Frontiers of Nanotechnology with Optical Tweezers

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Seminários em Nanociências e Materiais Avançados
UFABC, Santo André, 24 de Fevereiro de 2015.

Antonio Neves

Background

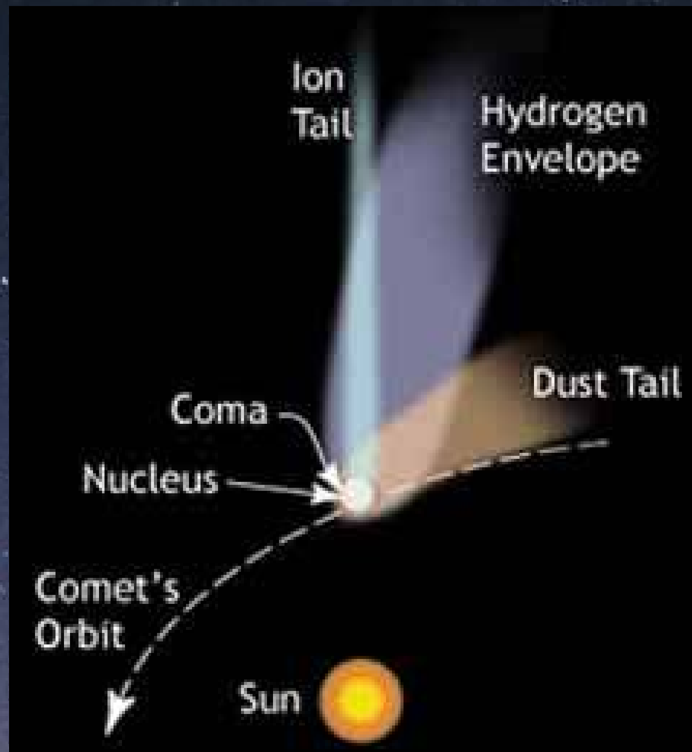
B.Sc. at Univ. Brasilia (1999)
M.Sc. at Unicamp (2002)
Ph.D. at Unicamp (2006)
Post-doc at NNL (2009)
Professor at UFABC (2012)

Research

Scientific Instrumentation; Synthesis & Characterization of Quantum Dots; Nonlinear Optics; Soft matter; **OPTICAL TWEEZERS**.

Email:
antonio.neves@ufabc.edu.br

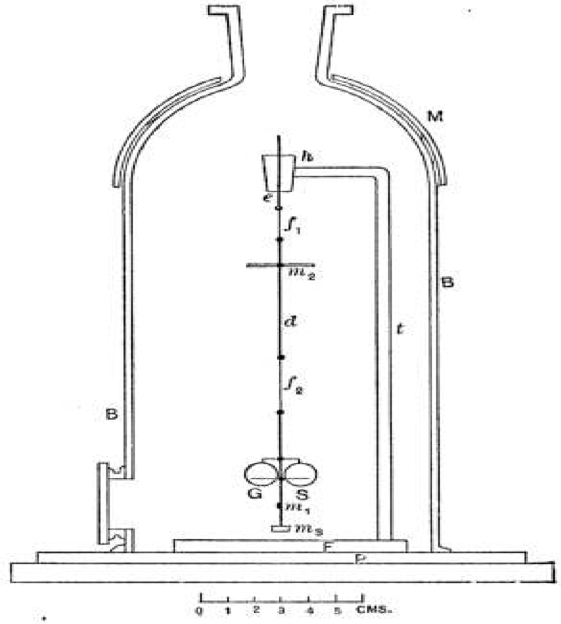
Examples from nature

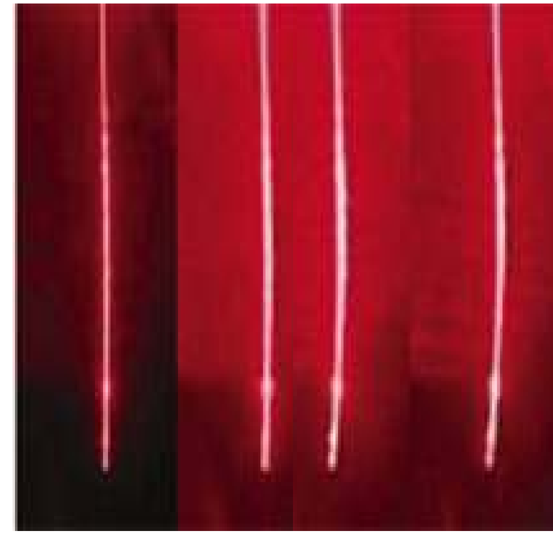


Hale-Bopp Comet (29/03/1997)

Johannes Kepler (Halley's comet 1607)

RADIATION PRESSURE





Phil. Trans. R. Soc. Lond. 164, 501(1874)

Crookes radiometer

Phys. Rev., 13, 307 (1901)

Nichols and Hull, torsion balance

Phys. Rev. Lett., 101, 243601 (2008)

She *et al.*, optical fiber kick

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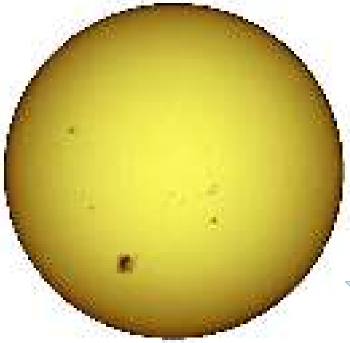
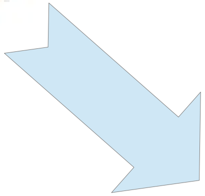
TYPICAL DIMENSIONS

Linear momentum $p = h/\lambda$

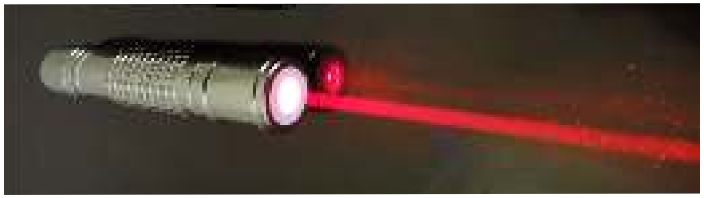
Energy $E = hc/\lambda = pc$

Force $F = \frac{\Delta p}{\Delta t} = 2\frac{E}{ct} = 2\frac{P}{c}$





The Sun exerts a pressure of up to 4,7 μN/m²



A laser-pointer (1 mW) reflection generates 7pN.

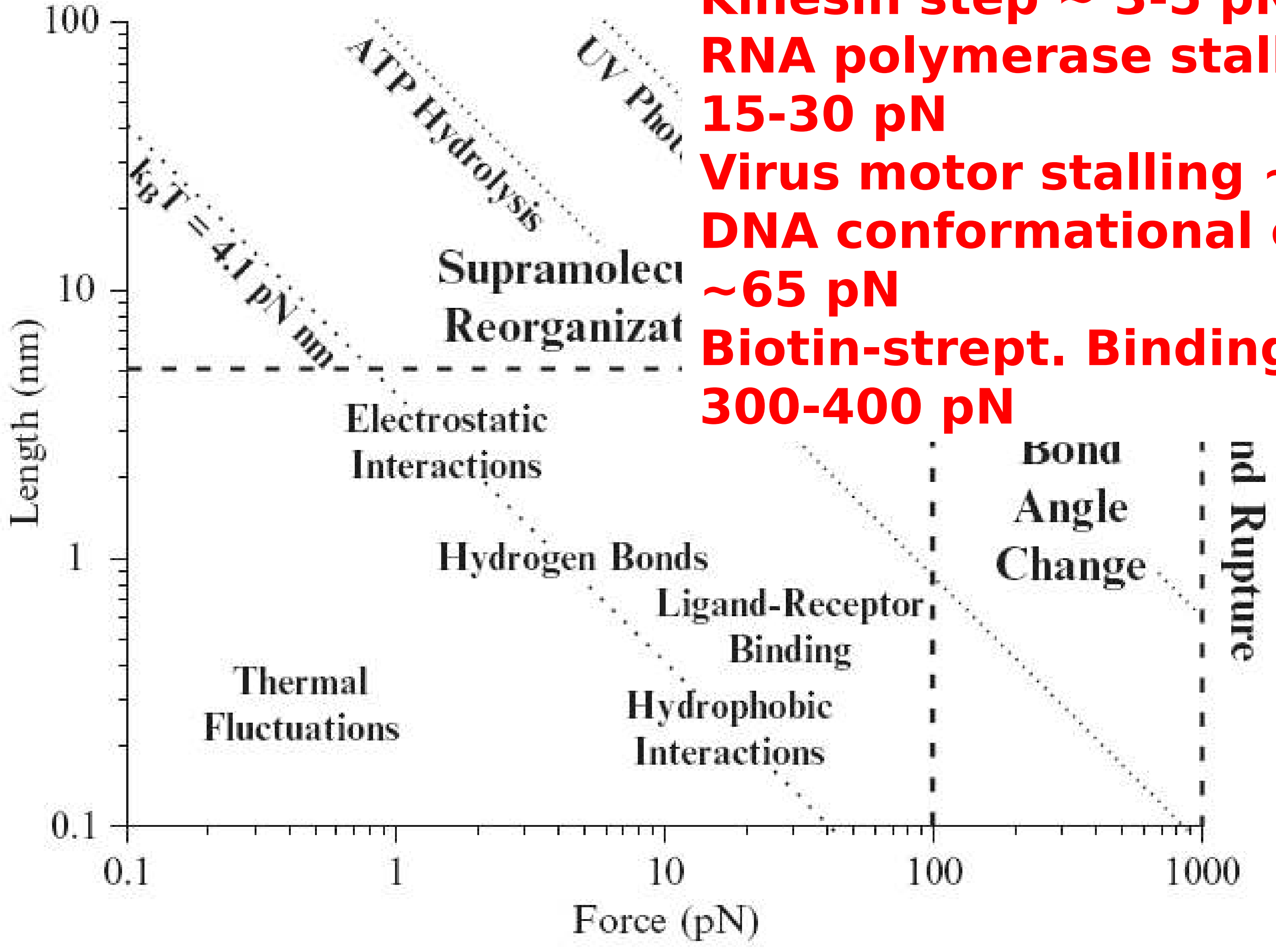
A spherical droplet of 5 μm in size, weights 5pN.

FORCE SPECTROSCOPY TECNIQUES

	Magnetic Tweezers	Optical Tweezers	Electrophoresis	AFM	Micropipette	Fluid Flow
Type	Global/ Point	Point	Global	Point	Point	Global
	Non-Contact	Non-Contact	Non-Contact	Contact	Contact	Non-Contact
Force Range (pN)	0.1–200	0.1–200	0.01–50	10–100000	1–1000	0.1–1000
3D Trap	Yes	Yes	No	Yes	Yes	No
Stiffness (pN nm^{-1})	10^{-6} – 0.1	10^{-6} – 0.1	-	10–10000	0.01–1000	-
Energy Dissipation	No	Yes	Yes	No	No	No
Surface Considerations	No	No	No	Yes	Yes	No
Low Cost	Yes	Yes	Yes	No	Yes	Yes
Parallel	Yes	Yes	Yes	No	No	Yes
Access inside a cell	Yes	Yes	Yes	No	No	No
Self-assembly	Yes	No	Yes	No	No	No

From: Handbook of Molecular Force Spectroscopy, Edited by Aleksandr Noy

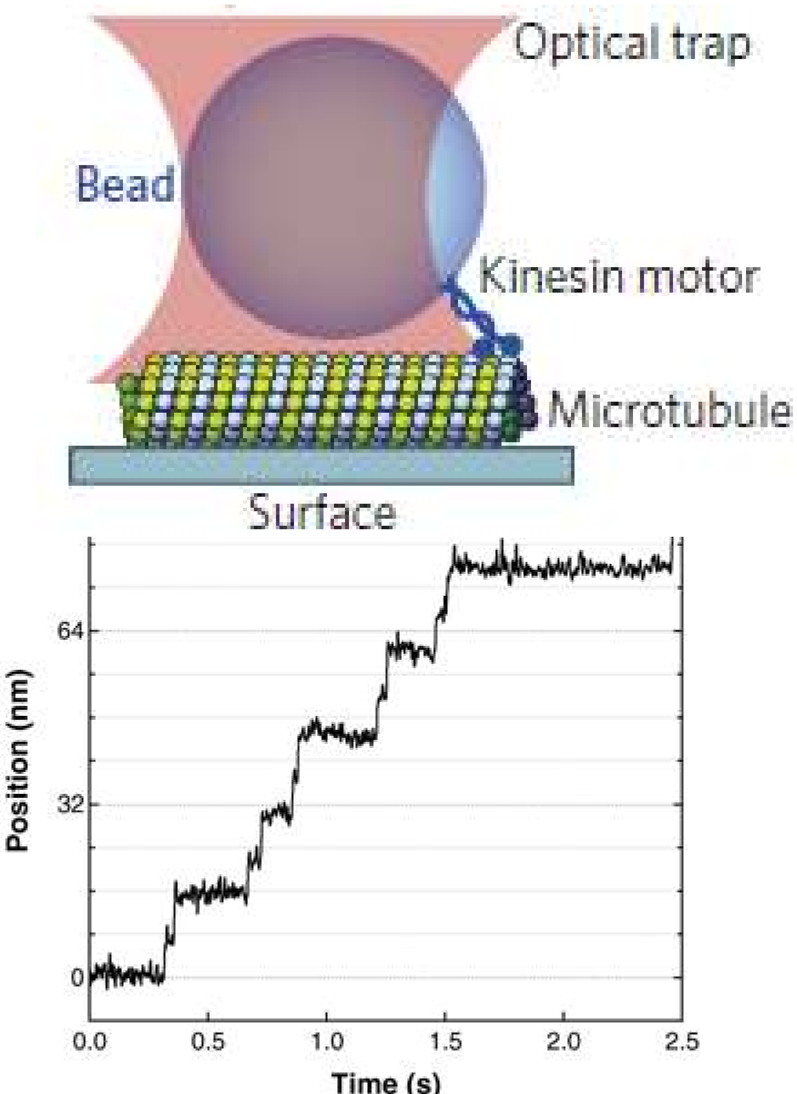
BIOMOLECULAR SCALES



Kinesin step ~ 3-5 pN
RNA polymerase stalling ~ 15-30 pN
Virus motor stalling ~50 pN
DNA conformational change ~65 pN
Biotin-strept. Binding ~ 300-400 pN

From: Handbook of Molecular Force Spectroscopy, Edited by Aleksandr Noy

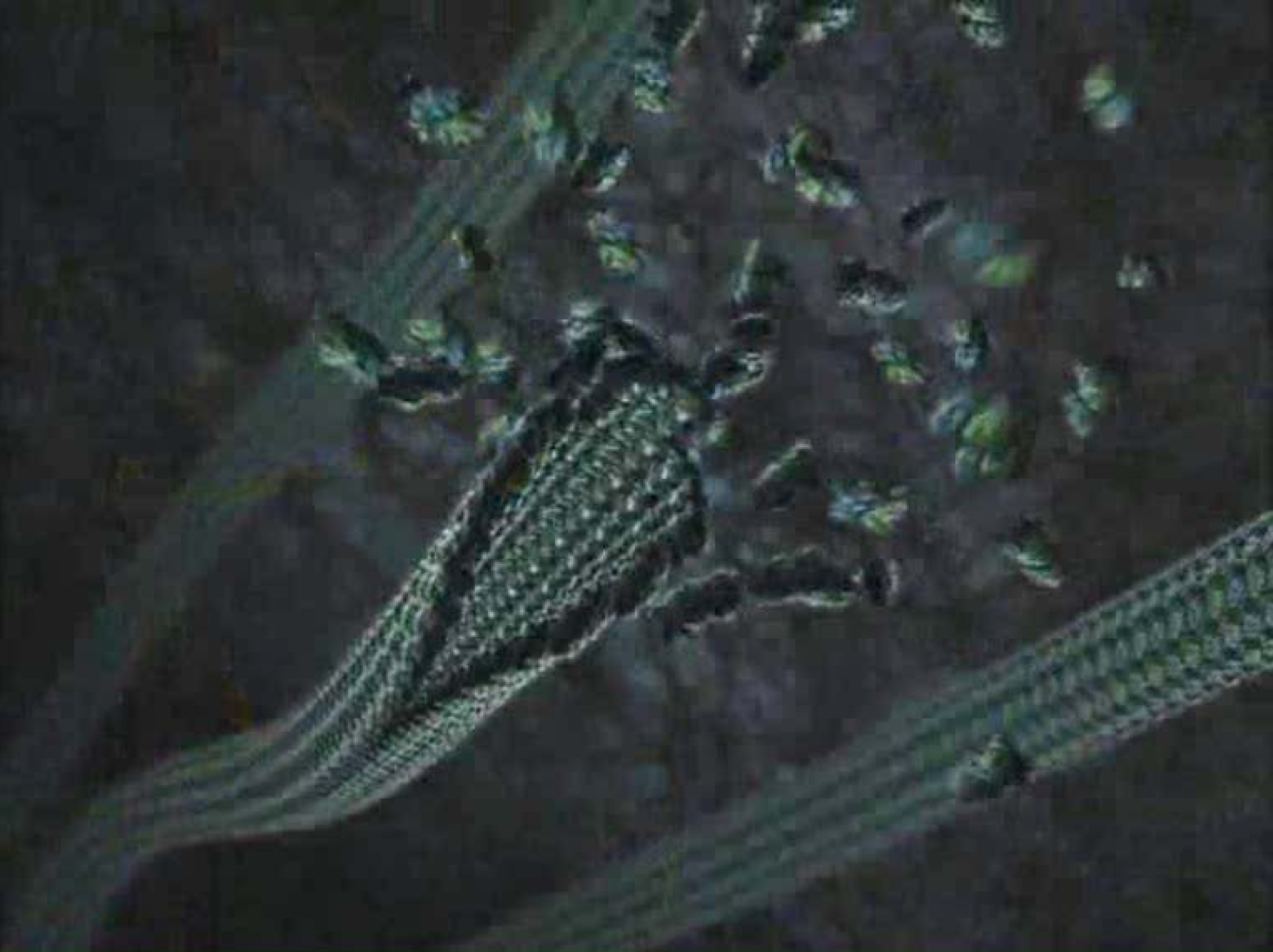
SPATIAL RESOLUTION?



From: Nature 348, 348 (1990)

Forces from < 1 pN to 100s pN
Length precision ~ 1 nm
Thermal energy (kBT)
4 pN nm = 1/40 eV = 25 meV

Kinesin - 8 nm step, 6 pN stall
RNA Polymerase – 0.3 nm step, 25 pN stall
DNA Unzipping - 15 pN

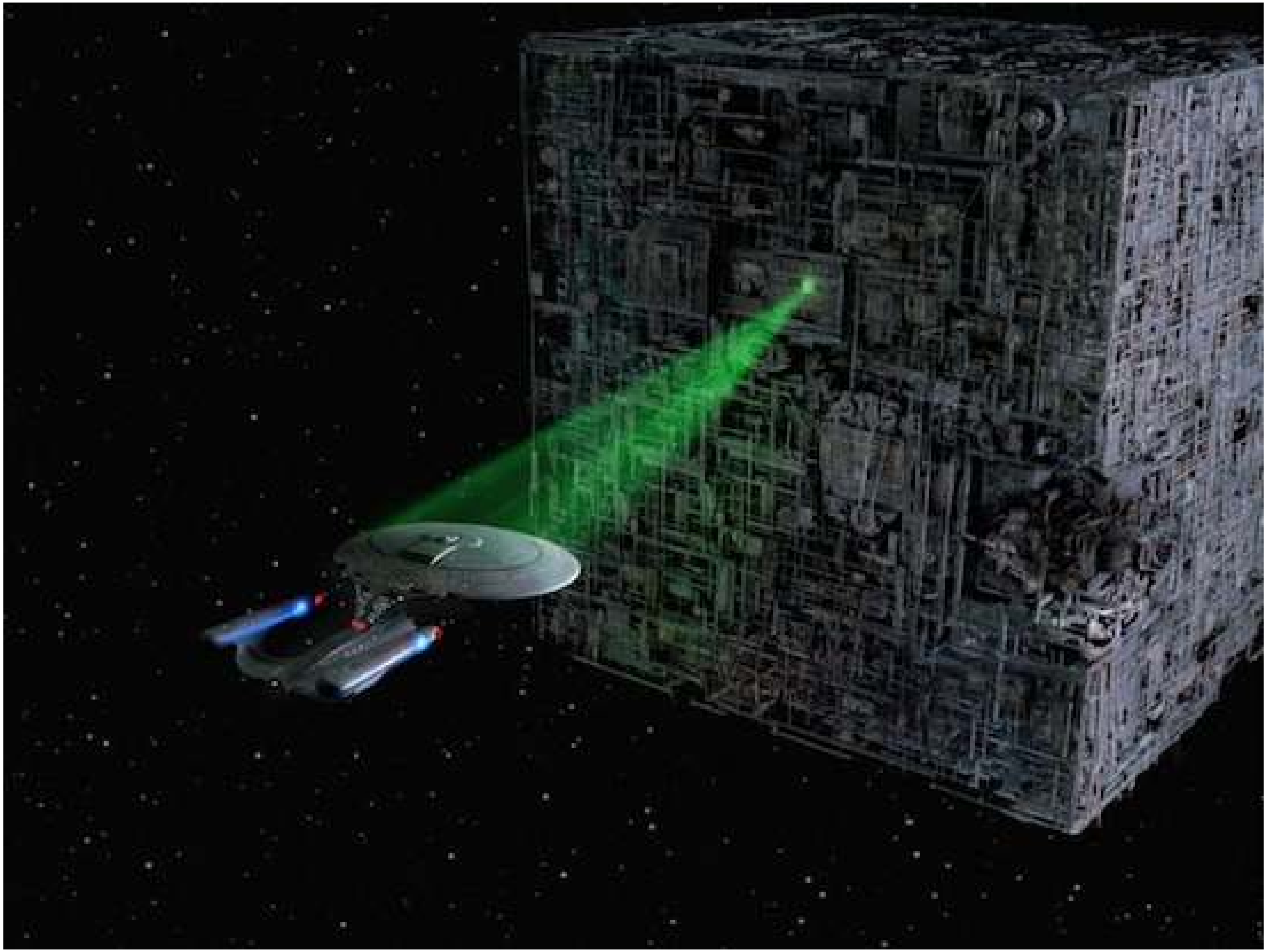


HUMAN IMAGINATION OR INSPIRATION

Jules Verne, From the Earth to the Moon, (1865)

Hermann Julius Oberth, Father of Space Travel, (1929)

