

*La spettroscopia vibrazionale di assorbimento  
Infrarosso e scattering Raman*

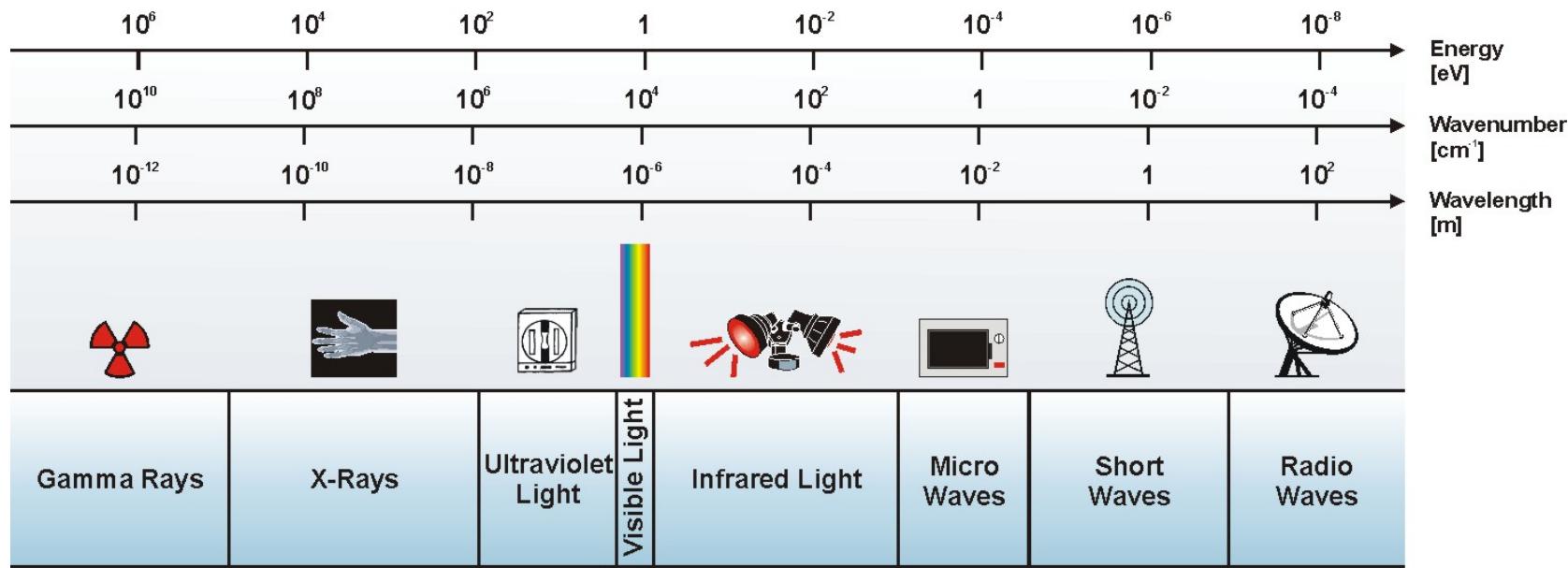
*Due facce della stessa medaglia*

Lisa Vaccari e Francesco D'Amico

# Infrared Spectroscopy

## Basic Concepts on Theory and Instrumentation

# Electromagnetic Spectrum



➤ Speed of light,  $c = 299.792.458 \text{ m/s} \sim 300.000 \text{ Km/s}$

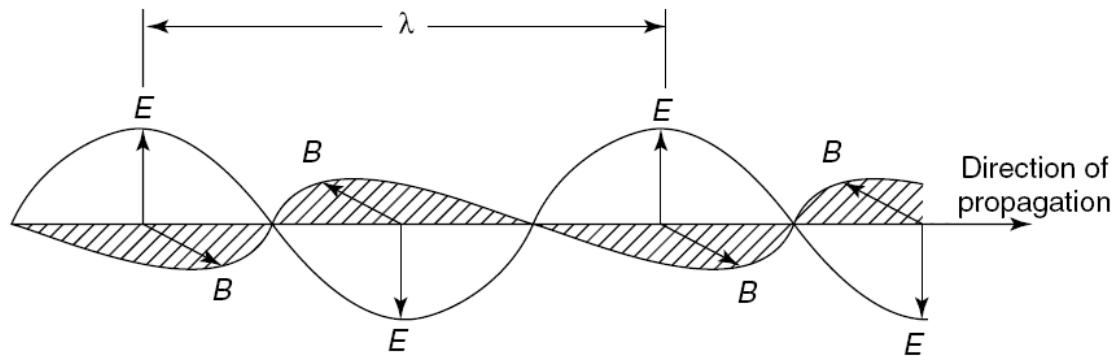
➤ Planck Constant,  $h = 6.62606957 \times 10^{-34} \text{ m}^2 \text{ kg / s}$

➤ The wavelength,  $\lambda$  ( $\mu\text{m}$ )

➤ The frequency,  $\nu$  ([Hz],  $\nu=c/\lambda$ )

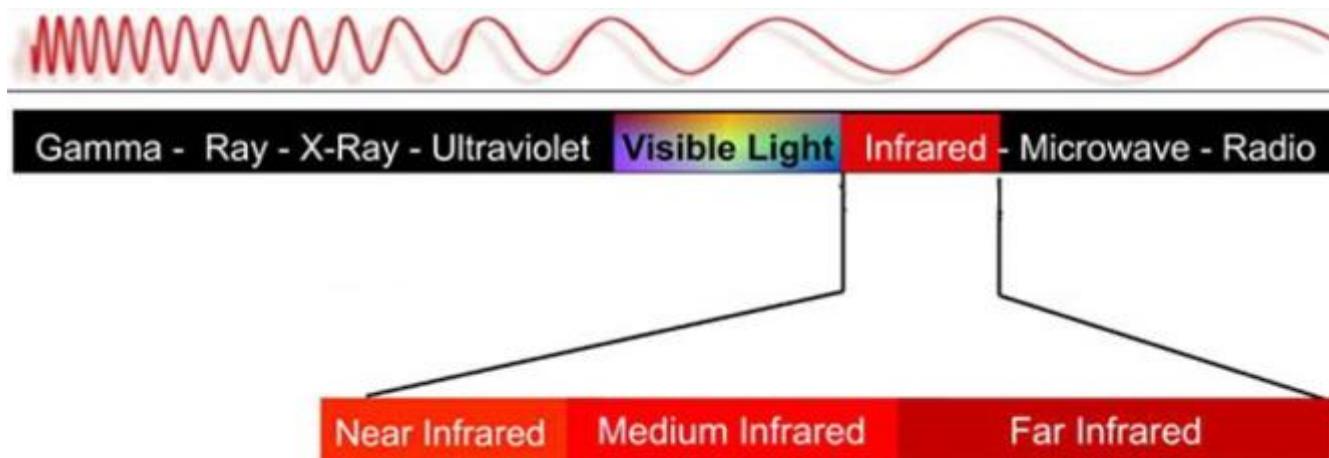
➤ The energy,  $E$  ([eV],  $E=h\nu$ )

➤ The wavenumber,  $\tilde{\nu}$  ([cm<sup>-1</sup>],  $\tilde{\nu}=1/\lambda$ )



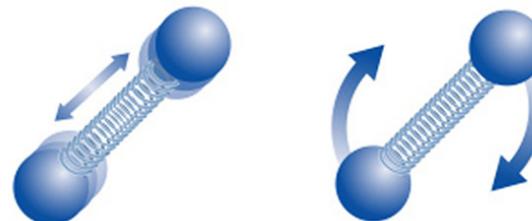
# Electromagnetic Spectrum

## A closer view into the IR spectral range



	NIR	MIR		FIR
$\lambda$ ( $\mu\text{m}$ )	0.74	3	30	300
$\nu$ (THz)	400	100	10	1
$\bar{\nu}$ ( $\text{cm}^{-1}$ )	$\sim 13000$	$\sim 3333$	$\sim 333$	$\sim 33$
E (eV)	1.65	0.413	0.041	0.004
E (Kcal/mol)	37	10	1	0.1

Molecular Vibrations



Molecular Rotations

# Infrared Spectroscopy

## Basic concepts on Theory

### The Born-Oppenheimer Approximation

**1- Electronic motion and nuclear motion in molecules can be separated and independently considered**

$$\Psi_{molecule}^{\uparrow}(r \downarrow i, R \downarrow j) = \Psi_{electrons}^{\uparrow}(r \downarrow i, R \downarrow j) \cdot \Psi_{nuclei}^{\uparrow}(R \downarrow j)$$

The electronic wavefunction depends upon the nuclear positions but not on nuclei velocities → The nuclear motion is so much slower than electron motion that nuclei can be considered to be fixed.

Electronic transitions ( $10^{-15}$  s) are at least  $10^2$  times faster than nuclear transitions and involve energies 10 to 50 times greater

### Degree of freedom

Degree of freedom is the number of variables required to completely describe the motion of a particle/molecule. For a molecule made by N atoms moving in 3-dimensional space, the degree of freedom becomes 3N. For non-linear molecules, all translational/rotational motions can be described in terms of translation/rotations along/around 3 axes. The remaining 3N-6 degrees of freedom constitute vibrational motion. For a linear molecule however there are only 2 rotational degrees of freedom for any linear molecule leaving 3N-5 degrees of freedom for vibration.

**2- Vibrational and rotational motion can also be considered independently**

- The energies involved in rotational transitions ( $10^{-10}$  s) are about  $10^3$  times smaller than the ones involved in vibrational transitions ( $10^{-13}$  s). Pure vibrational transitions falls in the MIR-FIR regime, while pure rotational transition in the FIR-THz regime

## Basic concepts on Theory

### The classical description of vibrational motion

The simplest example: a diatomic heteronuclear molecule AB

$$\mu \downarrow AB = m \downarrow A m \downarrow B / \text{Reduced Mass of AB molecule}$$

$$m \downarrow A + m \downarrow B$$

The equilibrium internuclear distance is denoted by  $r_{\text{eq}}$ . However as a result of molecular vibrations, the internuclear distance is continuously changing; let this distance be called  $r(t)$ .

Let  $x(t) = r(t) - r_{\text{eq}}$

When  $x$  is non-zero, a restoring force  $F$  exists which tries to bring the molecule back to  $x=0$ , that is equilibrium. For small displacements this force can be taken to be proportional to  $x$ .

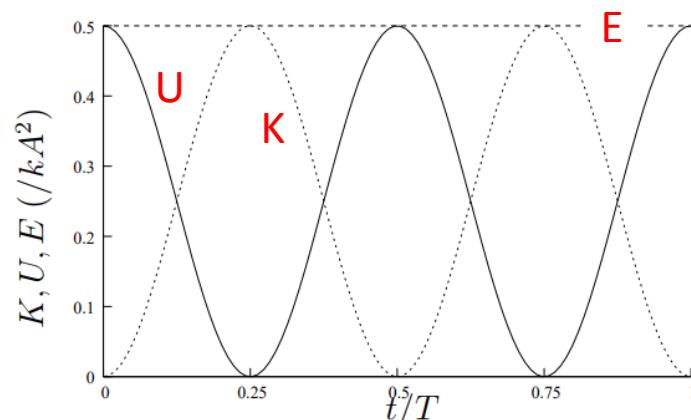
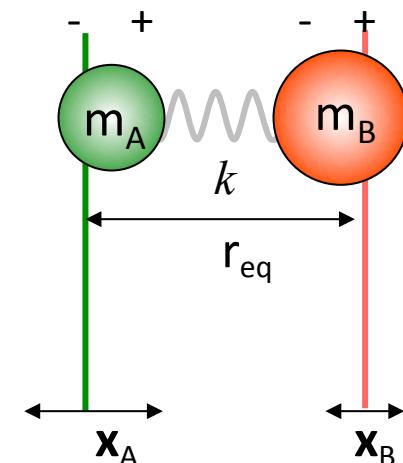
$F(\text{restoring force}) = -kx$

[The Hooke's law]

$k = \text{Force constant } [\text{Nm}^{-1}]$

$x(t) = A \sin(2\pi\nu t)$

$\nu = 1/2\pi \sqrt{k/\mu \downarrow AB}$        $E = K + U = 1/2 kA^2$



# Infrared Spectroscopy

## Basic concepts on Theory

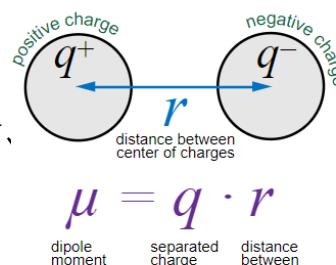
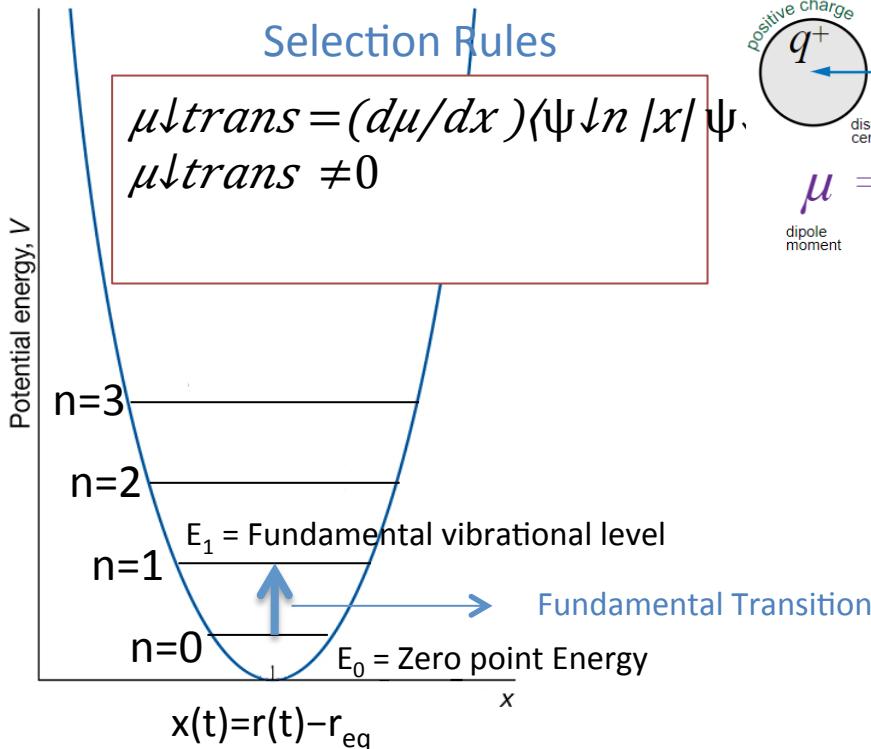
$$-\hbar^2 / 8\pi^2 \mu \nabla^2 AB \frac{d\Psi}{dx} + 1/2 kx^2 \Psi = E\Psi$$

Quantum mechanical Model of harmonic oscillator

$$E_{vib} = \hbar\nu(n+1/2)$$

n: Vibrational quantum number (0,1,2,3,...)

A series of equally spaced never ending vibrational levels



$$(d\mu/dx) \neq 0$$

Vibrations that do not induce variation of the dipole moment of the molecule are forbidden  
For a homonuclear molecule AA there are not vibrational transitions allowed

$$\langle \Psi \downarrow n | x | \Psi \downarrow n' \rangle \neq 0$$

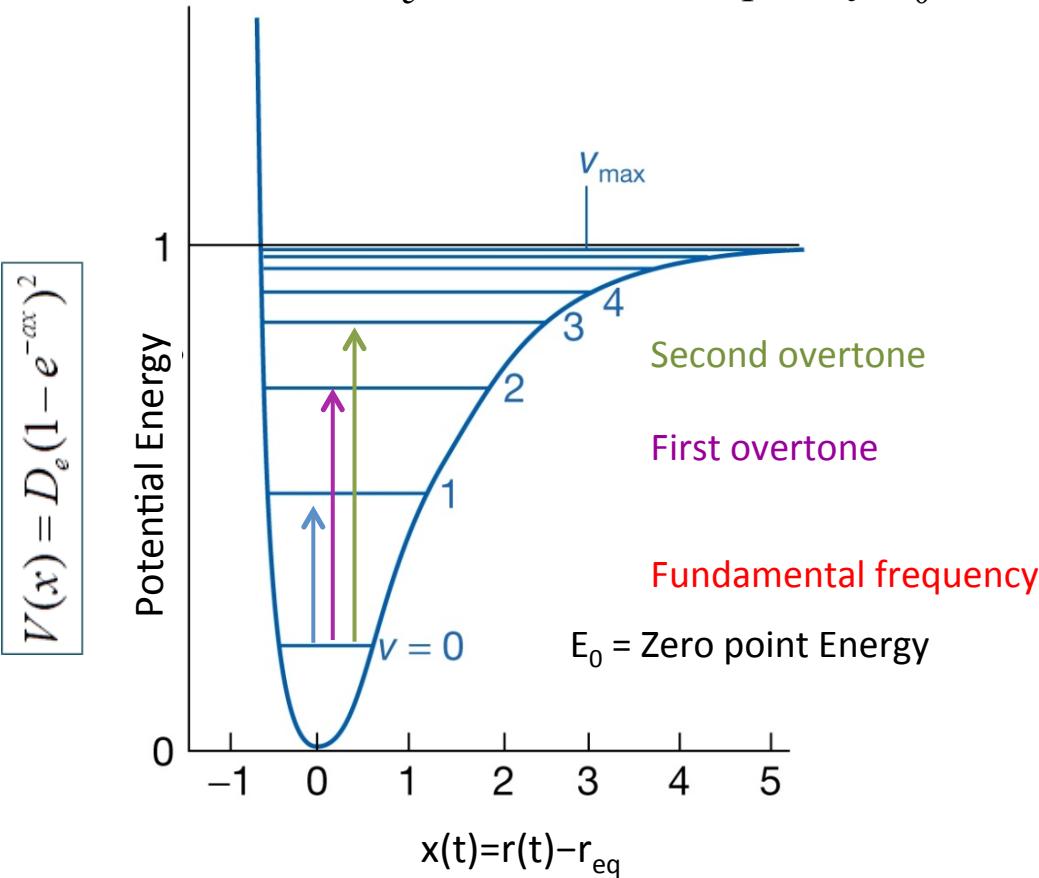
$$\Delta n = \pm 1$$

## Basic concepts on Theory

### Quantum mechanical Model of anharmonic oscillator

$$E_{vib} = h\nu_e [(n + 1/2) - x_0(n + 1/2)^2 + \text{higher terms}]$$

$\nu_e$  = harmonic frequency  $x_0$  = anharmonic constant



Selection Rules

$$(d\mu/dx) \neq 0$$

$\Delta n = \pm \text{integer}$

Overtone bands are observed, with frequencies usually lower than the whole multiples of fundamental.

Combination bands are also allowed (two vibrational quantum number changes at the same time)

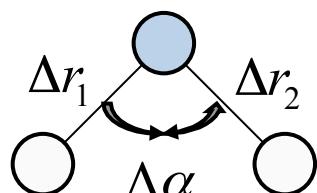
# Infrared Spectroscopy

## Basic concepts on Theory

### Normal modes of vibration

- A normal mode is a molecular vibration where some or all atoms vibrate together at the same frequency.
- The number of “normal modes” is equal to the vibrational degree of freedom available
- Each mode has a definite frequency of vibration. Sometimes 2 or 3 modes may have the same frequency but that does not change the fact that they are distinct modes; these modes are called degenerate.

