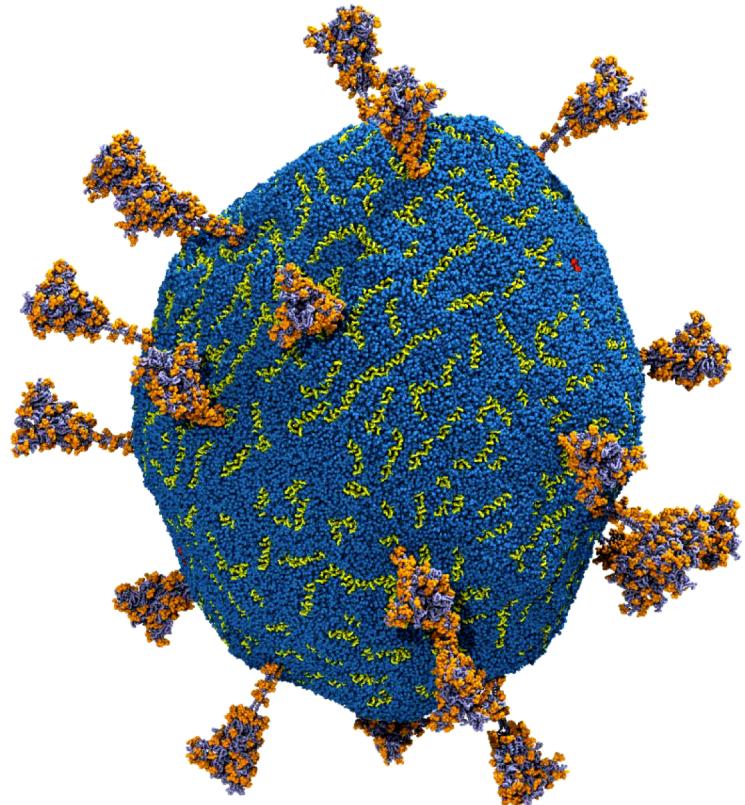
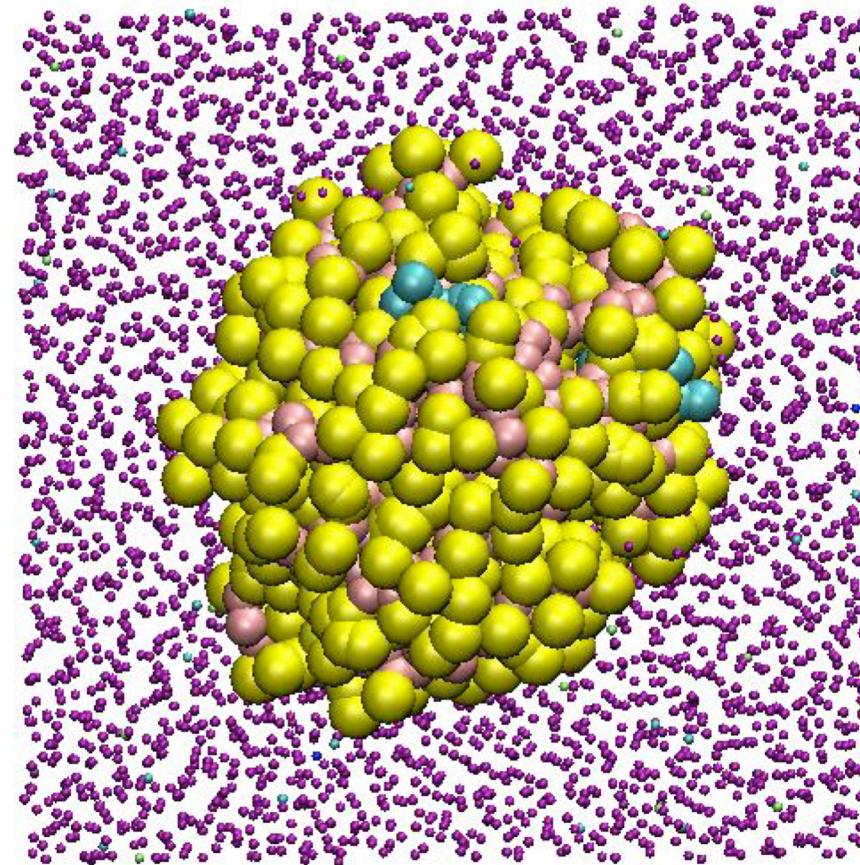


