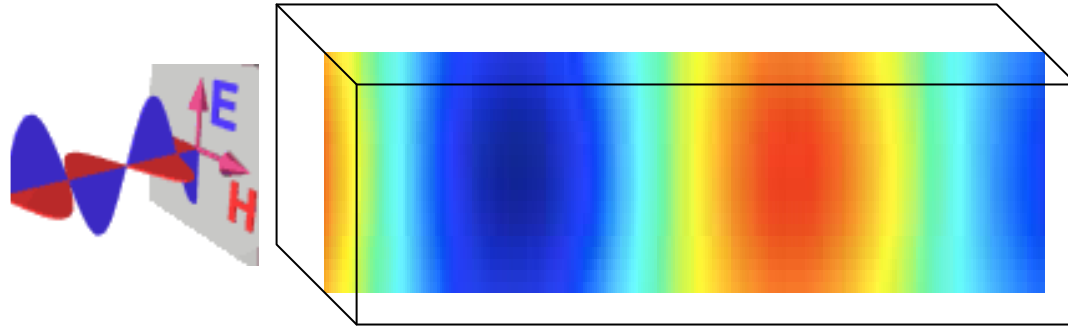


Colloid Chemistry - based Nanophotonics

Luis M. Liz-Marzán

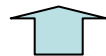
<http://webs.uvigo.es/coloides/nano>

Interaction of light with metals: **Plasmons** (charge density waves)

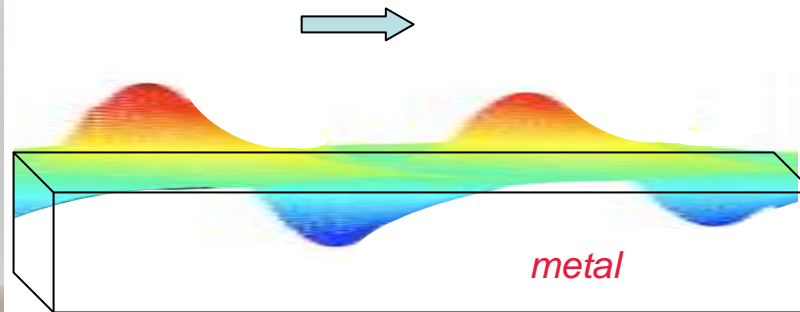
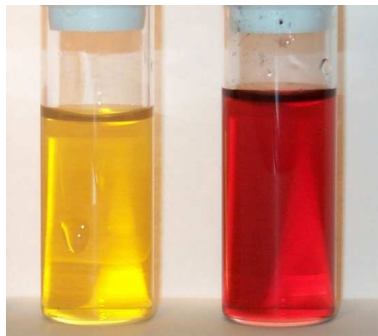


Bulk plasmons

$$\omega_p$$



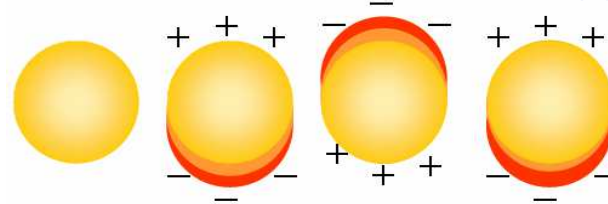
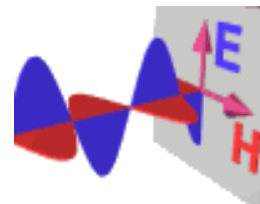
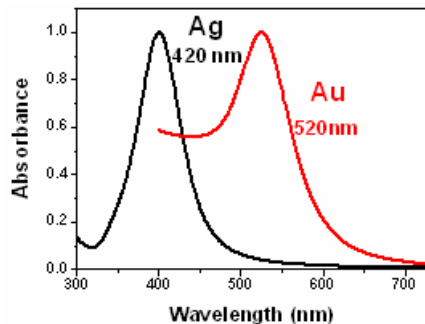
Purely longitudinal waves



Surface plasmons

$$\omega_p / \sqrt{2}$$

displacement

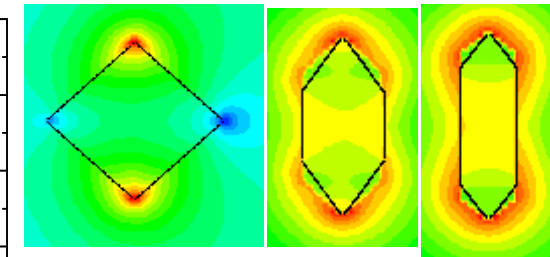
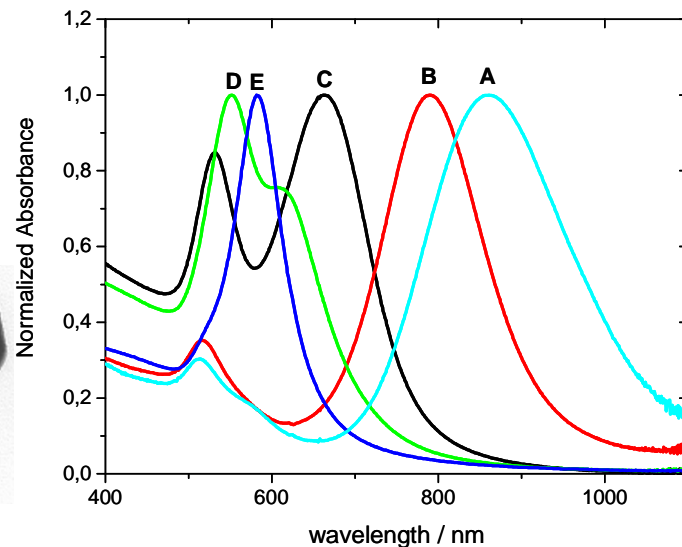
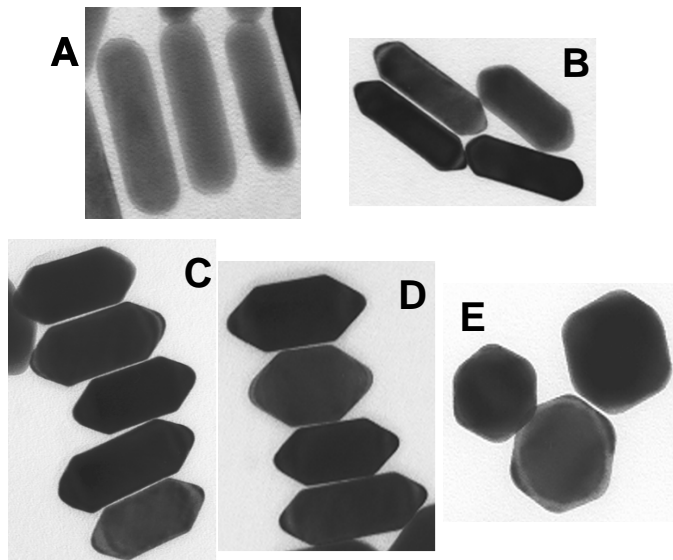
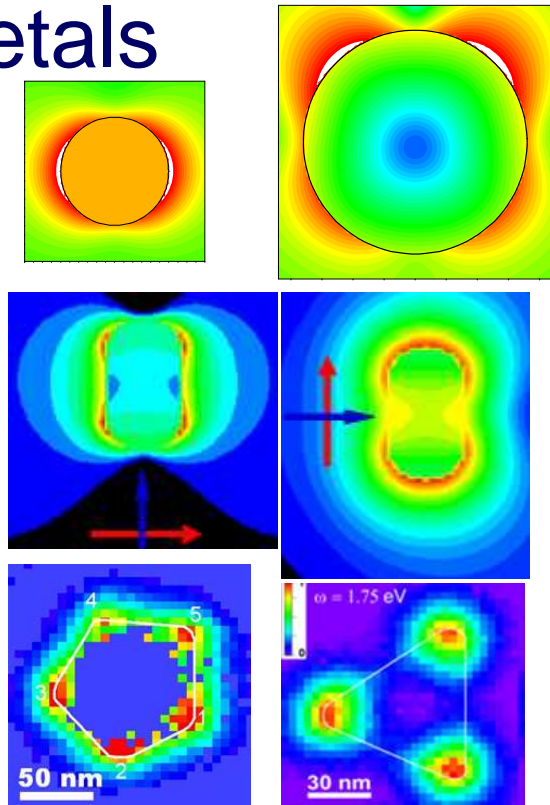
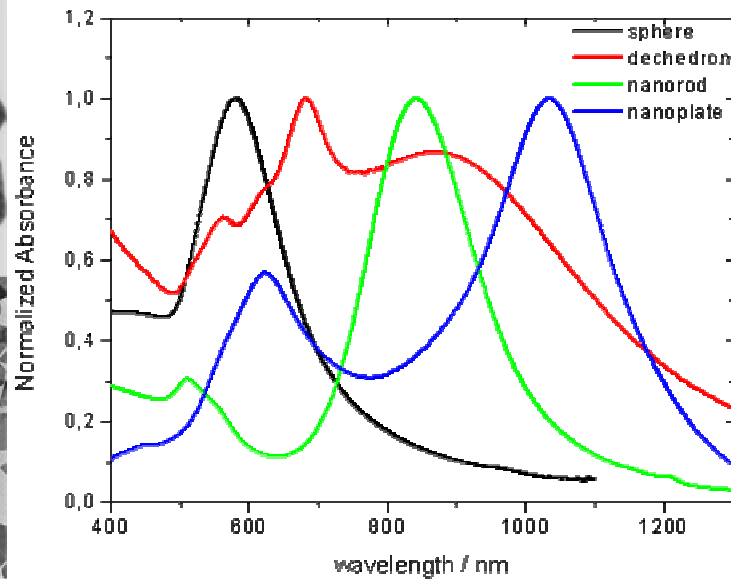
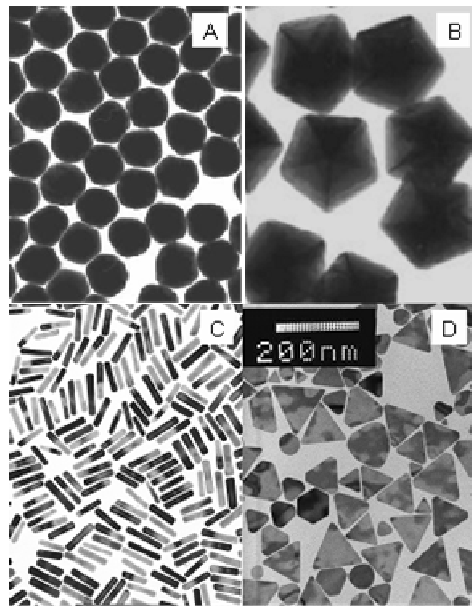


