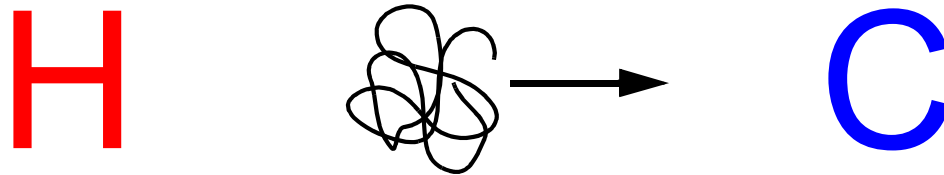


Thermophoresis of DNA: Trapping and Replicating by Heat

Dieter Braun
Rockefeller University

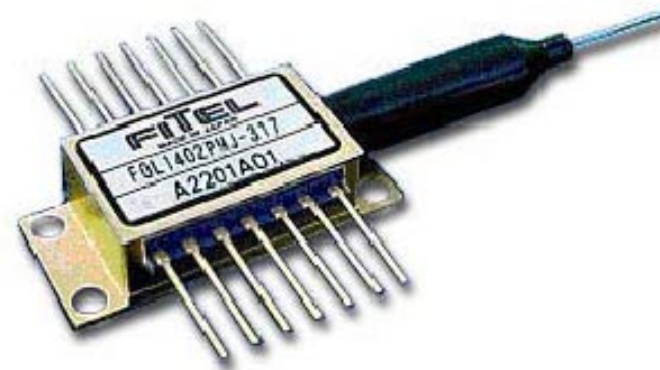
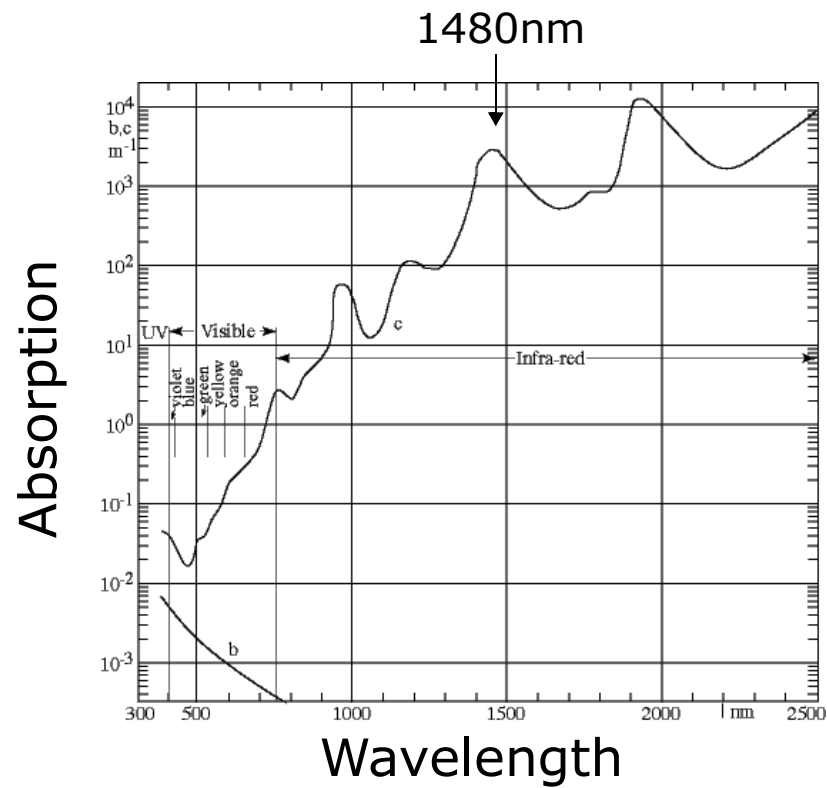
Thermophoresis, Soret Effect



Phenomenological approach

$$j = -D\nabla c - D_T c(1-c)\nabla T \stackrel{!}{=} 0 \quad \xrightarrow{D_T = \text{const.}} \quad \frac{c}{c_0} = e^{-\frac{D_T}{D}(T-T_0)}$$

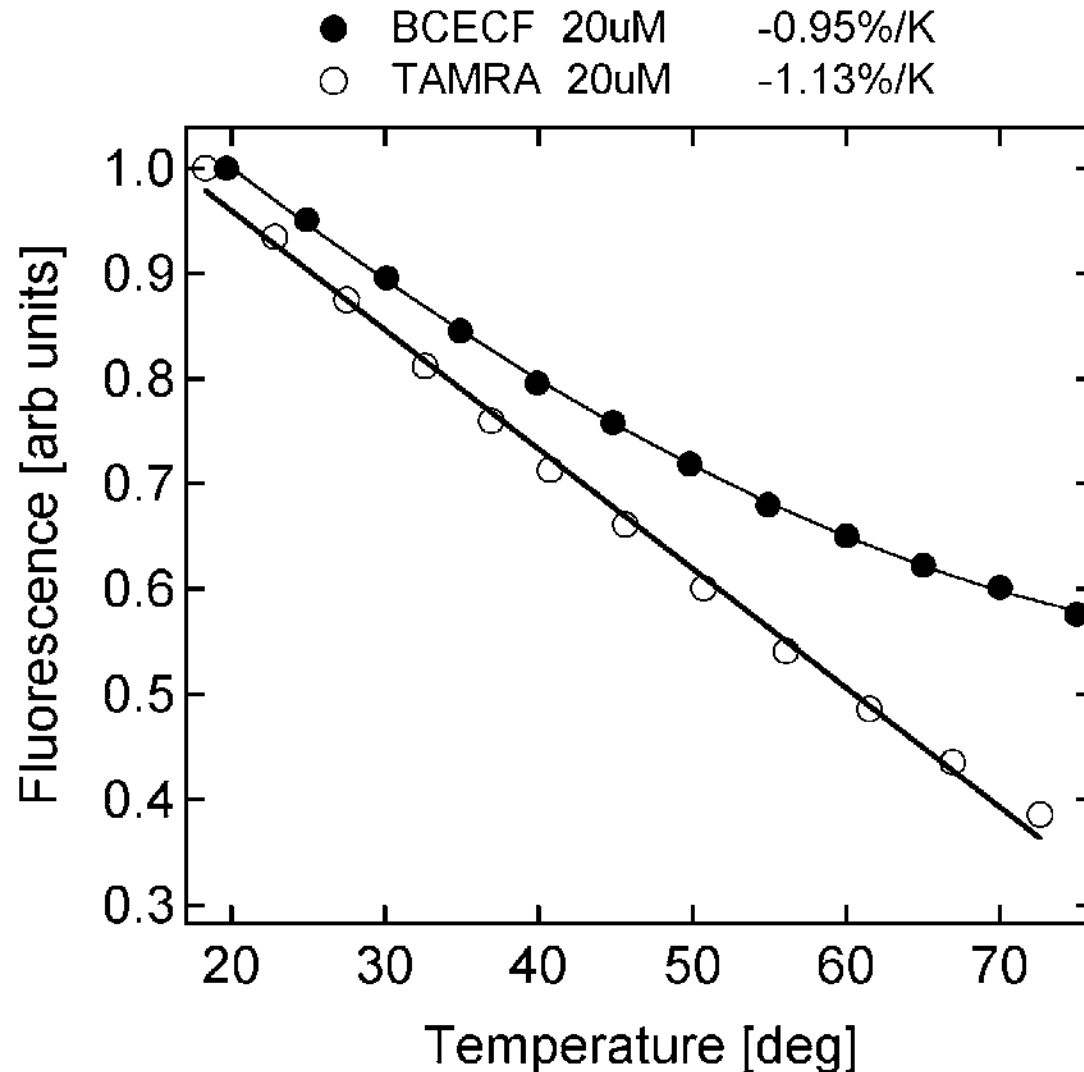
Infrared heating



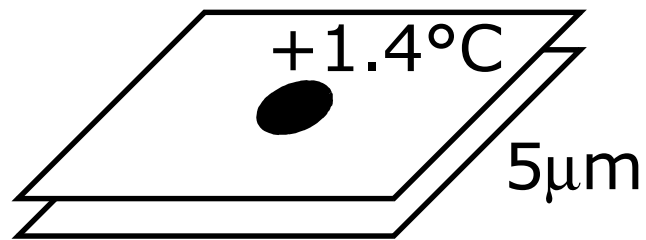
1480nm, 100mW

Using Dye Molecules as Thermometer

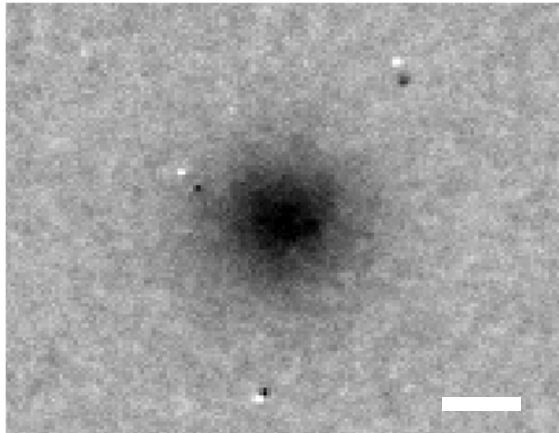
Temperature $\rightarrow$ pH of TRIS $\rightarrow$ pH Probe



