Full-wave modelling of wavefront shaping and memory effects through scattering media using the T-matrix method

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Outline

We present a physically realistic and efficient method of modelling wavefront shaping (WFS) and memory correlations through bespoke scattering media.

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    1. **What is wavefront shaping**
    2. **Requirements of a model of wavefront shaping**
    3. **Existing methods of simulating wavefront shaping**

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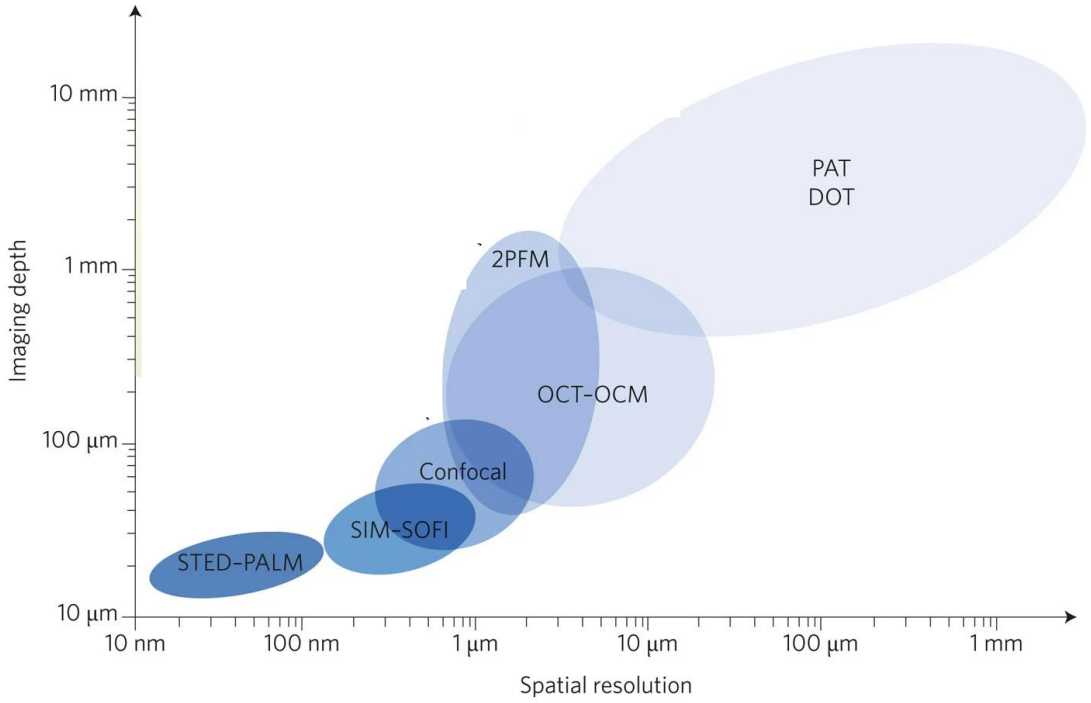
    3. Focusing through titanium dioxide phantoms
    4. Forming a focus inside tissue-like media
    5. What are memory correlations?
    6. Measuring memory correlations
3. Conclusions + acknowledgements

Background + Motivations

What is wavefront shaping?

Optical imaging techniques are depth limited



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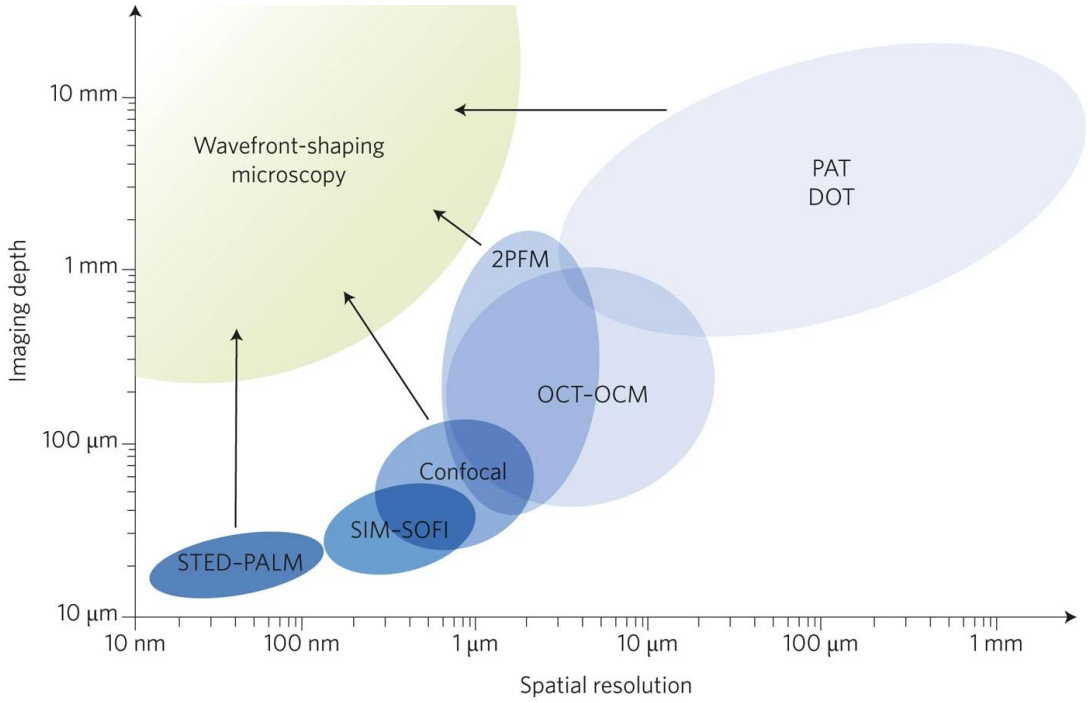

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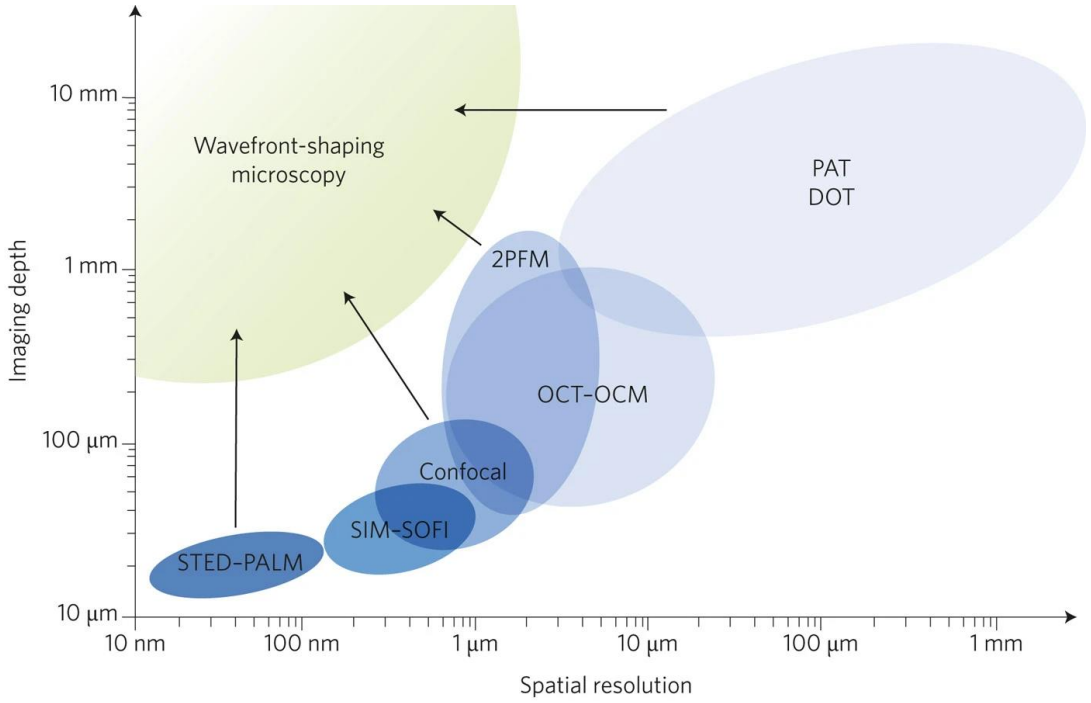

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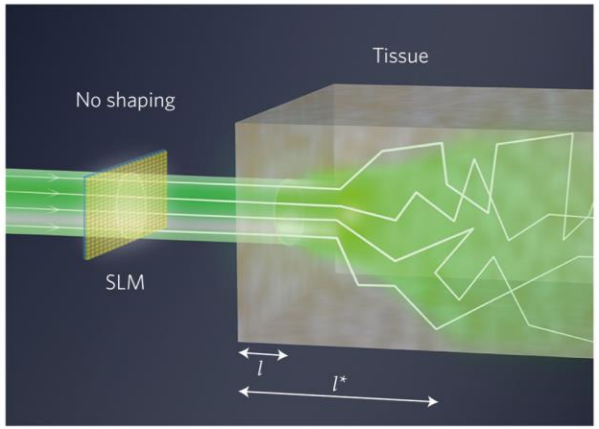

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Incident unoptimized light is scattered

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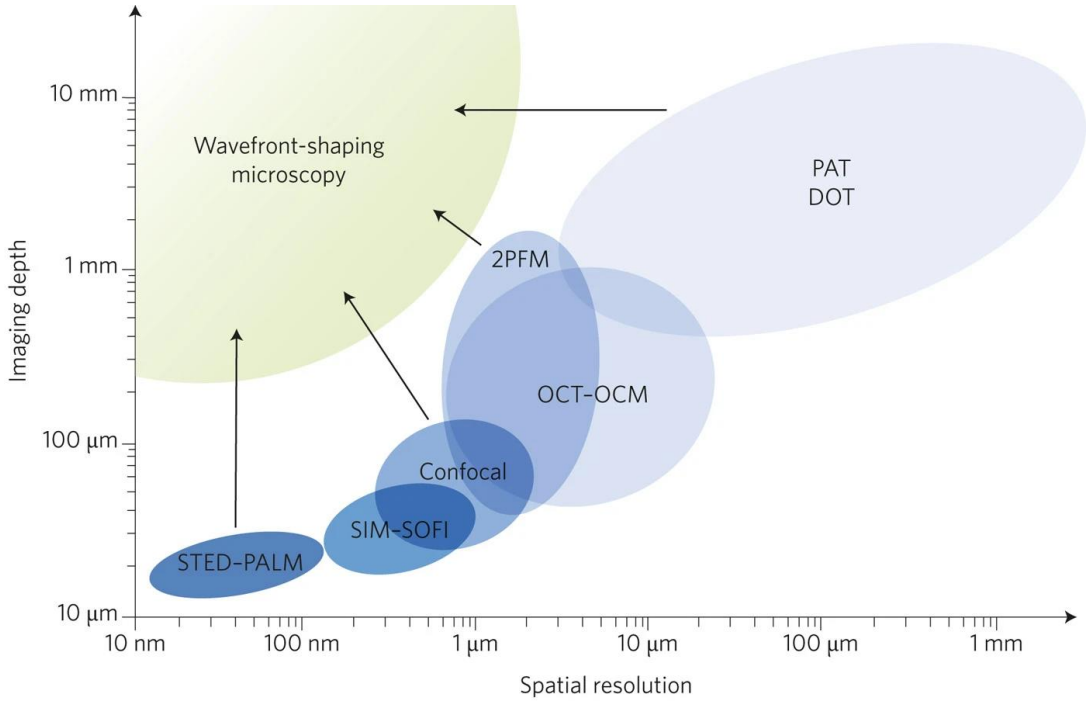

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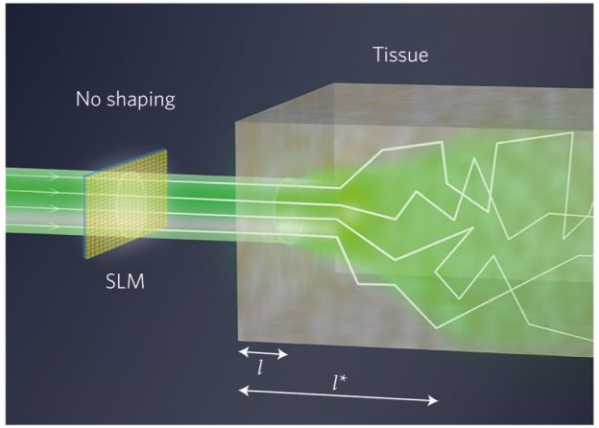

