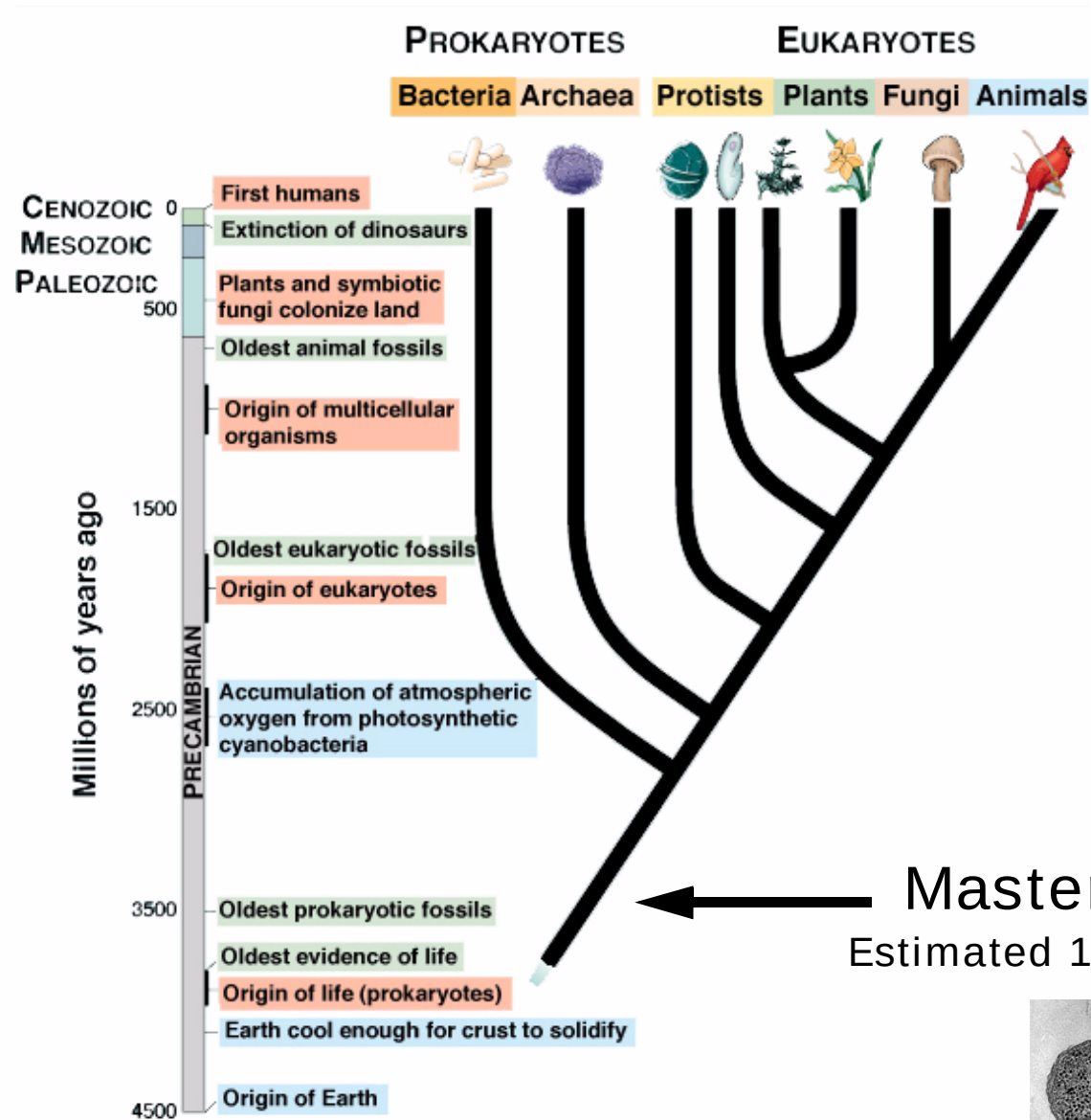
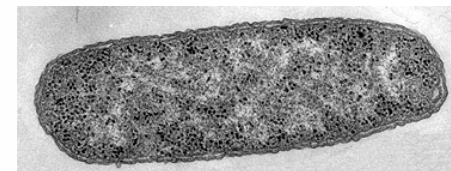


Physical Approaches to Early Evolution

Dieter Braun

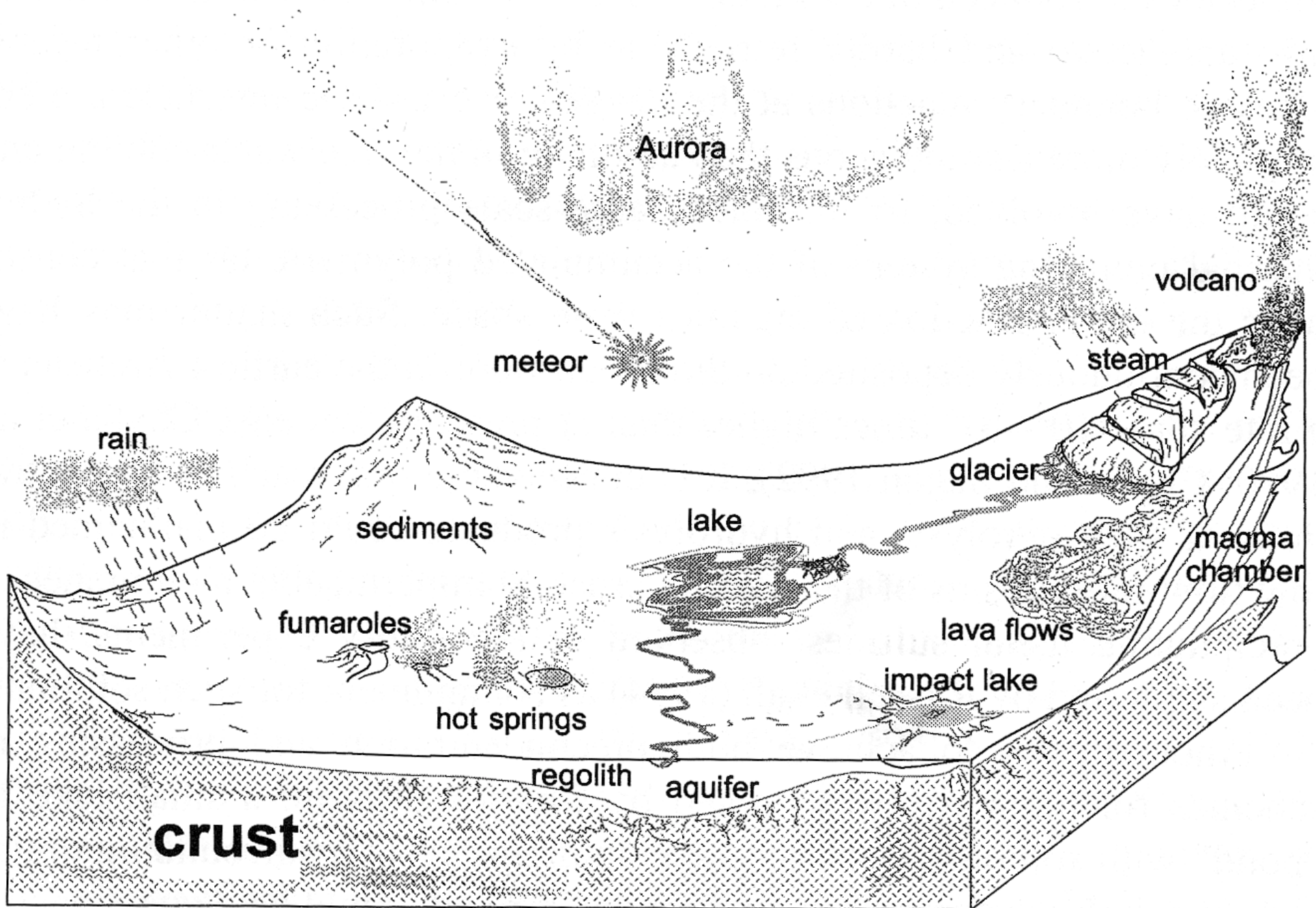


Masters of Metabolism
Estimated 10^5 - 10^7 procaryote species



1μm

The Origin of Life ?



Non-equilibrium thermodynamics

Dissipative Systems / Fluctuations(?)

Global Entropy S_{global} 

Local Entropy S_{local} 

Replication

Diffusion Barrier

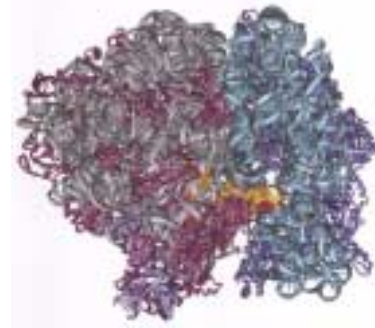


Replication

Diffusion Barrier



Ribozyme



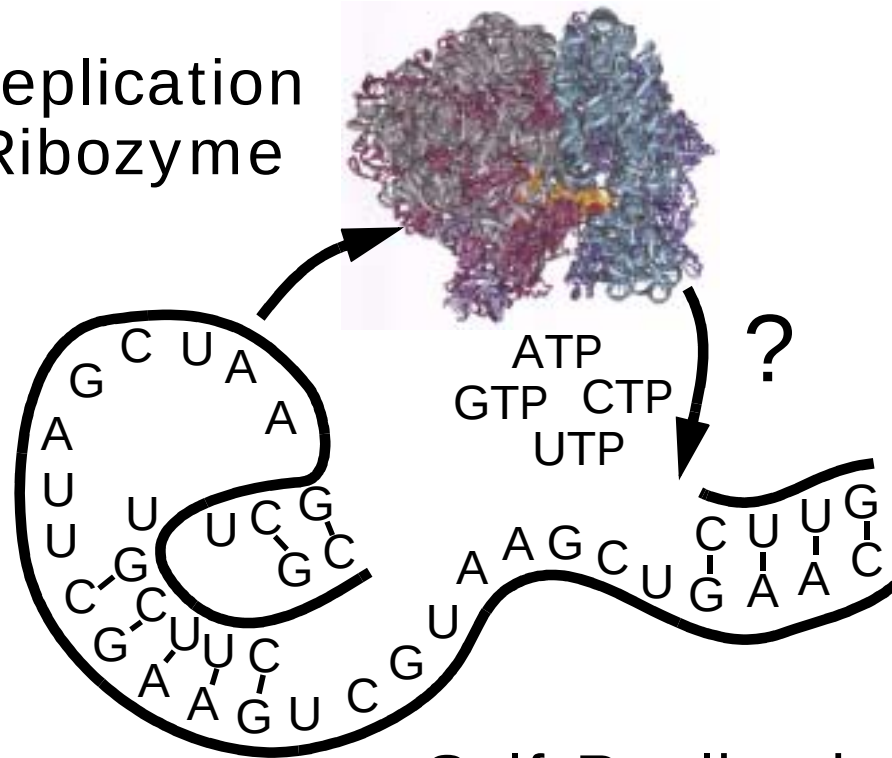
Replication

Diffusion Barrier



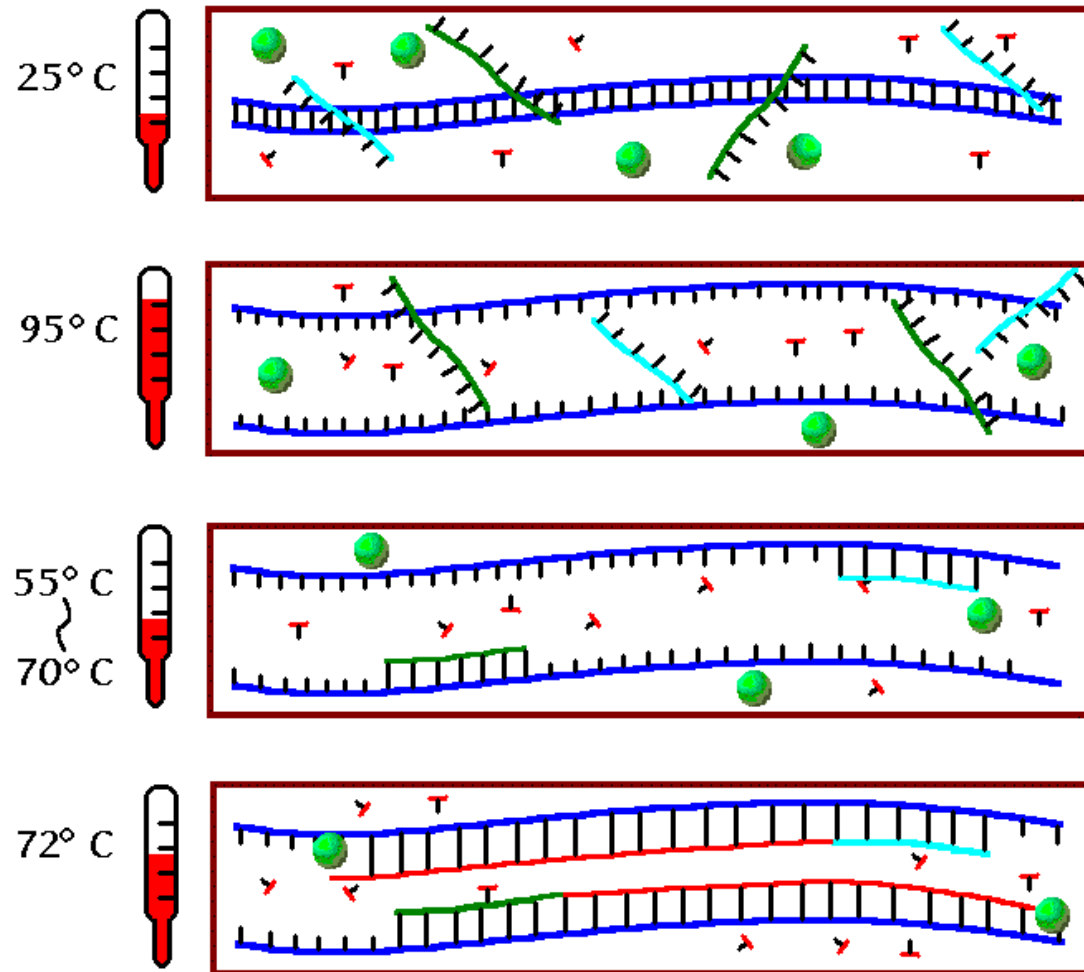
RNA
World

Replication
Ribozyme



Self-Replication

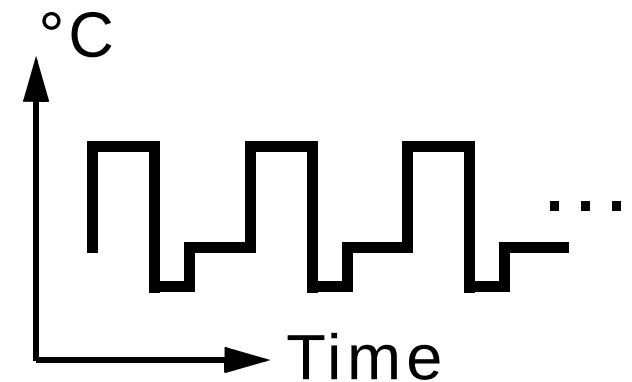
Polymerase Chain Reaction (PCR)



