Arthur Ashkin, pinças ópticas, Bell Labs e o Prêmio Nobel

Carlos Lenz Cesar

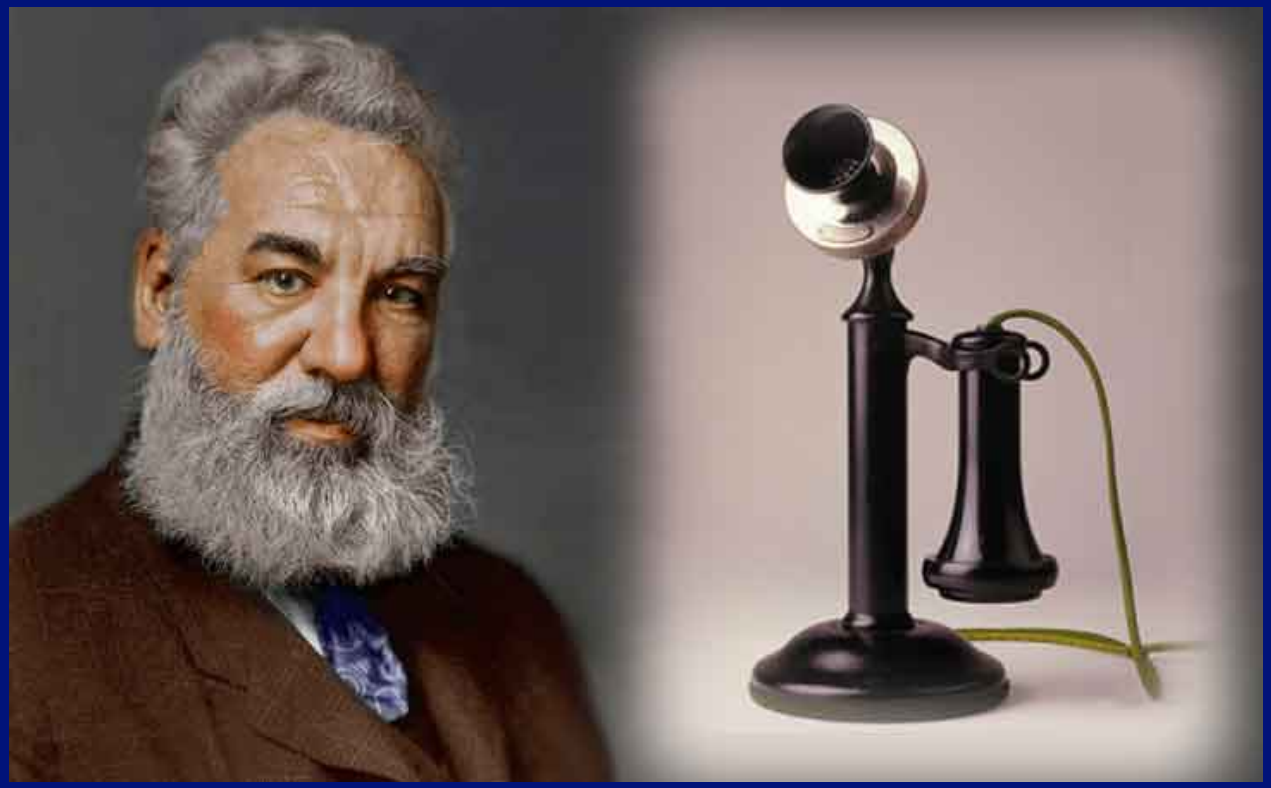
Department of Physics – Federal University of Ceará
UFC – Fortaleza, Ceará, Brazil

Gleb Wataghin Institute of Physics – State University of Campinas - UNICAMP - Campinas, São Paulo, Brazil

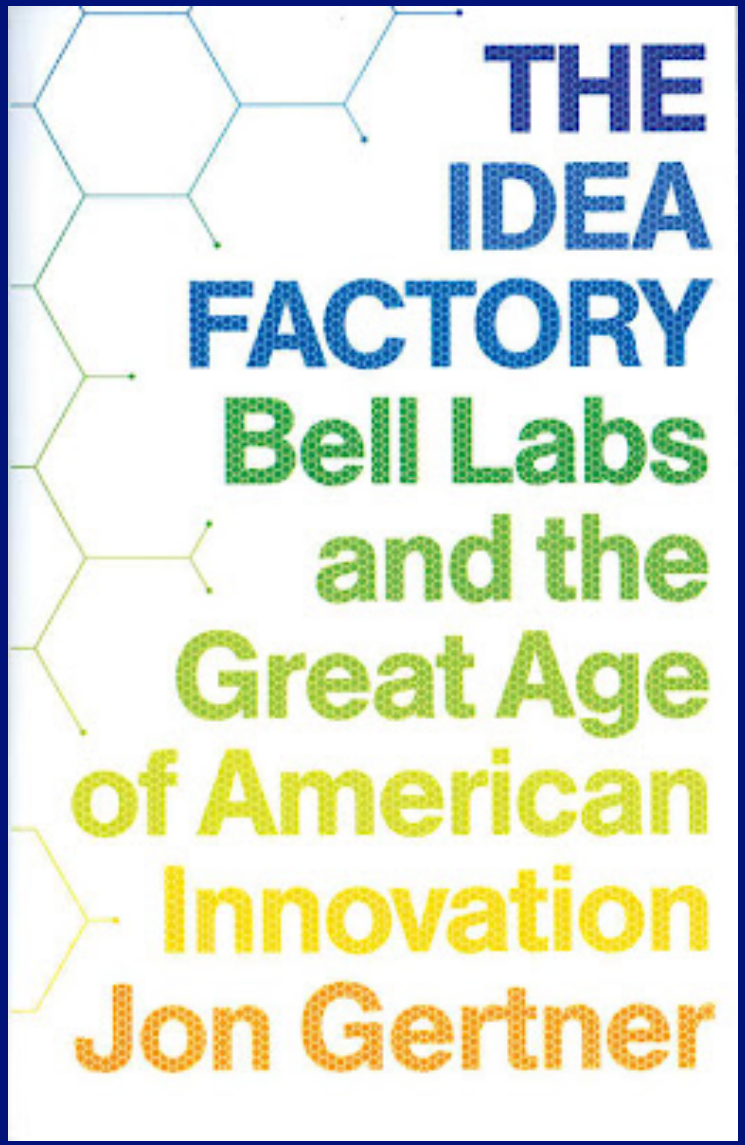
Bell Telephone Company:

1877 in Boston by Alexander Graham Bell

American Telephone and Telegraph [AT&T] - 1885



Bell Labs na Revolução da Informação



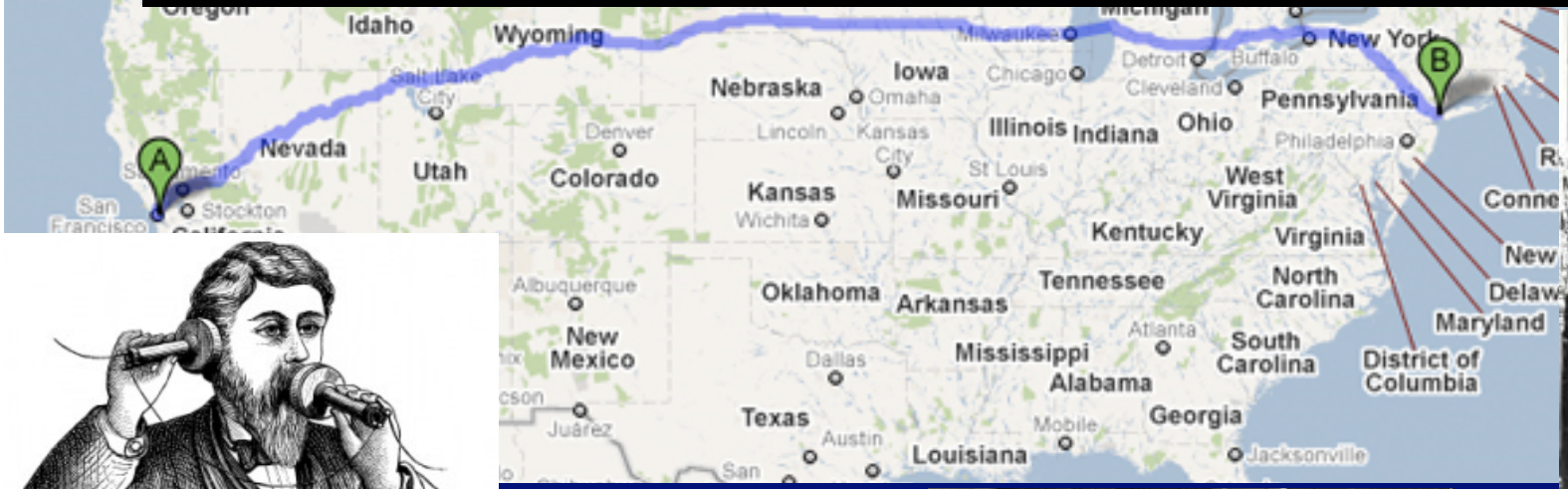
Theodore Vail

AT&T´s president in 1885 – 1889 and 1907 - 1919

1906 San Francisco earthquake

Amplification, amplification, amplification!

Beginning 20th century - Telephone calls < 30 km .
1913 - De Forest sell triode vacuum tube patent to AT&T
San Francisco 1915 World Fair 1st Transcontinental Call



Thomas Watson

Theodor Vail

Alexander Bell

Repercussions: AT&T became a monopoly

Management directions

1 - Go for Solid State - 90% failures in the tube filament and mechanical parts – transistor/ semiconductors/solar cells

2 – Radio waves – Radioastronomy, Satellites, Cell Phones

3 – Optics because of the bandwidth – lasers, optical fibers

1925: Bell Labs became a company

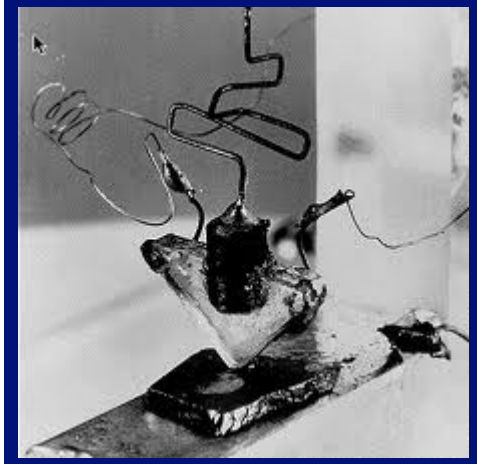
AT&T and Western Electric only costumers

Bell labs hired PhDs:
Millikan main provider
13 Nobel laureates

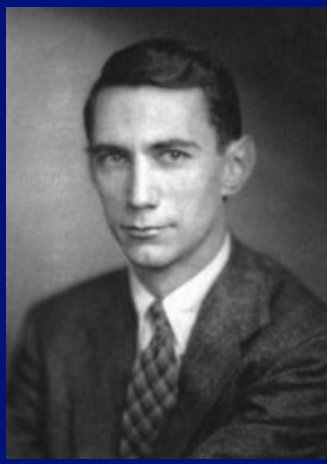
THE IDEA FACTORY
Bell Labs and the Great Age of American Innovation
Jon Gertner

1947 marvelous year

Solid State: Transistor - Bardeen + Brattain + Shockley



Information Theory – Claude Shannon



Shockley - Stanford
Silicon Valley

Traitorous 8
Fairchild – 1957

The beggining: 1971 first INTEL chip

1946 – ENIAC

1951 – Texas Instruments

1958 – Noyce & Kilby (Nobel 2000) 1st integrated circuit

1968 - INTEL – 1968 Robert Noyce e Gordon Moore

Gordon Moore

Robert Noyce

Bell Labs and Nobels

13 Nobel laureates – and counting

Clinton Davisson – 1937
Bardeen + Brattain + Shockley – 1956
Phil Anderson – 1977
Penzias + Wilson - 1978
Steven Chu – 1997
Stormer + Laughlin + Tsui - 1998
Boyle + Smith – 2009
Art Ashkin – 2018

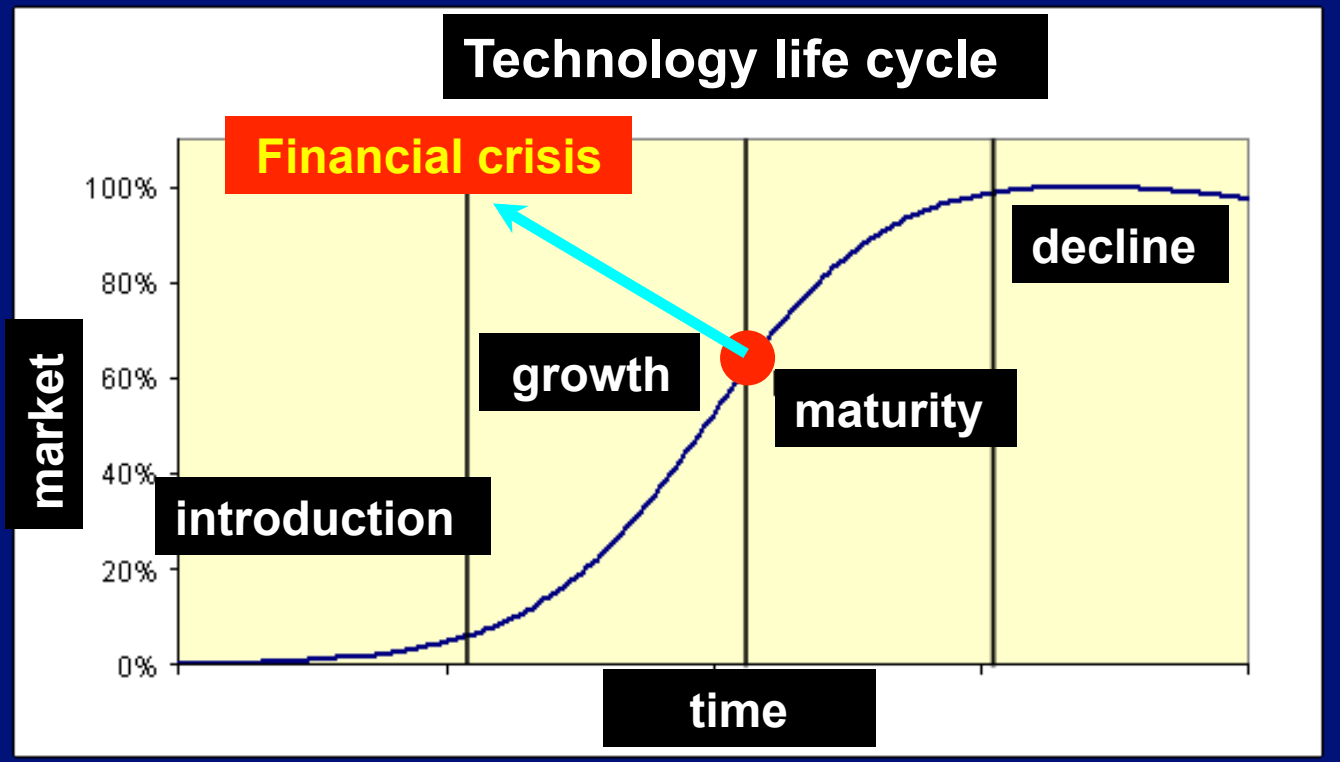
Charles Townes – 1964 Columbia
Arthur Schawlow - 1981 Stanford
Eric Betzig – 2014

Importance of Bell Labs

Vacuum tubes – Photovoltaics – semiconductors - transistor
Radio astronomy - Satellite communications - Cell phone
Maser: Townes + Jim Gordon –
Lasers: Ali Javan - HeNe laser + CKN Patel – CO2 laser
Raman revival – Sérgio Porto
Ultrafast lasers – Non Linear Optics
Laser trapping - Optical fibers

Information theory
C
UNIX

Carlota Perez: Technological Revolutions and Financial Capital



5 Revolutions - ~50- 60 years total cycle

1. Industrial Rev. – England – 1771
2. Steam and rail-road – England – 1829 [58 years after the 1st]
3. Steel and eletricity – England+USA+Germany – 1875 [46 ys after 2nd]
4. Oil, cars and mass production – USA – 1908 [33 ys after 3rd]
5. Information and comunications – USA – 1971 [63 ys] – [46 ys after 5th]

Hardware

IBM 486 – 1993

IBM 386 – 1991

IBM XT – 1983

IBM AT 286 1984

IBM PC 1981

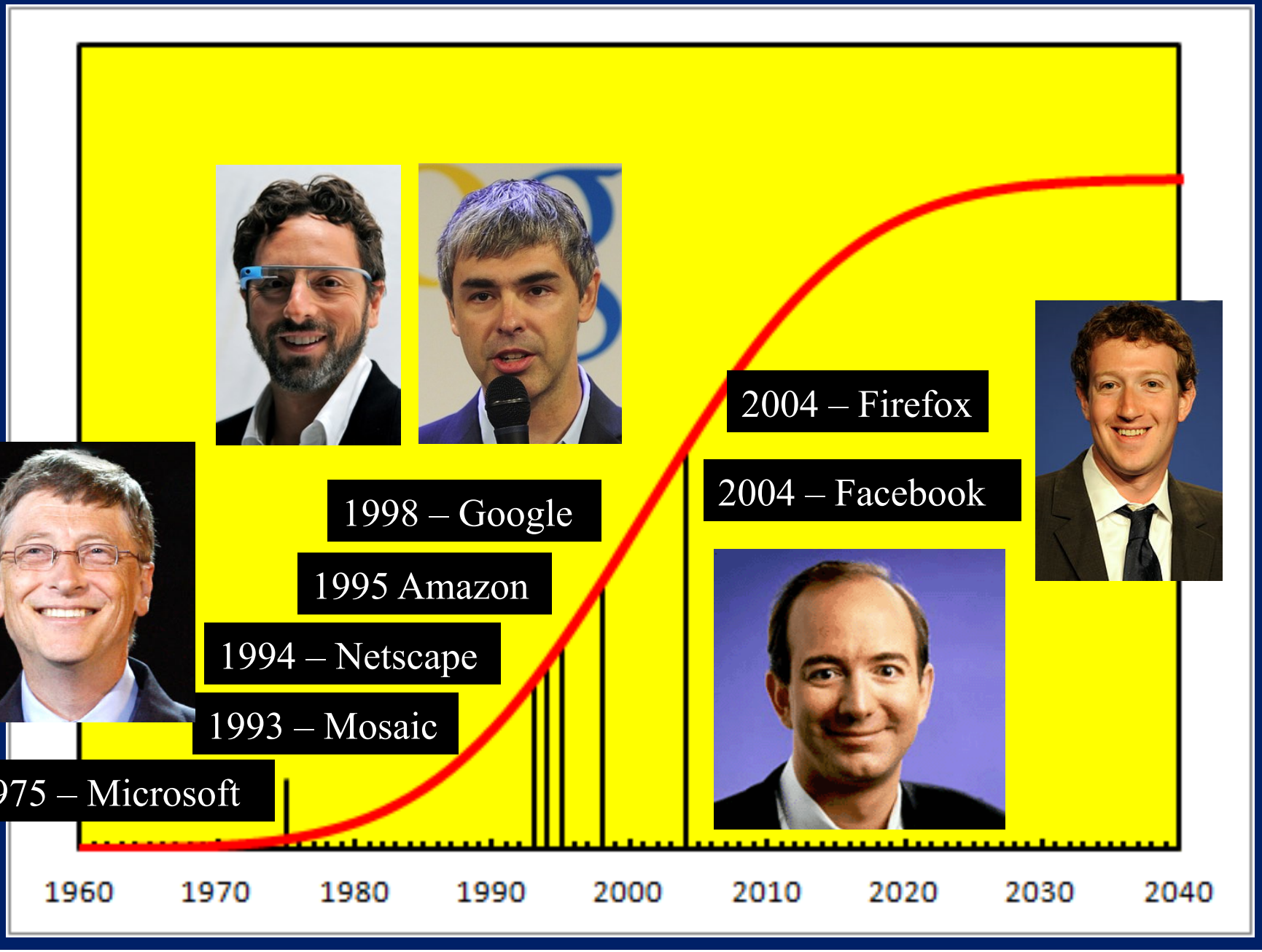
Apple 1977

Microsoft 1975

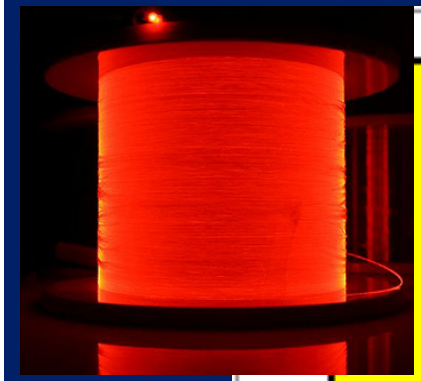
INTEL 1971

1960 1970 1980 1990 2000 2010 2020 2030 2040

Software


1975 – Microsoft
1993 – Mosaic
1994 – Netscape
1995 Amazon
1998 – Google
2004 – Facebook
2004 – Firefox
1960
1970
1980
1990
2000
2010
2020
2030
2040