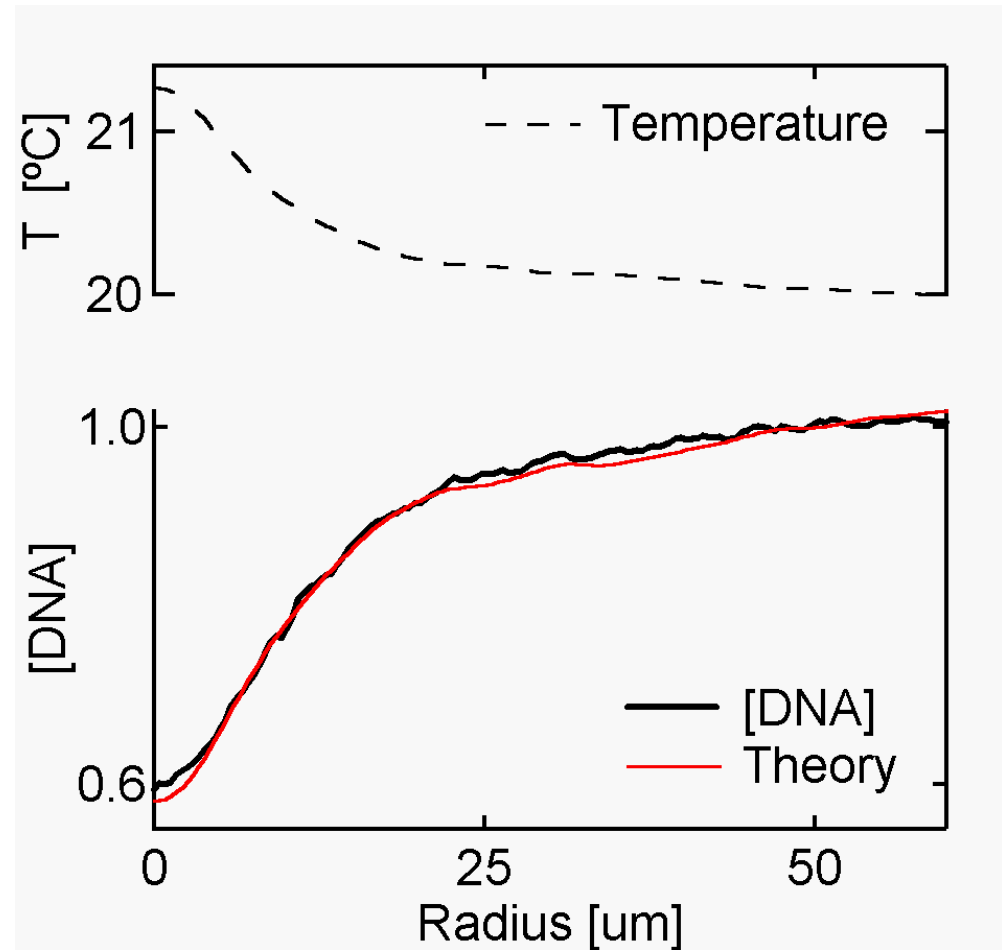
Thermophoresis



Laser
1480nm
5000bp DNA



50μm



$$\frac{c_0}{c} = e^{\frac{D_T}{D}(T - T_0)}$$

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

Origin of Thermophoresis?

Phenomenological approach

$$j = -D\nabla c - D_T c(1-c)\nabla T \stackrel{!}{=} 0 \quad \xrightarrow{D_T = \text{const.}} \quad \frac{c}{c_0} = e^{-\frac{D_T}{D}(T-T_0)}$$

Interfacial Free Energy argument for ionic thermophoresis (Piazza 2002, Ruckenstein 1981)

Debye Hückel Length $\lambda_{DH} = \sqrt{(\epsilon k_B T) / [2c_S e^2]}$

Interfacial Free Energy $\gamma = -\epsilon \psi_S^2 / 8\pi \lambda_{DH}$

Drift velocity (Ruckenstein) $v = -l \nabla \gamma / \eta = -\frac{\epsilon \psi_S^2}{32\pi \eta T} \nabla T$

$$\psi_S^2 = Z_{eff} e \lambda_{DH} / \epsilon a^2$$

$$l_B = e^2 / 4\pi \epsilon k_B T$$

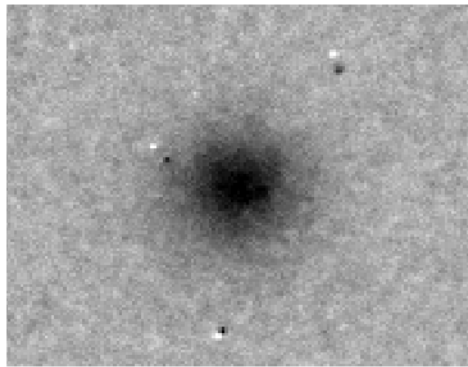
$$f_0 = 6\pi \eta a$$

$$D_0 = k_B T / f_0$$

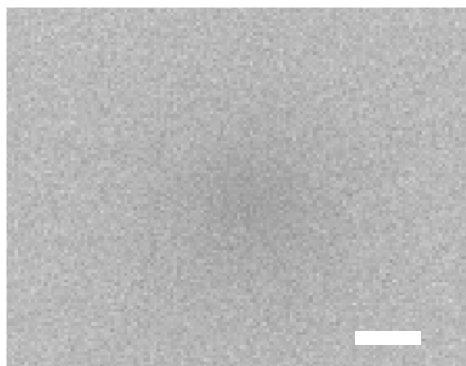
$$\left. \frac{D_T}{D_0} \right|_{ionic} = \frac{3\pi l_B Z_{eff}^2}{4T a^3} \lambda_{DH}^2 \sim \lambda_{DH}^2$$

Exponential Dependence on Length and Temperature ?

