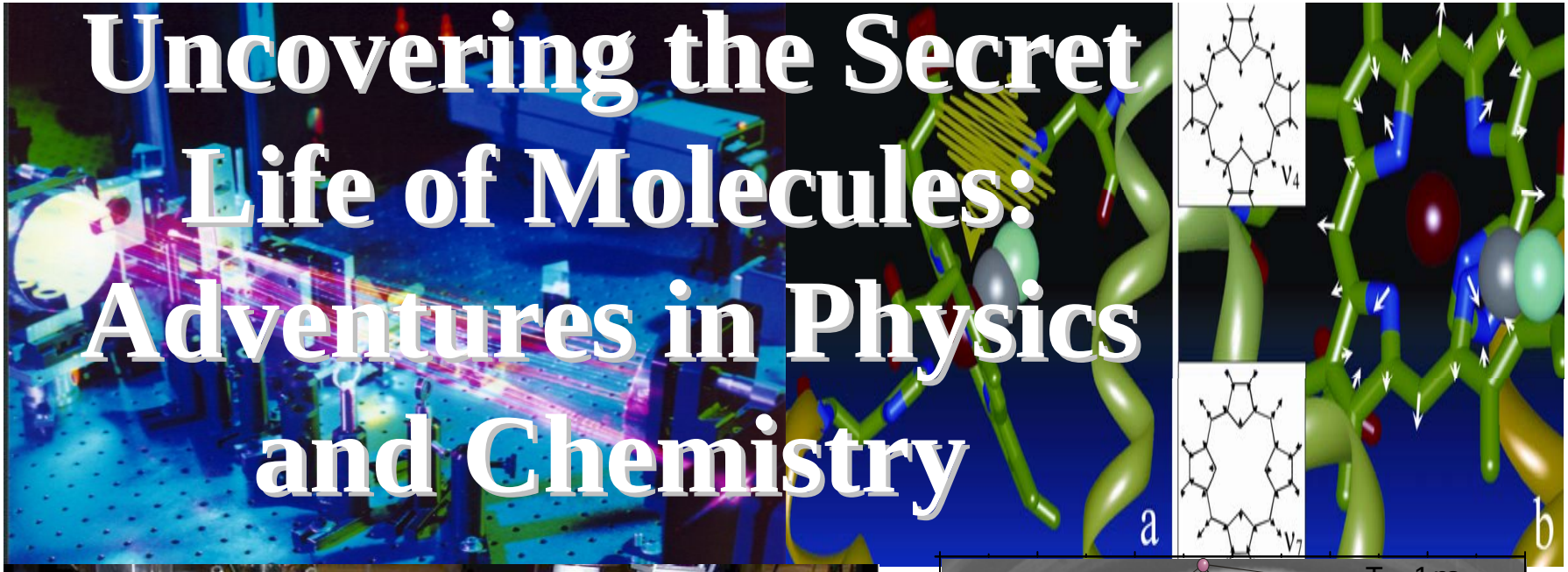
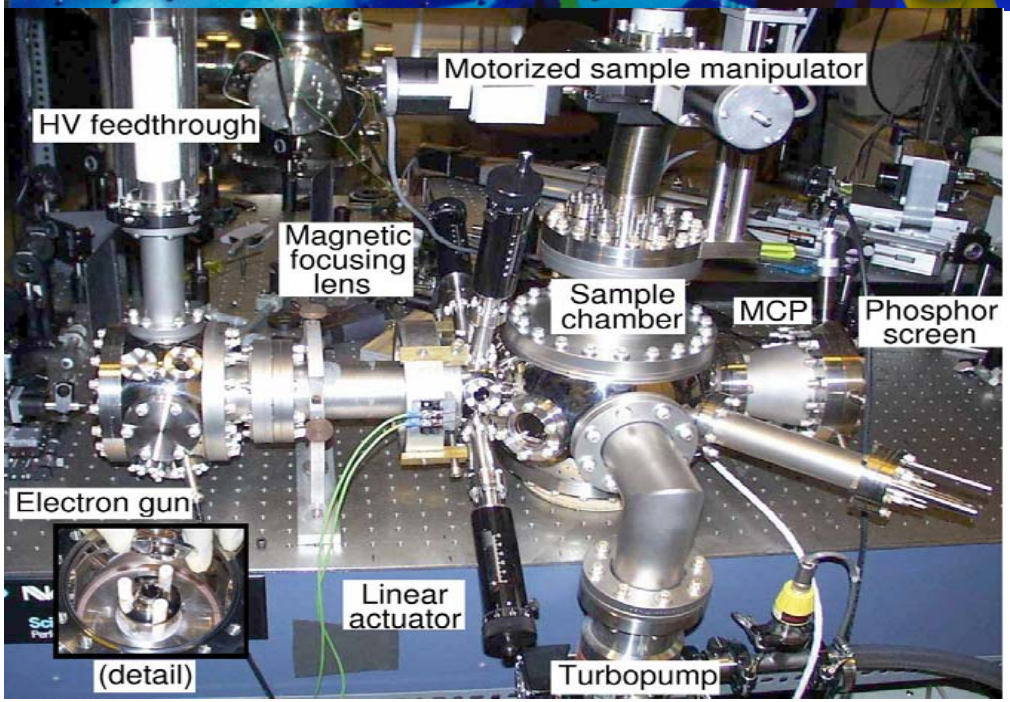
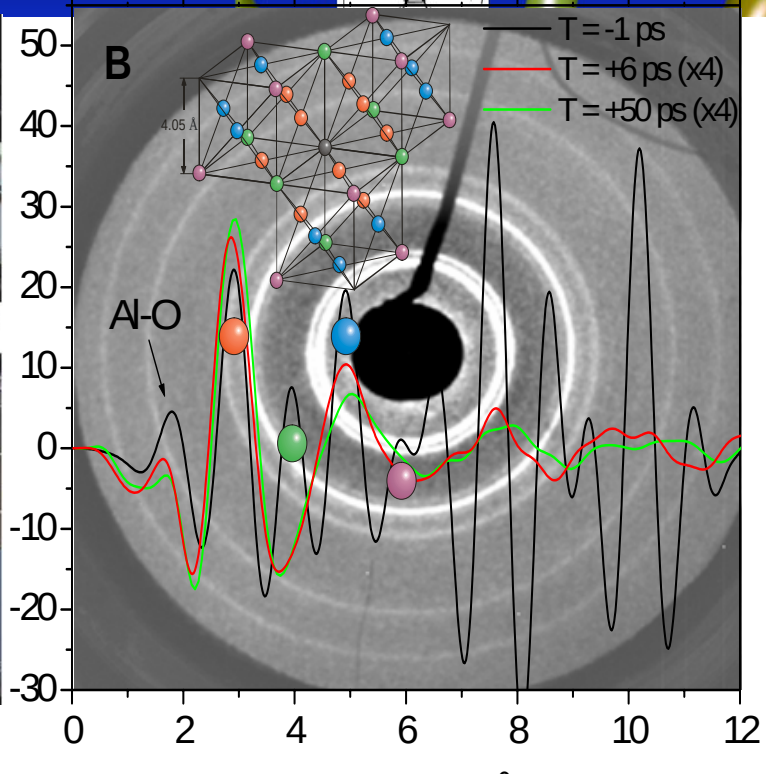
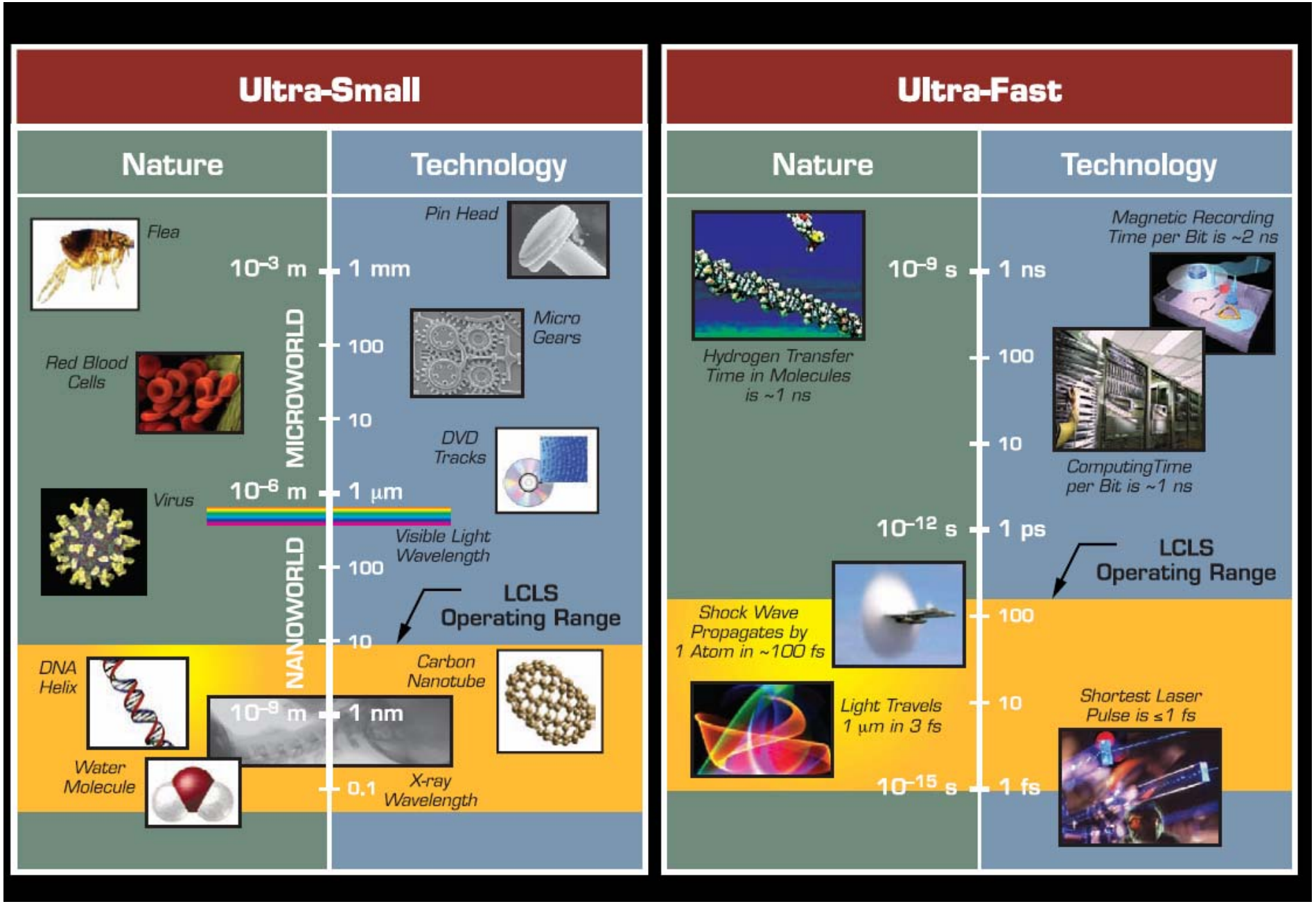
Uncovering the Secret Life of Molecules: Adventures in Physics and Chemistry

