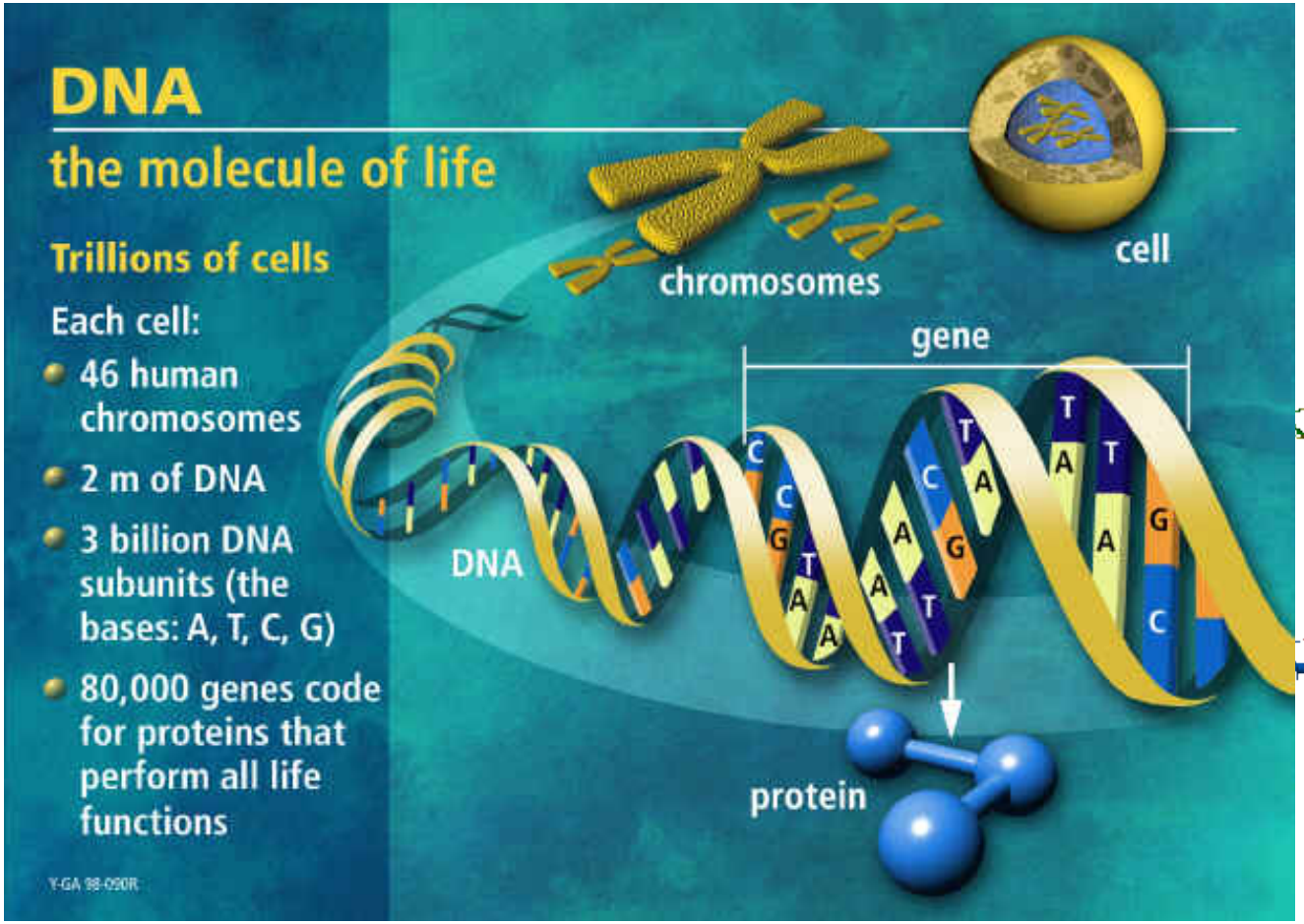
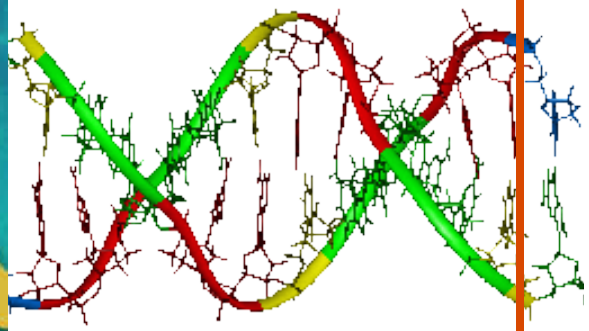
Multiscale Modeling of Structural and Electronic Properties of DNA

- Motivation: sequencing, epigenetics, replication and repair, ...
- Coarse-grained potential: model, simulations, validation
- Translocation dynamics through nanopores
- Electronic properties

EMRS – May 14-17, 2012, Strasbourg

Symposium J: DNA Directed Programmable Self-Assembly of Nanoparticles into Meta Materials for Energy and other Applications

