Center of InfraRed
Thermal Solutions

A new way to innovate in thermal and chemical fields

Multispectral Imaging Techniques

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Learning outcomes

At the end of the lecture, the learners will be able to:

1. Understand the link between the light wavelength and the medium chemical composition
2. Do the radiative energy balance
3. Link the radiative absorbance to the species concentration
4. Classify the different multispectral measurement apparatus
5. Understand the physic behind the FTIR spectroscopy

Outlines

I. Light spectrum
- Link with black body & Planck law
- Link between light frequency and atomic energy
- Application of spectroscopy techniques in a large domain

II. Kirchhoff & Beer-Lambert Law
- Radiative energy balance
- Beer-lambert law & chemical concentration measurements

III. Mutlispectral imaging technologies
- Different mode: active and passive
- Monochromator and Interferometer
- Different techniques: transmission, réflexion, ATR…

IIII. Focus on the FTIR spectrometer
- Principles
- Data processing
- Uncertainty principles

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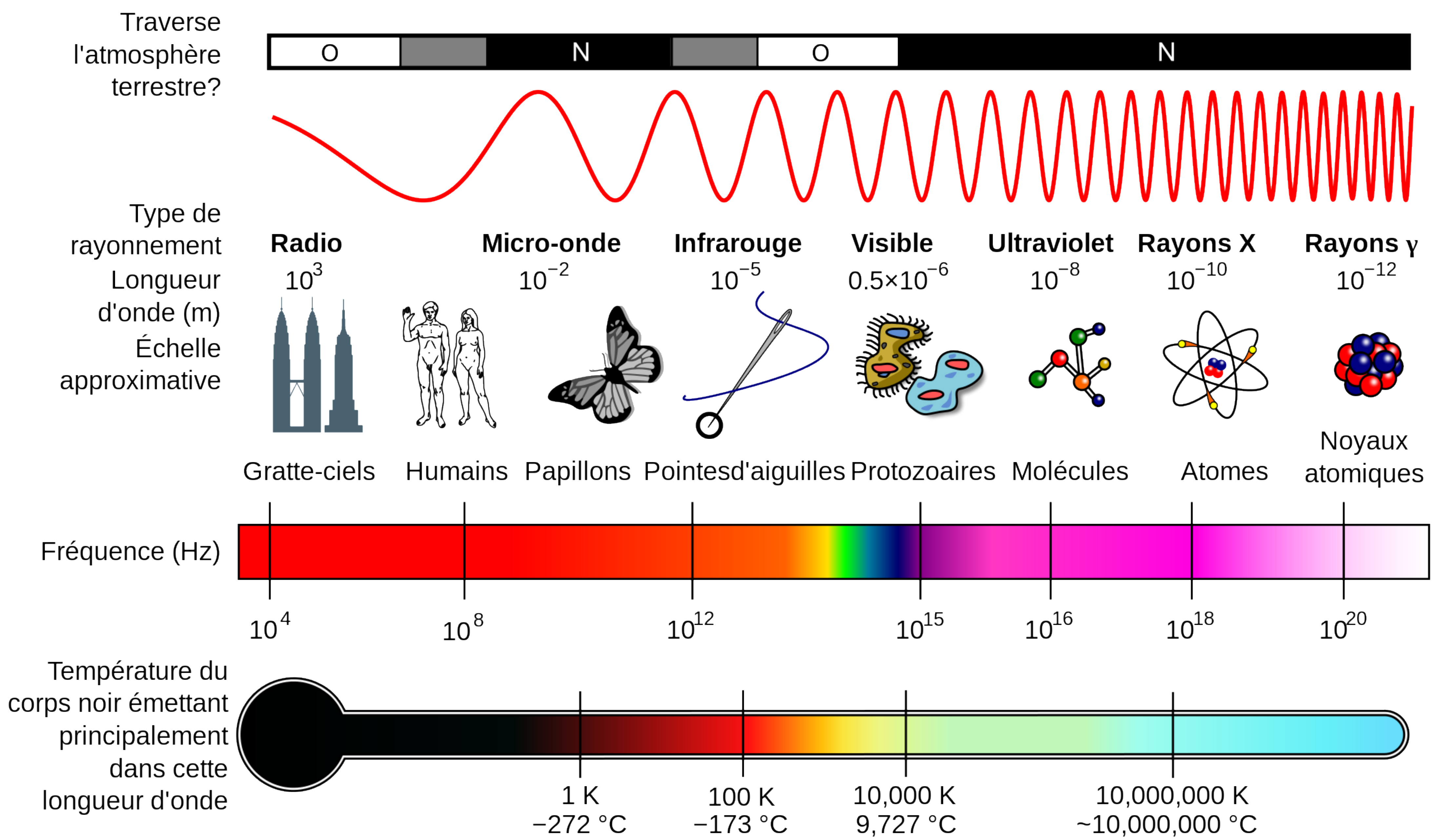
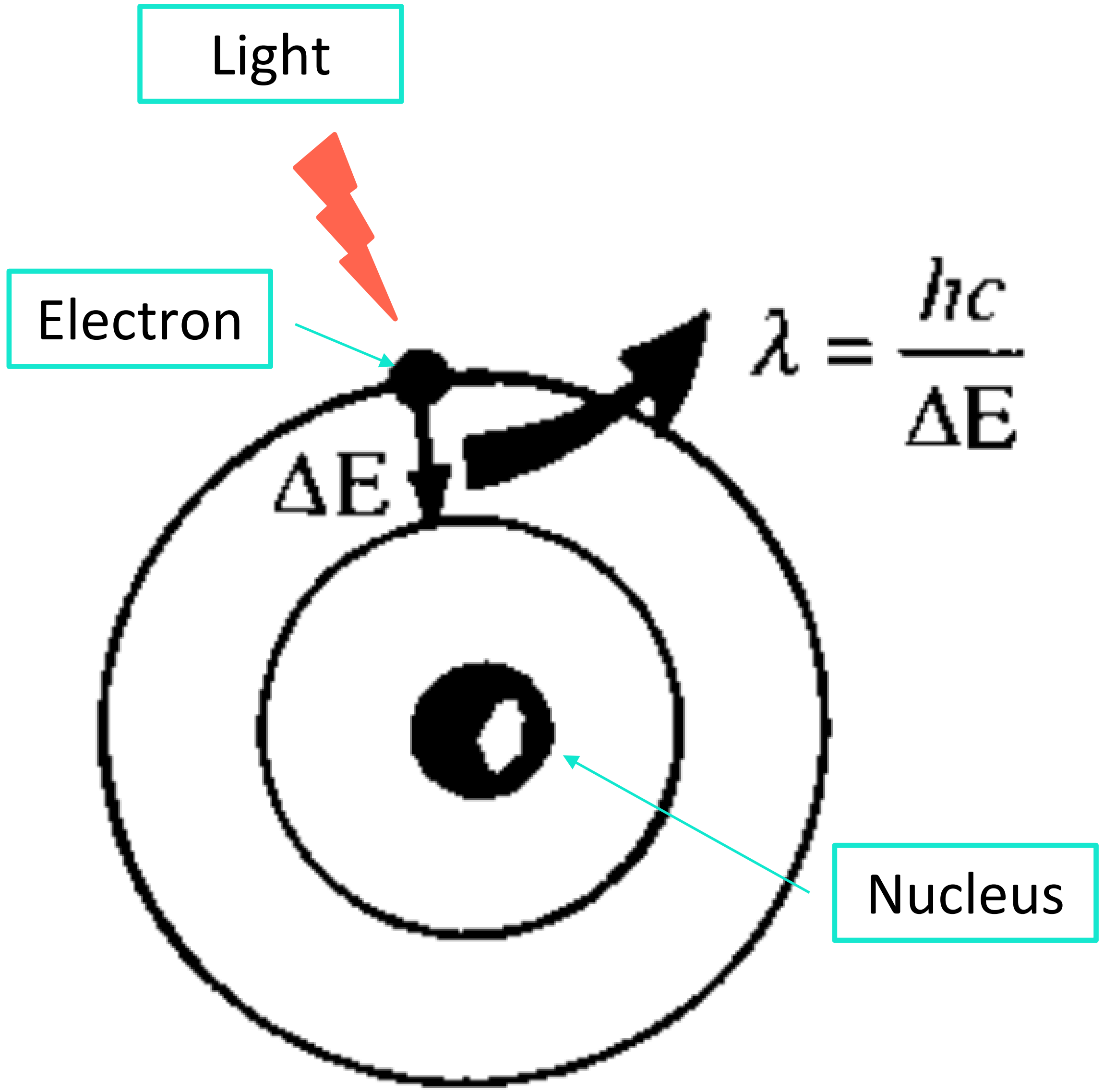
Radiation spectrum



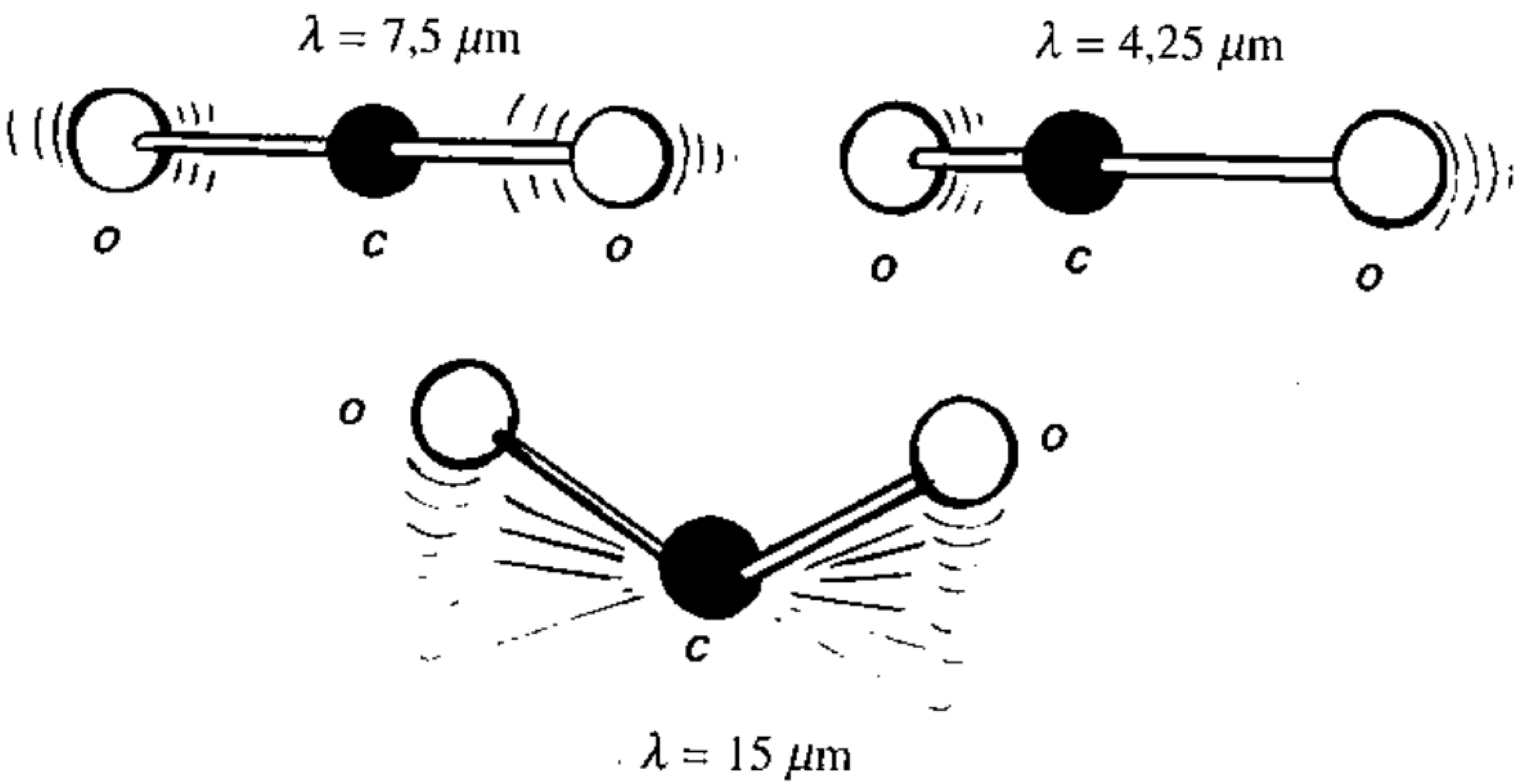
Link between energy and electronic bonding

