



Since 1959

# Can Water Microdroplets Make Soil?

A path to sustainable nanotechnology



Matter in confinement for sustainability

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Deepspectrum Analytics Pvt. Ltd.

**Thalappil Pradeep**

Institute Professor, IIT Madras

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Professor-in-charge



International Centre for Clean Water



## REMARKS

Spontaneous weathering of natural minerals in charged water microdroplets forms nanomaterials

In this work, we show that particles of comonomers break down spontaneously to different ring sizes and undergo various intramolecular rearrangements. We observed several kinds of chain branching and cyclization, 1,5- to 1,6-monomer-polymer shifts, ring opening to acyclic monomers, generated by electrophilic attack. We observed the cleavage of a cross-subunit, which led to linear polymer chains. We observed the formation of structures that appear to undergo post-polymerization, especially when subjected to heat and exposed to an oxidative field. This leads to further subunit and the formation of additional segments, which is not confirmed with mass spectrometry. This rapid work hypothesis may be interpreted for all polymers, also the monomers of chlorinated polymer as the monomers.

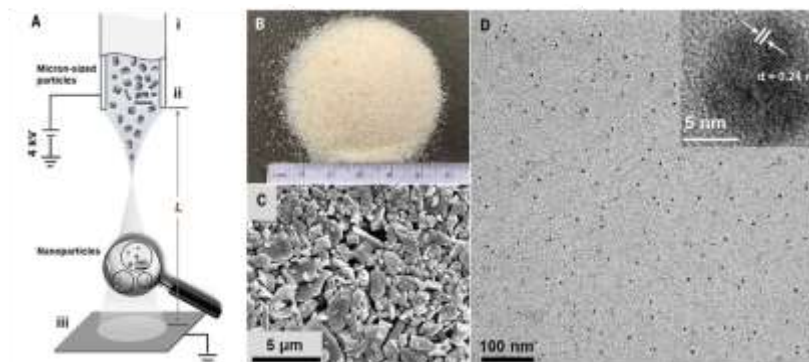
For our experiments, we prepared  $\text{SiO}_2\text{-Si}_3\text{N}_4$  thin films of various compositions ( $\text{SiO}_2$  molar ratio 0.5–1.0) by the sol-gel method [10]. The  $\text{SiO}_2$  and  $\text{Si}_3\text{N}_4$  thin films were prepared by the sol-gel method [10]. The  $\text{SiO}_2$  and  $\text{Si}_3\text{N}_4$  thin films were prepared by the sol-gel method [10].

Microtubule profiles and cross-sections (Fig. 2) demonstrate that the microtubule wall possesses both helical and paracrystalline lattice features. Interestingly, the helical pitch of the lattice varies with the diameter of the microtubule. The helical pitch of the lattice of a 5.0- $\mu$ m diameter microtubule is approximately 1.5  $\mu$ m (Fig. 2), while that of microtubules of the Kankakee and Kankakee-adjacent populations was found to be smaller: pitch values attributed to a 4.5- $\mu$ m diameter microtubule are 1.0  $\mu$ m (Fig. 2). These helical pitch values are also consistent with the paracrystalline lattice of microtubules of the Kankakee-adjacent population (Fig. 2). The helical pitch values of the Kankakee-adjacent population are also consistent with the helical pitch values of the Kankakee-adjacent population (Fig. 2). The helical pitch values of the Kankakee-adjacent population are also consistent with the helical pitch values of the Kankakee-adjacent population (Fig. 2).

[illegible]

To discuss this case before the Commission is to deny the very significant effects of this practice, we have learned in the course of this longer examination of the case. We must also acknowledge that the very small number of the cases is not a sufficient basis for the Commission to make any of the conclusions that it has reached. We must also acknowledge that the Commission is not in a position to make any of the conclusions that it has reached.

\*Department of Chemistry, Indian Institute of Technology Madras, Chennai 600 036, India; †Chemical Sciences Unit, Jawahar Institute of Physics for Advanced Scientific Research, Bangalore 560 025, India; ‡International Centre for Clean Water, IT Madras Research Park, Chennai 600 13, India



Downloaded from <http://ajph.org/> on June 11, 2015

**A scale of 1000**

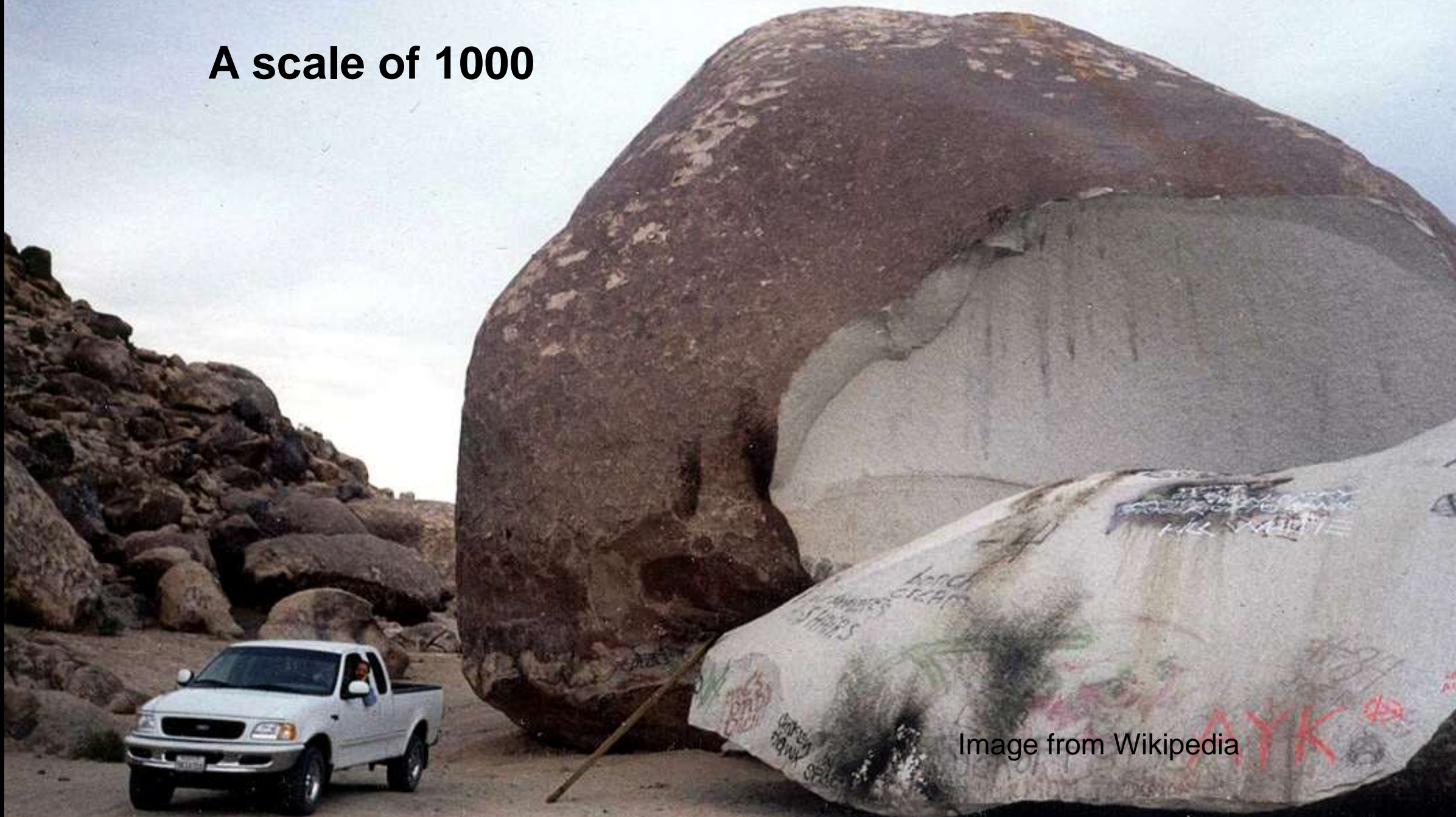
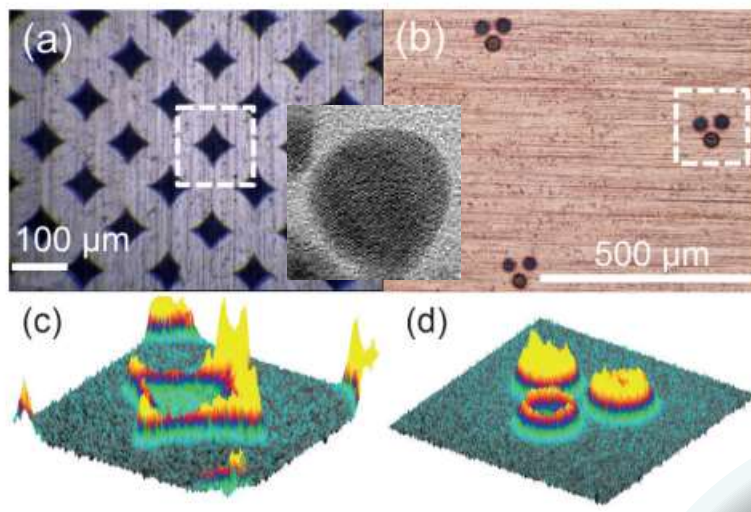
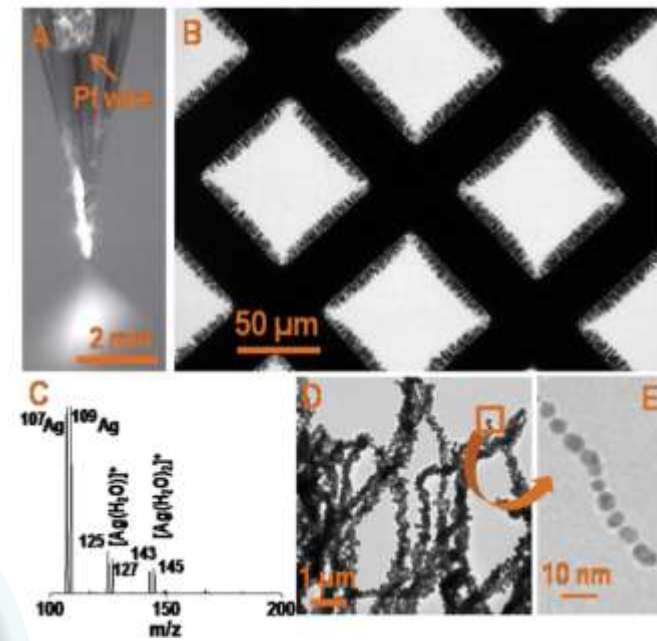


Image from Wikipedia

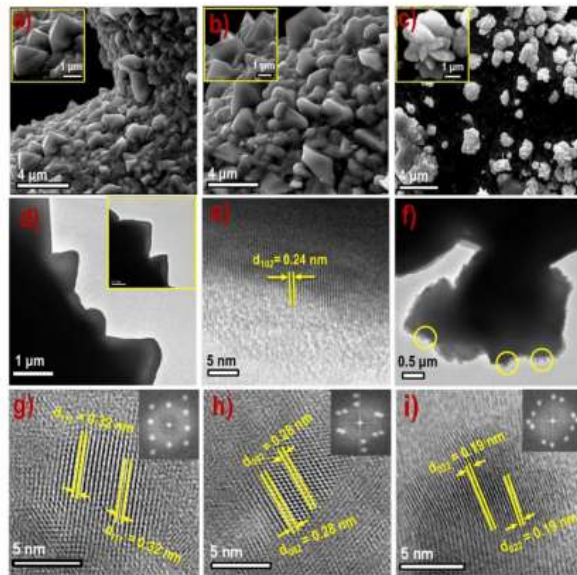
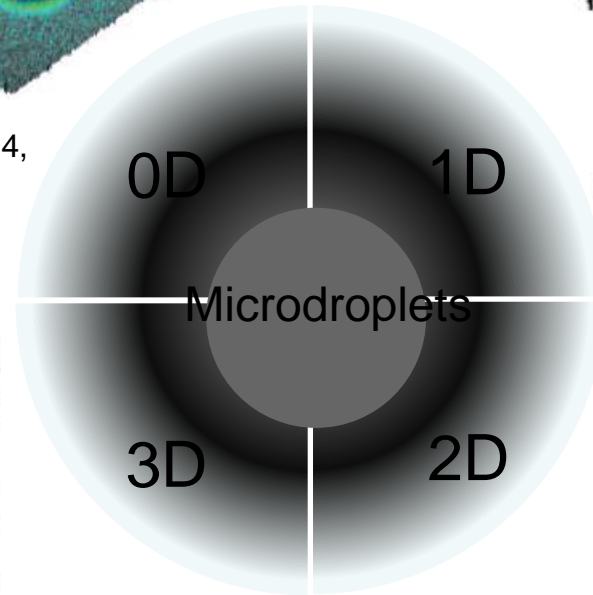
# **Functional Nanomaterials**



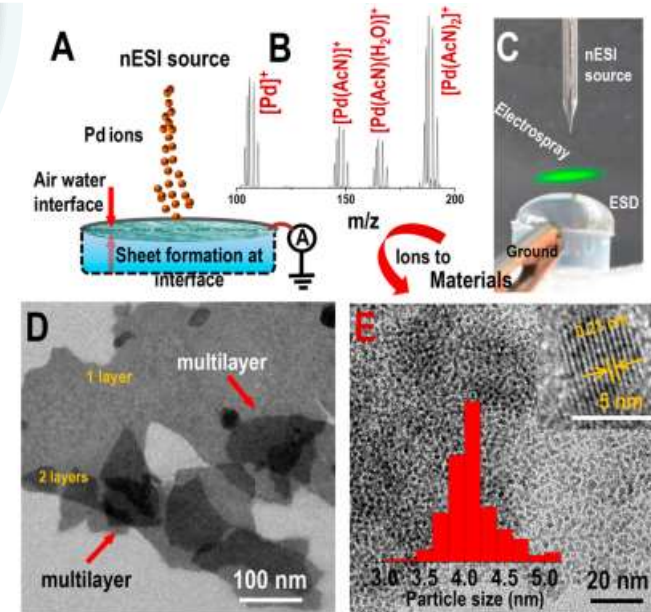
Anyin Li, et. al., *Angew. Chem. Int. Ed.* 2014, 53, 12528–12531.



Depanjan Sarkar et. al., *Adv. Mater.* 2016, 28, 2223–2228.



Arijit Jana et. al., *J. Mater. Chem. A*, 2019, 7, 6387–6394.



Depanjan Sarkar, et. al., *J. Phys. Chem. C* 2018, 122, 17777–17783.

# Chemical Science

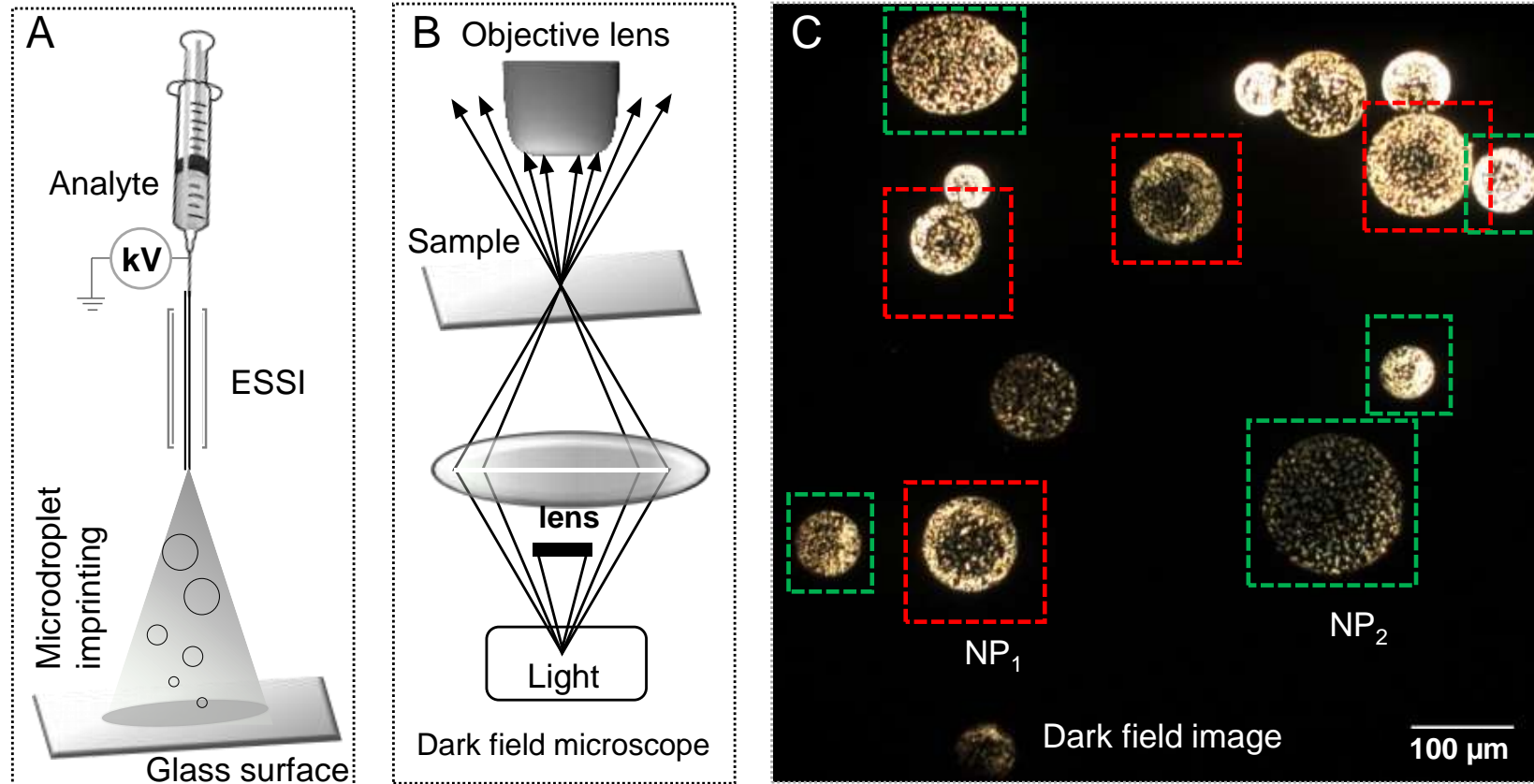
Volume 13  
Number 45  
7 December 2022  
Pages 13251–13634

[rsc.li/chemical-science](https://rsc.li/chemical-science)



ISSN 2041-6539

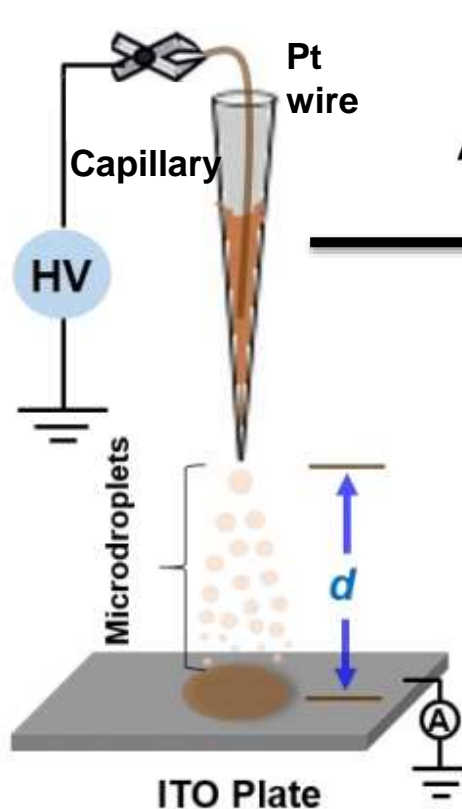
# Understanding Microdroplets



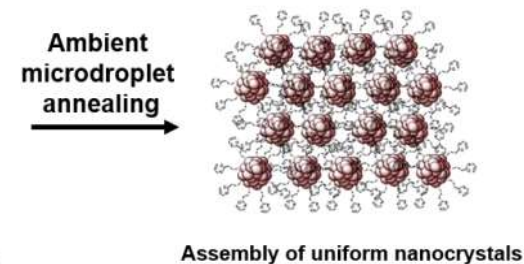
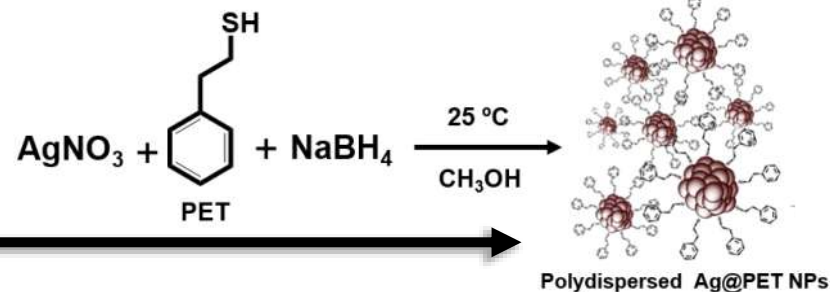
# **Transformation of Materials in Microdroplets**