Molecular Dynamics Simulations, A Quick Introduction

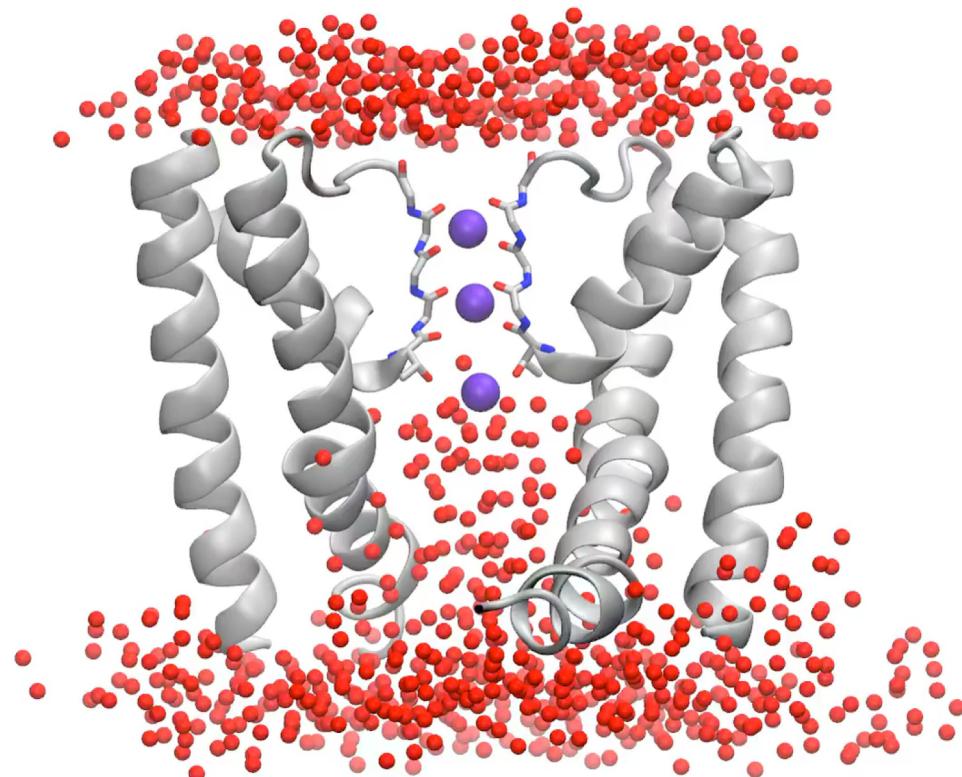
**Weria Pezeshkian,
Molecular Biophysics,
Niles Bohr International Academy**
weria.pezeshkian@nbi.ku.dk



Molecular dynamics simulation is a **numerical** approach to solve a **classical** many-body problem to obtain the physical movements of **atoms** and **molecules**.

