Don't stop me now! Superluminal travel in Einstein's universe

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Credit: AI-generated image (disclaimer)

The story of the drawn-out development of Albert Einstein's revolutionary rewrite of the laws of gravity has been told many times, but over the past 100 years it has given us extreme stars and black holes, expanding universes and gravitational mirages. Einstein also ensured you will never get lost, enabling the technology that helps your phone find your location with pinpoint accuracy!

Despite this scientific bounty, relativity appears to place strict limits on our exploration of Einstein's universe, with any rocketship limited to travelling no faster than the speed of light. With the distance between stars measured in light years, and the distance across galaxies being hundreds of thousands of light years, not to mention the complexities of time dilation, establishing and running a galactic empire is going to be a drawn out and messy affair.

Bending time, bending space

I've already written that all is not lost, as in 1994 physicist Miguel Alcubierre discovered something wonderful: that by bending space and time just the right way will allow you to travel at any speed you want! While there are some downsides, with such a warp drive, the speed of light *can* be broken.

However, a couple of questions spring to mind, not least how can this superluminal bubble of a warp drive be consistent with the rules of relativity. And if it is, why did it take until the 1990s for someone to notice this was the case.

After $E = mc^2$, the fact that nothing can move faster than light is probably the most common fact known about Einstein's special theory of relativity. So just what can superluminal motion actual mean?

Let's begin with what Einstein was actually saying about racing a light beam. To Einstein, the race takes place "locally", such as in a laboratory, where you start a particle with mass and a light beam off at the same time. In this case, the light beam always gets ahead.

But in his special theory, the details of space and time are the same everywhere. More technically, the union of the two – known as spacetime – is flat, and we can compare the speed of a particle in the laboratory to a light ray somewhere off in the universe.

Things get messier in the general theory, as the presence of gravity ensures that the curvature of spacetime here is different to spacetime over there, and it is not possible to uniquely compare the speed of the particle in your laboratory to a light ray off in the distant universe. The only sensible comparison you can make is in your laboratory, and here the light ray still always wins.

The same is true in the curved spacetime of the warp drive. If your traveller in the warp bubble tries to race a particle and a light beam together, the light beam will always win.

An observer watching the bubble go by would calculate the light beam to be travelling faster than any light ray they create in their own laboratory. But this is not a problem, as it really makes no sense to compare velocities "there" with velocities "here".

It is precisely this reason that cosmologists are happy to talk about galaxies receding from us faster than the speed of light due to the expansion of the universe.

Metric mechanics

Relativity had been around for almost 80 years before Alcubierre uncovered his solution. Why hadn't people realised superluiminal travel was part of the theory?

The problem, of course, is the mathematically fiendish nature of Einstein's equations. It is extremely difficult to calculate the curvature of spacetime and resultant action of gravity from any old distribution of mass and energy.

It can be mathematically simpler to define the properties of spacetime and then calculate the required distribution of mass and energy. And Alcubierre's great insight was to realise a bubble could move at any speed as a rolling wave in spacetime.

However, such "metric mechanics" come with a downside: we may be able to find spacetimes that allow superluminal motion, but the required distribution of mass and energy may not be physically possible.

Those familiar with classical mechanics may remember that it is easier define a gravitational potential to determine forces, but these might require negative matter to physically exist.

The same is true for the warp drive solution, requiring material with a negative energy density to bend and shape space-time appropriately. And while we have hints that such properties exist in the universe, we have no idea if we will be able to mine and forge it to fashion our spaceships. So we may never be able to build an Alcubierre warp drive.

But we should not allow this to demoralise us! Alcubierre's insights should inspire us to continue to bend and stretch spacetime, to tease out the possibles still hidden within the mathematics. Most may be physically impossible to ever realise, but with sufficient imagination, and a stroke of luck, we may stumble across our pathway to the stars.

Source: The Conversation

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