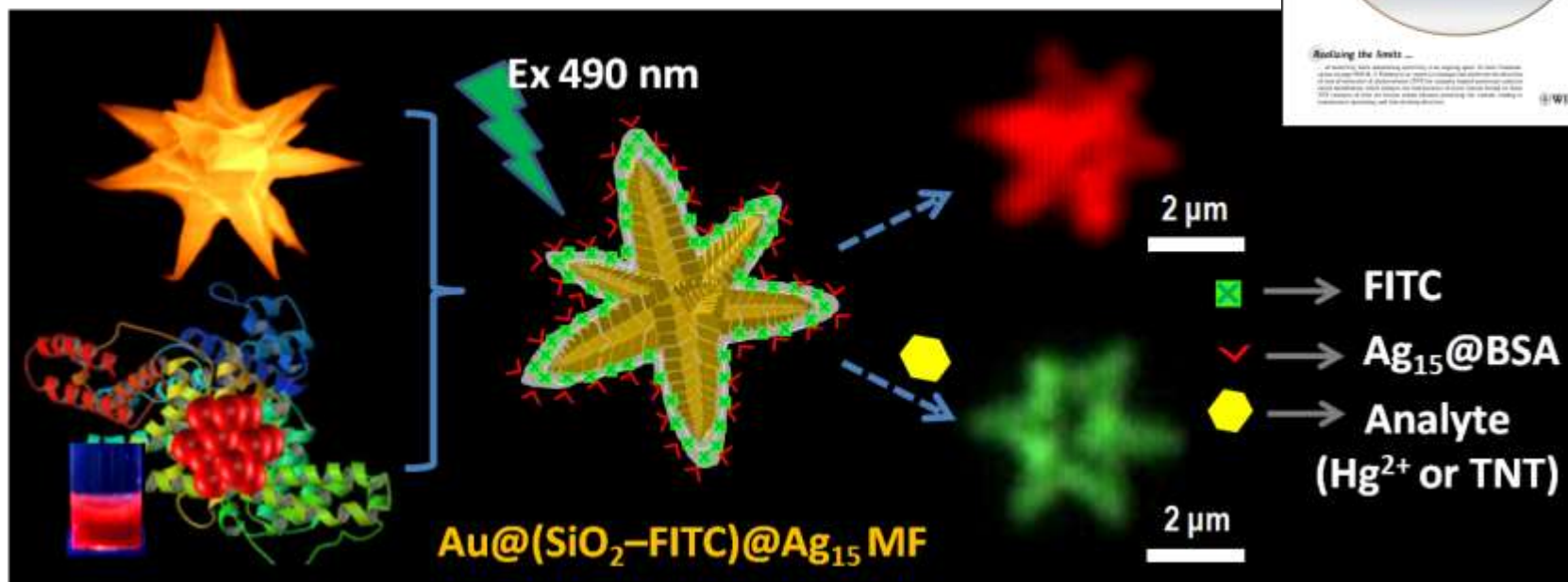
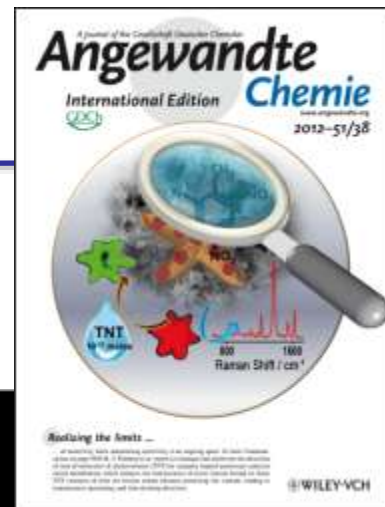
Approaching detection limits of tens of Hg^{2+}



Mercury quenching experiment using nanofiber



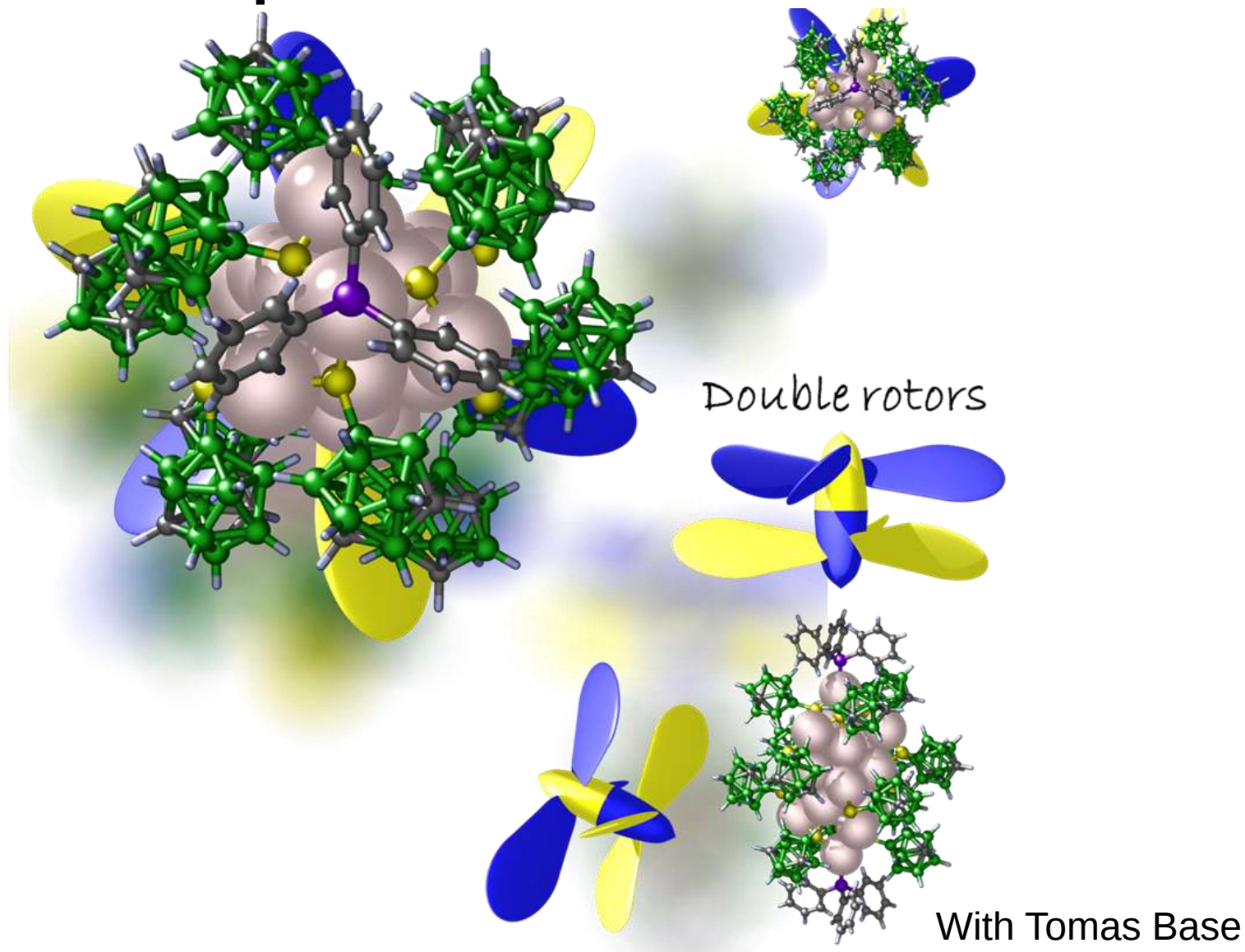
Sub-zeptomolar detection

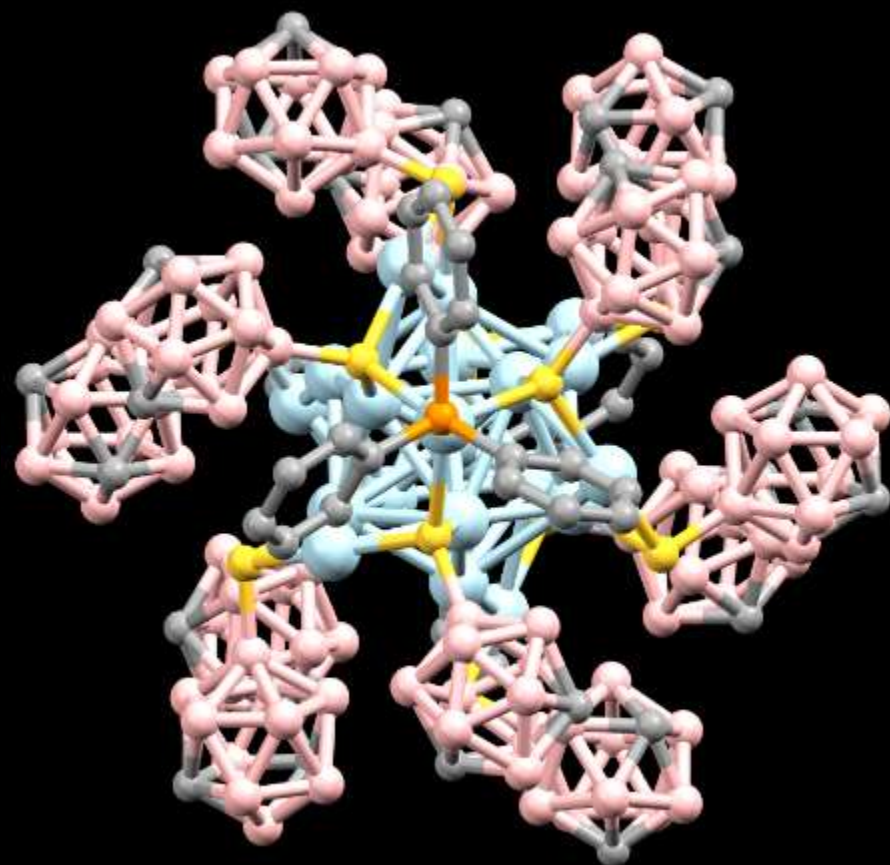
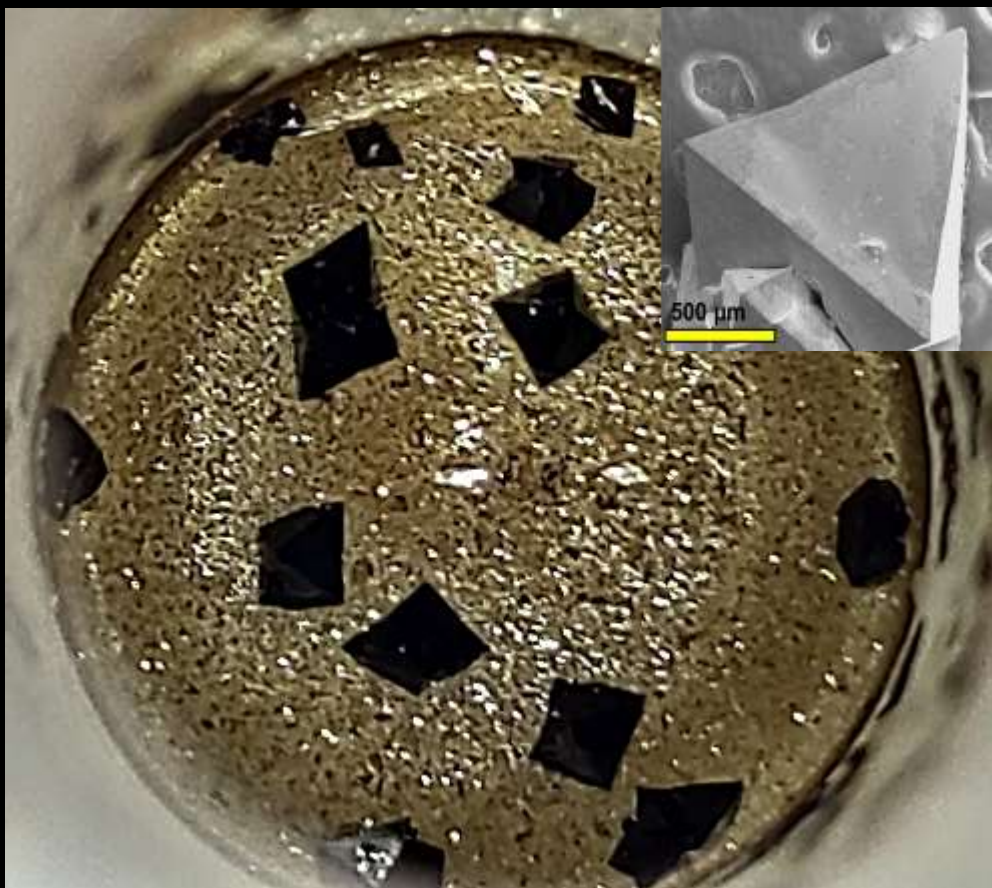


Featured in:
The Hindu, Telegraph, Times of India, etc.
C&E News
and many others

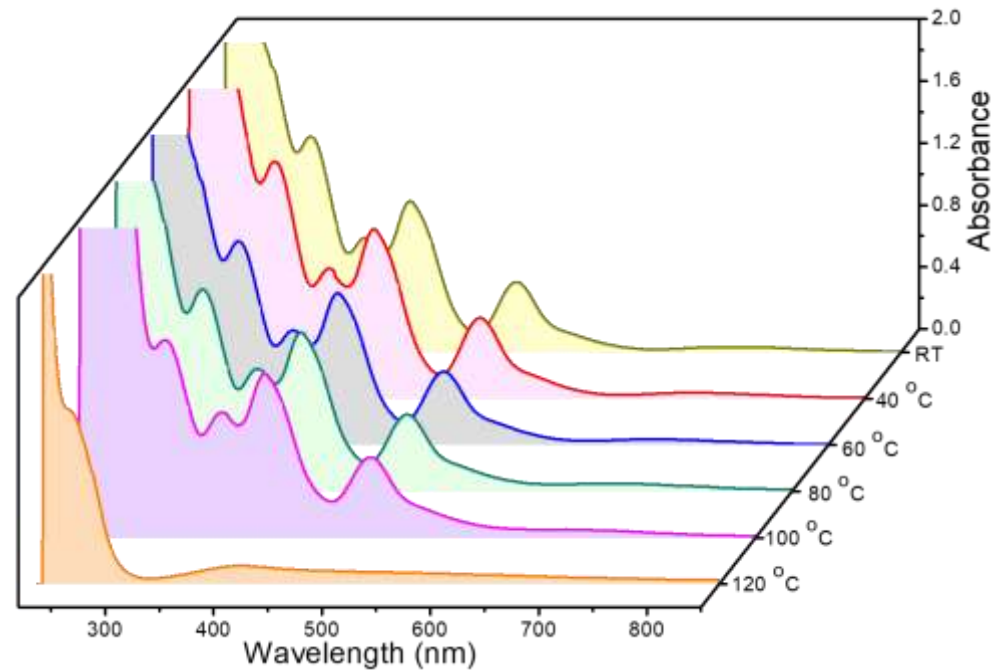
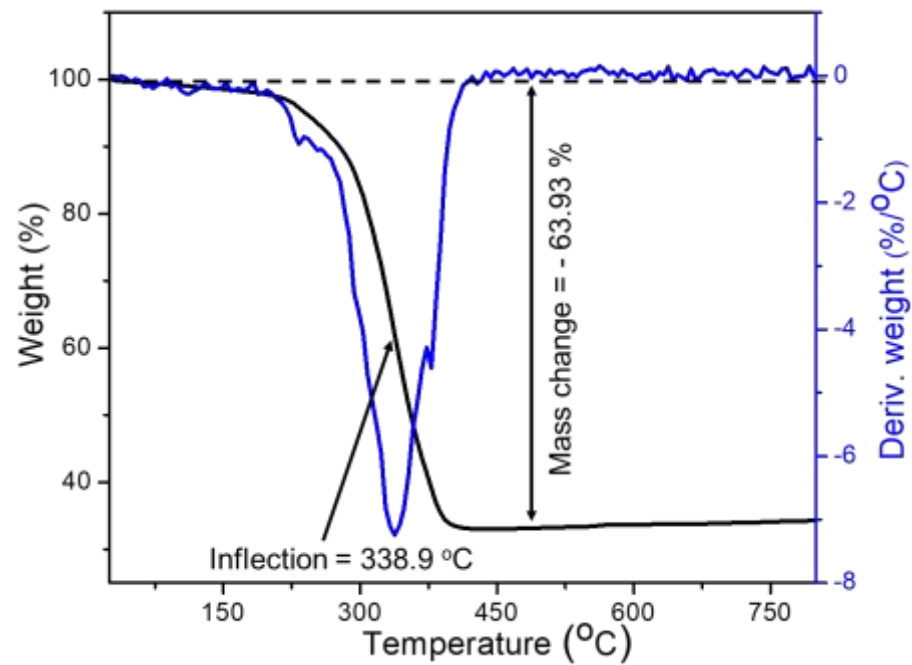
Ammu Mathew, et al. Angew. Chem. Int. Ed. 2012

