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Plasmonics and Nanomedical Challenges

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Outline

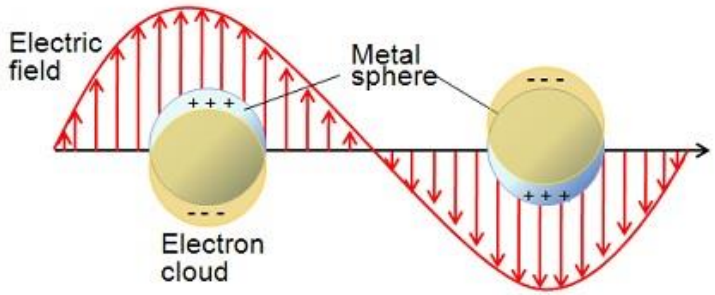
Plasmonics and localized plasmon resonances

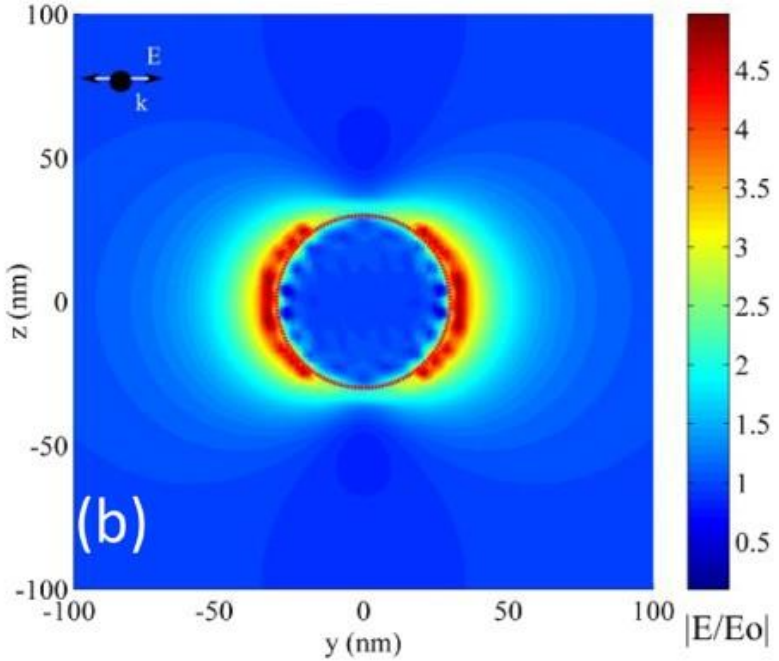
Nanoparticles as Theranostics platform

Case study:
1 Detection and identification of metallic nanoparticles (gold nanoshells) inside animal cells

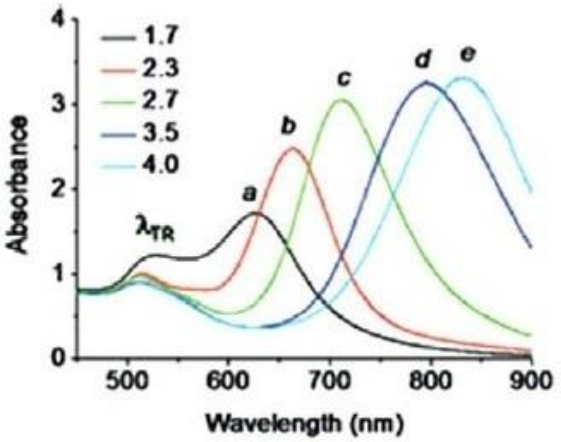
2 Raman SERS application in oncology

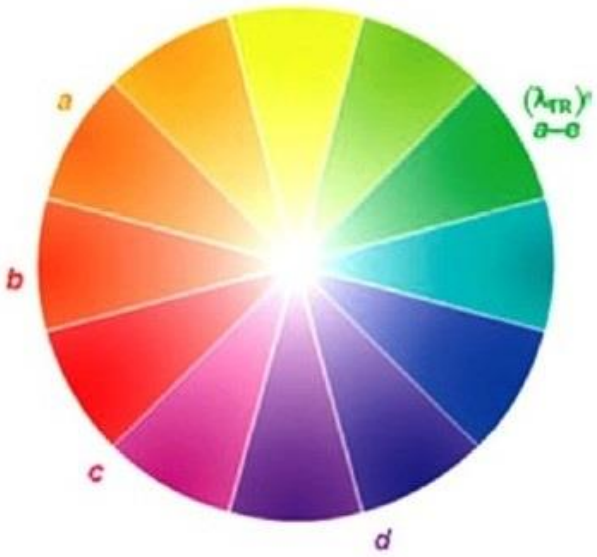
Plasmonic properties of metal nanoparticles



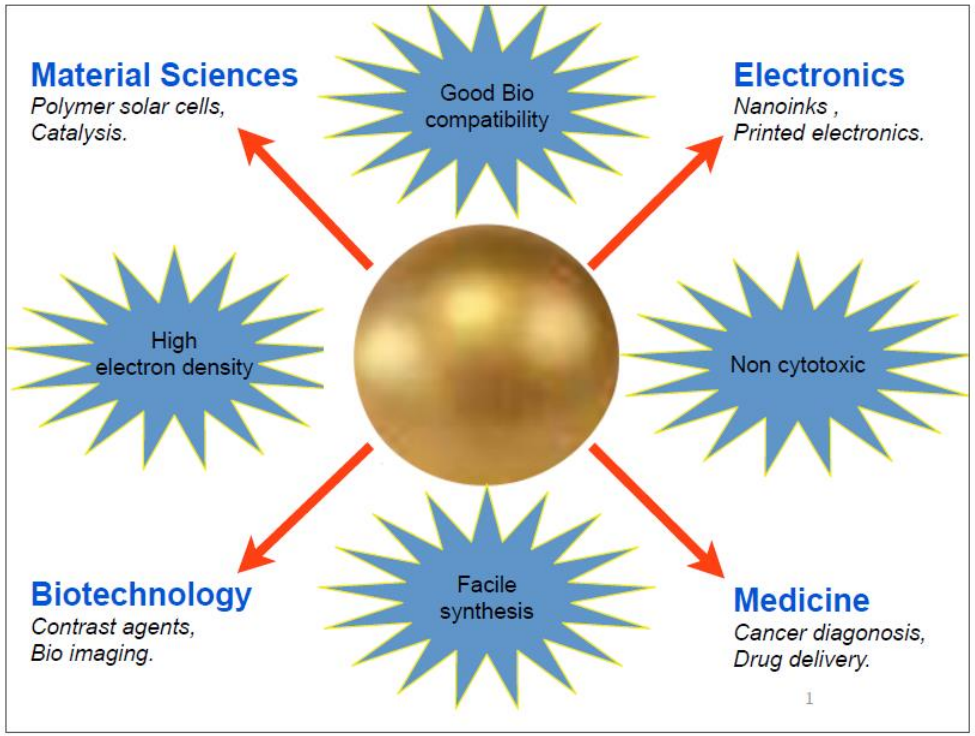


Simulation of the surface plasma resonance of a spherical particle





Different colors of gold nanoparticles and their respective light absorbance



Gold nanoparticles and nanoshells

are appealing model systems for three main reasons

1. **Gold is chemically inert and does not oxide**
2. **Gold has a bulk plasmon resonance meanly in the visible-NIR part of the spectrum**
3. **New methods for synthesis now enable a wide range of shapes and sizes of gold particles**

