On Estimation of Optical Properties in Near Infrared Spectroscopy with use of Cumulative Distributions of Times of Flight of Photons

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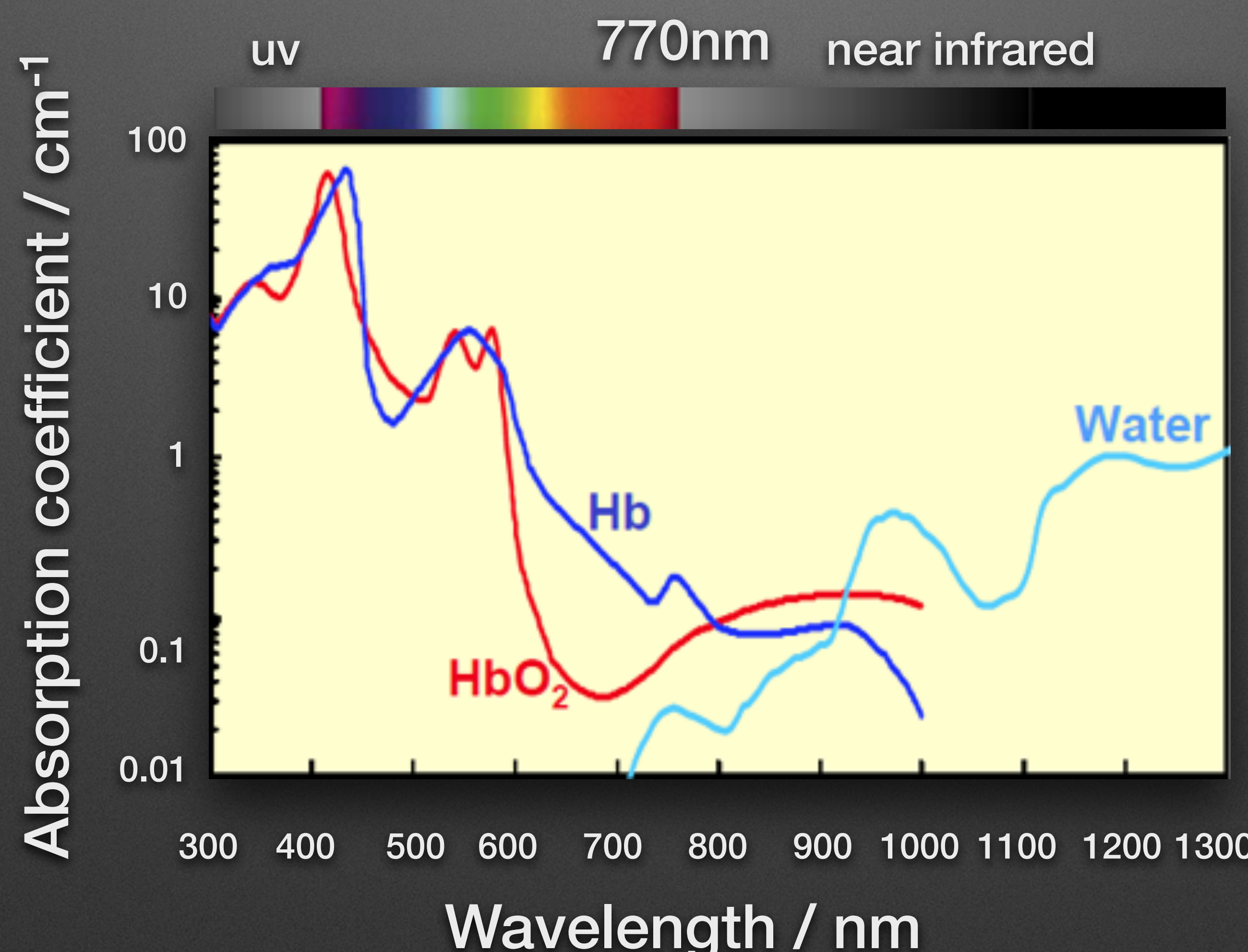
Near infrared spectroscopy

Absorption spectra of deoxy-hemoglobin, oxy-hemoglobin and water



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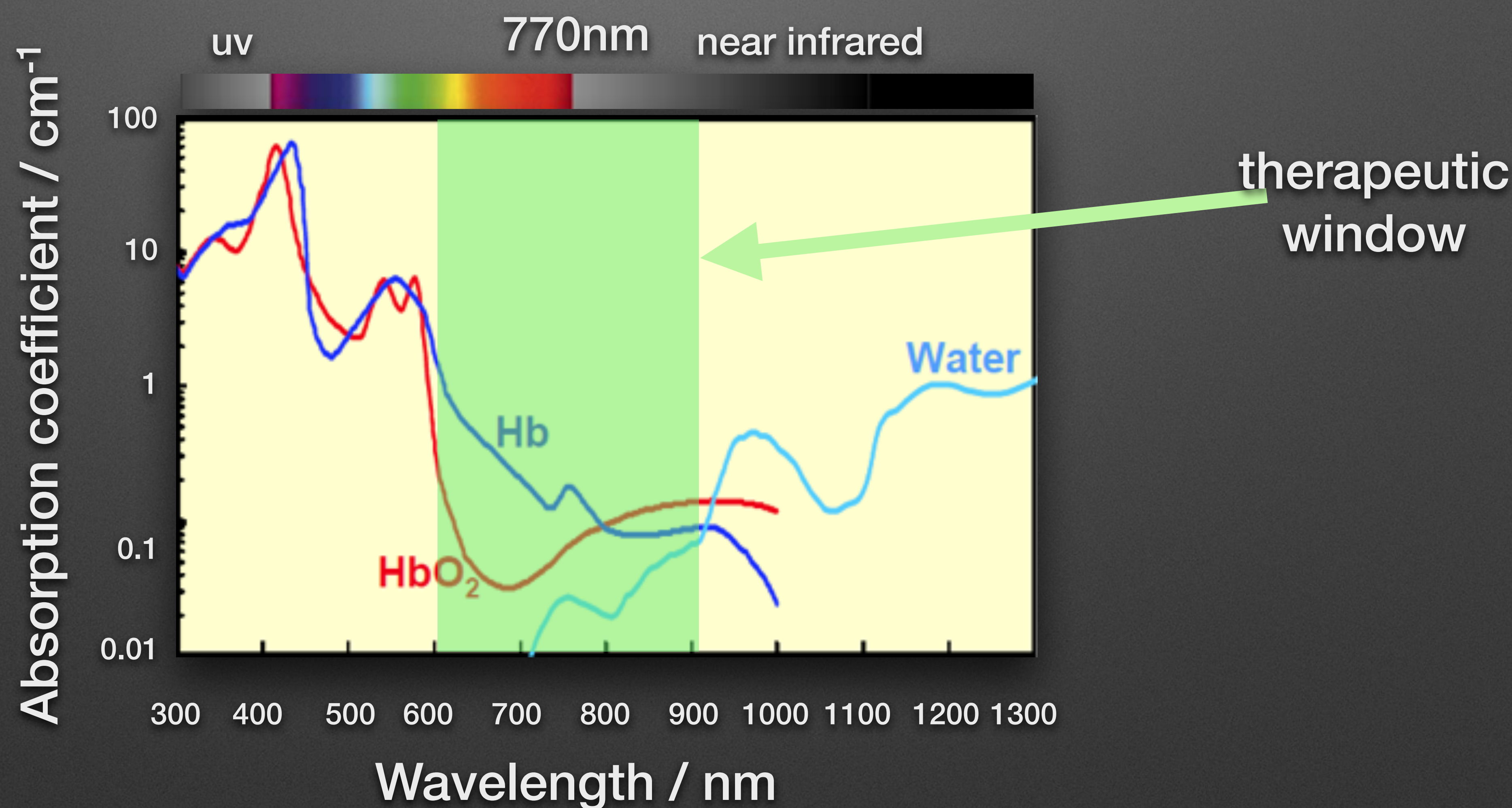

Calculation of hemoglobin concentration

absorption coefficient , extinction and hemoglobin concentration can be related in the formula:

$$\mu_a(\lambda_1) = \ln(10)\varepsilon_{HbO_2}(\lambda_1)C_{HbO_2} + \ln(10)\varepsilon_{Hb}(\lambda_1)C_{Hb}$$
$$\mu_a(\lambda_2) = \ln(10)\varepsilon_{HbO_2}(\lambda_2)C_{HbO_2} + \ln(10)\varepsilon_{Hb}(\lambda_2)C_{Hb}$$

Oxygen saturation can then be computed as

$$SO_2 = \frac{C_{HbO_2}}{C_{HbO_2} + C_{Hb}}$$

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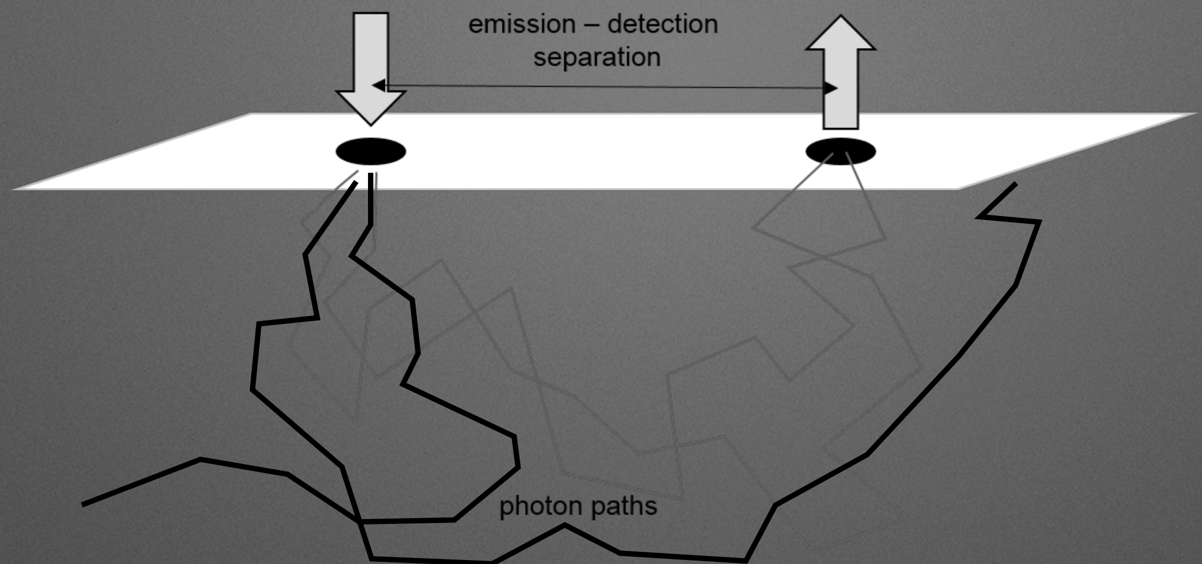
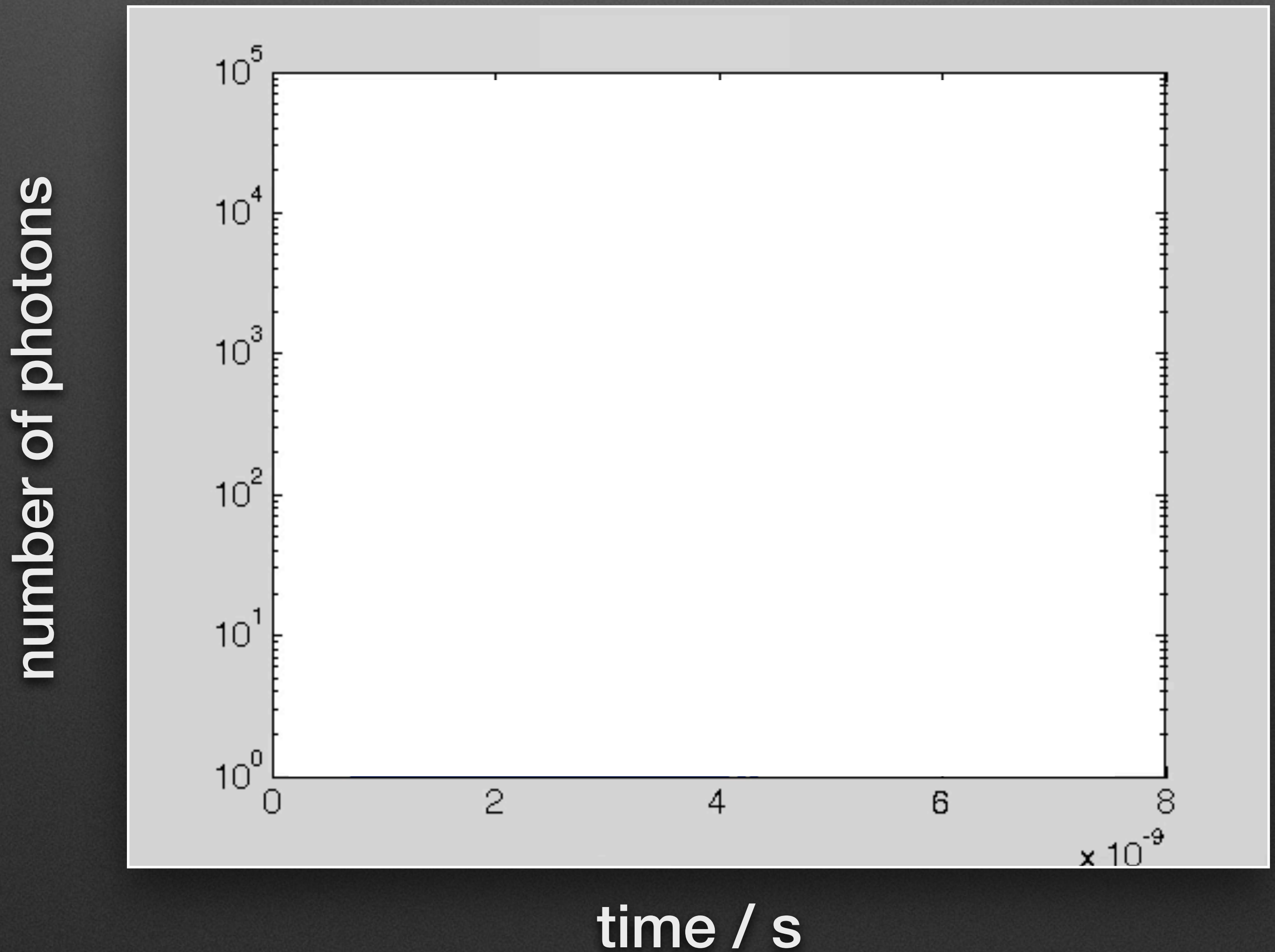
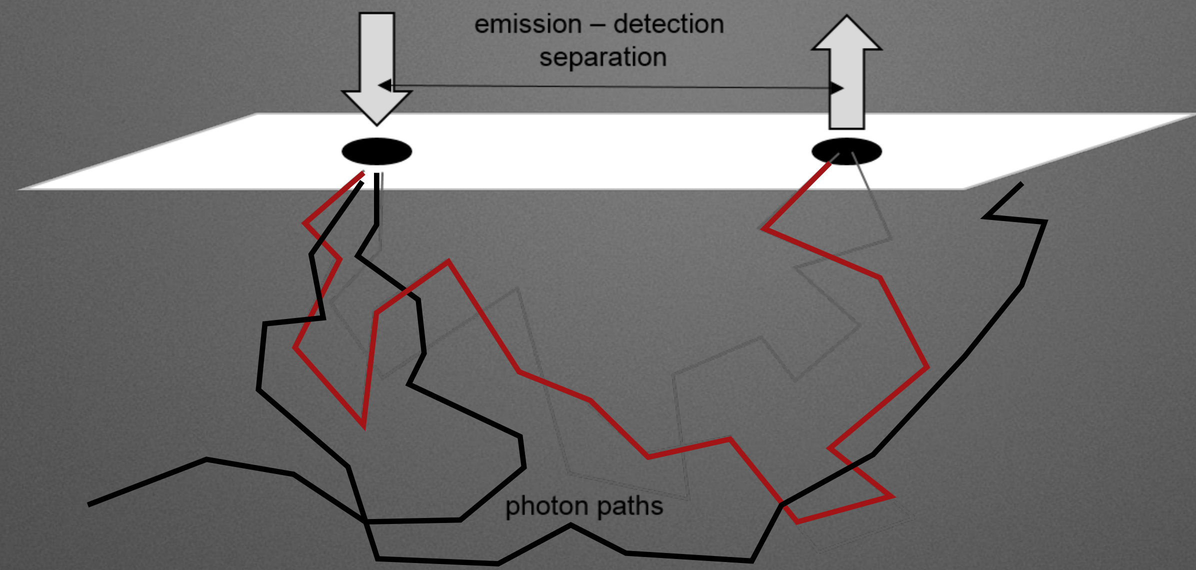
near infrared spectroscopy measurements

