physics/9904019 11 Apr 1999

Warp drives, wavefronts and superluminality

Eric Baird, eric_baird@compuserve.com

Coule's primary objection to the Alcubierre "warpdrive" is that the material producing the warp field needs to be superluminal. This difficulty is solved by placing the drive material inside its own warp field (making the drive system part of the payload), but we then have to deal with Low's related objection, that there is then a restricted rate at which this "naked" warp-field can propagate through the background metric. We argue that the propagation of this sort of gravitational wave is not a trivial problem, and that the possibility of ultrafast warpfield propagation should not be dismissed without further research.

1. Introduction

D. H. Coule [1] and Robert J. Low [2] have recently raised complementary objections against the legality of an Alcubierrre-style "warp drive" [3] [4]. Coule's argument is that although we might imagine a hypothetical drive system that encloses a "warp bubble" in which the speed of light is manipulated to allow arbitrarily-fast travel in a chosen direction, in order to stop the payload contents from overtaking the drive mechanism we either need the drive system to be arbitrarily long (eg a Krasnikov tube [5] [6]), or we need *the drive unit itself* to be already travelling arbitrarily quickly through the background metric (hence Coule's memorable phrase, "*you need one to make one*"). Coule's problem is avoided by stipulating that the drive system is itself part of the payload (the device is immersed inside its own warpfield, e.g. Will [7]), but a similar objection then applies to the properties of the exposed warpfield wavefront -- we have to explain how the front of the exposed warp-field wavefront could travel through the background metric at a greater speed than $c_{\mathrm{BACKGROUND}}$. Low argues (reasonably) that this behaviour seems contradictory.

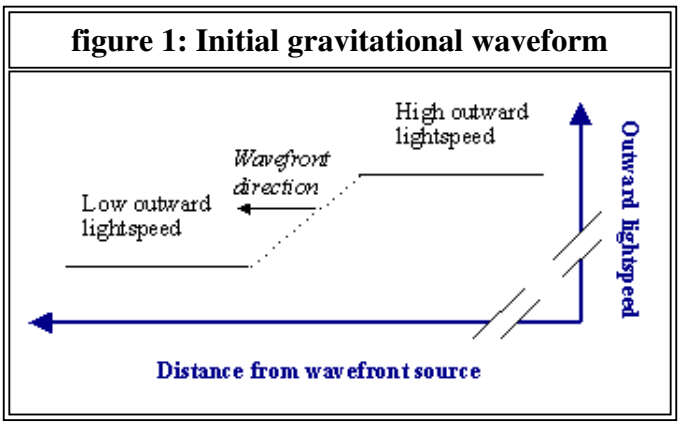
In this paper, we make a preliminary general examination of the question of how quickly a "gravitational rarefaction" wavefront (such as the repulsive component associated with the sudden forced acceleration of a mass towards the observer) propagates through the background metric. We conclude that this is not an easy question to answer.

2. Nature of the problem

Suppose that a star explodes, and that the sudden outward acceleration of its material creates a sudden outward increase in the speed of light away from its surface (dragging of light by accelerated matter). Measured along a line radial to the star, we then have a gravitational wavefront in which the outward

speed of light is greater behind the wavefront than before it (figure 1).

figure 1: Initial gravitational waveform



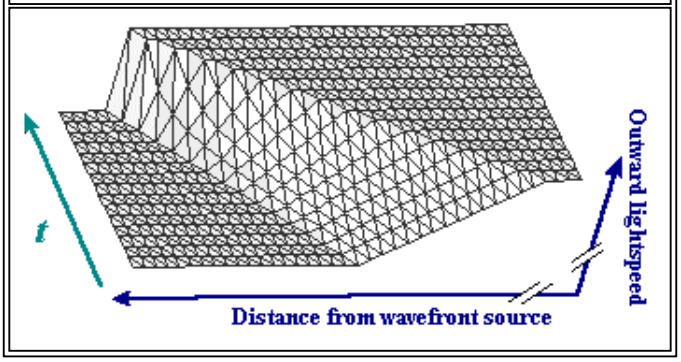
The question that we then need to answer is: How fast should this outward field-disturbance be allowed to travel? Do its components move outwards at the speed of light *within* the waveform, at the speed of light *outside* the waveform, or at some intermediate speed?