Optical Network



1994 – calls by OF > electronic calls

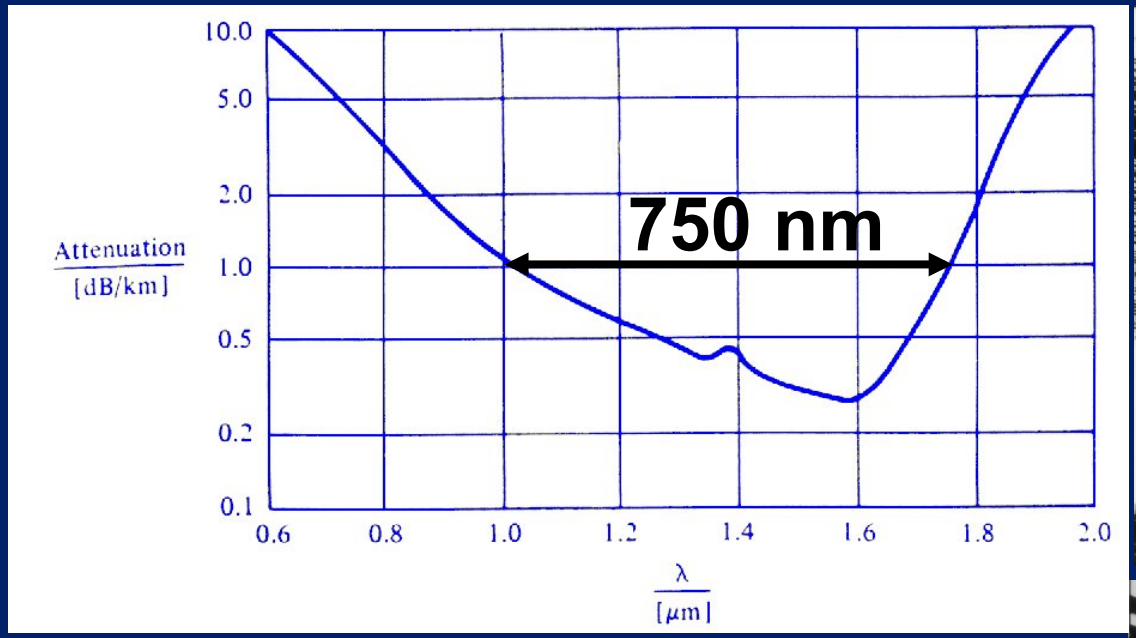
1988 – 1st TAT EDFA

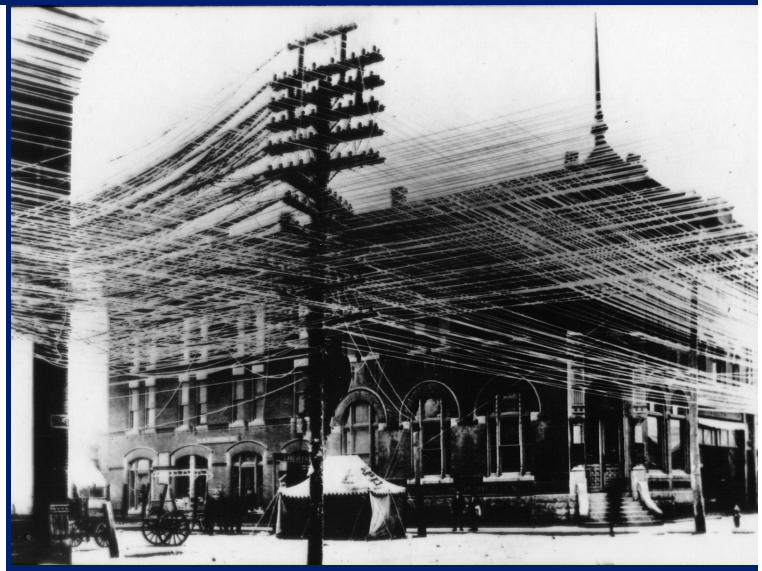
1987 – Optical Amplifier

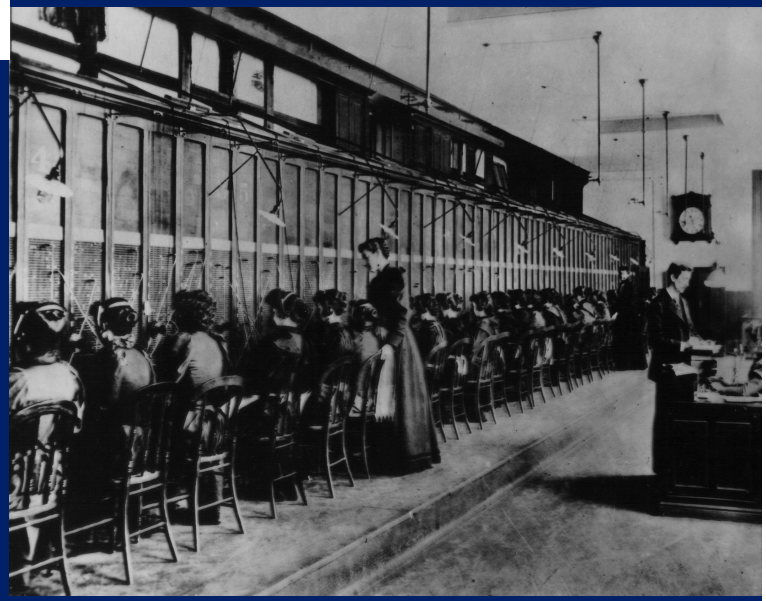
1975 OF communication

1970 Optical Fiber

Optical Communication - On the edge







Typical optical fiber attenuation

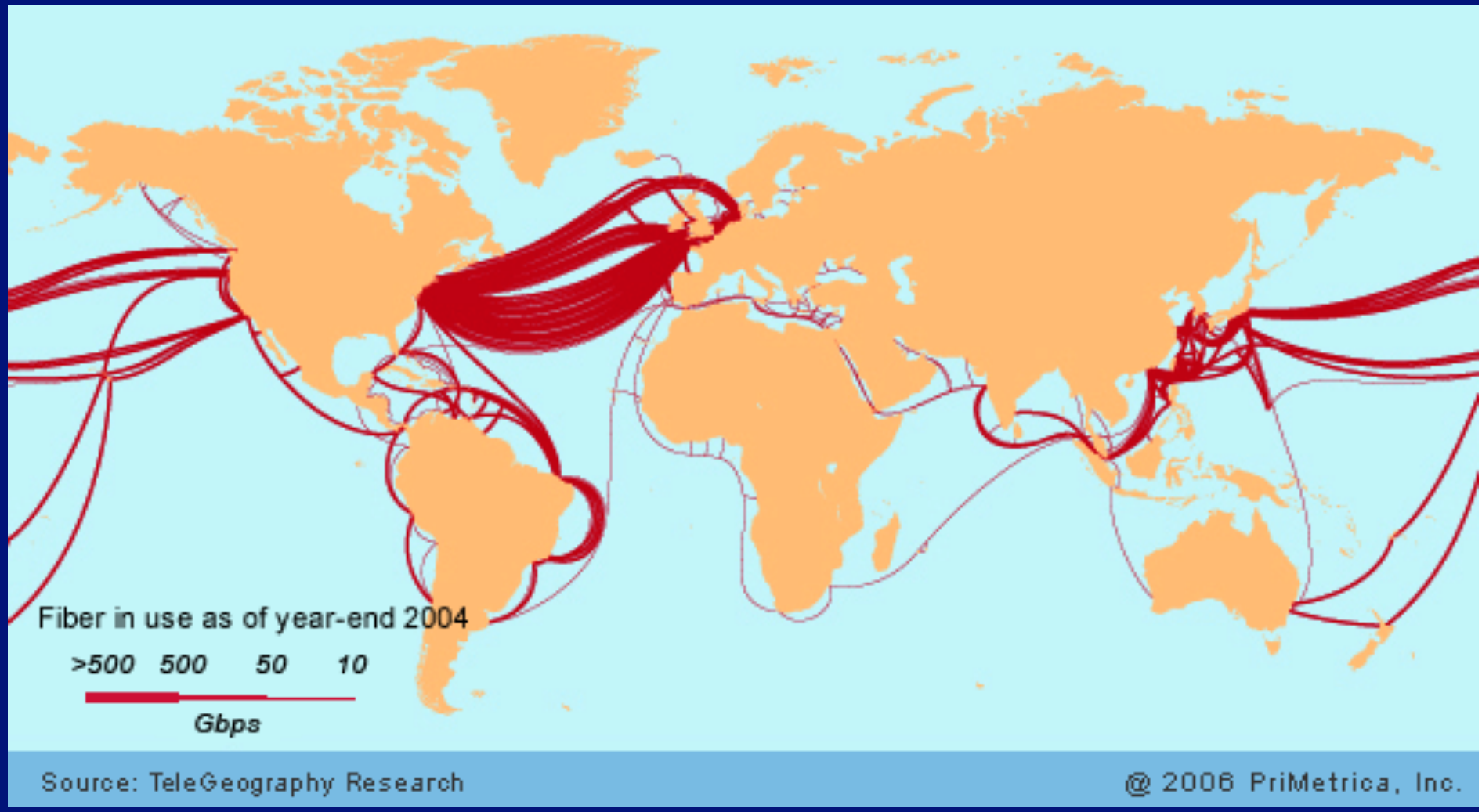
Bandwidth for 1 dB/km losses

$\Delta\lambda = 750\ \text{nm} \Rightarrow \Delta\nu\Delta\tau = 0.44$

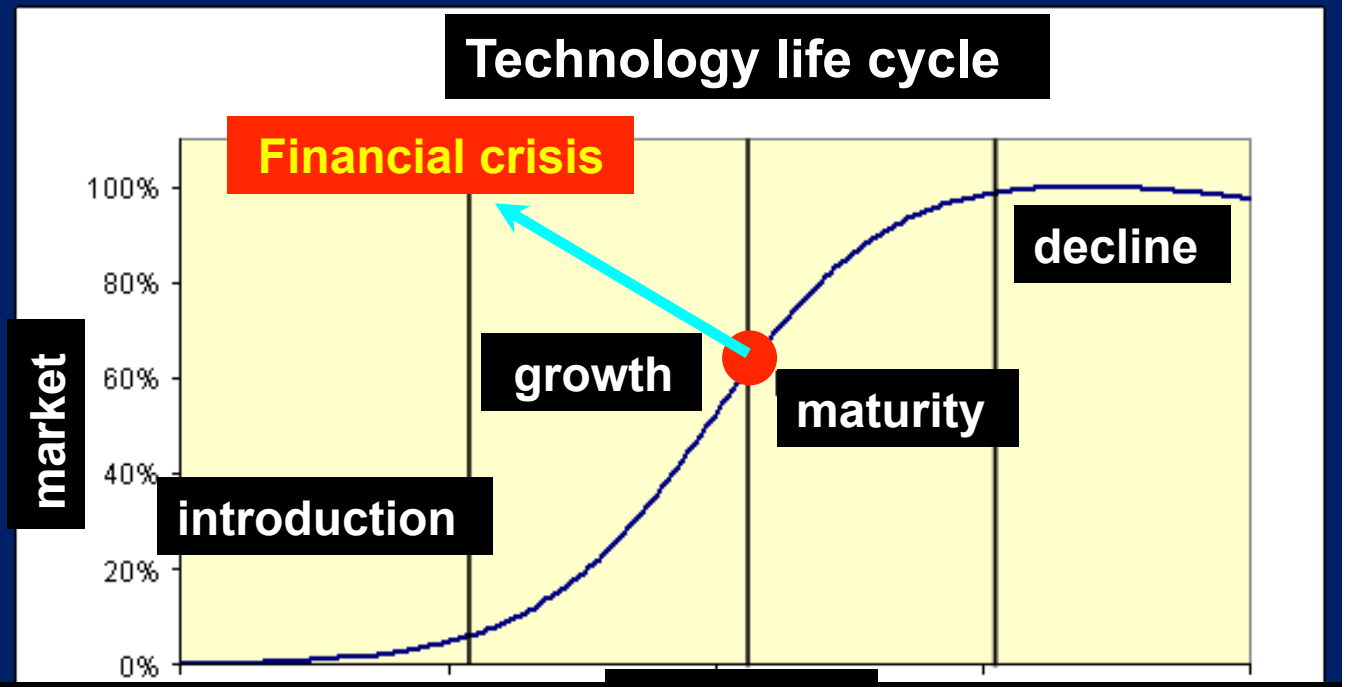
Total Capacity of only one fiber

10^{14} = 100 Tbit/s

Amplification, amplification, amplification!
Optical Erbium Doped Fiber Amplifier



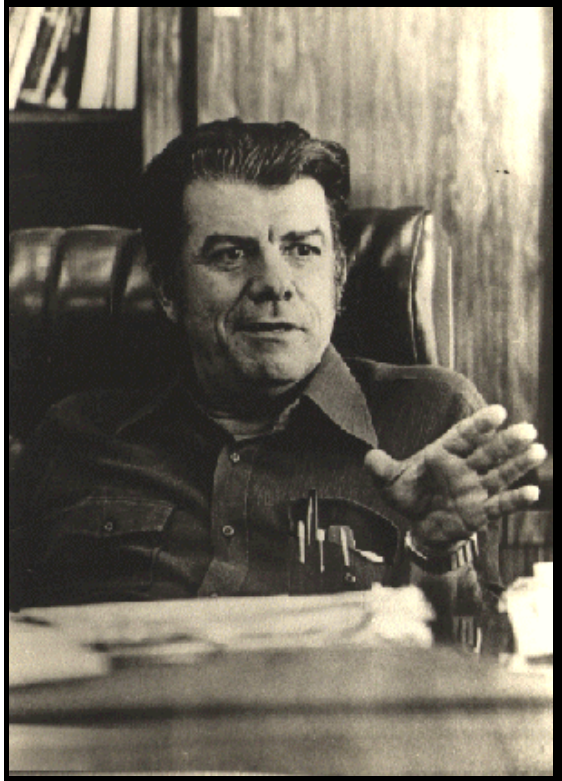
Carlota Perez: Technological Revolutions and Financial Capital



Trillion dollars question: Next Revolution???
Our bet: control of biology at cell/molecular level
BIOECONOMY

Bell Labs and Brazil

IFGW Founders



Sérgio Porto

Rogério Cerqueira Leite

José Ellis Ripper Filho

Alvin Kiel

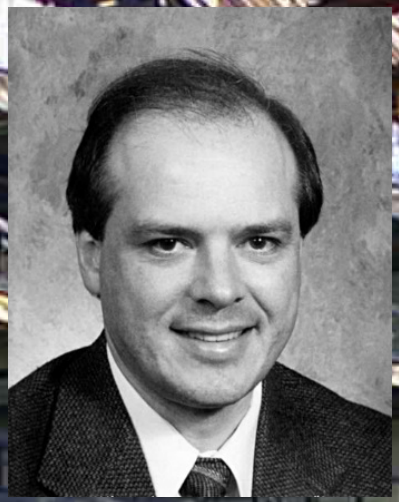
K. Shaklee

Antônio/Teresa Penna e Fernando Cerdeira

Photonics for Communications: Ultrafast Lasers, Semicondutors, Non linear Optics, Optical Fibers, Optical Amplifiers

Brito Cruz: 1986-1987

Charles Shank: diretor



David Miller

Hugo Fragnito: 1987-1989

Dear Prof. Cesar:

On behalf of Chuck Shank, Art Ashkin and myself, I would like to invite you to join during your Brazilian fellowship the Quantum Physics and Electronics Research Department at AT&T Bell Laboratories in Holmdel, New Jersey, USA. It will be my

CARLOS L CESAR
AT T BELL LABS
RM 4D 437
HOLMDEL NJ 07733

Carlos Lenz: 1988 – 1990

Decline

1983 – AT&T Divestiture – AT&T and baby Bells

Bell Labs and Bell Core

1990´s

AT&T + Lucent + NCR

Lucent sold to Alcatel sold to Nokia

Why Bell Labs was so unique?

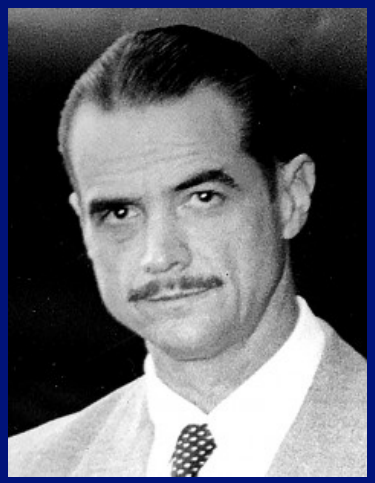
Big labs era is over? Bell, IBM, Xerox, GE

Is there any XXI century similar labs?

