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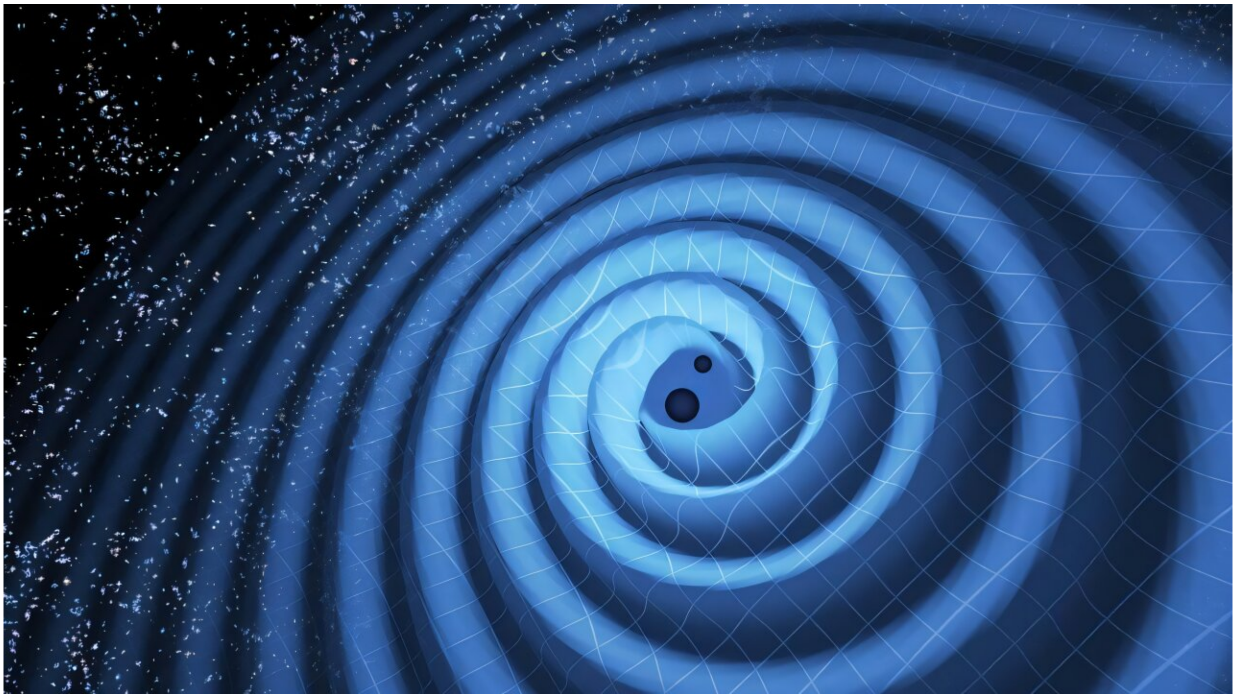
Could gravitational waves be the key to cosmic communication?

January 30 2025, by Evan Gough



This illustration shows the merger of two supermassive black holes and the gravitational waves that ripple outward as the black holes spiral toward each other. Credit: LIGO/T. Pyle

When astronomers detected the first long-predicted gravitational waves in 2015, it opened a whole new window into the universe. Before that, astronomy depended on observations of light in all its wavelengths.

We also use light to communicate, mostly radio waves. Could we use gravitational waves to communicate?

The idea is intriguing, though beyond our capabilities right now. Still, there's value in exploring the hypothetical, as the future has a way of arriving sooner than we sometimes think.

