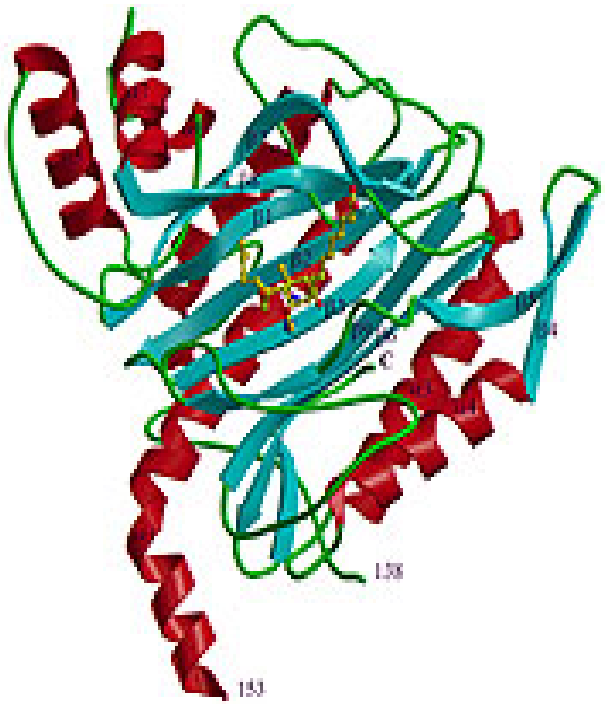
Some Physics for Proteins

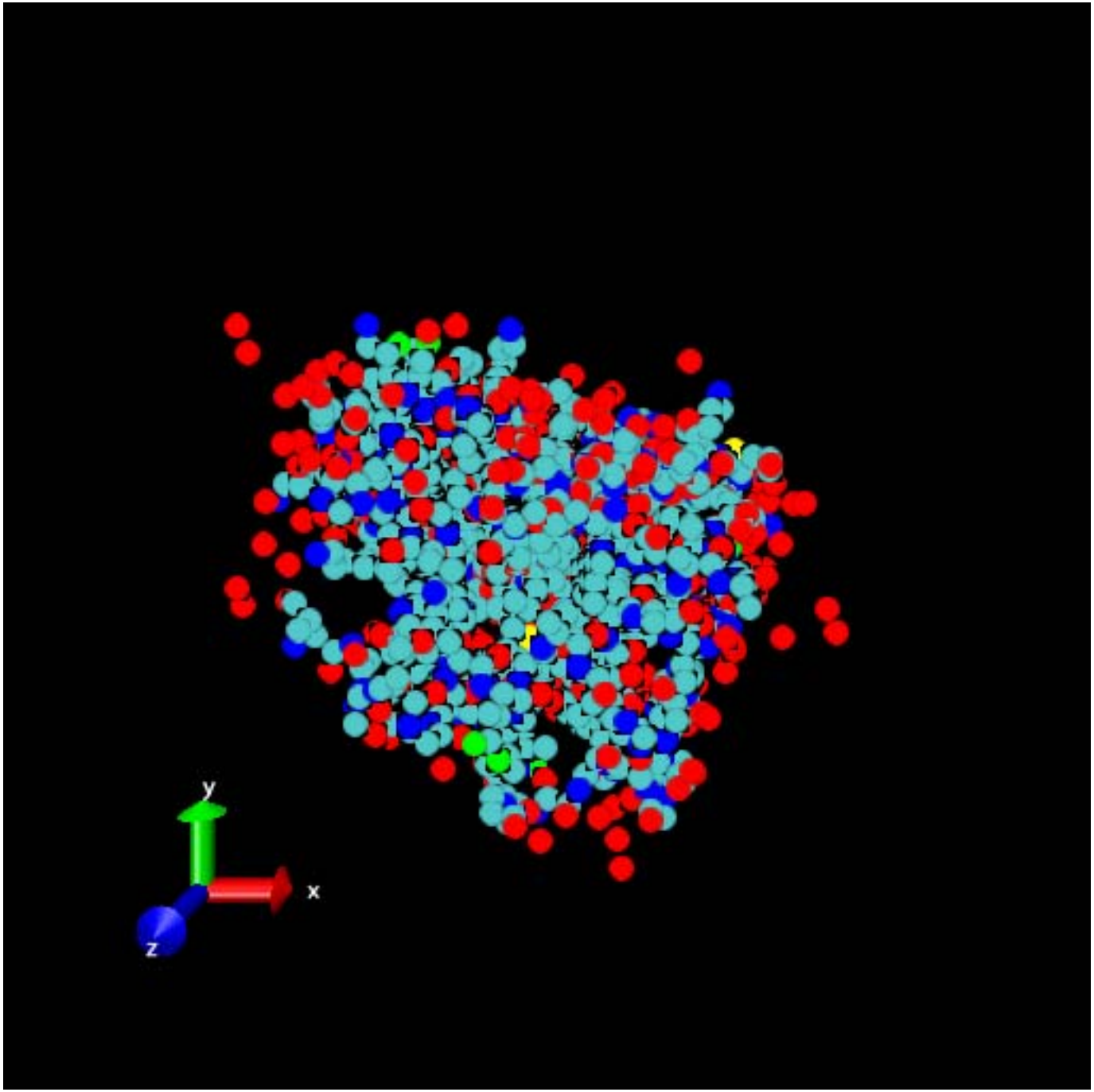


Stephen M. Durbin

Department of Physics

Purdue University

Friday, 27 July 2007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