Since 1959

From Molecular Acorns to Institutional Oaks

T. Pradeep

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https://pradeepresearch.org

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InnoDI Water Technologies Pvt. Ltd.
VayuJAL Technologies Pvt. Ltd.
Aqueasy Innovations Pvt. Ltd.
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EyeNetAqua Solutions Pvt. Ltd.
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E. S. Shibu and colleagues

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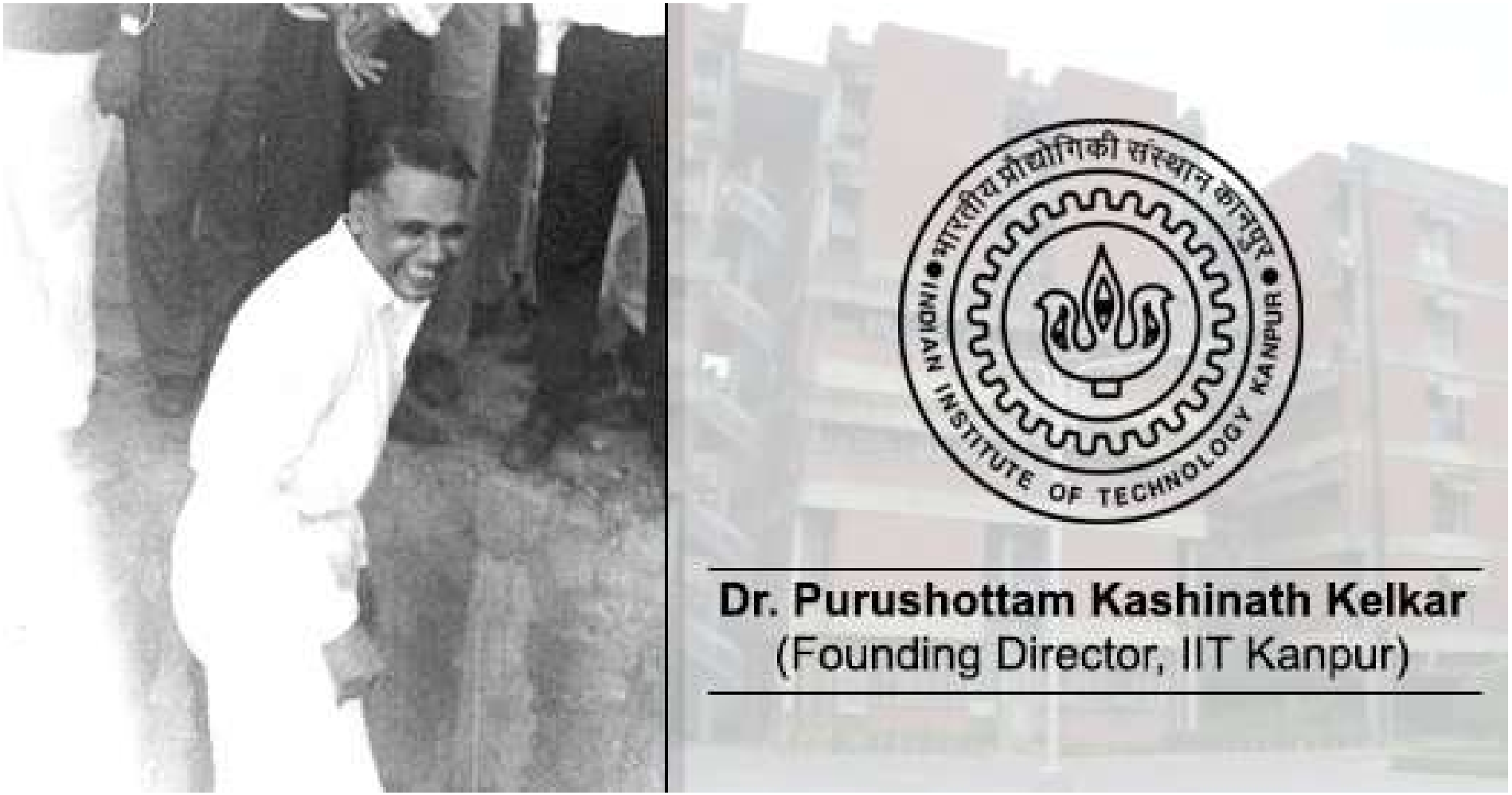
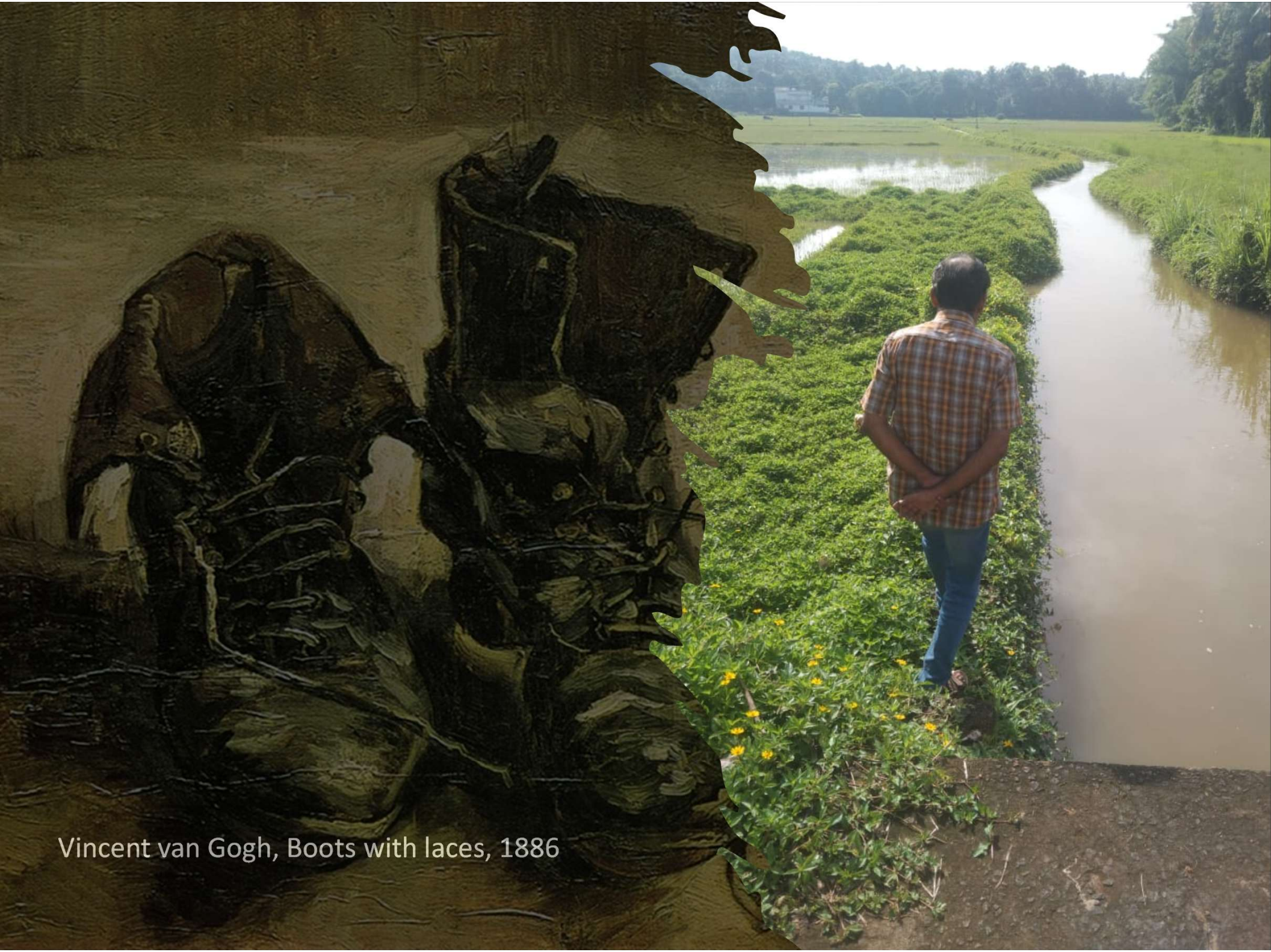
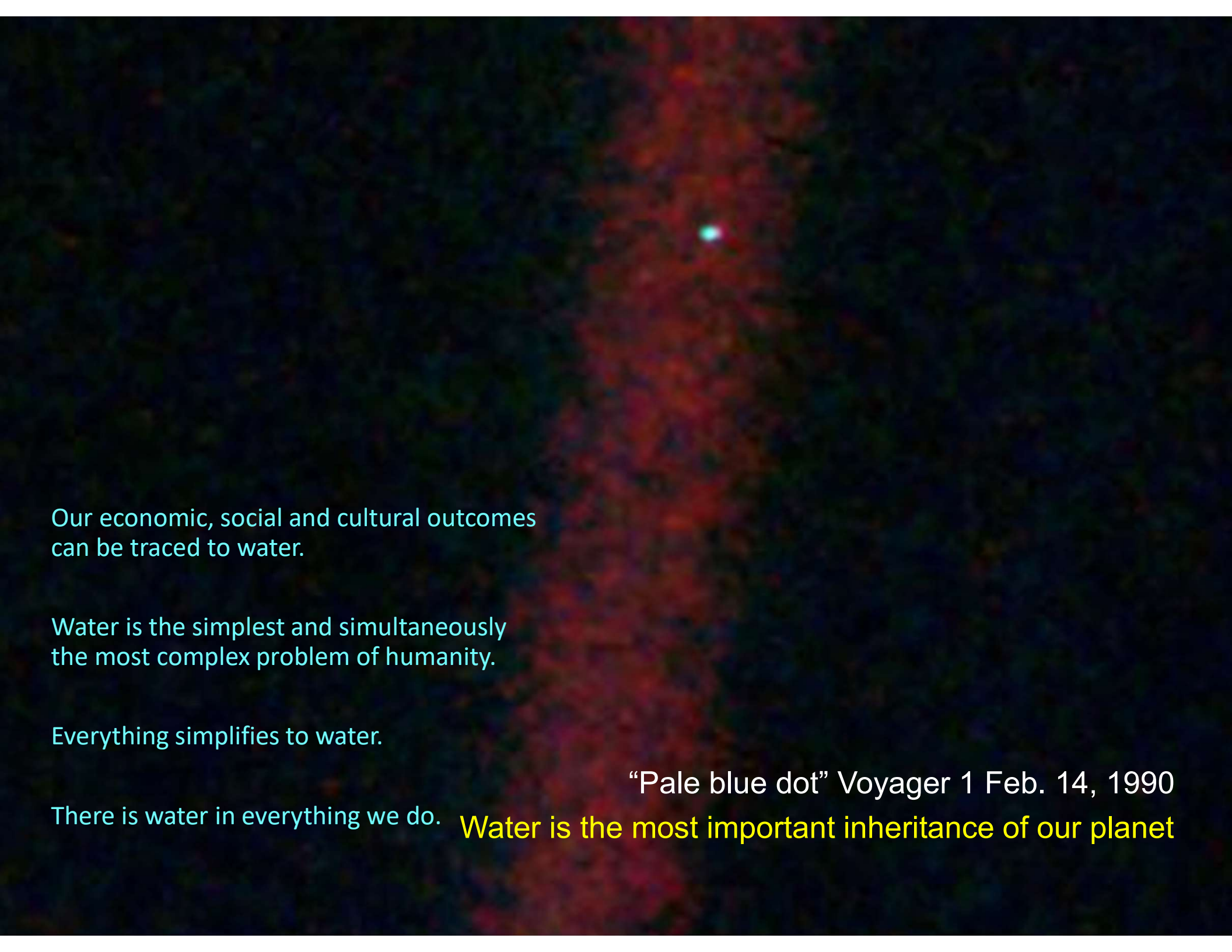
THEMATIC UNIT OF EXCELLENCE

Frontier Lecture -1, School of Physical Sciences, University of Calicut, June 20, 2022



People, enabling environment and hard work

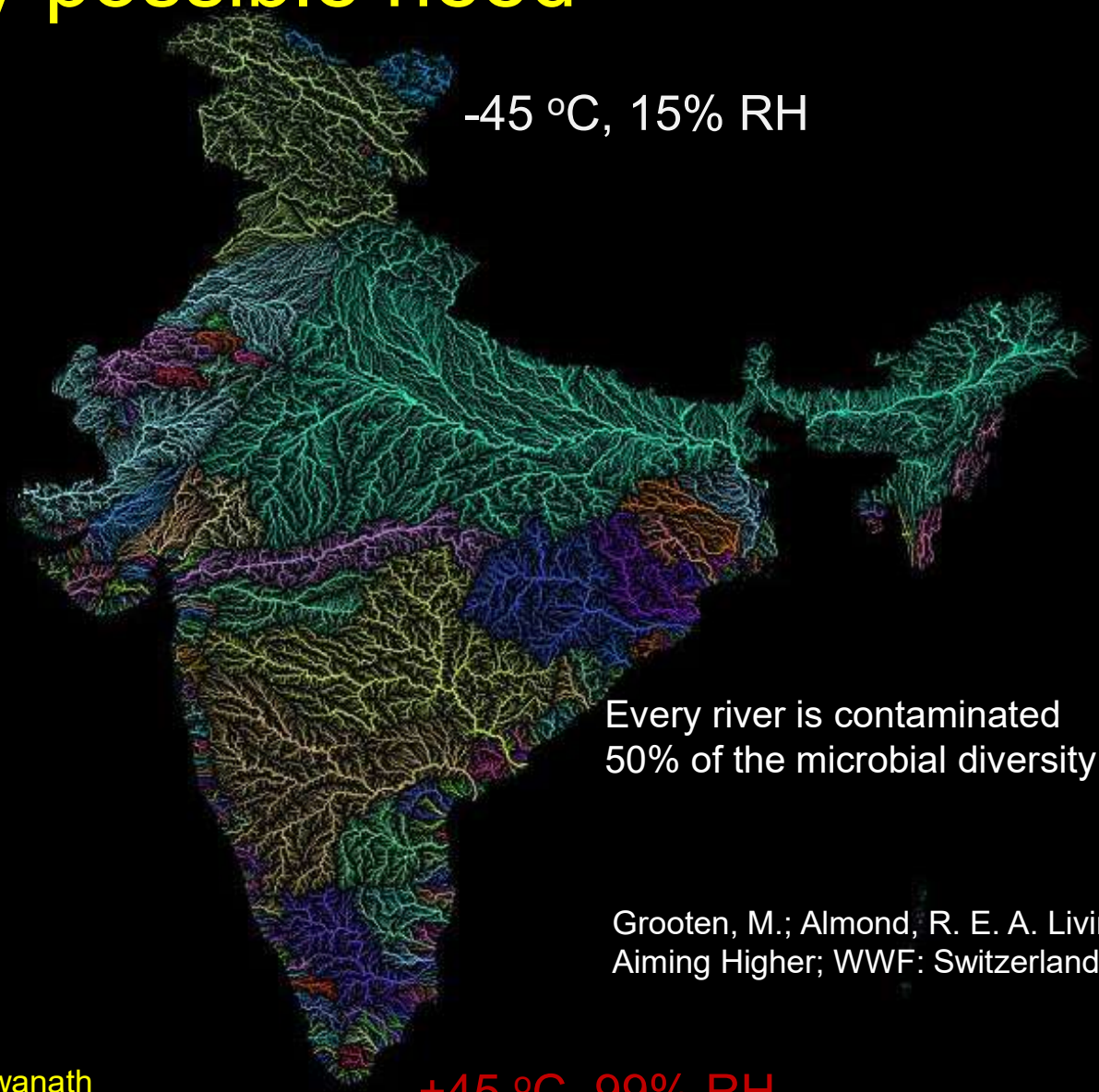

Vincent van Gogh, Boots with laces, 1886


Our economic, social and cultural outcomes
can be traced to water.
Water is the simplest and simultaneously
the most complex problem of humanity.
Everything simplifies to water.
There is water in everything we do.
“Pale blue dot” Voyager 1 Feb. 14, 1990
Water is the most important inheritance of our planet

Water is at the entre of action

Variety and diversity are part of water, in problems and opportunities

Challenges
Every possible need



-45 °C, 15% RH

+45 °C, 99% RH

Arsenic
Fluoride
Uranium
Mercury
Chromium
Perchlorate
Nitrate
Pesticides
Antibiotics
Plastics
Detergents
…..

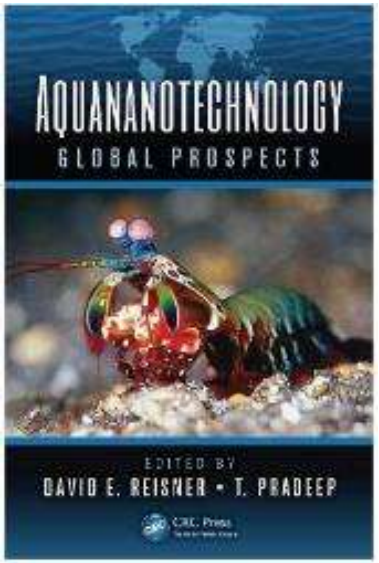
Every river is contaminated
50% of the microbial diversity is lost for ever

Grooten, M.; Almond, R. E. A. Living Planet Report - 2018: Aiming Higher; WWF: Switzerland, 2018.

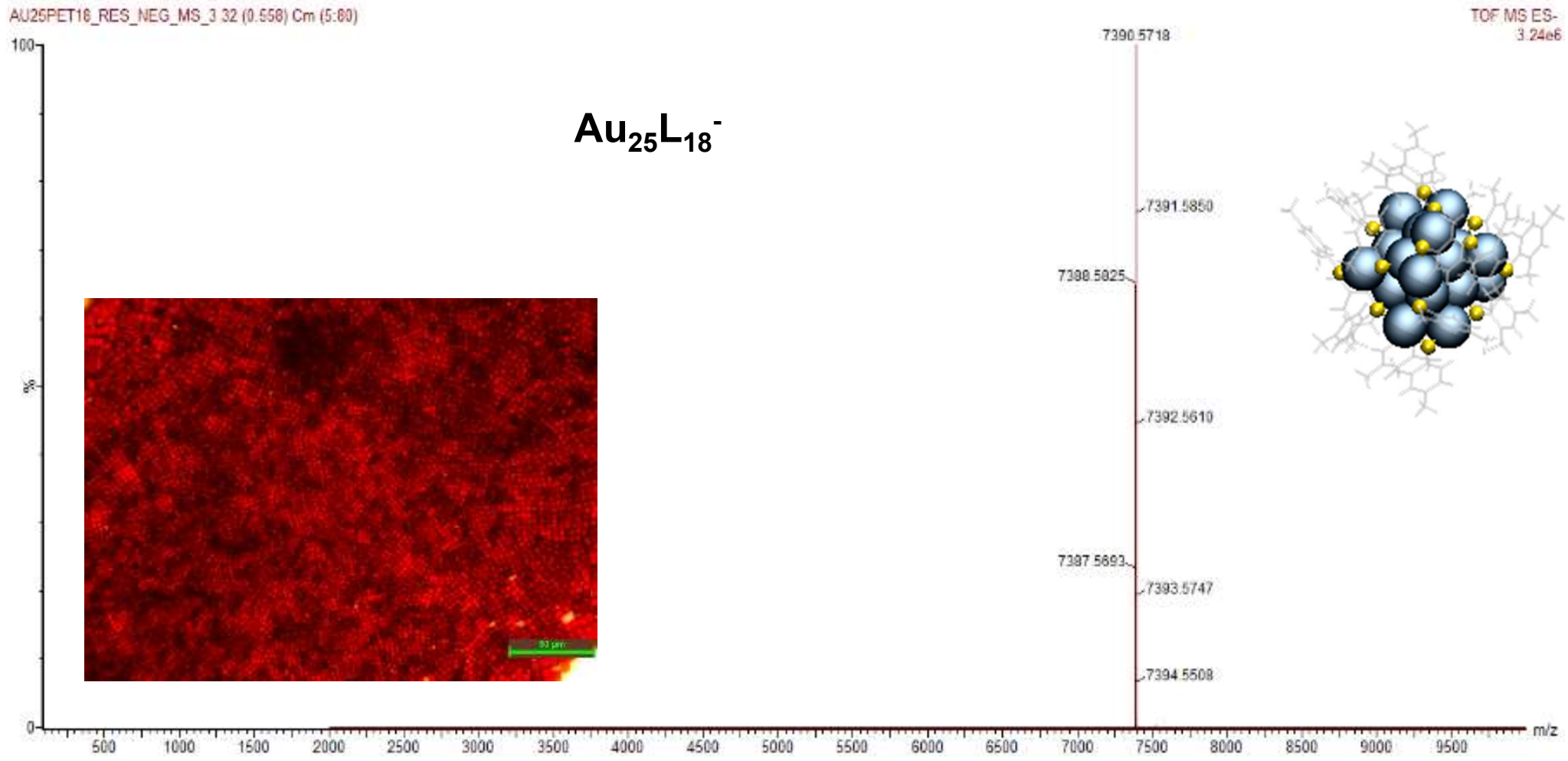
From S. Vishwanath

Affordable clean water is a problem of advanced materials

New adsorbents
New sensors
New catalysts
Novel phenomena
New devices



Nanomaterials have become atomically precise



$Au_{25}L_{18}^-$

T. Pradeep et. al. *Acc. Chem. Res.* 2018; 2019.

Nanomaterials can solve real problems

ACS Sustainable Chemistry & Engineering Editorial, December 2016

CHEMICAL REVIEWS

Review

pubs.acs.org/CR

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

Indranath Chakraborty[†] and Thalappil Pradeep[*]

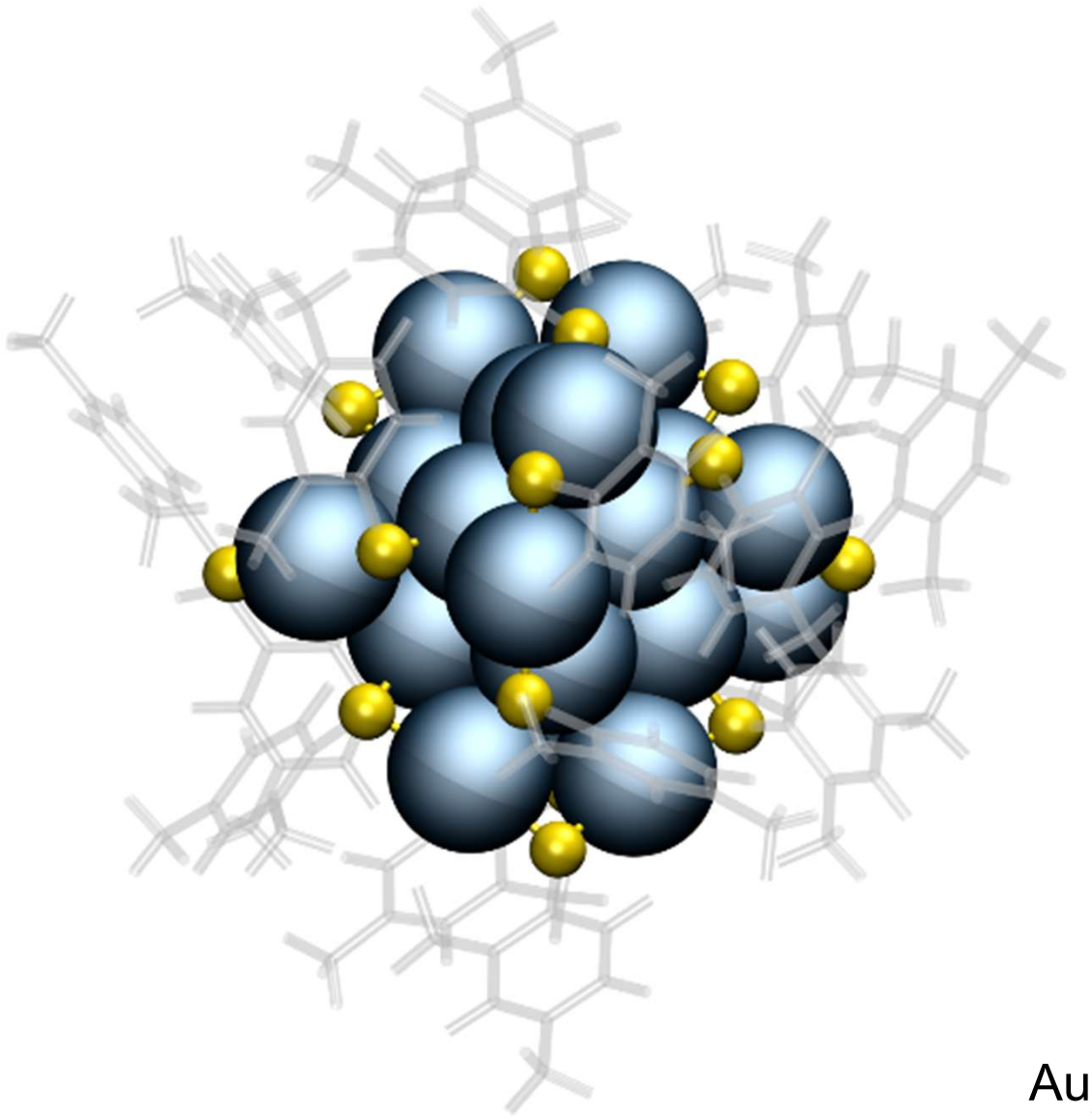
DST Unit of Nanoscience (DST UNS) and Thematic Unit of Excellence, Department of Chemistry, Indian Institute of Technology Madras, Chennai 600036, India

Supporting Information

Citations: >1100

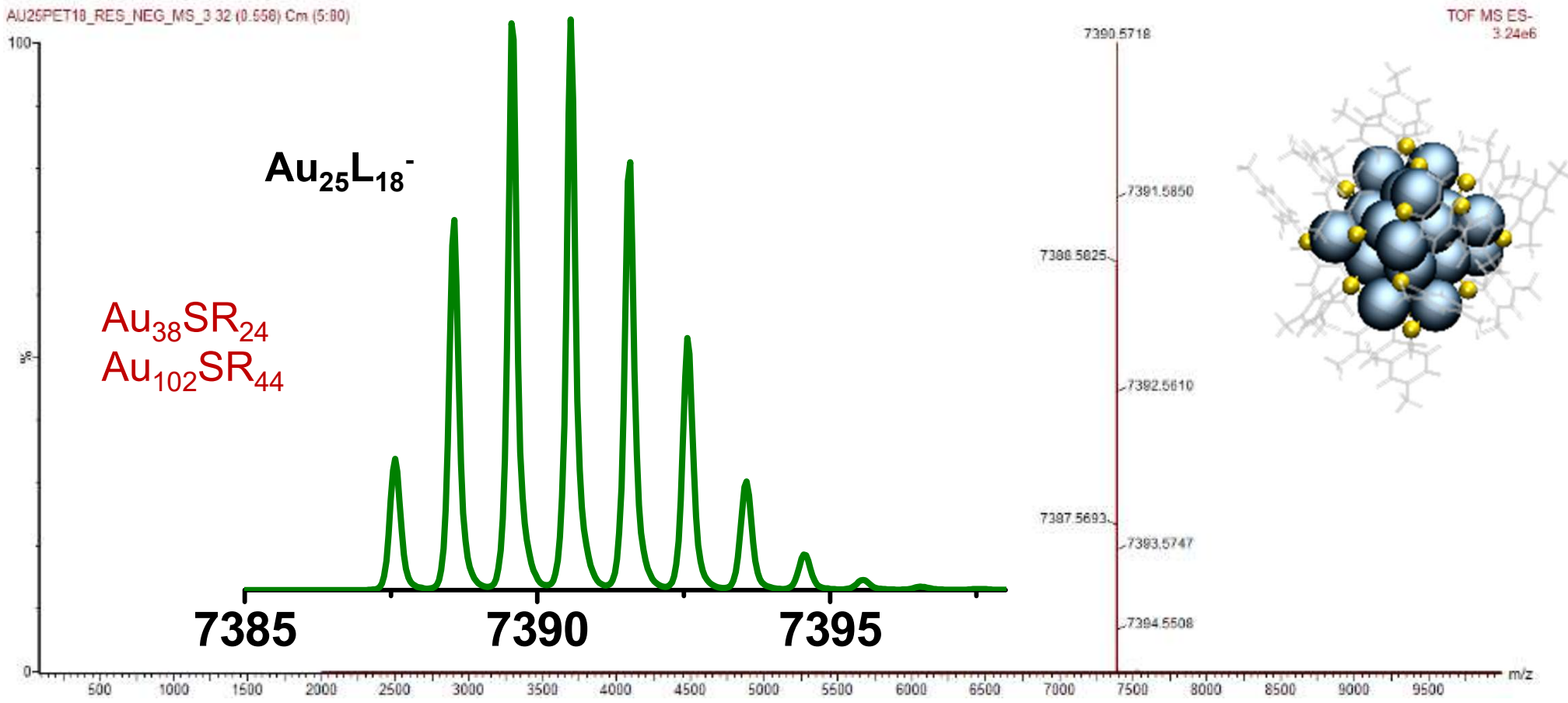
ABSTRACT: Atomically precise pieces of matter of nanometer dimensions composed of noble metals are new categories of materials with many unusual properties. Over 100 molecules of this kind with formulas such as $Au_{25}(SR)_{18}$, $Au_{38}(SR)_{24}$, and $Au_{102}(SR)_{44}$ as well as $Ag_{25}(SR)_{18}$, $Ag_{29}(S_2R)_{12}$, and $Ag_{44}(SR)_{30}$ (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.