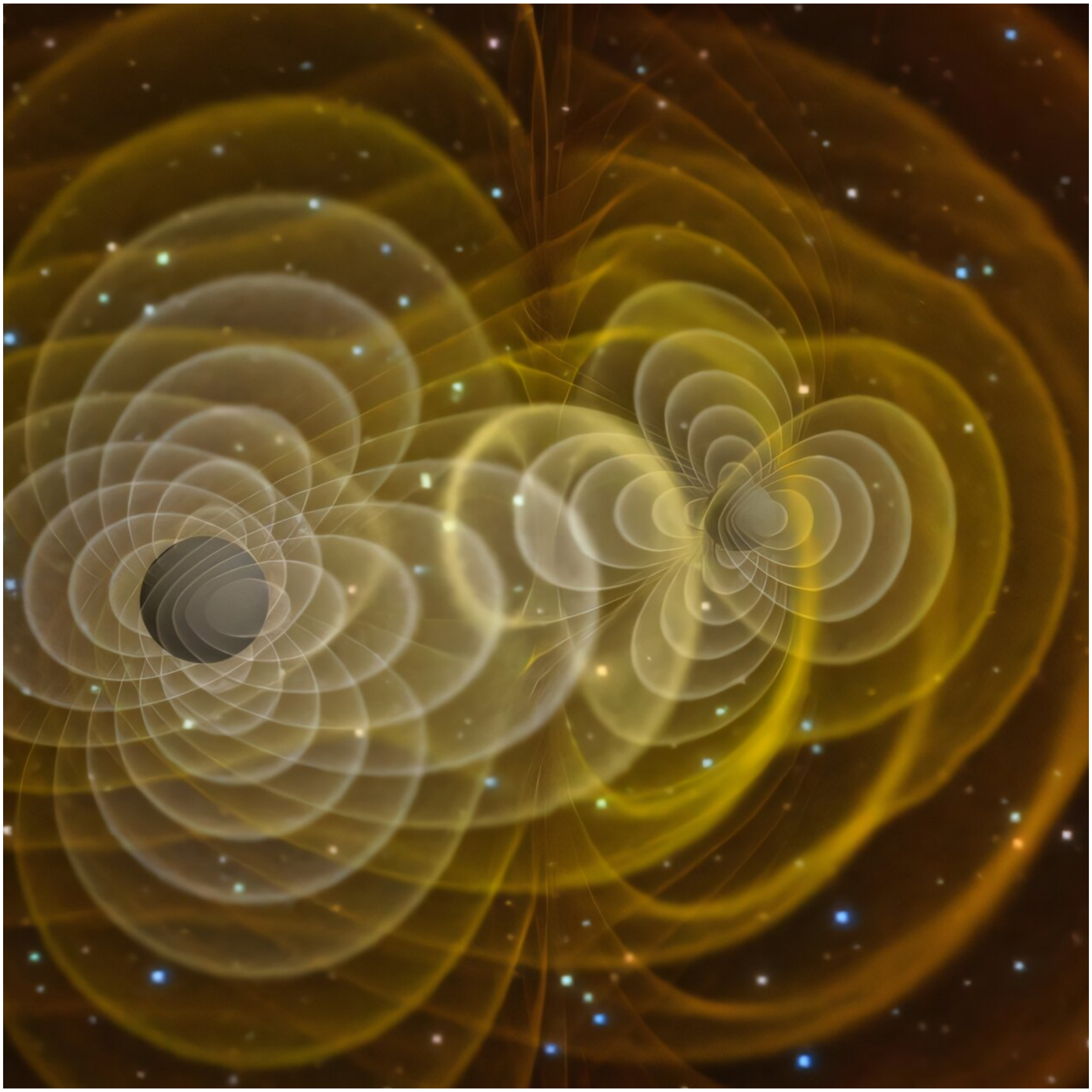
New research examines the idea and how it could be applied in the future. It's titled "Gravitational Communication: Fundamentals, State-of-the-Art and Future Vision," and it's available on the *arXiv* preprint server. The authors are Houtianfu Wang and Ozgur B. Akan. Wang and Akan are both with the Internet of Everything Group, Department of Engineering, University of Cambridge, U.K.

"The discovery of gravitational waves has opened a new observational window for astronomy and physics, offering a unique approach to exploring the depths of the universe and extreme astrophysical phenomena. Beyond its impact on astronomical research, gravitational waves have also garnered widespread attention as a new communication paradigm," the authors explain.

Traditional electromagnetic communications have definite drawbacks and limitations. Signals get weaker with distance, which restricts range. Atmospheric effects can interfere with radio communications and diffuse and distort them. There are also line-of-sight restrictions, and solar weather and space activity can also interfere.

What's promising about gravitational wave communication (GWC) is that it could overcome these challenges. GWC is robust in extreme environments and loses minimal energy over extremely long distances. It also overcomes problems that plague electromagnetic communication (EMC), like diffusion, distortion, and reflection. There's also the intriguing possibility of harnessing naturally created GWs, which means reducing the energy needed to create them.

"Gravitational communication, also known as gravitational wave communication, holds the promise of overcoming the limitations of traditional electromagnetic communication, enabling robust transmission across extreme environments and vast distances," the authors point out.



