Improving the angular resolution in the early-time diffusion imaging through random media [+]

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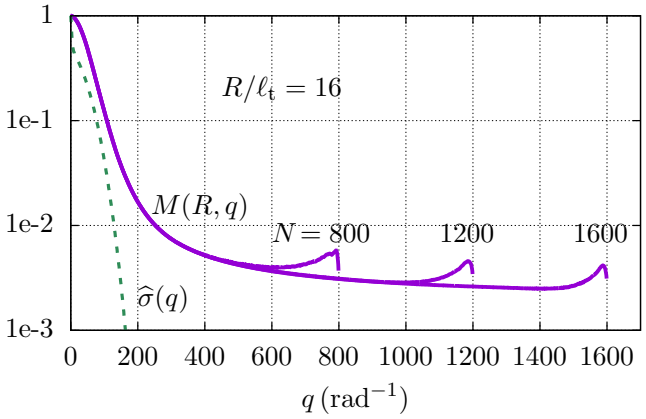
The early-time diffusion (ETD) phenomenon [1] arises in radiative transfer equation (RTE) solutions for a pulse propagation in a medium consisting of scatterers fairly large compared to the wavelength. Is is manifested by a sharply rising signal in the time-resolved intensity, which can be extracted by high-pass filtering and potentially used for imaging through obscuring discrete-scatterer media. While a very good range resolution can be achieved, the angular resolution is limited by the spread of the energy flux density in the RTE solutions.

In this paper we consider an approach allowing us to improve the angular resolution of the ETD image by Wiener-filter-type deblurring methods, utilizing the point-spread function (PSF) $\Lambda(R,\theta)$, as a function of the angle θ between the arriving flux direction and the optical axis of the system. The PSF is obtained from the solution of the RTE for a given propagation distance R.

A naive expectation is that the shape of the PSF would be similar to that of the differential cross-section $\sigma(\theta)$ for scattering on a single medium constituent. However, this is not the case, due to very significant multiple-scattering effects in the ETD component of the pulse. The modulation transfer function (MFT), $M(R,q) = \int \mathrm{d}\theta\, \theta\, \mathrm{J}_0(q\,\theta)\, \Lambda(R,\theta) / \int \mathrm{d}\theta\, \theta\, \Lambda(R,\theta)$, plotted in the Figure, contains a wide spectrum of spatial frequencies, much wider than the corresponding Hankel transform $\widehat{\sigma}(q)$ of the scattering cross-section, shown for comparison. The high spatial frequencies in the MTF, when enhanced by the deblurring filter, allow a significant improvement in the image resolution, ultimately dependent on the signal-to-noise ratio of the ETD signal.

The MTF of the ETD signal for the propagation distance of 16 mean-free-paths ℓ_{t} and for scatterers of average radius $a = 8\,\lambda$. The results were obtained for the RTE truncated in the angular momenta at the indicated values N.



[1] E. Bleszynski, M. Bleszynski, and T. Jaroszewicz, "Early-time diffusion in pulse propagation through dilute random media," Optics Letters, vol. 39, p. 5862 (2014).
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