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Propagation of electromagnetic paraxial beams in fluctuating fusion plasmas

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The wave kinetic equation [1, 2] has proved a suitable tool to tackle the problem of wave scattering from density fluctuations in fusion plasmas in the high-frequency limit. Its numerical implementation in the Monte Carlo code WKBeam [3] allowed a detailed study of the effects of beam scattering to be expected in ITER [4, 5]. This approach, although more efficient than a direct numerical solution of the wave problem (if this can be afforded at all) is still numerically expensive and does not allow the analysis of the results in terms of simple, physically relevant beam parameters.

In this work, a paraxial expansion of the Wigner function is introduced which allows us to derive phase-space paraxial equations following the example of the paraxial WKB (pWKB) method [6]. Analytic and numerical solutions obtained in simplified cases employing both, the paraxial Wigner function and the standard pWKB, approaches are shown to coincide in the case of no scattering.

In presence of fluctuations, a beam can be represented as an ensemble of solutions of the wave equation, each corresponding to a different realization of the random density field. Such an ensemble is the analogous of a "mixed state" in quantum mechanics, while the single solution obtained with a fixed density is a "pure state" [7]. As the beam propagates through a fluctuating plasma, the paraxial Wigner-function approach captures the decreasing purity of the state, which can be measured by an entropy function defined in analogy to quantum mechanics [8]. Methods for the numerical solution of the paraxial-Wigner-function approach are proposed and benchmarked with solutions obtained through alternative methods in simplified geometries [9].

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