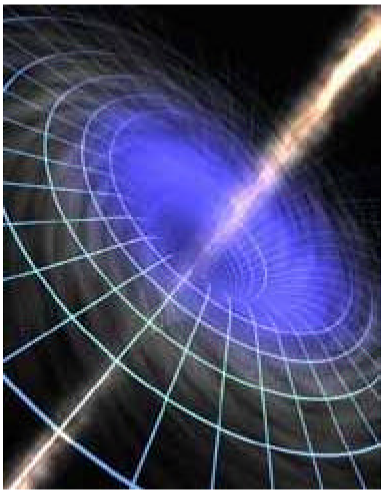
The Einstein-Rosen Bridge

By Samuel Joseph George



In 1916 Einstein first introduced his general theory of relativity, a theory which to this day remains the standard model for gravitation. Twenty years later, he and his long-time collaborator Nathan Rosen published a paper[1] showing that implicit in the general relativity formalism is a curved-space structure that can join two distant regions of space-time through a tunnel-like curved spatial shortcut. The purpose of the paper of Einstein and Rosen was not to promote faster-than-light or inter-universe travel, but to attempt to explain fundamental particles like electrons as space-tunnels threaded by electric lines of force. The Einstein-Rosen Bridge is based on generally relativity and work done by Schwarzschild in solving Einstein's equations; one of the solutions to these equations was the prediction of black holes.

A black hole is a region of space-time from which nothing can escape, even light. It can be said that black holes are really just the evolutionary end point of massive stars. But somehow, this simple explanation makes them no easier to understand or less mysterious.

Black holes are the evolutionary endpoints of stars at least 10 to 15 times as massive as the Sun. If a star that massive or larger undergoes a supernova explosion, it can leave behind a fairly massive burned out stellar remnant. With no outward forces to oppose gravitational forces, the remnant will collapse in on itself. The star eventually collapses to the point of zero volume and infinite density, creating what is known as a "singularity". As the density increases, the path of light rays emitted from the star are bent and eventually wrapped irrevocably around the star. Any emitted photons are trapped into an orbit by the intense gravitational field; they will never leave it. Because no light escapes after the star reaches this infinite density, it is called a black hole[2].

The basic idea of wormholes dates nearly as far back as the concept of general relativity. Barely a few months after Einstein wrote down his equations, the first exact solution of the Einstein equations was found by Karl Schwarzschild[3]. One of the remarkable predictions of Schwarzschild's geometry was that if a mass, M, were compressed inside a critical radius, r_s, nowadays called the Schwarzschild radius[4] (the farthest visible point), and then its gravity would become so strong that not even light could escape. The Schwarzschild radius, r_s, of a mass, M, is given by[5]:

$$r_s = \frac{2GM}{c^2} \tag{1.1}$$

Curiously, the Schwarzschild radius had already been derived (with the correct result, but an incorrect theory) by John Michell in 1784. The English geologist realized that it would be theoretically possible for gravity to be so overwhelmingly strong that nothing, not even light[6] could escape. To generate such gravity, an object would have

[1] In Physical Review 48, 73 (1935)
[2] Contrary to popular myth, a black hole is not a cosmic vacuum cleaner. If our Sun was suddenly replaced with a black hole of the same mass, the only thing that would change would be the Earth's temperature.
[3] This has a very important role in the verification of general relativity in the solar system.
[4] Also known as the horizon.
[5] Where *G* is Newton's gravitational constant and *c* is the speed of light.
[6] Travelling at 186,000 miles a second.(300,000 kms^{-1})

to be very massive and unimaginably dense. At the time, the necessary conditions for "dark stars", as Michell called them, seemed physically impossible. His ideas were published by the French mathematician and philosopher Pierre Simon Laplace in two successive editions of an astronomy guide, but were dropped from the third edition. In Laplace's 1795 edition, he put forward the following equation saying what the mass and radius would have to be to form a black hole.

$$V_{esc} = \sqrt{\left(\frac{2GM}{r}\right)} = c \qquad (1.2)$$

The complete Schwarzschild geometry consists of a black hole, a white hole, and two Universes connected at their horizons by a wormhole. The name "black hole" was invented in 1968 by John Archibald Wheeler. Before Wheeler, these objects were often referred to as 'black stars'[7] or 'frozen stars'.

