IS TIME TRAVEL POSSIBLE THROUGH BLACK HOLES? - A PRECISE REVIEW NOTE WITH FUTURE POSSIBILITIES

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Abstract

At present times, our understanding regarding the universe has almost reached a very complex and deep level. Through the discovery of black holes, the scientific community is able to probe deeper into this understanding. The theory of relativity is considered to be a masterpiece in the field of science. Moreover, the "LIGO experiment" has now confirmed the possibility of existence of gravitational waves. Before, they were the only existing theoretically but now have been proved 100 years after Einstein's prediction. The death of stars lead to the formation of the densest objects we know till date. These bizarre physical bodies which once were thought impossible to exist have directed us toward many other possibilities through warping of time and space, allowing us to question if time travel will be possible in the future. The laws of quantum gravity yield equal probability for existence of wormholes. Future findings and observations may confirm those theories what are now thought to be impossible. The current manuscript is equally likely a focused viewpoint and brief review and well as a discussion article based on available knowledge and future possibilities. We shall provide glimpse about current knowledge and possibilities based on information available in general domain along-with concepts proposed by Einstein through theoretical studies. We shall also pin our view-point in context to time-travel based on the concept of black hole.

Keywords: General relativity, black holes, time.

INTRODUCTION

The curious human nature in relation to the universe is obvious as we humans and all other living creatures are made from the remnants of stars that died billions of years ago. The

breakthroughs made in Space Science have proven to be helpful in moving further a step ahead where we have the basic data about natural time-machines, warping of time and space itself and phenomena in which the physics laws as known are broken completely.

In our endeavour to explore the universe, we discovered stellar bodies that forced us to think intensively which do not obey physics laws and where light itself cannot escape and nothing ever comes back. The subject is Black Holes, the strangest and most mysterious objects in the explored cosmos. The fundamental details are provided in this manuscript including time travel. The idea that 'time travel' is only an imaginary concept or does it have any logical or scientific basis will also be discussed fairly.

UNDERSTANDING BLACK HOLES

Black holes are extremely strange stellar bodies which are believed to be one of the densest and deadliest regions of space. Nothing can escape, not even light, once it travels beyond the event horizon. Einstein pointed out the possibility of existence of extremely dense objects such as the black holes in 1916 with his theory of relativity. These bodies are a extreme solution to Einstein's equations**.** The event horizon is a boundary in space-time with no point of return (as shown in figure 1). A singularity exists at the center of every black hole which is a region thought to have infinite density as shown in figure) forms within the black hole after the formation of an event horizon. In the early 20^{th} century, black hole was termed as a "gravitationally collapsed object" and "dark star" **(Mapping the heavens- 2016).** Anatomy of black hole is shown as follows:

1. Event Horizon

2. Singularity

3. Schwarzschild radius, $R_g = \frac{2GM}{C^2}$

Gathering information about black holes is nearly impossible as they do not reflect light and behave as ideal black bodies. The farthest observation about black hole is up-to the event horizon because once any mass passes through it, the events that occurs thereafter are unknown. Only the "accretion disk" can be observed which is composed of gas which gets heated up and emits radiation because of the huge gravity of the black hole. The black hole winds in this gas. The gas gets heated to a very high temperature and X-ray is released in all directions. The telescopes at NASA can measure this X-ray light (**What are black holes, 2020)**.