Artist’s impression of gravitational waves. Credit: NASA

To advance the technology, researchers need to create artificial gravitational waves (GWs) in the lab. That's one of the primary goals of GW research. GWs are extremely weak, and only enormous masses moving rapidly can generate them. Even the GWs we've detected coming from merging supermassive black holes (SMBHs), which can have billions of solar masses, produce only miniscule effects that require incredibly sensitive instruments like LIGO to detect.

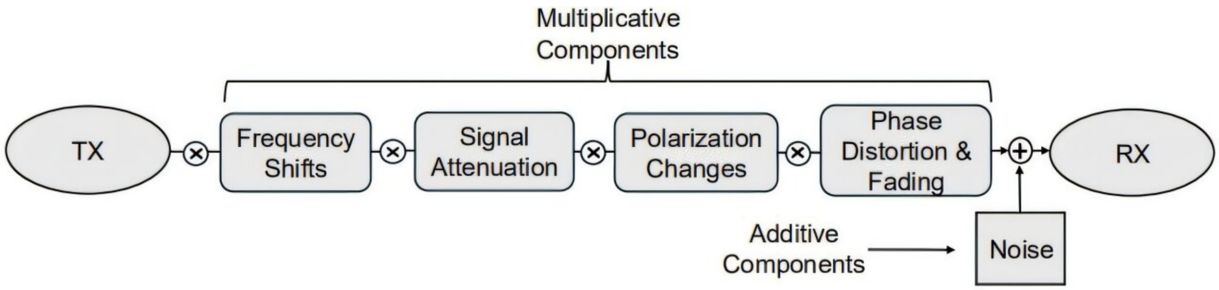
Generating GWs that are strong enough to detect is a necessary first step.

"The generation of gravitational waves is pivotal for advancing gravitational communication, yet it remains one of the foremost challenges in contemporary technological development," the authors write. "Researchers have explored various innovative methods to achieve this, including mechanical resonance and rotational devices, superconducting materials, and particle beam collisions, as well as techniques involving high-power lasers and electromagnetic fields."

There is plenty of theoretical work behind GWC but less practical work. The paper points out what direction research should take to bridge the gap between the two.

Obviously, there's no way to recreate an event as awesome as a black hole merger in a laboratory. But surprisingly, researchers have been considering the problem as far back as 1960, long before we'd ever detected GWs.

One of the first attempts involved rotating masses. However, the rotational speed required to create GWs was impossible to achieve, partly because the materials weren't strong enough. Other attempts and proposals involved piezoelectric crystals, superfluids, particle beams, and even high-power lasers. The issue with these attempts is that while physicists understand the theory behind them, they don't have the right materials yet. Some attempts generated GWs, scientists think, but they aren't strong enough to be detectable.



This conceptual illustration shows what effects GWs are subjected to as they propagate. "The signal first experiences large-scale influences such as gravitational and cosmological frequency shifts, followed by broad-scale amplitude attenuation due to cosmic expansion and weak scattering. Next, more region-specific factors induce polarization changes, and finally, localized distortions arise in the form of phase variations and fading effects caused by gravitational lensing and other fine-scale phenomena. Additive noise is introduced near the receiver end," the authors write. Credit: *arXiv* (2025). DOI: 10.48550/arxiv.2501.03251

"High-frequency gravitational waves, often generated by smaller masses or scales, are feasible for artificial production under laboratory conditions. But they remain undetectable due to their low amplitudes and the mismatch with current detector sensitivities," the authors explain.

More advanced detection technologies or some method to align generated GWs with existing detection capabilities are needed. Existing technologies are aimed at detecting GWs from astrophysical events. The authors explain that "Research should focus on designing detectors capable of operating across broader frequency and amplitude ranges."