DNA Detection
down to single
Molecules

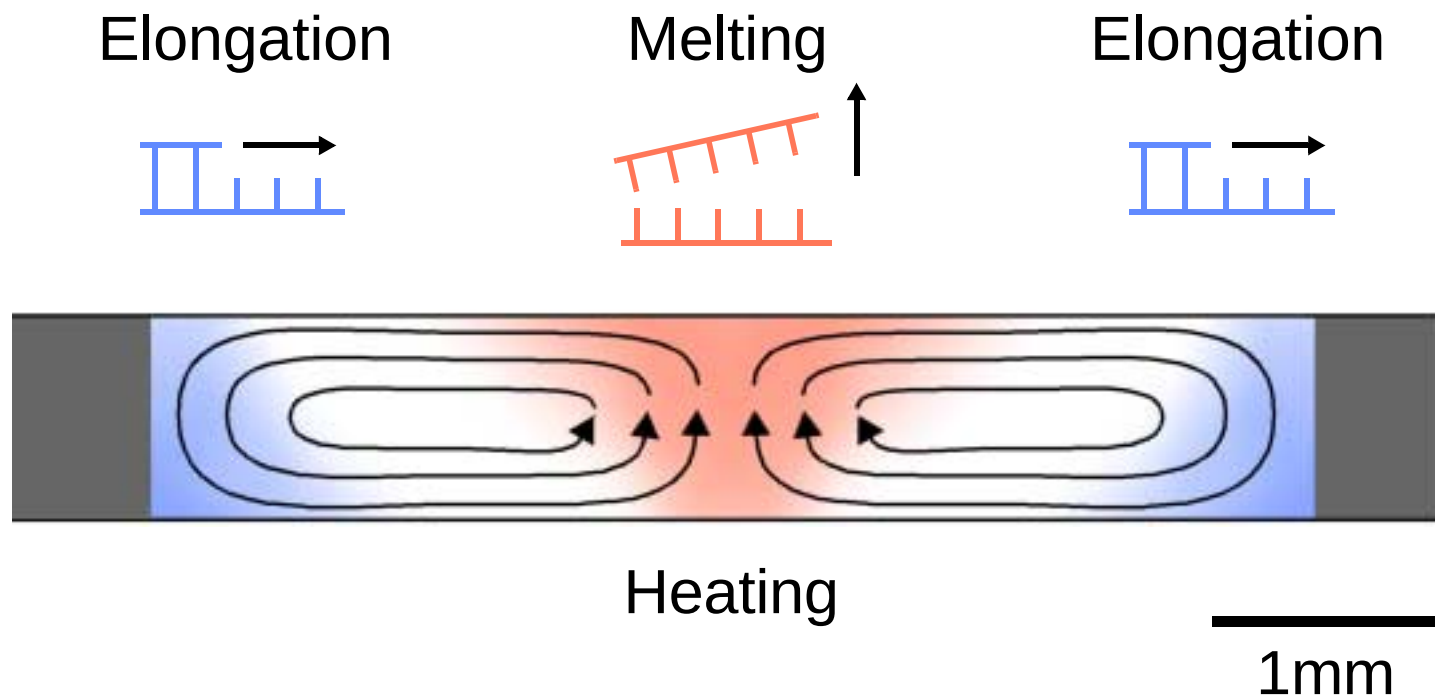
AIDS-Test

Future of
DNA Chips ?!



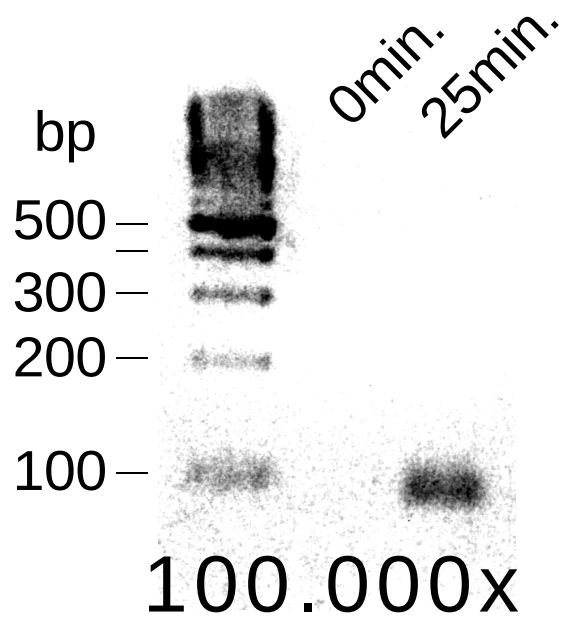
Replication driven by Convection

Braun, Goddard, Liabchaber, with referees

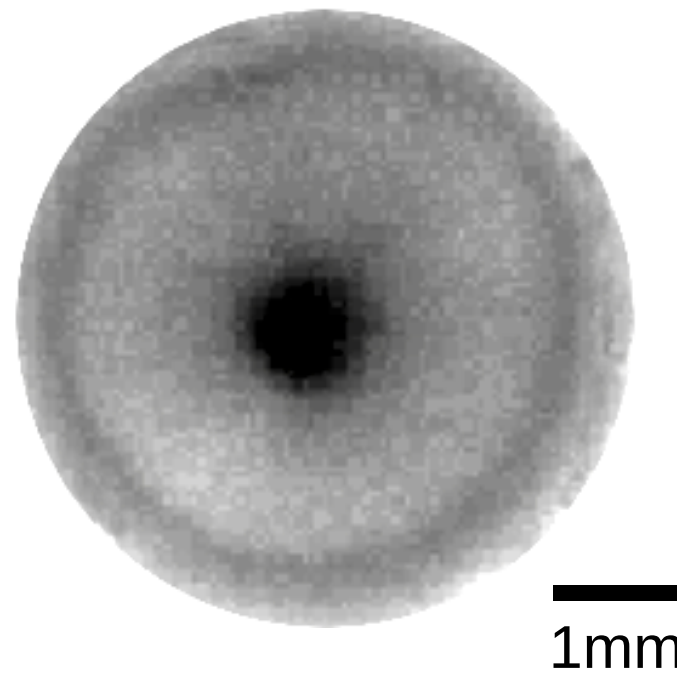
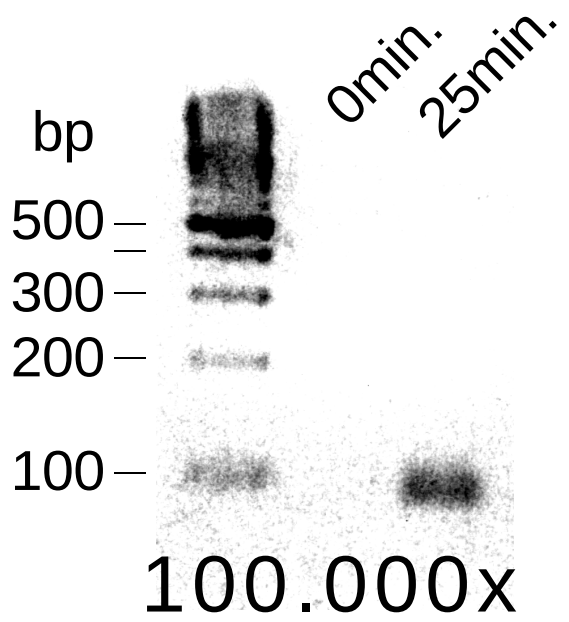


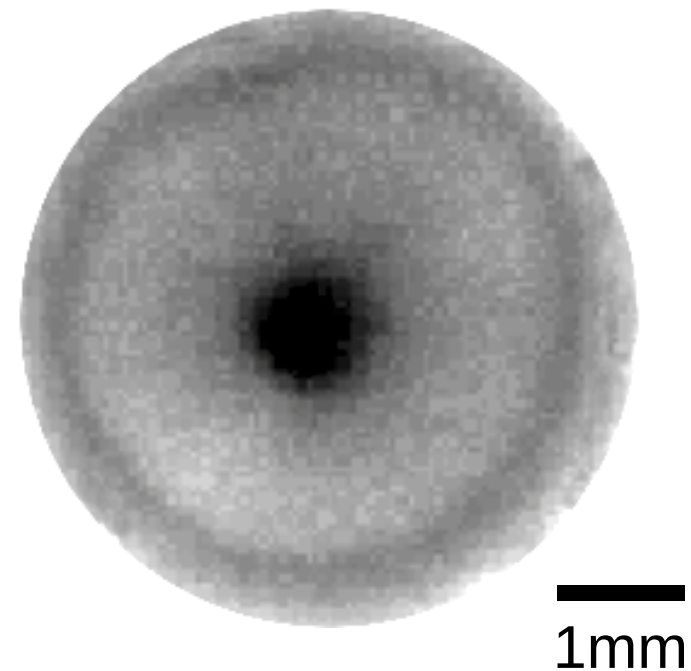
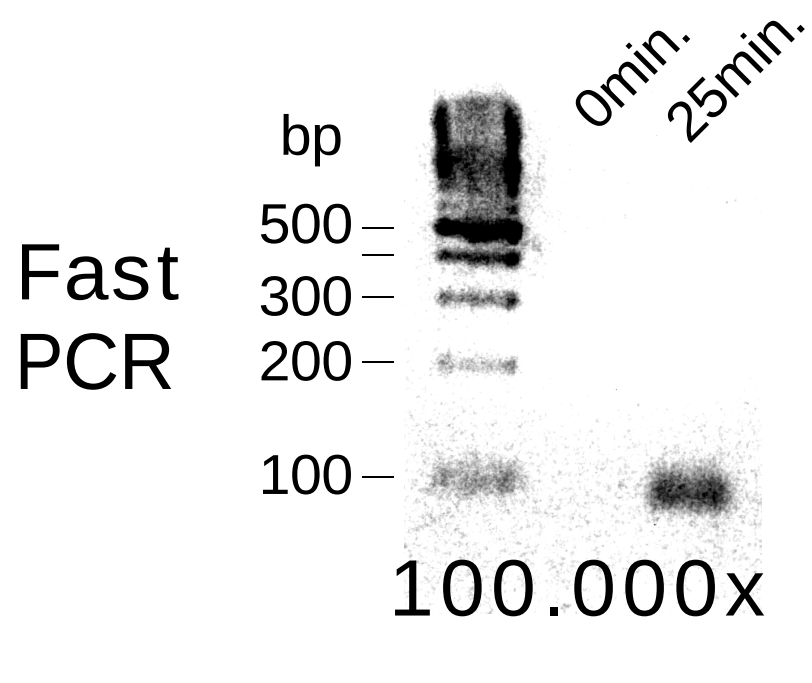
Movie Convection

Fast PCR

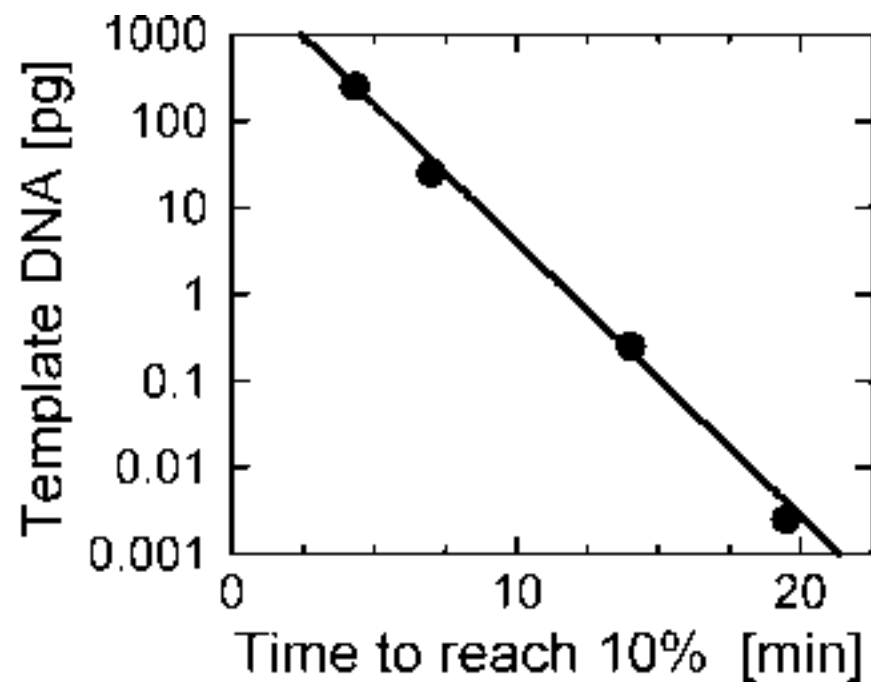
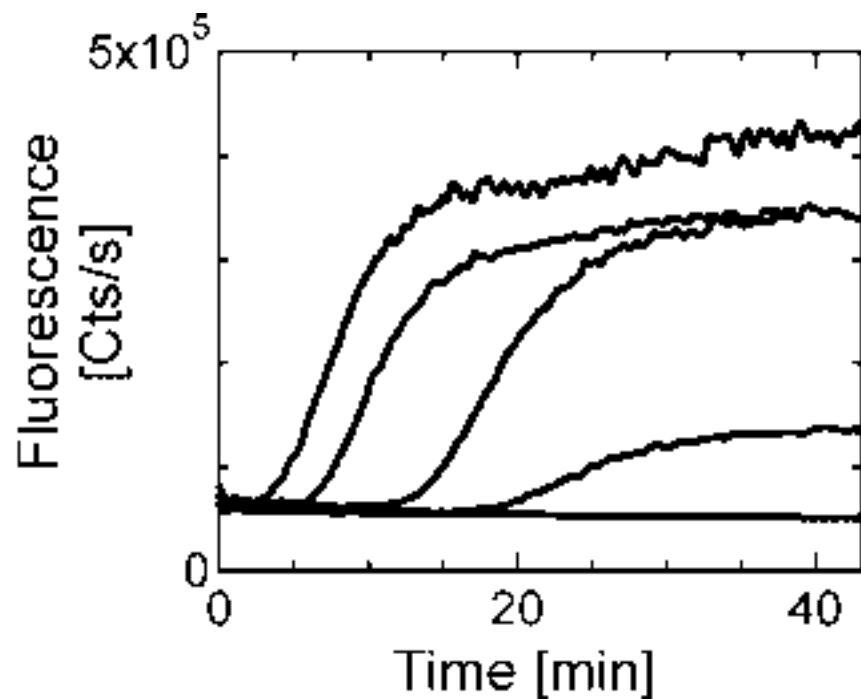


