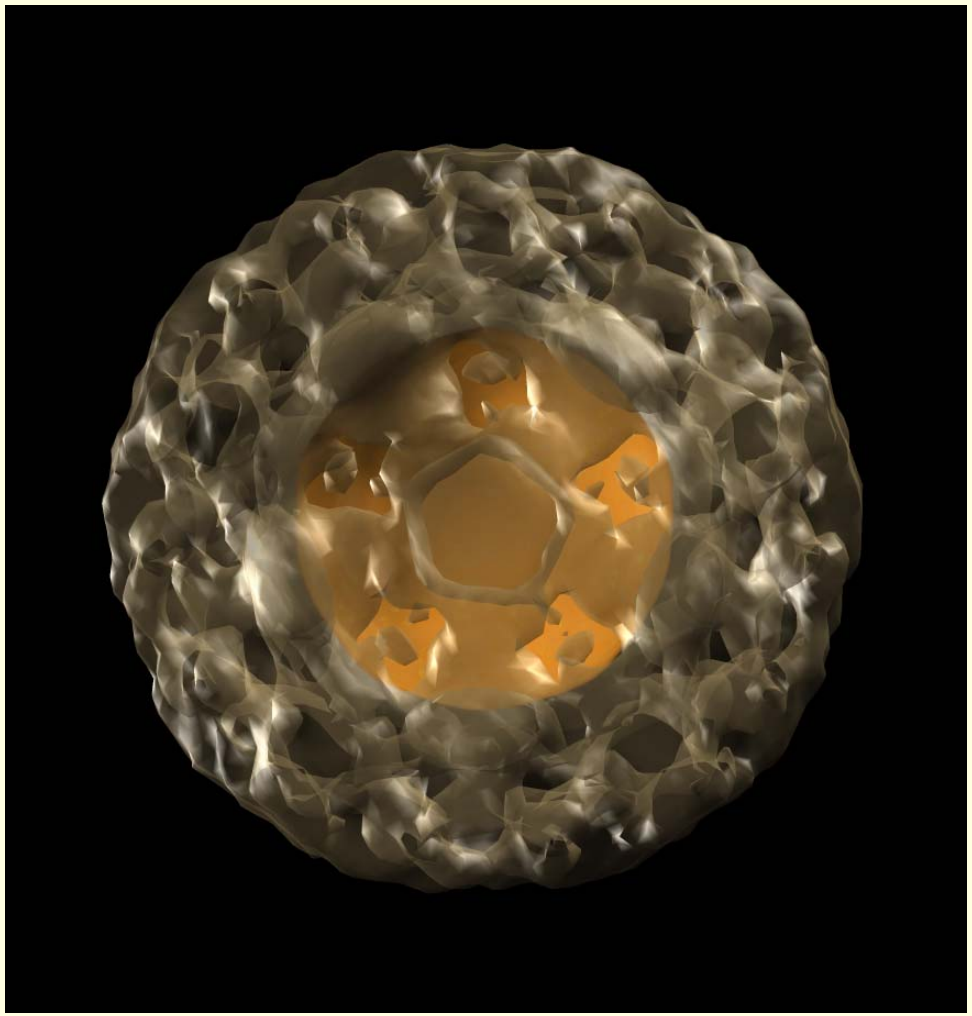
Physical aspects in the self-assembly of biological complexes



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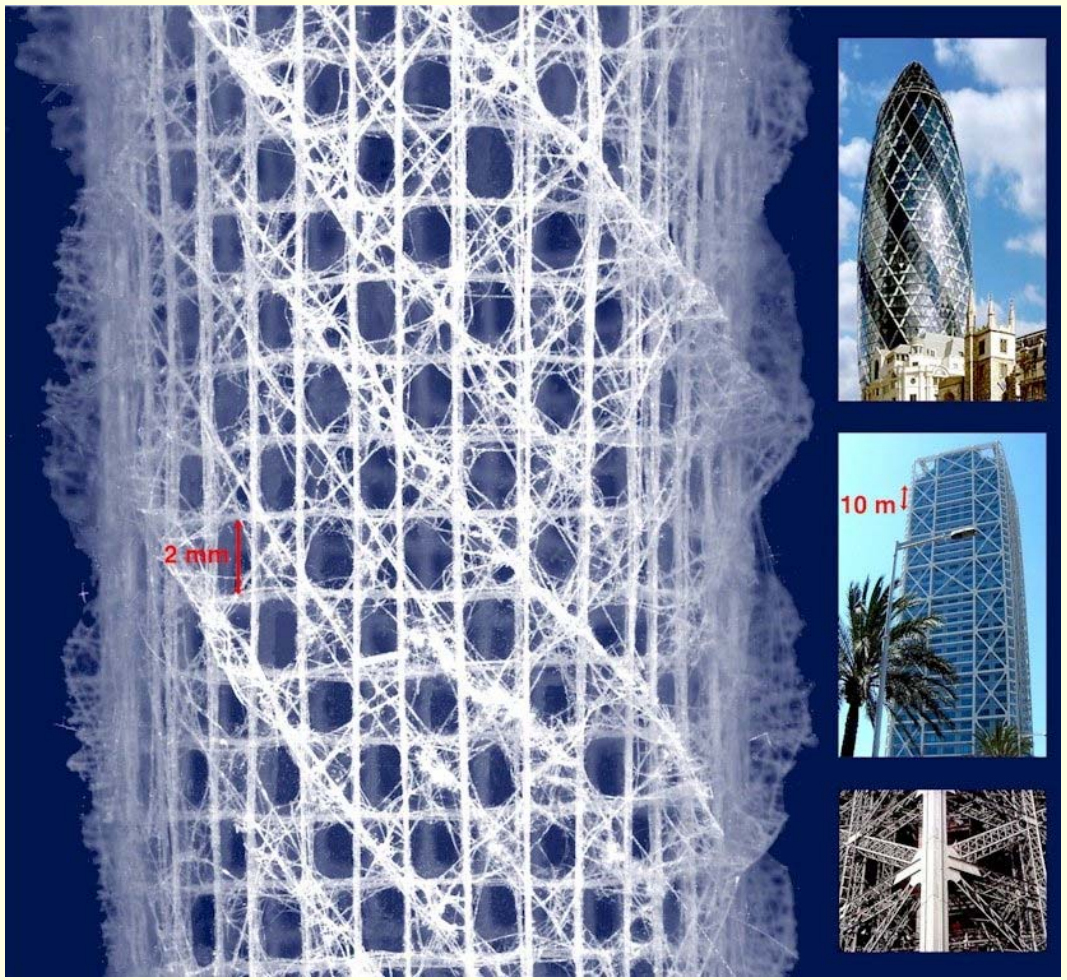
Self-assembling supra-molecular systems

- Example of supramolecular hierarchy: the skeleton of a sea sponge (Eupectella, J. Aizenberg, 2003)

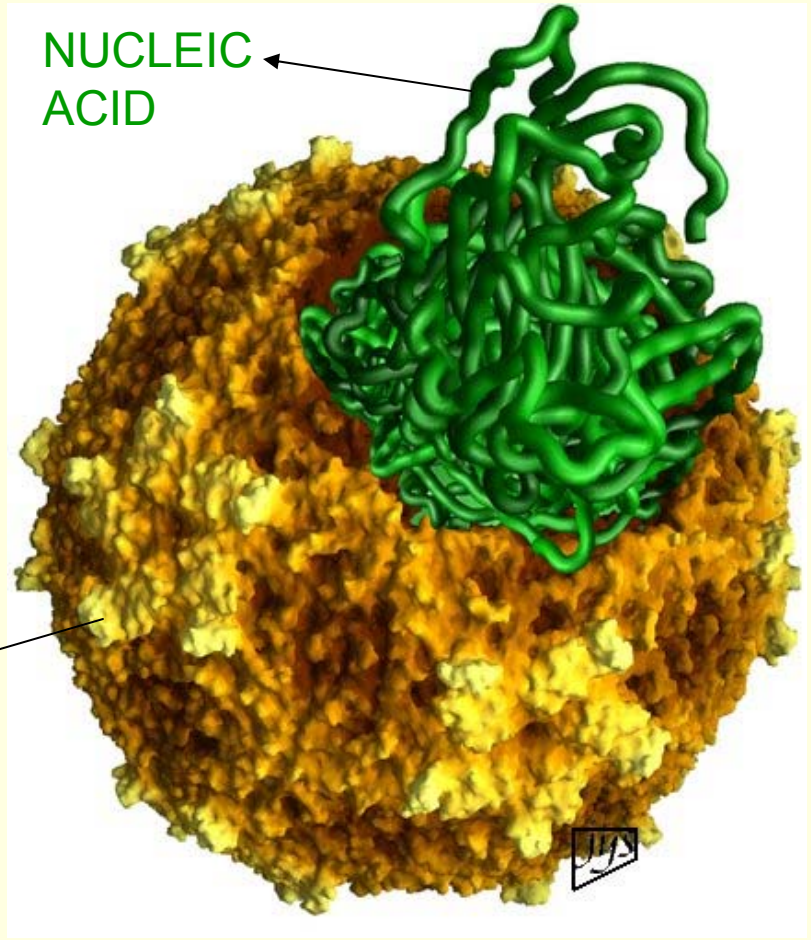


What questions can physicists answer?

- What is the mechanism of self-assembly?
  - What intermediates, kinetic bottlenecks?
  - How do the assembly pathways depend on environment?
- What are the dynamics of the final complex?
- What physical properties emerge from a given hybrid structure?
  - How to design a biological metamaterial.

Viruses: best size/complexity ratio?

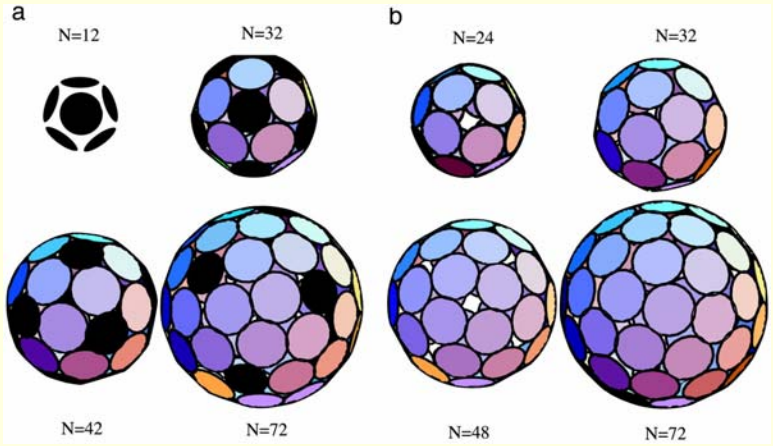
- Most viruses are symmetric: icosahedral or helical capsid structures.
- Most capsids are composed of a small number of types of proteins.



Session L34: Virus-Inspired Supramolecular Structures
Tuesday afternoon, March 6, 2007, APS Meeting.