STAR TREK: TRACTOR BEAM



REAL TRACTOR BEAM

nature photonics

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NATURE PHOTONICS | LETTER

Optical pulling force

Jun Chen, Jack Ng, Zhifang Lin & C. T. Chan

Nature Photonics 5, 531 (2011)

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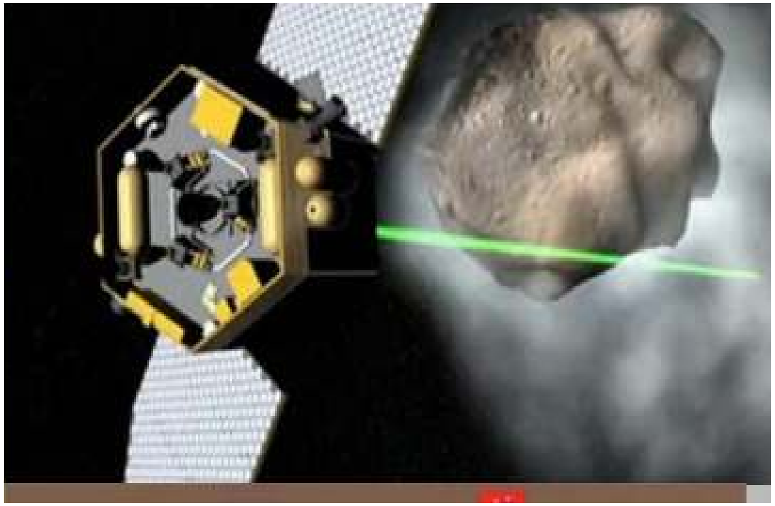
1 November 2011 Last updated at 10:42

Nasa examines 'tractor beams' for sample gathering



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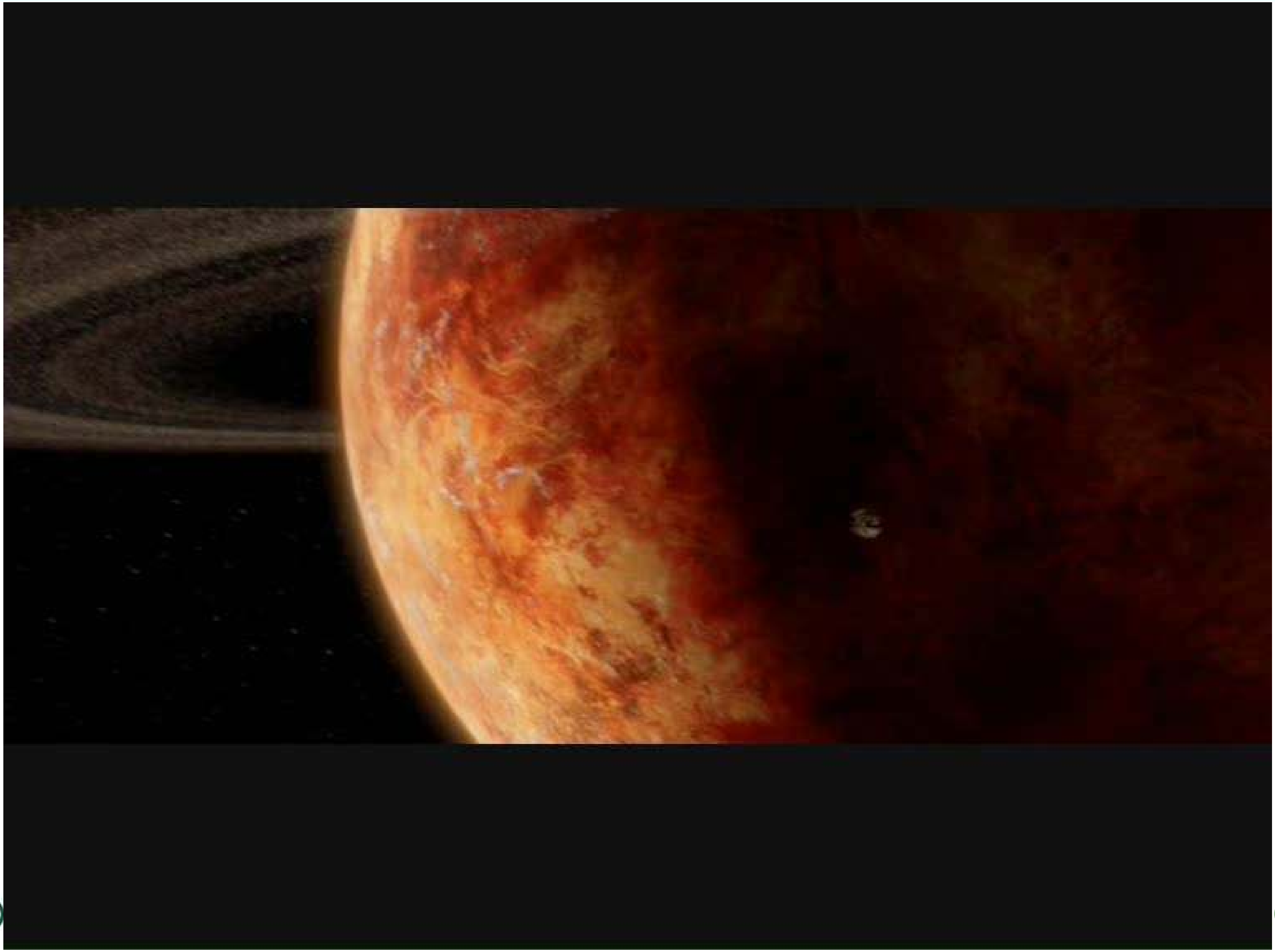
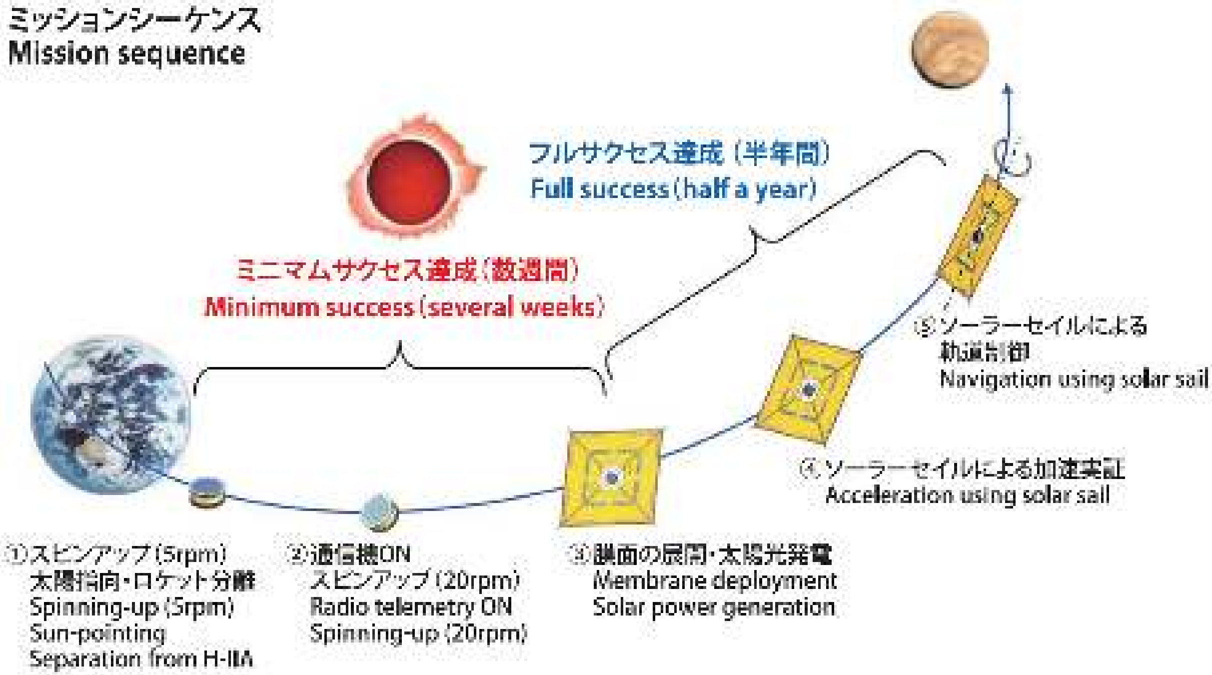
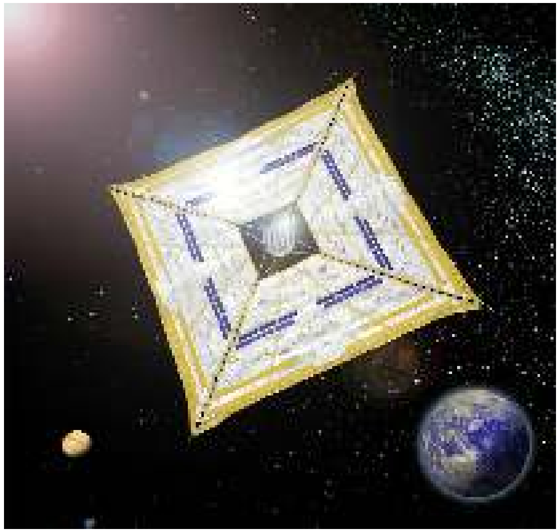
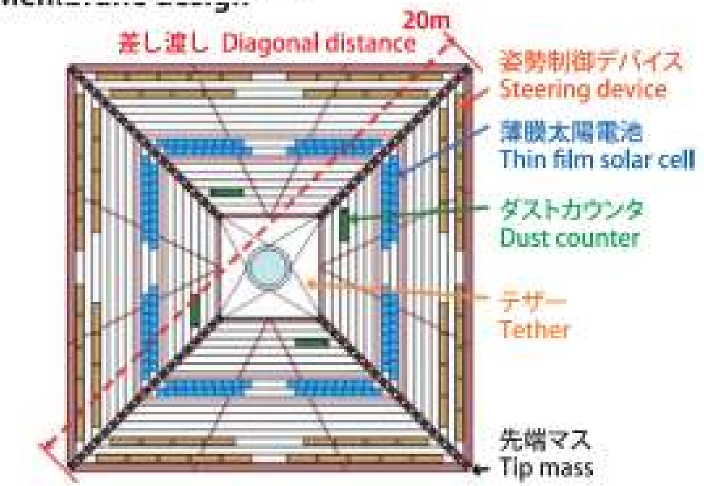
STAR WARS EPISODE II: ATTACK OF THE CLONES

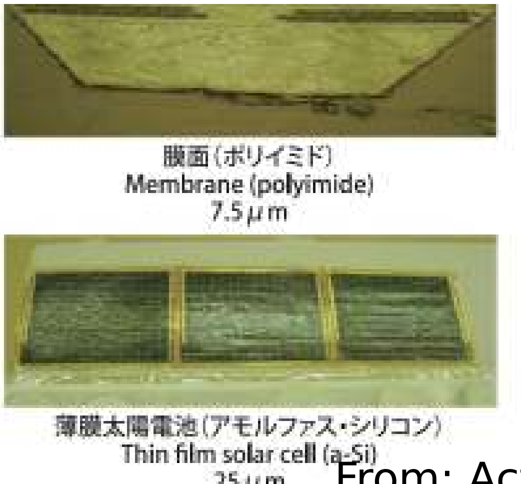


Interplanetary Kite-craft Accelerated by Radiation Of the Sun





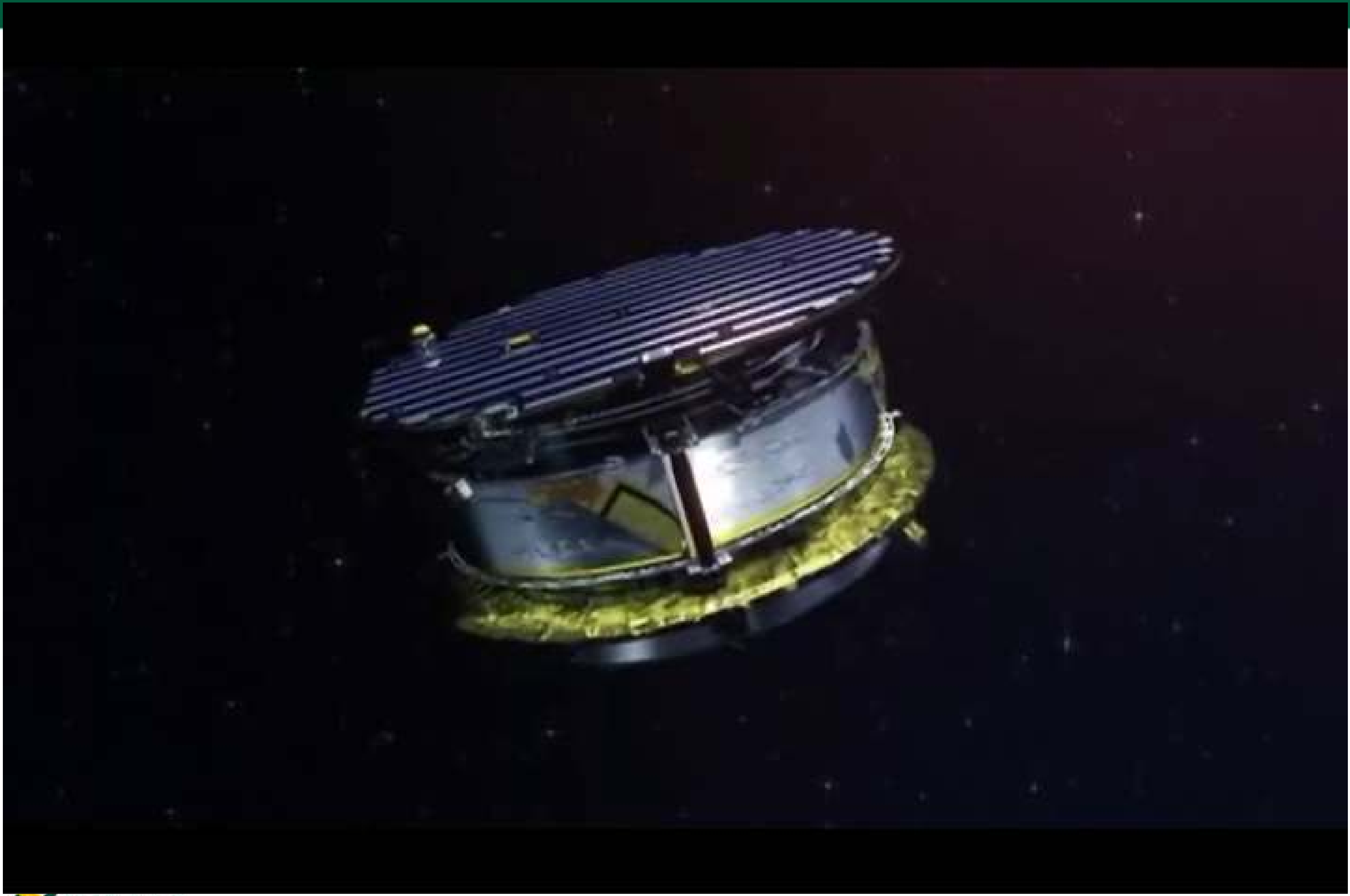




100 km/s in 6 months
~1.5 years from Sun to Pluto

From: Acta Astronautica 69, 833 (2011)

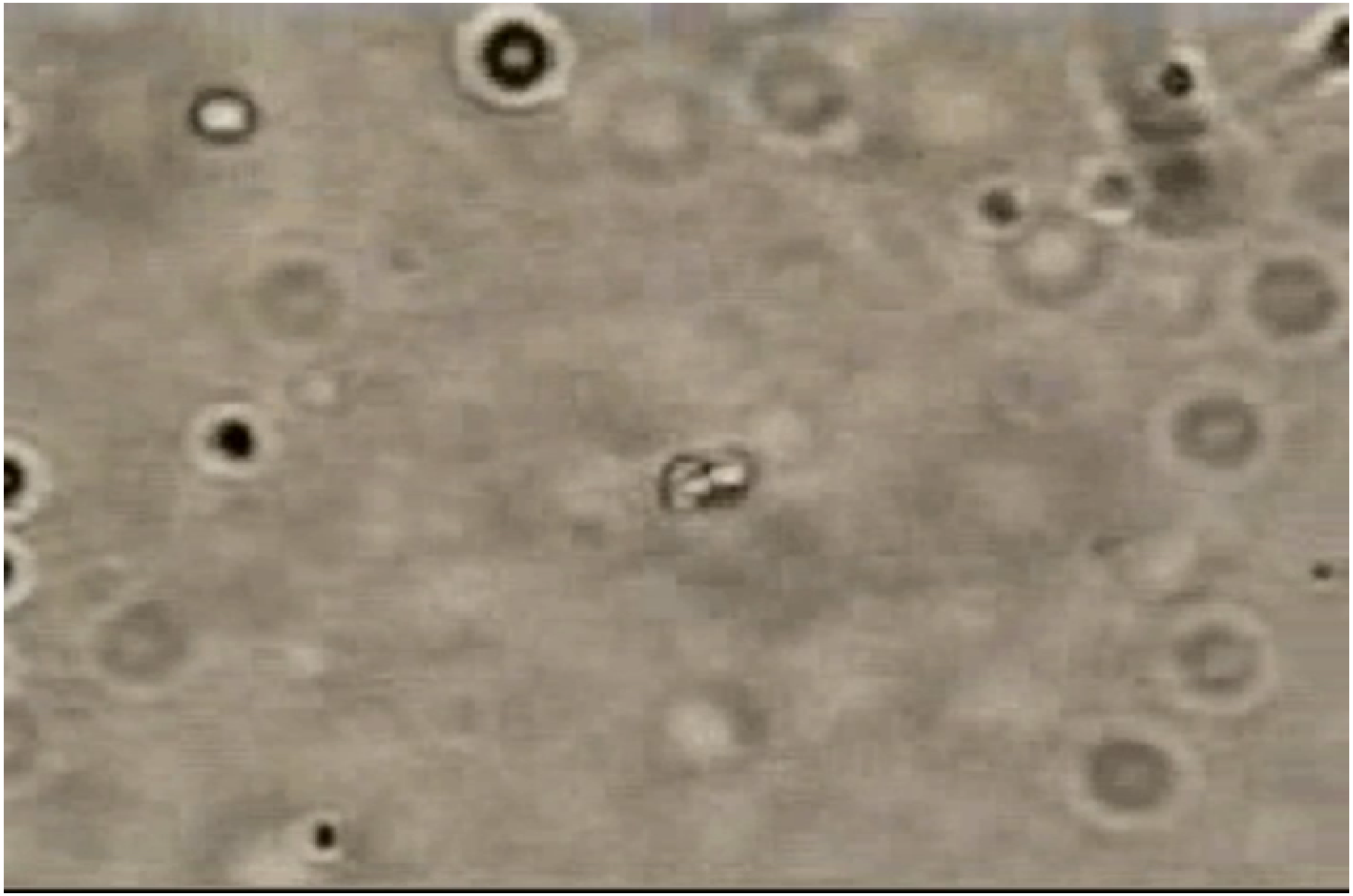
Interplanetary Kite-craft Accelerated by Radiation Of the Sun



PREVIOUS RESEARCH

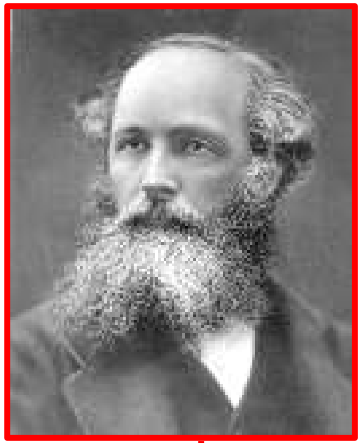
Chain of red blood cells in a double optical tweezers,
C. L. Cesar (Unicamp) e A. Fontes (UFPE)

PREVIOUS RESEARCH

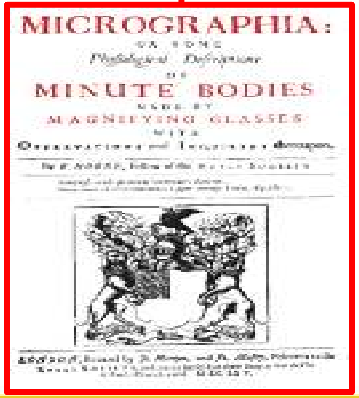


Sperm
C. L. Cesar (Unicamp) e A. Fontes (UFPE)

TIMELINE: Early Optical Discoveries



1609 **1665** **1873** **1958**


MICROGRAPHIA:
OR SOME
Physiological Descriptions
OF
MINUTE BODIES
MADE BY
MAGNIFYING GLASSES
WITH
OBSERVATIONS and INQUIRIES thereupon.

