The Theory Of The Wormhole

H M Wakeling

8 June 2015

Abstract

Through examination of the developments in the theory of the wormhole and its properties, it is shown that the wormhole is a highly improbable phenomenon that is likely to only exist in fiction. Theoretically, they are highly unstable, they are likely to reside in hypothetical quantum foam and through the manipulation of spacetime, they imply that backwards time travel is a possibility.

1 Introduction

From 1905, Einstein completely revolutionised the universally accepted Newton's laws of gravity with his theories of special and general relativity. These conceptualised many new astronomical phenomena, such as black holes and the Einstein-Rosen Bridge or 'wormhole'. The wormhole is a hypothetical object that could enable shortcuts through spacetime. This report will explore the progression of ideas leading to the theory of the wormhole. The theoretical properties of the wormhole will then be examined with real world application, including its depiction in the 2014 film 'Interstellar' which furthered previous understanding through the use of new technologies [1].

2 The physics behind the wormhole.

In 1915, Einstein postulated his theory of general relativity, which includes a four-dimensional combination of space and time - 'spacetime' - that can explain the properties of gravity [2]. He used 'non-Euclidean geometry' to formulate this theory, in which spacetime is not flat, but is warped by the presence of mass. Physically this means that, contrary to instinct, an object that travels in an apparently circular orbit is actually travelling in a straight path in spacetime that has already been warped [3]. Spacetime is commonly visualised using a two-dimensional membrane, or 'brane', where the warping effects of a mass are indicated as a gravitational well, as in Figure 1. A black hole warps spacetime drastically due to its high density of matter that has collapsed irreversibly. The region of singularity is where the matter at the centre of the

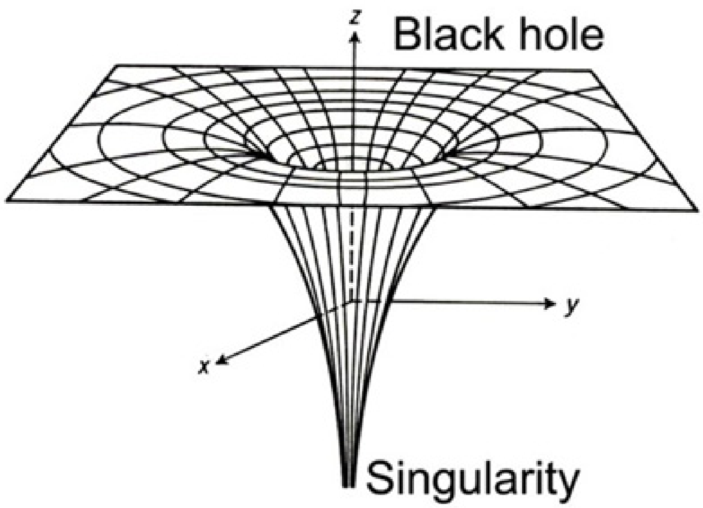

Figure 1: A depiction of a gravitational well of a black hole in the membrane of spacetime [4].

black hole is infinitely dense so it has an infinitely strong gravitational force [3]. General relativity was later demonstrated through 'gravitational lensing' - the effects of warped spacetime on light. The gravitational well of a massive object such as a black hole deflects light in a curved path, which alters the apparent position of astronomical objects to an observer [5]. General relativity explains the small departures from Newtons gravitational laws of the orbits of the planets, is a crucial component of the Global Positioning System (GPS), and is essential for the explanation of massive astronomical objects, theorised and observed alike [2].

3 The wormhole hypothesis.

In 1916, Karl Schwarzschild found a solution to Einstein's field equations which describes a particular type of black hole - the Schwarzschild black hole. Ludwig Flamm noticed that it has two solutions, both with the appearance of a black hole, but with future and past singularities due to the fact that the solutions ignore matter and the black hole is assumed to be a vacuum. The second solution indicates an intriguing phenomenon; a theoretical time reversal of a black hole, meaning that rather than consuming all matter that crosses the event horizon, it ejects all matter as a bright 'white hole' [6, 7]. Spacetime is warped by black and white holes in the same way as massive astronomical objects. Starting from the flat, asymptotic region that's unaffected by gravity, and moving to the centre of the diagram in Figure 2 (at a fixed time), one unexpectedly reaches another asymptotic region. Rather than meeting a point of singularity, there is a hole connecting two distant regions of the same spacetime through hyperspace [3]. It is theorised that this hole connects a black and a white hole, which could lead to the connection of different universes. It is even possible that such an