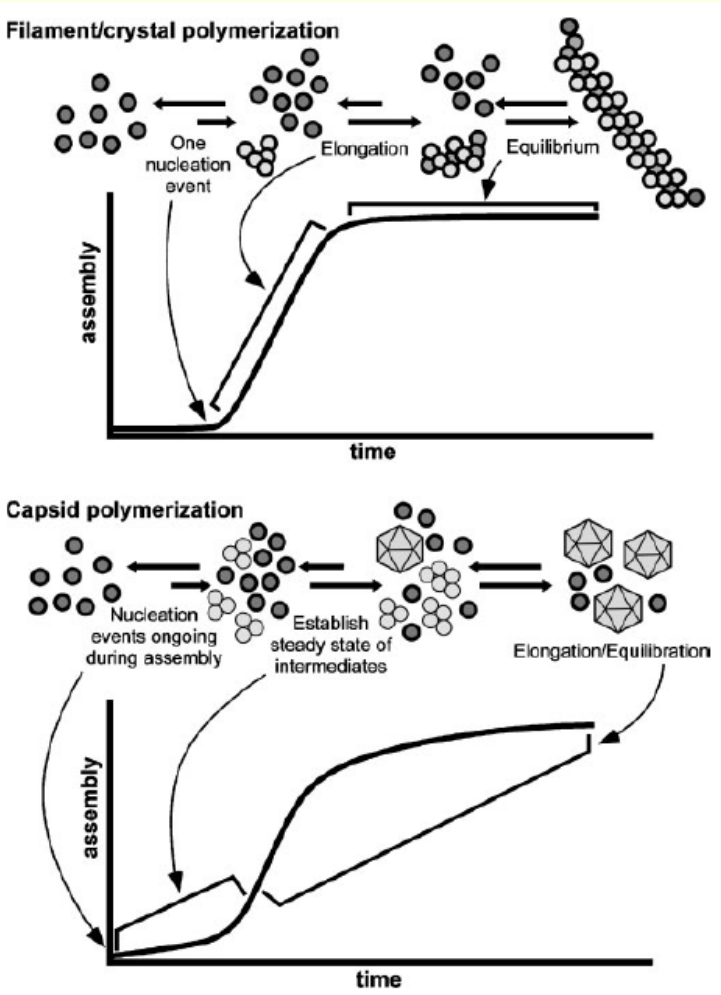
Mechanism of self-assembly: theory

- Thermodynamics



R. Bruinsma et al., Phys. Rev. Lett., 2003

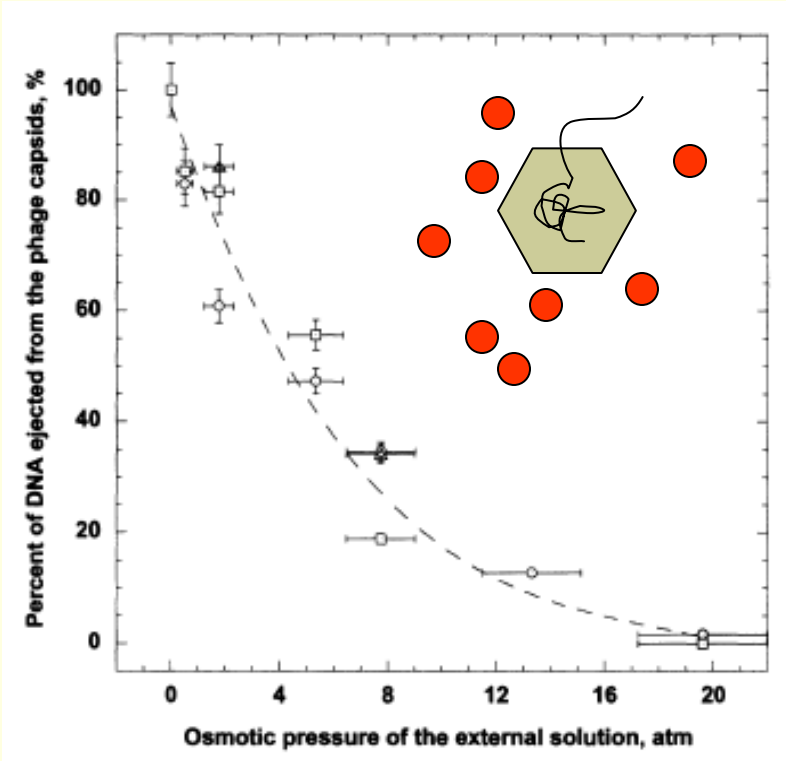
- Physical Kinetics



A. Zlotnick, J. Mol. Rec., 2005

Mechanism of self-assembly: experiment

- Thermodynamics



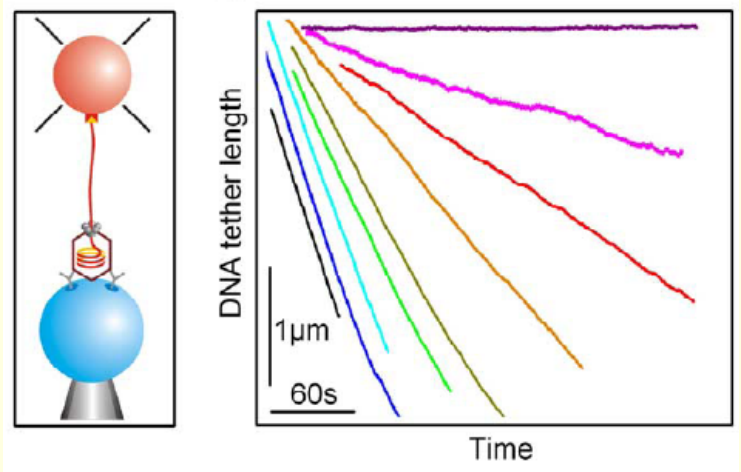
Gelbart et coll., PNAS, 2003
λ-phage packages DNA at a pressure of 20 atm.

- Kinetics (DLS)
- Cryo-TEM
  - Zlotnick et coll.: Capsid formation is a nucleated process and the nucleus is a pentamer of dimers.

NOTE: ensemble averaging methods do not provide direct insights into the pathways of assembly.

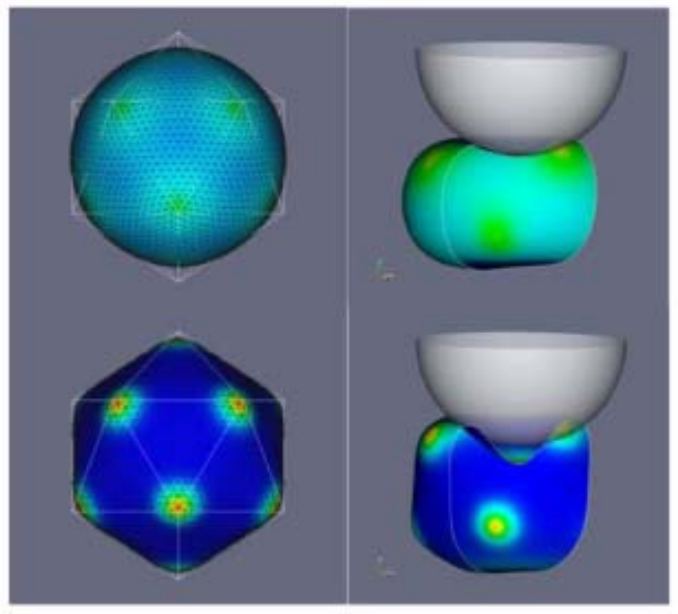
Assembly and dynamics – single virus

- Optical tweezers



Φ29: the strongest motor known
Characterization of the mechanical work cycle
Bustamante et coll., Cell, 2005

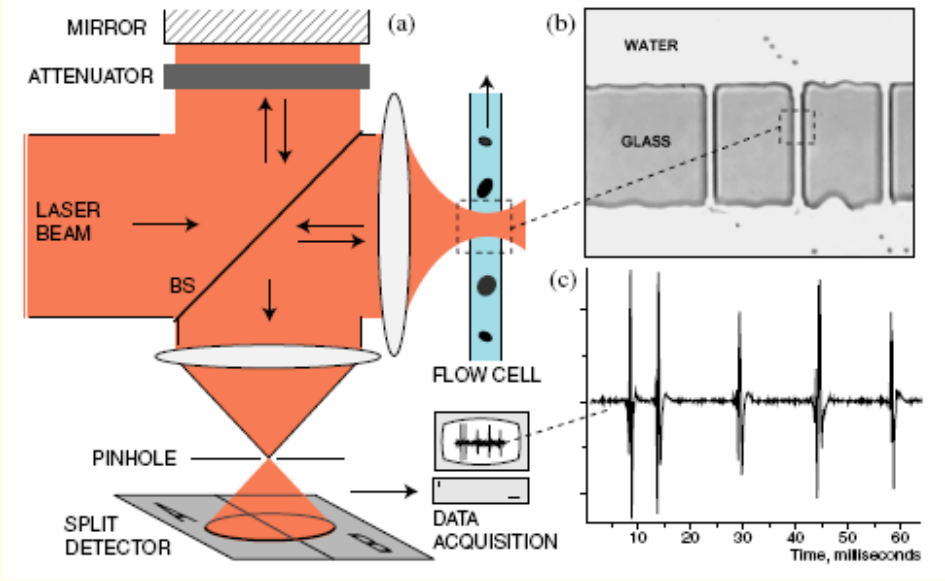
- Atomic force microscopy



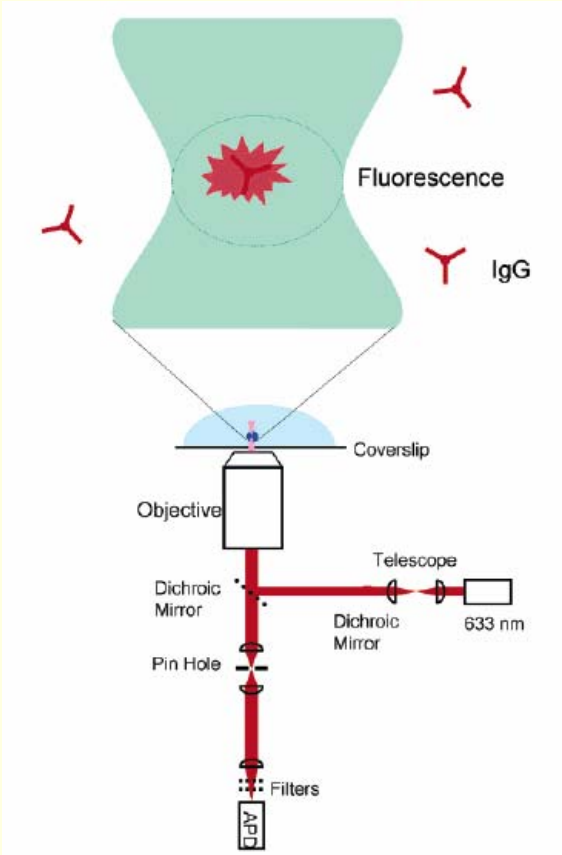
G. Wuite et coll., PRL, 2006
Continuum theory holds – important for interpretation of dynamics