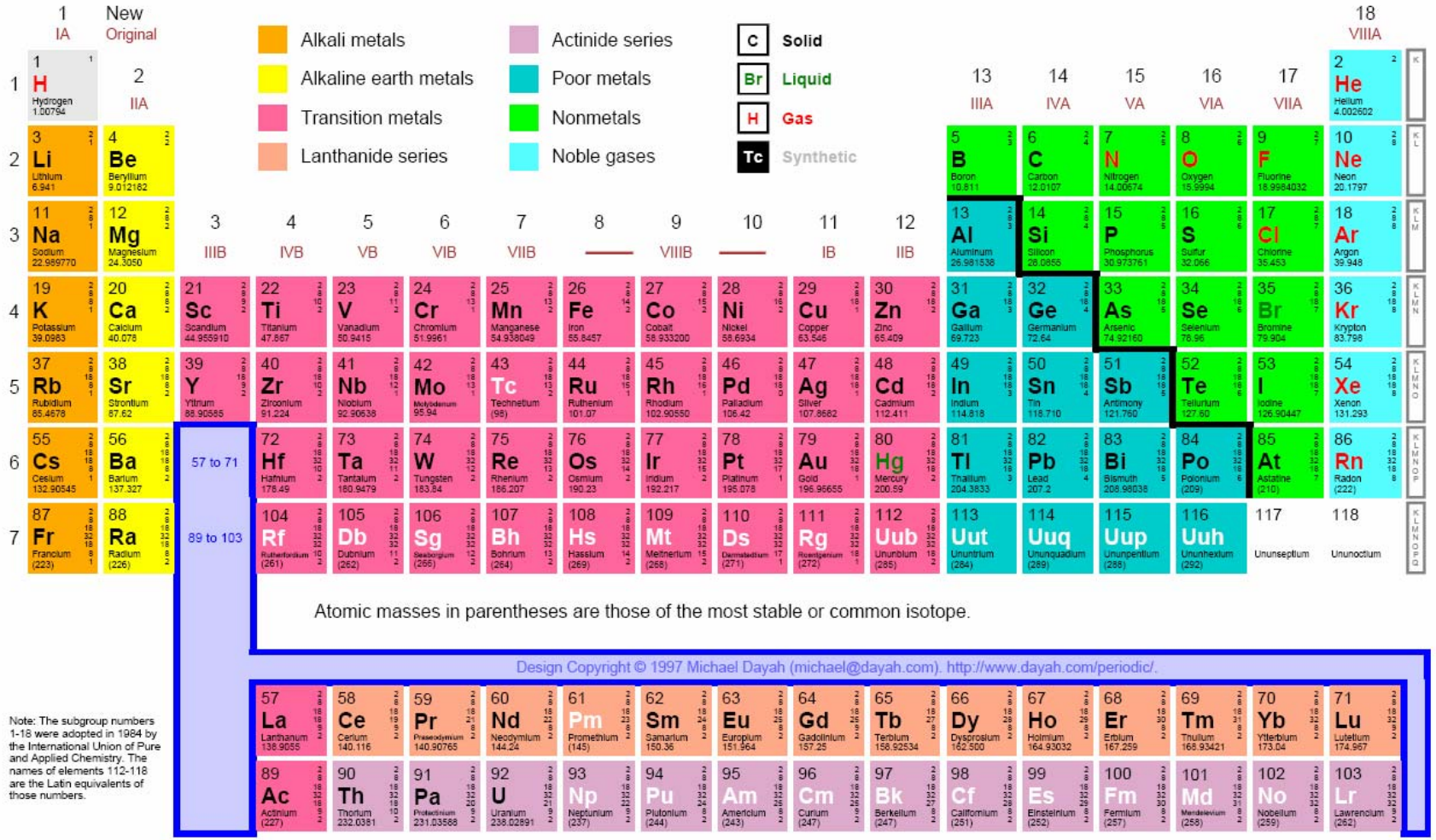







Ultra-Small
Nature
Technology
Flea
Pin Head
10^{-3} m
1 mm
Micro Gears
100
Red Blood Cells
MICROWORLD
10
DVD Tracks
Virus
10^{-6} m
1 μm
Visible Light Wavelength
100
NANOWORLD
LCLS Operating Range
10
DNA Helix
Carbon Nanotube
10^{-9} m
1 nm
Water Molecule
0.1
X-ray Wavelength
Ultra-Fast
Nature
Technology
Magnetic Recording Time per Bit is ~2 ns
10^{-9} s
1 ns
Hydrogen Transfer Time in Molecules is ~1 ns
100
10
ComputingTime per Bit is ~1 ns
10^{-12} s
1 ps
LCLS Operating Range
Shock Wave Propagates by 1 Atom in ~100 fs
100
Light Travels 1 μm in 3 fs
10
Shortest Laser Pulse is ≤1 fs
10^{-15} s
1 fs

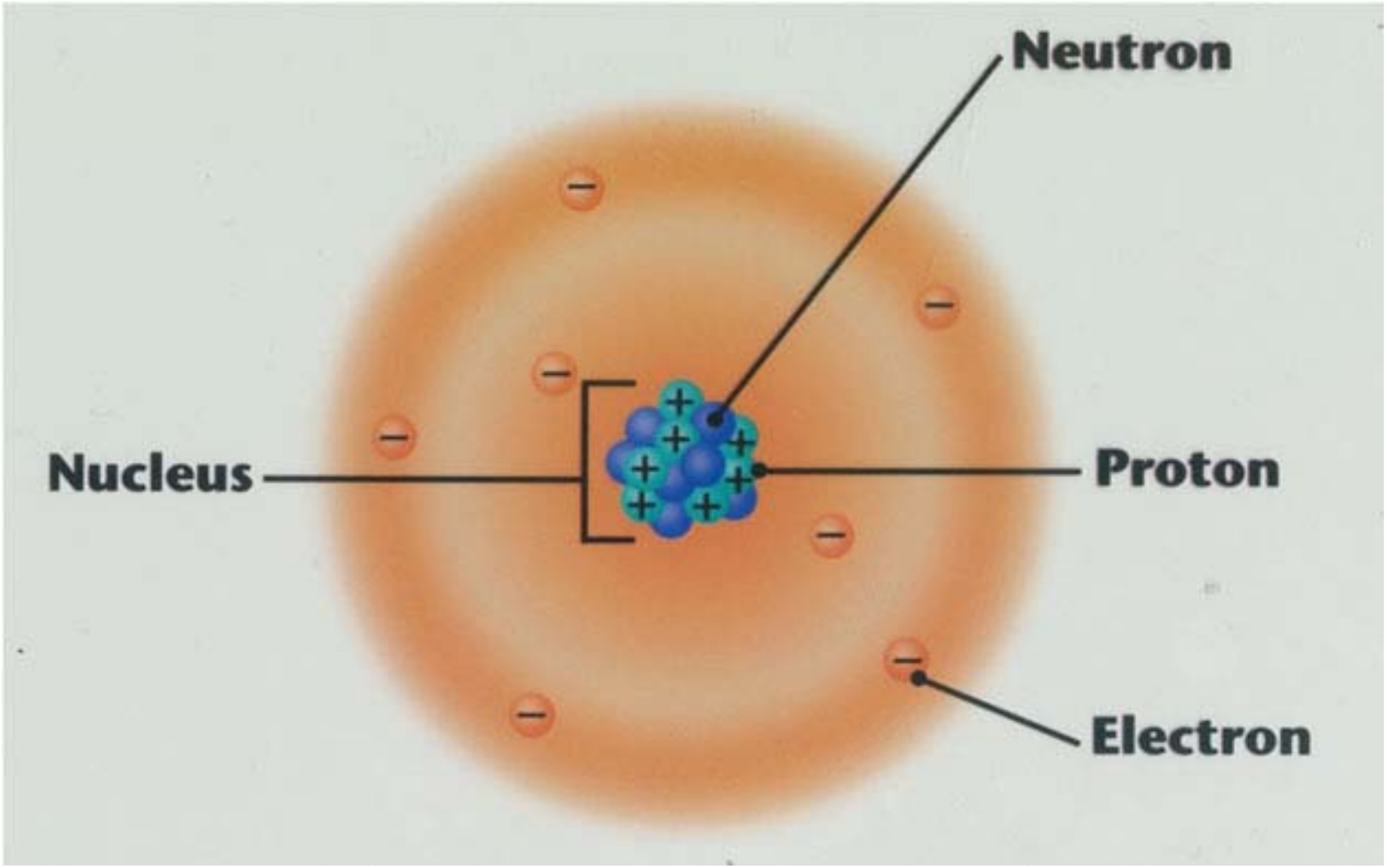
Periodic Table of the Elements



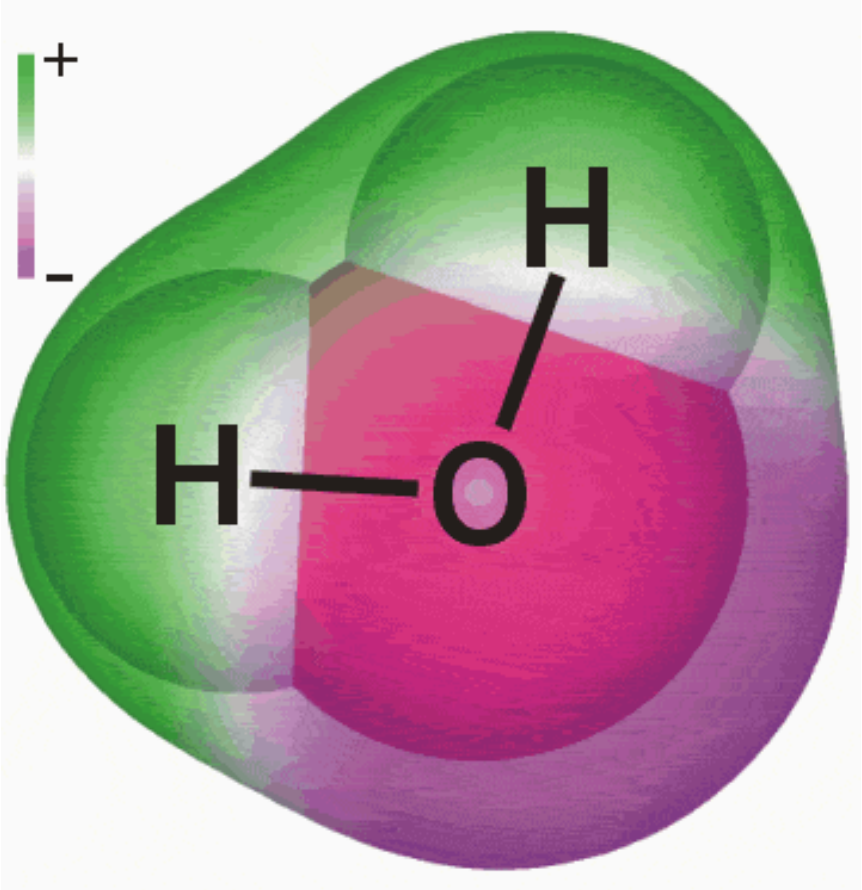
Atomic masses in parentheses are those of the most stable or common isotope.

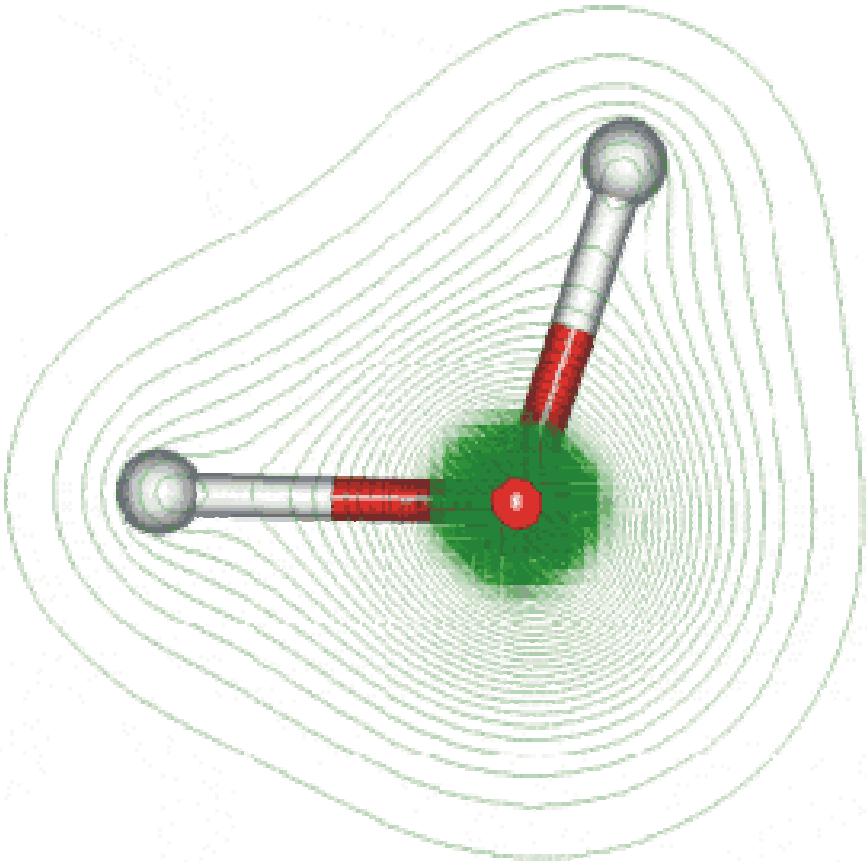
Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 112-118 are the Latin equivalents of those numbers.

