Warp drives could generate gravitational waves

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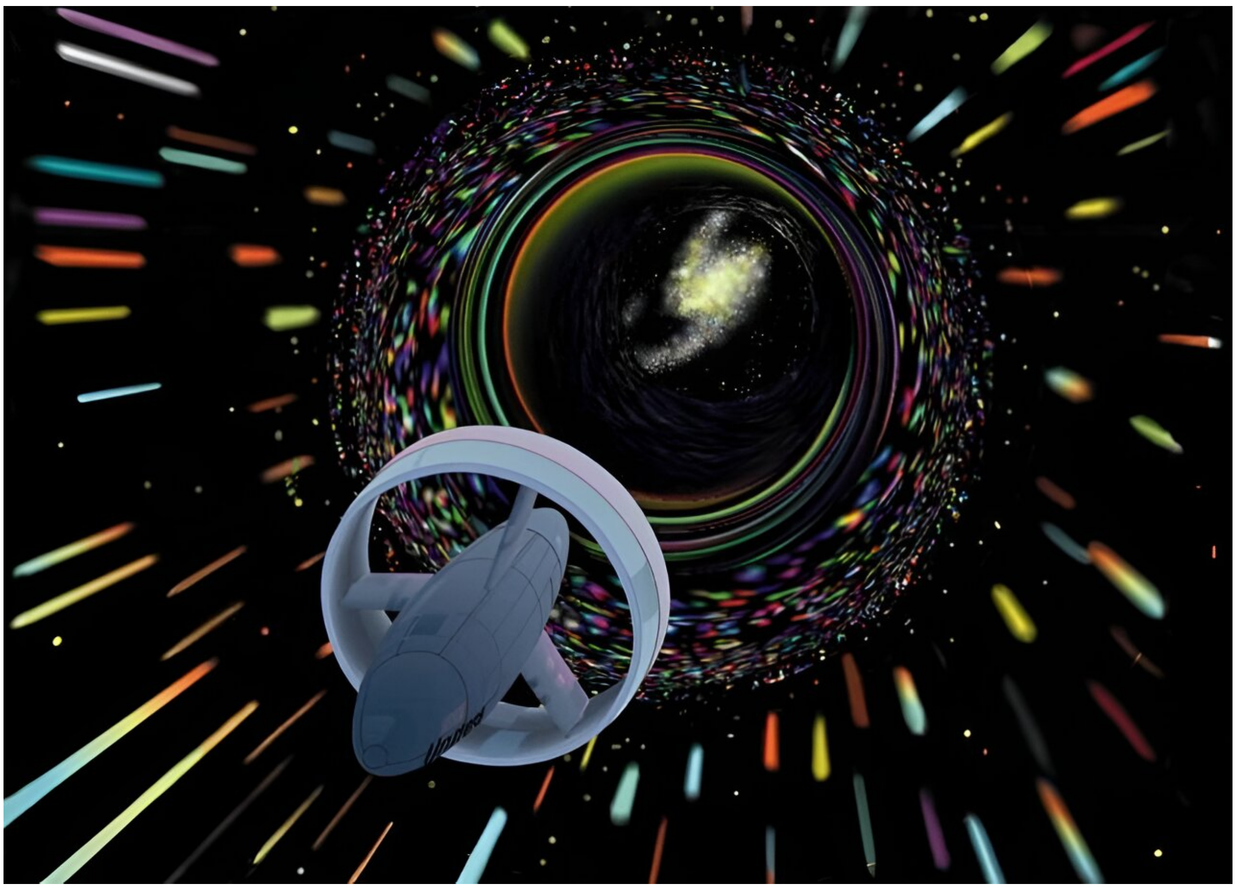

This artist's illustration shows a spacecraft using an Alcubierre Warp Drive to warp space and 'travel' faster than light. Credit: NASA

Will future humans use warp drives to explore the cosmos? We're in no position to eliminate the possibility. But if our distant descendants ever do, it won't involve dilithium crystals, and Scottish accents will have evaporated into history by then.

Warp drives have their roots in one of the most popular science fiction franchises ever, but they do have a scientific basis. A new paper examines the science behind them and asks if a warp drive containment failure would emit detectable gravitational waves.

The paper is titled "What no one has seen before: gravitational waveforms from warp drive collapse," and it is posted to the *arXiv* preprint server. The authors are Katy Clough, Tim Dietrich, and Sebastian Khan, physicists from institutions in the U.K. and Germany.

There's room for warp drives in General Relativity, and Mexican physicist Miguel Alcubierre described how they could theoretically work in 1994. He's well-known in space and physics circles for his Alcubierre Drive.