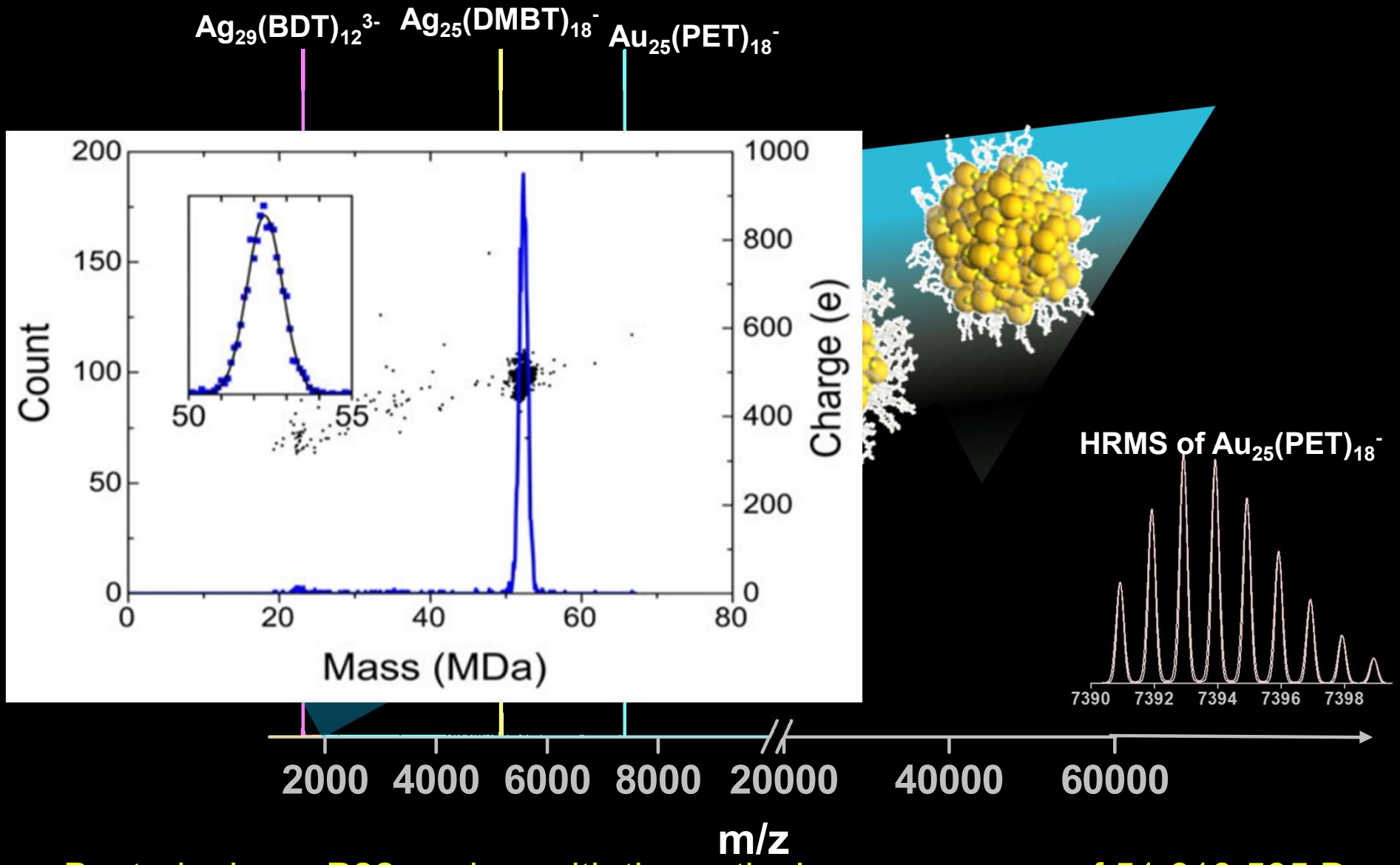
Also the pioneering work of R. W. Murray, Robert L. Whetten, Uzi Landman, Tatuya Tsukuda, Yuichi Negishi, Hannu Hakkinen, Rongchao Jin, Nanfeng Zheng, Terry Bigioni, Osman Bakr, Kornberg, Jianping Xie, C. M. Aikens, Thomas Buergi, Amala Dass, Ackerson, De-en Jiang, …. A. W. Castleman Jr., H. Schmidbauer,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



Au_{25}, Ag_{25}, Ag_{29}

Molecular formula, Molecular weight

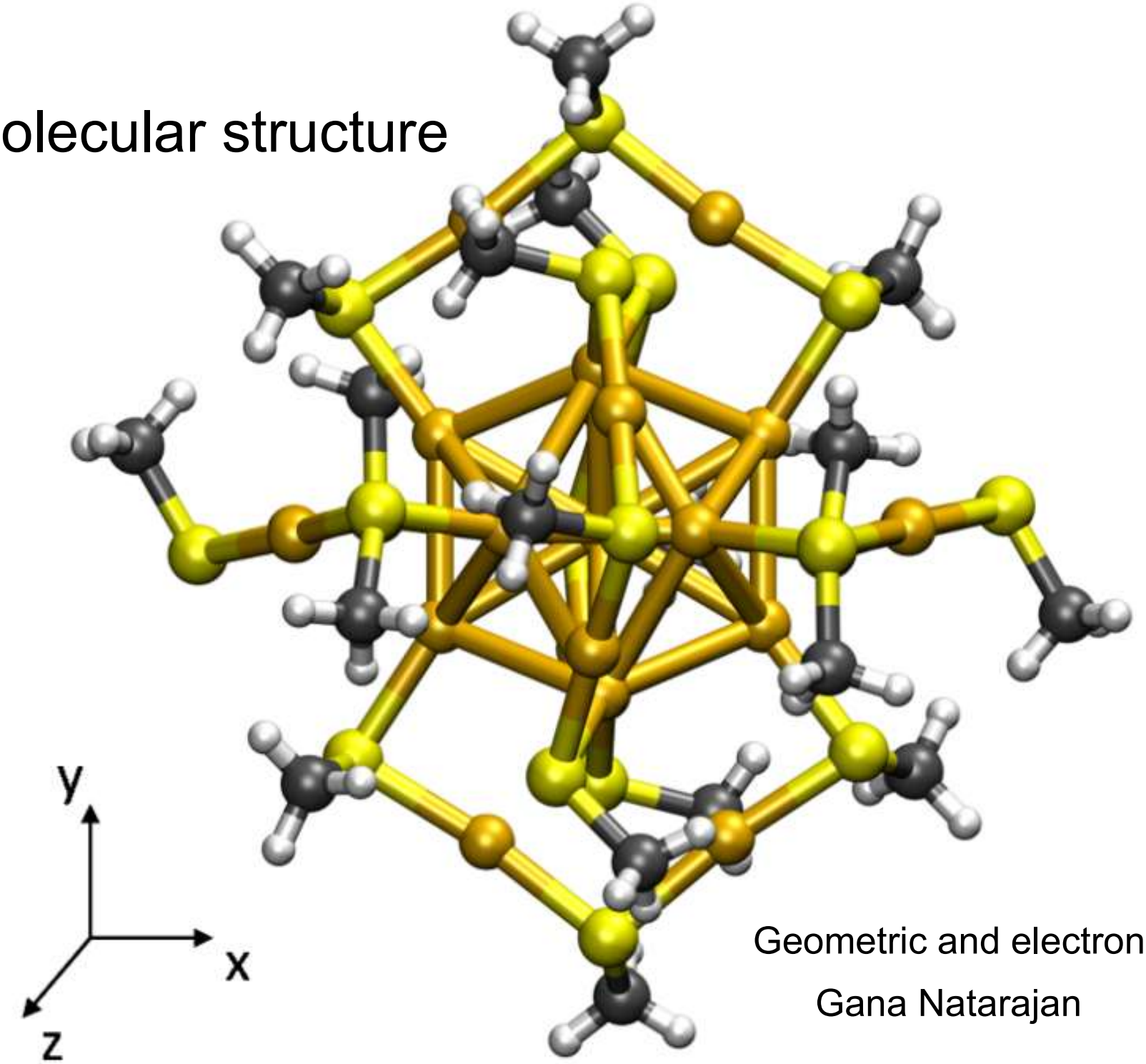




Bacteriophage P22, a virus with theoretical average mass of 51,613,585 Da

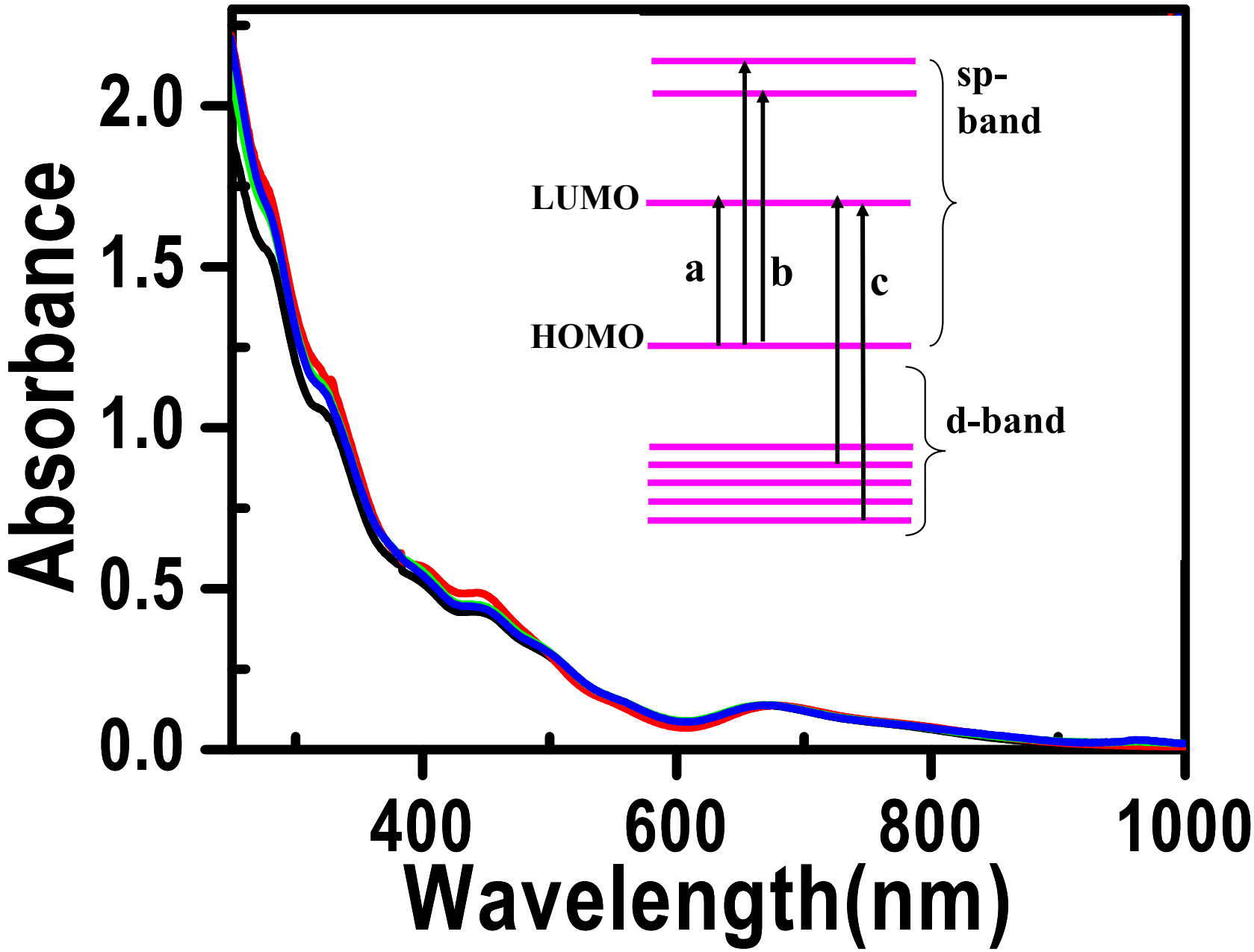
Au_{261998}

Molecular structure



Geometric and electronic shells

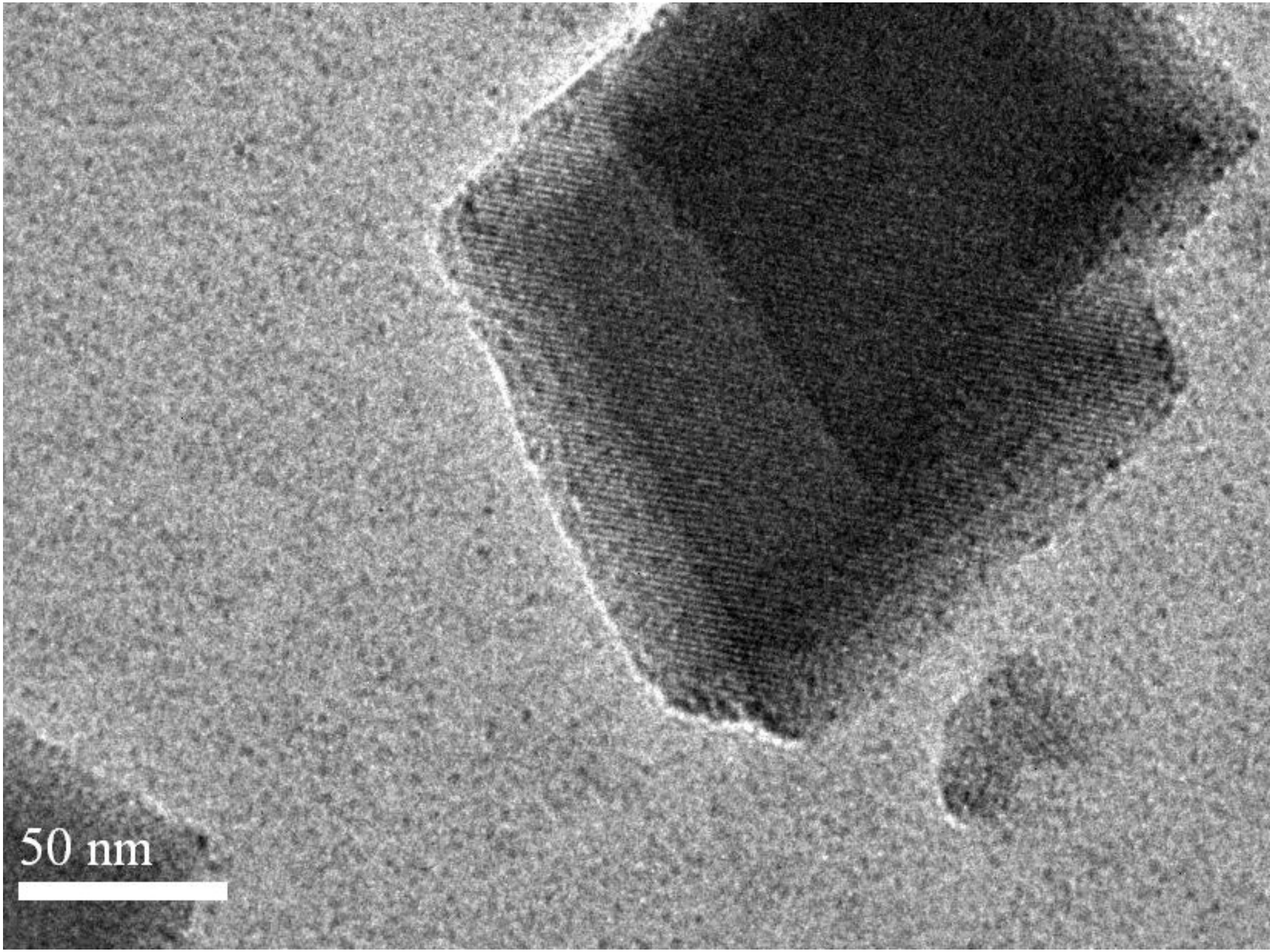
Gana Natarajan

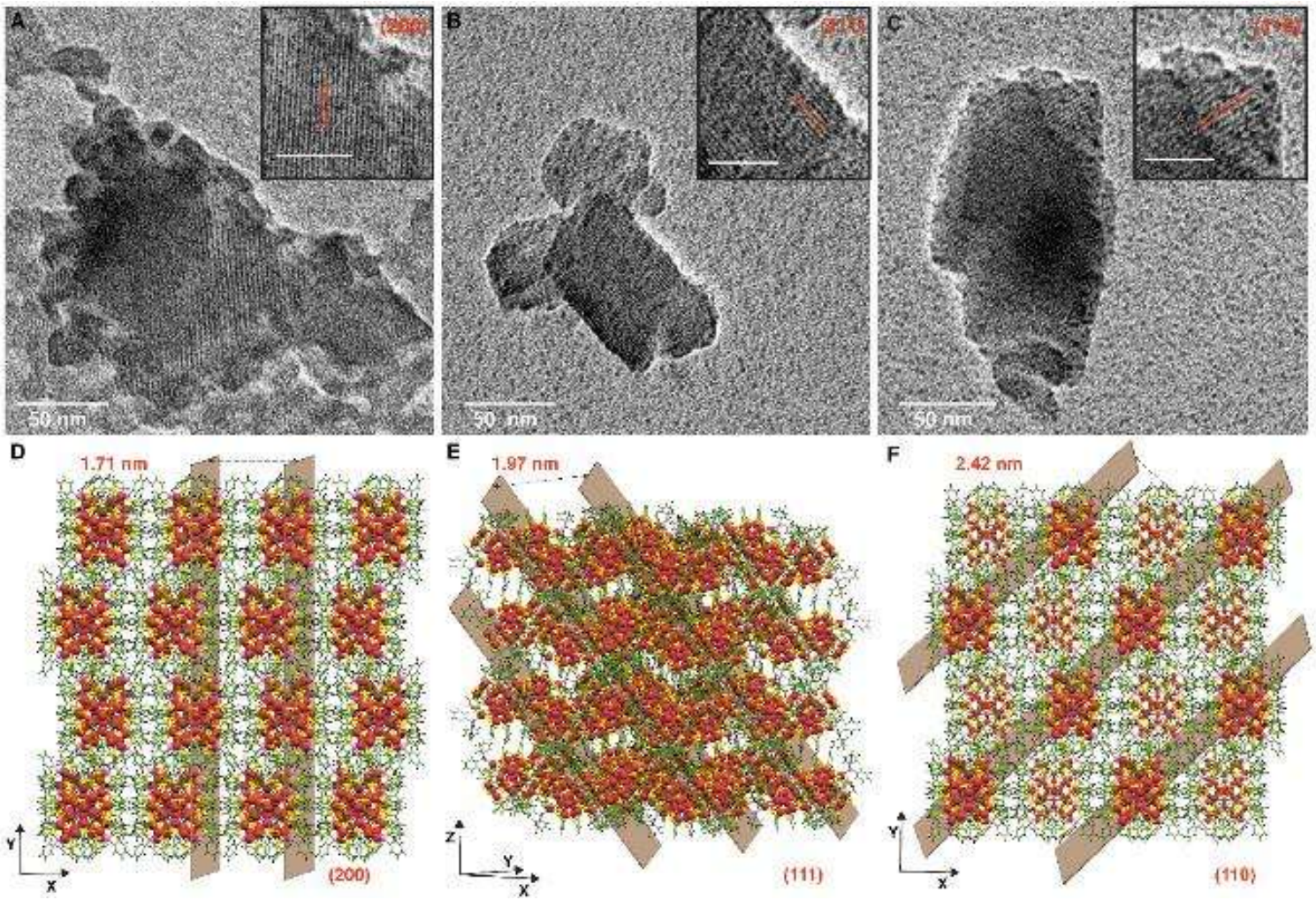


E. S. Shibu et al. J. Phys. Chem. C. 2008

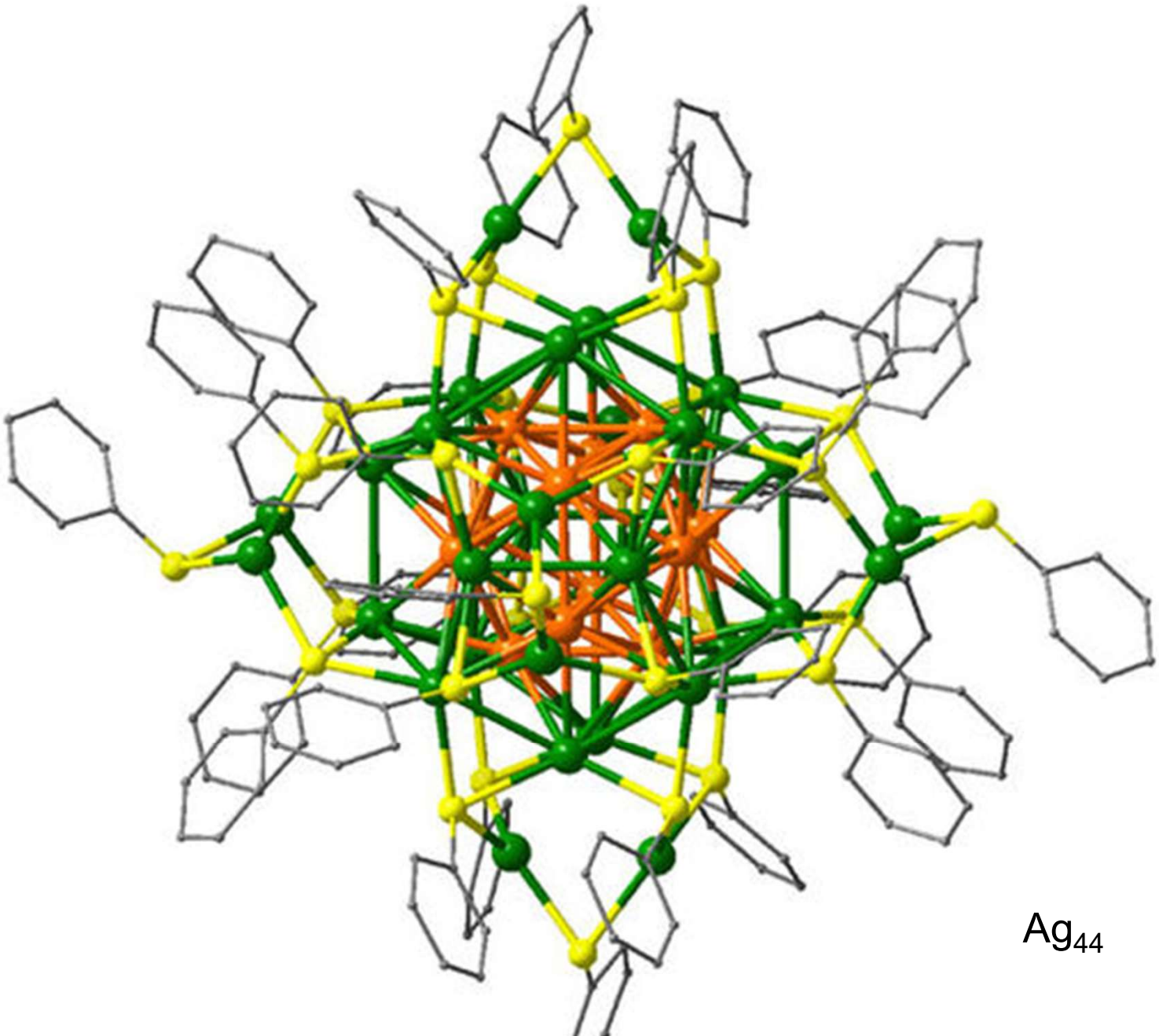
Molecules and their properties

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. × 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


50 nm



Ananthu Mahendranath et al. Chem.Comm.2021



Ag_{44}

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

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 $Ag_{44}(SR)_{30}$

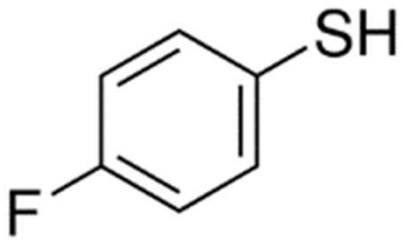
K. R. Krishnadas, Atanu Ghosh, Ananya Baksi, Indranath Chakraborty,† Ganapati Natarajan, and Thalappil Pradeep*

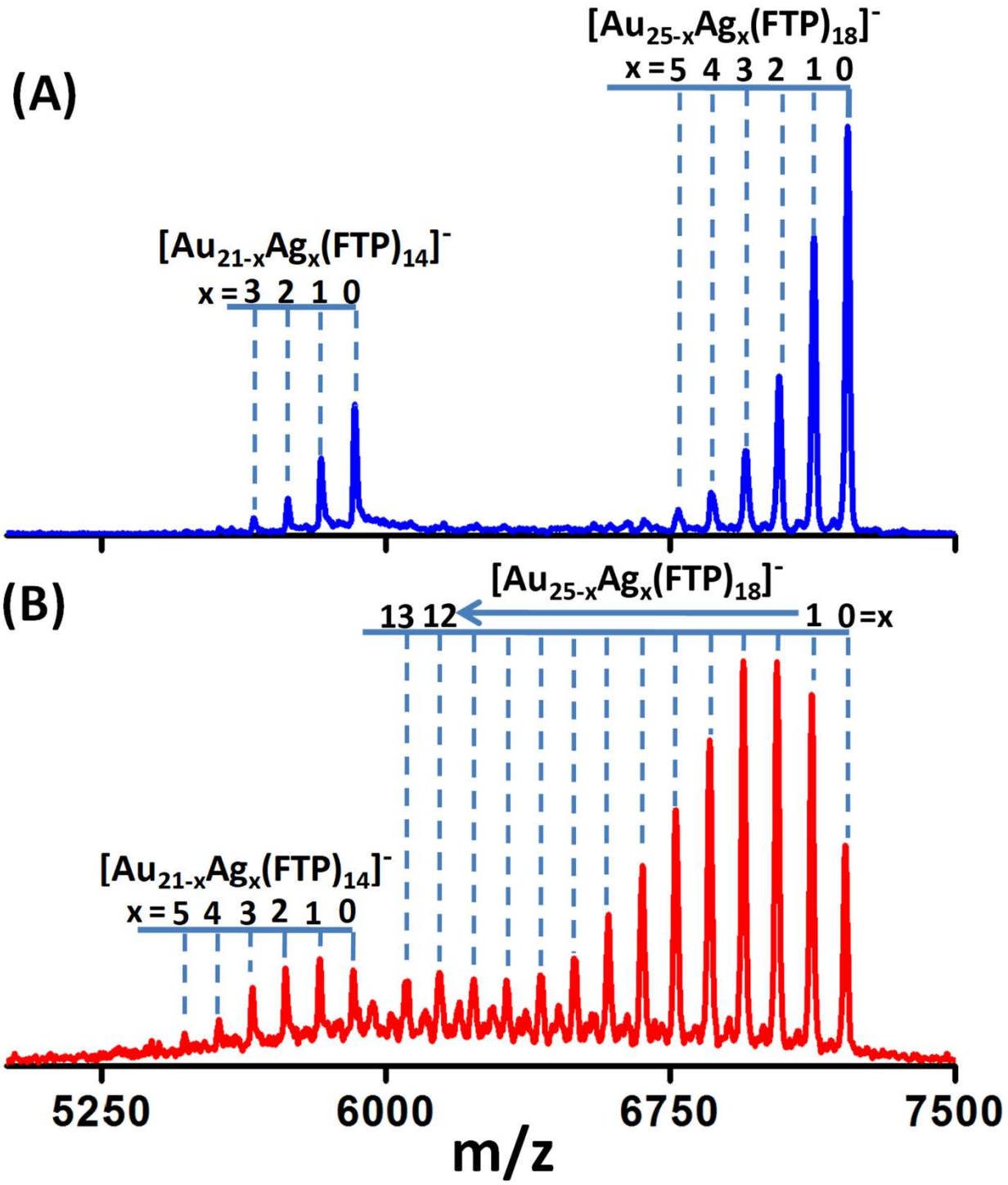
DST Unit of Nanoscience (DST UNS) and Thematic Unit of Excellence, Department of Chemistry, Indian Institute of Technology Madras, Chennai, 600 036, India

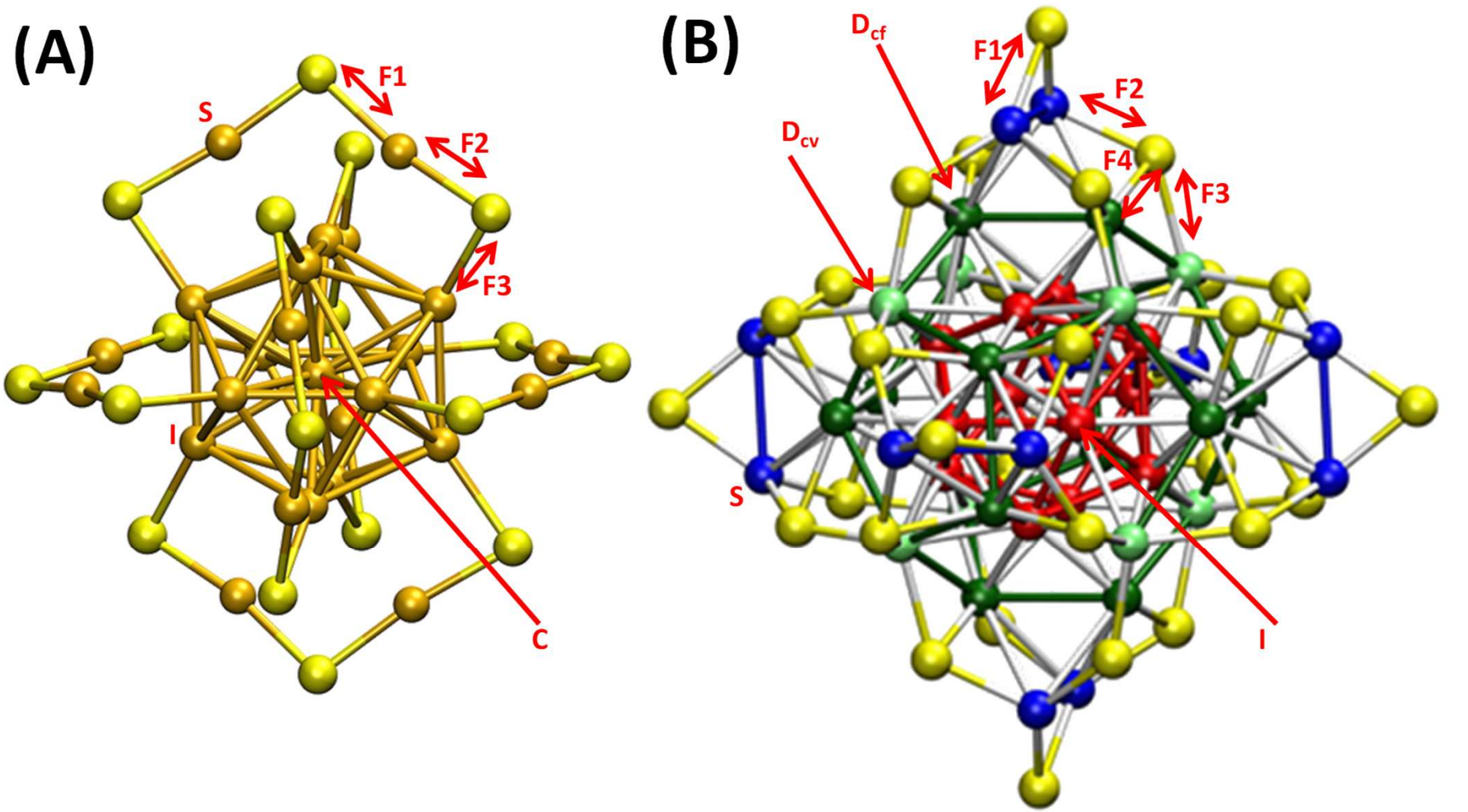
Supporting Information

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

$Au_{25}(FTP)_{18} + Ag_{44}(FTP)_{30} \longrightarrow Au_{25-x}Ag_x(FTP)_{18}$






(A)
S
F1
F2
F3
I
C
(B)
D_{cf}
F1
F2
D_{cv}
F4
F3
S
I

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

(A)

Location of Au in $Au_xAg_{44-x}(SR)_{30}$	ΔE/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 $Au_{25-x}Ag_x(SR)_{18}$	ΔE/eV
Central atom (C)	+0.71
Icosahedron (I)	+0.23
Staples (S)	+0.44

(C)

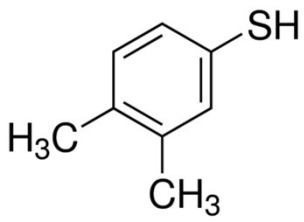
Location of Ag in $Au_{25-x}Ag_x(SR)_{18}$	Locations of Au in $Au_xAg_{44-x}(SR)_{30}$			
	I	D_{cv}	D_{cf}	S
C	-0.015	+0.564	+0.388	+0.226
I	-0.486	+0.093	-0.083	-0.245
S	-0.276	+0.303	+0.127	-0.035

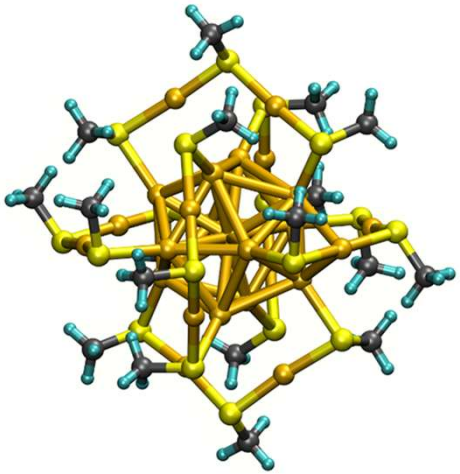
Ag_{25}-Au_{25} experiments

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

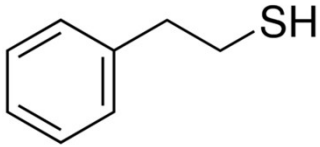
Reaction between $Au_{25}(PET)_{18}$ and $Ag_{25}(DMBT)_{18}$

