Transport of light in complex media

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SC'11

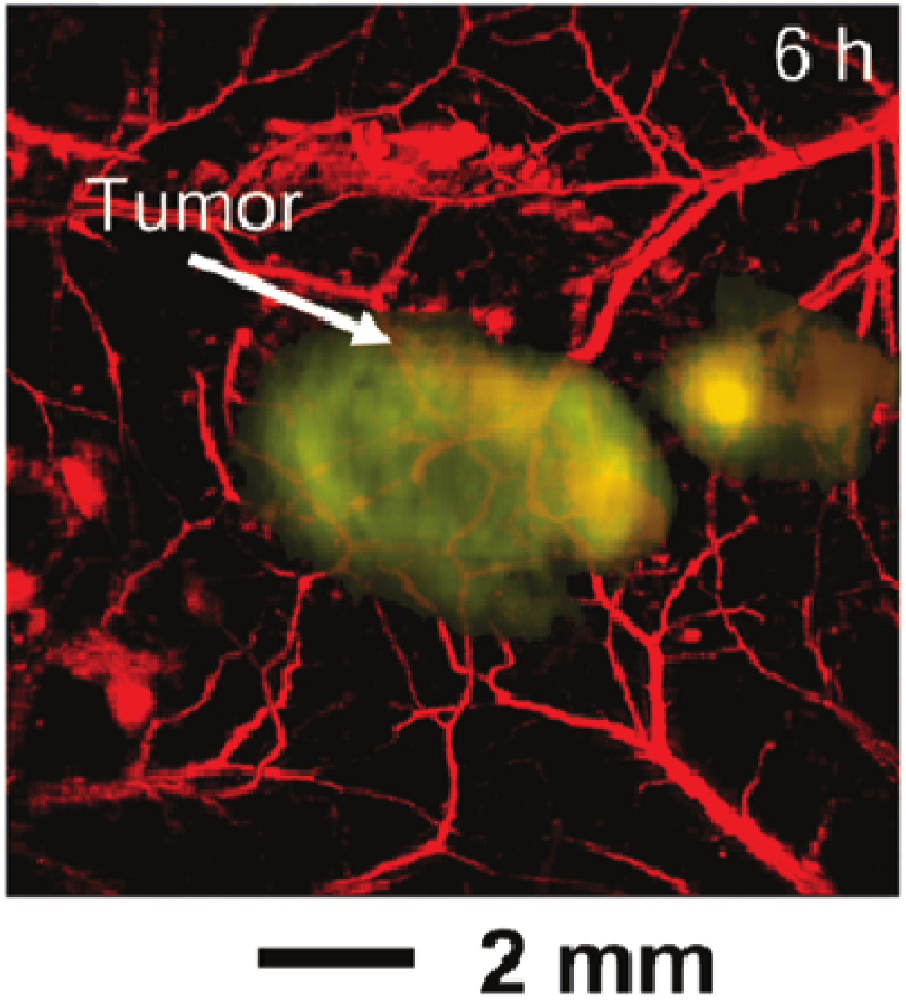
CUDA Research Fast Forward

http://www.nvidia.com/object/sc11.html