Janelia Farm – HHMI

Howard Hughes Medical Institute

18.2 billion USD endowment



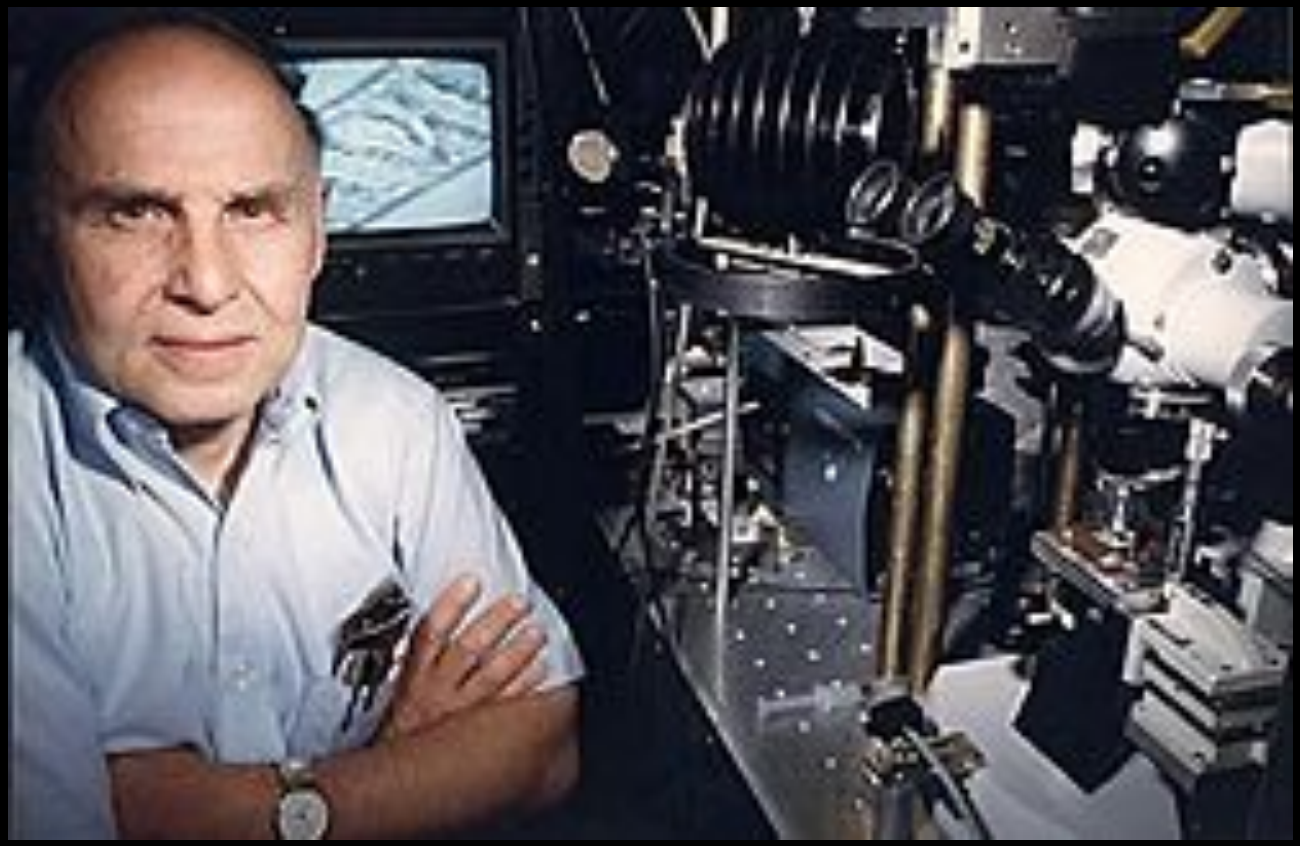
Two Optical Trapping Nobel Prizes

1997: Steven Chu - Atom Trapping

2018: Art Ashkin – Particle Trapping

Also know as Optical Tweezers

Optical Tweezers



Arthur Ashkin - 1986
Physicist – AT&T Bell Laboratories

Particle trapping preliminar work:

1970 – A. Ashkin, “Acceleration and trapping of particles by radiation pressure”, PRL Cited: 2,541

1971 – A. Ashkin and J. M. Dziedzic, “Optical levitation by radiation pressure”, APL Cited: 444

1976 - A. Ashkin and J. M. Dziedzic, “Optical levitation in high-vacuum”, APL Cited: 130

1977 - A. Ashkin and J. M. Dziedzic, “Observation of resonances in radiation pressure on dielectric spheres”, PRL Cited: 301

1981 - A. Ashkin and J. M. Dziedzic, “Observation of optical resonances of dielectric spheres by light-scattering”, Appl. Opt. Cited: 200

1983 - A. Ashkin and J. Gordon, “Stability of radiation-pressure particle traps - an optical earnshaw theorem”, Opt. Lett. Cited: 114

Particle trapping 2018 Nobel work:

1986 - A. Ashkin and J. M. Dziedzic, J.E. Bjorkholm, S. Chu et al, "Observation of a single-beam gradient force optical trap for dielectric particles", Opt. Lett. Cited: 3,854

1987 - A. Ashkin and J. M. Dziedzic, "Optical trapping and manipulation of viruses and bacteria", Science Cited: 1,173

1987 - A. Ashkin, J. M. Dziedzic and T. Yamane, "Optical trapping and manipulation of single cells using infrared-laser beams", Nature Cited: 1,309

Particle trapping posterior work:

1989 - A. Ashkin and J. M. Dziedzic, “Internal cell manipulation using infrared-laser traps”, PNAS Cited: 222

1990 - A. Ashkin, K. Schutze, J. M. Dziedzic et al., “Force generation of organelle transport measured in-vivo by an infrared-laser trap”, Nature Cited: 375

1992 - A. Ashkin, “Forces of a single-beam gradient laser trap on a dielectric sphere in the ray optics regime”, Biophys. J. Cited: 1,050

1994 - K. Schutze, A. Clementsengewald and A. Ashkin, “Zona drilling and sperm insertion with combined laser microbeam and optical tweezers”, Fertility and Sterility Cited: 53

Atom trapping:

1970 – A. Ashkin, “Atomic-beam deflection by resonance-radiation pressure”, PRL Cited: 257

1978 - A. Ashkin, “Trapping of atoms by resonance radiation pressure”, PRL Cited: 363

1979 - A. Ashkin and J. Gordon, “Cooling and trapping of atoms by resonance radiation pressure”, Opt. Lett. Cited: 73

1980 - J. Gordon and A. Ashkin, “Motion of atoms in a radiation trap”, PRA Cited: 498

Atom trapping Nobel work:

1985 - S. Chu, L. Hollberg, J.E. Bjorkholm, A. Ashkin et al, "3-Dimensional viscous confinement and cooling of atoms by resonance radiation pressure", PRL Cited: 477

1986 - S. Chu, J.E. Bjorkholm, A. Ashkin et al, "Proposal for optically cooling atoms to temperatures of the order of 10-6 K", Opt. Lett. Cited: 477

Nobel 1997

1986 - S. Chu, J.E. Bjorkholm, A. Ashkin et al, "Experimental-observation of optically trapped atoms", PRL Cited: 493

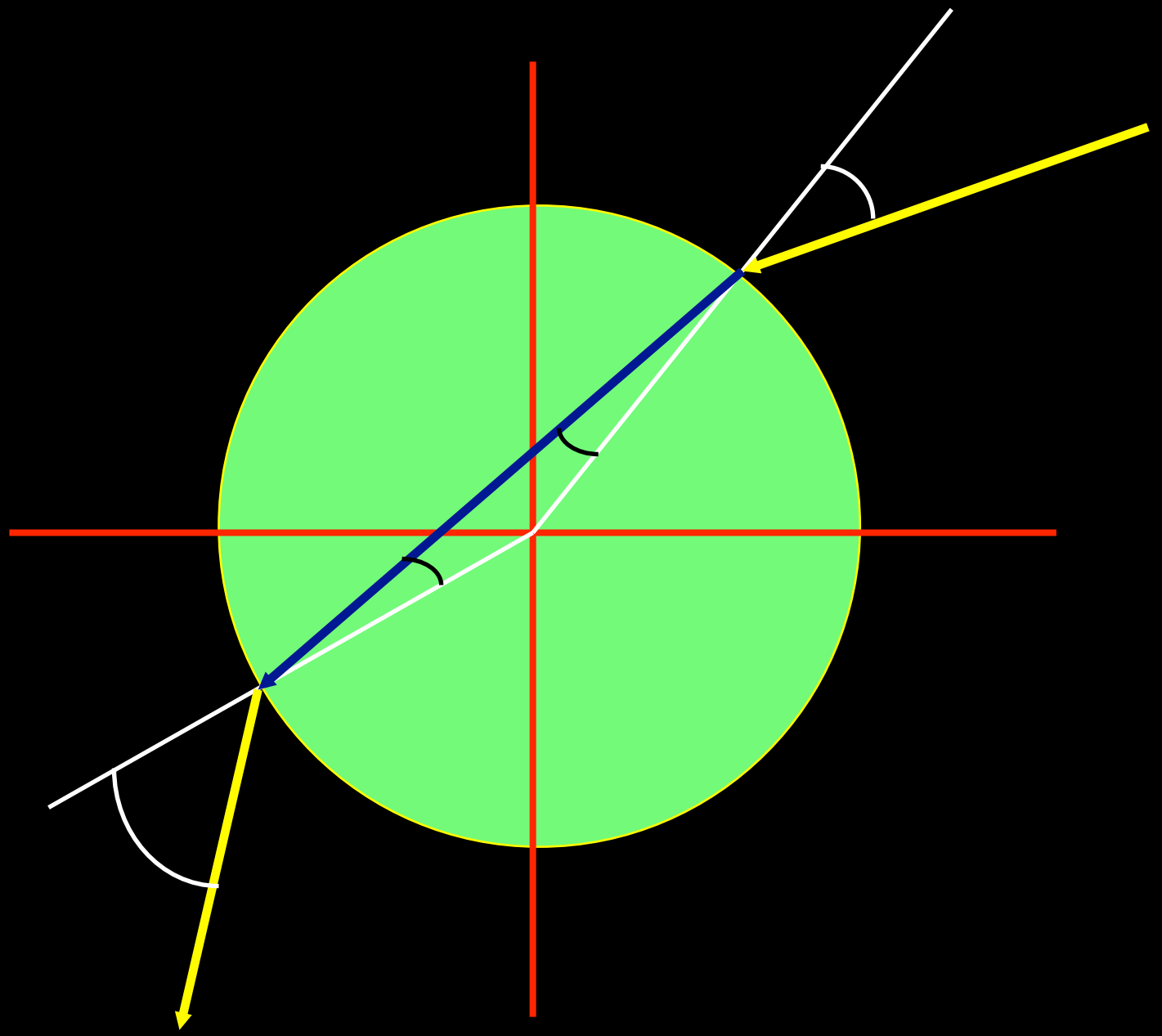
Optical tweezers: Waves for remote mechanical manipulation!!

Einstein 1905 (Photoelectric effect): light is made of particles called photons

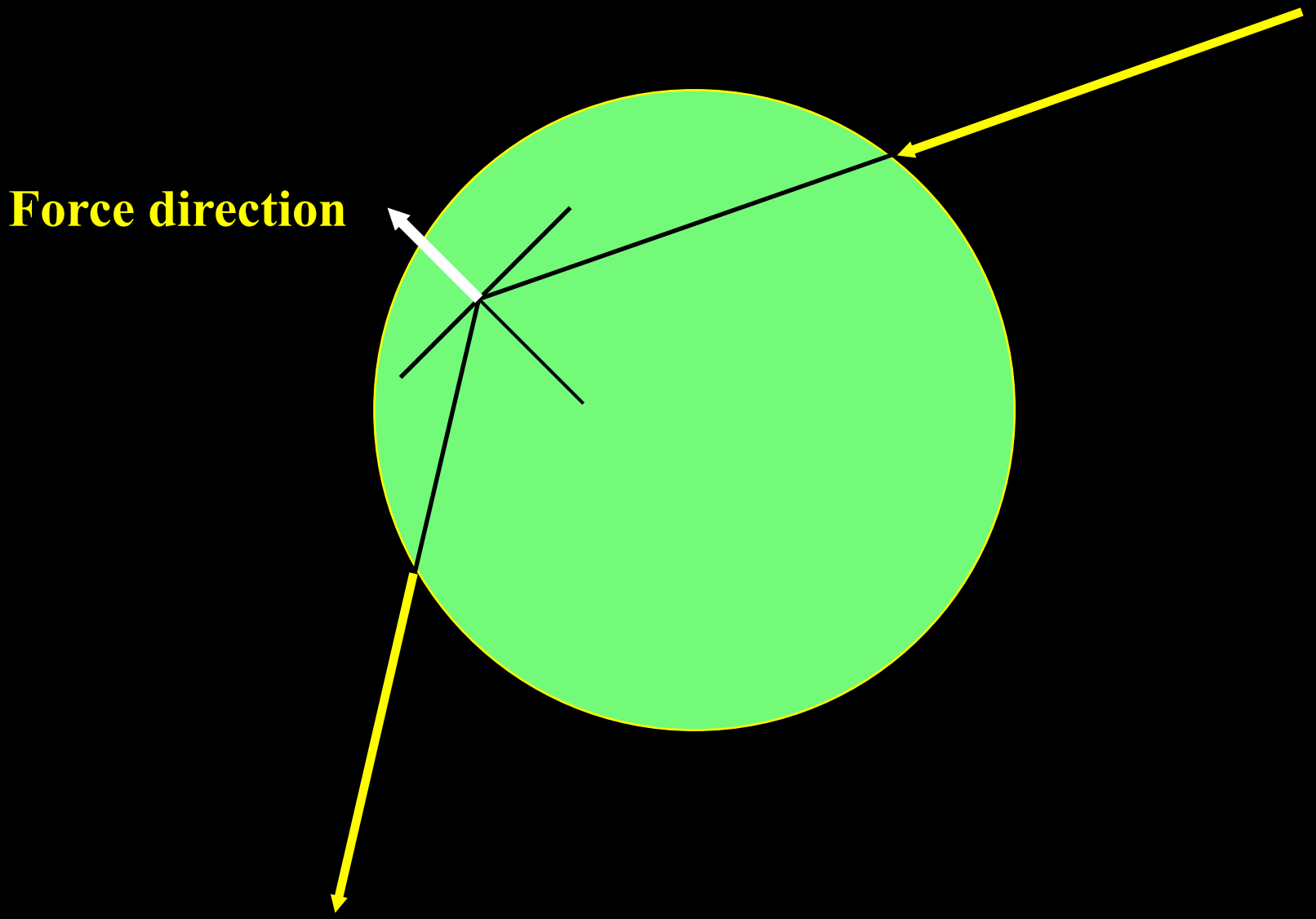
(Photo greek = light, like in photo-graphy)

