# Relativity and the Gravitational Potential of the Universe

Arindam Sinha[1,a)]

[1]*Independent Researcher, San Francisco Bay Area, California, USA*

**ABSTRACT:**

The Universe has a large and ubiquitous background gravitational potential at all points, created by its homogeneous and isotropic distribution of matter. This gravitational energy creates a local sidereal inertial frame at every location in space, with a 'rest state' defined by symmetrical distribution and velocity of Universal matter in all directions. Velocities in space are determined from this sidereal inertial frame, as is orientation (for rotation and revolution) in space. Velocity time dilation (differential aging) is a manifestation of differential gravitational potential, caused by blue shift of Universe's gravitational energy, when a body obtains a velocity in this local inertial frame. Gravitational time dilation is similarly an effect of differential gravitational potential, though created by relative proximity to large masses. Matter is a spatially stable configuration of constantly moving energy. Local speed of time (spacing of events) is proportional to the local speed of movement of light/energy including that which comprises matter. This speed is determined by the total gravitational potential, both from proximity of masses and velocity in the Universe's gravitational potential. 'Light speed invariance postulate' is a manifestation of slowdown of light propagation velocity from a moving source, which compensates for source velocity. The slowdown occurs because of blue shift of Universe gravitational potential in the direction of light propagation. These observations allow us to develop an intuitive understanding of relativity through separation of space and time dimensions. The concepts of current Theory of Relativity are examined in the light of the Universe gravitational potential's role, showing that $c$ is the maximum Universal speed limit only in orbits under transverse acceleration, or where velocity is achieved through acceleration from stationary sources, but no such restriction applies to velocities in the Universe in general. Relativity provides many thus far unexplored advantages for interstellar travel and makes it a practical possibility.

## I. INTRODUCTION

The cornerstone of this paper is the role of the background gravitational potential of the Universe in relativity concepts. Understanding of this allows relativity to be understood simply and intuitively by establishing velocity time dilation to be of gravitational origin as much as gravitational time dilation is, and establishing the relationship between the two.

The mathematical formulation of this slightly modified Theory of Relativity presented in this paper is consistent with results of all experimental tests of relativity to date, and explains the results in a much

---

[a)] Contact e-mail: arindam_sinha1@yahoo.com

more intuitive manner than existing Relativity Theory does. This is discussed in mathematical detail, in appropriate sections on the key experiments in relativity.

Some experiments are also suggested later in this paper where the results will differ from existing Relativity Theory.

First let us see why we need to look at a modification to the current Theory of Relativity at all, since it appears to have been working so well for nearly a century.

### A. Motivation behind this paper

Some of the main reasons for looking at a simpler and more intuitive theory of relativity are:

- The counter-intuitiveness of the existing Theory of Relativity limits the ability to make progress in this very fundamental area of physics. It is difficult to improve what we cannot understand or visualize intuitively, or to explore possible realistic applications. A theory like relativity may have many practical productive uses, as long as it can be understood intuitively by a broad population. In this paper we will see that a very intuitive understanding of relativity can be developed though separation of space and time dimensions, and the mathematics becomes much simpler (no tensors necessary). Concepts like 'relativity of simultaneity' and 'length contraction' are not needed to understand relativity.
- The purported impossibility of traveling faster than speed of light creates a hindrance towards serious research on practical interstellar travel. An intuitive understanding of the physics of relativity helps us establish whether the restriction is really universal, or only true under certain circumstances. As it turns out, this restriction is limited to orbital motion (from which considerations existing GR Theory is largely developed), and to remote accelerations from a stationary source only. We also establish that there are many unexplored advantages that relativity provides for interstellar travel, once we understand it intuitively.
- While the existing Theory of Relativity has worked well for most situations, there are questions that demand further investigation. Some of these are listed below.

### B. Questions and Areas of Investigation

Some of the main questions that need to be asked are:

- GPS satellites and Bailey et. al. experiment[1] (muon lifetime extension) may both be considered as orbital free fall motion under transverse (central) acceleration. Why is the time dilation factor for GPS satellites given by the Schwarzschild metric[2,3], while that of the Bailey experiment given by the Lorentz factor of Special Theory of Relativity[4] (SR)? Why does the SR time dilation formula appear to be the correct one in the Bailey experiment which uses a strongly accelerated frame?
- Light speed invariance postulate (local in GR, universal in SR) appears to associate an almost magical property to light. What is the physics behind this? [Existing Theory of Relativity is **not supposed to** explain this, as it is a **postulate**. However, investigating possible physical reasons behind this phenomenon provides valuable insights]

- Travel at or above the speed of light is impossible as per current theory. Is this something that can be generalized to all motion, or is it an artifact of orbital motion, based on which GR theory has been largely derived? This needs to be examined.
- Mathematical formulation of current theory leads to the concept of a singularity within black holes, where all known laws of physics break down. Is it the result of applying the current mathematical formulation beyond the domain of applicability of the theory?
- Mass of a body increases because of velocity (relativistic mass), and by extension, also because of gravitational potential (which is seen as equivalent to a velocity). Does the large background gravitational potential of the Universe (from matter distribution) then constitute some or all of the 'rest mass' of a body? What is mass, and why does it not have one consistent definition in General Relativity?

