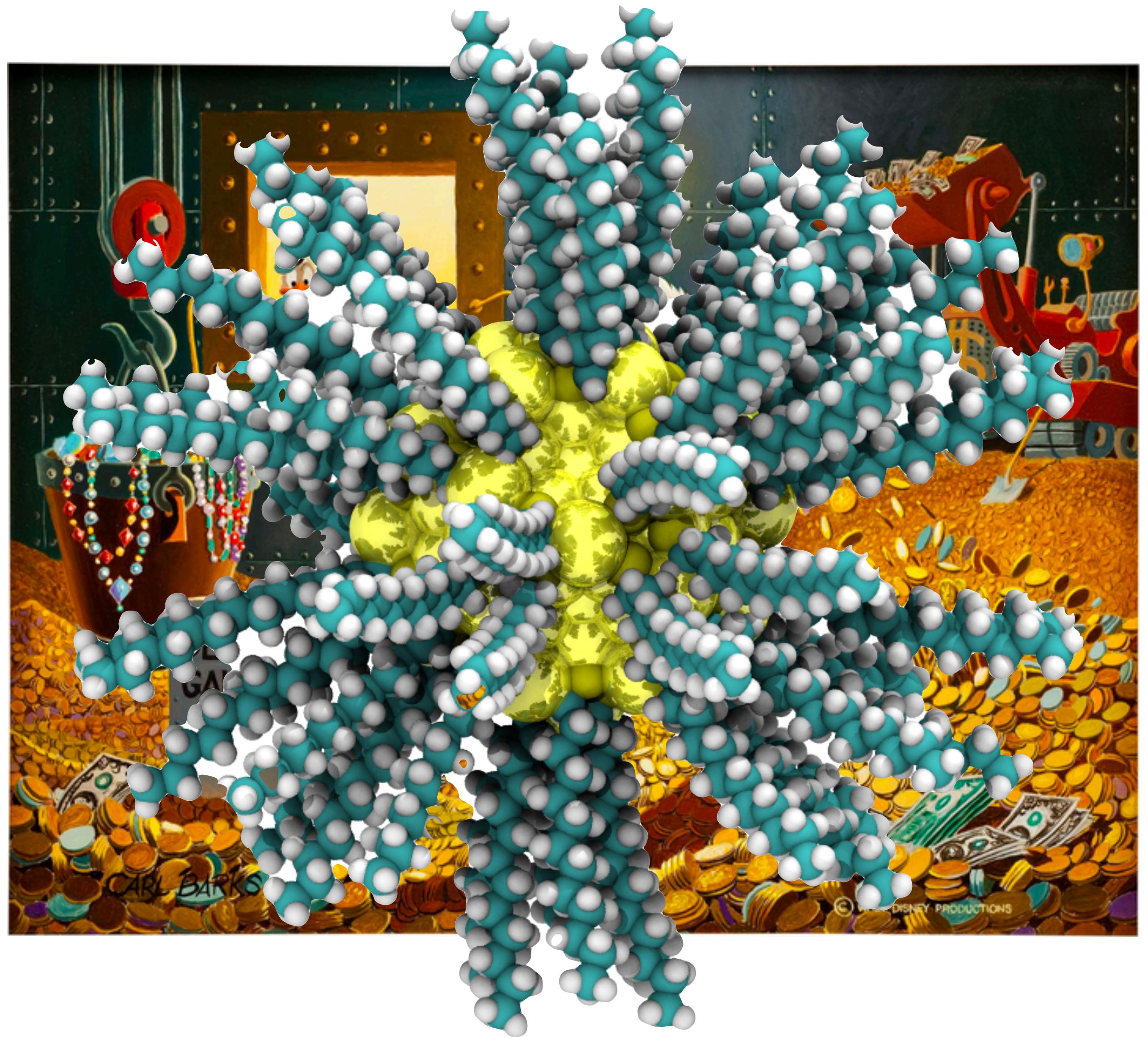


# A Molecular Dynamics Approach To Studying Gold Interactions

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Rutgers New Brunswick

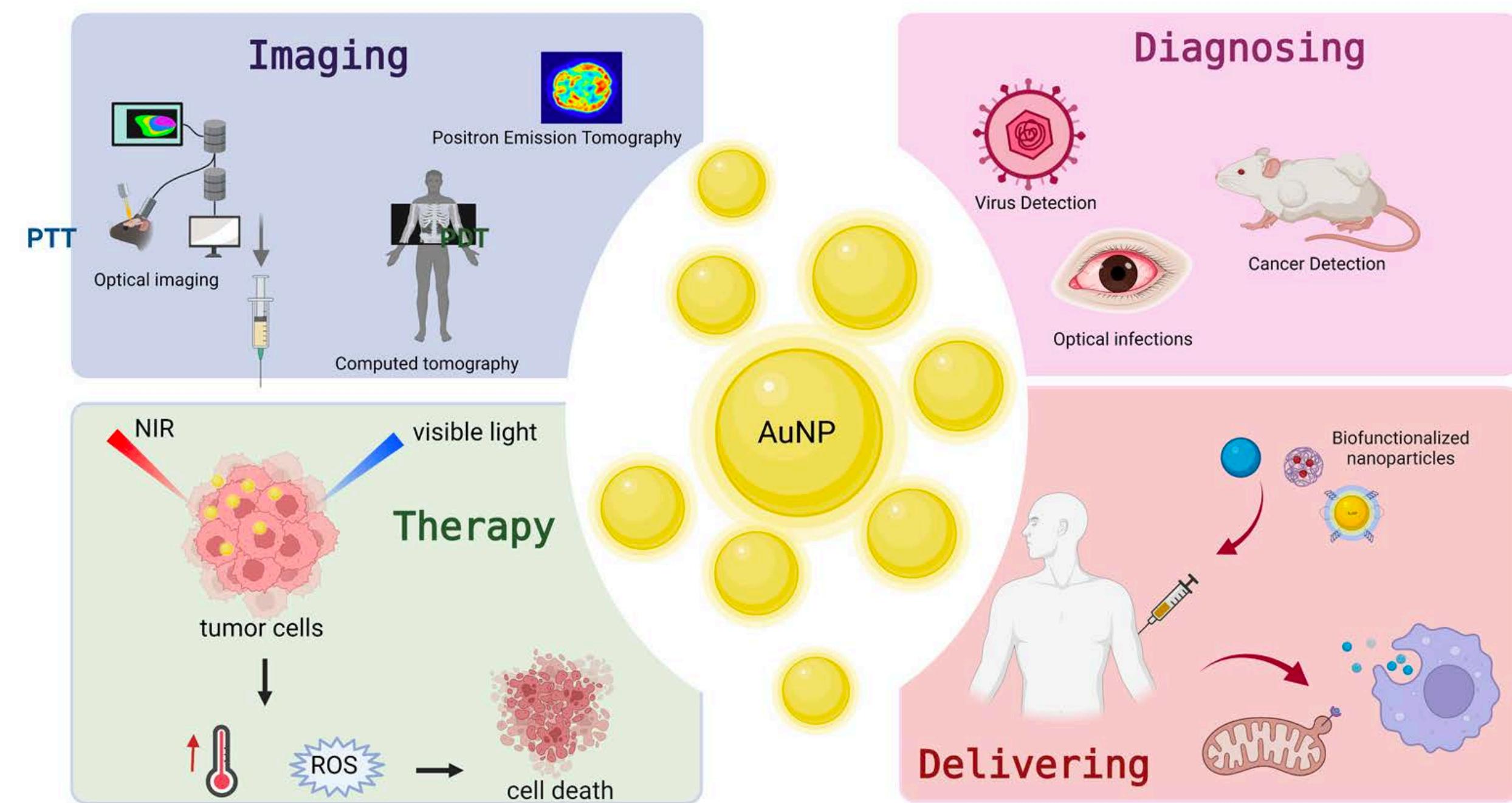


# Outline

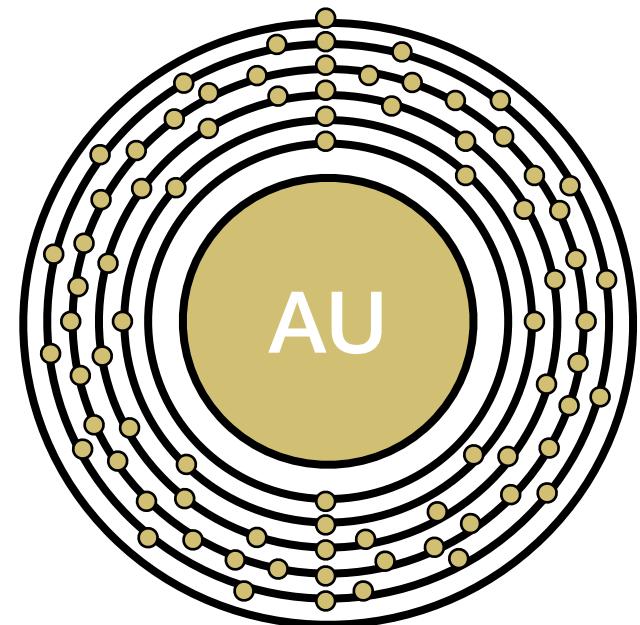
- Background/Motivation
- Methods & Approach
- Results
  - Gold core parameter effects on the membrane
  - Ligands cause lipid disordering
  - Aggregation is dependent on both core parameters and ligand length
- Summary

# Applications of Gold Nanoparticles Often Require Interactions with Biological System, Including Lipid Membranes

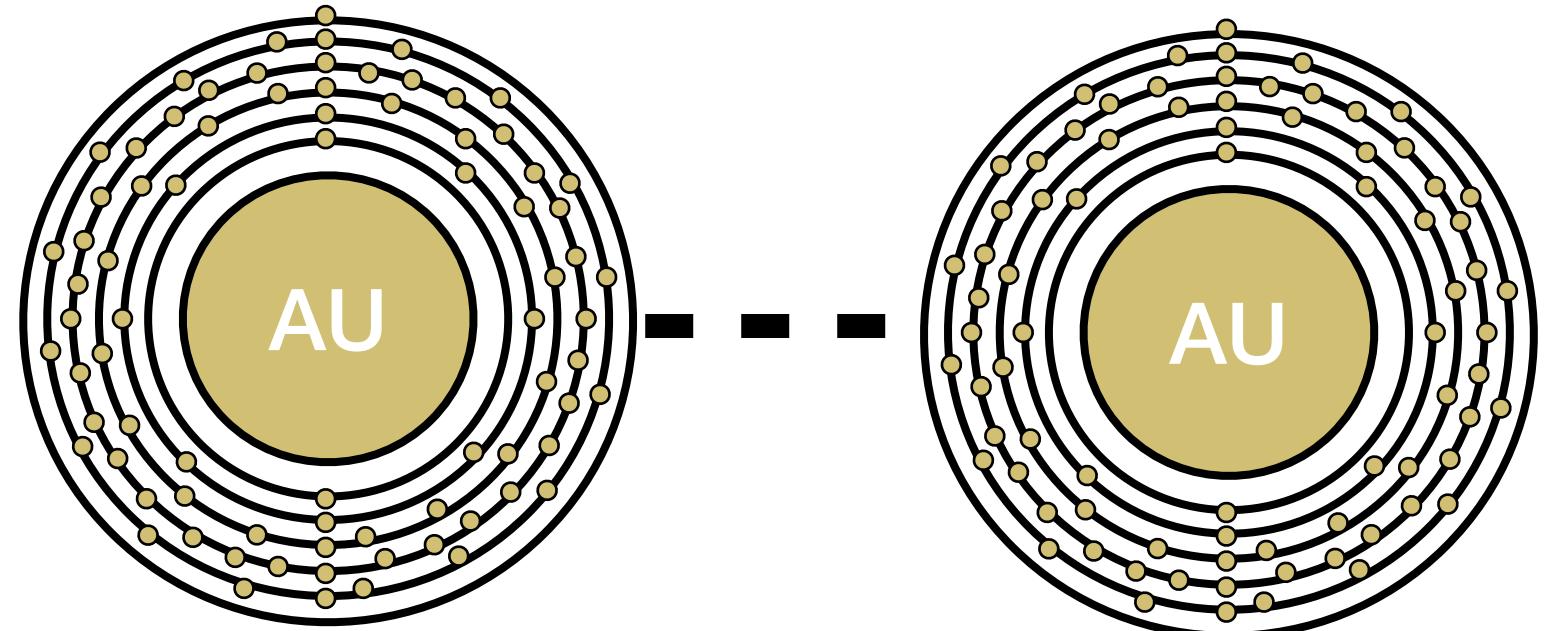
- Photodynamic Imaging
- Diagnostic Tool
- Targeted Drug Delivery Systems



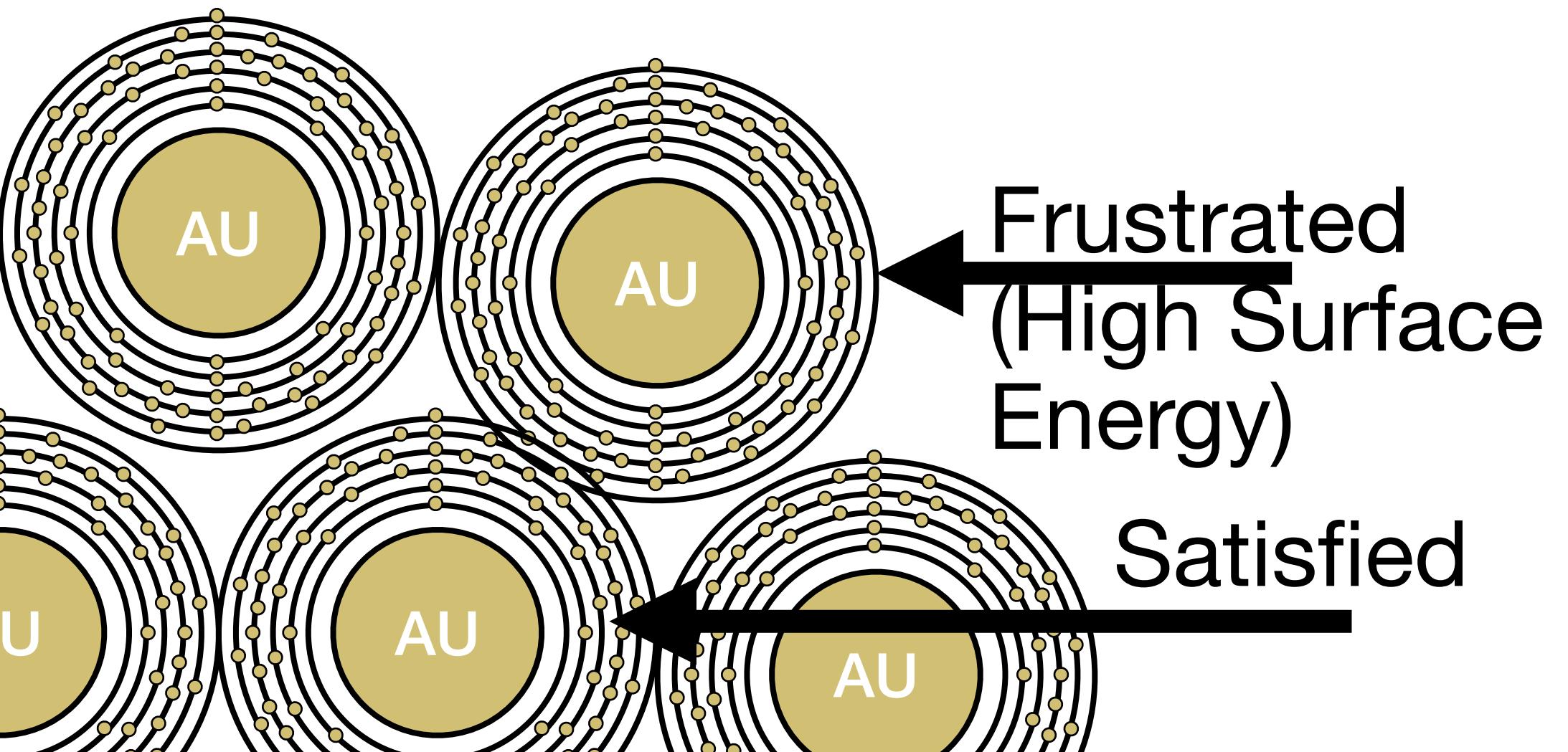
# Properties of Nanoscale Gold



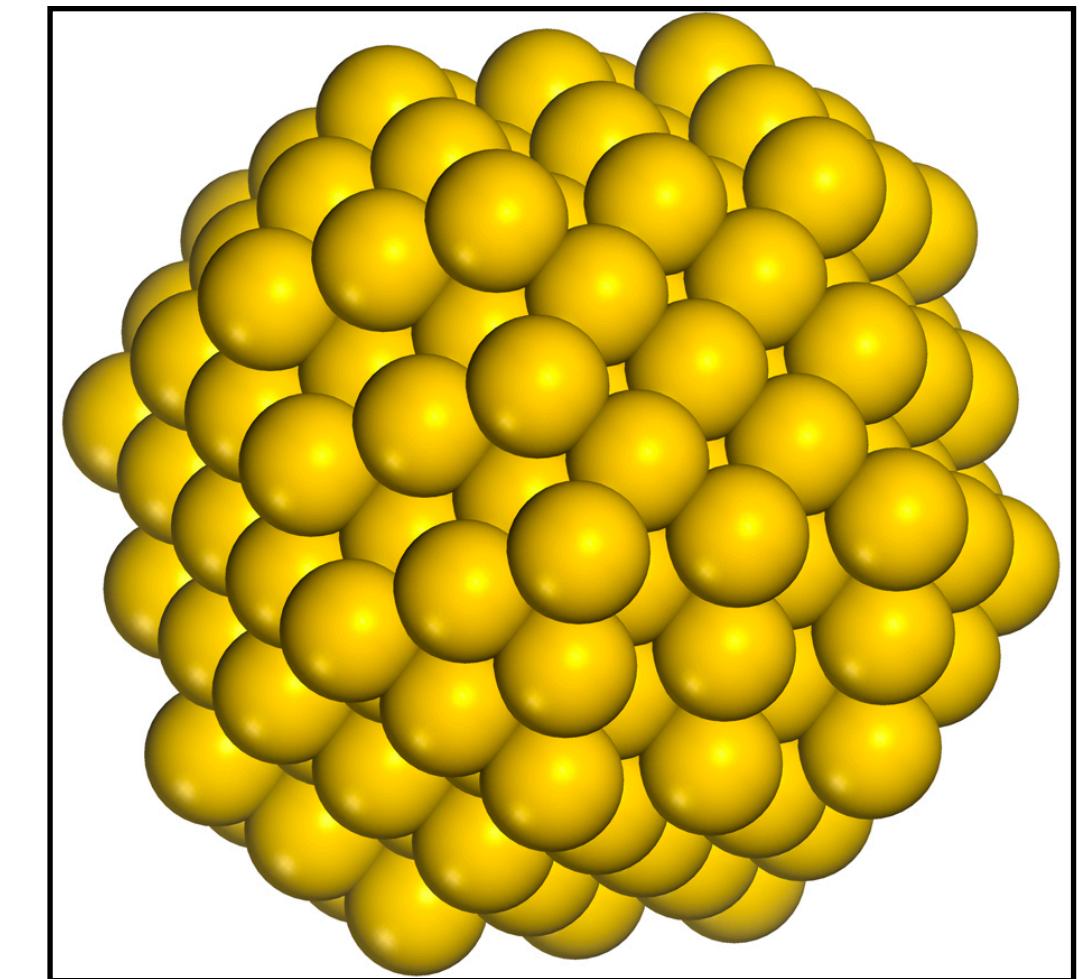
Large atoms with weak hold on their electrons