Localized Surface Plasmon resonance and biosensing

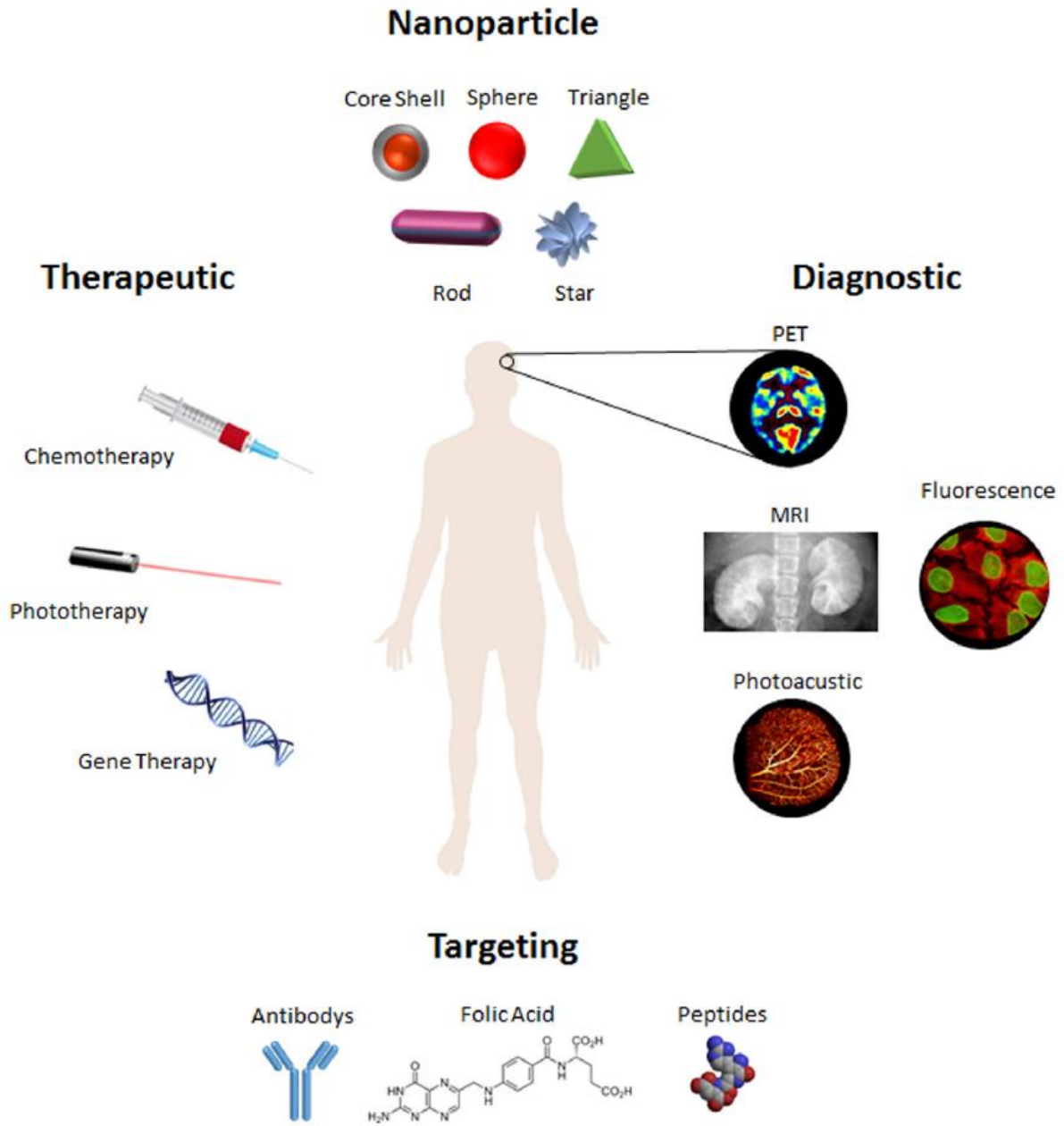
improving sensitivity and limit of detection,

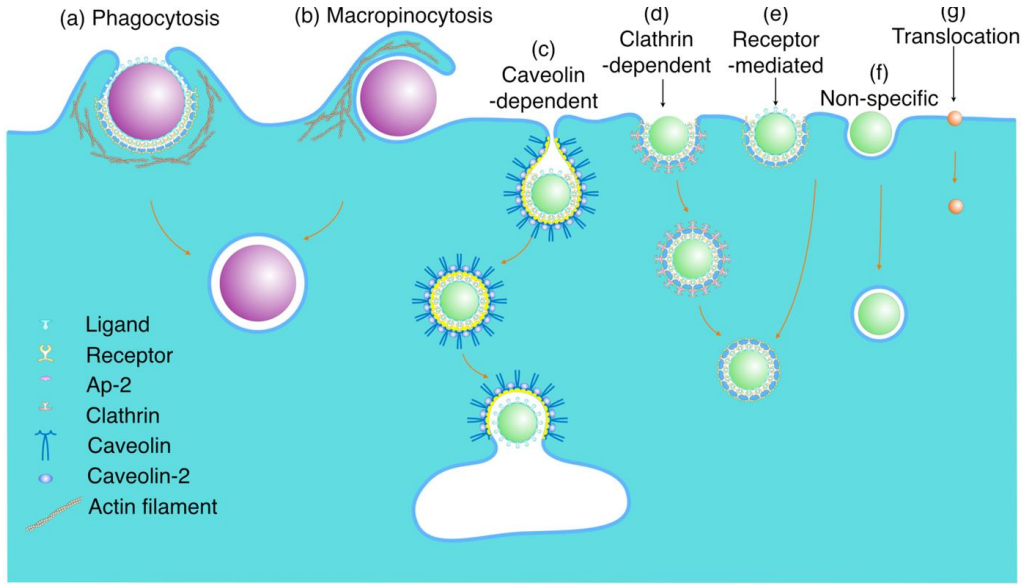
selectivity in complex biological solutions,

sensitive detection of membrane-associated species,

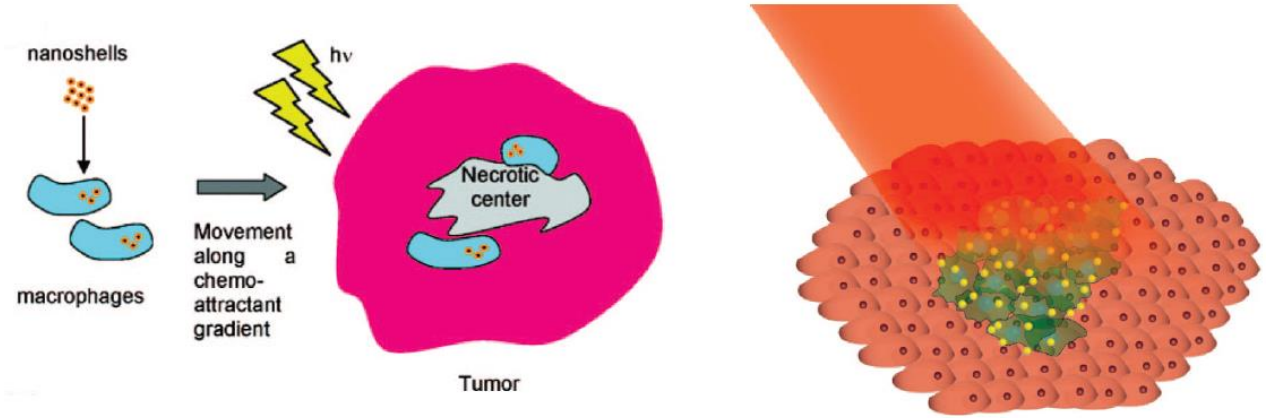
the adaptation of sensing elements for point-of-care diagnostic devices

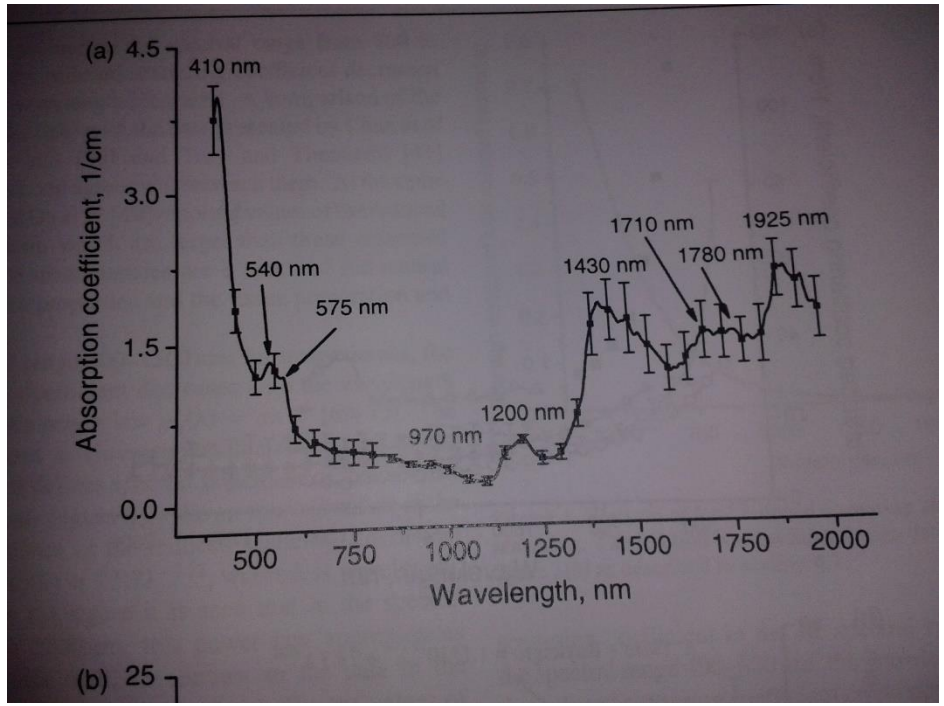
Theranostics: Diagnosy and Therapy in a single nanosystem