We will find satisfactory answers to these questions in this paper.

### C. Overview of this paper

The Universe's mass distribution creates an enormous gravitational potential at every point in space. This potential is orders of magnitude higher than that created by any single object like a planet, a star or even a galaxy in close proximity. For example, the Sun's gravitational potential on the surface of Earth (900 MJ/kg) is 15 times that of the Earth's own (60 MJ/kg), that of the Milky Way galaxy (≥ 130 GJ/kg) is over 2000 times, and even the distant Andromeda galaxy's potential is 7 times, not to mention the trillions of other celestial bodies.

This gravitation from the distribution of the matter in space creates a 'local' inertial rest frame at every location in space, and gives meaning to velocity and orientation. This inertial frame is sidereal (i.e. does not rotate in relation to distant fixed stars, or the mass distribution of the Universe in general). The sidereal nature provides the reference orientation to rotation and revolution of objects in space.

All velocities, from orbital velocity of satellites to velocities of aircraft in the Hafele-Keating[5] experiment are in practice computed from such sidereal axes, to satisfy the equations of Newtonian and relativity theories.

We will call this local inertial frame at any location as the Universe Inertial Reference Frame (UIF). The 'rest state' in the UIF corresponds to Einstein's description of being in a situation where velocities of all other distant Universal objects may be considered eliminated[6], and there is no rotation in regard to the distant objects. The gravitational potential at the location determines the local speed of light/energy $c$. This $c$, in turn defines the 'local' speed or rate of passage of time. Local speed of time (spacing of events) is a manifestation of the local speed of energy, whose movement causes all events.

The UIF is not just a reference frame like an aether. Interaction of matter and energy with the gravitational potential that creates the UIF is an integral part of the concept of relativity.

Proximity to large masses augments the ubiquitous Universe gravitational potential. Speed of light/energy at a location slows down with increase of gravitational potential. This is the reason behind gravitational time dilation[7,8] between locations, known to be caused by gravitational potential difference, as demonstrated by the Shapiro Delay[9,10] effect (radar signals passing near a massive object travel slower than they would in its absence), and also otherwise verified in experiments.

Gravitational time dilation is typically small even near very large masses, as the potential difference is small compared to the base potential of the Universe. Gravitational time dilation is intuitively understood, as the differential of gravitational potential between clocks at different altitudes provides the necessary asymmetry (intuitive physical justification) for observable “differential aging”/“time dilation” between clocks.

Velocity time dilation is also caused by increased gravitational potential because of a body’s velocity in the UIF, which results in a net blue shift of the Universe gravitational energy. Even small velocities cause time dilations comparable to gravitational time dilation, since the Universe’s gravitational potential is large compared to that of any single massive body.

Velocity time dilation appears unrelated to gravitational time dilation because of this, and has led to certain counterintuitive concepts. These concepts have hindered an intuitive understanding of time and time dilation. We will link velocity time dilation and gravitational time dilation in this paper, and show that local rate of passage of time and local speed of energy are the same thing. Time dilation is a manifestation of difference of energy speed, and therefore time speed, between locations.

Matter needs to be understood as a spatially stable configuration of constantly moving energy. Difference of energy speeds within matter at different locations leads to time dilation/differential aging.

We will denote the **speed of light in vacuum** in space, far away from all massive objects **as $\boldsymbol{c_U}$**. This is the speed of light in the UIF, as determined by the base potential of the Universe. The **reduced speed of light/energy** caused by any increase in gravitational potential (in space or within matter) will be denoted **as $\boldsymbol{c_I}$**.

[Note: In this paper, we use the term “time dilation” interchangeably with “differential aging”, not including the ‘apparent’ coordinate/observer dependent reciprocal time dilation based on Doppler effects. Reciprocal time dilation based on Doppler effects is equally valid even in Newtonian mechanics, but does not ultimately result in any actual differential clocks rates. The “time dilation”/“differential aging” term in this paper stands for the ‘invariant’ difference of clock rates at different locations/velocities.]

Far from massive bodies, the Universe’s base gravitational potential accounts for the complete mass/energy of any matter at rest. It is therefore exactly $c^2$ (henceforth $c_U{}^2$). A velocity $v$ will modify this potential, and the energy differential ratio $v^2/c_U{}^2$ will lead to existing relativity theory formulas simply and intuitively.