Form crystal lattices due to metal bonding

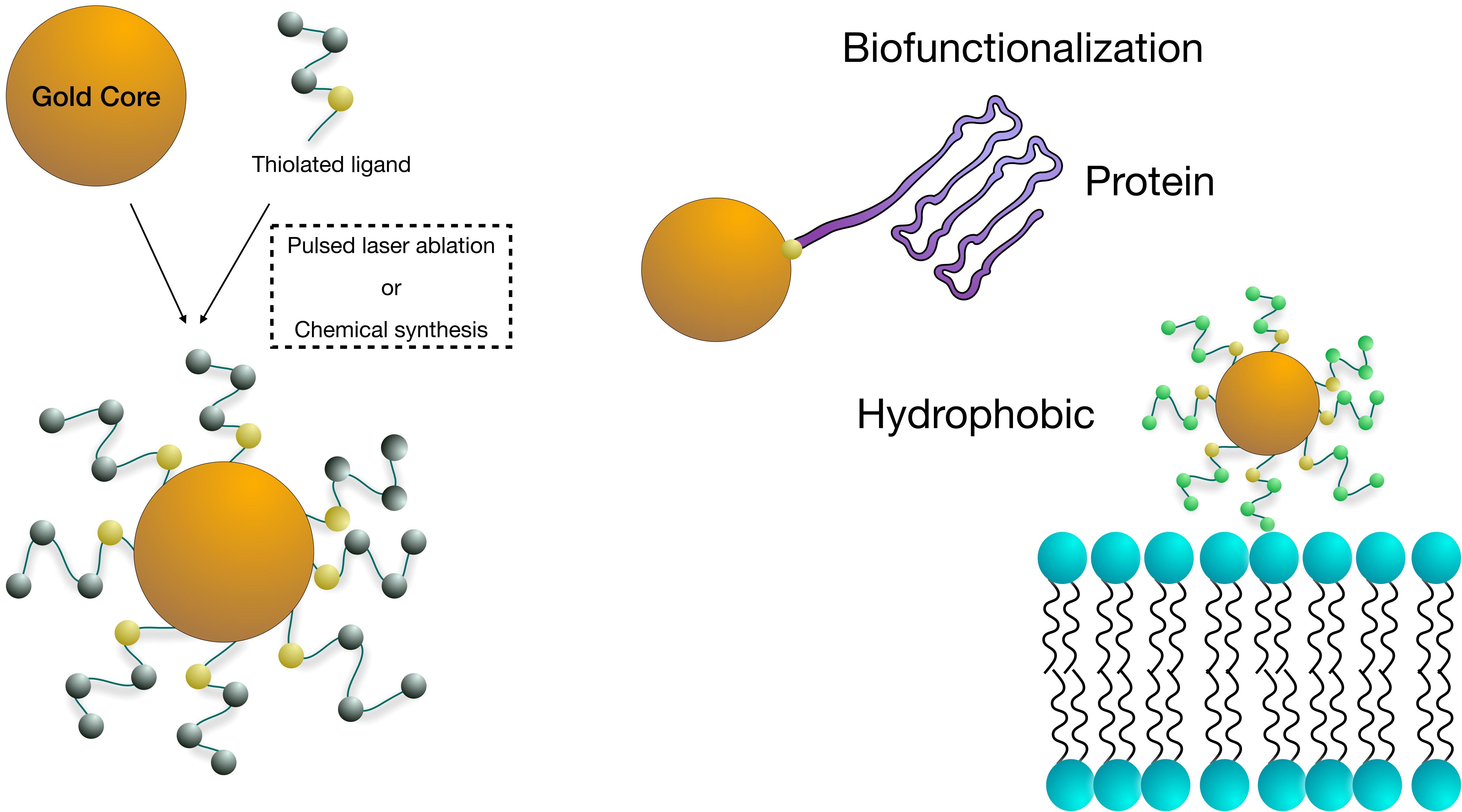


Increases epitaxial growth

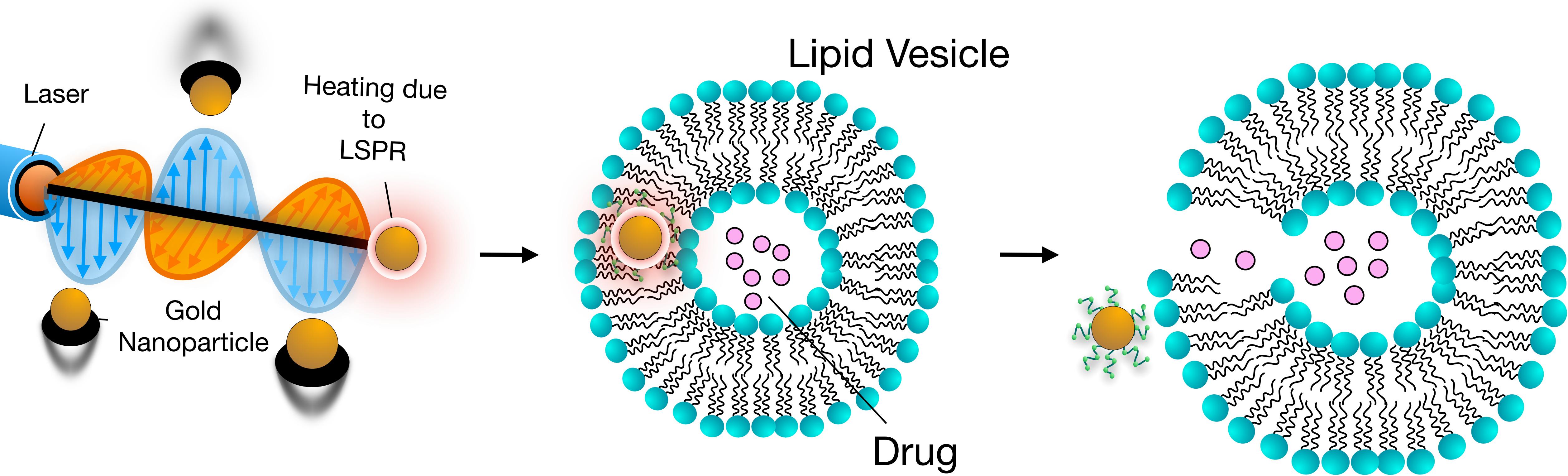


- 1 to 100nm
- Reactive
- Light sensitivity

# Functionalized Gold, a Non-Biological Material For Biological Applications

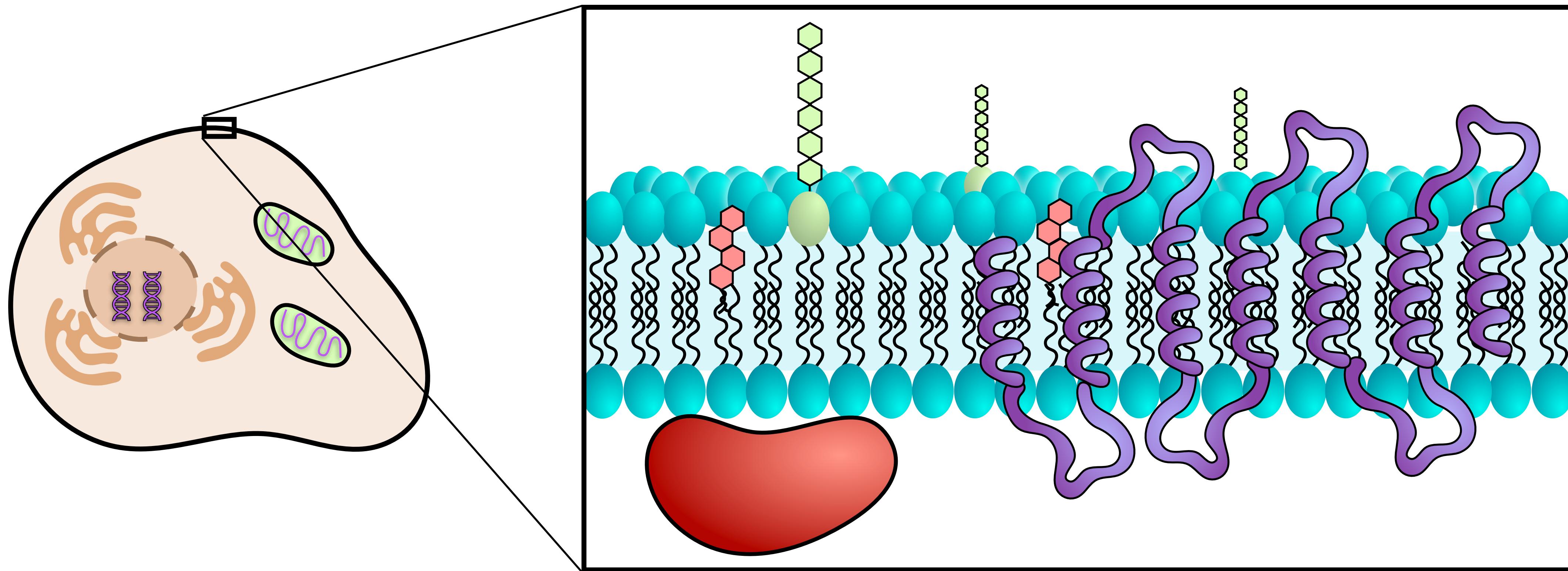


# Lipid-Nanoparticles Hybrid Vesicles, A Tool For Non-Invasive Drug Delivery



# Understanding Biology with a Physics Lens

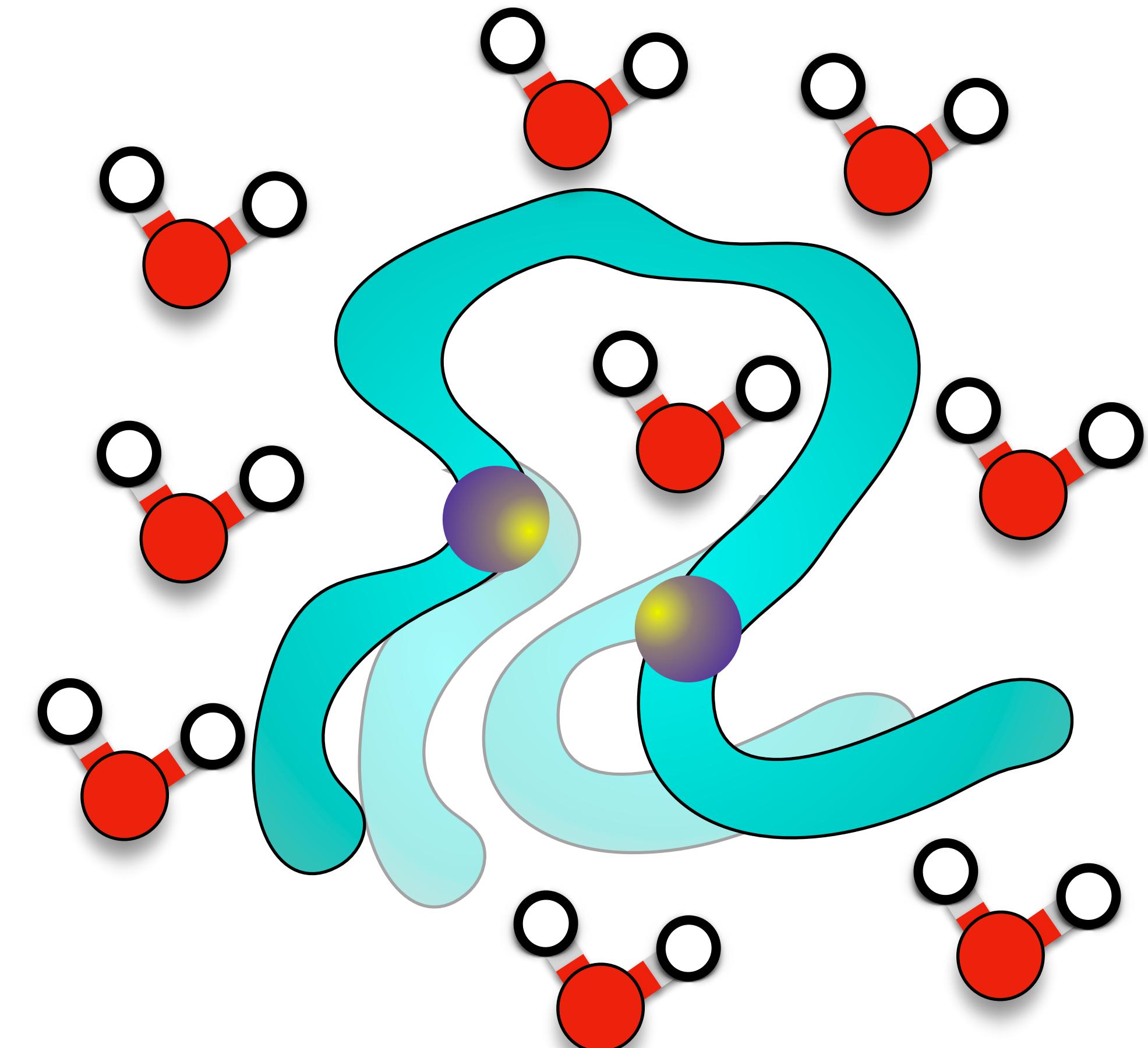
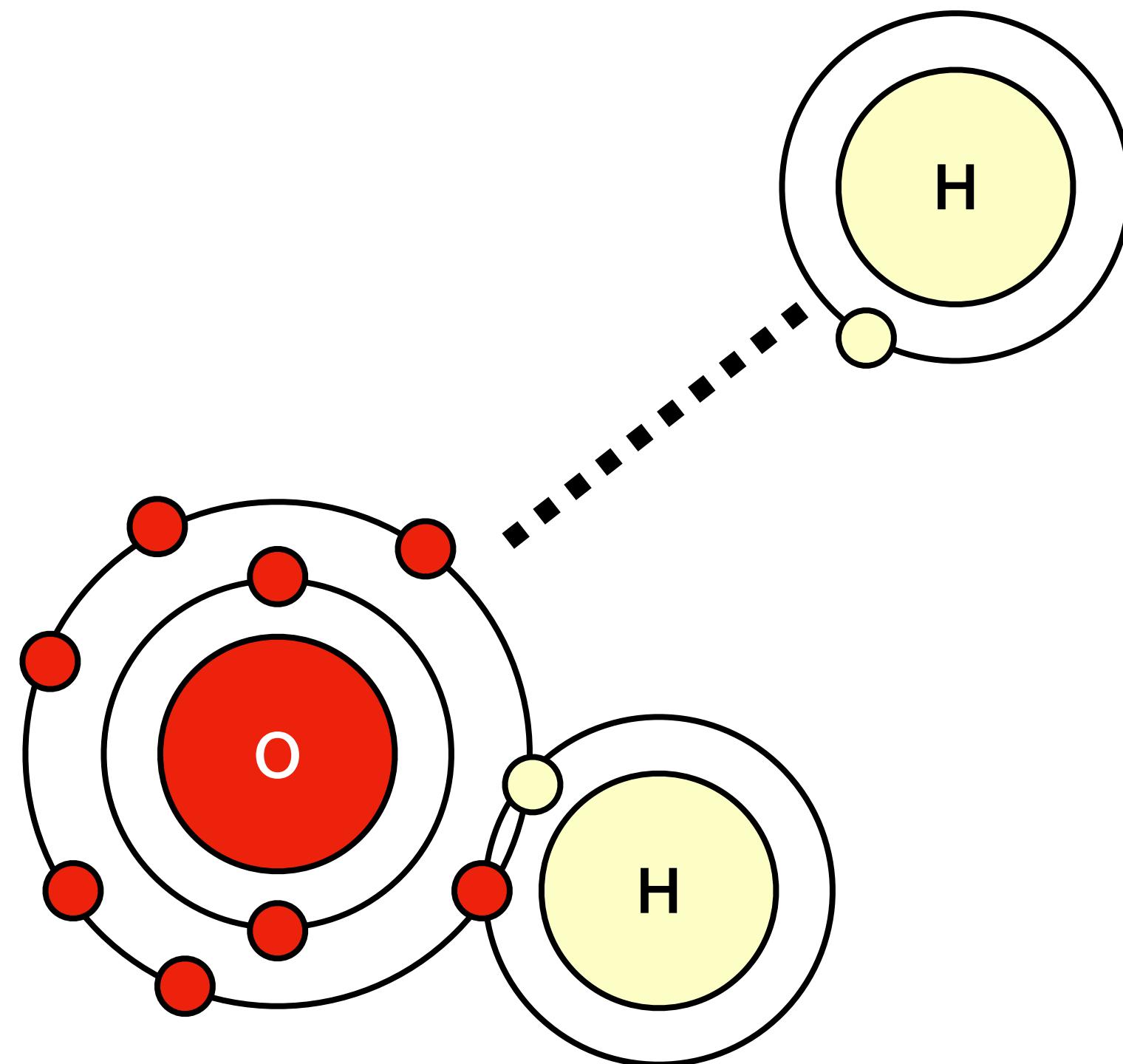
Plasma Membrane



Take messy biology and fit it into clean physics

# What are biophysicist interested in?

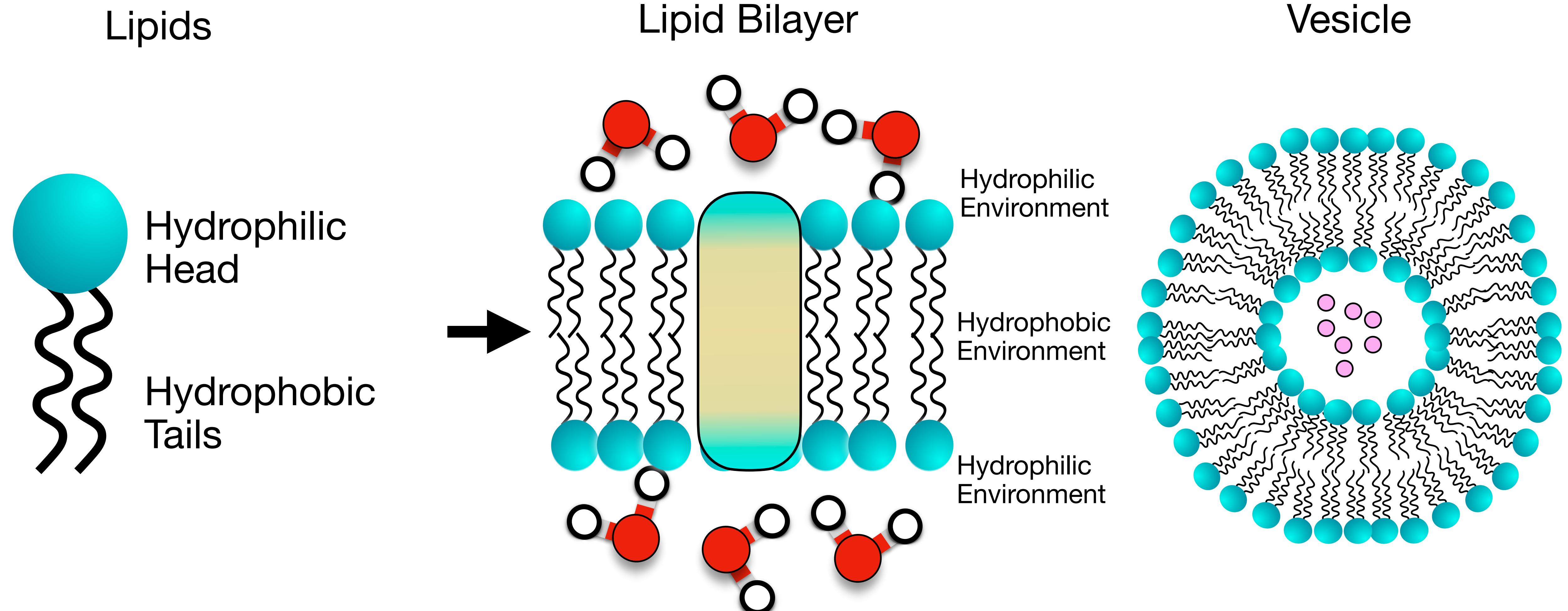
Interested in the interactions between particles



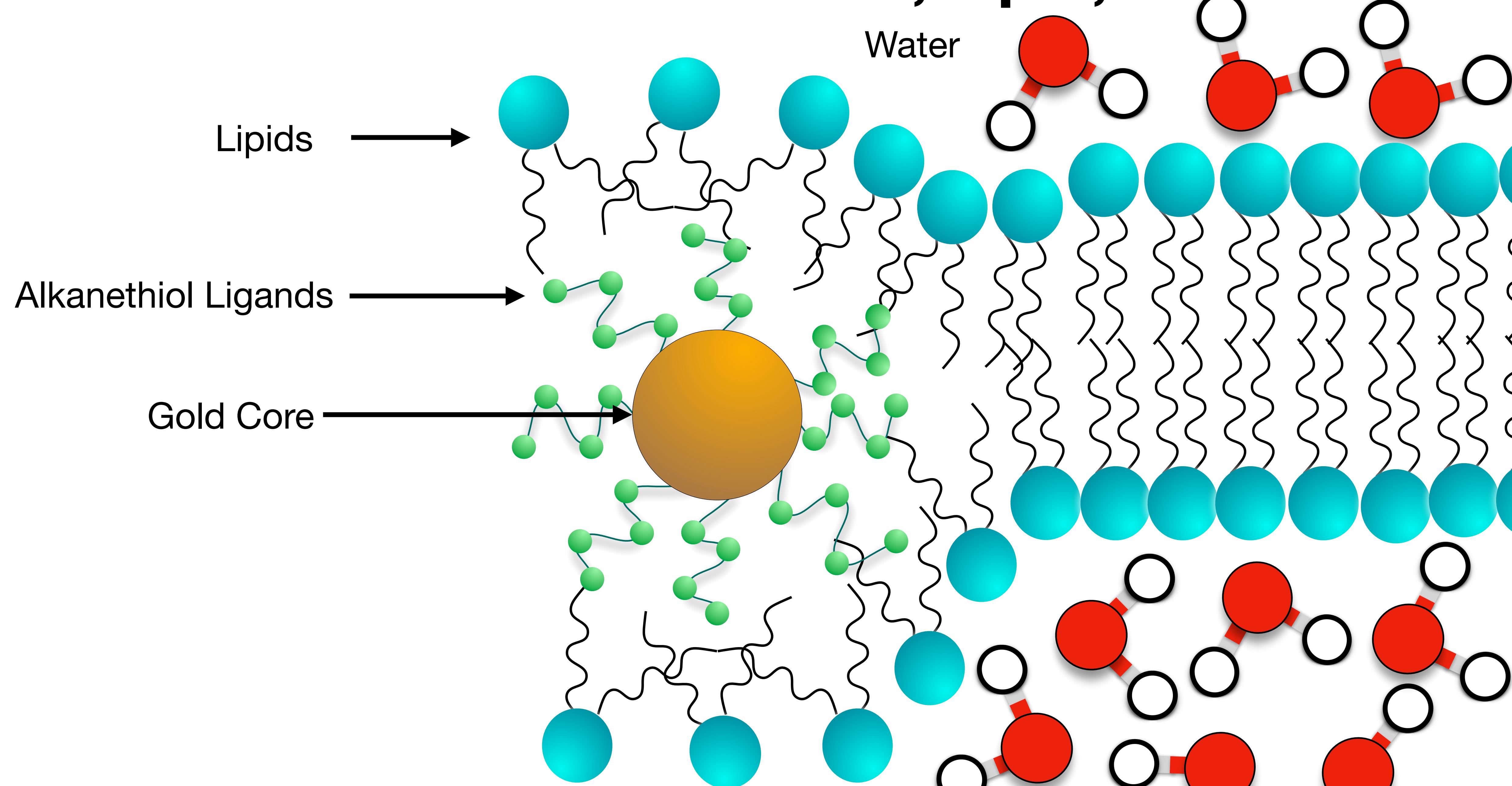
Chemistry primarily focuses  
on **bonds** between **atoms**