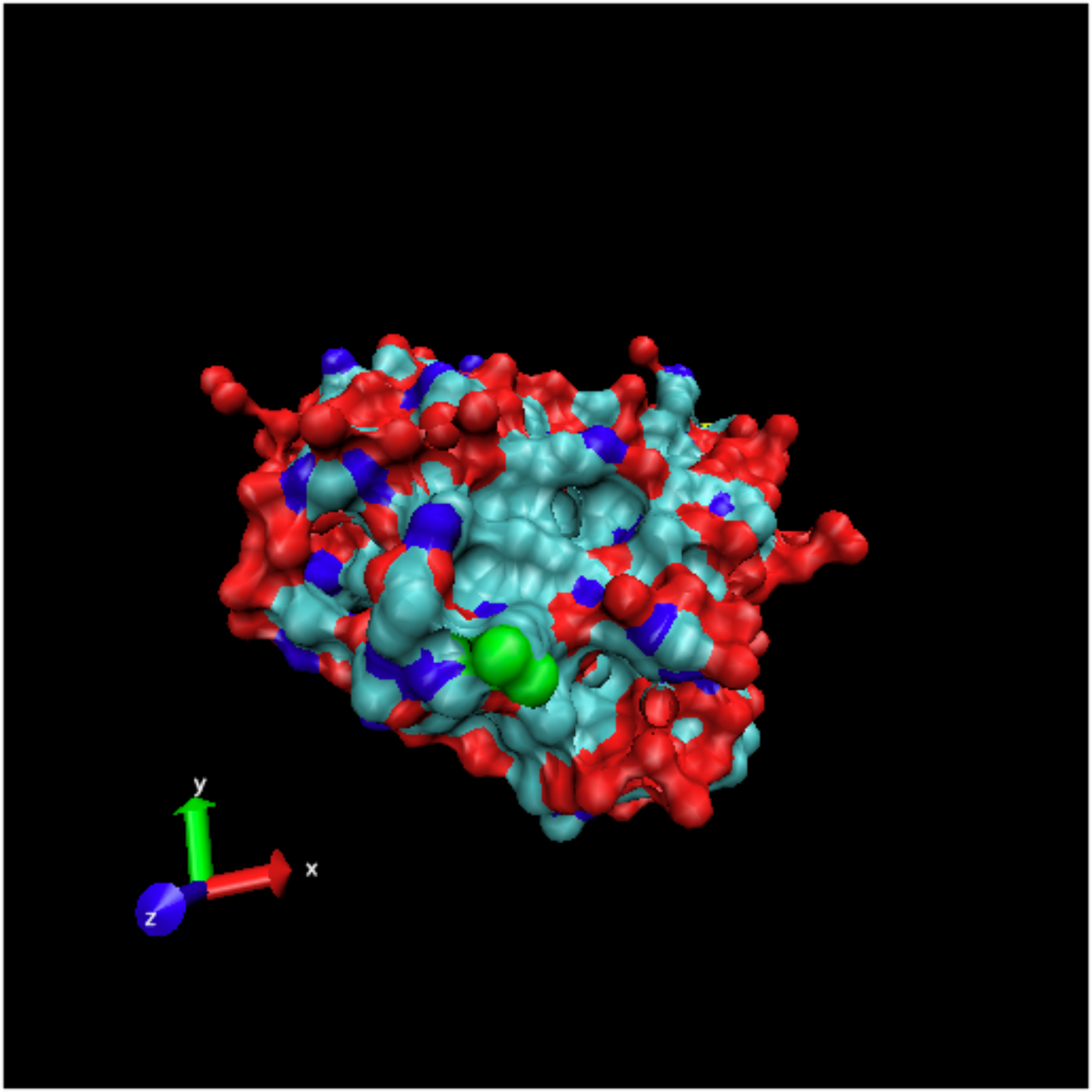
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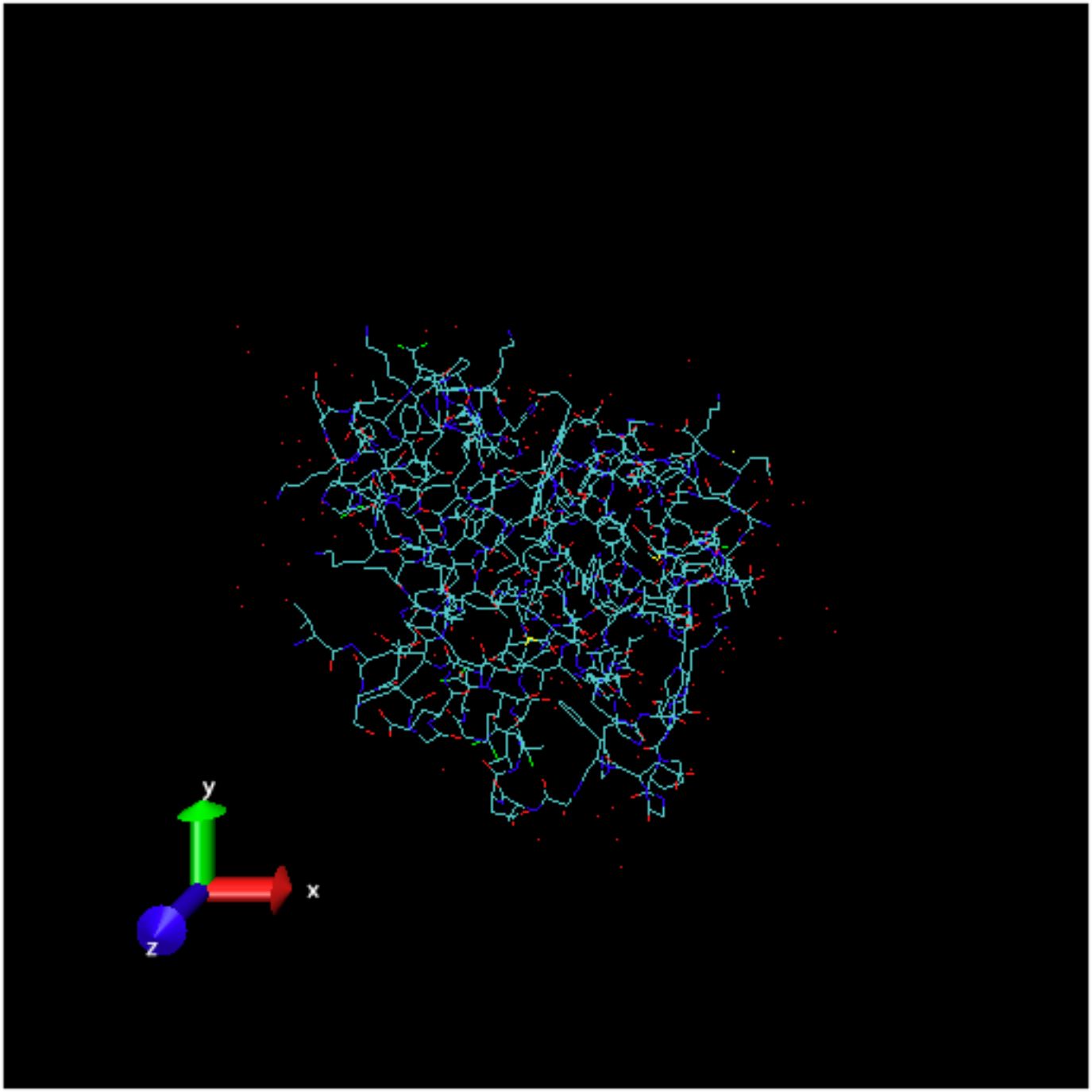
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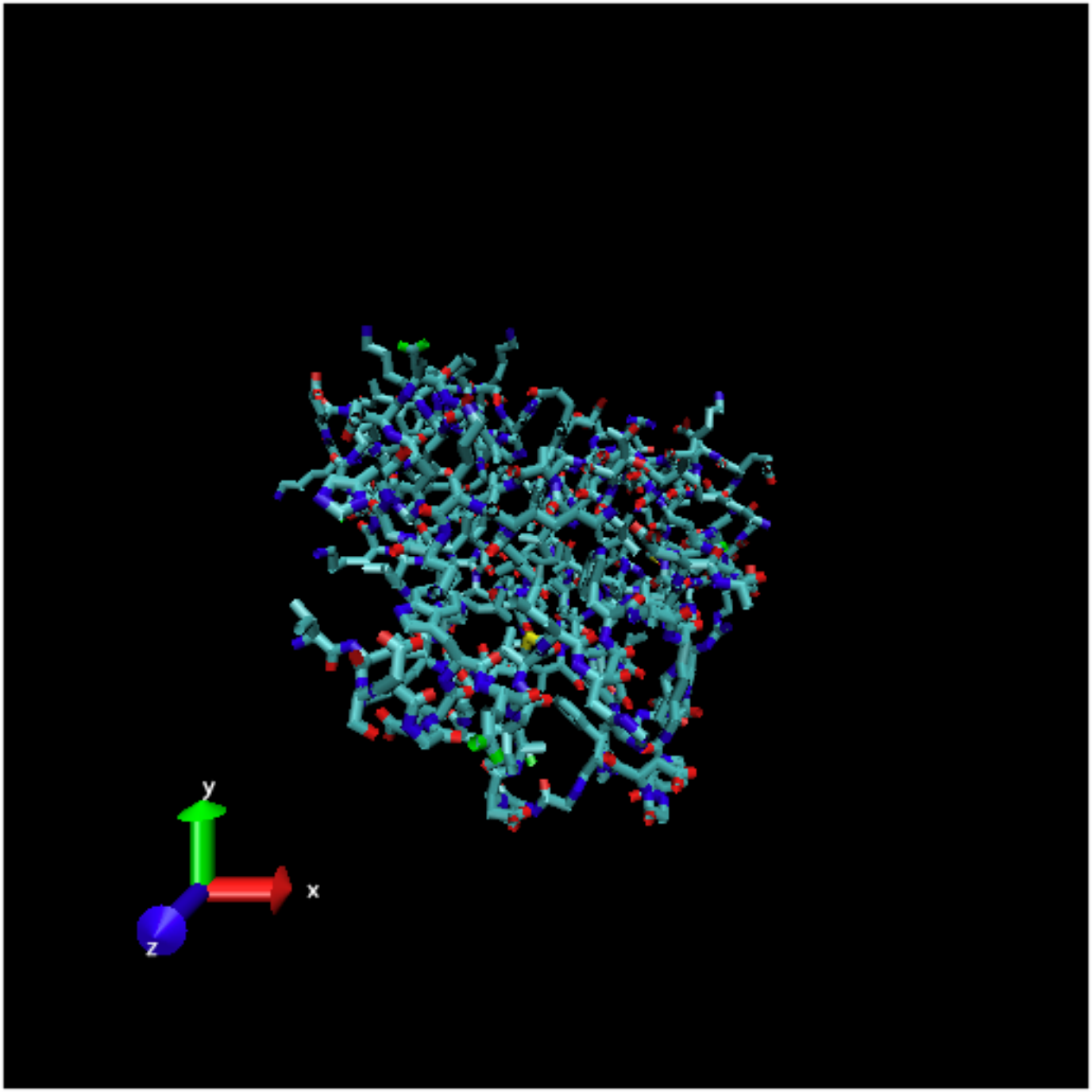
