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Optical stretcher

A novel tool for biological applications

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Main expertise:

- Nonlinear optics in $\chi^{(2)}$ and $\chi^{(3)}$ media and guided wave configuration
- Optical communication systems
- Properties of nonlinear optical materials
- Biological manipulation

Index

- Need for a single cell analysis device
- Theory of radiation pressure
- Theory of optical stretcher
- Setup
- Samples creation
- Experiment
- Analysis
- Conclusions

Need for single cell analysis devices

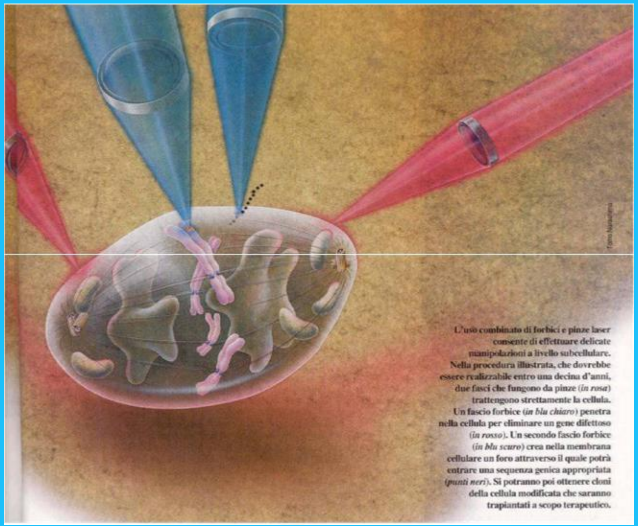
"Classical" Biological analysis: media of many "identical" cells

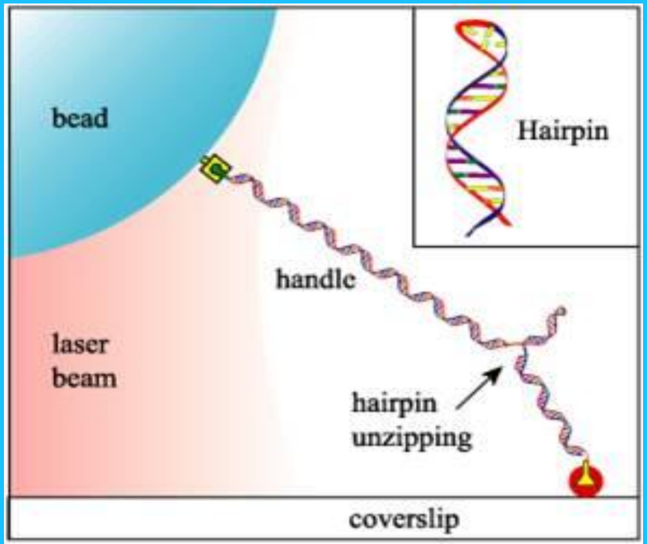
But even among "identical" cells there are many differences

→ Need for a single cell analysis device

Bio-photonics devices , based on optical forces, are extremely interesting:

- They can trap and move single cells without physical contact
- They can be combined with diagnostic methods
- They can be used for trapping, gene killing, cell transfection, cell sorting and they can analyze bacterial adhesion forces and membrane interactions

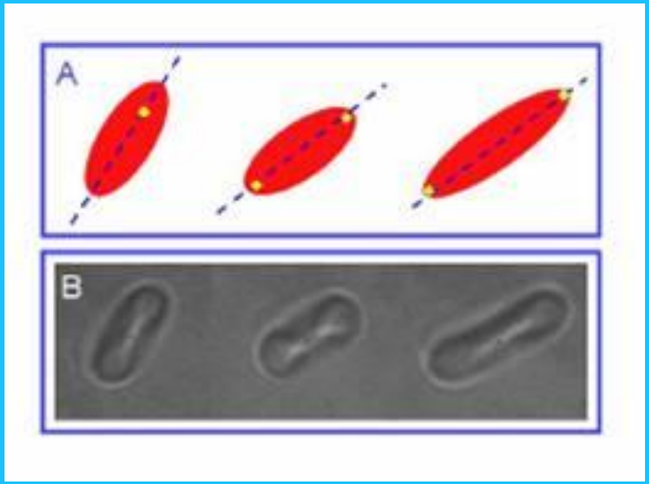


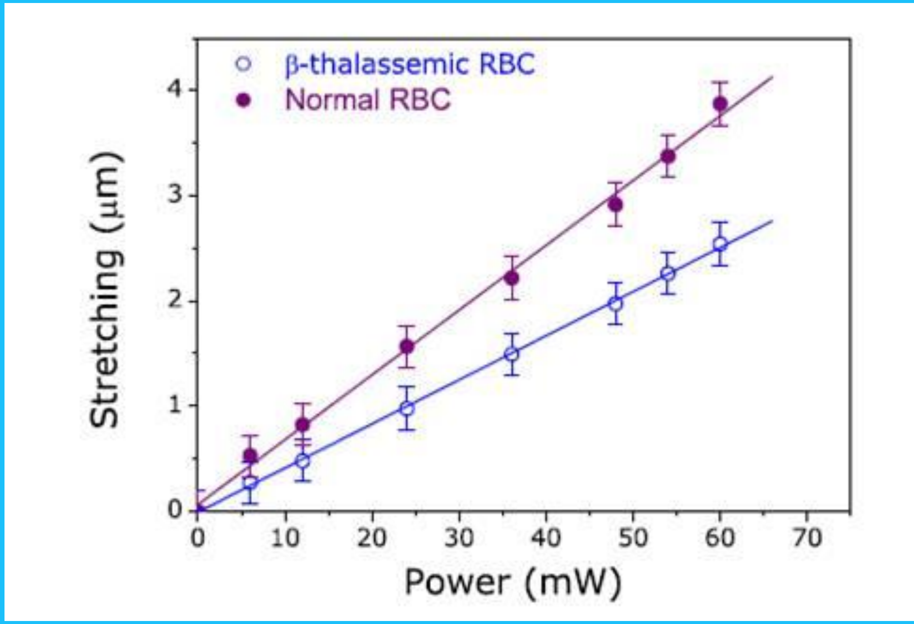


Application in biology

- In particular they can investigate the viscoelastic properties of trapped cells through the application of intense optical forces, able to cause a significant deformation of the cytoskeleton.

- The degree of cytoskeleton deformability is characteristically altered by many diseases, including cancer, and provides a unique and reliable marker of the cell status





A.C. De Luca et al " Spectroscopical and mechanica characterization of normal and thalassemic red blood cells by Raman Tweezers" Opt. Express, 16, 7943, 2008.

