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The Science of Wormholes: Exotic Matter and the Plausibility of Human or Object Space Travel

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ABSTRACT

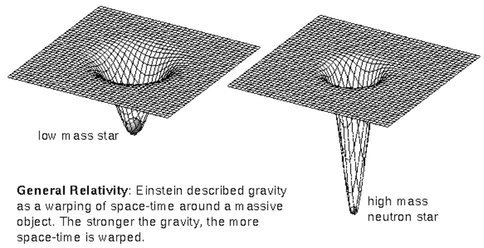
Space travel is often imagined in science fiction through dramatic scenes involving hyperspace, faster-than-light travel, and shortcuts across the universe. Movies such as *Star Wars* show spaceships moving through hyperspace to cross huge distances in a short amount of time. While this idea may seem fictional, wormholes offer a theoretical way to imagine how shortcuts through spacetime could be possible. What if we could really move that fast through space? This could all be theoretically possible through wormholes. Wormholes, also known as Einstein-Rosen bridges, are hypothetical structures that may connect two distant points in space and time. In order for humans to travel through traversable wormholes, it is predicted that exotic matter is required. This paper explores the theoretical structure, types, and possible uses of wormholes, as well as the conditions needed to make them stable and traversable. It also discusses the role of exotic matter and the challenges involved in using wormholes for human space travel. By examining these theories and diagrams, this paper explains how wormholes could expand our understanding of spacetime and possibly help humans explore distant regions of the universe.

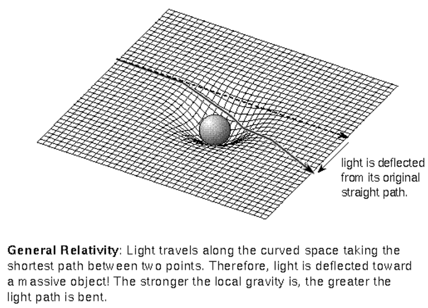
INTRODUCTION

In general relativity, is exotic matter required to sustain traversable wormholes, and how does this compare with wormhole solutions in modified theories of gravity? Wormholes, also known as Einstein-Rosen bridges, are theoretical structures with physical features in spacetime, predicted by Einstein's Theory of General Relativity. They connect two far points in space, which acts like a shortcut to get from one point in space to another. This unique structure could allow for space travel faster than the speed of light, however they are very unstable and are thought to require exotic matter to stay open. Wormholes currently aren't well studied because they haven't been confirmed observationally, but could help explain the fundamental nature of the universe as well as help to bridge the gap between general relativity and quantum mechanics. Einstein claimed gravity was not a force at all but rather the result of space-time curved by the presence of mass.