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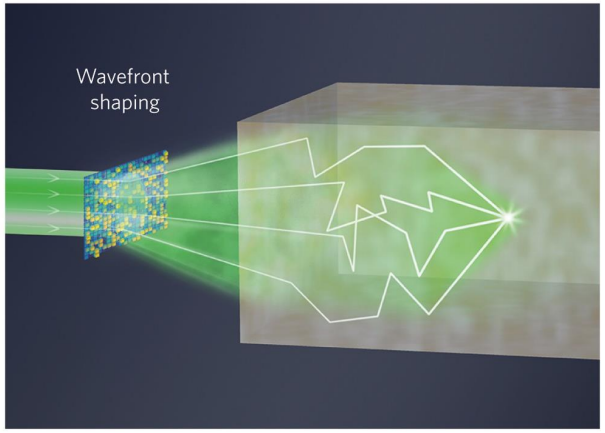
Incident unoptimized light is scattered

Shaped light constructively interferes and can produce a focus

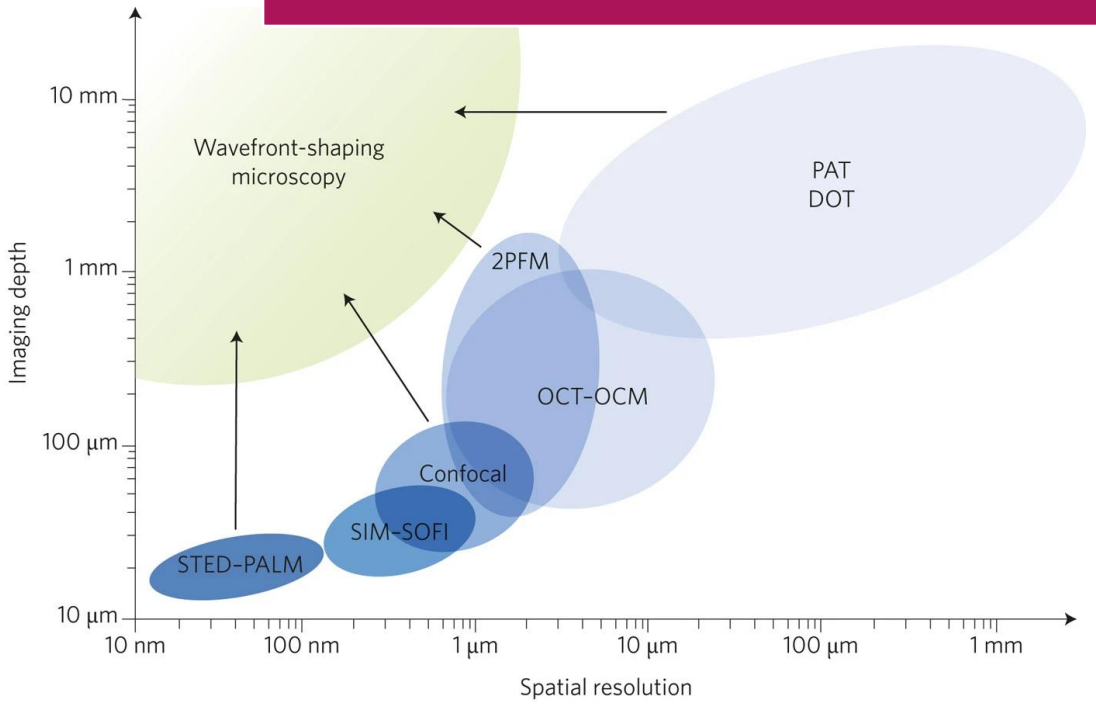


Background + Motivations

What is wavefront shaping?

Opt **aping**

How deep can we generate a focus?



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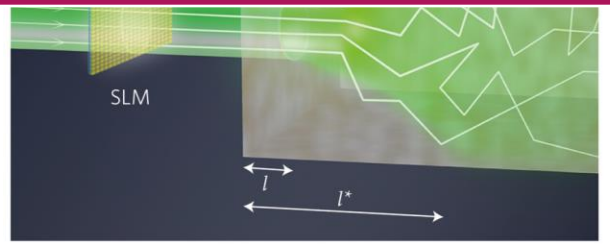

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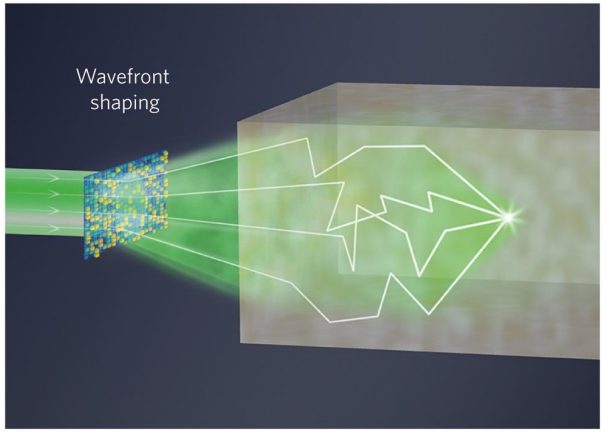

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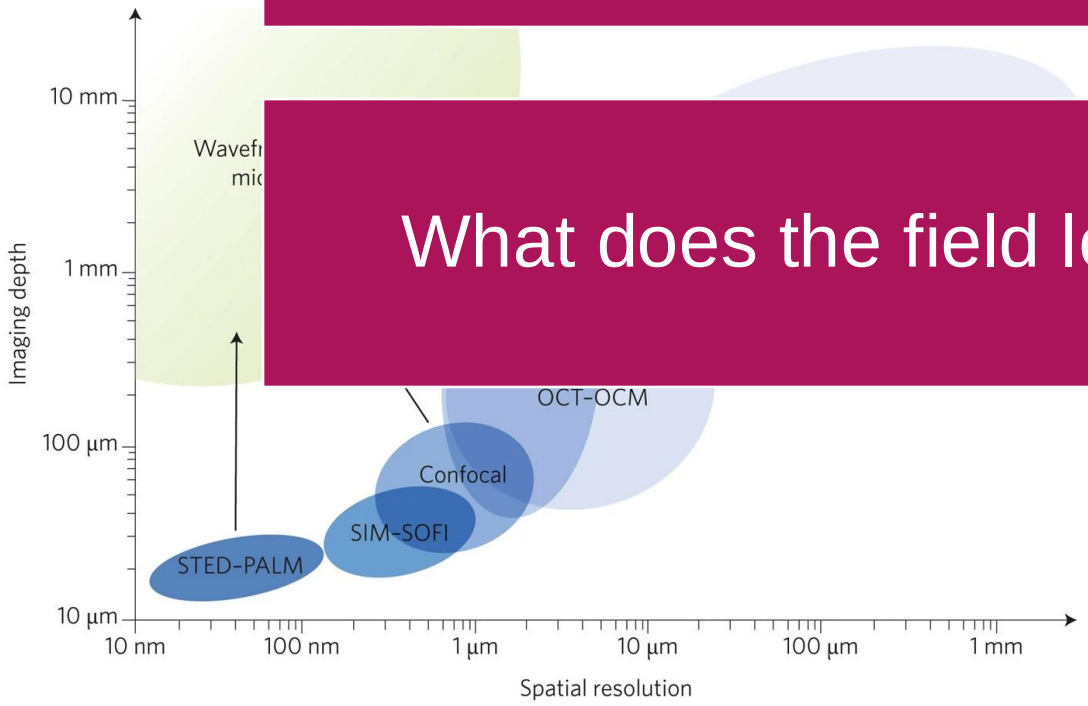

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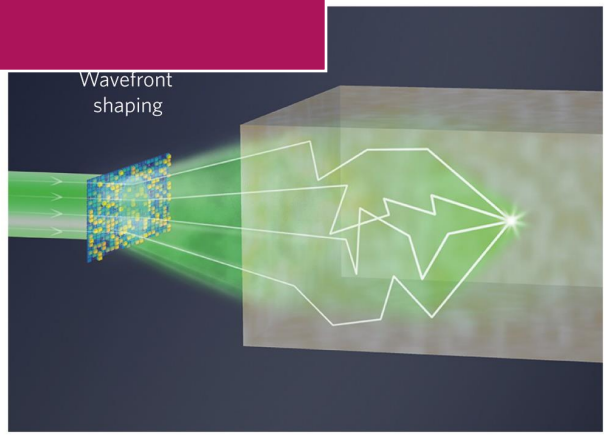

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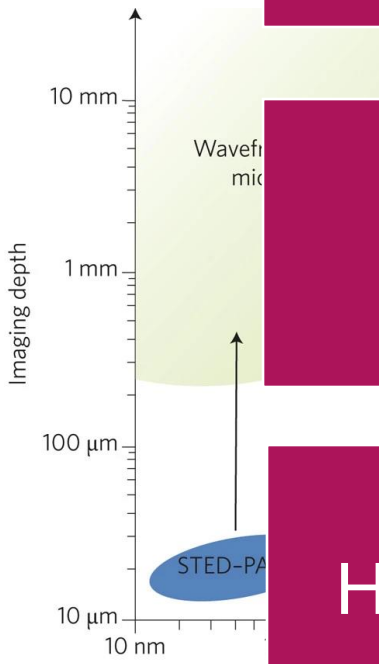
How can WFS benefit specific imaging modalities?



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Background + Motivations

Requirements of a model of wavefront shaping

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Full-wave

- Prioritise physical rigour + model phase for WFS

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Realistic medium

- Model WFS + related phenomena accurately

Background + Motivations

Requirements of a model of wavefront shaping

Full-wave	• Prioritise physical rigour + model phase for WFS
Realistic medium	• Model WFS + related phenomena accurately
Efficient	• Simulate tissue-like volumes of practical significance

Background + Motivations

Existing methods of simulating wavefront shaping

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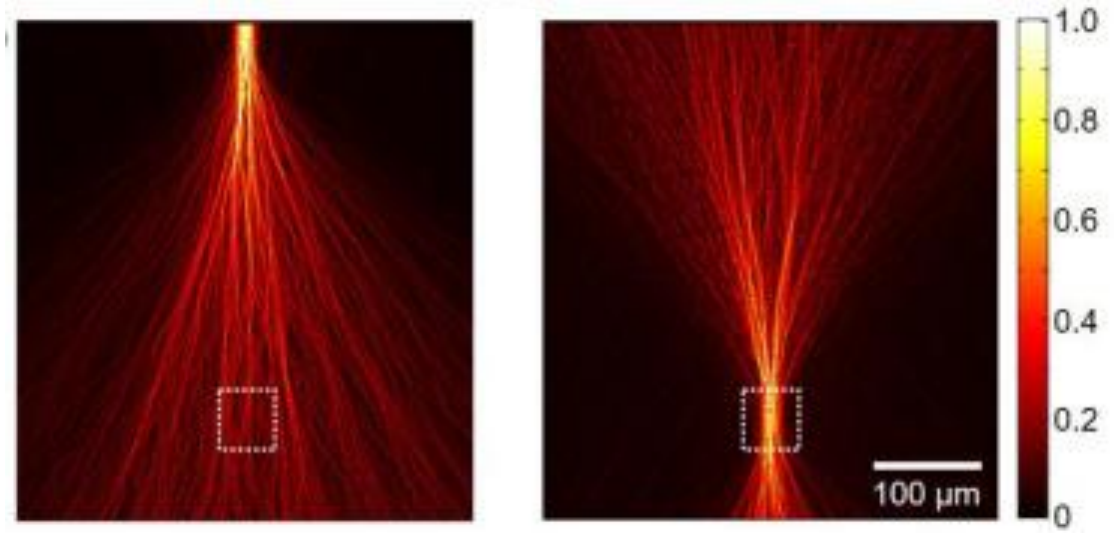
Full-wave modelling of WFS



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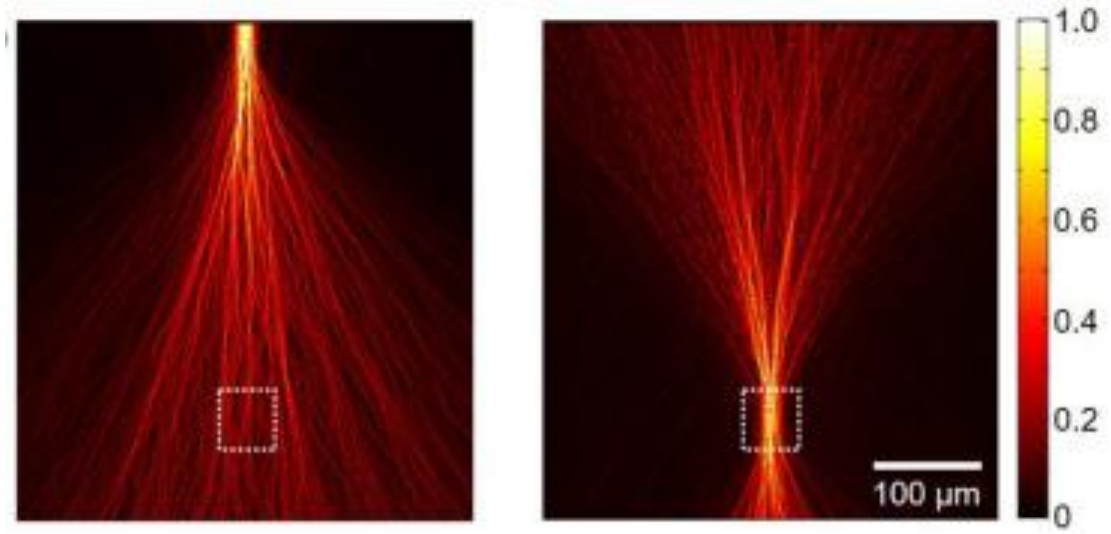

