The long-range correlations of time-resolved speckle patterns
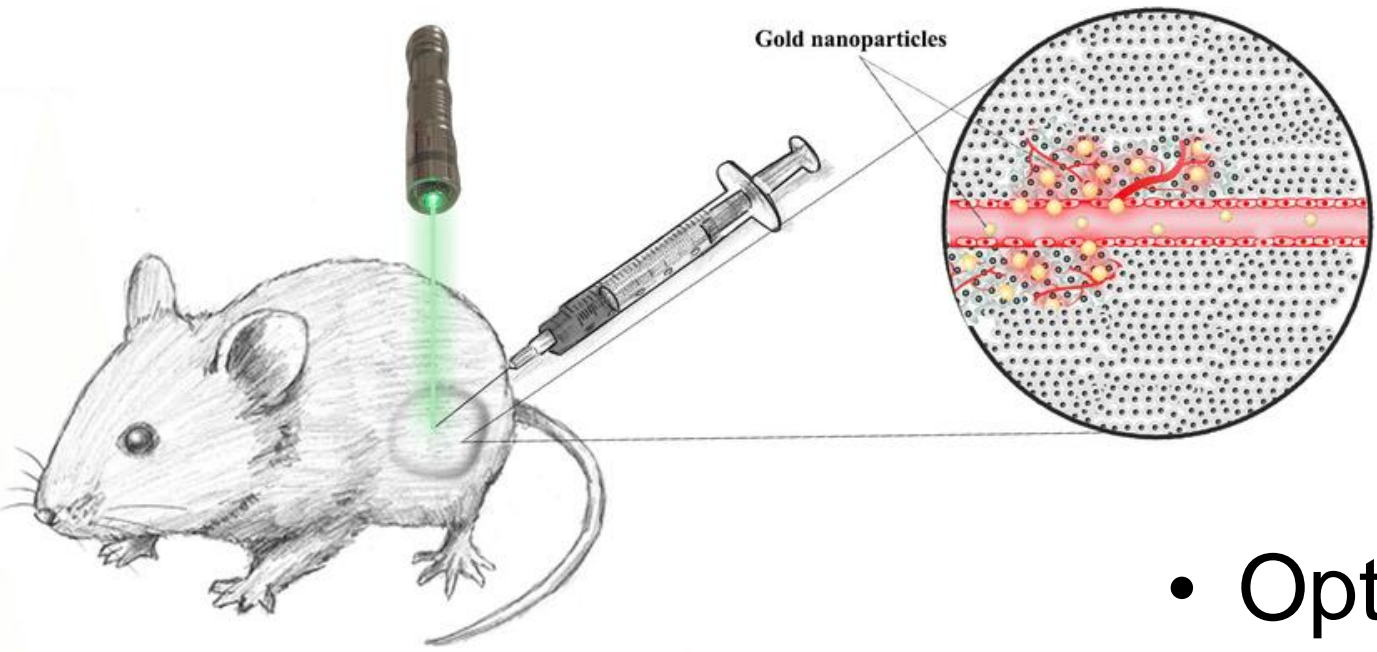
Wonjun Choi[a,b] and Wonshik Choi [a,b] *

