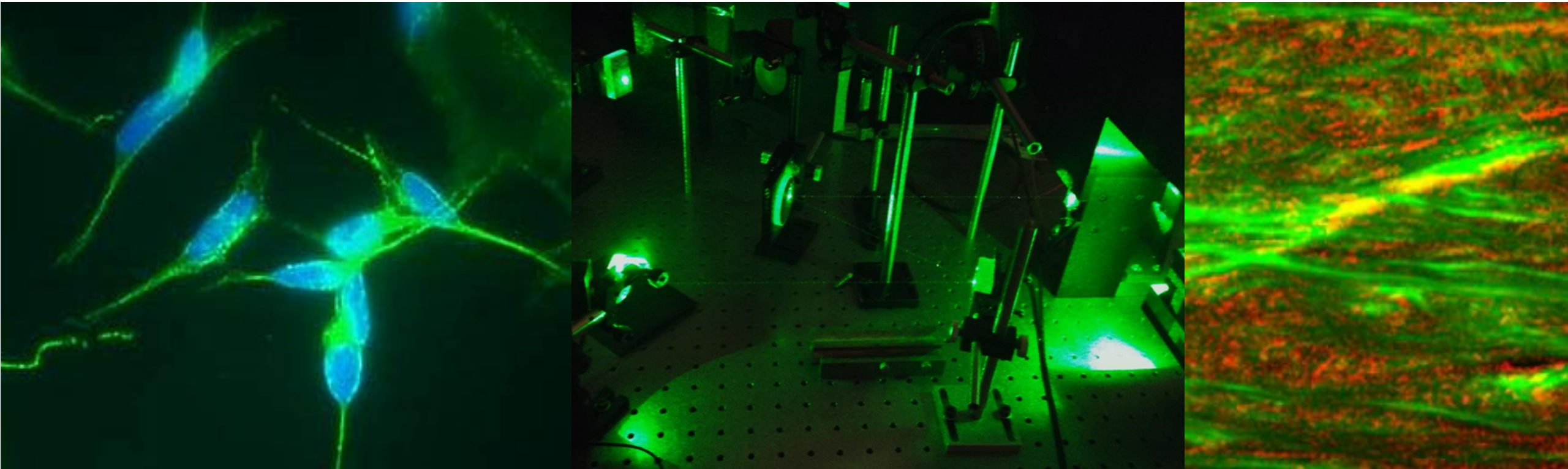
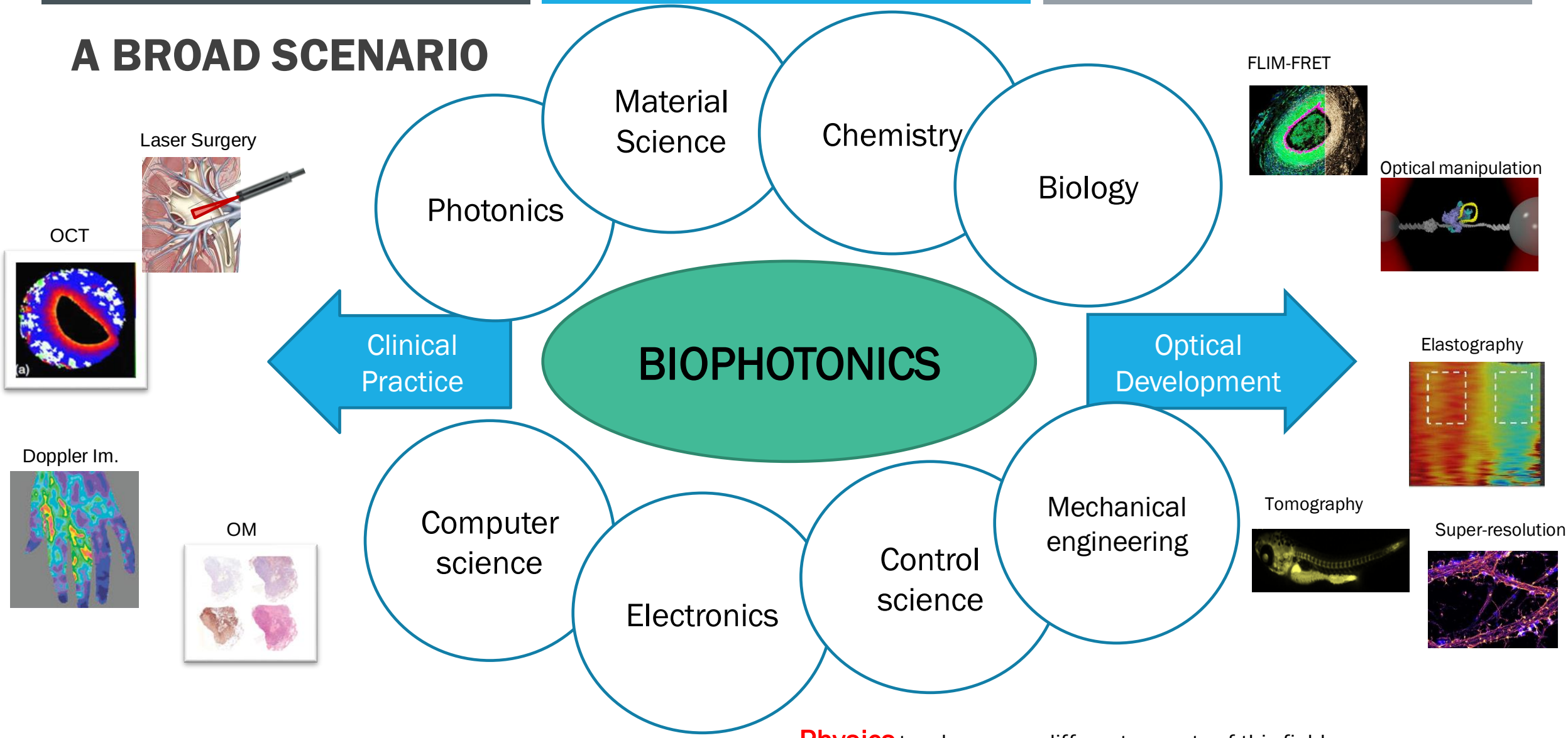
BIOPHOTONICS

MAURIZIO MATTARELLI, DANIELE FIORETTO (UNIPG)

SILVIA CAPONI (CNR)

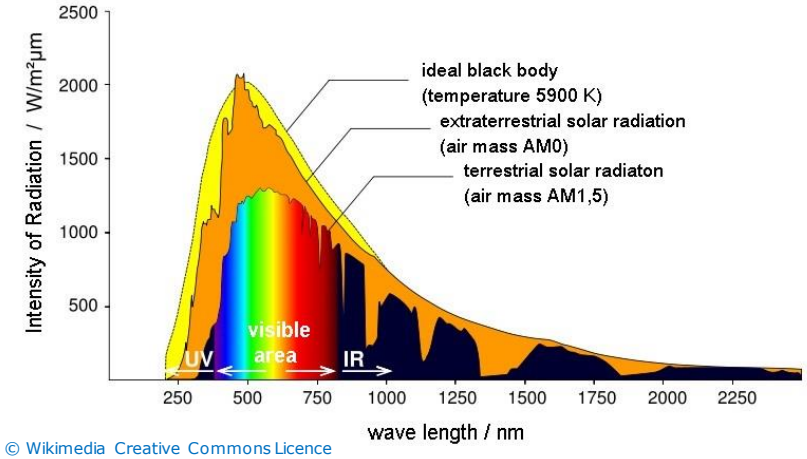


A BROAD SCENARIO

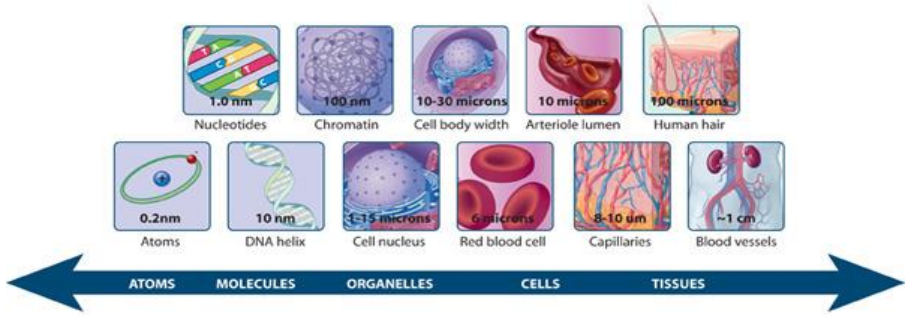


Physics touches many different aspects of this field:
from the optics of the instrument design, to the interaction mechanism of light and matter, to biophysics, to the design of biomimetic materials

WHY THE LIGHT TO STUDY BIOLOGICAL MATTER?