Schematic of an atom with a single electron:

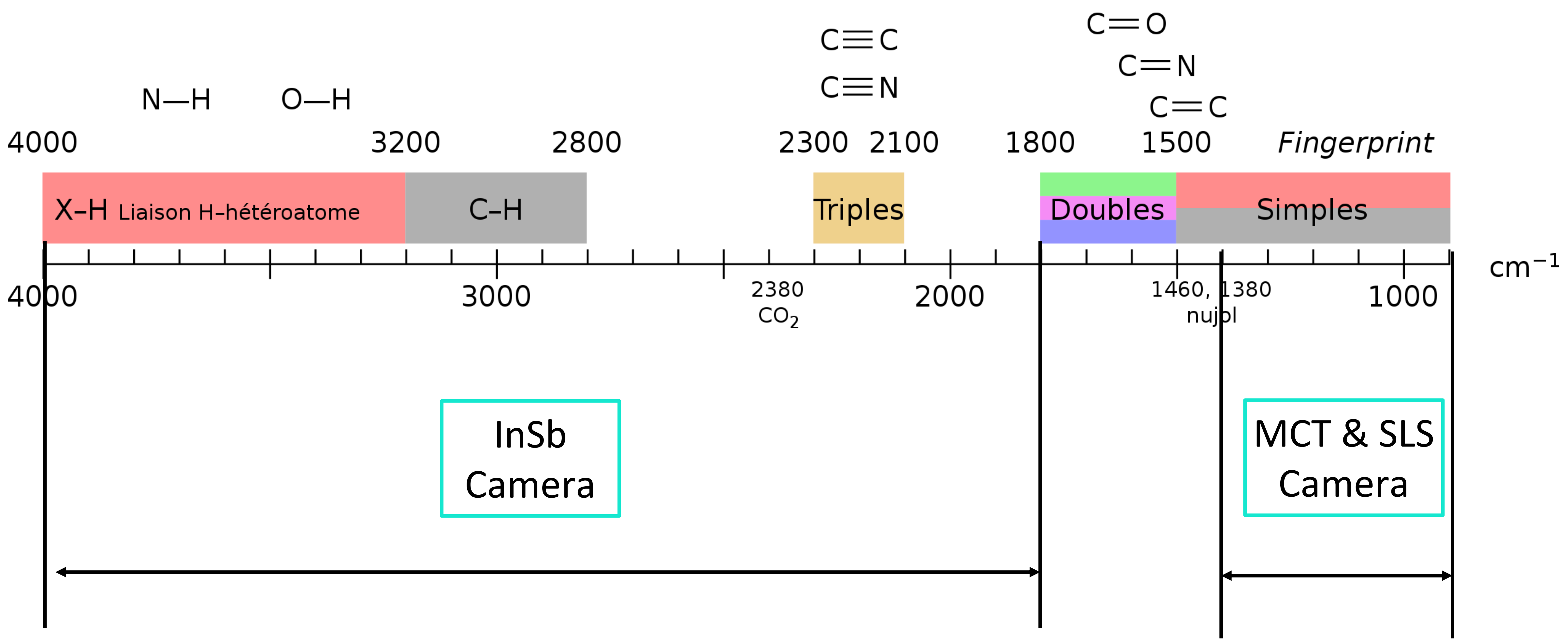


Link between energy and molecular bonding

Different light frequencies for different bonding energy for different molecular bonding:

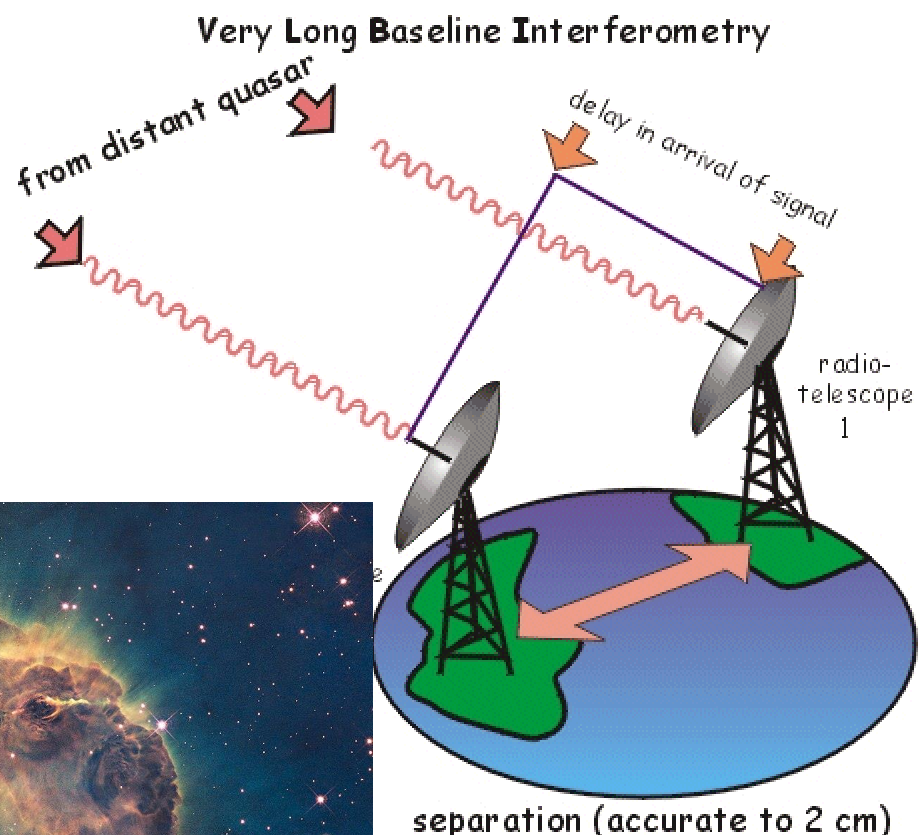


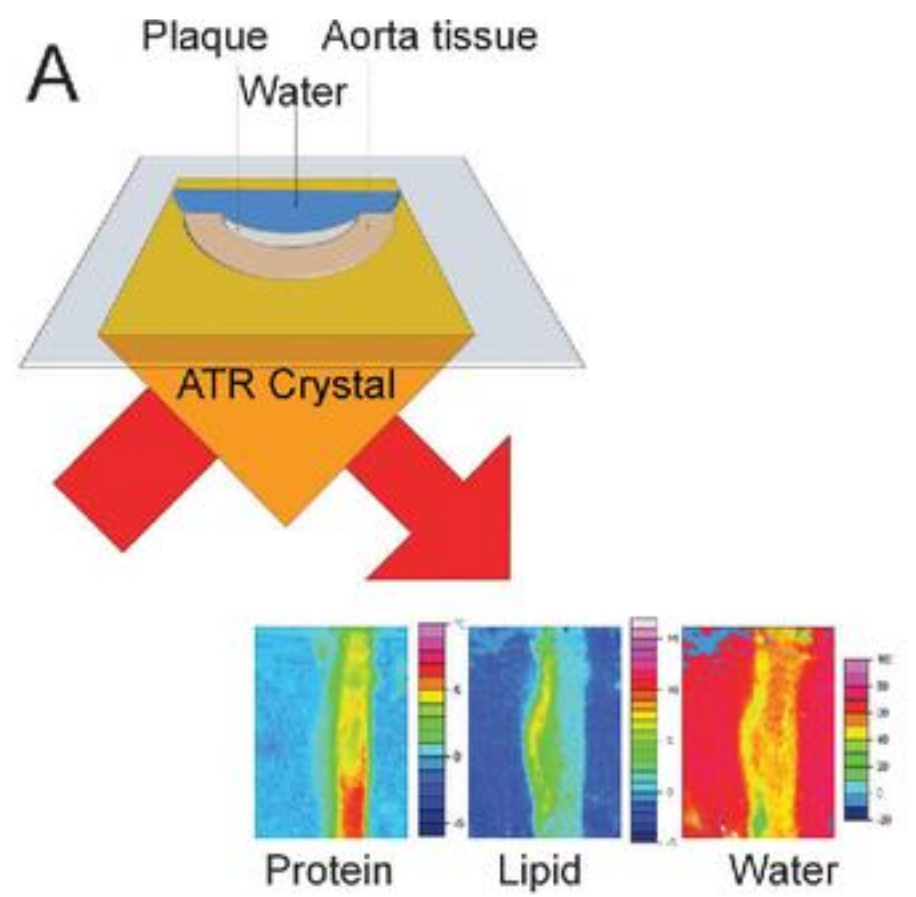
Link between energy and molecular bonding



Each wavelength reveals the signature of a specific molecule or specific molecular bonding