[a] Center for Molecular Spectroscopy and Dynamics, Institute for Basic Science (IBS), Seoul 02841, Republic of Korea
[b] Department of Physics, Korea University, Seoul 02841, Korea
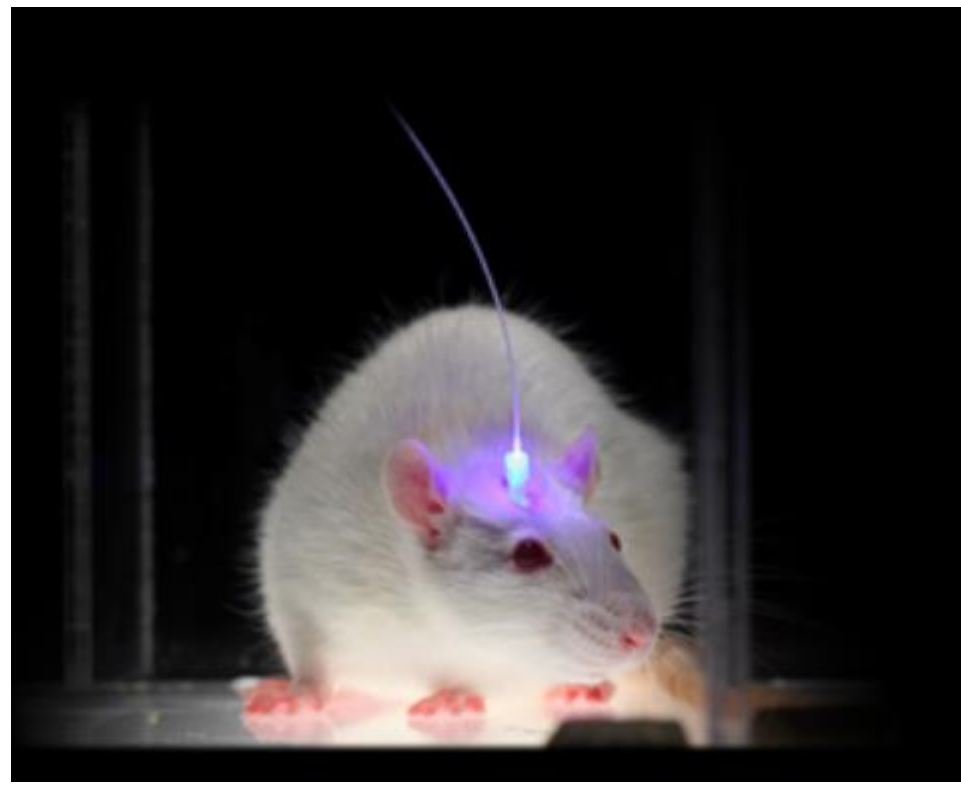
Abstract

Recently we were able to deliver light energy to the objects embedded in a disordered medium by coupling incident light into time-resolved reflection eigenchannels that control the transmittance or reflectance due to the interference between waves experiencing multiple scattering in disordered media. It is well known that the long-range correlations between speckle patterns generated by multiple scattering represent the degree of the interference of the waves in mesoscopic physics. The correlations can therefore be an indicator of the maximal transmittance of the eigenchannels. However, the long-range correlations of the time-resolved speckle patterns have not been studied yet. In this study, we theoretically calculated the long-range correlations of the time-resolved speckle patterns and demonstrated numerical simulations to verify the results.