Pan-American Advanced Studies Institute

Vegetables as Random Laser

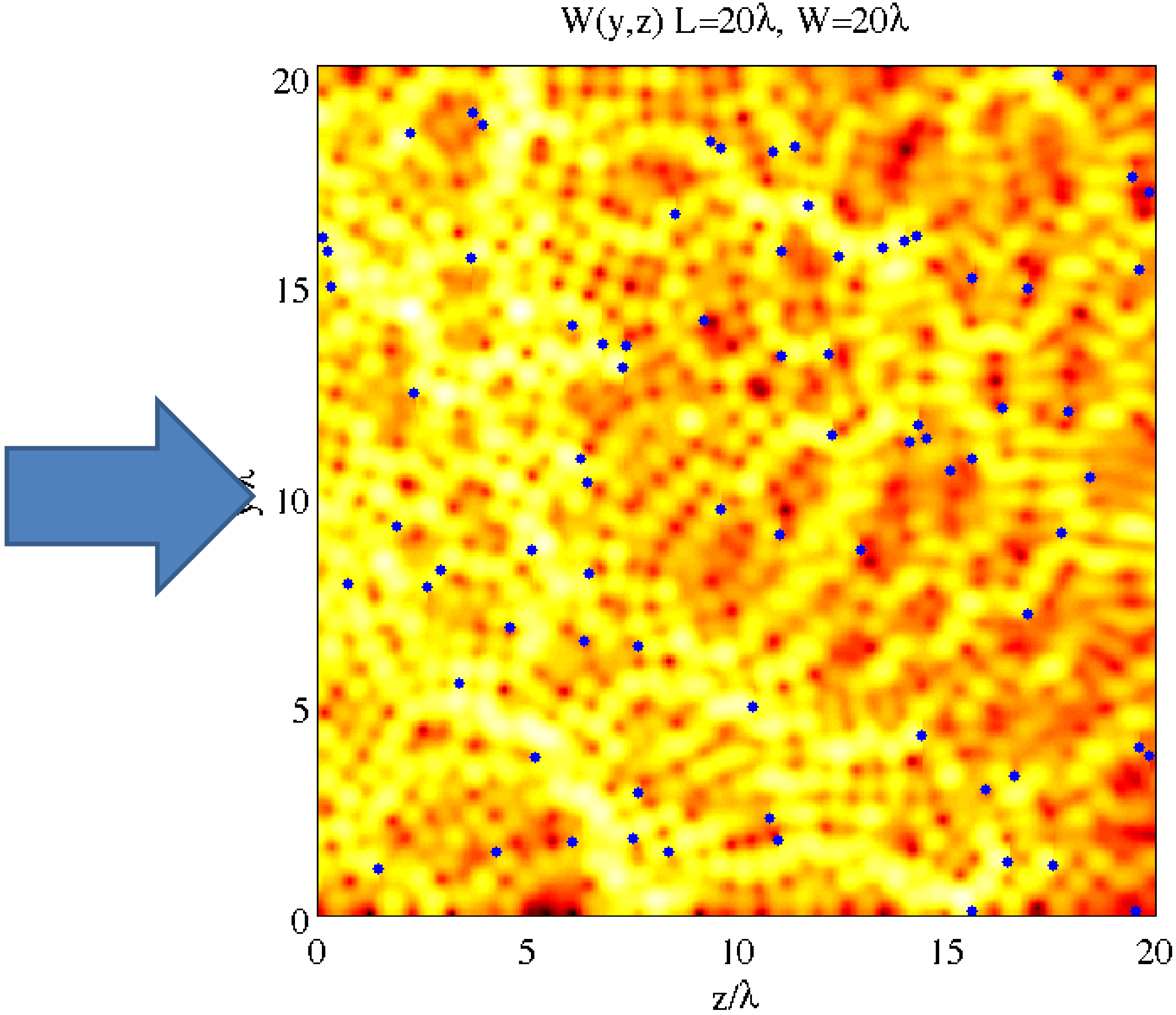
Cancer detection using light



http://labs.seas.wustl.edu/bme/Wang/image_gallery.html
Kim, et. al, ACS Nano 2010