Detection and manipulation of single viruses – a need for new methods

- Detection
  - Ignatovich and Novotny, PRL 2006



- Manipulation



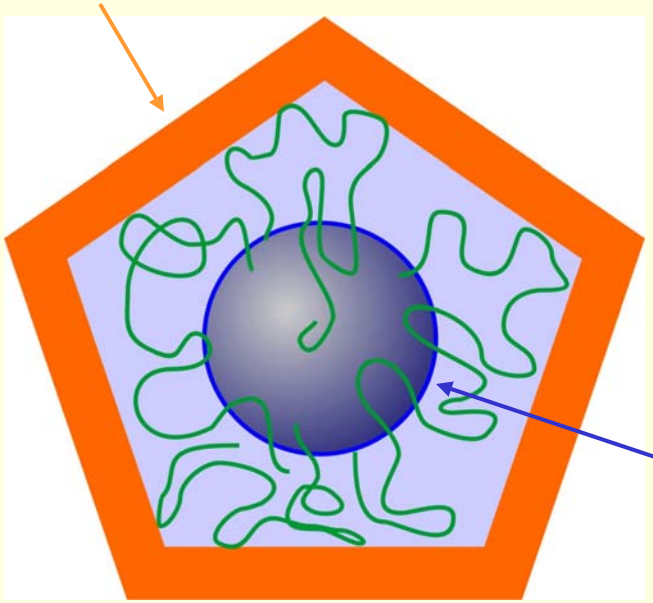
Klenerman et coll., JACS, 2006

$F = -\alpha \nabla E^2$

Two ways to reach subwavelength particle manipulation

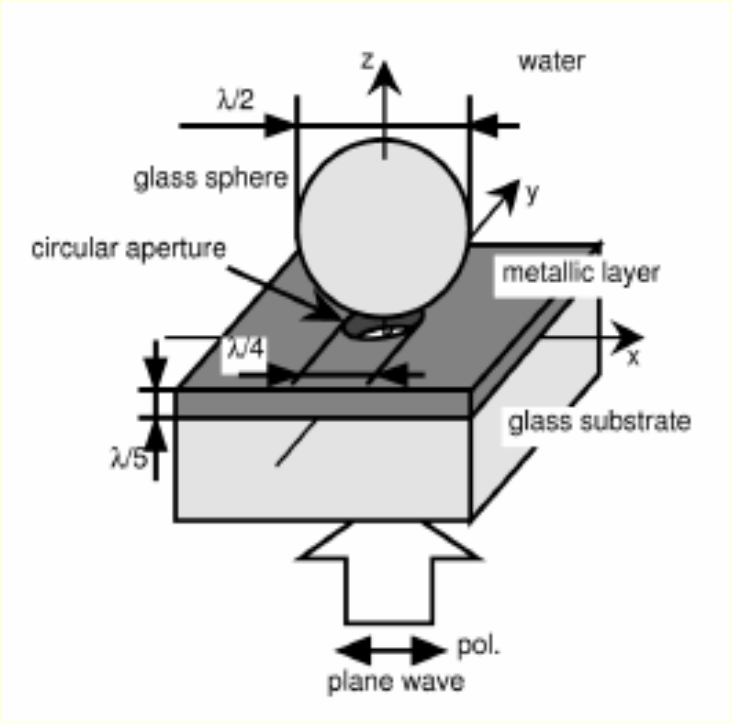
- Increase polarizability

Protein coat (capsid)



VLP's
C. Chen et al., Nano Lett., 2006

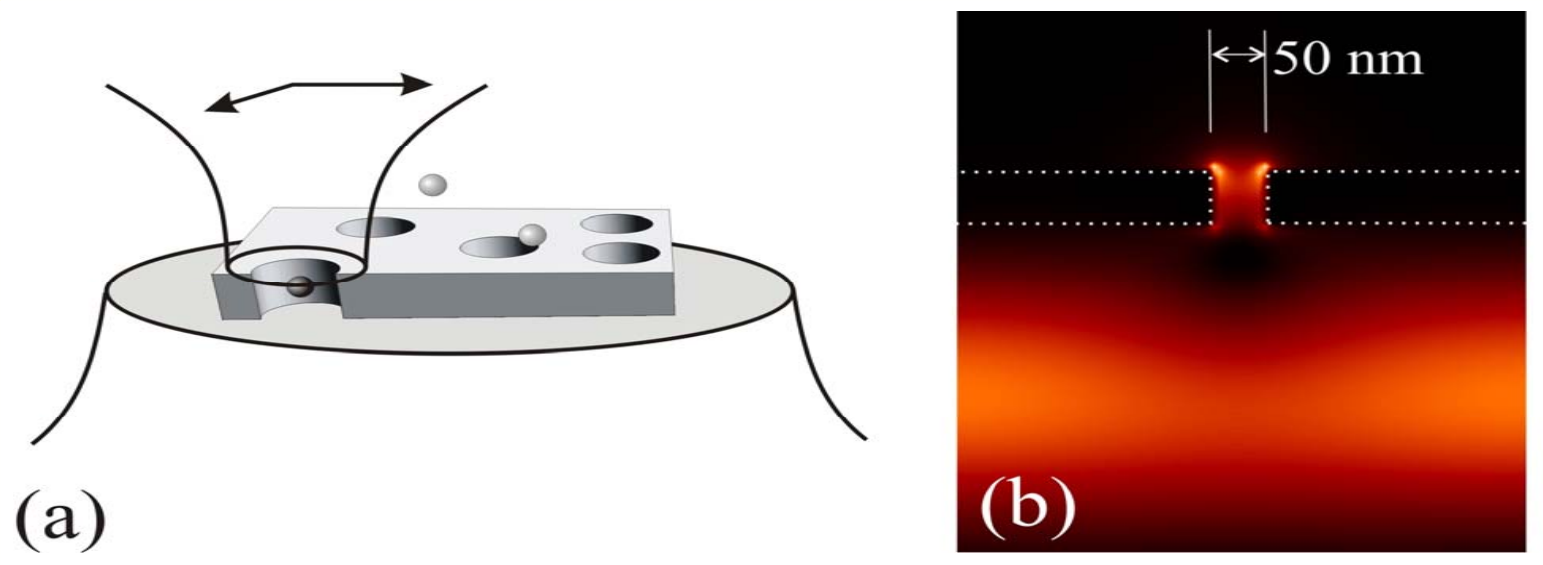
- Use near-field: sharper gradients and field enhancements



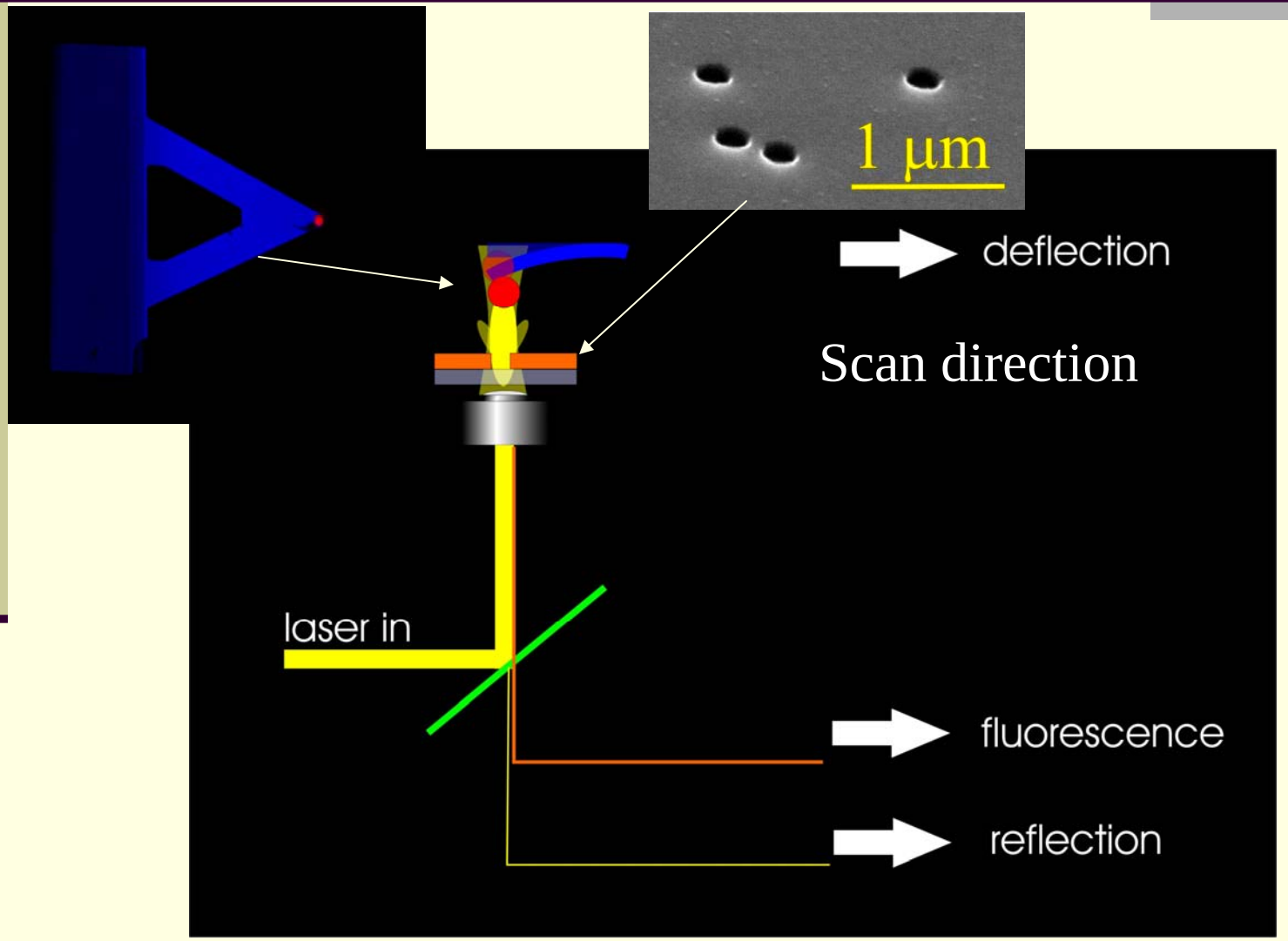
Okamoto and Kawata, PRL, 1999

The first questions

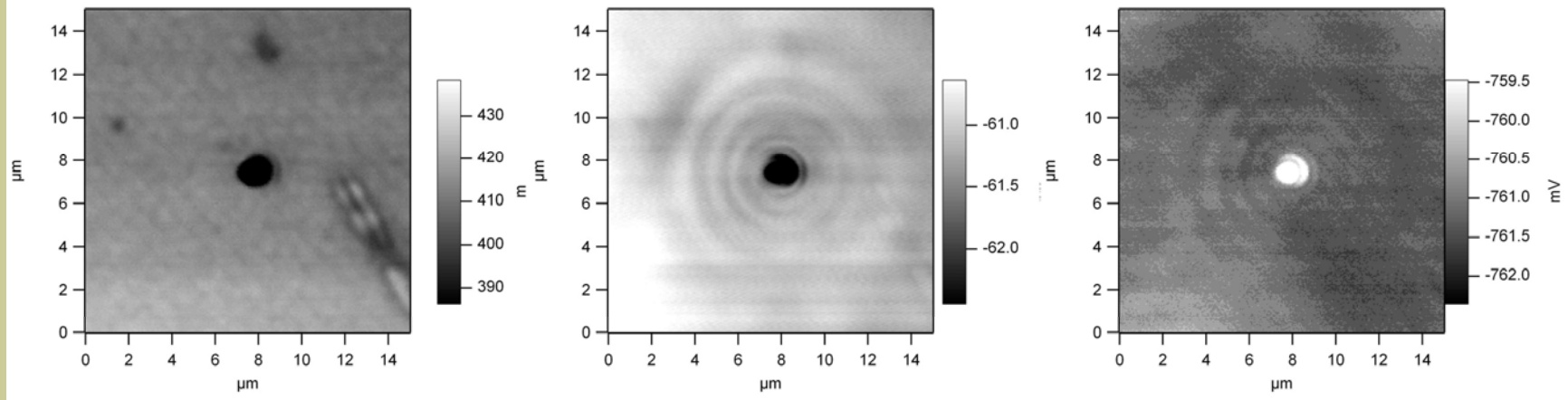
- Will VLP models be relevant for studying viral processes?
- What forces and what optical signals can be expected from near-field?