Localized Surface plasmons

$$\omega = \omega_p / \sqrt{3}$$

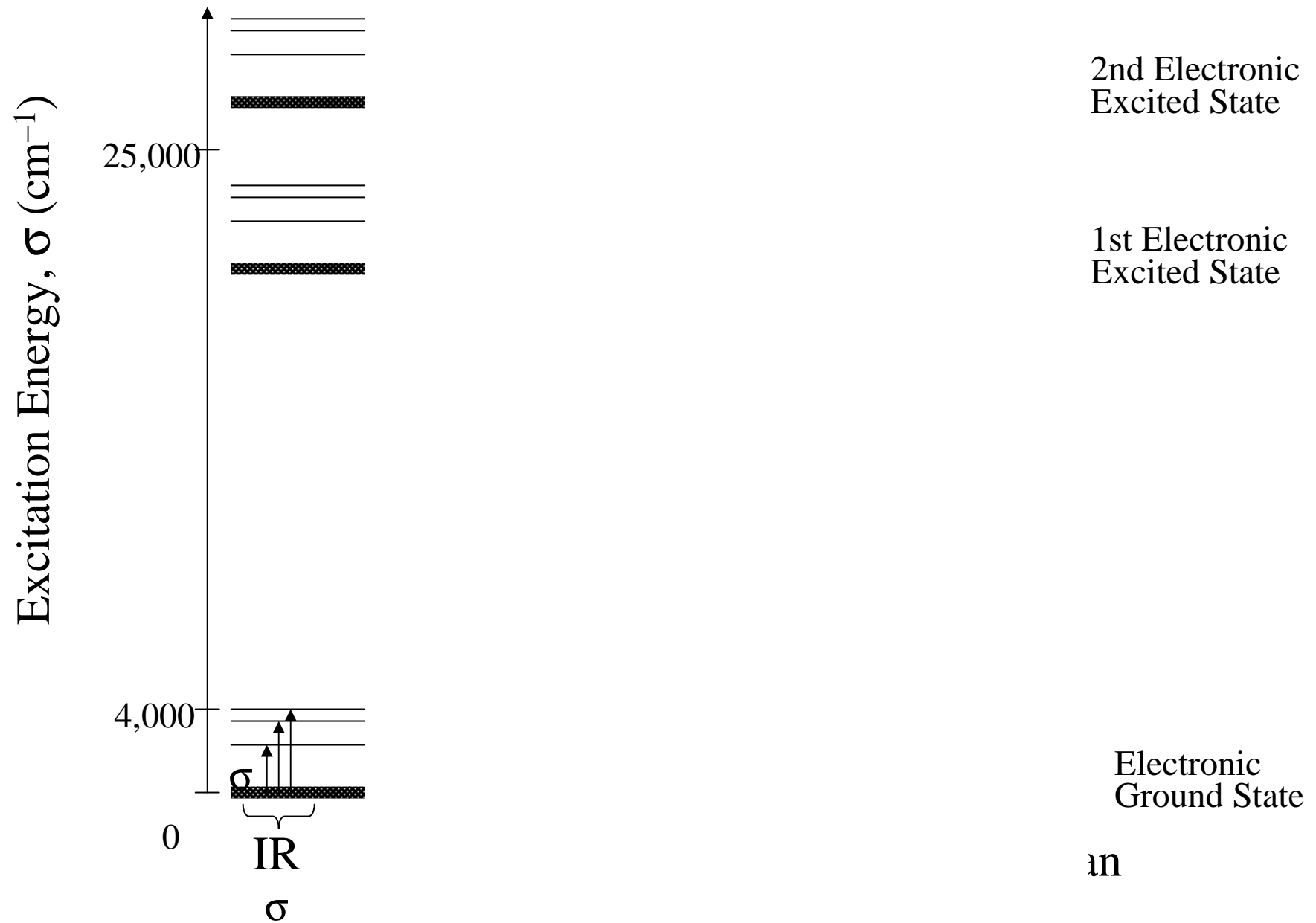
courtesy: K. Kempa, Boston College

Surface plasmon modes in nanometals



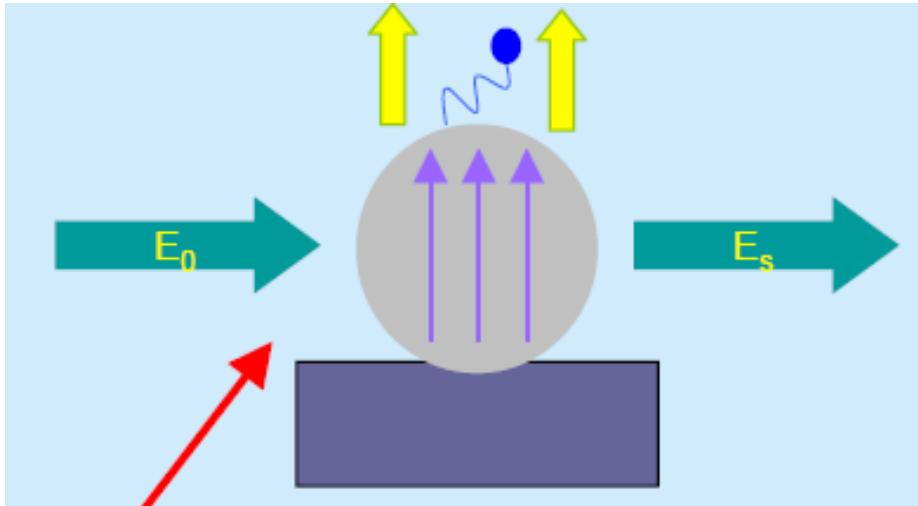
Coord. Chem. Rev. **2005**, 249, 1870
Langmuir **2006**, 22, 32
Langmuir **2006**, 22, 7007
Adv. Mater. **2006**, 18, 2529
Nature Phys. **2007**, 3, 348
Angew. Chem. Int. **2007**, 46, 3517
Angew. Chem. Int. **2007**, 46, 8983

Raman scattering

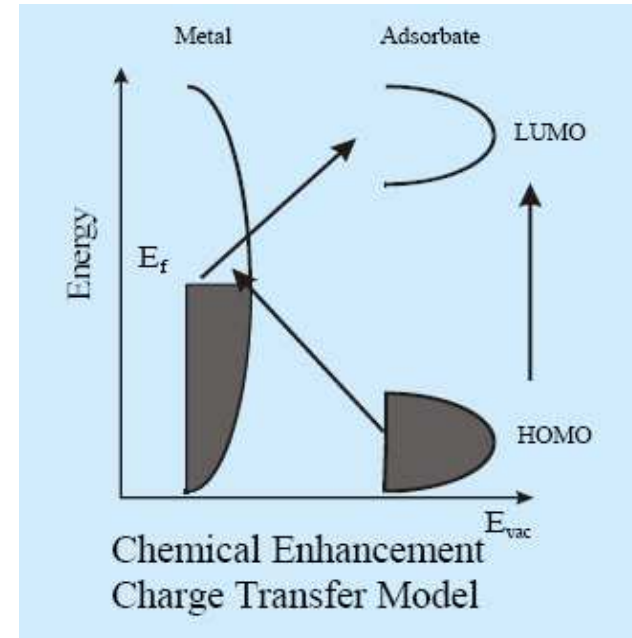


Surface Enhanced Raman Scattering

Electromagnetic Mechanism (EM)