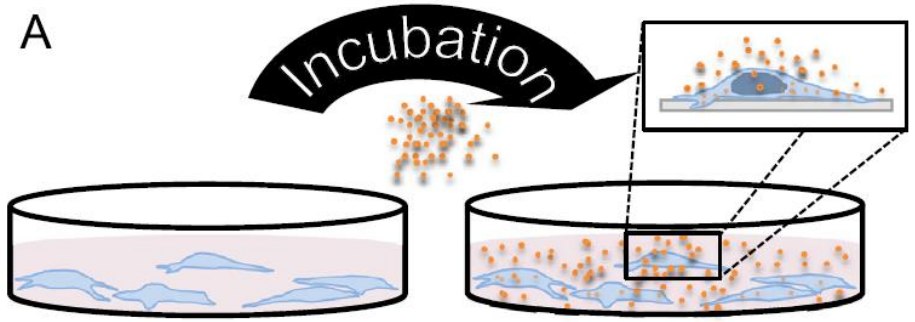
Cancer Photothermal Therapy (1)



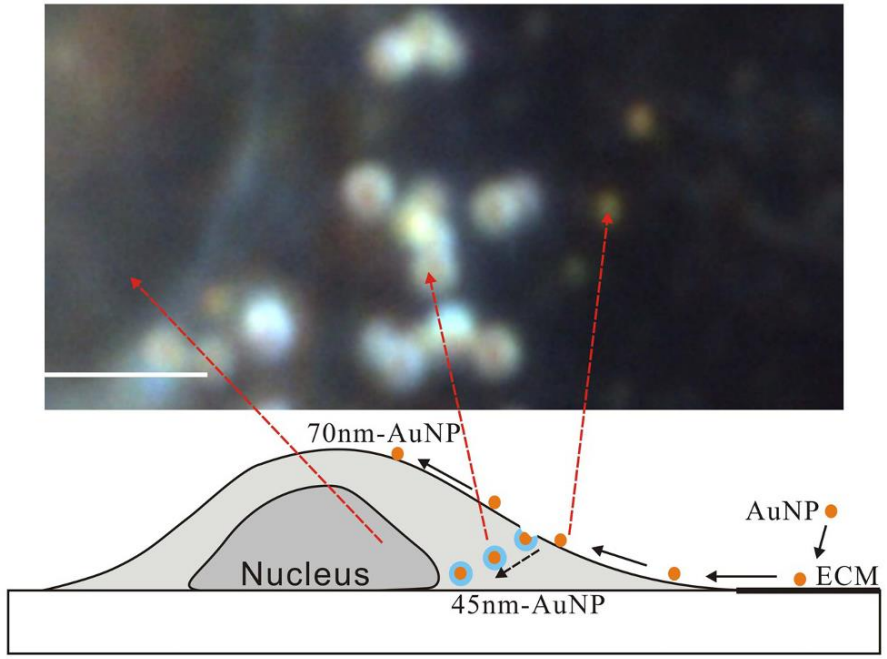


The near-infrared window extends from 750 to 1100 nm is ideal for investigations and treatments inside tissues: in this region, the combined absorption from hemoglobin and water are minimal and tissue is maximally transparent to light.

Cancer Photothermal Therapy (2)



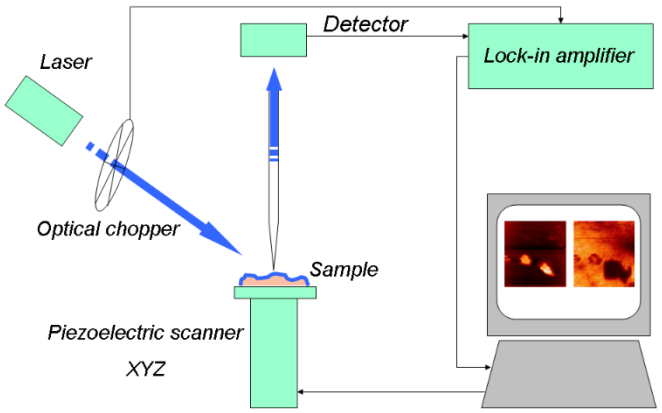
Cellular uptake recipe

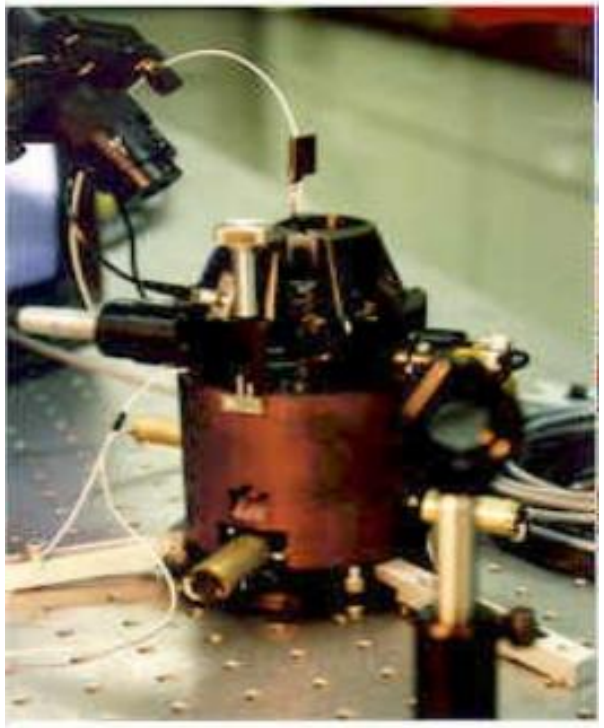


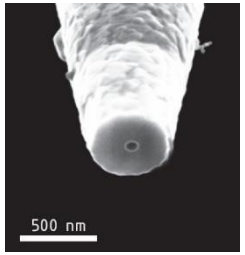
Source: Wang et al J. *Nanobiotech.*, 2010.

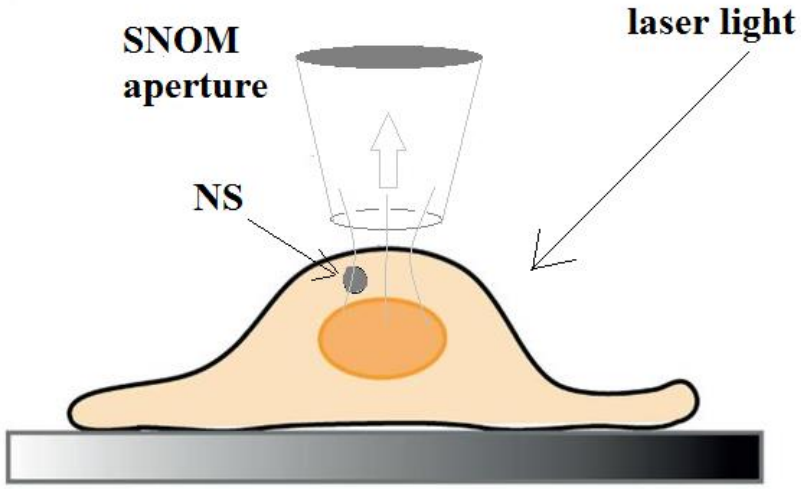
Near-Field detection of gold nanoshells inside cells

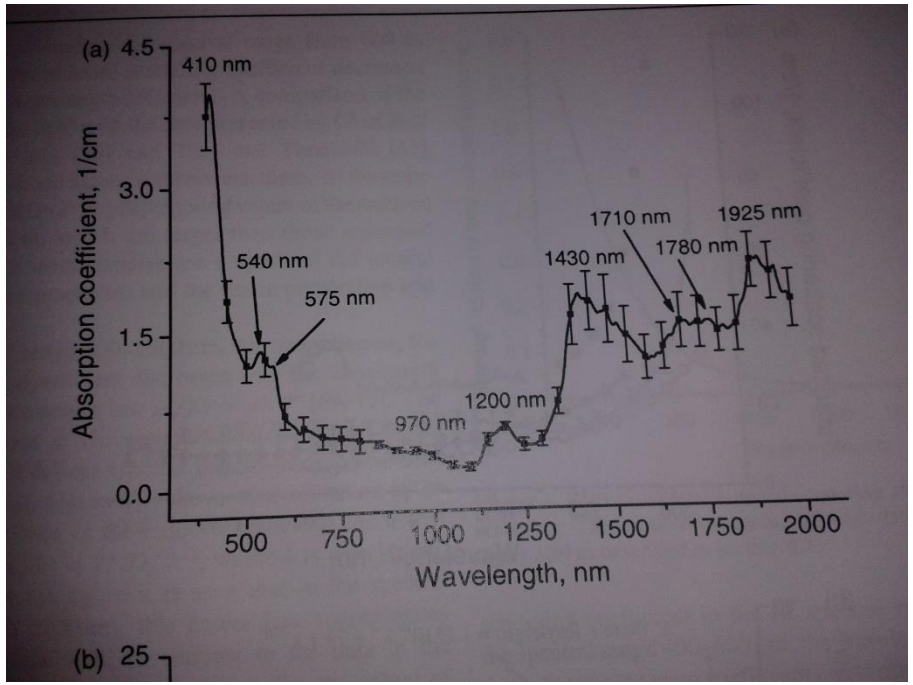
Home-made aperture Scanning Near Optical Microscopy