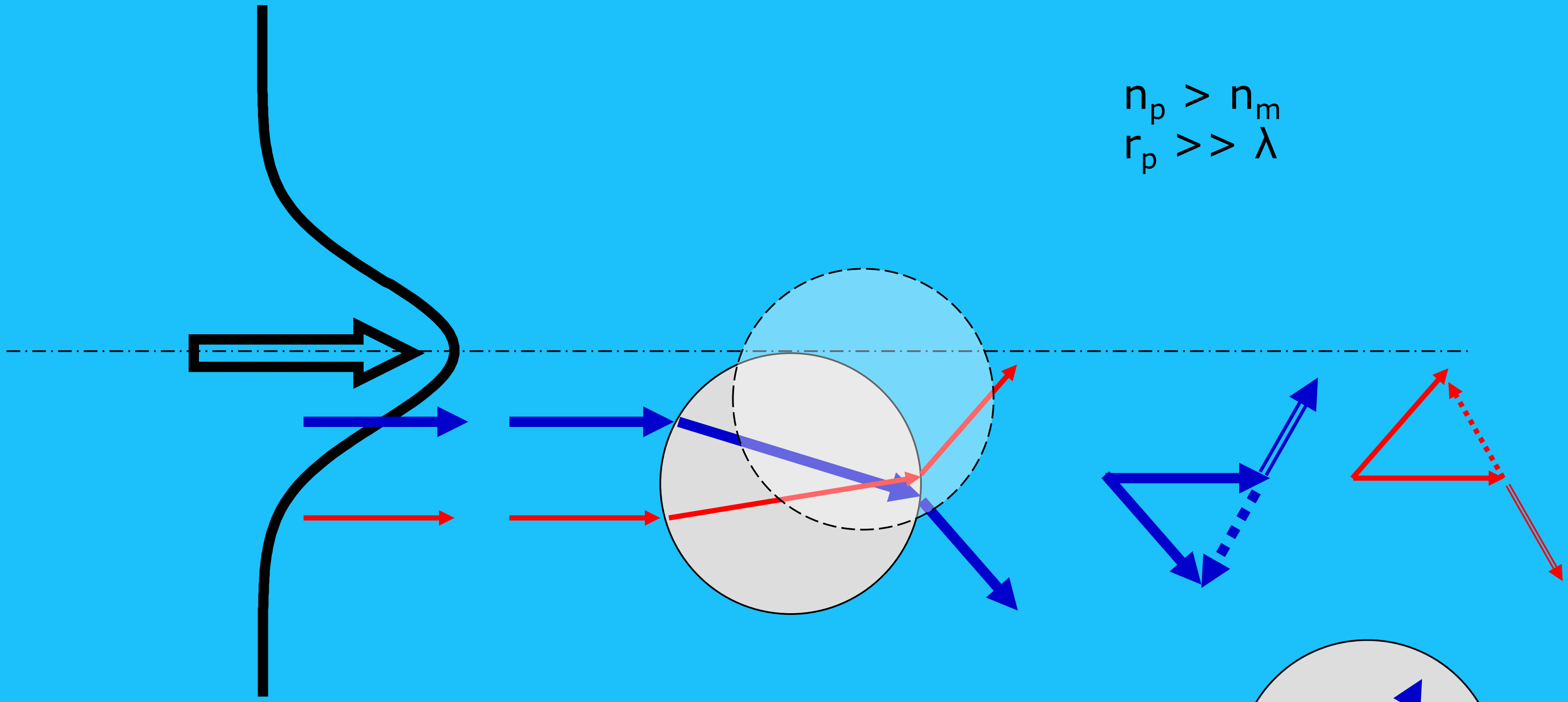
J. Guck et al "Optical Deformability as Inherent Cell Marker for Malignant Transformation and Metastatic Competence" Biophys. J. 88, 3689, 2005.

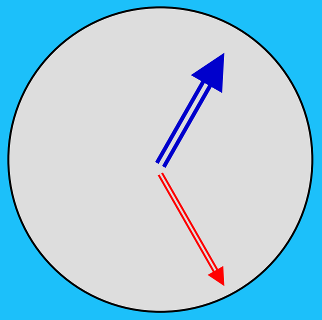
Special Issue on Cell Mechanics, Methods in Cell Biology, 83, 2007

Optical Stretcher: Theory

$n_p > n_m$

$r_p >> \lambda$



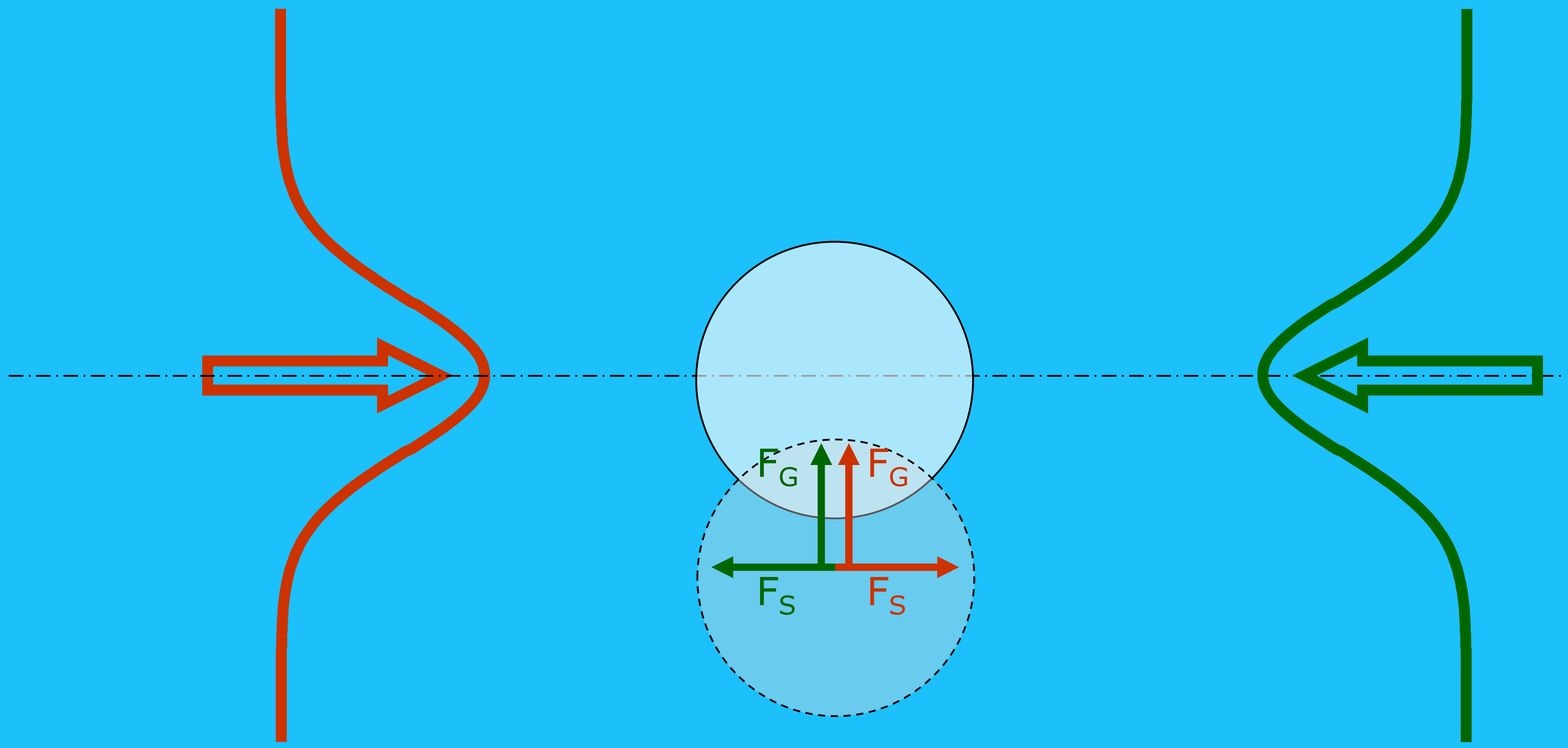


A laser beam incident on a particle changes its momentum during the refraction in the medium. This change generates a configuration of optical forces acting on the particle that:

- Push it forward ("scattering force")
- Pull it along the optical axis ("gradient force")