Fast
PCR





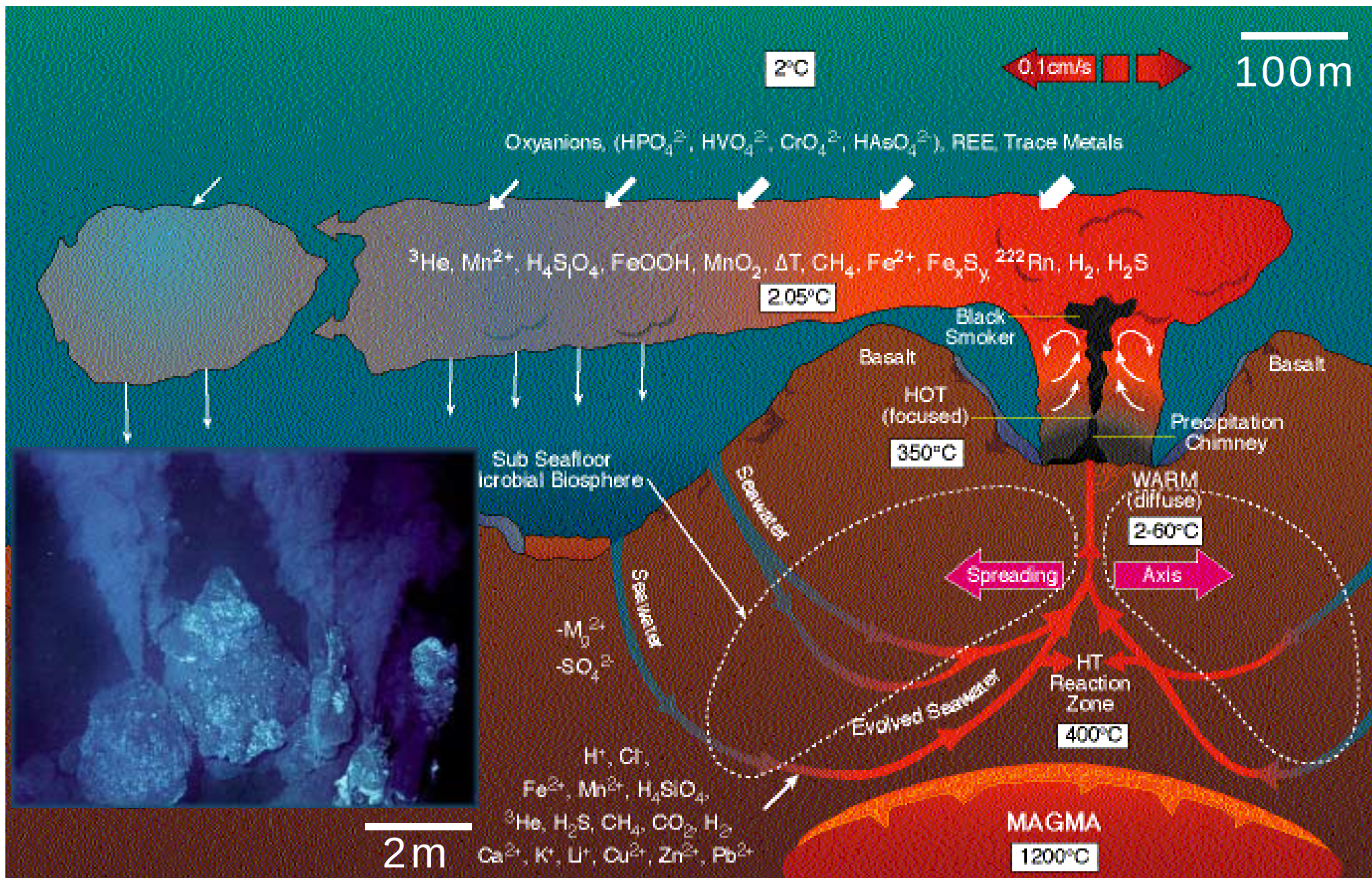
Quantitative PCR



Basalt



Hydrothermal Vents



Archaea



Prof. Stetter, Regensburg

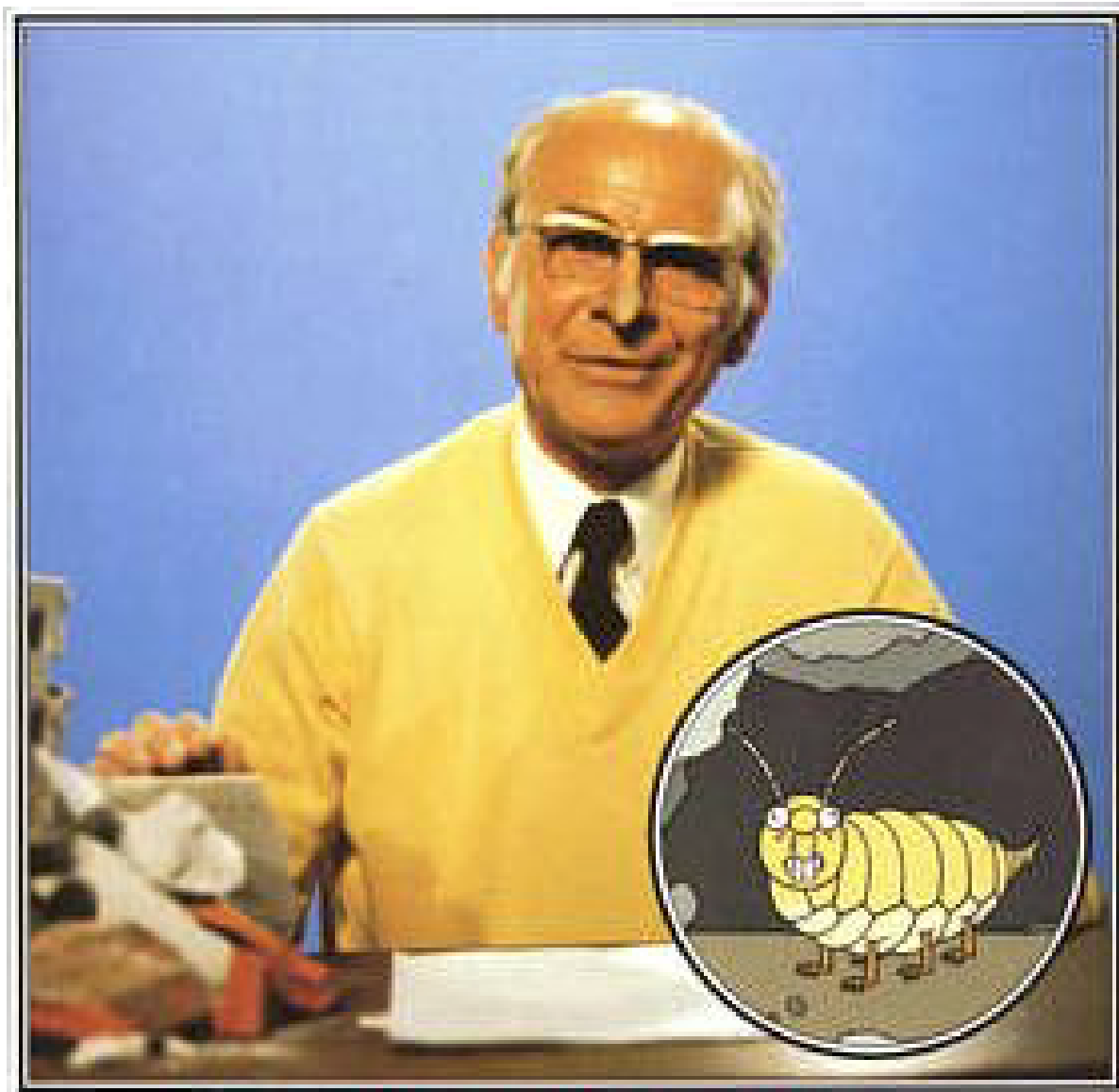
“The unseen majority”

(Whitman, PNAS, 95:6578, 1998)

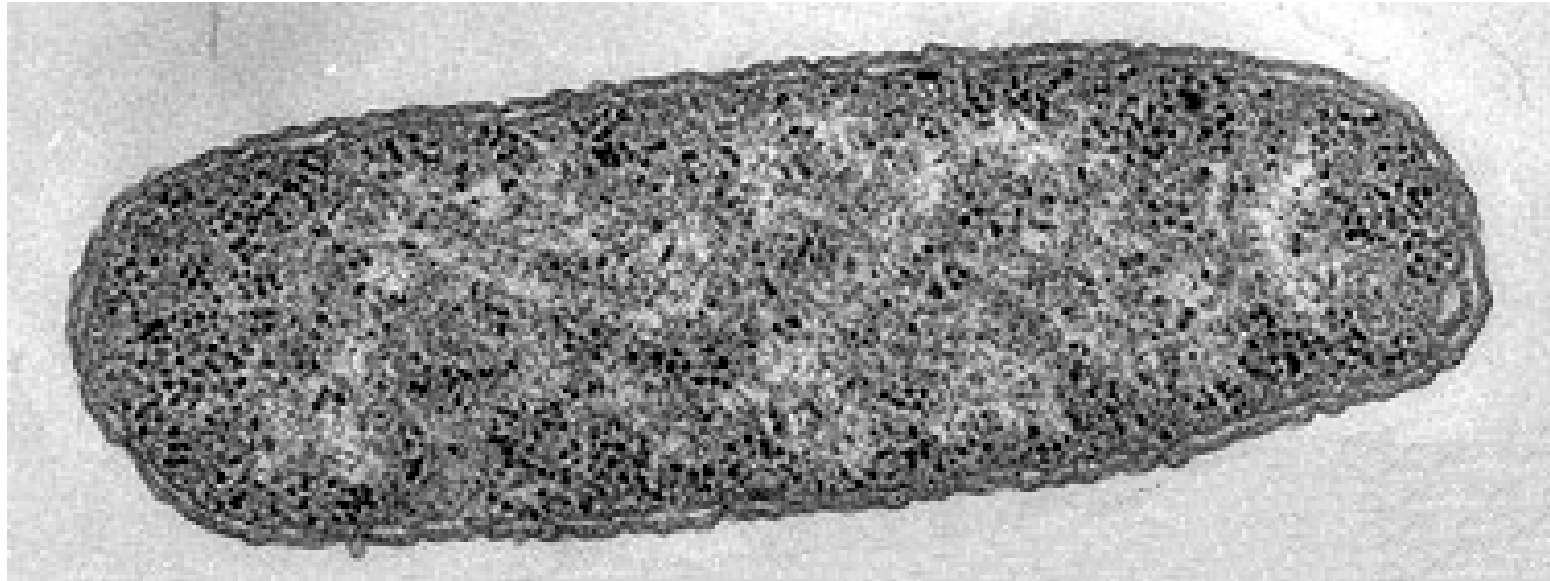
Table 5. Number of prokaryotes in the world

Environment	No. of prokaryotic cells, $\times 10^{28}$
Aquatic habitats	12
Oceanic subsurface	355
Soil	26
Terrestrial subsurface	25–250
Total	415–640

“There is plenty of room at the bottom”



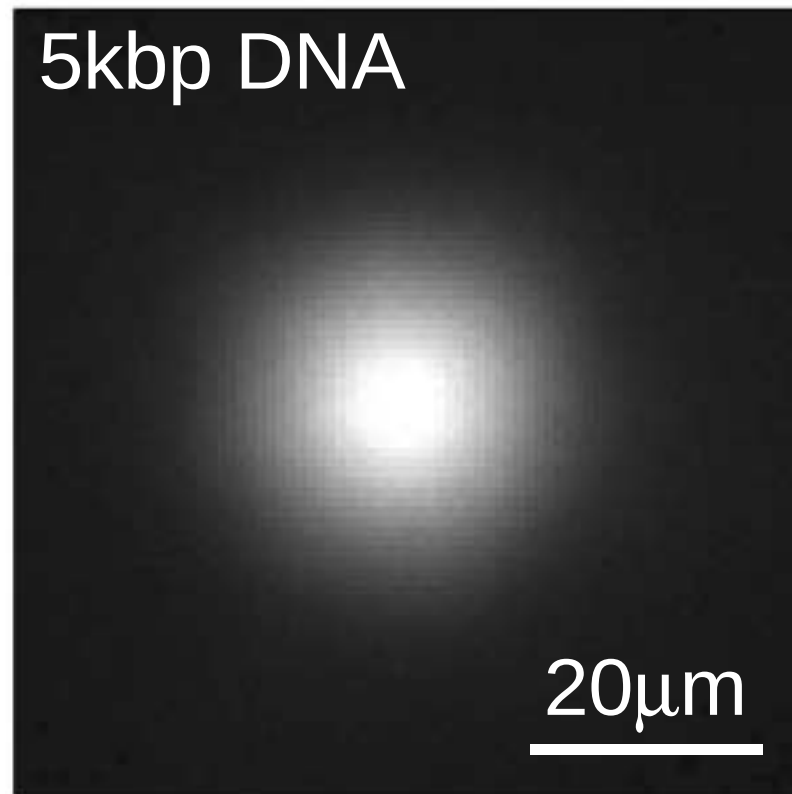
DIE STEINLAUS



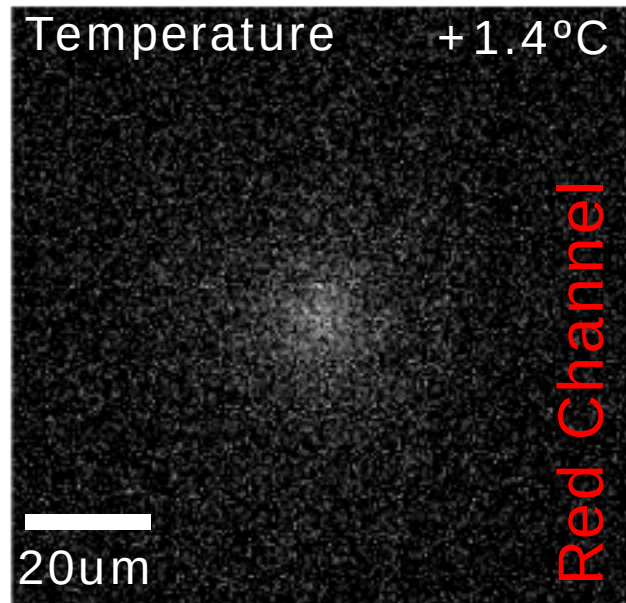
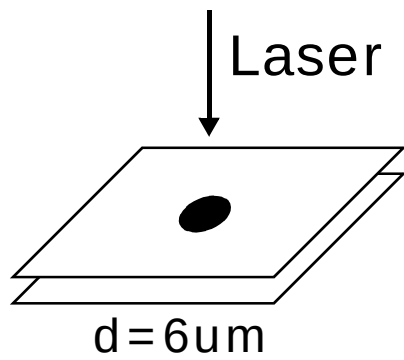
1 μ m

Thermophoretic Trapping of DNA

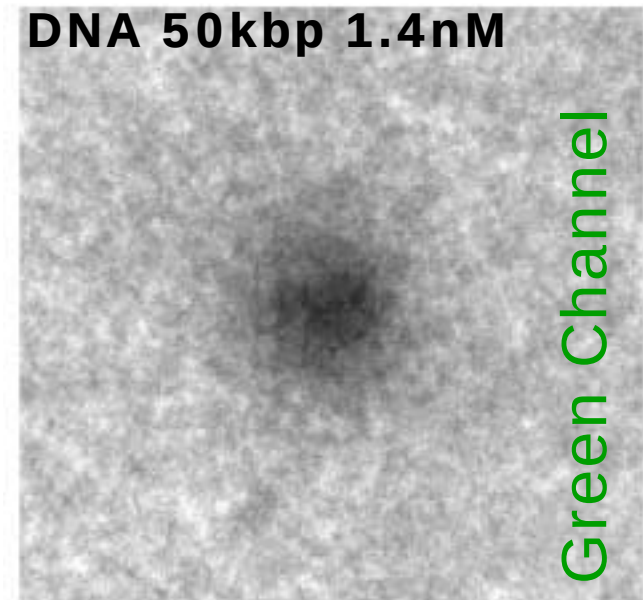
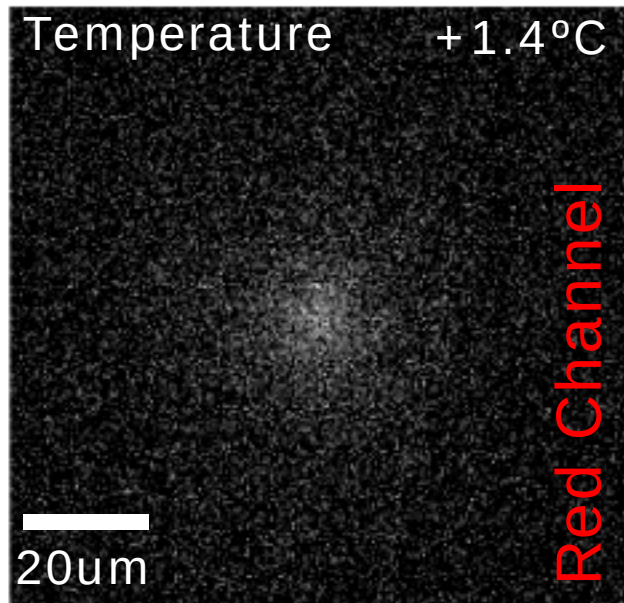
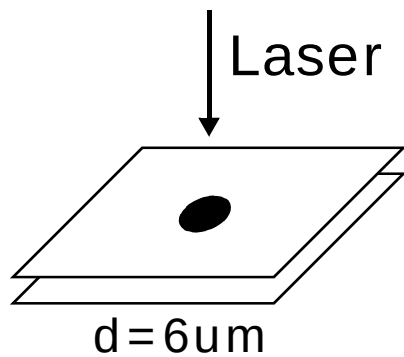
Braun & Libchaber, PRL 89:188103 (2002)