# Ambient Microdroplet Annealing of Nanoparticles

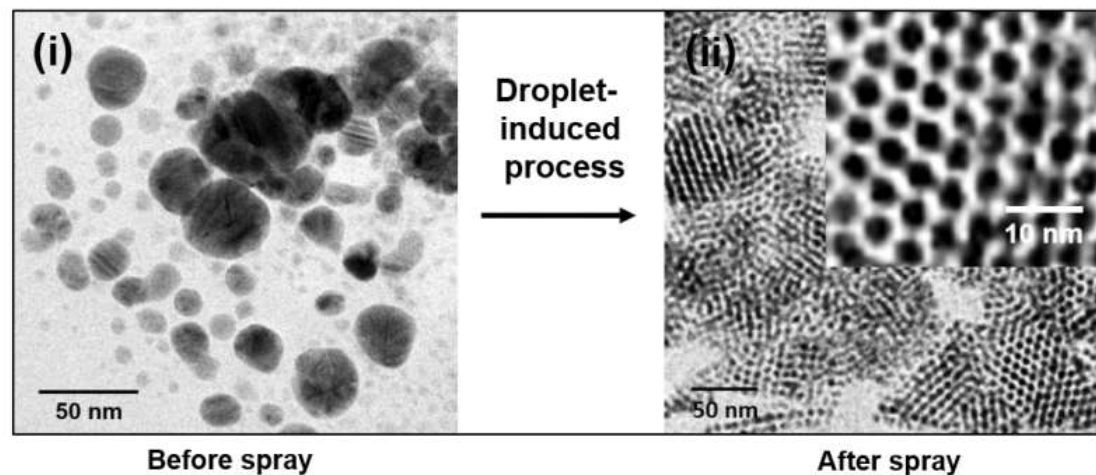
## Experimental set-up



## Synthesis of polydisperse NPs



## Transformation process





Thanks to ChatGPT

## Weathering in Nature

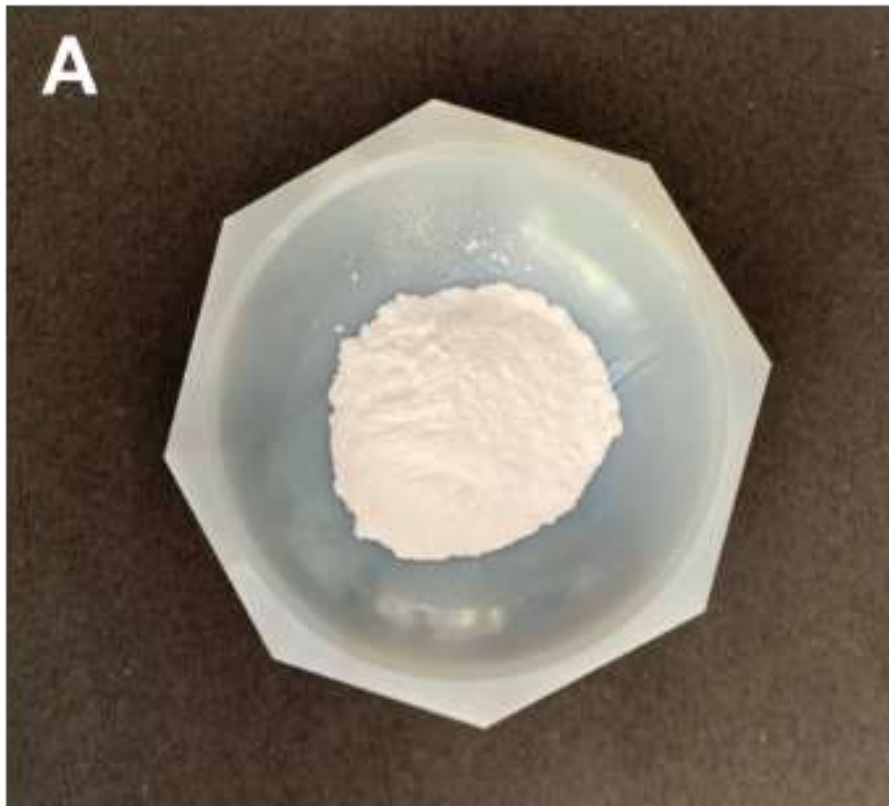


# Sand, the Ubiquitous Material

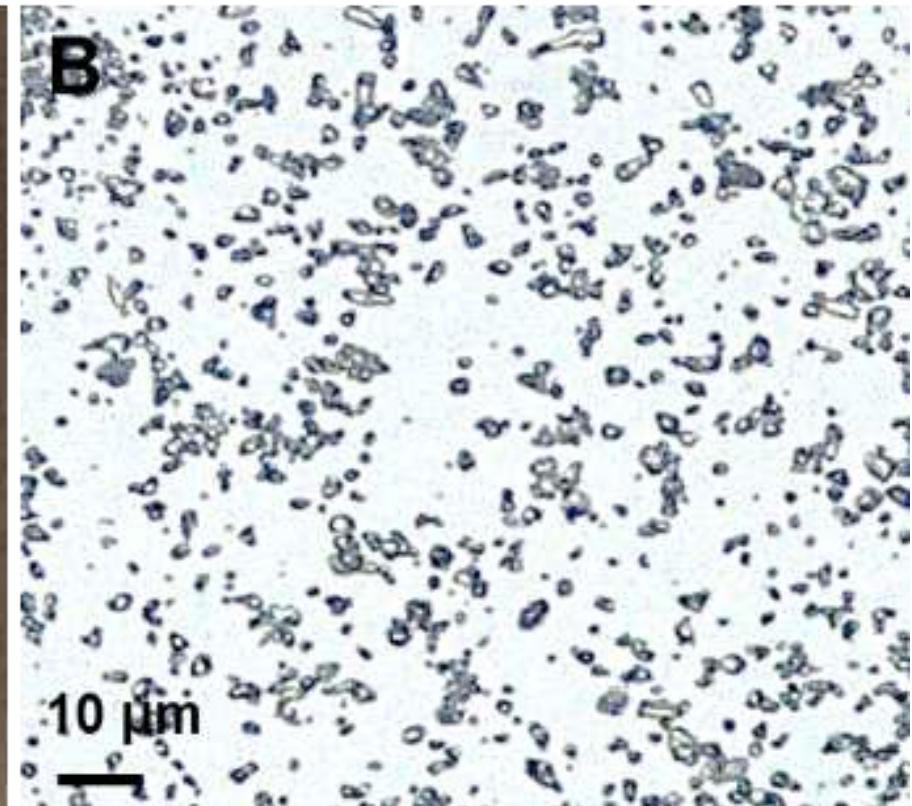


Images from Wikipedia



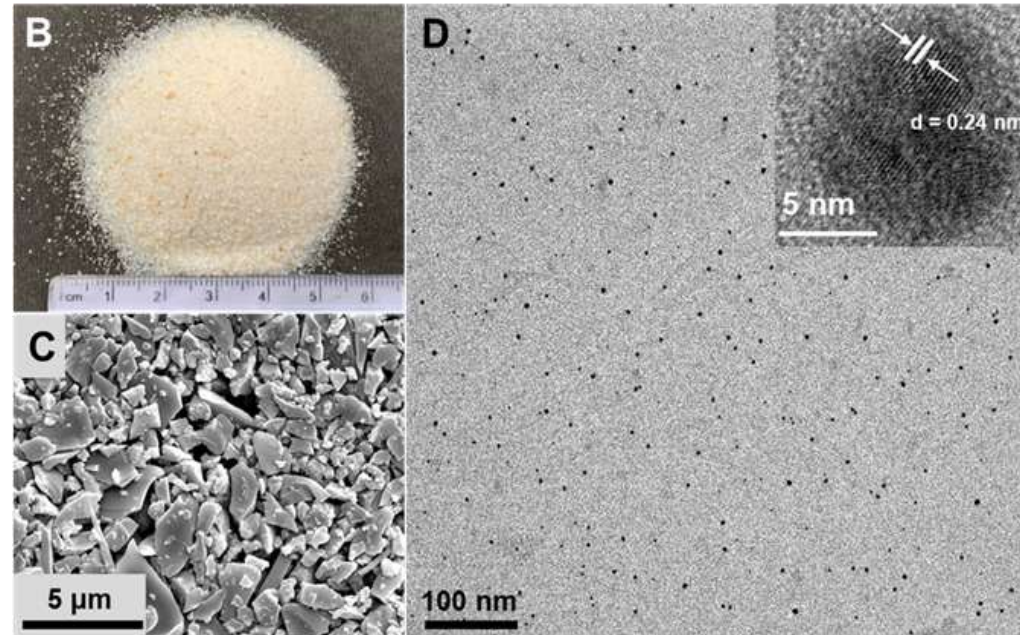
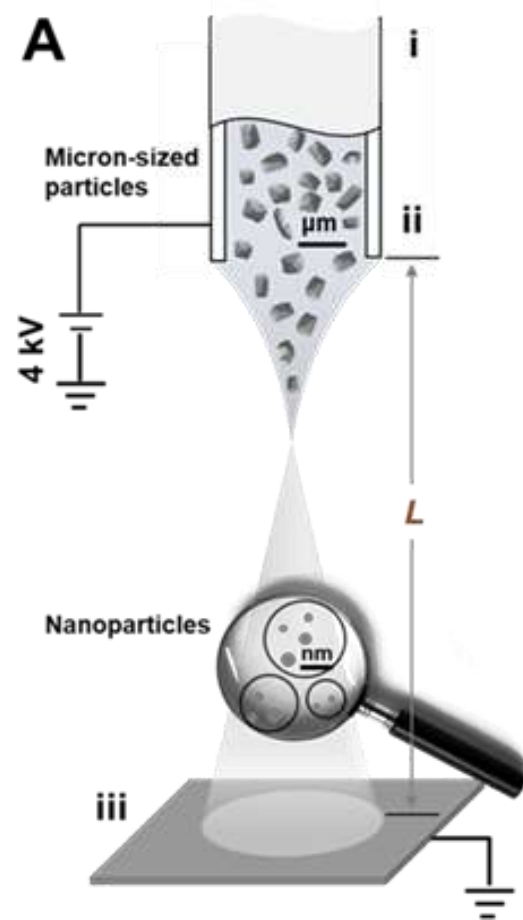


Ground silica

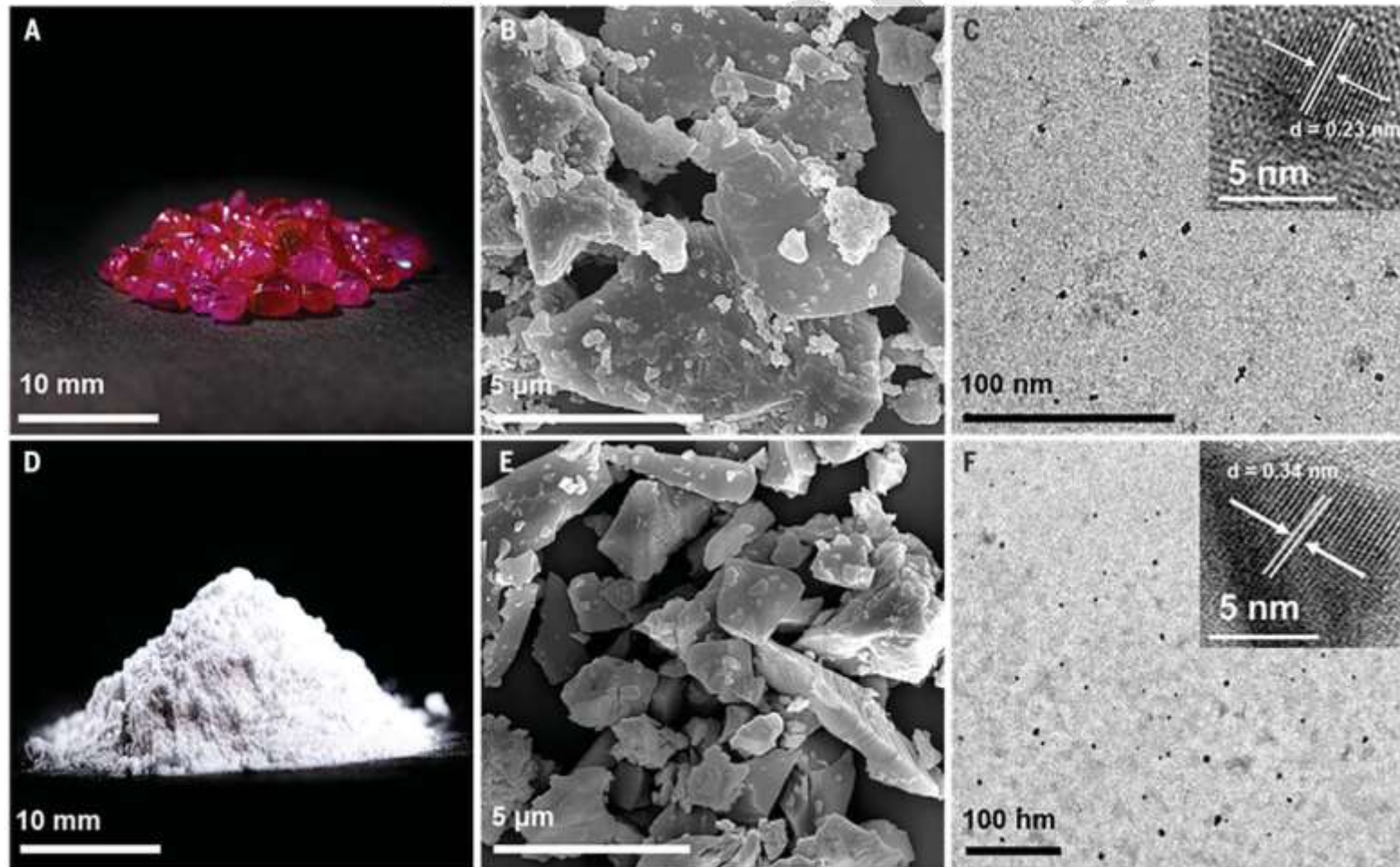


Optical image of silica

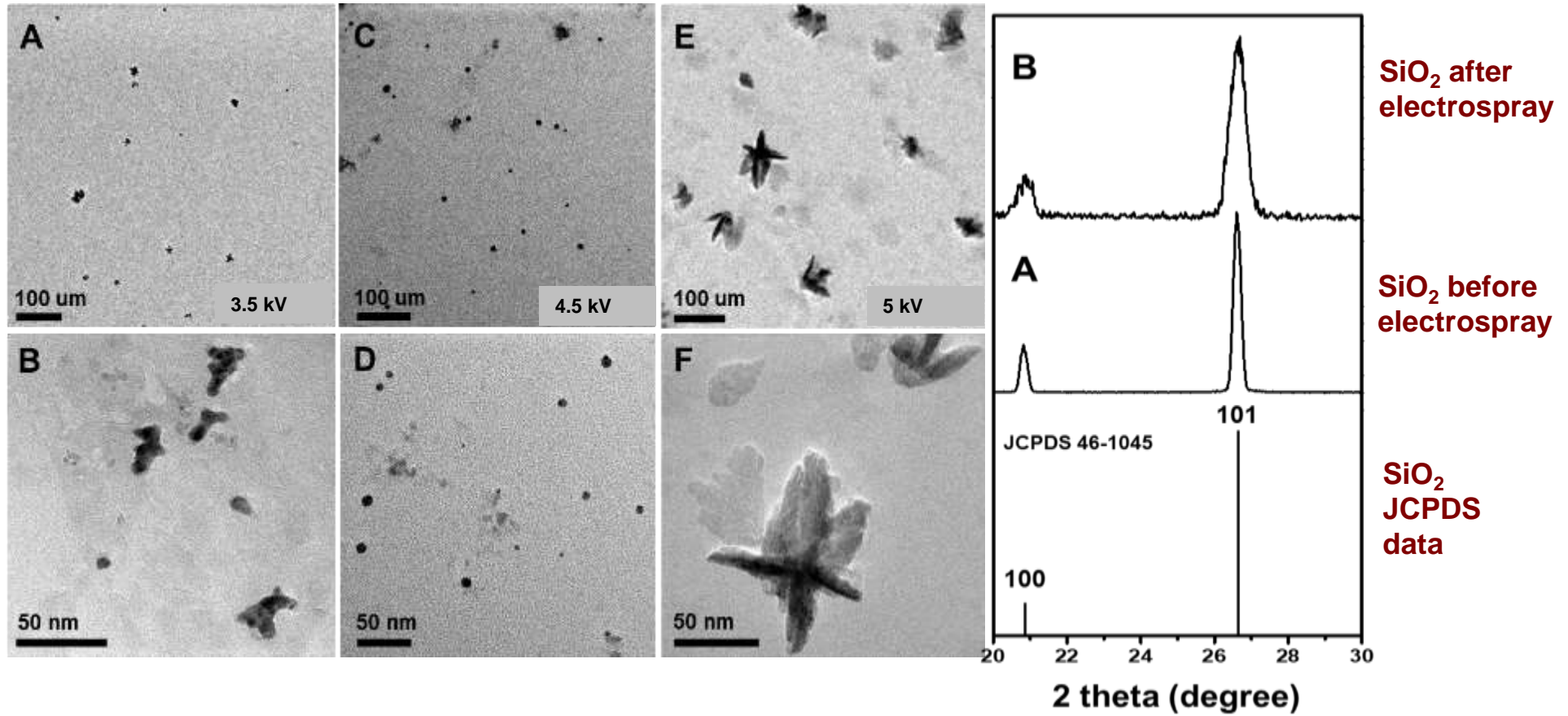
# Weathering of Minerals in Microdroplets



# Ruby, Fused Alumina

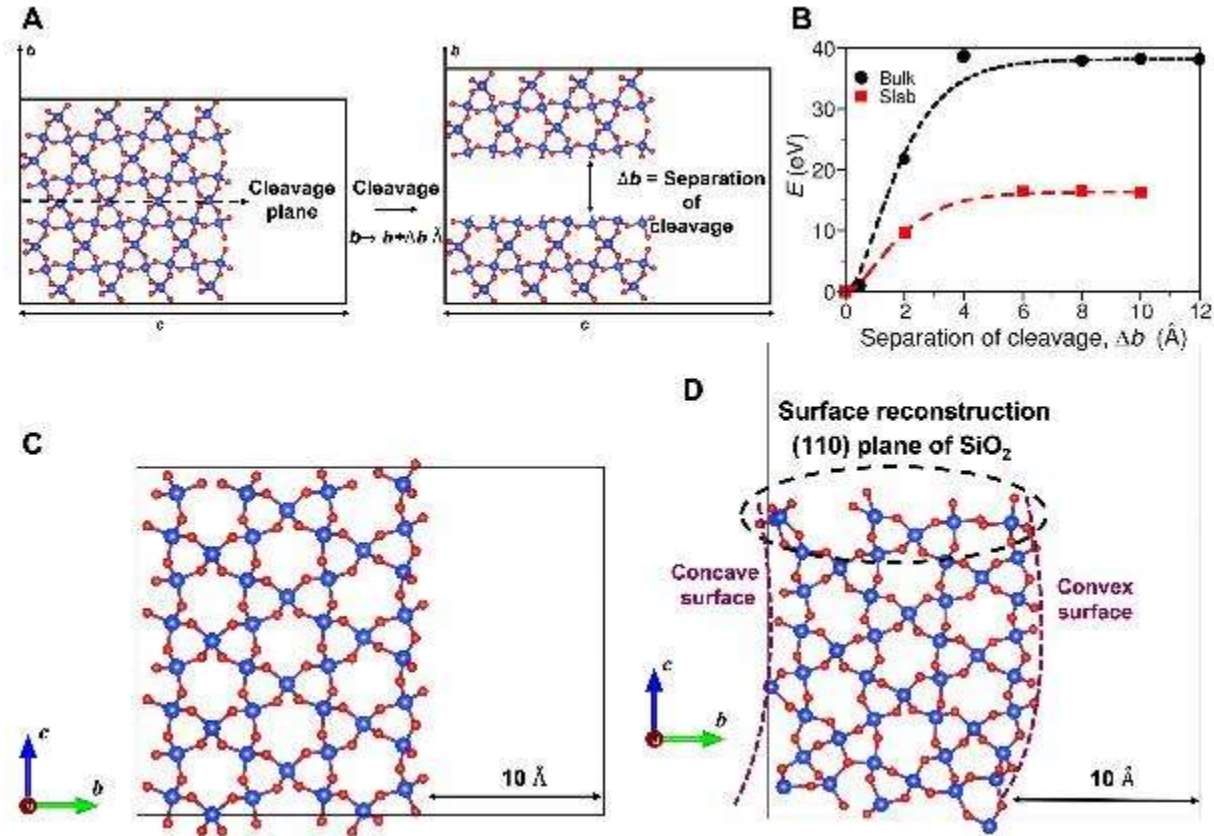
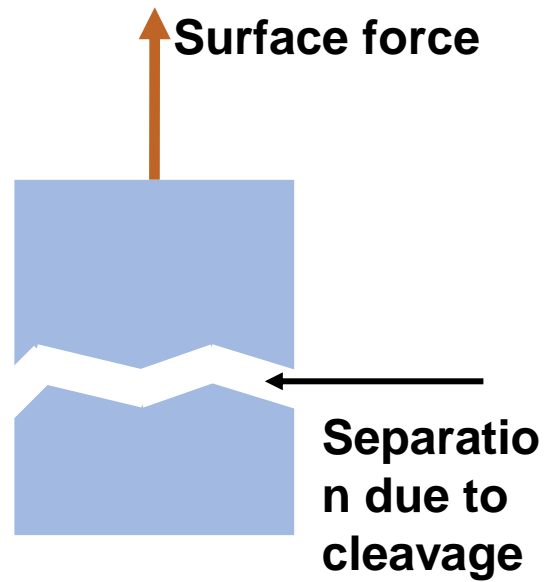