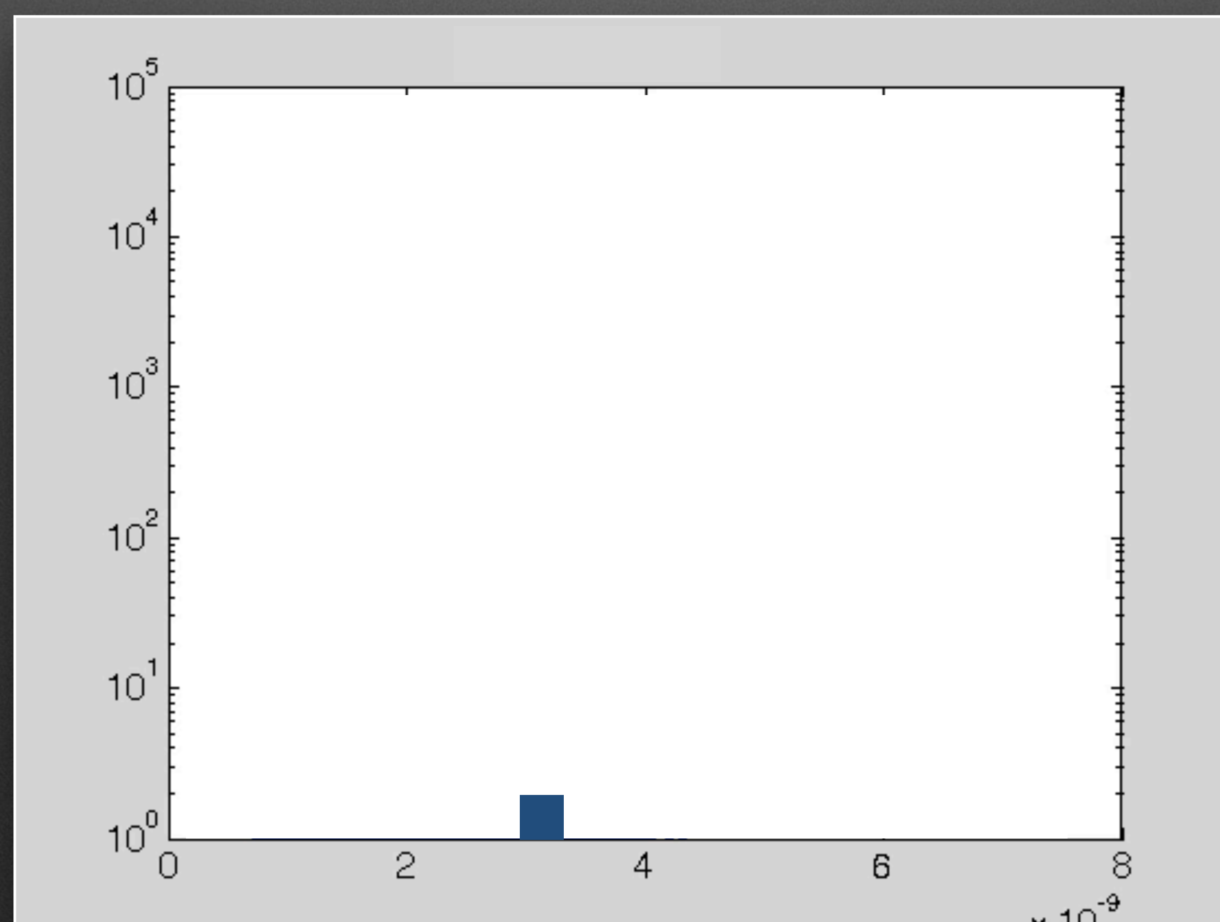
time resolved near infrared spectroscopy