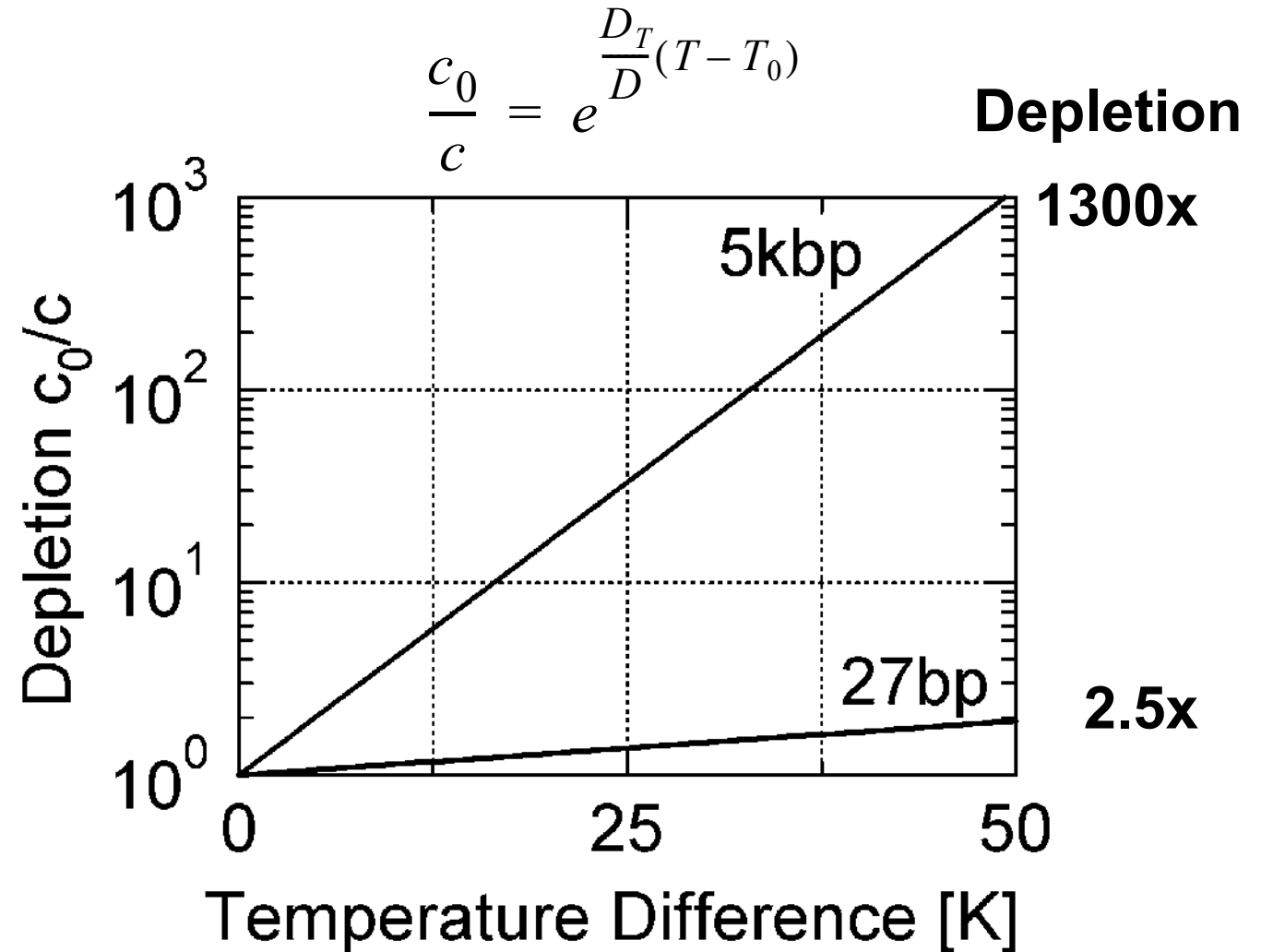
5000bp DNA



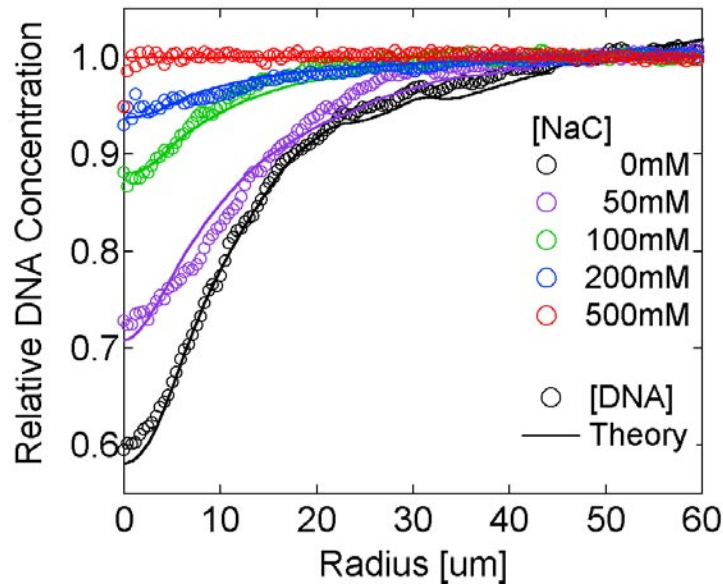
27bp DNA



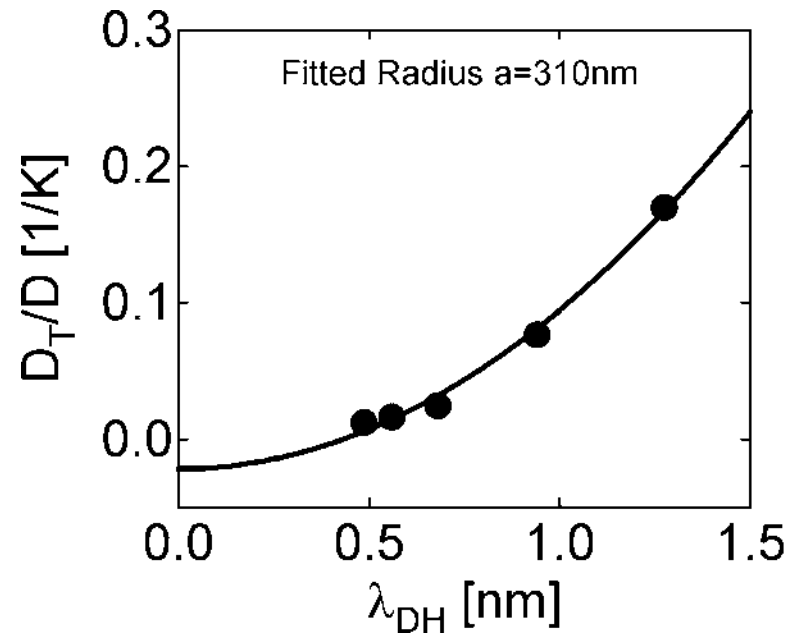
50μm



Scaling with Salt Concentration

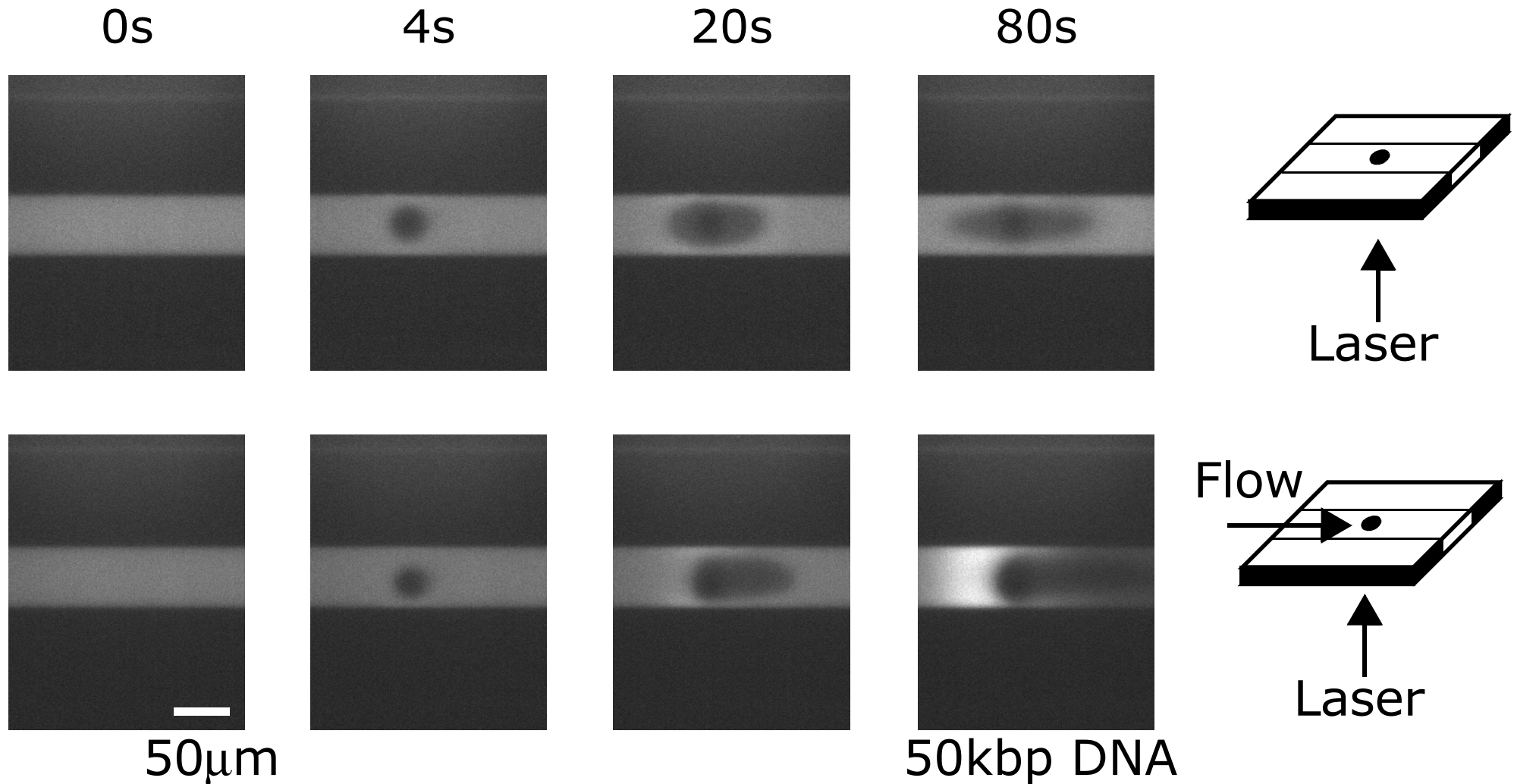


[Similar for 40nm Beads]