Biophysics focuses on **non-covalent  
interactions** within **solutions**

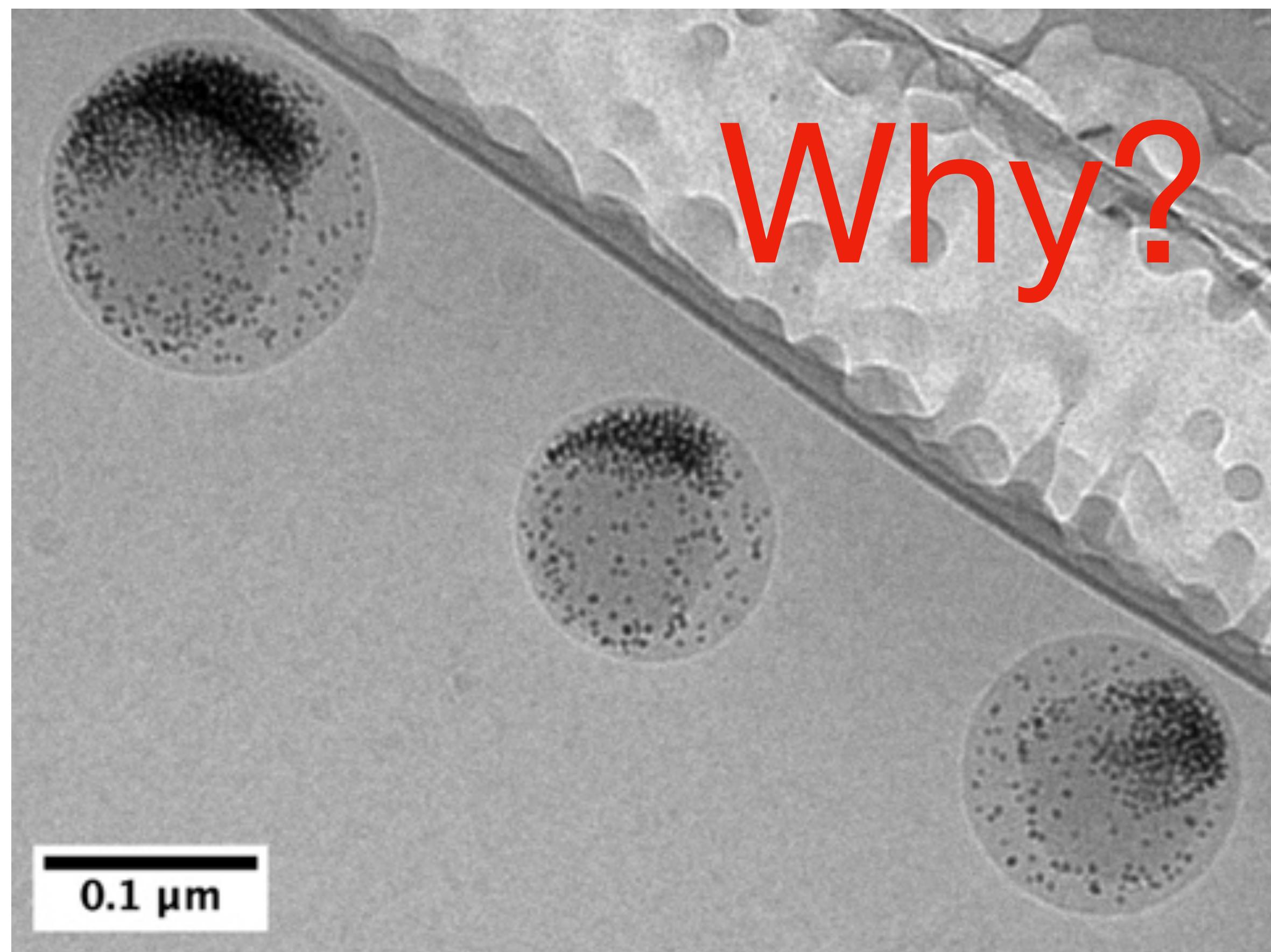
# The Key Features of Lipids and Membranes



# The Interfaces Between Gold, Lipid, and Water

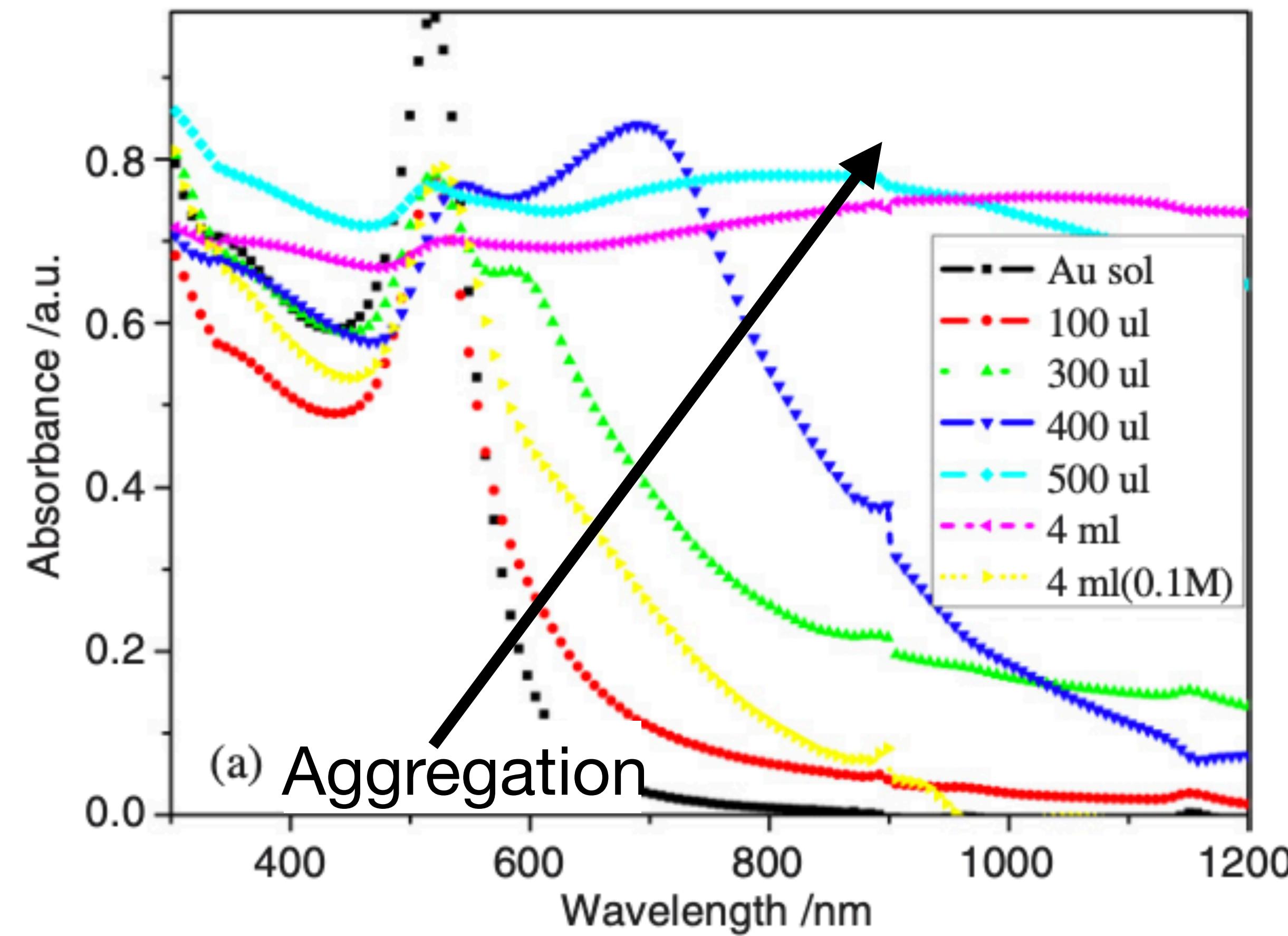


# Aggregation Changes the Optical Properties of Gold



Why?

Increasing GNP aggregation changes optical response

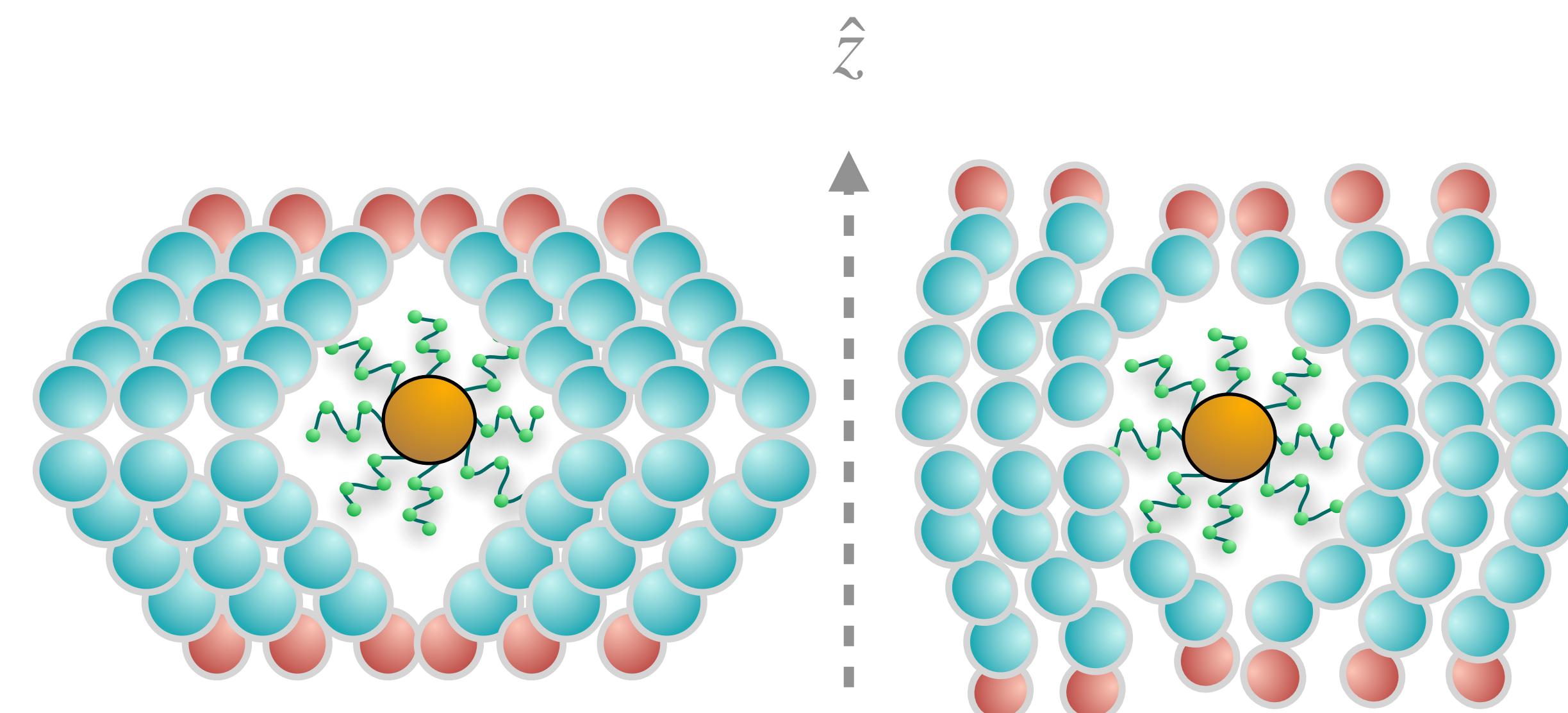


# Research Question:

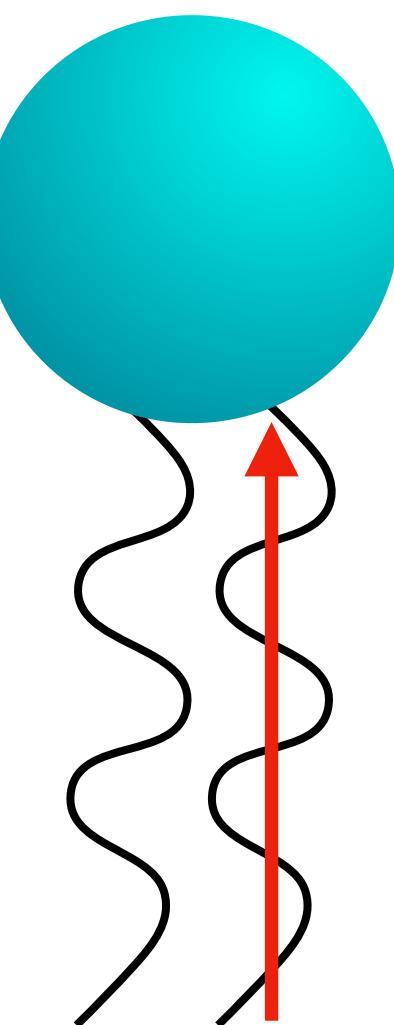
What is the mechanism of ligand coated gold nanoparticle aggregation in lipid membranes?

