Now in the 65th y
ear

Thalappil Pradeep

Institute Professor, IIT Madras
https://pradeepresearch.org/
pradeep@iitm.ac.in

InnoDI Water Technologies Pvt. Ltd.
VayuJAL Technologies Pvt. Ltd.
Aqueasy Innovations Pvt. Ltd.
Hydromaterials Pvt. Ltd.
EyeNe
pectrum Innovations Pvt. Ltd.

Associate Editor
ACS Sustainable Resource Management

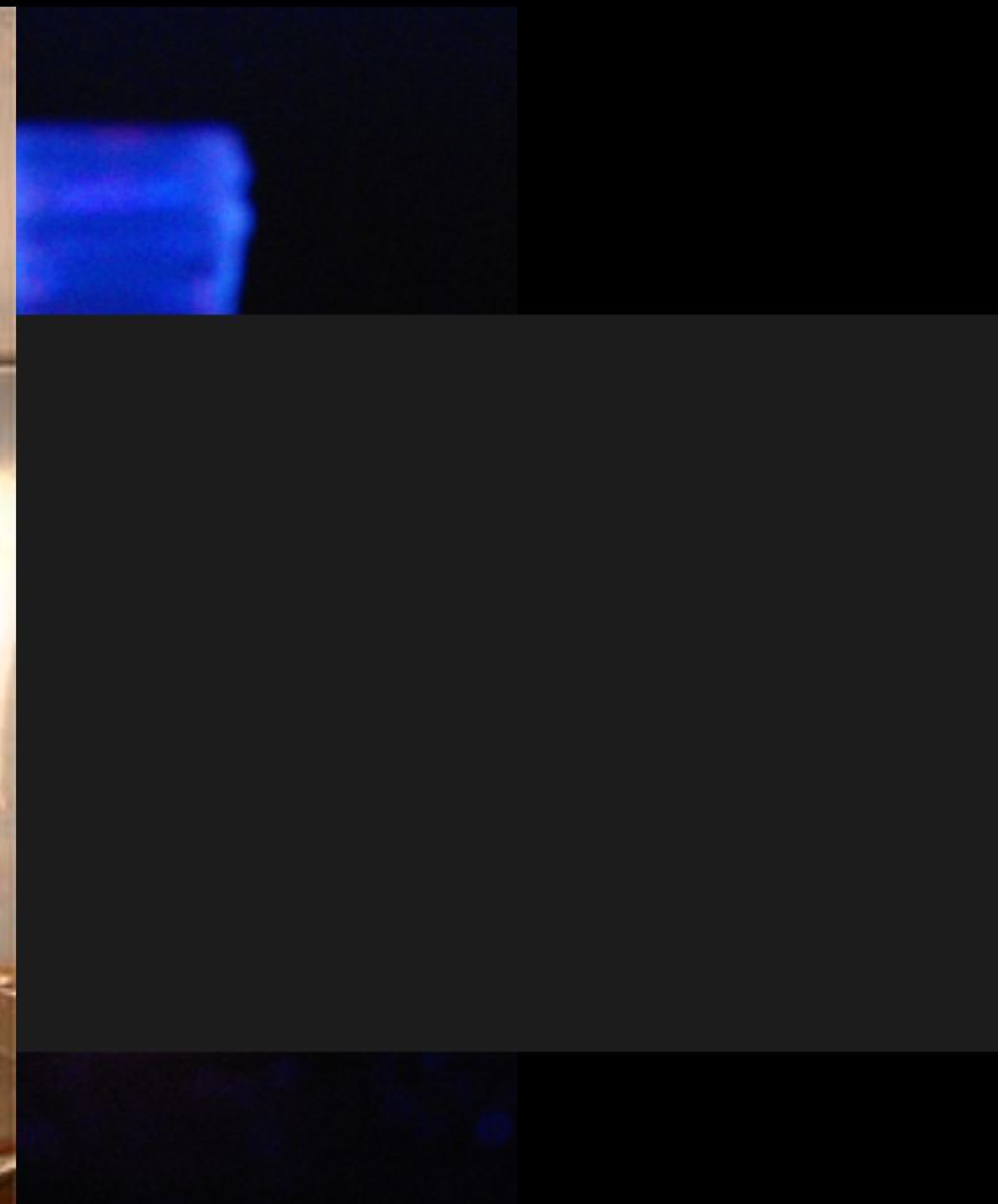
Professor-in-charge
ICCW INTERNATIONAL CENTRE FOR CLEAN WATER
International Centre for Clean Wa
ter

pradeep RESEARCH GROUP

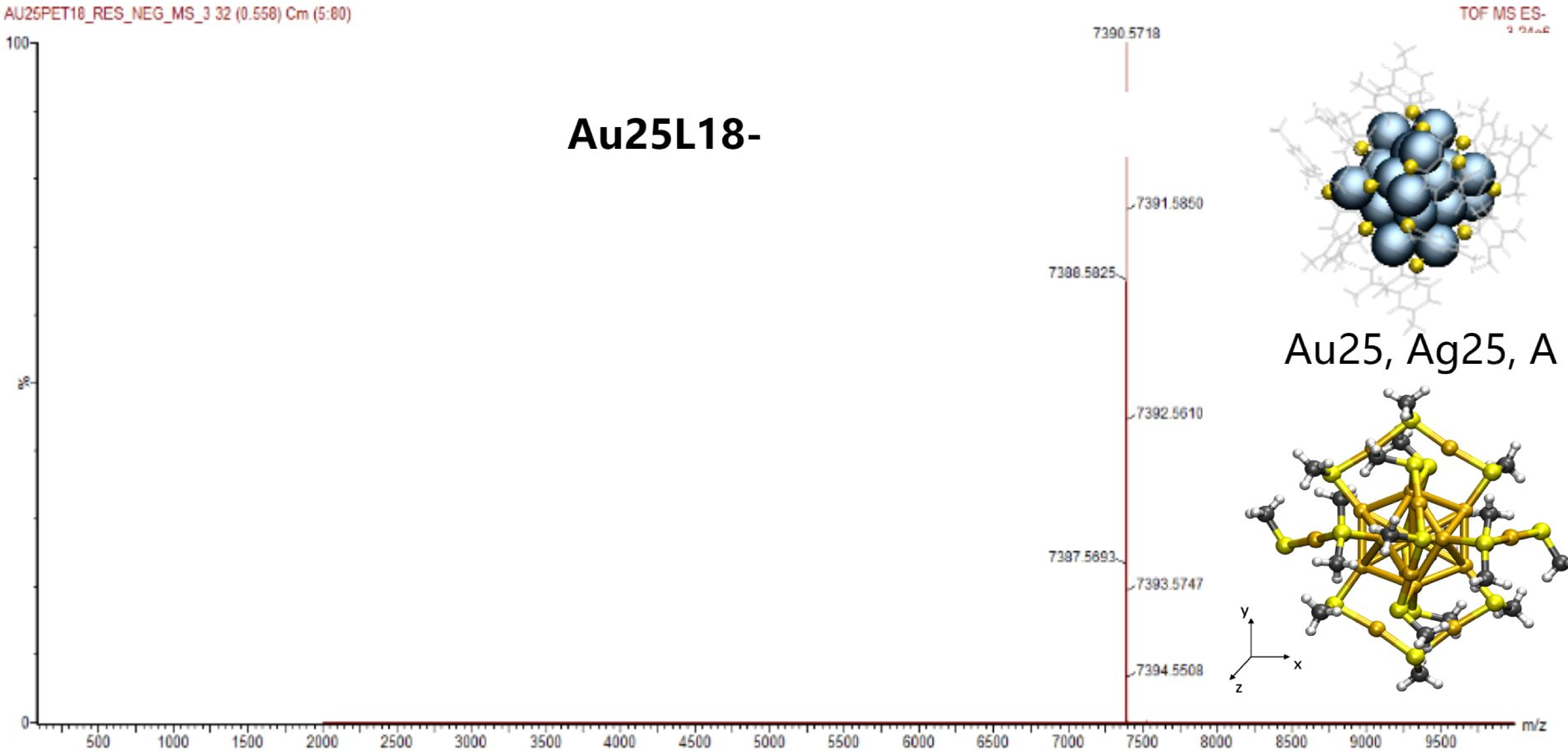
THEMATIC UNIT OF EXCELLENCE

Department of Chemistry, Technical University of Munich, Garching, June 16, 2025

Gas phase

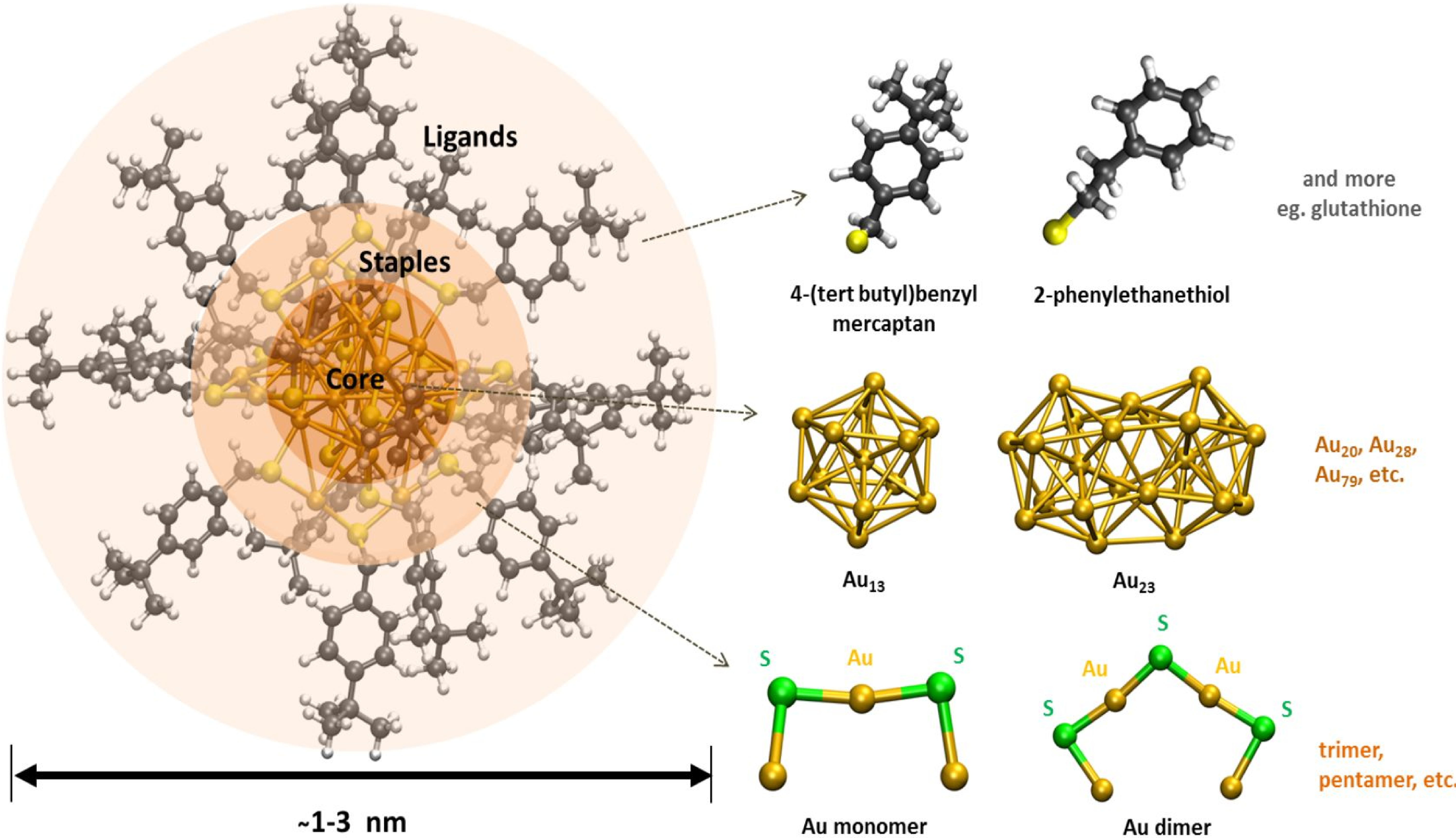


Atomically precise metal clusters as materia ls

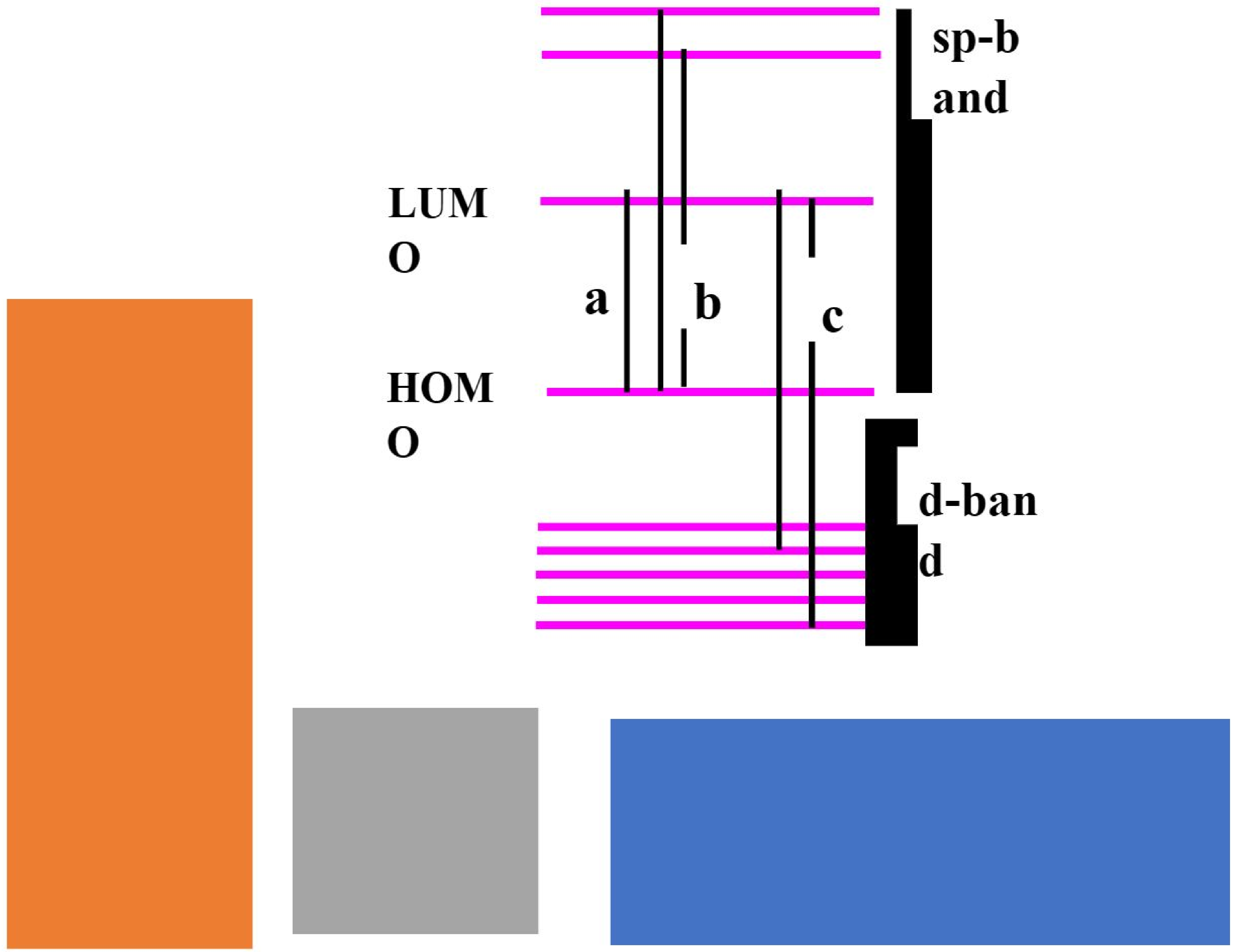


Au25, Ag25, A

T. Pradeep et. al. *Acc. Chem. Res.* 2018; 201 9.



Ligands
Staples
Core
~1-3 nm
4-(tert butyl)benzyl mercaptan
2-phenylethanethiol
and more
eg. glutathione
Au_{13}
Au_{23}
Au_{20}, Au_{28}, Au_{79}, etc.
S
Au
S
Au monomer
S
Au
Au
S
S
Au dimer
trimer, pentamer, etc.


sp-b
and
LUM
O
a
b
c
HOM
O
d-ban
d

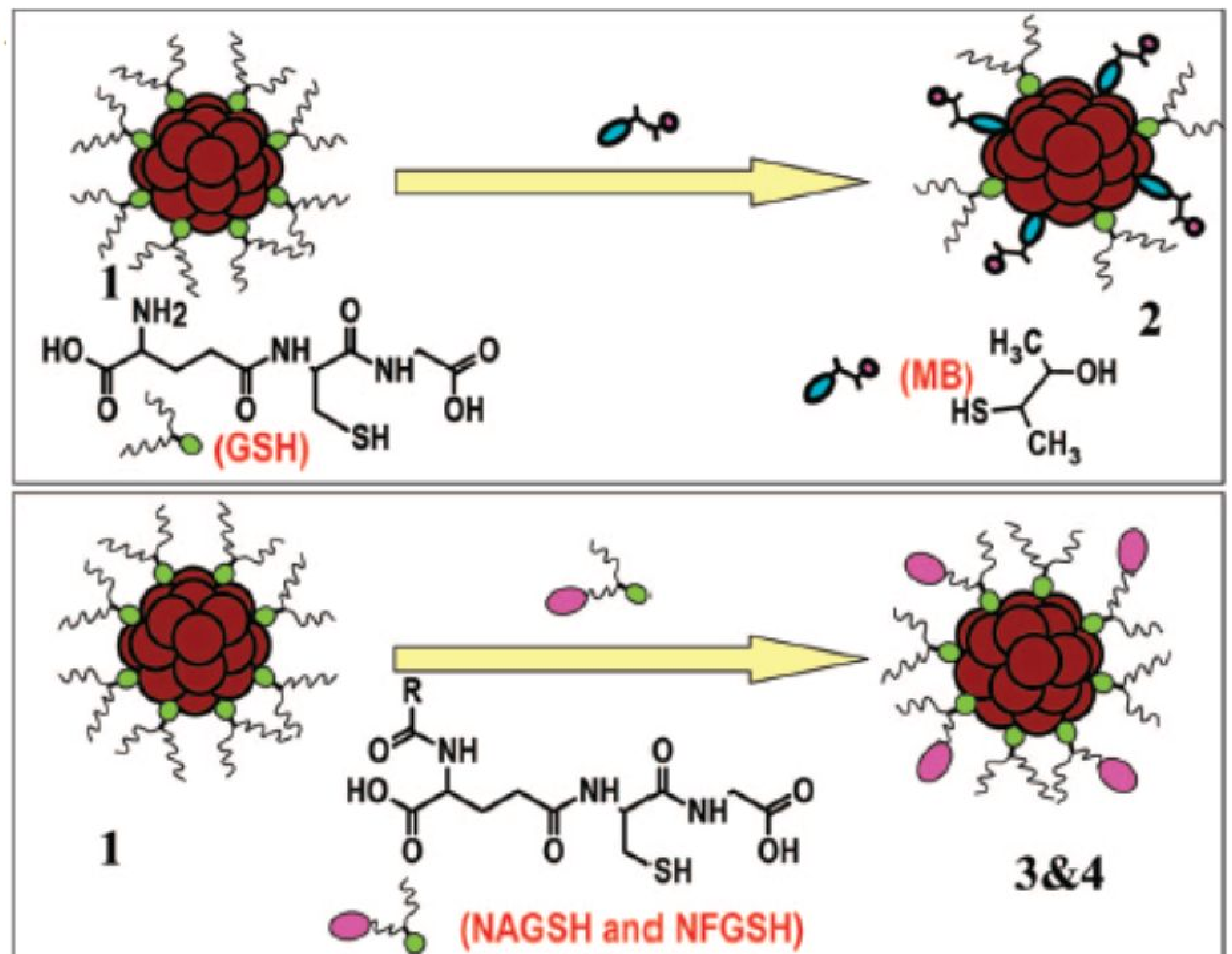
12168 *J. Phys. Chem. C* **2008,** *112,* 12168–12176

Ligand Exchange of $Au_{25}SG_{18}$ Leading to Functionalized Gold Clusters: Spectroscopy, Kinetics, and Luminescence

E. S. Shibu,[†] **M. A. Habeeb Muhammed,**[†] **T. Tsukuda,**[‡] **and T. Pradeep***[,†]

DST Unit on Nanoscience (DST UNS), Department of Chemistry and Sophisticated Analytical Instrument Facility, Indian Institute of Technology, Madras, Chennai 600 036, India and Institute for Molecular Science, Myodaiji, Okazaki 444-8585, Japan

Received: January 18, 2008;



With Tatsuya Tsukuda

Evolution of noble metal clusters

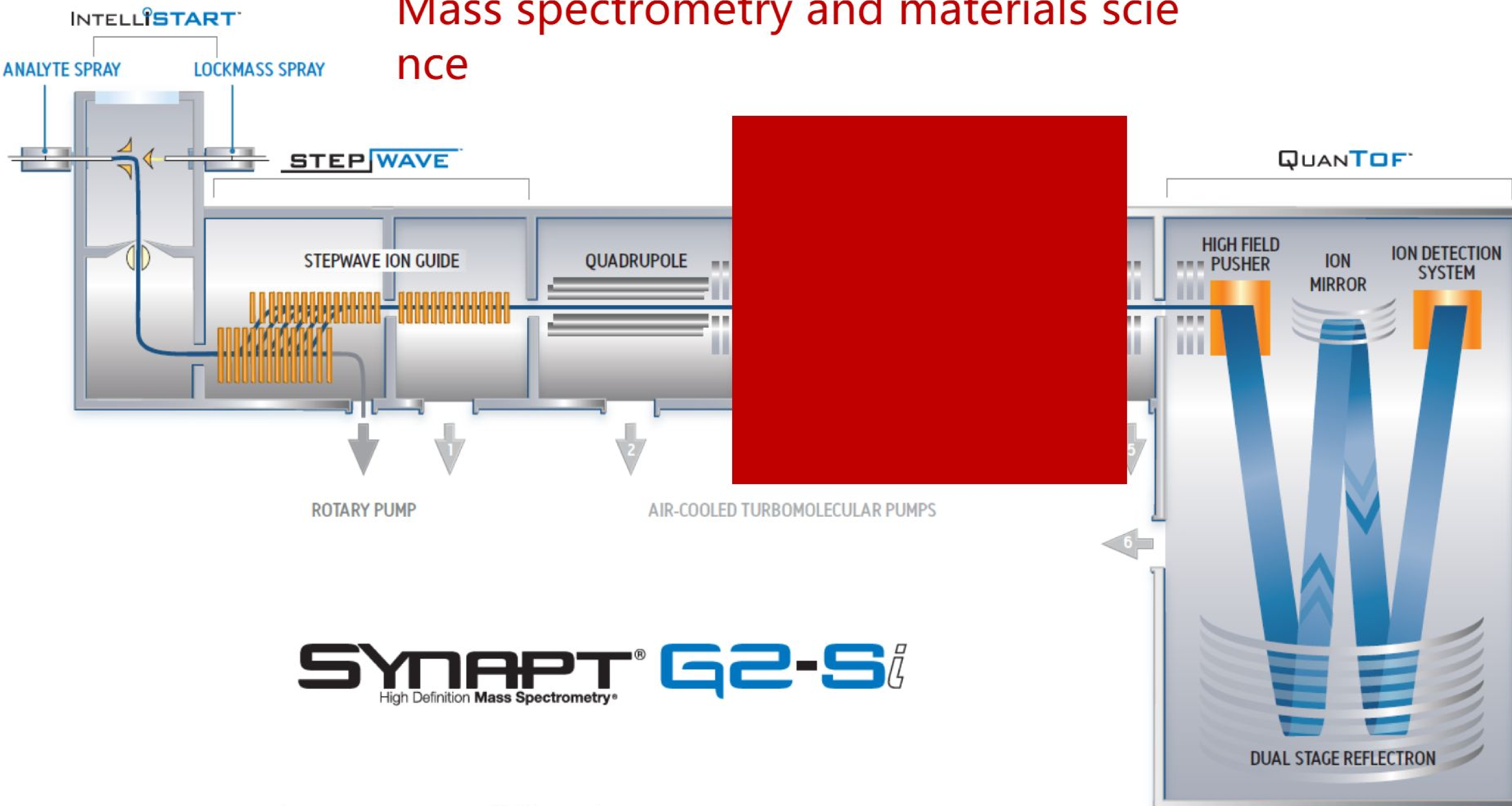
I. Chakraborty and T. Pradeep, *Chem. Rev.* 20

Citations: >200
0

Also the pioneering work of R. W. Murray, Robert L. Whetten, Uzi Landman, Tatuya Tsukuda, Yuichi Negishi, Hannu Hakkinen,

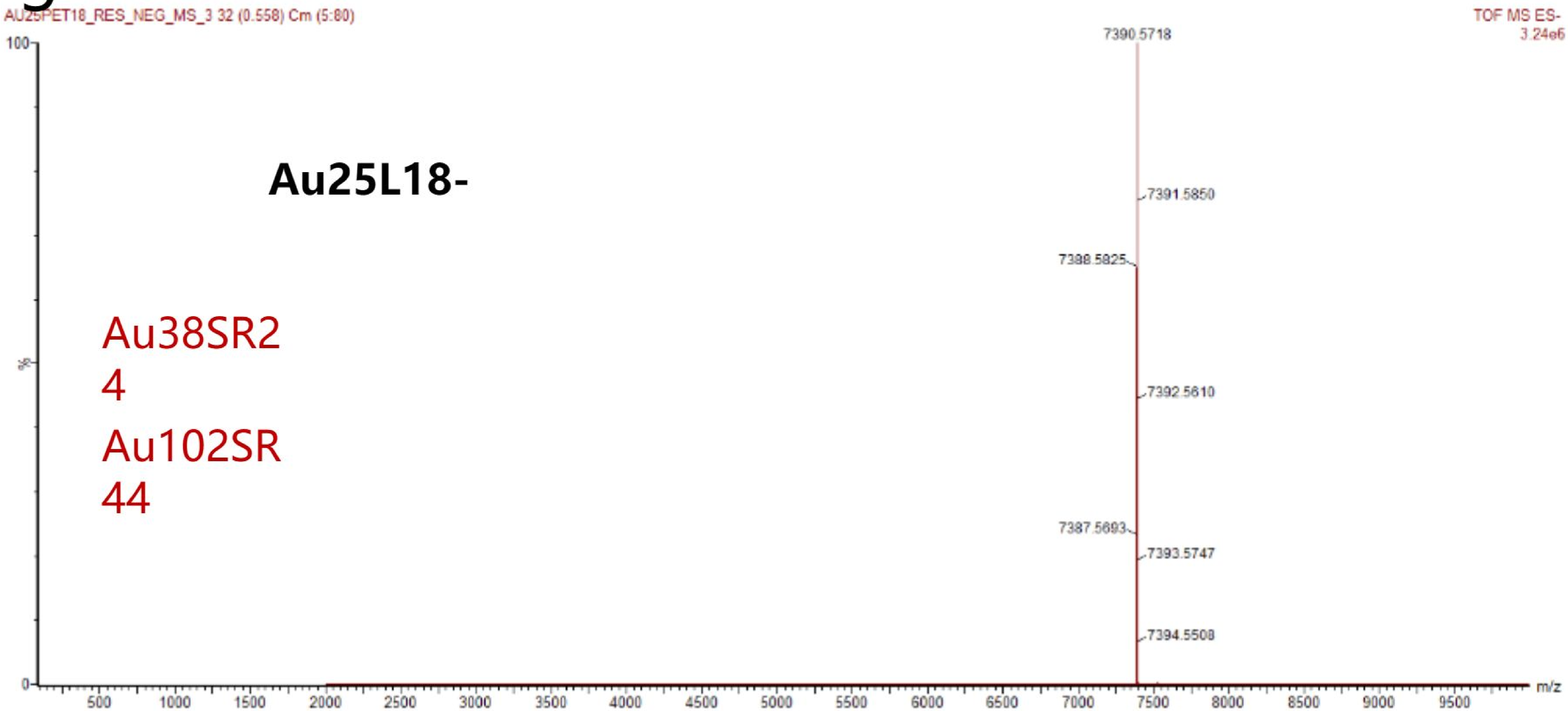
Rongchao Jin, Nanfeng Zheng, Terry Bigioni, Osman Bakr, Kornberg, Jianping Xie, C. M. Aikens, Thomas Buergi, Amala Dass, Ackerson, De-en Jiang, ... A. W. Castleman Jr., H. Schmidbauer, ... Robin Ras, Olli Ikkala

