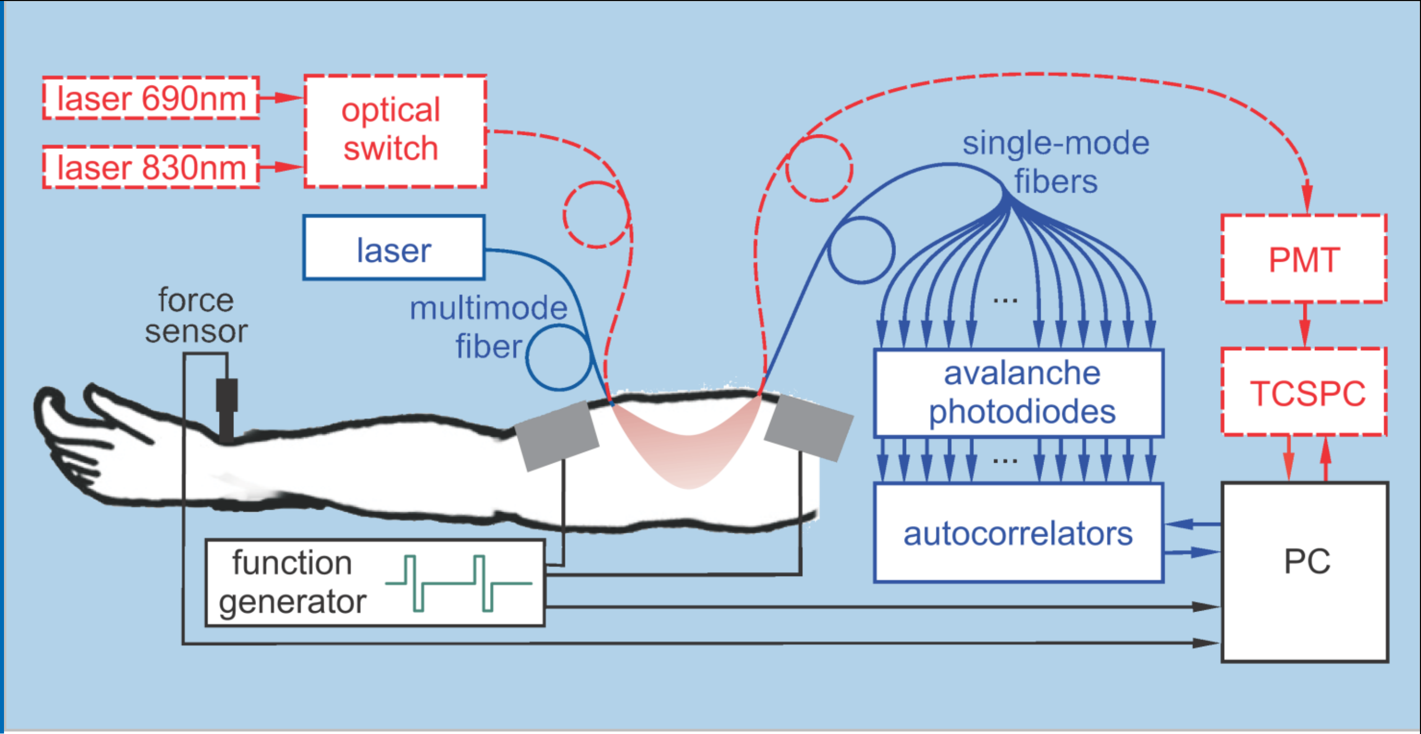
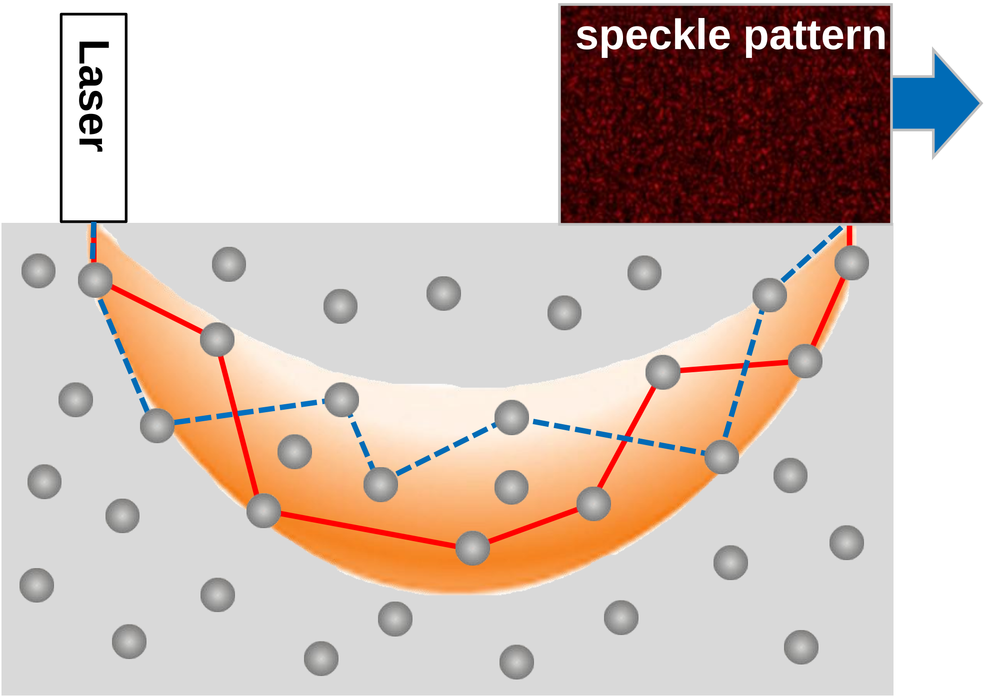