# How Do We Quantify Lipid Deformation?

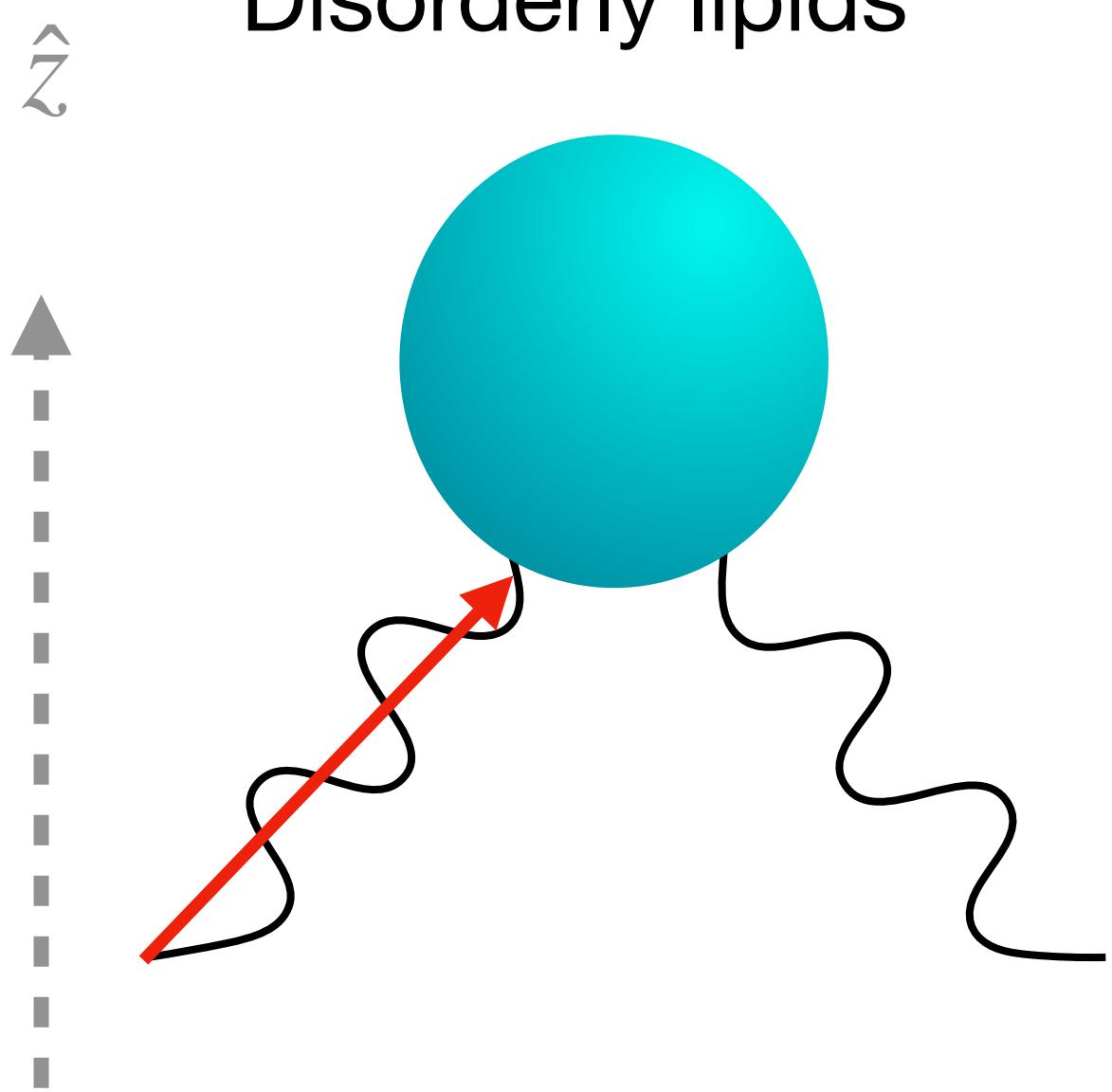
Ligand induced lipid deformation



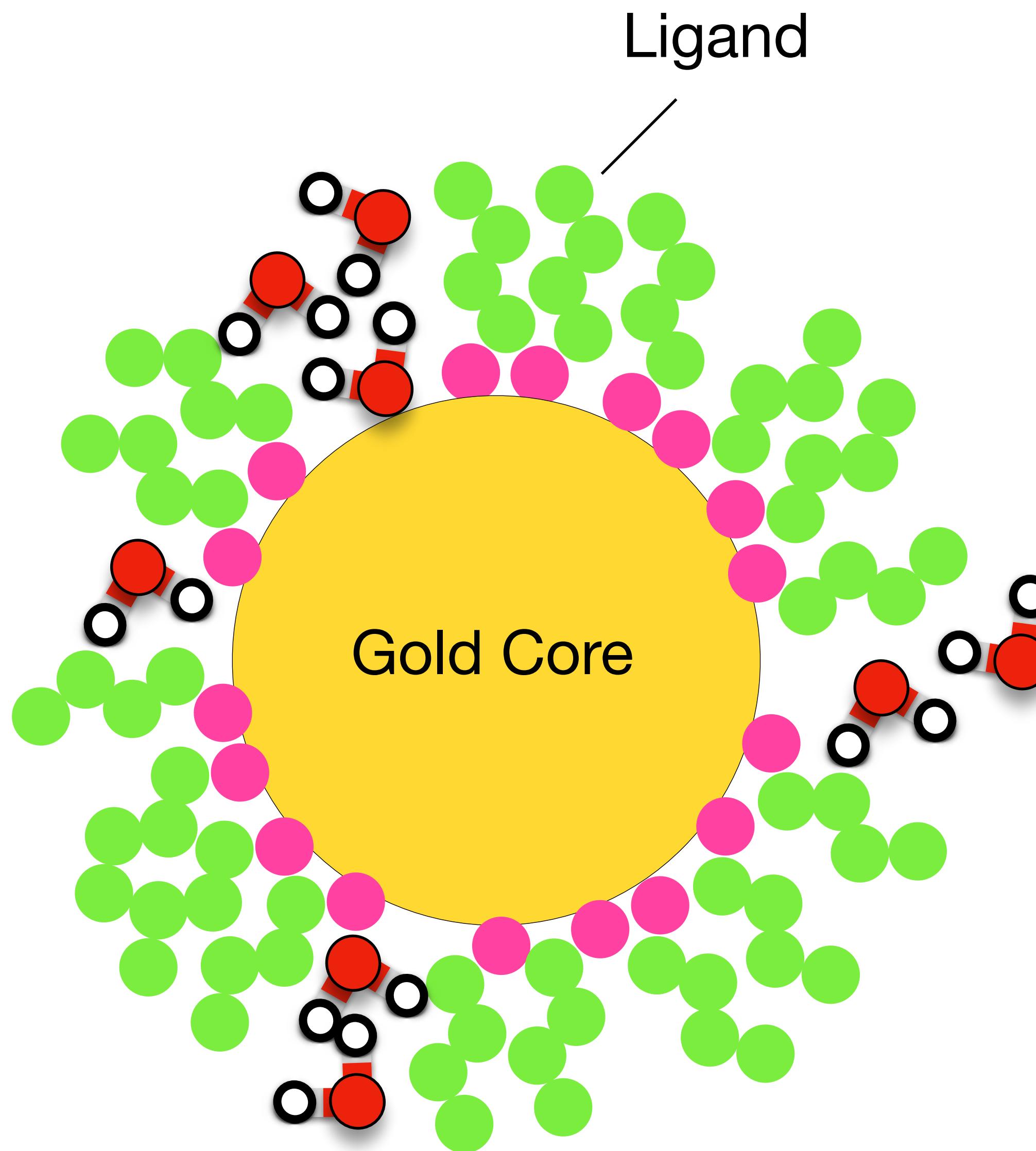
Orderly lipids



Disorderly lipids



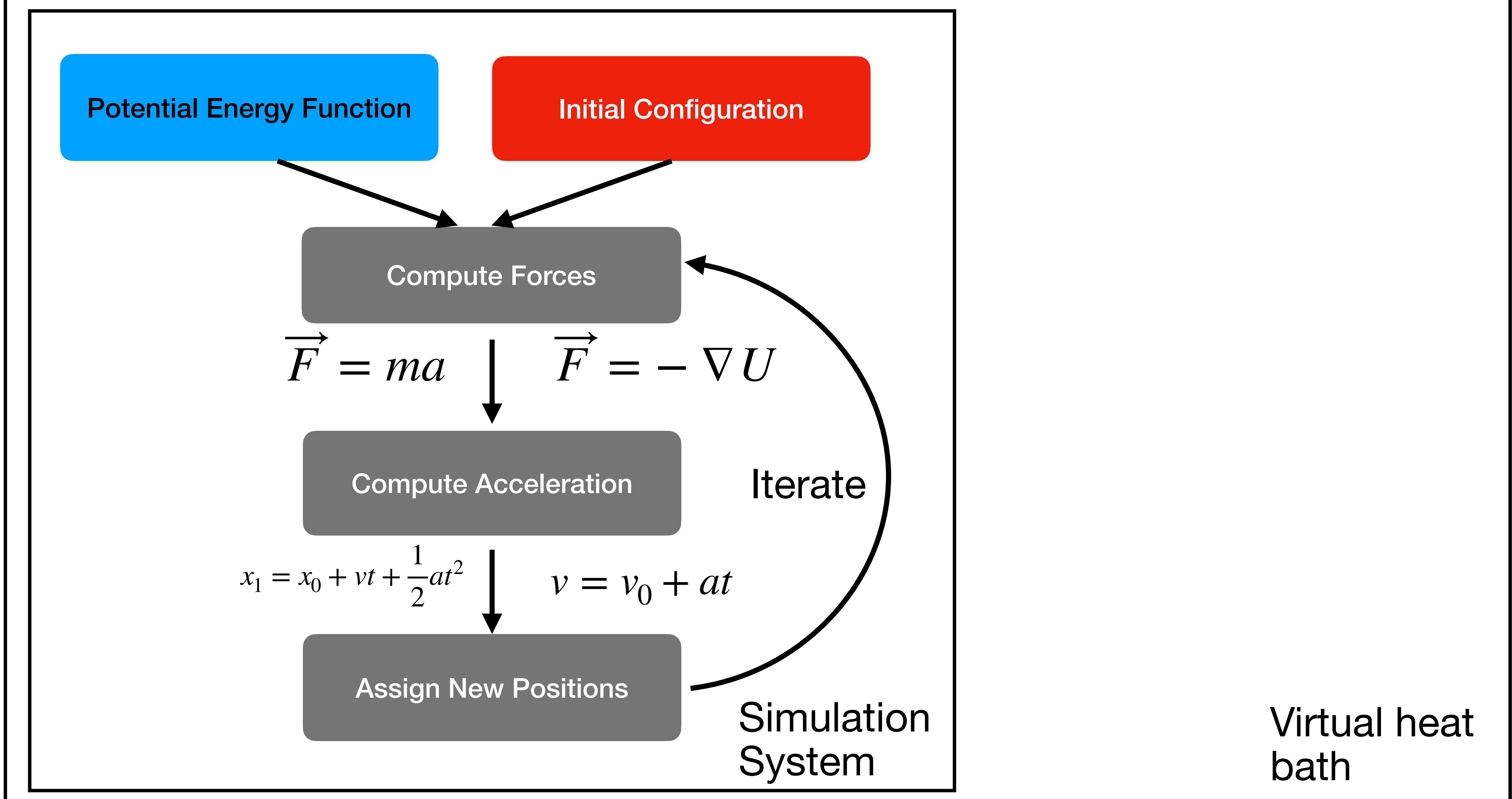
# Getting a Sense for Gold-Gold Interaction Through Exposed Surface



- Solvent Accessible Surface Area (SASA)
- May indicate regions of exposed surface which can interact

# **Method and Approach**

# Approaching the Question Using Molecular Dynamics



# Potential Energy Functions

Lennard Jones  
& Electrostatic

$$U_{LJ_{ij}} = \epsilon_{ij} \left[ \left( \frac{\sigma_{ij}}{r_{ij}} \right)^{12} - \left( \frac{\sigma_{ij}}{r_{ij}} \right)^6 \right]$$

$$U_{elec} = \frac{q_i q_j}{4\pi\epsilon r_{ij}}$$

-

Movie was here

+

Bonds & Angles

$$U_{bond_{ij}} = \frac{k_b(r_{ij} - r_0)^2}{2}$$

$$U_{angle_{ijk}} = \frac{k_\theta(\theta_{ijk} - \theta_0)^2}{2}$$

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Dihedral angles/  
torsions

$$U_{\phi_{ijkl}} = k_\phi [1 + \cos(n\phi_{ijkl} - \delta)]$$

Movie was here

# Total Potential

$$U_{total} = \sum_{nonbonded} U_{LJ} + U_{elec} + \sum_{bonds} U_{bond} + \sum_{angles} U_{angle} \\ + \sum_{dihedrals} U_{dihedral} + \sum_{impropers} U_{improper} + \text{corrections}$$

Calculate Forces:

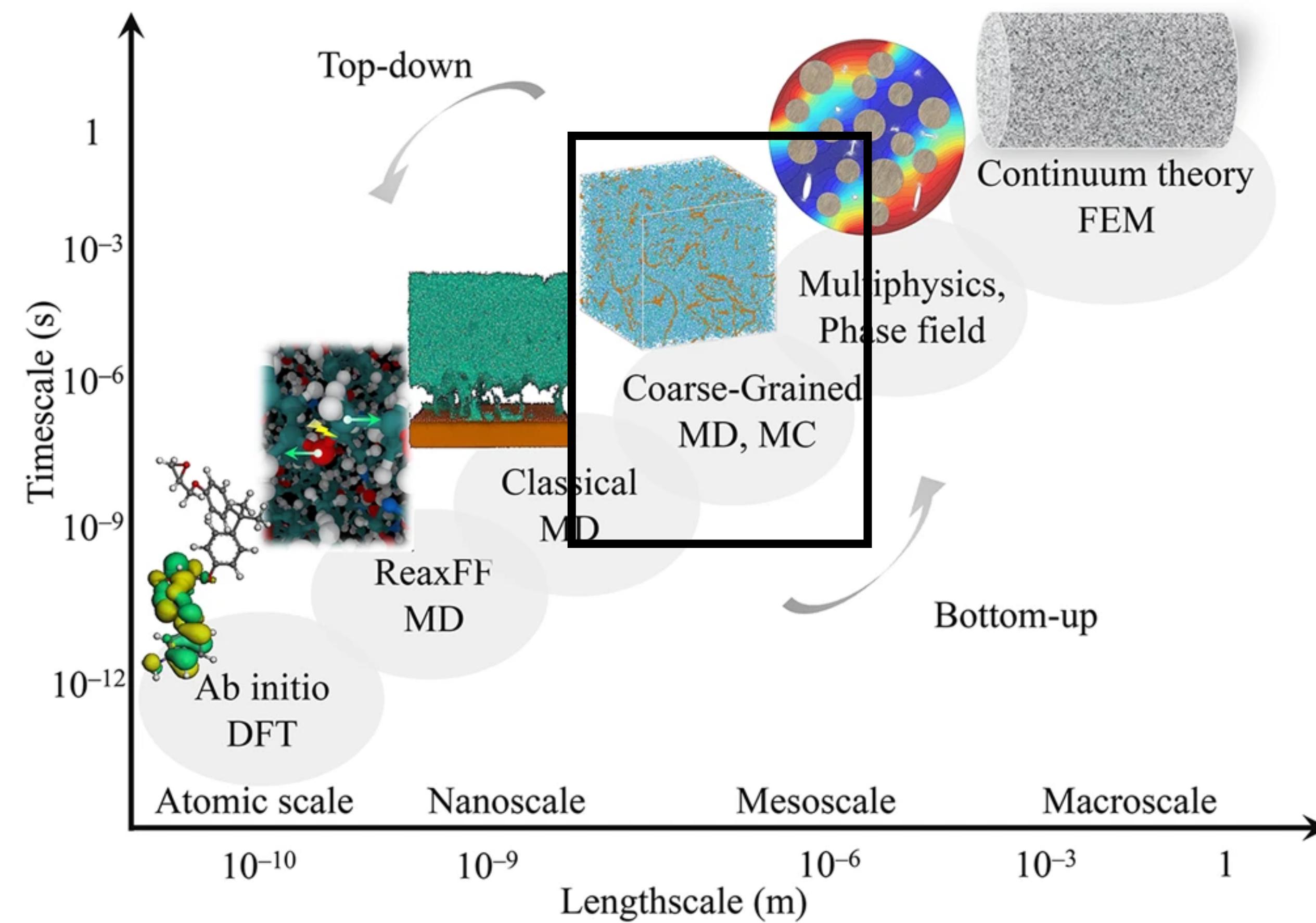
$$\mathbf{F} = -\nabla U$$

Calculate Acceleration:

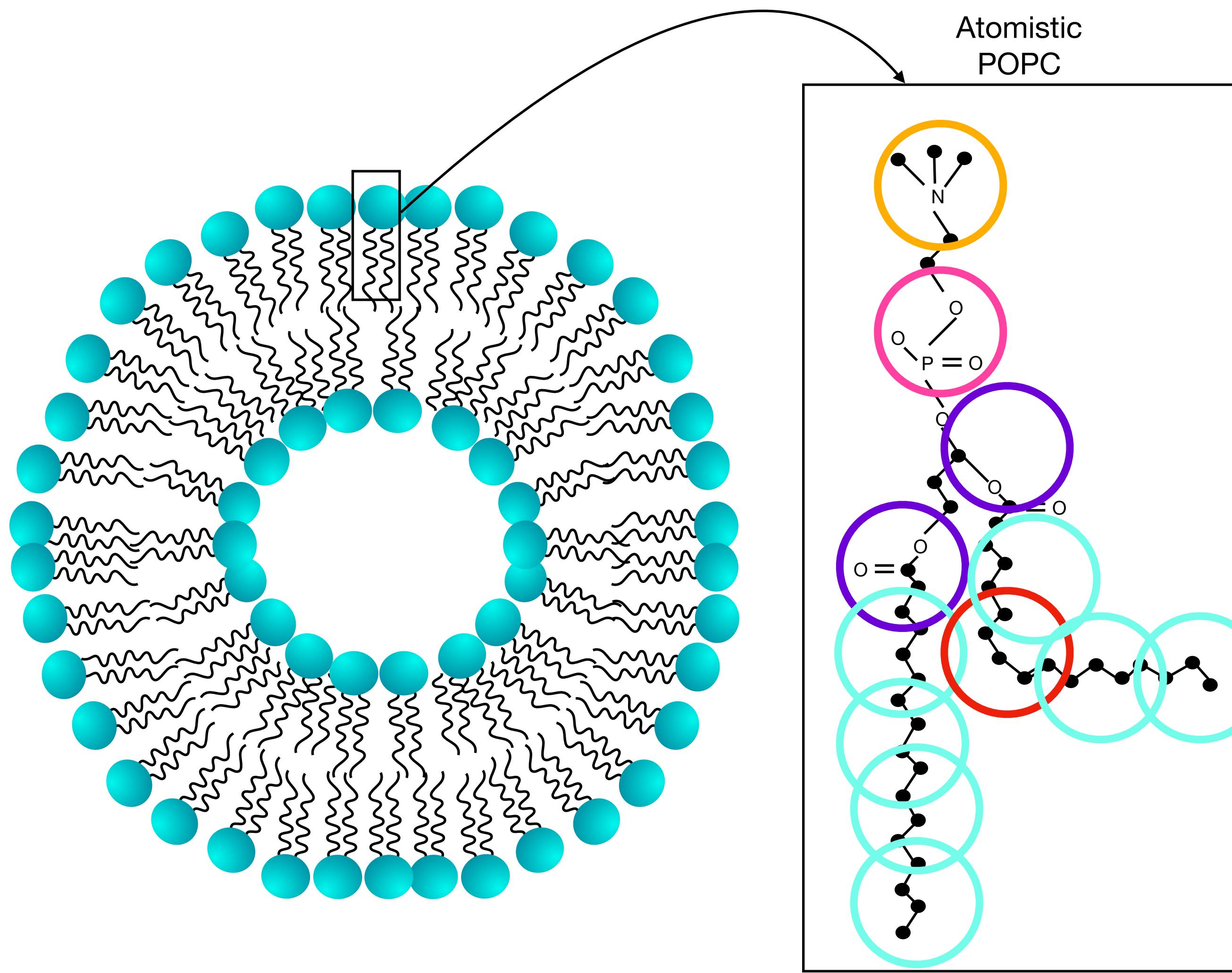
$$\mathbf{a} = \mathbf{F}/m$$

Update position and velocities for all atoms

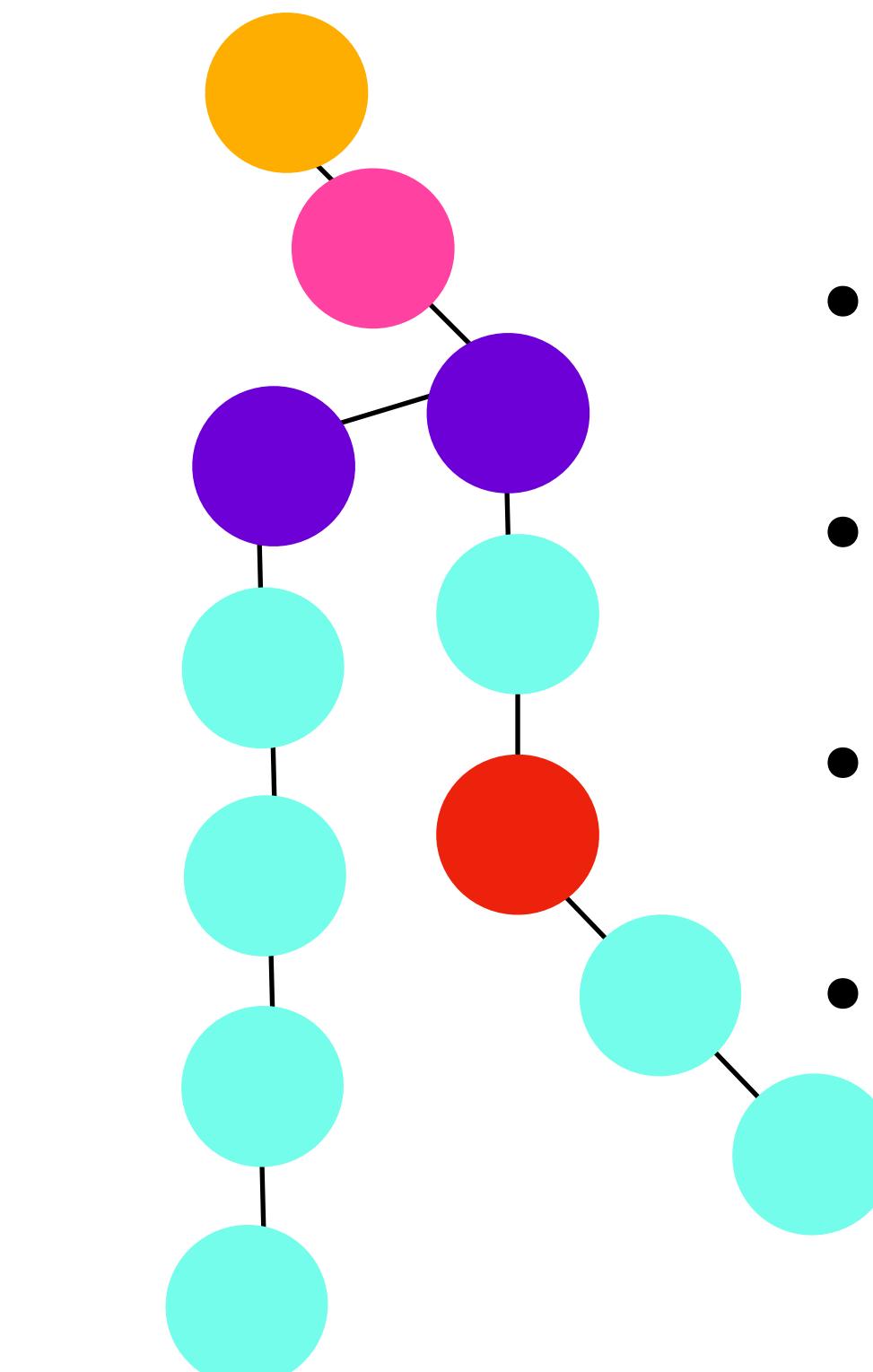
# The Length and Time Scales we Can Simulate Over Depend on Our Compute Resource