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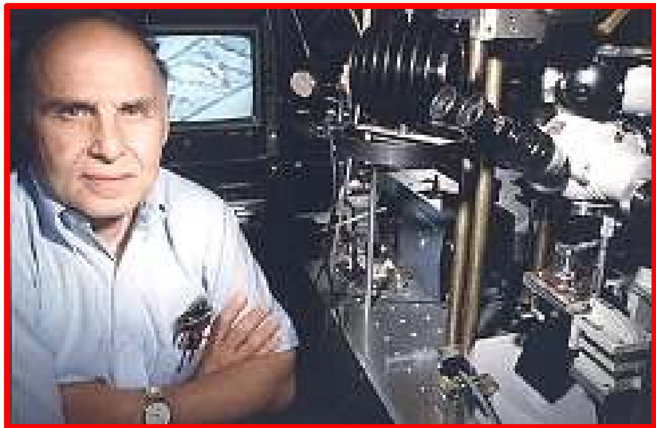
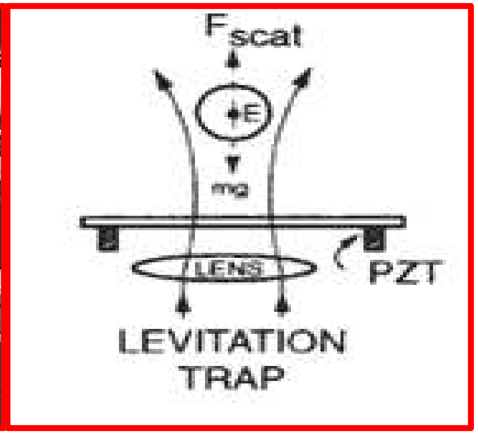
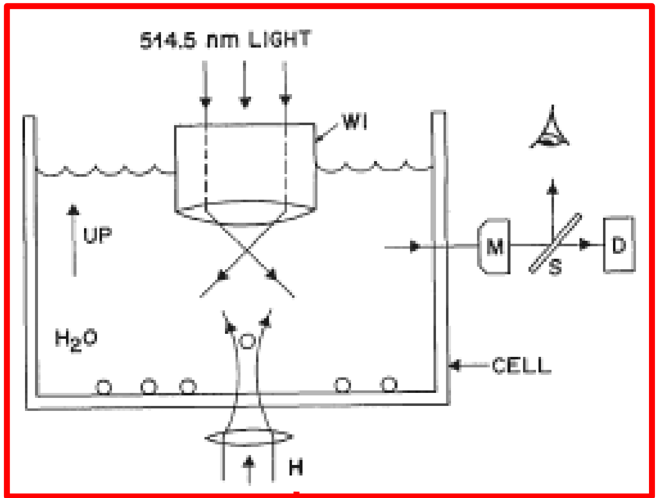
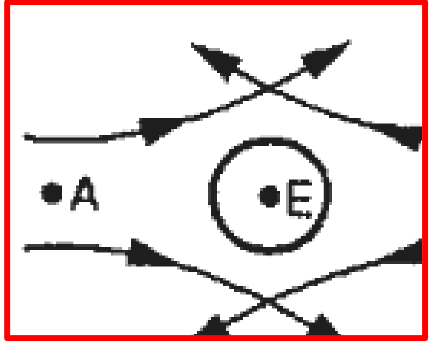
TIMELINE: Invention



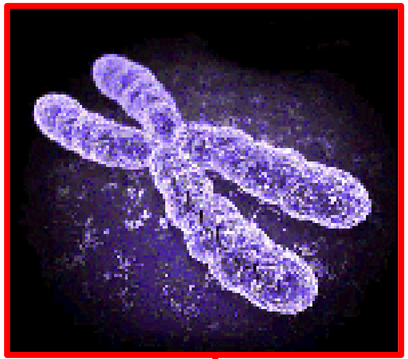




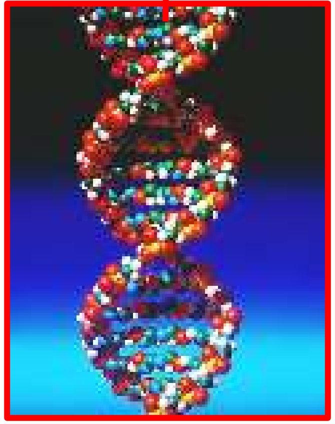
1970 **1978** **1986**



TIMELINE: Biological Aplications



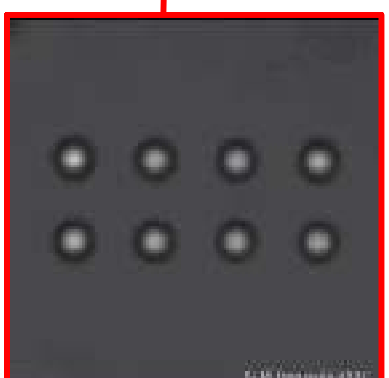
1987 1989 1990 1991



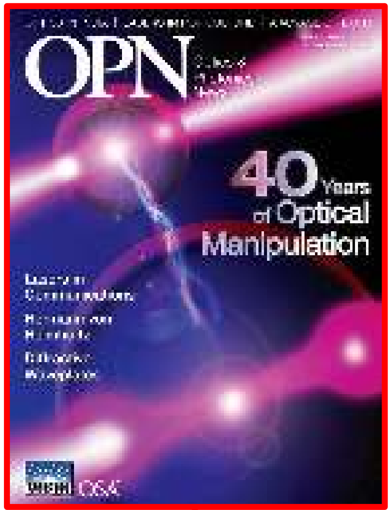
TIMELINE: Developments

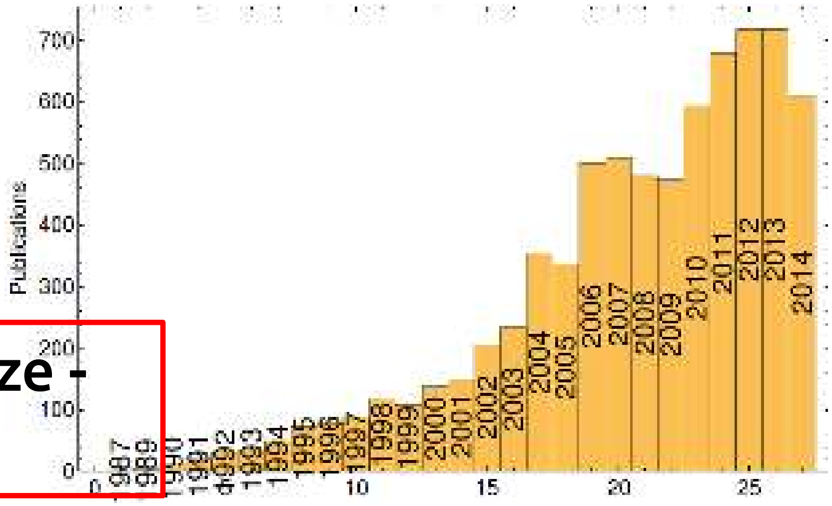
Physics Nobel Prize - optical fiber and CCD

1993 | 1997 | 2007 | 2009



TIMELINE: Very recent ...





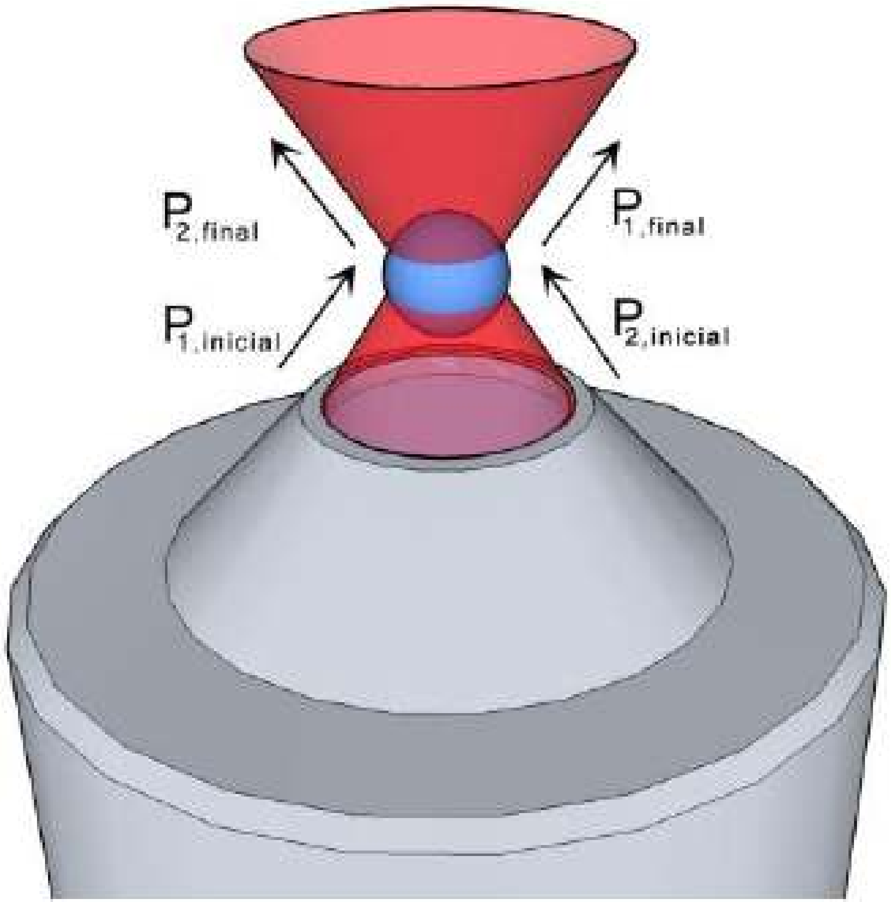
Physics Nobel Prize – LED

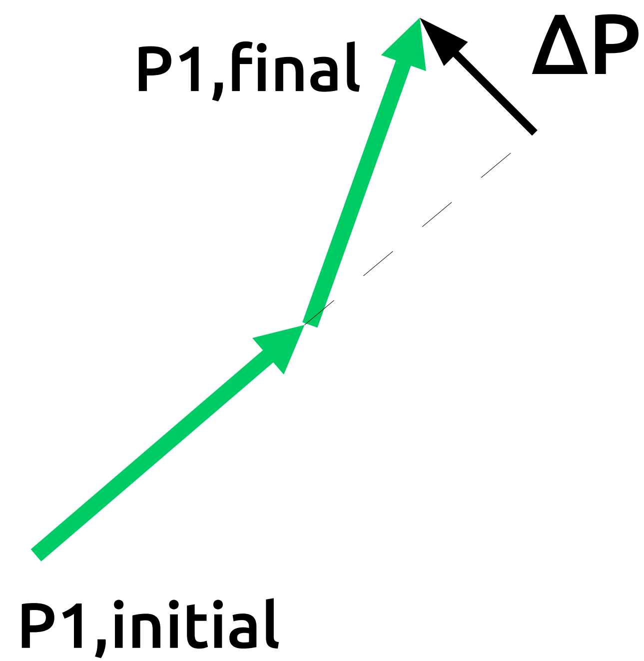
2010 **2014** **2015** **...**

Chemistry Nobel Prize – super-resolution microscopy

INTERNATIONAL YEAR OF LIGHT 2015

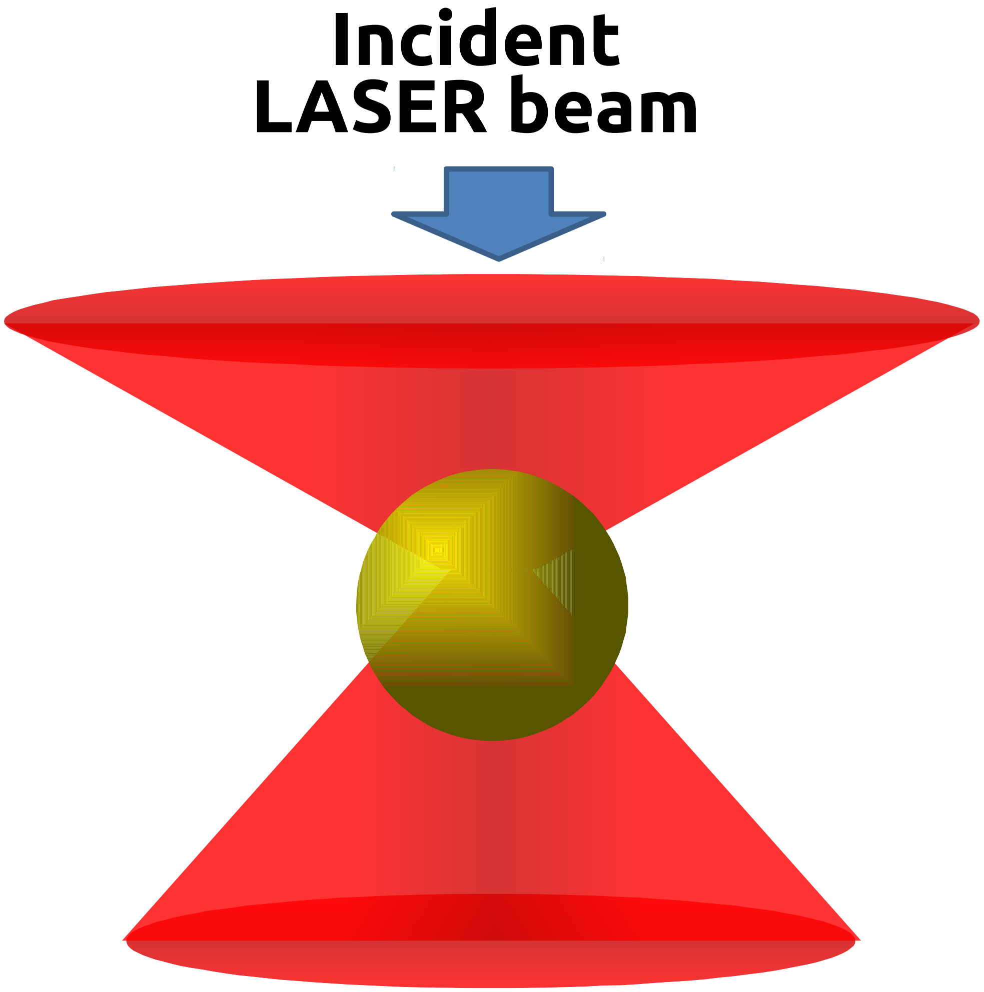
PRINCIPLES OF OPTICAL TRAPPING

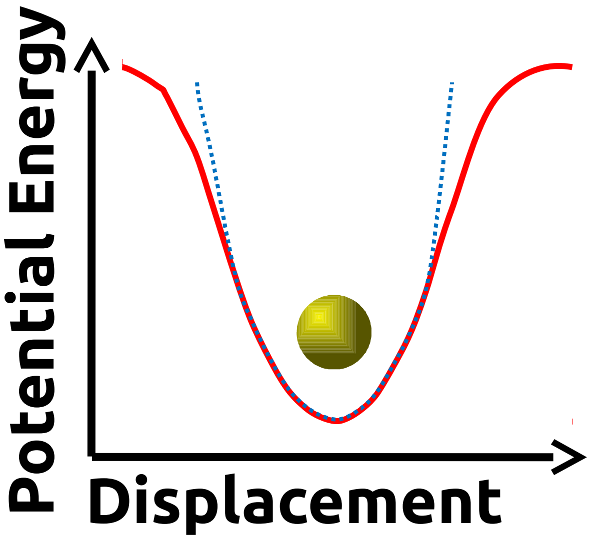




Transfer of momentum on the sphere as a result of the photon flux deflection.

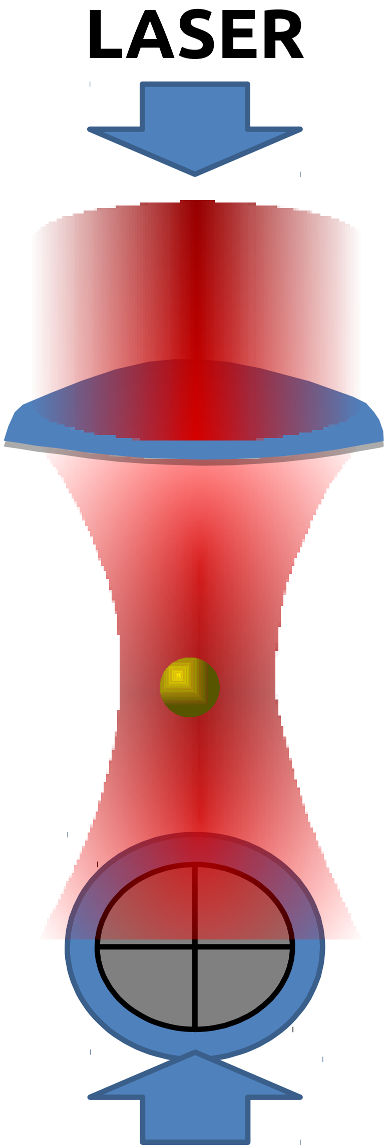
SPRING–MASS SYSTEM



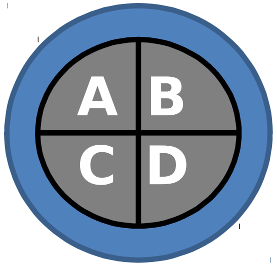


$$F = k\,\Delta x$$

MOTION DETECTION



Force proportional to displacement

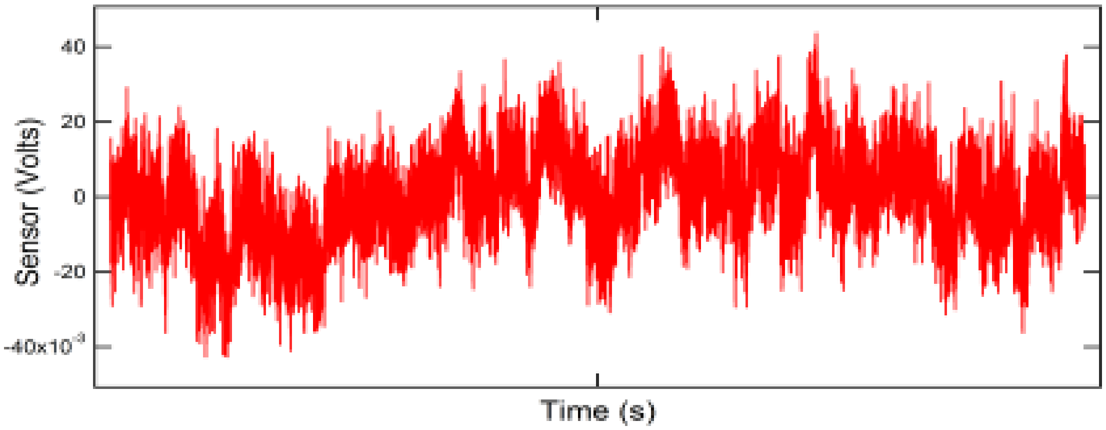


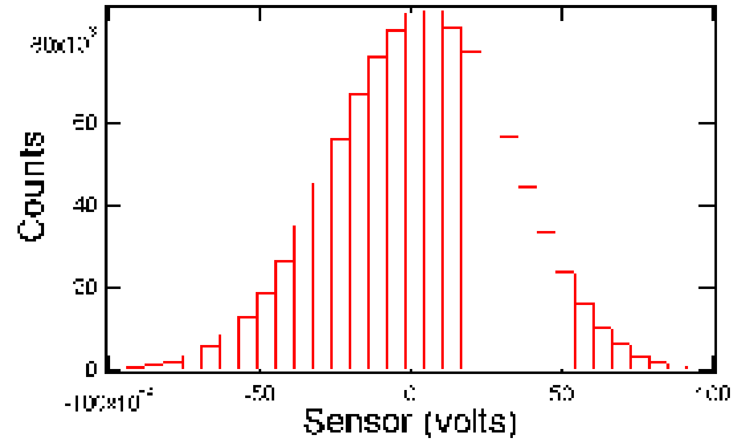
$$x = (A + C) - (B + D)$$

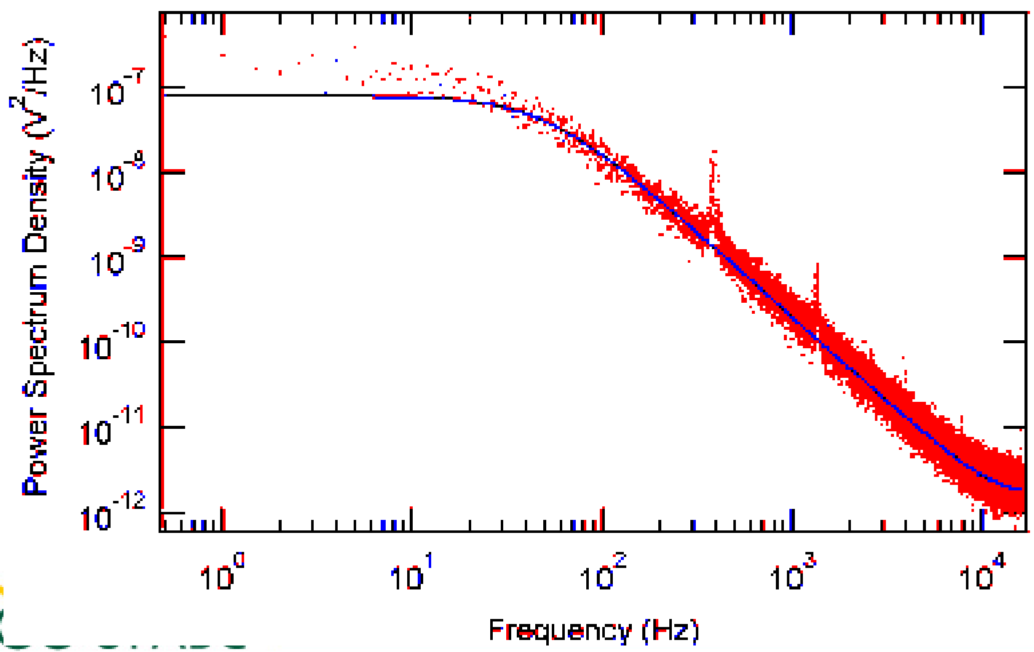
$$y = (A + B) - (C + D)$$

$$z = (A + B) + (C + D)$$

TRAP STIFFNESS DETERMINATION







Equipartition theorem

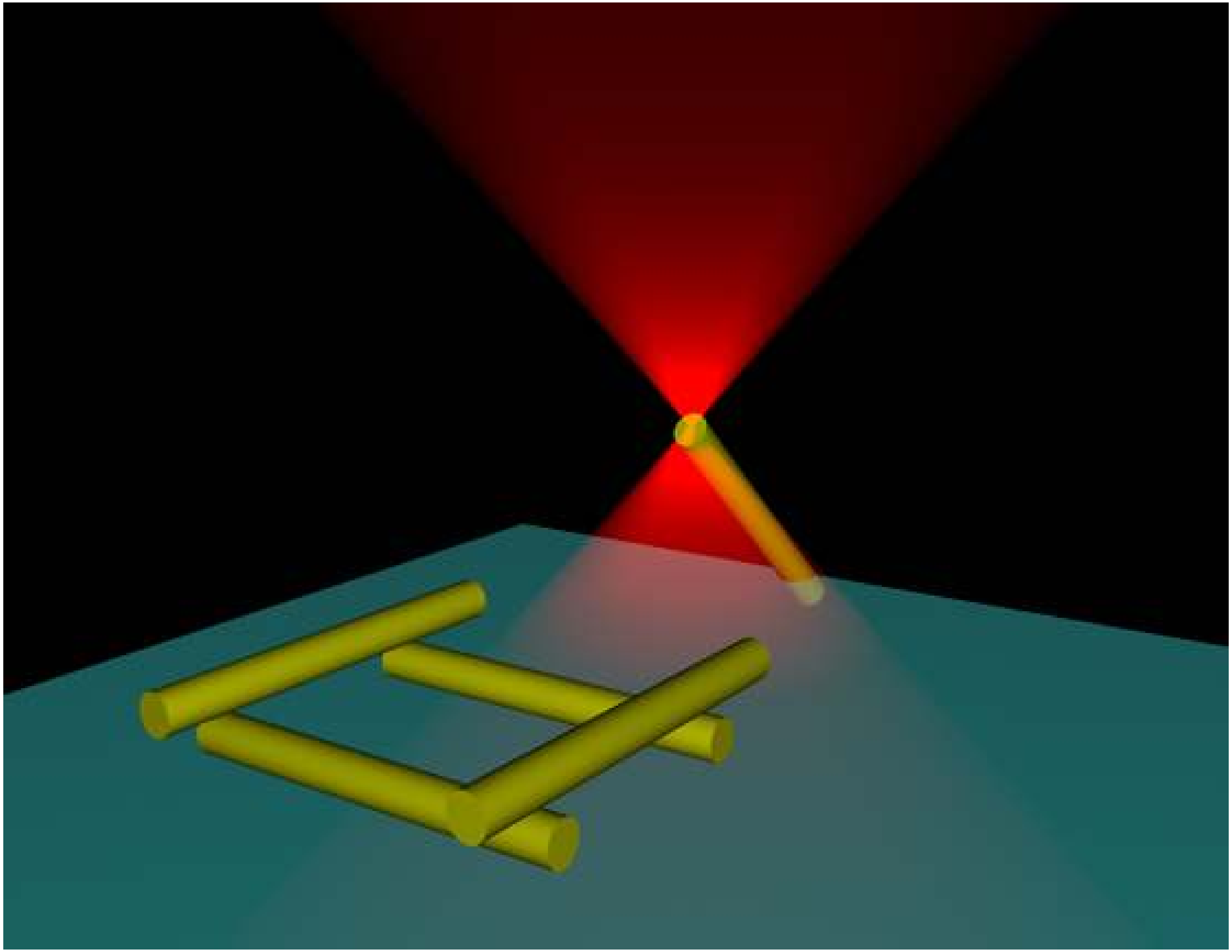
$$\frac{1}{2}k\left\langle x^2\right\rangle = \frac{1}{2}k_BT$$