The 3 normal modes of vibratine of a triatomic molecule , defined by 3 normal coordinates ( $Q_1$ ,  $Q_2$ ,  $Q_3$ ) may be defined in terms of internal coordinates



$$Q_1 = l_{11}\Delta r_1 + l_{21}\Delta r_2 + l_{31}\Delta\alpha \quad \nu_1 \quad \text{3 quantum numbers: } n_1, n_2, n_3$$

$$Q_2 = l_{12}\Delta r_1 + l_{22}\Delta r_2 + l_{32}\Delta\alpha \quad \nu_2 \quad \text{3 fundamental vibrations :}$$

$$Q_3 = l_{13}\Delta r_1 + l_{23}\Delta r_2 + l_{33}\Delta\alpha \quad \nu_3 \quad E(0,0,0) \rightarrow E(1,0,0) \quad \nu_1$$

$$E(0,0,0) \rightarrow E(0,1,0) \quad \nu_2$$

$$E(0,0,0) \rightarrow E(0,0,1) \quad \nu_3$$

Overtones and combinations bands

$$(000) \rightarrow (020) \quad 2\nu_2$$

$$(000) \rightarrow (110)$$

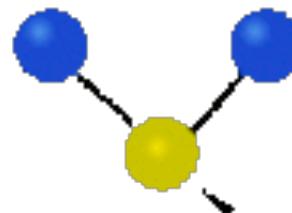
$$E_{vib} = \sum_{i=1}^{3N-6} \left( ni + \frac{1}{2} \right) h\nu_i$$

$$E_0 = \frac{1}{2} \sum_{i=1}^{3N-6} h\nu_i$$

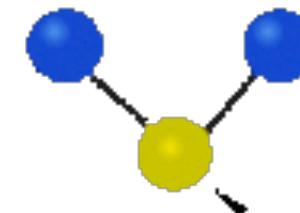
## Basic concepts on Theory

Stretching modes ( $\nu$ )

Symmetric Stretching

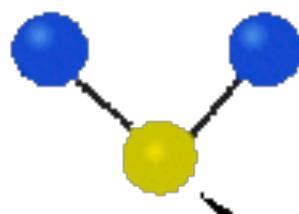


Antisymmetric Stretching

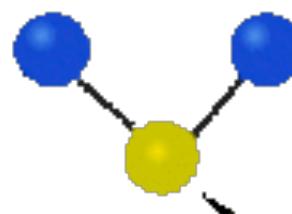


Deformation modes

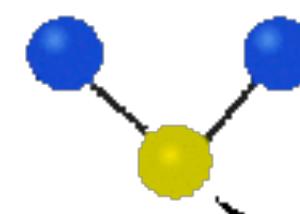
Scissoring ( $\delta$ )



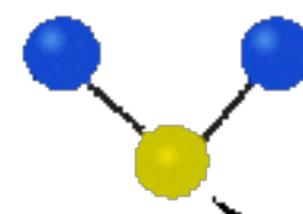
Rocking ( $r$  or  $\rho$ )



Wagging ( $\omega$ )



Twisting ( $\tau$ )



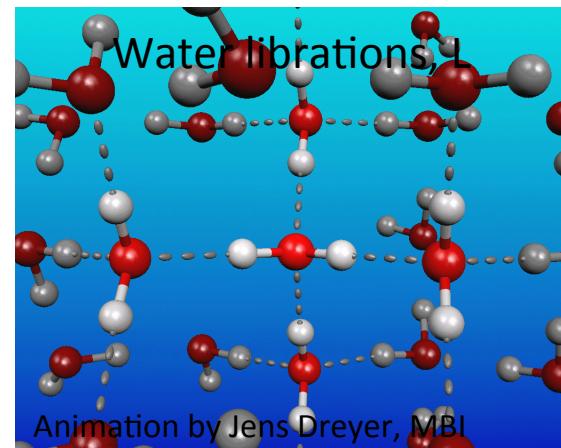
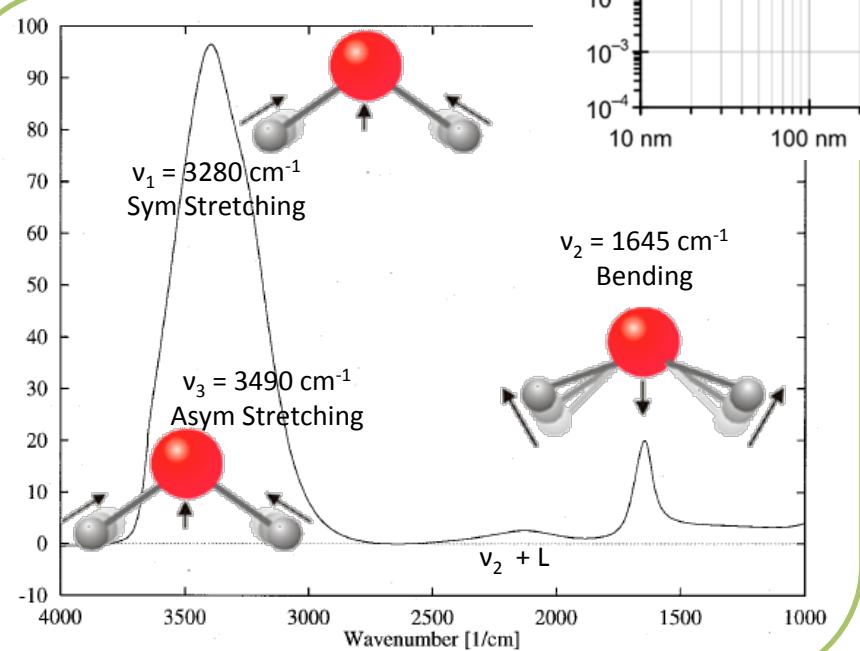
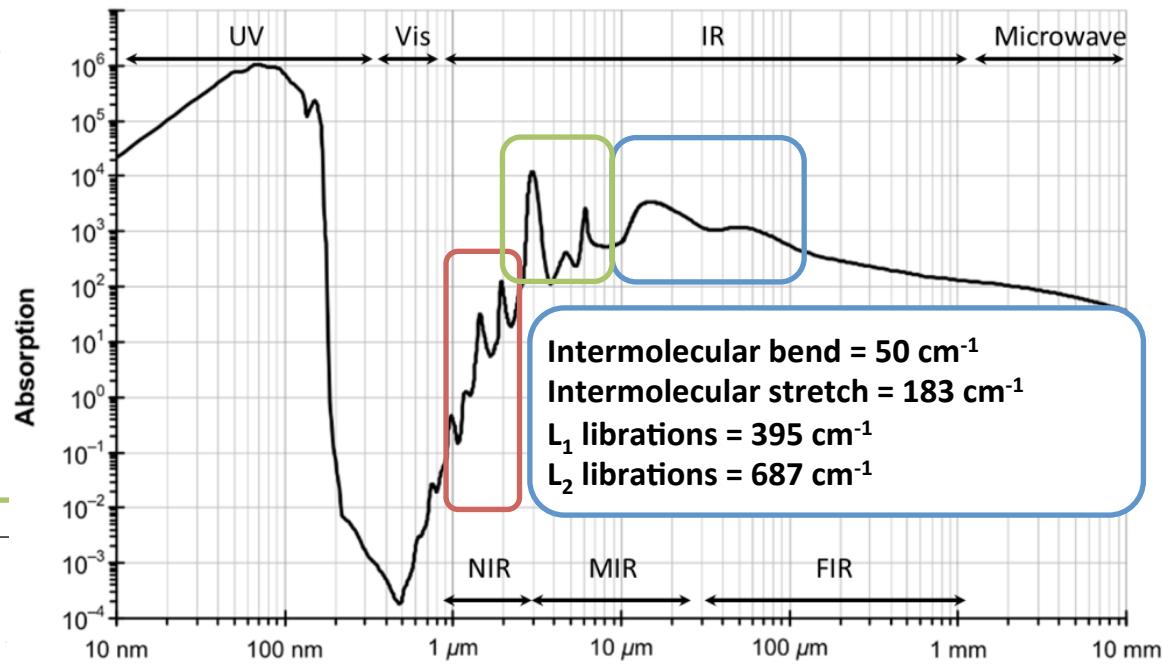
In plane deformations

Out plane deformations

## Basic concepts on Theory

### Vibrational Spectrum of liquid water

Overtones  
and  
combination bands



## Basic concepts on Theory

### FROM PEAK POSITION, INTENSITY AND WIDTH

CONCENTRATION OF THE SPECIES(BEER-LAMBERT LAW)

$$A = \varepsilon \cdot \text{absrptivity} \cdot l \cdot \text{path lenght} \cdot c \cdot \text{concnetration}$$

NATURE OF ATOMS INVOLVED IN THE SPECIFIC VIBRATION

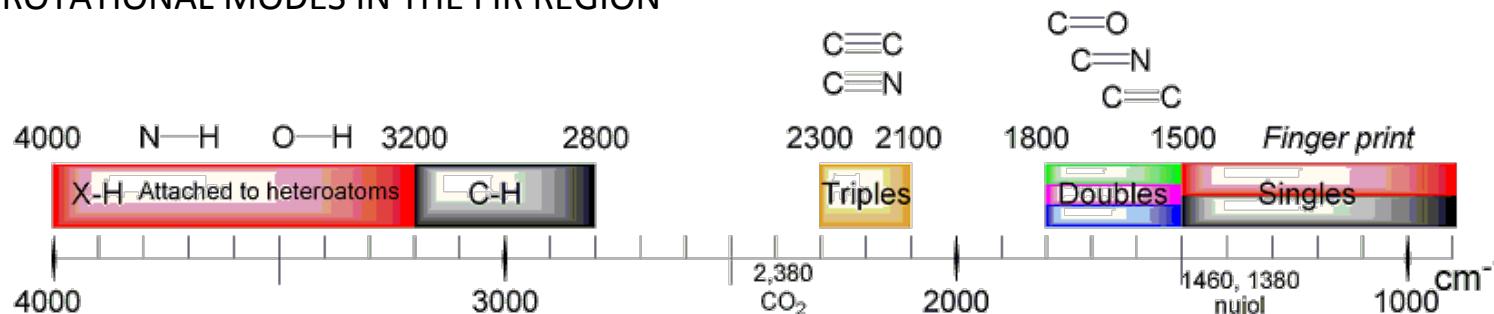
$$\nu = 1/2\pi \sqrt{k/\mu} \cdot A \cdot B$$

PARAMETERS OF THE ATOMIC BOND : BOND STRENGTH AND LENGTH

BOND CONFORMATION: DOUBLE BOND CIS/TRANS, .....

CHEMICAL ENVIRONMENT (THROUGH MODULATION OF THE DIPOLE MOMENT)

ROTATIONAL MODES IN THE FIR REGION



### FROM WHOLE SPECTRUM

NATURE OF THE MOLECULE: SPECTRAL FINGERPRINT=> MOLECULAR IDENTIFICATION

SAMPLE INTERACTIONS: FREE/BOUND WATER ...

SAMPLE EVOLUTION: REACTION KINETIC, AGING, PHYSICO CHEMICAL TREATMENT, CONSTRAINTS  
(PRESSURE, TEMPERATURE, pH) ...

### QUANTITATIVE or SEMI-QUANTITATIVE ANALYSIS

SIMPLE MIXTURES: BEER LAMBERT BOUGUER LAW

# Infrared Spectroscopy

## Basic concepts on Instrumentation

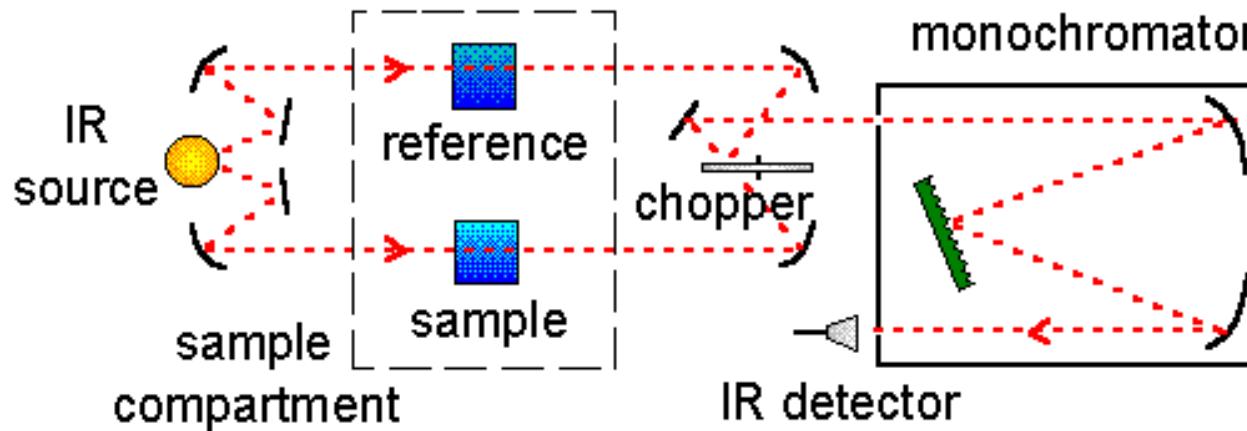
When dealing with molecular species (normal modes of vibration  $3N-6$ ), the absorption profile at a single frequency (or limited spectral range) is scarcely useful.

Only a multi-frequency profile can account for the system complexity and its interaction with the environment



An FTIR spectrum needs to be energy resolved over a large spectral range

### The past instrumentation: Dispersive Interferometers



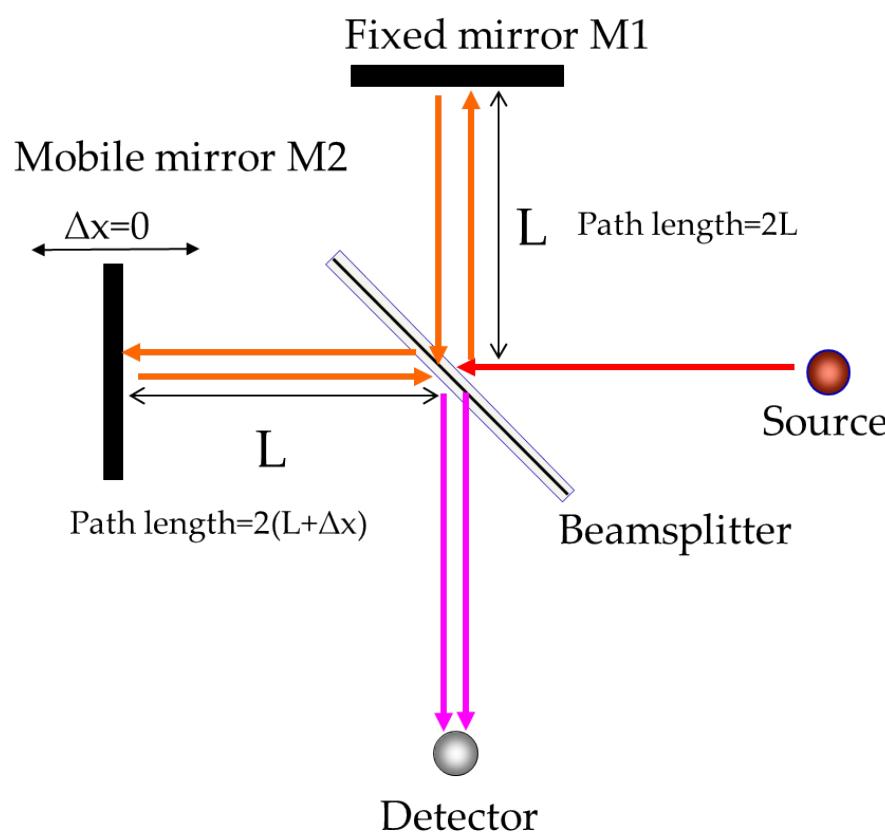
©1995 CHP

[http://www.chemicool.com/definition/fourier\\_transform\\_infrared\\_spectrometer\\_ftir.htm](http://www.chemicool.com/definition/fourier_transform_infrared_spectrometer_ftir.htm)

This slow acquisition time limited the wide spreading of infrared spectroscopy until 1960s', when Fourier Transform Interferometer have been first proposed. [www.ceric-eric.eu/project/pages](http://www.ceric-eric.eu/project/pages)

## Basic concepts on Instrumentation

The present instrumentation: Fourier Transform InfraRed Interferometers



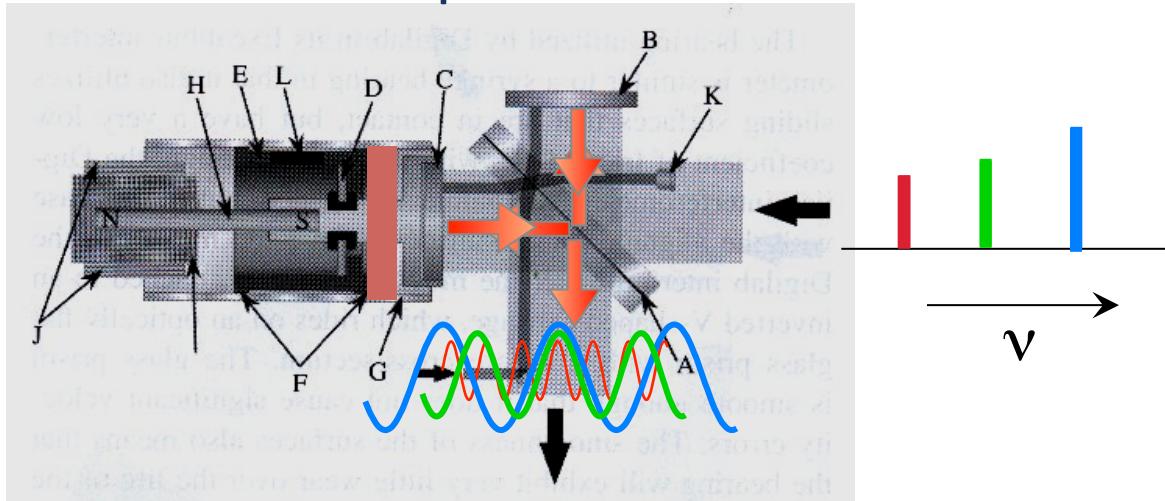
$$\text{Optical Path Difference - OPD}$$

$$2\Delta x = 2vt$$

$$v = \text{mirror velocity}$$

- ⇒ Conventional sources
  - NIR: Tungsten lamp
  - MIR: Glow bar (SiC)
  - FIR: Hg-Arc
  
- ⇒ Beamsplitters
  - NIR: CaF<sub>2</sub>
  - MIR: KBr
  - FIR: Mylar, Silicon
  
- ⇒ Detectors
  - NIR – InGaAs, InSb, Ge, Si room temperature detectors
  - MIR: Room temperature DLaTGS
  - Nitrogen cooled MCT
  - FIR – He Cooled Silicon Bolometer
  - Room temperature DLaTGS

## Basic concepts on Instrumentation



For a single wavelength

$$I(x) = I(\tilde{\nu})[1 + \cos(2\pi x \tilde{\nu})]$$

Fourier Transform (FT) →

For a polychromatic source

$$I(x) = \int I(\tilde{\nu})d\tilde{\nu} + \int I(\tilde{\nu}) \cos(2\pi x \tilde{\nu})d\tilde{\nu}$$