Carborane-thiol protected silver nanomolecule

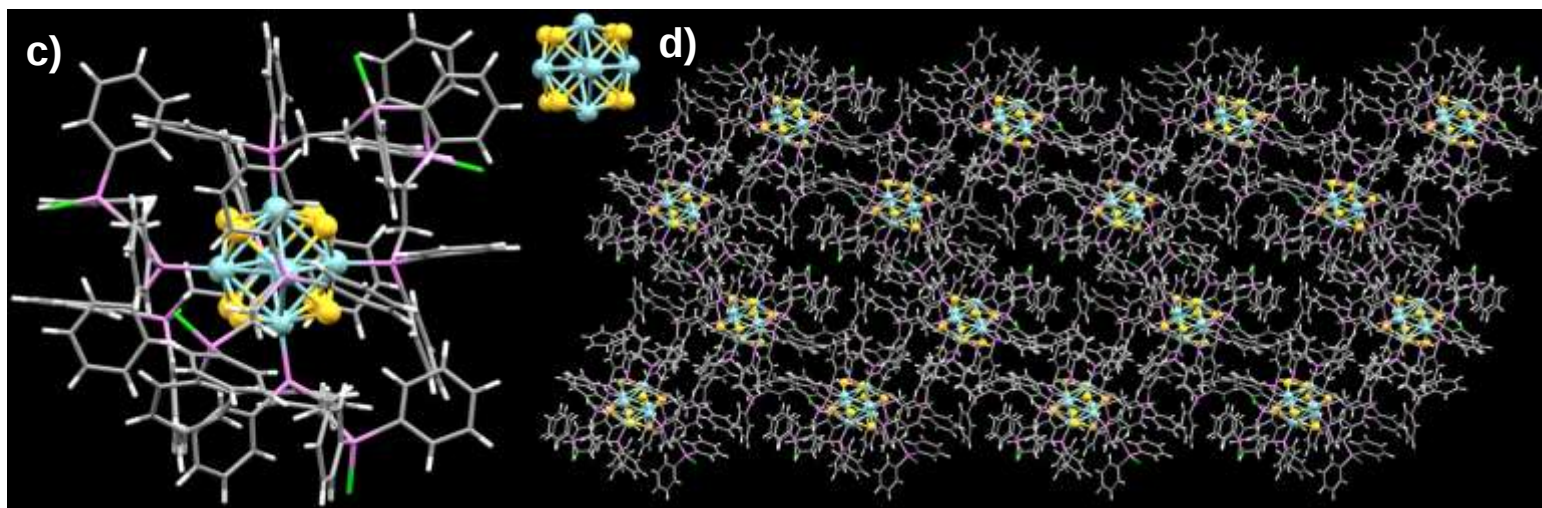
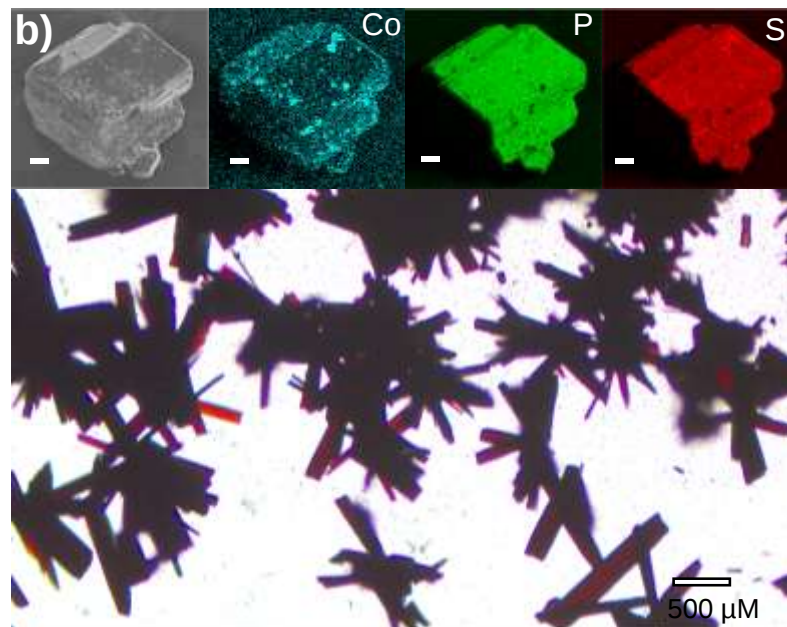
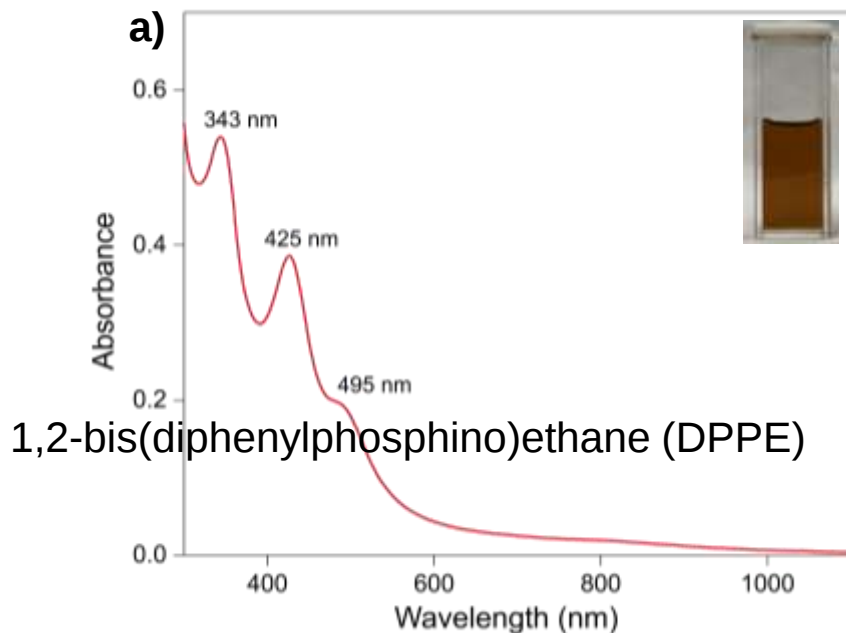




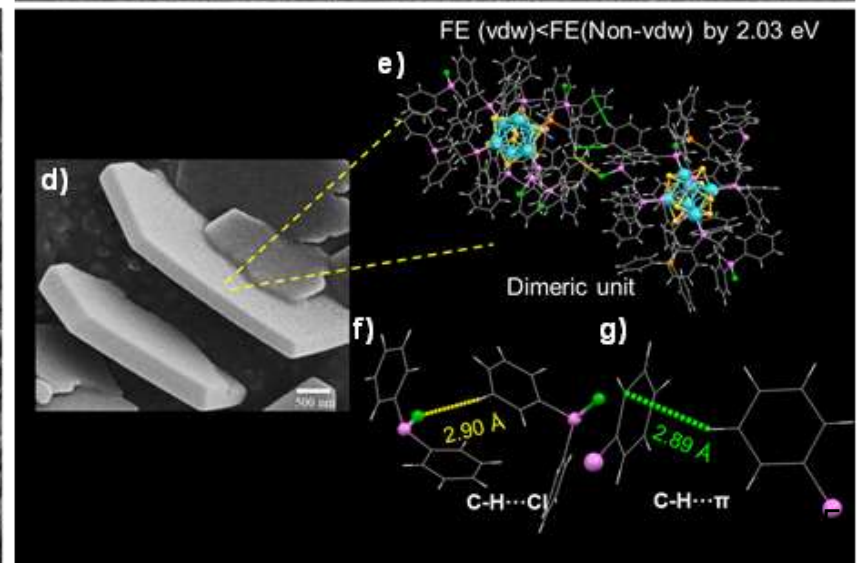
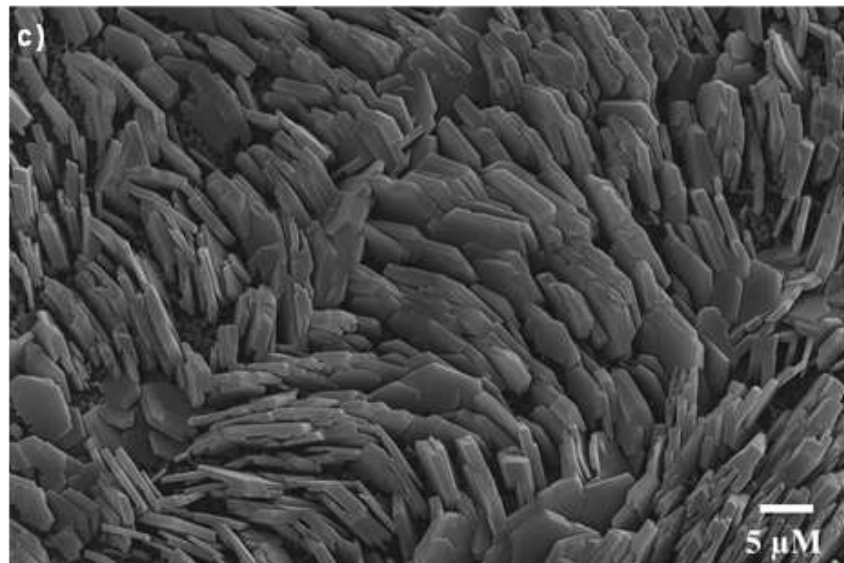
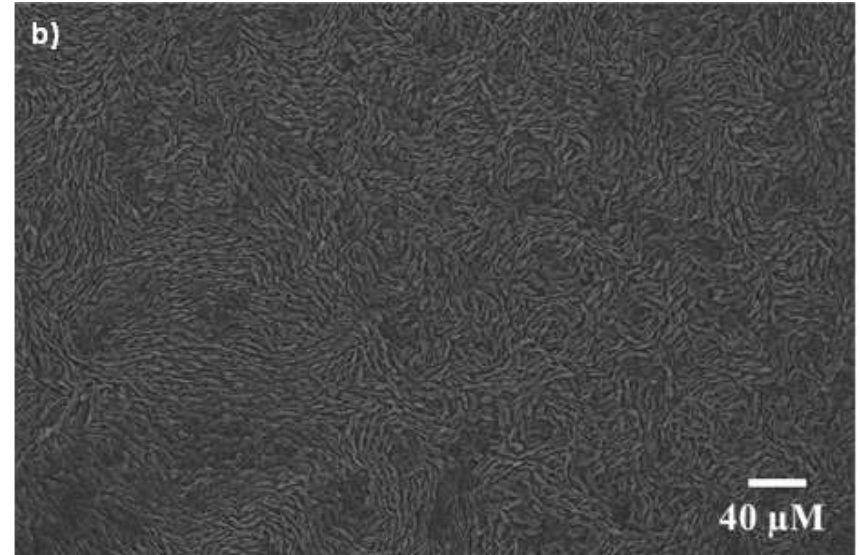
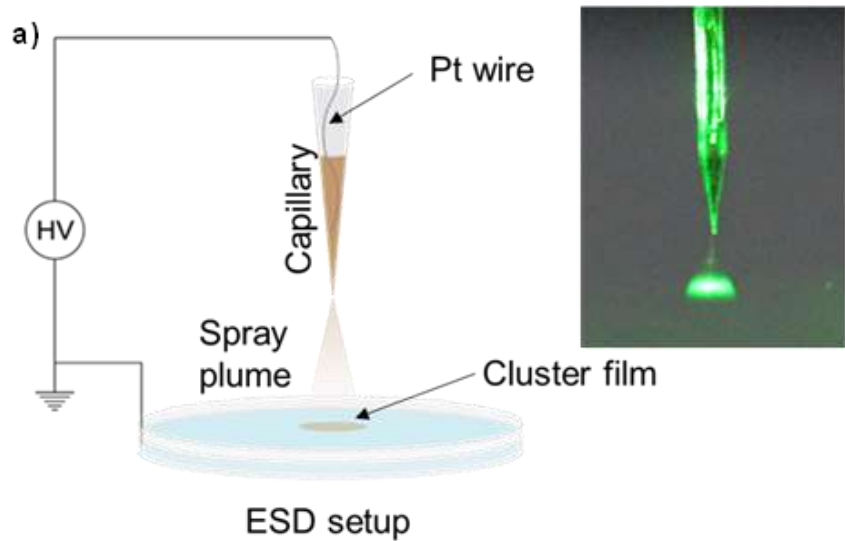
Thermal stability



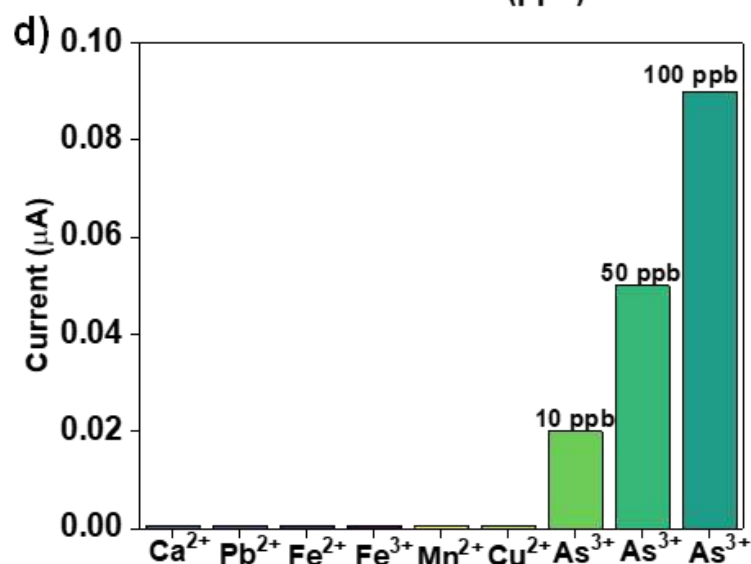
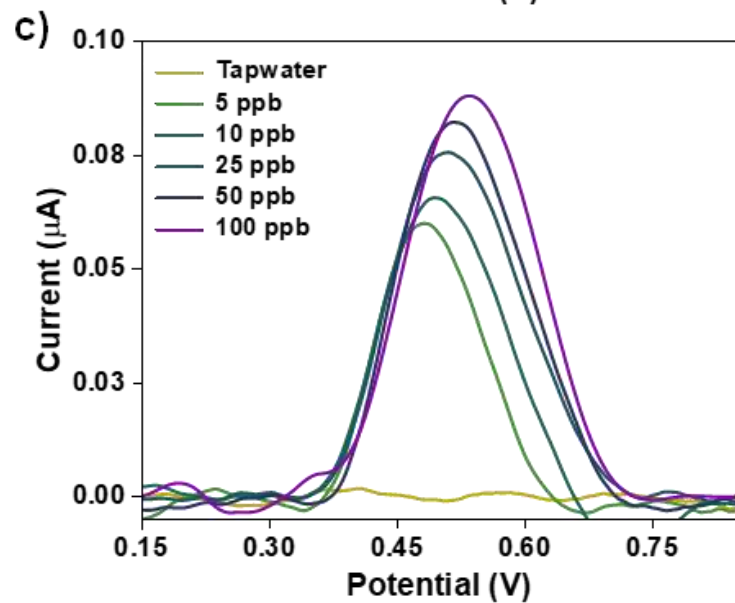
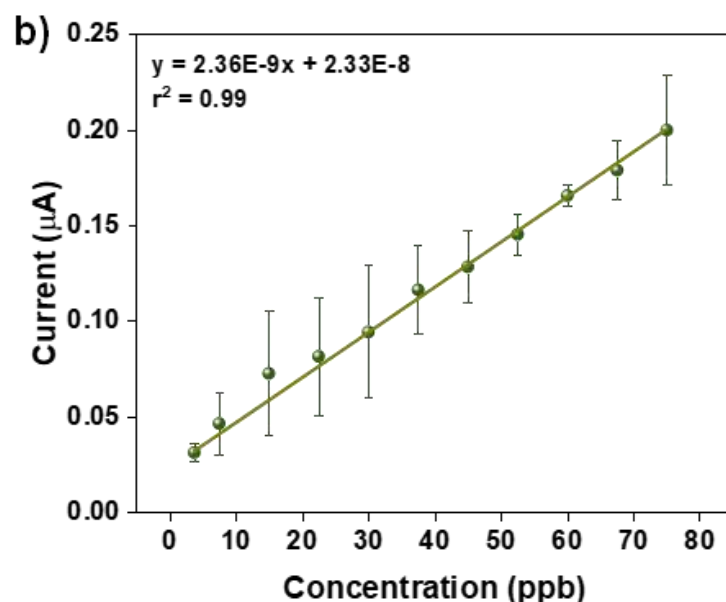
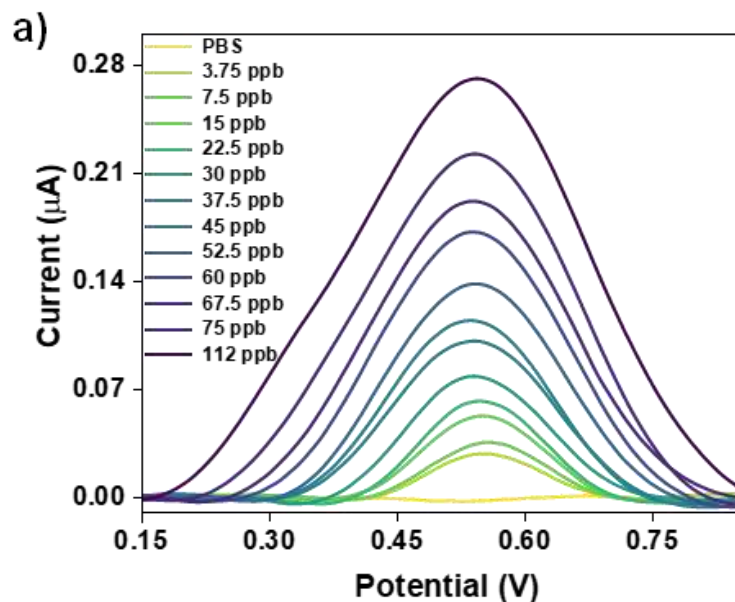
New electrodes - Aligned nanoplates of Co_6S_8