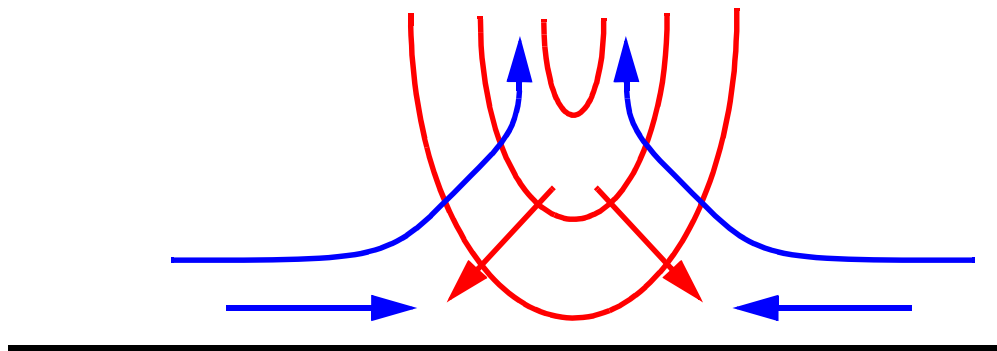
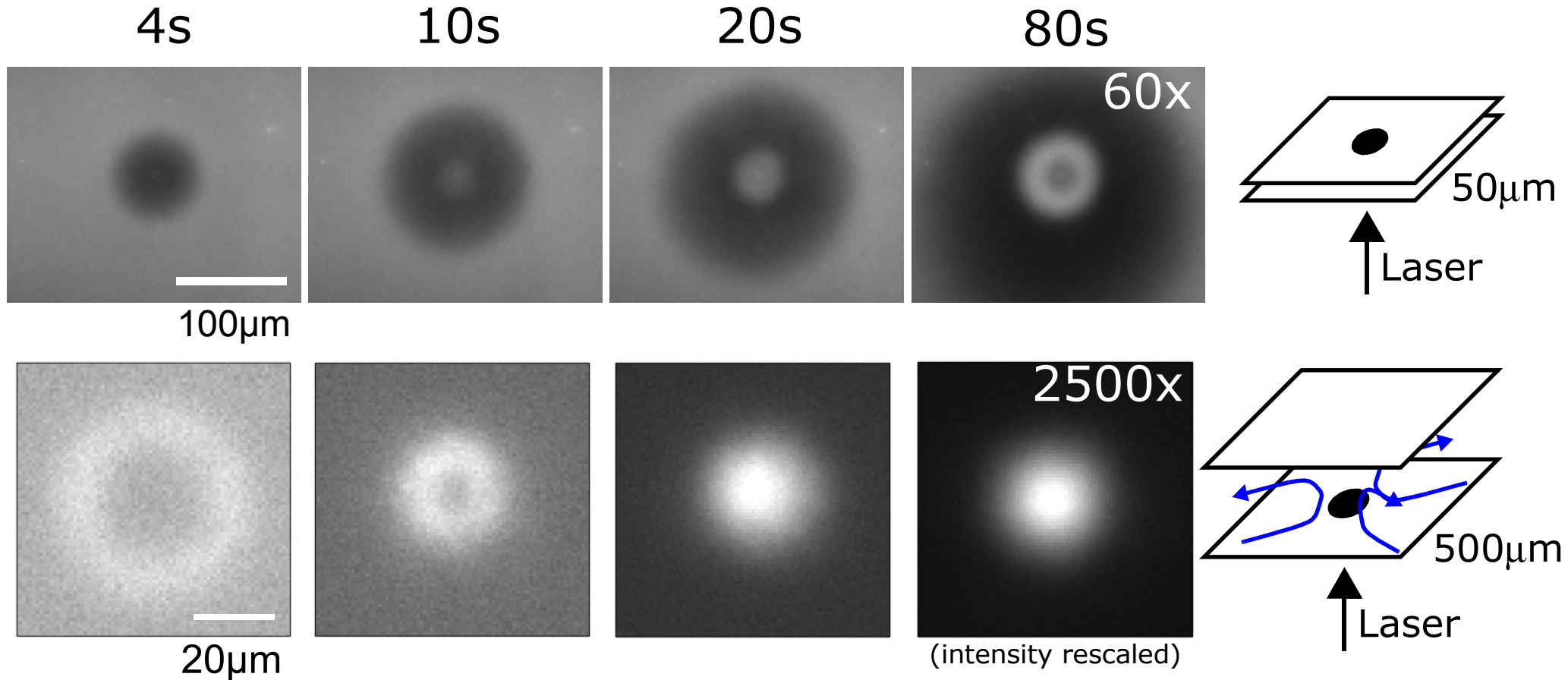


$$\left. \frac{D_T}{D_0} \right|_{ionic} = \frac{3\pi l_B Z_{eff}^2}{4Ta^3} \lambda_{DH}^2 \sim \lambda_{DH}^2$$

Thermophoresis in Microfluidics: Flow turns depletion into accumulation



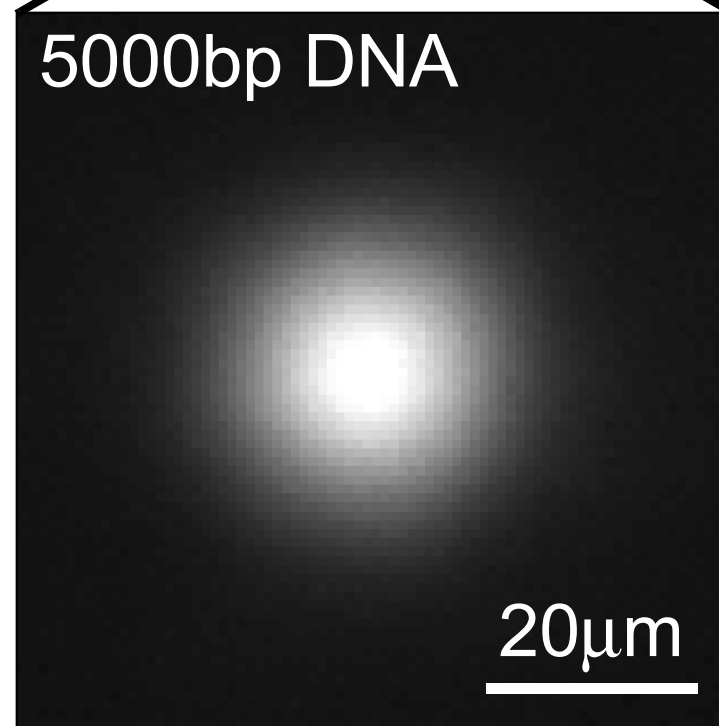
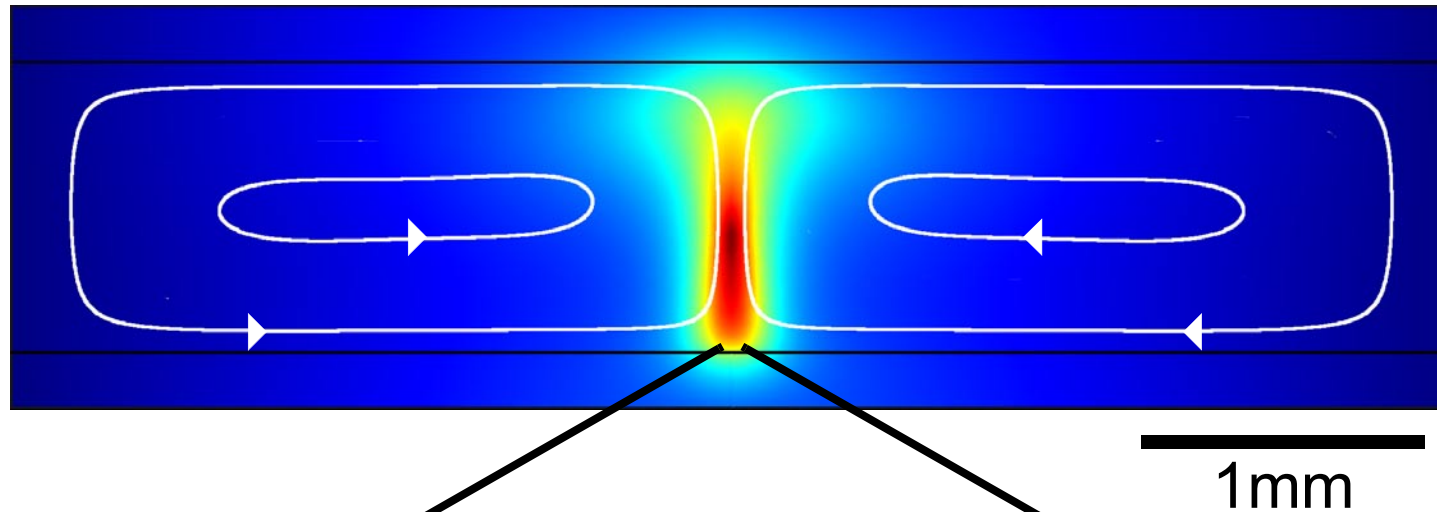
Thermophoretic Trapping by Convection



