Mechanics of DNA packaging and ejection in viruses

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Agenda

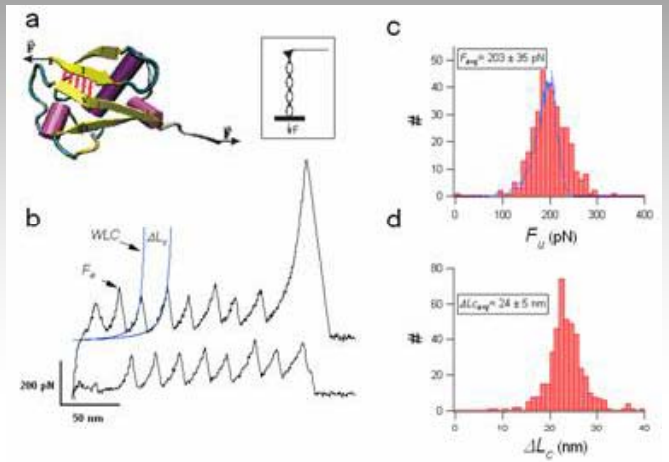
- Mechanics and Biology – experiment and theory

- Mechanics of DNA packaging in viruses

- Experiments and mechanics of DNA ejection from viruses

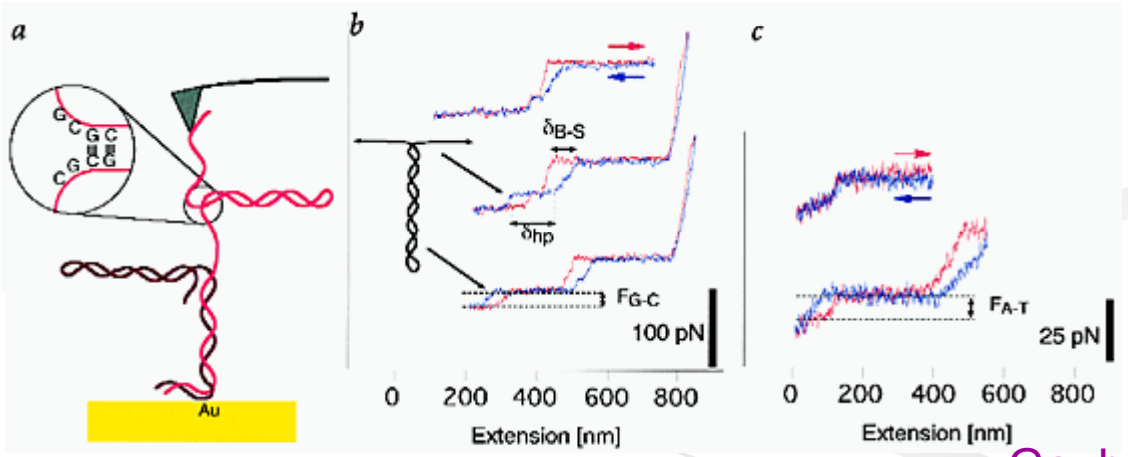
- Conclusions

Mechanics and biology

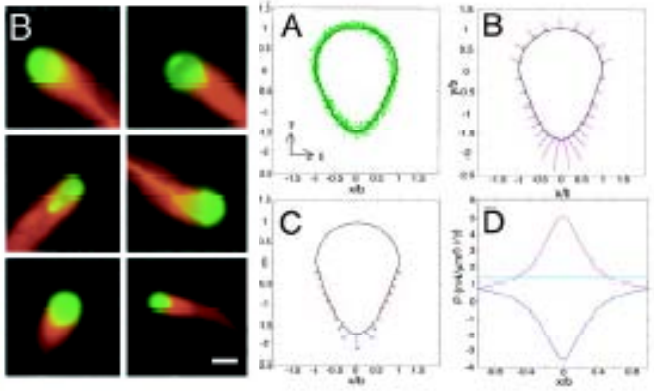


Fernandez

- Protein denaturation by force
- Sequence dependent elasticity
- Actin based locomotion



Gaub



Theriot

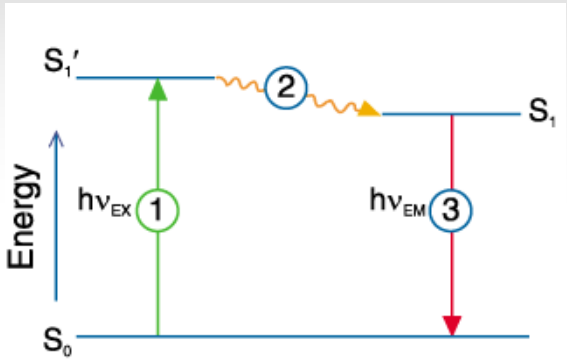
Mechanics experiments!