Wave Interference

Model wave propagation



Numerical model description

- Transfer matrix method
- renormalization

$$
\left[\begin{array}{cc:cc}
\cos(k_{\parallel}\Delta z)\ \ddots & 0 & -\sin(k_{\parallel}\Delta z)\ \ddots & 0 \\
0 & \cosh(i\kappa_{\parallel}\Delta z)\ \ddots & 0 & \sinh(i\kappa_{\parallel}\Delta z)\ \ddots \\
\hdashline
-\sin(k_{\parallel}\Delta z)\ \ddots & 0 & \cos(k_{\parallel}\Delta z)\ \ddots & 0 \\
0 & \sinh(i\kappa_{\parallel}\Delta z)\ \ddots & 0 & \cosh(i\kappa_{\parallel}\Delta z)\ \ddots
\end{array}\right]
\left[\begin{array}{cc:cc}
1 \ \ddots \ 1 & 0 & 0 & 0 \\
0 & 1 \ \ddots \ 1 & 0 & 0 \\
\hdashline
\Gamma_{oo} & \Gamma_{co} & 1 \ \ddots \ 1 & 0 \\
\Gamma_{oc} & \Gamma_{cc} & 0 & 1 \ \ddots \ 1
\end{array}\right]
\left[\begin{array}{cc:cc}
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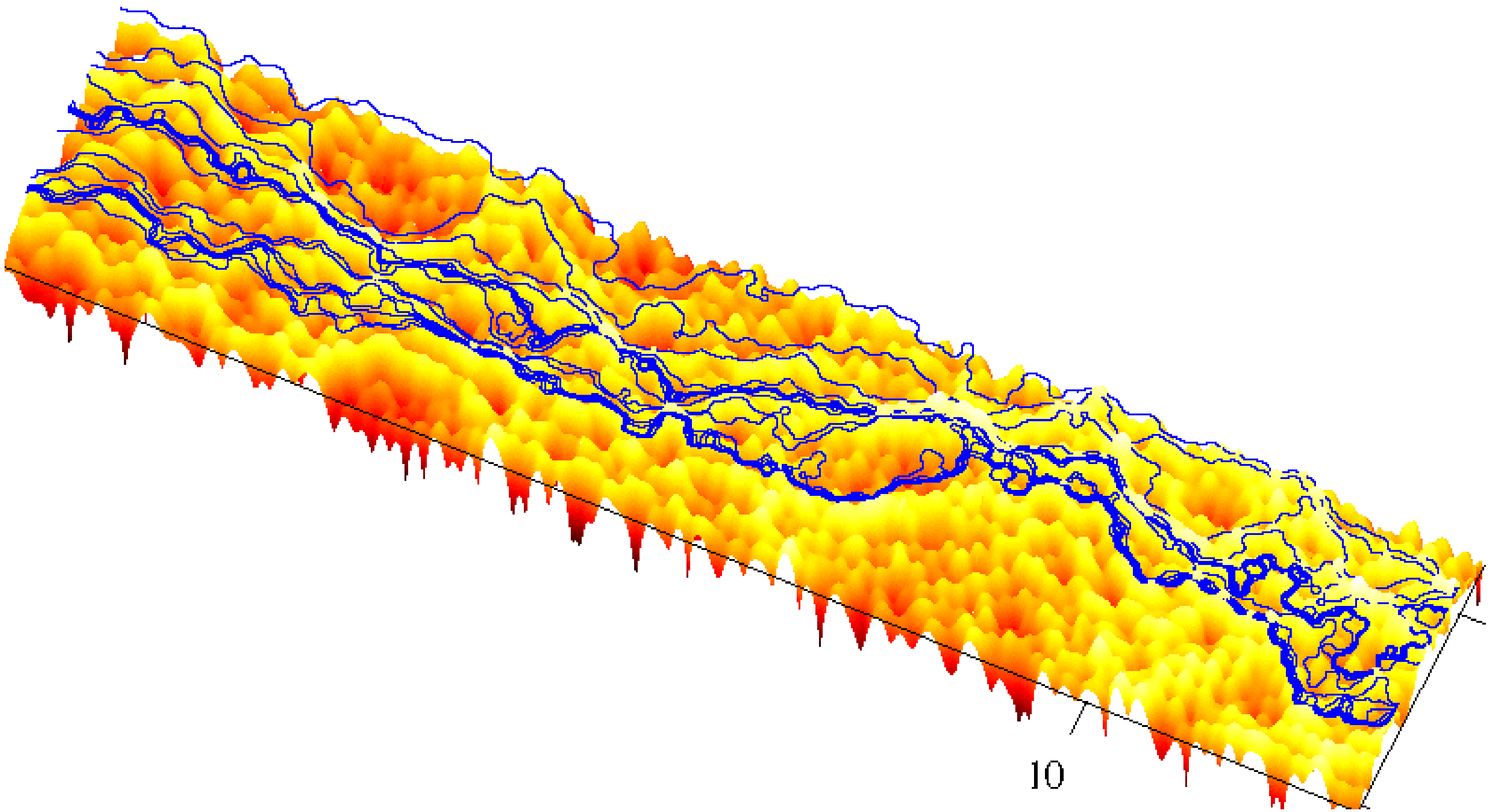
\end{array}\right]
$$

Why model light?

- Experimentally hard to vary absorption
- Determine reasons behind observed effects

Capabilities

- Any aspect of single realization of disordered waveguide
- Statistics of $>10^7$ distinct waveguides



Computational Model Capabilities

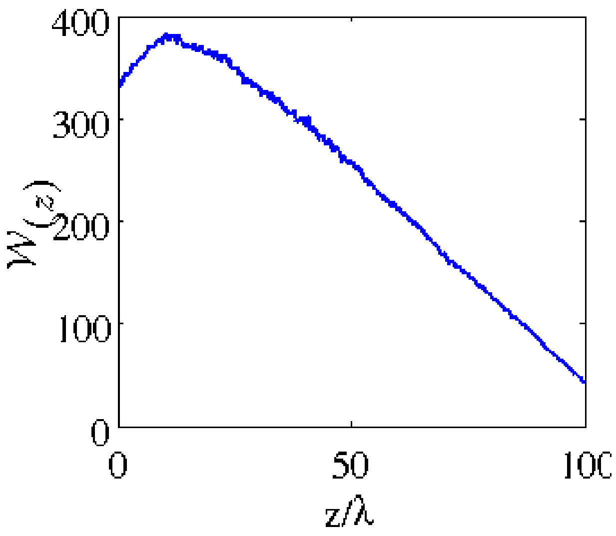
- Eigenvalues
- Eigenvalue distribution
- Conductance distribution
- Scaling of conductance: Ohm’s Law
- Critical lasing threshold
- Poynting vector paths
- Position dependent diffusion coefficient
- Inverse participation ratio
- Flux as a function of position
- Intensity
- Electric fields
- Eigenmodes of waveguide
- Ensemble statistics and individual realizations

