Transmission Electron Microscopy

Fu-Rong Chen

Transmission Electron Microscopy

David B. Williams

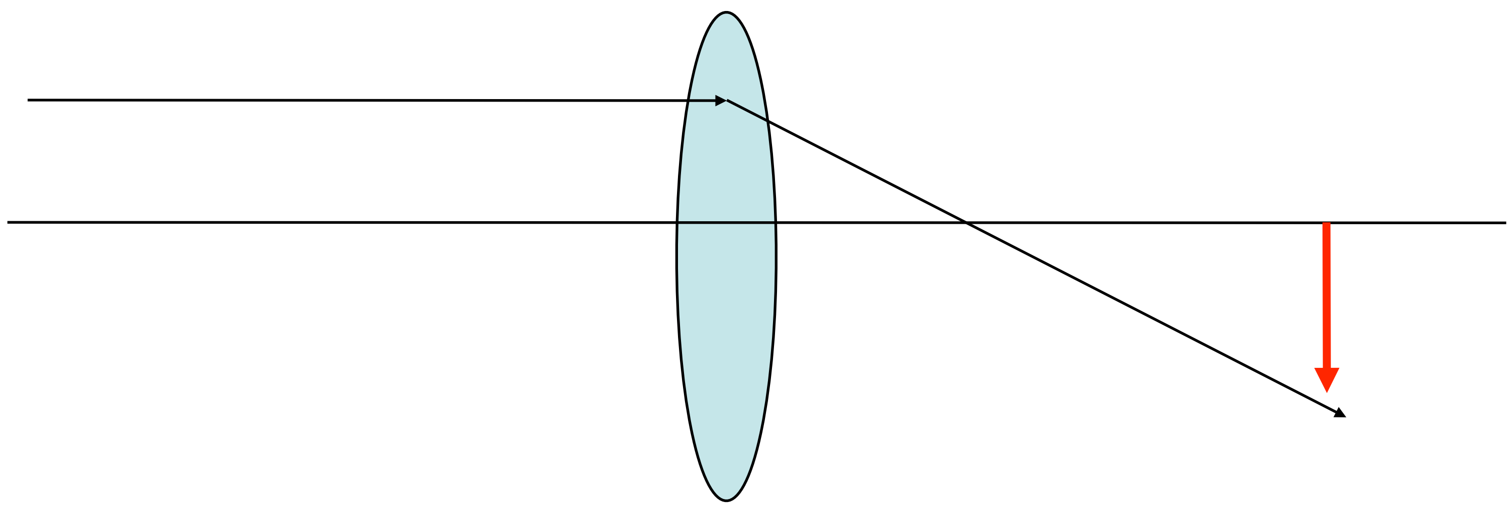
C. Barry Carter

Background：Solid State Physics
Materials Science

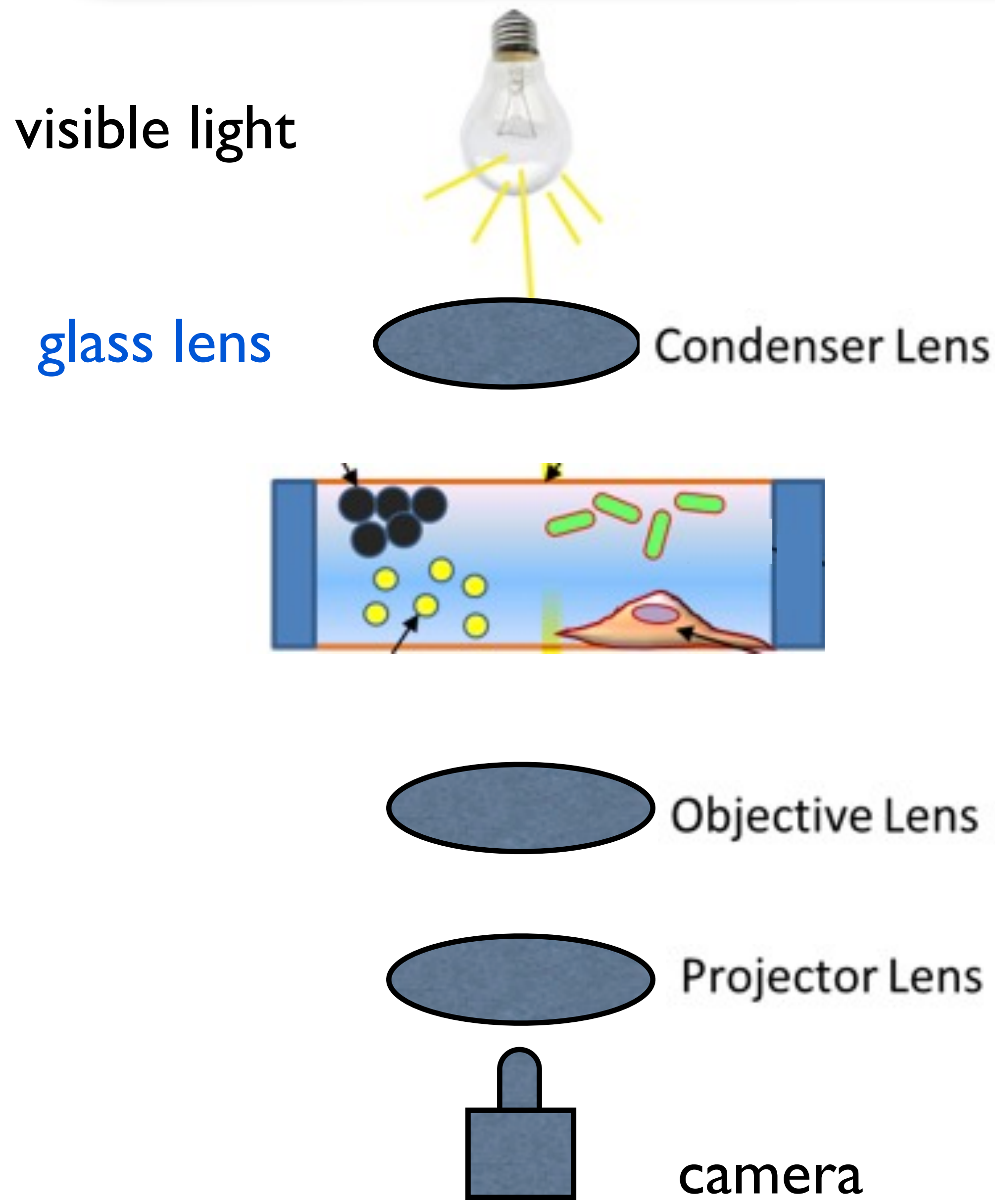
1.1 Why Electron Microscope?

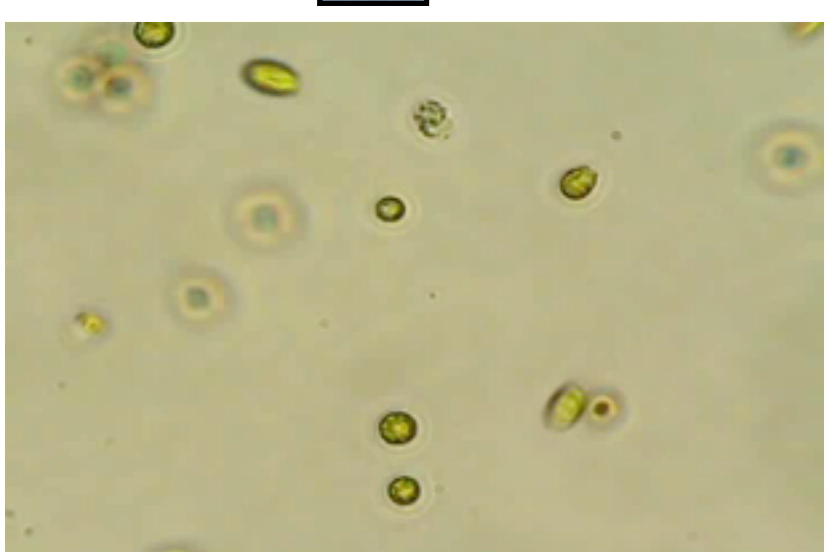
1.1 Why Electron Microscope?

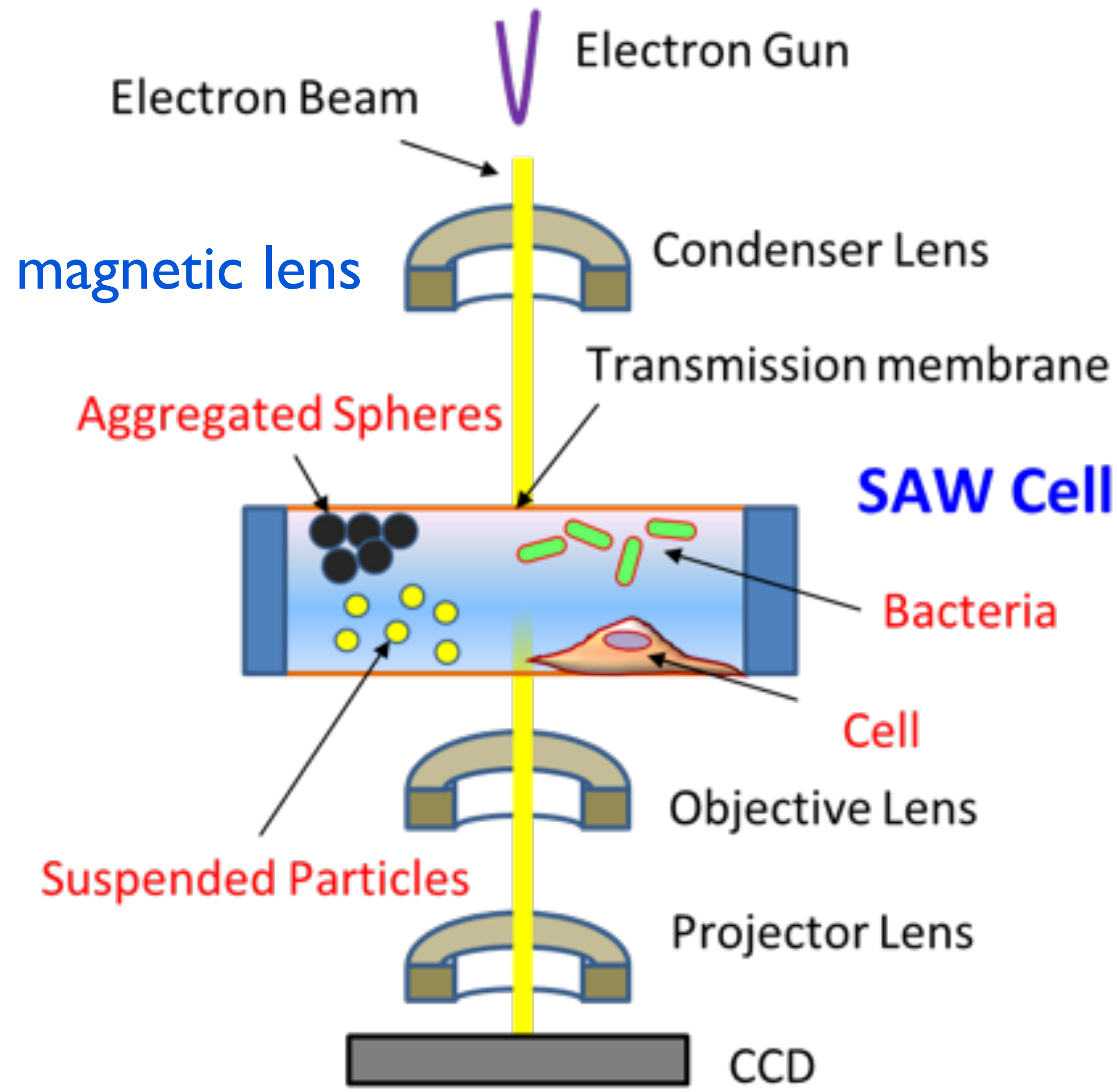
	Optical Microscope	Electron Microscope
source	visible light	electron
lens	glass	electro-magnetic lens



Optical Microscope   Electron Microscope

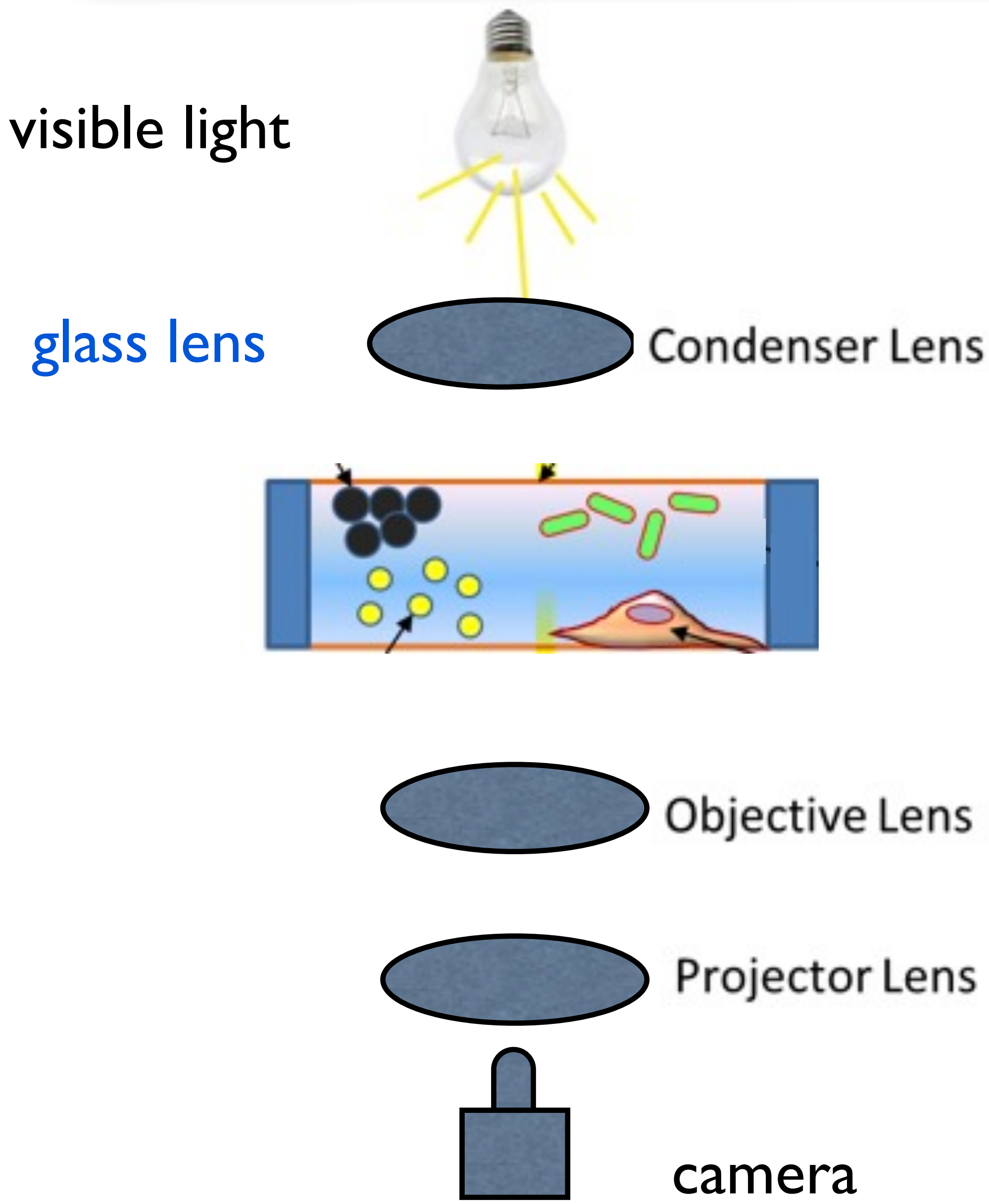


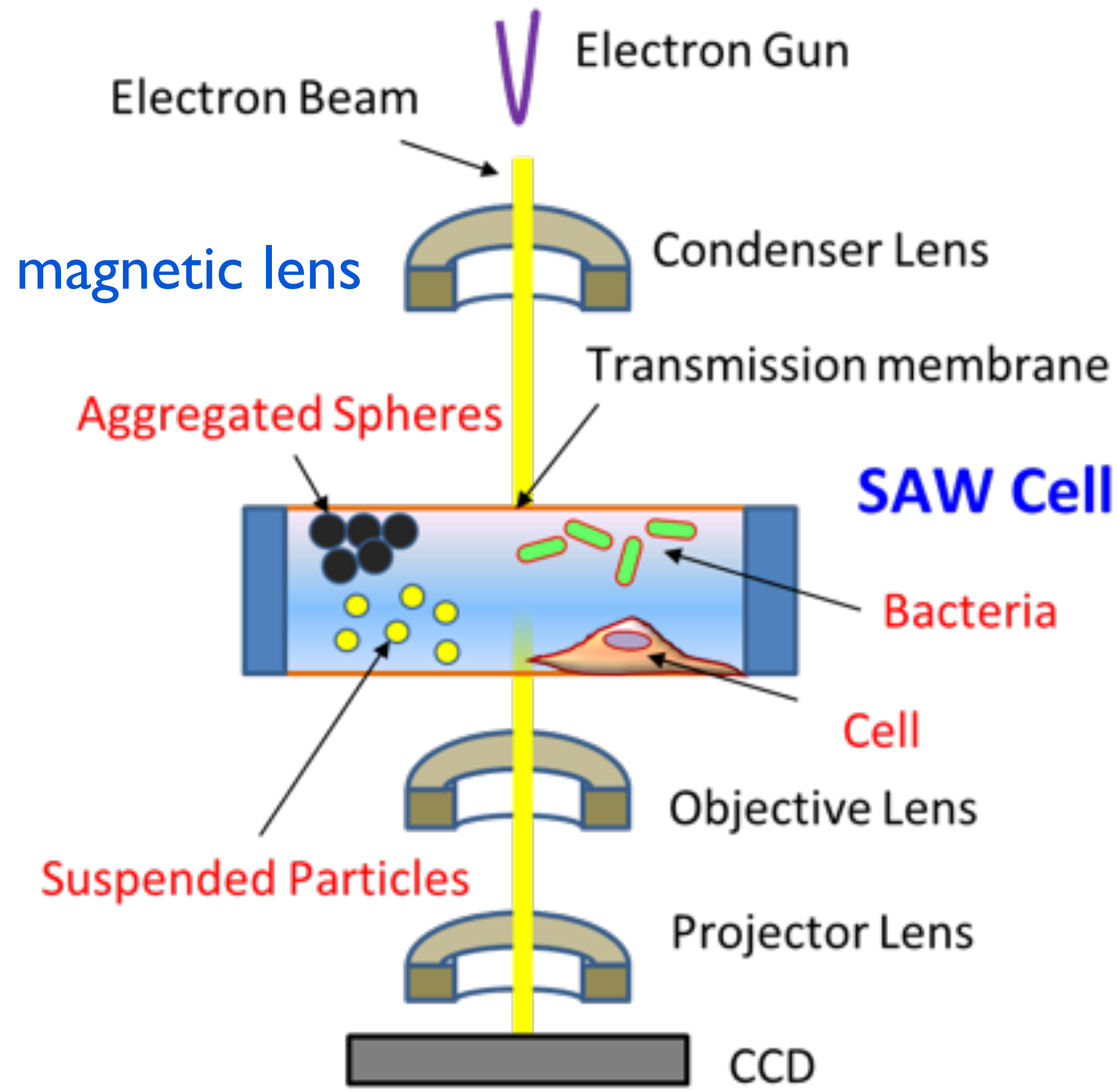




Liquid TEM image

Optical Microscope / Electron Microscope





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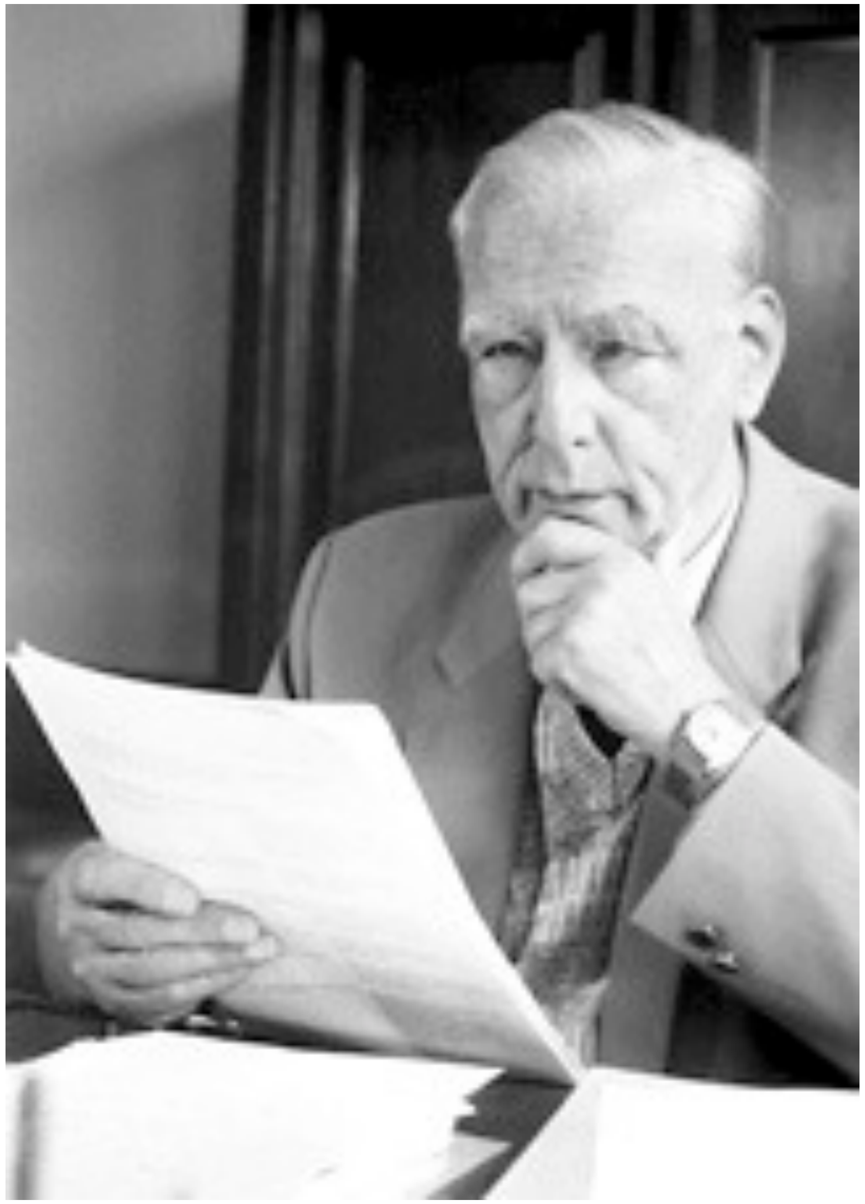
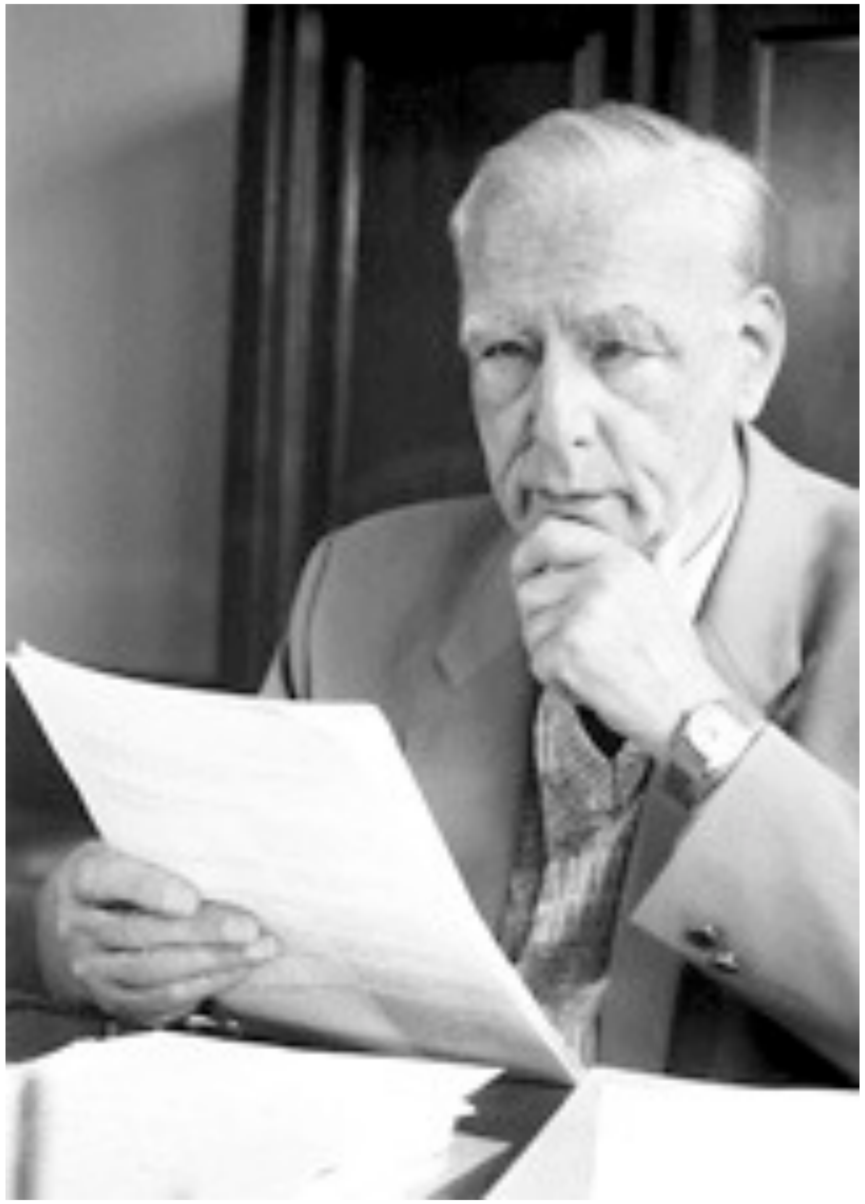
Liquid TEM image

Ernst Ruska



Nobel Prize in Physics 1986

Ernst Ruska



Nobel Prize in Physics 1986

Better Electron Microscope

.... If we can see where the atoms are，then the analysis of chemical substance become very easy ......

The most difficulty is the power of electron microscope must be improved 100 times..

-Richard F. Feynman

-12.29.1959 American Physics Society, CIT

A. Resolution

NTHU

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- visible light : λ~ 6000Å

Rayleigh resolution

$$\delta = \frac{0.61\lambda}{\mu \mathrm{Sin}\beta} \quad (1.1)$$

δ:Rayleigh resolution

λ: wavelength

μ: refractive index

β: semi-angle of lens

μSinβ:Numerical Aperature~1

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A. Resolution

A the resolution of an optical microscope is limited by the wavelength。

- visible light : λ~ 6000Å

Rayleigh resolution

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Particle/ Wave Duality

Louis de Broglie

Nobel laureate in 1929

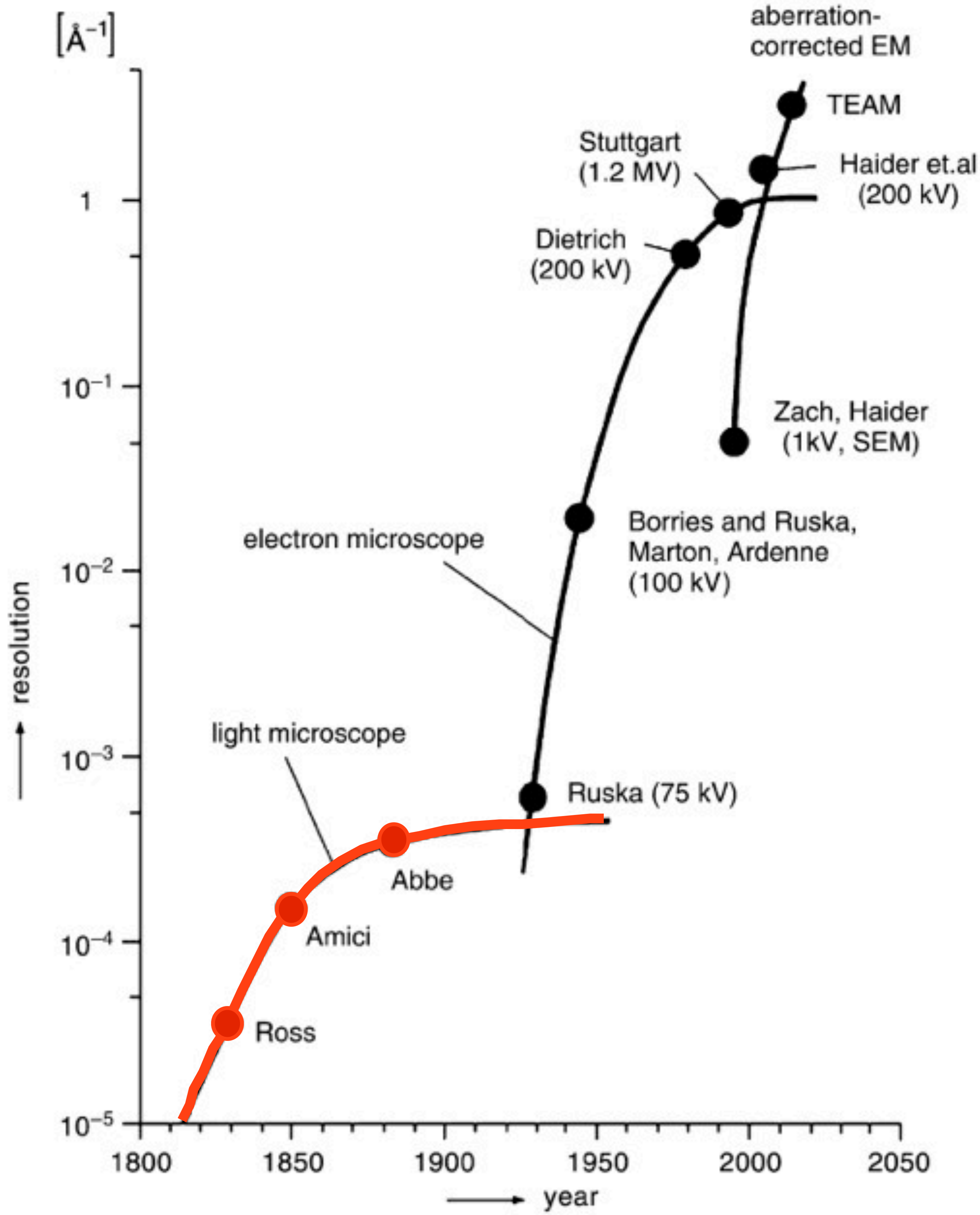
- de Broglie's matter/ wave theory

$$\lambda \sim \frac{1.22}{E^{1/2}}$$

$$E = 1/2\ m_o \upsilon^2$$

E (kev)	λ(Å)
100	0.037
200	0.025
300	0.0196
400	0.0169

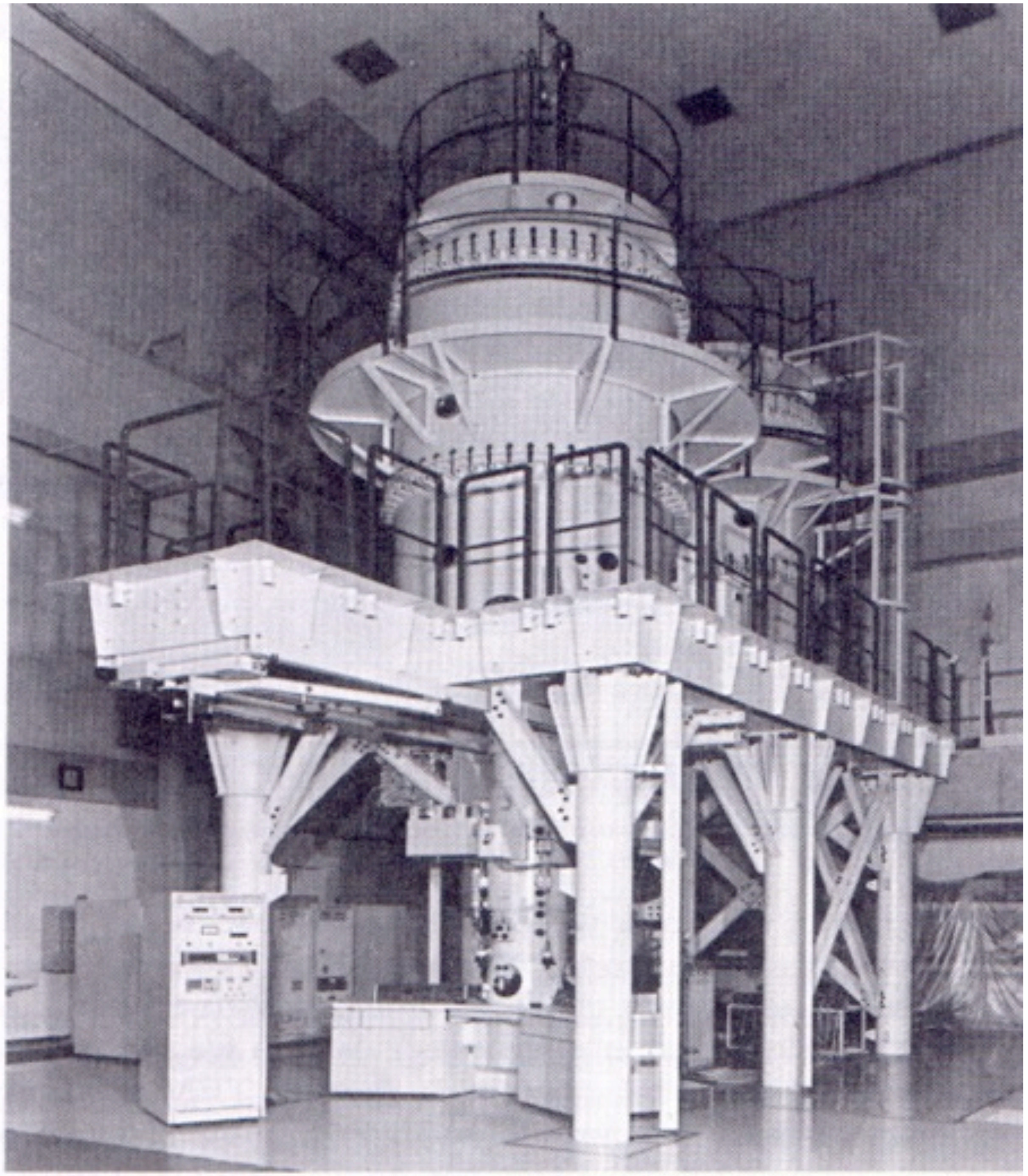
Evolution of resolution in EM



High and Median Voltage TEM

200keV

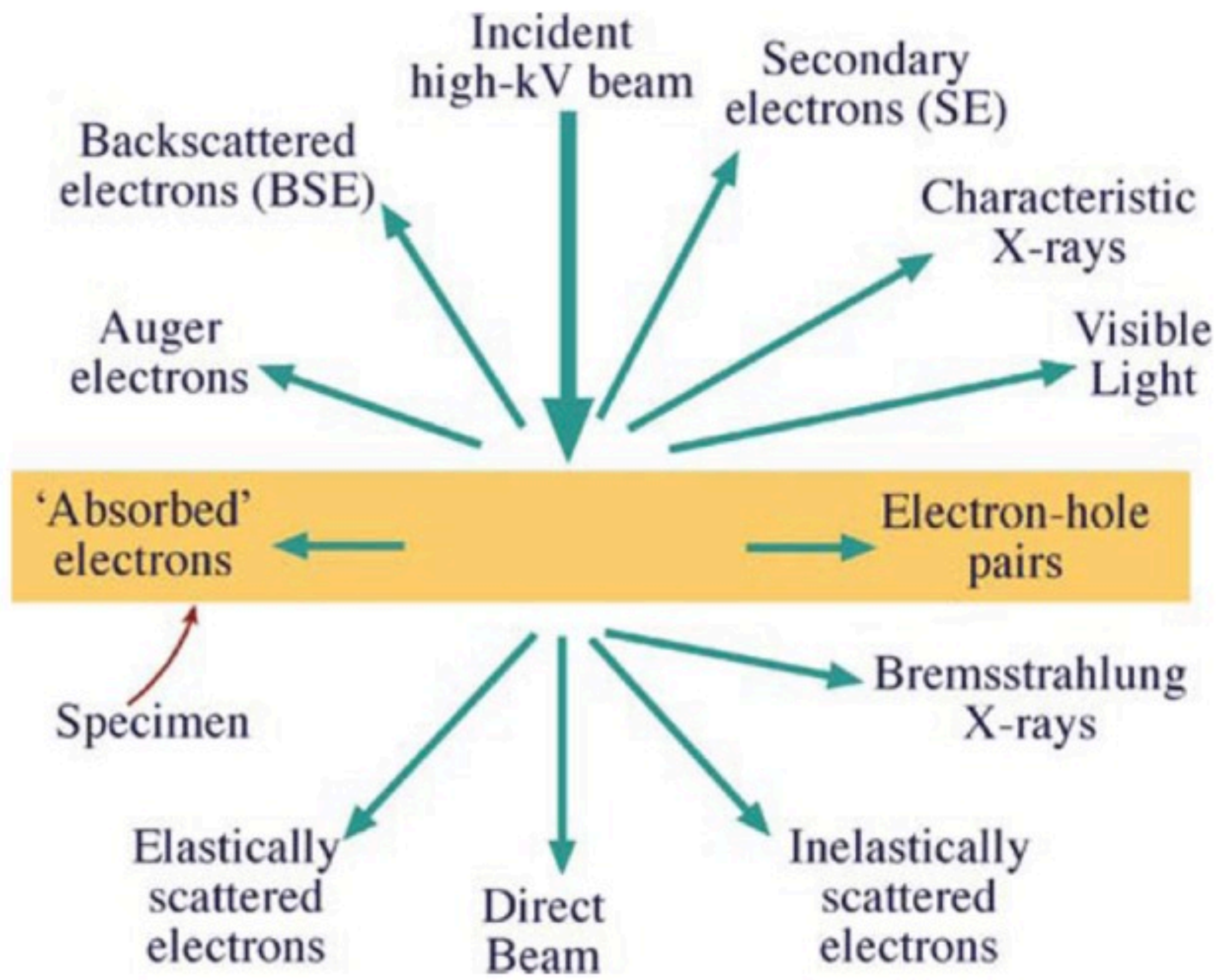
High and Median Voltage TEM



1MeV

200keV

B. MIcroanalysis，(X-Ray)，(EELS)



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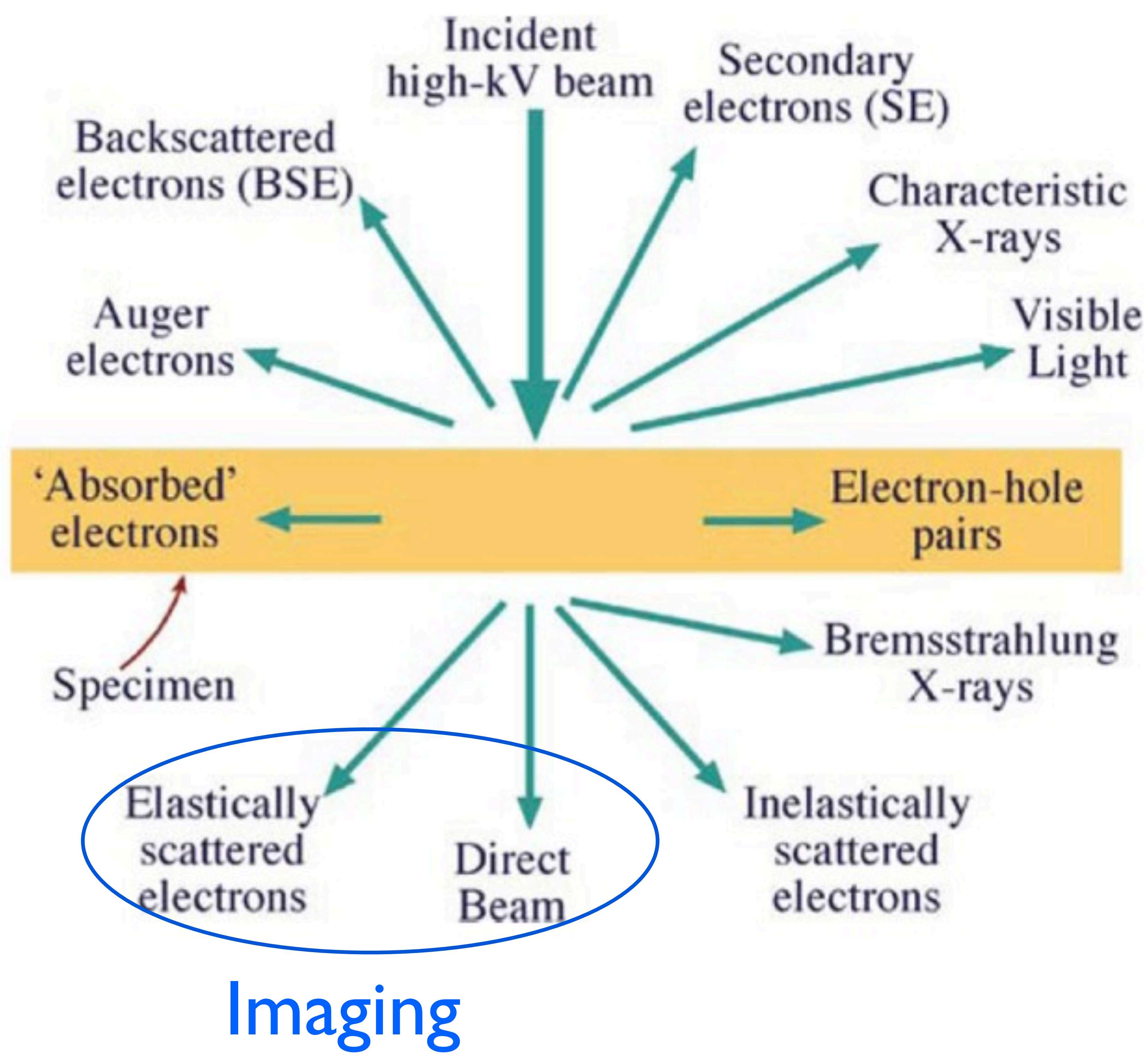

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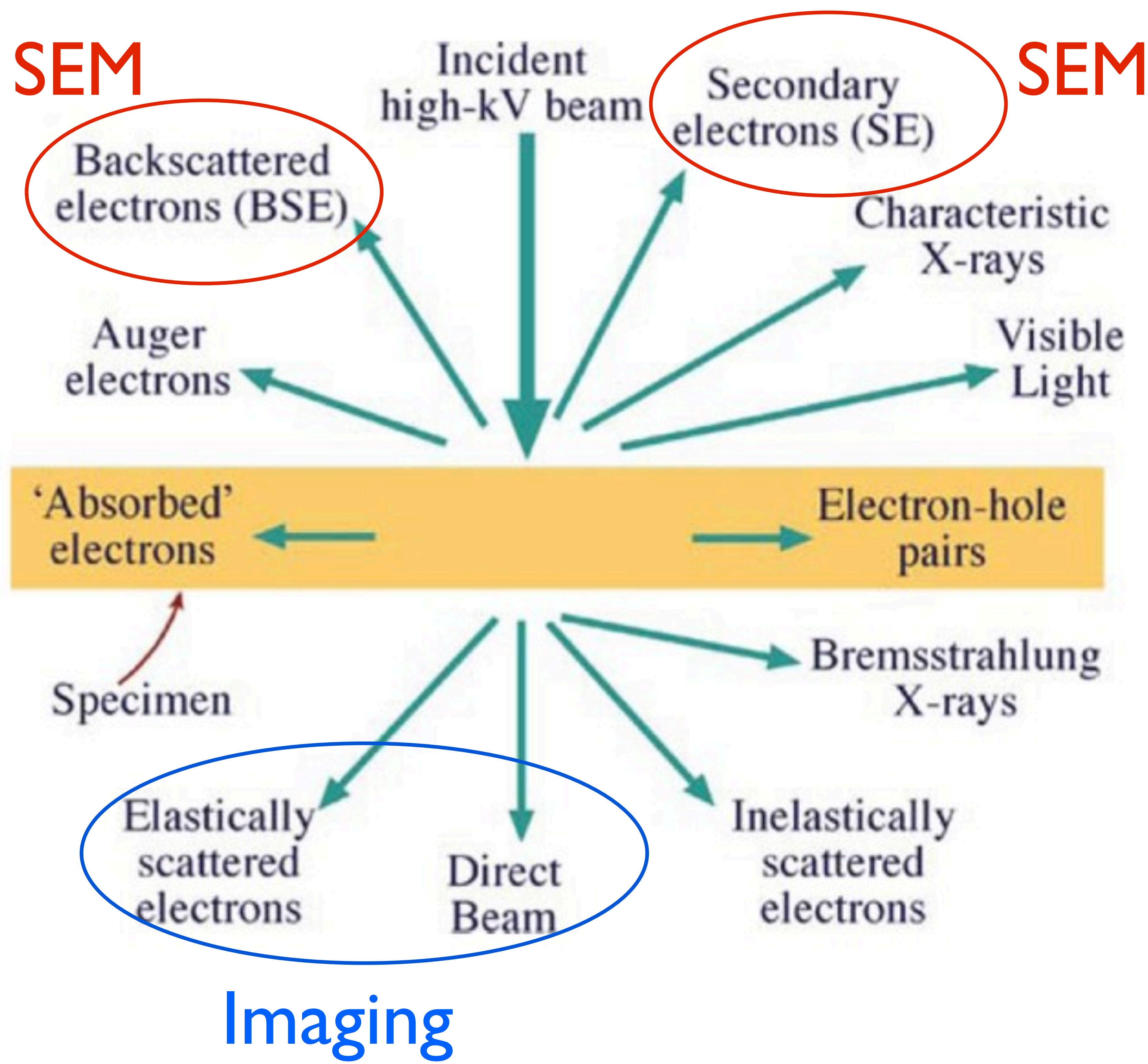