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⊕ Physically rigorous

⊖ Computationally inefficient

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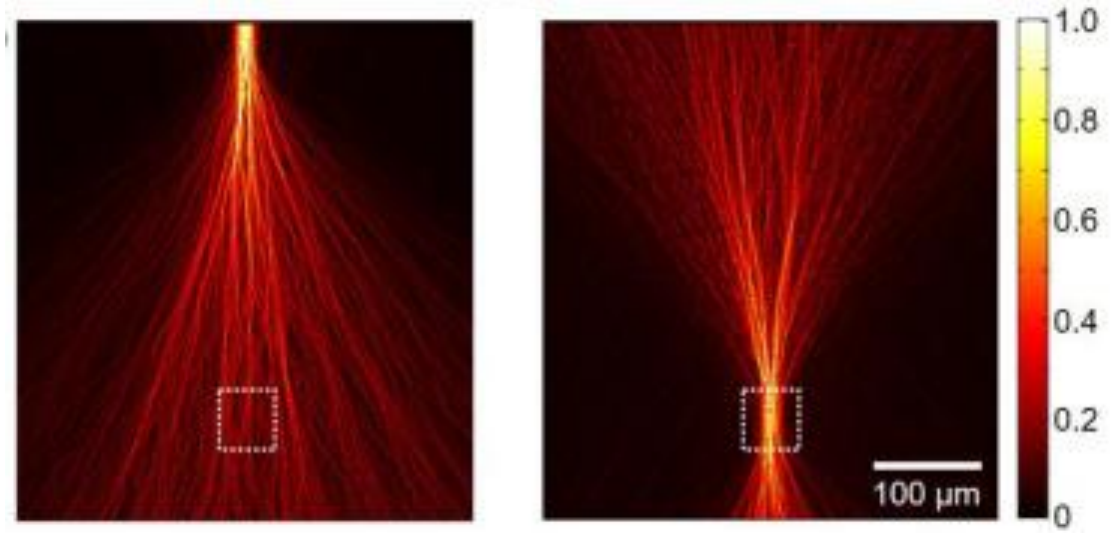

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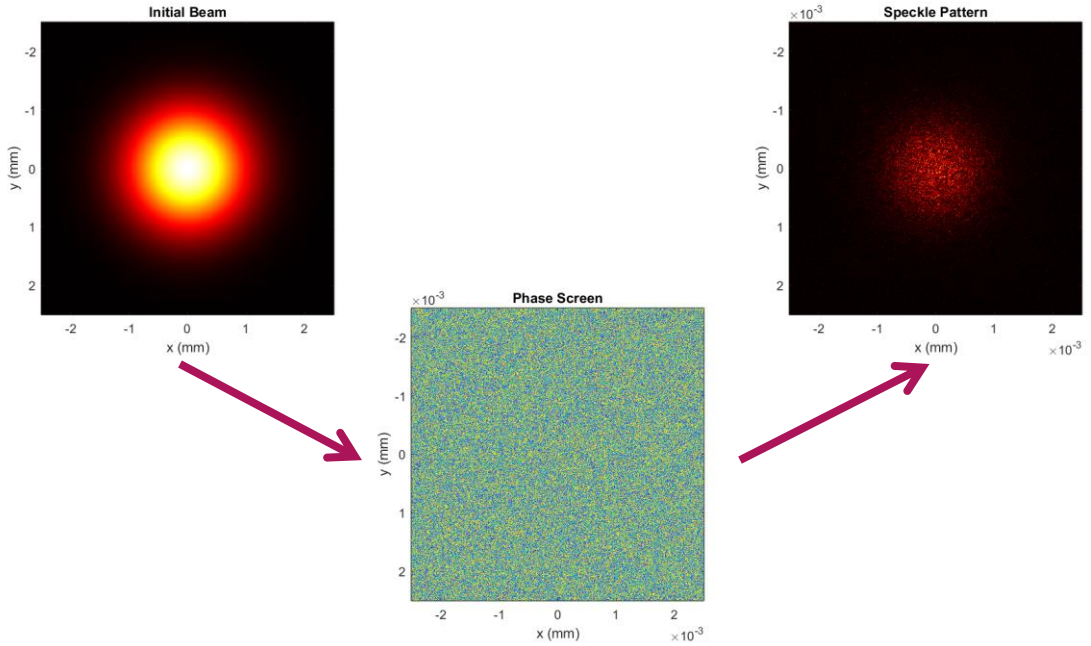

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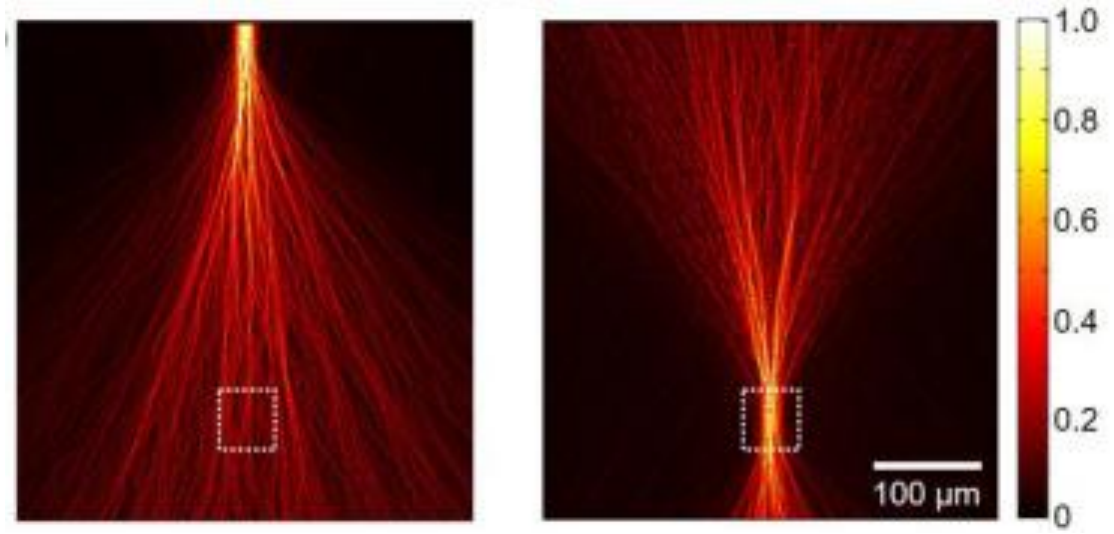

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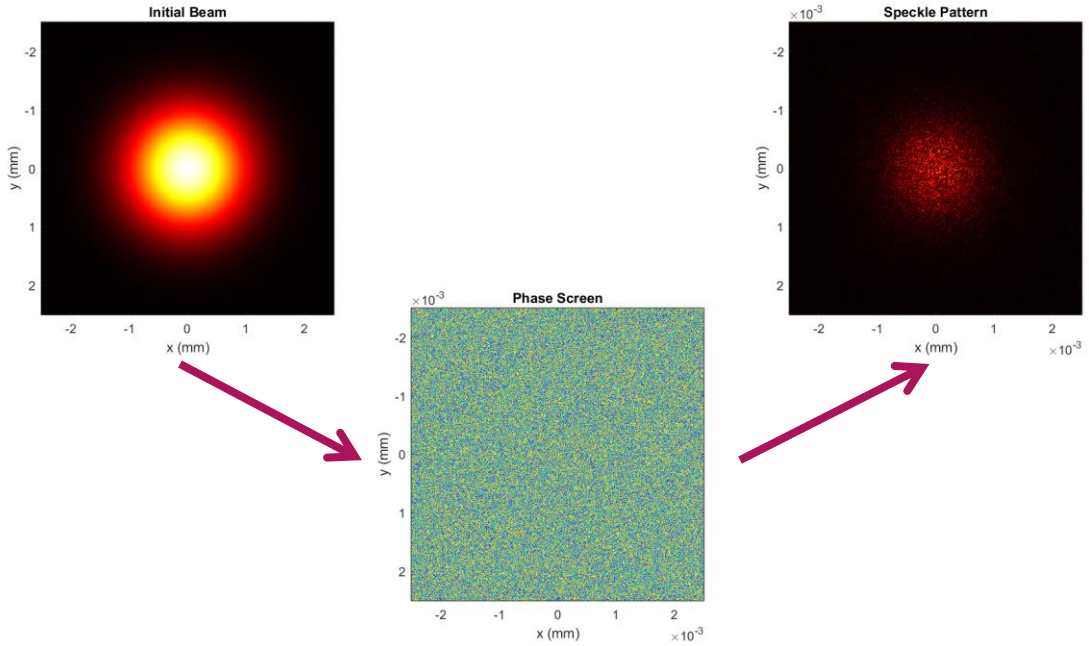

⊕ Computationally efficient

⊖ Simplified physics

Constructing and demonstrating our model

Simulating light propagation through scattering media

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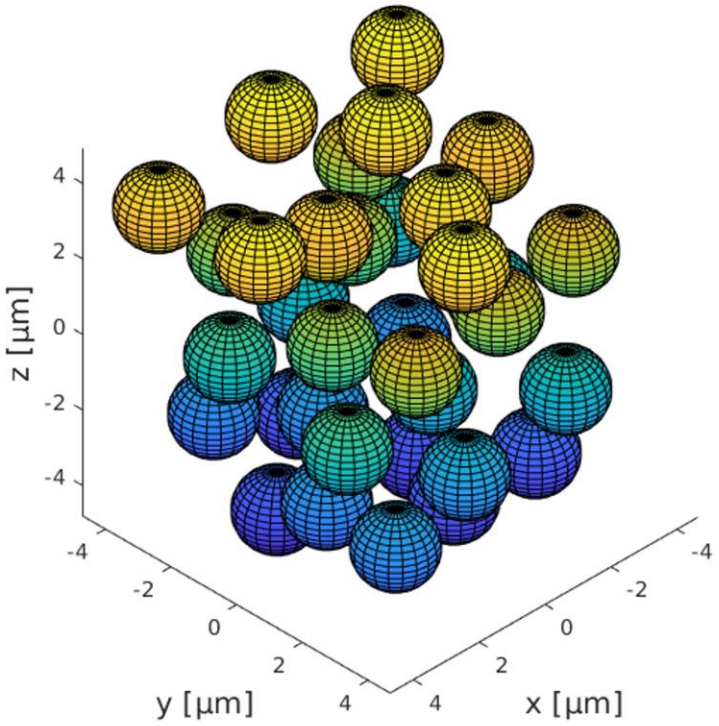
The discrete particle model of scattering media



Macroscale tissue optical properties can be represented as **collection of spheres**

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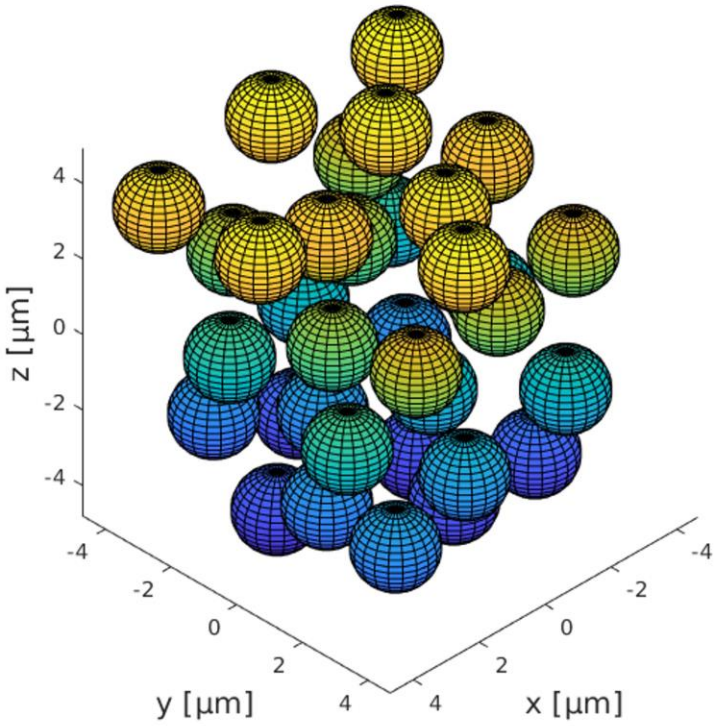