Mass spectrometry and materials science

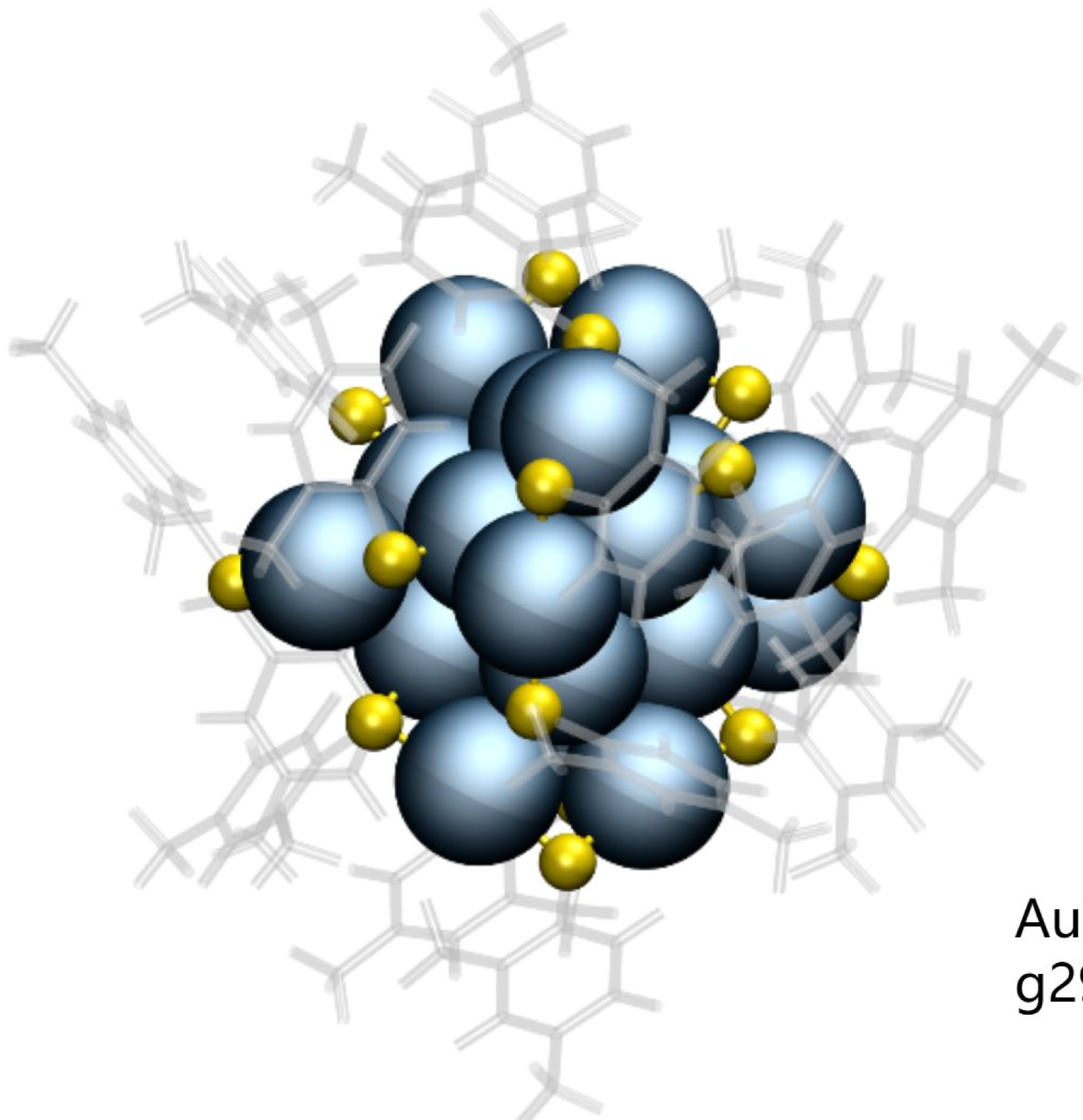


...and many modifications

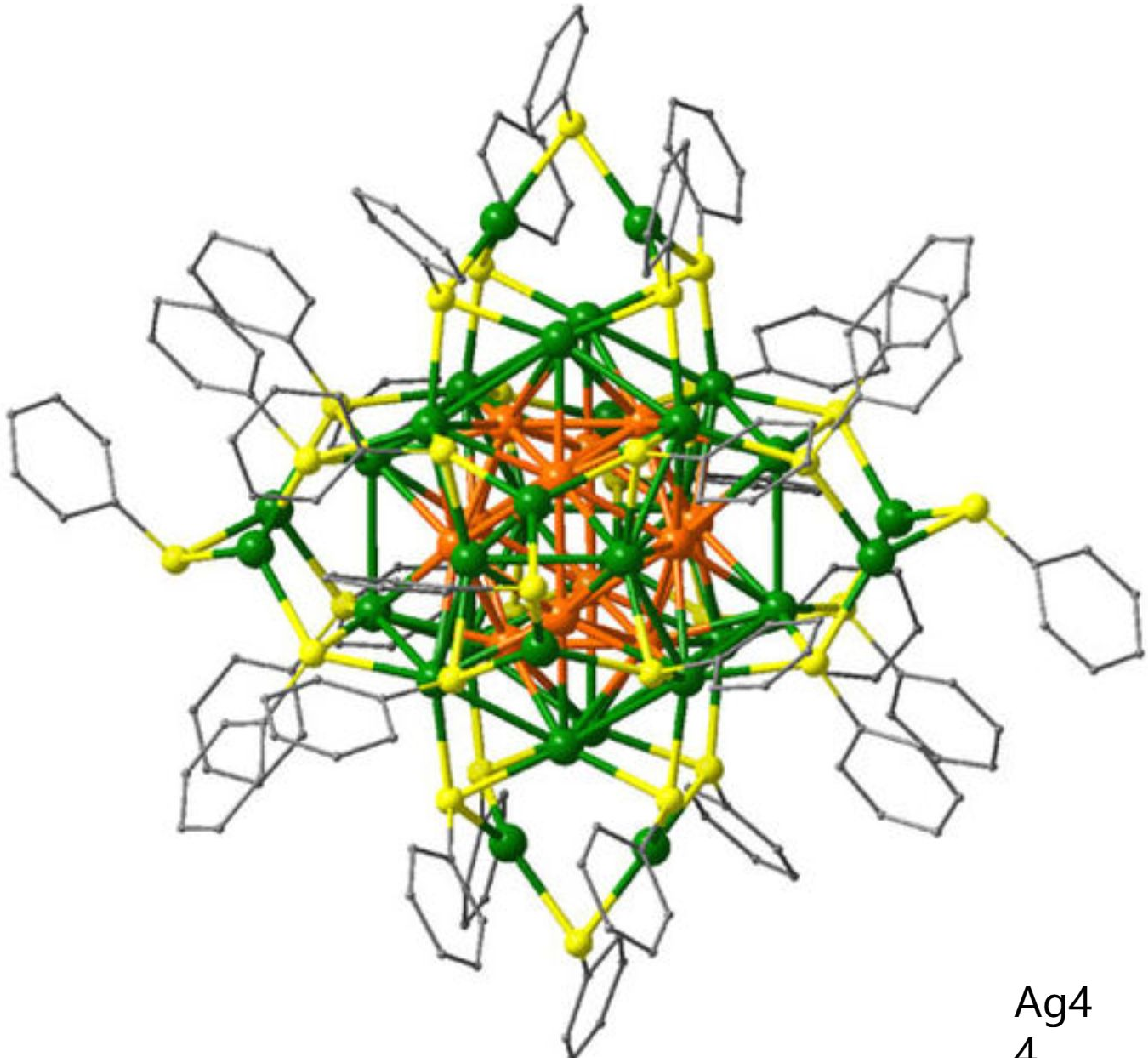
Molecular formula, Molecular weight



New molecules



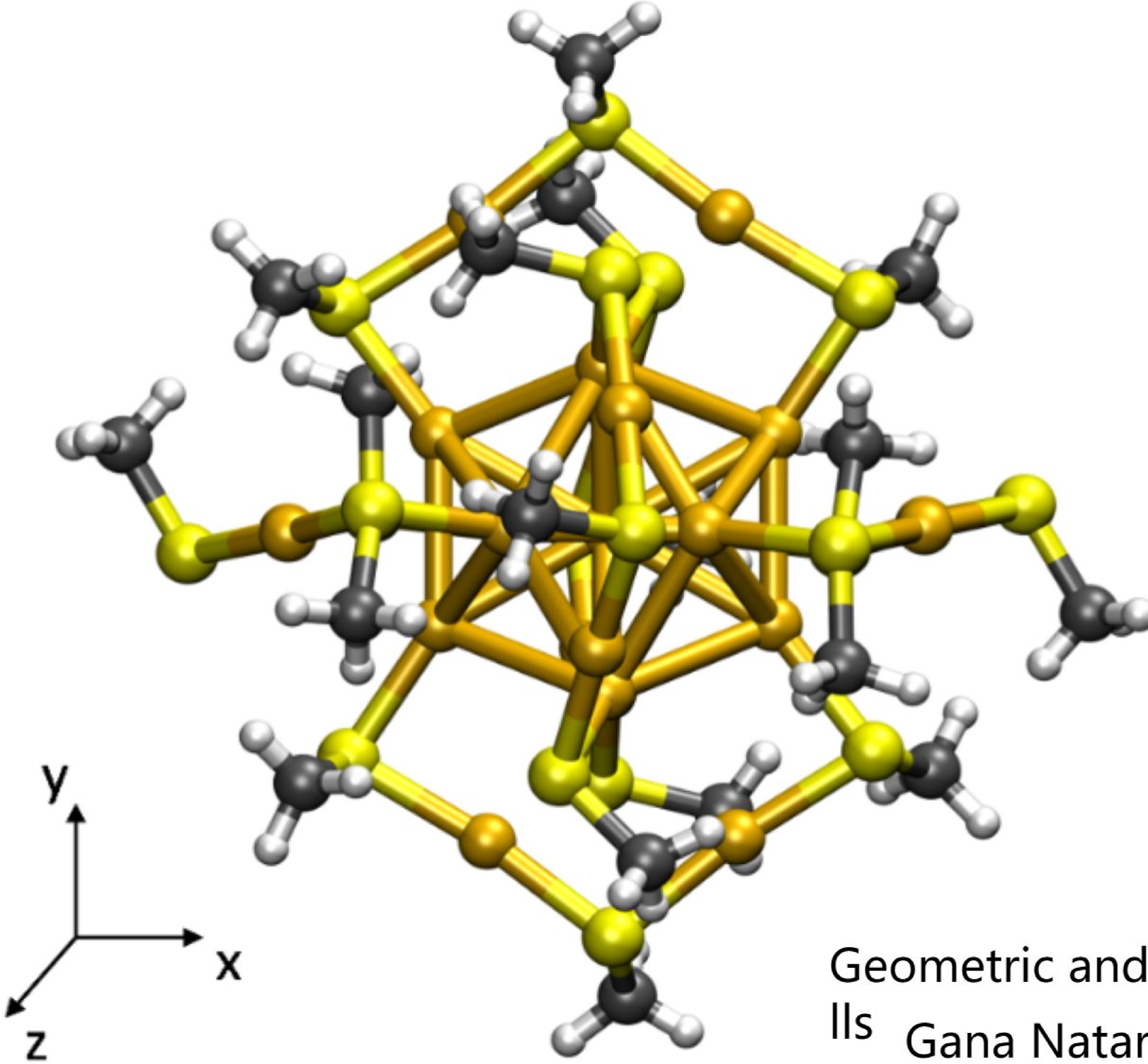
Au25, Ag25, Ag29



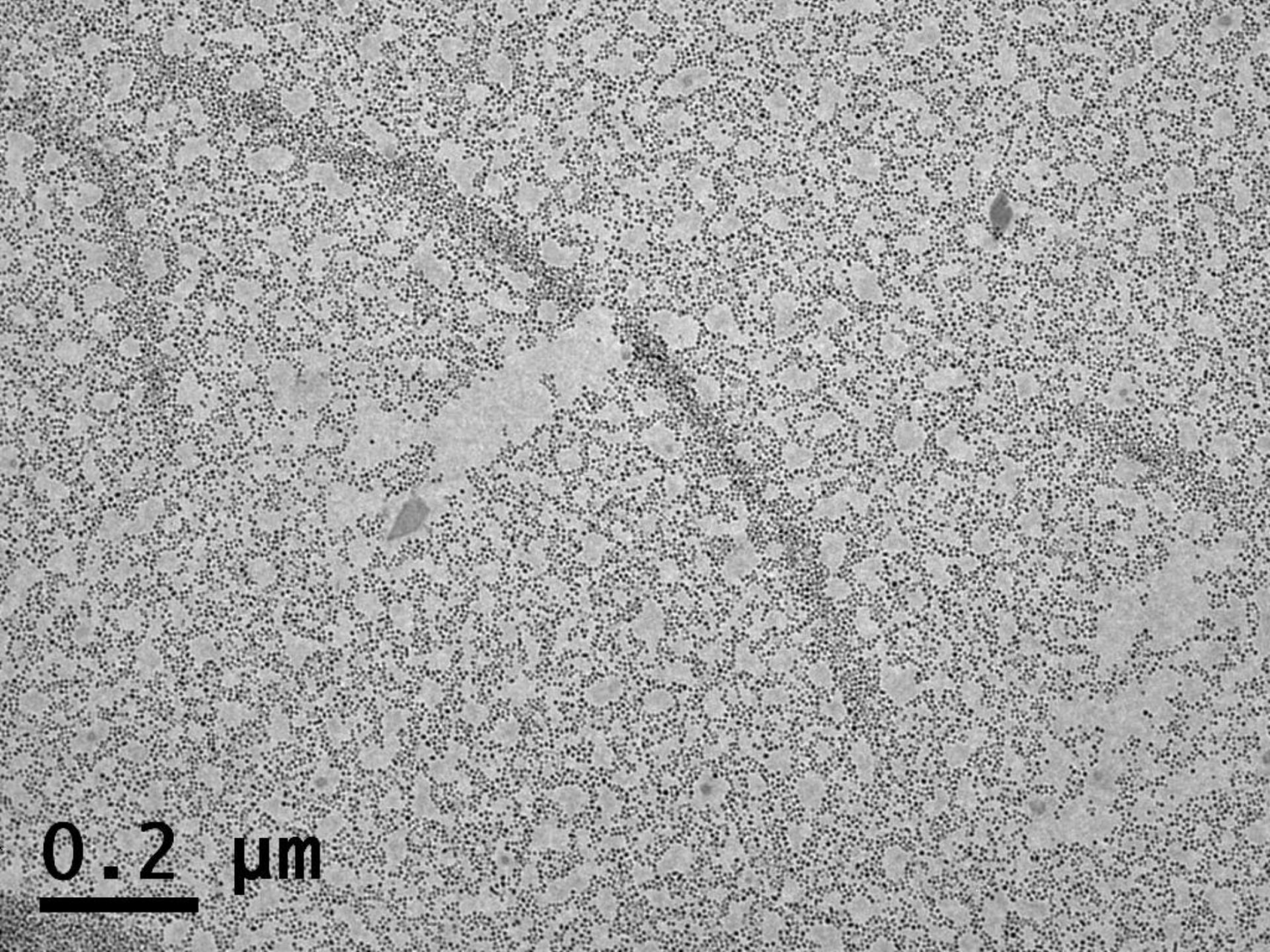
Ag4
4

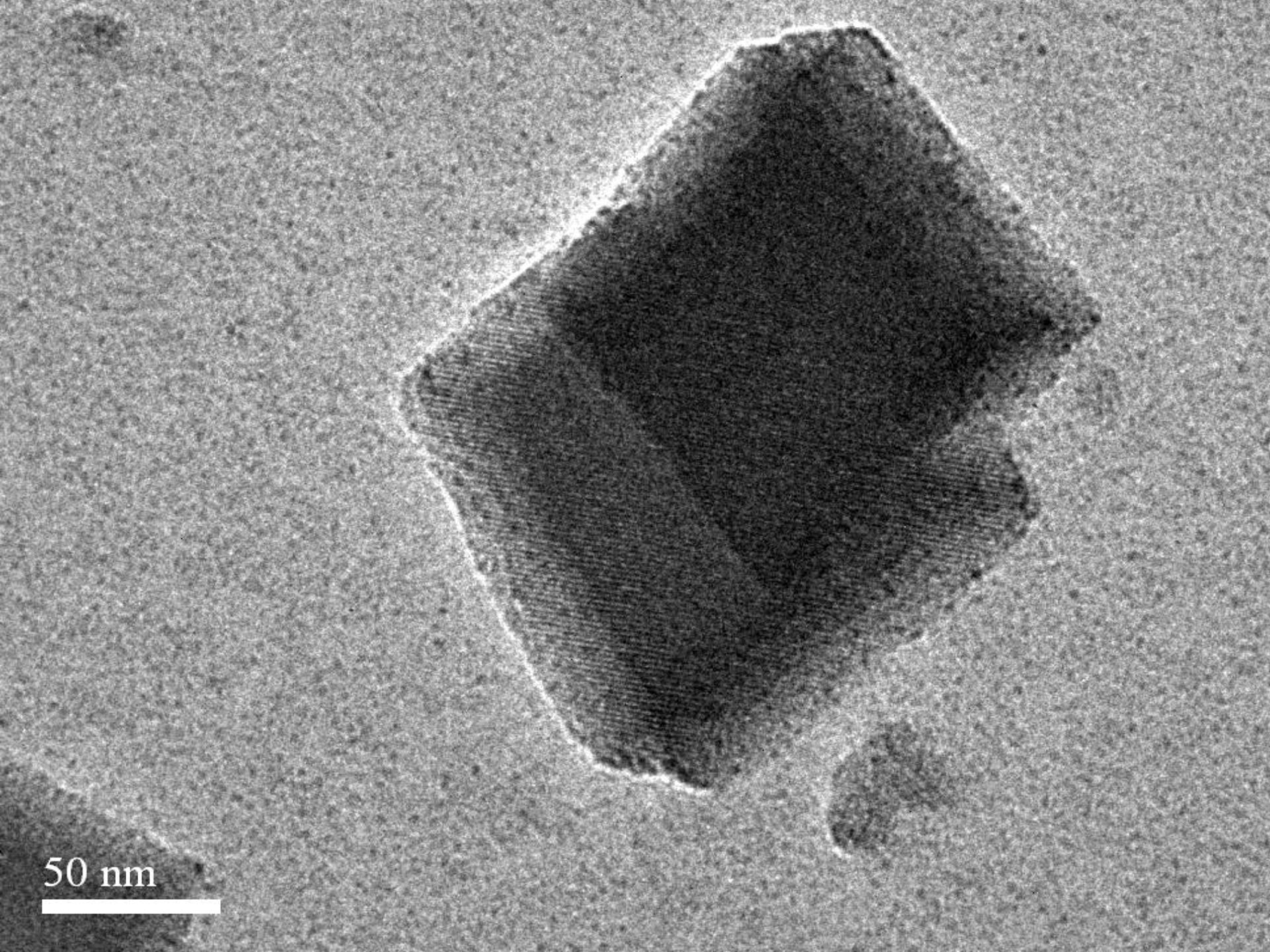
Nanfeng Zheng et al. *Nature Communications*, 2
013

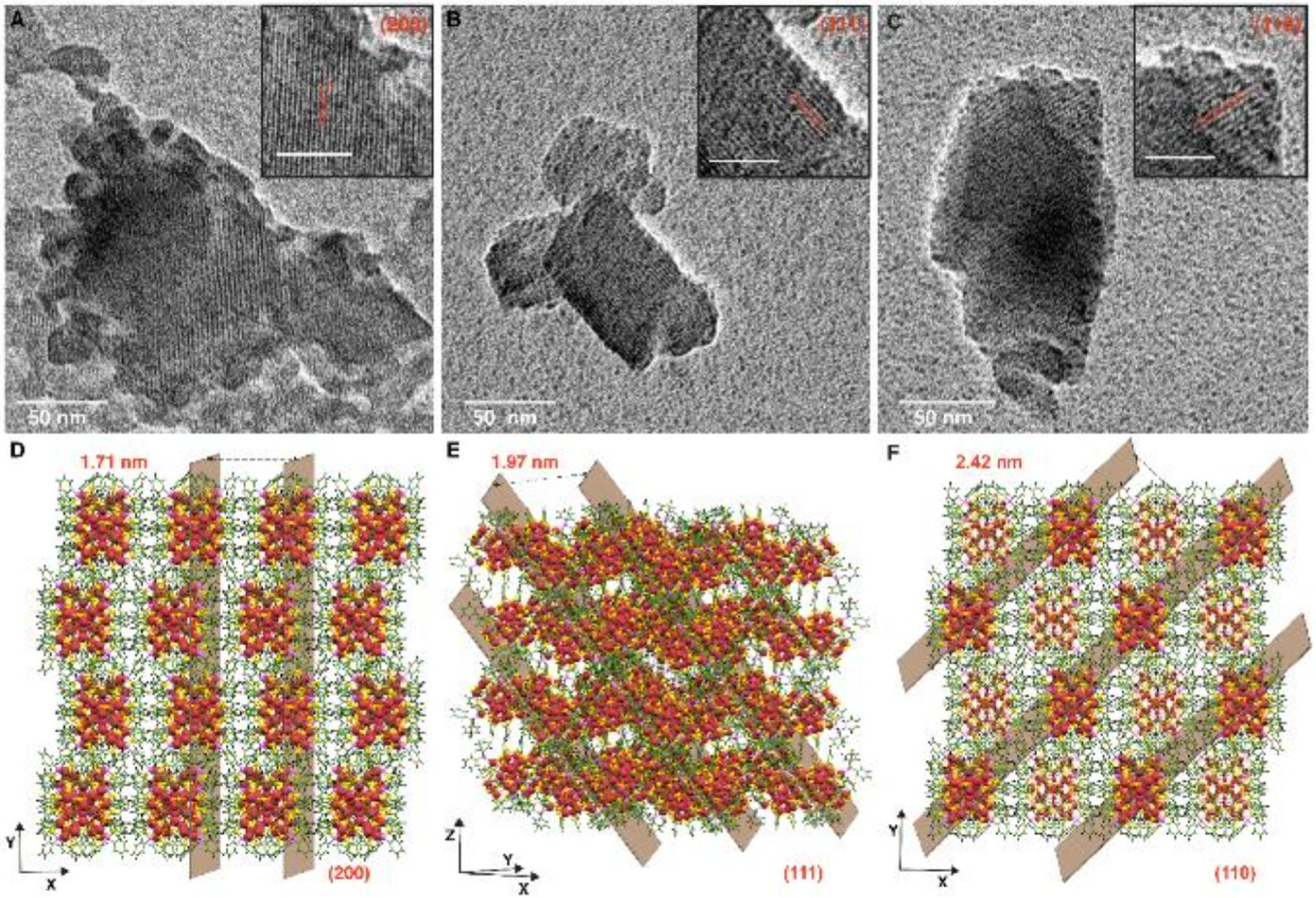
Molecular structur
e



Geometric and electronic she
lls Gana Nataraja
n


0.2 µm


50 nm



Ananthu Mahendranath et al. Chem.Comm.2
021

Ag29(BDT)123
-
Ag25(DMBT)1
8-
Au25(PET)18
-

HRMS of Au25(PET)18
-

m/z

Molecular materia
ls

Molecules and their propert ies

Chemical formula	H_2O
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	$480. \times 10^{-12}$ 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 emiss ion

Molecular reactions

Molecular assembly

Molecular co-crystals

Phases - phase transitions

Physical properties

Electrical, magnetic

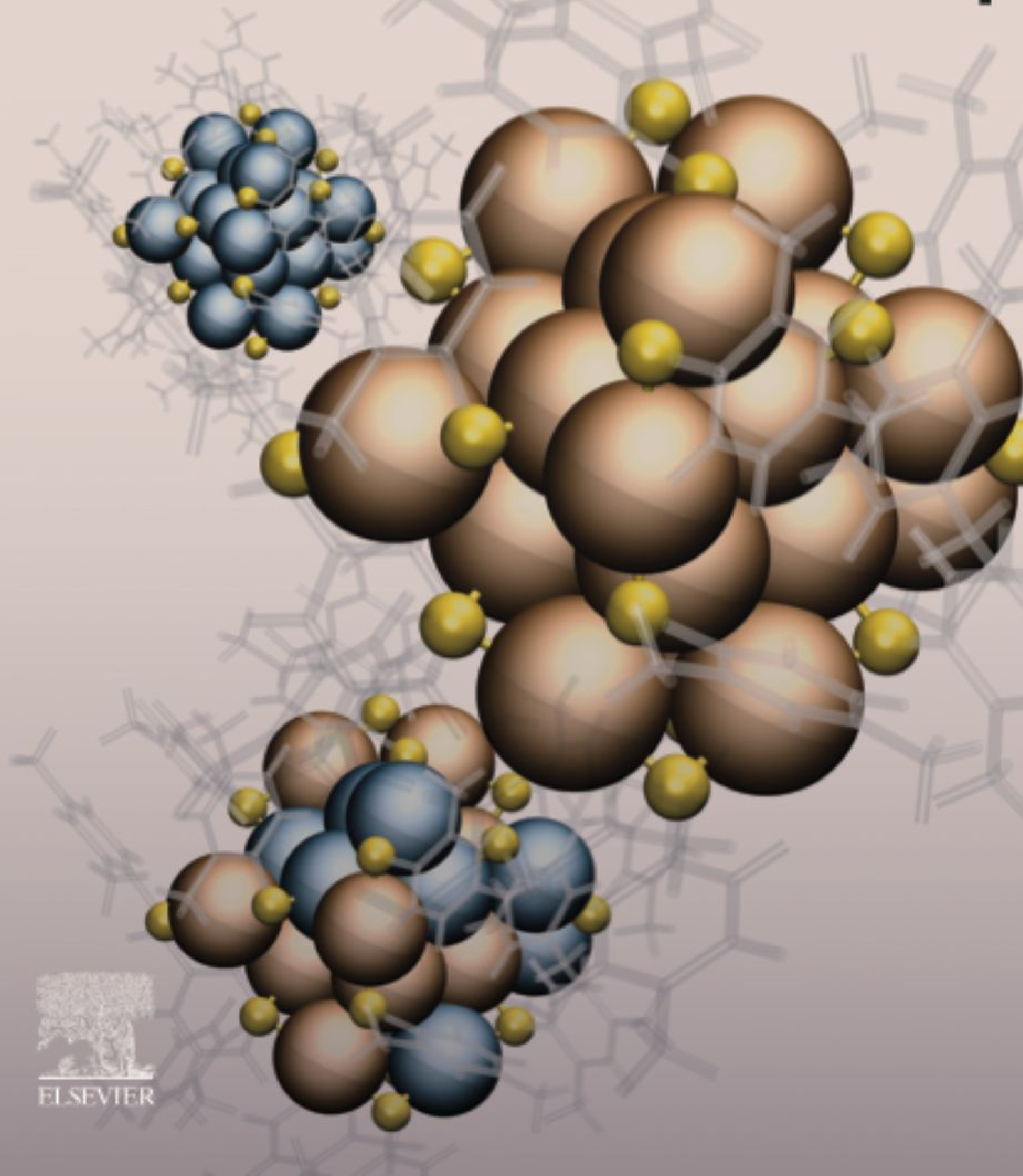
Mechanical properties

Electrochemical properties

Future?

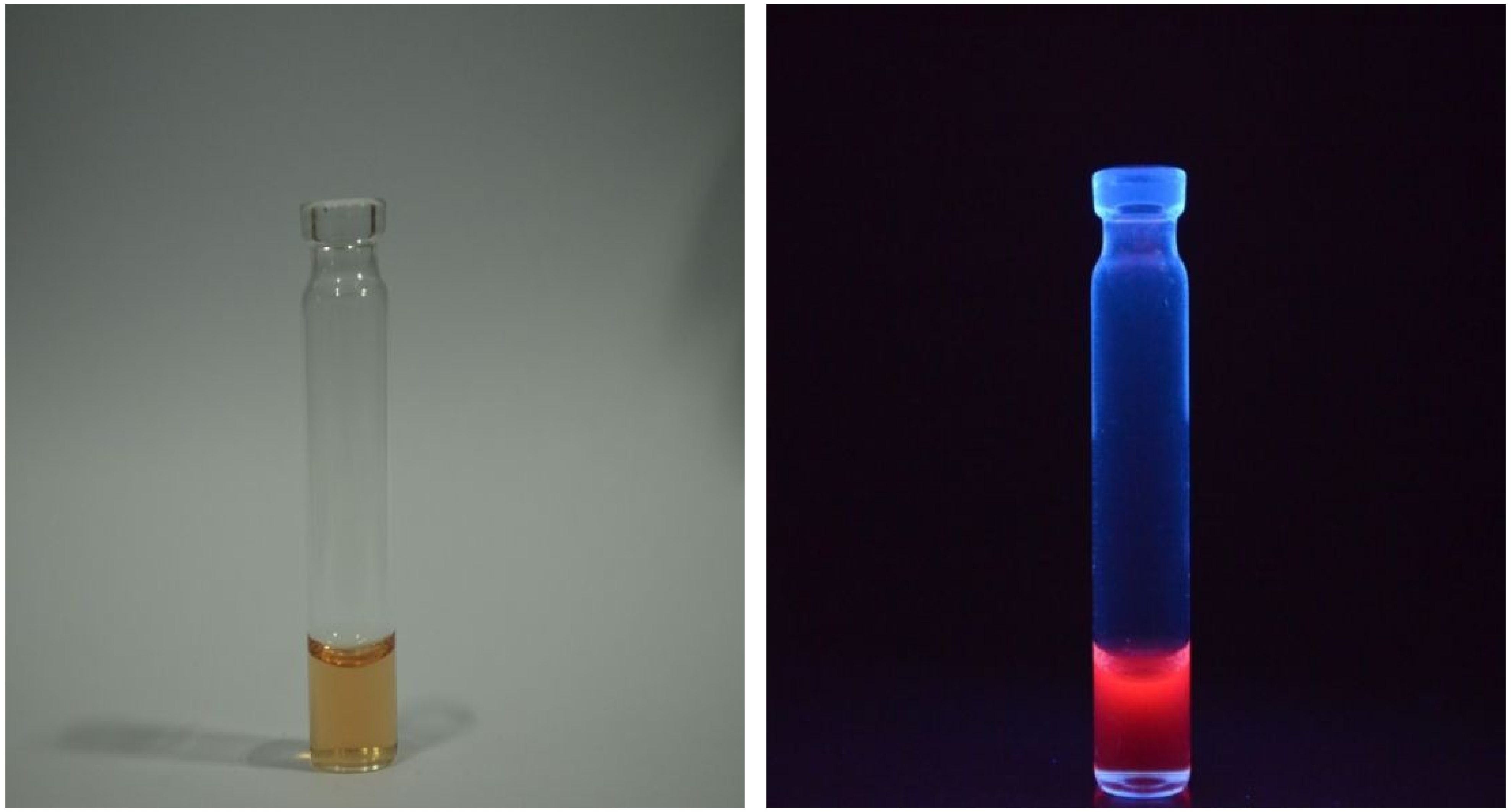
Edited by
Thalappil Pradeep

ATOMICALLY PRECISE METAL NANOCLUSTERS



ELSEVIER

Molecular reactions



Reactions on clusters

Reactions between clusters

Inter-cluster reactions

JACS
JOURNAL OF THE AMERICAN CHEMICAL SOCIETY
Article
pubs.acs.org/JACS

Intercluster Reactions between $Au_{25}(SR)_{18}$ and $Ag_{44}(SR)_{30}$

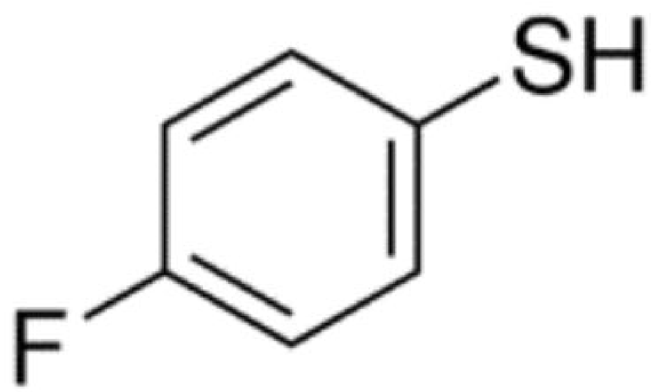
K. R. Krishnadas, Atanu Ghosh, Ananya Baksi, Indranath Chakraborty,[†] Ganapati Natarajan, and Thalappil Pradeep*

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

$$A + B \rightarrow C + D$$

Au25(FTP)18 + Ag44(FTP)30 Au25-xAgx(FTP)18



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

Ag25-Au25 experiments

K. R. Krishnadas et al. *Nature Commun.* 20
16

Reaction between Au25(PET)18 and Ag25(DMBT)18

DMBT

PE
T

[Ag25(DMBT)18+Au25(PET)18]2-

DMBT

PE
T

Ag25(DMBT)
18

[Ag25(DMBT)18+Au25(PET)1
8]2-

Au25(PET)
18

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

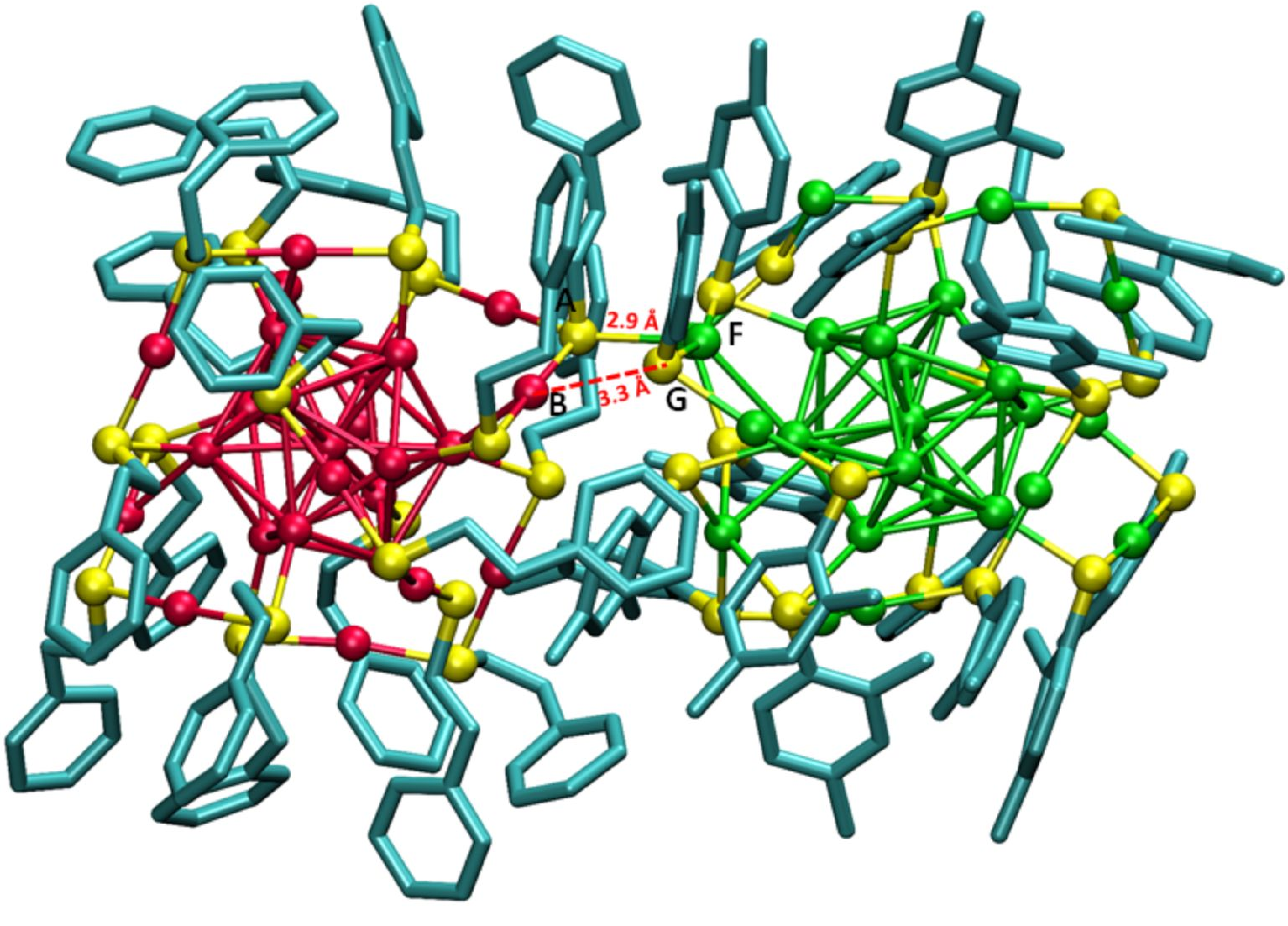
within 5 min

$Ag_{25}(DMBT)_{18}$:$Au_{25}(PET)_{18}$

0.3:1.0

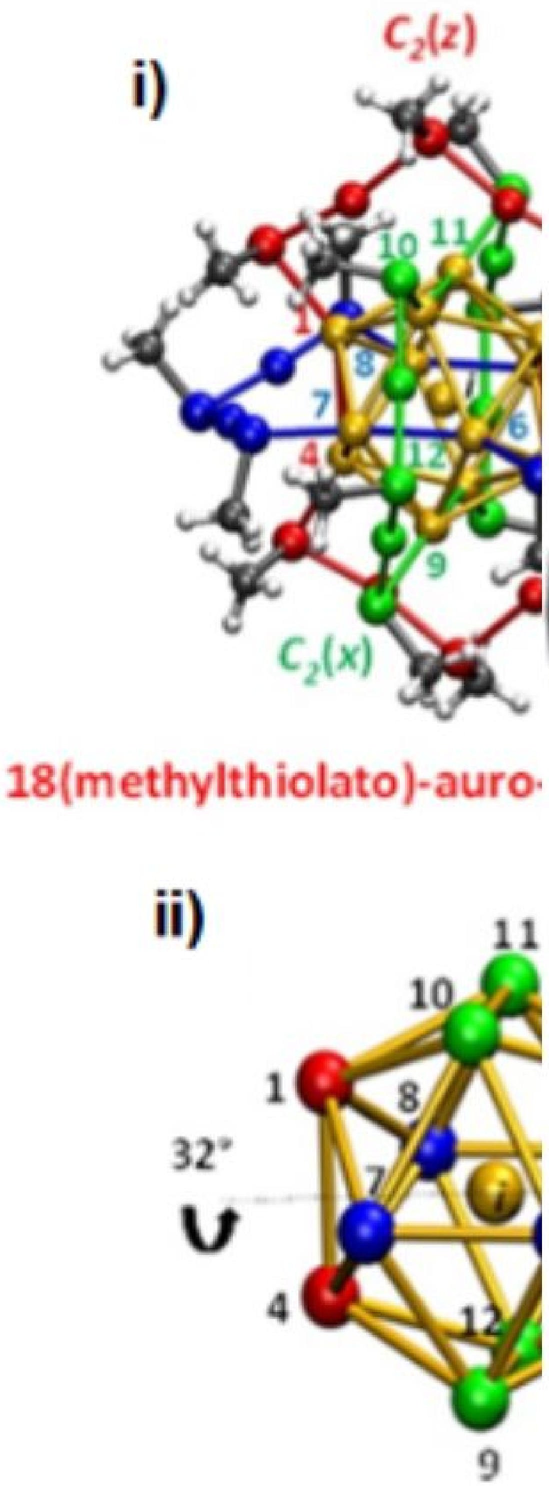
within 2 min

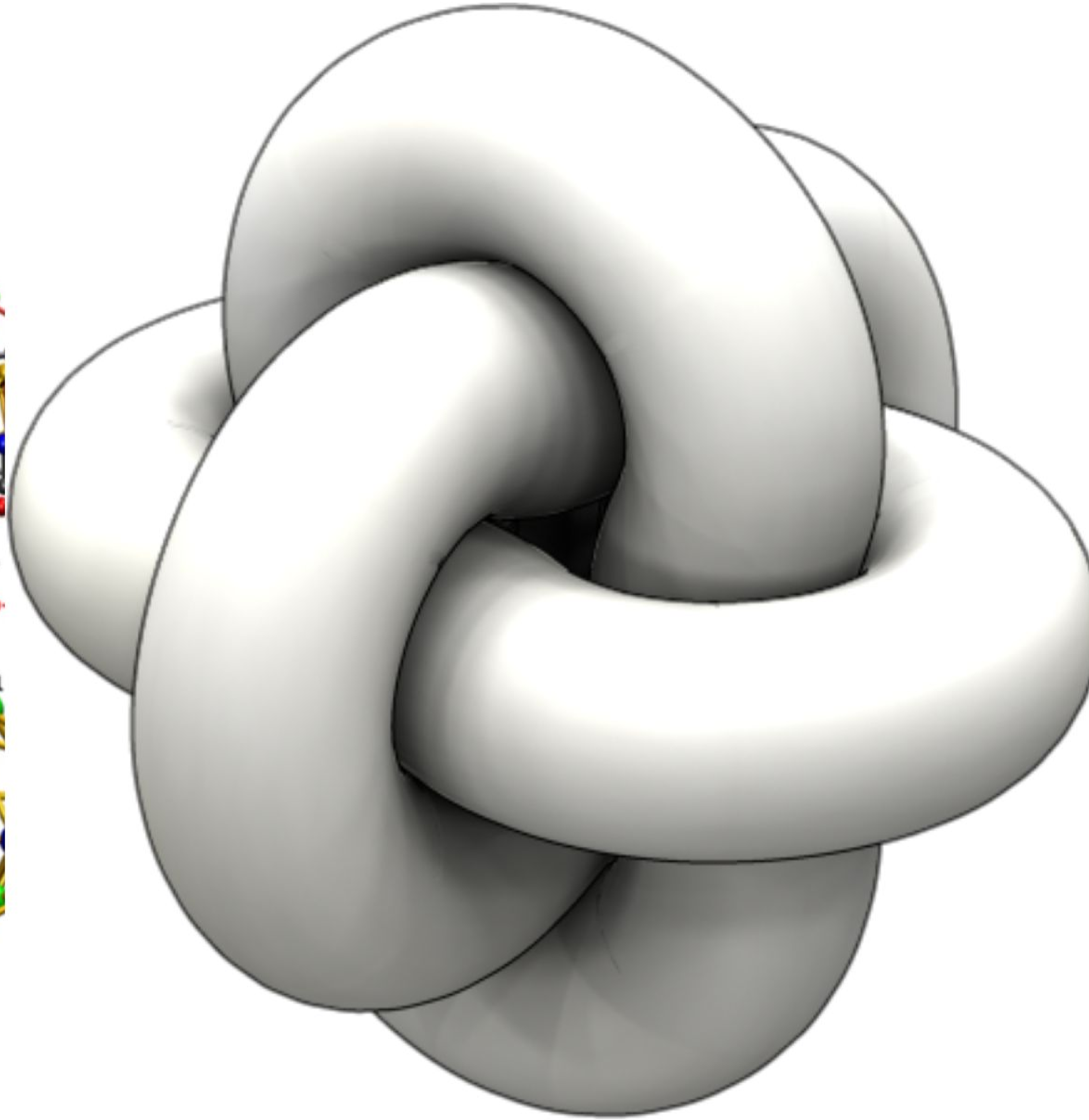
Optimized structure of [Ag25Au25(DMBT)18(PET)18]2-

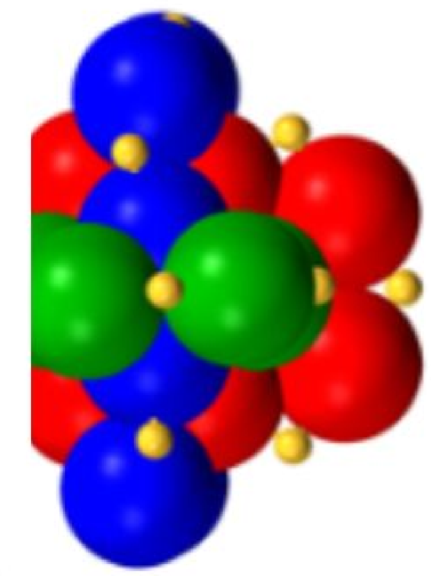


How do we comprehend this?

Nomenclature







Gana Natarajan et. al. *JPC C* 2015

Aspicule
s

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

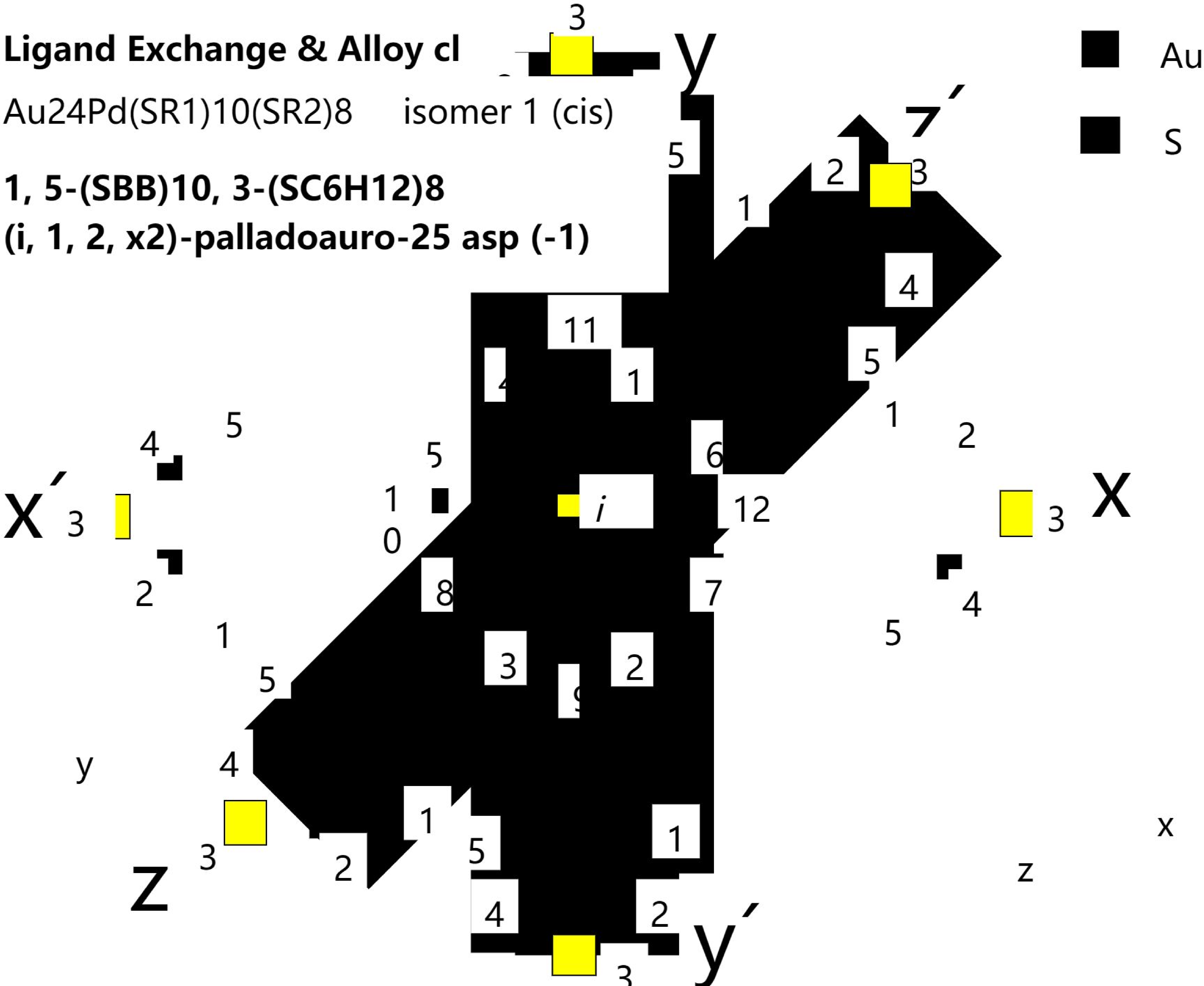
(D1-3,D2-3)-(PET)2,(SMe)16-auro-25 aspicule(1-)

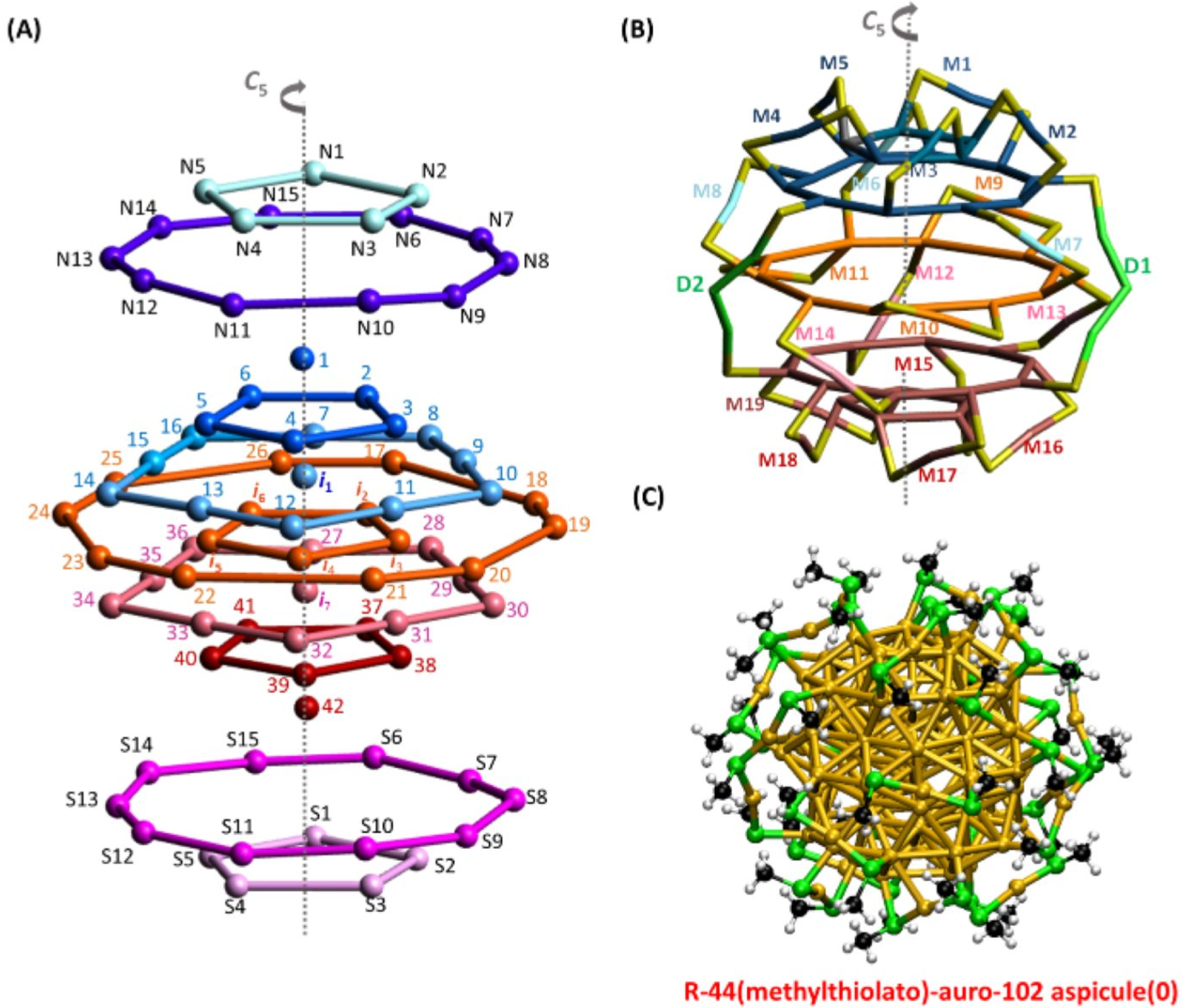
Ligand Exchange & Alloy cl

Au24Pd(SR1)10(SR2)8   isomer 1 (cis)