# Fragmentation of Silica – Varying Conditions

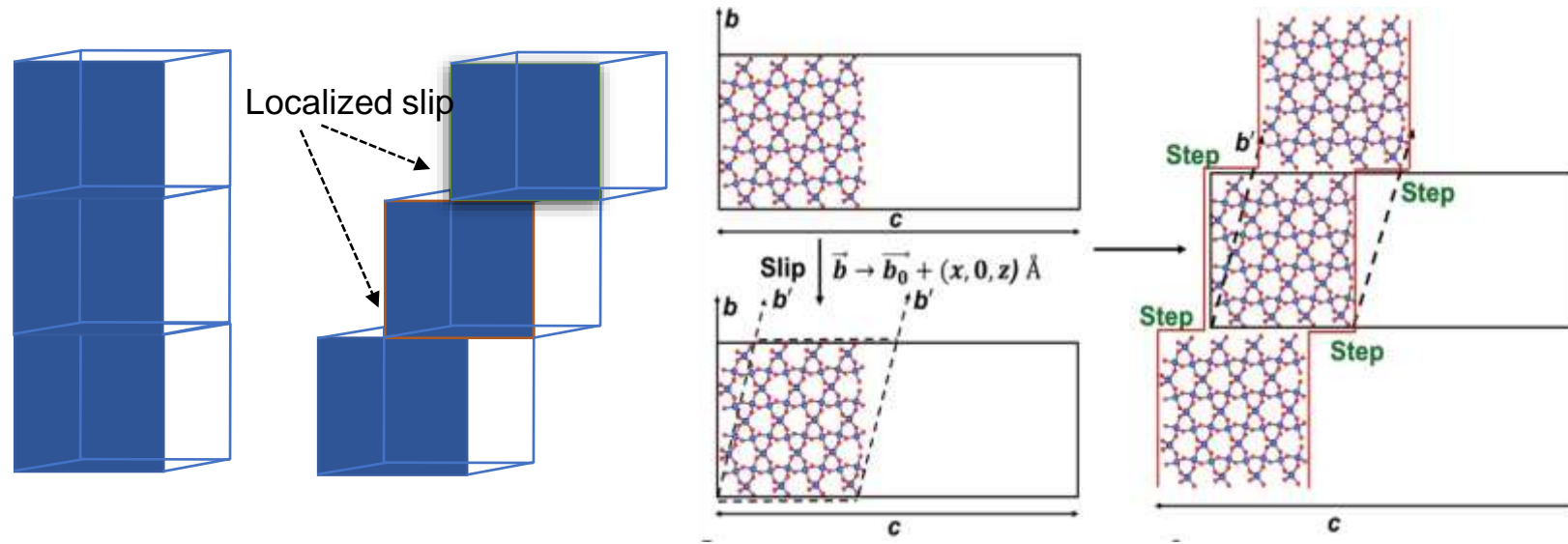


# Mechanism: Cleavage

The process of cleavage and surface reconstruction visualized with first-principles simulations



# Mechanism: Slip



This instability leads to the formation of a stacking fault on the (010) plane, achieved with slip localized at (010) plane

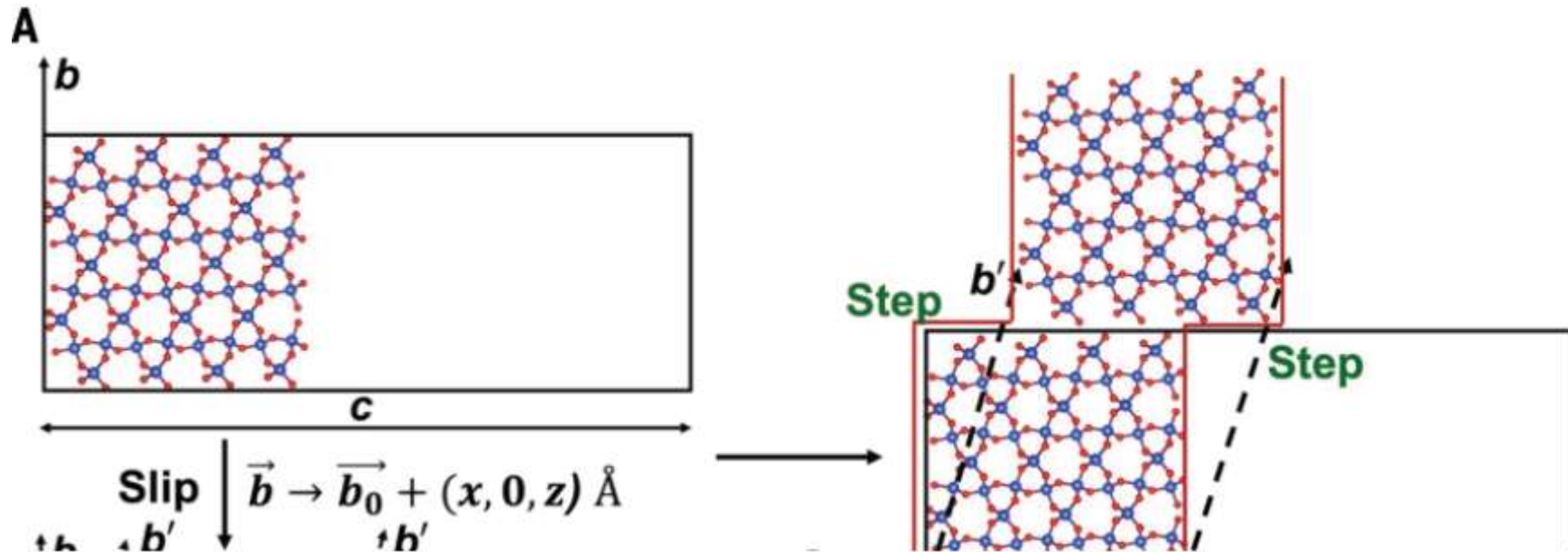
Stacking fault

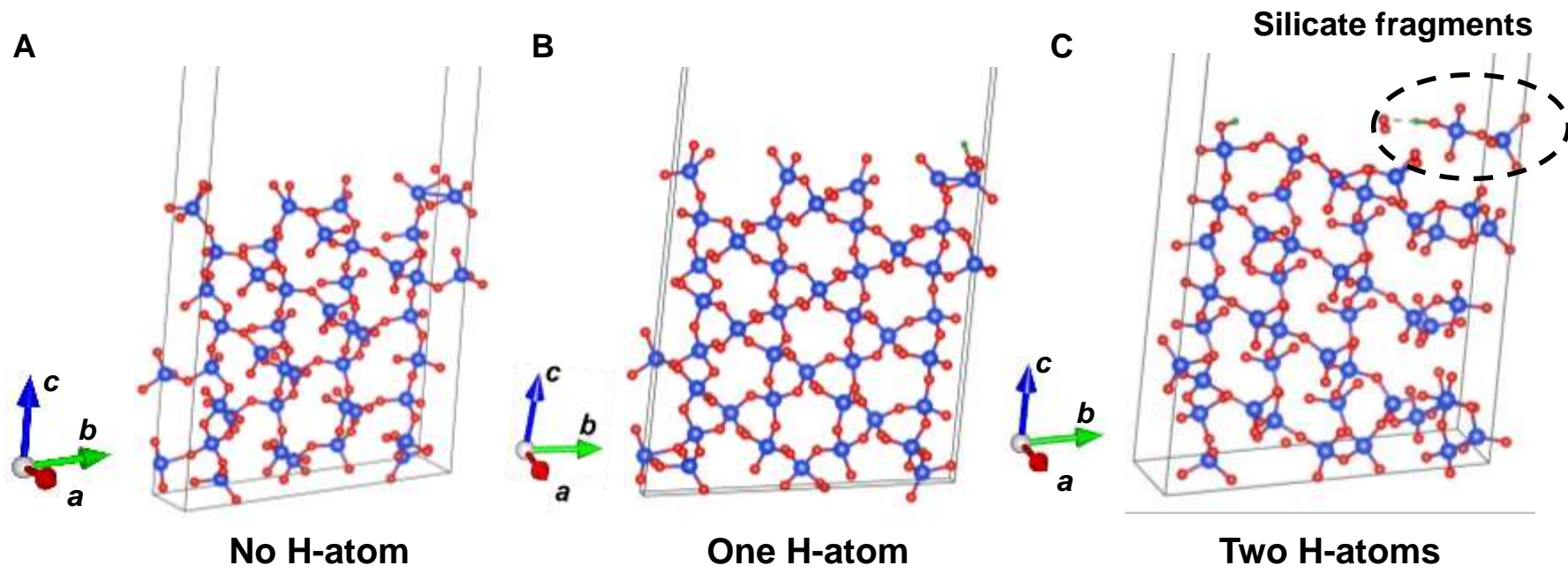
$$\vec{b} \rightarrow \vec{b}_0 + (x, 0, z),$$

$(x, z \in [0, 1])$  - fractional coordinates

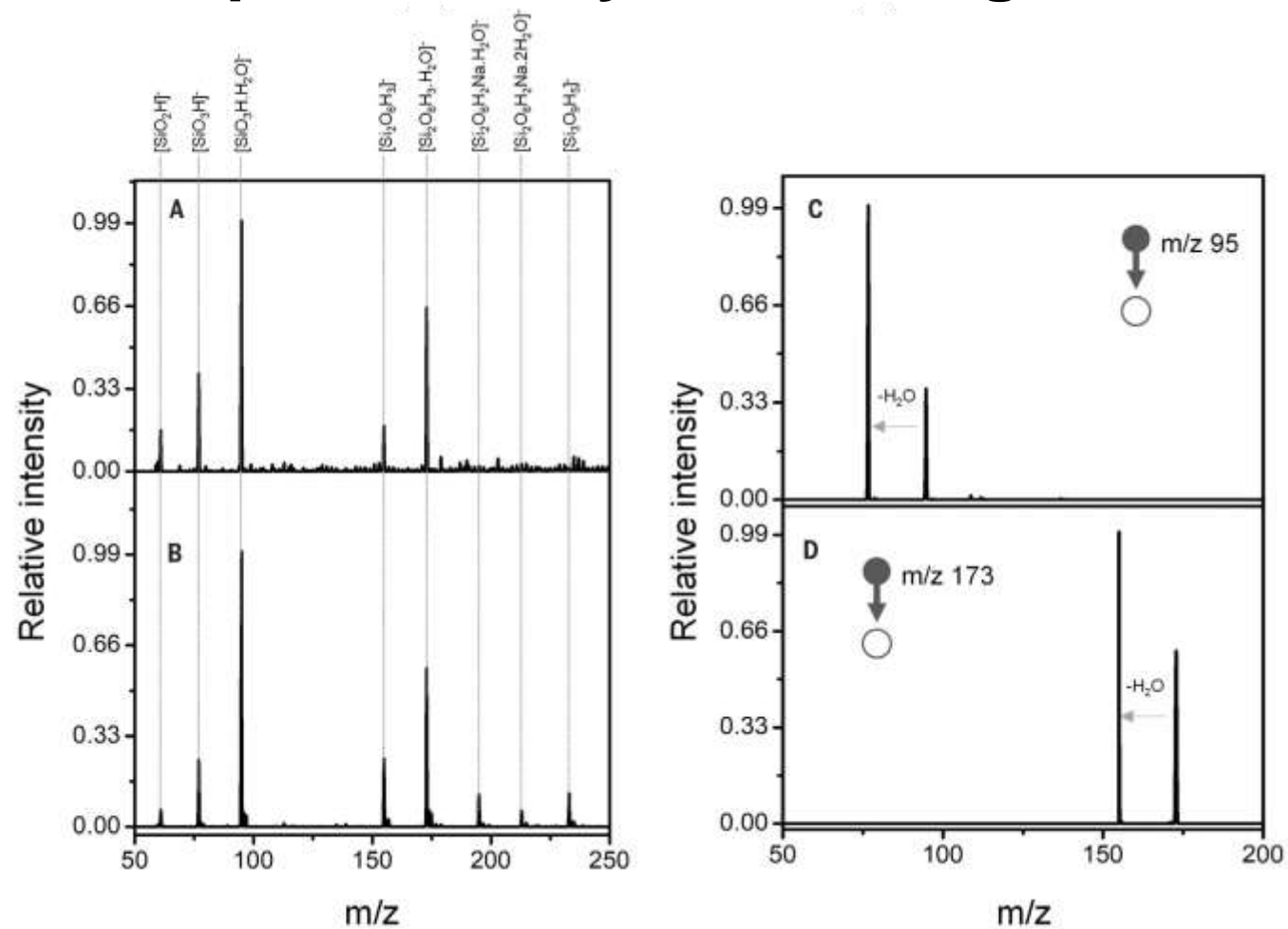
SFEs of (010) direction with (0, 0), (0, 0.5), (0.5, 0) and (0.5, 0.5) slip configurations on the (110) plane of  $\text{SiO}_2$

SFE ( $J/m^2$ )	Slab					
	$x$	$z$	w/o H-atom	1 H-atom	2 H-atoms	$E$
	0.0	0.0	0	0	0	0
	<b>0.5</b>	<b>0.5</b>	<b>-1.21</b>	<b>-0.93</b>	<b>-0.88</b>	<b>-1.20</b>
	0.5	0.0	1.20	1.18	0.90	1.12
	<b>0.0</b>	<b>0.5</b>	<b>-0.07</b>	<b>0.89</b>	<b>-0.83</b>	<b>-0.09</b>

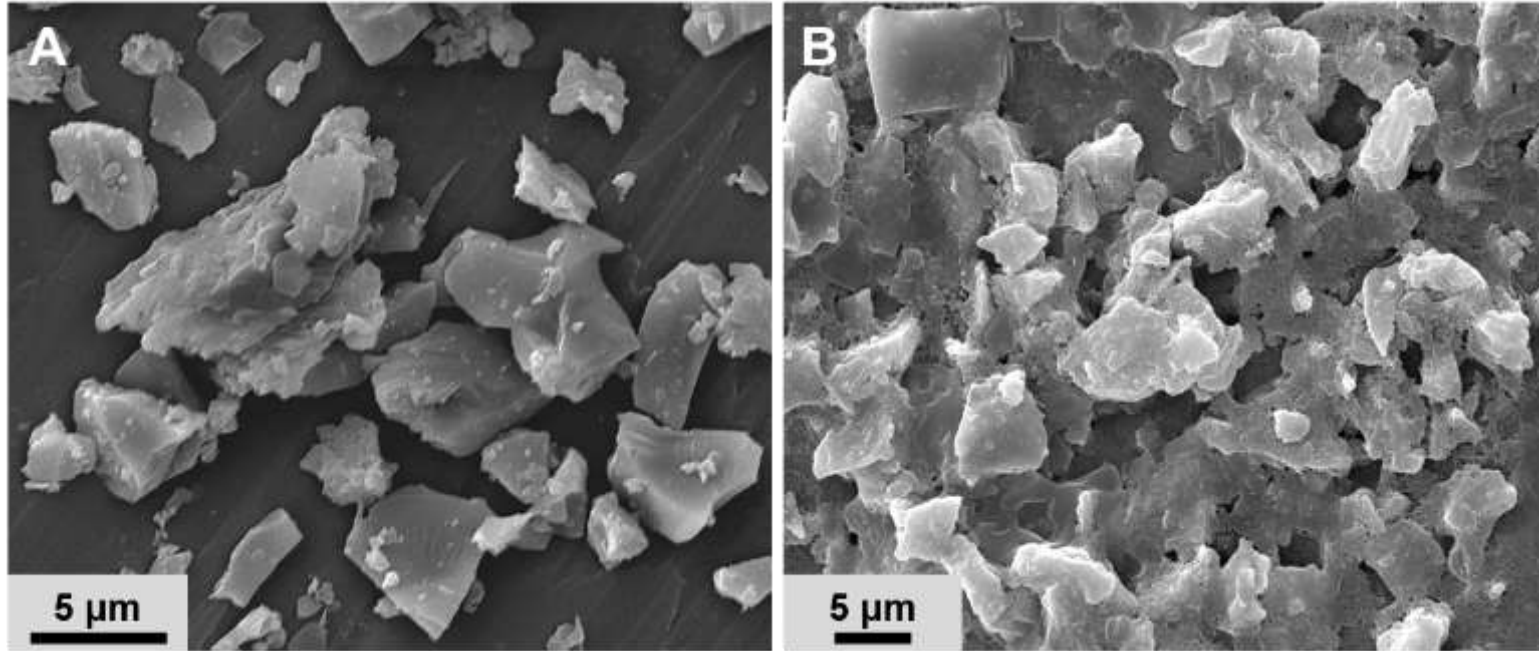




# Mass Spectrometry of the Fragments

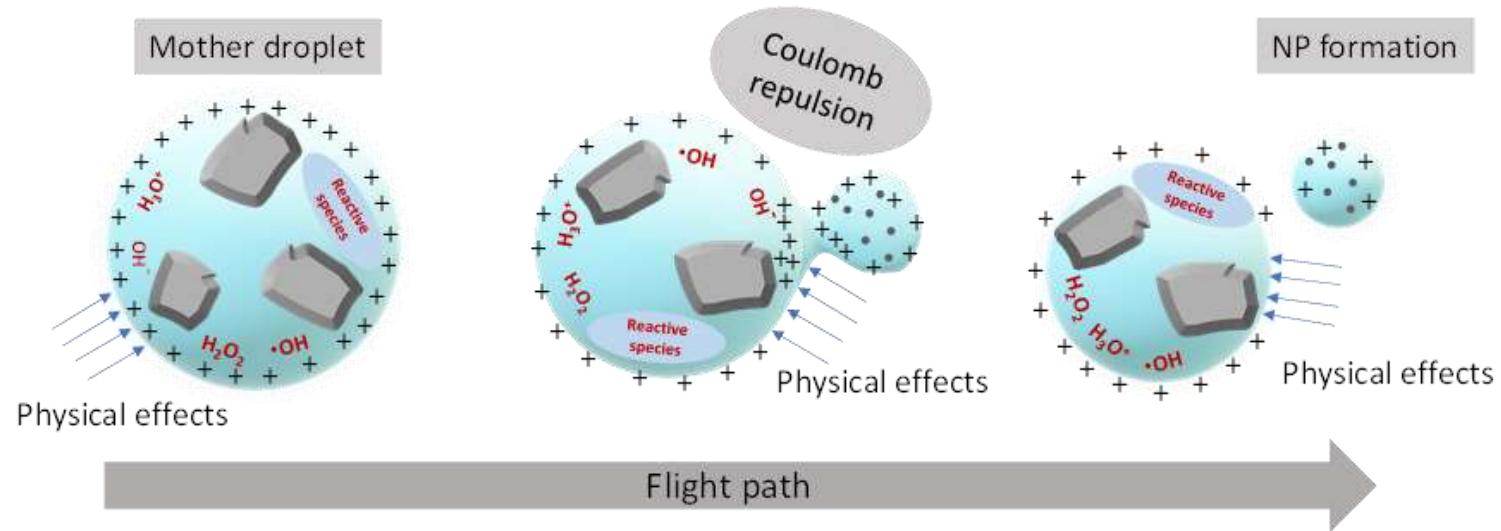


# Effect of charged microdroplets on quartz



Increased surface roughness after the spray

# Mechanism of nanoparticle formation



**Rayleigh**, On the  
equilibrium of liquid  
conducting masses  
charged with electricity,  
Philosophical Magazine,  
1882