DMBT

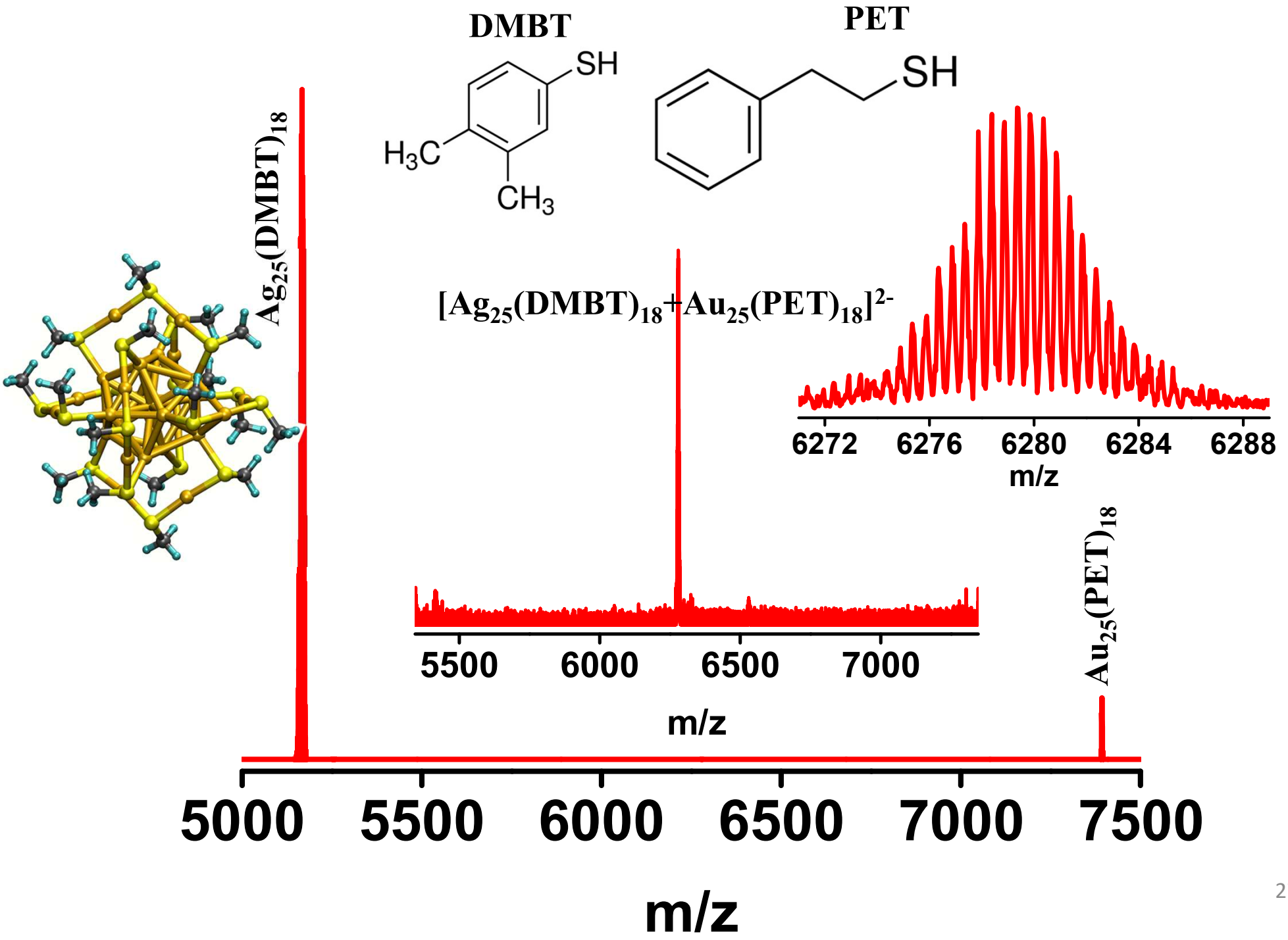




PET

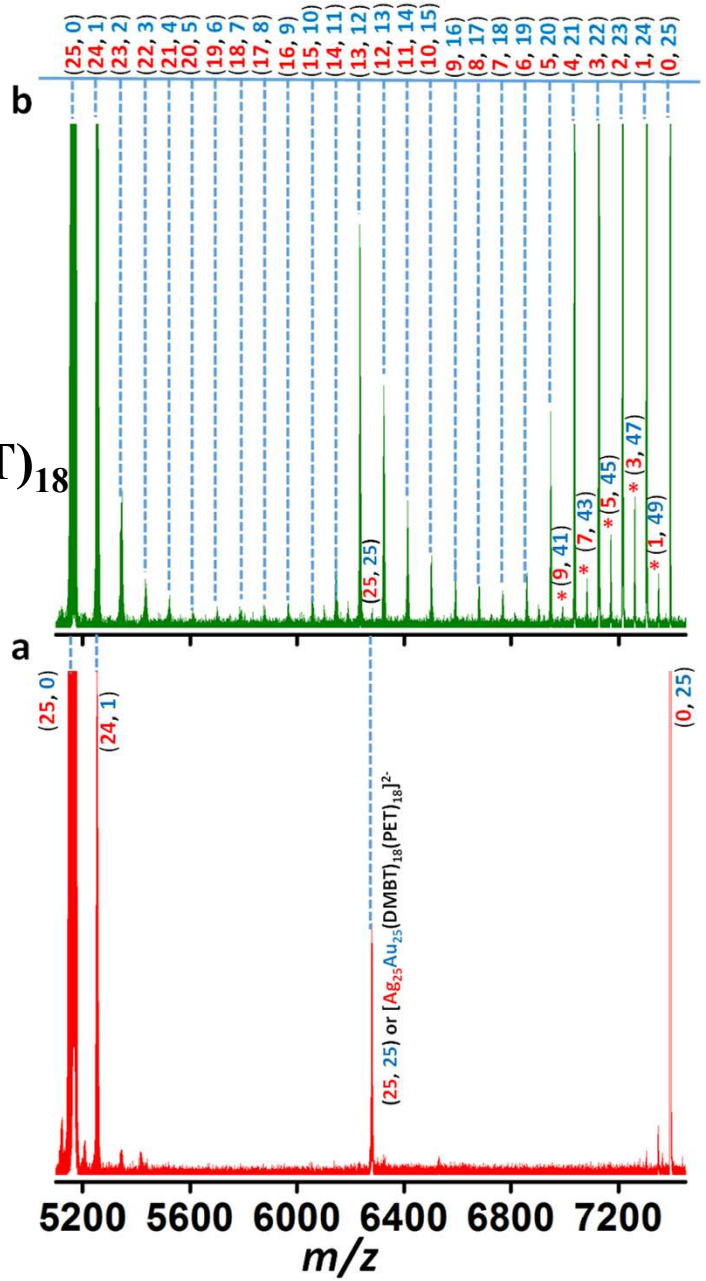


$[Ag_{25}(DMBT)_{18}+Au_{25}(PET)_{18}]^{2-}$



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

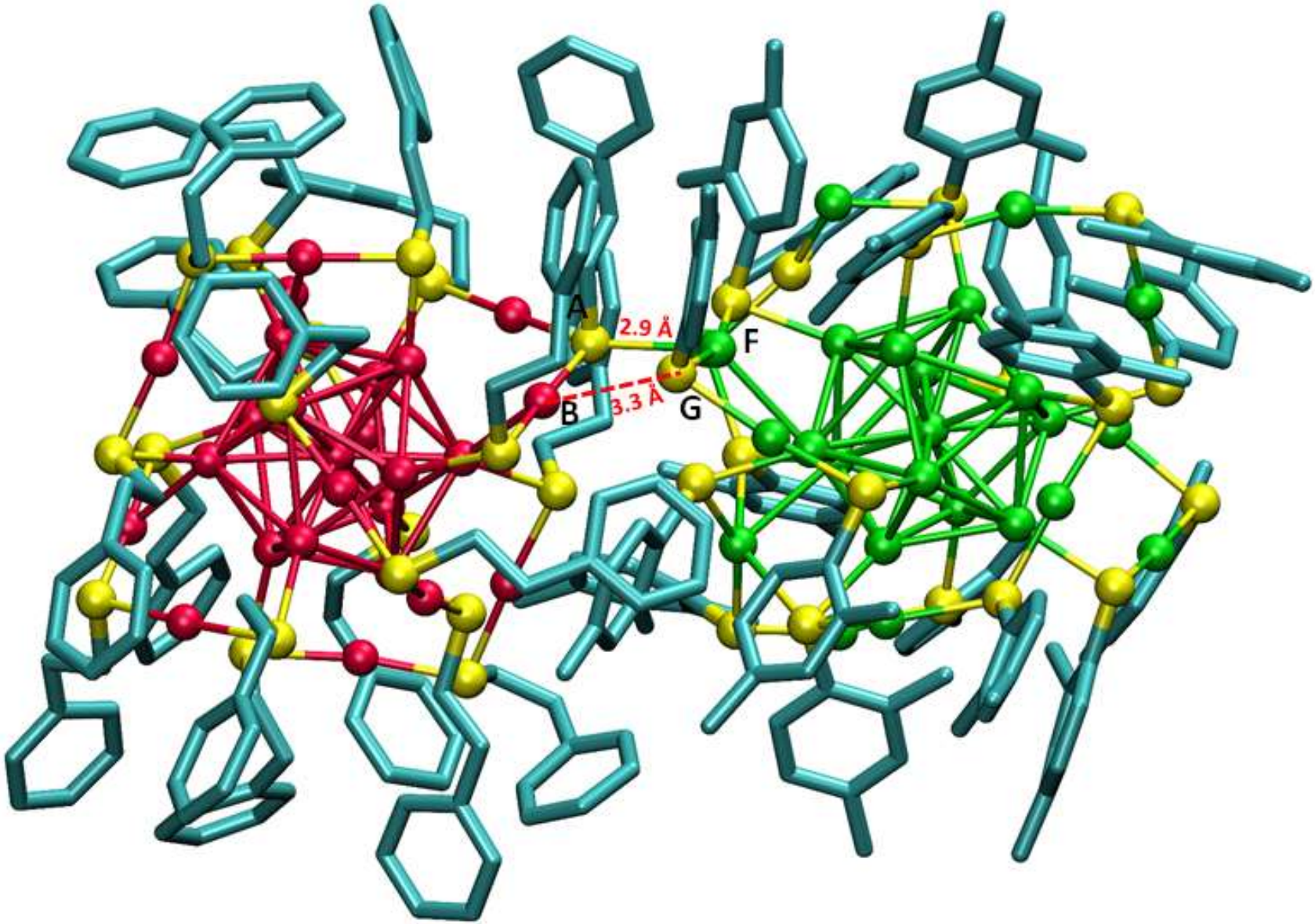
$Ag_{25}(DMBT)_{18}$:$Au_{25}(PET)_{18}$
0.3:1.0

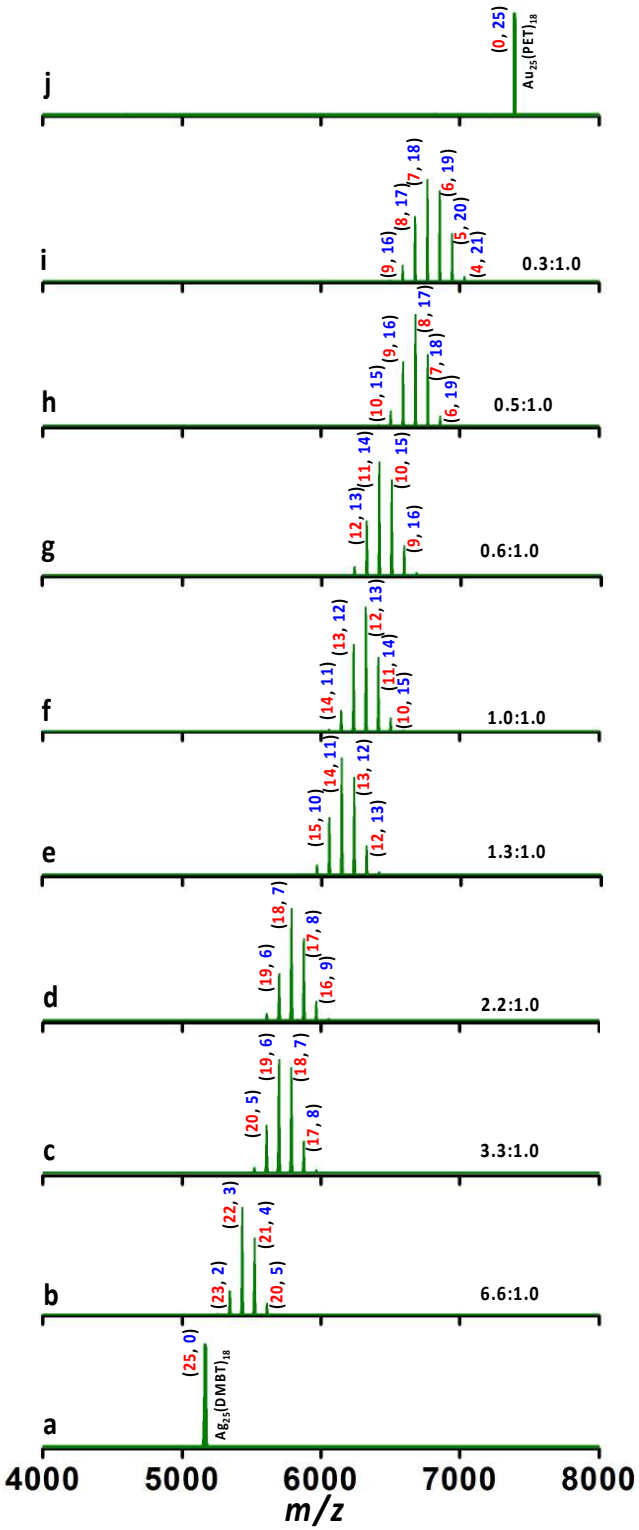


within 5 min

within 2 min

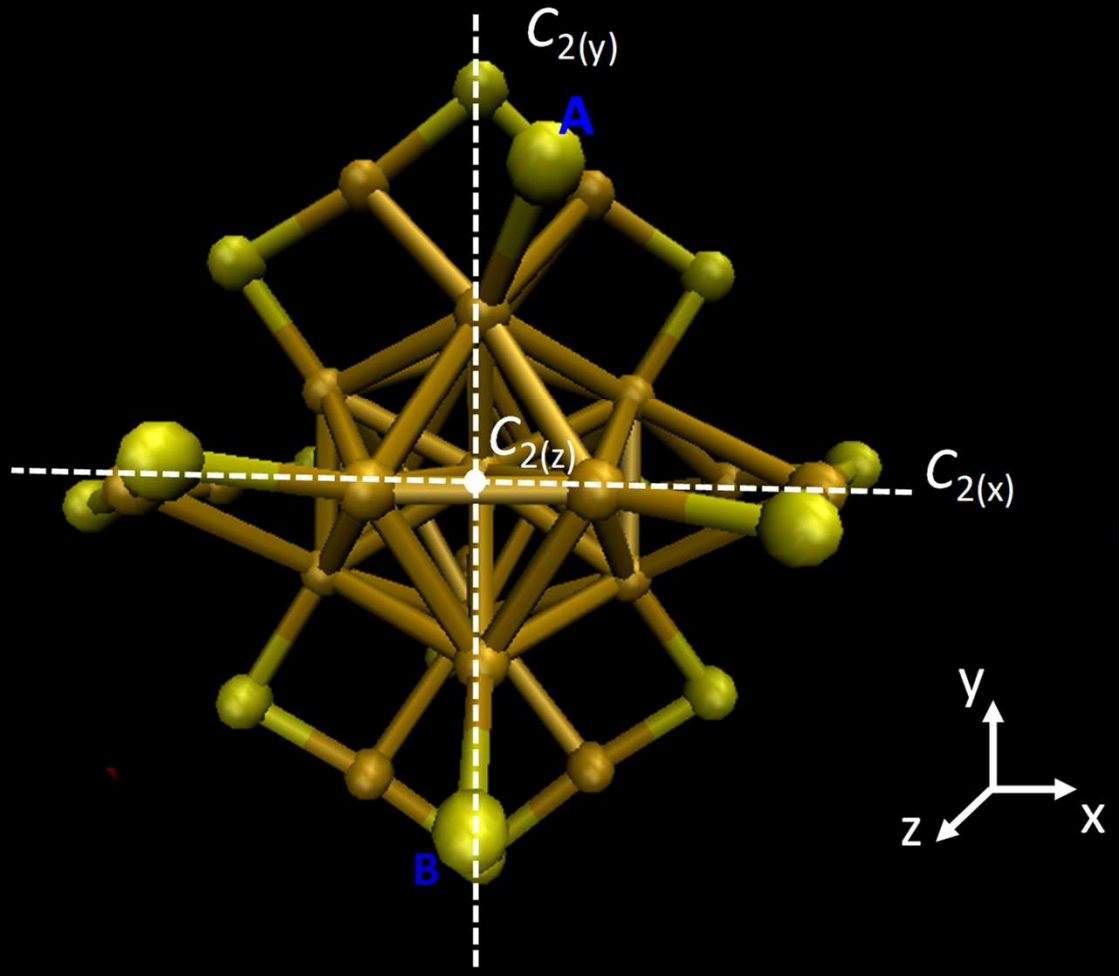
Optimized structure of $[Ag_{25}Au_{25}(DMBT)_{18}(PET)_{18}]^{2-}$



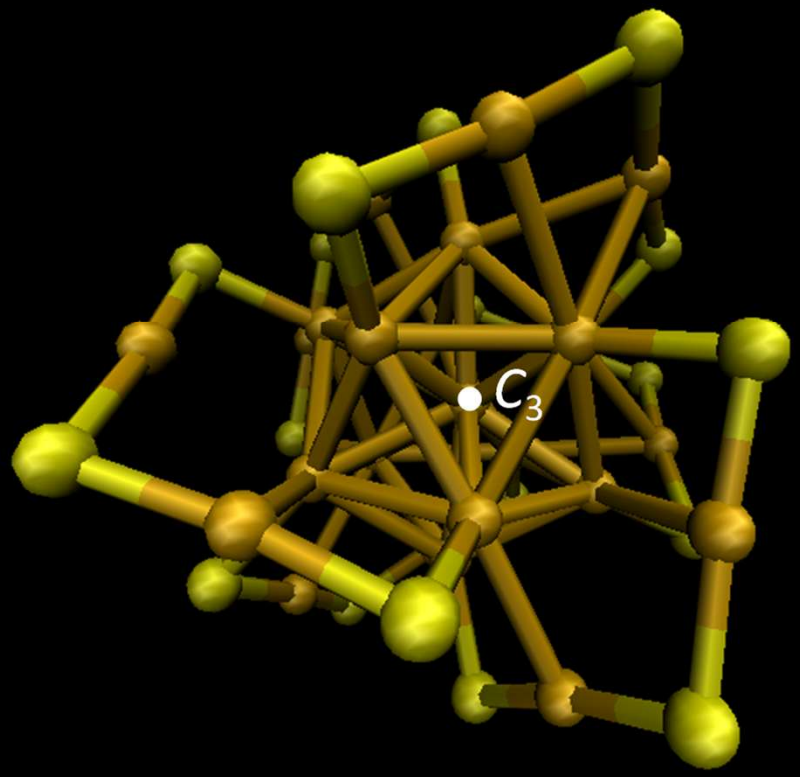

j
(0, 25)
Au25(PET)18
i
0.3:1.0
(9, 16)
(8, 17)
(7, 18)
(6, 19)
(5, 20)
(4, 21)
h
0.5:1.0
(10, 15)
(9, 16)
(8, 17)
(7, 18)
(6, 19)
g
0.6:1.0
(12, 13)
(11, 14)
(10, 15)
(9, 16)
f
1.0:1.0
(14, 11)
(13, 12)
(12, 13)
(11, 14)
(10, 15)
e
1.3:1.0
(15, 10)
(14, 11)
(13, 12)
(12, 13)
d
2.2:1.0
(19, 6)
(18, 7)
(17, 8)
(16, 9)
c
3.3:1.0
(20, 5)
(19, 6)
(18, 7)
(17, 8)
b
6.6:1.0
(23, 2)
(22, 3)
(21, 4)
(20, 5)
a
(25, 0)
Ag25(DMBT)18
4000
5000
6000
7000
8000
m/z

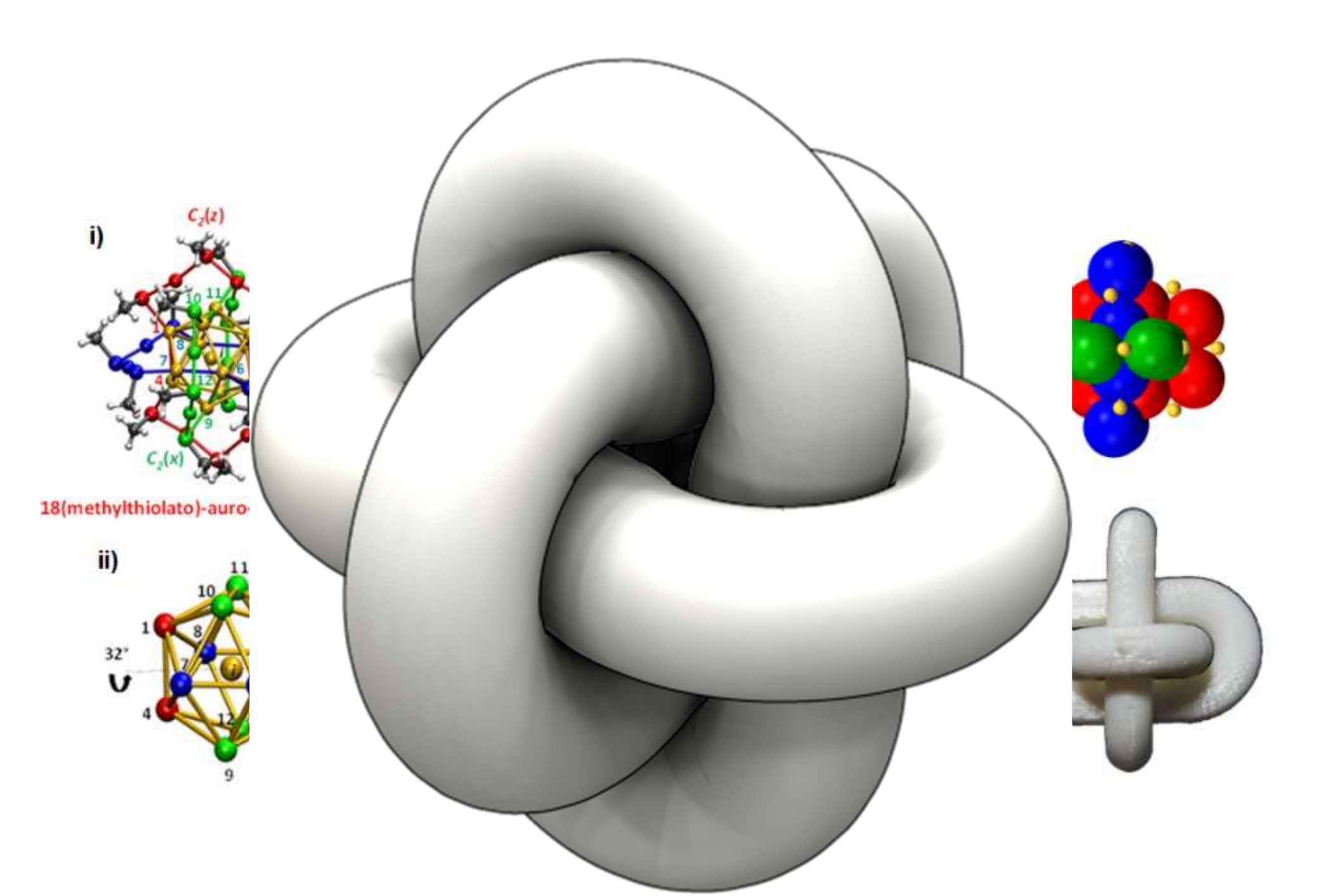
How do we comprehend this?

1) Edge projection



2) Face Projection





Gana Natarajan et. al. *JPC C* 2015

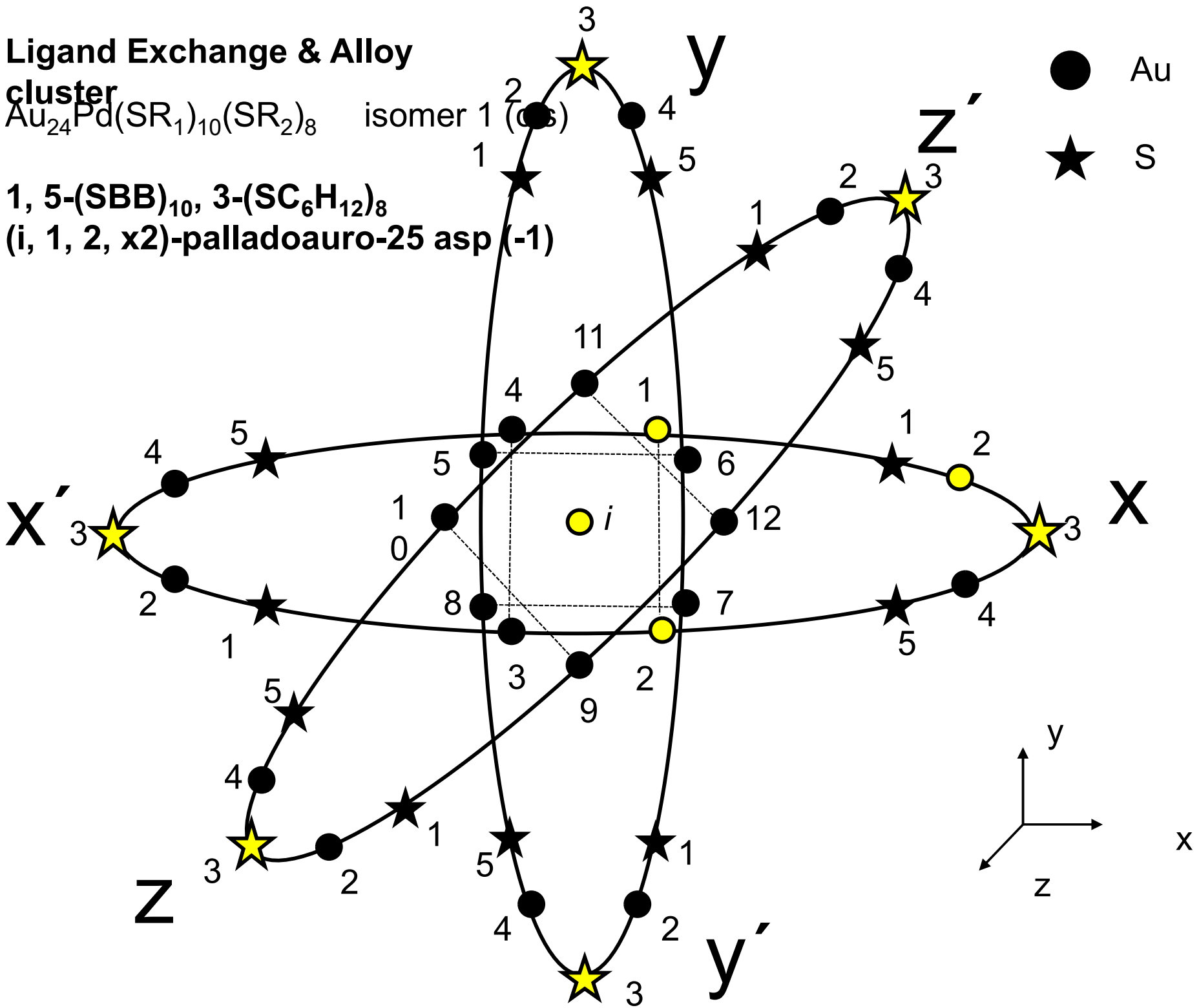
Aspicules

(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

$Au_{24}Pd(SR_1)_{10}(SR_2)_8$ isomer 1 (cis)

1, 5-$(SBB)_{10}$, 3-$(SC_6H_{12})_8$
(i, 1, 2, x2)-palladoauro-25 asp (-1)



ACCOUNTS of chemical research

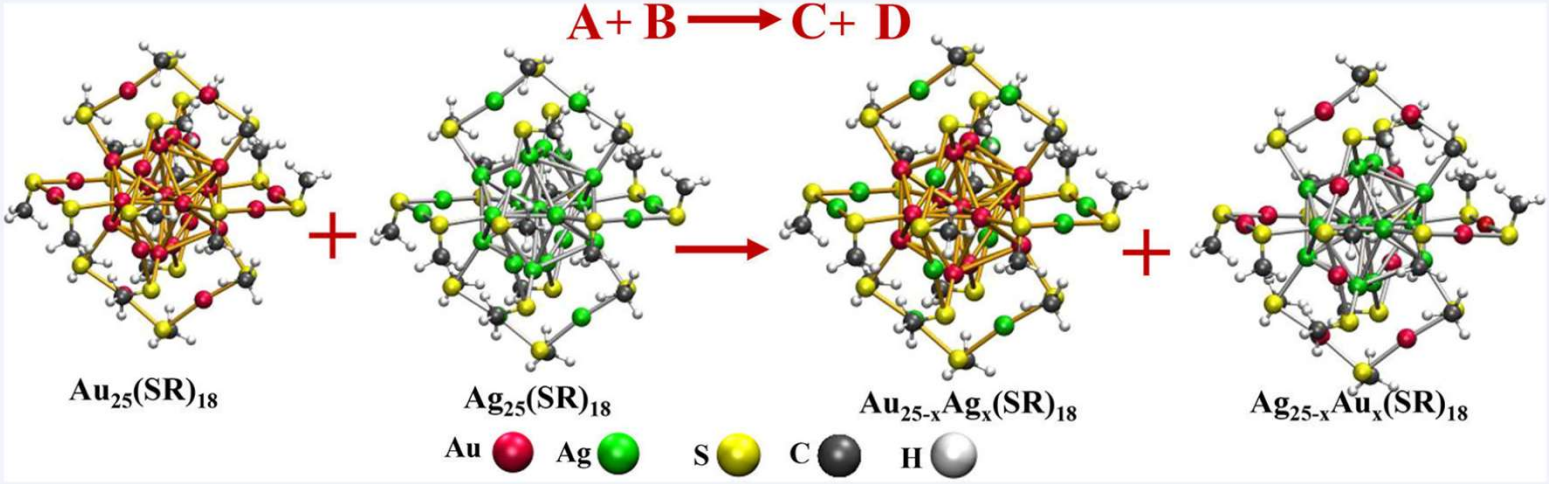
Article

pubs.acs.org/accounts

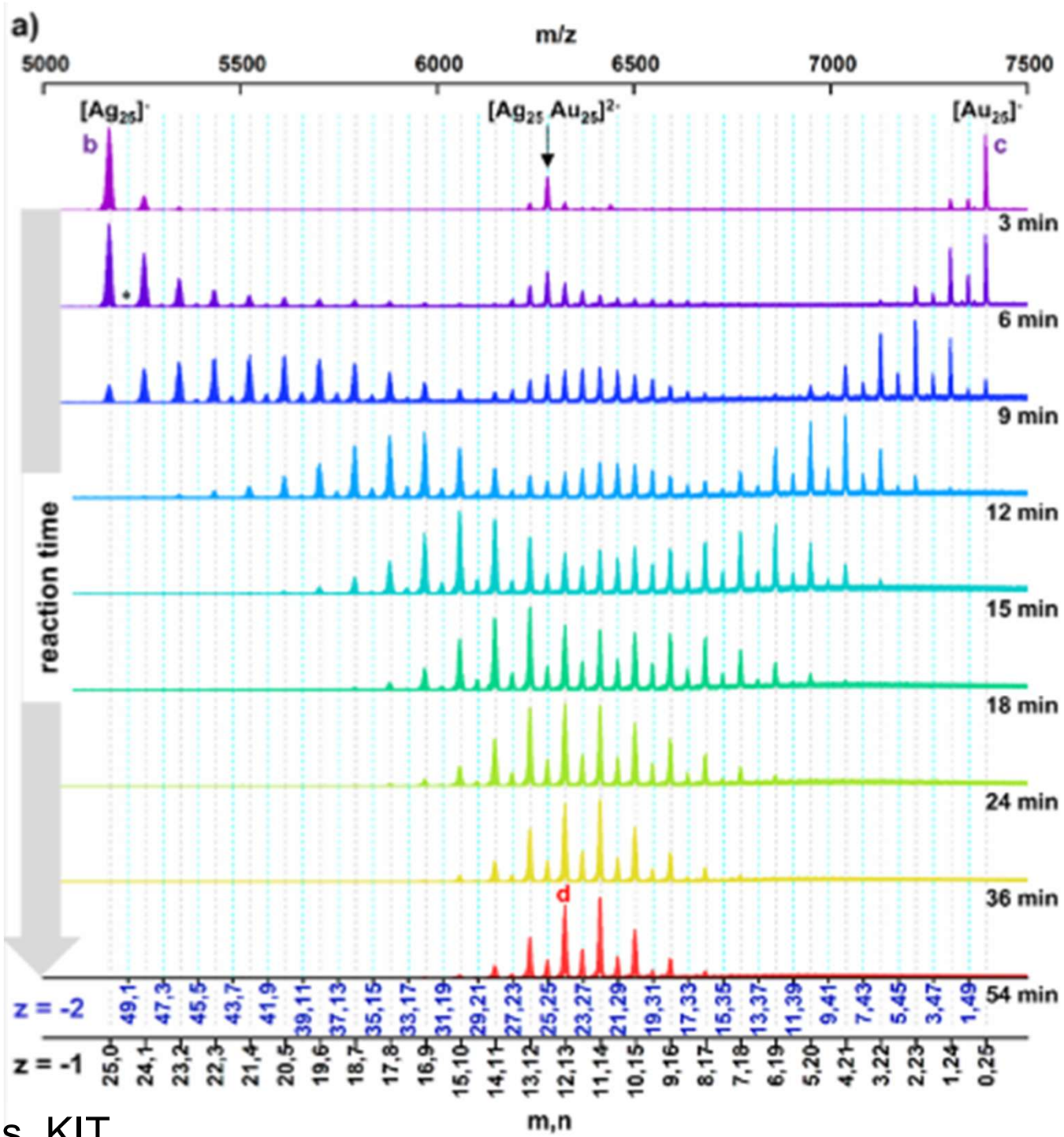
Interparticle Reactions: An Emerging Direction in Nanomaterials Chemistry

