Speckle fluctuations resolve the interdistance between incoherent point sources in complex media

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Abstract

We propose a method to capture the interaction between two identical sources in a scattering environment, based only on the measurement of intensity fluctuations [1]. The principle of the method is schematically illustrated in Fig. 1, and is based on the analysis of the intensity-intensity correlation function and the intensity fluctuations in the speckle pattern formed by two identical and mutually incoherent point sources. This approach permits in principle to monitor the relative distance between the sources in the range 10-500 nm, with a precision that is not limited by diffraction, but by the microstructure of the scattering medium.

A key issue affecting subwavelength imaging methods is the optical transparency of the media surrounding the light emitters. Taking advantage of the transparency of cells, fluorescence microscopy uniquely provides noninvasive imaging of the interior of cells and allows the detection of specific cellular constituents through fluorescence tagging. However, certain biological tissues or soft-matter systems (such as foams or colloidal suspensions) look turbid due to intense scattering of photons traveling through them [2]. The image formed at a given point in the observation plane consists in a superposition of multiple fields, each arising from a different scattering sequence in the medium. This gives rise to a chaotic intensity distribution with numerous bright and dark spots known as a speckle pattern, producing a blurred image carrying no apparent information about the source position [3].
Techniques to measure the distance between individual nano-objects without actually imaging their position exist [4], Fluorescence Resonance Energy Transfer (FRET) being the most widespread example [5]. It relies on the near-field energy transfer between two fluorophores (donor and acceptor) emitting at different wavelengths. The FRET signal (e.g. the ratio between the intensities emitted by the donor and the acceptor at different wavelengths) depends on the donor-acceptor distance in the range 2 $\sim$ 10 nm. As such, it is not very sensitive to scattering problems. However, determining distances between two emitters in the range of 10 to 500 nm in a scattering medium still remains a challenging problem, not accessible either by fluorescence microscopy or FRET techniques.
Our main goal here is to introduce a new approach to obtain information about the relative distance between two identical incoherent point sources in a disordered environment, based on the analysis of the fluctuations of the emitted light. This is an issue of much interest, for example, in the study of conformational changes in biomolecules in living tissues.

References

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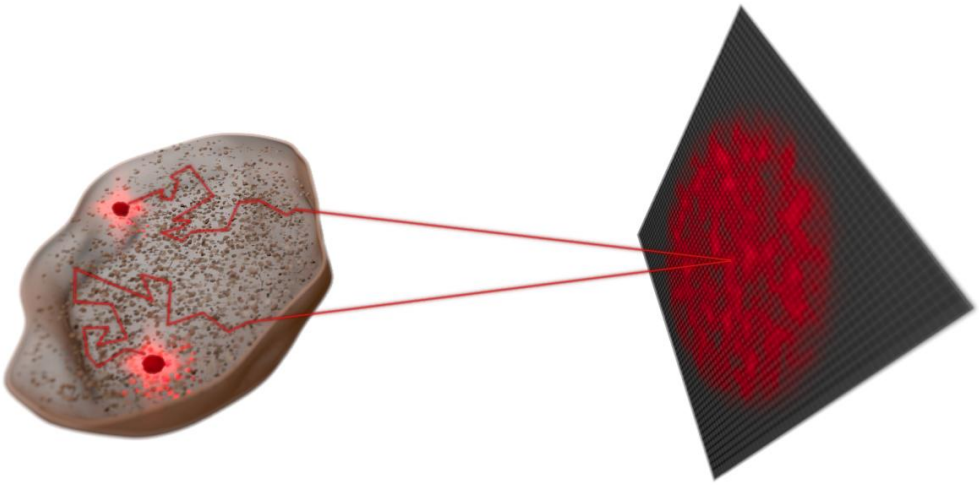

Fig. 1 The intensity radiated by two incoherent point sources in a complex medium form a speckle pattern that fluctuates in both space and time. The speckle fluctuations encode the relative distance between the sources [After Ref. 1]