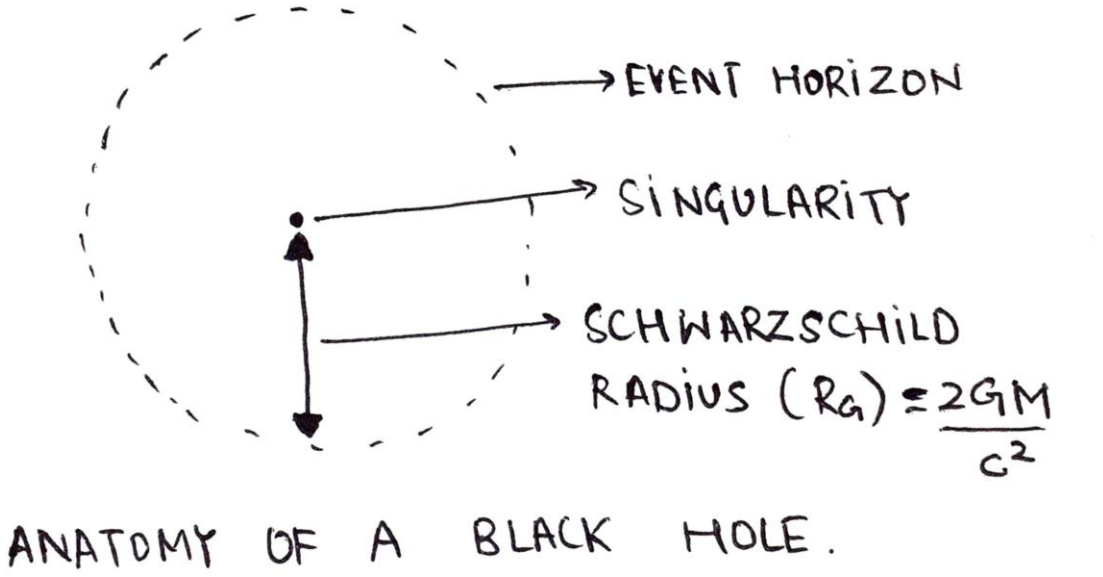

Figure 1: A black hole's anatomy.

The effects a mass suffers inside a black hole are unknown and the best hypotheses suggests that the huge amount of gravitational force has the capacity to rip the body apart to a distance just one atom wide due to the process called spaghettification. This effect is recognized as a noodle effect. This is in actual the compression of objects into long thin shapes due to vertical stretching and horizontal compression under the strong influence of non-homogeneous gravitational field). Scientists have concluded on the basis of their observations that every galaxy contains a super-massive black hole at its center. Our own galaxy, the Milky Way owns the majestic and super-massive black hole (mass = 4 billion suns, diameter = 44 million km) called the Sagittarius A, located in the constellation Sagittarius **(Black Hole Bounty Captured in the Milky Way Center, 2018).**

A black hole's size can range from that of a medium sized asteroid to the mass of 4 billion suns. So far, three types of black holes have been discovered: Primordial black holes, Stellar black holes, and the third one as Super-massive black holes **(What are black holes?, 2020)**

The smallest black hole is called the Unicorn and is just three times as the mass of our sun. It is approximately 1500 light years away**(One of the smallest black holes, 2021)**. The largest ultra-massive black hole is Ton- 618 which has a mass of the order of 66 billion solar masses**(Black holes size comparison chart, 2021**). The first ever black hole was discovered in the year 1971, called the Cygnus X-1 is understood to be positioned within the Milky Way (in the constellation Cygnus) **(Cygnus X-1: A Stellar Mass Black Hole, 2011).**

SPACE-TIME FABRIC

According to Einstein, space is curved and matter is the source of curvature**.** Any massive object can warp space-time around it and the actual effect the warp has on the object is called gravity. In the case of black holes, the gravity is really strong that it punctures the space-time fabric.

LINKAGE OF LIGHT AND TIME

There is an understanding that time slows down as one approaches a black hole. If a body happens to orbit a black hole at a safe distance, time would pass slowly when compared with people on earth. On its return, the body will be coming back to the future on planet Earth. This simple example indicates how black holes may warp time and space. According to Einstein, everybody with mass is capable of slowing down time. This phenomenon is called Time Dilation (this phenomenon states that time passes comparatively slow for an observer who is moving relative to the other observer) based on concept of relativity, caused by the nature of space-time itself . The famous thought experiment of Einstein in special relativity, called 'the twin paradox' is as such: One of the twin makes a journey in outer-space. He travels on a spaceship which almost approaches the speed of light. When he returns home, he finds that the other twin has aged more. This is a paradox having linkage with time dilation **(The Universe in a Nutshell, 2001).**

To understand the concept of time dilation in a precise manner, the postulates of special relativity are stated below:

1. The physics laws are same in any inertial frame (constant velocity) of reference, no matter what the position or velocity of the object.