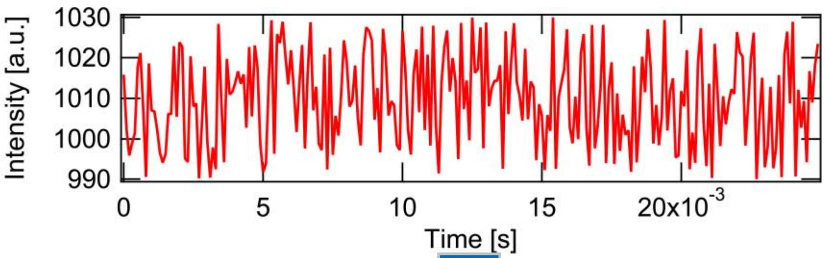
Non-invasive measurement of skeletal muscle contraction with time-resolved reflection and diffusing-wave spectroscopy

Markus Belau

Universität Konstanz, Fachbereich Physik, 78457 Konstanz, Germany

Basic principle of Diffusing Wave Spectroscopy





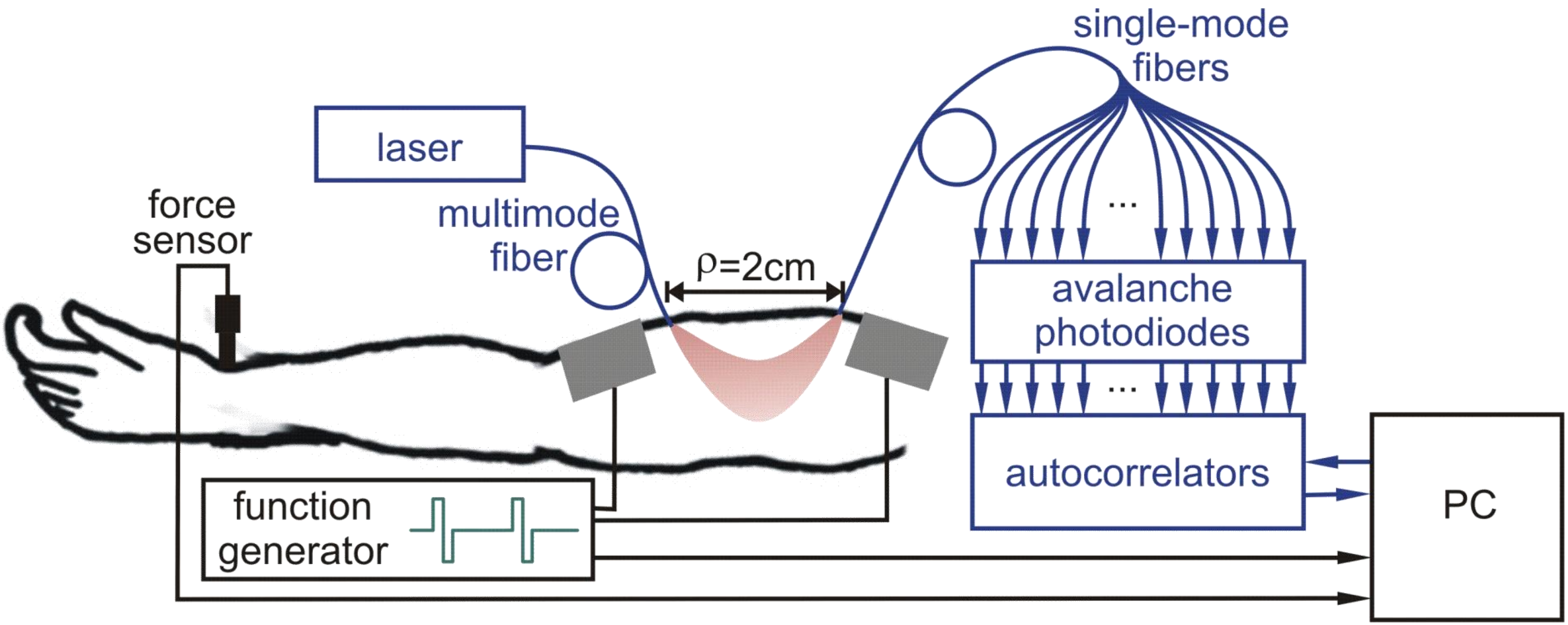
$$g_1(\tau) = \frac{\langle E^*(t) E(t+\tau) \rangle}{\langle |E(t)|^2 \rangle}$$

decay time :

$$\tau_d = \int_{t_1}^{t_2} g_1(\tau)\, d\tau$$

- **DWS measures scatterer dynamics**
  - **shape of g_1 gives information about type of motion**
  - **decay time is a model independent measure of dynamics**