‘Picture’ of an atom



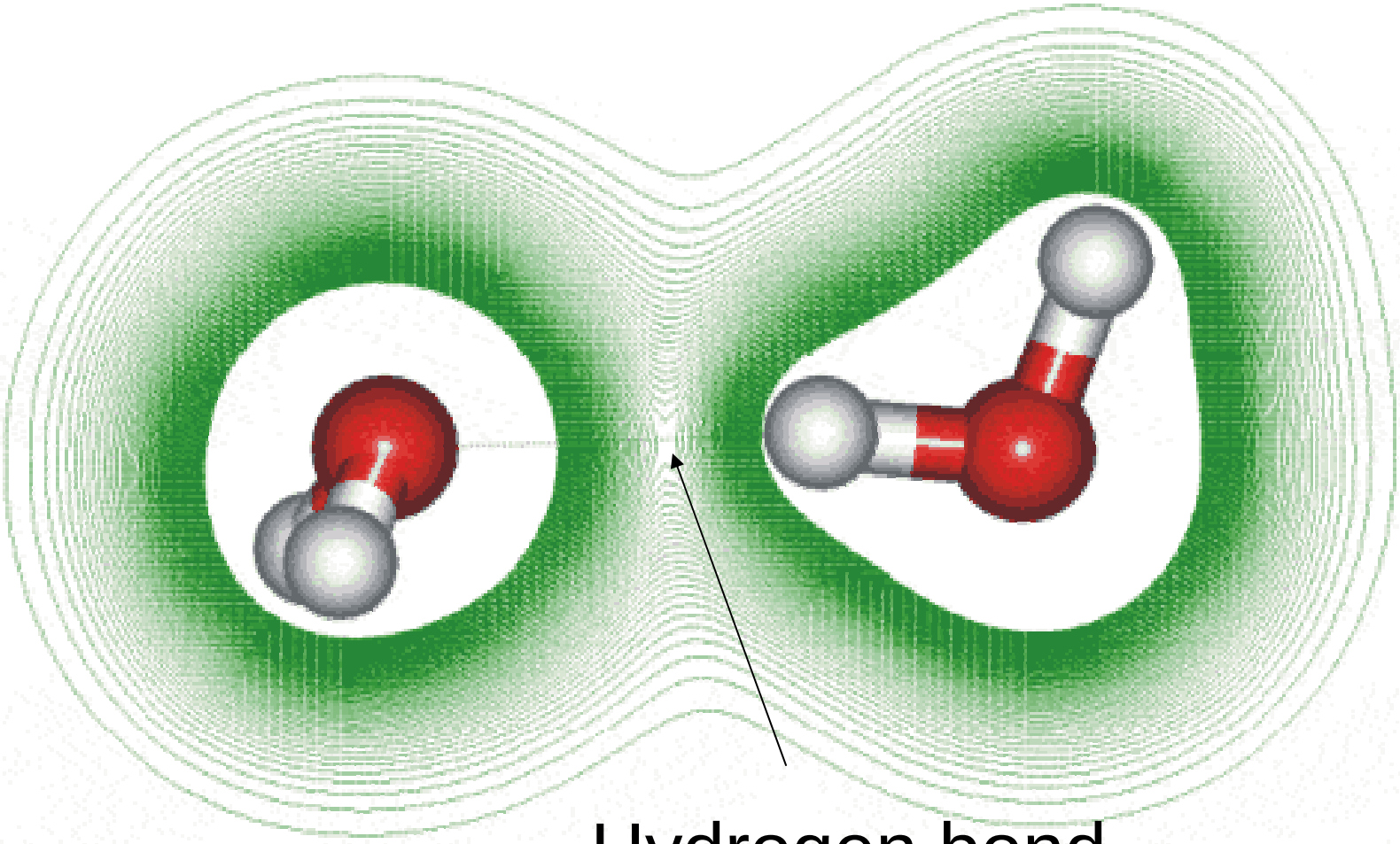
Molecules: Water



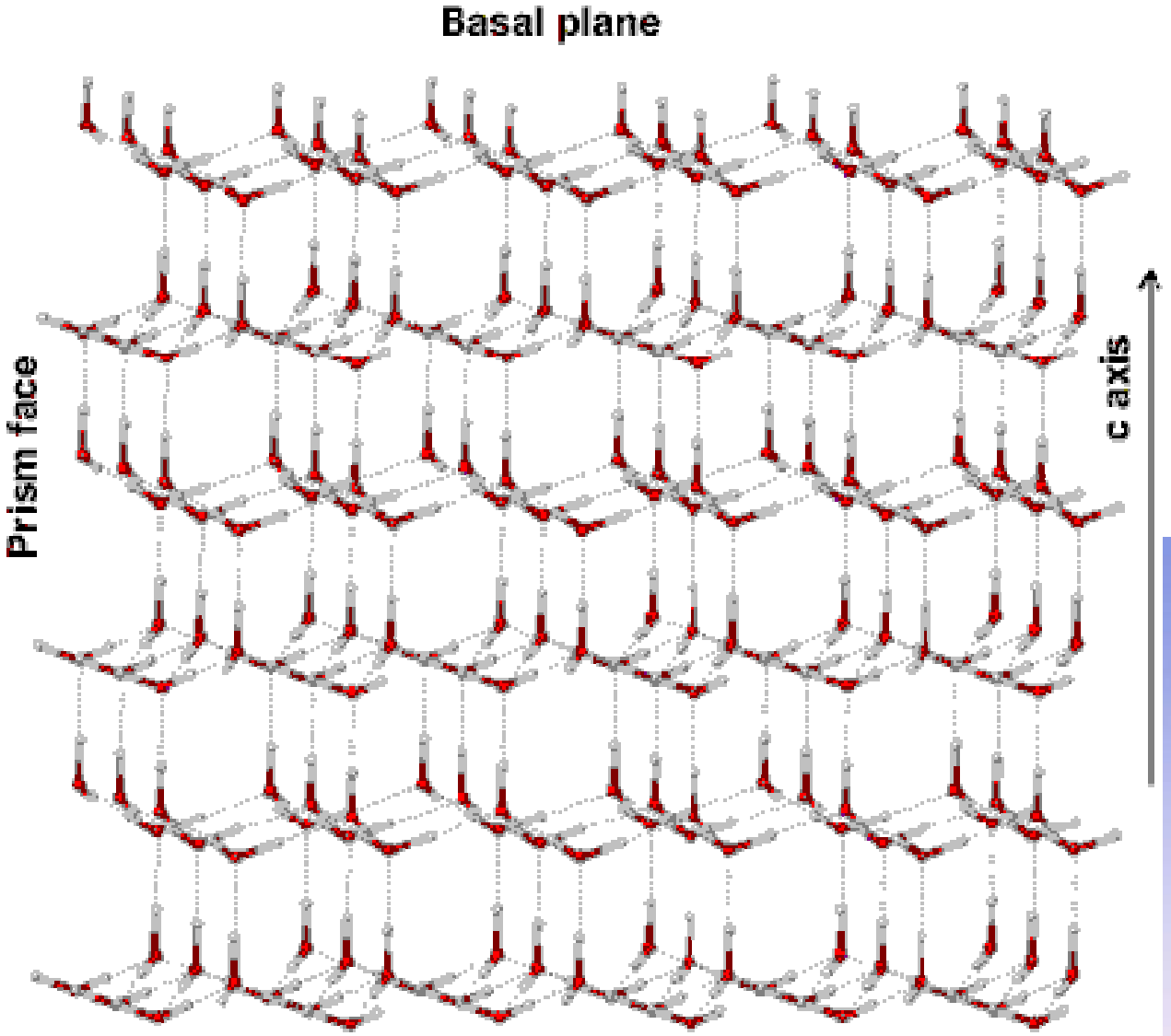


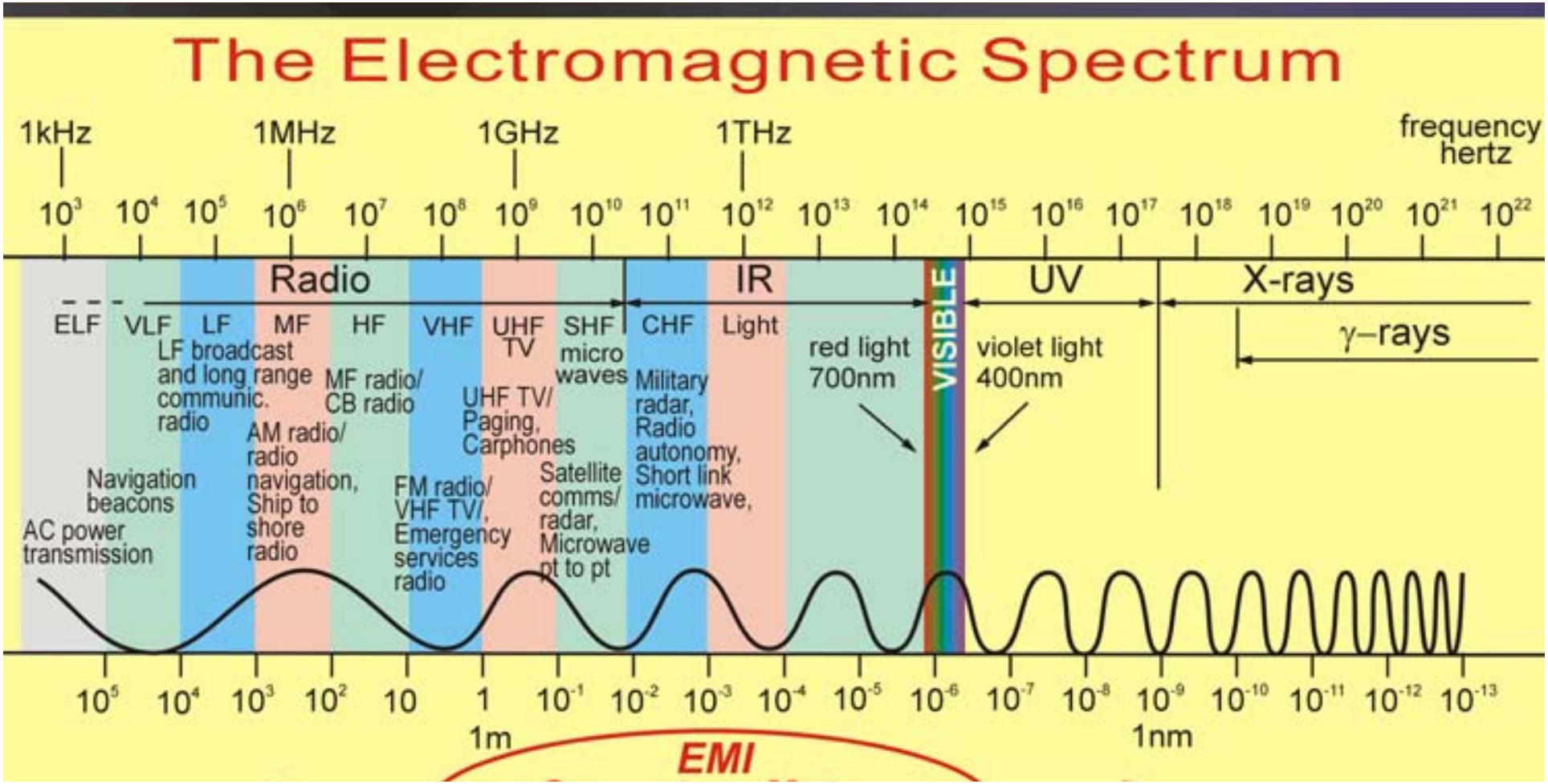
Electron density around the Oxygen atom is 10x that around the Hydrogen atoms

Dimer (2 water molecules)



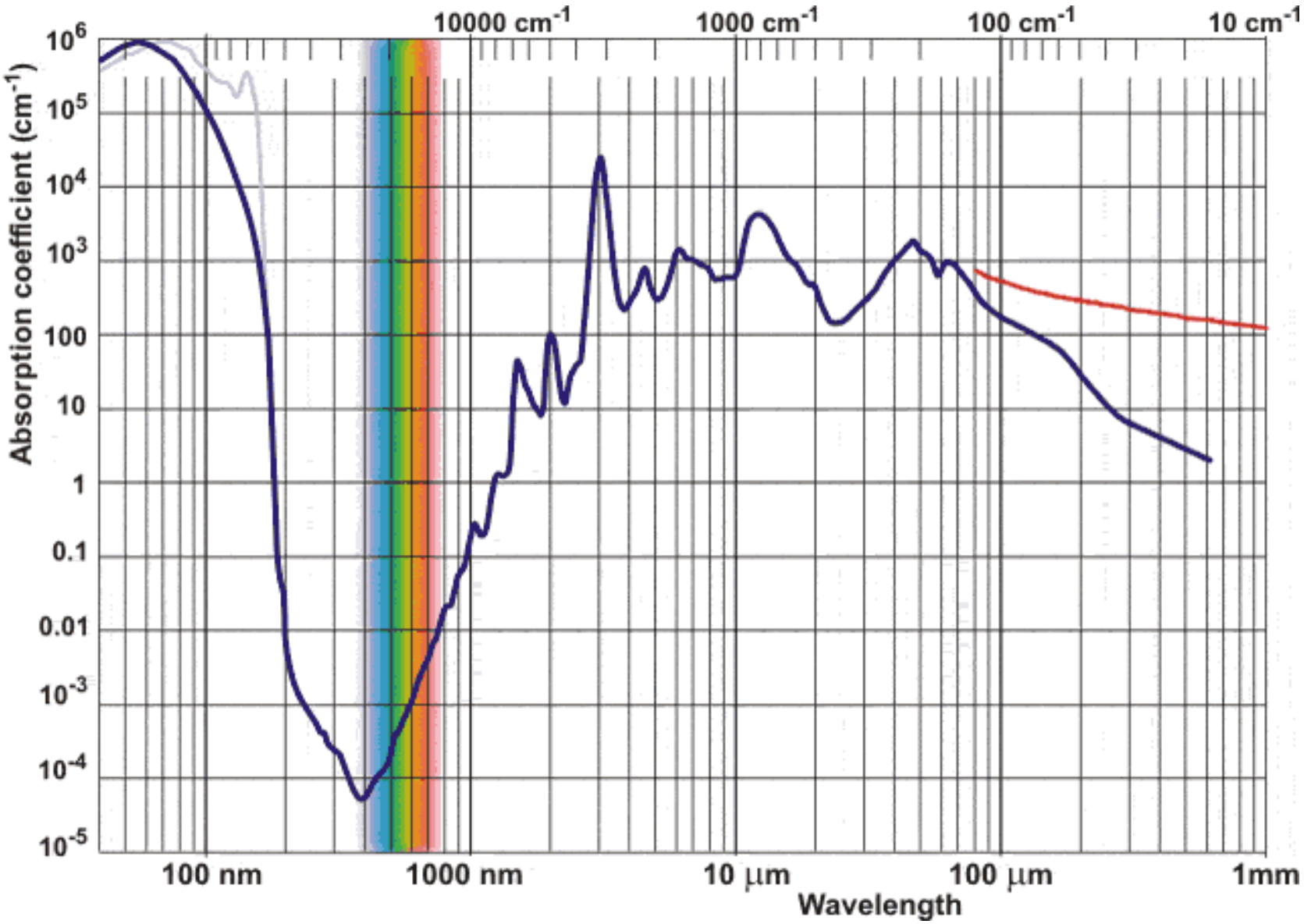
Structure of Ice: Solid water (*more* is *different*!)