$$\left|X(f)\right|^2 = \frac{k_BT}{\pi^2\gamma(f_c^2+f^2)}$$

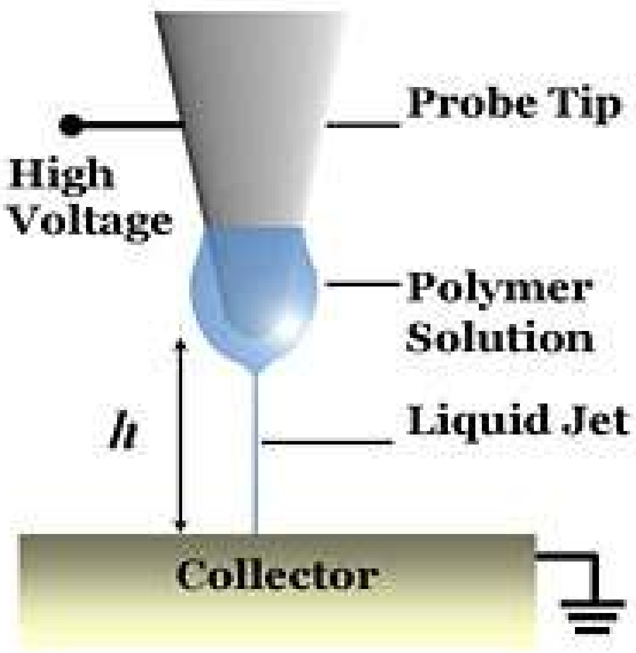
NA UFABC

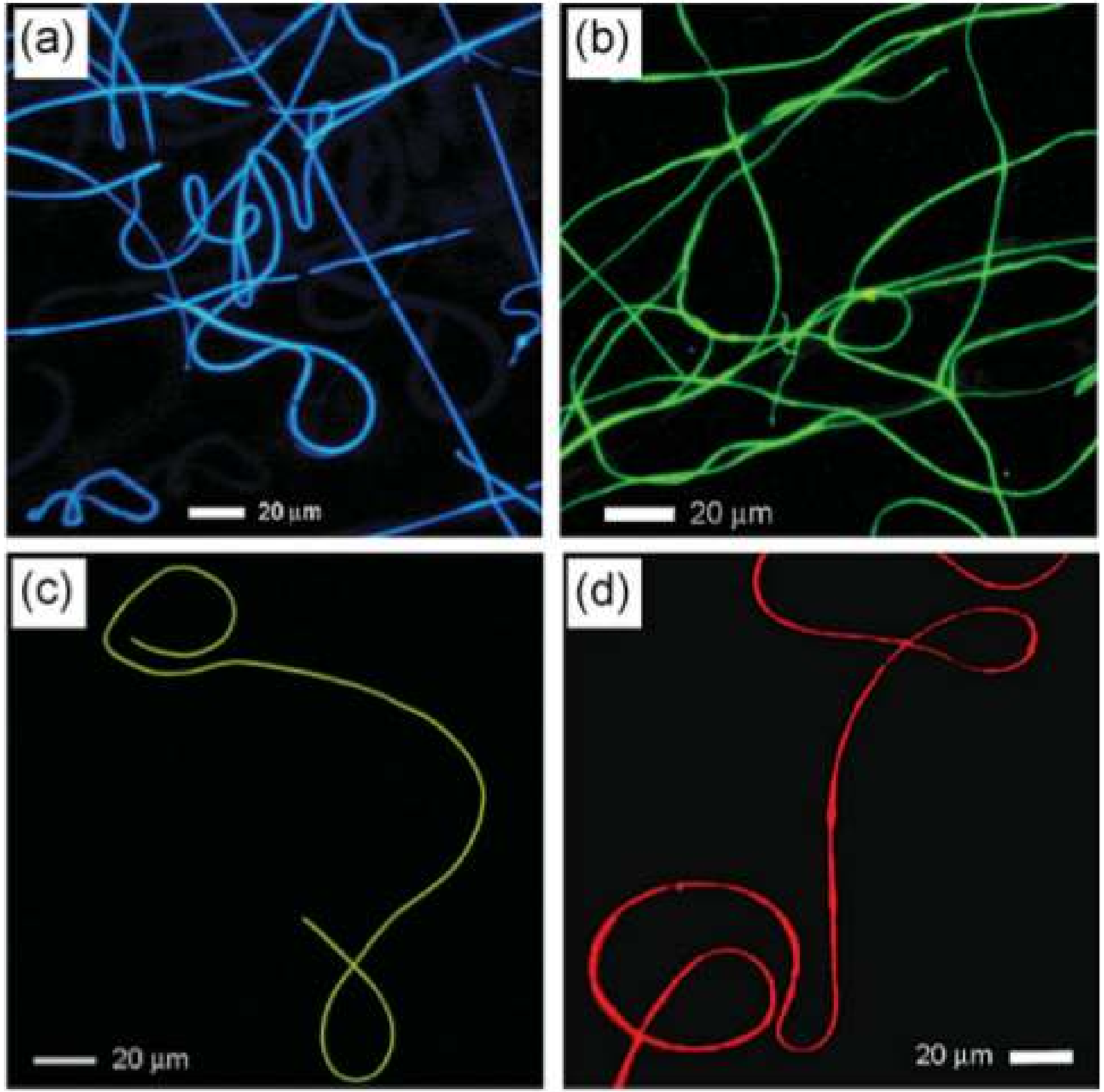
Collective movement of micro-spheres
T. Magrini e T. Dreyer (UFABC)

OPTICAL CIRCUITS WITH NANOFIBERS



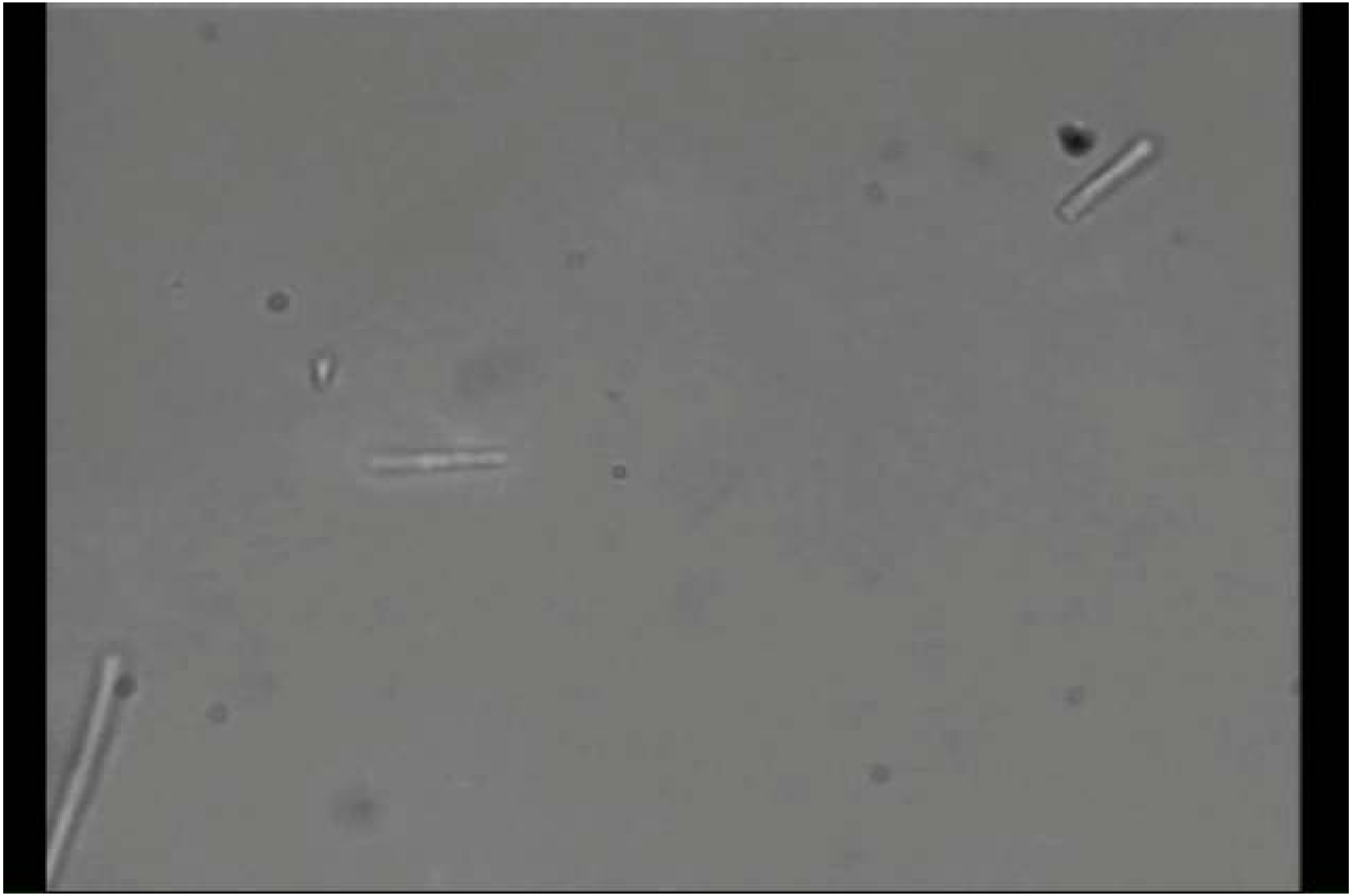
NANOFIBER FABRICATION



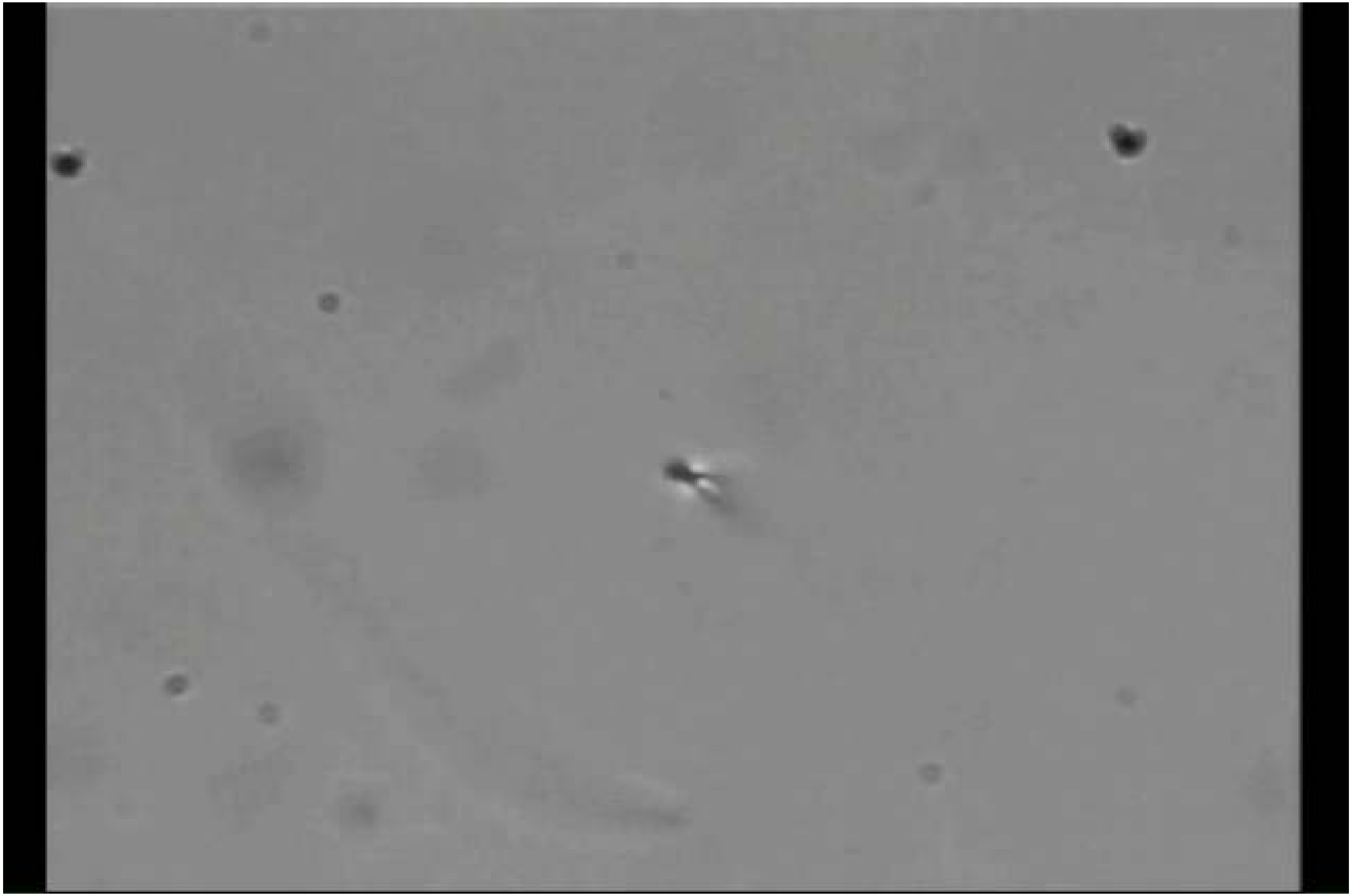


Small 5, 562 (2009)