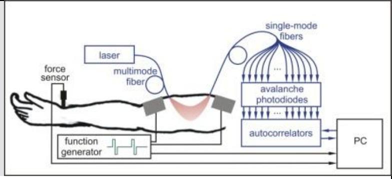
Experimental Set-up



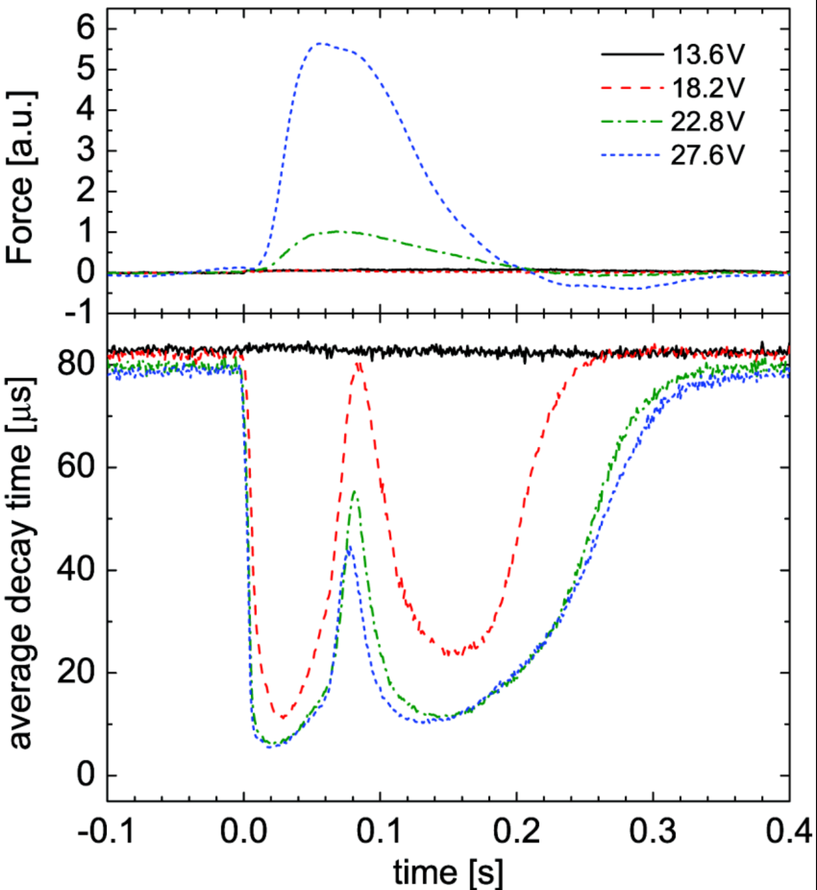
- **measurement protocol**
  - **60s pre-stimulation**
  - **100s measurement**
- **Very reproducible data ➡ measured data was stimulus averaged**

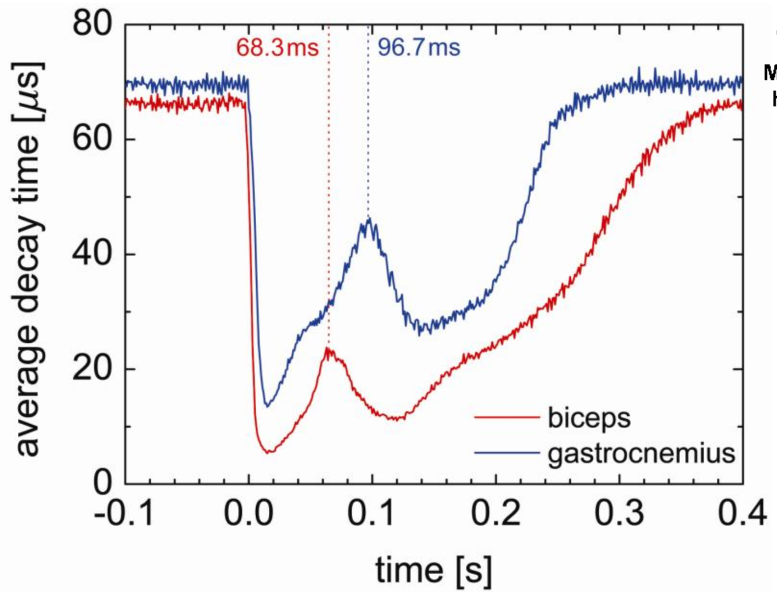
Belau et al. 2010, *J. Biomed. Opt.* **15**, 057007

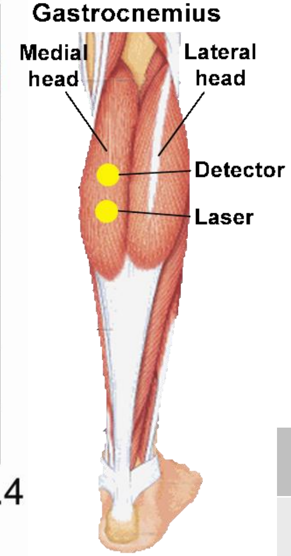
Average decay time



- **in contrast average decay time shows a biphasic response corresponding to contraction and relaxation**
- **good correlation with force**

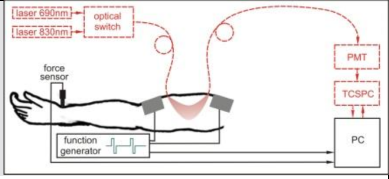






	CT (ms)		Authors
M. biceps brachii	66	8.9	**Bellemare et al. 1983,** *J Neurophysiol* **50**, 1380-1392
M. lateral gastrocnemius	118	6.5	**McComas and Thomas 1968,** *J Neurol Sci* **7**, 301-317