From the astronomic- to the micro-scale





From gas Nebula ~ 10^9 m .... to microfluidic ~ 10^{-6} m

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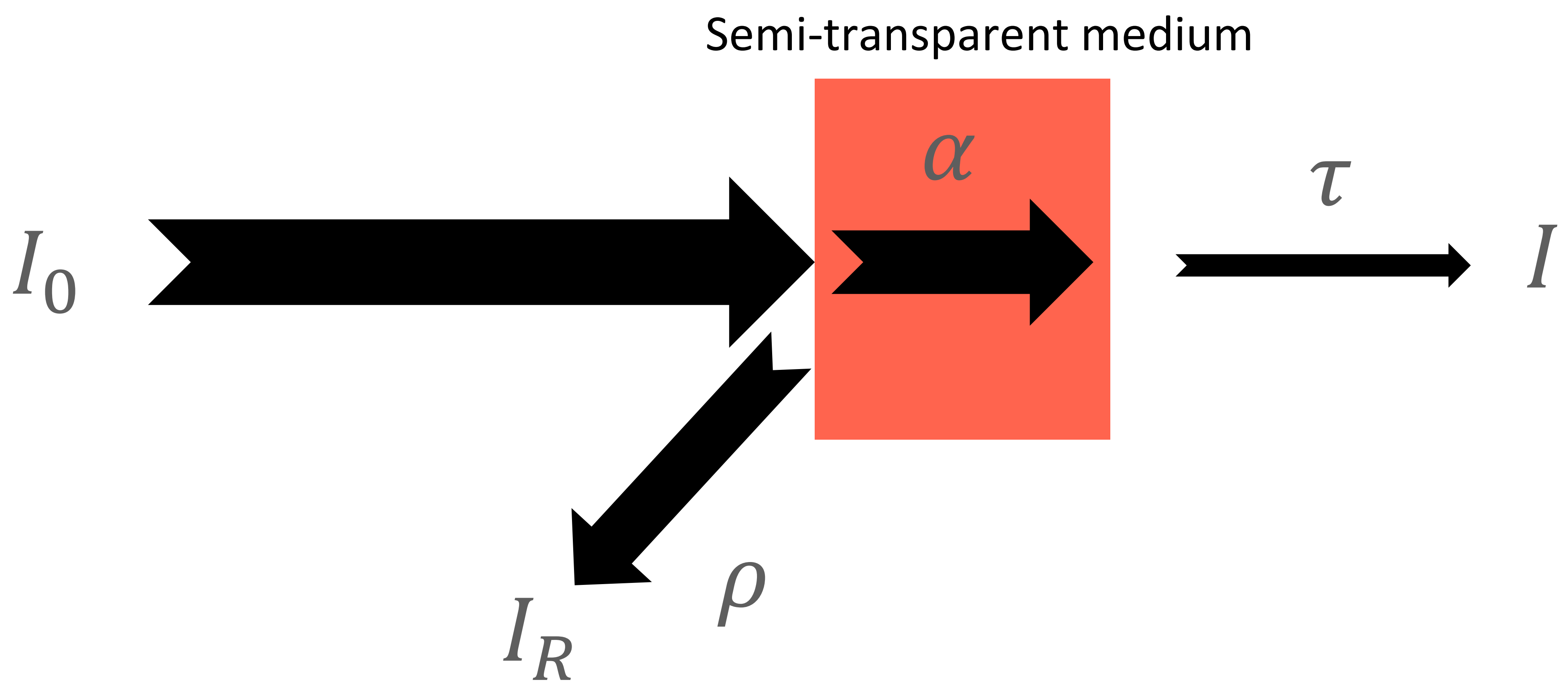
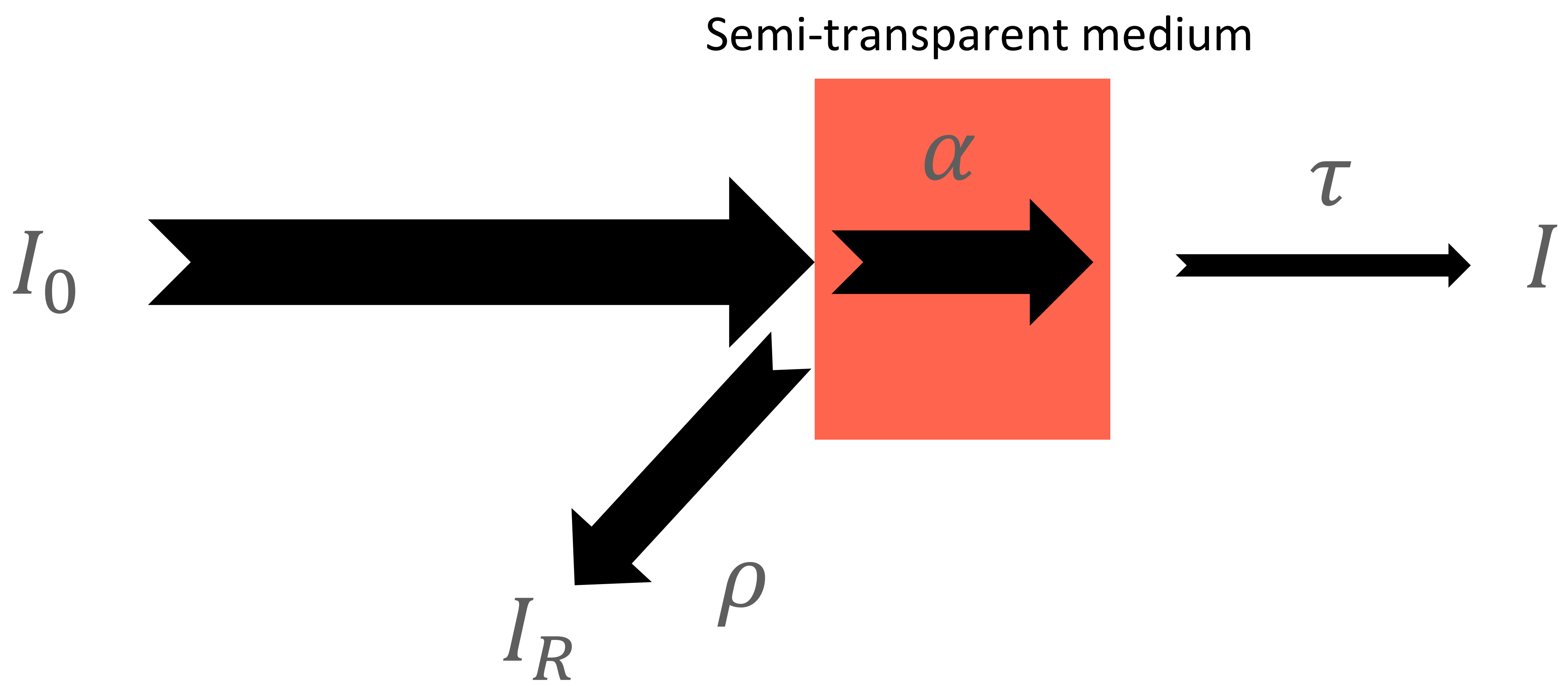
Radiative energy balance (Kirchhoff law)



$$\rho + \alpha + \tau = 1$$

All these properties dépend on the light wavelength

Radiative energy balance (Kirchhoff law)

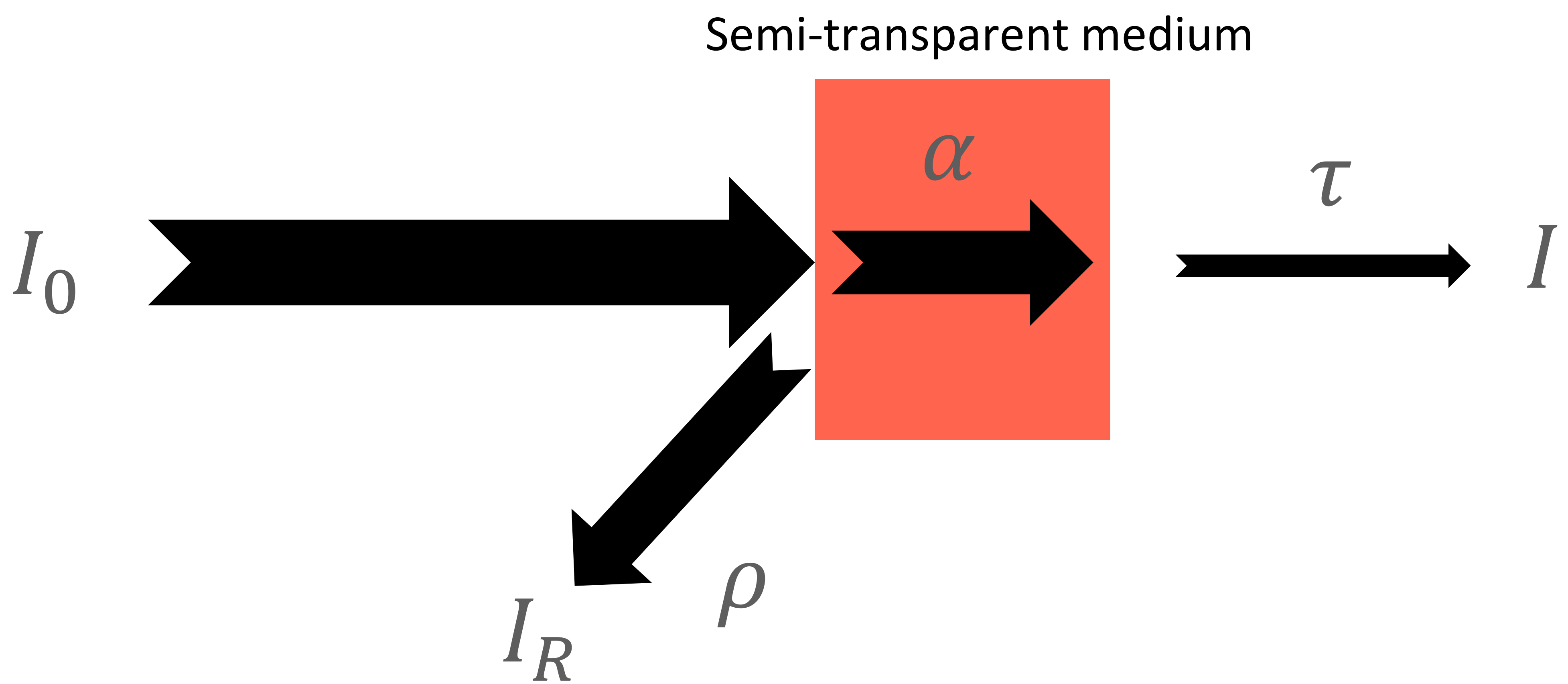


I_0: Light source intensity (W/m^2)

I_R: Reflected light intensity (W/m^2)

I: Transmitted light intensity (W/m^2)

Radiative energy balance (Kirchhoff law)

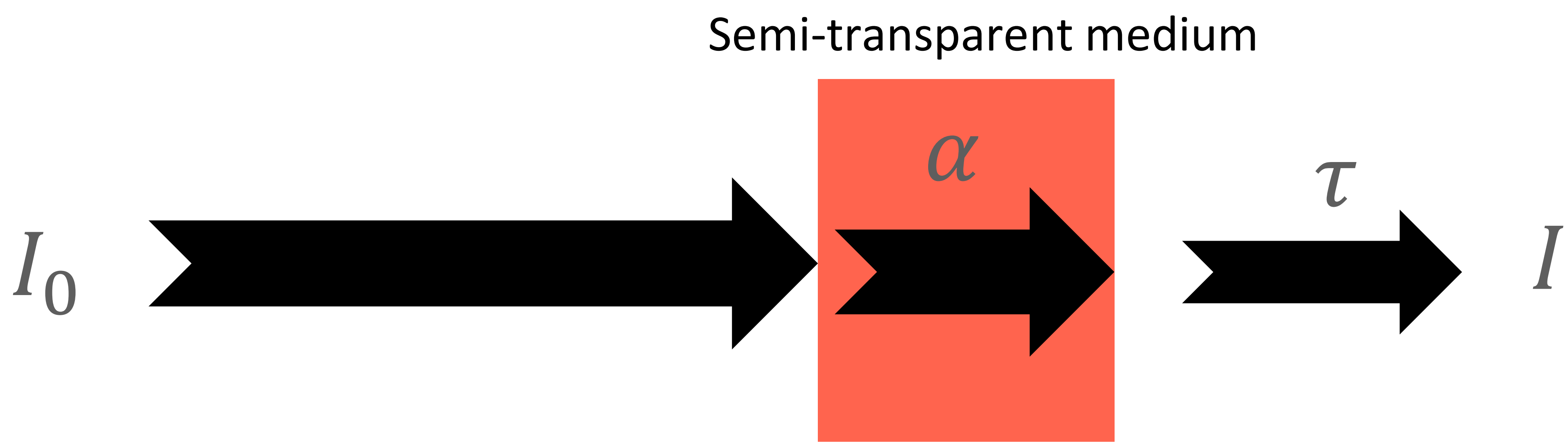


$\rho = \frac{I_R}{I_0}$: Reflectivity

$\tau = \frac{I}{I_0}$: Transmittivity

$\alpha = 1 - \rho - \tau$: Absorptivity

Radiative energy balance (Kirchhoff law)