Heat

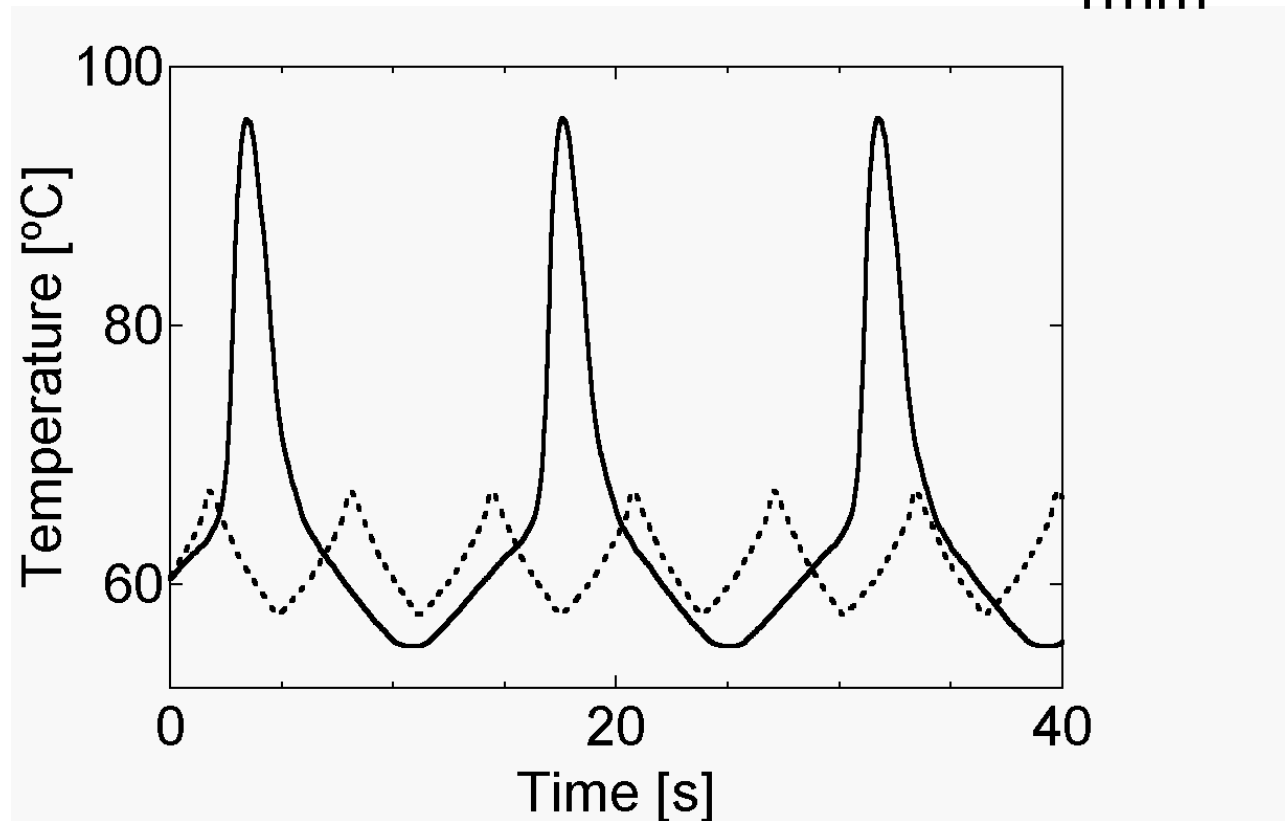
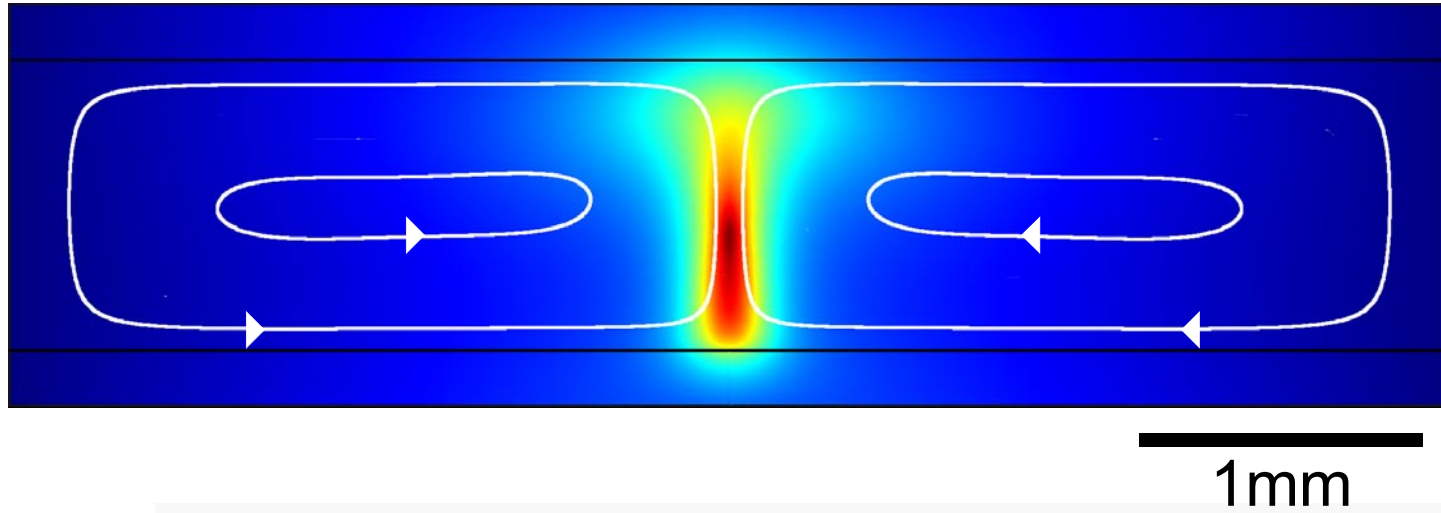
- (1) attracts convection
- (2) repels DNA