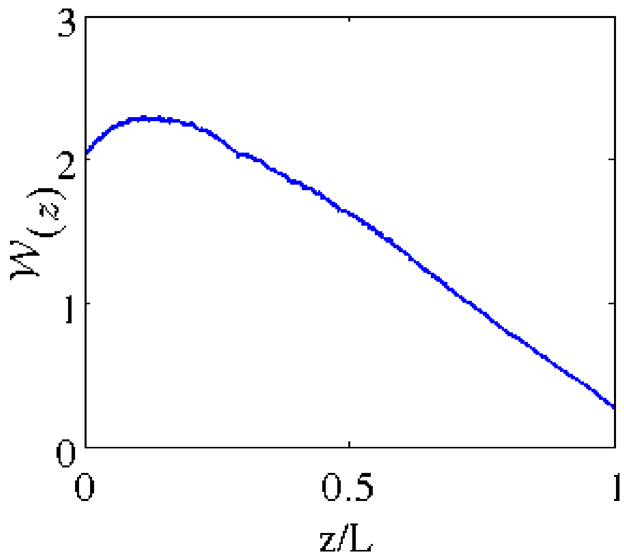
- Incident flux method
  - plane wave
  - unit flux per channel
- Wavefront shaping
- Random incident phase
- Phase coherent length
- Local Density of States
- Mode line width
- Mode separation
- Complex transmission matrix
- Complex reflection matrix
- forward and backward flux per channel
- Variable waveguide geometry
- Singularities due to size

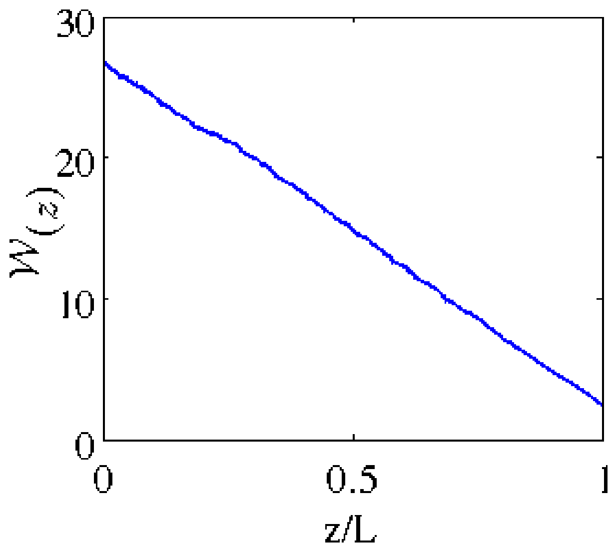
Any well-defined metric

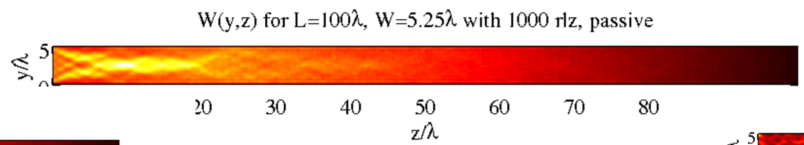
Any combination of parameters

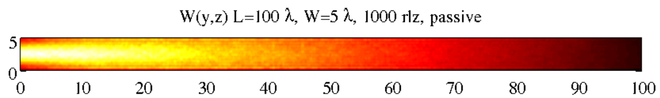
Comparison of Intensity for various incident flux