$$Q = 8\pi (\epsilon_0 \gamma R^3)^{1/2}$$

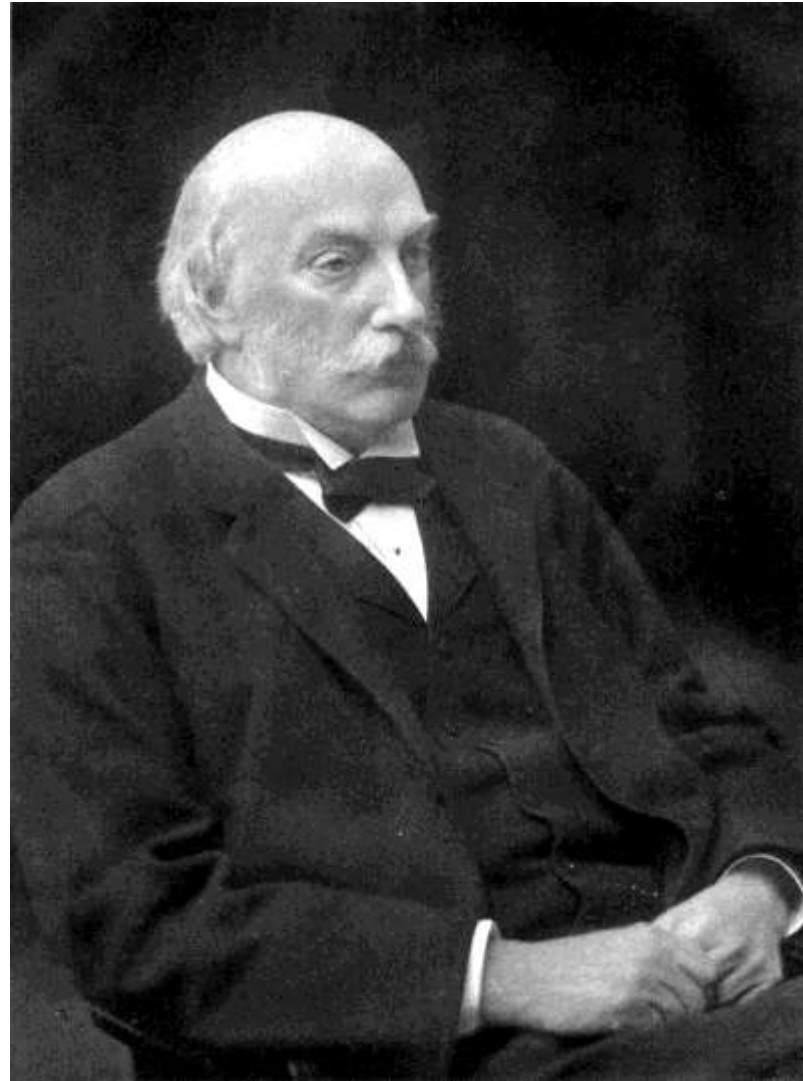
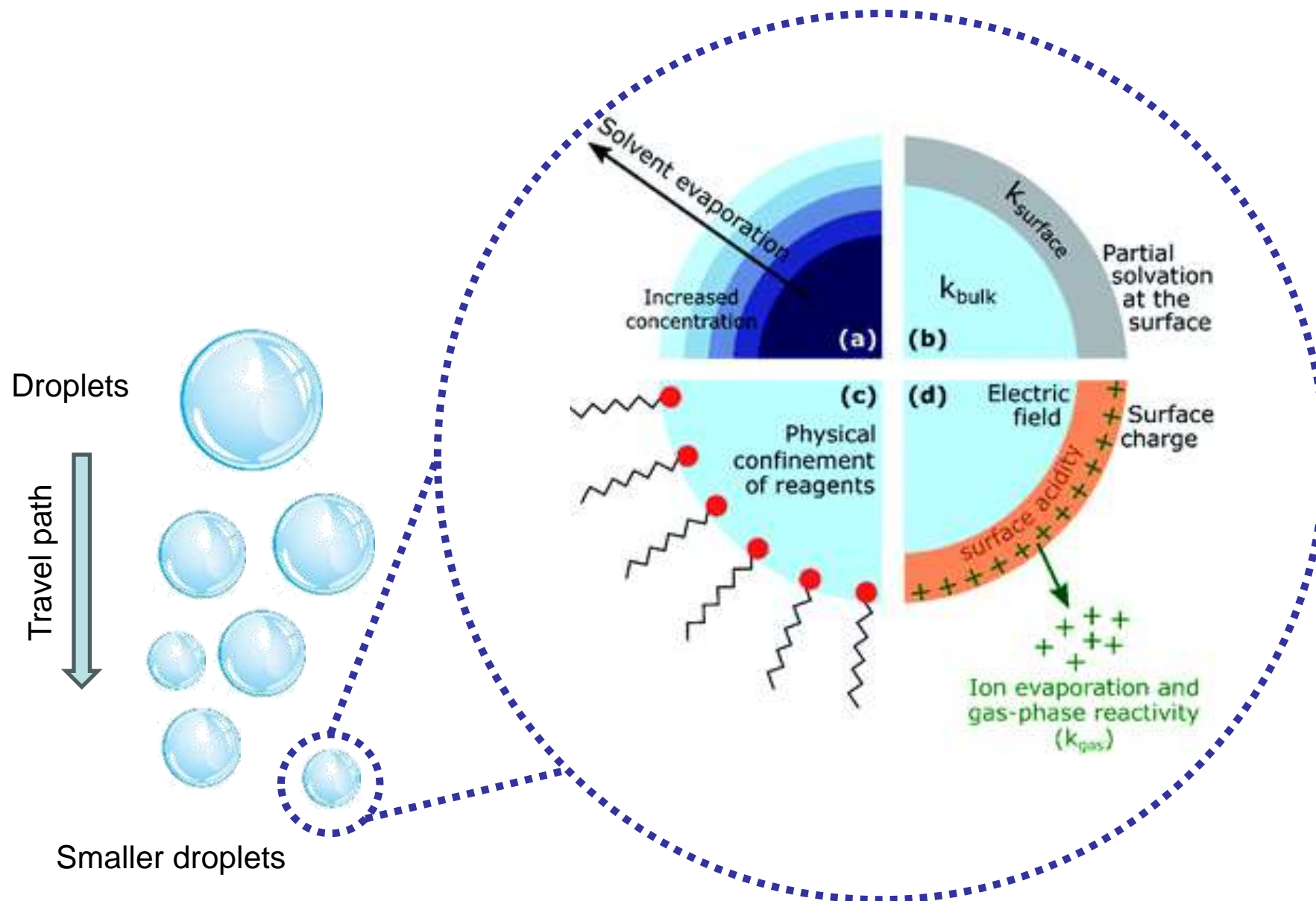


Image from Wikipedia

# Understanding Microdroplets



## PERSPECTIVES

## CHEMISTRY

# Breaking down microdroplet chemistry

Charged microdroplets accelerate mineral disintegration

By R. Graham Cooks and Dylan T. Holden

Charged microdroplets are commonly observed in clouds, sea spray, and other natural aerosols. The chemistry that occurs at the air-water interface of these droplets is often distinct from what is observed in bulk solution, which is of considerable interest because chemical reactions can be accelerated at this boundary (1, 2). This may have implications for environmental processes such as the weathering of rocks, which contributes to soil formation. On page 1012 of this issue, Spoorthi *et al.* (3) report that micrometer-scale mineral particles can rapidly break down into nanoparticles when in charged aqueous microdroplets (see the figure). This points to a potential role for atmospheric water droplets in the natural disintegration of minerals.

To examine material degradation, Spoorthi *et al.* borrowed methodology used to accelerate bond-forming chemical reactions. By spraying an aqueous suspension of microparticles of natural minerals, the authors produced nanoparticles of minerals in high yield. Specifically, Spoorthi *et al.* used an electrospray device to emit a jet of liquid droplets (by applying high voltage) containing mineral particles of natural quartz, ruby, or synthetic alumina that ranged in size from 1 to 5  $\mu\text{m}$  in diameter. The authors observed the production of nanoparticles that were 5 to 10 nm in diameter. Moreover, the fragmentation occurred in approximately 10 ms.

Such material degradation and chemical synthesis experiments are united by the extremes of chemical reactivity that occur at the air-water interface, where reagents are partially solvated (4). Whether formed through nebulization, splashing from a surface, or other means, microdroplet populations will include droplets with nonzero net charges. The small radius of curvature in a microdroplet produces a very strong electric field (5) that can support a double layer of electric charge at the air-water interface. The change in geometry (radius of curvature)

converts a two-dimensional air-water interface with limited electric field into a sphere with an electric field of a strength approaching the order of chemical bond energies (3 to 4.5 eV/Å). Coulombic fission (the splitting of charged microdroplets due to excess charge overcoming the surface tension) and evaporative processes further increase the surface area, reduce the radius of curvature, and augment the surface electric field of the droplet.

The unusual chemical nature of the air-water interface results in much remarkable chemistry. For example, amino acids in water undergo dehydration to form peptides in this environment (6), whereas bulk water simply solvates amino acids. The superacidic interface activates amino acids and removes water to yield peptides. In addition to such acid-base reactions, redox chemistry results from the formation of strong oxidants and reductants from water at the interface. For example, a high hydronium ion ( $\text{H}_3\text{O}^+$ ) concentration at the interface derived from fleetingly charged surface water molecules ( $\text{H}_2\text{O}^+/\text{H}_2\text{O}^-$ ) coexists with oxidative species such as hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) and  $\text{OH}^\bullet$ . These redox species enable a variety of spontaneous chemical trans-

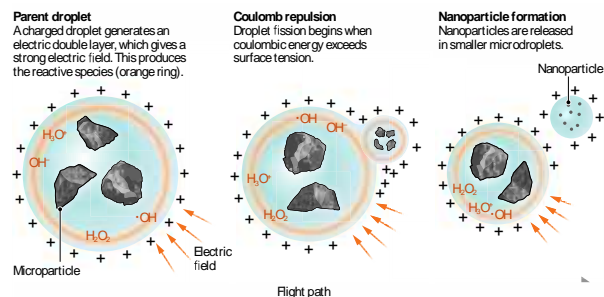
formations, including carbon-oxygen (C-O) bond cleavage in phosphonates, which yields the corresponding phosphonic acid (7), and in the Baeyer-Villiger oxidation of aryl ketones to give esters (8). These considerations thereby enable simultaneous acid-base and oxidation-reduction chemistry in a single population of droplets (7).

Through their study, Spoorthi *et al.* have added natural weathering to a list of processes in which accelerated interfacial microdroplet reactions play an important role. Other processes include those in the atmosphere, both natural and anthropogenic, the latter typified by pollution that involves nitrate photochemistry (9). A substantial number of accelerated catalyst-free microdroplet reactions form the basis for chemical syntheses that generate a variety of small molecules (10), including the facile and high-throughput functionalization of drugs. This latter approach can be scaled up so that microdroplet reactions produce substantial small-molecule products. Prebiotic chemistry, including peptide and nucleotide formation, is another process that is accelerated at the microdroplet air-water interface (11).

The millisecond timescale of quartz degradation reported by Spoorthi *et al.* matches the known microsecond-to-millisecond timescale for accelerated bond-formation and bond-cleavage chemical reactions in microdroplets (1). This reinforces the conclusion that the chemical basis for accelerated weathering lies in the powerful acidic and hydrolytic nature of the air-water interface. The authors further suggest a role for the superacid interface in inducing slippage at crystal plane boundaries in quartz and ruby fragmentation. Their simulations show that individual protons inserted into the slip configuration mineral

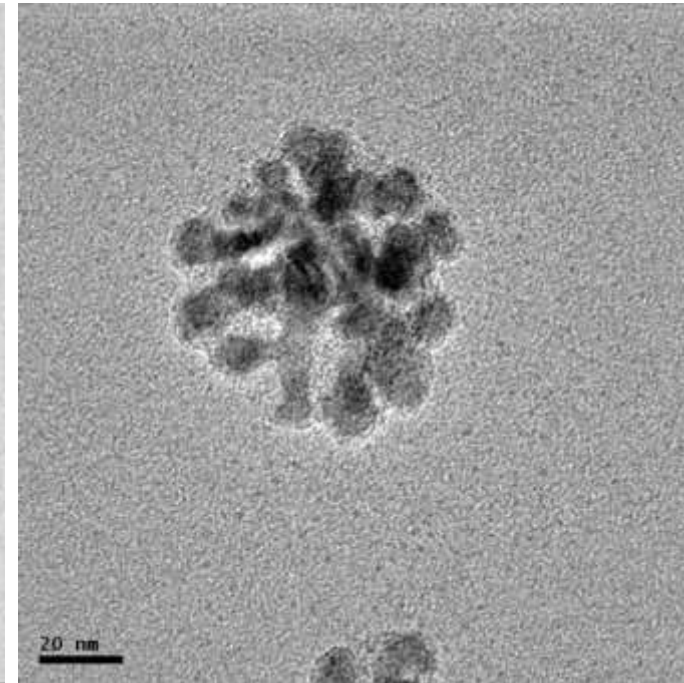
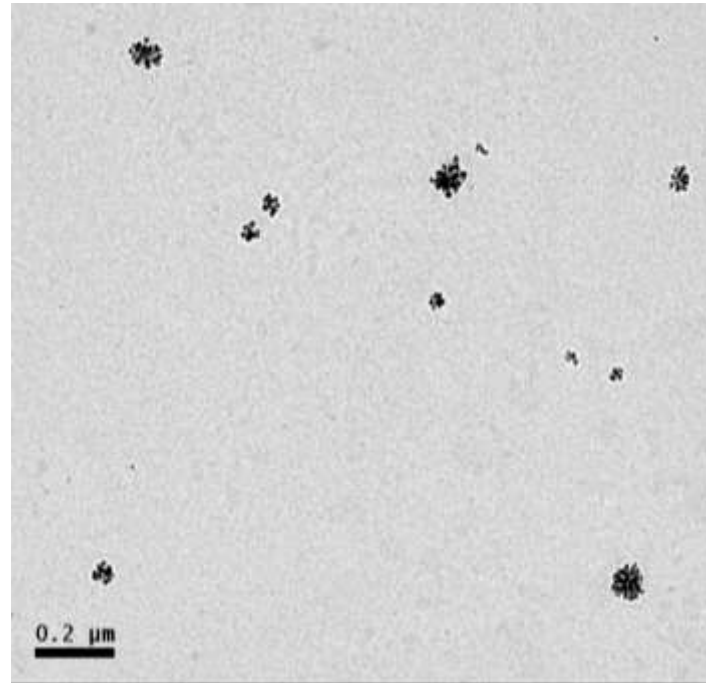
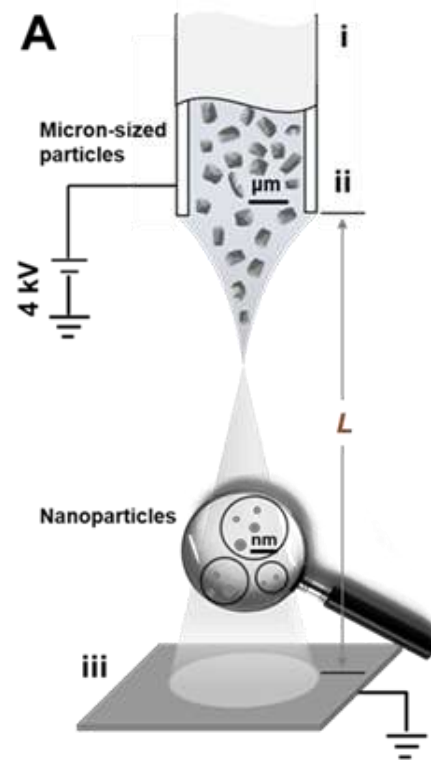
## Micro-to-nano transitions in minerals at the air-water interface

Reactions that promote mineral disintegration are accelerated at the air-water interface of microdroplets. Key reactive species are the result of the effects of a high electric field at the surface of the water droplets.



Department of Chemistry, Purdue University, West Lafayette, IN, USA. Email: cooks@purdue.edu

# How do they form?

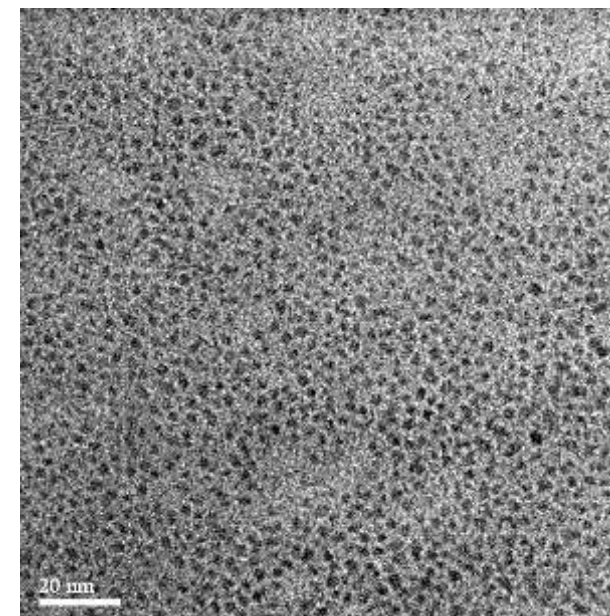
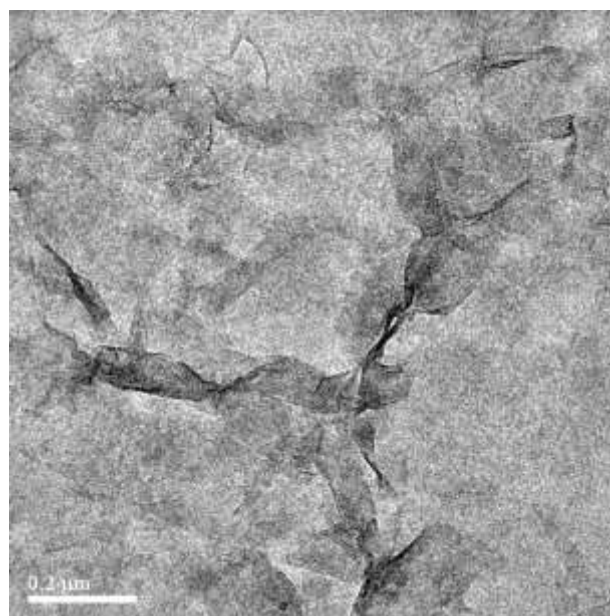
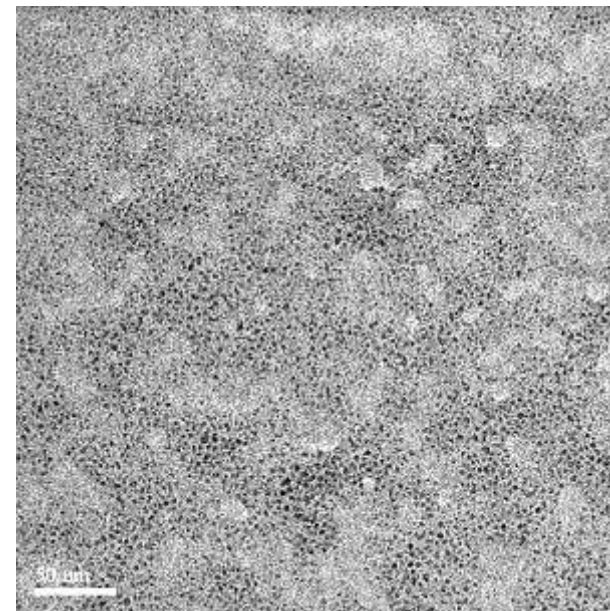
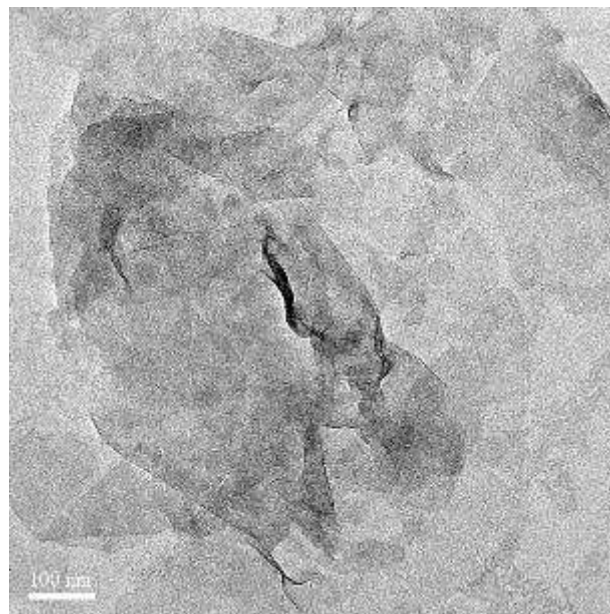
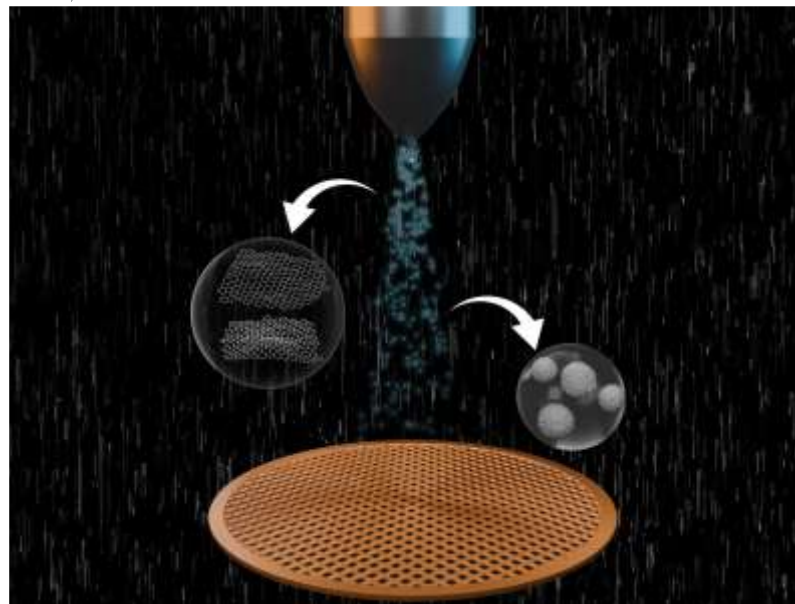