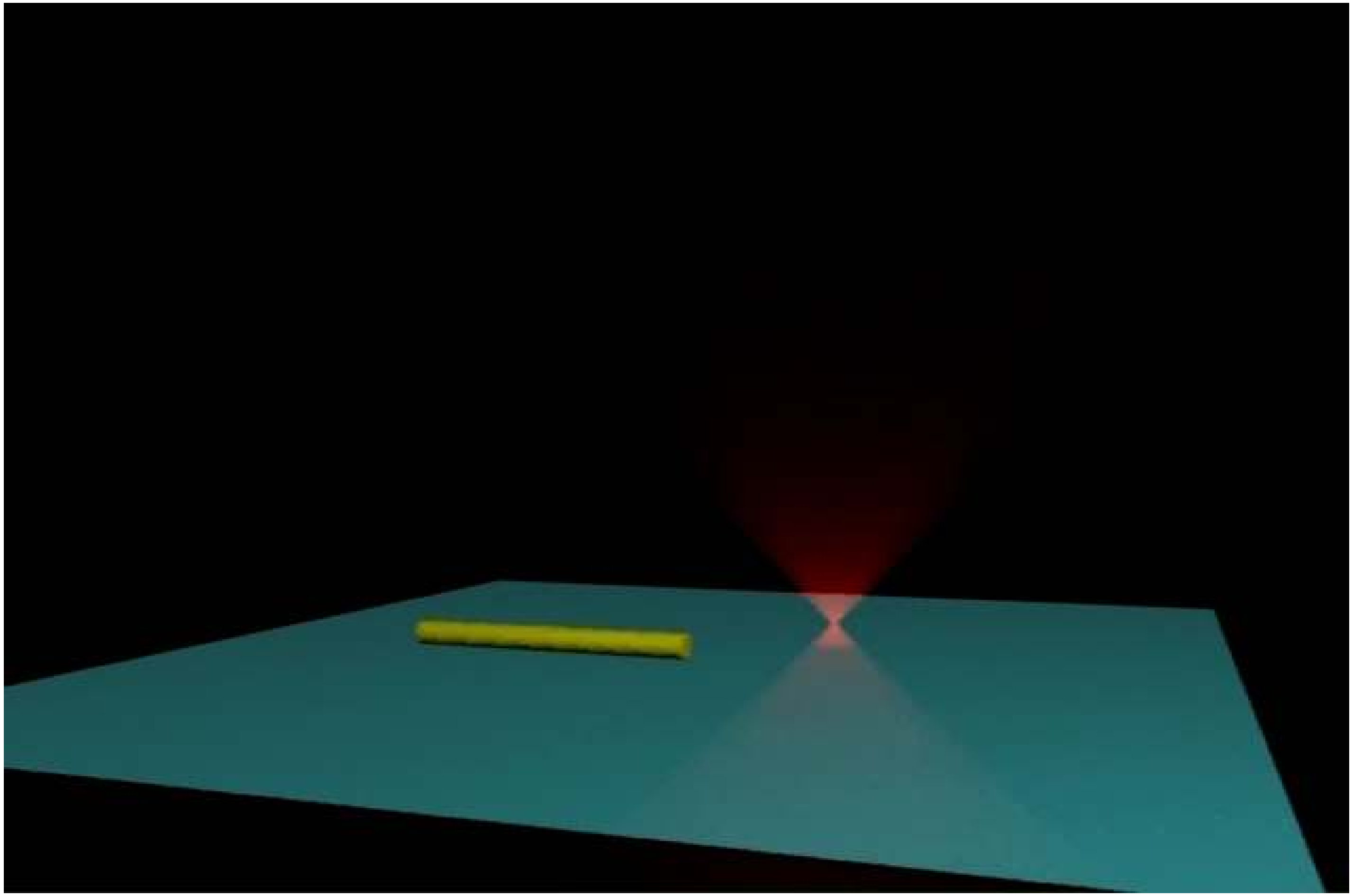
NANOFIBERS BEING TRAPPED



NANOFIBER ROTATION

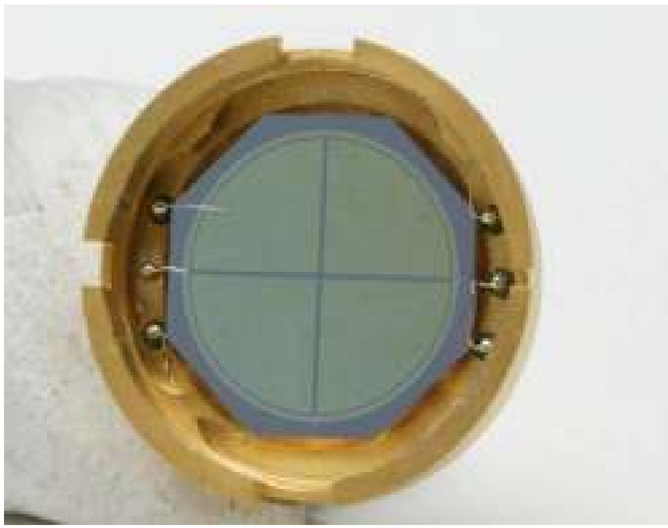


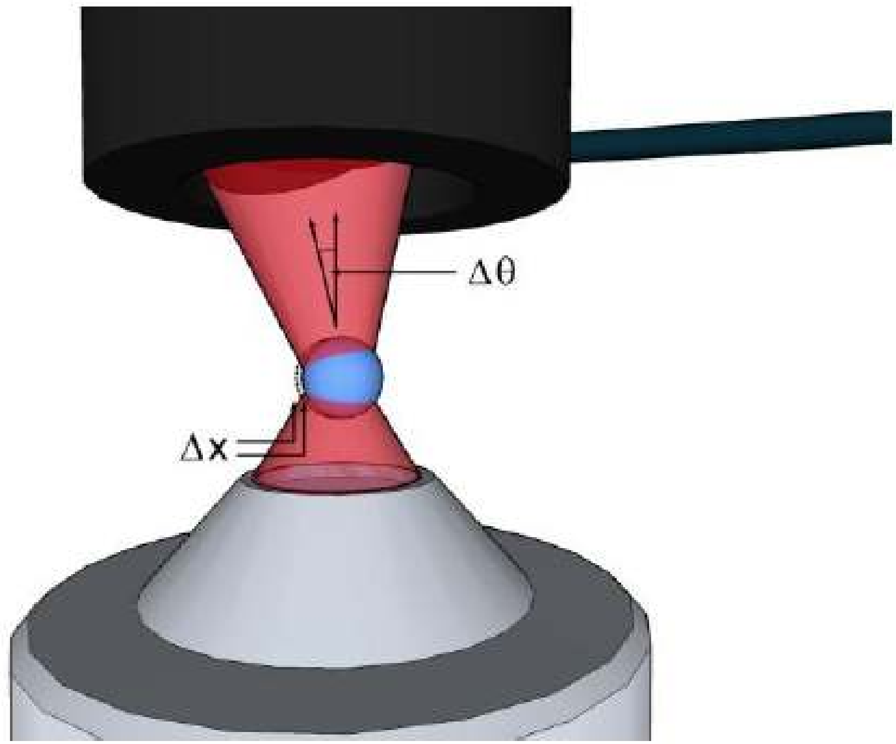
ANIMATION



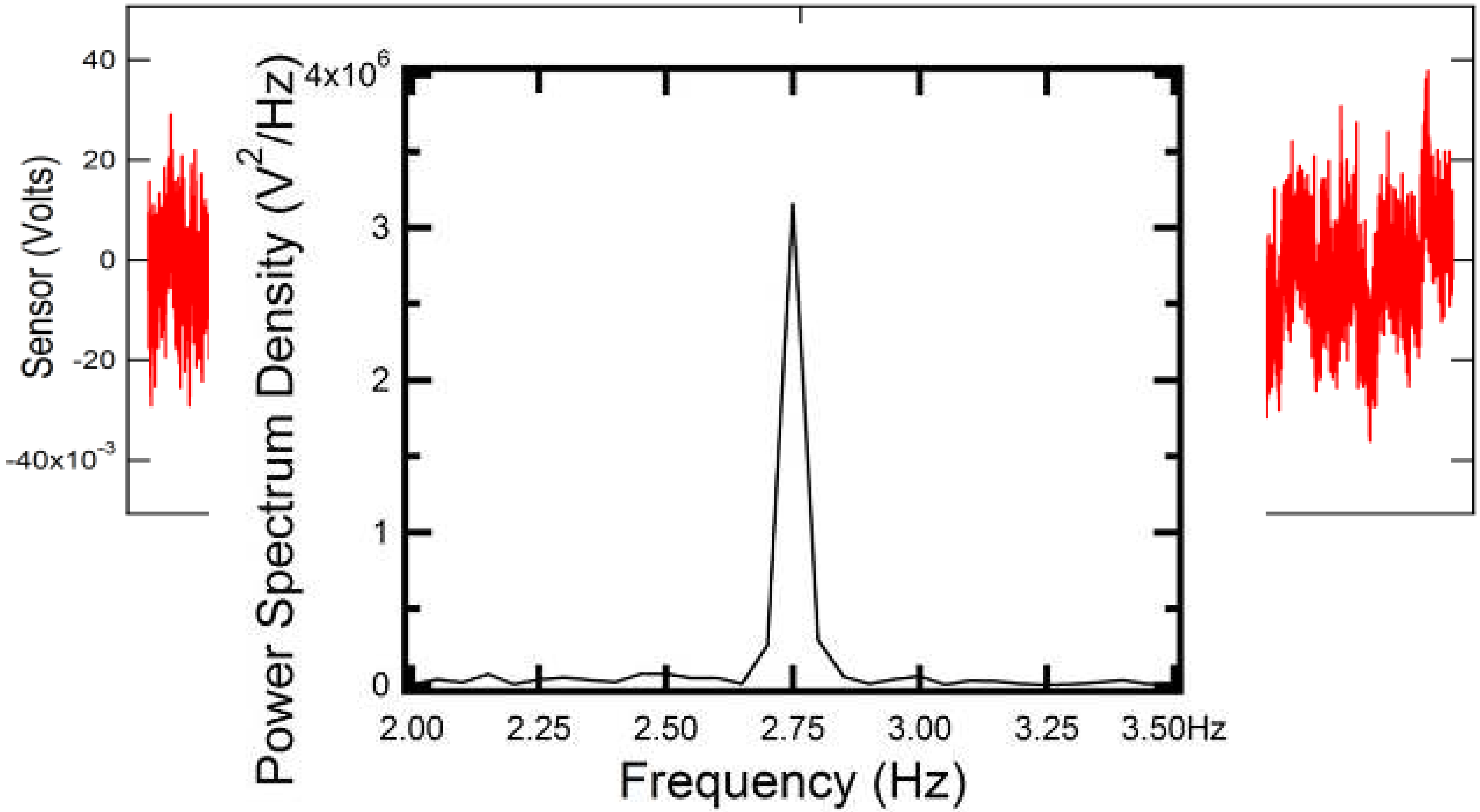
THE SETUP

HOW TO MEASURE ROTATION



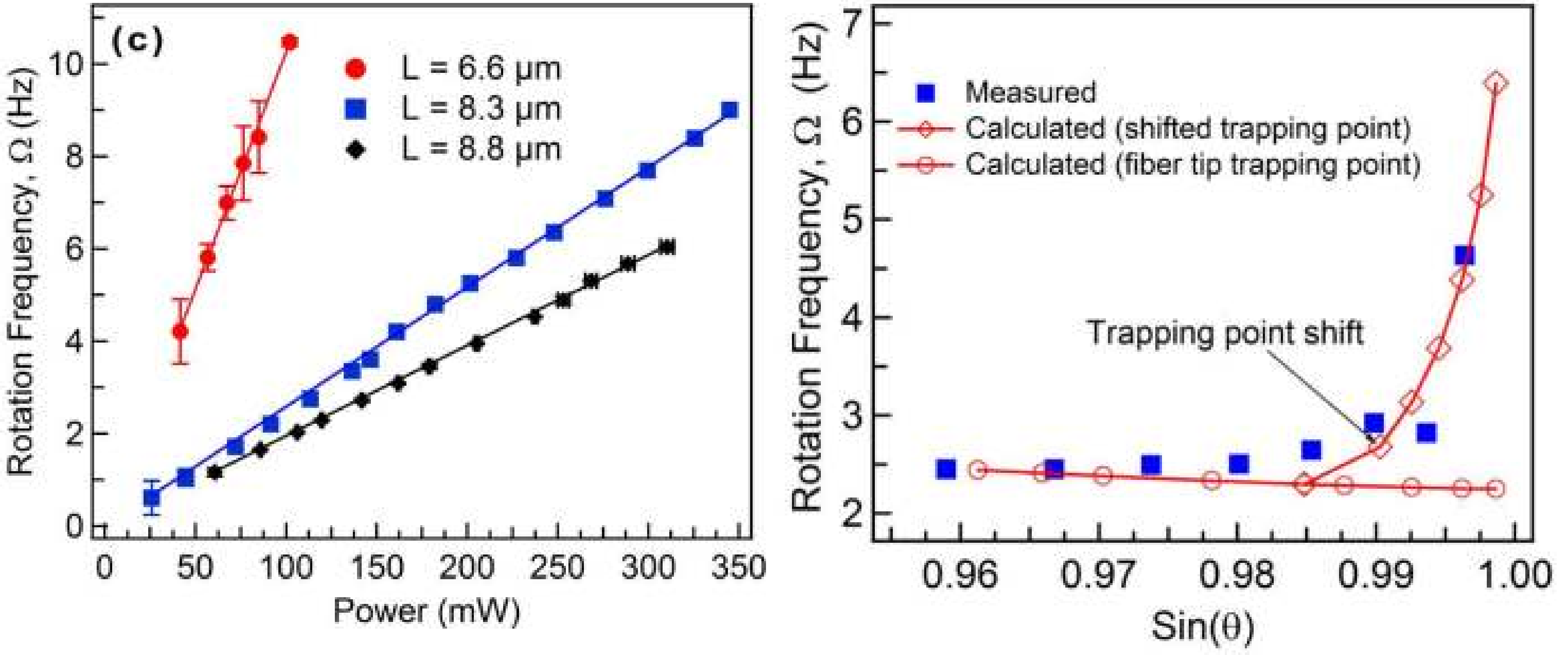


ROTATION FREQUENCY



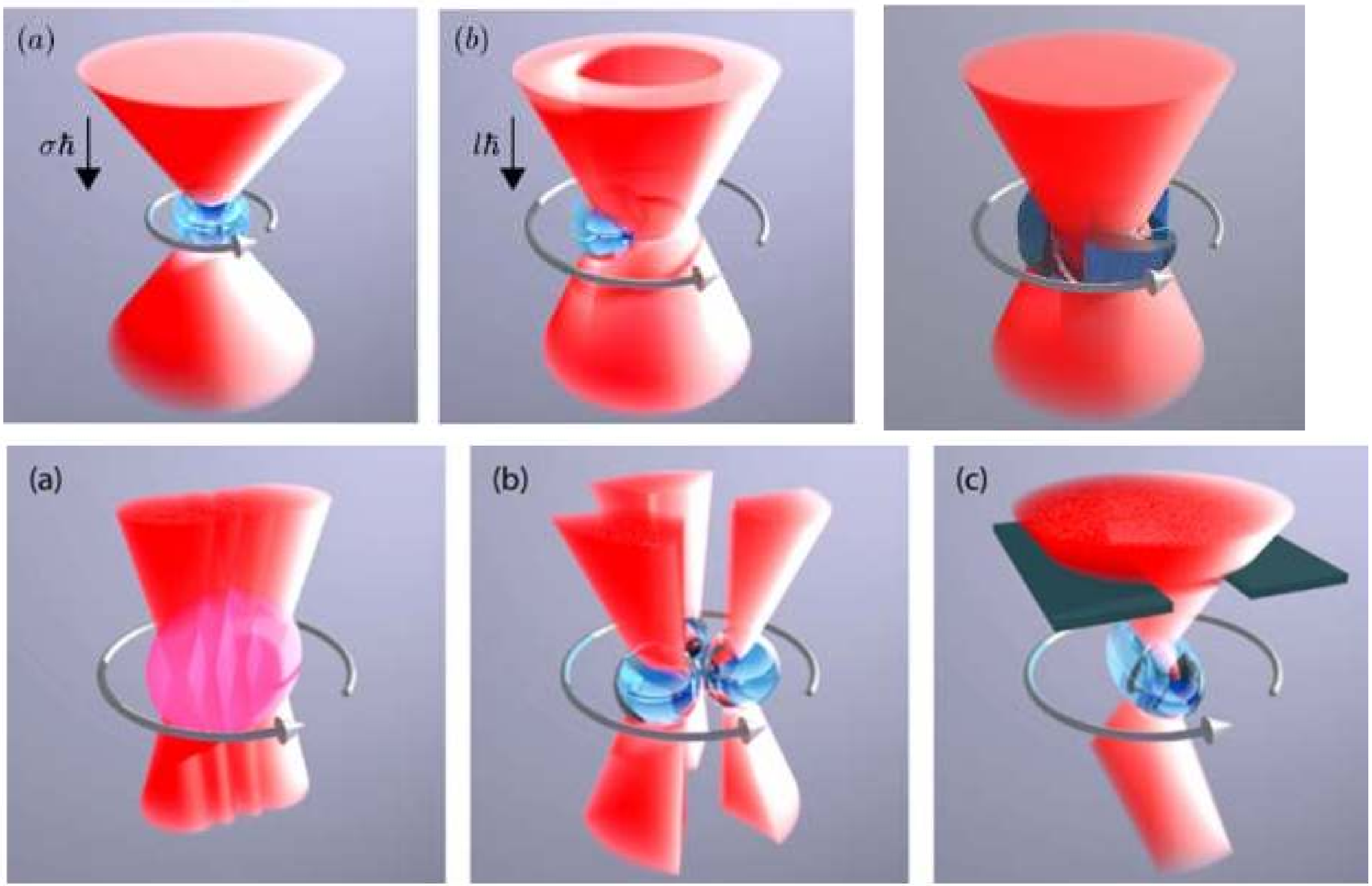
Opt. Express 18, 822 (2010)

STUDY OF ROTATION



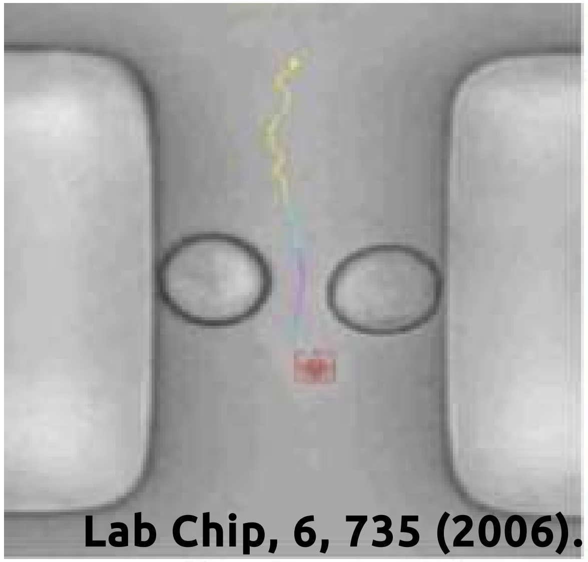
Opt. Express 18, 822 (2010)

HOW TORQUE IS APPLIED

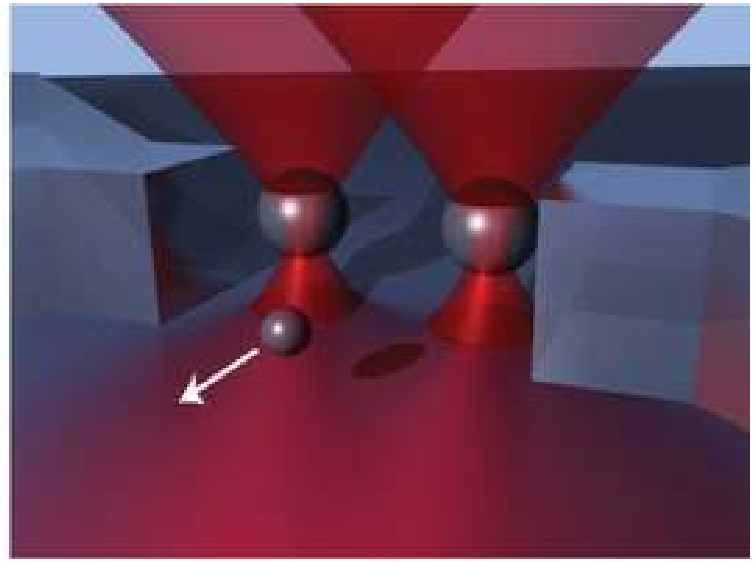


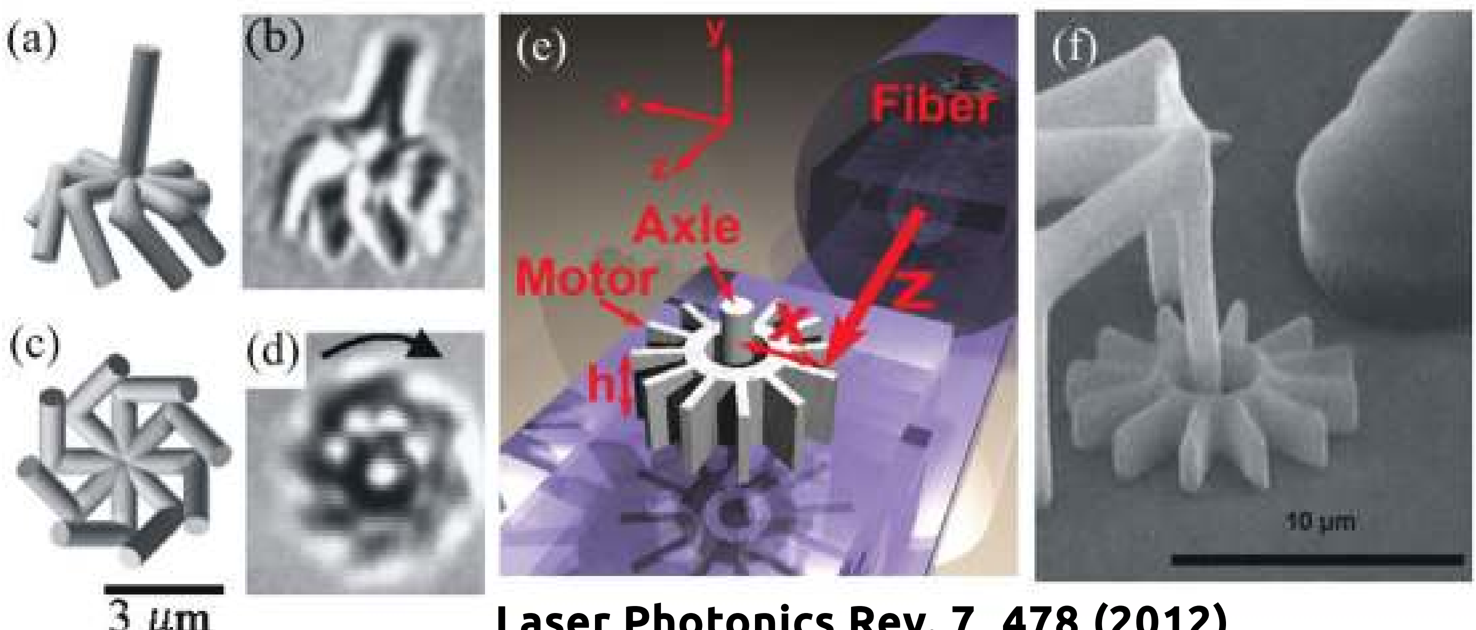
Nature Photonics 5, 343–348 (2011).

WHY ROTATIONS ARE IMPORTANT



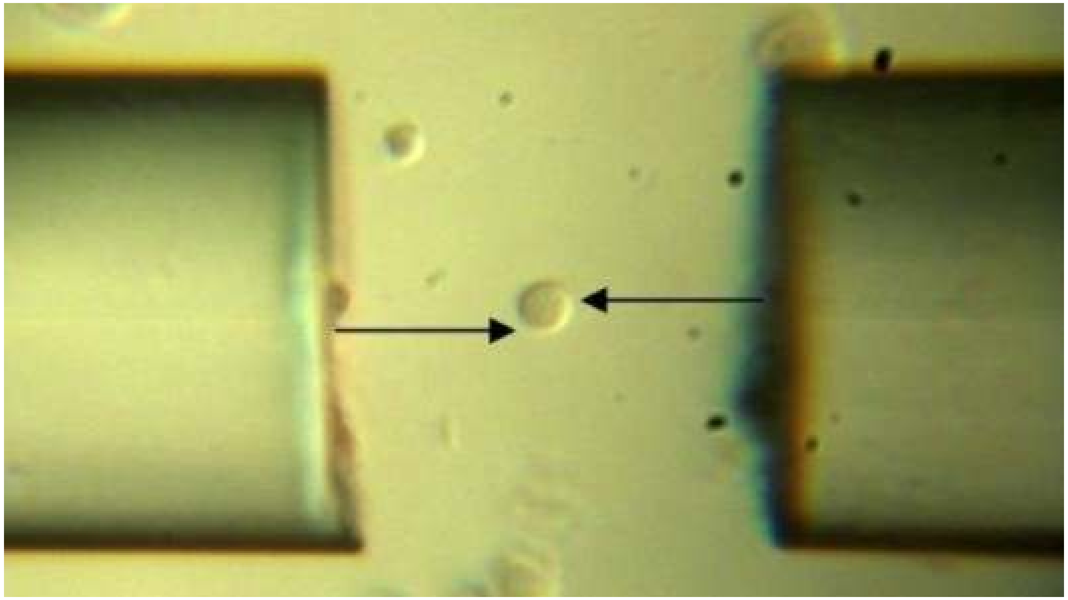
Lab Chip, 6, 735 (2006).



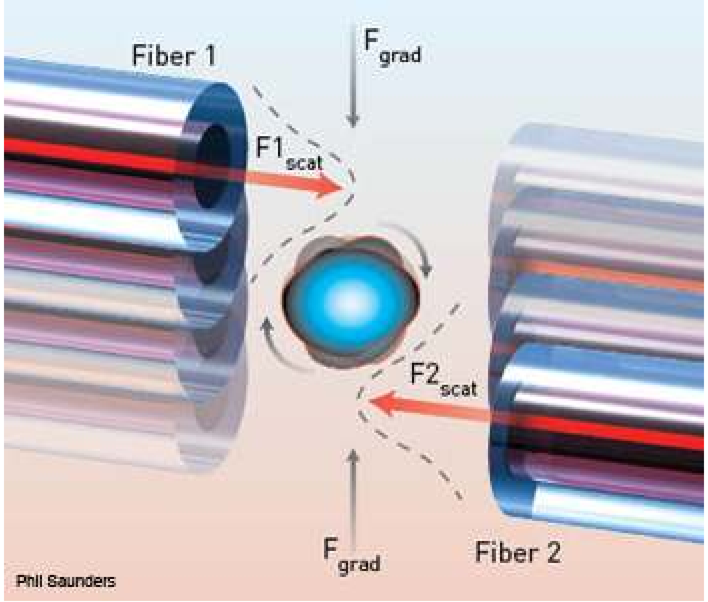


Laser Photonics Rev. 7, 478 (2012)

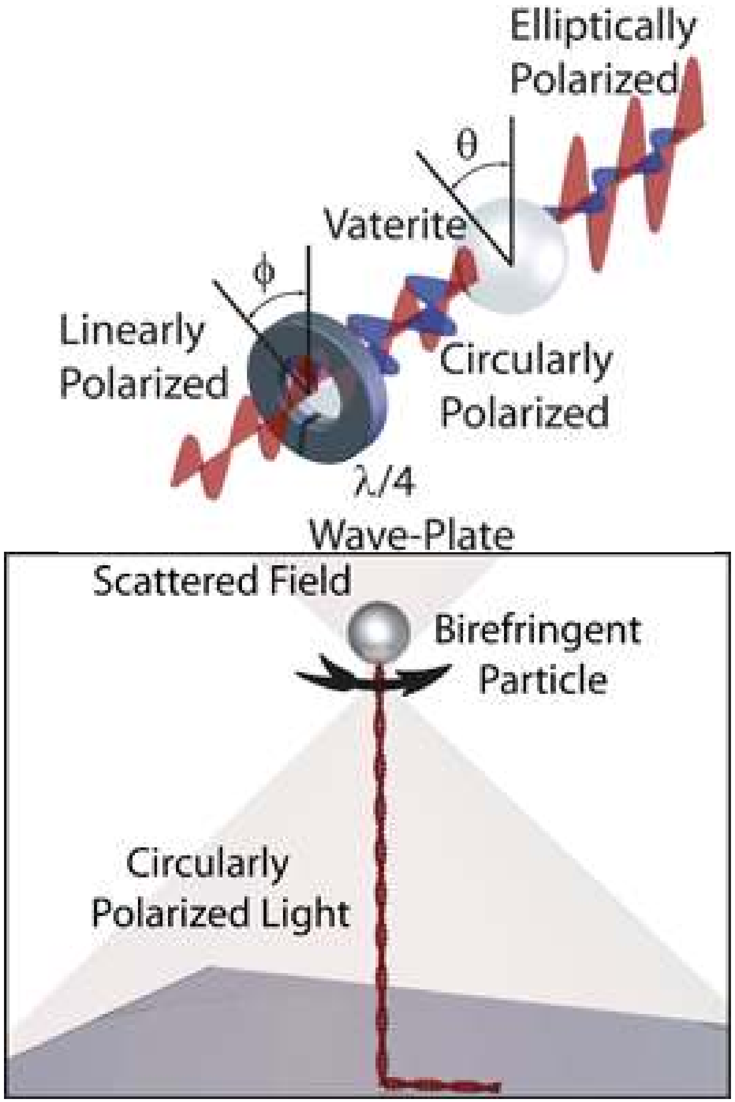
FIBER-OPTIC SPANNER



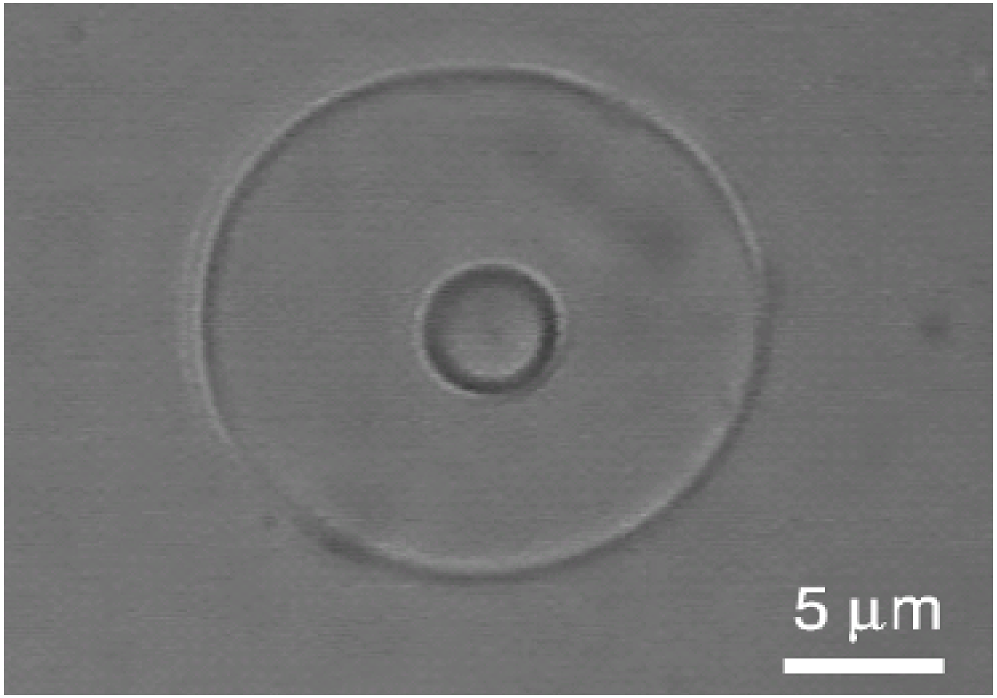
Opt. Lett. 37, 5030 (2012)