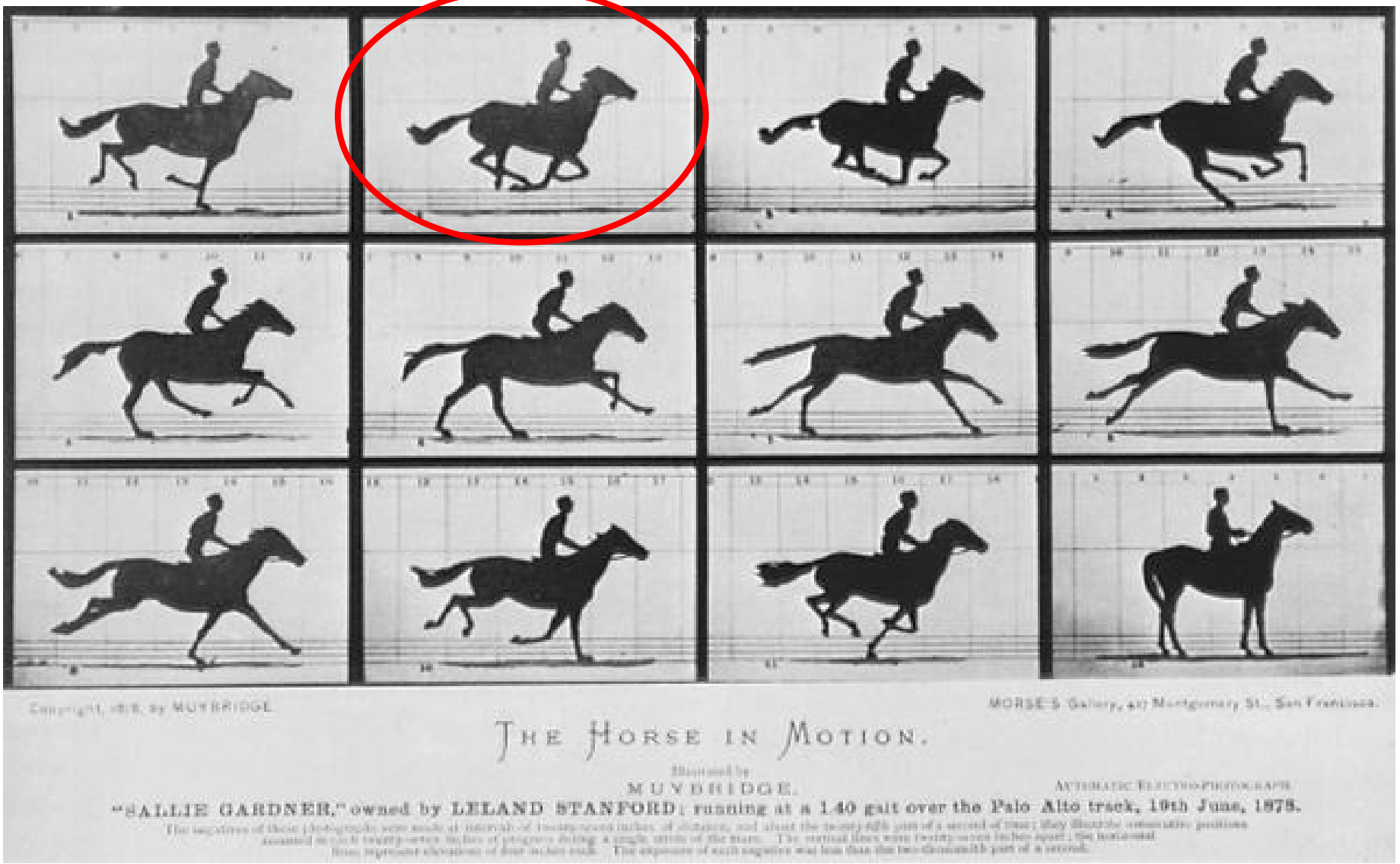

The Electromagnetic Spectrum
1kHz
1MHz
1GHz
1THz
frequency hertz
10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21} 10^{22}
Radio
IR
UV
X-rays
ELF
VLF
LF
MF
HF
VHF
UHF TV
SHF micro waves
CHF
Light
VISIBLE
γ–rays
red light 700nm
violet light 400nm
LF broadcast and long range communic. radio
MF radio/ CB radio
UHF TV/ Paging, Carphones
Military radar, Radio autonomy, Short link microwave,
Navigation beacons
AM radio/ radio navigation, Ship to shore radio
FM radio/ VHF TV/, Emergency services radio
Satellite comms/ radar, Microwave pt to pt
AC power transmission
10^5 10^4 10^3 10^2 10 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12} 10^{-13}
1m
1nm
EMI