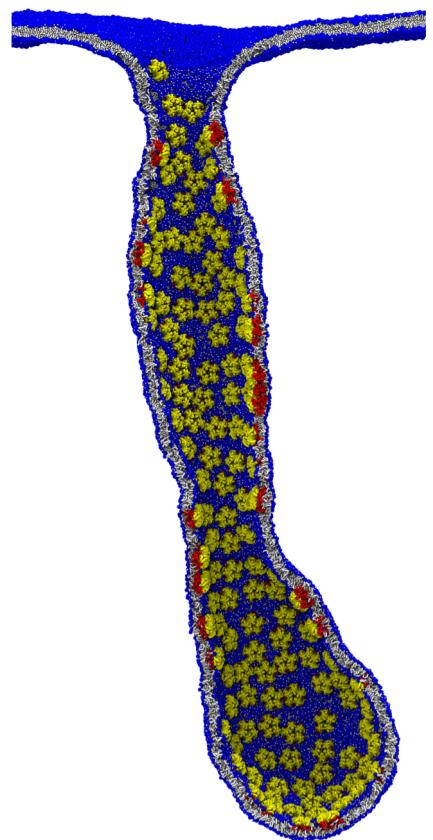
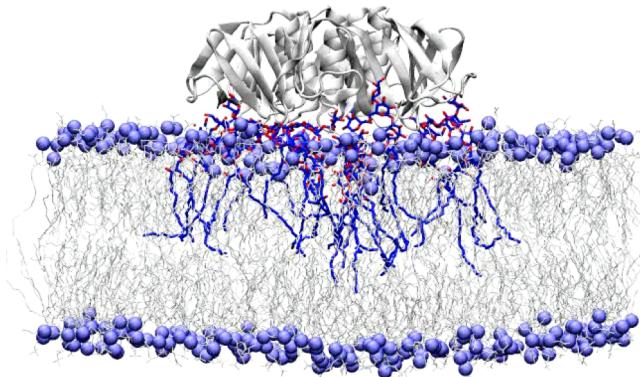
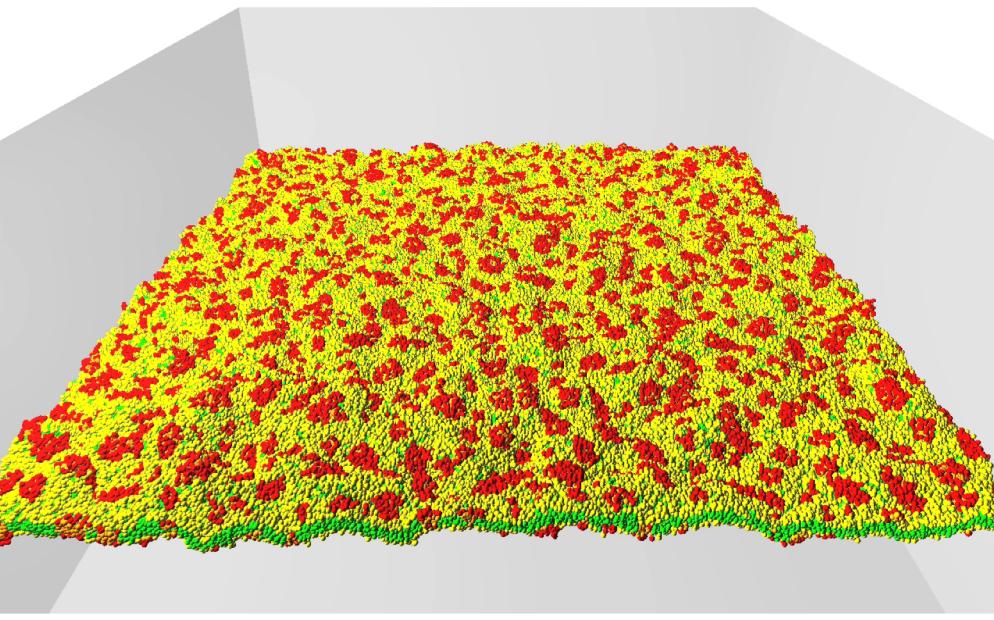
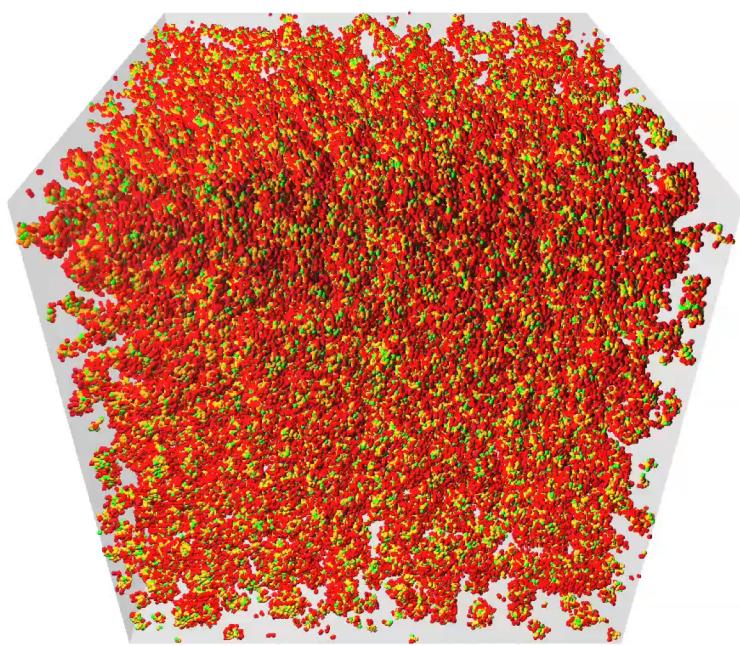