Local, mild heating

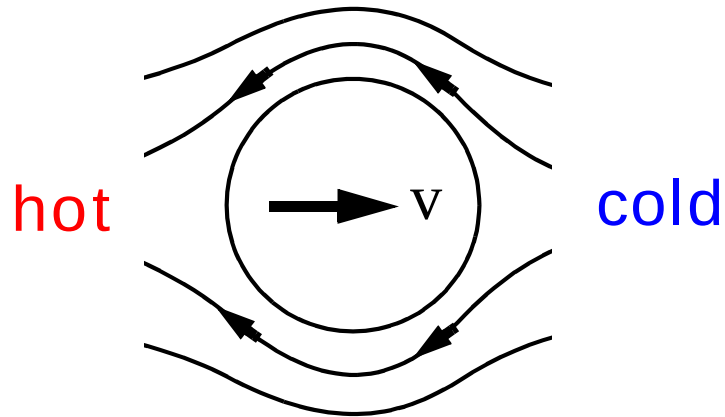


Depletion of DNA from heat



No optical tweezing
No temp. dep. of DNA stain
No optical lensing

Thermophoresis - Theory

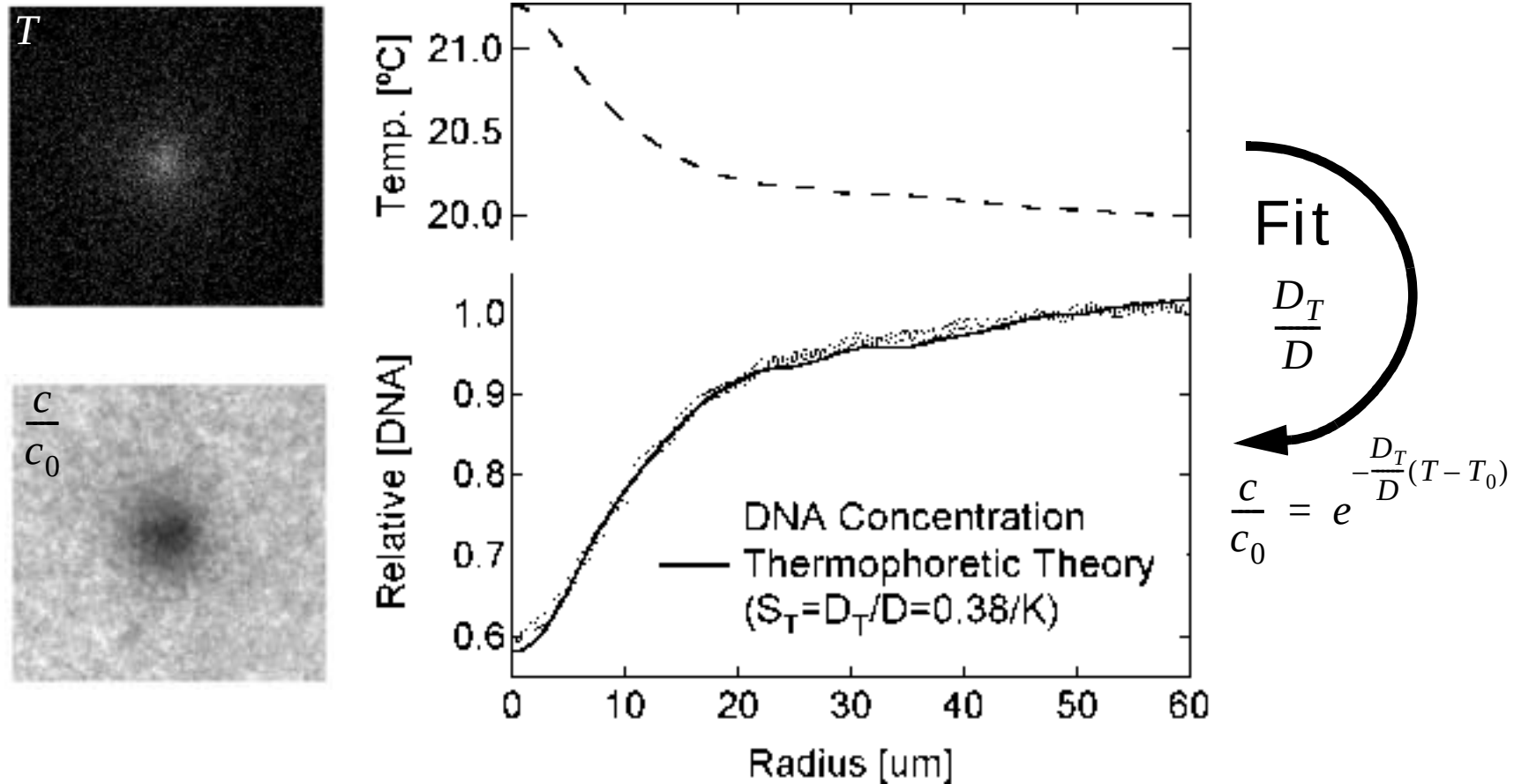


Heuristic approach

$$j = -D\nabla c - D_T c(1-c)\nabla T \stackrel{!}{=} 0 \longrightarrow \frac{c}{c_0} = e^{-\frac{D_T}{D}(T-T_0)}$$

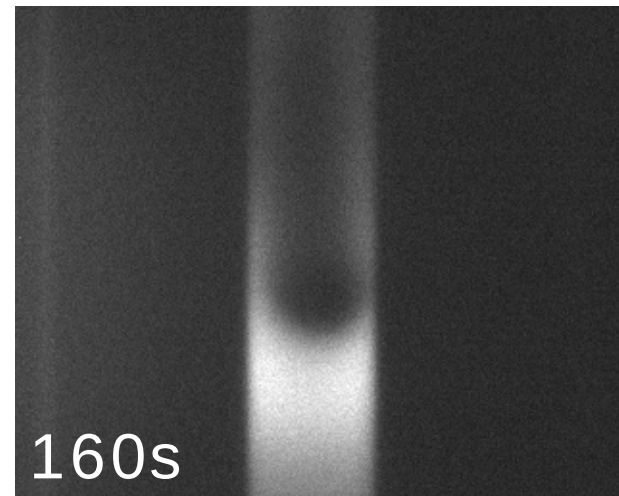
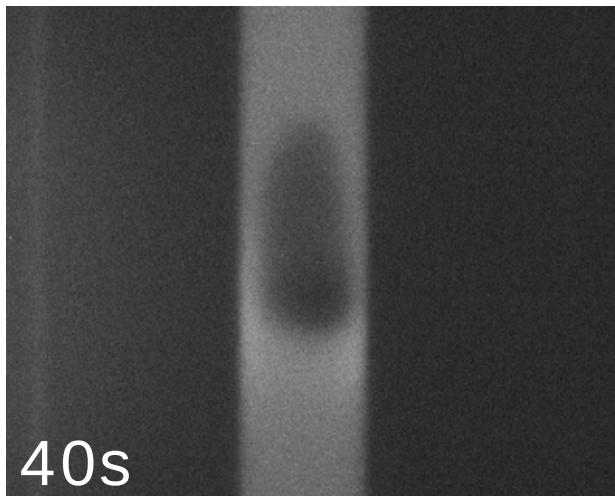
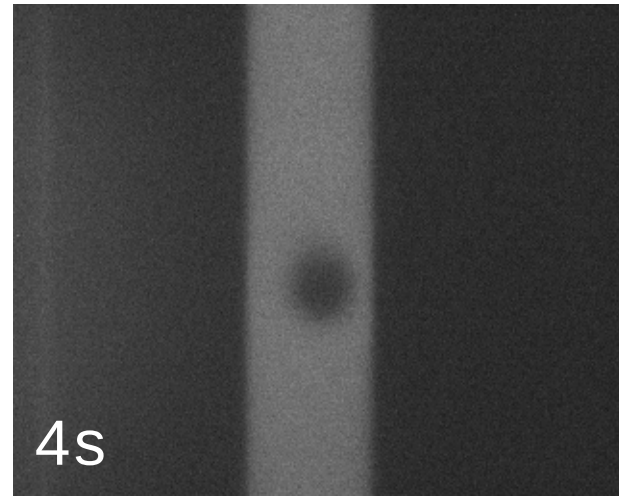
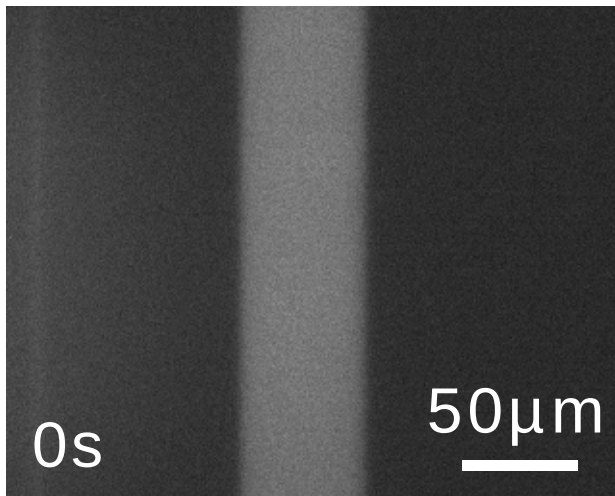
Exponential in Temperature
Exponential in DNA Length

Measure D_T/D of DNA

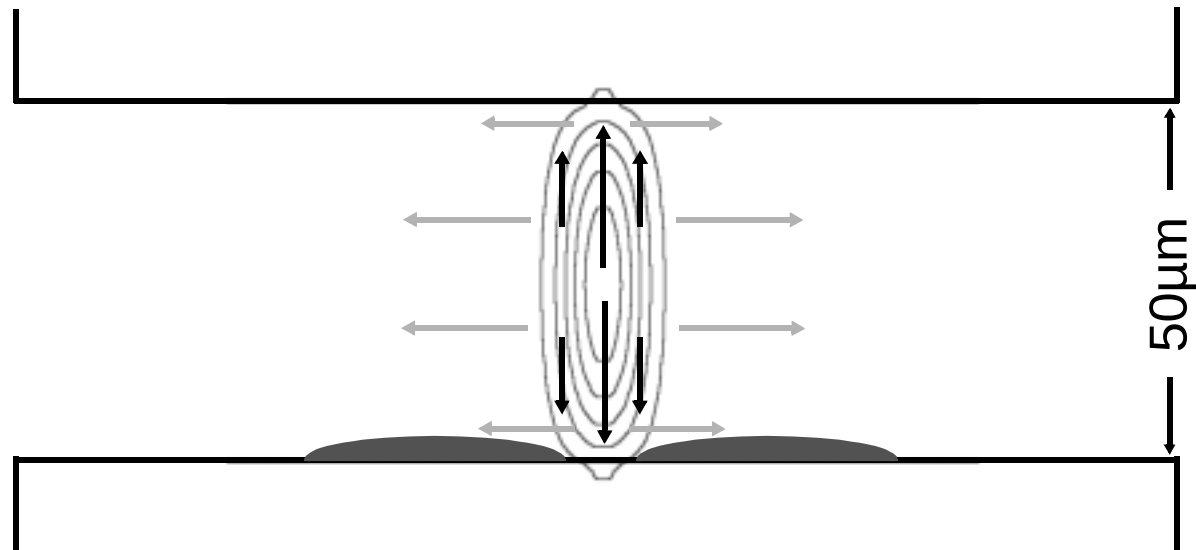
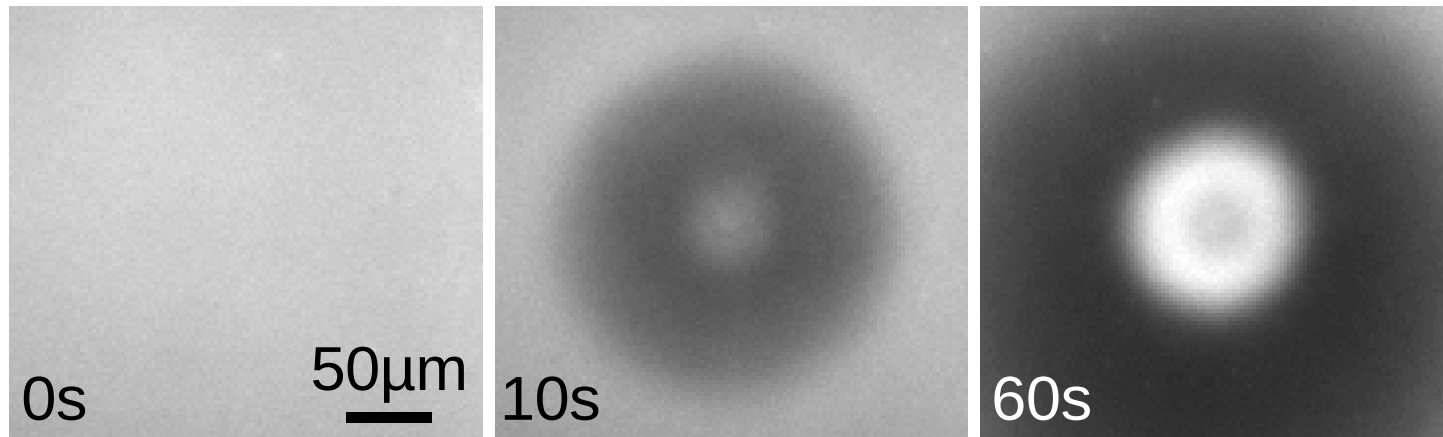


From Backdiffusion: $D_T = 0.4 \times 10^{-8} \text{ cm}^2/(\text{sK})$

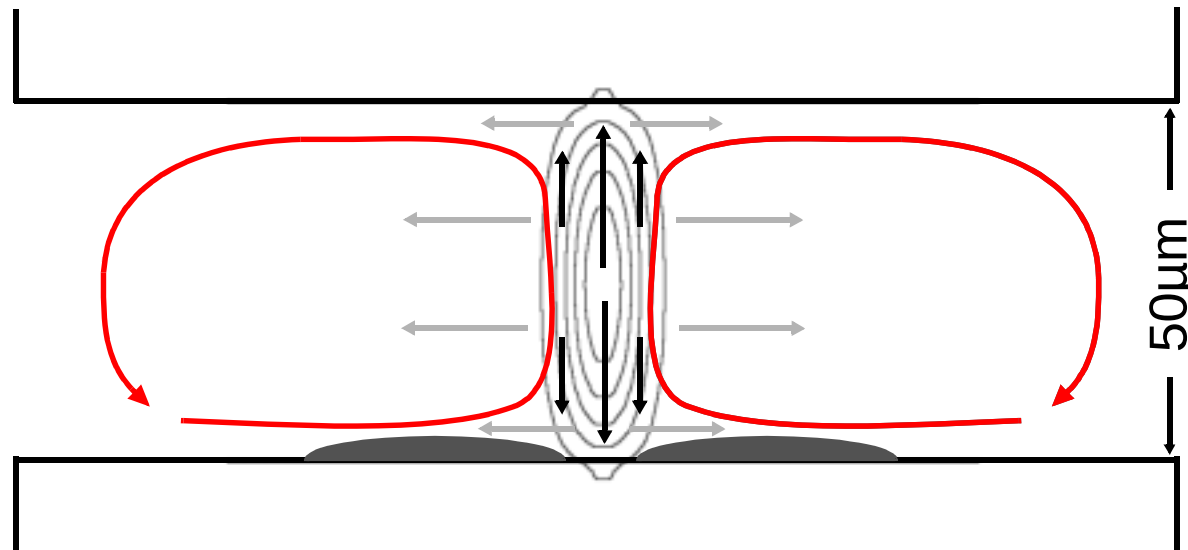
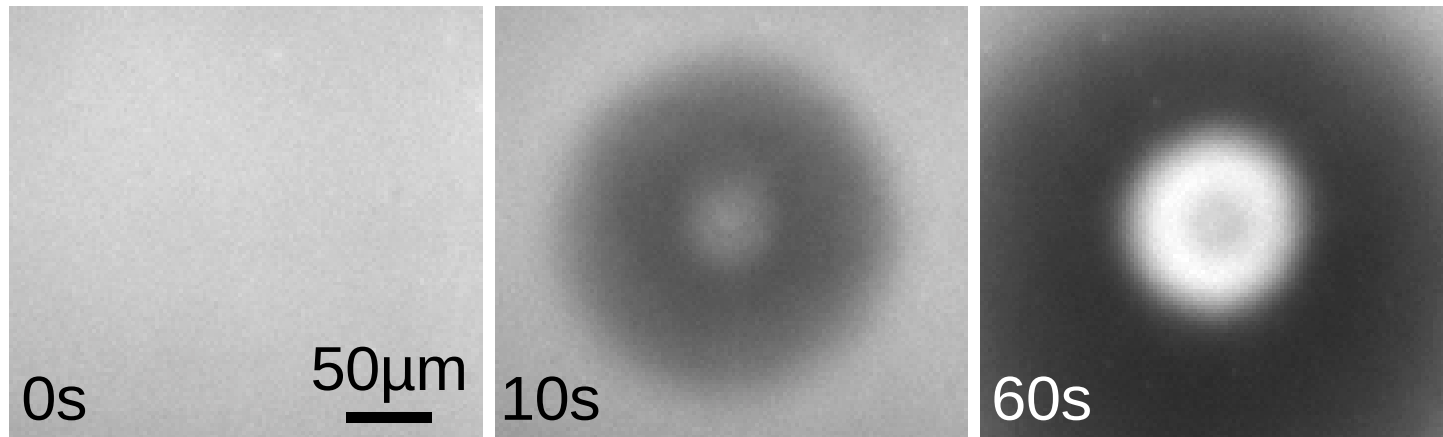
Thermophoresis against a microfluidic flow