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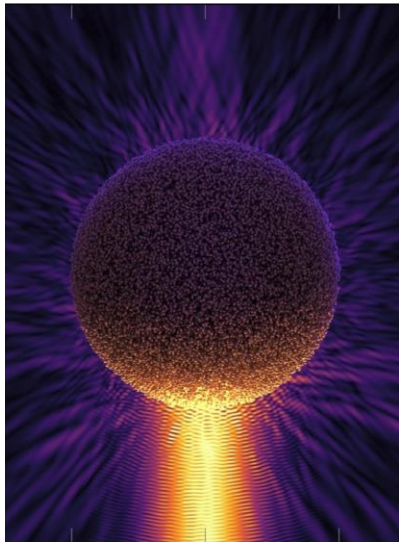

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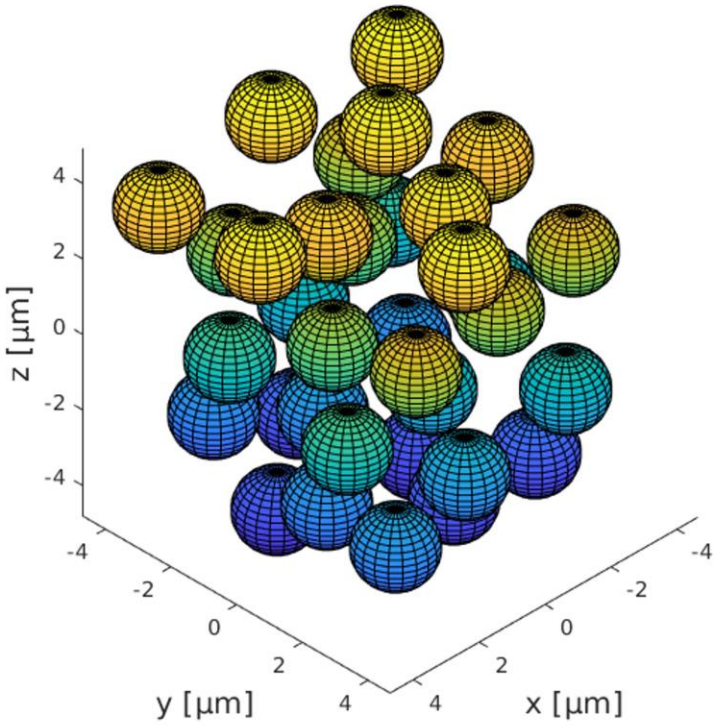

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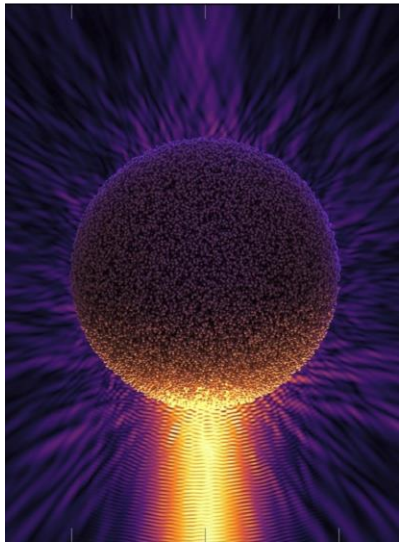

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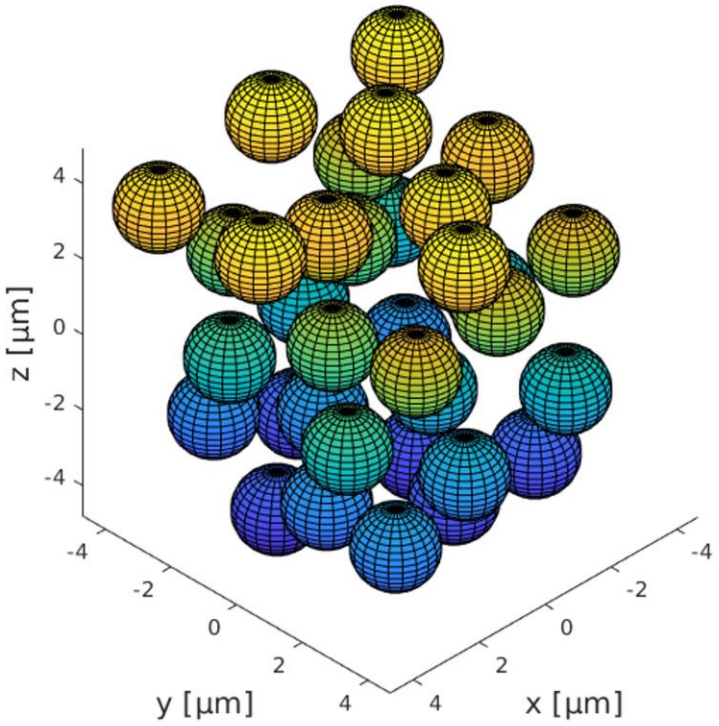

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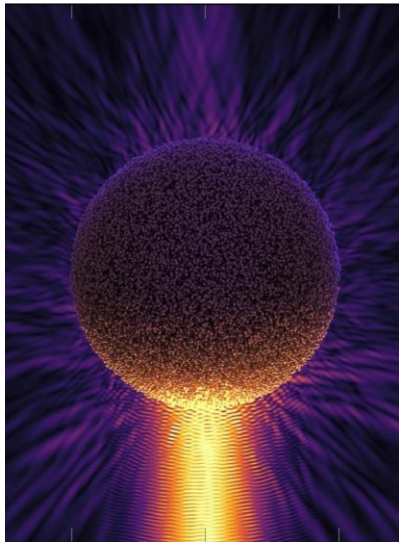

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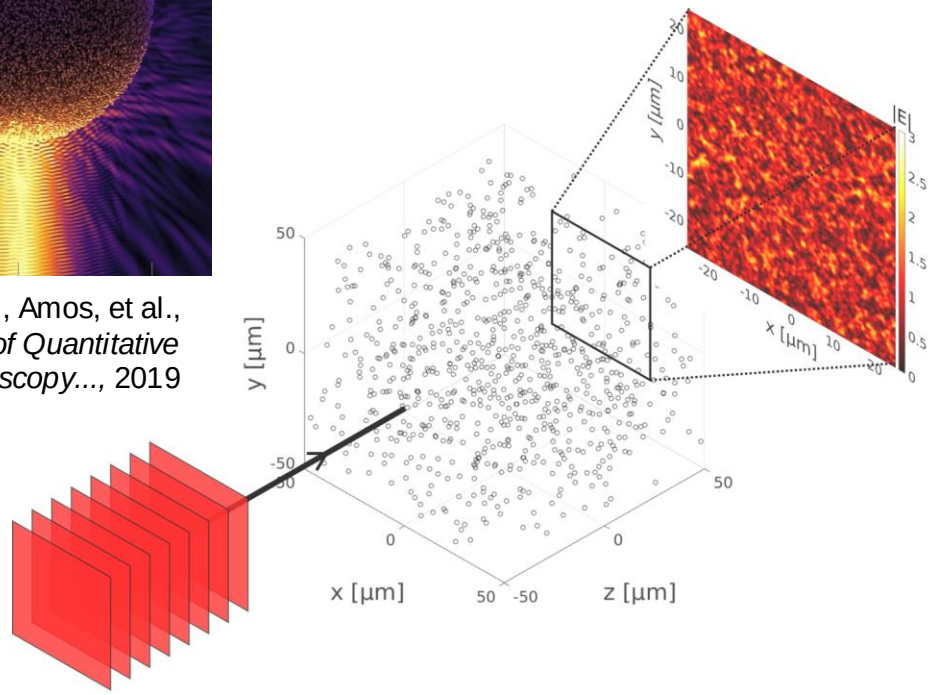

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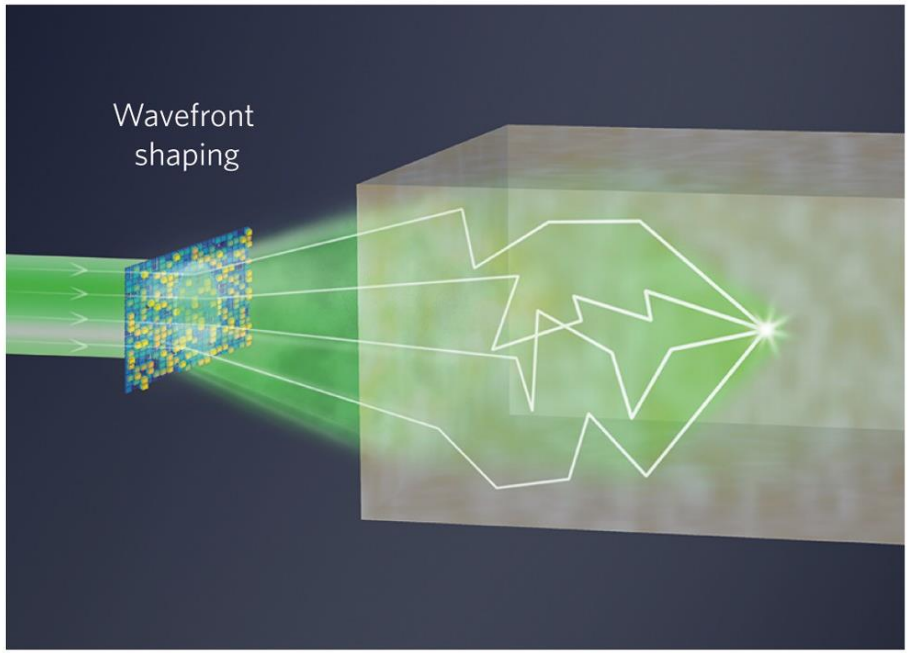

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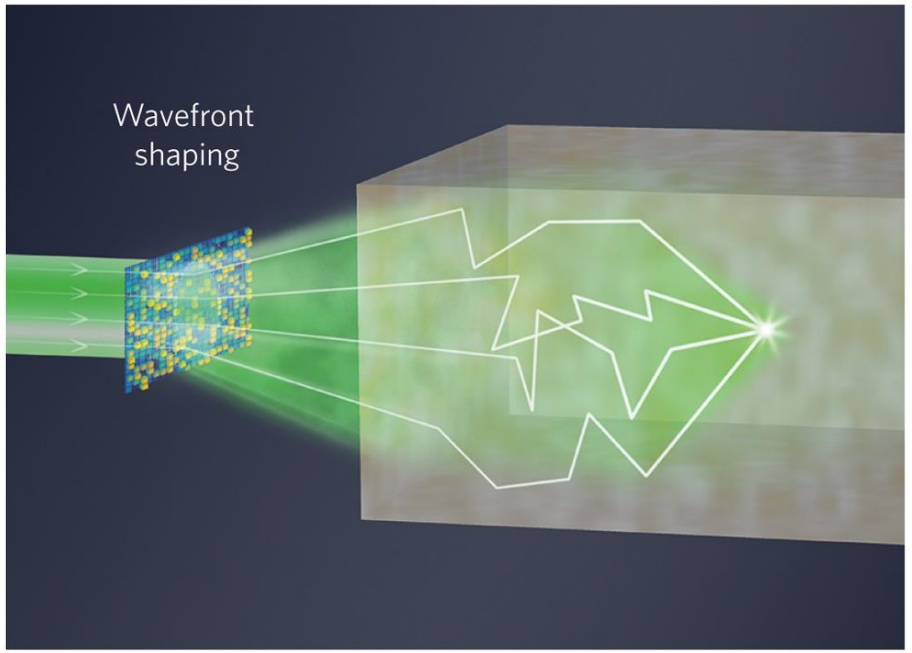

