How gravitational waves could help detect Star Trek-style warp drive spaceships

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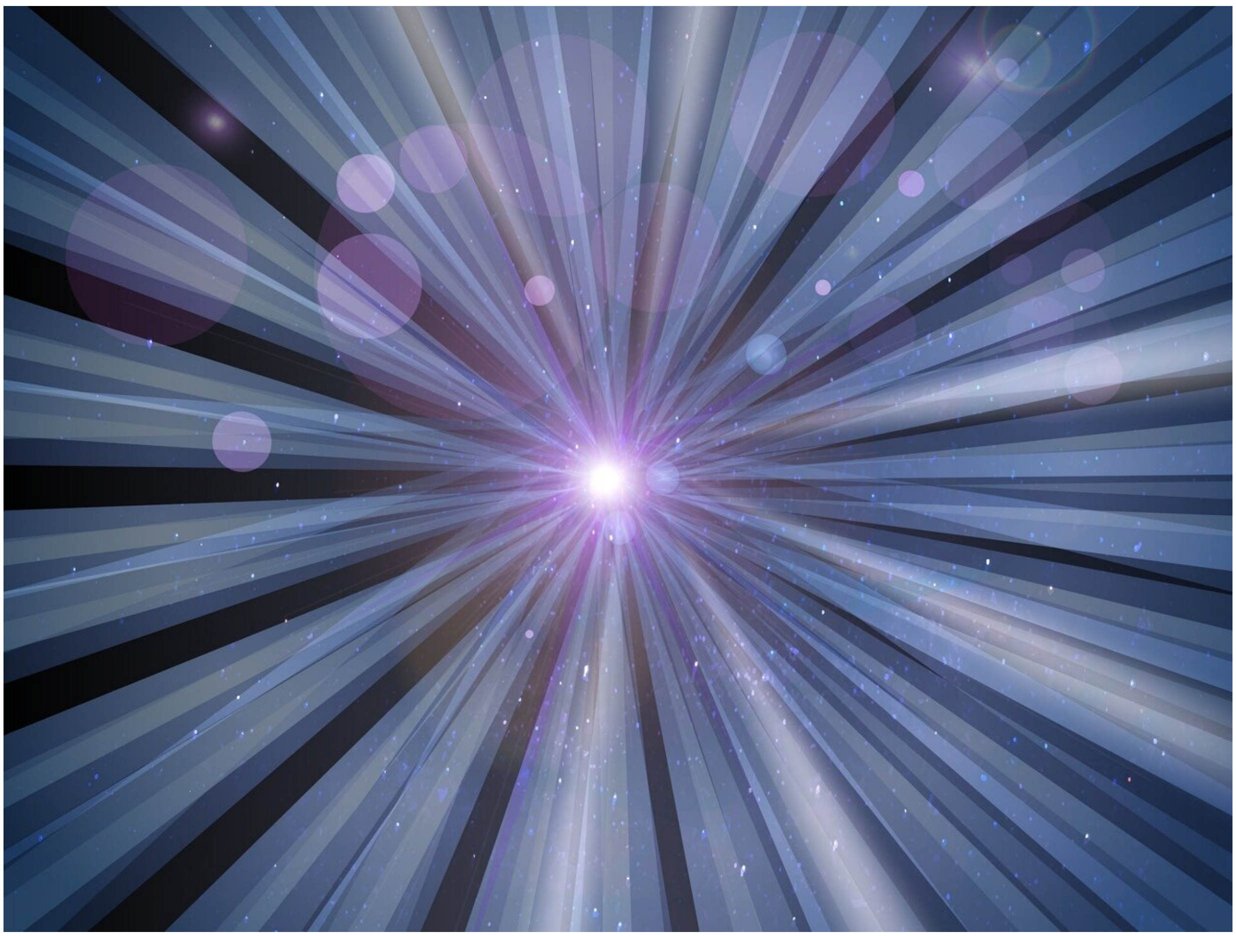

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How much do we really know about what else is out there in the universe?

Let's take an outlandish example. If there were aliens flying around our galaxy with the sort of warp drive technology we often see in sci-fi shows, what would the signal from their ships look like? Perhaps, surprisingly, our research shows we have the tools to answer this question, regardless of whether such things really exist.

Telescopes that use light to probe space can now see almost to the edge of what is observable. Each new frequency we have explored—from gamma rays and X-rays, to infrared and radio—has taught us something new and unexpected.

In 2015, a new kind of telescope, a detector called Ligo, was turned on, not looking for light waves but for gravitational waves, which are invisible "ripples" in space and time. Again nature surprised us with a signal labeled GW150914 from a pair of black holes. Each were about thirty times the mass of our sun, merging together in a violent collision 1.4 billion light years away.