# MoS<sub>2</sub> Nanosheets

**ChemComm**

Chemical Communications  
rsc.li/chemcomm

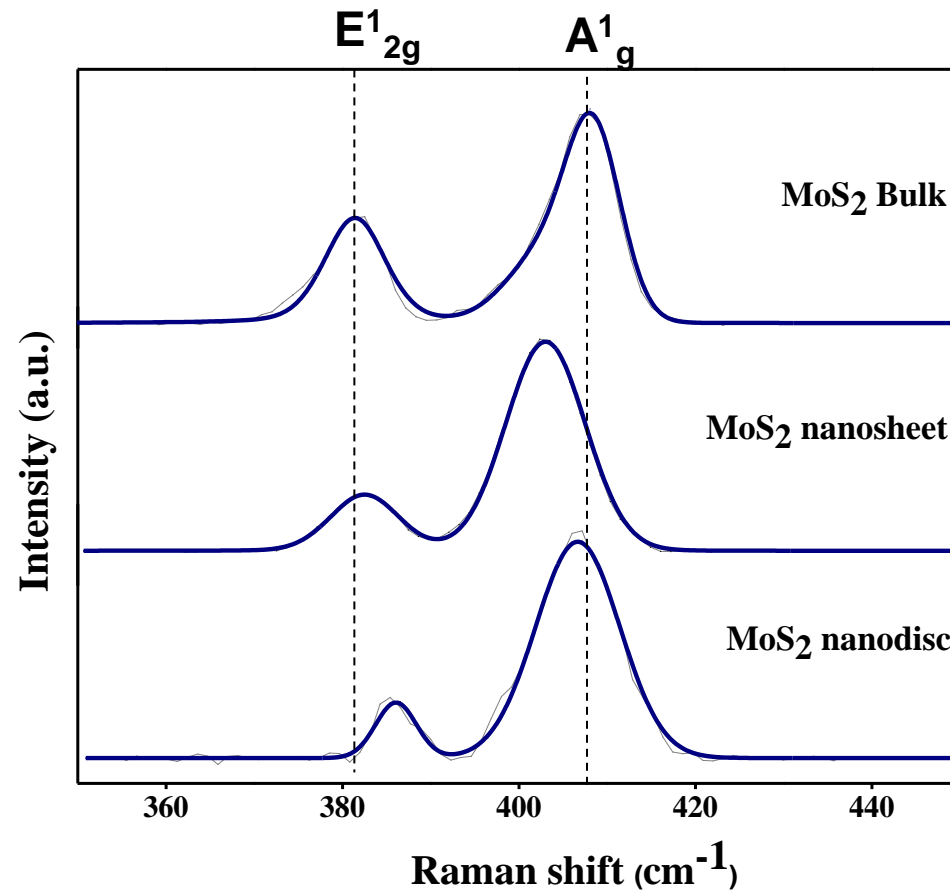
Volume 61  
Number 30  
18 April 2025  
Pages 5529–5676



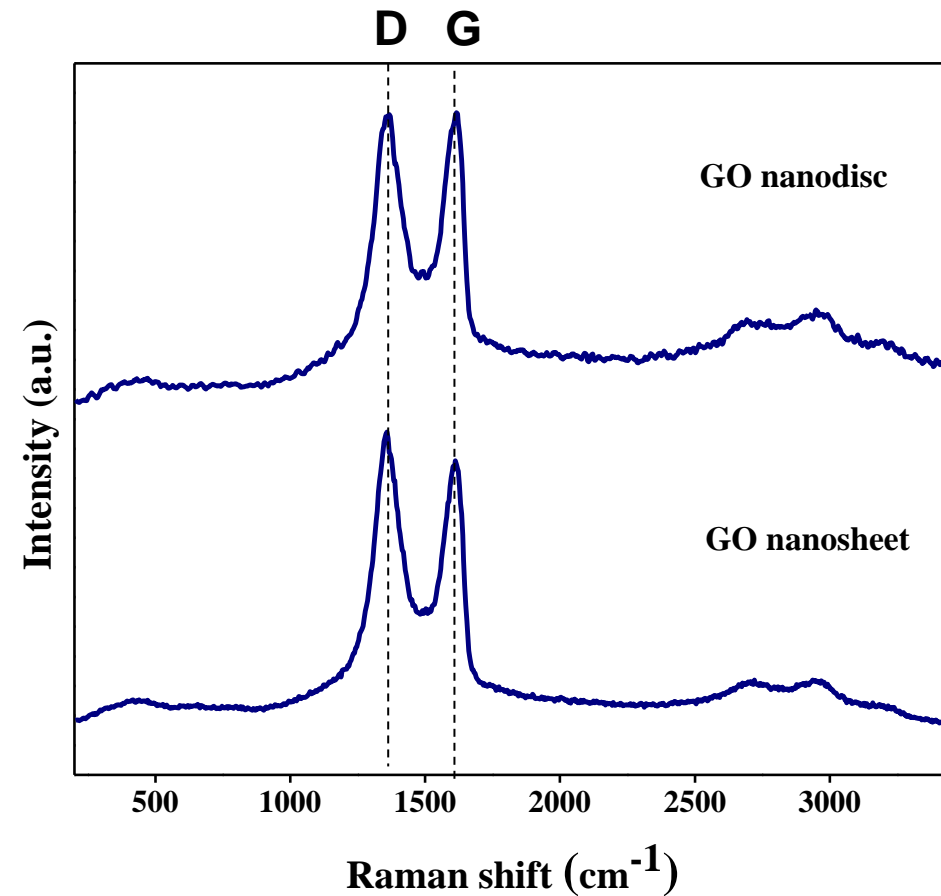
MoS<sub>2</sub> Nanosheet

MoS<sub>2</sub> Nanoparticles

# Raman Spectra of MoS<sub>2</sub> and Graphene Oxide Nanosheets



	$E^1_{2g}$ (cm <sup>-1</sup> )	$A^1_g$ (cm <sup>-1</sup> )
Bulk	381.34	407.67
NS	382.88	402.95
ND	386.01	406.67



Relative peak intensity

Spoorthi et al. Chem. Comm. 2025

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

Mohan Udhaya Sankar<sup>1</sup>, Sahaja Aigal<sup>1</sup>, Shihabudheen M. Maliyekkal<sup>1</sup>, Amrita Chaudhary, Anshup, Avula Anil Kumar, Kamalesh Chaudhari, and Thalappil Pradeep<sup>2</sup>

<sup>1</sup>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 vily. The ability to prepare nanostructu ambient temperature has wide releva water purification.

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

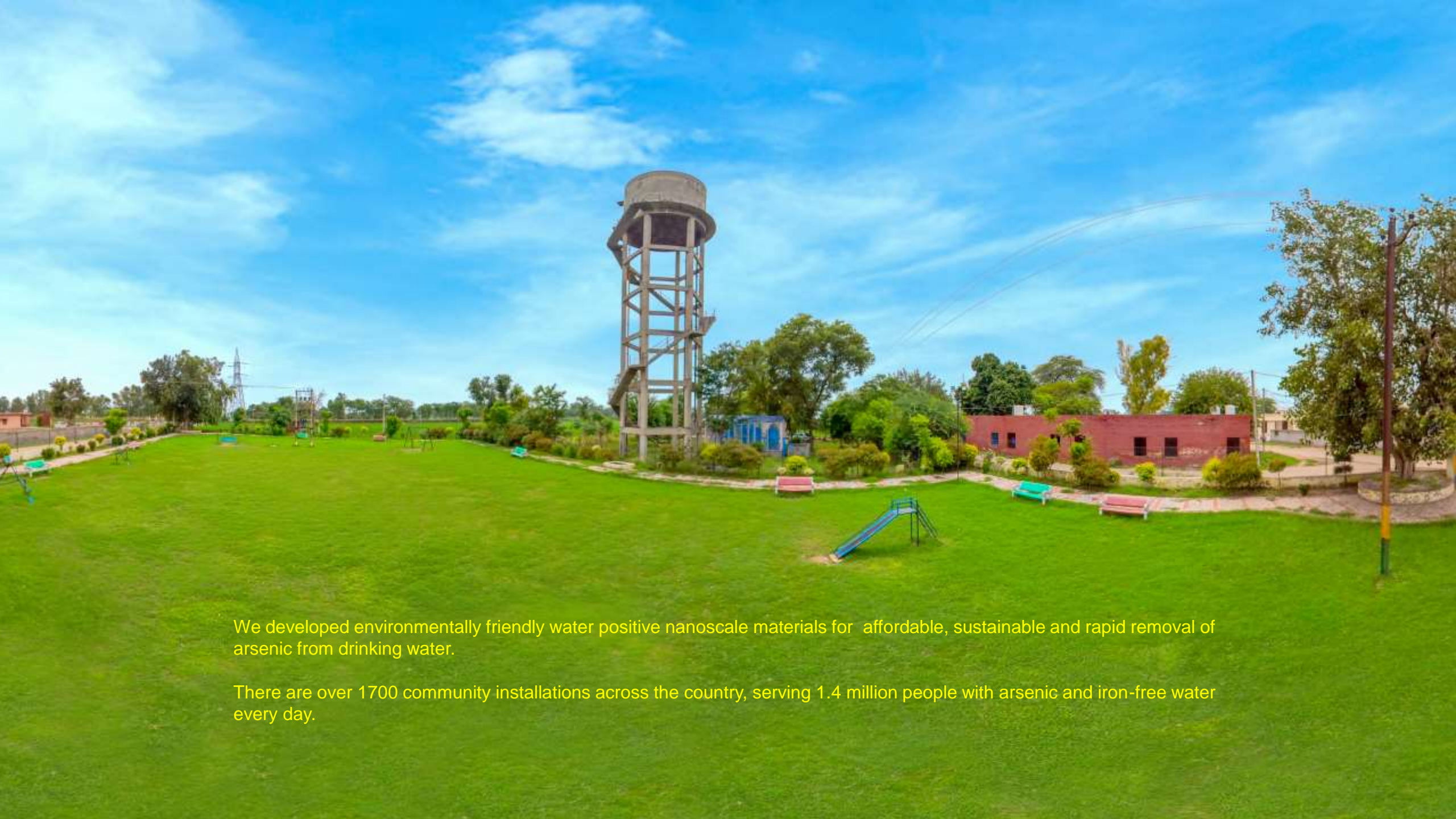


Madras, Chennai 600 036, India

(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 ial antimicrobial activity in drinking osites have been developed that can its in water. We demonstrate an af- device based on such composites de- nd undergoing field trials in India, as spread eradication of the waterborne

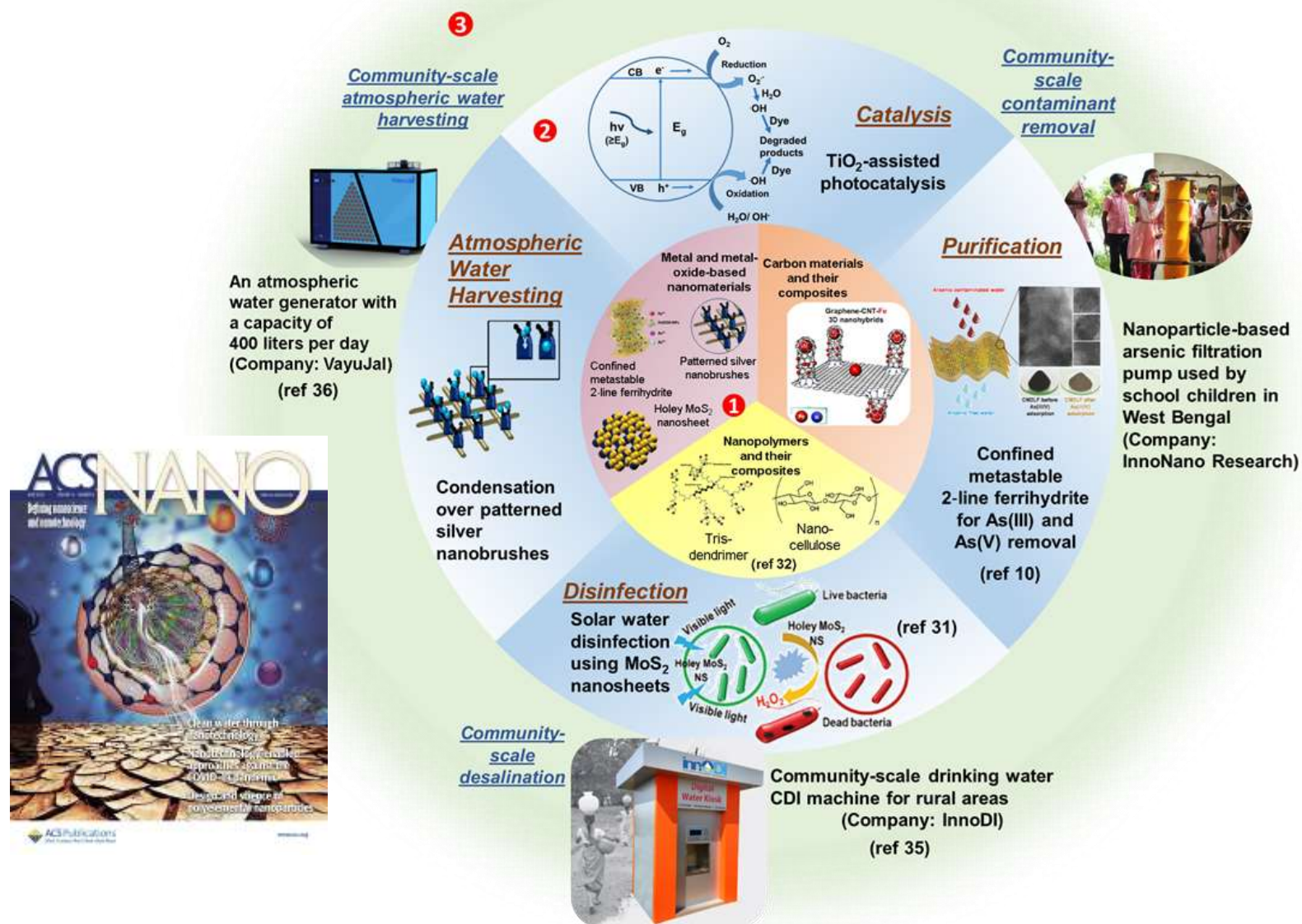
RESULTS AND DISCUSSION



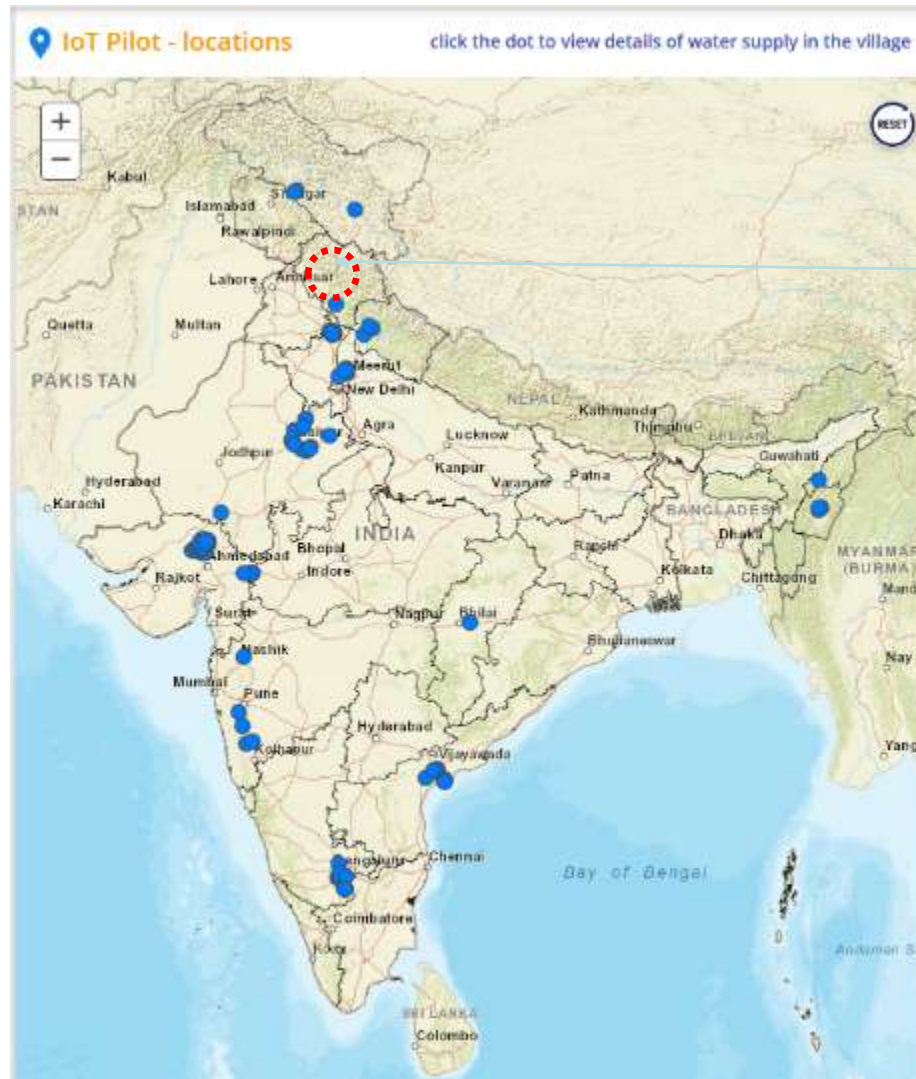
We developed environmentally friendly water positive nanoscale materials for affordable, sustainable and rapid removal of arsenic from drinking water.

There are over 1700 community installations across the country, serving 1.4 million people with arsenic and iron-free water every day.

