Ray tracing in weakly turbulent, randomly fluctuating media: A quasilinear approach

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Ray propagation of electromagnetic and sound waves in turbulent media is important in a wide range of research areas, which can vary from astronomy and free-space communications to the scattering of rf waves in plasmas.

We describe the ray propagation in weakly turbulent media using a quasilinear (QL) approach, which relies on the Hamiltonian form of the ray equations and makes use of a second-order expansion (in the medium and ray fluctuations) of the dispersion relation and ray equations, in order to integrate the ensemble-averaged ray and its root-mean-square (rms) spreading. Due to the second-order terms, the averaged ray may exhibit a drift when compared with the zero-order, unperturbed one.

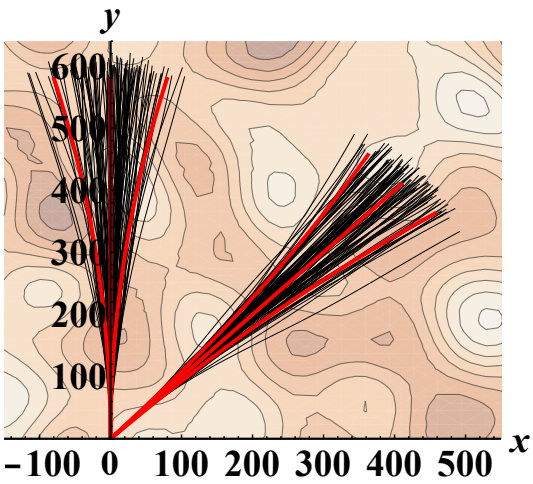

Figure 1: *Average ray trajectories and their rms spreadings from the QL formalism (red) vs. a MC calculation using 100 rays (black)*

The QL formalism is validated against Monte Carlo (MC) calculations and, when possible, verified using analytical predictions. For this, a single random mode and a multimode isotropic turbulent spectrum (see Fig. 1) was used as practical examples. The level of turbulence fluctuations and its maximum wavenumber are chosen to be not too small, yet small enough such that the second order expansion and the geometrical optics approximation remain valid.

Overall, the agreement between the QL and MC results is fair, particularly for the distance travelled by the average ray, its perpendicular rms spread and the averages of the wave-vector components. This approach comes as an efficient alternative to MC calculations and, while similar to the so-called statistical ray tracing [1], it appears to be much easier to implement in the case of more complex geometries or dispersion relations (as when tracing rays in tokamaks).

References

[1] R. Epstein and R. S. Craxton, Phys. Rev. A **33**, 1892 (1986)