Scattering and Absorption coefficient

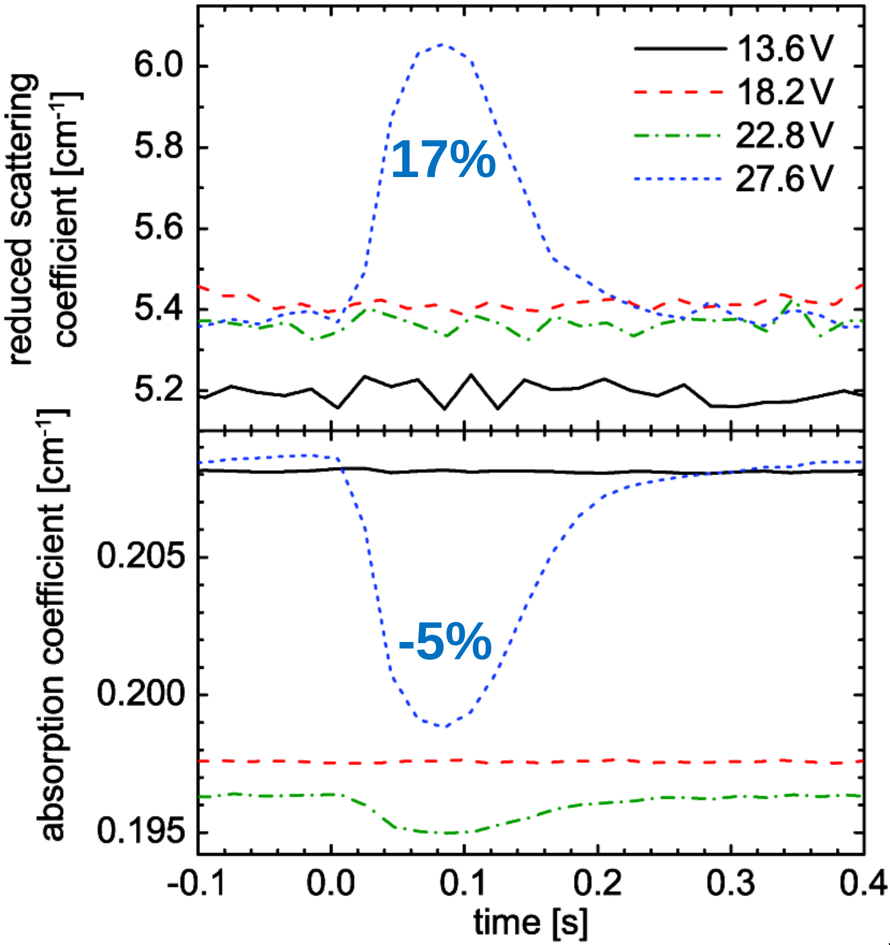


- **Optical Properties were measured with TRS**

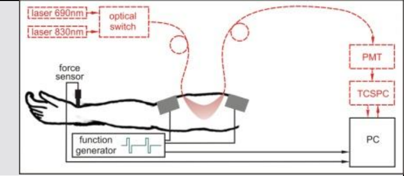
- **change in optical parameters is dependent on stimulation voltage**