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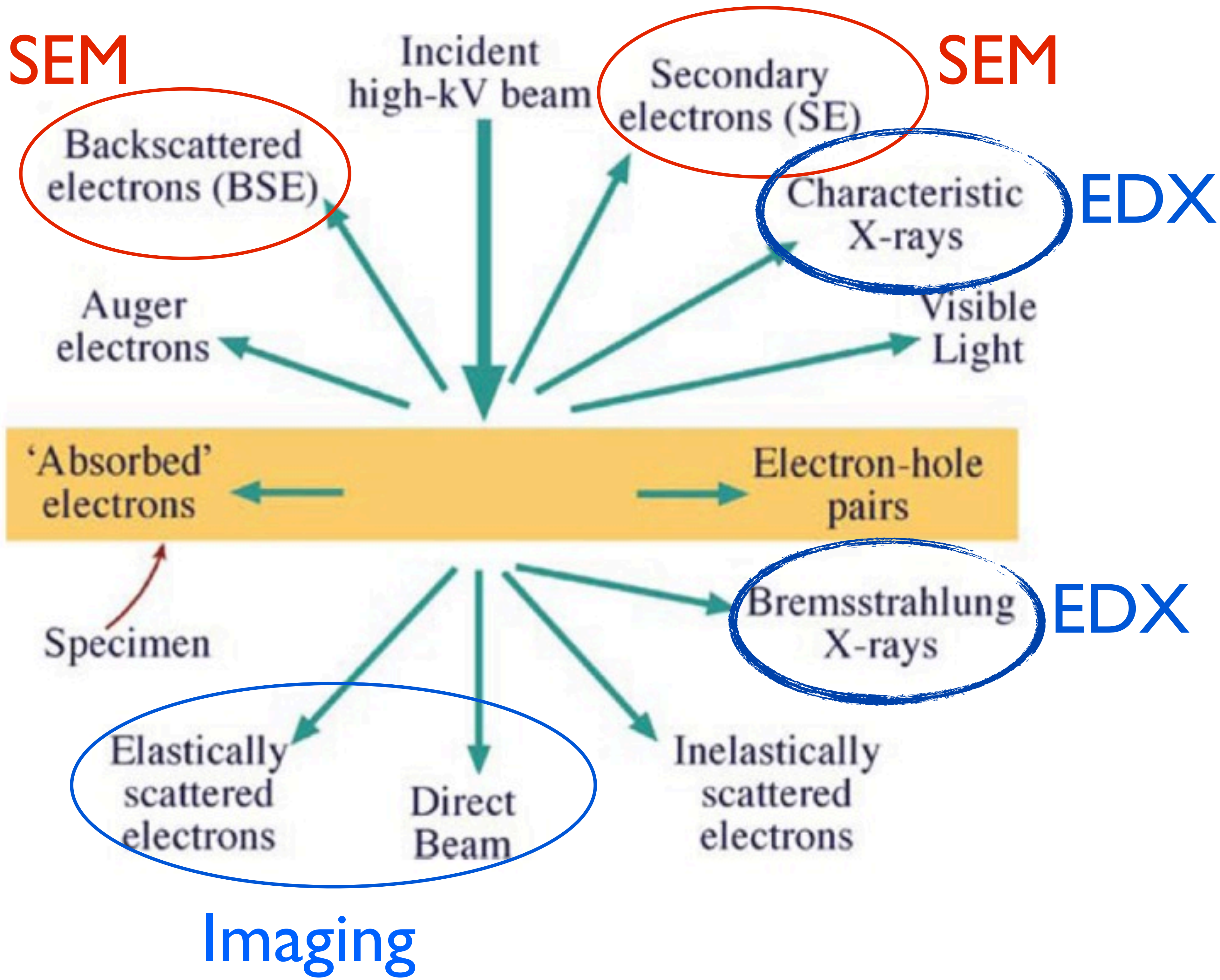

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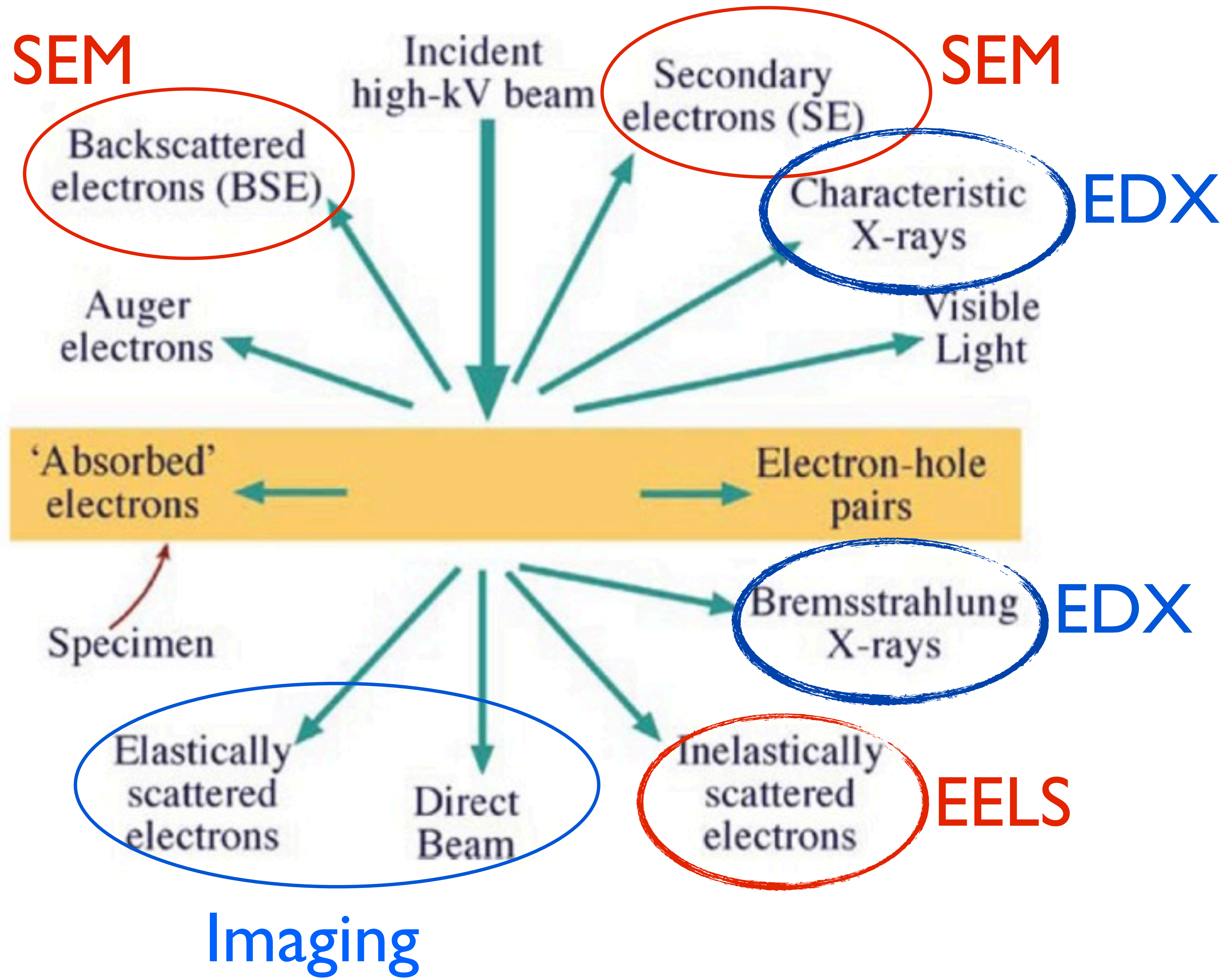

Typical TEM+EDX+EELS

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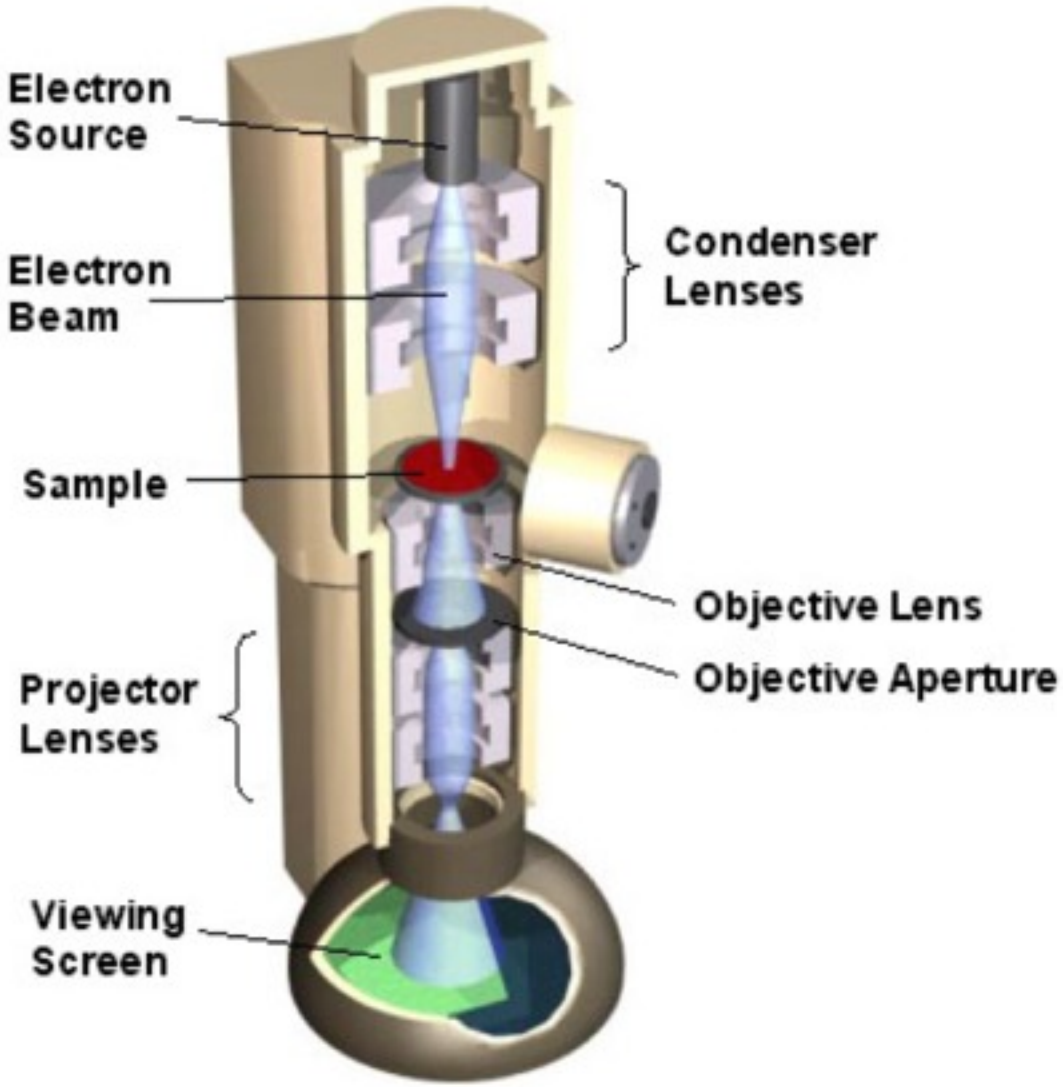

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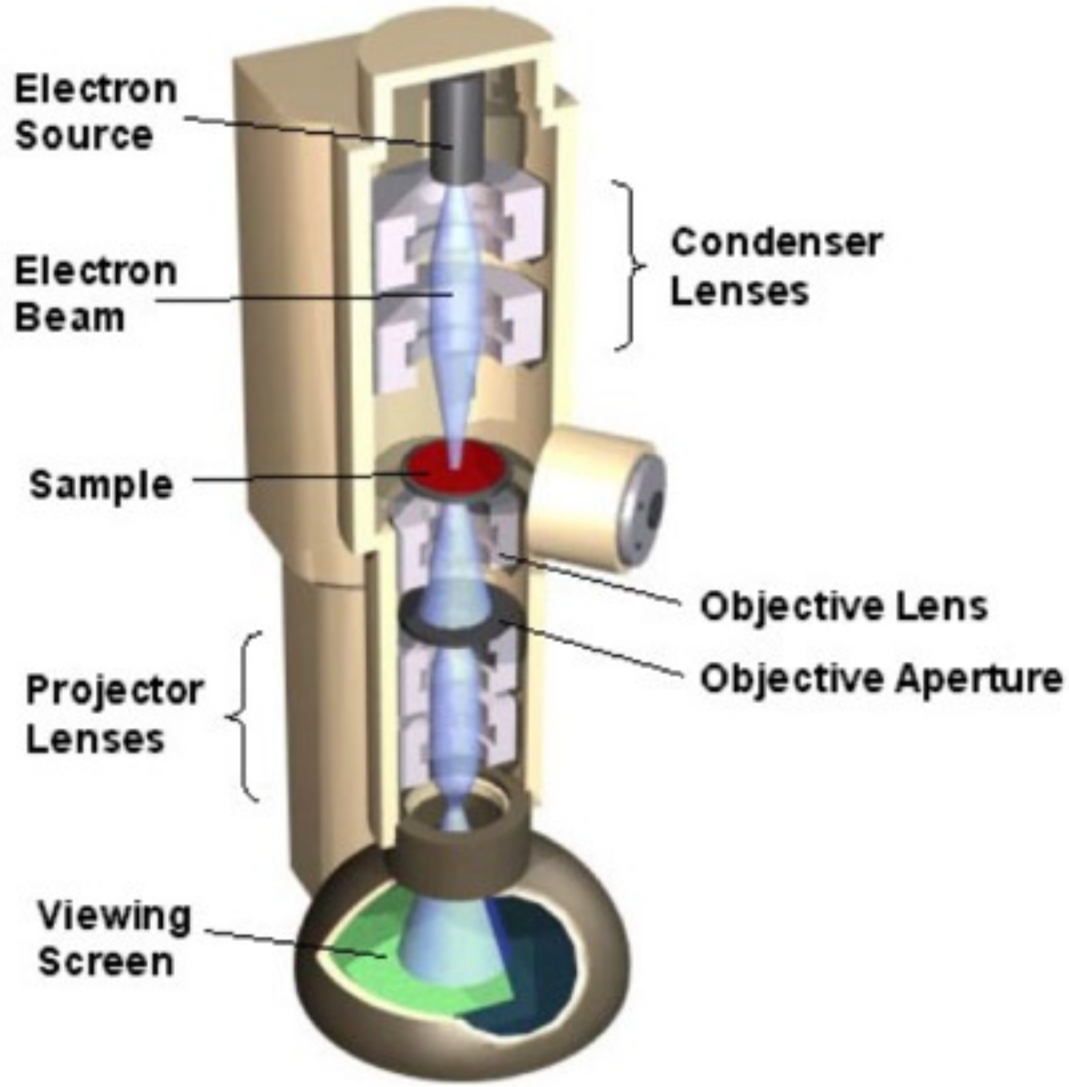

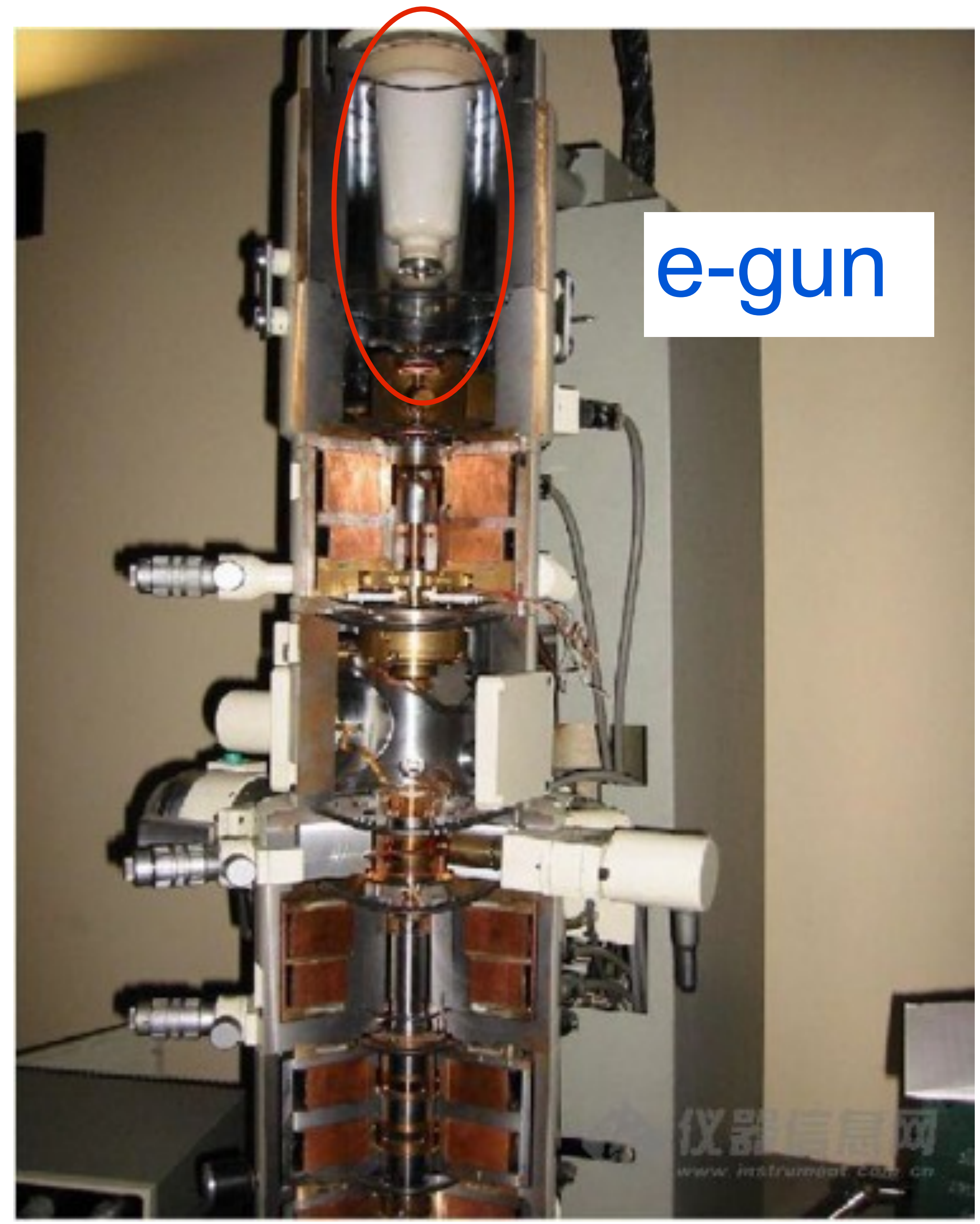

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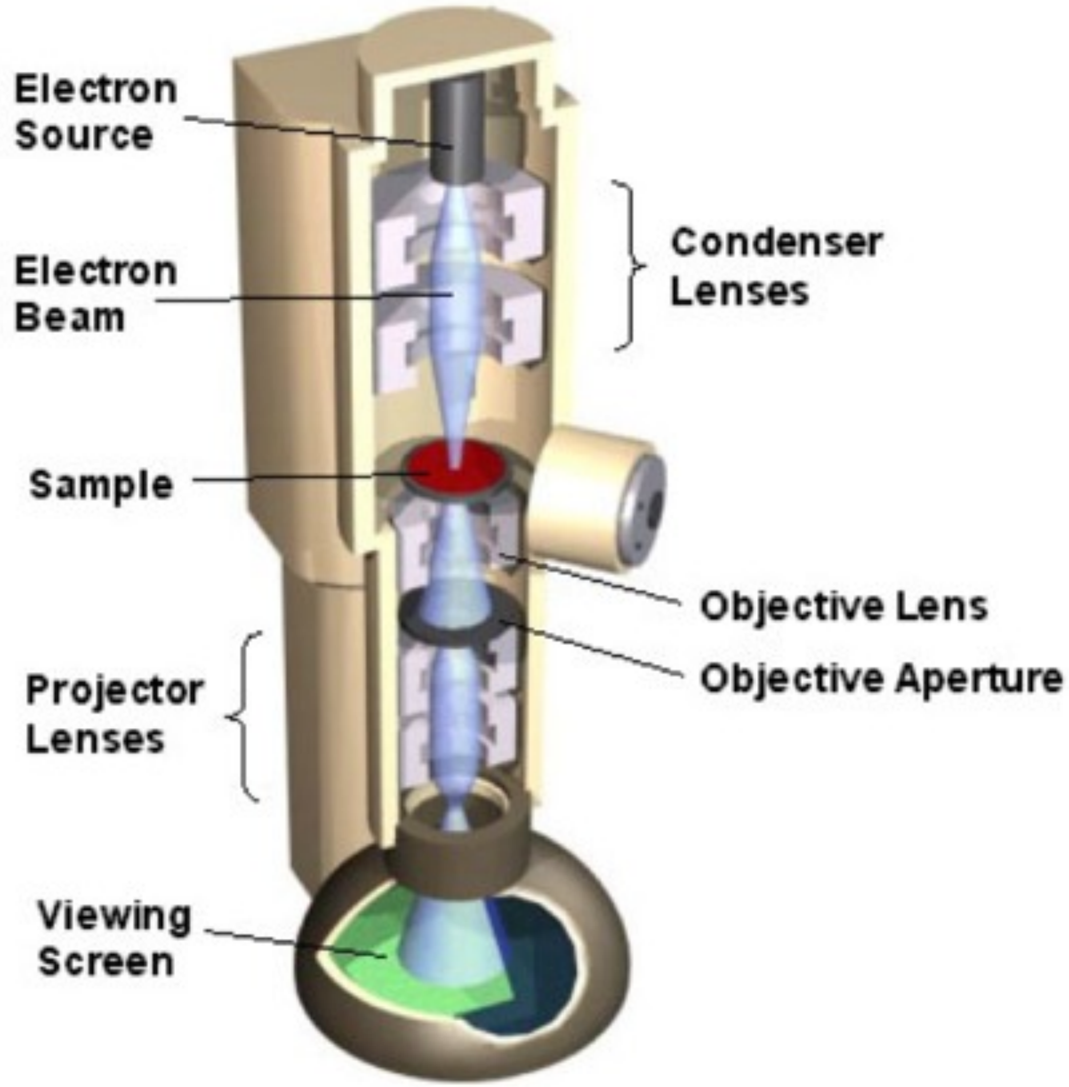

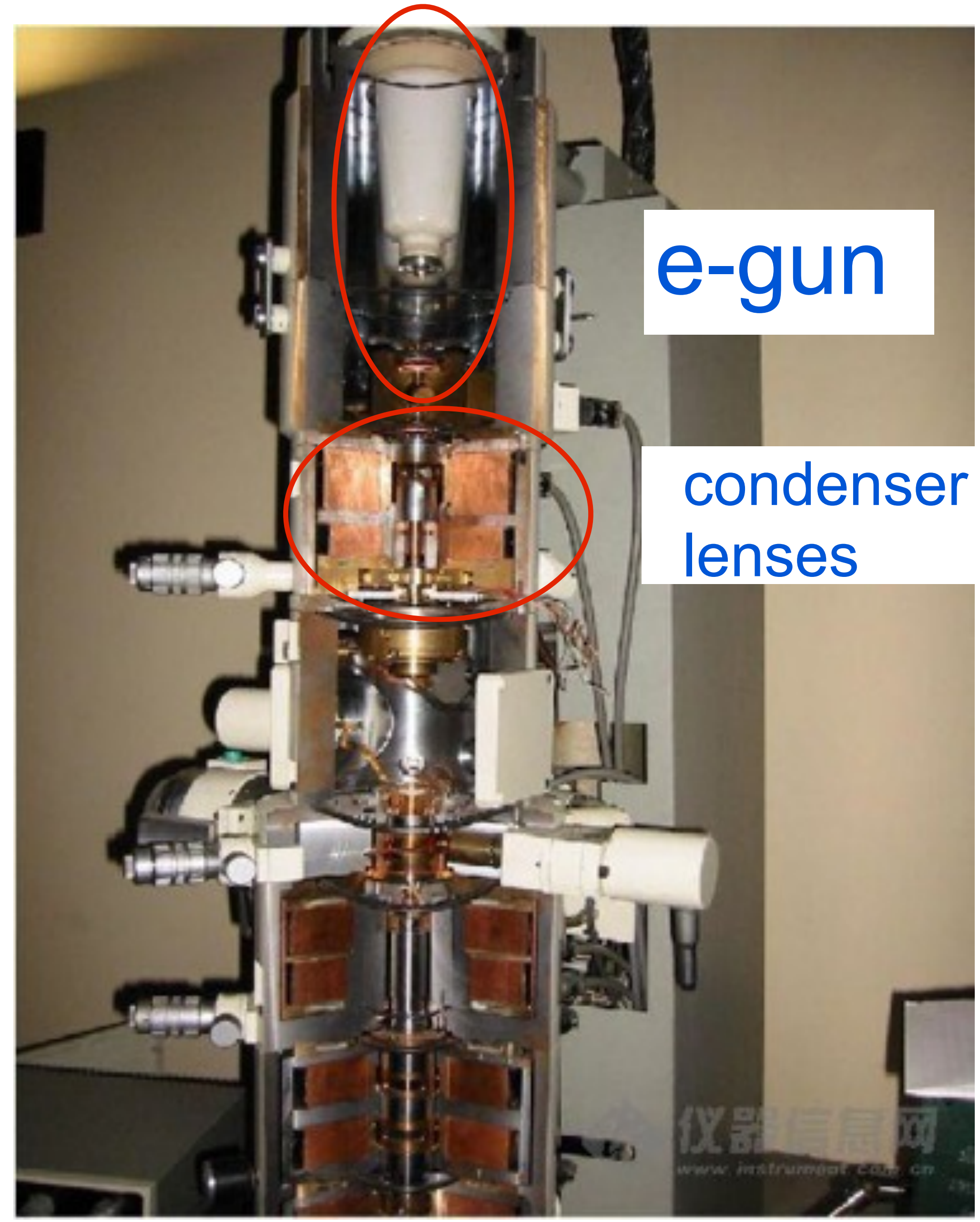

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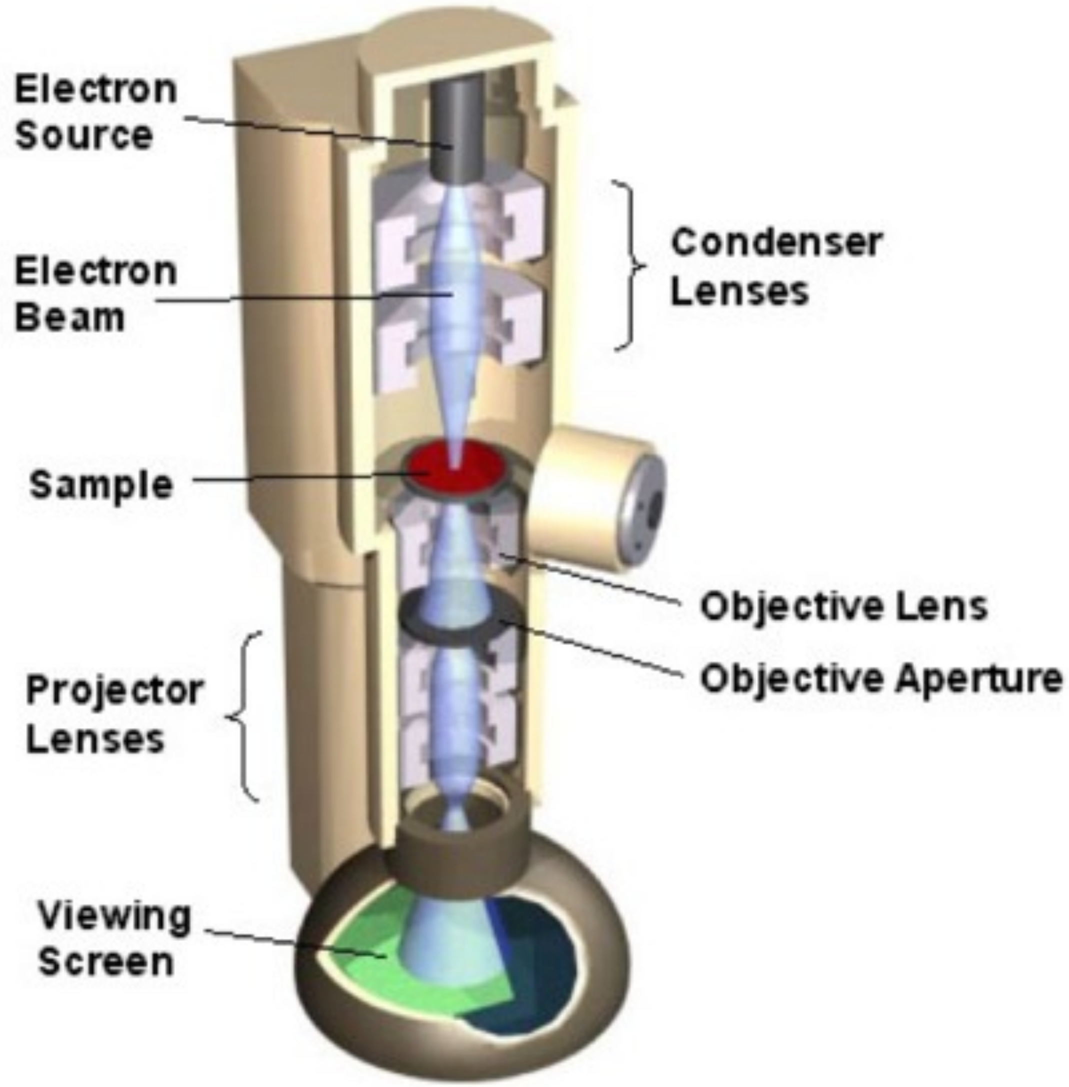

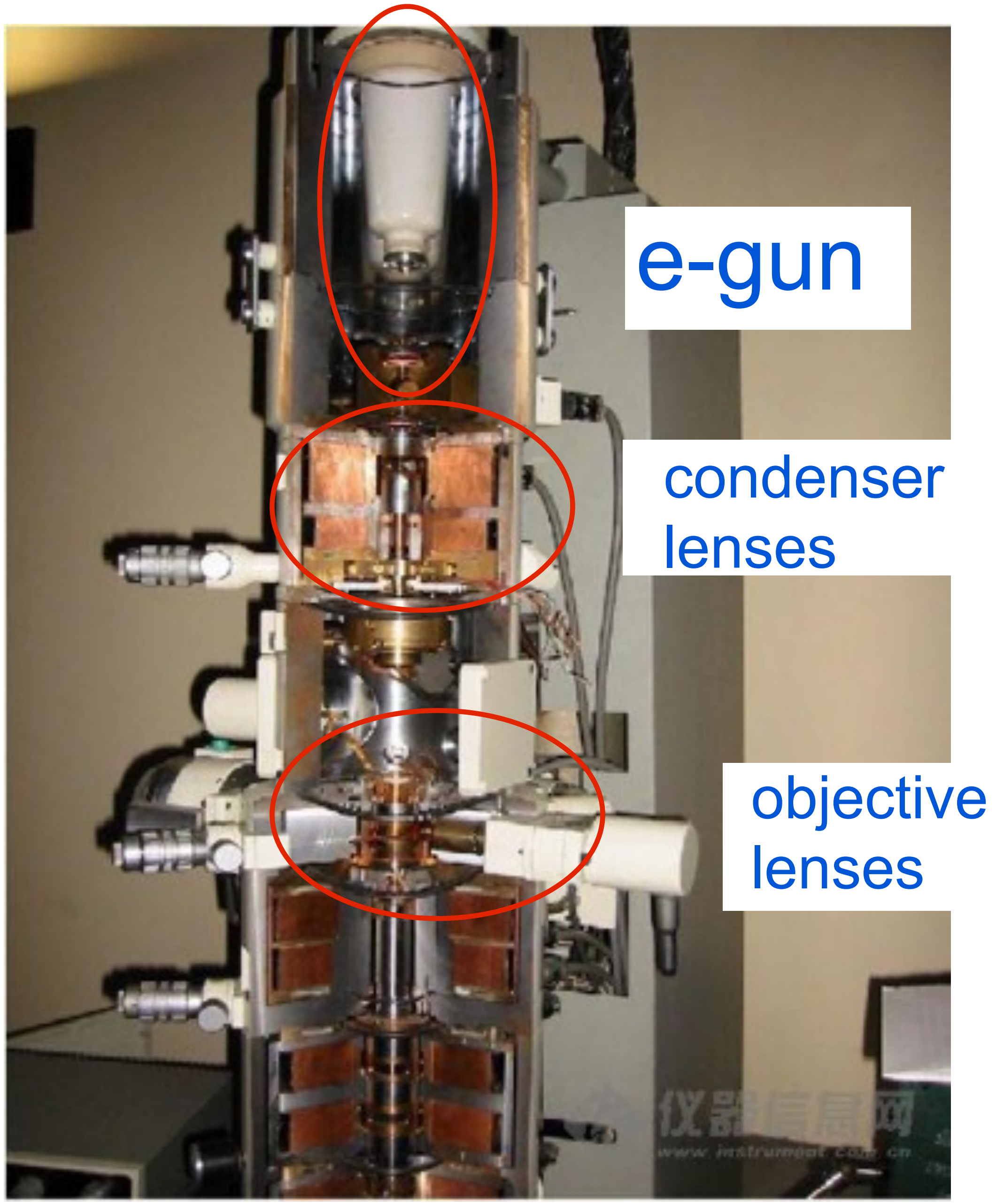

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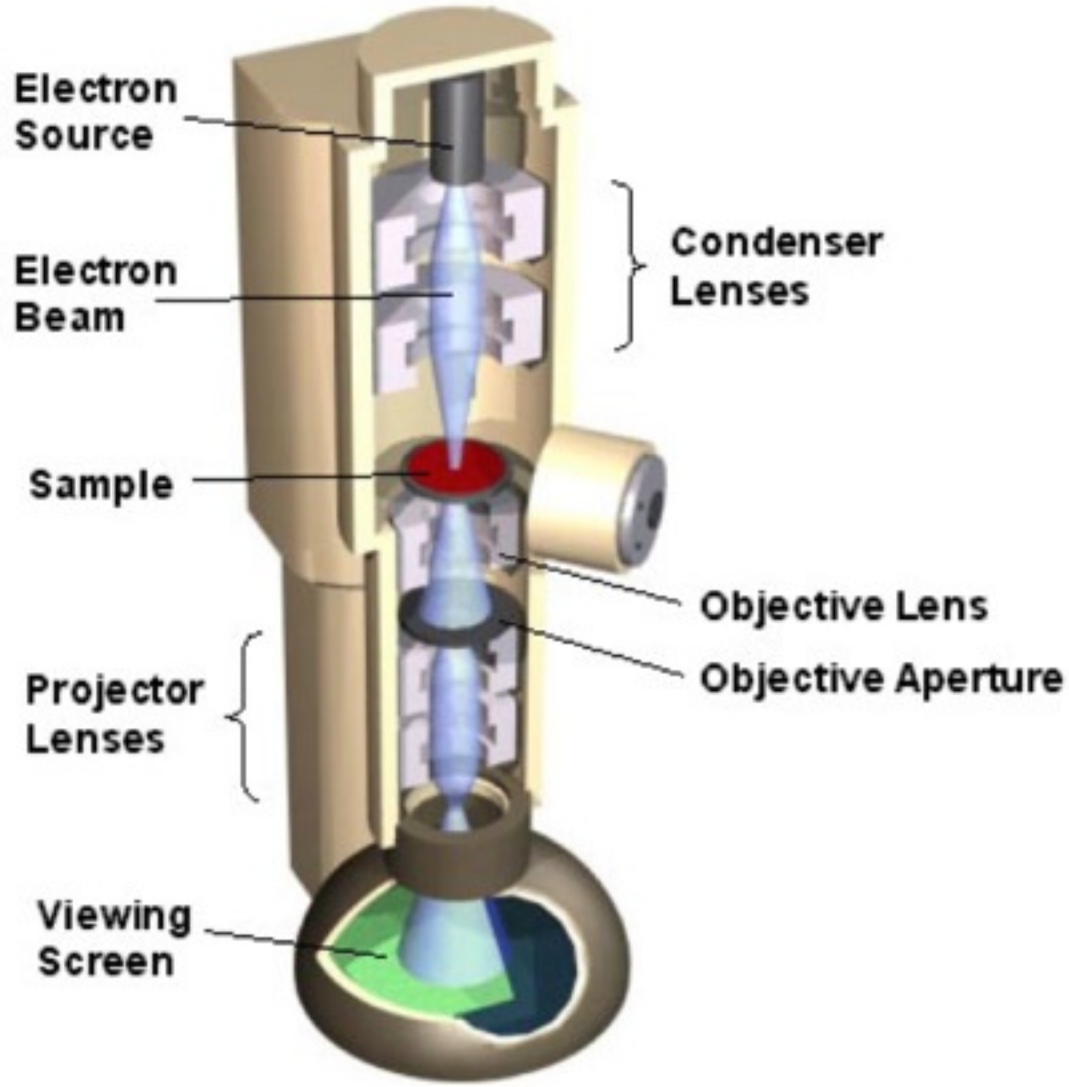

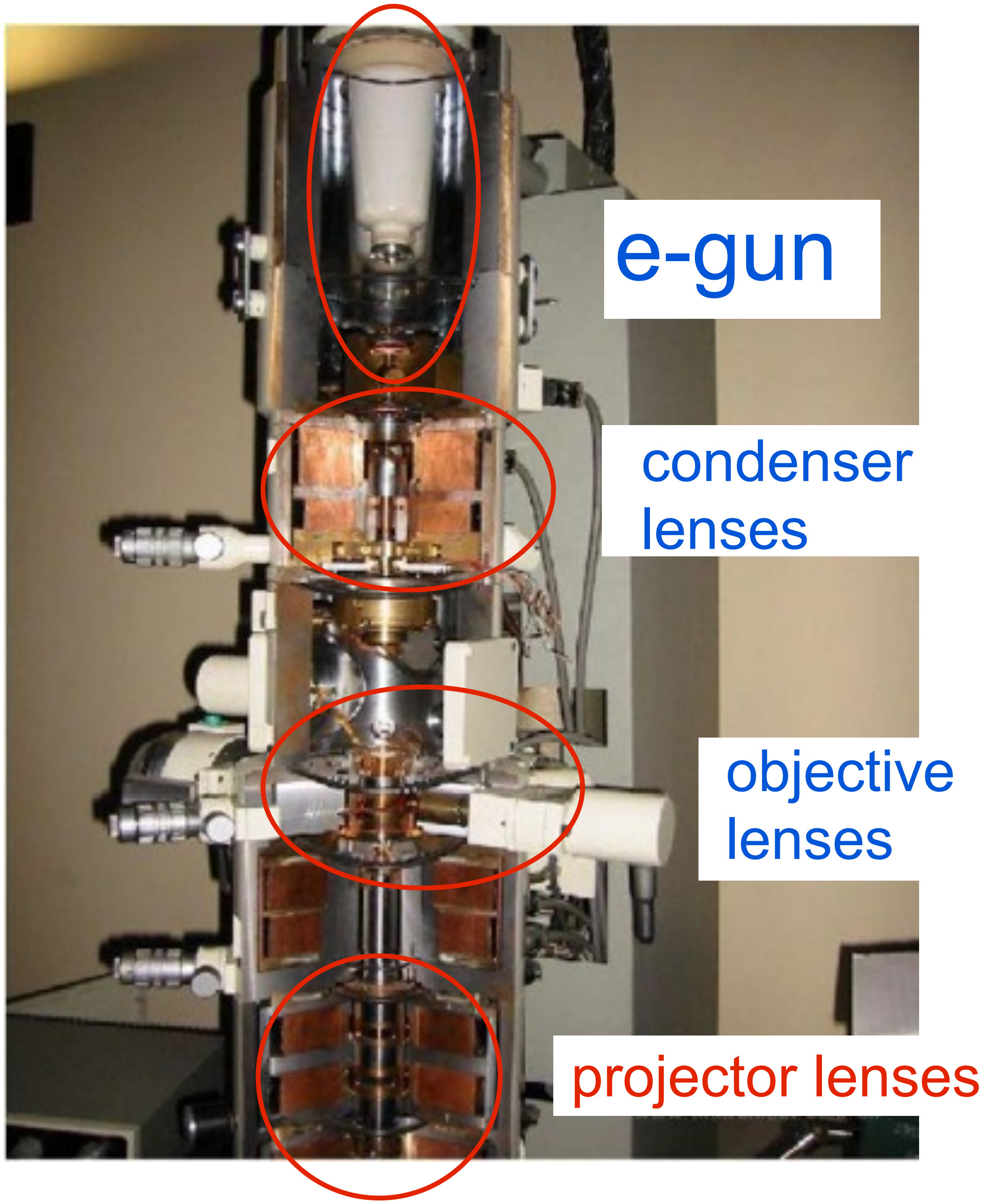

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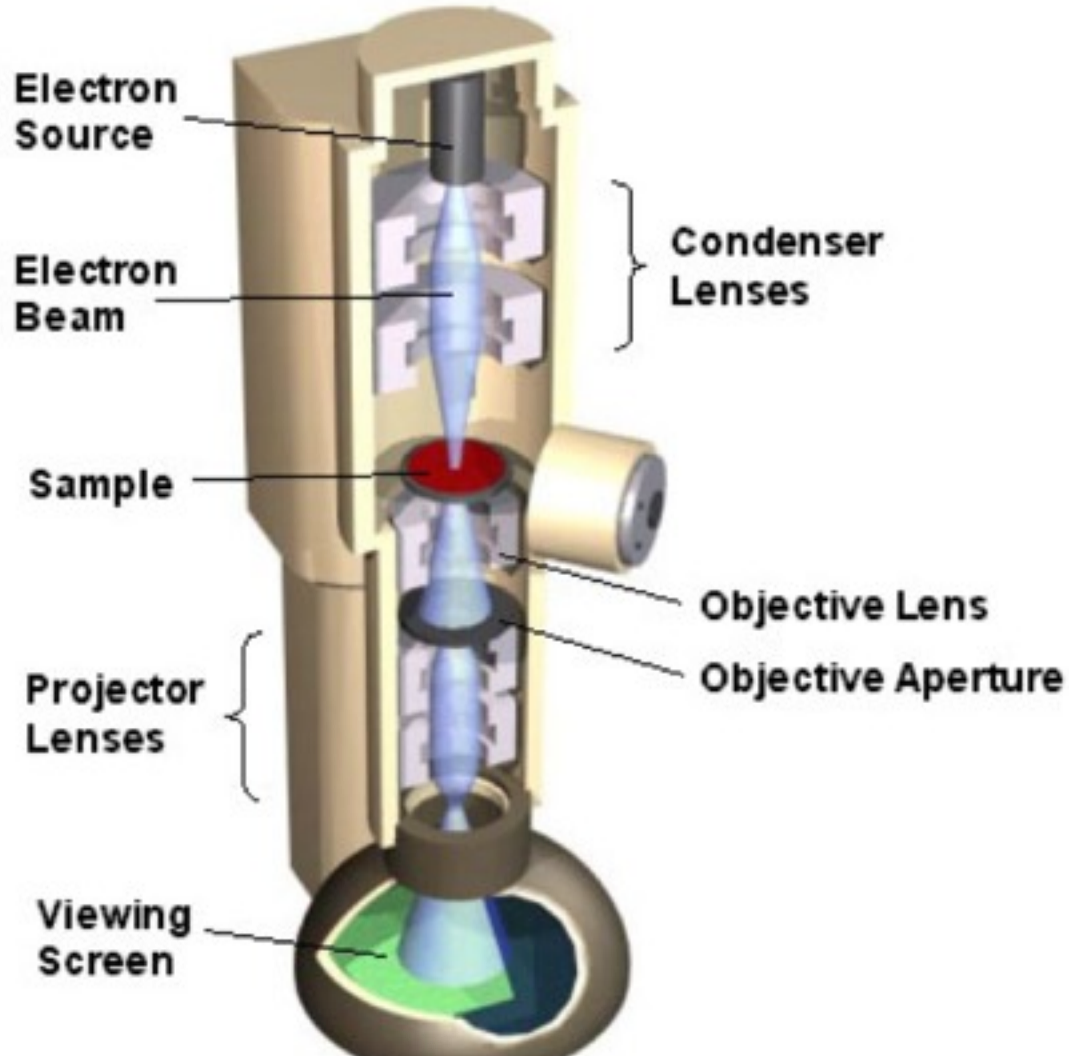

