LECTURE 25: Molecular Tagging Techniques

Part - 02

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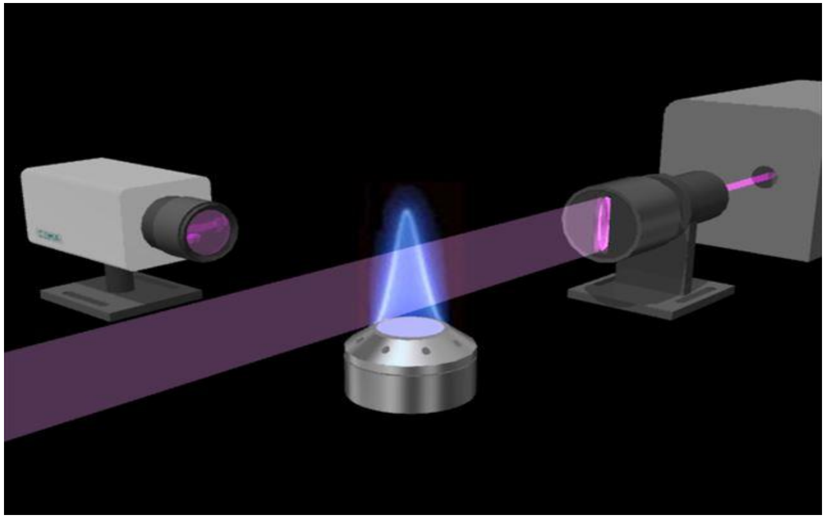
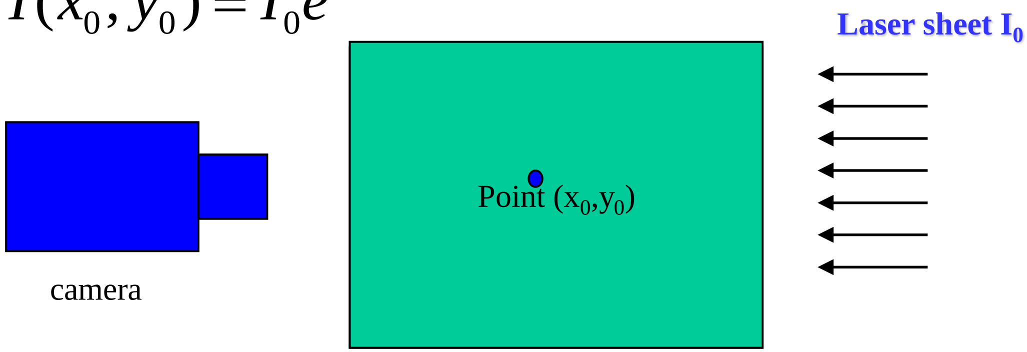
❑ PLIF - intensity at point (x_0, y_0)

$$H_f(x_0, y_0) = I(x_0, y_0) A \Phi(T) \varepsilon(T) C(x_0, y_0)$$

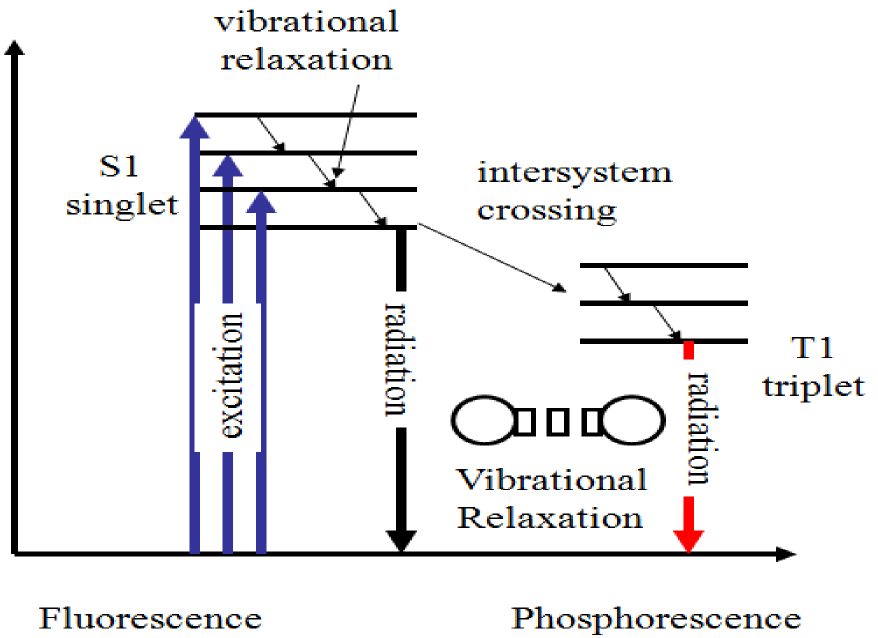
$H_f(x_0, y_0)$:	*measured fluorescence intensity*
A:	*the fraction of the fluorescence light collected by camera.*
Φ :	*quantum efficiency,*
L:	*the length of the sampling volume along the path of excitation beam*
ε:	*molar absorption coefficient*
$C(x_0, y_0)$:	*the molar concentration of the fluorescent dye.*
$I(x_0, y_0)$:	*the intensity of excitation light beam at the point (x_0, y_0)*

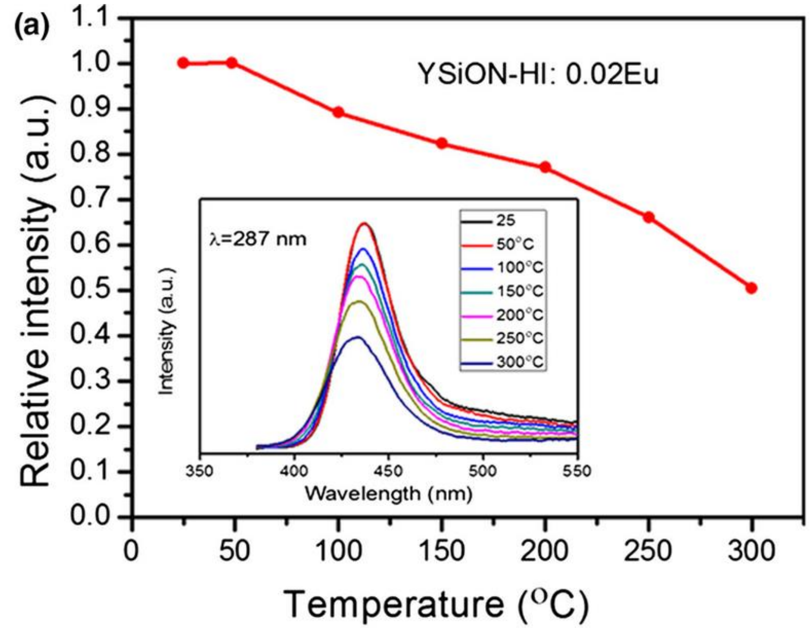


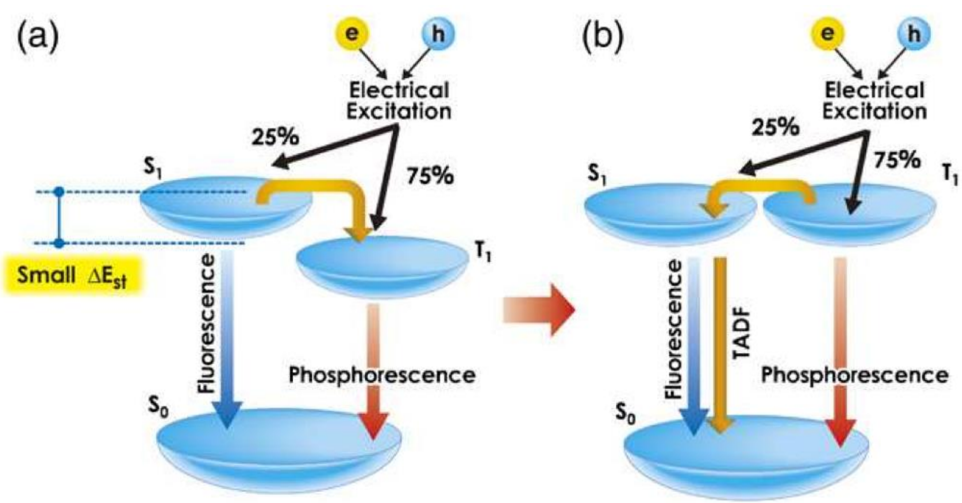
$$I(x_0, y_0) = I_0 e^{-\varepsilon l c}$$