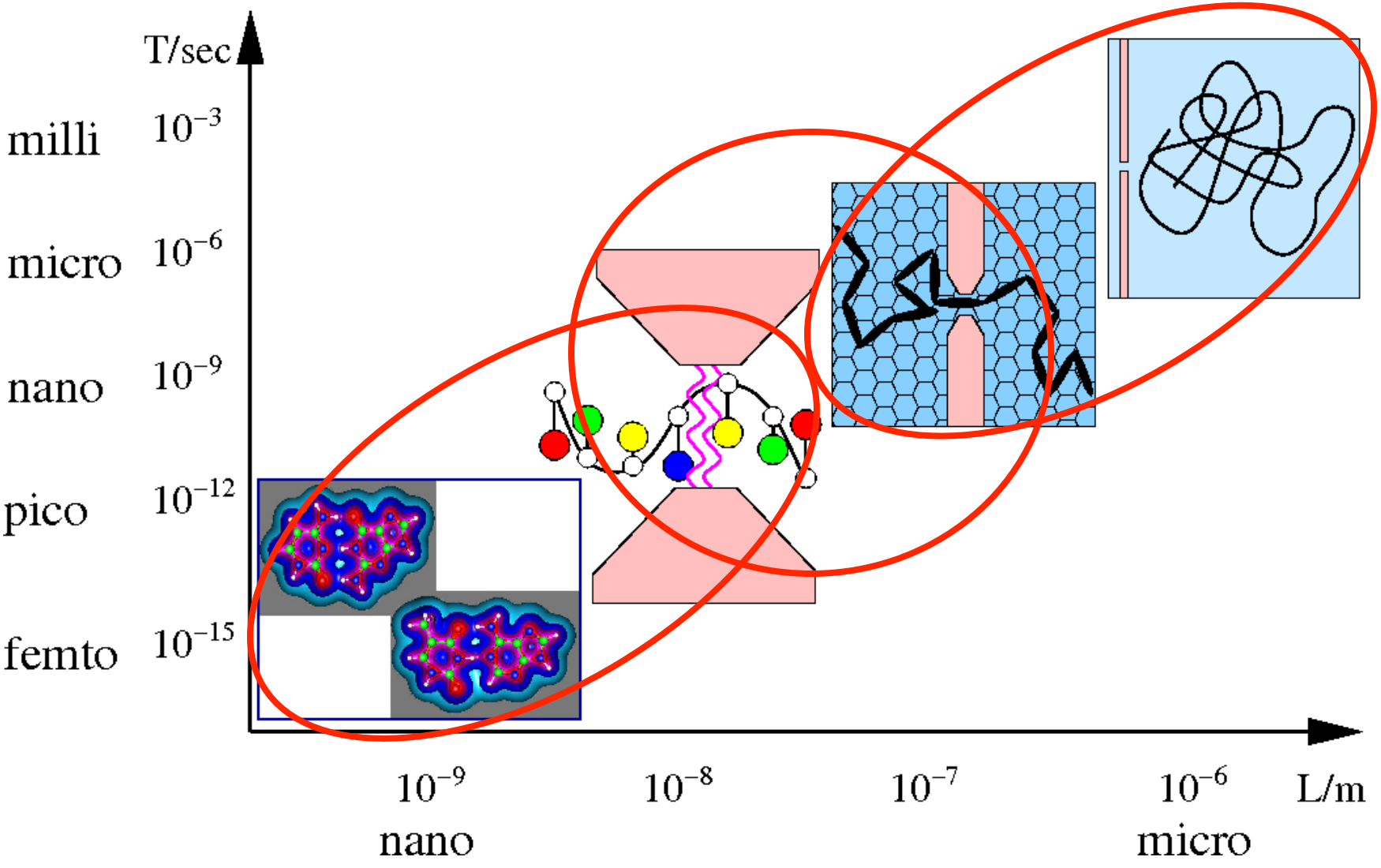


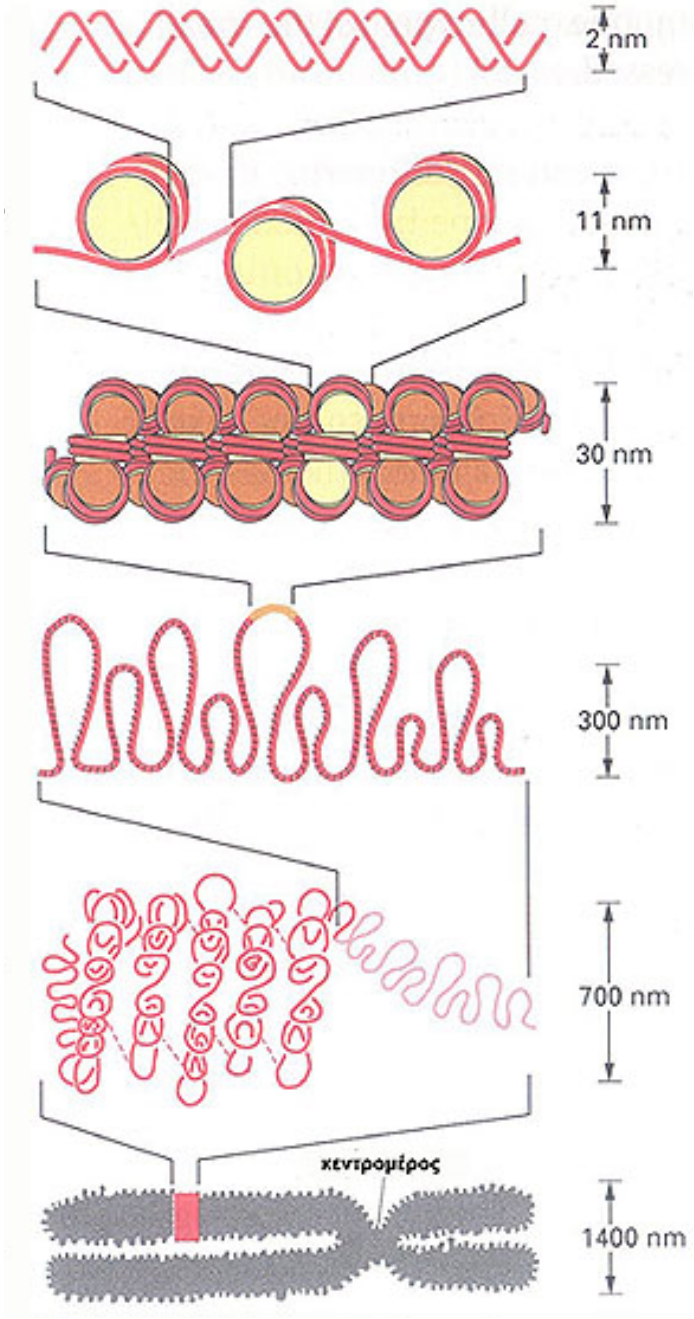


DNA sequencing: biochemical methods – cut pieces (ending at specific bases), measure by **gel electrophoresis**.

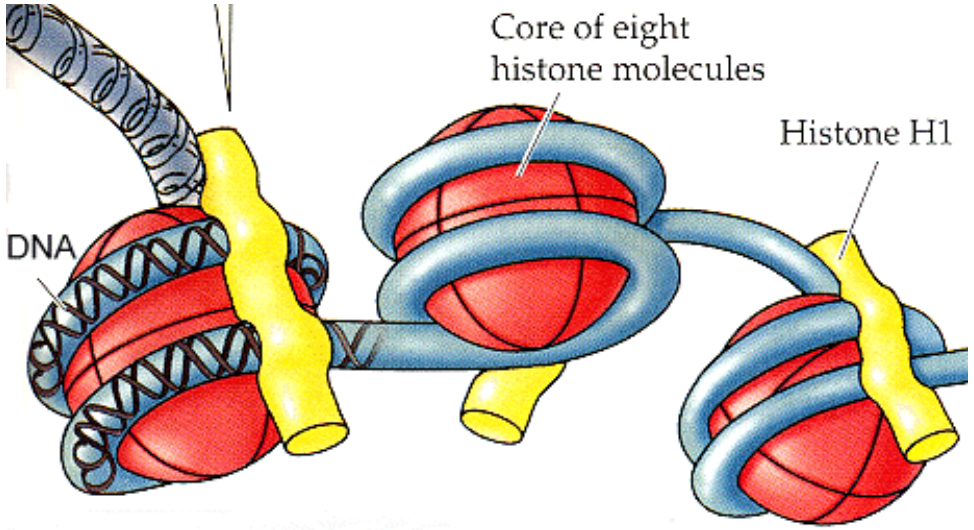
Instead, use **electronic signature** for sequencing – multiscale process