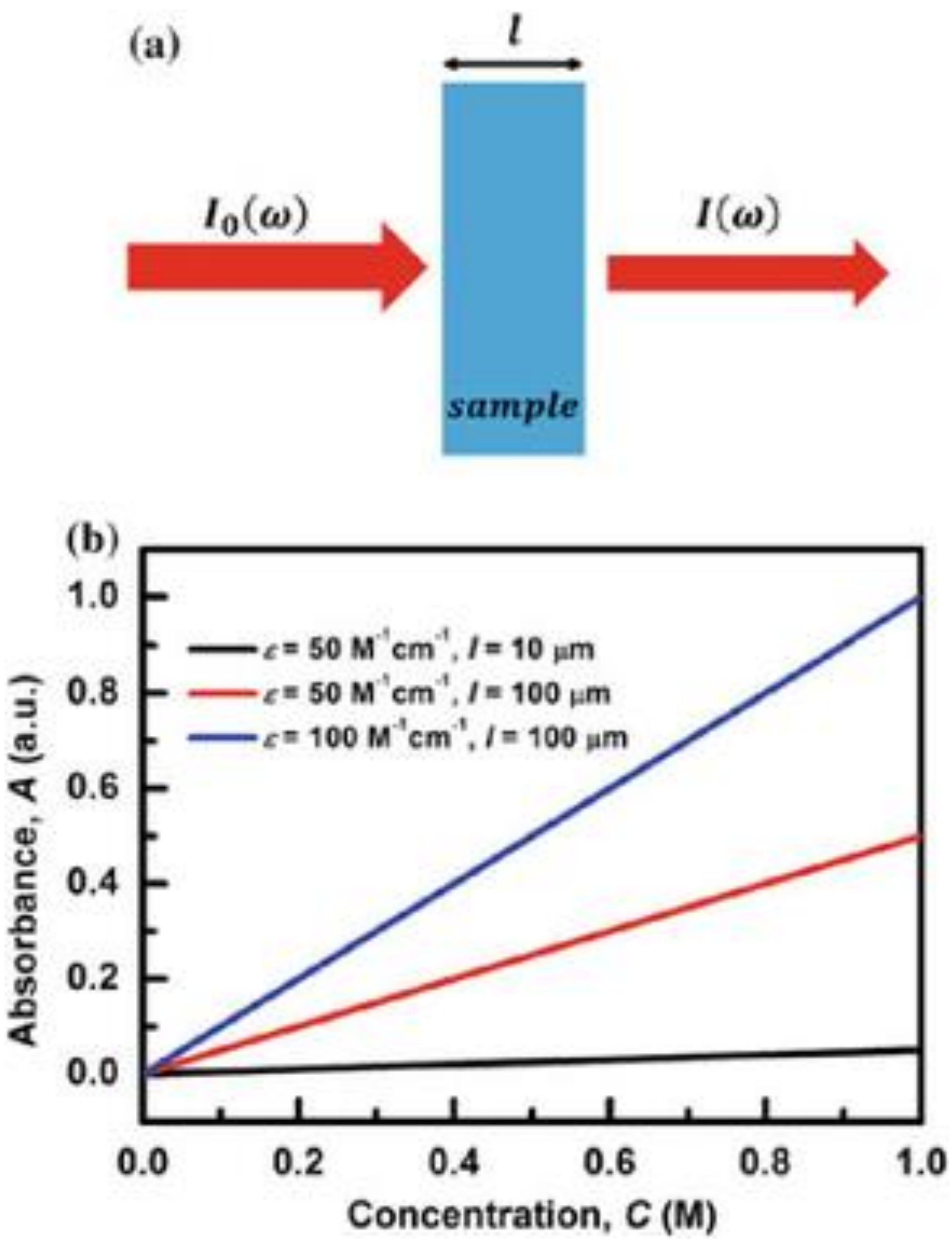
In practice : $\rho \approx 0$ ➔ $\alpha \approx 1 - \tau$

And one can define the absorbance of the medium as:

$$A = -\log_{10}\tau = \Sigma_i \mu_i C_i \times e$$

C is the concentration and μ the absorptivity coefficient

The Beer-Lamber law (Transmission mode)

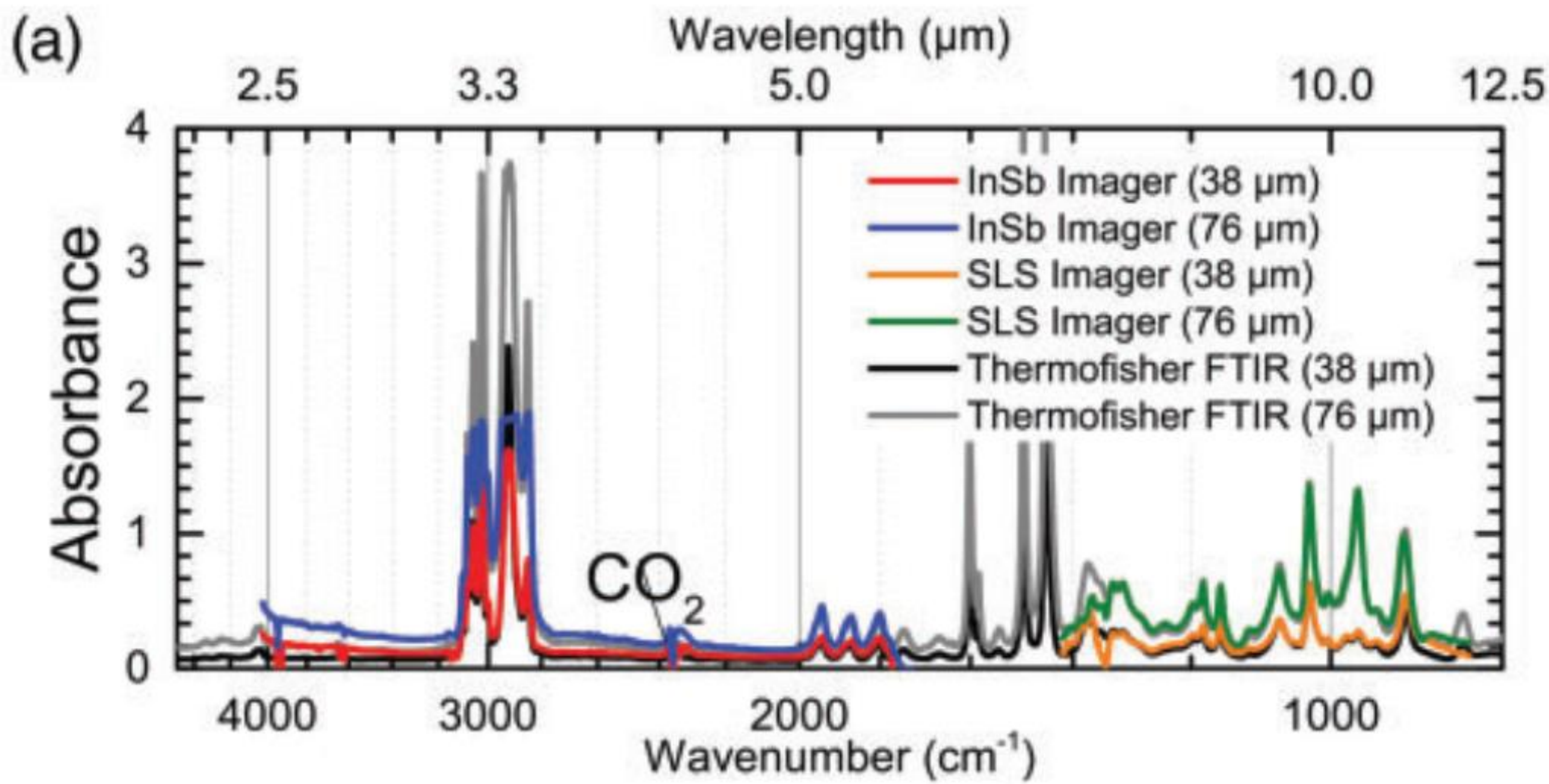


$$A = \Sigma_i \mu_i C_i \times l$$

C is the concentration (M)
μ the absorptivity coefficient ($M^{-1}.m^{-1}$)
l is the optical path (m)

Works only with a monochromatic light

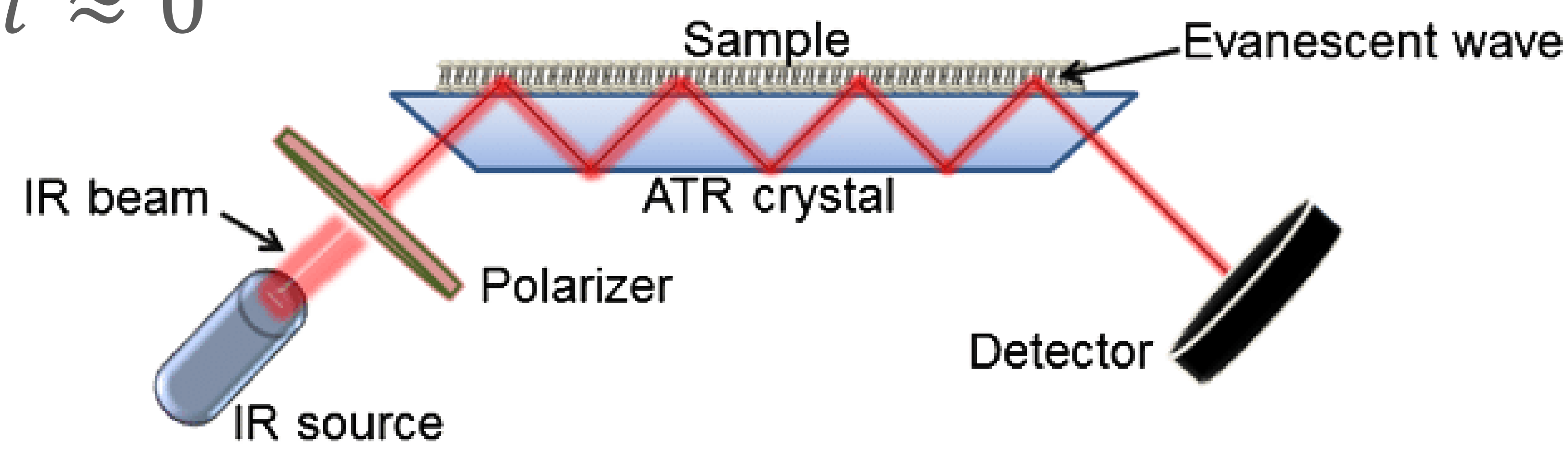
Polystyrene spectrum

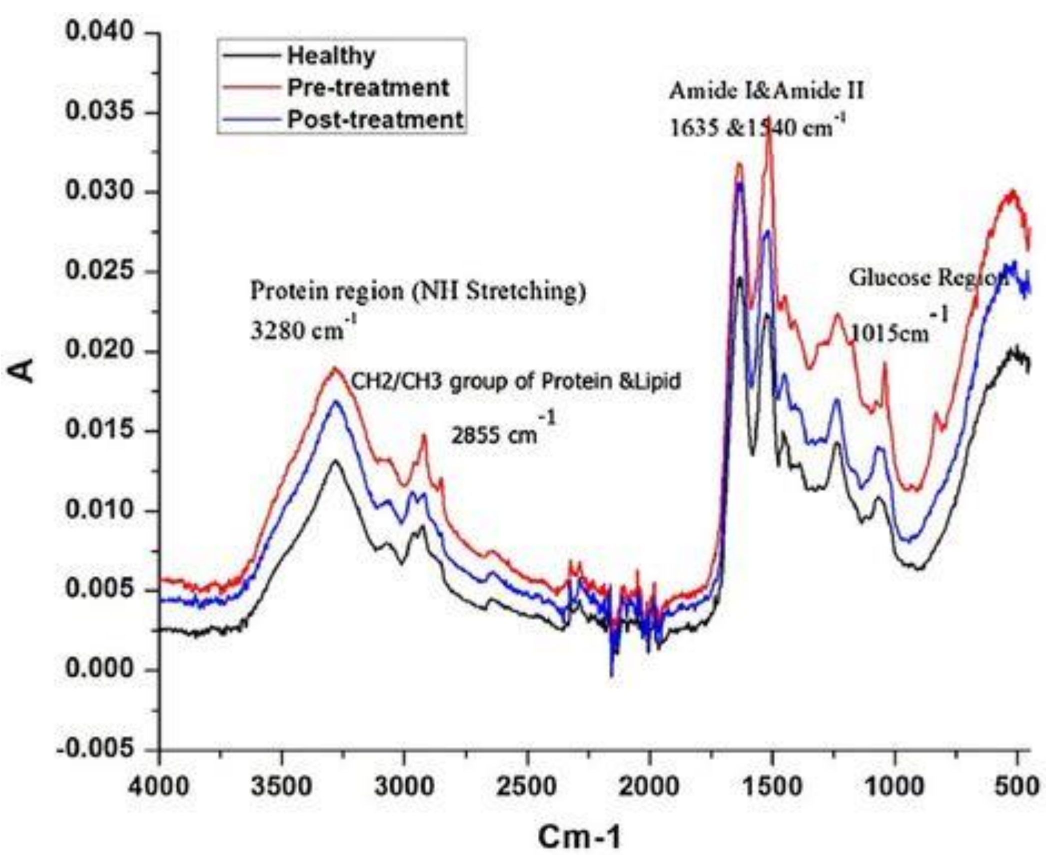


The intensity of each peak of the spectrum can be linked to a specific species with a specific concentration !