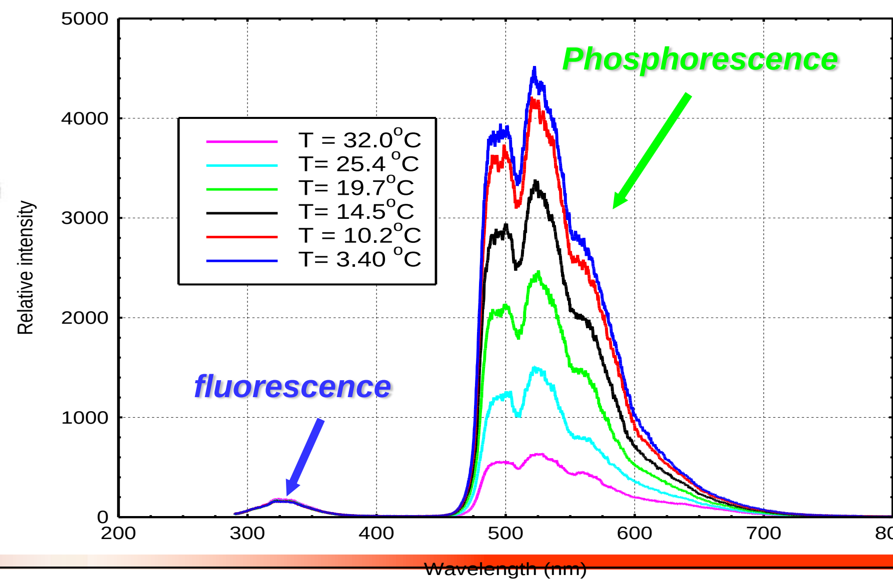
❑ Thermal Quenching of Photoluminescence



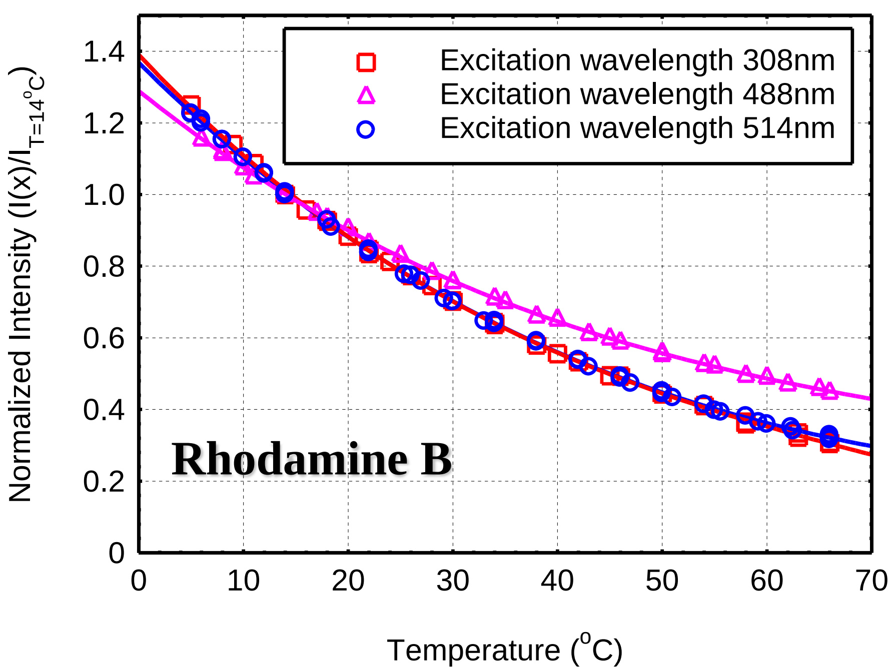


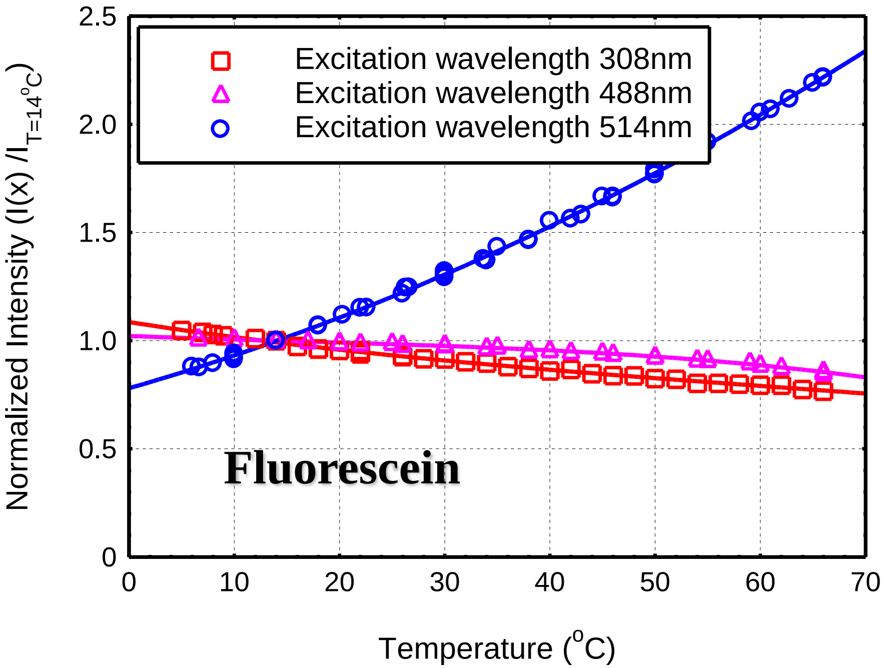


Spectraphotometer Output vs Wavelength



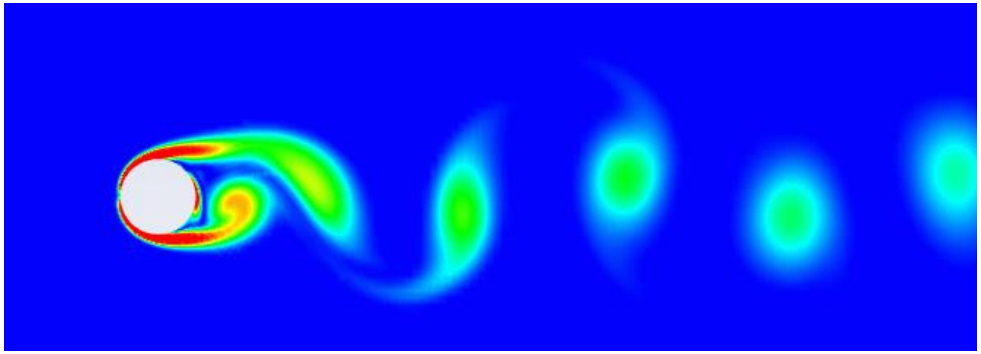
❑ LIF with Temperature Dependent Fluorescent Dyes: Rhodamine B and Fluorescein