Laser lab in Amsterdam

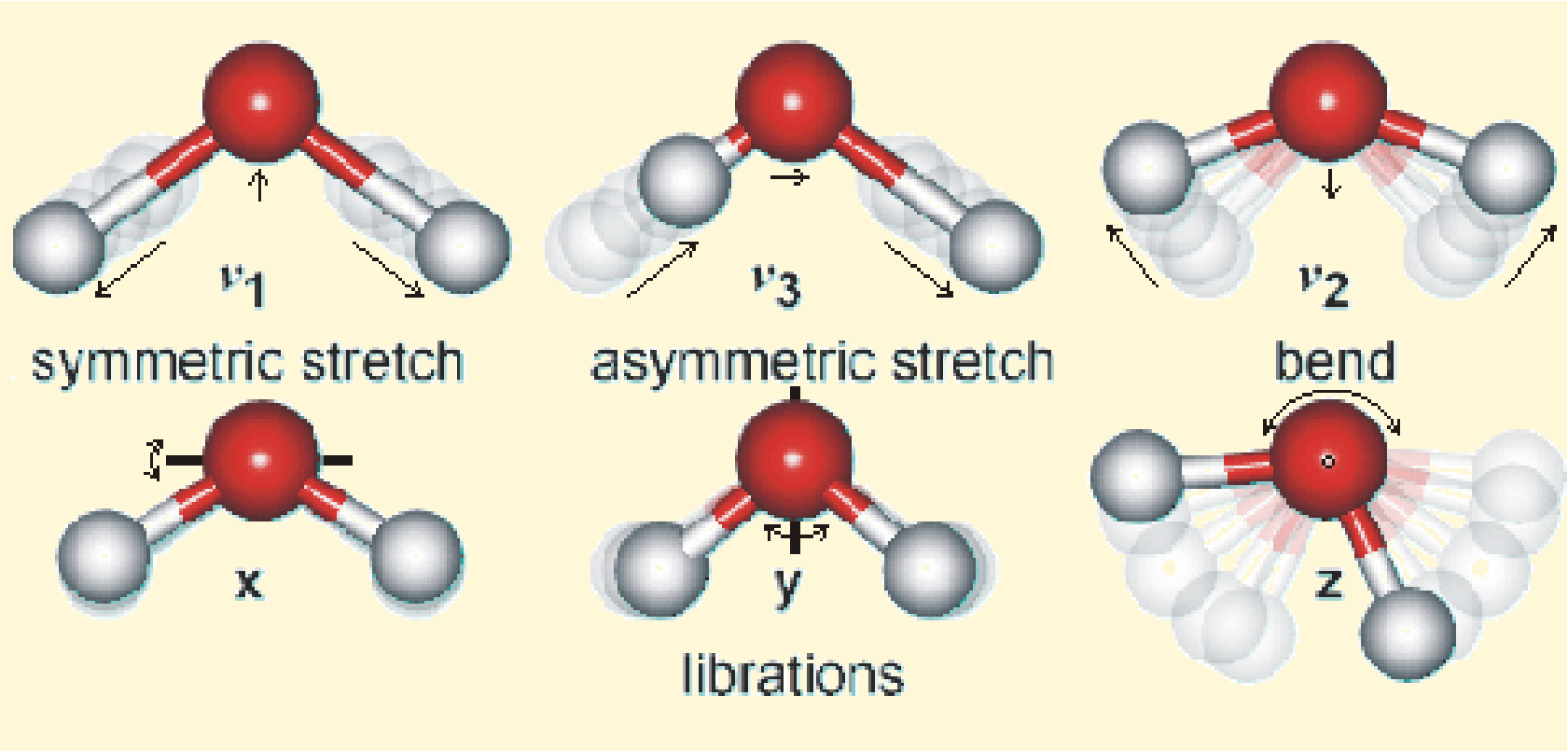
Absorption Spectrum of Liquid Water



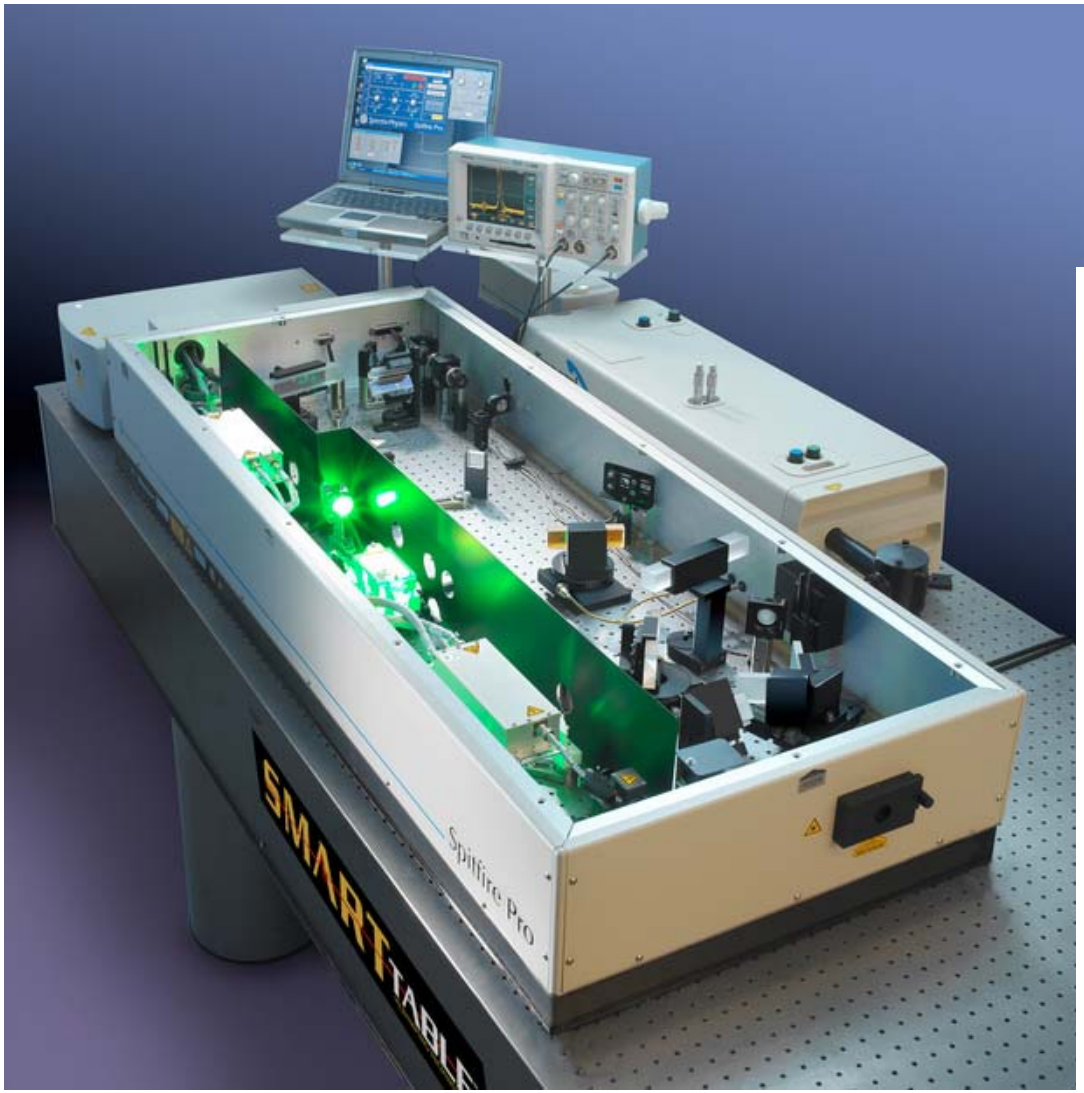
The Horse in Motion: Muybridge 1878

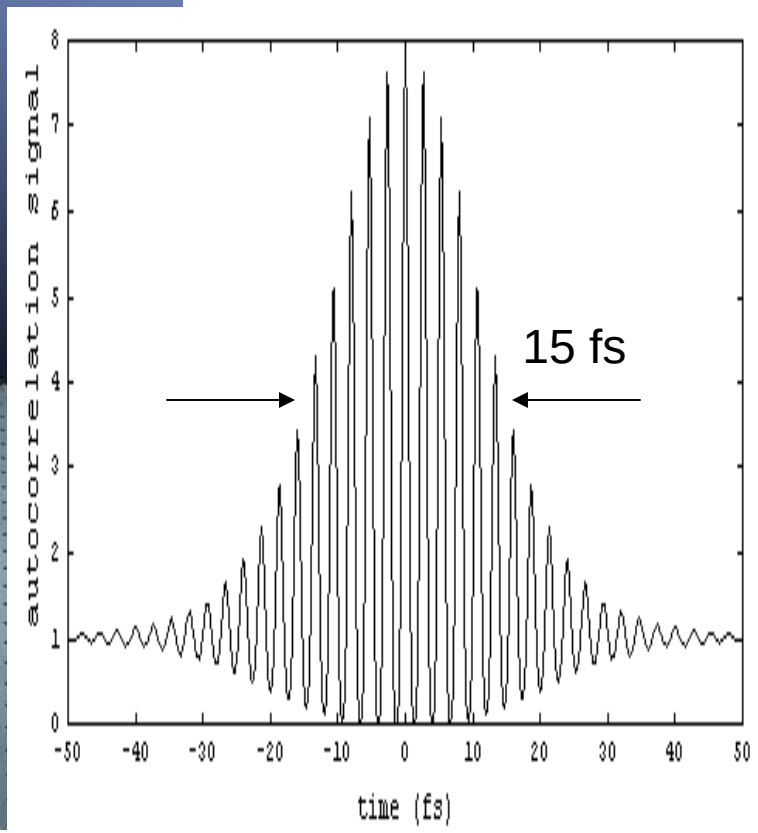


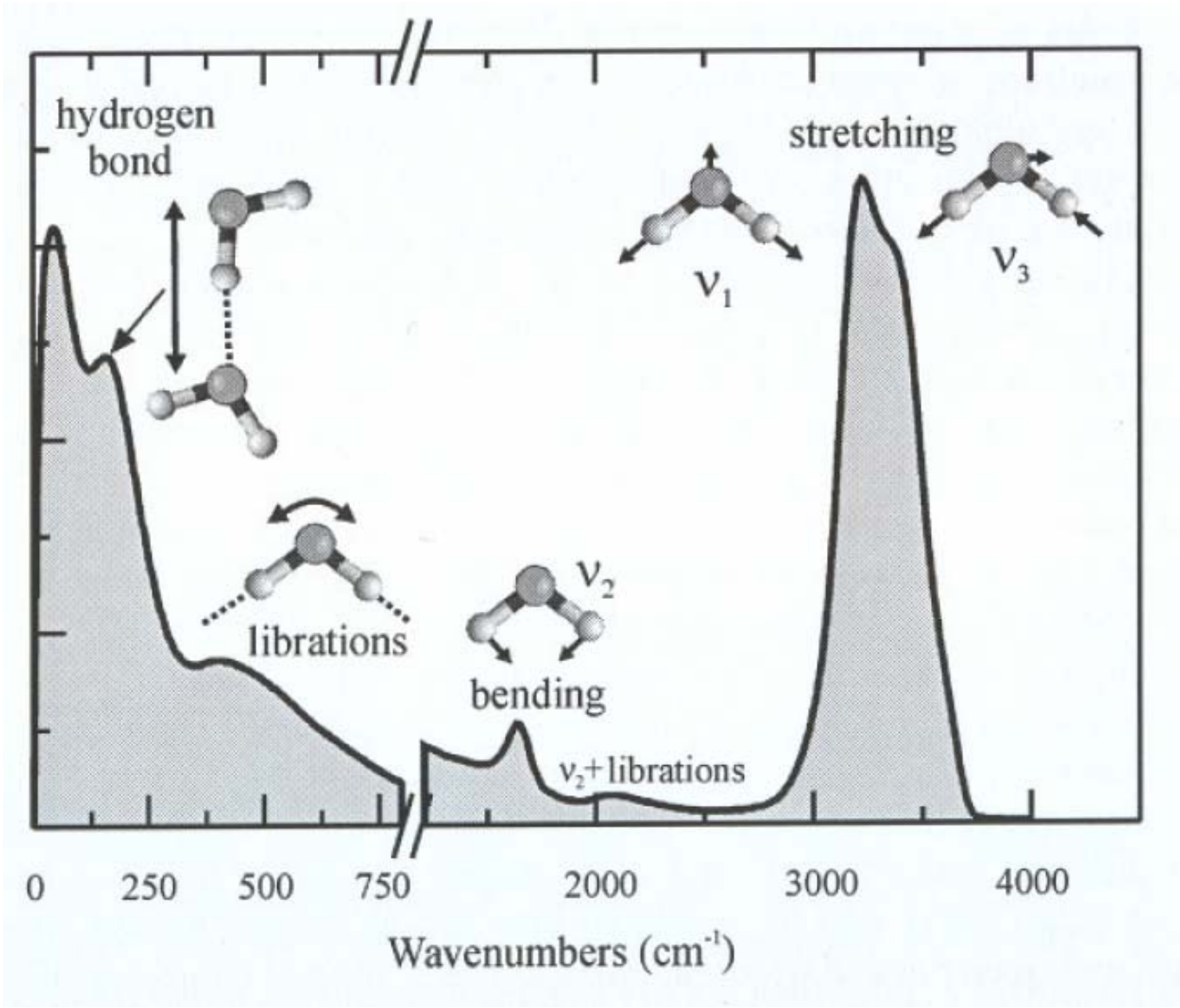
Water Molecule Vibrations

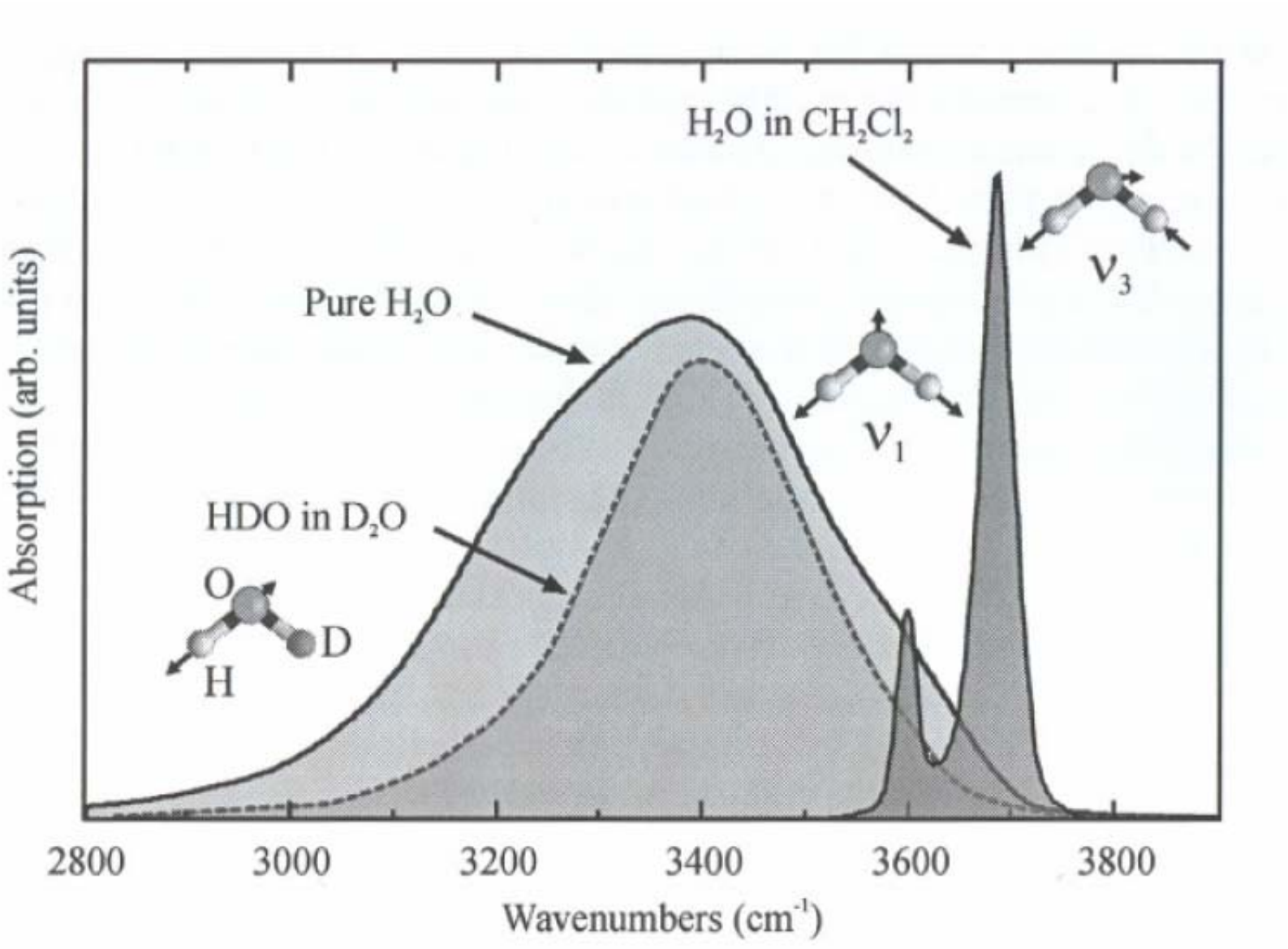


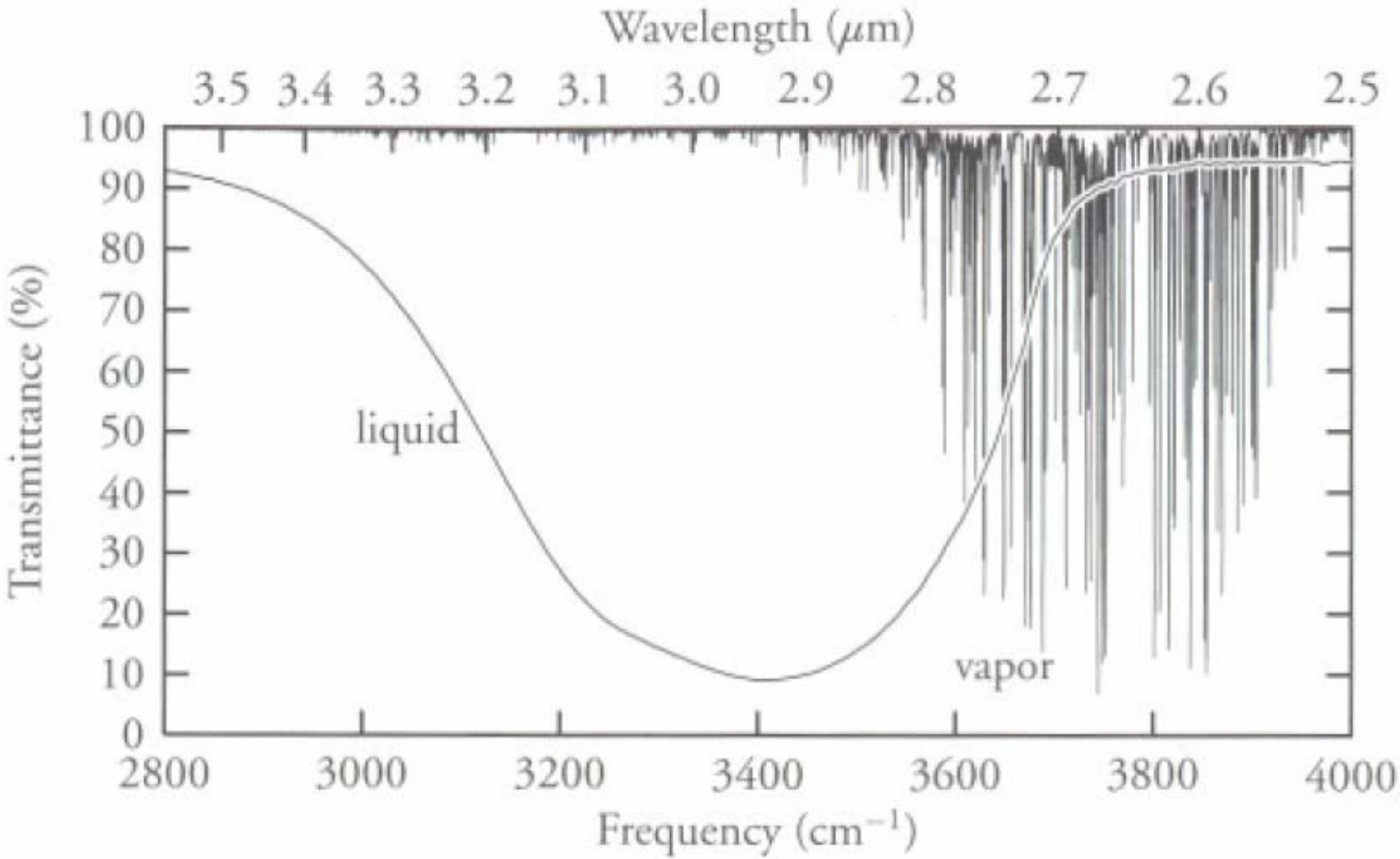
Femtosecond lasers

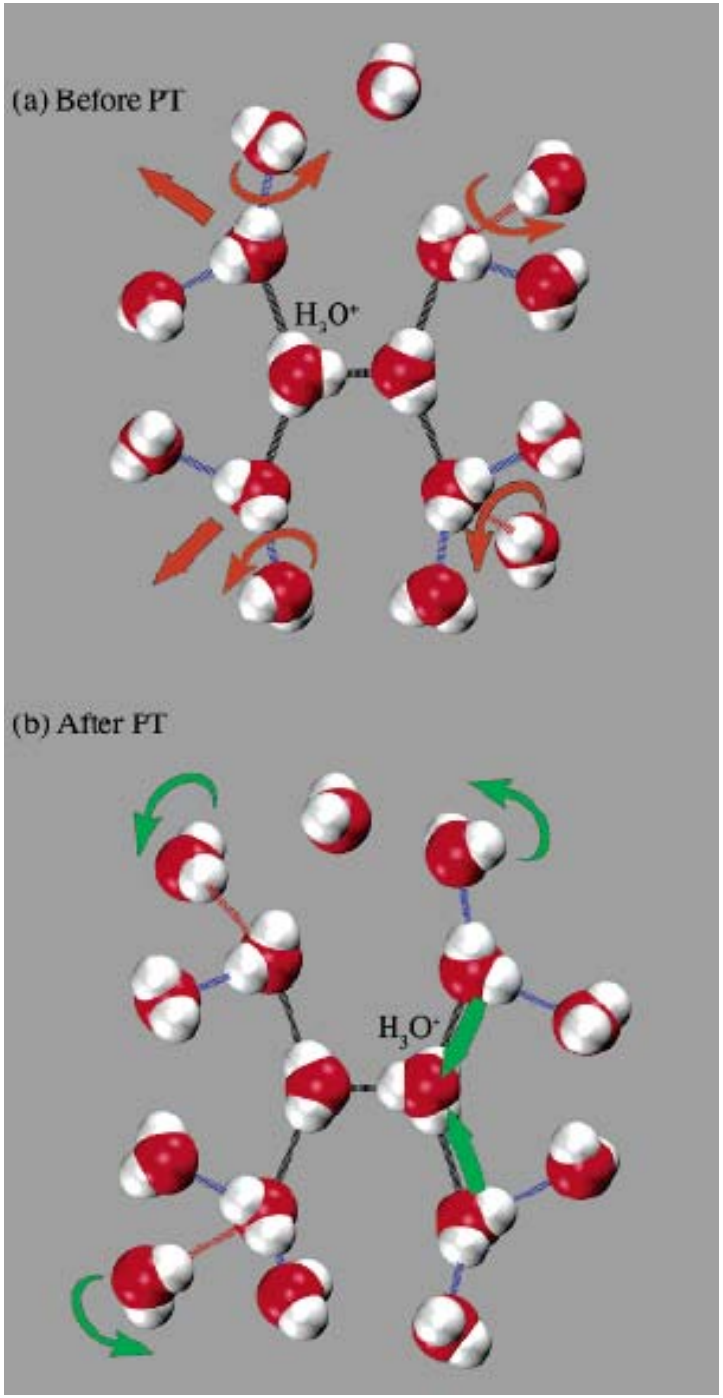


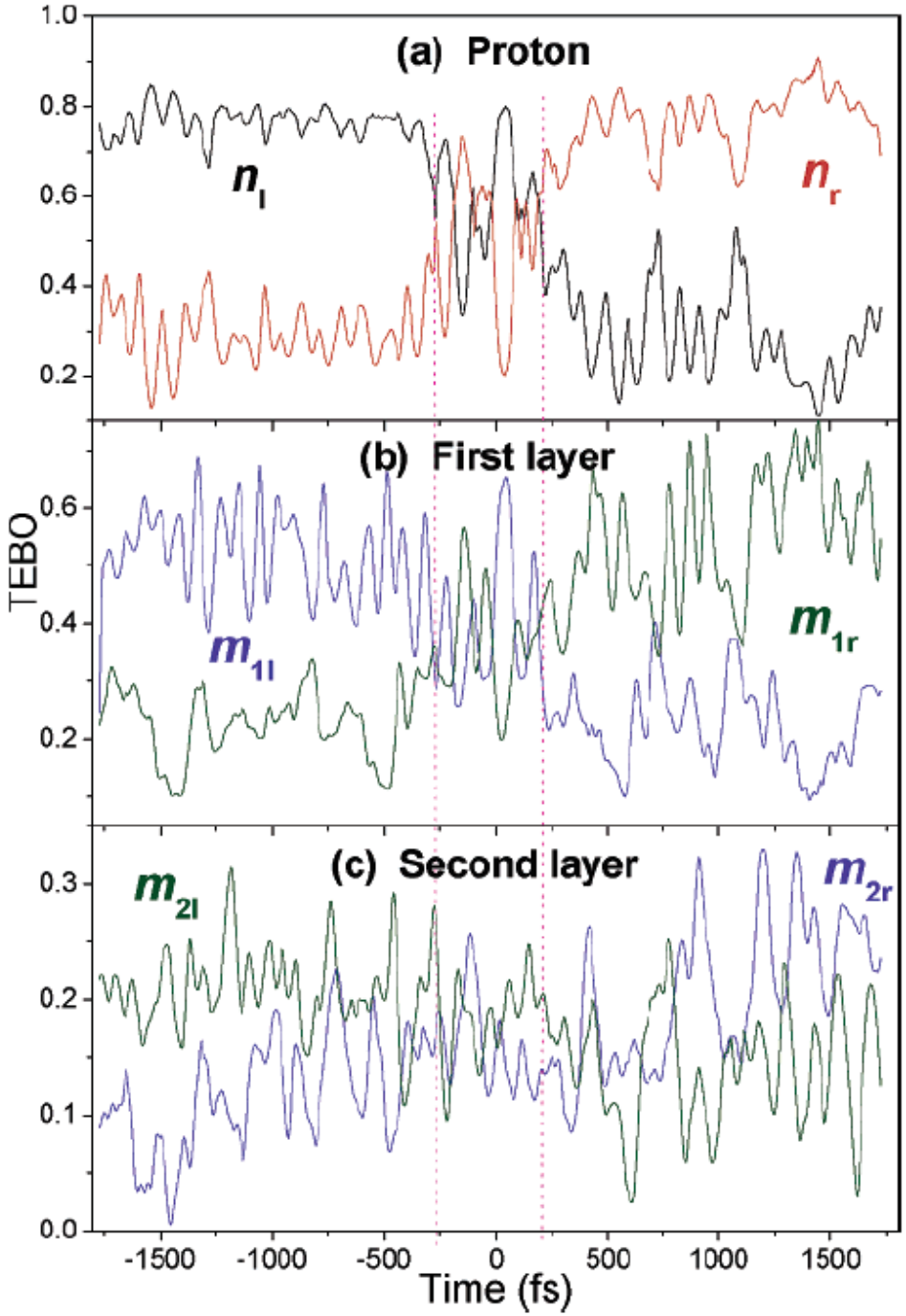



hydrogen
