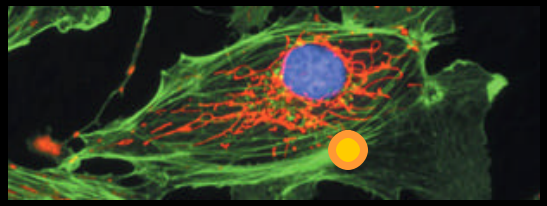
Microrheology of Complex Fluid

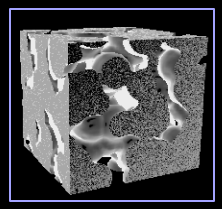
- Rheology: Science of the deformation & flow of matter
- Microrheology
  - Microscopic scale samples
  - Micrometer lengths



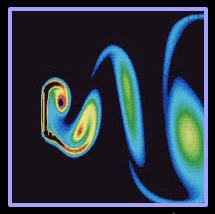
Complex shear modulus G*(ω)

$$\sigma = G^* \varepsilon$$

- G* (ω) = G' (ω) + j G'' (ω)
- Solid *vs.* fluid
- Resistance to deformation



Storage modulus G'
Energy storage
Elasticity ~ Solid



Loss modulus G''
Energy dissipation
Viscosity ~ Fluid

High Frequency Microrheology Measurement

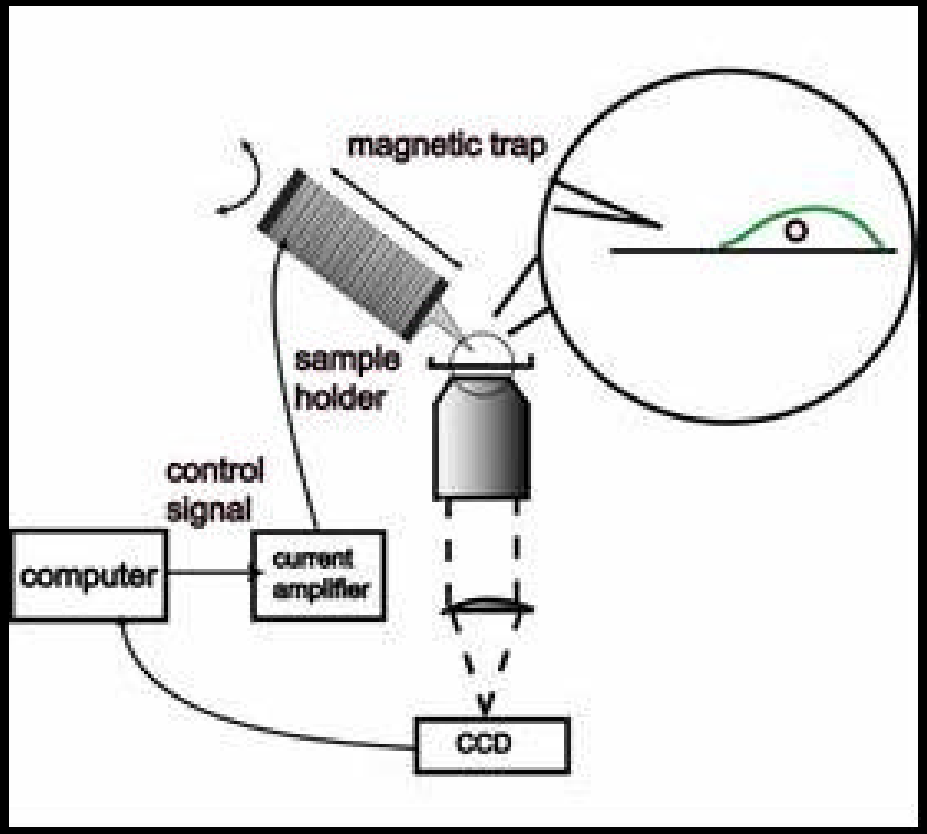
Active Method:

Magnetic microrheometer – Baush, BJ 1998
Huang, BJ 2002

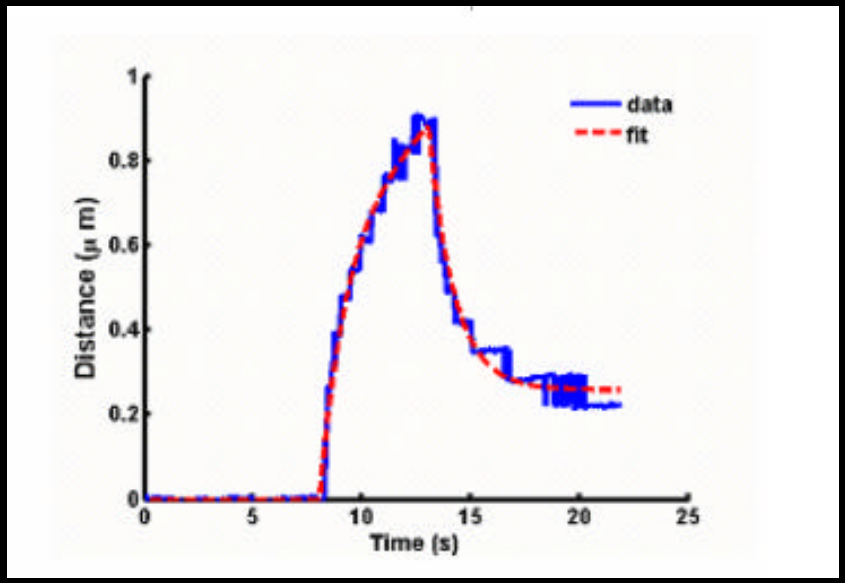
Passive Method:

Single particle tracking – Mason, PRL 1995
Yamada, BJ 2000
Multiple particle tracking – Crocker, PRL 2000

Magnetic Microrheology



Magnetic Microrheology



5 sec Step Response

Basic Physics of Magnetic Microrheometer

Ferromagnetic particle

$$\mathbf{F} = \frac{1}{2} m_0 \nabla(\mathbf{m} \cdot \mathbf{H})$$

Particles cluster together!
Doesn't work!