Optical Stretcher: Theory

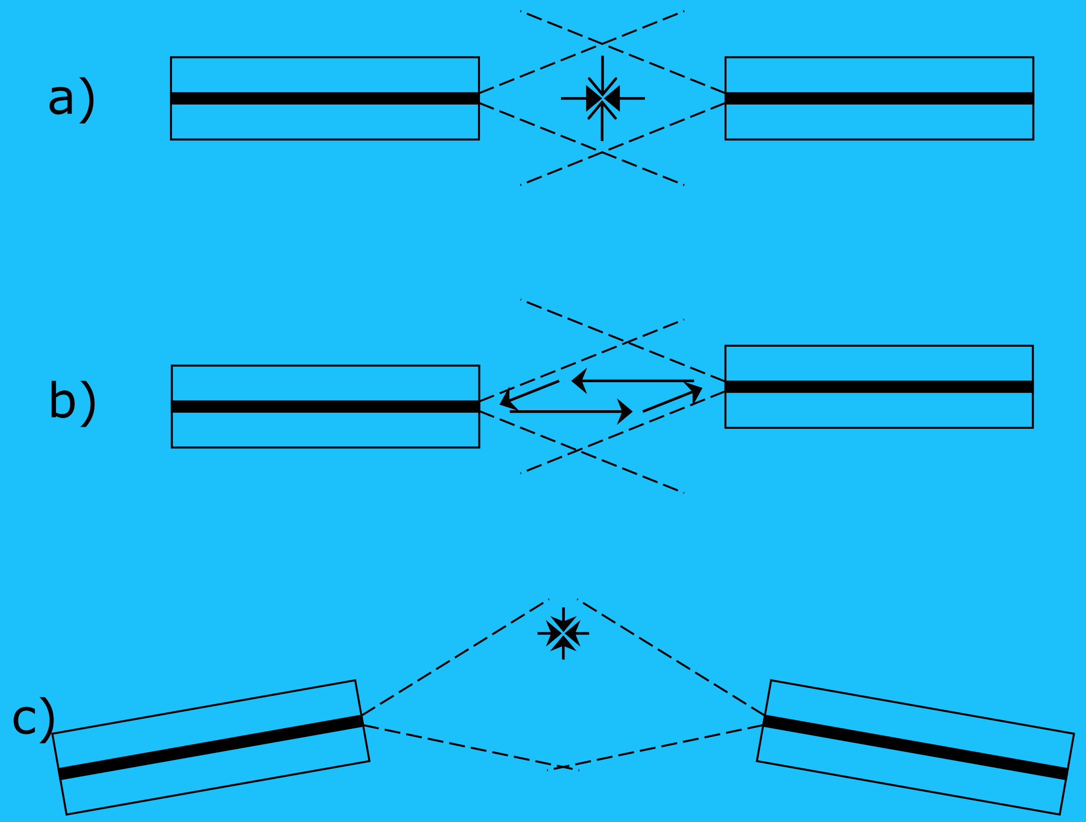
With two counter-propagating, identical laser beam, the scattering force is suppressed and the particle is pulled along the optical axis



So, the particle is trapped

Optical Stretcher: Theory

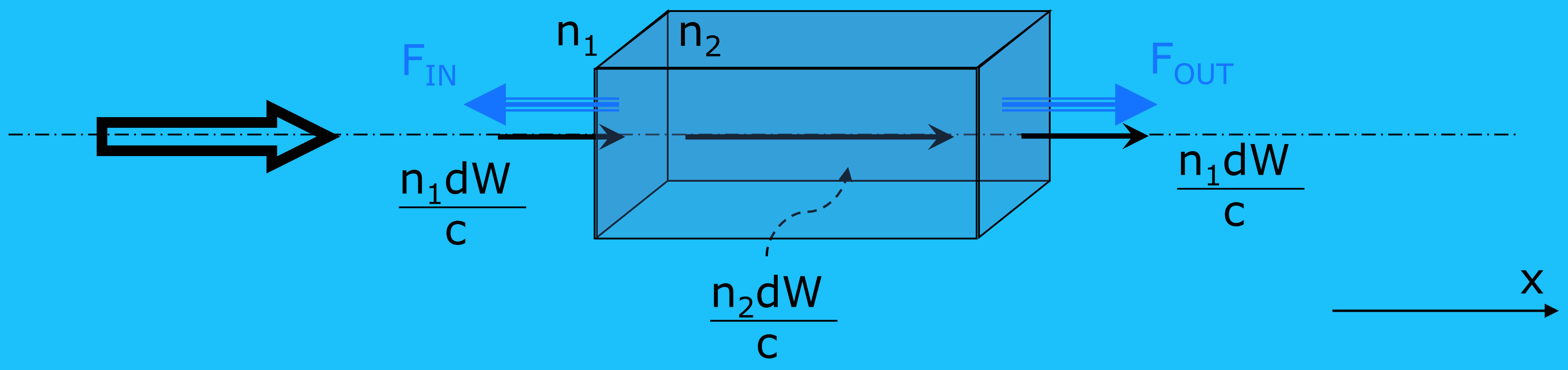
The misalignment could prevent the trapping



Scattering → Gradient → Total →

Optical Stretcher: Theory

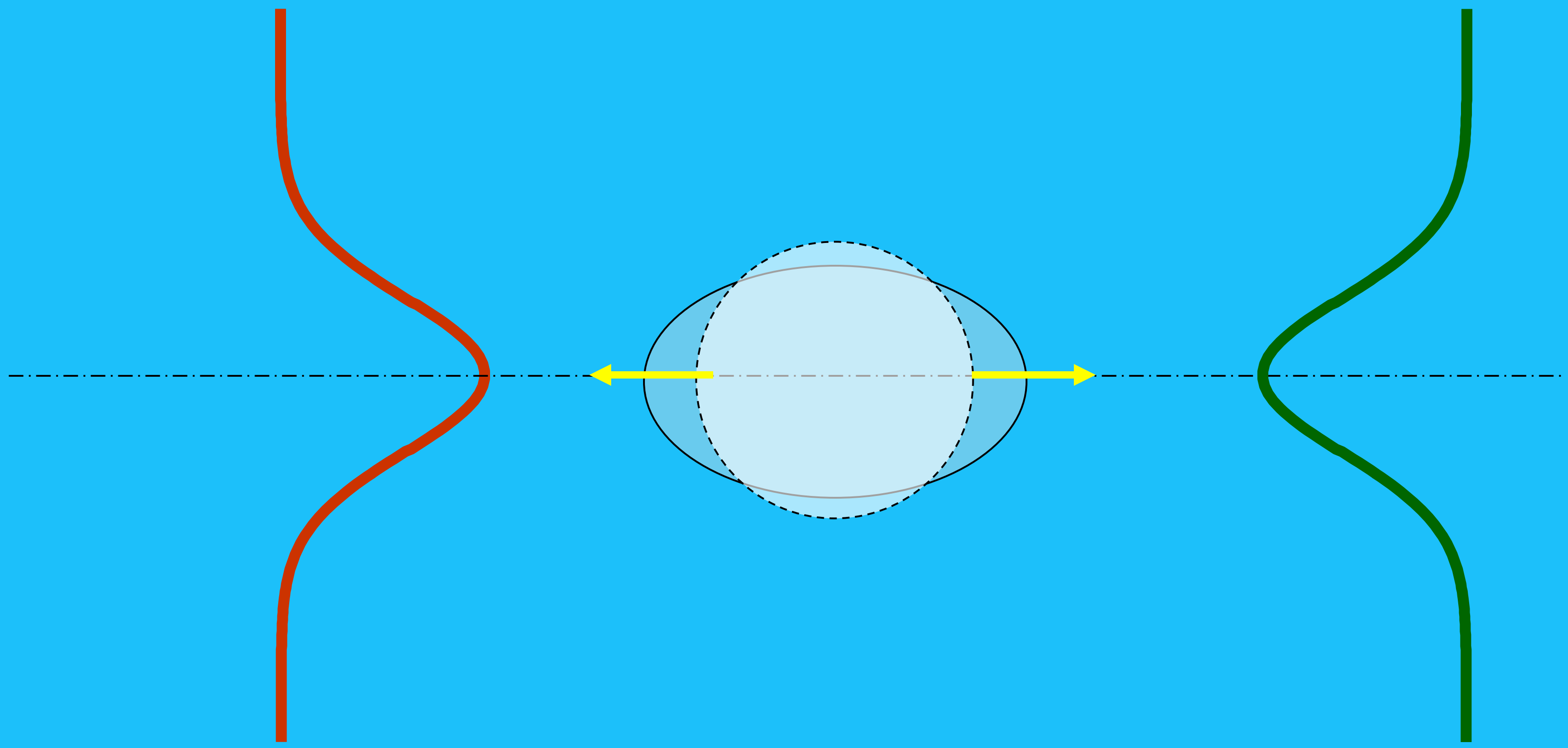
To explain the stretching, we simplify the particle structure, modeling it with a rectangular block. The beam incident on the block changes its momentum and generate unbalanced forces on the lateral surfaces of the block.