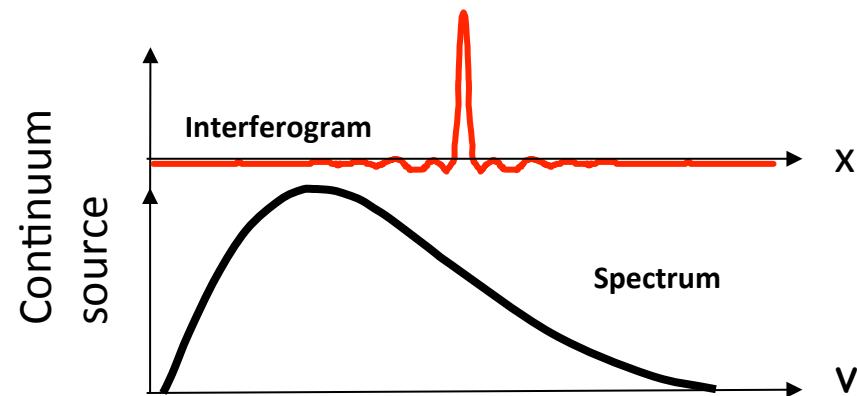
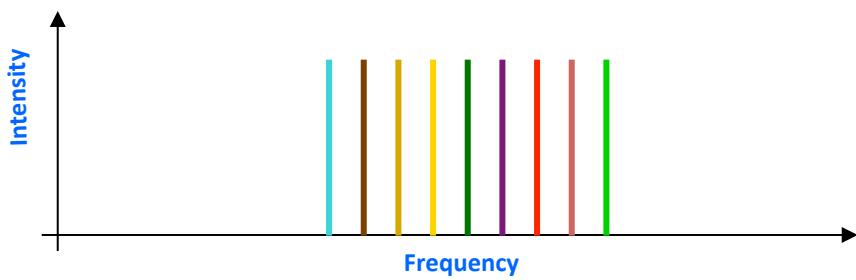
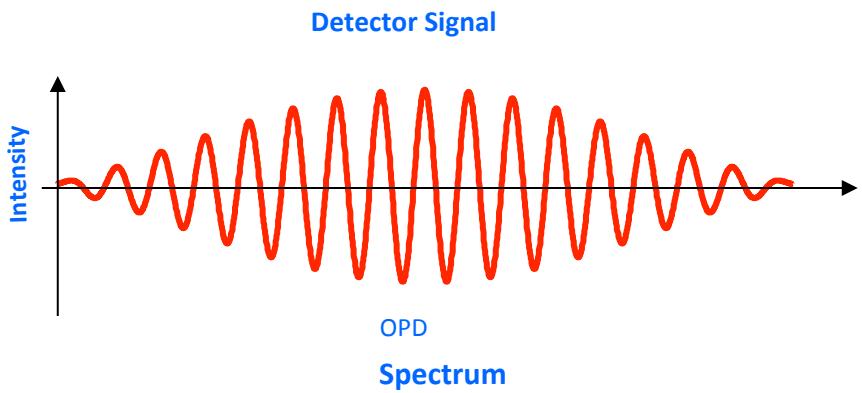
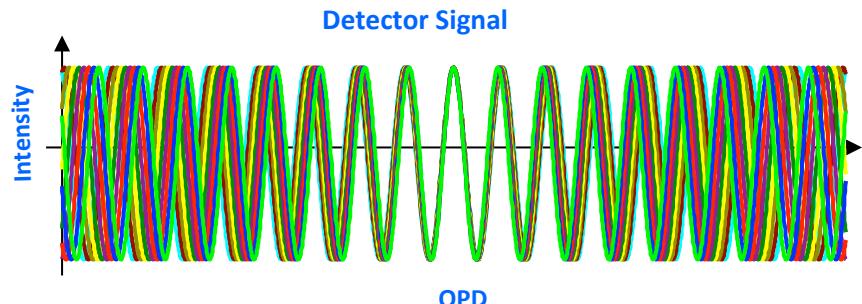
$$I(ZPD) = 2 \int I(\tilde{\nu})d\tilde{\nu} = I_0$$

$$I(x) = \frac{1}{2} I_0 + \int I(\tilde{\nu}) \cos(2\pi x \tilde{\nu})d\tilde{\nu}$$

$$I(x) - \frac{1}{2} I_0 = I'(x) = \int_{-\infty}^{+\infty} I(\tilde{\nu}) \cos(2\pi x \tilde{\nu})d\tilde{\nu}$$

$$I(\tilde{\nu}) \propto \int_{-\infty}^{+\infty} I'(x) \cos(2\pi x \tilde{\nu})dx$$

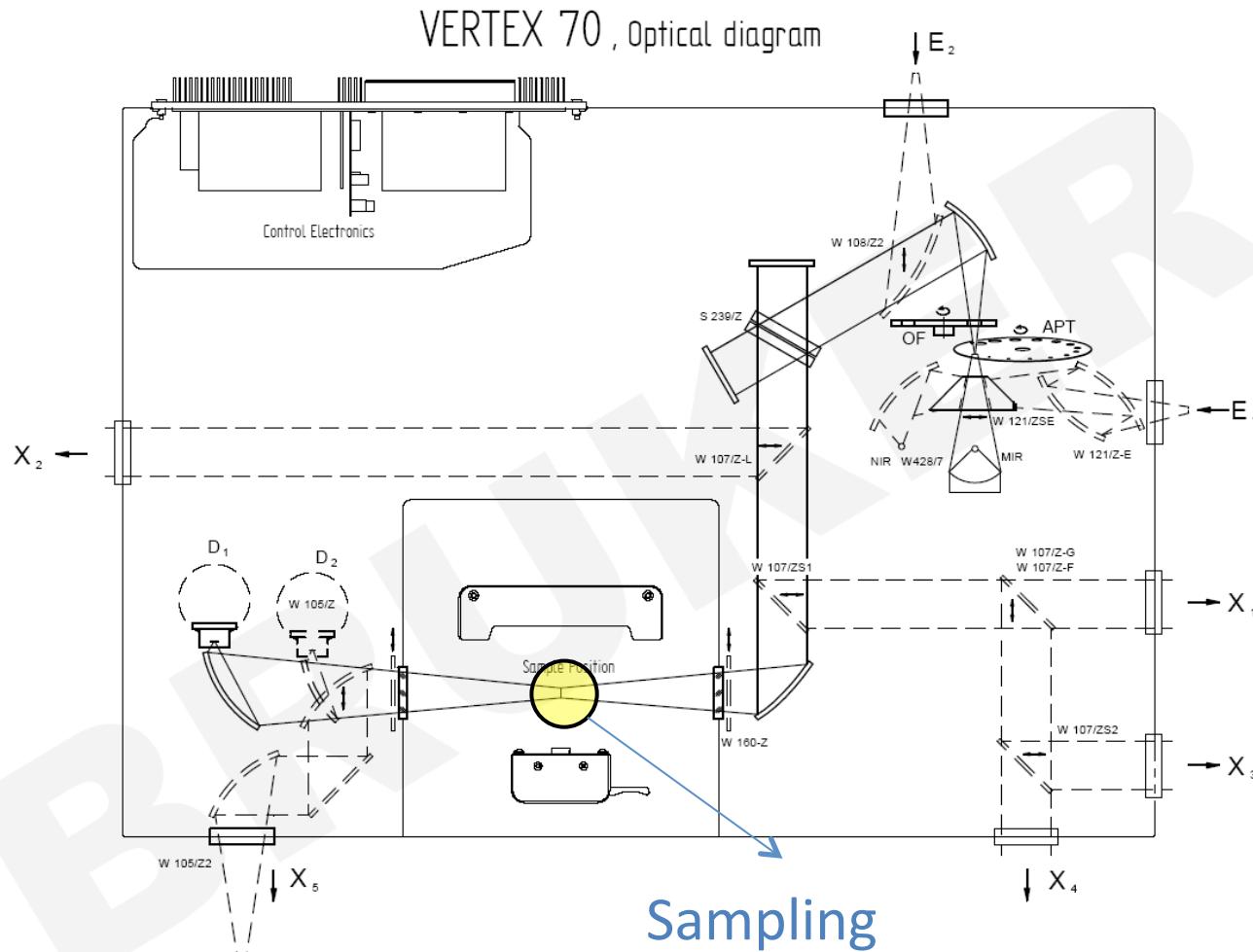
## Basic concepts on Instrumentation



# Infrared Spectroscopy

## Basic concepts on Instrumentation

### Optical Scheme of a FTIR spectrometer

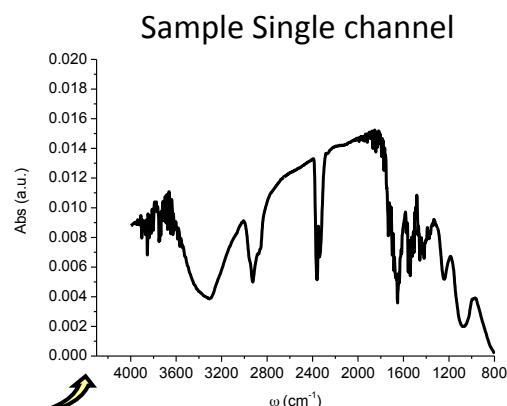
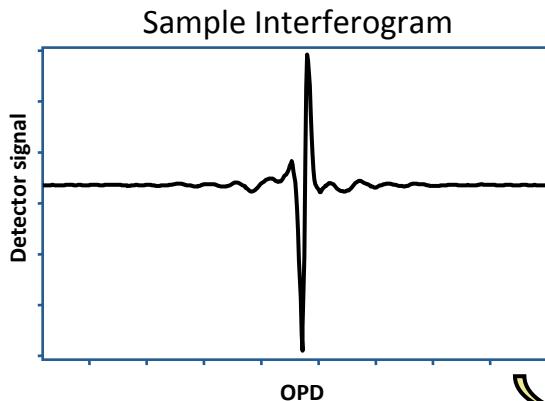


Sampling  
techniques ?

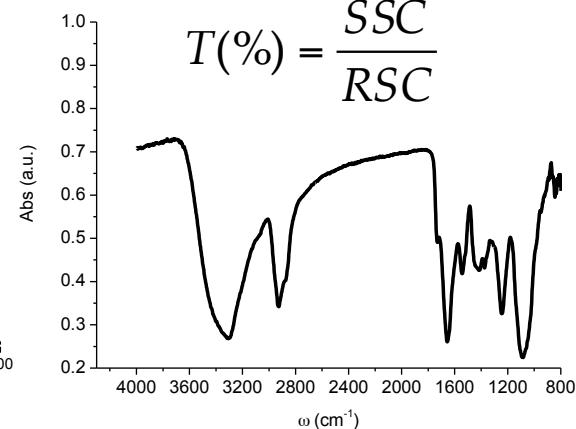
# Infrared Spectroscopy

## Basic concepts on Instrumentation

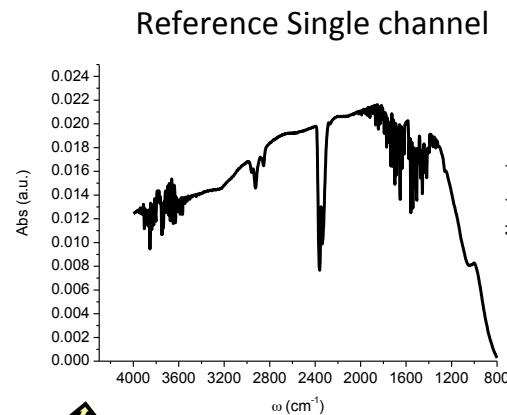
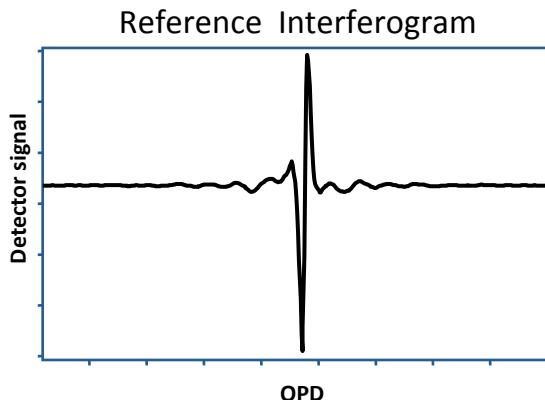
### Acquisition of an infrared spectrum



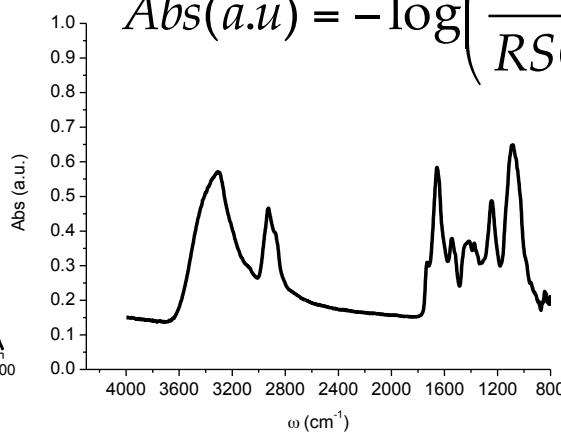
$$T(\%) = \frac{SSC}{RSC}$$



FT



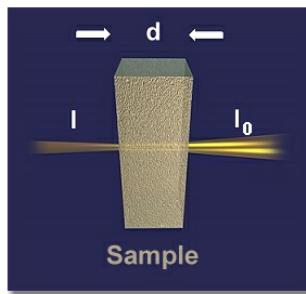
$$Abs(a.u) = -\log\left(\frac{SSC}{RSC}\right)$$



FT

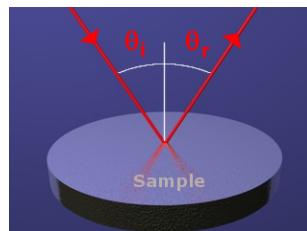
## Basic concepts on Instrumentation

- TRANSMISSION



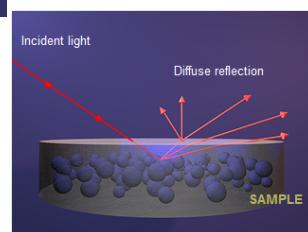
- REFLECTION

- SPECULAR



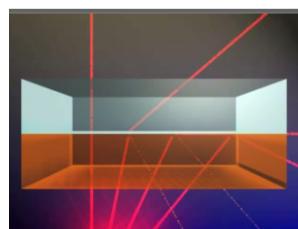
Typical angle of incidence = 10-30°  
The refraction behavior of the bulk sample is investigated

- DIFFUSE



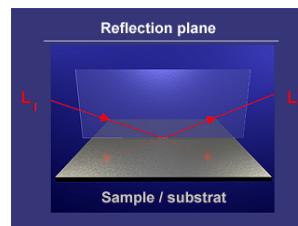
The diffusive-reflection spectrum is defined by the absorption-scattering behavior of the sample

- TOTAL



**Attenuated Total Reflection:** The surface properties of the material are investigated for penetration depth of hundreds of nanometers

- GRAZING INCIDENCE



Typical angle of incidence = 50-85°  
The surface properties of the sample are investigated

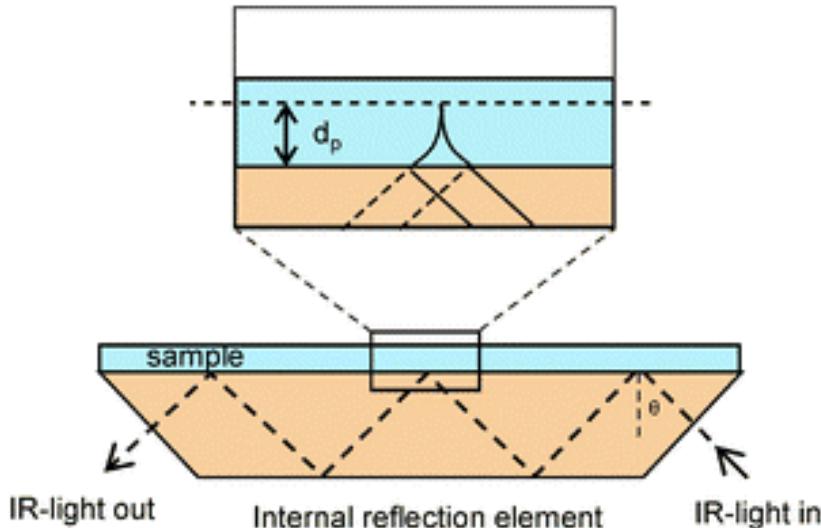
### Lambert-Beer Law

$$-\log_{10} (I/I_0) = \varepsilon dc$$

$$L \cdot mol^{-1} \cdot cm^{-1}, [c] = mol \cdot L^{-1}, [d] = cm$$

# Infrared Spectroscopy

## Basic concepts on Instrumentation

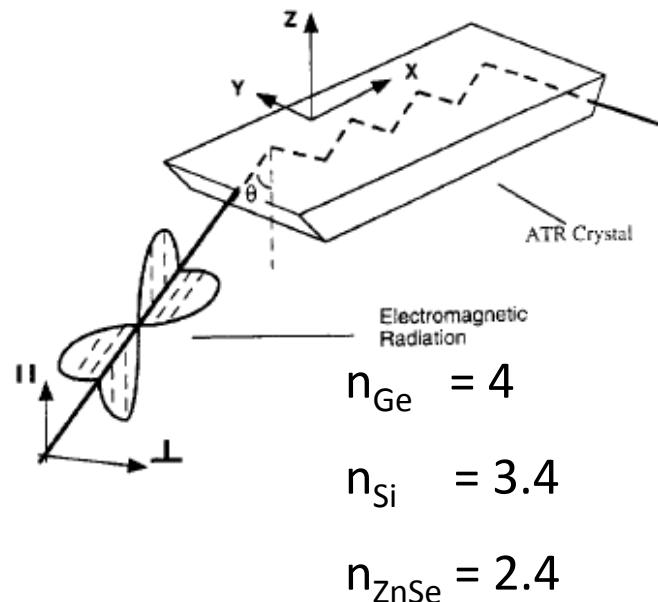


$$E = E_0 \cdot e^{-\frac{z}{d_p}}$$

$$dp = \frac{\lambda}{2\pi n_1 \sqrt{(\sin^2 \theta - n_{21}^2)}}$$

$$N = \left( \frac{\text{length of ATR crystal}}{\text{Thickness of ATR crystal}} \right) \tan^{-1}(\vartheta)$$

Attenuated total reflection



Ge ( $n_1=4$ ),  $\theta = 45^\circ$

organic medium  $n_2 = 1.5$

$d_p (1550\text{cm}^{-1}) = 428 \text{ nm}$

# Infrared bio-spectroscopy

## From macro to nanoscale on the molecules of Life

# Biospectroscopy

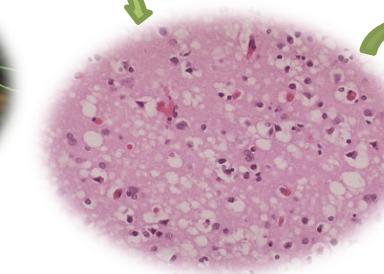
**Biospectroscopy** is the spectroscopy of the **Molecule of Life**

Organic molecules are the Molecules of Life.  
They are built on chains of carbon atoms, usually very long (bio-macromolecules)

There are four main groups of bio-macromolecules to build sub-cellular structure, cells, tissue, organs up to living beings:

**Proteins; Lipids; Nucleic Acids; Carbohydrates**

Samples conventionally studied by FTIR Spectroscopy

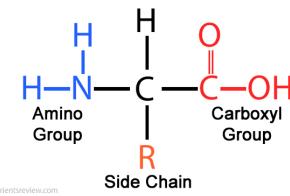
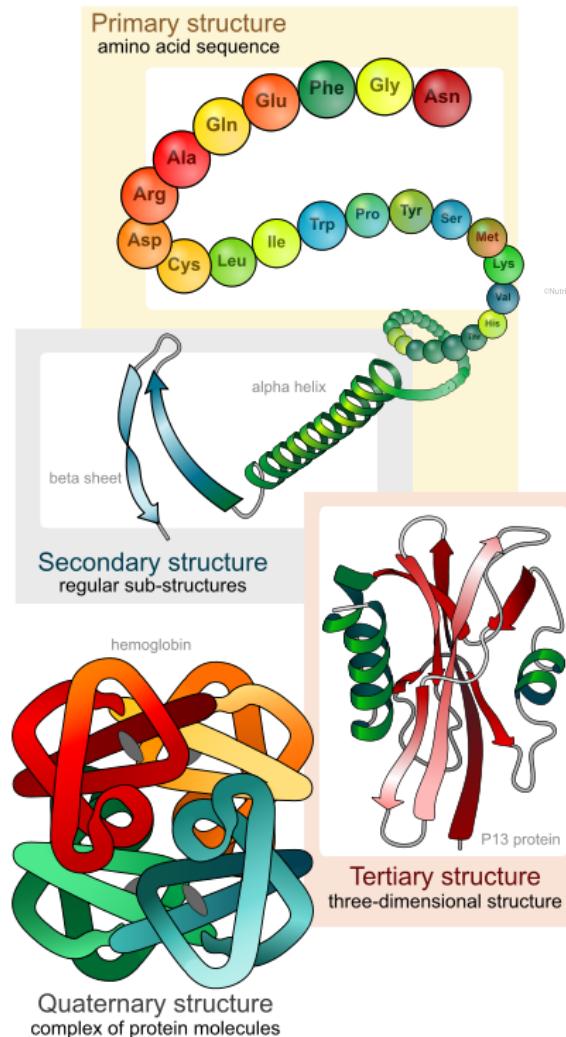
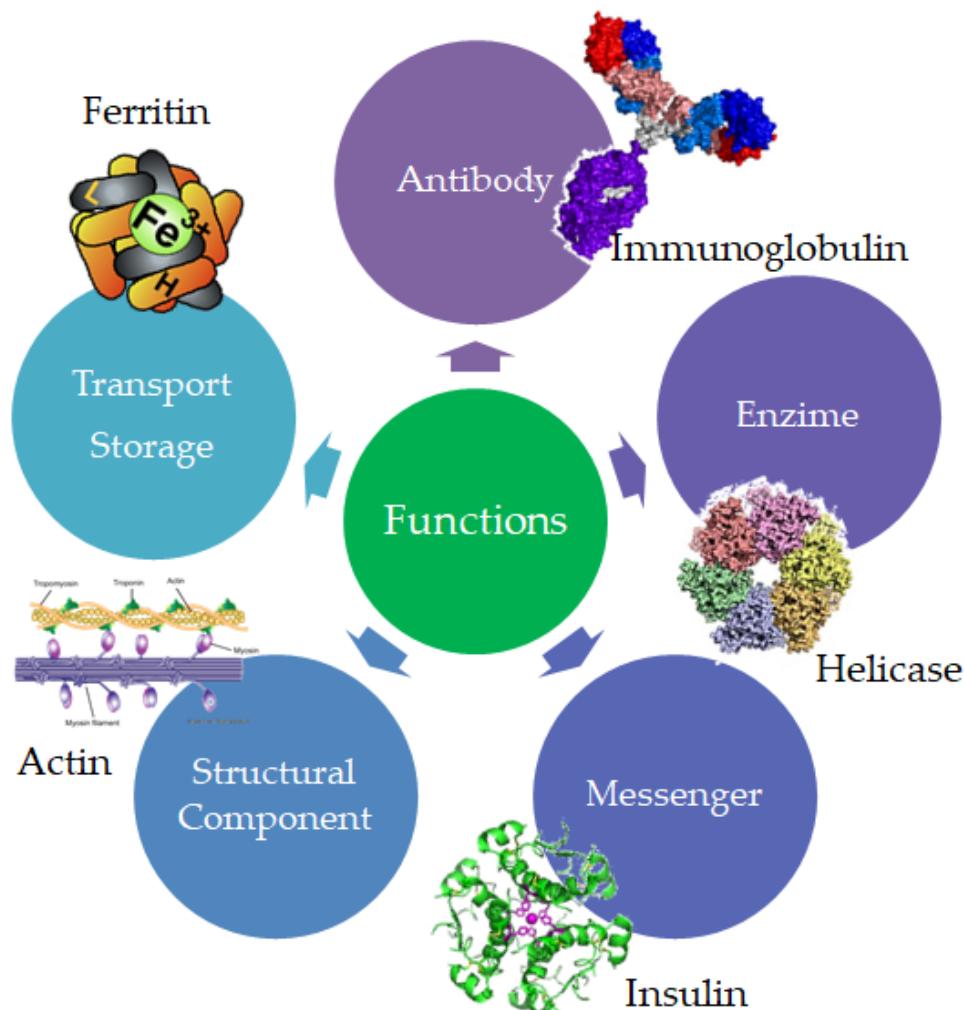


Samples conventionally studied by FTIR Microscopy

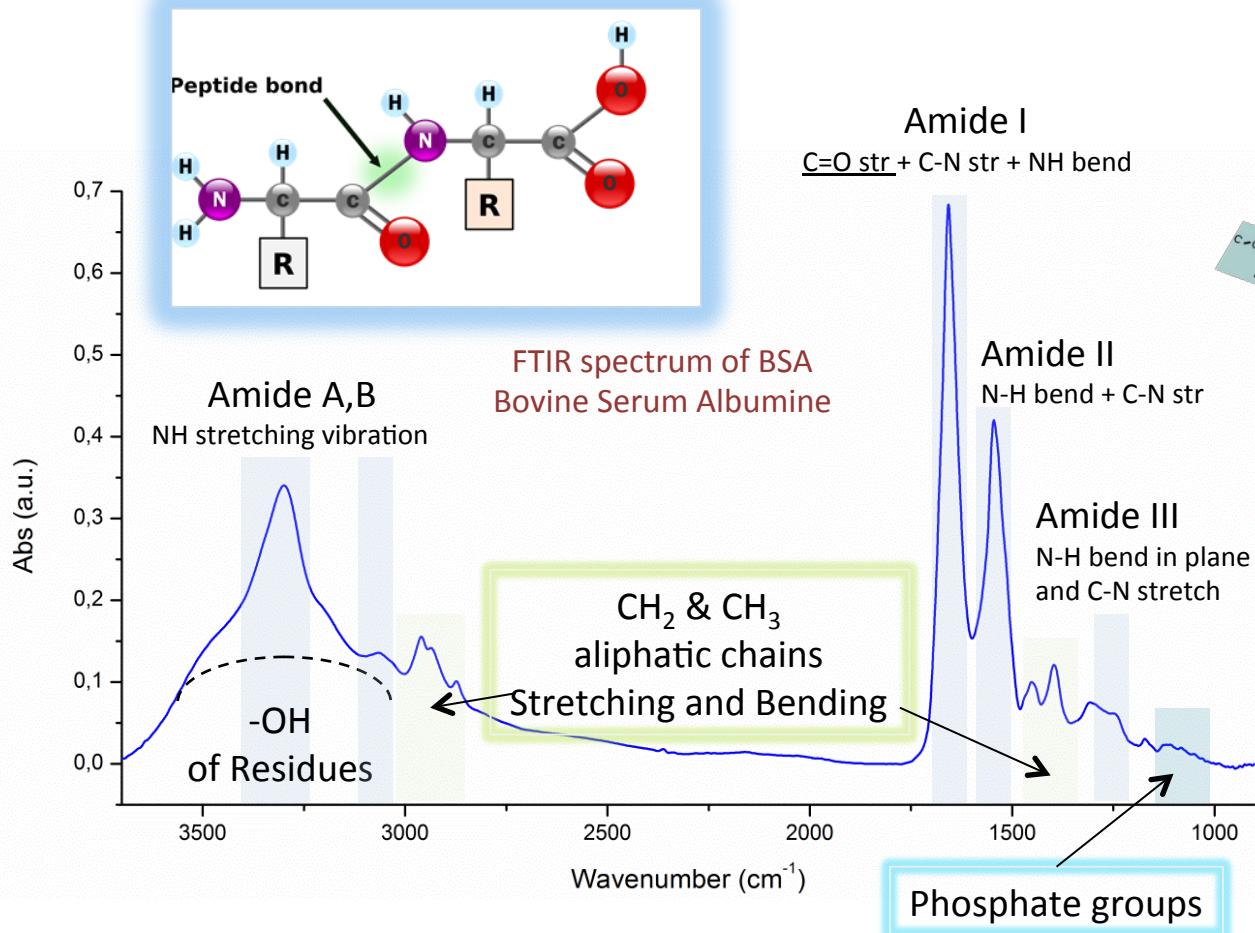
# Proteins

## Functions and Structure

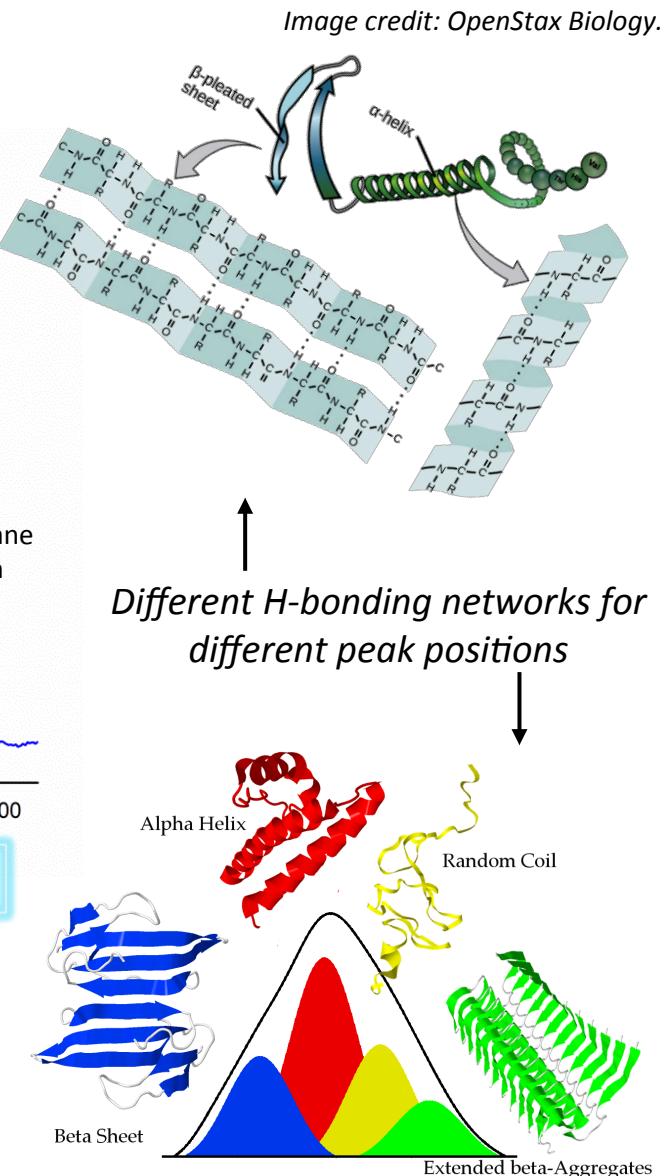
Proteins perform a vast array of functions within organisms, exhibiting activity strictly related to their structure (Structure-Activity relationship)



# FTIR spectroscopy for protein conformational studies

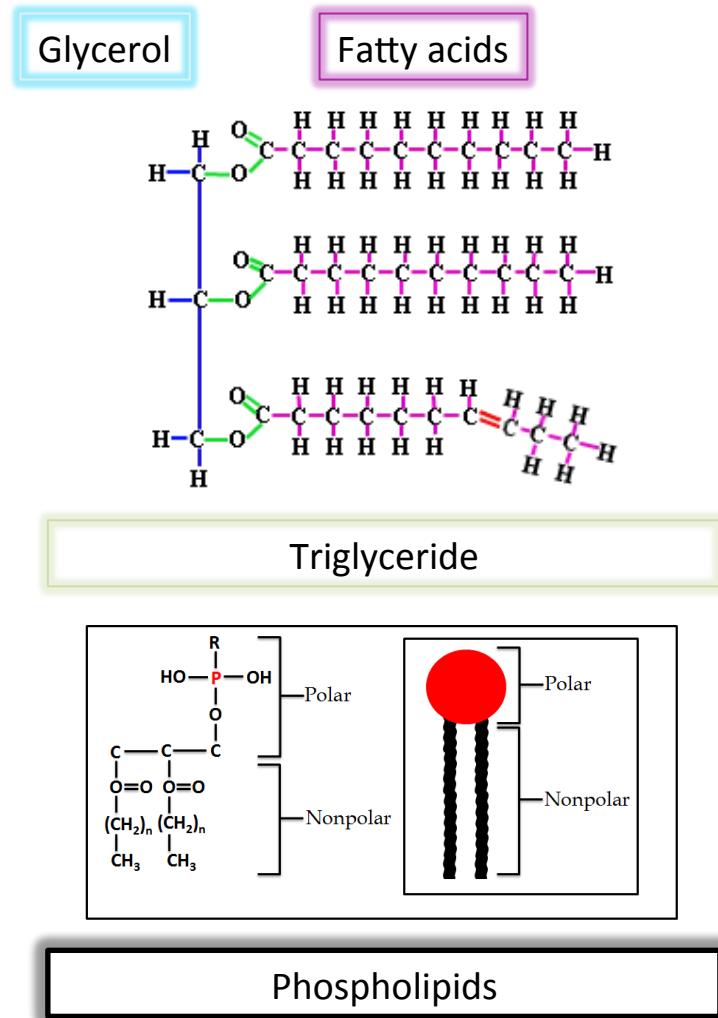
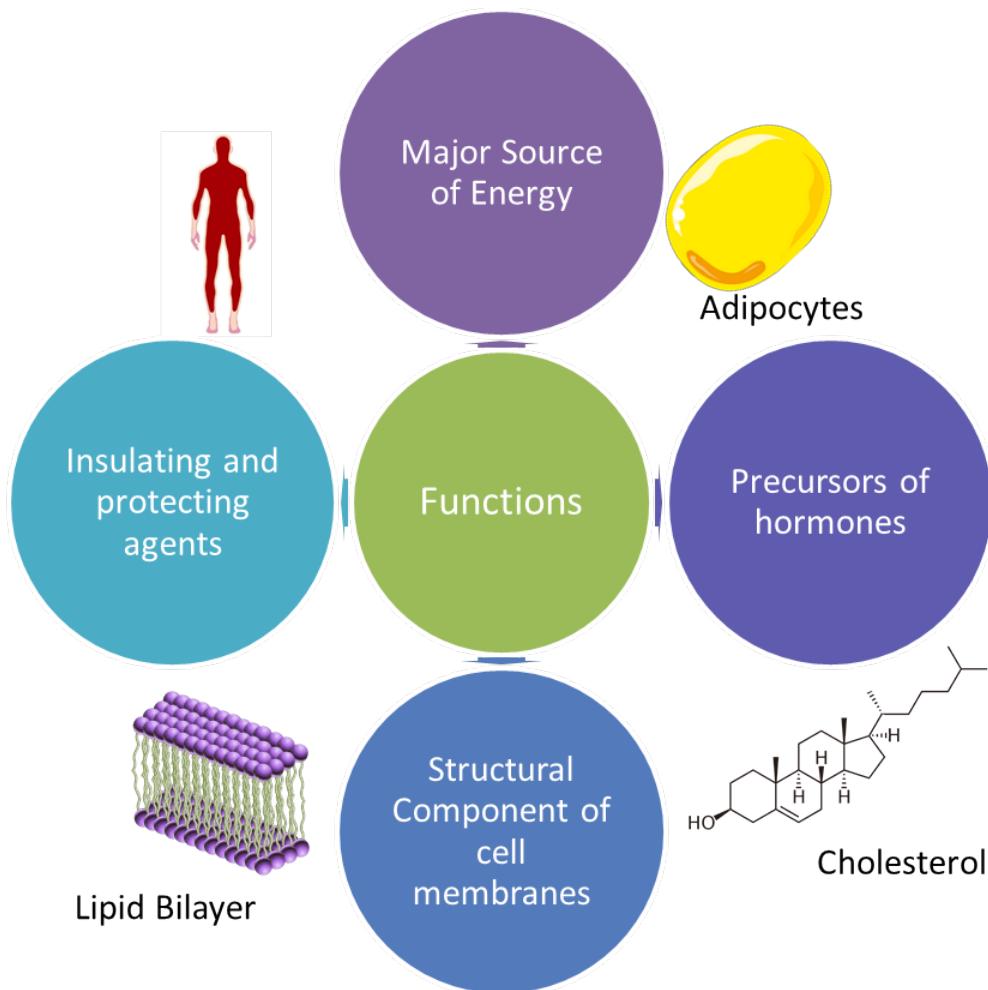


Amide I band is particularly sensitive to protein secondary structure, and conventionally employed for protein conformational studies



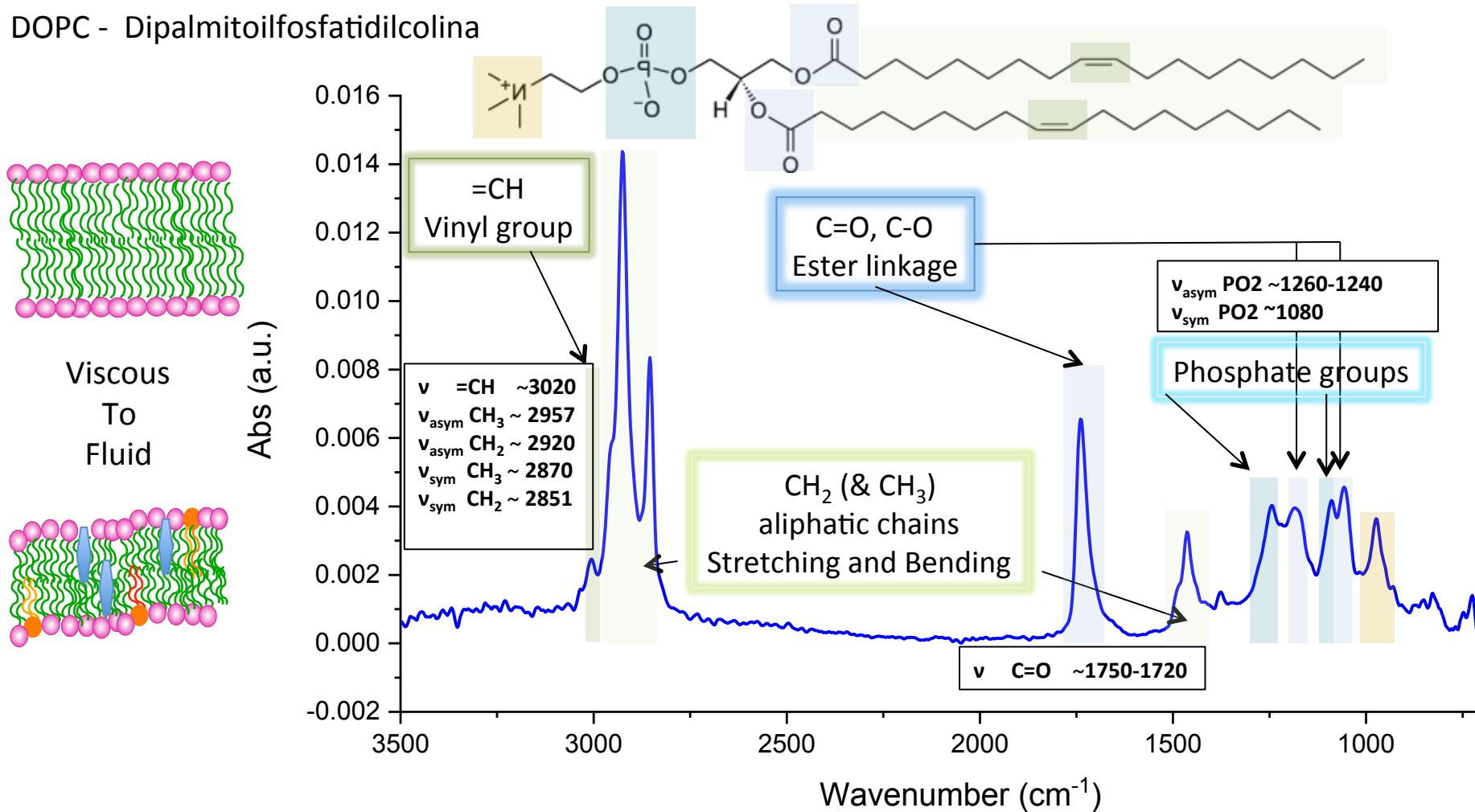
# Lipids

## Functions and Structure



# FTIR spectroscopy of lipid

DOPC - Dipalmitoilofofatidilcolina



$\text{CH}_2/\text{CH}_3$  ratio: methyl-branched fatty acids increase membrane fluidity