ONE FUNDAMENTAL REASON:
It can interact with biological matter, without distructing it



https://www.nature.com/scitable

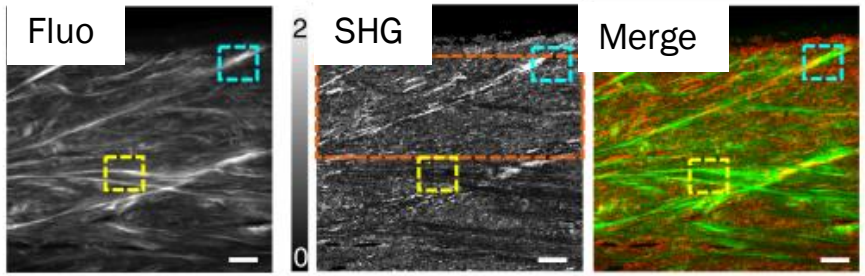
MANY PRACTICAL ONES:

Wide temporal and spatial scales

Multifunctional (morphology, chemistry, structure)

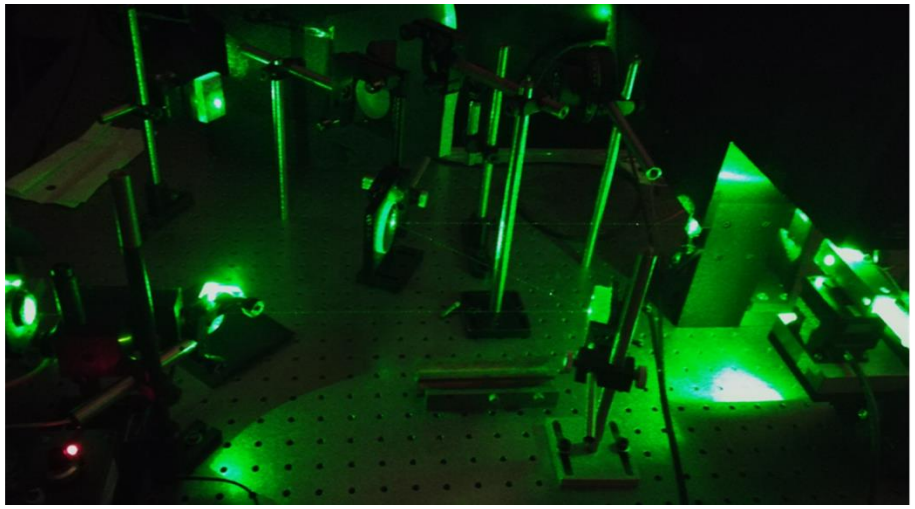
Compatibility (use of more simultaneous techniques)

Practicity (price, invasiveness)



Mercatelli *et al., Commun Biol* **2,** 117 (2019).

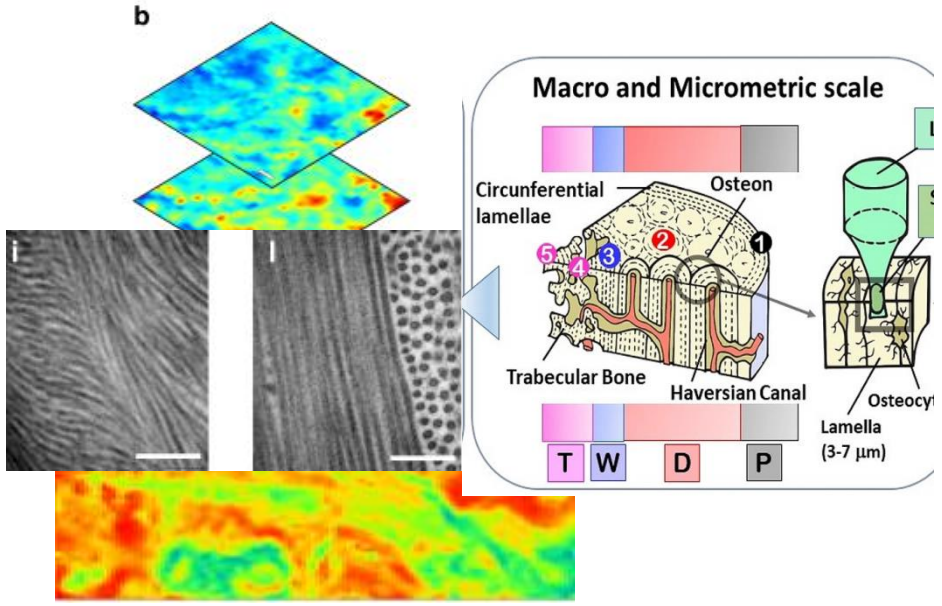
BIOPHOTONICS IN PERUGIA



- Instruments development:

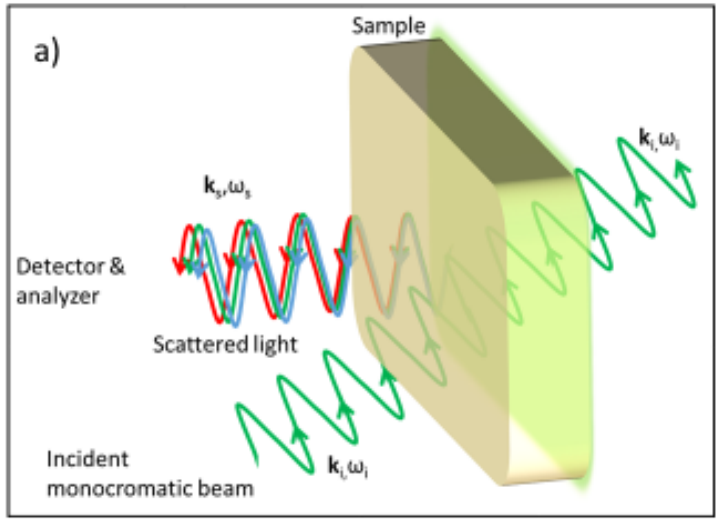
phenomenology of the light matter interaction and new experimental strategies

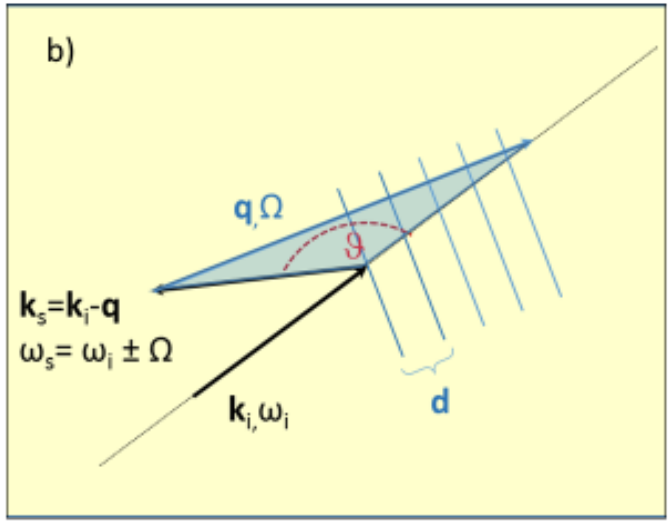
- Study of relevant biological structures (from tissues to single cells)



Cardinali, M.A.*et al. Sci Rep* **10,** 17341 (2020).
Mercatelli *et al., Commun Biol* **2,** 117 (2019).

INELASTIC LIGHT SCATTERING



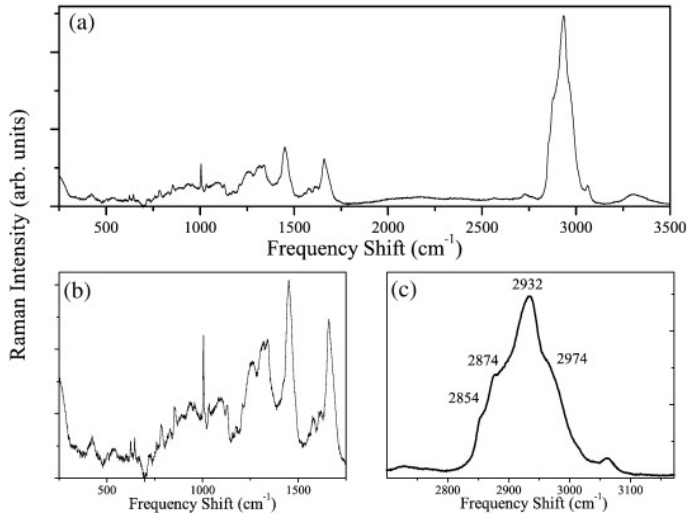


Sound waves and molecular vibrations thermally activated induce a modulation of the refractive index

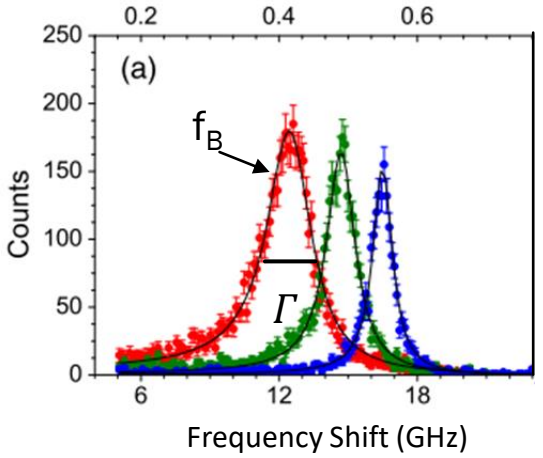
$$I_{\alpha\beta}(\mathbf{q},\omega) \propto \int dt e^{-i\omega t}\langle \delta\epsilon^{*}_{\alpha\beta}(\mathbf{q},0)\delta\epsilon_{\alpha\beta}(\mathbf{q},t)\rangle,$$