The Chemical Effect



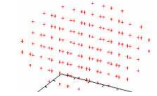

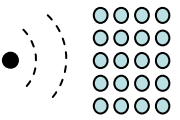
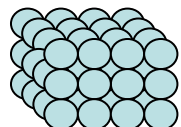
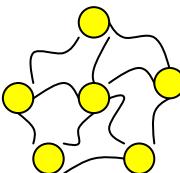
Jeanmarie & Van Duyne, *J. Electroanal. Chem.* **1977**, 84, 1
Albrecht & Creighton, *J. Am. Chem. Soc.* **1977**, 99, 5215
Moskovits, *J. Chem. Phys.* **1978**, 69, 4159

Otto et al., *Surf. Sci. Lett.*, **1980**, 92, A50

Otto, in a recent review: *“For sure, without the EM mechanism there would be no signal. But the chemical mechanism determines what is observed.”*
J. Raman Spectrosc., 36, 2005, 497

Numerical solutions for the 3D electromagnetic problem

V. Myroshnichenko et al., *Chem. Soc. Rev.* **2008**, 37, 1792

	periodic systems	finite geometries	convergence with high ϵ (e.g. metals)	effective dimensionality	
discrete dipole approximation Purcell & Pennypacker Draine & Flateau					
boundary element method García de Abajo & Howie				2D	
finite difference in the time domain Joannopoulos				3D	
plane wave expansions Leung	✓		poor	3D	
transfer matrix approach Pendry	✓		poor	2D	
multiple scattering Ohtaka; Wang; García de Abajo	✓	✓			

Maxwell's Equations: 3D

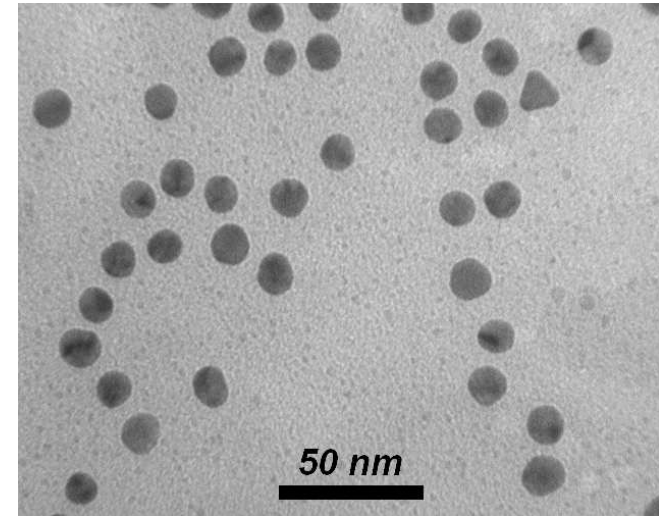
$$\nabla \cdot \mathbf{D} = \rho_f$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\partial \mathbf{B} / \partial t$$

$$\nabla \times \mathbf{H} = \mathbf{J}_f + \partial \mathbf{D} / \partial t$$

Colloidal synthesis of nano-Au

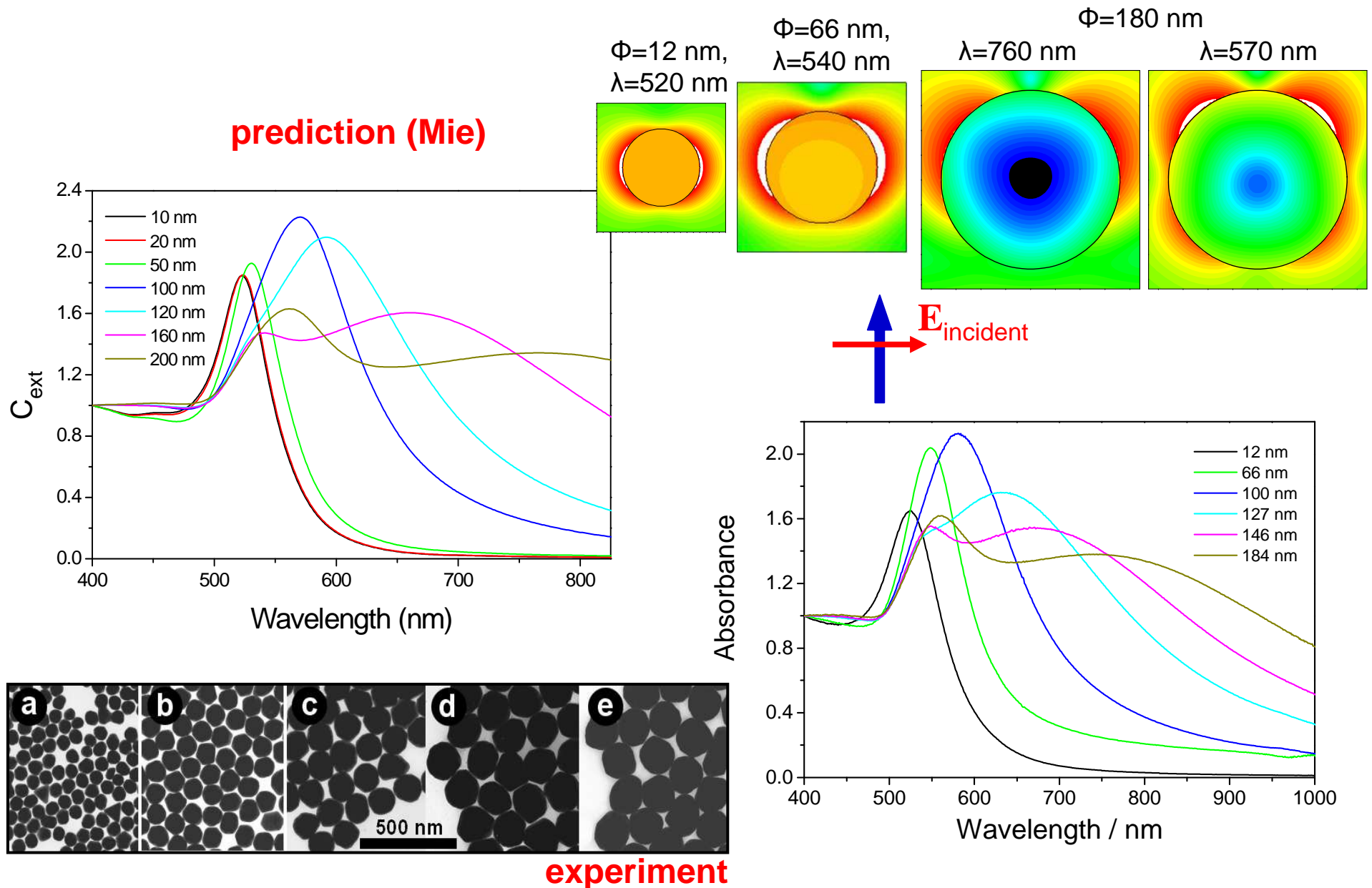


M. Faraday, "Experimental relations of gold
(and other metals) to light",
Philos. Trans. Roy. Soc. London **1857**, 147, 145-181.