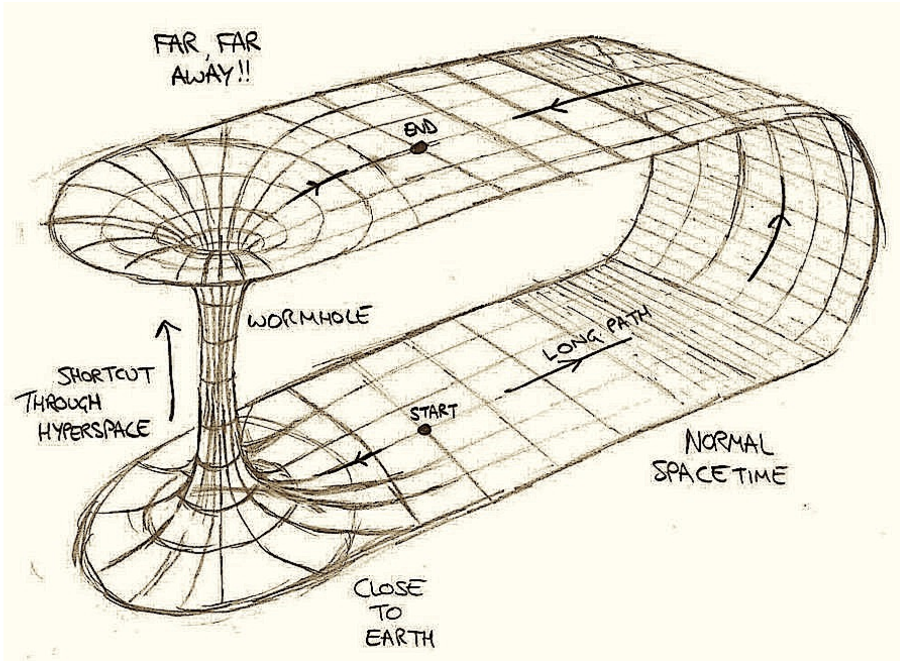

Figure 2: A sketch of a theoretical wormhole traversing the membrane of spacetime. [8]

event could have resulted in the Big Bang. In 1935, Einstein and Nathan Rosen explored the ideas of Flamm and Schwarzschild further to achieve the solution known as the Einstein-Rosen bridge or the Schwarzschild wormhole [6]. In 1974, Stephen Hawking proposed that black holes have a temperature, however, this has not yet been experimentally observed due to the immeasurability of the low thermal radiation of known black holes. If it is observed that black holes do have thermal properties, one would be able to conclude that black holes behave as quantum mechanical systems as it is known that temperature is due to the movement of particles in multiple possible microstates. This then conceeds the theory of the wormhole, as if all of the microstates of two black holes are then 'entangled', a wormhole would be created. The geometry of this wormhole is given by Schwarzschild geometry, which could lead to the impression that signals could be sent through the wormhole at a speed faster than that of light. This, however, is not the case, signals cannot be sent faster than light according to special relativity [3].

3.1 A more recent development in the theory of the wormhole.

Kip Thorne, a theoretical physicist and scientific consultant of the 2014 film 'Interstellar', advanced the theories of the black hole and the wormhole through the manipulation of visual effects for this film [1]. Previously programs had been written with the prerequisite that light travelled in straight lines. Using Einstein's laws of general relativity, Thorne worked on the equations that were to be used in the CGI rendering software for the computer simulations of the gravitational effects on the bending of light [9]. The visuals that resulted facilitated Thorne to write two papers on the progression made [10], as discussed in Section 4.1.