bond
stretching
ν_1
ν_3
librations
ν_2
bending
ν_2+librations
0
250
500
750
2000
3000
4000
Wavenumbers (cm^{-1})

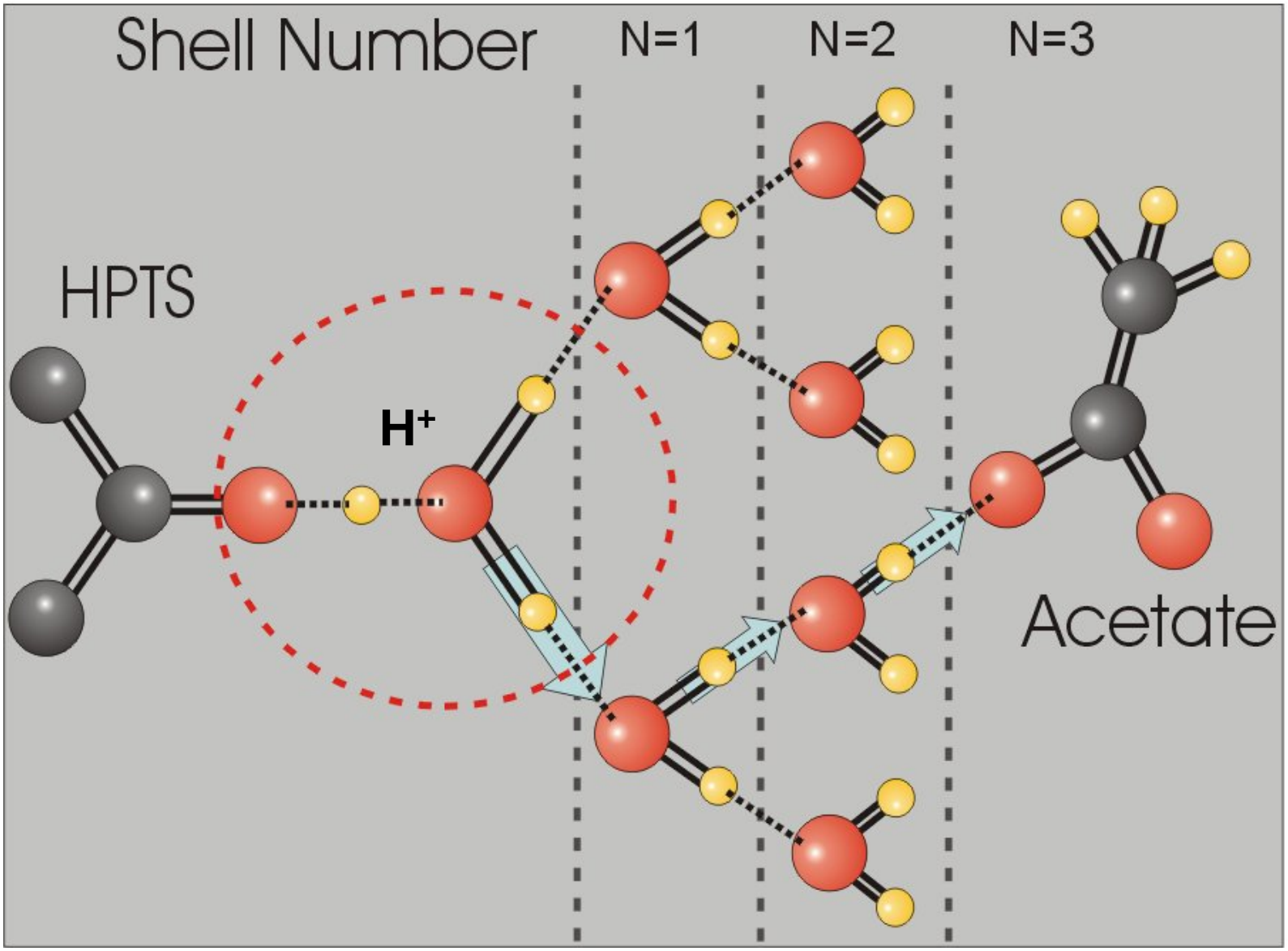

H2O in CH2Cl2
Pure H2O
HDO in D2O
O
D
H
ν1
ν3
Absorption (arb. units)
2800
3000
3200
3400
3600
3800
Wavenumbers (cm-1)

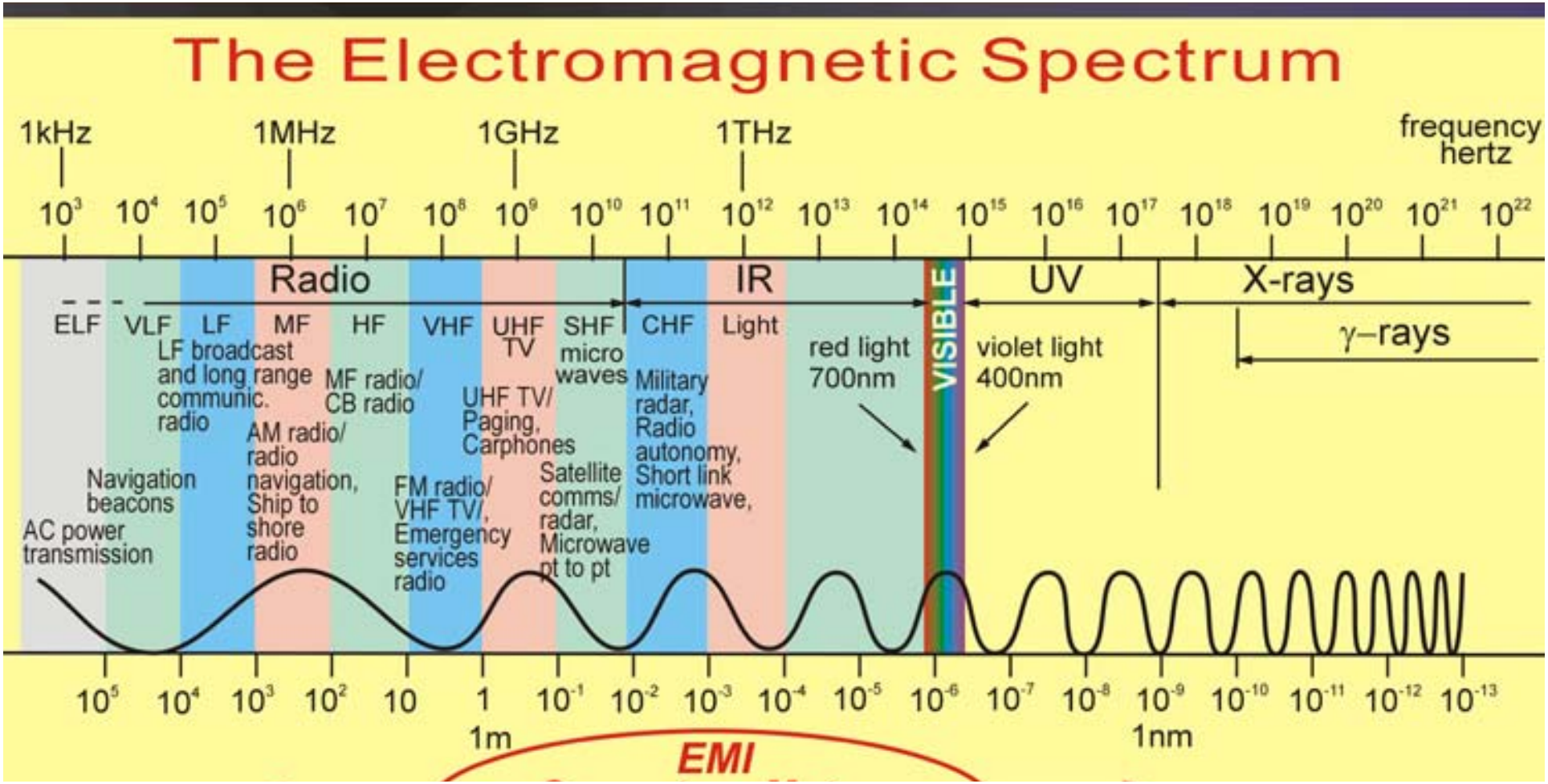

Wavelength (μm)
3.5 3.4 3.3 3.2 3.1 3.0 2.9 2.8 2.7 2.6 2.5
Transmittance (%)
100
90
80
70
60
50
40
30
20
10
0
liquid
vapor
2800 3000 3200 3400 3600 3800 4000
Frequency (cm⁻¹)