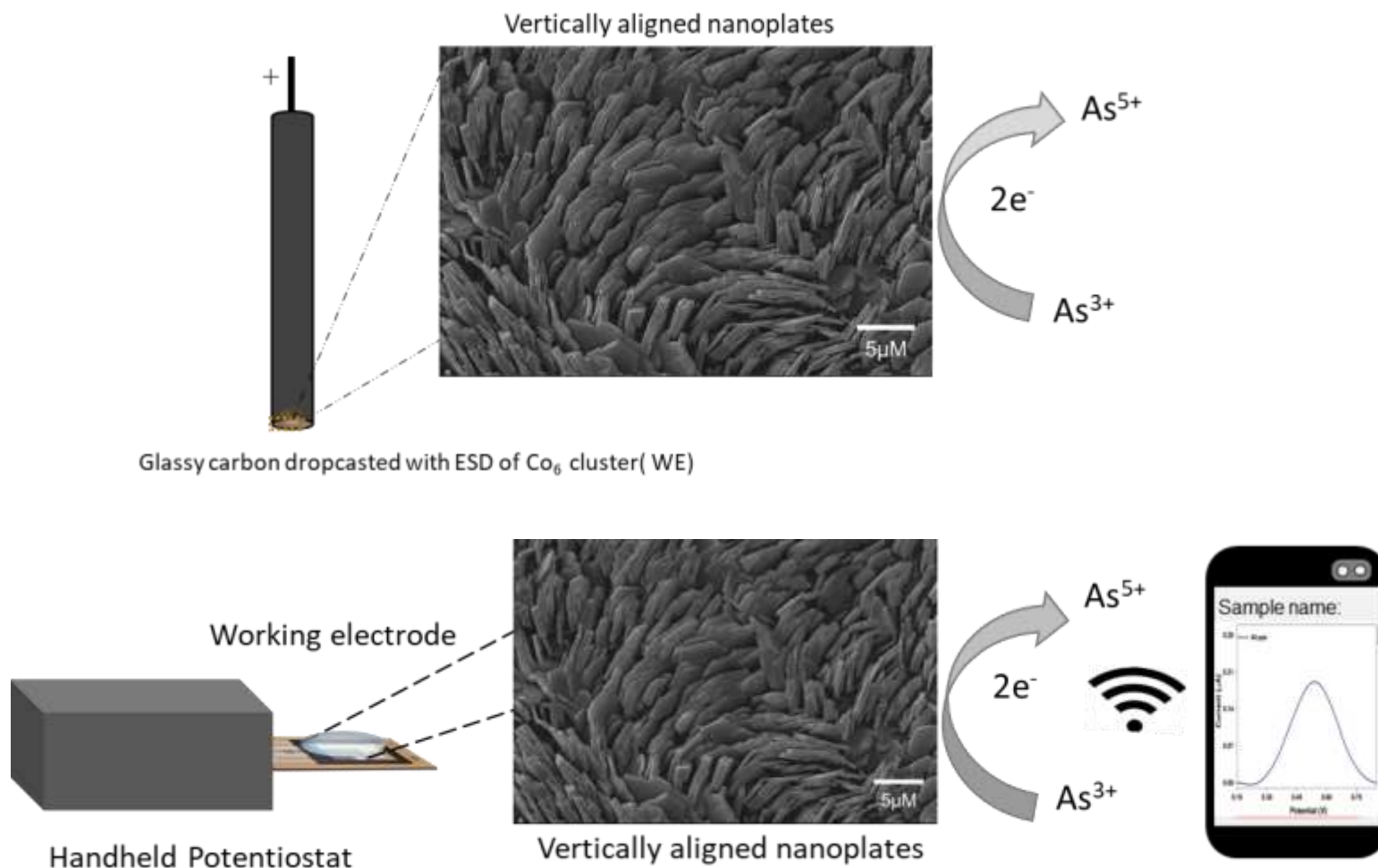
Electrospray deposition



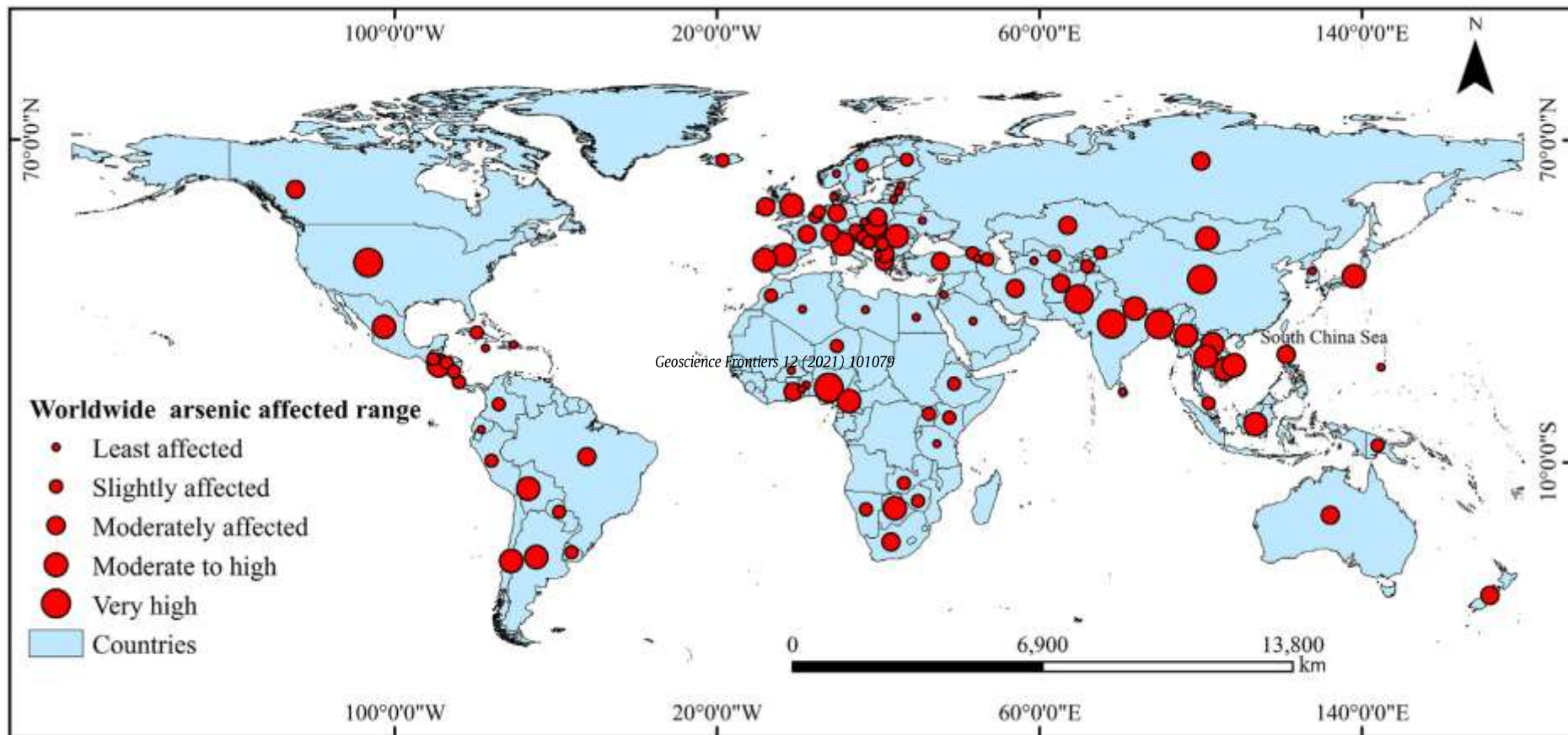
Sensing



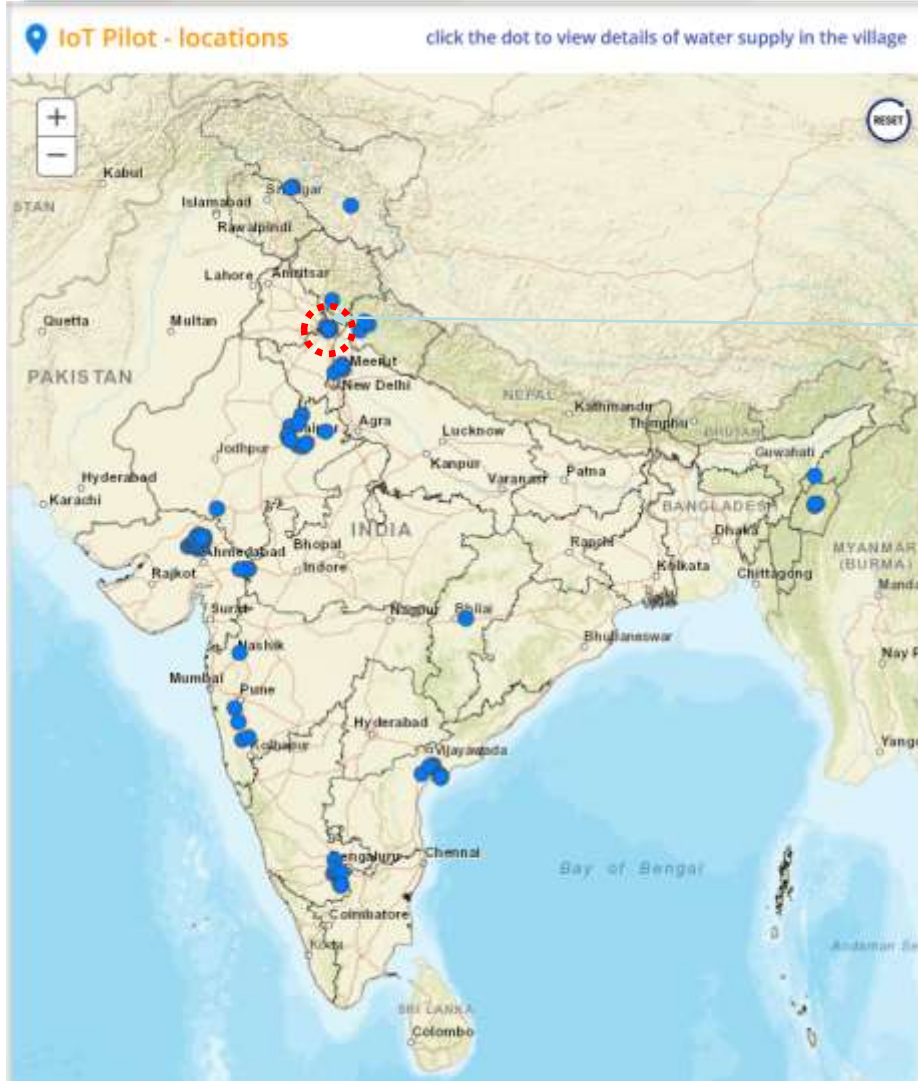
Working electrode



Arsenic poisoning across the world

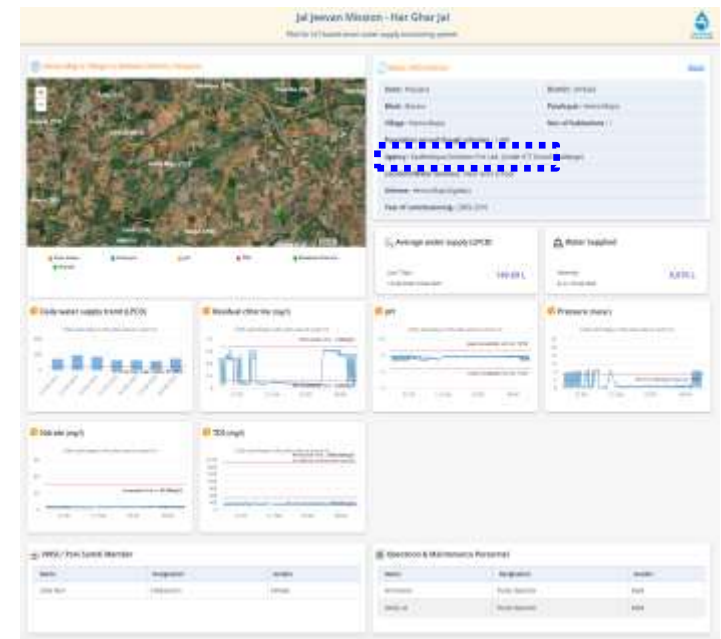


India's water is being monitored



IITM/IISc

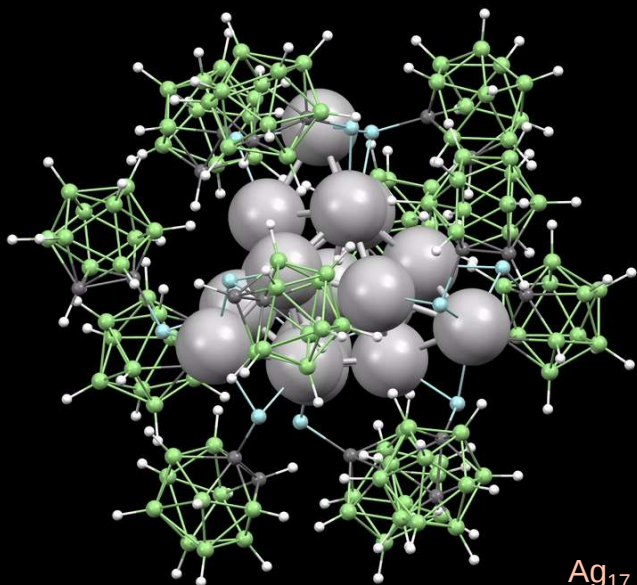
Installations made by four companies



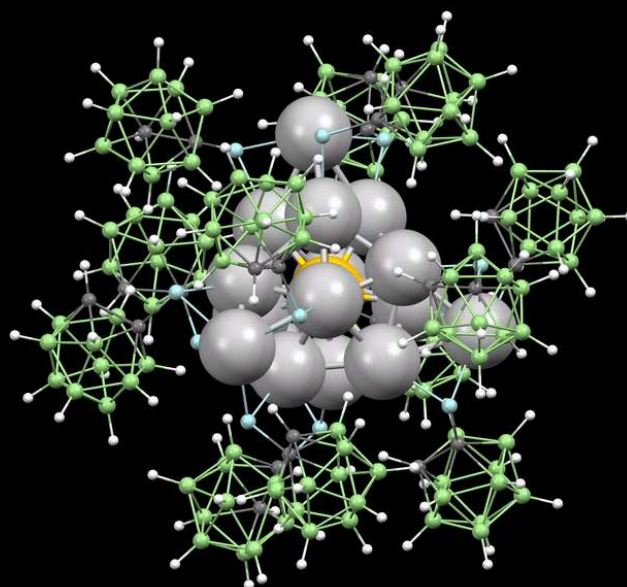


Vivek Yadav, et. al., *Nature Communications*, 2025

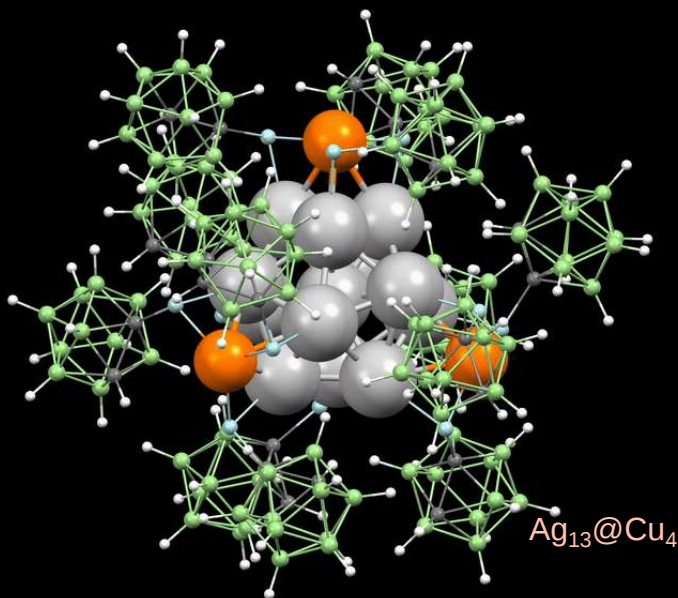
Structure of M_{17} Nanoclusters



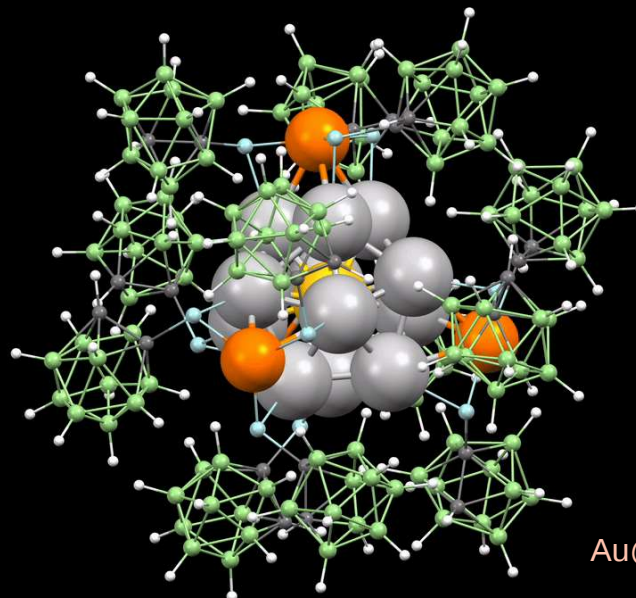
Ag_{17}



$Au@Ag_{16}$

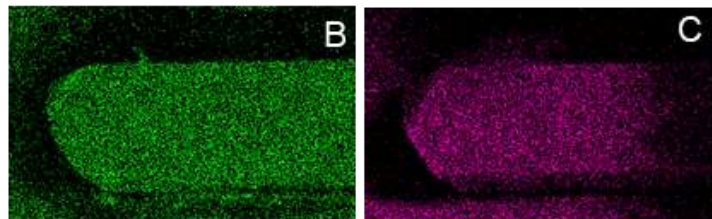
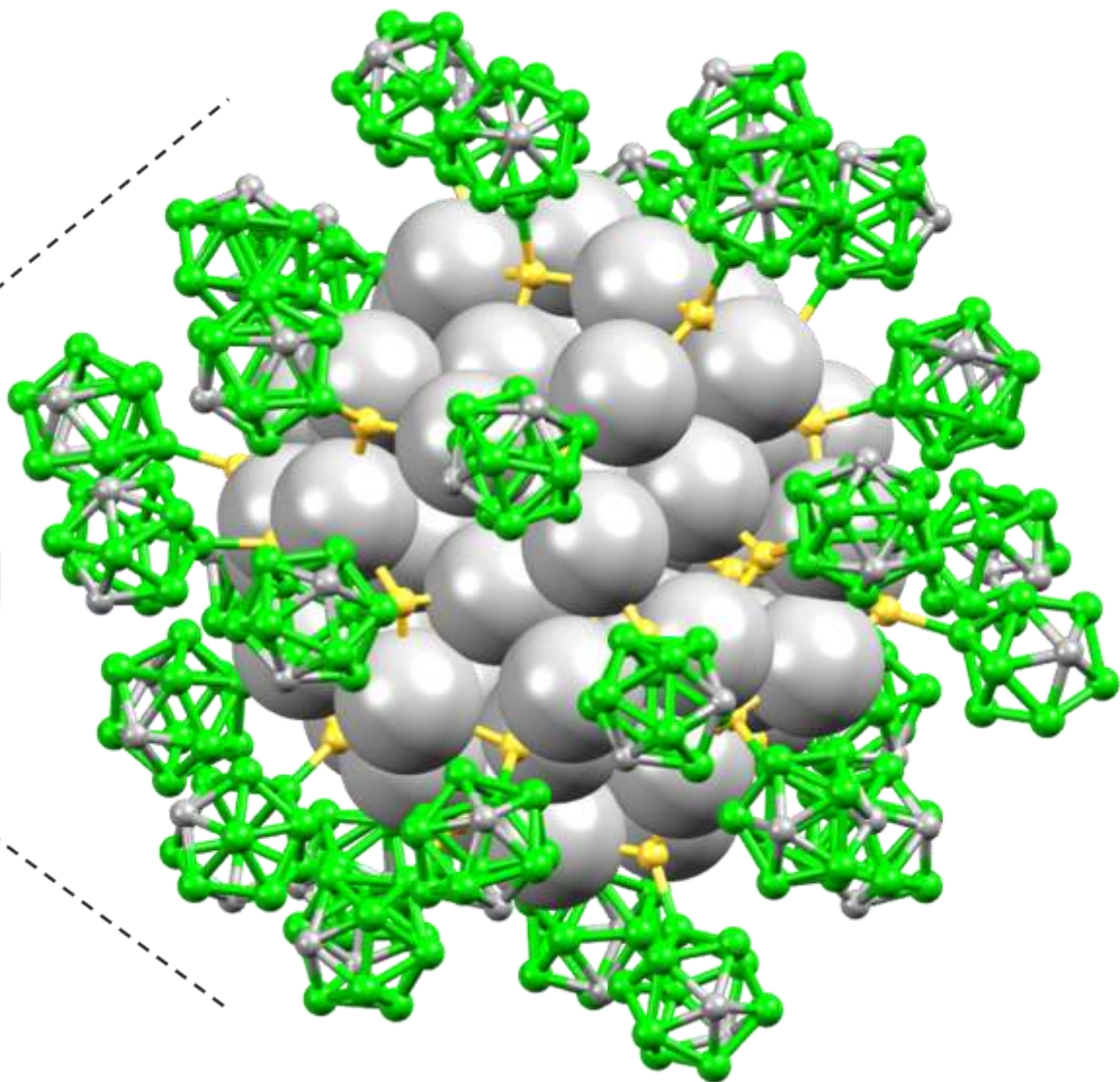
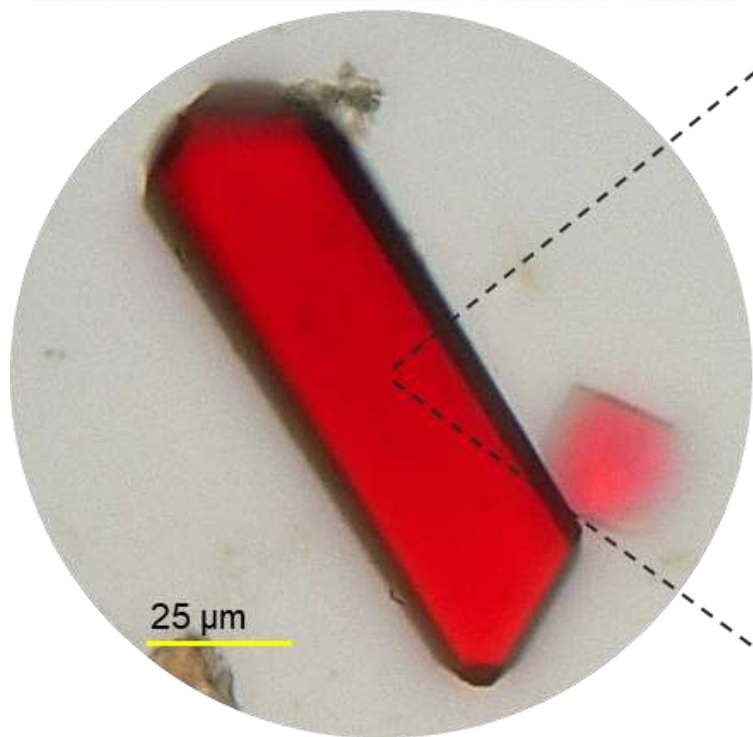
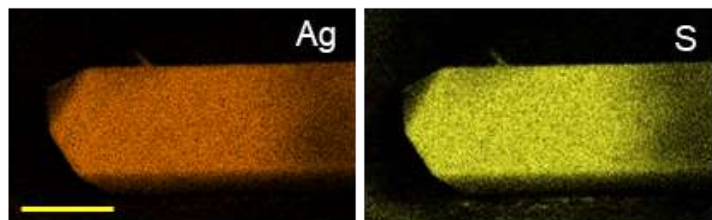