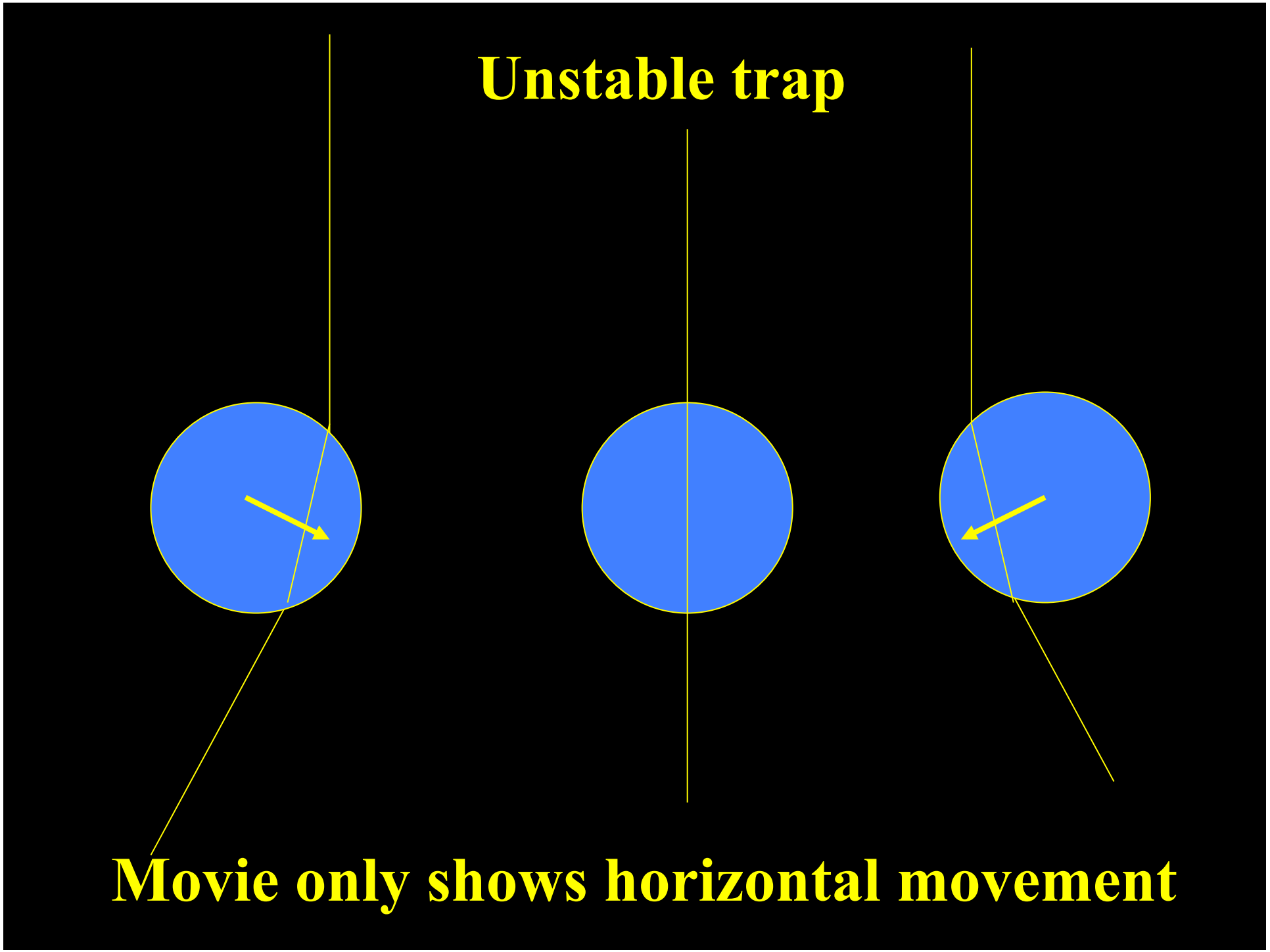
Particles can transfer momenta

Light, as wave, is refracted



Light, as particle, transfers momentum

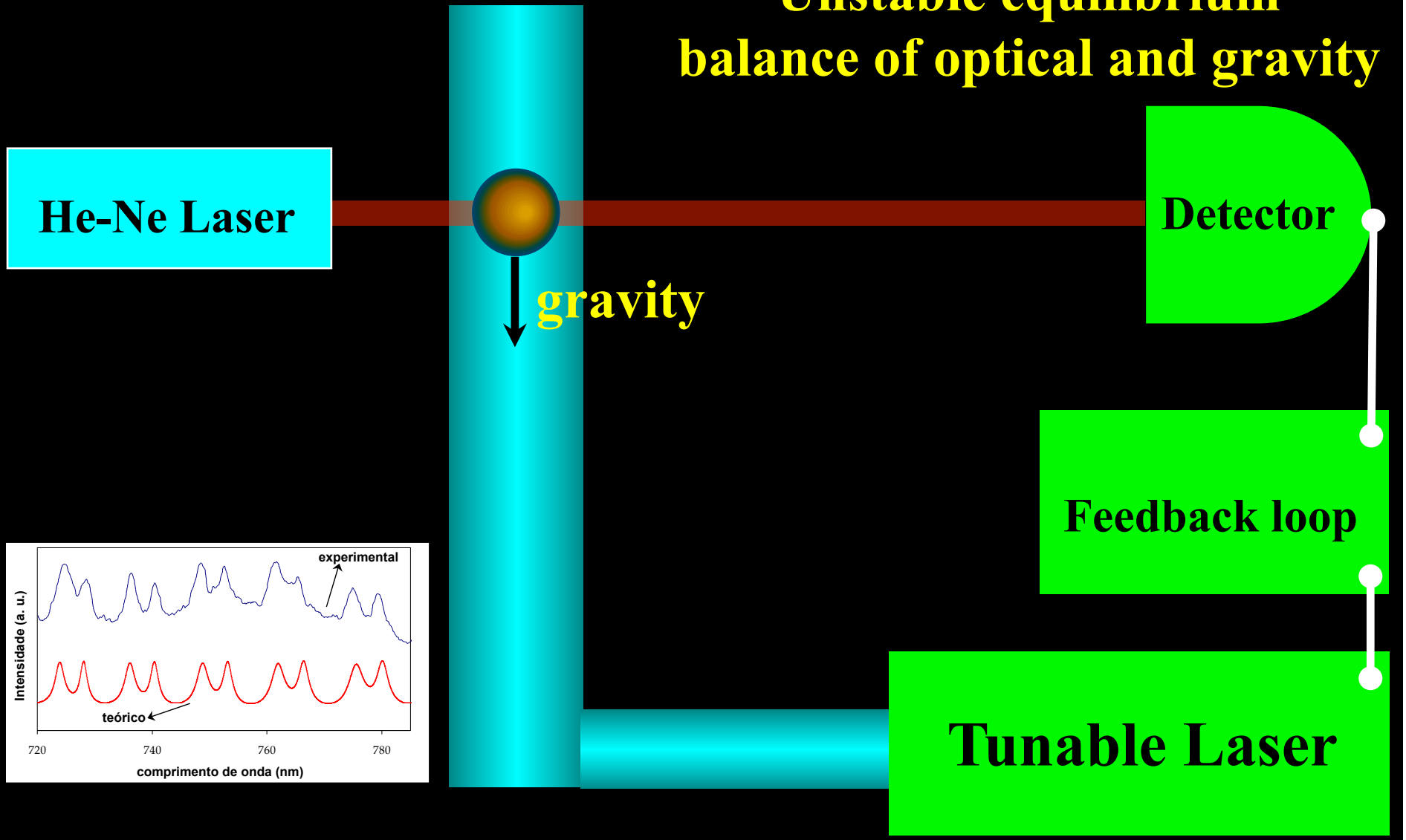



Unstable trap
Movie only shows horizontal movement

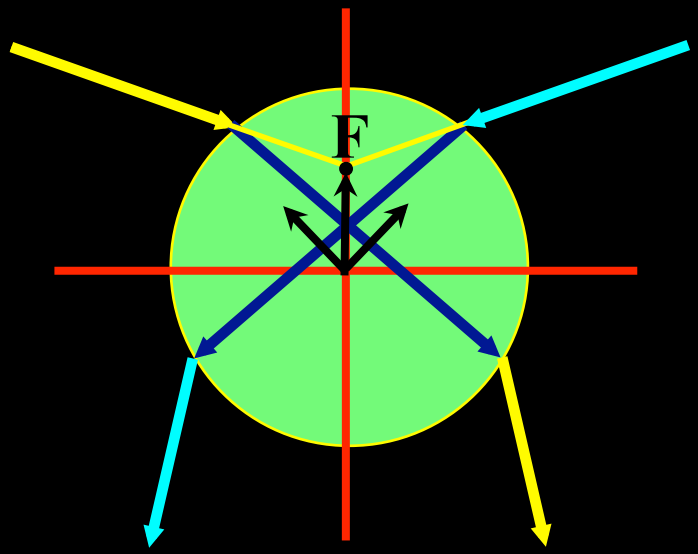
A.Ashkin optical Force Spectroscopy (1977)

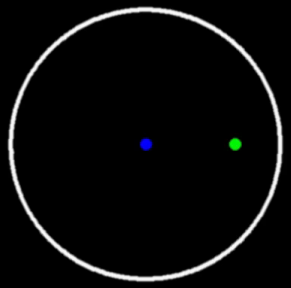
Levitation Experiment

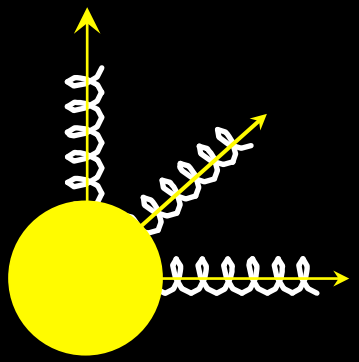
Unstable equilibrium
balance of optical and gravity



Stable trap: Single Beam Optical Tweezers







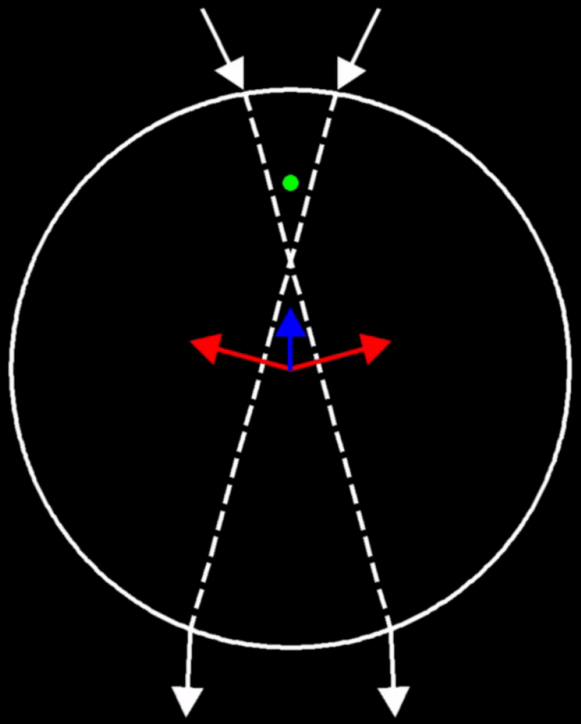
Restorative force: always tending to bring the center to the focus

Orders of magnitude

1μm particle mass ~ 10^{-15} Kg - acceleration ~ 10,000 g's

100 μm particles ~ 0.01 g's

Ansisotropic force



High NA ~ 1-1.4: to increase z force component

Conditions for trap stability:

Particle refraction index > fluid refaction index

Otherwise particle is expelled.

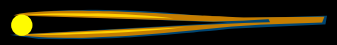
Low reflection and absorption.

Thermal effects expel particle

Optical tweezers

Single beam 3 dimension restorative anisotropic trap

very good optical tweezers: forces up to 200pN



Weak optical tweezers forces < 10 pN

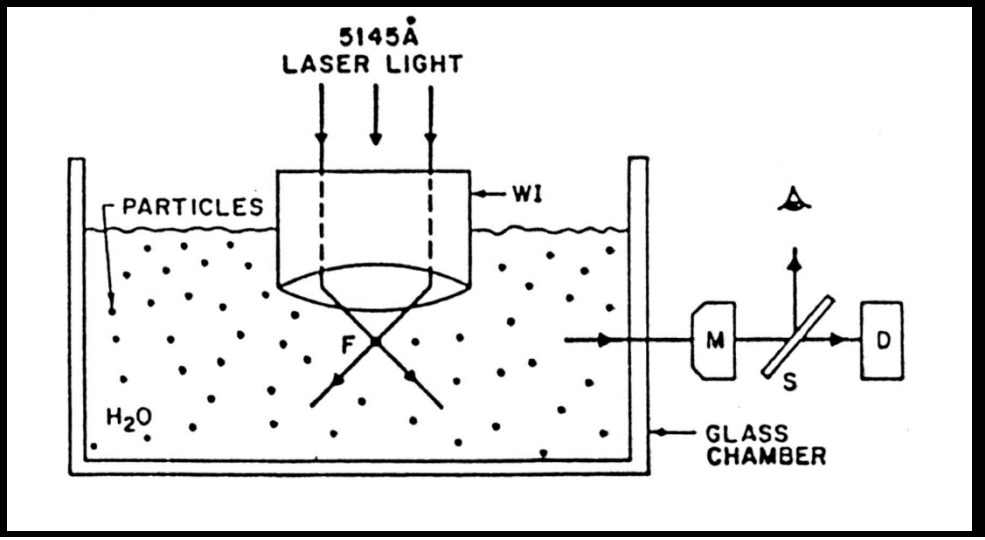
Play around with beads

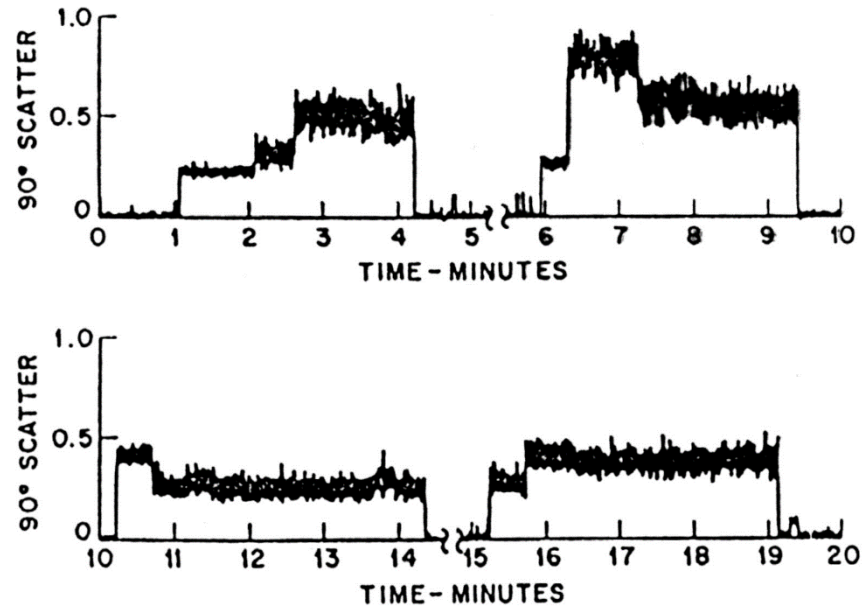
Optical Tweezers Sperm Test: capturing & holding a spermatozoid

Art Ashkin & Steven Chu capturing atoms

Argon Laser

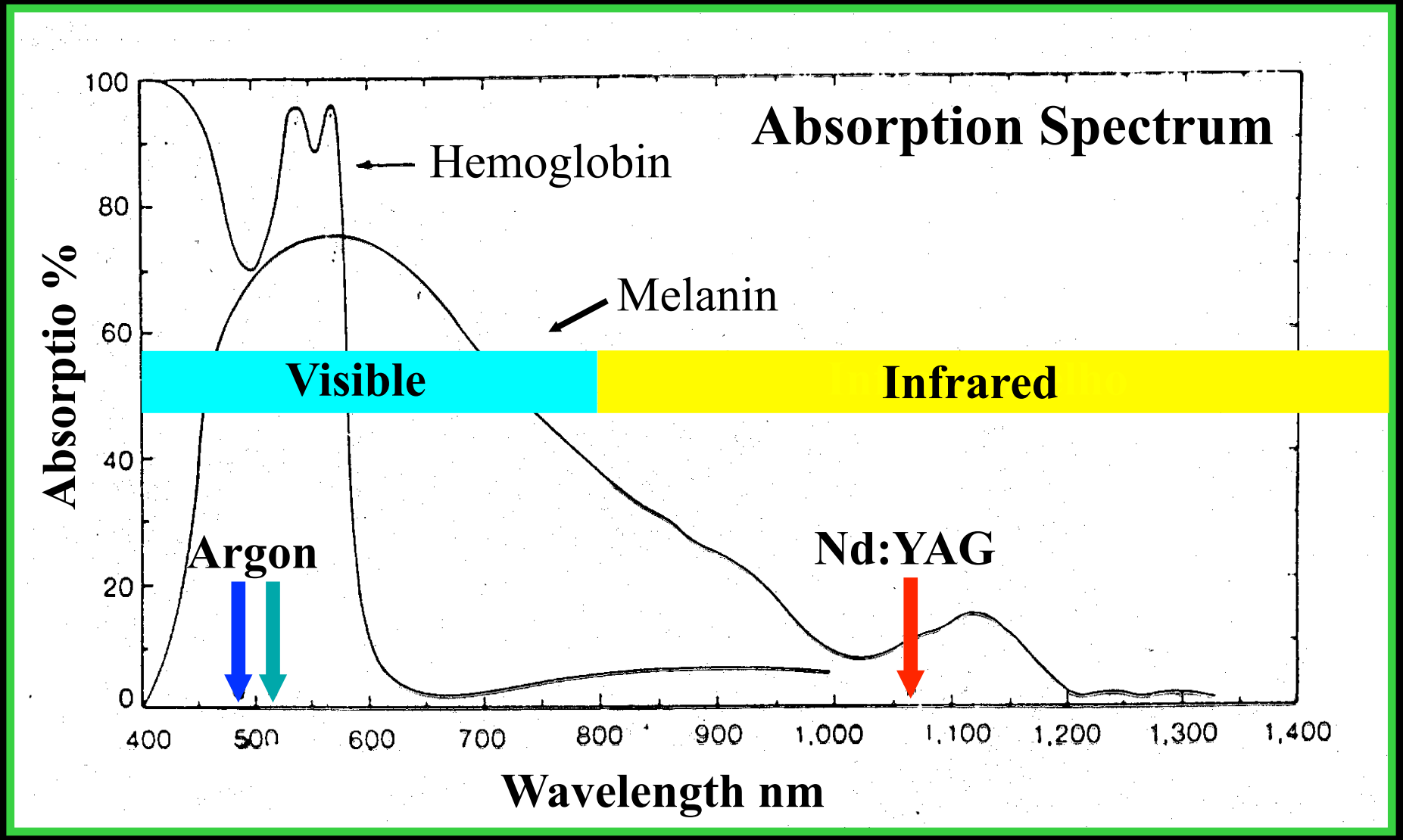
New Jersey water after hollidays: bacterias cooked au laser





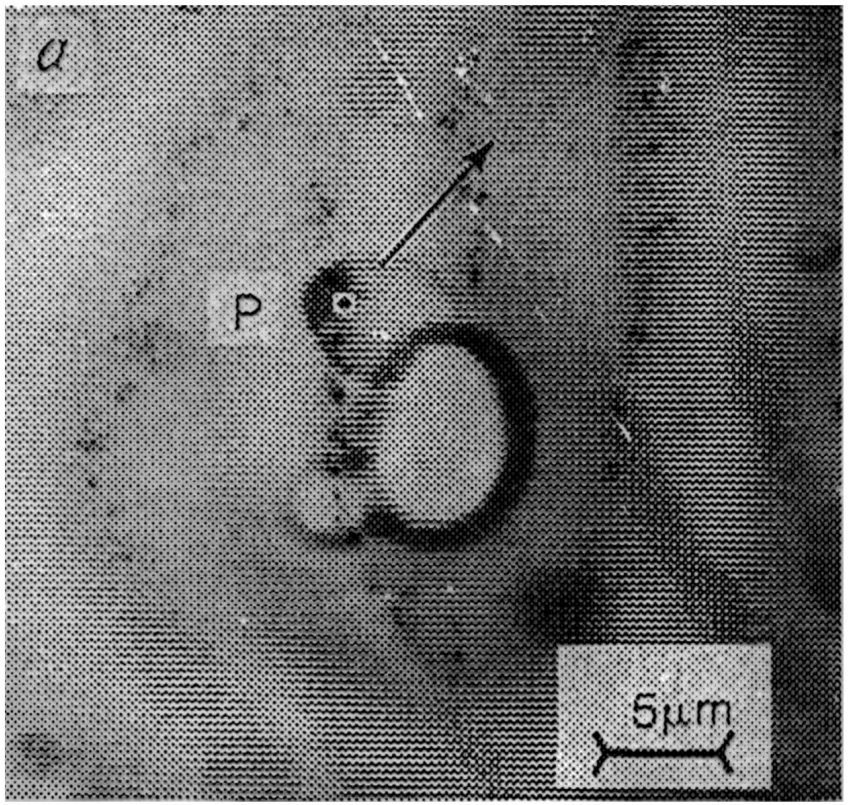
Lesson: avoid thermal effects

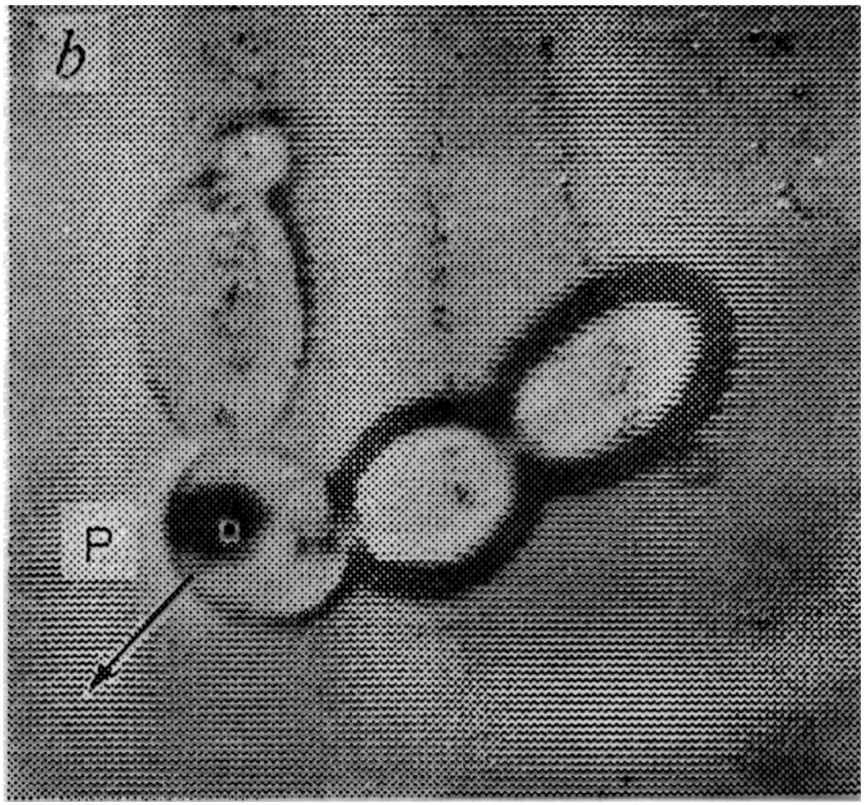
Wrong Laser: Argon - 488 e 514 nm



Exchange lasers: Nd-YAG 1064 nm

☺ Keeping alive!