=C-H: Unsaturated fatty acids increase membrane fluidity

Shifts and broadening of the methyl and methylene bands are indicative of increased lipid disorder/fluidity

# Nucleic acids

## Structure and Function

DNA stores information

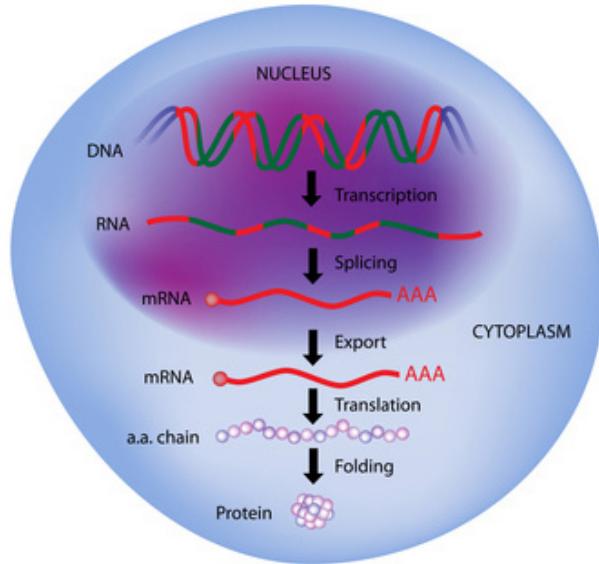


Image credit

<https://www.wonderwhizkids.com/gene-expression>

RNA transfer information

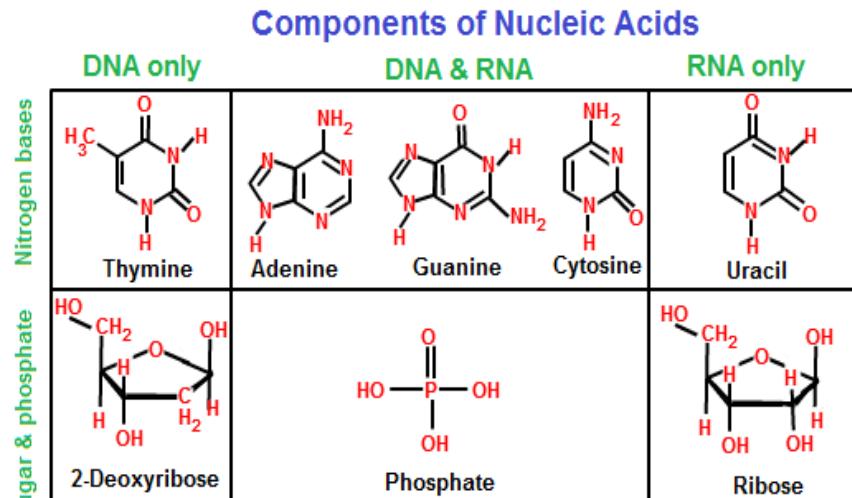
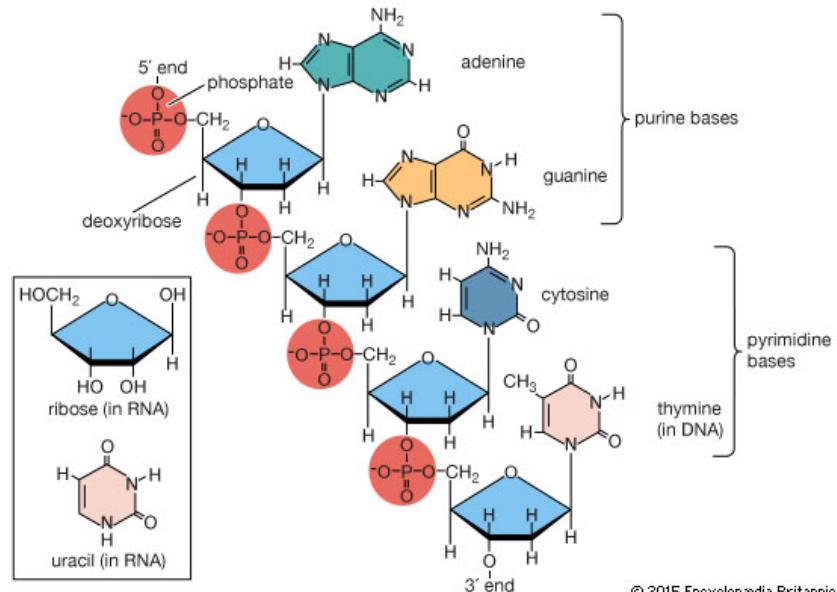
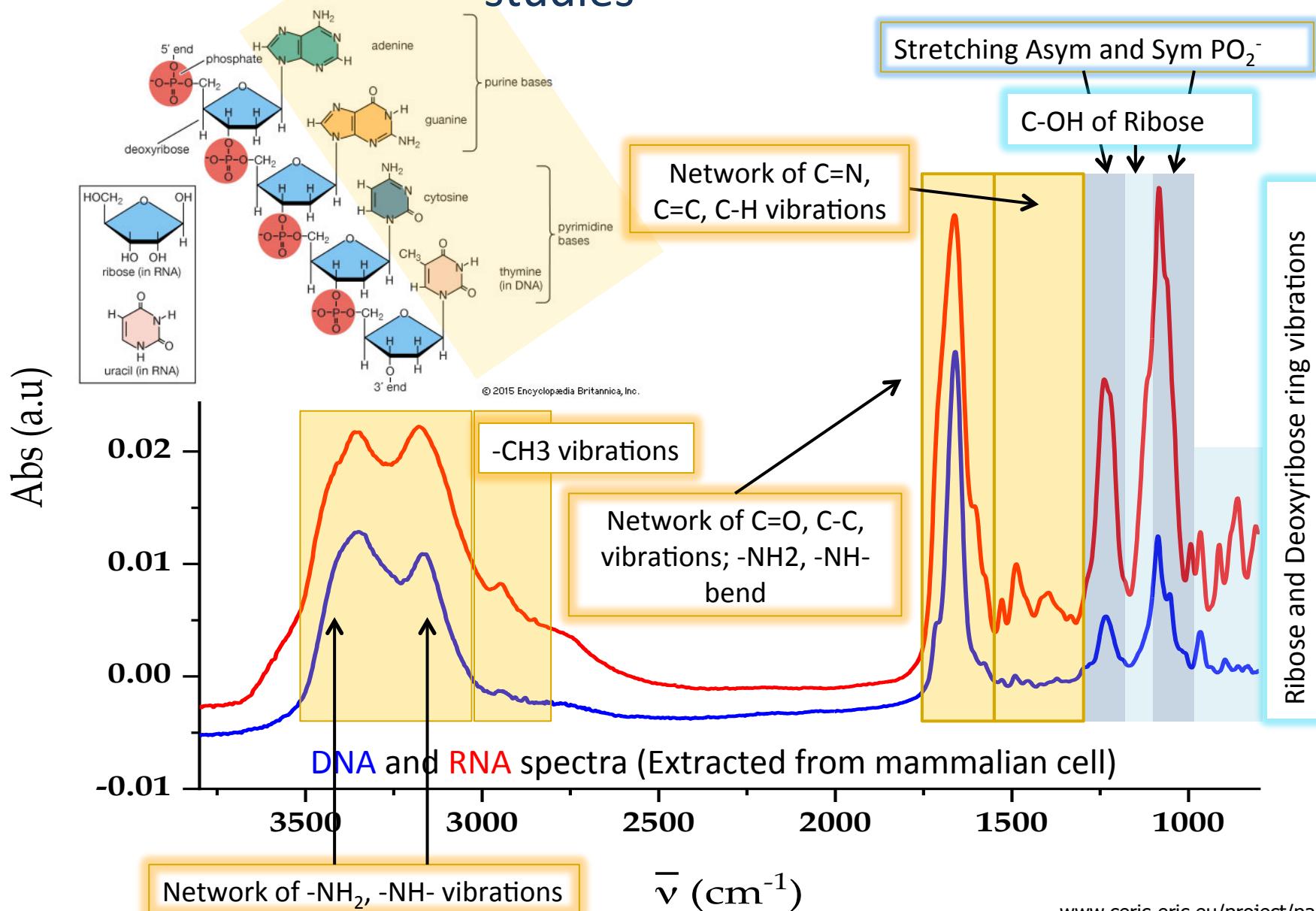


Image credit

<https://biology.tutorvista.com/biomolecules/nucleic-acids.html>

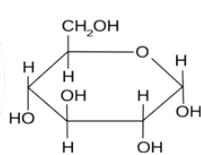
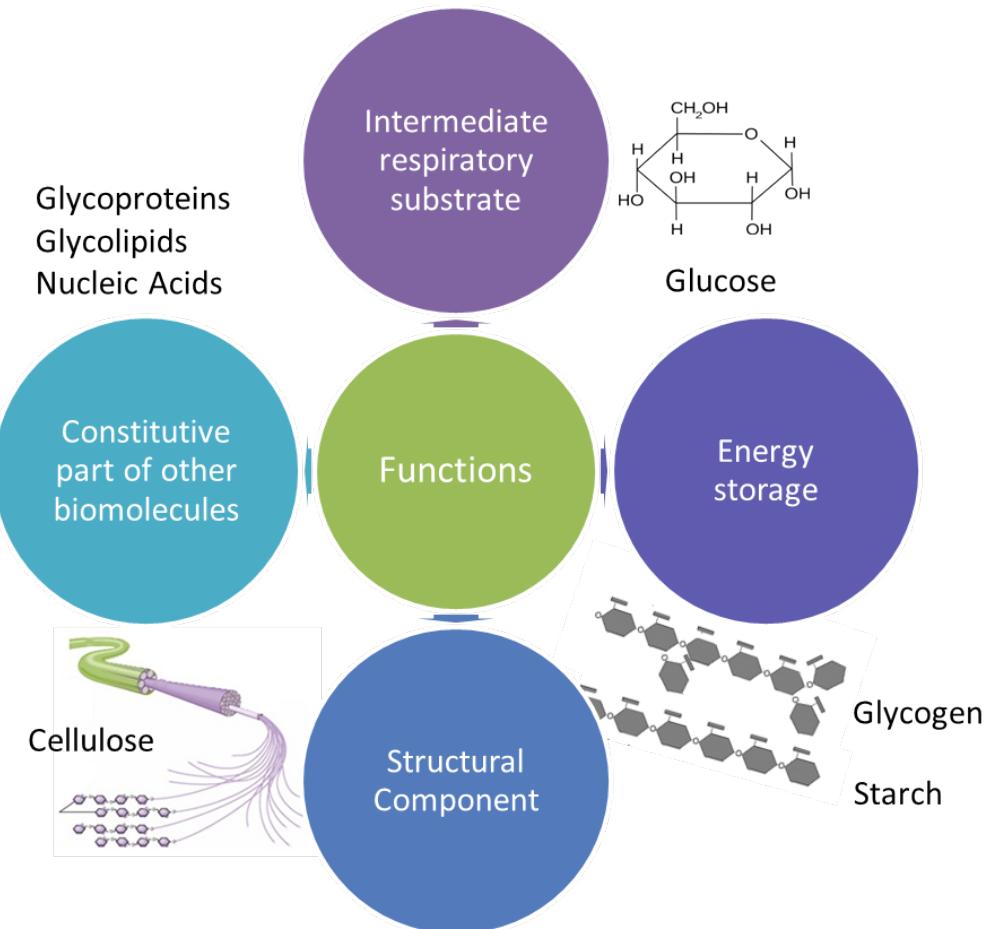