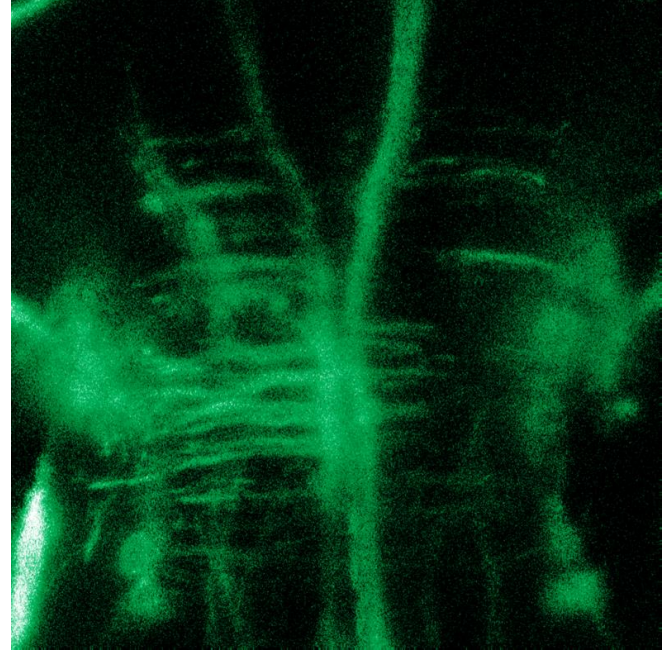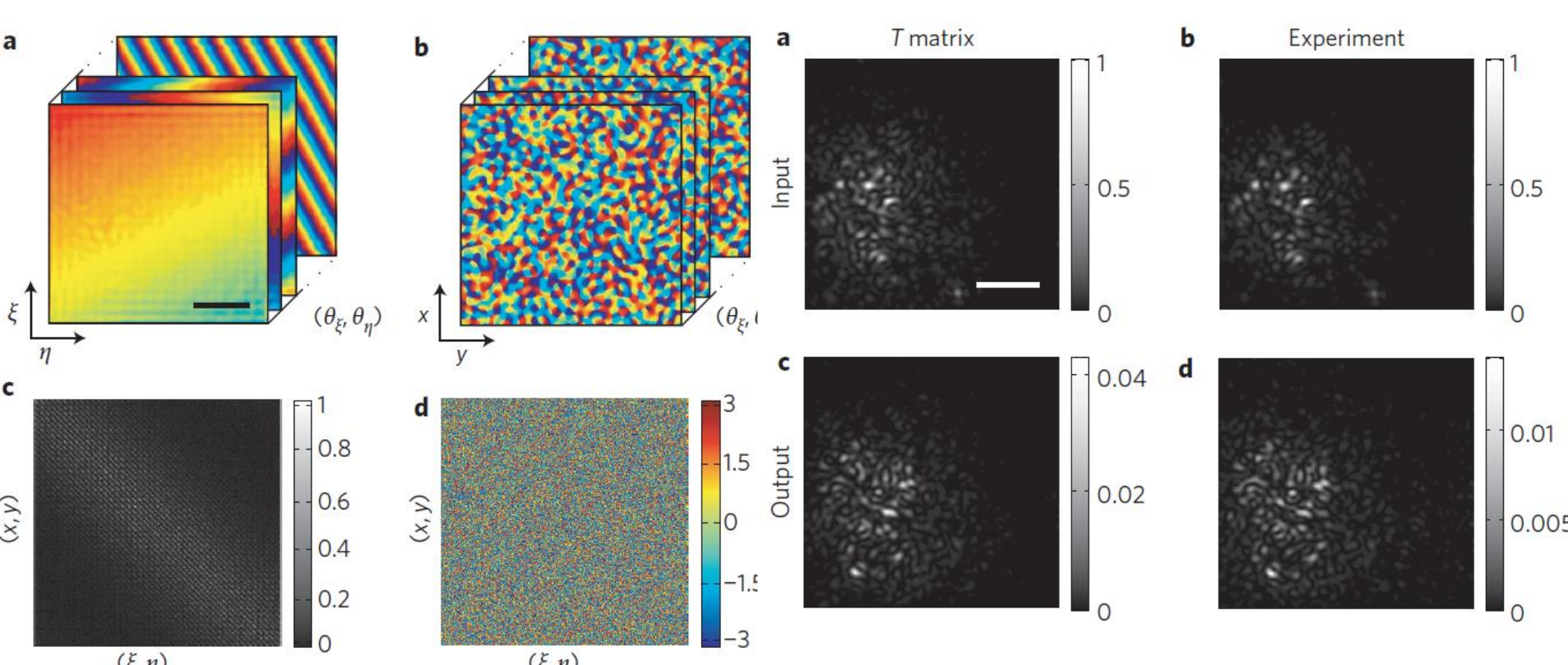