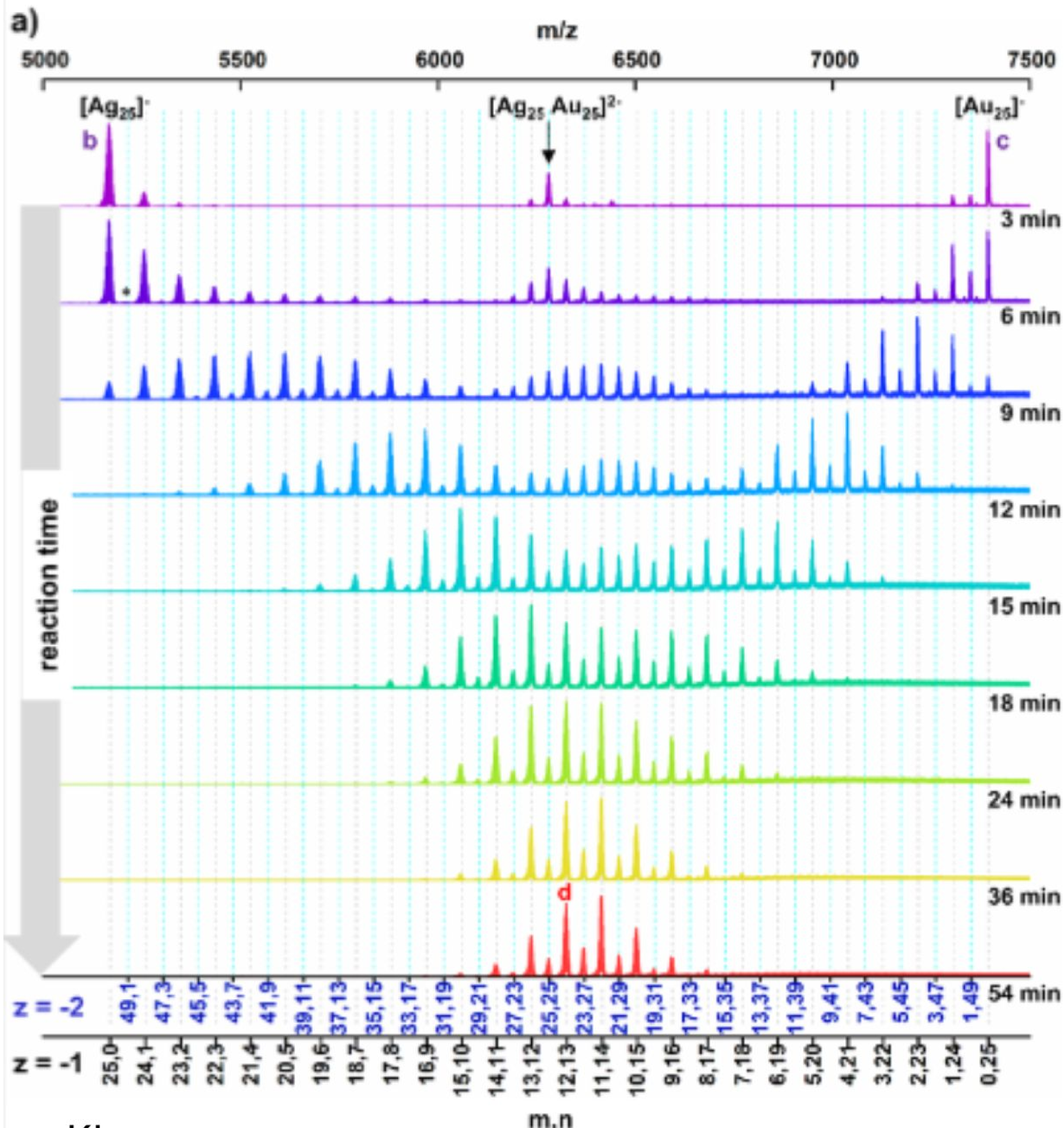
1, 5-(SBB)10, 3-(SC6H12)8

(i, 1, 2, x2)-palladoauro-25 asp (-1)



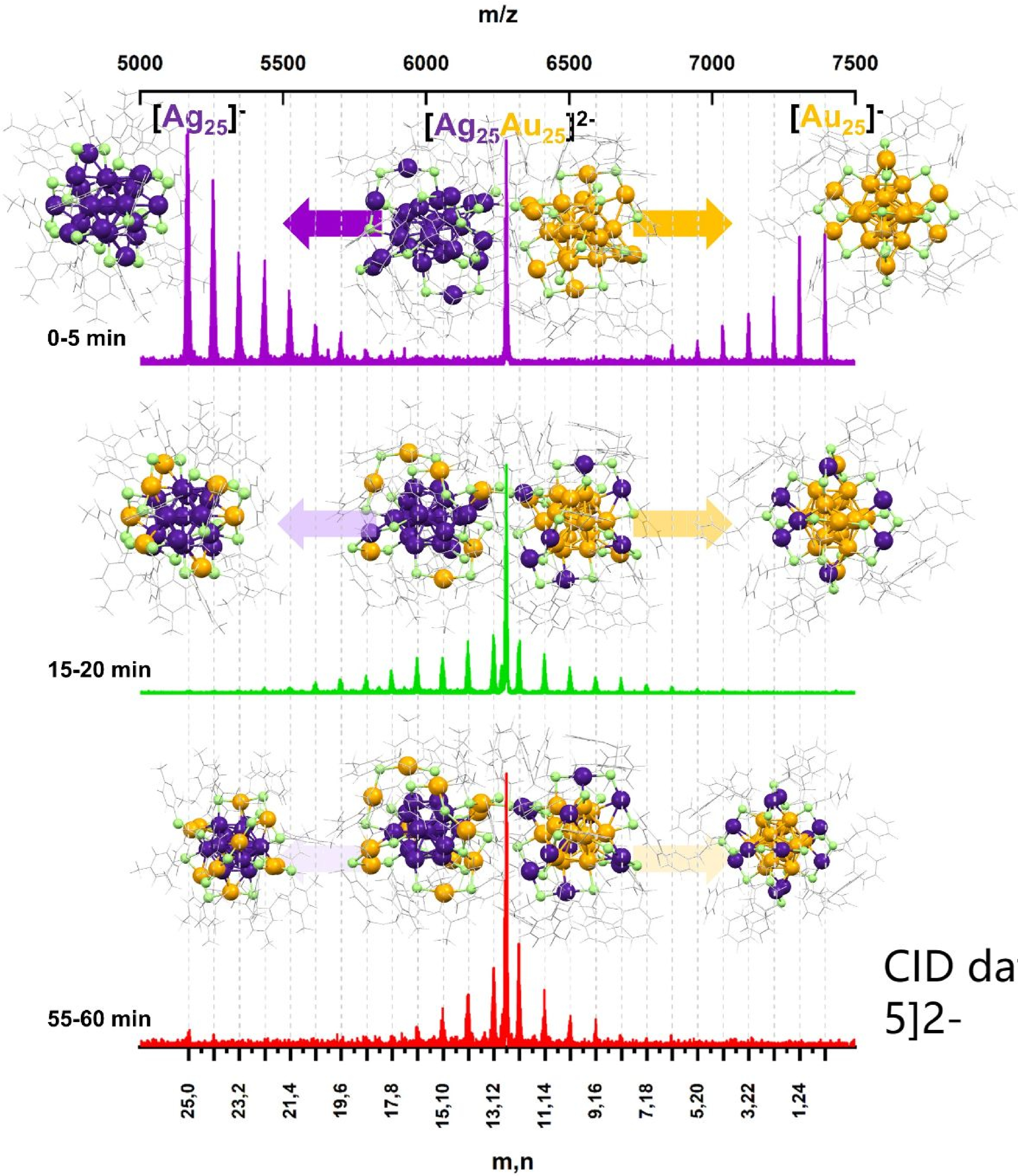


R-(SMe)44-auro-102 aspicule**(**0**)** and L-(SMe)44-auro-102 aspicule**(**0**)**



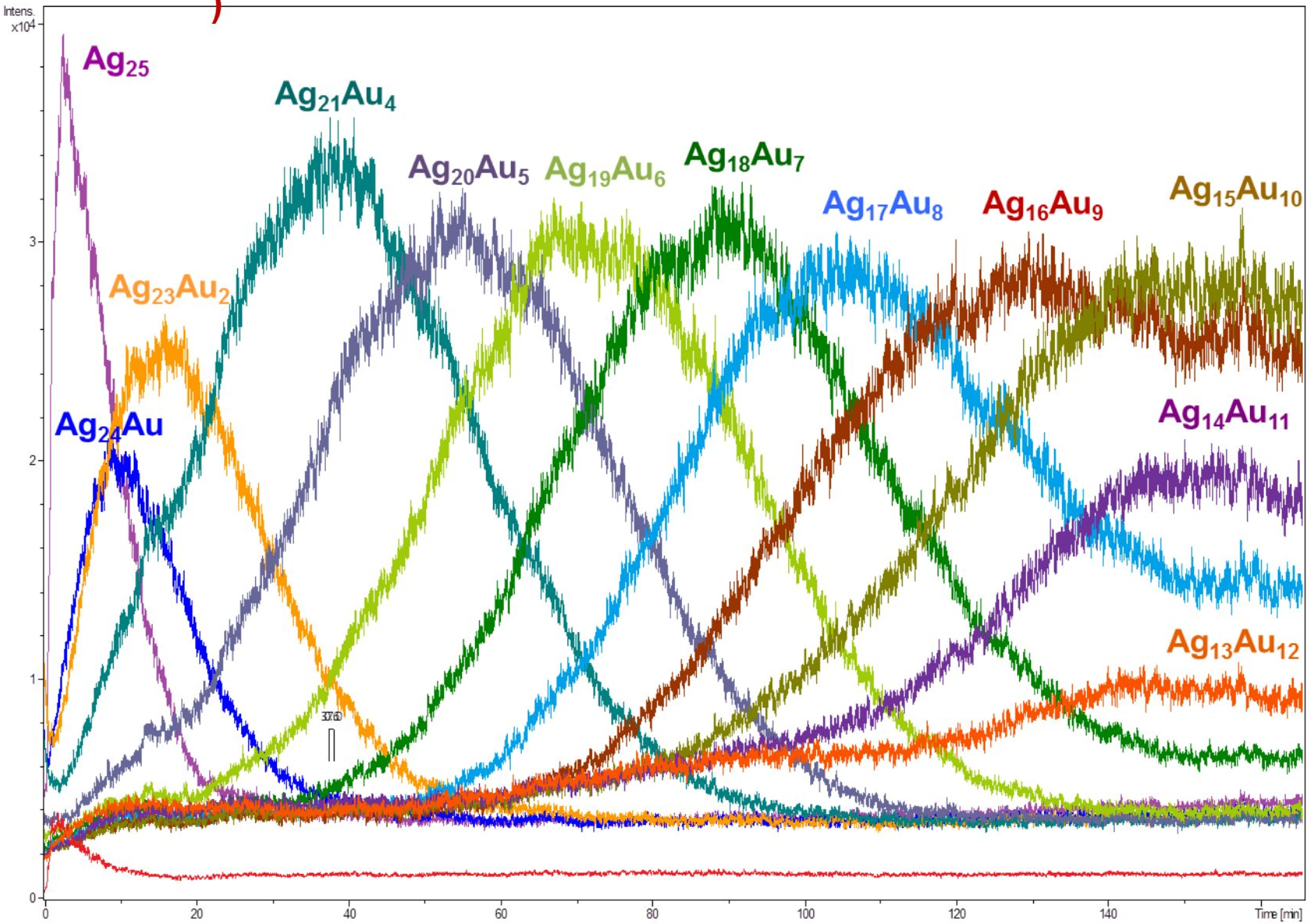
Manfred Kappes, KI
T

M. Neumaier, A. Baksi, et. al., *JACS* 202
1

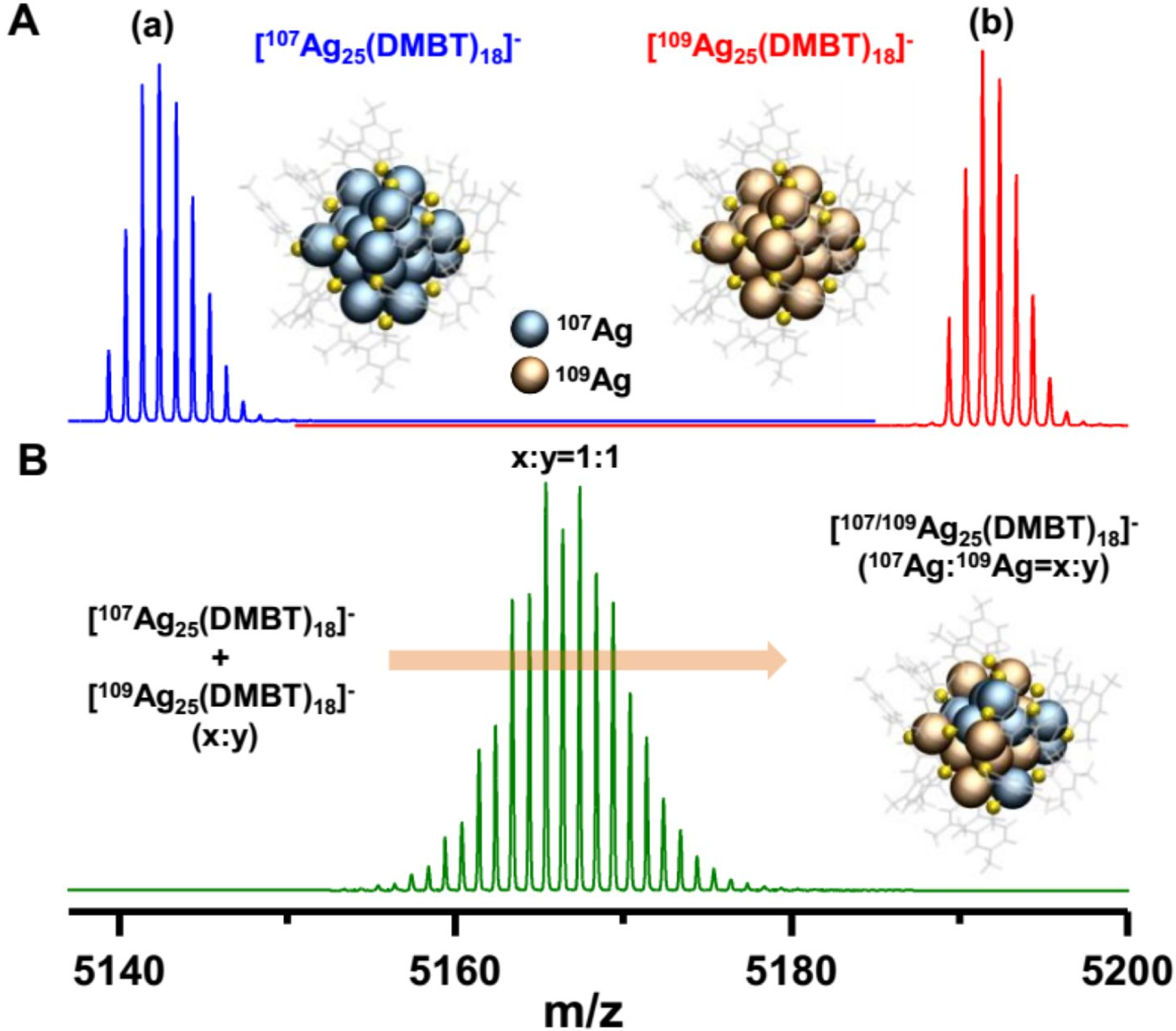


CID data of [Au25Ag2
5]2-

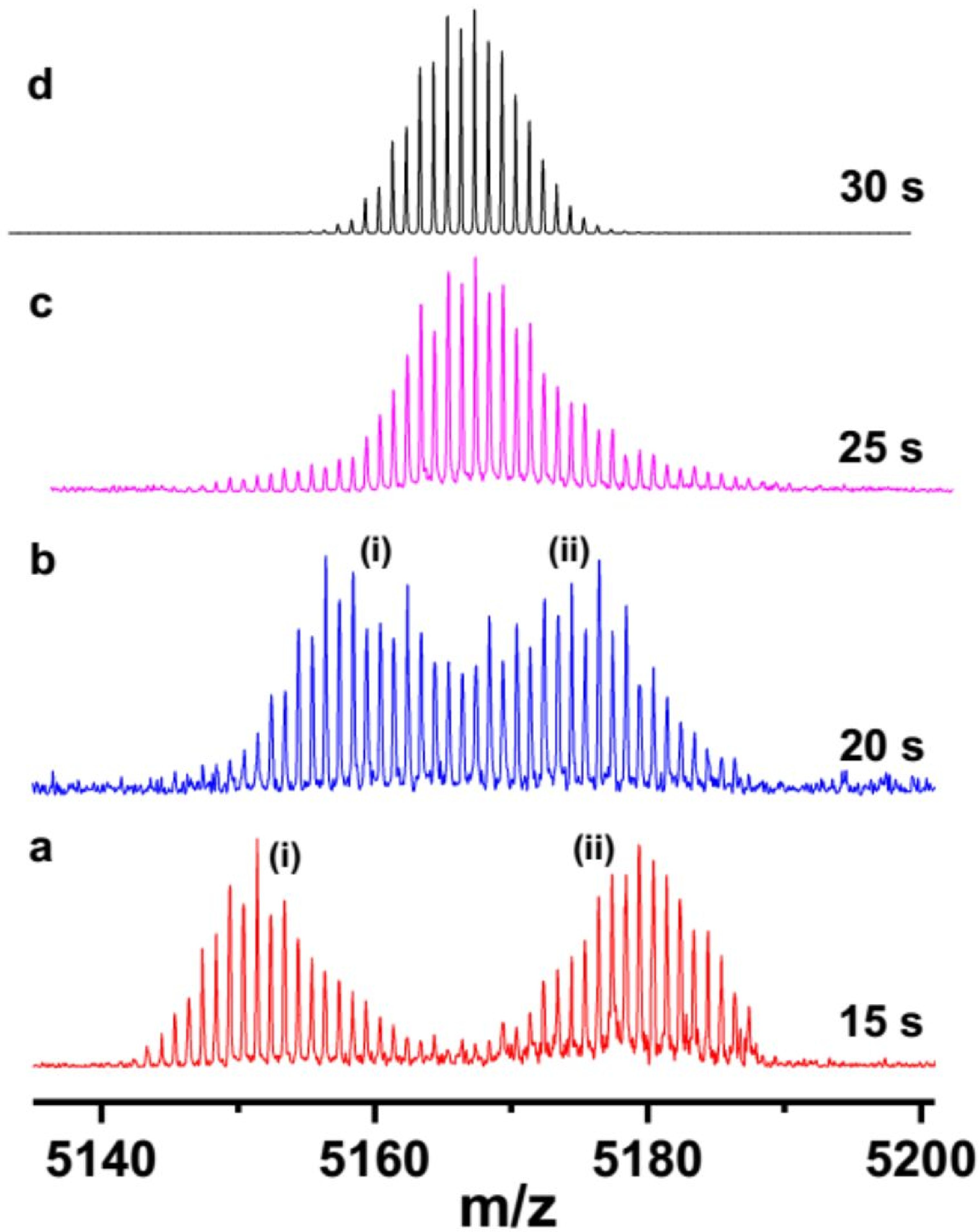
Kinetics of the exchange (monitored on the Ag25 side)



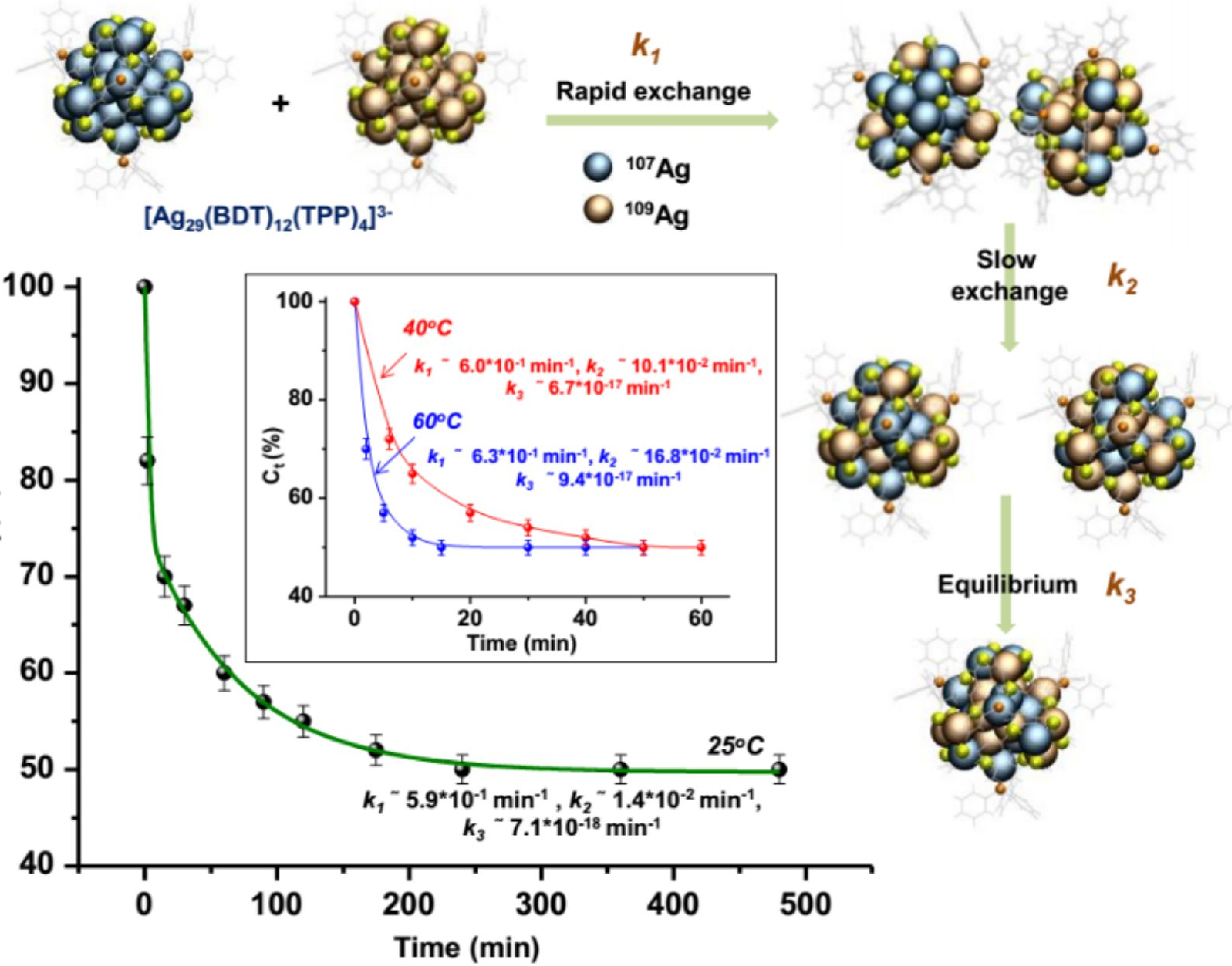
ESI MS of **A)** 107Ag25(DMBT)18 and **B)**109Ag25(DMBT)18. Insets shows the respective isotope patte
rns.



A
(a)
[$^{107}Ag_{25}(DMBT)_{18}]^-$
[$^{109}Ag_{25}(DMBT)_{18}]^-$
(b)
^{107}Ag
^{109}Ag
B
x:y=1:1
[$^{107/109}Ag_{25}(DMBT)_{18}]^-$
($^{107}Ag:^{109}Ag$=x:y)
[$^{107}Ag_{25}(DMBT)_{18}]^-$
+
[$^{109}Ag_{25}(DMBT)_{18}]^-$
(x:y)
5140
5160
5180
5200
m/z



Papri Chakraborty, et. al. *Science Advances* 2019

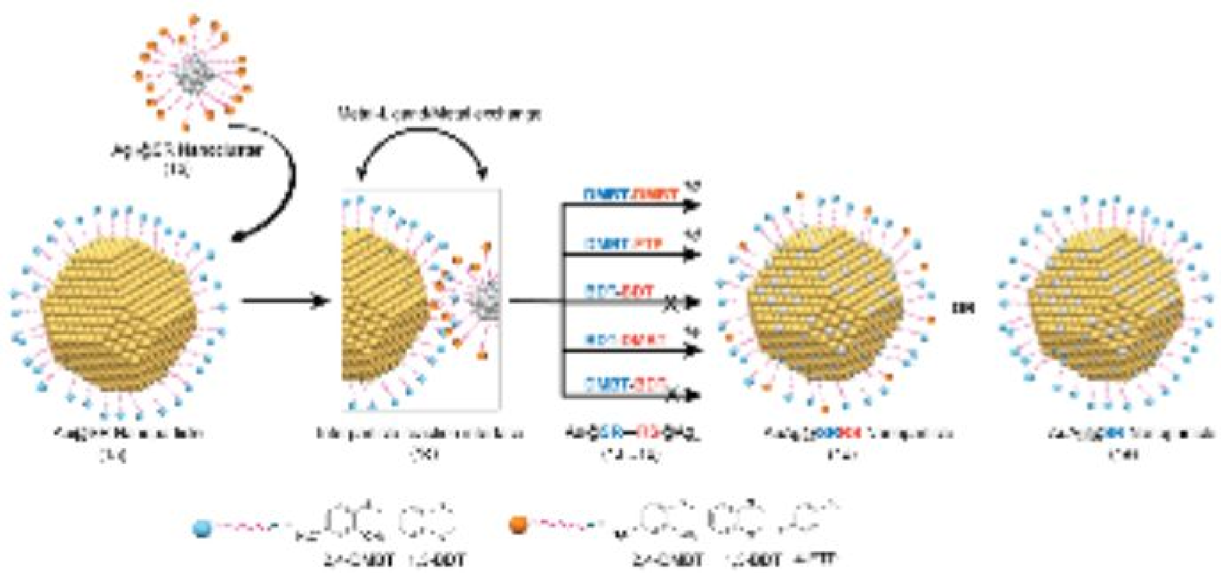


$[Ag_{29}(BDT)_{12}(TPP)_4]^{3-}$
+
k_1
Rapid exchange
^{107}Ag
^{109}Ag
Slow exchange
k_2
Equilibrium
k_3
C_t (%)
Time (min)
25°C
k_1 ~ 5.9*10⁻¹ min⁻¹ , k_2 ~ 1.4*10⁻² min⁻¹,
k_3 ~ 7.1*10⁻¹⁸ min⁻¹
40°C
k_1 ~ 6.0*10⁻¹ min⁻¹, k_2 ~ 10.1*10⁻² min⁻¹,
k_3 ~ 6.7*10⁻¹⁷ min⁻¹
60°C
k_1 ~ 6.3*10⁻¹ min⁻¹, k_2 ~ 16.8*10⁻² min⁻¹
k_3 ~ 9.4*10⁻¹⁷ min⁻¹

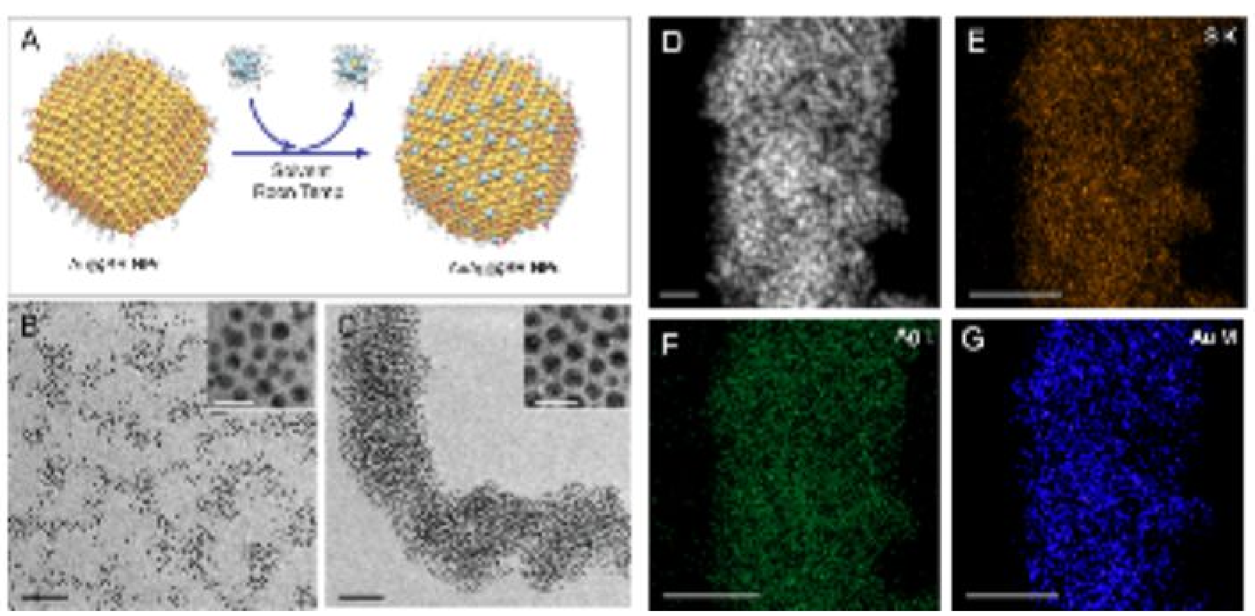
Can clusters react with nanoparticle
s?

