Use of Dark Matter and Energy in Achieving Faster-Than-Light Travel

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Abstract: Faster-than-light (FTL) travel has been implemented throughout science fiction to indicate highly advanced civilizations. Going past the cosmic speed limit would be a big leap for mankind, allowing for possibilities from exploration, improved chances of species survival, and availability of resources. However, there are many barriers associated with FTL travel, from the infinite mass plight in conventional travel to the necessity of exotic matter for warp drives. In this paper, the barriers associated with FTL travel are examined and a hypothetical improvement is presented through the utilization of dark matter and energy.

Introduction

Making up 27% and 68% of the universe, dark matter and dark energy respectively compose around 95% of the vast universe. Along with constituting most of the universe, it also dominates interactions on a larger scale. Apart from not interacting with any wavelength of the electromagnetic spectrum, the only reason it is believed that dark matter exists is due to its major gravitational effects on visible matter. Dark energy is even more interesting, and the claim to its existence is simply that –if it were not present– the universe would not be accelerating at the rate that it is.

Although knowledge of dark matter energy is limited, mankind should not be deterred from theorizing about their potential applications. Exploring the potential uses of these domineering components could lead to groundbreaking innovations and also improve understanding of the properties of these components. Theoretical understanding has not always preceded practical use. When the electric capacitor, the battery, and the lamp were invented between 1745 and 1802, the basis of the transfer of electrical energy through materials was unknown. This basis - which was the presence of charged particles - was discovered only in 1834. A gap of 89 years between the development of a device to use the presence of ions and the proof of its presence. [1,2,3,4]

Background

Composition of the universe [5]

In this vast universe, what humans directly observe and interact with is matter. The planets, the Sun, trees, air, buildings, cars, and everything else that is directly observed and interacted with is matter. However, this matter that is directly interacted with – in stars and galaxies – only composes ~0.5% of the universe. The rest of the universe comprises ~0.1-0.7% neutrinos, ~4.4% regular matter (electrons, protons...) which are neither in galaxies nor stars, ~27% dark matter, and ~68% dark energy.

Dark Matter

Dark matter is a major component of the universe that does not emit, absorb, or reflect electromagnetic radiation, making it detectable only through its gravitational effects. Exerting gravitational influence on visible matter, it plays a major part in large-scale interactions in the universe. It is believed that galaxies and clusters of galaxies are held together by oceans of dark matter.

Despite dark matter only interacting through gravitational interactions, its existence is supported by 2 main pieces of evidence. Firstly, as the force of gravity decreases with radius squared,

$$F_{grav} = \frac{GMm}{r^2} \tag{1}$$

it is expected that the speeds of stars and solar systems revolving around the center of a galaxy would decrease further towards the edge of galaxies. This is because as the force of gravity decreases, the velocity required for stars and solar systems revolving around the center of a galaxy to remain in a constant orbit decreases. However, as shown in Figure 1, the recorded speeds of stars and solar systems indicate that they revolve at almost the same speed regardless of where they are in a galaxy.

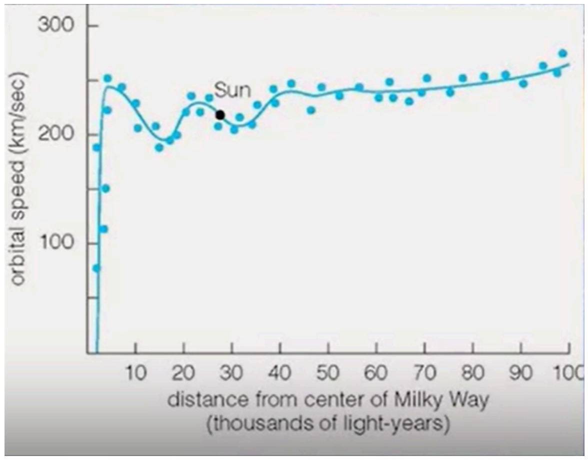

Figure 1: Revolution speed of gas and stars against distance from the center of the Milky Way [5]

Secondly, the behavior of light around galaxies or clusters of galaxies. Gravitational lensing occurs when a celestial body with a lot of mass causes a visible bend in the path of light, due to the body's matter's impact on spacetime. Due to a large amount of mass, it creates a curvature in spacetime. A lot of gravitational lensing is noticed around galaxies or clusters of galaxies, and the amount of this lensing can not be attributed to just regular matter. Gravitational lensing also allows the mapping of regions or clouds where dark matter is believed to be in the universe.

There have been no discoveries of dark matter interacting in any way other than through its gravitational interactions yet. It forms oceans that hold galaxies and clusters of galaxies together, its gravitational effects cause gravitational lensing, and through bullet clusters, it has been noticed that it is highly noninteractive with regular matter, electromagnetic radiation, and itself.