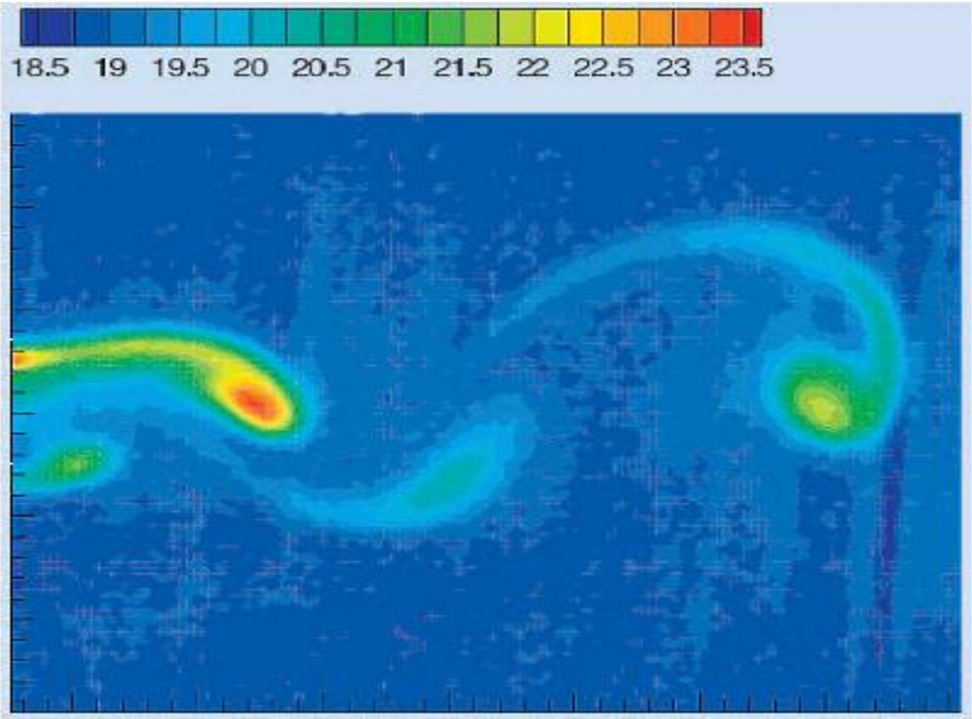




	308nm UV laser	*488nm Argon-ion laser*	*514nm Argon-ion laser*
Rhodamine B	*-1.55% K^{-1} (5^0C ~ 65^0C)*	*-1.17% K^{-1} (6^0C ~ 66^0C)* **Sakakibara and Adrian* *-2.3 % K^{-1} (15^0C ~ 40^0C)*	*-1.48% per K^{-1} (6^0C ~ 66^0C)* **Coppeta and Roger* *-1.54 % K^{-1} (20^0C ~ 60^0C)*
Fluorescein	*-0.45% K^{-1} (5^0C ~ 65^0C)*	*-0.25% K^{-1} (6^0C ~ 66^0C)* **Coppeta and Roger* *-0.16 % K^{-1} (20^0C ~ 60^0C)*	*+2.25% K^{-1} (6^0C ~ 66^0C)* **Coppeta and Roger* *+2.43 % K^{-1} (20^0C ~ 60^0C)*

Quantification of Heat Transfer around a Heated Cylinder





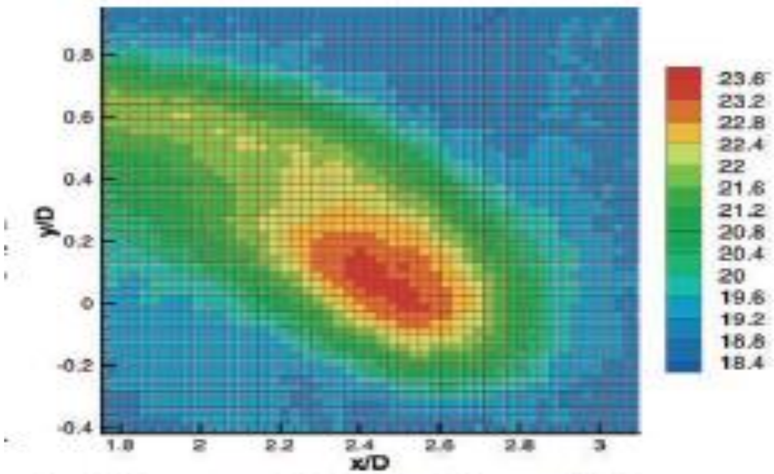


Fig. 10. Temperature distribution in the warm blob

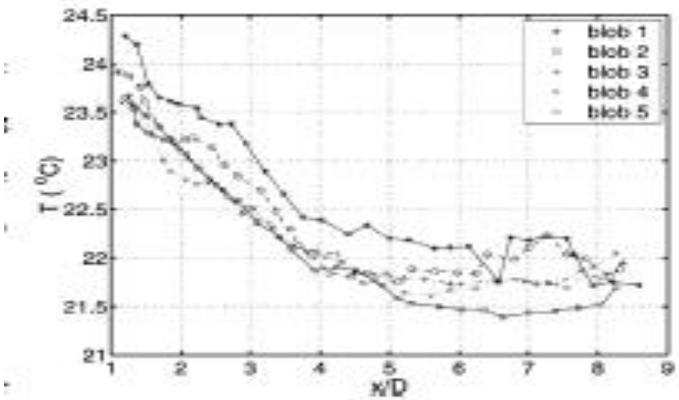


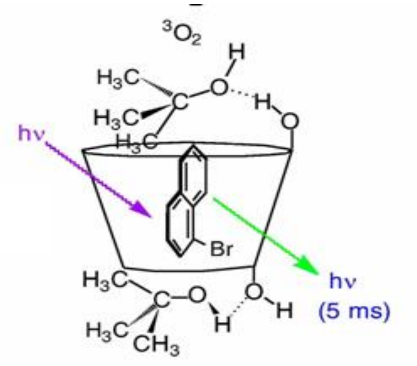
Fig. 11. The maximum temperature in the warm blob as function of the downstream position

- *Seuntiëns, H. J.; Kieft, R. N.; Rindt, C. C. M.; van Steenhoven, A. A., "2D temperature measurements in the wake of a heated cylinder using LIF", Experiments in Fluids, Volume 31, Issue 5, pp. 588-595 (2001).*

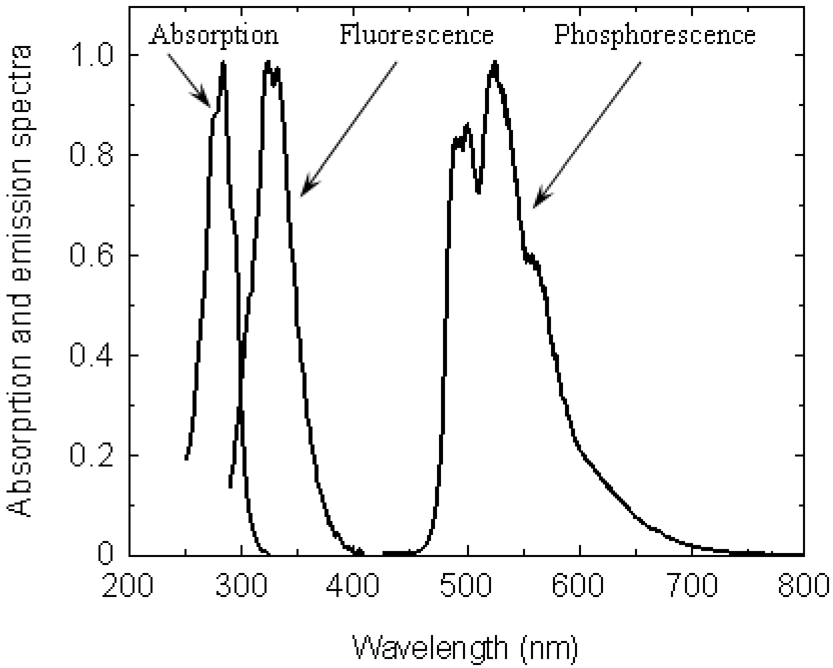
❑ Long Lifetime Phosphorescent Molecular Tracers