A similar conclusion can be drawn in Relexion mode

In practice : $\tau \approx 0$





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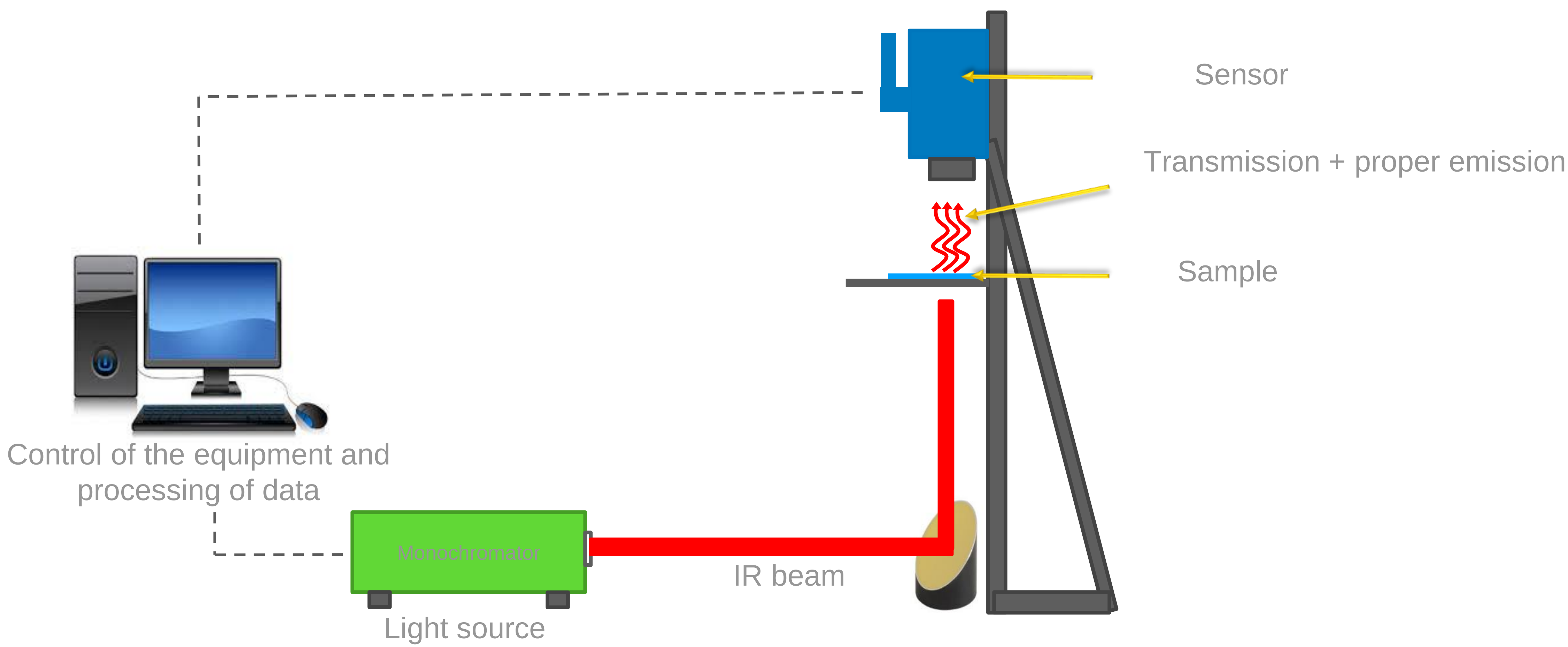
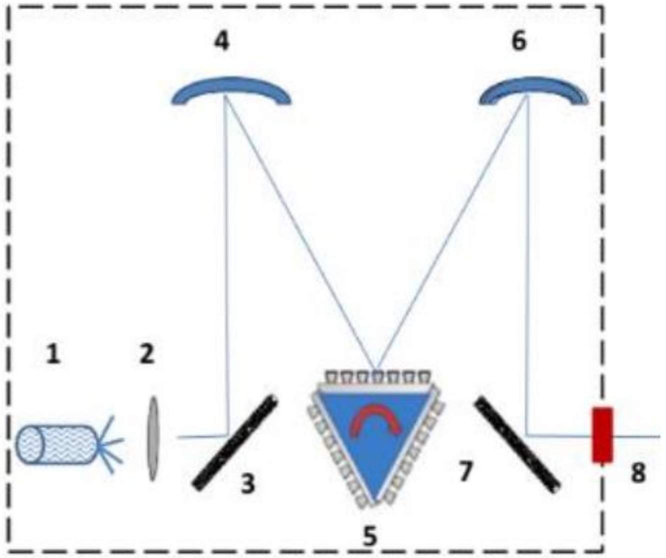
Active mode : the ligth wavelength is selected in the source



Advantage: monochromatic light is easier to image (avoid all the chromatic issues)

Inside the monochromator



Bentham Monochromator

(1) Lampe multispectrale Nernst, (2) Tourelle mécanique supportant les filtres, (3,7) Miroir plan, (4,6) Miroir parabolique, (5) Réseau réglable, (8) Fente avec chopper mécanique

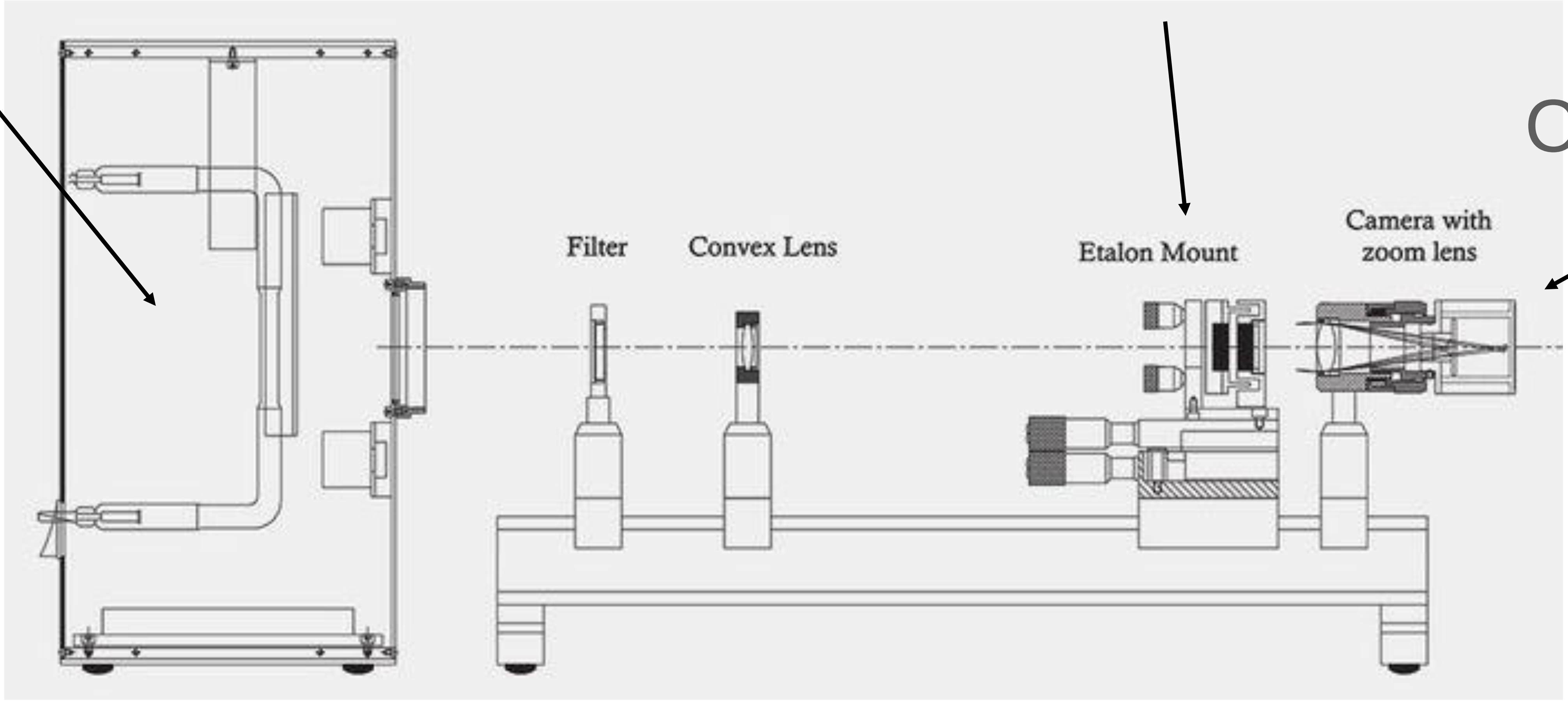
The spectral resolution of our grating is around 20 nm.