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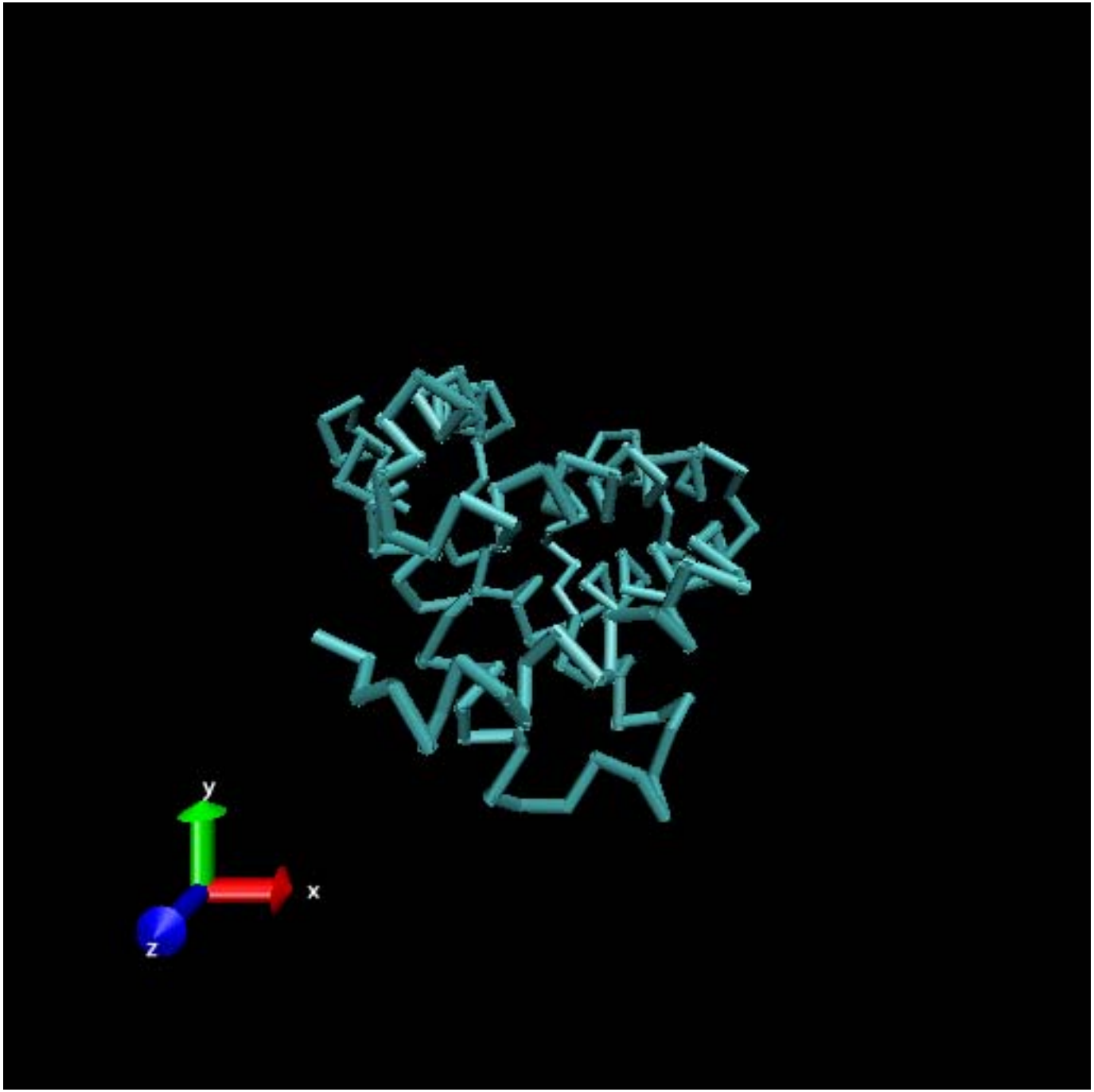
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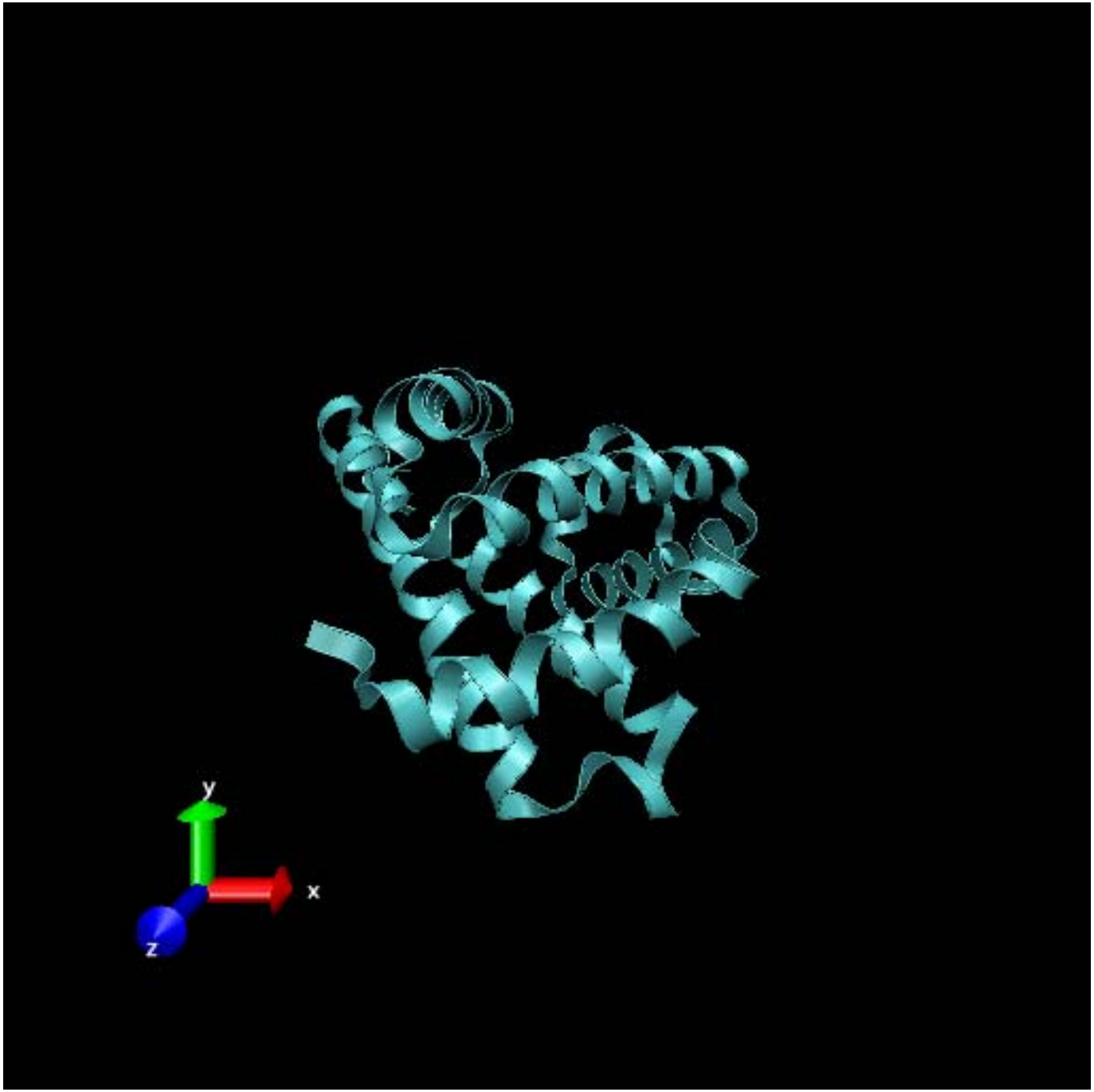
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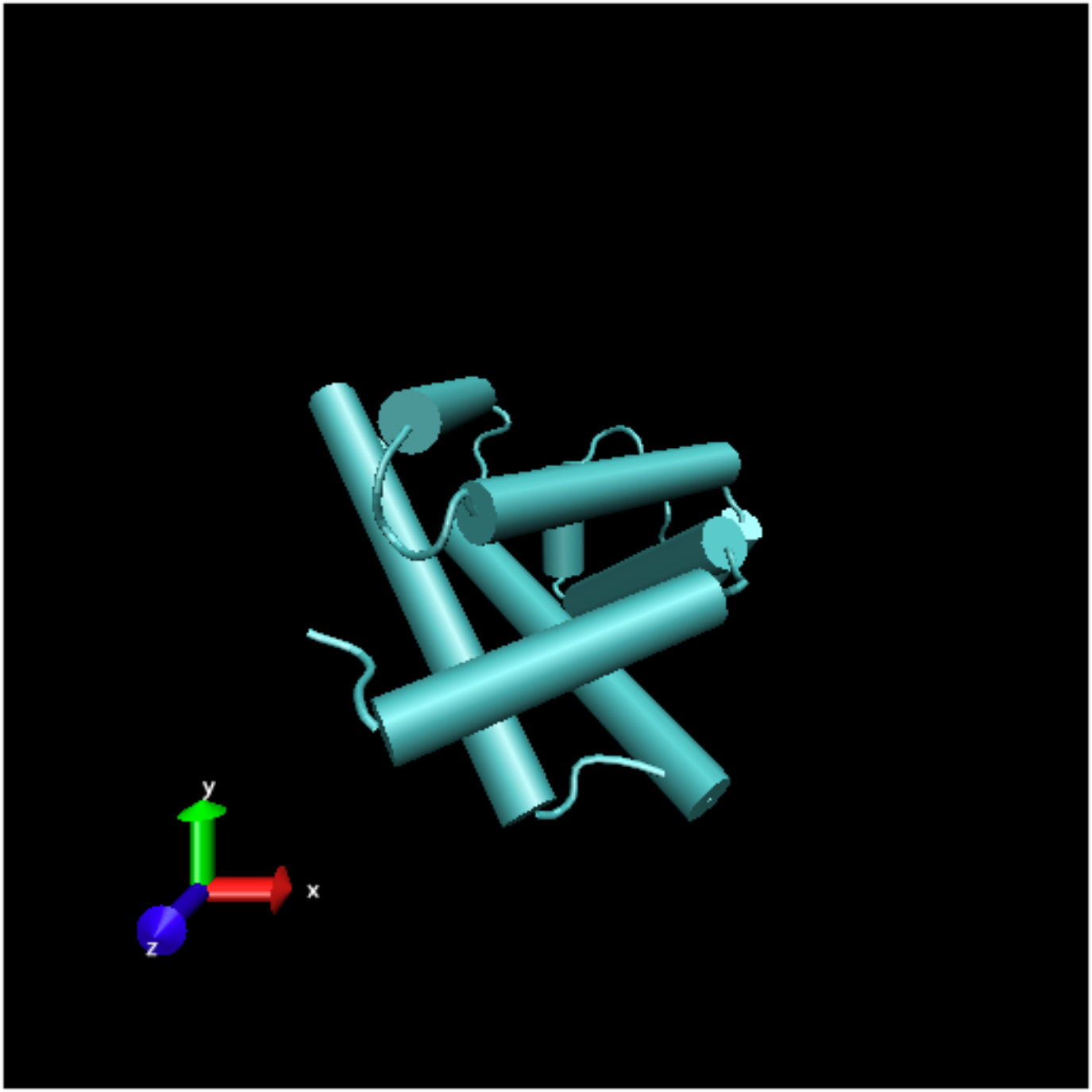
