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On the (im)possibility of warp bubbles

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Abstract

I discuss the objections raised by several authors against Alcubierre's warp drive geometry. I argue that all of these objections may, in principle, be overcome, although important practical difficulties remain.

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1 Introduction

Since Alcubierre published his 'warp drive' spacetime [1], the proposal has been criticized from various viewpoints by a number of authors [2, 3, 4, 5]. One of these criticisms, concerning the amount of exotic matter needed to support a warp bubble capable of transporting macroscopic objects [3], was partly countered in [6]. However, some conceptual problems remain, which I will try to address one by one.

2 Energy moving locally faster than light

Alcubierre–like spacetimes suffer from a dangerous flaw. This is the behaviour of the negative energy densities in the warp bubble wall [2, 5]. If the Alcubierre spacetime is taken literally, part of the exotic matter will have to move superluminally *with respect to the local lightcone*. The metric is

$$ds^2 = -dt^2 + (dx - v_s(t) f(r_s) dt)^2 + dy^2 + dz^2, \tag{1}$$

with $r_s = \sqrt{(x - x_s(t))^2 + y^2 + z^2}$, and $v_s = \frac{dx_s}{dt}$, where $x_s(t)$ is the path followed by the center of the warp bubble. It is easy to see that all exotic matter outside a sphere with radius r_c such that $f(r_c) = 1 - \frac{1}{v_s}$ (let us call this the critical sphere), will move in a spacelike direction. For $v_s > 1$, there has to be exotic matter outside the critical sphere, since the function f must reach the value 0 for some r_s (which, of course, can be infinity), and the negative energy density is proportional to $\left(\frac{df}{dr_s}\right)^2$ for an 'Eulerian observer' [1].

The problem may not be as big as it seems. Superluminal motion of energy density can be simulated; consider e.g. the beam of a pulsar at a sufficiently large distance from its source. In the case of the warp drive, one might envisage that the 'pilot' inside the warp bubble sends signals to the back of the bubble wall, generating an appropriate increase of exotic matter at some points, and a decrease at other points further behind, spacelike separated from the former for signals moving in the forward direction, thus simulating a superluminally moving energy distribution. A practical problem (apart from the difficulty to find a physical mechanism to implement such a scheme) is that the pilot is cut off from a sizeable part of the *front* of the bubble by a horizon (see figure 1 for a sketch). [1] The presence of the horizon means that the control would have to be carried out partly from outside, possibly by devices placed along the bubble's path in advance by a conventional

[1] In [4], the critical sphere was also called a horizon. In four dimensions, this term becomes a misnomer, and it is not what I mean by 'horizon' here.

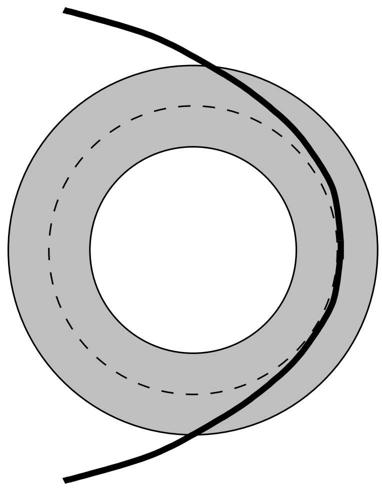

Figure 1: The function f varies in the shaded region. The dotted circle represents the sphere with $r_s = r_c$, while the thick line is the horizon. (We have assumed that f has compact support and becomes exactly 1 for some r_s.)

spaceship moving at subluminal speed [2]. "To boldly go where no man has gone before" would seem to be impossible for a warp drive.

3 A warp bubble with a singularity

However, even that obstacle may not be insurmountable. Consider a superluminal warp drive manipulated from outside as explained above. Now, suppose the outside controller at some point stops generating new negative energy for the simulation of the 'unphysical' motion, and lets the energy–momentum four–vector density evolve to physical values in front of the horizon. In the mean time, the pilot keeps manipulating the negative energy densities in the regions he is in causal contact with, so that the warp drive geometry is maintained behind the horizon. One could consider a spacelike hypersurface acting as an initial–data surface with an energy–momentum tensor describing this situation. It is not difficult to predict what will happen. The exotic matter in front will, in a finite time, be overtaken by the superluminally moving horizon, leaving only Minkowski spacetime ahead of it. Part of the horizon will turn into a singular surface, extending backward up to the points where it intersects the sphere defined by $f = 0$. The result is shown in figure 2.

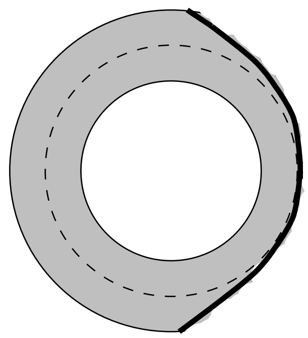

Figure 2: An independently moving warp bubble. The dotted circle again represents the critical sphere; the thick line now indicates the singular surface.

4 Quantum fields on an Alcubierre background

I would also like to comment on the objection against warp bubbles raised in [4]. Hiscock calculated the expectation value of the stress–energy tensor for a free conformally invariant scalar field living on an Alcubierre background. It was proven that the expectation value $\langle\rho\rangle$ of the density as observed by some freely falling observer would diverge at $r_s = r_c$, presumably creating a back–reaction in the metric that would make it impossible to create superluminal warp bubbles. The calculation has only been performed in two dimensions, and it is not clear what conclusions we should draw from this for the four–dimensional case. In the best–case scenario, the divergence occurs only along the single spatial direction in which the bubble is traveling. Let us assume the worst–case scenario, in which $\langle\rho\rangle$ becomes singular on the entire critical sphere. Hiscock himself suggested that there might be ways in which the pilot could manipulate the field such that the divergence would disappear. His main objection against this was that the singular surface (or points, in his case) would first appear at an infinite distance when $v_s = 1$, moving inward as the warp velocity is increased. The difficulty would then be to manipulate the field at such great distances from the bubble. However, this situation only occurs if the function f does not have compact support and only goes to zero asymptotically. If we let the negative energy density reach zero at a finite distance from the bubble center (which would be much more natural), then r_c is finite even for $v_s = 1$. The pilot can manipulate the field anywhere on the critical sphere, except at the point where it touches the horizon. But at that point, the geometry will become singular anyway, as we have argued.

5 Conclusions

The following could be a scenario for a warp drive flight without the need for continuous outside assistance. First, a superluminal warp bubble is created with the help of outside controllers. Then the controllers stop manipulating the exotic matter in front of the horizon, so that the four–momentum density becomes 'physical', while the pilot keeps controlling the part of the bubble that is accessible to him. Part of the horizon quickly developes into a surface singularity. The warp bubble then independently makes the trip to its distant destination, without any outside assistance. Upon arrival, the pilot engineers the back part of the warp bubble wall such that it smoothly changes into Minkowski spacetime, so that he drops out of the bubble. The singularity in the front of the bubble is waste.

I have tried to show that the criticisms on the warp drive should not be taken at face value; they need to be carefully reconsidered. Even so, it is clear that warp bubbles present enormous practical difficulties, which may never be overcome. Nevertheless, the warp drive seems to be the best candidate geometry for superluminal travel, and as such, it deserves further research.

Acknowledgements

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