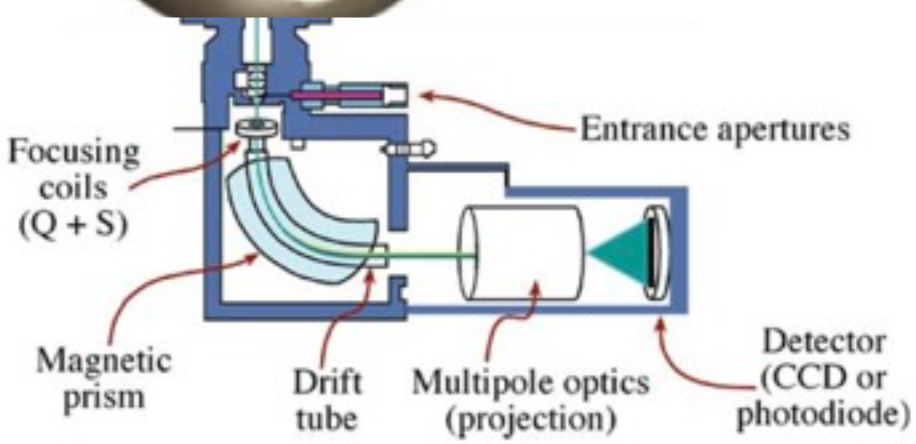

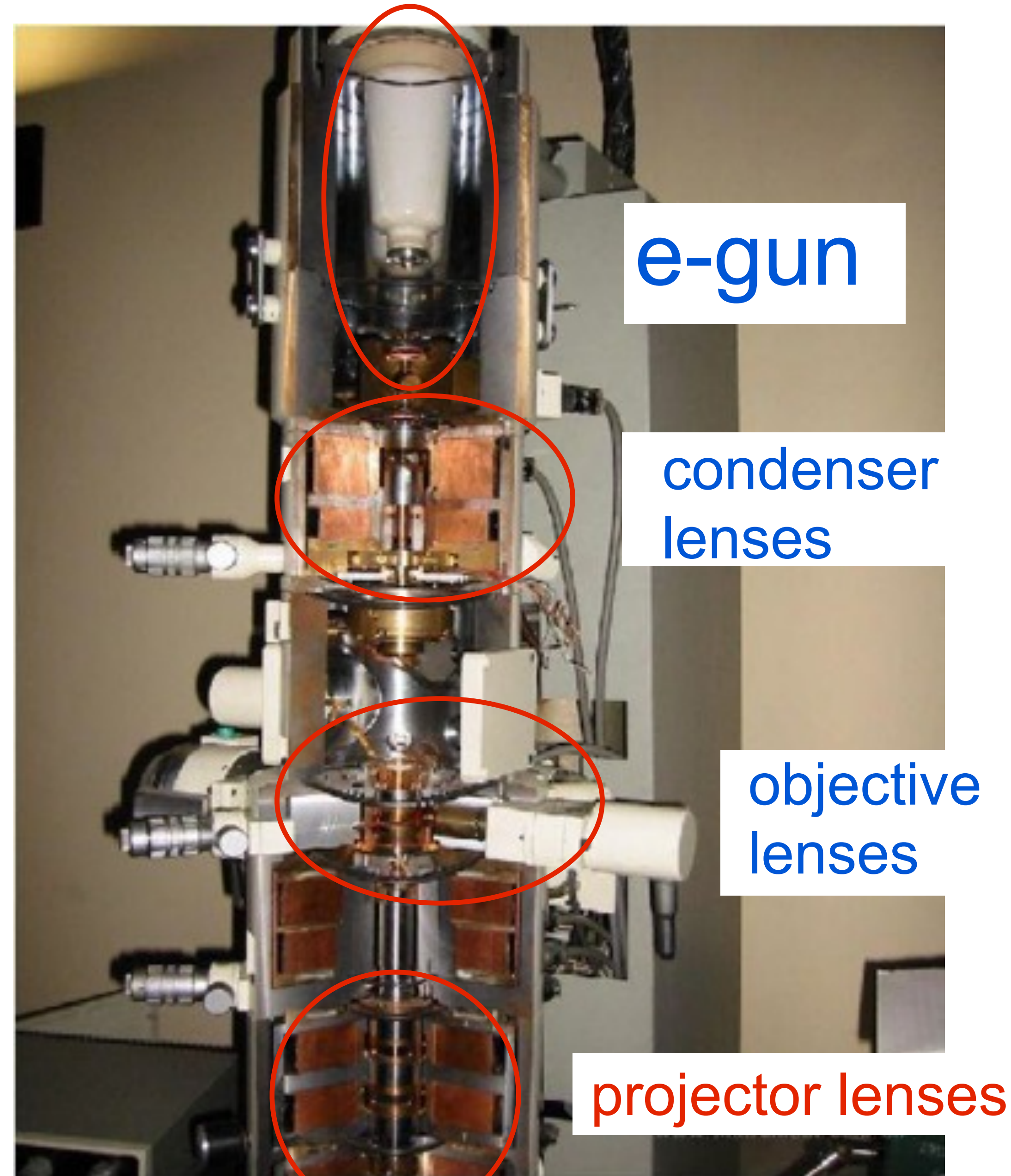

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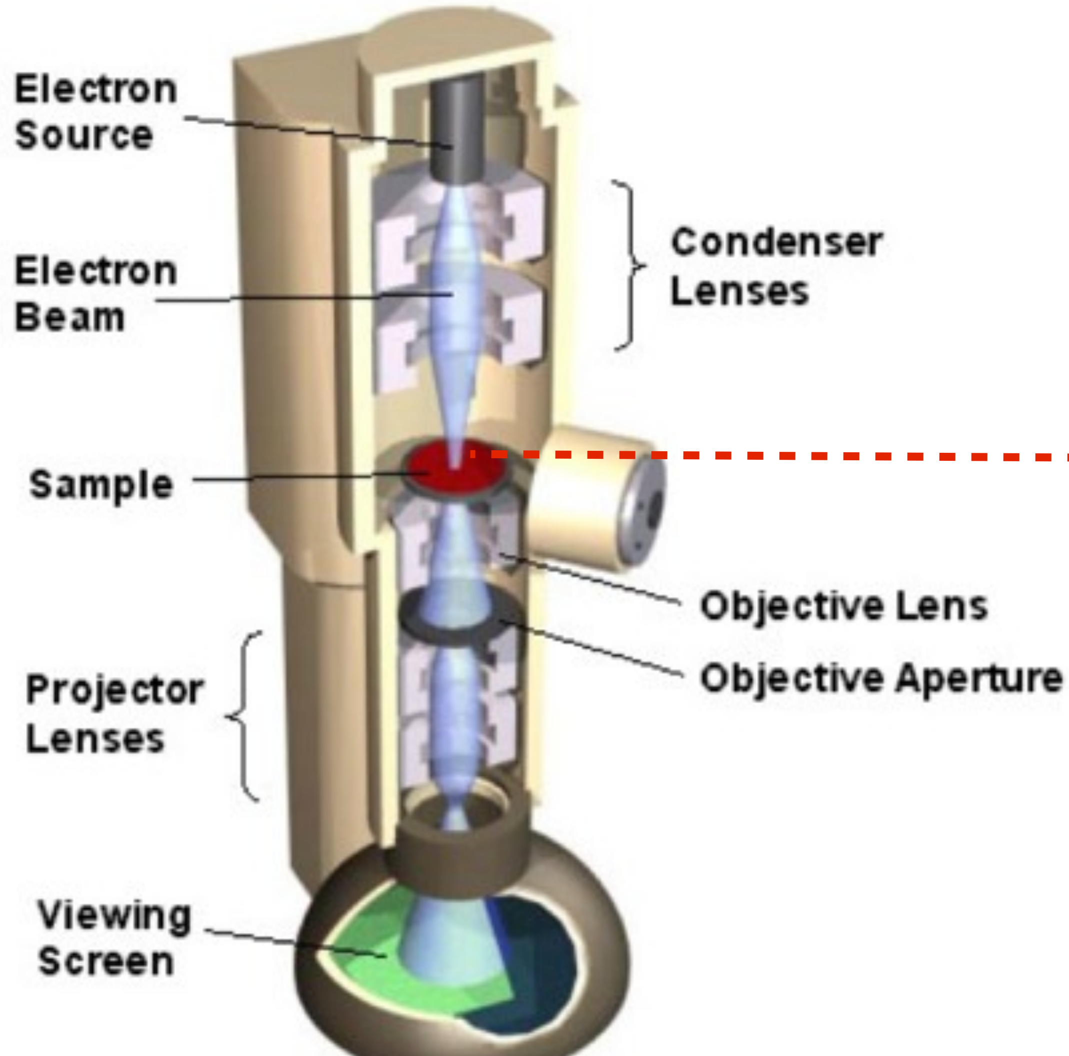

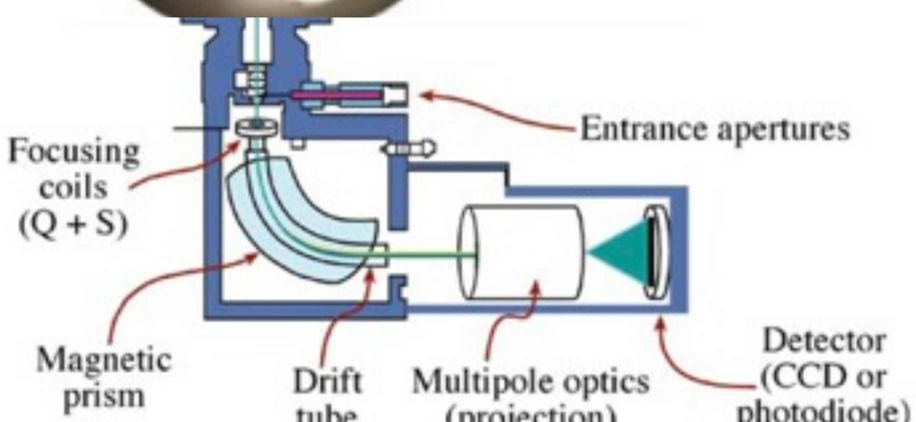

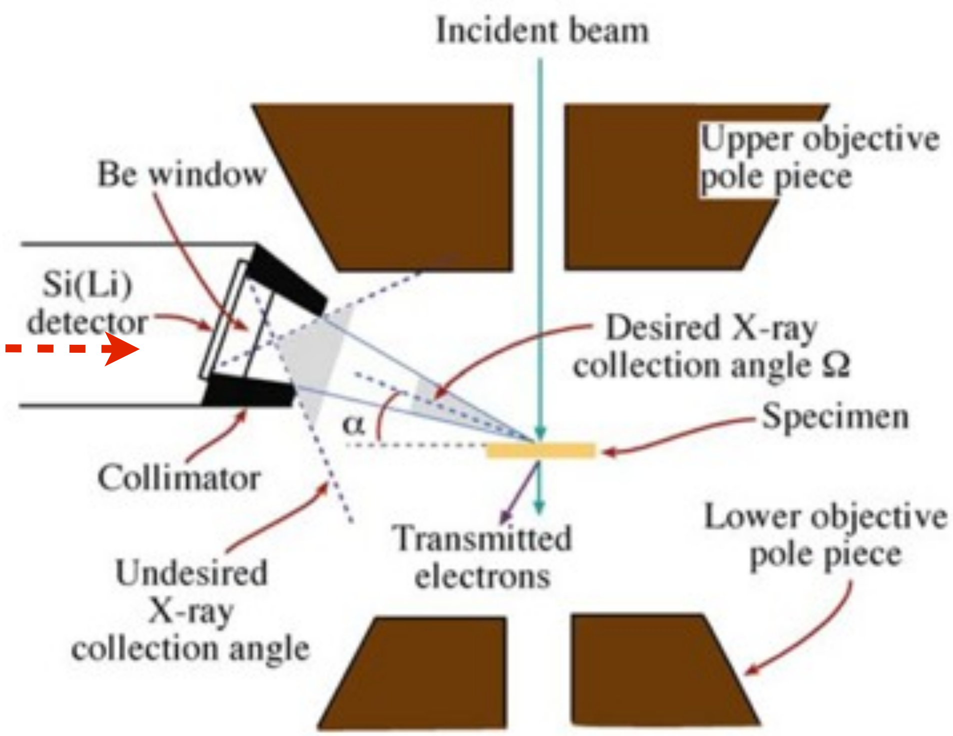

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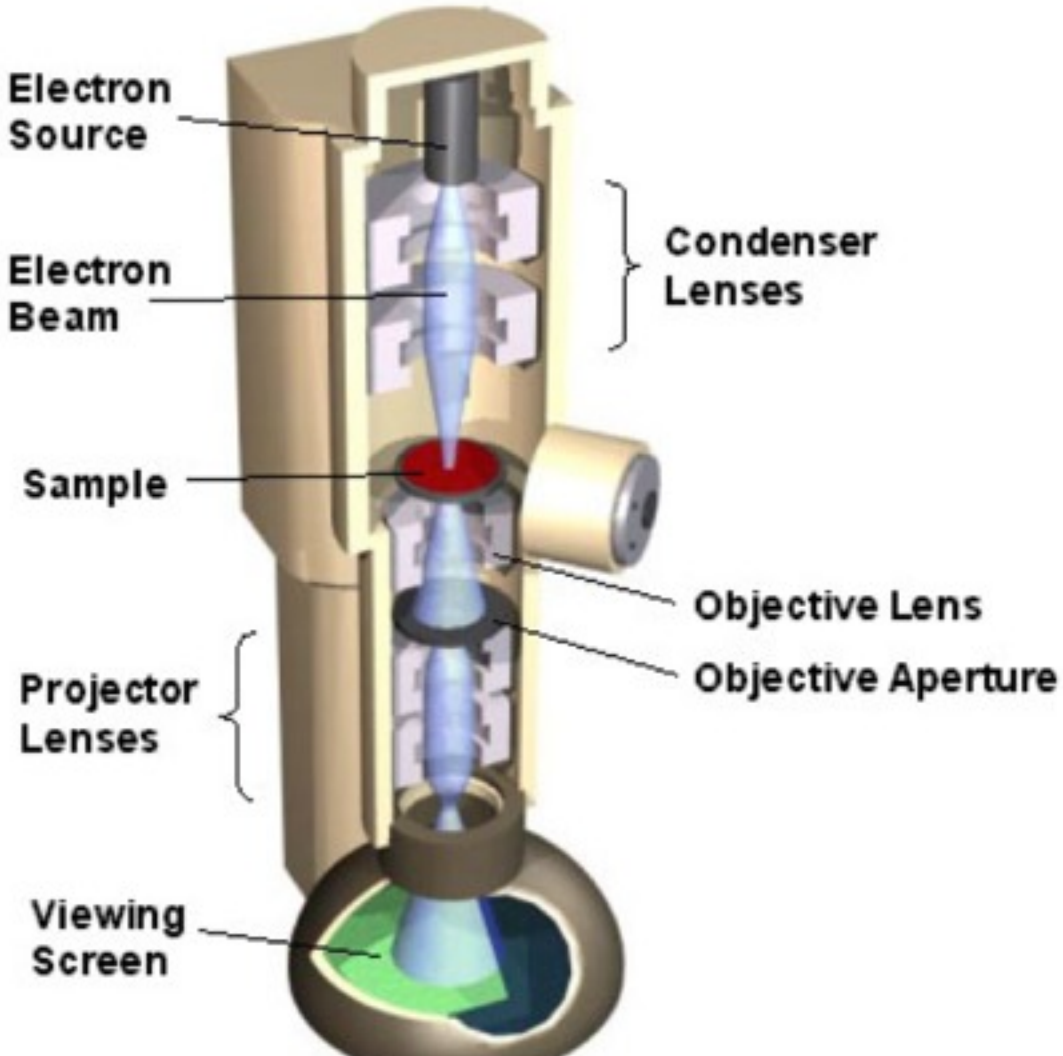

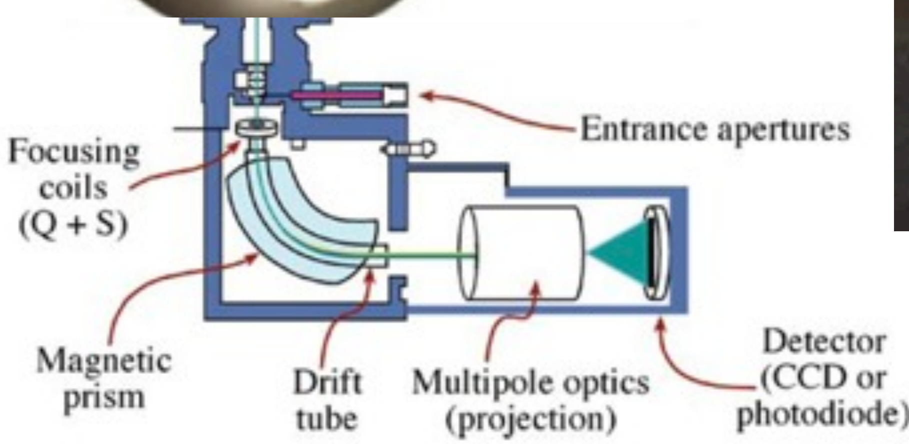

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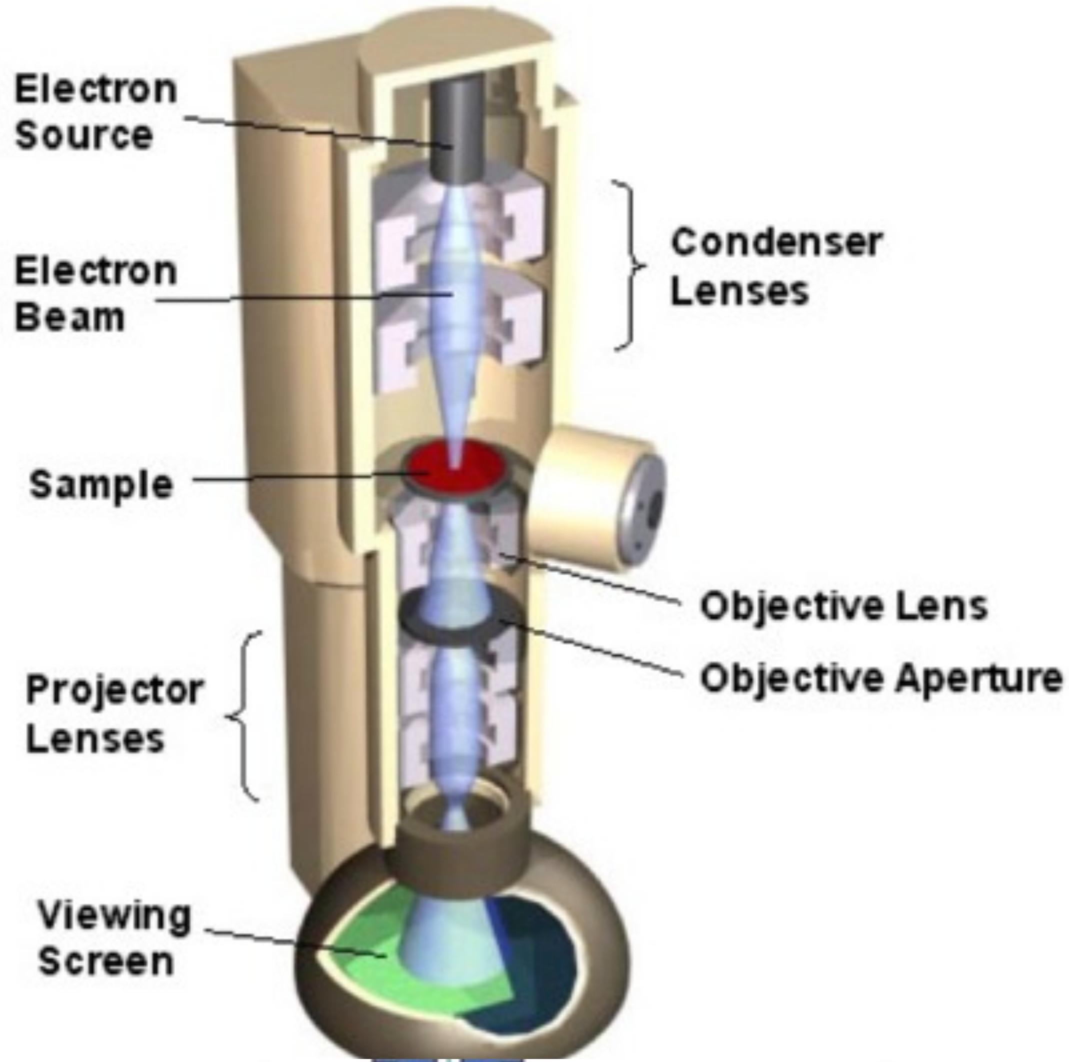

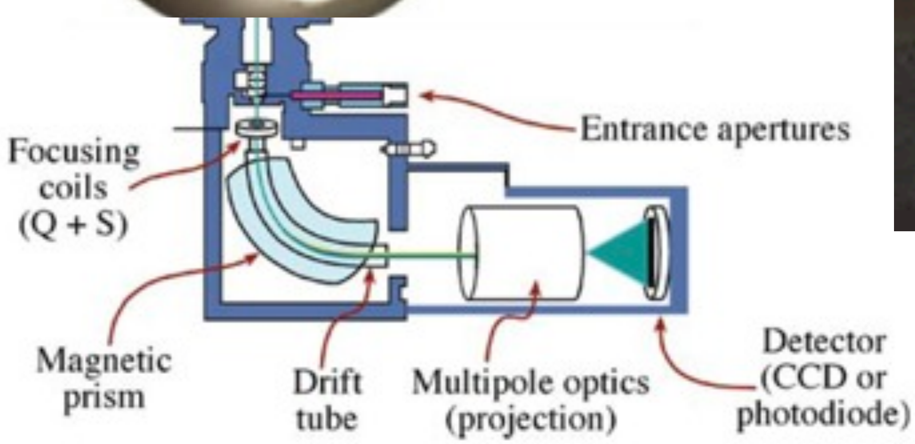

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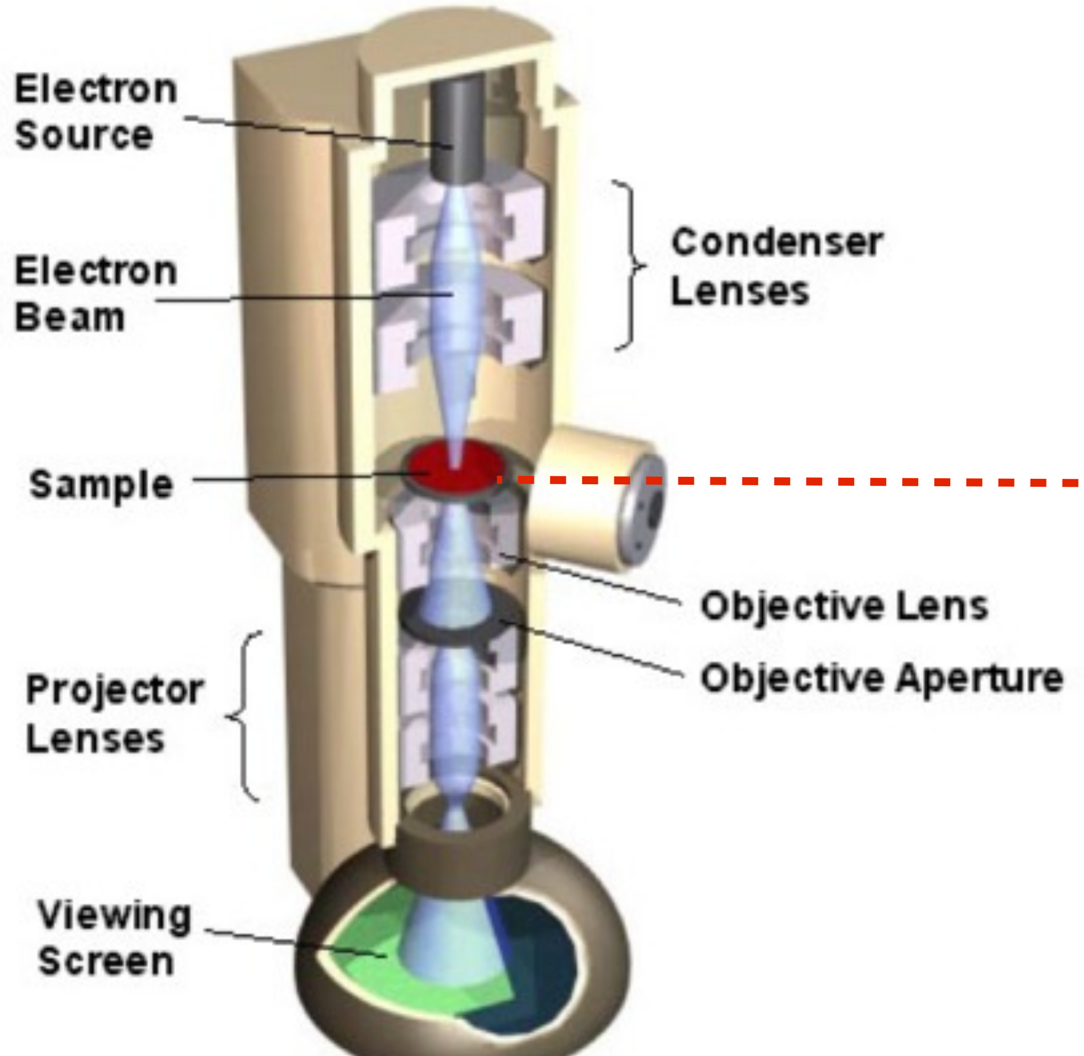
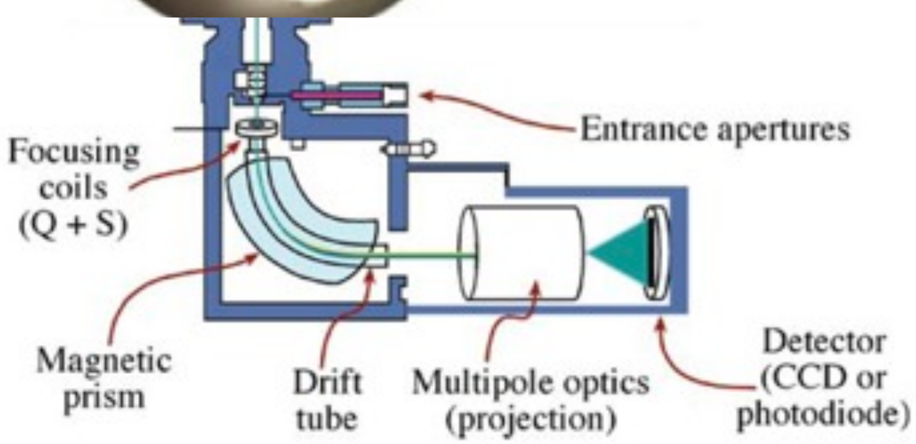
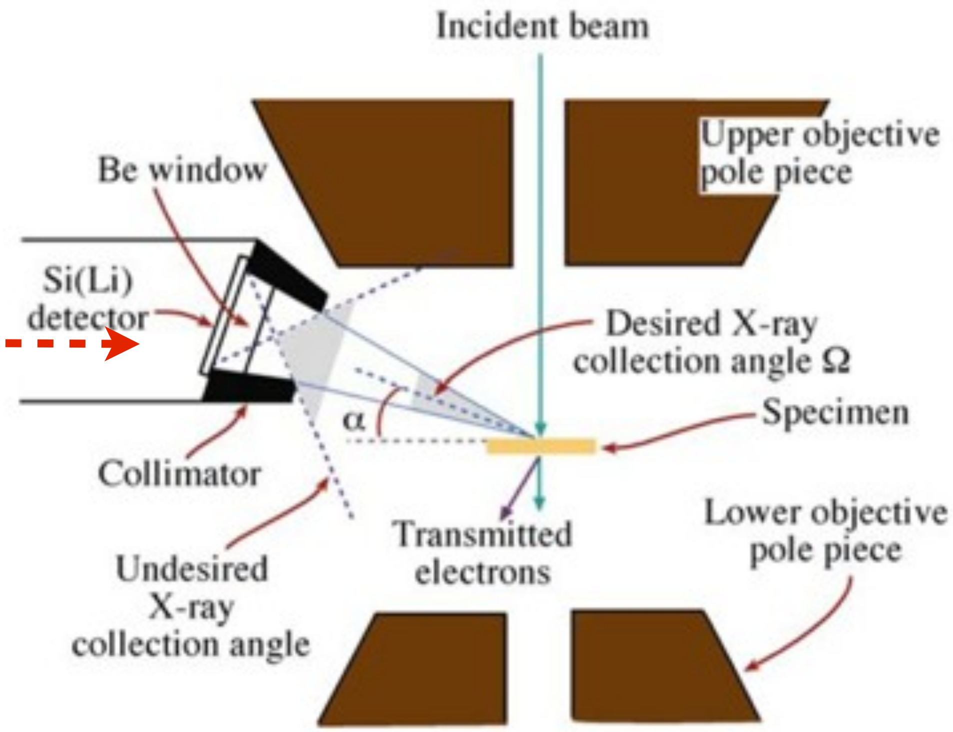


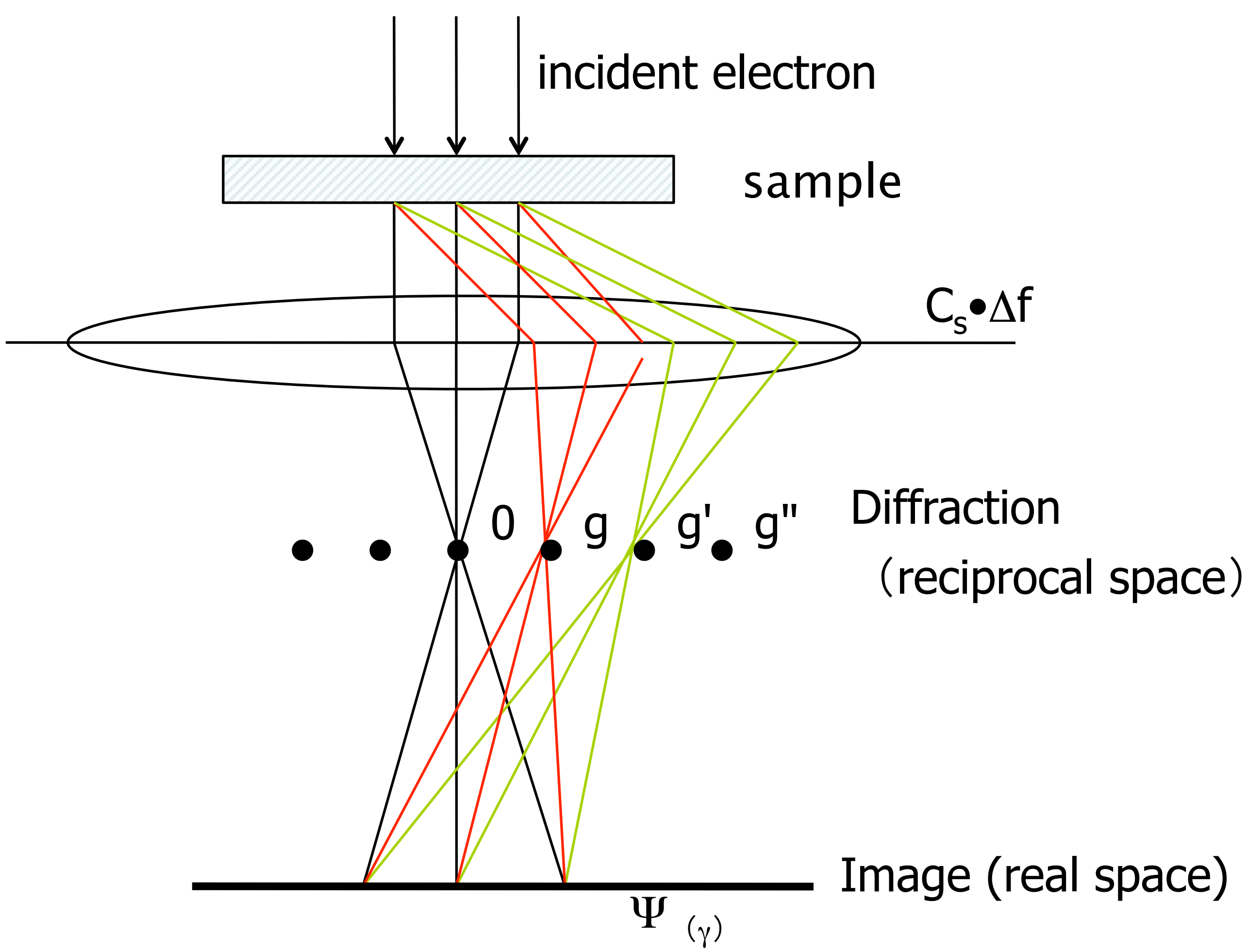


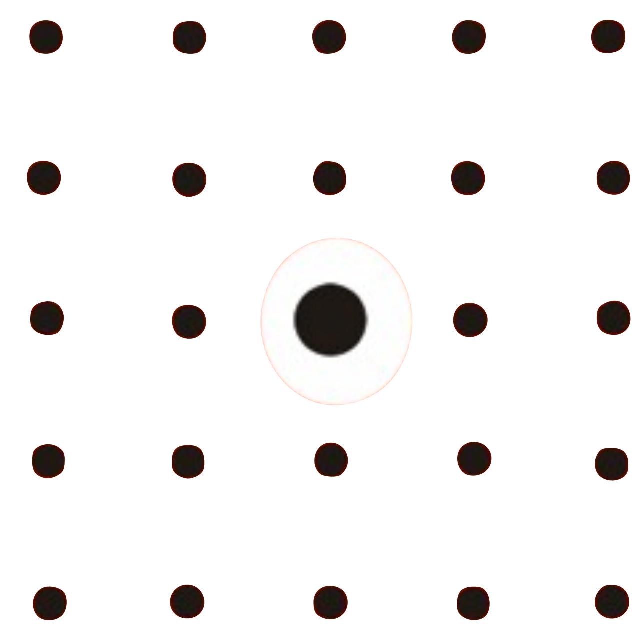


C. Diffraction

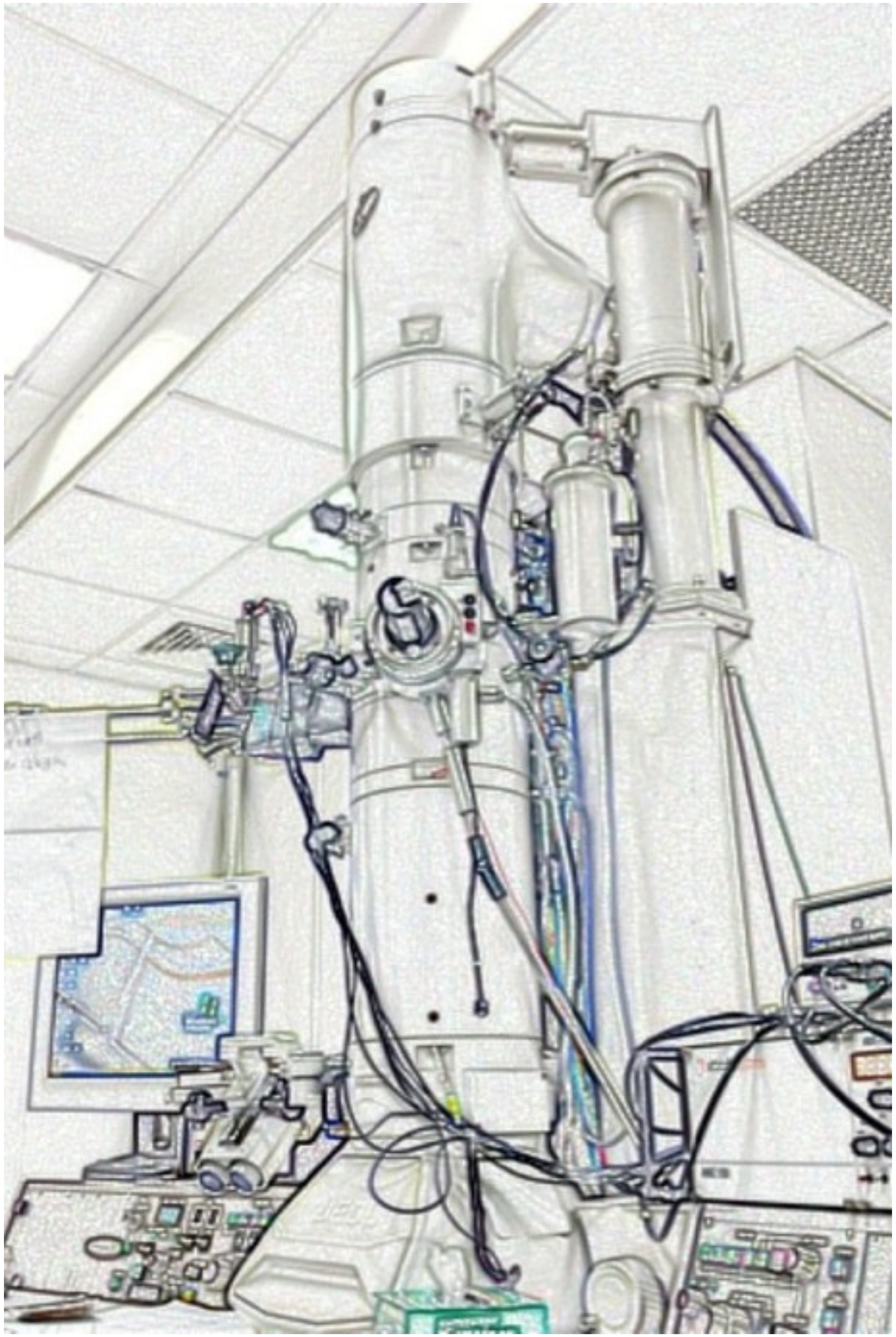
No lens for X-ray: Only diffraction can be seen

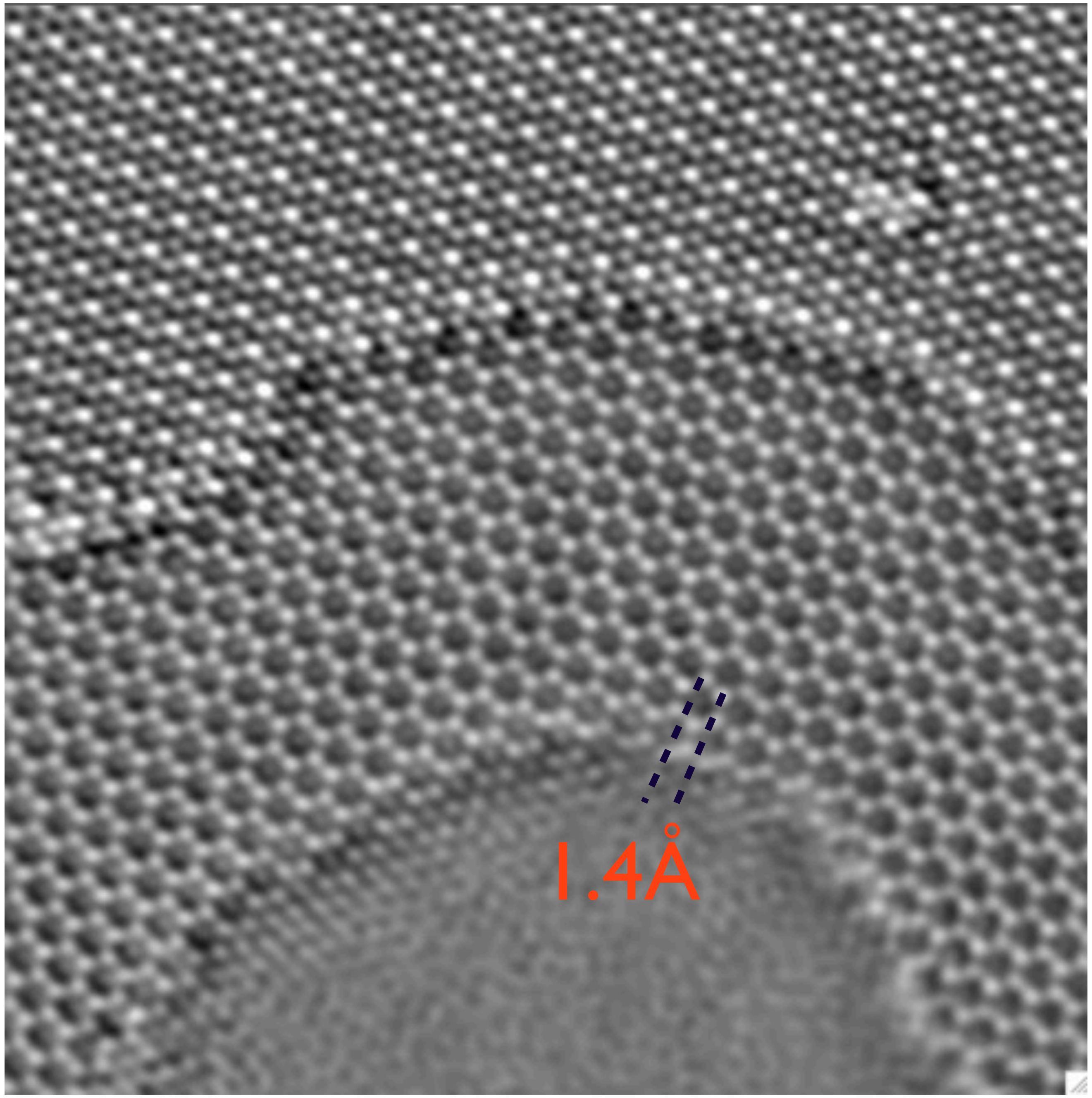
Electron microscope utilizes magnetic lens to see both image and difffraction





Imaging, Spectroscopy and Diffraction

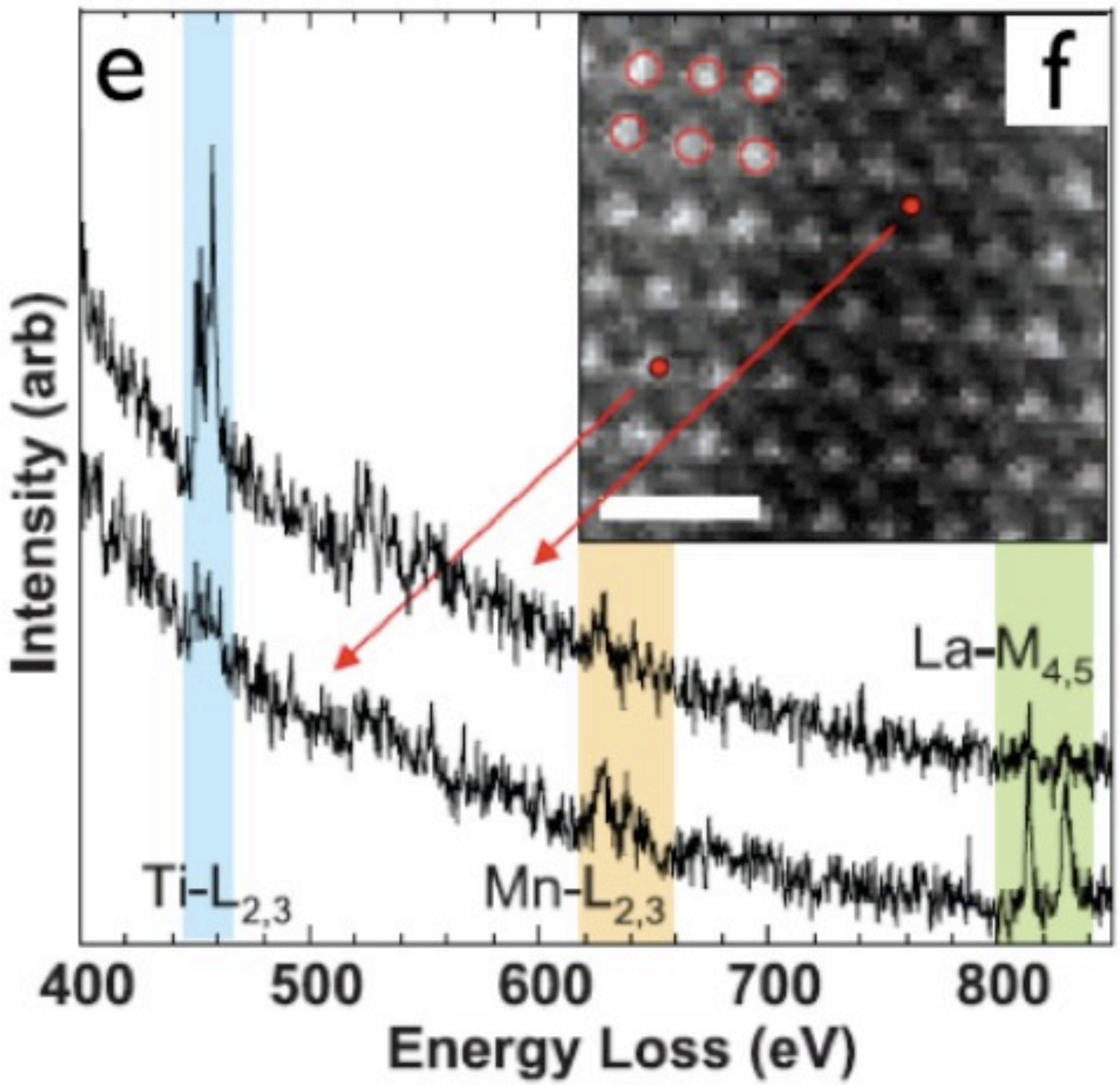




Atomic Resolution

Imaging, Spectroscopy and Diffraction

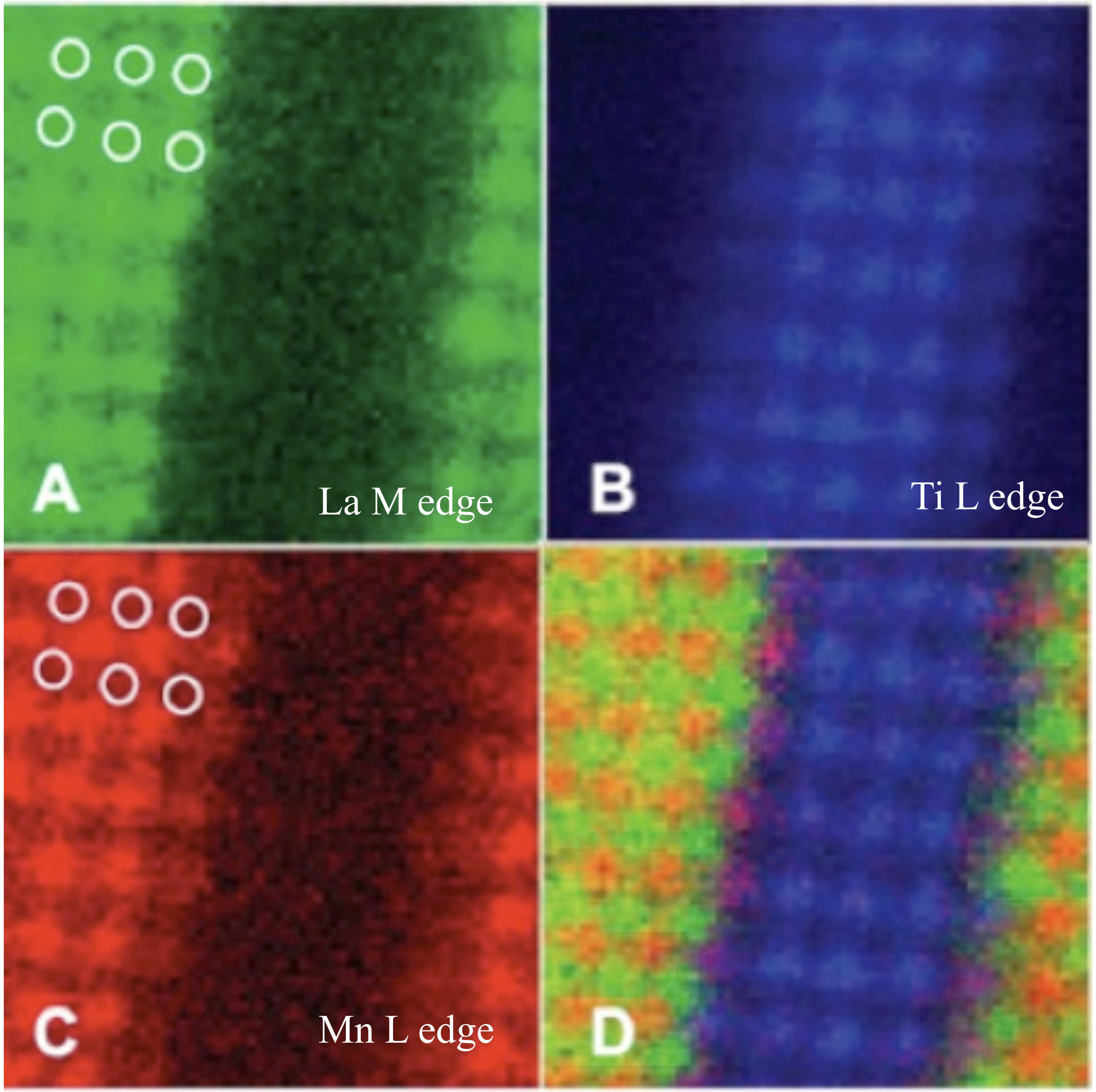
Imaging, Spectroscopy and Diffraction



Atomic resolution of EELS of $La_{0.7}Sr_{0.3}MnO_3/SrTiO_3$ multilayer

- D. A. Muller, et al, SCIENCE **319** 1073-1075 (2008)