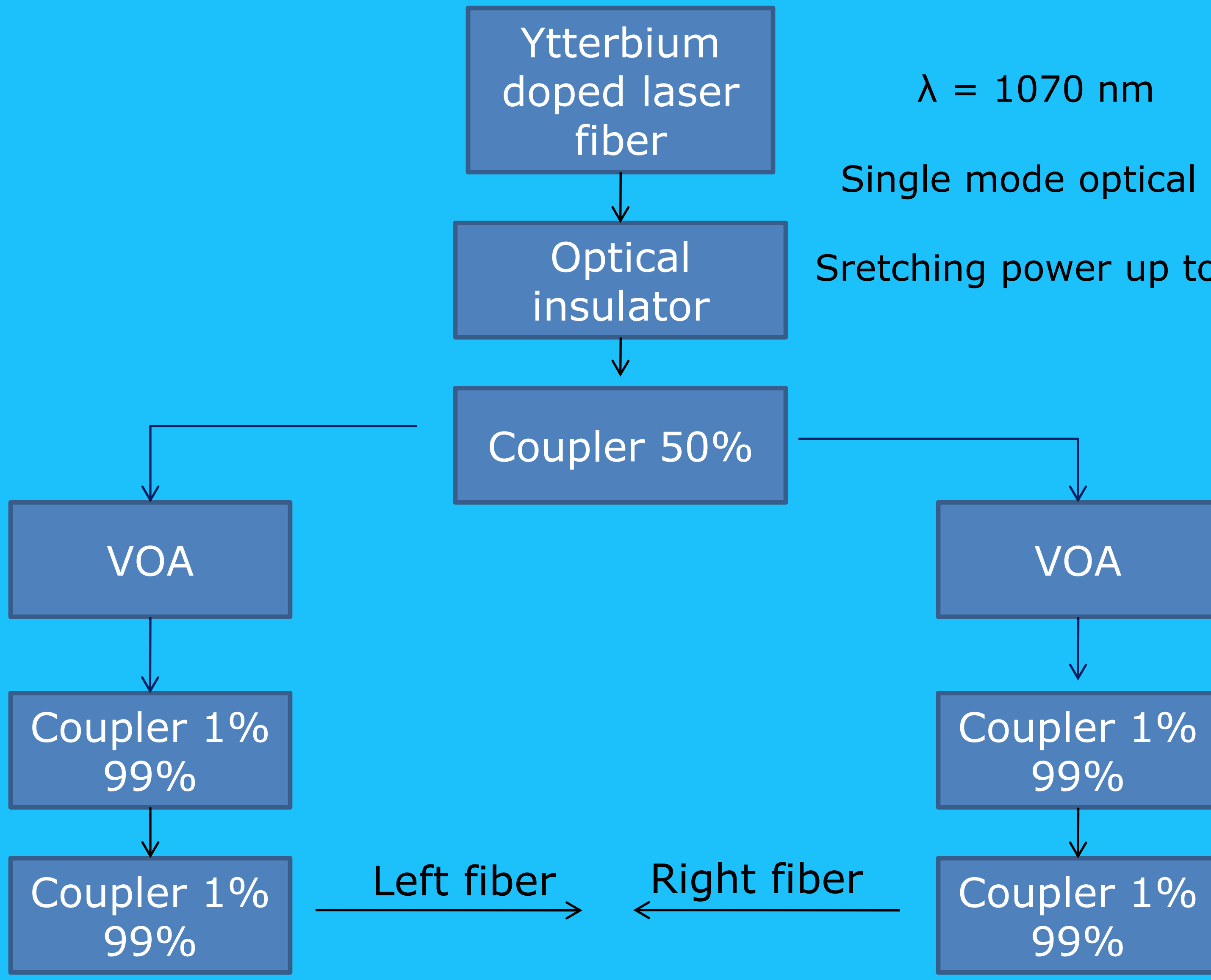
When two identical beams act together, the forces acting on the two lateral surfaces are equal. So when we increase the optical power, the particle stretches