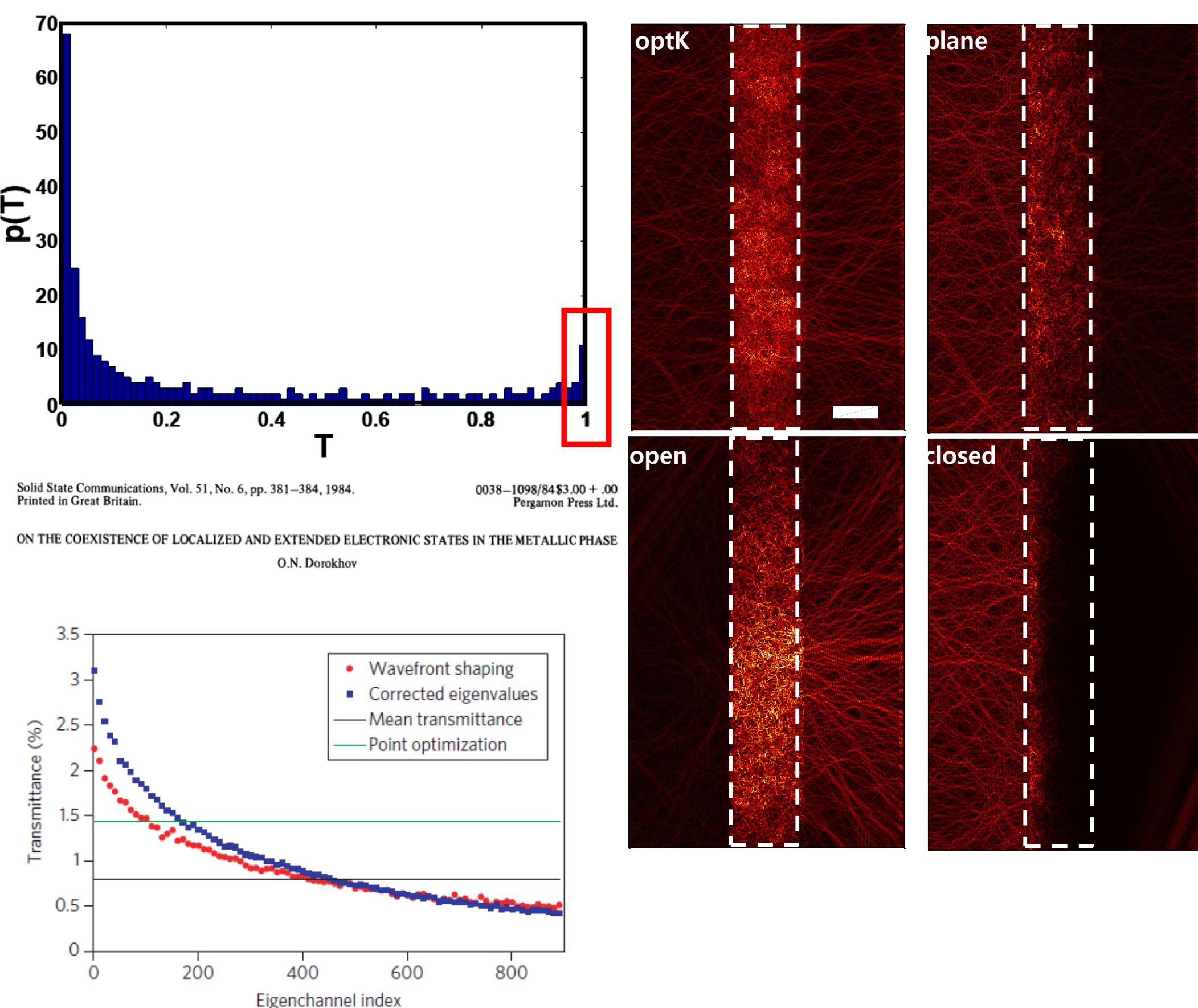## Motivation of light energy delivery