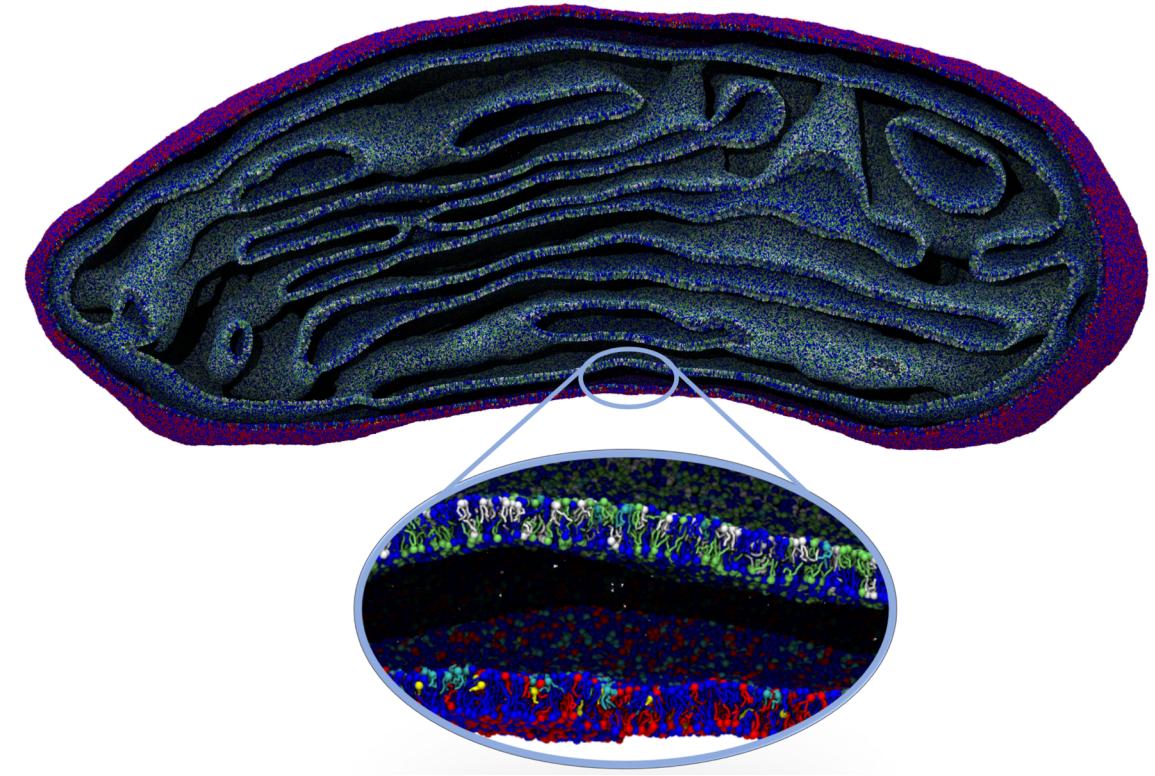
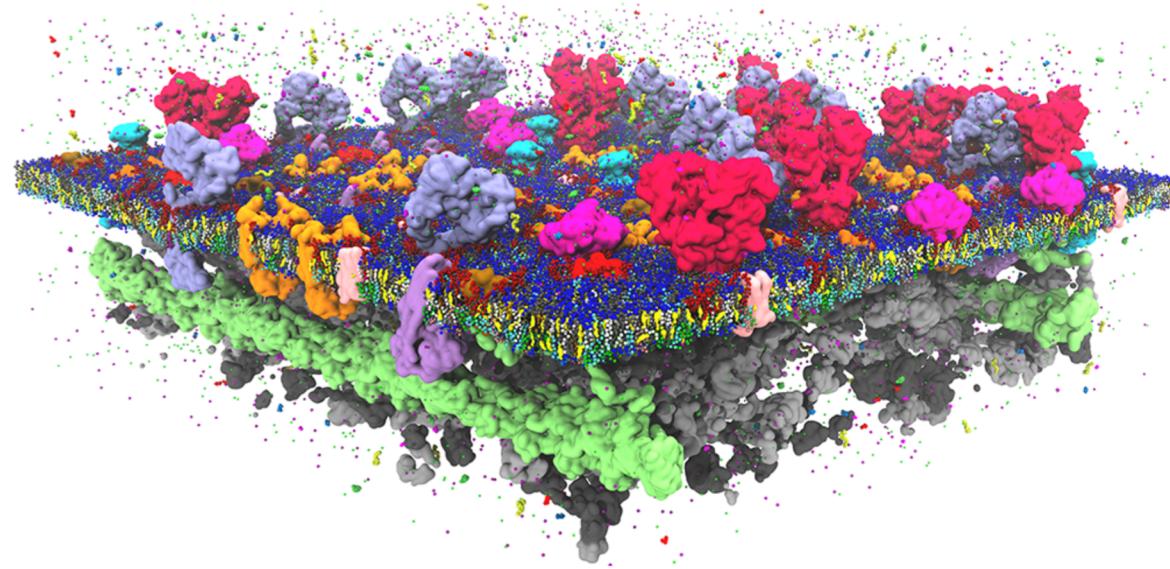
Computational microscopy!



Kopec et al., Nature Chemistry 2018

A few examples

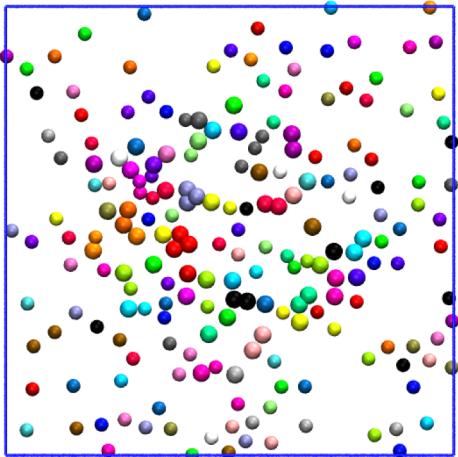




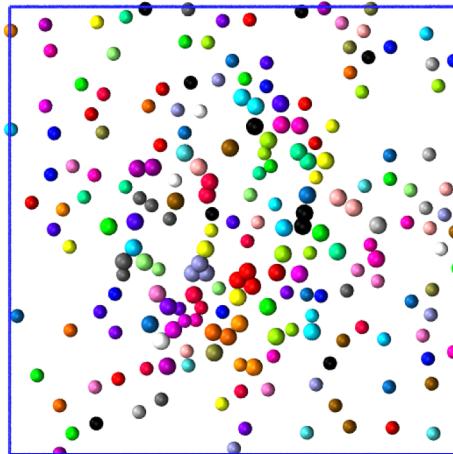
Pezeshkian, et al, *Nat. Commune.* **11**, 2296 (2020)
Marrink, et al, *Chemical Reviews* **119**, 6184 (2018)