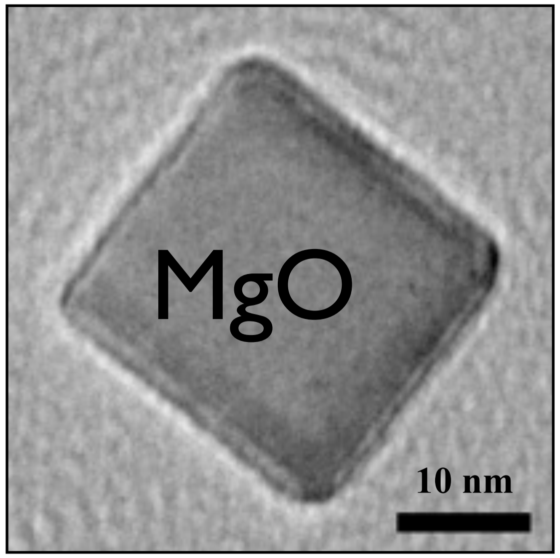
Imaging, Spectroscopy and Diffraction

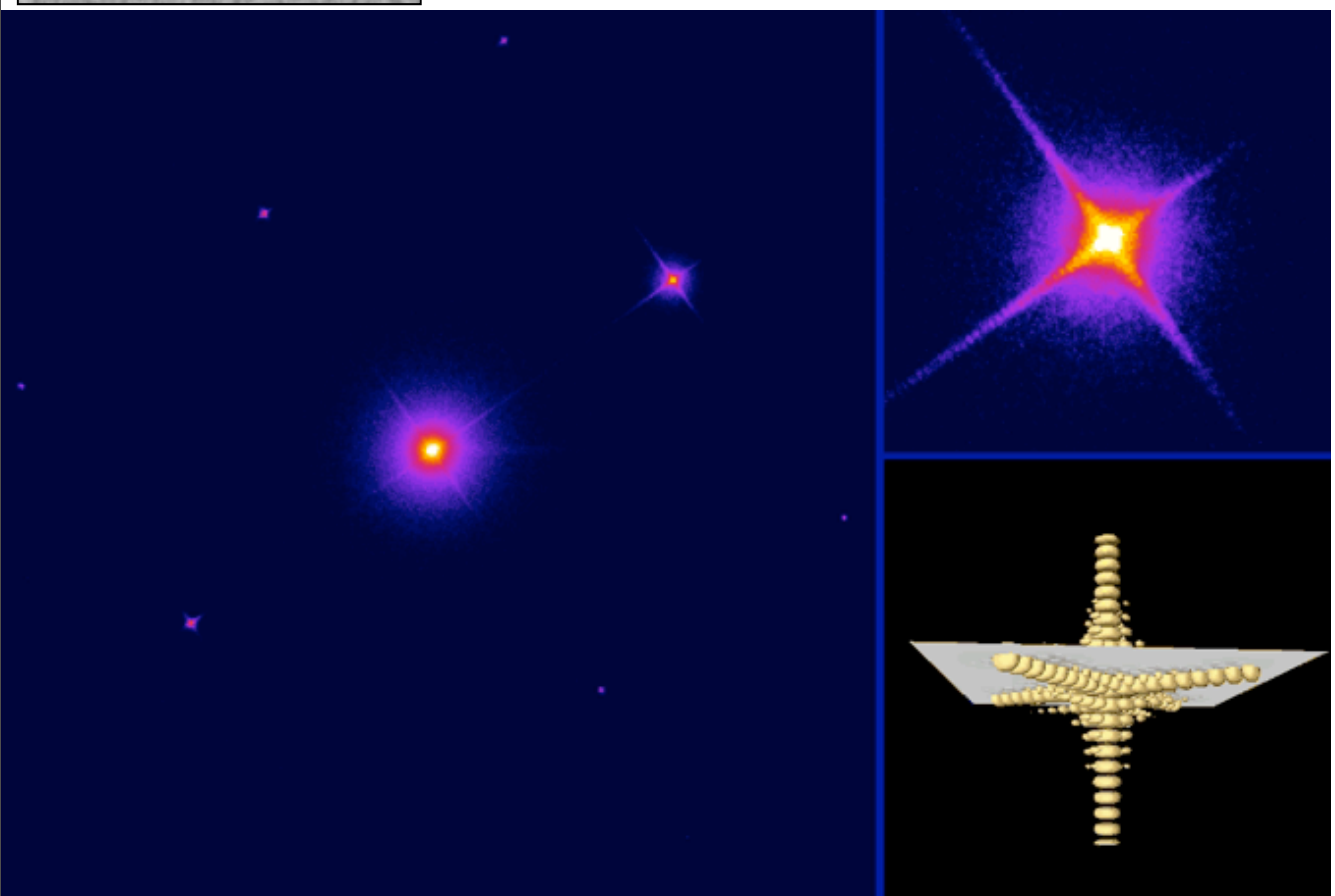


Atomic resolution compositional and bonding maps

Imaging, Spectroscopy and Diffraction

Atomic-resolution phase recovery with dynamic support





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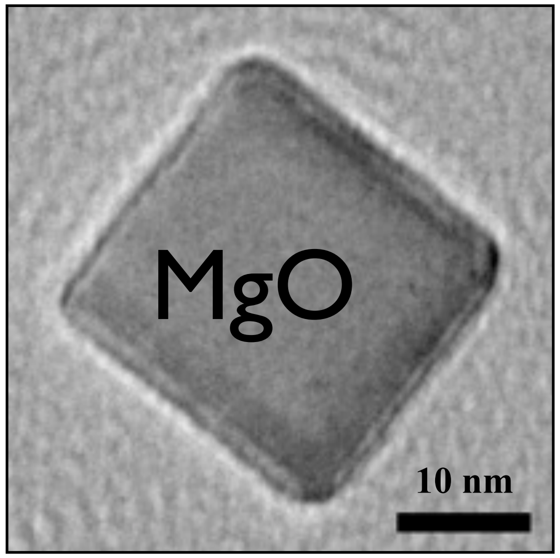

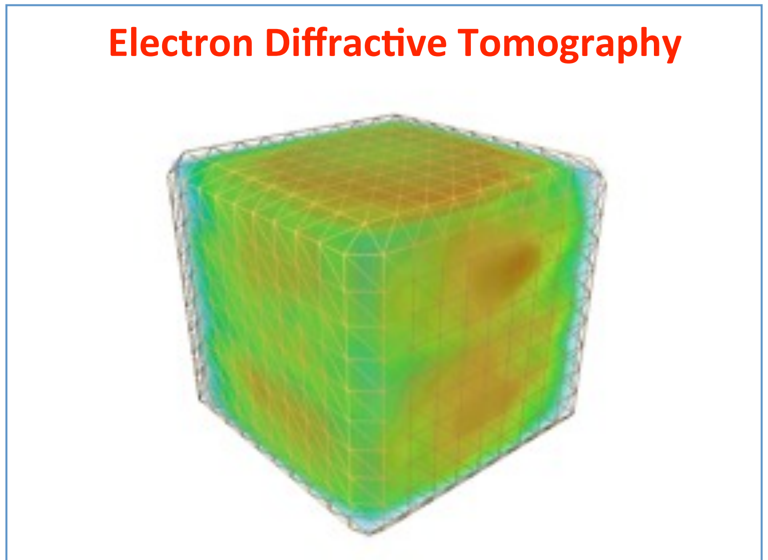

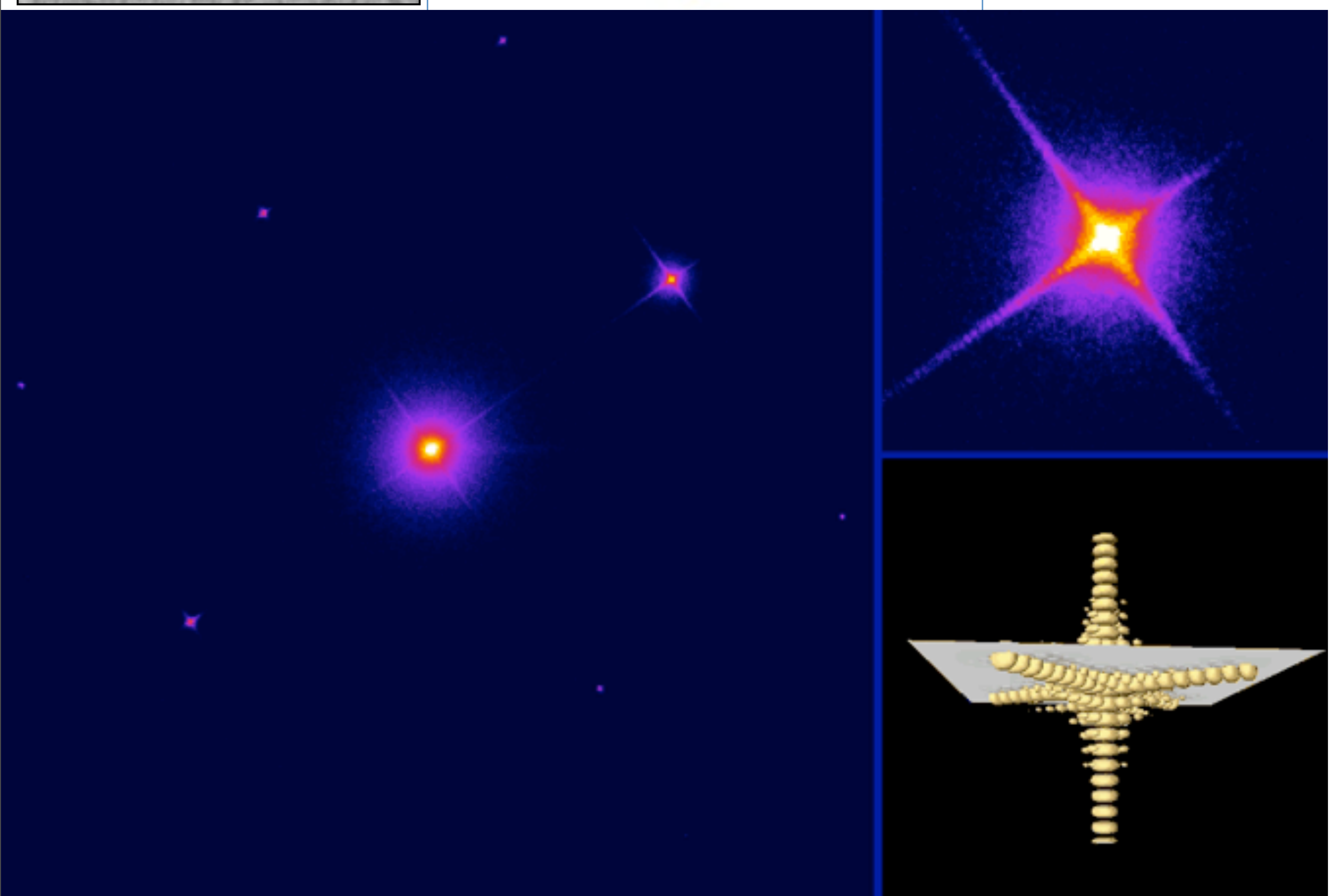

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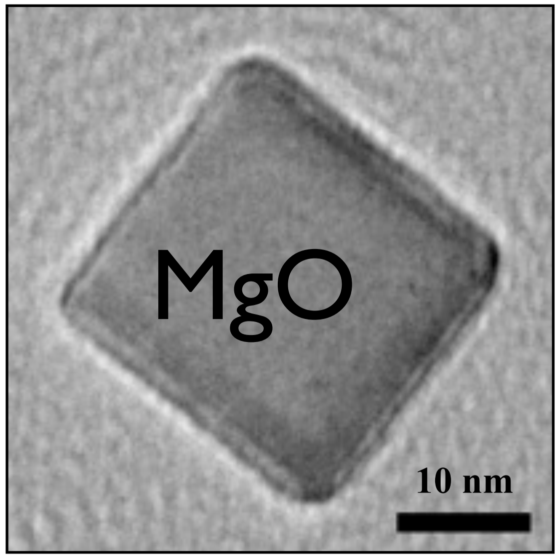
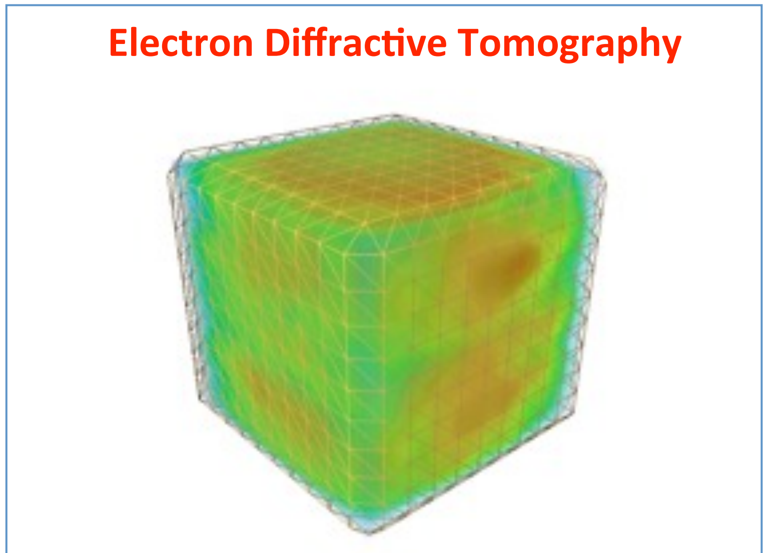
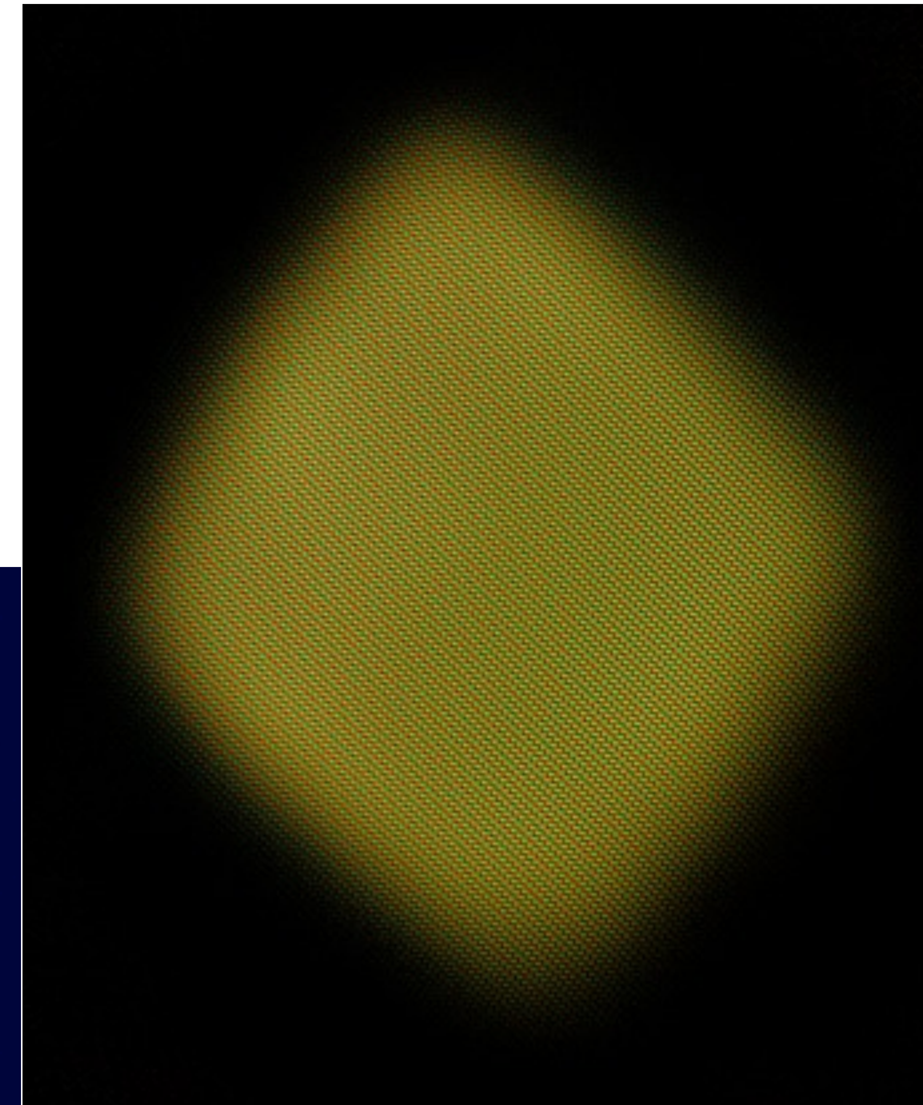
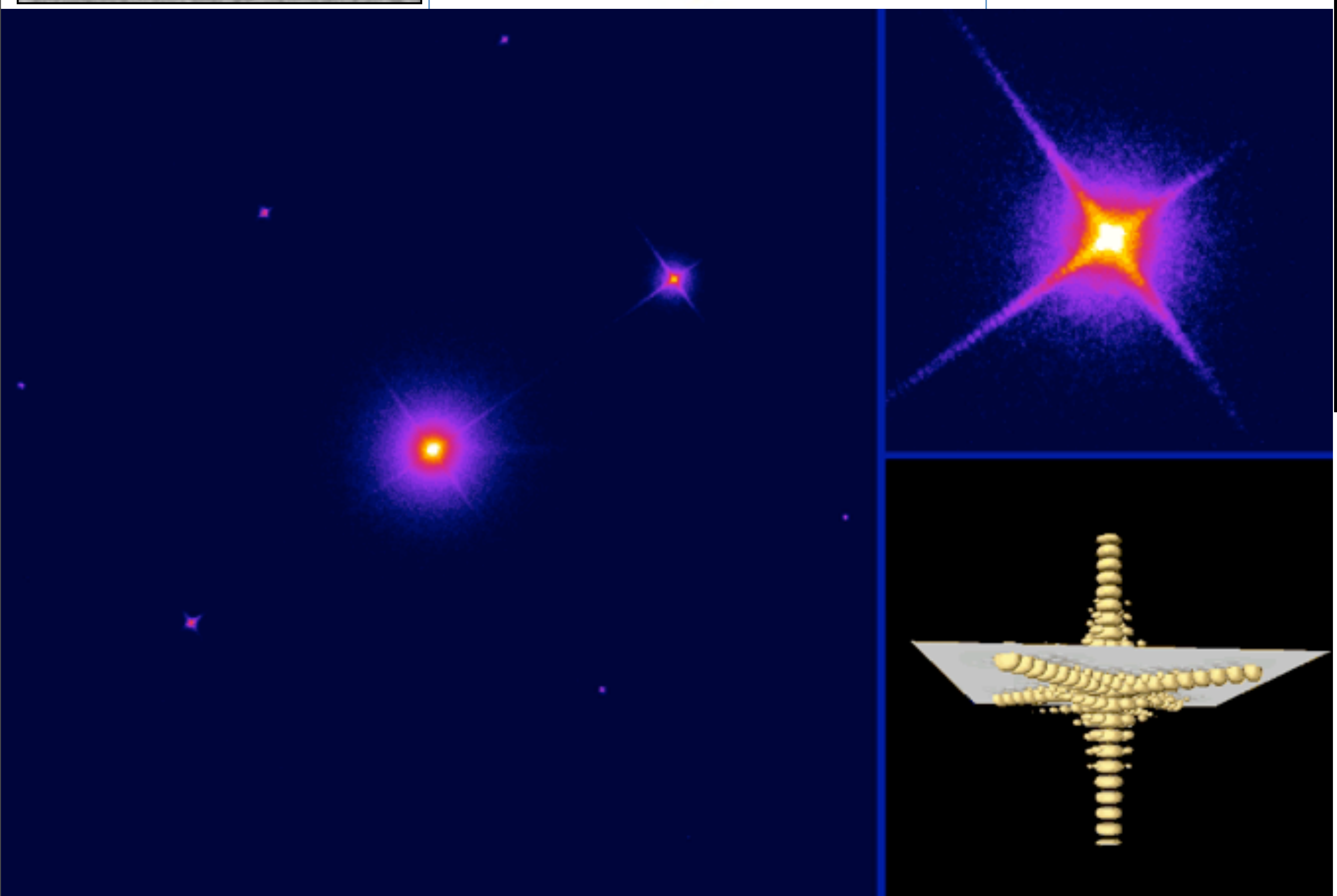




reconstructed wave





Imaging, Spectroscopy and Diffraction

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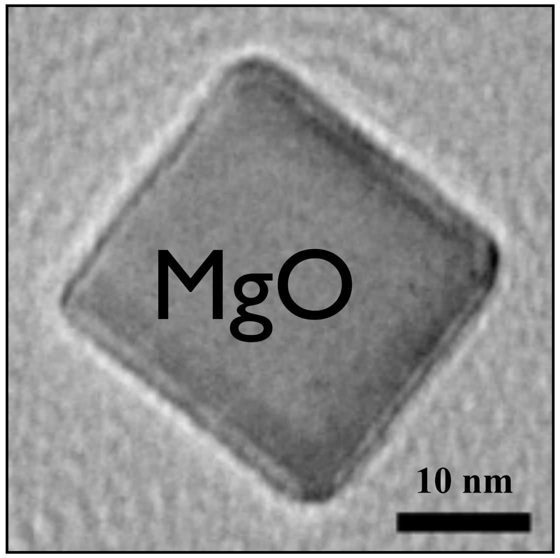

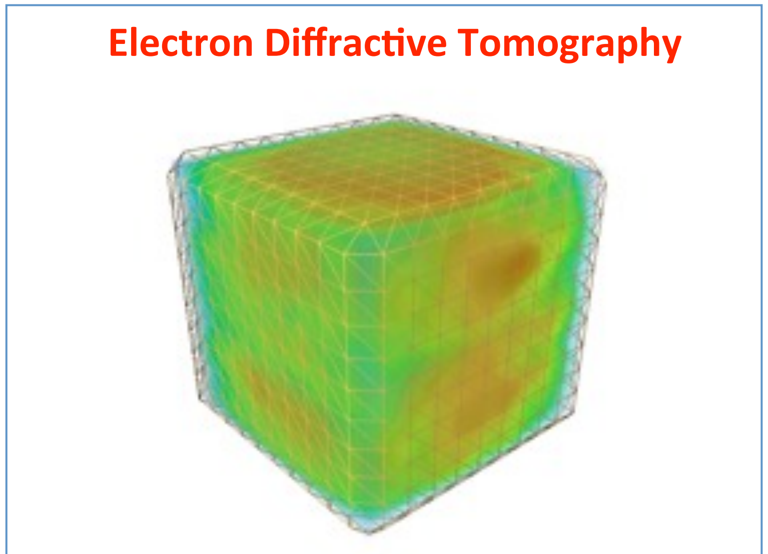

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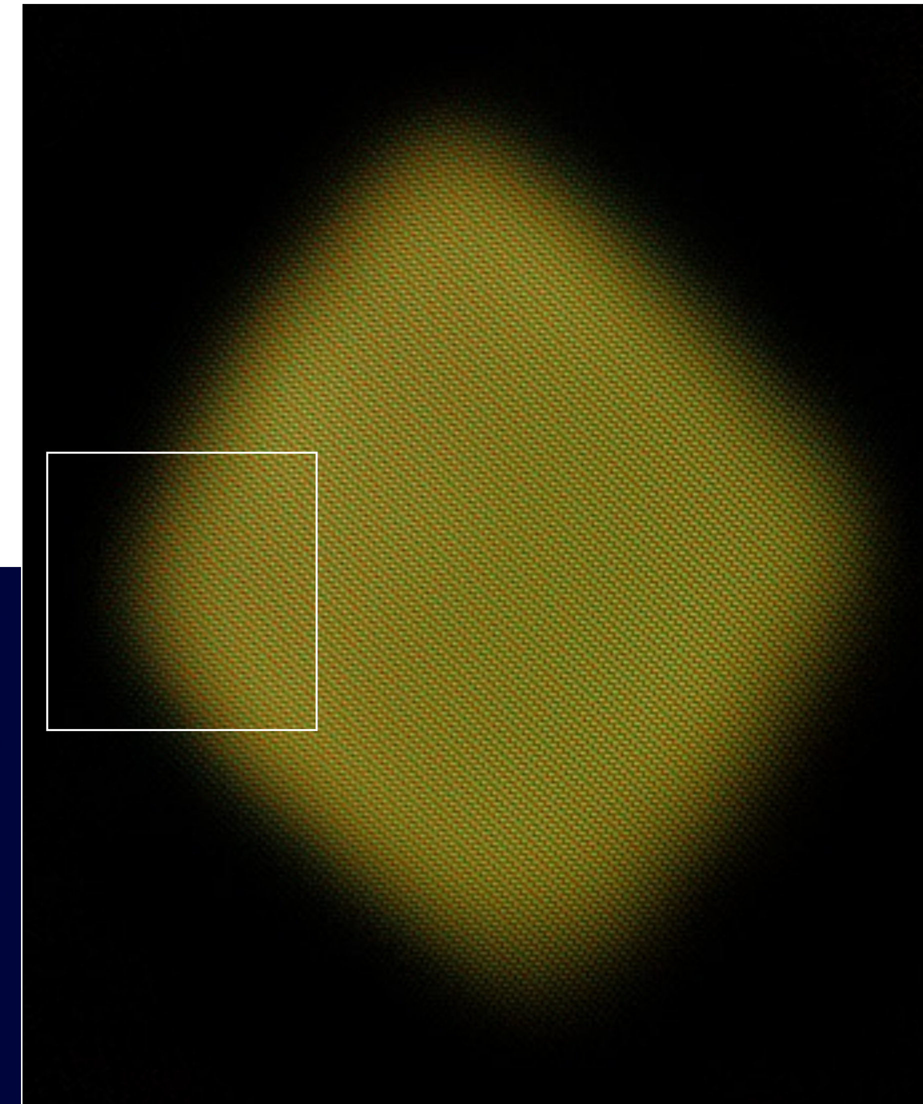
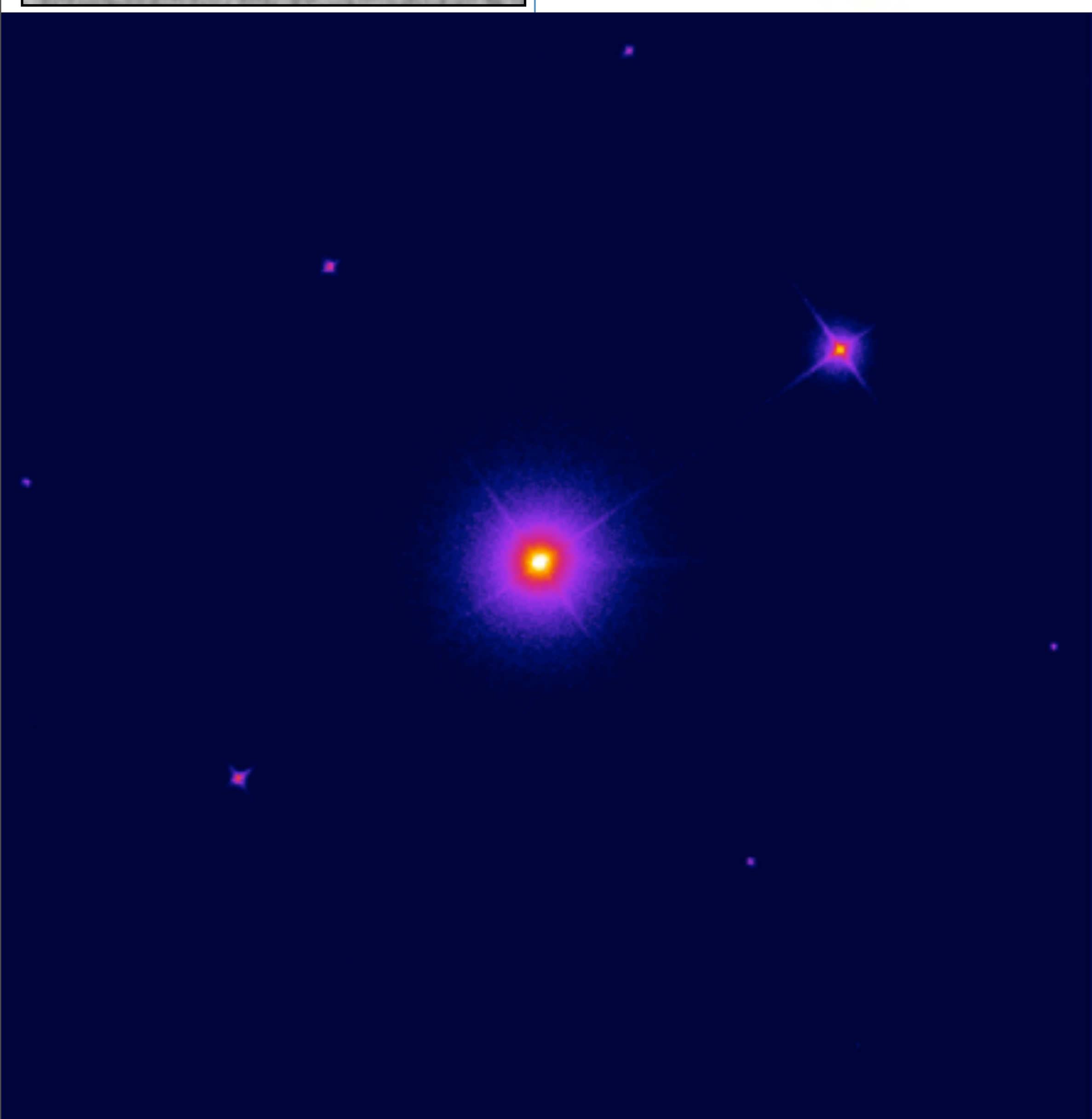
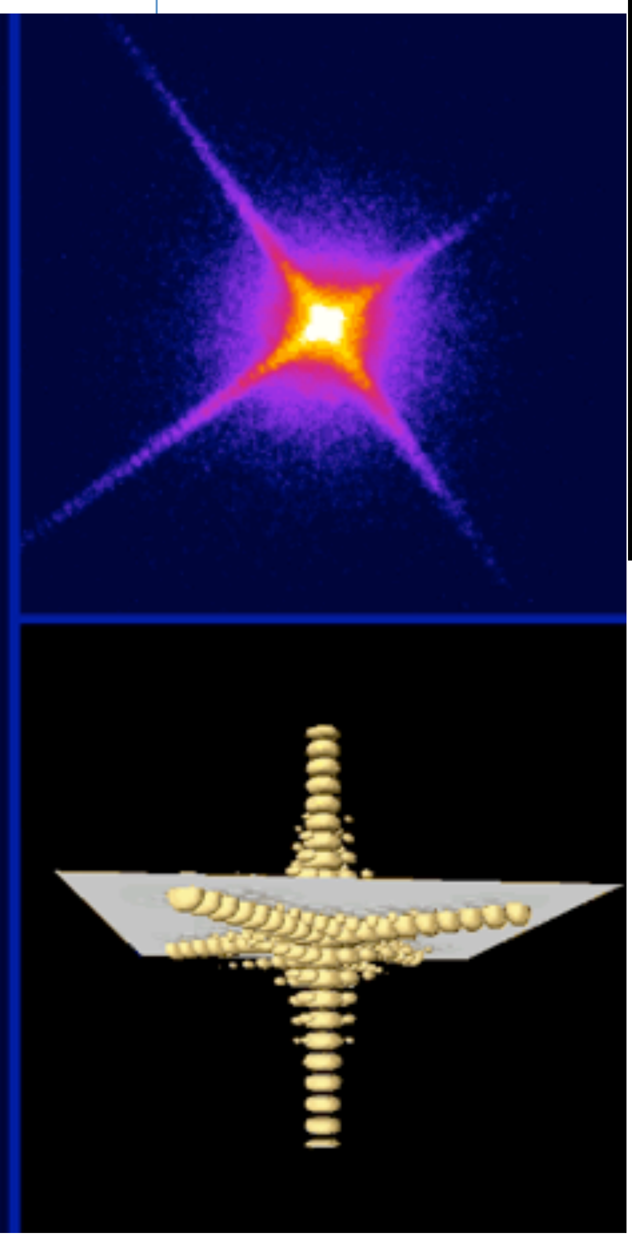
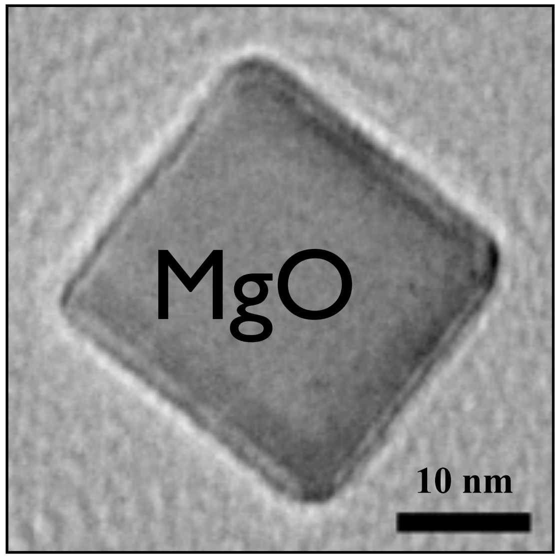


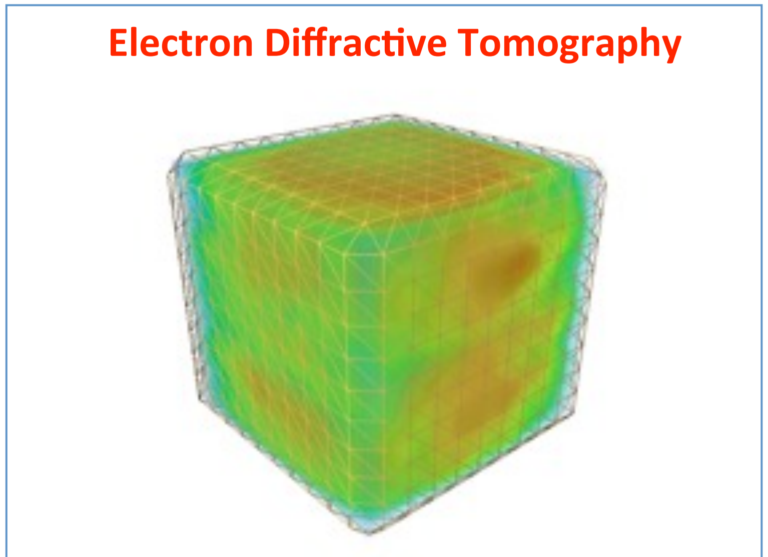




Imaging, Spectroscopy and Diffraction

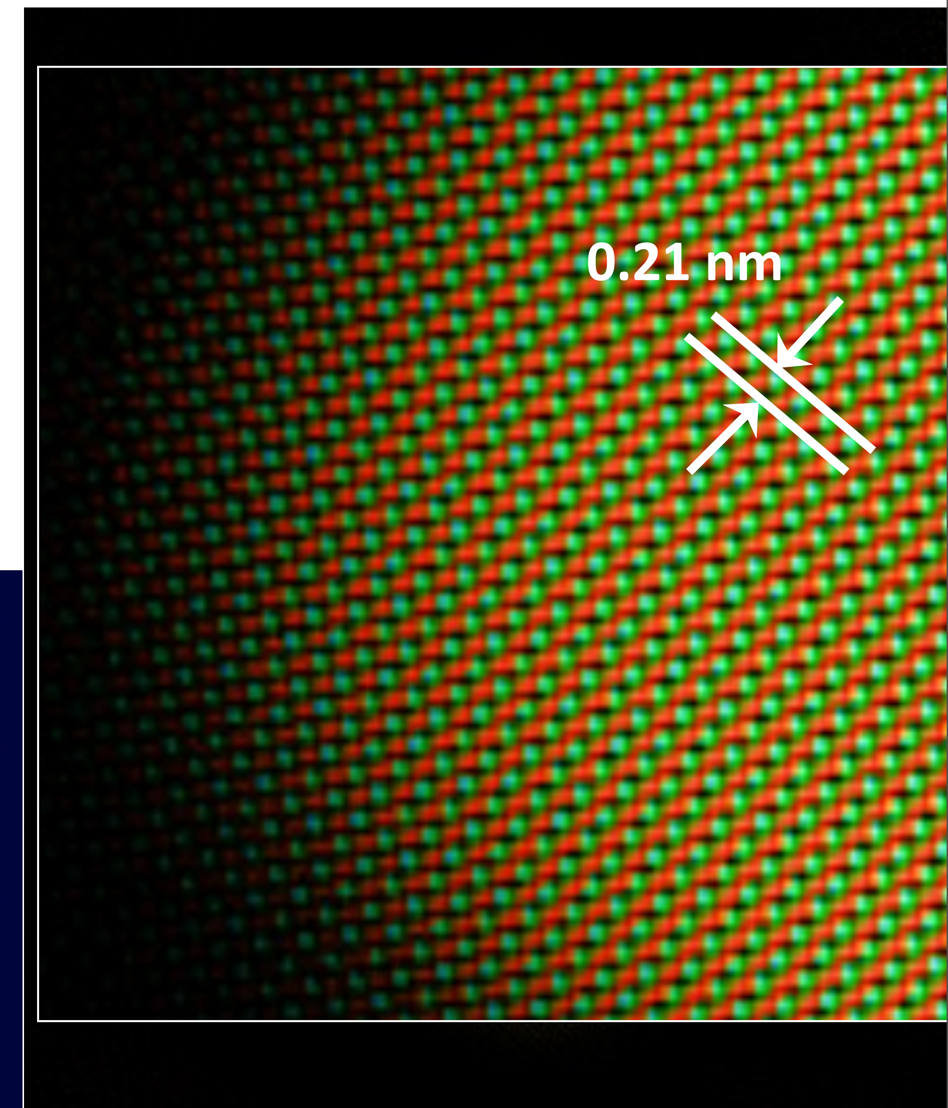
Atomic-resolution phase recovery with dynamic support

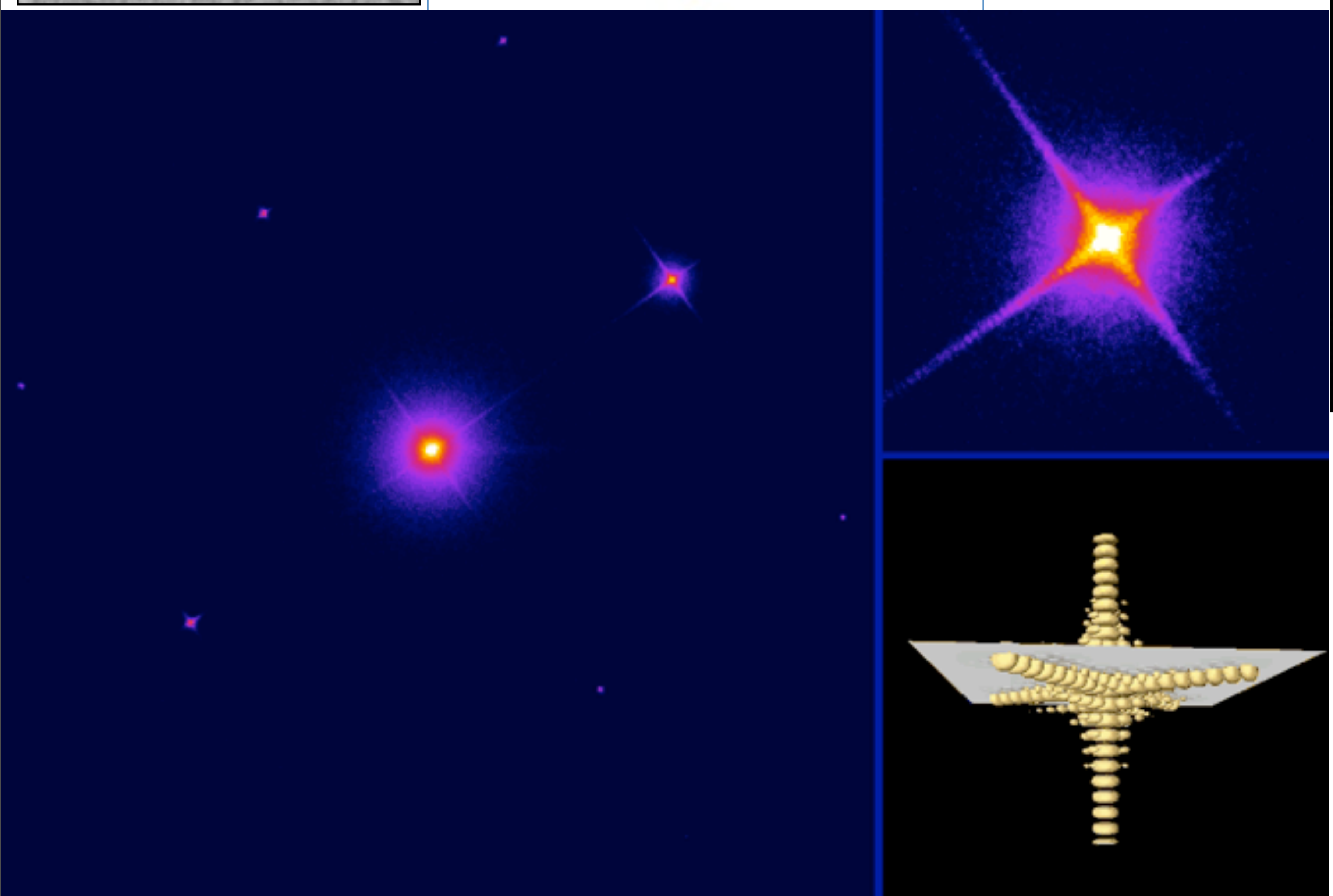




reconstructed wave

reconstructed phase





1.2 limitation of TEM

- A 2D projection: Averaged from the thickn sample

  --------> tomography
- B Radiation Damage——polymer, bio-sample and ceramics。

- C “thin” sample is very difficult to be made

  t ＜50nm ～ 100nm
- D only dry sample can be observed
- E . NO time resolved capability

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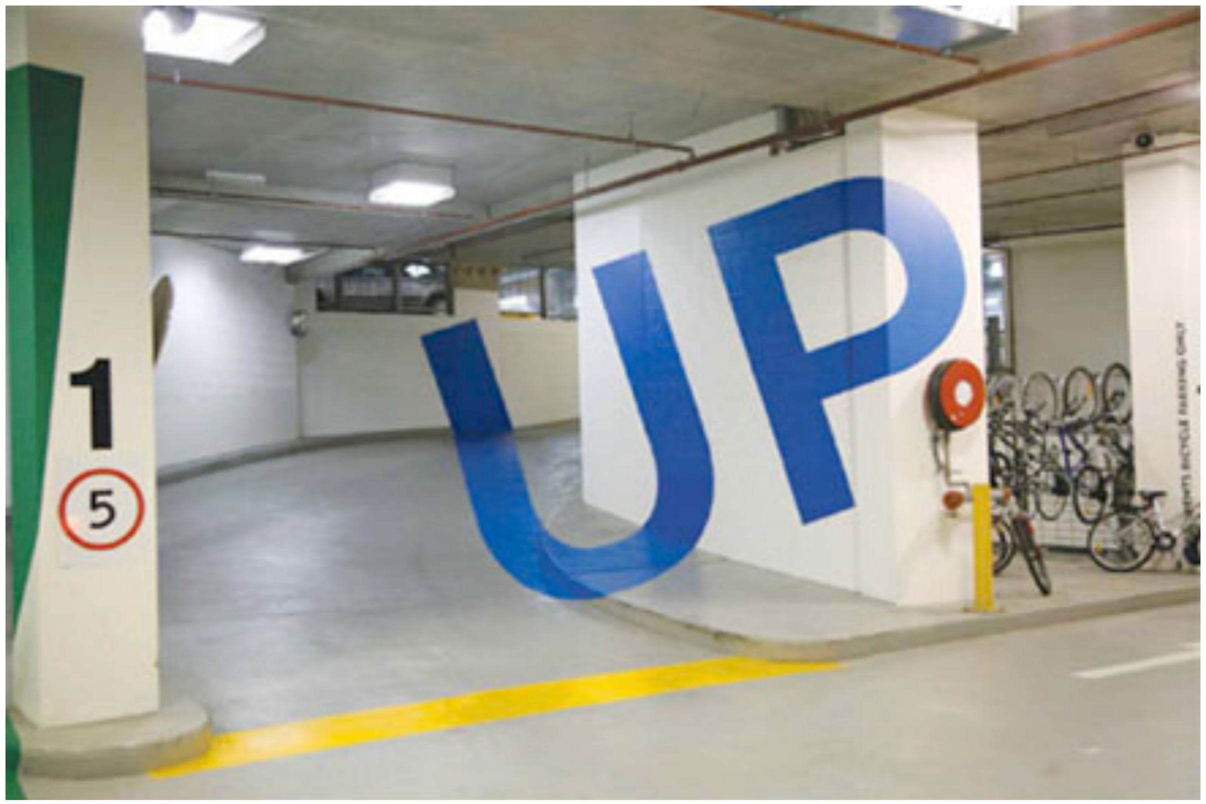
The Future of TEM: 3D atomic resolution in wet environment with time resolved