(a) Before PT
H_3O^+
(b) After PT
H_3O

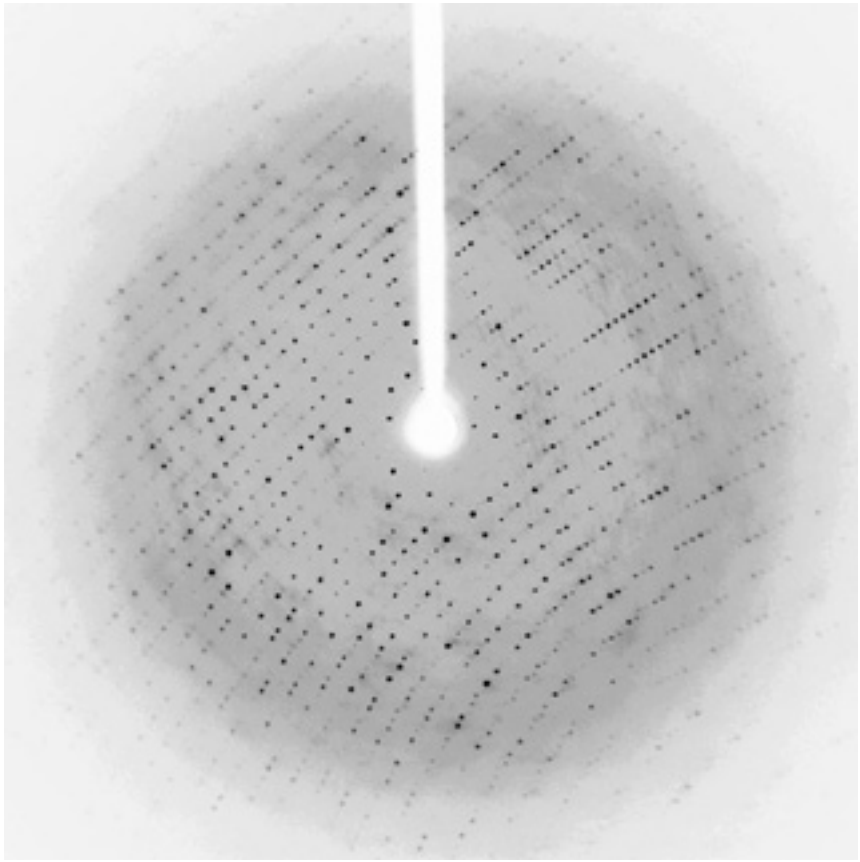

(a) Proton
n_l
n_r
(b) First layer
m_{1l}
m_{1r}
(c) Second layer
m_{2l}
m_{2r}
TEBO
Time (fs)
1.0
0.8
0.6
0.4
0.2
0.6
0.4
0.2
0.3
0.2
0.1
0.0
-1500
-1000
-500
0
500
1000
1500

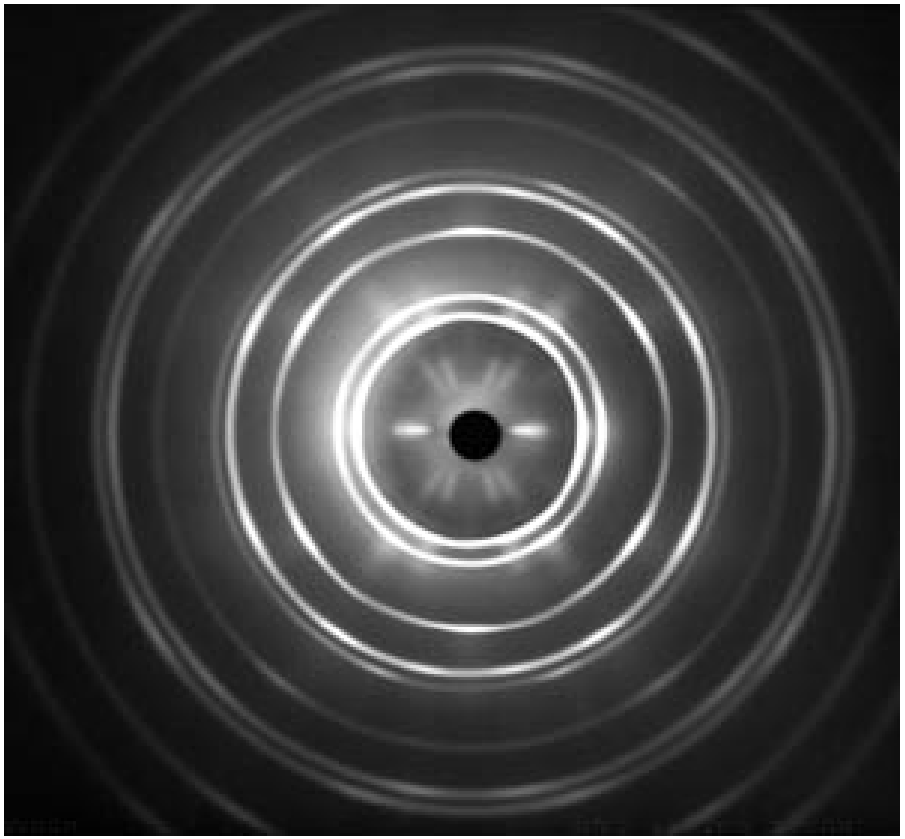
Intermolecular Proton Transfer



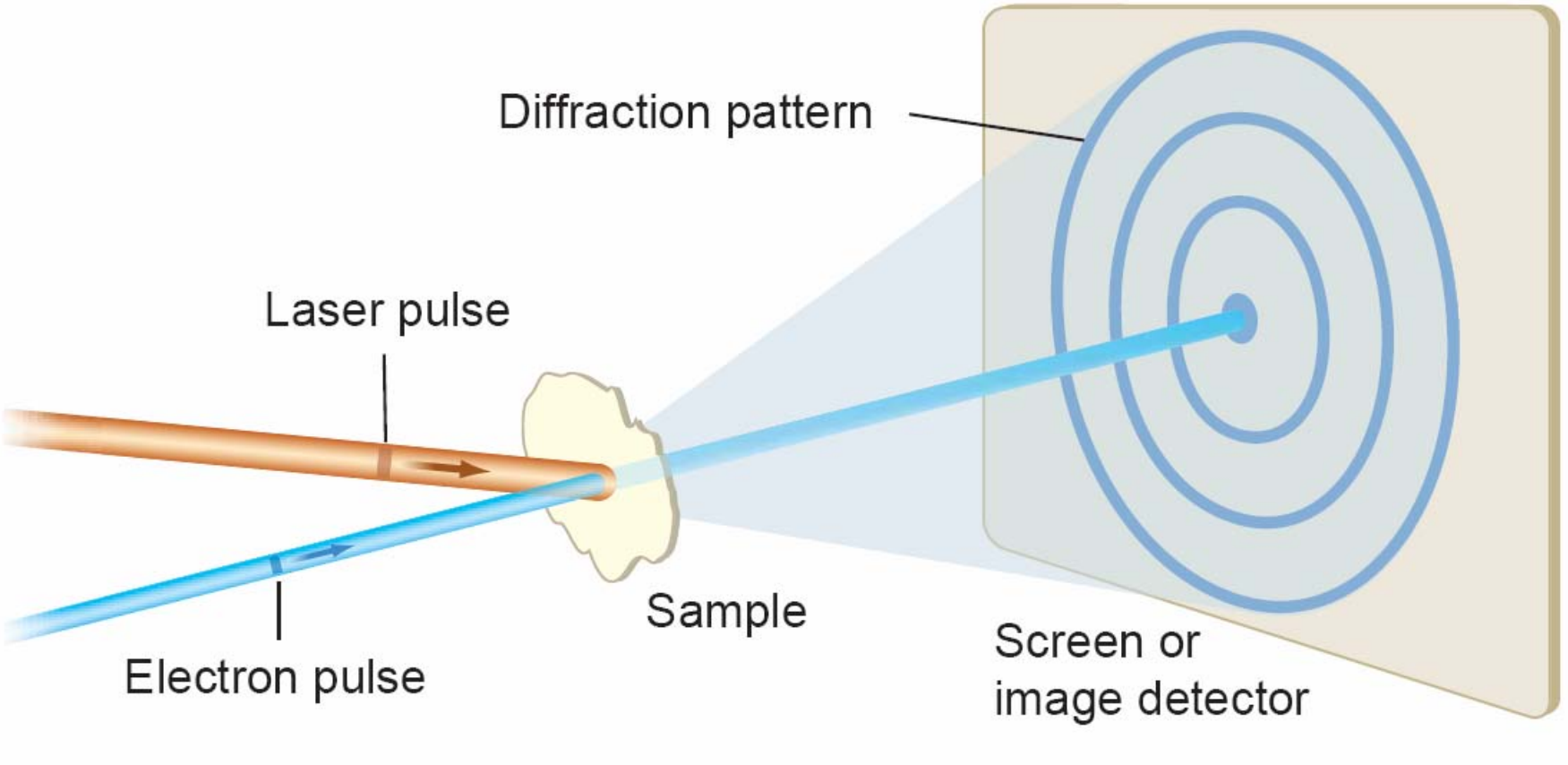

The Electromagnetic Spectrum
1kHz
1MHz
1GHz
1THz
frequency hertz
10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21} 10^{22}
Radio
IR
UV
X-rays
ELF
VLF
LF
MF
HF
VHF
UHF TV
SHF micro waves
CHF
Light
VISIBLE
γ–rays
red light 700nm
violet light 400nm
LF broadcast and long range communic. radio
MF radio/ CB radio
UHF TV/ Paging, Carphones
Military radar, Radio autonomy, Short link microwave,
Navigation beacons
AM radio/ radio navigation, Ship to shore radio
FM radio/ VHF TV/, Emergency services radio
Satellite comms/ radar, Microwave pt to pt
AC power transmission
10^5 10^4 10^3 10^2 10 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12} 10^{-13}
1m
1nm
EMI