State of the science

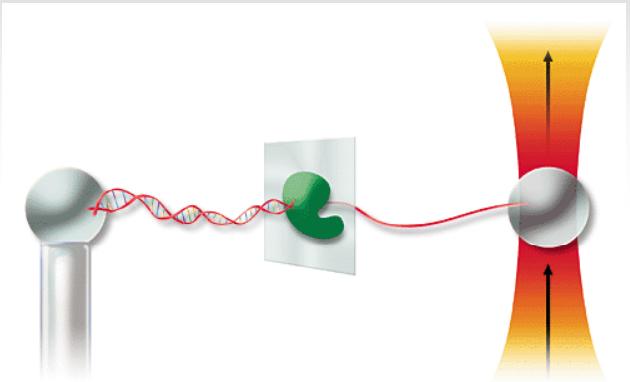
Three main technologies drive the experiments

Atomic force microscope

FRET



Optical tweezers

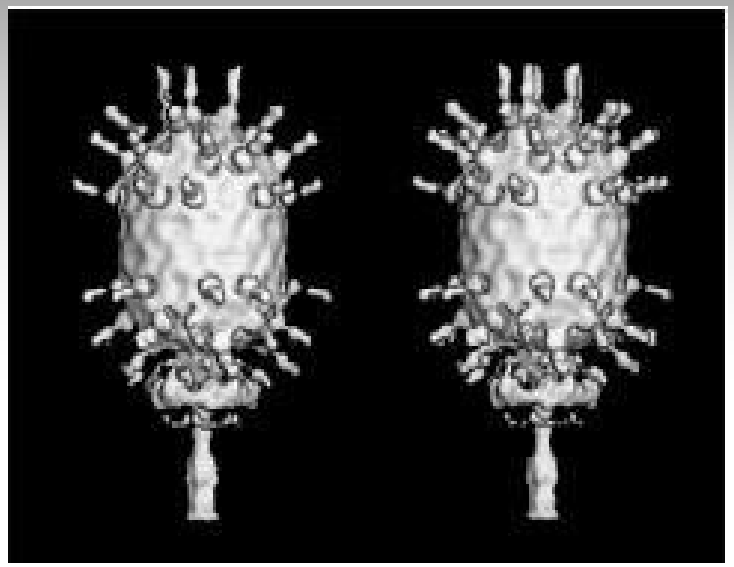


Need theoretical tools

The challenge is to do mechanics at small scales with:

- Thermal and entropic effects (stochastic)
- Chemistry and chemical kinetics
- Electrostatics in solution