Optical Stretcher: Theory

So, with higher power, the particle stretches



Setup

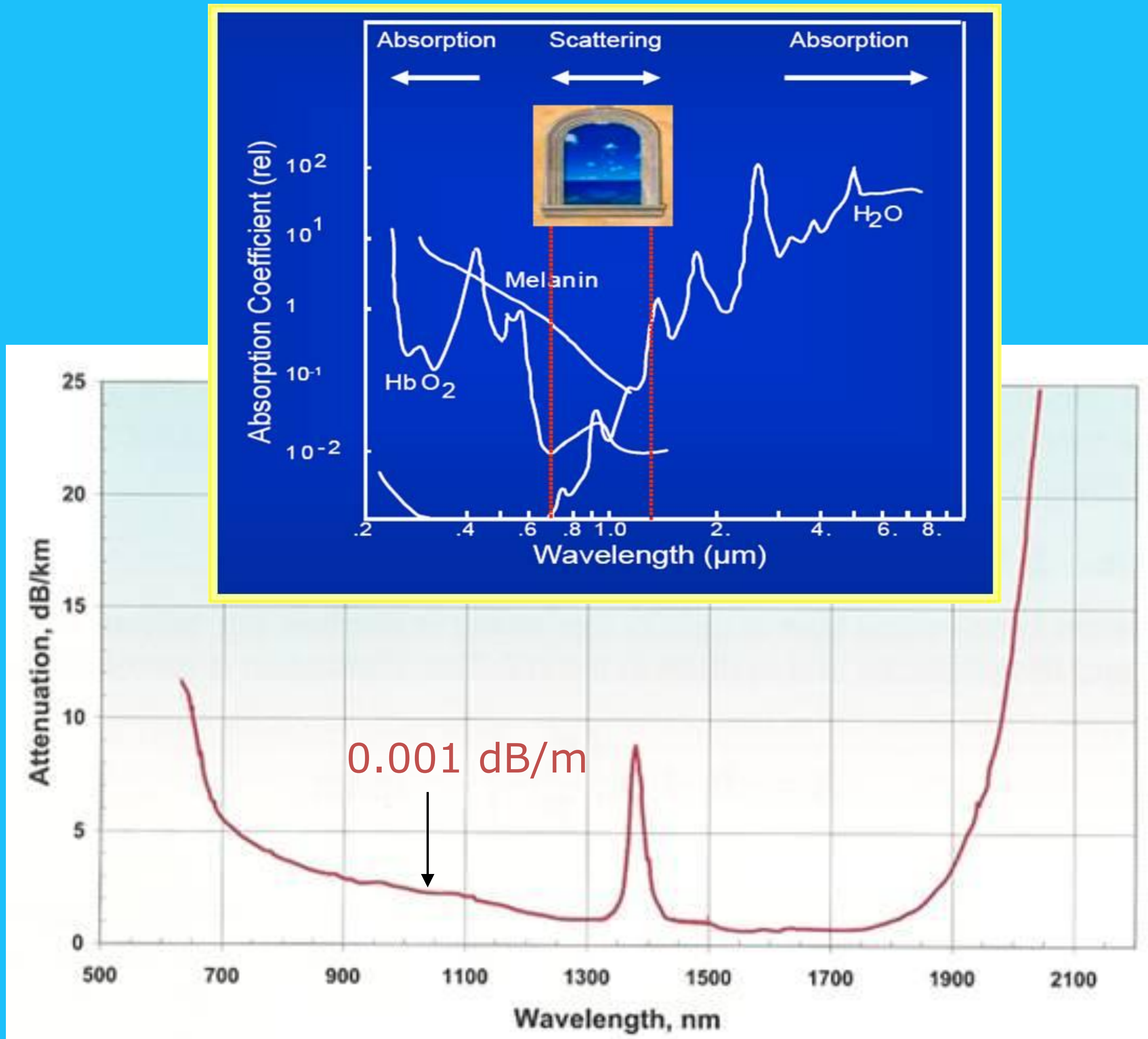


λ = 1070 nm

Single mode optical fiber

Sretching power up to 500 mW

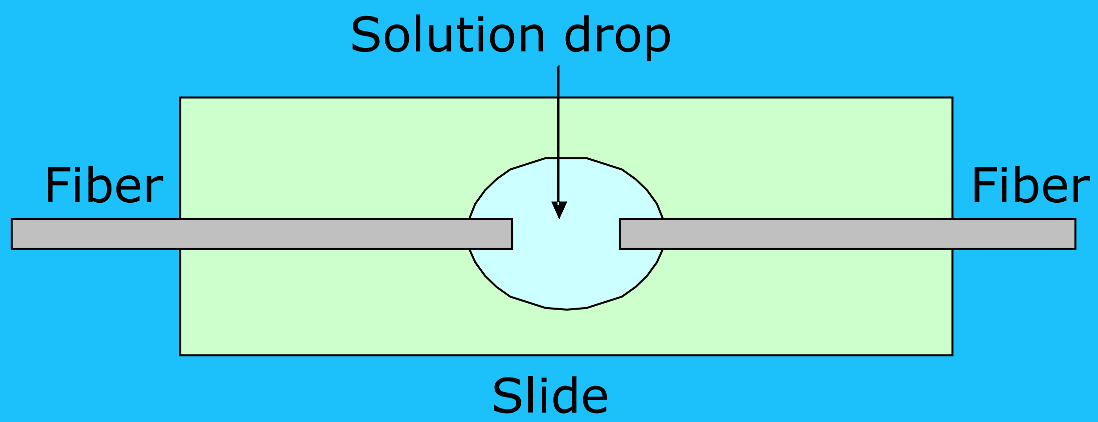
Cells spectrum



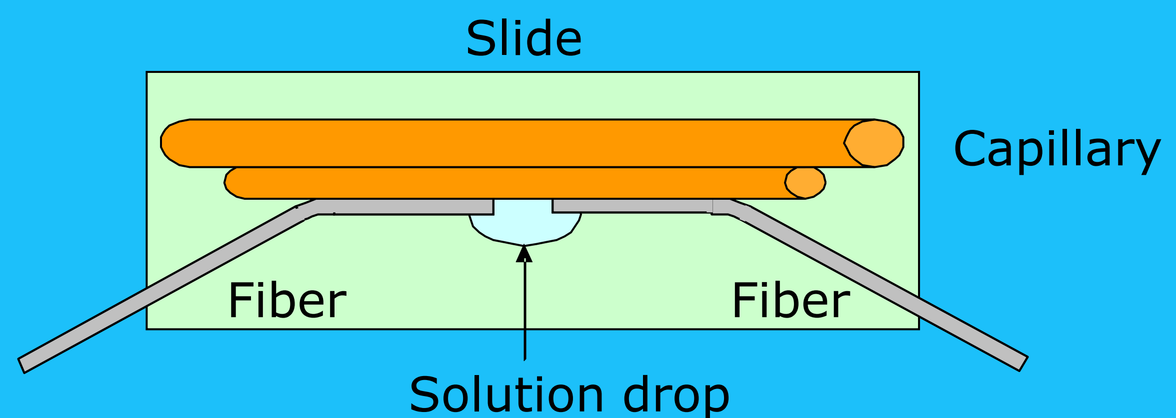
Trapping configurations

We used different configurations to trap and stretch the micro-particles

1- Fibers immersed directly in the solution and slightly suspended over the slide

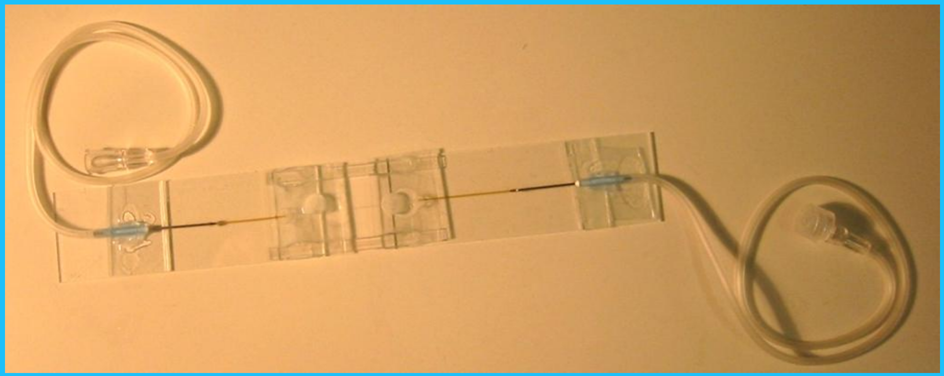


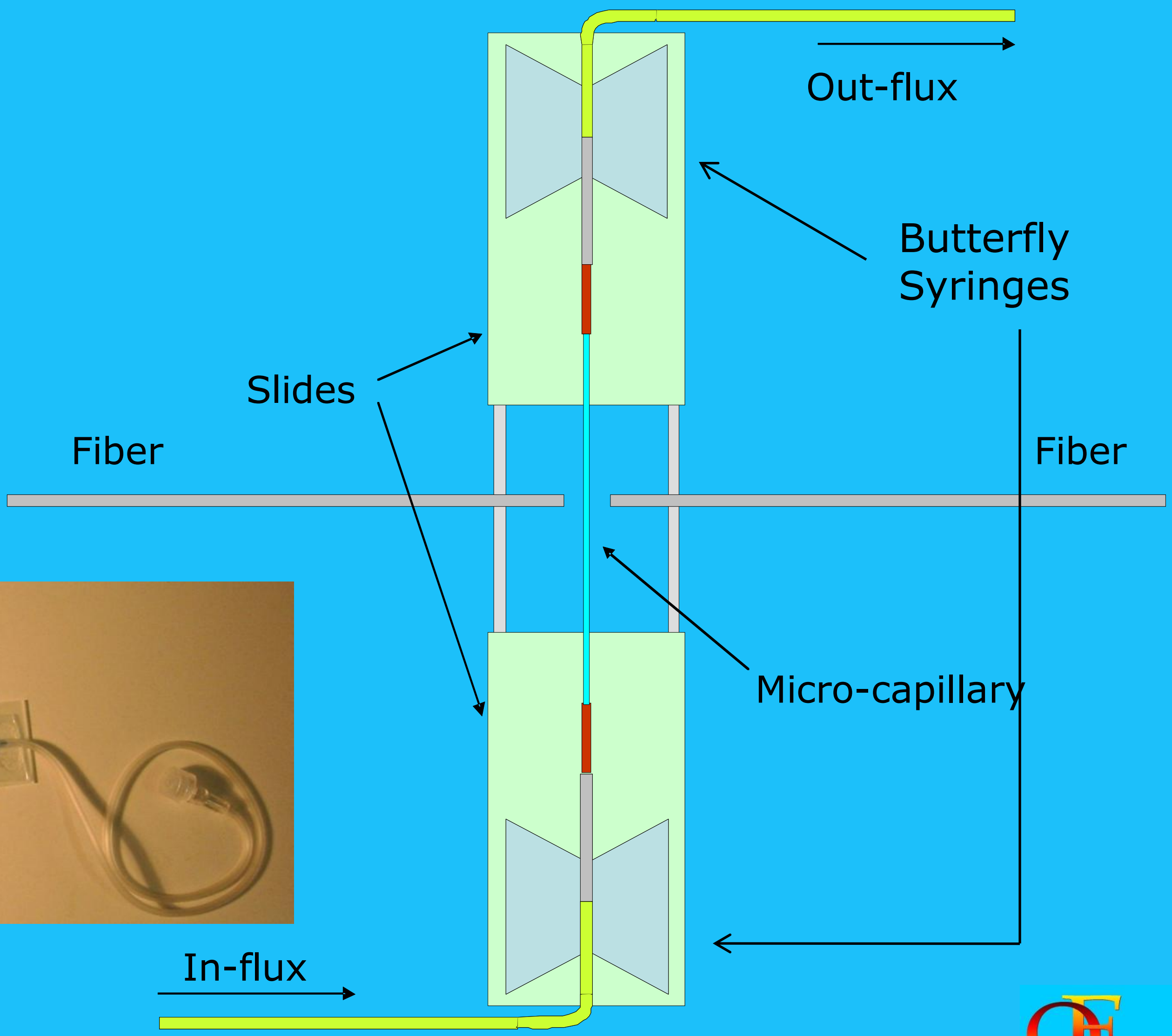
2- Fibers immersed directly in the solution with a capillary-guided configuration