- **changes in μ_s' and μ_a are at most 17%, and -5%, respectively**

Changes in decay time are mainly due to dynamics

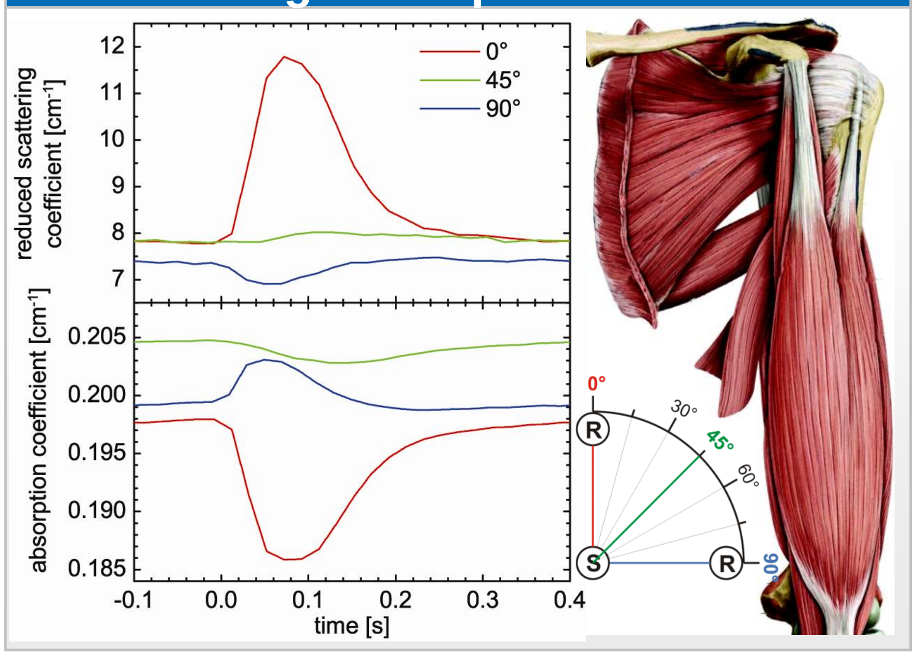


Scattering and Absorption coefficient

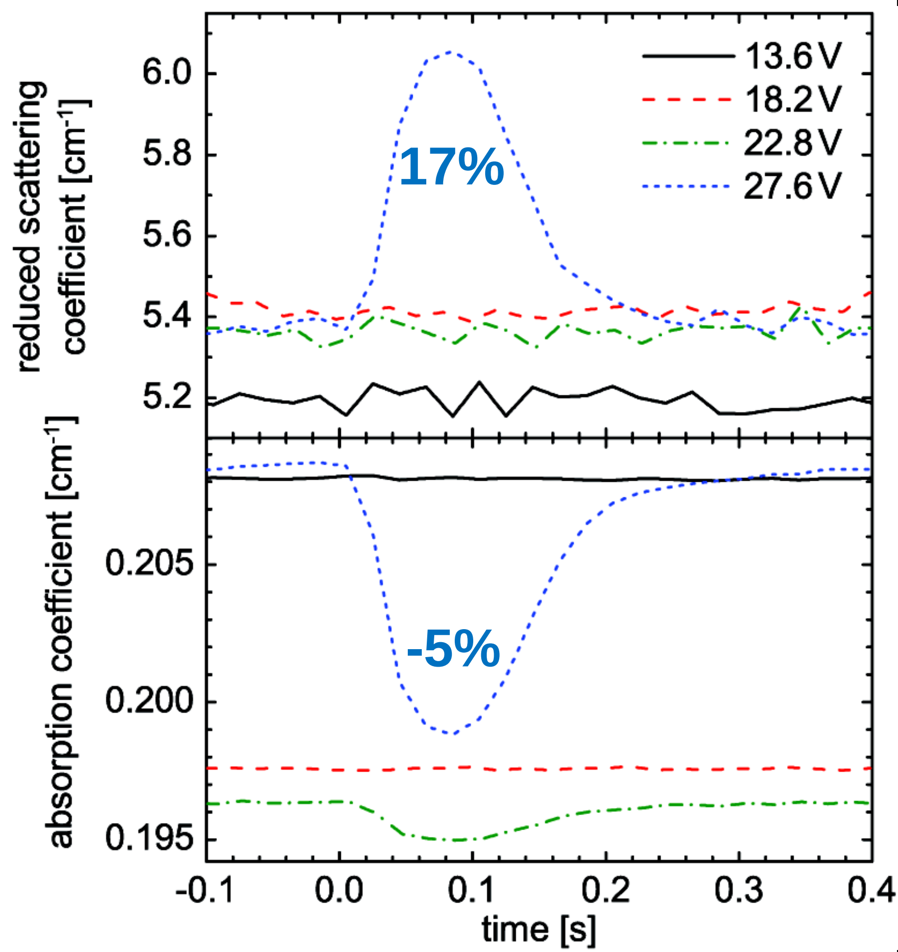


- **Optical Properties were measured with TRS**

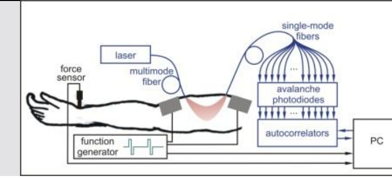
Angular dependence



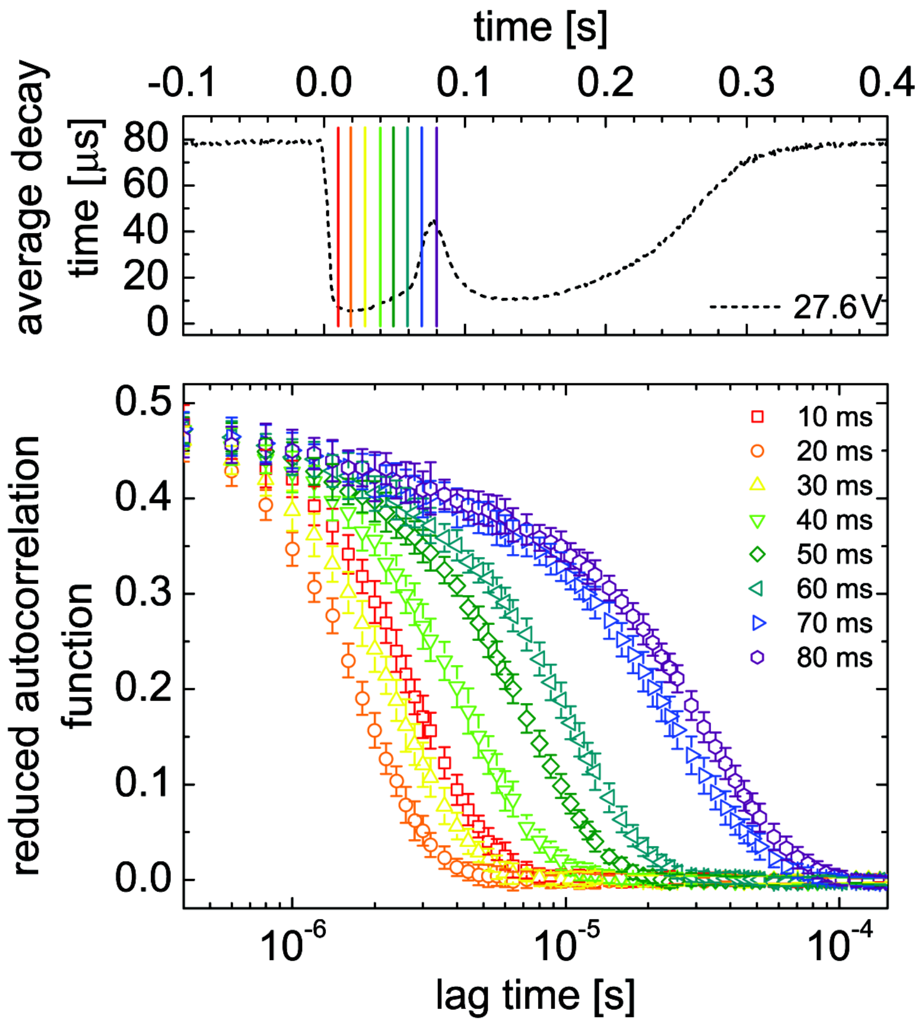
Changes in decay time are mainly due to dynamics



Tissue dynamics



- **analyze the shape of the reduced autocorrelation function**



Analytical model of g_1

- **Semi-infinite model:**

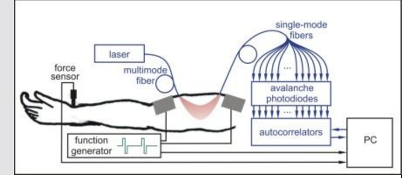
$$g_1(\tau) = \frac{\exp[-\alpha(\tau) r_1] - \exp[-\alpha(\tau) r_2]}{\exp[-\alpha(0) r_1] - \exp[-\alpha(0) r_2]}$$

$$r_1 = \sqrt{\rho^2 + z_0^2} \quad r_2 = \sqrt{\rho^2 + (z_0 + z_e)^2}$$

- **dynamic absorption coefficient**

$$\alpha(\tau) = \sqrt{3\mu_s' \mu_a + \frac{3}{2}\mu_s'^2 \langle \Delta\varphi^2(\tau) \rangle}$$

Tissue dynamics



- **analyze the shape of the reduced autocorrelation function**
- **mean square phase fluctuations**