Dark Energy

Dark energy is a mysterious force that permeates the universe, driving its accelerated expansion. Unlike matter and dark matter, which exert attractive forces, dark energy creates a repulsive effect, causing the universe to expand at an accelerated rate.

Evidence for the existence of dark energy comes from astronomical observations, notably the measurements of type 1-a supernovae. These observations of supernovae allowed an understanding of the rate of expansion of the universe at different points in time and space. Through this data, it is inferred that the universe is expanding at an accelerated rate, which doesn't match predictions made based on the presence of just radiation, matter, and dark matter. The cause of this accelerated expansion is attributed to dark energy.

Dark energy drives the accelerated expansion of the universe. Unlike matter and radiation, which become less dense as the universe expands, dark energy is believed to maintain a constant density, so it dominates the large-scale interactions as the universe expands.

Interstellar travel

Problems associated with FTL travel

Conventionally, acceleration in space is achieved through the use of fuel such as liquid hydrogen and oxygen. However, the use of this method of chemical propulsion –wherein fuel is used– is insufficient to achieve faster-than-light travel. Regardless of what fuel is used, the conventional method of propulsion makes it impossible to achieve FTL speeds. As matter approaches the speed of light, its relativistic mass increases extraordinarily. The relativistic mass (m_r) is given by

$$m_r = \frac{m_0}{\sqrt{1-\beta^2}} \tag{2}$$

Where $\beta = \frac{v}{c}$ the ratio of the velocity to the speed of light. Therefore, as the object's mass approaches infinity, then no amount of energy would be enough to accelerate the object further using standard propulsion methods which is the infinite mass plight [6].

Wormholes

Wormholes can be imagined to be shortcuts through the universe, causing faster-than-light travel by offering a shorter route to connect 2 points in space that are far apart. Wormholes can be utilized to move faster than light from point A to B relative to if light traveled from A to B outside of a wormhole. Through the use of a wormhole, a traveler does not necessarily need to travel faster than the speed of light, but they would arrive at the equivalent location faster than light traveling through the standard 3-dimensional space, by taking a shorter path through the wormhole. It is hypothesized that wormholes occur naturally near objects that produce extreme gravitational effects, such as black holes. In a 1994 NASA/ Jet Propulsion Laboratory-sponsored workshop, it was discovered that such wormholes (formed by exotic, negative matter) would cause a gravitational lensing effect different from the same from positive matter [6].

Creating a wormhole requires 2 holes in spacetime and the manipulation of spacetime to allow the 2 holes to converge into a tunnel-like shape. Additionally, the 2 holes must be held together. For simplicity in visualization, this can be imagined in a 2-dimensional universe, since it requires the addition of a higher dimension, which is difficult to comprehend for a 3-dimensional system. In a 2-dimensional universe (like a piece of paper), this would mean cutting out 2 pieces and folding the paper to allow for the "wormhole" to form; a 2-dimensional wormhole can be imagined as shown in Figure 2.

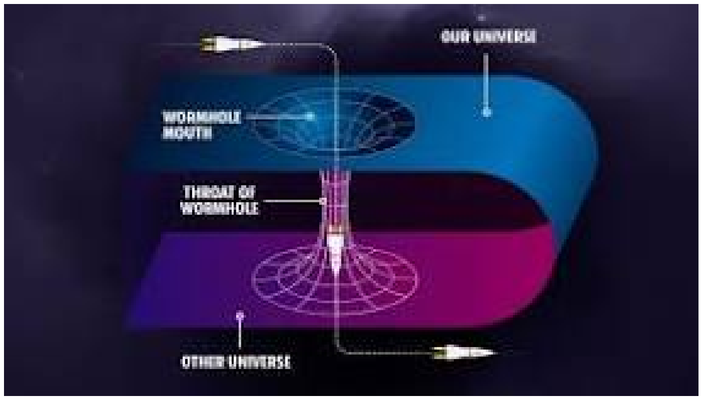

Figure 2 - Illustration of a Wormhole in a 2-Dimensional Universe. [7]

For the wormhole to be navigable, there are a few additional requirements (apart from the creation of the wormhole) [6]:

1. A tension of ~10^37 dyn/cm^2 throughout the throat of the wormhole to keep the wormhole open. (1dyn/cm^2 = 0.1 N/m^2 = 0.1 Pa) [13]
2. The wormhole must be 2-way, with no type of event or anti-horizon to allow passage through both ends.
3. Gravity must not be too extreme nor too different throughout the wormhole: a difference in gravity gradients across our spacecraft body, tidal forces, must be small. Large tidal forces would lead to the spacecraft breaking apart or overheating.
4. Minimizing radiation from the matter-energy interactions forming and maintaining the wormhole is required to prevent harm to the passengers.
5. The time taken to construct the wormhole and travel through it must be reasonable enough to be accomplished.
6. The mode of transport must not interact with any of the components forming, maintaining, or comprising the wormhole itself, to prevent damage to it.
7. Proper time measured by starship passengers should not be dilated by relativistic effects as this would cause a discrepancy between the recorded time and the time perceived by the passengers.