---

3. Linear propagation

If the speeds of all parts of the waveform in figure 1 are determined only by the nominal light-velocities that appear on the graph, then we have a problem. If the trailing edge of the wavefront travels outwards faster than the leading edge, the wavefront will become progressively more compacted as it travels, and for an initial waveform depth of x metres and a a speed difference of Dc, these two edges could be expected to meet each other (after a period of x/Dc seconds) at a distance of cx/Dc metres from the original position.

figure 2: Compacting waveform



If the waveform's spatial depth *really* compacts to zero size, we do not only have to worry about energy-changes associated with the wavelength-reduction of a gravitational waveform, but also have to consider the (infinite) energy required for the infinite compaction of any outward-moving EM signals that are moving in the same direction as the wave, and are trapped between the waveform's leading and trailing edges.

This situation marks the upper limit at which a simple linear-propagation model appear to break down -- if we try to extrapolate the wave-edge positions *through* this limit, we get a strange situation in which the rear of the waveform is supposed to be further forward than the leading edge.

---

4. Nonlinear propagation

If energy-conservation arguments dictate that there is a lower limit to the amount of compaction that is allowed, we find ourselves dealing with a situation in which the actual signal speed at any point on the graph does not depend just on the height of the graph at that point, but also on the properties of adjacent regions. In this situation, "lightspeed" becomes a more elusive property than our graph indicates, and we can no longer assign simple lightspeed values to individual pointlike regions without also taking into account the properties of the surrounding metric.

Classical nonlinear propagation models can show properties that confound the usual logic associated with general relativity -- for instance, while general relativity describes a gravitational horizon as being a completely one-way surface, models with nonlinear propagation can allow information to "bleed" outwards through the horizon in response to events that occur behind the surface (if we believe that a linear classical model is correct, these "forbidden" indirect-radiation effects will tend to be instead described as "non-classical" time-reversal and particle-pair production effects [8]). The strangeness of these descriptive artifacts (and the difficulty of building a nonlinear description in which observed causality is not a fundamental property [9]) may account for the unpopularity of nonlinear models, despite Einstein's suggestion that perhaps mainstream classical and quantum models disagree because of our taking a linearised approach to what might be inherently nonlinear physical phenomena [10].

Work by Unruh and Visser has now shown that the suspicious similarity between indirect radiation effects in a nonlinear "dark star" model and Hawking radiation in a QM description of a black hole [11] [12] [13] is more than mere coincidence [14] [15], so it is difficult to dismiss the possibility that an unfamiliar form of classical physics may be operating in these extreme situations [16]. If Unruh's and Visser's success in modelling black hole quantum field propagation as "sonic" wave-propagation can be extended to this problem, it seems entirely possible that we may get a description in which our warpfield is quite capable of advancing at speeds greater than general relativity's default definition of $c_{BACKGROUND}$.

---

5. Quantum mechanics

Less controversially, we could argue that perhaps current linear-propagation models do provide an appropriate classical description, but that this description becomes progressively less valid as the waveform's compaction becomes more extreme, with quantum mechanical effects preventing the waveform's complete compaction (this is similar to the argument that outward Hawking radiation pressure inside a black hole horizon, which might be expected to be infinitely strong at a point-singularity, prevents total gravitational collapse and prevents the singularity from actually forming).

This approach might appear to be more acceptable than an explicitly nonlinear approach, but the two

sets of physical predictions are at least qualitatively similar [8], and might even be equivalent [15]. Once we lose the principle that the gravitational waveform's components advance at the nominal rates expected from the graph, we have to consider the possibility that perhaps these quantum effects allow waveform components to travel at more than, as well as less than, the official nominal speed. Using the language of quantum mechanics, we could suggest that the superposition of a quantum field onto a onto a highly-compressed warpfield wavefront may allow warpfield information to "tunnel" outward through the lightspeed barrier represented by the warpfield's leading edge, as Hawking radiation.

Since hybrid "GR+QM" descriptions of warpfield propagation produce a scenario in which there is a very significant gravitational differential across a warpfield perimeter that is eventually compressed down to dimensions where QM effects become important, quantum tunnelling effects do need to be part of these descriptions.

---

6. Conclusions

If we start by assuming that the leading edge of a warpfield cannot propagate at more than $c_{\mathrm{BACKGROUND}}$, the assumption of classical linear propagation gives us a description in which the warpfield's perimeter compacts to zero (and then negative!) thickness, giving rise to infinite energy-densities. If we try to avoid these infinities by introducing quantum effects that become significant when the wall thickness is still small-but-finite, and which prevent complete compaction, we then have to accept the possibility that perhaps these quantum effects also give us a mechanism by which warpfield effects might "tunnel" forwards across the warpfield's leading edge in a manner similar to the way that particles can pass outwards through the **r=2M** surface of a "sonic black hole" or dark star.