Ag25 with Au nanoparticles

1

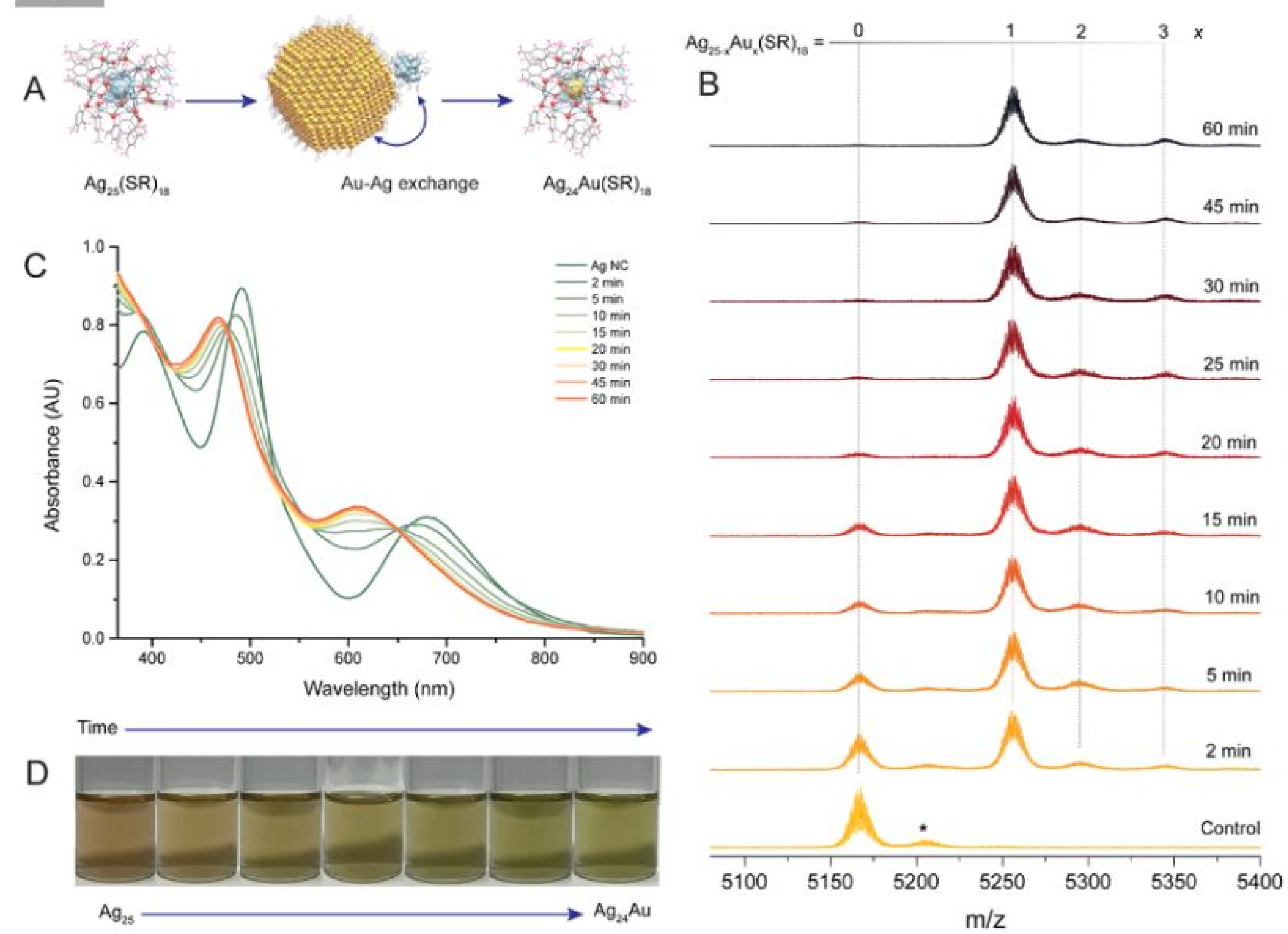


2



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

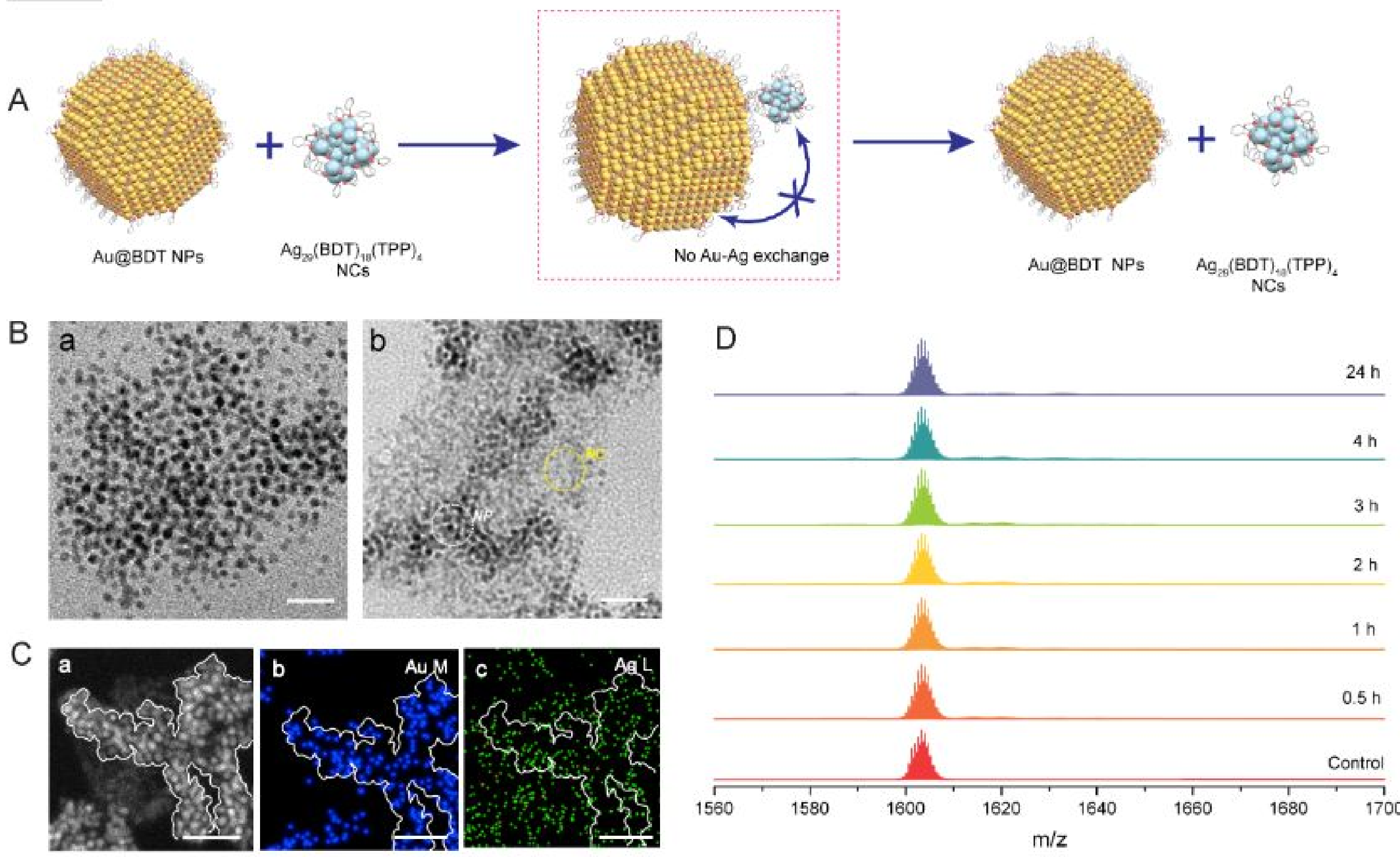
3



Paulami Bose, et al. *Chem. Mat.* 2024

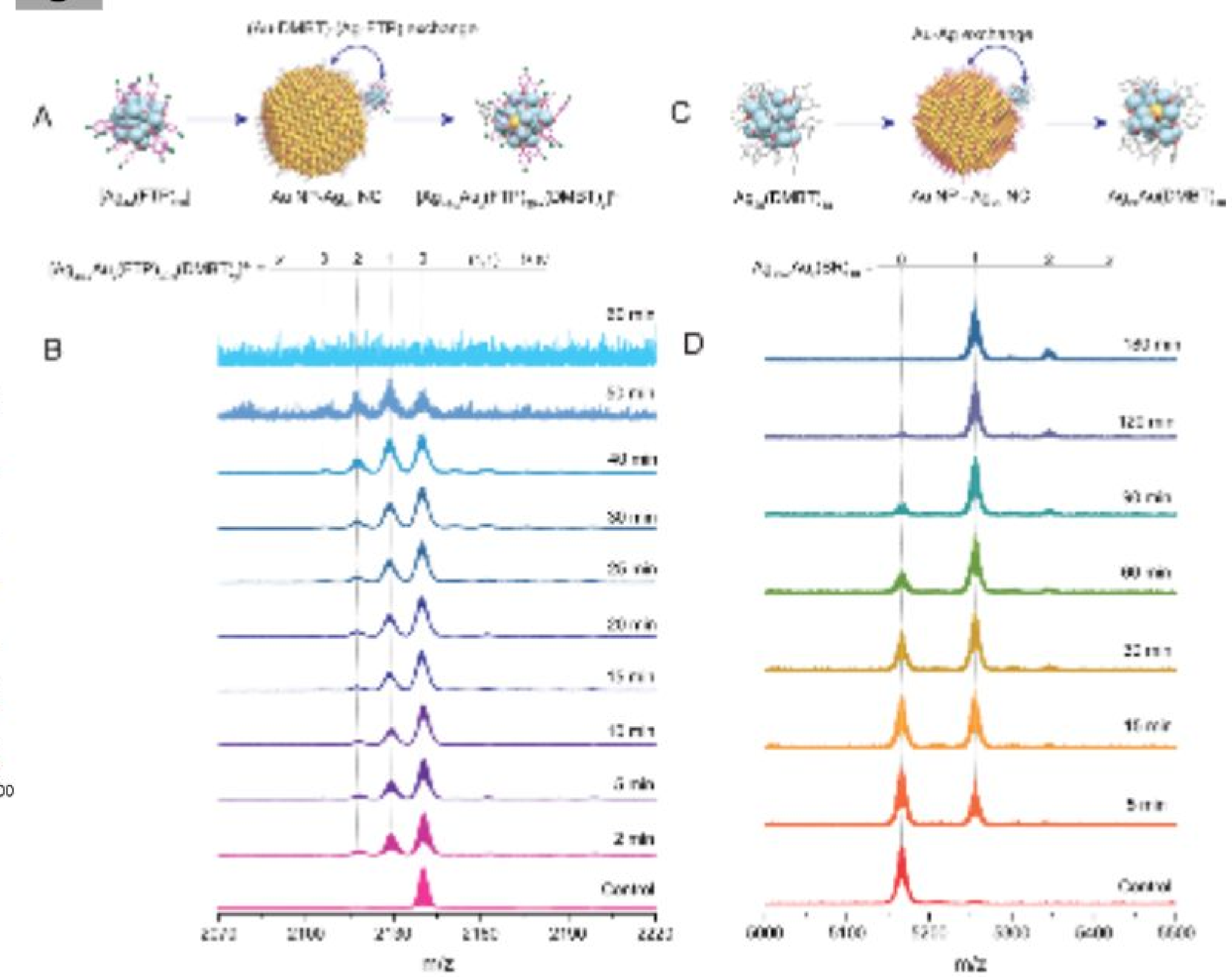
Interface controls the reaction

4



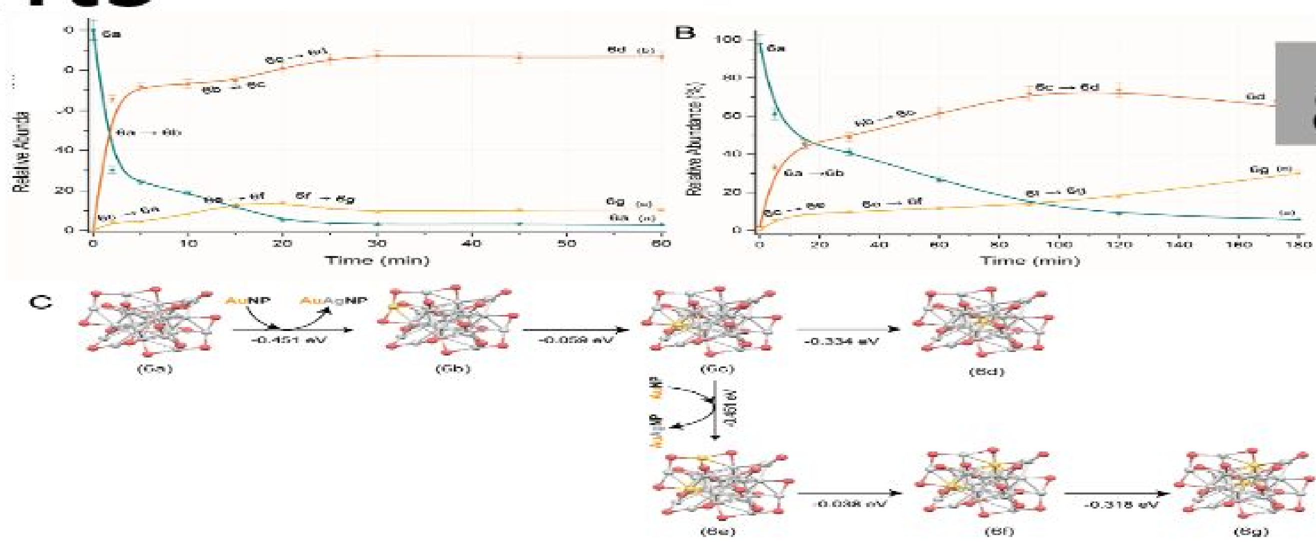
Scale bars: 20 nm

5

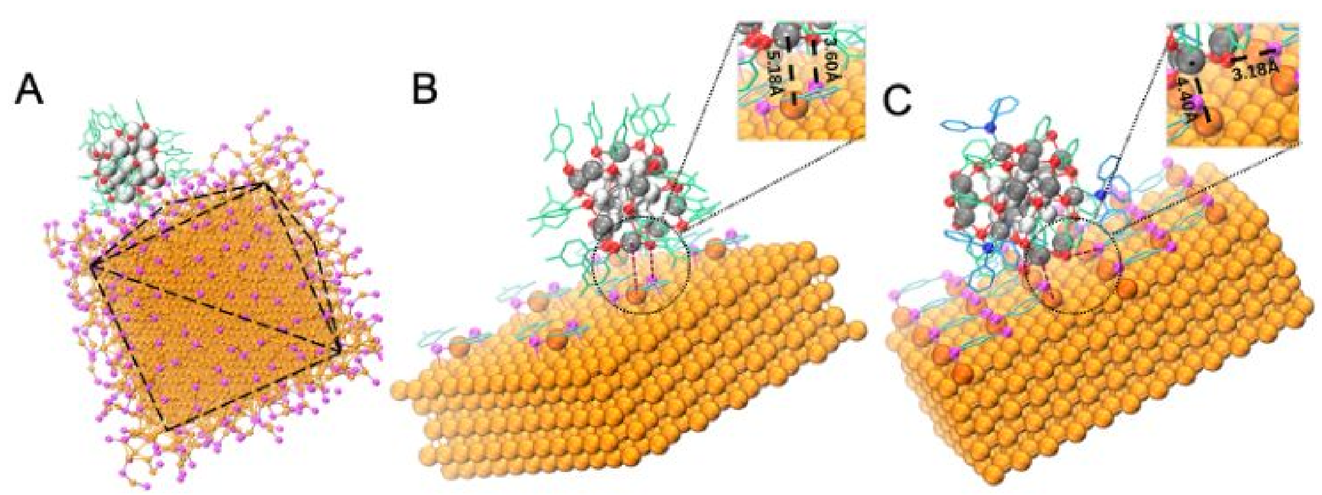


Computational insights

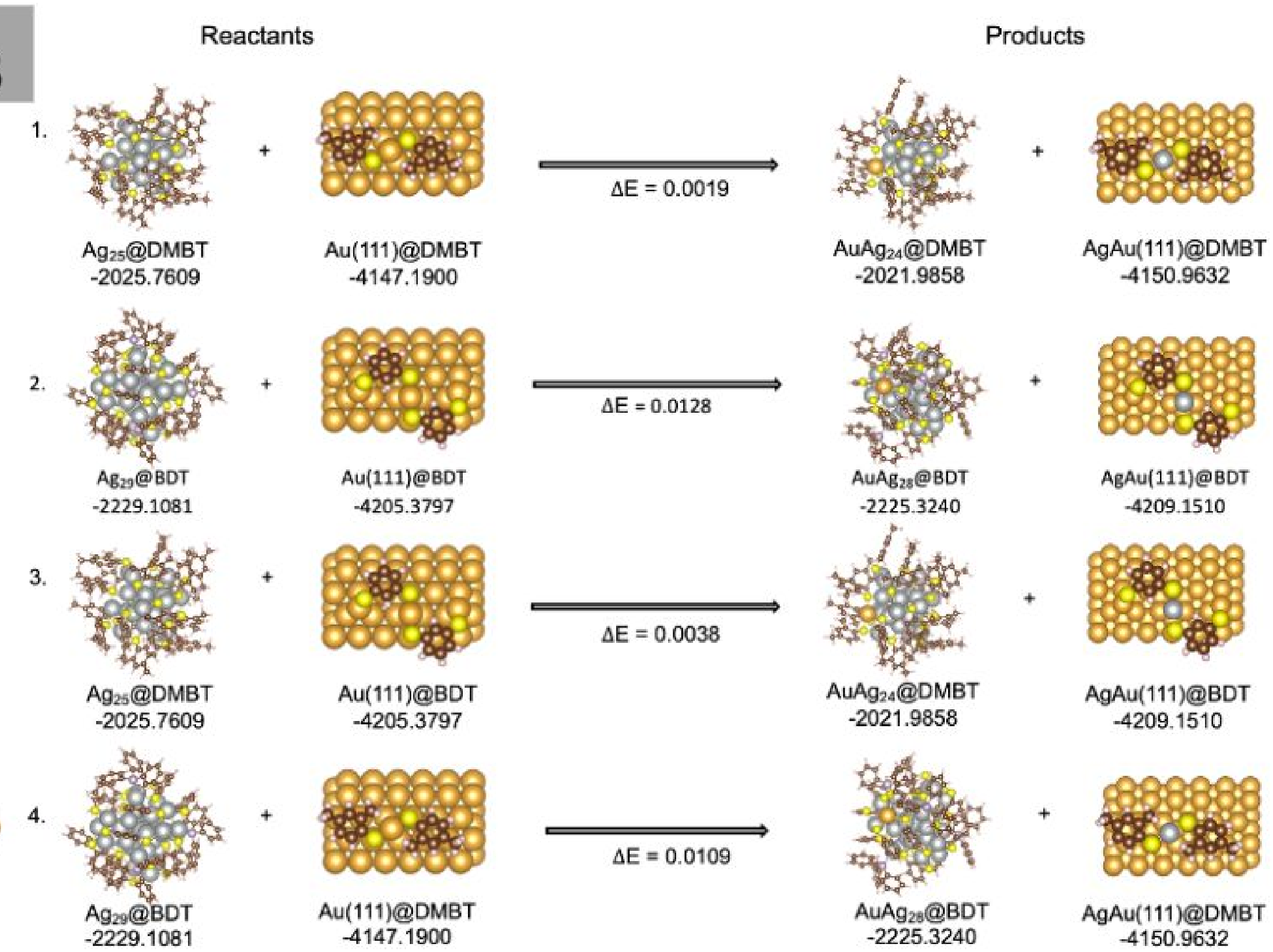
6



7



8



Reactions and new materia
ls

Reactions leading to co-crystals

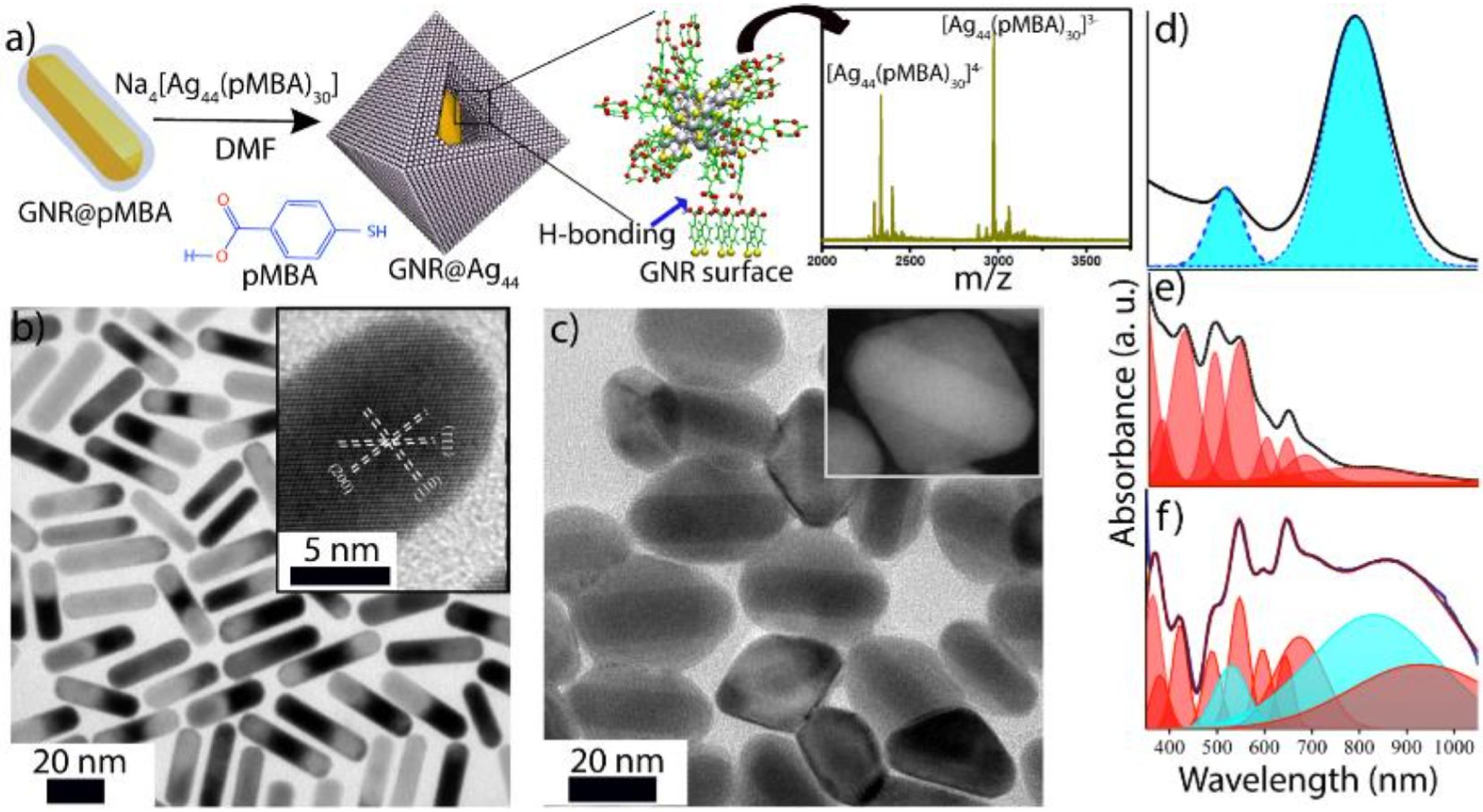
Supramolecular chemistr
y

Papri Chakraborty, et,. al. *ACS Nano* 20
18

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 $[Ag_{29}(BDT)_{12}(C_{60})_4]^{3-}$.

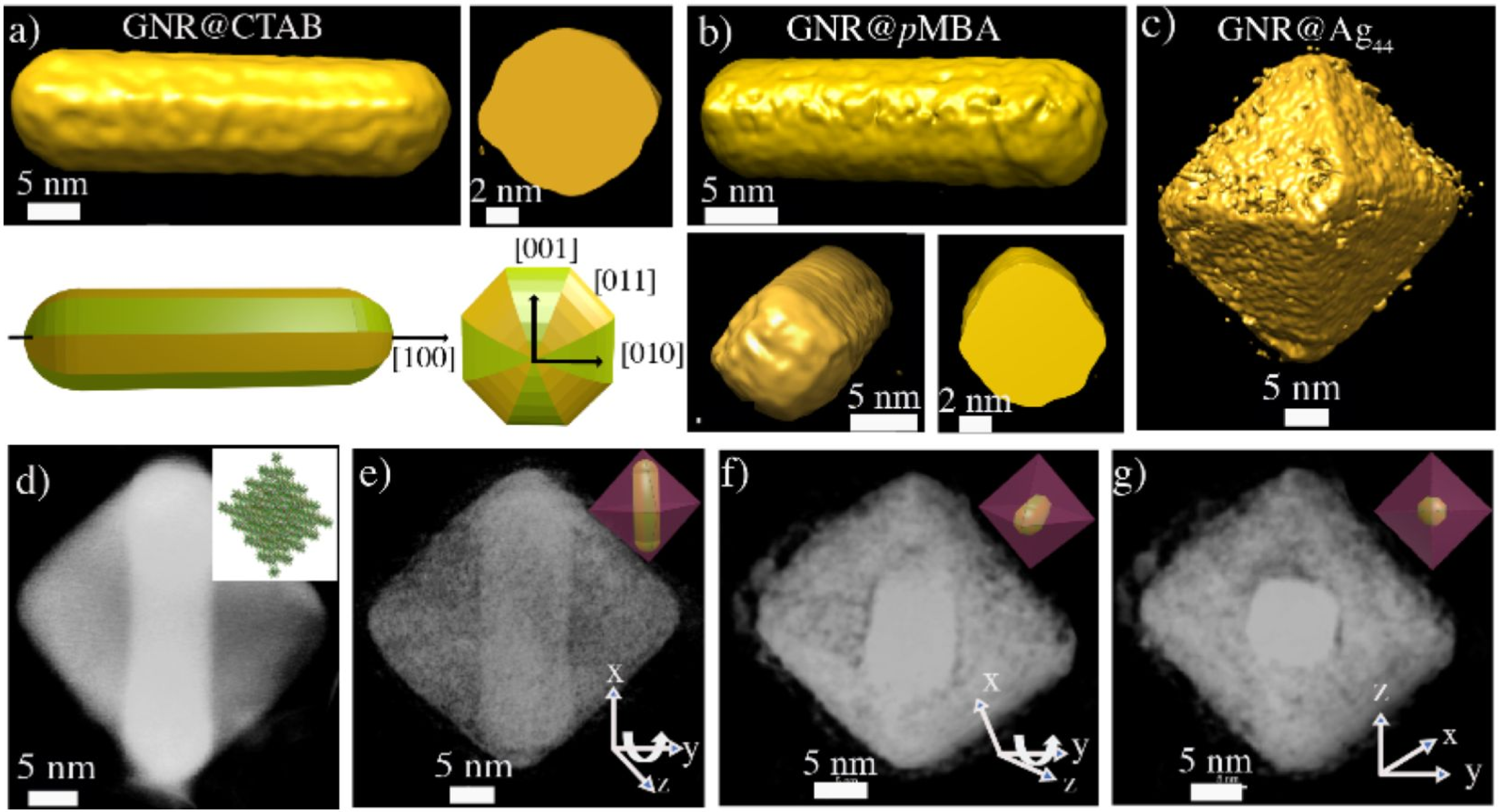
Assemblies and superstructures

Atomically precise nanocluster assemblies encapsulating plasmonic gold nanorods

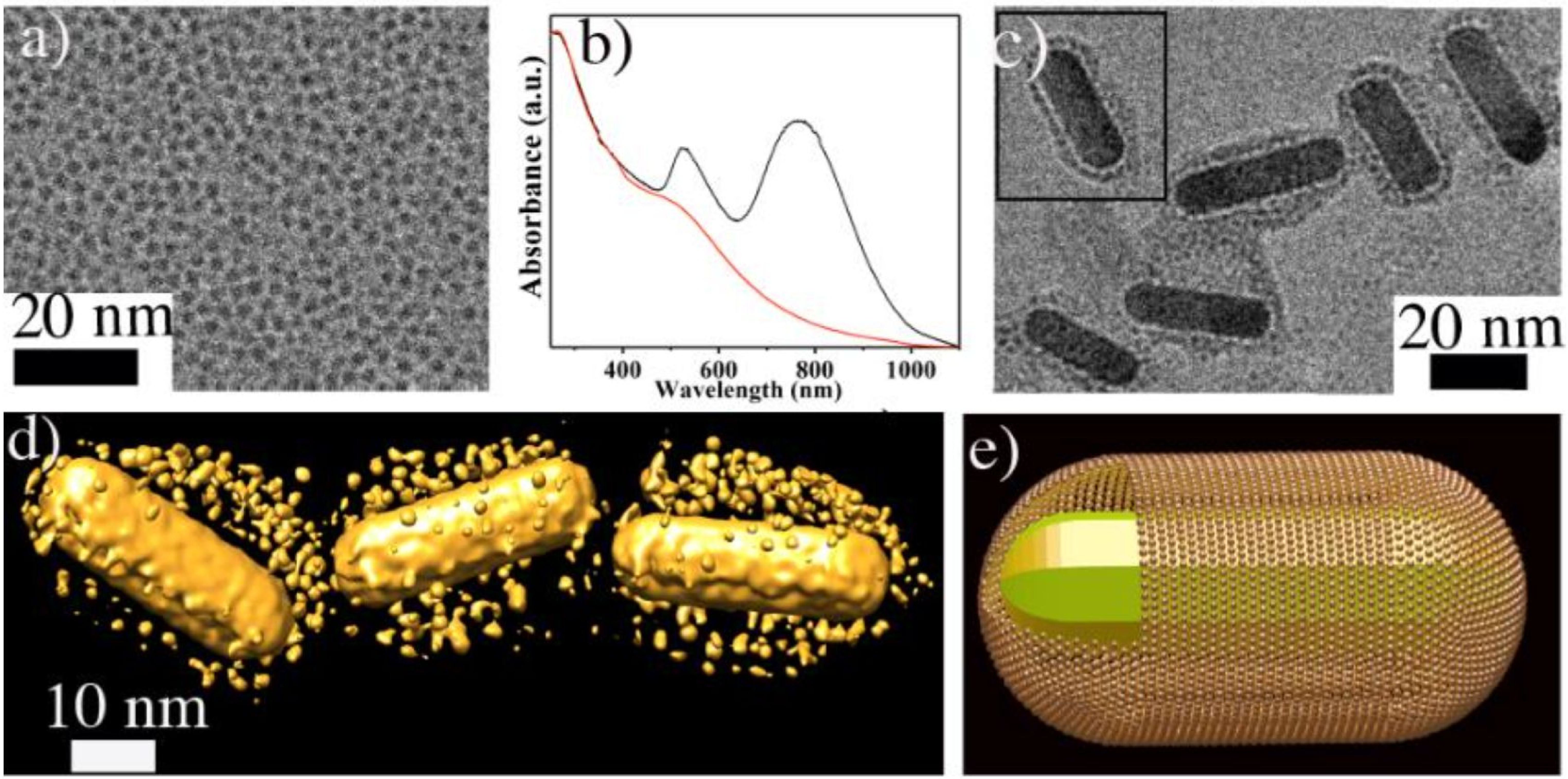


Chakraborty, A. et al., *Angew. Chem. Int. Ed.* **2018,** *57*, 6522–6526.

3D morphological analysis



Works for Au250(*p*MBA)n and aqueous solvent



Co-crystals

Ag40 and Ag46 with the same shell

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

Isomerism in supramolecular adducts

Abhijit Nag, et al. *JACS* 201
8

A)

Ag29BDT12 = X β-cyclodextrin = CD

X∩CD13-

Calculated

Experimental

X∩CD23-

a)

X∩CD13- X∩CD33-

m/z

X3-

X∩CD43-

b)

CD-

X∩CD53-

X∩CD63-

X∩CD13-

m/z

a)

X∩CD33-

Isomer 1 Isomer 2

613.0 Å2 628.0 Å2

b)

X∩CD23-

Isomer 1 Isomer 2

526.0 Å2 540.0 Å2

c)

X∩CD13-

438.0 Å2

Drift time (ms)

d)

X∩CD63-

903.0 Å2

e)

X∩CD53-

812.0 Å2

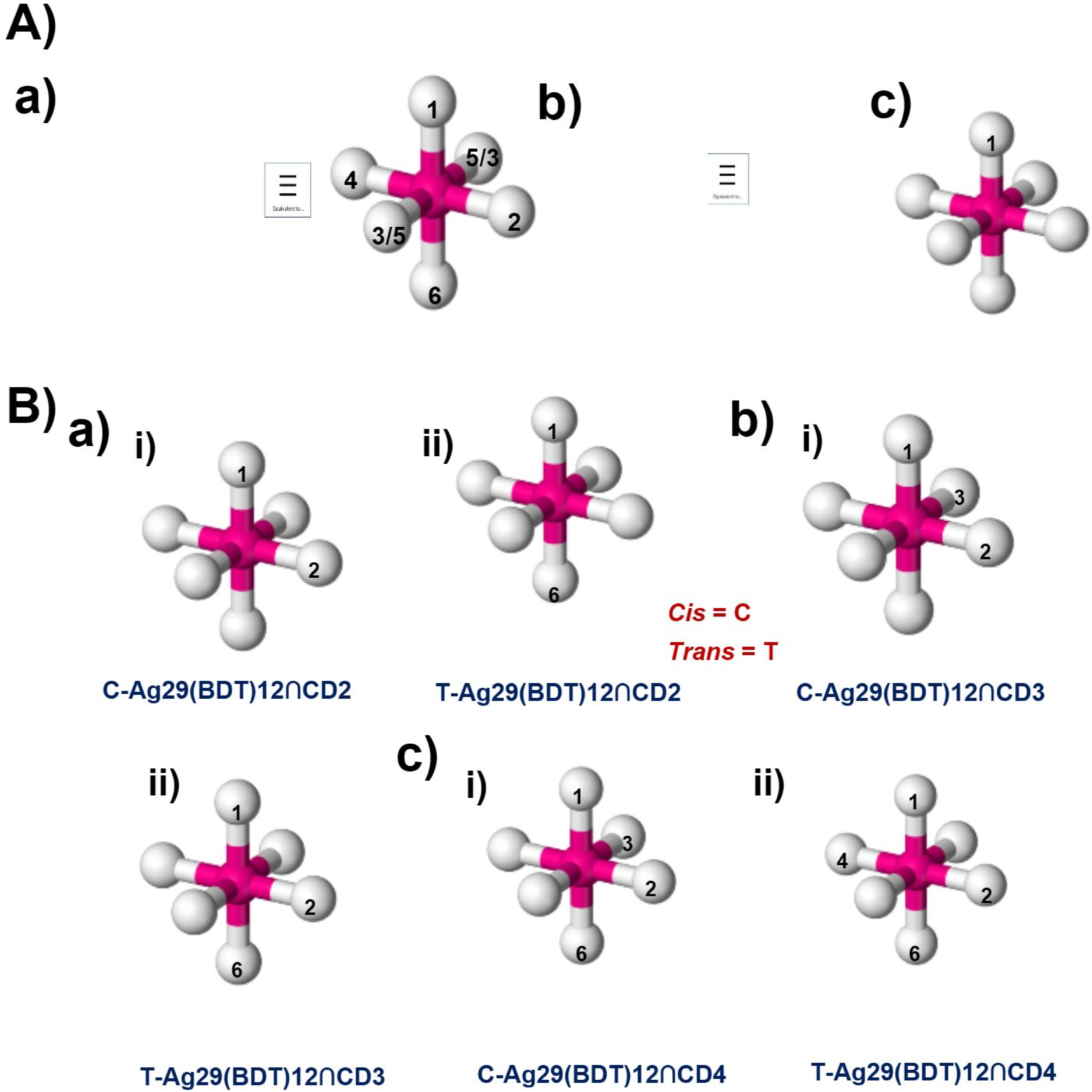
f)

X∩CD43-

Isomer 1 Isomer 2

705.0 Å2 724.0 Å2

Drift time (ms)


A)
a)
1
5/3
4
2
3/5
6
b)
c)
1
B) a)
i)
1
2
C-Ag29(BDT)12∩CD2
ii)
1
6
T-Ag29(BDT)12∩CD2
Cis = C
Trans = T
b)
i)
1
3
2
C-Ag29(BDT)12∩CD3
ii)
1
2
6
T-Ag29(BDT)12∩CD3
c)
i)
1
3
2
6
C-Ag29(BDT)12∩CD4
ii)
1
4
2
6
T-Ag29(BDT)12∩CD4

Where are they taking us to?

PNAS PNAS PNAS PNAS

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

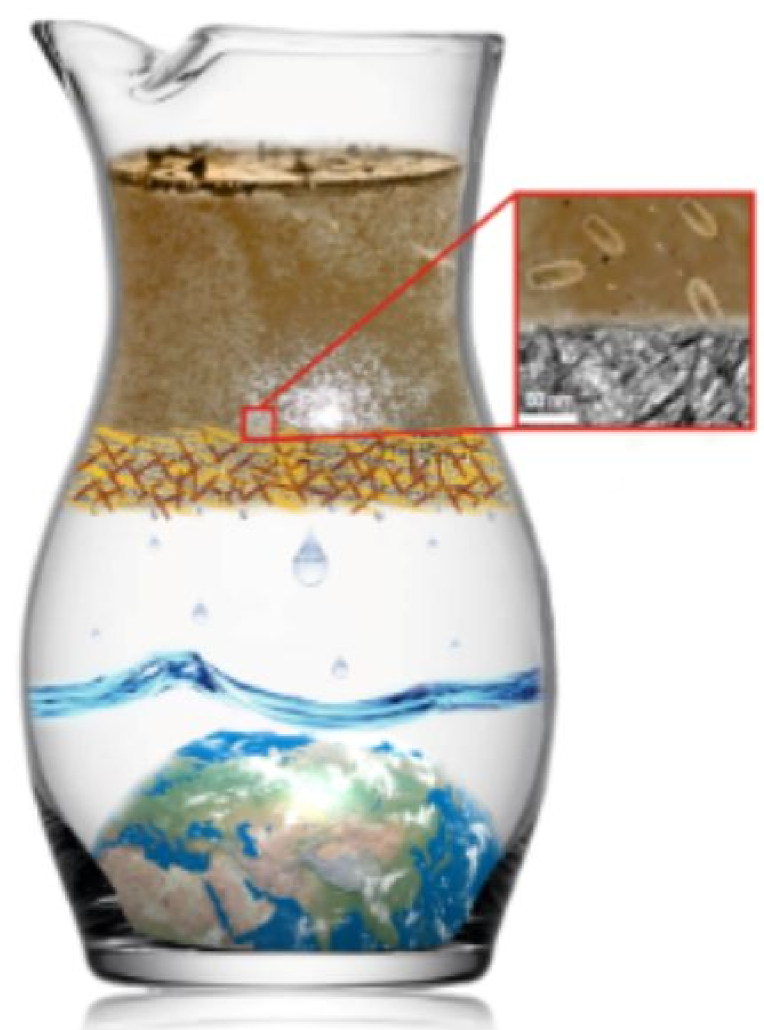
Mohan Udhaya Sankar[1], Sahaja Aigal[1], Shihabudheen M. Maliyekkal[1], Amrita Chaudhary, Anshup, Avula Anil Kumar, Kamalesh Chaudhari, and Thalappil Pradeep[2]

Unit of Nanoscience and Thematic Unit of Ex … Madras, Chennai 600 036, India

Edited by Eric Hoek, University of California, … (received for review November 21, 2012)

Creation of affordable materials for cons
water is one of the most promising ways
drinking water for all. Combining the
composites to scavenge toxic species
other contaminants along with the abo
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 con
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

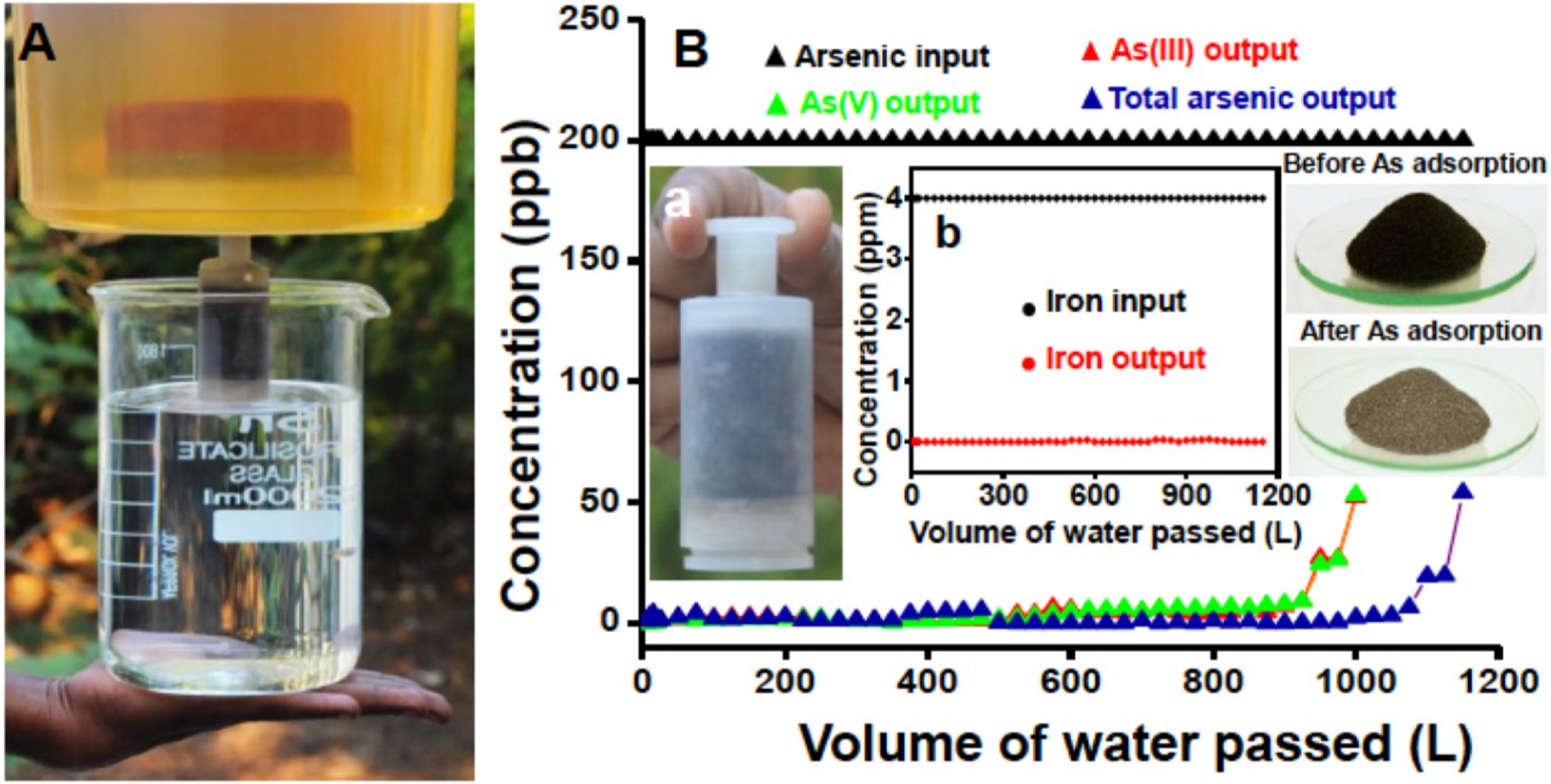


vailable; and (*c*) continued retention
matrix is difficult.
ate a unique family of nanocrystalline
n granular composite materials pre-
ature through an aqueous route. The
mposition is attributed to abundant -O-
on chitosan, which help in the crys-
oxide and also ensure strong covalent
surface to the 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
disease burden.

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) 1 604260.

Safety of spent media, TCLP

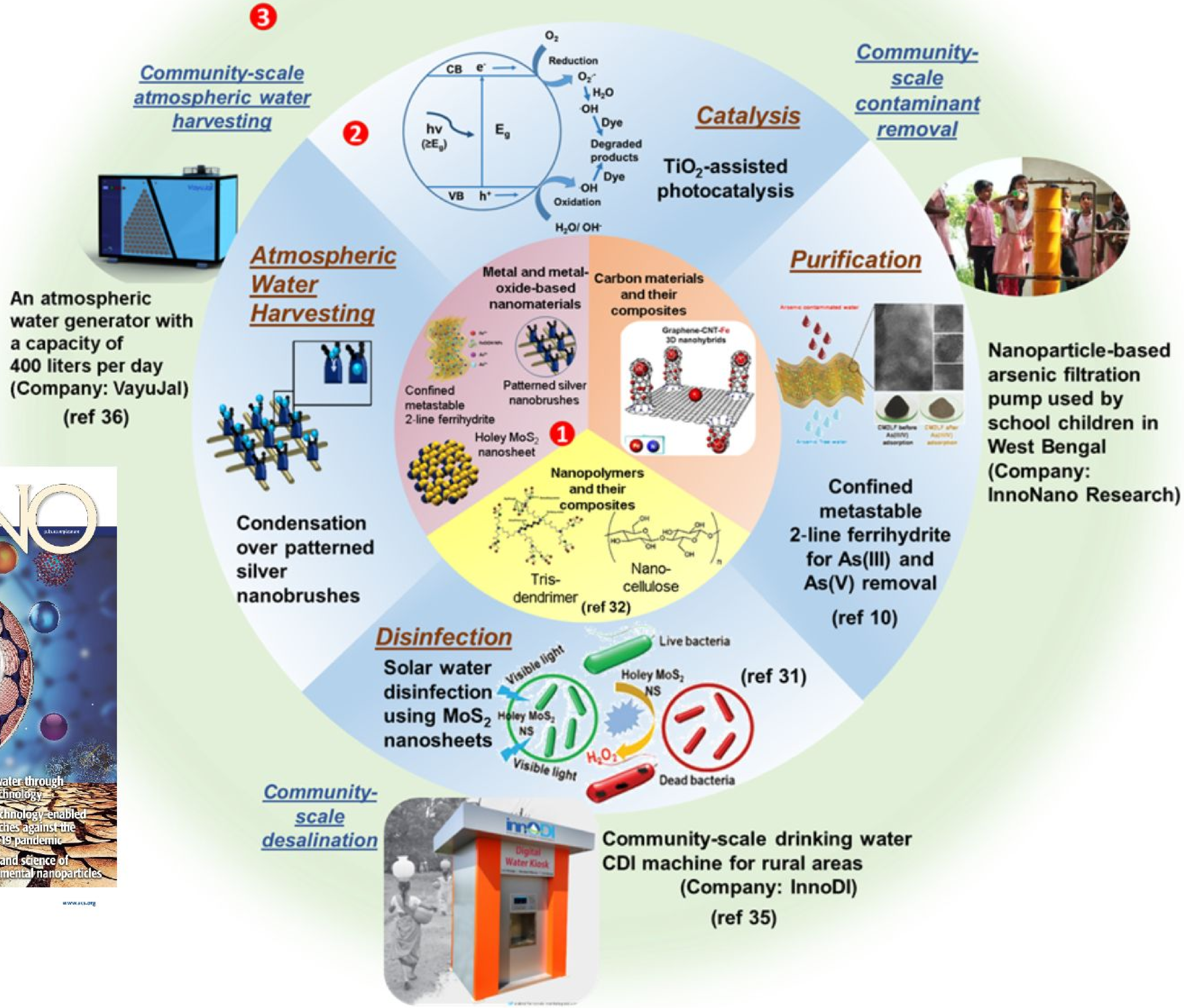
Clean water for everyone

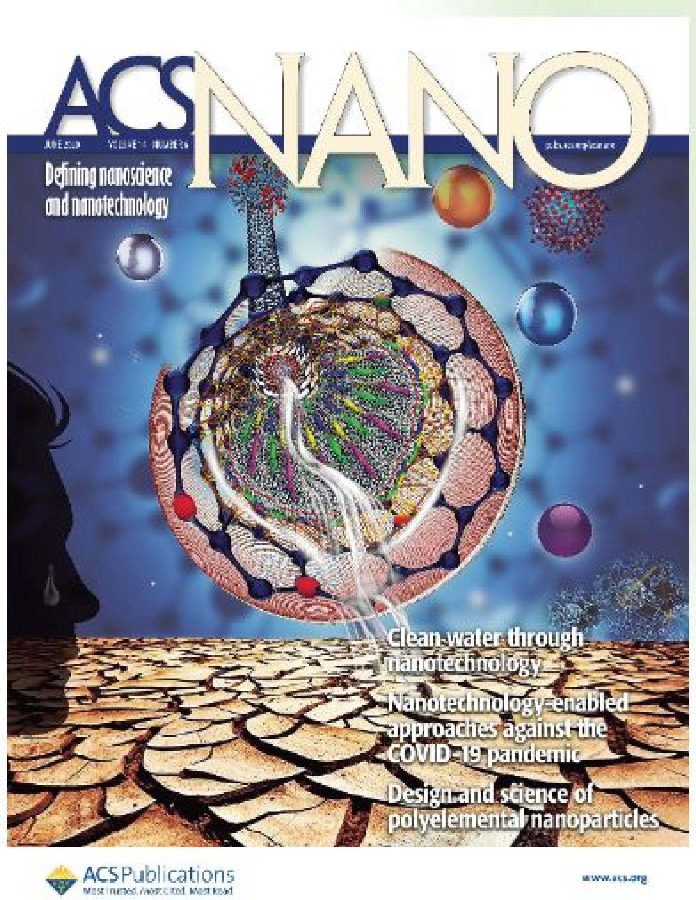
ACS Sustainable Chemistry & Engineering Editori
al, December 2016

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

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

Evolution of materials to products



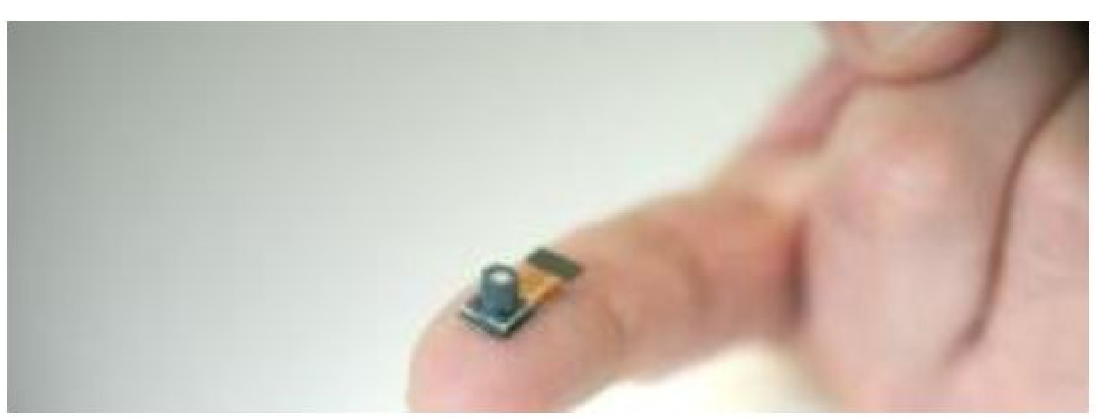


Ankit Nagar and T. Pradeep 14(2020). *ACS Nano*, 6420-6435

Smart water purifiers and big data

Ankit Nagar and T. Pradeep 14(2020). *ACS Nano*, 6420-6435

Sensors and new opportunities



Water quality measurement – In the pipe line

Cluster-based metal ion sensing

Decrease in the absorption of Au15 as a biofilm is dipped into the cluster soluti
on. Inset: Free standing quantum cluster loaded film in visible light and UV light
.