Trapping of DNA by Temperature

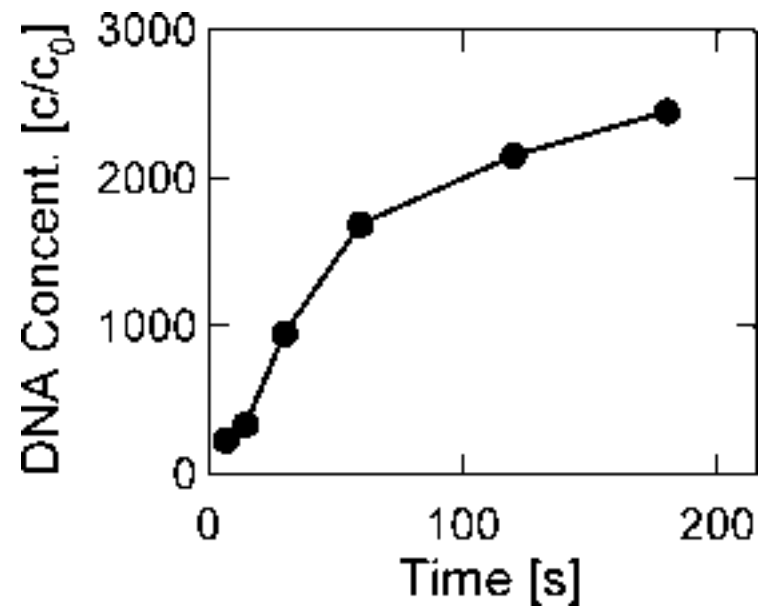
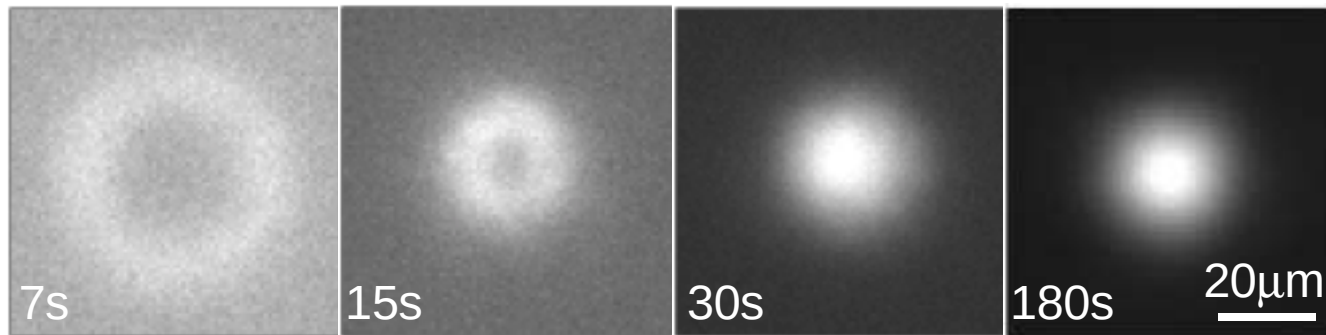


Trapping of DNA by Temperature

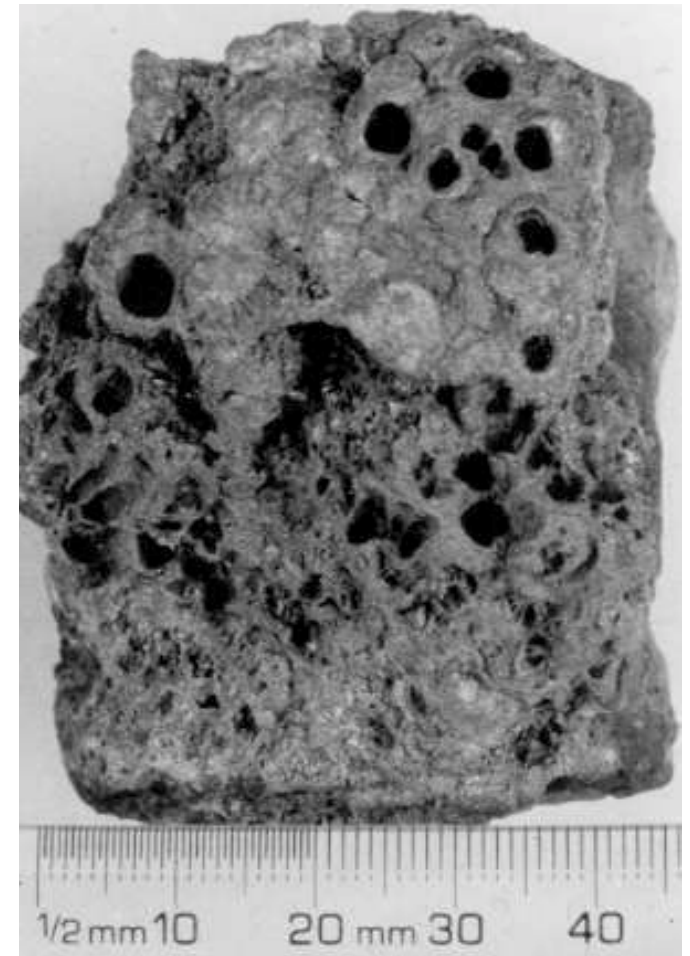


Concentration increase approx. 60-fold

Strong accumulation



Pyrite



Metabolism on Pyrite (Wächtershäuser)

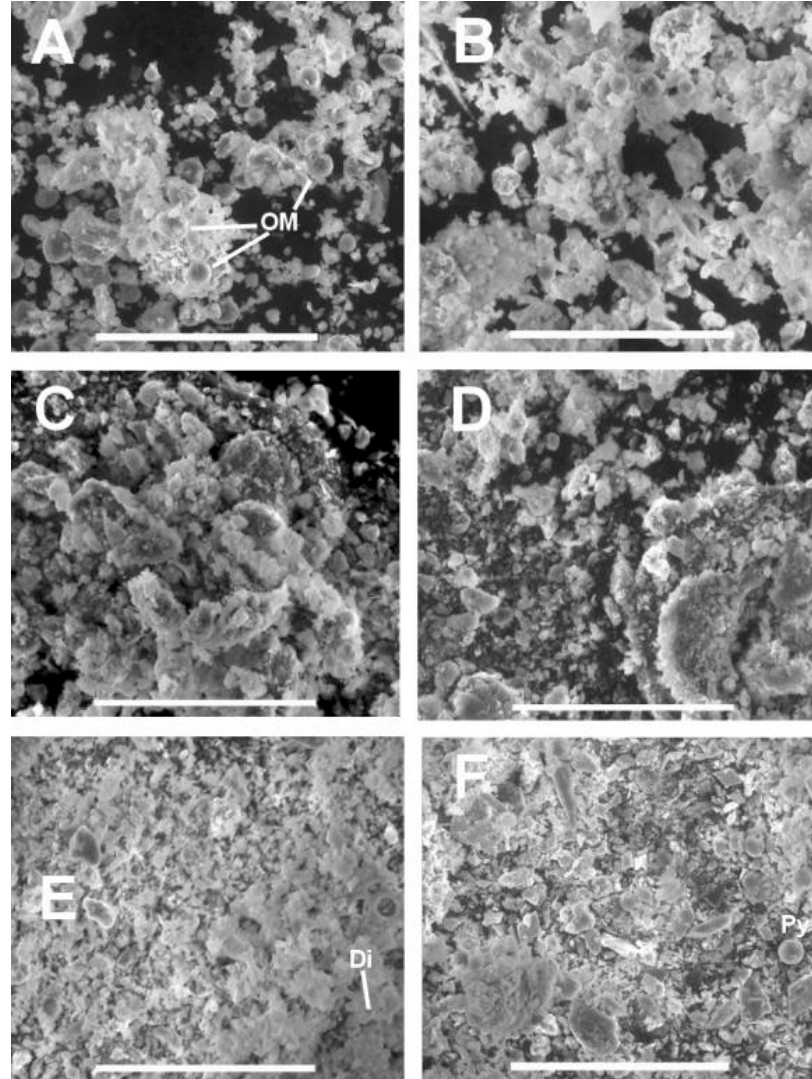
Montmorillonite Clay (“mud”)



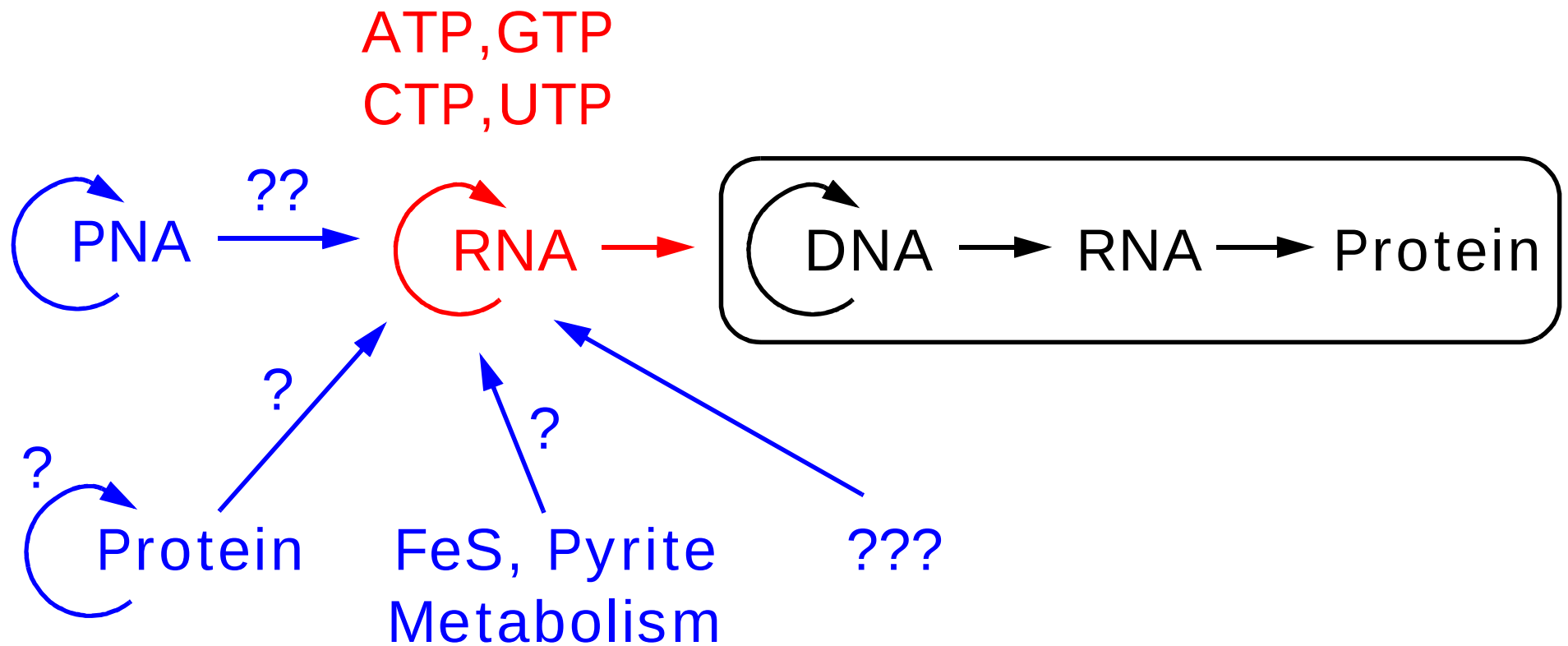
Energy rich
NTP's



RNA-Oligos
(J. Ferris)