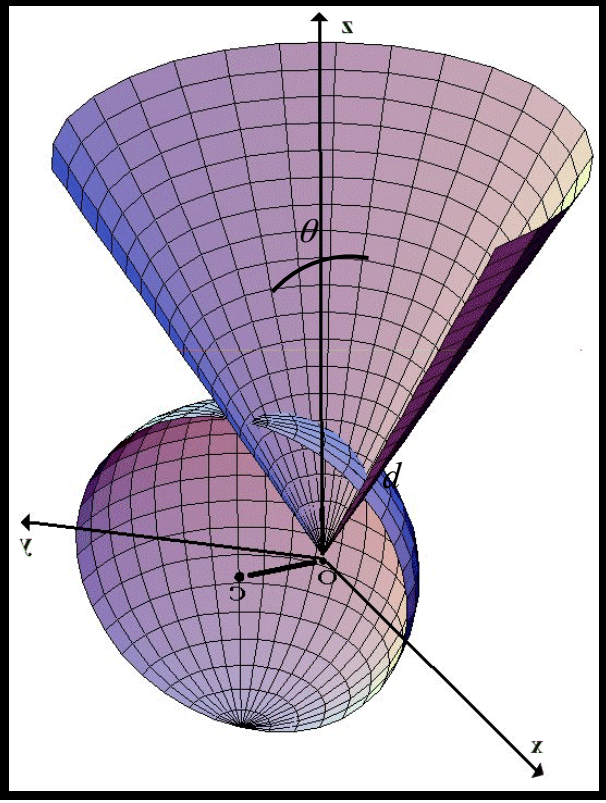
Yeast cells after 3 hours trapped with Nd:YAG

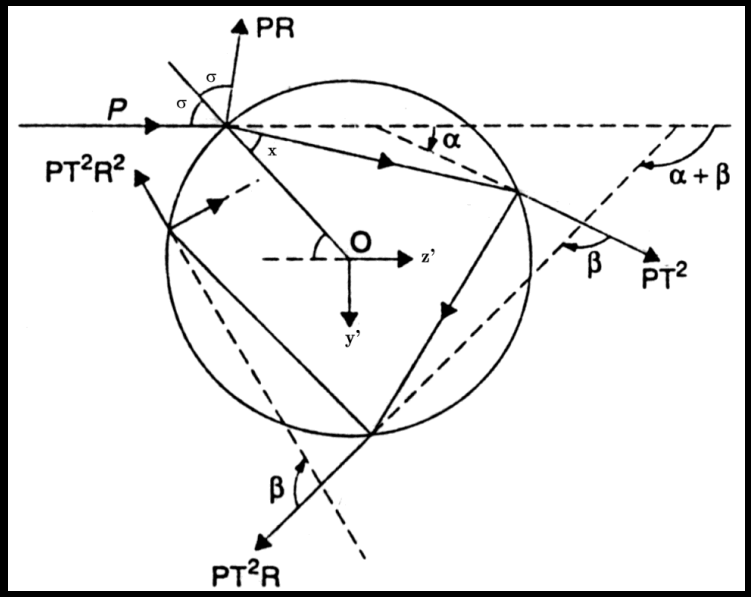
Necessary condition (not sufficient) for reproduction: been alive!

A. Ashkin, J. Dziedzic and T. Yamane, Nature 330, 769 (1987)

Brasilian: today working at Butantan SP

Força óptica - teoria complicada mas possível para esfera!





Considerar reflexões

$$F_{z'} = \frac{n_1 P}{c}[1 - R\cos(\pi + 2\sigma) + \sum_{n=0}^{\infty} T^2 R^n \cos(\alpha + n\beta)$$

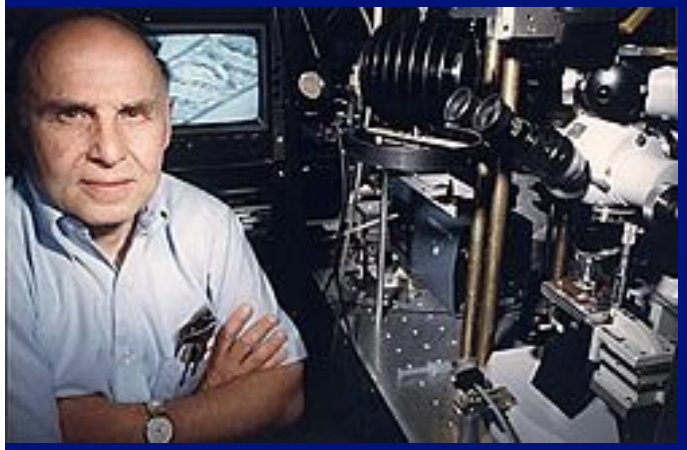
$$F_{y'} = \frac{n_1 P}{c}[-R\,\mathrm{sen}(\pi + 2\sigma) + \sum_{n=0}^{\infty} T^2 R^n \,\mathrm{sen}(\alpha + n\beta)$$

$$F_c = F_{z'} + iF_{y'}$$

$$F_{\acute{o}ptica} = F(P, n_1, n_2, a, \theta, \phi, d)$$

Optical Tweezers at UNICAMP/Brazil:

1988 - Pos-Doc AT&T Bell Labs Holmdel - Dr Arthur Ashkin



1991 - setup of an optical tweezer in Brazil

1995 - collaboration with the Hemocenter

2001 - femtosecond lasers + optical tweezer

2005 - Chemotaxy

"Light Sucks"

XXI century Group's history:

2000 – CEPOF

2000 – NLO + OT integration – Raman/Mi

2005 – First Olympus Multiphoton Conf

2005 – First SHG image in Brazil

2007 – First FLIM in Brazil

2008 – National Institute for Photonics Applied to Cell Biology

2008 – First THG image in Brazil

2009 – Zeiss LSM 780 NLO inverted

2009 - Multiuser project

2010 - OPO for CARS

2010 - AFM for tip-enhacement

2010 – Zeiss LSM 780 NLO upright

2010 – Multiple Optical Tweezers + Laser cutting

2011 – first FRET

2014 – towards super resolution/single molecule

CePOF

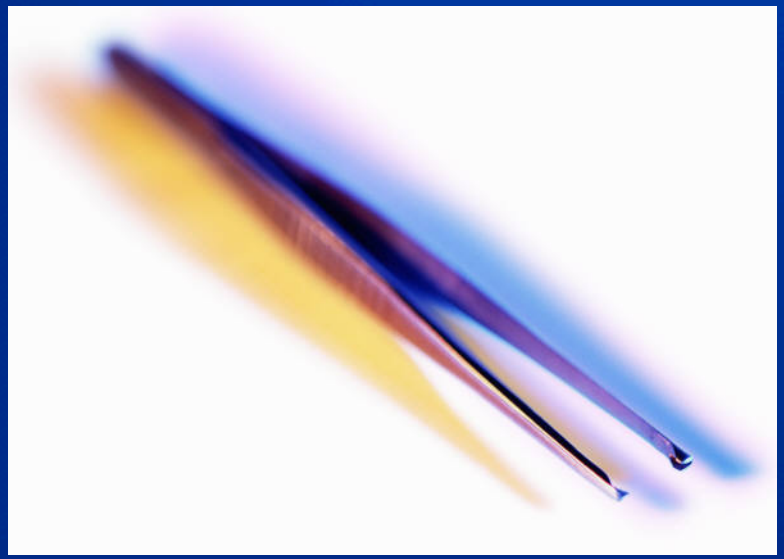
Centro de Pesquisa em Óptica e Fotônica

INFABIC

INSTITUTO NACIONAL DE CIÊNCIA E TECNOLOGIA DE FOTÔNICA APLICADA À BIOLOGIA CELULAR

At UNICAMP

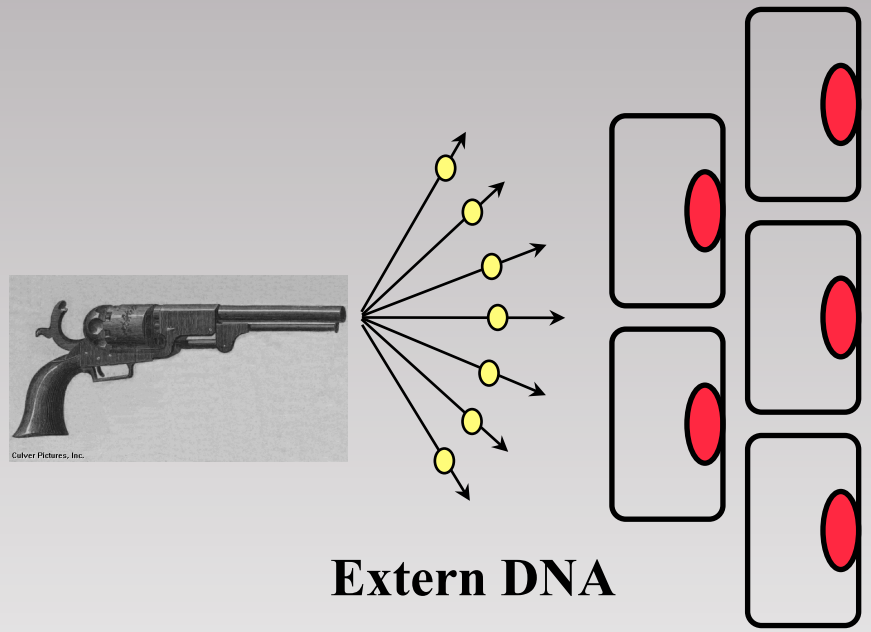
Paulo Arruda interest: optical tweezers for manipulations

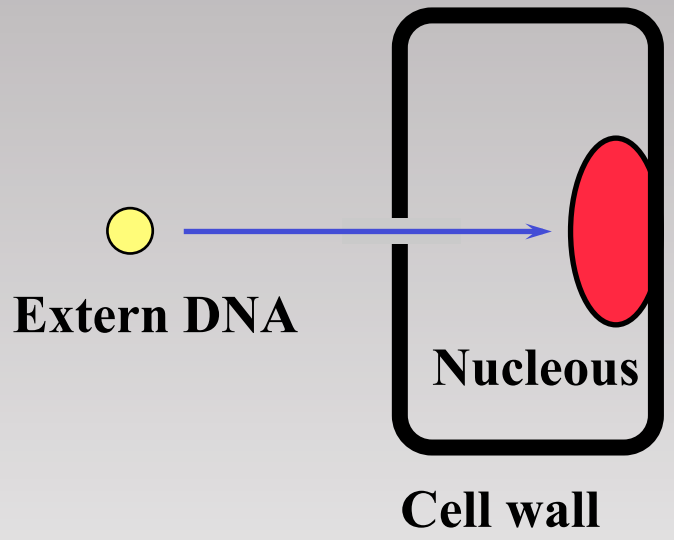


Optical Tweezers

Optical scalpel

Objective: genetic manipulation

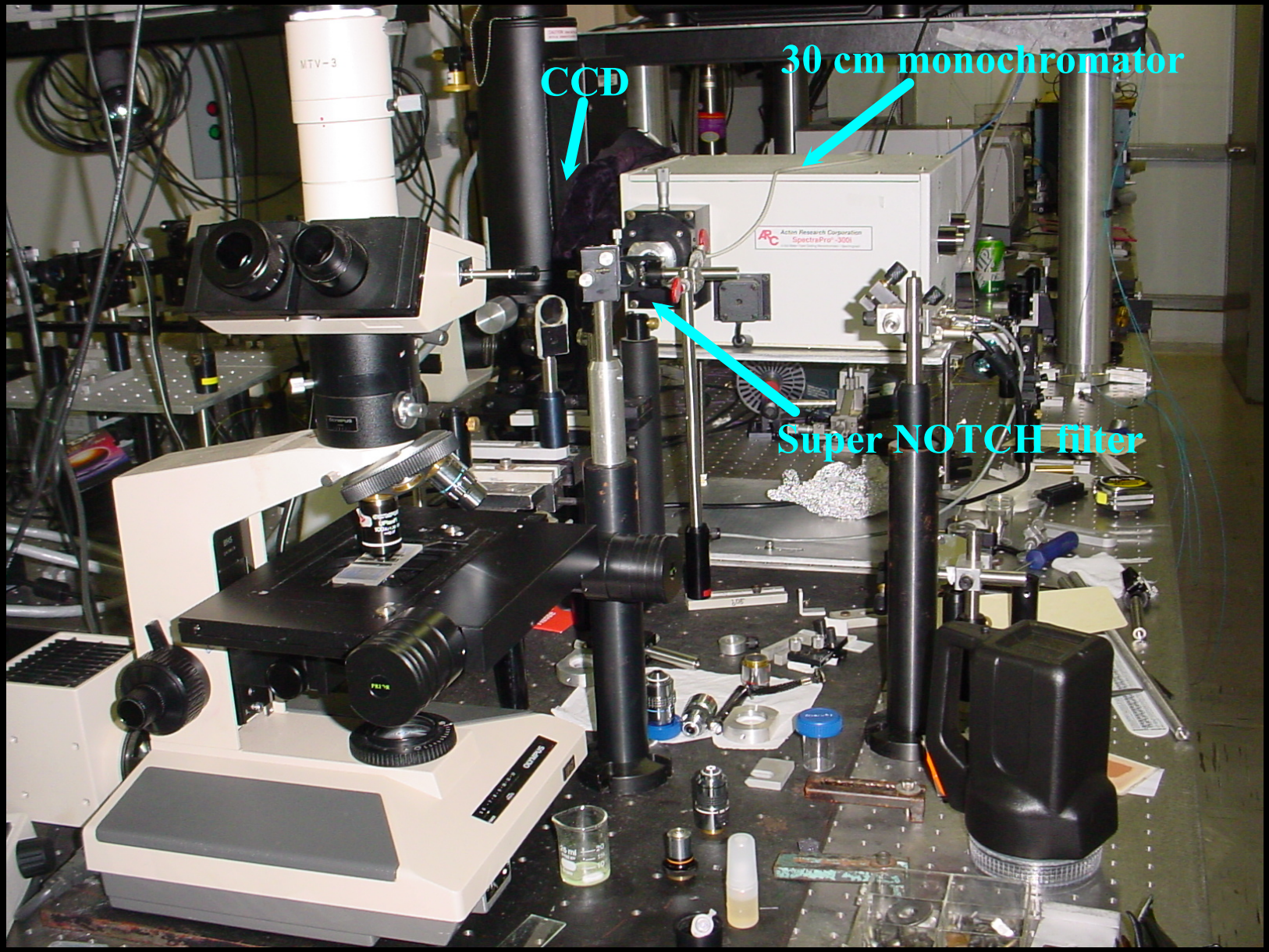




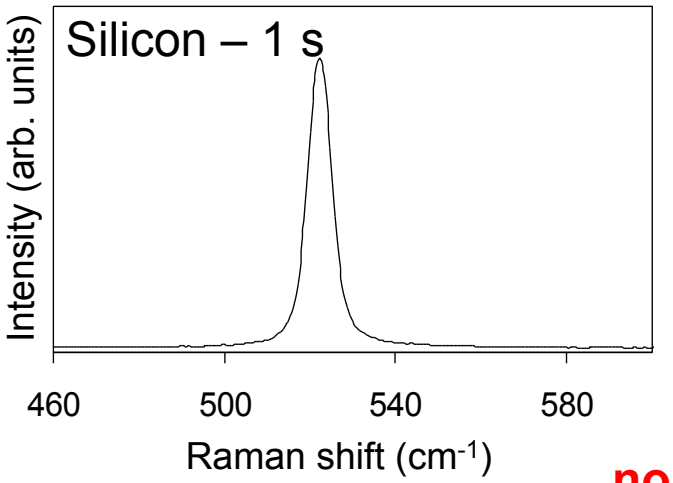
Conventional Method

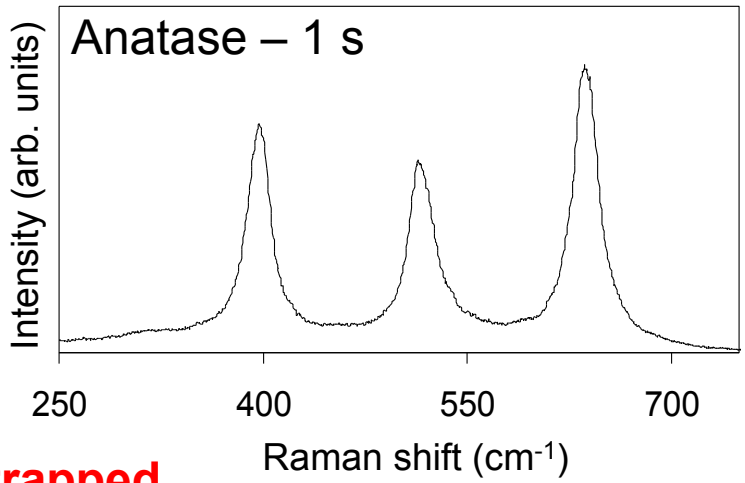
Optical Tweezers + scalpel method

Microspectroscopy system

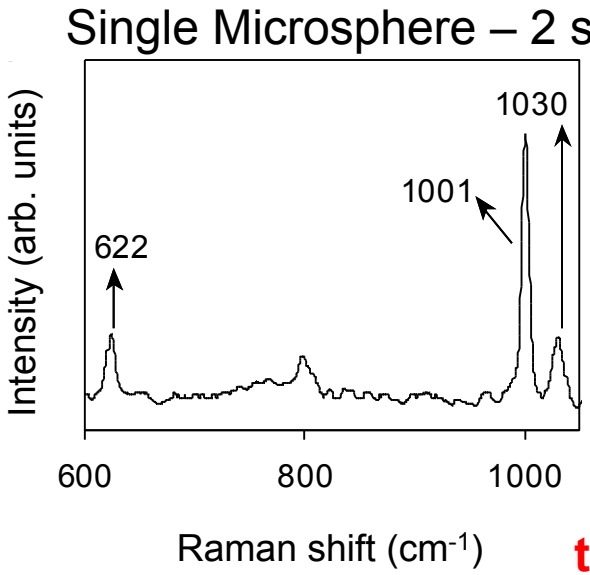


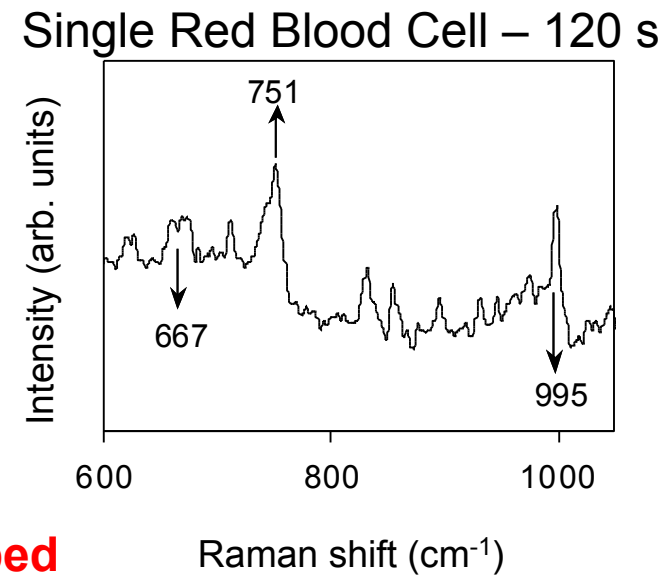
Raman Results:





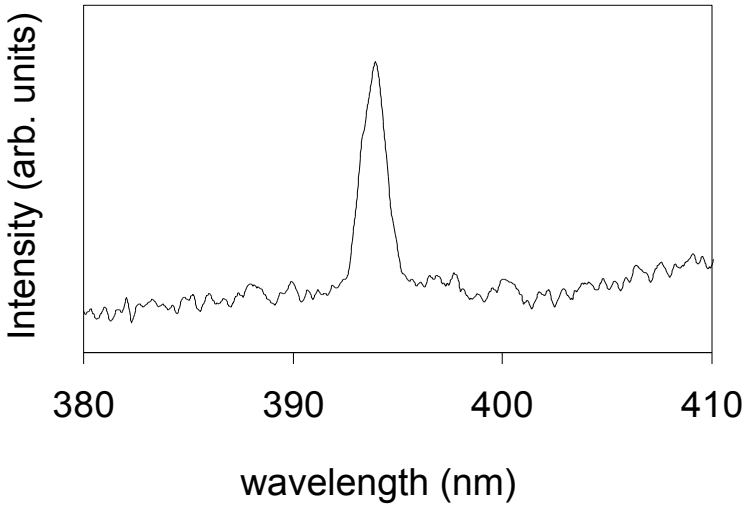
non-trapped

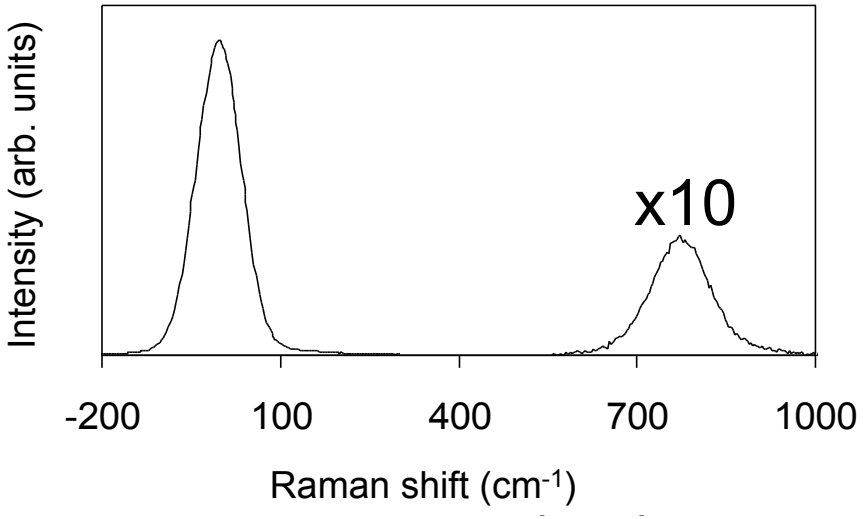




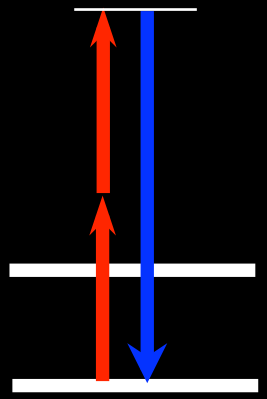
trapped

Hyper Raman and Hyper Rayleigh Results:

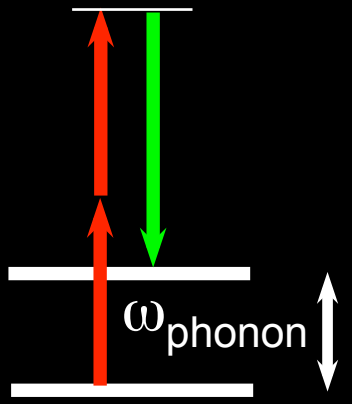




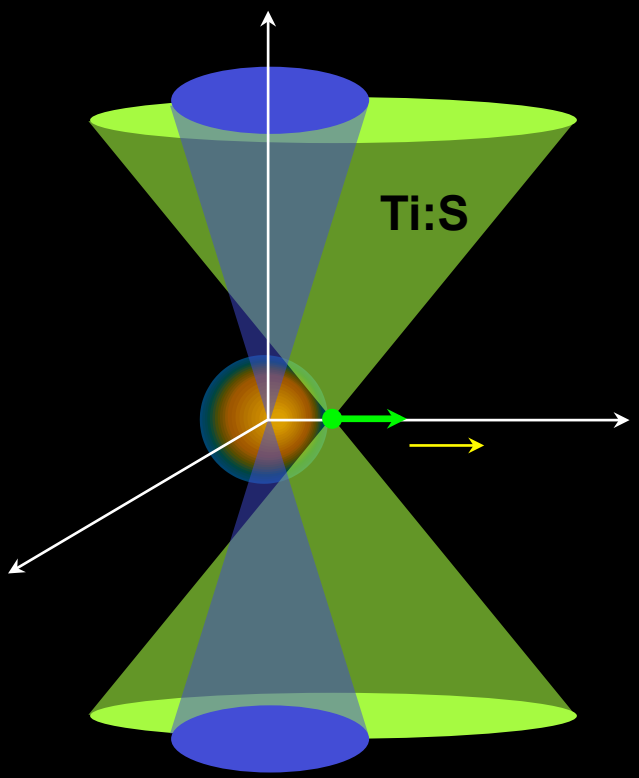
Hyper Rayleigh (SHG):
single silica microsphere – 120 s

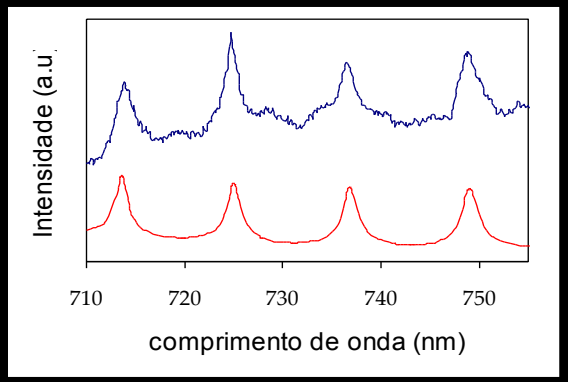


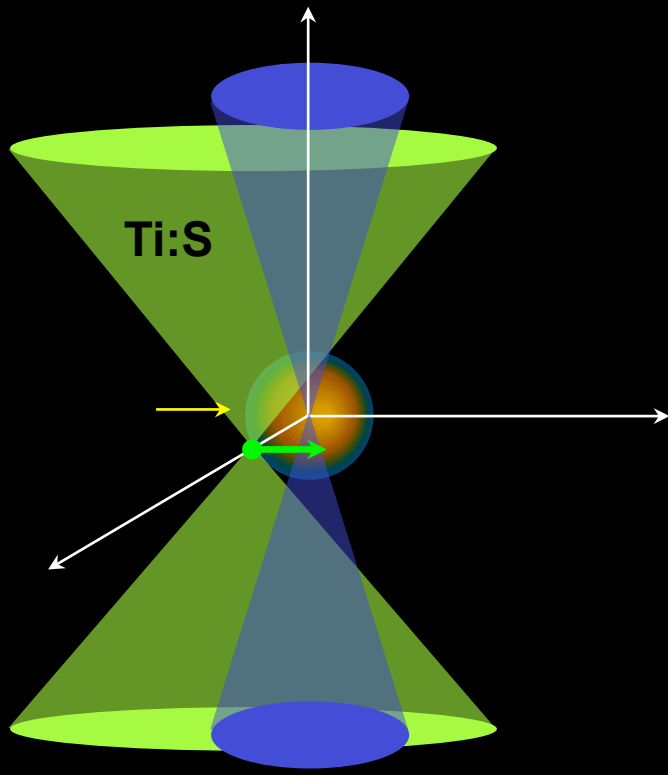
Hyper Raman:
$SrTiO_3$ – Only 60 s

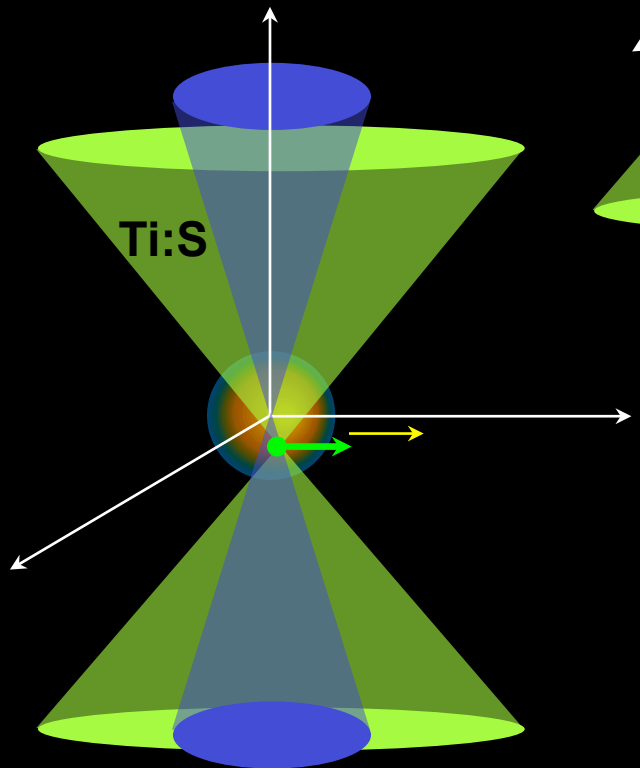


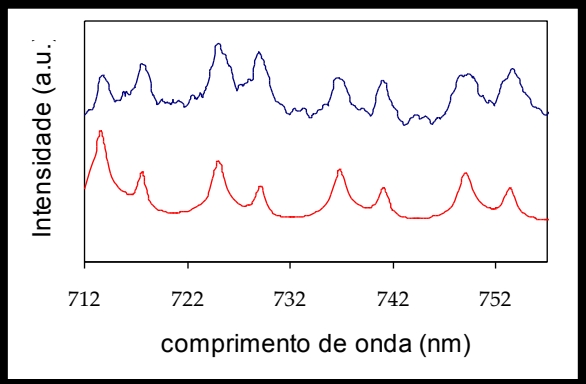
Mie Resonance Polarization dependent Force

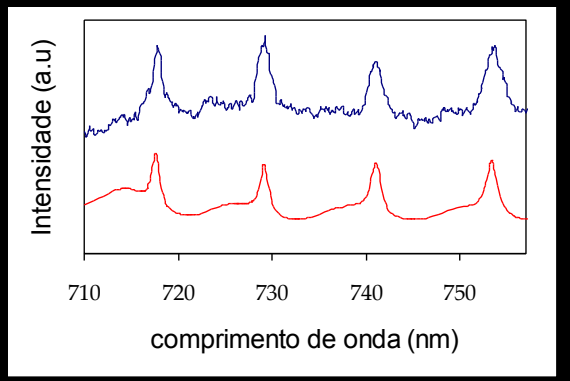




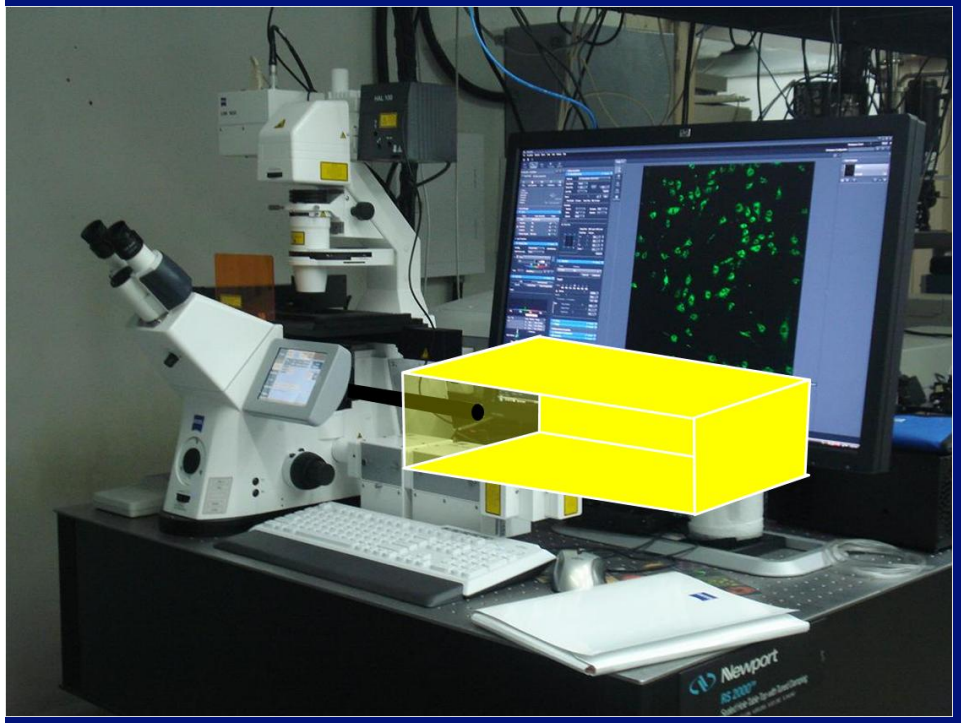








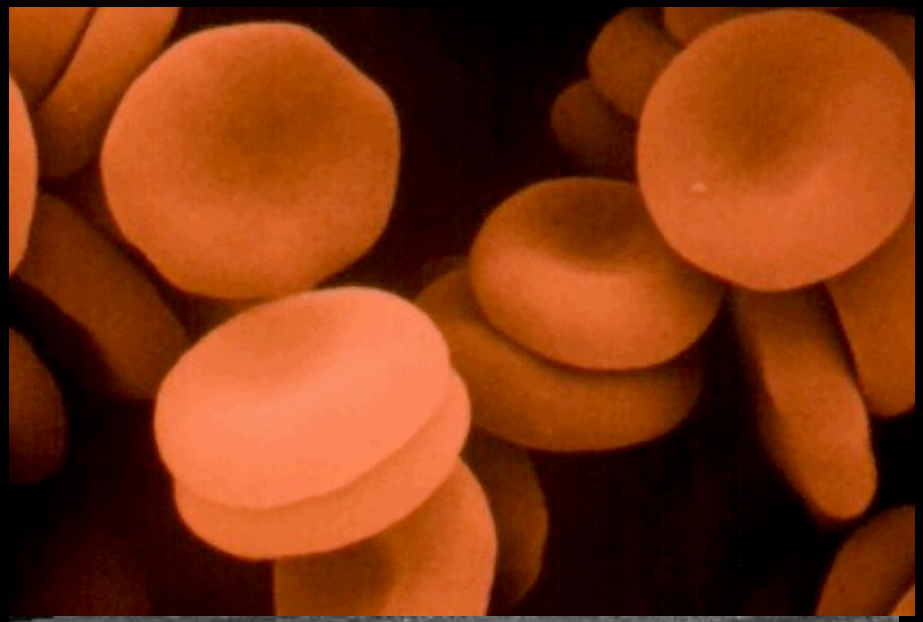
Optical Tweezers & Laser Cutting

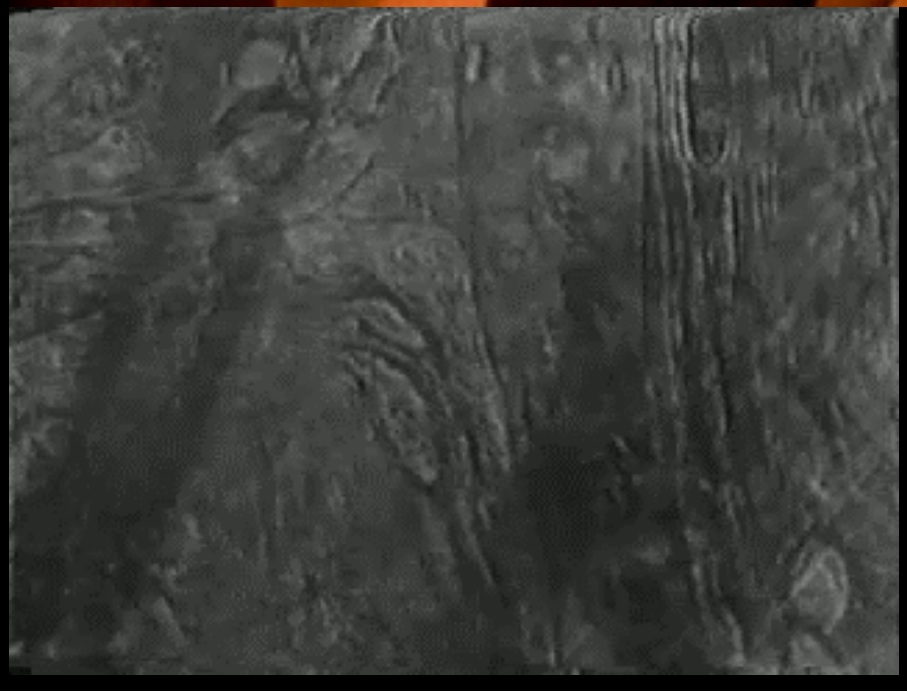


Biomechanics F~500 pN
Cell rheology; manipulation;
Zeta potential ...

+ Laser cutting:
Controlled transfection;
Cell surgery;
Material collection; ...

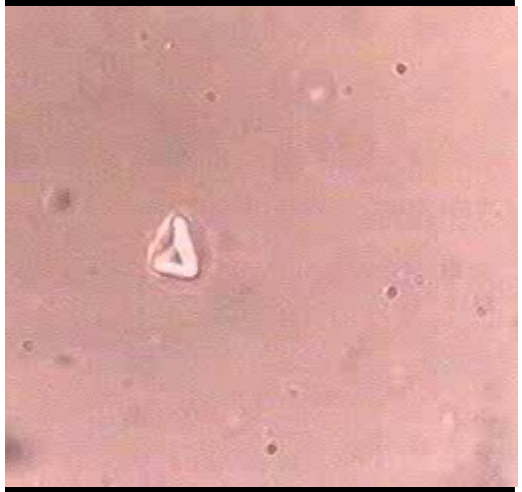
Understanding the blood

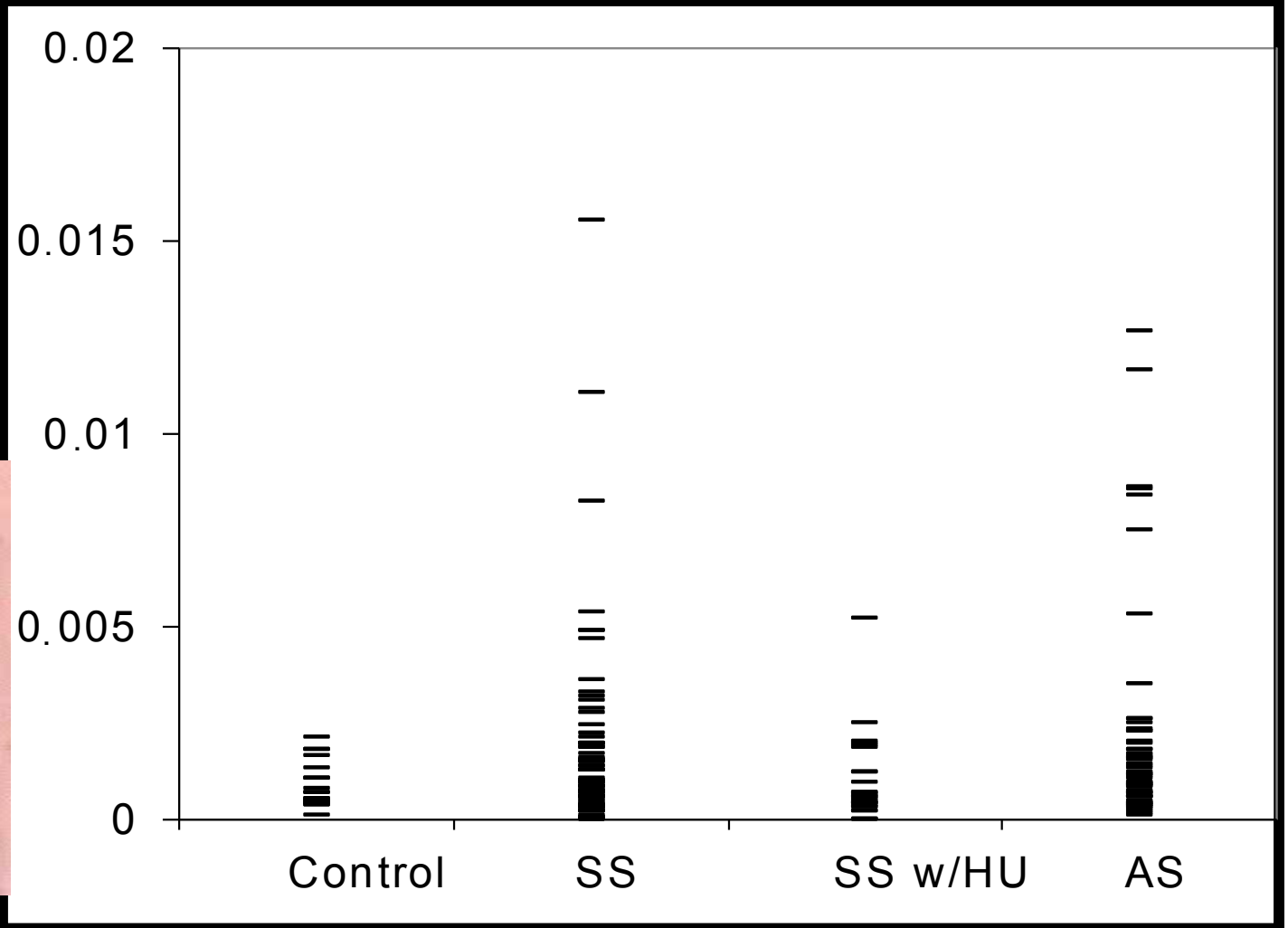




- **Size: 7 – 9 μm**
- **Pass through 3-4 μm vases in the spleen**
- **Aging: becomes more rigid - extracted from the circulation**
- **Patologies: Sickle cell anemia, spherocitosis, etc**

Red Blood Cells: Sickle Cell anemia





Important: individual cell measurements

M. M. Brandão et al; European Journal of Haematology 70 (4), 207-11 (2003).

Elasticity of irradiated RBCs

Transfusion reaction: imune cells of the donnor attack the host cells!