This explanation of velocity time dilation also provides the necessary condition of physical asymmetry between clocks, for cases where actual differential clock rates are seen in experiments. Experiments and observations have clearly indicated that actual clock rate differences arise only when two objects in question have differential velocities as measured from a single sidereal inertial frame (e.g. Hafele-Keating experiment and GPS clock synchronization[11] computations depend on measurements from a sidereal inertial frame through the center of Earth).

Moreover, this single inertial frame in question coincides with the gravitational sidereal reference frame in all practical cases, showing that it is not a locally determined phenomenon, and in itself hints at a gravitational origin of velocity time dilation.

This refined understanding of velocity time dilation also removes the need for concepts like ‘relativity of simultaneity’ and ‘length contraction’, which today makes relativity theory counterintuitive and overly complex.

Space and time dimensions can be separated, and relativity concepts become extremely intuitive and simple.

We will consider gravitational time dilation first. Then we will derive velocity time dilation as an effect of modified gravitational potential from both the Universe background potential and proximal masses.

In this context, it is appropriate to quote Einstein’s thoughts in Scientific American in April 1950[12]:

> “I do not see any reason to assume… the principle of general relativity is restricted to gravitation and that the rest of physics can be dealt with separately on the basis of special relativity ... I do not think that such an attitude, although historically understandable, can be objectively justified ... In other words, I do not believe that it is justifiable to ask: what would physics look like without gravitation?”

With the advantage of hindsight of a hundred years of experiments and observations, we need to reassess some of the assumptions and conclusions of the Special Theory of Relativity (SR) and General Theory of Relativity (GR)[13] from a fresh perspective. This allows us to refine the theory further, and get a very intuitive understanding of how relativity applies to our Universe. The mathematical formulation becomes exceedingly simple.

## II. MATTER, ENERGY AND TIME DILATION

As a first step, we need to visualize the relationship between matter and energy, and how the speed of energy relates to time dilation and time.

### A. Matter as a stable configuration of Energy

Matter is a spatially stable configuration of constantly moving energy. The equivalence of matter and energy is well established by experiment. We may consider matter to be an aggregate of energy, with equal parts of constituent energy travelling in all spatial directions at a given time, preserving the spatially stable structure of the aggregates (like electrons, protons, sub-atomic particles or even atoms). While these spatially stable aggregates which we call matter may remain at rest or, move at any velocity, the energy within continues to move at $c$.

The vector sum of velocity of energy constituting matter is zero in every direction at the aggregate level, allowing matter to be at rest as opposed to energy which does not have a rest state.

**For understanding relativistic effects intuitively, we must visualize matter as being entirely comprised of a certain amount of continuously moving energy, constrained in a particular volume of space in a stable configuration.**

Energy never stops moving, whether it is energy comprising matter or free energy. Events are observable outcomes of energy movements at the fundamental level.

Gravitational potential (energy density) at a location inversely affects the speed of all energy at the location – even energy which is part of matter. This is what leads to time dilation.

## B. Time Dilation

### *1. Meaning of time dilation*

Consider two identical configurations of matter as described below, so we can establish a clear understanding of time dilation and time.

Each configuration consists of a light-clock and a mechanical clock. The only difference we stipulate is that the first configuration (left side in figure (Fig. 1) below) is in a higher gravitational potential. It does not matter whether the difference is caused by large mass proximity or velocity. The impact on local energy velocities depends only on the gravitational potential and not on the specific mechanism that caused it.

The light ray in the left side light-clock moves slower compared to light ray in the right side light-clock, being in a higher gravitational potential.