Paramagnetic particle – no permanent magnetic moment

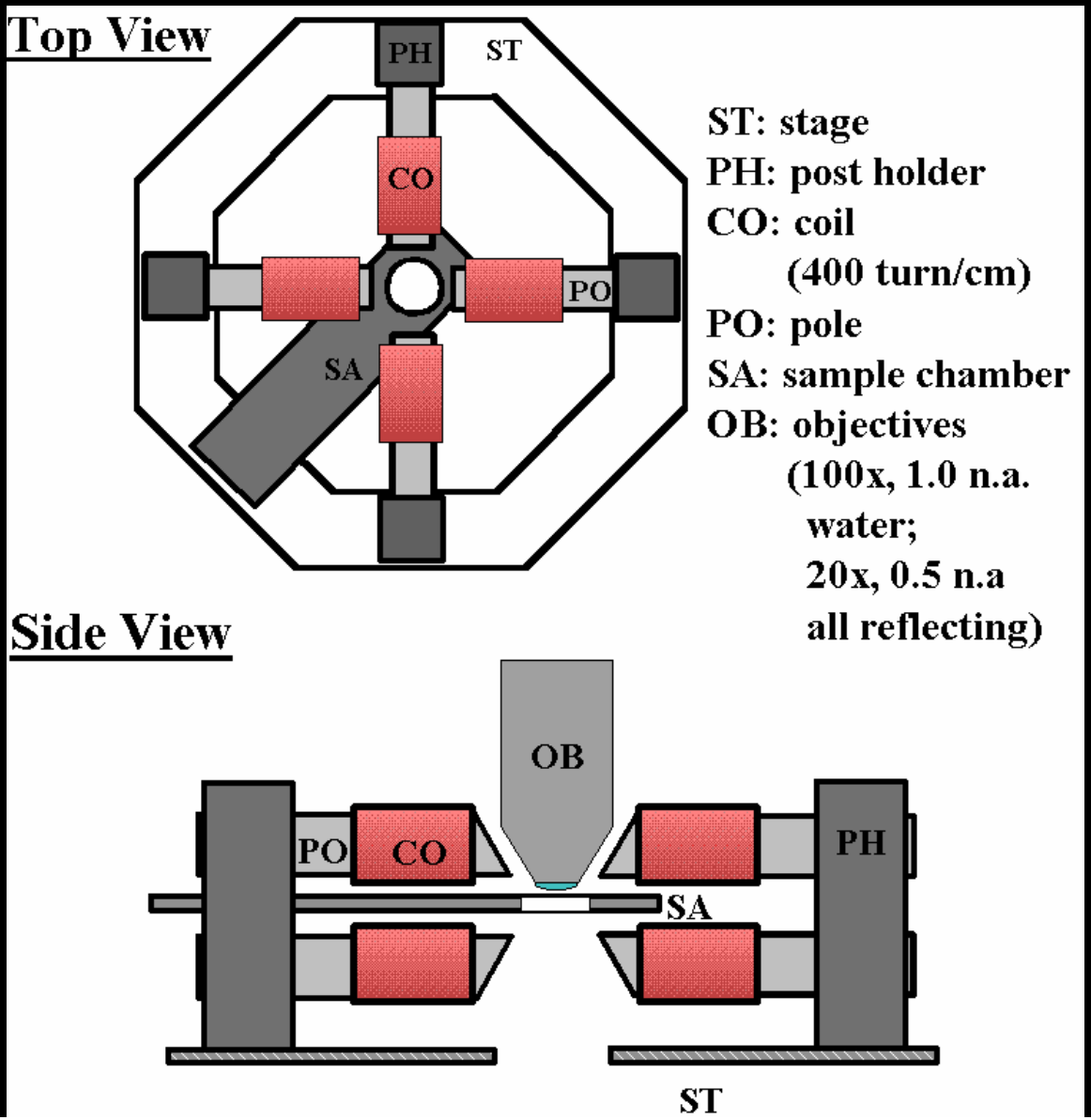
$$\mathbf{F} = m_0 \, c V \nabla(\mathbf{H} \cdot \mathbf{H})$$

χ is suceptibility

V is volume

Note: (1) force depends on volume of particle
(5 micron bead provide 125x more force)
(2) force depends on magnetic field GRADIENT