Basic Algorithm

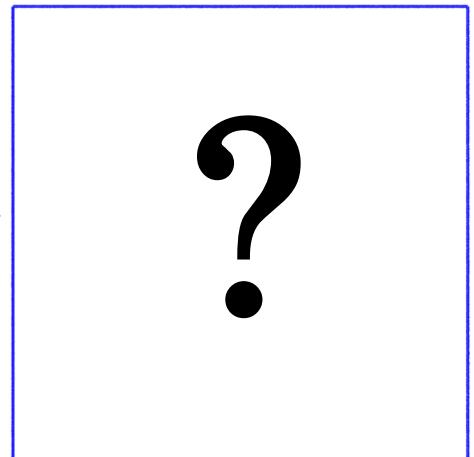
$t = t_1$



$t = t_1 + \Delta t$



$t = t_2$



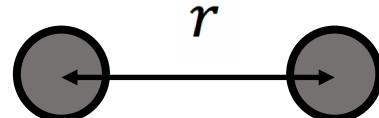
leap-frog integrator

$$\mathbf{v}_i \left[t + \frac{1}{2} \Delta t \right] = \mathbf{v}_i \left[t - \frac{1}{2} \Delta t \right] + \frac{\Delta t}{m} \mathbf{F}_i[t]$$

$$\mathbf{X}_i[t + \Delta t] = \mathbf{X}_i[t] + \Delta t \mathbf{v}_i \left[t + \frac{1}{2} \Delta t \right]$$

Potentials and Force Field

Non-Bonded



Lennard-Jones

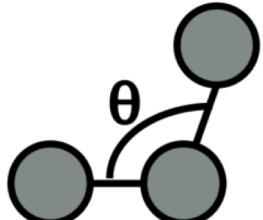
$$V_{LJ}(r) = \varepsilon_{ij} \left[\left(\frac{\sigma_{ij}}{r} \right)^{12} - \left(\frac{\sigma_{ij}}{r} \right)^6 \right]$$

Bonded

$$V_{bond}(r) = \frac{k_b}{2} (r - l_0)^2$$

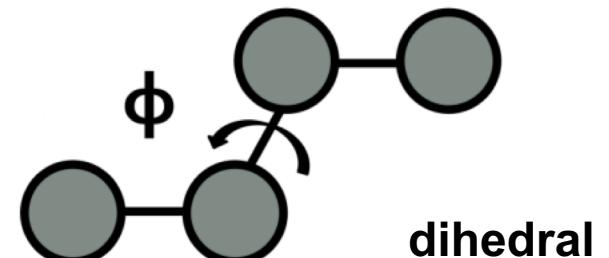


$$V_{angle}(\theta) = \frac{k_a}{2} (\theta - \theta_0)^2$$



Electrostatic

$$V_E(r) = k \frac{q_1 q_2}{r}$$



$$V(\Phi) = \sum_{n=0}^N A_n \cos[n\Phi - \delta]$$

How many computations do we need?

System size = 0.5 million

Time = 1 microsecond

Time steps = 1 femtosecond

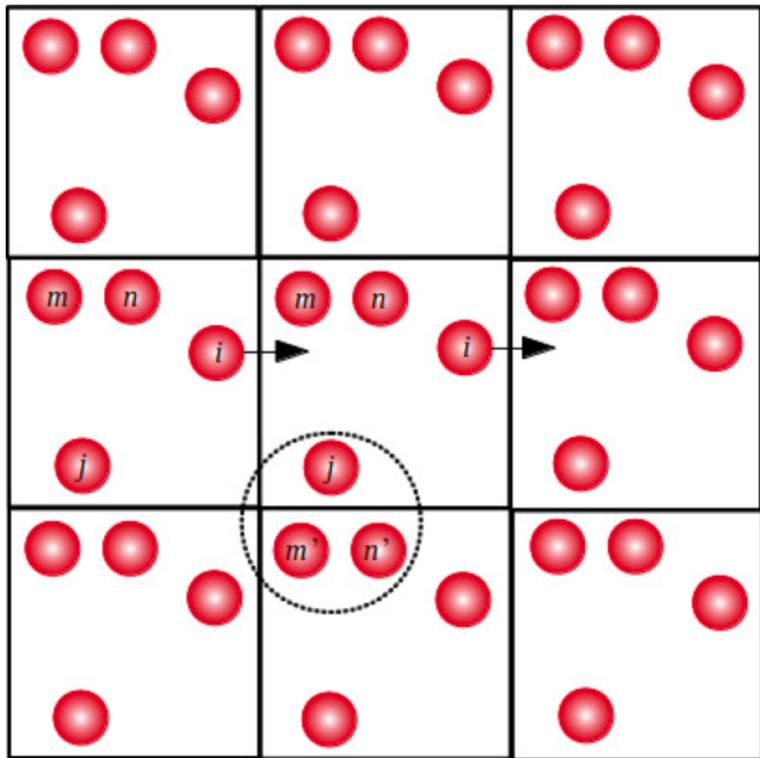
$$V_{LJ}(r) = \varepsilon_{ij} \left[\left(\frac{\sigma_{ij}}{r} \right)^{12} - \left(\frac{\sigma_{ij}}{r} \right)^6 \right]$$