Why 3D？



Why 3D？

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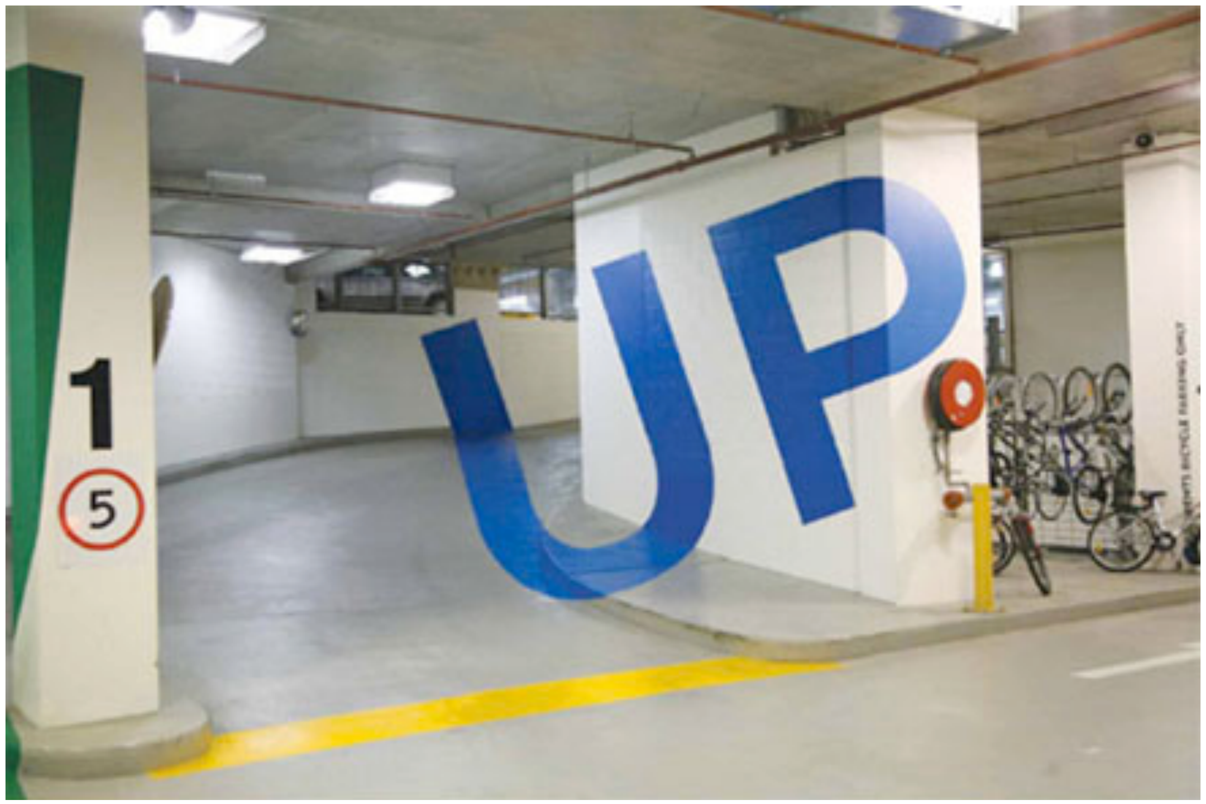
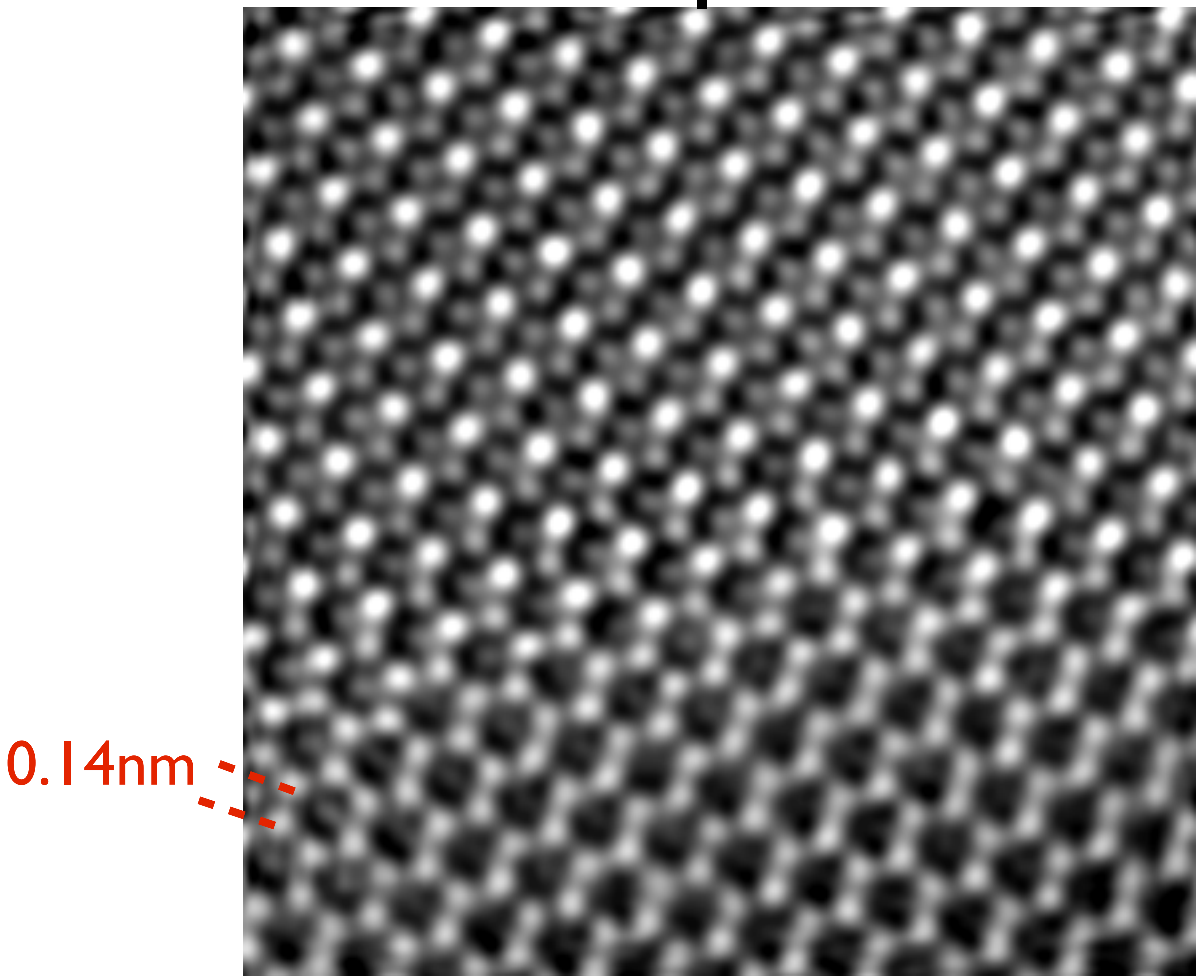


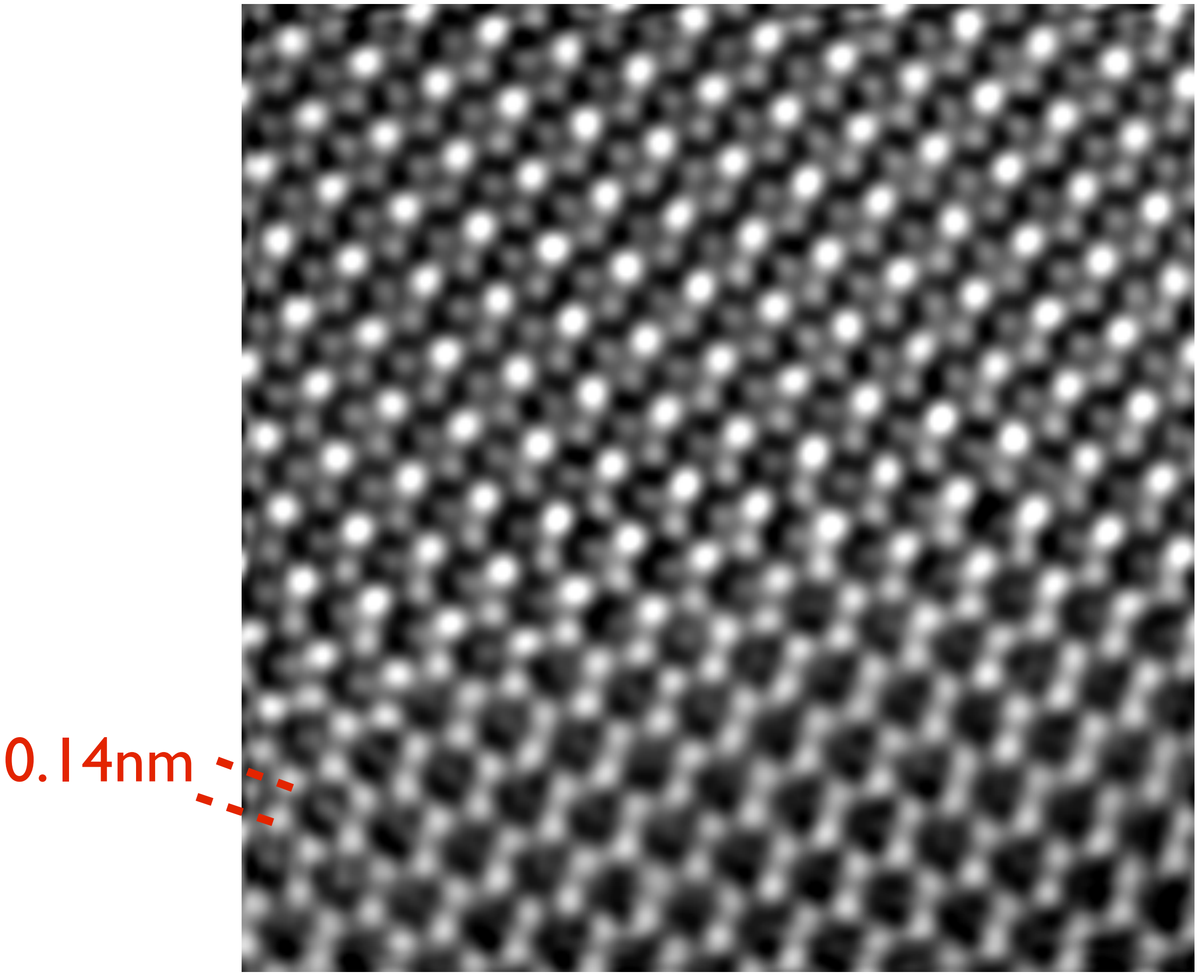
Atomic Resolution Tomography

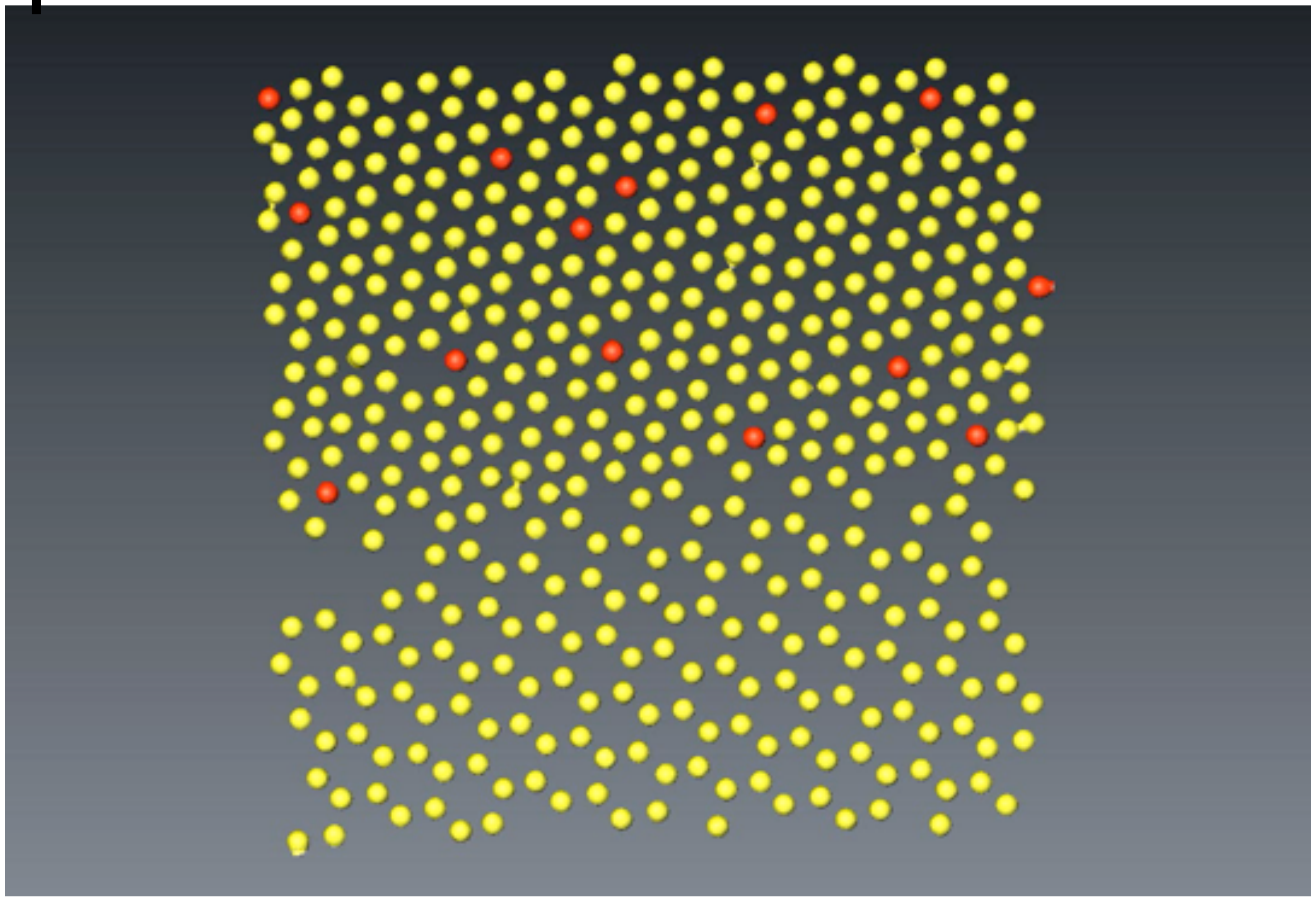
Graphene



Atomic Resolution Tomography

Graphene





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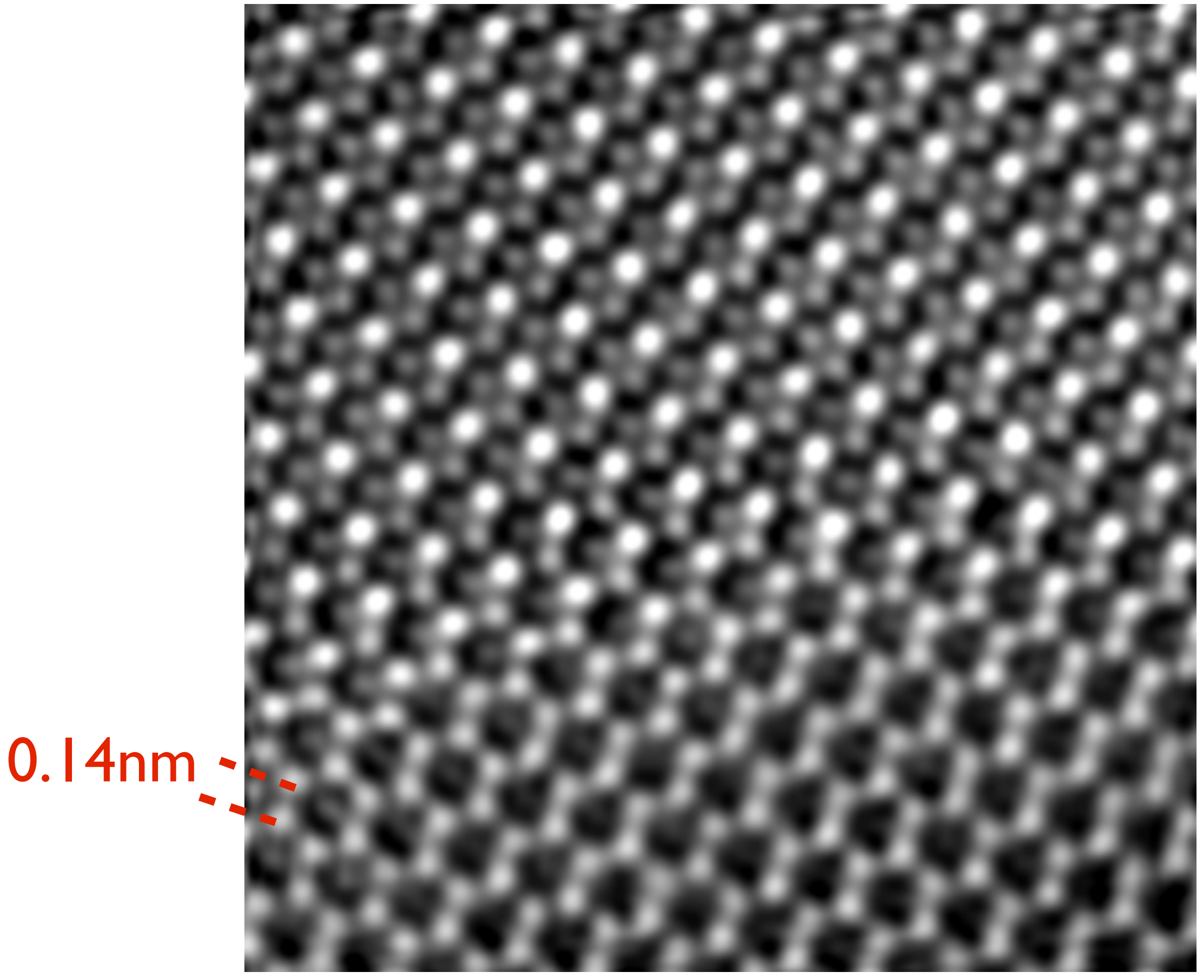
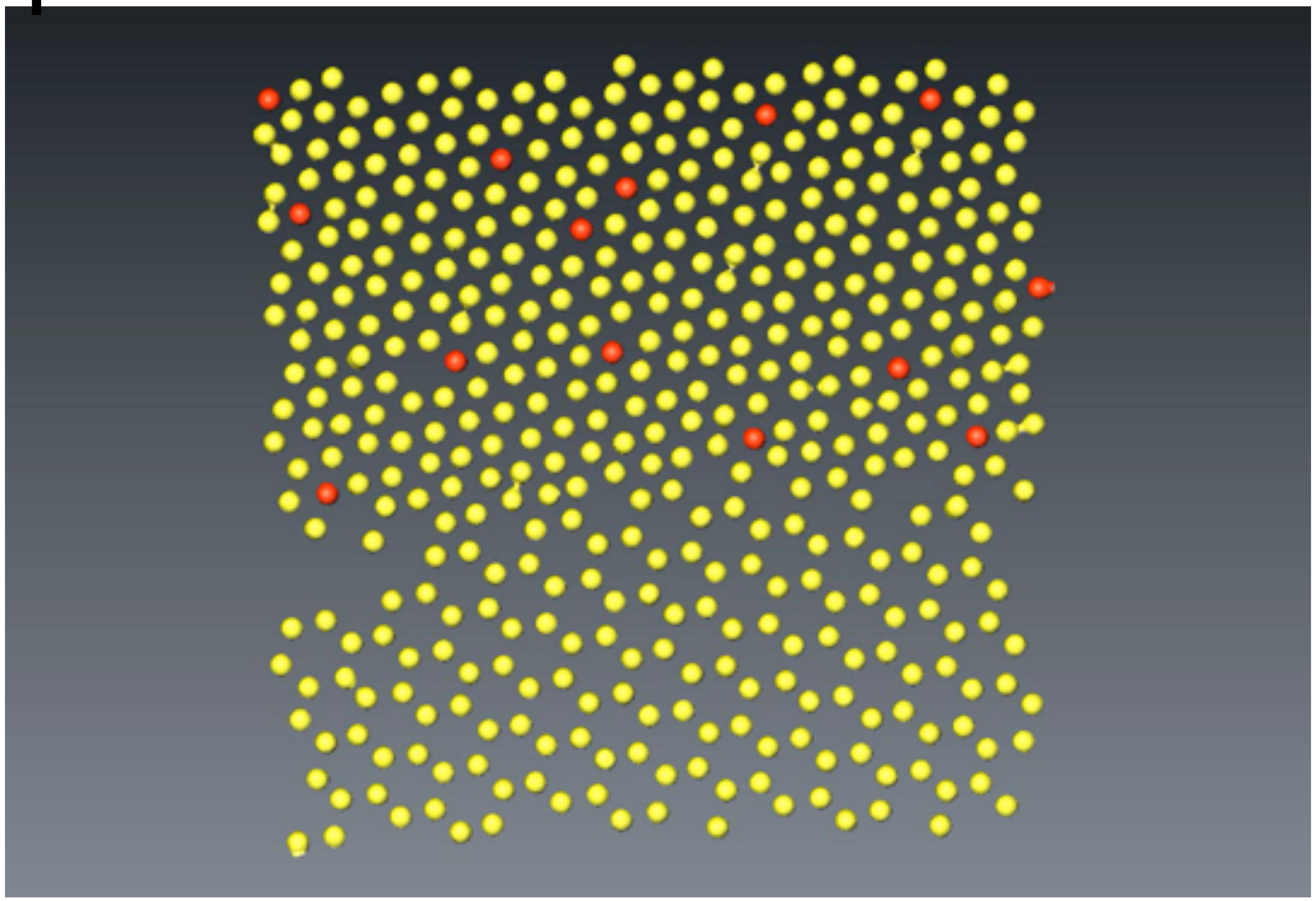
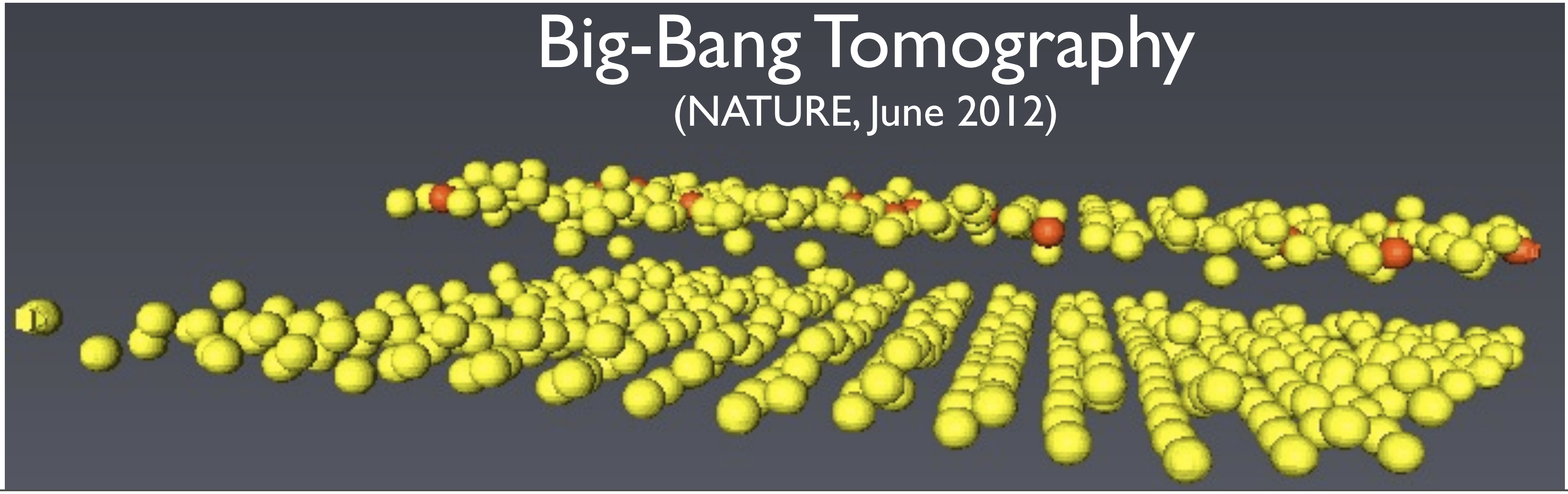
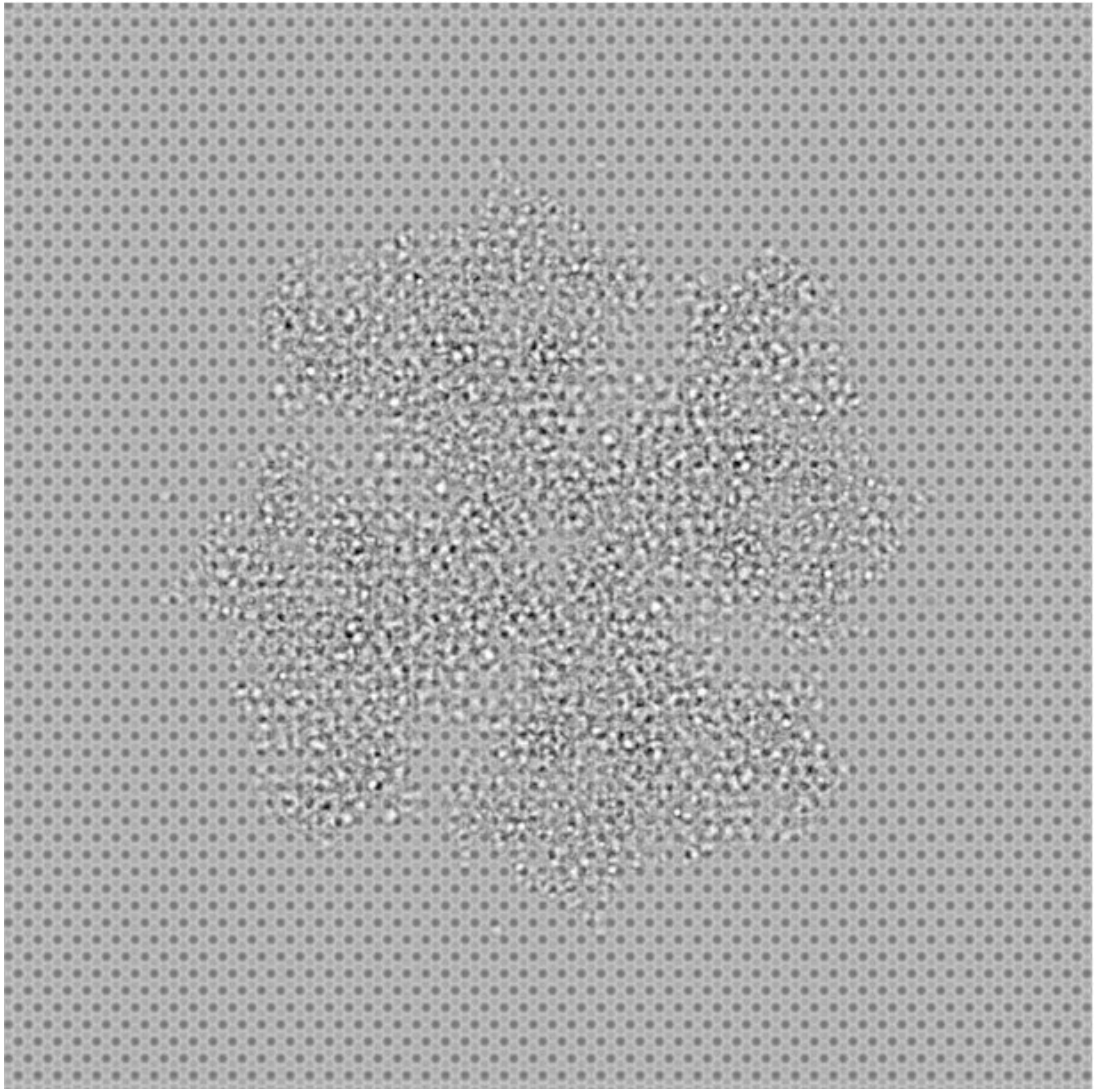






A1HJP Protein on Graphene



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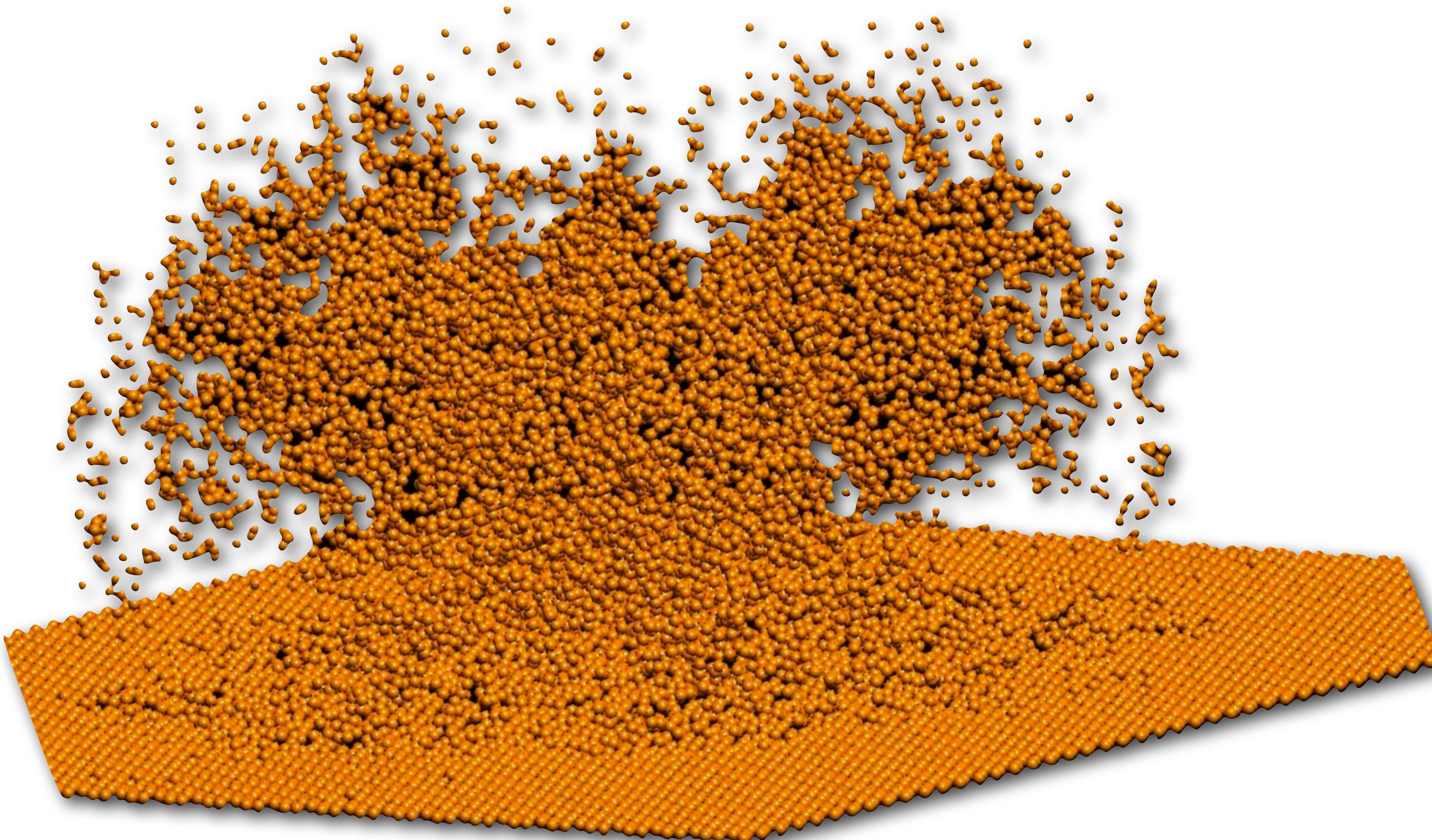
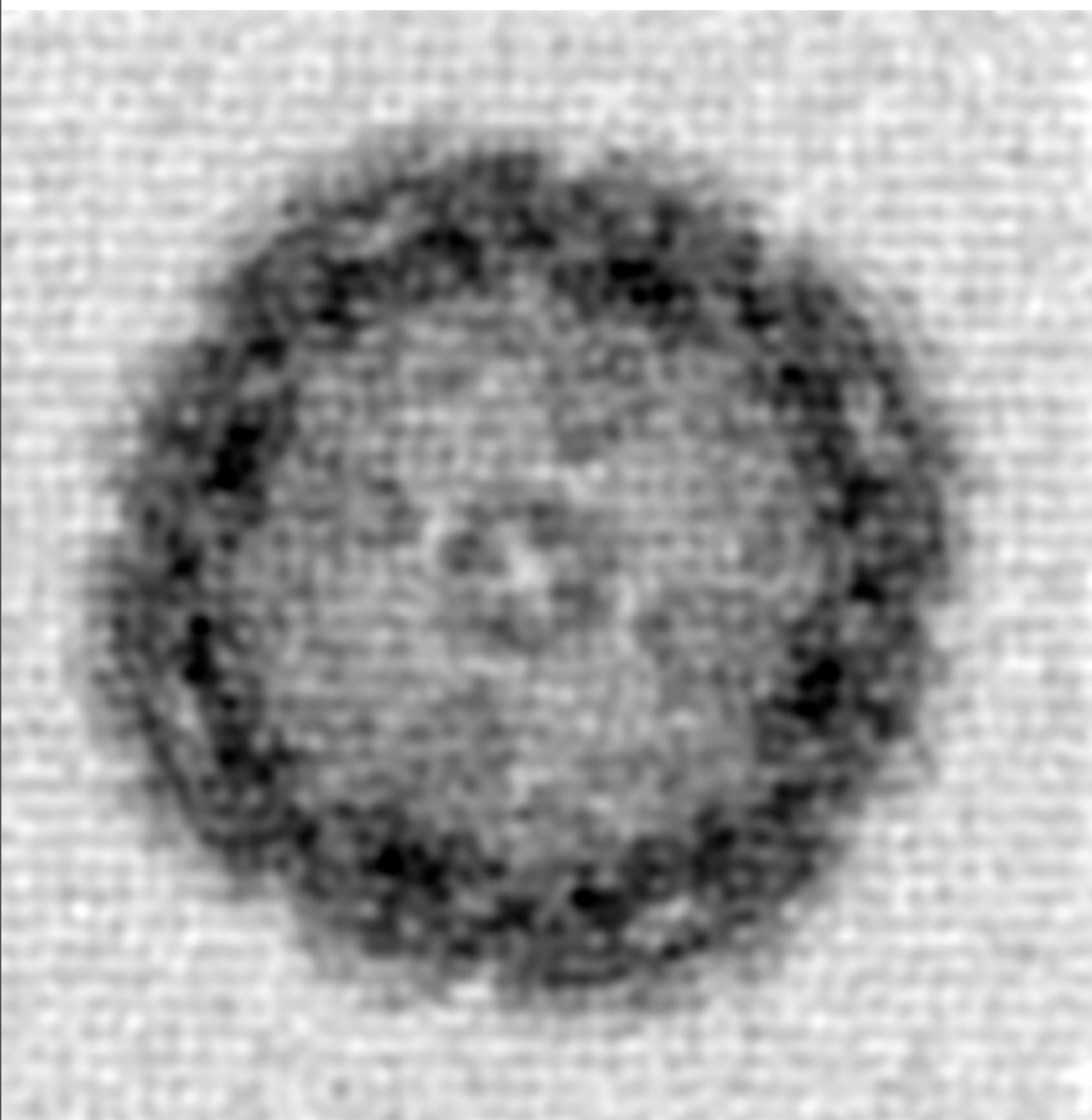
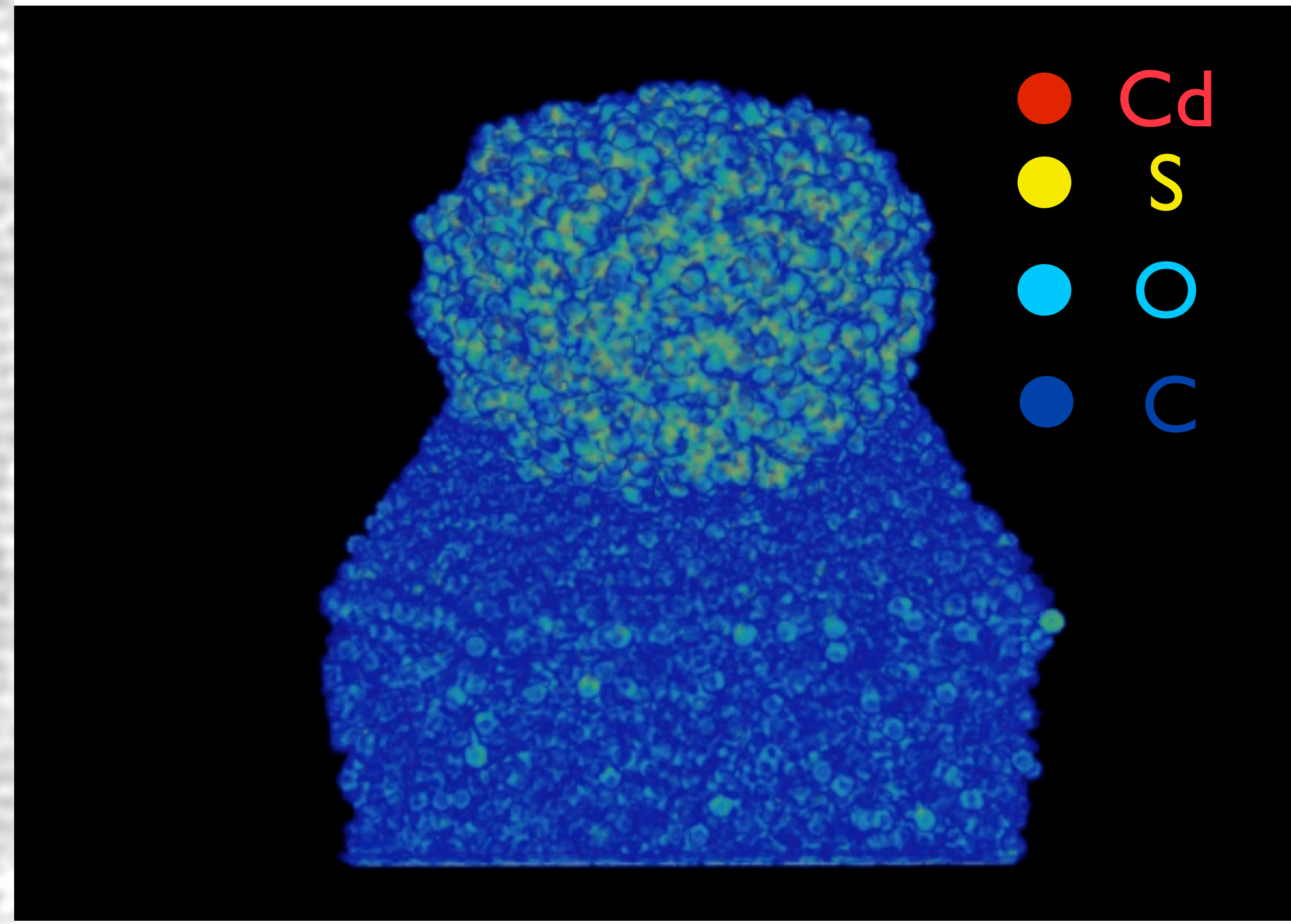
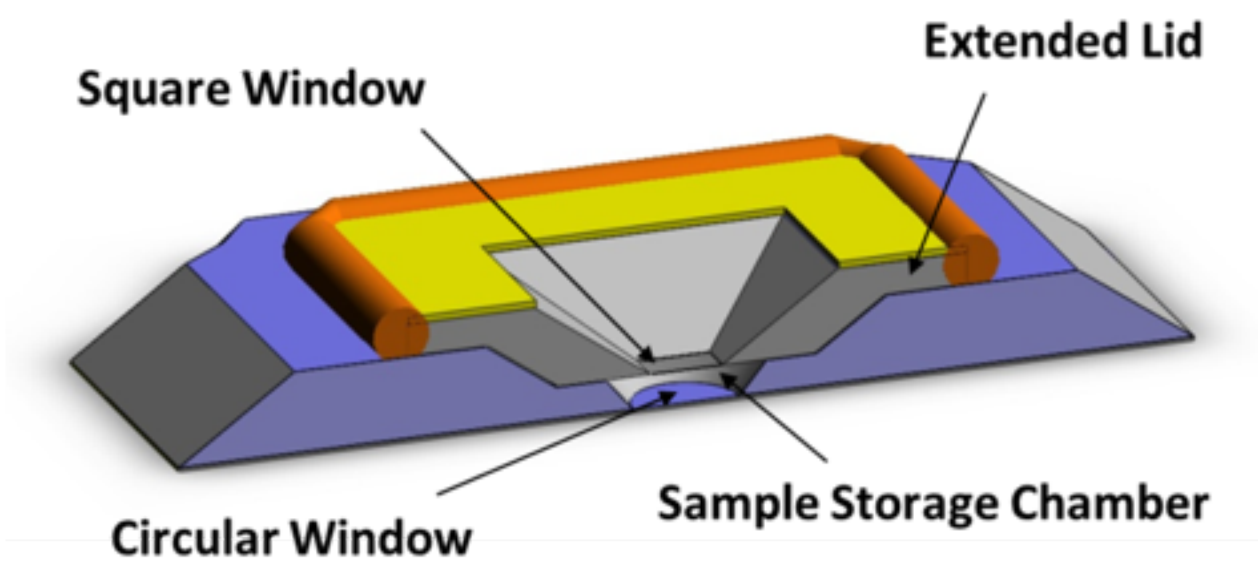


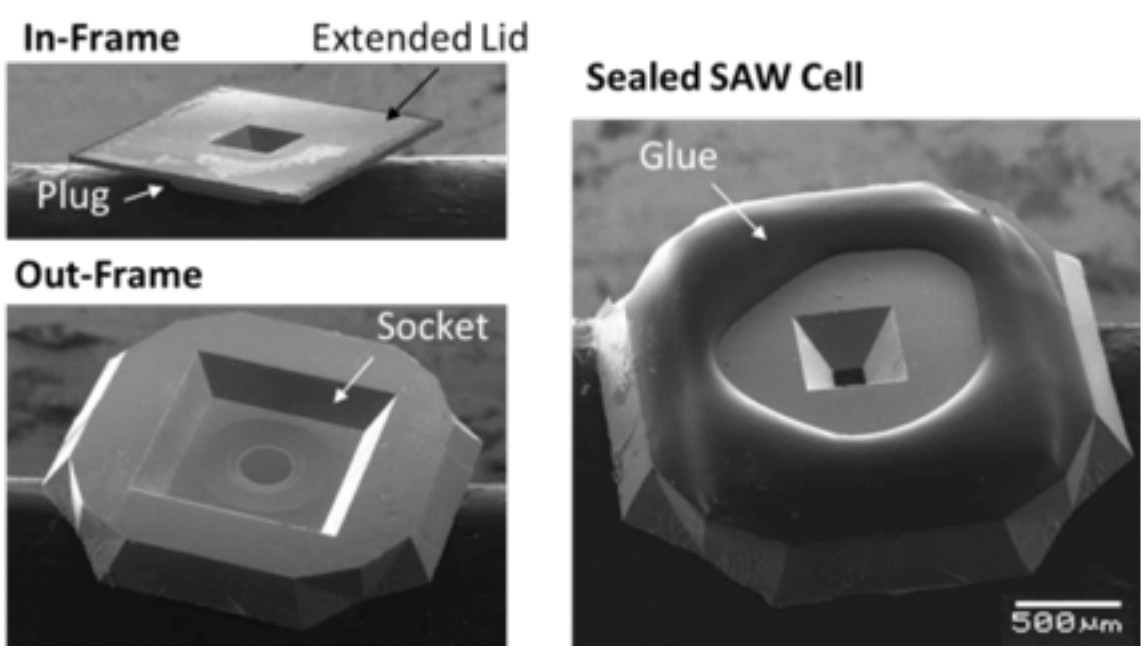
Ferritin on Carbon Film

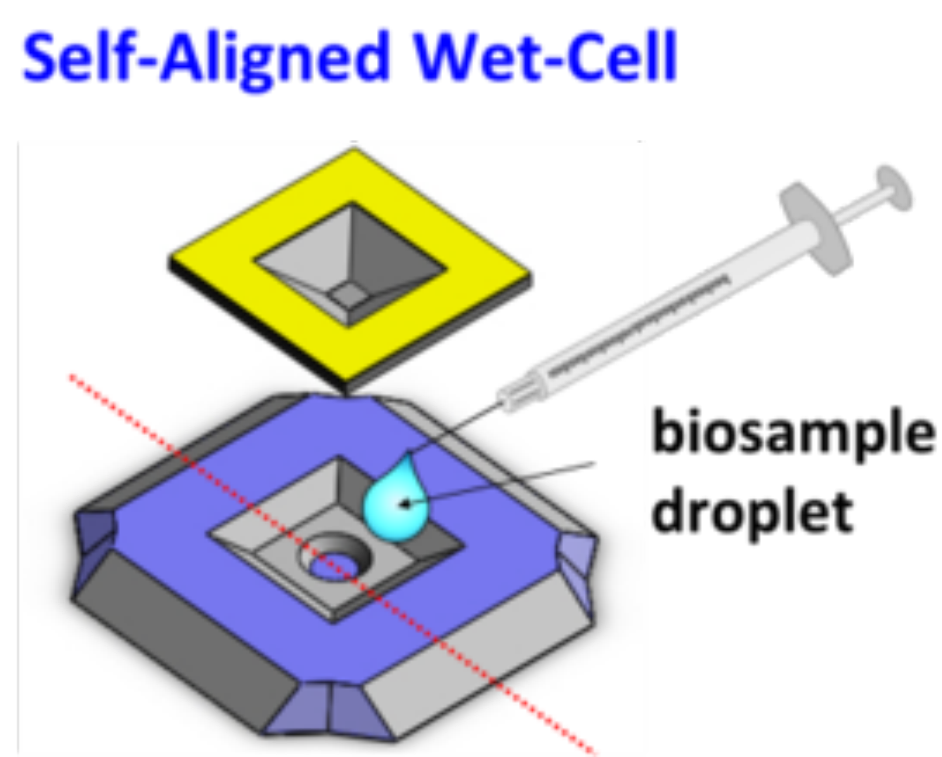




Self Aligned Wet (SAW) Cell







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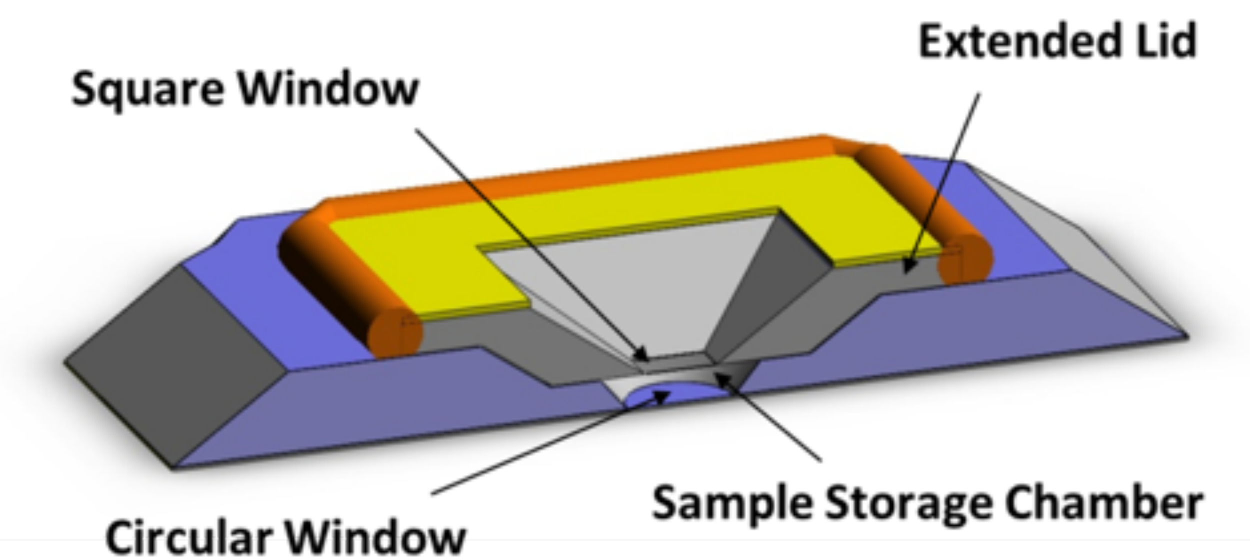

