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Detectability of Wormholes through Various Methods

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Abstract

There are three methods that can possibly detect wormholes: Negative Temperature, Hawking/Phantom Radiation, and *Kα* iron emission lines. This paper discusses whether or not any of these three methods are useful ways to detect wormholes with today's technology and if so, which one is the best and which is the worst. As it turns out, all of these methods have their flaws and impracticalities. After looking through all the evidence and comparing it to what capabilities we have currently, there is clearly a best and worst method. The best method to detect possible wormhole candidates is through the detection of radiation using indirect methods. Indirect detection of radiation is by far the most practical with the least amount of disadvantages. The worst detection method is through the detection of negative temperature as it has many impractical needs to work.

Introduction

Since the beginning of the field of science fiction, people have speculated ways to travel across the universe instantly, without having to deal with the effects of time. However, according to special relativity, traveling via a spaceship across the universe and back would take so much time that when you got back to the planet it may have finished its life cycle. This conundrum leads to many questions about space travel, especially when considering travel outside our solar system.

Wormholes may provide an answer to the pesky issue of special relativity and time dilation. People have speculated ways for them to exist and be stable enough for anyone to travel through, but until recently, it was still considered science fiction. The concept of the wormhole started in the early 20th century when Einstein proved the existence of an Einstein-Rosen bridge, which fell out of his equations for the theory of general relativity in 1916 (Martìn-Moruno & González-Díaz, 2009a). The term 'wormhole' was not coined until much later, in 1957 when Misner and Wheeler published their paper on the topic (Martìn-Moruno & González-Díaz, 2009a).

To understand the different variants of wormholes, you must first understand what a wormhole is in general. In 1988, Morris, Thorne, and Yurtsever came up with the first mathematical solution to show that wormholes can, in fact, exist within the laws of thermodynamics. These science fiction objects weren't only shown to be possible, but they were shown to be potentially stable using exotic matter. This type of matter is unique because it is essentially the time reversed version of regular matter (Martìn-Moruno & González-Díaz, 2009b). This time reversed property exists because exotic matter is thought to violate the null energy condition (Martìn-Moruno & González-Díaz, 2009a). Therefore, if you were to combine exotic matter with a black hole, you may create a wormhole (Martìn-Moruno & González-Díaz, 2009b). However, if you were to attempt to

make a wormhole with normal matter, it would be thermodynamically unstable and would collapse into the black hole.

Lorentzian Wormholes

In reference to the field of physics, there are two main types of wormholes, the Lorentzian wormhole, which is a hole through space and time, and the Euclidian wormhole, which relies on particle physics and quantum mechanics. There are several special properties that make Lorentzian wormholes one of the most popular versions to study and for which to look (Martìn-Moruno & González-Díaz, 2009b).

Lorentzian wormholes are interesting because of their special properties. First, they are stable and traversable both ways. These two unique properties potentially allow for time travel, covering vast distances in an instant and then coming back. Another property special to wormholes is they do not have an event horizon, like their counterpart, the black hole (Rehman & Saifullah, 2021). The lack of an event horizon, which is the boundary of a black hole through which no light or radiation can escape, is what allows the Lorentzian wormhole to be traversable (Rehman & Saifullah, 2021). With these properties and the uniqueness of exotic matter, the equations showing wormholes exist also suggest that they have both a negative pressure and energy density, which is very strange.

To look for Lorentzian wormholes, scientists can rely on properties thought to be specific to wormholes. The first is negative temperature, which arises from the distribution of exotic matter within the wormhole itself. With exotic matter thought to produce a negative temperature, the possibility exists that this property can be observed and measured. The second method is through the detection of certain types of radiation. Phantom radiation, or radiation that violates the null energy condition, was proposed by Martín-Moruno and González-Díaz (Martìn-Moruno & González-Díaz, 2009a). They used the Hayward Formalism of general relativity for spherically symmetric solutions regarding trapped horizons to show that the accretion of phantom radiation is possible. Martín-Moruno and González-Díaz also showed the thermodynamics that describe phantom radiation (Martìn-Moruno & González-Díaz, 2009a). In addition, Hawking, or black body, radiation thought to be emitted from gravitinos coming from the wormholes may be measured. Hawking radiation is proposed to have a negative temperature as well (Sakalli & Ovgun, 2015). The last way to detect these types of wormholes is through the broad relativistic $K\alpha$ iron emission line that is thought to be around the accretion disk of a wormhole. The accretion disk is the region in which matter swirls inward toward the black hole because of gravitational pull (Bambi, 2013). The $K\alpha$ iron emission line that should be around a slow rotating wormhole has been compared to the same emission line that comes from a Kerr black hole with a high spin (Bambi, 2013). This suggests that a Kerr black hole may be a wormhole with a slow spin (Bambi, 2013). Detecting $K\alpha$ iron emission lines may be a useful way to discover wormholes.

