

Master Internship and PhD Proposal

Shaping light's propagation through dynamic complex media

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Location – LuMin laboratory, bâtiment 505 rue du Bélvédère 91400 Orsay

Possibility of PhD thesis – Yes, funding has been secured for a PhD thesis via an ANR grant.

Summary – When light propagates through complex media, such as biological tissue, paint, clouds or even multimode fibers, it is mixed into a high number of degrees of freedom leading to the formation of a speckle pattern at the output, as shown in Fig. 1. While the process leading to the generation of this intricate interference pattern is complex, the response of the system between a set of input and output modes is fully represented by a transmission matrix (TM) due to the deterministic and linear nature of the propagation of light in such media. Once measured using wavefront shaping techniques, this matrix gives us full control over the wave propagation [1], and can be used to image through highly scattering biological tissue, or transmit information through multimode fibers [2]. However, changes to the medium due to external perturbations or its own dynamical evolution entail changes in the TM, thus rendering our previous knowledge approximate at best. For changes due to a single parameter, it remains possible to use the TM to find input fields that avoid or enhance the interaction with the perturbation [3–5]. In more general cases it is no longer possible to define or measure a TM.

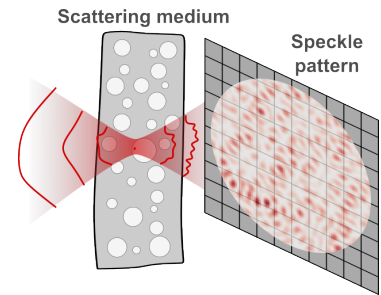


Figure 1 | Speckle forming by a scattering medium.

This project seeks to fill this gap by developing a framework that can describe the propagation of light through dynamic complex media such as the one shown in Fig. 2. Given that the output field becomes partially coherent due to the dynamics of the medium, its relation to the input needs to be described by higher-order tensors—the multidimensional extension of matrices—and exploited via tensor decomposition techniques [5, 6]—a tool from machine learning and applied mathematics. Figure 2 shows how they can be used to find simpler lower rank approximations to model the output. The goal of the master internship and PhD thesis is to verify, develop and exploit this tensor-based formalism through numerical simulations and experimental implementations.

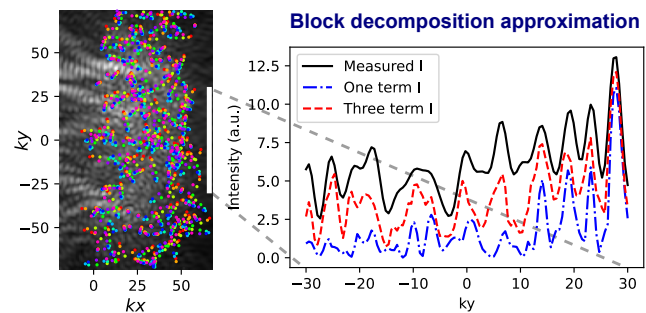


Figure 2 | Simulation of light propagating through a dynamic complex medium, with its output and lower-rank approximations.

Methods and techniques – The numerical simulations will be based on the couple dipole and recursive Green function methods, upon which dynamic effects need to be added. These simulations will allow the development of the tensor formalism while the experimental setup is built. Experimentally, wavefront shaping techniques with spatial light modulators will be essential to measure and exploit the tensor relation, and to implement a reconfigurable scattering medium. Finally, to exploit the tensor formalism, we might have to implement nonlinear optimization routines implemented using machine learning libraries.

Profile and skills – The applicant is expected to have a taste for experimental optics, wave physics, and coding. The project will require an extensive use of Python for interfacing, data acquisition, post-processing and numerical simulations.

References –

- [1] Popoff, S. M. *et al.* Measuring the transmission matrix in optics: An approach to the study and control of light propagation in disordered media. *Phys. Rev. Lett.* **104**, 100601 (2010).
- [2] Gigan, S. *et al.* Roadmap on wavefront shaping and deep imaging in complex media. *J. Phys. Photonics* **4**, 042501 (2022).
- [3] Matthès, M. W., Bromberg, Y., de Rosny, J. & Popoff, S. M. Learning and avoiding disorder in multimode fibers. *Phys. Rev. X* **11**, 021060 (2021).
- [4] Gutiérrez-Cuevas, R. *et al.* Characterization and exploitation of the rotational memory effect in multimode fibers. *Phys. Rev. X* **14**, 031046 (2024).
- [5] Gutiérrez-Cuevas, R., Bouchet, D., de Rosny, J. & Popoff, S. M. Reaching the precision limit with tensor-based wavefront shaping. *Nat. Commun.* **15**, 6319 (2024).
- [6] Kolda, T. G. & Bader, B. W. Tensor decompositions and applications. *SIAM Review* **51**, 455–500 (2009).