2. The speed of light is constant in every inertial frame of reference, regardless of motion of the source relative to the observer **(The Feynman lectures on physics-Volume 1, 1963).**

In case (I)-figure 2, a rocket is shown which is moving at almost the speed of light. It consists of a set up which includes two mirrors, A and B and a light clock. The bottom mirror B is fitted with a sensor to record readings. When the light reflects back from mirror A and falls back on mirror B, it gives us the distance between them which is denoted as 'x' as the speed of light is constant in any inertial frame (constant velocity) of reference (postulate 2). Time taken by the light to complete this distance is denoted as 'τ'. For any observer inside the rocket, light appears to move absolutely straight (it covers a distance 'x').

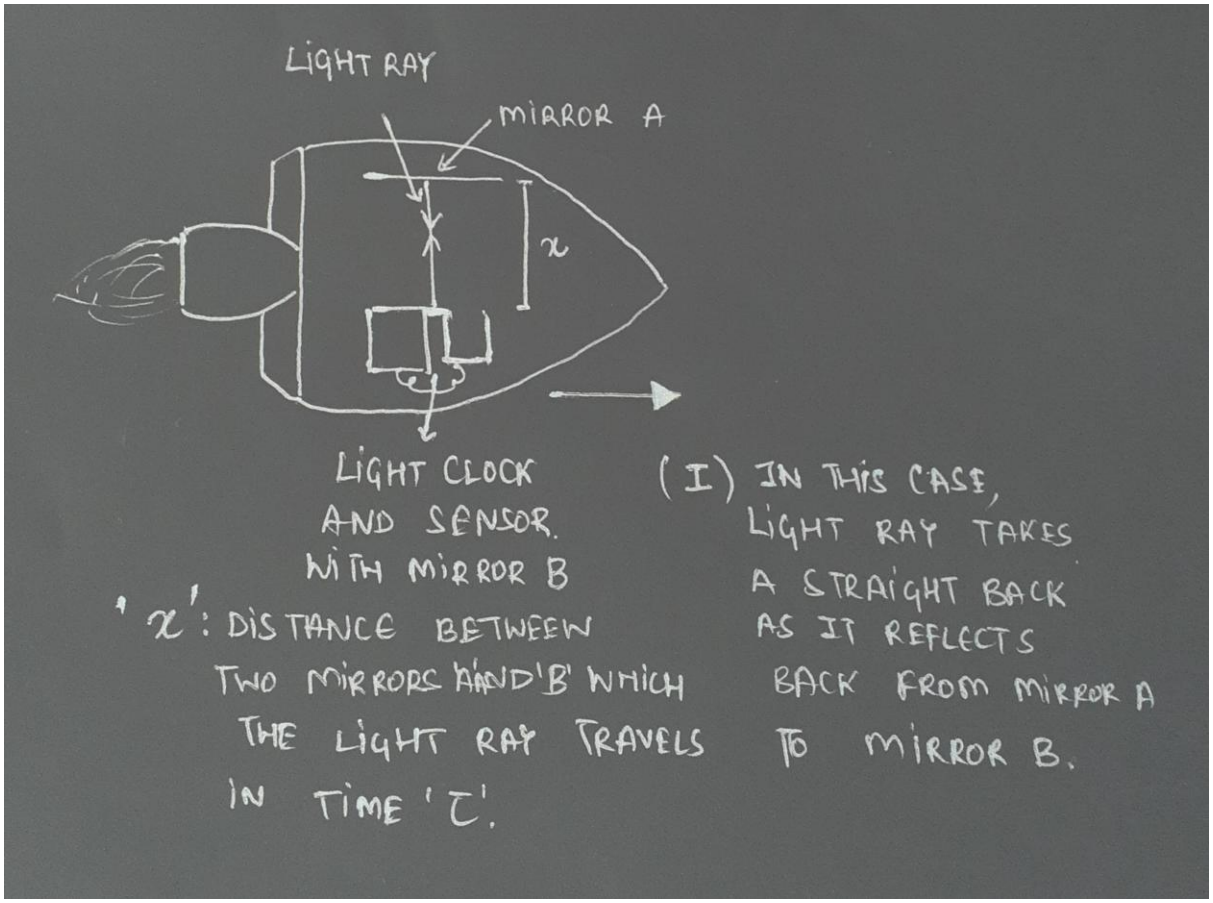

Figure 2: An example of time dilation with the use of a light clock and a rocket moving almost approaching the speed of light in accordance to an observer inside the rocket

However, in case (II)- figure 3, light appears to be moving away to the observer on earth i.e. light instead of taking a straight path appears to take a diagonal path as the rocket is in motion (near the speed of light).