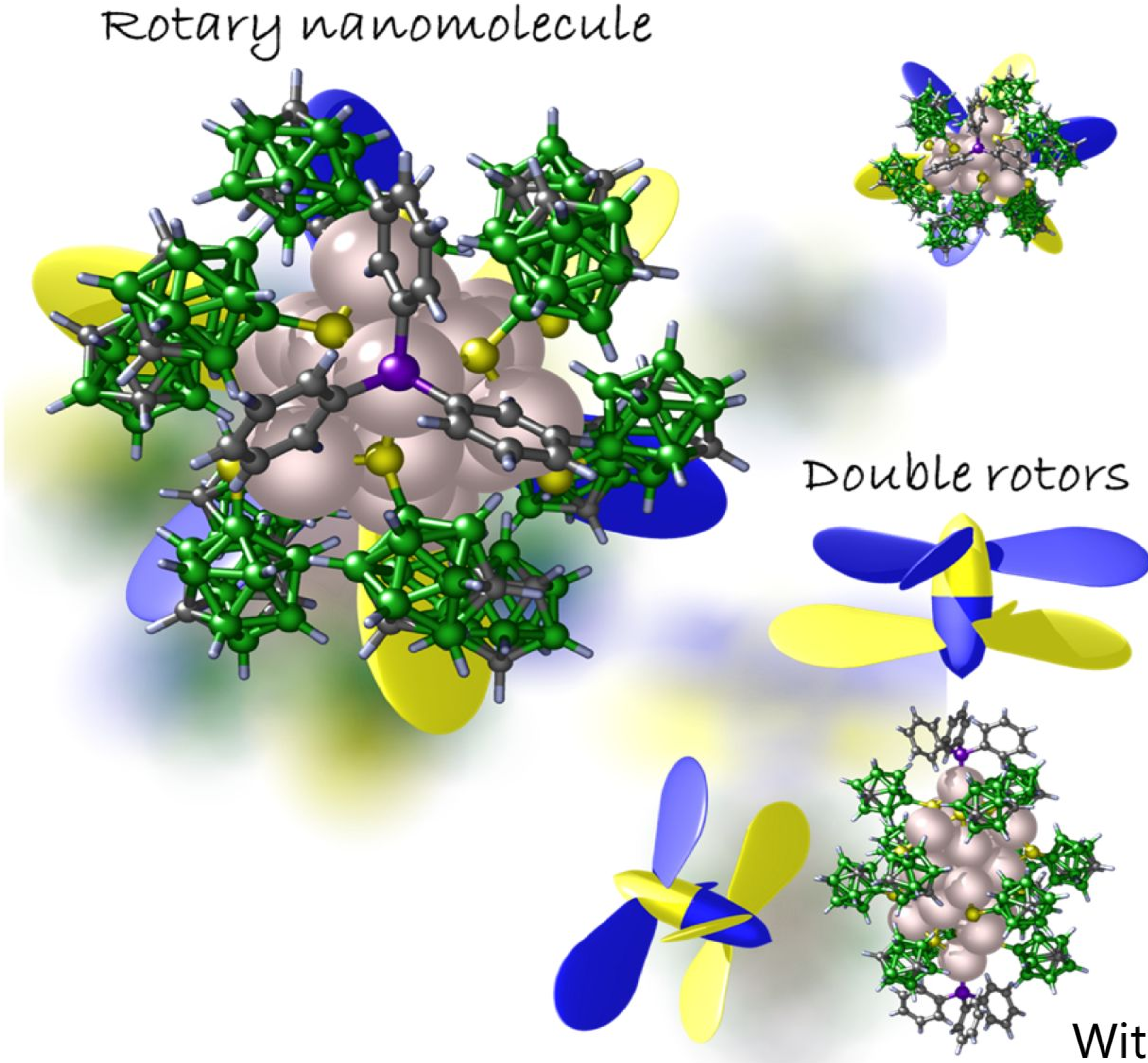
Anu George et al. *ACS Applied Materials & Interfaces*, 2012

Approaching detection limits of tens of Hg2
+

Atanu Ghosh et al. Anal. Chem. 201

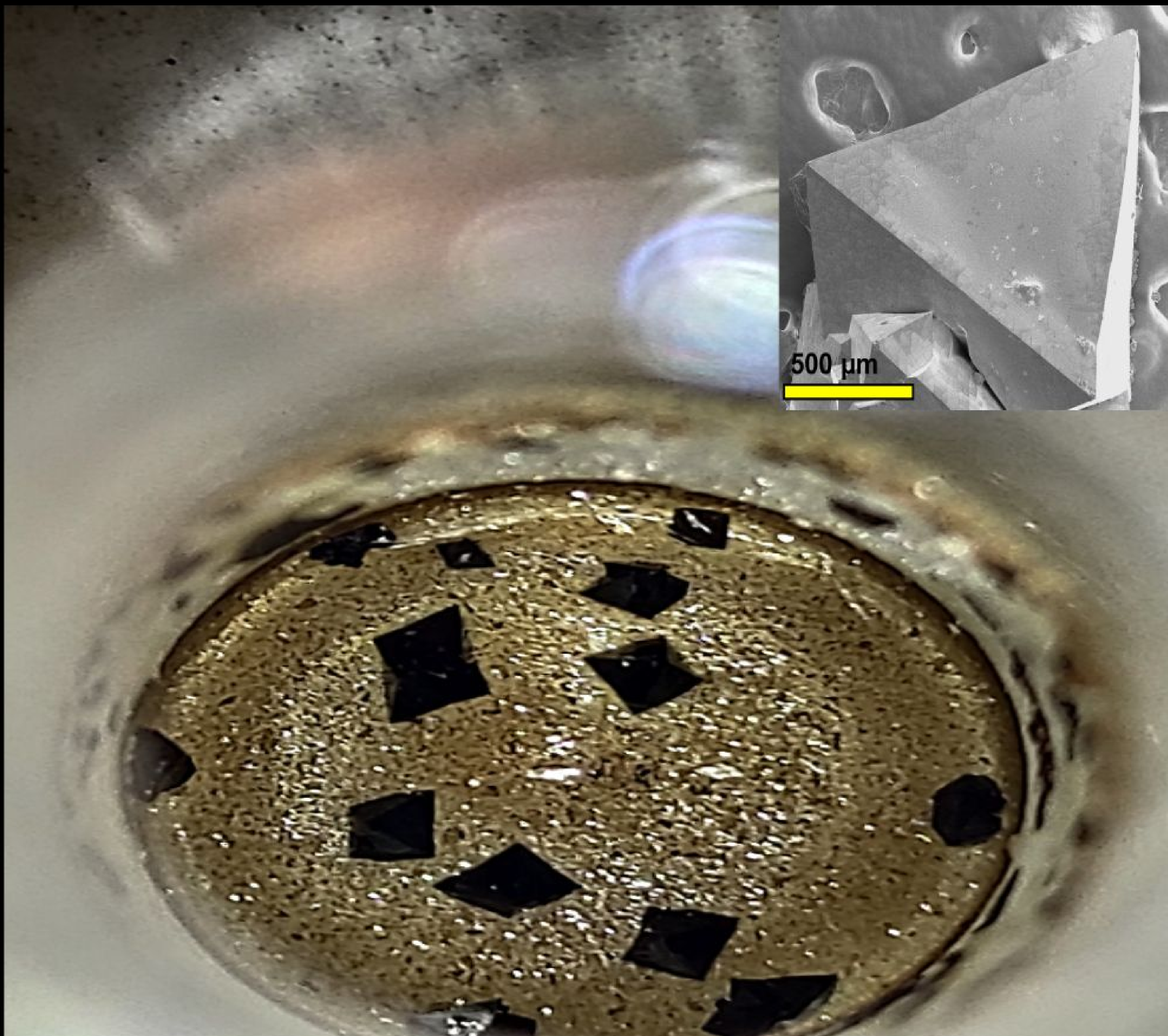
Mercury quenching experiment using nanofiber

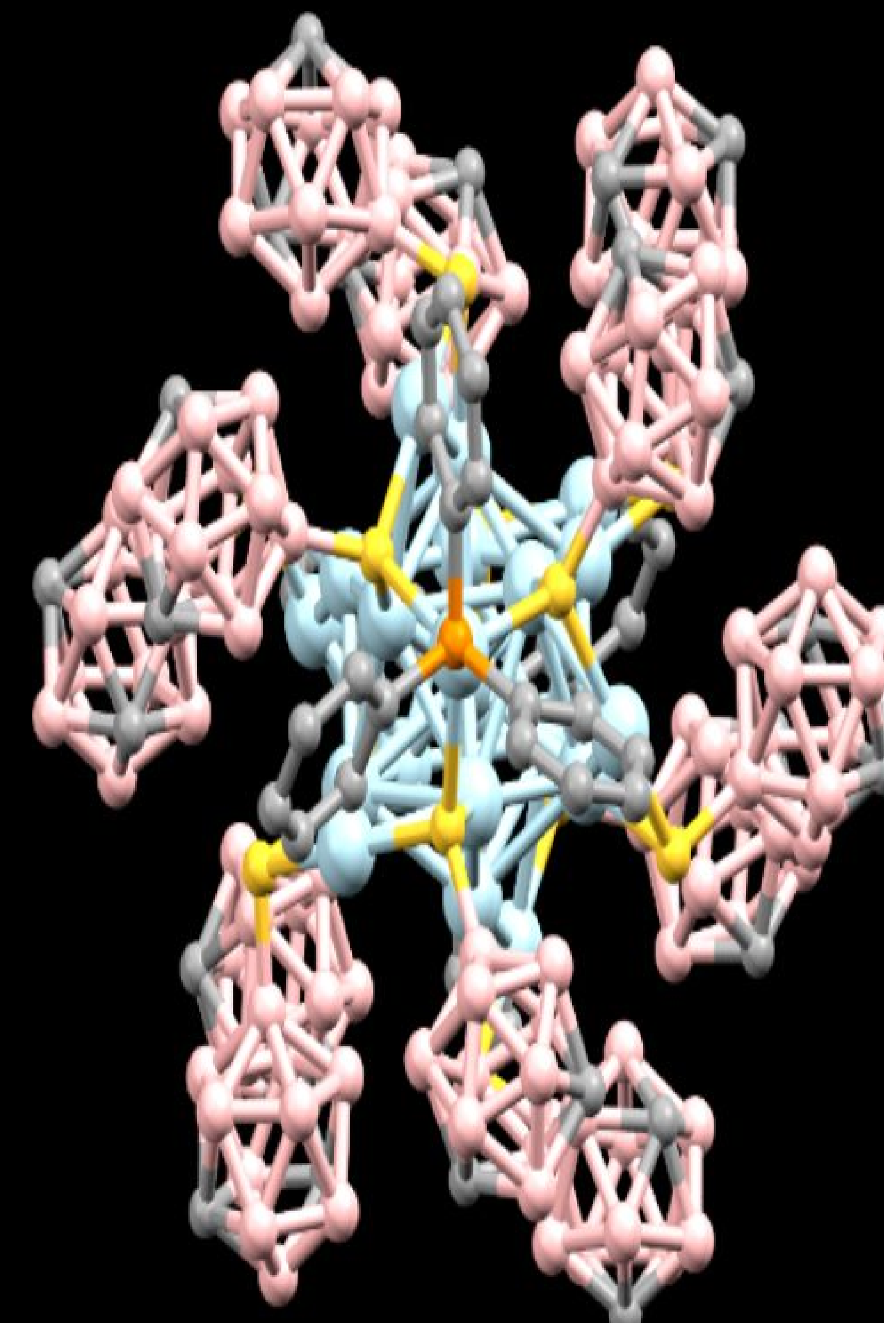
Carborane-thiol protected silver nanomolecule



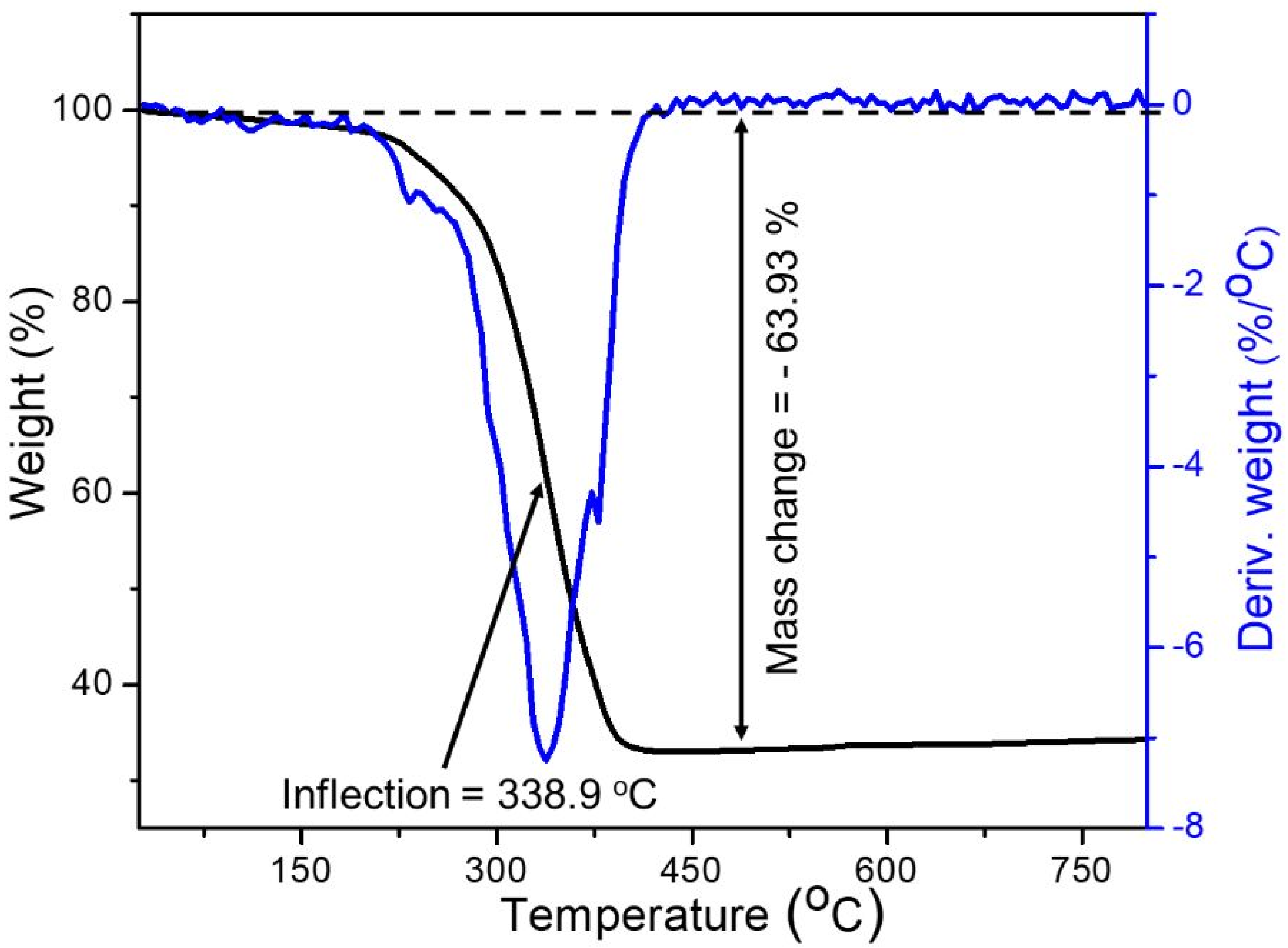
With Tomas Bas
e

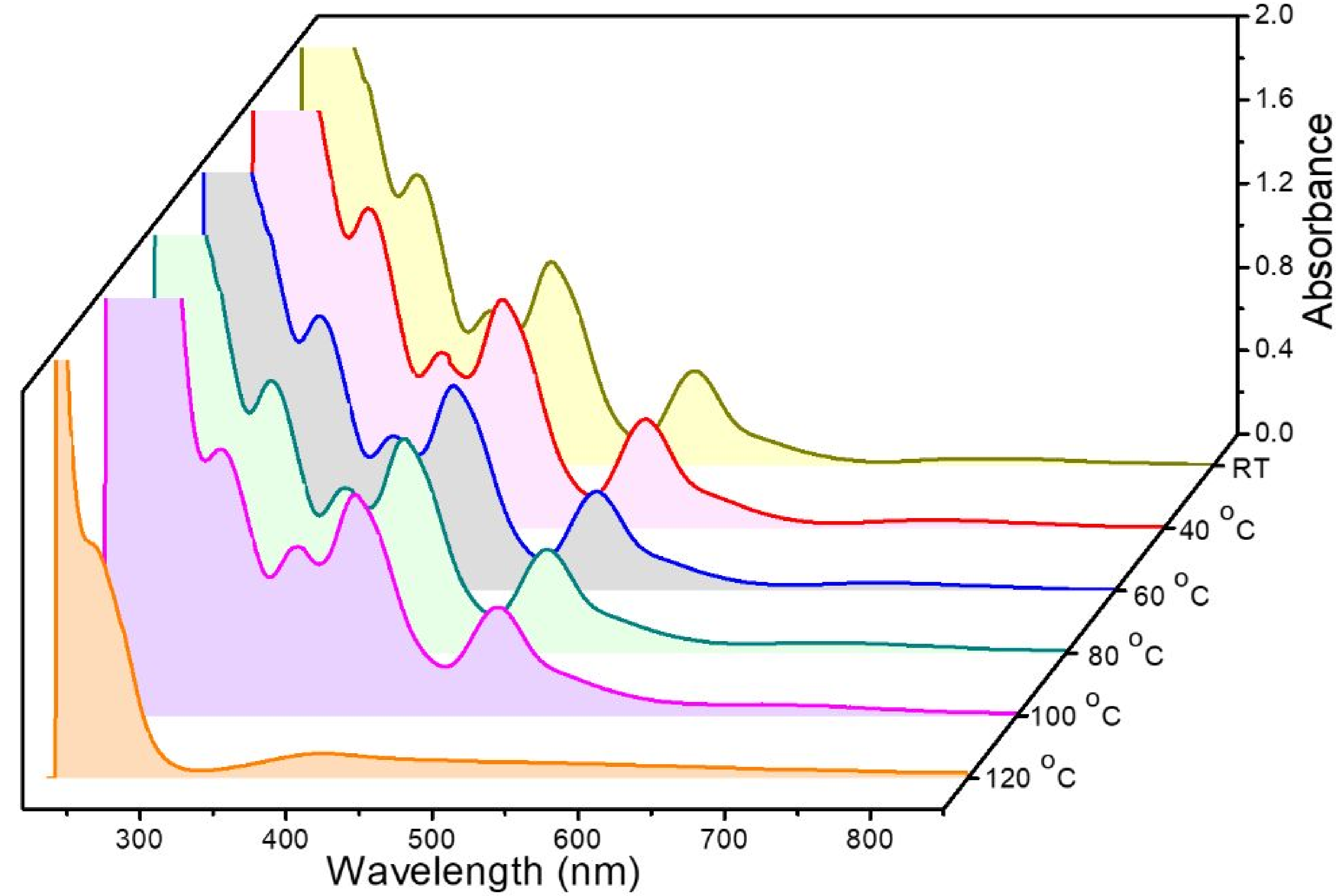
Jana *et. al*, Inorganic Chemistry (2022)


500 µm



Thermal stabilit
y

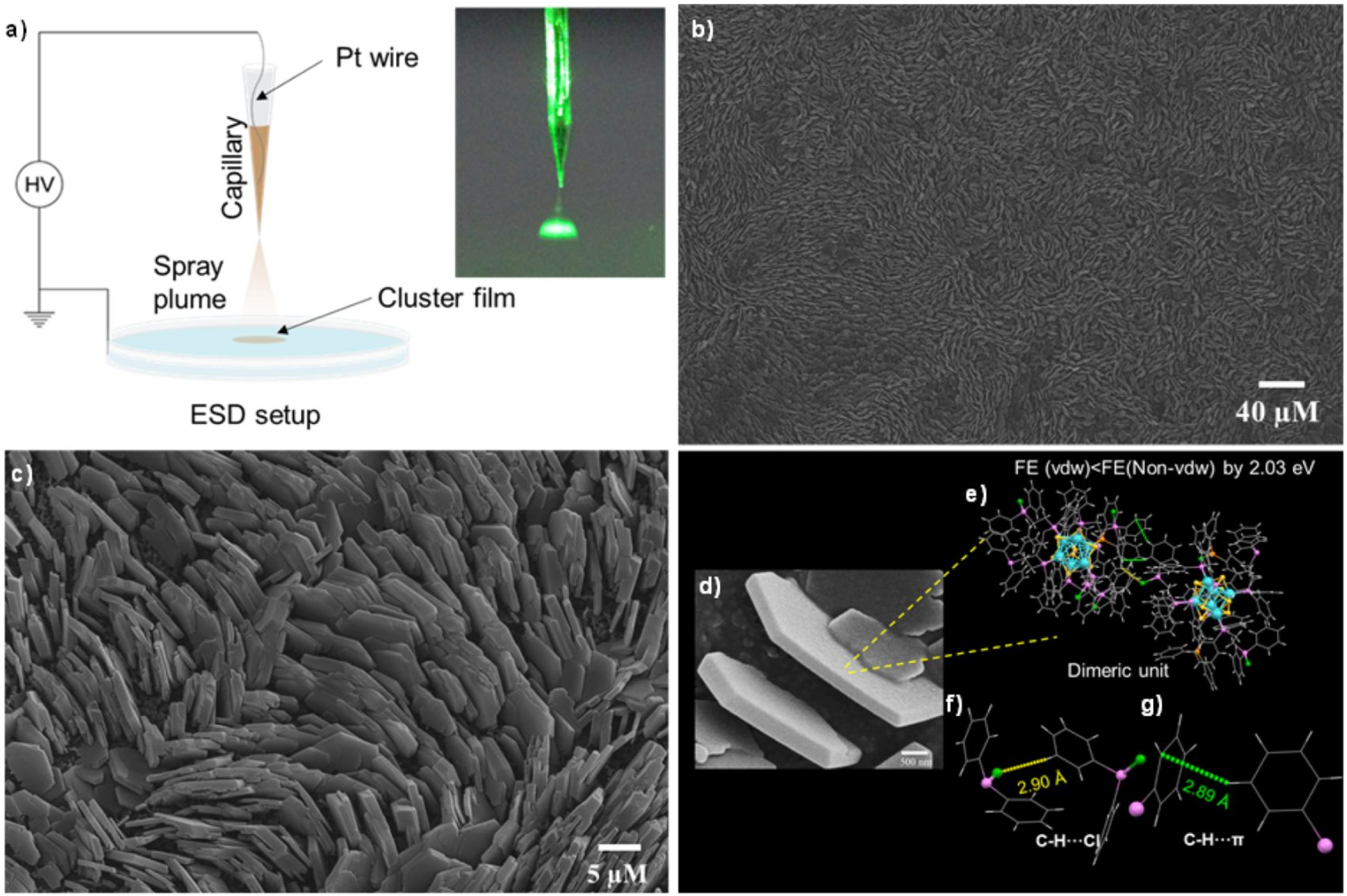




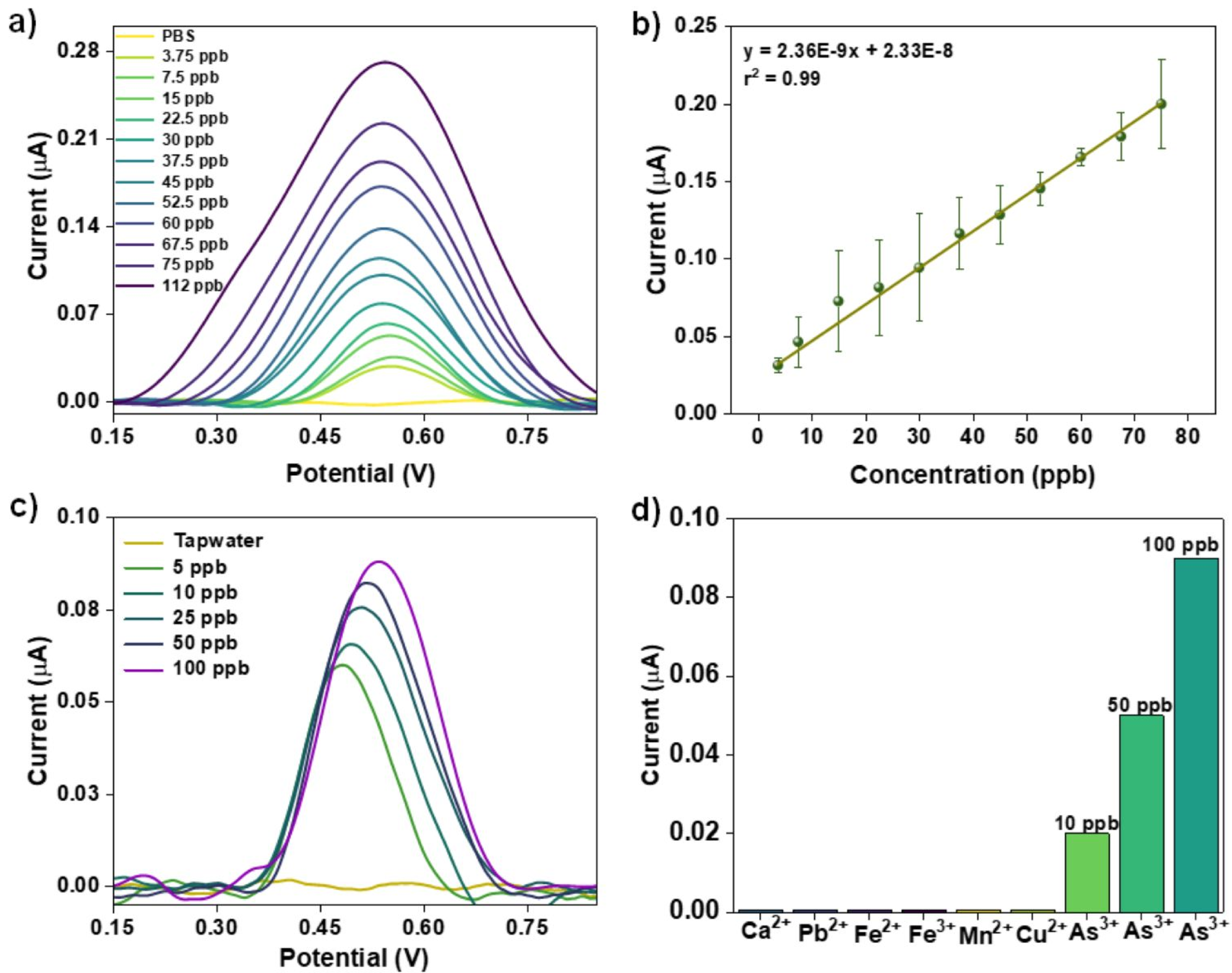
New electrodes - Aligned nanoplates of Co6S 8

1,2-bis(diphenylphosphino)ethane (DPPE)

Electrospray deposition

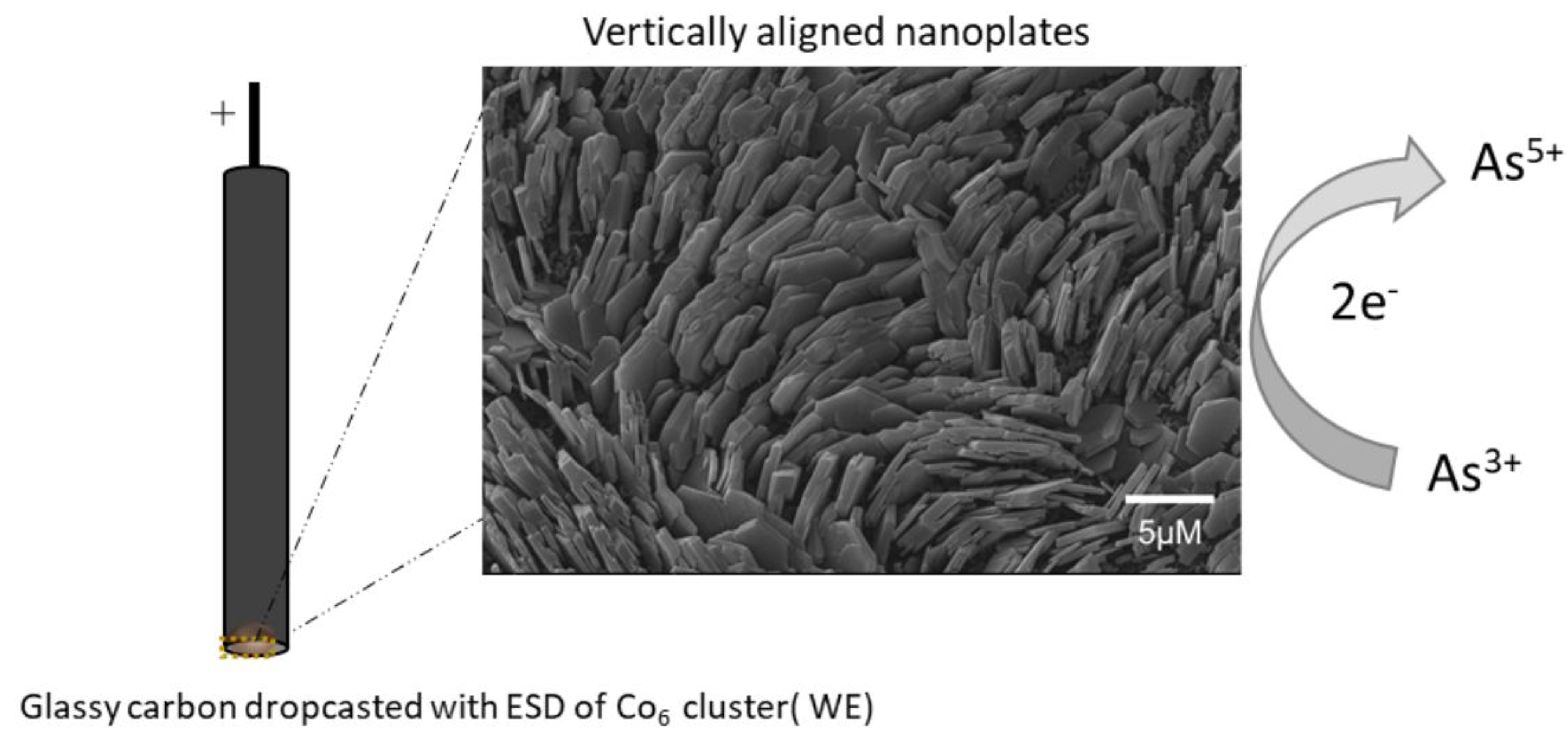


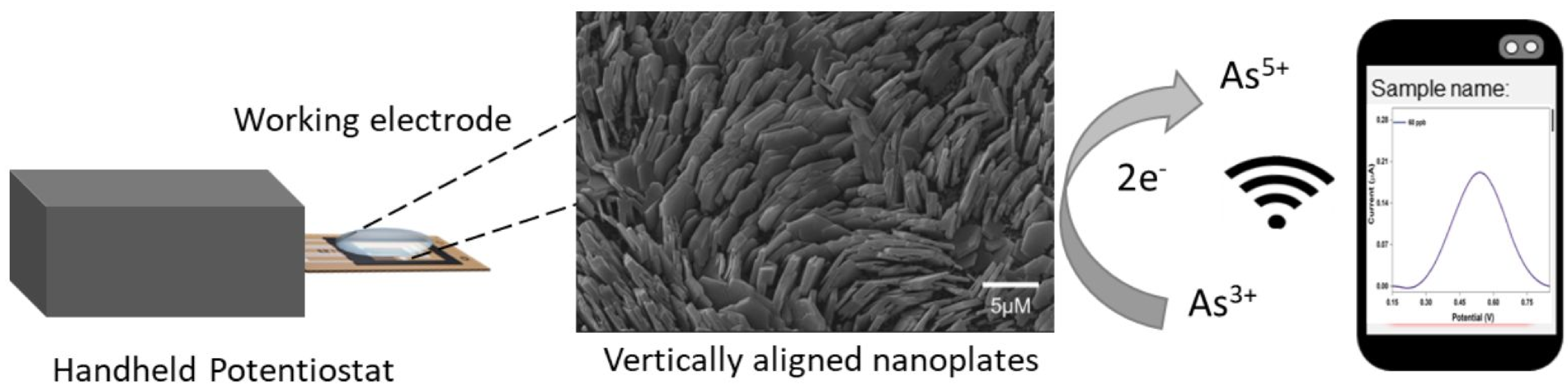
Sensing



a)
PBS
3.75 ppb
7.5 ppb
15 ppb
22.5 ppb
30 ppb
37.5 ppb
45 ppb
52.5 ppb
60 ppb
67.5 ppb
75 ppb
112 ppb
Current (μA)
Potential (V)
b)
y = 2.36E-9x + 2.33E-8
r^2 = 0.99
Current (μA)
Concentration (ppb)
c)
Tapwater
5 ppb
10 ppb
25 ppb
50 ppb
100 ppb
Current (μA)
Potential (V)
d)
100 ppb
50 ppb
10 ppb
Current (μA)
Ca^{2+} Pb^{2+} Fe^{2+} Fe^{3+} Mn^{2+} Cu^{2+} As^{3+} As^{3+} As^{3+}

Working electrode





Anagha Jose et al. *ACS Materials Lett.,* 5 (2023) 893–89
9.