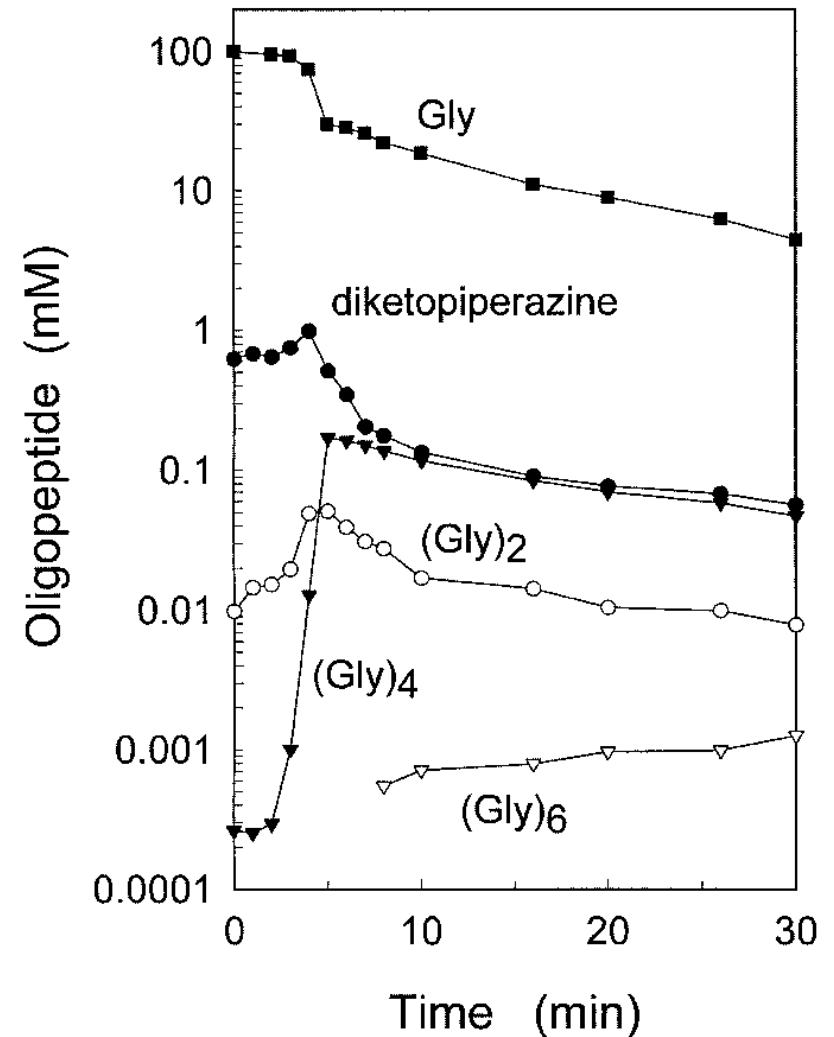
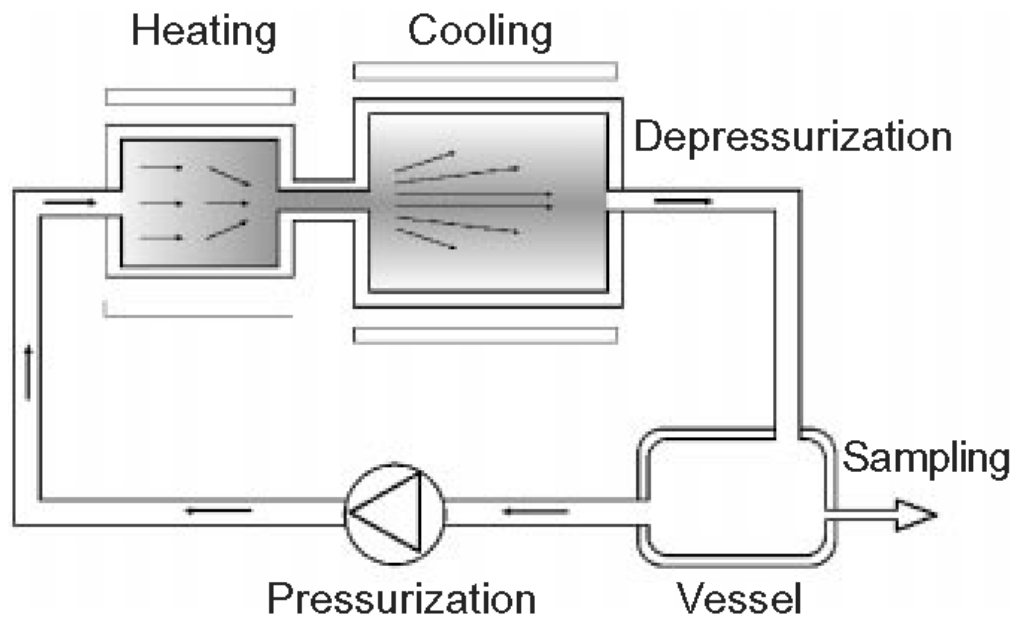


RNA World ?



Peptide Synthesis from quenched Heating

Koichiro Matsuno et.al. Science 283:831 (1999)

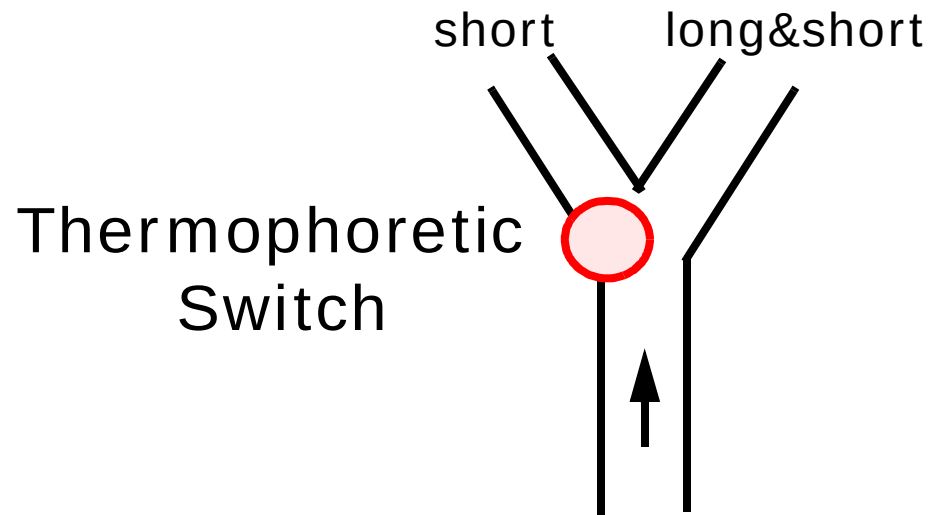


Temperature Gradients
can

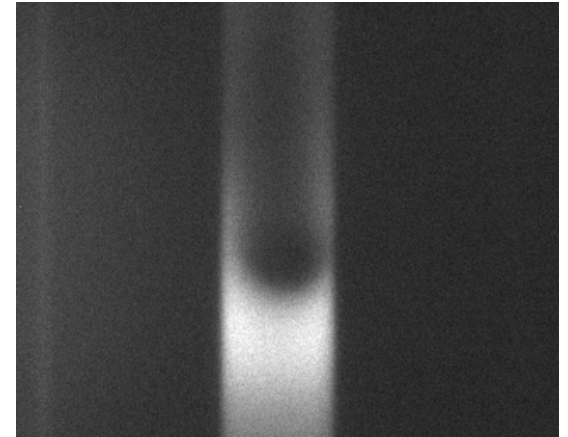
Accumulate DNA & Protein(?)
Induce DNA Replication
Synthesize Peptides (?)

= > Definition of a Protocell ?

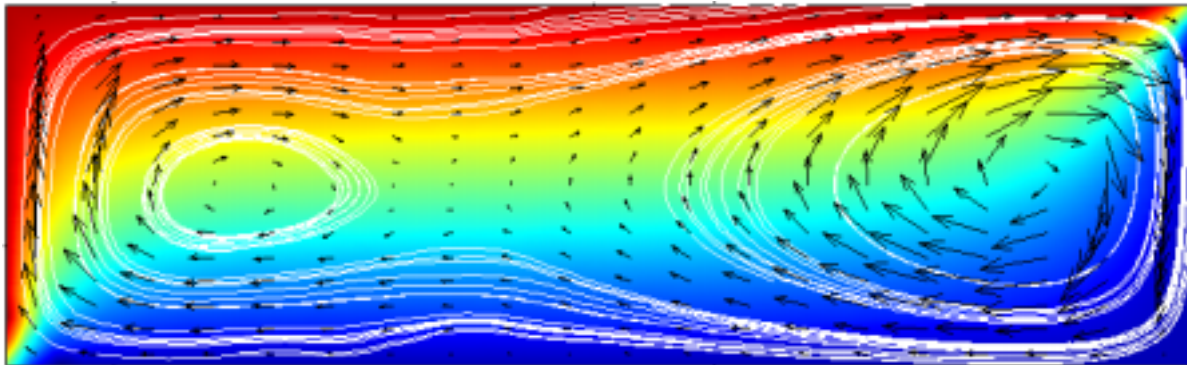
Future Directions



Thermophoresis
+ Electrophoresis

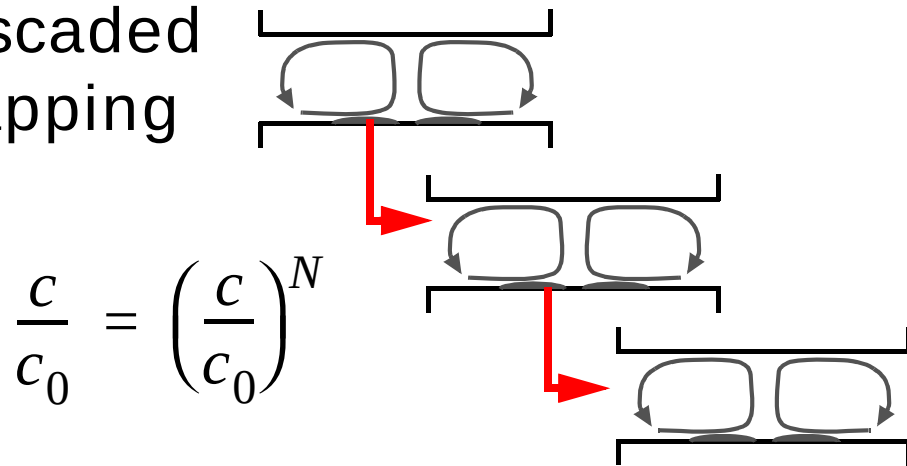


Convection PCR + Trapping



Future Directions

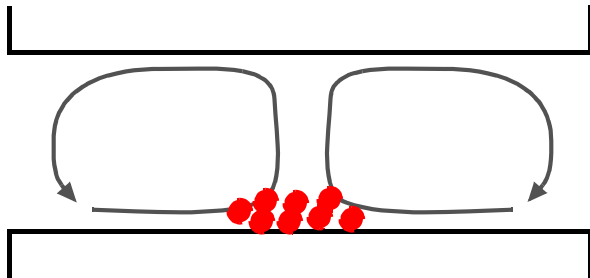
Cascaded Trapping



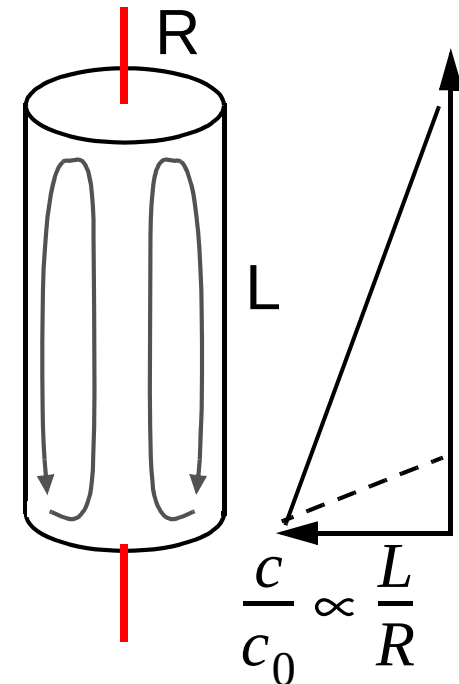
$$\frac{c}{c_0} = \left(\frac{c}{c_0} \right)^N$$

Improving Trapping by “mud” co-accumulation

$$D \searrow \Rightarrow \frac{c}{c_0} \nearrow ?$$

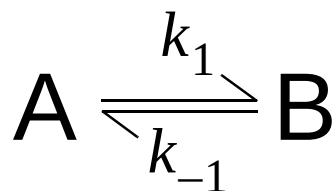


Microscopic Clusius Separation Tube



Protein Polymerization
by turbulent Convection?

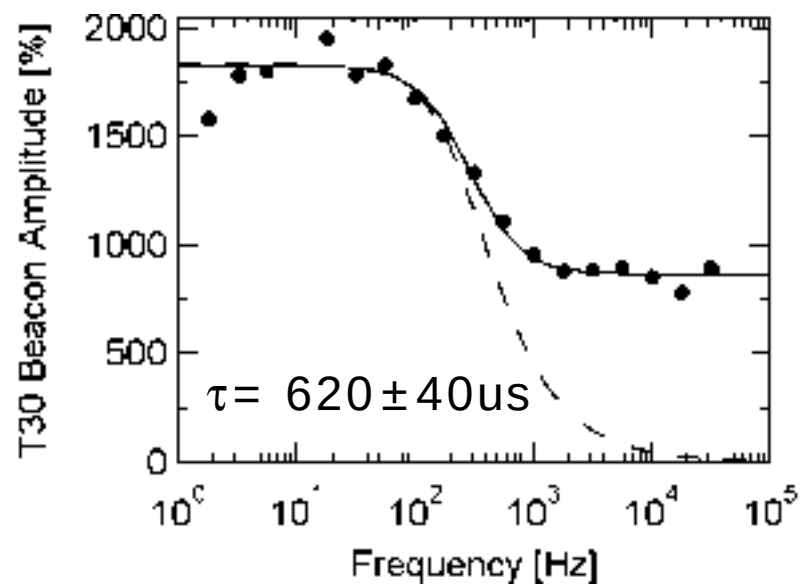
Lock-In Kinetics



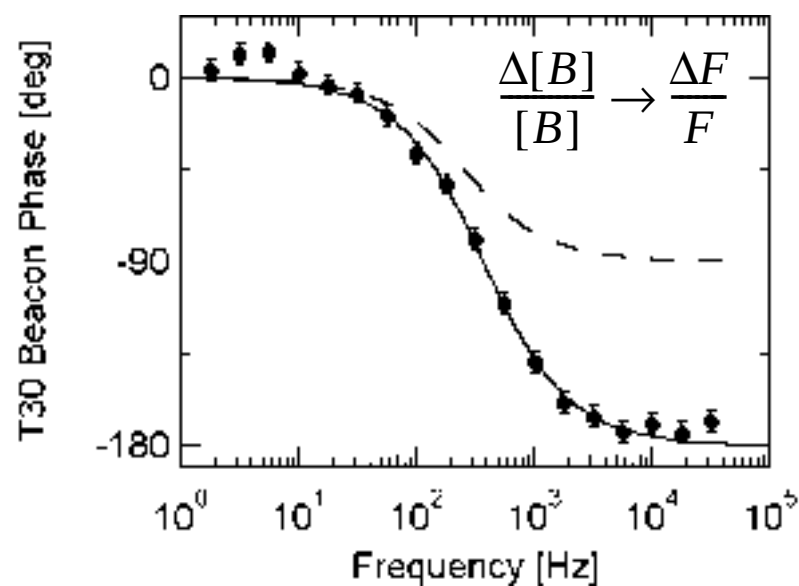
$$\frac{\Delta[B]}{[B]} = \underbrace{-\frac{\Delta H}{RT} \frac{1}{1+K}}_{\text{Transfer}} \frac{1}{1+i\omega\tau} \frac{\Delta T}{T}$$