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$$E_b = \sum_a t_{ba} E_a$$

input modes

medium

output modes

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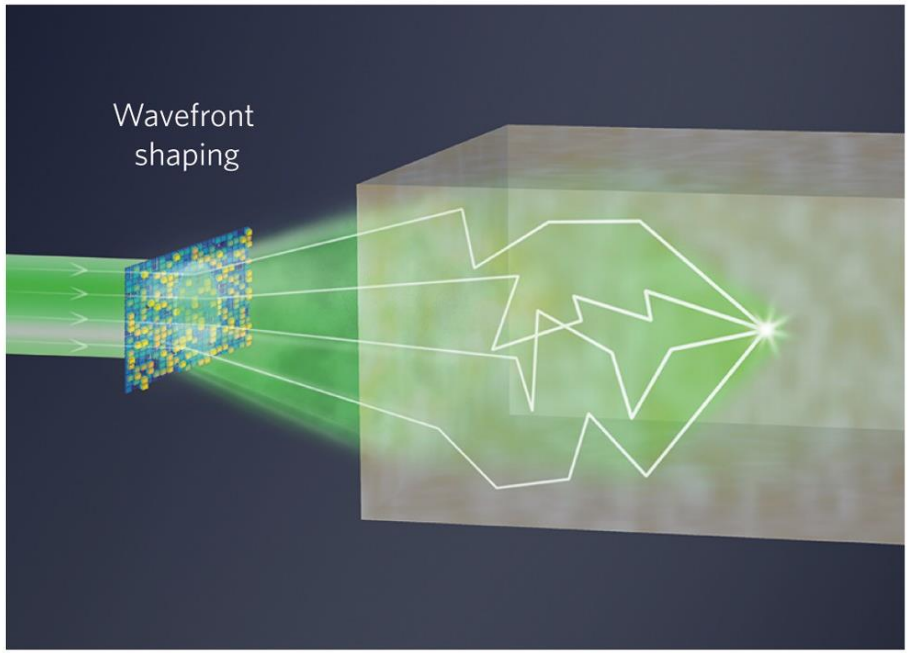

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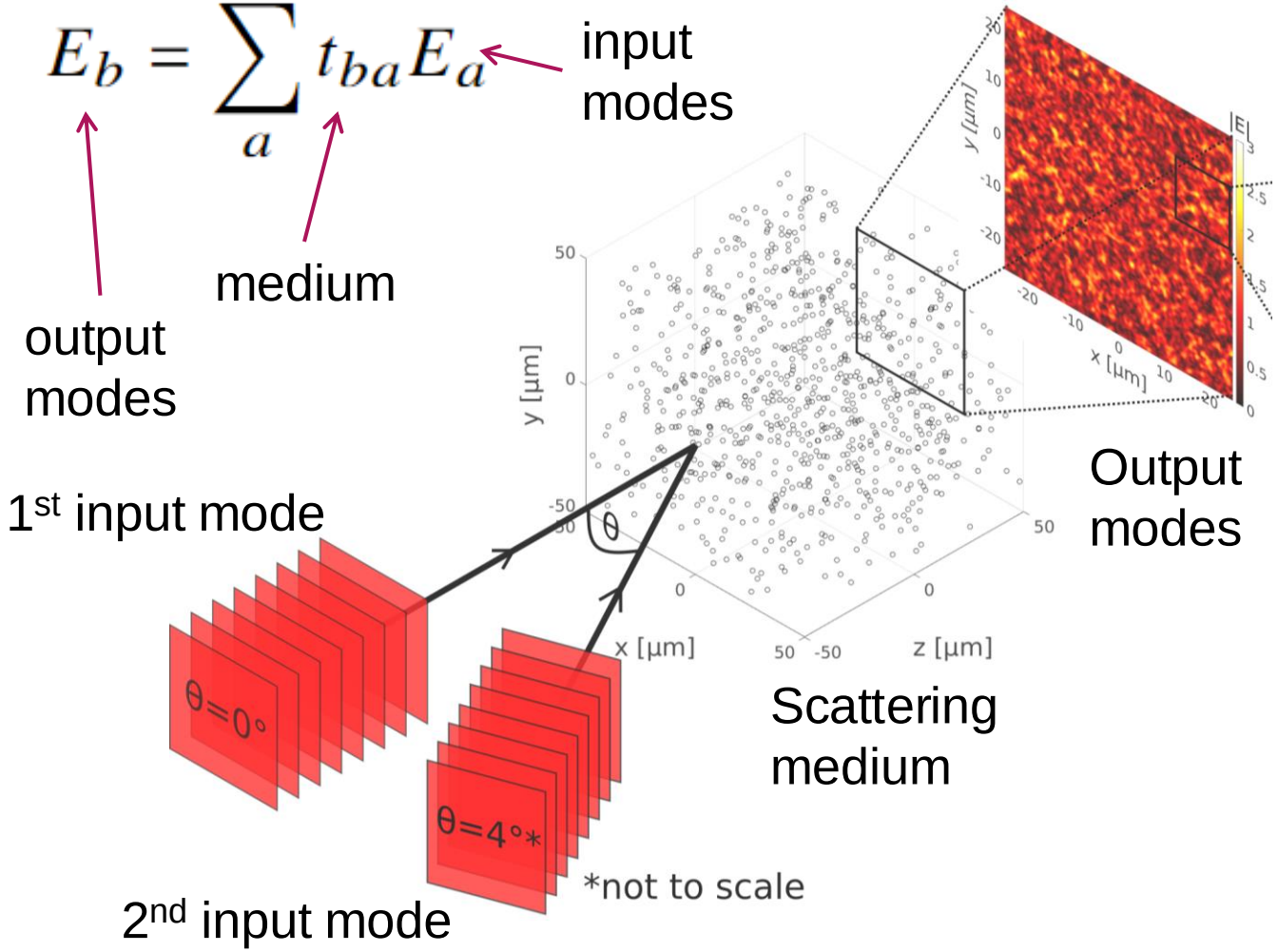

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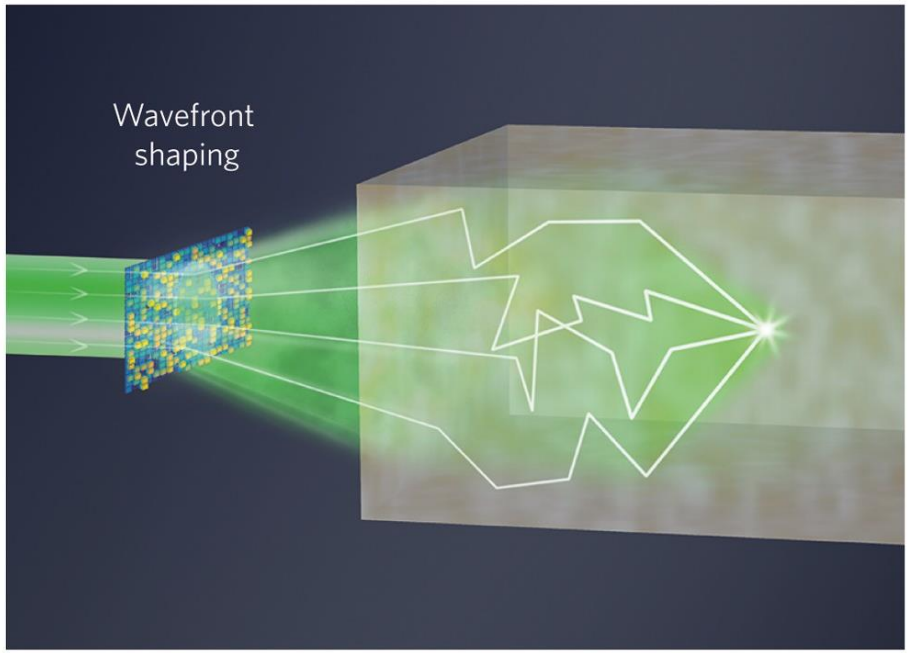

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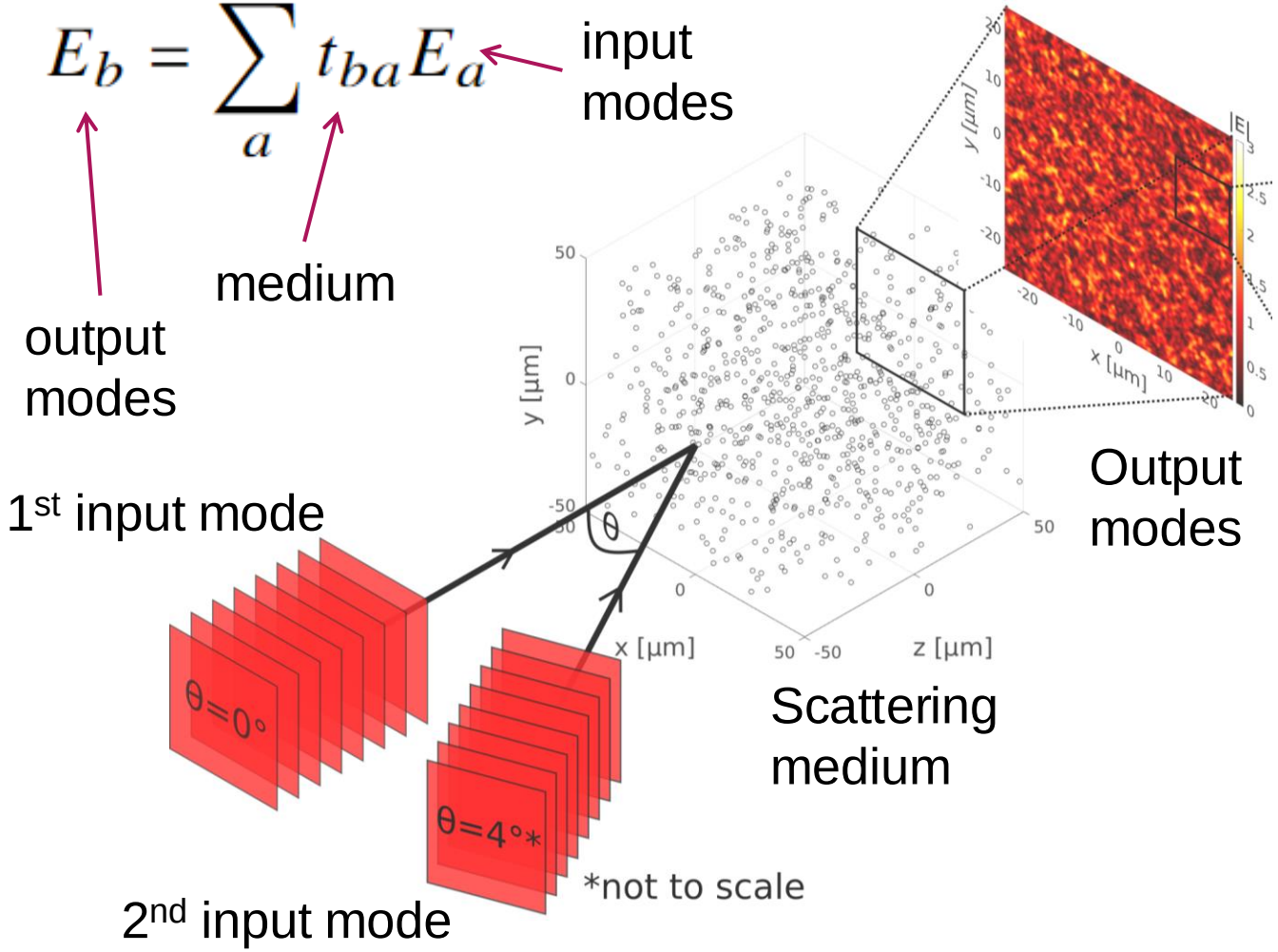

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Angular spectrum of 441 modes.

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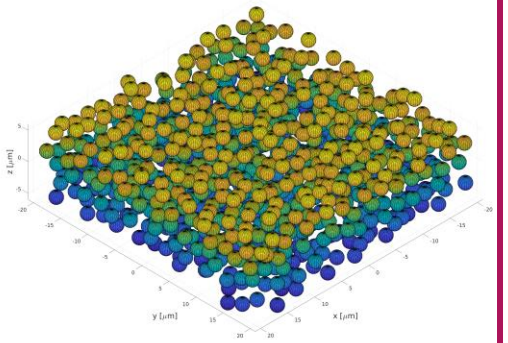

Transport mean free path of ~5μm^{-1}.