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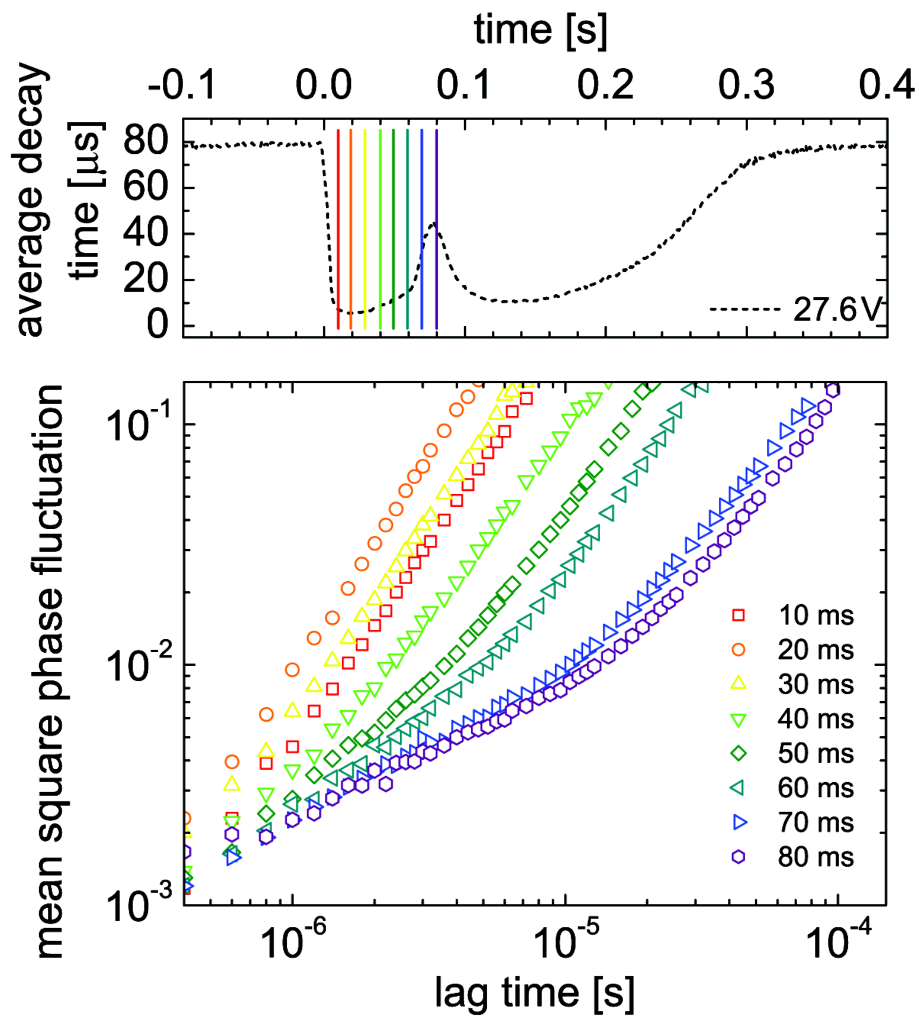

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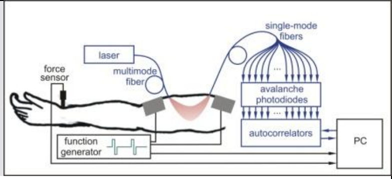


- analyze the shape of the reduced autocorrelation function
- mean square phase fluctuations

