SETI, the Velocity-of-Light Limitation, and the Alcubierre Warp Drive: An Integrating Overview

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Abstract

In SETI (Search for Extraterrestrial Intelligence) conventional wisdom has it that the probability of direct contact by interstellar travel is vanishingly small due to the enormous distances involved, coupled with the velocity-of-light limitation. Alcubierre's recent "warp drive" analysis [Class. Quantum Grav. 11, L 73 (1994)] within the context of general relativistic dynamics, however, indicates the naivete of this assumption. We show here that Alcubierre's result is a particular case of a broad, general approach that might loosely be called "metric engineering," the details of which provide yet further support for the concept that reduced-time interstellar travel, either by advanced extraterrestrial civilizations at present or ourselves in the future, is not, as naive consideration might hold, fundamentally constrained by physical principles.

Key words: SETI, velocity of light, general relativistic dynamics, space-time metric, interstellar travel, vacuum energy, Casimir effect, vacuum engineering, warp drive, superluminal travel

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SETI researchers routinely subscribe to the view that interstellar travel between civilizations is exceedingly improbable due to the velocity-of-light limitation, with but few dissenting views offered.(1,2). Hence there has evolved, on the one hand, the emphasis on searches of the electromagnetic spectrum for information-bearing signals and, on the other, the reasoned dismissal by the scientific community of any evidence purported to be a signature of extraterrestrial visitation. (3)

As shown recently by Alcubierre, however, rejection of the concept of hyperfast (superluminal) travel is not justified when one takes into account the possibility of engineered dynamic space-times within the context of general relativity. (4) Specifically, Alcubierre showed by example that by distorting the local space-time metric in the region of a spaceship in a certain prescribed way, it would be possible to achieve motion faster than the speed of light as seen by observers outside the disturbed region, without violating the local velocity-of-light constraint within the region.

Furthermore, the Alcubierre solution shows that the proper acceleration along the spaceship's path would be zero and the spaceship would suffer no time dilation, features presumably attractive in interstellar travel. We present here a supporting viewpoint that further explicates the Alcubierre approach as a special case of an overarching concept of metric engineering that can be stated in an especially compact form, fully incorporating general relativistic dynamics.

To elaborate the metric engineering perspective, we begin with the apparent velocity-of-light limitation. As a *physical* concept this limitation is based on the fact that mass and energy find mathematical expression in a form proportional to $1/[1-(v/c)^2]^{1/2}$, which implies that an infinite amount of energy would be required just to accelerate a mass to the velocity of light $v = c$. A hidden assumption in the argument that this constitutes a practical limitation with regard to interstellar travel, however, is the idea that the value *c* is a fixed, immutable constant of nature, understood in a straightforward, natural way. It is this crucial assumption that is called into question and redefined, however, by the metric engineering approach.

In engineering terms the velocity of light in free space *c* is given by the expression $c = 1/(\mu_0\ \ _0)^{1/2}$, where in mks units $\mu_0 = 4\ \ \ \mathrm{x}\ 10^{-7}$ H/m and $\ \ _0 = 8.854\ \mathrm{x}\ 10^{-12}$ F/m, are, respectively, the magnetic permeability and dielectric permittivity of the vacuum. Therefore, the argument that *c* is fixed is, at base, an argument that μ_0 and $\ \ _0$ are fixed and not subject to manipulation by technological means. If, on the other hand, these vacuum constants were subject to change such that within a localized region the value *c* could be made to assume a new value, say $c' = 10c$, then, without violating the governing equations of physics, travel at speeds greater than the conventional velocity of light would be possible; it is just that a new restriction would apply involving the (elevated) local velocity of light, and travel inside the local light cone would still obtain, a point demonstrated in detail in the Alcubierre example.