# Evolution of materials to products

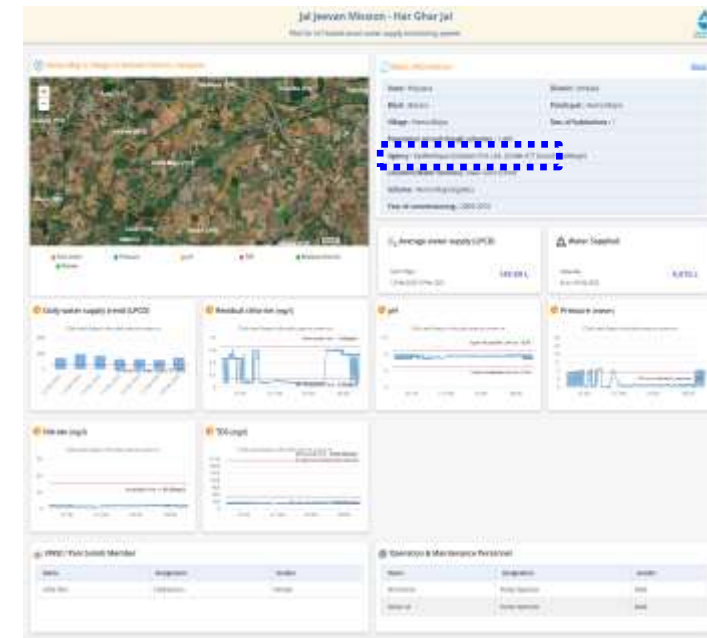


# India's water is being monitored



IITM/IISc

Installations made by four companies

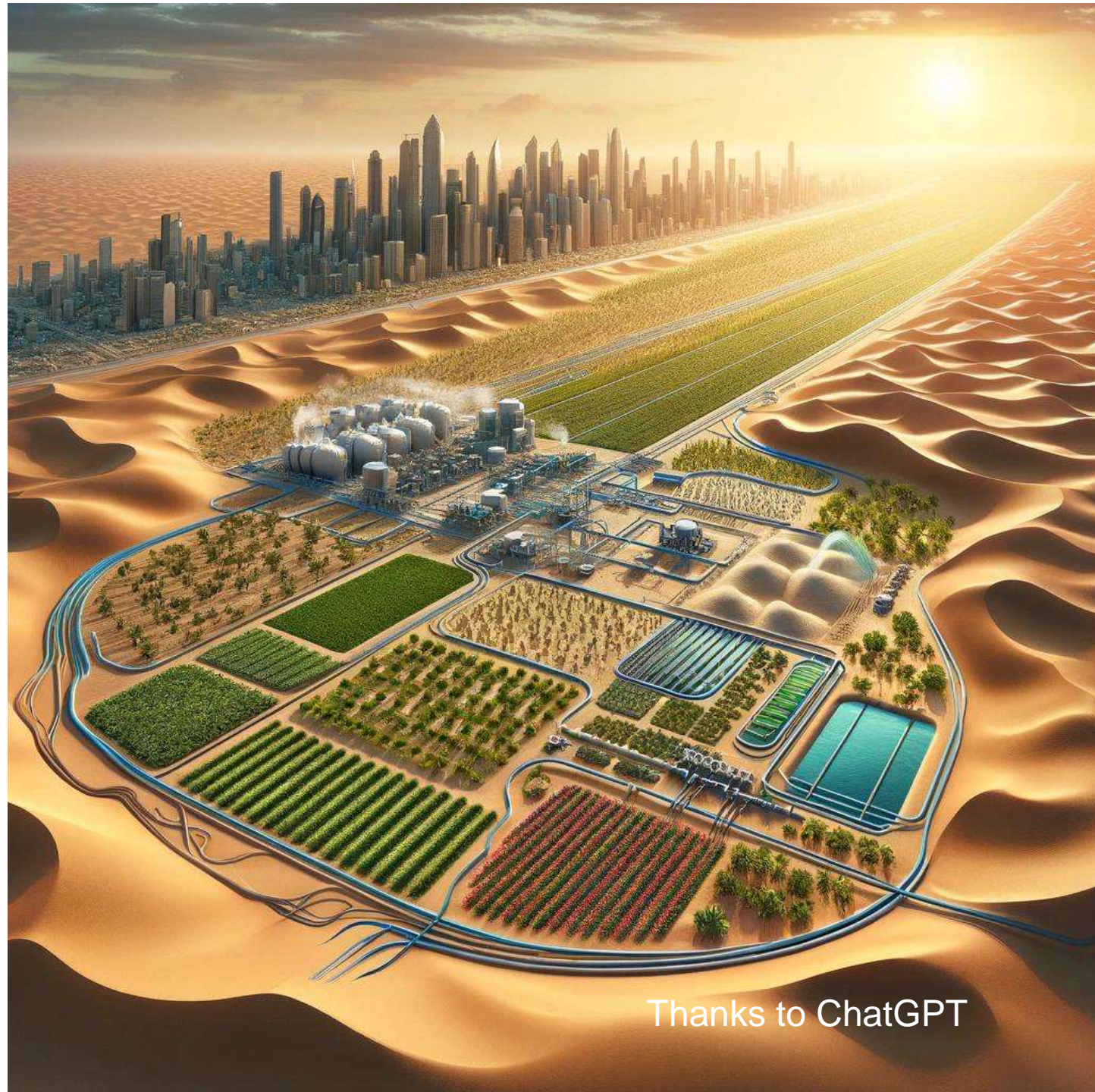




Thanks to ChatGPT

# Vision

Make soil using  
processed wastewater  
and make deserts  
bloom.



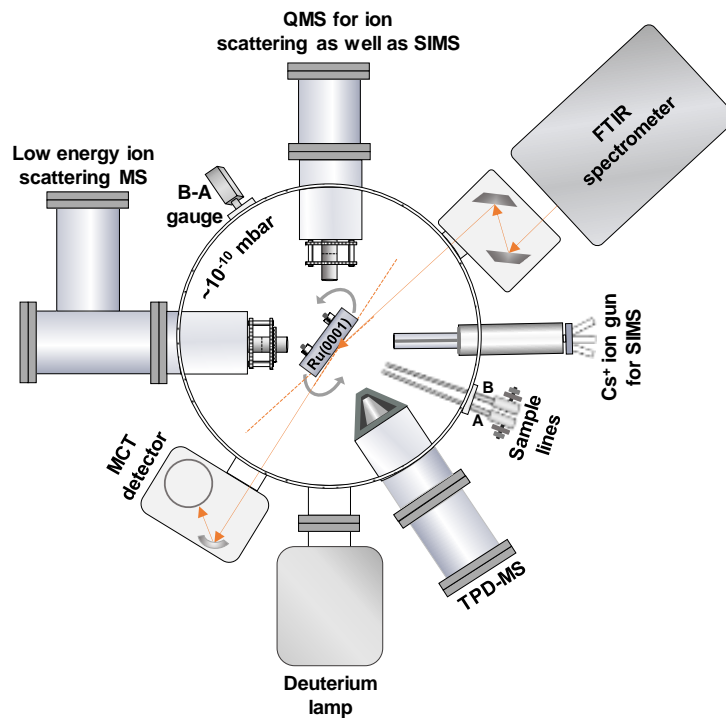
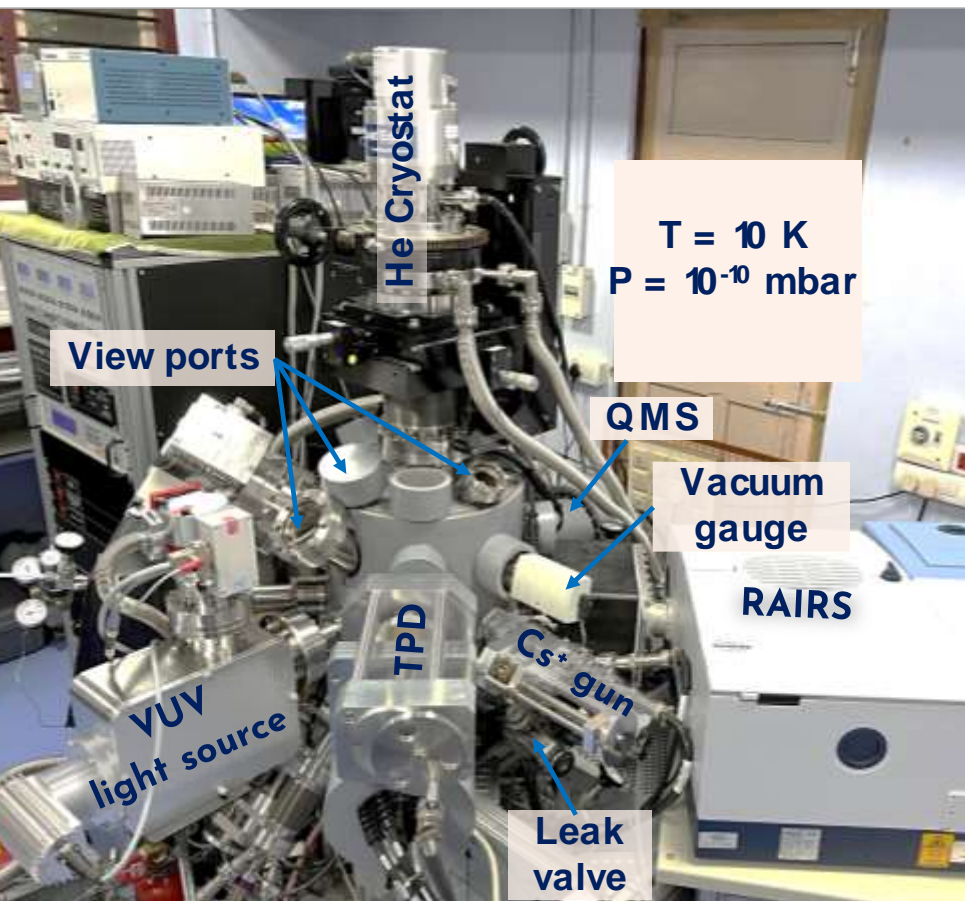
Thanks to ChatGPT



# **Can Clathrate Hydrates Exist in Space?**

Exploring astrobiology

# Instrumentation

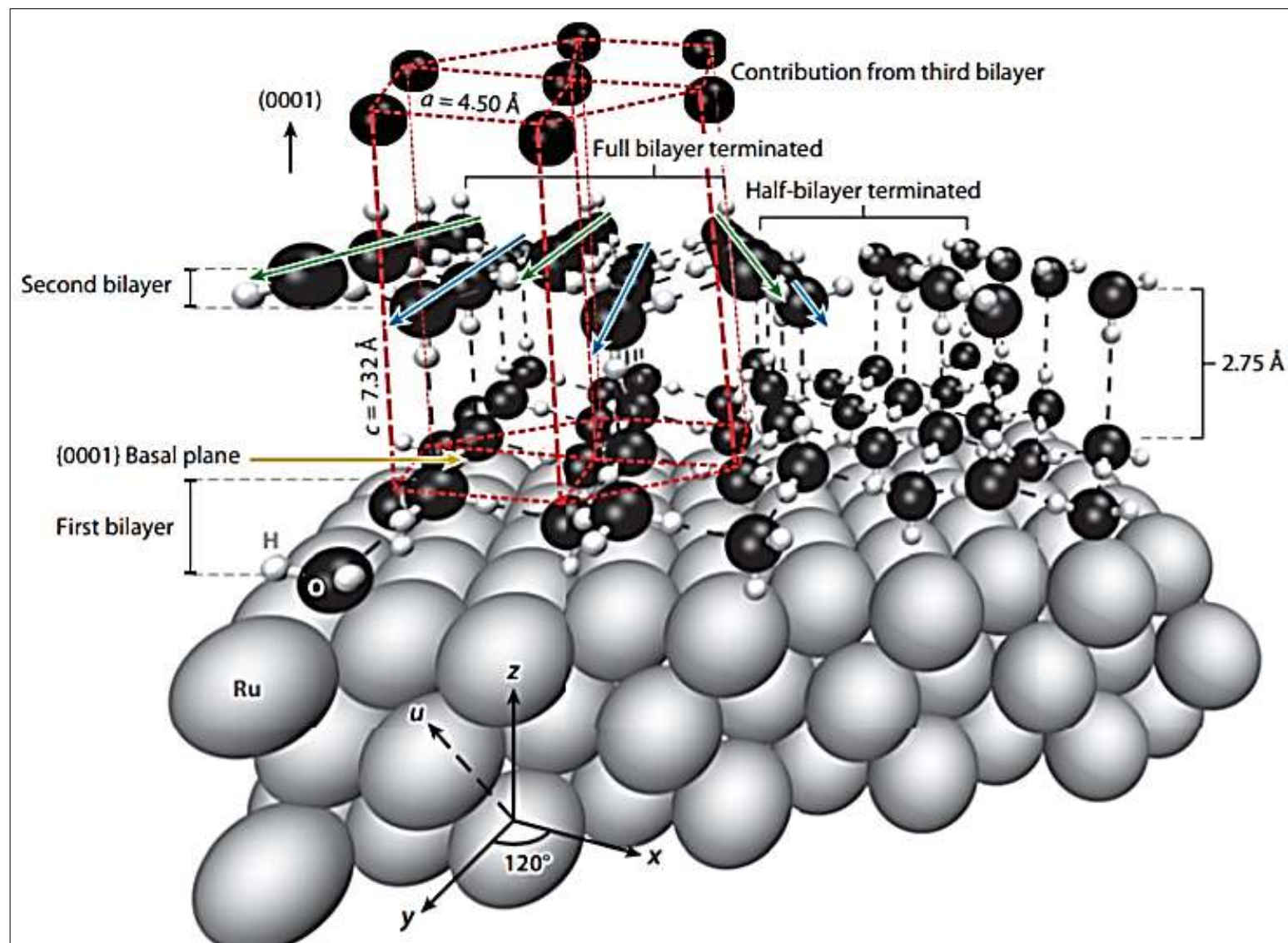


115-400 nm



Bag, S. et al., *Rev. Sci. Instrum.* **2014**, 85, 014103/1-014103/7

Viswakarma, G. et al., *J. Phys. Chem. Lett.*, **2023**, 14, 2823–2829

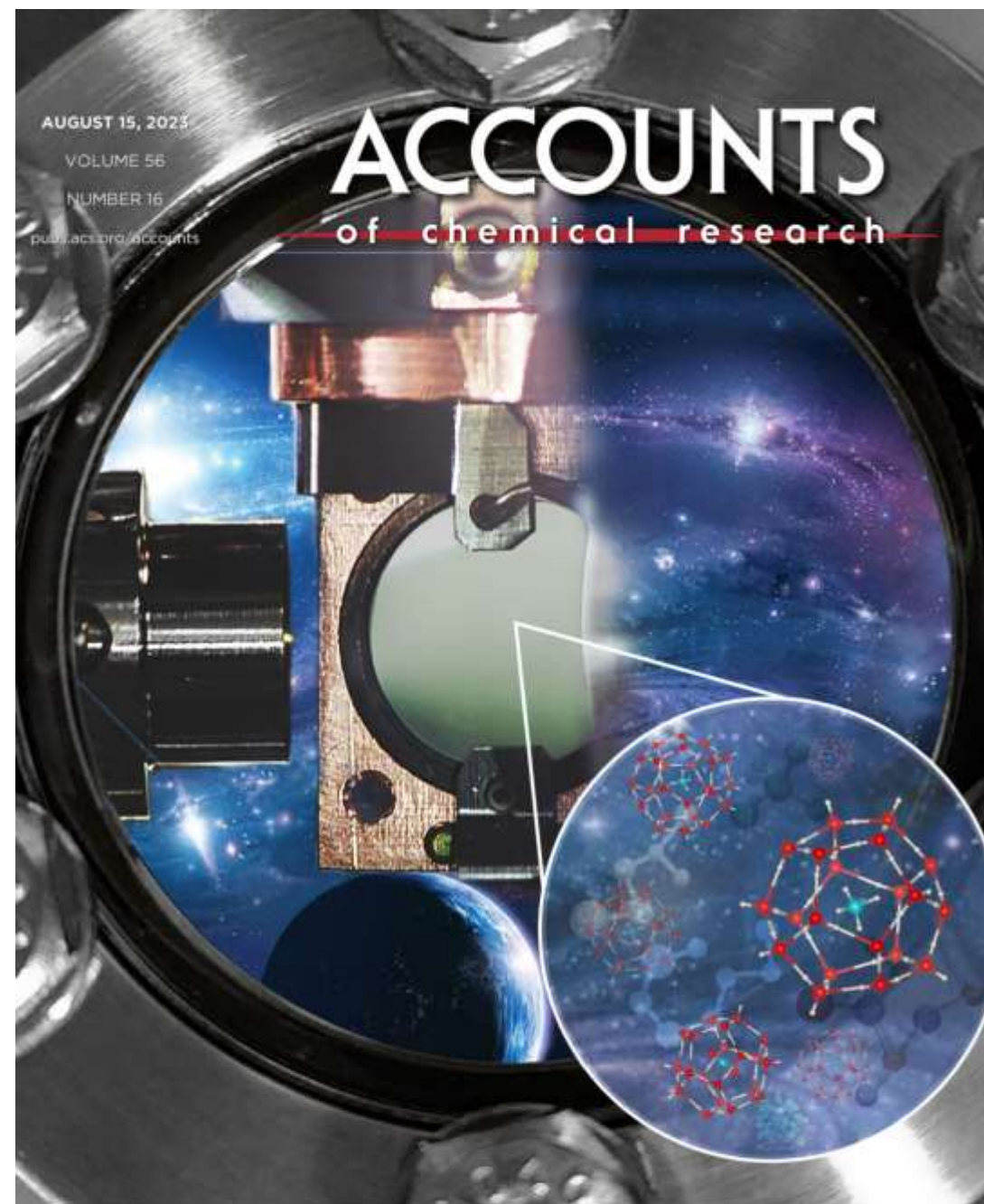


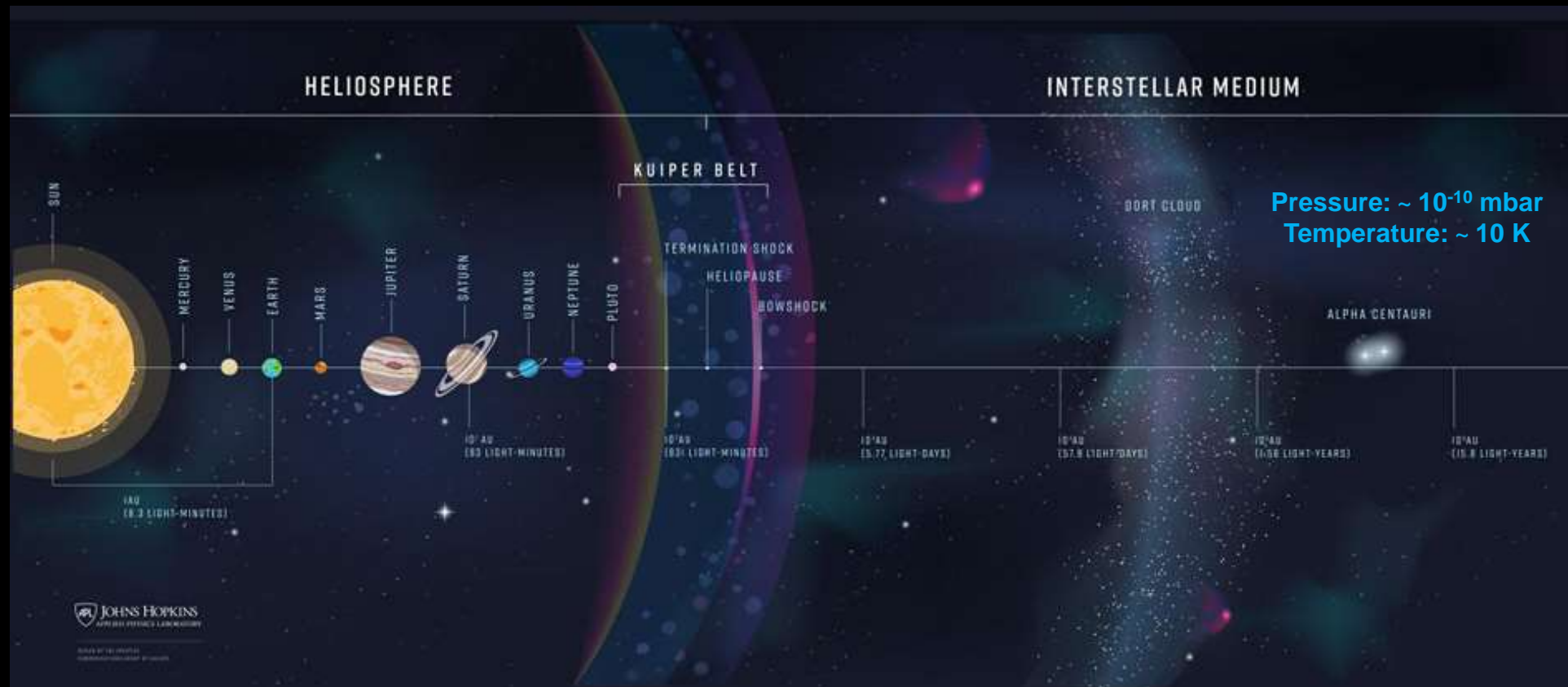
## Formation and Transformation of Clathrate Hydrates under Interstellar Conditions