Multiple length/time scales: DNA electronic sequencing



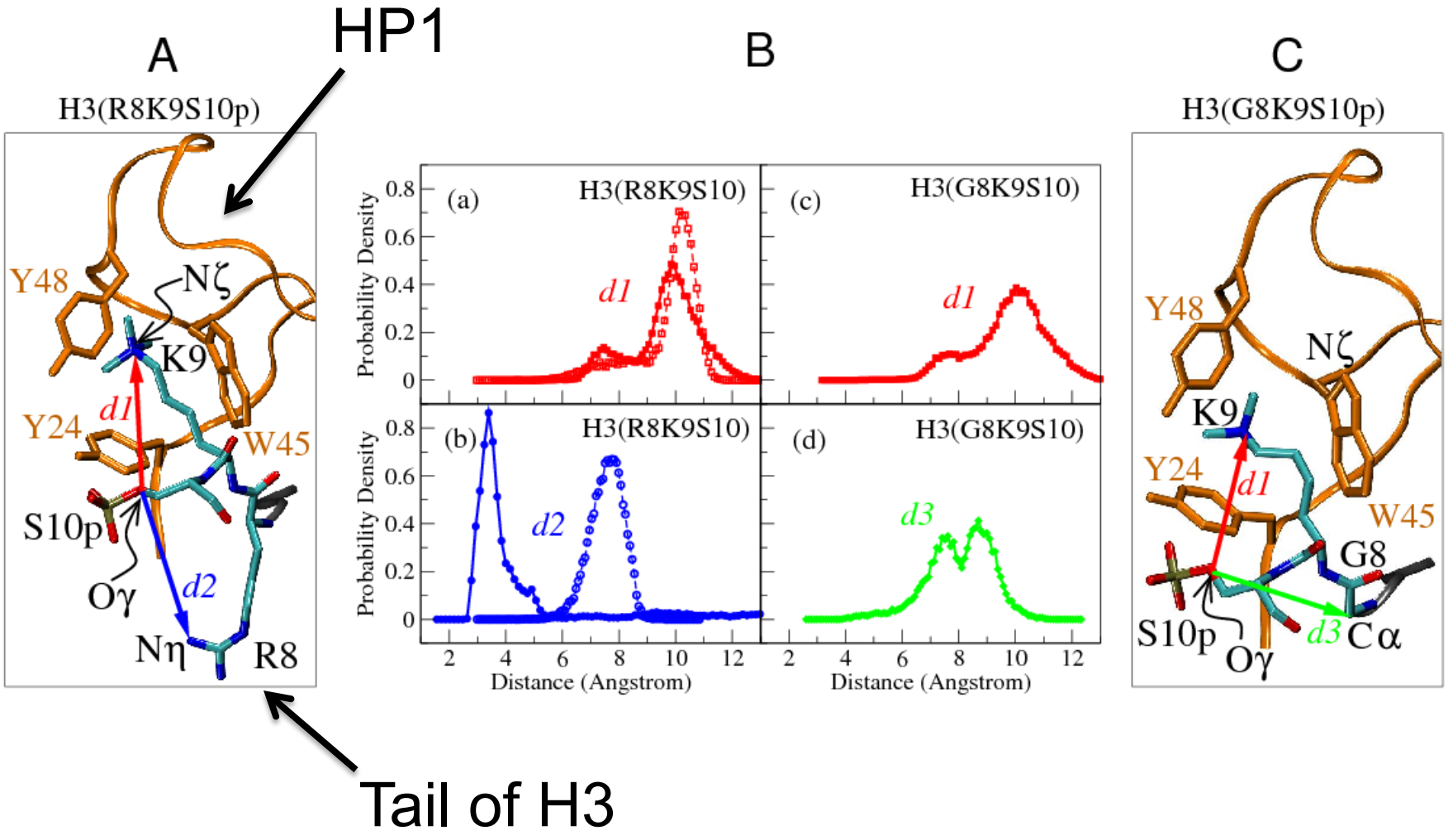


Structure of DNA on several scales: From NUCLEOSOME to CHROMOSOME



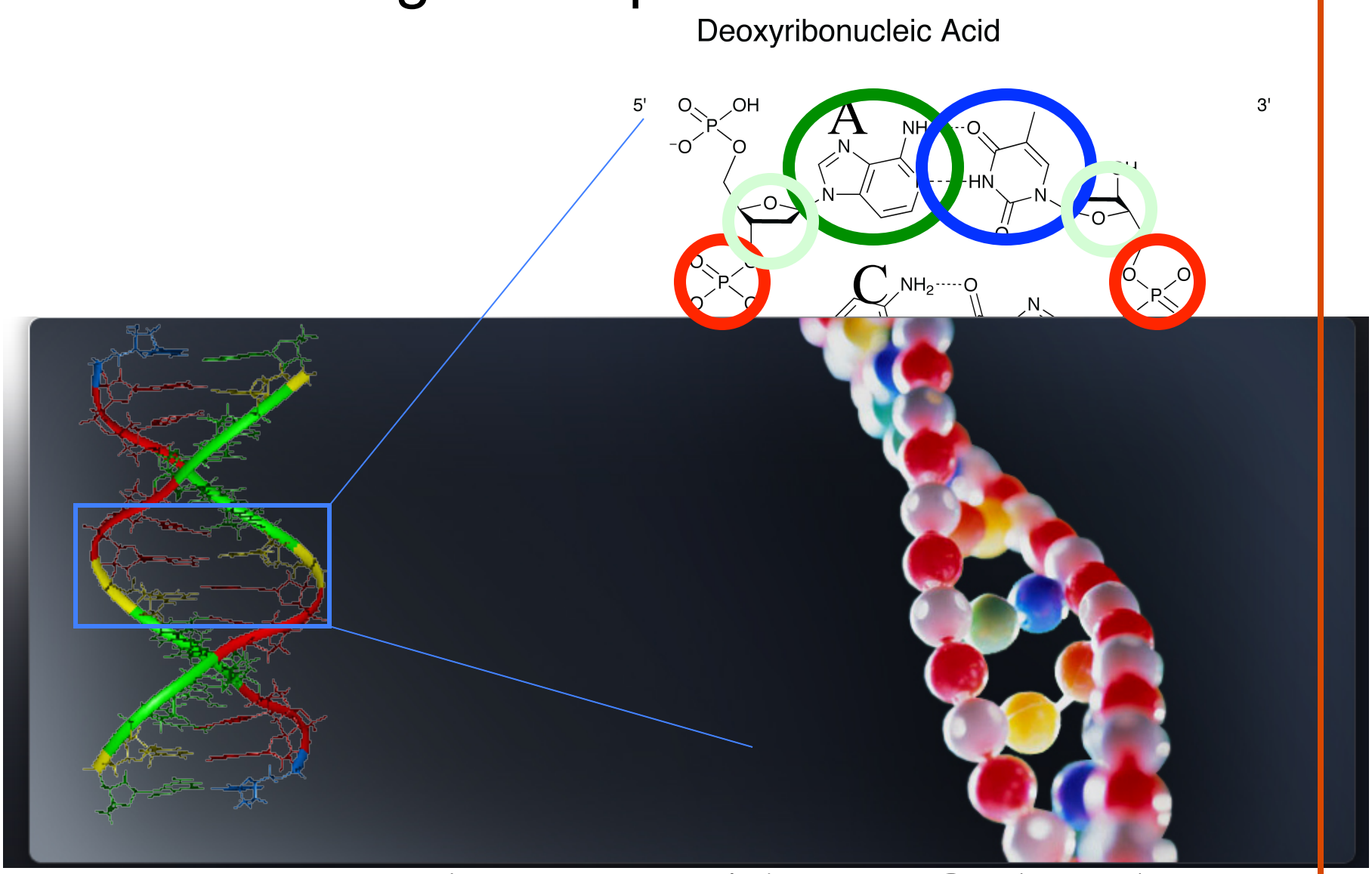
EPIGENETICS: passing genetic information **NOT** encoded in DNA base sequence

Papamokos *et al.*,
Biophysical J.
(April 2012)



Papamokos *et al.*, Biophysical J. (2012)

Coarse-grained potential fo DNA



W. Hsu, M. Fyta, G. Lakatos, S. Melchionna, EK (2012)

Goal: derive coarse-grained potential:
minimal (but sufficient) model;
all parameters from *ab-initio* calculations*.
Assumption: **separable** interactions

- Hydrogen bonding (distance; dihedral, flip angles)

- Stacking interactions (distance; twist angle)

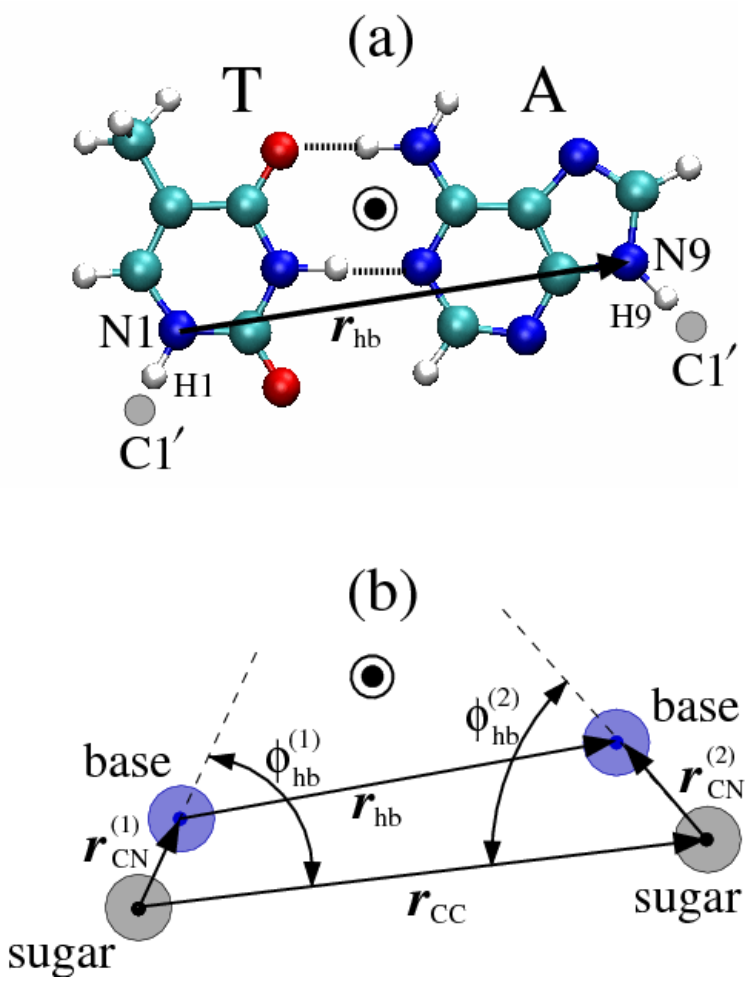
- Backbone interactions (distance; 3'-5' orientation)