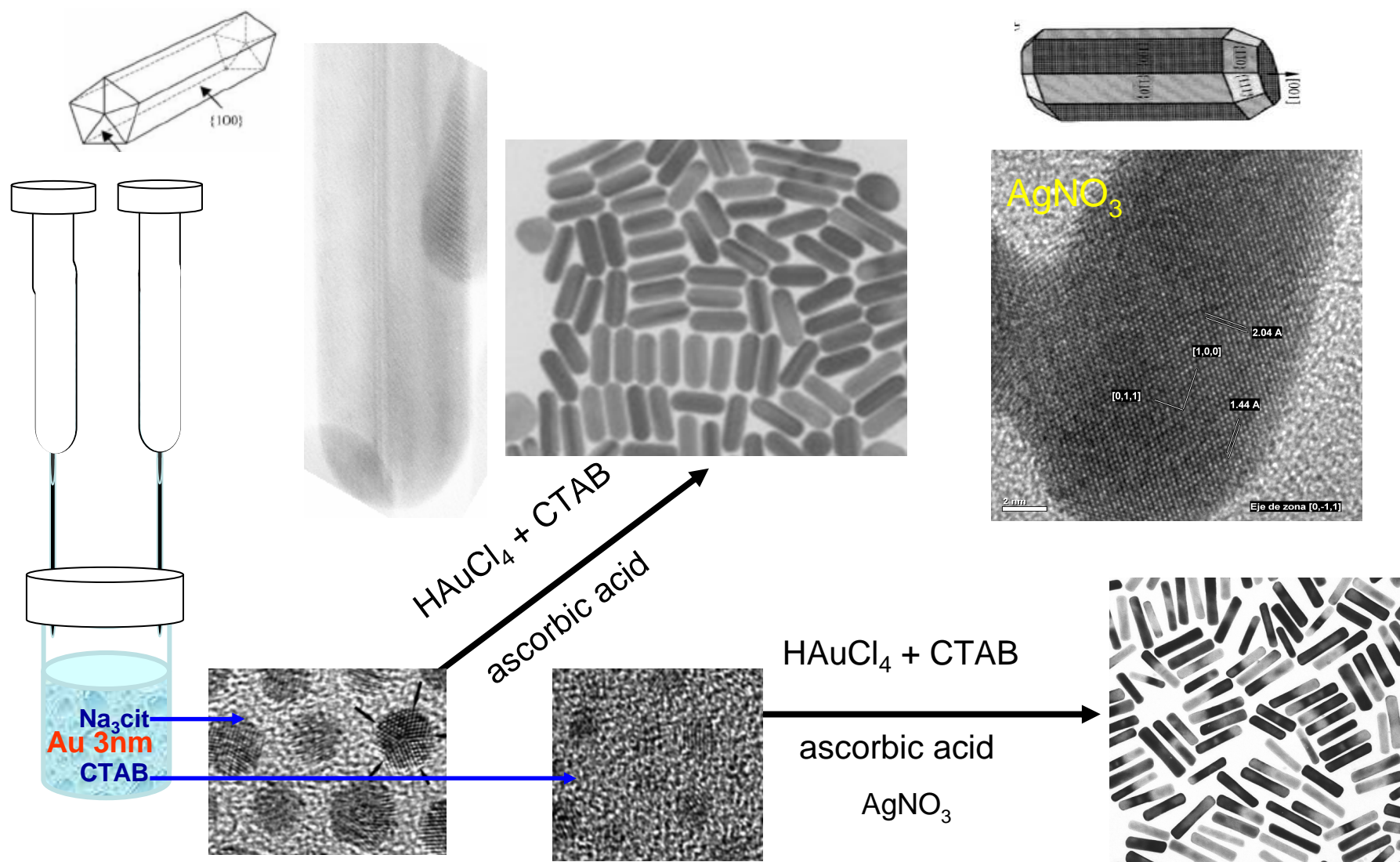
B. V. Enüstün and J. Turkevich,
J. Am. Chem. Soc. 1963, 85, 3317

<http://mrsec.wisc.edu/Edetc/nanolab/gold/>

Growth of Au spheres and optical effects



Aqueous seeded growth of gold nanorods

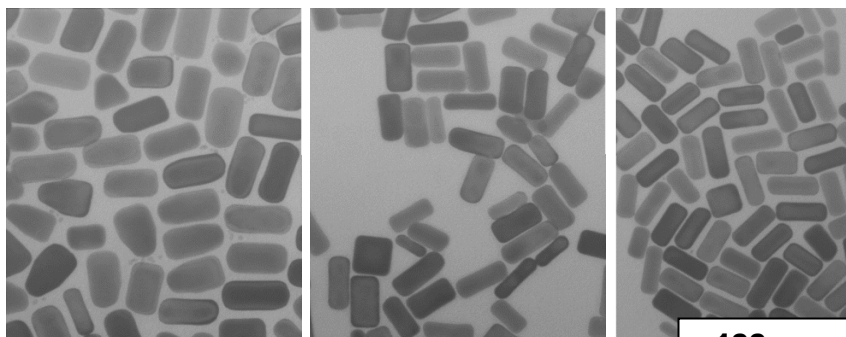


Optical response of Au nanorods

1.94

2.35

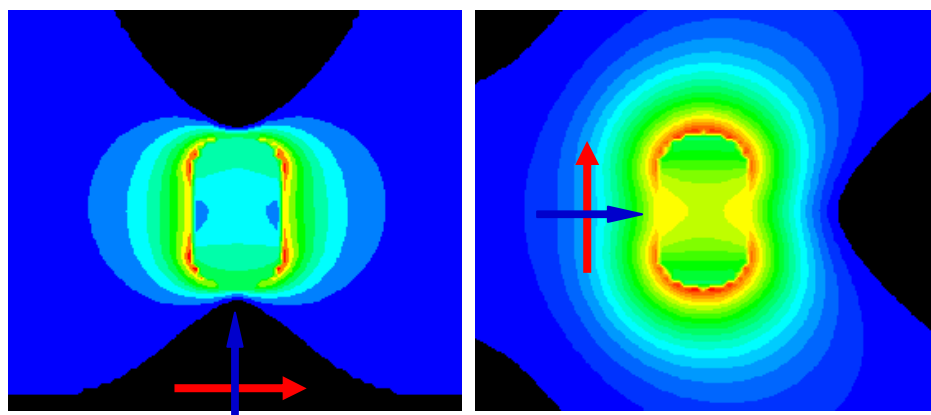
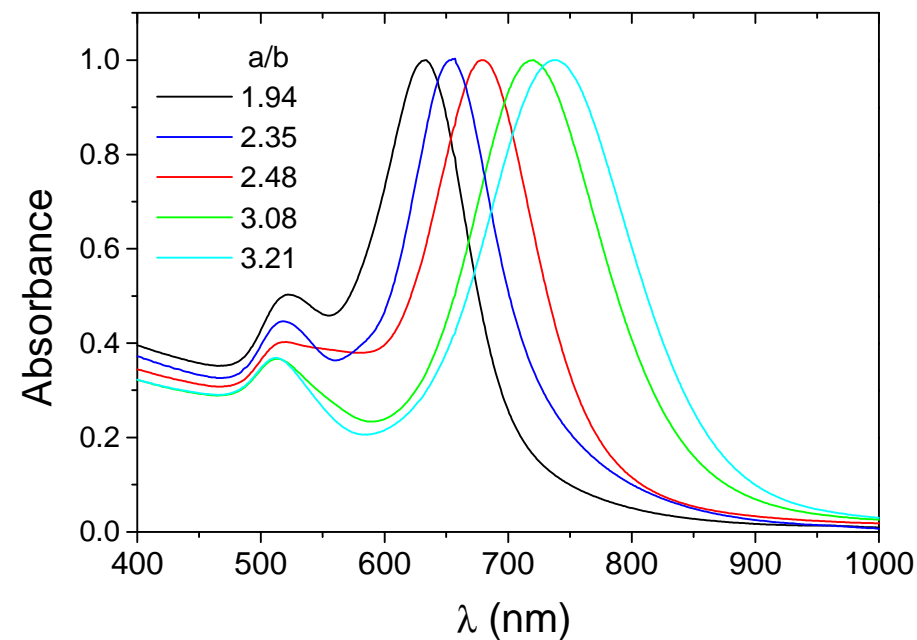
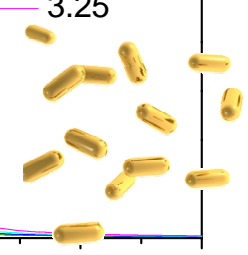
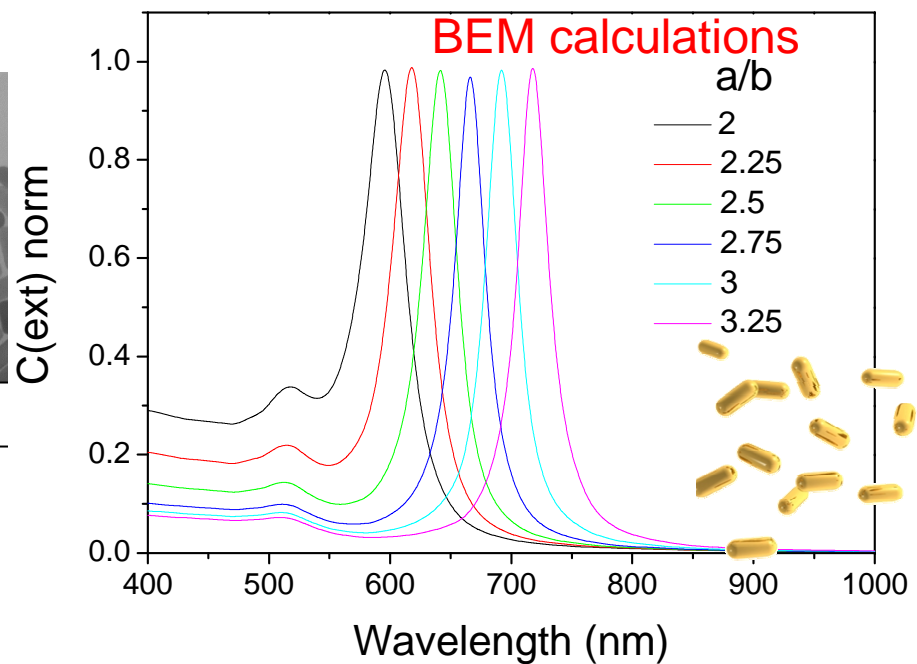
2.48