time resolved near infrared spectroscopy

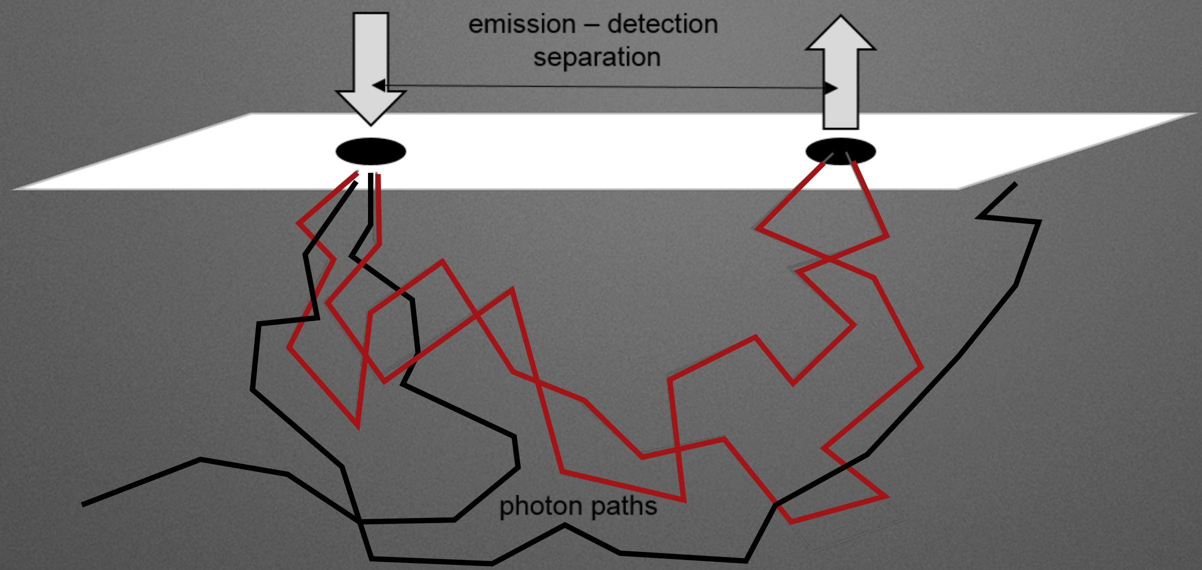


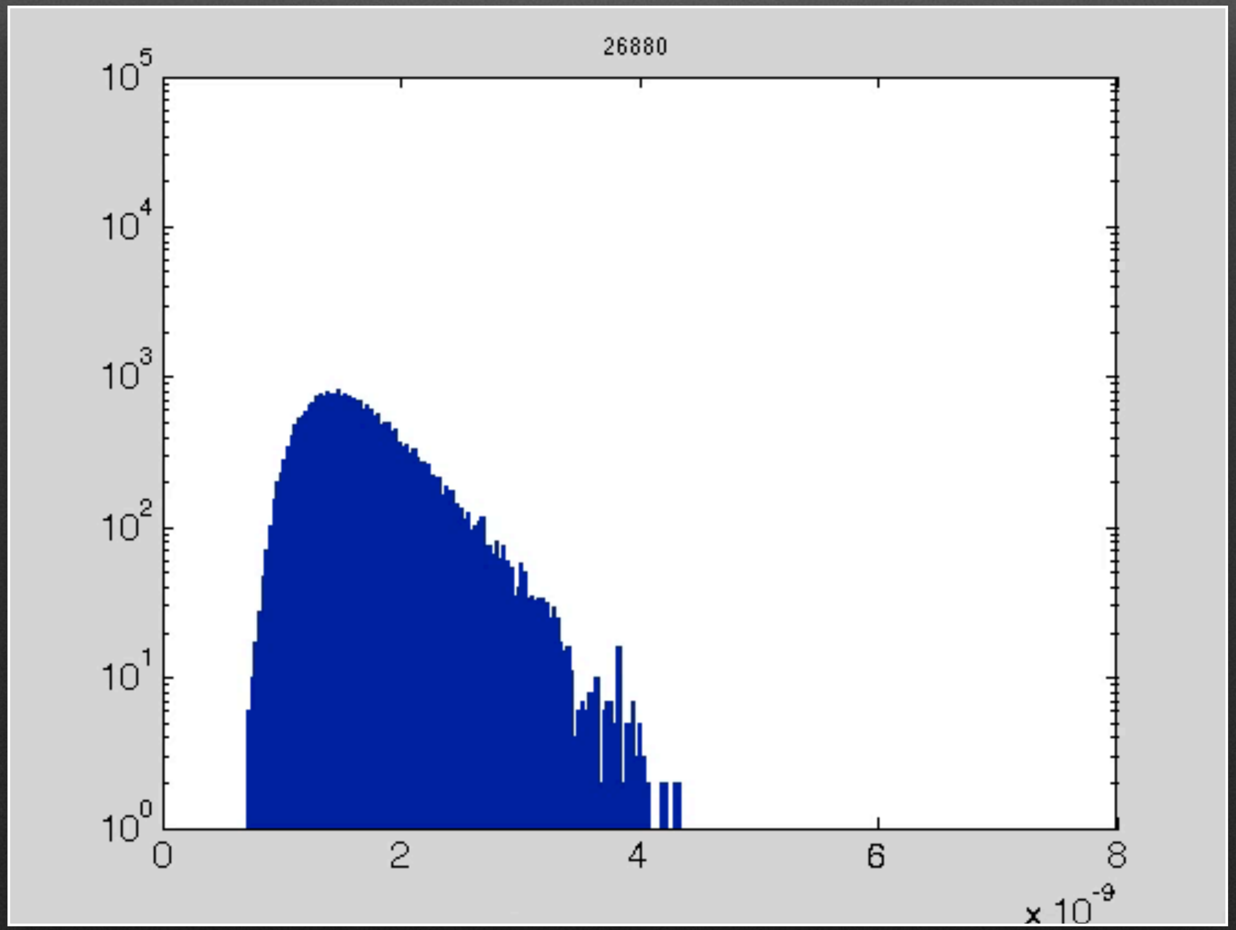


number of photons

time / s

time resolved near infrared spectroscopy





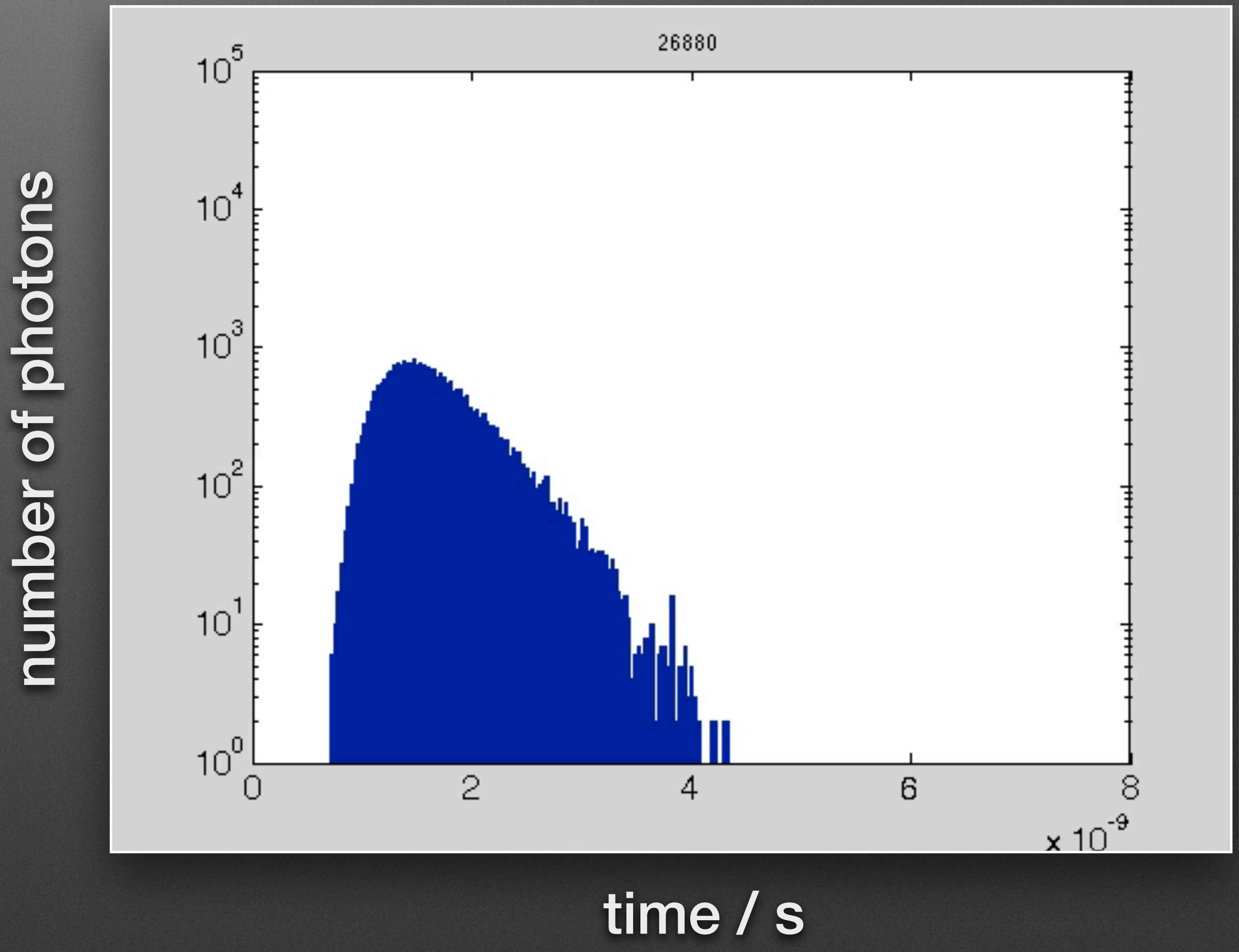
number of photons

time / s

Monte Carlo algorithm for modeling

- describing the medium using macroscopic optical properties as absorption and scattering coefficient , the propagation of light (time of flight of photons) can be simulated using Monte Carlo method

- NVIDIA GEFORCE GTX TITAN BLACK (late 2014) general purpose GPU, allows to simulate trajectories of more than 4.5 million photons per second

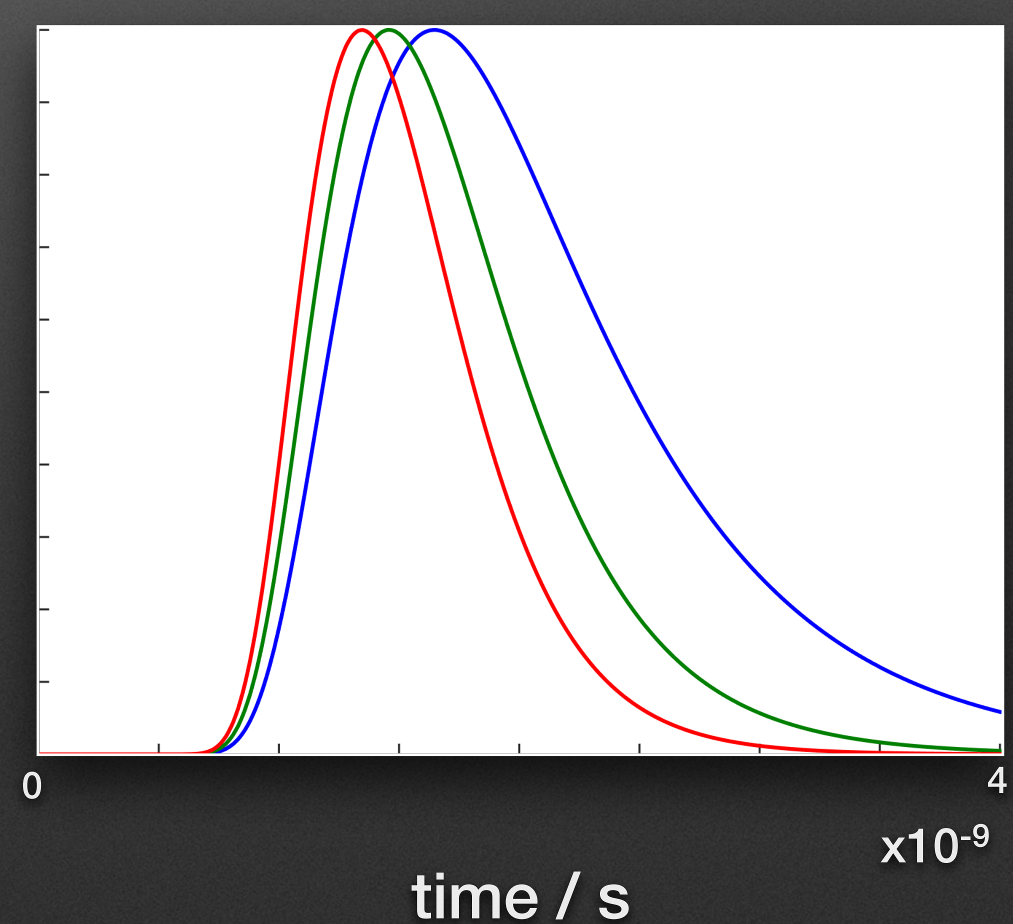


OpenCL

Former methods of optical properties analysis

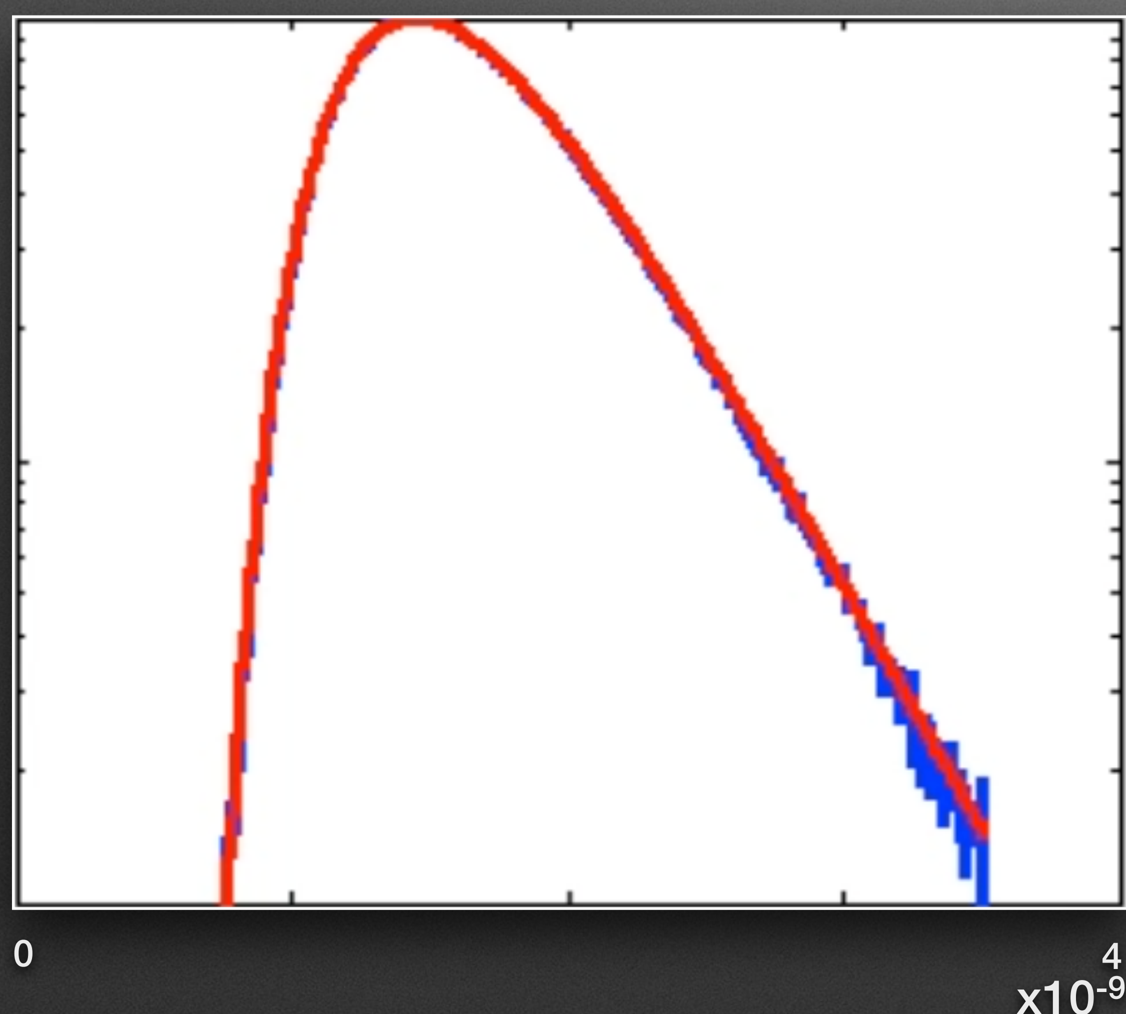
analysis of distributions of times of flight of photons with a method of

- statistical moments (Liebert A.)
- fitting the theoretical model to distributions of times of flight of photons (using diffussion equation) (Pifferi A., Kienle A., …)
- sensitivity coefficients (Steinbrink J.)
- time windows (Spinelli L.)
- neural networks (Kienle A.)
- …