It was Austrian Ludwig Flamm who had realised that Schwarzschild's solution (called the Schwarzschild Metric) to Einstein's equations actually describes a wormhole connecting two regions of flat space-time; two universes, or two parts of the same universe.

A white hole (from the negative square root solution inside the horizon) is a black hole running backwards in time. Just as black holes swallow things irretrievably, so white holes spit them out. However white holes cannot exist, since they violate the second law of thermodynamics[8].

General Relativity is time symmetric. It does not know about the second law of thermodynamics, and it does not know about which way cause and effect go. However we do. The negative square root solution outside the horizon represents another Universe. The wormhole joining the two separate Universes is known as the Einstein-Rosen Bridge.

The prediction of the existence of black holes did not trouble Einstein, but he found that the black holes contained a singularity at its centre; this is a point of infinite density where time comes to an end. At the point of the singularity, all the known laws of physics start to breakdown. For Einstein this was a very troubling thought and he did not like them, the idea that they were shielding from the outside world by the event horizon of the black hole was not enough for him and he did not like the "concept that if you can not see it then do not worry about it."

So he went to work with Nathan Rosen and in 1935 they produced a paper that produced evidence for a bridge between a black hole and a white hole, this was called the Einstein-Rosen Bridge.

[7] The first episodes of Star Trek had been made before this, and contain the phrase "black star".
[8] The second law of thermodynamics prohibits the construction of a perpetual motion machine of the second kind. Kelvin's formulation states that it is impossible for a system operating in a cycle and in contact with one thermal reservoir to perform positive work in the surroundings.

The purpose of the paper of Einstein and Rosen was not to promote faster-than-light or inter-universe travel, but to attempt to explain fundamental particles like electrons as space-tunnels threaded by electric lines of force. However science fiction took the idea of Einstein-Rosen Bridges and applied it to moving spaceships faster than the speed of light through what was now being called 'wormholes'. So what Einstein originally theorised was now being used by science fiction writers to get around the problems with not being able to go faster than the speed of light that Einstein's General Relativity had inflicted upon them. The diagram[9] (figure 1) shows an Einstein-Rosen Bridge with a spaceship entering the wormhole. However in the Einstein-Rosen theory the idea of objects larger than electrons being able to pass through a wormhole was not even considered and so the scenario that science fiction writers portray about the Einstein-Rosen Bridge is not correct.

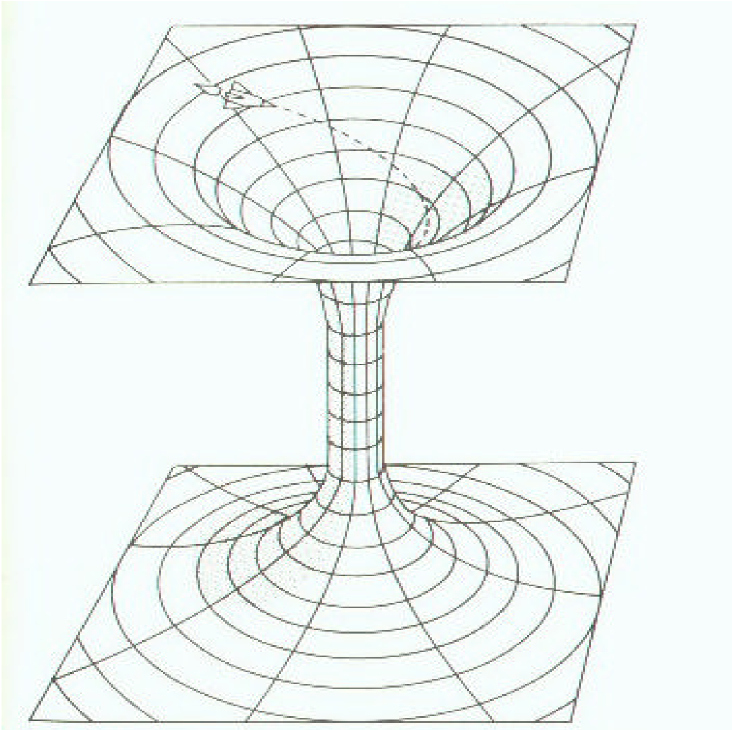


Figure 1

The Einstein-Rosen work was disturbing to many physicists of the time because such a 'tunnel' through space-time, could in principle allow the transmission of information faster than the speed of light in violation of one of the key postulates of special relativity known as 'Einsteinian causality'.