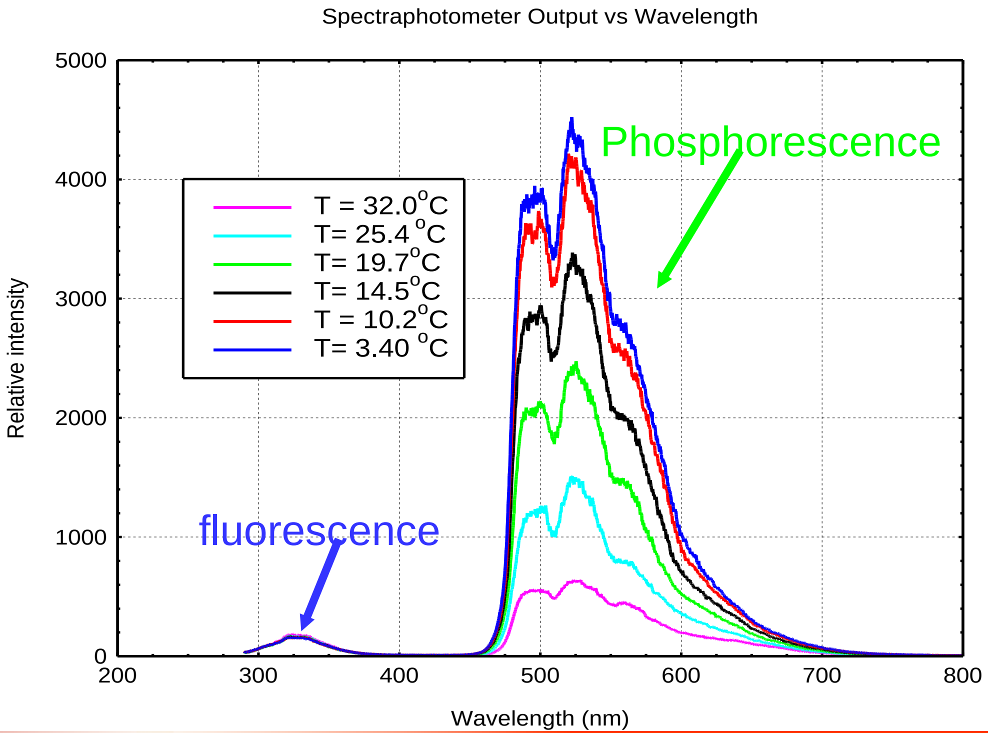
***Phosphorescent triplex* (1-BrNp • Gβ-CD • ROH)**

1. ***Bromonaphthalene (1-BrNp)***
2. ***Cyclodextrin (Gβ-CD)***
3. ***Alcohols (ROH)***



Molecular structure of the phosphorescent triplex





❑ Technical Basis for Temperature Measurement

- *According to **quantum theory**, the decay of phosphorescence **emission intensity** (I_{em}) follows an **exponential law:***

$$I_{em} = I_o e^{-t/\tau} = I_i C \varepsilon \Phi_p e^{-t/\tau}$$

I_o : Initial phosphorescence intensity:

$$I_o = I_i C \varepsilon \Phi_p$$

I_i : the local incident laser intensity

C : concentration of phosphorescence dye

ε : the absorption coefficient

*Φ_p: phosphorescence quantum yield, **temperature-dependant***

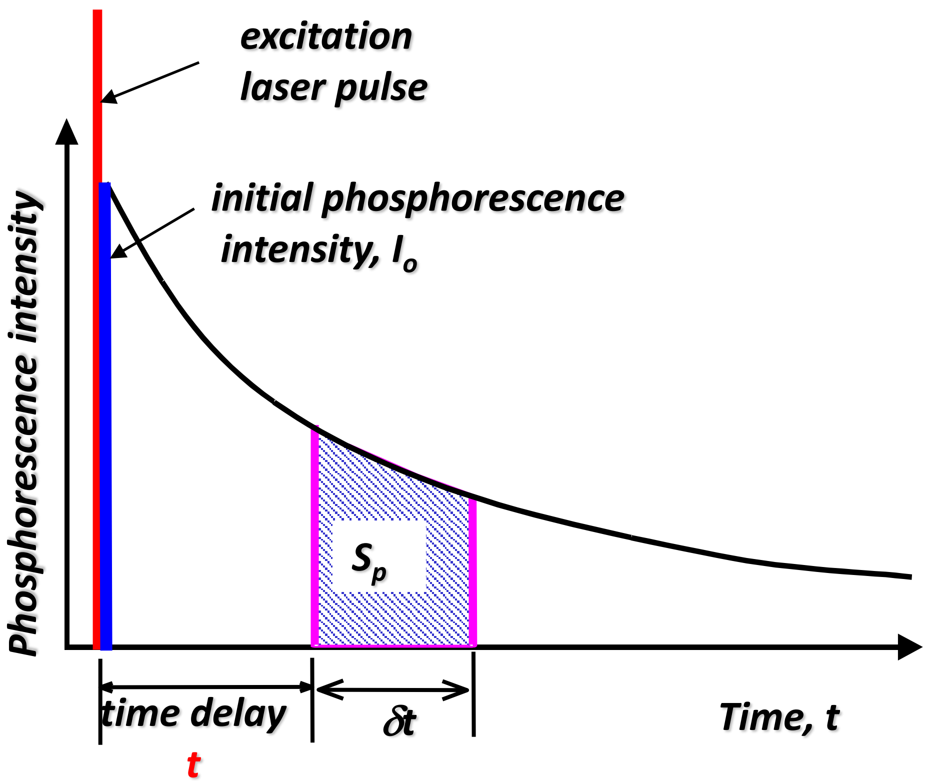
*τ : **phosphorescence lifetime,** which refers to the time when the intensity drops to 37% (i.e. 1/e) of the initial intensity (I_0), **temperature-dependant.***

$$\left.\begin{aligned} \Phi &= \Phi(T) \\ \tau &= \tau(T) \end{aligned}\right\} \Rightarrow \left\{\begin{aligned} I_o &= I_o(T) \\ I_{em} &= I_{em}(T) \end{aligned}\right.$$

❑ Technical Basis for Temperature Measurement

- *Capturing the phosphorescence emission at time t using a gated CCD detector:*

$$S_p = \int_t^{t+\delta t} I_{em} dt = I_o(T)\cdot\tau(T)\left(1-e^{-\frac{\delta t}{\tau(T)}}\right)e^{-\frac{t}{\tau(T)}}$$



- *At a prescribed temperature $T = T_o$*

$$S_{p_o} = I_o(T_o)\cdot\tau(T_o)\left(1-e^{-\frac{\delta t}{\tau(T_o)}}\right)e^{-\frac{t}{\tau(T_o)}}$$

- *Relative intensity:*

$$R = \frac{S_p}{S_{p_o}} = \frac{I_o(T)\cdot\tau(T)\left(1-e^{-\frac{\delta t}{\tau(T)}}\right)}{I_o(T_o)\cdot\tau(T_o)\left(1-e^{-\frac{\delta t}{\tau(T_o)}}\right)} e^{-\left[\frac{1}{\tau(T)}-\frac{1}{\tau(T_o)}\right]\bullet t}$$

$$= \mathbf{R(T,t)}$$

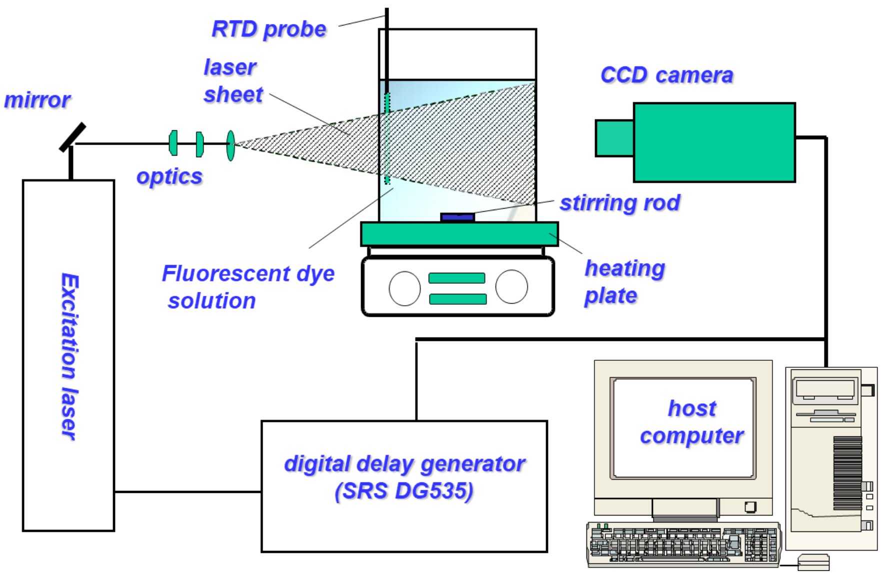
- *Relative intensity R is the function of temperature, T, and time delay after laser pulse, t !!!*