$Ag_{13}@Cu_4$



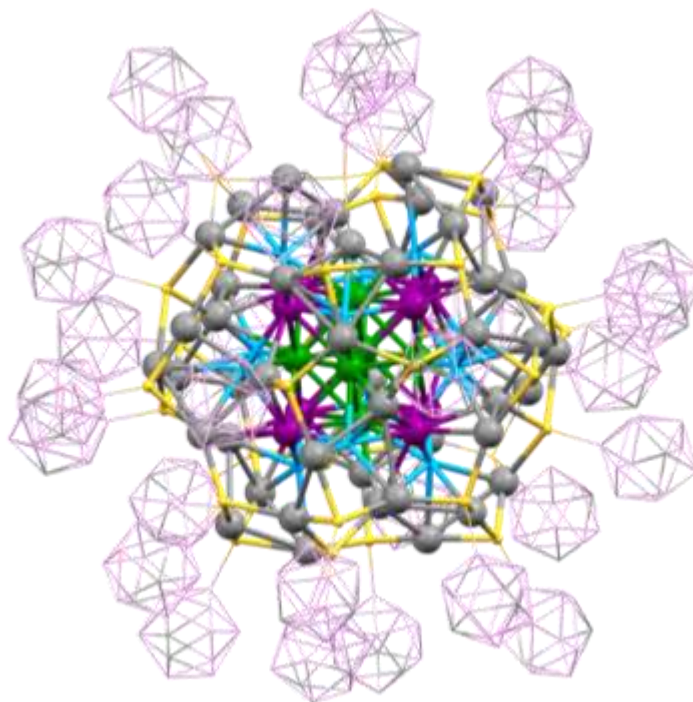
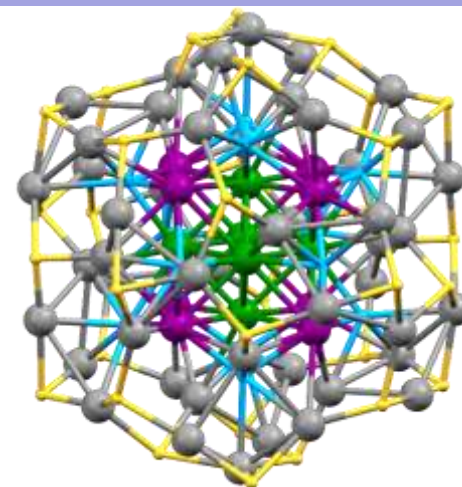
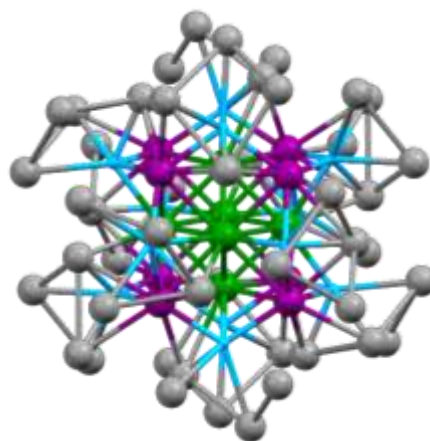
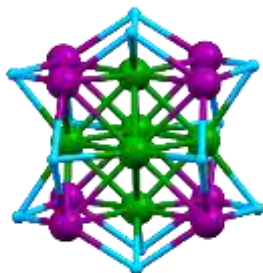
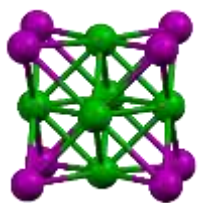
$Au@Ag_{12}@Cu_4$

$[Ag_{62}S_{12}(CBT)_{32}]$ Nanocluster

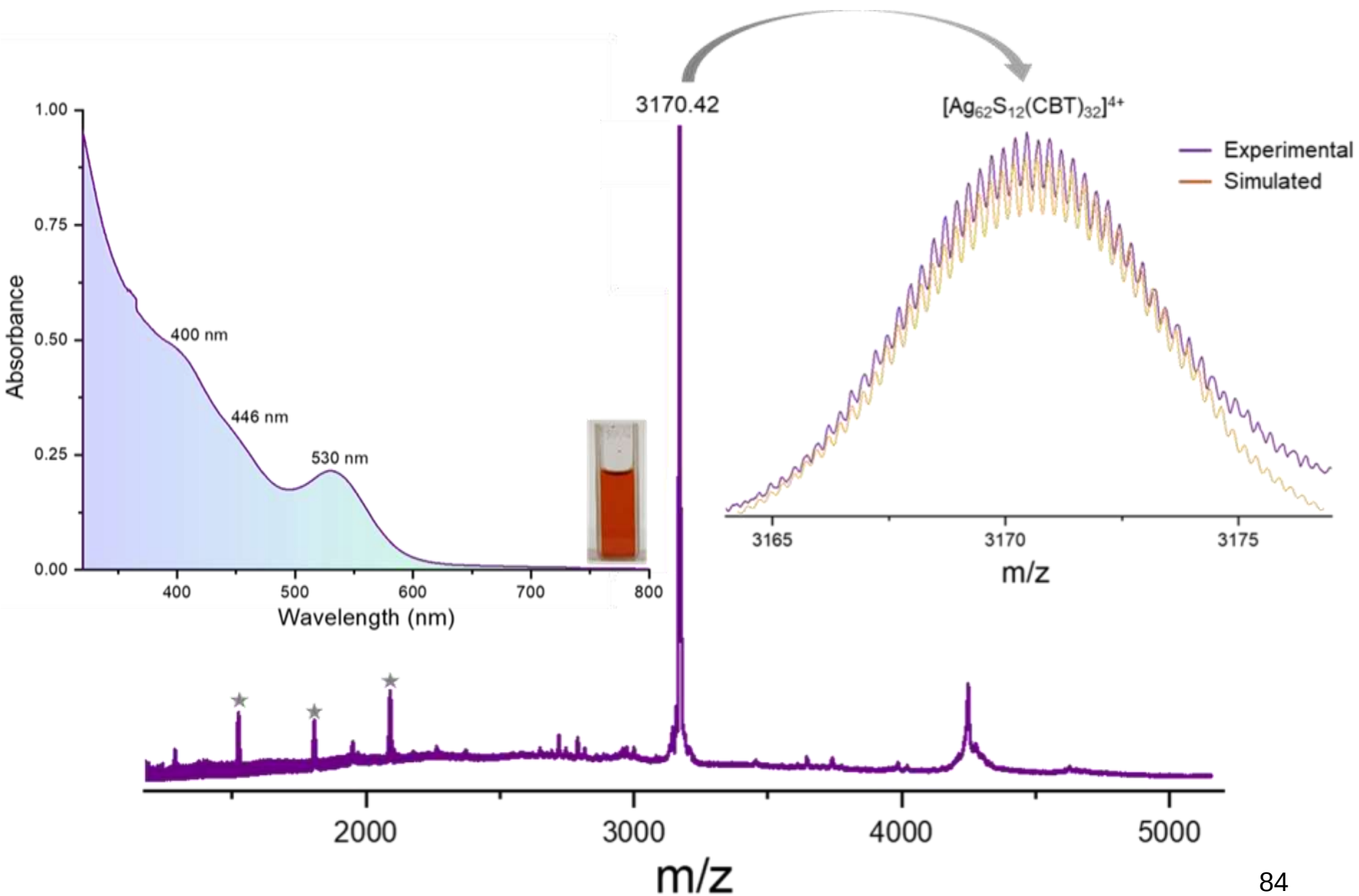


Largest molecule with carboranes so far....
82

Structural anatomy of $[\text{Ag}_{62}\text{S}_{12}(\text{CBT})_{32}]$ Nanocluster

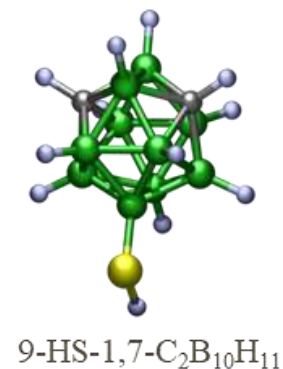
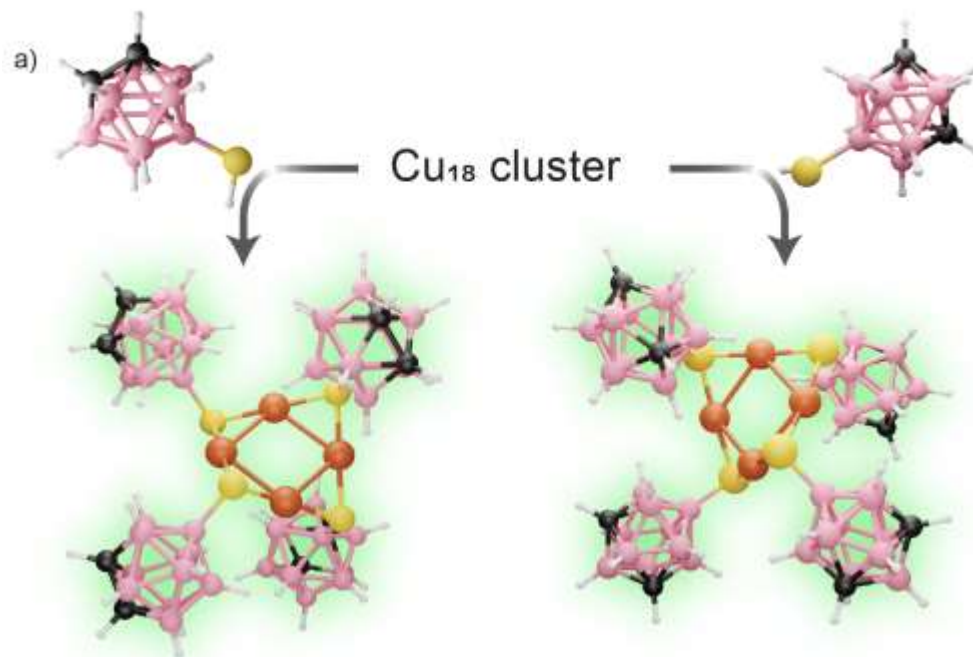
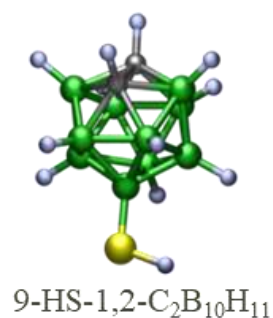


Characterization of Ag_{62} cluster

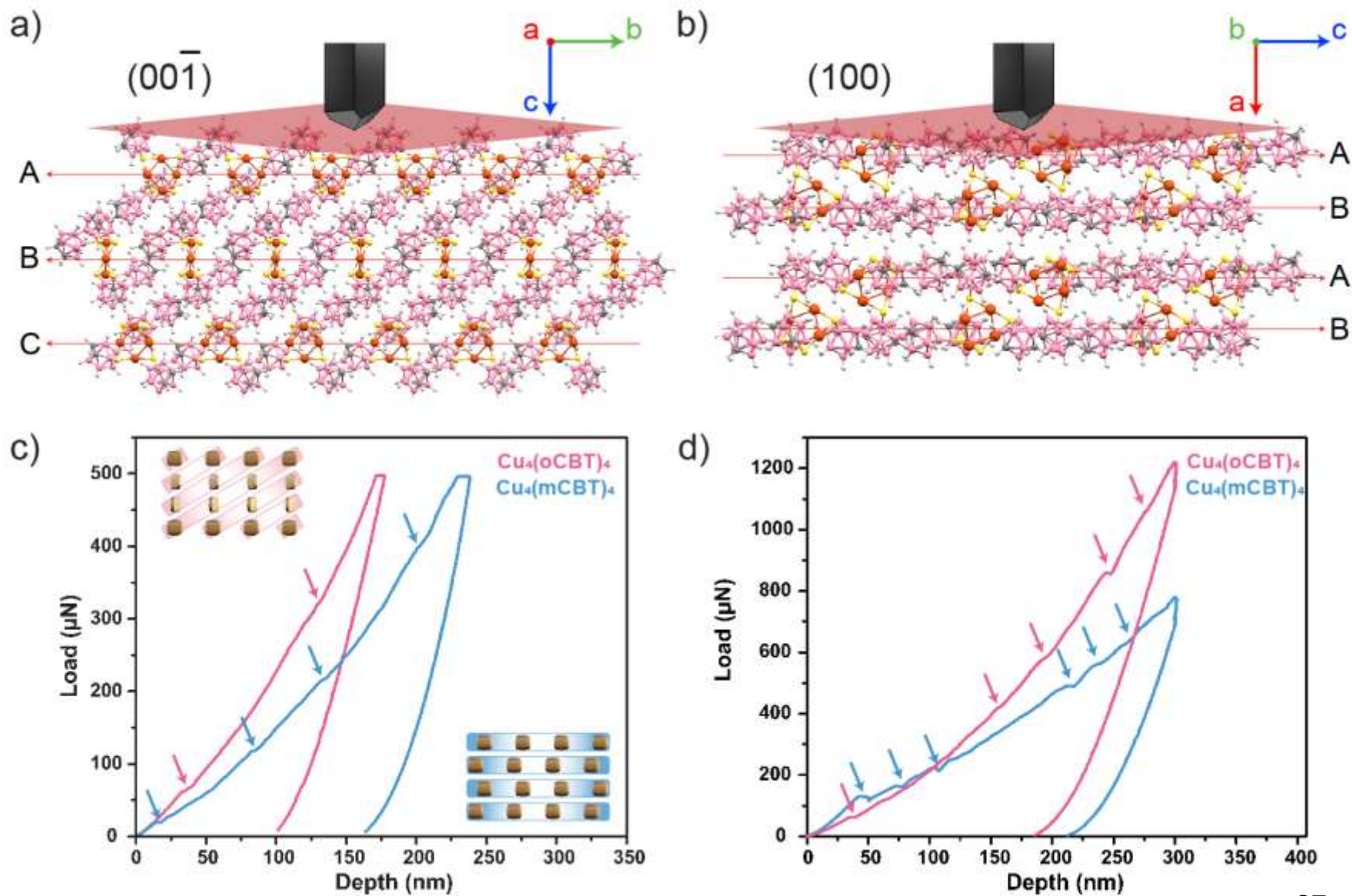


Properties

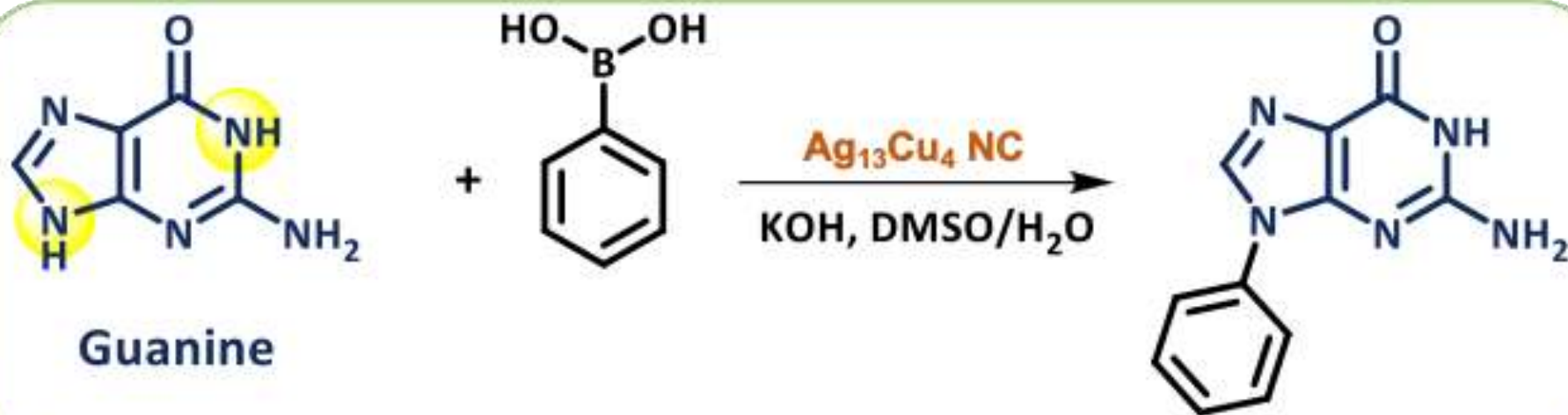
Nanomechanical Properties of Cu₄ Nanoclusters