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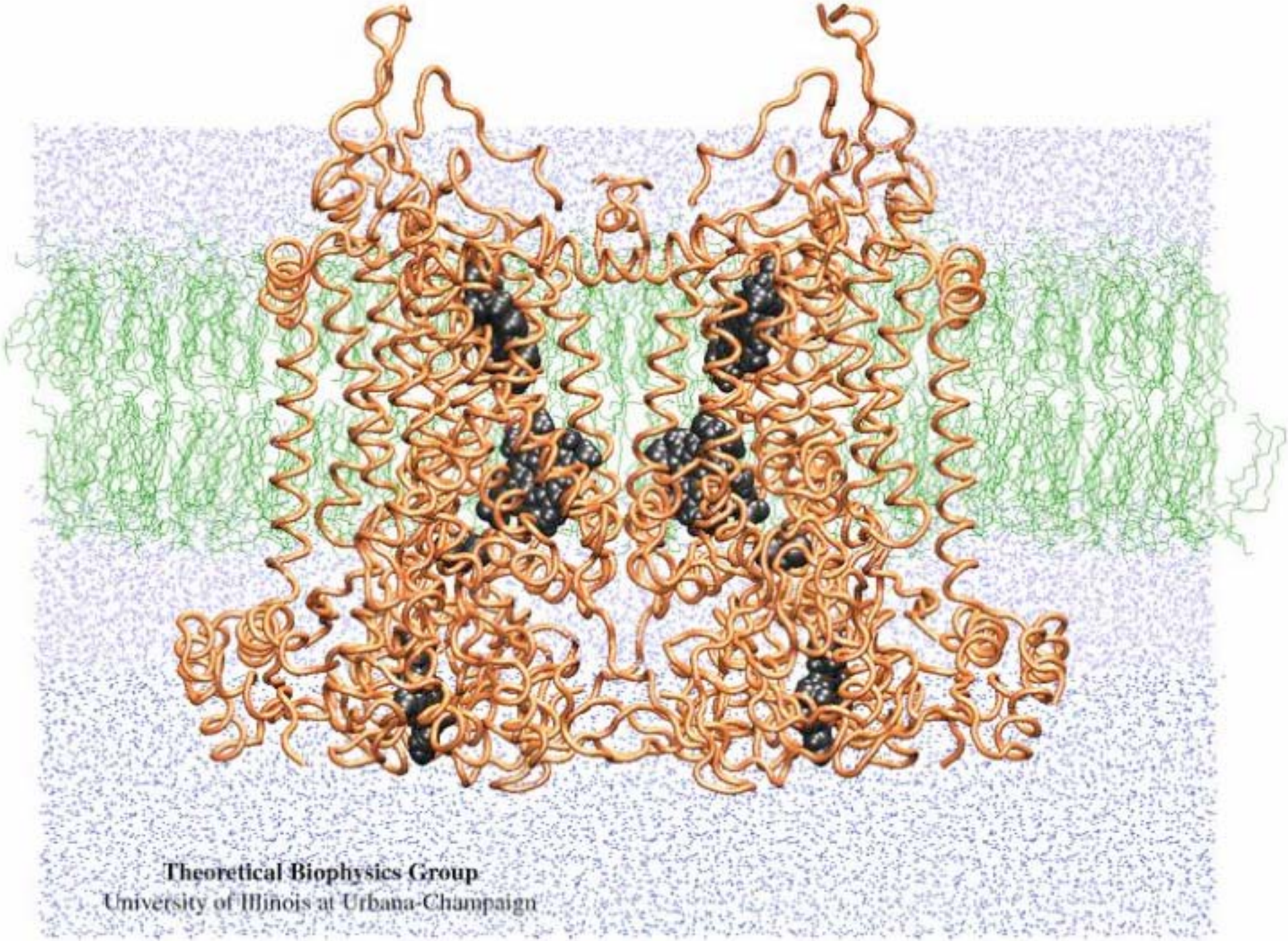
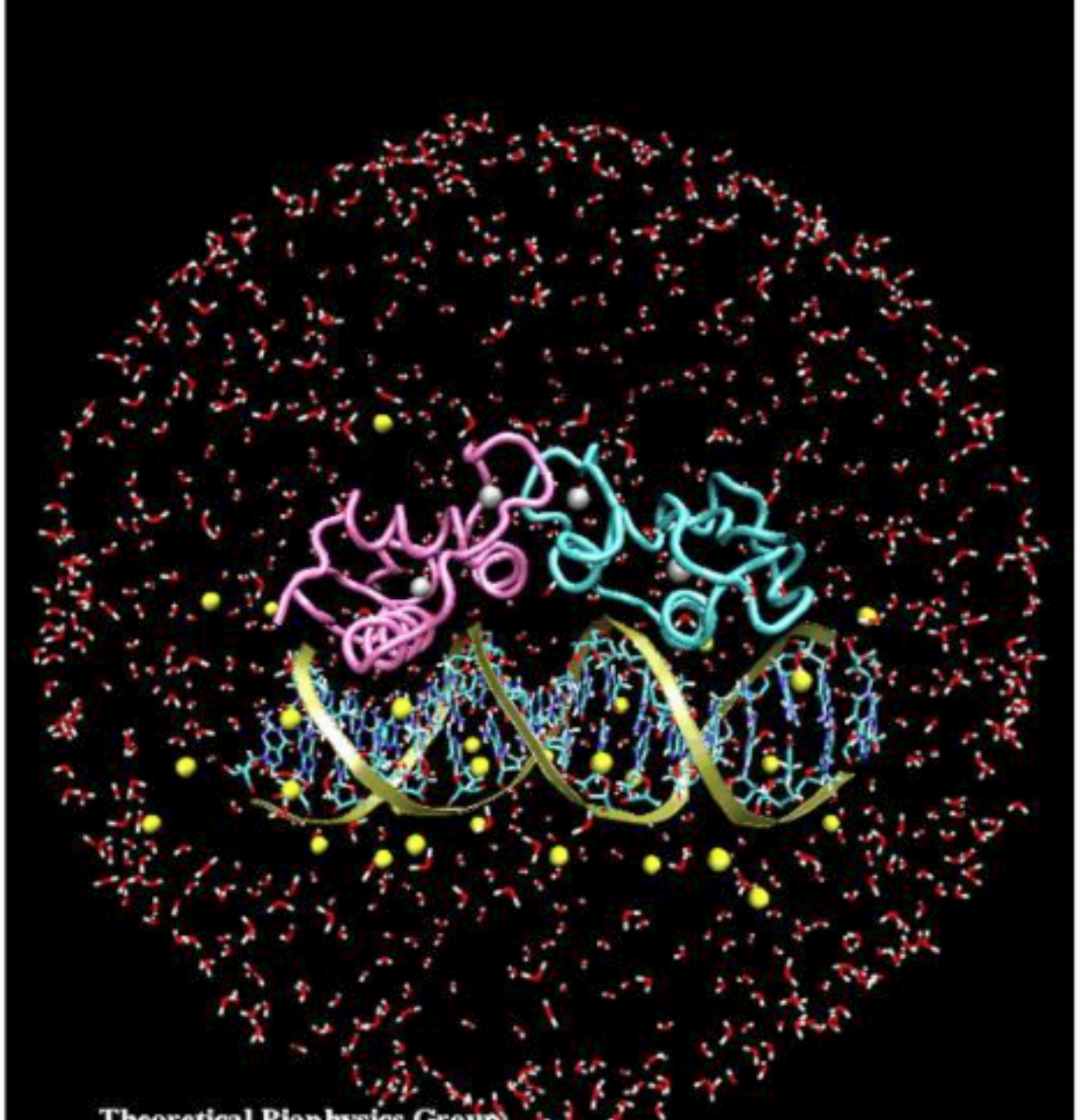
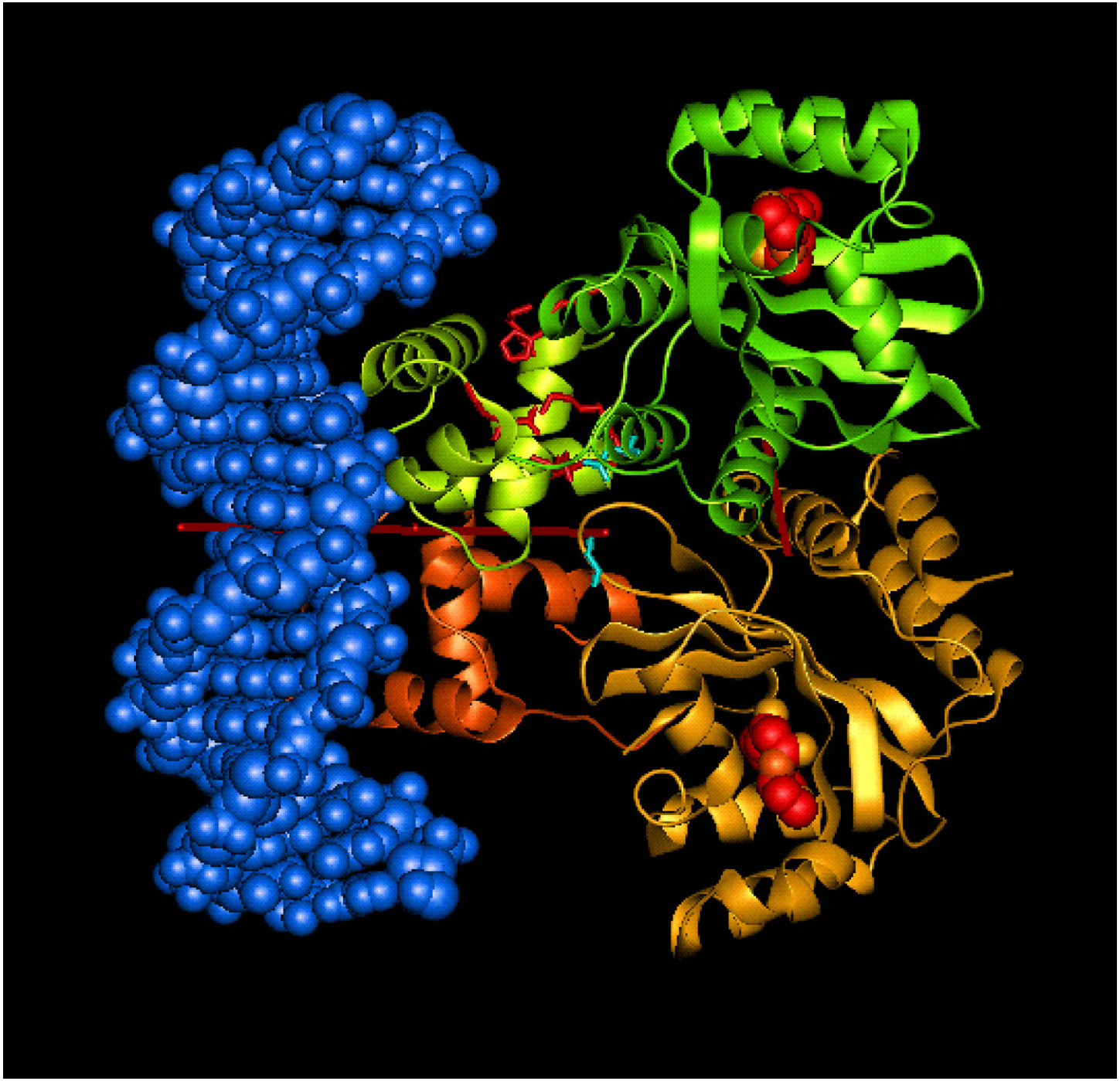
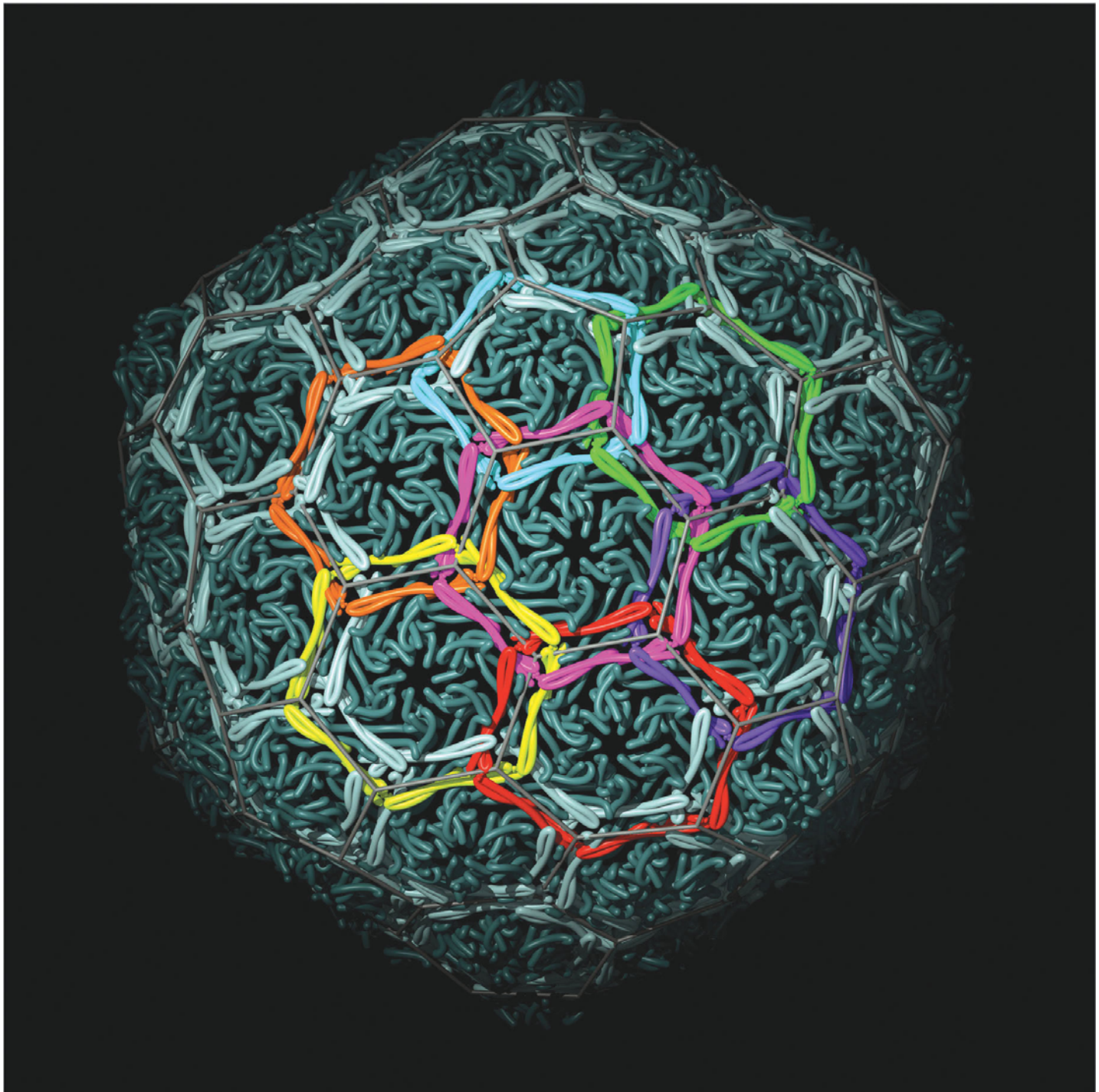