It is clear that in case (II), light travels a longer distance as the diagonal path is longer than the straight path. Therefore, time taken will also be longer in this case in comparison to case (I) as time = distance/ speed. This is a very simple example explaining the concept of 'time dilation' **(The Feynman lectures on physics-Volume 1, 1963).** Time dilation can be approximated as:

$$t' = \frac{t}{\sqrt{\left(1-\frac{v^2}{c^2}\right)}}$$ where,

t' = dilated time or time observed outside the frame of reference

t = stationary time / time measured by the observer when inside the frame of reference

v = velocity of the object

c = the speed of light

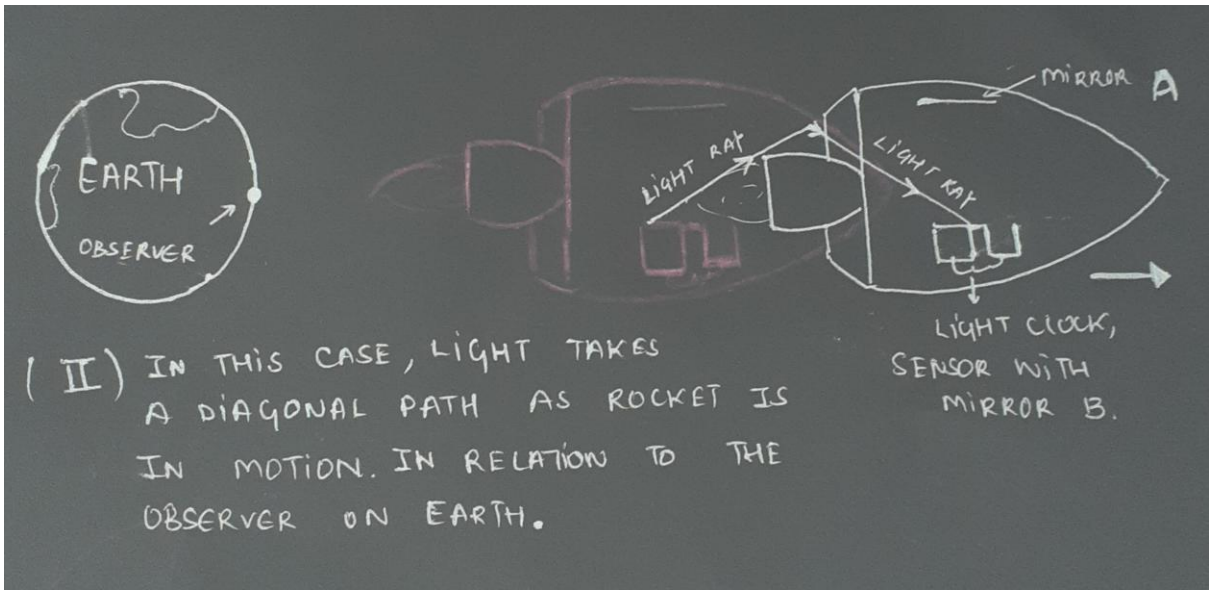

Figure 3: An example of time dilation with the use of a light clock and a rocket moving away, at almost the speed of light in accordance to the observer on earth

TIME DILATION IN CASE OF BLACK HOLES

The apparent flow of time can be significantly influenced by a strong gravitational field. Gravitational force is huge around the event horizon of a black hole. Therefore, time dilation is also huge.