GENERAL RELATIVITY

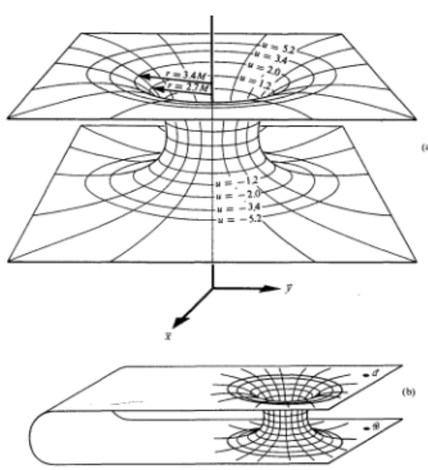
General Relativity explains how gravity warps spacetime based on an object's mass. The more mass an object has, the greater of an impact it has on the space around it. Einstein's Field Equation ($G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$) solutions have predicted the existence of black holes, which have now been confirmed observationally. A black hole is a singularity in spacetime where gravity is so strong that not even information can escape. Black holes and wormholes are both solutions to Einstein's Field Equation, where a wormhole can connect two black holes, or a black hole and a white hole. In this paper, we will discuss the theoretical existence of wormholes and how they affect spacetime around them. We will expand on the types of wormholes, and if exotic matter is truly needed for traversable vs. non-traversable wormholes. We will also discuss the two solutions to wormholes including a black hole vs. white hole. We want to prove the plausibility of human space travel through great distances, which are possibly faster than the speed of light, via the use of traversable wormholes. Prior to Einstein's Theory of General Relativity, the accepted model for gravitational interactions was the Newtonian Model, which describes gravity as an invisible force pulling two objects together. While this model works for general astrophysical cases, for more extreme physics General Relativity is needed to explain gravitational behavior. General Relativity predicts how gravity warps spacetime based on an object's mass (DOE 2021). Einstein's Theory of General Relativity predicts the existence of Black Holes and Wormholes, and is the foundation for understanding how wormholes interact with spacetime. Solutions to Gravitational Field Equations predict that wormholes exist. According to Stephen Hawkings, macroscopic wormholes may provide the mechanism for black holes to evaporate and disappear completely, while microscopic wormholes seem to have an important effect on physical constants, particularly the cosmological constant. General relativity relates an object's mass to its effect on spacetime; as shown in Figure 1. A small object with a large mass has a greater effect on the spacetime around it in comparison to a larger object with less mass. For example, a high mass neutron star would have a greater impact on its space than a star with less mass. Therefore, the radius of the celestial body doesn't directly correlate to how massive the object is. The first wormhole solution to Einstein's Field Equation is the Schwarzschild wormhole which is interchangeable with the second solution, the Einstein-Rosen Bridge.



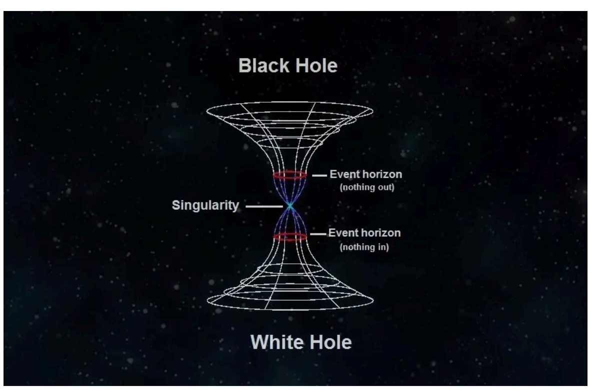


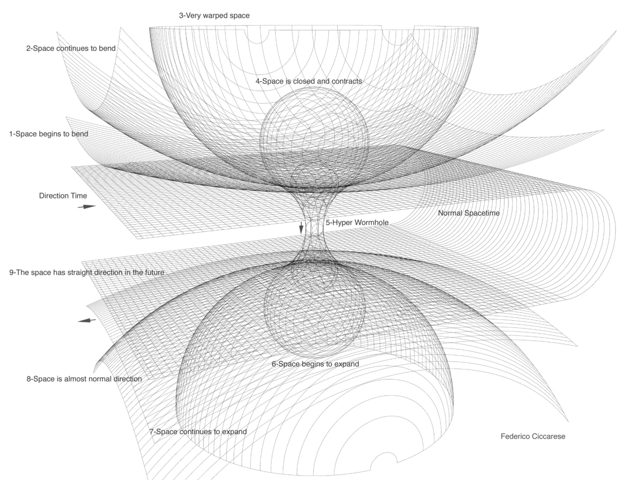
THE STRUCTURE OF WORMHOLES

Einstein-Rosen Bridges are a solution for a specific type of wormhole that is considered non-traversable.The Einstein-Rosen Bridge theory states that two points in space can be connected by a a shorter path of travel through a bridge,or tunnel, from one point to the other, also known as a wormhole. As shown in Figure 2, there is a point F (north of the bridge) and point X and Y (south of the bridge). This diagram shows that the shortest distance between the two points is the bridge,or throat, in between the two points. In this theory, the traveler would travel faster than the speed of light to get from one point to another by going through the bridge , whereas if you went the long route without using the bridge, it would take an exceedingly longer time.