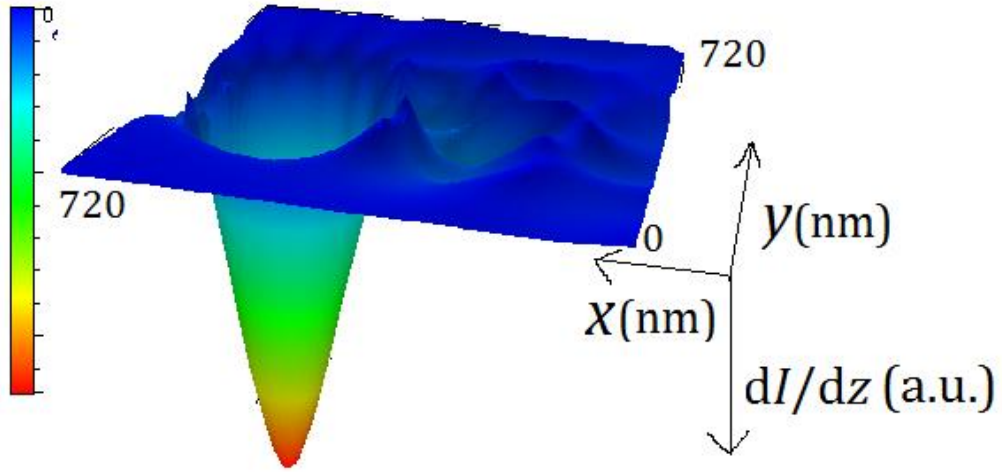


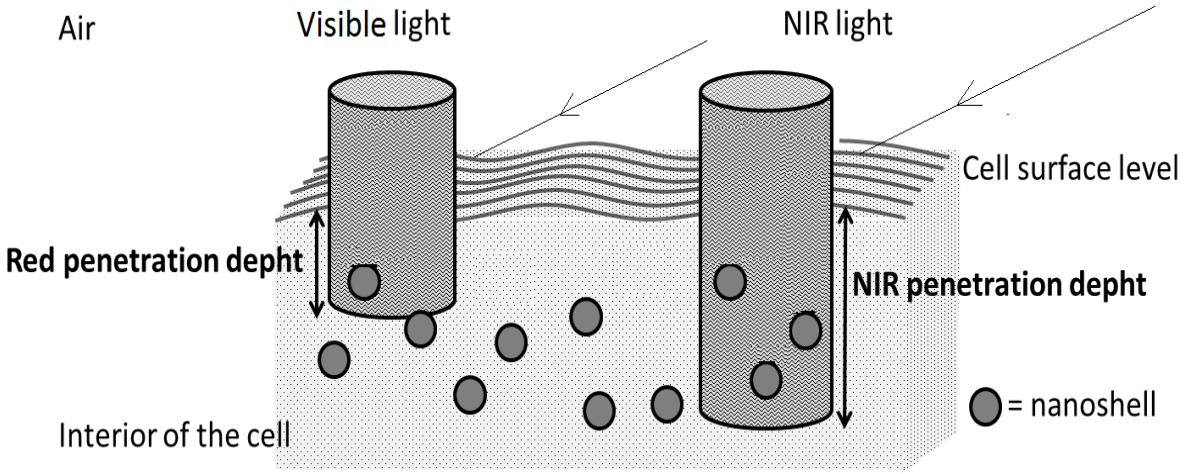


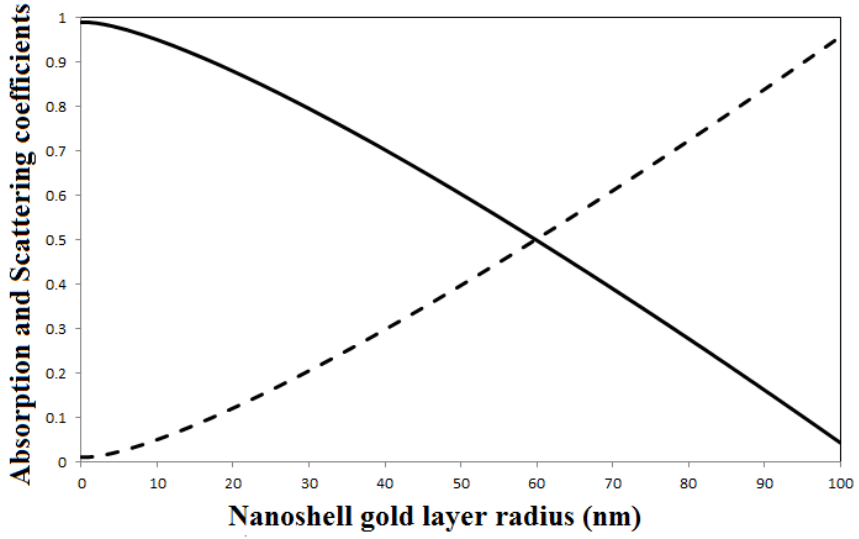





(a) 4.5
3.0
1.5
0.0
Absorption coefficient, 1/cm
410 nm
540 nm
575 nm
970 nm
1200 nm
1430 nm
1710 nm
1780 nm
1925 nm
500
750
1000
1250
1500
1750
2000
Wavelength, nm
(b) 25

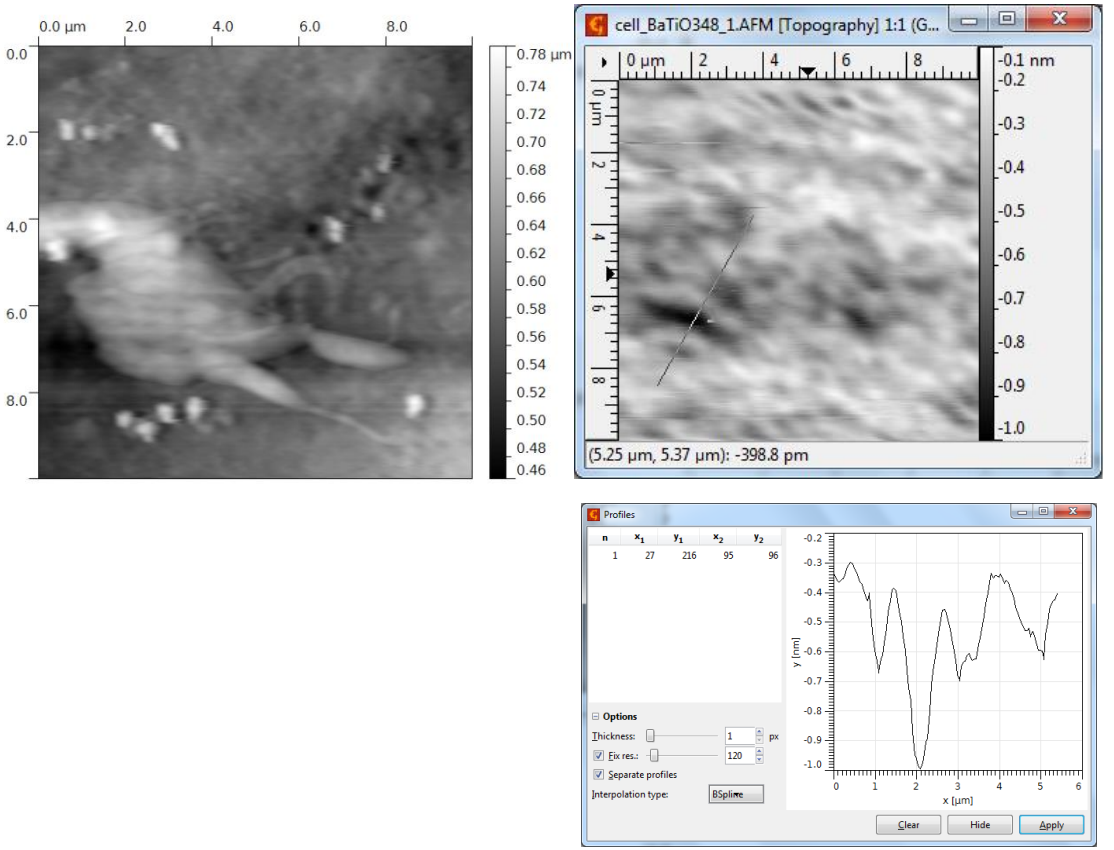

720
720
0
0
y(nm)
X(nm)
dI/dz (a.u.)