Everyone knows that no object can travel faster than the speed of light. But warp drives may offer a workaround. By warping spacetime itself, a spacecraft with a warp drive wouldn't be breaking the faster-than-light (FTL) rule.

"Despite originating in science fiction, warp drives have a concrete description in general relativity, with Alcubierre first proposing a spacetime metric that supported faster-than-light travel," the authors write.

There are clear scientific barriers to actually making a warp drive. But it's possible to simulate how one would work and how they may be detectable via gravitational waves in the event of a failure.

Warp drives distort spacetime itself, just like binary mergers of compact objects like black holes and neutron stars. It's theoretically possible that they emit a gravitational wave signal in the same vein as mergers.

"To search for such signals and to correctly identify them in the measured data, it is important to understand their phenomenology and properties," the authors explain.

It begins with understanding how warp drives might work, and for that, we have to delve deeply into physics.

"The principal idea behind a warp drive is that instead of exceeding the speed of light directly in a local reference frame, which would violate Lorentz invariance, a 'warp bubble' could traverse distances faster than the speed of light (as measured by some distant observer) by contracting spacetime in front of it and expanding spacetime behind it," the paper states.

The first barrier is that warp drives require a Null Energy Condition (NEC). Physics states that a region of space cannot have a negative energy density. There are theoretical workarounds for that, but for now, none of them are practical.

"Other issues with the warp drive metric include the potential for closed time-like curves and, from a more practical perspective, the difficulties for those in the ship in controlling and deactivating the bubble," the authors explain.

This is because there would be no way for the crew to send signals to the front of the ship. It's difficult for events inside the bubble to influence events outside the warp bubble, as an earlier paper explains.

"From the perspective of simulating the warp drive dynamically, the key challenge is stability," the authors explain. Equations show that the Alcubierre Drive can initiate a warp bubble using the Einstein Equation, but no known equations can sustain it.

"There is (to our knowledge) no known equation of state that would maintain the warp drive metric in a stable configuration over time. Therefore, while one can require that initially, the warp bubble is constant, it will quickly evolve away from that state, and, in most cases, the warp fluid and spacetime deformations will disperse or collapse into a central point."

Though instability is a prime obstacle to warp drives, it's also what could make them detectable. If an Alcubierre Drive achieves a constant velocity, it's not detectable. It generates no gravitational waves and has no ADM mass. ADM stands for Arnowitt–Deser–Misner, named for three physicists.

But the warp drive is only undetectable if it's constant and stable. Once it breaks down, accelerates or decelerates, it could be detectable. In their work, the authors allow the warp drive bubble to collapse.

"Physically, this could be related to a breakdown in the containment field that the post-warp civilization (presumably) uses to support the warp bubble against collapse," they write.

In their formulations, the nature of the ship itself isn't important. Only the warp bubble and the warp fluid inside are significant.

The researchers simulated the breakdown of the warp bubble. They found that the collapse generated gravitational waves with characteristics different from those generated by mergers. "The signal comes as a burst, initially having no gravitational wave content, followed by an oscillatory period with a characteristic frequency of order 1/[R]," they write.

"Overall, the signal is very distinct from the typical compact binary coalescences observed by gravitational wave detectors and more similar to events like the collapse of an unstable neutron star or the head-on collision of two black holes."

The authors point out that though the warp drive creates a GW signal, it's outside the frequency range of our current ground-based detectors. "Proposals for higher frequency detectors have been made, so in the future, one may be able to put bounds on the existence of such signals," they write.

The ship itself could also send some type of multi-messenger signal, but it's difficult to know how the ship's matter would interact with regular matter. "Since we do not know the type of matter used to construct the warp ship, we do not know whether it would interact (apart from gravitationally) with normal matter as it propagates through the universe," the researchers explain.

This is a fun thought experiment. It's possible that some type of workaround to FTL travel will exist one day in the distant future. If it does, it may be related to a better understanding of dark matter and dark energy. If any ETIs exist, they may be in a position to exploit fundamental knowledge of the universe that we don't yet possess.

If they've figured out how to construct and use a warp drive, even with all of its seeming impossibilities, their activities might create gravitational waves that our future observatories could detect, even in other galaxies. But for now, it's all theoretical.

"We caution that the waveforms obtained are likely to be highly specific to the model employed, which has several known theoretical problems, as discussed in the Introduction," the authors write in their conclusion. "Further work would be required to understand how generic the signatures are and properly characterize their detectability."

Without a doubt, some curious physicists will continue to work on this.

More information: Katy Clough et al, What no one has seen before: gravitational waveforms from warp drive collapse, *arXiv* (2024). DOI: 10.48550/arxiv.2406.02466

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