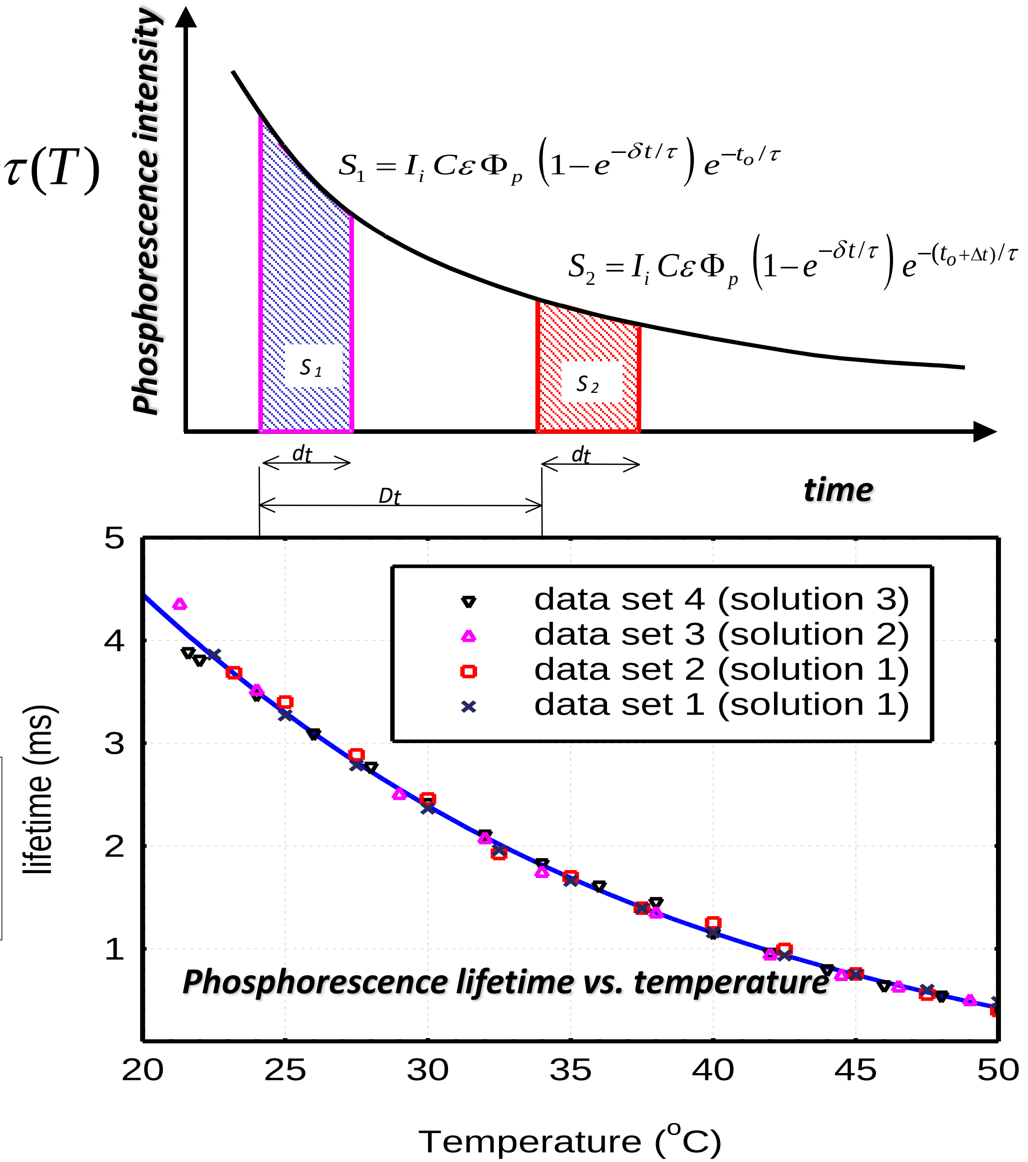
- *The sensitivity for temperature measurement is adjustable by changing the time delay, t !!!*

❑ Phosphorescence Lifetime vs. Temperature

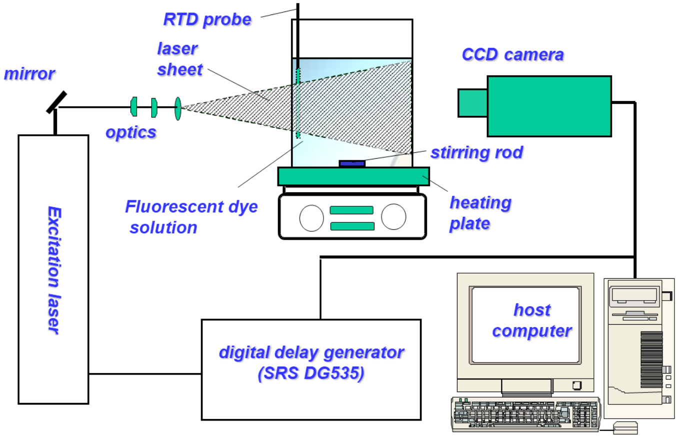
- ***Lifetime imaging technique:***

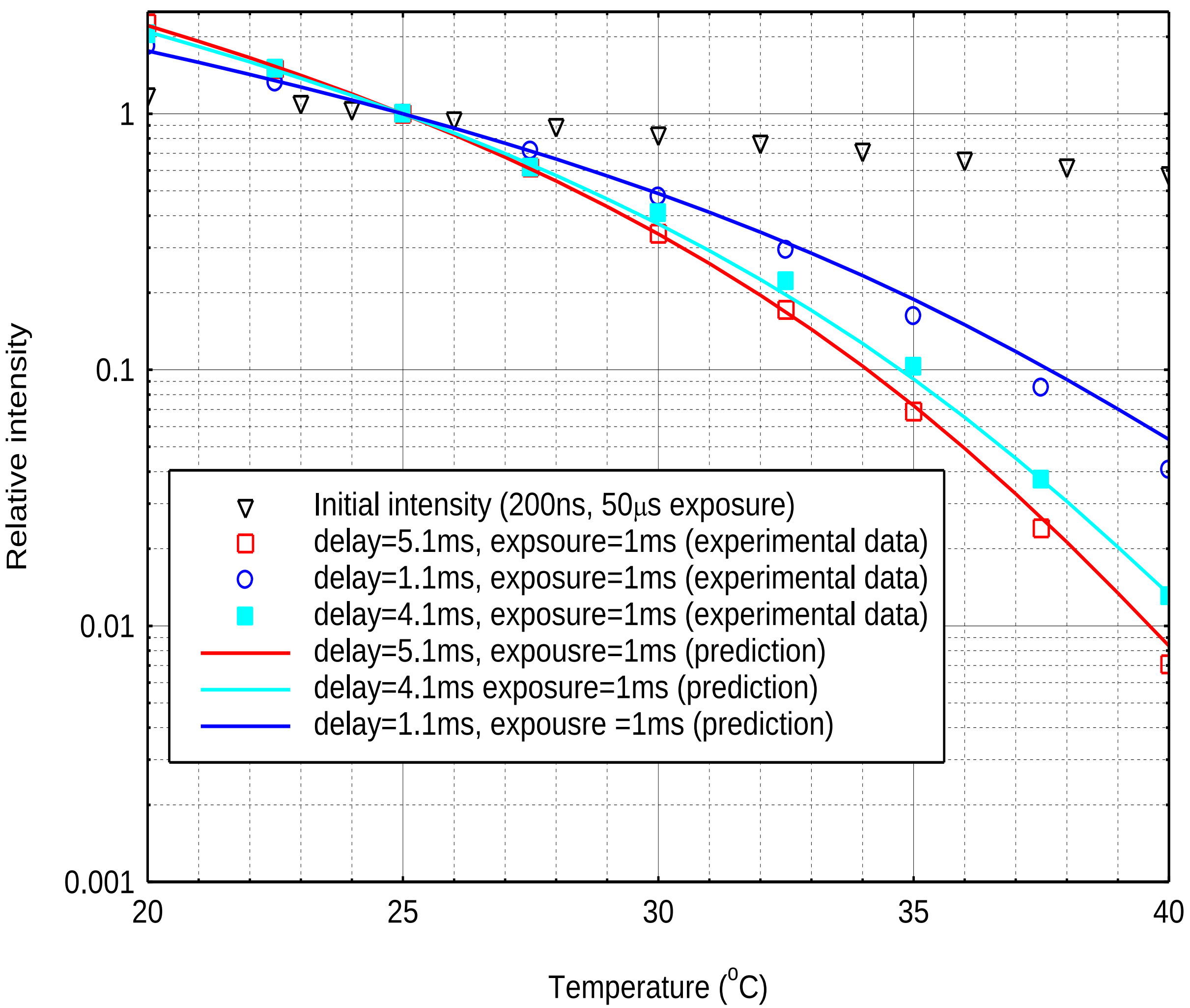
$$\frac{S_2}{S_1} = e^{-\Delta t/\tau} \quad \Rightarrow \quad \tau = \frac{\Delta t}{\ln(S_2/S_1)} \quad \Rightarrow \tau = \tau(T)$$