Theoretical Biophysics Group
University of Illinois at Urbana-Champaign

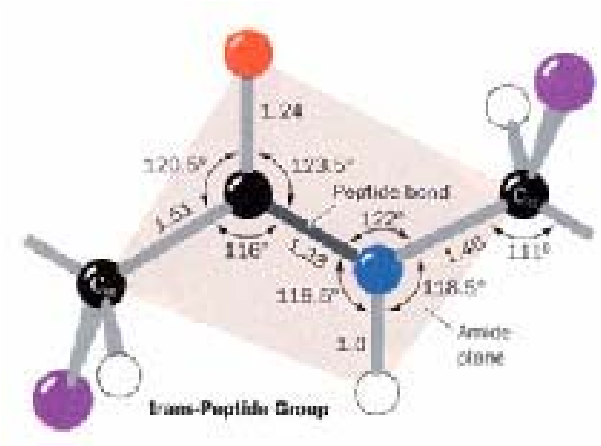


Theoretical Biophysics Group
Beckman Institute
University of Illinois at Urbana-Champaign

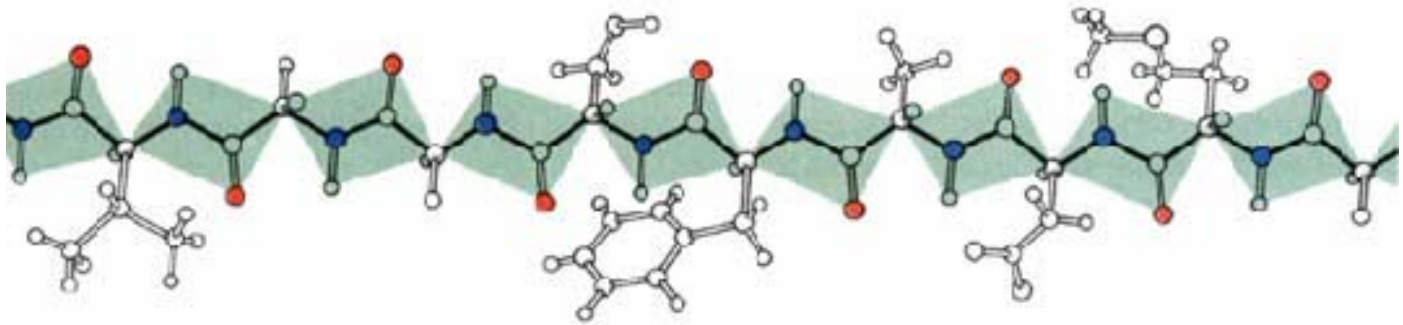


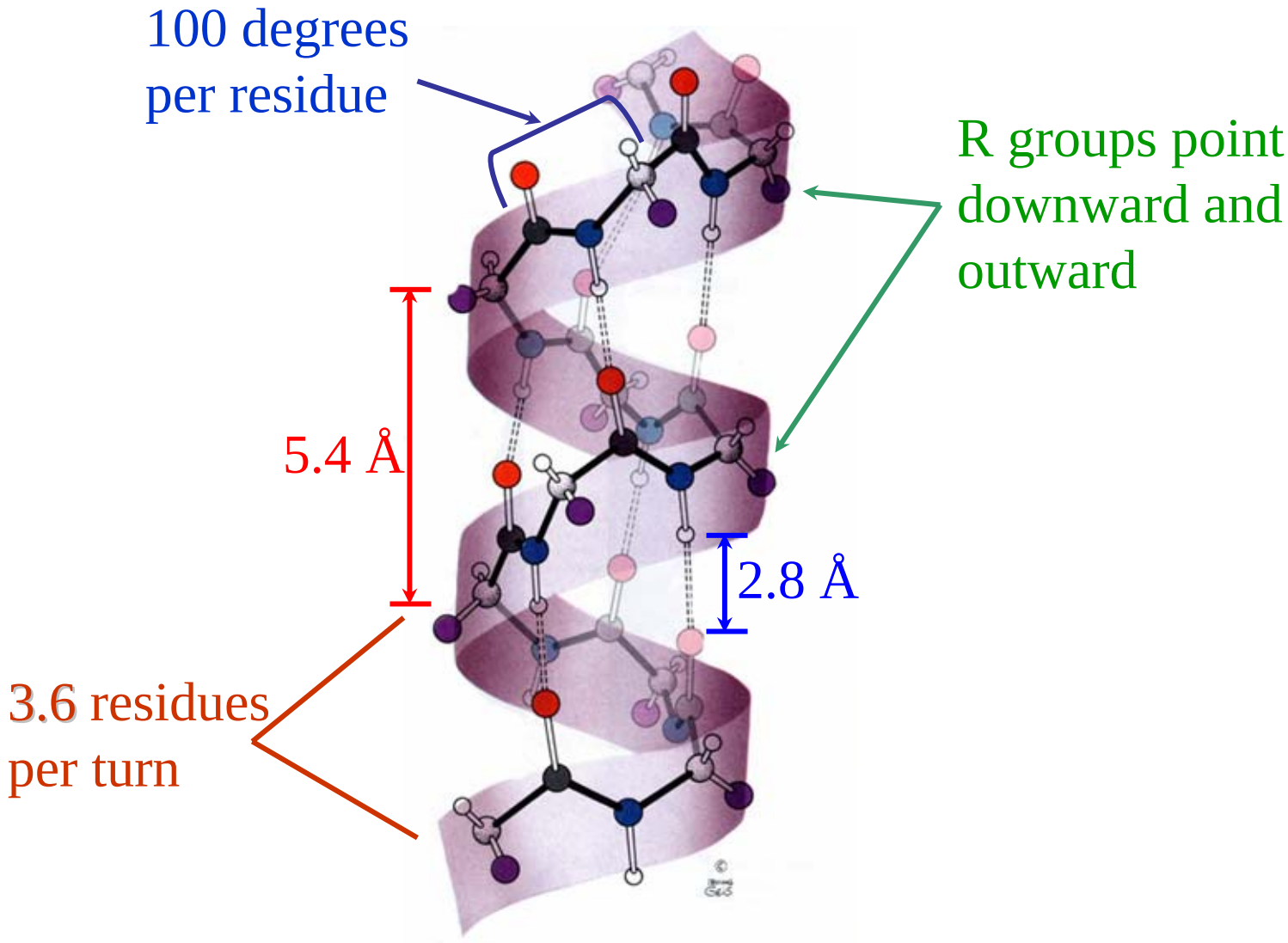


Peptide group



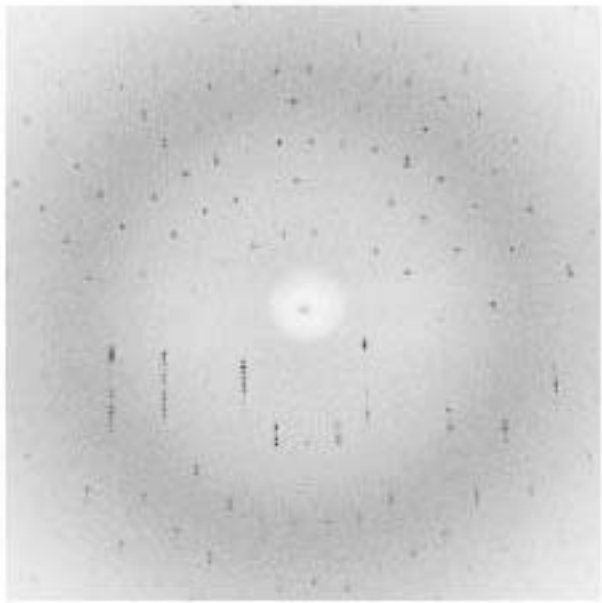
Fully extended polypeptide chain





other types of helices exist…


138
153



The Advanced Photon Source

James Maxwell 1860's

Shake electrons to make light!