Air
Visible light
NIR light
Cell surface level
Red penetration depht
NIR penetration depht
= nanoshell
Interior of the cell

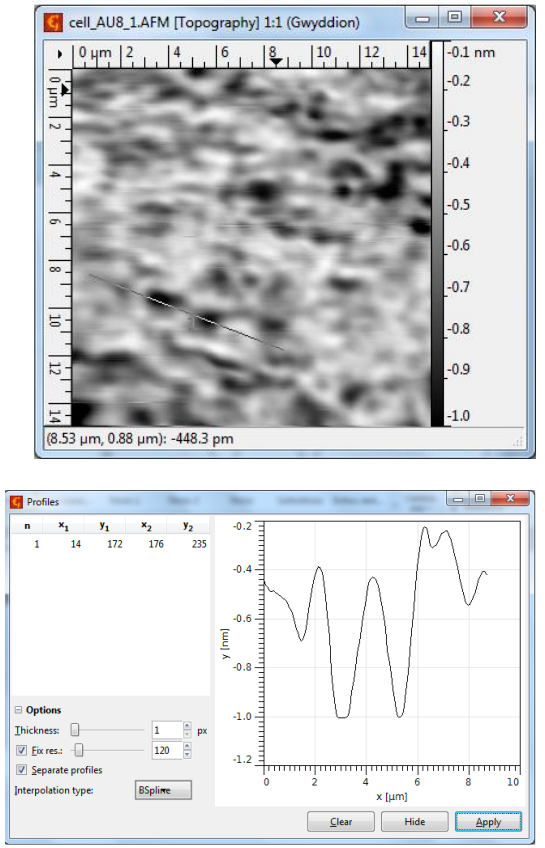

Absorption and Scattering coefficients
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
Nanoshell gold layer radius (nm)

$BaTiO_3$-Gold nanoparticles (120-150nm) inside mouse cells (H9c2)

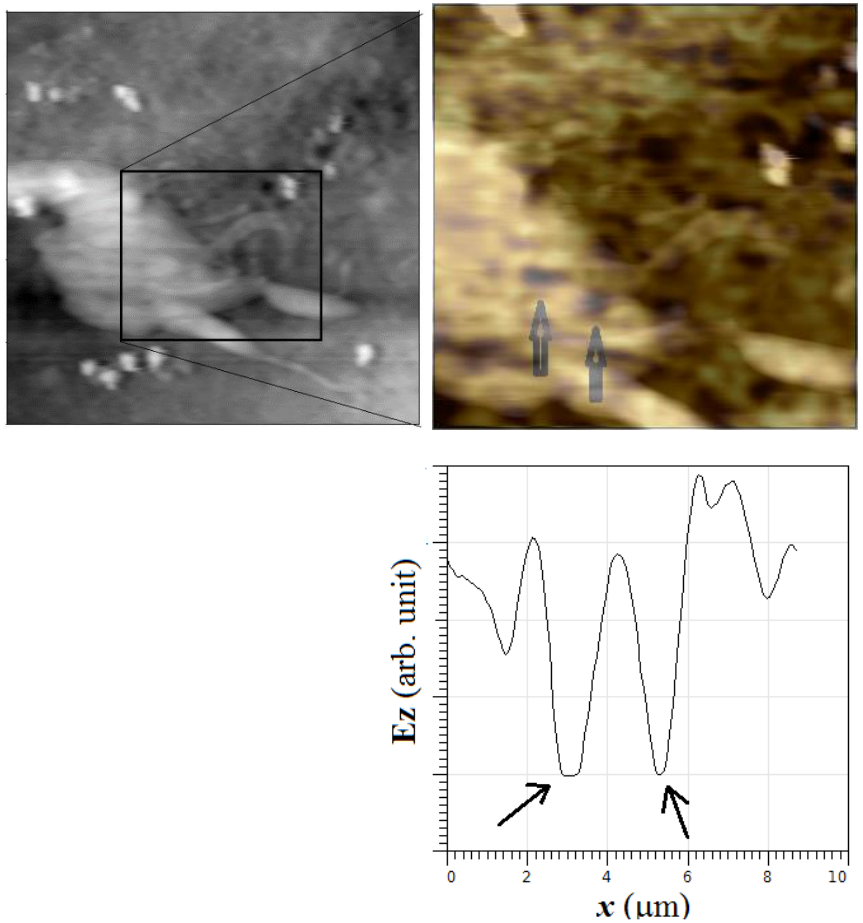
λ=632nm

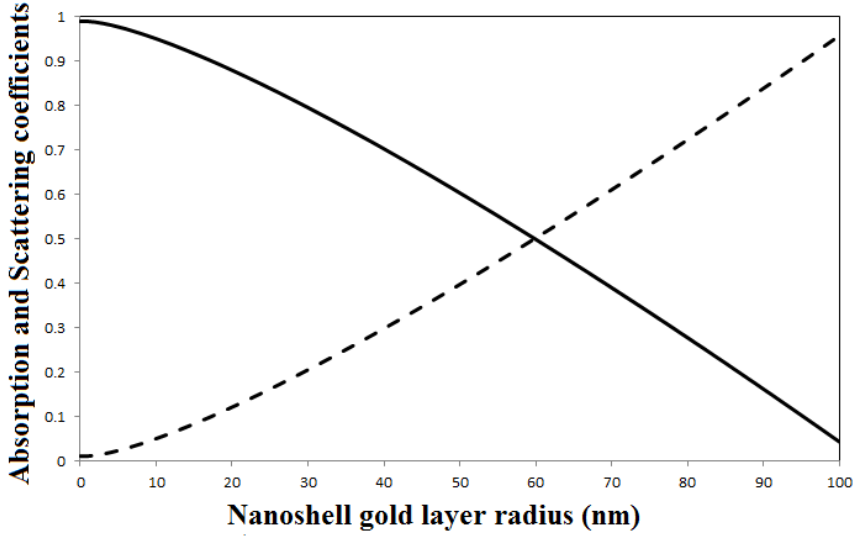


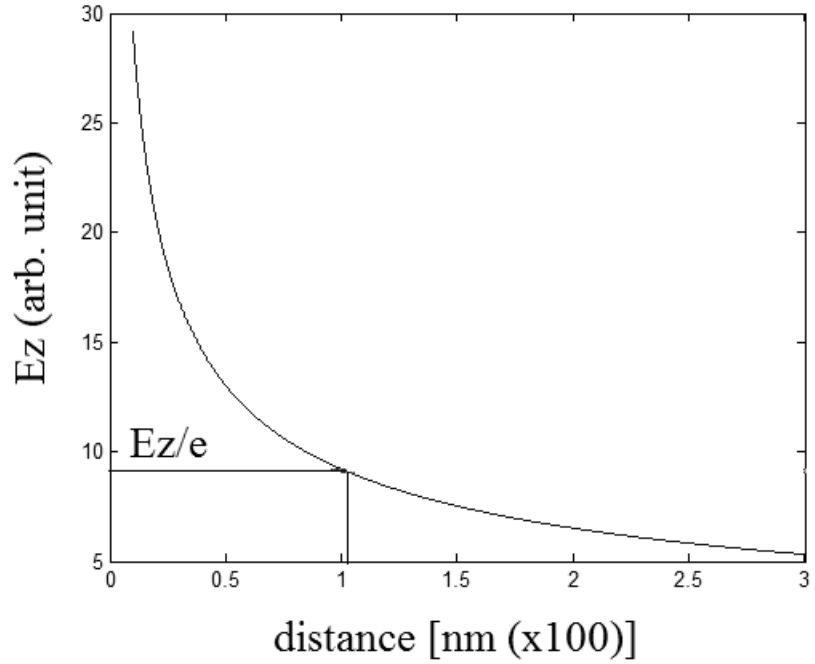
λ=780nm



Source: **D'Acunto, Cricenti, Luce, Dinarelli, Nanospectroscopy 2015**

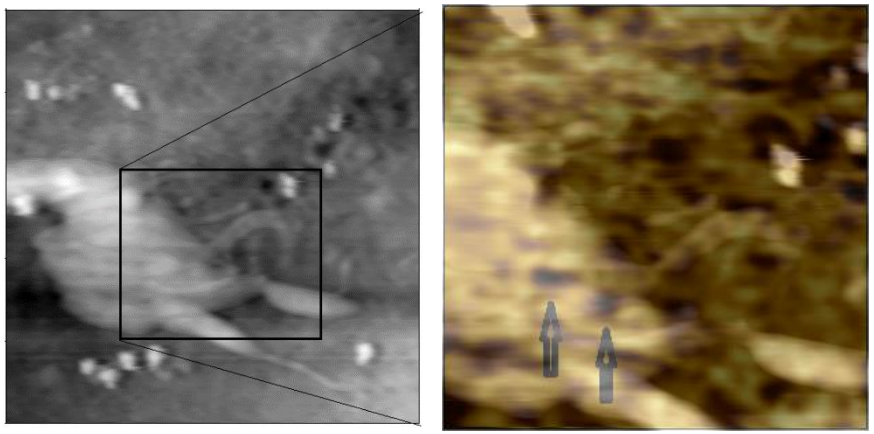

Ez (arb. unit)
0
2
4
6
8
10
x (μm)

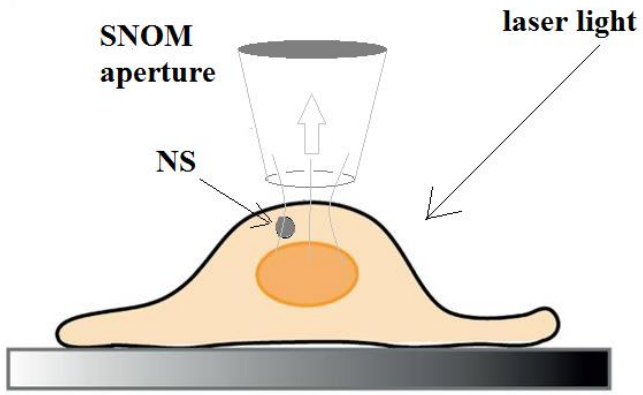

Absorption and Scattering coefficients
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
Nanoshell gold layer radius (nm)



Calculation of SNOM penetration depth d_p as a function of the SNOM aperture-NS upper part. The SNOM aperture is 50nm diameter, the wavelength λ=780nm, the incidence angle is θ=45°.