Nanomechanical Properties of Cu_4 Nanoclusters

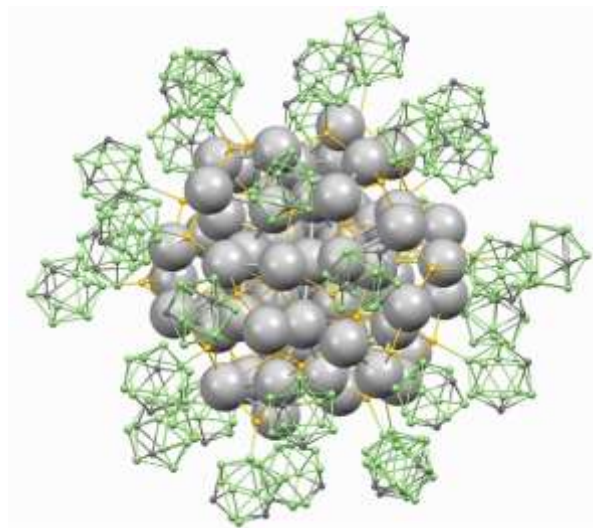
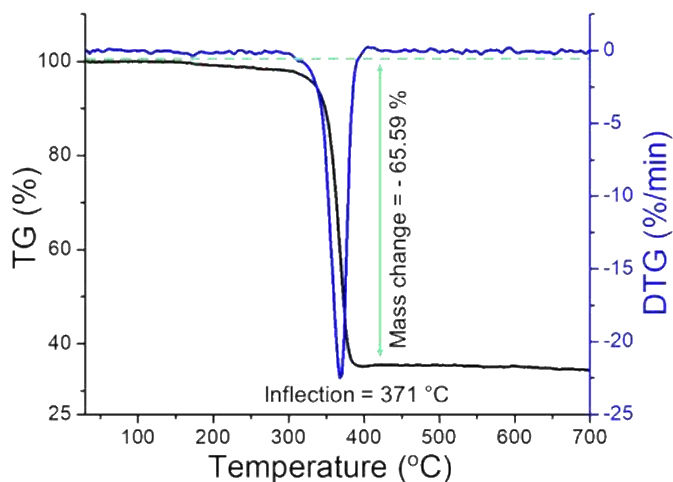


- ❖ Direct N⁹-arylation of Guanine with Phenylboronic Acid Catalyzed by Cu-doped Silver Nanocluster

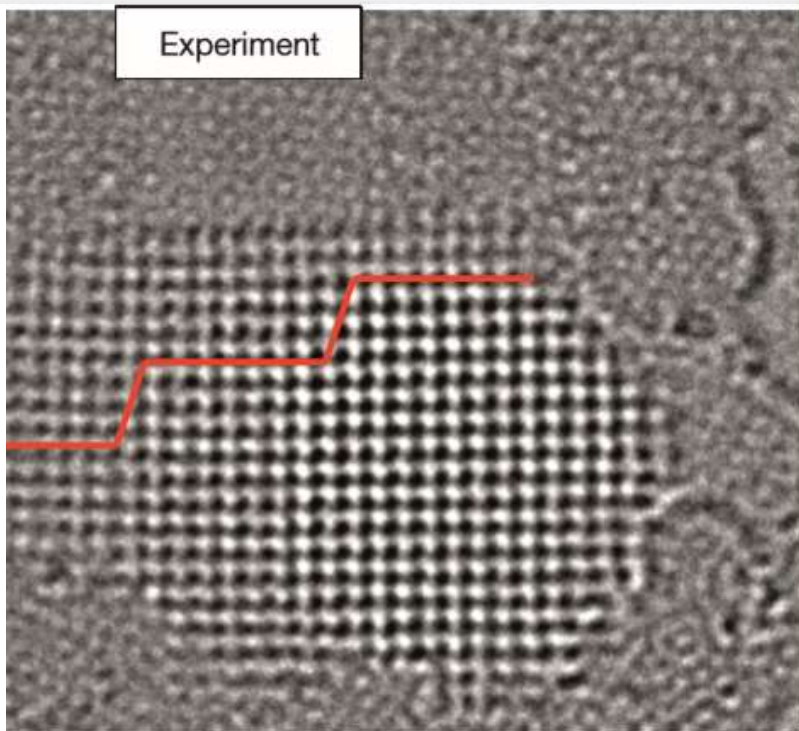


Summary

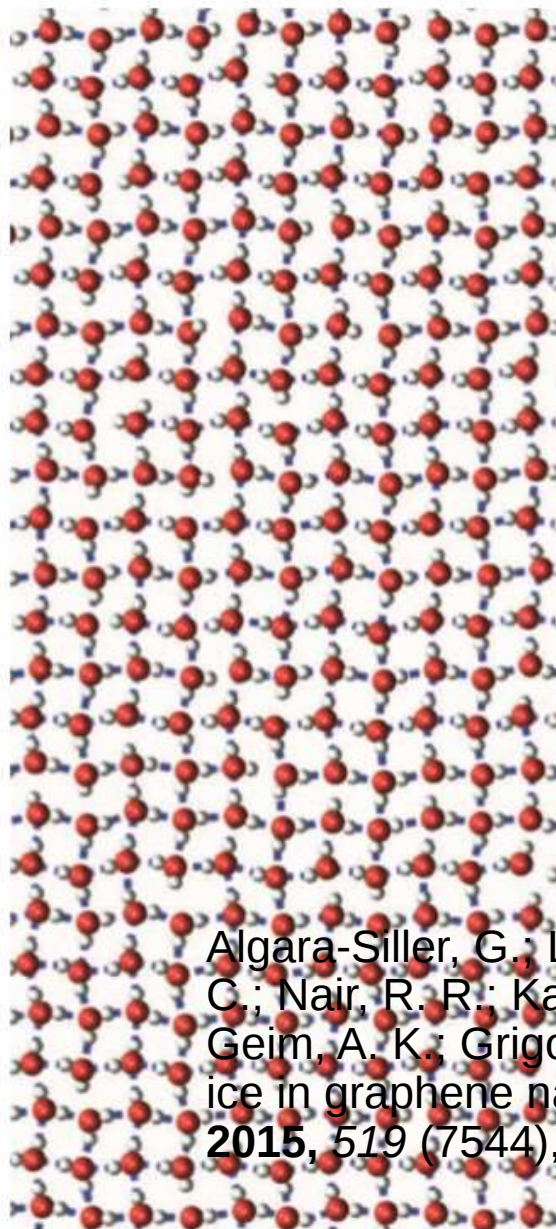
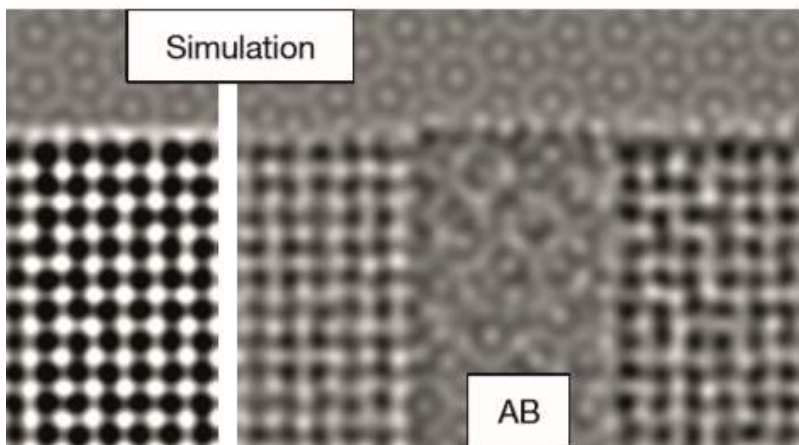
- Atomically precise clusters are a category of new materials
- They are molecules
- Clusters are thermally stable up to 400° C.
- They exhibit useful applications



Observing Molecules

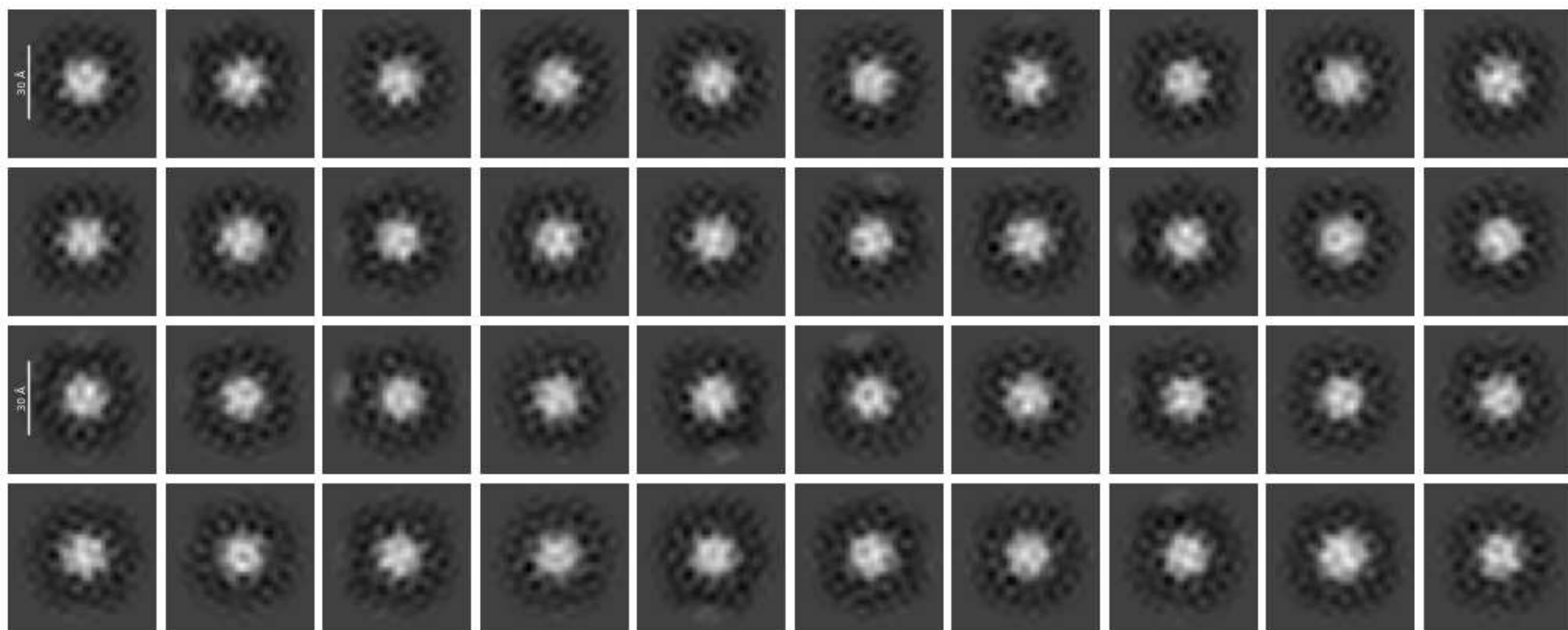


c



Algara-Siller, G.; Lehtinen, O.; Wang, F. C.; Nair, R. R.; Kaiser, U.; Wu, H. A.; Geim, A. K.; Grigorieva, I. V., Square ice in graphene nanocapillaries. *Nature* **2015**, 519 (7544), 443-445.



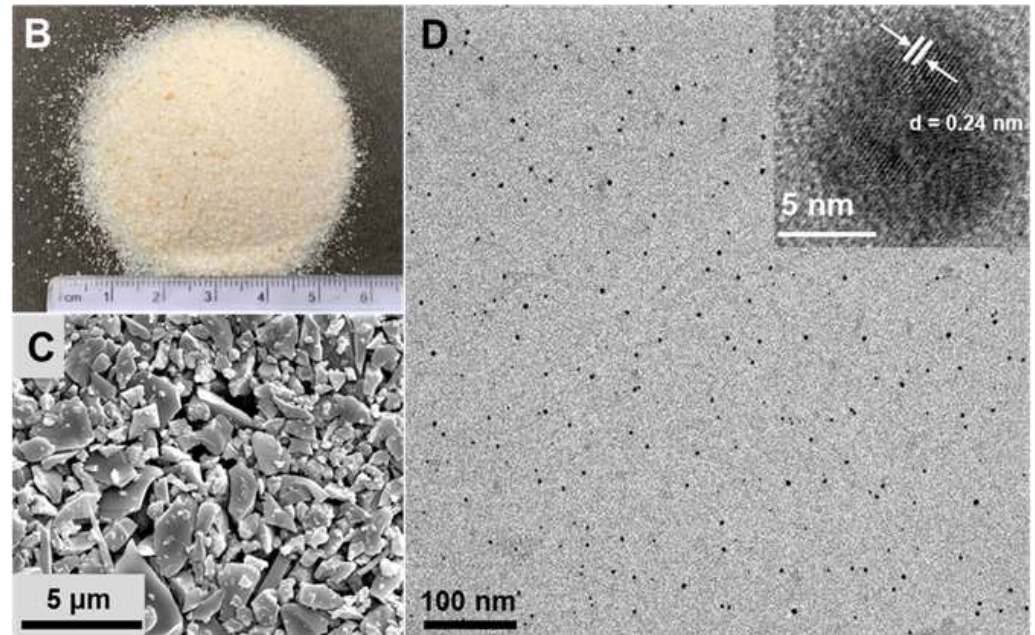
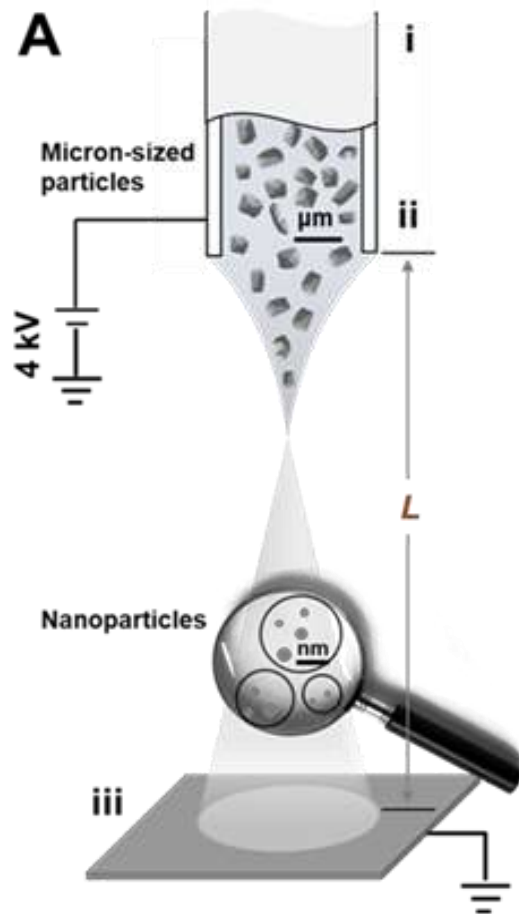