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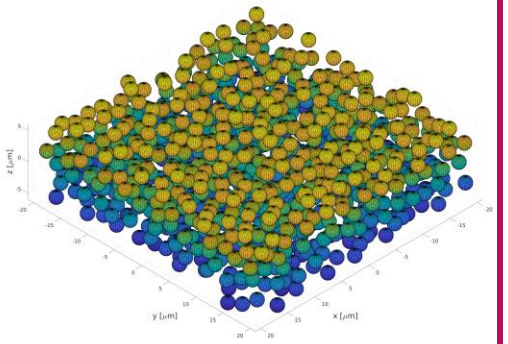

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Output modes:

2D plane 20µm behind medium

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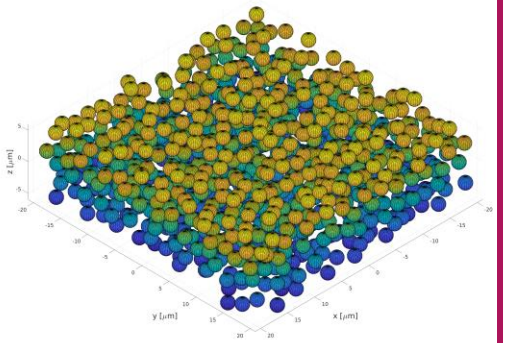

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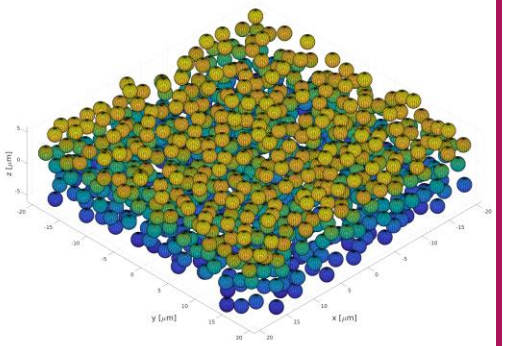

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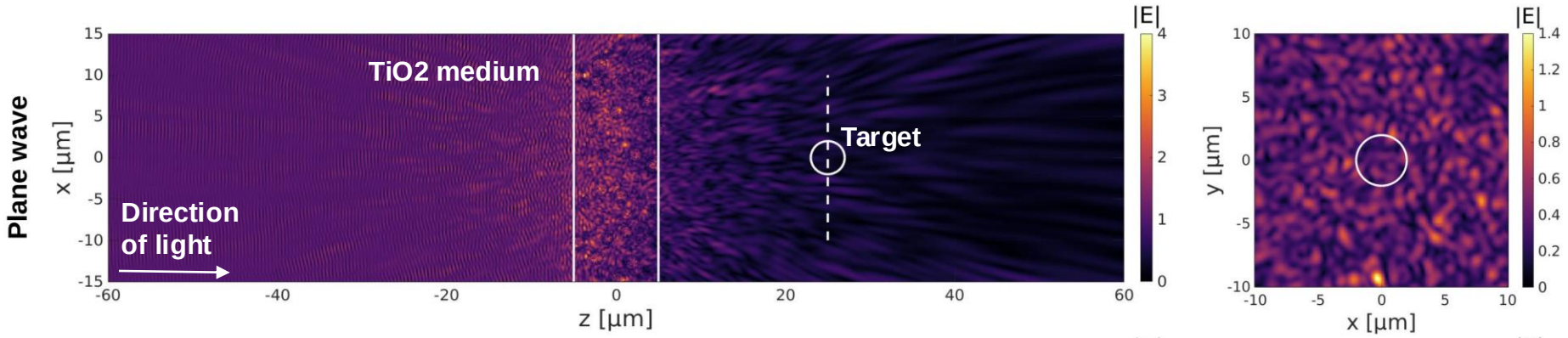

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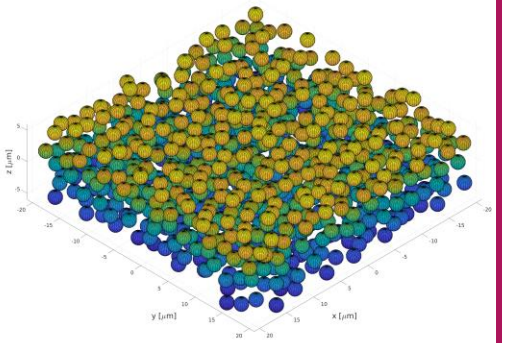

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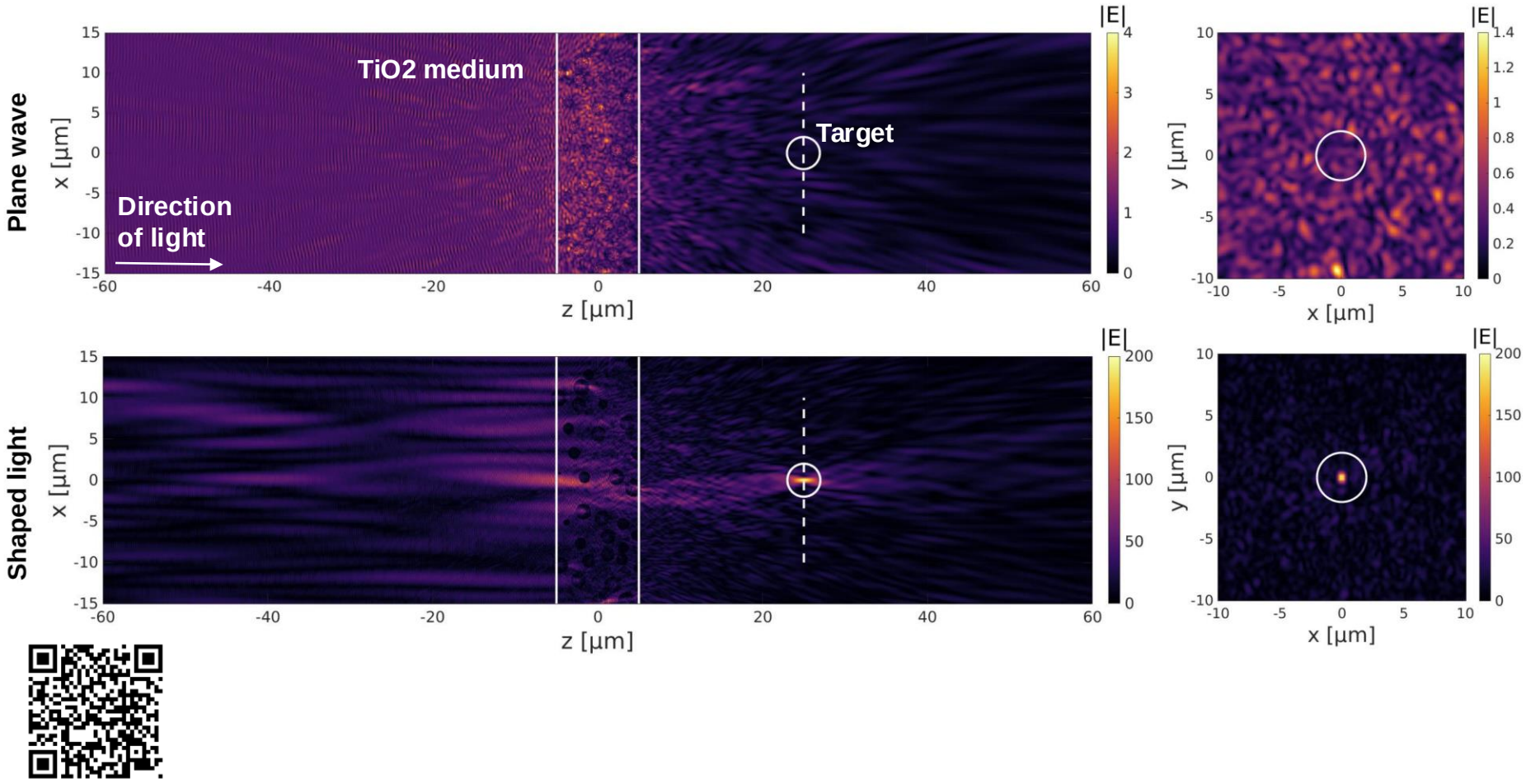

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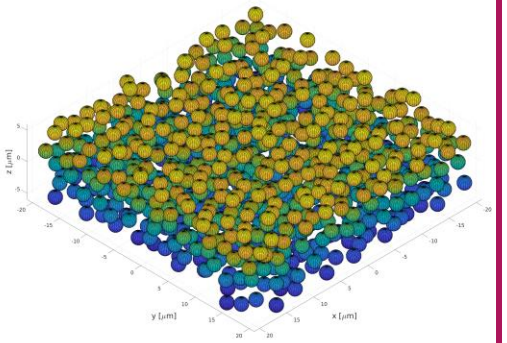

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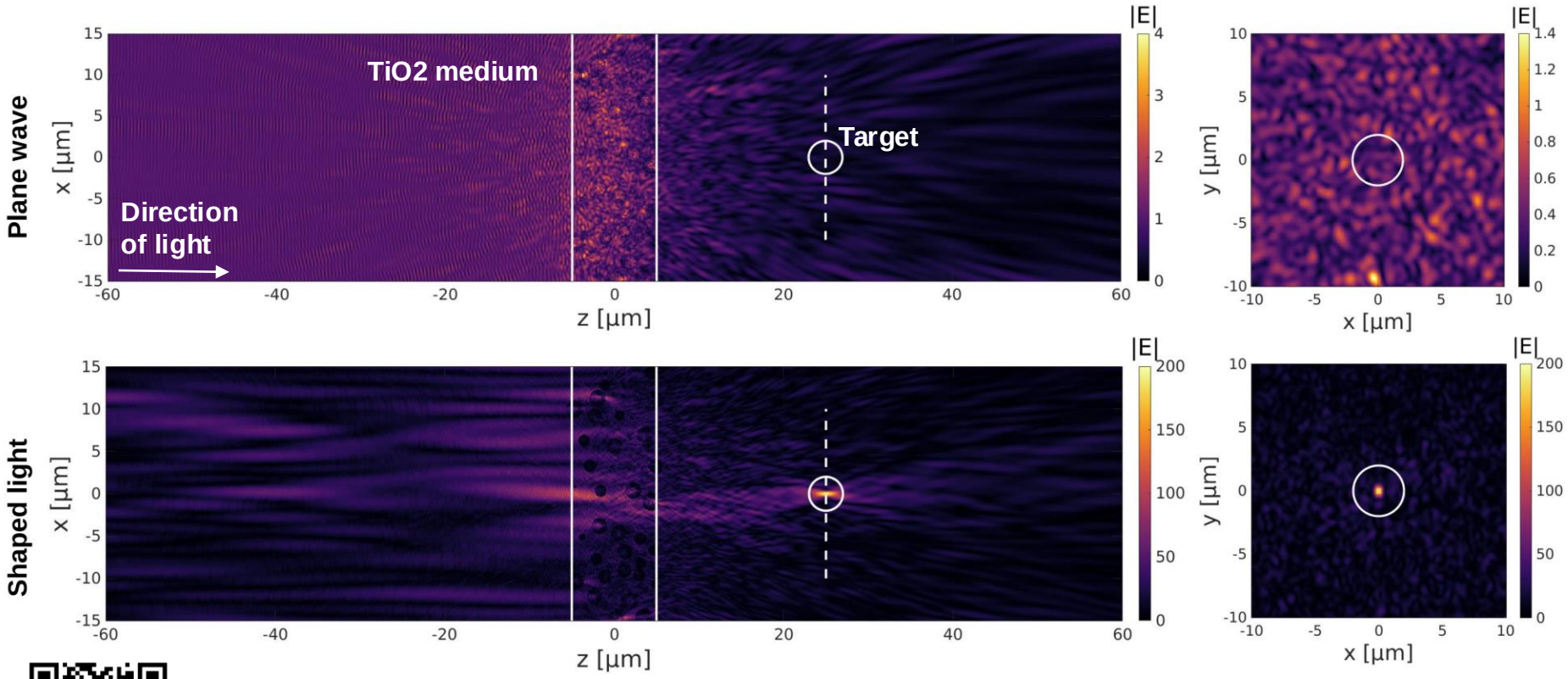


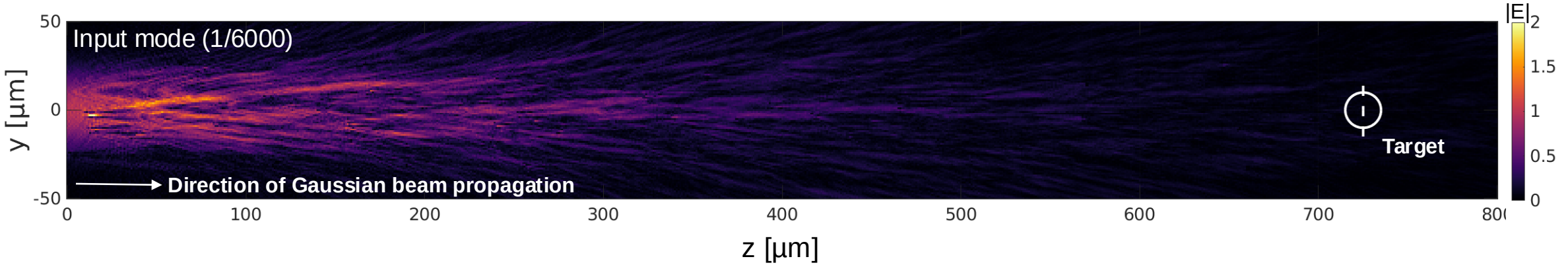
Our model can simulate WFS through highly scattering media