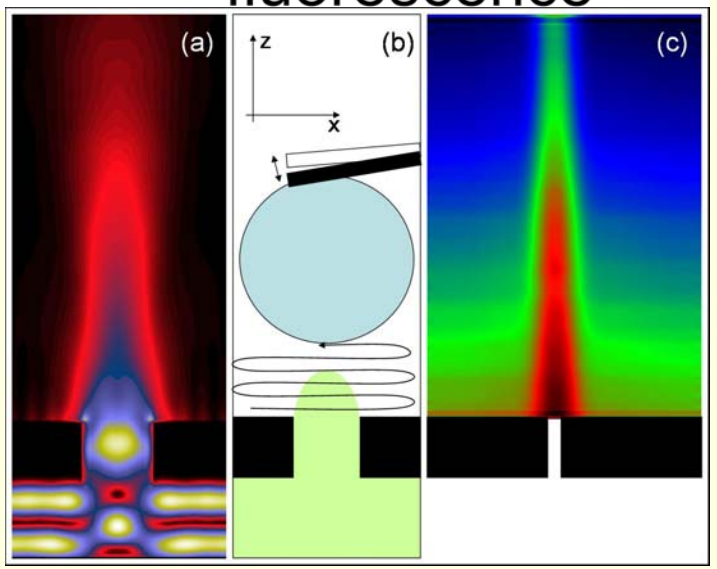
Aperture-trap: experimental setup



First results

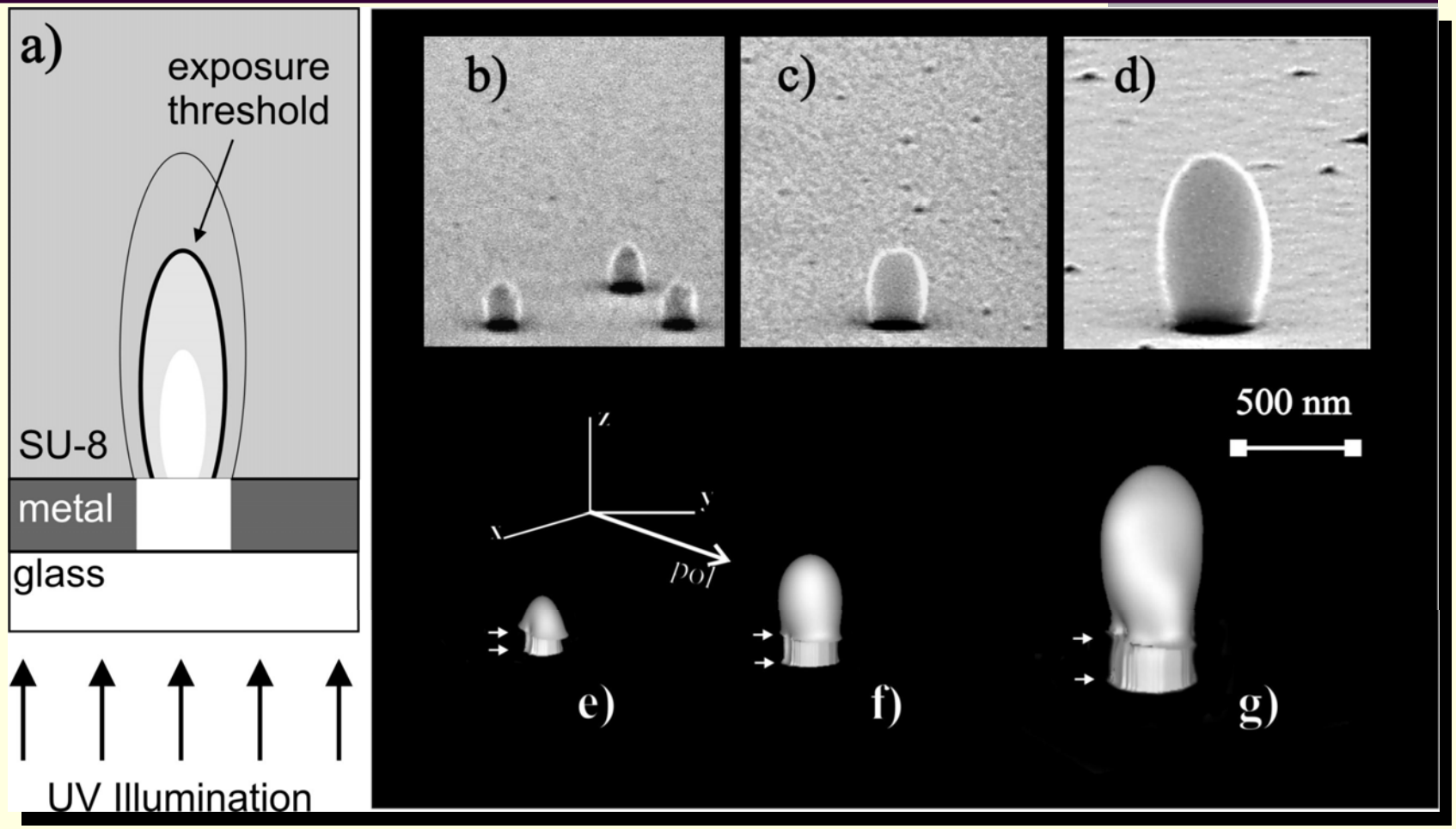


reflection deflection fluorescence



V44.00008 Lensless focusing and optical trapping
Thursday, March 8, 2007, 12:39PM - 12:51PM, Chris DuFort

3D field intensity mapping

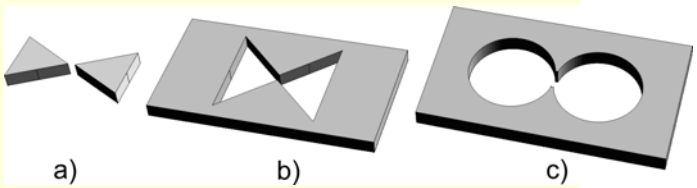


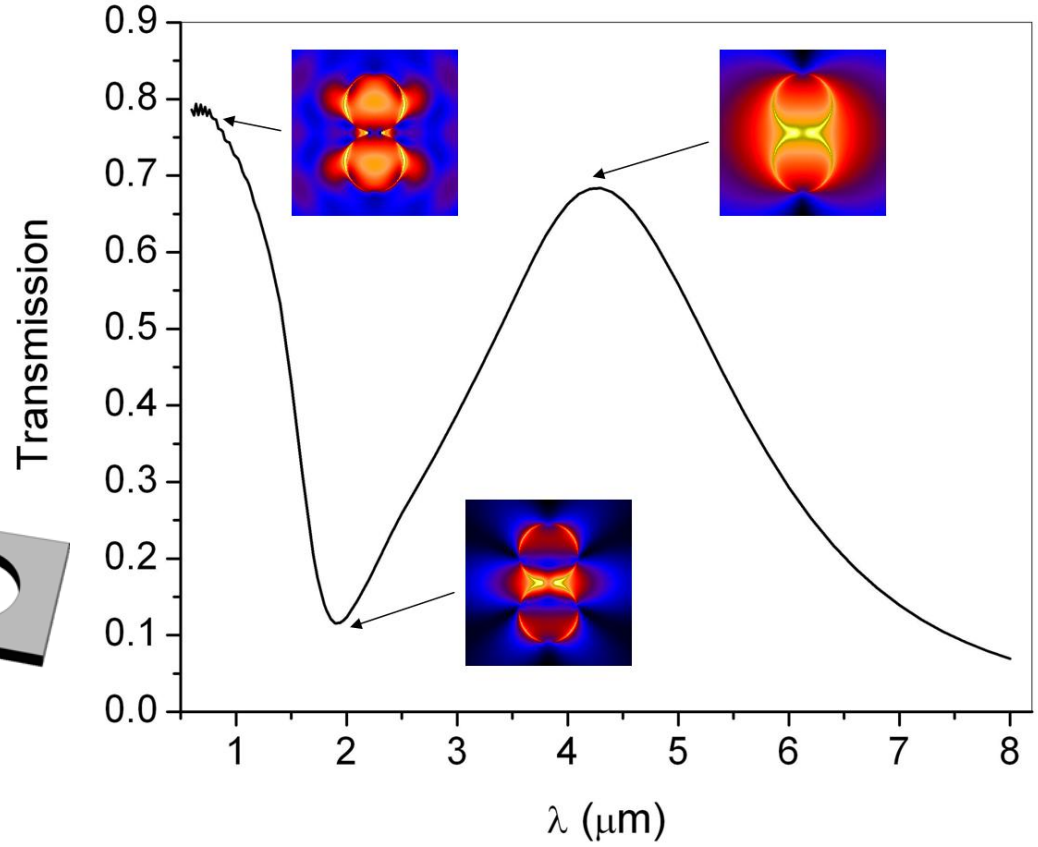
Amarie D, Rawlinson ND, Schaich WL, et al.
Three-dimensional mapping of the light intensity transmitted through nanoapertures
NANO LETTERS 5: 1227-1230 JUL 2005