number of computations $\sim 10^{20} = 10^{10}$ billions

$$V_E(r) = k \frac{q_1 q_2}{r}$$

Particle mesh Ewald (PME): $N \log N$

Periodic Boundary Conditions

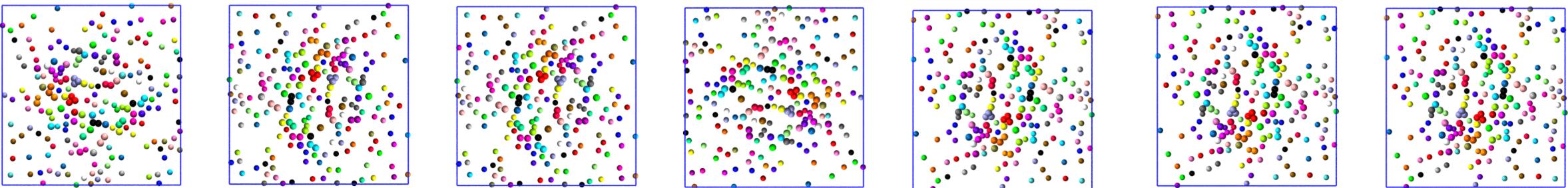


Minimum-image convention

Ergodic hypothesis

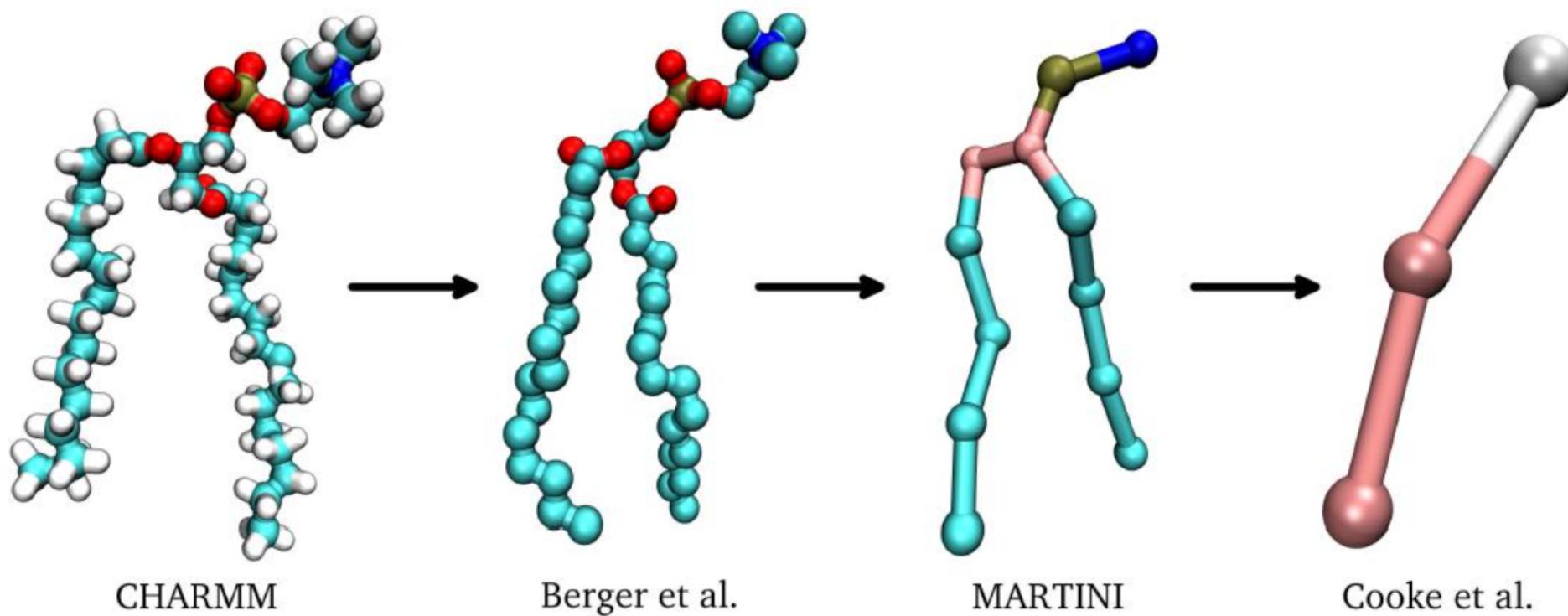