Negative Temperature

Temperature in the sense of black holes and wormholes is not the same as with regular matter. The temperature of these objects is specifically defined by their geometry. The only characteristic needed to calculate the temperature of these objects is their geometric surface gravity (Hong & Kim, 2006). Negative temperature is just as it sounds, when you work out the equations of general relativity for a typical black hole you find that it is impossible for there to be a negative temperature. The impossibility of a negative temperature is produced because if you take the limit as the temperature goes to zero, the black hole produces unstable thermodynamics, which then makes it impossible to occur (Hong & Kim, 2006). However, when you solve the same equations

for a wormhole and account for the exotic matter that exists within, the limit as the temperature goes to zero doesn't produce unstable thermodynamics. This shows negative temperature is possible for wormholes because they have exotic matter keeping them stable (Hong & Kim, 2006).

The wormhole temperature is related to the Hawking temperature, which is defined as

$$T_H = \frac{a_7}{2\pi} = \frac{1}{2\pi}\Phi'(r)\left(1 - \frac{b(r)}{r}\right)^{\frac{1}{2}} \quad , \qquad (1)$$

where α_7 is the specific acceleration that comes from the Rindler motion from the surrounding flat space around a black hole. Along with the surface gravity that is described after the second equal sign, this produces the Hawking radiation for a typical black hole in the universe.

From the Hawking temperature (shown in Eq. 1), we can substitute in the surface gravity k_s and resolve to get the equation for the wormhole temperature

$$T_o = \frac{k_s}{2\pi} = T_H e^{\Phi(r)} \quad , \qquad (2)$$

It is important to keep in mind that these equations are as *r* approaches *b(r)*, which is the event horizon of a typical black hole. The event horizon does not exist for a traversable Lorentzian wormhole. The reason these equations are written with this limit is to get a good approximation as to the limit of the temperature that is possible. It considers both Hawking radiation from black holes as well as the temperature of the wormhole (Hong & Kim, 2006).

Although a potentially useful parameter for detecting wormholes, it is important to note that it is unknown whether the negative temperature can be detected outside of the wormhole. The temperature inside a wormhole where the exotic matter is distributed is negative. As you pass the Schwarzschild radius for a wormhole, the temperature becomes positive. Once $r > r_o$ where r_o is the Schwarzschild radius, the temperature goes from negative to positive at that transition (Hong & Kim, 2006).

If the negative temperature is not detectable from the outside perspective, then it would not be possible to detect at all. The only way to detect this property would be to directly go inside a wormhole, which obviously defeats the purpose of detecting one in the first place. Even though this is a unique property that only wormholes produce, this property does not appear to be detectable with our current technology. The infrared telescopes we have today would not be able to see the negative temperature emitted from wormhole candidates in the universe. However, if we could invent or modify an instrument able to detect a negative temperature out near the middle of galaxies, then this unique property applicable only to wormholes could be used for detection (Hong & Kim, 2006).

Hawking Radiation

Stephen Hawking surprised many people when he published his first paper on Hawking radiation (Sakalli & Ovgun, 2015). While some were sceptics and some were believers, the presence of radiation leads to a very good candidate for wormhole detection. Hawking radiation is when a black hole emits energy spontaneously, like black body radiation. Hawking proposed this effect through his calculations using quantum field theory and changed the way we look at black holes (Sakalli & Ovgun, 2015).

Hawking radiation then gives rise to the idea of phantom radiation, which comes from the mouth of a wormhole in a similar way. It is argued that this phantom radiation is what gives rise to the wormhole's existence (Martìn-Moruno & González-Díaz, 2009a). It is also hypothesized that active galactic nuclei, which are regions with a higher degree of brightness than can be explained by the stars in that region, are not super massive black holes, but the opening to a massive wormhole (Piotrovich, et al., 2020). If this is indeed the case for active galactic nuclei, then there would be consequences that would produce observable

effects. One of these effects would be the production of gamma radiation as the accretion flows collide within the wormhole itself (Piotrovich, et al., 2020).