❑ Initial Phosphorescence Intensity vs. Temperature

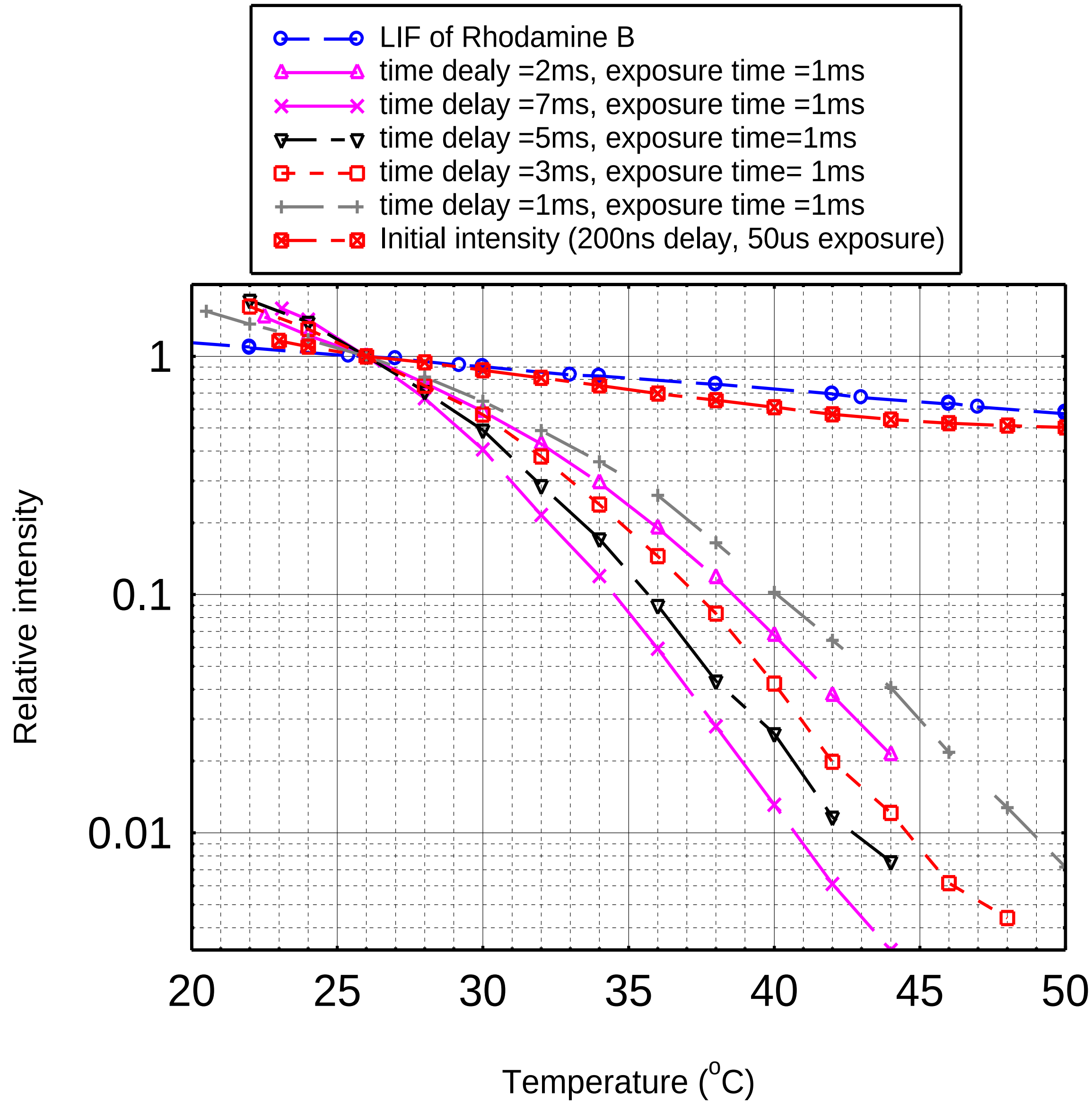




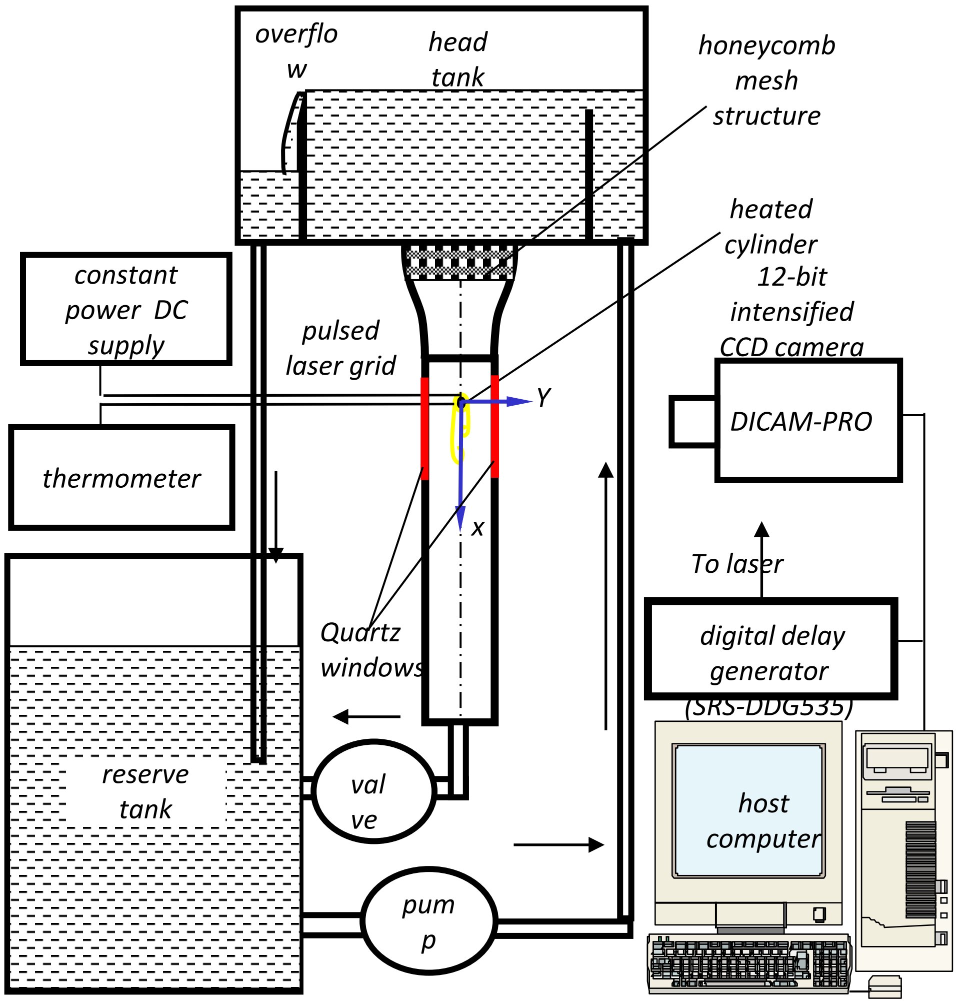
❑ Calibration Profiles with Different Time Delay