- Electrostatic interactions

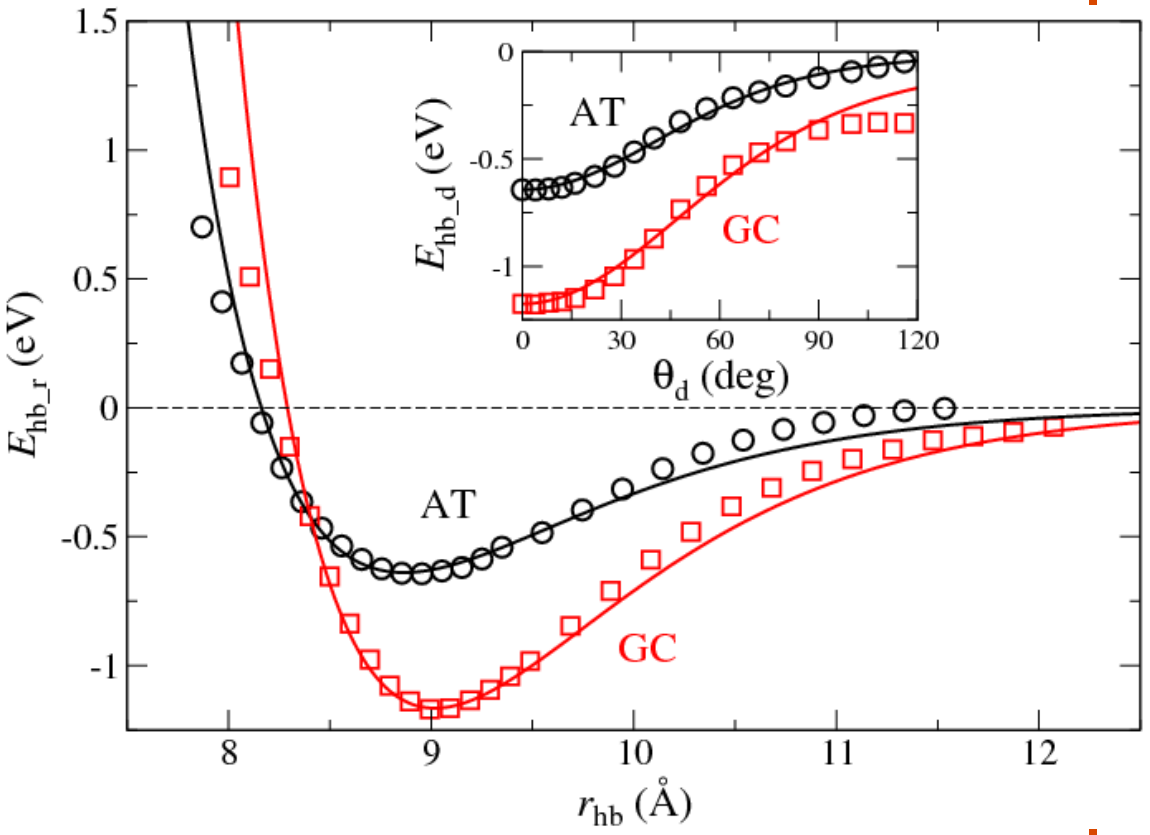
* To the extent possible

Data points: DFT calculations,
Lines: fits with simple curves

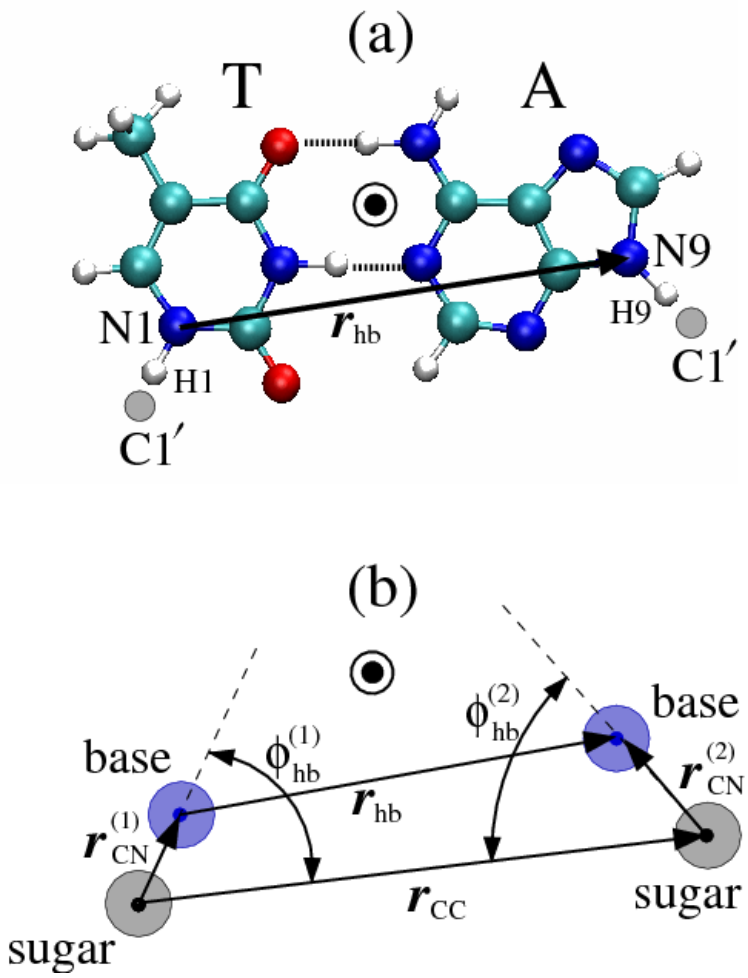
Coarse-grained potential – hydrogen bonding I



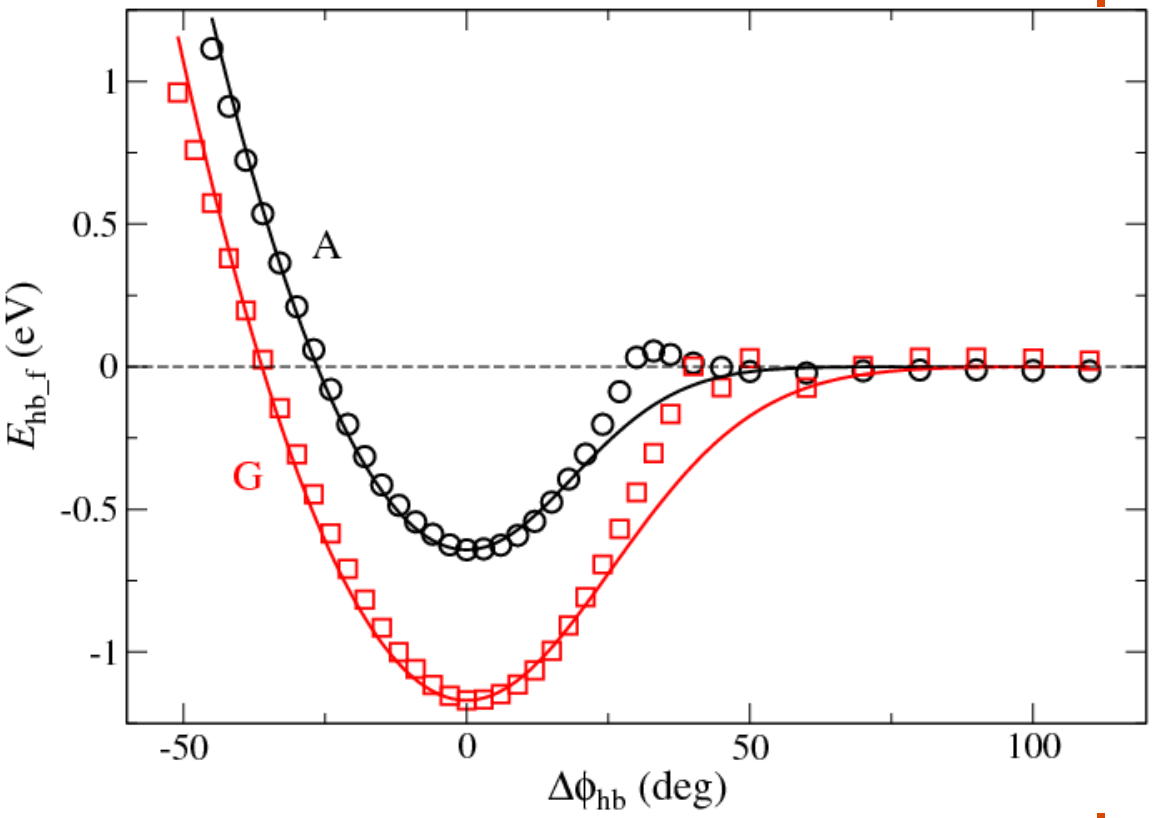
Distance between bases, dihedral angle



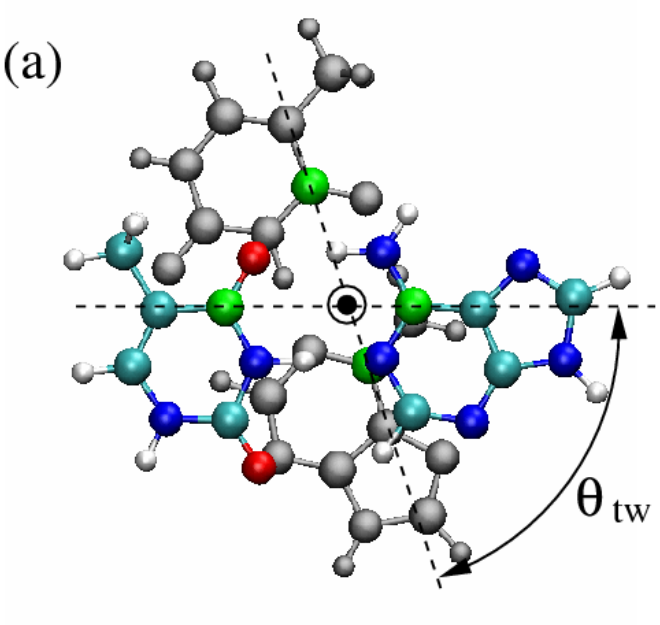
Coarse-grained potential – hydrogen bonding II