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

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

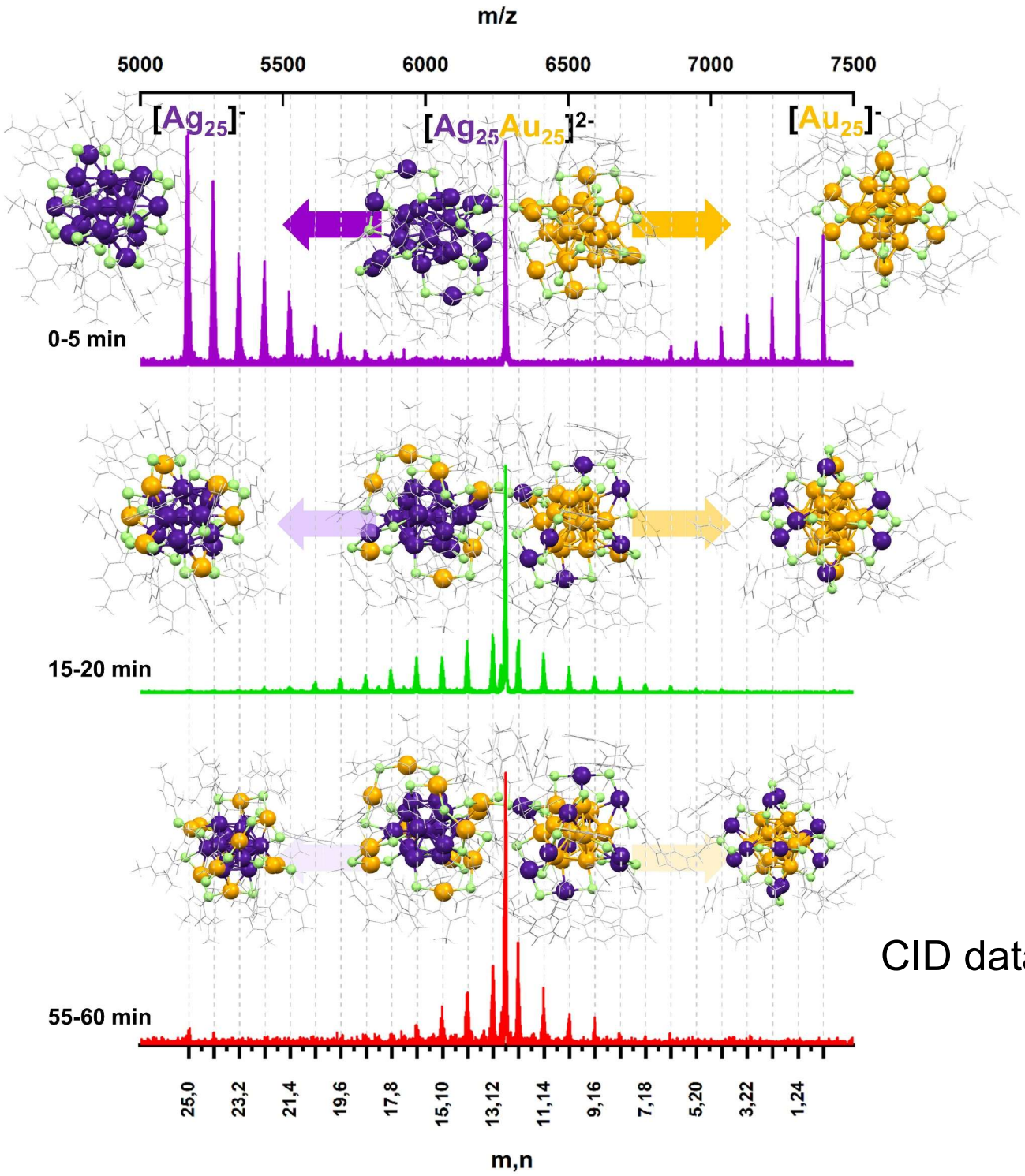


CONSPECTUS: Nanoparticles exhibit a rich variety in terms of structure, composition, and properties. However, reactions between them remain largely unexplored. In this *Account*, we discuss an emerging aspect of nanomaterials chemistry, namely, interparticle reactions in solution phase, similar to reactions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



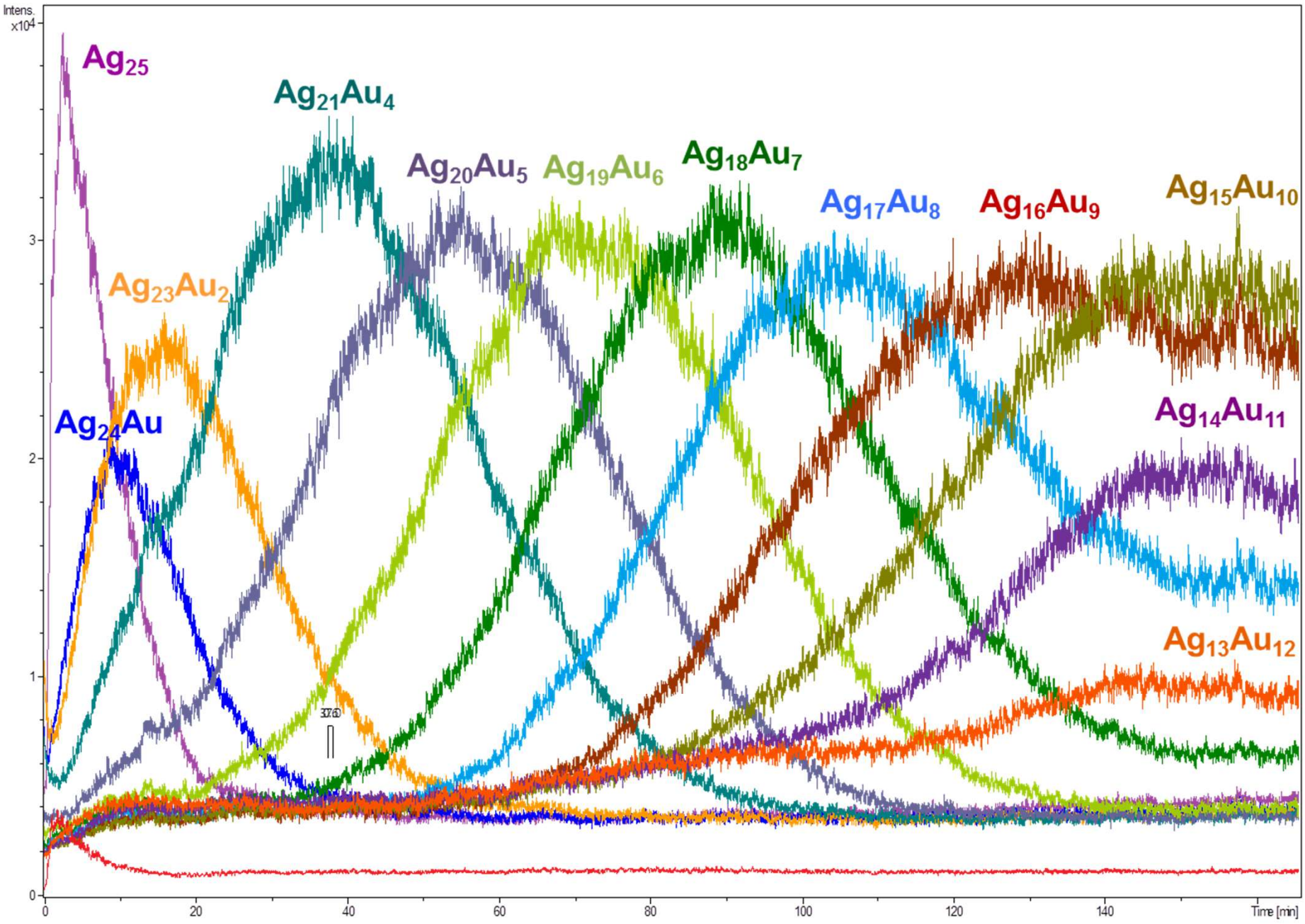
Manfred Kappes, KIT

M. Neumaier, A. Baksi, et. al., *JACS* 2021



CID data of $[Au25Ag25]^{2-}$

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



Atom transfer dynamics

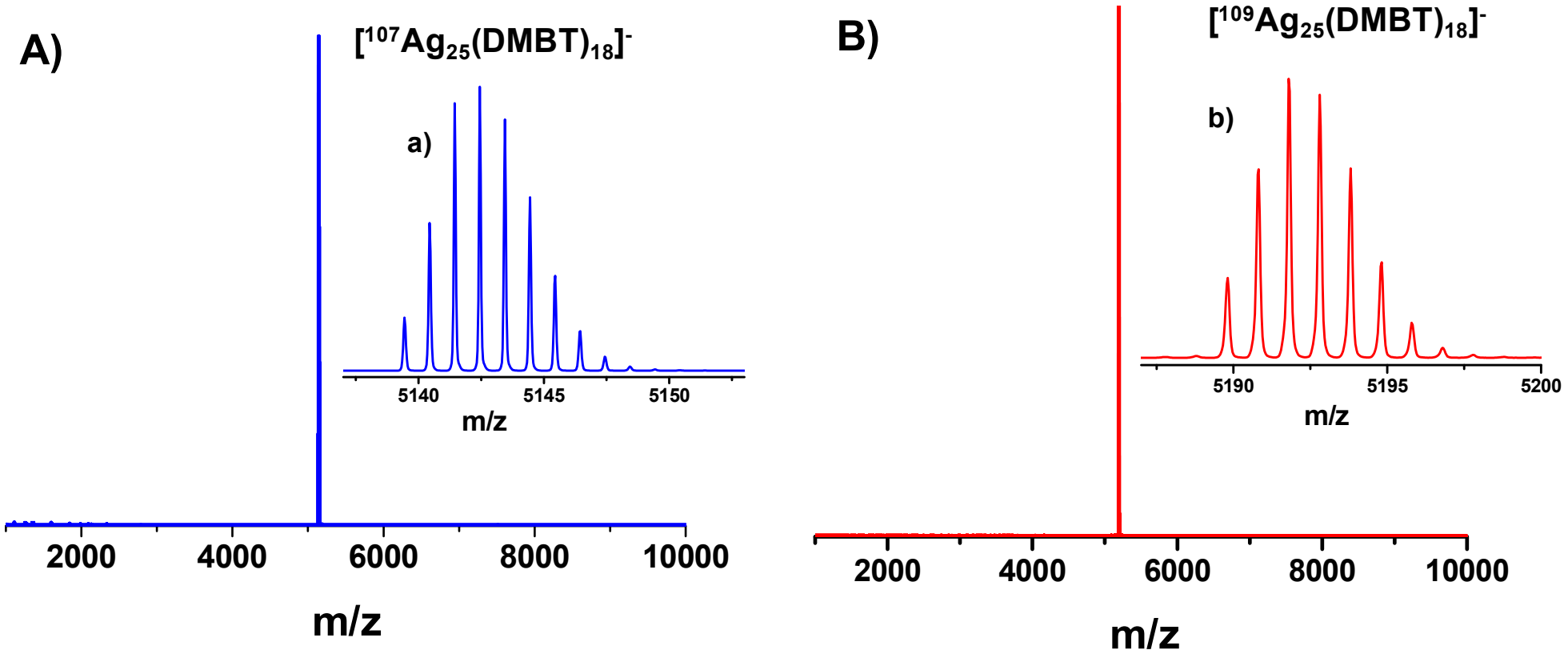
They are indeed molecules!

CONDENSED MATTER PHYSICS

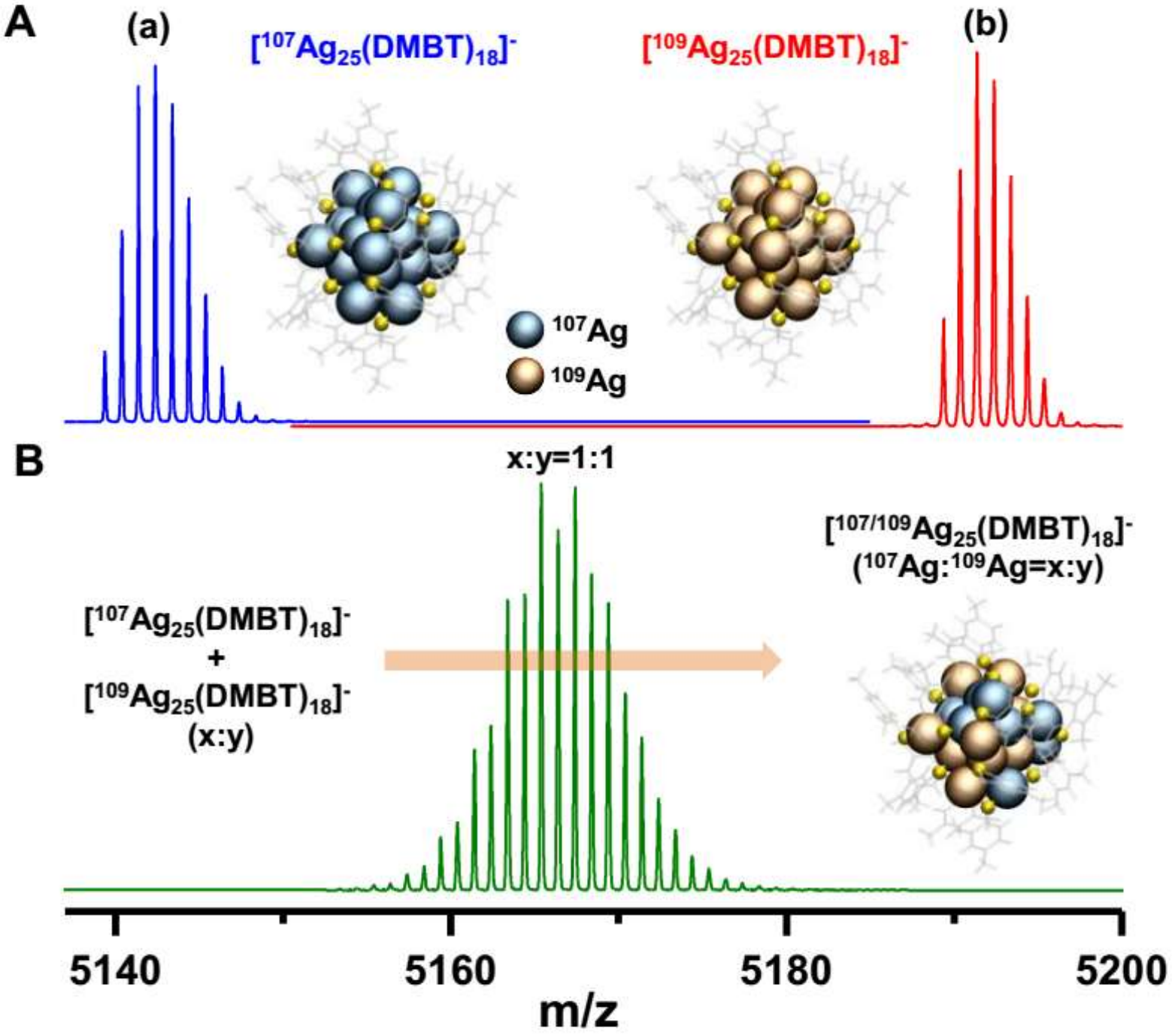
Rapid isotopic exchange in nanoparticles

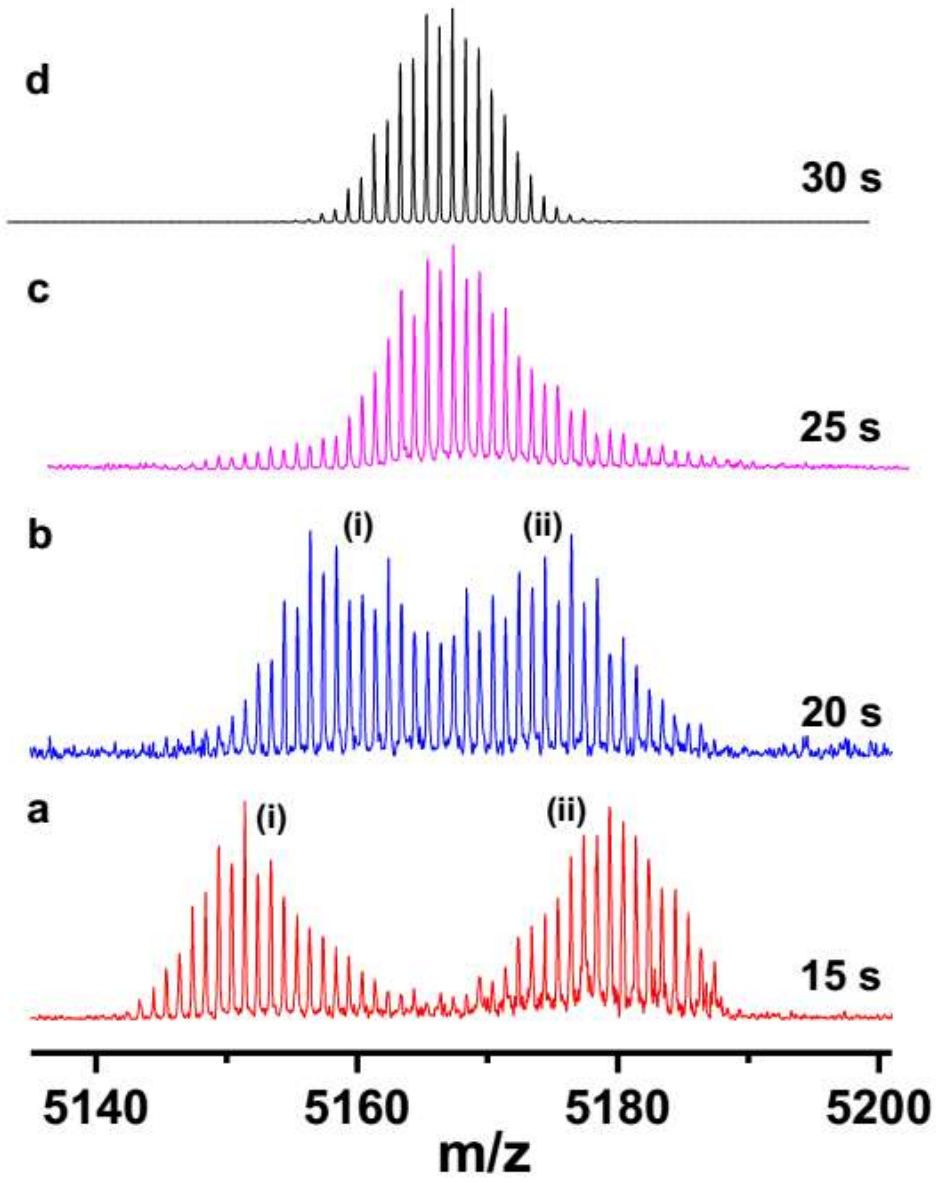
Papri Chakraborty[1], Abhijit Nag[1], Ganapati Natarajan[1], Nayanika Bandyopadhyay[1], Ganesan Paramasivam[1], Manoj Kumar Panwar[1], Jaydeb Chakrabarti[2], Thalappil Pradeep[1]*

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.

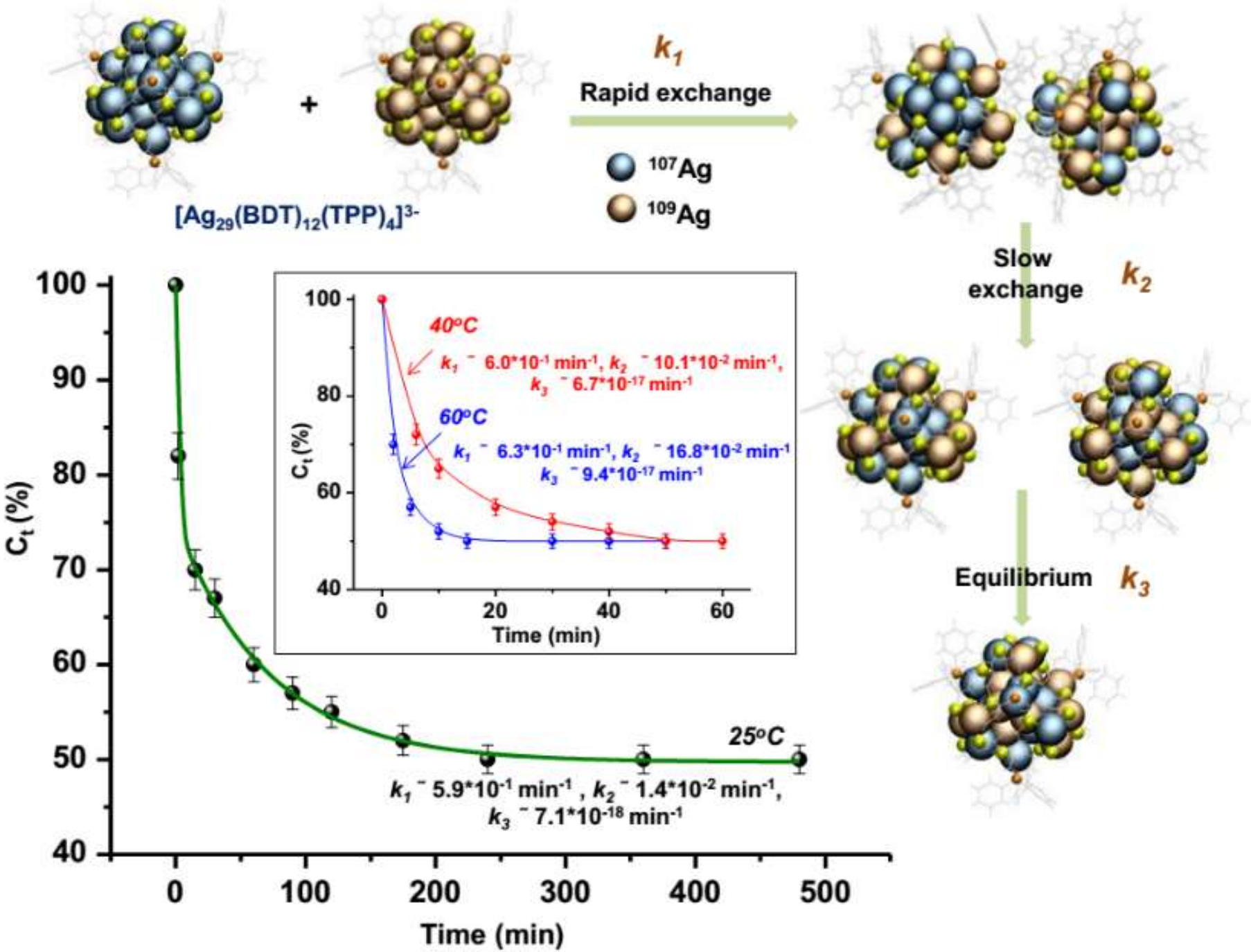


ESI MS of **A)** $^{107}Ag_{25}(DMBT)_{18}$ and **B)** $^{109}Ag_{25}(DMBT)_{18}$. Insets shows the respective isotope patterns.


A
(a)
[107Ag25(DMBT)18]-
[109Ag25(DMBT)18]-
(b)
107Ag
109Ag
B
x:y=1:1
[107/109Ag25(DMBT)18]-
(107Ag:109Ag=x:y)
[107Ag25(DMBT)18]-
+
[109Ag25(DMBT)18]-
(x:y)
5140
5160
5180
5200
m/z

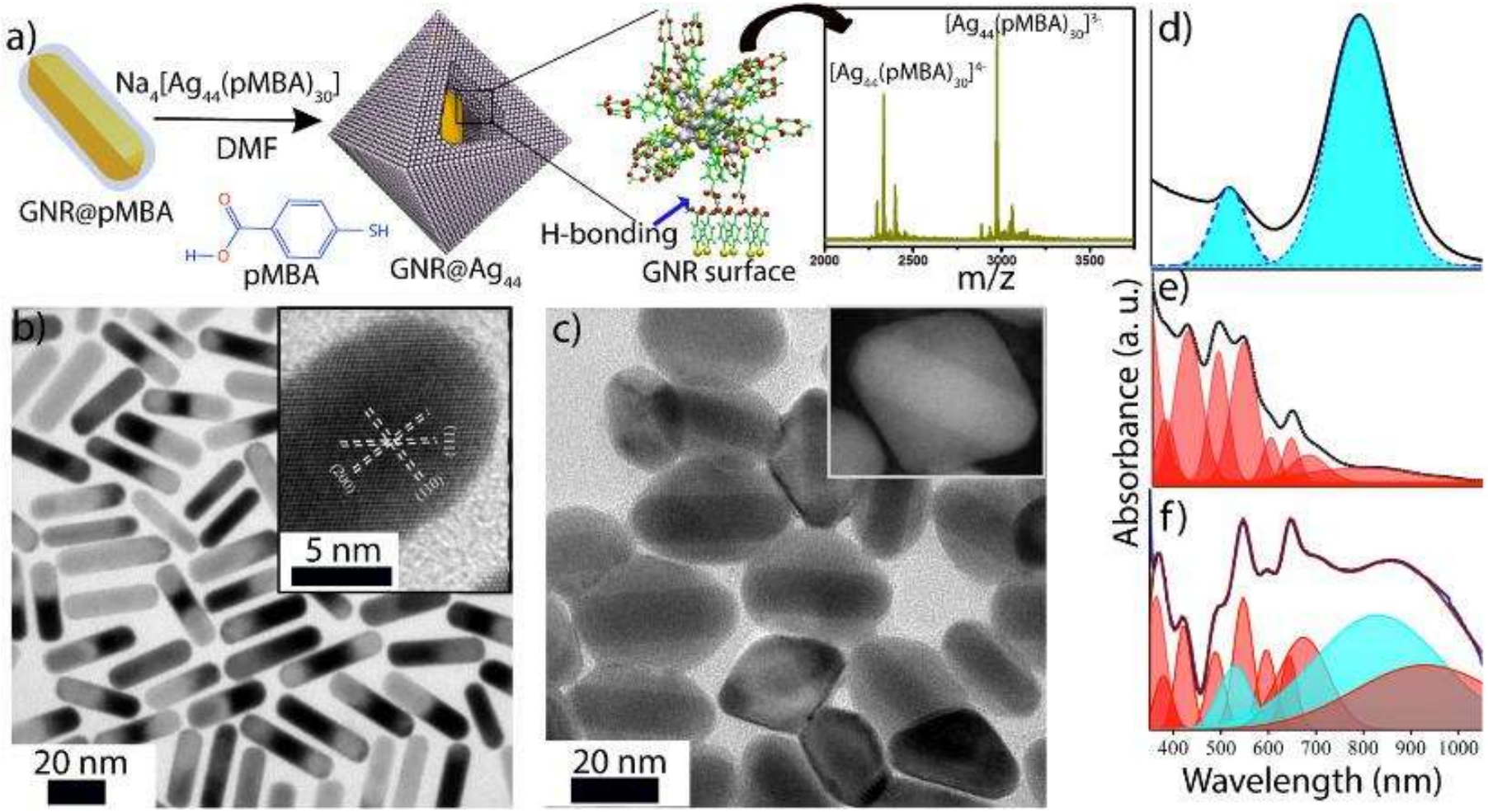


Papri Chakraborty, et. al. *Science Advances* 2019


k_1
Rapid exchange
^{107}Ag
^{109}Ag
$[Ag_{29}(BDT)_{12}(TPP)_4]^{3-}$
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}

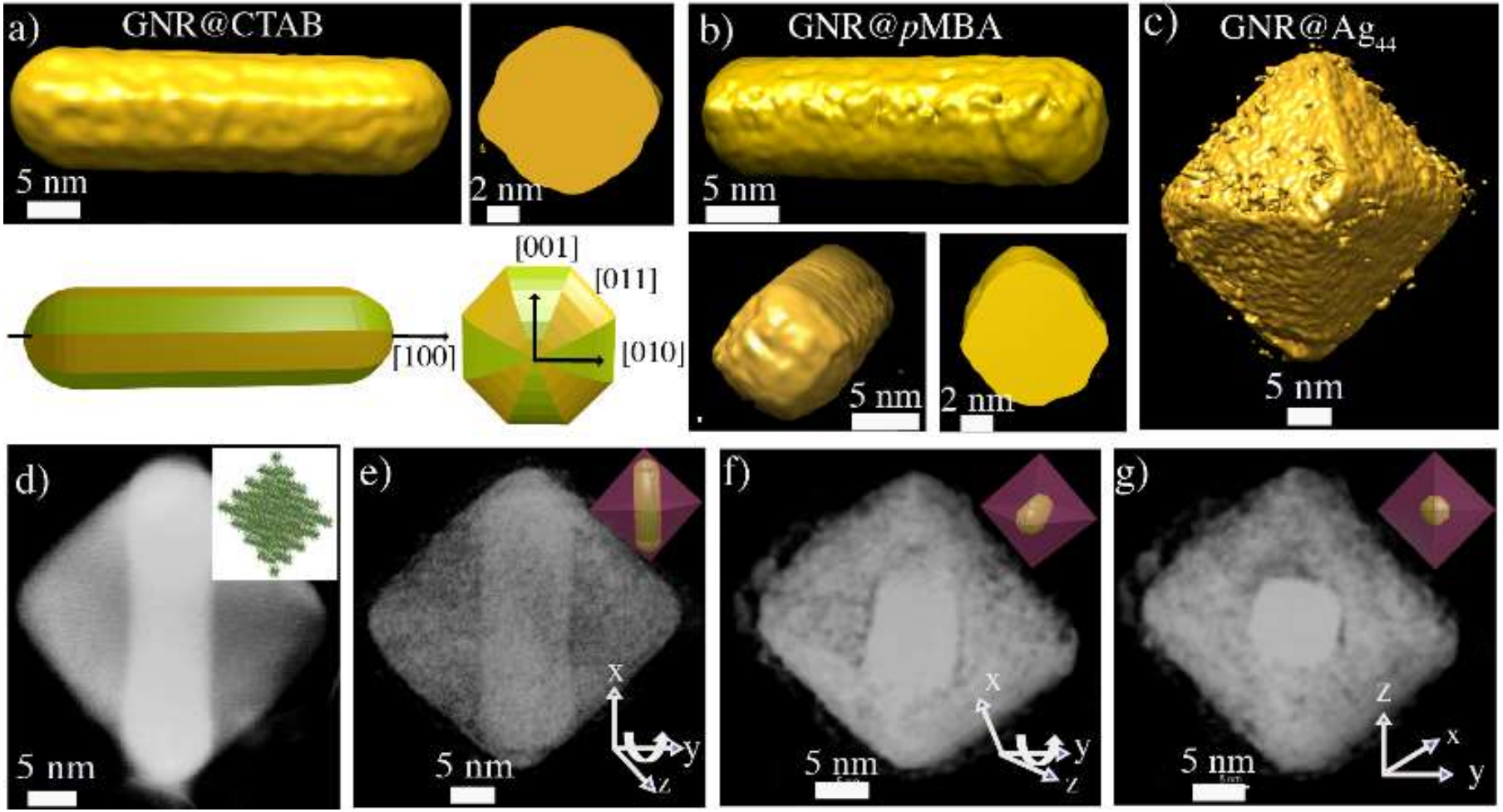
Assemblies and superstructures

Atomically precise nanocluster assemblies encapsulating plasmonic gold nanorods

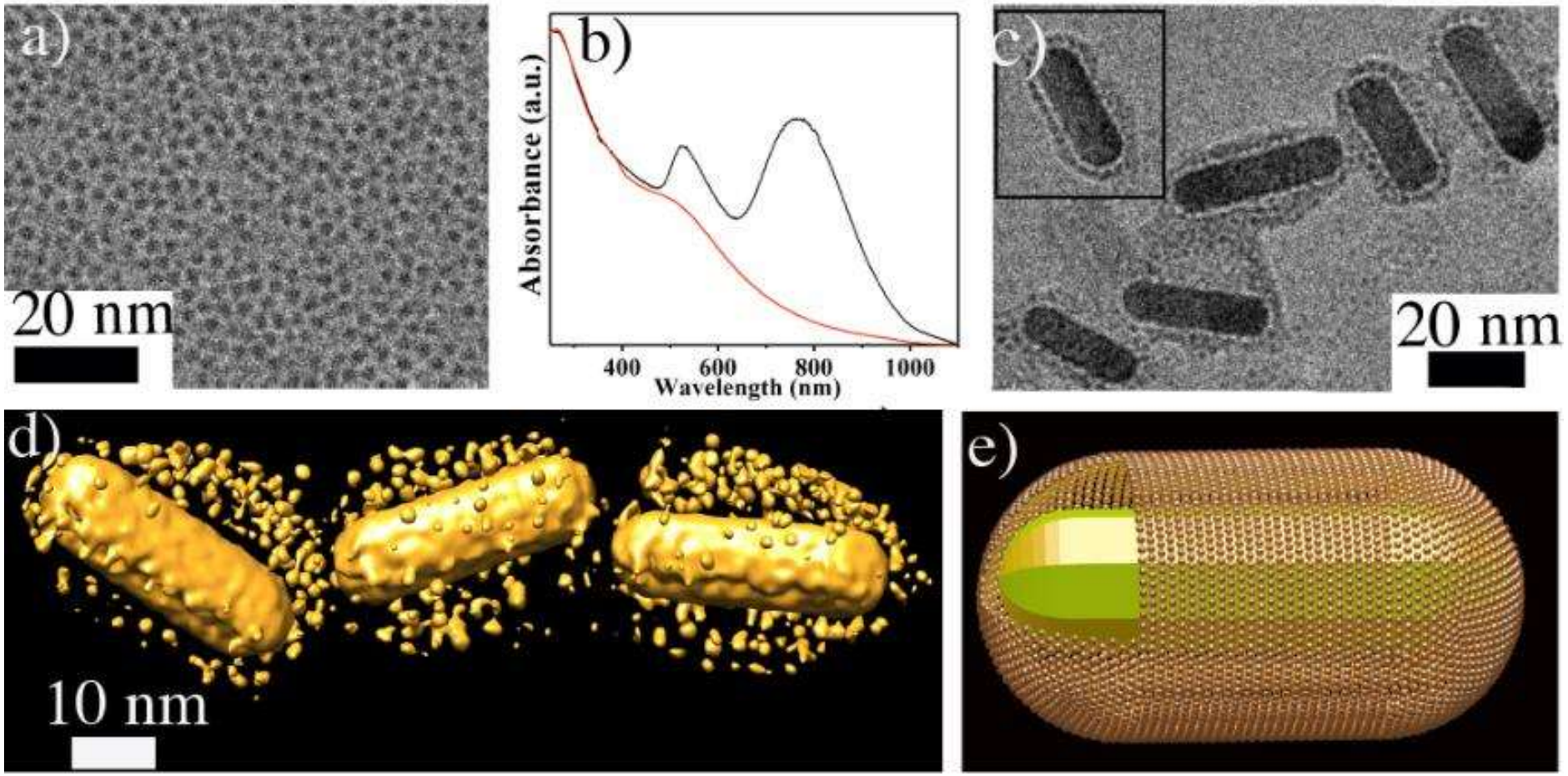


Chakraborty, A. et al., *Angew. Chem. Int. Ed.* **2018,** *57*, 6522–6526.