Trapping configurations

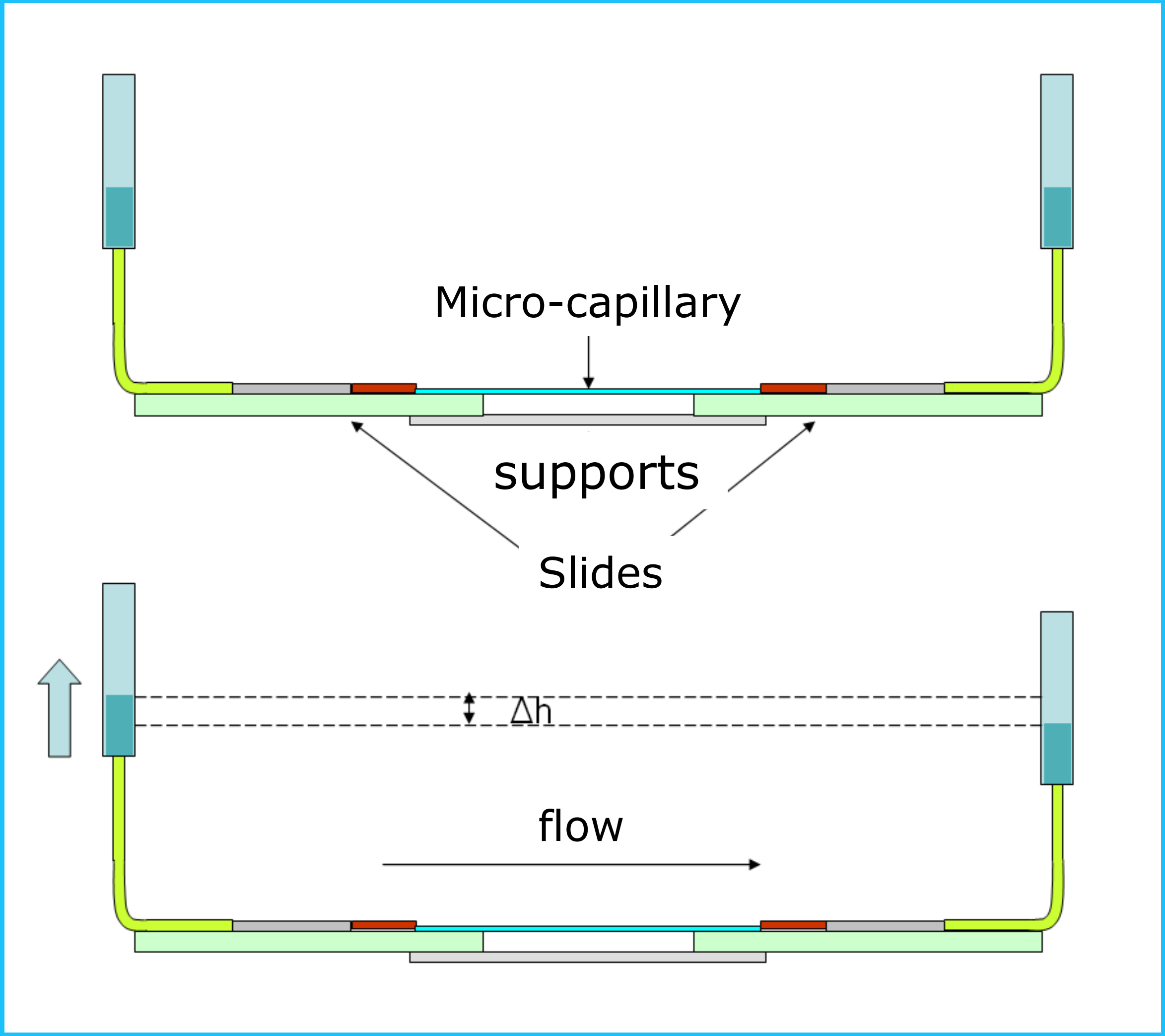
3. Micro-fluidic system





Trapping configurations

Flow control technique

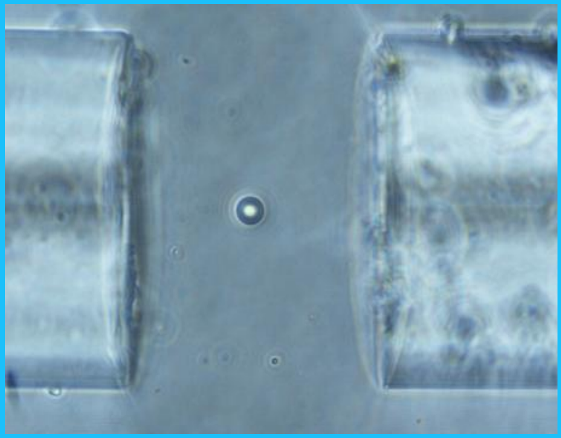


Changing the heights of the reservoirs with a micro-manipulator we can control the solution flow

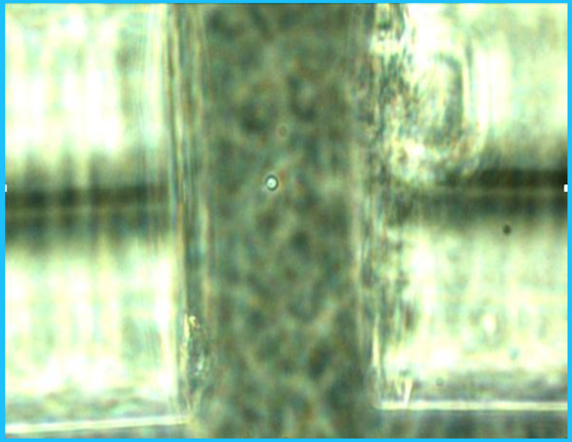
Analyzed particles

We tried to trap many kind of particles:
•Biological particles (RBCs, stem cells, yeast)
•Non-biological particles (polystirene, liquid crystals)

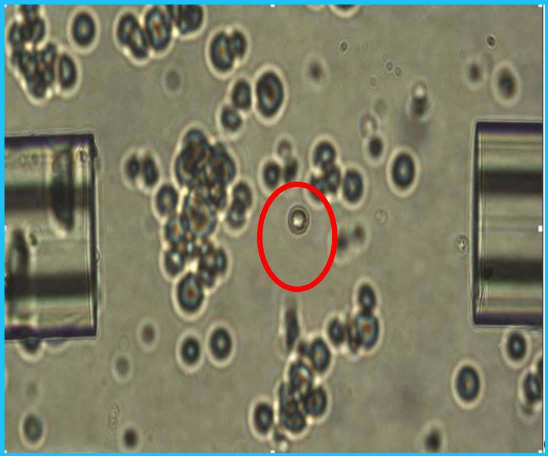
Polystyrene (d~10 μm)



liquid crystals (d~5-20 μm)



yeast (d~10 μm)



Stem cells (d~10 μm)

Samples preparation

At the moment we're focusing on red blood cells (d~6 μm)

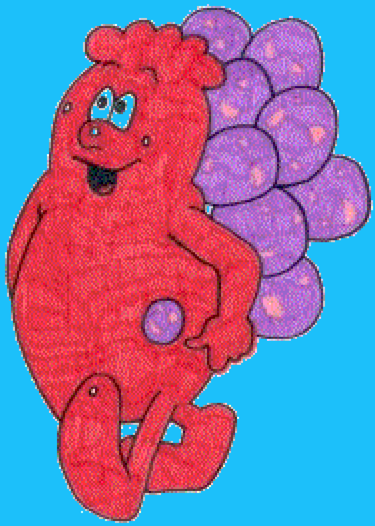
To simplify the stretching we need swollen cells, so we need a hypotonic solution