- Photothermal therapy

- Fluorescence imaging

- Optogenetics
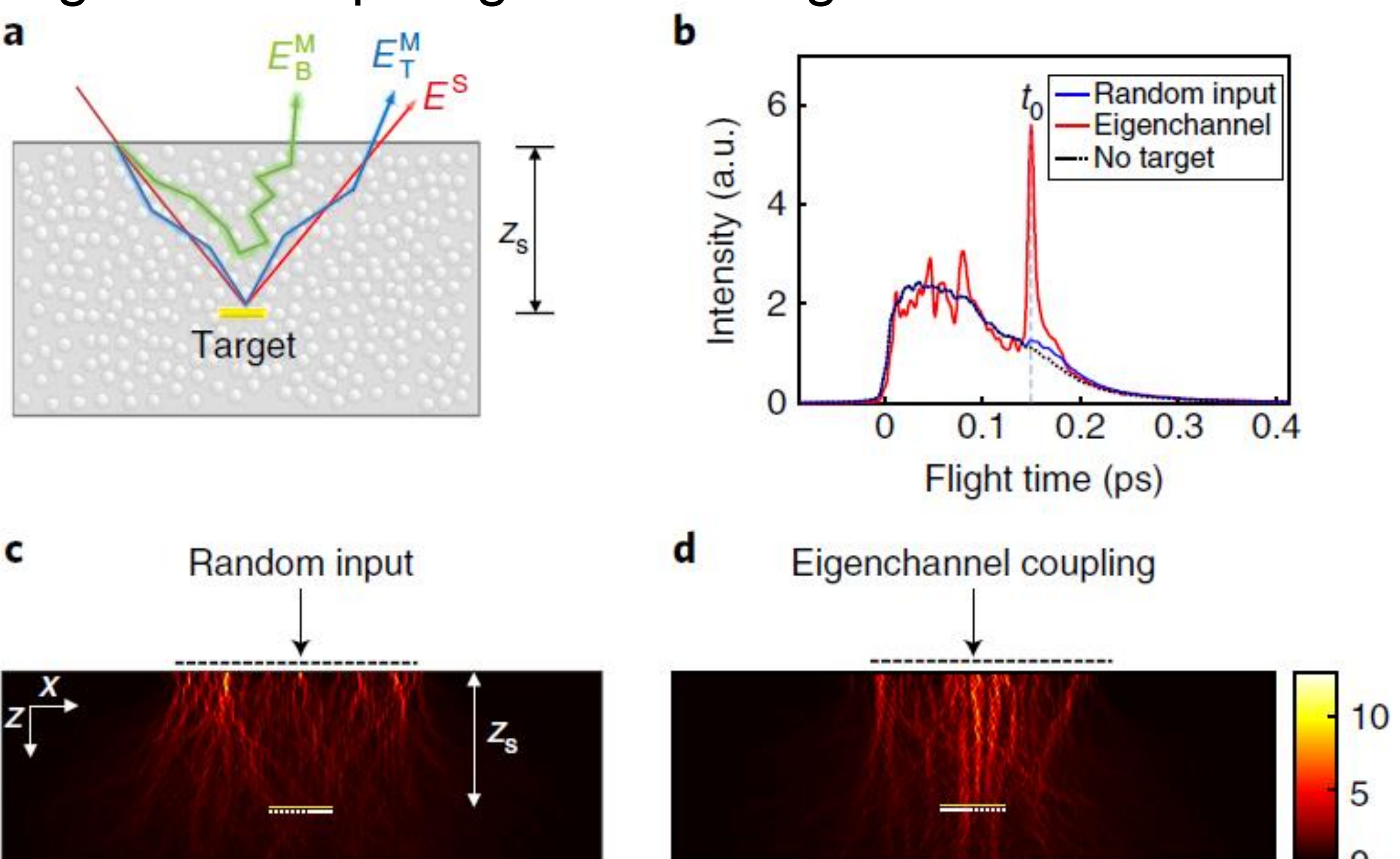

Motive researches

- Perfect transmission by Eigenchannel

Solid State Communications, Vol. 51, No. 6, pp. 381–384, 1984.
ON THE COEXISTENCE OF LOCALIZED AND EXTENDED ELECTRONIC STATES IN THE METALLIC PHASE
O.N. Dorokhov

- Focusing of light energy by controlling time-gated multiple light scattering

Theoretical background

- Diffuson approximation

$$P(r,r') \propto \overline{\sum_{i,j} a_i^*(r,r')a_j(r,r')}.$$

$$(r,r') \propto \overline{\sum_j |a_j(r,r')|^2} + \overline{\sum_{i \neq j} a_i^*(r,r')a_j(r,r')}.$$