Frequency of the normal modes

$$\sim \nu = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$



S. Caponi et al. Biophysical Chemistry 182, 1 58 (2013)



Viscoelastic properties

$v = \sin(\theta/2)\, fB\, \lambda_0/(2n)$

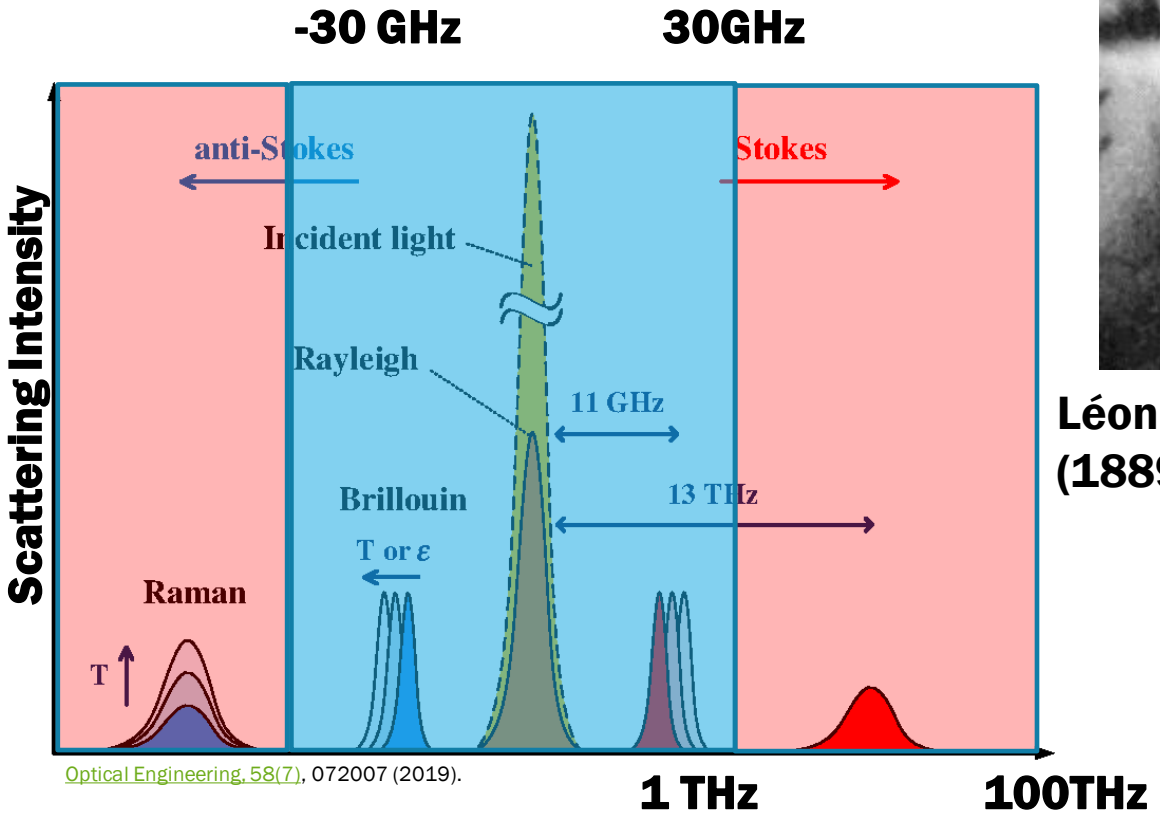
$M' = v^2\rho$

$$M'' = fB\eta_L = \frac{f_B\rho\Gamma}{(4\pi n)^2}$$

S. Caponi, C. Canale, O. Cavalleri, M.Vassalli
«Characterization tools for mechanical probing of biomimetic materials" SPRINGER book (2019)

BRILLOUIN AND RAMAN SPECTROSCOPY

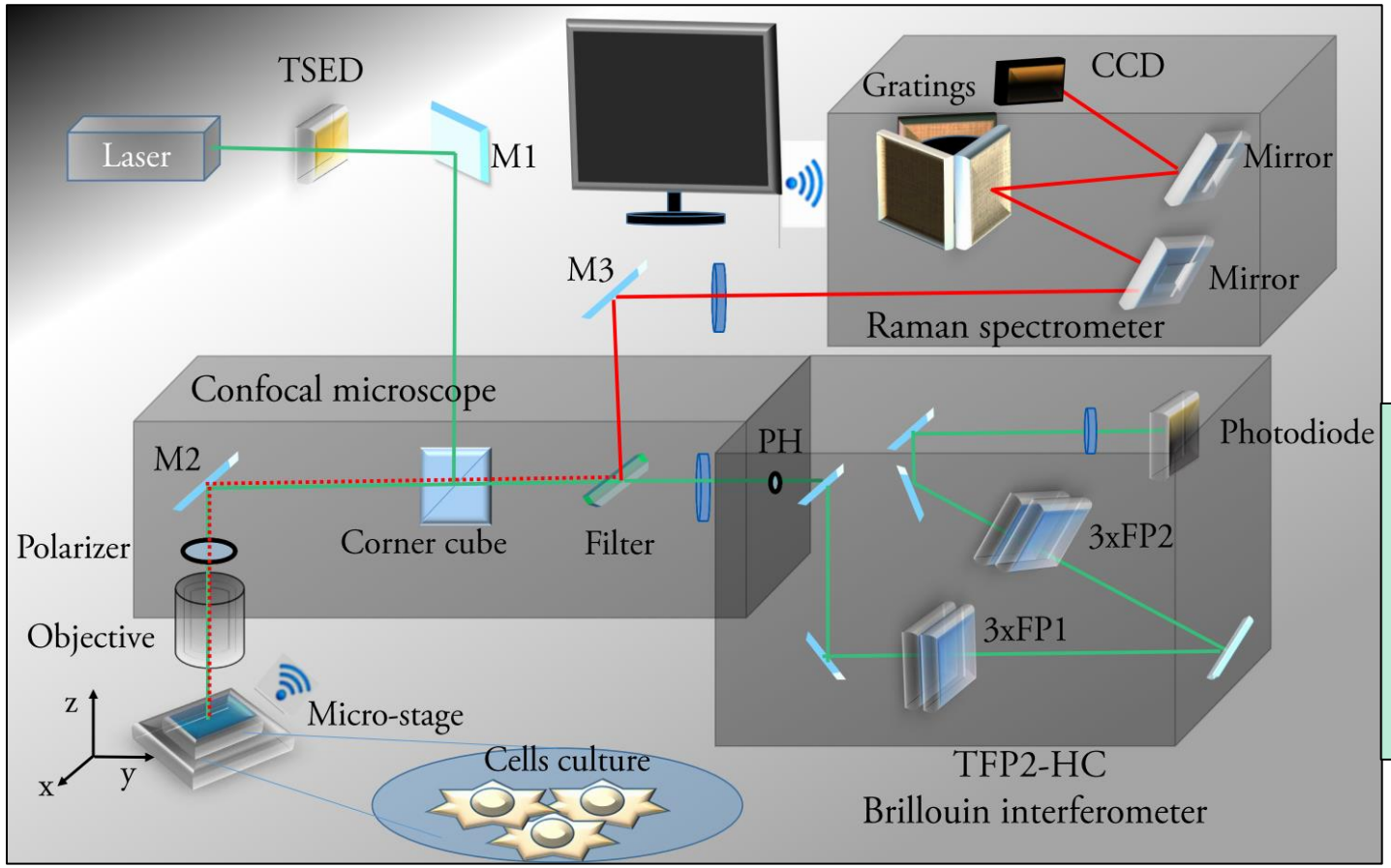
Sir C. V. Raman
(1888 –1970)



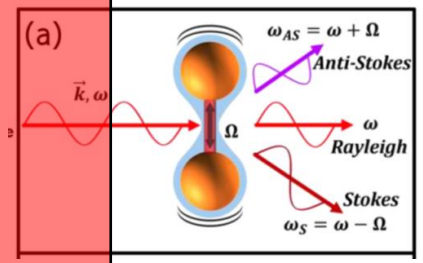
Optical Engineering, 58(7), 072007 (2019).

Léon Nicolas Brillouin
(1889–1969)

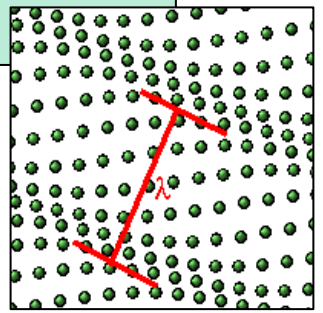
NEW SETUP FOR SIMULTANEOUS μ-BRILLOUIN AND μ-RAMAN SPECTROSCOPY



vibrational modes of molecules
Chemical properties - composition, structure



thermally activated acoustic waves
Mechanical properties
In the continuum description

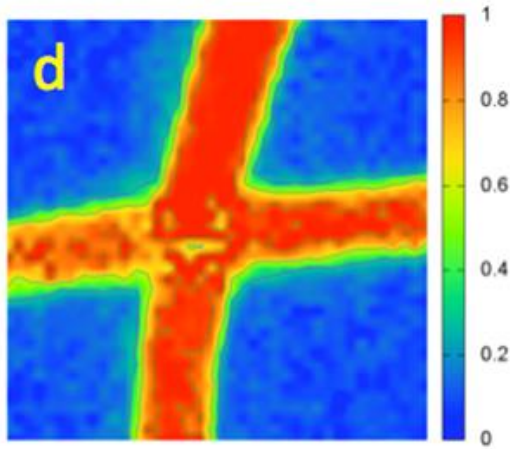


F. Scarponi et al. PRX **7**, 031015 (2017);
S. Mattana et al. Nature Light: Science & Applications **7**, 17139 (2018);
R. Mercatelli et al. Nature: Comms Biology 2 117 (2019).