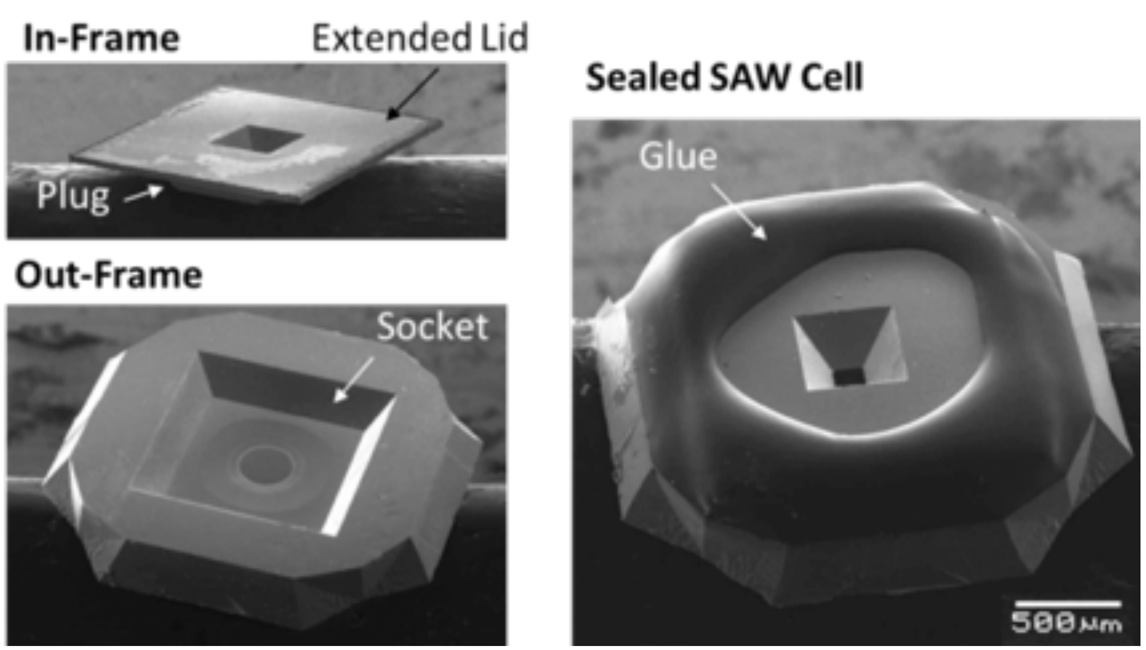

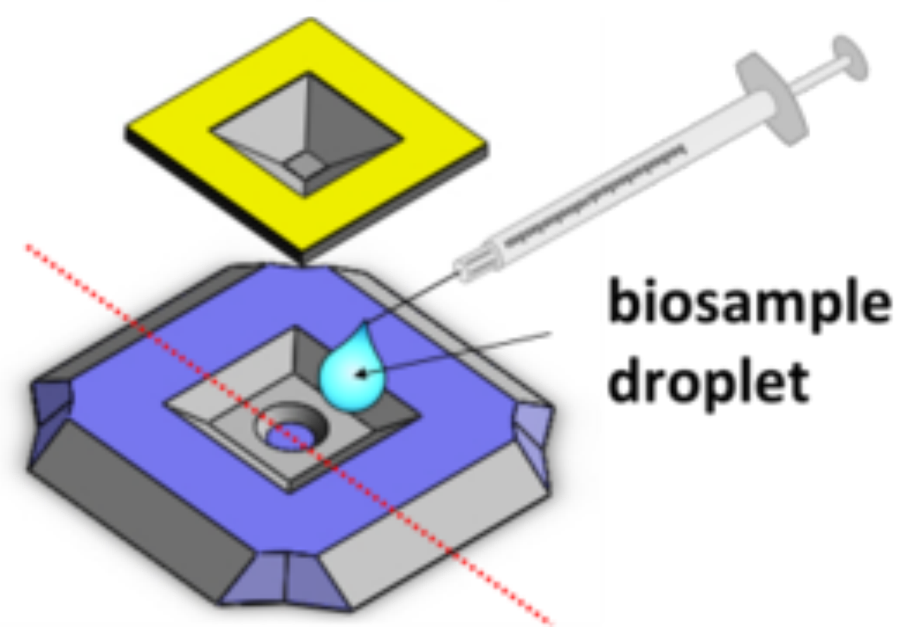

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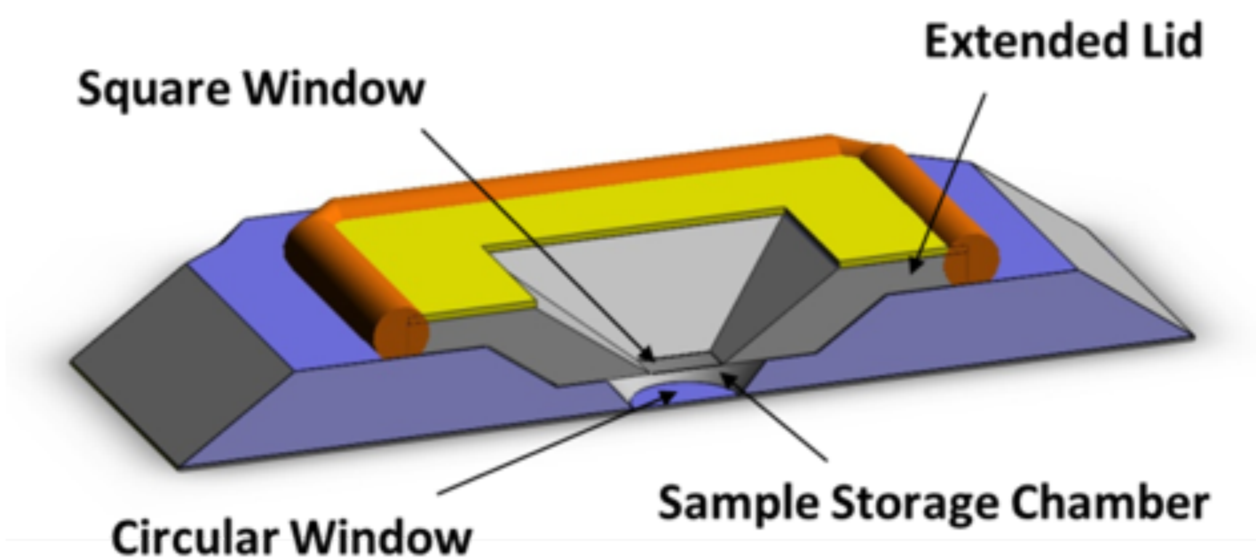

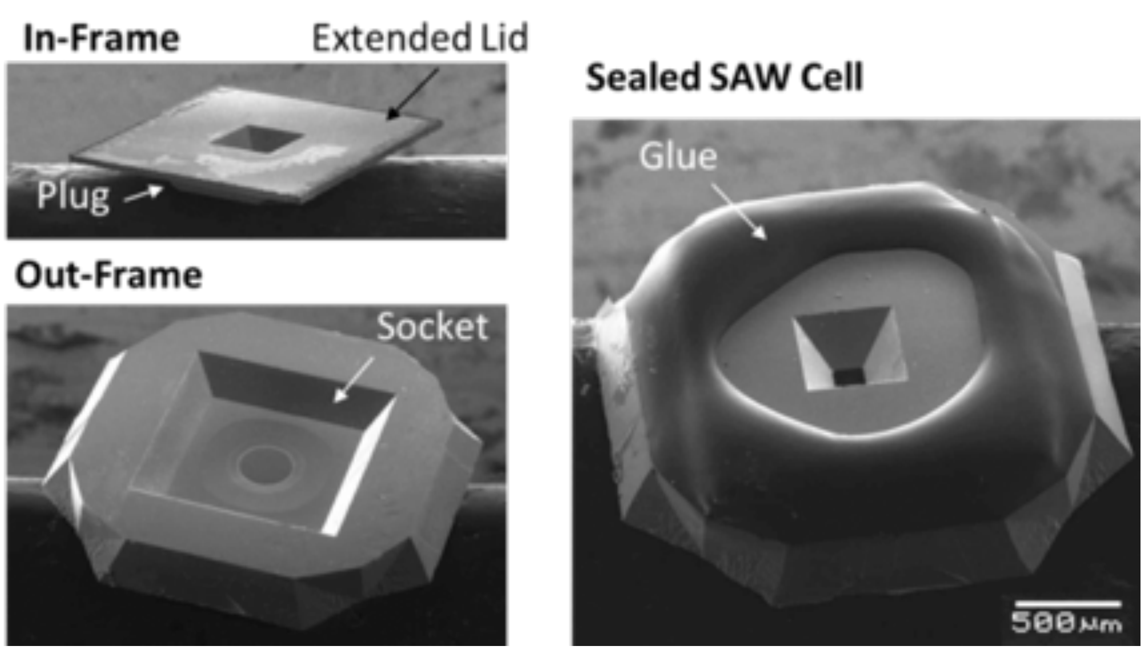

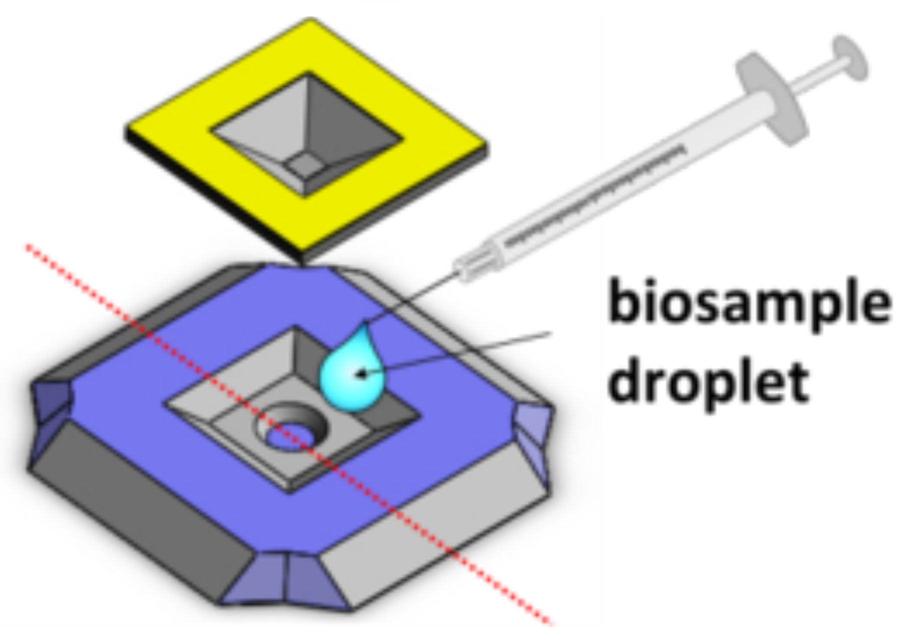

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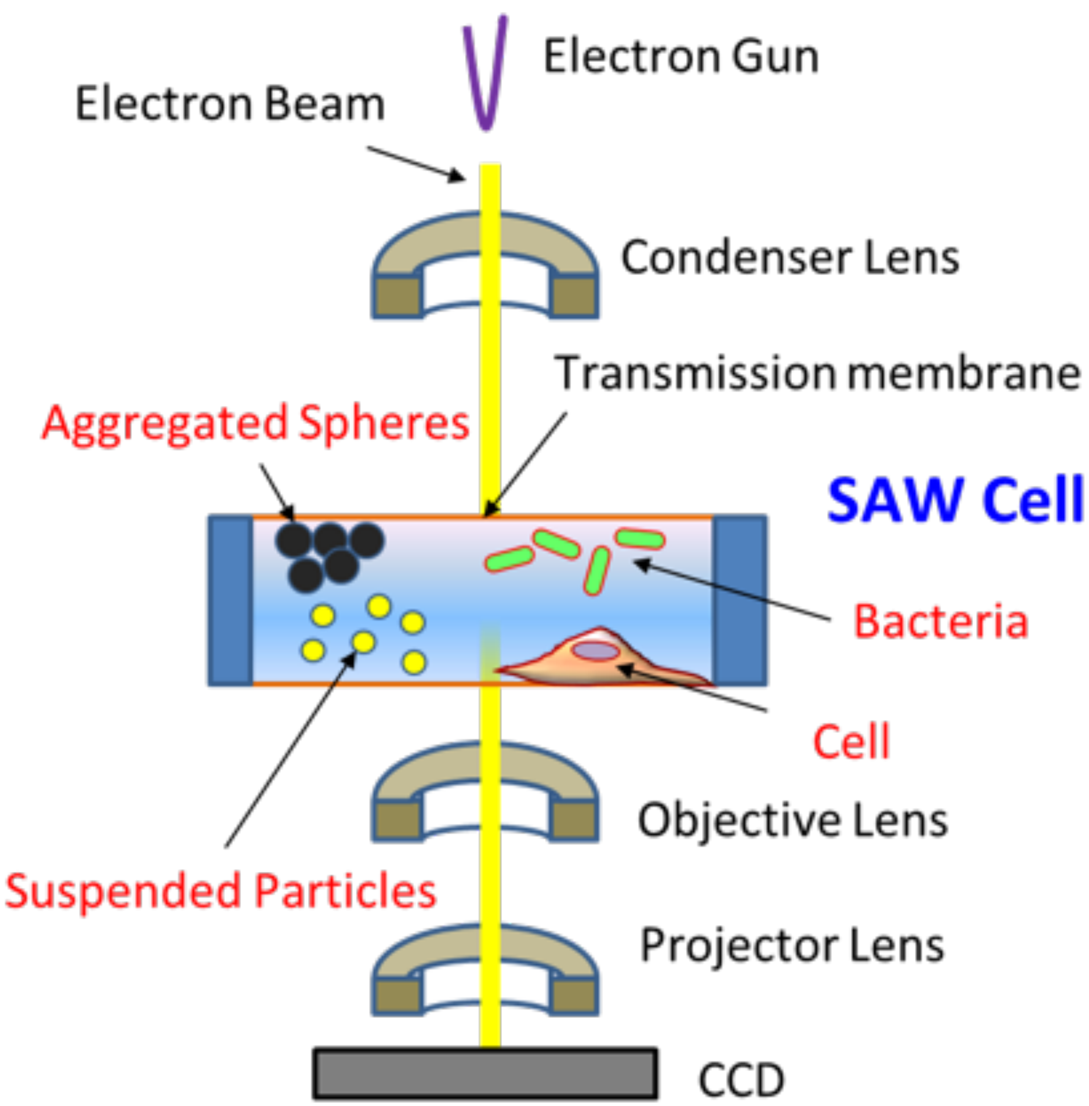
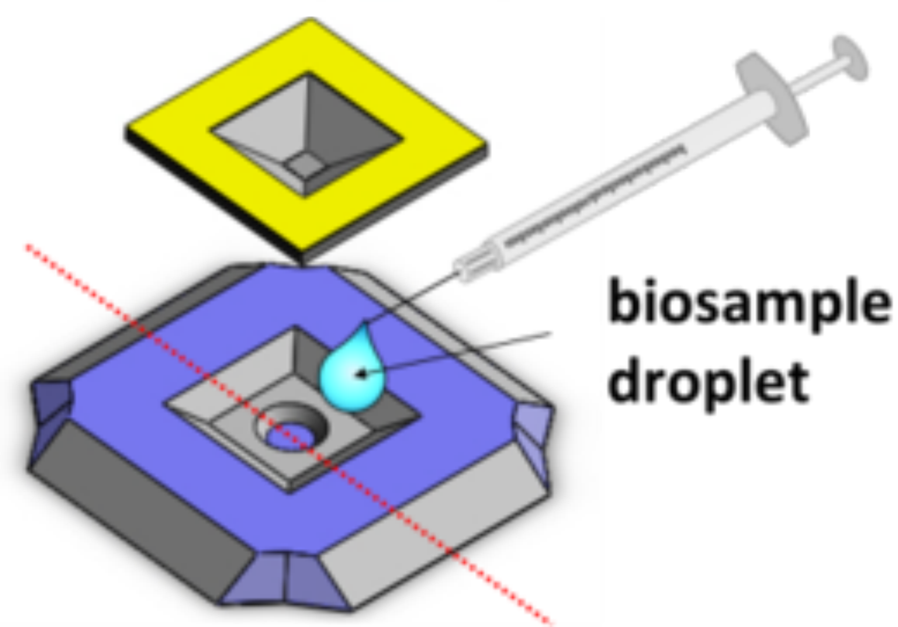
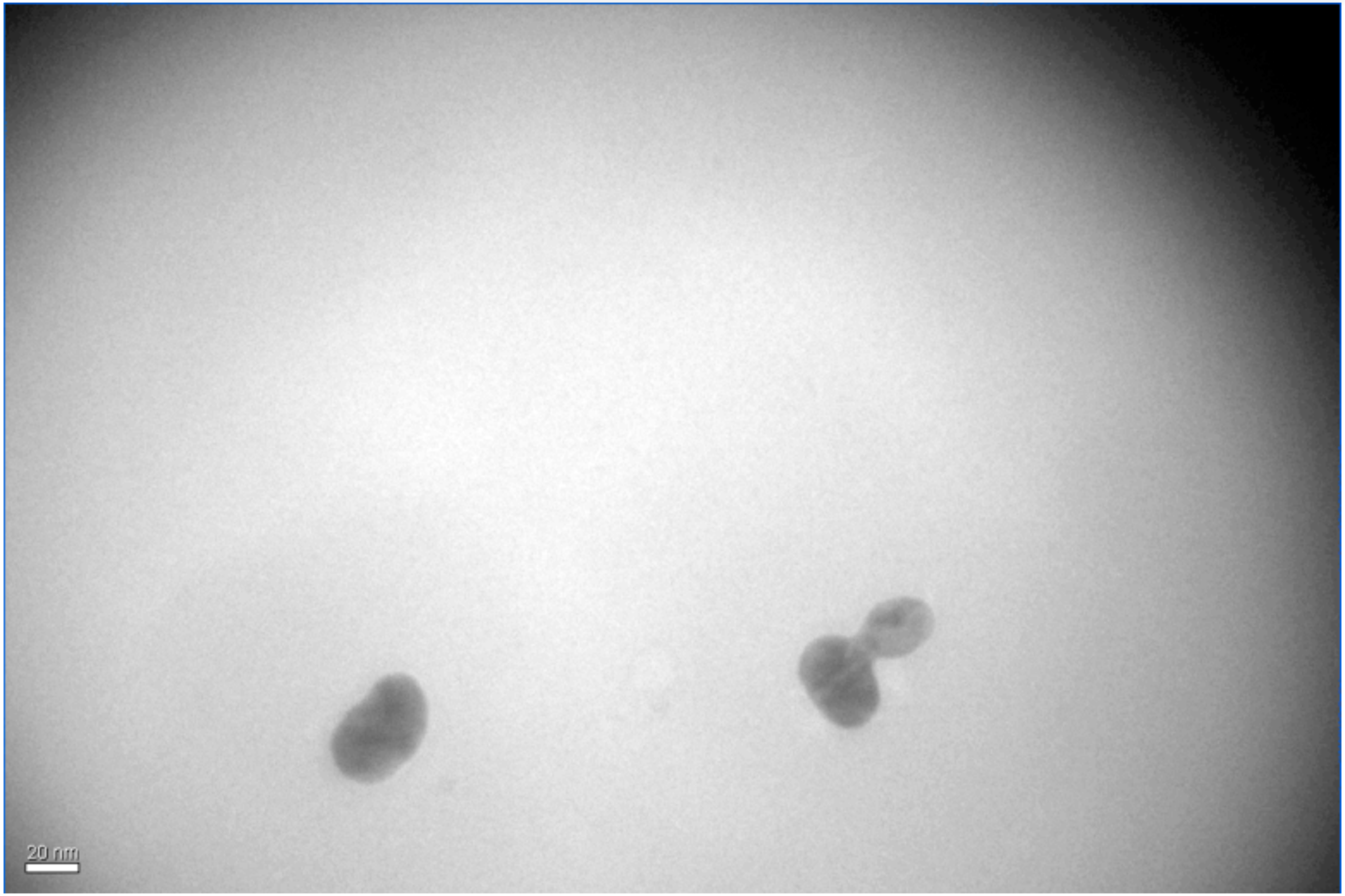
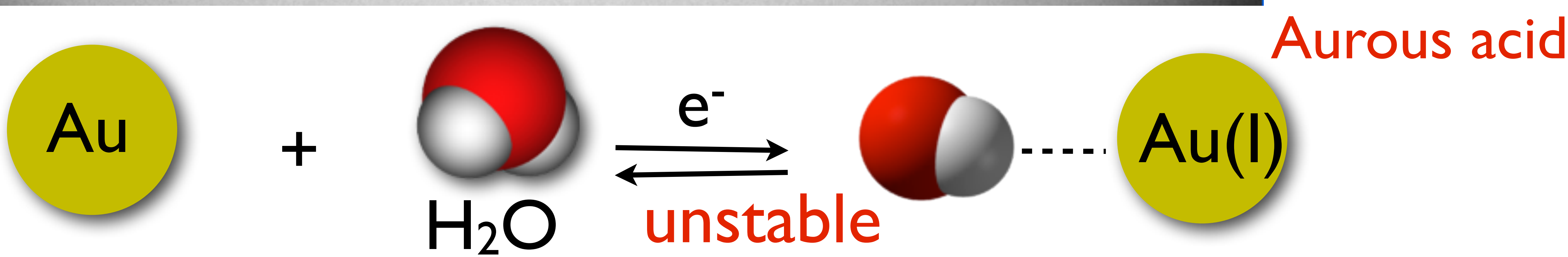




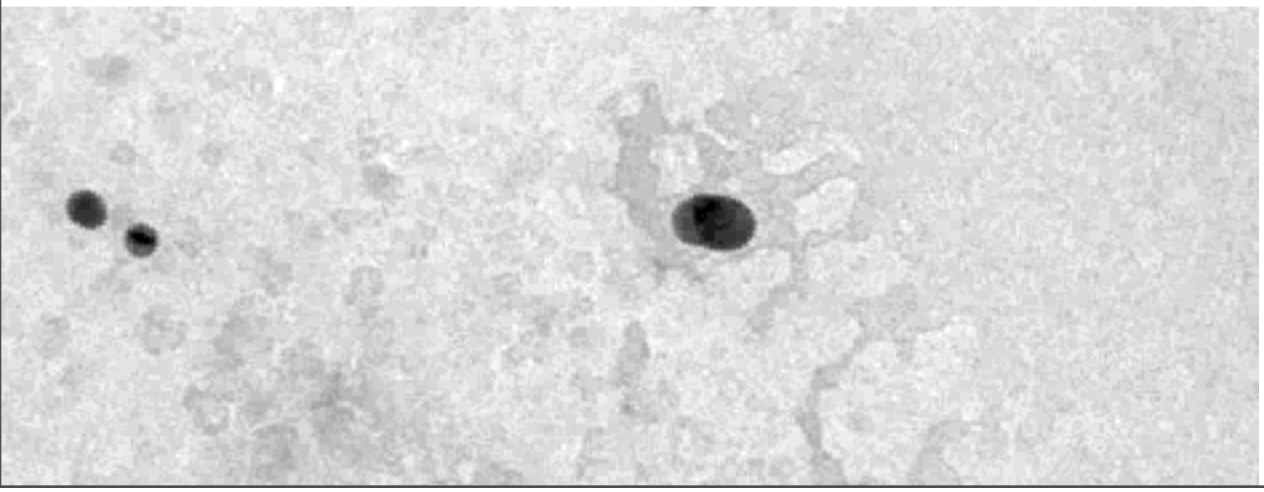
"Self-Aligned Wet-Cell for Hydrated Microbiology Observation in TEM," ***Lab on a Chip***, 12(2), pp.340-347, 2012.

dissolution of Au nano-particles





Dynamics of NW Growth from GNPs



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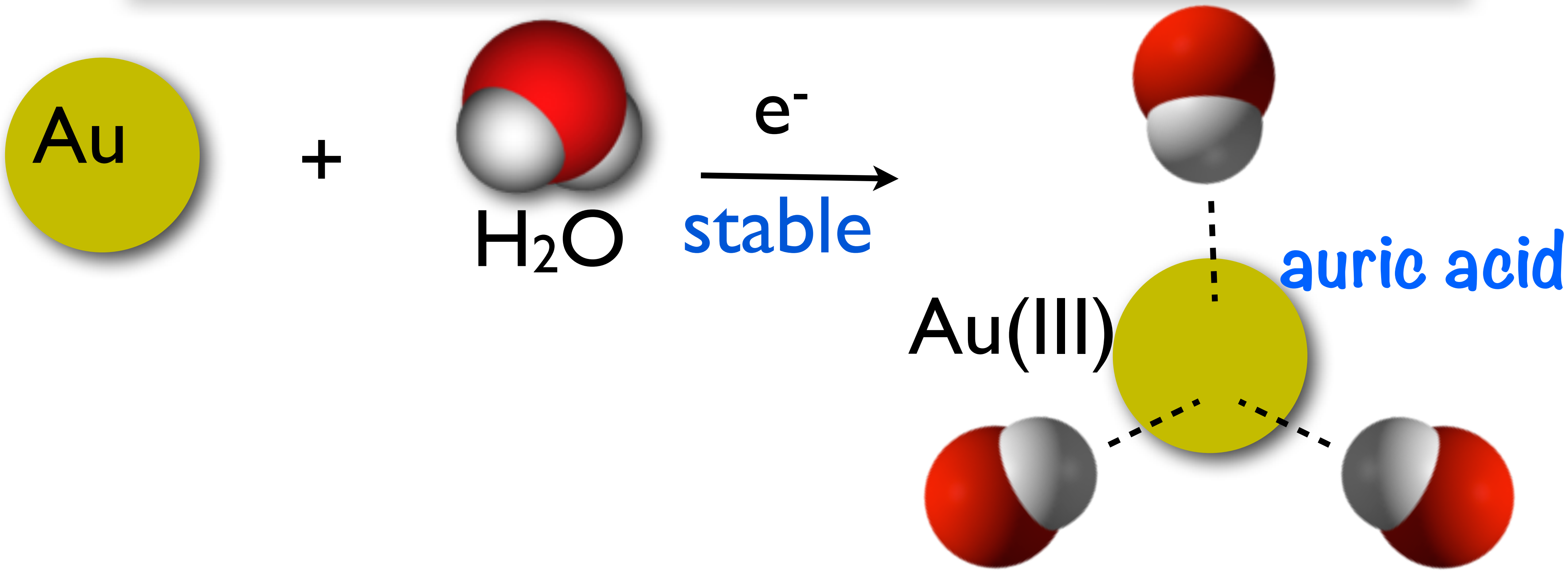

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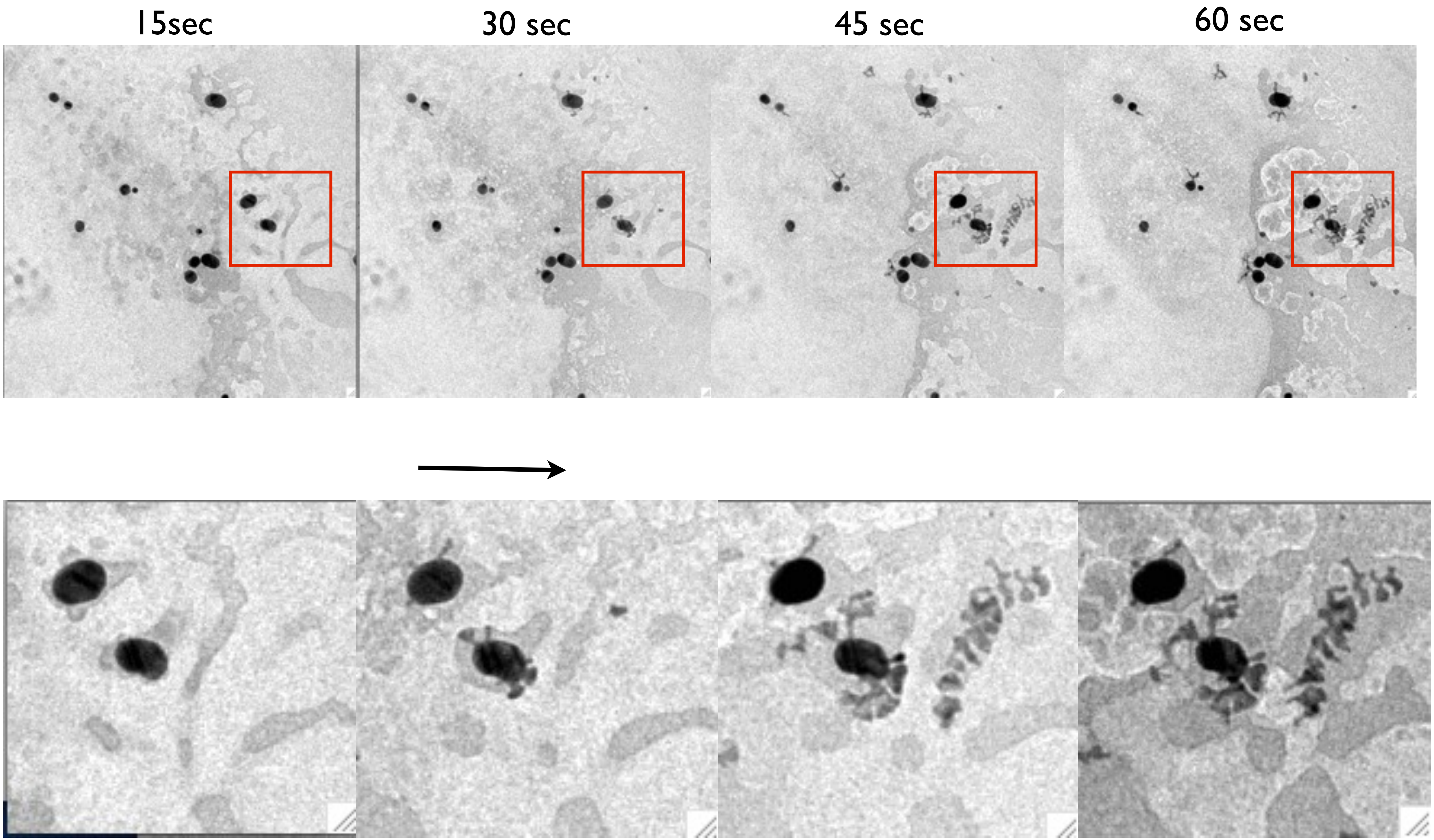
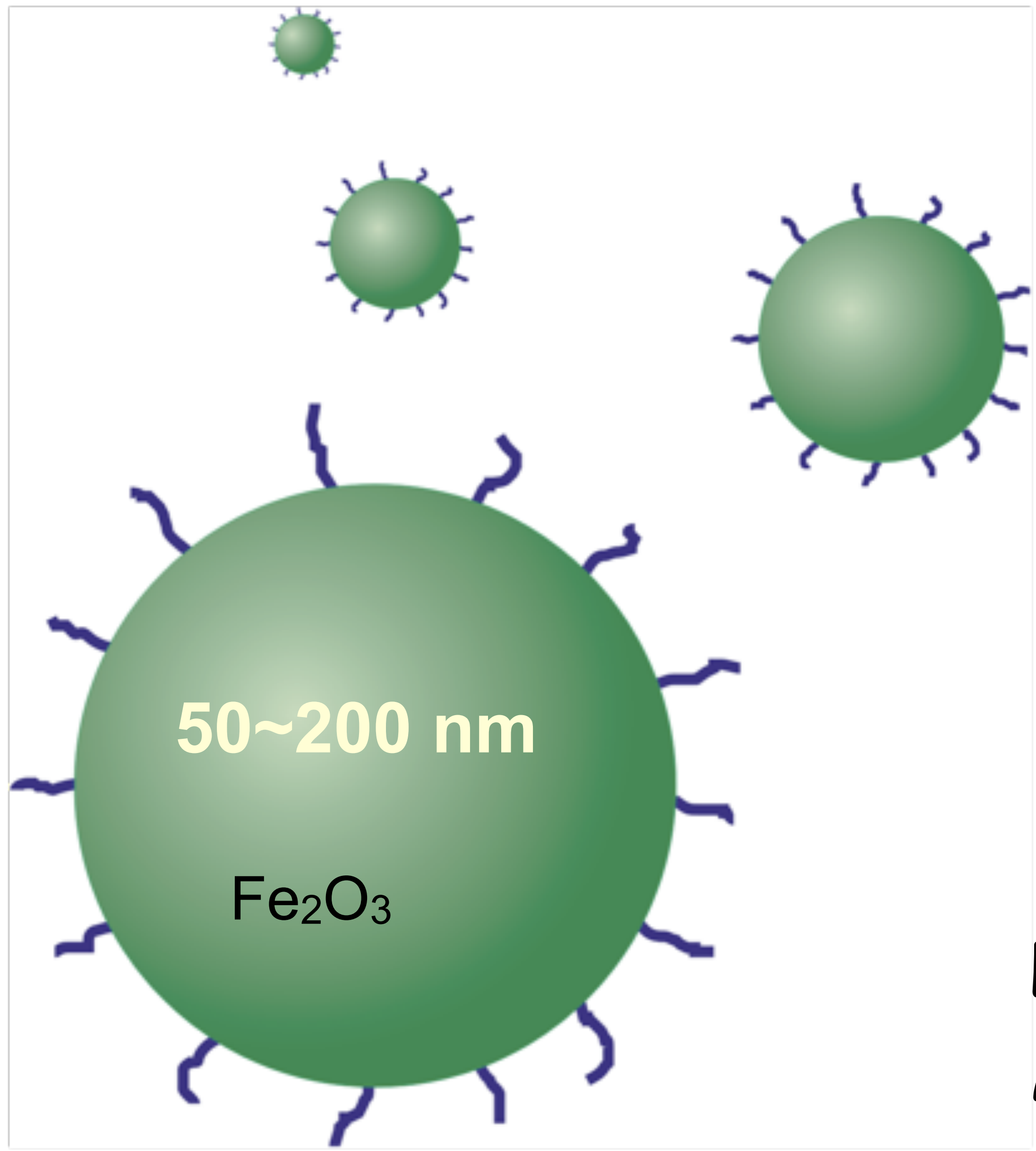


Magic Bullet: Targeting Drug

~ proposed by Nobel Prize winner (1908)   Paul Ehrlich



Easy Storage

High Drug Content

Stimuli Responsive

Large Surface Area

Modification

Superparamagnetic iron oxide (SPIO)

Magic Bullet: Targeting Drug

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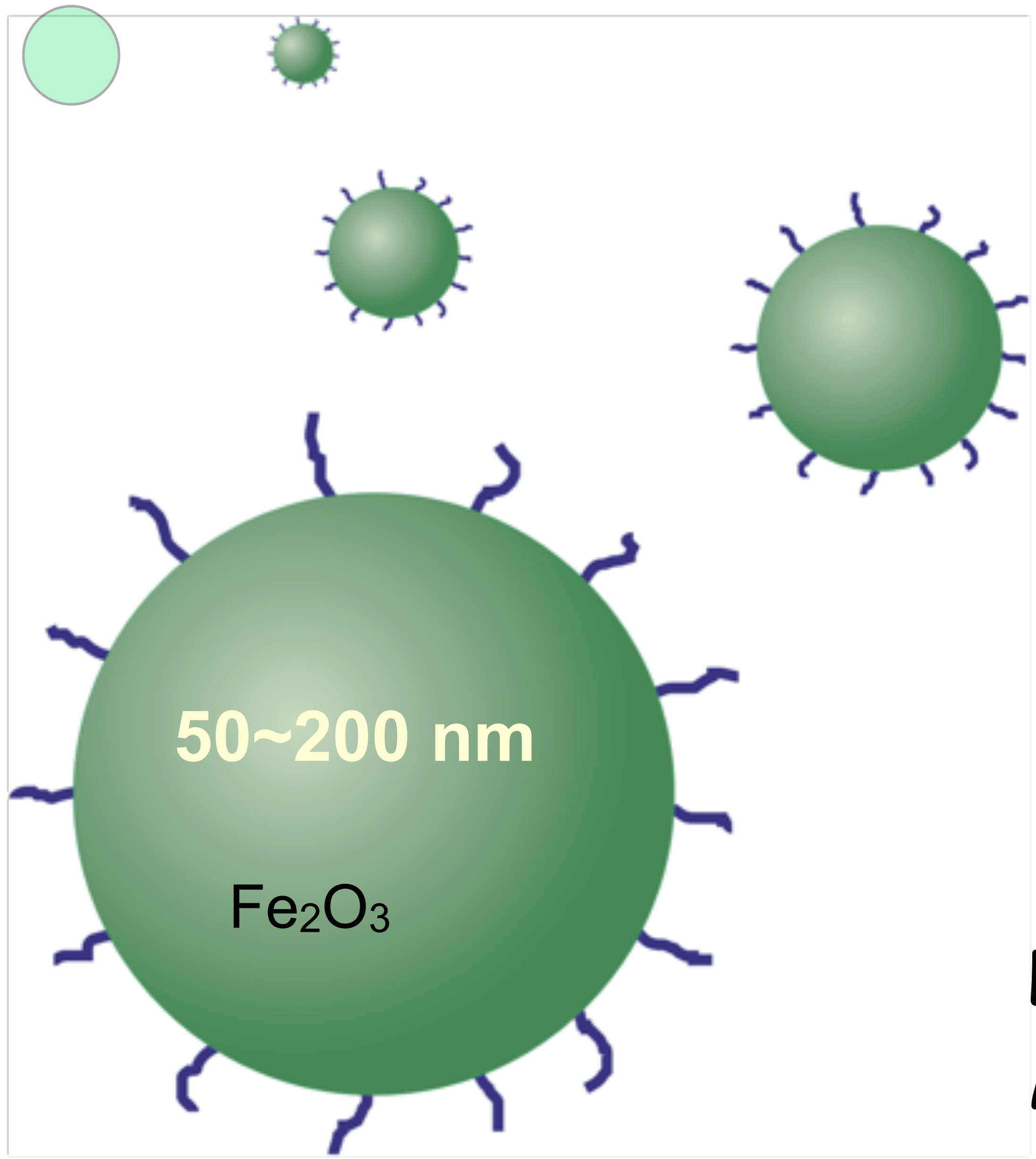
Chitosan



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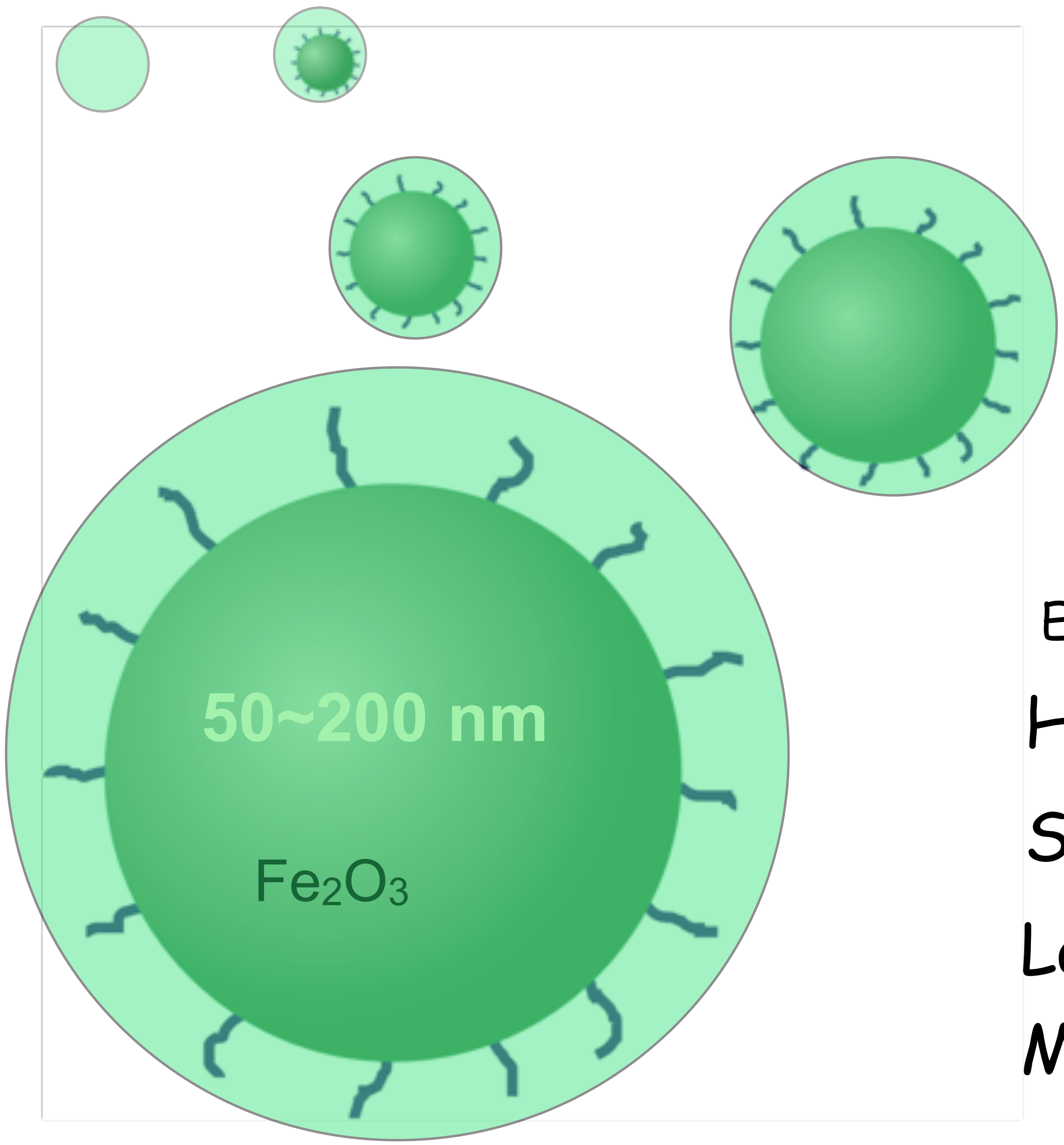

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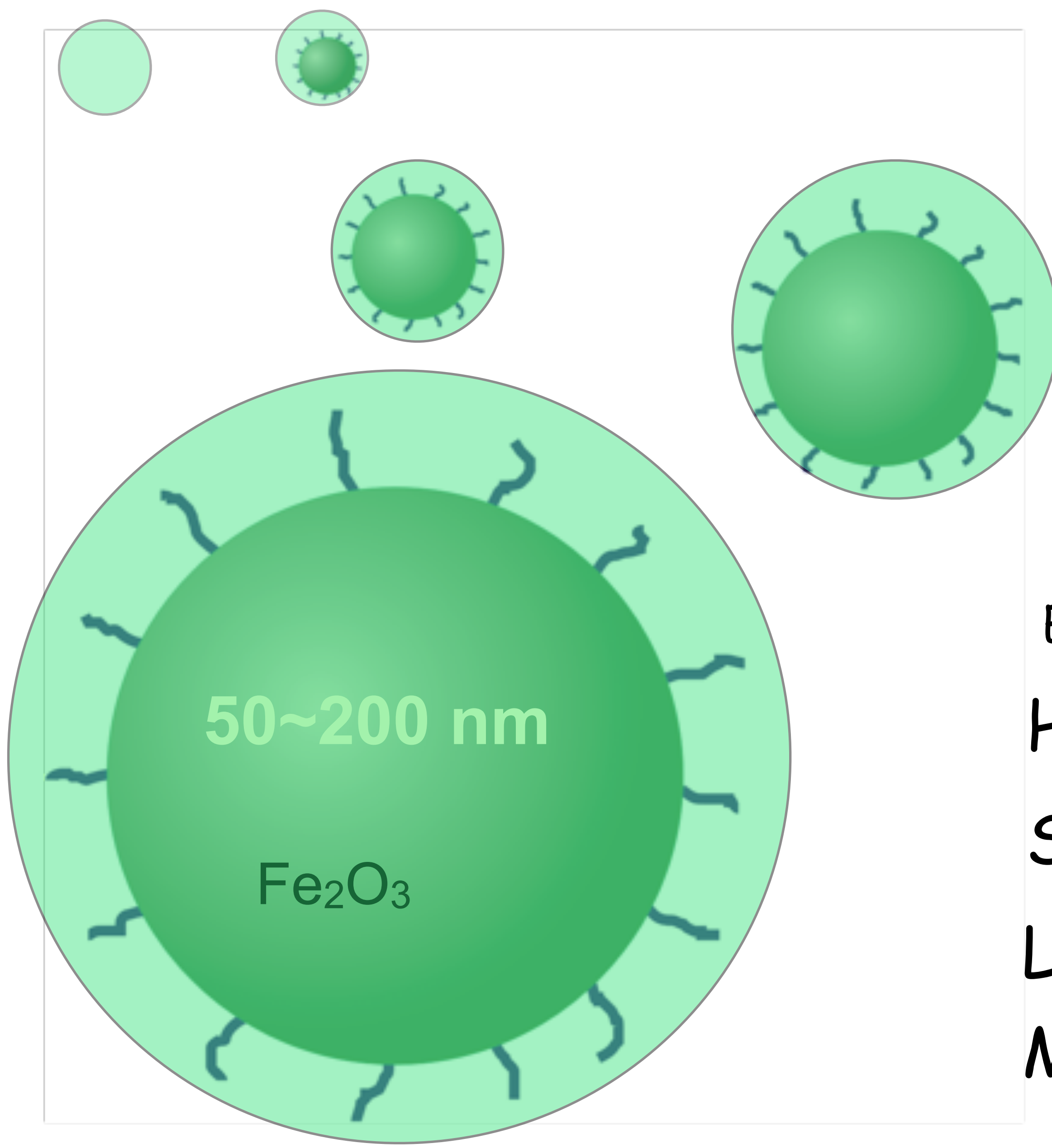
Chitosan-SPIO: Targeting drug for MRI contrast agent