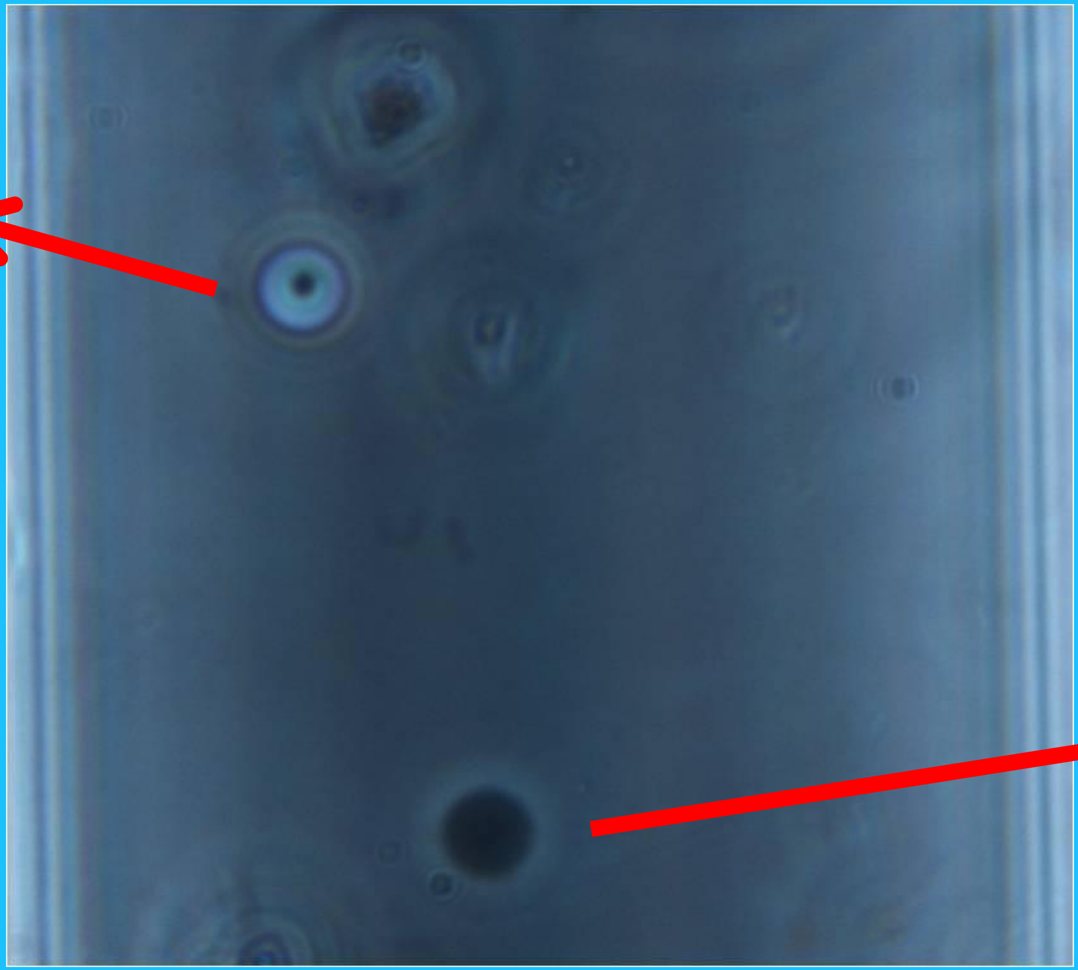
We dilute blood with physiological solution and distilled water and we add some albumin, glucose, calcium and heparin

We insert the solution in the micro-fluidic system and we trap one cell at a time

RBCs in a microfluidic channel

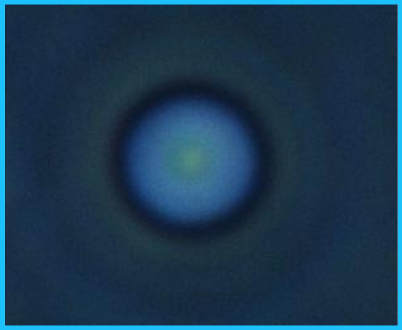
During the preparations, some RBCs are more stressed than the others and they lost hemoglobin



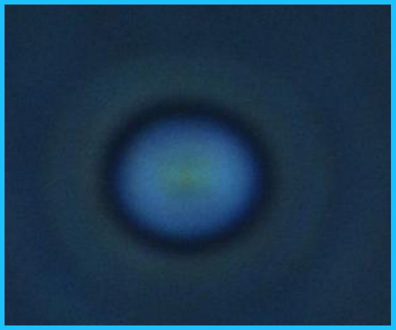


RBC deformation

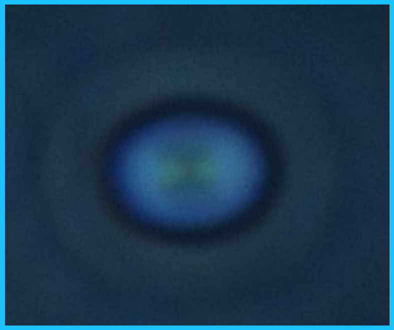
In this example we show the deformation of a trapped RBC increasing and decreasing the optical power



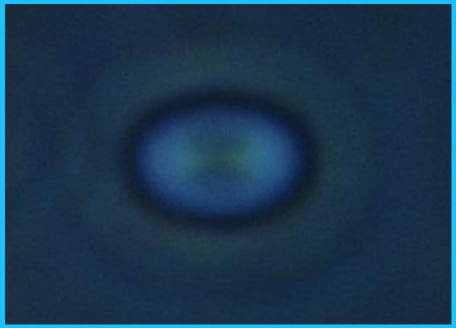
P = 10 mW



P = 100 mW



P = 190 mW



P = 280 mW

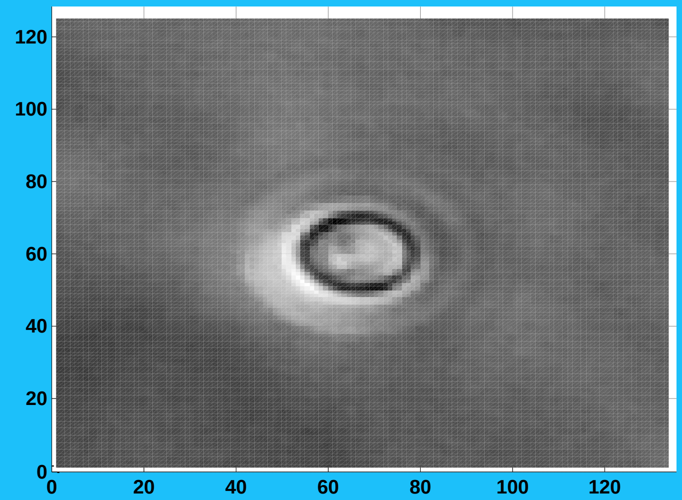
P = 370 mW

P = 450 mW
The membrane breaks

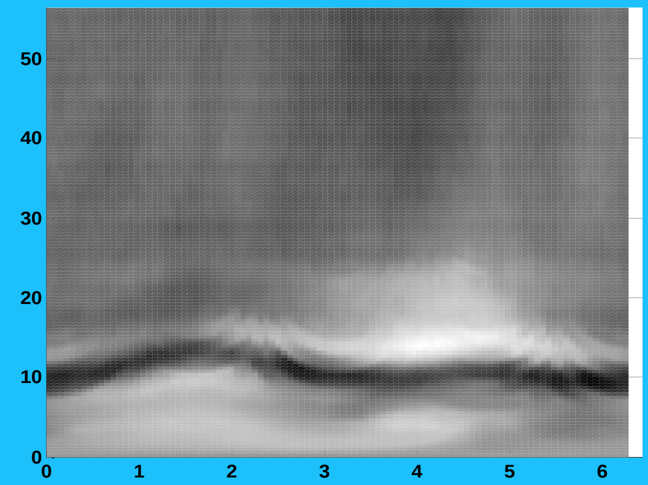
Analysis software

We created a Matlab program to analyze the images of the stretched cells to obtain mechanical parameters