Tailoring field distributions and enhancements

- Max. Enhancement: 3000
- SP Modes

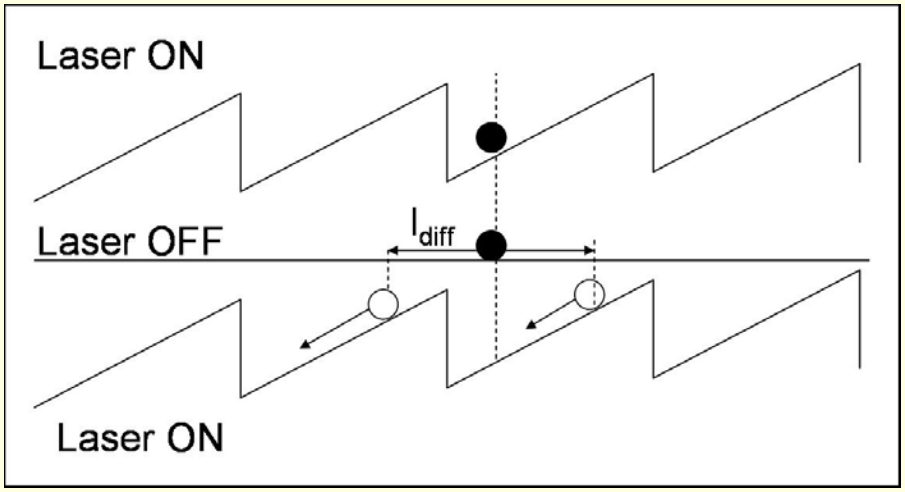
Tonuta et al., Nano Letters, 2007

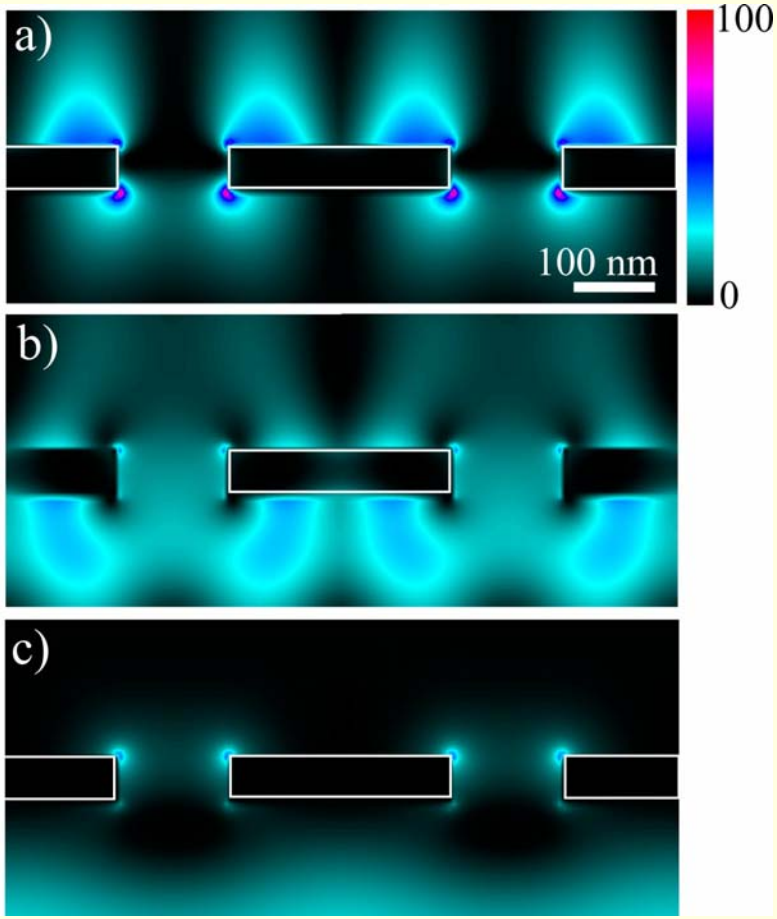




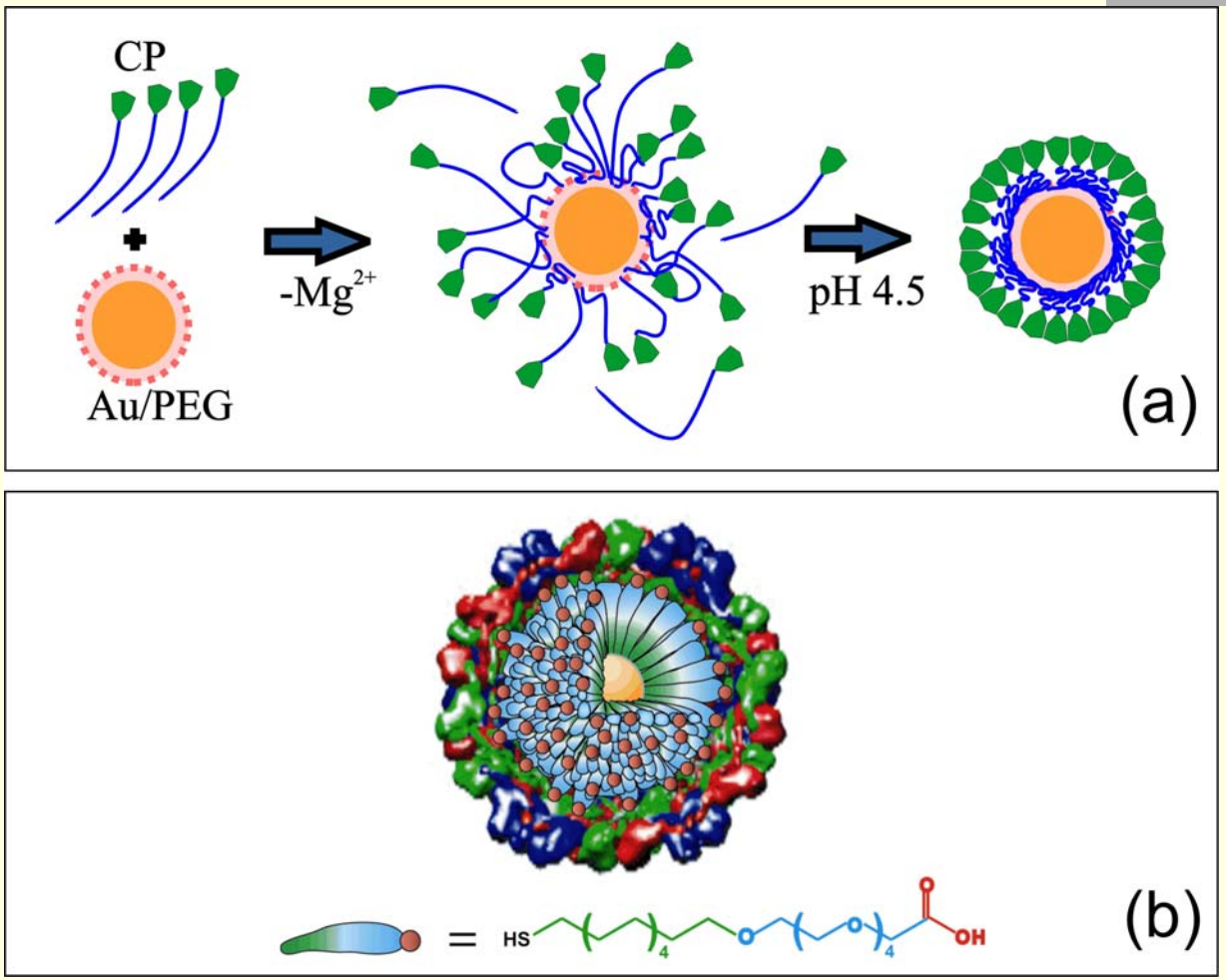
On-going projects

- Optothermal ratchet



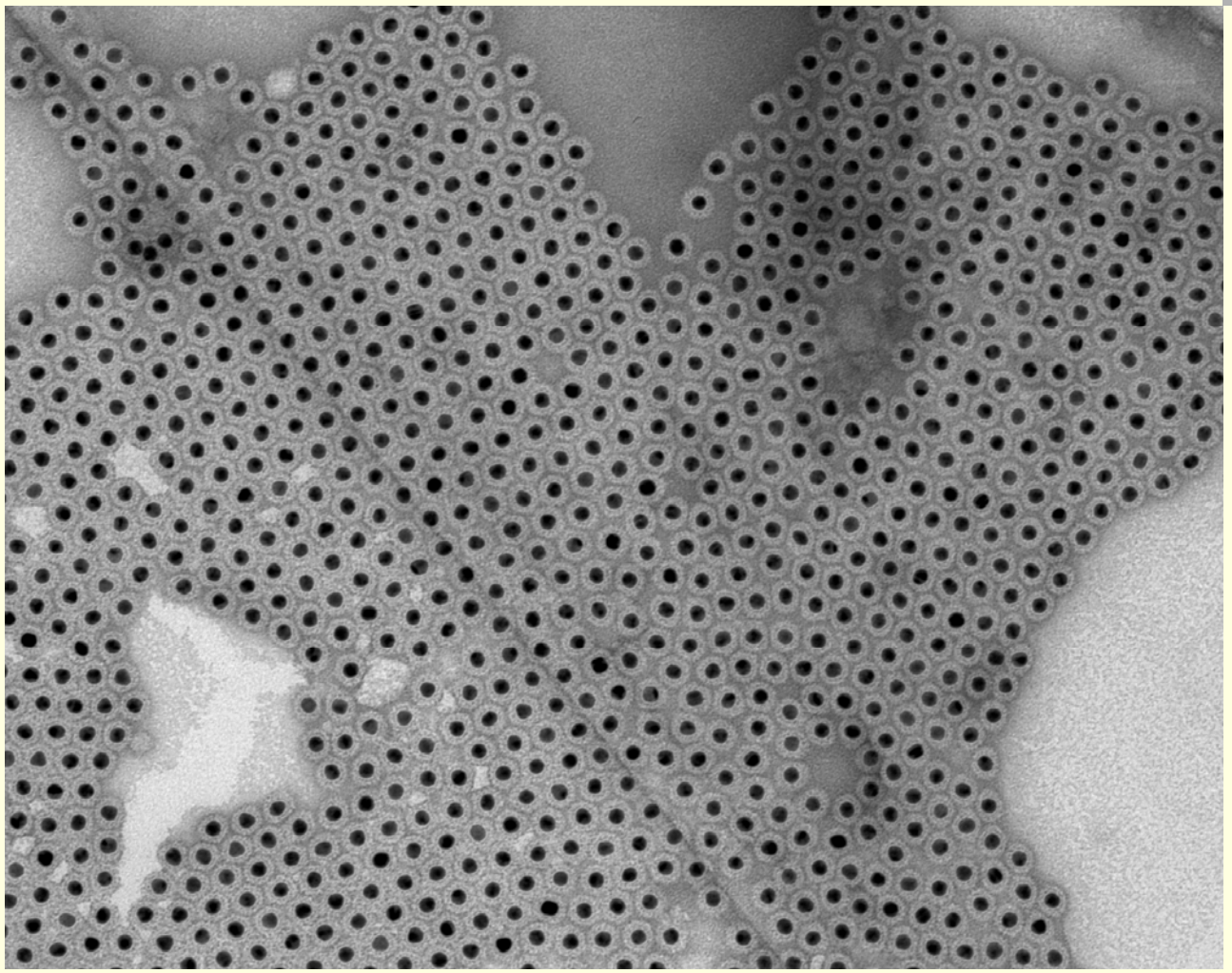


Virus-like particles
-from probes to metamaterials-



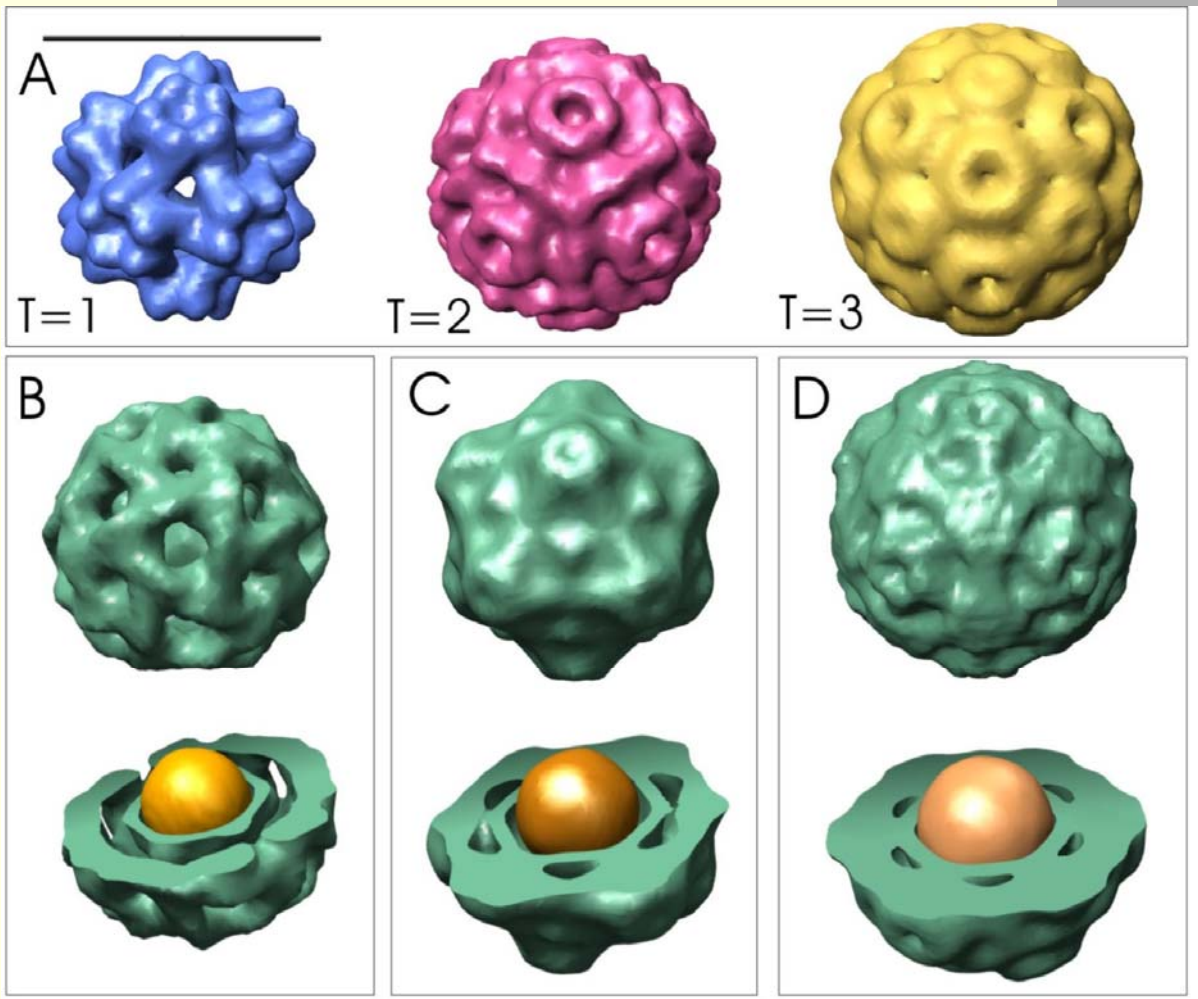