3D morphological analysis



Works for $Au_{250}(p\text{MBA})_n$ and aqueous solvent



Outlook

2019

ACCOUNTS of chemical research

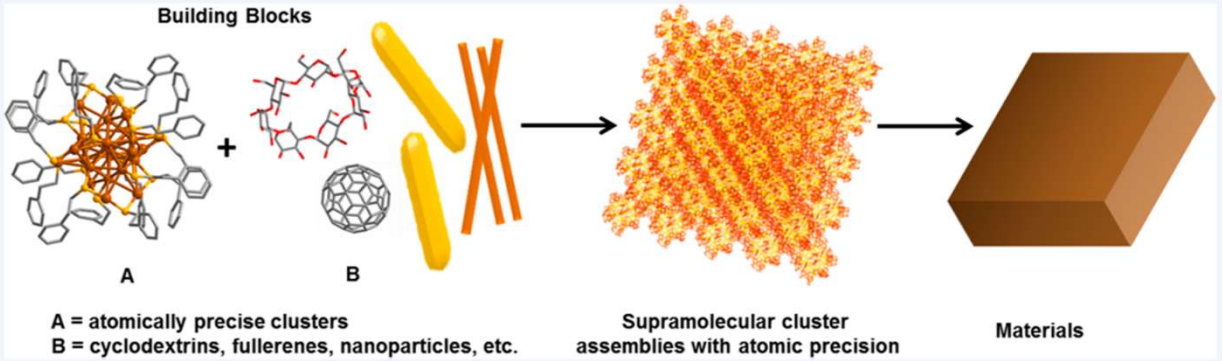
Article

pubs.acs.org/accounts

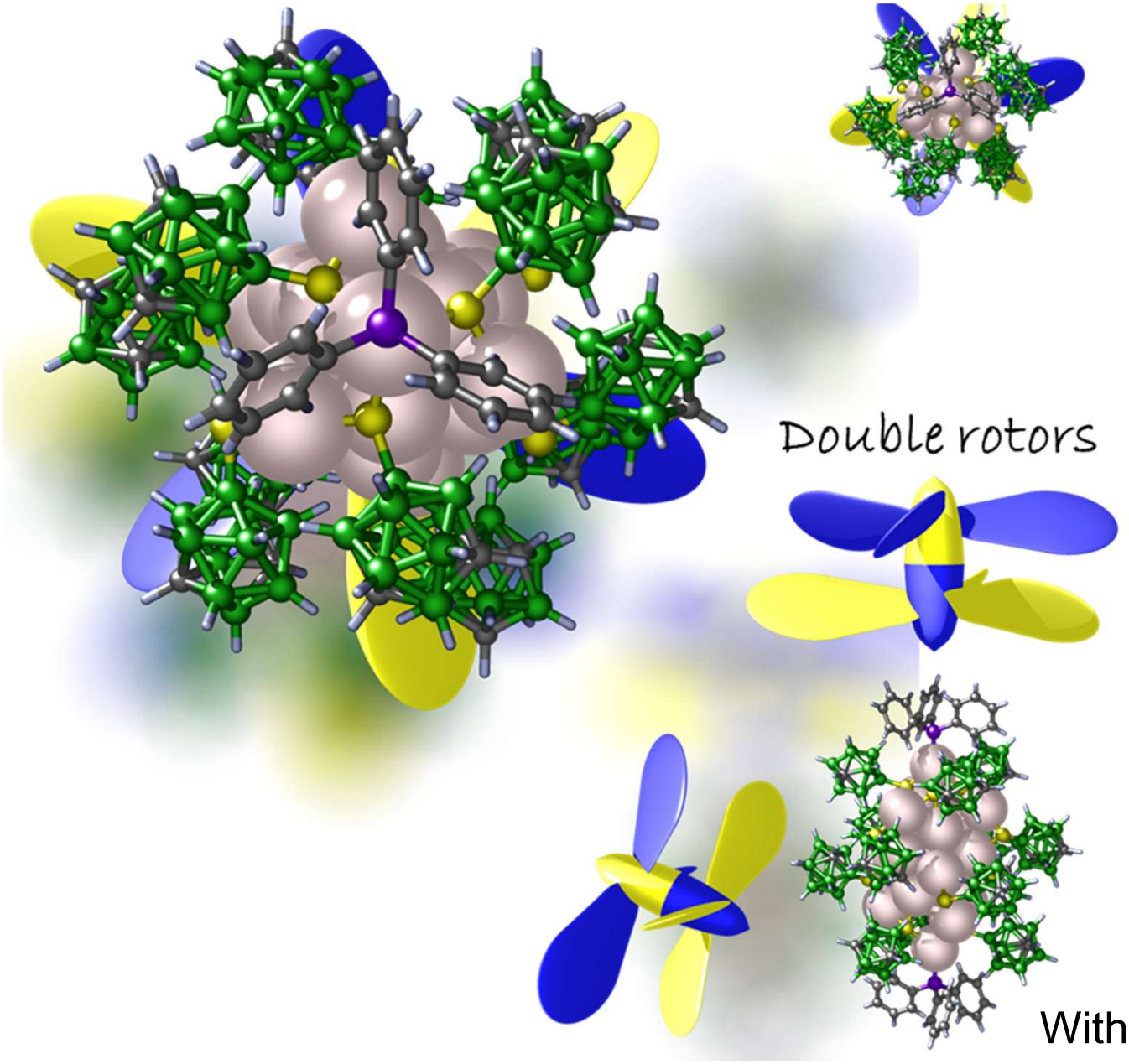
Approaching Materials with Atomic Precision Using Supramolecular Cluster Assemblies

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

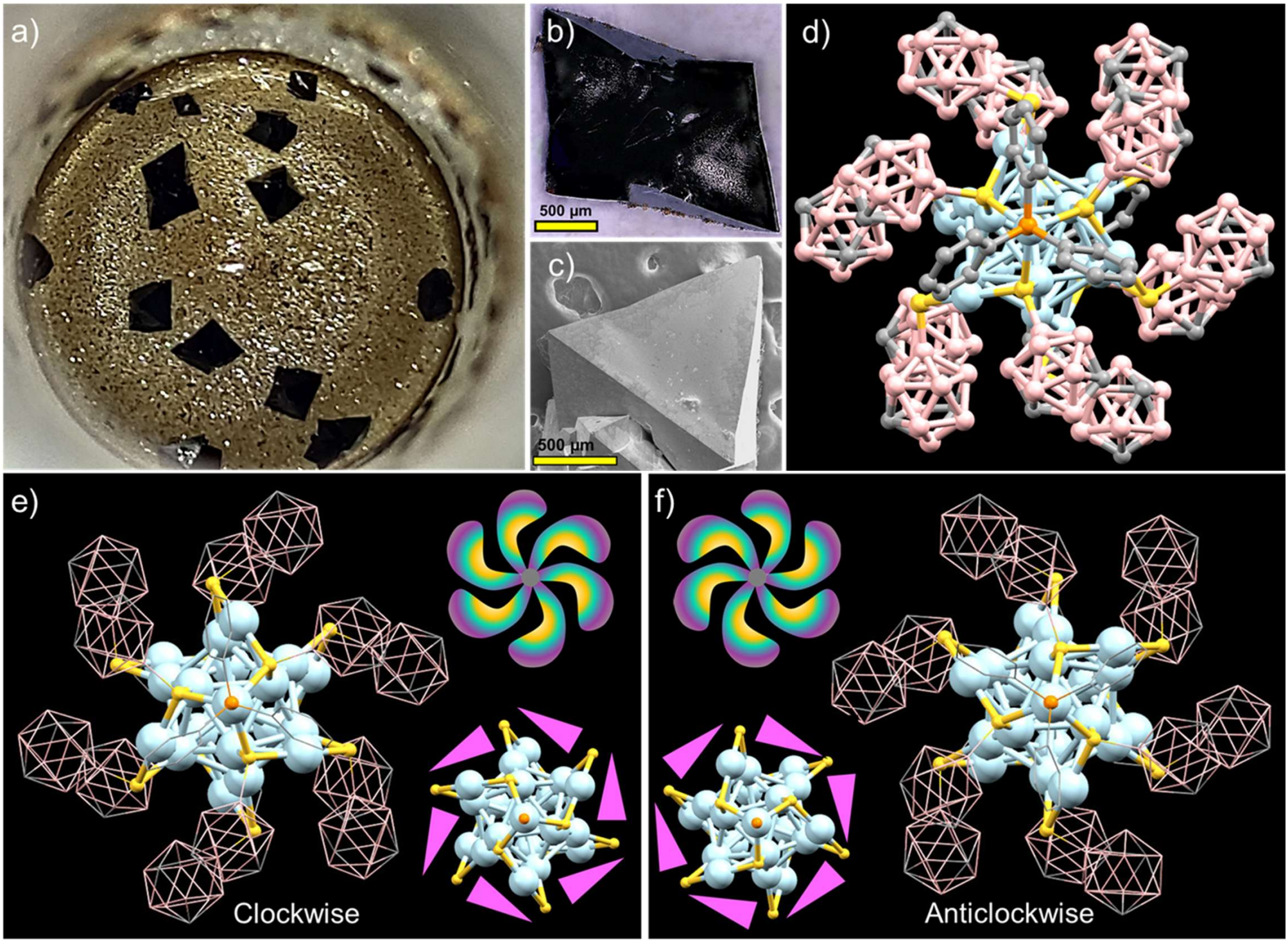


Carborane-thiol protected propeller-shaped photoresponsive silver nanomolecule

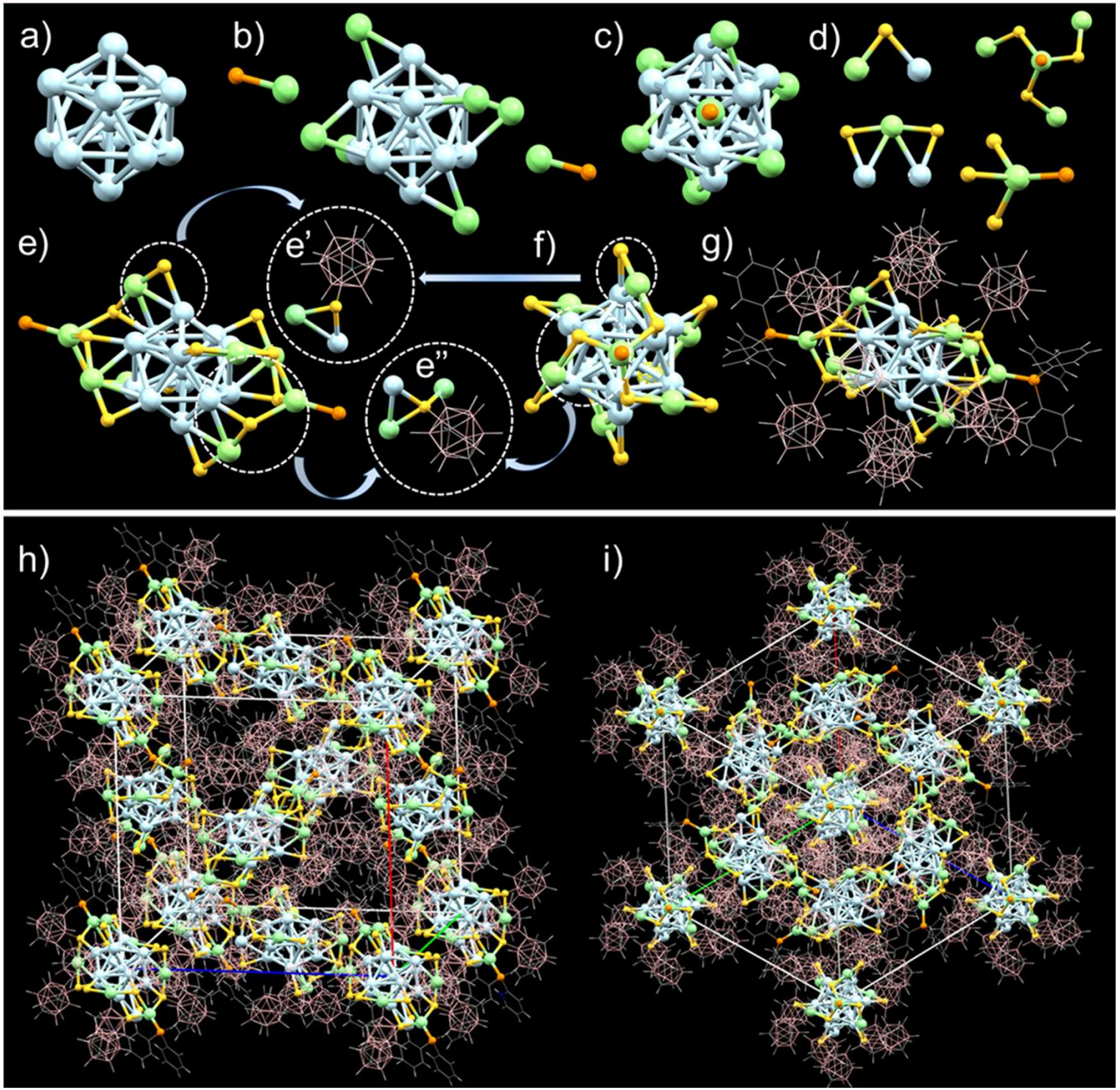


Jana *et. al*, Inorganic Chemistry (just accepted)

Structural details of Ag_{21}



Structural details of Ag_{21}



Molecules and their properties

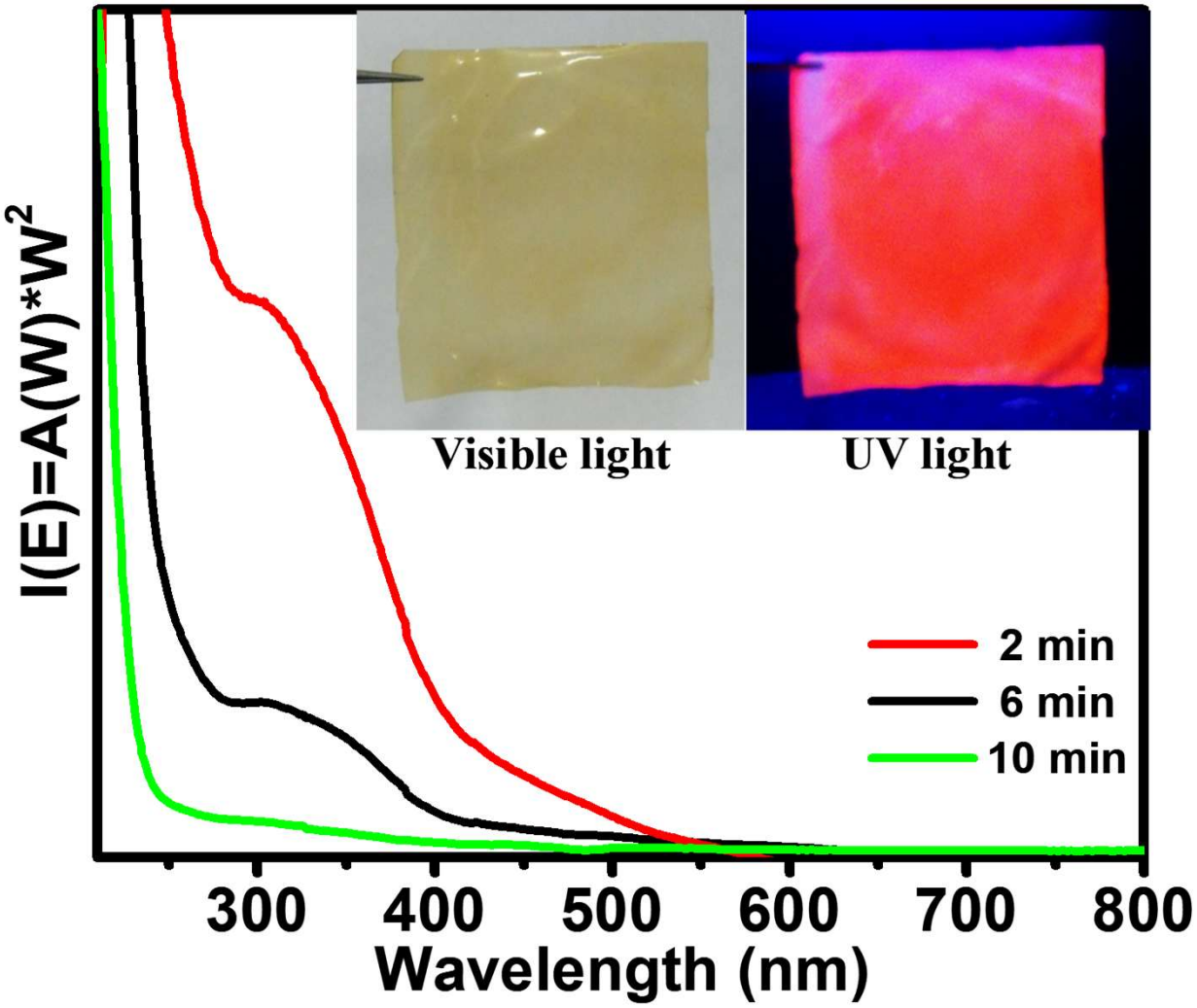
Chemical formula	H_2O
Molecular weight	18.0148
Critical temperature	373.91°C
Critical pressure	22.05 MPa
Critical density	315.0 kg/m^3
Triple point temperature	0.01°C
Triple point pressure	615.066 Pa
Normal boiling point	100.0°C
Normal freezing point	0.0°C
Density of ice at normal melting point	918.0 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. × 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?

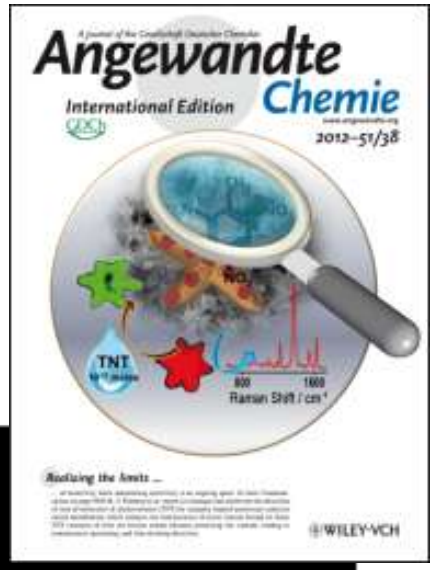
Quantum cluster based metal ion sensing paper
Large area uniform illumination using quantum cluster

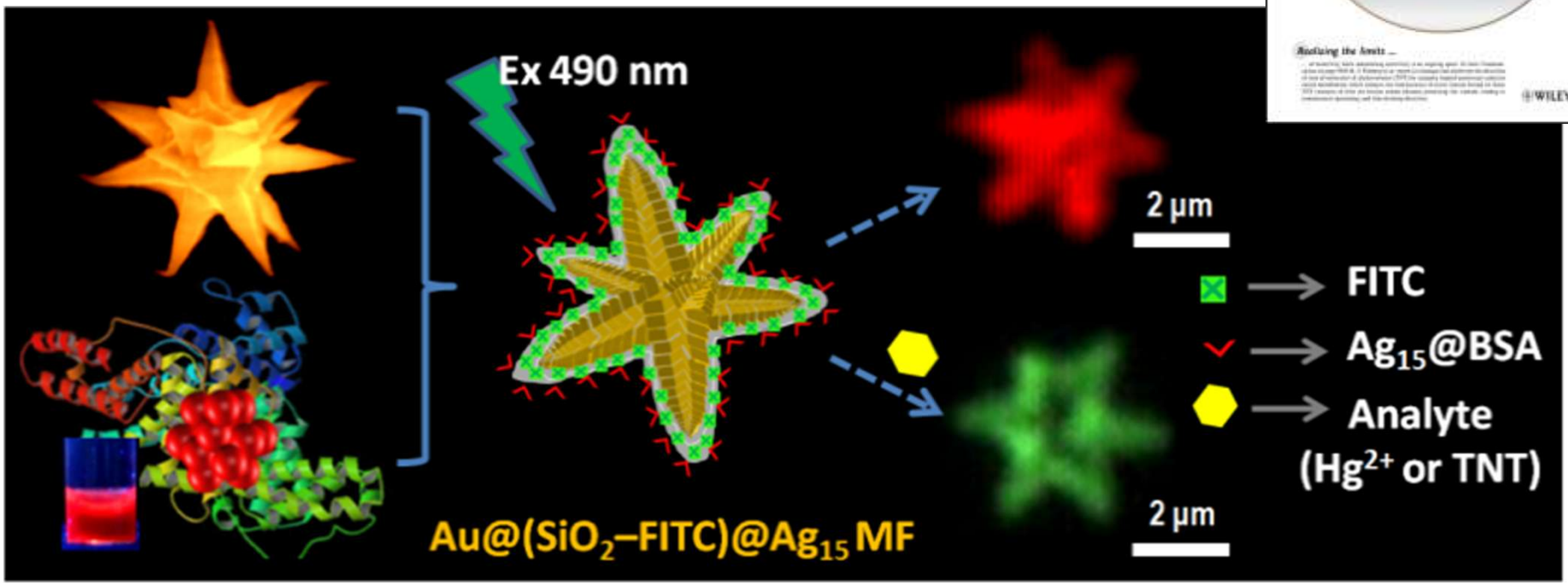


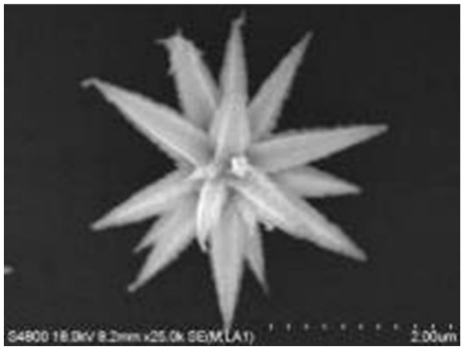
Decrease in the absorption of Au_{15} as a biofilm is dipped into the cluster solution. Inset: Free standing quantum cluster loaded film in visible light and UV light.

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

Sub-zeptomolar detection



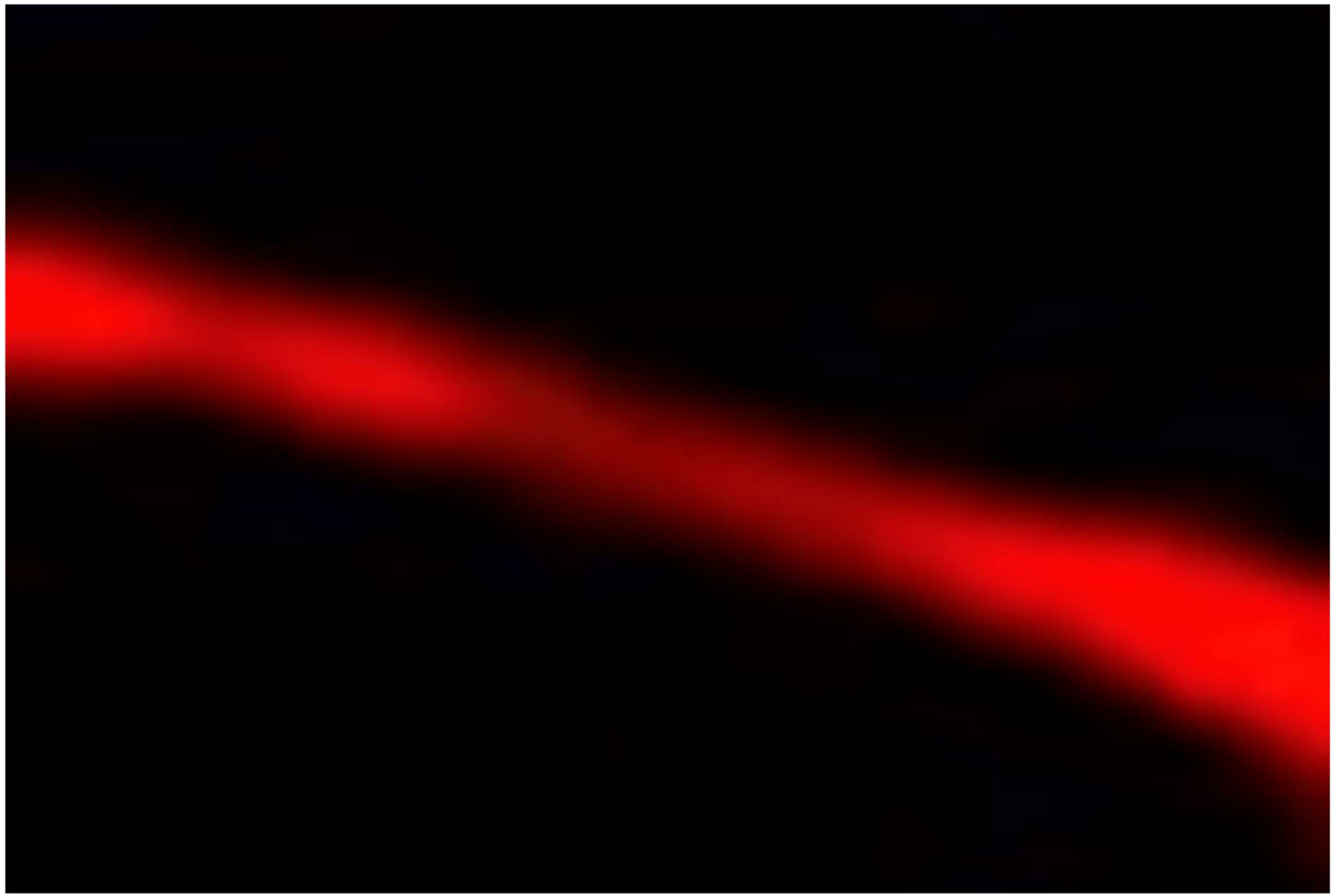




Featured in:
The Hindu, Telegraph, Times of India, etc.
C&E News
and many others

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

Video of mercury quenching experiment using the nanofiber



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 Excellence, Department of Chemistry, Indian Institute of Technology Madras, Chennai 600 036, India

Edited by Eric Hoek, University of California, Los Angeles, CA and accepted by the Editorial Board April 4, 2013 (received for review November 21, 2012)

Creation of affordable materials for constant release of silver ions in water is one of the most promising ways to provide microbially safe drinking water for all. Combining the capacity of diverse nano-
composites to
other contami
affordable, all-
without electr
synthesis of st
uously in the
drinking wate
surfaces. Here
be synthesized
out the use of
sand-like prope
forms. These n
water purifier
ily. The ability
ambient temp
water purifica

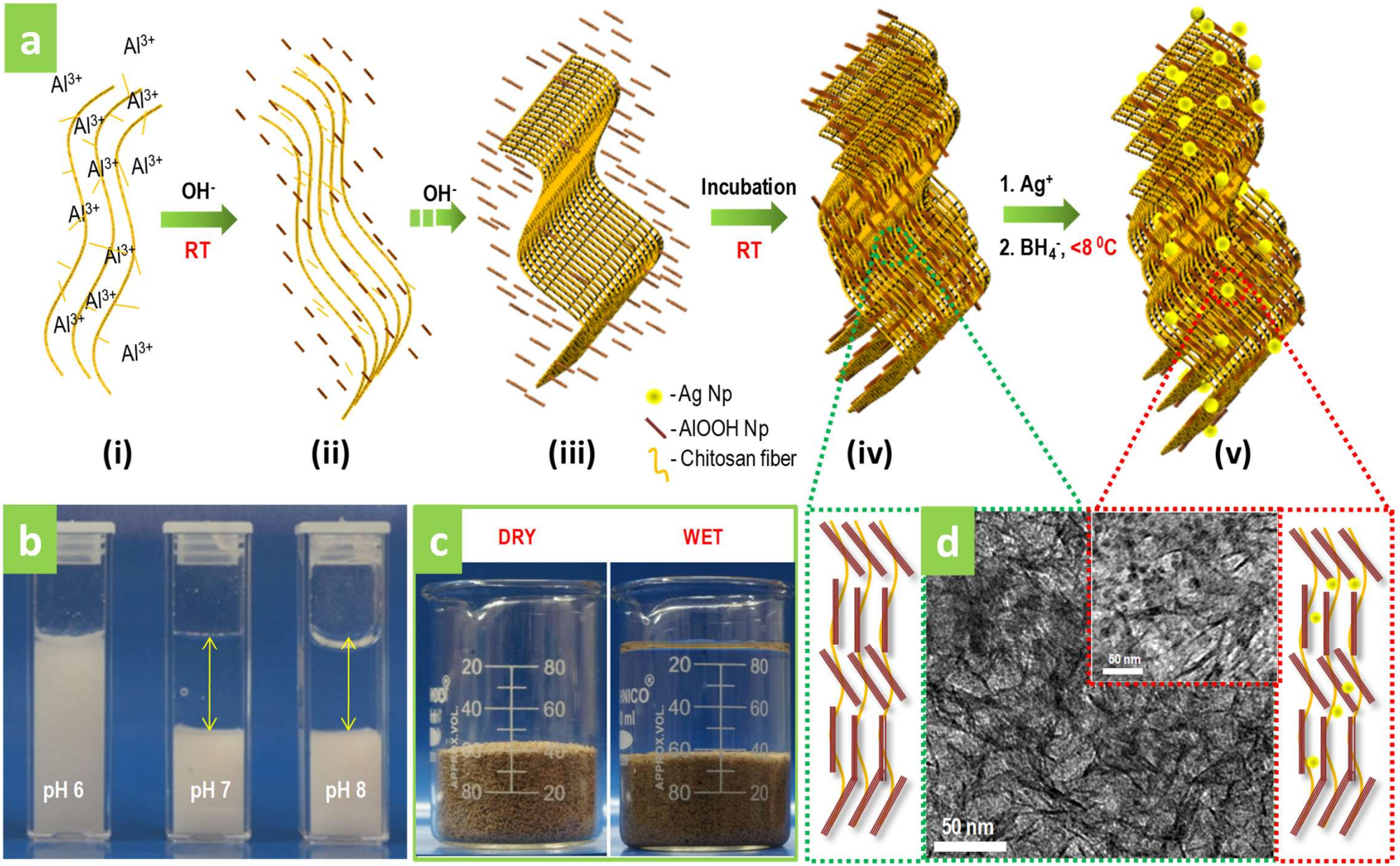
release into water are not available; and (*c*) continued retention of the nanoparticles in the matrix is difficult.

In this work, we demonstrate a unique family of nanocrystalline tal oxyhydroxide-chitosan granular composite materials pre-ed at near room temperature through an aqueous route. The gin of crystallinity in the composition is attributed to abundant -O- l -OH functional groups on chitosan, which help in the crys-ization of metal oxyhydroxide and also ensure strong covalent ding of the nanoparticle surface to the matrix. X-ray photo-ctron spectroscopy (XPS) confirms that the composition is rich h surface hydroxyl groups. Using hyperspectral imaging, the ence of nanoparticle leaching in the water was confirmed. ther, a unique scheme to reactivate the silver nanoparticle face is used for continual antimicrobial activity in drinking ers. Several other composites have been developed that can venge other contaminants in water. We demonstrate an af-dable water purification device based on such composites de-oped over several years and undergoing field trials in India, as otential solution for widespread eradication of the waterborne ease burden.