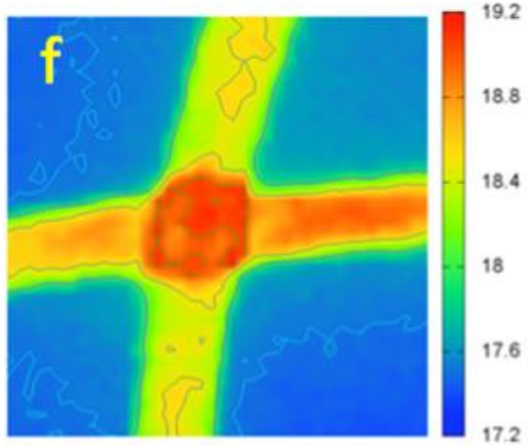
BRILLOUIN AND RAMAN MAPPING

Two wool fibers embedded into epoxy film

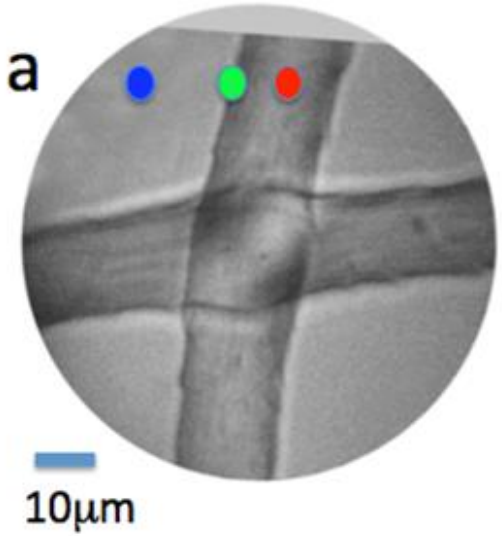
2μm step, 40×40 points
10 s
P=5mW

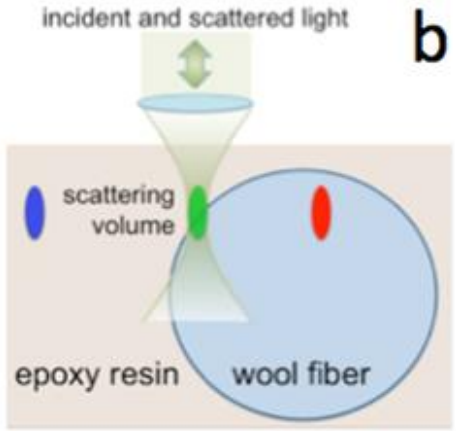


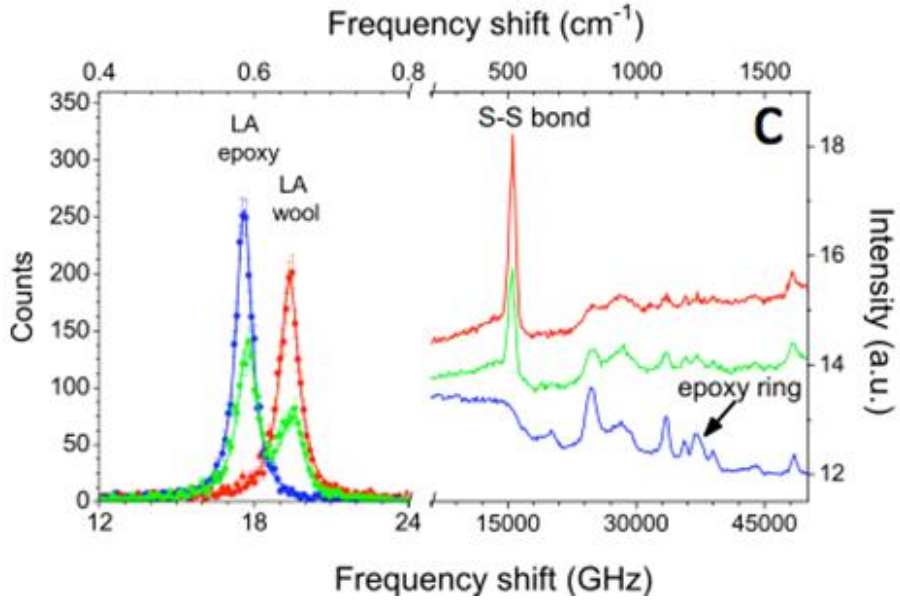
Chemical mapping



Mechanical mapping



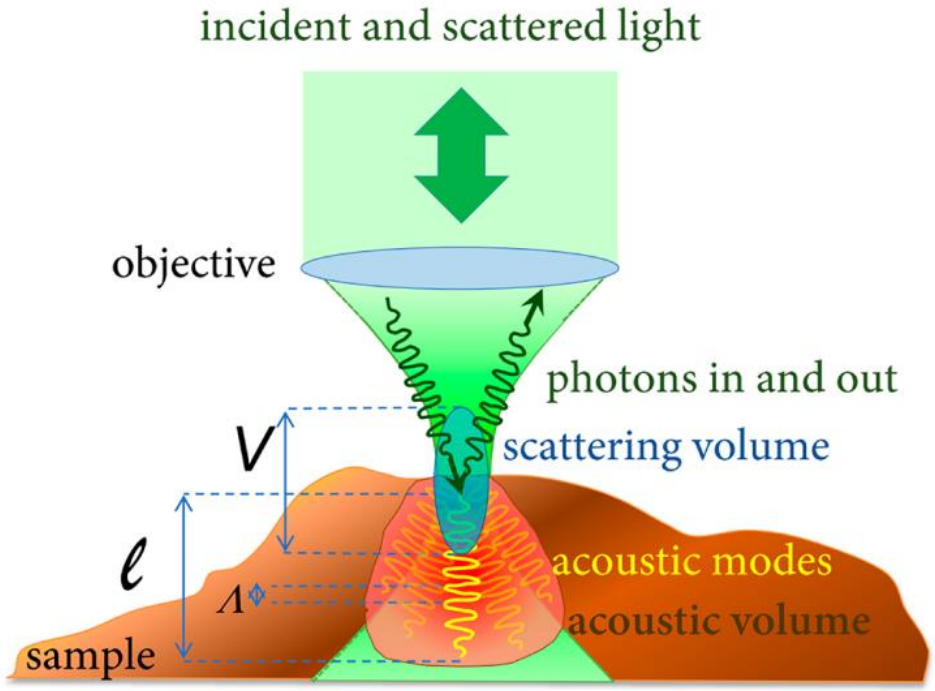




Fioretto et al. Biomedical Optics Express (2019)

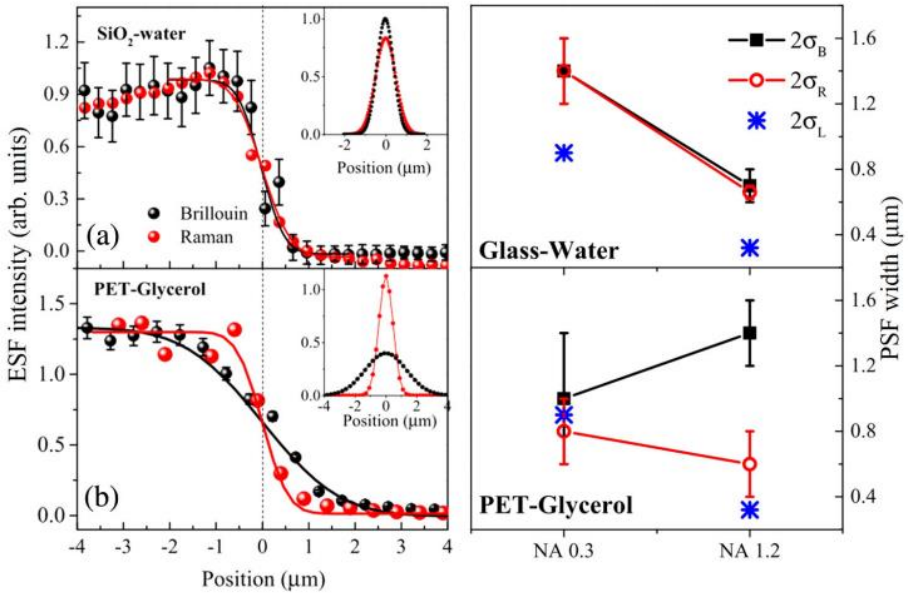
SPATIAL RESOLUTION IN BRILLOUIN IMAGING

The propagating acoustic phonon is the probe of the sample visco-elastic properties



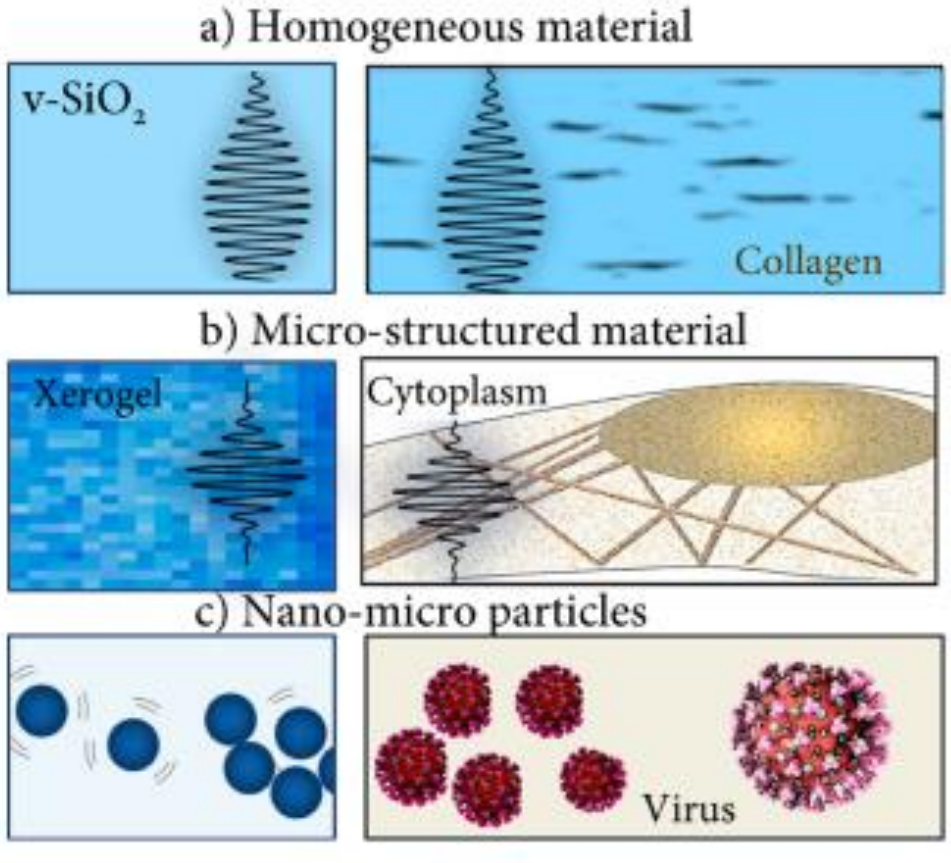
The acoustic volume (red) takes into account the broadening induced by the phonon propagation