# FTIR spectroscopy for Nucleic acids conformational studies

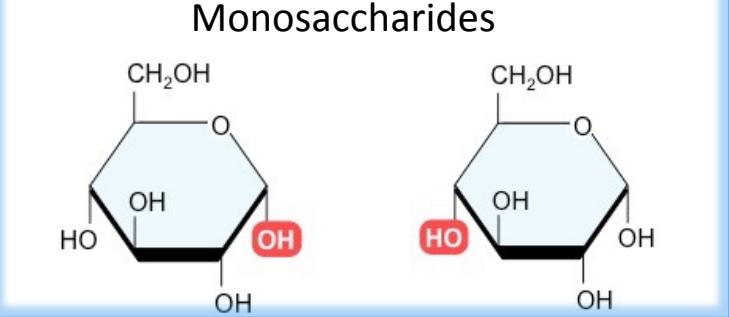


# Carbohydrates

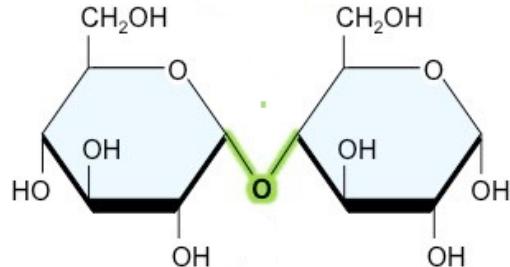
## Structure and Function



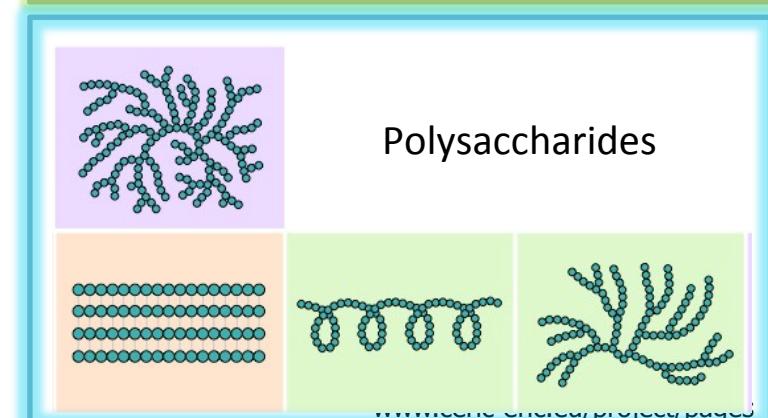
Glucose



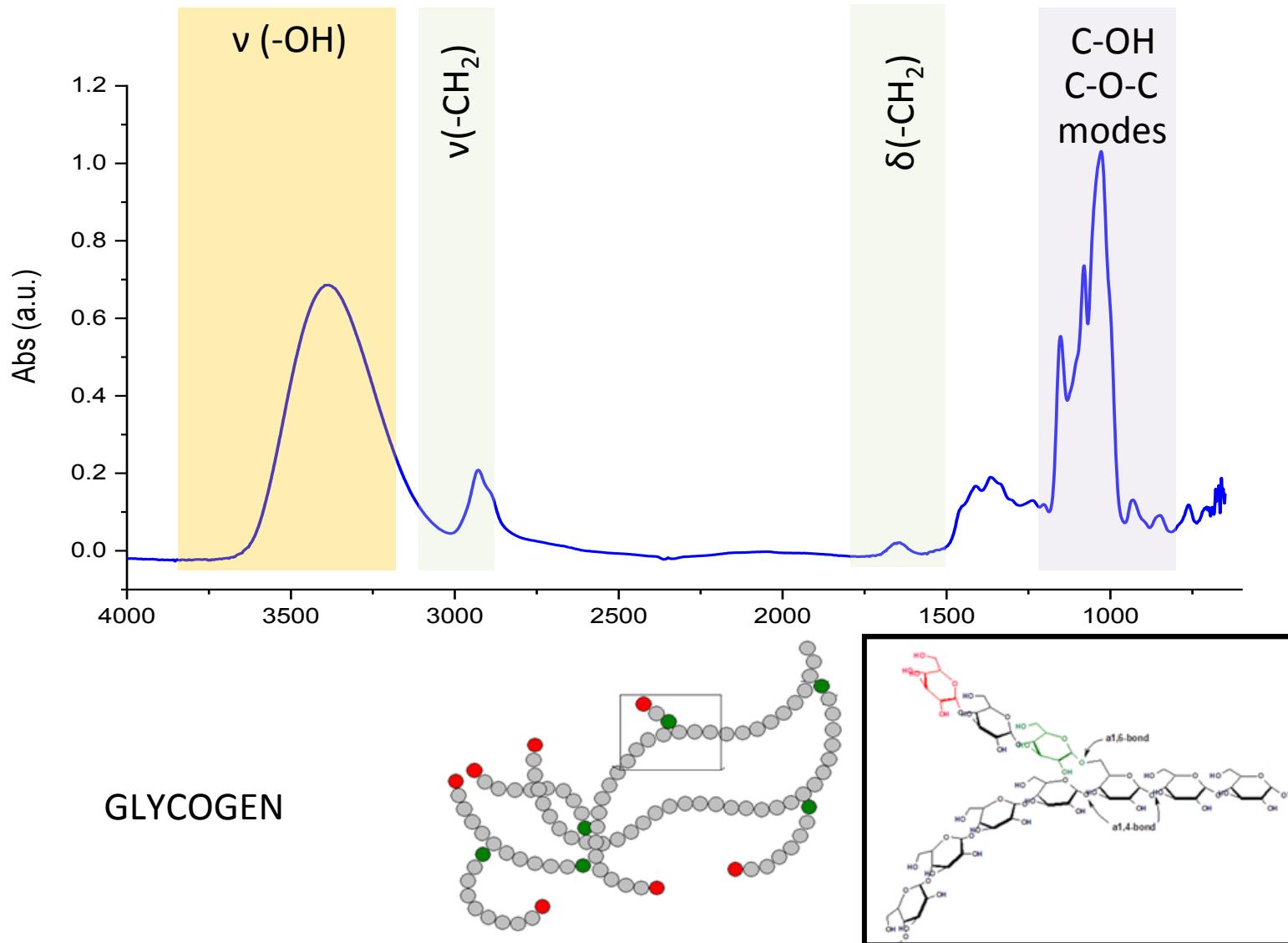
Disaccharides



Glycosidic bond



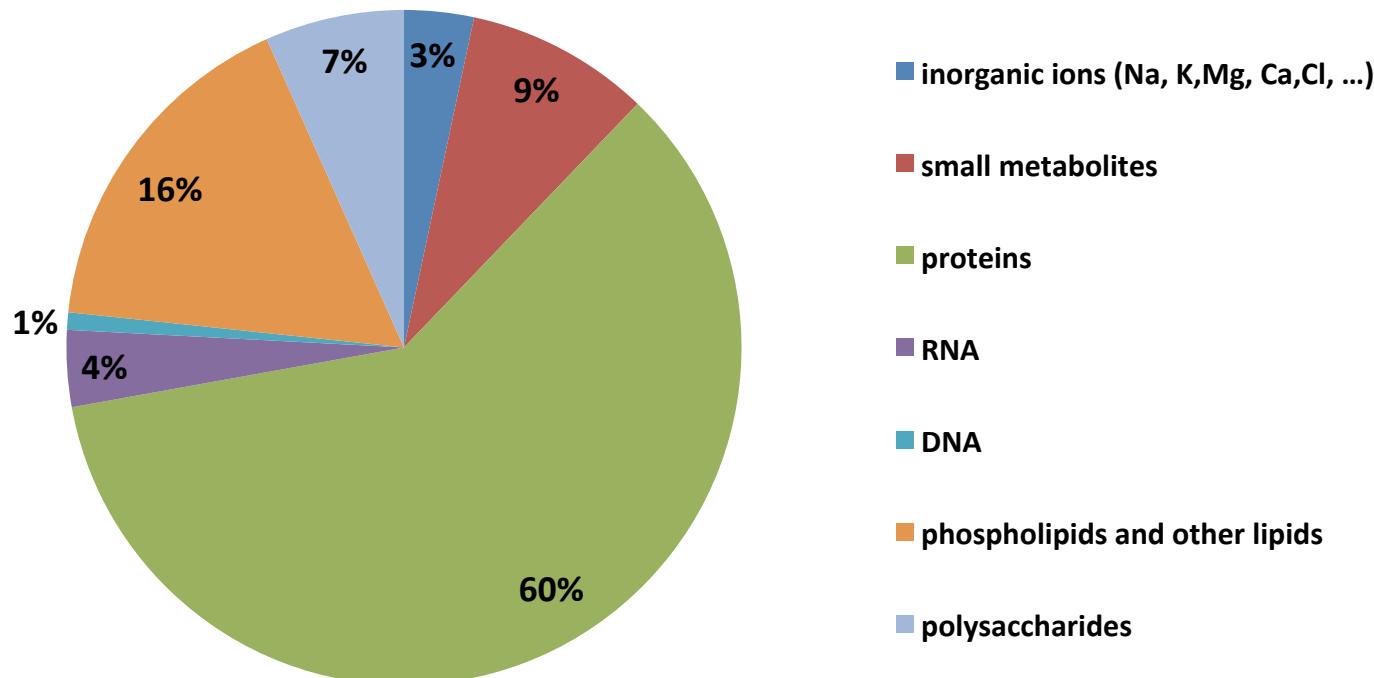
# FTIR spectroscopy of Carbohydrates



# Mammalian cells

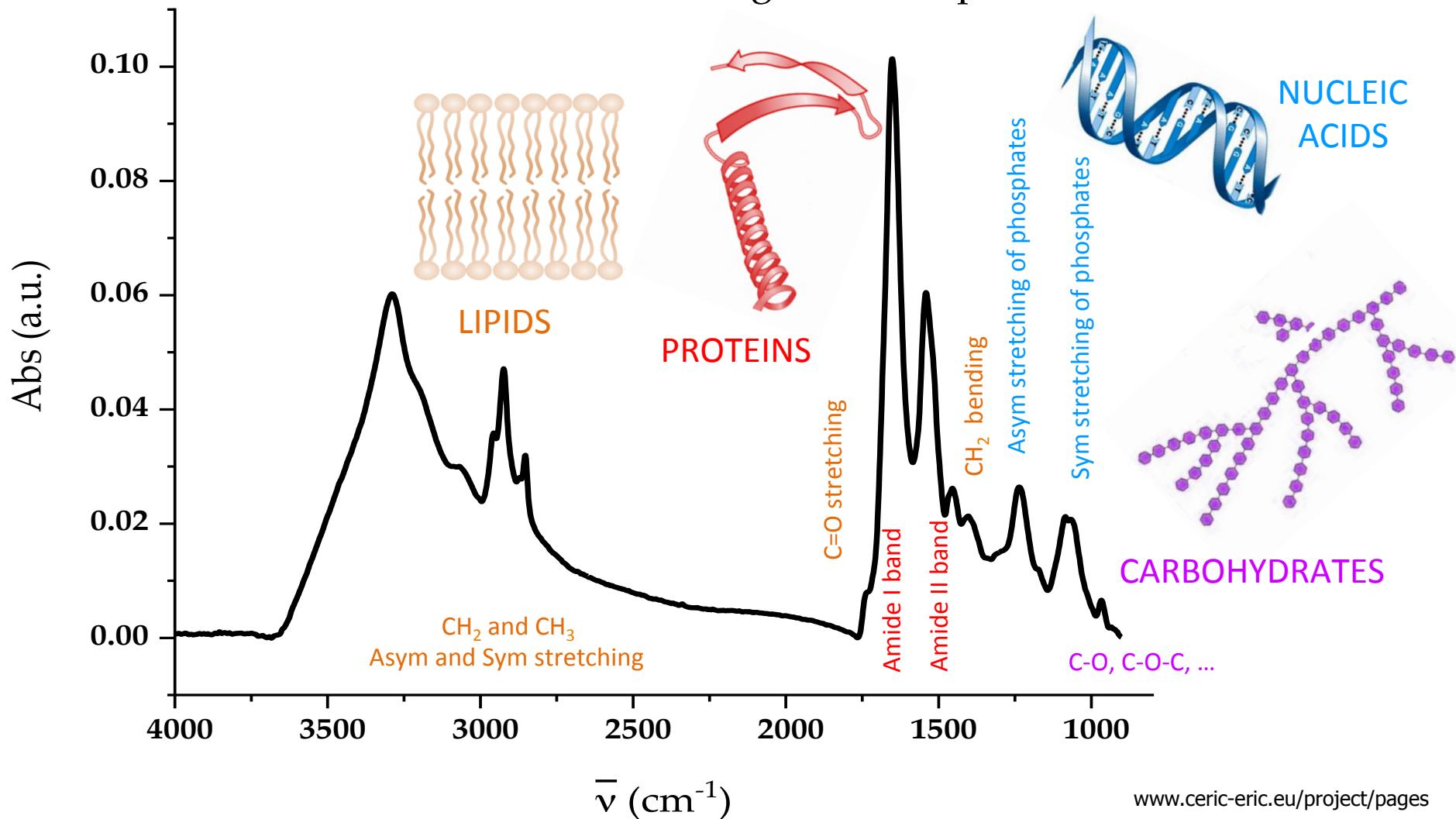
At a first glance, the FTIR spectrum of a mammalian cell can be viewed as the over imposition of the diverse spectral contribution of each individual components

**Typical mammalian dried cell chemical composition  
(component percent of total cell weight)**



# Mammalian cells

Band intensity, position, width and shape (band components) are sensitive to subtle biochemical changes of bio-specimens.



# Letterature

- (1) Barth, A. Infrared Spectroscopy of Proteins. *Biochim. Biophys. Acta BBA - Bioenerg.* **2007**, *1767* (9), 1073–1101.
- (2) Dreissig, I.; Machill, S.; Salzer, R.; Krafft, C. Quantification of Brain Lipids by FTIR Spectroscopy and Partial Least Squares Regression. *Spectrochim. Acta. A. Mol. Biomol. Spectrosc.* **2009**, *71* (5), 2069–2075.
- (3) Banyay, M.; Sarkar, M.; Gräslund, A. A Library of IR Bands of Nucleic Acids in Solution. *Biophys. Chem.* **2003**, *104* (2), 477–488.
- (4) Kuhn, L. P. Infrared Spectra of Carbohydrates. *Anal. Chem.* **1950**, *22* (2), 276–283.
- (5) Tipson, R. S. Infrared Spectroscopy of Carbohydrates, National Bureau of Standards Monograph 110, June 968
- (6) Movasaghi, Z.; Rehman, S.; ur Rehman, D. I. Fourier Transform Infrared (FTIR) Spectroscopy of Biological Tissues. *Appl. Spectrosc. Rev.* **2008**, *43* (2), 134–179.

# Proposed Experiments at SISSI

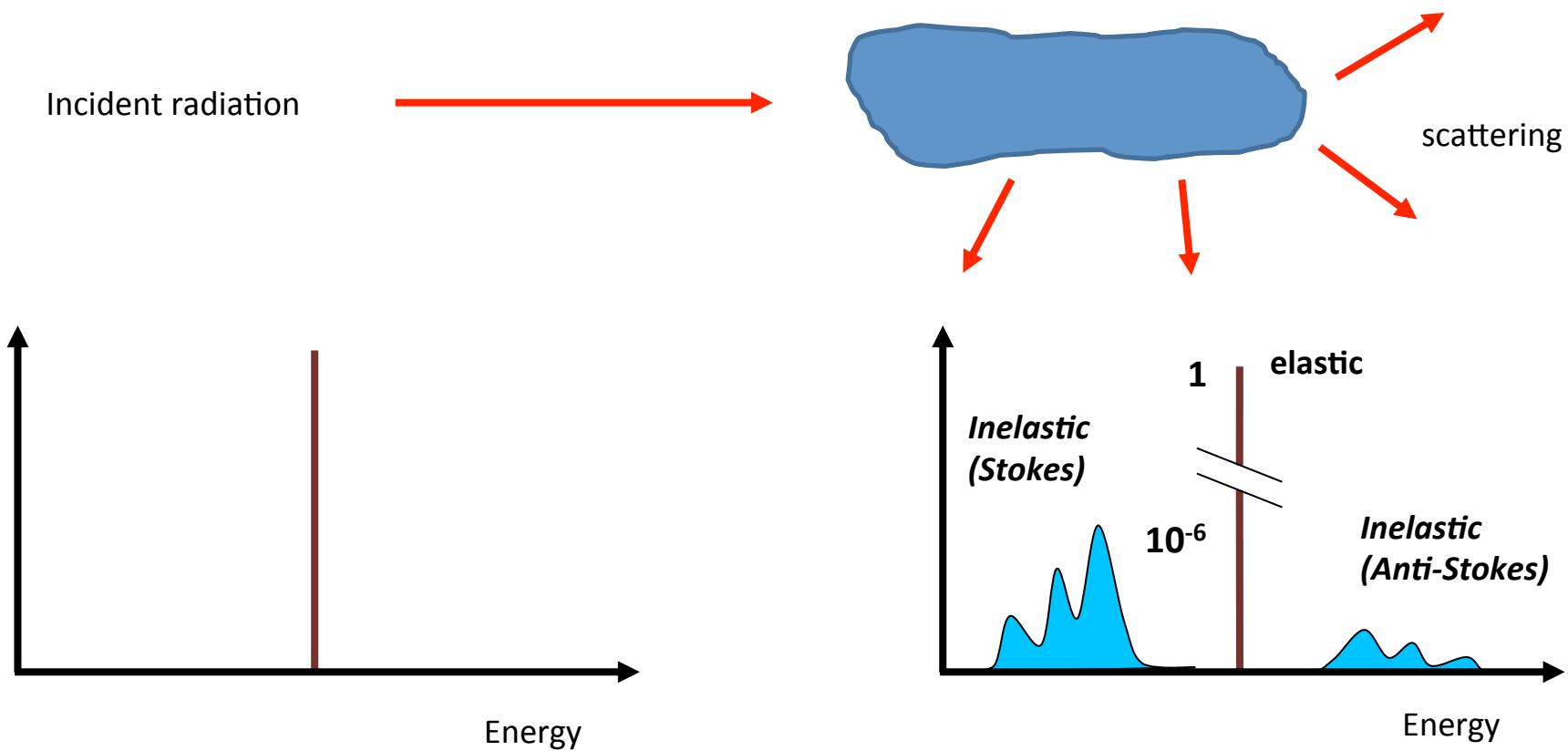
- (1) The students will have the opportunity to look “inside” the interferometer
- (2) The spectra will be acquired starting from hydrated molecules  
→ Water features will be highlighted as well the dominant effect on IR spectra
- (3) They will start to become confident with IR spectral interpretation  
They will collect spectra of:
  - Proteins (with different conformations) -> IR sensitivity to protein secondary structure
    - Raman spectra of the same molecules will be commented for highlighting technique complementary
  - Nucleic acids (DNA) -> IR sensitivity to DNA folding
    - Raman spectra of the same molecules will be commented for highlighting technique complementary
  - Sugars (Trehalose) -> RAMAN SPECTRA WILL BE AQUIRED AT DIFFERENT CONCENTRATIONS FOR HIGHLIGHTING THE DIFFERENT CONTRIBUTION OF WATER TO IR AND Raman spectra

# UV Resonant Raman Spectroscopy

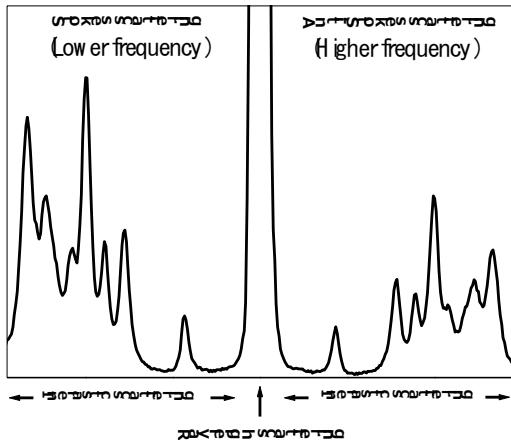
## Basic Concepts on Theory and Instrumentation

# Raman scattering

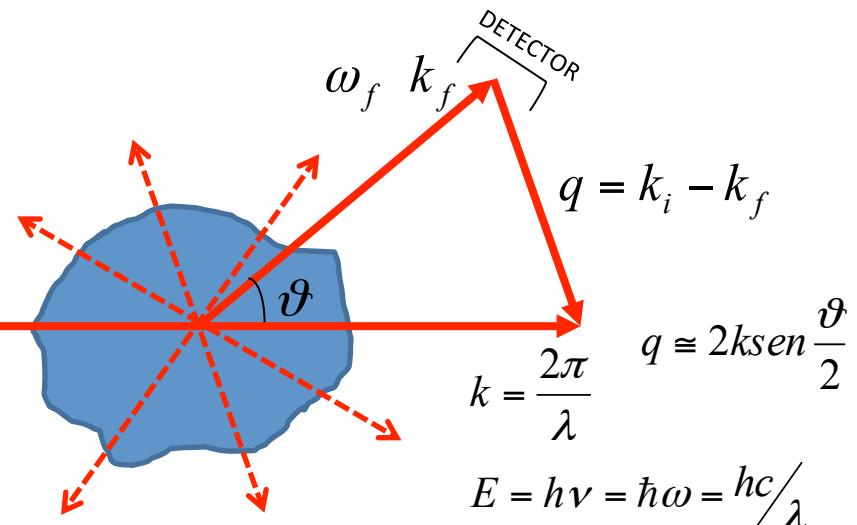
When the electromagnetic radiation interacts with matter and its energy is not in resonance with any energy level difference, absorption does not take place but **scattering processes** can occur at second order in perturbation theory



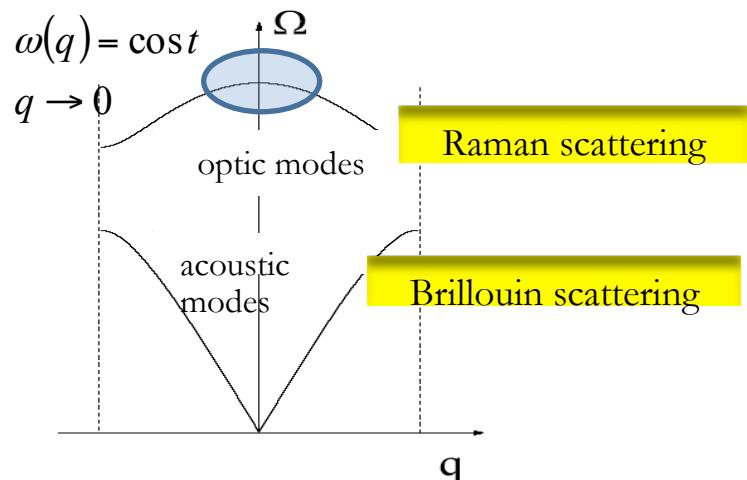
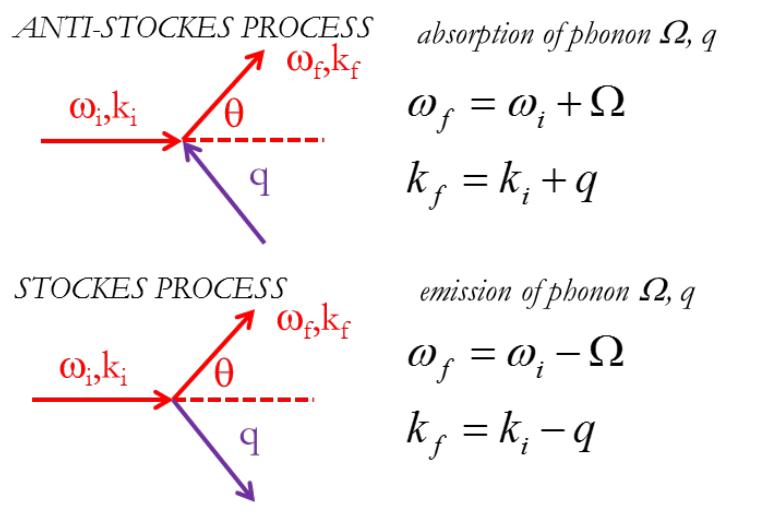
# Inelastic scattering experiments