Bustamante experiment



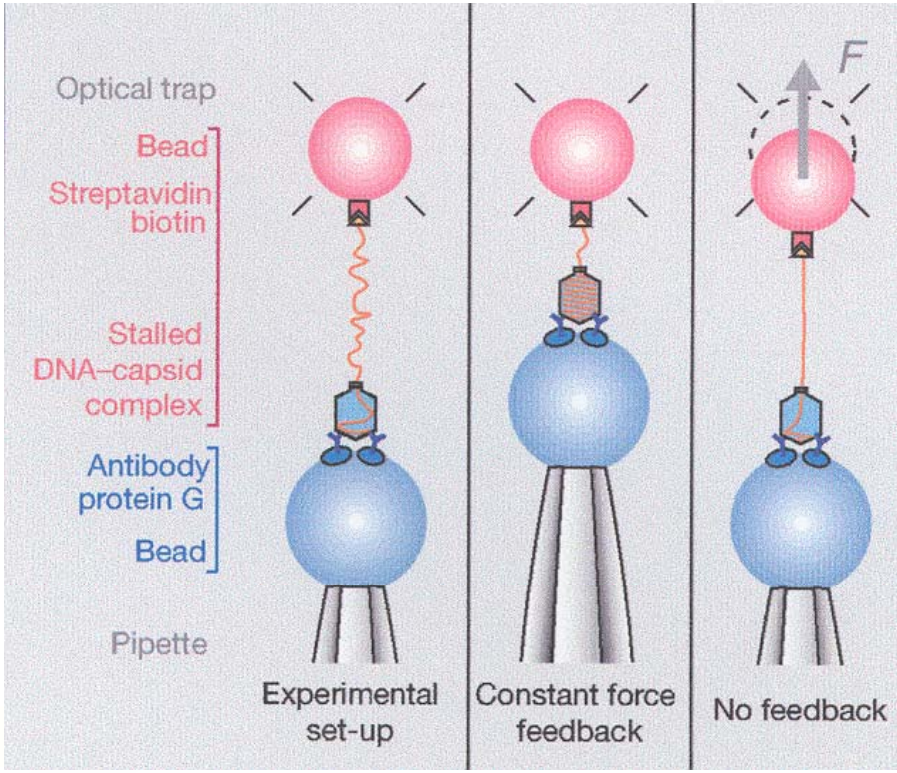
ϕ29 bacteriophage in NaCl solution

Maximum force ⌊ 60 pN

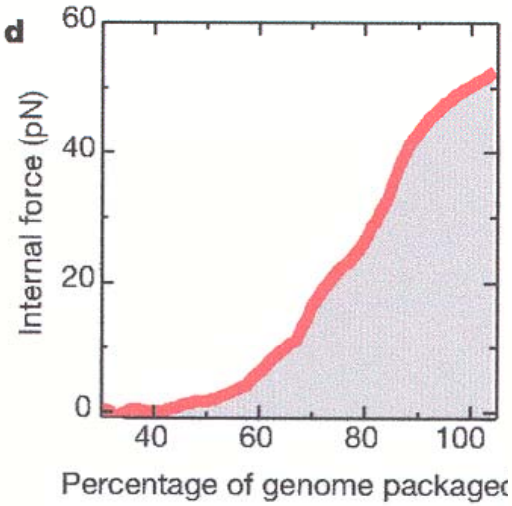
Maximum packing rate ⌊ 100 bp/s

Genome length ⌊ 6600 nm

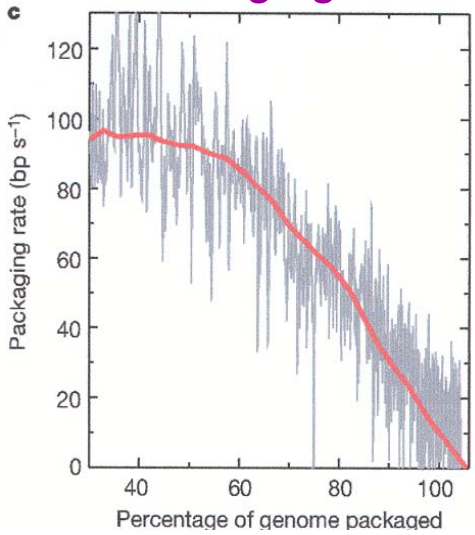
Optical tweezers



Force curve

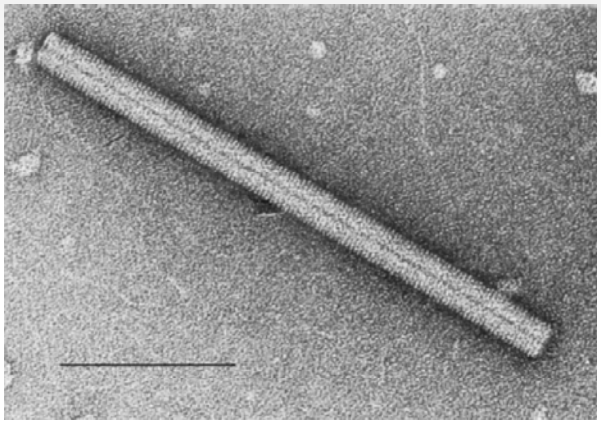


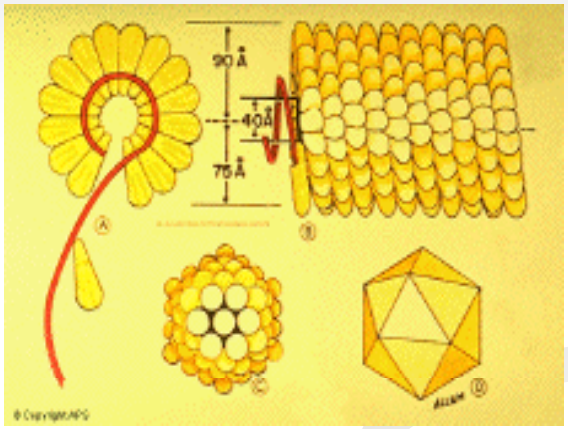
Packaging rate



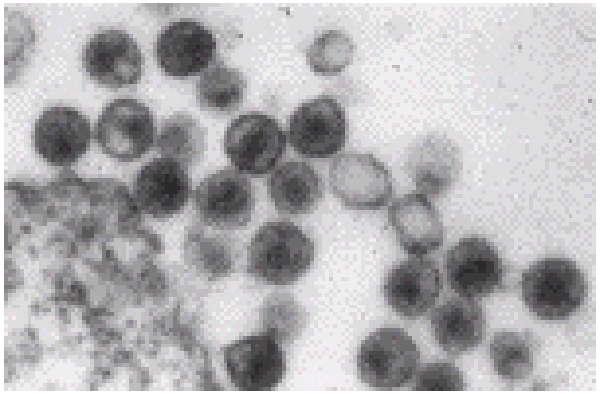
What is a virus?

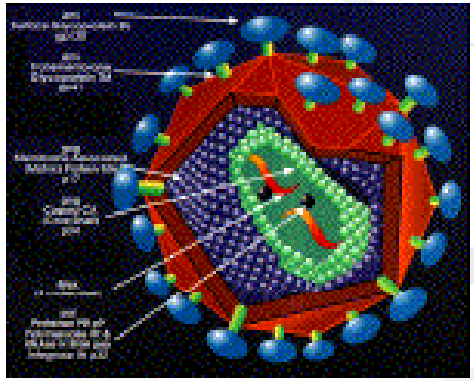
A virus is a protein shell filled with genetic material like RNA or DNA. They attack plants, animals and bacteria.





Tobacco Mosaic Virus





HIV

From the big picture book of viruses on the web

Bacteriophages

- Capsids are icosahedral
- Made of protein
- 10nm to 100nm in size
- 1nm to 3nm thick
- Portal motor at the neck
- Tightly packed genome

How tight, why, who packs it?