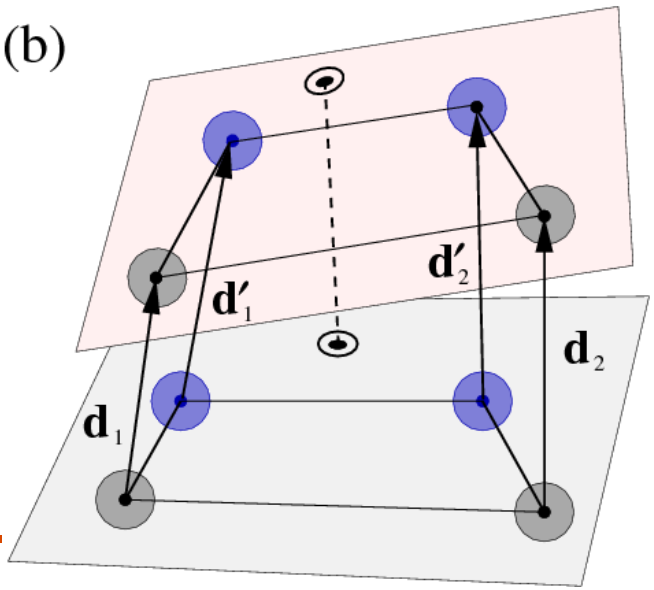


Flip angle

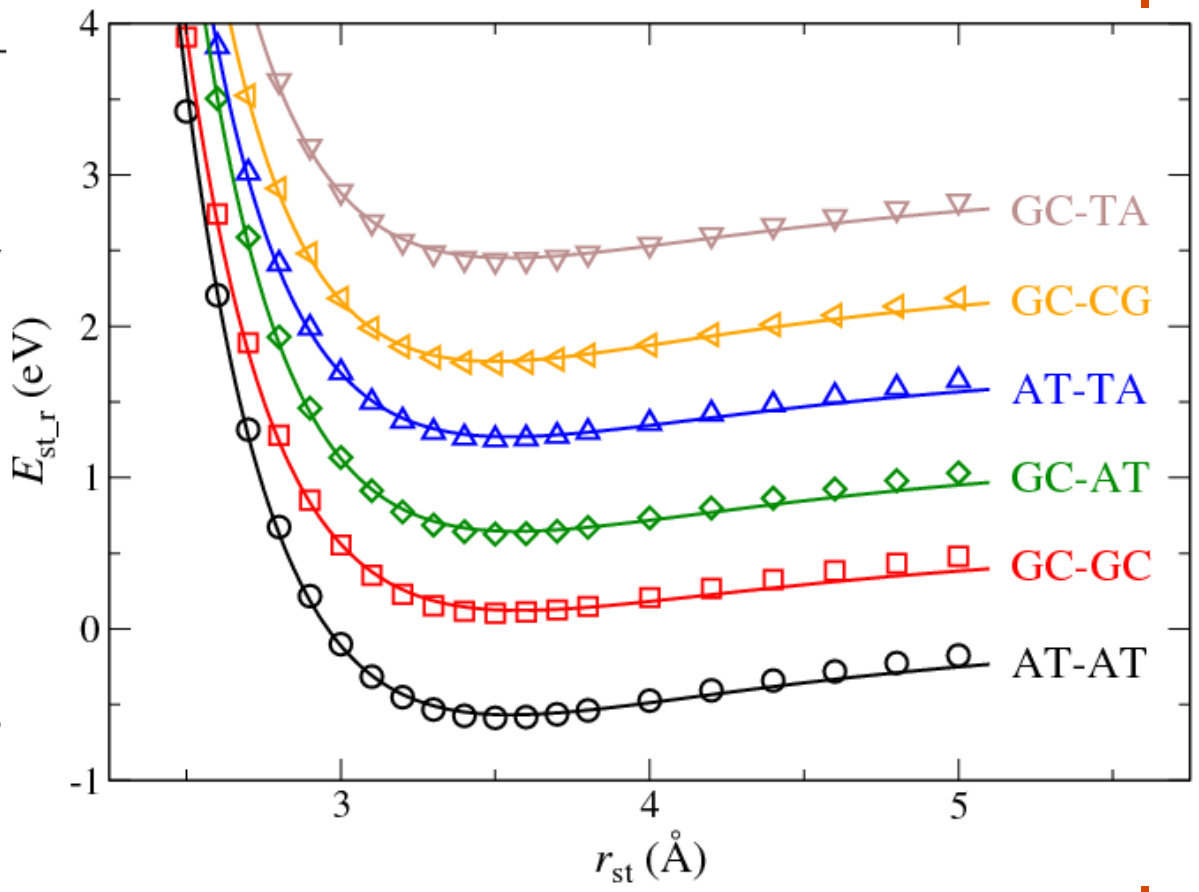


Coarse-grained potential – stacking interactions

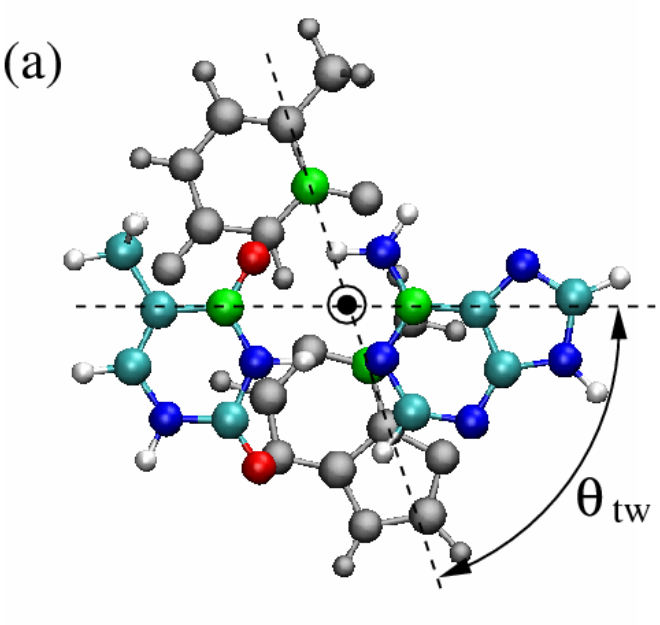


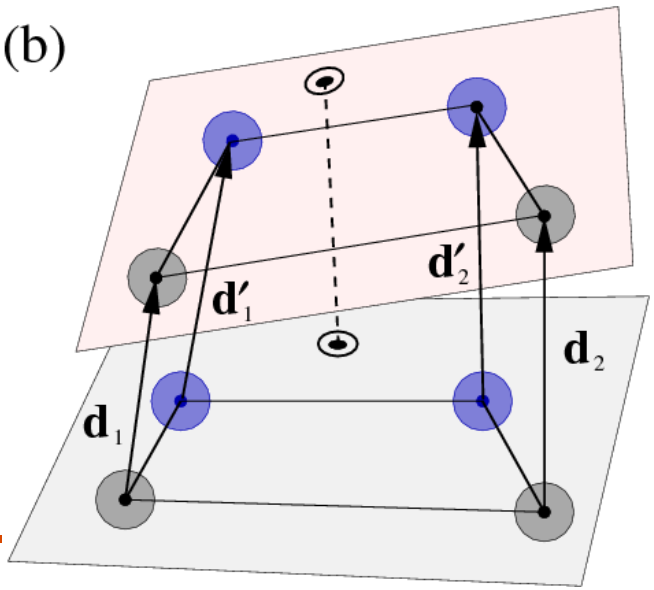


Distance between planes

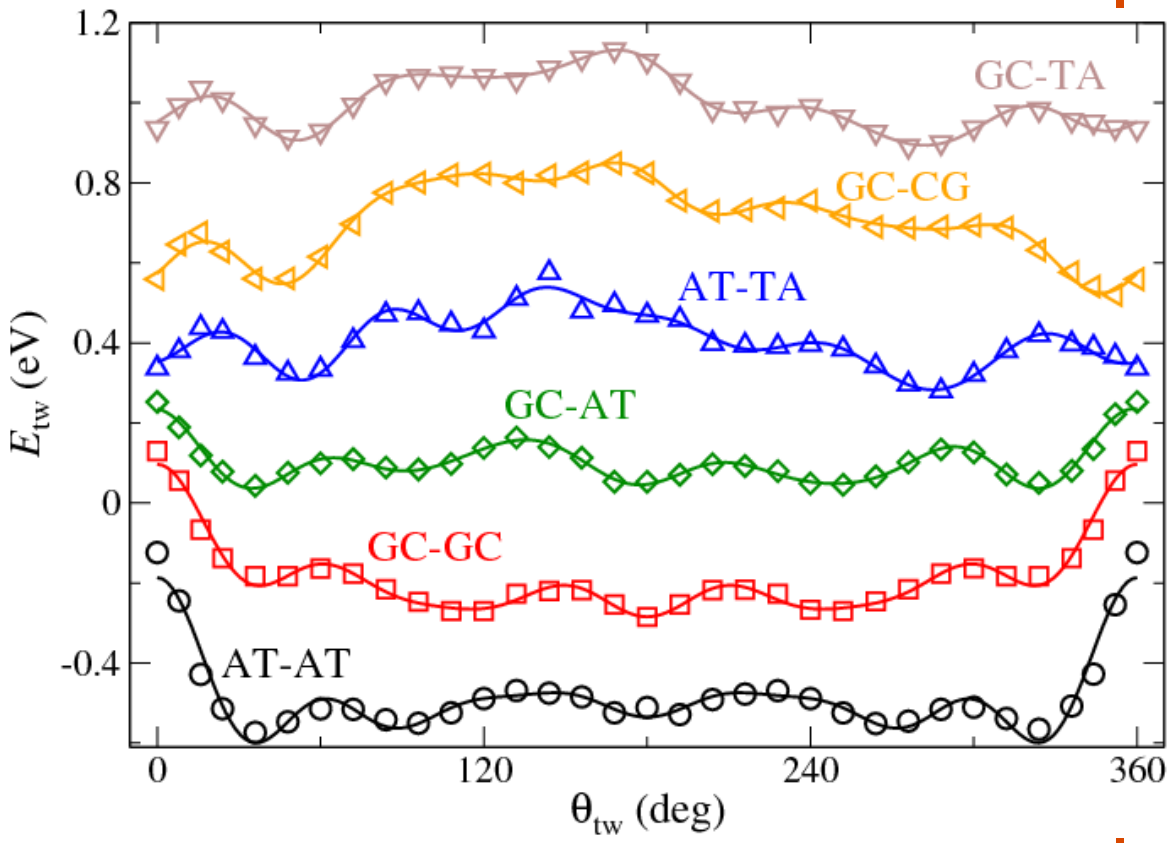


Coarse-grained potential – stacking interactions

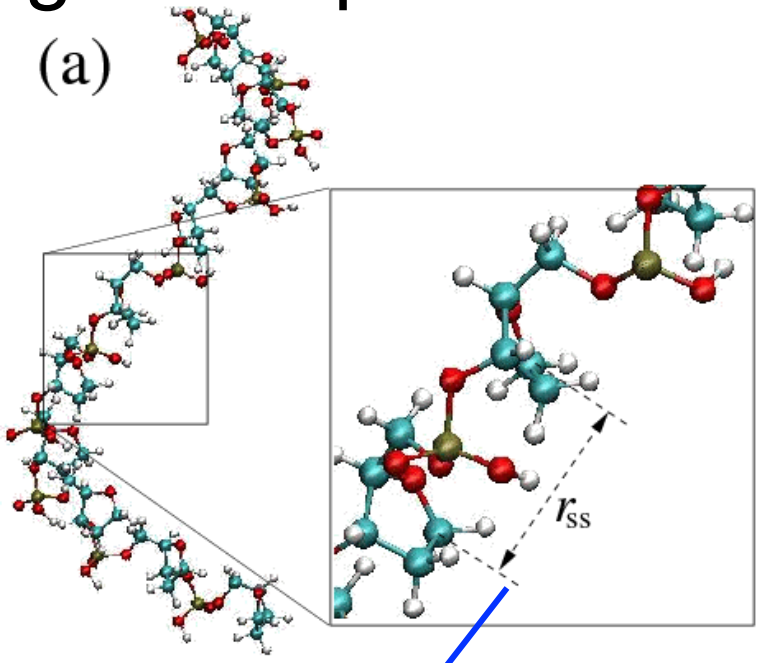