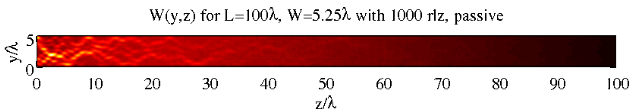












plane wave,
lowest mode only
1000 realizations

plane wave,
1000 realizations

simultaneous unit flux,
random incident phase,
1000 realizations

Computational Challenge

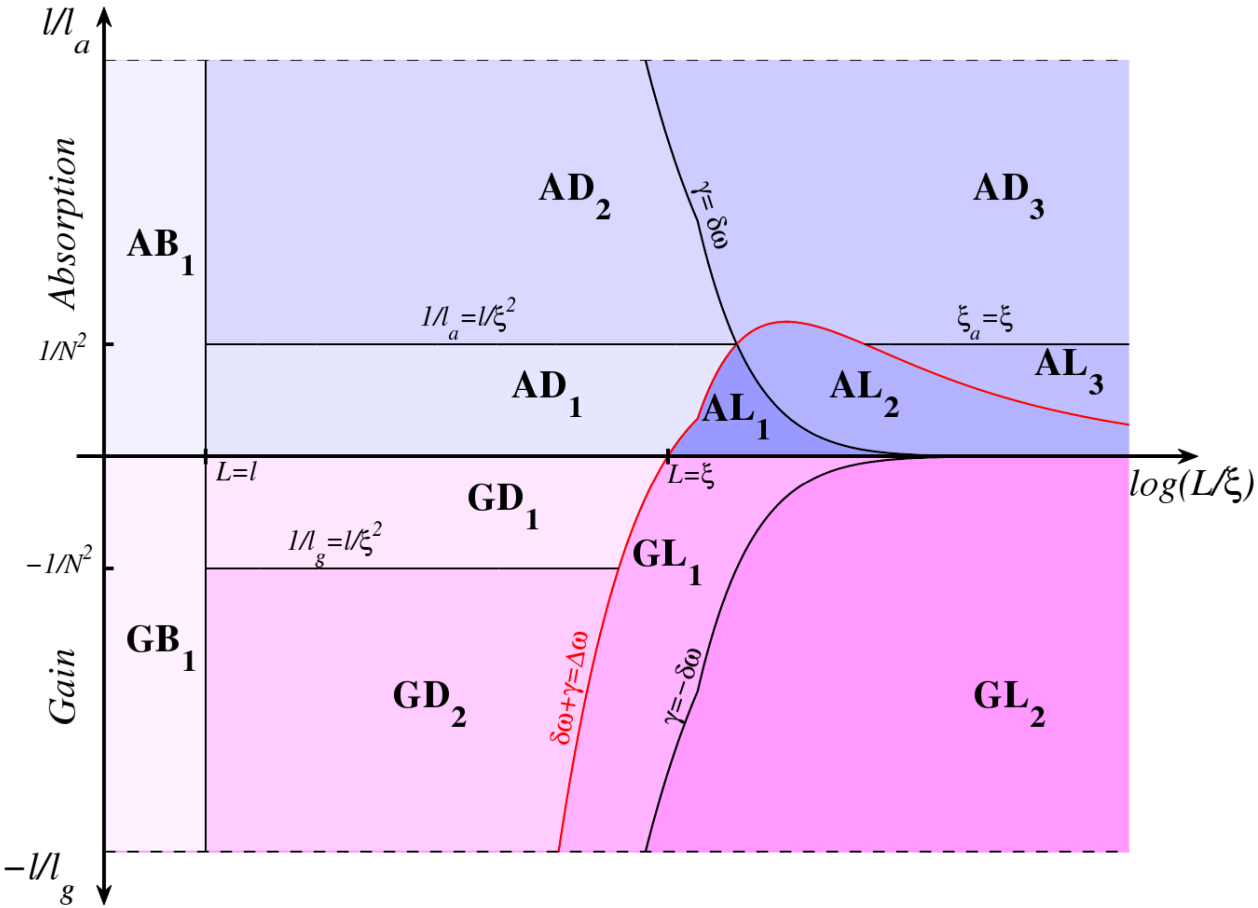
Parameter space of

- varying geometry
- absorption, gain

16,000 CPUs

1M hours

Phase diagram of light transport



“Classification of regimes of wave transport in non-conservative random media”
Alexey Yamilov and Ben Payne; Journal of Modern Optics (2010)

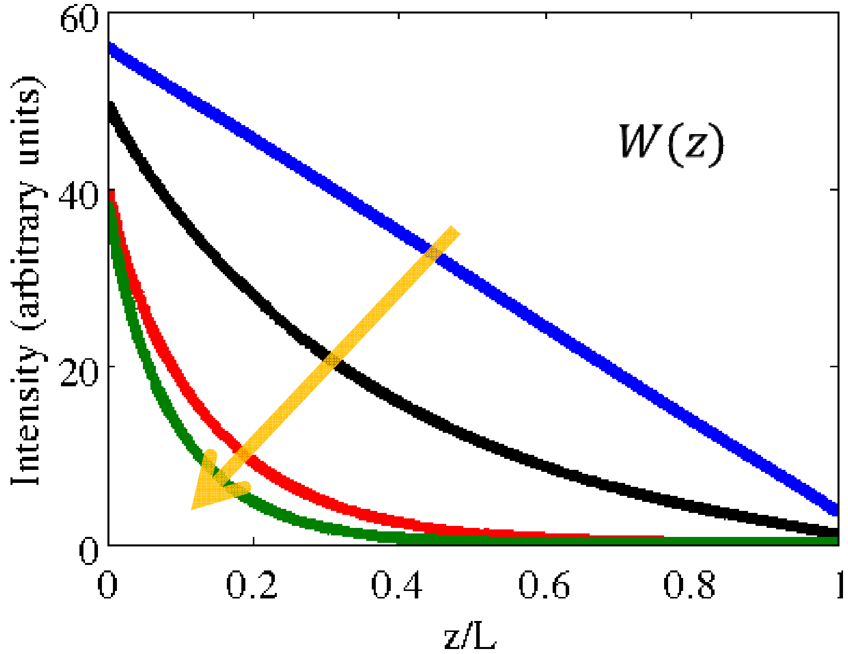
Position-dependent diffusion coefficient