Mean square phase fluctuations

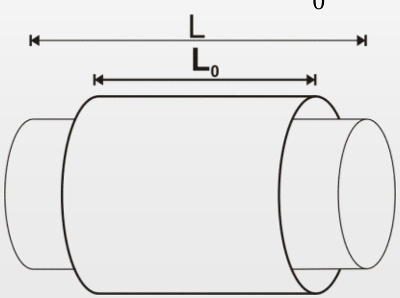
- **Brownian motion:**

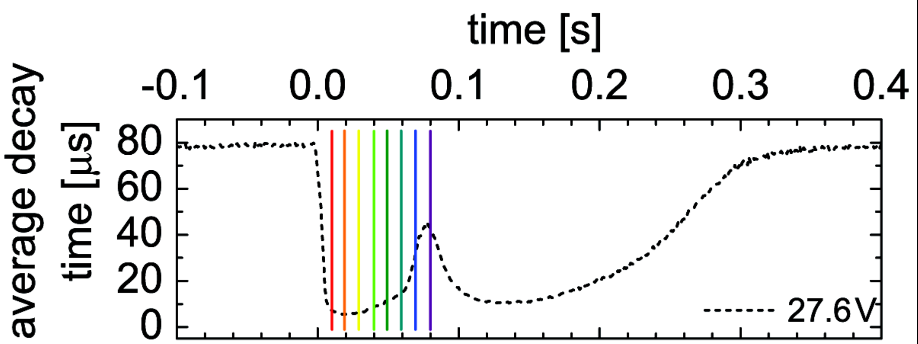
$$\frac{2}{3}k_0^2\,6D\,\tau$$

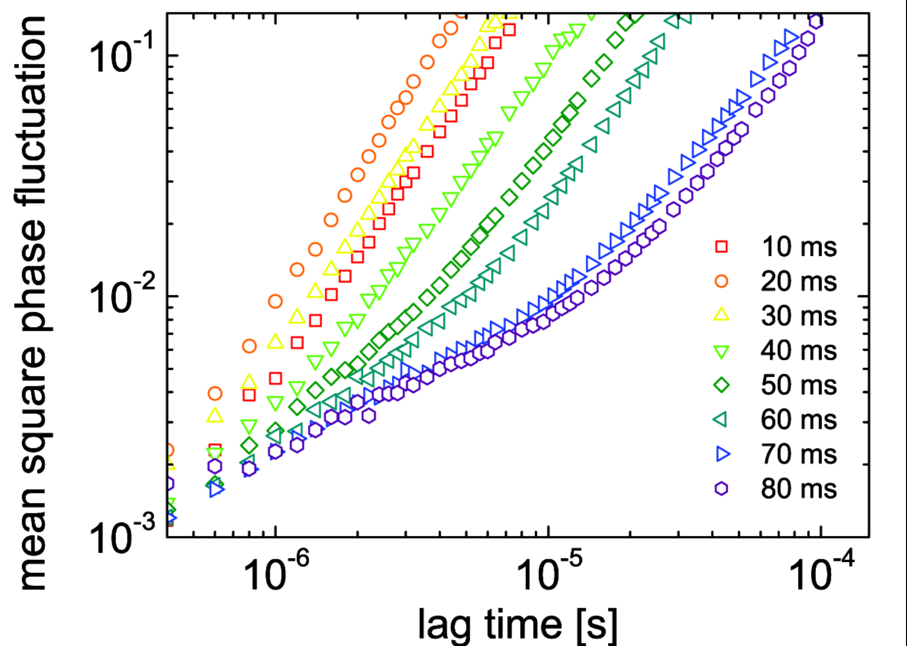
- **directed motion:**

strain : $e = \dfrac{L - L_0}{L_0}$

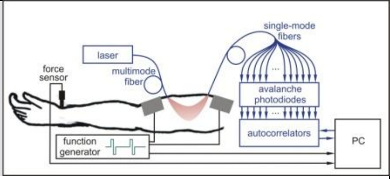
$$\frac{2}{3}k_0^2\,\frac{3}{5}\,\frac{\dot{e}^2}{\mu_s'^{\,2}}\,\tau^2$$







Tissue dynamics



- **analyze the shape of the reduced autocorrelation function**
- **mean square phase fluctuations**
- **Use binomial fit and extract diffusion coefficient & shear rate**

Binomial fit

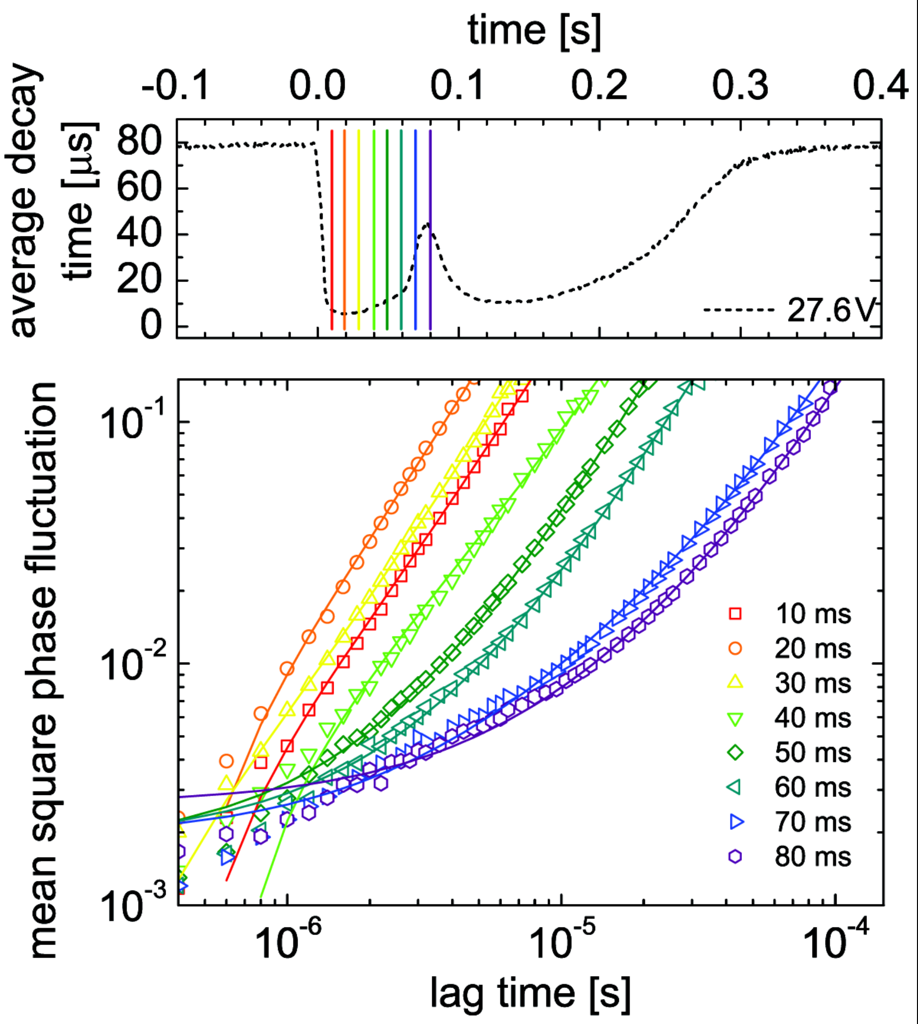
$$\left\langle \Delta\varphi^2(\tau,t) \right\rangle = a_0(t) + a_1(t)\tau + a_2(t)\tau^2$$

diffusion coef.

$$D(t) = \frac{a_1(t)}{4k_0^2}$$

strain rate

$$|\dot{e}| = \sqrt{\frac{5}{2}\frac{\mu_s'^2}{k_0^2}\,a_2(t)}$$



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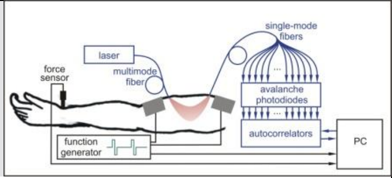