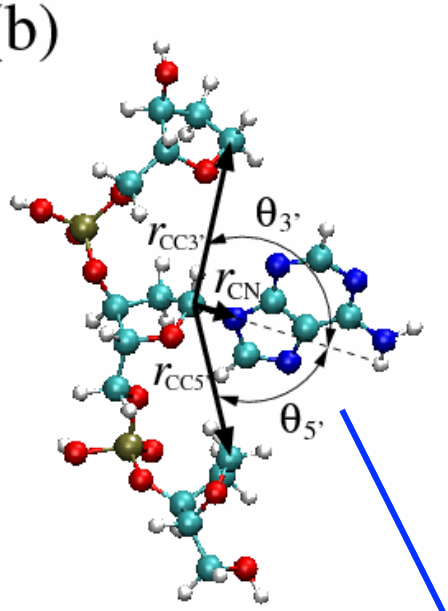


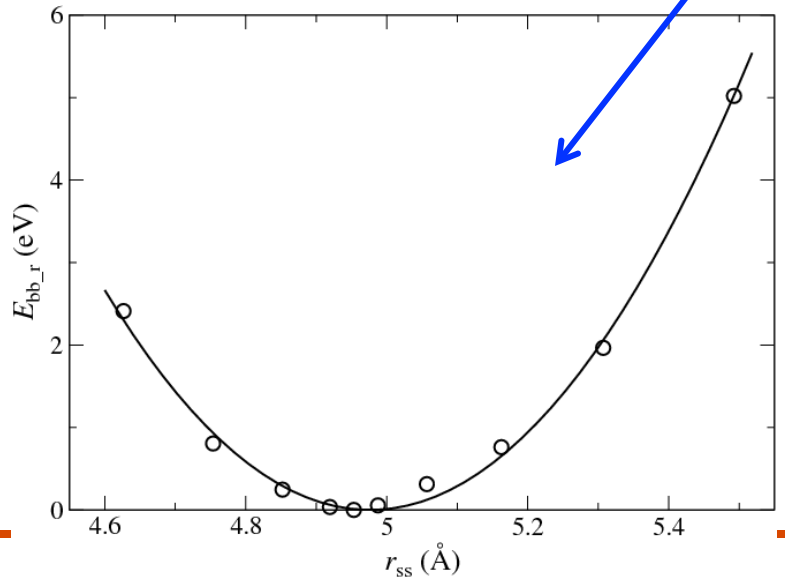
Twist angle between pairs

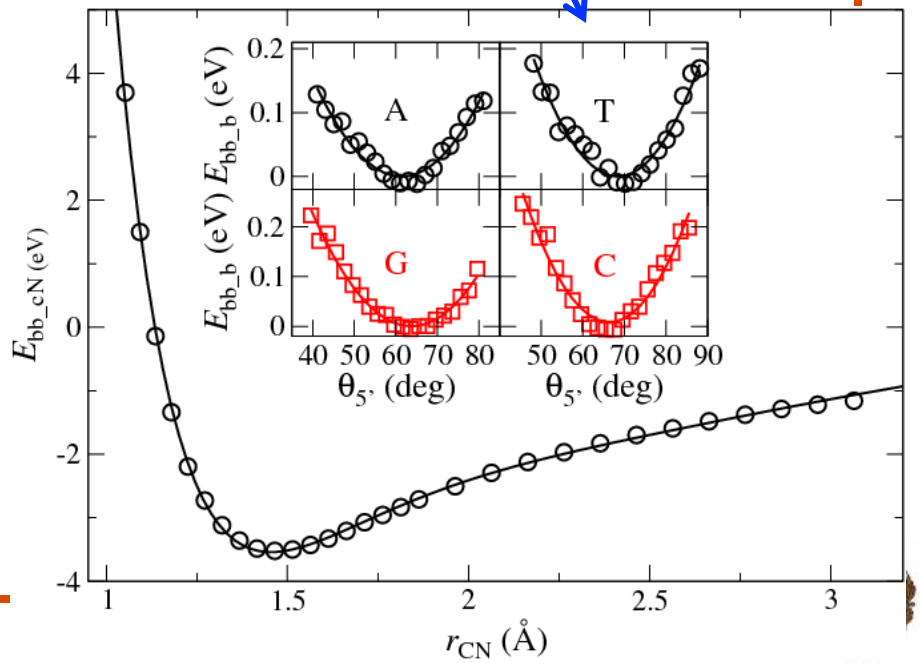


Coarse-grained potential – backbone interactions



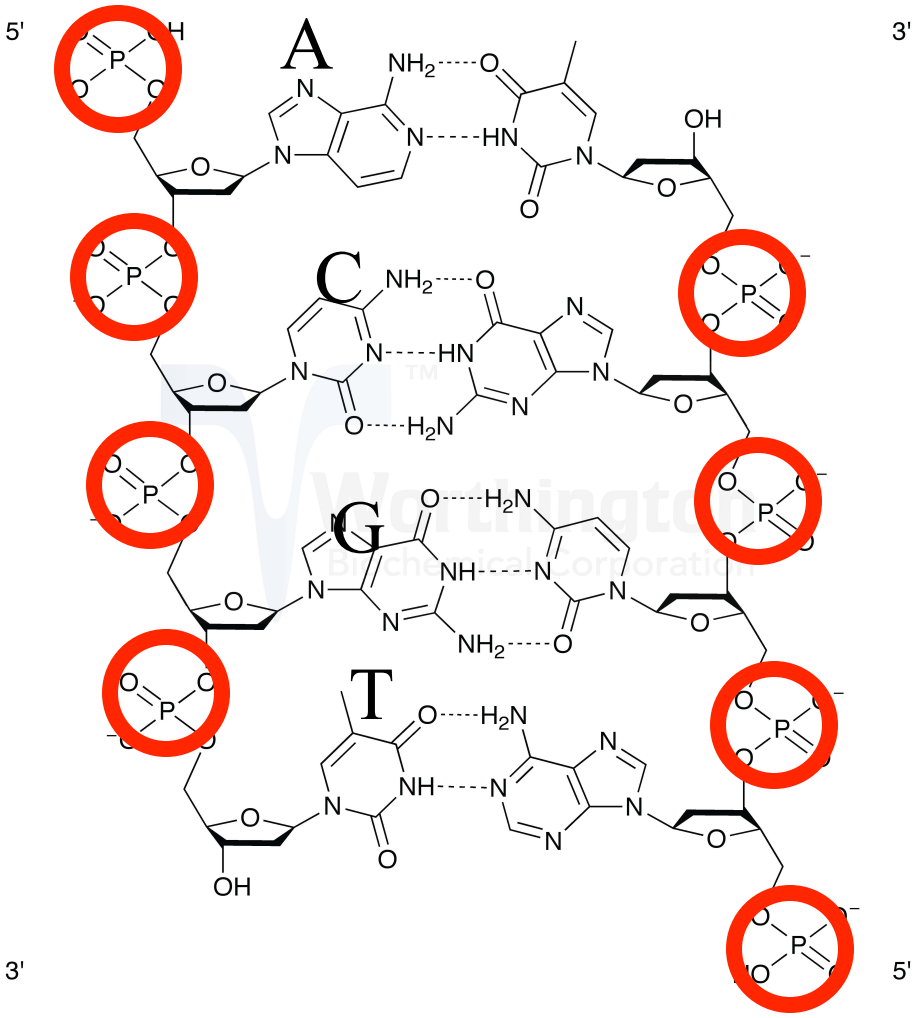






Coarse-grained potential – electrostatic interactions

Deoxyribonucleic Acid



5'-Adenine-Cytosine-Guanine-Thymine-3'