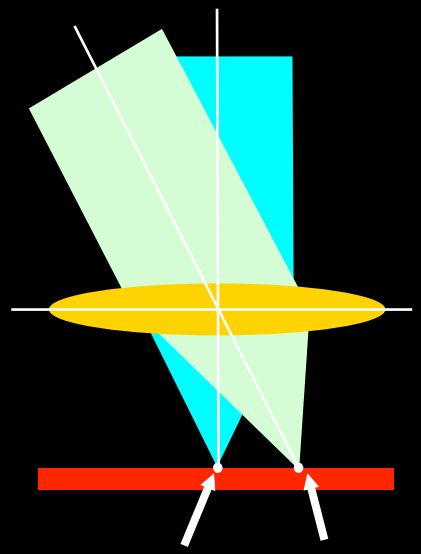
Irradiation kills the nuclear cells (white cells) but not the non-nuclear (RBC).
Question: what are the effects over RBCs?

Dias de estocagem	Elasticidade - μ (dyn/cm) x 10^{-3} (média ± desvio padrão)	
	Controle	Irradiadas
1	0.17 ± 0.02	0.22 ± 0.02
14	0.20 ± 0.02	0.29 ± 0.03
21	0.22 ± 0.03	2.15 ±0.69

Barjas-Castro et al, Transfusion 42 (9), 1196-9 (2002)

Blood Bank standard:
accept up to 28 storage days

Double Optical Tweezers



Red Blood Cells Rouleaux

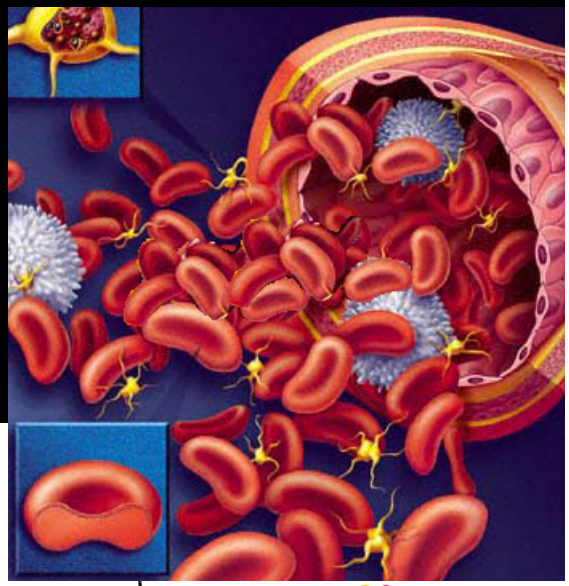
Cells slide easily one over the others but are strongly connected by their edges.

Questions:

(1)Why are they binding [blood clotting]

(2) What are the forces to slide and to bind

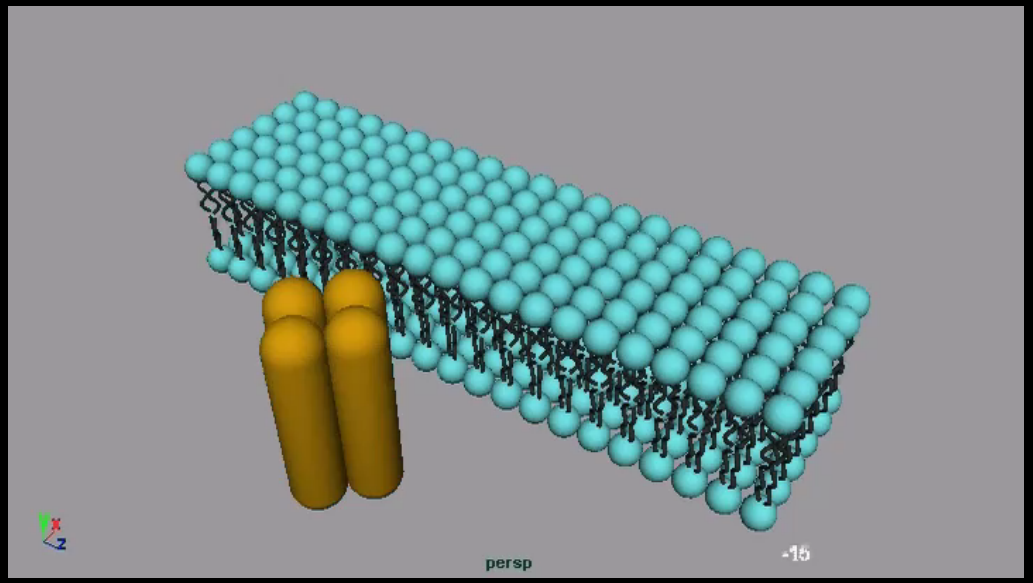
Blood

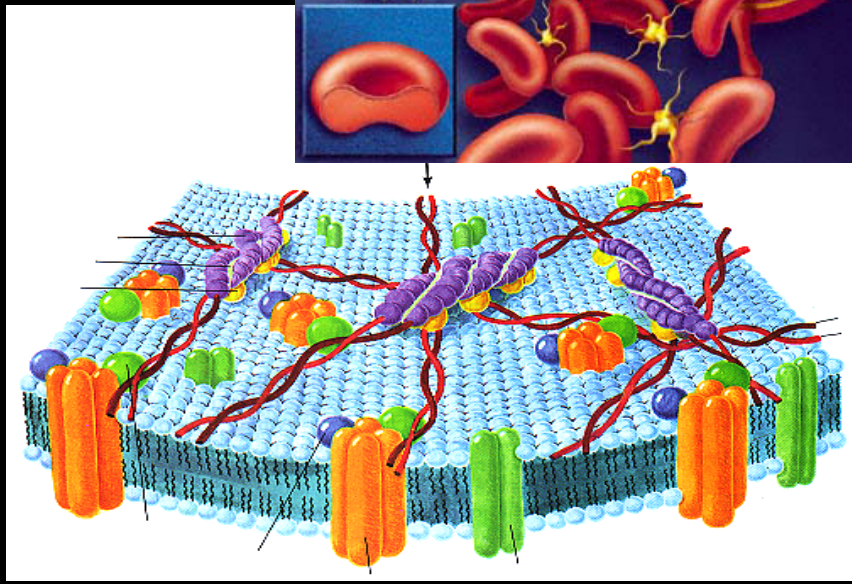


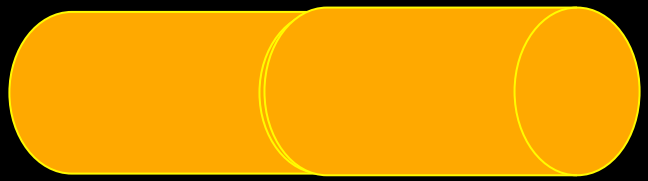
• **Membrane viscosity**

Proteins dragged through the lipid membrane

Viscous drag: F ~ V



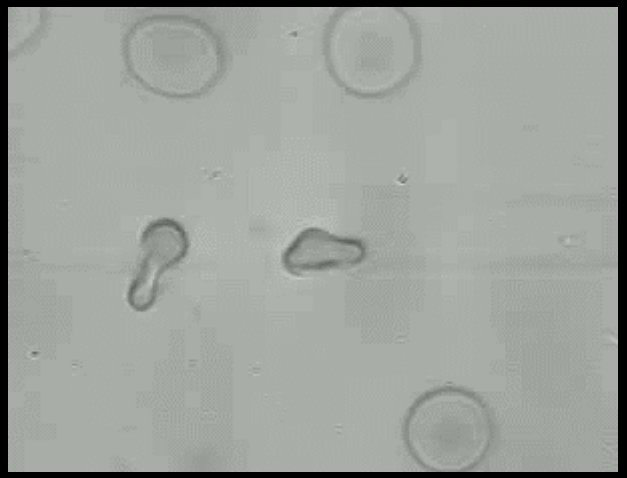


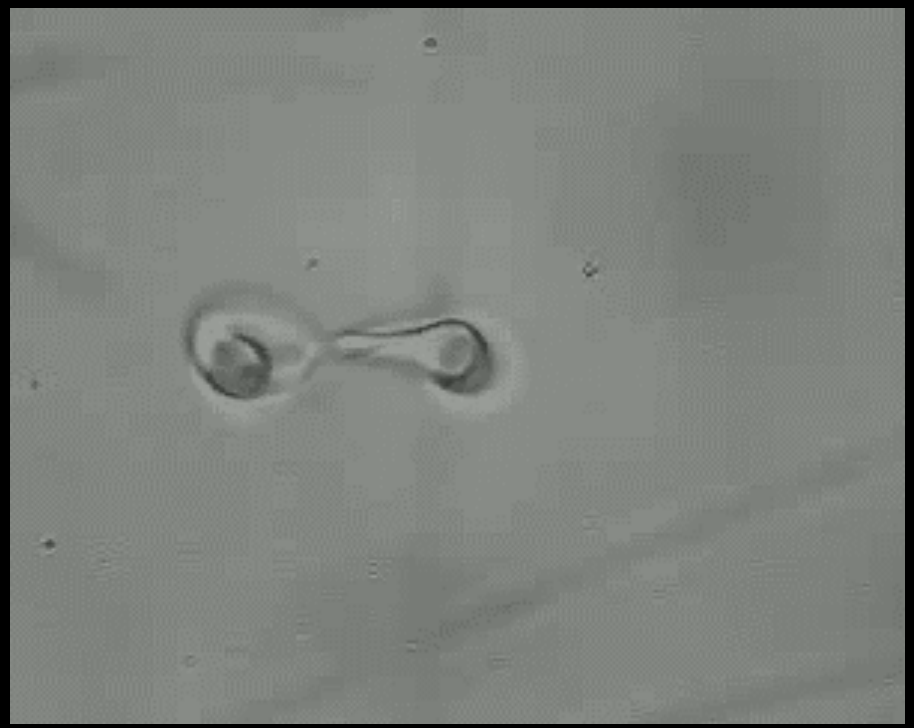


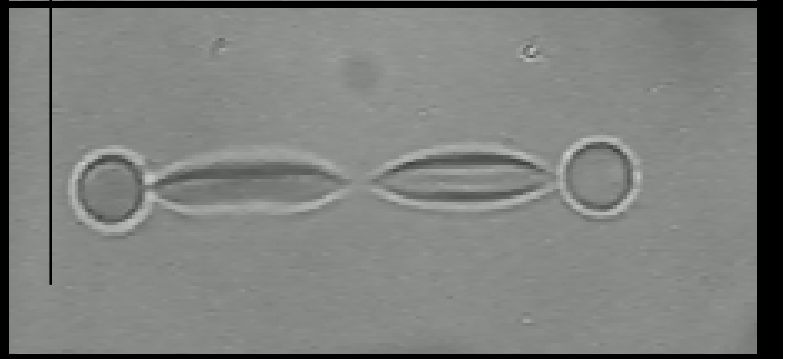
• **Adhesion**

Binding proteins & protein network

RED BLOOD CELL ADHESION

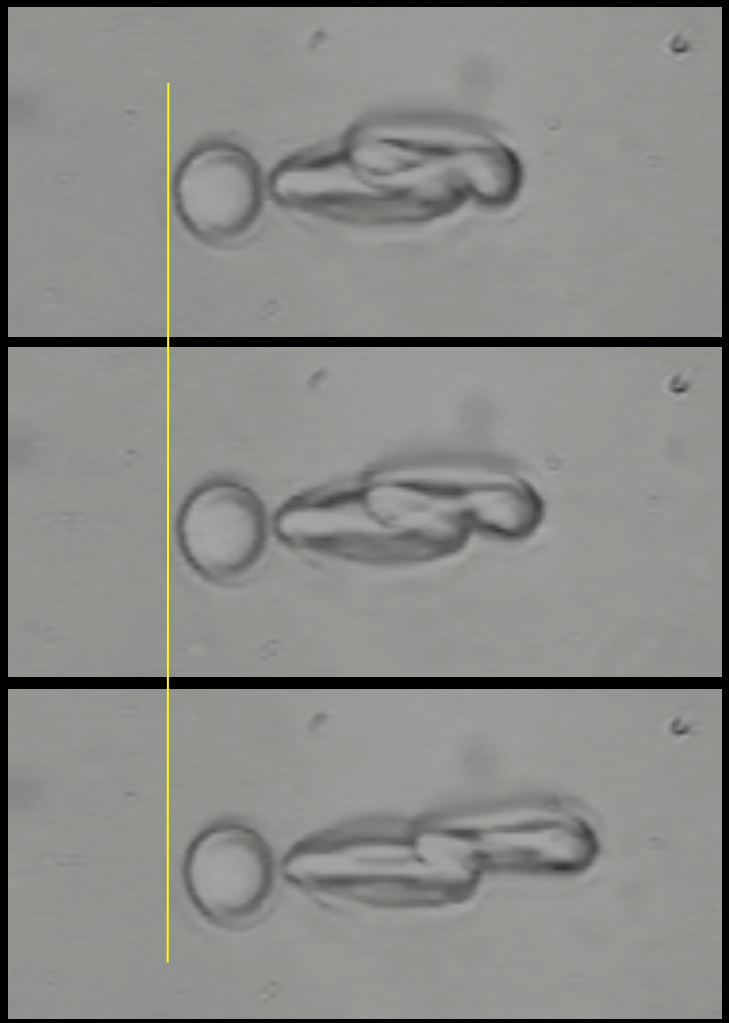


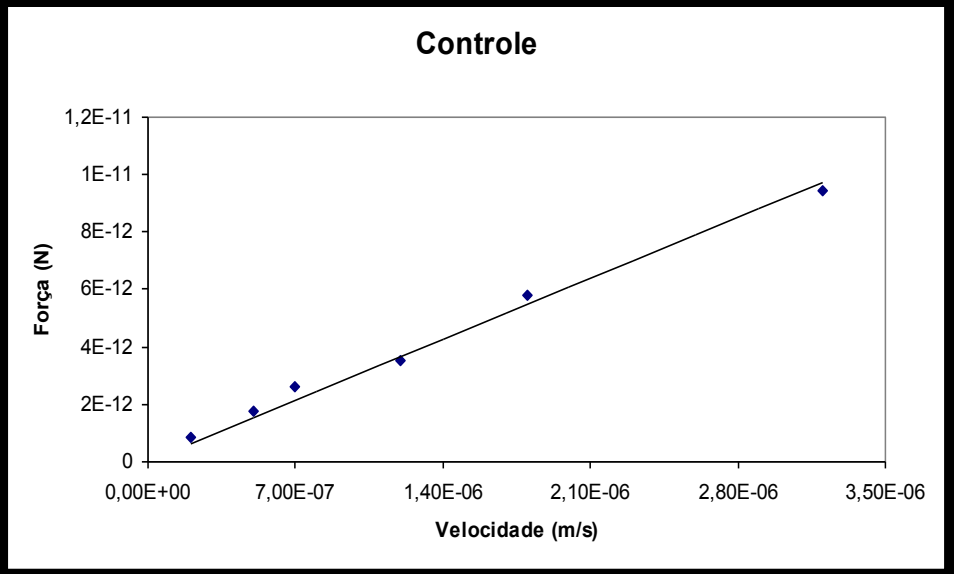


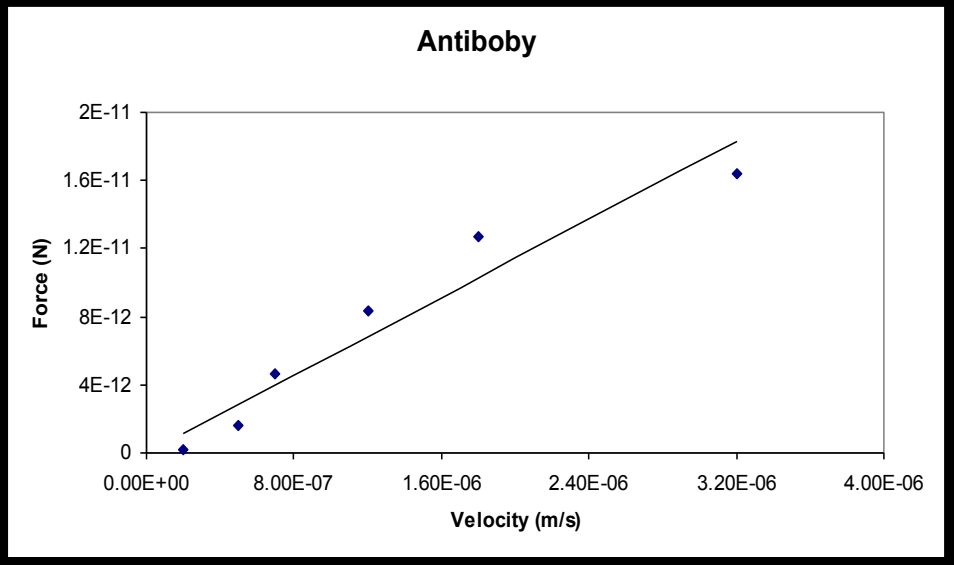


$F_{adhesion}$ = 14 pN.