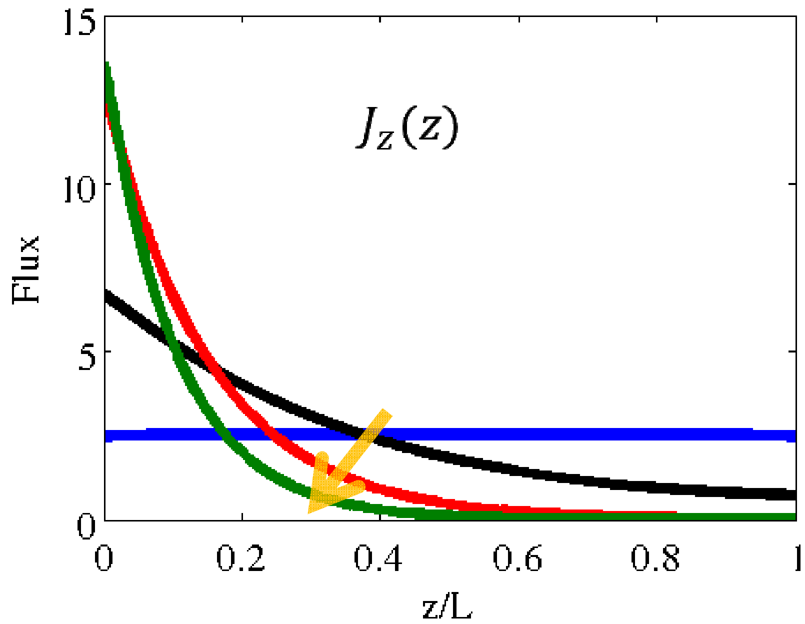
$$D(z) = \frac{-J_z(z)}{\frac{d\mathcal{W}(z)}{dz}}$$

Corrections to diffusion due to interferences of waves

How to find D(z)

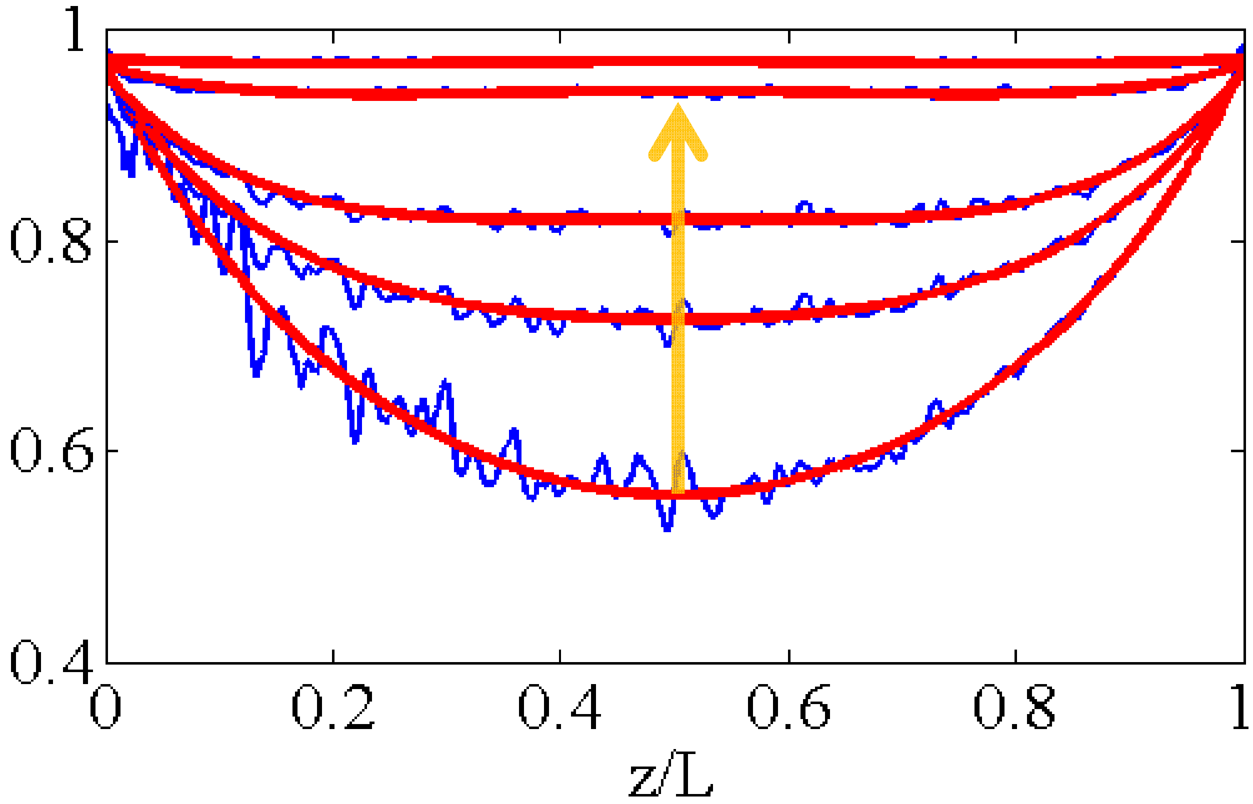
$$D(z) = \frac{-J_z(z)}{\frac{d\mathcal{W}(z)}{dz}}$$