THE ORIGIN OF BLACK HOLES

In the universe, stars of different masses and sizes exist, from medium sized (our Sun) to giants (Betelgeuse). The death of various sizes and masses of stars results in the formation of different celestial bodies. The Sun will swell as one red giant consuming all life on earth and finally turn into a white dwarf star. Giant stars die in a different manner. A star holds balance between two forces which act opposite to each other. Gravity forces the star to squeeze inward while the nuclear fuel creates an outward pressure. When stars run out of fuel i.e., when they exhaust their nuclear fuel, the balance between radiation and gravity breaks down. Gravity becomes way stronger than outward pressure. Therefore, the star collapses under its own weight and the outer layers explode as shock waves. This is known as a Supernova explosion (**The Universe in a Nutshell, 2001).**

Deaths of the massive stars (depending on their size) result in the formation of two types of strangest and densest bodies in the Universe- black holes and neutron stars. Neutron stars are termed as strange stars. When the core of a star is about 1-3 solar masses, it leads to the formation of a neutron star and prevents the collapse to black holes. Dense remnants of stars, too small to become black holes give birth to binary star systems or individual ones which are mostly observed as pulsars (rapidly spinning neutron stars) **(N.A.S.A., Neutron Stars, 2021).** Some of these neutron stars will continue to collapse and form stellar-mass black holes in the end.

When black holes (stellar mass) are formed, they continue to grow by absorbing matter like gases and interstellar dust. Some of them merge with stars and other black holes**.** Observations suggest that the black holes present at the heart of every galaxy may have been formed in the early universe. Massive star formation and their collapse may have resulted in black holes which are believed to be the cause of origin of the super-massive black holes. Some black holes also might have formed because of the collapse of dense interstellar clouds in the early universe i.e., the initial density disturbances that could potentially grow under their own gravity **(Massive black holes: Formation and evolution, 2007).**

EVAPORATION

In the year 1974, Stephen Hawking predicted that black holes are not completely black. They emit small amounts of radiation (thermal) at some temperature ($\hbar c^3/(8\pi GMkb)$. This is known as the Hawking Radiation, the black body radiation which is released by the black holes. The particles thus emitted should display a perfect black body spectrum. Considering this theory, black holes should evaporate after shrinking as time passes because of loss of mass due to emission of particles. Therefore, negative energy density might be possible because of the evaporation of black holes. This would warp space-time in such a direction which might be suitable to build a wormhole with its own horizon (**The Universe in a Nutshell, 2021).** Evaporation of black holes gives rise to the 'Black hole information paradox'(**Information Loss Paradox, 2015. https://arxiv.org/abs/1412.8366)** .

PREDICTED AND PROVED

In April 2019, first ever image of black holes was released by the EHT- the Event Horizon Telescope. They used a method called the VLBI- Very Long Baseline Interferometry, which is used to capture far-away celestial bodies. The black hole in the image taken is located at the centre of an elliptical galaxy Messier 87, or M87. It is 53 million light years away. The synchronization of smaller telescopes and the open-source software's helped all scientists put the data together to generate this marvellous image **(2021 Phys. World 34 (9)).**

Interestingly, in 2015, the detection of gravitational waves shocked the entire world. Their existence lead to many other possibilities like the presence of black holes in the universe which were only considered pathological solutions to Einstein's equations before. The

consistent signal suggested that two black holes- one with 36 solar masses and 29 solar masses had merged. In 2015, as stated previously, the LIGO interferometer confirmed that the gravitational waves actually exist, 100 years after Einstein's prediction. This was the result of an event that took place 1.3 billion years ago when two black holes collided. In a fraction of a second, extremely large amounts of gravitational waves were produced by conversion of a mass equivalent to three times our sun's mass **(Observation of Gravitational Waves from a Binary Black Hole Merger, 2016).**