Since then gravitational waves have become an essential new tool for scholars exploring the universe. But we are still at the very beginning of our explorations. What signals might we see in the data, and will they change how we see the physics of the cosmos?

There is, however, a more practical question that often gets overlooked—if something is out there, how would we recognize it?

From sci-fi to serious science

You may have seen warp drives in series like Star Trek. A warp drive is a hypothetical form of technology that compresses the space in front of a starship and expands it behind. While nothing can travel faster than the speed of light, in a warp drive we can cheat by making our distance shorter. So, the time it takes to go from A to B is less than the time light takes on another uncompressed path.

The jump from sci-fi to real science was made by theoretical physicist Miguel Alcubierre in 1994, when he was inspired to model a warp drive using Einstein's equations of general relativity.

General relativity is a relationship between spacetime curvature (gravity) and a distribution of matter or energy (stuff). Typically, we start by knowing the "stuff." For example, we know that we have a blob of matter that represents a planet or star. We then put that stuff into the equations to determine how the spacetime curves. And how it curves tells us the gravity we would measure around the object.

You could say that this is exactly what Isaac Newton's picture of gravity does—giving a relation between an object's mass and the gravitational force it exerts. And you would be right. But the concept of spacetime curvature gives rise to a much richer range of phenomena than a simple force. It allows a kind of repulsive gravity that drives our universe to expand, creates time dilation around massive objects and gravitational waves in spacetime and—in theory at least—it makes warp drives possible.

Alcubierre tackled his problem from the opposite direction to the usual one. He knew what kind of spacetime curvature he wanted. It was one in which an object could surf on a region of warped spacetime. So, he worked backwards to determine the kind of matter configuration you would need to create this. It wasn't a natural solution of the equations, but rather something "made to order." It wasn't exactly what he would have ordered though. He found he needed exotic matter, something with a negative energy density, to warp space in the right way.

Exotic matter solutions are generally viewed with skepticism by physicists, and rightly so. While mathematically, one can describe material with negative energies, almost everything we know appears to have a positive energy. But in quantum physics, we have observed that small, temporary violations of energy positivity can occur, and so, "no negative energy" can't be an absolute, fundamental law.

From warp drives to waves

Given Alcubierre's model of the warp drive spacetime, we can begin to answer our original question—what would a signal from it look like?

One of the cornerstones of modern gravitational wave observations, and one of its greatest achievements, is the ability to accurately predict waveforms from physical scenarios using a tool called "numerical relativity".

This tool is important for two reasons. First, because the data we get from detectors is still very noisy, which means we often have to know roughly what a signal looks like to be able to pull it out of the datastream. And second, even if a signal is so loud that it stands out above the noise, we need a model in order to interpret it. That is, we need to have modeled many different types of event, so we can match the signal to its type; otherwise we might be tempted to dismiss it as noise, or mislabel it as a black hole merger.

One problem with the warp drive spacetime is that it doesn't naturally give gravitational waves unless it starts or stops. Our idea was to study what would happen when a warp drive stopped, particularly in the case of something going wrong. Suppose the warp drive containment field collapsed (a staple storyline in sci-fi); presumably there would be an explosive release of both the exotic matter and gravitational waves. This is something we can, and did, simulate using numerical relativity.

What we found was that the collapse of the warp drive bubble is indeed an extremely violent event. The enormous amount of energy needed to warp spacetime gets released as both gravitational waves and waves of positive and negative matter energy. Unfortunately, it's most likely the end of the line for the ship's crew who would be torn apart by tidal forces.

We knew a gravitational wave signal would be emitted; any movement of matter in a messy way creates such a wave. But we couldn't predict the amplitude and frequency, and how these would depend on the size of the warped region.

We were surprised to find that for a 1km sized ship, the amplitude of the signal would be significant for any such event within our galaxy and even beyond. At a distance of 1 megaparsec (slightly further than the Andromeda galaxy), the signal is similar to our current detector sensitivity. However, the frequency of the waves is about a thousand times higher than the range they are looking at.

We should be honest and say that we can't claim our signal as the definitive warp drive signal. We had to make quite a few specific choices in our model. And our hypothetical aliens may have made different ones. But as a proof of principle, it shows that cases beyond standard astrophysical events can be modeled, and may have distinctive forms and shapes that we can search for in future detectors.

Our work also reminds us that compared to the study of light waves, we are still at the stage of Galileo, taking pictures of the universe in the narrow frequency band of visible light. We have a whole spectrum of gravitational wave frequencies still to explore, which will be sensitive to a range of phenomena happening across space and time.

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