$$\tau = \frac{1}{k_1 + k_{-1}}$$

Amplitude Transfer

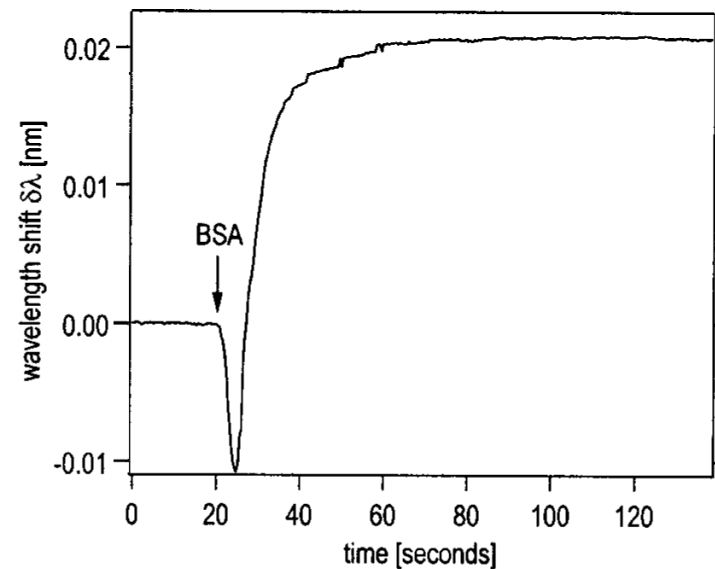
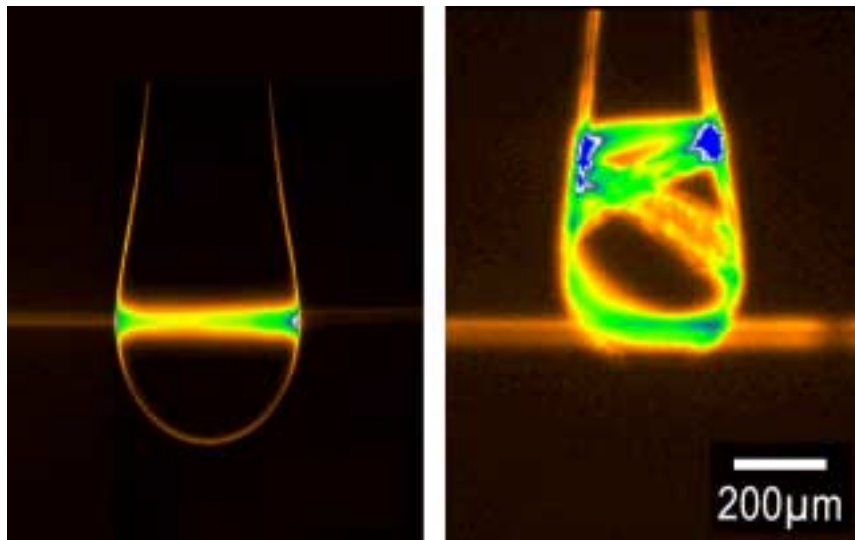
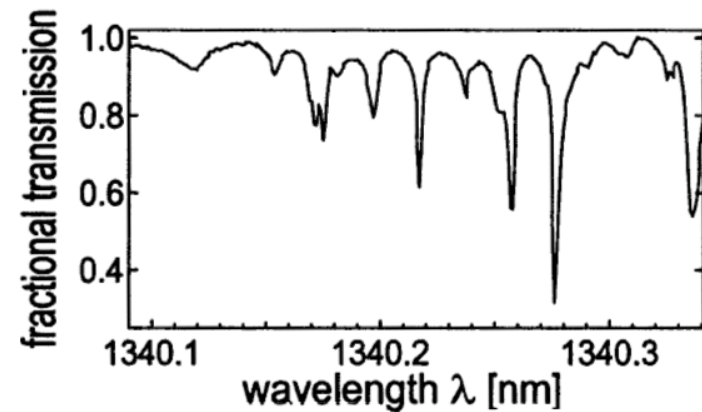
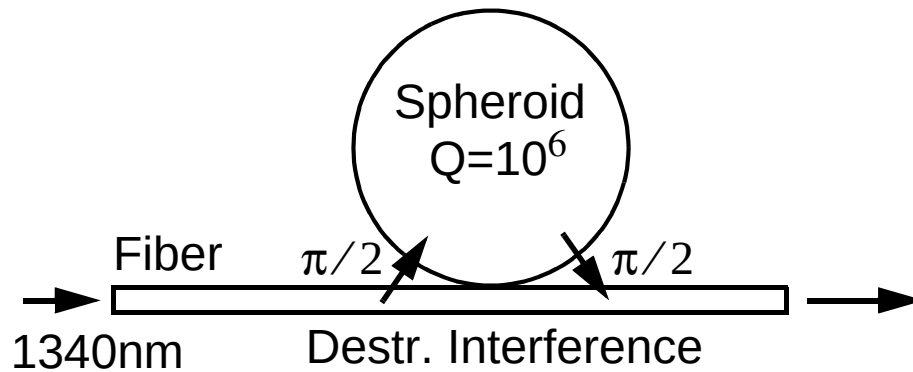


Phase Transfer



Protein detection by optical Resonance

F. Vollmer, D. Braun, A. Libchaber, M. Khoshsiman, I. Teraoka and S. Arnold
Appl. Phys. Lett. 80:4057-4059 (2002)



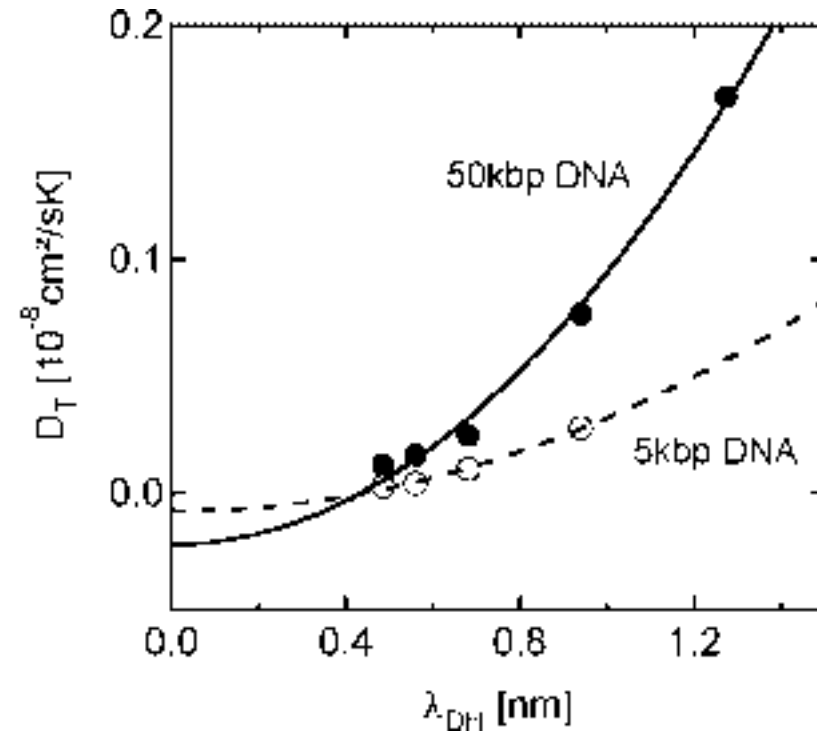
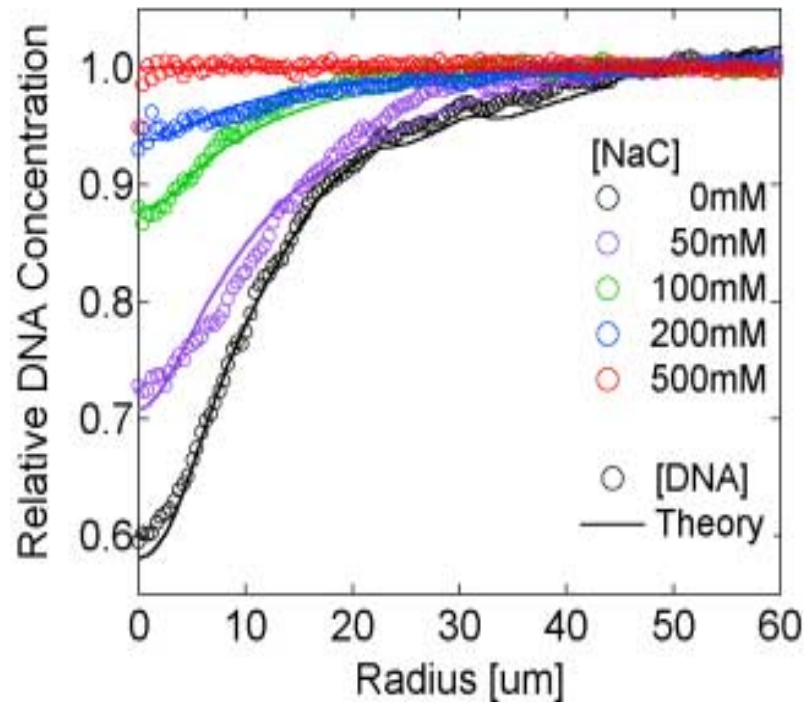
Acknowledgements

Libchaber Lab

Emmy Noether Scholarship, DFG

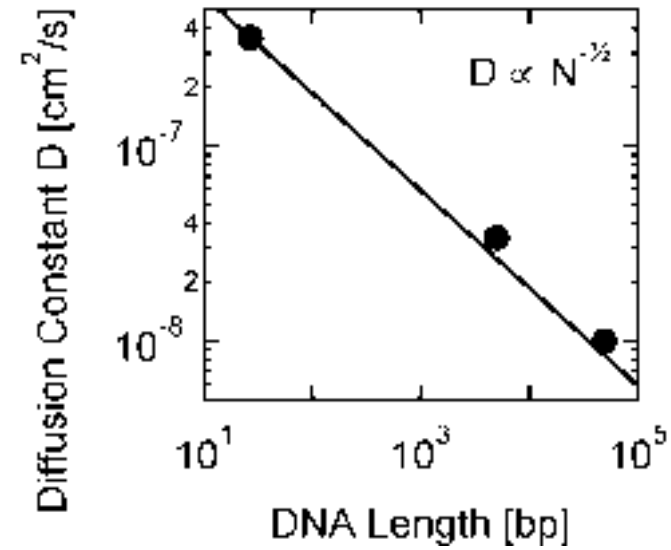
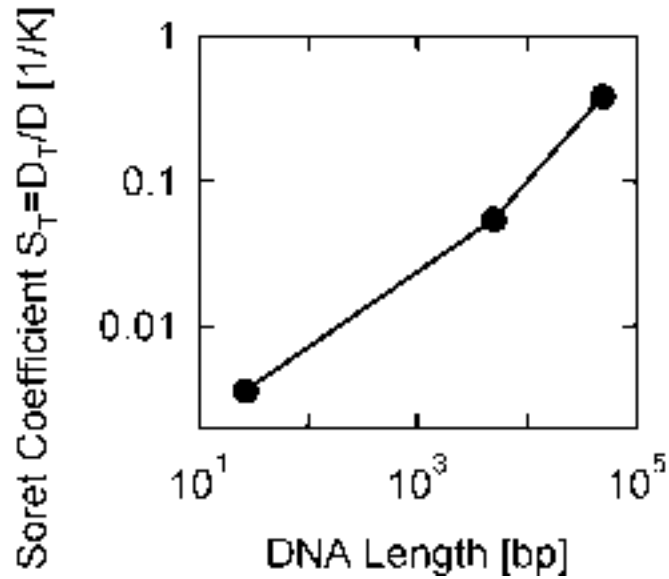
mail@dieterb.de

Salt Dependence

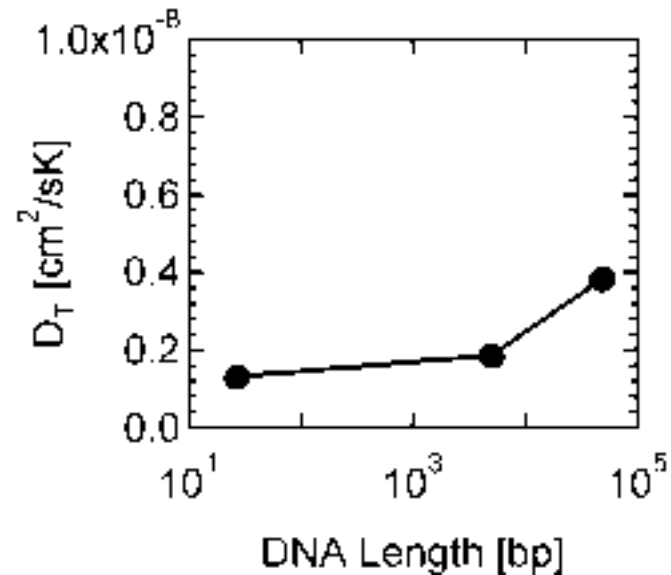


R. Piazza & A. Guarino
PRL 88:208302 (2002)

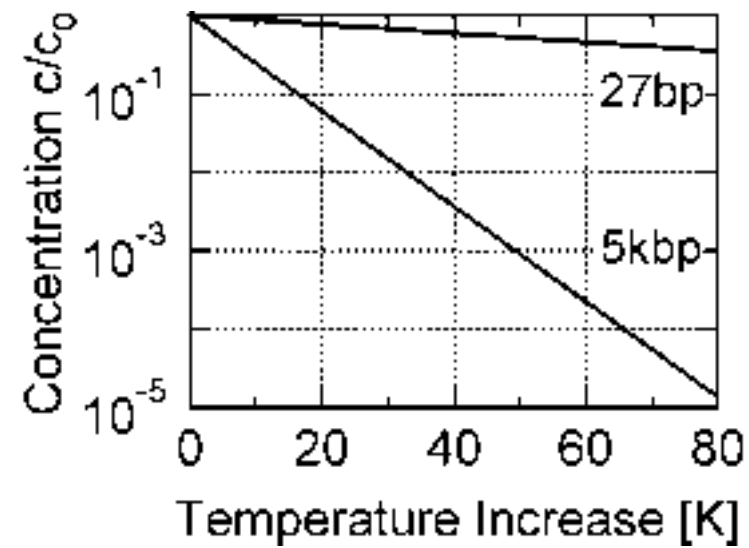
Length dependence



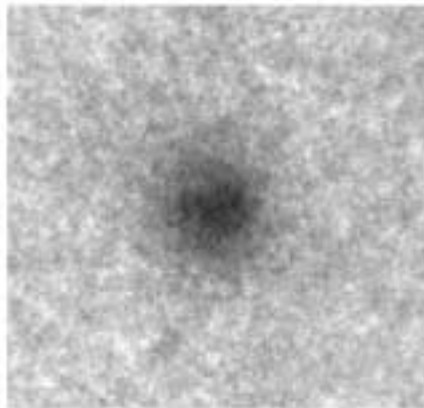
$$\frac{D_T}{D} \rightarrow D_T$$



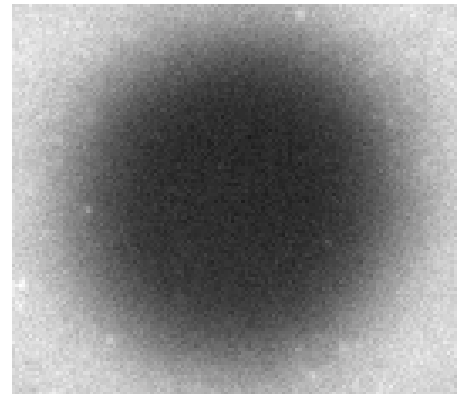
Temperature Dependence



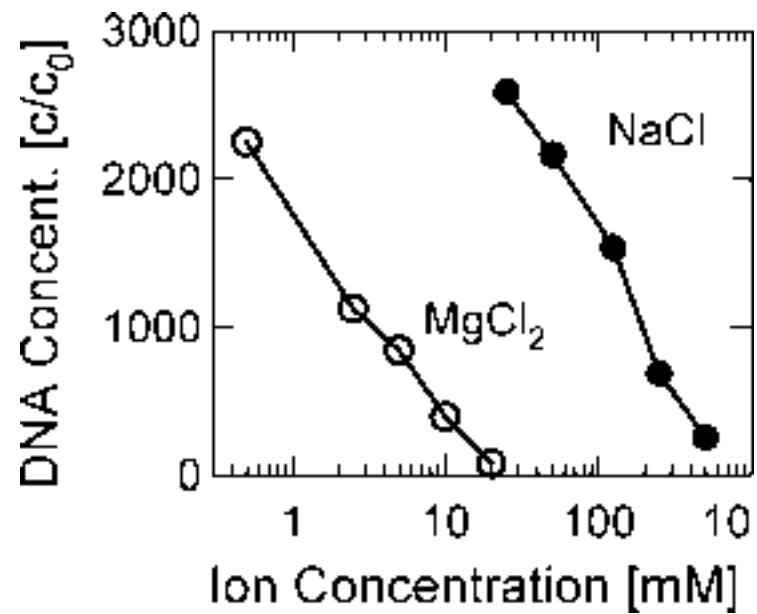
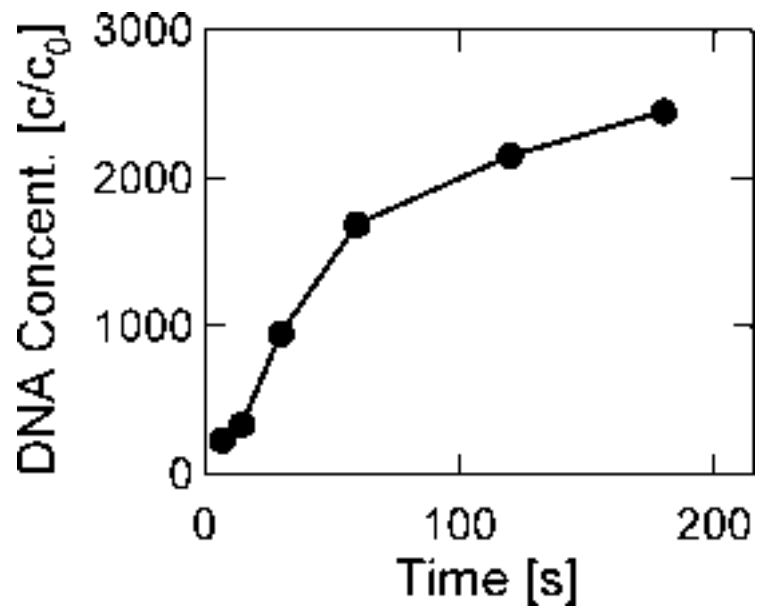
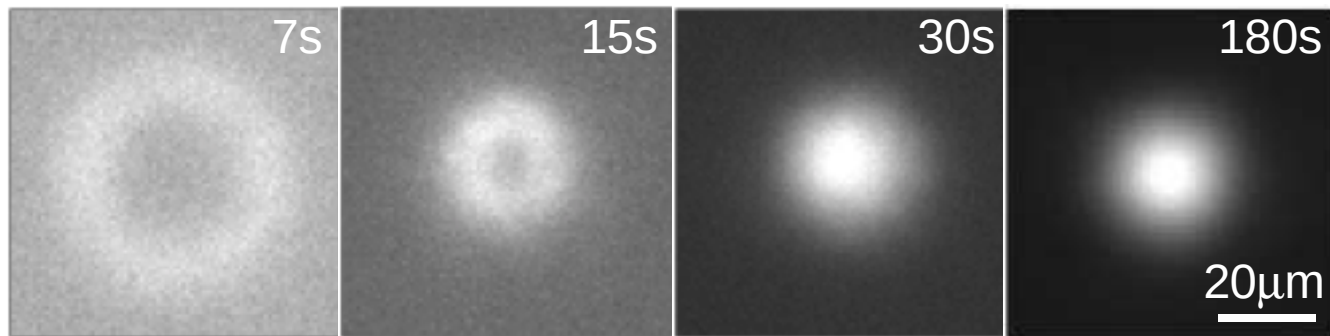
$\Delta T = 1.4\text{K}$