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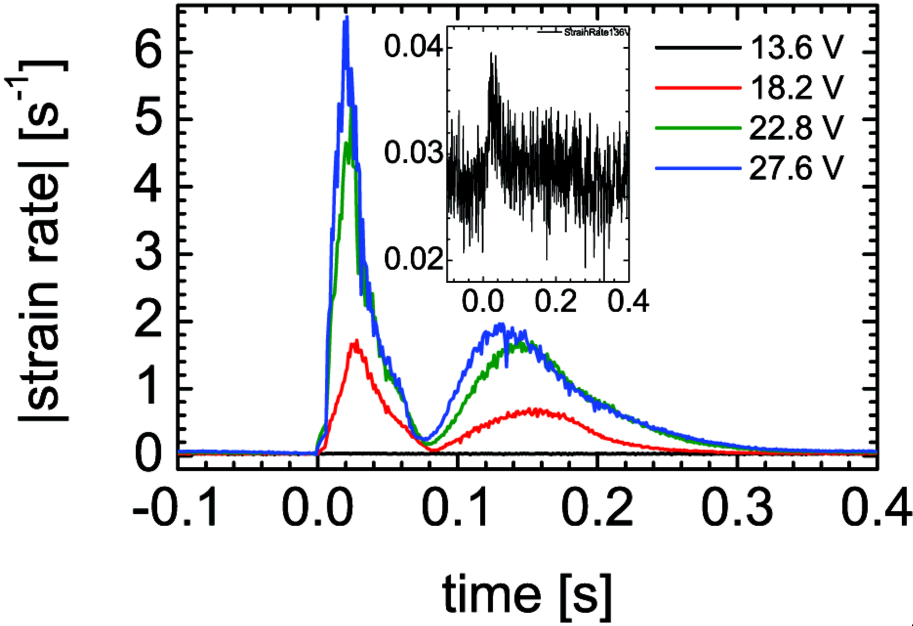

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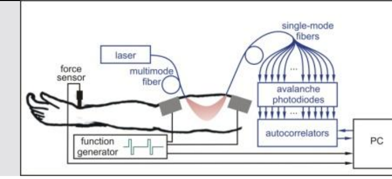
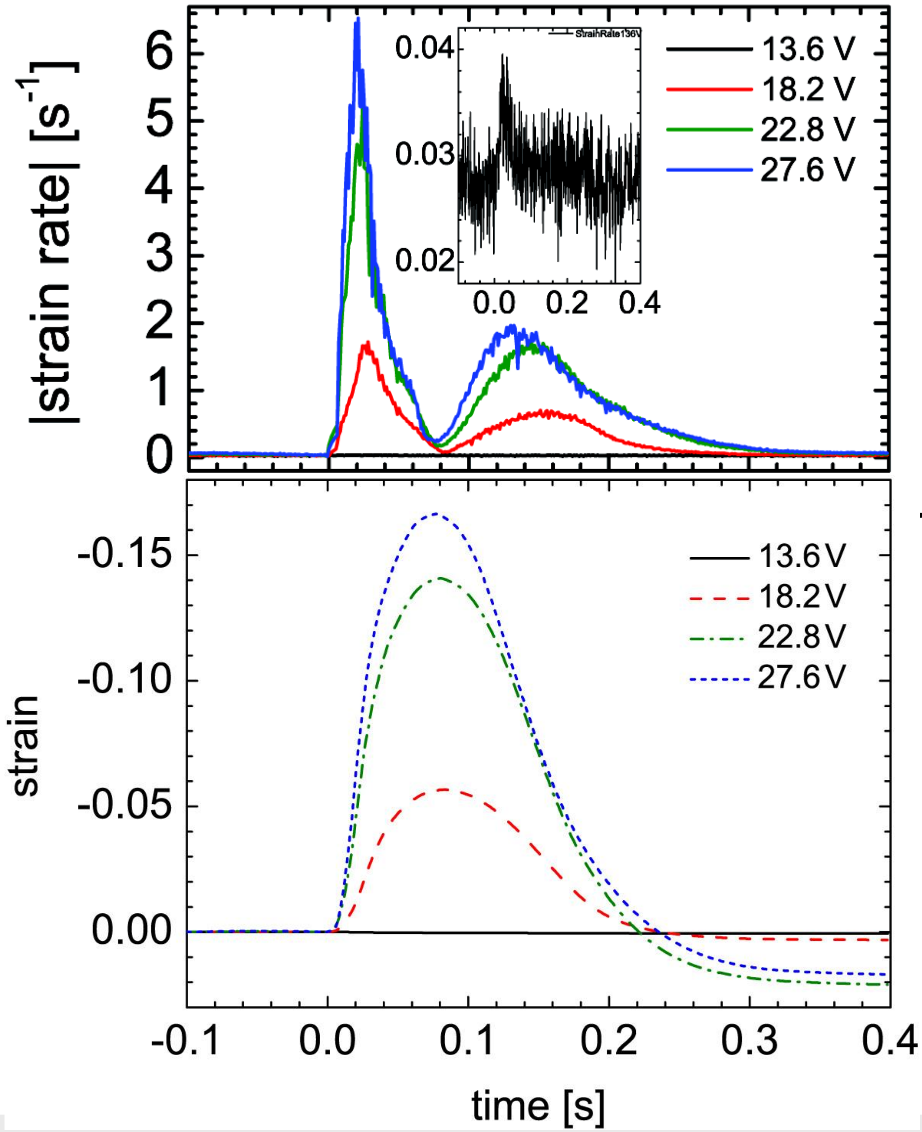


- analyze the shape of the reduced autocorrelation function
- mean square phase fluctuations
- use binomial fit and extract diffusion coefficient & shear rate
- calculate strain

strain

$$e(t) = \int_0^t \dot{e}(t')\,dt' \quad \begin{cases} \dot{e}(t') = -|\dot{e}(t')| : \text{contraction} \\ \dot{e}(t') = |\dot{e}(t')| : \text{relaxation} \end{cases}$$

good agreement with literature
cat gastrocnemius 0.18-0.28
Griffiths 1991, *J Physiol* **436**, 219-236



Conclusion

- **DWS is a novel method for non-invasively measuring muscle contraction**

- **Biphasic response of DWS reflects contraction and relaxation phase**
  - **Allows the discrimination between slow and fast twitch muscles**

- **Using a mixed diffusion shear model the strain can be measured quantitatively**

- **μ_a and μ_s' show a change with stimulation which is angle dependent**

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Thank you for your attention