Sensitivity for temperature measurement at 25 °C

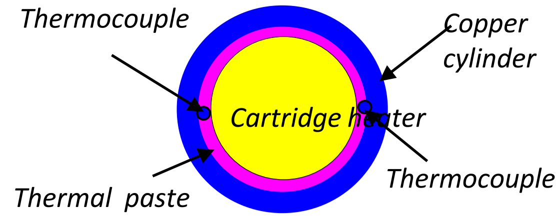
Time delay after laser pulse	*Temperature sensitivity (K^{-1})*
Delay=1 ms	***5.8 %***
Delay=2 ms	***8.9 %***
Delay=3 ms	***13.0 %***
Delay=5 ms	***15.2 %***
Delay=7 ms	***21.5 %***
LIF using Rhodamine B	***2.2 %***



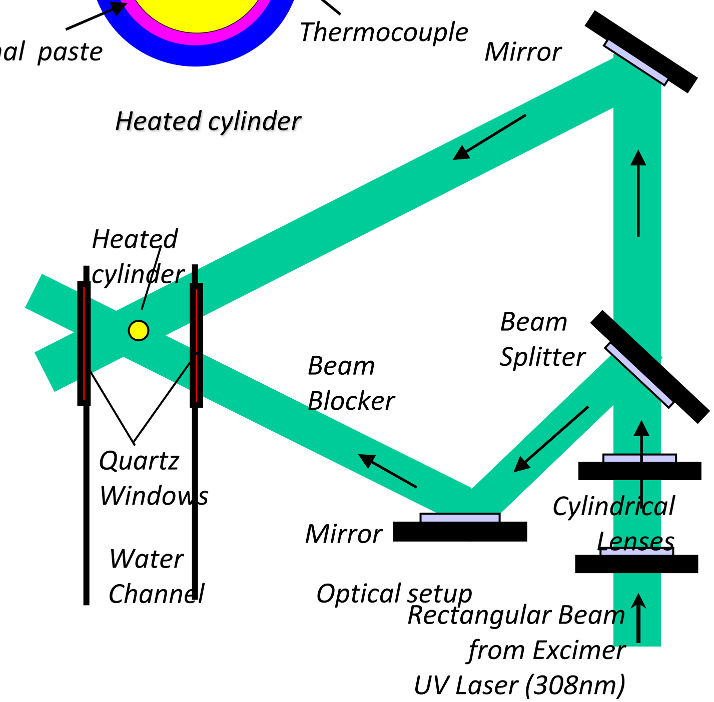
❑ Demonstration Experimental Setup



Experimental setup



Heated cylinder



Optical setup

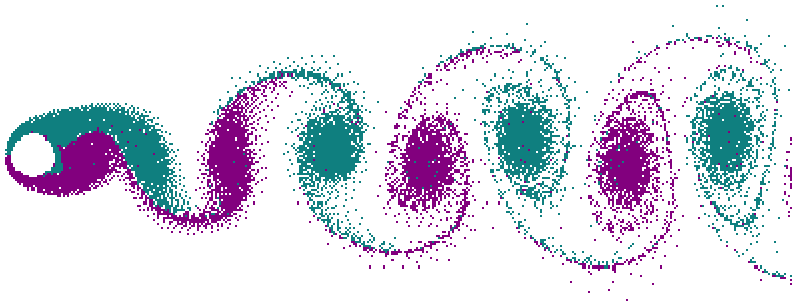
Present experimental parameters:

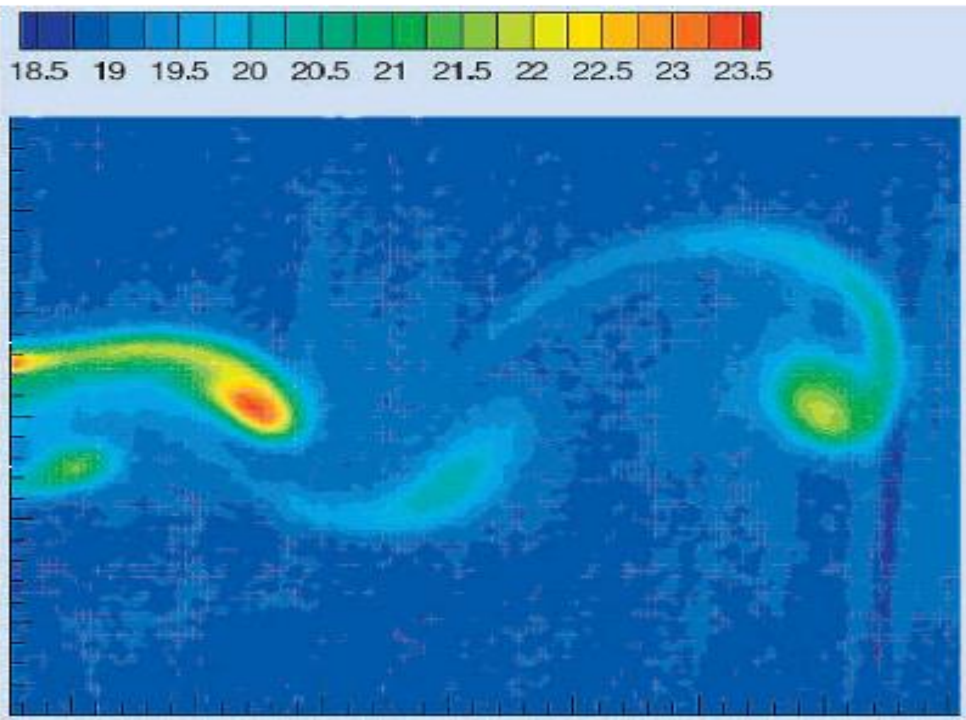
U_{in}= 0.034 m/s *D = 4.76mm*

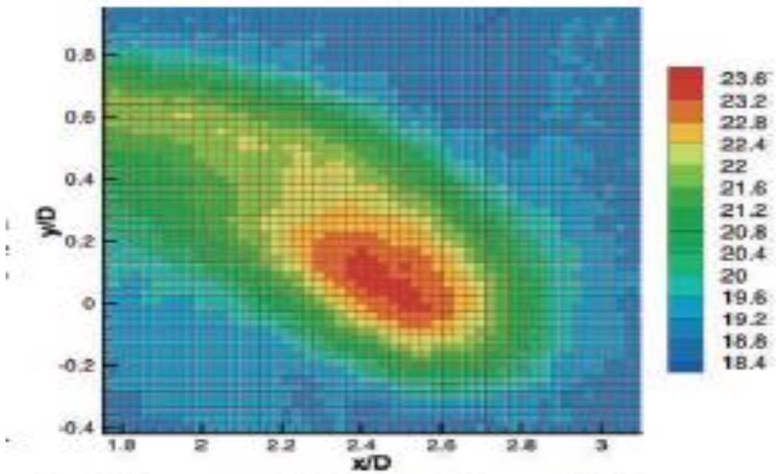
T_{fluid} = 24.0 ℃ *$T_{cylinder}$= 57.0 ℃*

Re = 170

❑ Quantification of Heat Transfer around a Heated Cylinder







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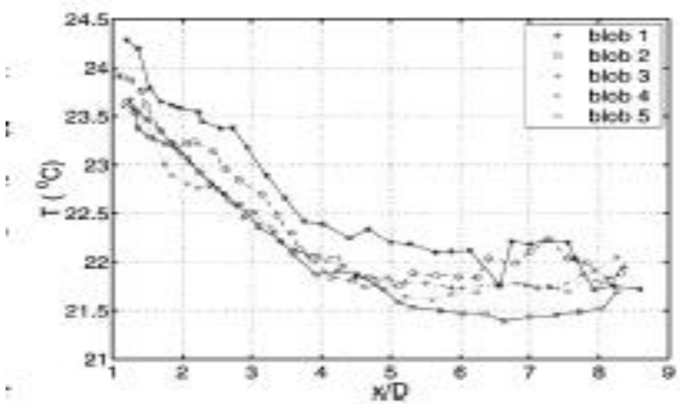