Constructing and demonstrating our model

Focusing a focus inside tissue-like media

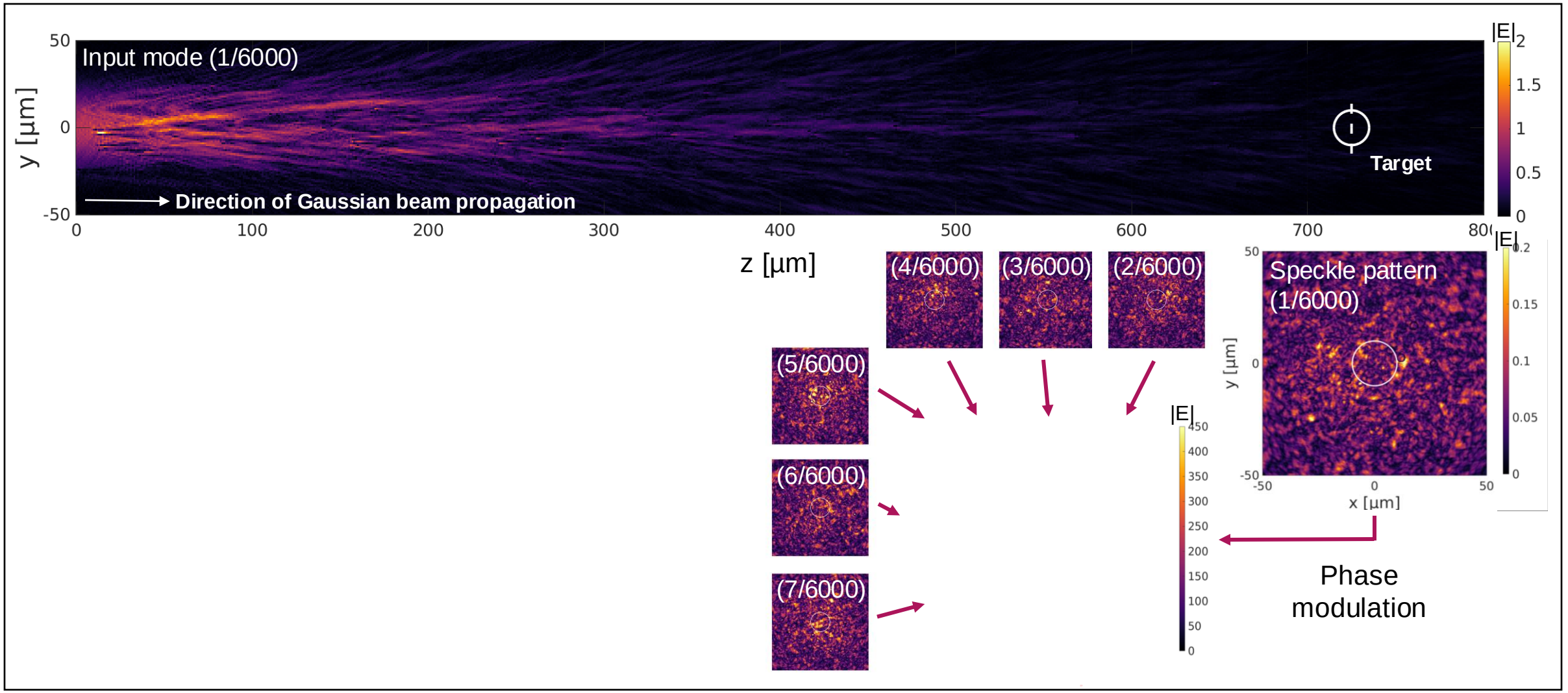
Constructing and demonstrating our model

Focusing a focus inside tissue-like media



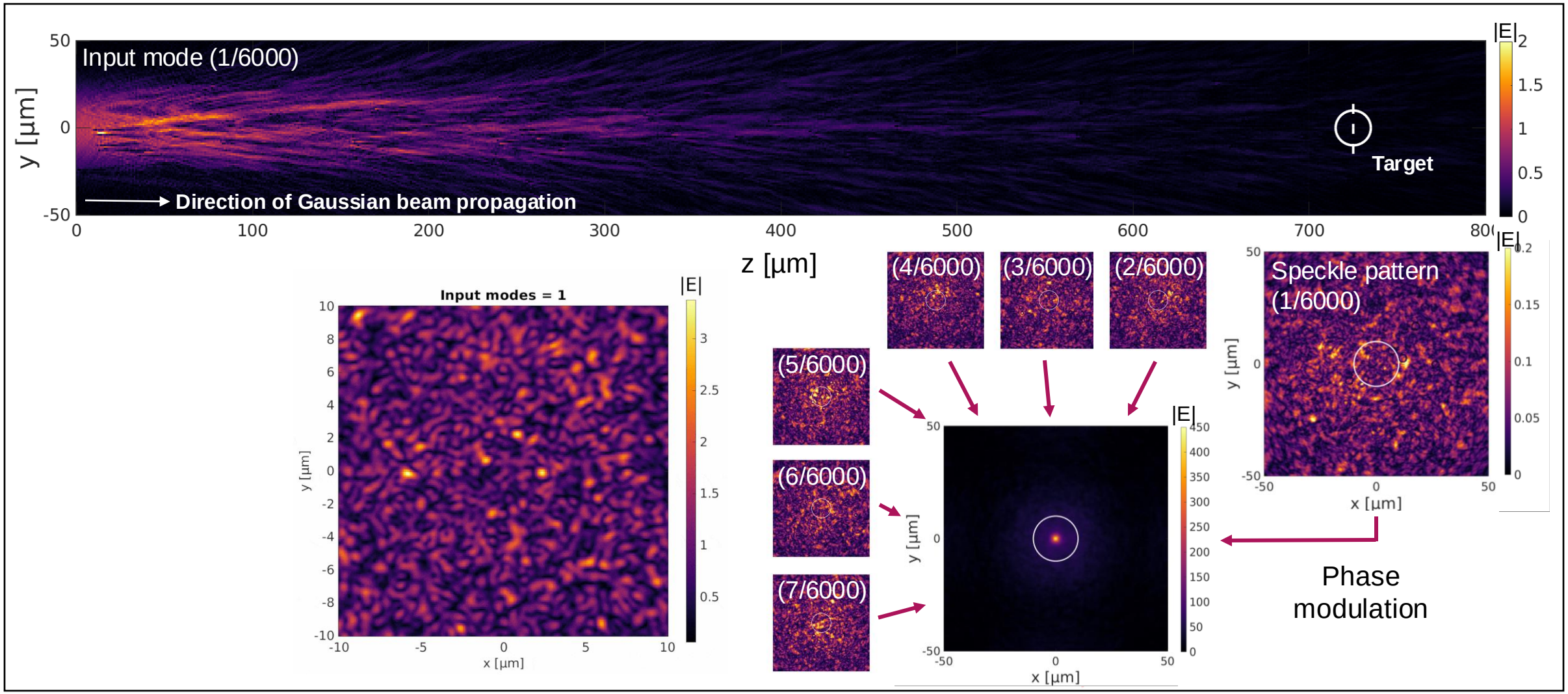
Constructing and demonstrating our model

Focusing a focus inside tissue-like media



Constructing and demonstrating our model

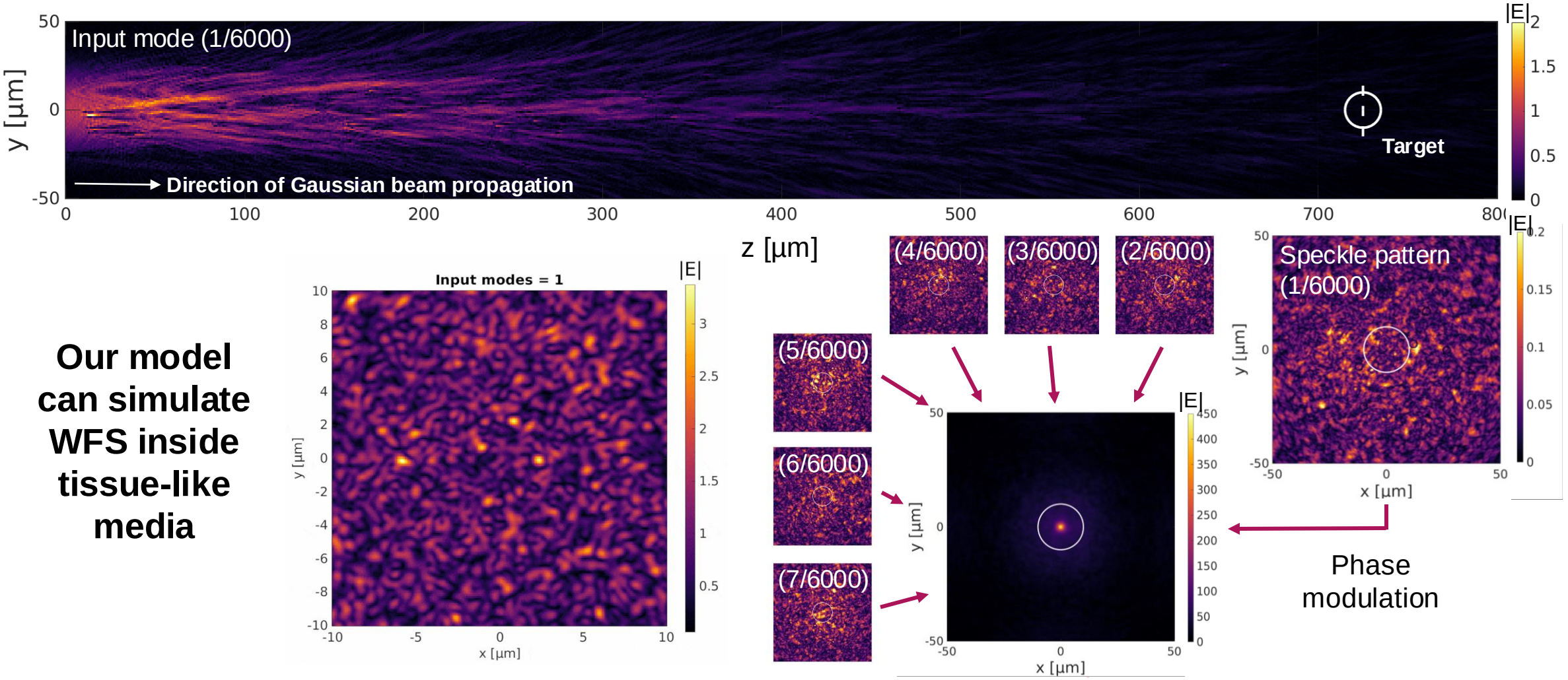
Focusing a focus inside tissue-like media