B. S. Sooraj, et. al. Unpublished

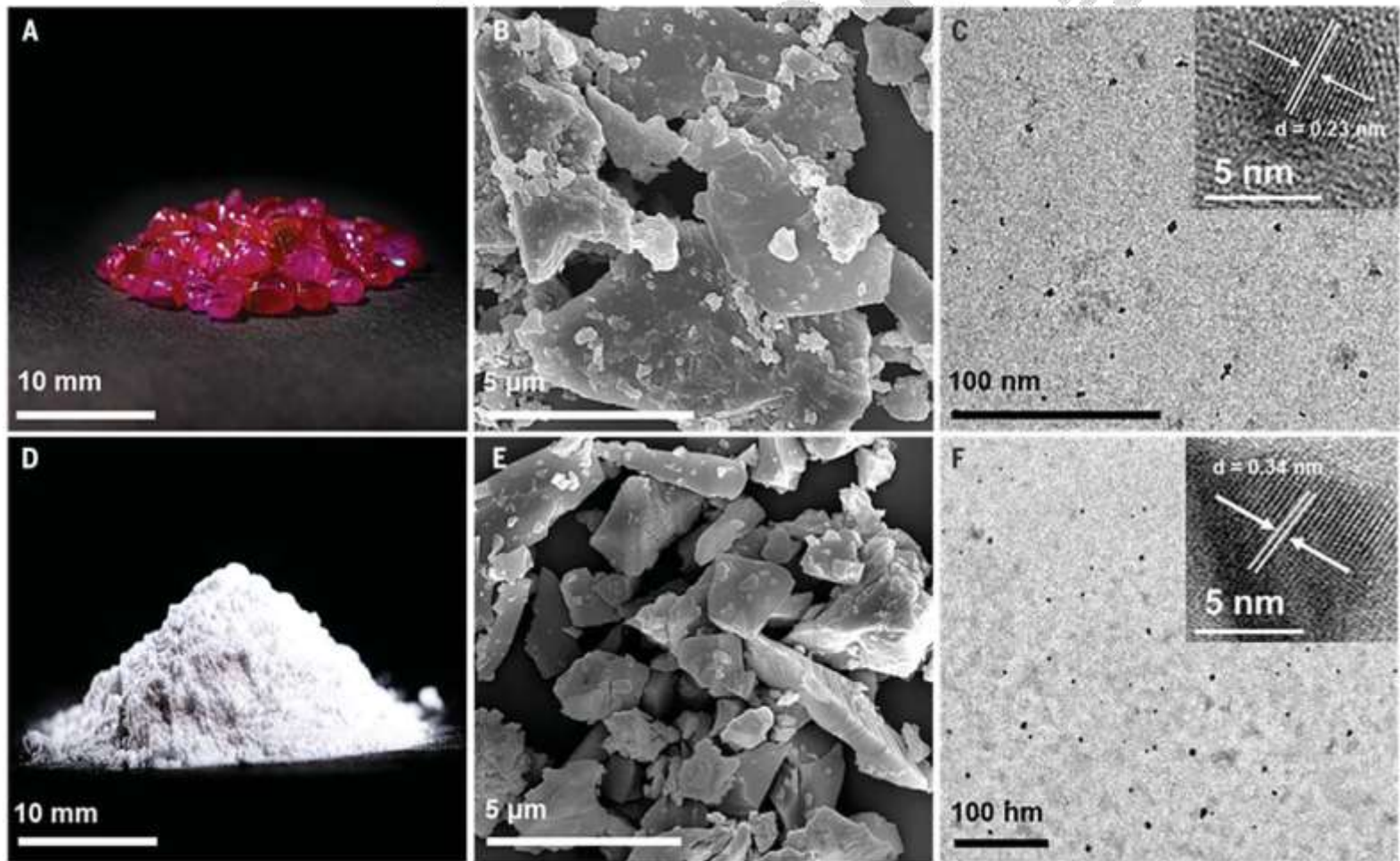
Weathering of Minerals in Microdroplets



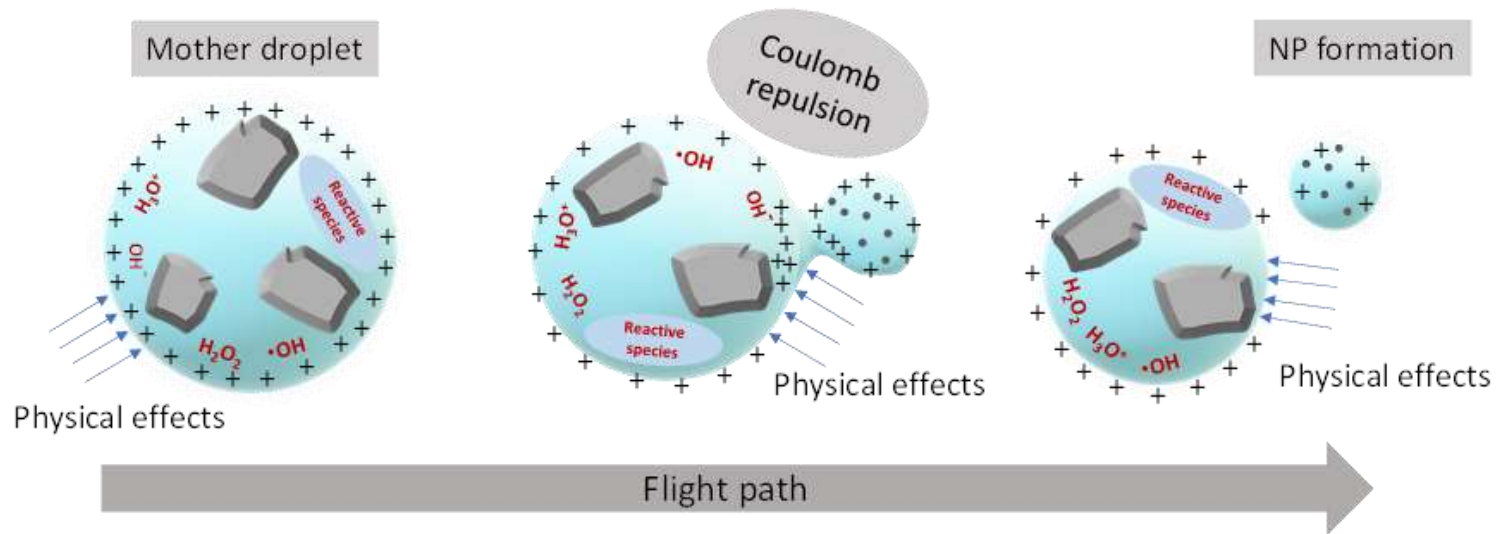
Spontaneous Weathering of Natural Minerals in Charged Water Microdroplets Forms Nanomaterials



Ruby, Fused Alumina



Mechanism of nanoparticle formation





PHISHING ALERT · GRC SPEAKERS AND DISCUSSION LEADERS ARE BEING TARGETED BY PHISHING ATTEMPTS DESIGNED TO COLLECT PAYMENT FOR REGISTRATION OR LOGGING.

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Atomically Precise Nanochemistry

Gordon Research Conference

Diversity, Symmetry and Functions of Molecular Materials

February 4 - 9, 2024

Chairs

Thalappil Pradeep and Stefanie S.
Dehnen

Vice Chairs

Stacy Copp and Hannu Häkkinen

Contact Chairs

Grand Galvez

2024 Seawall Boulevard
Galveston, Texas, United States

Venue and Travel Information

Conference Description

The Atomically Precise Nanochemistry GRC is a premier, international scientific conference focused on advancing the frontiers of science through the presentation of cutting-edge and unpublished research, prioritizing time for discussion after each talk and fostering informal interactions among scientists of all career stages. The conference program includes a diverse range of speakers

Conference Links

- » [Conference History](#)
- » [Atomically Precise Nanochemistry \(GRS\)](#)

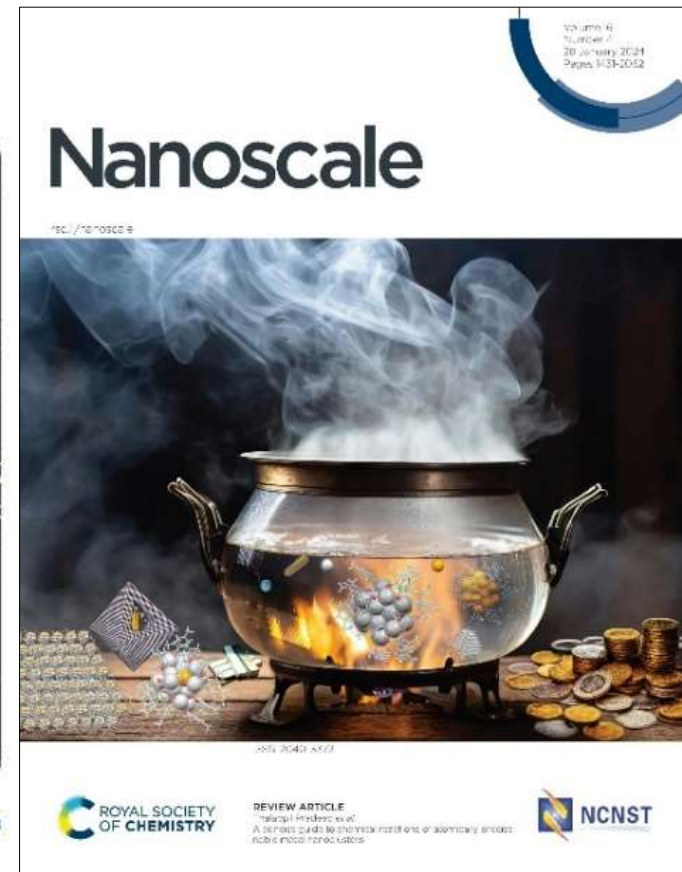
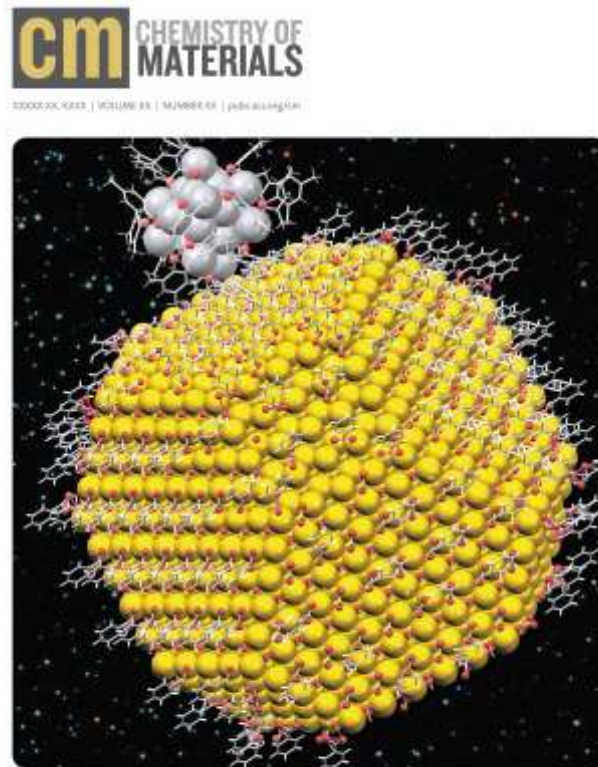
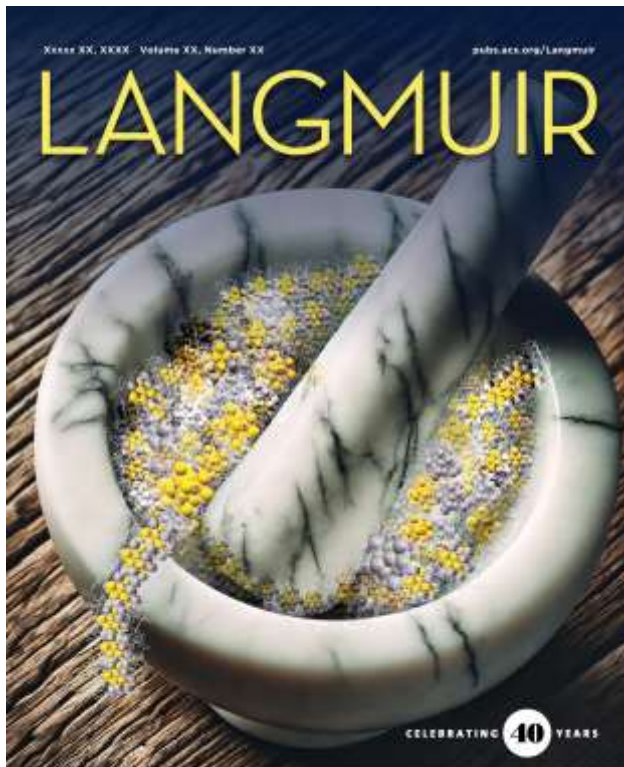


International Centre for Clean Water

People's Water Data



Affordable, inclusive, sustainable and contextual excellence



Department of Science and Technology

Institute of Eminence

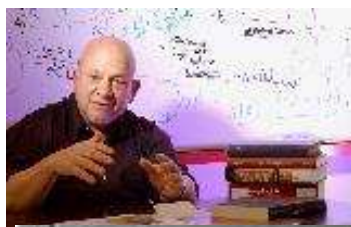
Many Outstanding Individuals



The AMRIT Team, 2013



Collaborators



Robin Ras

Nonappa

Tomas Base



Manfred Kappes

Olli Ikkala

Horst Hahn

Tatsuya Tsukuda
Keisaku Kimura
Yuichi Negishi
Uzi Landman
Hannu Hakkinen
Rob Whetten



Shiv Khanna

Biswarup Pathak K. V. Adarsh

G. U. Kulkarni

Vivek Polshettiwar

Water team at IIT: A. Sreekumaran Nair, Anshup, M. Udhaya Sankar, Amrita Chaudhary, Renjis T. Tom, T. S. Sreeprasad, Udayabhaskararao Thumu, M. S. Bootharaju, K. R. Krishnadas, Kalamesh Chaudhari, Soujit Sengupta, Depanjan Sarkar, Avijit Baidya, Swathy Jakka Ravindran, Abhijit Nag, S. Vidhya, Biswajit Mondal, Krishnan Swaminathan, Azhardin Gnayee, Sudhakar Chennu, A. Suganya, Rabiul Islam, Sritama Mukherjee, Tanvi Gupte, Jenifer Shantha Kumar, A. Anil Kumar, Ankit Nagar, Ramesh Kumar Soni, Tanmayaa Nayak, Sonali Seth, Shihabudheen M. Maliyekkal, G. Velmurugan, Wakeel Ahmed Dar, Ganapati Natarajan, N. Pugazhenthiran, A. Leelavathi, Sahaja Aigal, S. Gayathri, Bibhuti Bhusan Rath, Ananthu Mahendranath, Harsh Dave, Erik Mobegi, Egor Moses, Hemanta R. Naik, Sourav Kanti Jana, Tanmayaa Nayak, Sonali Seth...

Avula Anil Kumar, Chennu Sudhakar, Sritama Mukherjee, Anshup, and Mohan Udhaya Sankar

Funding: Department of Science and Technology, Government of India

Start-ups and partners:

PhD Theses: Bindhu Varughese, M. R. Resmi, M. Venkataramanan, N. Sandhyarani, R. Selvan, A. Sreekumaran Nair, M. J. Rosemary, Renjis T. Tom, C. Subramaniam, Jobin Cyriac, V. R. Rajeev Kumar, D. M. David Jeba Singh, Akshaya Kumar Samal, E. S. Shibu, M. A. Habeeb Muhammed, P. R. Sajanlal, T. S. Sreeprasad, J. Purushothaman, T. Udayabhaskararao, M. S. Bootharaju, Soumabha Bag, Robin John, Kamalesh Chaudhari, Ammu Mathew, Indranath Chakraborty, Radha Gobinda Bhuin, Ananya Baksi, Amitava Srimony, Anirban Som, Rabin Rajan Methikkalam, K. R. Krishnadas, Soujit Sengupta, Depanjan Sarkar, Atanu Ghosh, Rahul Narayanan, Avijit Baidya, Shridevi Bhat, Papri Chakraborty, Swathy Jakka Ravindran, C. K. Manju, Abhijit Nag, S. Vidhya, Jyoti Sarita Mohanty, Debasmita Ghosh, Jyotirmoy Ghosh, Md. Bodiuzzaman, Biswajit Mondal, Tripti Ahuja, Esma Khatun, Krishnan Swaminathan, K. S. Sugi, Amrita Chakraborty, Sudhakar Chennu, Sritama Mukherjee, Madhuri Jash, Sandeep Bose, Md. Rabiul Islam, Pallab Basuri, Mohd Azhardin Ganayee, Tanvi Gupte, Ankit Nagar, Srikrishnarka Pillalamarri, Arijit Jana, Paulami Bose, Gaurav Viswakarma, Vishal Kumar, Jayoti Roy, A. Anil Kumar, Jenifer Shantha Kumar

MS Theses: Ananthu Mahendranath, Ramesh Kumar Soni

>25 Post-doctoral fellows, >130 masters students and visitors





Indian Institute of Technology Madras



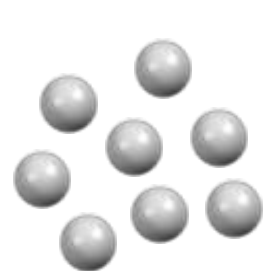
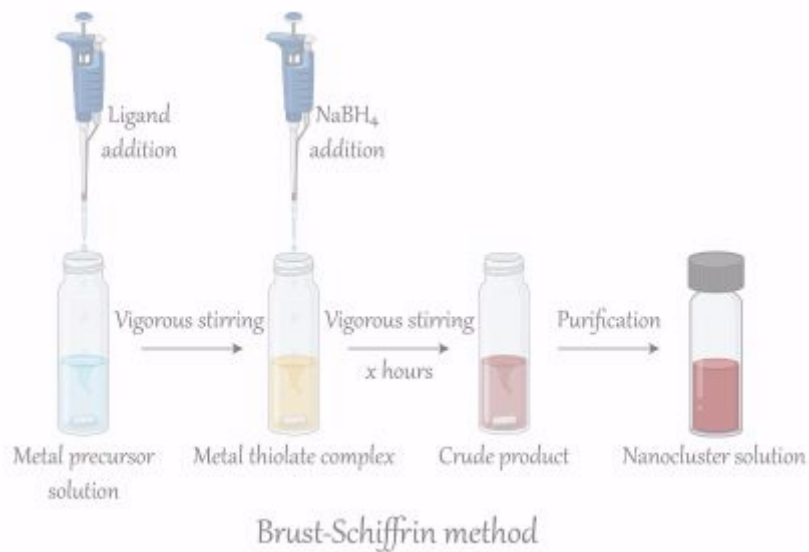
Associate Editor
ACS
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Resource Management

Bhaskar Ramamurthi/V. Kamakoti



Manswita Mandal for help with the slides

Synthesis Schematic of $[\text{Ag}_{17}(\text{o}_1\text{-CBT})_{12}]^{3-}$ Nanocluster