Warp drives

An alternative proposed method for FTL travel is a warp drive. A warp drive creates a bubble of space and the bubble of space moves through spacetime, allowing for FTL travel of the whole system without the need for propulsion.
This avoids the infinite mass plight because the spacecraft itself isn't moving through spacetime, rather the space itself is moving. Modern warp drive theories are all associated with the Alcubierre warp drive: a warp drive in which spacetime ahead of the mode of transport, spacecraft, is contracted and spacetime behind the spacecraft is contracted. It could be said to

be analogous to surfing; the warp bubble is analogous to the surfboard, the occupant is analogous to the surfer, and the waves are analogous to expansions and contractions of spacetime. The representation of the warp field, with the spacecraft said to be moving in the z direction with constant velocity (v_*) is

$$v^i(x, y, z, t) = (0, 0, 1)^i v_* f(\sqrt{(x^2 + y^2 + (z - v_* t)^2})$$

(3)

where f is the function

$$f(x) = \frac{tanh\,(\sigma(x+R)) - tanh\,(\sigma(x-R))}{2tanh(\sigma R)}$$

(4)

with σ>0 and R>0 arbitrary parameters. Here, f(0) = 1, and f(∞) = 0. [8,9]
As defined by the warp field metric above, Figure 3 depicts the current interpretation of what the warp field would look like in 2-D space (x and ρ representing the 2 dimensions) in York time– a measure of expansion/ contraction of space which is represented by [10]

$$\theta = v_s \frac{x_s}{r_s} \frac{df(r_s)}{dr_s}$$

(5)

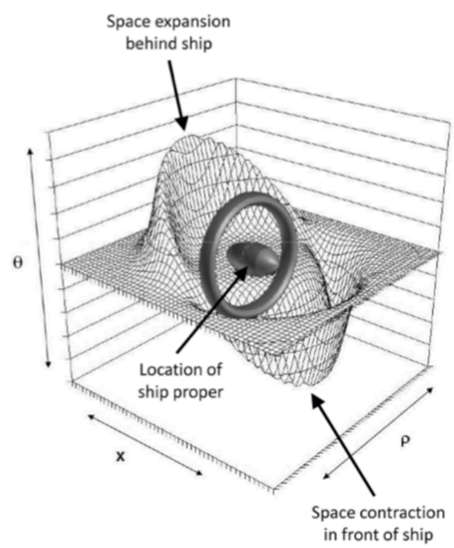

Figure 3 - 2-dimensional spatial visualization of an Alcubierre Warp Drive.

Here, the spacecraft would be moving from left to right along the x dimension, where θ is York time and ρ represents the 2nd dimension [11]

Application of a warp drive

Consider two stars A and B, a distance D from each other, a spacecraft is assumed to travel a distance d from point A at a subliminal velocity v<c starting at time t_0. Then, produce a disturbance in spacetime as required for the Alcubierre warp drive causing the spacecraft to be pushed away from A with an acceleration that increases rapidly from 0 to a value a. At a distance of D/2, the disturbance is altered such that the acceleration rapidly reduces to -a in order to slow down to a stop upon arrival at the destination planet. Given such a situation, the spacecraft will come to rest at a distance of d from star B. Thereby, it will complete the journey at subluminal velocity v<c.

In the situation considered, the coordinate time elapsed T for a one-way trip is given by

$$T = 2[\frac{d}{v} + \sqrt{\frac{D-2d}{a}}] \tag{6}$$

On the other hand, proper time measured on the spaceship τ is given by

$$\tau = 2[\frac{d}{y\,v} + \sqrt{\frac{D-2d}{a}}] \tag{7}$$

with $y = (1 - v^2)^{-1/2}$. As time is only dilated during the travel at subluminal velocity, and assuming that R<<d<<D holds

$$\tau \simeq T \simeq 2\sqrt{\frac{D}{a}} \tag{8}$$

This indicates that T can be reduced as much as needed by increasing a. Regardless, the mode of transport -spaceship- is still moving within its light cone, because light would also be pushed by the distortion of space. A light cone is the path that light emanating from a single event would take, under the conditions of special and general relativity. The outer edges of a light cone are the farthest points that the light from the event could reach.