BIREFRINGENT PARTICLES

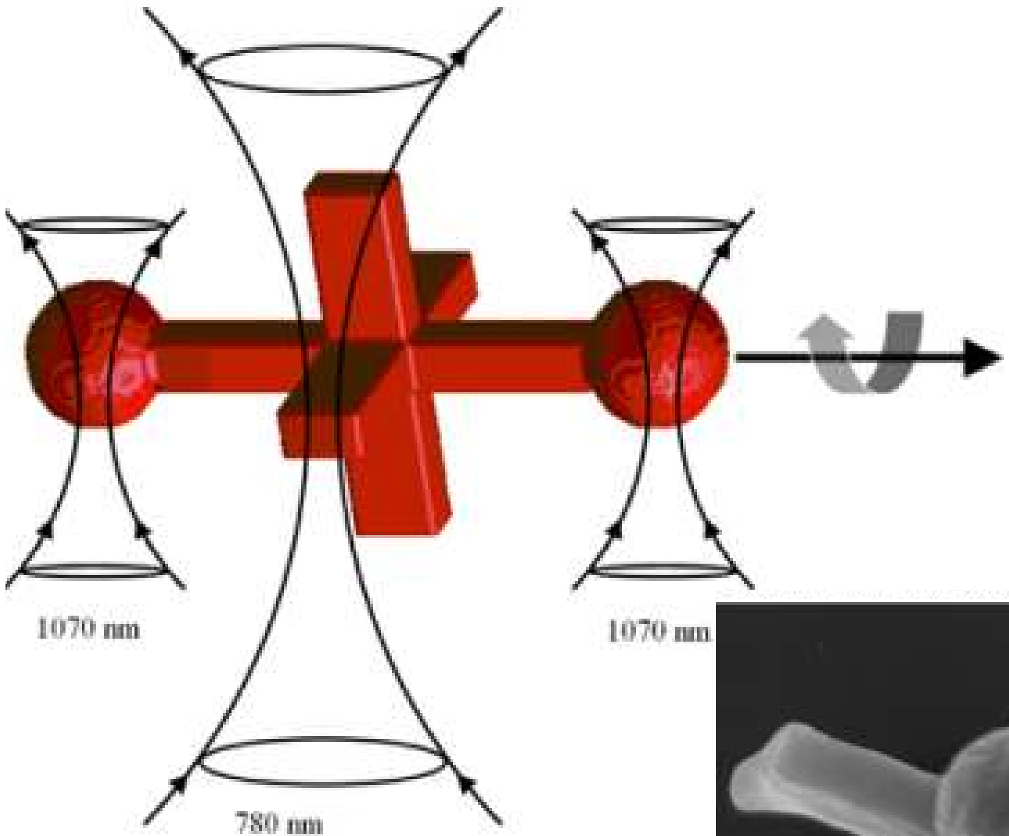


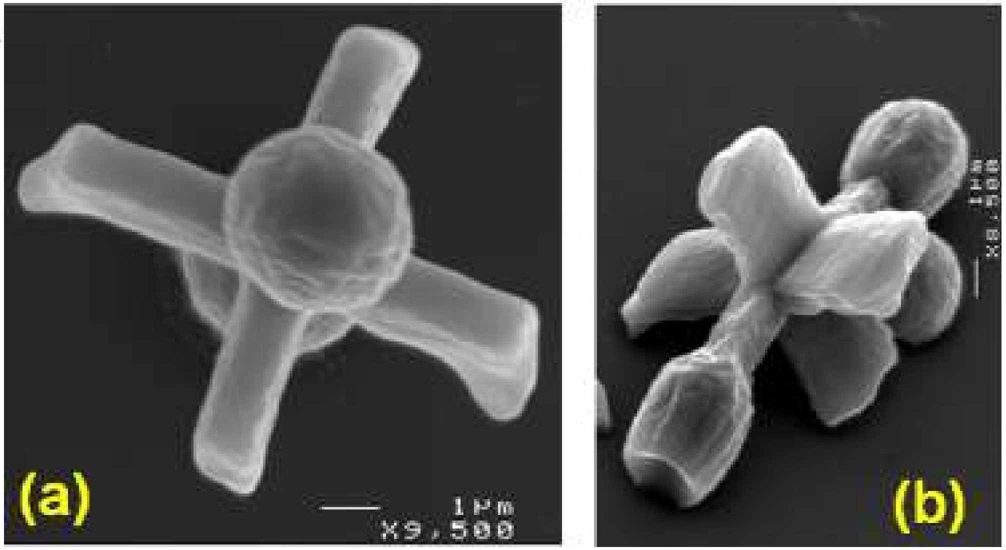
Applied Optics, 47, 6428 (2008).



PRL 92, 198104 (2004)

PADDLE-WHEEL

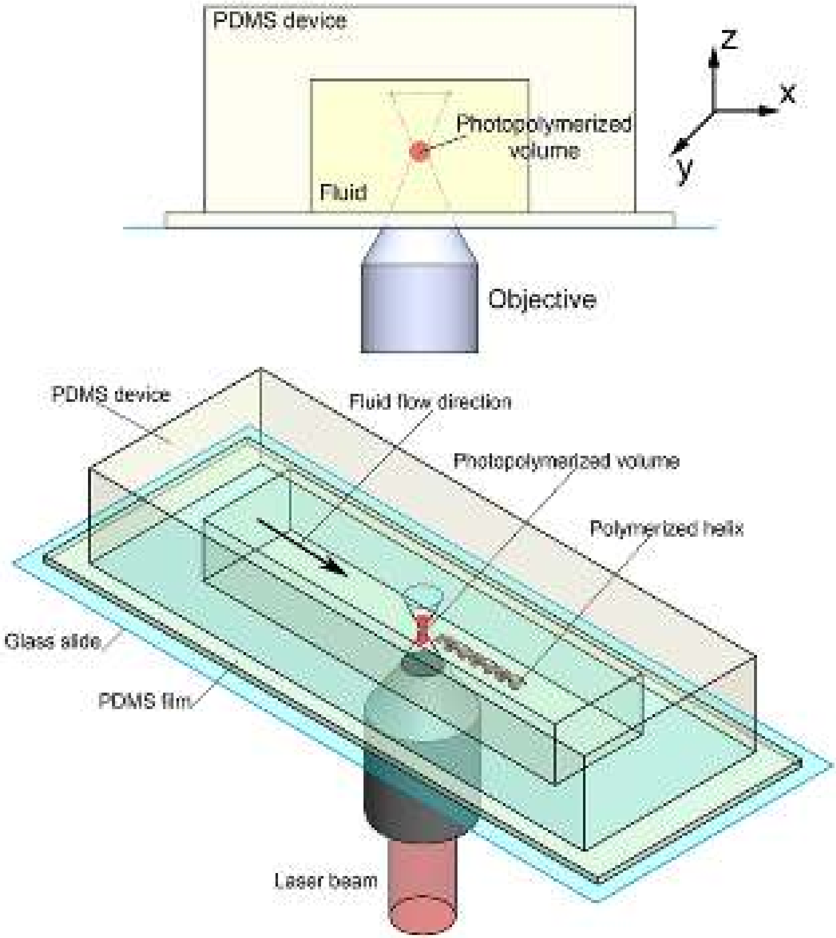




New J. Phys. 15 063016 (2013)

Annu. Rev. Biophys. 42, 583 (2013)

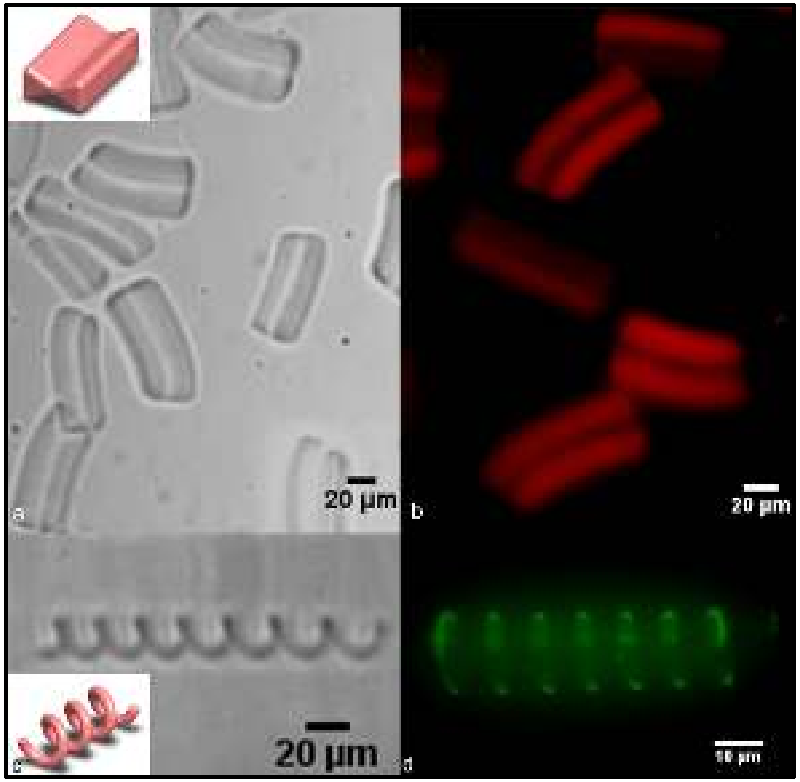
CONTINUOUS FLOW LITHOGRAPHY

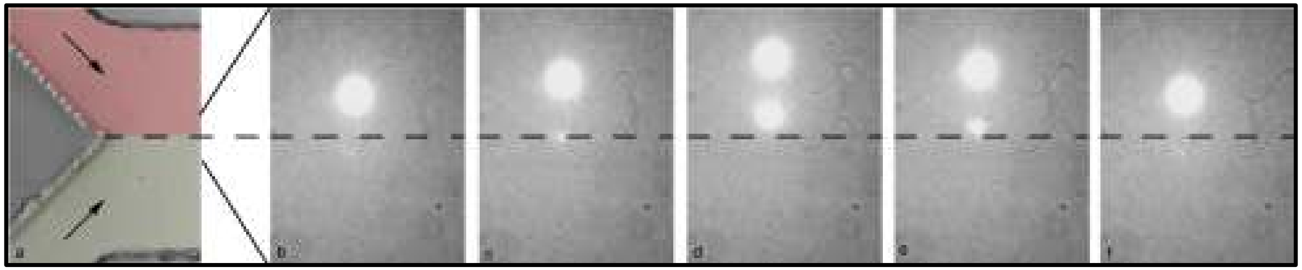


Advanced Materials, 24, 1304 (2012).

Where to from here?

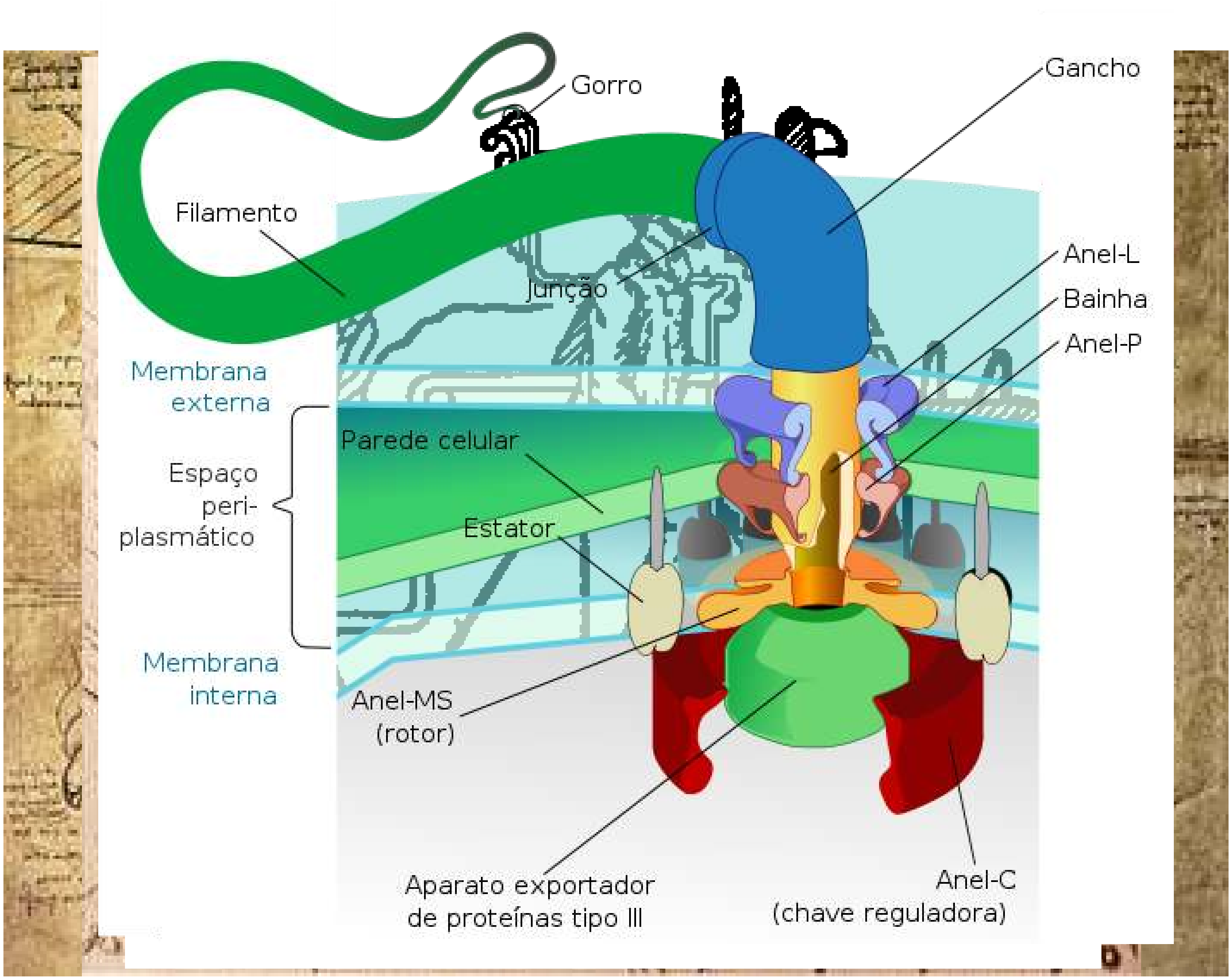
HELICES





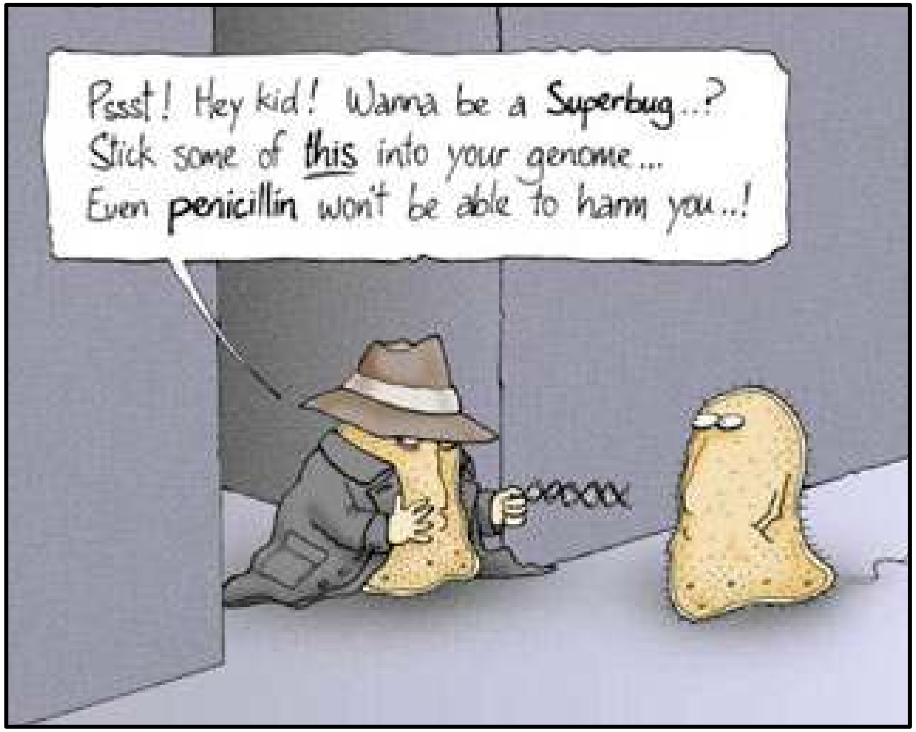
Advanced Materials, 24, 1304 (2012).

WHY HELICES



Gorro
Gancho
Filamento
Junção
Anel-L
Bainha
Anel-P
Membrana externa
Parede celular
Espaço peri-plasmático
Estator
Membrana interna
Anel-MS (rotor)
Aparato exportador de proteínas tipo III
Anel-C (chave reguladora)

DRUG EFFECTS



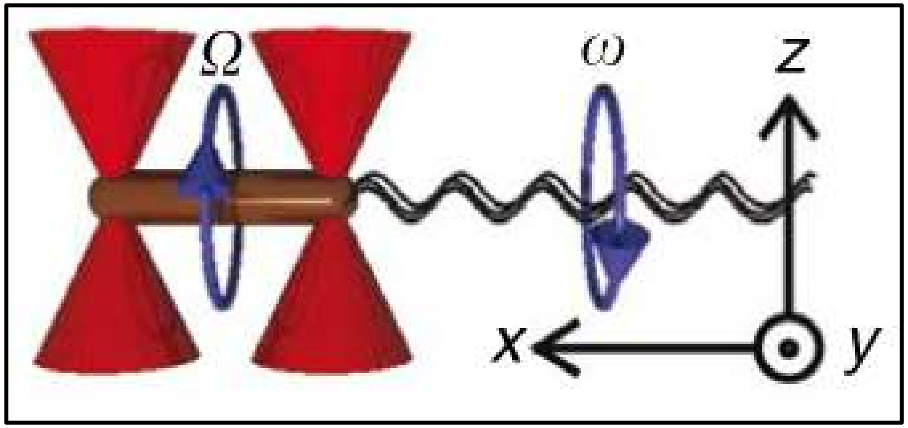
Recent case in 2011

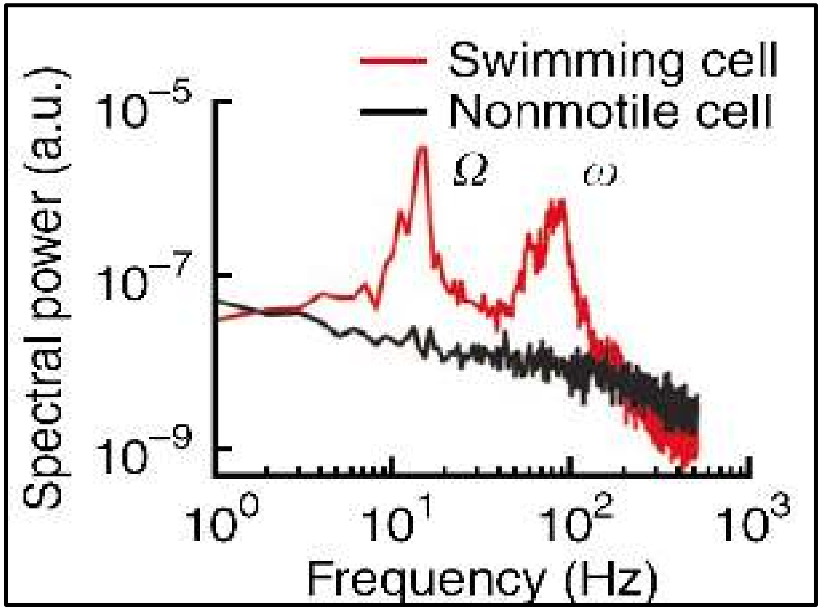
- +4000 people contaminated
- 50 killed in Europe
- Daily loses of $7m for Germany, and $40m for Spain

Why is it relevant?

