Statistical properties and giant fluctuations for laser beam propagating in a turbulent medium

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Abstract

A statistical properties of a laser beam propagating in a turbulent medium are studied. It is proven that the intensity fluctuations at large propagation distances possess a Gaussian probability density function and establish quantitative criteria for realizing the Gaussian statistics depending on the laser propagation distance, laser beam waist, laser frequency, and turbulence strength. We calculate explicitly the laser envelope pair correlation function and corrections to its higher-order correlation functions breaking Gaussianity. At intermediate distances the laser intensity fluctuations follows the Poisson distribution (i.e. the amplitudes satisfies the Gaussian statistics) while the tail is strongly non-Gaussian with square-root dependence on the intensity in the exponent. The transition between the Poisson distribution and the non-Gaussian tail occurs at the values of intensity which quickly increases with the propagation distance. We find the explicit analytic expression for the fourth order correlation function vs. propagation distance and the turbulence strength which is determined by non-Gaussian tails. We find that this correlation function is in excellent agreement with the large scale supercomputer simulations of laser wave propagation. We discuss also statistical properties of the brightest spots in the speckle pattern and find that the most intense speckle approximately preserves both the Gaussian shape and the diameter of the initial collimated beam while losing energy during propagation. After

propagating 7km through typical atmospheric conditions, approximately one in one thousand of atmospheric realizations produces an intense speckle with 20-30% of the initial power. Such optimal atmospheric realizations create an effective lens which focuses the intense speckle beyond the diffraction limit of the propagation in vacuum.