1905: Einstein's Theory of Special Relativity

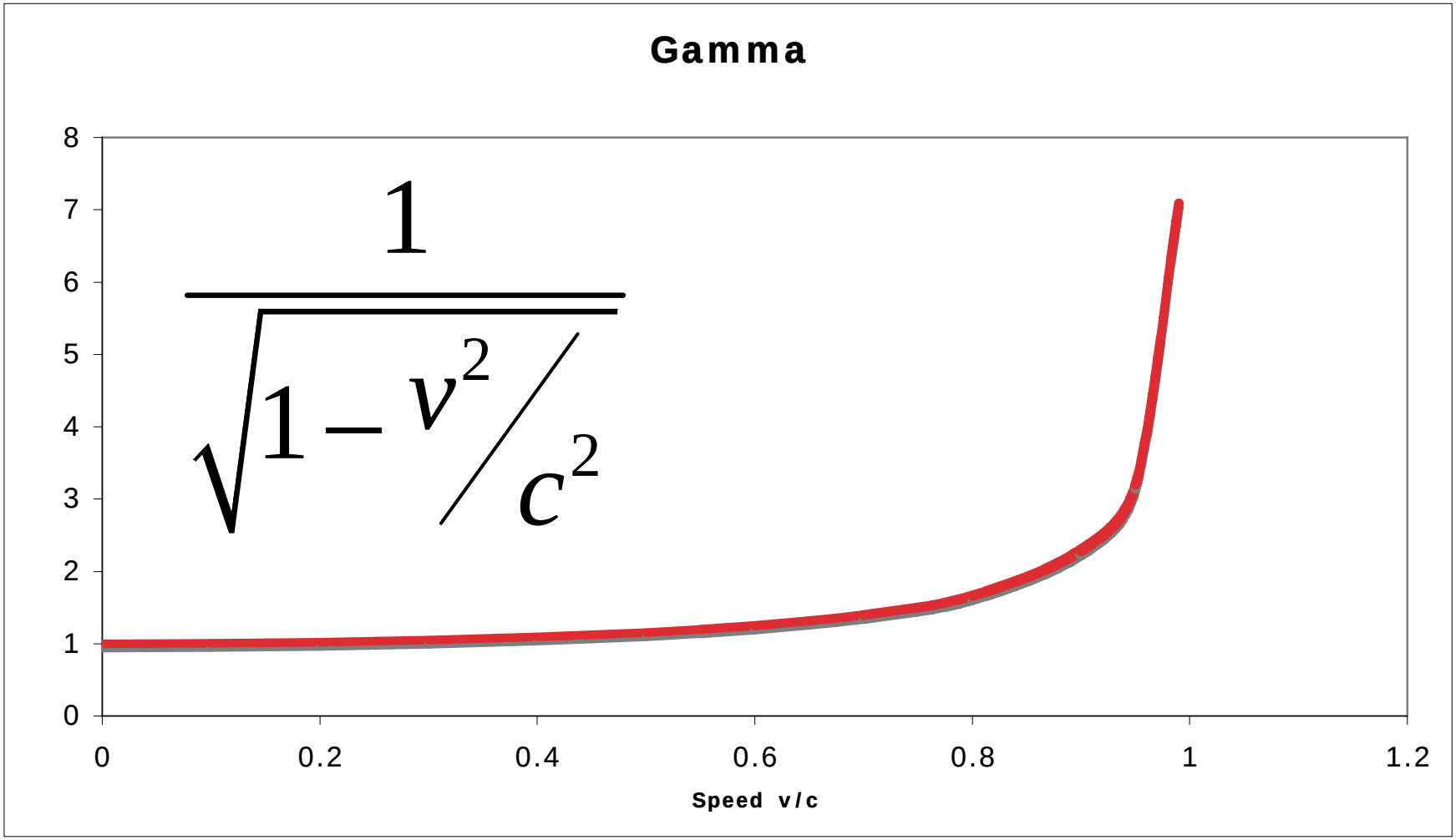
Time and Space are different!!

An object gets more massive when moving.

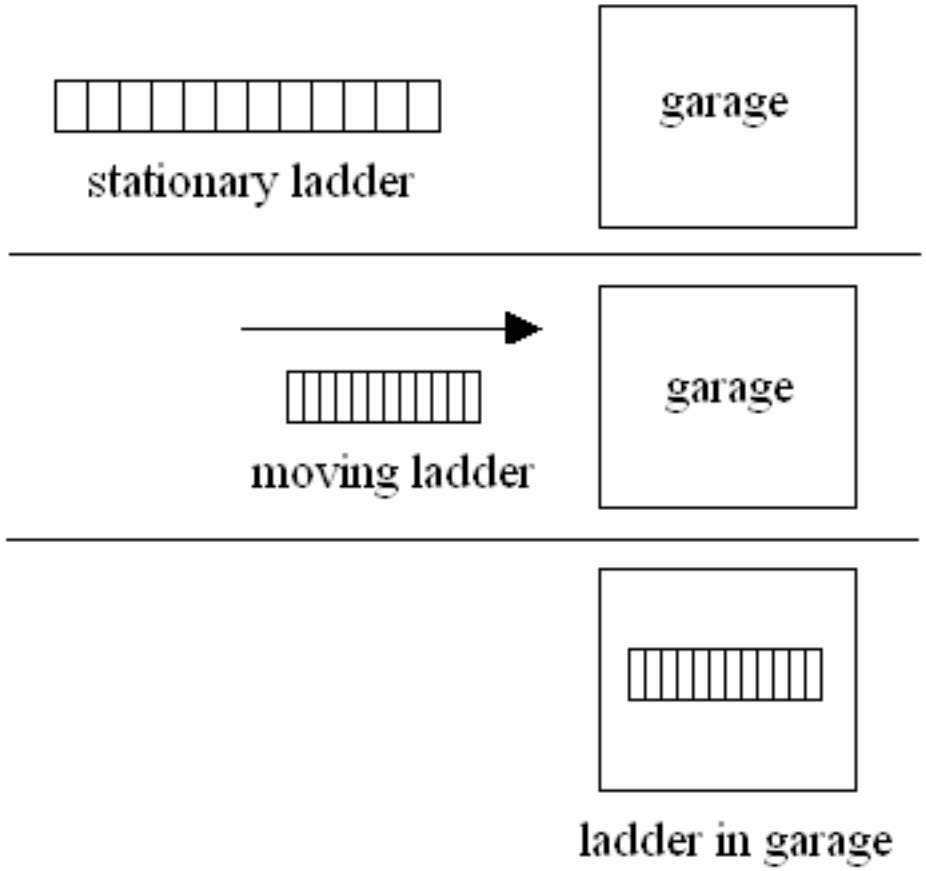
A clock slows down when moving.

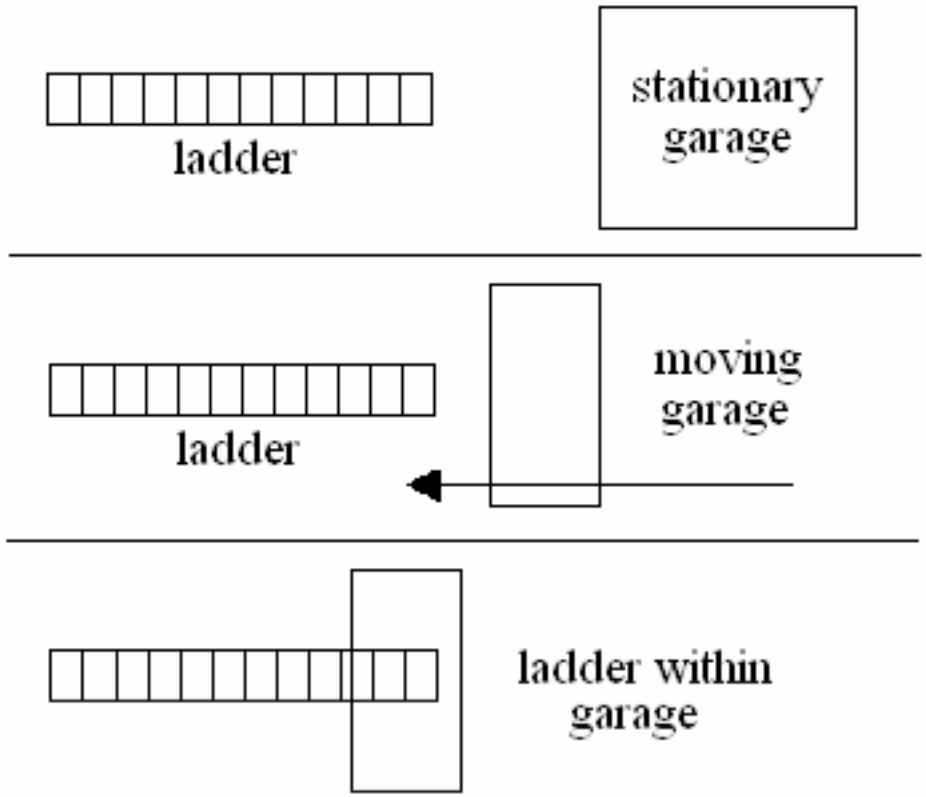
A meter stick gets shorter when moving.