Magnetic manipulation in 3D



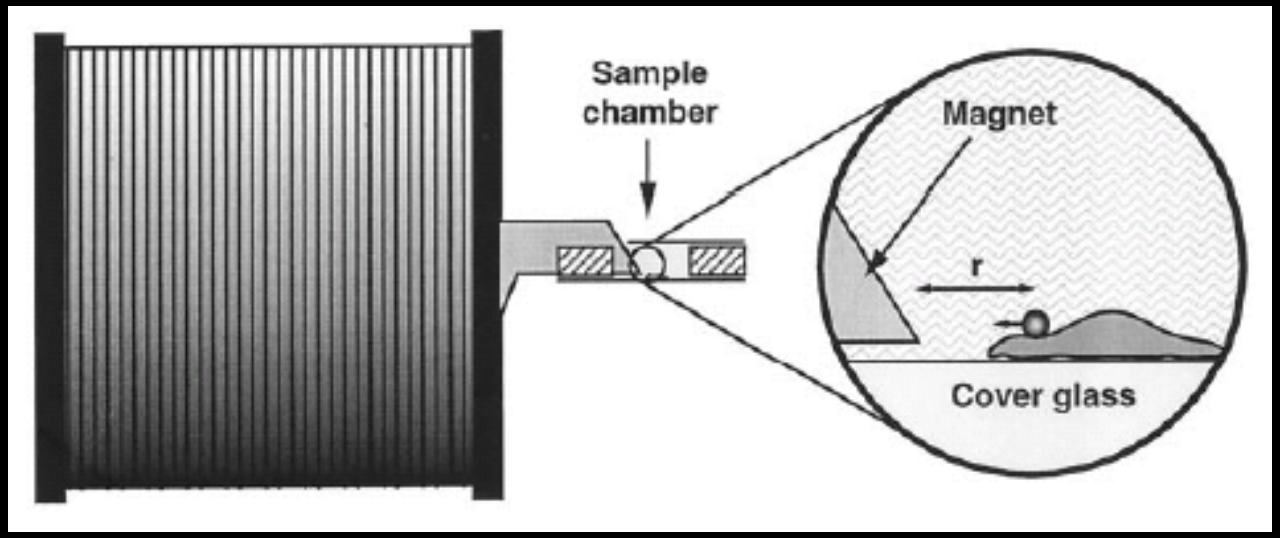
*Lower Force
nN level

*3D

*Uniform gradien

Amblad, RSI 1996
Huang, BJ 2002

Magnetic manipulation in 1D



*High force
>10 nN

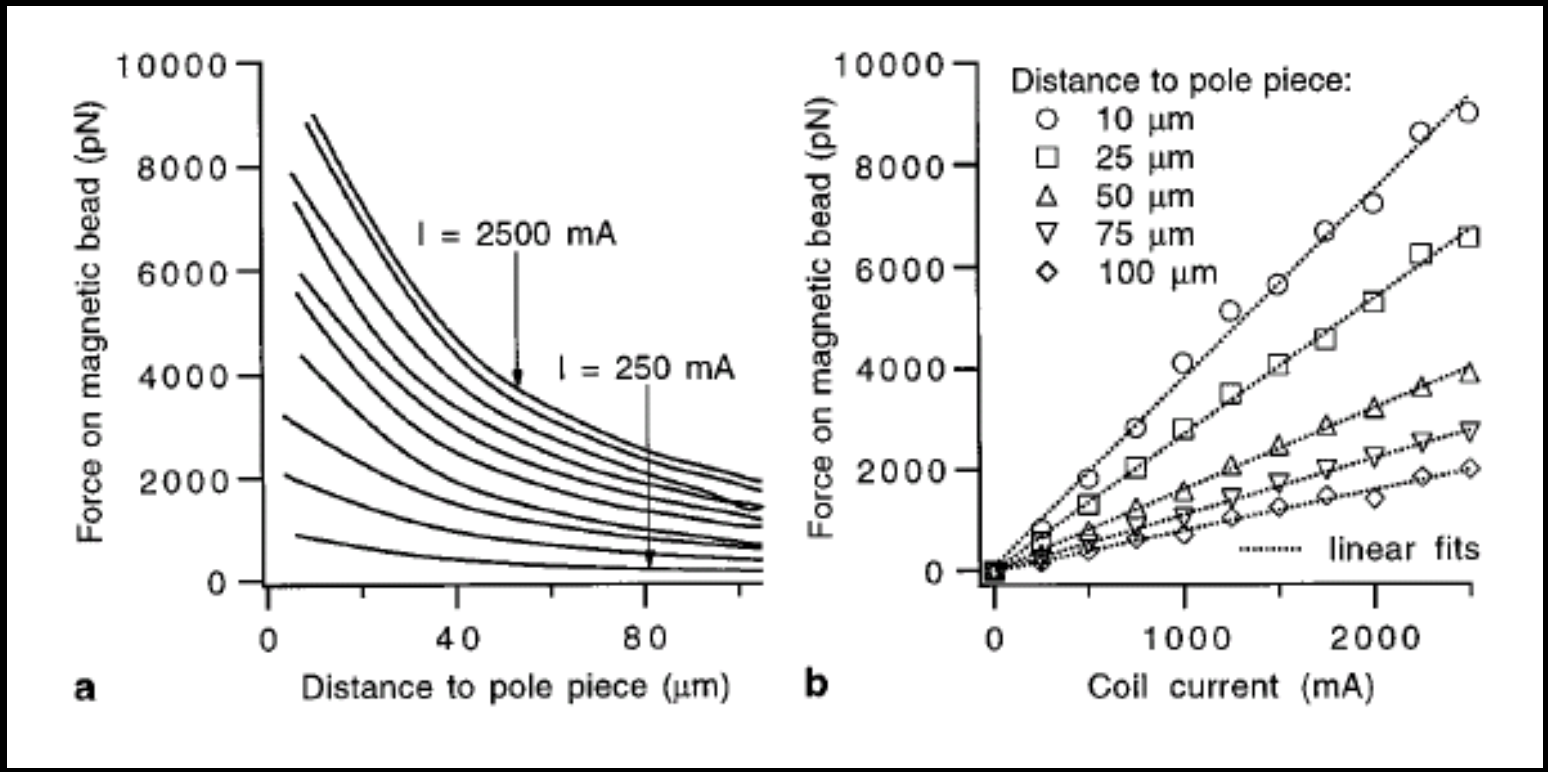
*Field non-uniform
Needs careful
alignment of tip
to within microns