Chitosan



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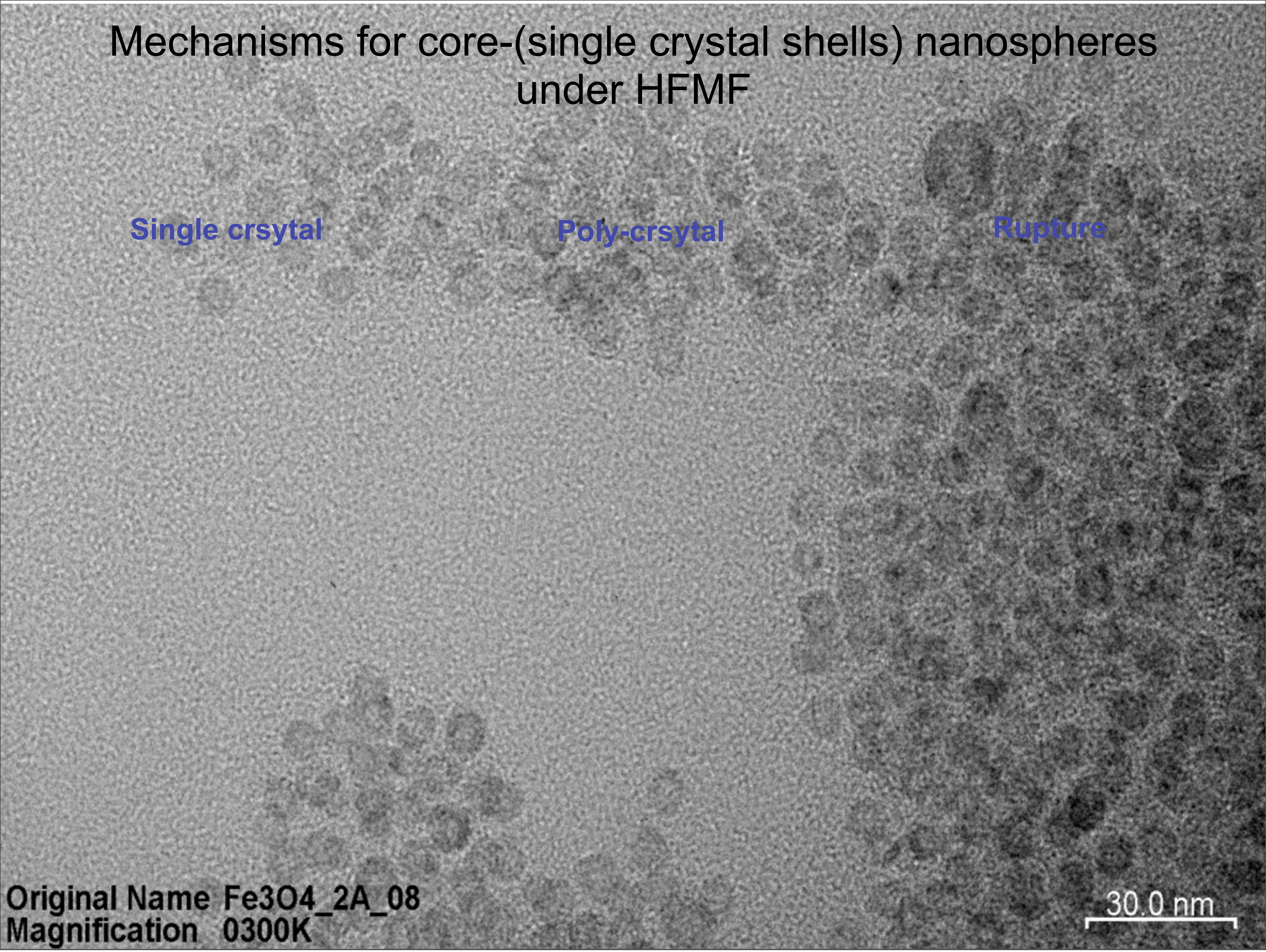
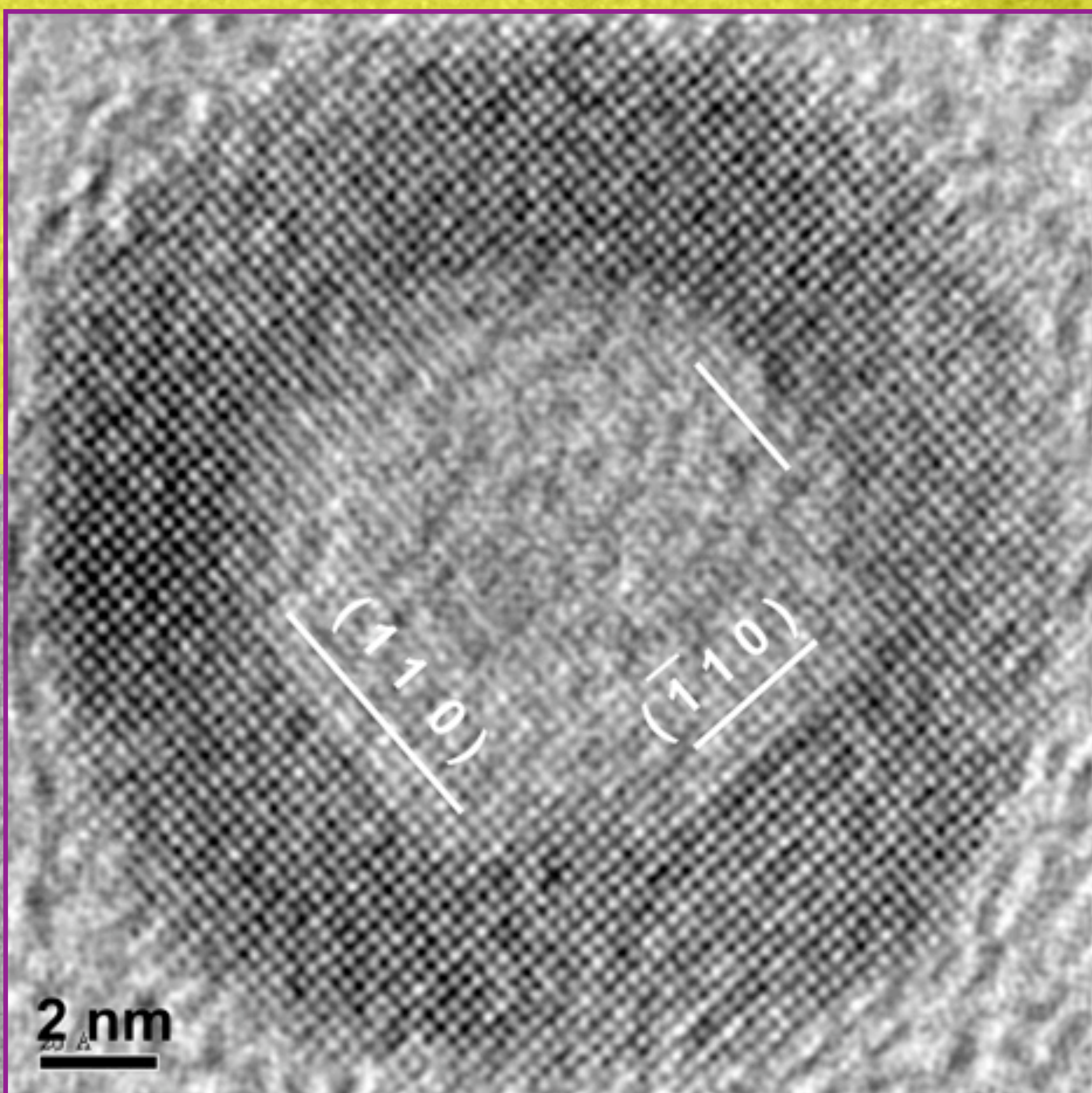
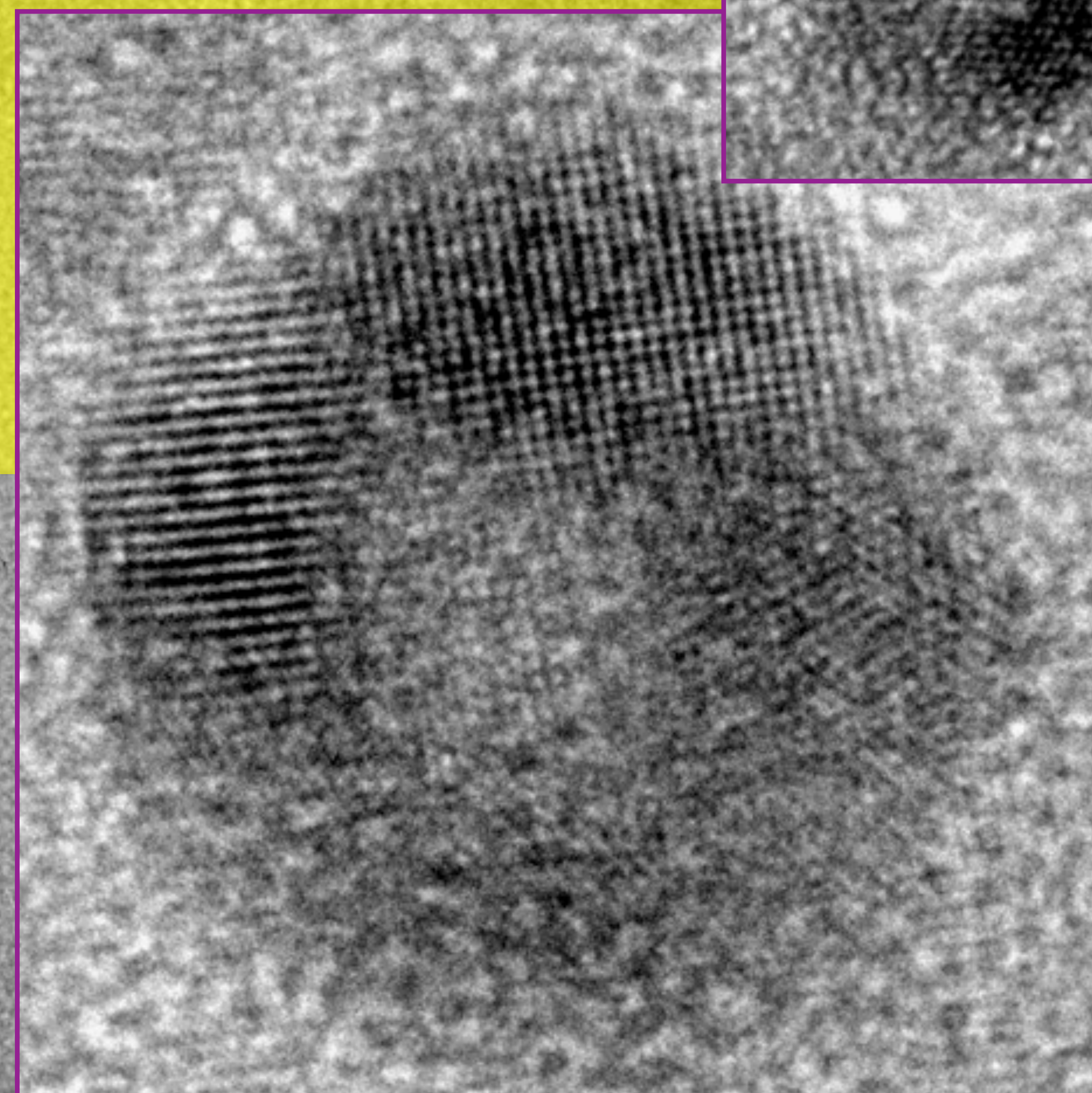
Mechanisms for core-(single crystal shells) nanospheres under HFMF

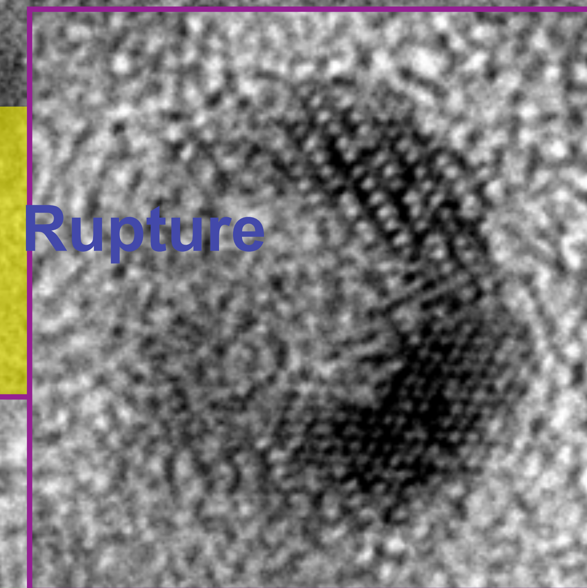


Mechanisms for core-(single crystal shells) nanospheres under HFMF

Single crsytal **Poly-crsytal** **Rupture**



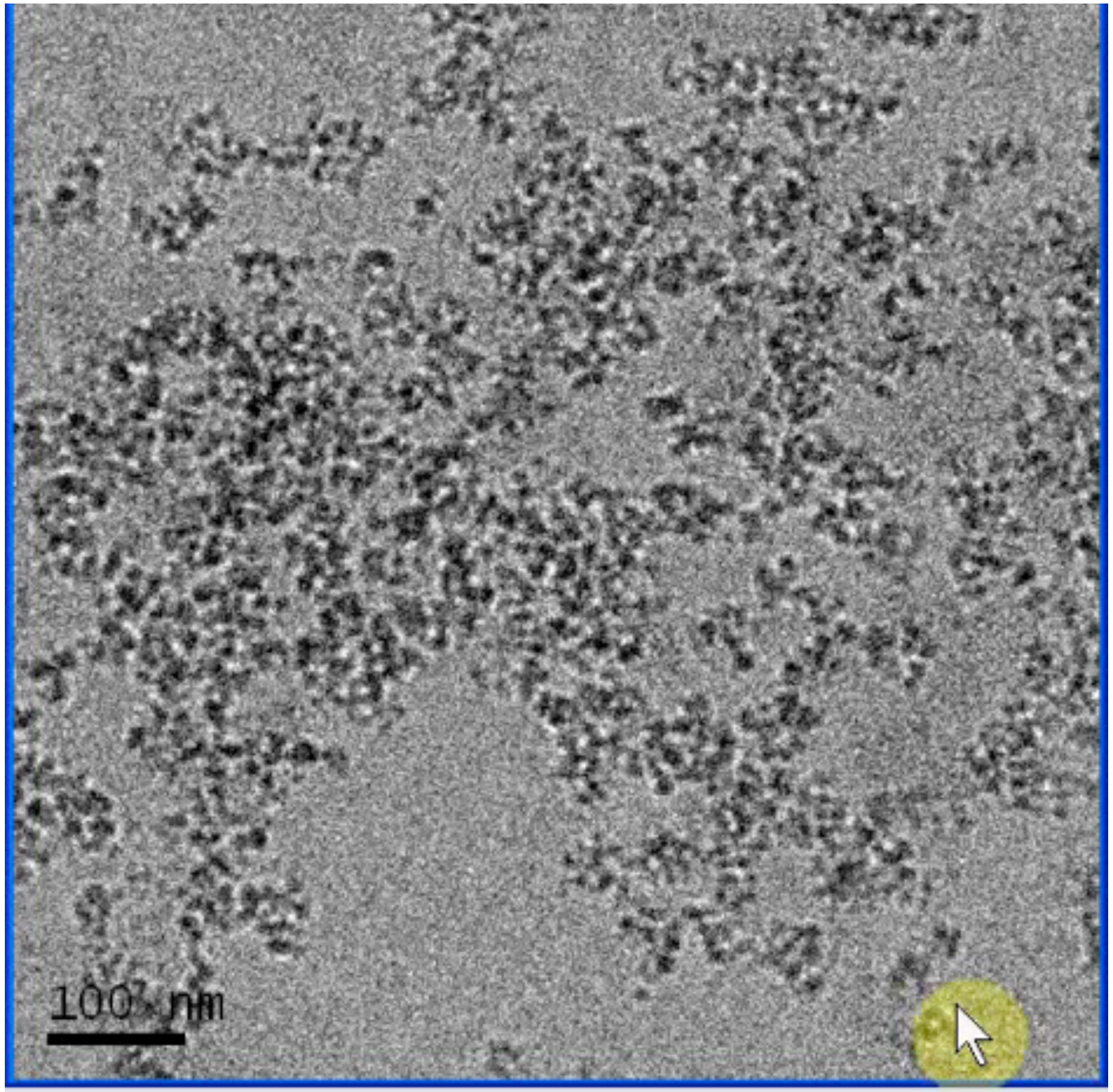




Original Name Fe3O4_2A_08
Magnification 0300K

30.0 nm

Reduction of Fe_2O_3 NPs



$$(1/3Fe_3O_4 + (2-b)H^+ + 1/3H_2(g) = Fe(OH)_b^{(2-b)+} + 4/3H_2O$$

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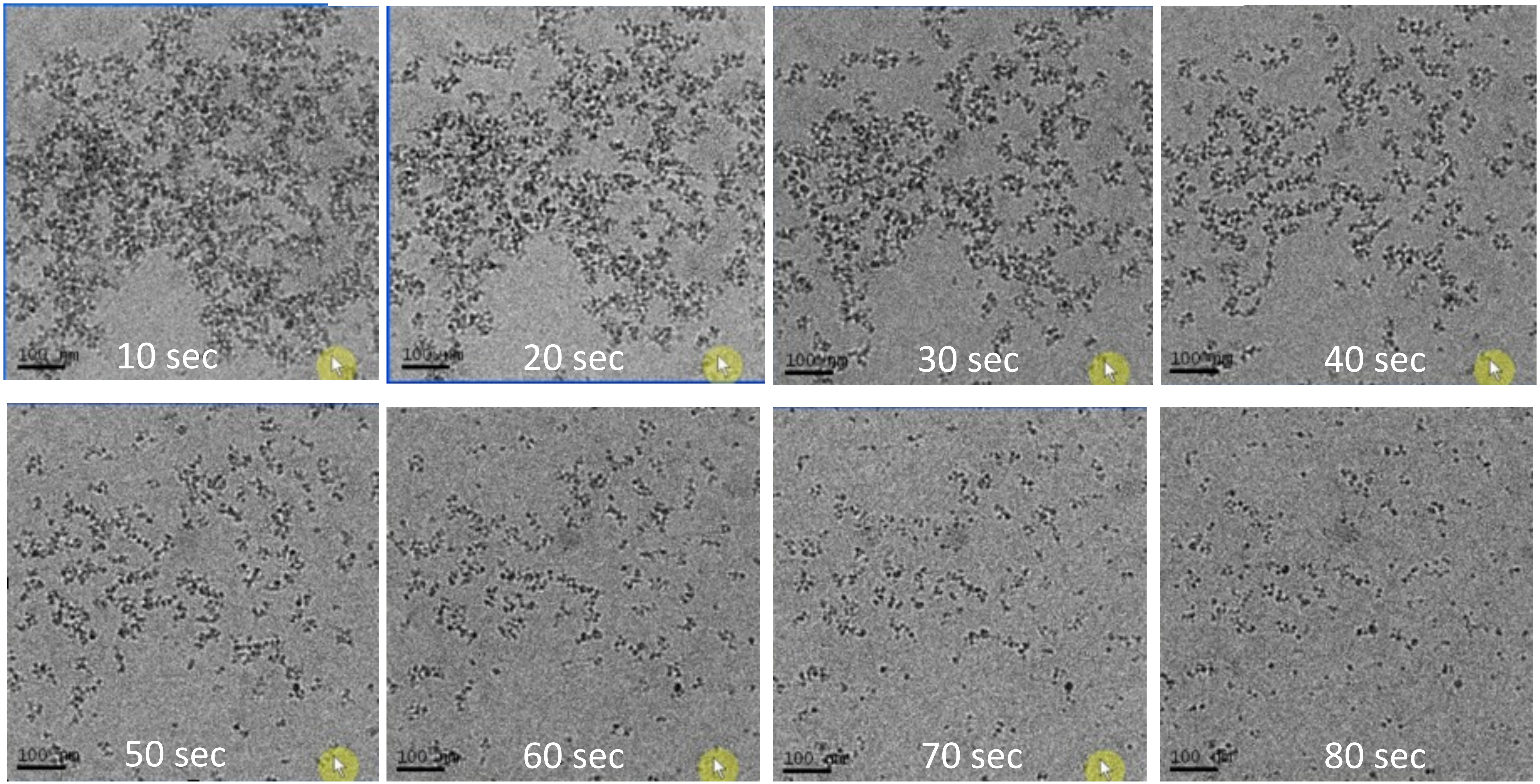
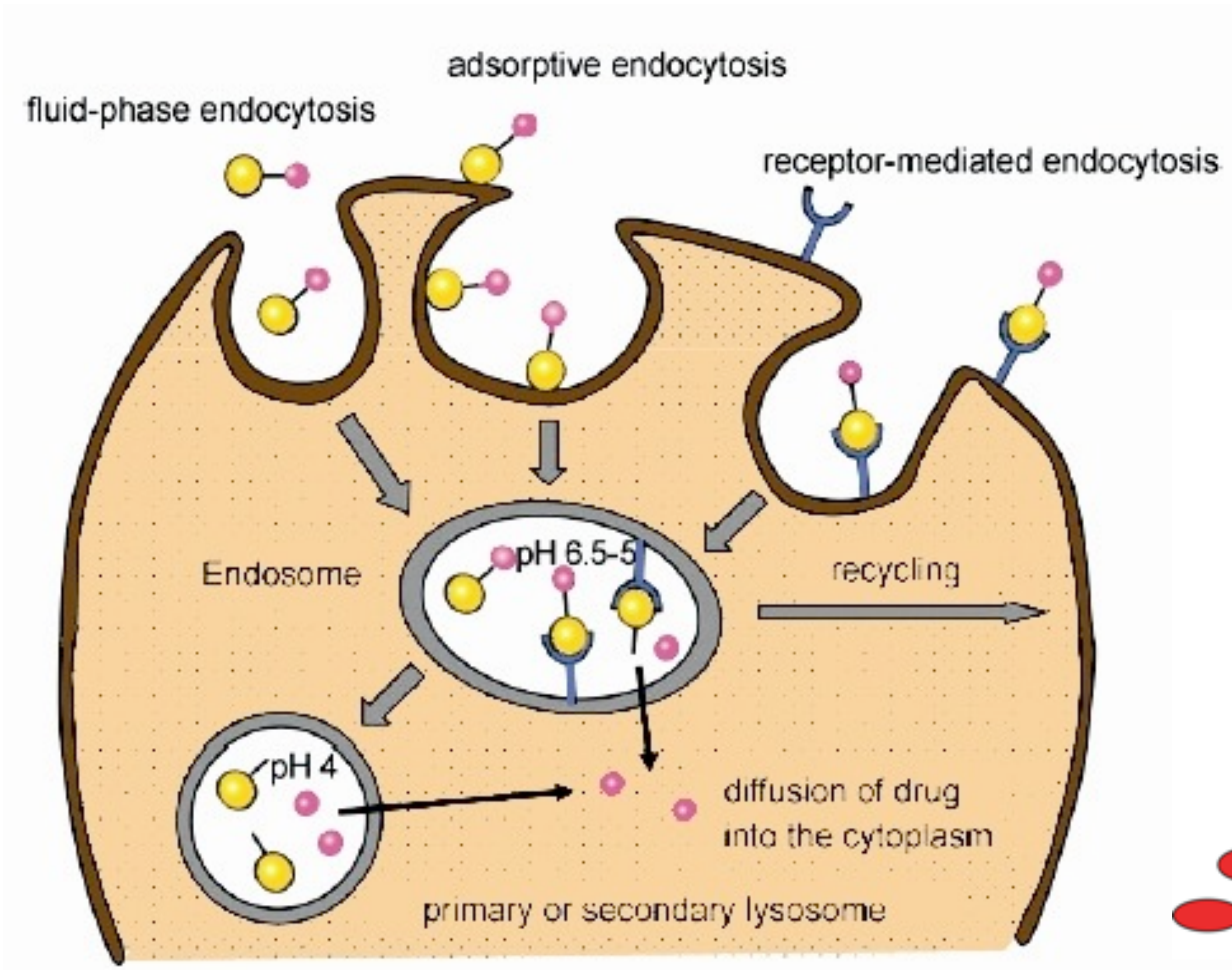


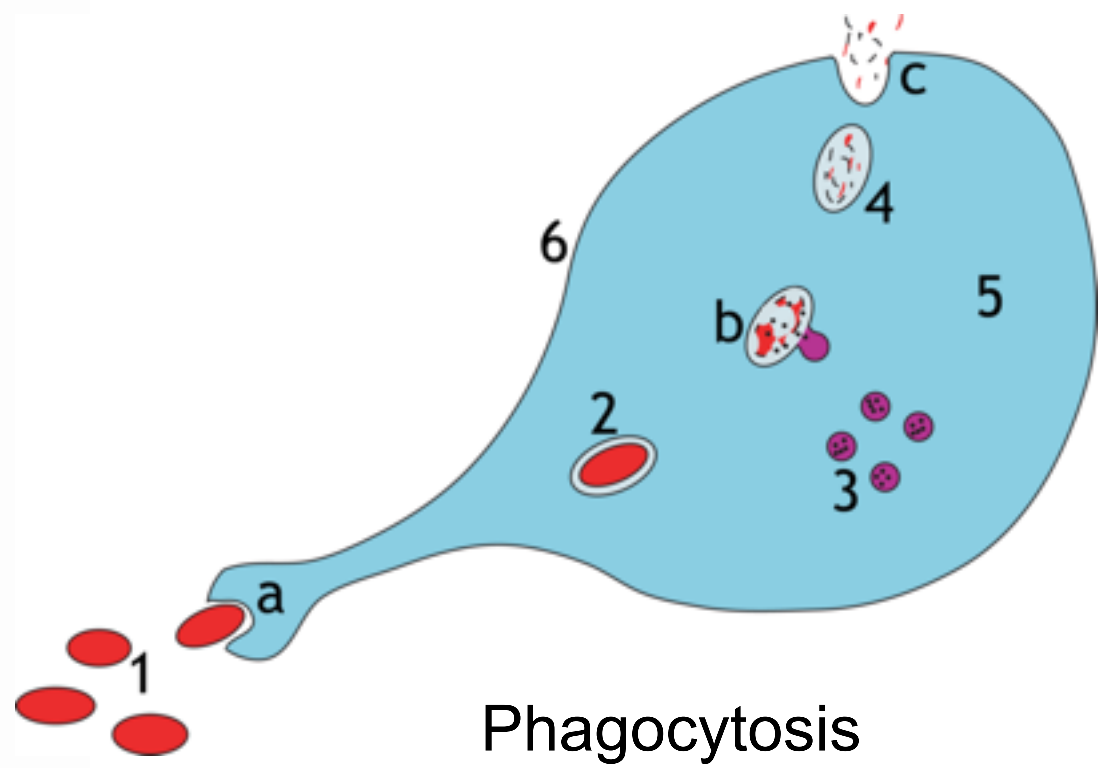
$$(1/3Fe_3O_4 + (2-b)H^+ + 1/3H_2(g) = Fe(OH)_b^{(2-b)+} + 4/3H_2O$$

Nano-drug Tumor Targeting

MRI contrast agent

Endocytosis





Phagocytosis

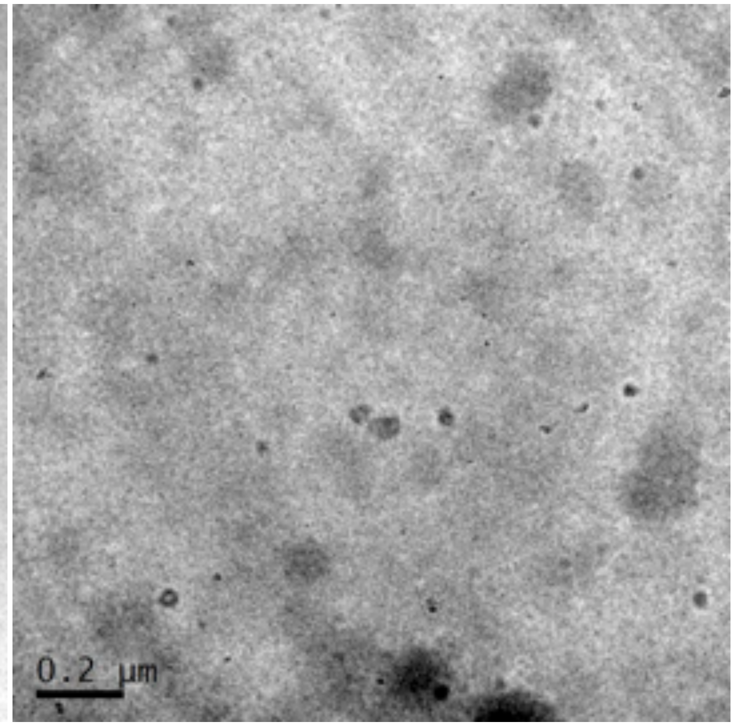
Nano-Bubbles for Cancer Therapy

Protein Liquid   Au NPs in Protein Liquid

$P=2\gamma/R$

Nano-Bubbles for Cancer Therapy

Protein Liquid



Au NPs in Protein Liquid

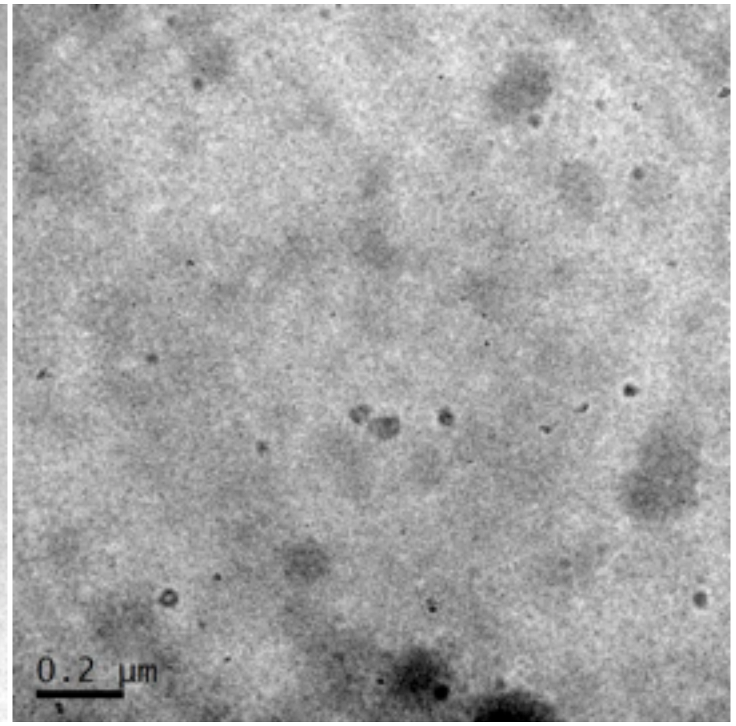
$$P=2\gamma/R$$

H_2 Knudsen gas (classical ideal gas)

Bose gas (quantum gas: Bose–Einstein condensate

Nano-Bubbles for Cancer Therapy

Protein Liquid



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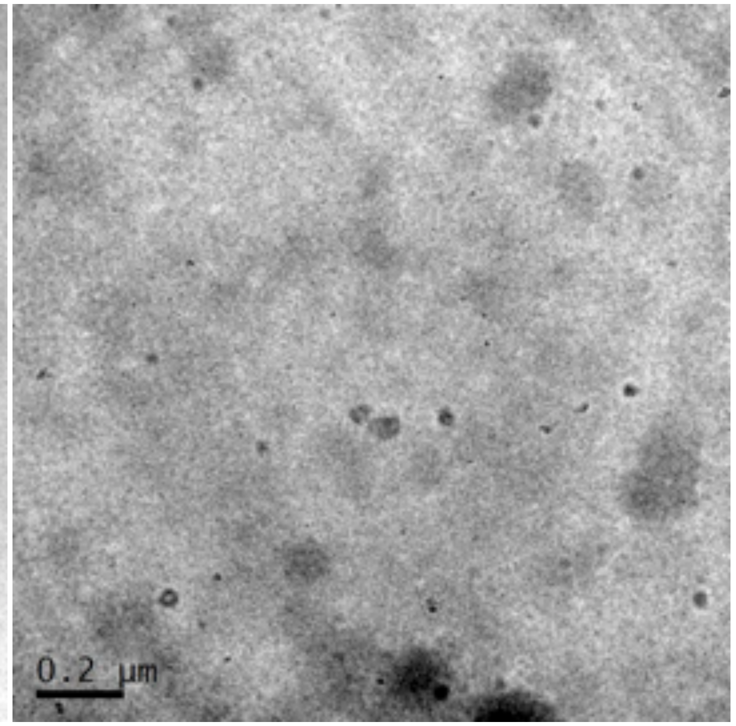
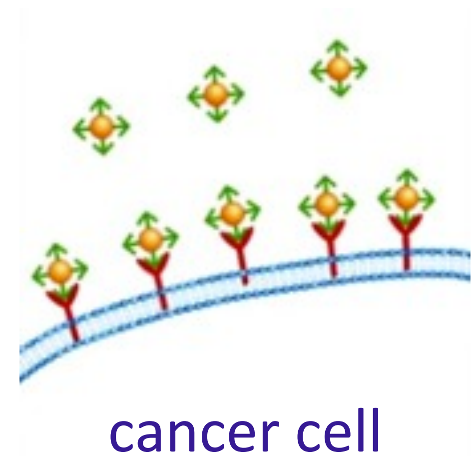


Au NPs in Protein Liquid

Au NPs with antibody



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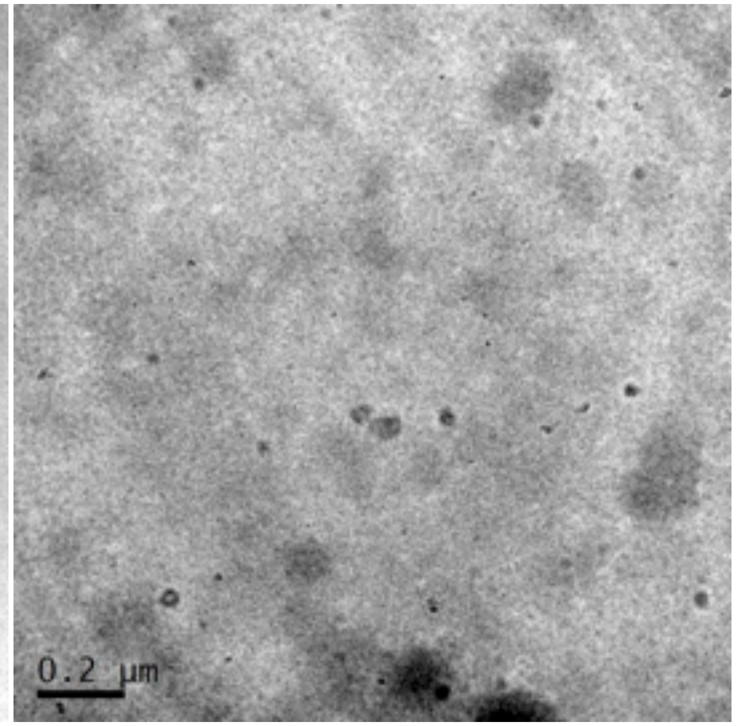
Nano-Bubbles for Cancer Therapy

Protein Liquid



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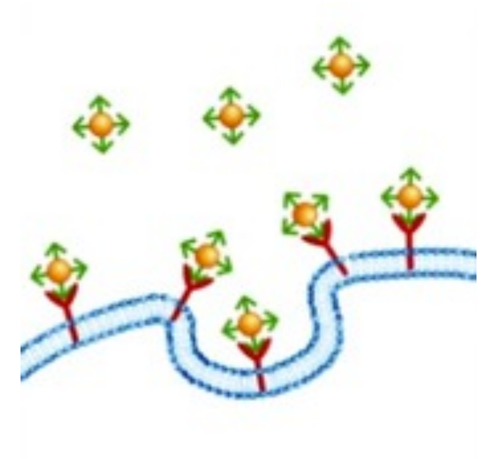

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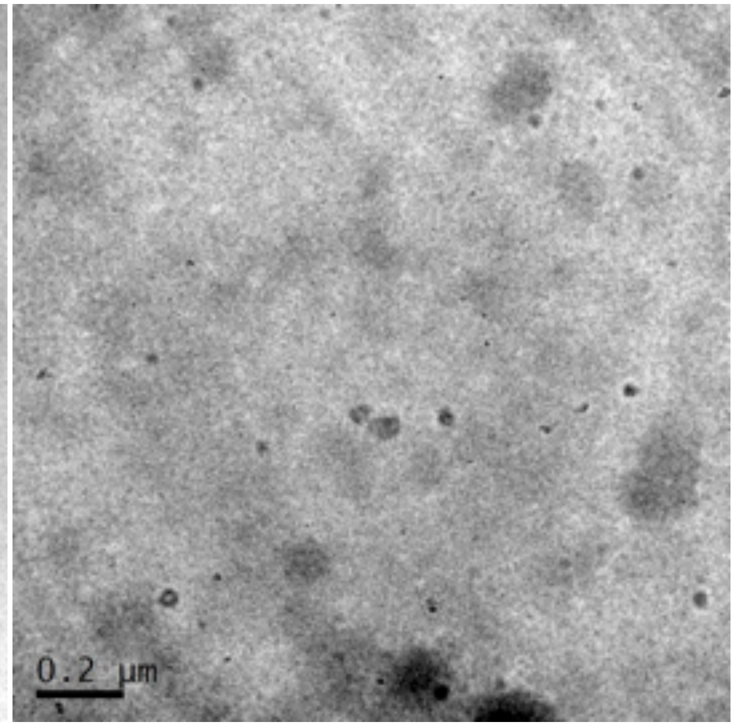

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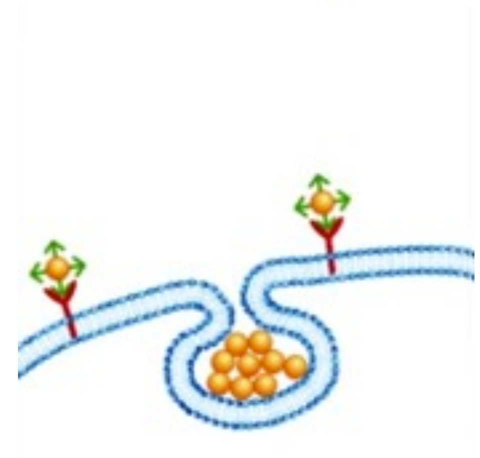

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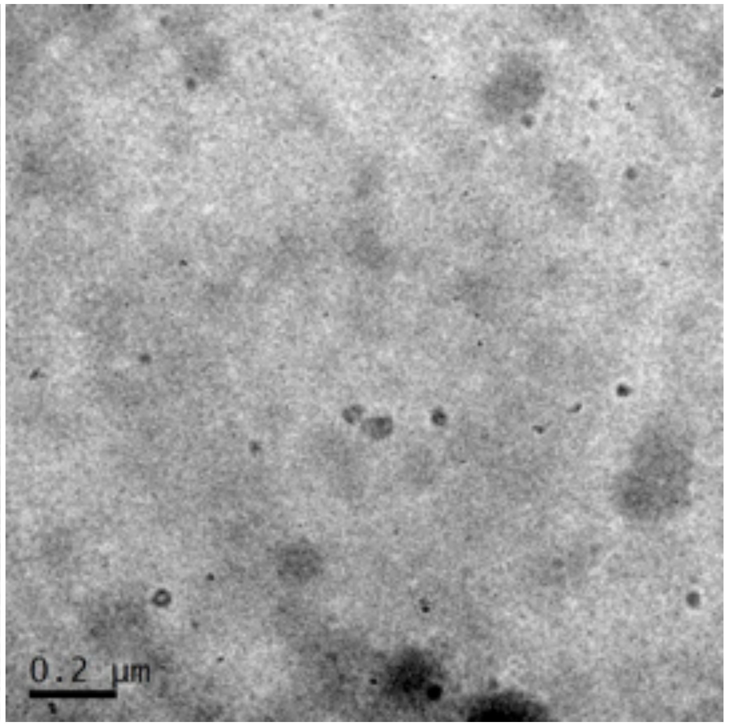

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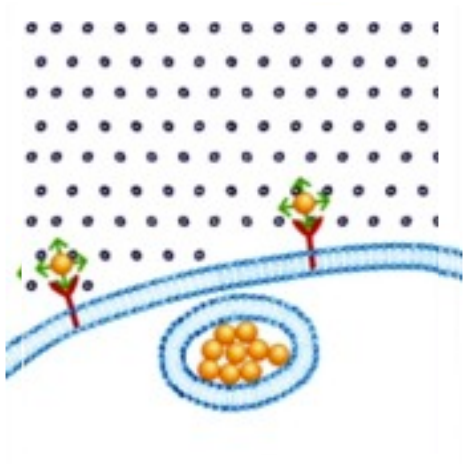

cancer drug

$$P=2\gamma/R$$

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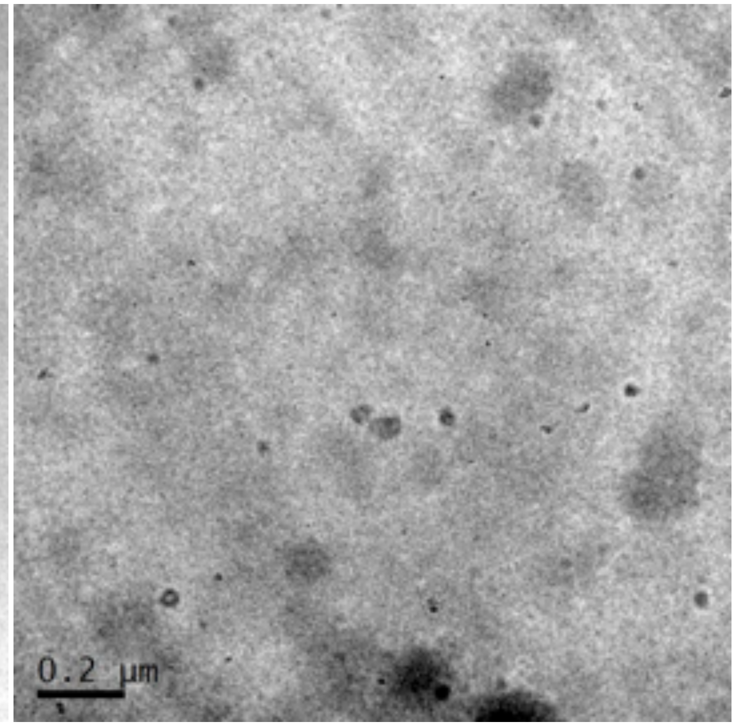
Protein Liquid



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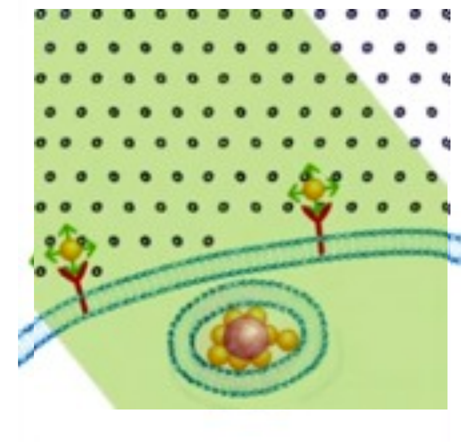

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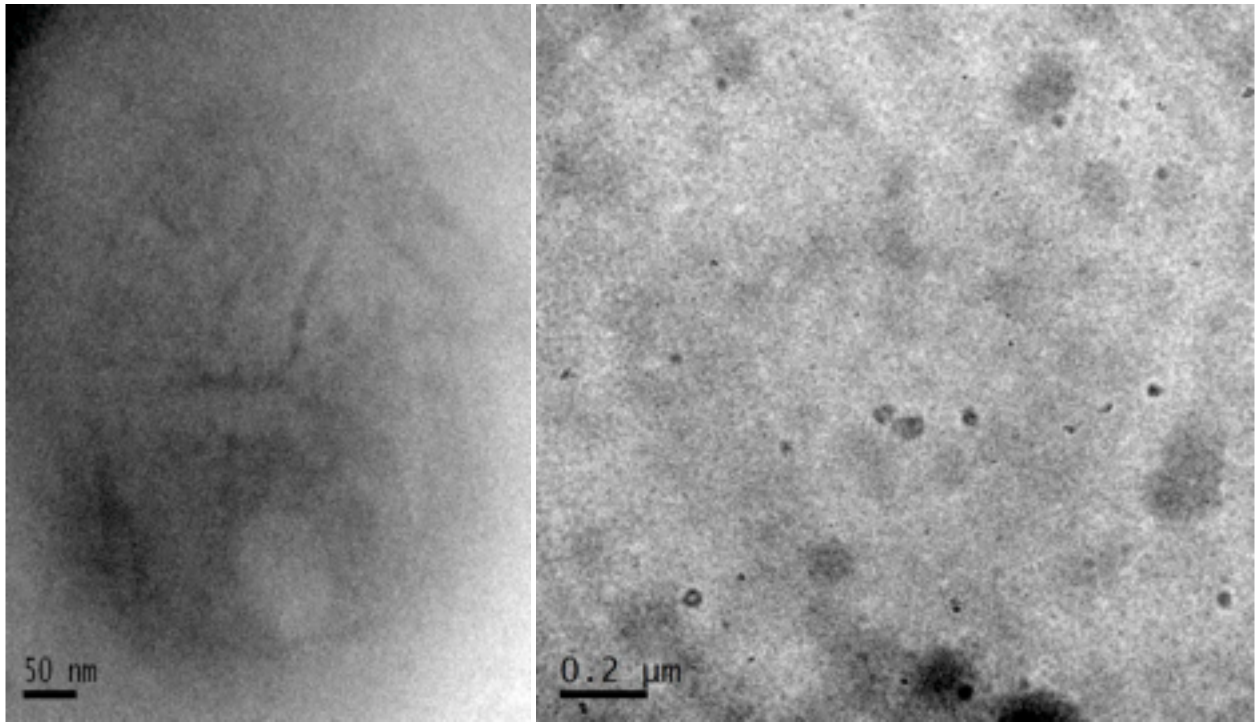

Protein Liquid   Au NPs in Protein Liquid

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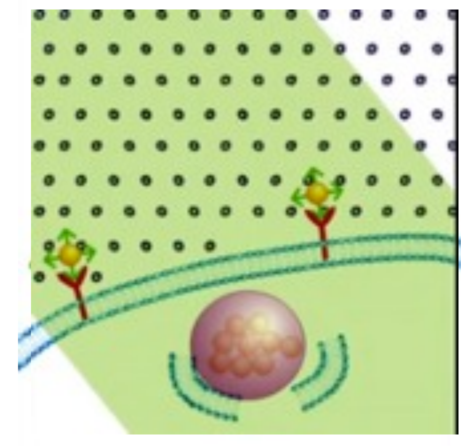

cancer drug

Laser

Plasmonic Nanobubble

$$P=2\gamma/R$$

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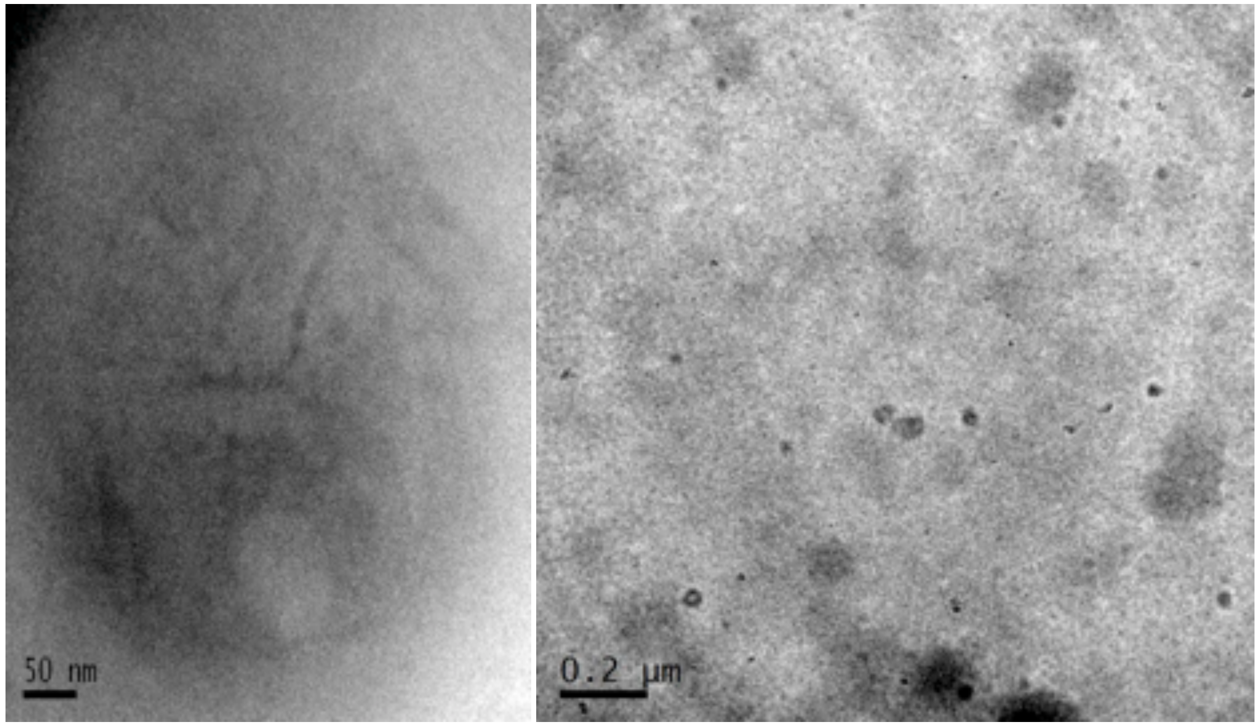