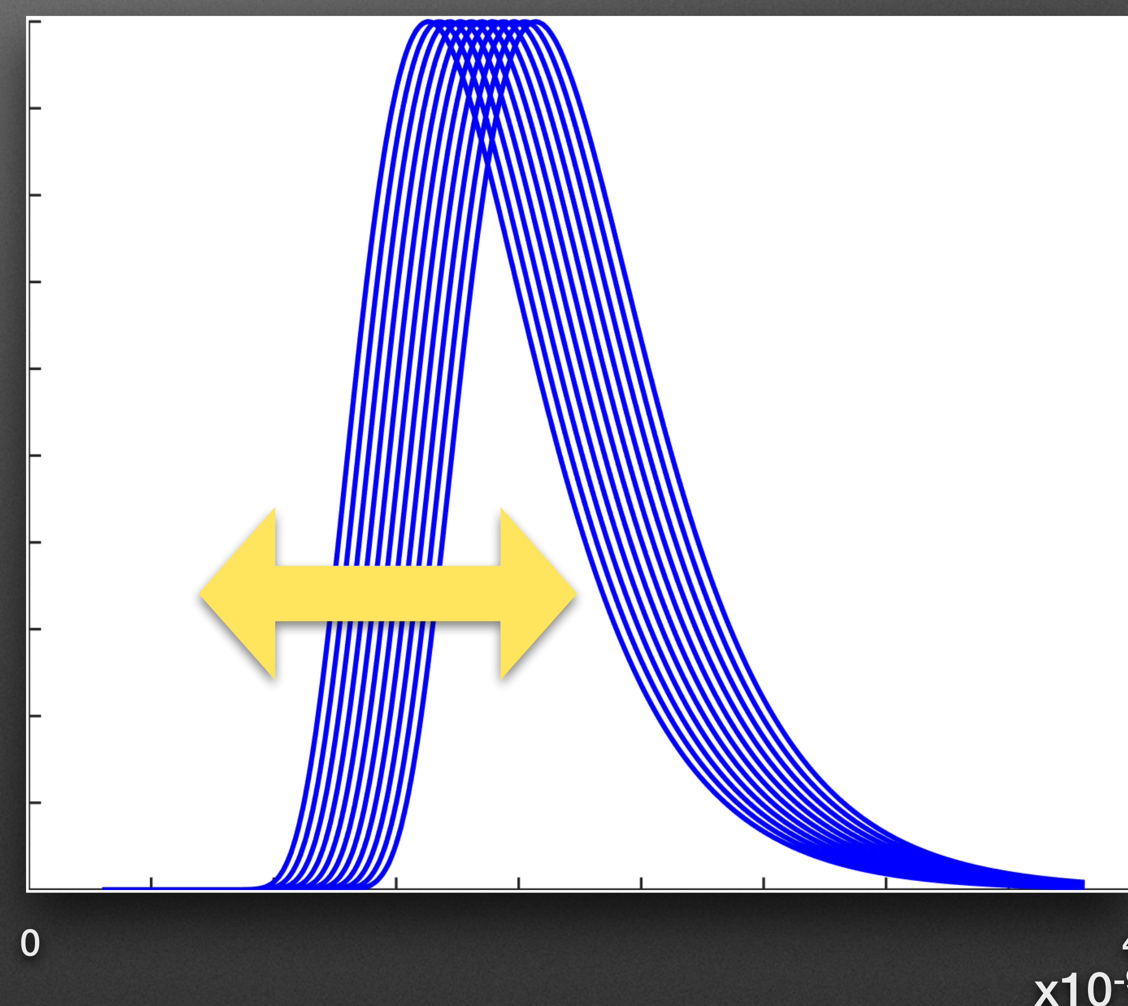


The main issues with optical properties estimation

noise



instrumental time shift



number of photons

time / s

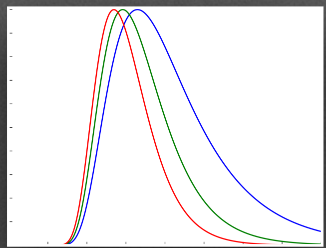
Analysis
of stochastic processes

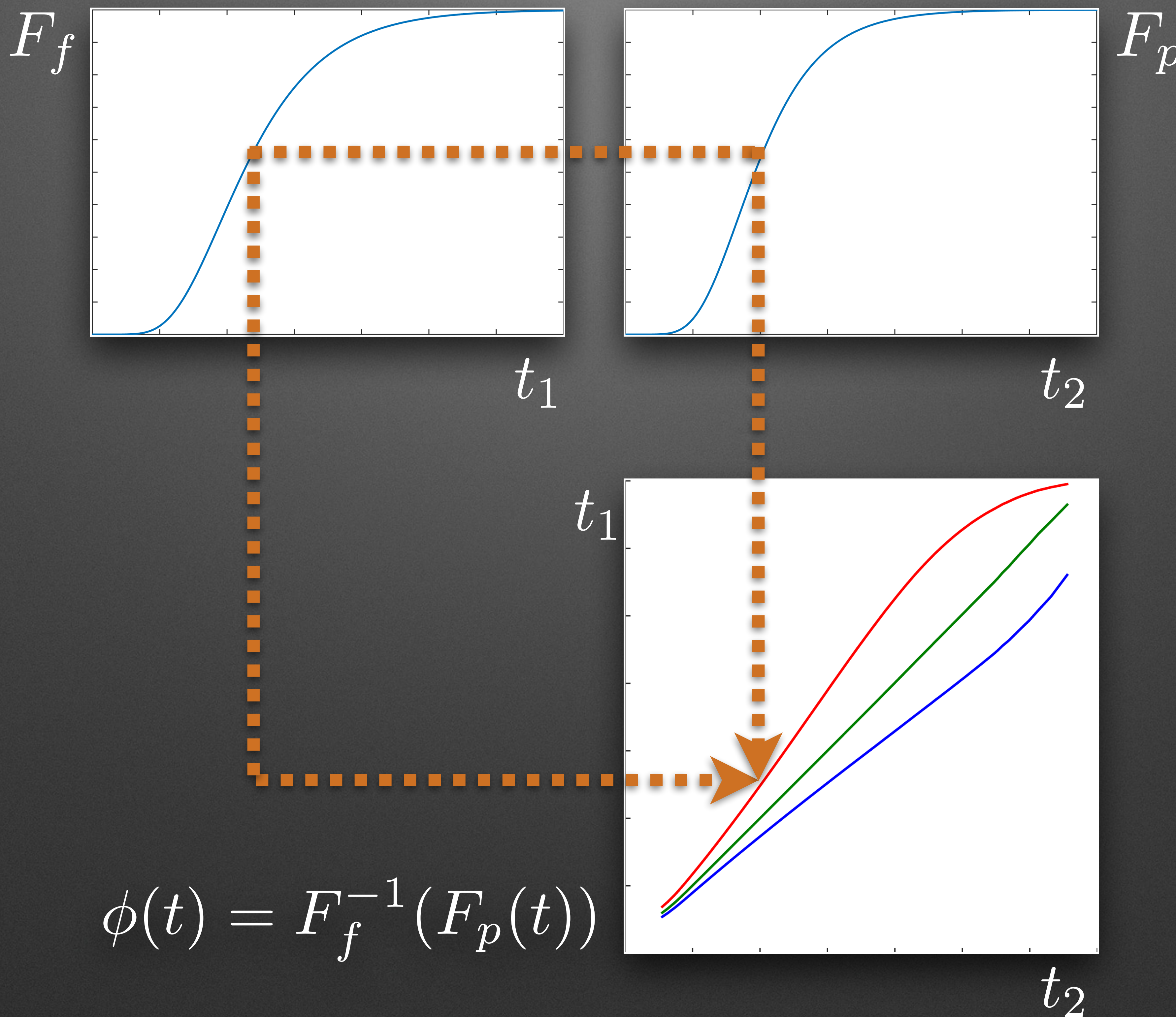
Time of flight of photons in optically turbid medium is stationary stochastic process

The distribution of the random variable describes its characteristics but to estimate how well this distribution fits to the data the cummulative distribution is used

- statistical tests
- Analysis of function connecting two cummulative distributions (Distribution Function Method - Rix H. - 1980)