In 1962 John Wheeler discovered that the Einstein-Rosen bridge space-time structure[10] was dynamically unstable in field-free space. They showed that if such a wormhole somehow opened, it would close up again before even a single photon could be transmitted through it, thereby preserving Einsteinian causality.

This work lead there to being two different classifications of wormholes: Lorentzian wormholes and Euclidean wormholes[11].

Lorentzian wormholes are essentially short cuts through space and time but they instantaneously close unless some form of negative energy can hold them open. It is possible to produce small amounts of negative energy in the laboratory by a principle

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[9] The diagram was taken from Hyperspace by Michio Kaku.

[10] Wheeler re-christened as a 'wormhole'.

[11] Lorentzian wormholes are from general relativity and Euclidean wormholes are form quantum field theory.

known as the Casimir[12] effect. However this energy would not be enough to keep open a wormhole.

A by product of Lorentzian wormholes would be that objects passing through them would not only be moved spatially but also temporally (assuming parallel universes exist).

Lorentzian wormholes come in at least two varieties:

1) Inter-universe wormholes, wormholes that connect ‘our’ universe with ‘another’ universe (Figure 2).

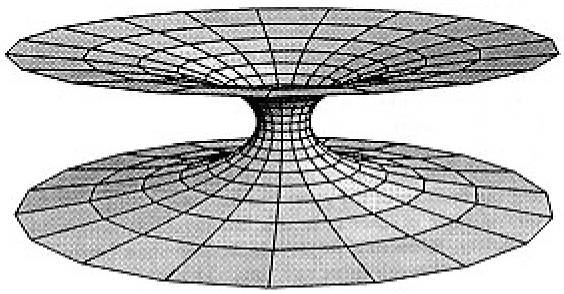

Figure 2

2) Intra-universe wormholes, wormholes that connect two distant regions of our universe with each other [13](Figure 3).

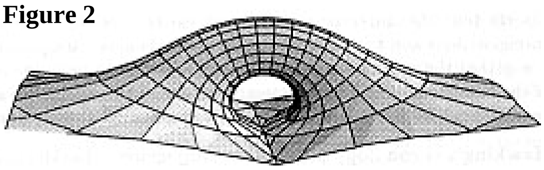

Figure 3

Euclidean wormholes are even stranger given that they live in "imaginary time" and are intrinsically virtual quantum mechanical processes. These Euclidean wormholes are of interest mainly to quantum field theorists.

In 1865 when there was no relativity, quantum mechanics and modern cosmology Charles Dodgson[14] wrote Alice in Wonderland a children’s story on the subject of parallel universes. There is a famous part of the story when Alice chases the white rabbit down a hole, this hole could now be described as an Einstein-Rosen Bridge. In Wonderland the laws of physics in this universe no longer applied and so strange processes could take place. It is however important to remember that Dodgson would not have known what type of mechanism would allow this to happen. In fact this idea, of using a ‘wormhole’ to travel large distances was used by Sagan in writing a novel ‘Contact’ in 1985. In his novel he wanted a method of moving a character faster than the speed of light though not in a manner violating Relativity.

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[12] The Casimir effect is a small attractive force which acts between two close parallel uncharged conducting plates. It is due to quantum vacuum fluctuations of the electromagnetic field. The effect was predicted by the Dutch physicist Hendrick Casimir in 1948.
[13] Diagrams from Lorentzian Wormholes by Matt Visser

[14] An English Mathematician under the name of Lewis Carroll

Unfortunately, worm holes are currently more science fiction than they are science fact. A wormhole is a theoretical opening in space-time that is the mathematical solution to general relativity. If one day this was proven it could be used to travel to far away locations very quickly. It has never been proven that worm holes exist and there is no experimental evidence for them (due to black holes being hard to detect), but it is certainly testing to think about the possibilities their existence might create.

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