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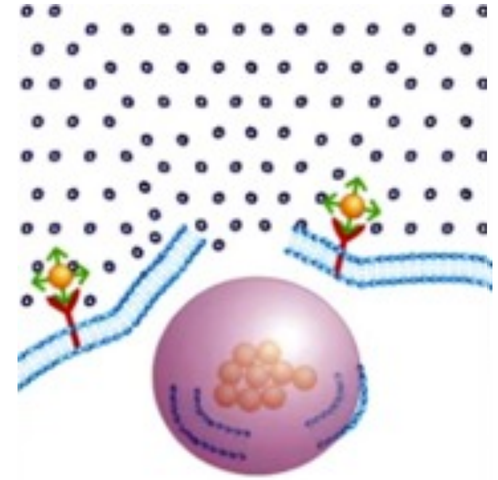

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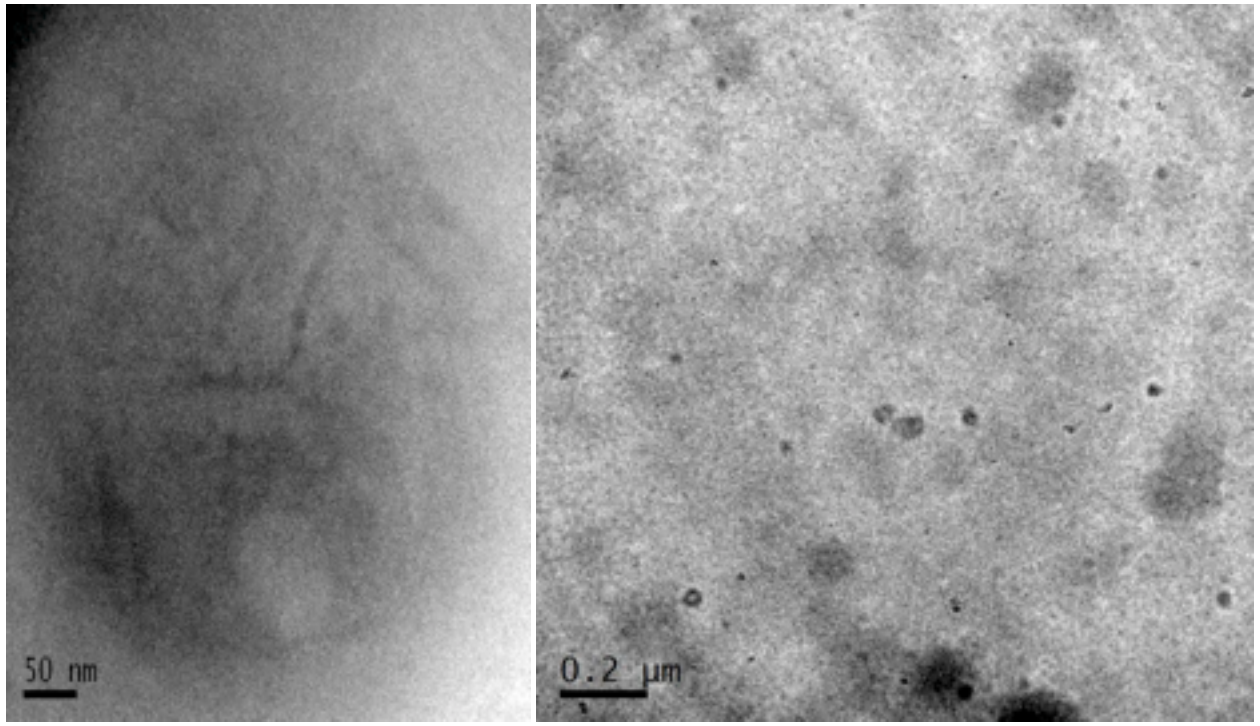

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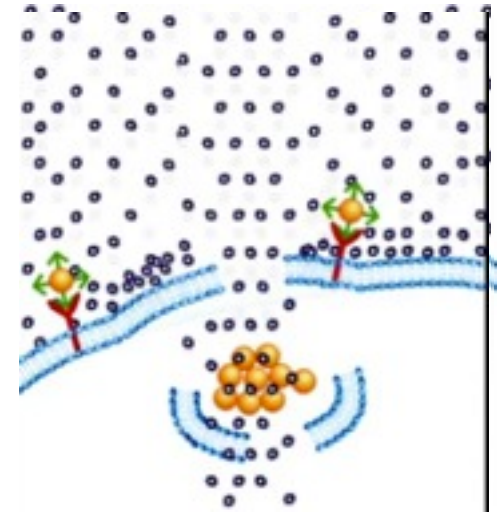

cancer drug

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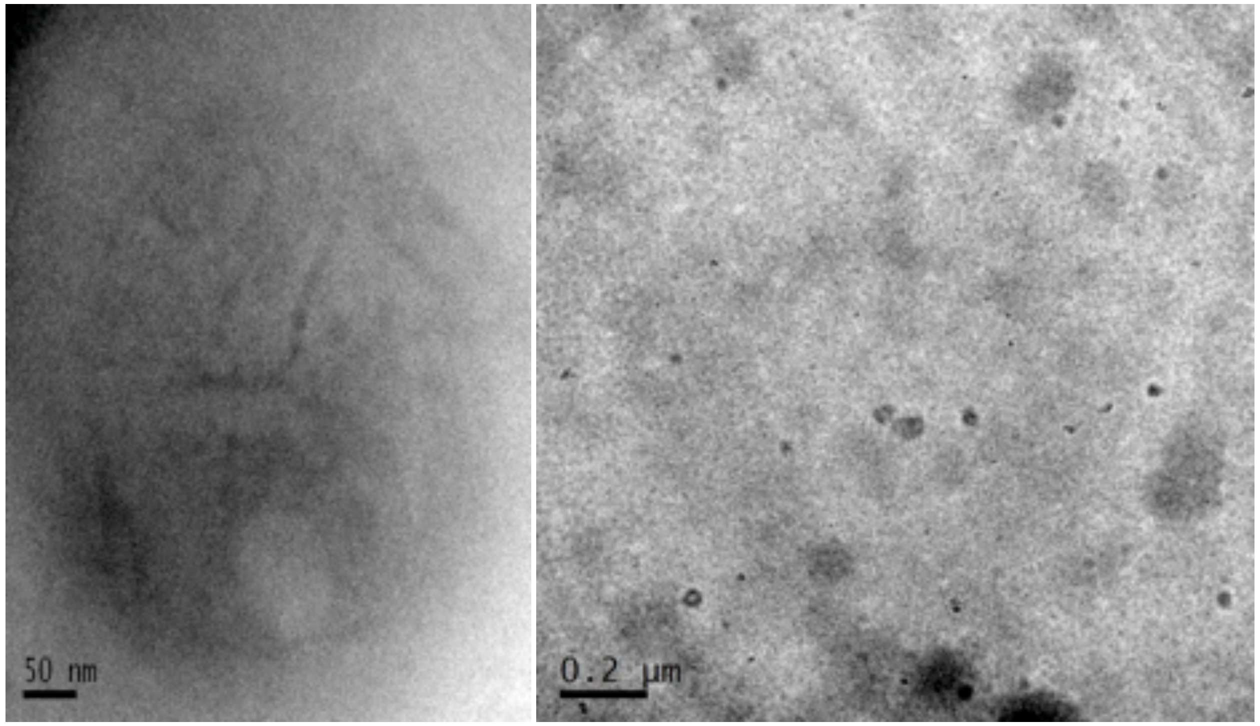

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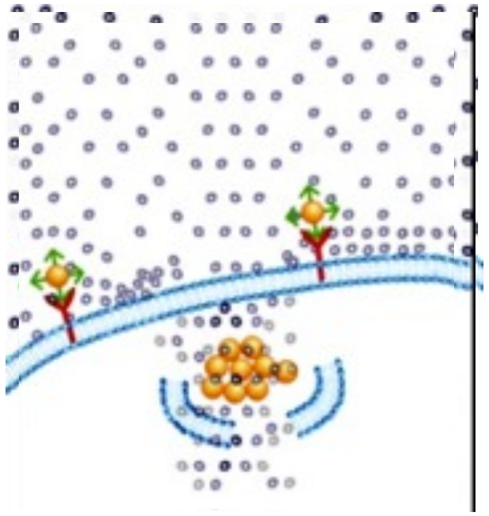

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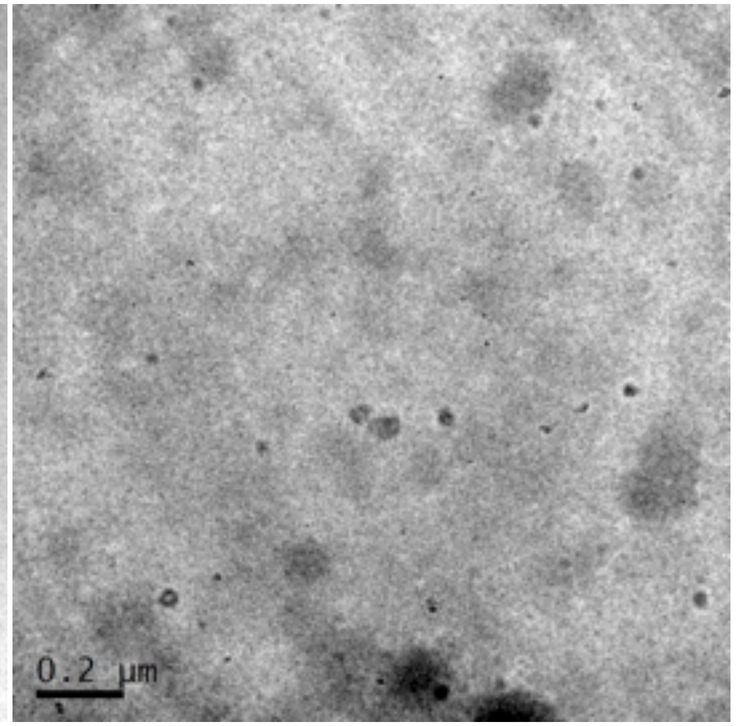

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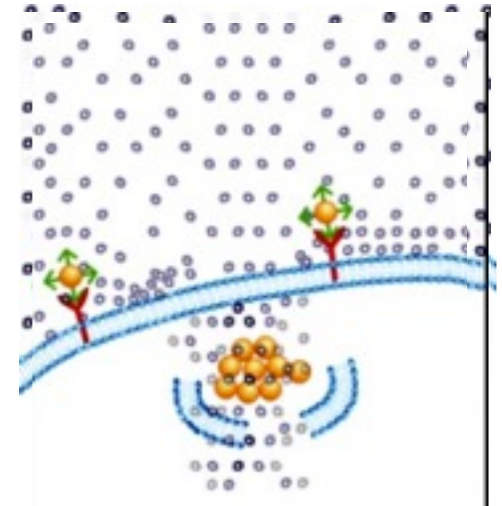

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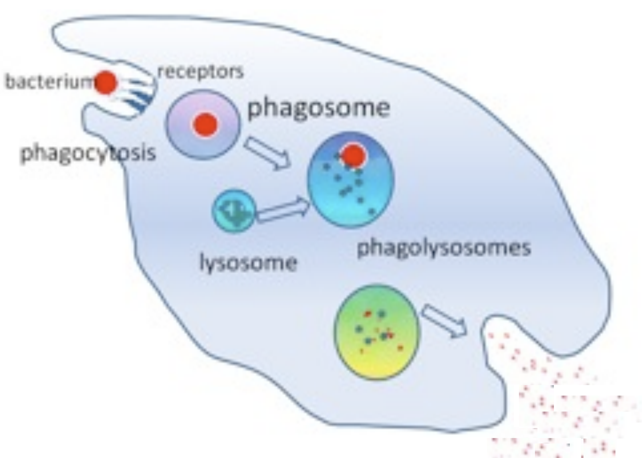
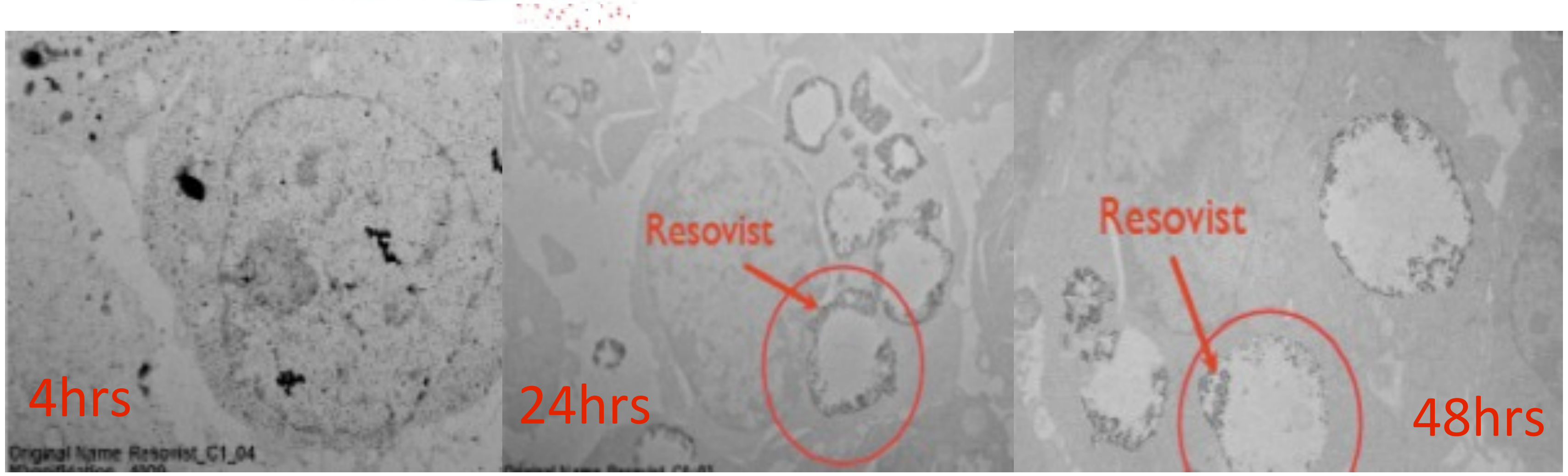
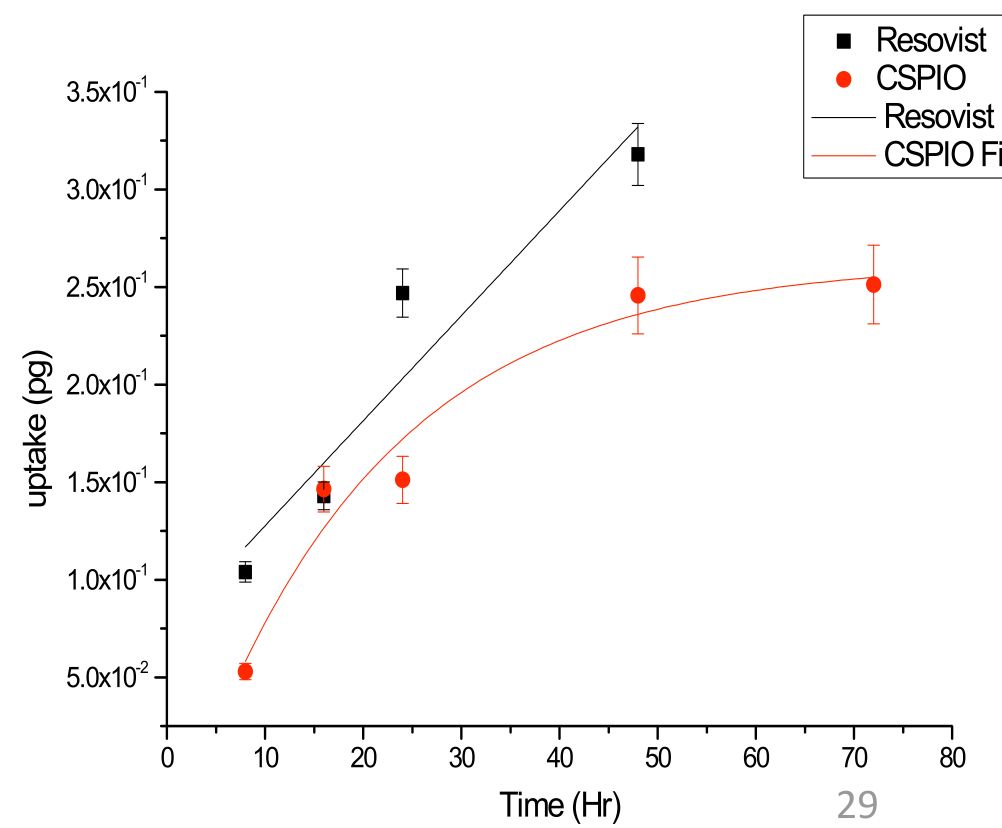


CSPIO (or PLGA+Fe_3O_4)





Ultra-fast Electron Microscope

Ultra-fast Electron Microscope

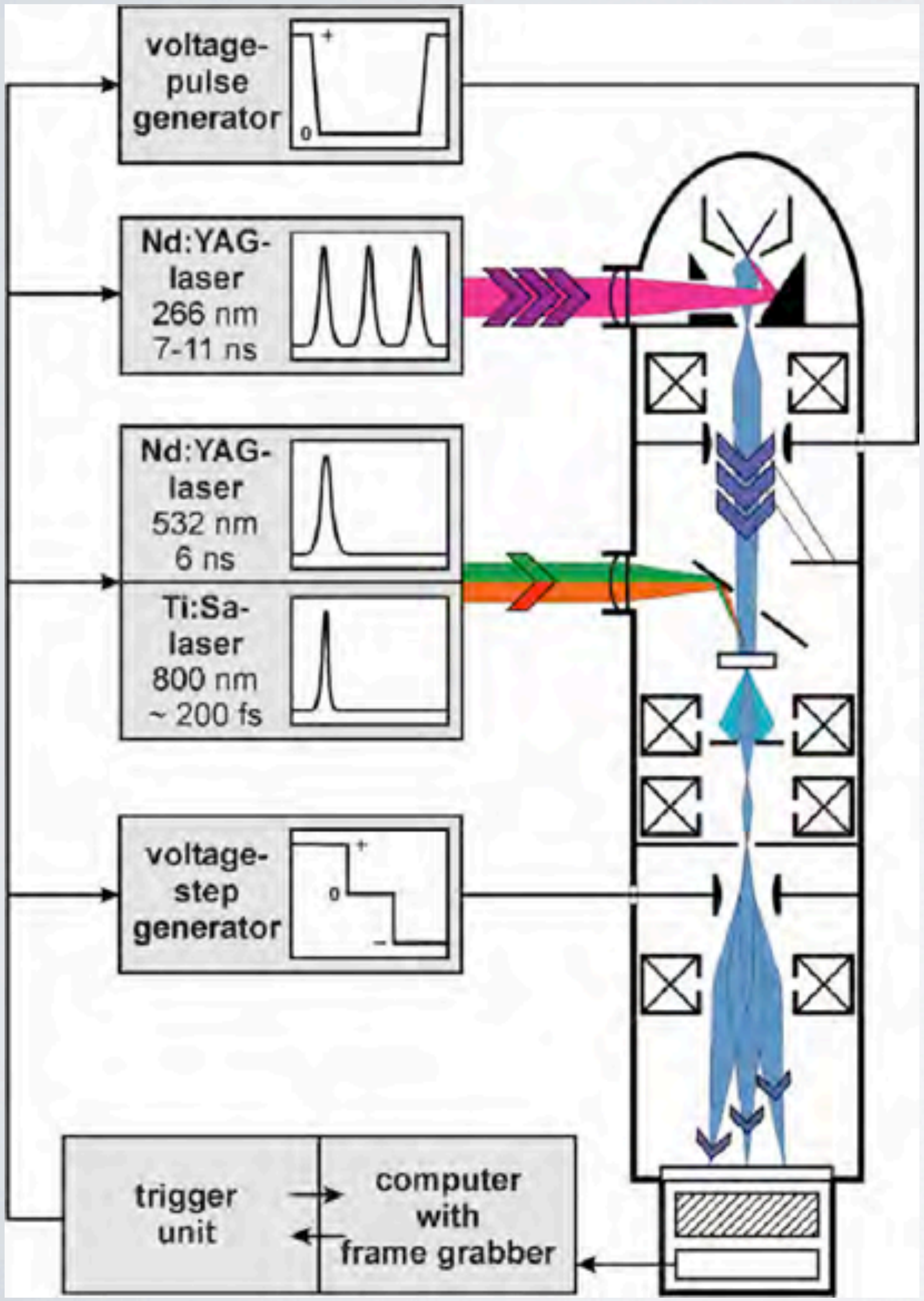
Ultra-fast Electron Microscope

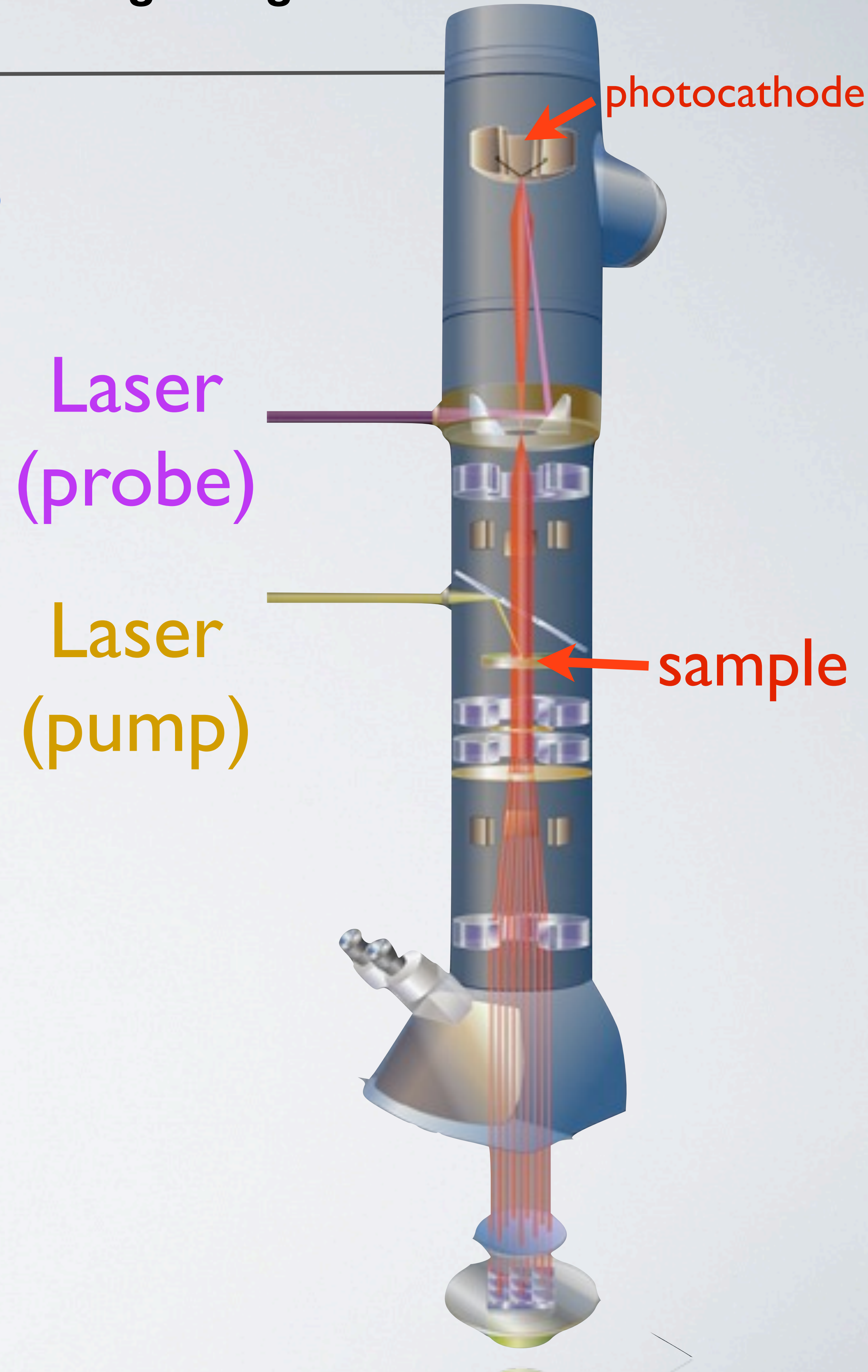
A falling apple photographed by stroboscopic illumination at intervals of ~1/25 s. The acceleration due to gravity is clear.

Time-resolved TEM was developed at TU-Berlin beginning in the late 1970's

Oleg Bostanjoglo

H. Dömer and O. Bostanjoglo, Rev. Sci. Inst. 74, 4369 (2003)

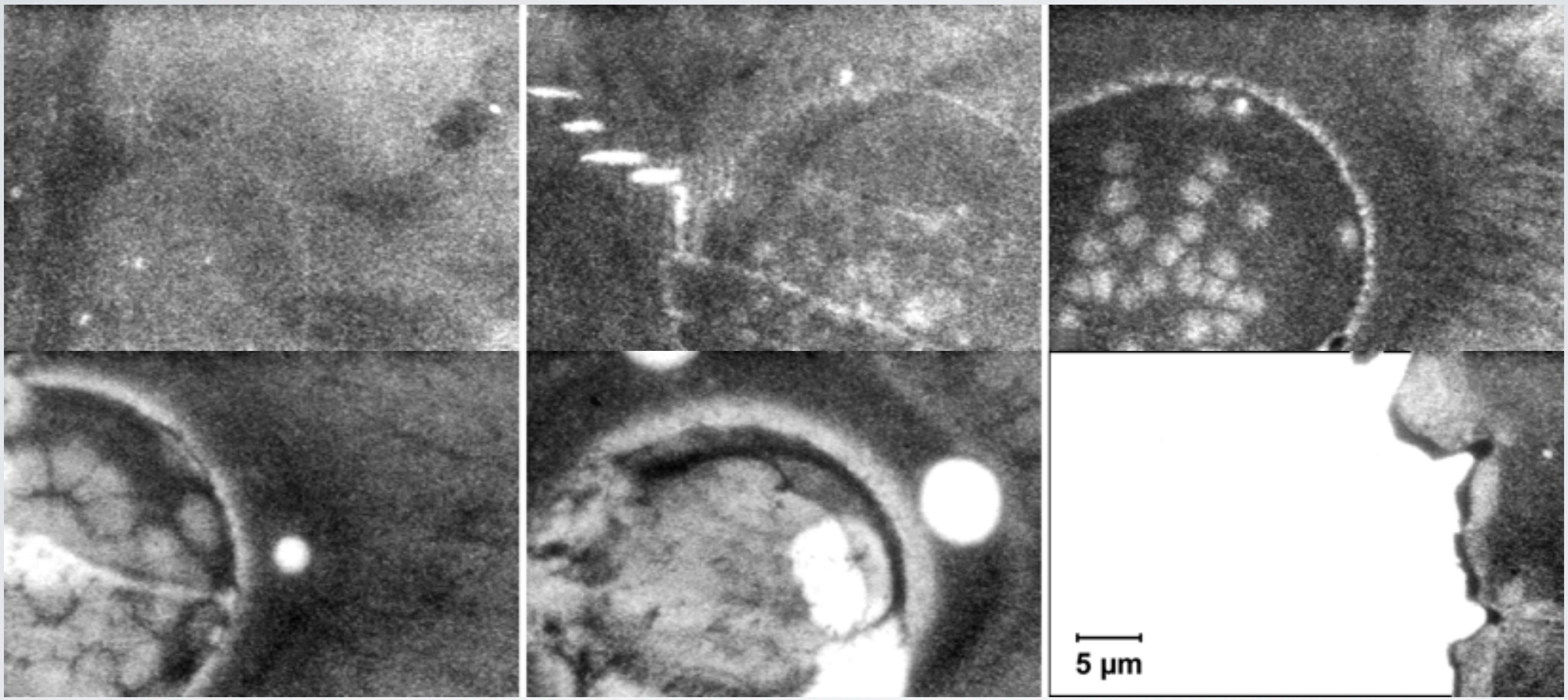




Time-resolved TEM

ablation of Ni film by ultrashort laser pulse

2.5 ns 5 ns 10 ns

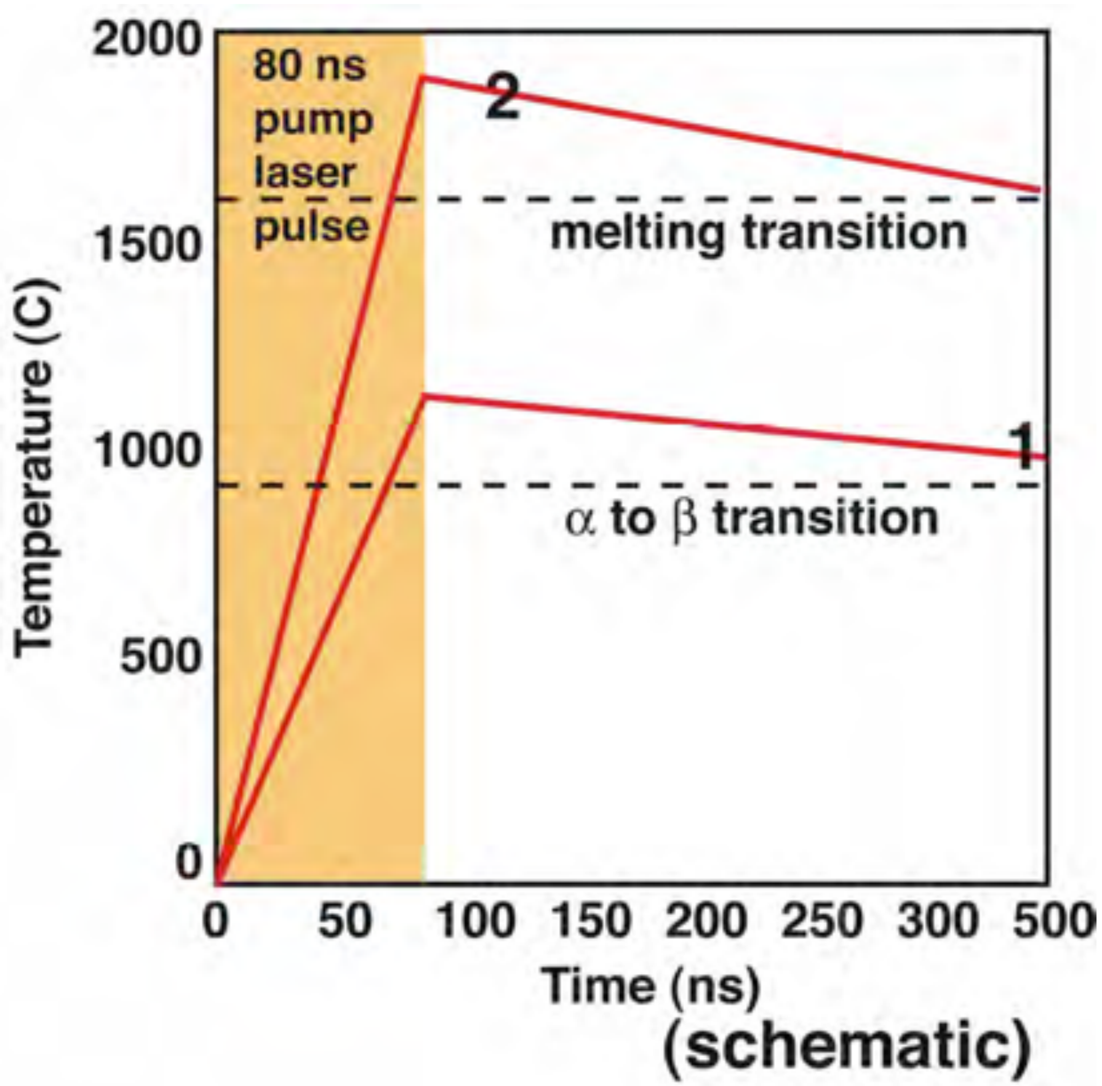


20 ns 40 ns + ∞

H. Domer and O. Bostanjoglo, Journal of Applied Physics **91,** 5462-5467 (2002).

Time-resolved electron diffraction

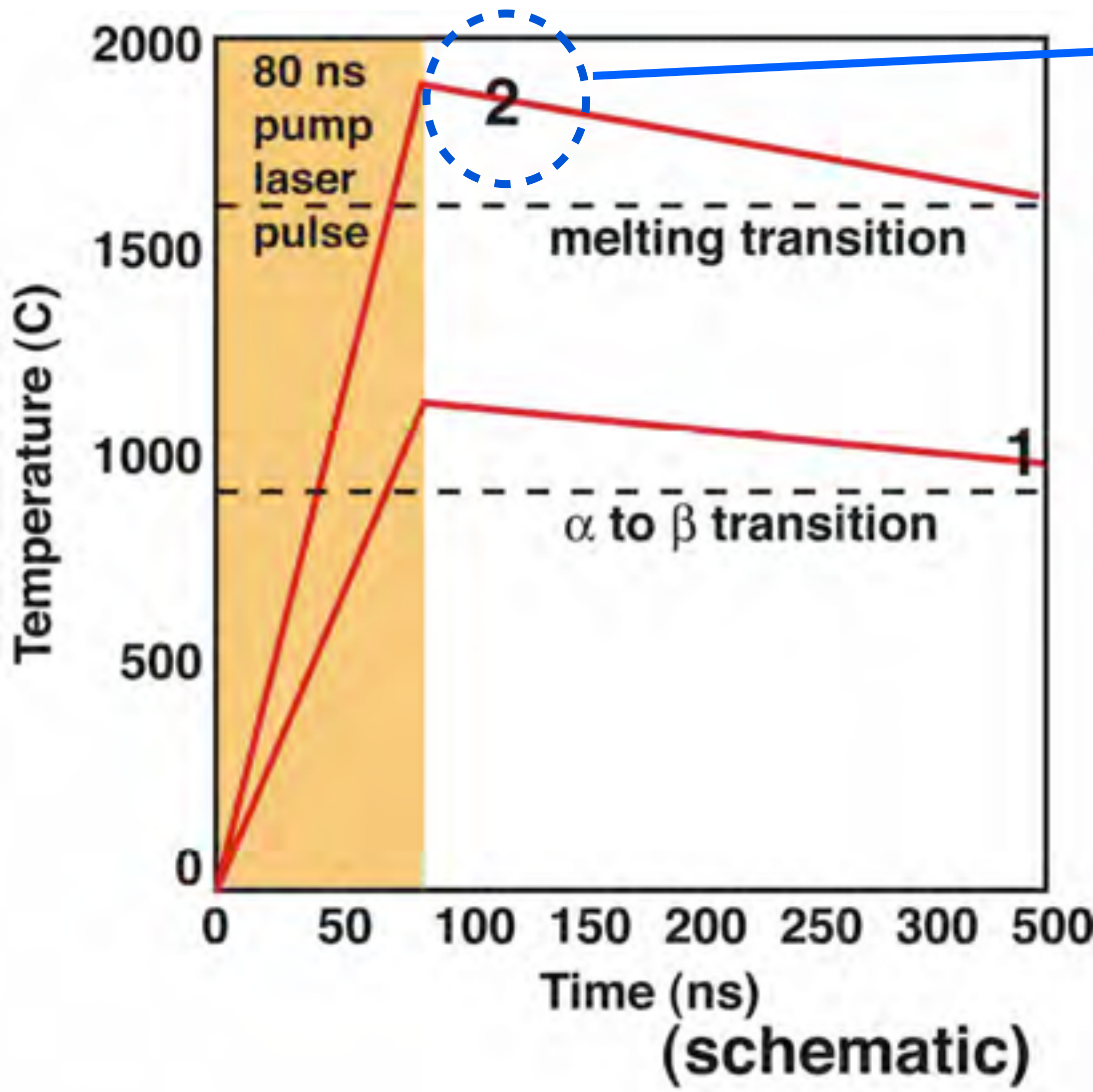
α-Ti (hcp)---> β-Ti(bcc) martensiic transformation



Bryan W. Reed, NLLB, UC, 2008

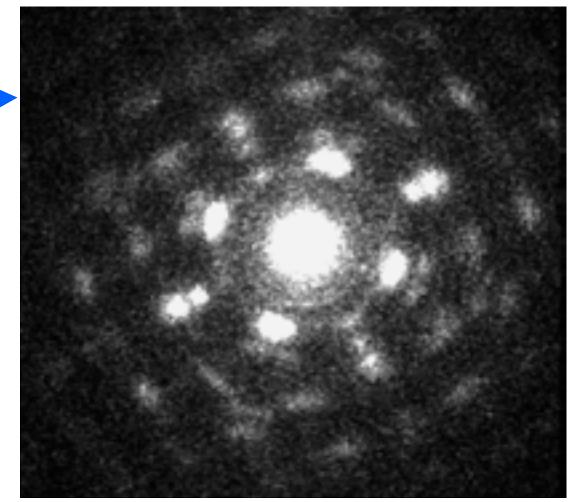
Time-resolved electron diffraction

α-Ti (hcp)---> β-Ti(bcc) martensiic transformation

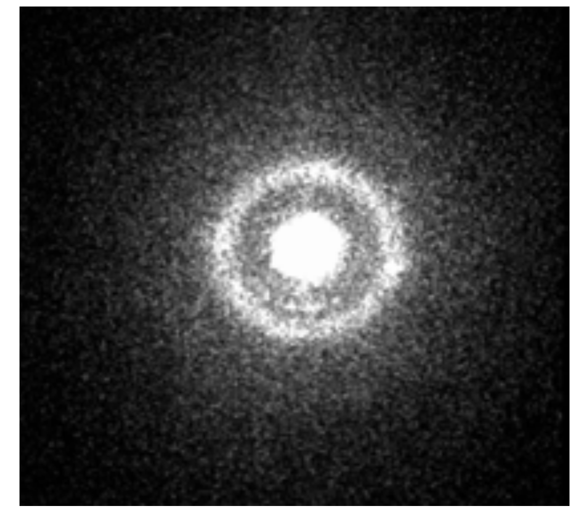


Bryan W. Reed, NLLB, UC, 2008

Melting transition



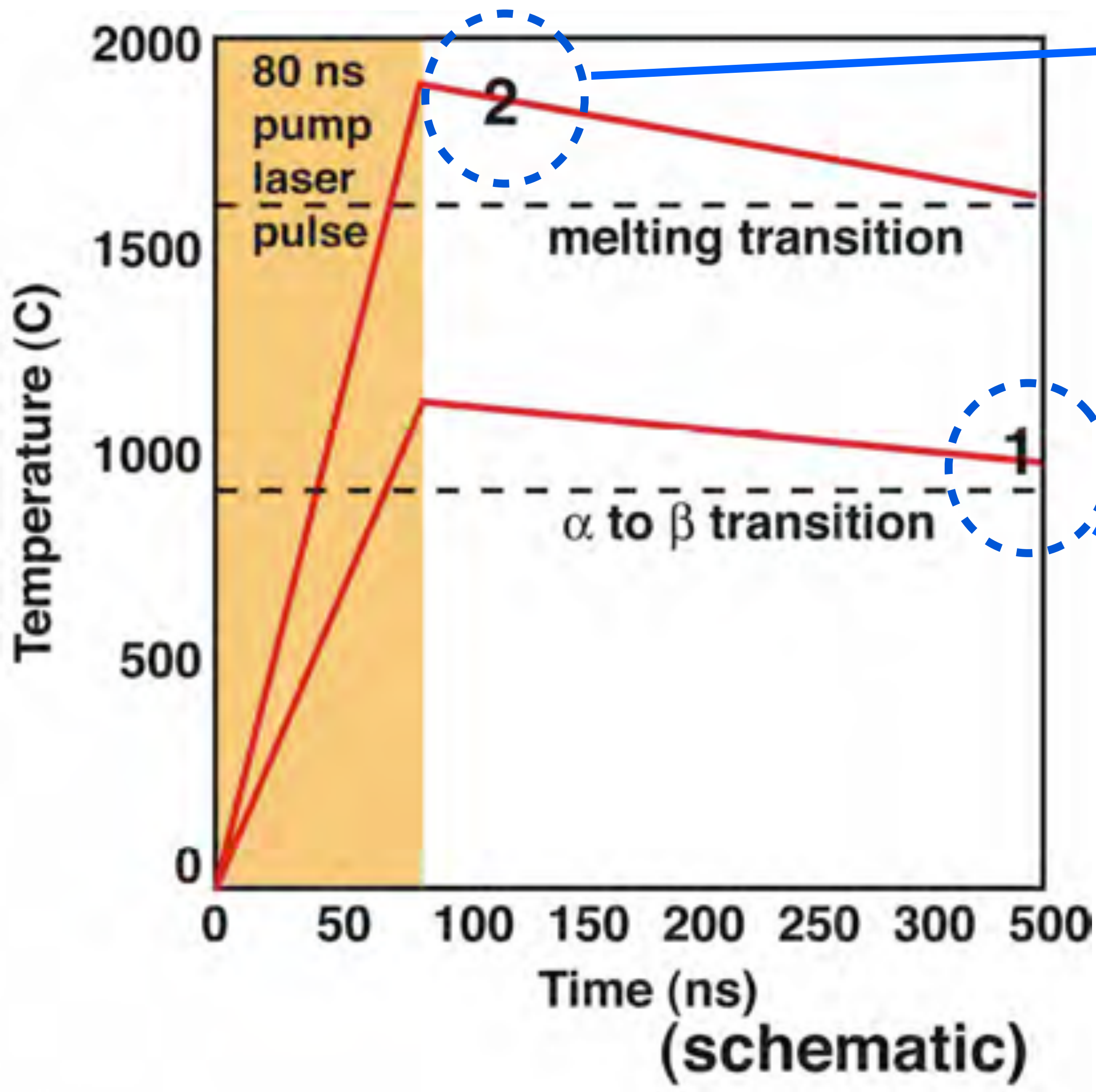
hcp Ti, α-phase



Melt structure

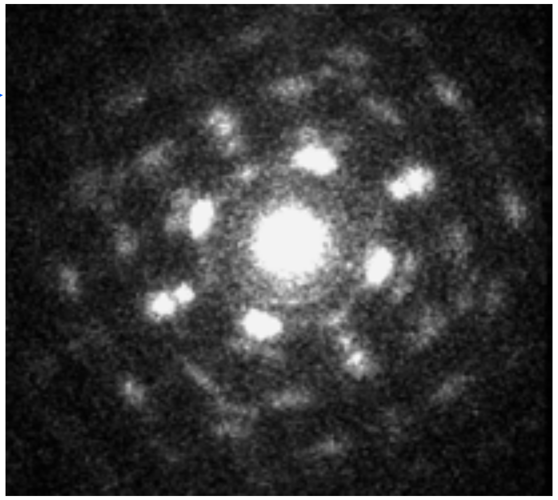
Time-resolved electron diffraction

α-Ti (hcp)---> β-Ti(bcc) martensiic transformation

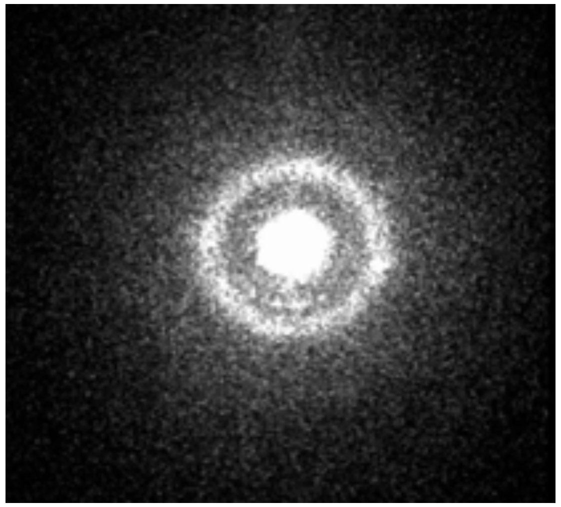


Bryan W. Reed, NLLB, UC, 2008

Melting transition

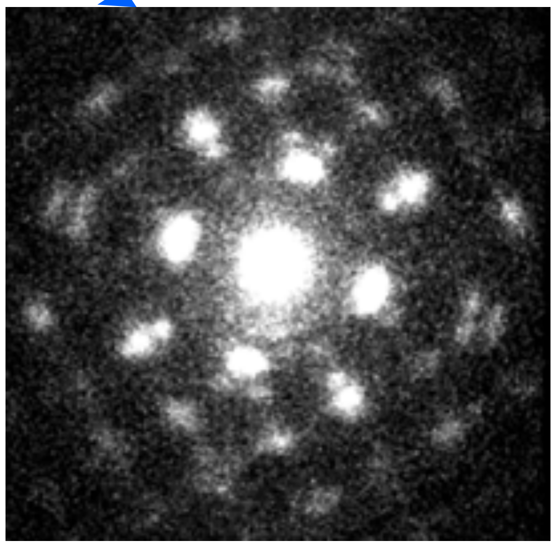


hcp Ti, α-phase

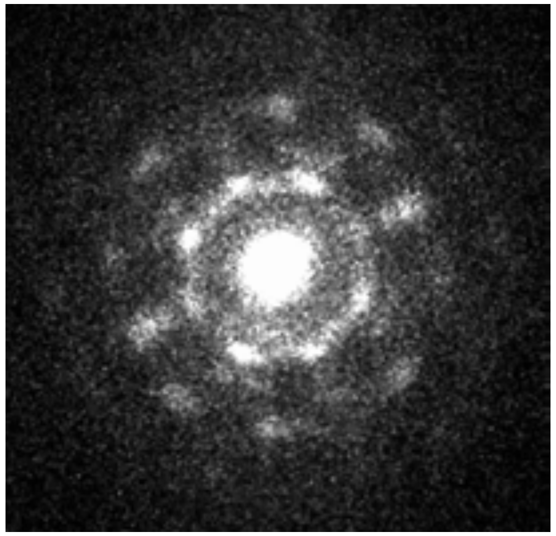


Melt structure

Phase transformation (α to β)



hcp Ti, α-phase



bcc Ti, β-phase

The

END