*1D

Baush, BJ 1998

The bandwidth of ALL magnetic microrheometer is limited by the inductance of the eletromagnet to about kiloHertz

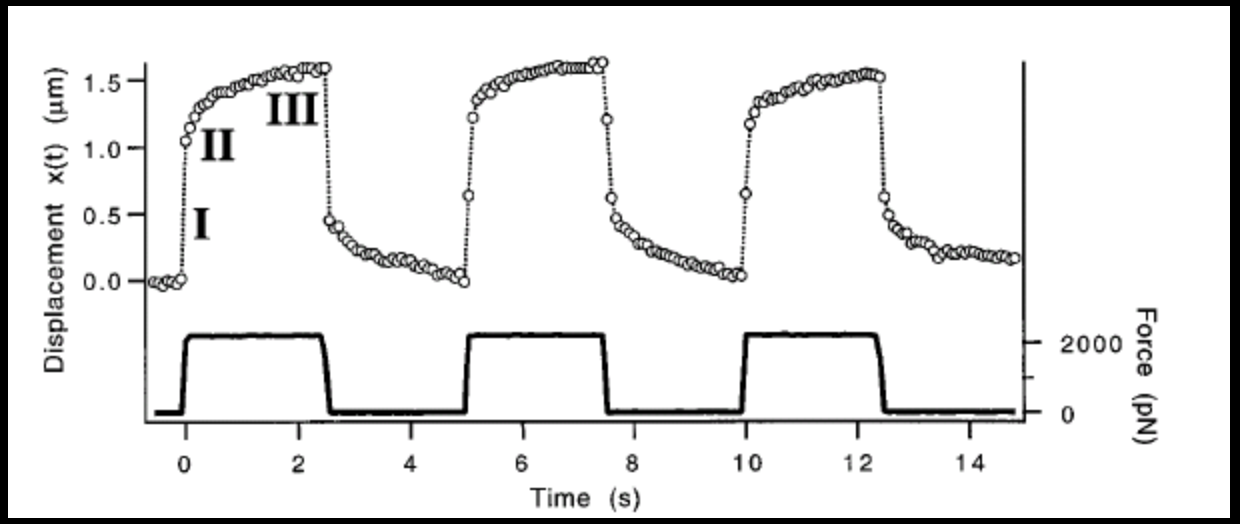
Magnetic Rheometer Requires Calibration

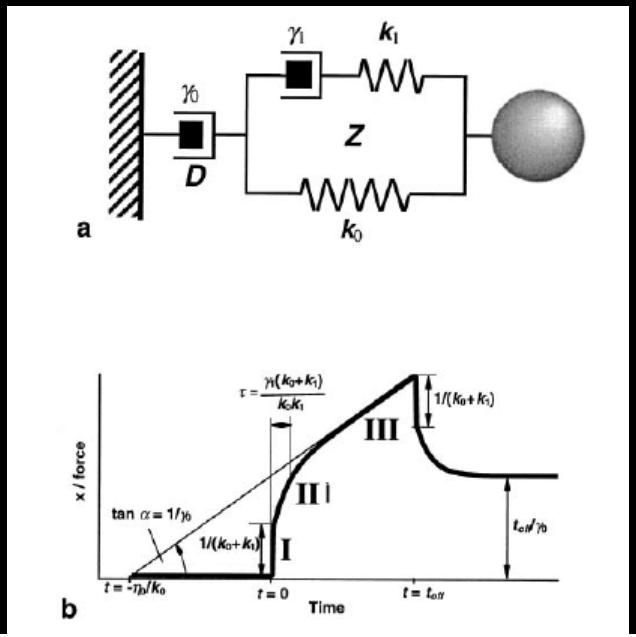


Baush, BJ 1998