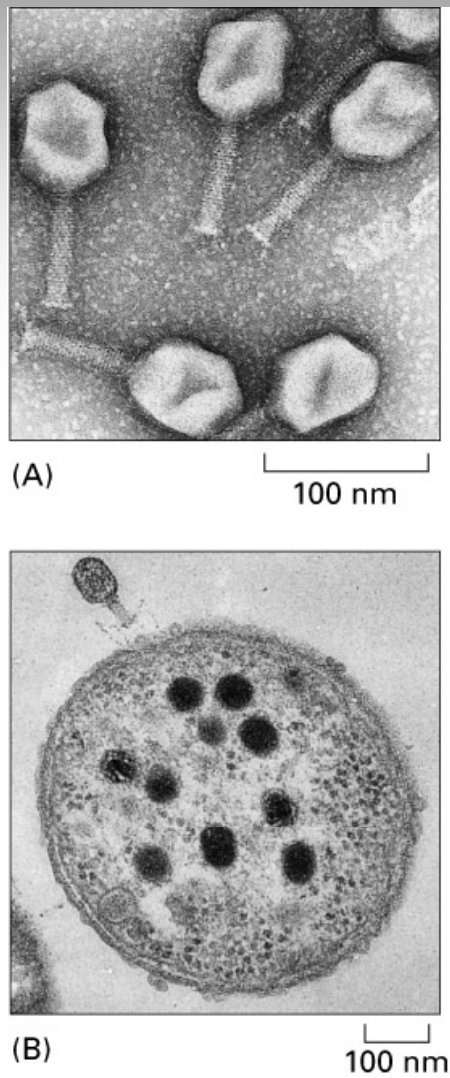


Figure 1–27. Molecular Biology of the Cell

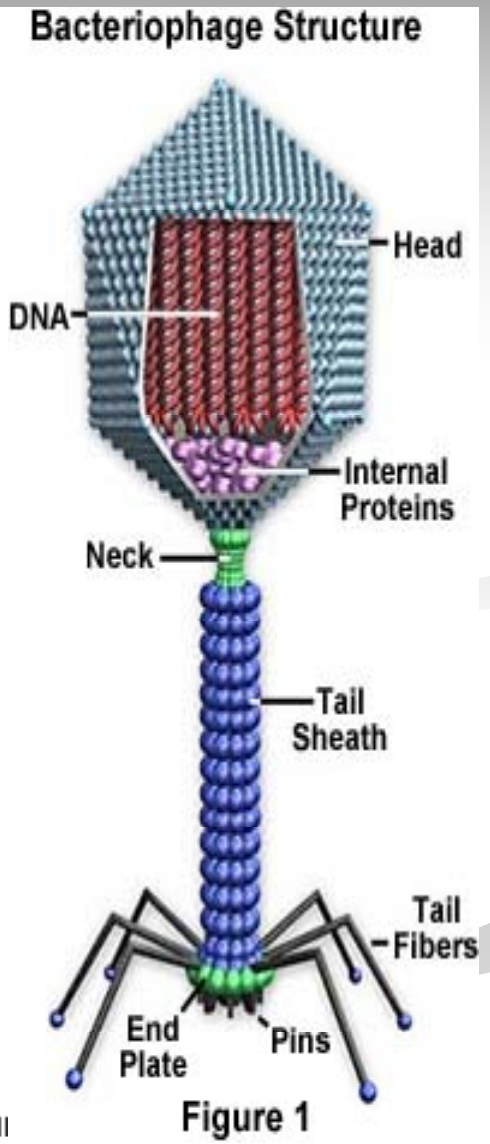


Figure 1

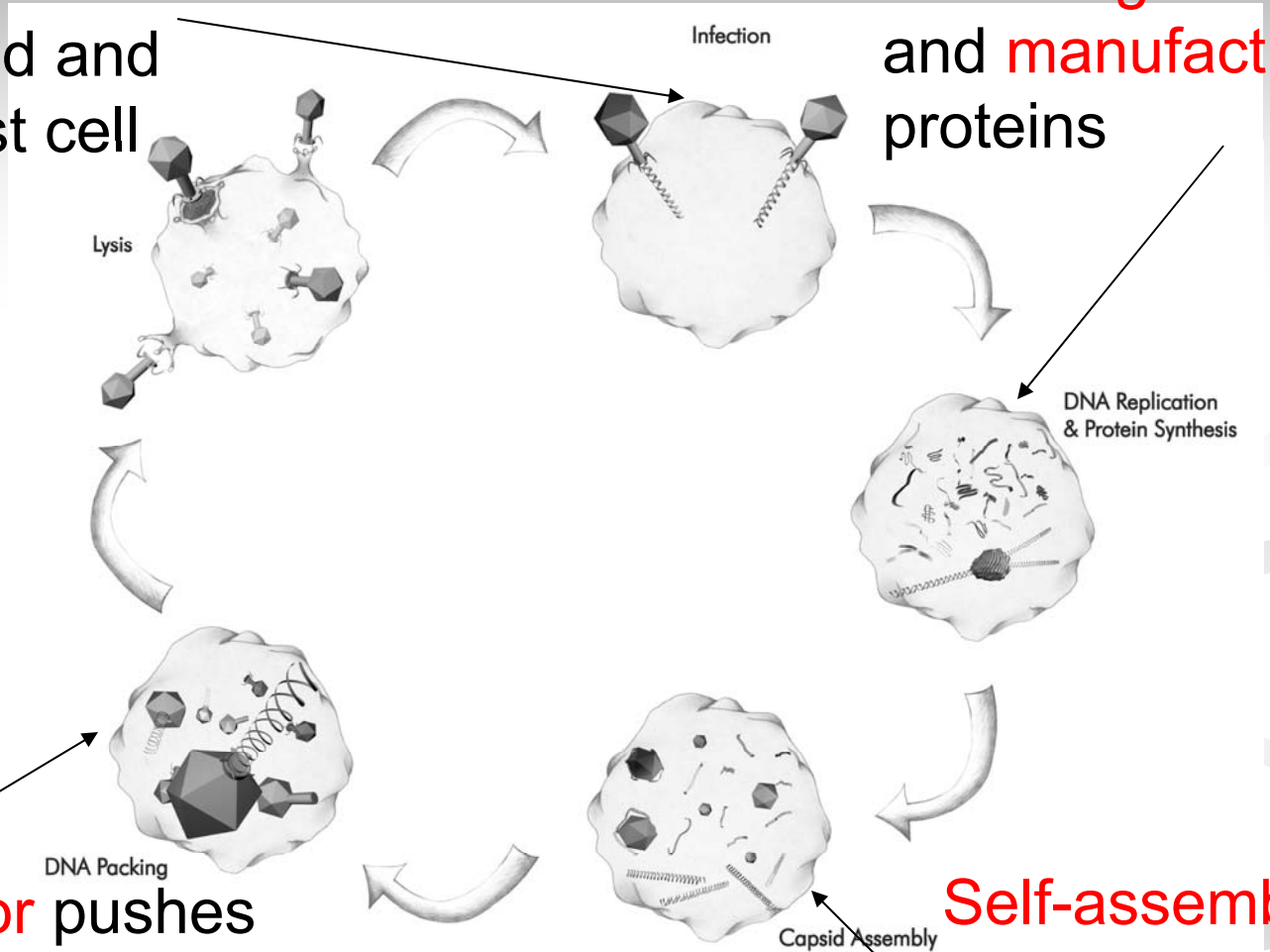
Phages packed tightly

Virus type	Genome size (bp)	Diameter (nm)	Packing density
Polyoma virus SV 40	5243	49.5	0.083
Human adenovirus C	36000	80.0	0.134
Papillomavirus BPV-1	7945	60.0	0.070
Paramecium bursaria chlorella virus-1	330743	190.0	0.092
Bacteriophage φ29	19366	45.5	0.393
Bacteriophage P22	41724	63.0	0.319
Lambdoid phage HK97	48500	65.0	0.337
Bacteriophage λ	47000	63.0	0.356

Virus life-cycle