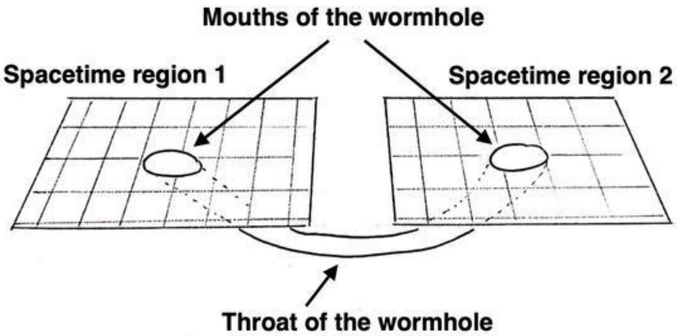


The basic foundation of an Einstein-Rosen Wormhole includes a black hole and a white hole merging together, shown in Figure 3. Another proposed solution is if two black holes merge together. Finally, the last proposed solution explores the idea that the wormhole connects a black hole to an alternate or parallel universe. The existence of wormholes is dependent on black holes which are also predicted by Einstein's Theory of General Relativity. Black holes have been observed, but it's unclear what lies on the other side.A wormhole is generally thought to be connected by two black holes, but there's the theoretical case of a wormhole connecting a black hole to a white hole . To get through a black hole one must travel through a white hole which could be connected to another black hole in another point of space, or another white hole. There is no observational confirmation of how wormholes are created. They are theoretical, which makes it difficult for scientists to fully understand the mechanics. As seen in Figure 4, the main theory is that wormholes may connect a black hole and white hole. This could hypothetically be because while black holes go backwards slower, white holes go forward and faster. Black holes also tend to pull objects into themselves, whereas white holes like to push things out. We predict that since black holes are black, and have an orange and yellow frame around itself, white holes are most likely white, but with a more purple and blue frame to it, which has been predicted in many sci-fi movies and comics, and because we have no recorded evidence of what a white hole truly looks like, this description makes the most sense. This is because one possibility sucks in light, and the other spits out all the light.





Another key concept for wormholes is the Cosmic String and String Theory. String theory is that the distance from both spacetimes (or points in space) is so far away, but can still be faster than the speed of light to get to via a wormhole. In the image, the throat of the wormhole can be as long as possible. One spacetime can even be in a completely different galaxy, and it would take barely a millisecond to get to. Cosmic string theory also helps keep wormholes traversable (able to go through). Cosmic strings "tug" on the mouths of a wormhole by threading it. This, along with exotic matter, helps keep wormholes stable and open.



Exotic Matter

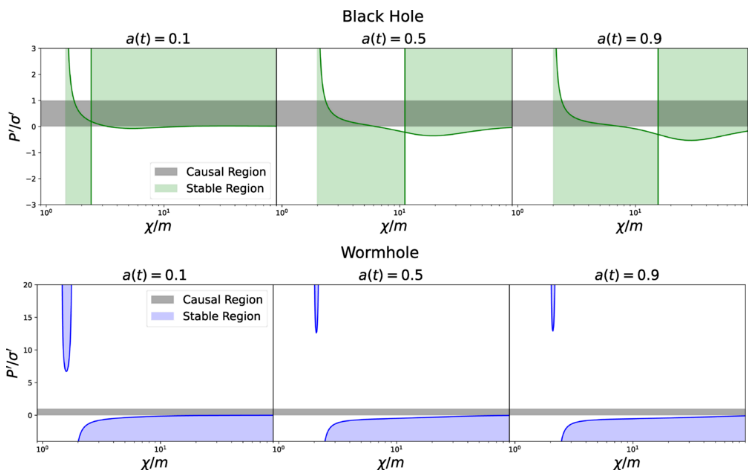
Exotic matter is a theoretical form of negative matter that is thought to keep wormholes open and help turn non-traversable wormholes traversable (Garattini 2021). It is a form of matter that is far from the "normal" matter we have seen here on earth, and has not been observed yet, hence why it is a theoretical area of wormholes that we study. In this definition, the term "exotic" means that the matter is made of different, and very rare, forms of elements. Other than normal

matter, exotic matter is used like a popper, and normal matter is a puller. For instance, if we put exotic matter into a collapsing wormhole, it would push open the walls or throat) of the wormhole out, and since gravity seems to squeeze or push object together, the exotic matter would keep the wormhole open in response to that, whereas normal matter would just cause it to collapse faster.