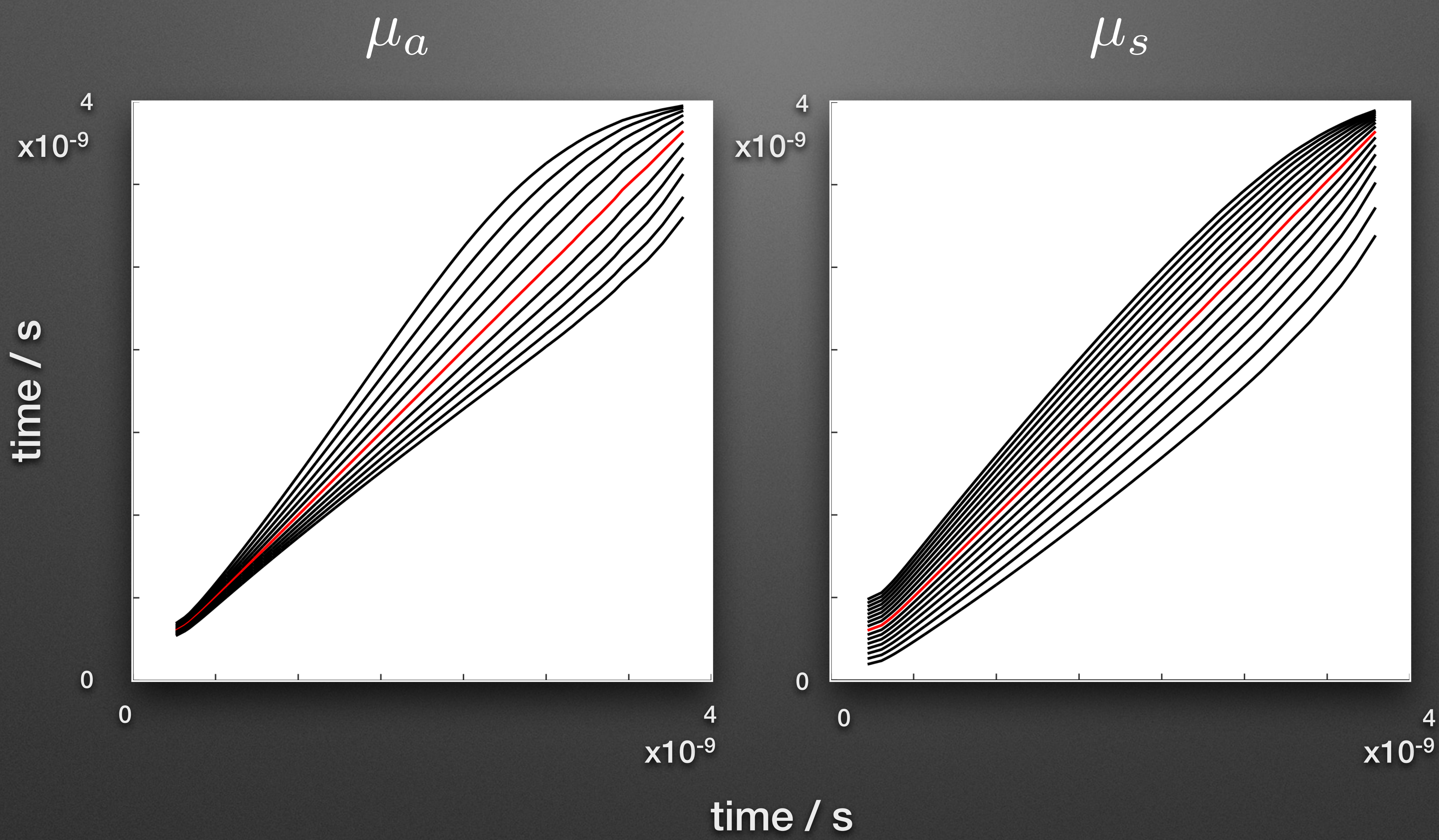
DFM properties





$$\phi(t) = F_f^{-1}(F_p(t))$$

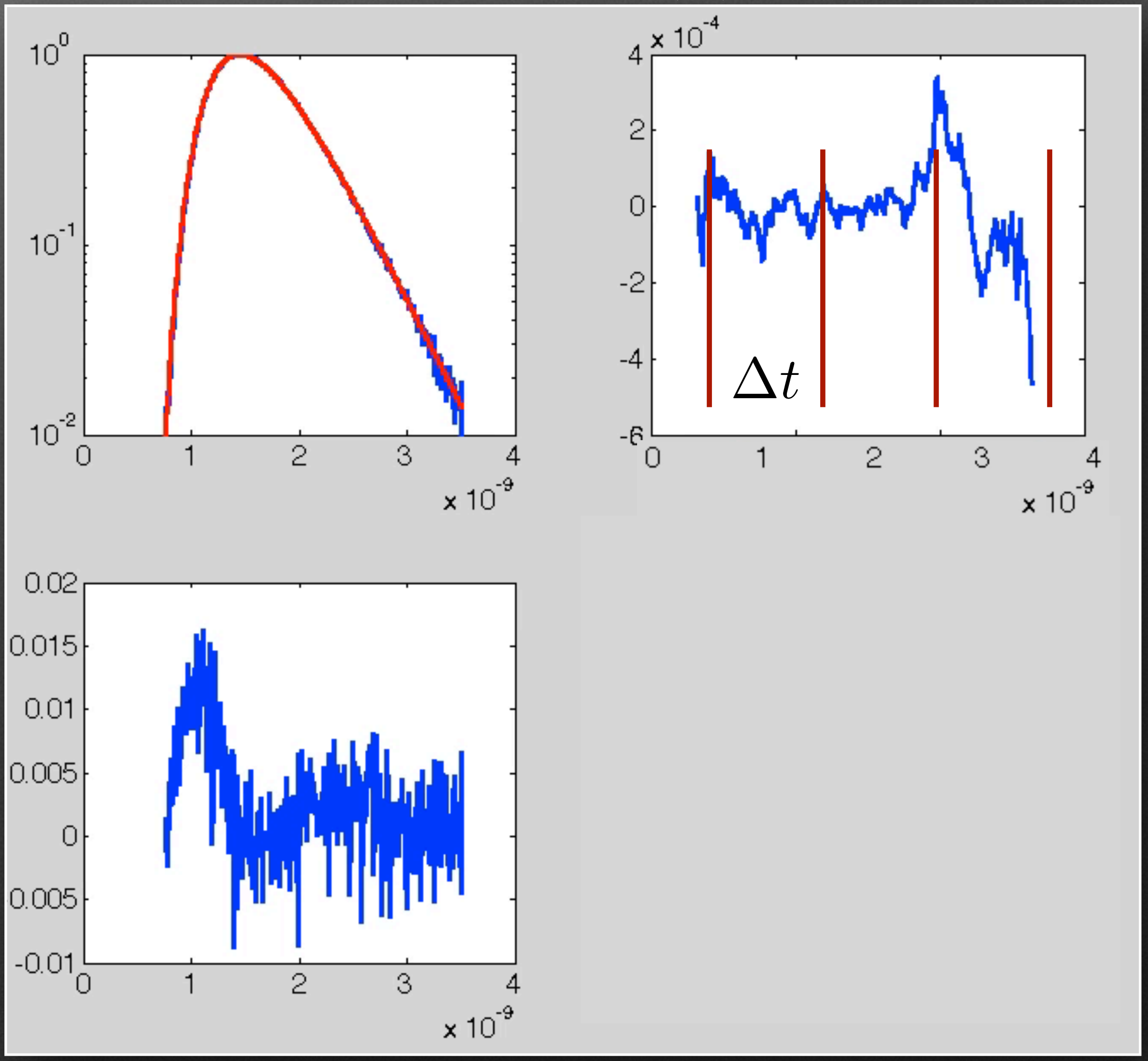
DFM properties cont.



Error function

$$err = \sum_{j=1}^{K} \sum_{i=1}^{j} \int_{t_b+(i-1)\Delta t/j}^{t_b+i\Delta t/j} \left(\phi(s) - a_{ij}s - b_{ij}\right)^2 ds$$

$\phi(t) - at - b$



where

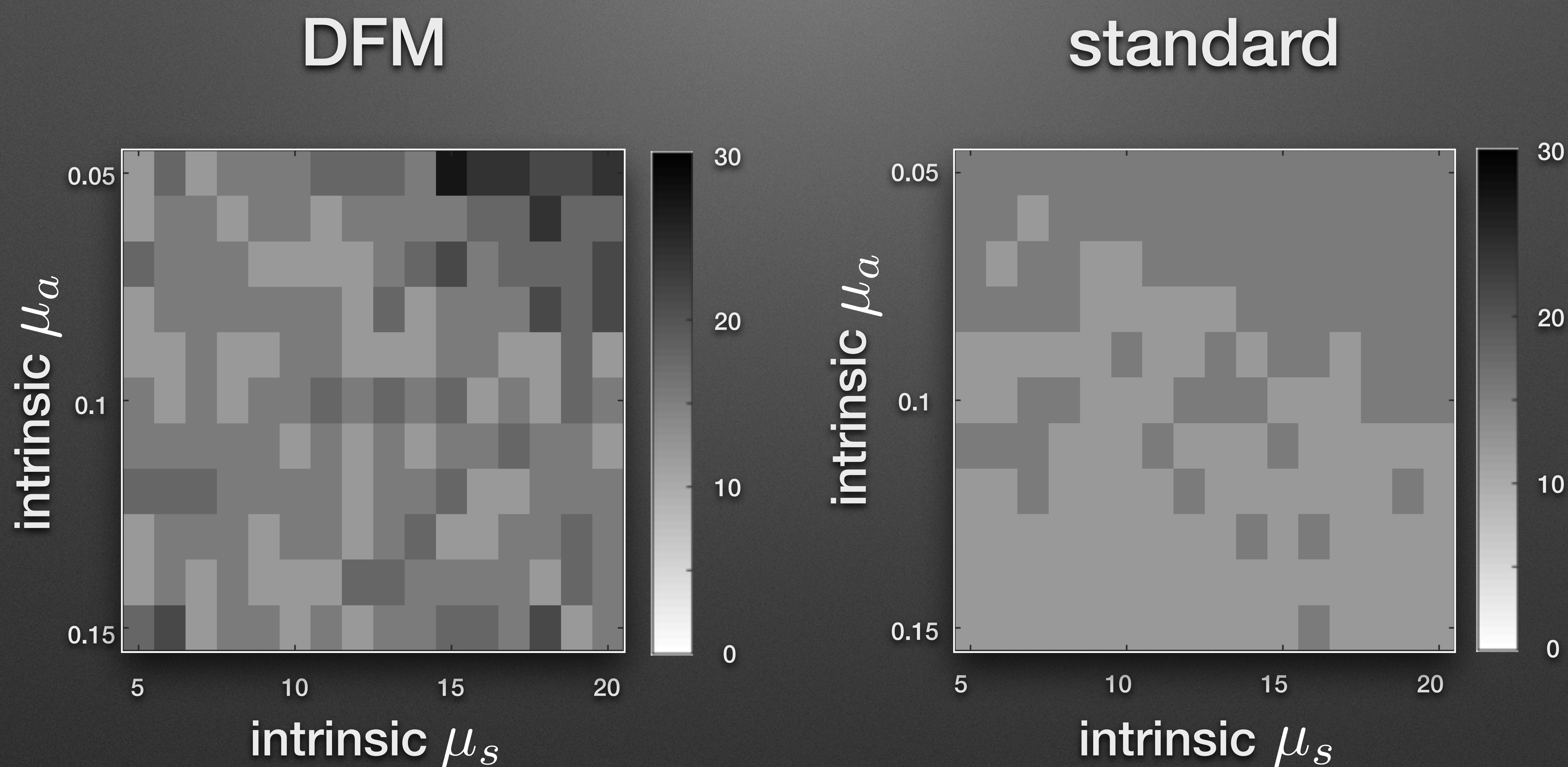
$$\phi(t) = F_f^{-1}(F_p(t))$$

and

$$a_{ij} \;\; b_{ij}$$

coefficients from best fit of linear function to the $\phi(t)$ function

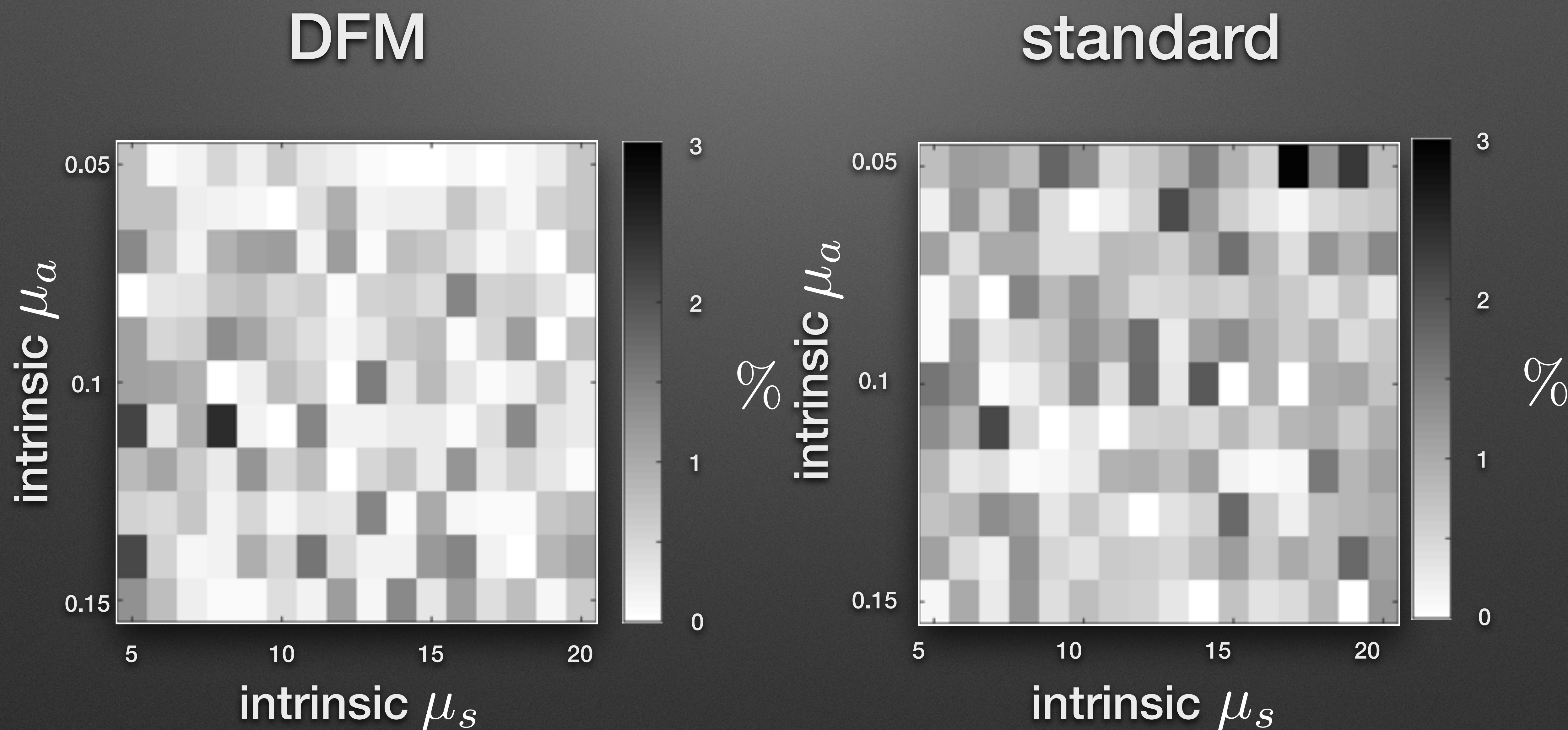
number of iterations to get minimum of the error function