Hawking radiation led to the development of the thermodynamics for this specific type of radiation to see if it could exist. This development and Hayward's formalism characterized the thermodynamics of a spherical black hole with a trapping horizon. They were able to come up with thermodynamics regarding wormholes that also had a trapping horizon because they were so similar (Martìn-Moruno & González-Díaz, 2009a).

To calculate a set of thermodynamic equations for this type of wormhole, you need to assume it has a non-zero temperature that characterizes a non-zero surface gravity. With this assumption, you can use a specific *f(R)* model from the background radiation to derive the thermodynamic field equations for a wormhole at the apparent horizon (Saiedi, 2012),

$$dE = TdS + WdV + TdS^{-}, \tag{3}$$

where dE is the energy of the system, T is the non-zero temperature, W is the work, dV is the volume, and dS which is the normal entropy term. The only term that separates this equation from the typical first law of thermodynamics is the extra entropy term TdS that comes up when those specific assumptions are made (Saiedi, 2012).

It was also found that density and tangential pressure have no effect on the horizon, which leads to another relationship within the first law shown below as heat flow dQ (Debnath et al., 2014). This relationship is shown as

$$T_H dS_H = dQ = -dE_H, \tag{4}$$

where the heat flow is described by temperature T_H and entropy dS_H regarding enthalpy H. This is then related to the energy dE_H (Debnath et al., 2014).

A few issues that could make this method more difficult is the fact that this type of radiation is very small in quantity. The sensitivity needed to detect Hawking radiation around a black hole is a great deal higher than most, if not all, detectors currently constructed. The other issue is if we can construct a device capable of detecting Hawking radiation at the center of galaxies, there is no way we can determine whether it is the phantom radiation from a wormhole or just regular Hawking radiation from a black hole.

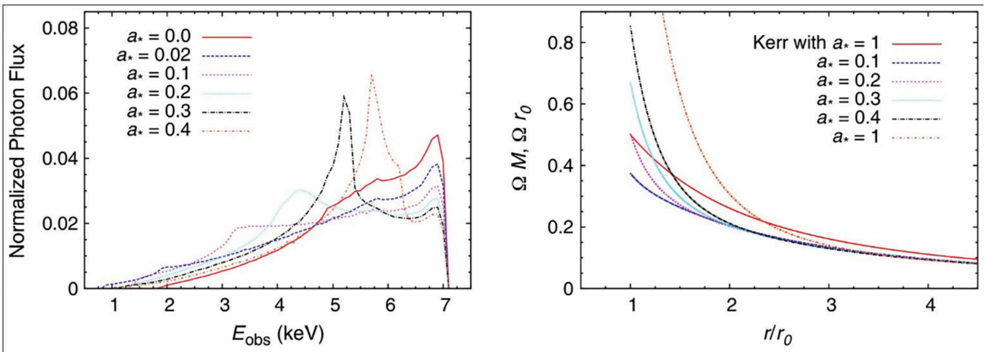
Instead of looking for the direct radiation coming off a wormhole, we could look for radiation scattering from wormhole candidates (Kirillov & Savelova, 2018). There are a few effects that could be useful in discovering wormholes using indirect detection. One method is to look for a diffused source in the background radiation of the universe. There should be a distinct distortion that can only be caused by a wormhole. We could also look for the subtle changes in the cosmic microwave background to find the possible locations for wormhole candidates (Kirillov & Savelova, 2018).

The only issue with this method is determining how subtle these distortions are and what to look for that definitively says this distortion is a wormhole. Even with the cosmic microwave background essentially mapped out over the observable universe, we would have to figure out if there would be a sensitivity issue that arises to show the relatively small distortions created by wormholes.

Emission Lines

When we look at objects in the universe, the only physical phenomena that can be observed is radiation such as, light. Many objects and elements give off specific combinations of colors that can be separated and identified. These are called emission lines. Black holes and wormhole candidates are no different; they produce unique emission lines that can be detected from vast distances. What makes wormholes and black holes unique is that there is no light coming

A. B.



from the object, but we get these emissions from the accretion disk around the object. The emission from these disks allows us to look deeper into the geometry around possible wormhole candidates (Bambi, 2013).