# Coarse-Grained Molecular Dynamics



Coarse Grained  
POPC

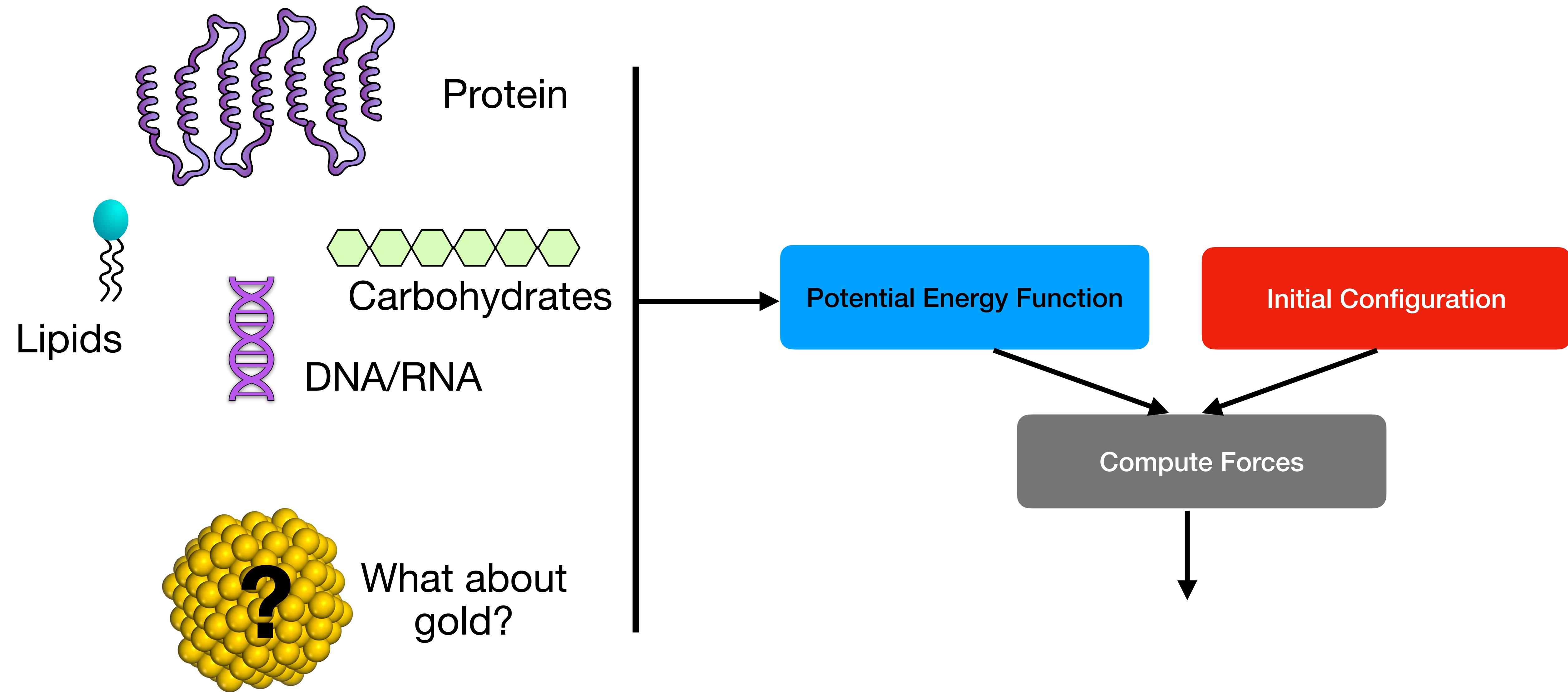


4 types of interactions

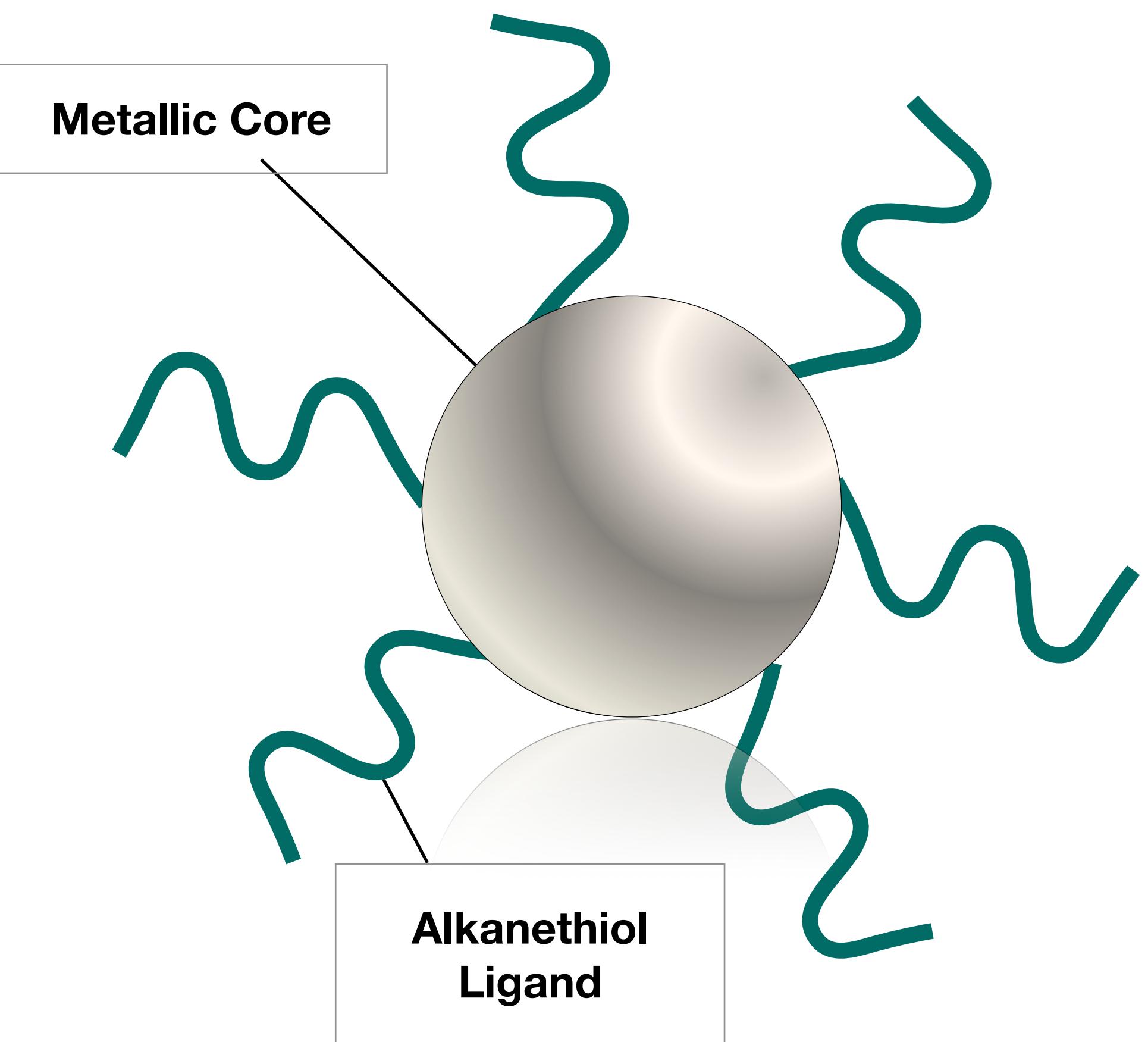
- Polar
- Nonpolar
- Apolar
- Hydrophobic

Movie was here

# Understanding Gold Interactions in Systems Designed for Biology

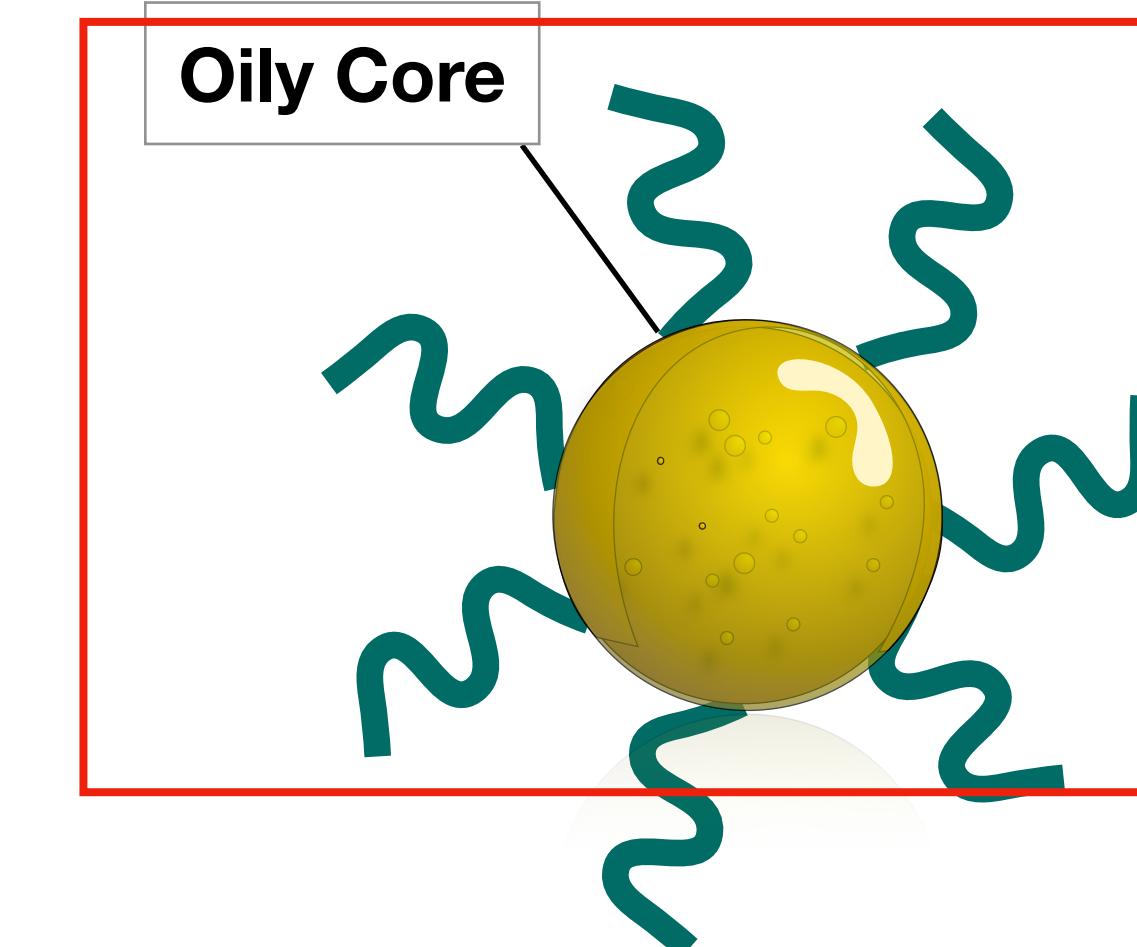


# What we Want in a Model

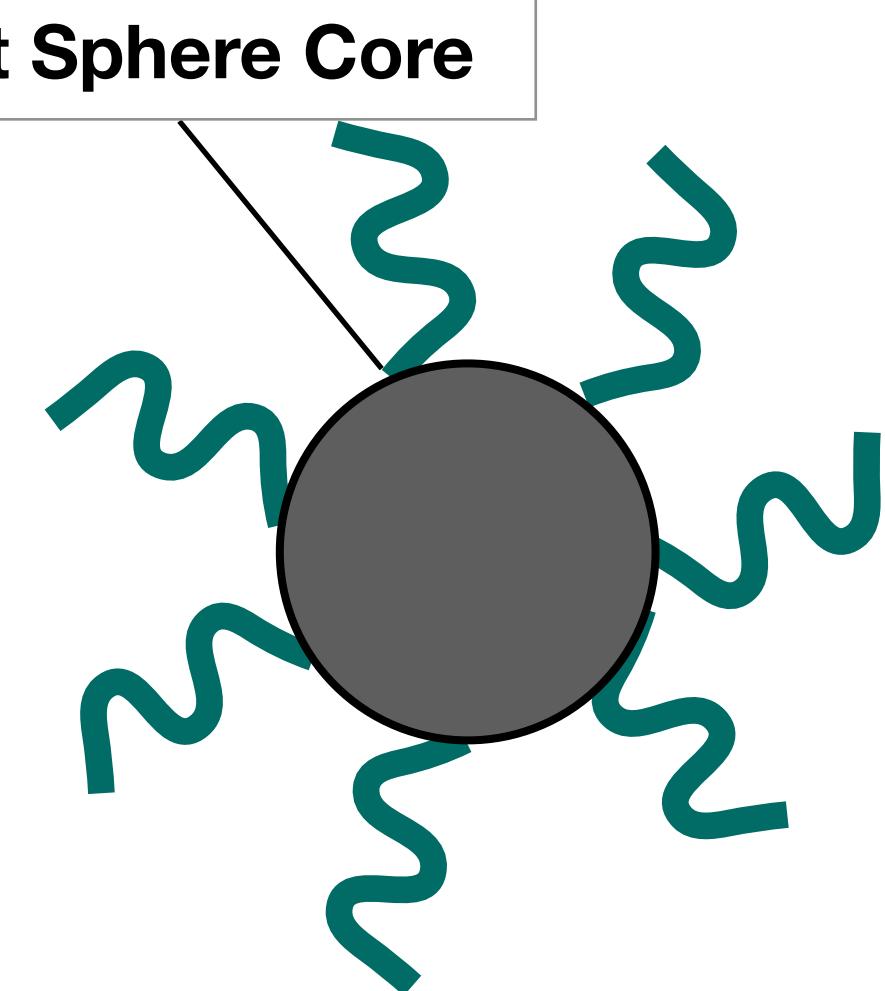


- Strong metal-metal interactions
- Strong interactions with charges

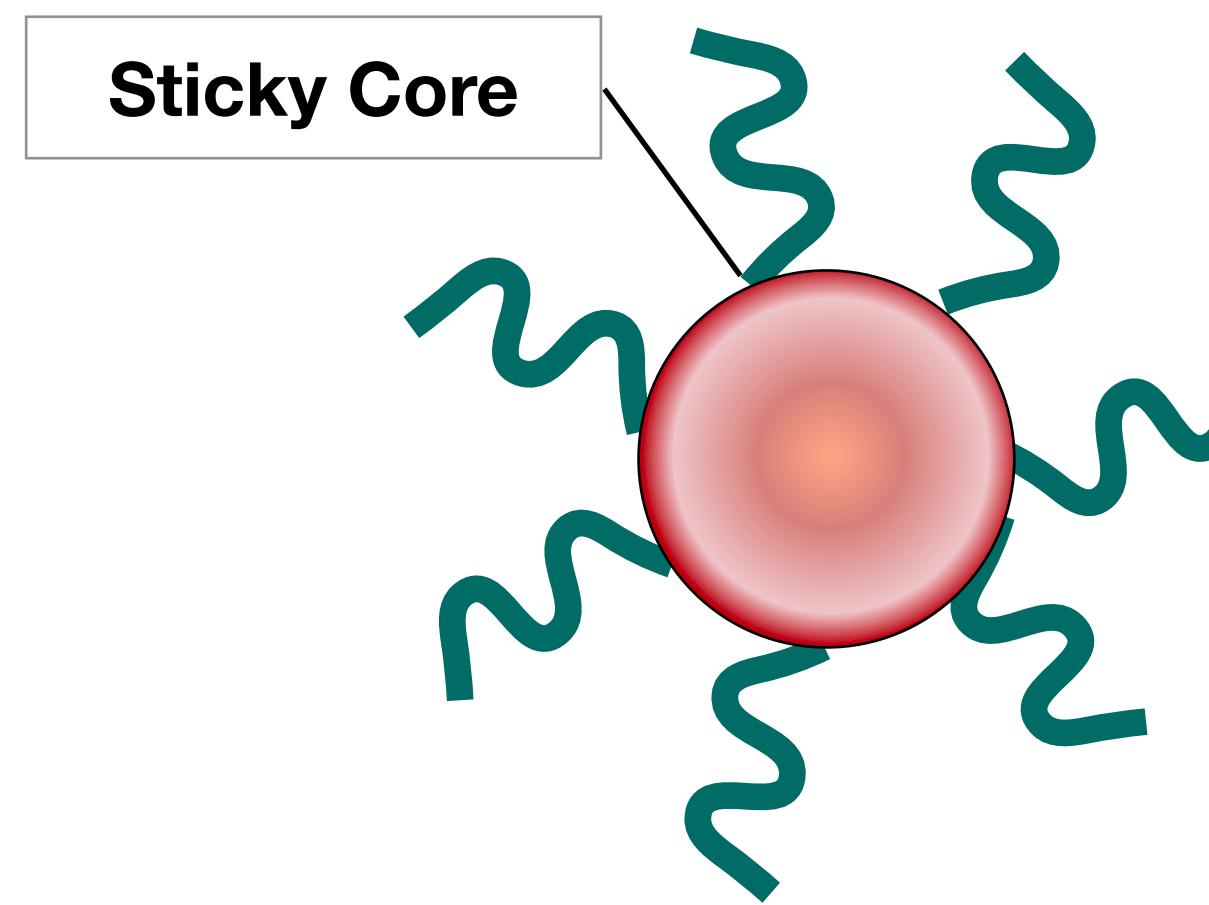
# Available Model Choices



- No strong self-interactions
- No strong charge interactions



- No interactions



- Strong self-interactions
- Strong charge interactions

# Approach

## Model

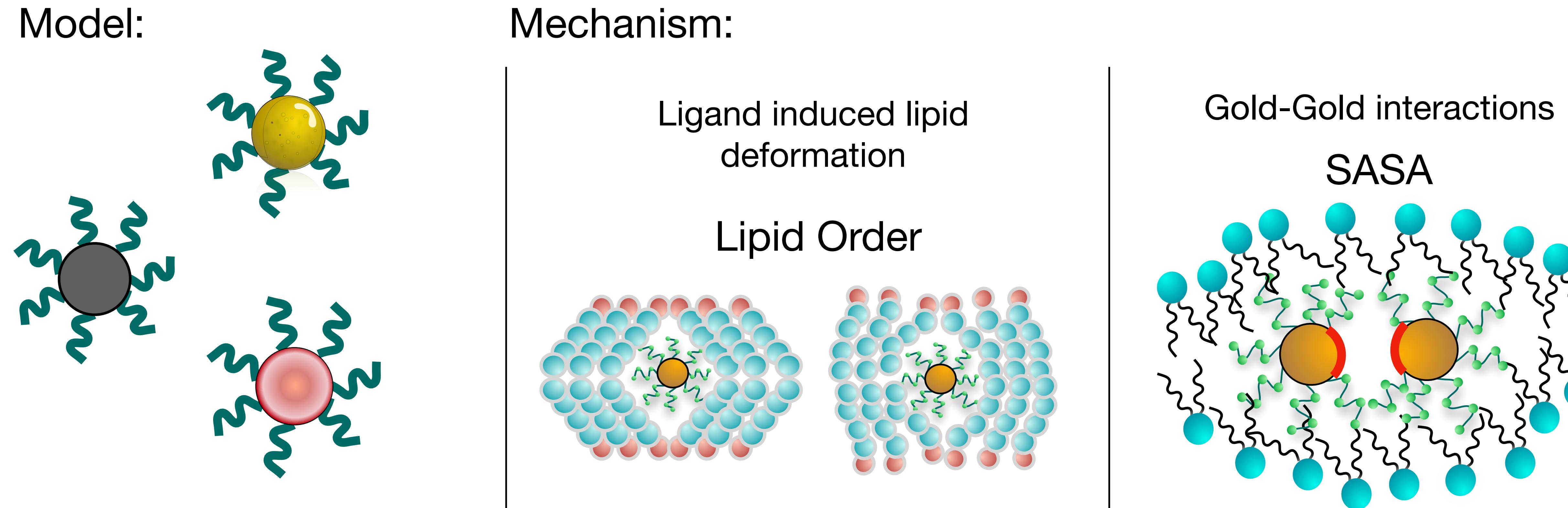
- Determine the effect of parameterization on aggregation
  - If we change core parameters then aggregation should remain the same

## Mechanism

- Vary ligand length and measure order parameter
  - If we increase the ligand length then lipid order will decrease
- Vary gold core stickiness and measure the solvent accessible surface area
  - If we increase stickiness then gold core solvent accessible surface area will increase

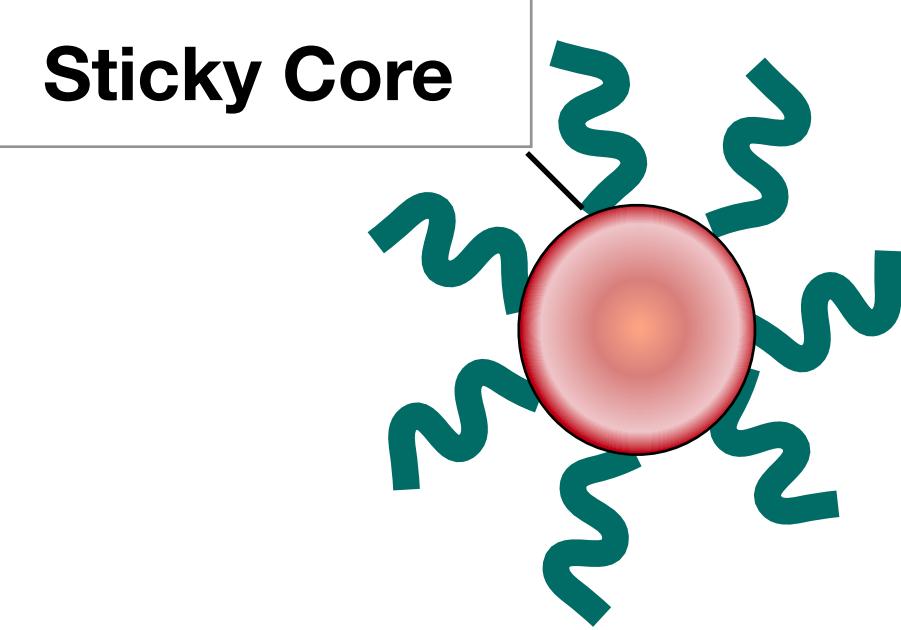
# Graphical Approach

- Question: What is the mechanism of ligand coated gold nanoparticle aggregation in lipid membranes?
- Tool: Coarse Grained Molecular Dynamics