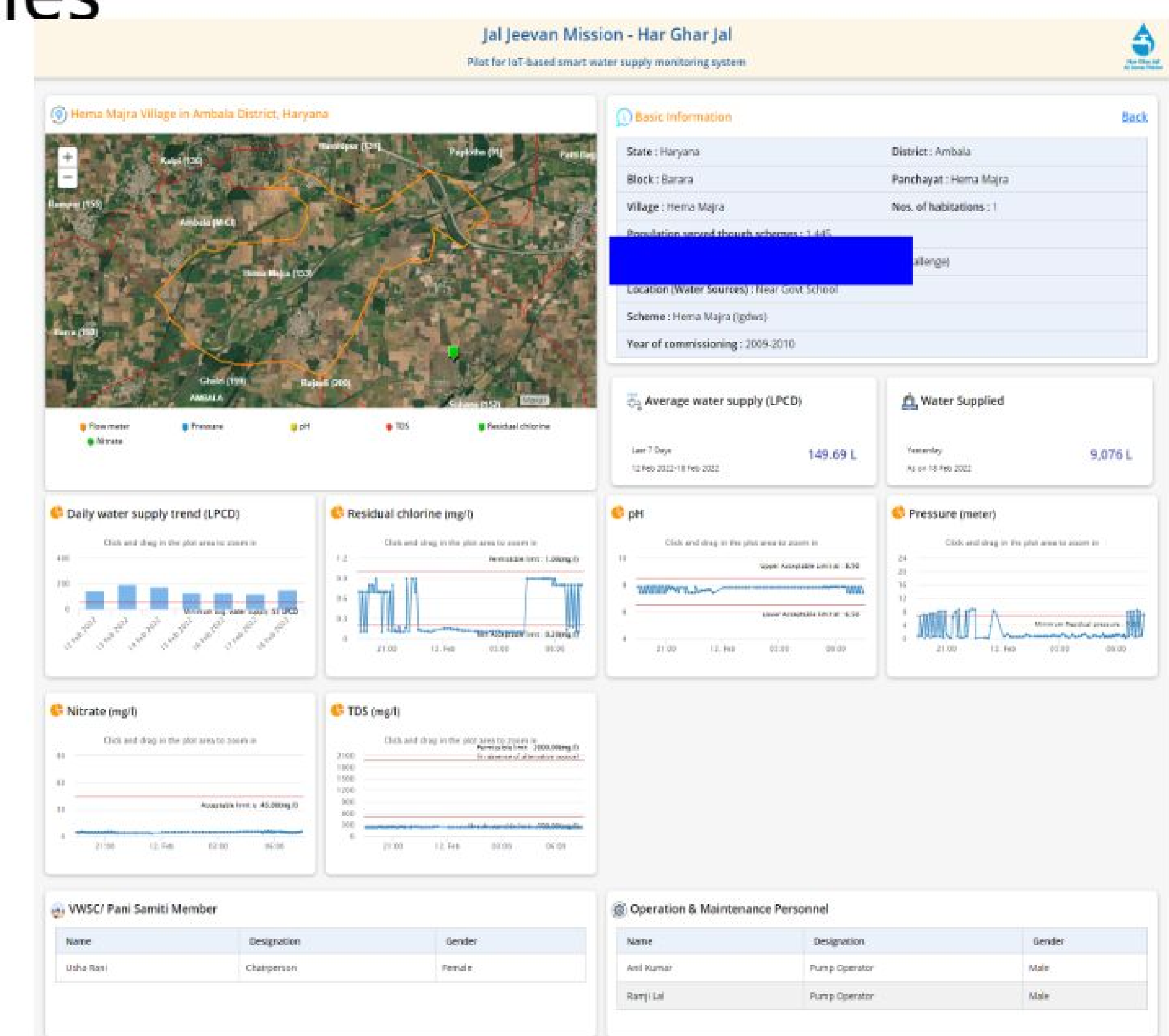
Arsenic poisoning across the world

E. Shaji, M. Santosh, K. V. Sarath, Pranav Prakash, V. Deepch and B. V. Divya, Geoscience Frontiers, 12 (2021) 101079.

India's water is being monitored

IITM/IISc

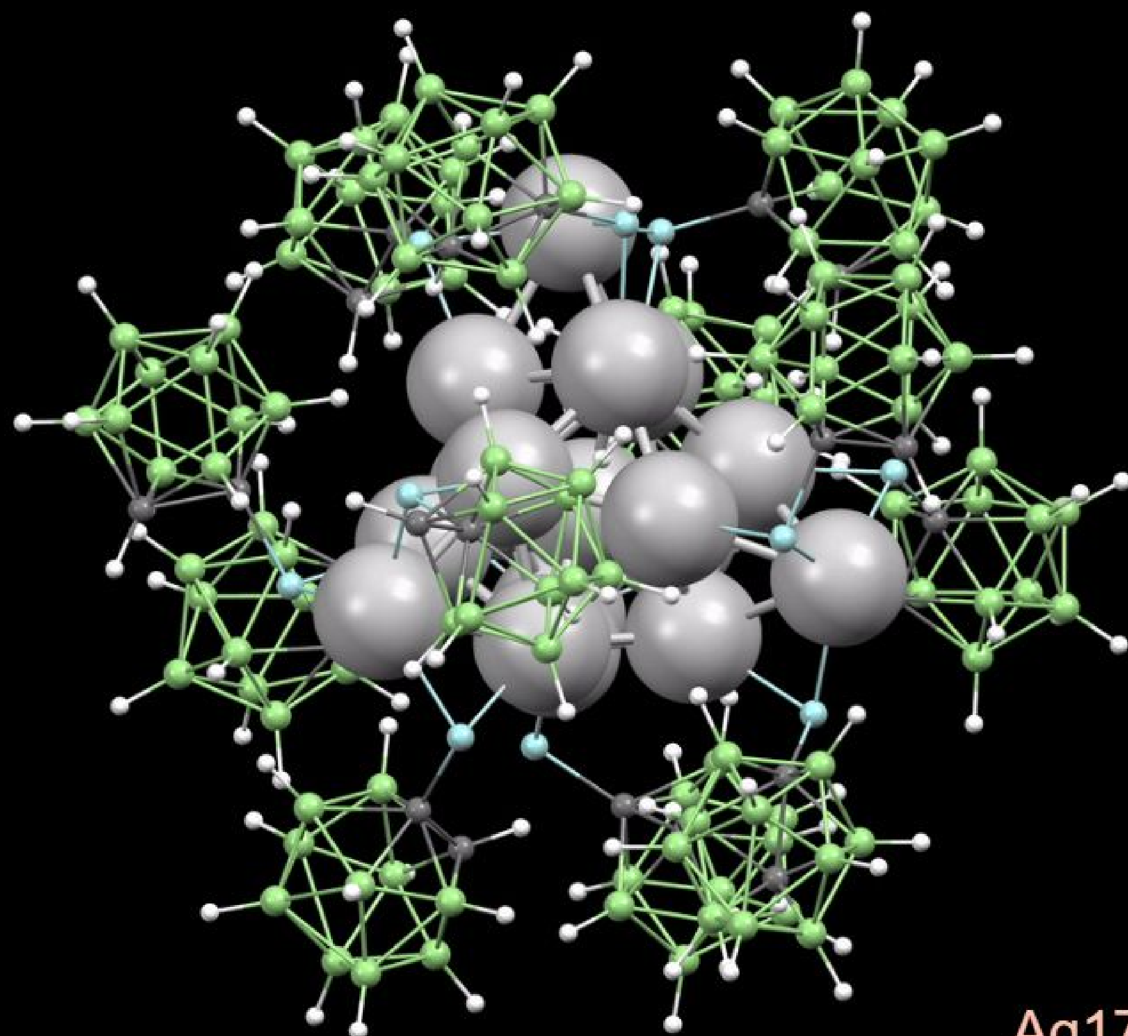
Installations made by four companies



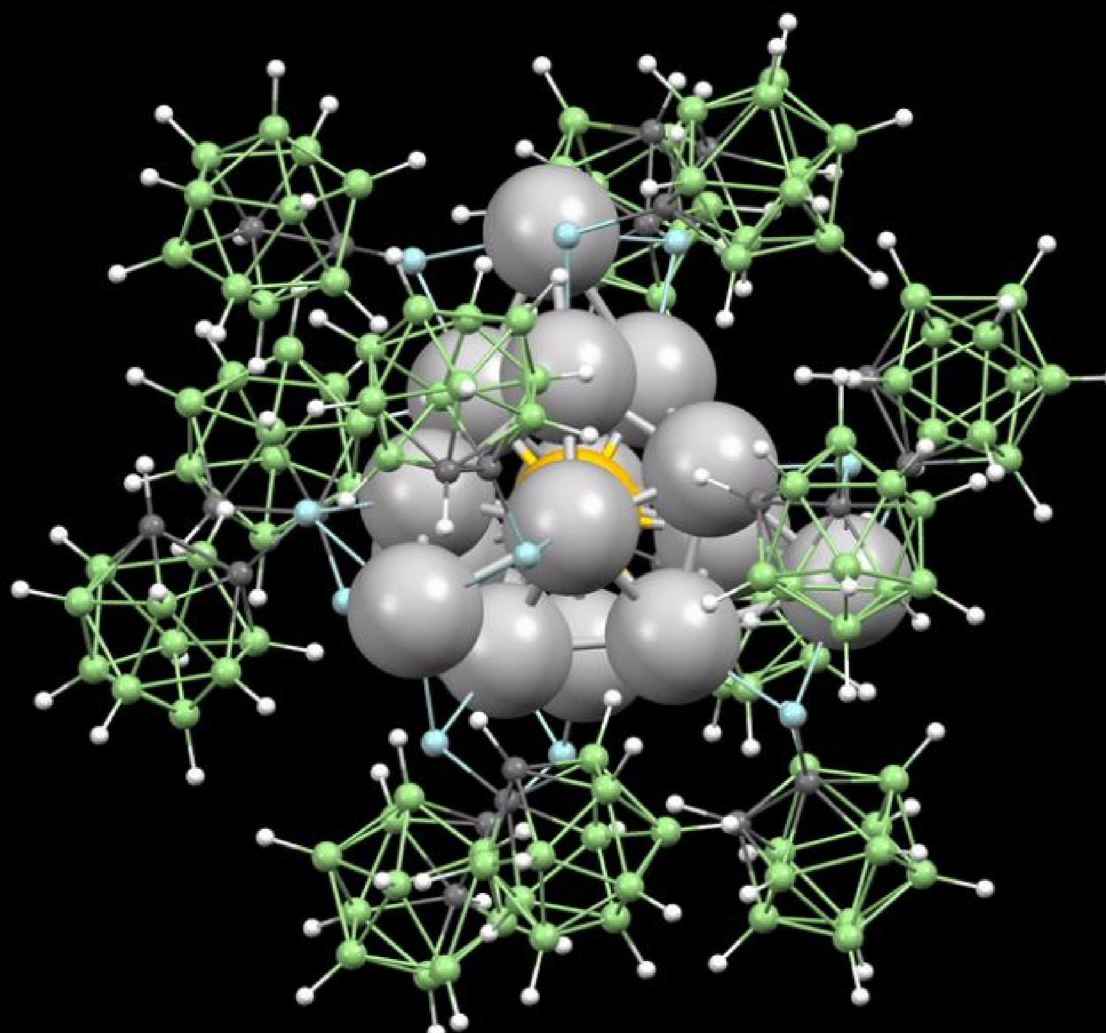
Ag_{17} $AuAg_{16}$ $Ag_{13}Cu_4$ $AuAg_{12}Cu_4$

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

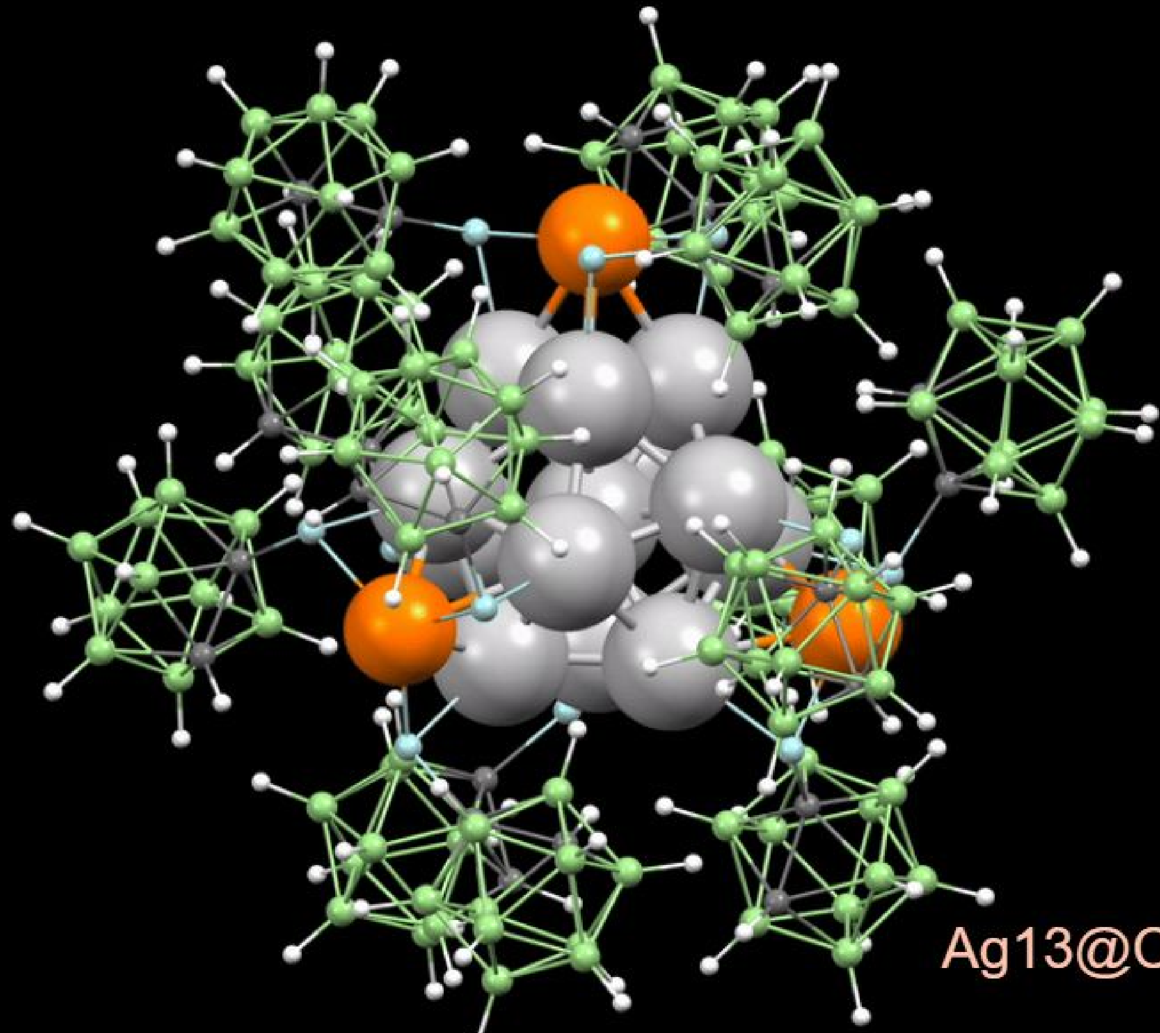
Structure of M17 Nanoclusters



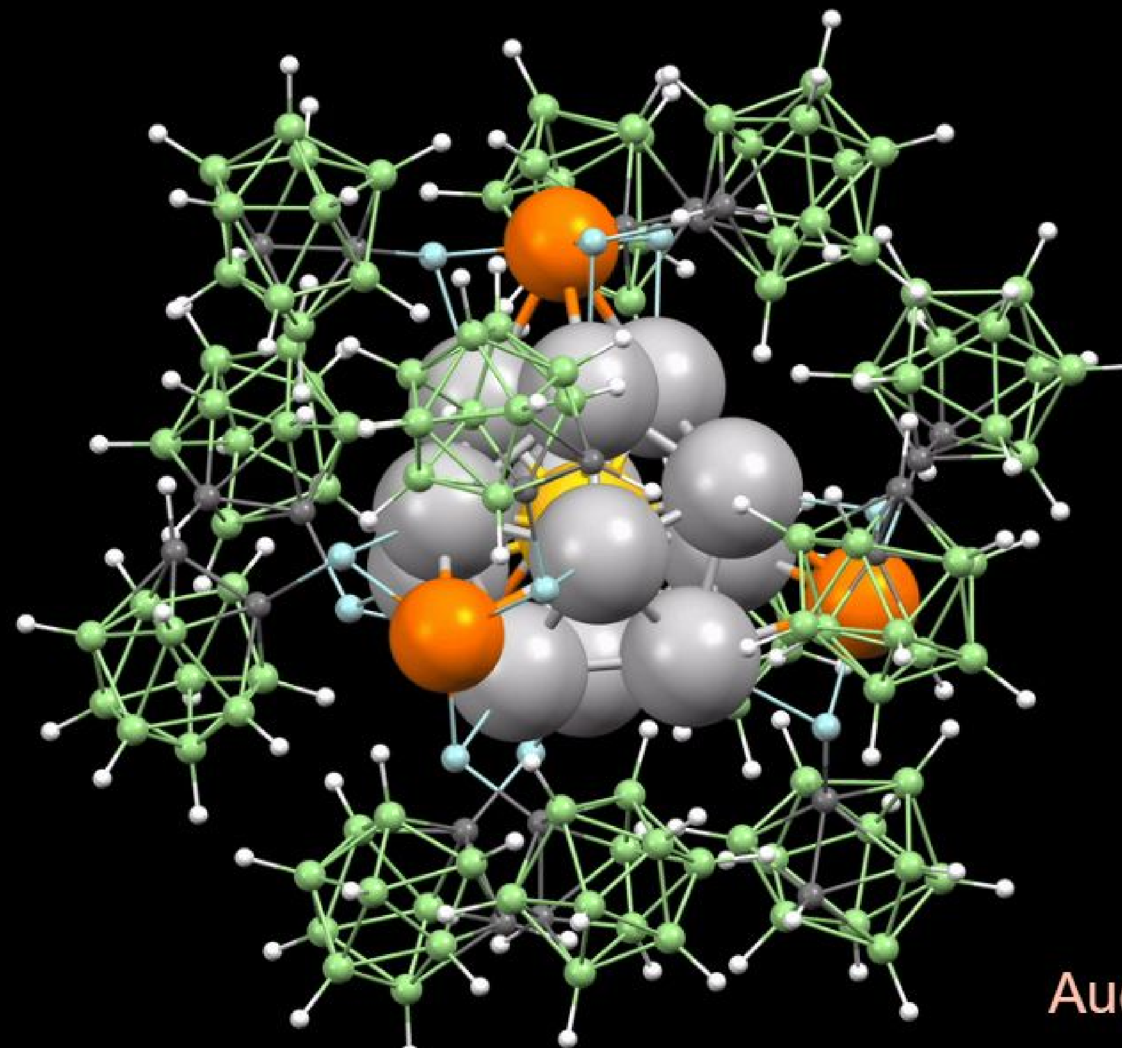
Ag17



Au@Ag16

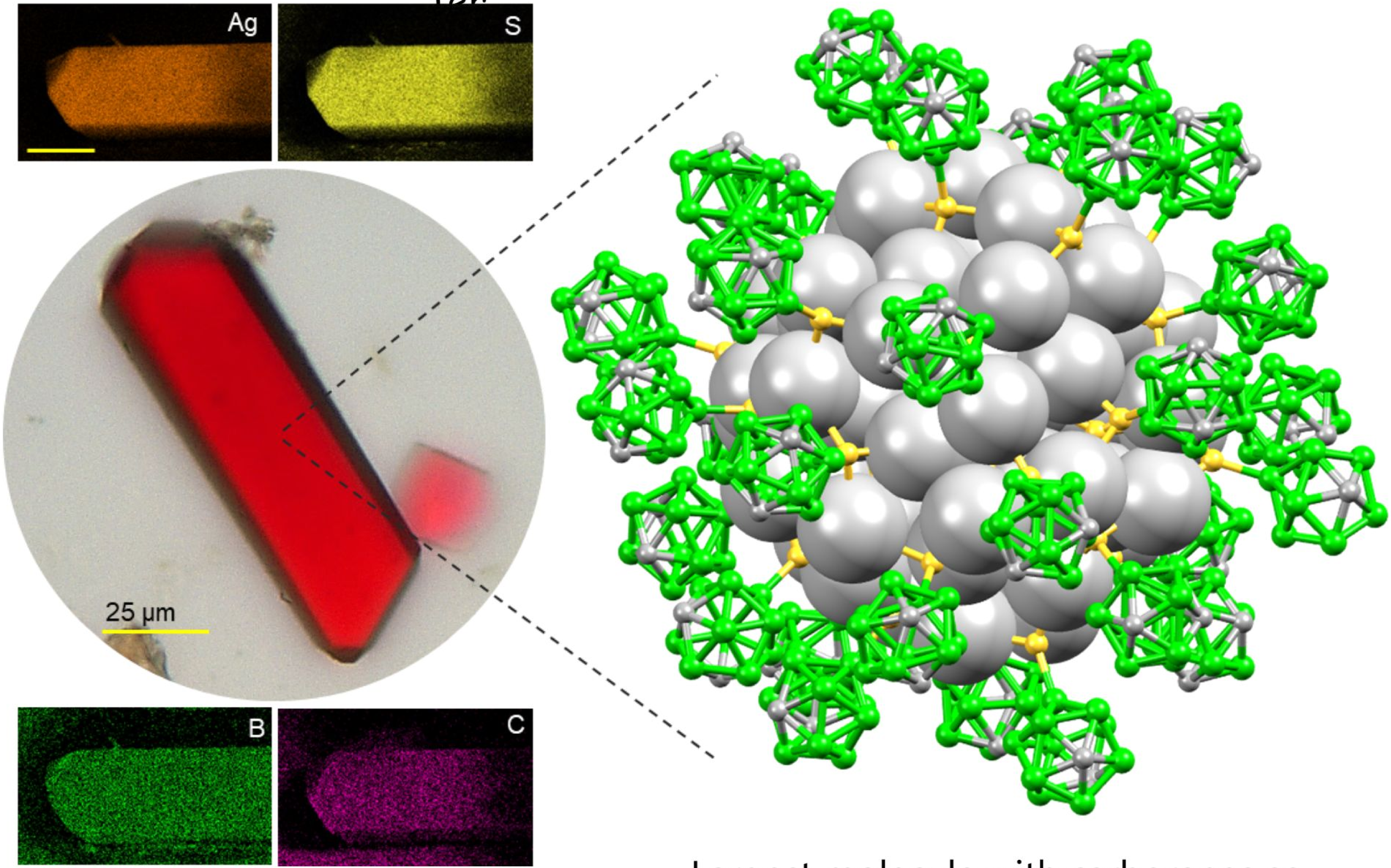


Ag13@Cu4



Au@Ag12@Cu4

[Ag62S12(CBT)32] Nanocluster

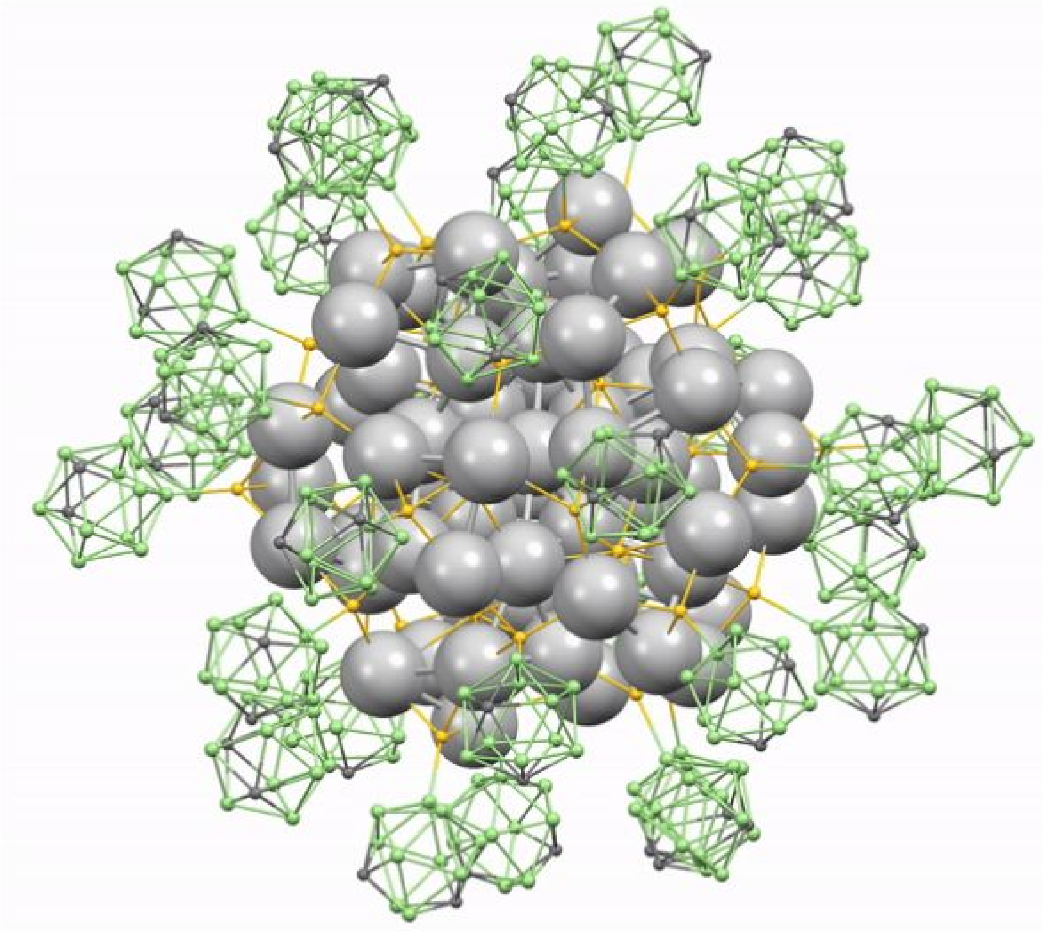


Largest molecule with carboranes so far......

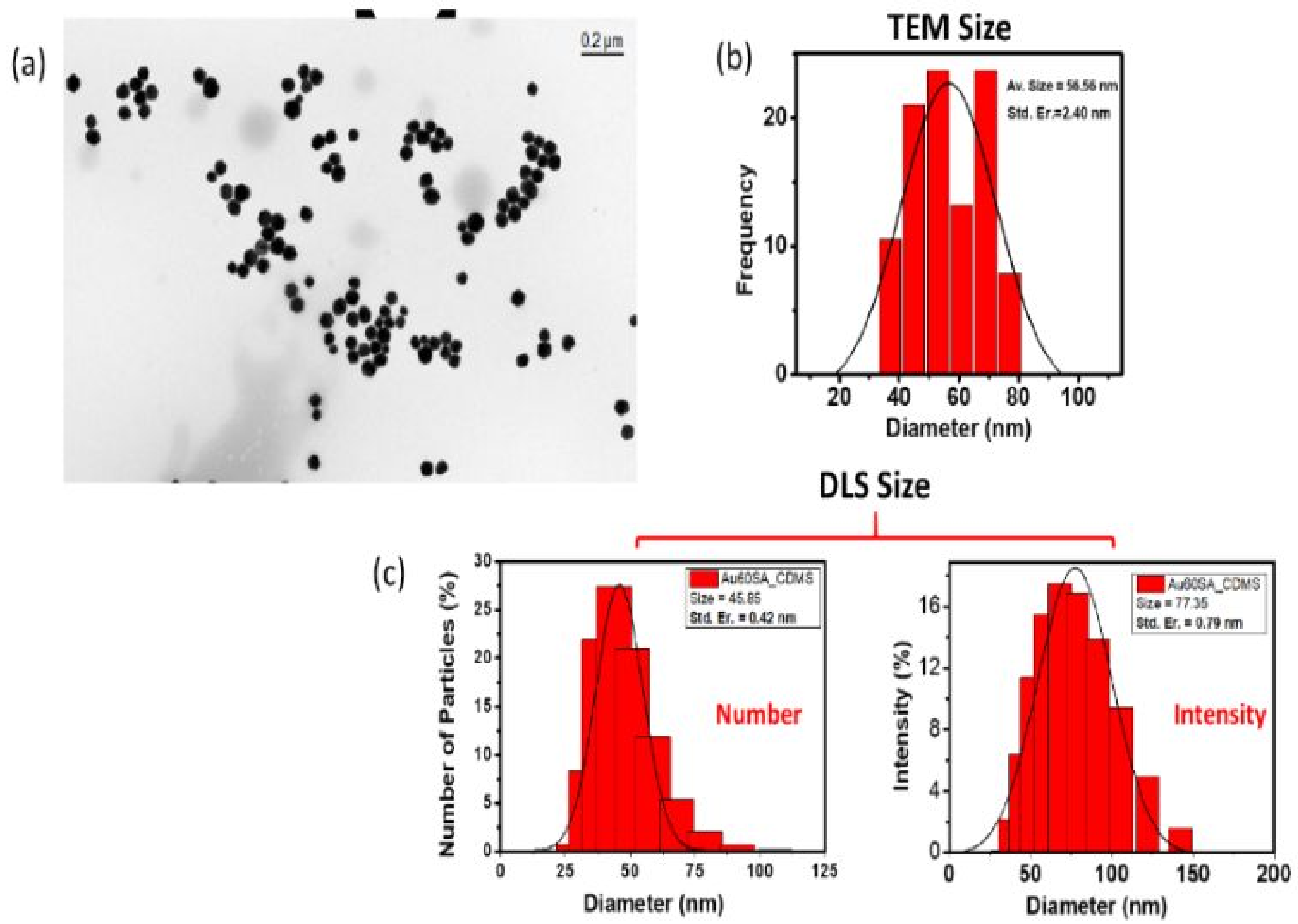
Jana *et al.*, Submitted

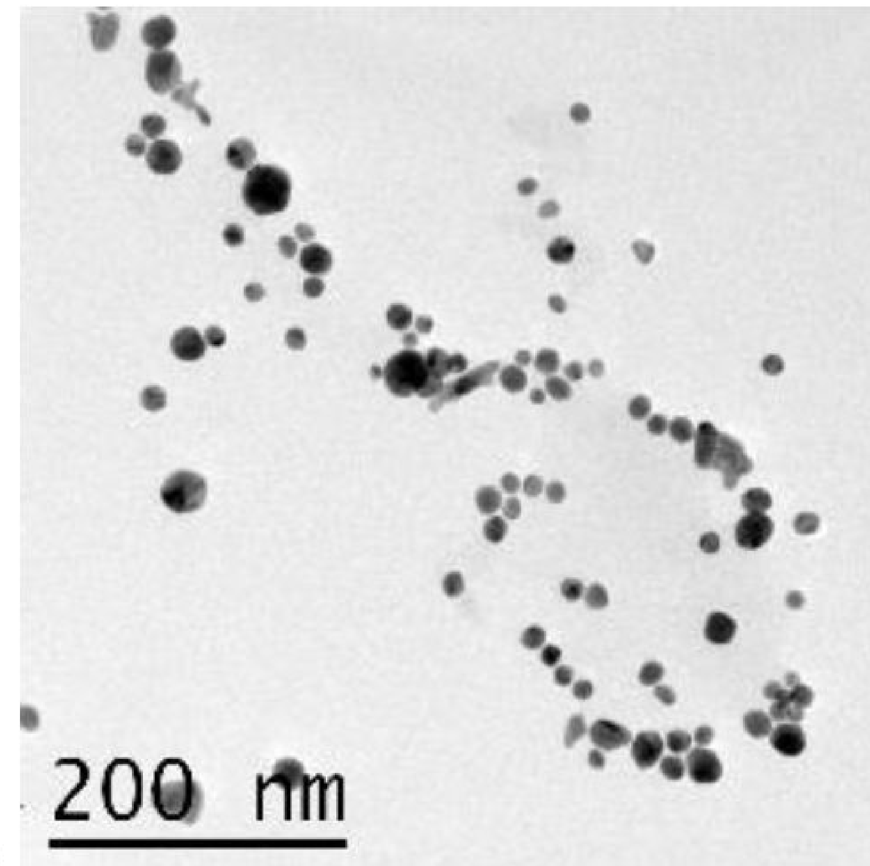
Summary

- Atomically precise clusters are a category of new materials
- They are molecules – properties, nomenclature,…
- Clusters are thermally stable up to 400°C.
- They exhibit useful applications
- Atomic precision across the periodic table
- An era cluster-based materials is being born