- Λ =phonon wavelength (200 nm using λ=532nn)
- ℓ = mean free path of the acoustic phonons $\ell = (\omega_B/2\Gamma)\,\Lambda$
- V = the dimension driven by the optical system

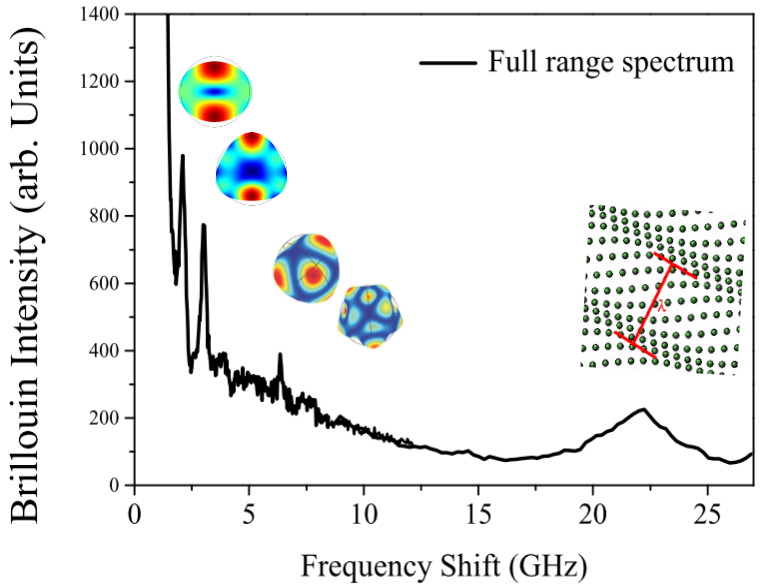


M. Mattarelli, M. Vassalli, S.Caponi, ACS Photonics (2020)
S.Caponi, D. Fioretto, M. Mattarelli, Optics Letters (2020)

WHAT IF THE SIZE DECREASES?



M. Mattarelli, M. Vassalli, S.Caponi ACS Photonics (2020)



$\omega_B^2 = M/\rho \cdot q^2$

$\omega_k^2 = C_k\, M/\rho \cdot 1/d^2$

$C_k = C_k\,(M, G)$

The normal modes are sensitive to the environment → Particles as elastic probes (on a much reduced length-scale!)

SCIENTIFIC REPORTS

OPEN

Efficient Structure Resonance Energy Transfer from Microwaves to Confined Acoustic Vibrations in Viruses

Received: 22 June 2015
Accepted: 05 November 2015
Published: 09 December 2015

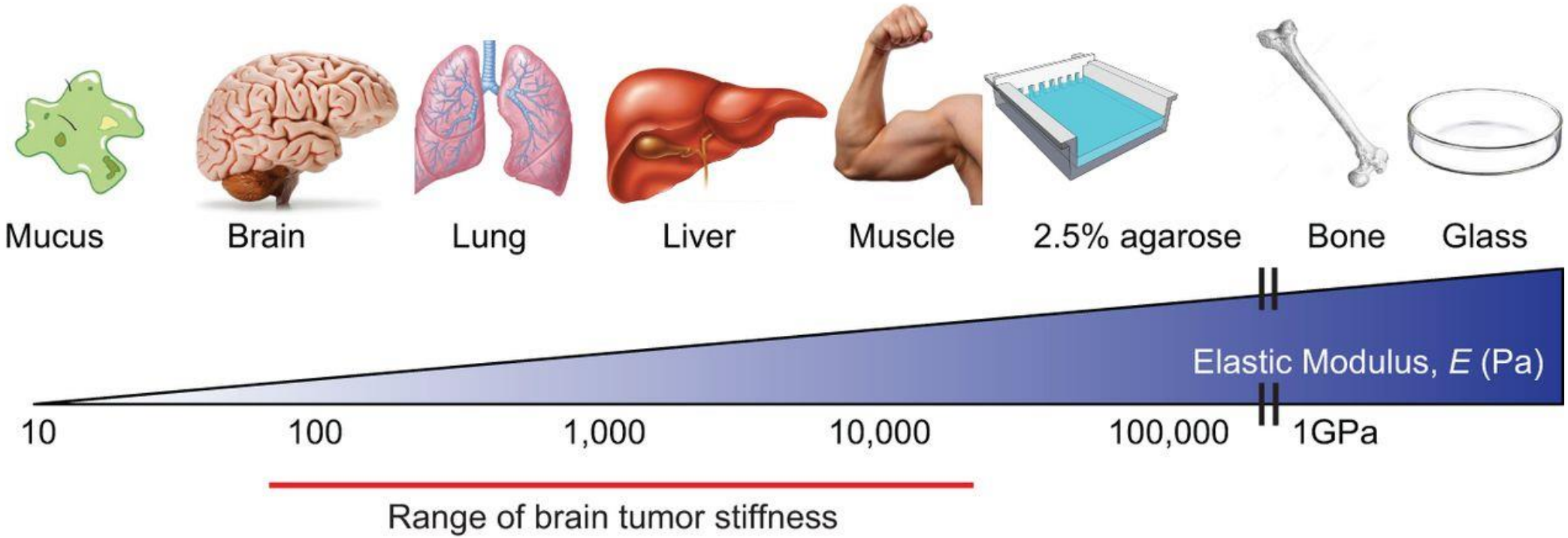
Szu-Chi Yang[1], Huan-Chun Lin[2], Tzu-Ming Liu[3], Jen-Tang Lu[1], Wan-Ting Hung[4], Yu-Ru Huang[1], Yi-Chun Tsai[1], Chuan-Liang Kao[2], Shih-Yuan Chen[4] & Chi-Kuang Sun[1,5]

It is possible to «physically» inactivate virus by em excitation if…

USING LIGHT TO PROBE AND IMAGE THE MATERIALS PROPERTIES

Mechanics in biology

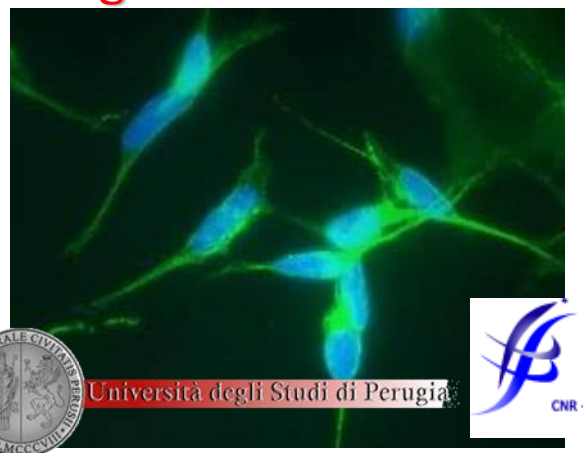
Tissues and cells shape, size and also mechanical properties strongly depend on their function