Passive mode : the ligth wavelength is selected after the sample

Multispectral source

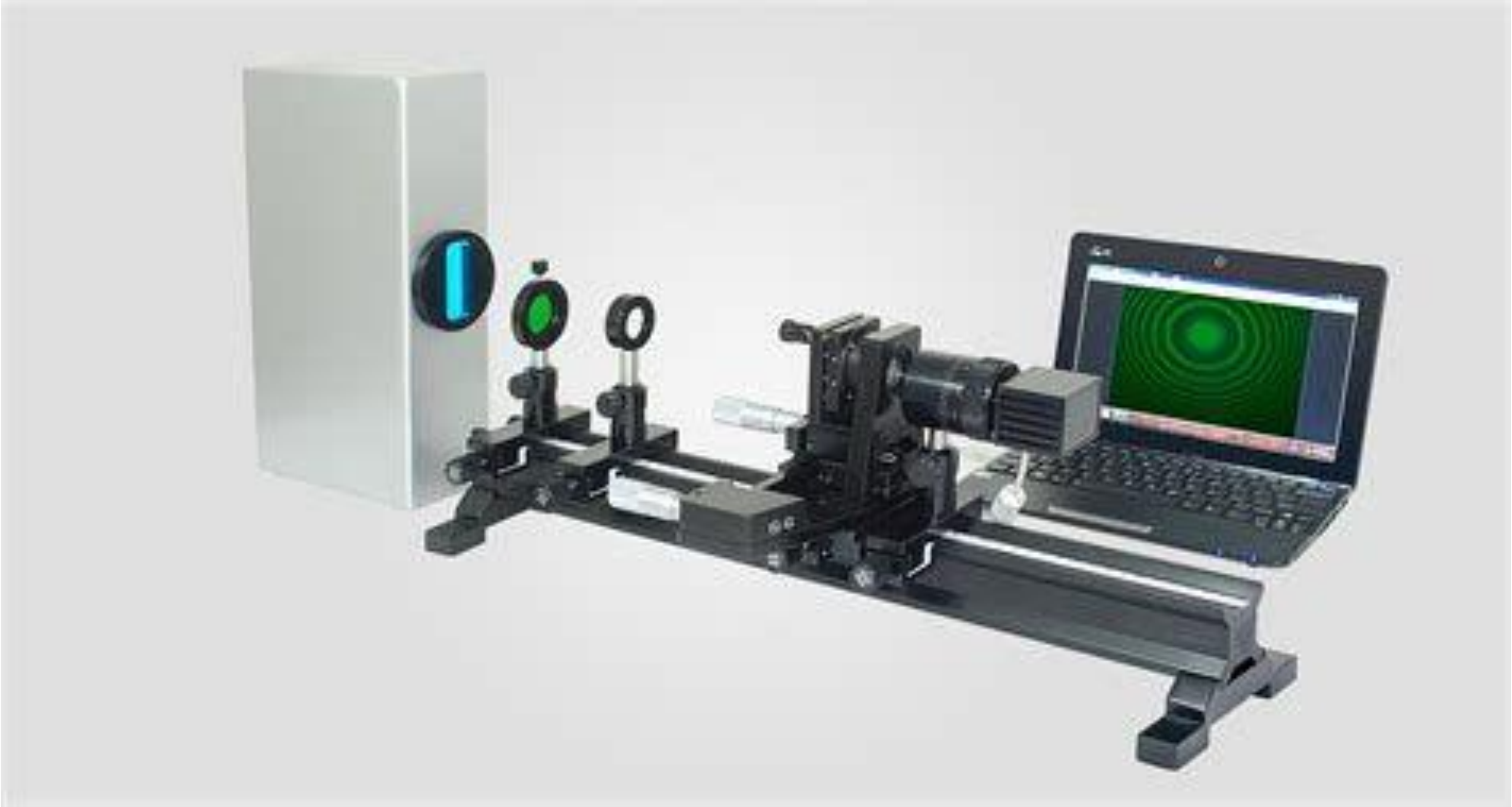
Interferometer

Camera

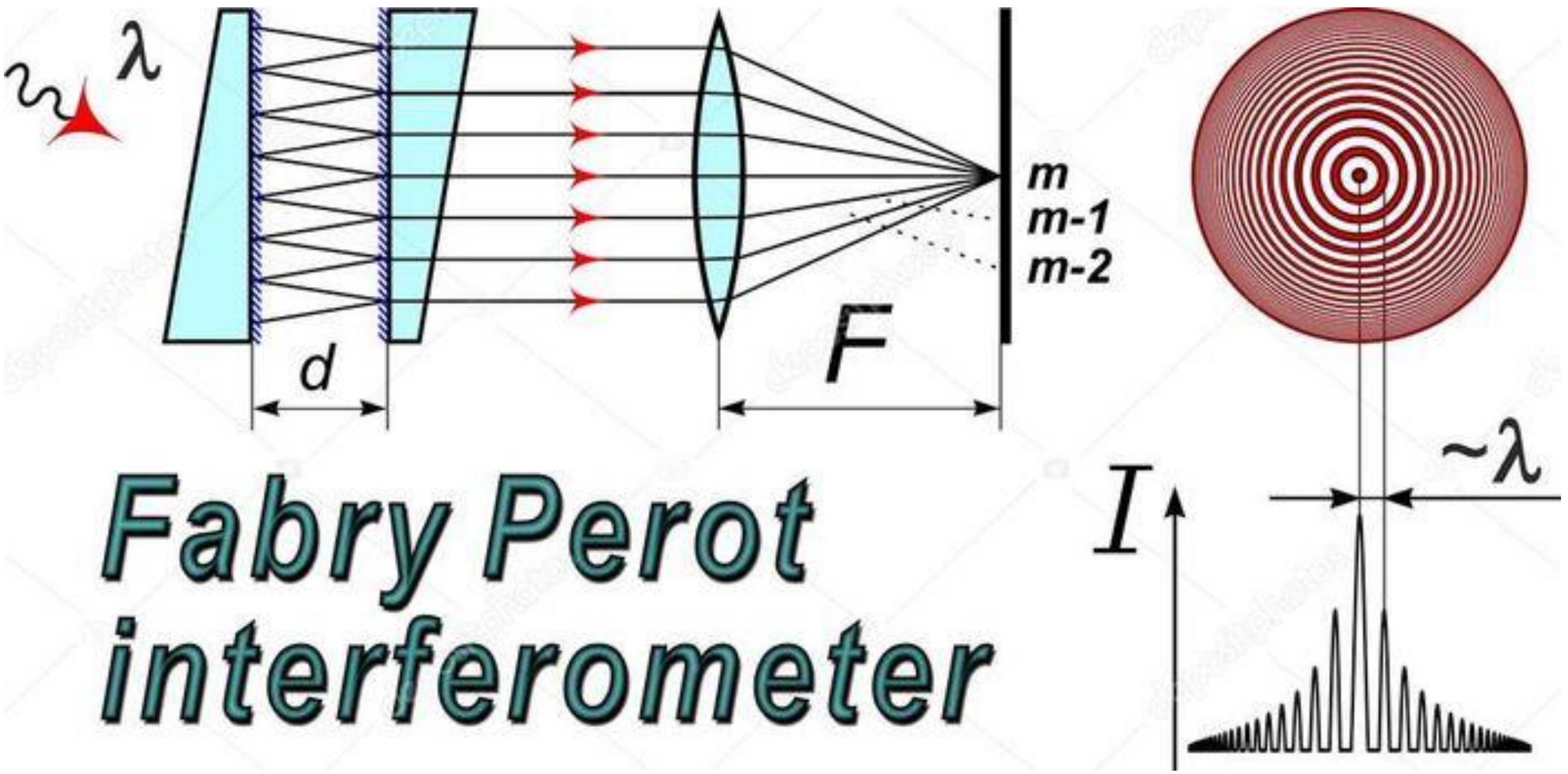


Advantage: no source is needed !