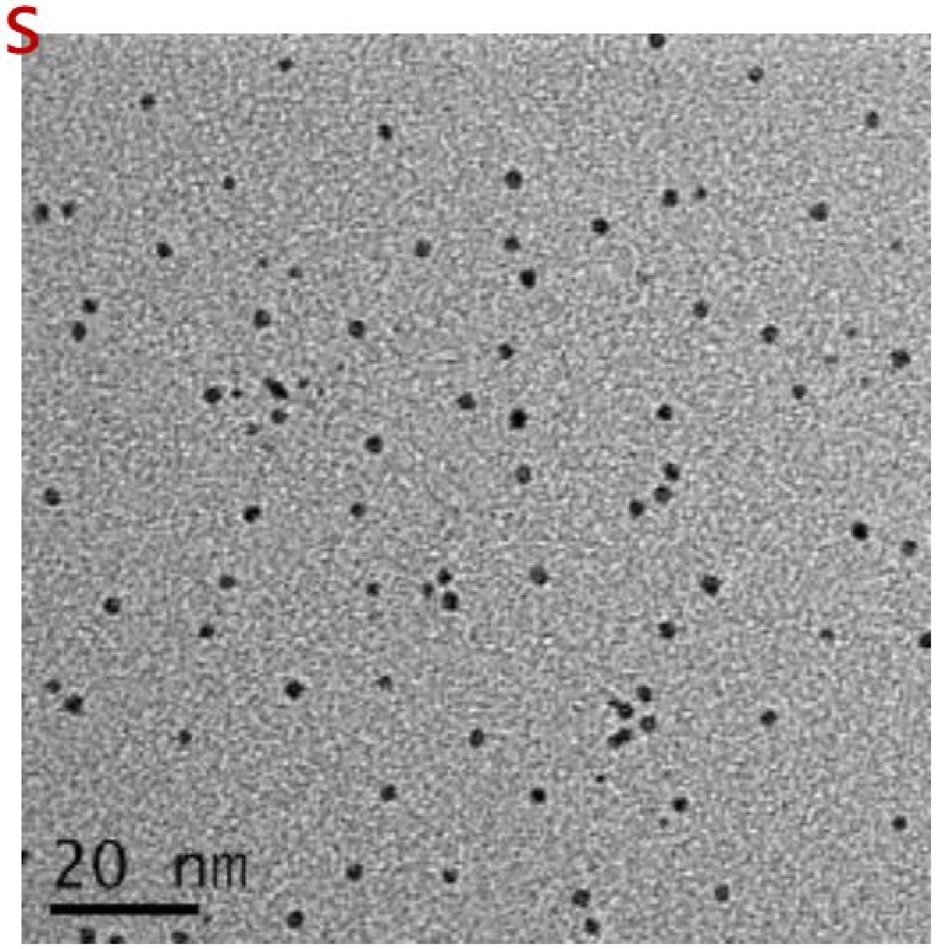
Larger clusters - TEM

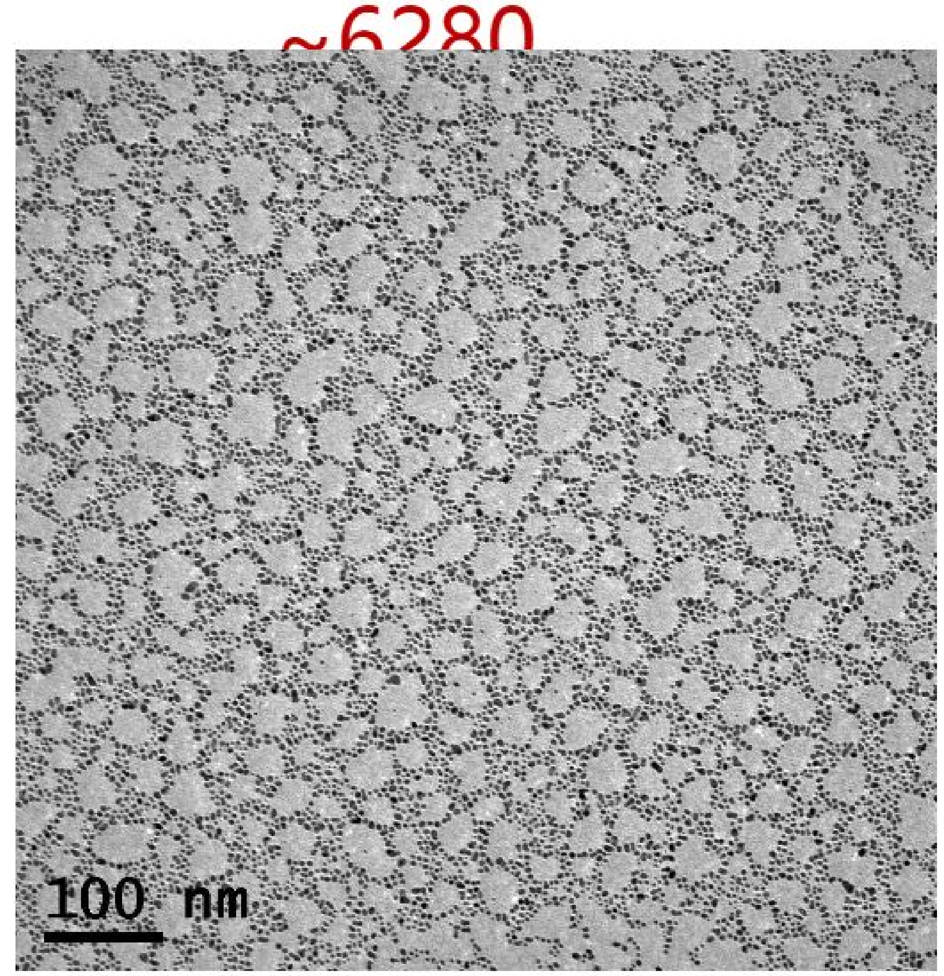


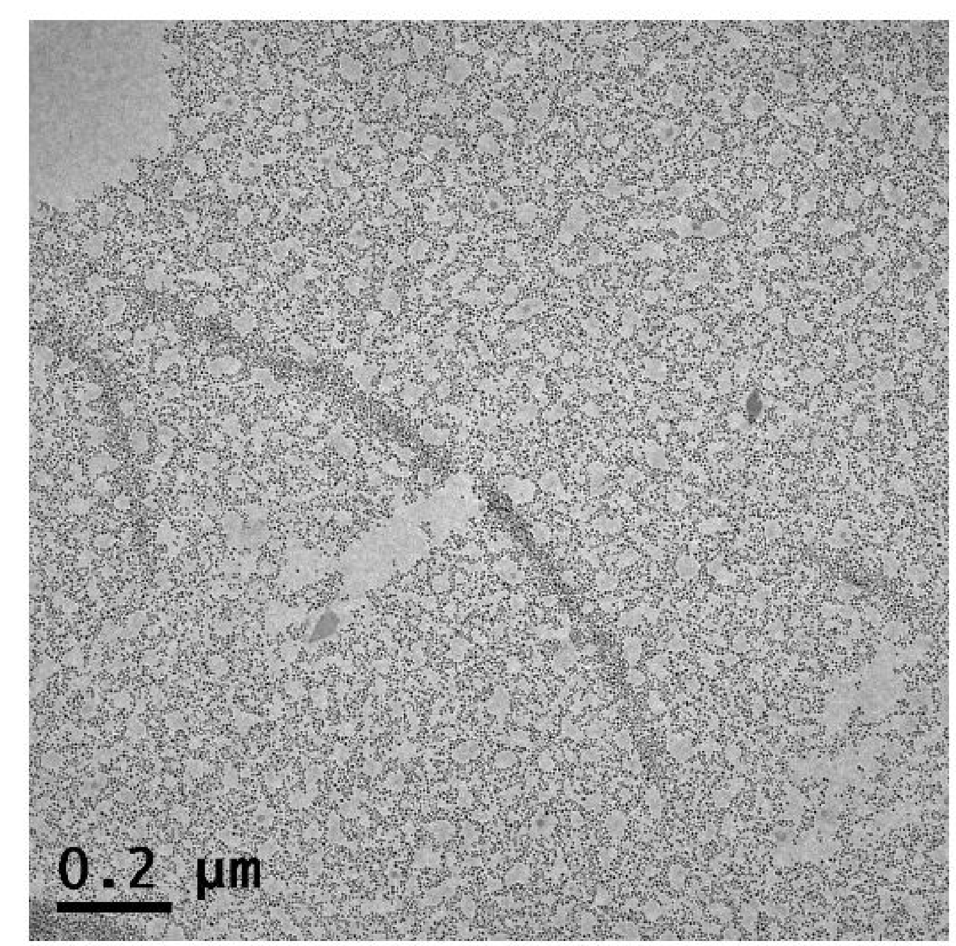


60 nm sized Au-citrate nanoparticles

Au~246000(MUTAB)~6280







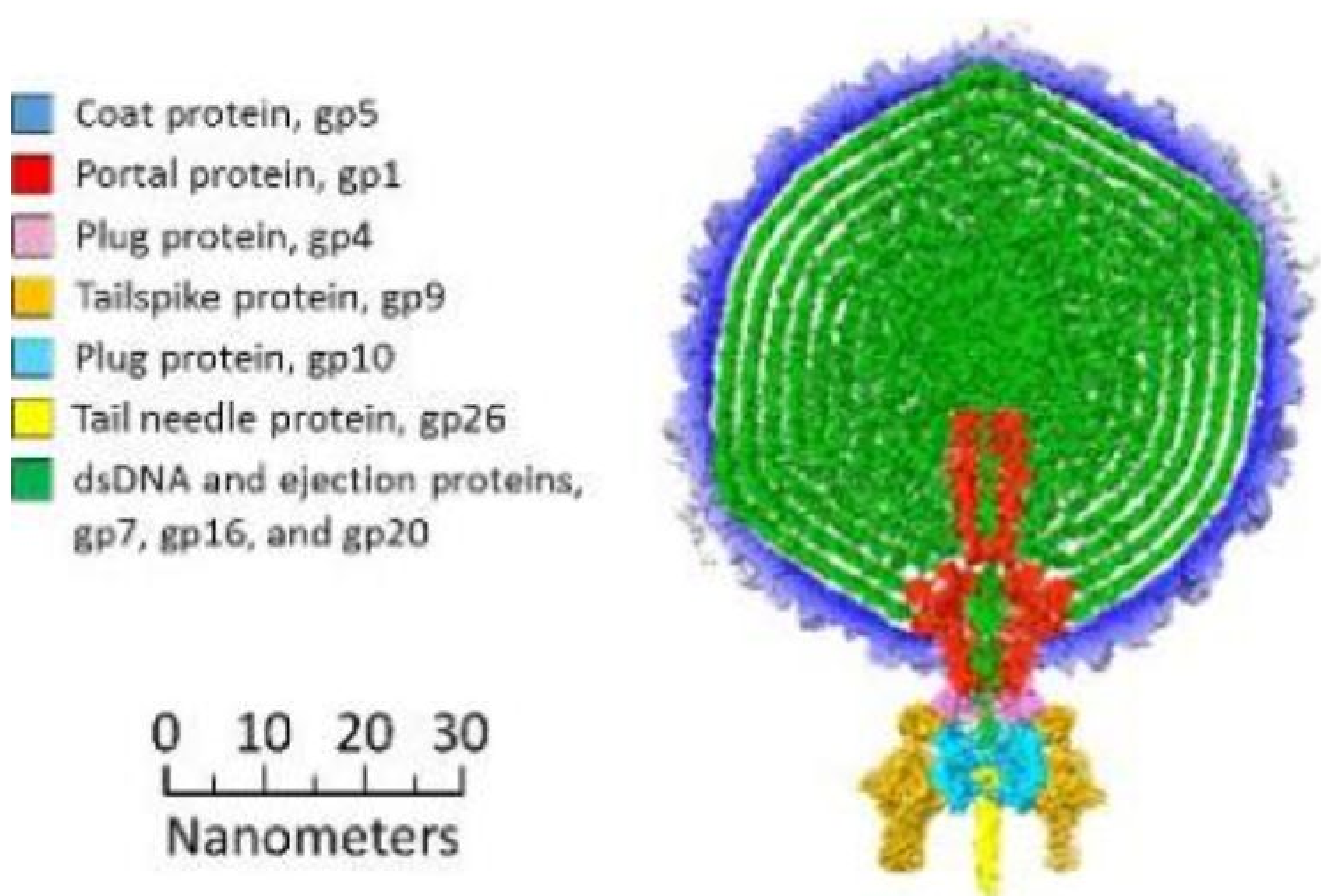
Au279(TBBT)84

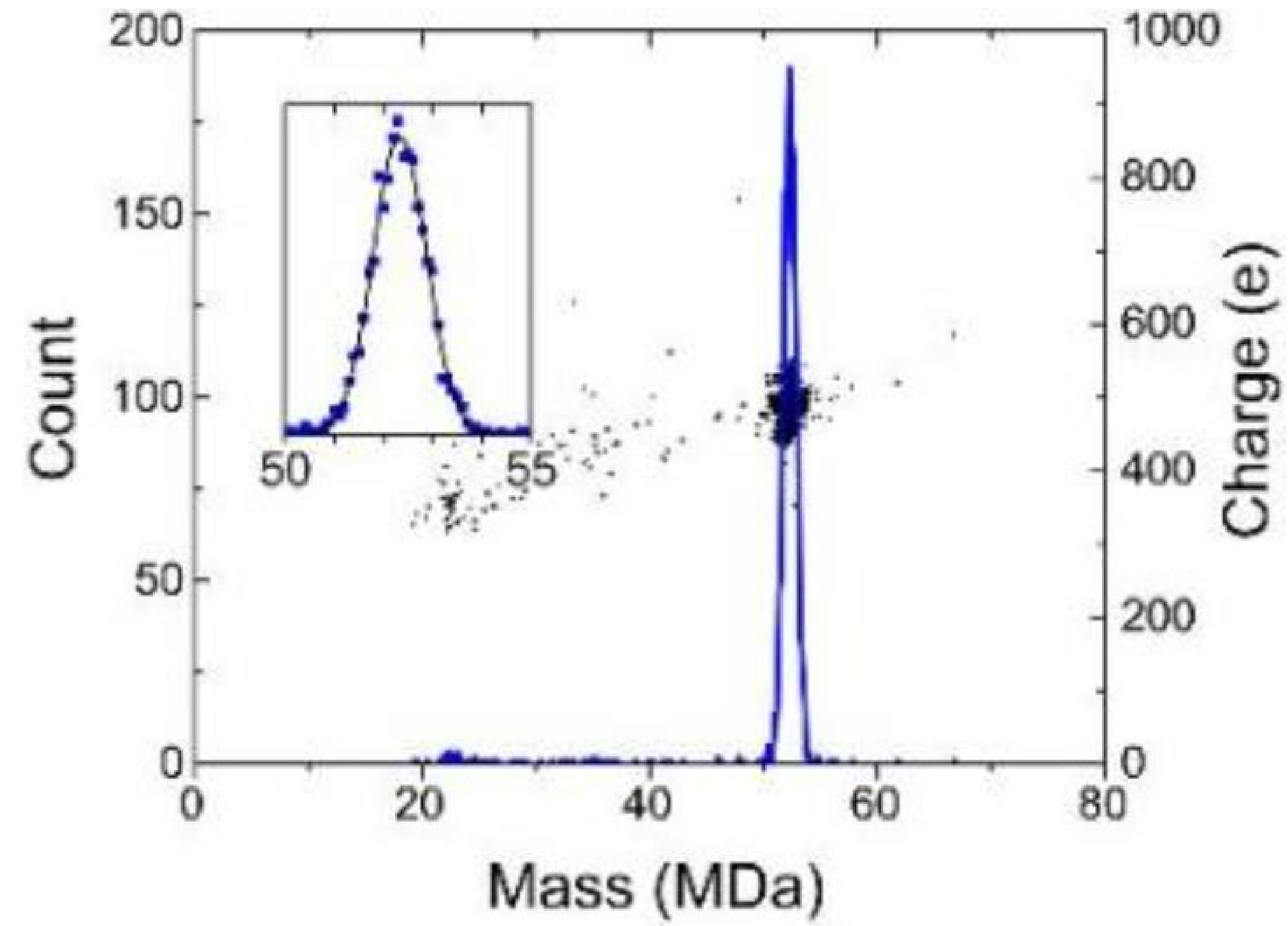
Au144(PET)60

Au25(PET)18

CDMS of viruses and nanoparticl

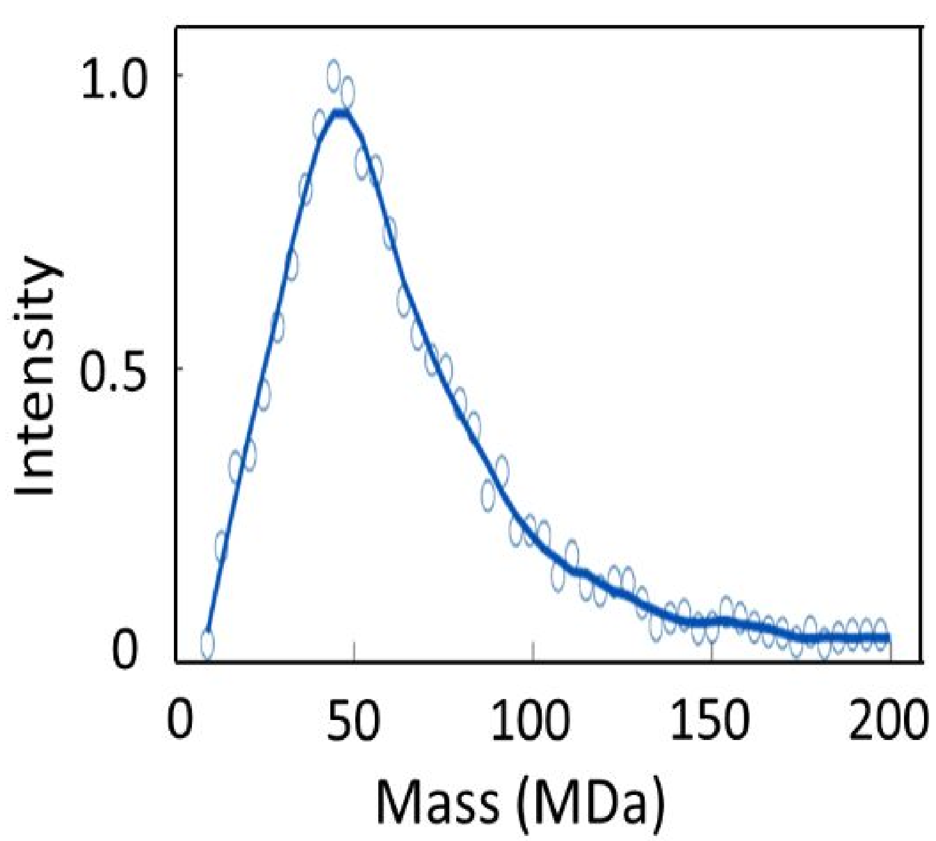
(a
)

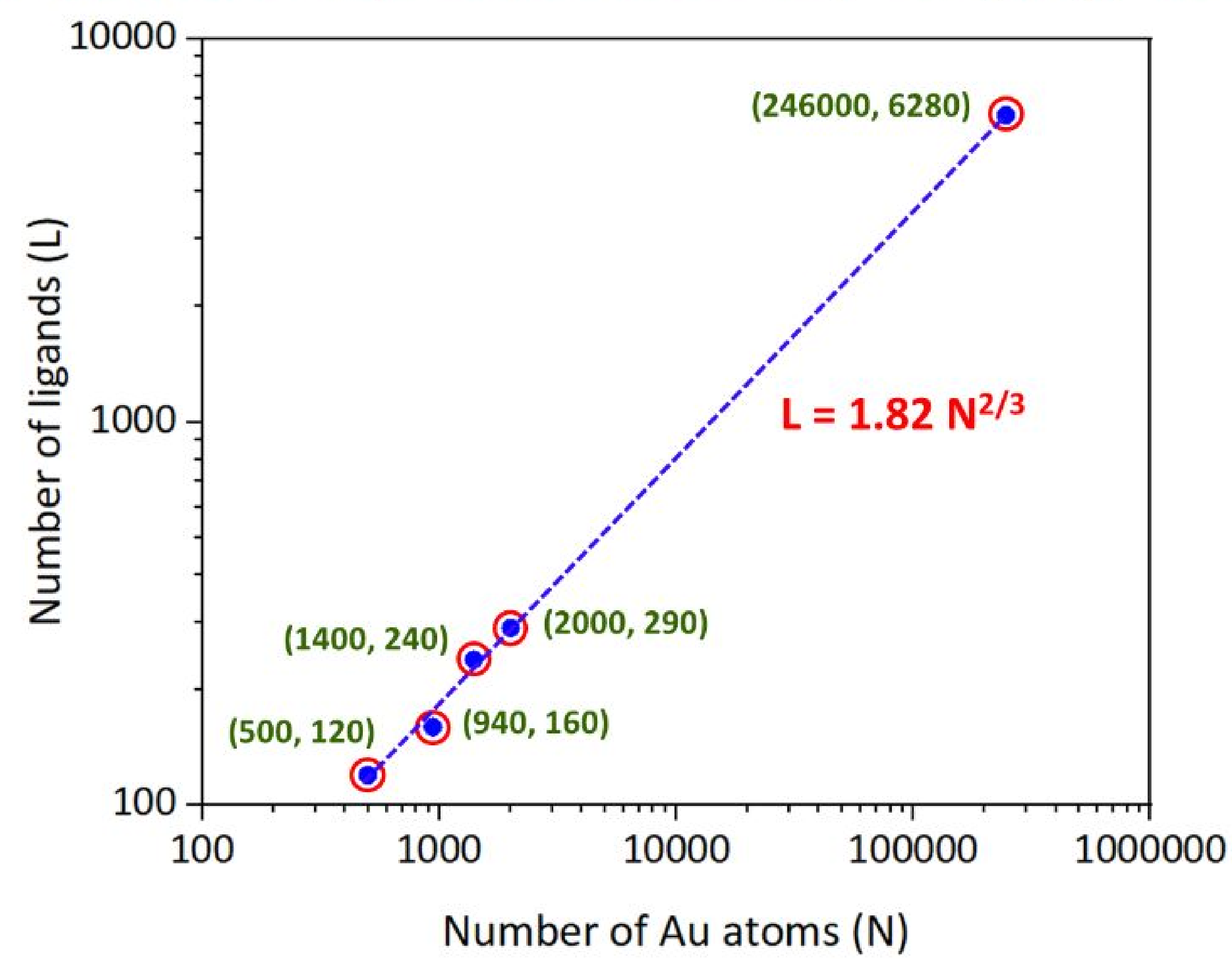




Keifer, D. Z.; Motwani, T.; Teschke, C. M.; Jarrold, M. F. Measurement of the Accurate Mas s of a 50 MDa Infectious Virus. *Rapid Commun. Mass Spectrom.* **2016**, *30* (17), 1957–1962.

(b
)

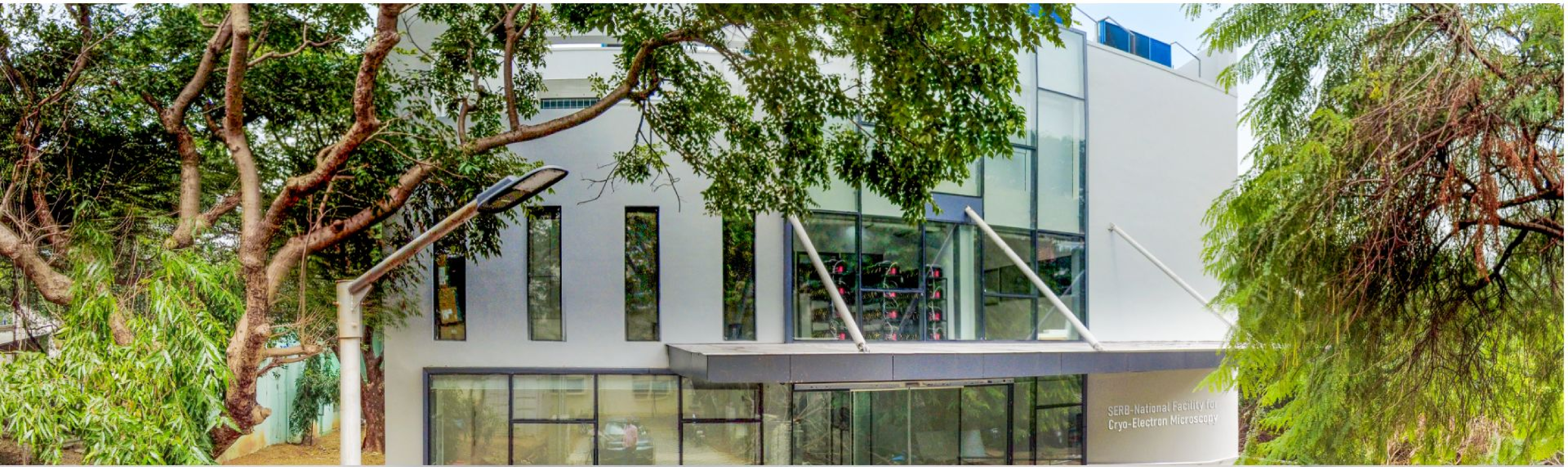




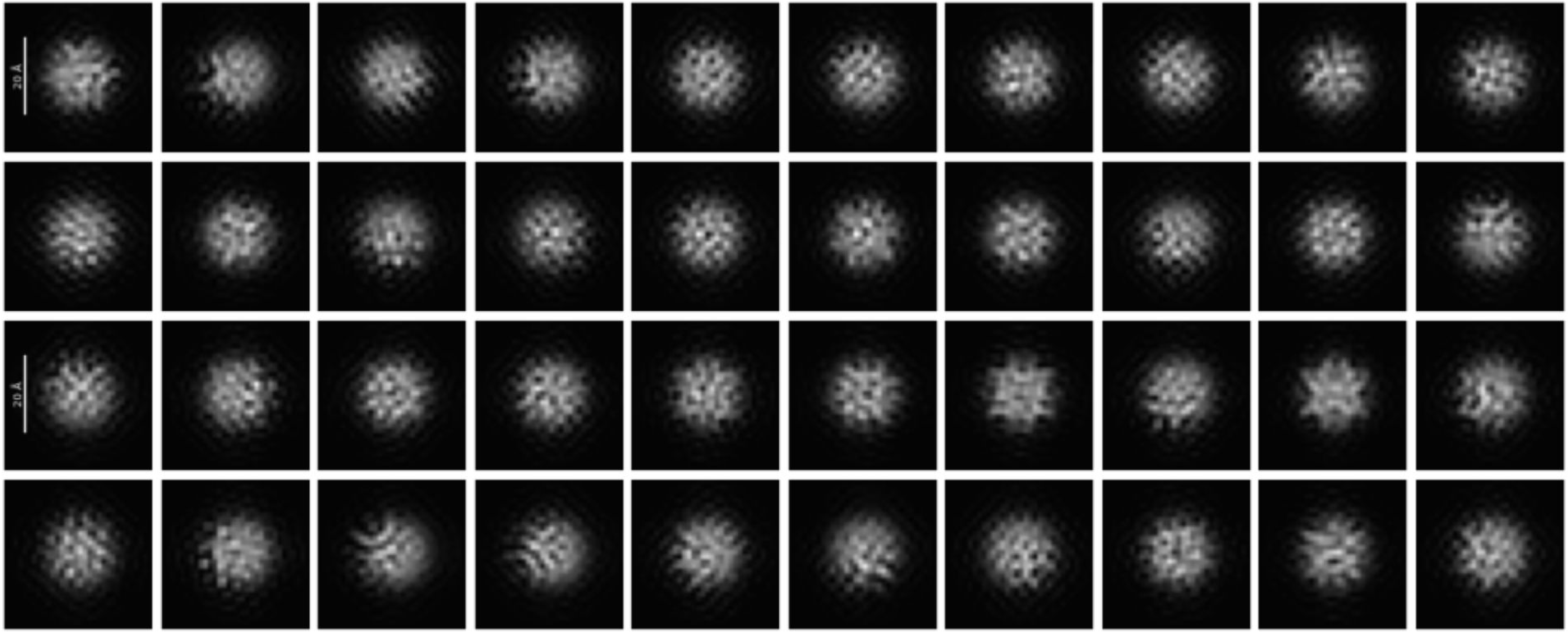
B. S. Sooraj, et. al. Revised and submitt

Resolving Structural Transitions through Microcrystal Electron Diffraction

Harshita Nagar, Anirban Som,... Chem. Comm. 2025


SERB-National Facility for
Cryo-Electron Microscopy

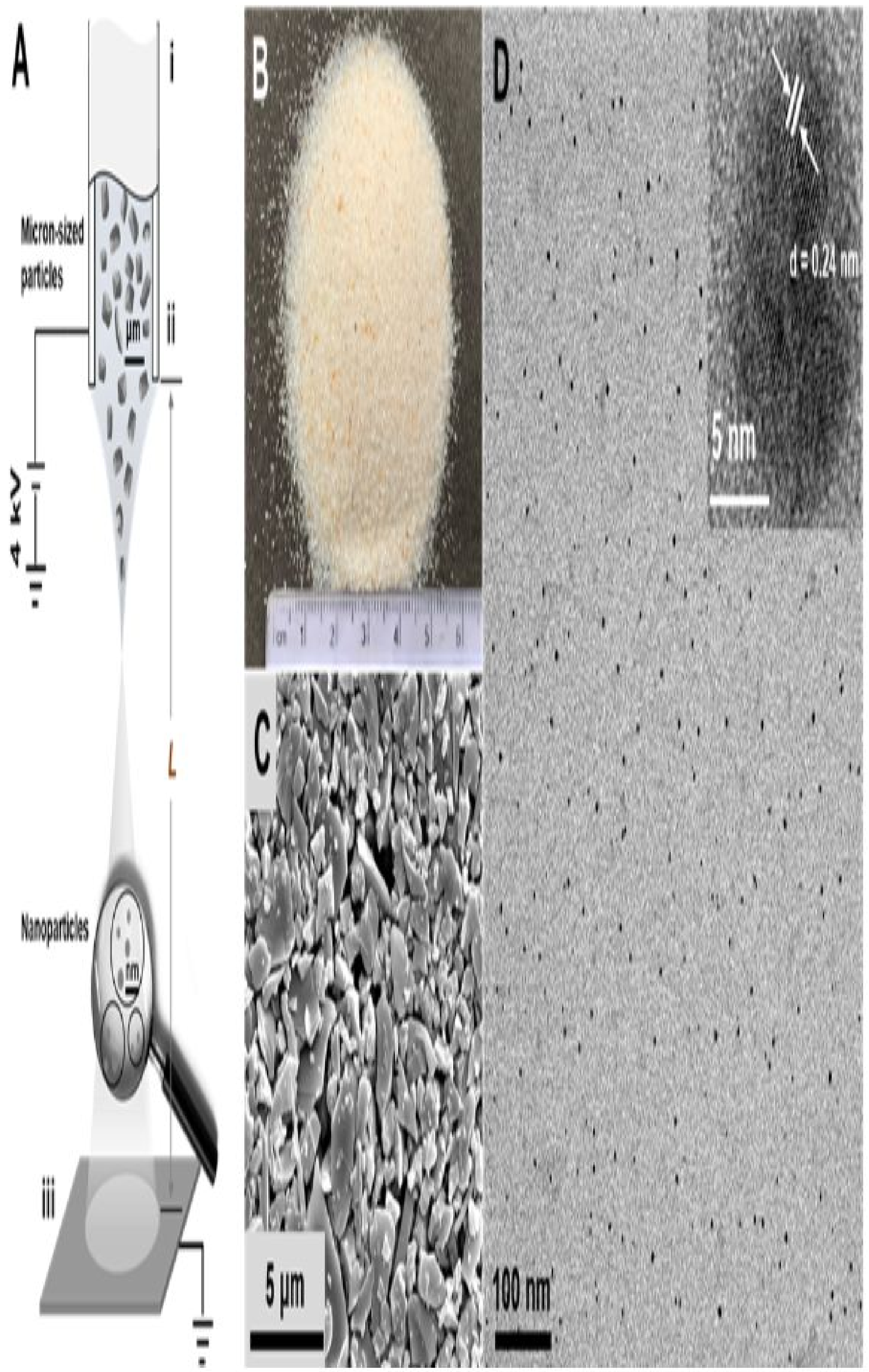

thermoscientific
ThermoFisher
SCIENTIFIC

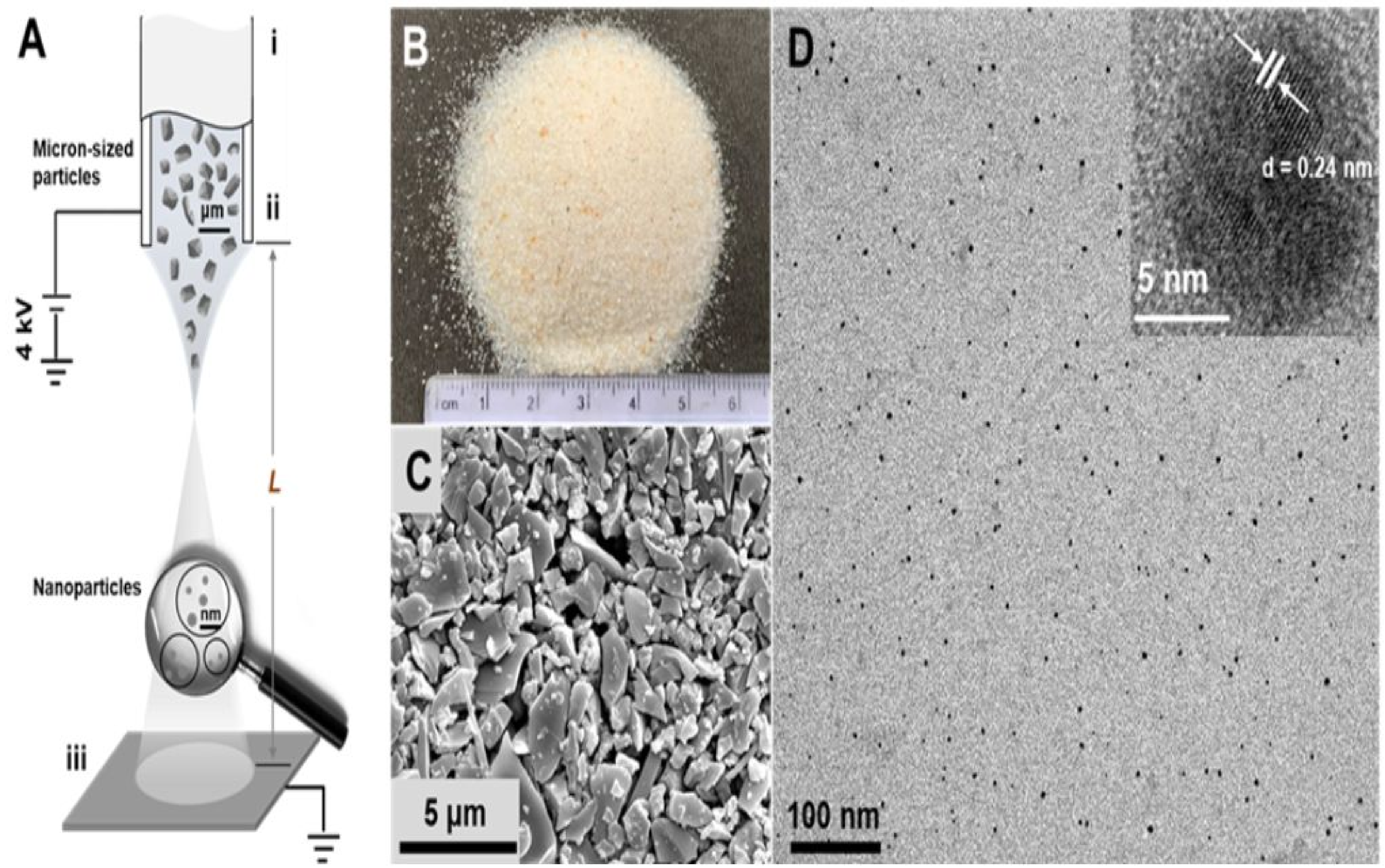


B. S. Sooraj, et. al. Unpublishe
d

Weathering of Minerals in Microdroplets

Spontaneous Weathering of Natural Minerals in Charge d Water Microdroplets Forms Nanomaterials

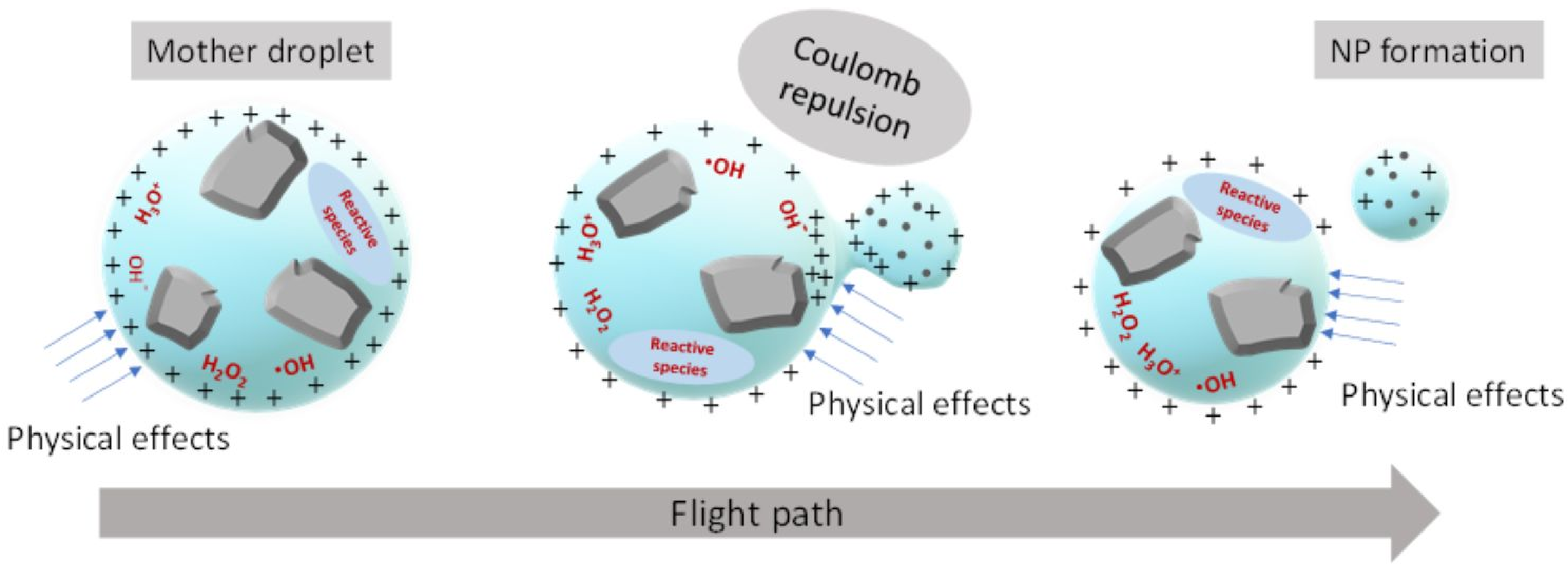




Spoorthi, et. al., *Science*, 384 (2024) 1012-1017.

Ruby, Fused Alumin
a

Mechanism of nanoparticle formation



International Centre for Clean Wa
ter

People’s Water Data

A course by IIT M

Collaborator
s






Robin Ras

Nonappa

Tomas Bas
e

Manfred Kappes

Olli Ikkal
a

Horst Hah
n

Tatsuya Tsukuda K
eisaku Kimura Yui
chi Negishi

Uzi Landman Han
nu Hakkinen Rob
Whetten

Biswarup Patha

K. V. Adars

G. U. Kulkarn

Vivek Polshettiw

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 Mahedranath, Ramesh Kumar Soni

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

Department of Science and Technology, Government of India

Institute of Eminence

Many Outstanding Individuals

Indian Institute of Technology Madras

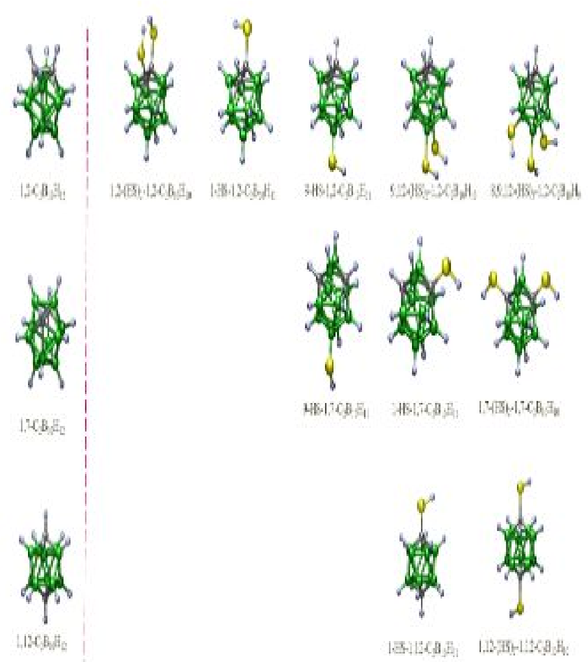
Associate Editor

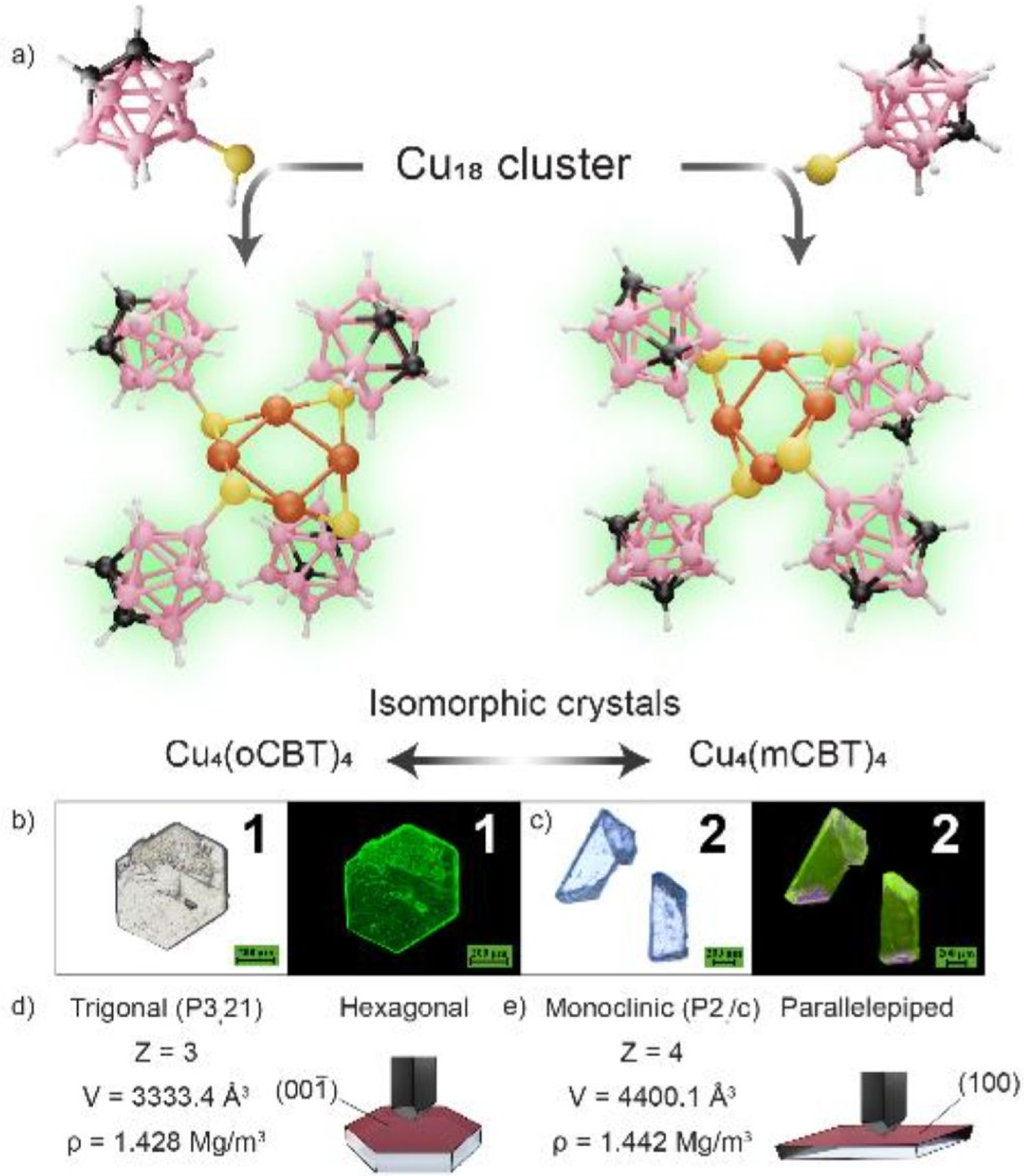
amurthi/V. Kamakot
i

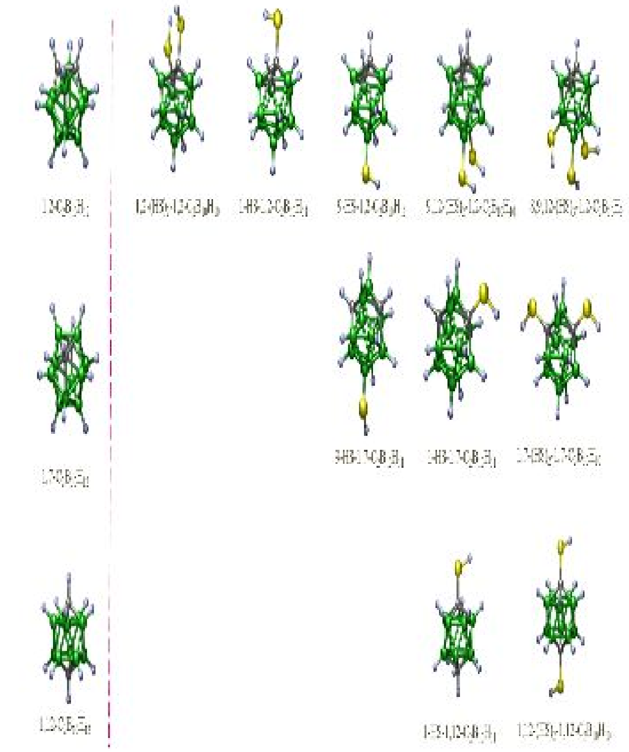
Manswita Mandal for help with the sli
des

Properti
es

Nanomechanical Properties of Cu4 Nanoclusters

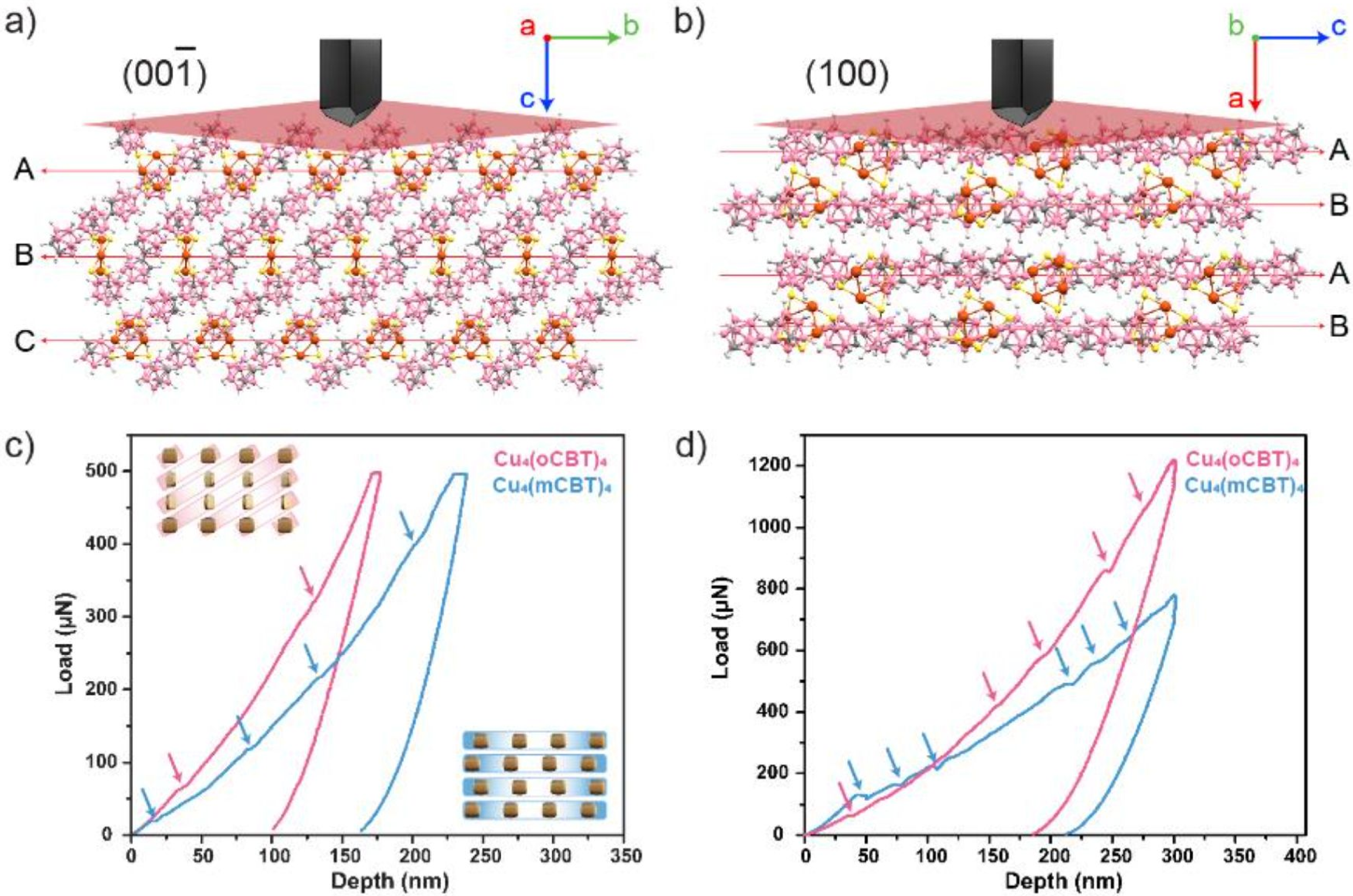






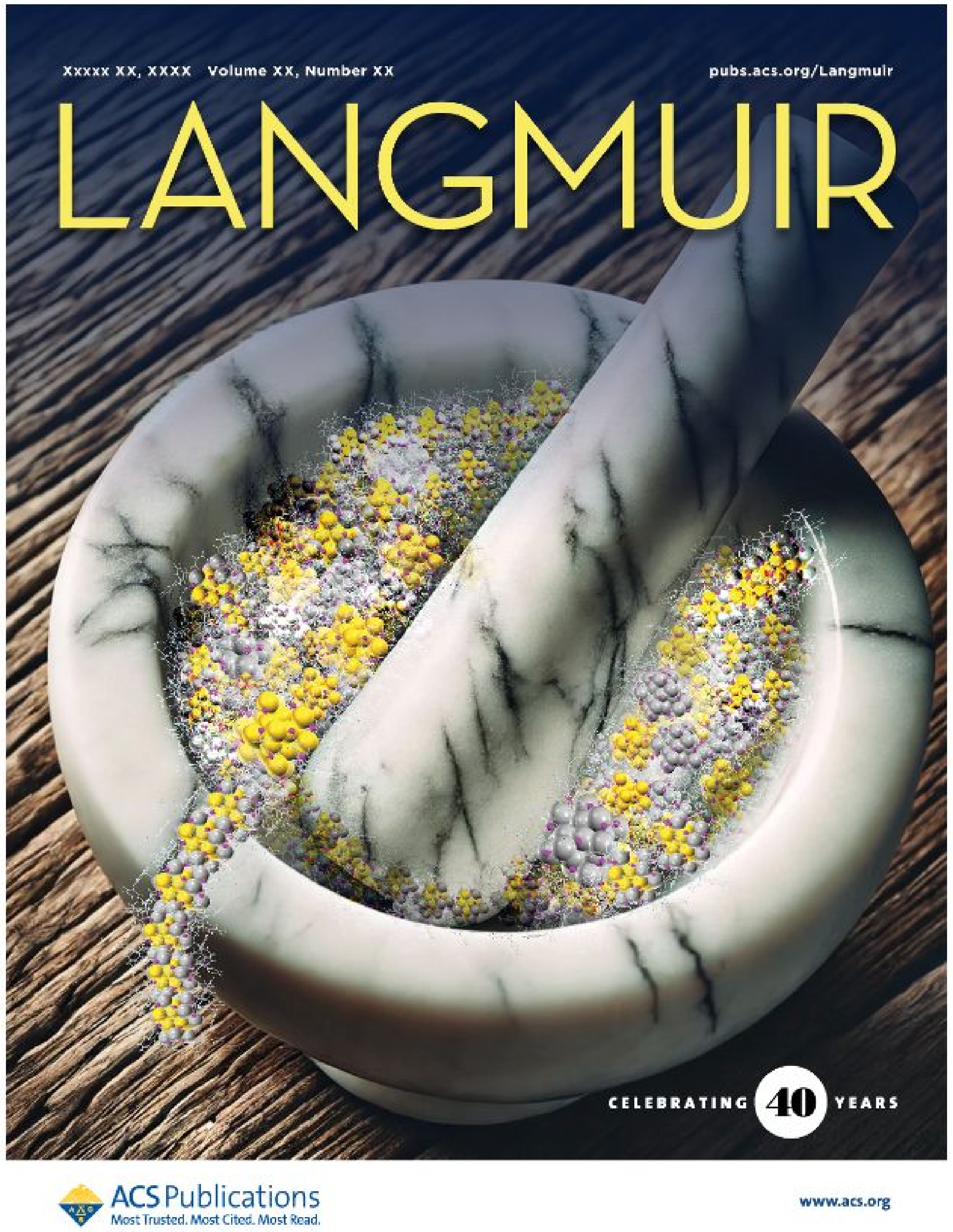
Amoghavasha Ramachandra Kini, et. al., *Chem. Mater.* 2025