absorption coefficient estimation error

$$\Delta\mu = \frac{\mu_{fit} - \mu_{intrinsic}}{\mu_{intrinsic}} 100\%$$

$$\mu_a$$

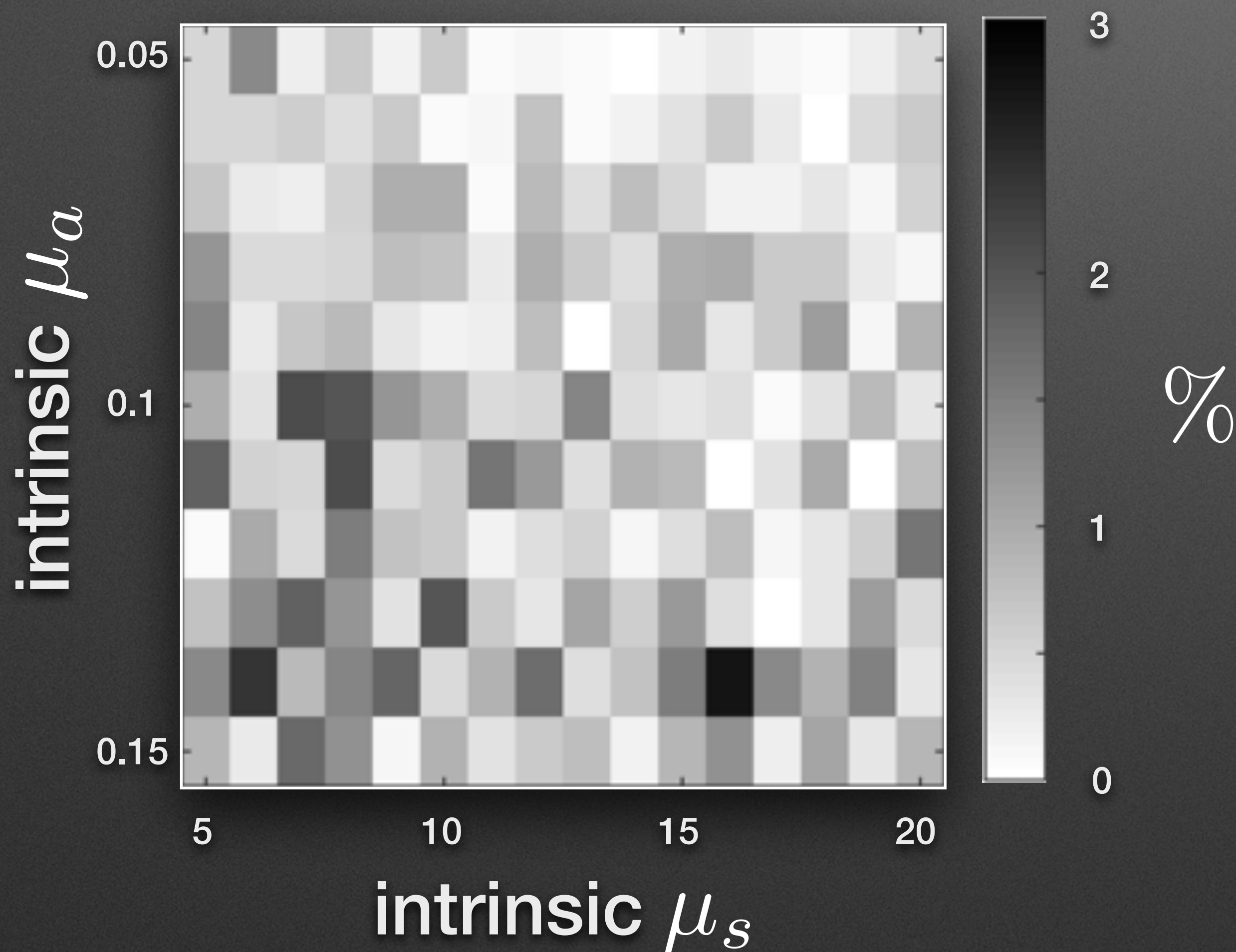


scattering coefficient estimation error

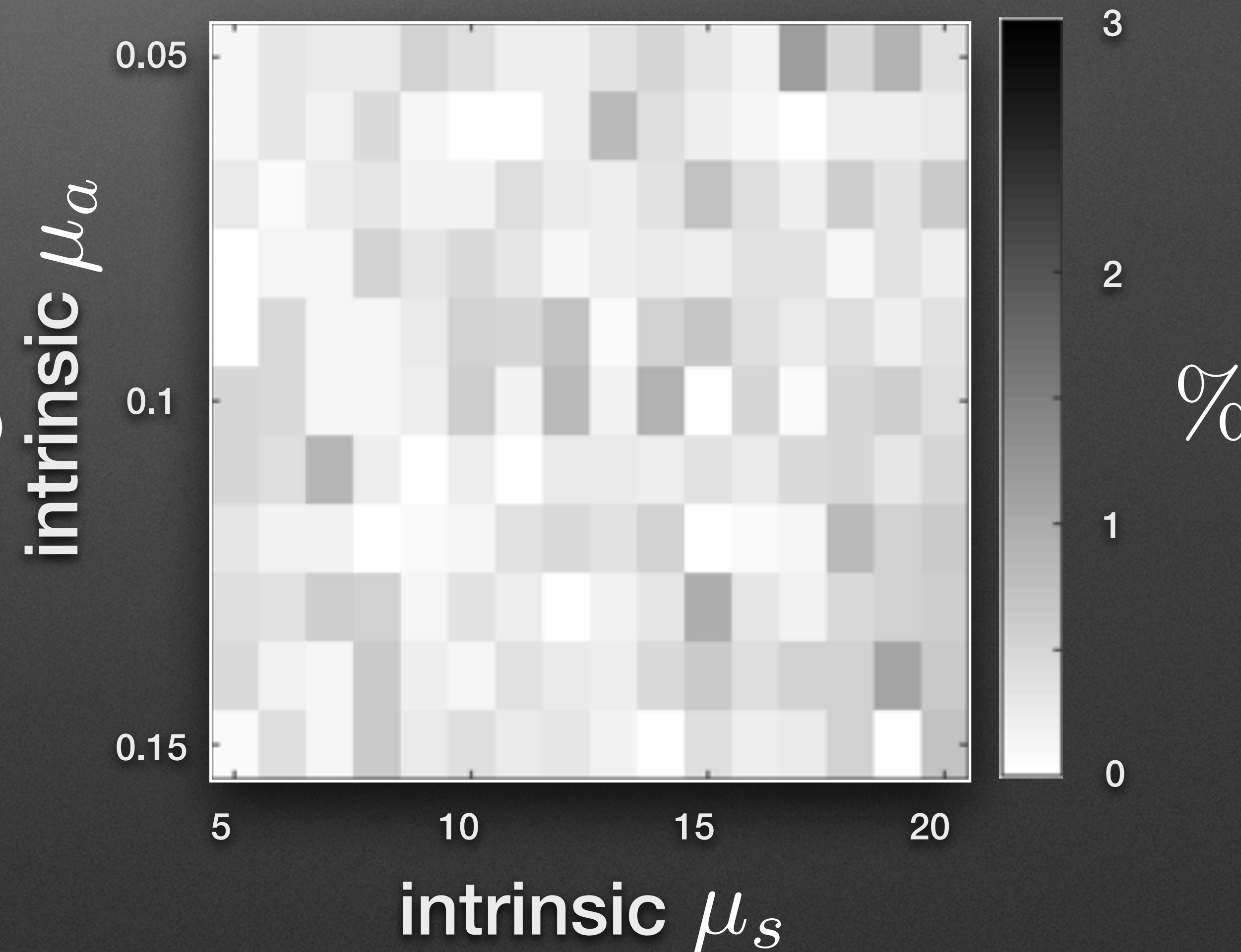
$$\Delta\mu = \frac{\mu_{fit} - \mu_{intrinsic}}{\mu_{intrinsic}} 100\%$$