Diffraction Patterns: Learning about the arrangement of atoms



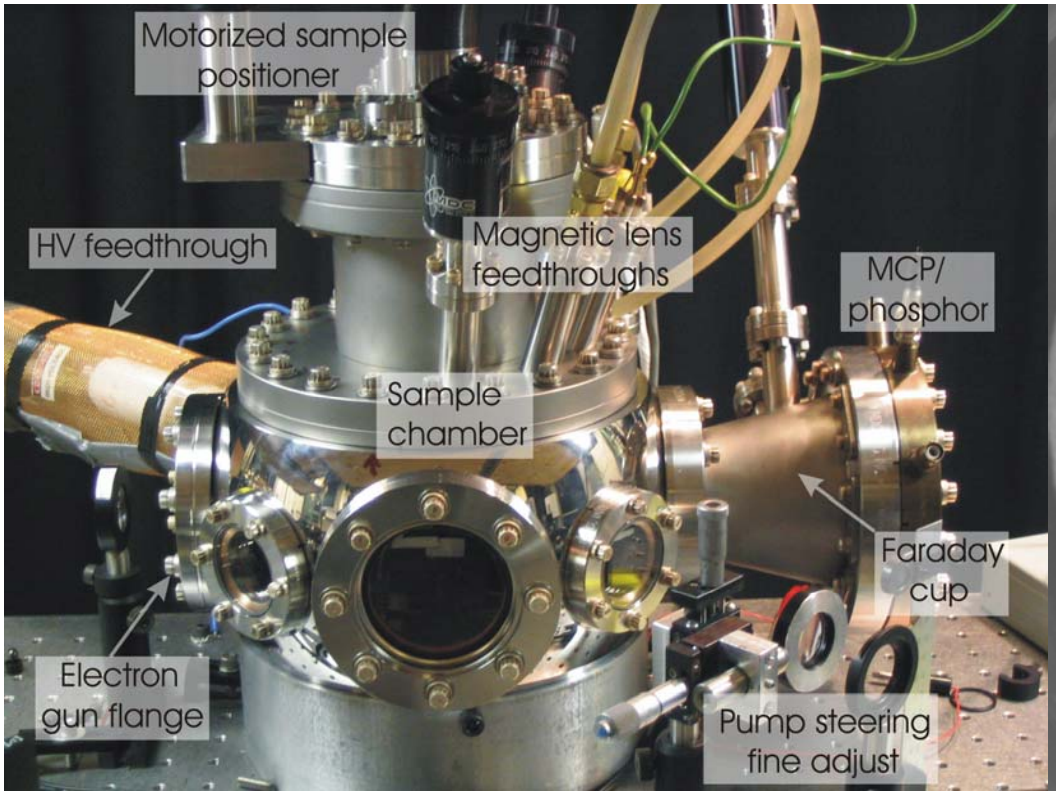


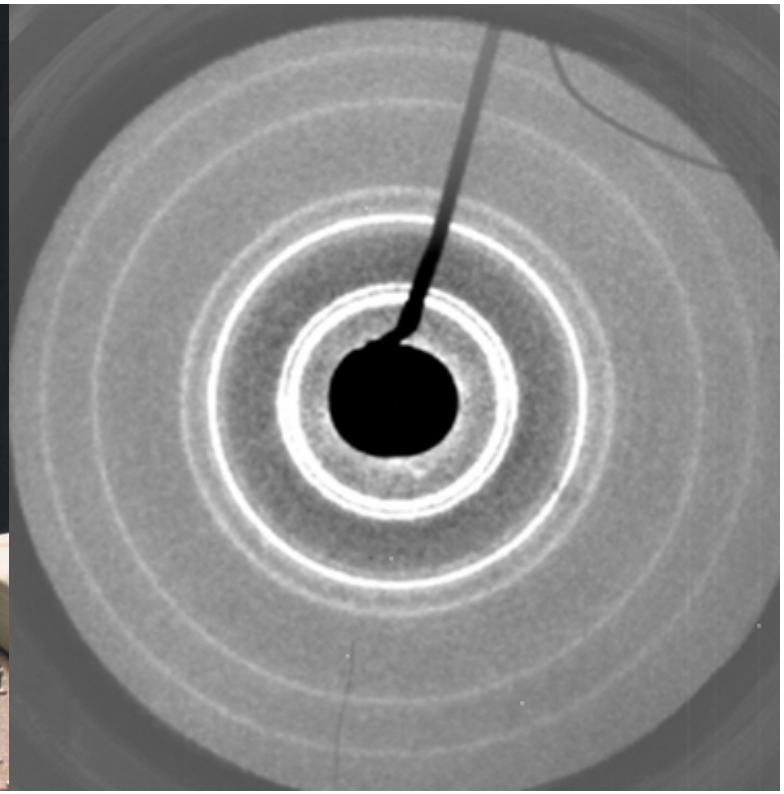
Making Movies of Molecules with Ultrafast Electron Diffraction



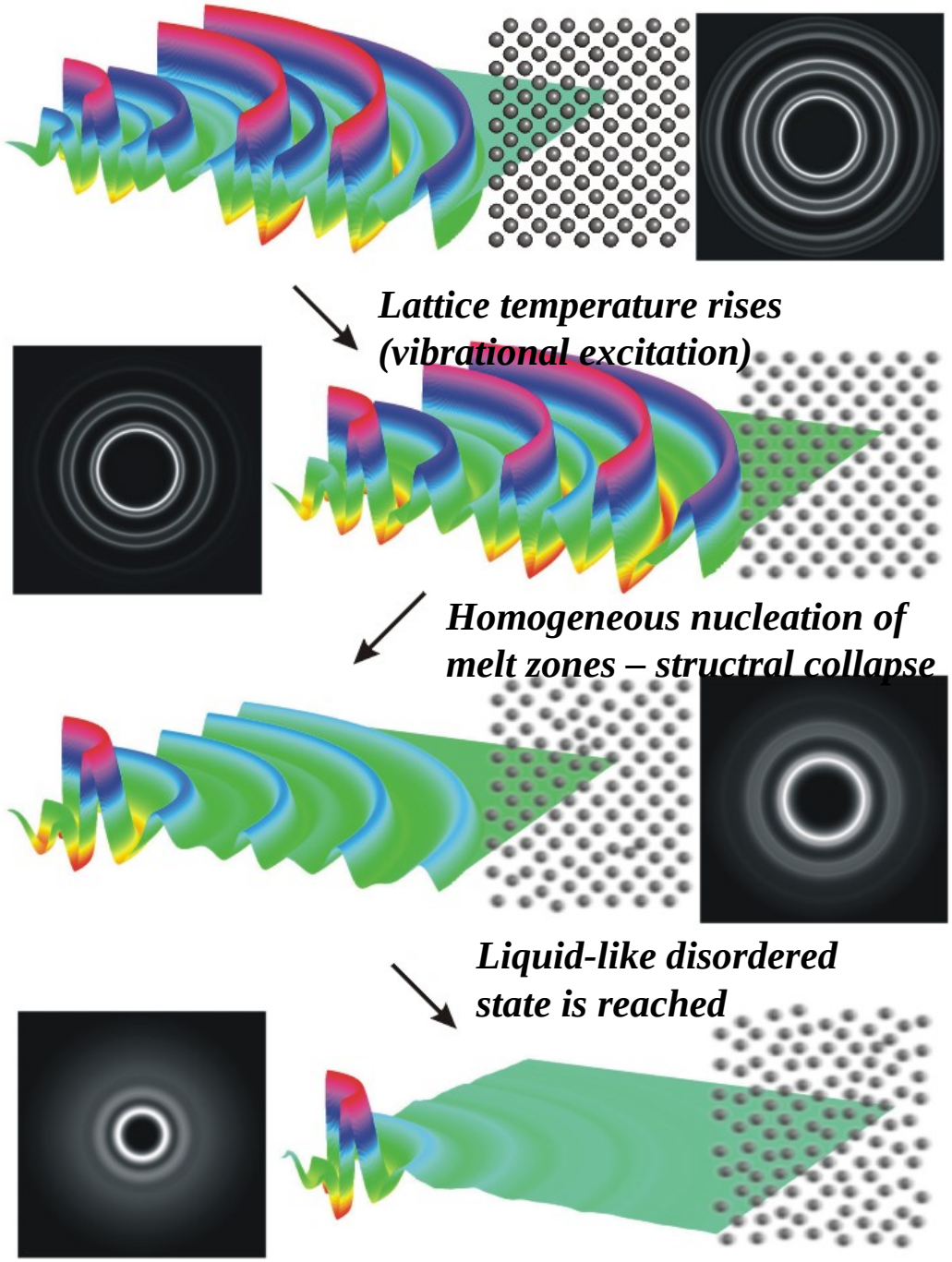
UED is a stroboscopic technique that can determine the 'instantaneous' atomic configuration of molecules and materials during photoinduced processes

Ultrafast ($t<10^{-10}$ s) diffractometer

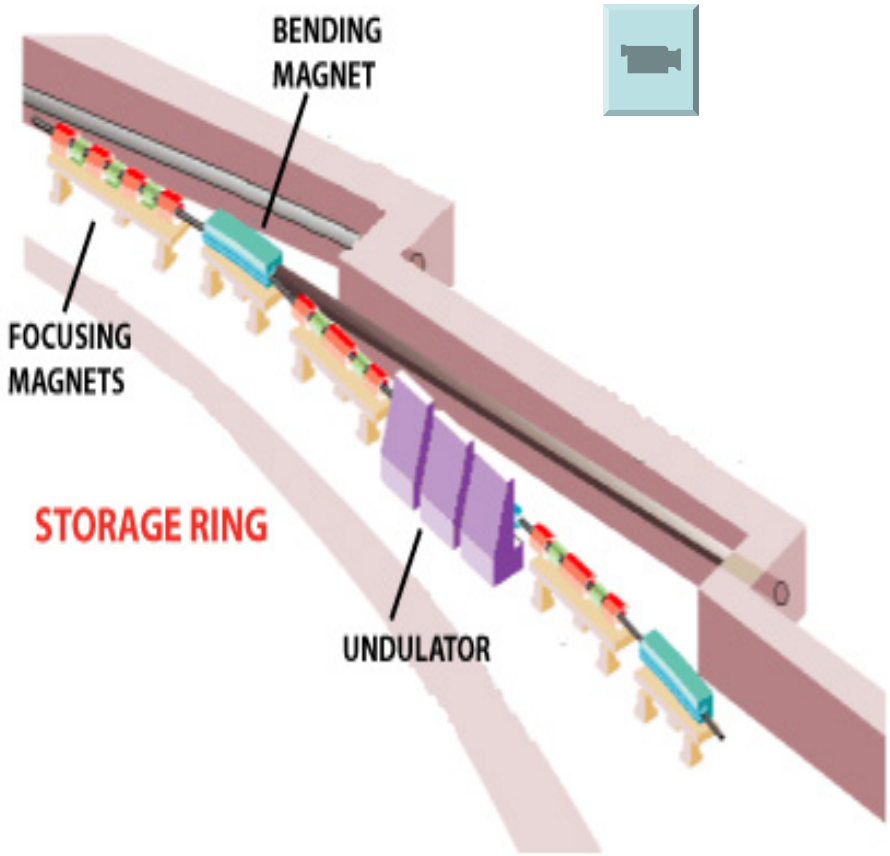


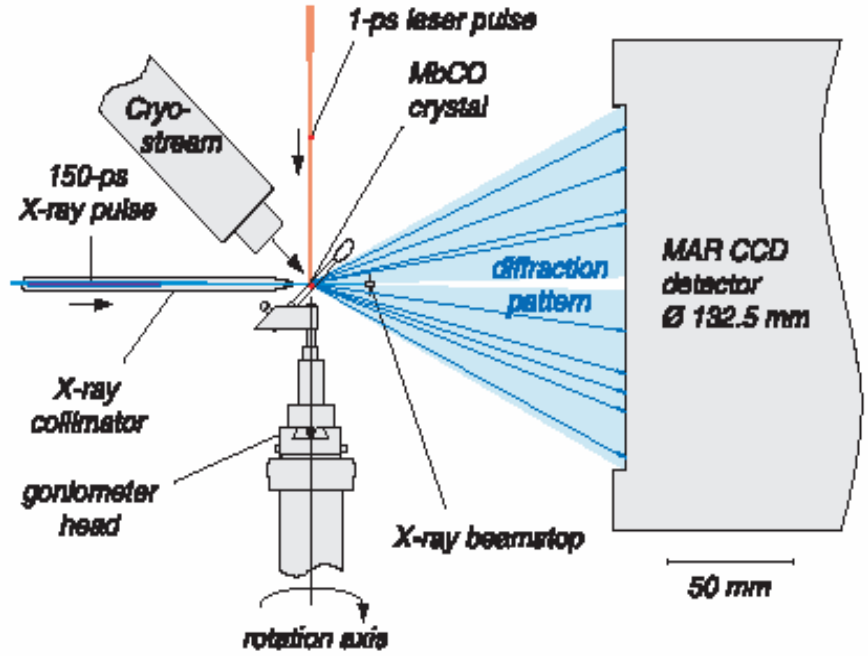


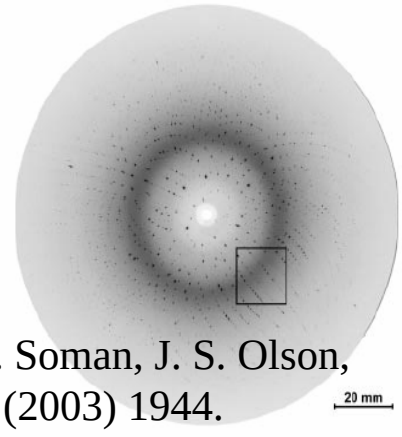
An atomic level view of melting

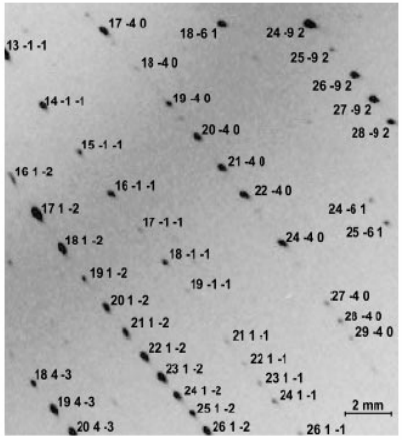


Time-Resolved (150 ps) X-ray Crystallography at the ESRF









F. Schotte, M. H. Lim, T. A. Jackson, A. V. Smirov, J. Soman, J. S. Olson, G. N. Phillips, M. Wulff, P. A. Anfinrud, Science **300** (2003) 1944.

Watching a Protein as it Functions

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