Thermophoretic Trapping by Convection

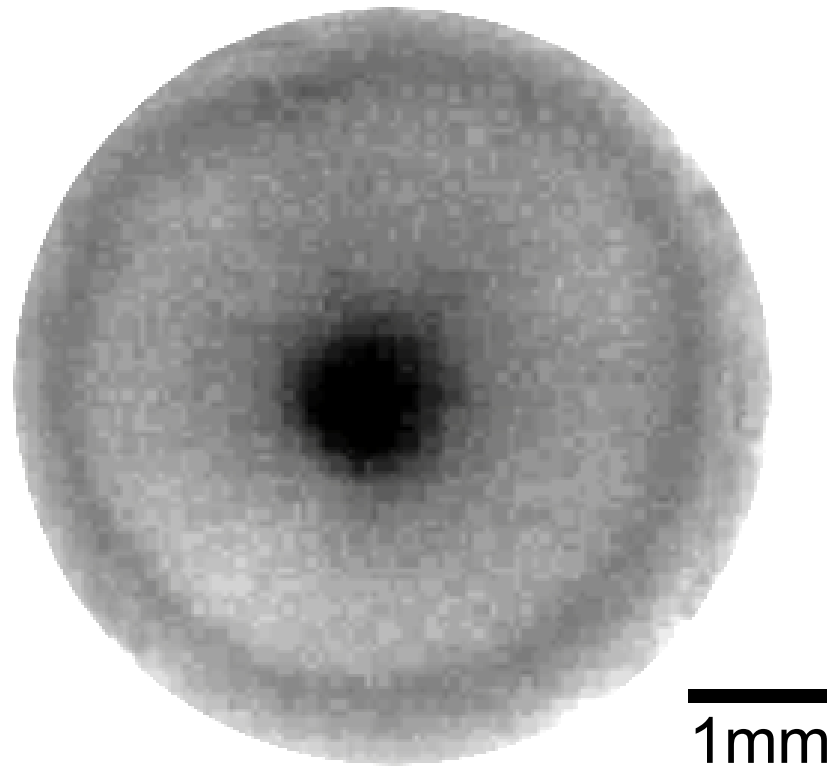
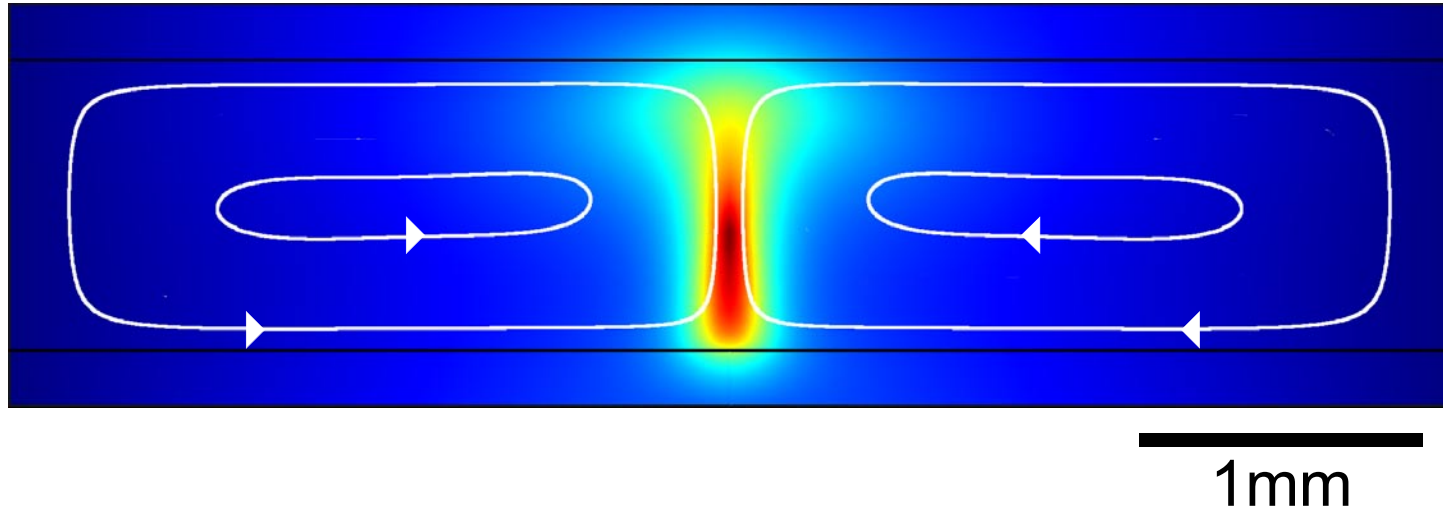