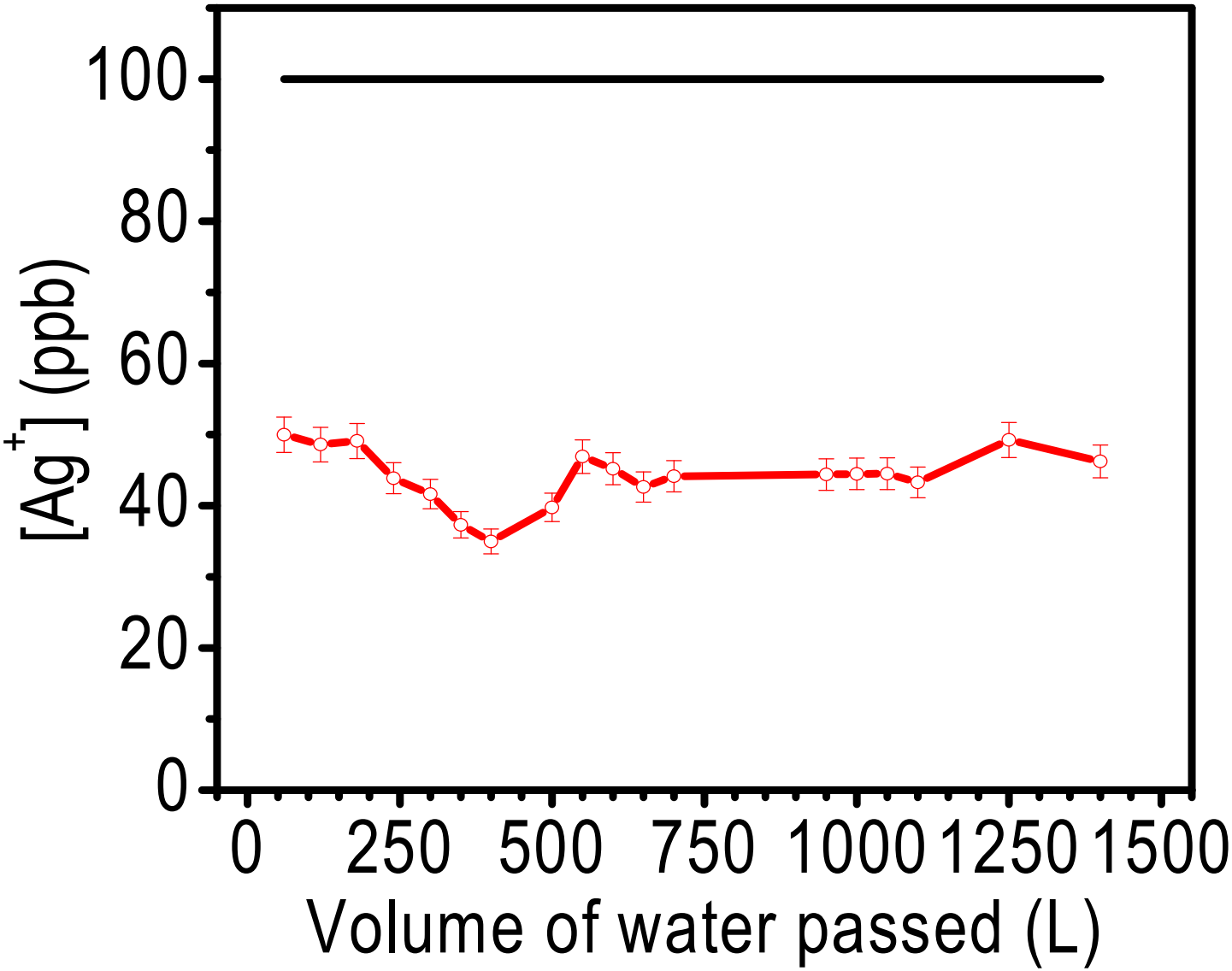
hybrid | green |

ults and Discussion

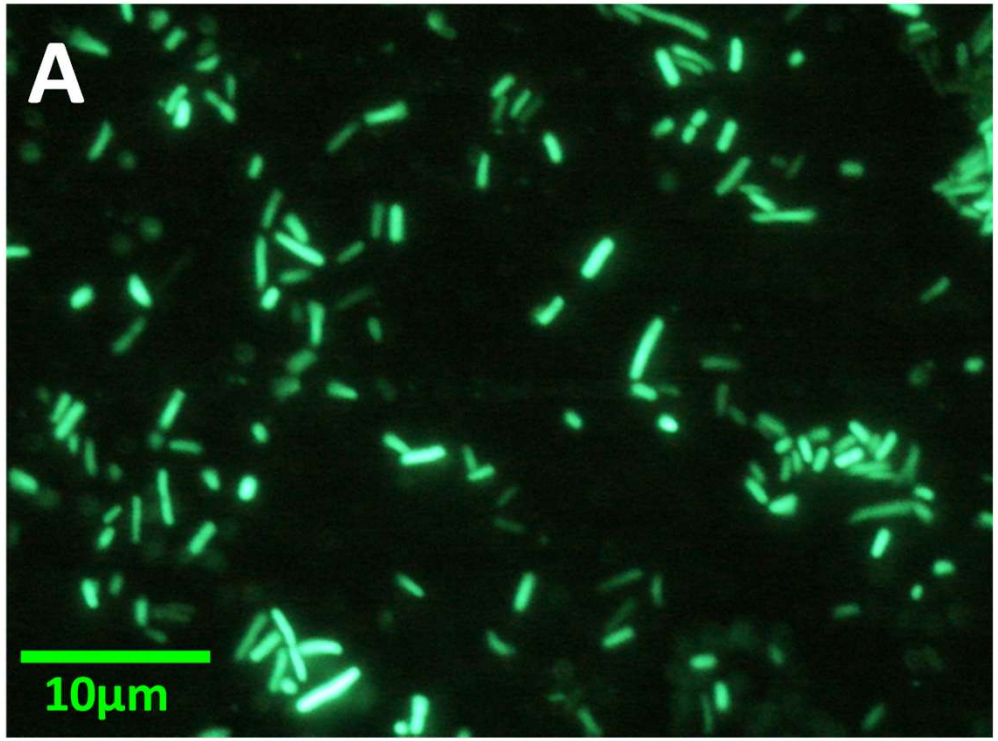
New materials

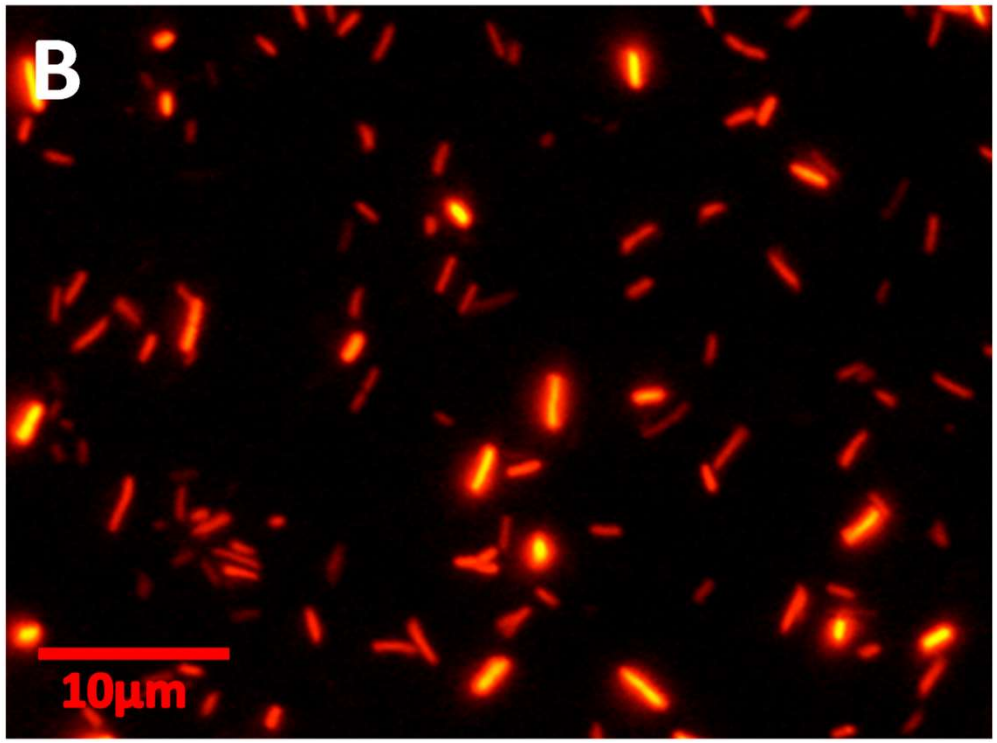


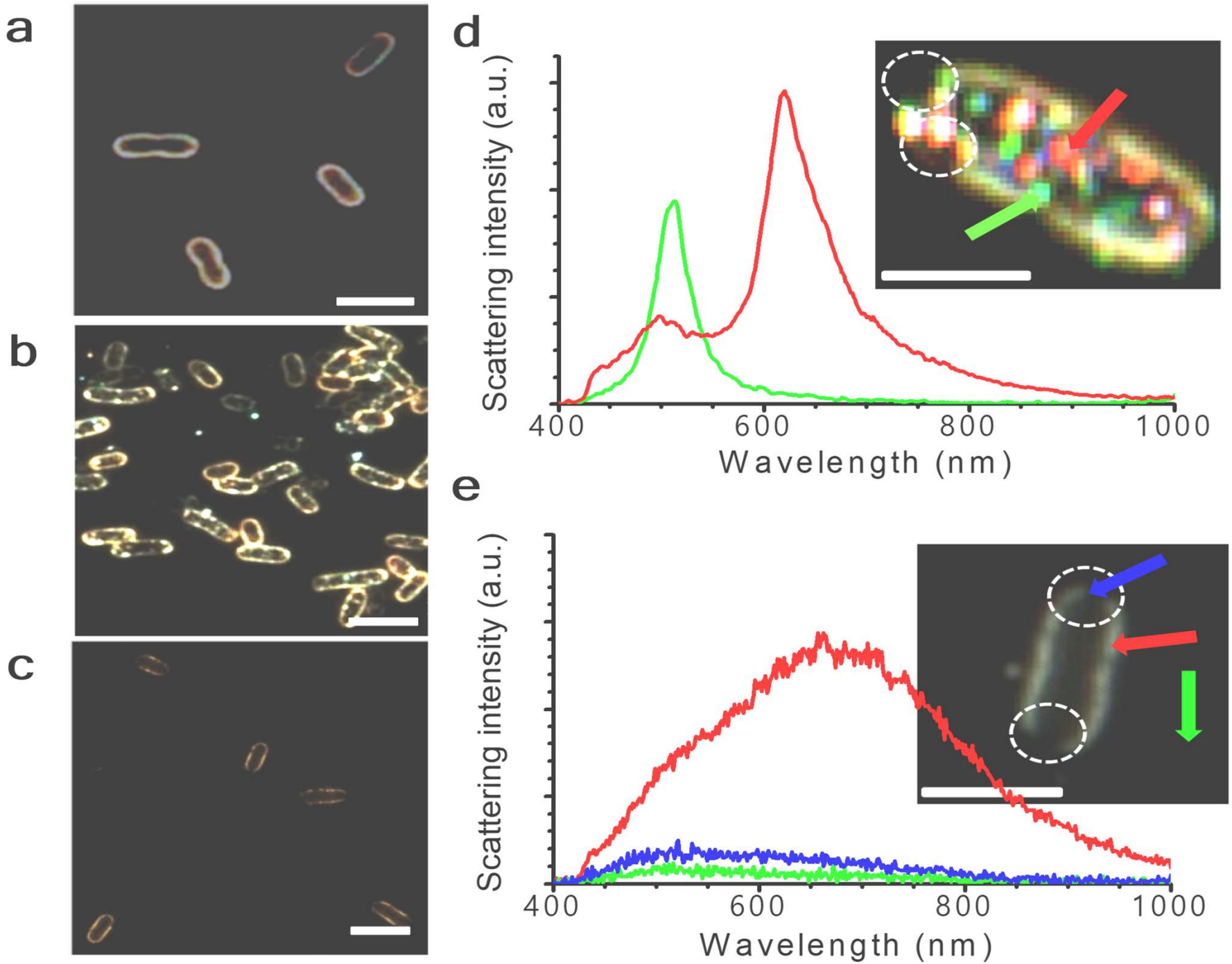
What is special?

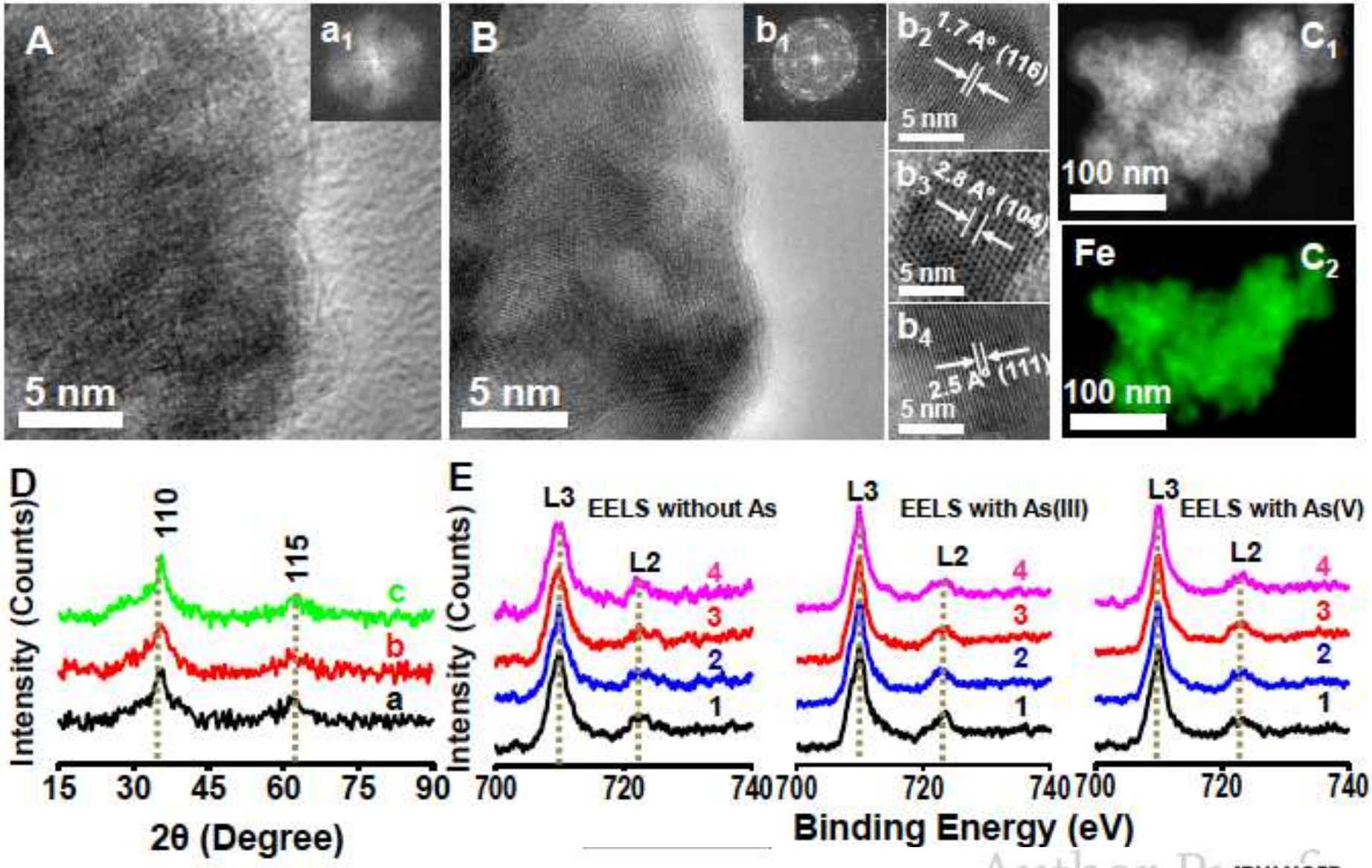


Live/dead staining experiments






a
b
c
d
Scattering intensity (a.u.)
400
600
800
1000
Wavelength (nm)
e
Scattering intensity (a.u.)
400
600
800
1000
Wavelength (nm)



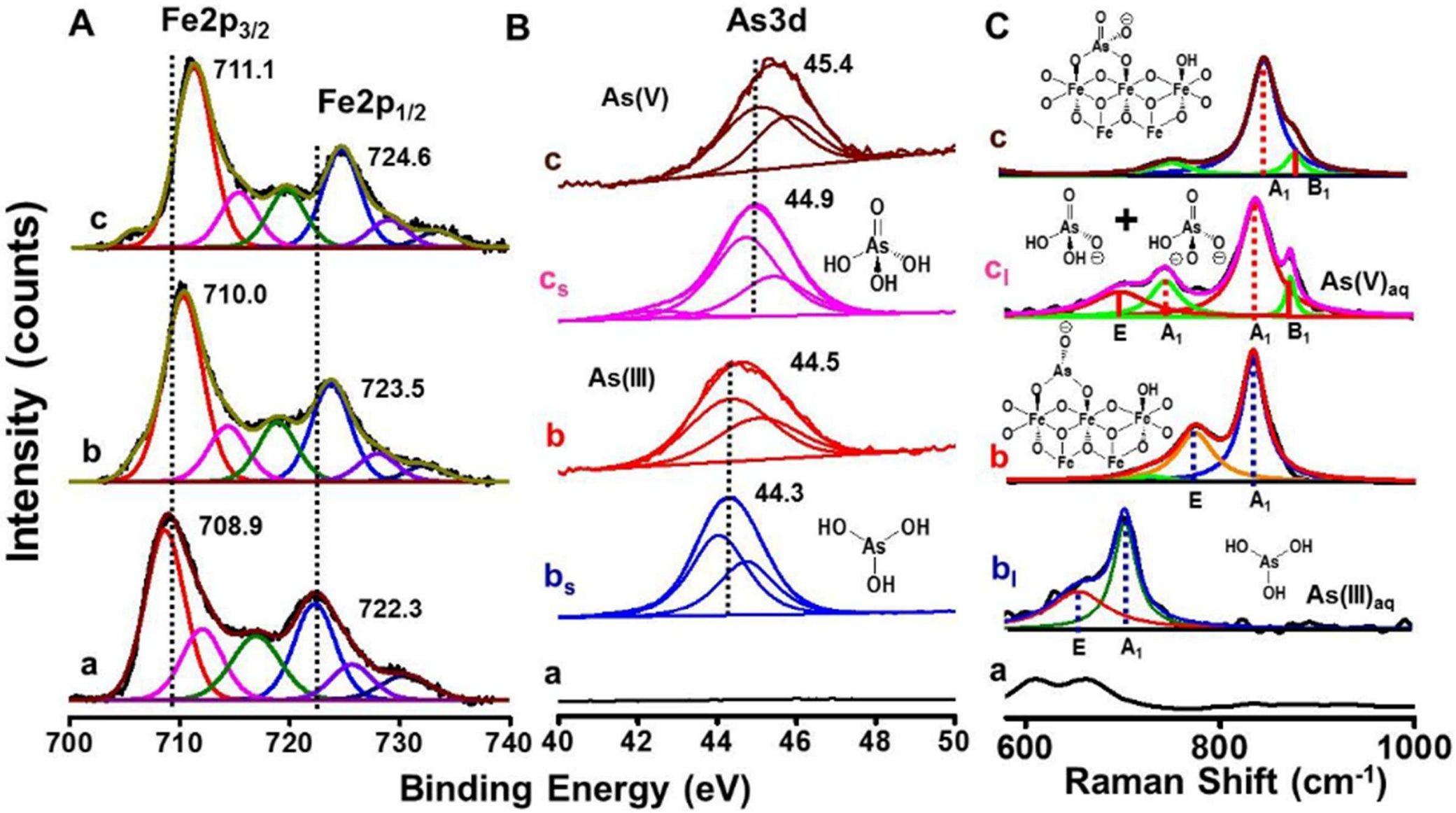
www.advmat.de ADVANCED MATERIALS

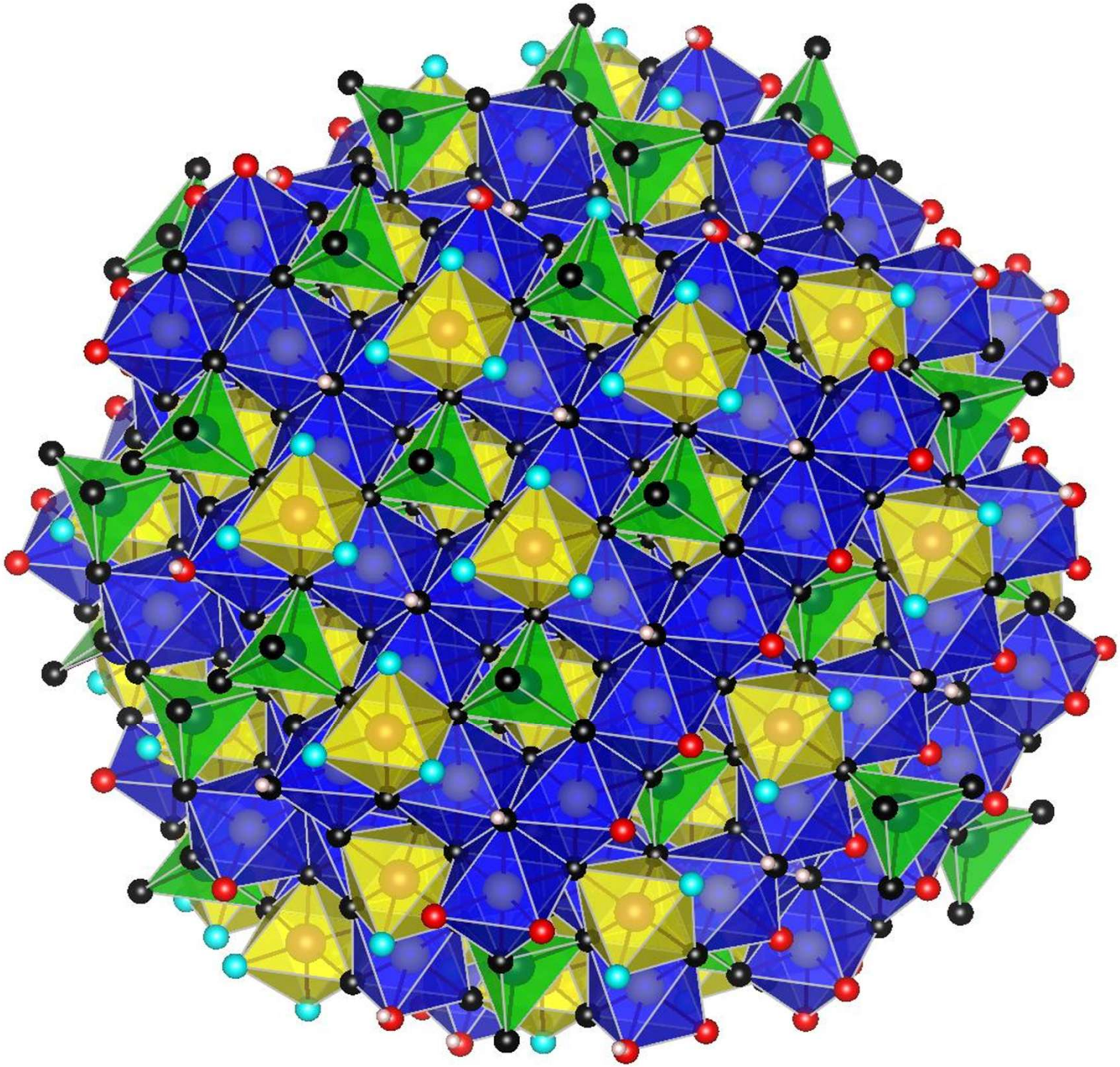
Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

By *Avula Anil Kumar, Anirban Som, Paolo Longo, Chennu Sudhakar, Radha Gobinda Bhuin, Soujit Sen Gupta, Anshup, Mohan Udhaya Sankar, Amrita Chaudhary, Ramesh Kumar, and T. Pradeep**

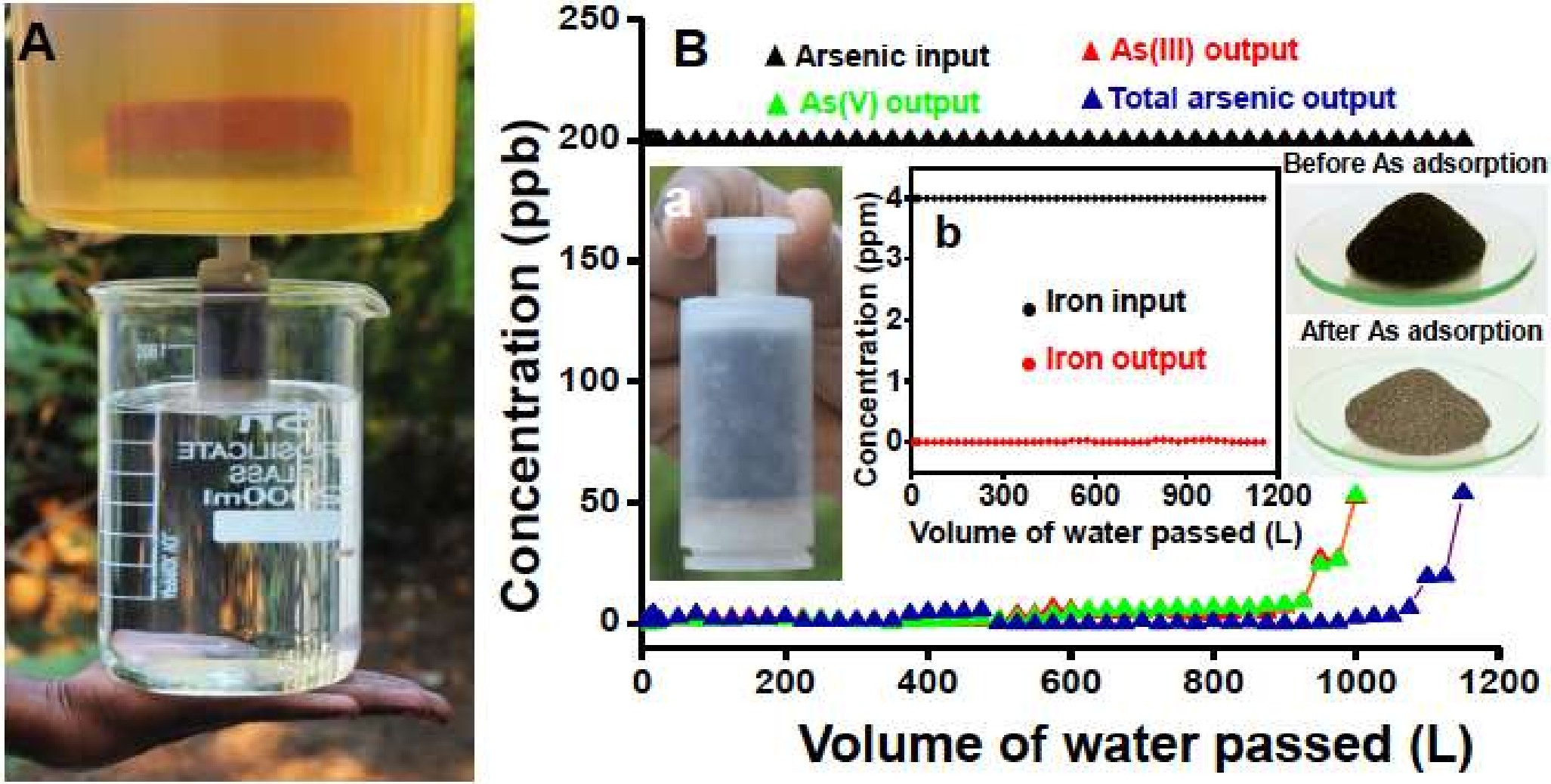
A. Anil Kumar, et. al. *Adv. Mater.*, 29 (2016) 1604260.

Mechanism


A
Fe2p3/2
711.1
Fe2p1/2
724.6
c
710.0
723.5
b
708.9
722.3
a
Intensity (counts)
700
710
720
730
740
B
As3d
As(V)
45.4
c
44.9
cs
As(III)
44.5
b
44.3
bs
a
40
42
44
46
48
50
Binding Energy (eV)
C
c
A1
B1
cl
As(V)aq
E
A1
b
bl
As(III)aq
a
600
800
1000
Raman Shift (cm-1)

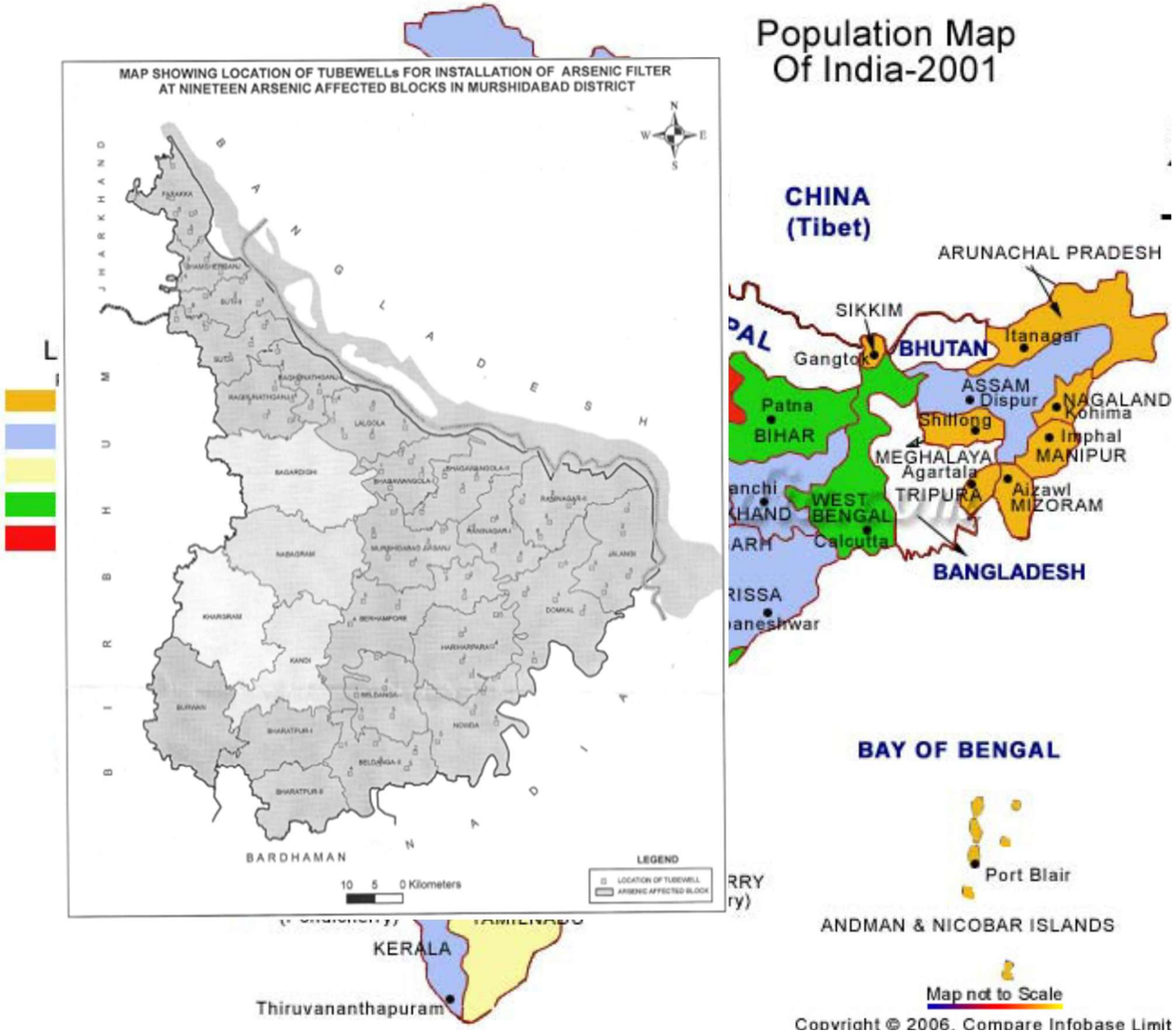


Chennu Sudhakar, et al. *ACS Sustainable Chemistry & Engineering*, 6 (2018) 9990-10000



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


AMRIT
DRINKING WATER
ARSENIC & METAL REMOVAL BY INDIAN TECHNOLOGY
INDIAN INSTITUTE OF TECHNOLOGY MADRAS


MAP SHOWING LOCATION OF TUBEWELLs FOR INSTALLATION OF ARSENIC FILTER AT NINETEEN ARSENIC AFFECTED BLOCKS IN MURSHIDABAD DISTRICT
JHARKHAND
BIHAR
BARDHAMAN
LEGEND
10 5 0 Kilometers
Population Map Of India-2001
CHINA (Tibet)
ARUNACHAL PRADESH
SIKKIM
Gangtok
BHUTAN
Itanagar
ASSAM
Dispur
NAGALAND
Kohima
Patna
BIHAR
Shillong
Imphal
MANIPUR
MEGHALAYA
Agartala
TRIPURA
Aizawl
MIZORAM
WEST BENGAL
Calcutta
BANGLADESH
BAY OF BENGAL
Port Blair
ANDMAN & NICOBAR ISLANDS
KERALA
Thiruvananthapuram
Map not to Scale
Copyright © 2006. Compare Infobase Limit

