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New insight in the propagation of wave fronts in the vicinity of a refractive object

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The transmission of electromagnetic energy along rays has been of interest in our community. The question has always been how accurate the ray-type of approximation is in representing the actual state of affairs of sending and receiving electromagnetic signals. In fact it is a high-frequency approximation derived from Maxwell's equations, leading to the Eikonal equation. We argue that the ray approximation does not meet up to its expectations. It fails to image the boundary of an object correctly, due to the fact that the method does not support all frequencies.

In our analysis we start with Maxwell's equations in tensor format going from a Cartesian geometry to a Riemannian geometry with a given metric tensor. From the behaviour of the stationarity of the Poynting vector we conclude that the metric tensor is functionally dependent on the refractive index of the medium. Our first choice is a simple diagonal metric tensor where the diagonal terms are given by the inverse square of the refraction index. This represents an orthogonal transformation and leads to the standard ray theory. However it cannot accommodate the structure of the ray in vacuum in the vicinity of the boundary of an object, since the metric tensor only has an expression in material media and has a Dirac form in vacuum. We then extend our analysis to a non-orthogonal transformation. In order to guarantee uniqueness we borrow the trace of the operator from our first choice, the diagonal operator. This leads to a new symmetric metric tensor as a function of a refractional potential for all media in vacuum. The refractional potential gives rise to a "tension" that determines the definition of the geodetic line. This tension is also present in vacuum outside the object. The geodetic lines are determined by Fermat's principle of least time.

As illustration, we consider ray propagation from an electric horizontal dipole located 60 m distance from a spherical object with 60 m radius and a refractive index of 1.5. Comparing the results for standard ray theory with the geodesics show clearly the difference (see left and middle picture of Figure 1). The standard ray has a definition inside and outside the object, which are not connected. The geodesic wave front "feels" the object and shows how inside and outside are connected. To verify our results we carry out a full 3D numerical simulation based on the contrast-source integral equation for the electric field vector. These experiments (see right picture of Figure 1) corroborate our wave-front analysis that only the geodesics support the wave front of the numerical simulation.

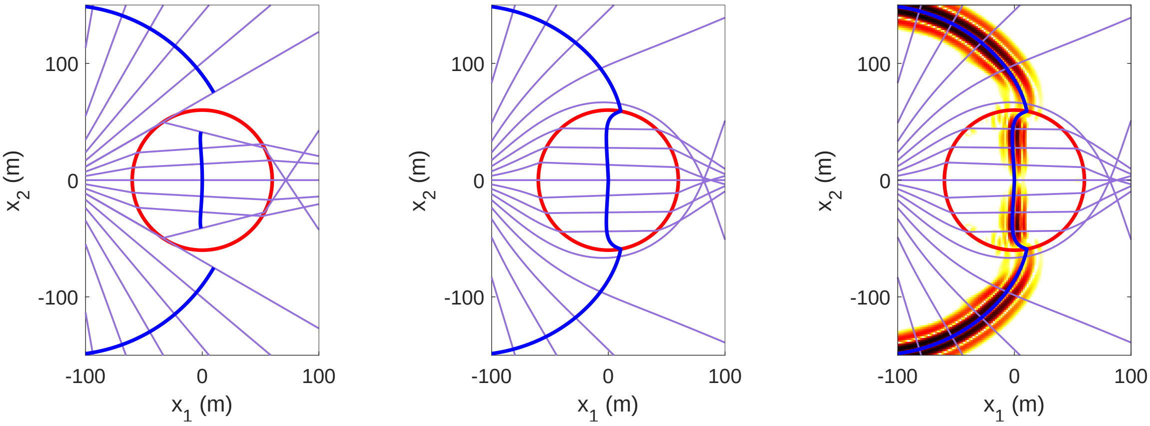

Figure 1. Ray paths (*purple lines*) and its wave front at $t = 0.5\mu$s (*thick blue curves*) (***left***); Geodesics and geodetic wave front in the same configuration (***middle***); Similar as the middle picture, but now with the actual wave front as overlay (***right***).

This result has consequences for the bending of electromagnetic waves around the Sun. Apart of coronal effects, Einstein (1911) conclusion is that the bending of light passing a massive star, the Sun, was caused by the "heaviness" of the light in reaction to the gravitational force of the Sun. We are not debating this conclusion, but we see, based on Maxwell's equation, that there is room, next to the gravitational tension, for an additional refractional tension. In fact the total potential interaction energy and the presence of the Corona control the bending of the light. With our extended model we investigated historical "radio-light" deflection measurements. Our conclusion is that our model explains these measurements very well. It adds a significant correction to solar gravitational lensing.