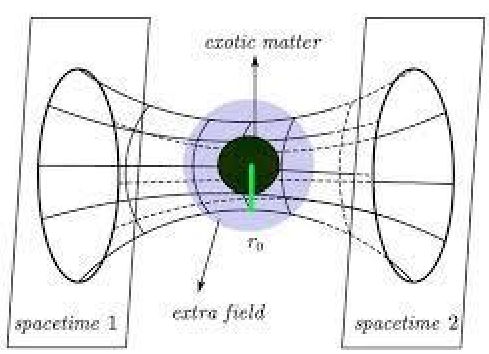
TRAVERSABILITY AND STABILITY

Wormholes are extremely unstable, which connects to the idea of traversability, or whether something could safely pass through them. Some wormholes, such as Einstein-Rosen bridges, are considered non-traversable because they would collapse too quickly for matter or people to cross. In contrast, Morris-Thorne wormholes are theoretical models designed to remain open long enough for travel. Garattini explains that "an Einstein-Rosen (ER) bridge is a non-traversable theoretical construct tied to the geometry of black holes, whereas a Morris-Thorne (MT) wormhole is a theoretical model specifically engineered to be traversable by matter" (Garattini, 2021, p. 2). In other words, a traversable wormhole would need to stay open at both ends without collapsing. A non-traversable wormhole, however, would close too quickly, likely destroying anything inside. This is why exotic matter is so important: its unusual negative properties could theoretically hold the wormhole's throat open and make safe passage possible.

However, exotic matter may not be required in every possible wormhole theory. In standard general relativity, traversable wormholes usually need matter that violates certain energy conditions, which is why exotic matter is often treated as necessary (Visser et al., 2003). However, (Visser et al. 2003) also argue that some wormhole models may require only very small amounts of this unusual matter, meaning exotic matter might still be needed, but not in large quantities. Another possible scenario is modified gravity, where the rules of gravity are changed or expanded. In these theories, the wormhole could be supported by extra curvature effects in spacetime instead of by exotic matter itself (Lobo & Oliveira, 2013). Therefore, exotic matter is probably required for traversable wormholes in standard general relativity, but some alternative theories suggest that wormholes might stay open through modified gravity, special spacetime geometry, or very small amounts of exotic matter rather than large quantities of it.



In general relativity, traversable wormholes are usually predicted to require exotic matter, but modified theories of gravity suggest this may not always be the case. Einstein's theory allows for the mathematical possibility of wormholes, including Einstein-Rosen bridges, also known as Schwarzschild wormholes. These structures could connect two regions of spacetime, but they are considered non-traversable because they would collapse too quickly for matter, light, or spacecraft to pass through safely. In contrast, models such as the Morris-Thorne wormhole suggest that traversable wormholes could theoretically exist if their throats were kept open.



CONCLUSION

The biggest challenge is that most traversable wormhole models require matter with unusual properties, especially matter that violates the null energy condition. This is often called the exotic matter condition. Since exotic matter has not been observed, wormholes remain purely theoretical and are currently supported more by mathematical models than by physical evidence. However, wormhole research is still important because it helps scientists test the limits of general relativity and explore deeper connections between gravity, black holes, quantum theory, and the structure of spacetime. Although no wormhole has been observed yet, studying them helps us better understand how spacetime might behave and whether future discoveries could one day make travel across vast regions of the universe possible. But until they are officially observed, wormholes will remain hypothetical.

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