Constructing and demonstrating our model

Focusing a focus inside tissue-like media

Our model can simulate WFS inside tissue-like media



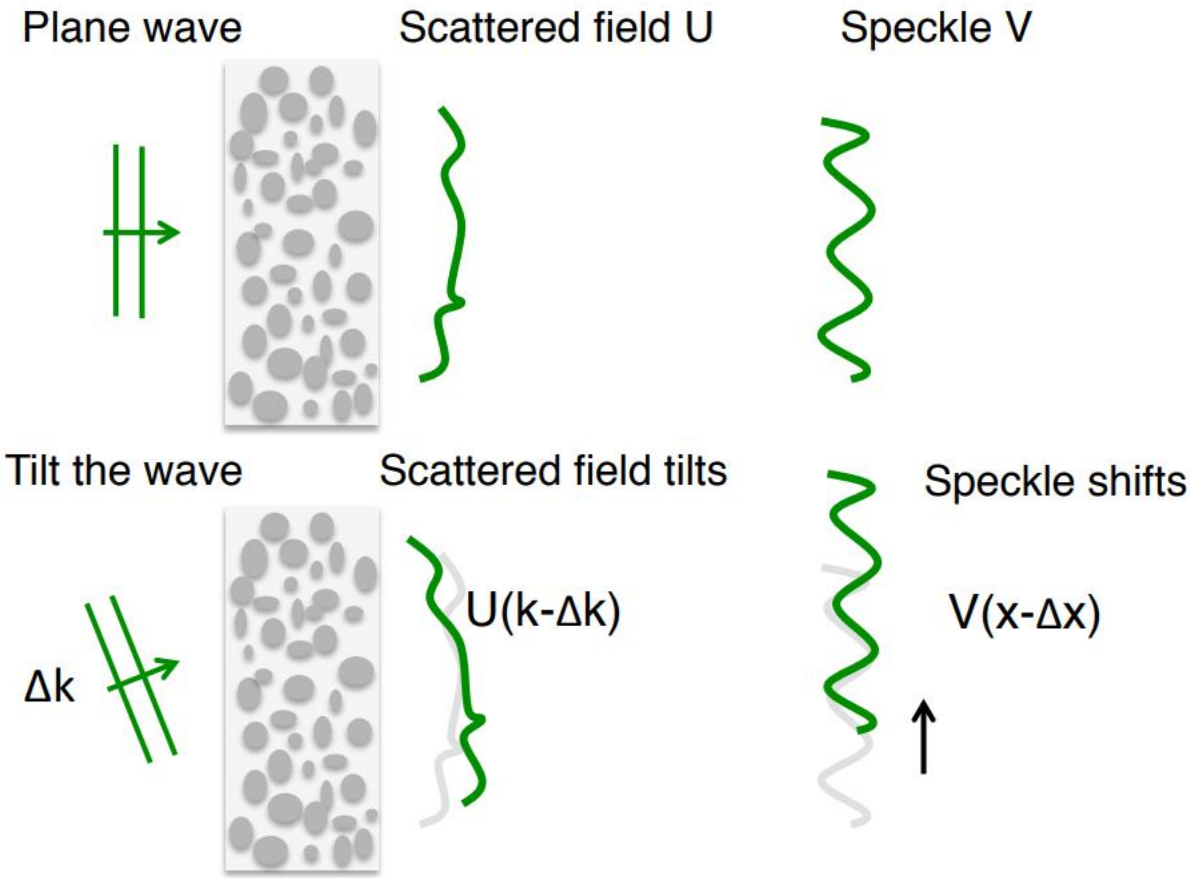
Constructing and demonstrating our model

What are memory correlations?

Constructing and demonstrating our model

What are memory correlations?

Principles of the optical memory effect



Horstmeyer, R., et al., *ICERM Waves and Imaging in Random Media* , 2017

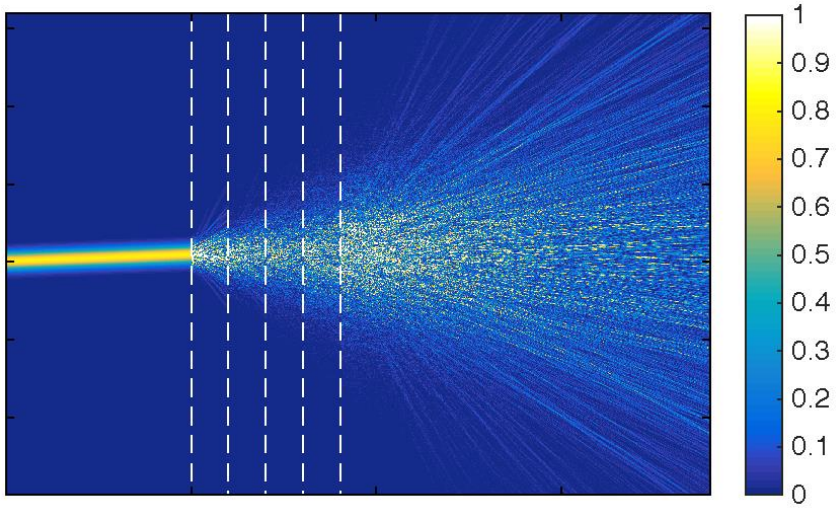
Constructing and demonstrating our model

Measuring memory correlations

Constructing and demonstrating our model

Measuring memory correlations

Existing attempts to model the memory effect

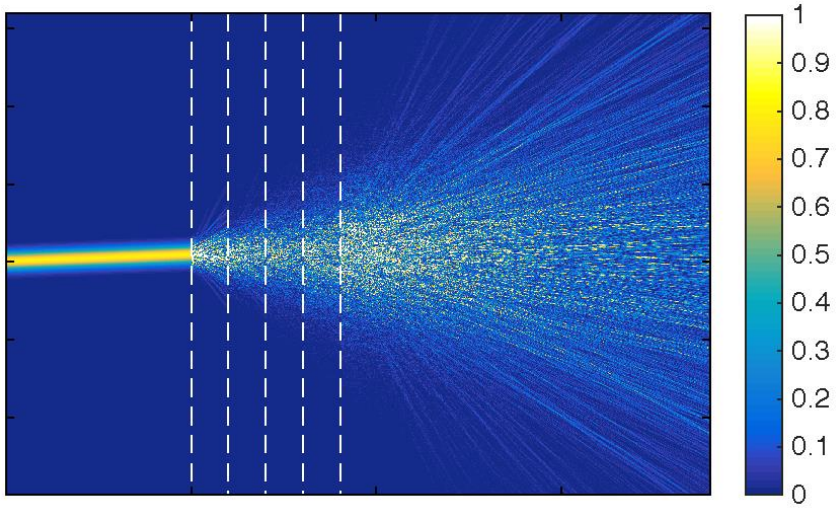


Schott, Sam, et al. *Optics express* 2015

Constructing and demonstrating our model

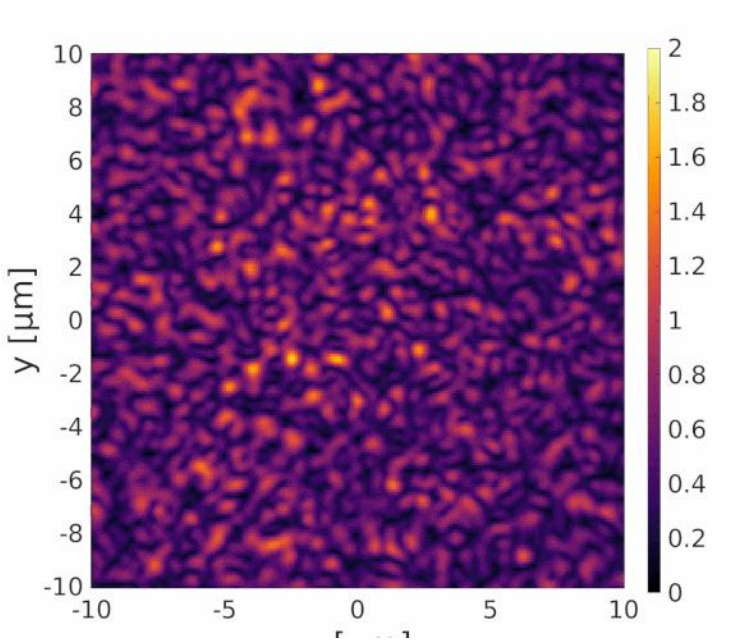
Measuring memory correlations

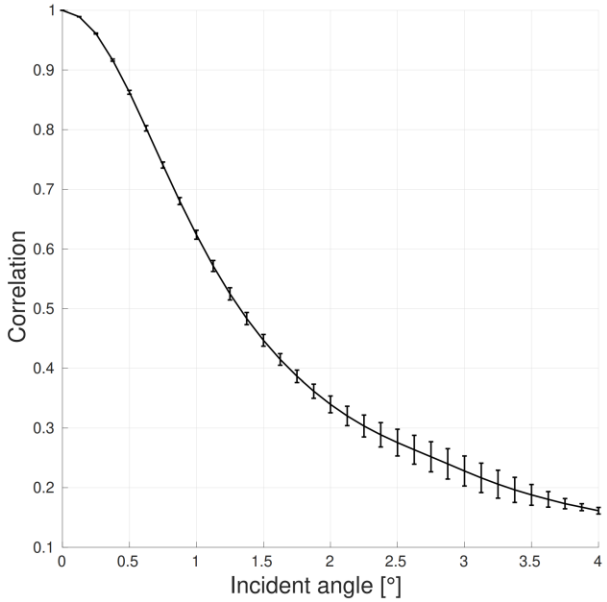
Existing attempts to model the memory effect



Schott, Sam, et al. *Optics express* 2015

Modelling angular memory effect ranges

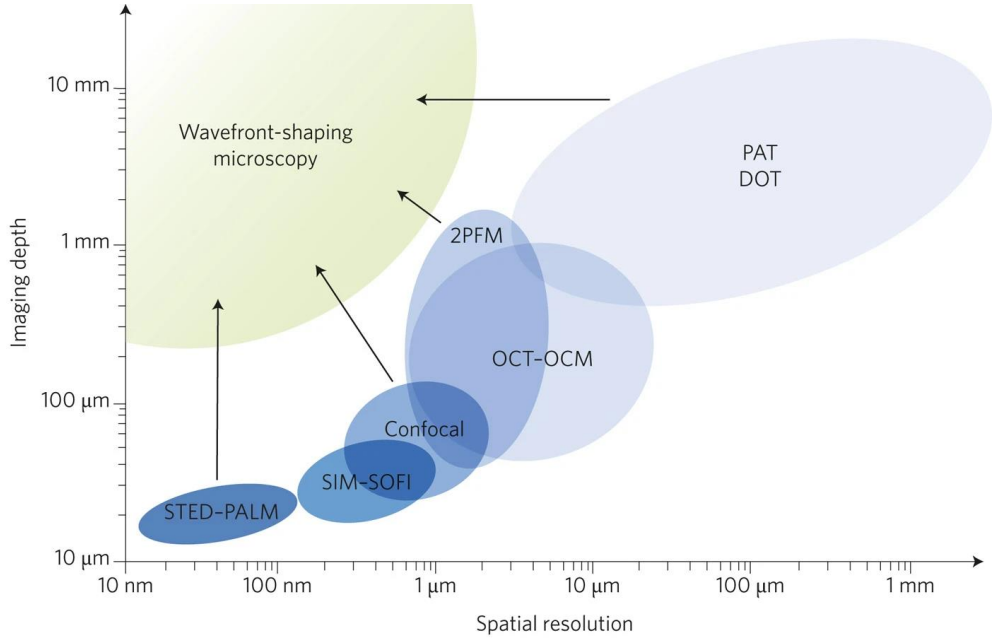




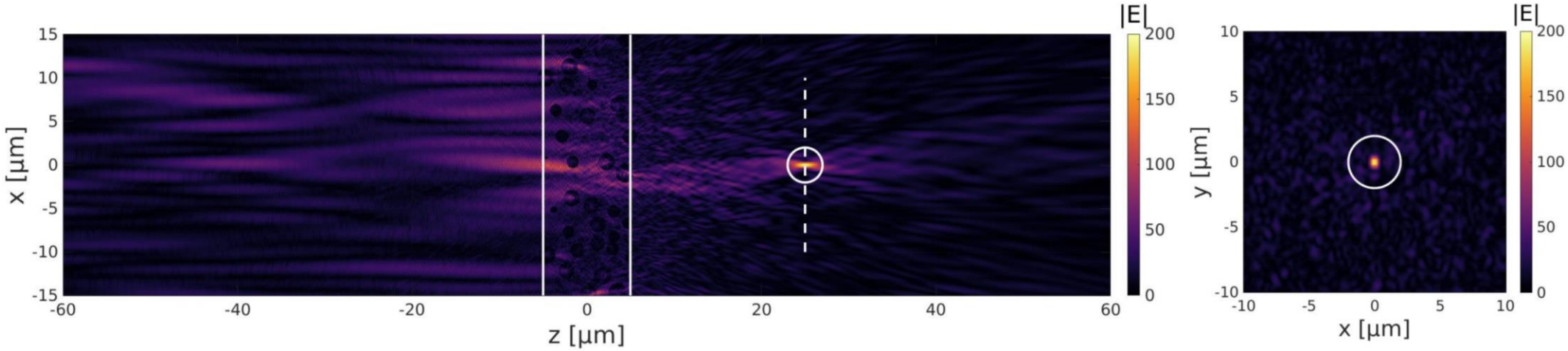
Conclusions

1. **WFS has the potential to enhance the depth of optical imaging modalities.**
2. **Computational models can augment research of WFS by allowing for the measurement of internal fields and phase.**
3. **We have presented and validated a physically realistic yet computationally efficient model of WFS. The model has replicated existing WFS research and is being exploited to investigate the shaping of light into biological tissue.**

Happy to answer any questions you have.



Gigan, Sylvain., *Nature Photonics*, 2017



Acknowledgements

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Full-wave modelling of wavefront shaping and memory effects through scattering media using the T-matrix method

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