Chen, C. *et al.* Nanoparticle-Templated Assembly of Viral Protein Cages. *Nano Letters* **6**, 611-616 (2006).

Particle acts as a template promoting self-assembly



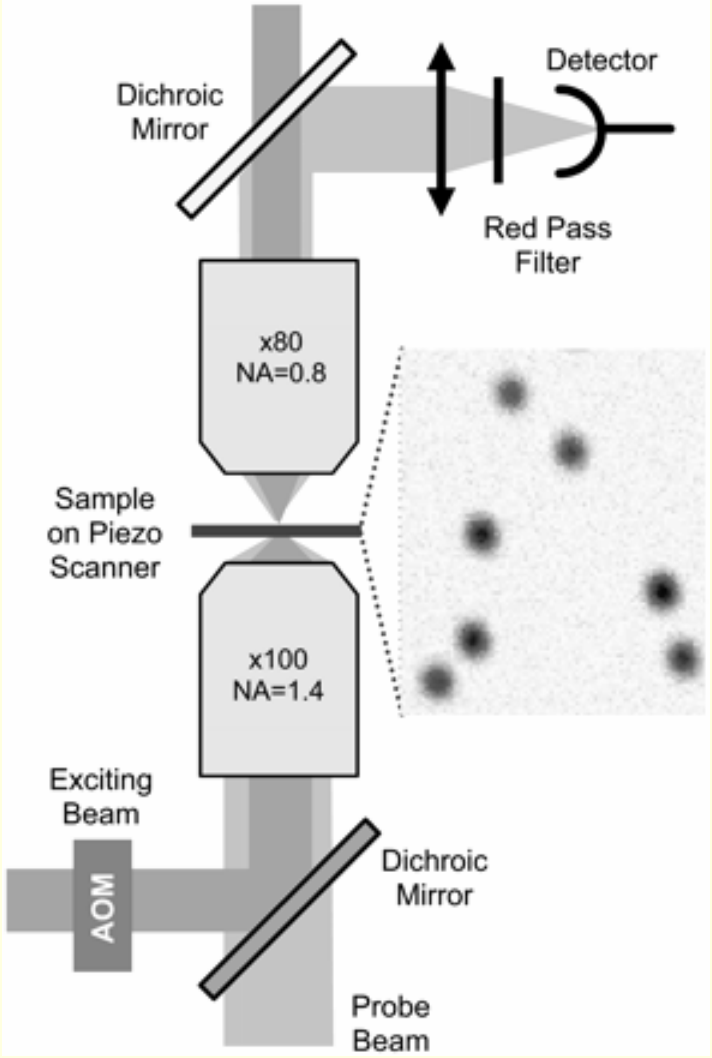
~ 90% encapsulation efficiency. (As good as viral RNA)

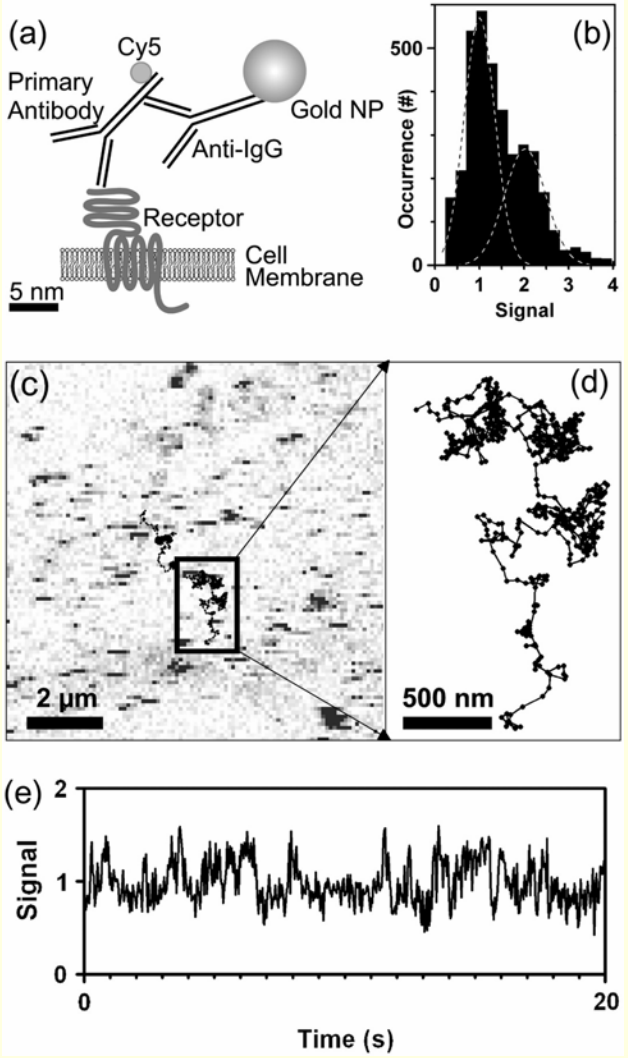
Core-induced polymorphism



Sun et al., PNAS, 2007

Photothermal in-vivo tracking of metal nanoparticles





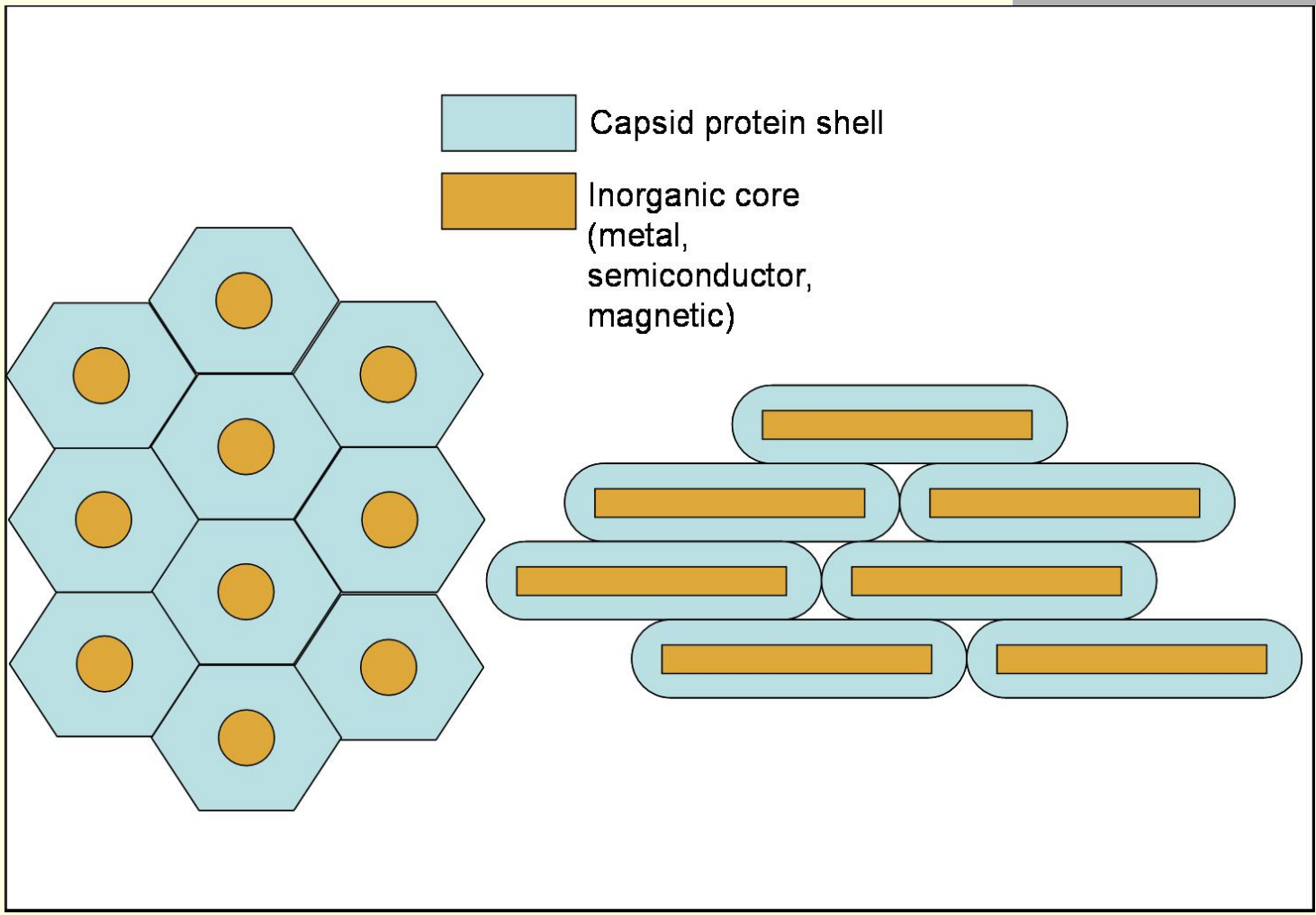
Single Nanoparticle Photothermal Tracking of 5-nm Gold Beads in Live Cells