Source: D'Acunto et al. Applied Optics 2015.

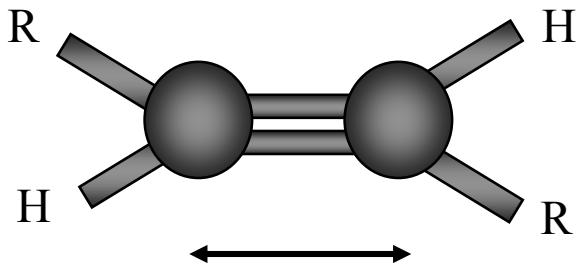


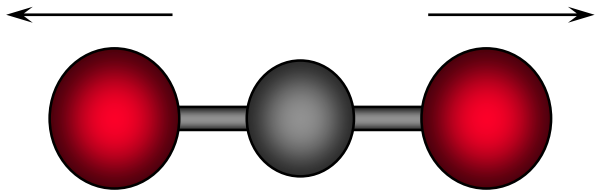


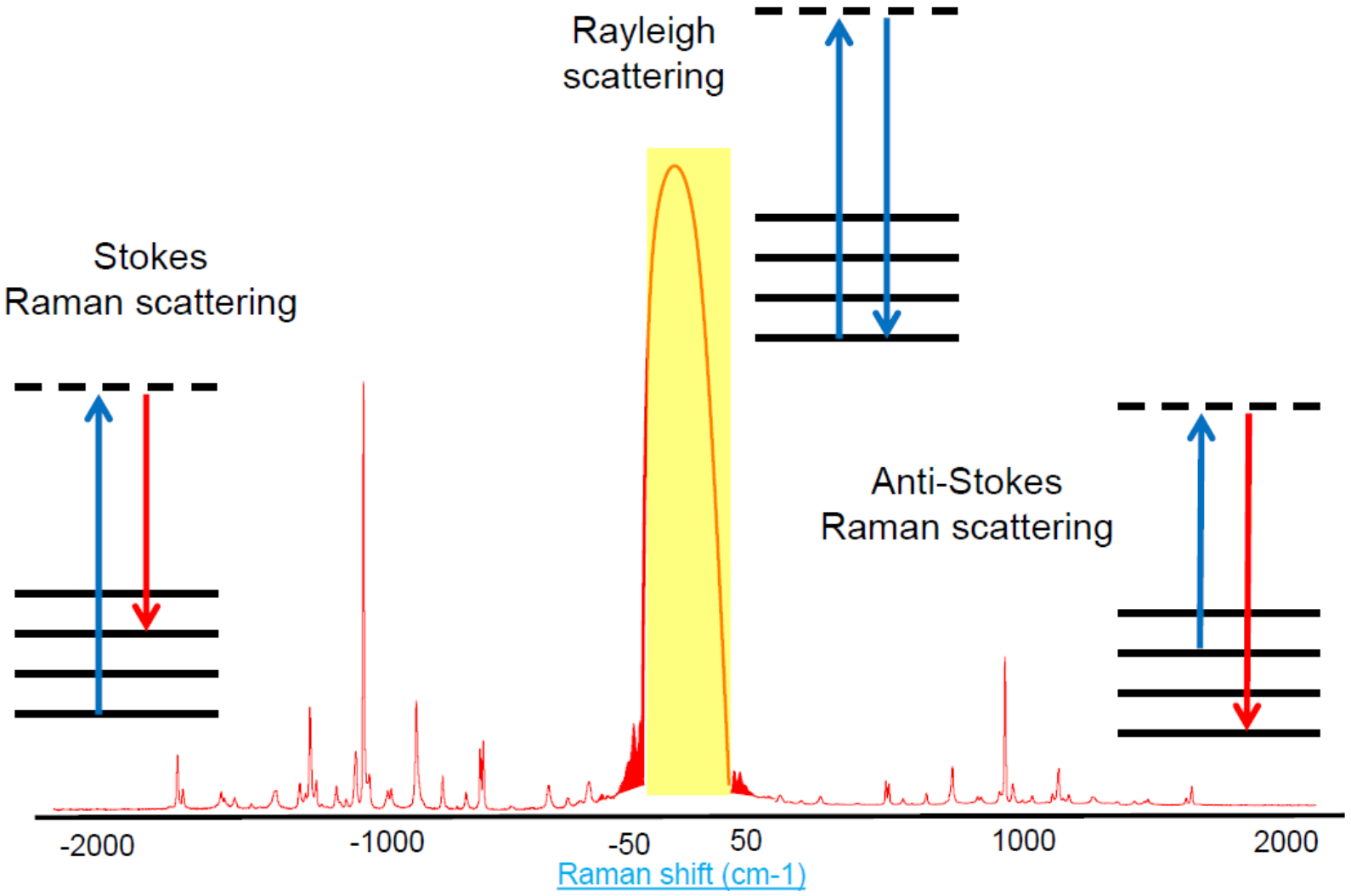
- Raman spectroscopy is a laser light scattering technique
  - A form of Vibrational Spectroscopy
    - Records vibrations of covalent bonds
    - Provides detailed molecular information
  - Most sensitive to symmetric bonds
    - A good tool for characterizing molecular backbones
  - Sensitive to even slight changes in bond angle or strength
    - Highly sensitive to geometric structure
    - Highly sensitive to stresses in molecules or modifications which impact bond properties

Chandrasekhara Venkata Raman

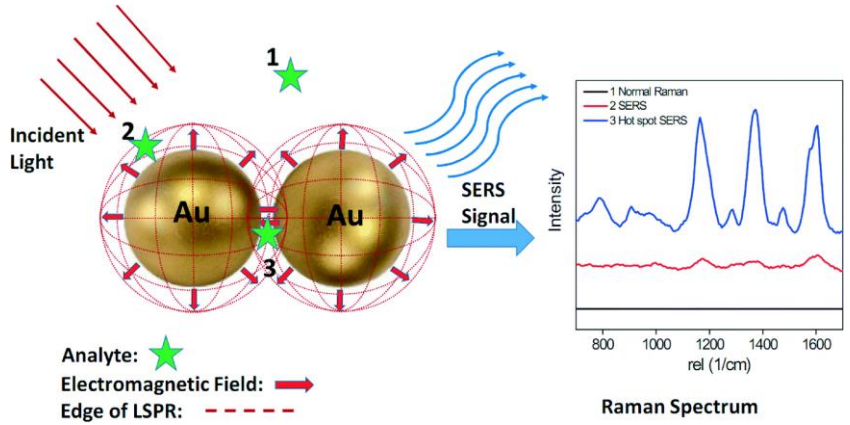
Nobel Prize 1930

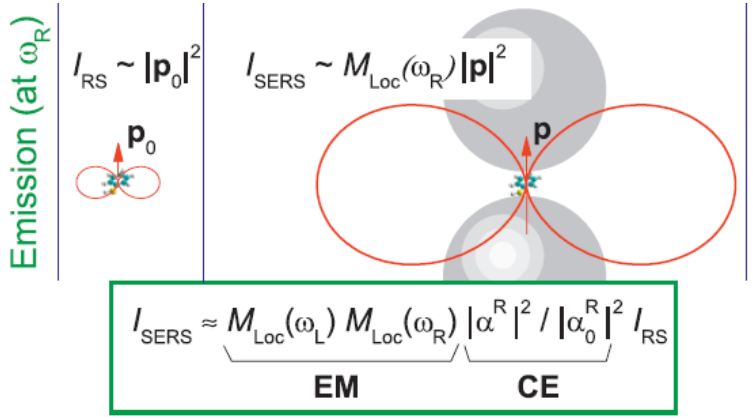





Rayleigh
scattering
Stokes
Raman scattering
Anti-Stokes
Raman scattering
-2000
-1000
-50
50
1000
2000
Raman shift (cm-1)