PRL 89:188103 (2002)
Physics Today Feb. 2003

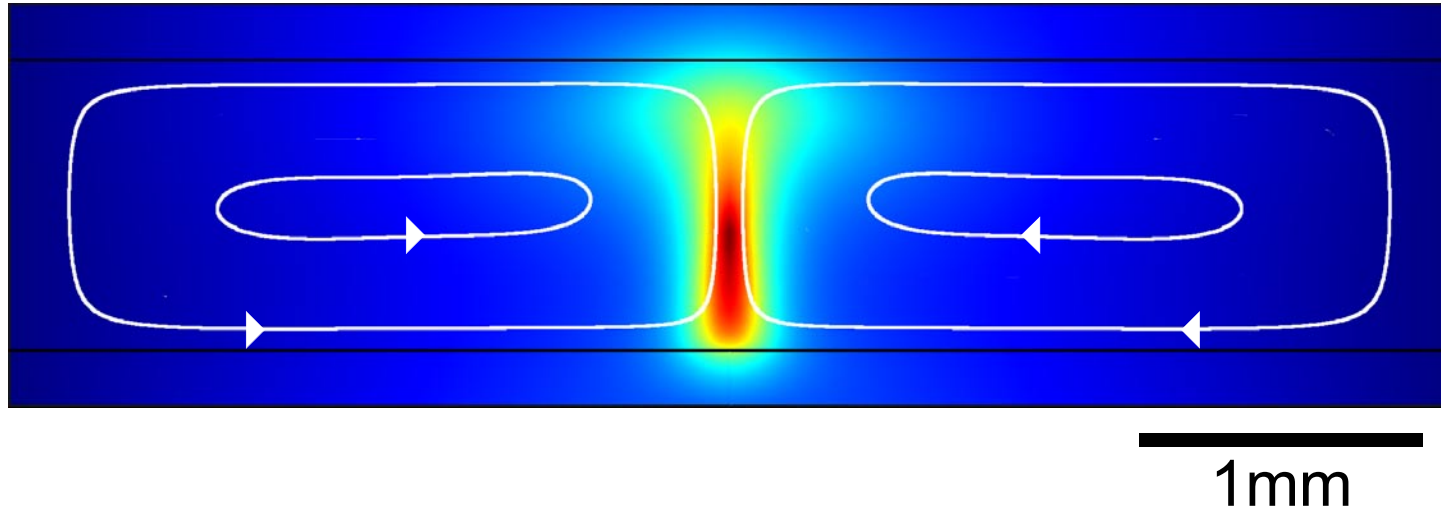
PCR by Convection



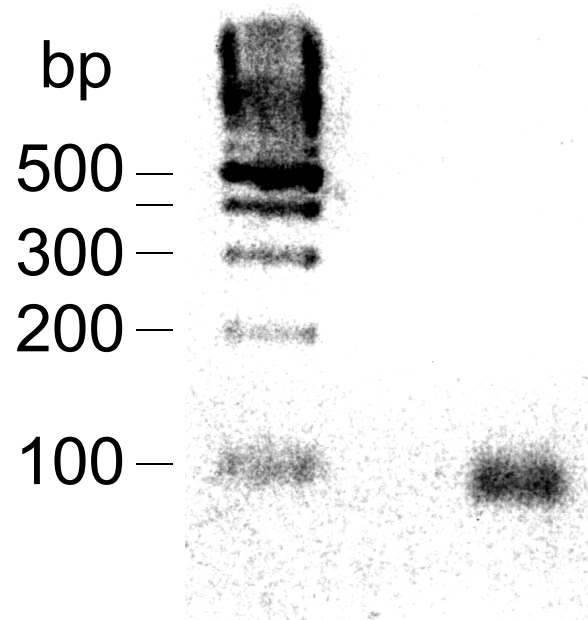
PCR by Convection



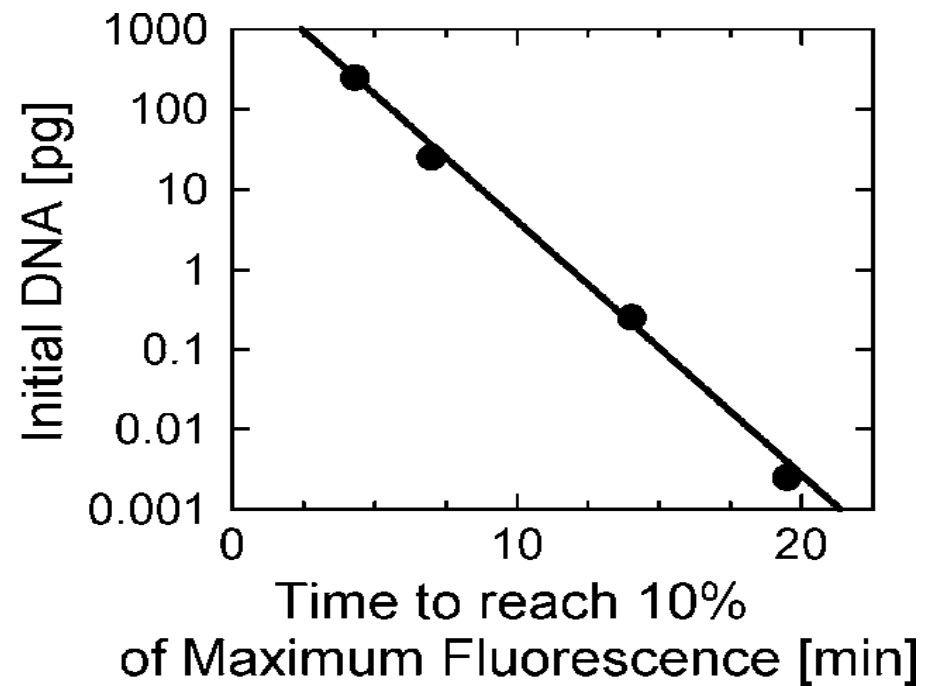
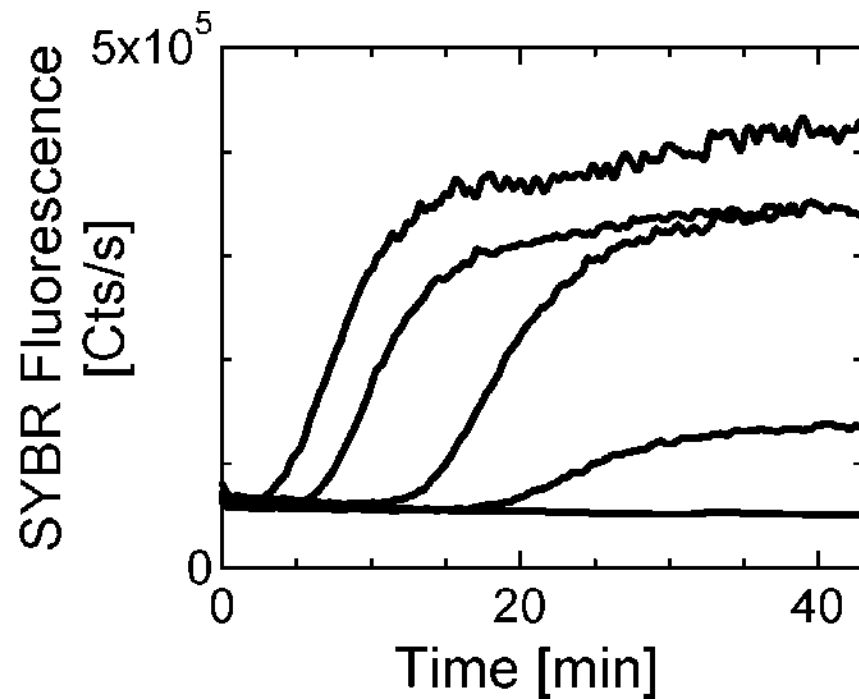
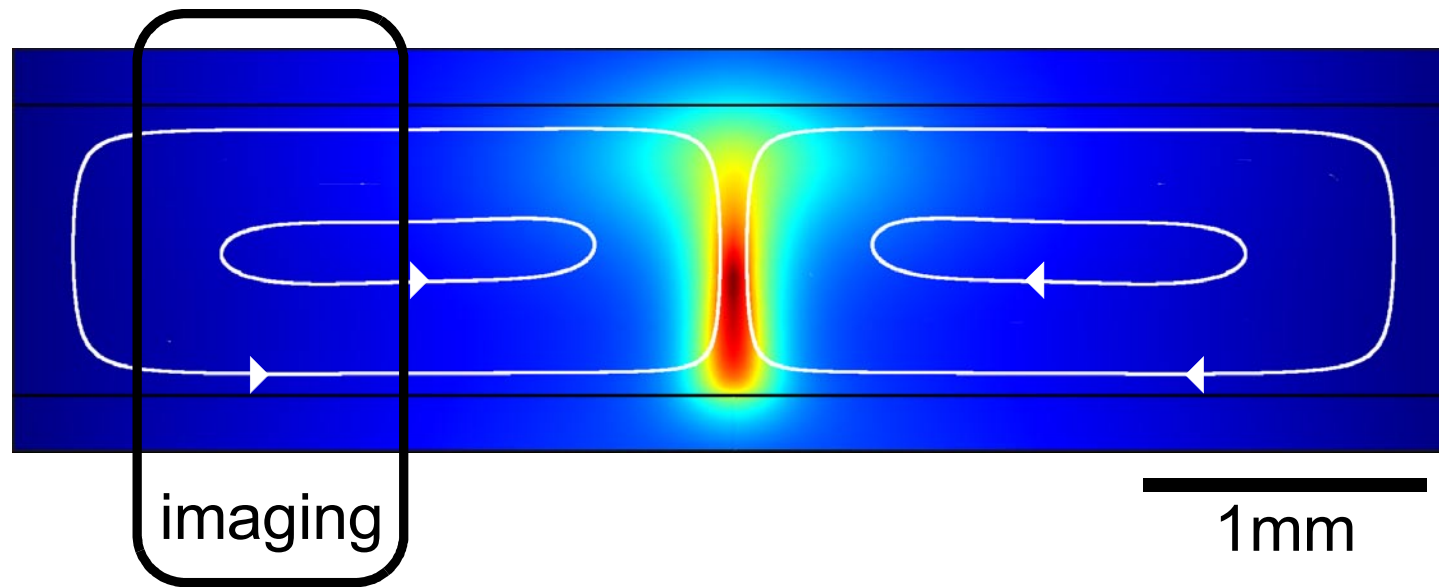
PCR by Convection