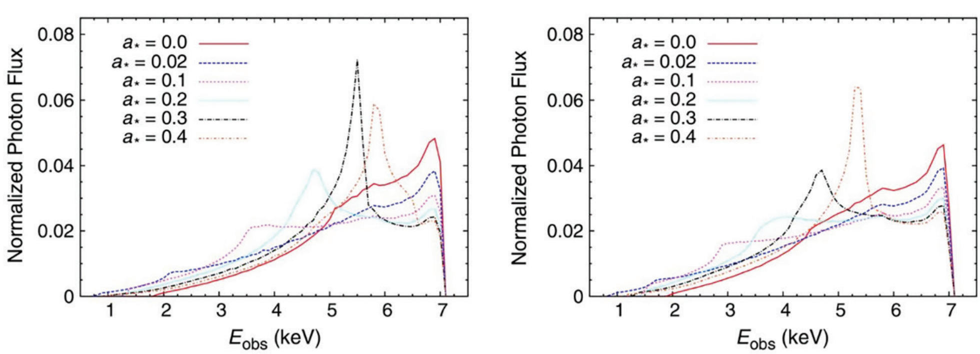
This idea came together because a specific type of black hole called the Kerr black hole with a medium to high spin parameter produces a very similar *K*α iron line to the theoretical wormhole (Bambi, 2013). A Kerr black hole is just a rotating black hole with only mass and angular momentum. These objects have no net charge, which is possible for other types of black holes. This can be shown graphically (Figure 1). As spin parameter (α.) is increased, it becomes more related to the known Kerr black hole line (α. = 1, red solid line). This could be a useful method of detection for wormholes. On the other hand, one could ask why the Kerr black hole is the only type that matches and whether Kerr black holes are actually wormholes (Bambi, 2013). There needs to be more research done to answer a question like that, and maybe detection is the first step.

Figure 1. Comparison of the different parameters for wormhole space time with that of the Kerr black hole. (A) The profile of the *K*α iron line produced in the accretion disk around wormholes with γ = 1 and different α. values. (B) The angular frequency of equatorial circular orbits shown as a function of the radial coordinate *r* (Bambi, 2013).

Theoretical measures using different γ values show similar results (Figure 2). A medium to high spin Kerr black hole has similar properties to a slow spinning wormhole when g is changed from 1. In this code they also attempted to use higher flux values but got reduced energy in the peaks due to red and blue shifts at a smaller radius. This gives more evidence to show that these *K*α iron lines are likely to indicate a promising result if they were to be detected (Bambi, 2013).

Figure 2. *K*α iron lines in wormholes with different backgrounds. (A) The *Kα* iron line with a photon flux (γ) of 2 at different spin parameters for a wormhole. (B) The *Kα* iron line with a photon flux (γ) of one half at different spin parameters (Bambi, 2013).

A. B.



These *Kα* iron lines are very good candidates for a detection method. Emission lines are already one of the most common methods of detecting objects and gathering data in the universe today. The main issue with this detection method is understanding the signal that we find. If we detect a potential wormhole candidate, we need to have a way to, without a doubt, say whether it is a wormhole. Otherwise, there will always be evidence supporting that it may just be a Kerr black hole because they are more likely.

Discussion

With the knowledge and technology we have today, wormhole detection seems to be close but not quite there yet. With current detection methods that are possible, there is no way to distinguish between wormhole candidates and black holes. Maybe in ten to twenty years there will be a breakthrough and equipment sensitive enough to detect these objects, but it does not currently appear that way. If wormholes do exist, it will be like the discovery of a black hole in the sense that it was predicted and then many years later it was indirectly detected. Objects that produce no light are notorious for being difficult to detect and it's expected that wormholes are no different.

One of the most important ideas that mankind needs to figure out about Lorentzian wormholes is exotic matter. This concept is discussed several times throughout many papers, and it seems that they all come to the same conclusions. We don't know exactly what it is, but it is the reason wormholes can exist in the first place. Once there is more research done to understand what exotic matter is, the ability to detect wormholes should increase.

It also depends on the different types of wormholes that are possible, which is just one specific type out of many. It is unknown which one is the most likely to exist. The type chosen in this paper is the most popular because it is stable and traversable, which makes it extremely useful if humankind can find a way to harness and reproduce the effects. Lorentzian wormholes are currently the most likely link between science fiction and the real world.

It is tricky attempting to detect the property of negative temperatures. According to the equations of wormhole temperature, it is only negative on the inside of the Schwarzschild radius. This is equivalent to the event horizon for a black hole in which no information can escape. It is currently unknown if that information would be able to come out of that radius. The reason it would need to escape is because outside of that radius the temperature would be positive and if it can't escape the Schwarzschild radius then it would be impossible to detect.