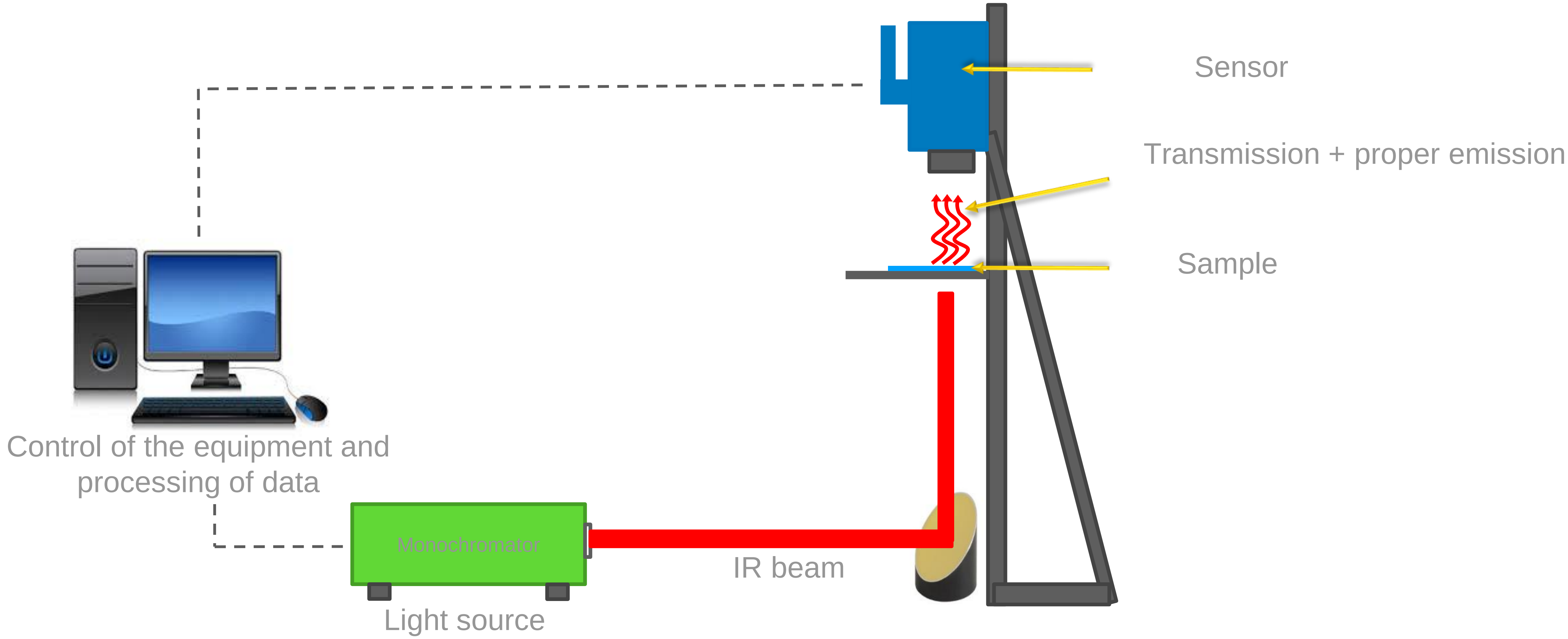
Fabry Perot interferometer



Fabry Perot interferometer

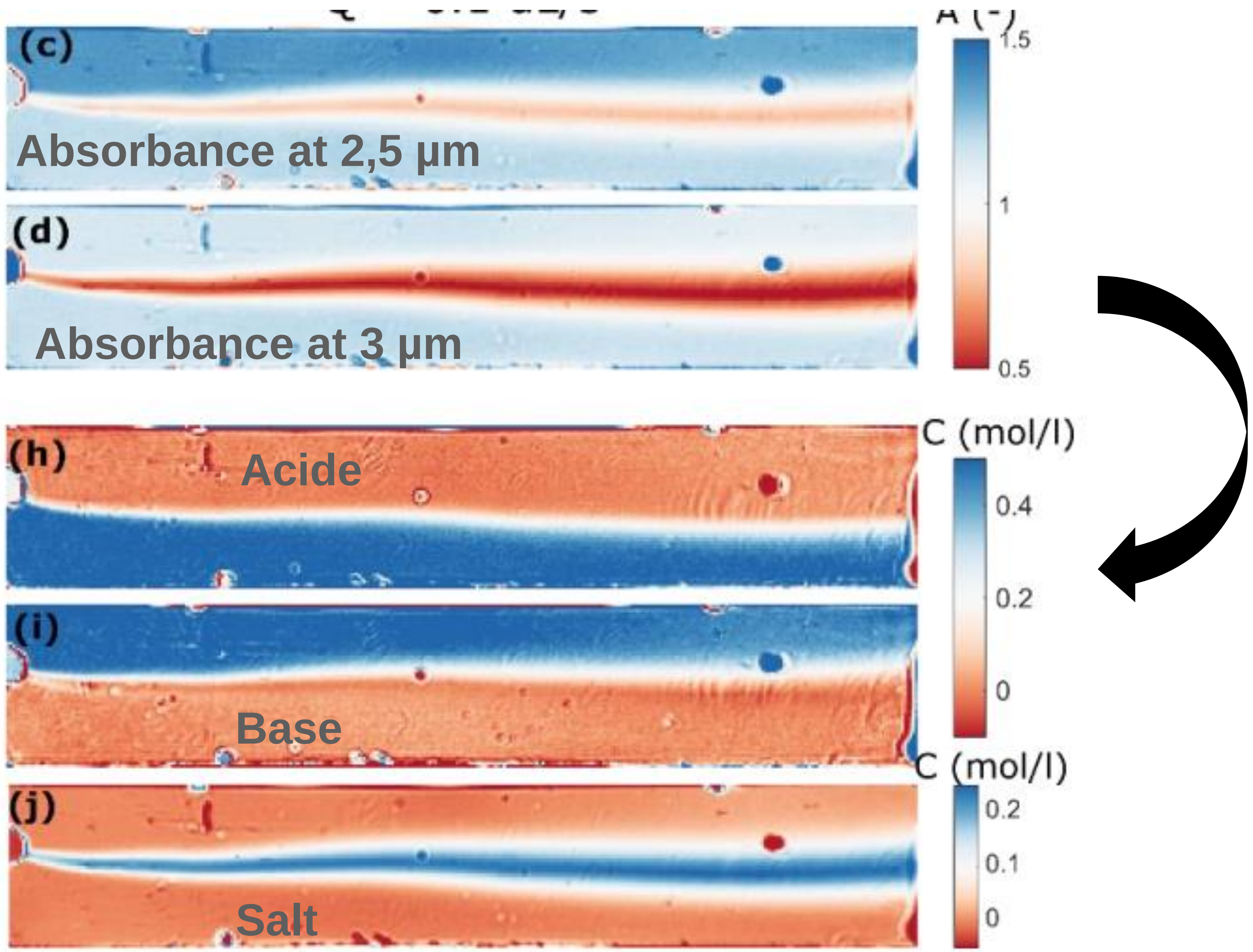


Transmission mode



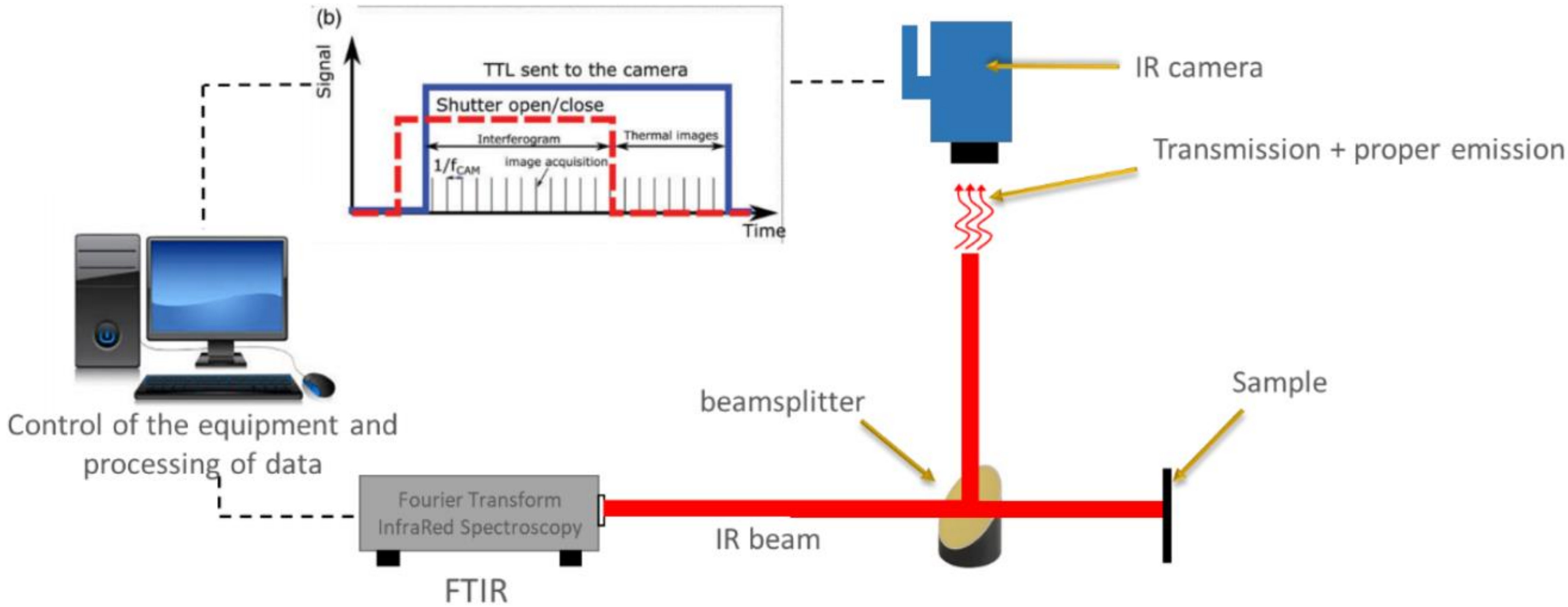
The light passes through the entire sample ➔ more sensitive to the chemistry of sample.
However, the sample needs to be very thin !

Transmission mode



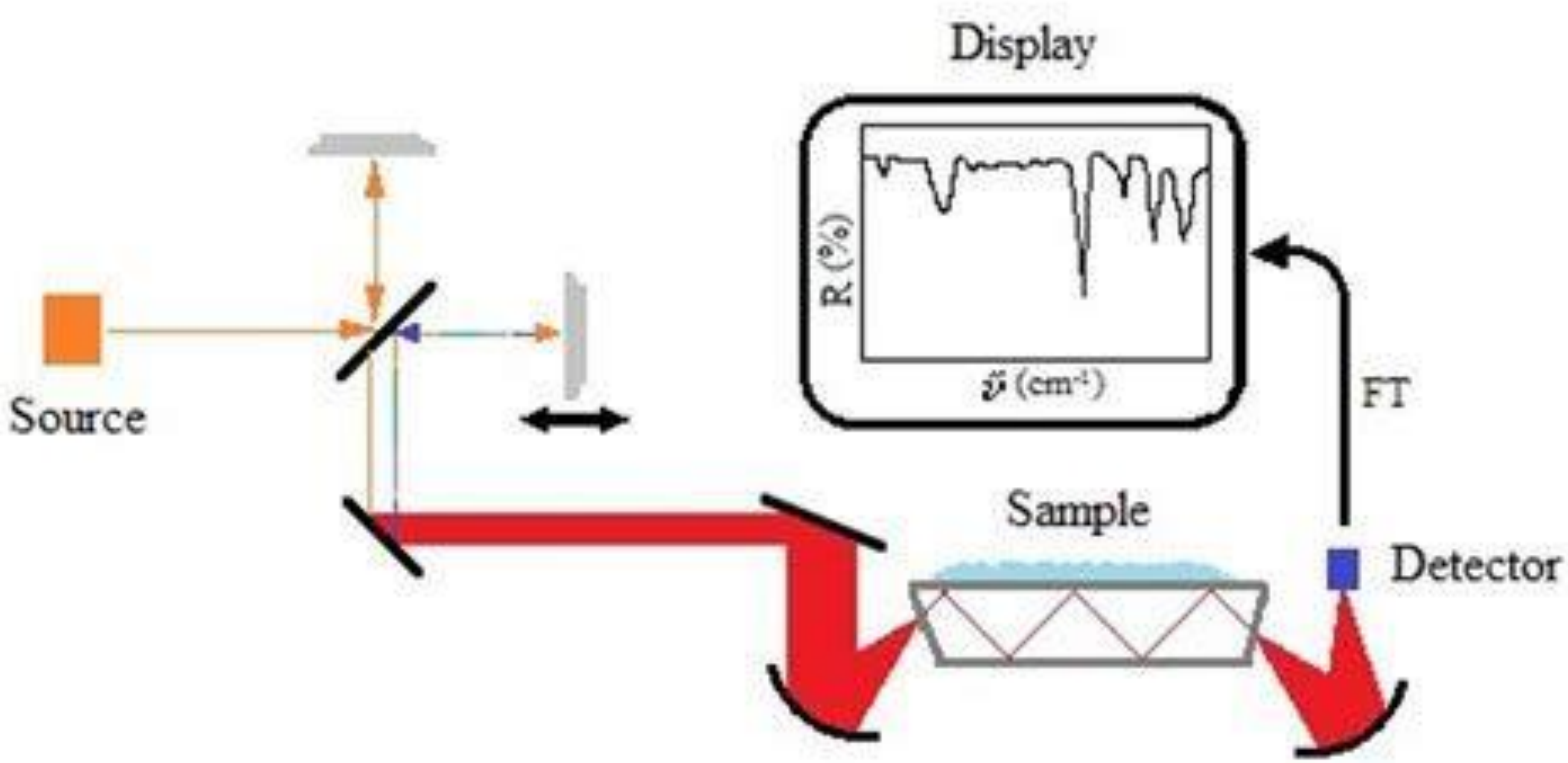
Conversion of multispectral images into chemical fields

Réflexion mode



The light is reflected at the surface of the sample ➔ useful to capture the chemistry at surface of a solid.

Réflexion mode (ATR: Attenuated Total Reflectance)



The light is reflected in a highly refracted crystal and penetrates at the surface of the sample.
➔ Useful to characterize thick material (solid or liquid)

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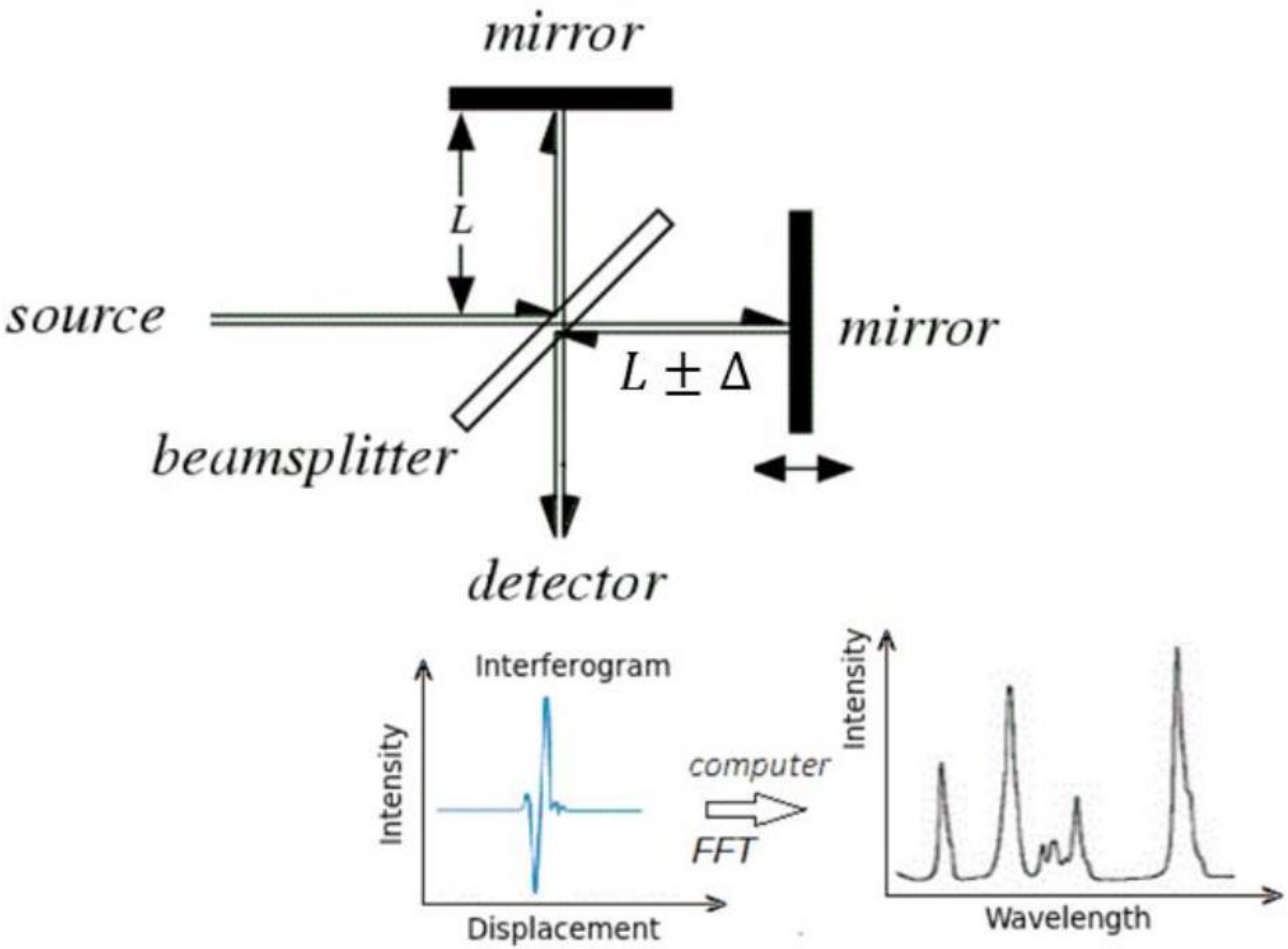
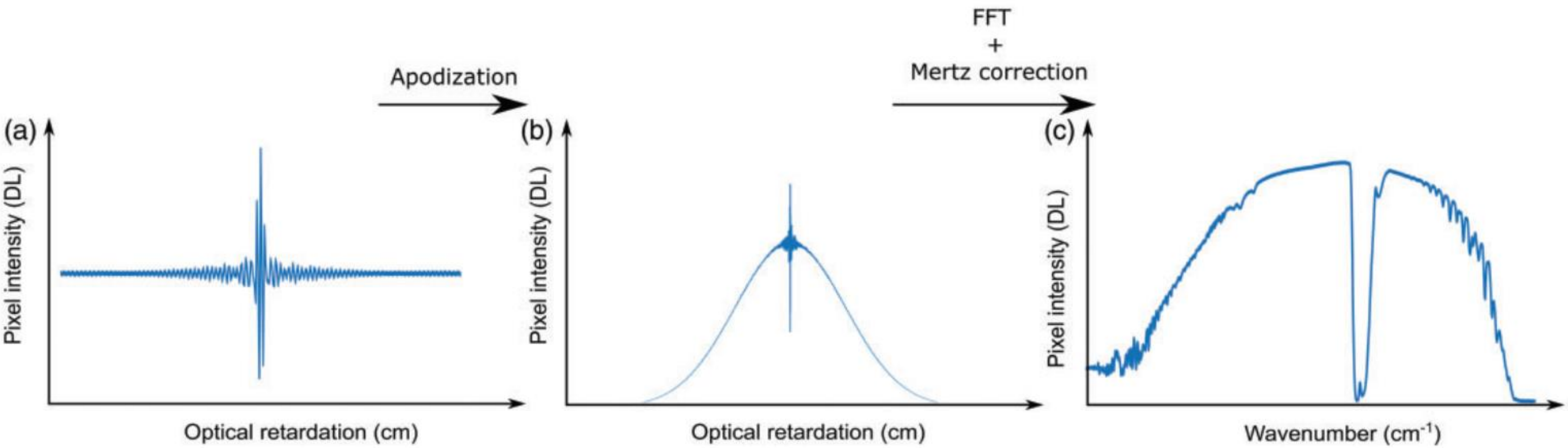
Focus on the FTIR spectrometer