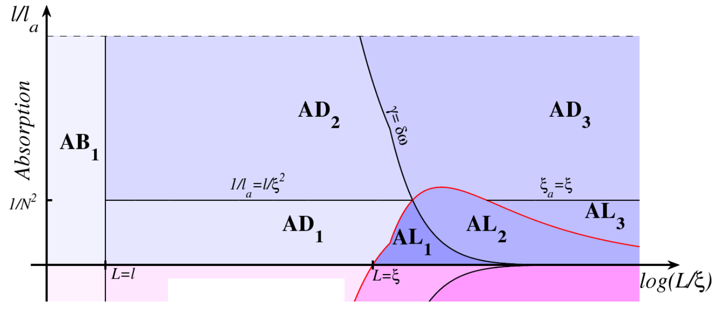
Position-dependent diffusion coefficient
Varying absorption

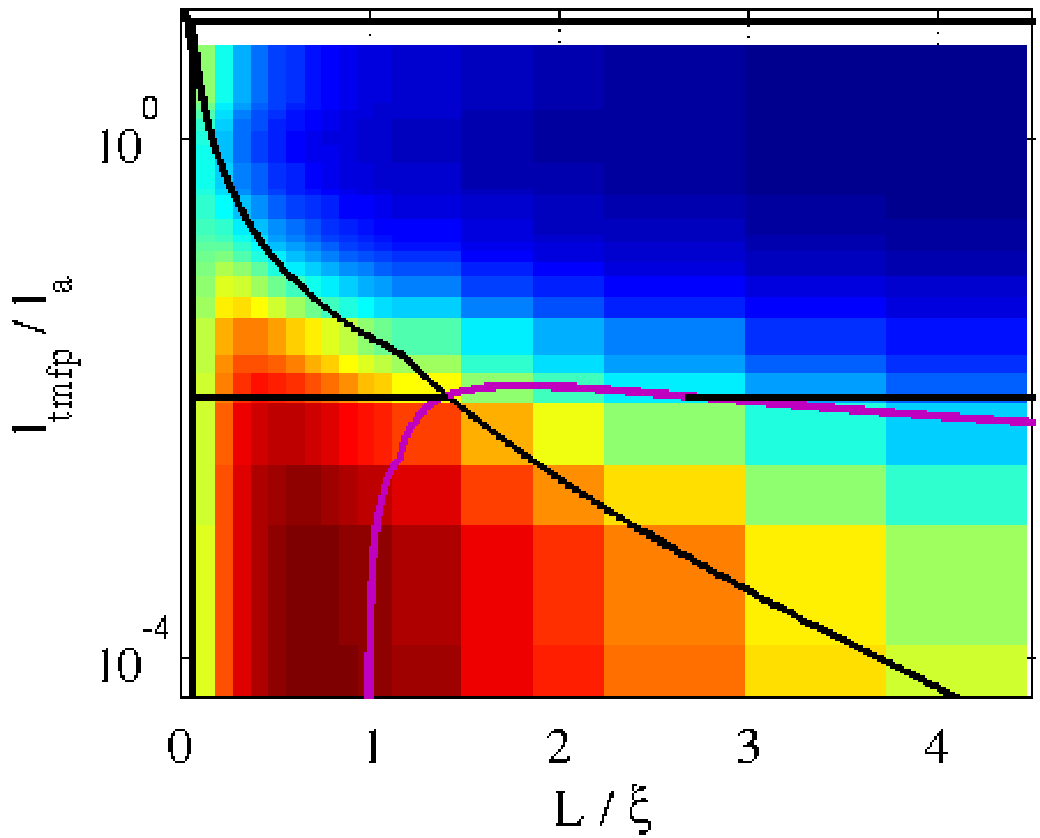
$$D(z) = \frac{-J_z(z)}{\frac{d\mathcal{W}(z)}{dz}}$$