Mag Rheometer Experimental Results

Baush, BJ 1998



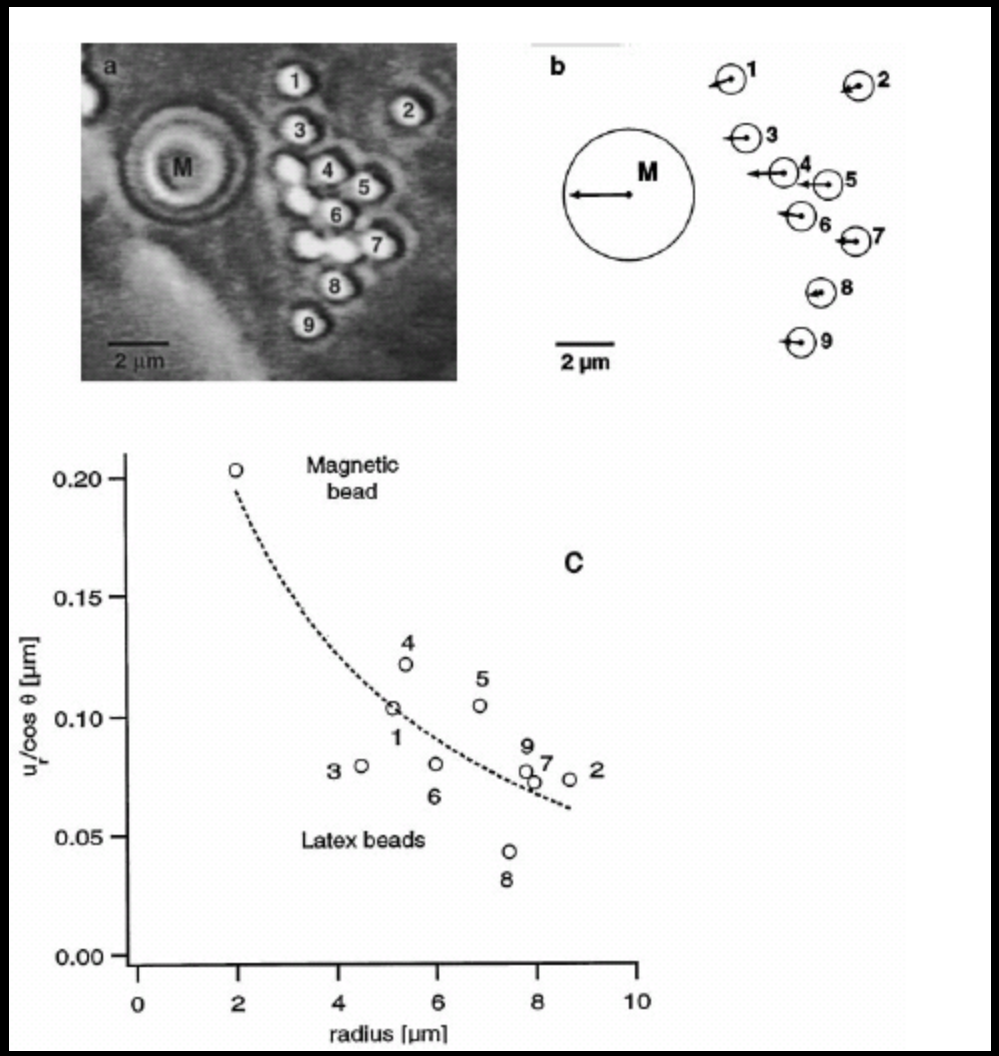


Transient responses allow fitting to micro-mechanical model

Problem – Magnetic bead rolling

Solution – Injection, Endocytosis Modeling (Karcher BJ 2003)

Model Strain Field Distribution



Baush, BJ 1998