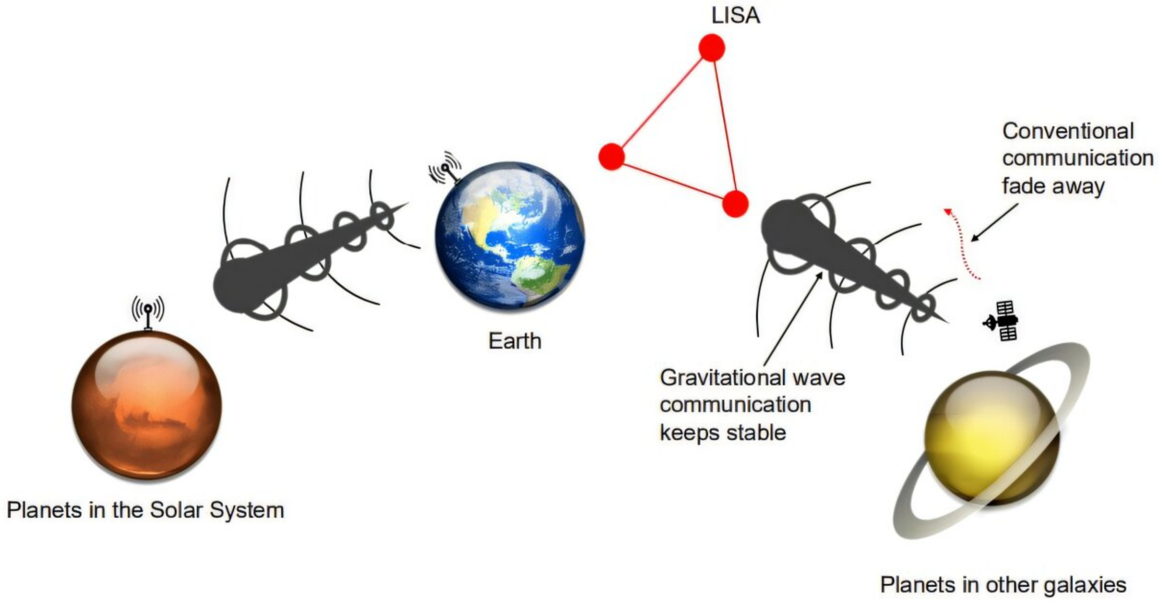
While GWs avoid some of the problems that EM communications face, they aren't without problems. Since they can travel vast distances, GWC faces problems with attenuation, phase distortion, and polarization shifts from interacting with things like dense matter, cosmic structures, magnetic fields, and interstellar matter. These can not only degrade the signal's quality but can also complicate decoding.

There are also unique noise sources to consider, including thermal gravitational noise, background radiation and overlapping GW signals. "Developing comprehensive channel models is essential to ensure reliable and efficient detection in these environments," the authors write.

In order to ever make use of GWs, we also need to figure out how to modulate them. Signal modulation is critical to communications. Look at any car radio and you see "AM" and "FM." AM stands for "Amplitude Modulation" and FM stands for "Frequency Modulation." How could we modulate GWs and turn them into meaningful information?

"Recent studies have explored diverse methods, including astrophysical phenomena-based amplitude modulation (AM), dark matter-induced frequency modulation (FM), superconducting material manipulation, and nonmetricity-based theoretical approaches," the authors write. Each one of these holds promise as well as being choked with obstacles.

For example, we can theorize about using dark matter to modulate GW signals, but we don't even know what dark matter is. "Frequency modulation involving ultralight scalar dark matter (ULDM) depends on uncertain assumptions about dark matter's properties and distribution," the authors write, addressing an elephant in the room.



How GWC can be used in our own solar system and in interstellar communications. Where conventional communications would simply fade away on the long journey between stars, GWC will not. Credit: *arXiv* (2025). DOI: 10.48550/arxiv.2501.03251

It might seem as if GWC is out of reach, but it holds so much promise that scientists are unwilling to abandon it. In deep space communications, EM communication is hamstrung by the vast distances and interference from cosmic phenomena. GWC offers solutions to these obstacles.

A better method to communicate over long distances is critical to exploring deep space, and GWC is exactly what we need. "Gravitational waves can maintain consistent signal quality over immense distances, making them suitable for missions beyond the solar system," the authors write.

Practical gravitational wave communication is a long way off. However, what was once only theoretical is gradually shifting into the practical.

"Gravitational communication, as a frontier research direction with significant potential, is gradually moving from theoretical exploration to practical application," Wang and Akan write in their conclusion. It will depend on hard work and future breakthroughs.

The pair of researchers know that much hard work is needed to advance the idea. Their paper is deeply detailed and comprehensive, and they hope it will be a catalyst for that work.

"Although a fully practical gravitational wave communication system remains unfeasible, we aim to use this survey to highlight its potential and stimulate further research and innovation, especially for space communication scenarios," they conclude.

More information: Houtianfu Wang et al, Gravitational Communication: Fundamentals, State-of-the-Art and Future Vision, *arXiv* (2025). DOI: 10.48550/arxiv.2501.03251

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