Ensemble average equals time average

$$\langle A \rangle = \frac{\sum_i A_i e^{-\beta E_i}}{\sum_i e^{-\beta E_i}}$$

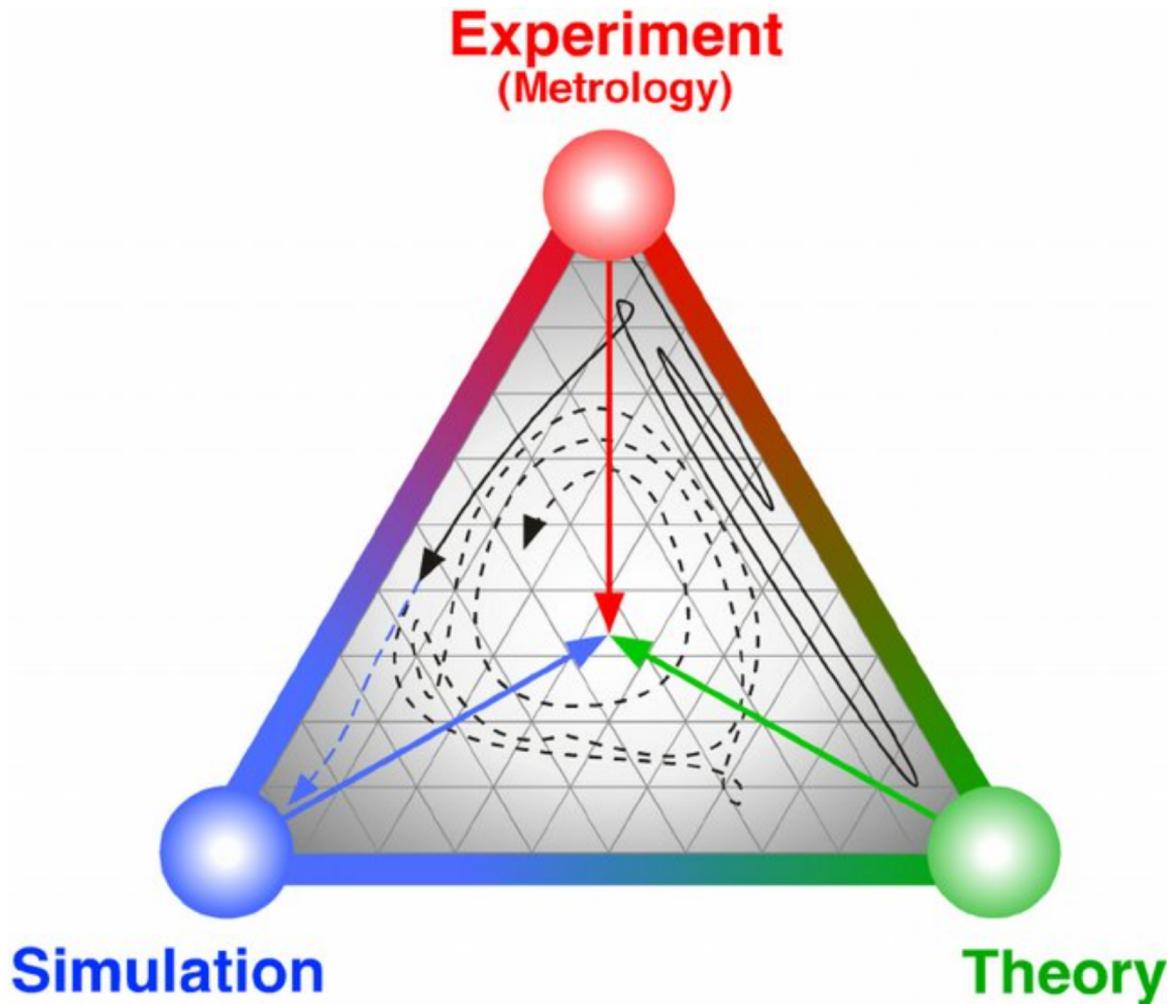


$$\langle A \rangle = \frac{1}{N} \sum_t A_t$$

Coarse-grained models



Theory or experiment?