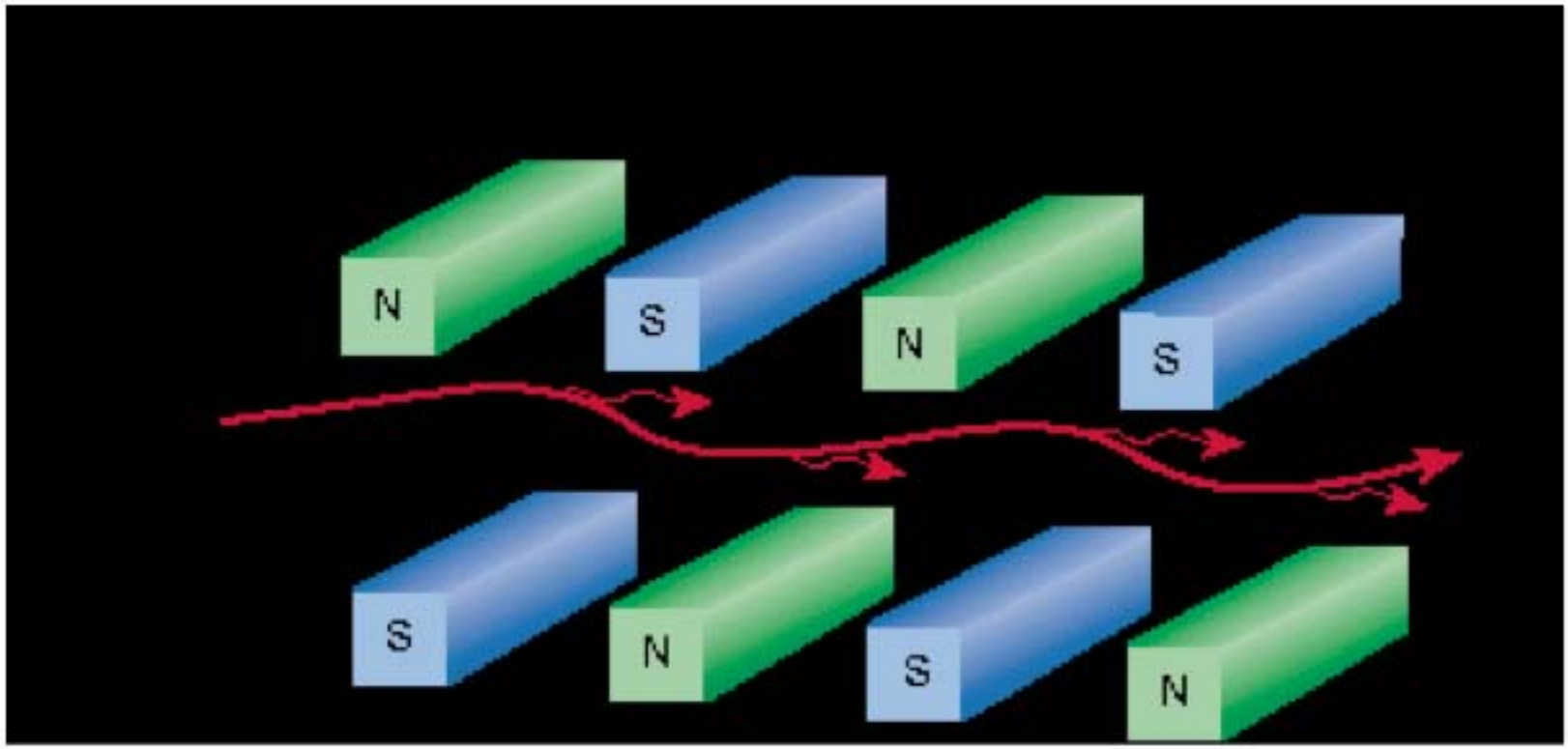
Einstein was thinking about Maxwell……


Gamma
$$\frac{1}{\sqrt{1-v^2/c^2}}$$
8
7
6
5
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1
1.2
Speed v/c

If this looks BLUE, you're driving too fast!


garage
stationary ladder
garage
moving ladder
ladder in garage


ladder
stationary garage
ladder
moving garage
ladder within garage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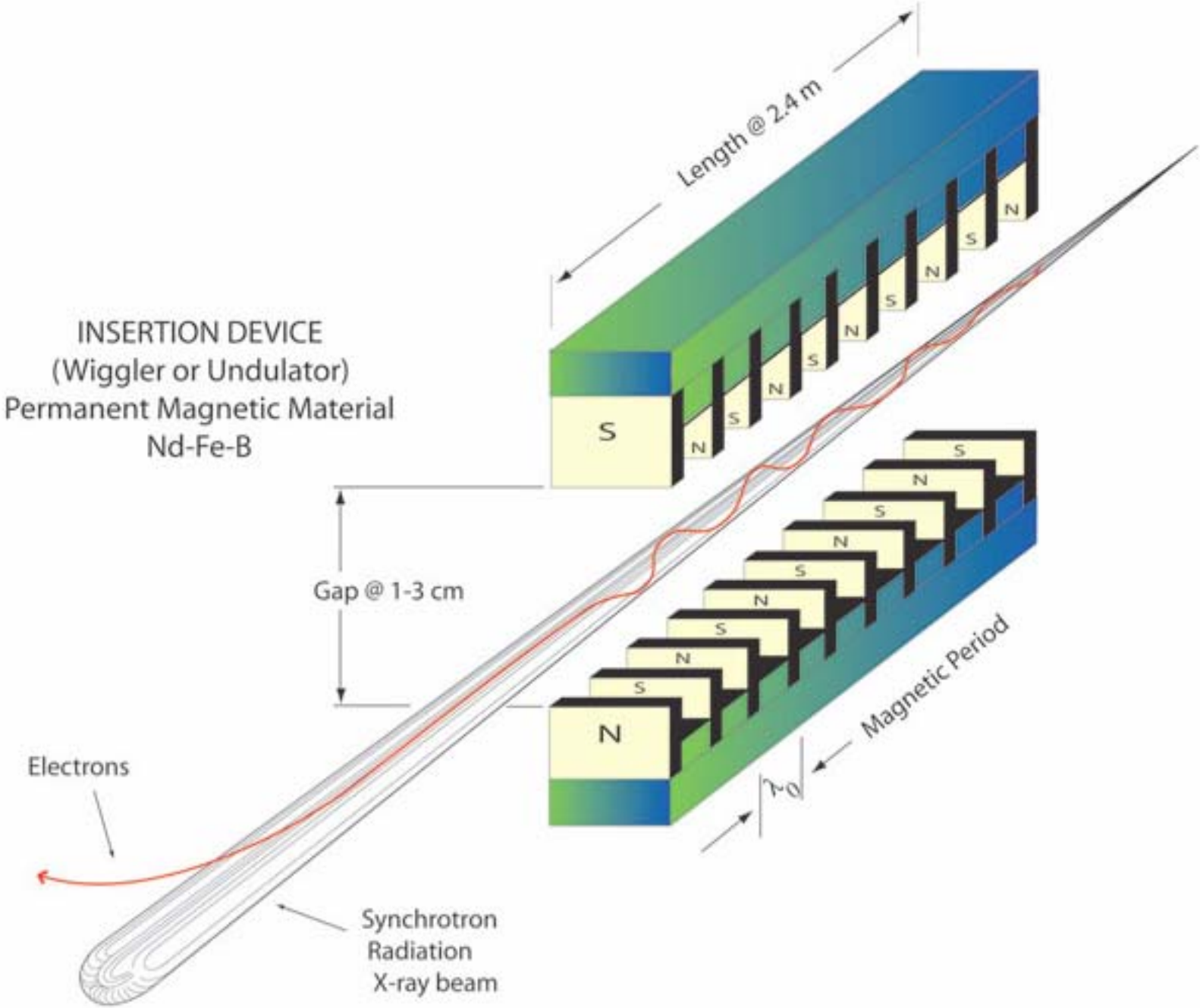

INSERTION DEVICE
(Wiggler or Undulator)
Permanent Magnetic Material
Nd-Fe-B
Length @ 2.4 m
Gap @ 1-3 cm
Magnetic Period
Electrons
Synchrotron
Radiation
X-ray beam
S
N

If you saw things from the point of view of the electrons, how big are the magnets?

A meter stick is now only 1/10 of a millimeter!!!

(gamma ~ 10,000)

The electron radiates (like Maxwell says) with a wave length of 1/10 millimeter, BUT:

We see a wave length smaller by another factor of 10,000!!

That means, we get X-Rays instead of radio waves.

Because of Maxwell, electrons radiate when we shake them.

Because of Einstein, we can build accelerators and magnets that make X-Rays of incredible power.

Because of this synchrotron radiation, we now learn the atomic structures of hundreds of proteins every year, instead of one every few years!

Theoretical Physics from a century ago gives us the latest scientific advances in biology!

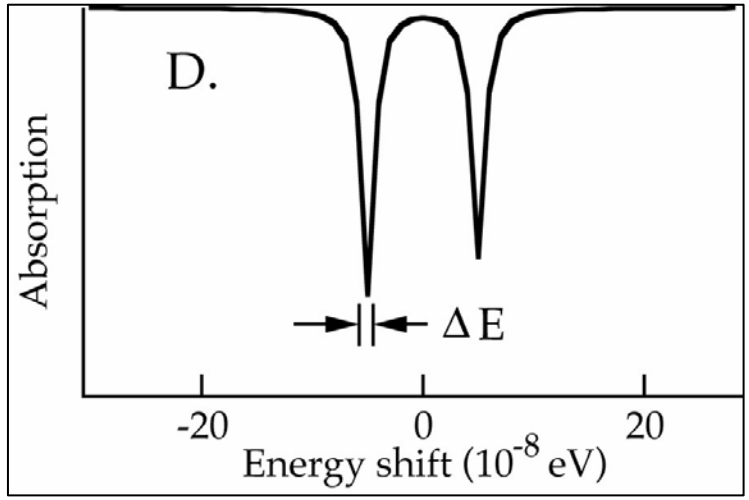
What about Quantum Mechanics,

and the Heisenberg Uncertainty Principle?

$$\Delta p \Delta x \geq \mathrm{h}$$

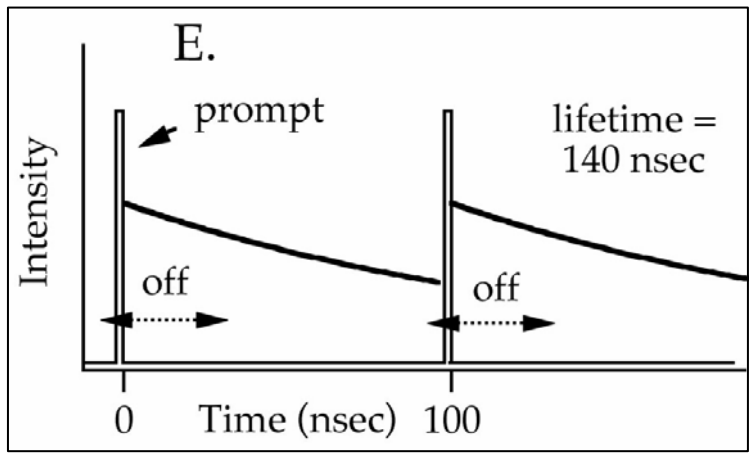
$$\Delta E \Delta t \geq \mathrm{h}$$

3. Absorption is governed by the Mossbauer energy width, leading to lifetime of the excited states of ~140 nanoseconds (Heisenberg uncertainty).