Jyotirmoy Ghosh, Gaurav Vishwakarma, Rajnish Kumar,\* and Thalappil Pradeep\*

Cite This: <https://doi.org/10.1021/acs.accounts.3c00317>

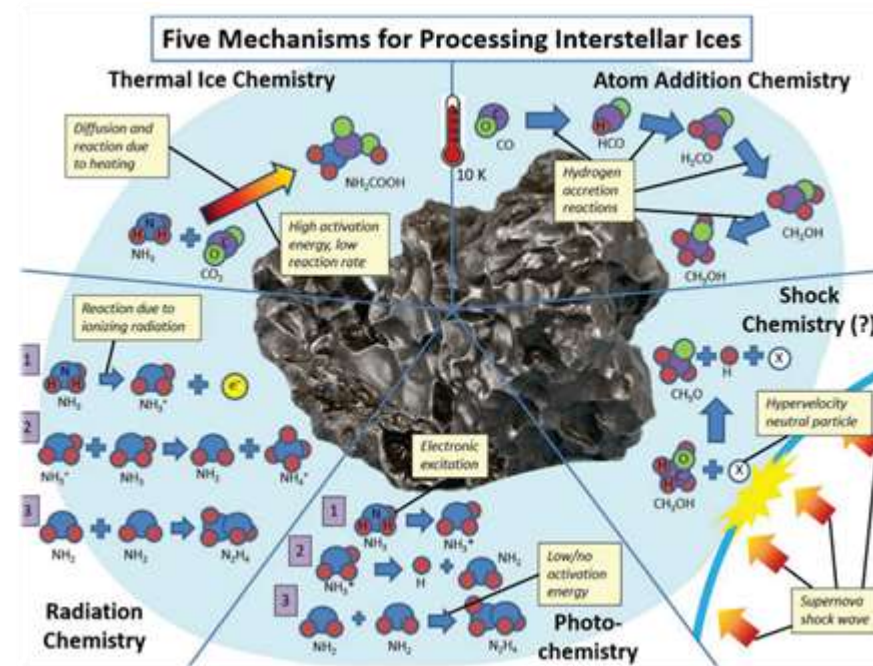
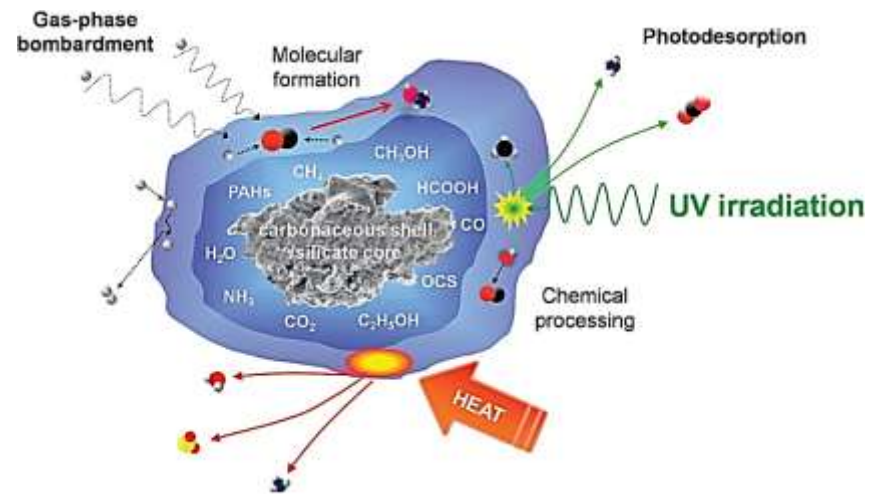
Read Online





Diffuse clouds:  $T \sim 100$  K,  $n \sim 100$  molecules per  $\text{cm}^3$   
 Dense clouds:  $T \sim 10$ - $100$  K,  $n \sim 10^4$ - $10^8$  molecules per  $\text{cm}^3$   
 On Earth sea level:  $T \sim 300$  K,  $n \sim 3 \times 10^{19}$  molecules per  $\text{cm}^3$

# Interstellar ices



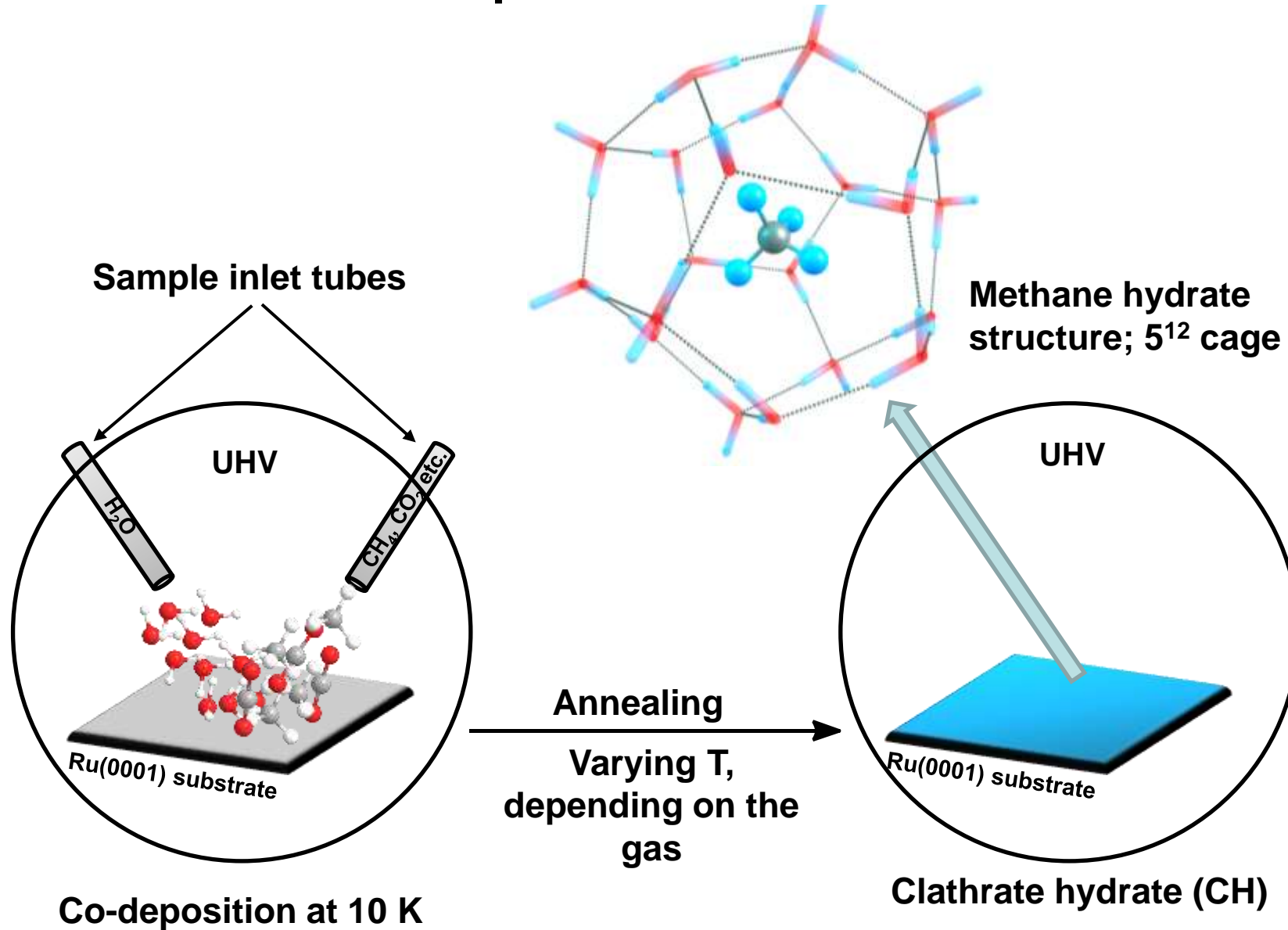
**Silicates and carbonaceous material – 0.01-0.5  $\mu\text{m}$**

Arumainayagam, C. R. *et al.*, *Chem. Soc. Rev.*, **2019**, 48, 2293–2314

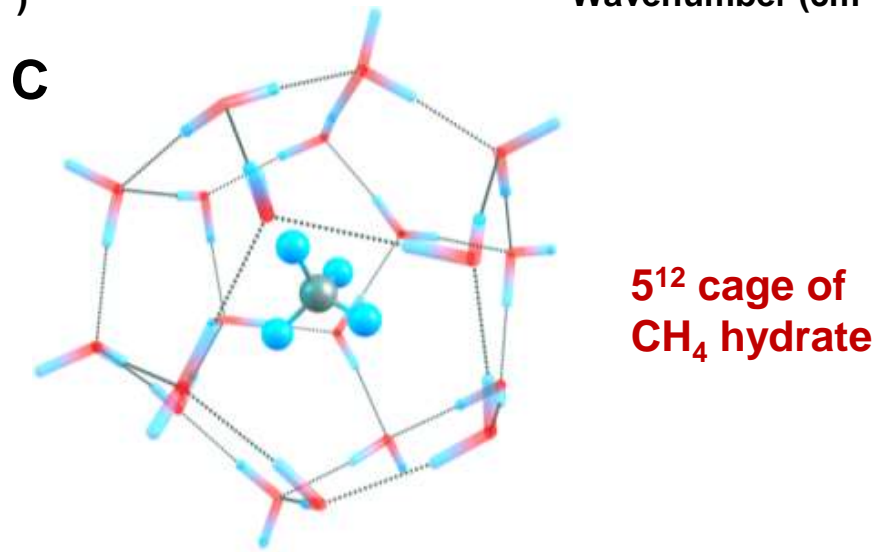
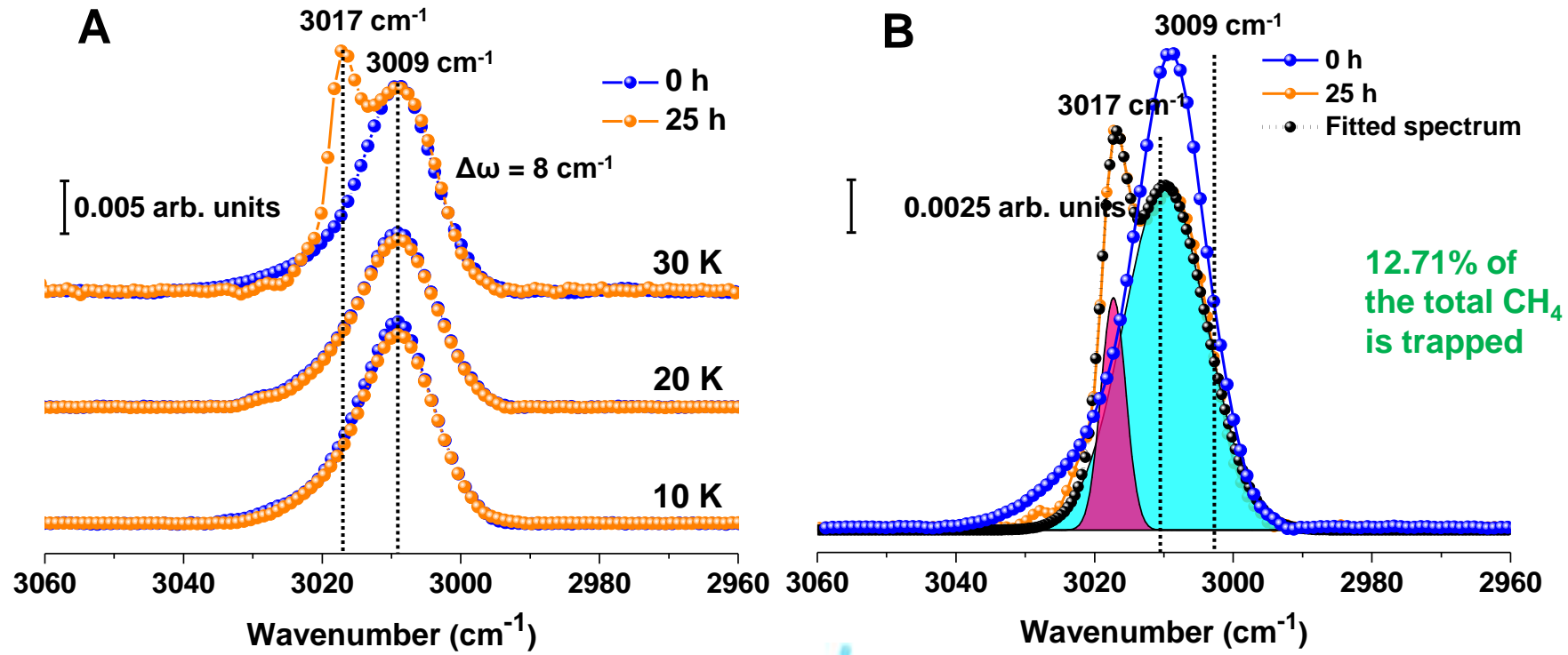
# ***Clathrate hydrates in interstellar environment***

Ghosh, J. *et al.*, *Proc. Natl. Acad. Sci. U.S.A.*, **2019**, 116, 1526-1531

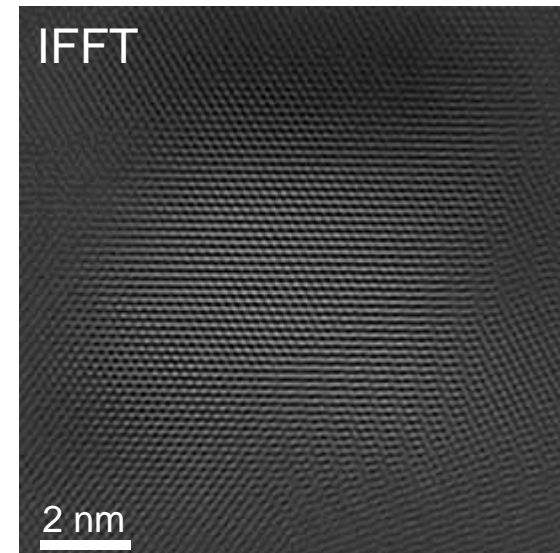
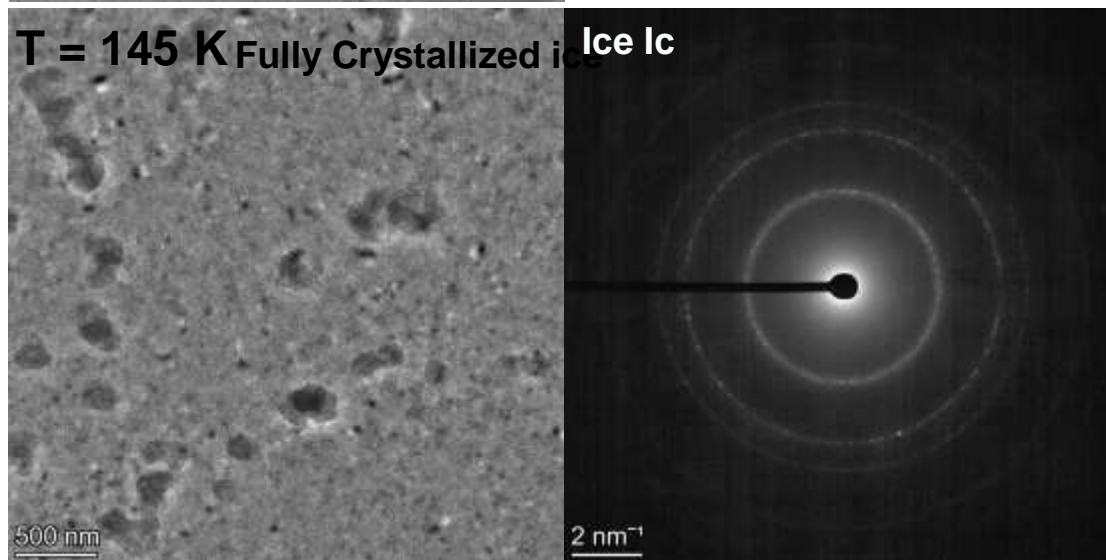
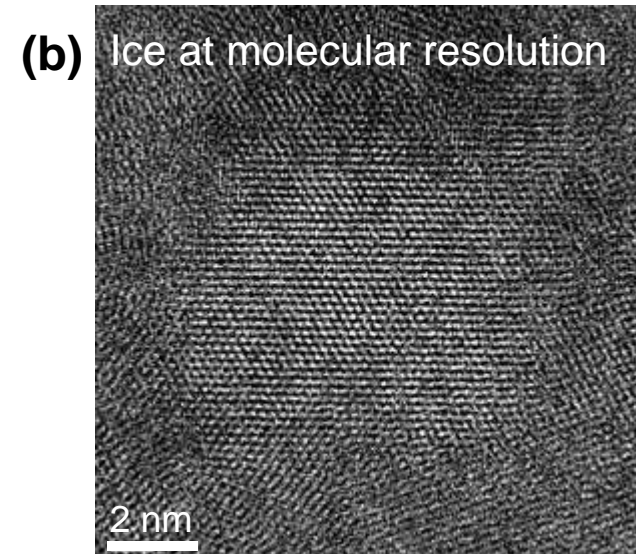
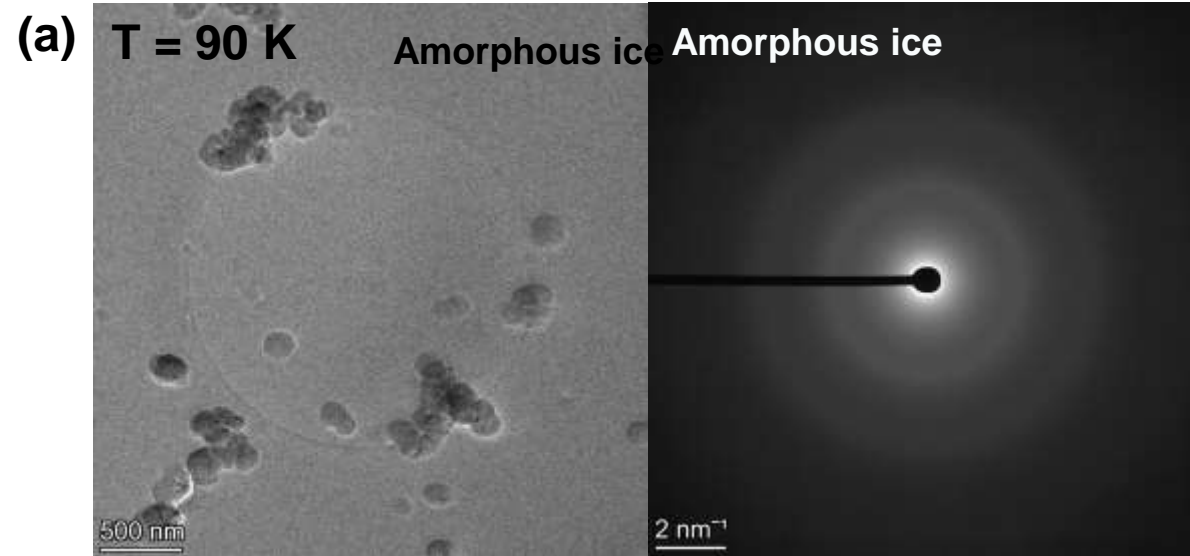
# Experimental method