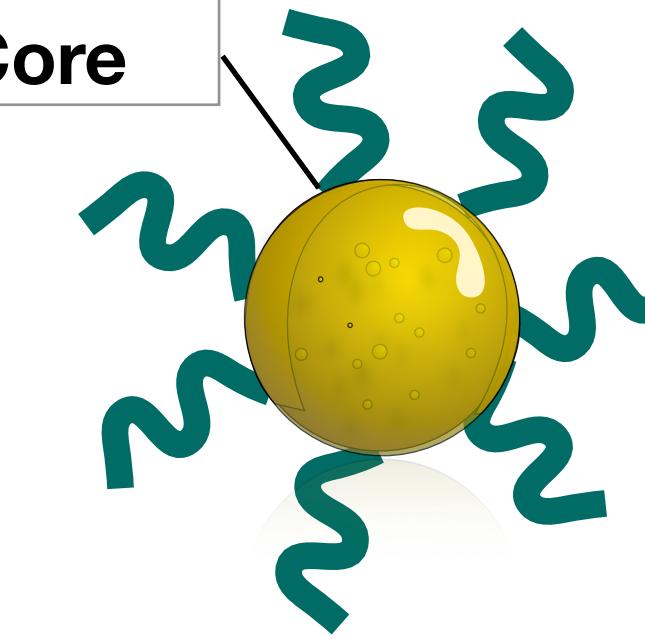
# **Results**

**Question 1: Does varying gold core parameters affect aggregation?**



Lipids

Gold Nanoparticle



Movie was here

Movie was here

# Different Gold Core Models Have Different Aggregation Behavior

Soft Sphere

Image was here

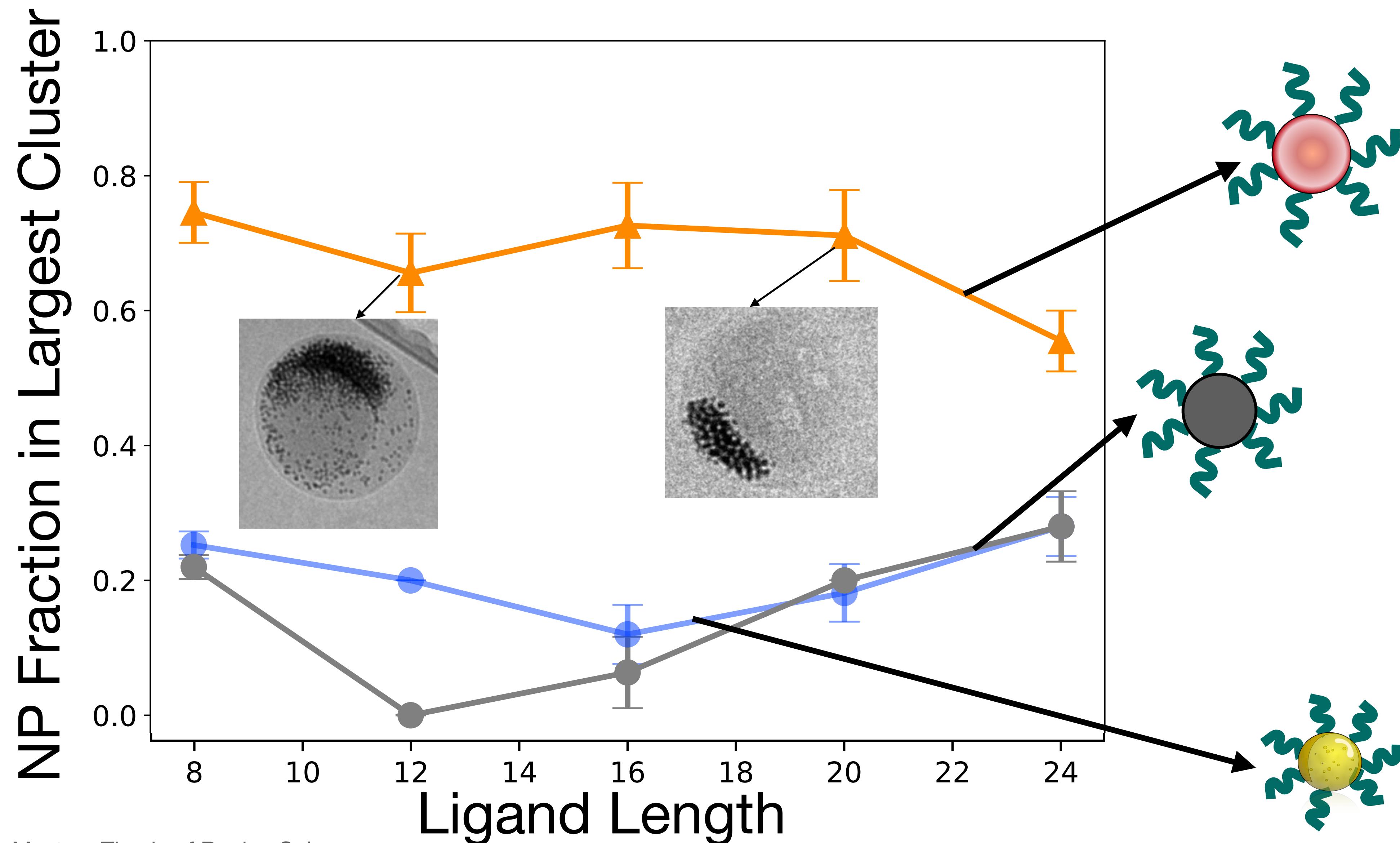
Oily

Image was here

Sticky

Image was here

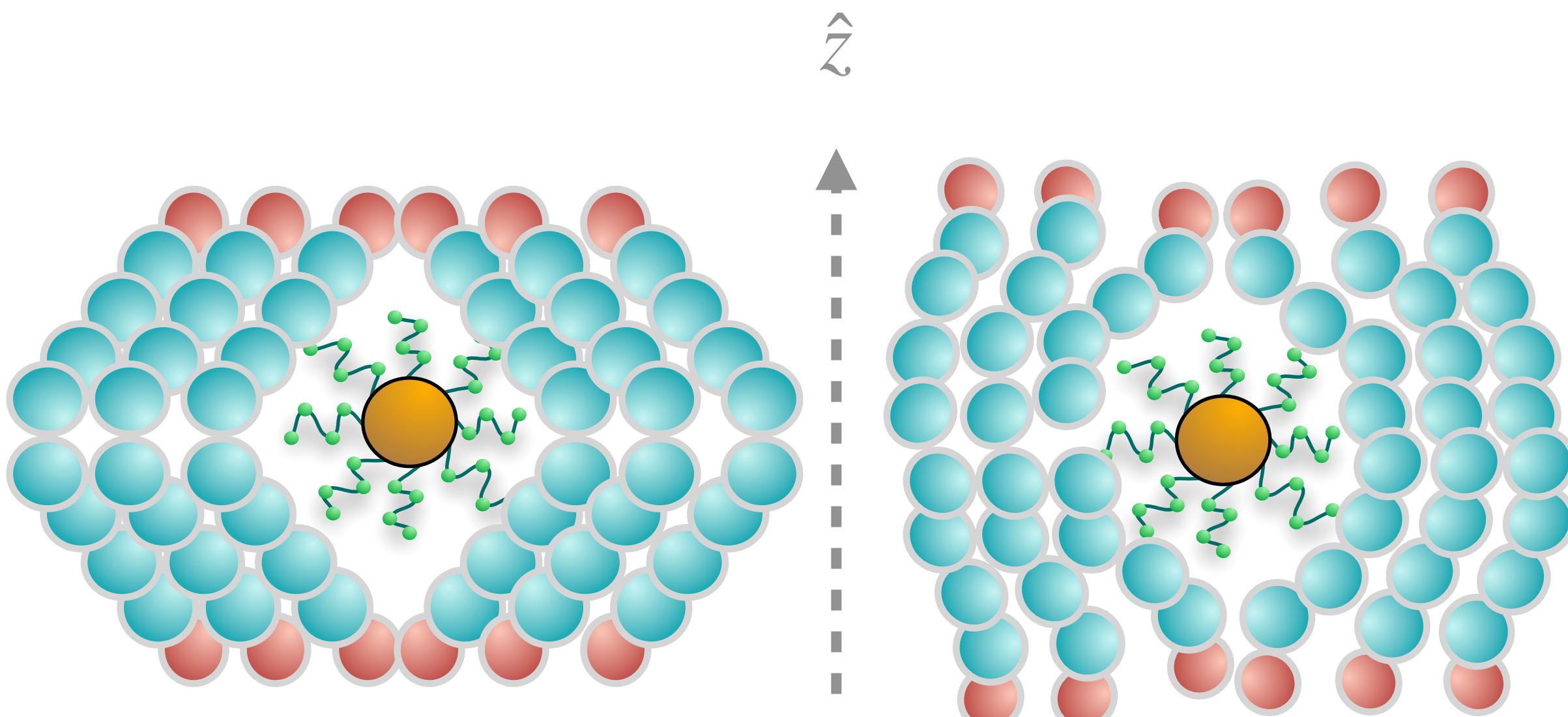
# Aggregation Behavior is Sensitive to Ligand Length and Core Parameter



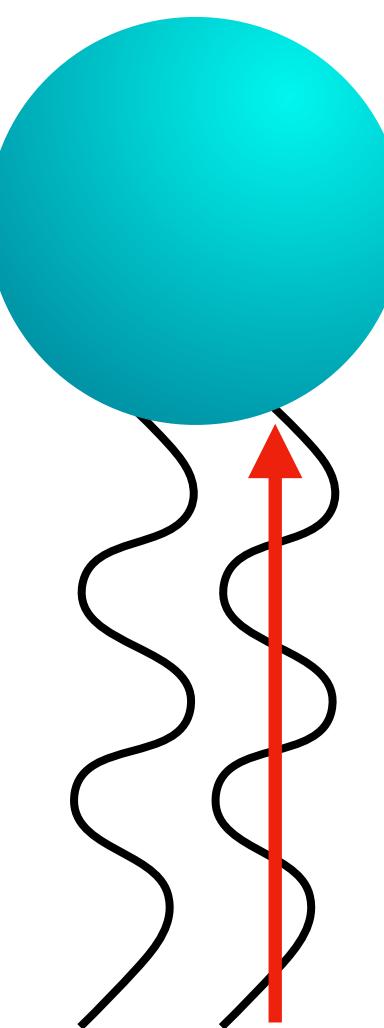
**Question 2: How does increasing ligand length affect lipid order?**

# How Do We Quantify Lipid Deformation?

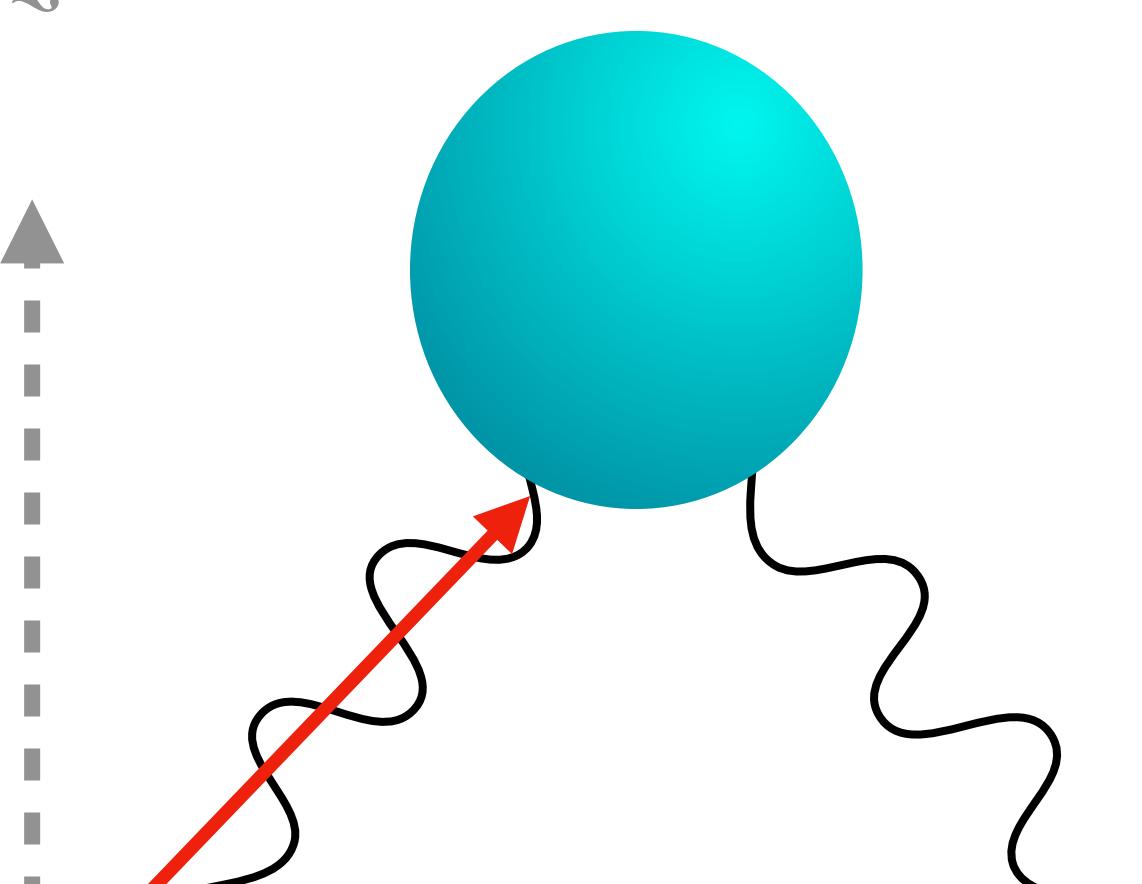
Ligand induced lipid deformation



Orderly lipids



Disorderly lipids

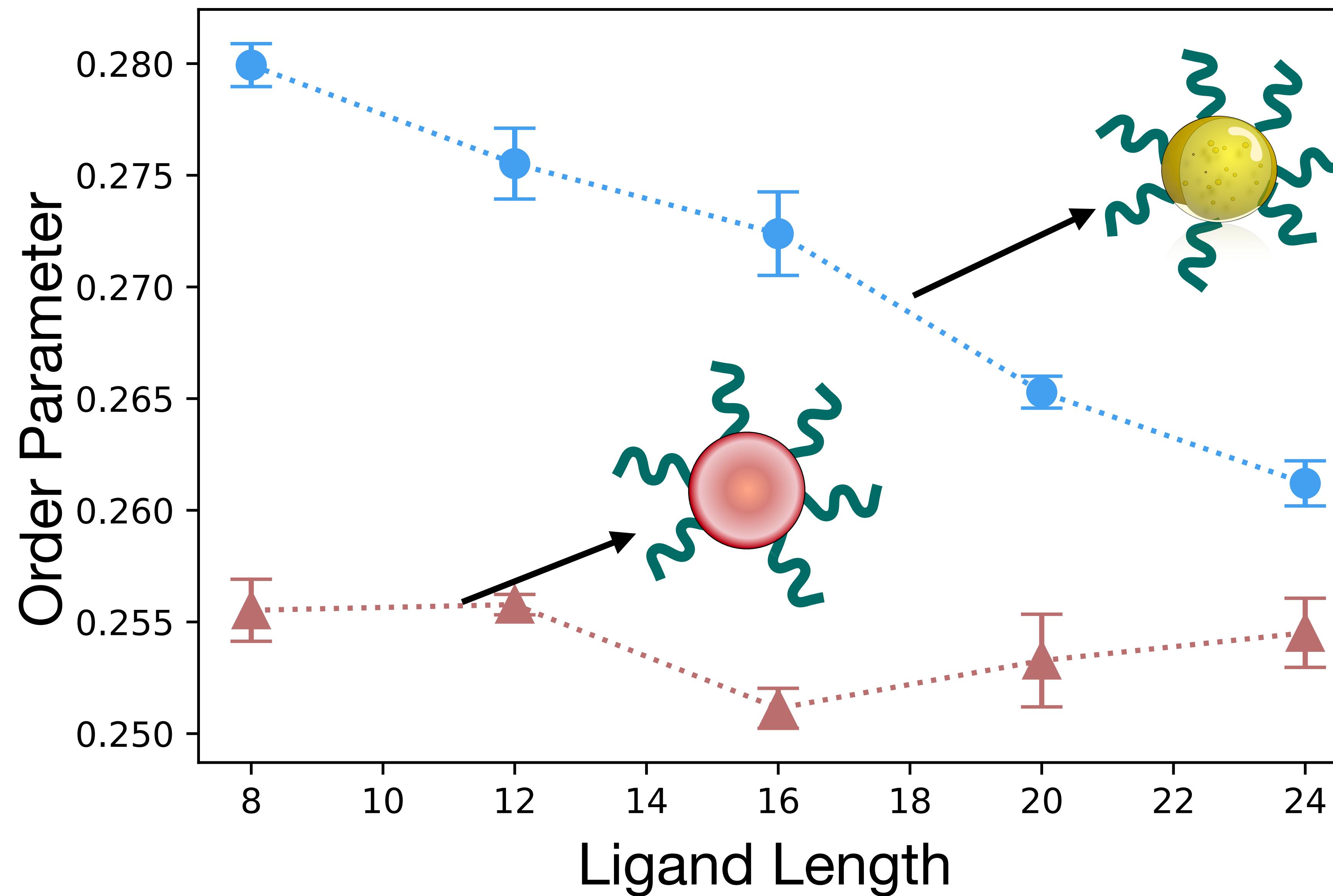


1: Completely Ordered

-0.5 : Completely Disordered

$$S_C = \frac{1}{2} \langle 3\cos\theta \rangle - 1$$

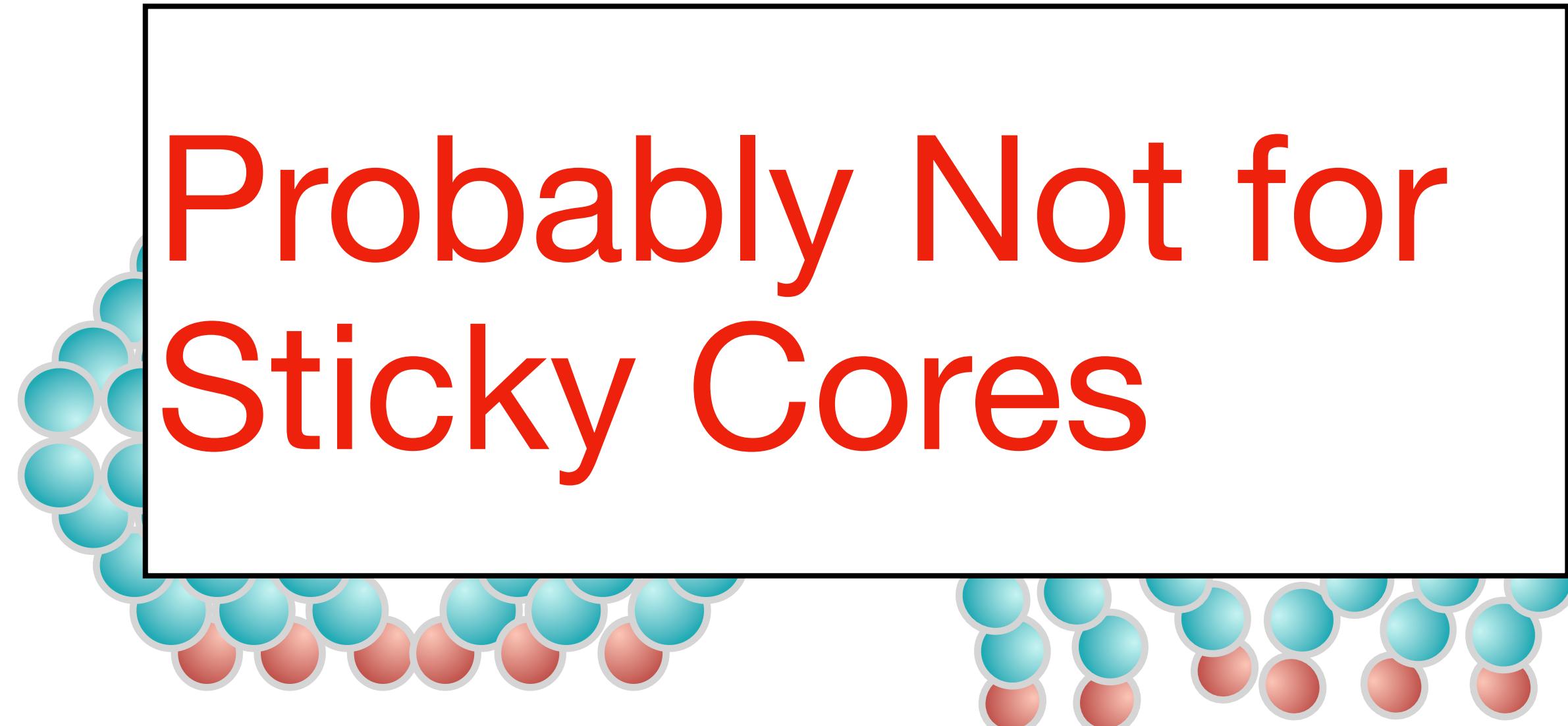
# Do longer ligands decrease lipid order?