Raman SERS spectroscopy of cancer cells



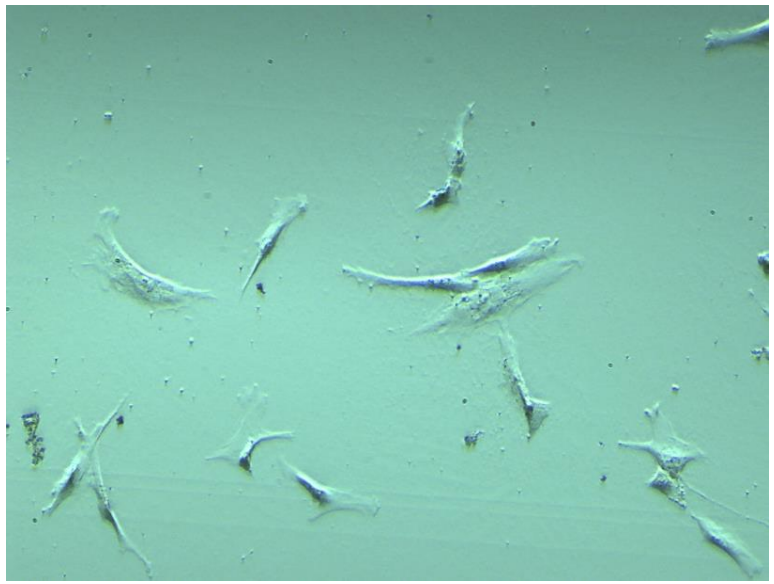


$$\mathbf{p}(\omega_R) = \alpha^R(\omega_L, \omega_R)\mathbf{E}_{Loc}(\omega_L)$$

$$EF_{EM} \approx \frac{|\mathbf{E}(\omega_L)|^4}{|\mathbf{E}_0(\omega_L)|^4}$$

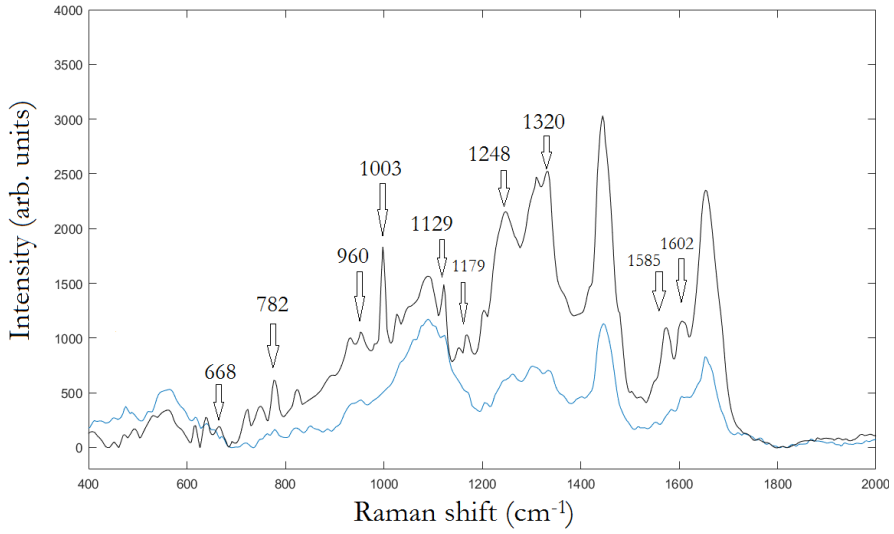
$$EF = \frac{I_{SERS} / N_{Surf}}{I_{RS} / N_{Vol}}$$

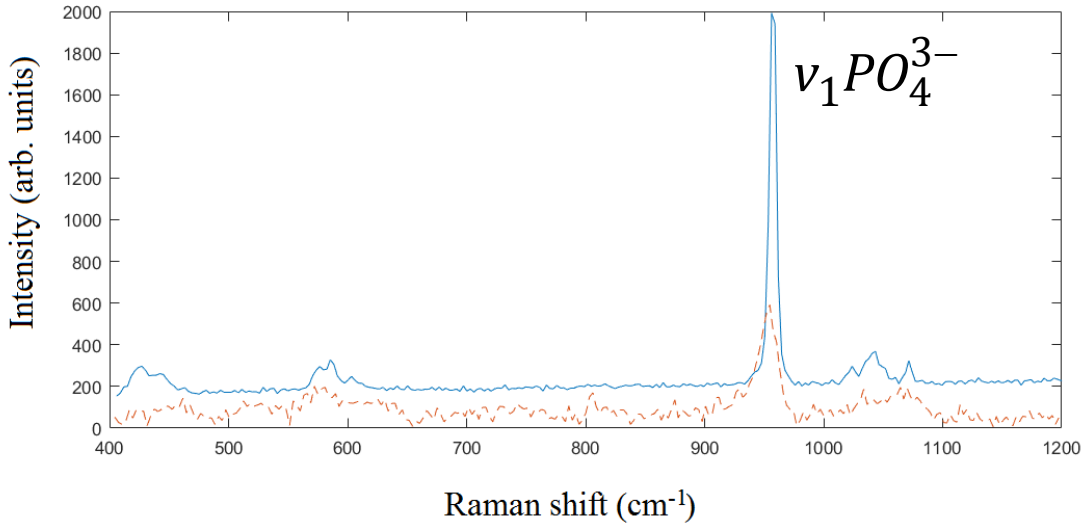
MSC differentiated-osteoblasts vs Osteosarcoma (MG-63) cells