$$P_{cl}(r,r') \propto \overline{\sum_j |a_j(r,r')|^2}.$$
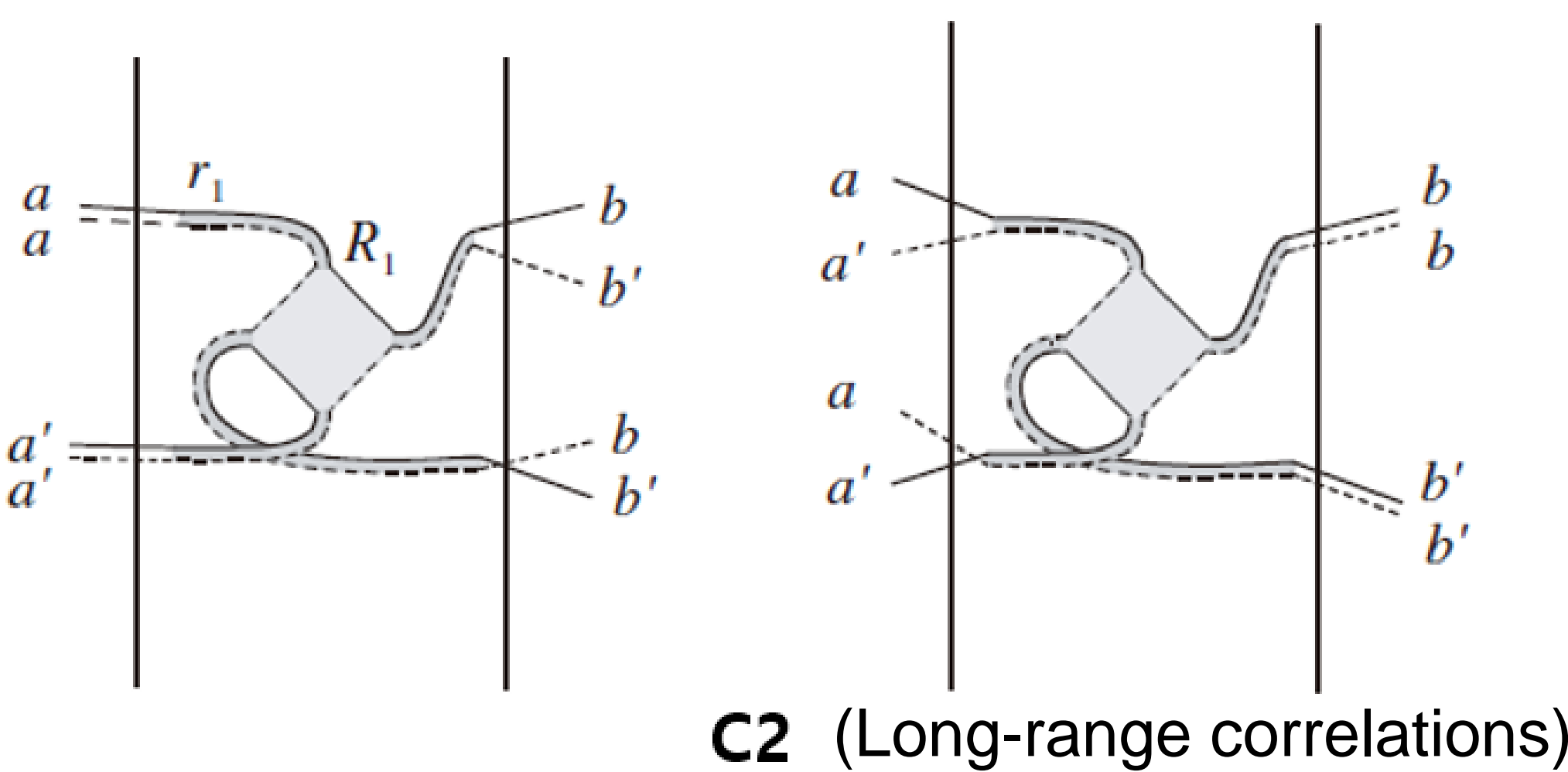
- Quantum crossing
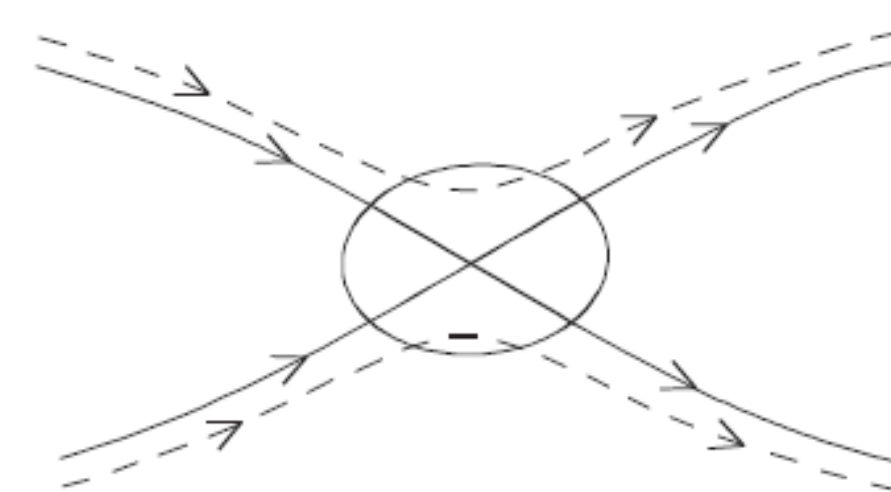
- Angular correlations

$$C_{aba'b'} = \frac{\overline{\delta T_{ab}\delta T_{a'b'}}}{\overline{T}_{ab}\overline{T}_{a'b'}}$$

$$= \frac{\overline{T_{ab}T_{a'b'}}}{\overline{T}_{ab}\overline{T}_{a'b'}} - 1$$

$$= C^{(1)} + C^{(2)} + C^{(3)}$$

C1 (Short-range correlations)