As a warp drive, this avoids the infinite mass plight; however, this warp drive metric violates all three energy conditions (weak, dominant, and strong). The former 2 energy conditions require the energy density to be positive for all observers. If the Einstein tensor is calculated from $ds^2 = -dt^2 + (dx - v_s f(x) dt)^2 + dy^2 + dz^2$ and the fact that the 4-velocity of the Eulerian observers is given by $n^\alpha = \frac{1}{\alpha}(1, -\beta^i)$ $n_\alpha = -(\alpha, 0)$, then it can be shown that all observers will see an energy density given by

$$T^{\alpha\beta} n_\alpha n_\beta = \alpha^2 T^{00} = \frac{1}{8\pi} G^{00} = -\frac{1}{8\pi} \frac{v_s^2 \rho^2}{4r_c^2} \left(\frac{df}{dr_s}\right)^2 \tag{9}$$

As shown, the expression is negative everywhere, implying that the weak and dominant energy conditions are violated. Similarly, it can also be proven that the strong energy condition is violated. [8]

There are a few more drawbacks associated with the Alcubierre warp drive metric for FTL travel:

1. The energy requirement of about 3 solar masses
2. The shell of the material needs to be as thin as the Planck's length
3. Occupants inside the warp bubble can not interact with anything outside the warp bubble
4. External harmful radiation production and hawking radiation production (order of 10^32 kelvin)
5. A catch 22 where to make a warp bubble move faster than light, there is a need for a structure to move faster than light and modify spacetime ahead of the warp bubble.

While most of the problems associated with the Alcubierre warp drive are engineering problems, the metric breaking the energy conditions, catch-22, and the inability to interact with anything outside of the warp bubble are theoretical physics-based issues that have to be overcome. [12]

Solutions

Wormhole

A major issue that makes the maintenance of a wormhole seem unlikely is that dark energy is theorized to be the only substance that produces a radial tension greater than or equal to its density of mass-energy. Furthermore, the radial tension required to keep a wormhole open is ~10^37 dyn/cm^2 which is at the same magnitude as the pressure found at the center of a neutron star.

A method that could potentially allow for navigable wormholes to be created is through the manipulation of dark matter and energy present in the universe. The manipulation of dark matter and energy would allow for the creation of navigable wormholes because:-

1. Dark energy produces an expansionary tension on space, which could be equal to or above the necessary ~10^37 dyn/cm^2.
2. Dark energy doesn't produce any radiation, nor does it interact with any known forms of matter or energy.
3. Dark matter manipulation could be used to minimize tidal forces by controlling their distribution.

Warp drive

Formation of the warp bubble

Wormholes require less energy to be created than warp bubbles; so an alternate approach to form a warp bubble would be to:

1. Create a short-distance wormhole
2. Travel into the wormhole
3. Collapse the ends of the wormhole while still in it, while maintaining the radial tension around the mode of transport -spaceship

This would allow for a warp bubble to be formed around the mode of transport -spaceship.

Travel

A different method for achieving a fast, but not necessarily FTL travel would include manipulating dark energy and matter. Unlike a traditional warp drive where spacetime is constantly manipulated to contract ahead of the mode of transport -spaceship-; here spacetime is contracted & expanded once, the warp bubble is formed and it “surfs the spacetime wave” to the end and then breaks apart. This is repeated until the destination is reached.

Advantages

1. Energy requirements would decrease
2. Negative energy was not a requirement for wormhole formation, so no negative energy would be required to form the wormhole
3. The catch-22 situation would be avoided, because spacetime would not need to be manipulated during travel and the method for manipulating space-time could be located with or in the mode of transport-spaceship.
4. Occupants would not be able to interact with anything outside the warp bubble, but once the bubble breaks they could recalibrate as needed

The only problems that remain with this method are the engineering requirement for a Planck width for the shell of material and the production of hawking radiation which will harm the occupants.

Conclusion

Superluminal interstellar travel is one of mankind's major goals. On top of it being only conjecture at this stage, the theory is faced with multiple barriers from engineering to exotic matter requirements. However, this paper proposes that some of these barriers may be overcome through the manipulation of dark matter and energy.

In 1974, Stan Sadin established a scale called Technology Readiness Levels (TRL), which now has 9 levels to measure the maturity of a technology. Currently, FTL is measured as a level 1 on the scale, which is “Basic principles observed and reported.” This indicates that FTL is merely speculation and just in the realm of theory. Therefore to further FTL, the next goal would be to reach level 2 “Technology concept and/or application formed.” The final goal, TRL 9 is “Actual flight system proven through successful mission operatives.”

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