Data processing



$$I_{tot}(x, y, \delta) = E(x, y) + I_{dc}(x, y) + I_{ac}(x, y, \delta)$$

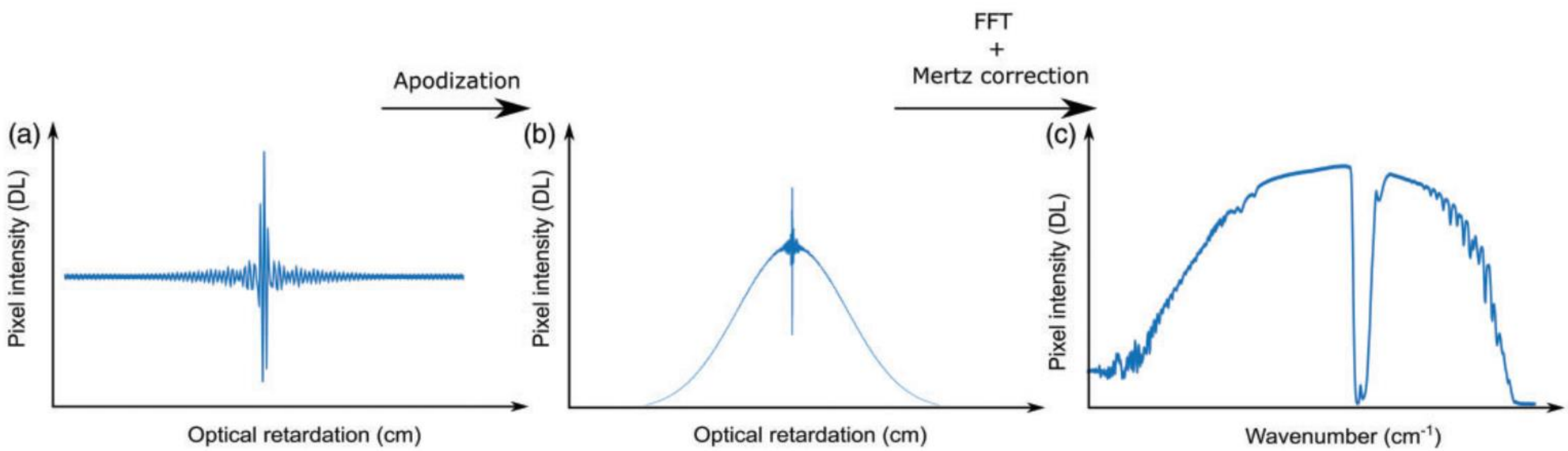
Signal measured by the camera

Proper emmision

Spectrometer continuous signal

Spectrometer interferred signal

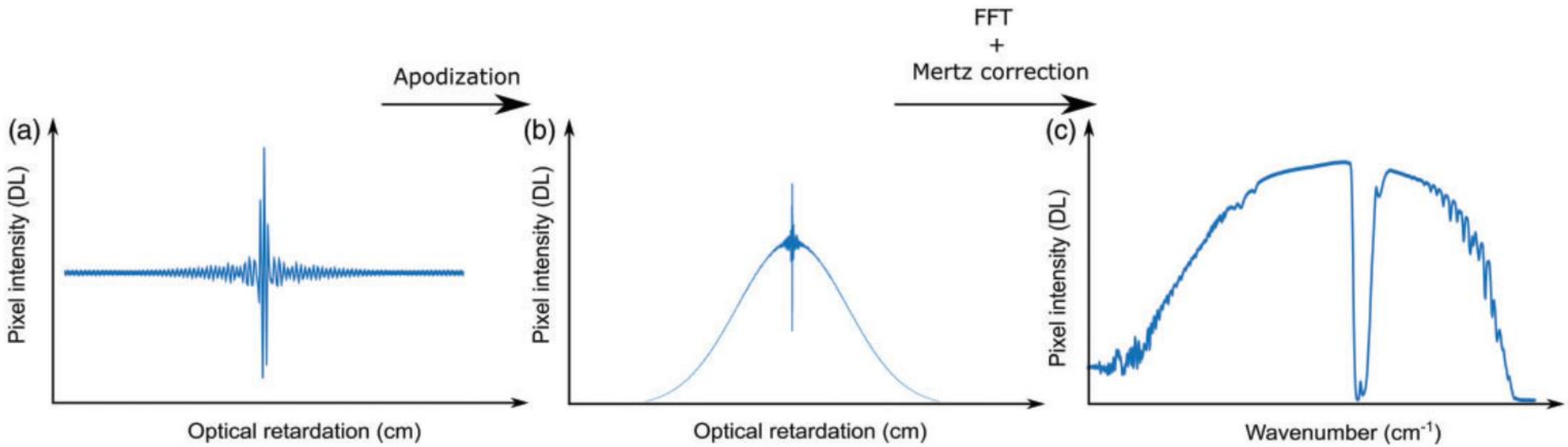
Data processing



$$I_a(x,y,\delta) = (I_{tot}(x,y,\delta) - E(x,y)) \times \exp\left(-\left(k\frac{N_{frame}}{N_{ref}}\delta^*\right)^2\right)$$

Gaussian apodization to remove the small oscillation in Fourier transformed (increase the SNR)

Data processing

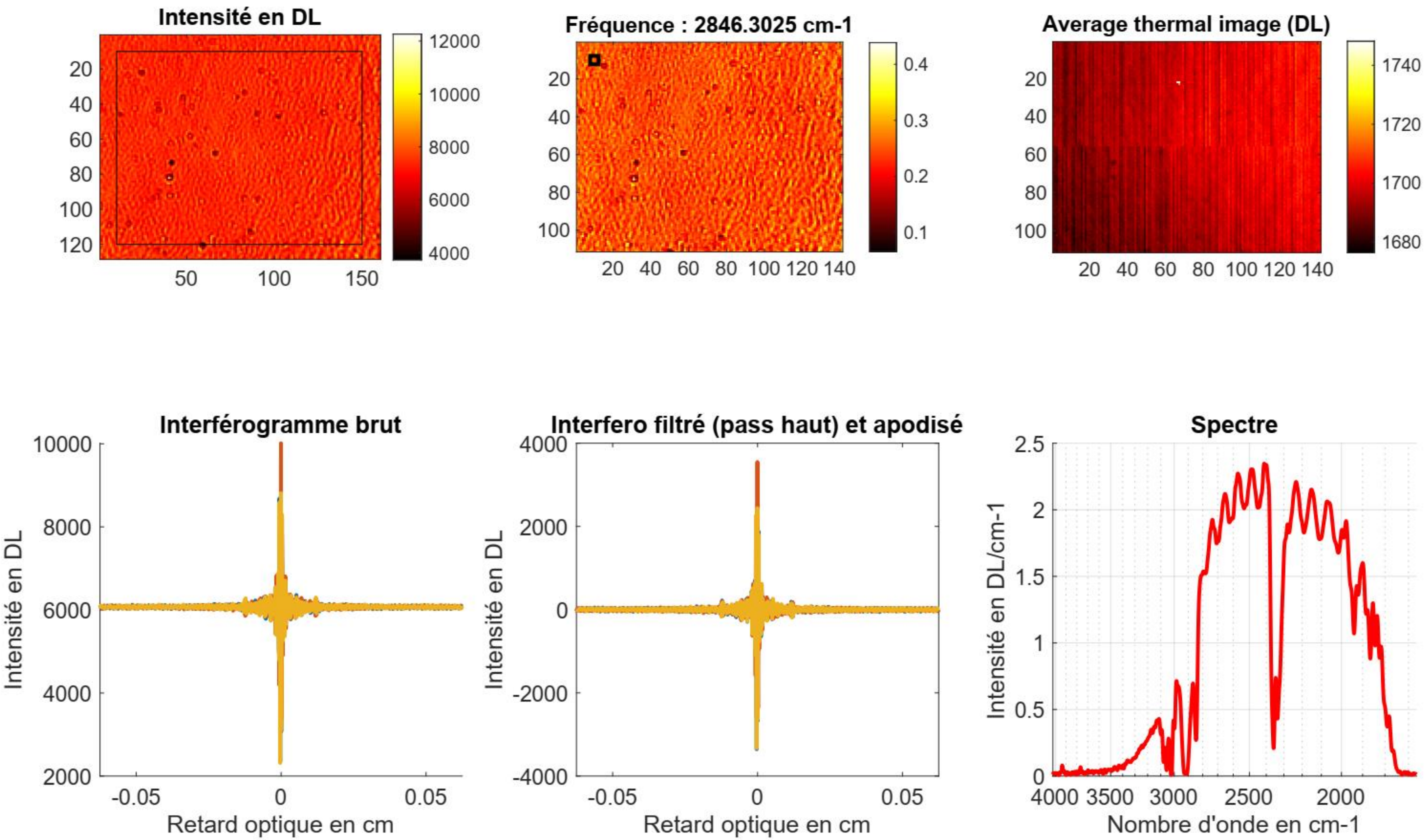


Fourier transform of the interferogram using the phase Mertz correction:

$$S(x,y,\lambda) = \Re(S^*(x,y,\lambda))\cos\Phi + \Im(S^*(x,y,\lambda))\sin\Phi$$

where $S^*(x,y,\lambda)$ is the Fourier transform of $I_a(x,y,\delta)$, and $\Re$, $\Im$ and Φ denote the real part, imaginary part, and phase of S^*, respectively.

Data processing



Uncertainty principle

$$\Delta t \Delta r = \frac{2\nu_{max}}{f_{cam}}.$$

Δt : Accuracy on the time when the measurement was performed

Δr : Accuracy on the spectral resolution

ν_{max}: Maximum wavenumber of the IR spectrum

There is a tradeoff between the spectral resolution and the temporal resolution of the measurement.
➔ Can be partially solved using a high speed camera

Conclusions on the FTIR spectroscopy

Main advantages:

- High spectral resolution
- No need for a 2 images method (the sample proper emission is automatically removed)
- Very fast to measure the complete IR spectrum

Main drawbacks

- Impossible to select one wavelength (no monochromatic beam)
- Tradeoff between spectral and temporal resolution

ANNEXES