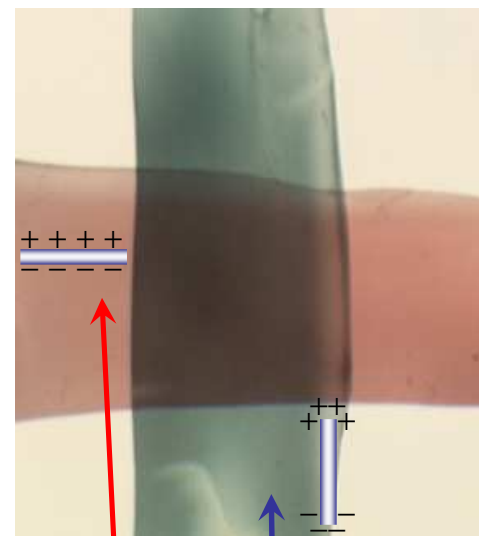
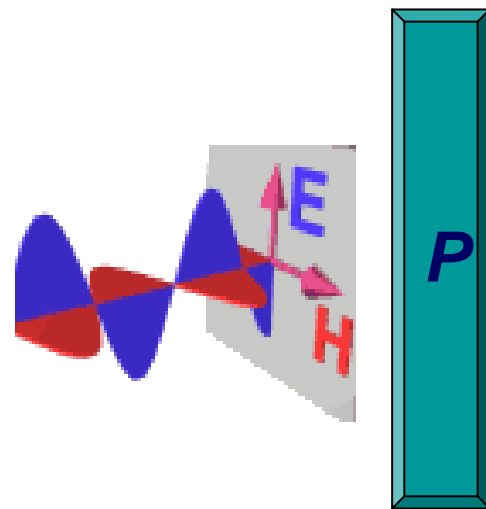
$\lambda=517$ nm

a.r.=2

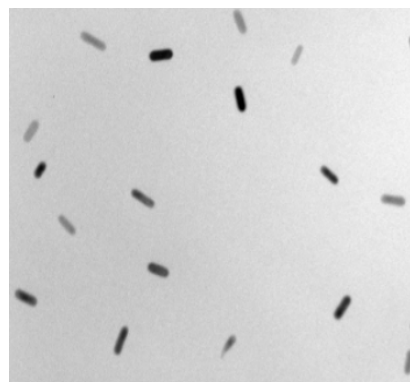
$\lambda=600$ nm



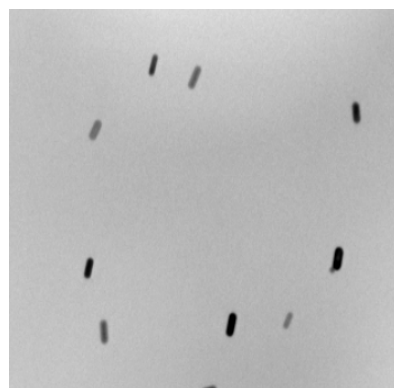
Probing the anisotropic response of Au rods



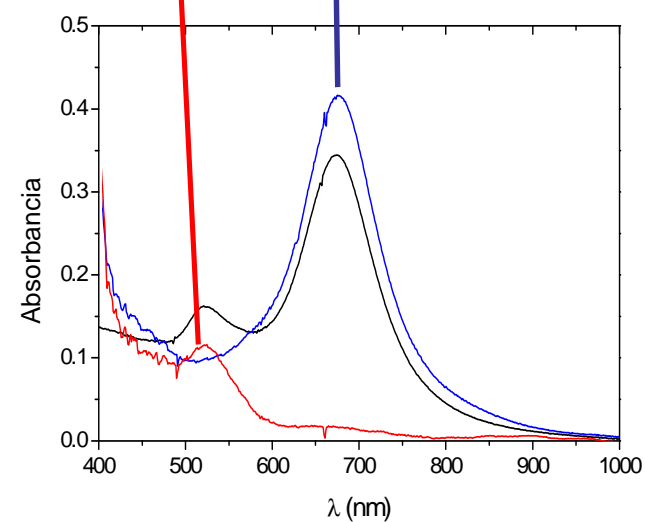
Au nanorods in PVA



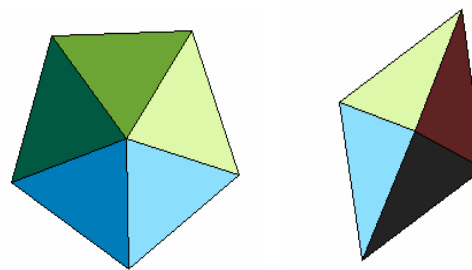
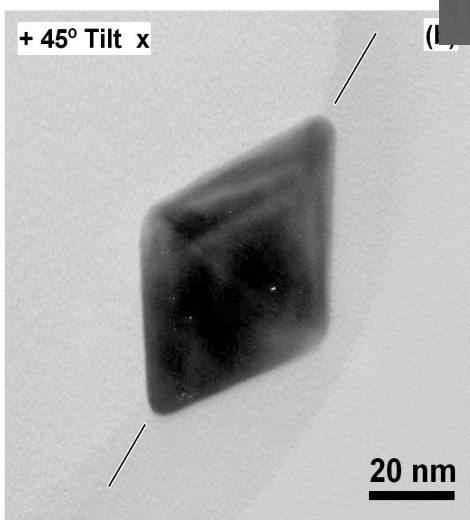
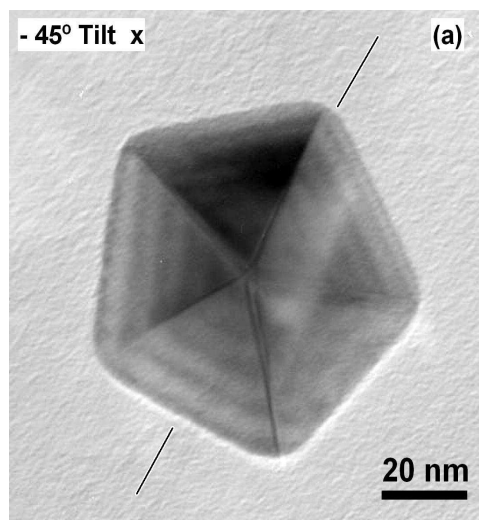
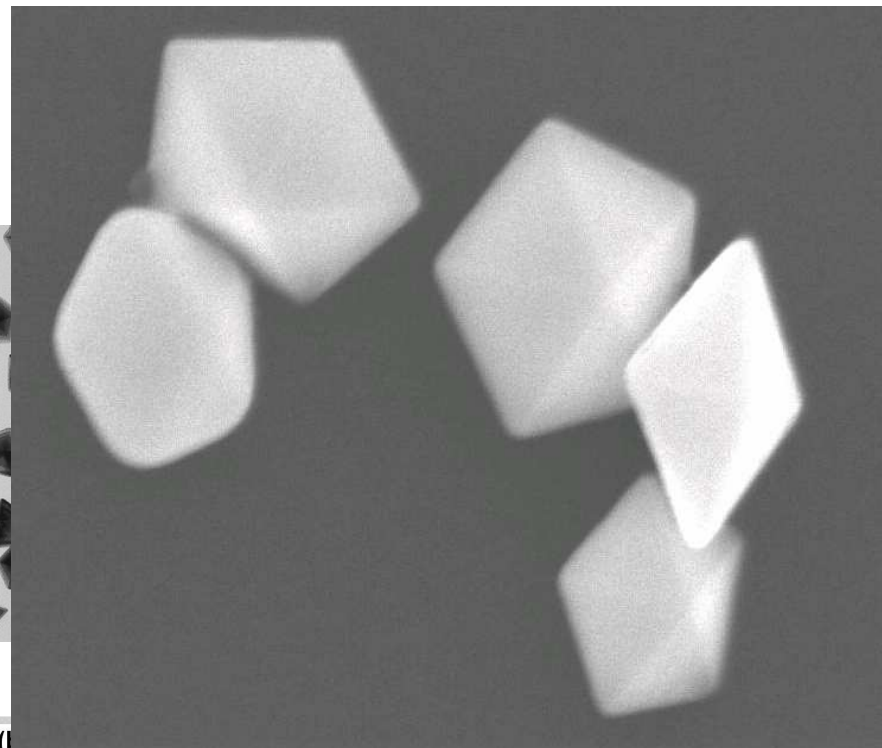
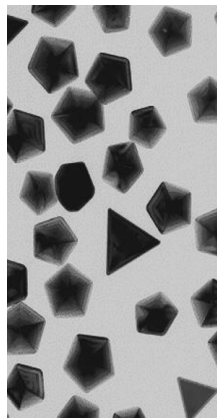
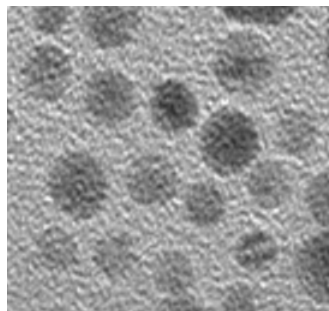
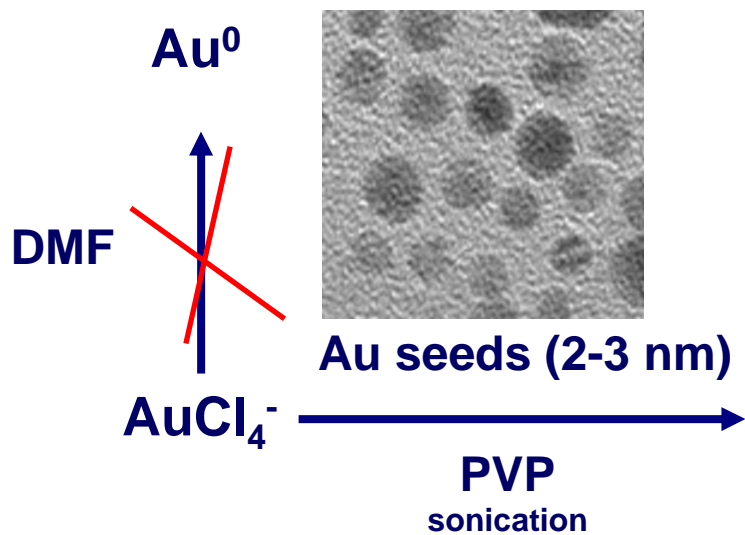
non-stretched