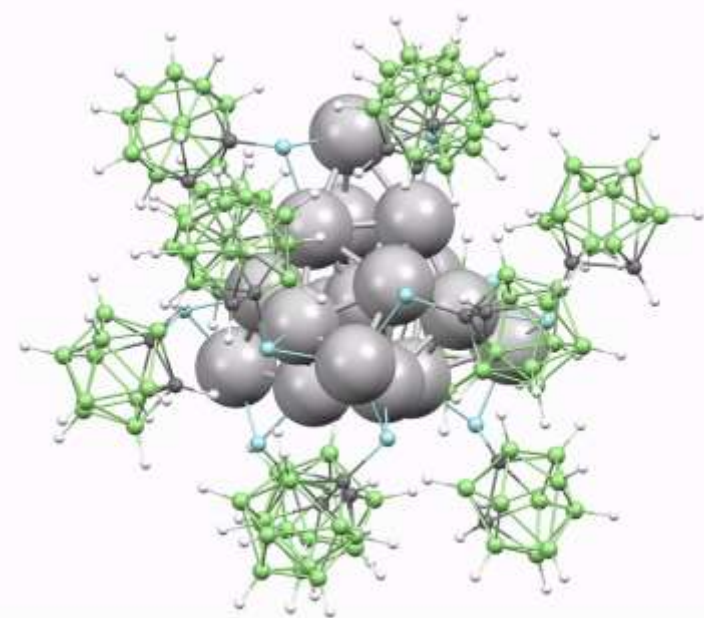


Ag Solution

+

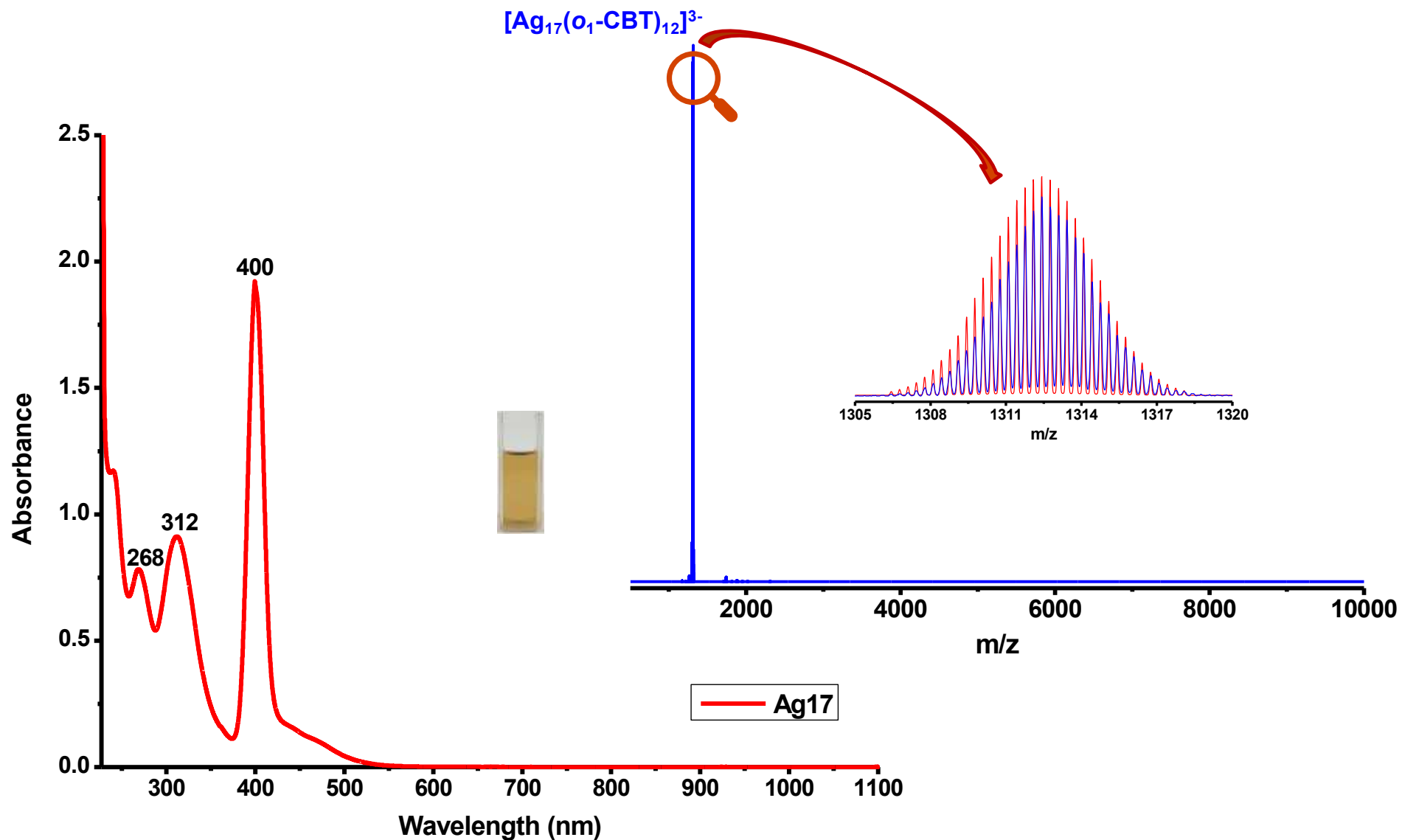


$\text{o}_1\text{-Carborane Thiol}$

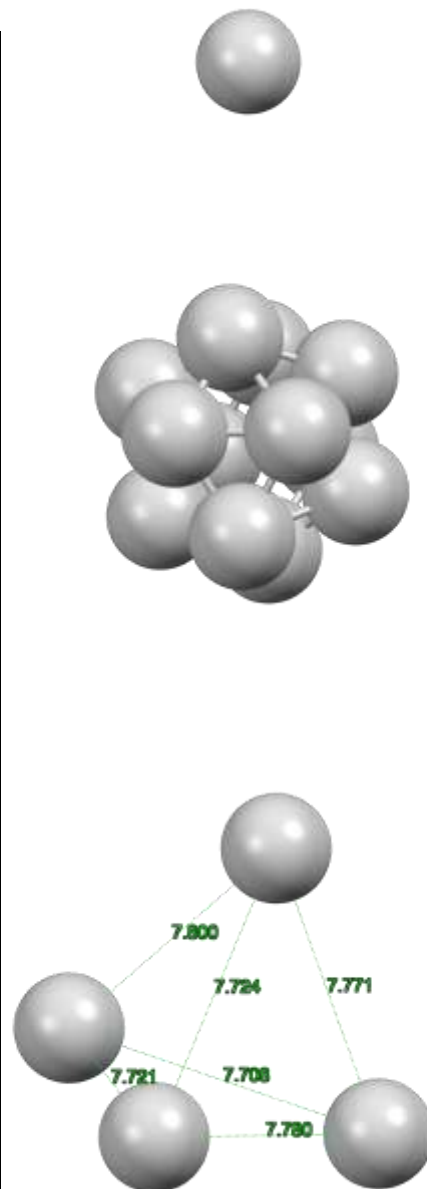
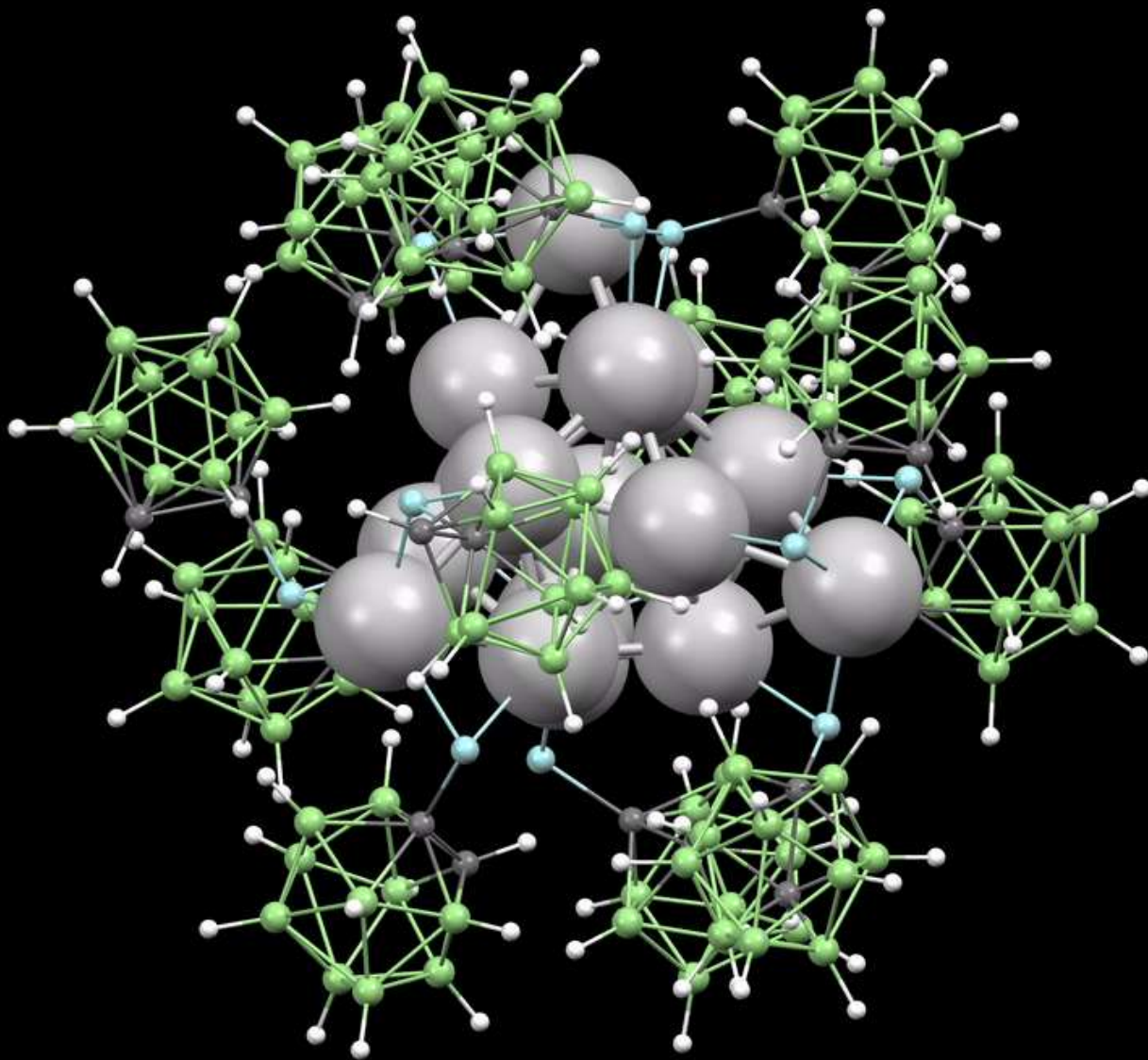


$[\text{Ag}_{17}(\text{o}_1\text{-CBT})_{12}]^{3-}$

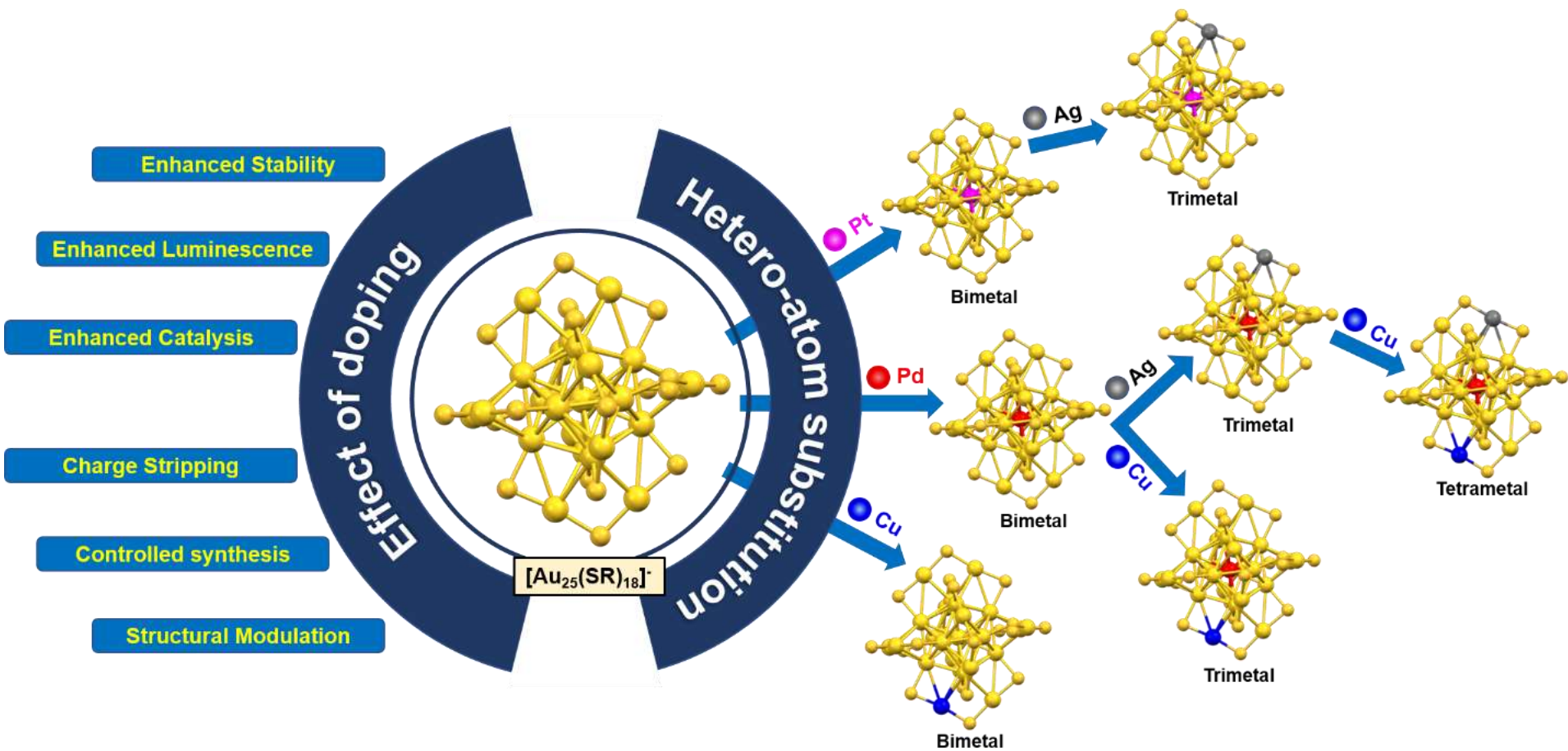
Characterisation of $[\text{Ag}_{17}(\text{o}_1\text{-CBT})_{12}]^{3-}$ Nanocluster



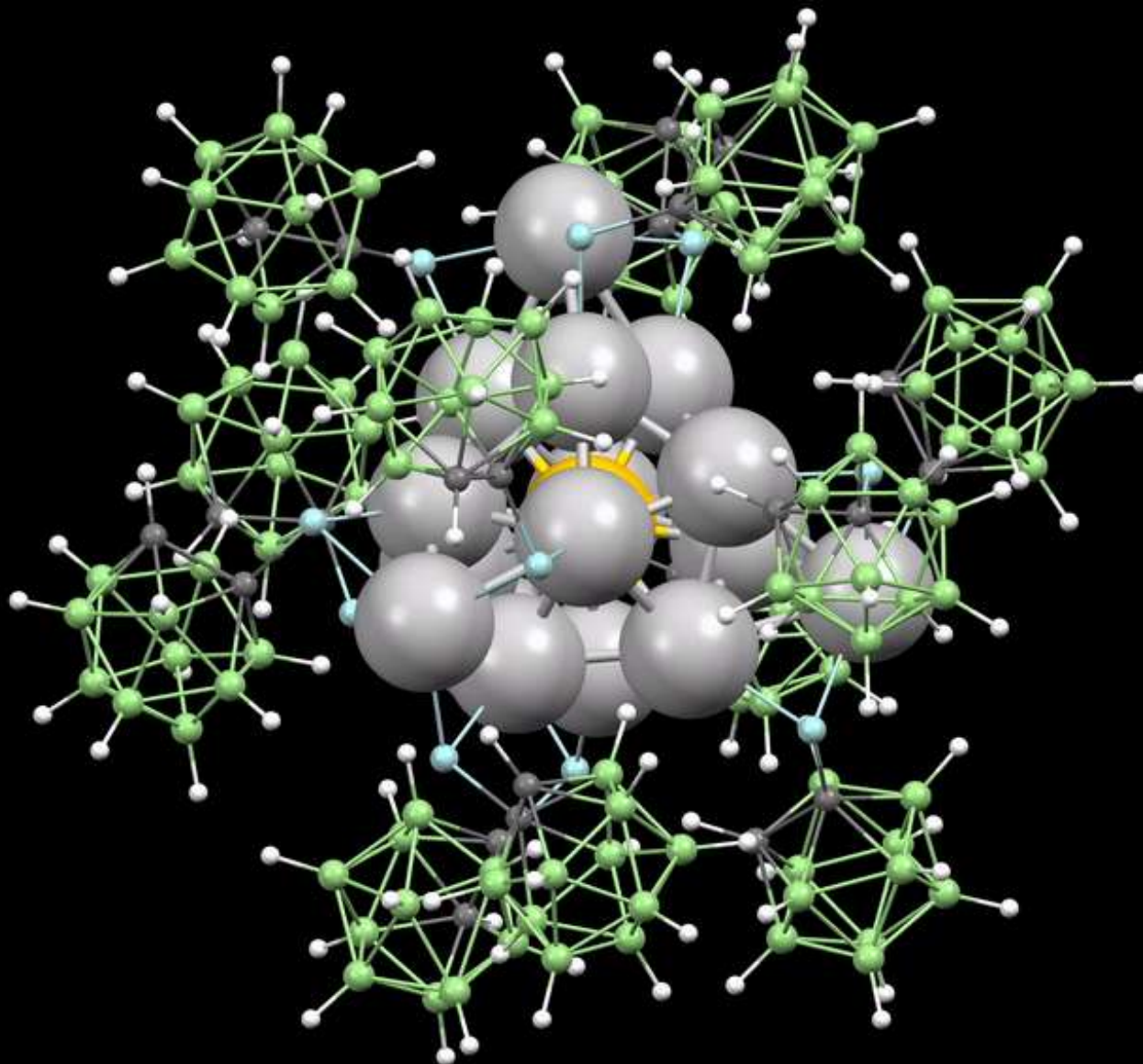
Structure of $[\text{Ag}_{17}(\text{o}_1\text{-CBT})_{12}]^{3-}$ Nanocluster