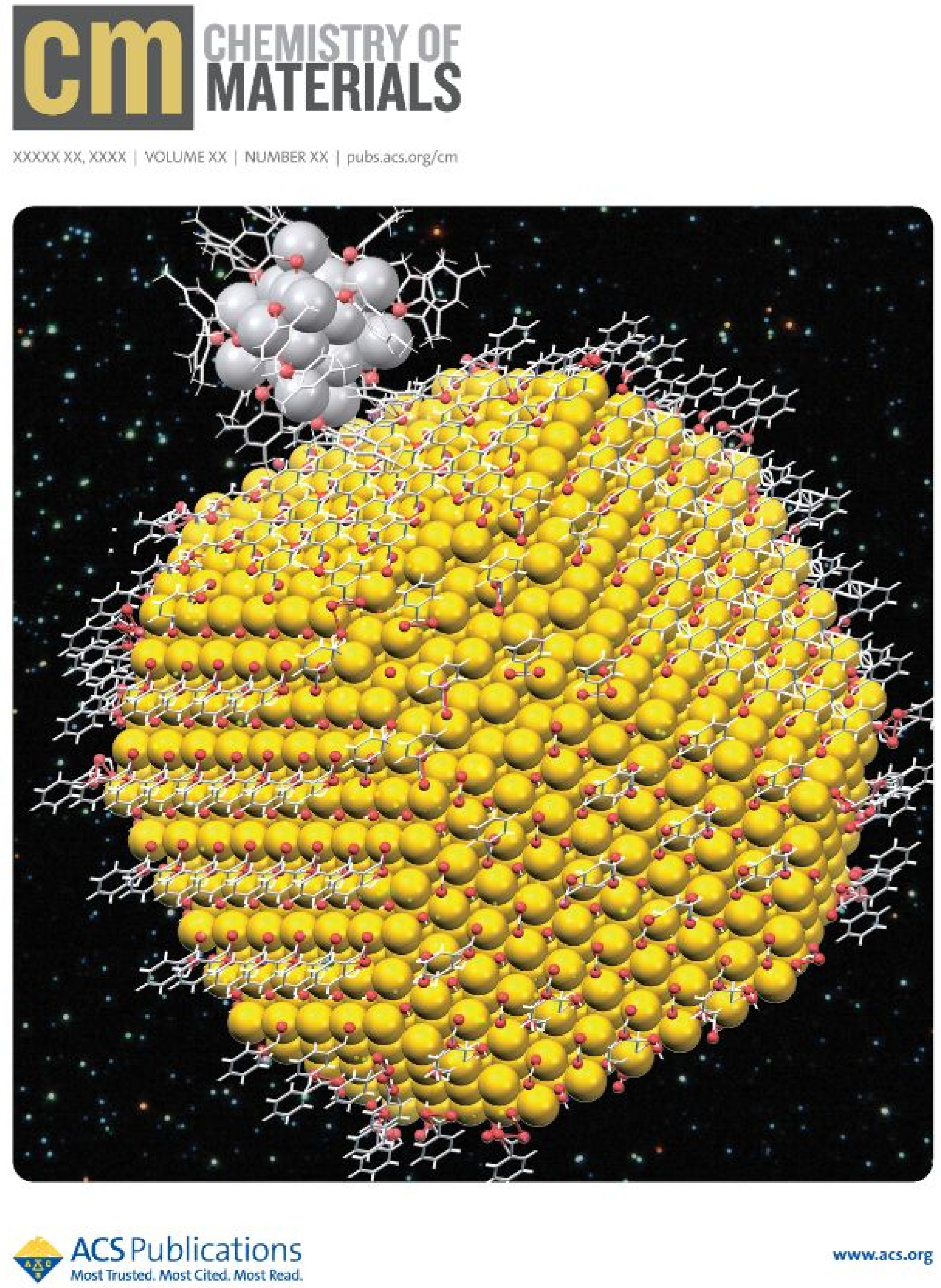
Nanomechanical Properties of Cu4 Nanoclusters

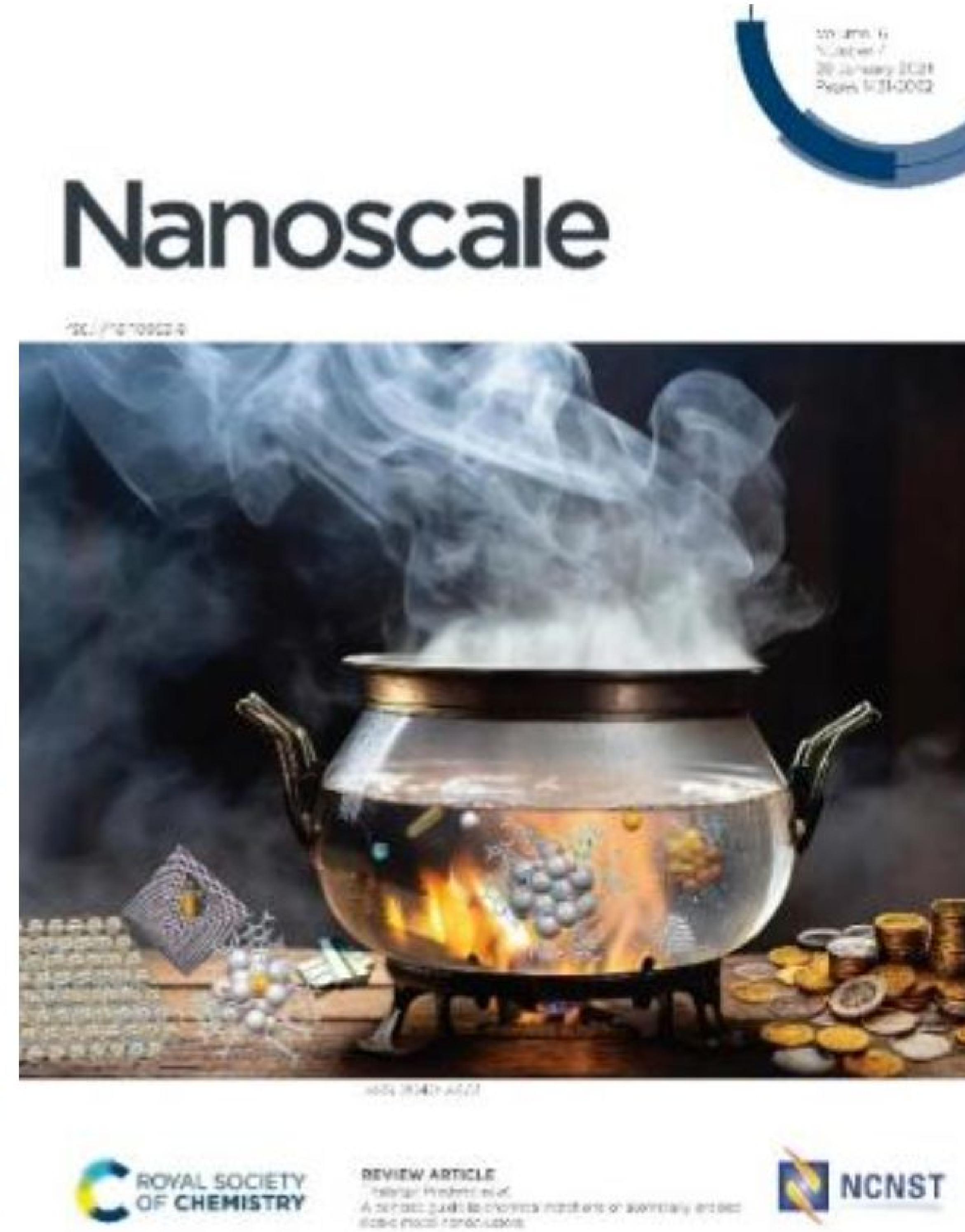


Catalysis by Ag13Cu4 Nanoclusters

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







Department of Science and Technology

**Institute of Eminenc
e**

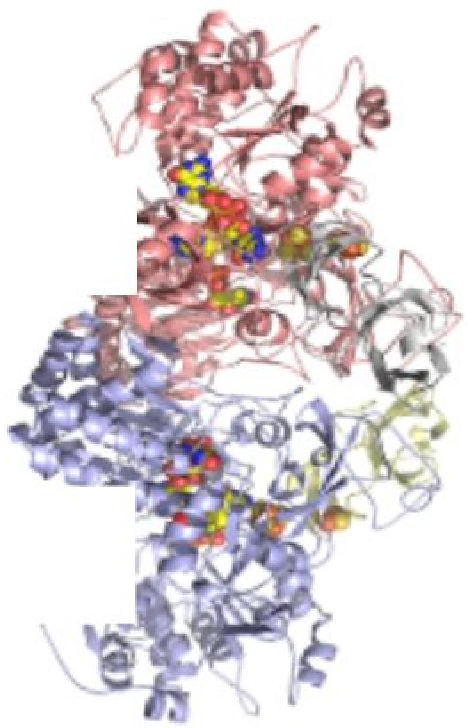
**Many Outstanding Individu
als**

Biosensor Design

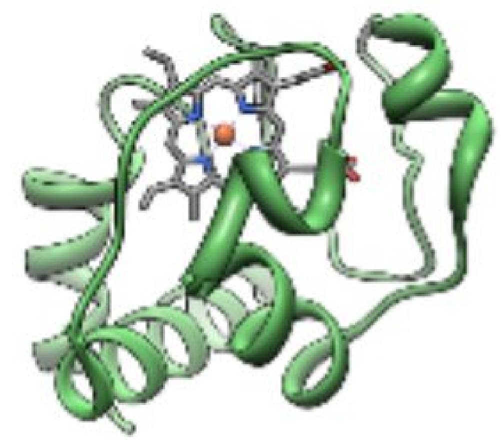
[redacted]
y)

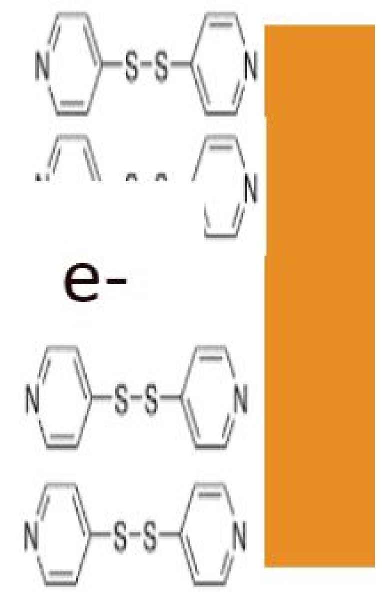
As(III)

As(V)



e-





Buffer: pH 7-8

Recombinant Arsenite Oxidase NT-26 Aio

Horse Heart Cytochrome C

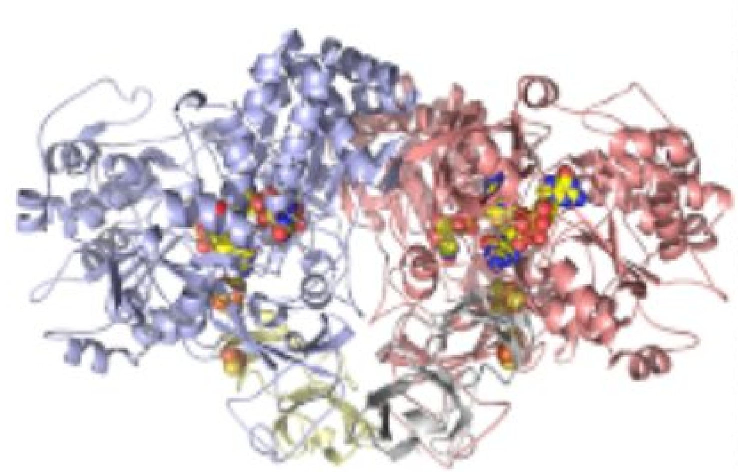
Aldrithiol

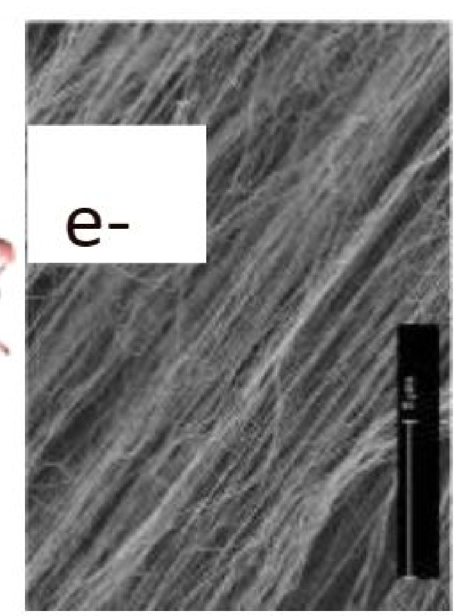
Low-cost Gold sputtered thin film on PET substrate

[redacted]
sfer)

As(III)

As(V)

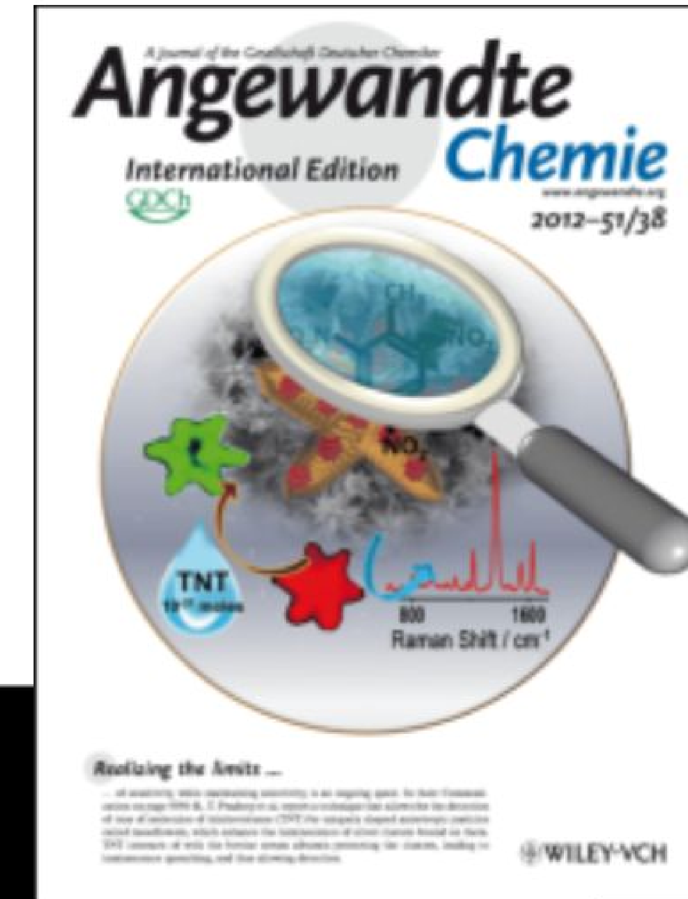


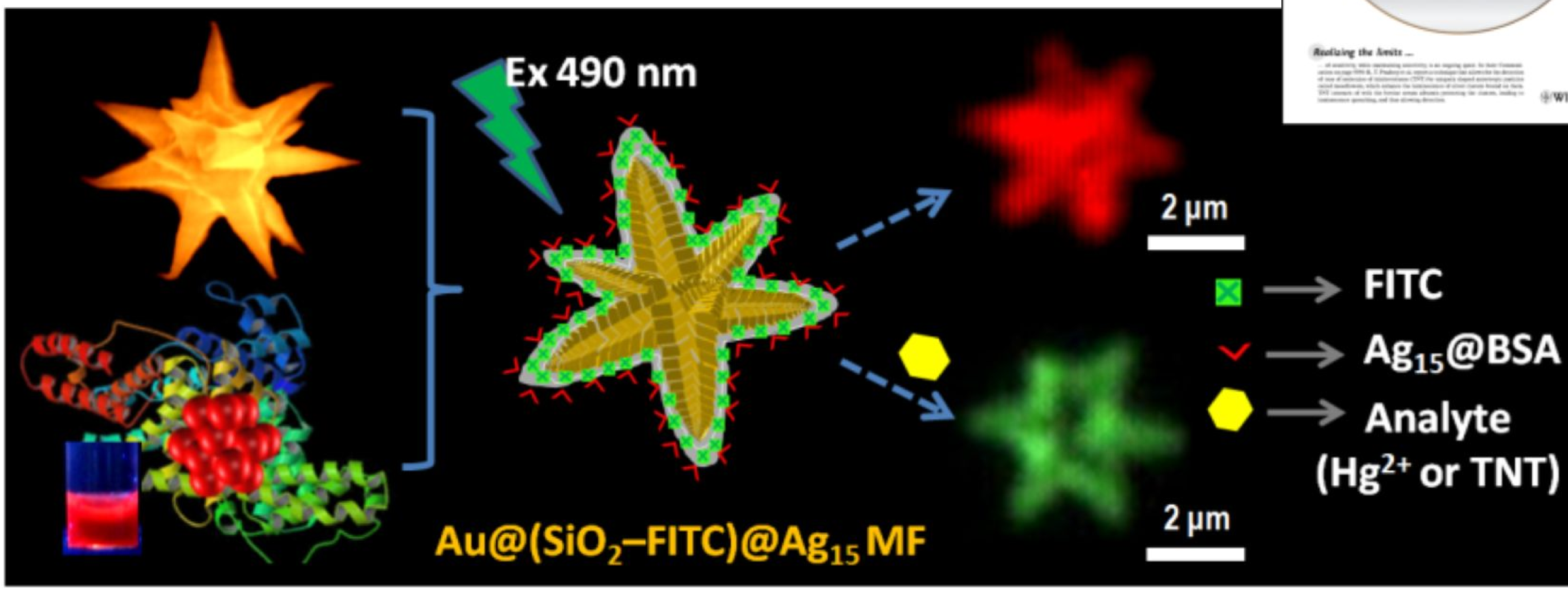


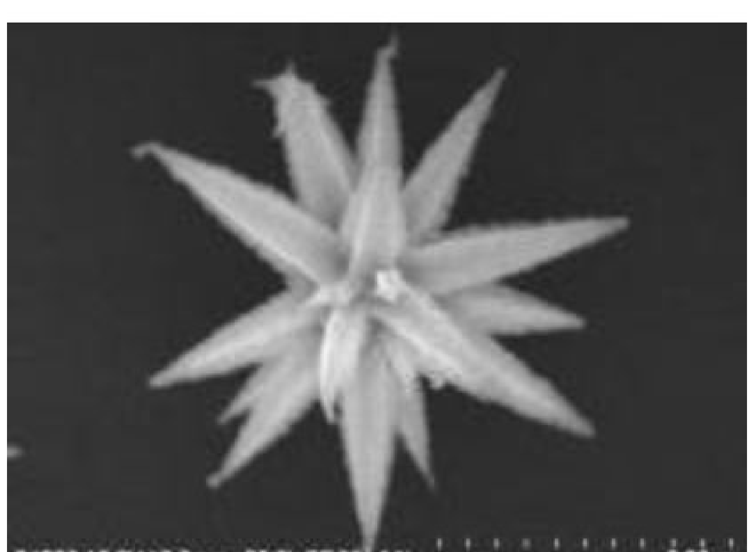
low-cost nanostructured electrodes which interact directly with enzyme (e.g. graphene or CNT).

Recombinant Arsenite Oxidase NT-26 Aio

Sub-zeptomolar detection







Featured in:

The Hindu, Telegraph, Times of India, etc.

C&E News

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

How do we know that they exi st?

Charge detection MS

KUNGL. VETENSKAPS-AKADEMIEN THE NOBEL PRIZE IN CHEMISTRY 2023

POPULAR SCIENCE BACKGROUND

Illustration of quantum dots

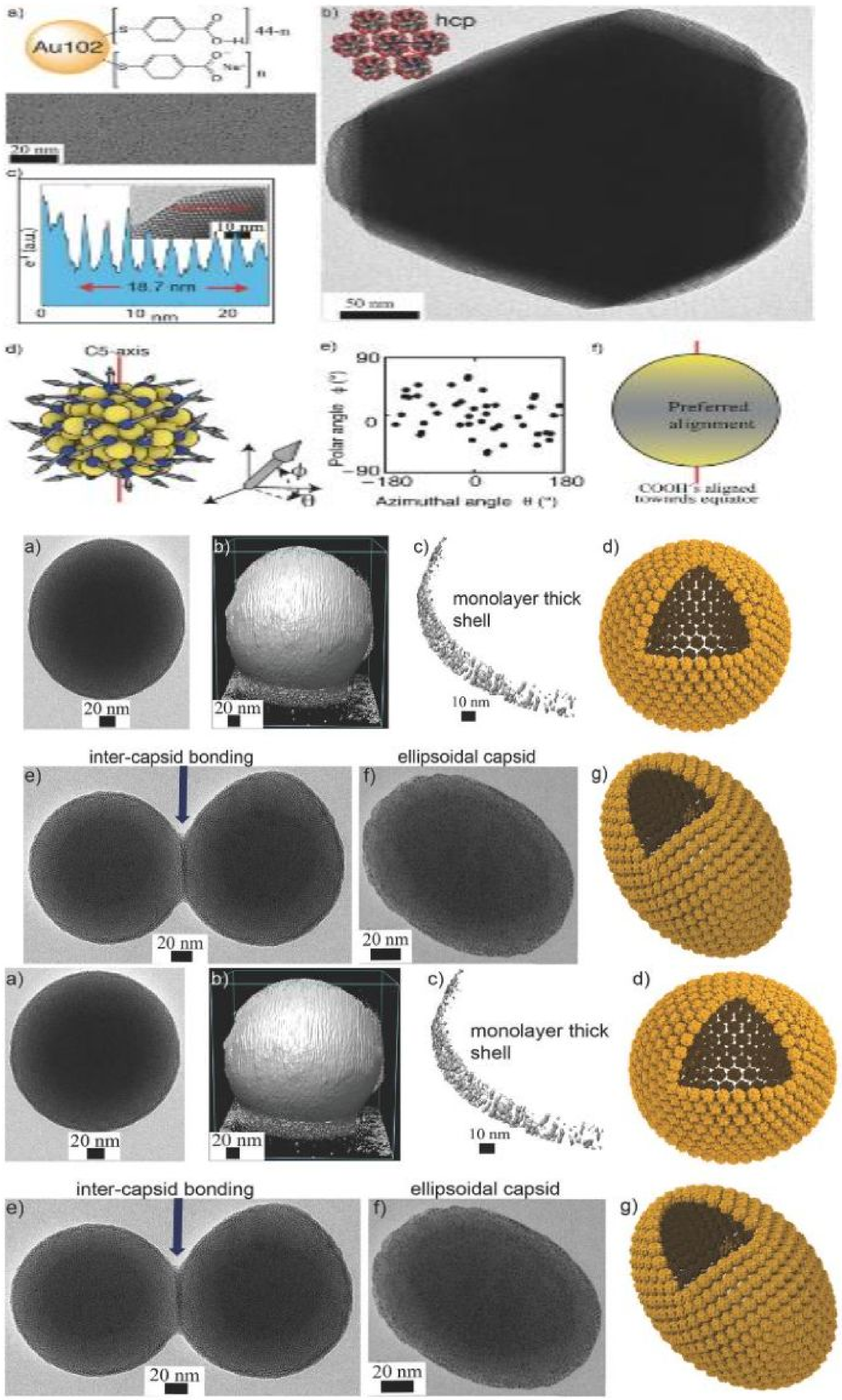
Left: transmission electron microscope image of a CdSe nanocrystal. Centre: Atomic struc ture of a nanocrystal. Right: Electronic states in a core-shell quantum dot, with the dot its elf in the centre bracketed by a wide-bandgap shell.

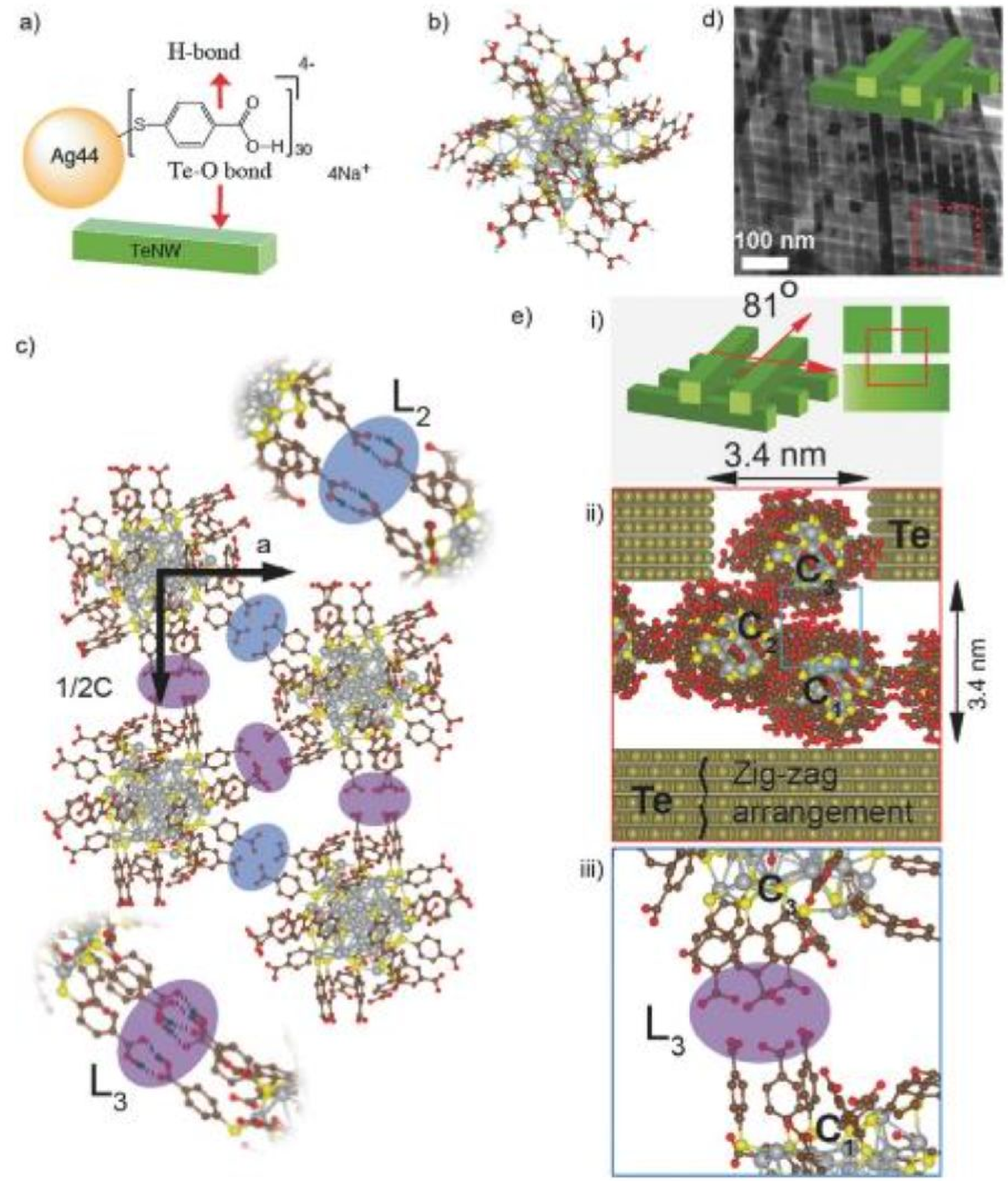
A. L. Efros and L.E. Brus, ACS Nano 15, 6192 (2021).

Today, ‘quantum dot’ refers to a nanostructure in which quantum m echanical effects manifest themselves in the electronic structure.

- Either through quantum size effects, many-body interactions (excitonic states) or high surface-to-volume ratio such that surface states dominate the electronic structure.
- In addition to a small size comparable to the carriers’ de Broglie wavelength, it is now recognized that the qu antum phase coherence length (typically limited by inelastic scattering) needs to exceed the system size.

Nanoclusters in colloidal assemblies

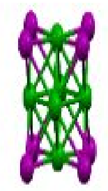




Som, A. et al., *Adv. Mater.* **2016**, *28*, 2827–2833

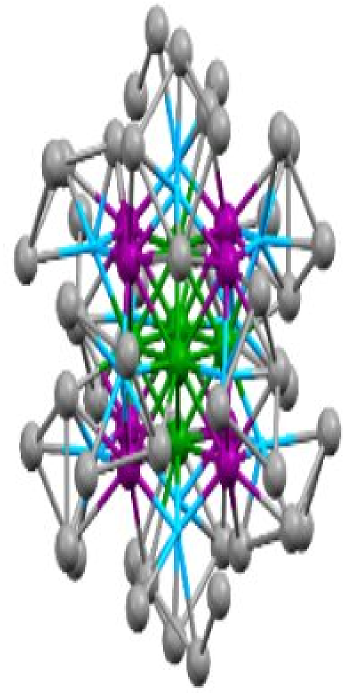
Nonappa et al., *Angew. Chem. Int. Ed.* **2016**, *55*, 16035–16038.

Structural anatomy of [Ag62S12(CBT)32] Nanocluster

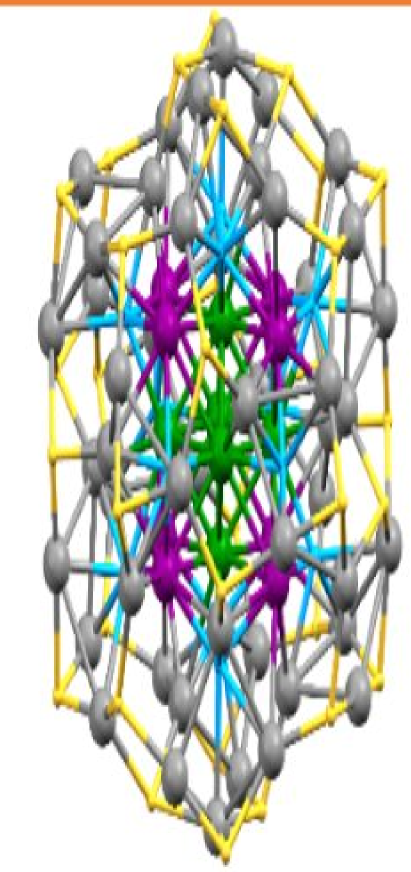


Ag6@Ag8

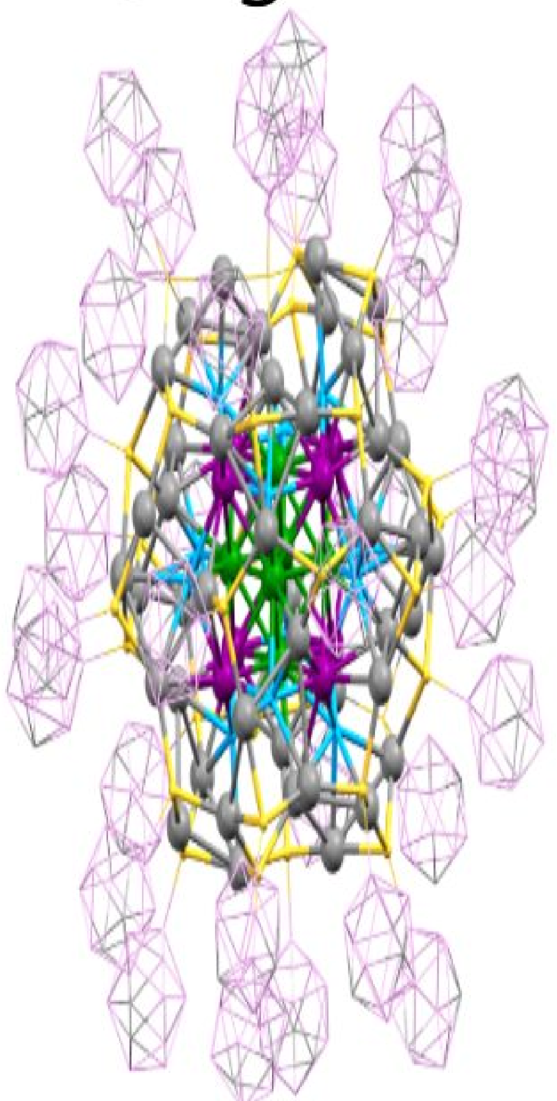
Ag6@Ag8S12



Ag6@Ag8S12@Ag48

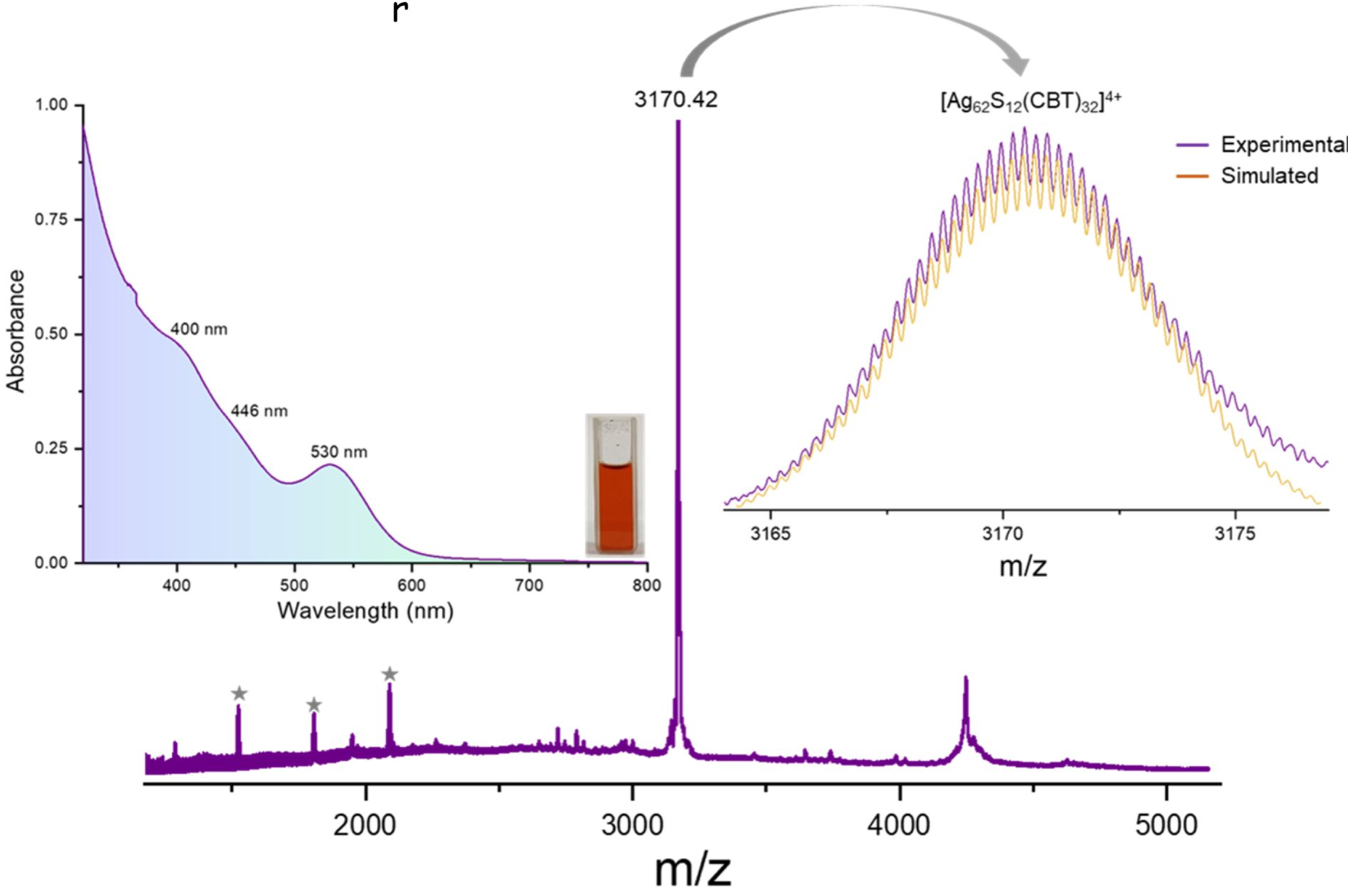


Ag6@Ag8S12@Ag48S32



Ag6@Ag8S12@Ag48S3

Characterization of Ag62 cluste
r



**Gas phas
e**