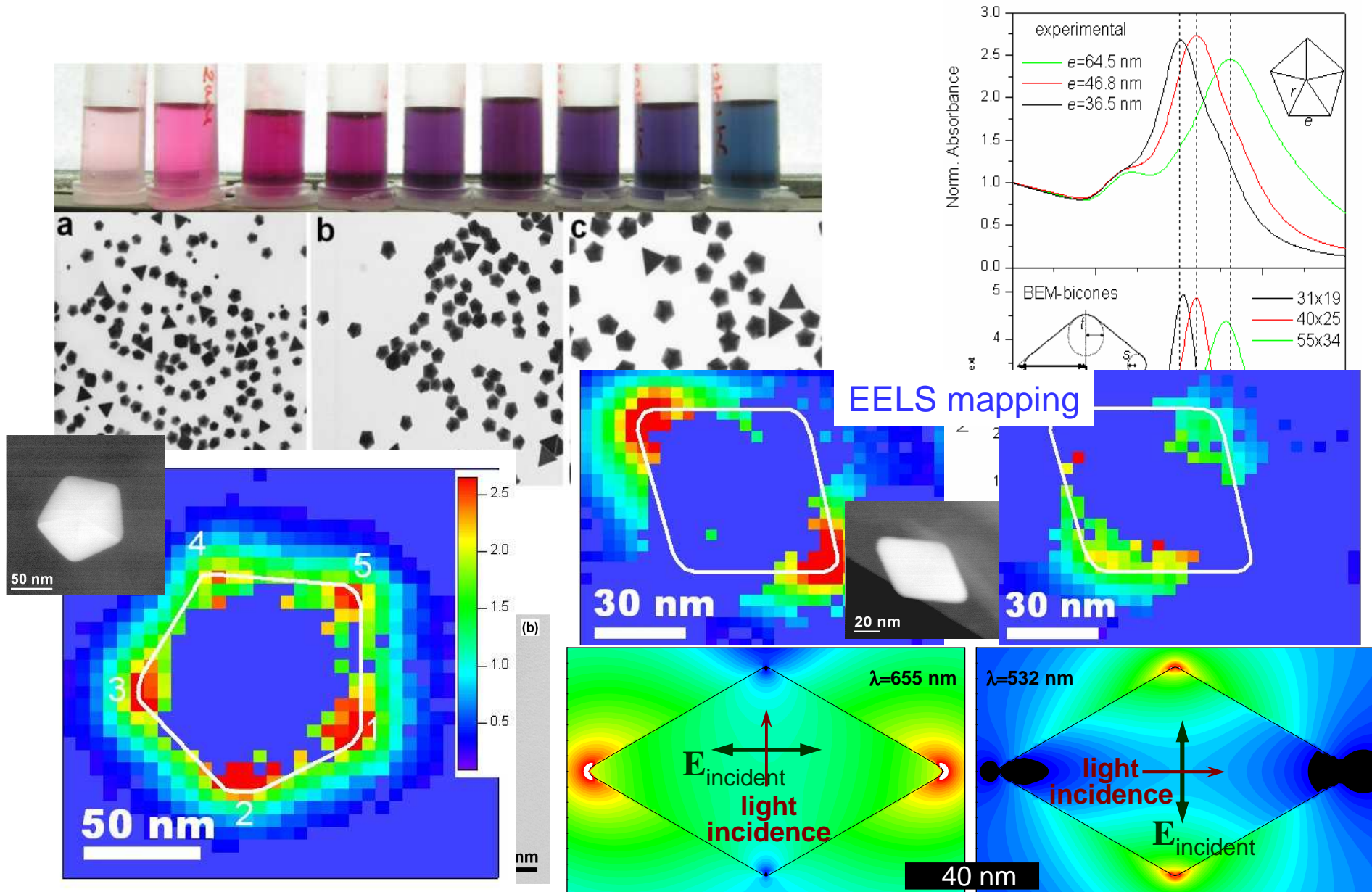
stretched



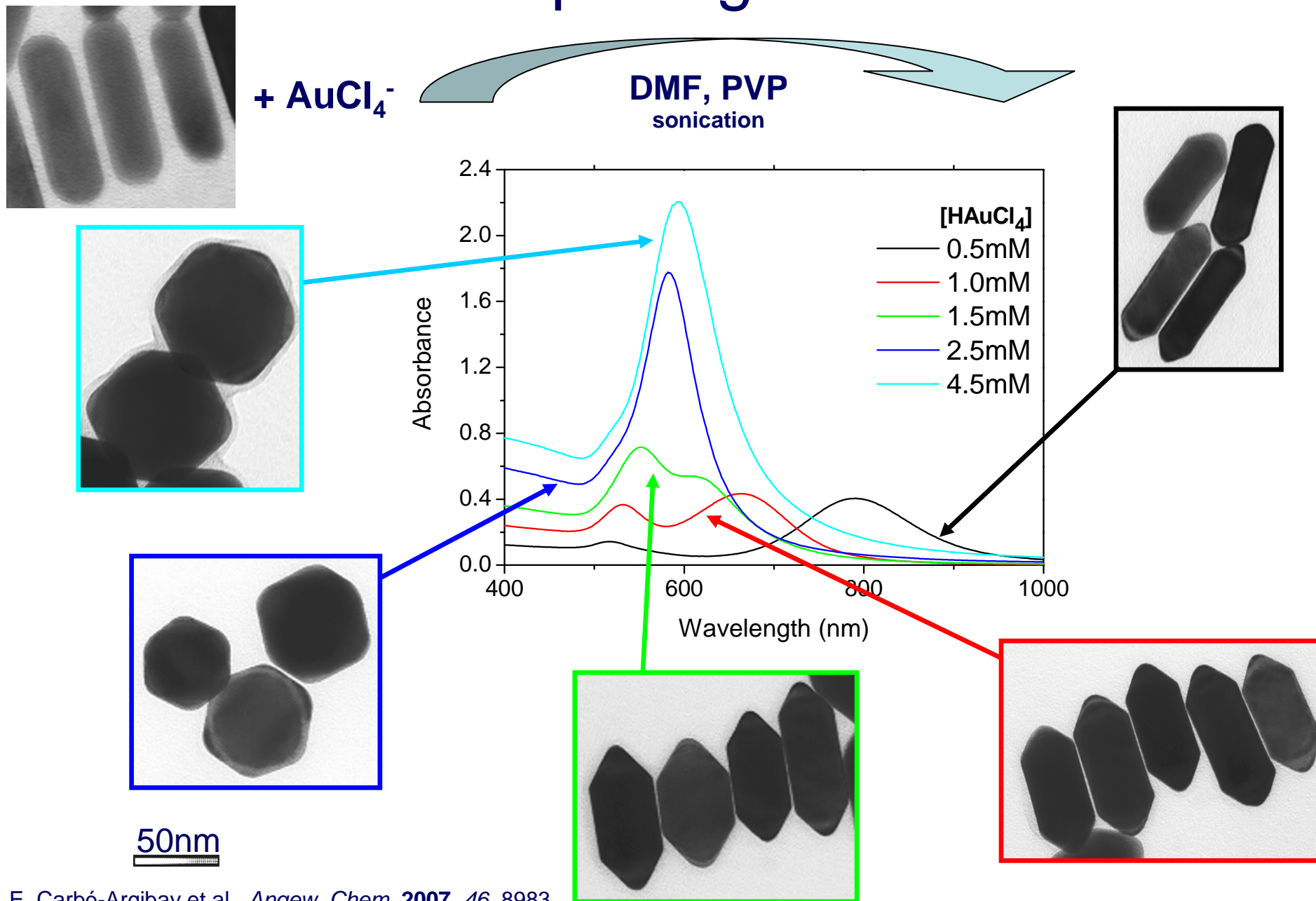
Seeded growth in N,N-dimethylformamide (DMF)