Ejection of DNA into crowded and viscous host cell

Decoding templates and manufacture of proteins

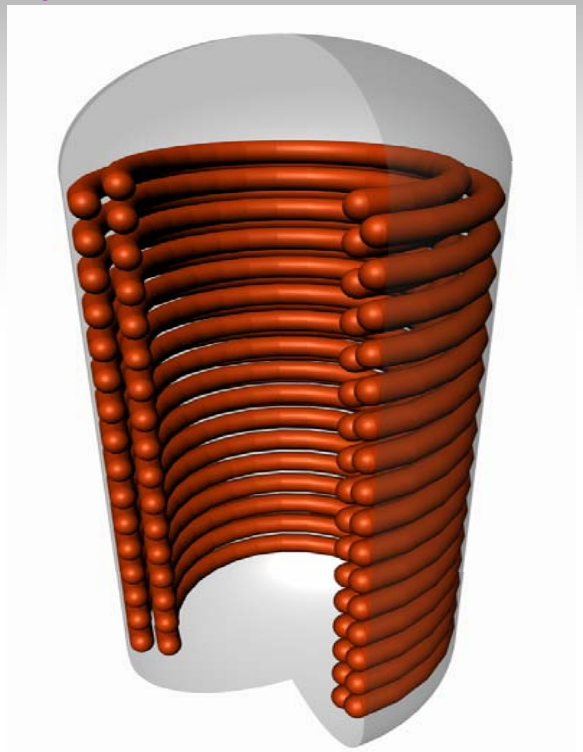


Portal motor pushes DNA in against large internal forces

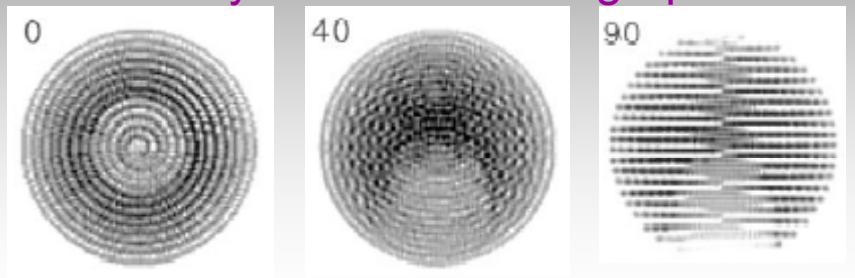
Self-assembly of proteins into well defined structures

DNA in circular hoops

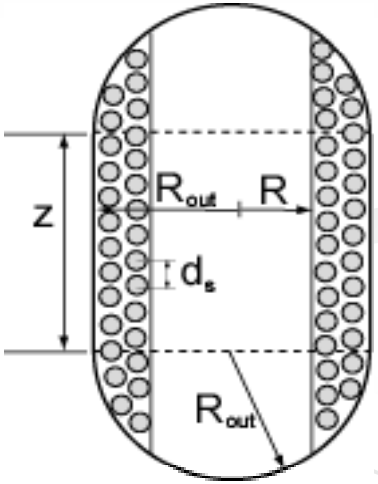
Cylinder with hemispherical caps



Cryo-electron micrograph



Cerritelli et al.



Cross-section of capsid

- DNA spools in from outside => inverse spool.
- Inter-axial spacing is 25-30

DNA is stiff as a rod