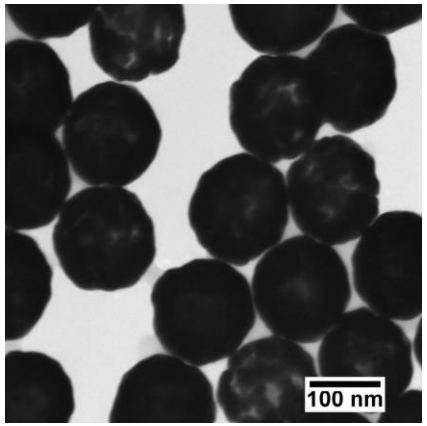
Raman Imaging
ThermoFisher DXR2xi

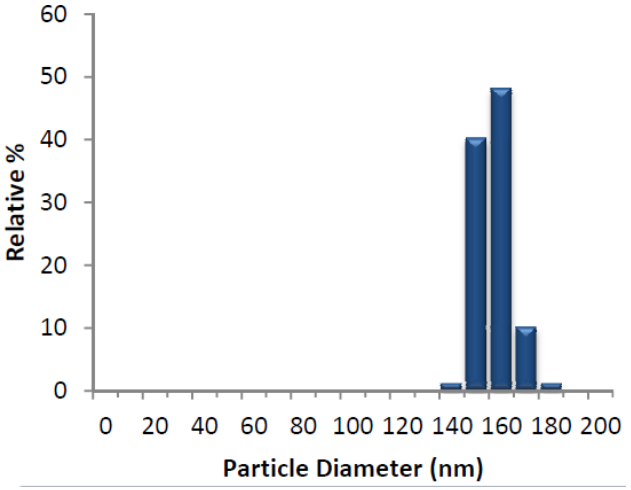
$HA = (Ca_{10}(PO_4)_6(OH)_2$

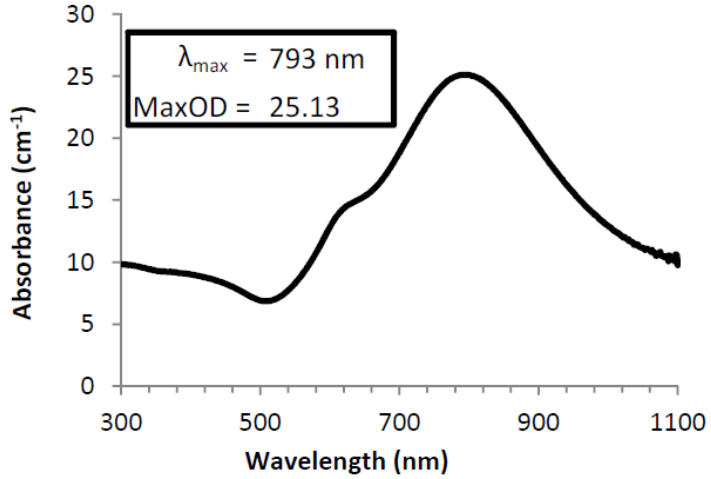


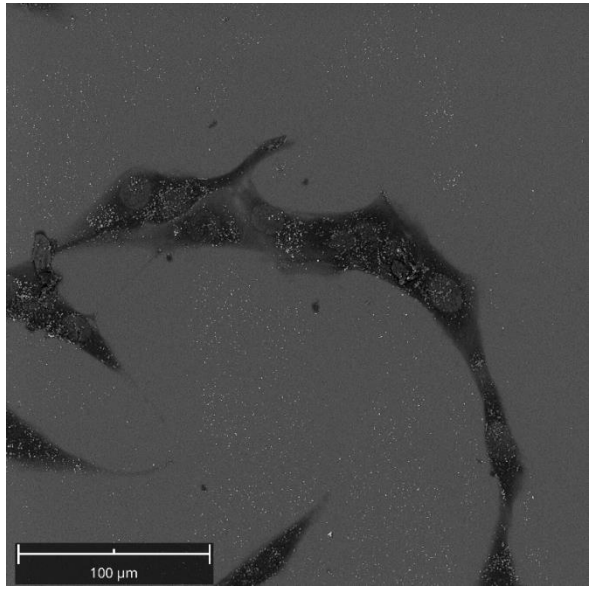


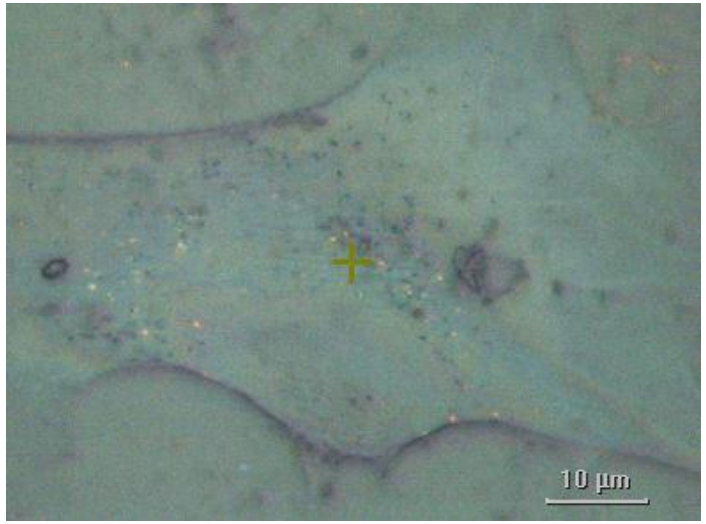
Gold Nanoshells properties (Supplied by Nanocomposix)

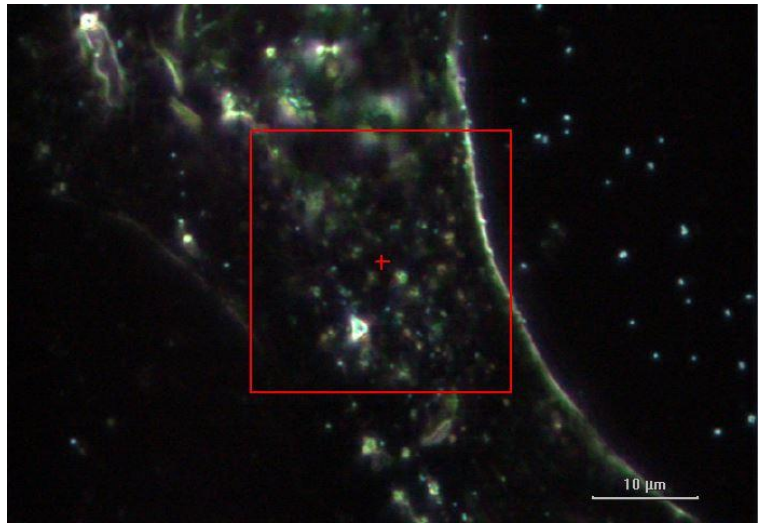


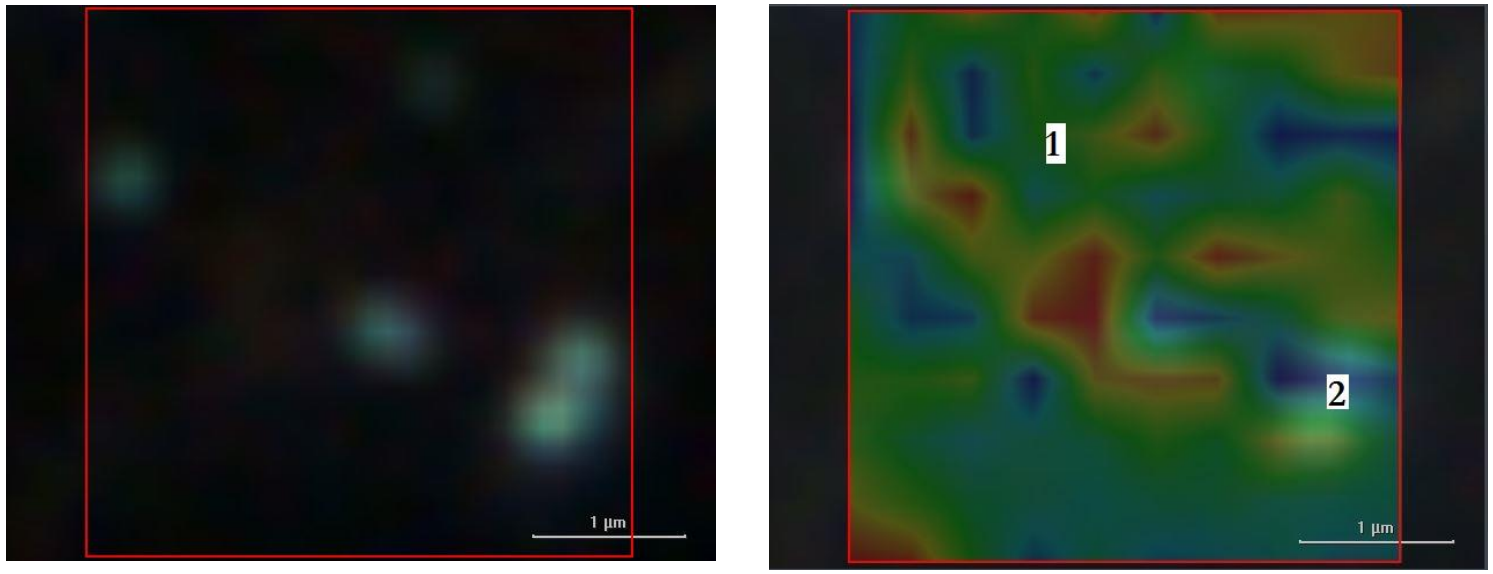


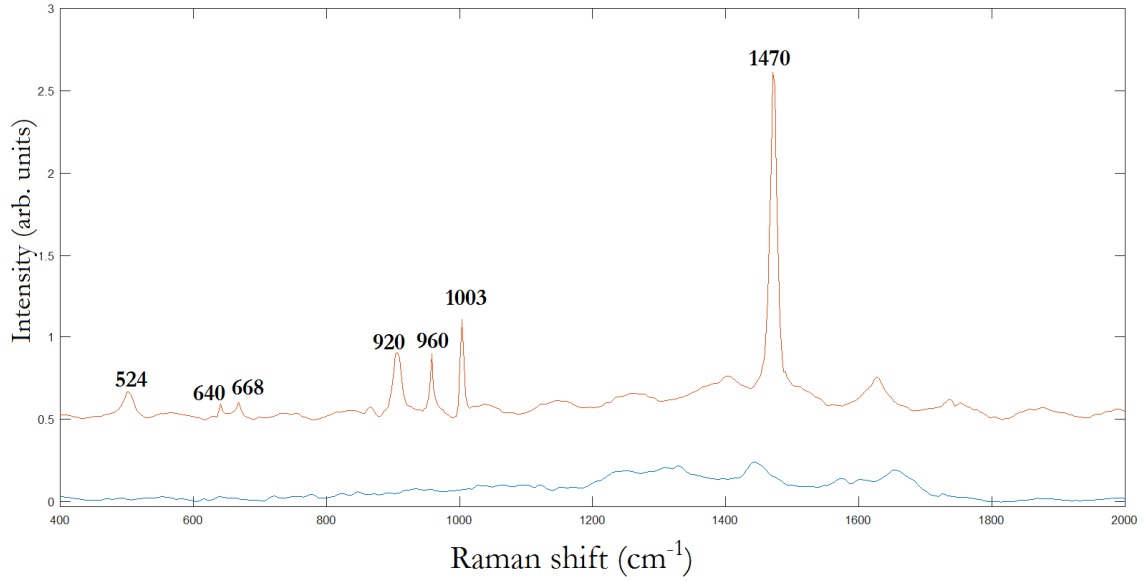












Source:
D'Acunto et al, Physical Biology 2019

Conclusive Remarks and Future Perspectives

Metal Nanoparticles a fundamental tool for Nanomedicine

1 Detection and identification of metallic nanoparticles (gold nanoshells) inside animal cells

2 Raman SERS application in oncology for early diagnosis

We have a new tool to study the inner cells dynamics (*and for cancer treatments* ?)

ACKNOWLEDGEMENTS

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&
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Japan **NICT, Tokyo, Japan**

University of Yokohama

Many Thanks for the attention !!