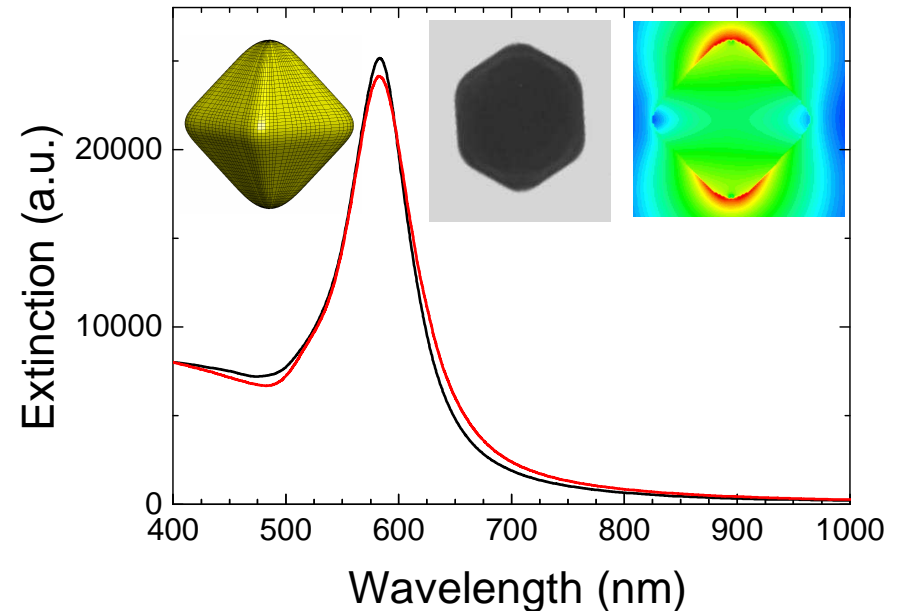
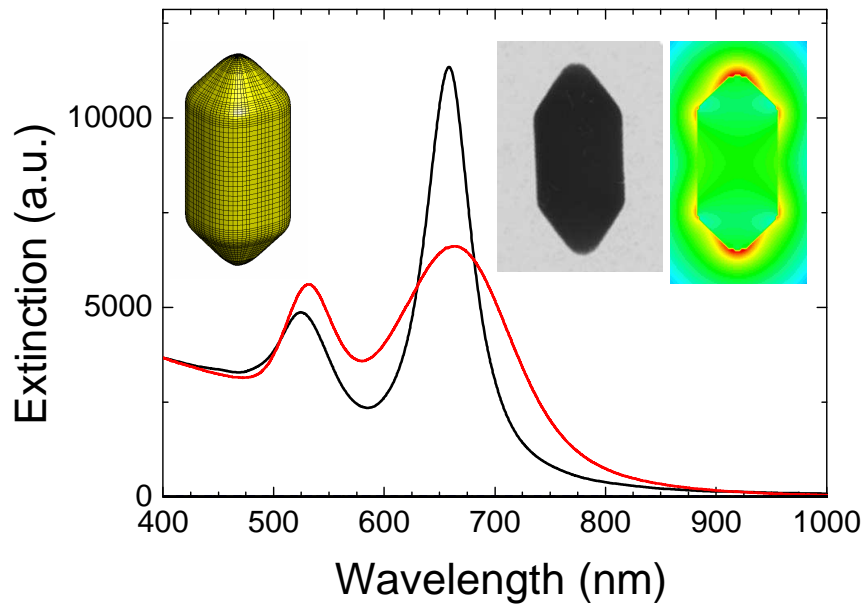
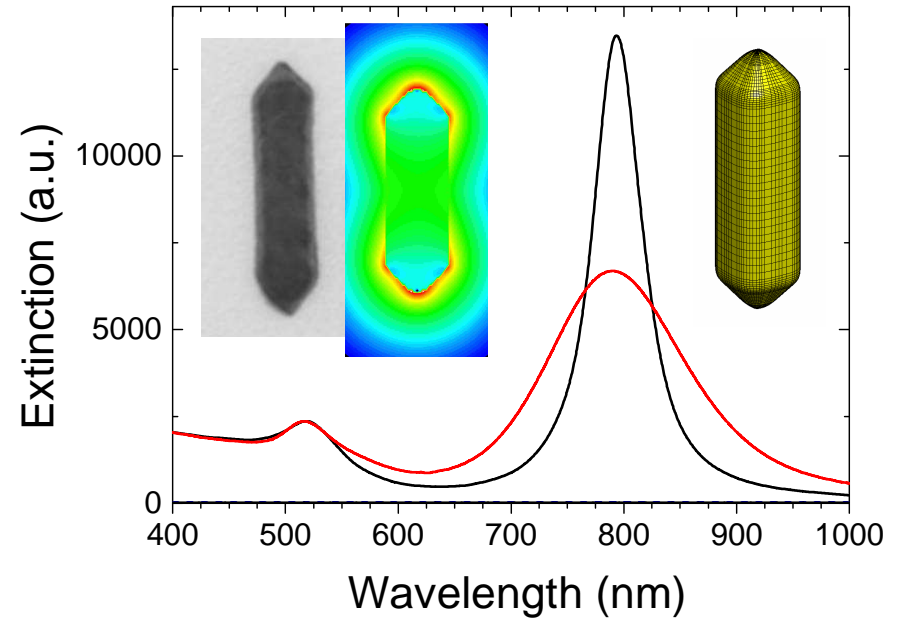
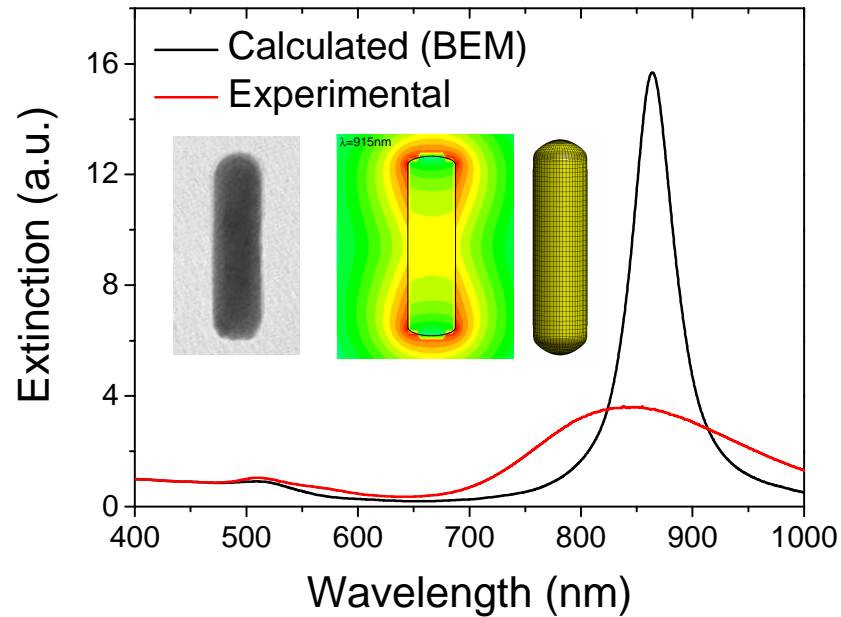
Size tuning and optical effects