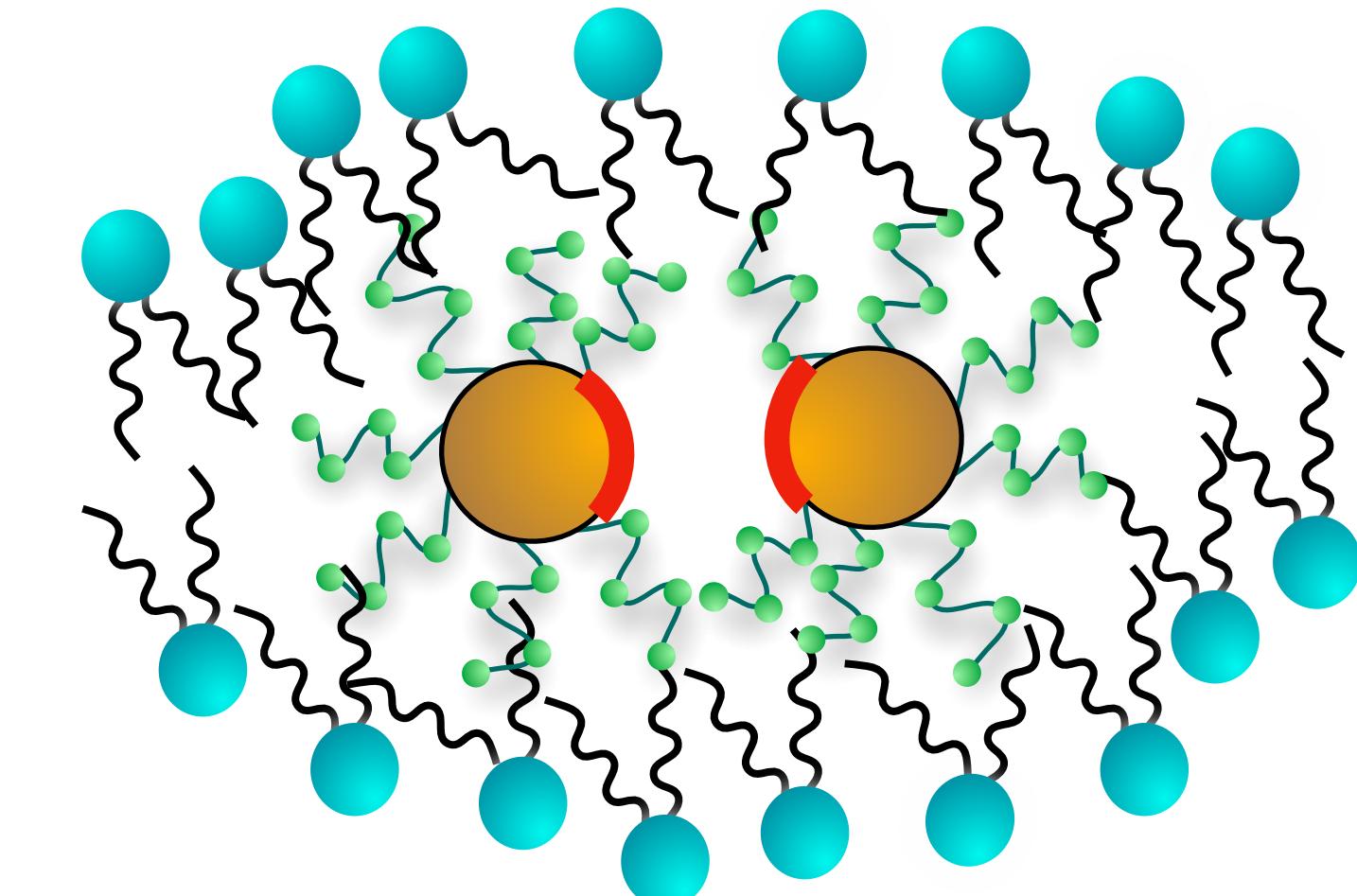
# Possible Aggregation Mechanisms

- Question: What is the mechanism of ligand coated gold nanoparticle aggregation in lipid membranes?
- Tool: Coarse Grained Molecular Dynamics
- Possible Mechanisms:

Ligand induced lipid deformation

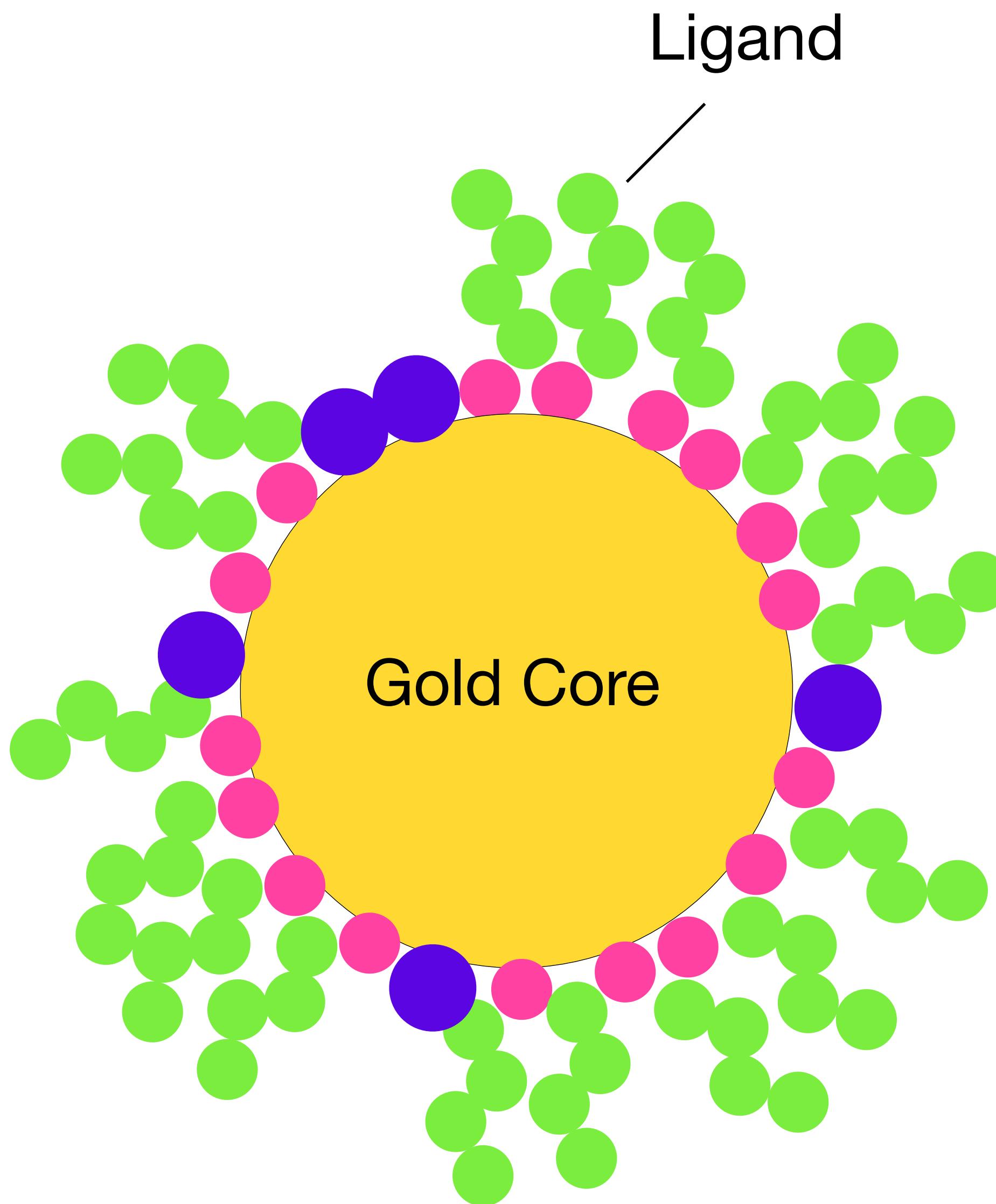


Gold-Gold interactions



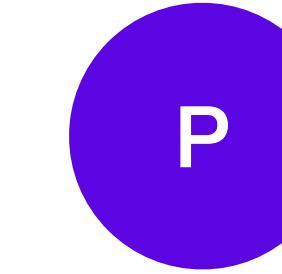
**Question 3: How does changing gold core parameter affect core exposure?**

# Quantifying the Exposed Surface Area

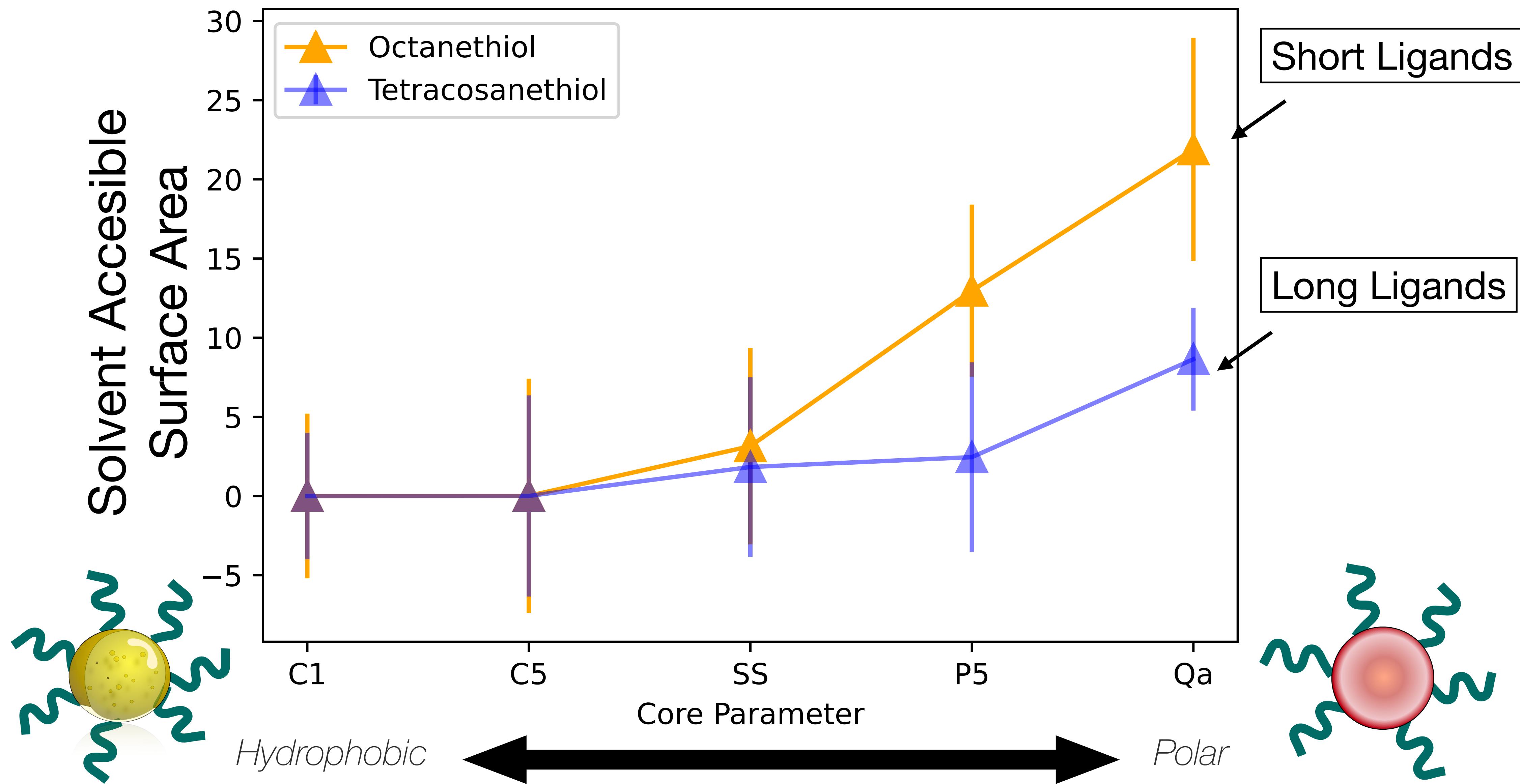


$$sasa = 4\pi r^2 p$$

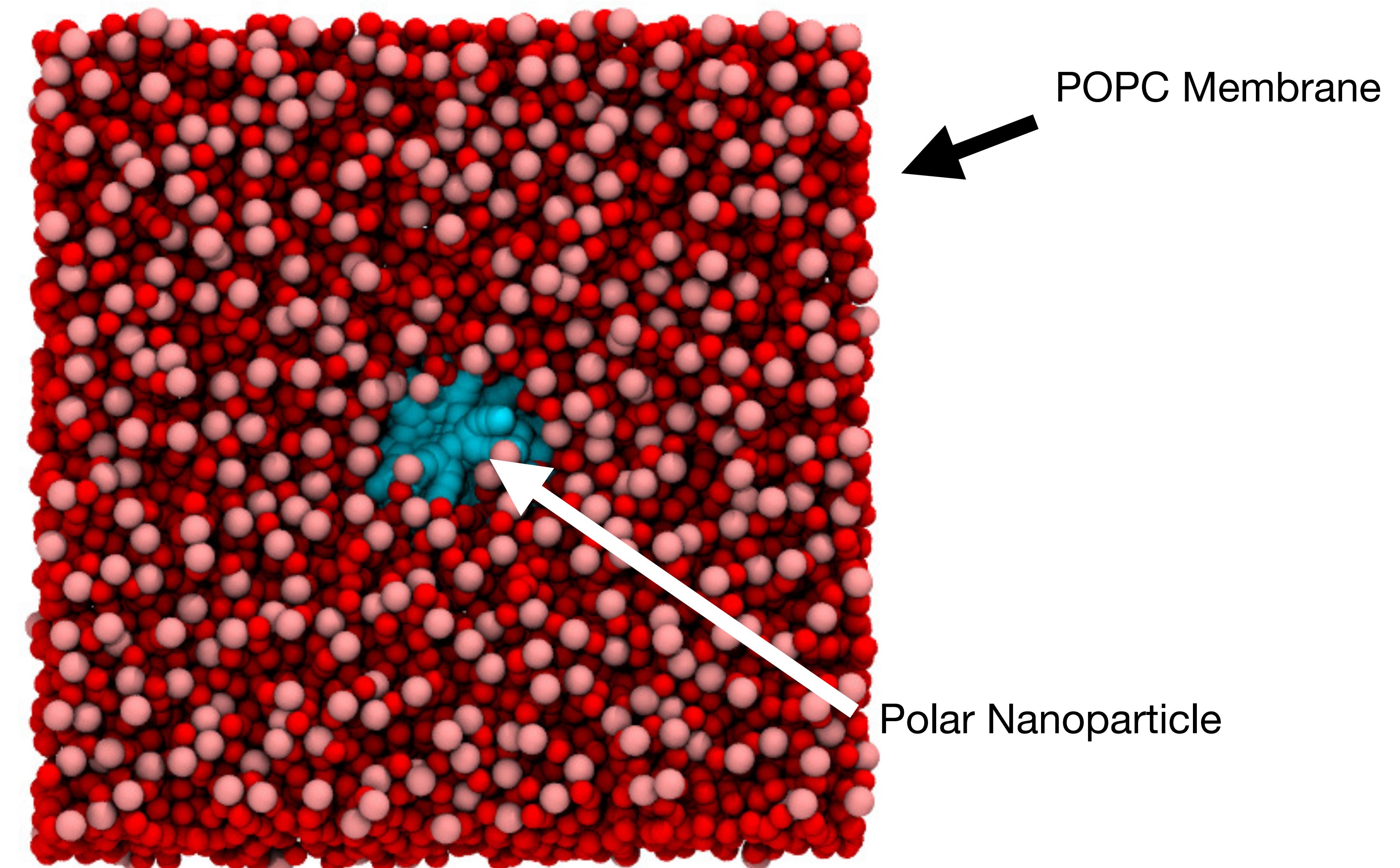
$p$  = # of probes



# Core polarity increases surface accessibility of nanoparticles embedded in the membrane

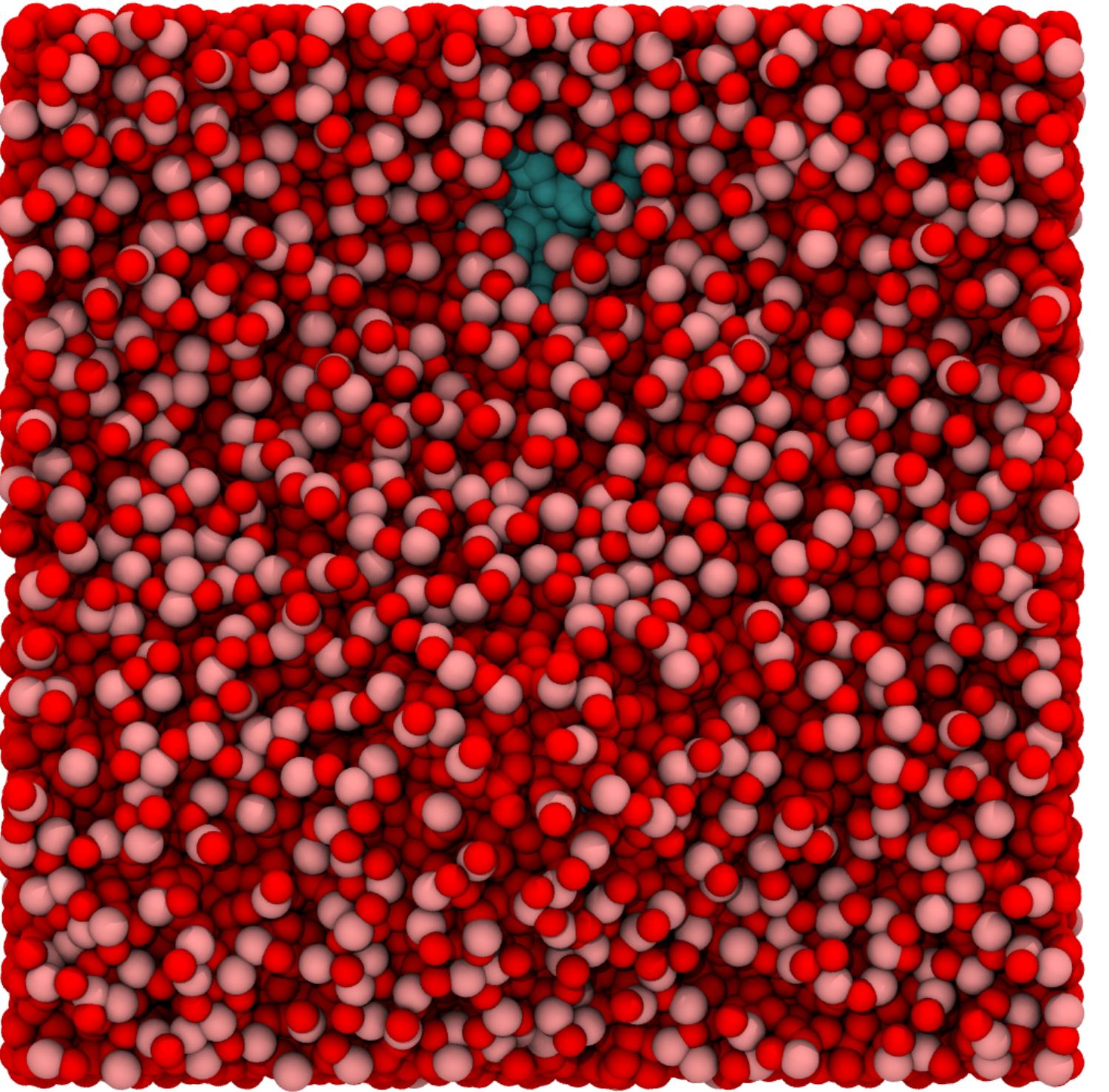


# Increasing Nanoparticle Polarity Leads to Pore Formation In Single Nanoparticle Systems

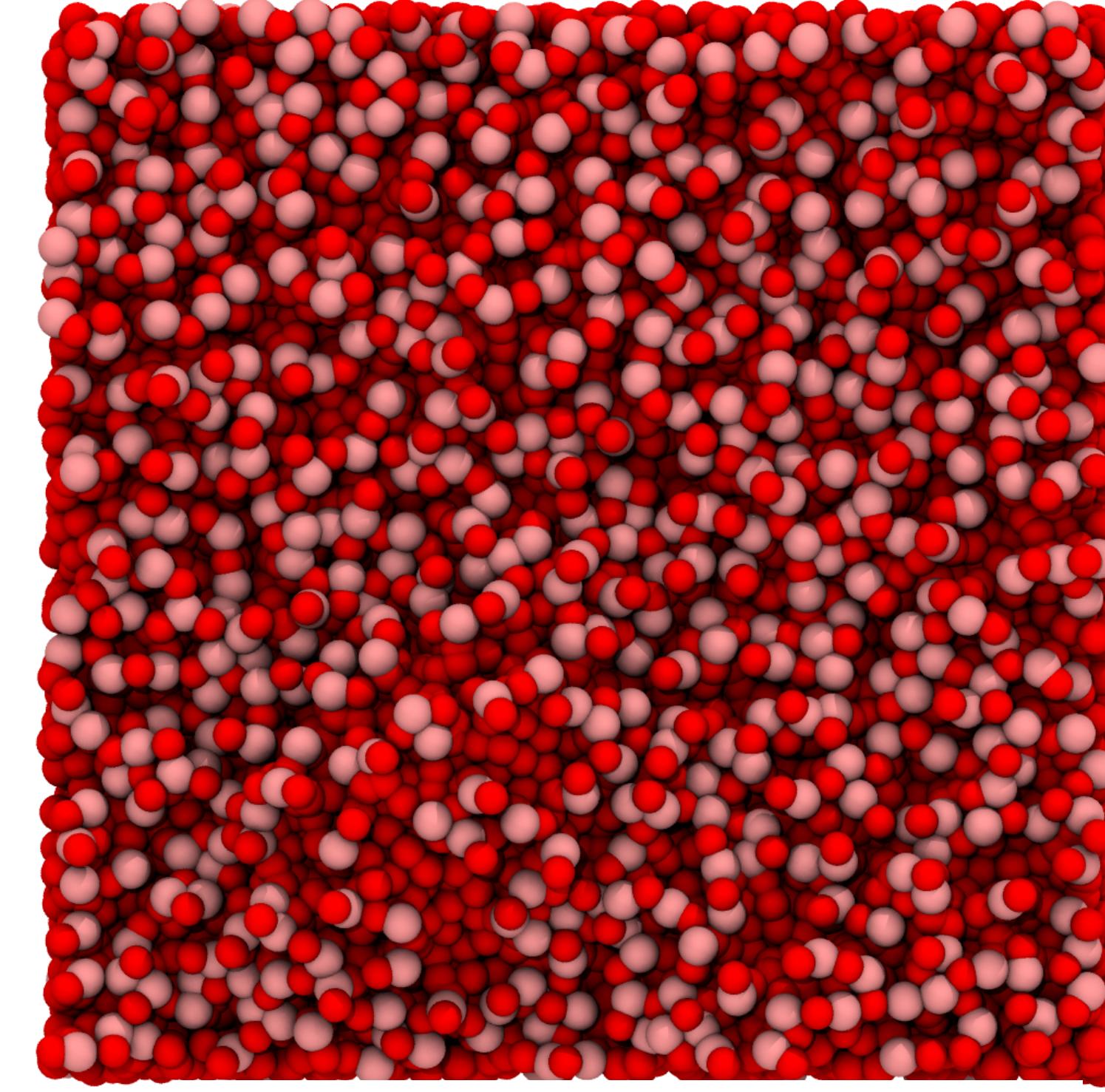


# Aggregation Minimizes Pore Formation and Shifts Polar Interactions From Solvent to Gold Cores

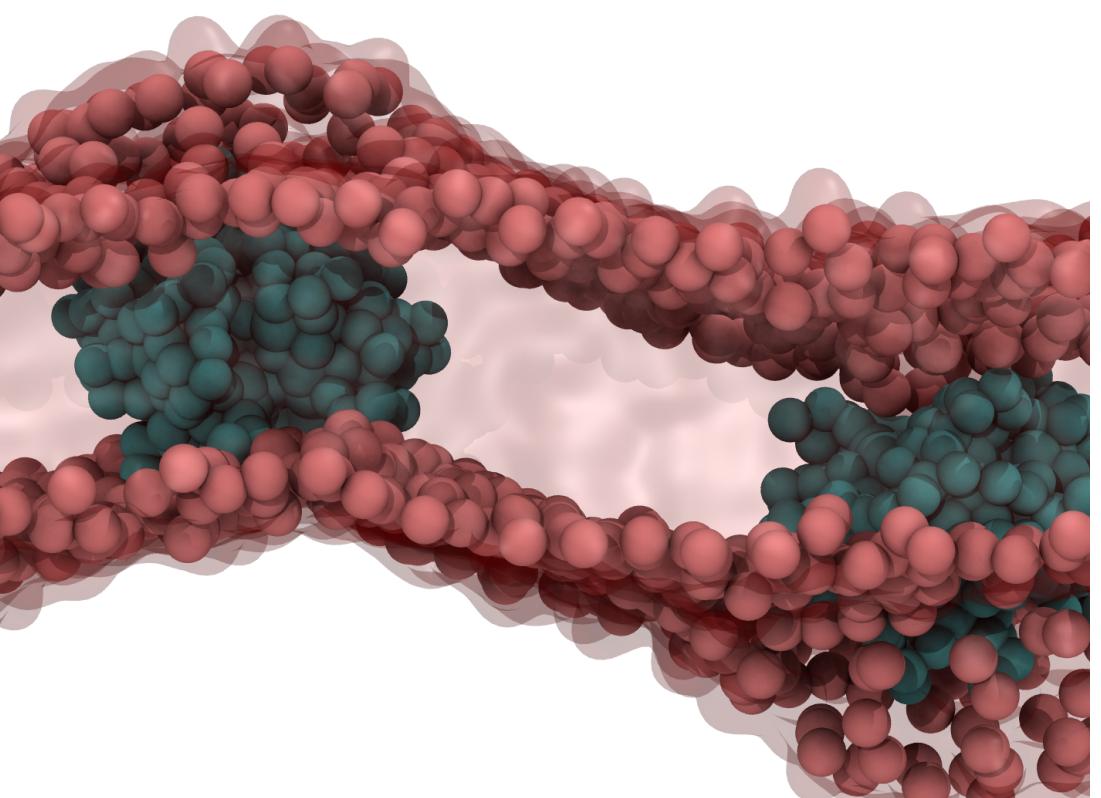
Non-Aggregated( $1\mu s$ )