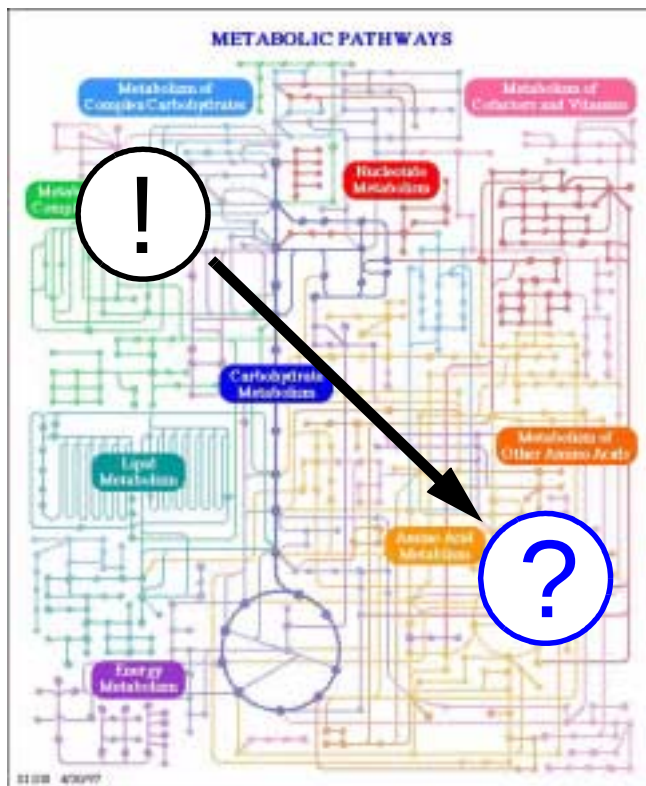
$\Delta T = 25\text{K}$



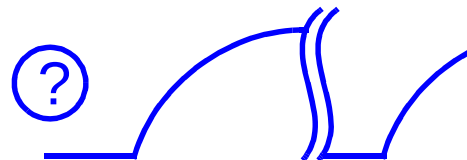
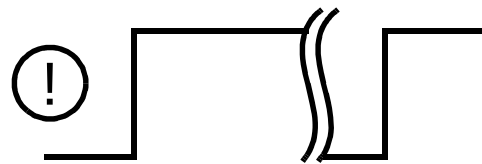
Strong accumulation



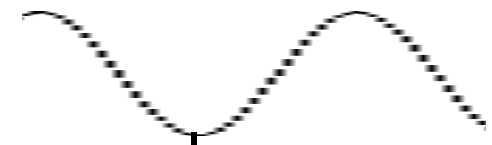
Probing network dynamics



Step



Lock-In

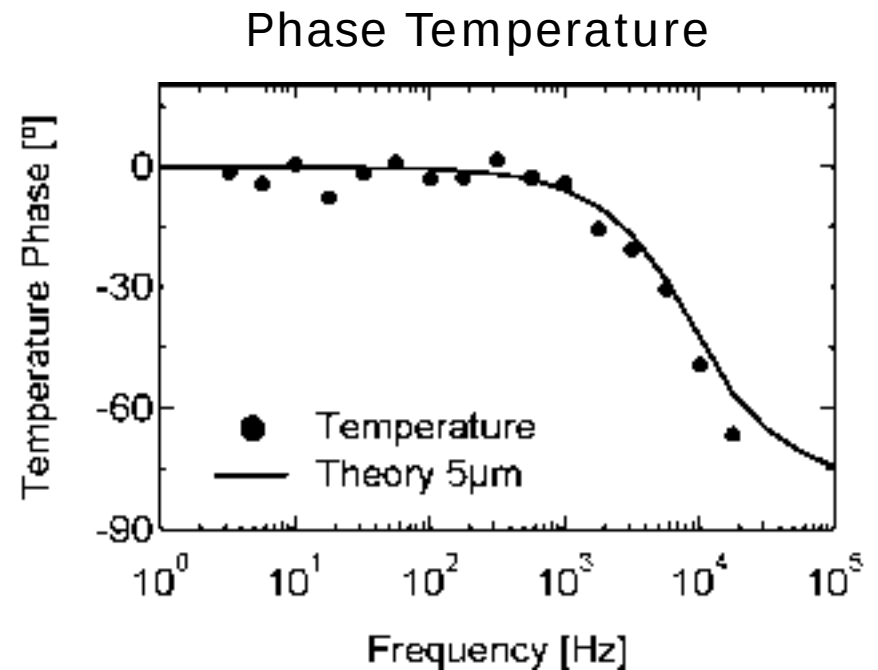
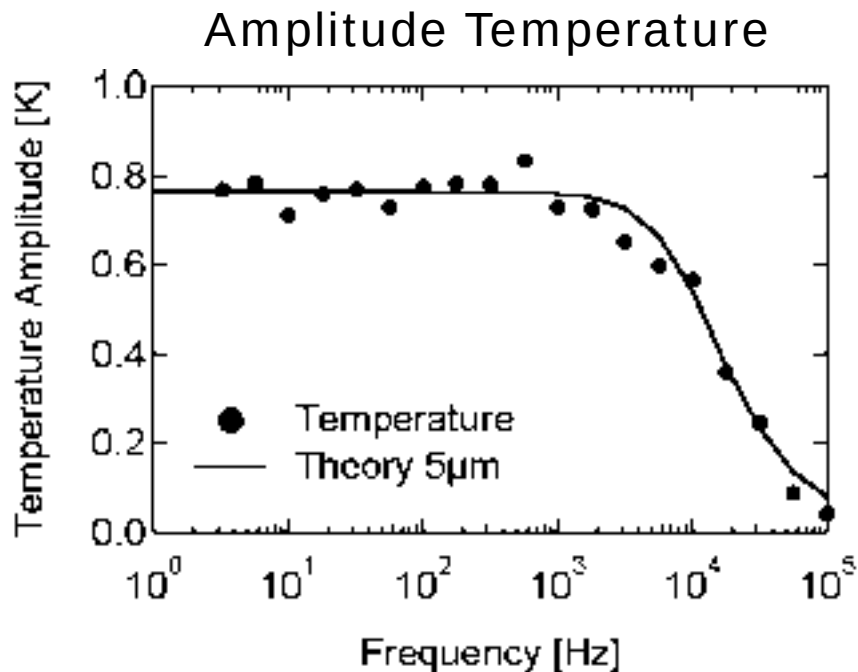
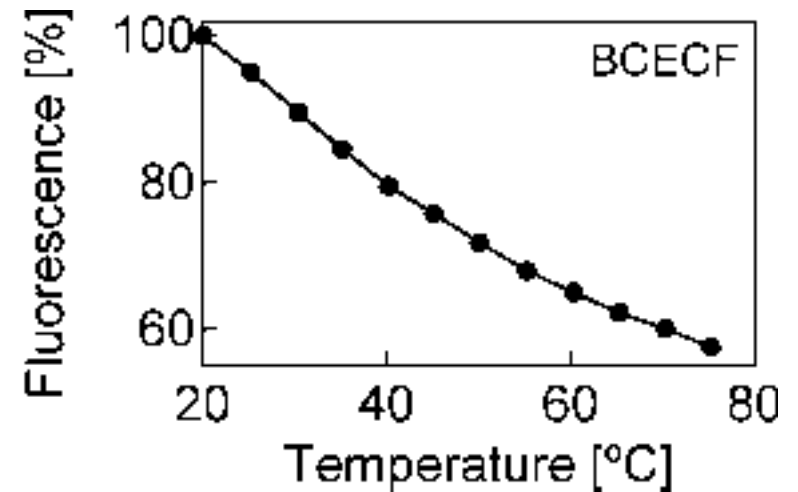
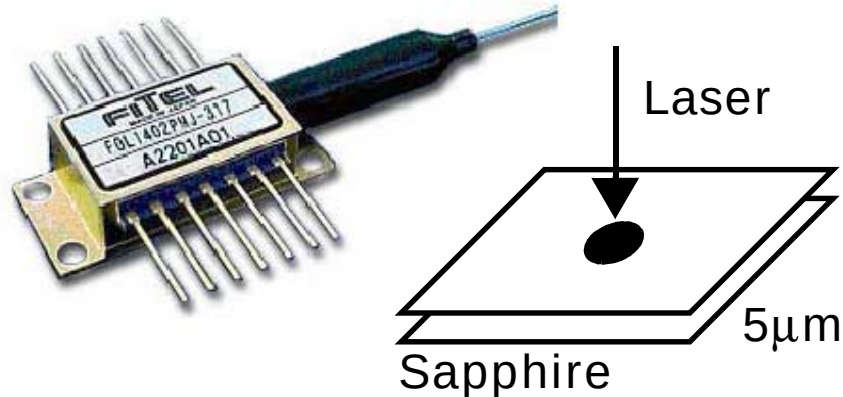


ϕ Phase

Amplitude

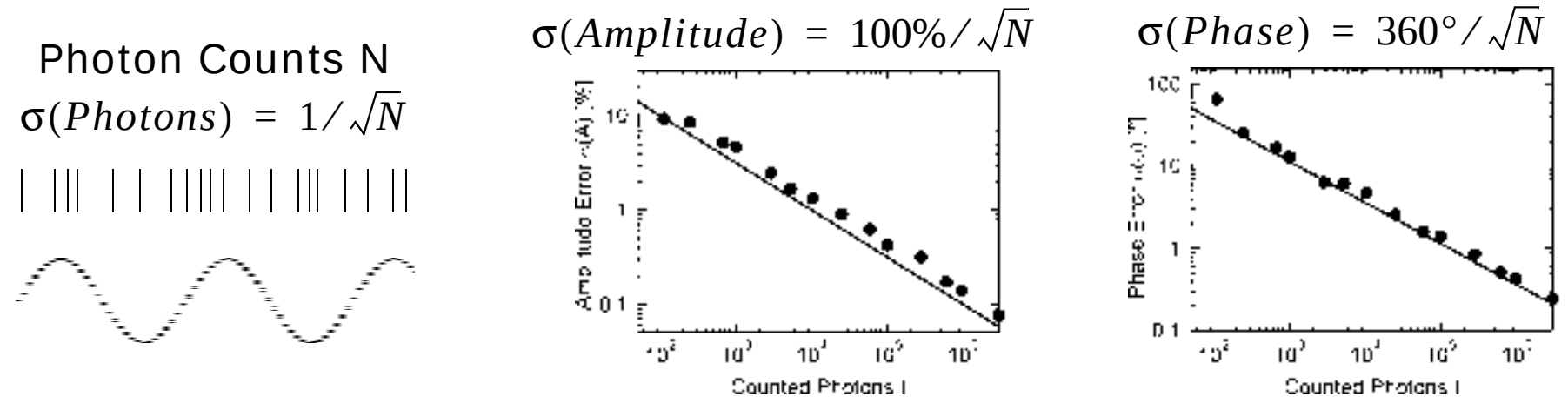
Fast Temperature Oscillations

IR Laser @ 1480nm



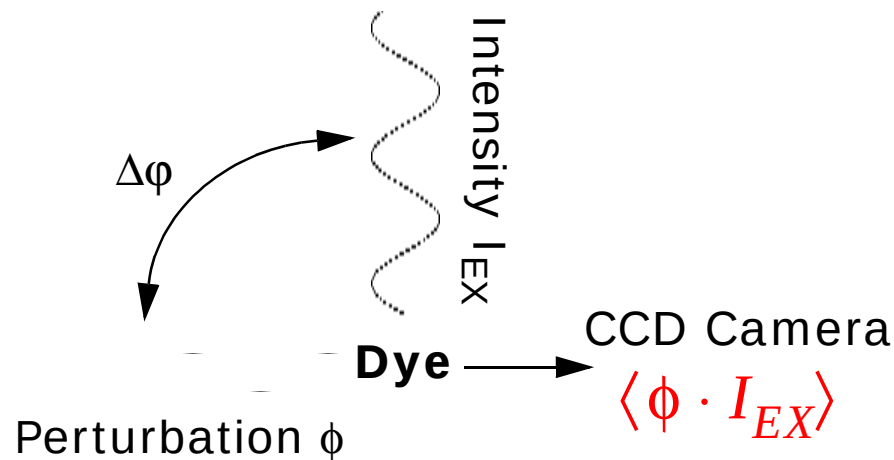
Single Photon Lock-In

Braun & Libchaber, Optics Letters, 27:1421-1423 (2002)

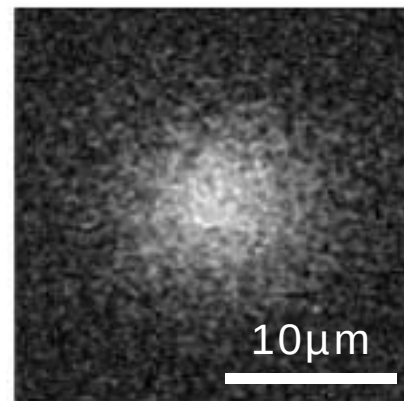


CCD Imaging Lock-In

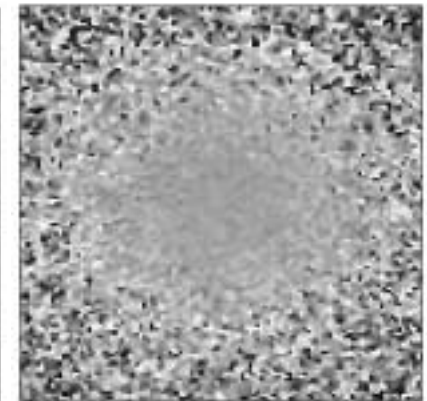
Braun & Libchaber, in preparation



Amplitude Image



Phase Image



$f=1\text{kHz}$, CCD Time 4s

Movie PCR