Since these issues do not yet appear to have been resolved, the assumption that a warpfield can only travel at the nominal speed associated with $c_{\mathrm{BACKGROUND}}$ would still seem (at this time) to be unsafe.

APPENDIX: "Pseudo-linear" propagation

We might instead have tried to avoid the apparent paradoxes of section 3 by declaring that the travelling waveform does *not* compact as it propagates, suggesting three possible types of behaviour:

i. **Waveform is uncompacted and travels at $c_{\mathbf{BACKGROUND}}$:**
   -- if the whole waveform travels at $c_{\mathrm{BACKGROUND}}$, signals aimed at the rear of the receding wavefront are able to catch up with it, and run into a lightspeed discontinuity.
ii. **Waveform is uncompacted and travels at $c_{\mathbf{FAST}}$:**
   -- if the whole waveform travels at the faster rate, we have a lightspeed discontinuity that is able to catch up with "slow" signals ahead of the wavefront and speed them up ("cowcatcher" behaviour).
iii. **Waveform is uncompacted and travels at an intermediate speed:**
   -- in this scenario, we have both sorts of discontinuity.

In each case we lose the principle that waveform components travel at c_{LOCAL}, and nonlinear behaviour and/or quantum mechanics still needs to be invoked to remove the resulting lightspeed discontinuities. This approach does not seem to get us anywhere.

REFERENCES

1. D. H. Coule, "No warp drive,"
   Class. Quantum Grav. **15** 2523-2527 (1998).

2. Robert J. Low, "Speed Limits in General Relativity,"
   Class. Quantum Grav. **16** 543-549 (1999). gr-qc/9812067

3. Miguel Alcubierre, "The warp drive: hyper-fast travel within general relativity,"
   Class. Quantum Grav. **11** L73-L77 (1994).

4. Michael Spzir, "Spacetime hypersurfing,"
   American Scientist **82** 422-423 (Sept/Oct 1994).

5. Allen E. Everett and Thomas Roman, "Superluminal subway: The Krasnikov tube,"
   Physical Review **D 56** 2100-2108 (1997). gr-qc/9702049

6. S. V. Krasnikov, "Hyperfast travel in general relativity,"
   Physical Review **D 57** 4760-4766 (1998). gr-qc/9511068

7. Clifford Will, "The renaissance of general relativity," in
   The New Physics ed. Paul Davies (Cambridge University Press, Cambridge, 1989) pp.31-32.

8. Eric Baird "Superluminality and Pair Production,"
   Report No. physics/9807016 (1998).

9. Eric Baird "GR without SR: first-order Doppler effects considered as gravitational phenomena,"
   Report No. gr-qc/9807084 (1998).

10. Albert Einstein, **The Meaning of Relativity** 6th ed. (Chapman and Hall, London, 1955) Appendix II, pp.157.

11. S. W. Hawking, "Black hole explosions?,"
    Nature **248** 30-31 (March 1, 1974).

12. Kip S. Thorne, Wojciech H. Zurek, and Richard H. Price, "The Thermal Atmosphere of a Black Hole," in,
    Black Holes: The Membrane Paradigm, eds. Kip S. Thorne, Richard H. Price, and Douglas A. Macdonald (Yale University Press, New Haven, 1986) pp. 280-341.

13. Ulf H. Danielsson and Marcelo Schiffer, "Quantum mechanics, common sense, and the black hole information paradox,"
    Physical Review **D48** 4779-4784 (1993). gr-qc/9305012

14. Unruh, "Experimental black hole evaporation?,"
    Physical Review Letters **46** 1351-1353 (1981).

15. Matt Visser, "Acoustic black holes: horizons, ergospheres, and Hawking radiation,"
    Class. Quantum Grav. **15** 1767-1791 (1998). gr-qc/9712010

16. John Preskill, "Do Black Holes Destroy Information?" hep-th/9209058, in
    1992 International Symposium on Black Holes, Membranes, Wormholes and Superstrings eds. Sunny Kalahara and D. V. Nanopoulos (World Scientific Pub. Co., Singapore, 1993), pp.22-39.