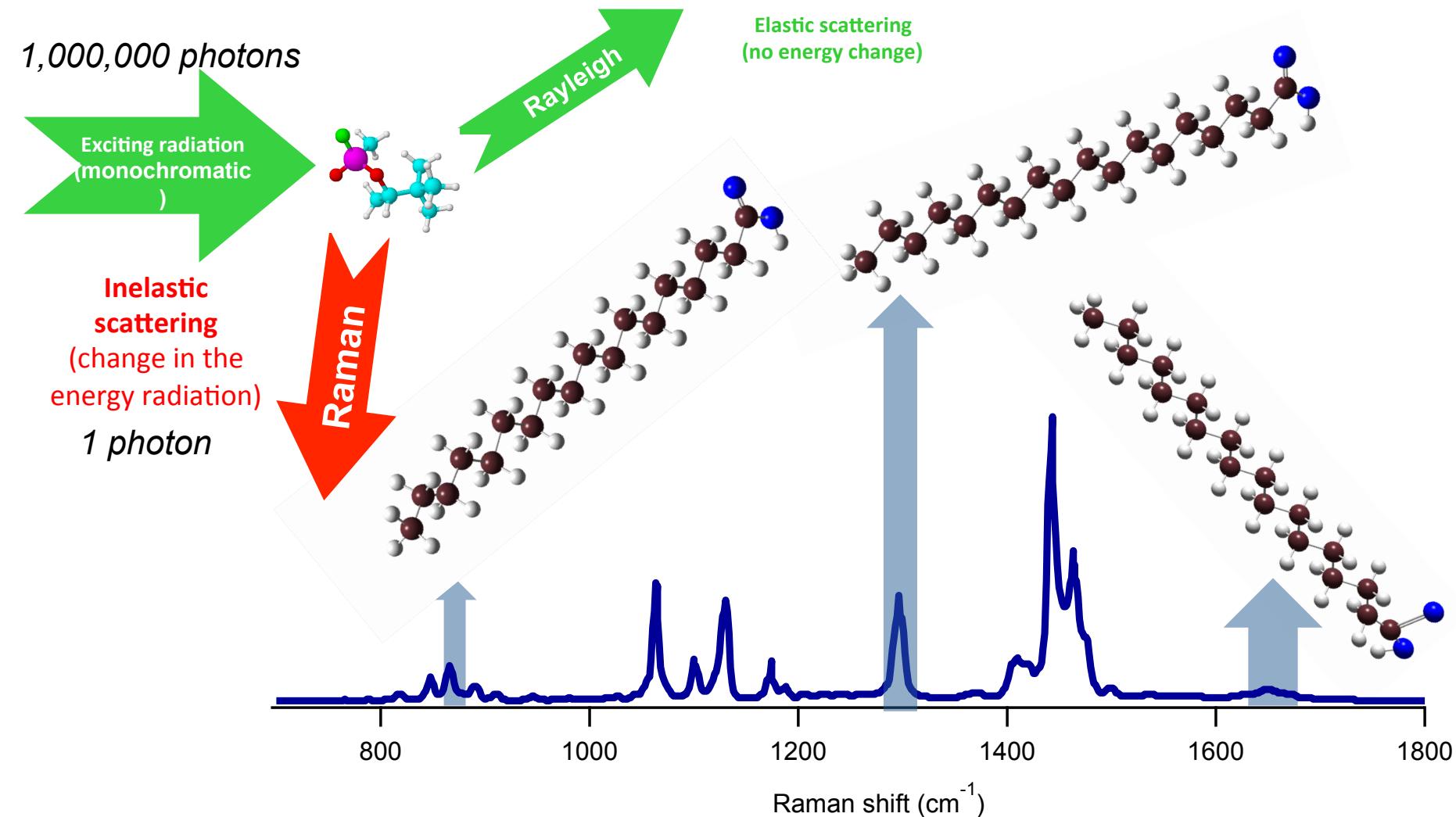
$$\begin{aligned}\omega_f &= \omega_i \pm \Omega \\ k_f &= k_i \pm q \\ \omega_i & k_i\end{aligned}$$



$$E = h\nu = \hbar\omega = hc/\lambda$$



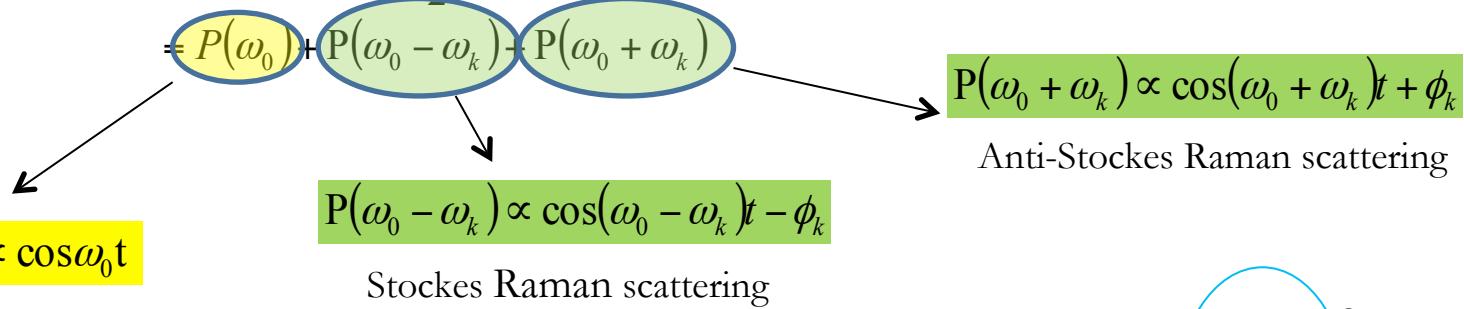
# Raman scattering



# Raman effect

*Raman bands arise from **changes in the molecular polarizability** during the vibrations*

$$P(t) = \alpha_0 E_0 \cos \omega_0 t + \frac{1}{2} \delta \alpha_k Q_k^0 E_0 [\cos(\omega_0 - \omega_k)t - \phi_k + \cos(\omega_0 + \omega_k)t + \phi_k]$$



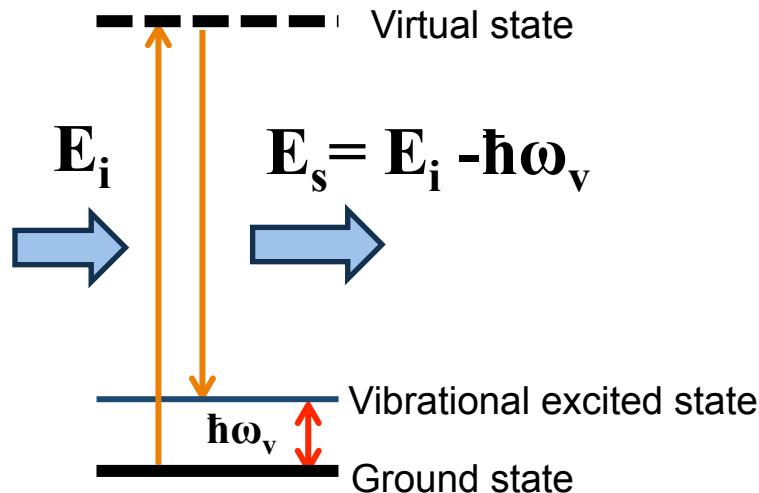
**Raman scattering total intensity:**

$$I(\theta)_{av} = B(\nu_0 \pm \nu)^4 I_0 \left( \frac{\partial \alpha_{xx}}{\partial Q_1} \right)_0^2 \sin^2 \theta$$

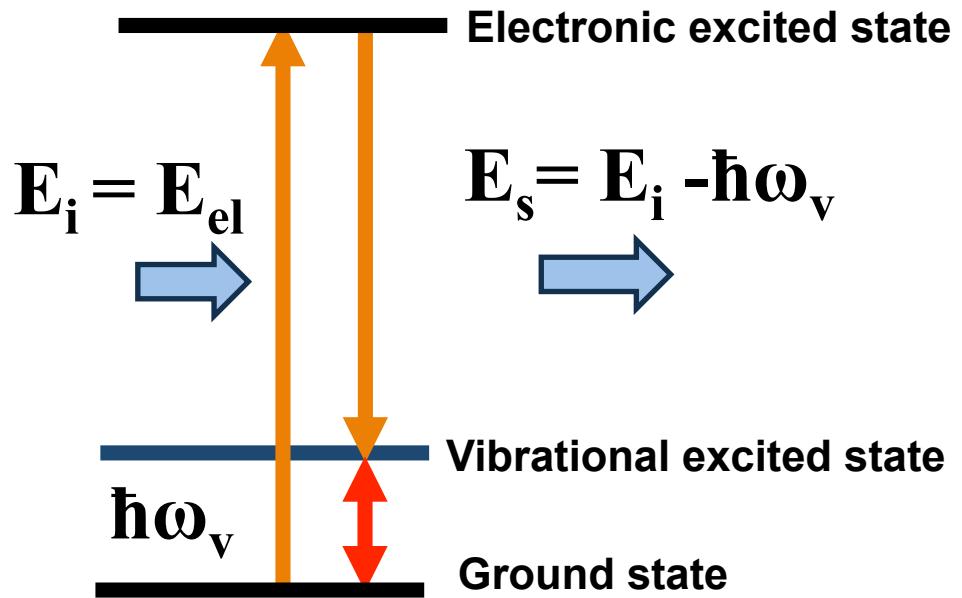
*derived polarizability tensor*

# Resonant Raman scattering

*Spontaneous Raman*

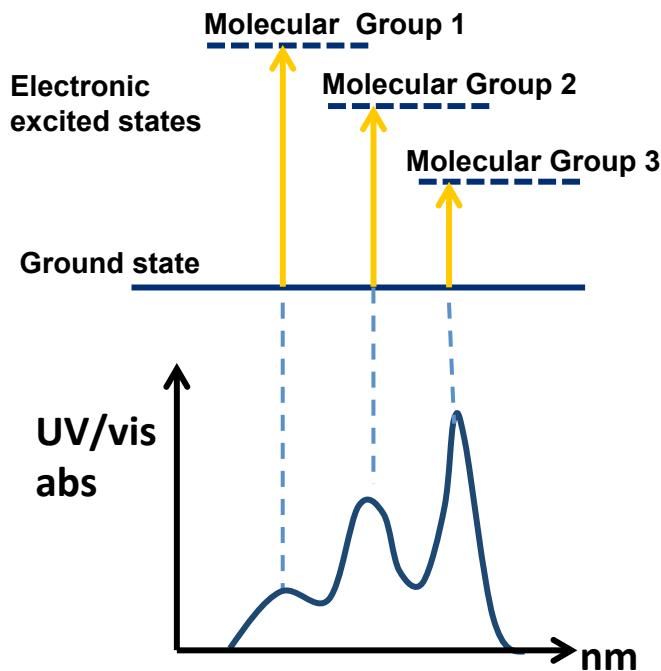


*Resonant Raman*

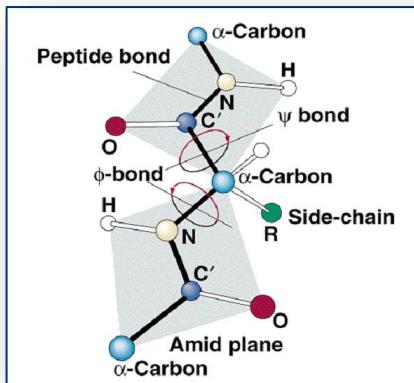


Raman cross section increased

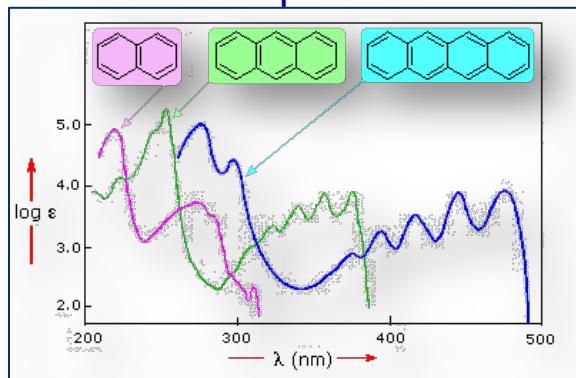
# UV Resonant Raman scattering



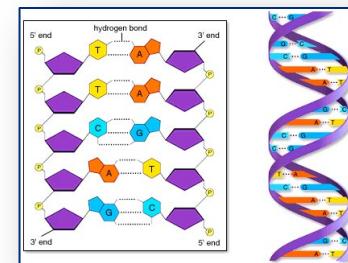
## 200-220 nm Peptide bonds



## 200-300 nm Aromatic compounds



## 225-300 nm DNA nitrogenous bases



S. A. Oladepo et al. *Chem. Rev.* 2012.

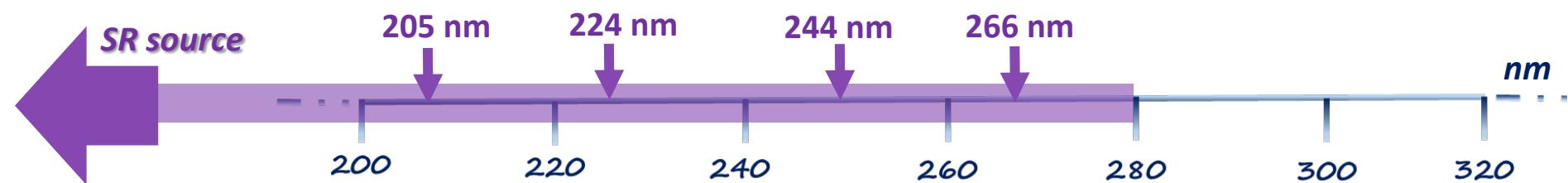
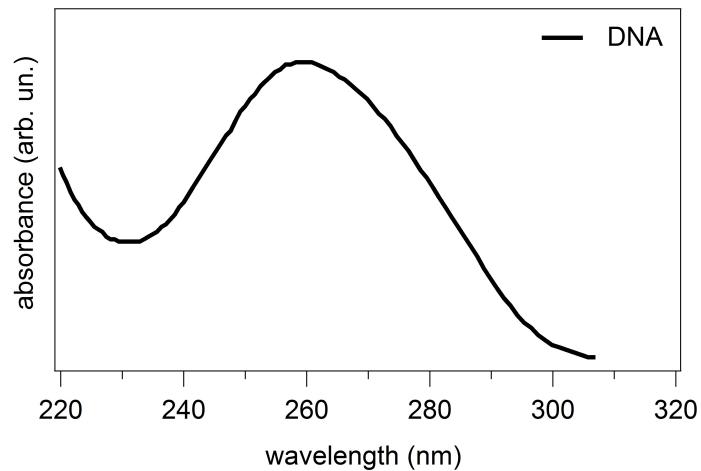


# Further advantages on the use of UVRR

- **Absence** of *fluorescence background* on the spectra
- Measurements in **water** and/or **buffer solutions** at low solute concentrations
- **Higher Raman cross section** with respect to the Raman scattering performed exploiting visible near/IR laser sources

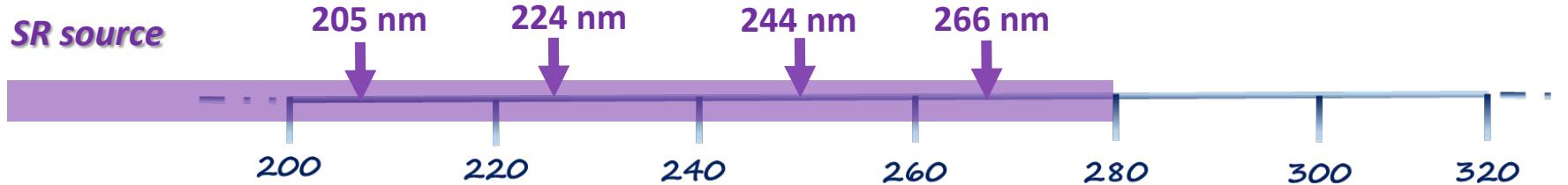
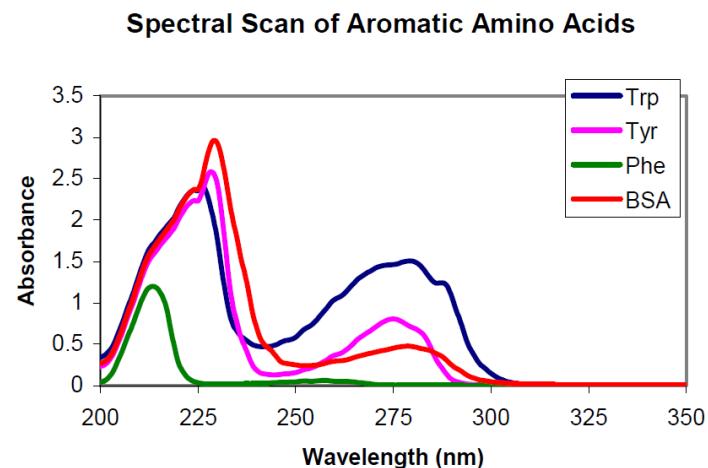
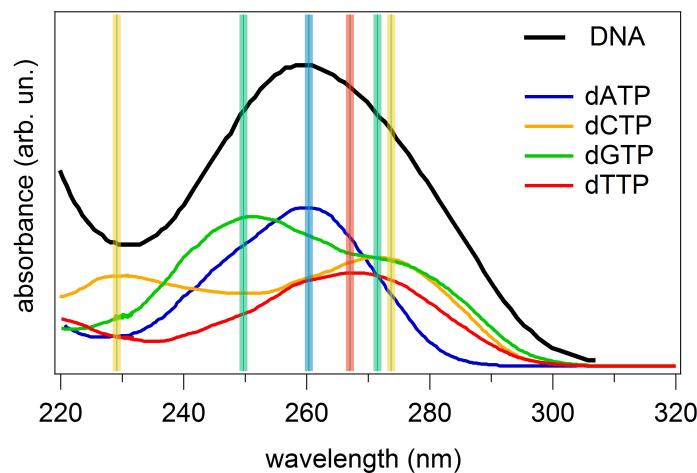
# Exciting wavelength selectivity

- Laser: *fixed wavelength sources*
- SR: *tunable CW wavelength source* → better selectivity