Barnes et al., Journal of Cell Science 2017 130: 71-82; doi: 10.1242/jcs.191742

NEW SETUP FOR SIMULTANEOUS μ-BRILLOUIN AND μ-RAMAN SPECTROSCOPY

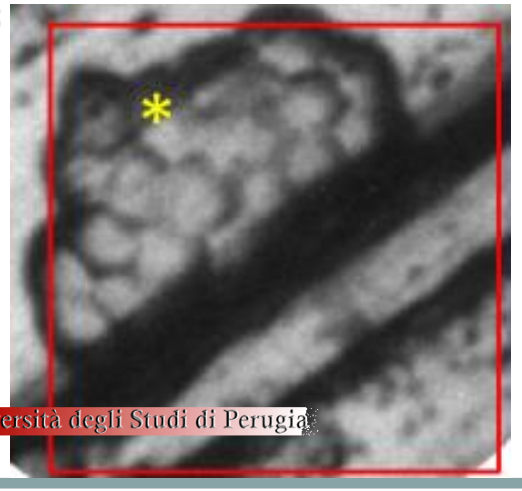
Living cells



Università degli Studi di Perugia

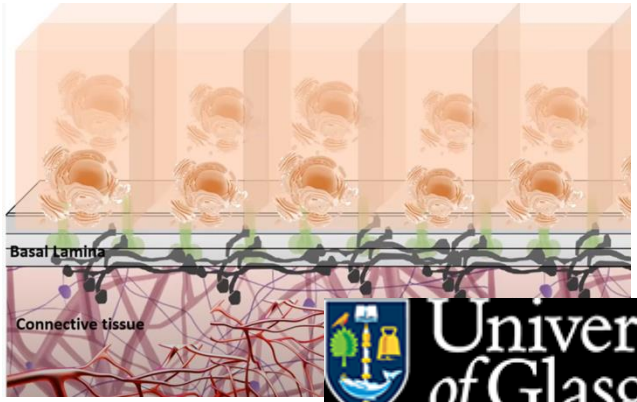
ibf
CNR - Istituto di Biofisica

Biofilms



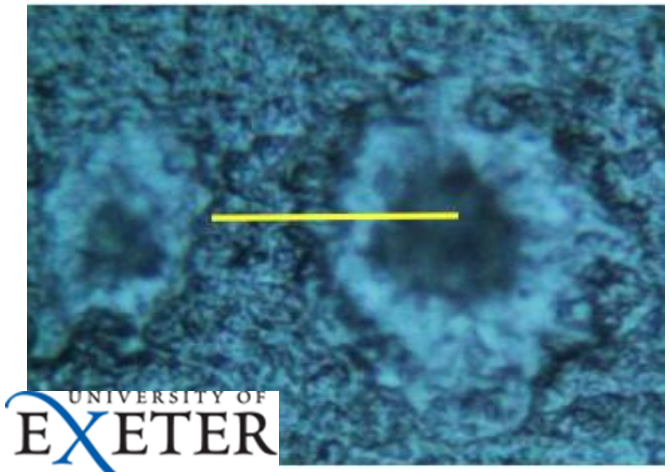
Università degli Studi di Perugia

Biomimetic materials : ECM



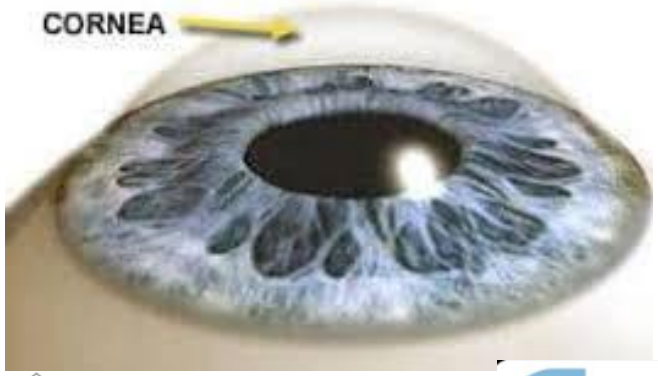
University of Glasgow

Amyloid Plaques in Transgenic Mouse Brain



UNIVERSITY OF EXETER

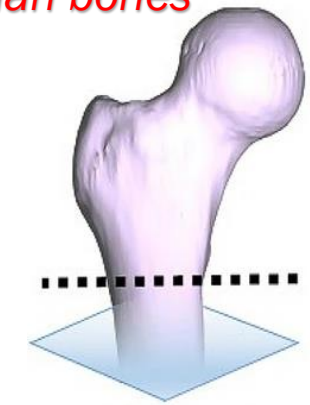
Human cornea

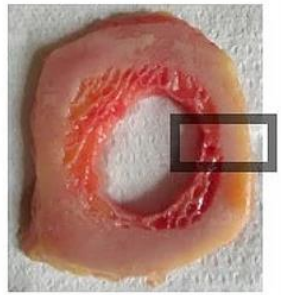


INO-CNR
ISTITUTO NAZIONALE DI OTTICA

IFAC

Human bones

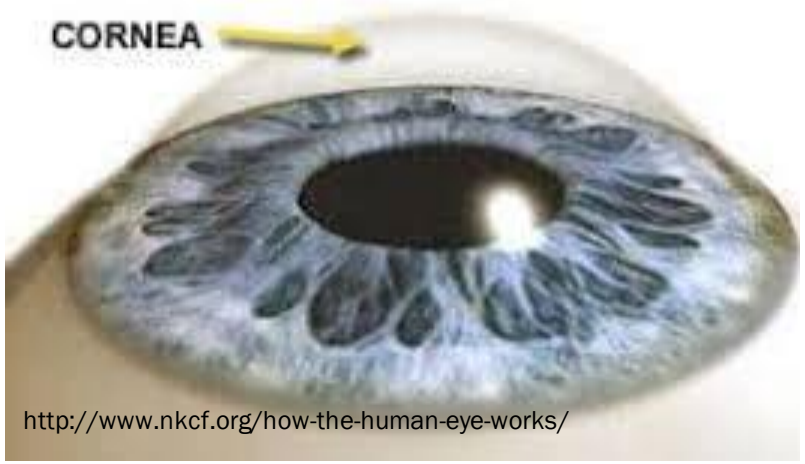




Diaphysis

Istituto Ortopedico Rizzoli di Bologna
Istituto di Ricovero e Cura a Carattere Scientifico

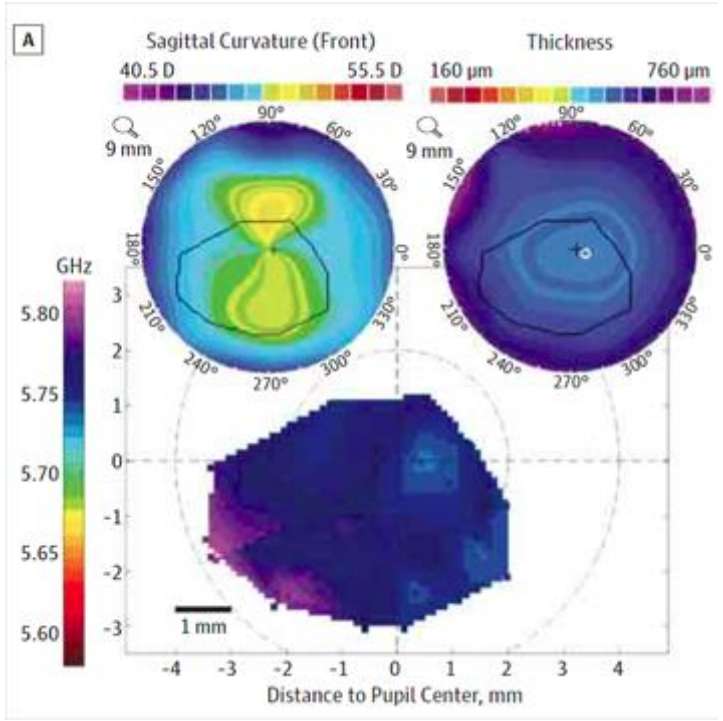
Link between biomechanics and diseases: analysis on human cornea

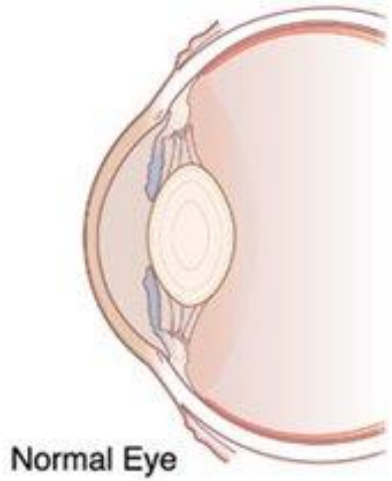


http://www.nkcf.org/how-the-human-eye-works/

The first in vivo imaging effort was reported by a team at Harvard Medical School, aiming at evaluating biomechanical properties of cornea and crystalline lens in animal models, and then in human in 2012.

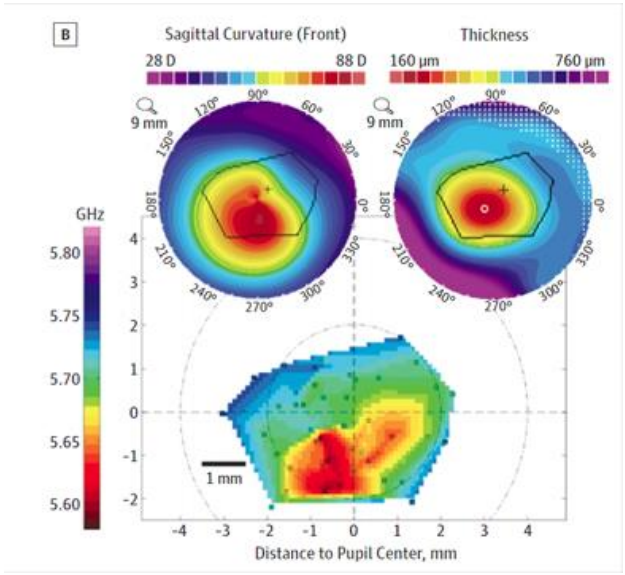
healthy cornea

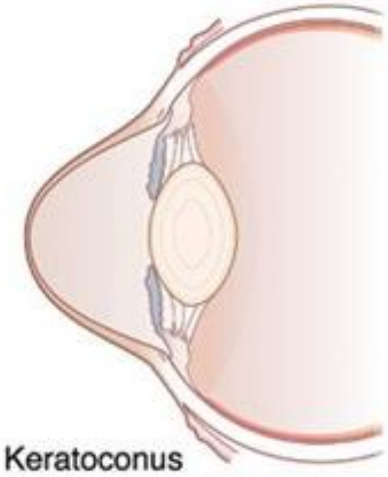




cornea with advanced keratoconus

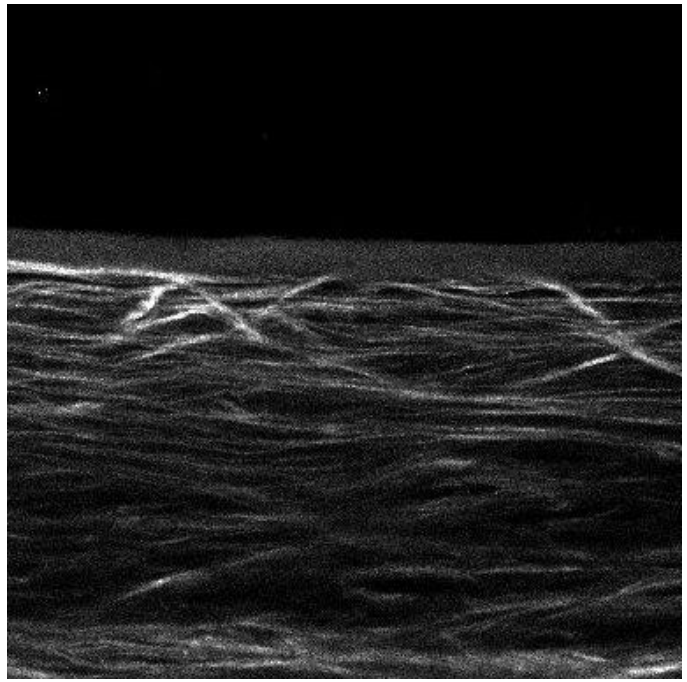
JAMA Ophthalmology April 2015 Volume 133, Number 4