MEMBRANE VISCOSITY



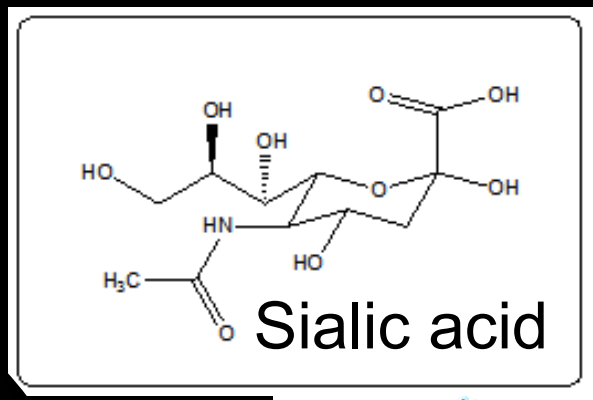


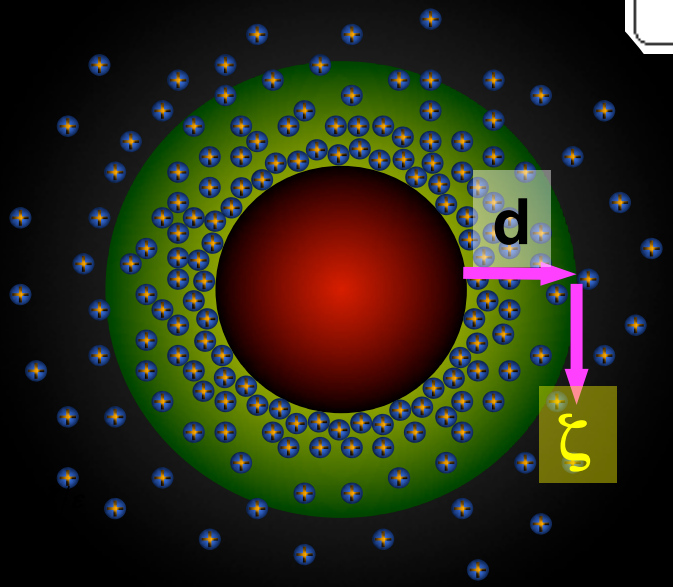


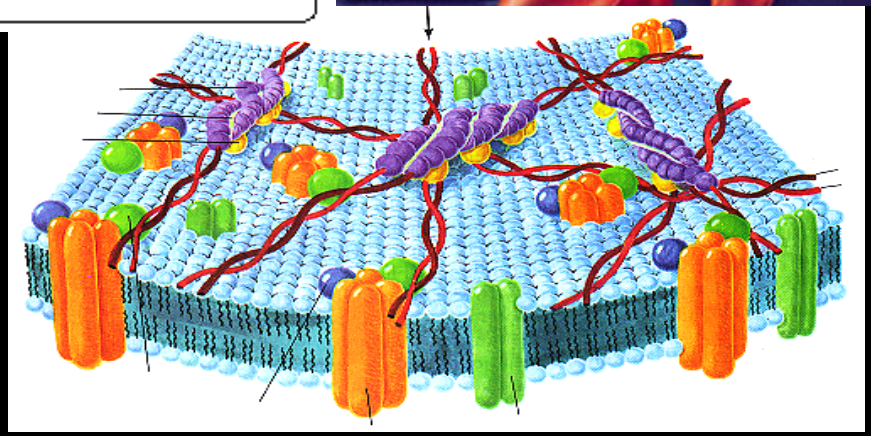
Why are they binding?

Red Blood Cells are - charged
In electrolite solution

Zeta Potential





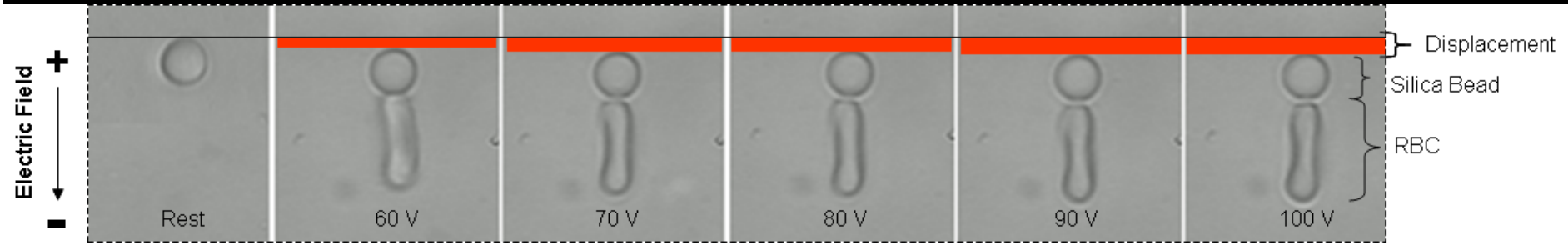


Counter ions cloud. Compact Layer d follows the movement rigidly.
ZETA POTENTIAL is the electric potential at shear interface.

COMPACT LAYER'S SIZE AND ZETA POTENTIAL

Compact Layer: force vs E

Silica bead displacement



Zeta potential: by terminal velocity.

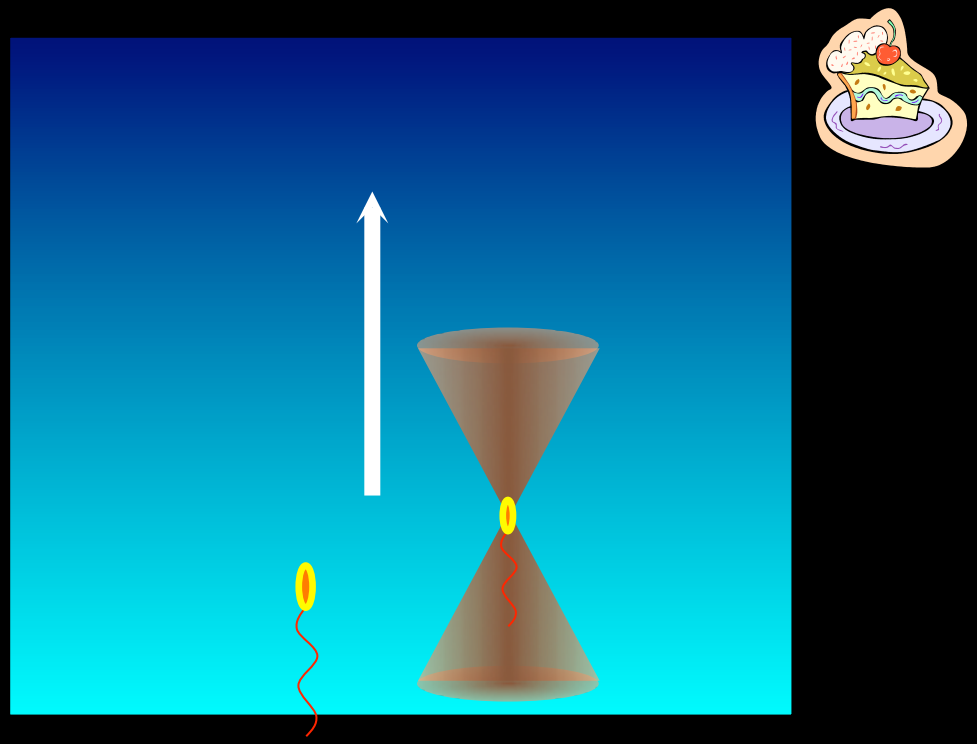
d = 0.85 μm ζ = -12.5 mV

Results agrees with literature.

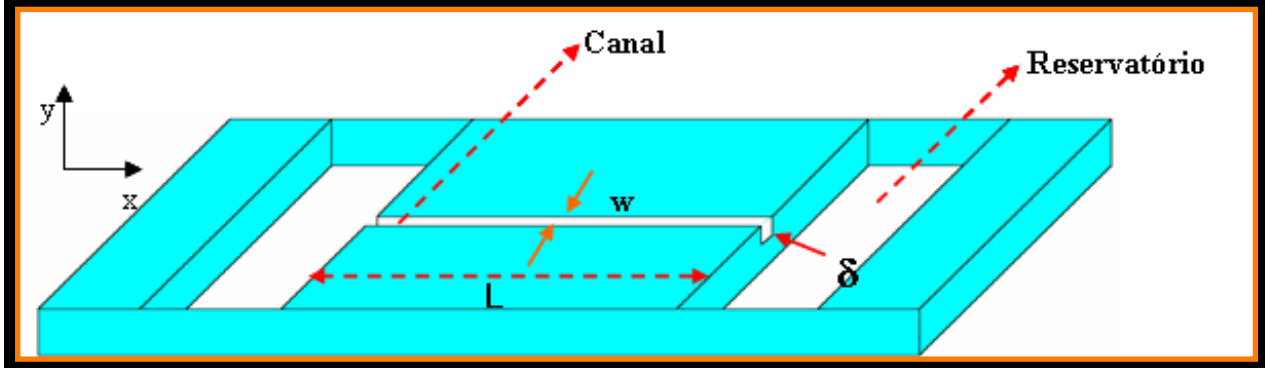
Optical Tweezers used for:

Chemotaxis: *Leishmania amazonensis*

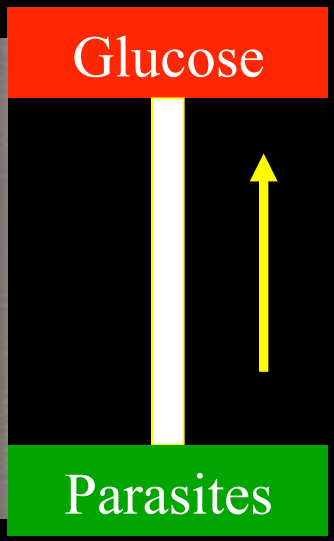
Chemotaxis: Microorganism responses to chemicals gradient

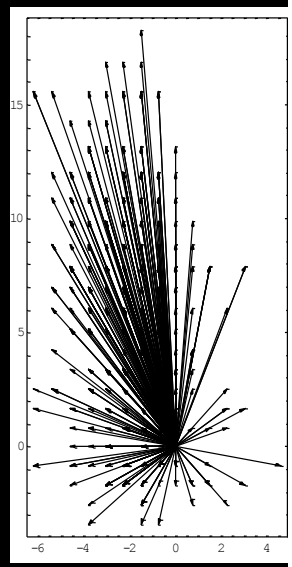


Chemotaxis – Leishmania amazonensis

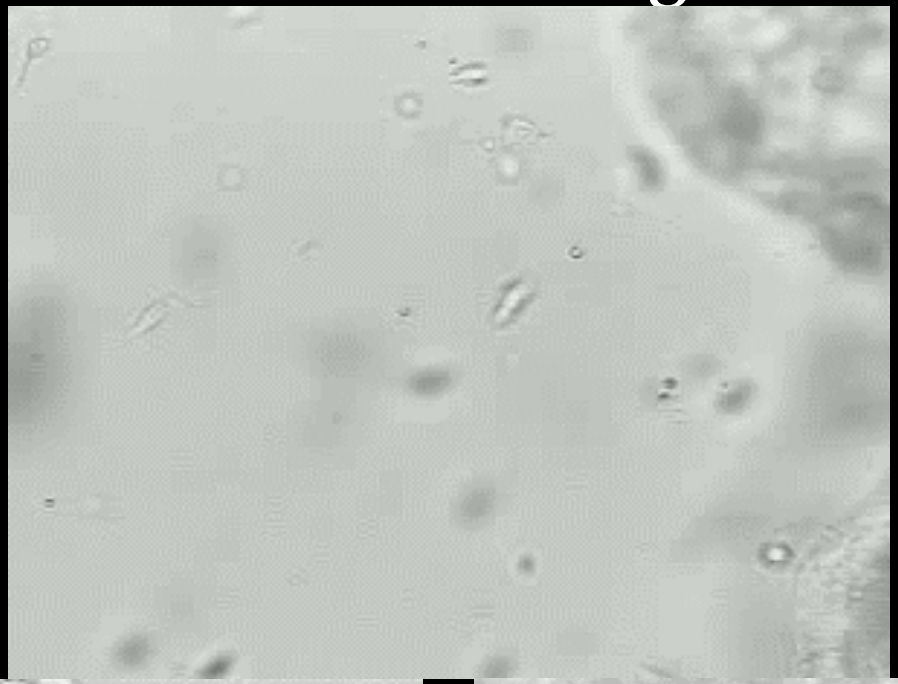


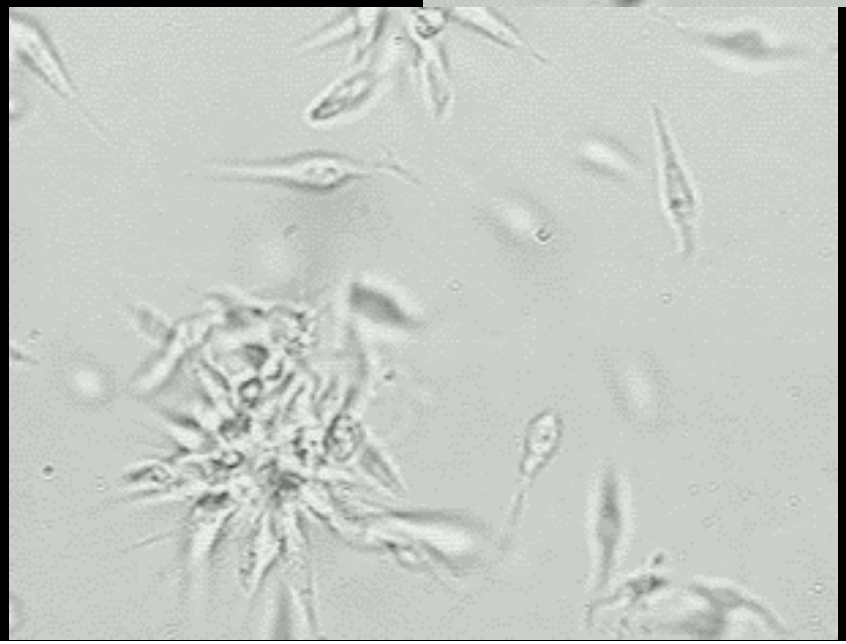
✓ Circular Movement

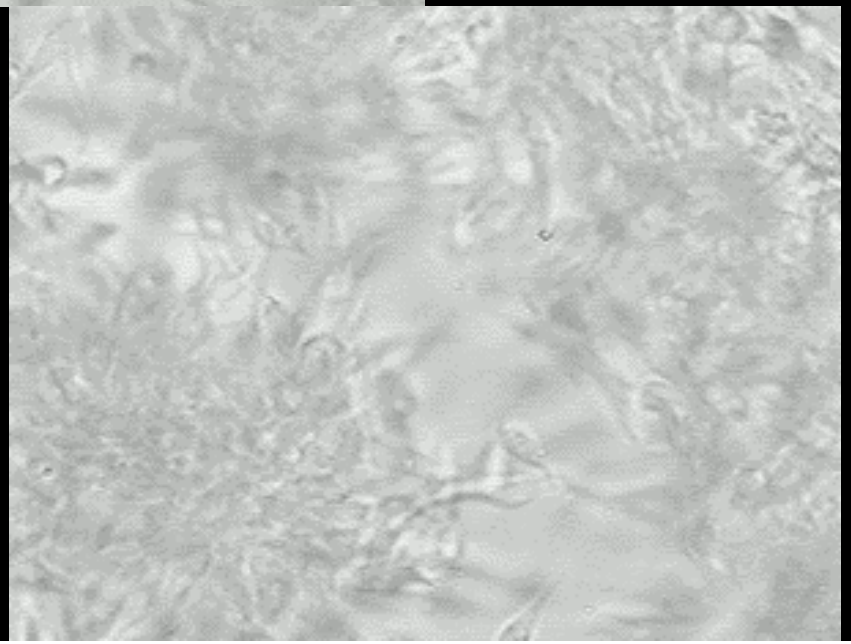




Trypanosoma Cruzi: Chagas Disease





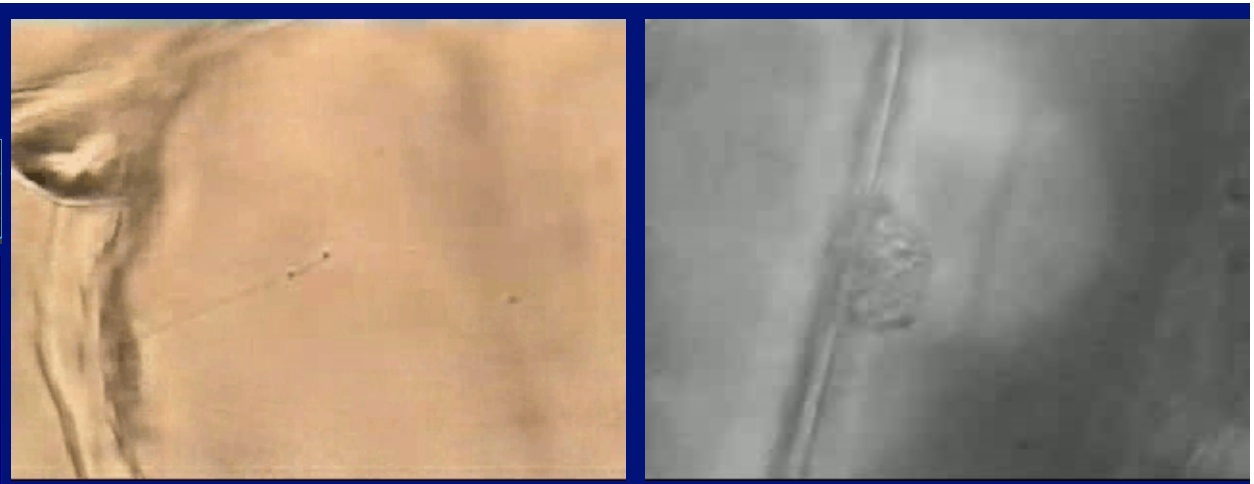


Optical Tweezers

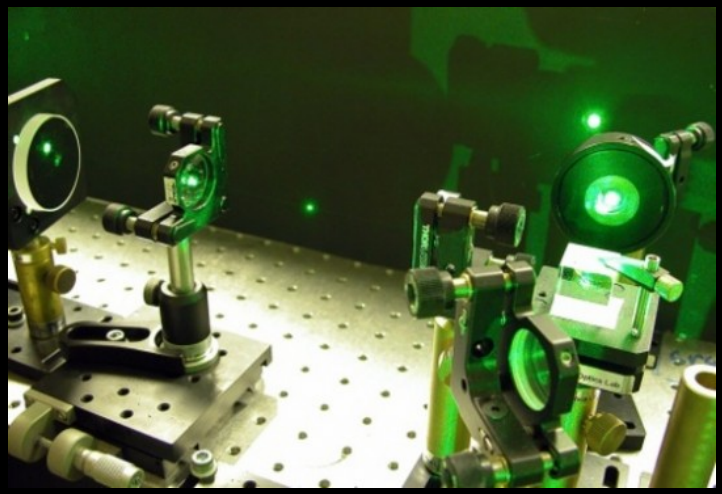
“Light Sucks”

Biomechanics F~200 pN
Cell rheology
Cell manipulation
12 papers with hemocenter

+ Laser microdissection:
Controlled transfection;
Cell surgery;
Material collection;



Nasa: tractor beam no espaço sideral



Integrated techniques into inverted platform

3D + time-lapse capabilities

Single/multiphoton fluorescences: intensity spectral + FLIM + PLIM + FCS + FRET + F…

SHG + THG + SFG

Raman + CARS + (CCARS?)

Tip-enhancement + conventional AFM

Optical Tweezers + laser cutting

Physiological controlled cell – temperature + atmosphere

Thanks for the attention