- Health Issues
- Economic Factors
- Drawbacks in Development

MONITORING MOTILITY





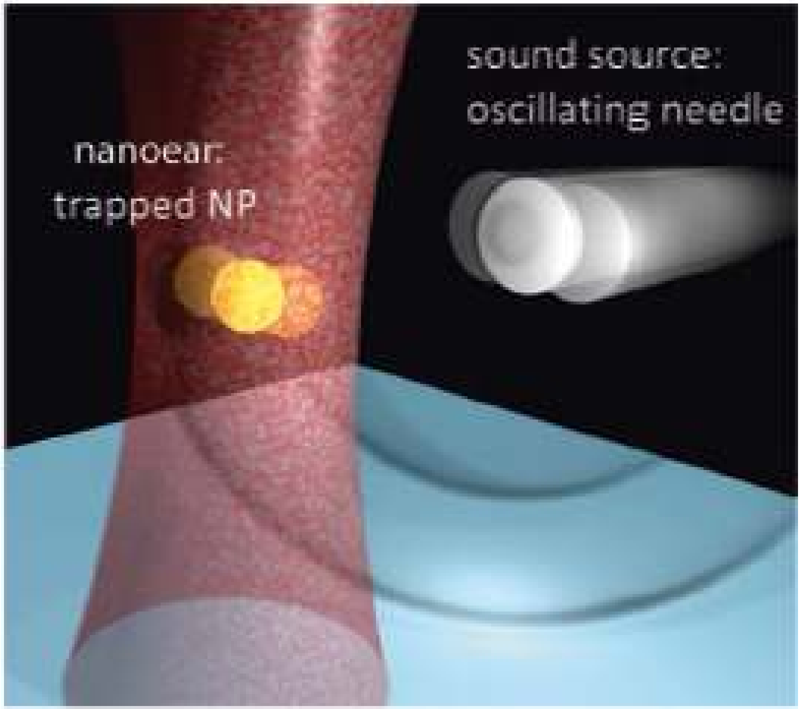
Nature Methods, 6, 831 (2005)

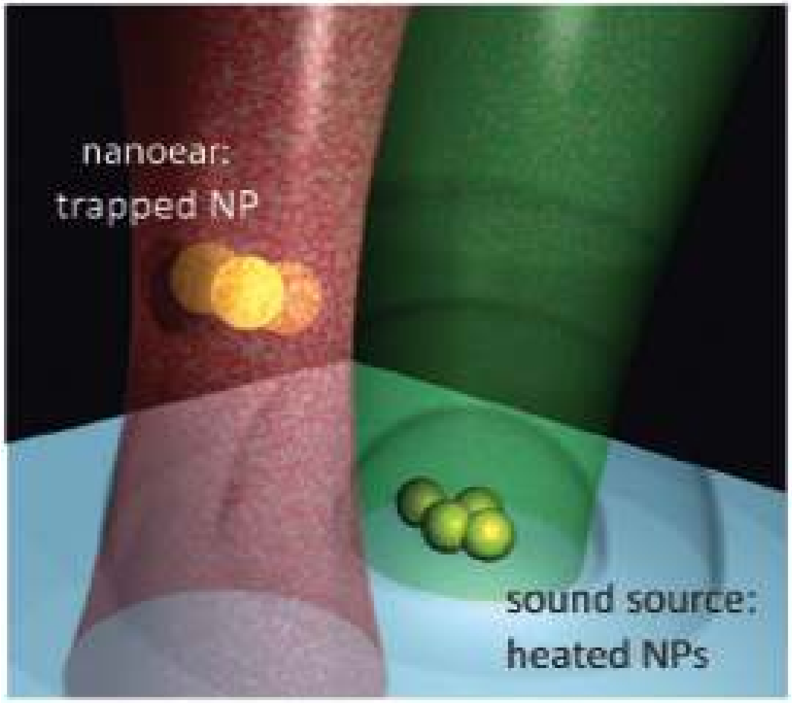
Some interesting questions:

- Motility on drug concentration
- Study strong mutant strain
- Lacking studies in plant cells
- Study drug on cancer cells
- Food conservation

What's hot?

LISTENING AT THE NANOSCALE

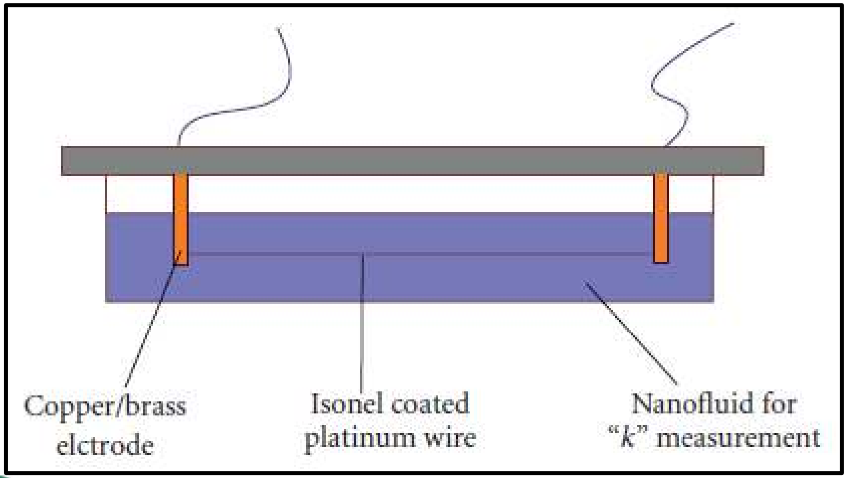




Phys. Rev. Lett. 108, 018101 (2012)

- 90 μeV de energia acústica transferida
- nível de potência sonora detectada até -60dB

NANOFLUIDS



Critical Issues

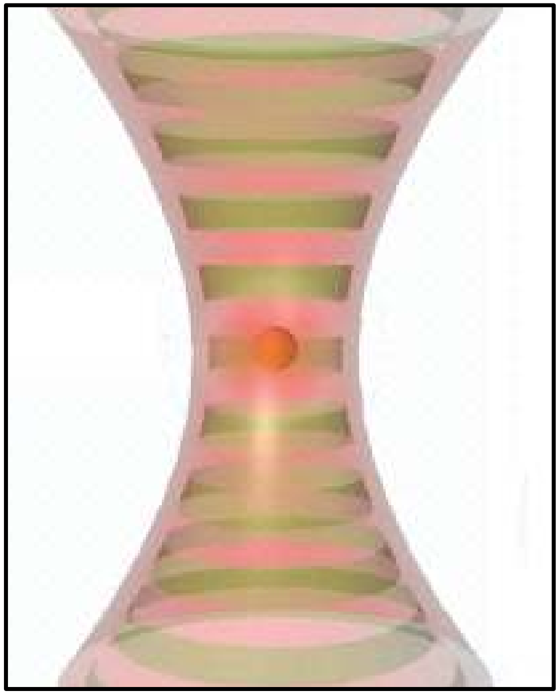
- No agreement between theories
- Ensemble average
- Transient hot-wire

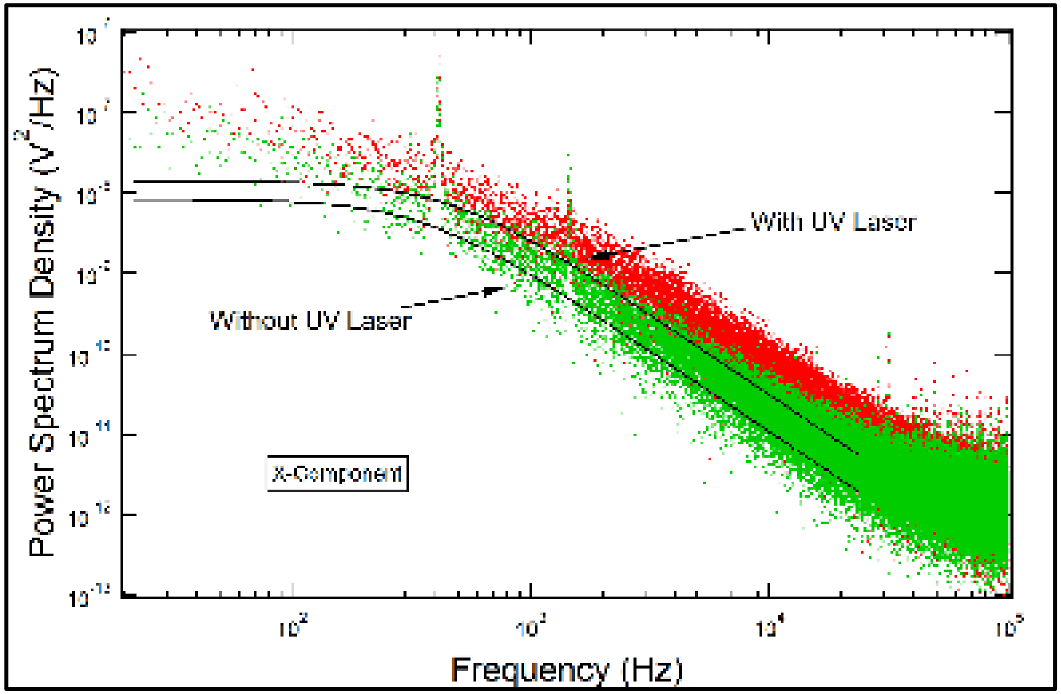
$$k = \frac{q}{4\pi L}\left(\frac{\ln(t)}{\Delta T}\right)$$

Why is it relevant?

- Energy efficiency
- Cooling
- Smart fluids

NANO HEAT SOURCE





$$T(r) = T_o + P_{heat}/(4\pi K r)$$

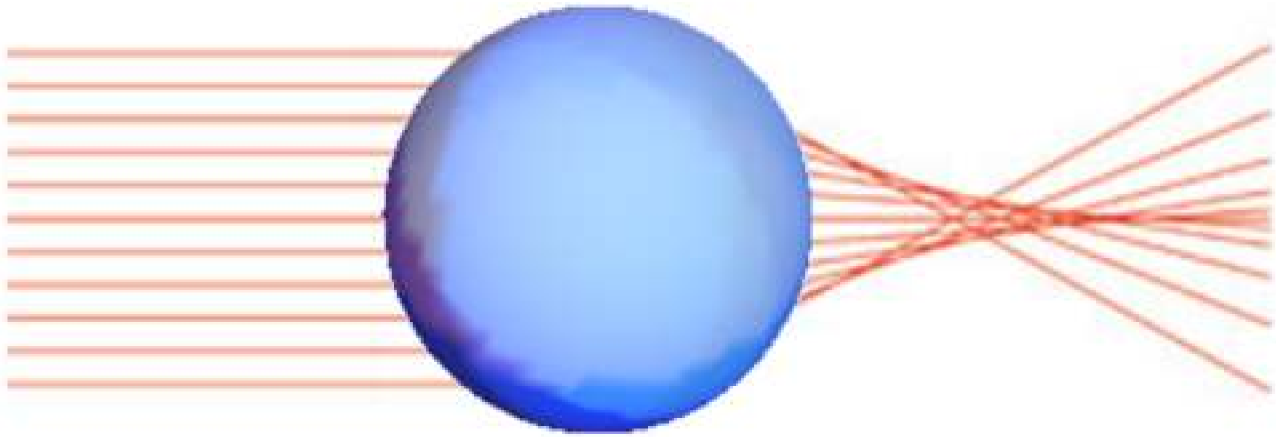
Phys. Rev. Lett. 105, 090604 (2010)

Interesting applications:

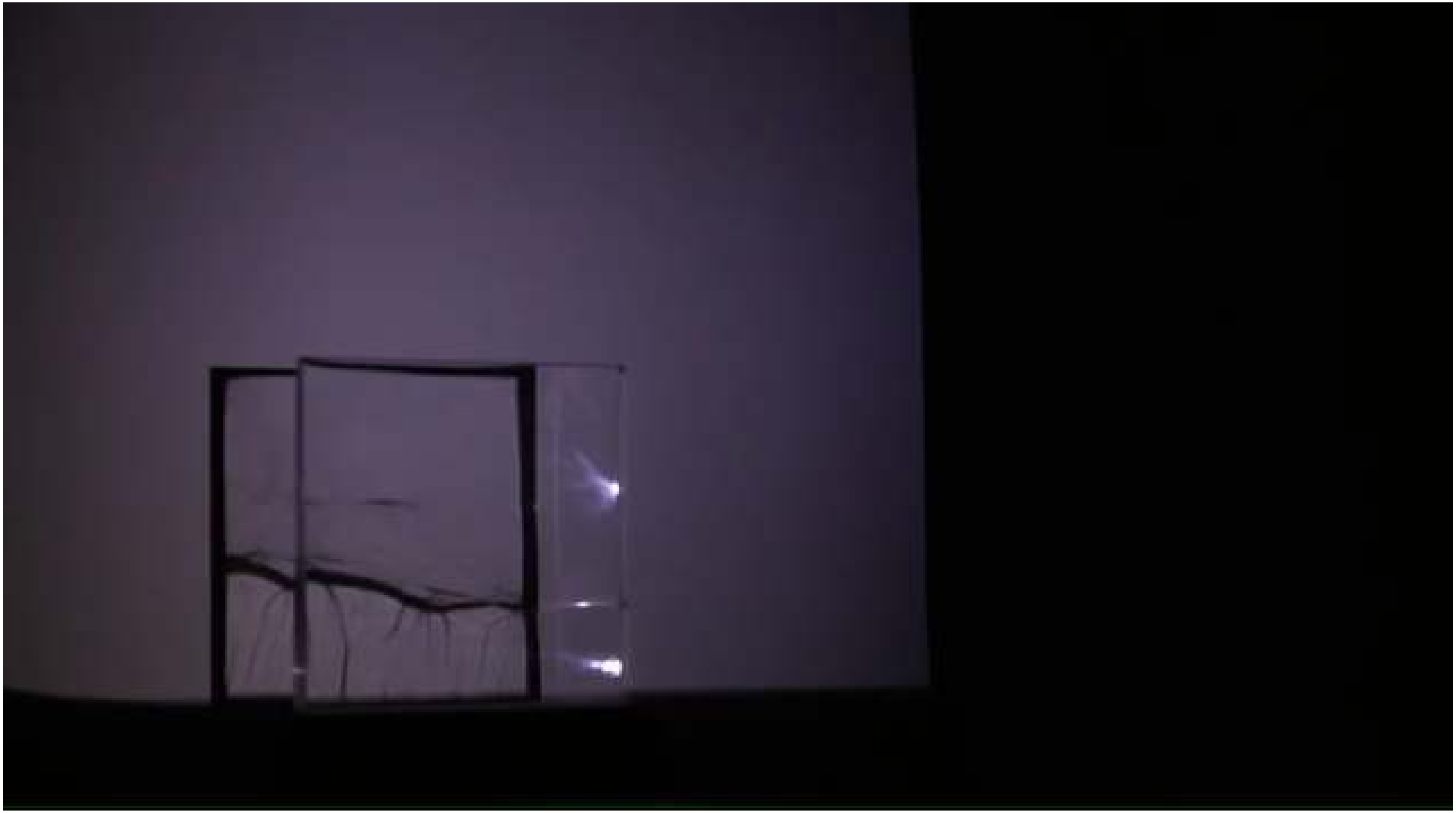
- Determine thermal conductivity
- Build a nano-calorimeter
- Localized heating source

What's caustic?

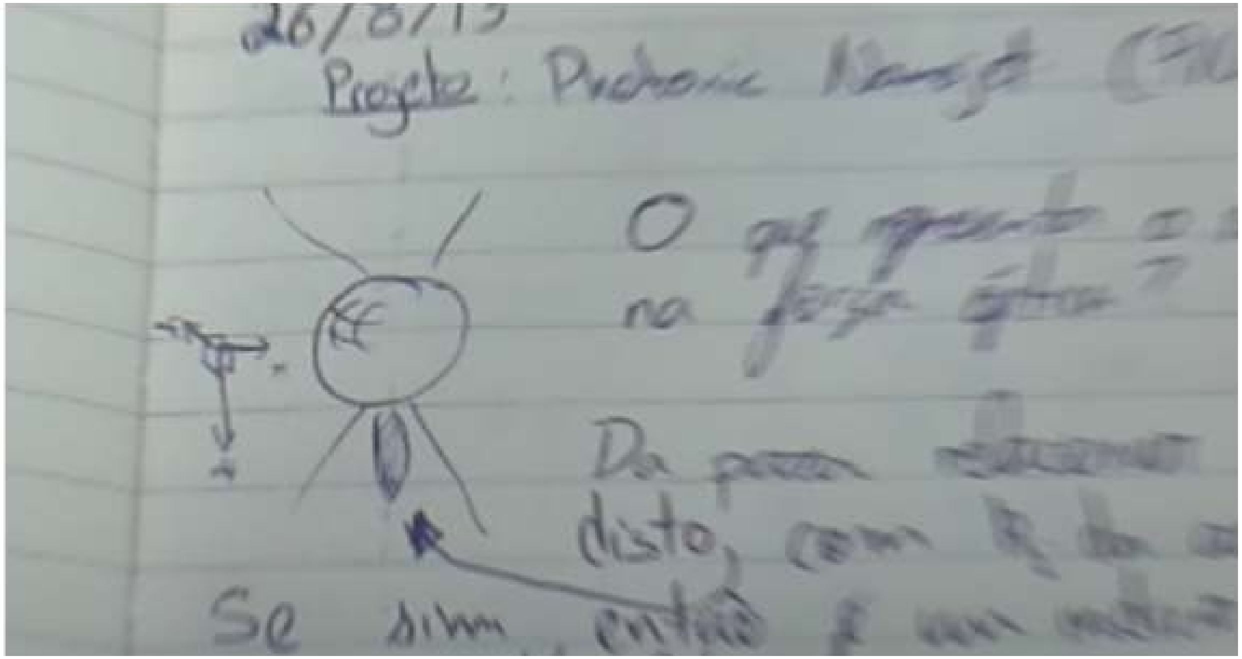
PHOTONIC NANOJETS



CAUSTIC ART



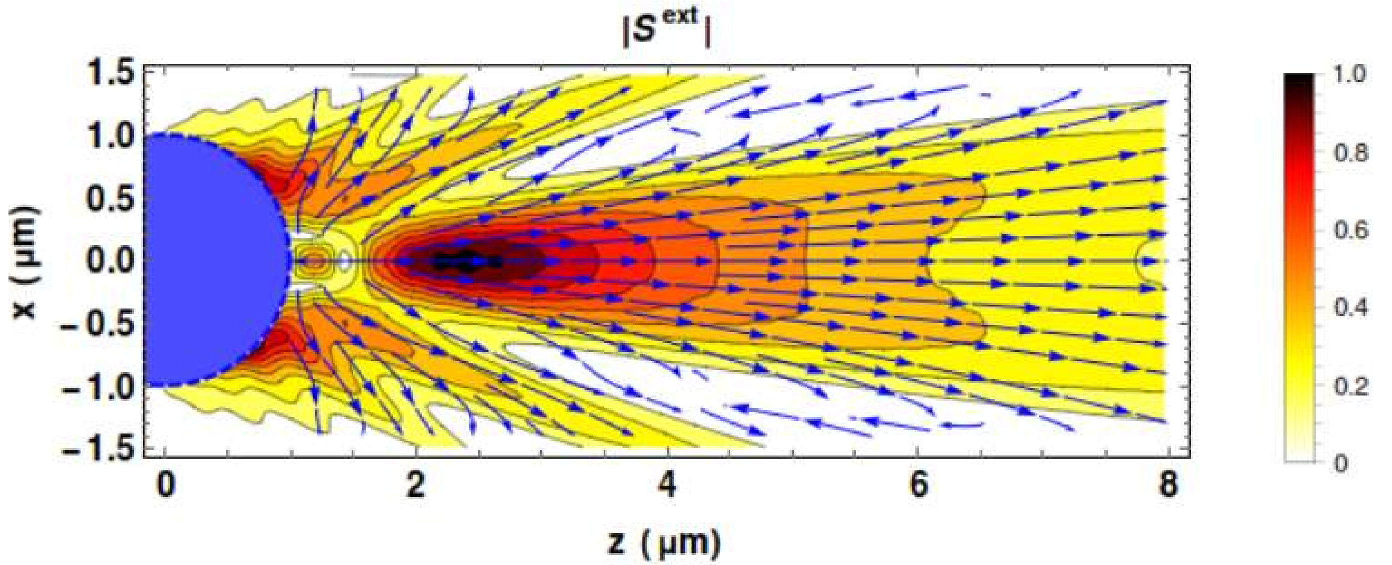
PHOTONIC NANOJETS IN OT

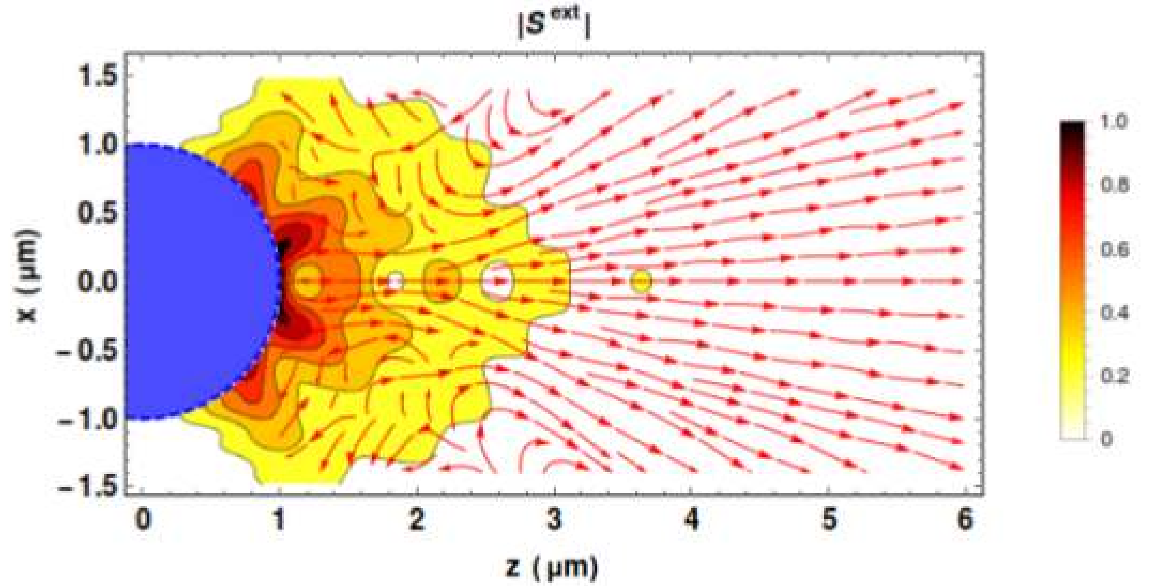


Important for:

- Sensing and Metrology (enhanced backscattering, two-photon enhancement, single molecule fluorescence 5-fold)
- Nano-patterning (dry laser cleaning, surface patterning, optical data storage)