Corrections to diffusion due to interferences of waves

Numerically validate predicted regimes





Consequences

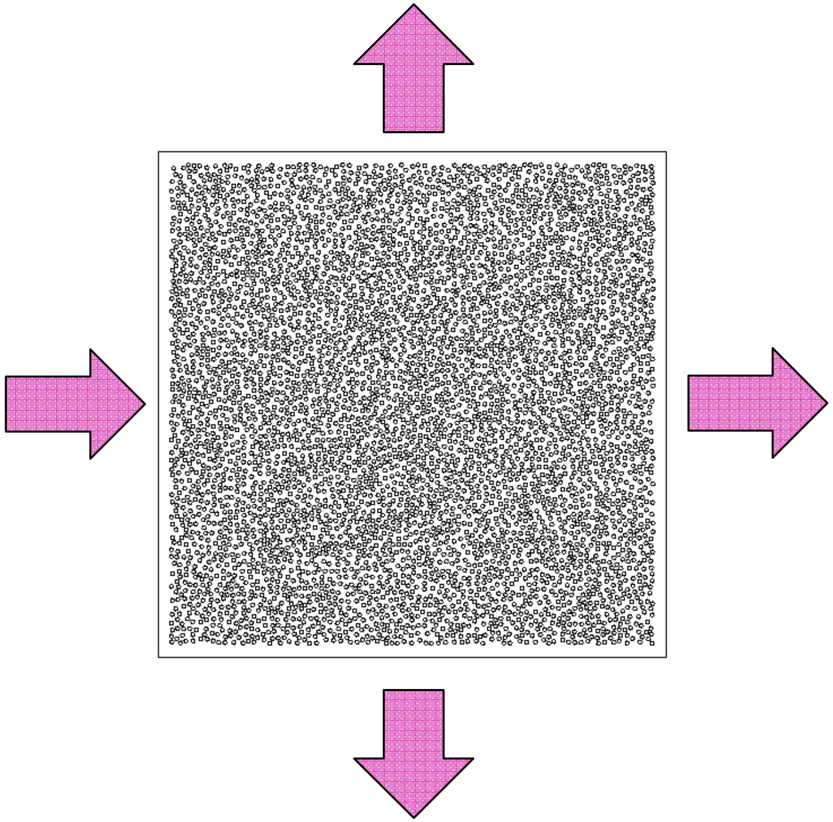
- Made prediction; verify computationally
- Guide experiment

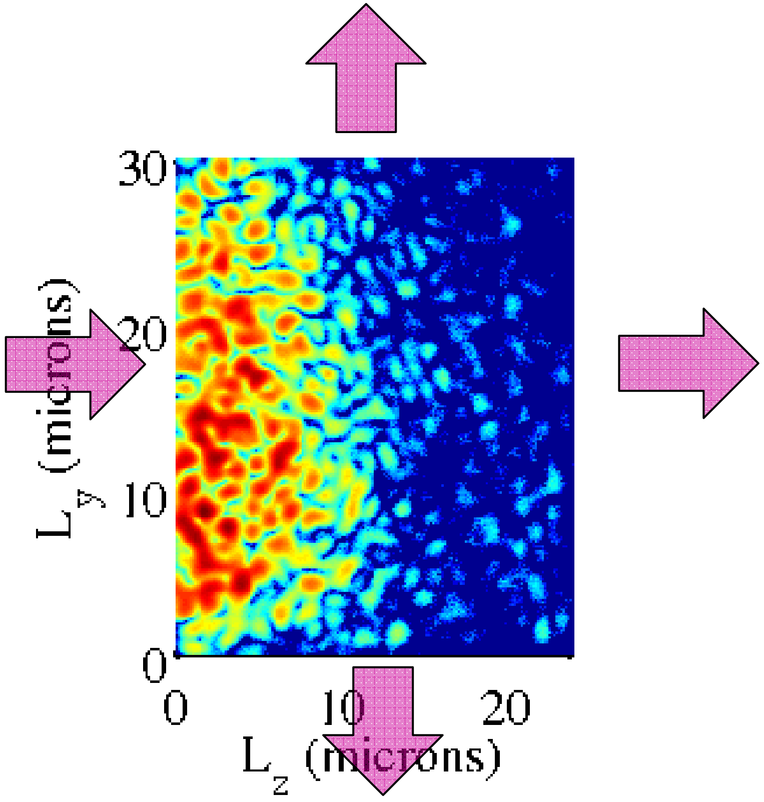
Consequences

- Made prediction; verify computationally
- Guide experiment
- Explain results

Compare Experiment and Numerical Simulation

Random scattering, fit intensity

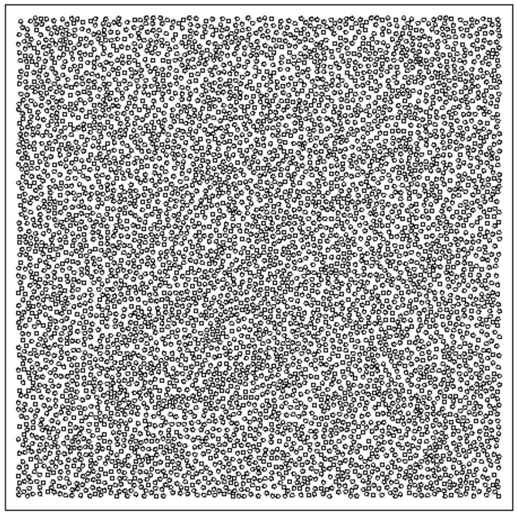




Design novel transport media

Instead of looking for unusual behavior, create it!

Random



Aperiodic