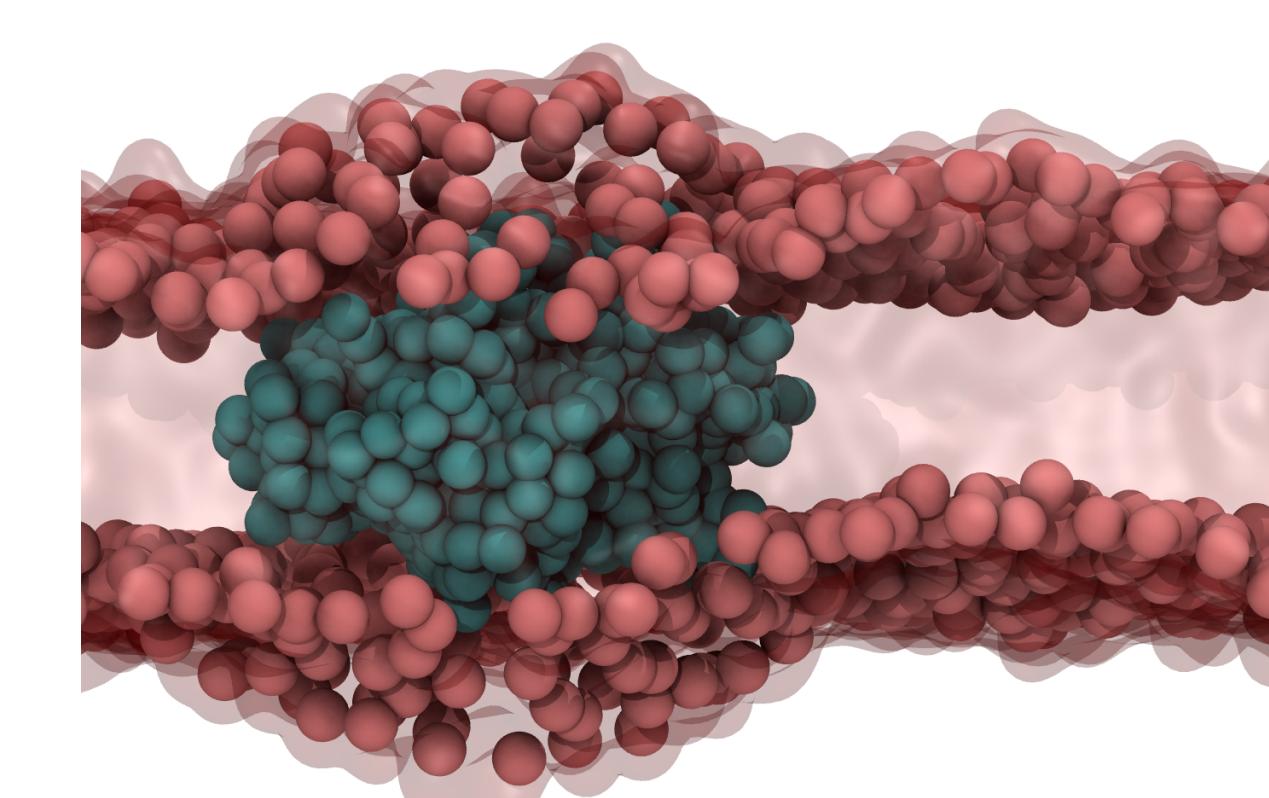
Aggregated( $5\mu s$ )



Top View



Side View



# Possible Aggregation Mechanisms

- Question: What is the mechanism of ligand coated gold nanoparticle aggregation in lipid membranes?
- Tool: Coarse Grained Molecular Dynamics
- Possible Mechanisms:

Ligand induced lipid deformation

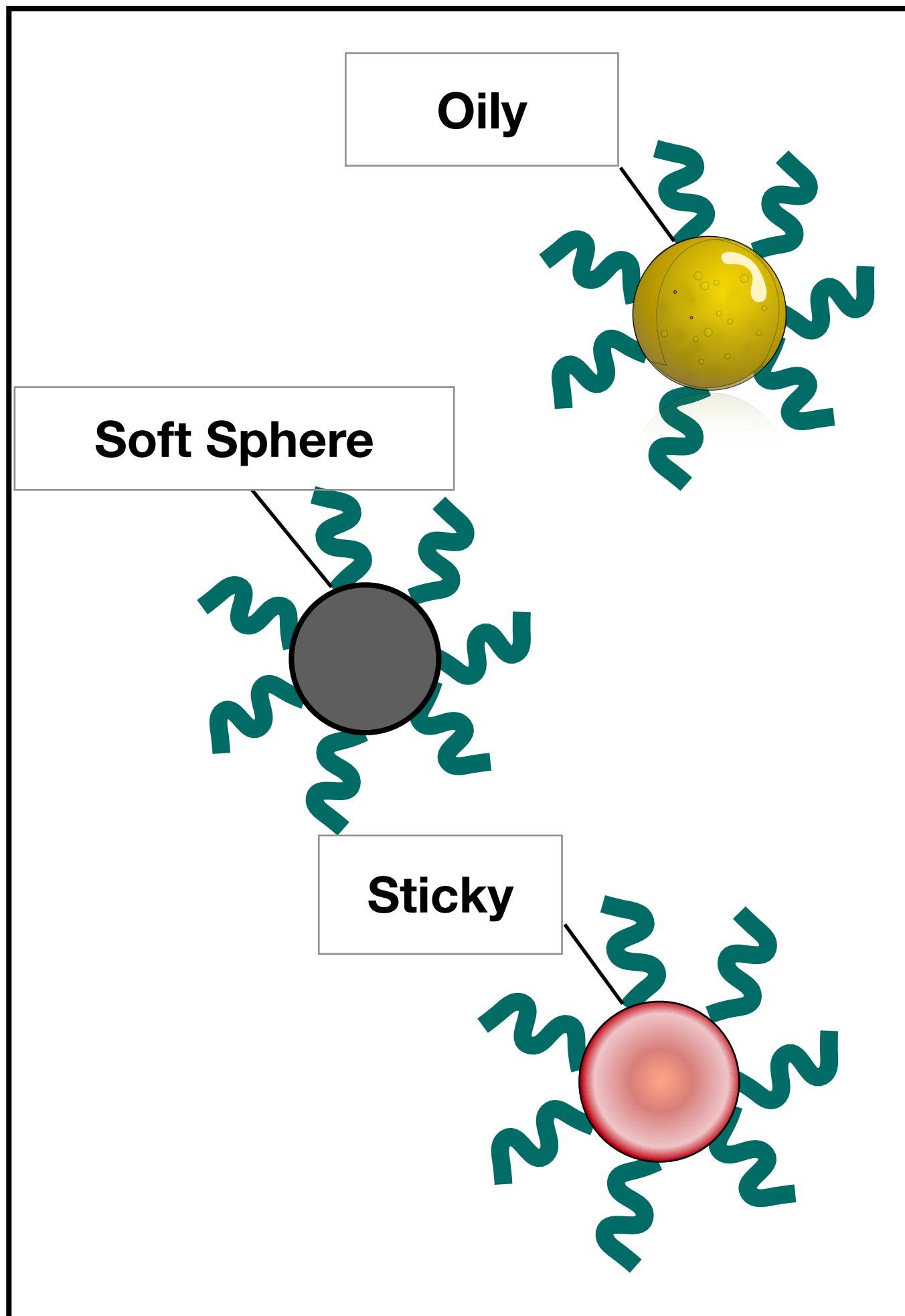
Gold-Gold interactions

Probably Not for  
Sticky Cores

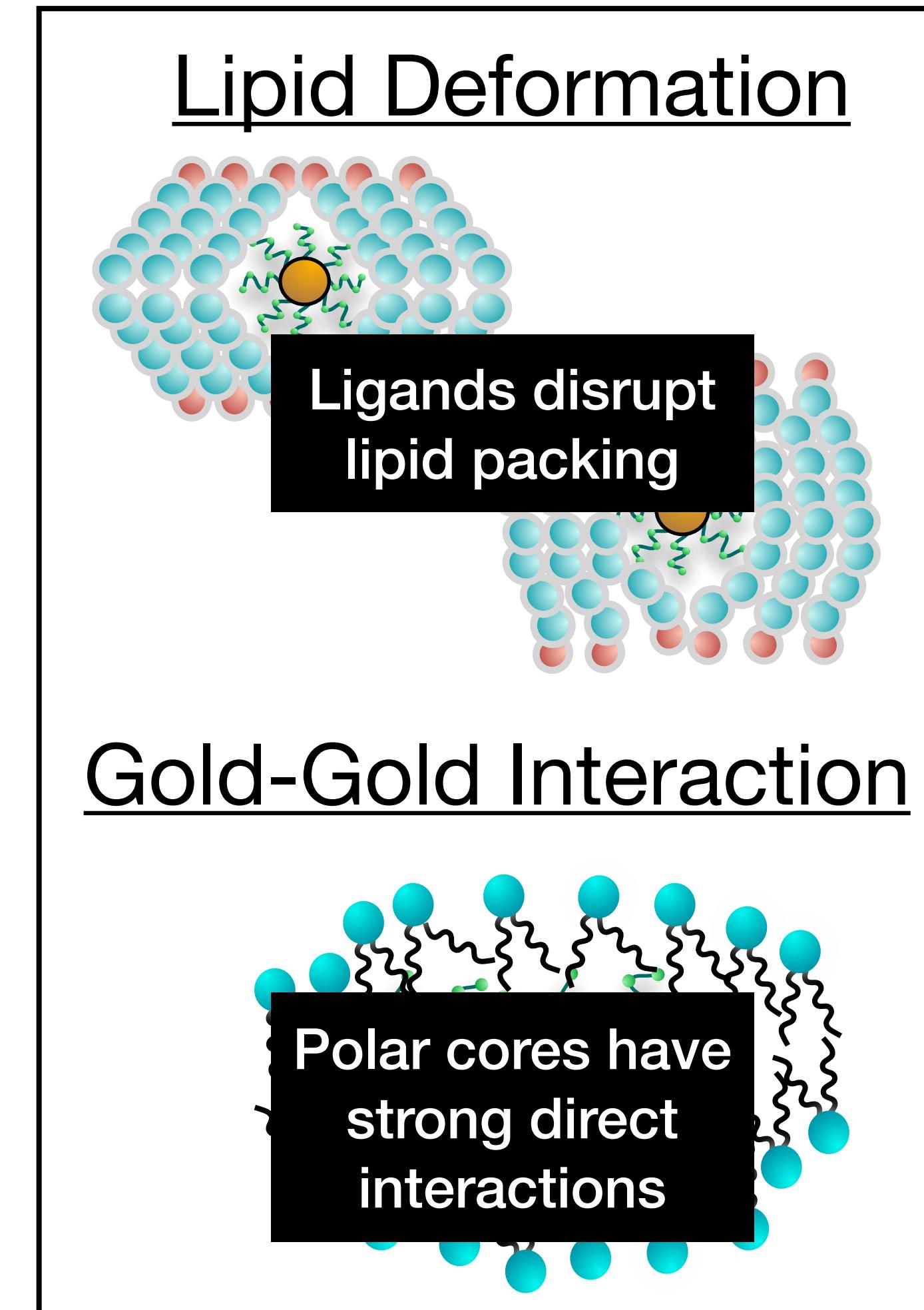
Some Evidence  
For Direct Gold-  
Gold Interaction

# Summary

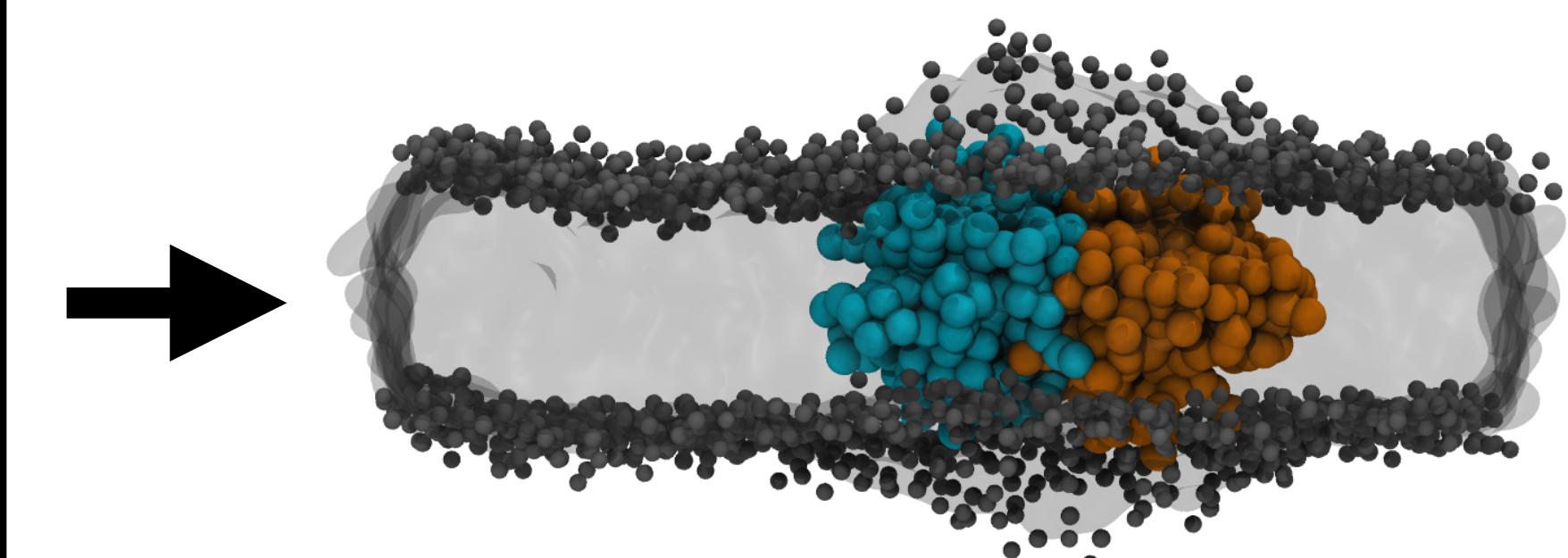
Tested 3 different gold models and compared to experimental data

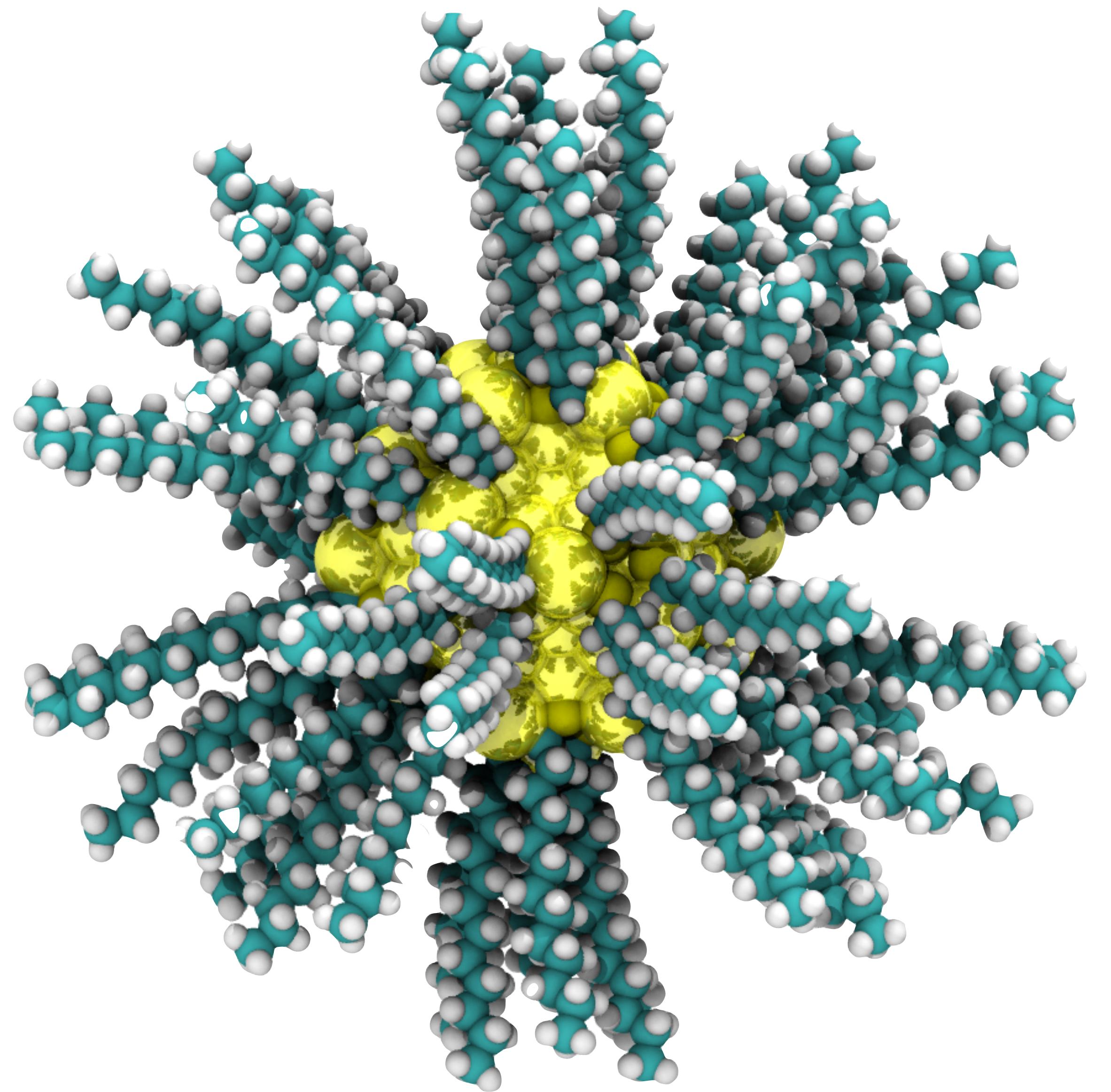


Tested two possible mechanisms



Gold-Gold Interaction is the main driving mechanism in sticky nanoparticles





# Acknowledgements



## PI

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- Dr. Julianne Griepenburg

## Brannigan Lab Members

- Jesse Sandberg
- Ezry St. Iago-McRae
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- Regina Salzer
- Lindsey Riggs
- Ryan Lamb

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- Rutgers OARC
- ACCESS
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