Spatio-Spectral Correlations through Forward Scattering Media

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Light is scattered when encountering complex media such as biological tissues. After a few scattering events, no amount of ballistic energy is left. This has been a major challenge for optical microscopy where focusing deep into biological tissue is required. So far, few analytical and numerical models have been proposed to understand the propagation of light in the regime where light is totally scattered.
Recently, a strong spatio-spectral coupling has been observed [1] wherein a spectral detuning over 200nm-widths was experimentally demonstrated to result in a simple axial translation of the focused laser beam through a 1mm-thick brain slice. Further, it was shown that the center of axial homothety is located at a virtual plane at $L/3$ inside the forward scattering slab [2].
We hereby propose a model for forward scattering media such as biological tissue which has an important interest both for studying the propagation of light in this regime and for applications in 3D imaging. Based on our analytical model and numerical simulation tools, we will discuss the possibility to achieve three-dimensional ultrashort laser focusing and scanning inside forward scattering media by simultaneously taking advantage of spectral & spatial correlations known as "Memory Effects (ME)". Our forward scattering media is characterized by the thickness L which is greater than the scattering mean free path ($l_s \ll L \ll l^*$) and anisotropy factor g.
Our theoretical and numerical study, inspired by the experimental evidence of the two latter studies, is based on a 2D random walk in the k-space where the central limit theorem is valid and on a succession of N thin refractive diffusers generated as smooth random phase patterns with Gaussian statistics respectively. Our results show a perfect agreement between our analytical and numerical model.

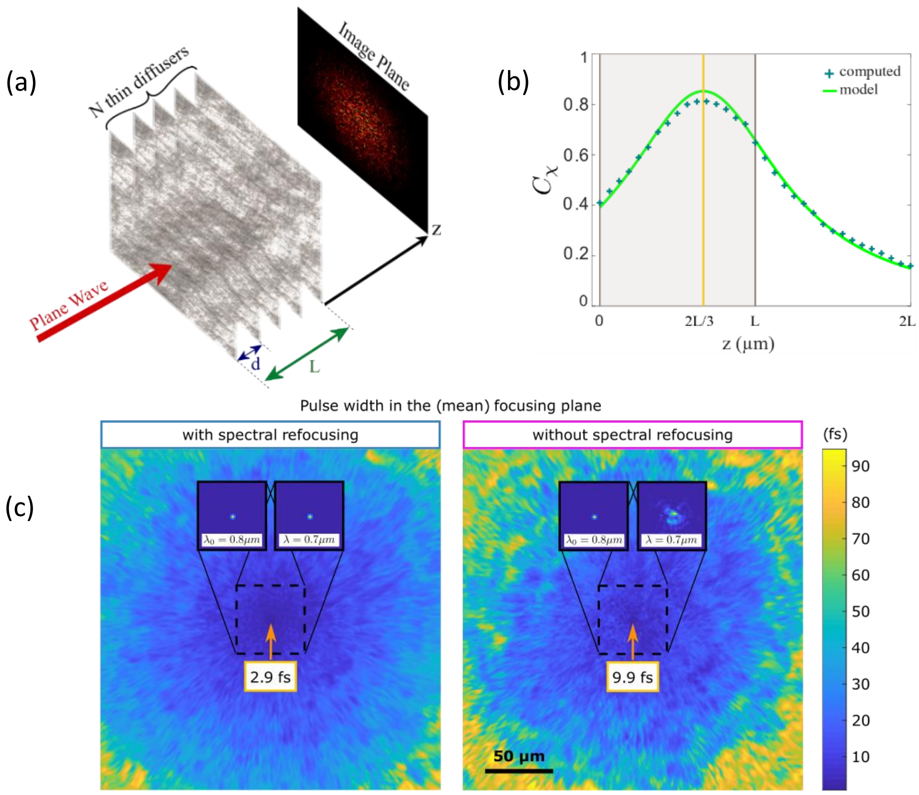

Fig 1. (a) Scheme of our numerical model. Our forward scattering media made of a pile of N thin refractive diffusers separated by a distance d, is illuminated by a plane wave. (b) The cross-correlation product between two different speckle patterns at λ_1=800 nm and λ_2=820 nm. The speckle is achromatic at a virtal plane inside the scattering slab at z=2L/3. (c) Spatial focusing by achromatic wavefront shaping with and without applying the proper dispersive spherical wavefront for compensating for the axial shift (left and right side respectively).

1] A. G. Vesga *et al.*, "Focusing large spectral bandwidths through scattering media," Opt. Express **27**(20), 28384–28394 (2019).
[2] L. Zhu *et al.*, "Chromato-axial memory effect through a forward-scattering slab," Optica **7**(4), 338–345 (2020).