Reply to 'Comment on 'Towards gravitationally assisted negative refraction of light by vacuum''

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REPLY

Reply to 'Comment on 'Towards gravitationally assisted negative refraction of light by vacuum''

Akhlesh Lakhtakia[1,2] **and Tom G Mackay**[3]

[1] CATMAS — Computational and Theoretical Materials Sciences Group, Department of Engineering Science and Mechanics, Pennsylvania State University, University Park, PA 16802-6812, USA
[2] Department of Physics, Imperial College, London SW7 2 BZ, UK
[3] School of Mathematics, University of Edinburgh, Edinburgh EH9 3JZ, UK

E-mail: akhlesh@psu.edu and T.Mackay@ed.ac.uk.

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Abstract

Negative T_{00} is indeed a characteristic of any plane wave whose phase velocity vector casts a negative projection on its time-averaged Poynting vector, but that quantity does not appear to be necessarily meaningful in the context of energy densities of electromagnetic signals which are necessarily of finite spatiotemporal extent. The astrophysical literature contains several negative-energy scenarios.

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We reply to the comment [1] on our recent letter [2].

Indeed, $T_{00} < 0$ for a plane wave whose phase velocity vector casts a negative projection on its time-averaged Poynting vector. The same conclusion arises for isotropic, homogeneous, dielectric–magnetic materials that refract negatively [3]; but that does not seem to be a limitation because such materials have been artificially fabricated as composite materials comprising various types of electrically small inclusions, and their plane-wave response characteristics (over limited frequency ranges) are substantially as predicted [4, 5].

Electromagnetic energy densities for plane waves are not necessarily indicative of the true picture. This is because an electromagnetic signal is of finite spatiotemporal extent, while plane waves are infinitely extended over the entire spacetime. Therefore, the energy density of a signal is meaningful, but the time-averaged energy density of a plane wave may not be. Plane waves with negative phase velocity (NPV) could appear in gravitationally affected vacuum as part of a pulsed electromagnetic beam (of finite cross-section) which has positive and finite energy density. Furthermore, the spatiotemporal fluctuations of gravitation can act as a source term. Thus, one must consider the total energy density, not just the electromagnetic part of it.

Very significantly, negative-energy densities are invoked for the formation of certain black holes [6] as well as for the phenomenon of superradiant scattering of electromagnetic, gravitational and scalar waves [7, section 12.4]. Violations of energy conditions are commonplace in the astrophysics literature [8–10]. This situation arises because the local energy density of a gravitational field cannot be defined uniquely in the general theory of relativity.

We conclude that the issue of energy density remains to be carefully investigated for electromagnetic fields in gravitationally affected vacuum, regardless of the satisfaction of any NPV condition. A similar resolution is needed for the Casimir effect [11].

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