Imagining how new adsorbents are changing the dynamics at ground level

- Existing unit for iron and arsenic removal – 20 m^3/h
- Uses activated alumina and iron oxide (old generation of adsorbents)

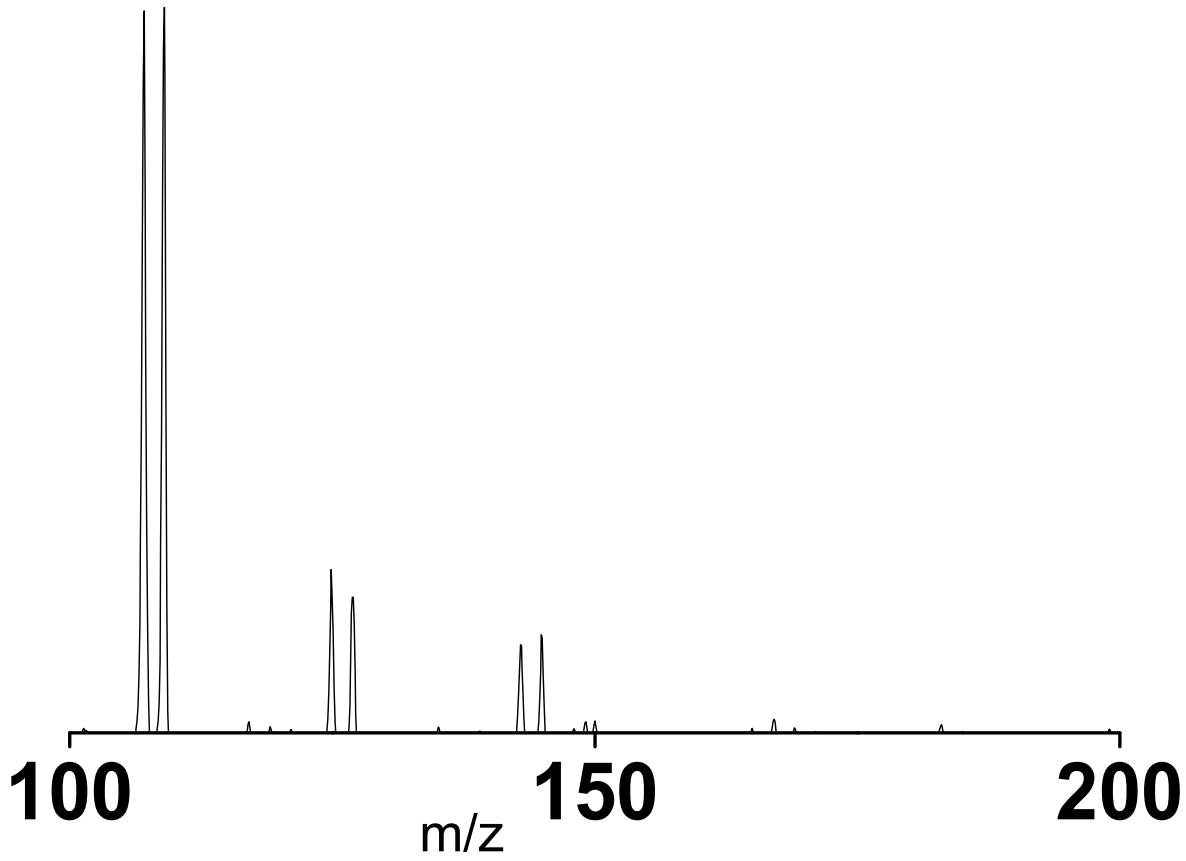
- Existing unit for iron and arsenic removal – 18 m^3/h
- Uses iron oxyhydroxide (new generation of adsorbents)
- Input arsenic concentration: 168 ppb
- Output arsenic concentration: 2 ppb

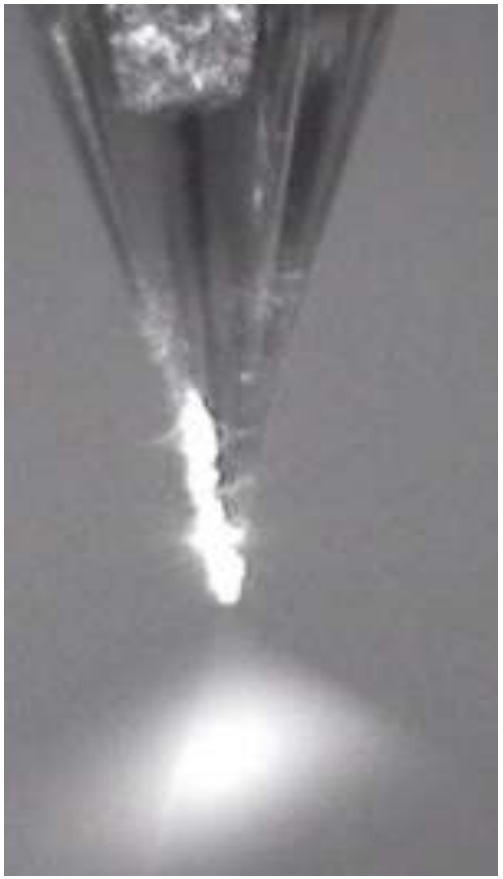
Seeing how the new adsorbents are changing the dynamics at the ground level (type 1 of our efforts)

Name of the scheme: Mahilan Wala (TW9144), District: Amritsar
Population: 2610, Daily demand@70 LPCD: 188 kLD, OHSR Capacity: 100 kL


Completed 3 years maintenance (stipulated: 2 years)
for 330 bamboo unit project in Nadia, WB
03471-250221
Minimum uptime: 91%, Maximum: 98%
Only 4/330 have reported arsenic above 10 ppb
Benefiting over 100,000 children and villagers
Glimpse of Installed units (330 nos)

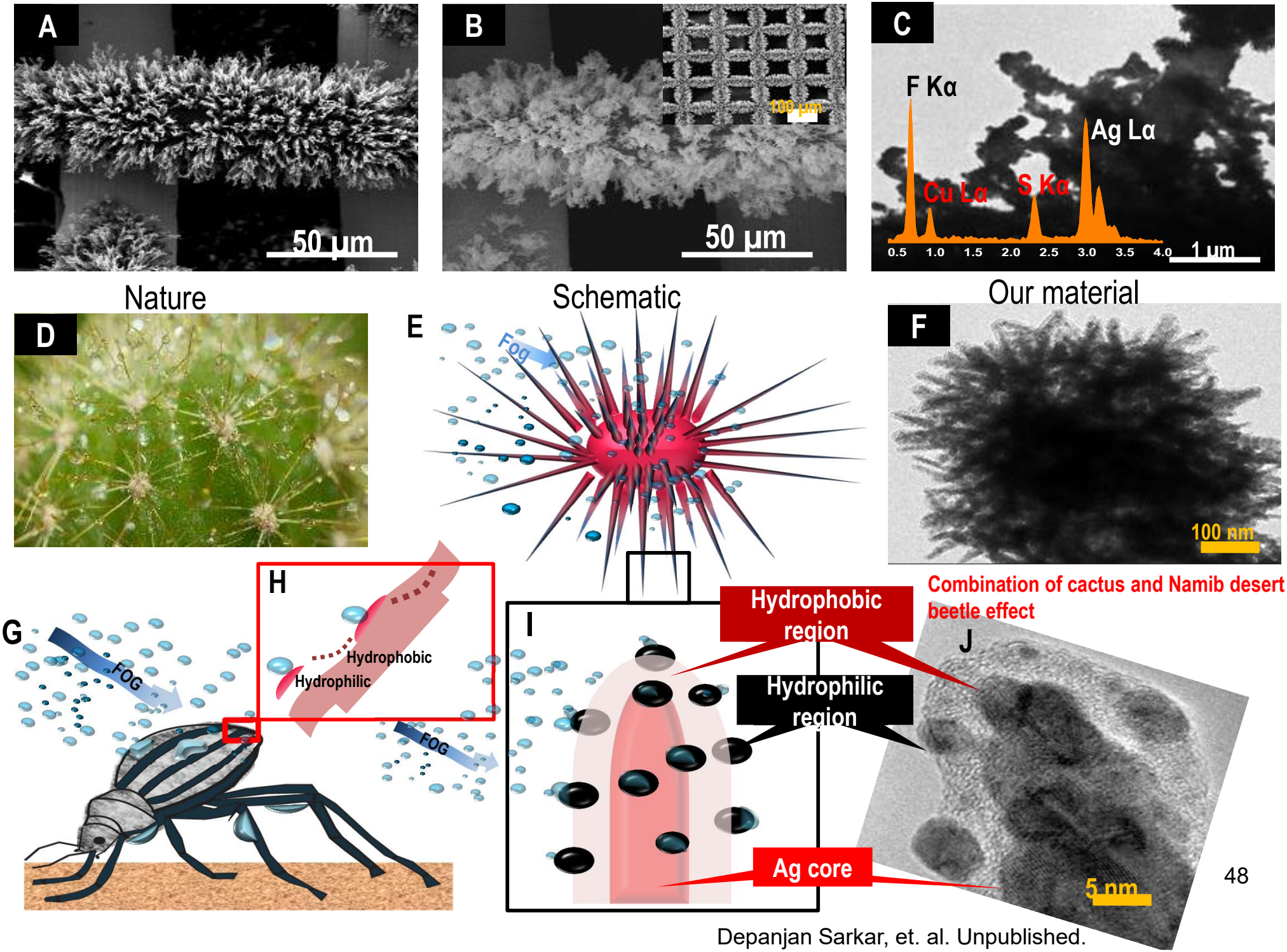
Atmospheric water harvesting



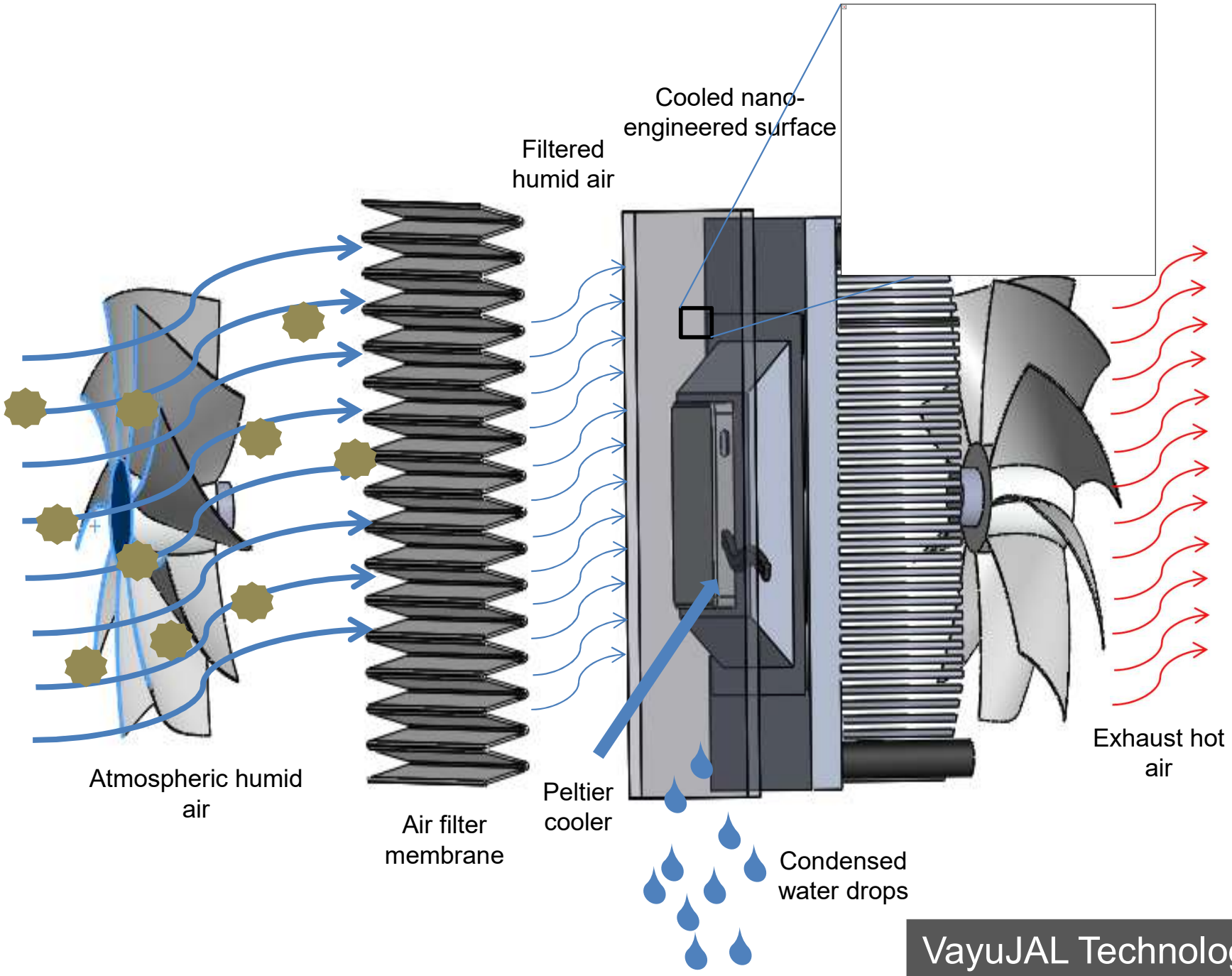


New harvesters

Depanjan Sarkar, et. al. *Advanced Materials*, 28 (11), 2016.



Depanjan Sarkar, et. al. Unpublished.

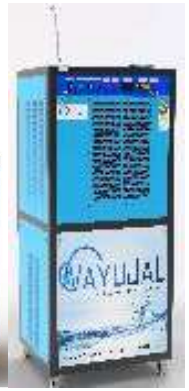


VayuJAL Technologies Pvt. Ltd.

Ramesh Kumar Soni and Ankit Nagar

Products in the field

35 LPD



120 LPD

400 LPD

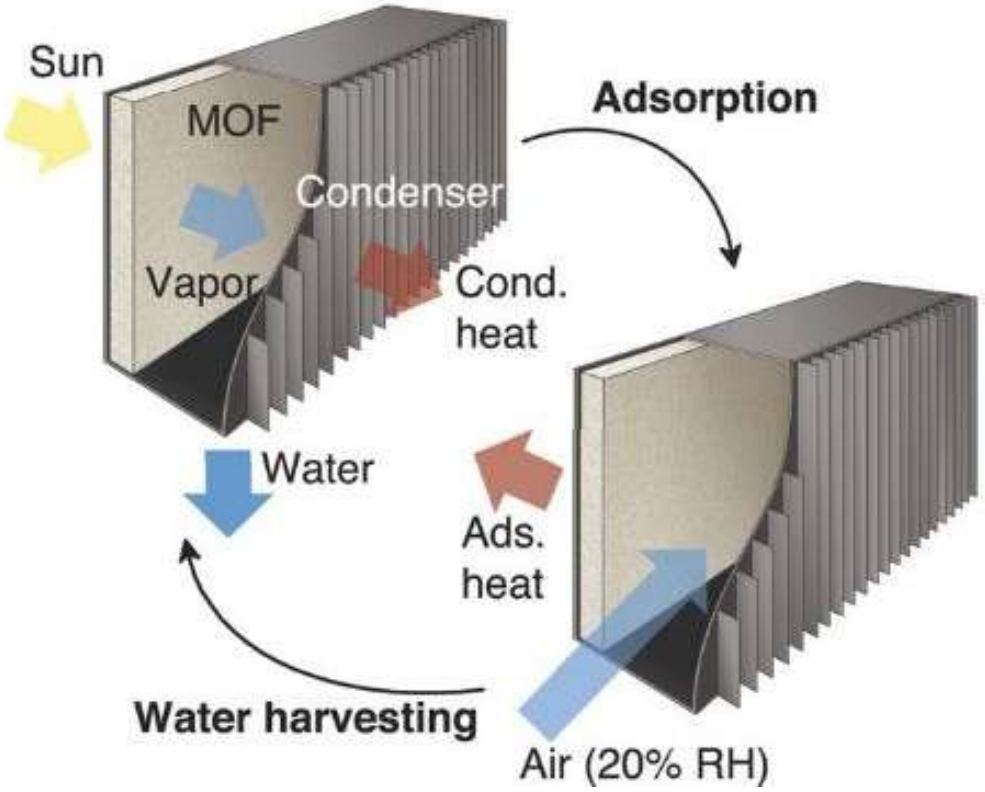
1000 LPD

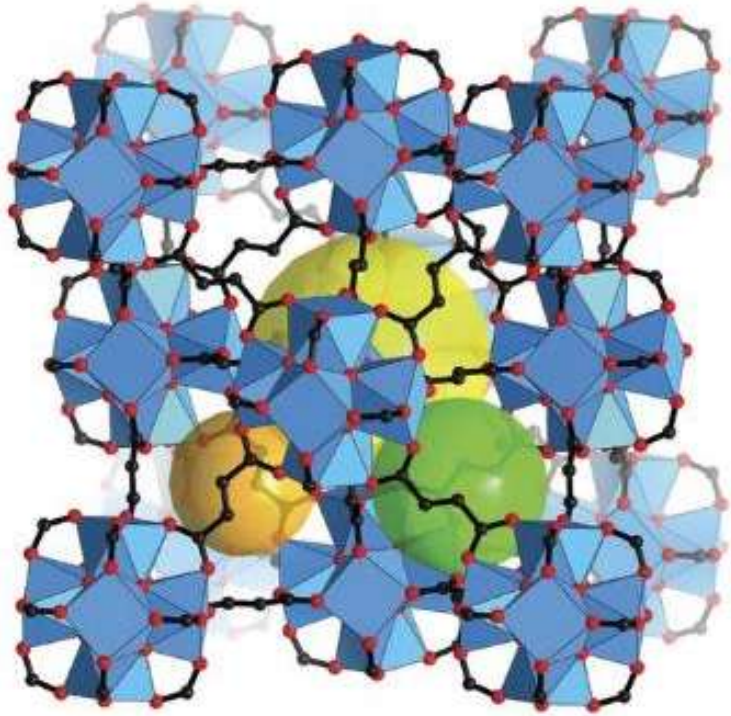
2000 LPD

(LPD: Litres per day)

Sustainable atmospheric water harvesting

Solar- heat-enabled atmospheric water capture at a relative humidity as low as 20%

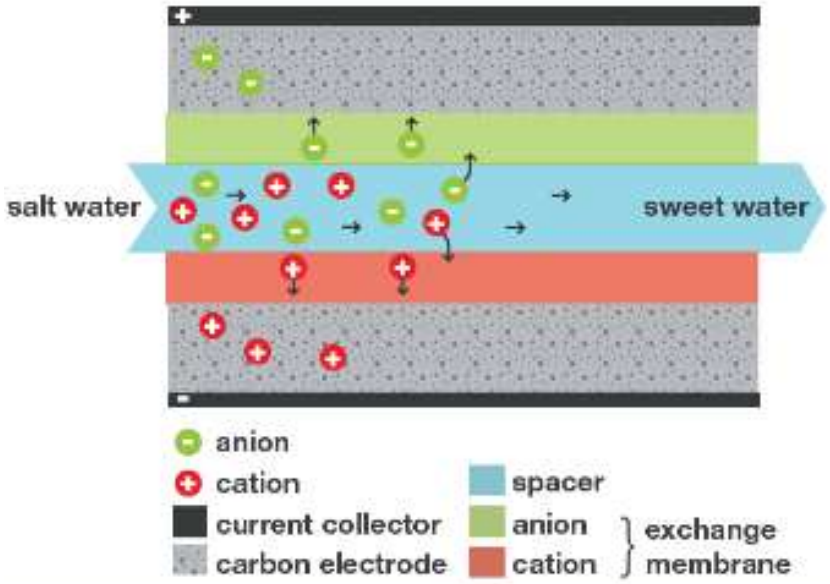


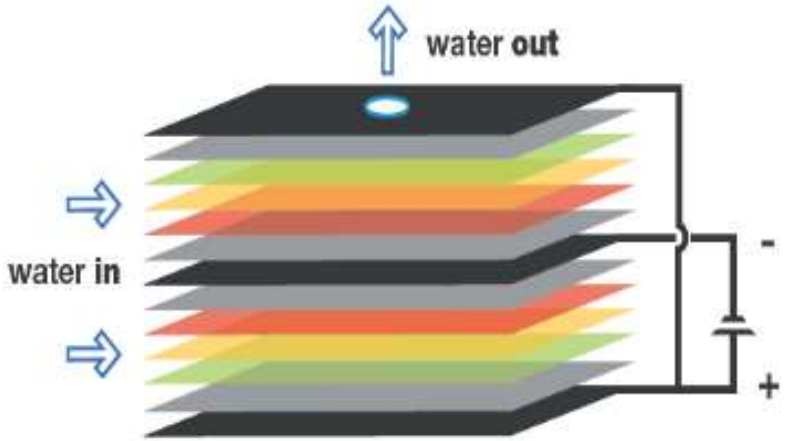


Porous metal-organic framework (MOF-801, $Zr_6O_4(OH)_4(fumarate)_6$)

Kim Hyunho, et al. *Science,* 356 (6336) 2017

Capacitive Desalination (CDI)

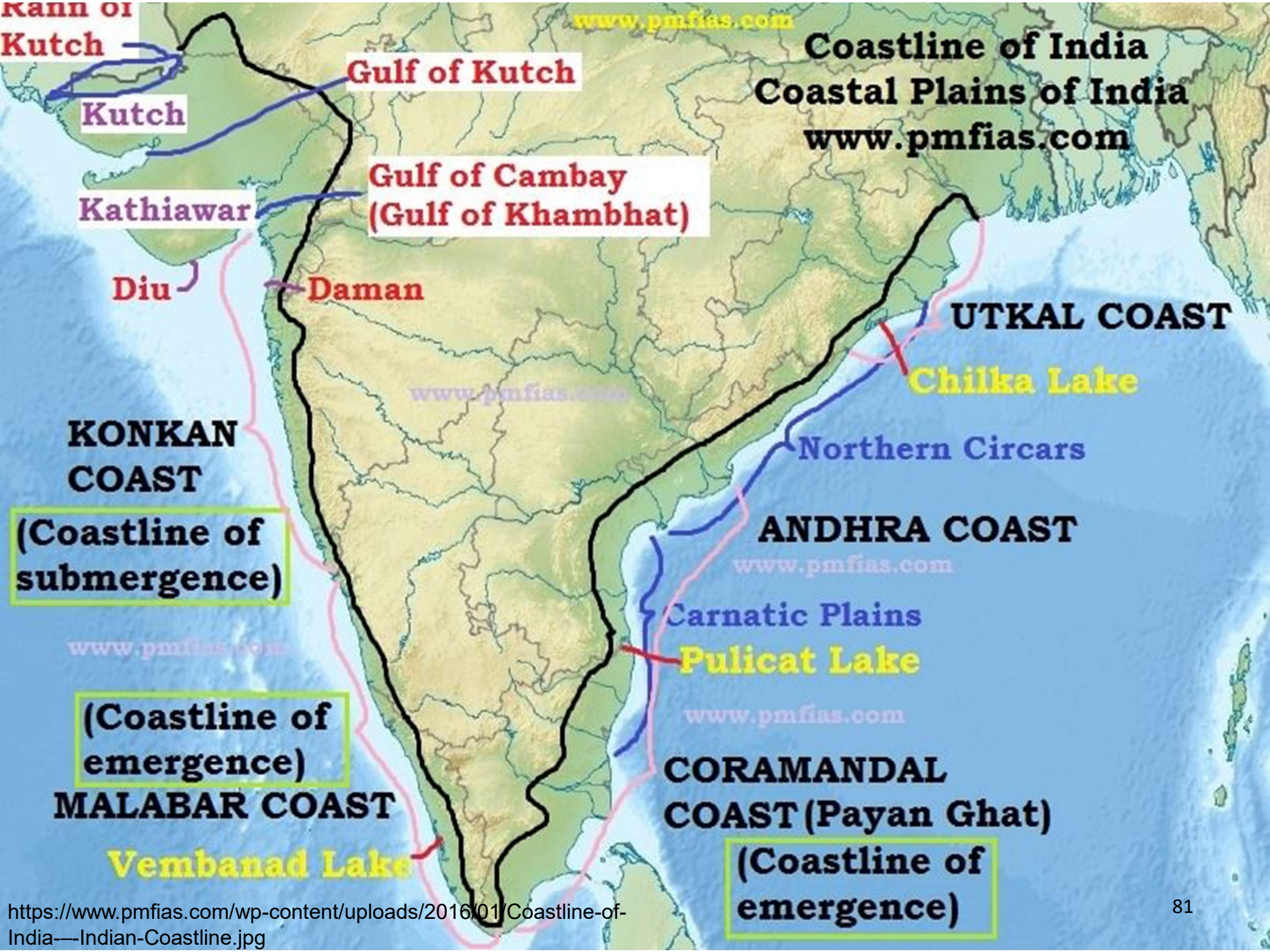




innODI

Our new company

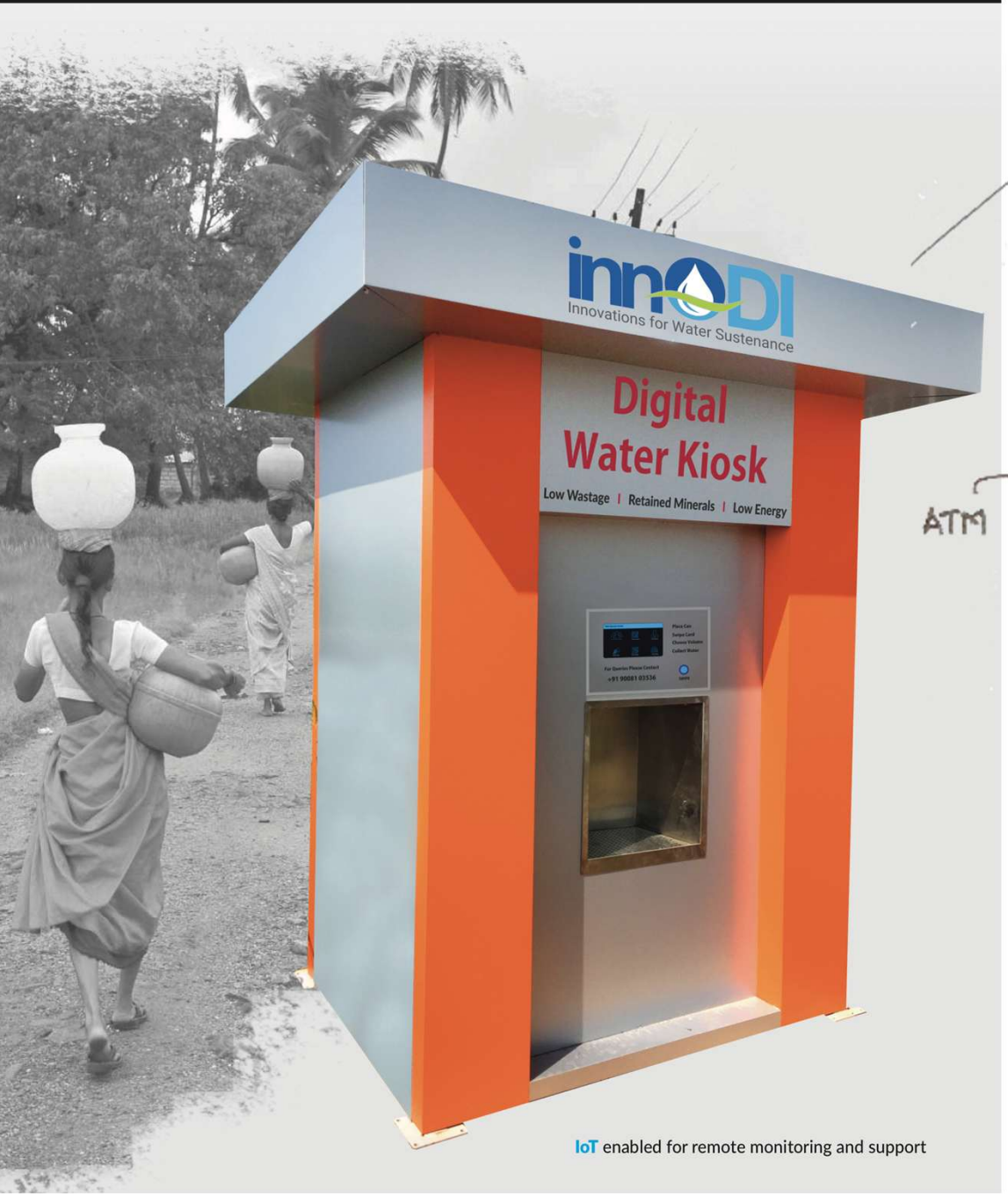
Soujit Sengupta, Rabiul Islam and others

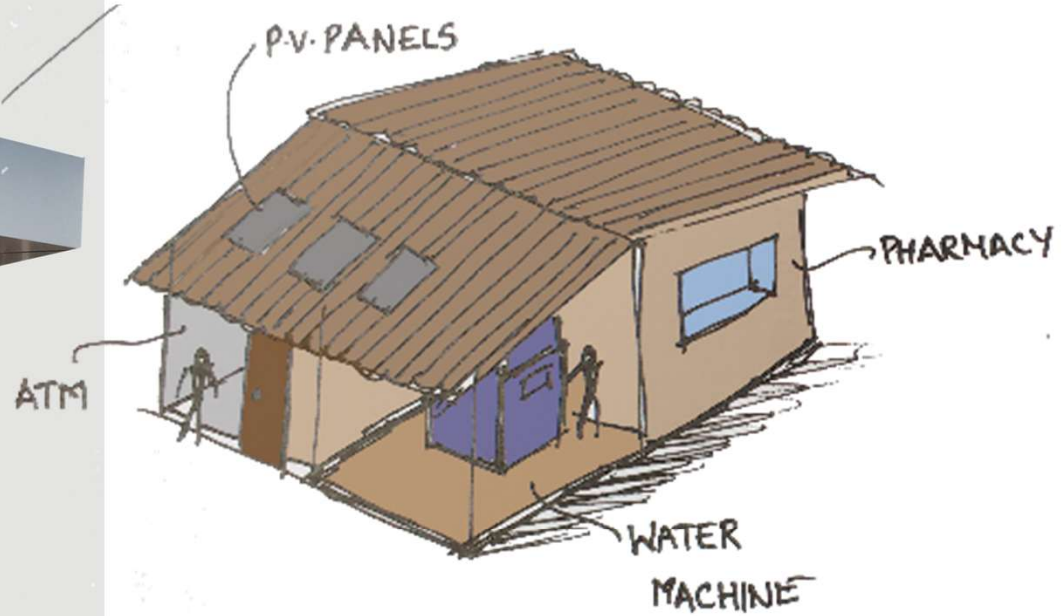


https://www.pmfias.com/wp-content/uploads/2016/01/Coastline-of-India-–-Indian-Coastline.jpg