C2 (Long-range correlations)

Experimental setup for measurement of C2(t)

- Experimental setup for measurement of C2(t)

$\lambda_0 = 800$ nm
$\Delta\lambda = 10$ nm

Ti:sapphire laser

$\Delta t \sim 100$ fs
$l_c \sim 30 \mu m$

BS1
Sample Arm
GM

NA = 1.0
WD = 2.8 mm
Field of view: 100 μm x 100 μm

OL_{ill}
5.6 mm
OL_{col}

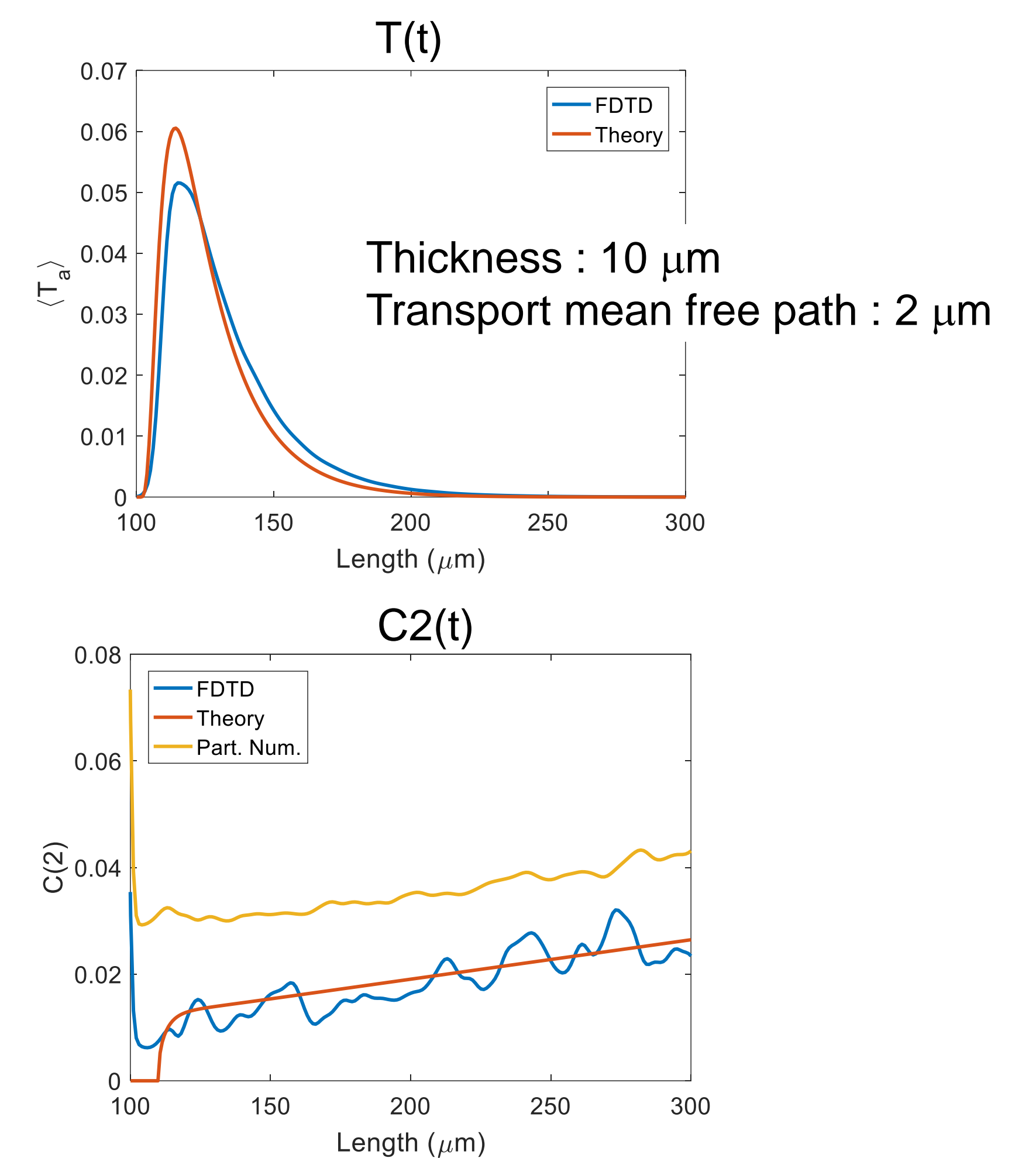M   BS2   G   BS3   sCMOS

Reference Arm

Long-range correlations of time-resolved speckle patterns

- Diagram for long-range correlations of time-resolved system
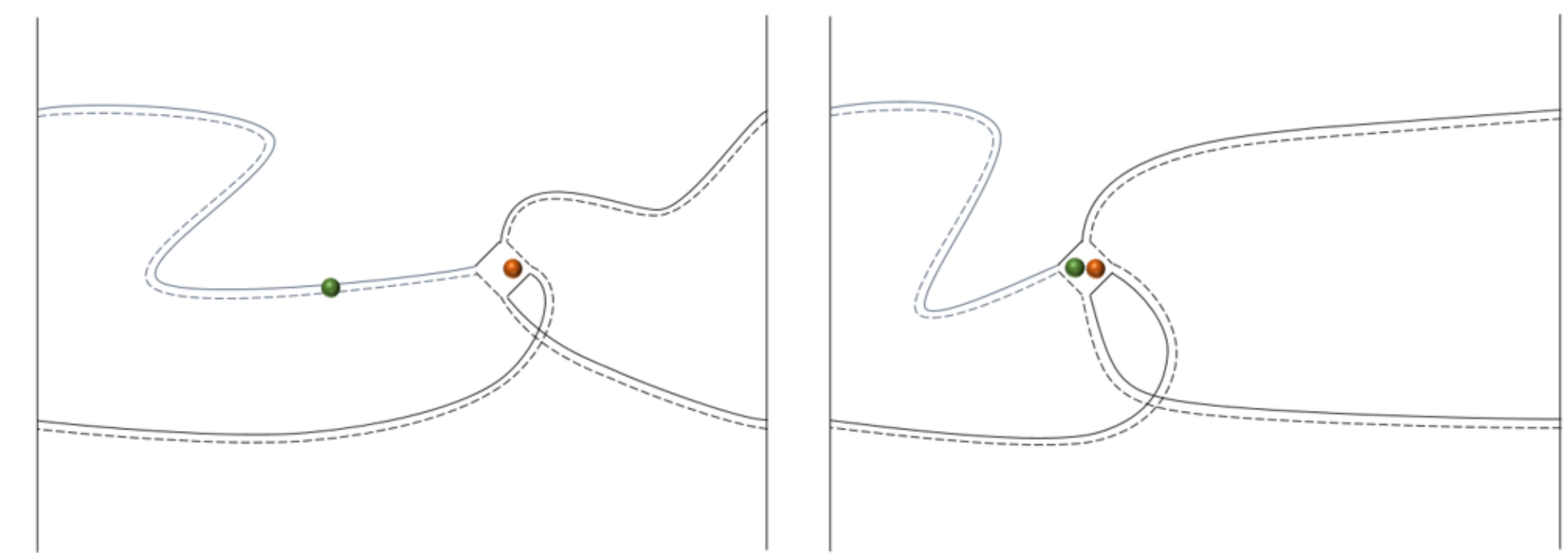
- Theoretical and Numerical calculation

T(t)

Thickness : 10 μm
Transport mean free path : 2 μm

C2(t)

Summary

- It is well known that the long-range angular correlations are related with the interference to increase the transmittance in disordered medium.

- We suggested the diagram to model the long-range angular correlations of time-resolved speckle patterns

- We theoretically calculated the C2(t) by means of our diagrammatic model and confirmed that our calculations are matched with the numerical calculation (finite difference time domain).

- We are conducting the experimental study to measure the C2(t).

- Our study is helpful to understand the energy delivery by controlling multiple scattered light in time-resolved system.

ibs 기초과학연구원 Institute for Basic Science   고려대학교 KOREA UNIVERSITY   CMSD Center for Molecular Spectroscopy and Dynamics, IBS-Korea University