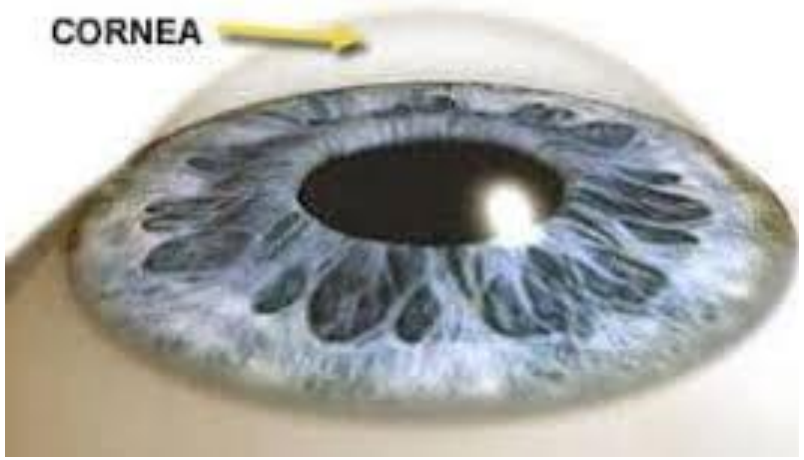
Microstructure drives biomechanics: analysis on human cornea

Healthy Cornea

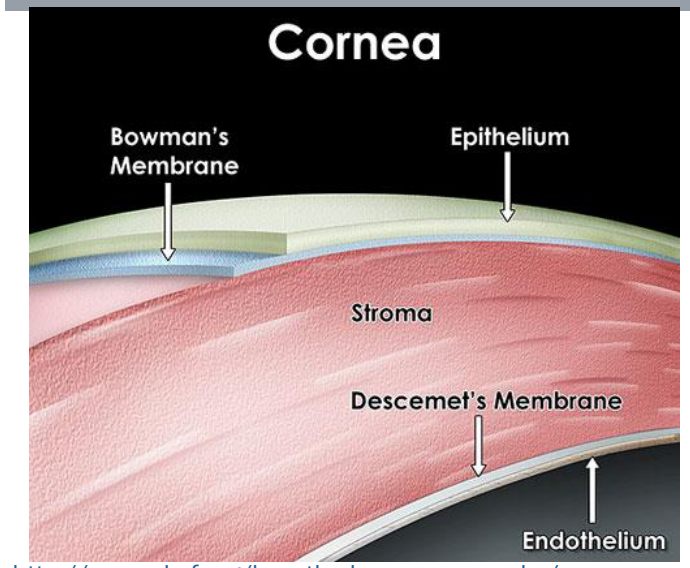


SHG-imaging

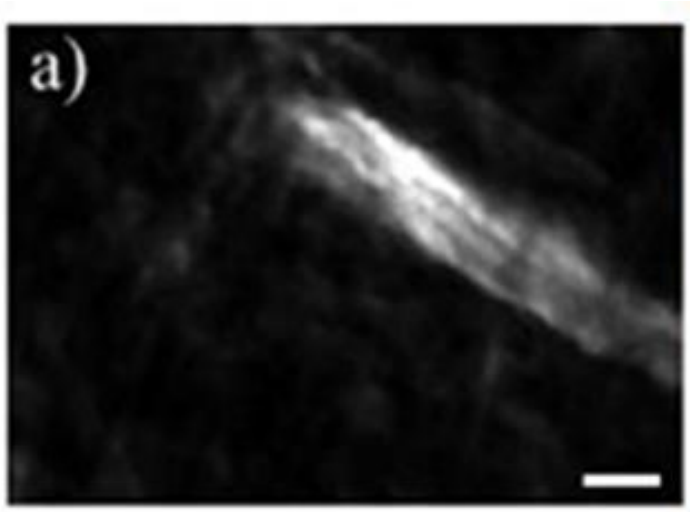
- The **sutural lamellae**, immediately l membrane

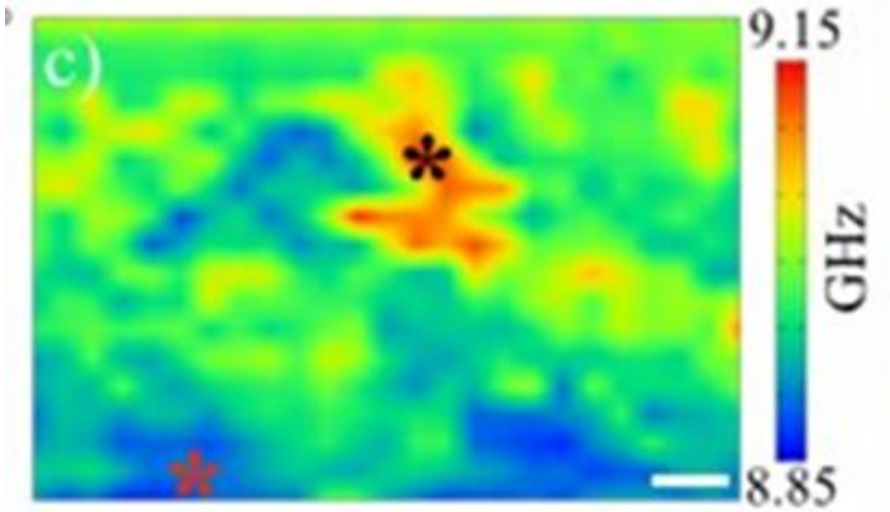


http://www.nkcf.org/how-the-human-eye-works/



http://www.nkcf.org/how-the-human-eye-works/



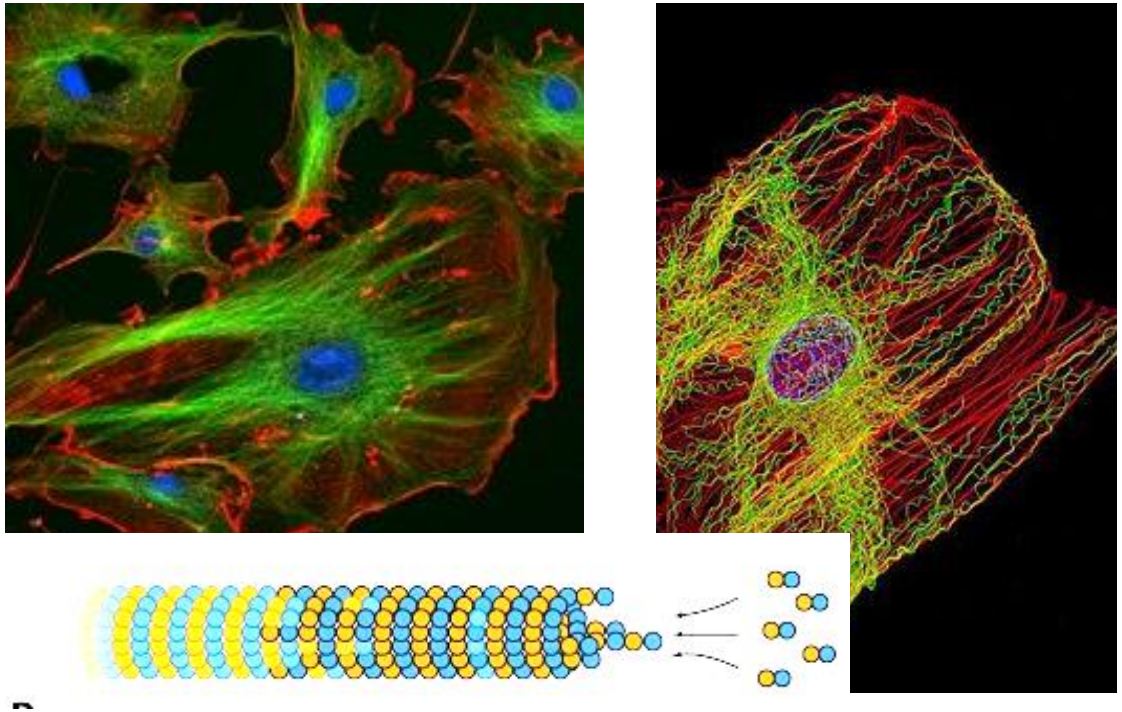


The use of a correlative approach was key to achieve a deeper morphological interpretation of the mechanical properties, otherwise inaccessible to ordinary methods based on a single mechanism of optical contrast.

Mercatelli et al. 10.1038/s42003-019-0357-y.

COMMUNICATIONS BIOLOGY

CELLS ARE MECHANICAL OBJECTS…

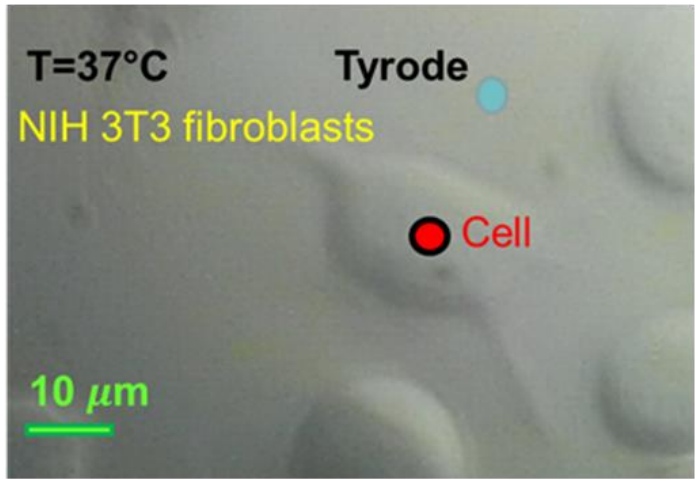


The mechanical properties of cells influence their cellular and subcellular functions, including

- cell adhesion,
- migration,
- differentiation,
- organelle organization
- trafficking inside the cytoplasm.