Modern Molecular Dynamics Packages and Force fields

Software

**GROMACS
NMAD
LAMMPS
AMBER
CHARMM
OpenMM**

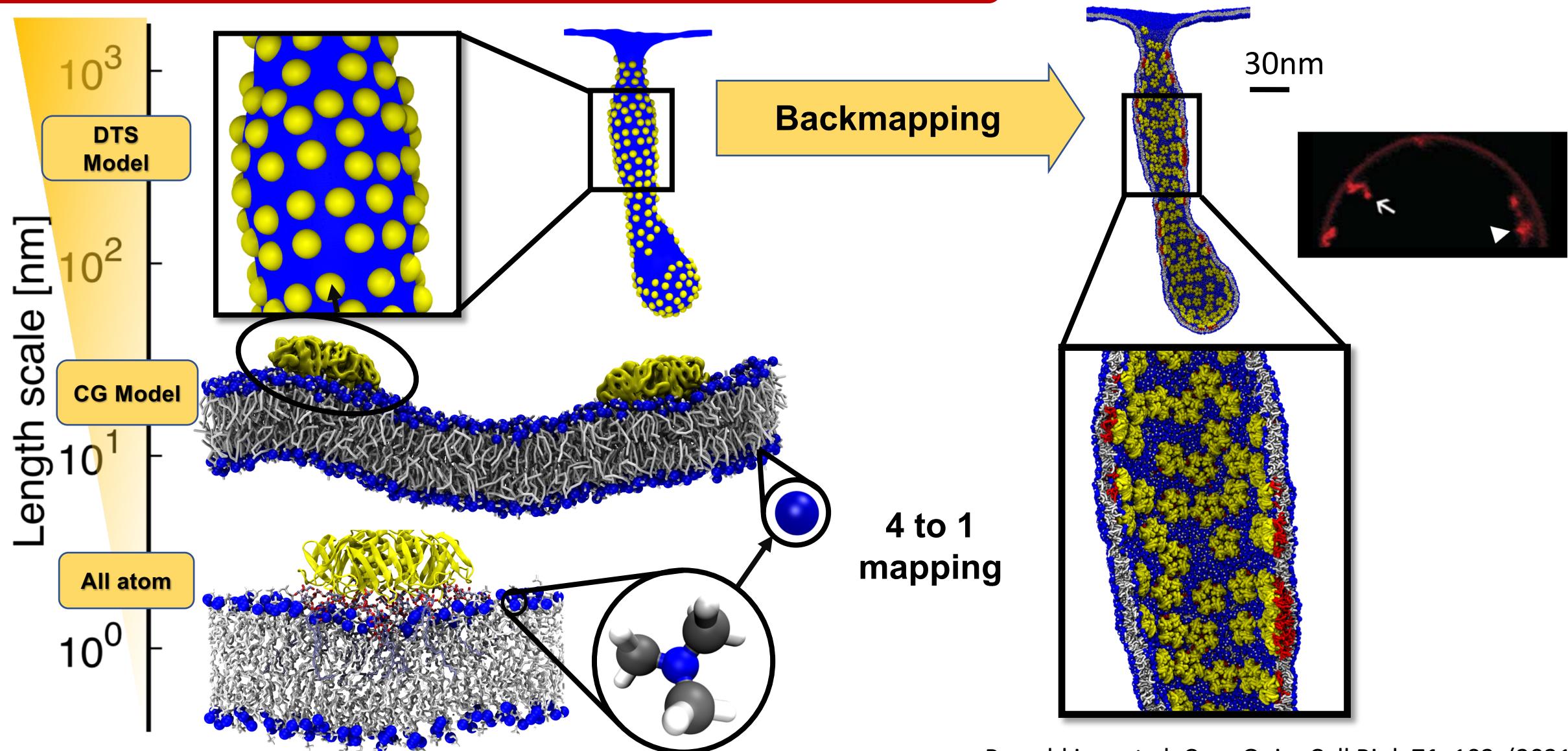
All atoms Force field

**CHARMM
AMBER
GROMOS
OPLS**

Coarse-Grained Force field

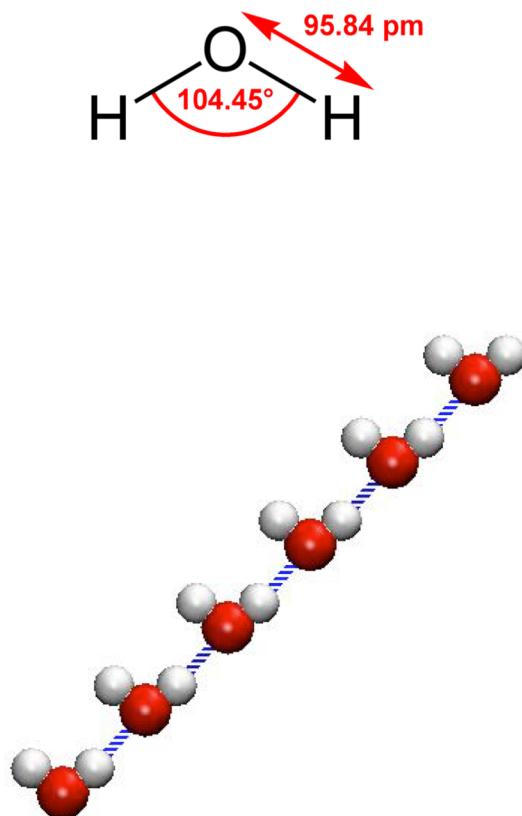
**MARTINI
SIRAH**

Multiscale simulation at a glance



Water Model, TIP3P

Hydrogen bond dynamics



Hydrophobic effect