$$\mu_s$$

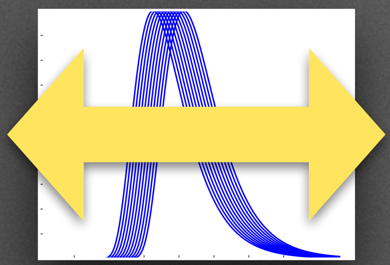
DFM

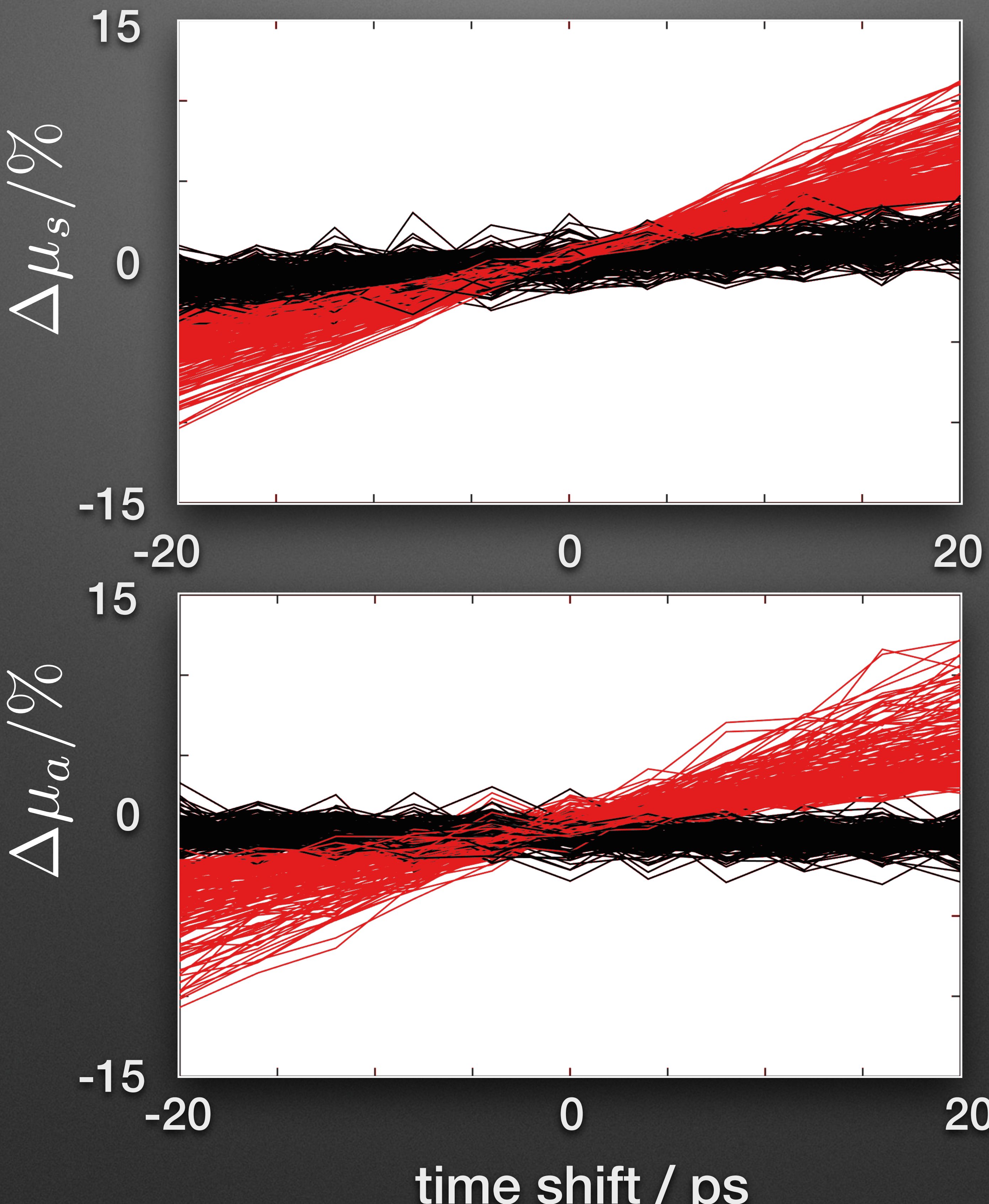


standard



influence of instrumental time shift





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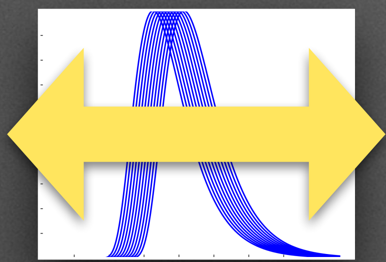
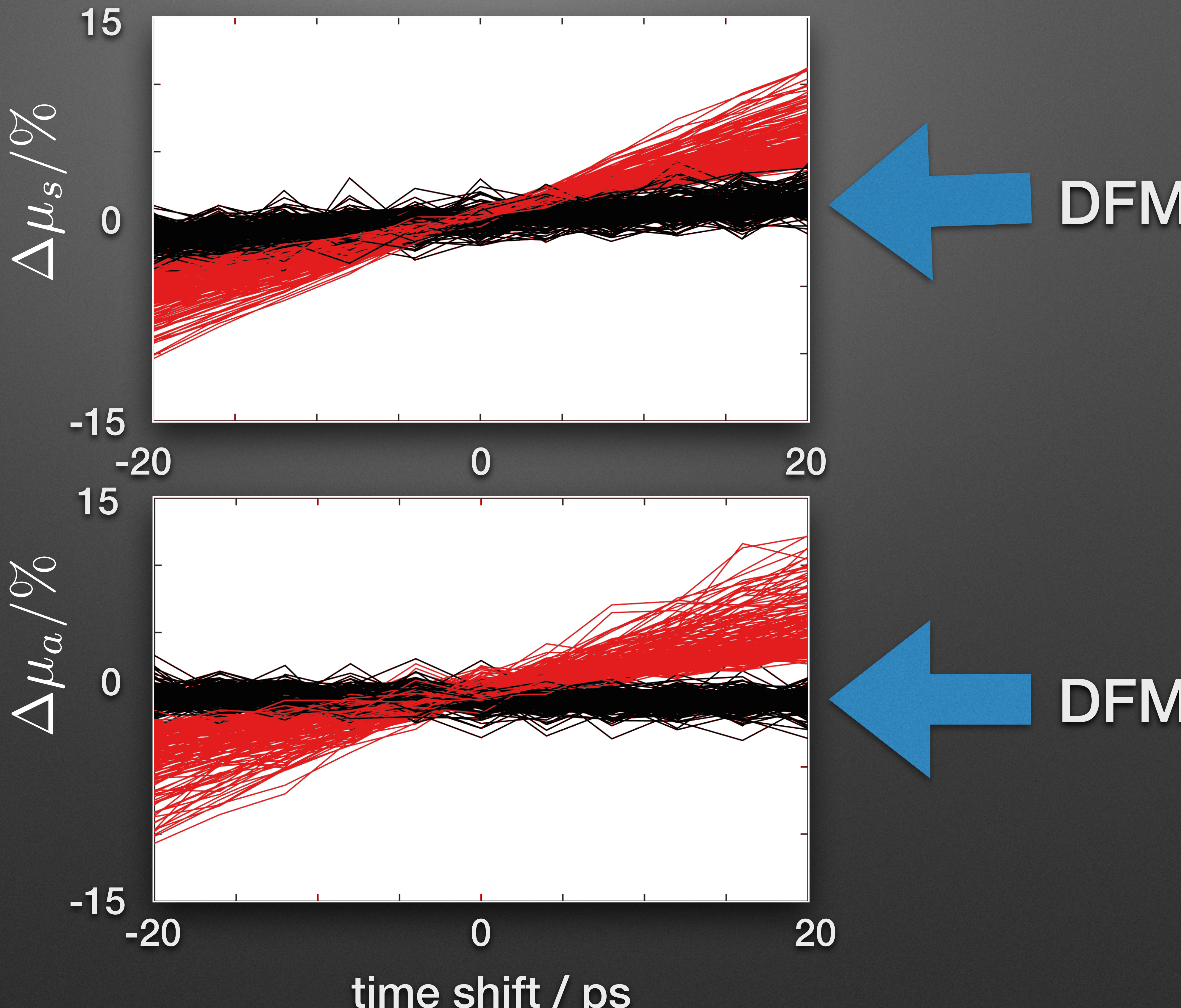
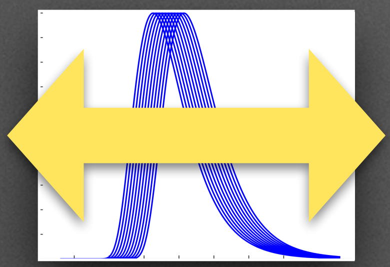
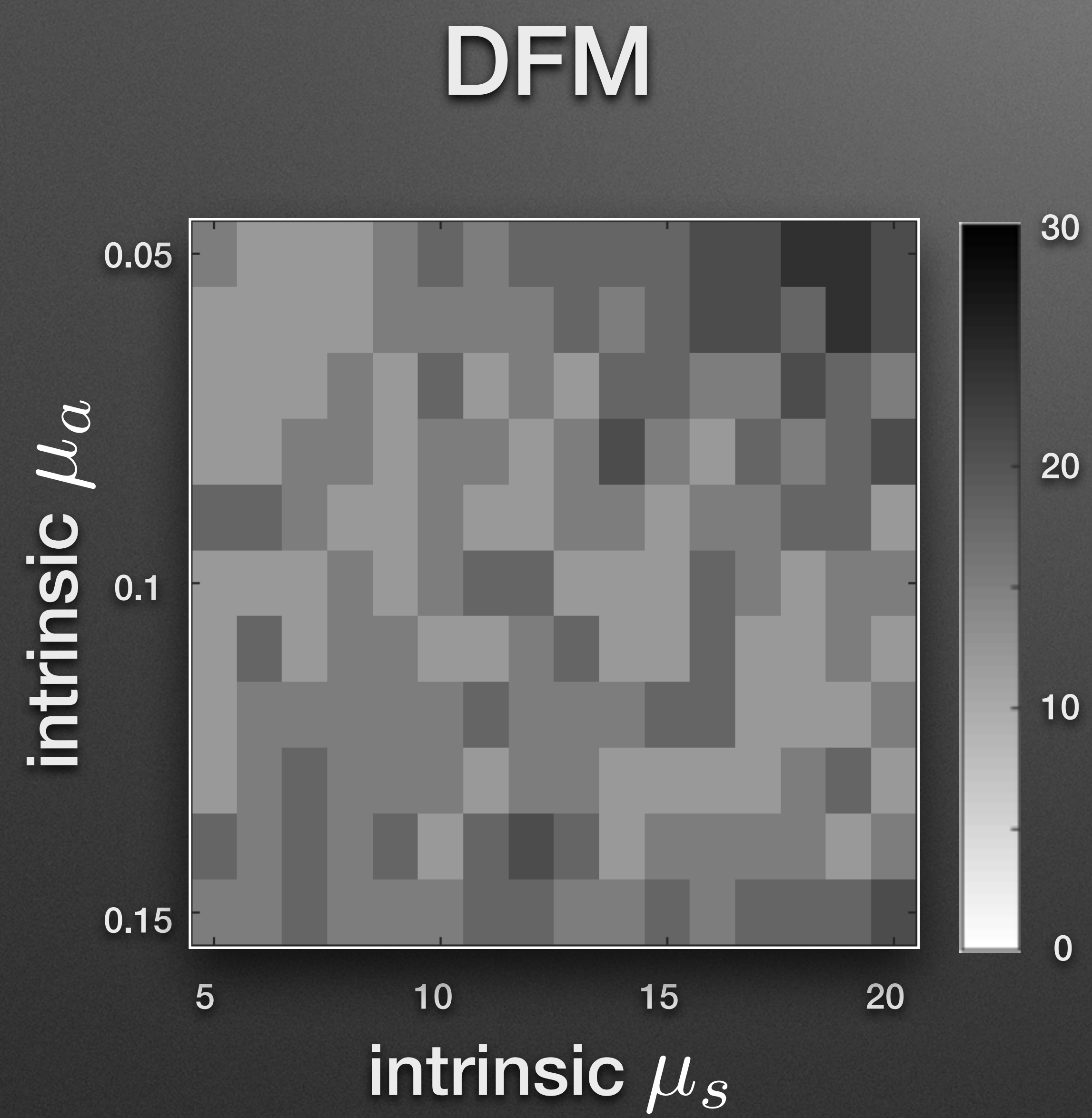
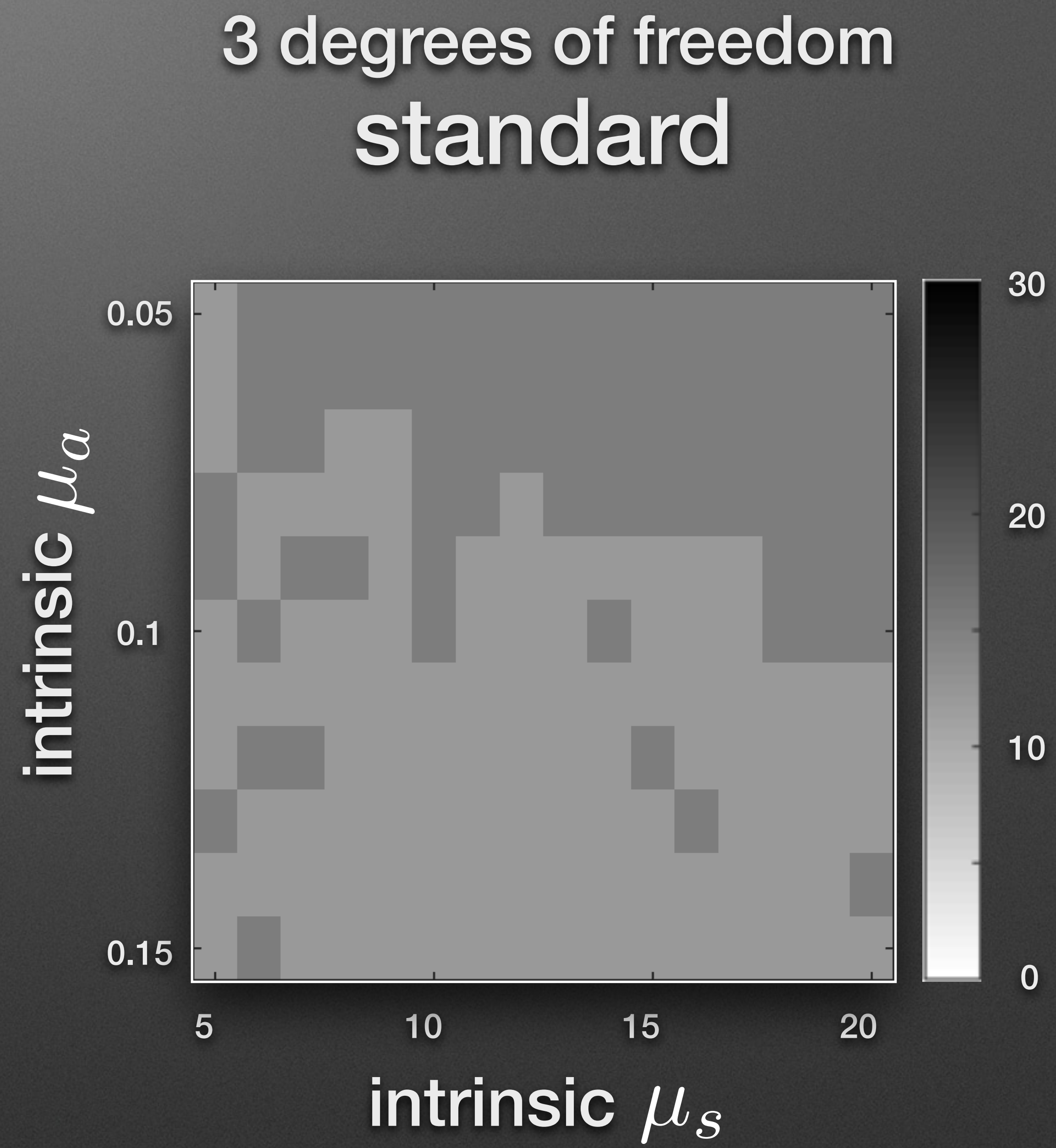




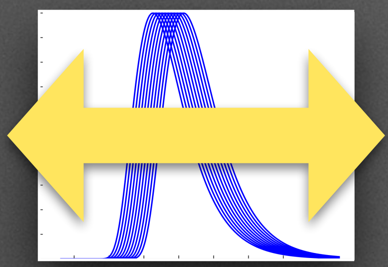
number of iterations to get minimum of the error function