4 The theorised properties of a wormhole.

4.1 The shape of wormholes.

Due to the solutions of Einstein's field equations, the shape of a wormhole is widely agreed to adhere to Figure 2. The problem, however, is the shape of the universe. For a wormhole to exist, spacetime itself needs to be 'folded', or even 'torn', to allow the hole through hyperspace. This would then suggest the possibility of travel through hyperspace from one point in spacetime to another, which will be further discussed in Section 4.4. The manipulation of spacetime is difficult to justify as one would require the use of negative energy and closed spacetime curves. This would mean that it would be possible to travel backwards in time. The laws of physics are likely forbid this, though theory is not yet unambiguous on this subject [10]. In Interstellar the wormhole is depicted as a sphere rather than just a hole in space, and displays the connected galaxy through a fishbowl-like distortion [1]. This depiction was calculated by Thorne using never before used computer simulations and is theoretically sound [9].

4.2 The size of wormholes.

The speculative size of wormholes is widely debated amongst physicists. Hawking postulated that wormholes could exist in a hypothetical quantum foam, which is the smallest environment in the universe. It is on the Planck scale, $\sqrt{G\hbar/c^3} \sim 10^{-35}$ m, so would not be a detectable phenomenon at present. These minuscule tunnels would regularly blink in and out of existence. Speculation could allow the size of the wormhole to be expanded, as shown in Interstellar [1]. It is highly improbable that the size of wormholes could be increased by a factor of 10^{37} for the use of humans, as will be explained in Sections 4.3 and 4.4.

4.3 The stability of wormholes.

A generally accepted property of wormholes is that they are highly unstable. It is inferable that their existence would be extremely short due to quick collapse. If any amount of matter were to attempt to traverse the wormhole, as discussed in Section 4.4, it would collapse or 'pinch off' instantaneously as an 'unequivocal conclusion of Einstein's relativistic laws' [9]. To hold a wormhole open, exotic matter that is gravitationally repulsive is required, such as negative energy. Such energy is permitted by the laws of physics (for example in the Casimir effect), however quantum inequalities reside that limit the amount that can be collected in a small region of space and how long it can be there [10]. An additional problem is that negative energy is probably not quite repulsive enough, leading to the argument that the wormhole is likely to collapse [9]. Hawking also claims that if it were possible to lengthen the life of a wormhole, a radiation feedback loop could cause the wormhole to collapse [11]. In Interstellar, it is assumed that this universe resides in a higher dimensional bulk with one or more large extra dimensions [1]. This permits, in principle, a wormhole to stay open without the need for gravitationally repulsive matter [10].

4.4 The potential uses of wormholes for spacetime travel.

Wormholes are a regular tool used in science fiction. Their most attractive property is the ability for humans to travel many light years in a fraction of the distance and time. For this fiction to be theoretically possible, the wormhole would be of a certain type - a traversable wormhole. In 1963, the mathematician Roy Kerr used Einstein's equations of gravity to predict that that a spinning black hole would not collapse to a point but converge to a 'ring of fire'. The centrifugal forces of the spinning black hole would keep it from collapsing, possibly allowing for matter, or even a human, to travel through the wormhole unscathed [12]. Conversely, John Wheeler and Robert Fuller demonstrated that wormholes cannot be traversable as the theory of a wormhole includes the properties of a black hole. This in turn includes the region of spacetime past the event horizon in which gravity is so strong that any human that crosses it would be crushed to oblivion before they would reach the point of singularity [3]. In Interstellar the wormhole exists due to the bulk mentioned in Section 4.3, it is large enough to be used for travel through to another galaxy, and is held open for many years. This is only possible due to the hypothetical bulk however, and is not yet a reality [1].

5 Summary

The idea of the wormhole is highly improbable; there is no known natural or artificial mechanism that could create such a phenomenon [2, 7, 10]. No one knows categorically if wormholes could exist. If they do exist, it's not clear whether they could span vast regions of spacetime, even multiple universes, or whether they're only microscopic. The incompatibility of the wormhole with macroscopic physics indicates that if they were to exist they are expected to dwell in hypothetical quantum foam. Wormholes are particularly unstable, and therefore their possible existence would only last an instant. Yet, through the application of a higher dimensions of physics, the negative energy that is needed in wormhole theories today, may not be needed in the future. The shape of the wormhole is more widely acknowledged to adhere to the two-dimensional diagram in Figure 2 despite the indication that backwards time travel would be possible. To further the theory on the shape, size and stability of a wormhole, it is fundamental to discern whether or not the fabric of space can tear [13].

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