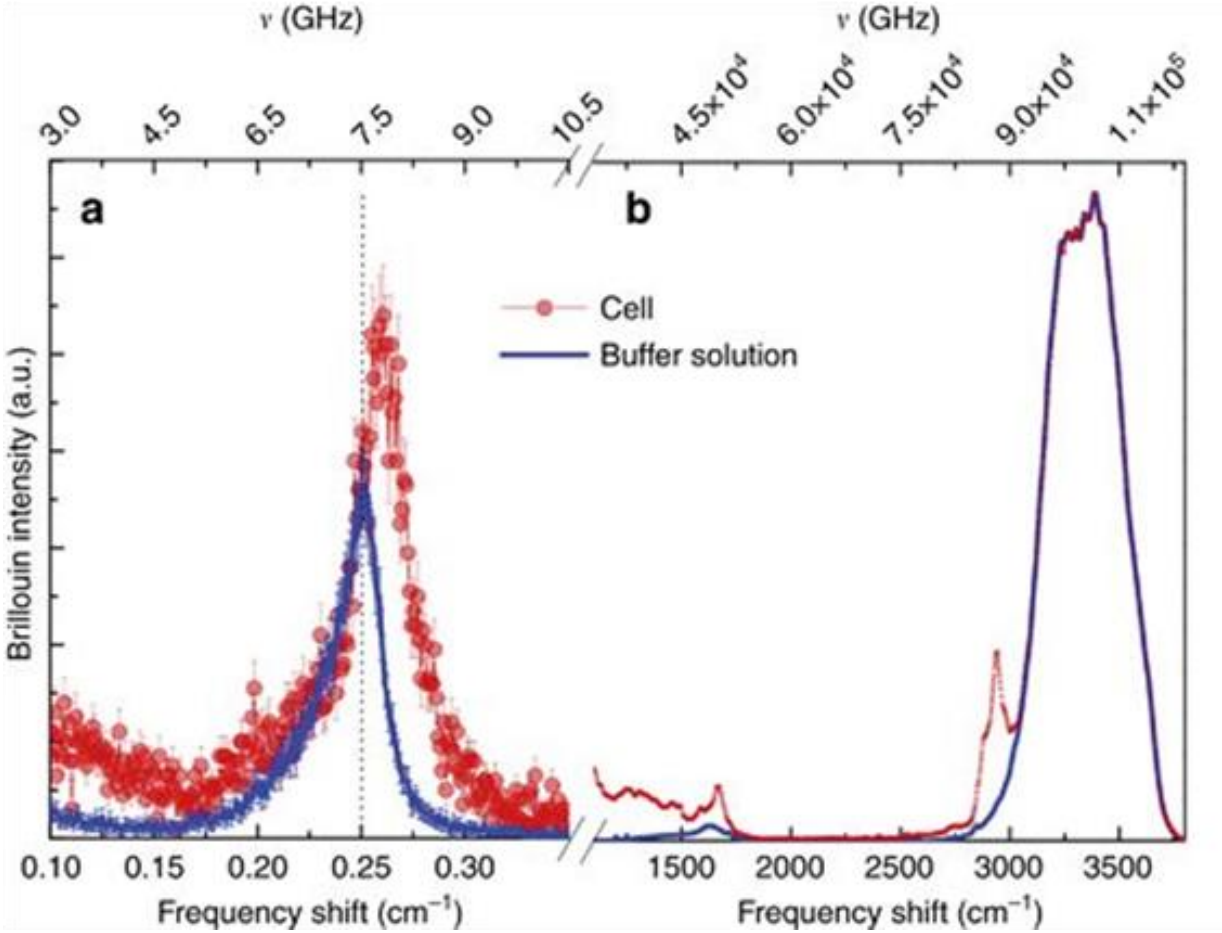
- Biomechanics are crucial in the onset of several diseases (cancer, Atherosclerosis,glaucoma, amyotrophic lateral sclerosis…)

MECHANICAL AND CHEMICAL ANALYSIS OF SINGLE LIVING CELLS



MULTISCALE ANALYSIS
(from molecular to collective dynamics)

- Label free
- Non contact
- In physiological condition
- Sub-micrometric resolution

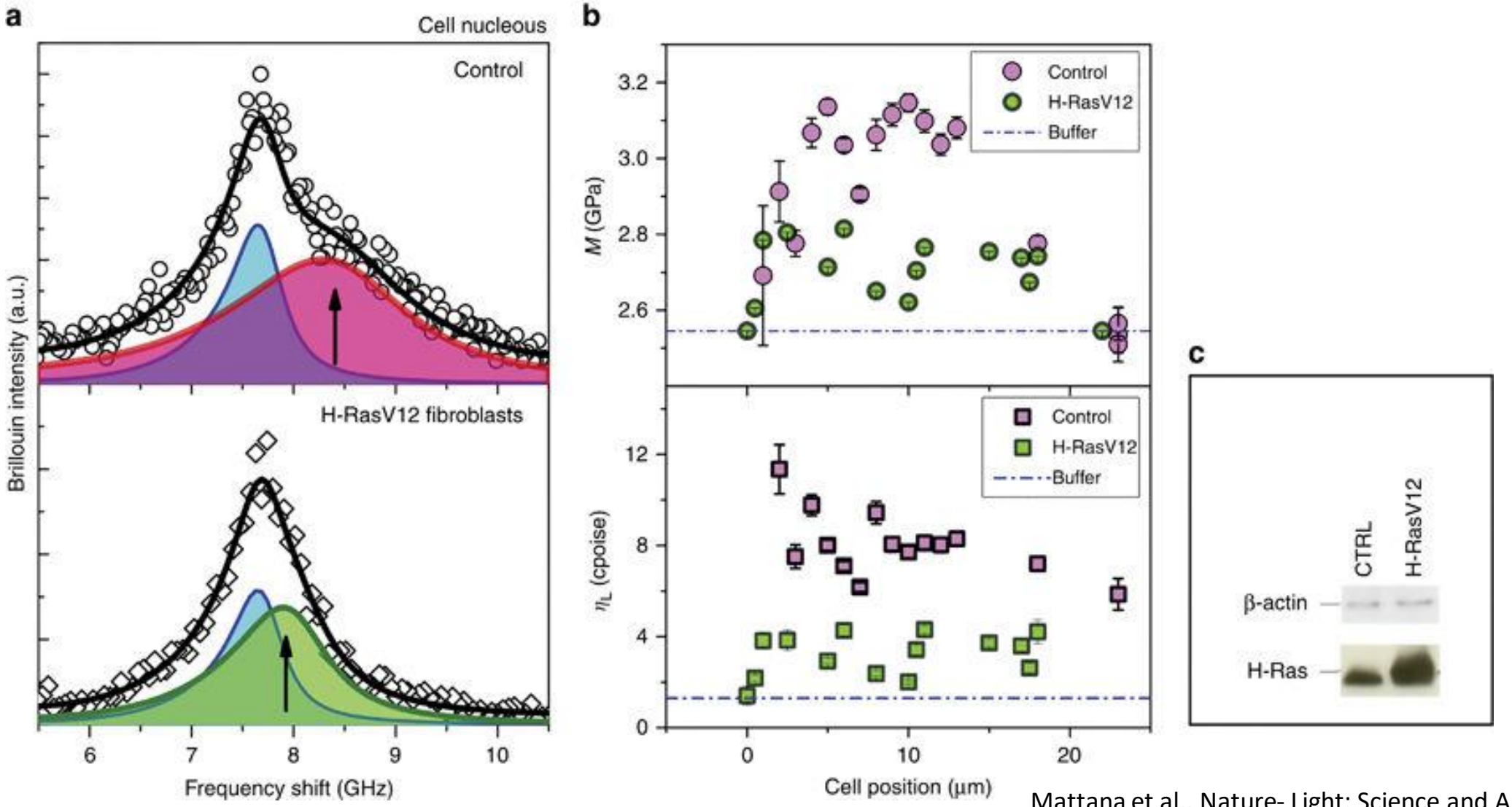


nature.com > light: science & applications

Light | Science & Applications

Mattana et al., Nature- Light: Science and Applications 7, 17139 (2018)

EVIDENCE OF DIFFERENT ELASTIC PROPERTIES IN TRANSFECTED TUMURAL CELLS



Mattana et al., Nature- Light: Science and Applications 7, 17139 (2018)

THE COMMUNITY

BIOBRILLOUIN

WG1 Medical & Clinical Applications

WG2 Phenotyping & Novel Applications

WG3 Instrument Design & Data Analysis

WG4 Correlative & Comparative Methods

Different partners for specific tasks: biology, medicine, optics, instrumentation, fundamental issues.

Lens
European Laboratory for Non-Linear Spectroscopy

University of Glasgow

iLM
INSTITUT LUMIÈRE MATIÈRE

UNIVERSITY OF EXETER

ESIEE PARIS

IZZOLI Research Innovation Technology

THE TABLE STABLE LTD.
Vibration Isolation and JRS Optical Instruments

TESI

- Caratterizzazione meccanica e chimica di sistemi biomimetici
  (Dep. Biomedical Engineering Università di Glasgow)
  Progetto Royal Society (UK)

- Analisi di singole cellule in condizioni fisiologiche e patologiche
  (Dipartimento Di Chimica, Biologia e Biotecnologie)

- Ottimizzazione e sviluppo di strumentazione innovativa
  per analisi spettroscopica di materiali biologici

CONCLUSIONE

- Utilizzare la luce per investigare la materia biologica (attraverso le vibrazioni): un ampio spettro di attività.

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ISTITUTO OFFICINA DEI MATERIALI

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