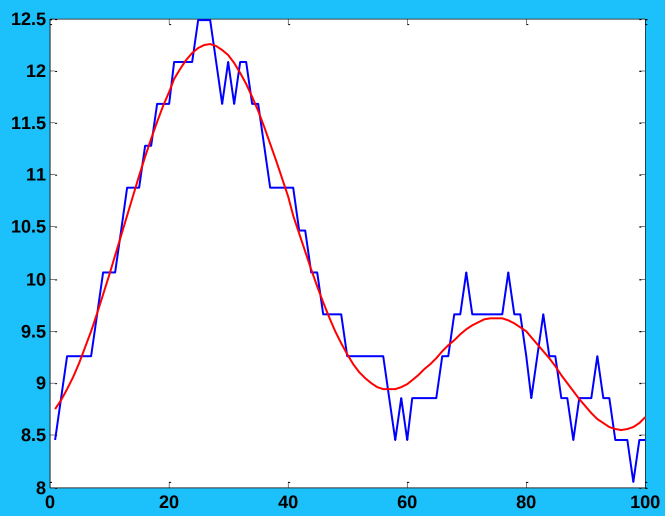
Original Image



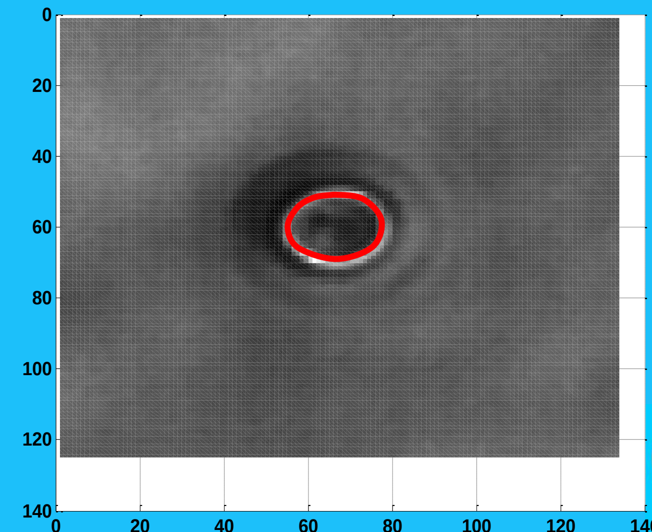
Polar coordinates



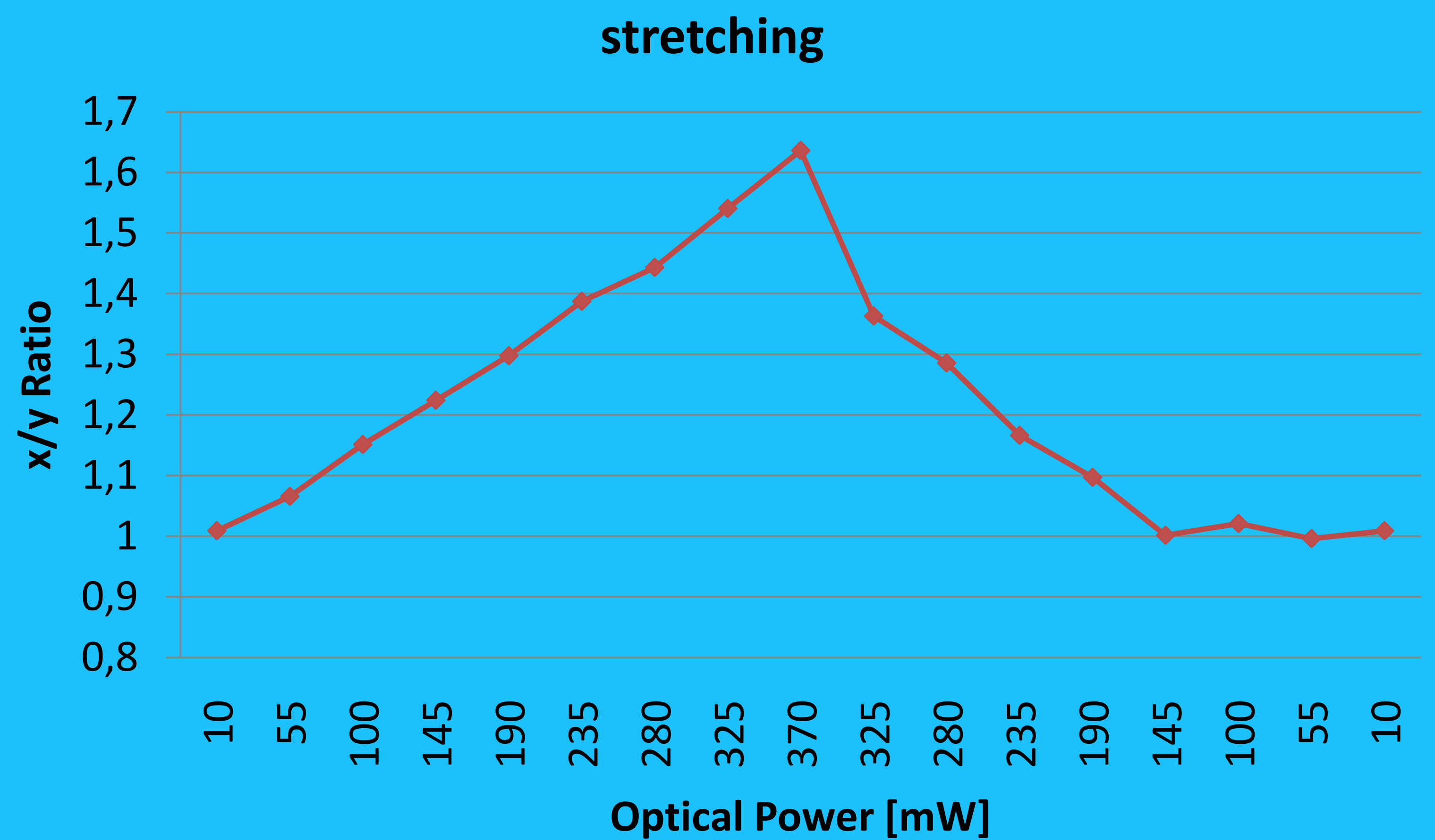
Filter



Reconstruction



Results



As we can see, RBCs stretch for increasing power and return swollen when the optical power decreases. This way we can obtain important parameters on the cells elasticity, like Young's modulus .

Conclusions and future

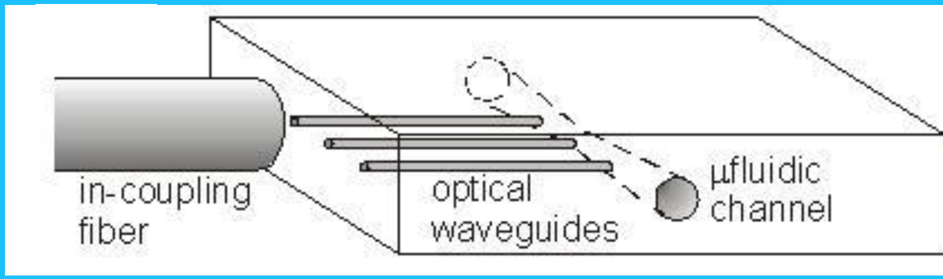
We implemented a fiber-optical device for non invasive single cell manipulation

We're able to trap and stretch biological material (RBCs, stem cells, yeast) and not biological material (polystyrene, liquid crystals)

This device could be the base for early diagnosis instruments

We're planning to create monolithic biophotonic devices

Lab-on-chip device



Monolithic optical device
to perform cell sorting
on the basis of mechanical
and optical properties