DIGITAL WATER KIOSK

for community drinking using CDI Technology

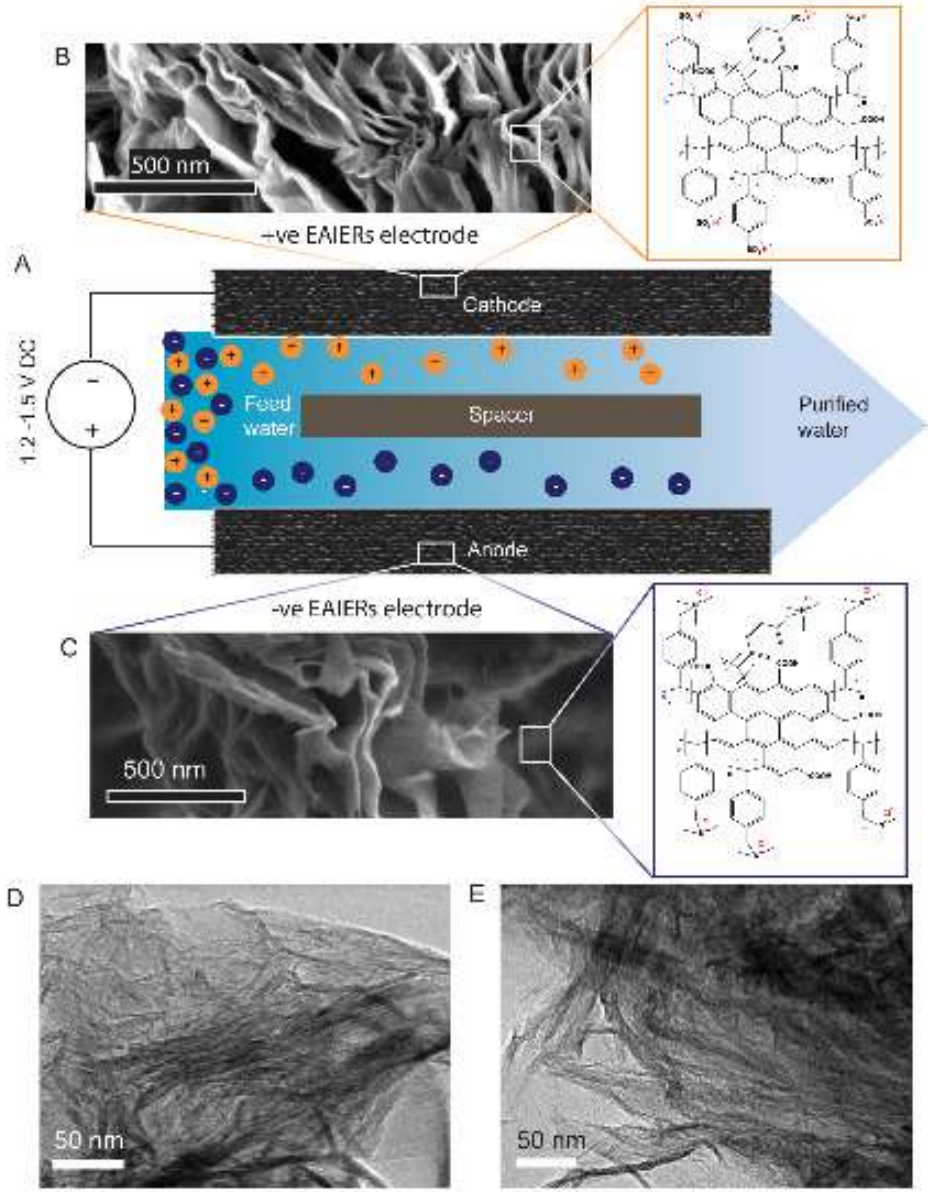




Products under implementation

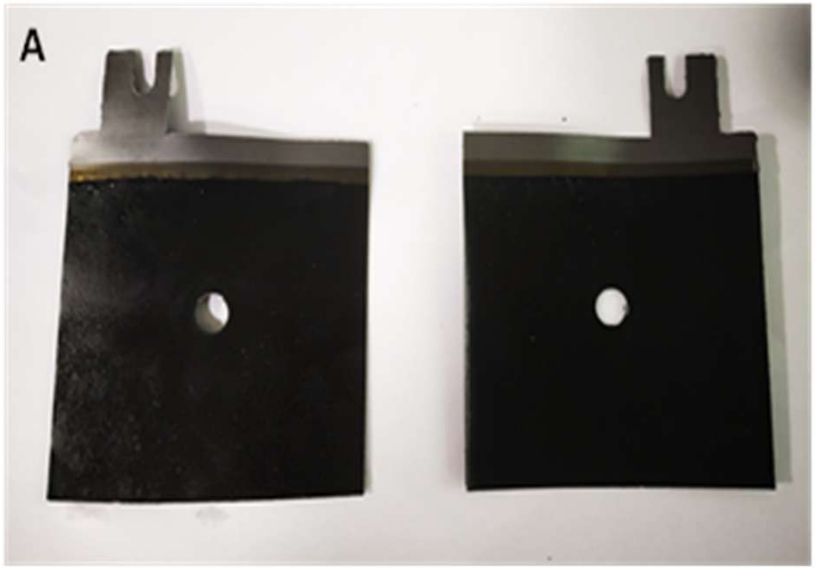
Vijay Sampath and Tullio Servida

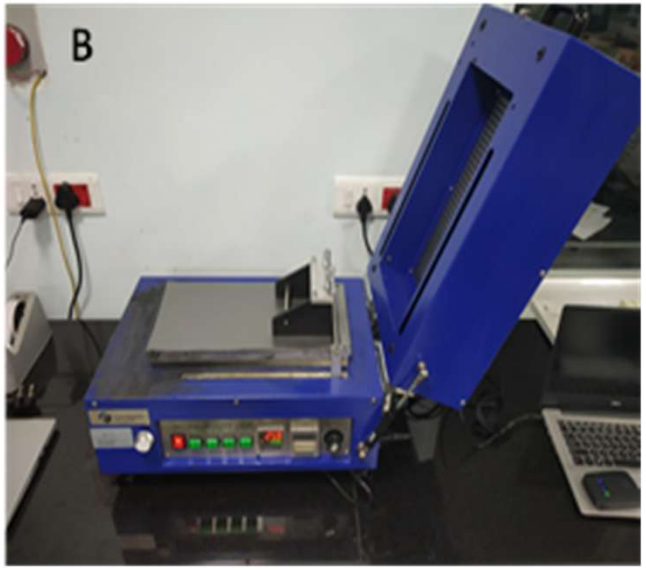
A Covalently Integrated Reduced Graphene Oxide -Ion Exchange Resin Electrode for Efficient CDI

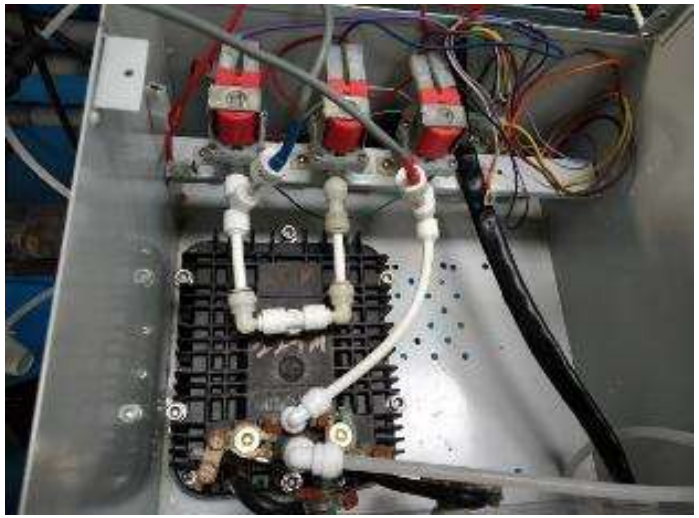


Rabiul *et al., Adv. Mater. Interfaces* **2021**, *8,* 2001998

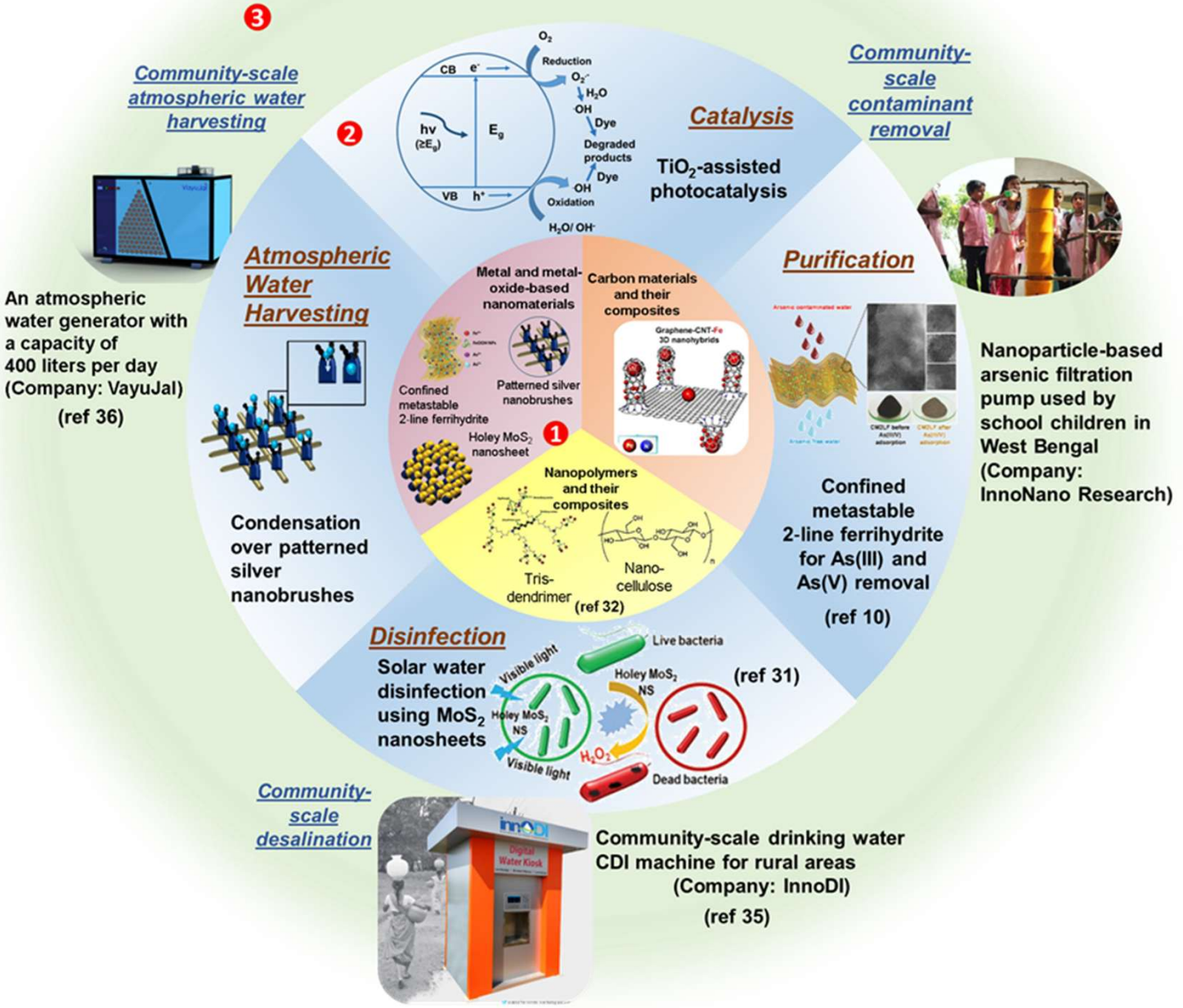
Various stages of electrode preparation







Evolution of materials to products



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

Plan for immediate future

ARSENIC TOXIC WATER

India Mark II hand water pump – most common water pump used globally

InnoNano Research's in-line arsenic removal filtration system

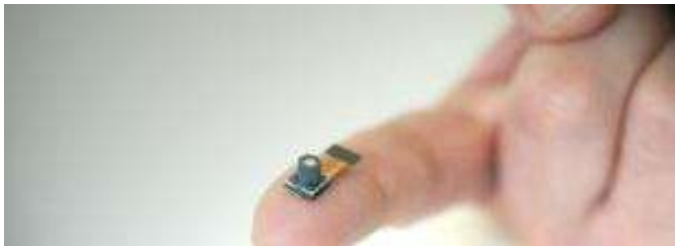
In-line arsenic sensor and remote data management – indicates when filtration systems require maintenance. **IMPROVED FILTER SUSTAINABILITY**

SUSTAINABLE SOURCE OF ARSENIC FREE SAFE DRINKING WATER

Sensors and new opportunities

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

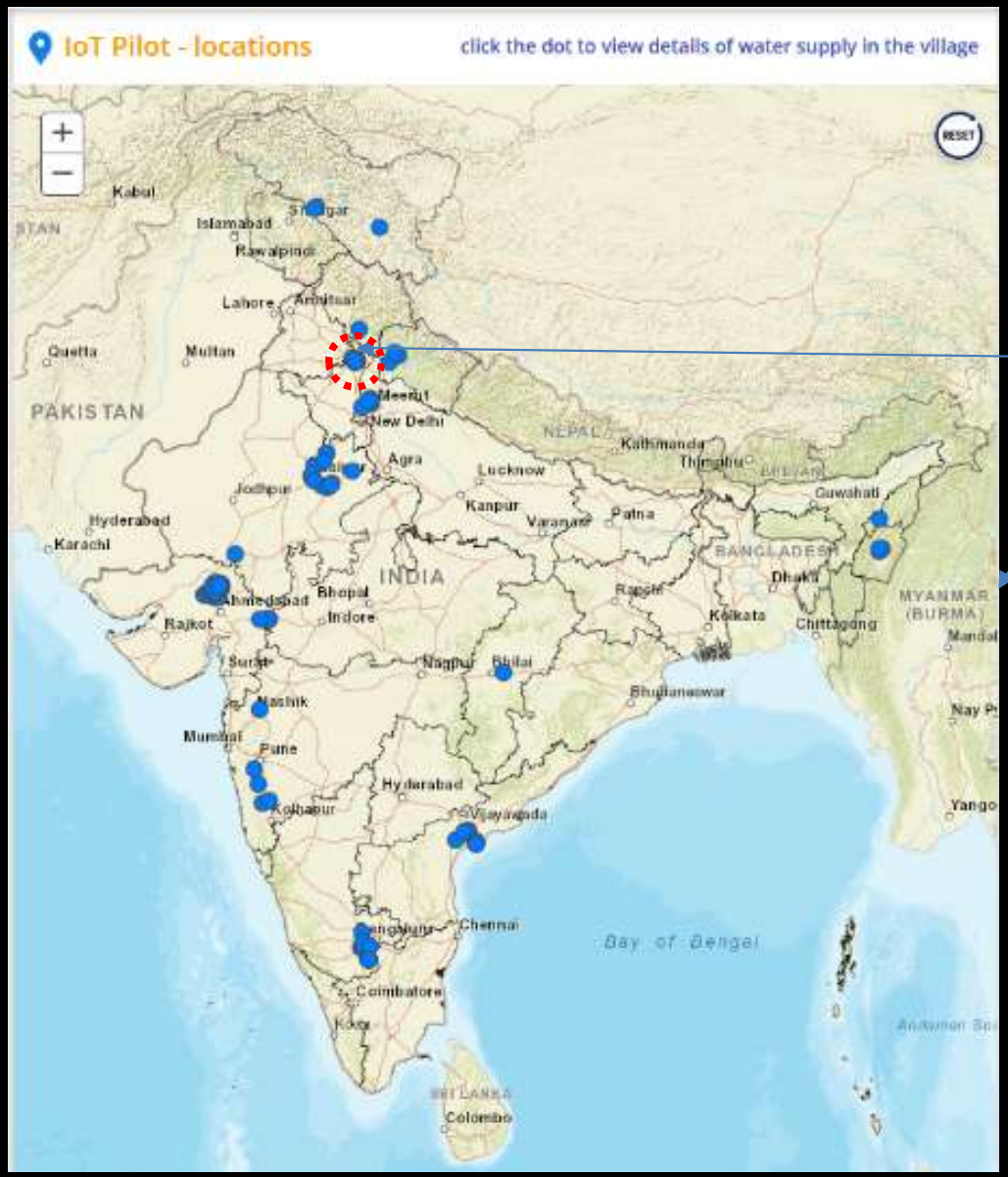
Ultra compact Low Cost
Spectral Sensor Module
~ Billions units (? 2027)



Water quality measurement – In the pipeline

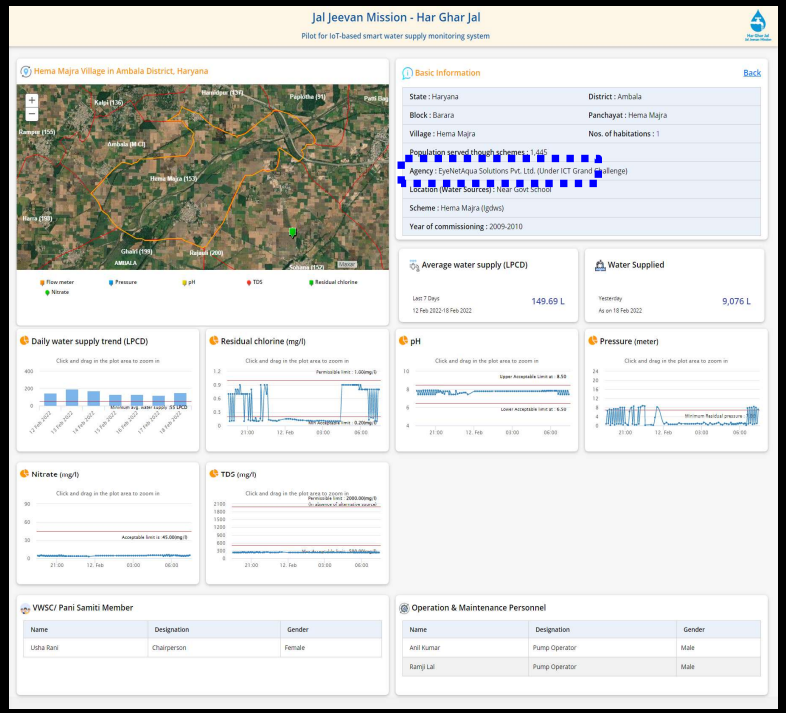
nanoλ

India’s water is being monitored



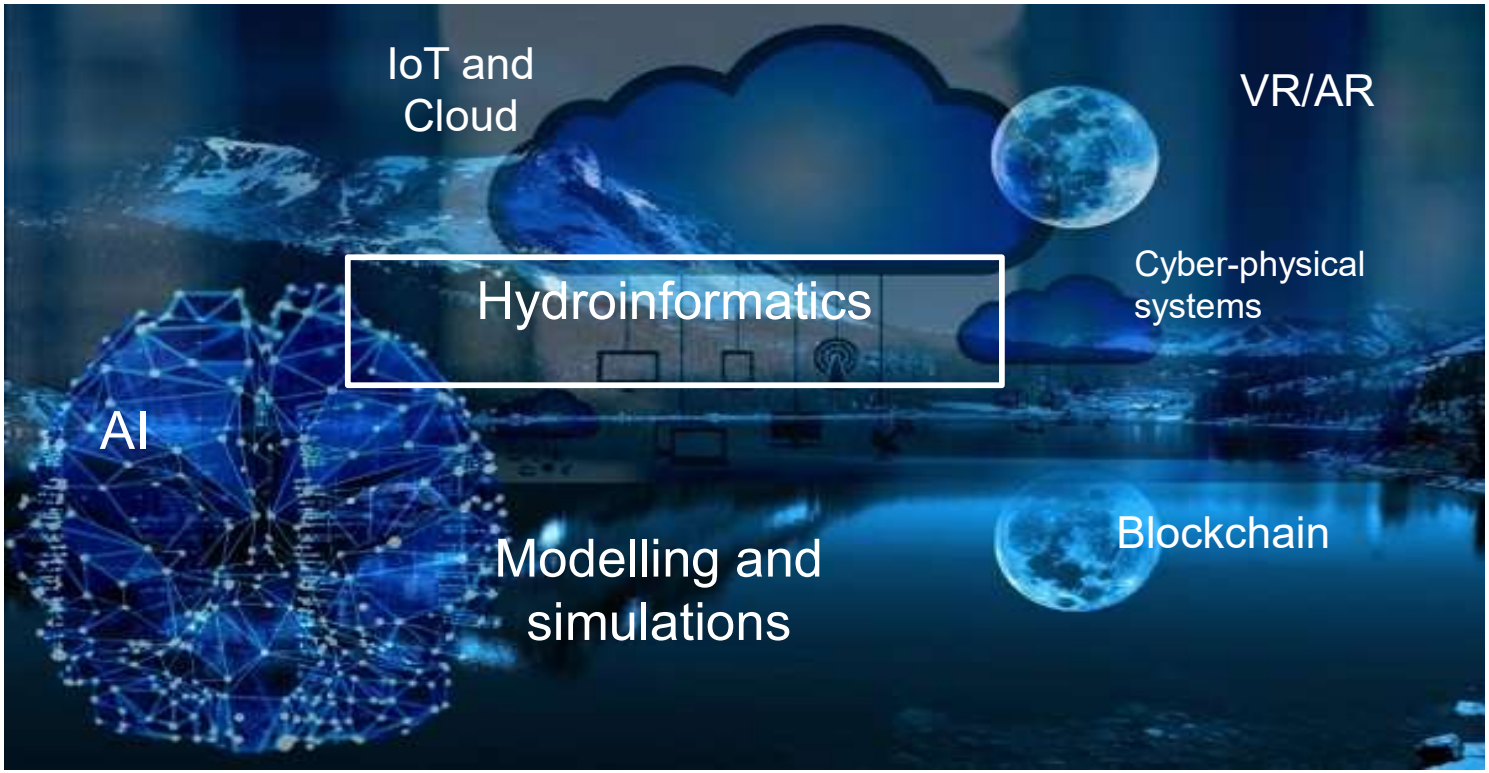
IITM/IISc

Installations made by four companies



Hydroinformatics

Application of computing technologies for efficient, sustainable and equitable water management.



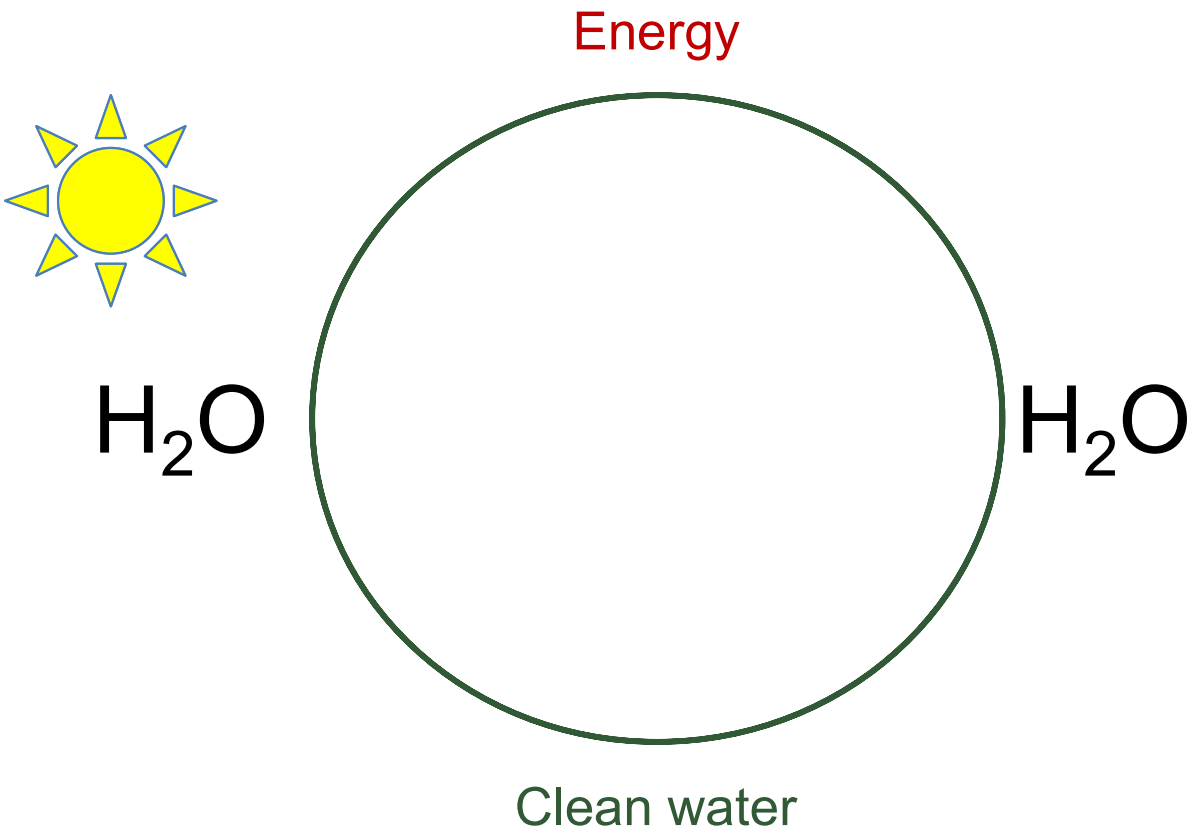
Digital water or water 4.0 will revolutionize water management.

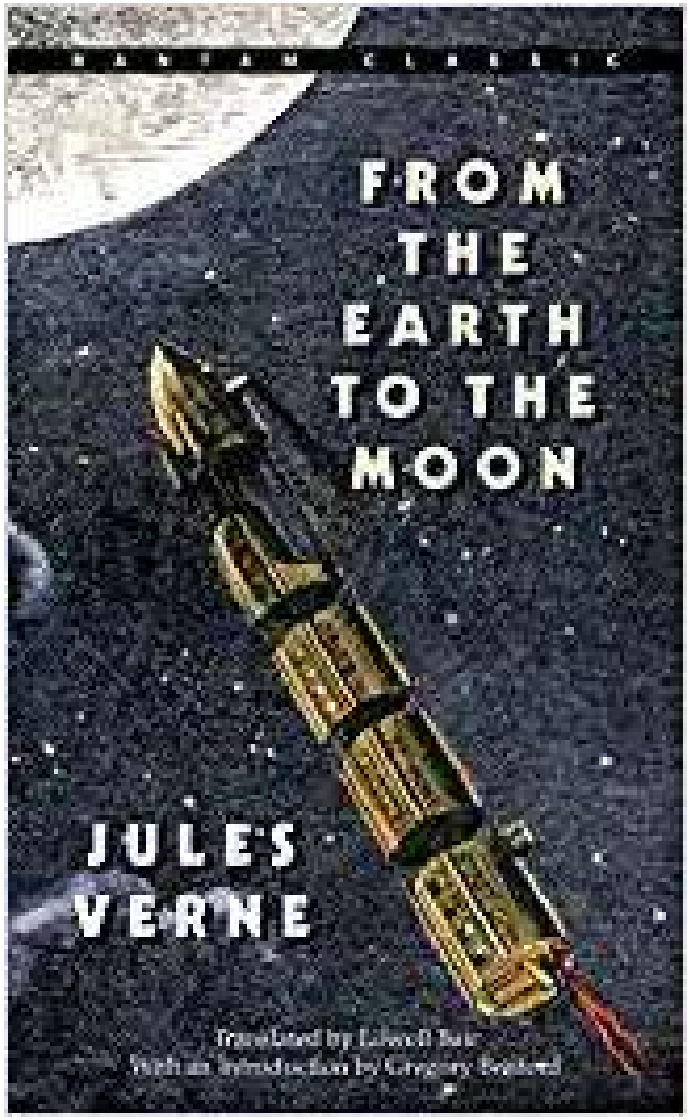
Traditional knowledge

https://www.unnatisilks.com/blog/naturally-colored-cottons-a-regain-in-popularity/


Policy

Our dreams become reality with materials





Affordable, inclusive, sustainable and contextual excellence

Some simple calculations

Hydrogen + Oxygen → Water + 286,000 joules of energy per mole

1 kg of solar hydrogen is now at Rs. XX and could be Rs. 150 soon.

It can make 143 million J of energy.

Desalination needs 2.4 kWh or 8.84 million joules for 1 CM of water.

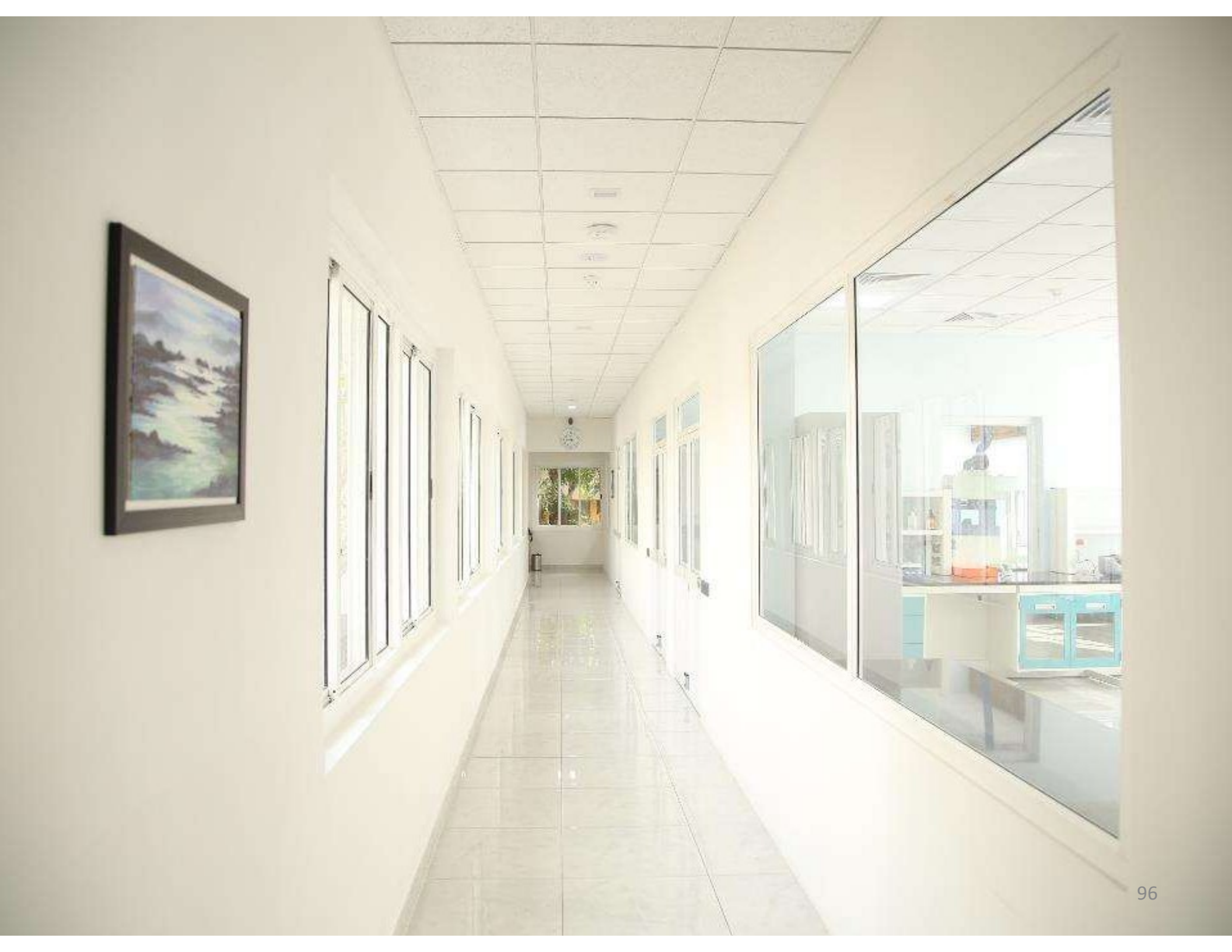
1 kg of hydrogen can therefore make 16.56 CM of water.

Or Rs. 9.06 per cubic meter, 0.9 paise per litre!

Well, add efficiency, other costs of plant, transportation, etc.

That world will need water literacy

January 2016




International Centre for Clean Water
April 2020


IIT Madras Research Park


INDIAN INSTITUTE OF TECHNOLOGY MADRAS

1995

The AMRIT Team, 2013

Group during 2018, along with Prof. Graham Cooks

People (clusters): E. S. Shibu, M. A. Habeeb Muhammed, T. Udaya Bhaskara Rao, Kamalesh Chaudhuri, Ammu Mathew, Ananya Baksi, K. R. Krishnadas, Atanu Ghosh, Sridevi Bhat, Papri Chakraborty, C. K. Manju, Abhijit Nag, Jyoti Sarita Mohanty, Debasmita Ghosh, Md. Bodiuzzaman, Esma Khatun, K. S. Sugi, Amrita Chakraborty, Madhuri Jash, Ganapati Natarajan, …

People (Water): A. Sreekumaran Nair, Anshup, M. Udhaya Sankar, Amrita Chaudhary, Renjis T. Tom, T. S. Sreeprasad, M. S. Bootharaju, Soujit Sengupta, Depanjan Sarkar, Avijit Baidya, Swathy Jakka Ravindran, 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, Shihabudheen M. Maliyekkal, G. Velmurugan, Wakeel Ahmed Dar, N. Pugazhenthiran, A. Leelavathi, Sahaja Aigal, S.Gayathri, Bibhuti Bhusan Rath, Ananthu Mahendranath, Harsh Dave, Erik Mobegi, Egor Moses, Hemanta R. Naik, Tanmayaa Naik, Sonali Seth,….

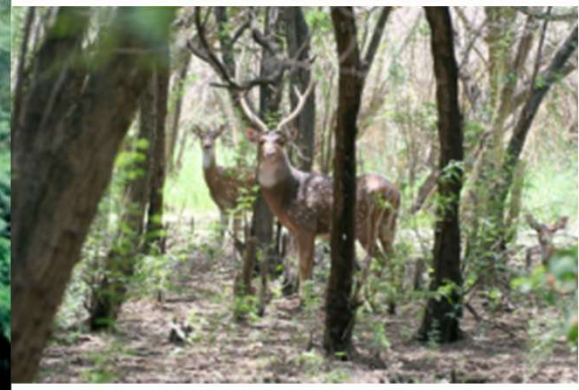
Funding: Department of Science and Technology, Government of India

Start-ups and partners:

सत्यमेव जयते

Partnerships

Indian Institute of Technology Madras



Associate Editor

ACS Sustainable Chemistry & Engineering

Directors - past and present

Thank you all

Pradeep Research Group

Thematic Unit of Excellence