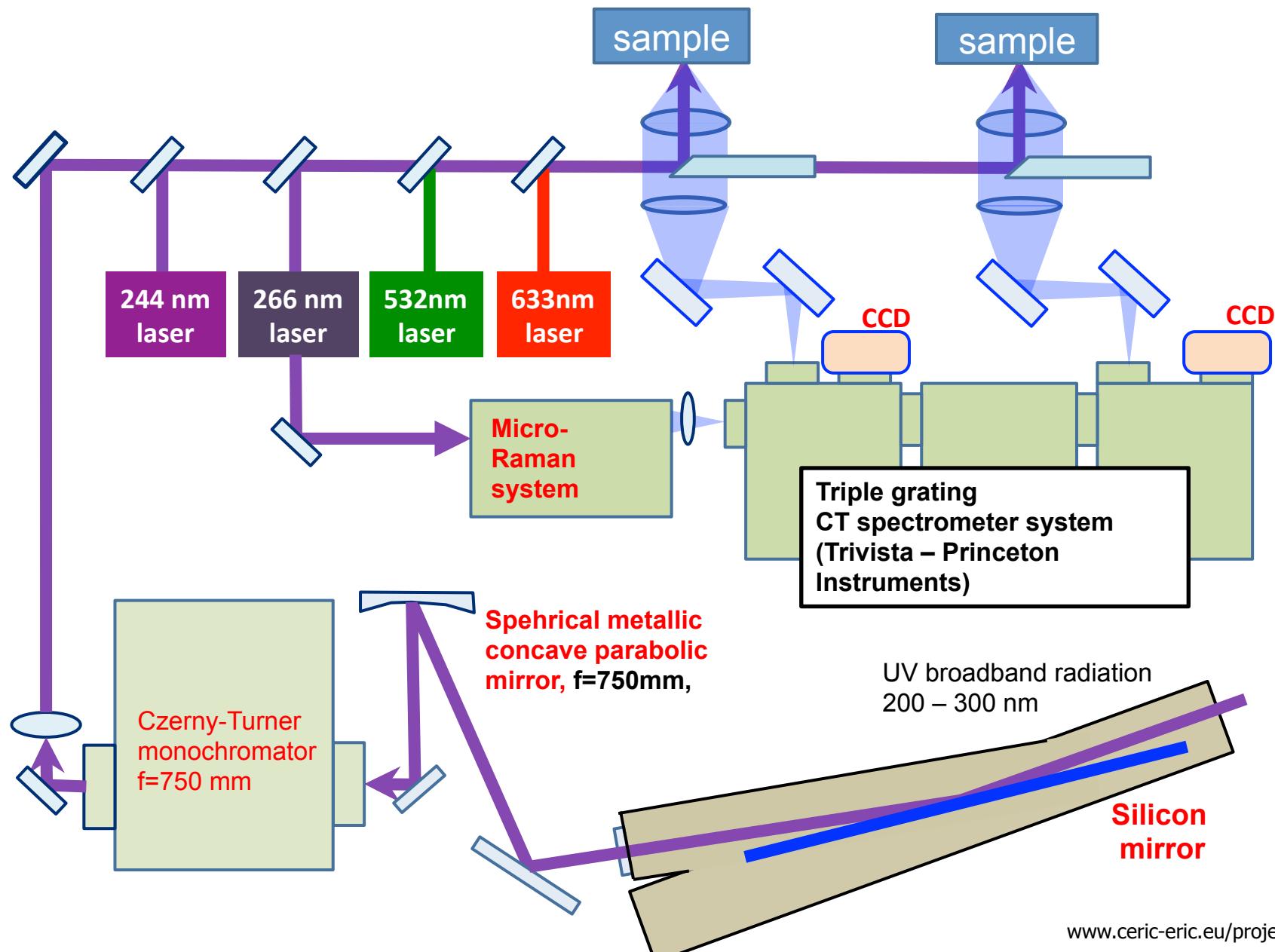


# Exciting wavelength selectivity

- Laser: *fixed wavelength sources*
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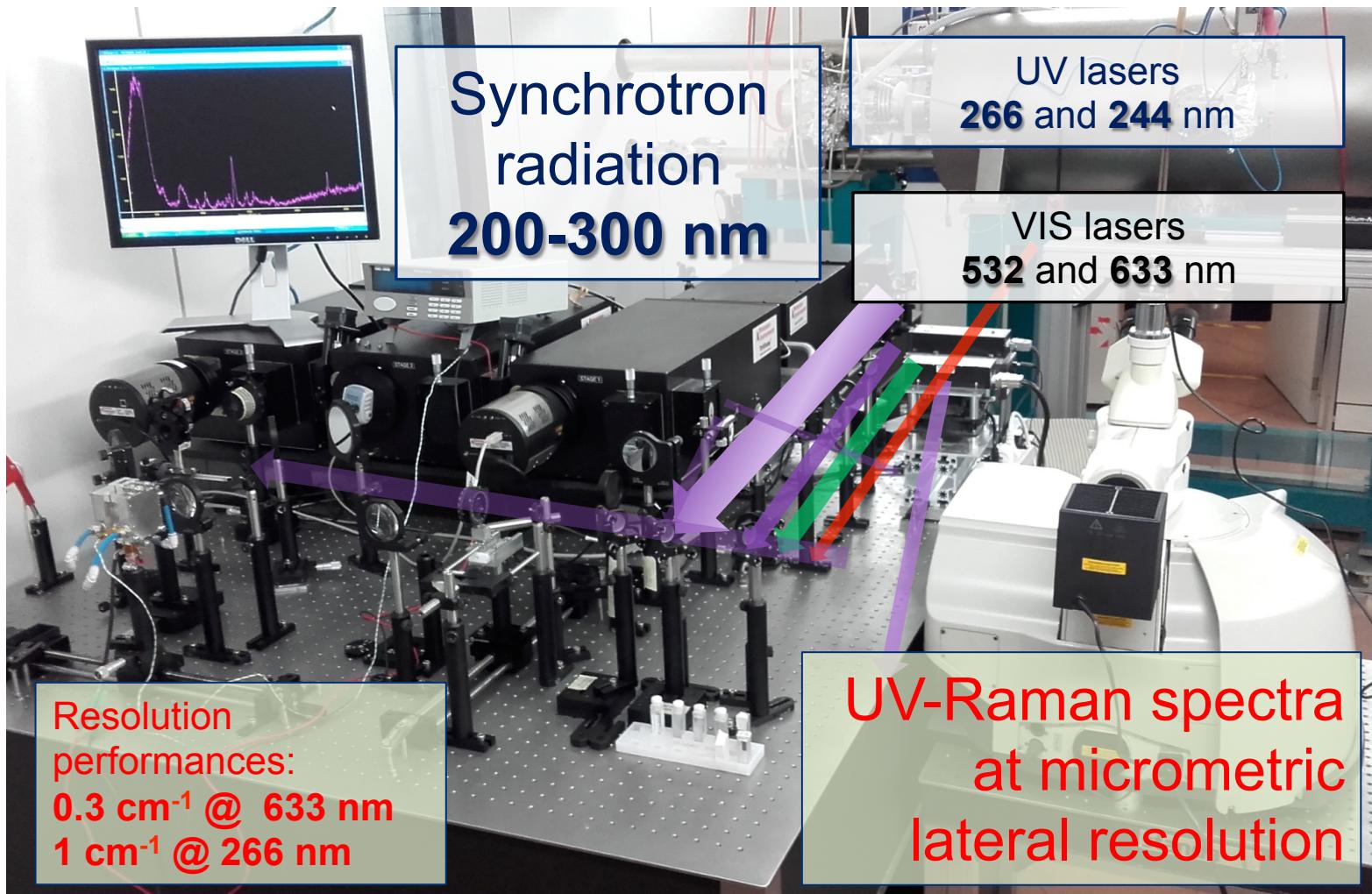


# UVRR set-up, IUVS at Elettra

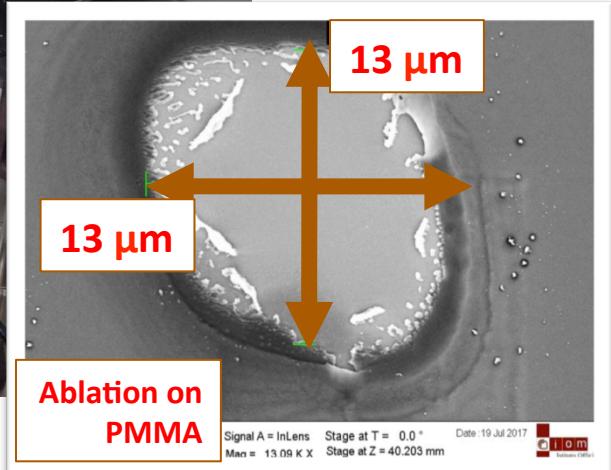
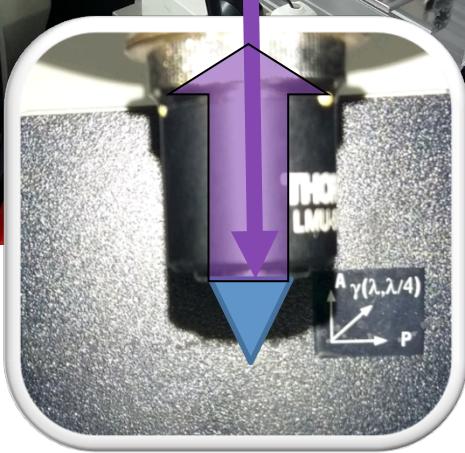
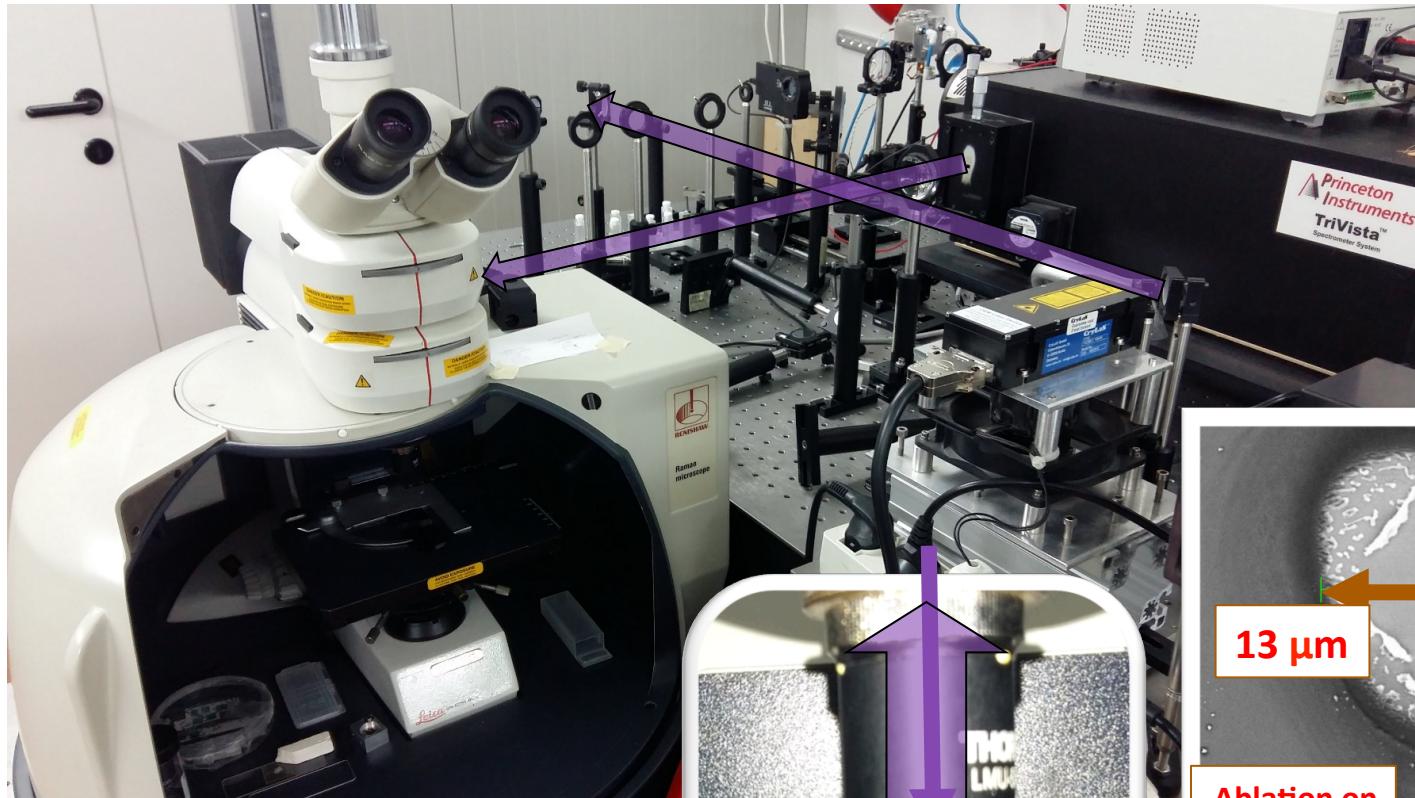


# UVRR set-up, IUVS at Elettra

F. D'Amico et al. *NIMA* 2013.

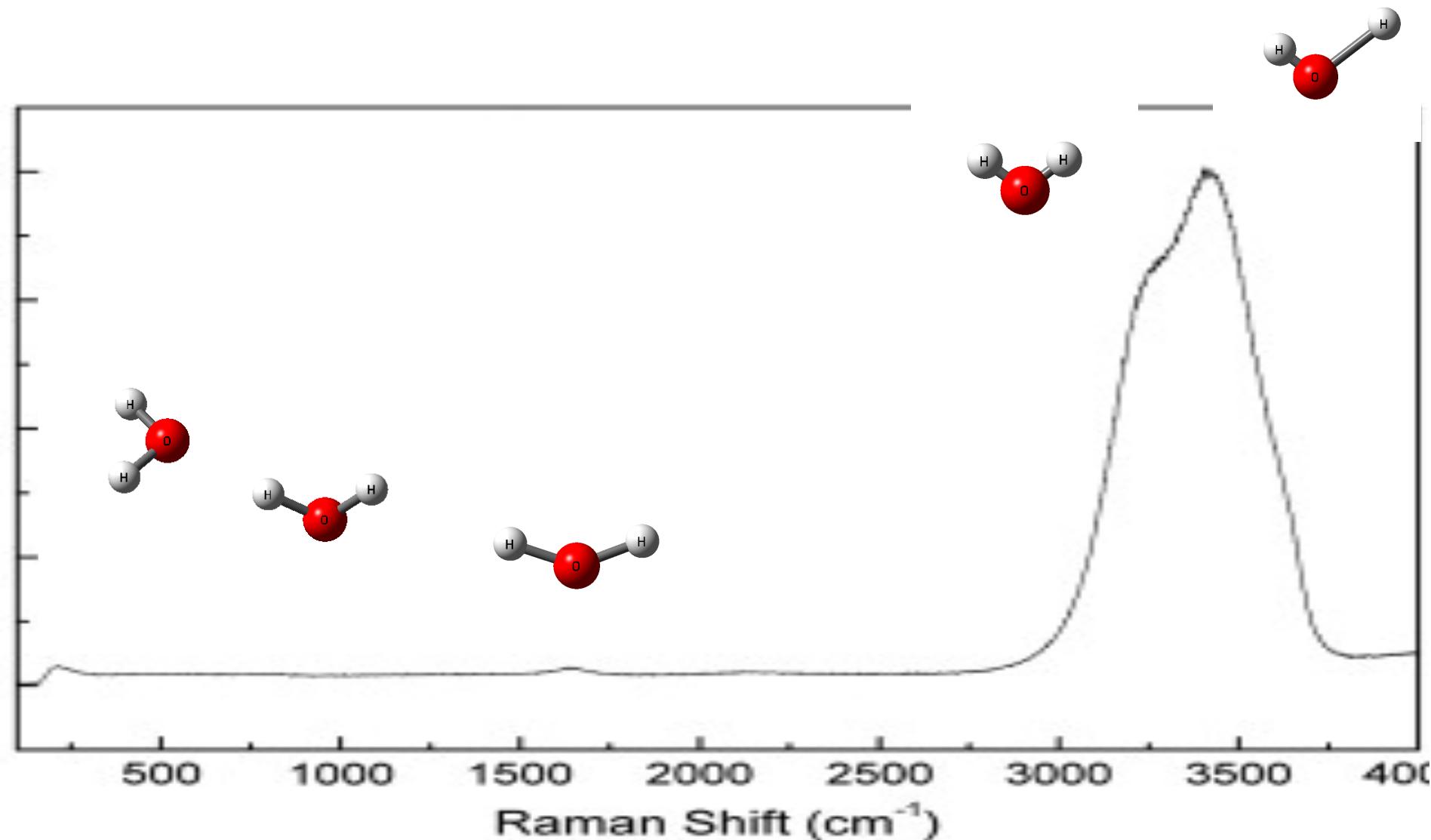


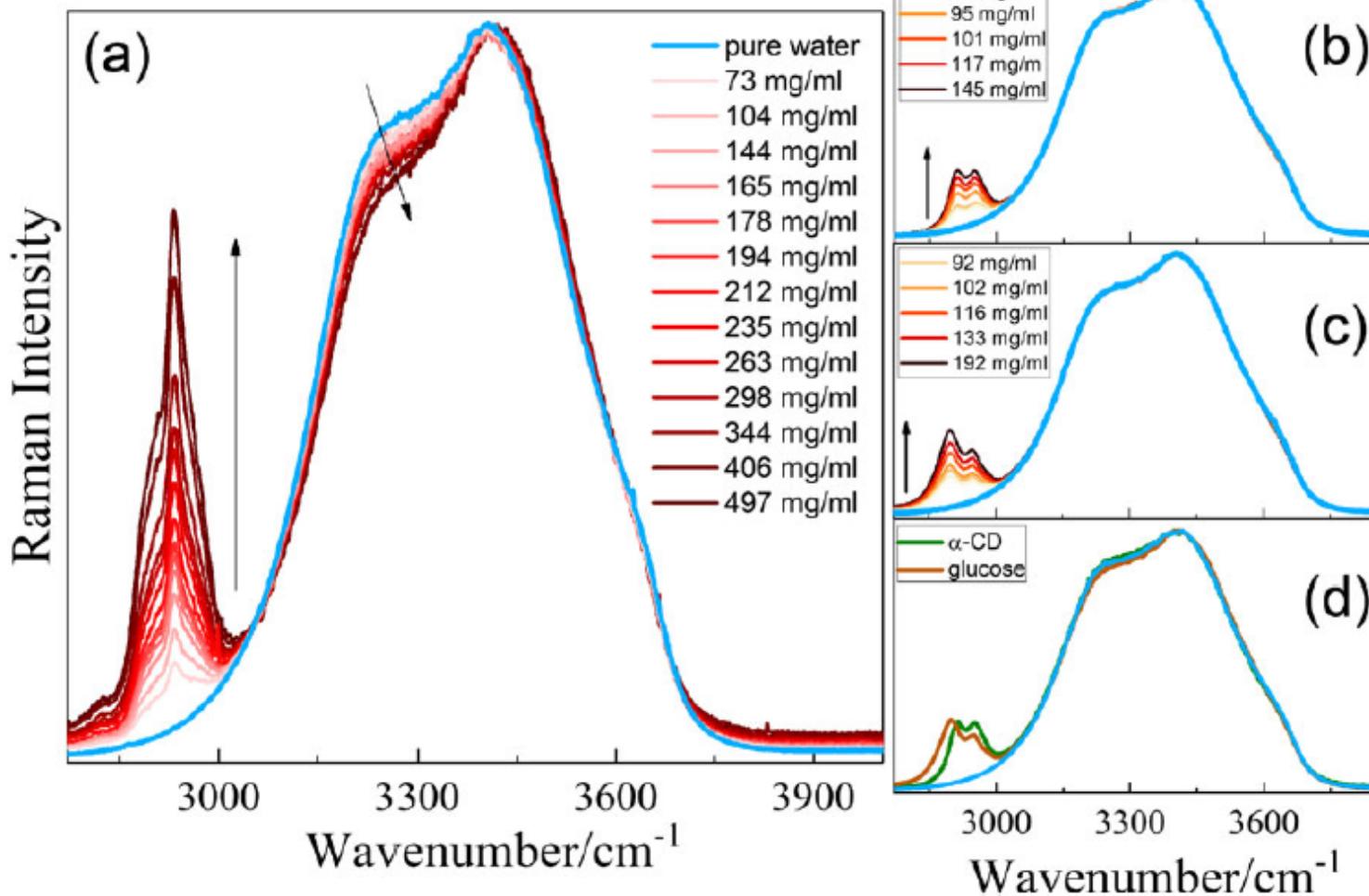
# UV micro Raman system



# Hydration of biomolecules studied by Raman spectroscopy

# Spettro Raman dell'acqua





C. Bottari et al., JRS 2018

# Caso scientifico: "memoria dell'acqua" ?

816

SCIENTIFIC PAPER

NATURE VOL. 333 30 JUNE 1988

## Human basophil degranulation triggered by very dilute antiserum against IgE

E. Dayen, F. Beauvais, J. Amara\*, M. Oberbaum\*, B. Robinzon t, A. Miadonna t, A. Tedeschit, B. Pomeranz§,

*transmission of the biological information could be related to the molecular organization of water.*

\* Departments of Zoology and Physiology, Ramsay Wright Zoological Laboratories, University of Toronto, 25 Harbord Street, Toronto, Ontario M5S 1A1 Canada

To whom co

When, human surface, are e  
The latter ca degranulatio dilutions nee related to the

### Editorial reservation

READERS of this article may share the incredulity of the many referees who have commented on several versions of it during the past several months. The essence of the result is that an aqueous solution of an antibody retains its ability to evoke a biological response even when diluted to such an extent that there is a negligible chance of there being a single molecule in any sample. There is no physical basis for such an activity. With the kind collaboration of Professor Benveniste, *Nature* has therefore arranged for independent investigators to observe repetitions of the experiments. A report of this investigation will appear shortly.

ype on its properties. peaks of ons. Since n could be

# Caso scientifico: "memoria dell'acqua" ?

NATURE VOL. 334 28 JULY 1988

## NEWS AND VIEWS

287

# "High-dilution" experiments a delusion

*The now celebrated report by Dr J. Benveniste and colleagues elsewhere is found, by a visiting Nature team, to be an insubstantial basis for the claims made for them.*

# Caso scientifico: "memoria dell'acqua" ?

Esperimento proposto:

**Verificare la presenza di un “effetto memoria” dell’acqua in soluzioni omeopatiche per mezzo dell’analisi di spettri vibrazionali raccolti tramite spettroscopia Raman.**

L'esperimento consiste nel preparare set di soluzioni acquose di trealosio e eventualmente glicina a diverse concentrazioni, diluendole progressivamente fino a raggiungere diluizioni di tipo omeopatico (meno di una molecola di trealosio per litro di solvente) .

Si mostreranno le modifiche alla banda OH-stretching dell’acqua in presenza di soluzione di trealosio (presenza della “hydration shell”) passando da concentrazioni alte a diluizione omeopatiche. Si verificherà se vi sono differenze tra la forma della banda OH stretching in soluzioni omeopatiche rispetto alla banda del solvente puro (acqua).

# Thank you

**Interreg**  
**Italia-Österreich**

European Regional Development Fund



EUROPEAN UNION

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[francesco.damico@elettra.eu](mailto:francesco.damico@elettra.eu)