B. Lounis *et coll.,* Biophys. J., 2006.

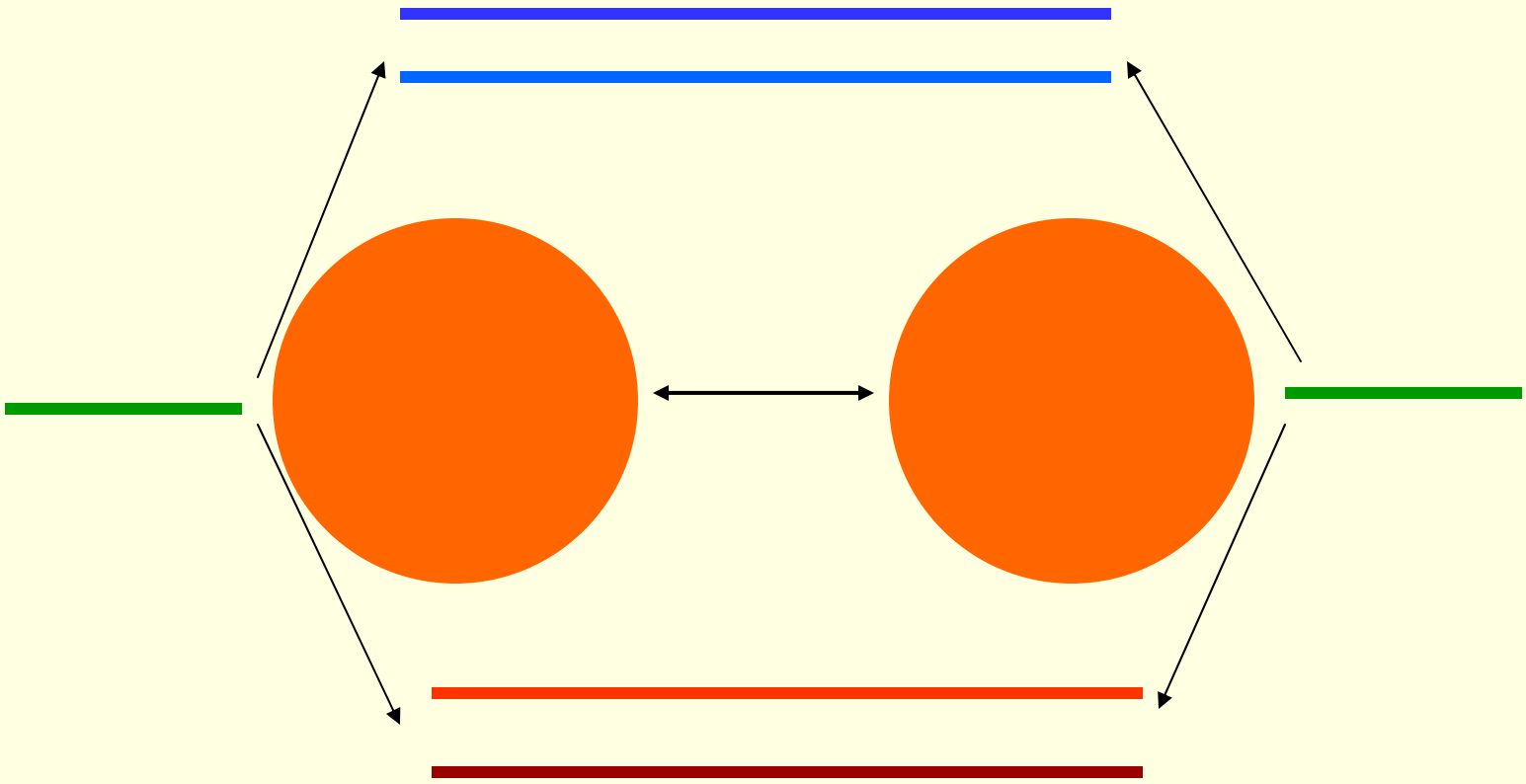
Towards bio-metamaterials

- **Metamaterials:** optical properties determined by their organized structure rather than inherited directly from the material properties of individual subunits.
- ***Metallodielectric* metamaterials** are composed of resonant metal inclusions in a dielectric matrix and have subwavelength lattice periods.
  - Smith et al., Metamaterials and negative refractive index. *Science* **305**, 788-792 (2004).
  - Brown et al., Large Electromagnetic Stop Bands in Metallodielectric Photonic Crystals. *Applied Physics Letters* **67**, 2138-2140 (1995).
  - Fan et al., Large omnidirectional band gaps in metallodielectric photonic crystals. *Physical Review B* **54**, 11245-11251 (1996).

Symmetric protein shells: 3D structures with sub-100 nm lattice parameter

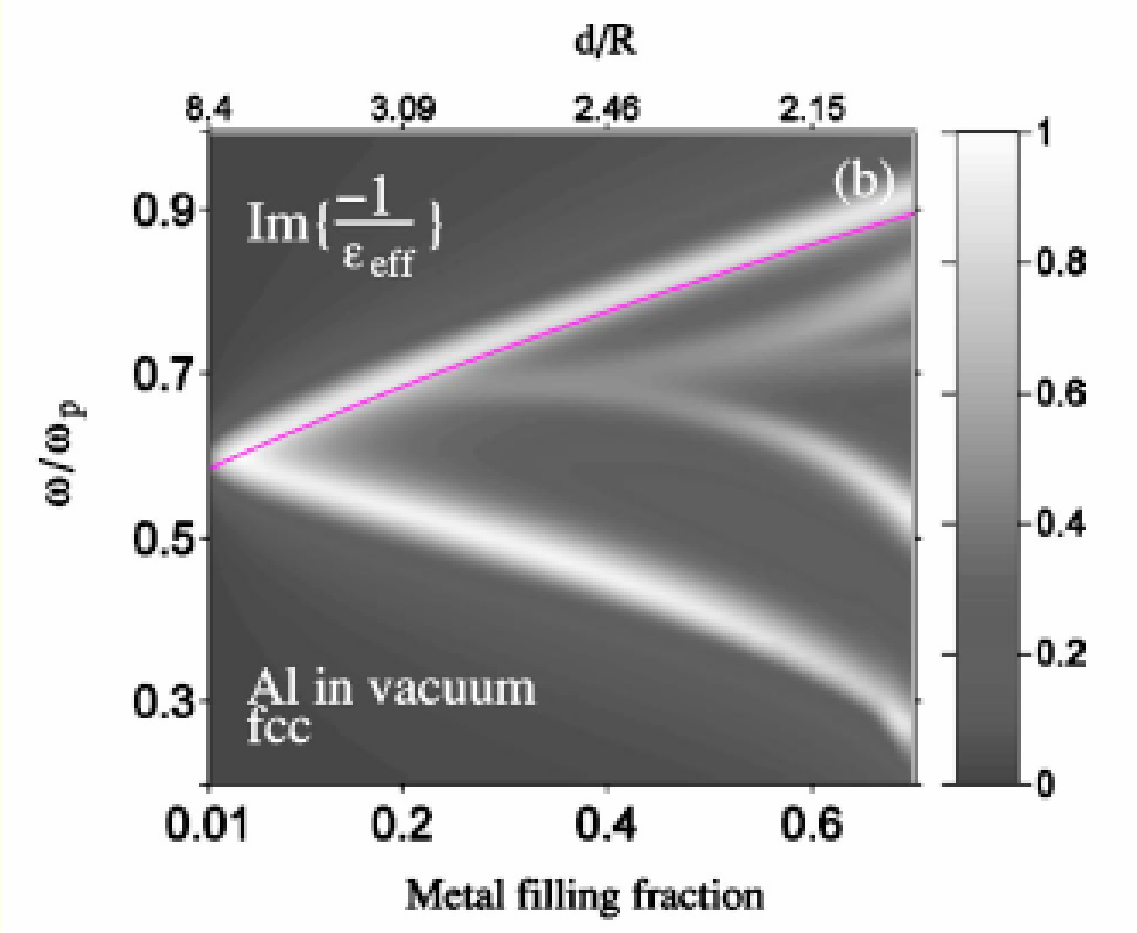


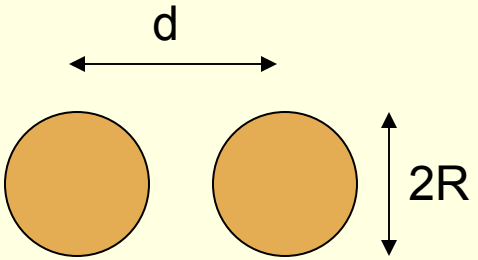
Plasmon hybridization (Nordlander, 2003)



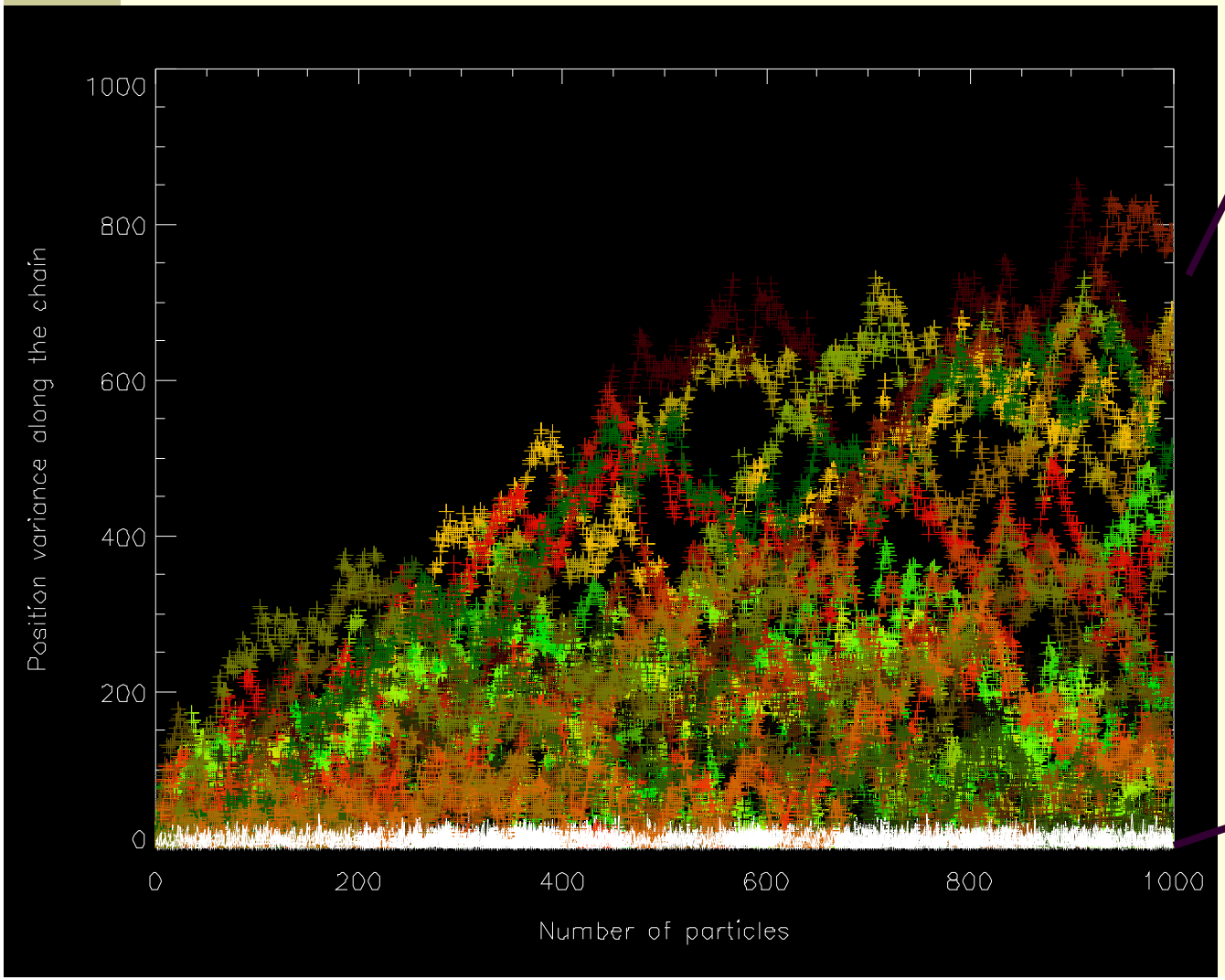
3D metallodielectric plasmonic band structure