$$E = \frac{1}{4\pi\varepsilon_0\varepsilon(r)}\frac{e^2}{r}$$

$$\varepsilon(r) = \varepsilon_{\text{in}} \qquad r < r_0$$

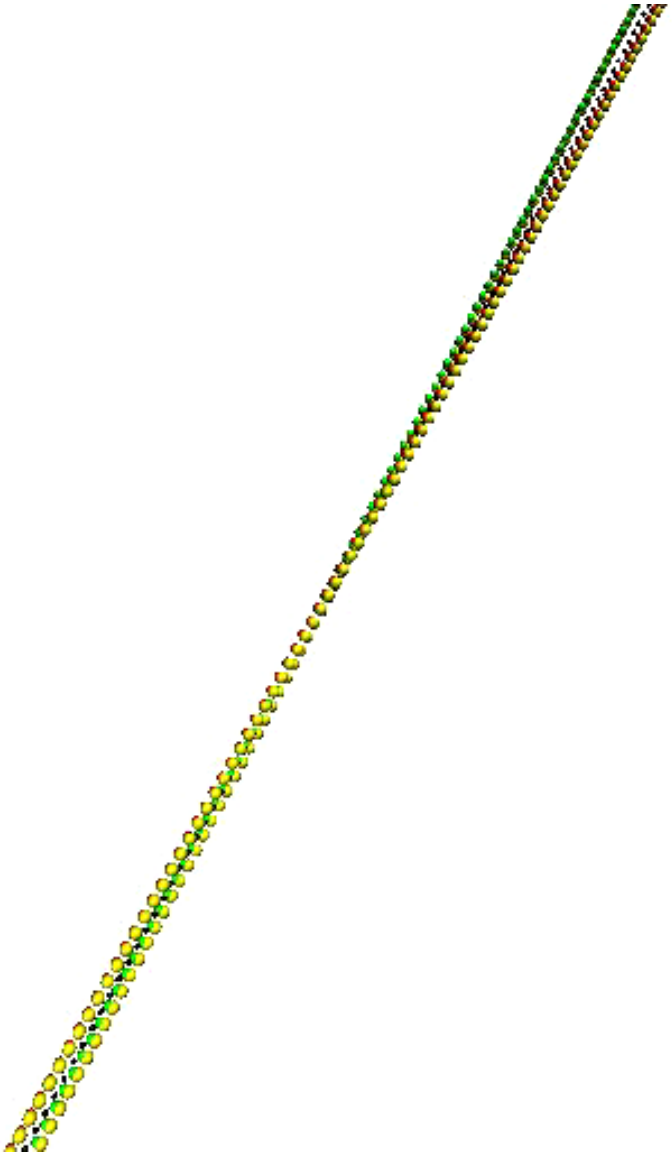
$$\varepsilon(r) = \varepsilon_{\text{in}} e^{\alpha(r-r_0)} \qquad r_0 < r < r_1$$

$$\varepsilon(r) = \varepsilon_{\infty} e^{-\kappa r} \qquad r > r_1$$

$$\kappa^{-1} = \sqrt{\frac{\varepsilon_0\varepsilon_{\infty}k_B T}{2N_A e^2 I}}$$

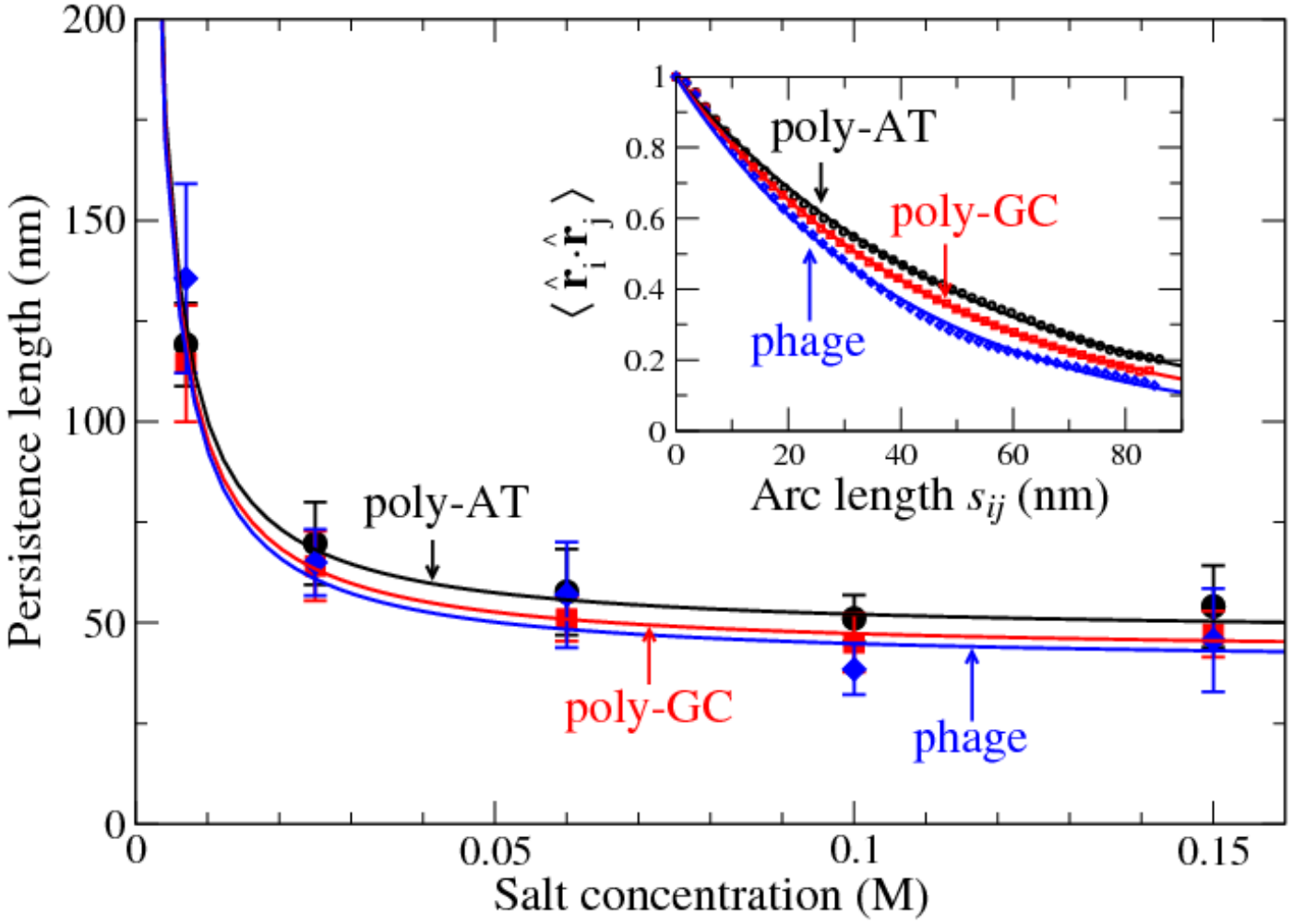
Three parameters !

Coarse-grained potential – validation



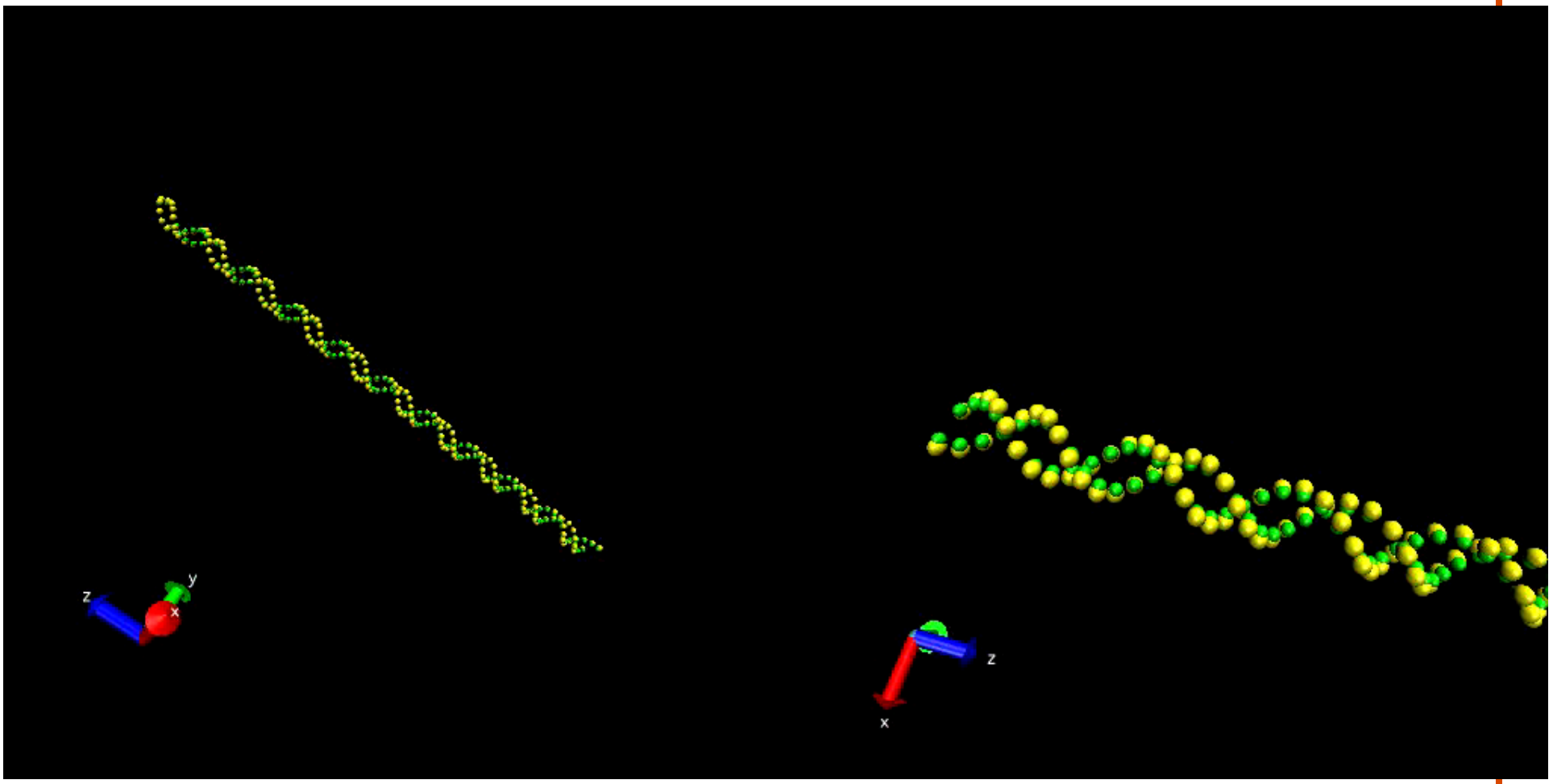
Two parallel strands
coil to form double-helix