absorption coefficient iteration error

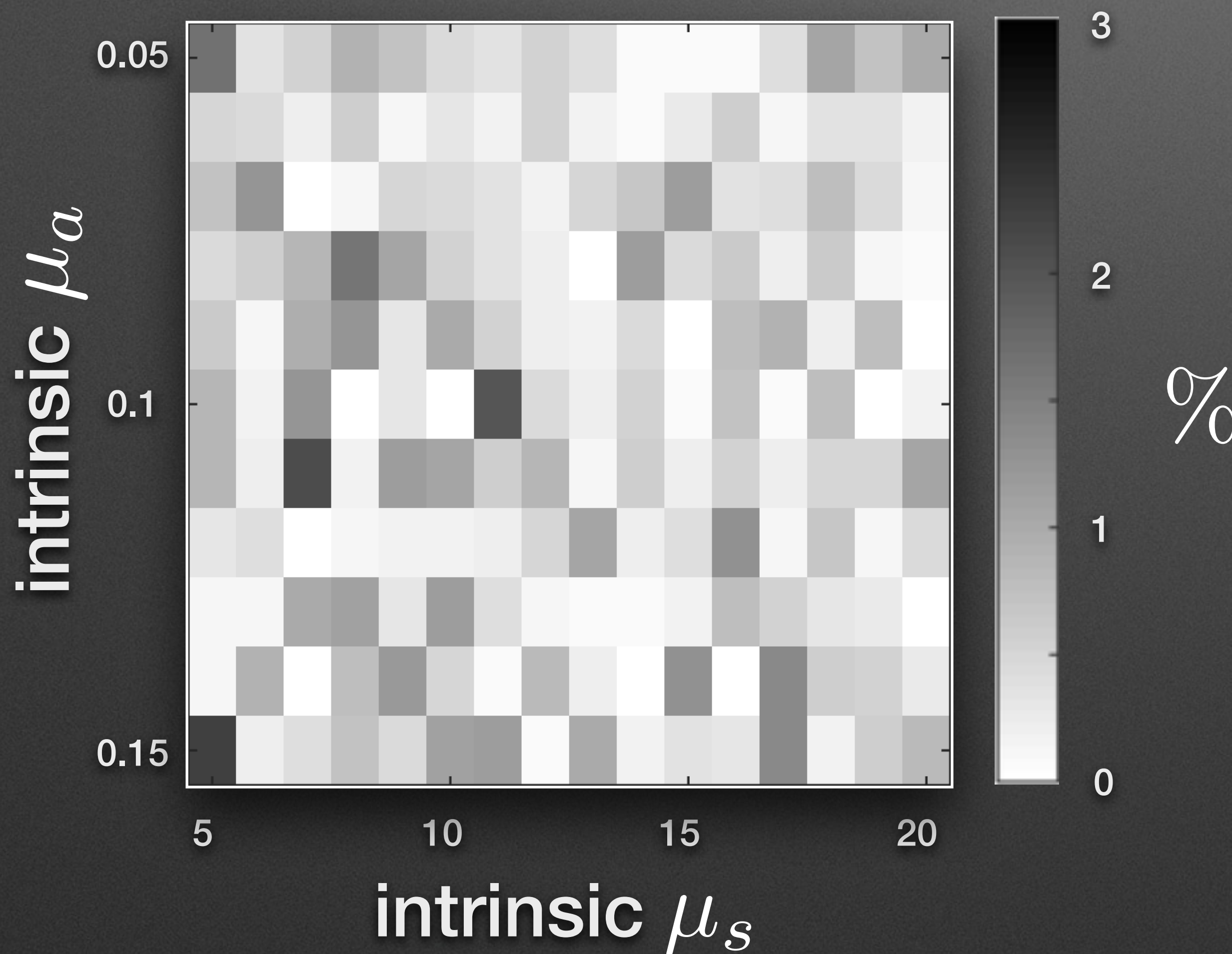


$$\Delta\mu = \frac{\mu_{fit} - \mu_{intrinsic}}{\mu_{intrinsic}} 100\%$$

μ_a

3 degrees of freedom

DFM



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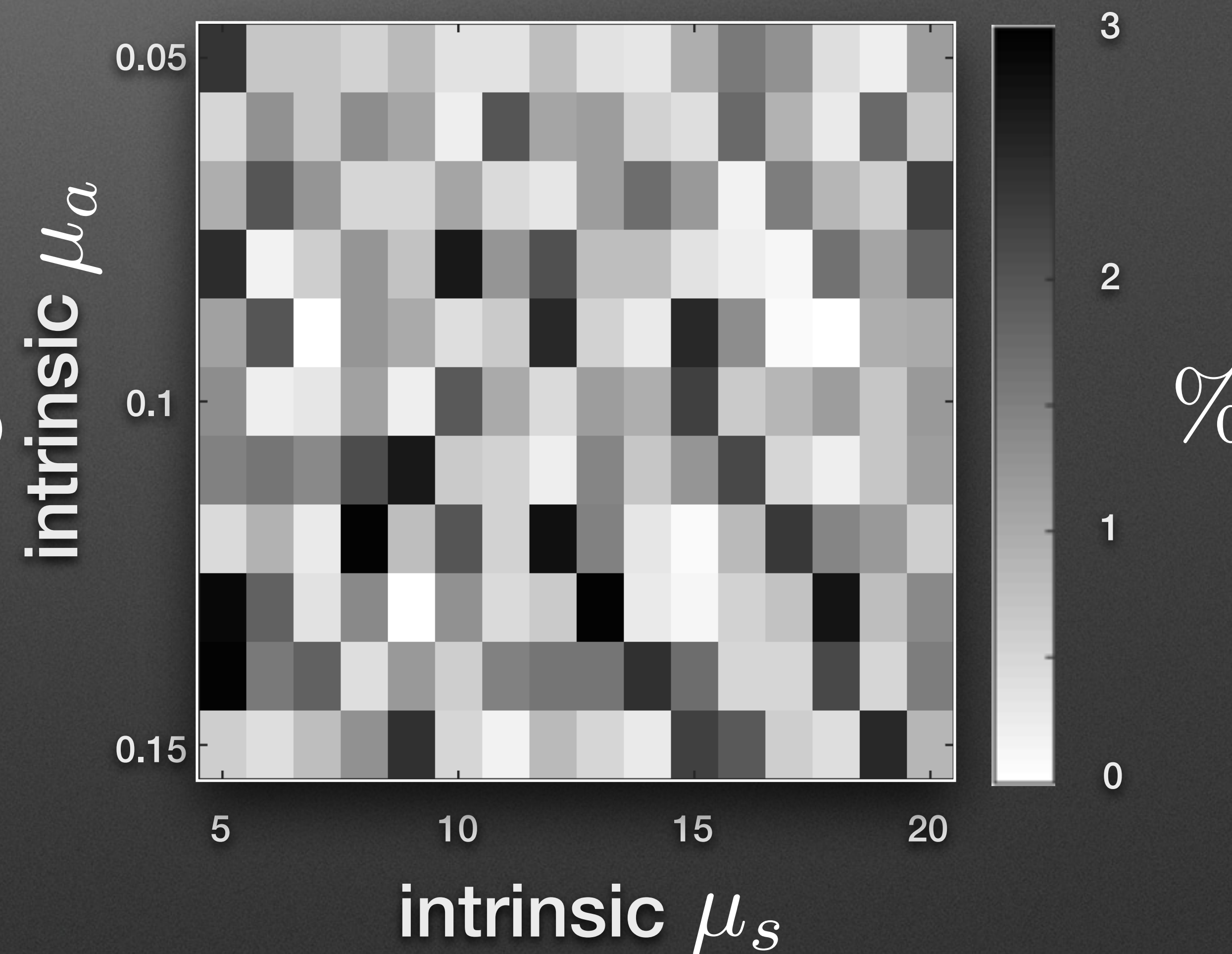
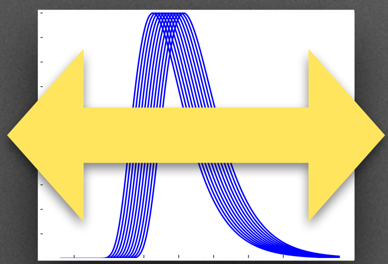


scattering coefficient iteration error

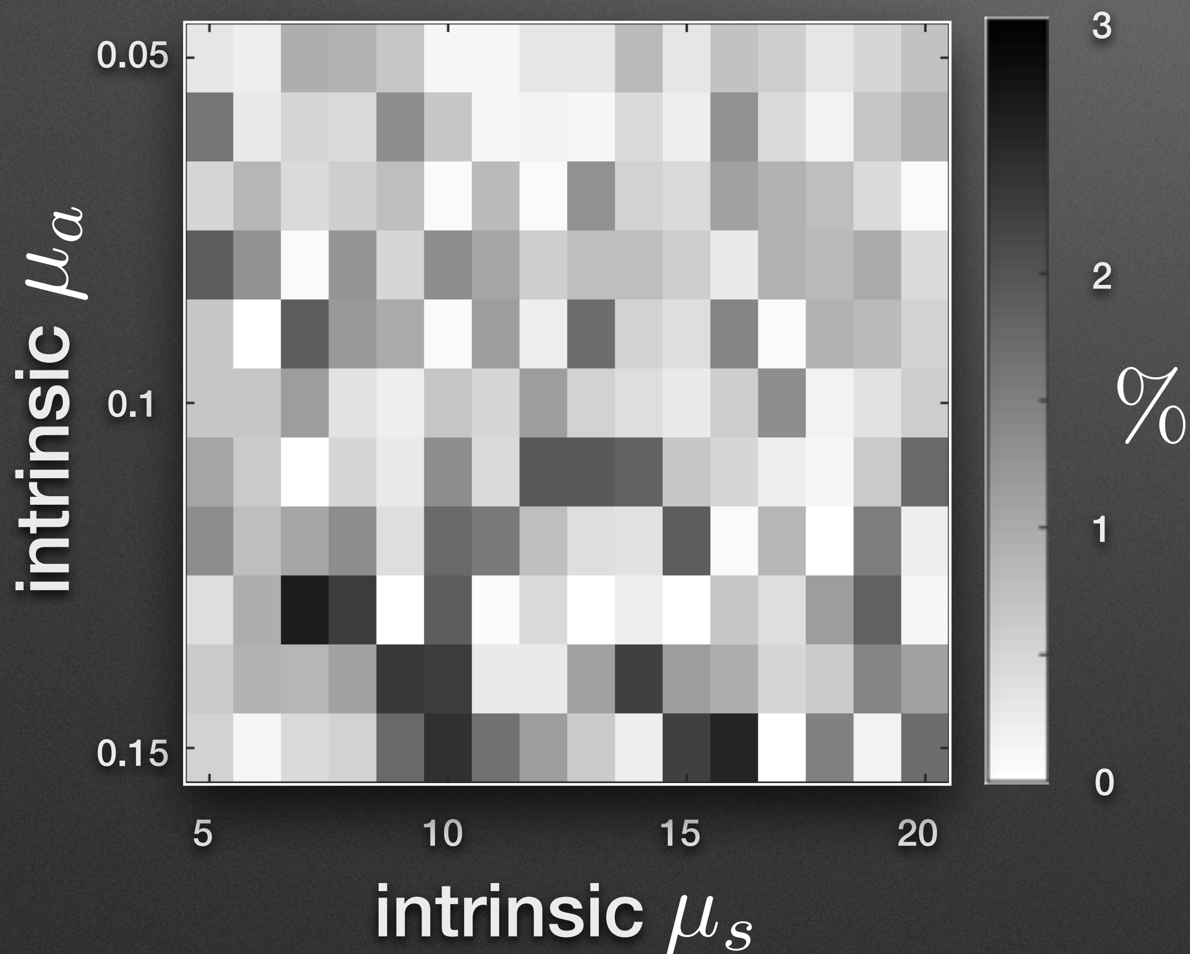


$$\Delta\mu = \frac{\mu_{fit} - \mu_{intrinsic}}{\mu_{intrinsic}} 100\%$$

μ_s

3 degrees of freedom

DFM



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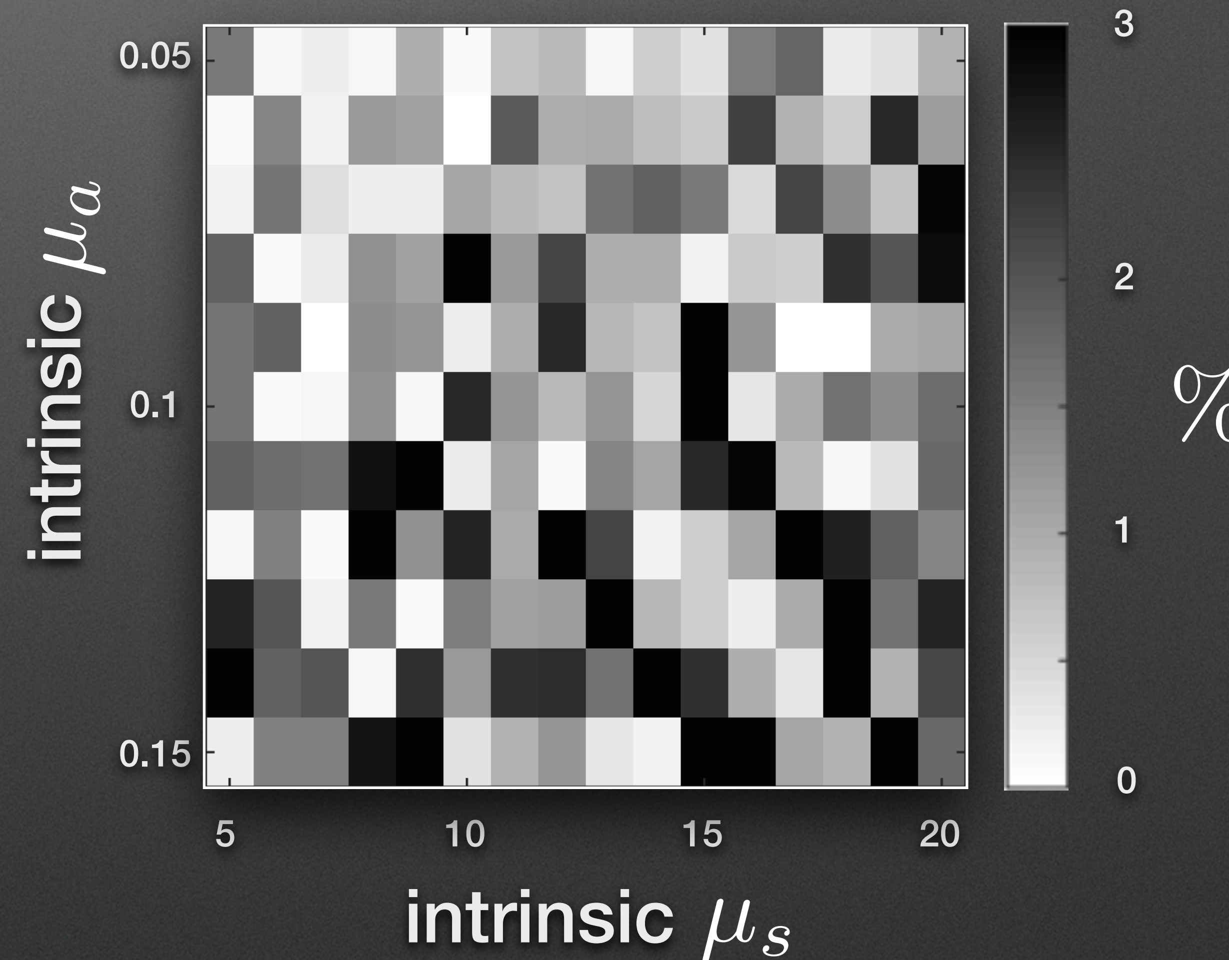

Conclusions

- Presented method of estimation of optical properties allows to precisely calculate macroscopic optical properties despite the noise in the signal and insrumental time shift in the measured data.

- The method is independent on forward model used to simulate times of flight of photons thank you