The most recent observation for the gravitational waves confirmation is in the year 2020-2021. The Advanced Laser Interferometer Gravitational Wave Observatory (LIGO) and Advanced Virgo recorded a huge 35 gravitational wave events (**High Energy Astrophysical Phenomena, 2021).**

What Einstein predicted was assumed to be impossible by his fellow scientists and the entire world until their existence was actually proved. It is worth mentioning that there still are a lot of theoretical results which seem bizarre, whose physical proof hasn't been observed yet. On the foundation of available research and information, we will discuss that how black holes are related to time? How can they serve as natural time-machines? Are all these time travel theories but a part of science fiction stories?

We cannot consider anything true until we observe it physically. A precise understanding of the subject can help us arrive at our answers which all seem to be hidden in the General Theory of relativity and quantum cosmology.

Einstein's law of space-time war-page, the Einstein's field equations state that mass and pressure warp space-time. According to his theory, the geometrical properties of space are not independent. They can be calculated by matter (the properties refer to the curving of space-time fabric). From this statement, it can be incurred that the space-time curvature (due to the presence of gravitational field) leads to the deflection of light. More specifically, a ray of light will experience a similar curvature as that of a projected body which is when allowed to pass through a same gravitational field **(Black Holes and Time Warps, 1994).**

An experiment was conducted in which the stars in the neighbourhood of sun were photographed. The positions of the same stars were noted when the sun's position was elsewhere in the sky. When these positions were compared, the stars in eclipsed photograph seemed to be displaced radially outwards. There was a deflection in angle. This is caused due to space curvature by the sun. It is evident that a celestial body with enough mass and gravity can warp the space around it (**Relativity: The special and the general theory, 1916).**

Let us consider a common example: suppose that your sibling orbits a black hole at a safe distance and enough speed which prevents the spaceship from falling into it. Space-time is highly warped in this region. Therefore, the expansion of space will cause time to pass slower around it while you will experience a normal flow of time on earth. If your sibling returns to earth after 10 year, they will come back to future because for them they had only been away for 5 years while you actually experienced 10 years here on earth. The black hole acted as a natural time machine because it has a dramatic effect on time. A very simple way to explain

this space-time curvature is to look at these diagrams where light has a constant speed (299792458 m/s).

Consider two light beams AB and A'B' travelling at a constant speed. In fig. 4 (left side), the light beam is passing through a gravitational field whereas in fig. 4 (right side), no gravitational field is acting on it. We know that Speed = Distance/ Time, here, the light beam has to travel a longer distance due to the curvature of space. The speed of light is constant, so time must pass slowly in order to make up for the expansion of space and constant speed. Time passes more slowly as the curvature of space grows.