Although perhaps surprising to the nonspecialist, within the context of general relativity and vacuum-energy physics, such variability of the free space velocity of light *c* (as seen from a distant frame) under certain conditions has long been part of the literature. For the case of propagation near a massive body, for example, we have a reduction in the velocity of light by an amount proportional to the gravitational potential, a result first noted by Einstein himself. [(5)] For the case of propagation between closely spaced conducting boundaries as in discussions of the Casimir effect, we have an *increase* in the velocity of light which is associated with the reduction of vacuum fluctuation energy between the plates. [(6)] In short, as emphasized by Wesson, the speed of light *c* is context-dependent and not as fundamental as widely believed.[(7)]

Such variations in *c*, considered in terms of its subcomponents μ and , are routinely treated in a compact form that recommends itself for simplicity of concept, the so-called "*TH* μ" formalism used in comparative studies of gravitational theories.[1] This approach has its foundation in the recognition that the covariant Maxwell equations in a Riemannian space with arbitrary metric are identical in form with the usual vector Maxwell equations for a material medium with variable and μ, where these parameters are themselves now a function of the metric.[(8)] This concept can be extended to nonmetric theories as well, and in the *TH* μ context goes under the name "gravitationally modified Maxwell equations."[1] The formalism is then completed by casting the Lagrangian for particle motion under the influence of electromagnetic and gravitational fields into a canonical form involving two additional metric-dependent functions, *T* and *H*. Such a formalism leads naturally to the concept of metric engineering in which one's familiarity with variable -μ media can act as an intuitive guide. [3,(8)] Although under *ordinary* conditions effects involving variations in vacuum values of μ, , and hence *c* typically are vanishingly small, they nonetheless indicate the possibility under *extraordinary* conditions of "vacuum engineering," as Nobel Laureate T. D. Lee put it.[(9)] The Alcubierre warp drive example, which can be reframed within the *TH* μ context, is an especially pithy example of such, and additional space-times with desired properties can be derived at will within this context. [4]

Therefore, the proper conclusion to be drawn by consideration *of engineered* metric/vacuum-energy effects is that, with sufficient technological means to appear 'magic" at present (to use Arthur C. Clarke's phrase characterizing a highly advanced, technological civilization), travel at speeds exceeding the conventional velocity of light could occur without the violation of fundamental physical laws. And, we might add, this could in principle be done without recourse to concepts as extreme as wormhole traversal.[10] (However, clearly, exotic matter/field states, e.g., macroscopic Casimir-like negative-energy-density vacuum states, would be required.) As a result, the possibility of reduced-time interstellar travel, either by advanced extraterrestrial civilizations at present or ourselves in the future, is not fundamentally constrained by physical principles.

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Endnotes

[1] A.P. Lightman and D. L. Lee, Phys. Rev. D 8, 364 (1973). See also, C. M. Will, Phys. Rep. 113, 345 (1984) for a later overview perspective. Extensions of the Lightman and Lee approach (point charges interacting classically with electromagnetic and gravitational fields) to include quantum mechanical analysis of atomic clocks and the standard model of fundamental (electroweak and strong) interactions are given in, respectively, C.M. Will, Phys. Rev. D 10, 2330 (1974) and J.E. Horvath, E.A. Logiudice, C. Riveros, and H. Vucetich, Phys. Rev. D 38, 1754 (1988).

[2] In the $TH\ \mu$ approach the functions T and H are introduced by requiring that the Lagrangian for the motion of charged particles under the joint action of gravity and the electromagnetic field A_i be expressed in the canonical form

$$L = \ Ldt = \ [-m_0(T - Hv^2)^{1/2} + eA_i v^i]dt,$$

where T and H, as well as and μ, are functions of the metric, that is, of a gravitational potential U. For standard theory of interest in this note (a metric theory), the four functions $TH\ \mu$ are related by $\ = \mu = (H/T)^{1/2}$. Although for ease of application in comparing a broad range of gravitational theories (e.g., scalar, vector, tensor, scalar-tensor, metric, and nonmetric) the required Lagrangian form is typically met by restricting consideration to static, spherically symmetric gravitational fields, Lightman and Lee emphasize that the $TH\ \mu$ approach is sufficiently general that all the results obtained can be shown to hold "even if U is an arbitrary but time-independent function of position."[1] Thus for a well-behaved standard metric type of theory of interest here, generation to nonsymmetric conditions can be carried out on a case-by-case basis without undue difficulty.

[3] For a detailed and explicit discussion of the isomorphisms between variable $-\mu$ media and general relativistic (metric) theories, see R.H. Dicke, Rev. Mod. Phys. 29, 363 (1957). See also as modified and corrected in R. H. Dicke, "Mach's Principle and Equivalence," *Proceedings of the Intentional School of Physics "Enrico Fermi" Course XX*, *Evidence for Gravitational Theories*, edited by C. Moller (Academic Press, NY, 196 1), p. 1.

[4] A detailed examination of the Alcubierre warp drive example within the TH μ-type framework is in preparation (to be published).

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