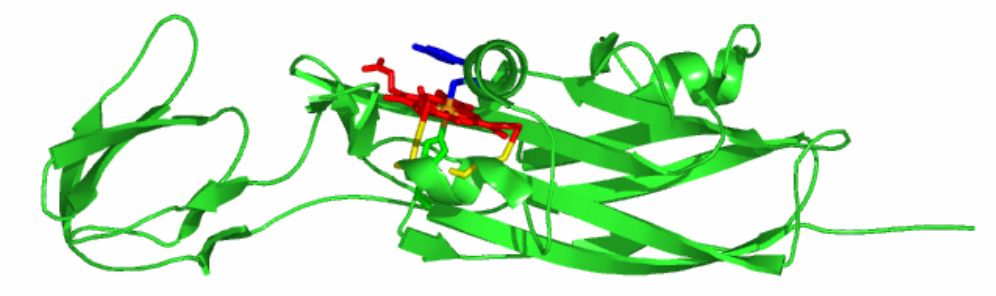


4. Time between x-ray pulses is ~100 nsec; APD detectors are gated off during the incident pulse time window.

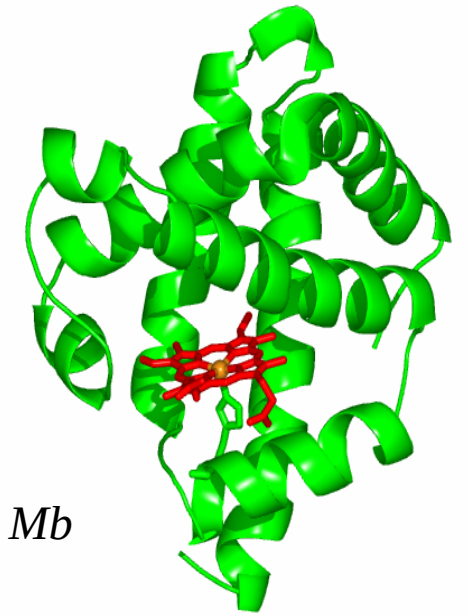
5. This ensures that any fluorescence detected arise from interaction with the nucleus, and NOT from the much more likely interaction with core electrons.



C. Comparison of heme proteins - cytochrome f *vs* myoglobin



Cytochrome f

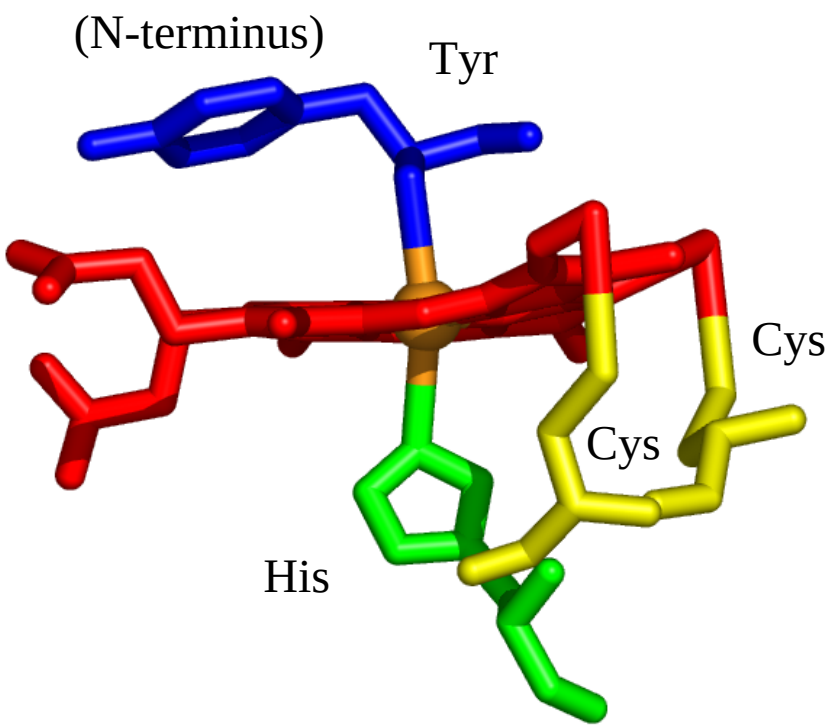


Mb

An electron-transfer membrane protein, part of the cytochrome b_6f complex of oxygenic photosynthesis. Has unusual Fe linkage to N-terminus of protein.

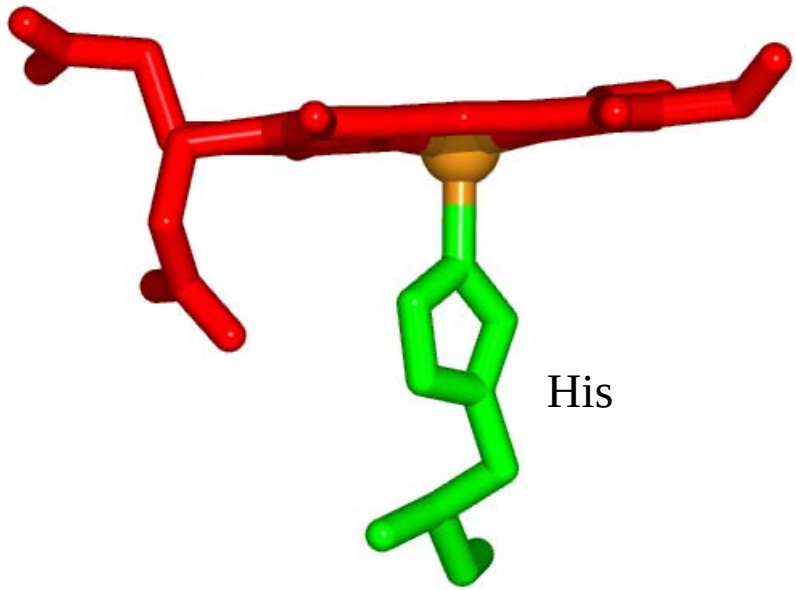
Oxygen ligand-binding protein, found in muscle tissues, etc.

Cytochrome f



Four strong bonds to protein

deoxy-Myoglobin

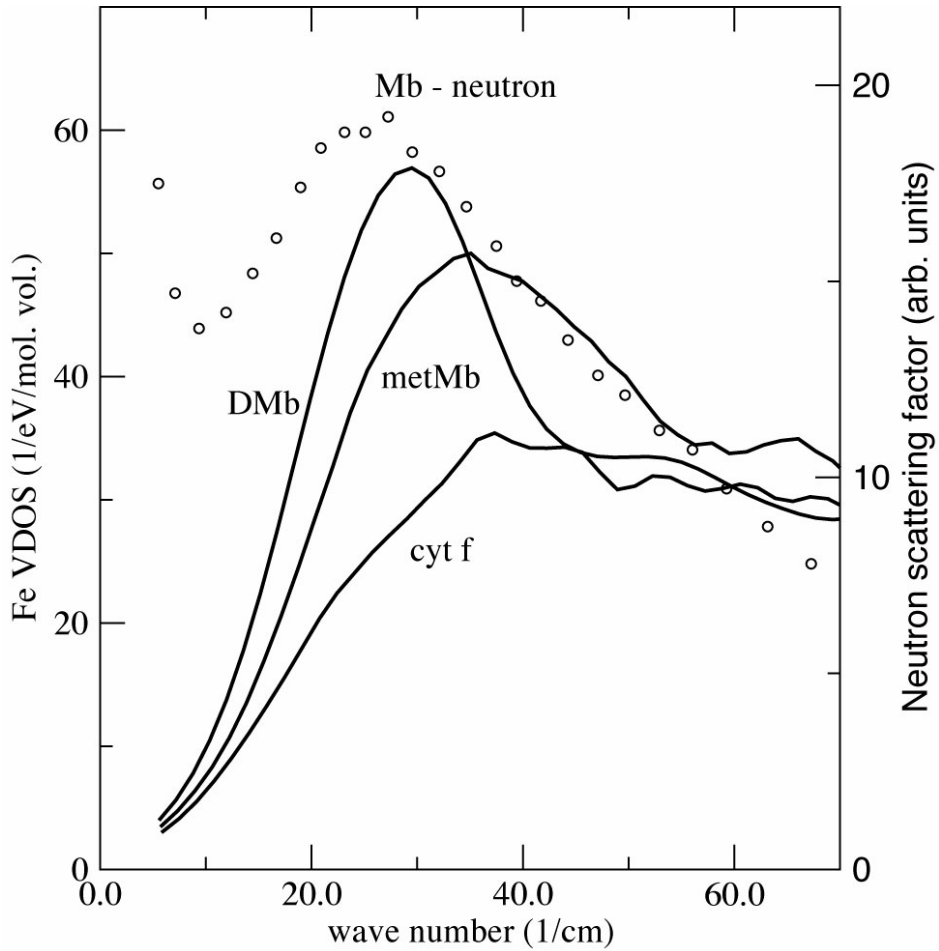


Only one bond to protein

Protein Peak Comparison:

• cyt *f* has the smallest displacements at low, protein peak frequencies, despite the most direct coupling to protein vibrations (N-terminus)

• existence of protein peaks shows that protein normal modes are long-lived, underdamped, <u>not</u> dissipative.



(Neutron - Cusack & Doster 1990)

What have learned about these two proteins?

The oxygen storage protein, myoglobin, has a heme molecule that is unusually floppy, probably related to the need for motion to accommodate a small ligand like O_2.

The electron-storage protein, cytochrome f, is unusually rigid. The reason for this is not clear, but one suspects it is related to the electron-storage function.