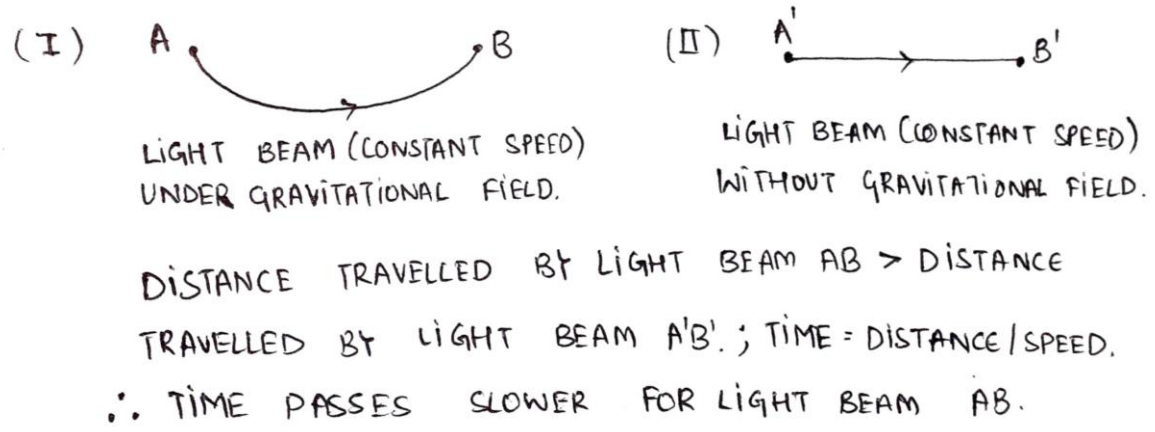

Figure 4: AB (left side) and A'B' (right side) are two light beams. At left side part (I), gravitational field exists; at right side i.e. part (II) no gravitational field exists.

Based on such logics we can proclaim about the good understanding of space and time warps. There is a very fascinating theory or possibility which seems to be quite bizarre to exist in reality called a "wormhole" which takes this space-time warp on a whole new complex level. Einstein and Rosen were the very first people to find out theoretically about the existence of wormholes which are also known as "Einstein-Rosen bridges". A wormhole could be assumed as a 'handle' in the space, connecting two locations in the universe which are separated widely. It is a hypothetical shortcut through space. If we assume space to be two dimensional, the hyperspace is folded so that 2 distant points i.e. the earth and the star can be closer. A wormhole will connect the two very distant points in space (Minkowski wormhole), thus act as a bridge. Ludwig Flamm discovered wormholes as potential solutions to Einstein's field equations. Therefore, these objects could be recognized as a very real mathematical proof. In due course, it was also observed that these wormholes are really short lived. The gravitational matter passing through a wormhole will force it to evaporate. A kind of exotic material which threads through is required to prevent them from pinching off and evaporating. A black hole's surface might act as a bridge which may connect to another point in space. Projecting two black holes in hyperspace we may end up with the singularities may

leading each other to annihilate which may form a wormhole (**Black Holes and Time Warps, 1994).**

SUMMARY

The science fiction moves akin to Star Trek etc portrays the imagination of human race which displayed a spaceship which may achieve a speed called warp speed, where a person could travel 299792 km's per second. The current Physics does not all any such adventure practically if we rely on our present understanding of the established laws of Physics. Future generations may witness the concept of time travel or related phenomena to be adopted with valid logic and proofs. Many scientific laws were broken to make way for the new ones. The biggest example being Albert Einstein who destroyed the hundred years old absolute laws of time and space. In the birth and death of theories and experiments, we will find our answers. We just need to keep looking for the perfect ingredients to extract the reality in the coming centuries. Science always sounds crazy until completely understood to the core of its heart. We may currently apprehend that if Einstein's theoretical predictions are justified experimentally then time travel will not be a completely impossible concept.

POSSIBILITIES AND OUTLOOK

1. In current times, the scientific community has admitted that black holes once seemed too bizarre to ever exist but have witnessed its first image in 2019. Therefore, we may predict that phenomenon that exists in the equations their solutions might become a reality one day.

2. The kind of exotic matter we are looking for might not be available on earth but maybe somewhere in this vast and unending Universe. The equations predict the existence of portals of time so we cannot rule that out as an impossible phenomenon.

3. One day we may get there just like after 100 years, we had a proof for black holes. One day we might understand the heart of quantum gravity.

4. Time travelling leads to many paradoxes and complex questions. Maybe a day will come when we completely understand and devise laws that explain if we will be able to trace back our origins, travel back and forth through time.

5. Space science is witnessing a lot of breakthroughs passed on as legacy to the next generation. We know for sure that the technology we are developing to look farther in space, all the testing will one day lead us to what we are looking for. One day, we might unravel those mysteries which change our views about quantum gravity completely.

6. The intimate details about the laws of quantum gravity will permit or forbid time-machines. When will we achieve that state of understanding? Well, we do not know but we have questions. One day we might reach the answers as well. The unified law has the

capacity to change everything. Maybe, the laws of quantum gravity are also not the ultimate set of laws. We have come really far in our quest of curiosity and science and we won't stop.

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