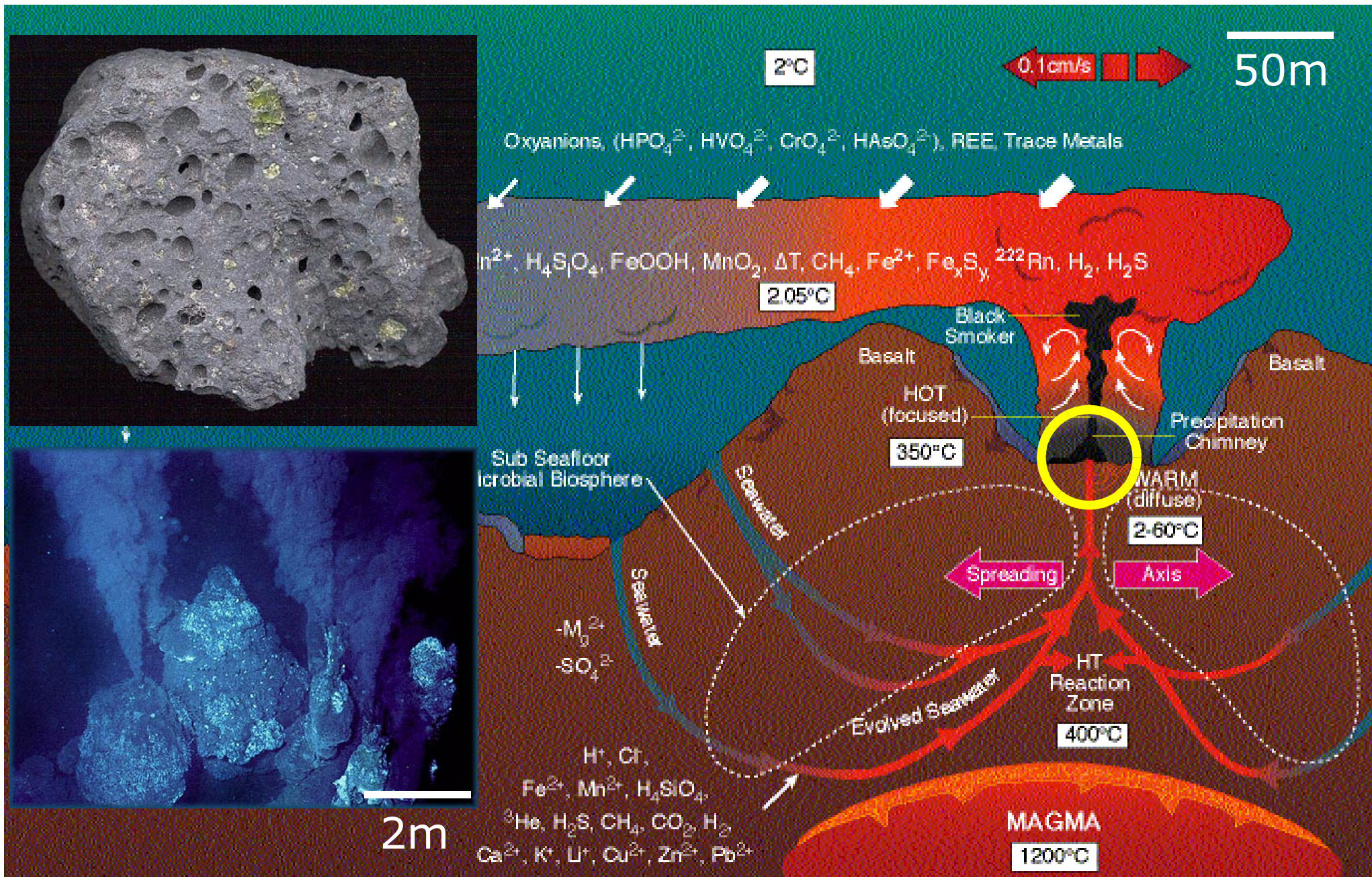
Amplification 100.000x
in 25 Minutes



Quantitative PCR by Convection

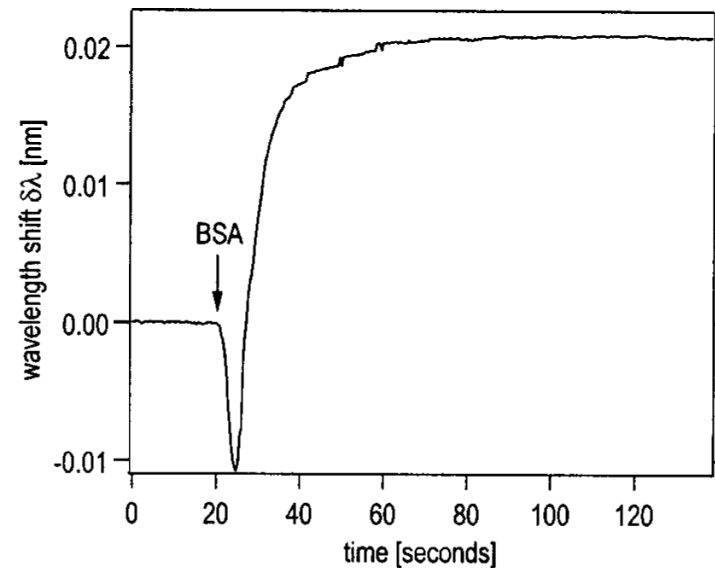
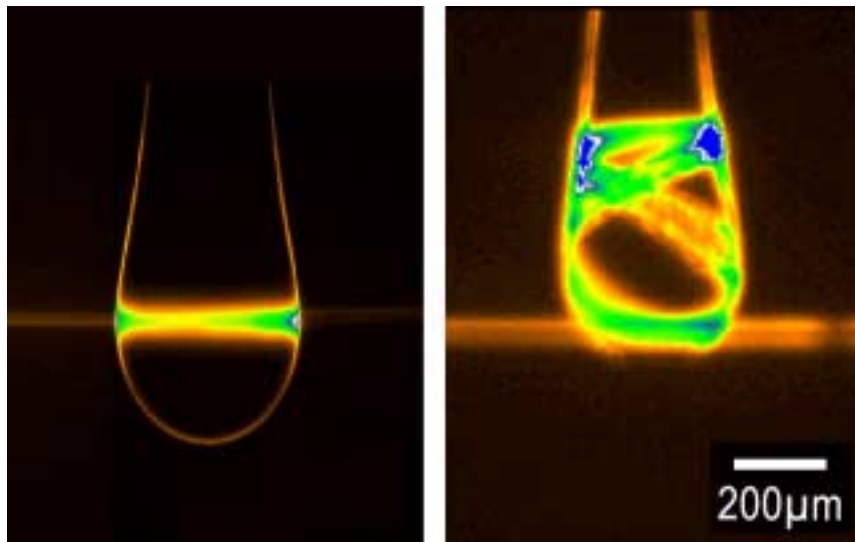
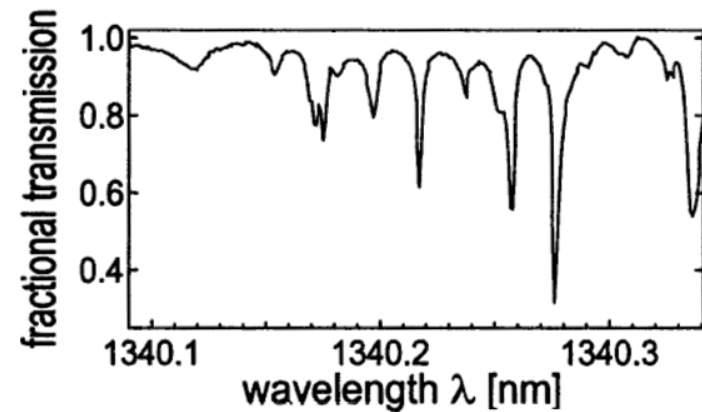
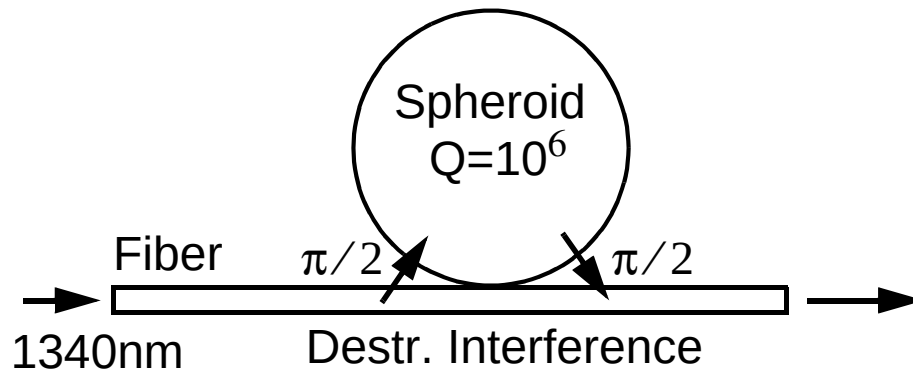


Origin of Life in pores near Hydrothermal Vents?



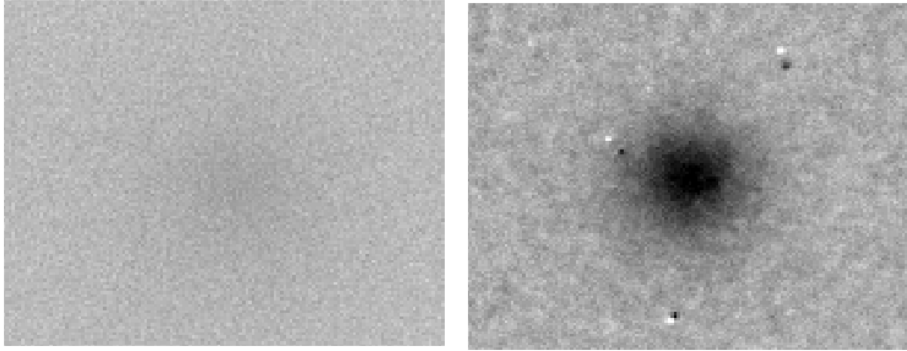
Protein detection by optical Resonance

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

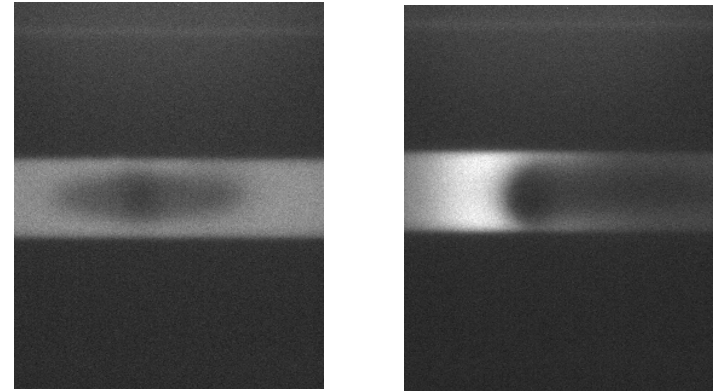


DNA Thermophoresis: Conclusion

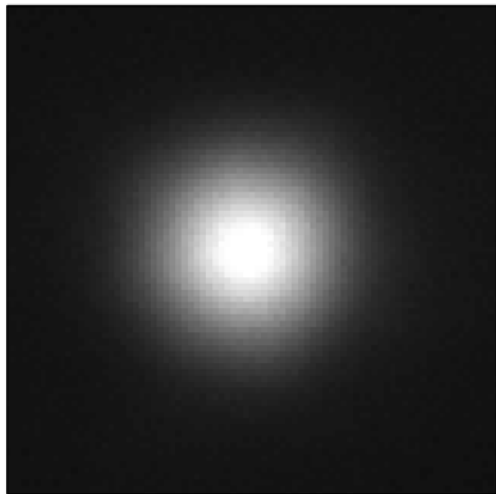
Depletion is highly length dependent



IR heating compatible with microfluidics



With Convection leads to strong accumulation



Laminar Convection can drive PCR fast