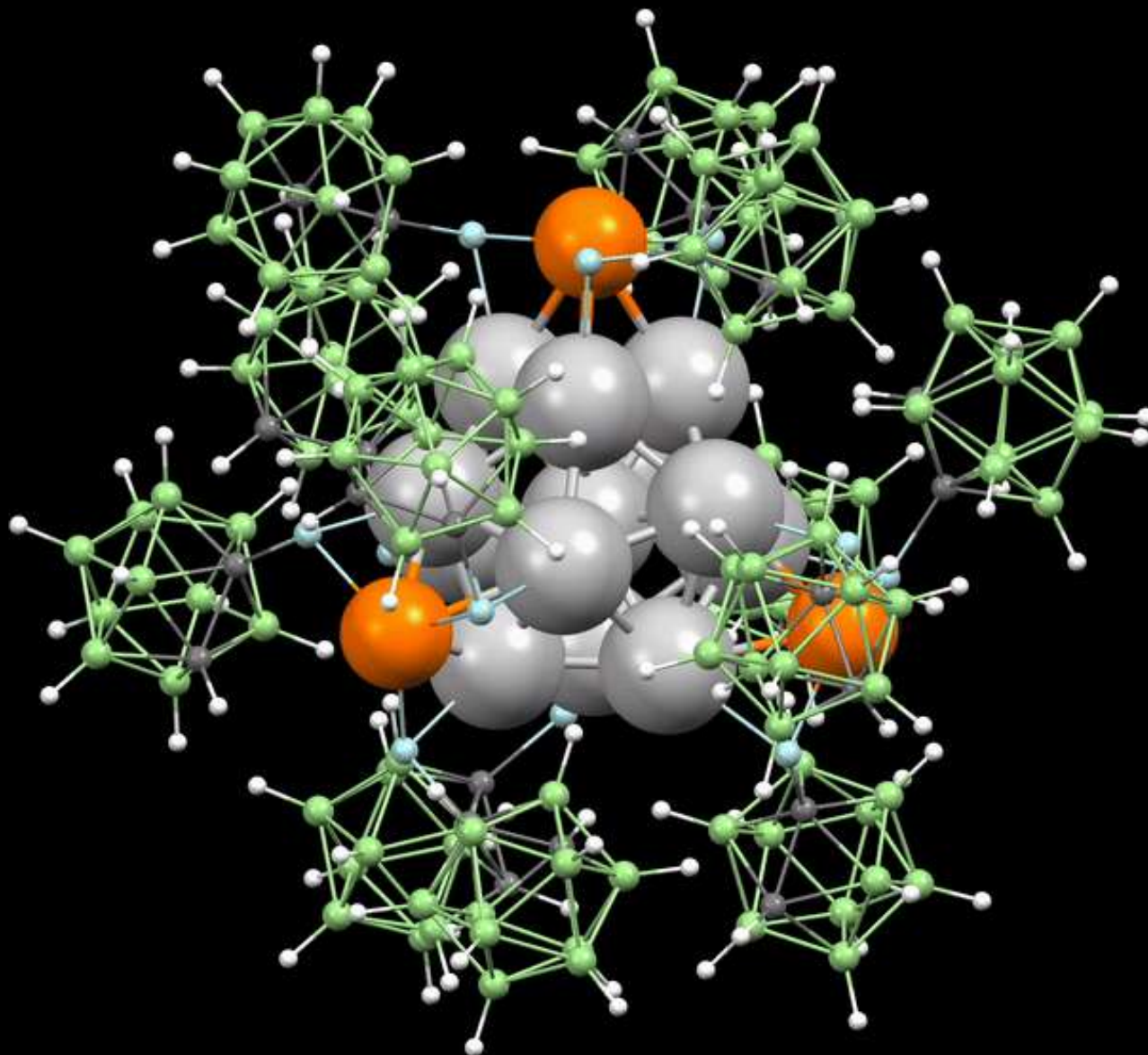
Alloying of Nanoclusters: The Work Plan



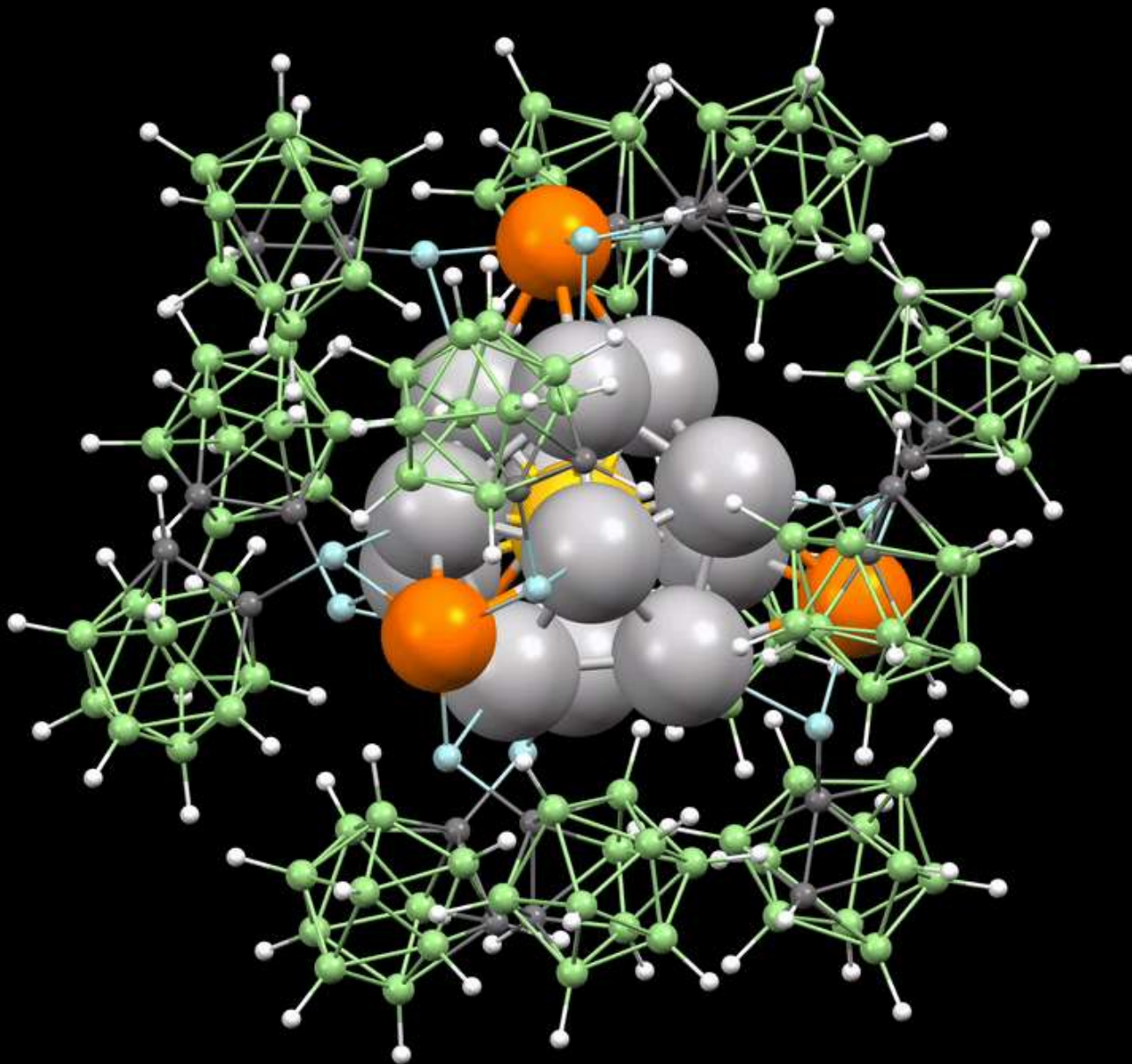
Structure of AuAg₁₆ Nanocluster



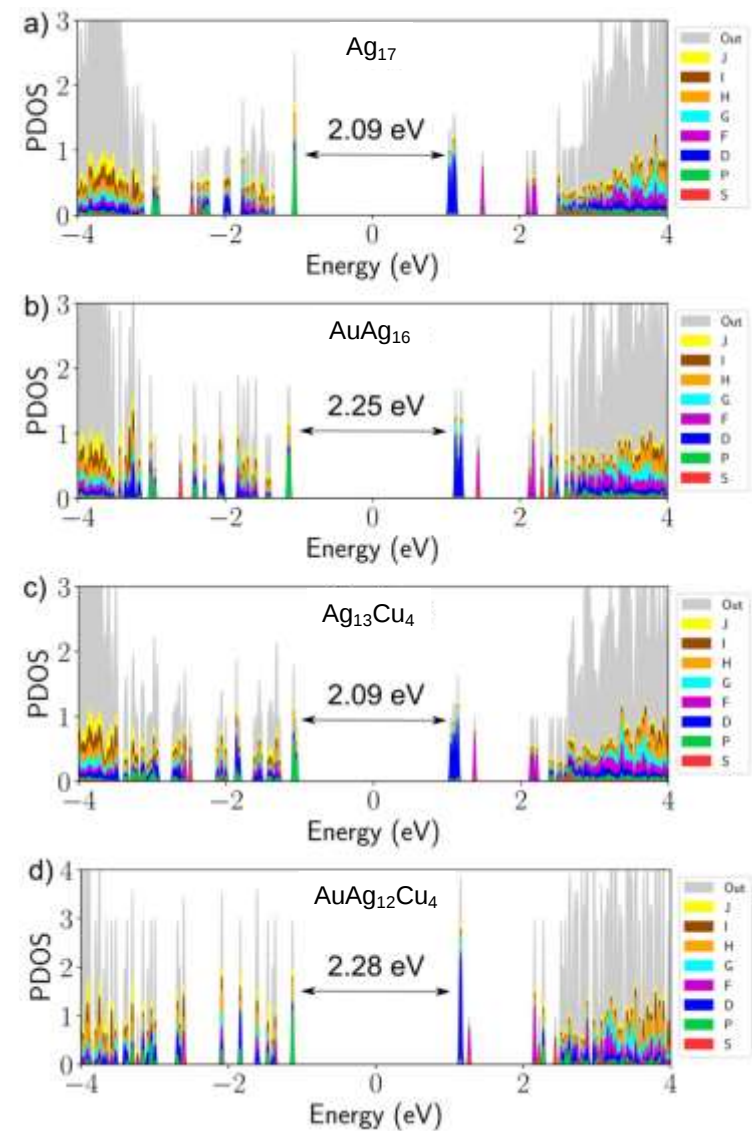
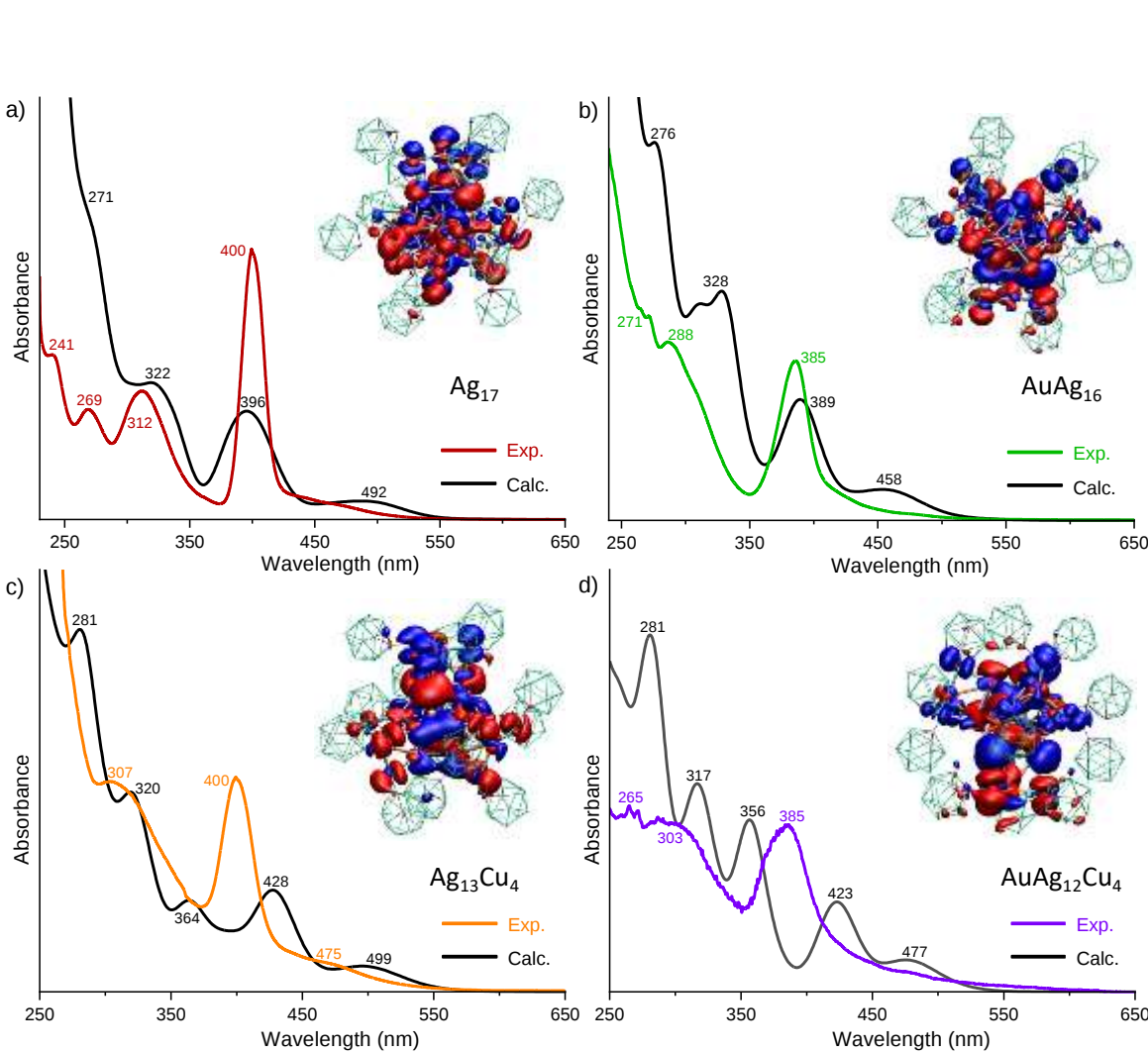
Structure of $\text{Ag}_{13}\text{Cu}_4$ Nanocluster



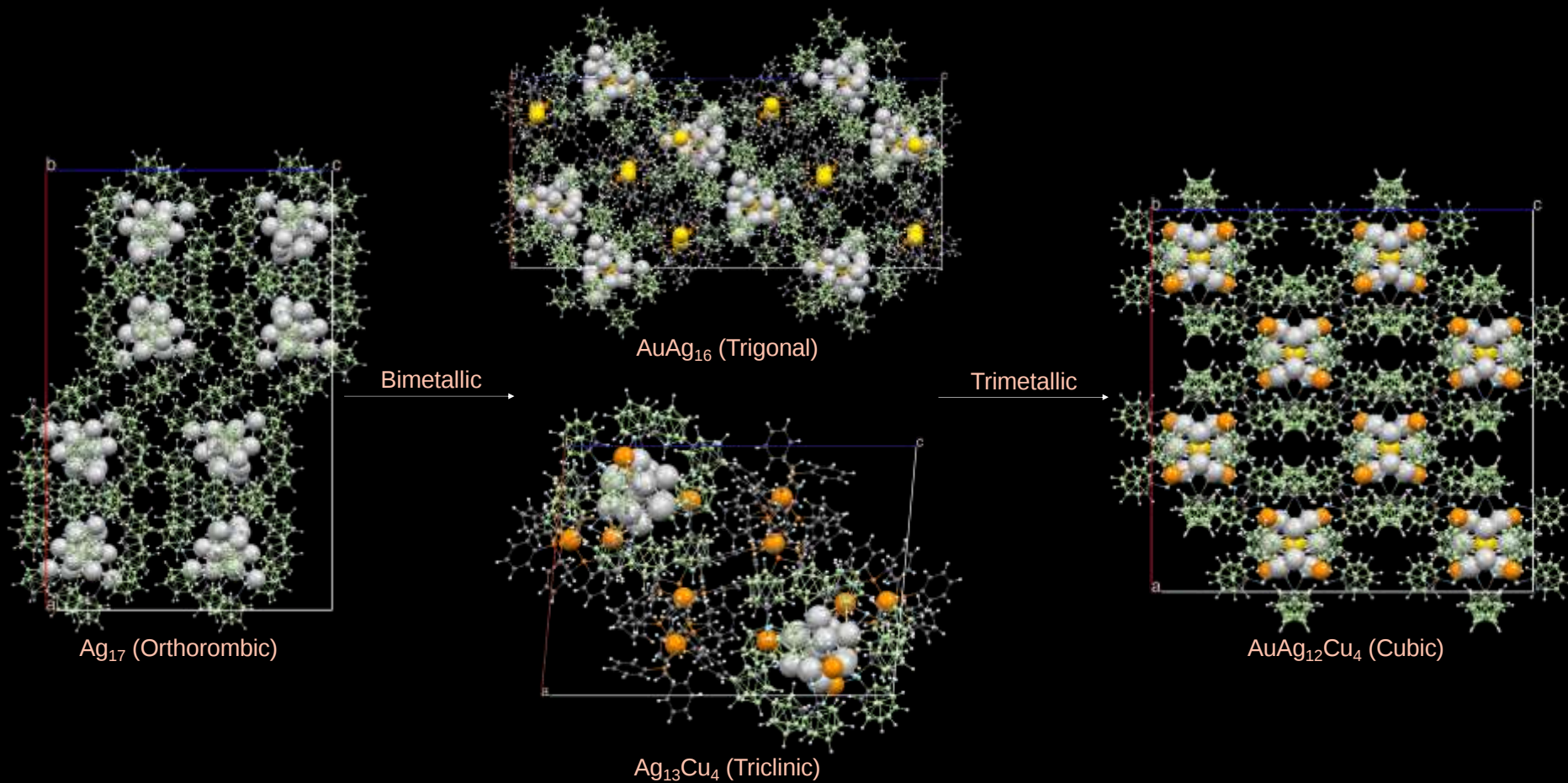
Structure of $\text{AuAg}_{12}\text{Cu}_4$ Nanocluster



Theoretical Understanding



Packing of M_{17} Nanoclusters



Structural Pores of $\text{AuAg}_{12}\text{Cu}_4$ Nanoclusters