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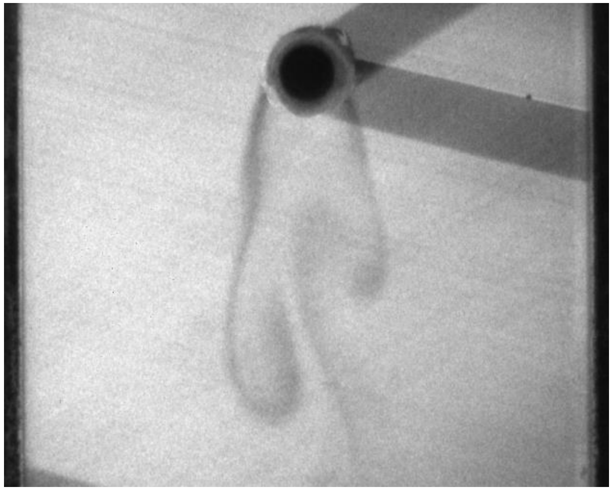
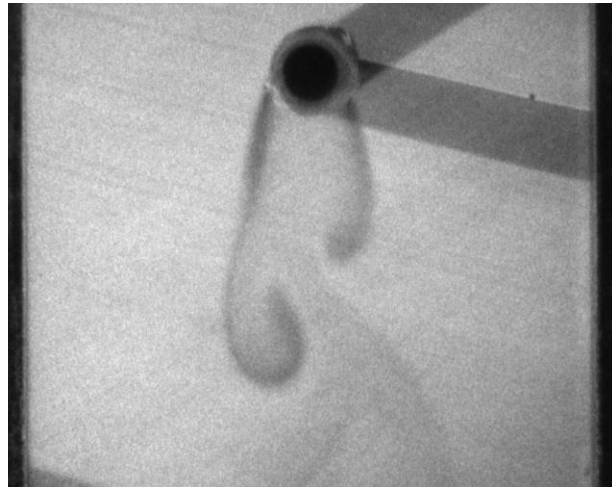
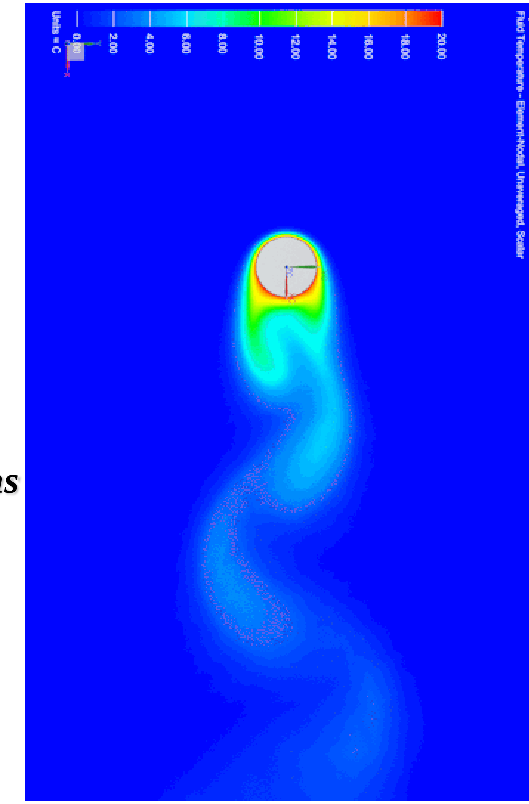
❑ Comparison of Raw Images with Different Time Delay

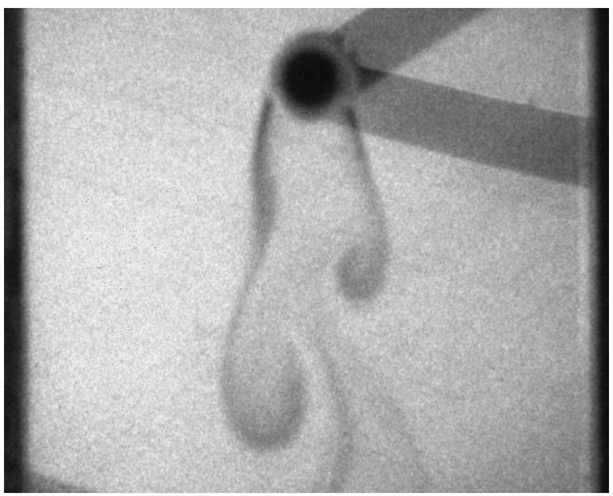


a. *1ms after laser pulse, exposure time 1ms*

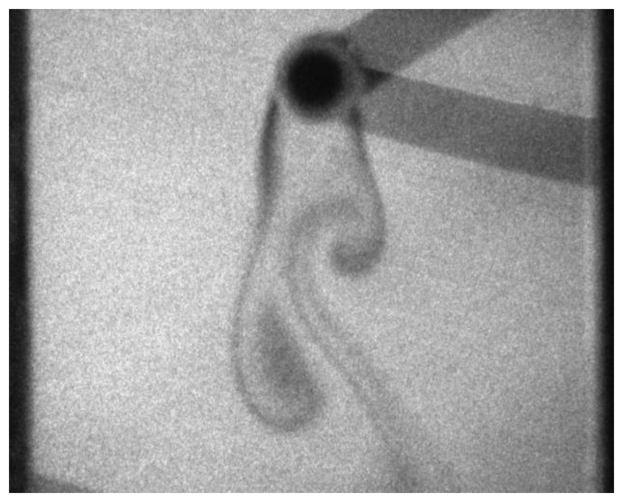


b. *3ms after laser pulse, exposure time 1ms*





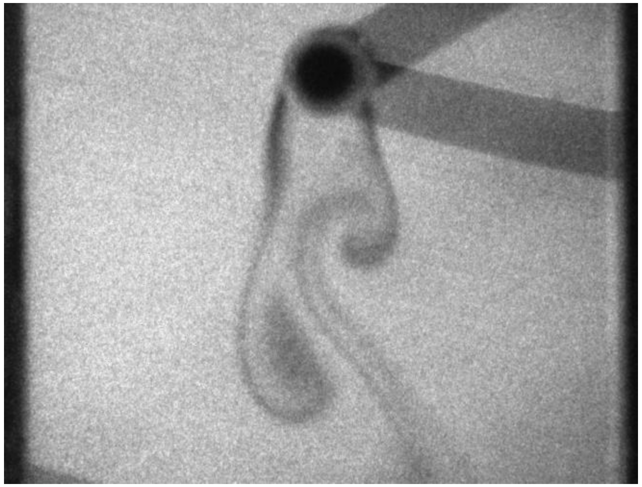
c. *5ms after laser pulse, exposure time 1ms*



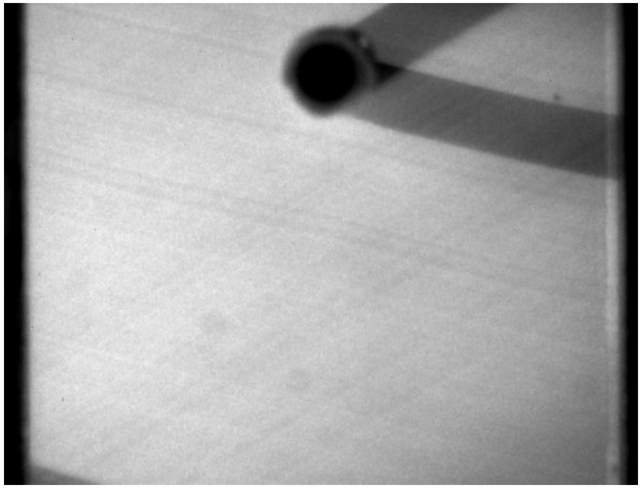
d. *7ms after laser pulse, exposure time 1ms*

❑ Molecular Tagging Thermometry (MTT) results

$$I_{em} = I_o e^{-t/\tau} = I_i C \varepsilon \Phi_p e^{-t/\tau}$$



a. 7ms after laser pulse, exposure time



b. Background