Negative temperature is a great method that would definitively show a wormhole if it was detected. The issue is how to detect it and whether we have the technology to create such an instrument. That is yet to be seen in the field of astronomy and astrophysics. Even though the thermodynamics clearly work and show that is it possible with the presence of exotic matter, the detectability aspect of this method is not practical. Out of the three methods discussed in this paper, negative temperature is by far the hardest and most far-fetched one to use as a reliable detection method.

Furthermore, Hawking radiation for wormholes, also known as phantom radiation, appears to be the best method for detection if we can create an instrument sensitive enough to detect radiation on that small of a scale. Using the phantom radiation method would also produce evidence that definitively shows the existence of wormholes due to the unique thermodynamics that explain this phenomenon. It would be useful to get a better understanding of phantom radiation. It is currently unknown whether phantom radiation is the same as Hawking radiation except for wormholes, or if it is uniquely different.

Direct detection of radiation may not be the way to go when it comes to the search for wormholes, just like when the scientific community first discovered

black holes. It wasn't through direct detection; it was observing the effects that black holes had on their surroundings. Indirect detection was used to calculate the size and mass of the invisible object and to learn about its properties. It wasn't until decades later that we finally took the first direct image of a black hole, and even that was mostly its accretion disk.

Maybe indirect detection is the way we need to go to detect wormholes. This is executed by looking for the effects of scattering off the inside of the wormholes and the unique distortion in the cosmic microwave background. These are already commonly used methods to detect dark objects within our universe. The key is to hone in on exactly what we need to look, so detection is possible.

With indirect detection for wormholes, there are several reasons why this method could be the best. The main reason is the effects are easier to detect with today's technology. We already have been mapping the cosmic microwave background for over thirty years so there is plenty of data to analyze. Once a wormhole candidate is discovered, then we have the means to observe the effects that object has on its surroundings. These observations will help prove whether the candidate really is a wormhole since we are able to compare the findings with what should and shouldn't occur for a wormhole.

The last method for detecting wormholes discussed in this paper is the $K\alpha$ iron line. On the surface, trying to find a detection method by comparing known objects to wormholes seems like a plausible idea but it leads to many concerns. Using a set of code to predict what the pattern might be according to a formula may lead people down the wrong rabbit hole. A lot of times, code like this has a lot of built-in assumptions that could be wrong. Even if the parameters seem to be right, according to the Kerr black hole, it may be just a coincidence that the data appears to line up. There are just too many uncontrollable variables at this point involved for this method to be viable.

Another issue with the $K\alpha$ iron line idea is not being able to distinguish between a Kerr black hole and a wormhole candidate to determine if they are similar. The only way to know for sure is if there was a way to prove that all Kerr black holes are wormholes. Proving Kerr black holes and wormholes were one in the same would take away the issue entirely, but it seems almost impossible to do that in today's time.

After going through and discussing all the methods outlined in this paper, the best candidate to look deeper into is the indirect detection of wormholes through scattering effects. If we could make a more sensitive scan of the cosmic microwave background and single out this event to study, it's more than likely that would be the best-case scenario. If the small distortions in the cosmic microwave background had a distinguishable pattern, this is by far the best method available to detect wormholes.

Conclusion

Overall, there are several great potential properties of wormholes that can be used for their detection. The common issue that arises is practicality: making it possible to detect with the current technology. All these methods would work if anything was possible, but unfortunately, that is not the case. The only methods that are possible with today's technology are the detection of the $K\alpha$ iron emission line coming from the accretion disk of wormhole candidates and the indirect detection of wormholes. However, these methods have their own red flags and need to be refined a lot before they can be useful as they are currently. They remain two of the only methods that are usable today.

The property that has the worst chance of being used and may be impossible to detect is the property of negative temperature. Until we figure out whether negative temperature is detectable outside of the Schwarzschild radius, this detection method will be impossible. Even if we figure out that negative temperature is detectable outside of the Schwarzschild

radius, it will still be many years away before we have the technology to do so.

Even though it is not currently usable, the most promising method must be the radiation approach by indirect detection. Because a wormhole is very similar to a black hole and that was the main approach, we used to detect those to begin with. We can look for unique properties using this approach that separates black holes from wormholes, including but not limited to cosmic background distortion and scattering of radiation off wormholes. With some refinement and new technology, there is a chance this method will be the one that ultimately determines whether wormholes exist at all.

In conclusion, wormhole detection may be possible under the right circumstances. Even though some of the methods are not practical, several avenues can be taken to ultimately determine the existence of wormholes. It is just a matter of time before someone figures out a practical method that can be repeated. What has been considered science fiction for decades will hopefully someday have an answer.

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