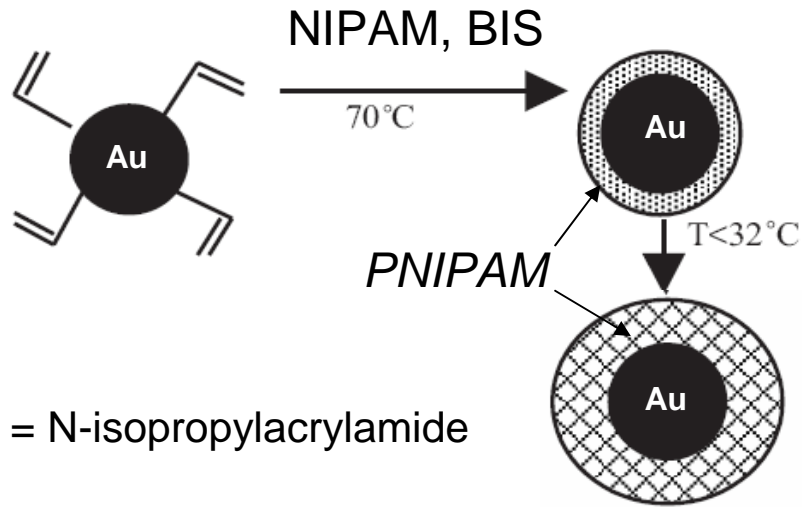
Chemical sharpening of Au nanorods



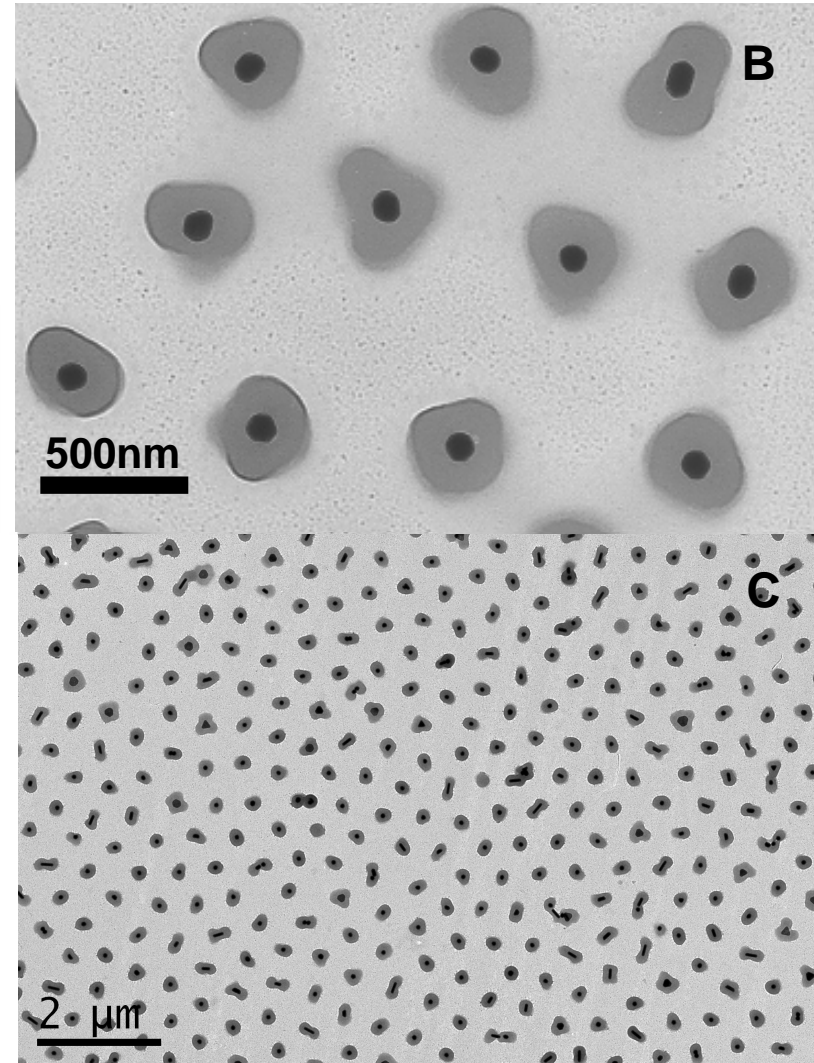
Modelling the optical response



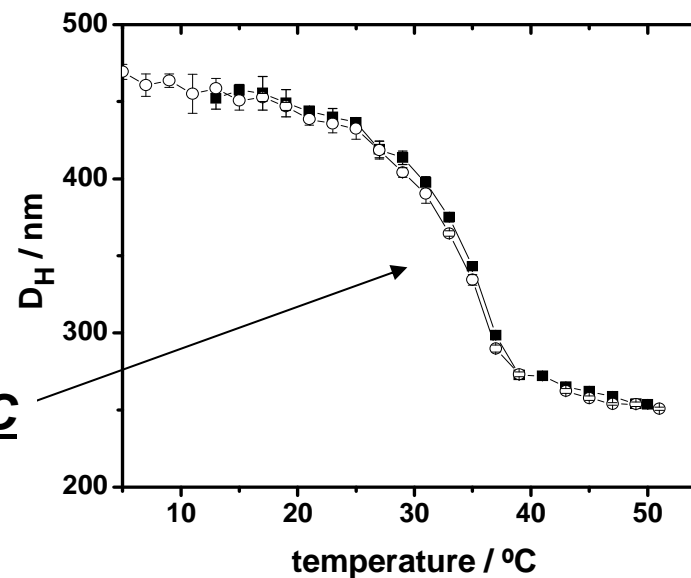
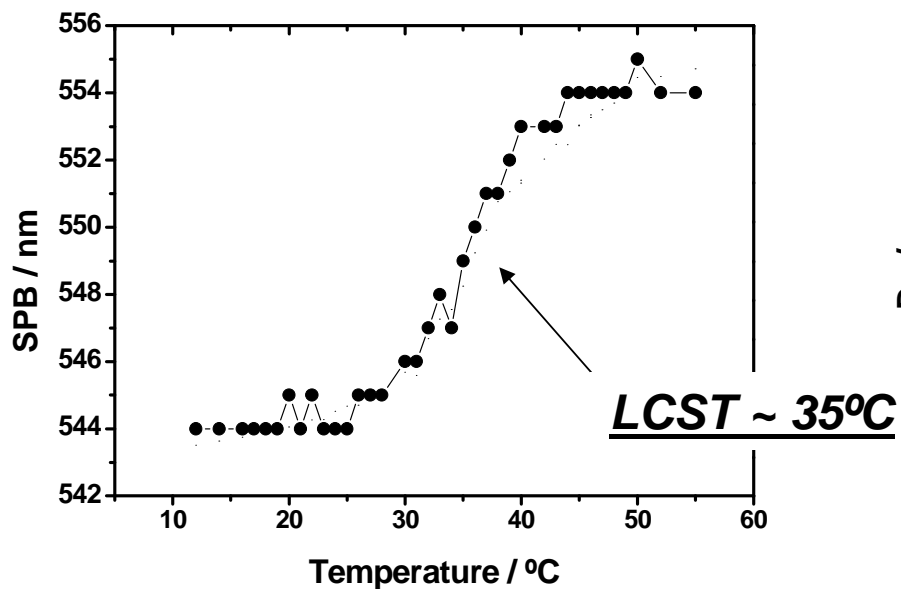
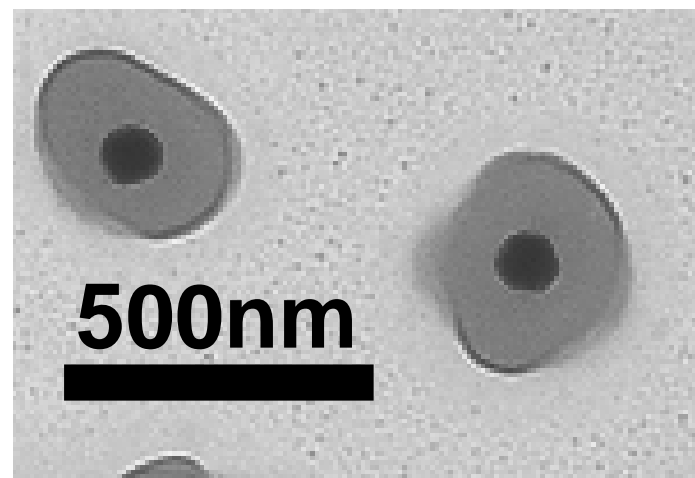
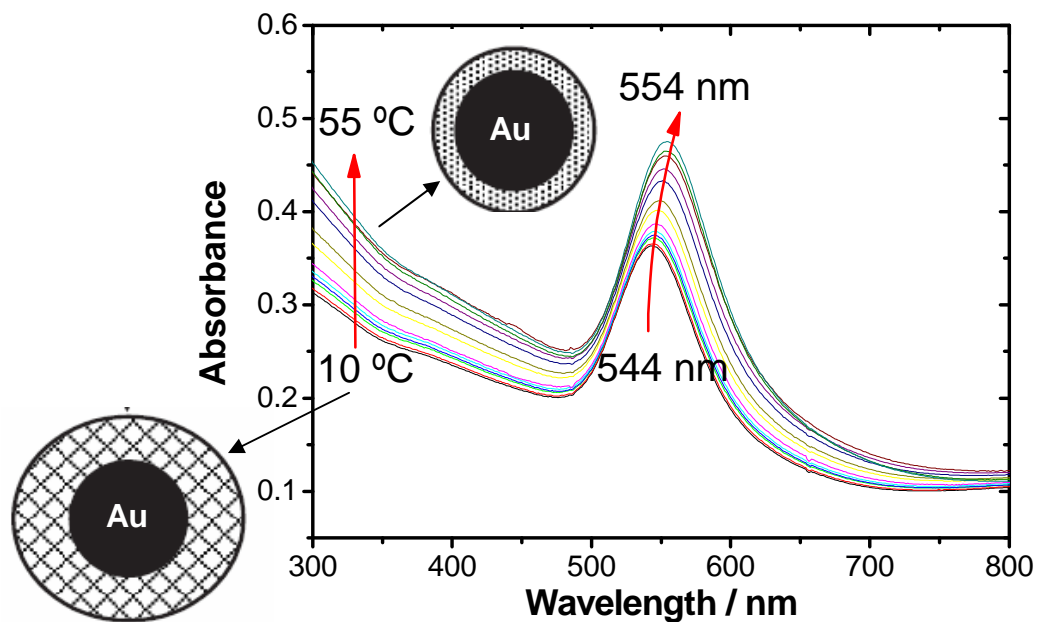
Au@PNIPAM core-shell particles



NIPAM = N-isopropylacrylamide



Au@PNIPAM: thermal sensitivity



CONCLUSIONS

- Morphology control
 - Understand crystallographic structure
 - Rectivity of different faces
 - Surface capping agents
 - Anisotropic reactivity
- Optical response
 - Fine tuning
 - Anisotropy effects
 - Electric field enhancement
 - Modelling

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