- De Abajo et coll., 2005



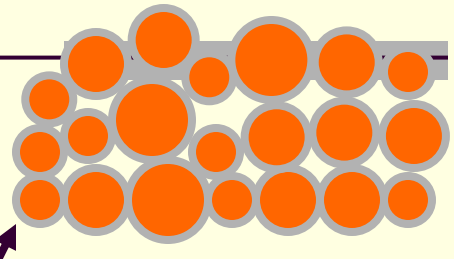


Why VLPs?
To preserve long range order



Colloidal crystal:

$\sigma_{position} = N^{1/2} \cdot \sigma_{Au}$



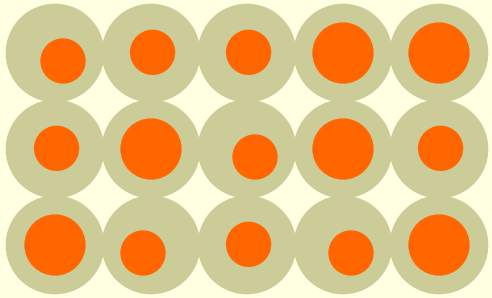
Characteristic lengths:

$\lambda_0 \approx 0.6\ \mu m$

$\lambda_{SP} \approx ?$

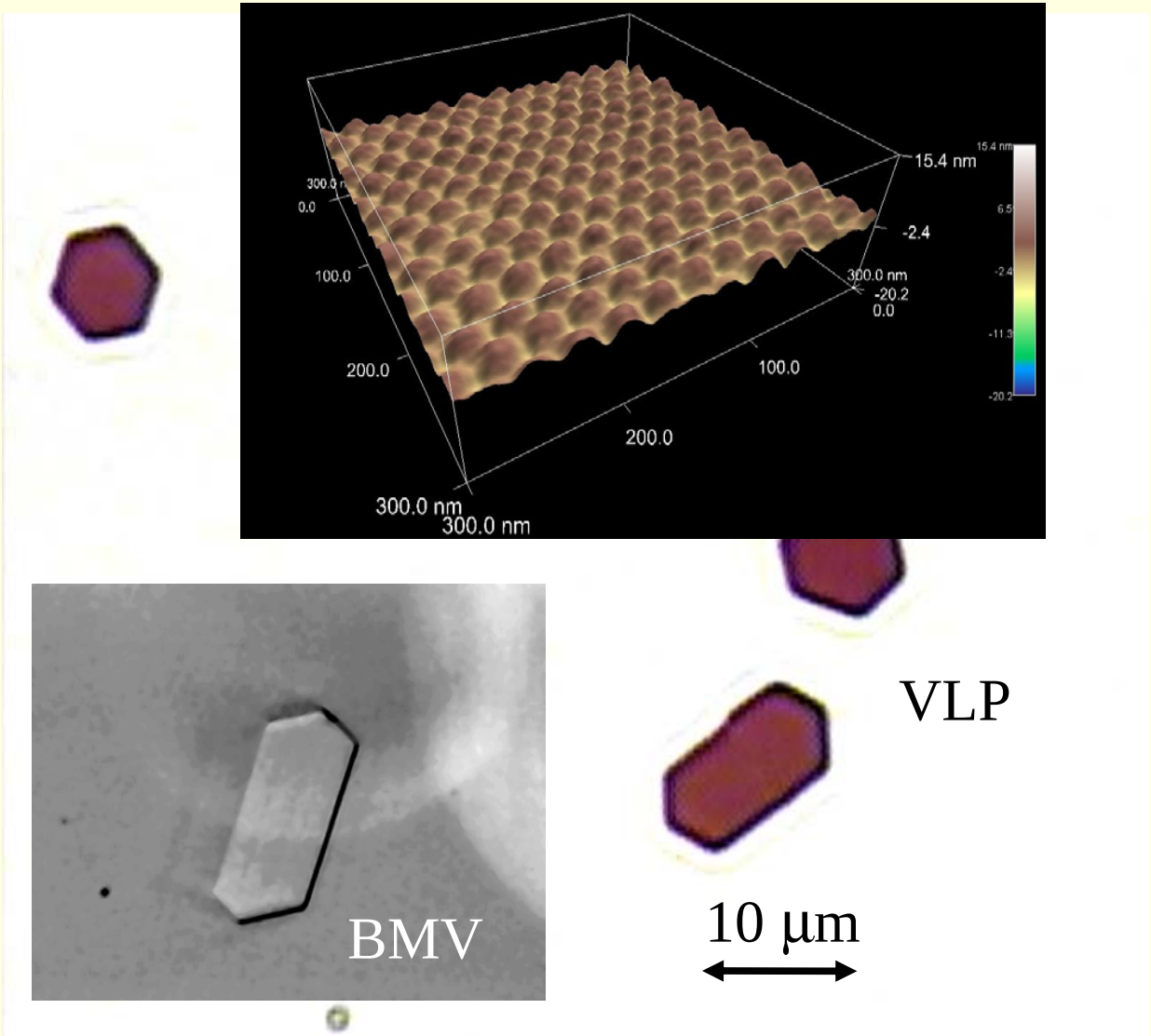
$\lambda_{decay} \approx 20\ \mu m$

VLP crystal:

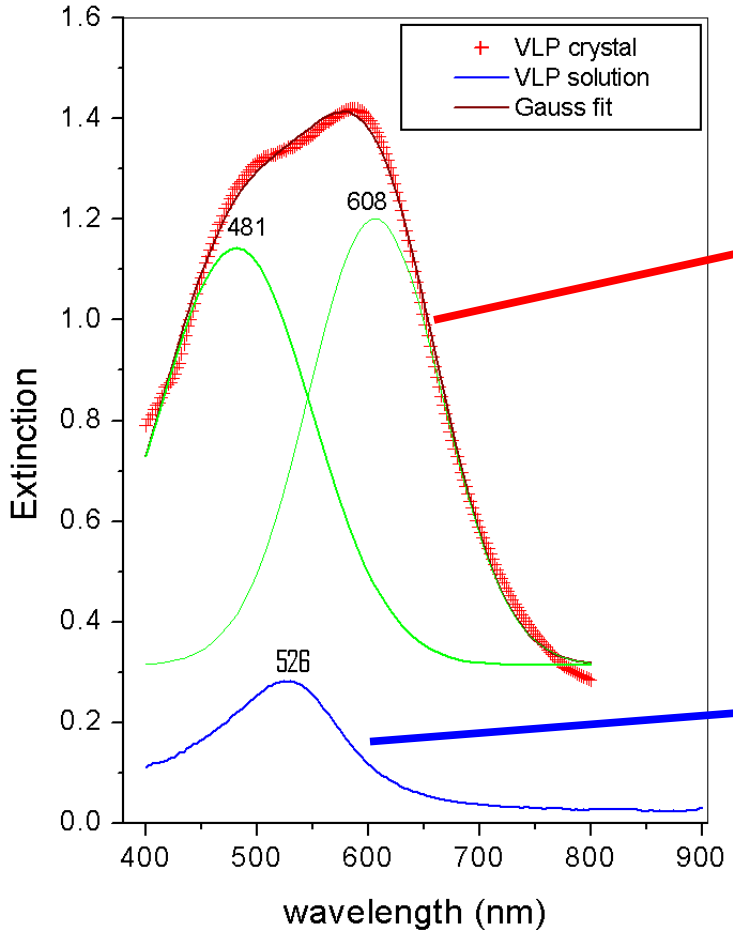


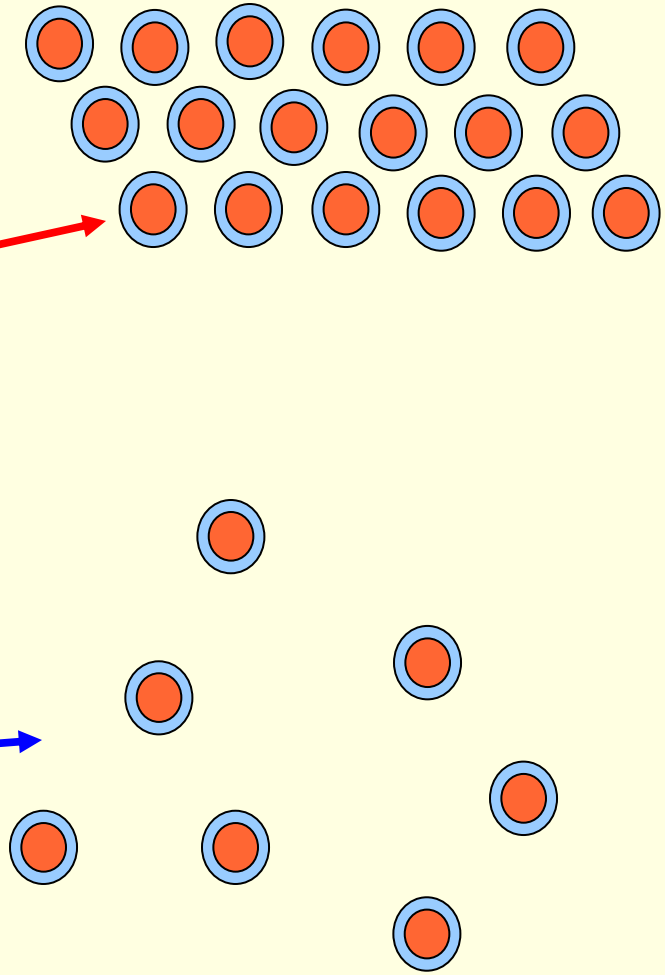
$\sigma_{position} = \sigma_{Au}$

VLPs crystallize in 3D metallodielectric arrays



Band splitting observed





Conclusions

- There is a vast unexplored territory in the area of mechanisms of self-assembly.
- New Tools (both theoretical and experimental) are needed to access:
  - Dynamics,
  - Intermediates,
  - Relationship between structure and properties.
- Optics provides convenient ways to manipulate, probe and build.
- Examples: near-field forces for trap integration, virus-mimic probes, biological metamaterials.

Acknowledgements

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- Dr. Marie-Christine Daniel
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- S. Dixit (P-Chem)
- X. Huang (P-Chem)
- M. Vieweger (P-Chem)
- D. Amarie (Phys/Jacobson/Glazier)
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- Chelsea Kennedy
- Zachary Quinkert
- Steve Irish
- David Pavkovich

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