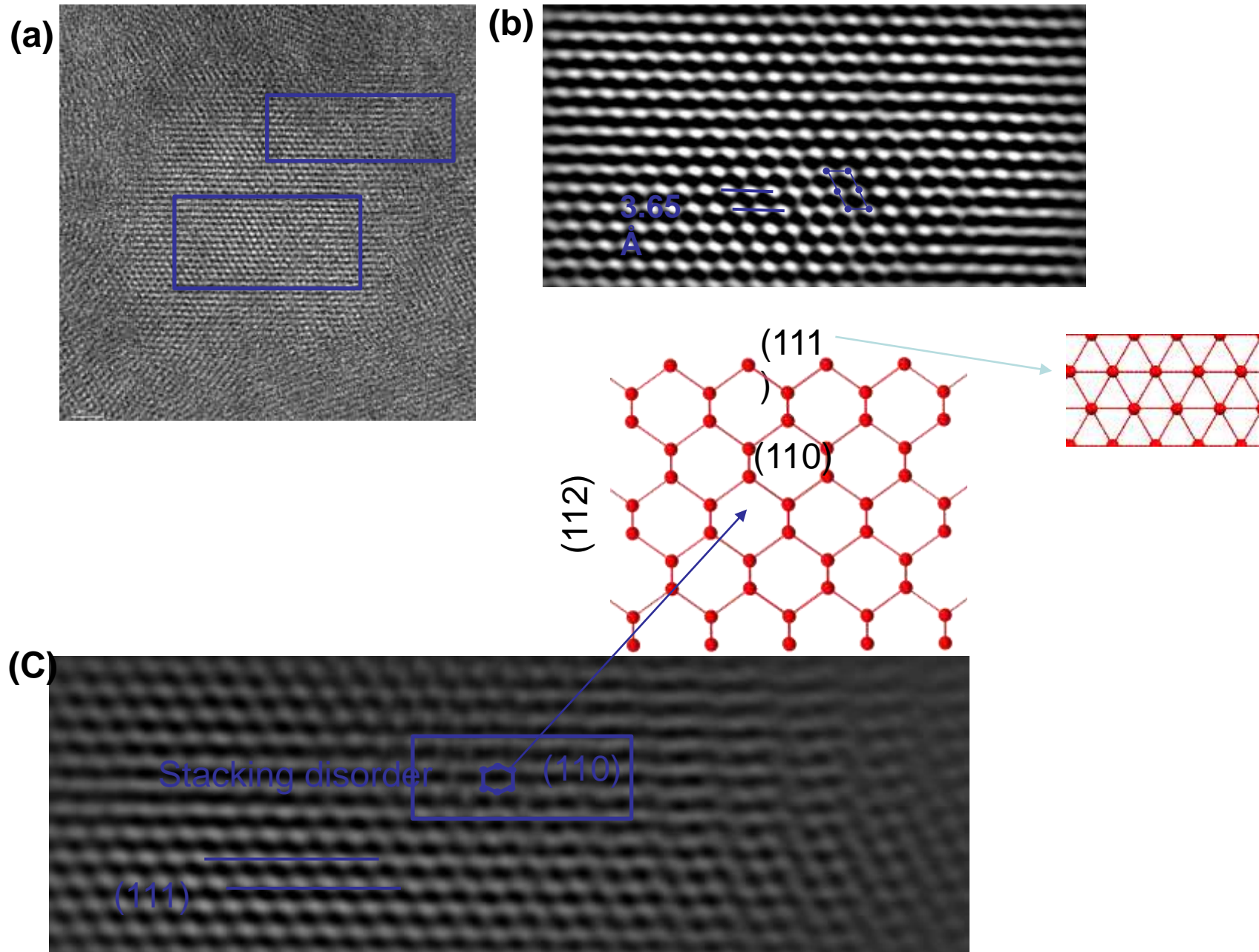
# Clathrate hydrates in interstellar environment



# Observing growth of crystalline ice from amorphous ice



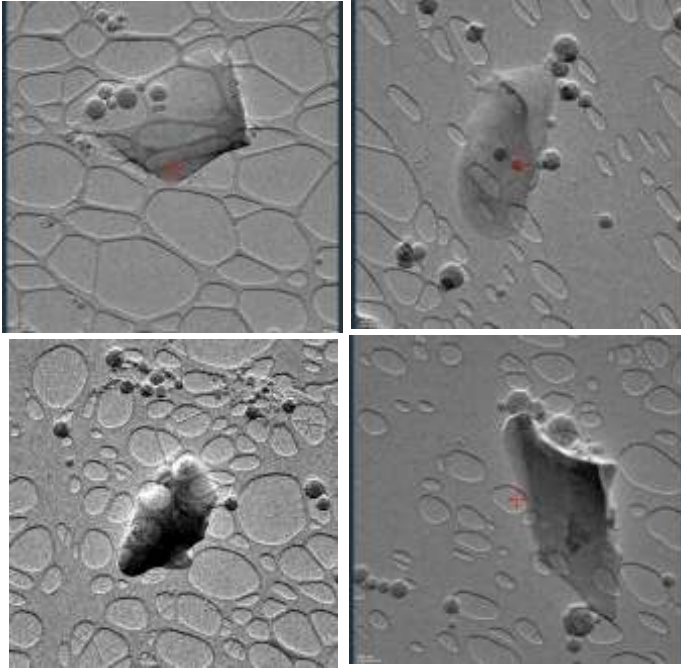
# Imaging cubic ice at molecular resolution



# Electron diffraction of nanometer-scale crystals of clathrate hydrate

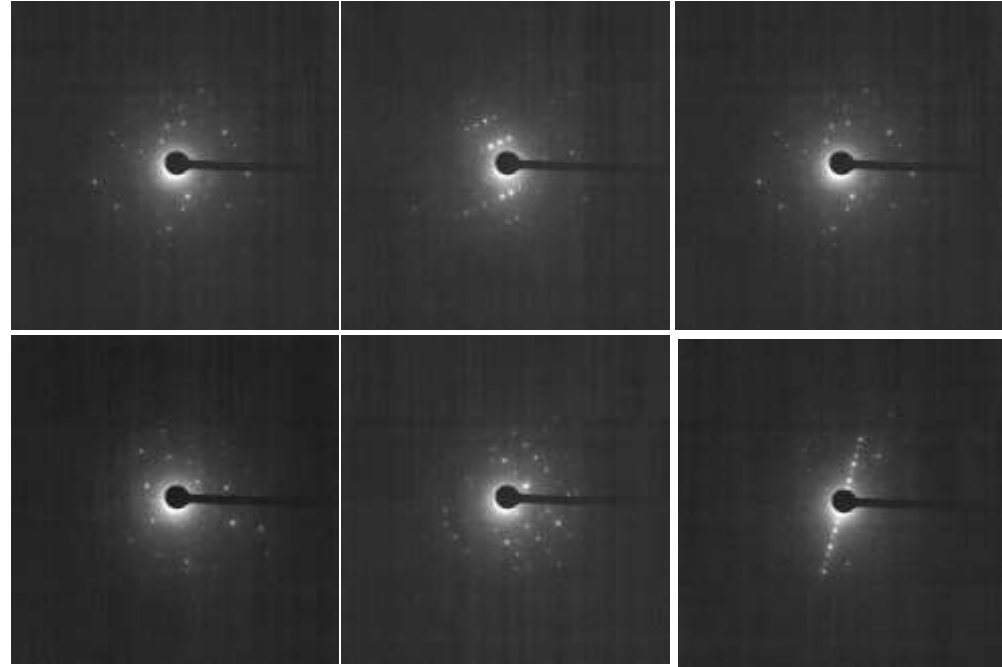
(a)

THF-CH<sub>4</sub> Clathrate hydrate crystal

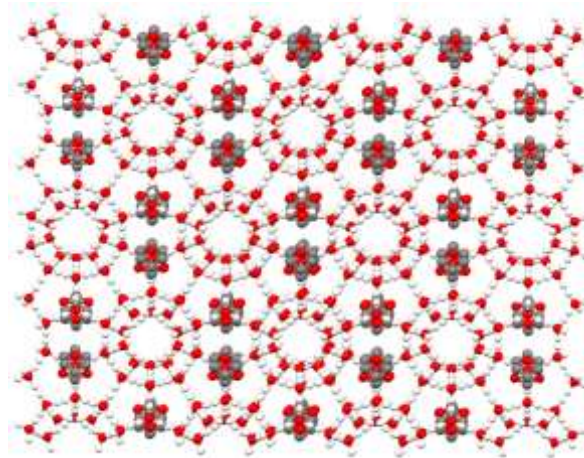
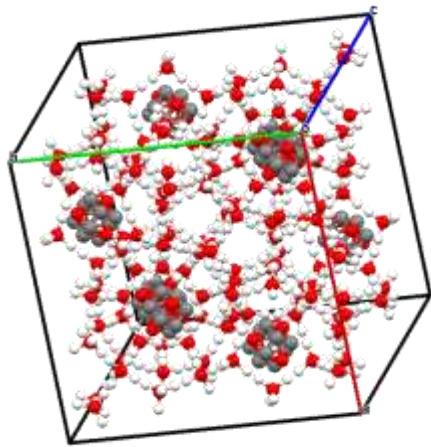


(b)

3 D electron diffraction



(c)

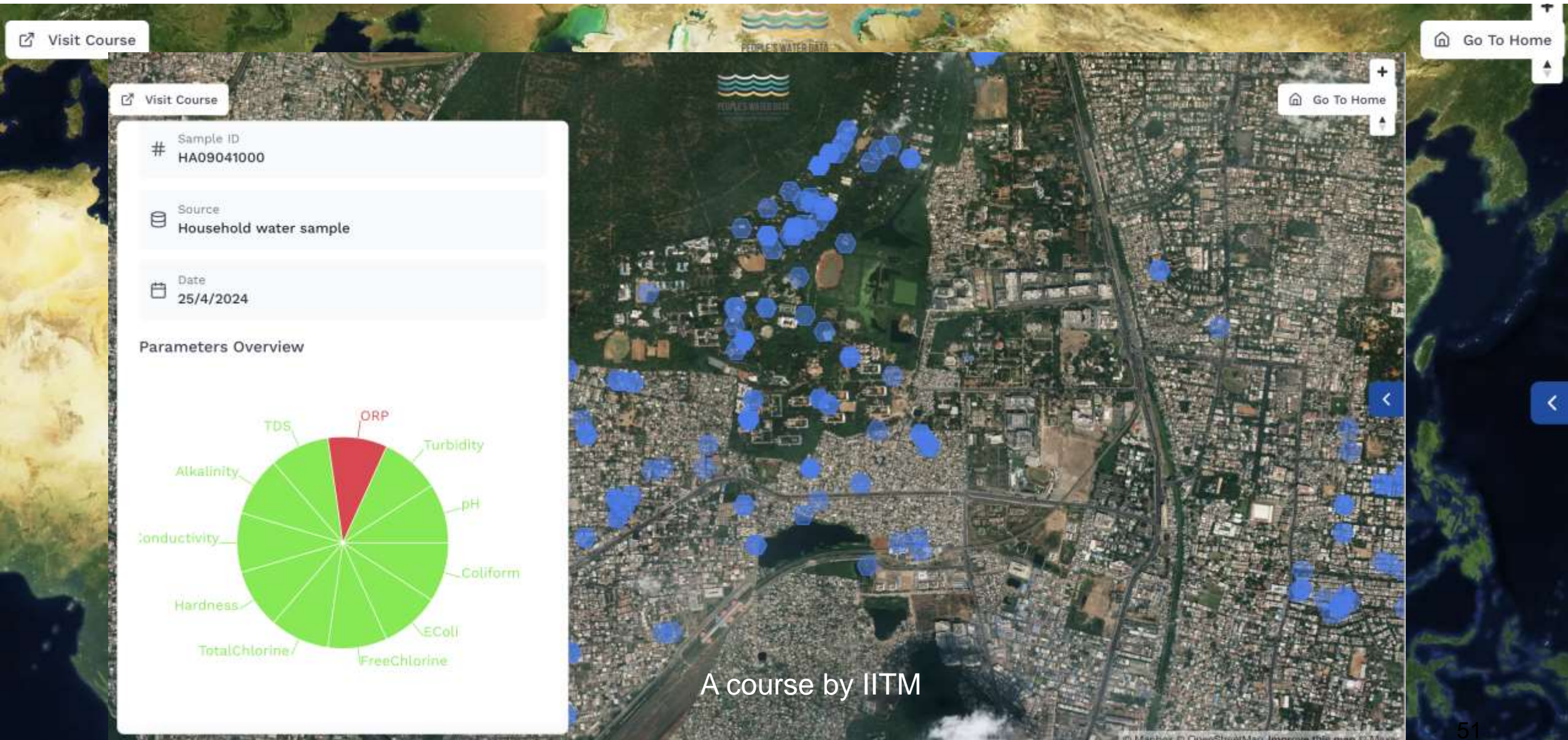


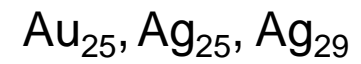
Crystal structure



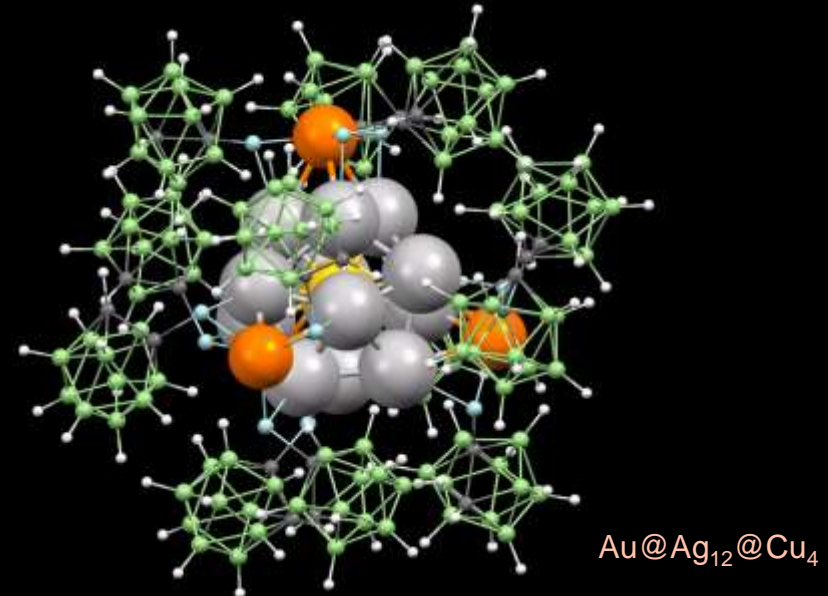
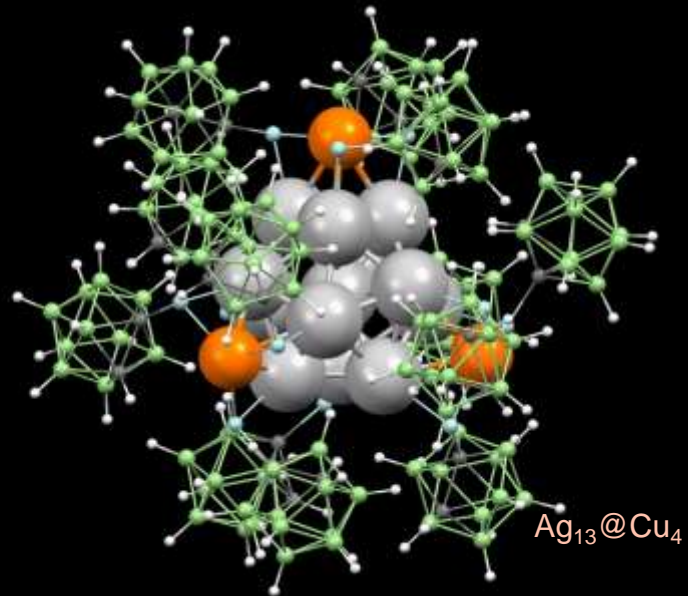
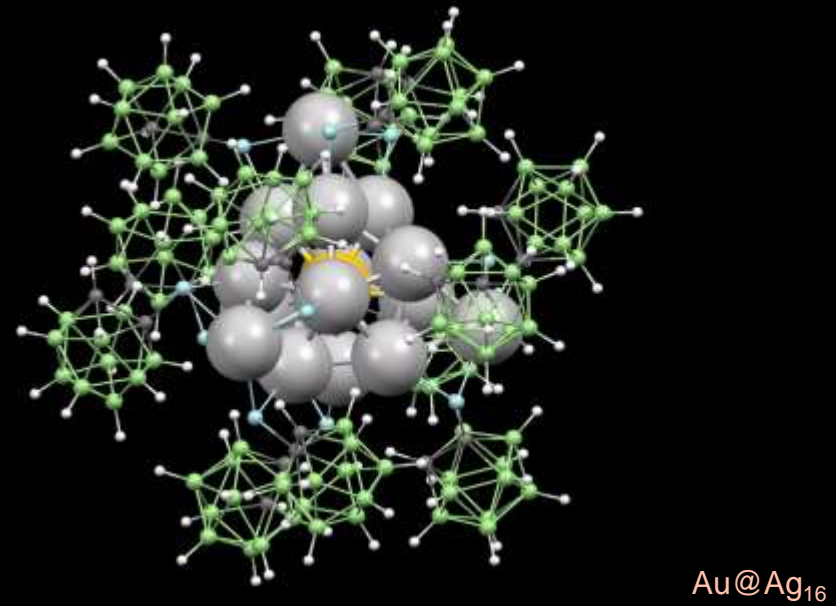
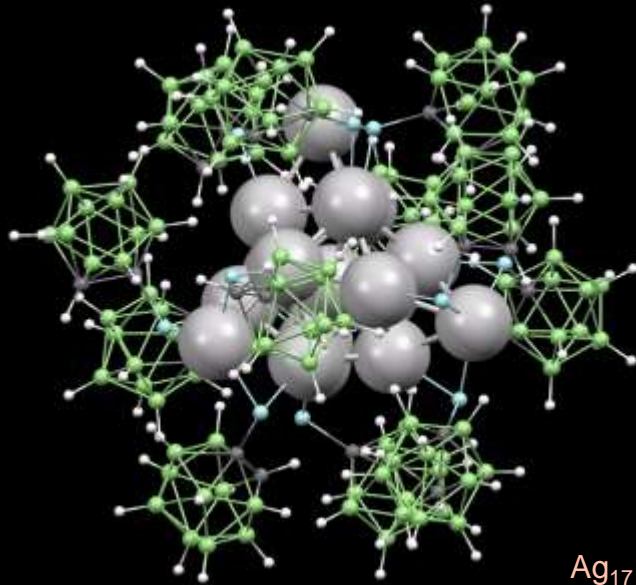
International Centre for Clean Water

# People's Water Data





# Structure of $M_{17}$ Nanoclusters



# Conclusions

Natural minerals break spontaneously in charged water microdroplets

It occurs only in water... so far

Studies on a variety of materials

Facile due to proton-induced slip

Detailed investigations are essential to know more

Implications to the production of specific nanomaterials and soil in general

## Other collaborators



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Yuichi Negishi  
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Shiv Khanna  
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Robin Ras



Manfred Kappes



Nonappa



Olli Ikkala



Tomas Base



Horst Hahn



Biswarup Pathak



K. V. Adarsh



G. U. Kulkarni

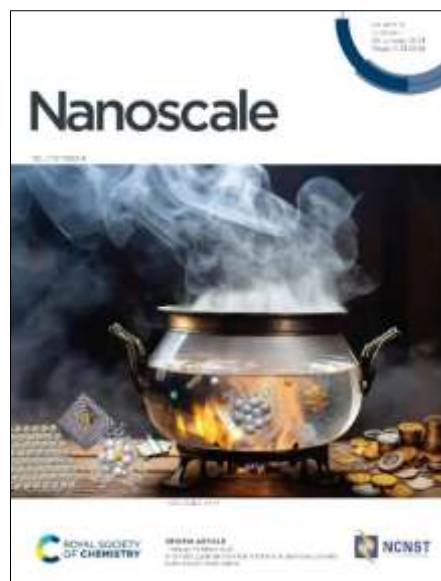
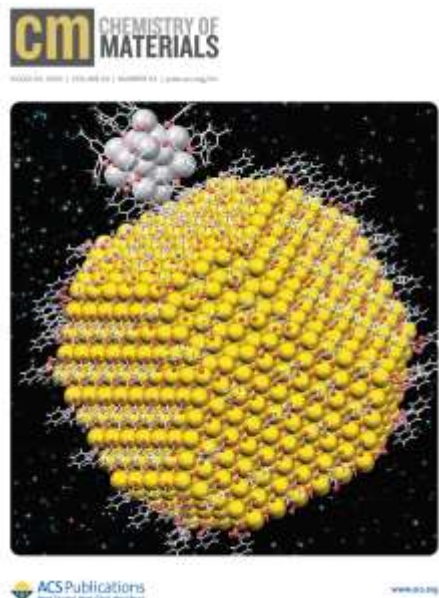
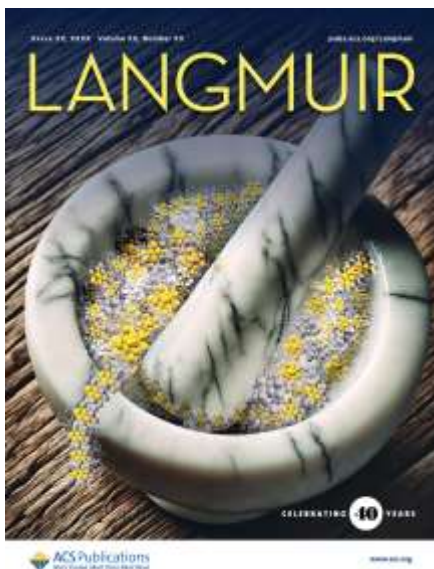


Vivek Polshettiwar

# Department of Science and Technology

Institute of Eminence

Many Outstanding Individuals







# Indian Institute of Technology Madras



Bhaskar Ramamurthi/V. Kamakoti

## Thank you all