Coarse-grained potential – validation

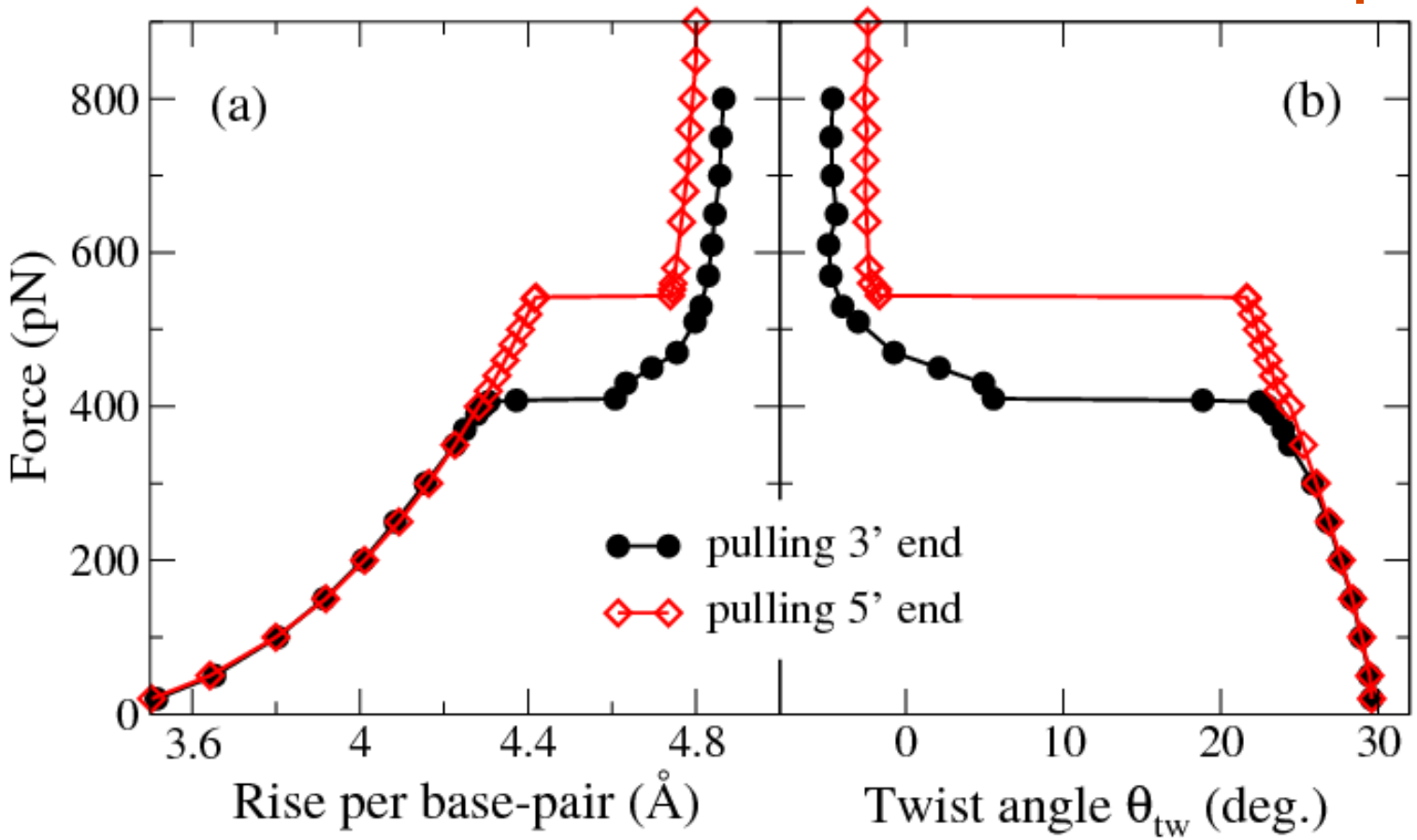


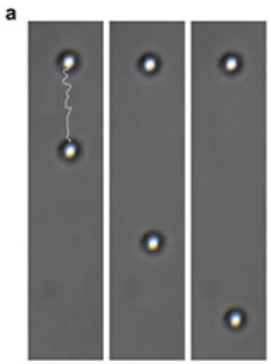
Persistence length (~50 nm)

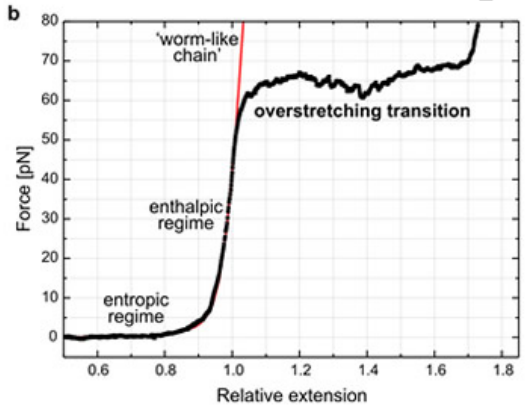
Force-extension simulations



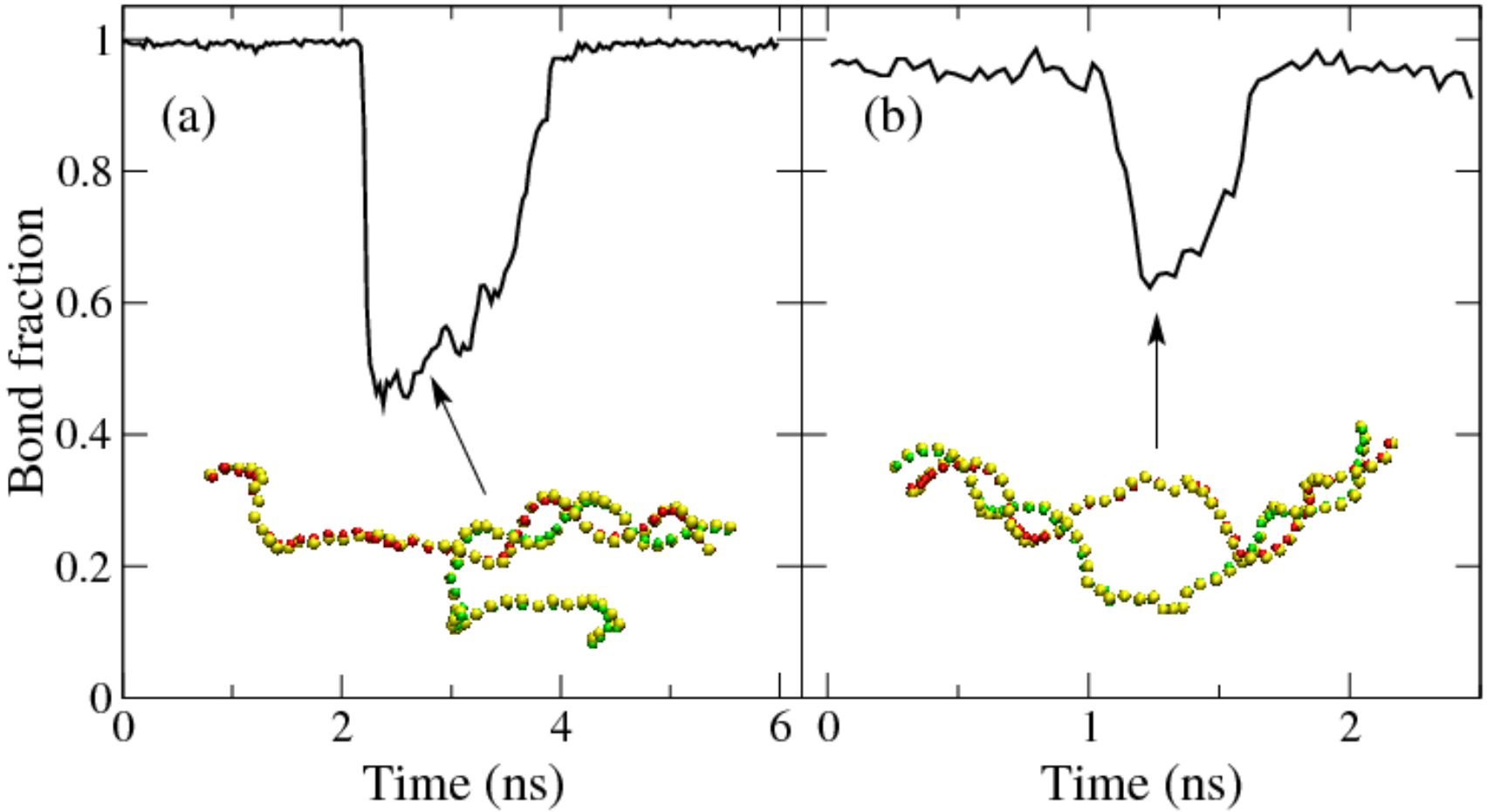
Force-extension simulations







Melting simulations



Students: Chia Wei Hsu
Ryan Barnett
Ari Turner

Postdocs: Maria Fyta
Greg Lakatos
Simone Meclhionna
Paul Maragakis
Gang Lu
Sheng Meng

Visitors: Sauro Succi
Costas Papaloukas
George Papamokos