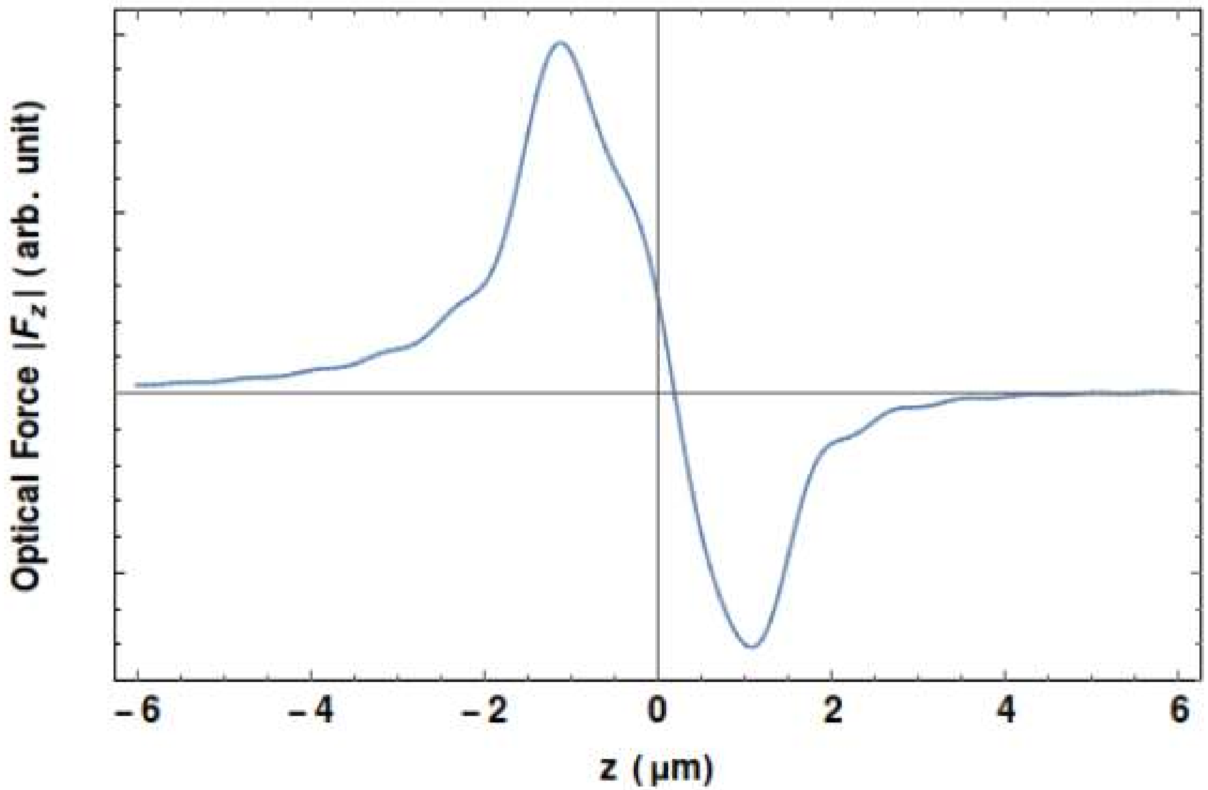
PLANE AND FOCUSED WAVES ON JETS





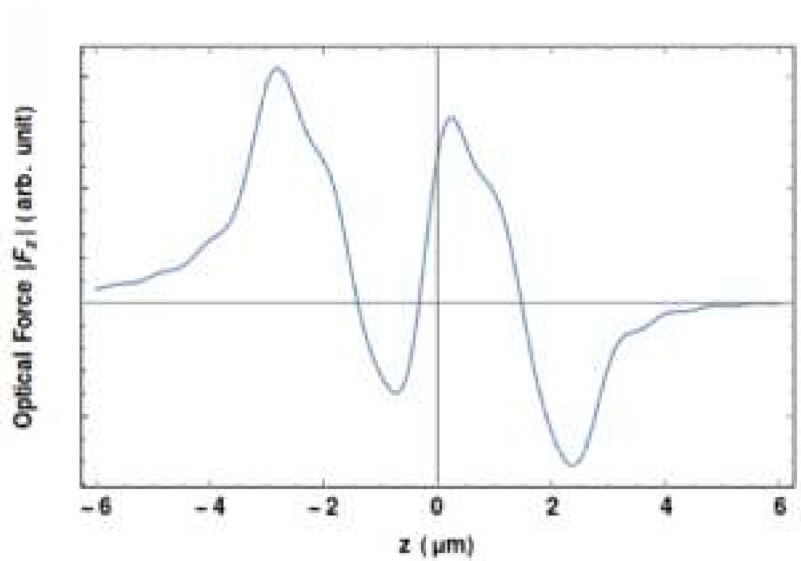
UFABC

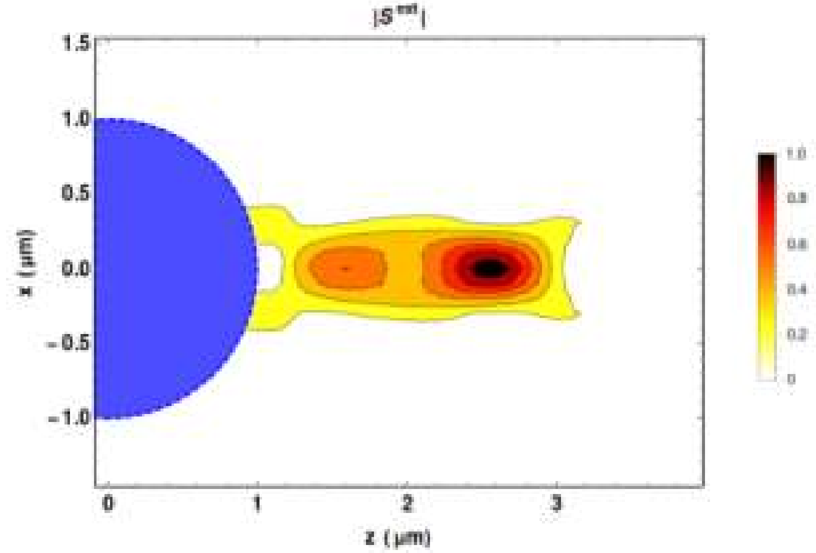
IN AN OPTICAL TRAP...

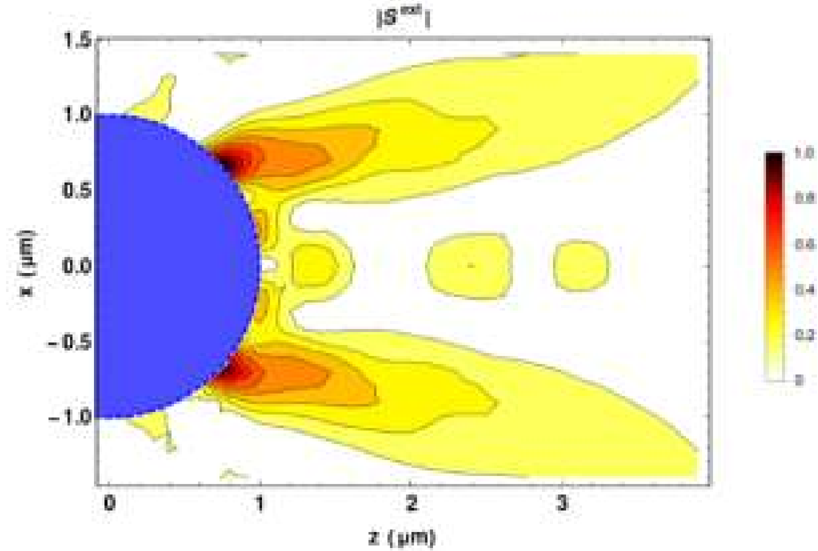


for $d = 2\mu$m and $z_{eq} \approx 0.2\mu$m, No jets!

PNJ IN AN OPTICAL TRAP



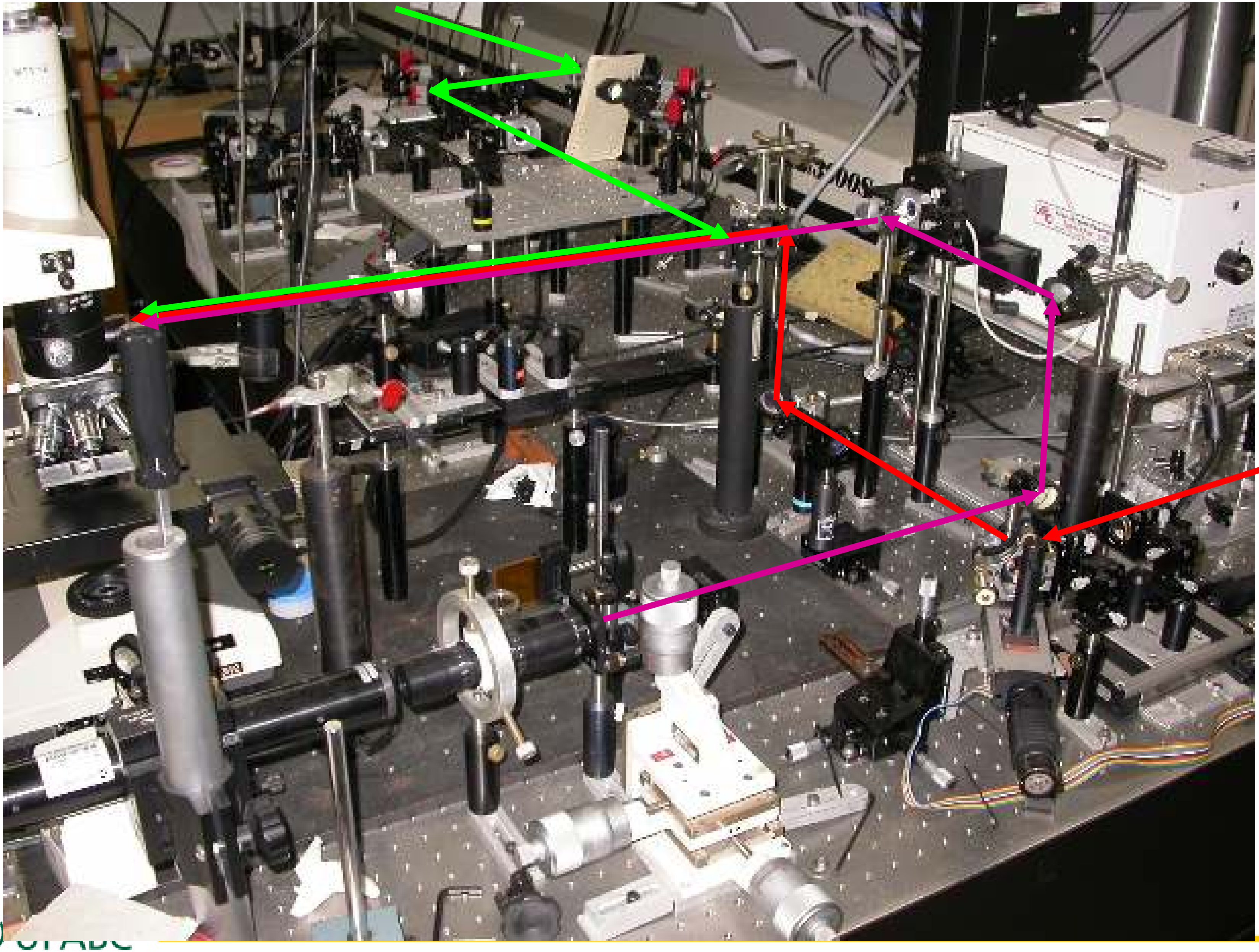




Sphere diameter $= 2\ \mu$m
Beam separation $= 3\ \mu$m
Equilibrium position 1 $\approx -1.4\mu$m
Stiffness 1 loss $\approx 46\%$
Equilibrium position 2 $\approx 1.5\mu$m
Stiffness 1 loss $\approx 36\%$

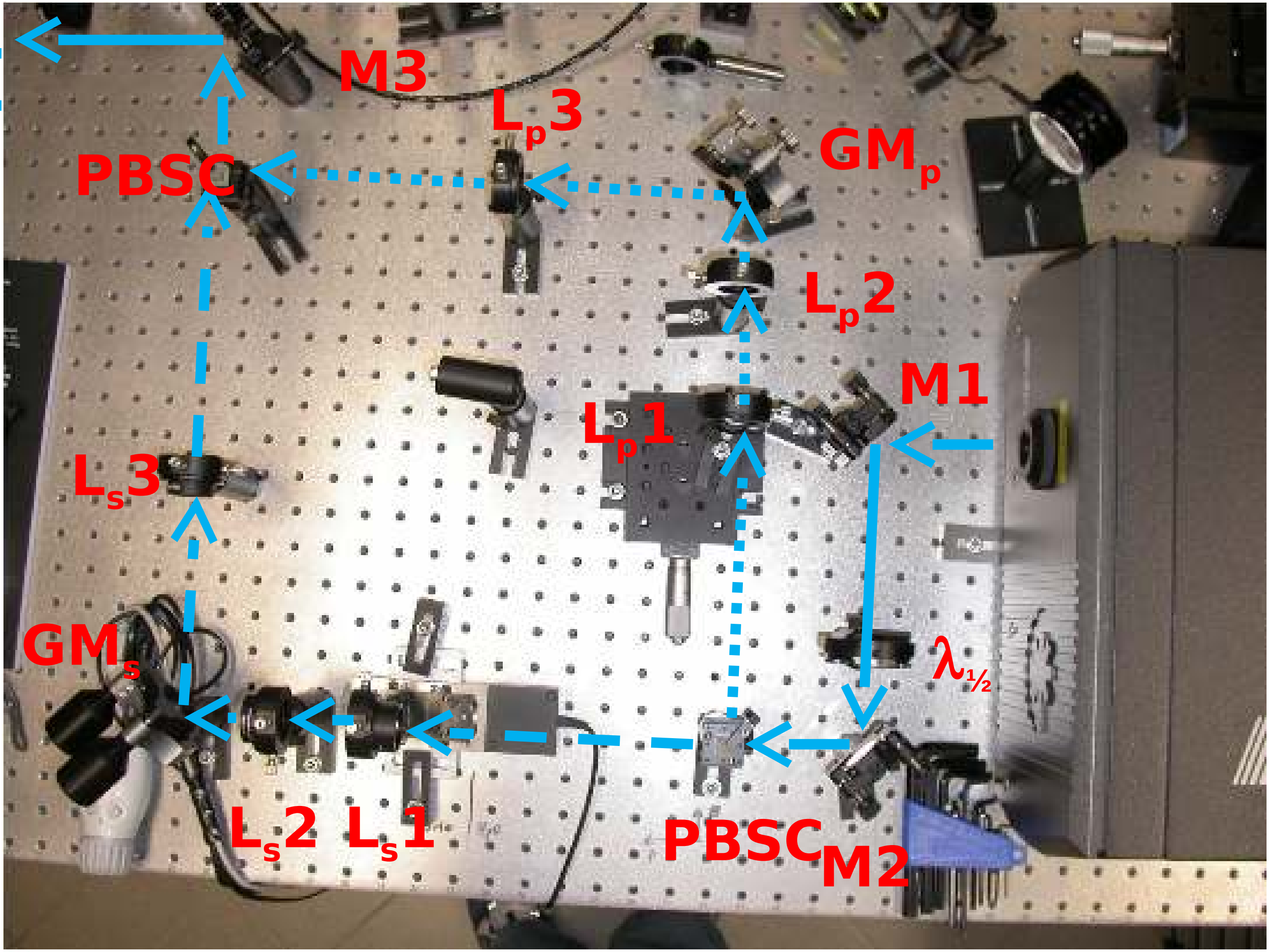
One more thing …

UNICAMP, Campinas (2006)

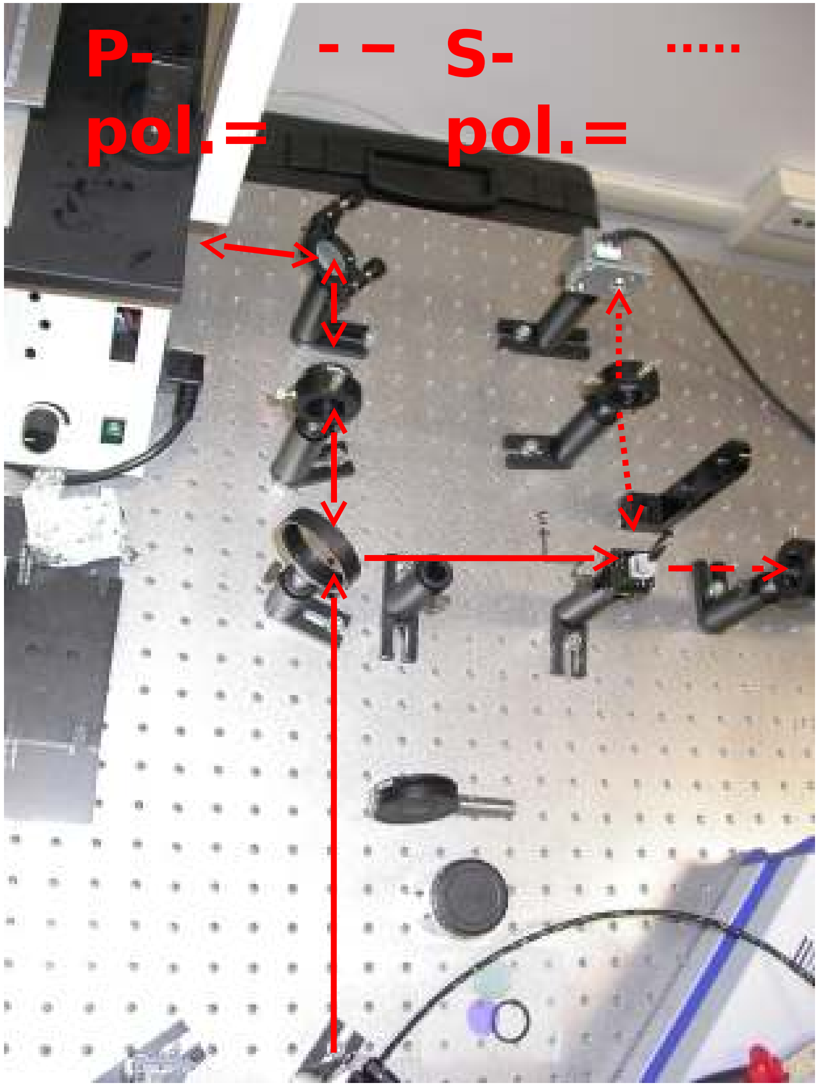


NNL, Lecce (1st Gen.) (2008)

P-pol.=
S-pol.=

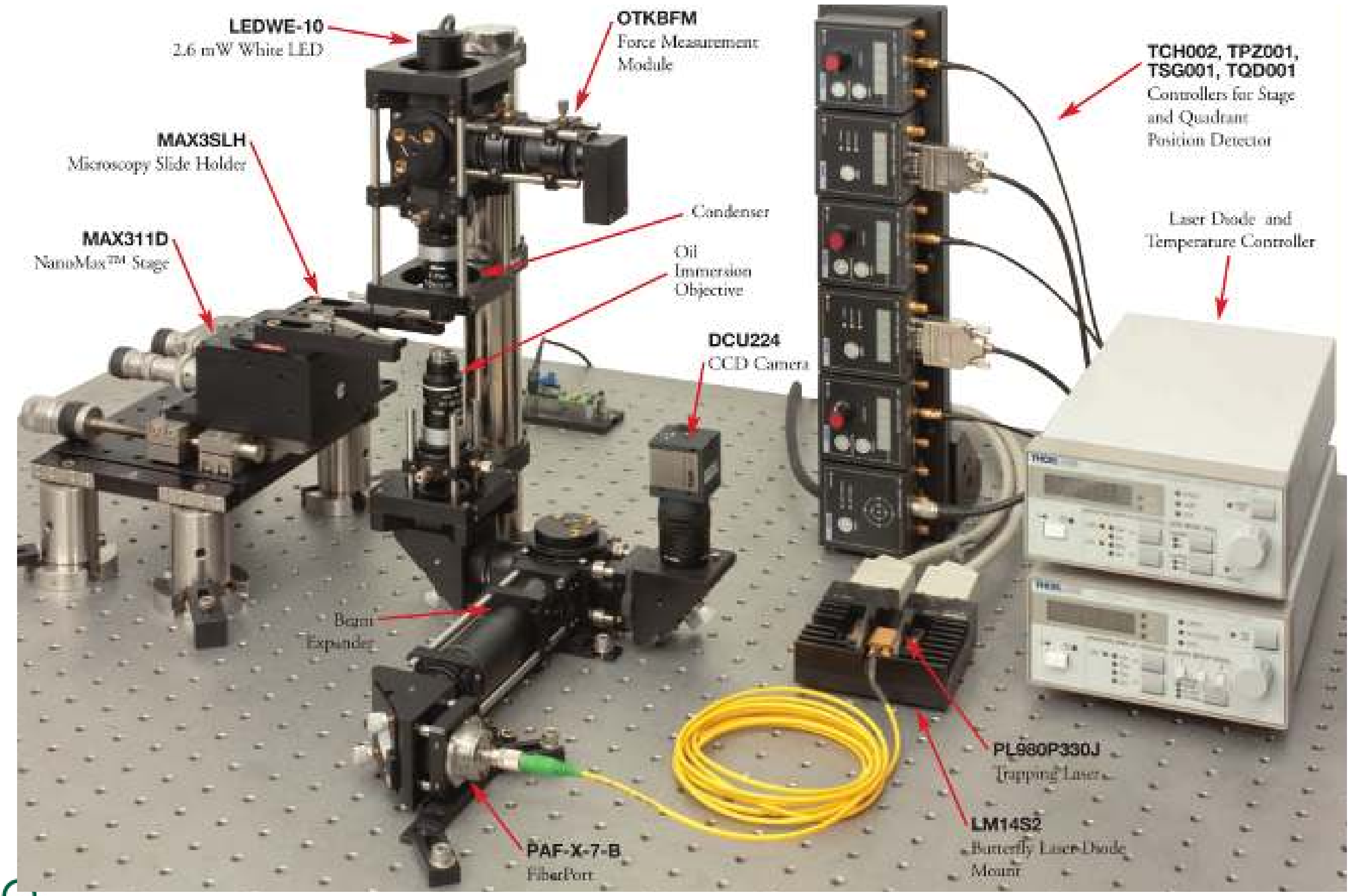


NNL, Lecce (1st Gen.) (2008)



NNL, Lecce (2nd Gen.) (2010)

UFABC, Santo André (2013)



THE END

http://opticaltweezers.blogspot.com.br/

“Optical tweezers have become one of the primary weapons in the arsenal of biophysicists, and have revolutionized the new field of single-molecule biophysics.” - **Steven M. Block** [Nature Photonics 5, 318 (2011)].

“The latest golden age of physics was the first half of the twentieth century, when quantum mechanics was developed. A comparable revolution is under way in biology.” - **Herch Moyses Nussenzveig** [Braz J Phys 41, 213 (2011)].