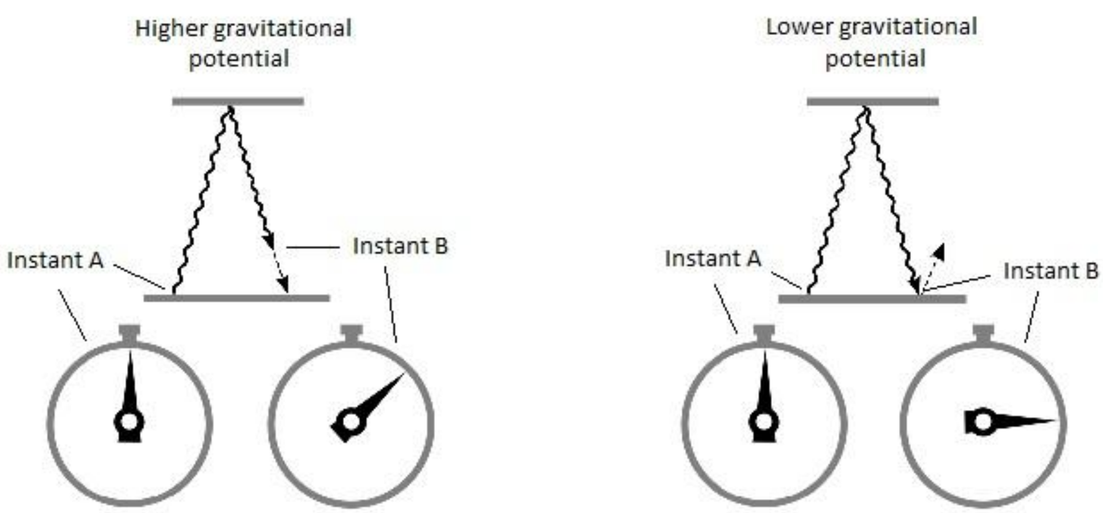


Fig **1:** The light clock and mechanical clock on the left are in a higher gravitational potential than the light clock and mechanical clock on the right. Light and all energy moves slower in the left side configuration. At instant A, both sets of light and mechanical clocks are synchronized. At a later instant B, the readings on the left side clocks will fall behind the right hand one, as light in the light clock and all energy within the mechanical clock on the left are traveling proportionately slower. The size of the 'second' in the left hand configuration is longer than the 'second' on the right hand side.

Now, it is not just the light in the light clock alone that will be so affected, but all energy, including that which comprises the matter of the mechanical clock. Since events or movements happen at the basic level because of movement of such energy, even the mechanical clock on the left must be moving slower in the same proportion as the light clock. The energy within the atoms are moving slower, leading to the electrons moving slower, leading to less number of transitions of the atoms compared to the right side configuration. This goes all the way down to base energy, and all the way up to all observable events, and thus all movement within the left side configuration is slower proportionally compared to the right side configuration.

This gives rise to time dilation between the two locations. An observer at the left location will consider the clock of the right location faster, and in reverse the right location observer will consider the left side clocks slower.

### *2. Local constancy of speed of light 'c'*

Importantly, observers at the two locations will obtain the same numerical value of $c$ (299,792,458 m/s) when they measure the speed of light locally. Since a 'second' is defined locally as one tick of either local clock, the relative size of a local 'second' depends on the local speed of light/energy, which also determines the rate at which events happen. This makes $c$ a 'local' constant, in spite of a comparative difference in light/energy speed between the two locations.

Local speed of time (relative spacing between observable events) is determined by the local speed of energy movement. In effect, speed of energy at a location is ultimately used to measure the speed of light at that location, naturally giving a constant numerical value depending on the choice of units alone.

The definition of the term 'local' depends on the accuracy of clock measurement desired. Higher the measurement accuracy needed, smaller the volume of space that may be considered 'local'.

### *3. Interpreting time dilation observations*

Two real life examples will make this clearer and demonstrate some important concepts.

- **GPS Satellites:** Light/energy travels a little faster in atomic clocks of GPS satellites compared to Earth, a combined effect of both reduced gravitational and increased velocity time dilation. Therefore the 'local' GPS second is a little shorter than that on Earth surface. In effect, the cesium atoms in the atomic clocks on board GPS satellites have slightly faster transitions compared to on Earth (along with all other matter and energy in the GPS satellite, of course). This is the reason GPS clocks are a little faster than Earth clocks, and need a small adjustment to keep in synch with Earth clocks. Note that there is no differential aging between clocks of different GPS satellites, although they travel in six different orbital planes and have significant proper relative velocities between themselves.
- **Cosmic muons[14]:** Cosmic muons show some lifetime extension, without which they would not have been able to reach Earth surface in the quantities they do. Their high velocities cause them to face a significantly higher Universe gravitational potential, slowing down their internal energy speed in the process. Thus, the 'clock' of the cosmic muon is much slower, it's 'seconds' being much longer than Earth surface seconds. Therefore, a muon will consider itself traveling at a

much higher velocity than someone on Earth would, given the same distance being travelled in less number of seconds.

This visualization removes the necessity of concepts like ‘relativity of simultaneity’ and ‘length contraction’, and paves the way to an intuitive understanding of relativity. Lengths remain a constant for all observers, while the size of the local second may vary.

Time dilation/differential aging is a ratio, not an absolute difference, and therefore cannot be infinite unless energy comes to a complete stop at a location (requiring gravitational potential to be infinite). The problem is that gravitational energy needs to move to create such a potential in the first place, which leads to a contradiction with all energy being stopped. This is another counterintuitive concept, as applied to black hole event horizons, which will be resolved in this paper.

## III. TIME

Based on the above discussion of time dilation, we can create a clear understanding of time itself.

Time, after all, is just the relative spacing between observable events. Each tick of the light clock or the mechanical clock’s ‘second’ hand, for example, is an observable event.

The rate of passage of time at a location is exactly proportional to the rate at which all energy moves at that location (free energy as well as that comprising matter). Time gets a meaning only in the context of observable events caused by such movement of energy.

This may be represented in the following manner for two locations $A$ and $B$ with different gravitational potentials:

$$\frac{T_A}{c_A} = \frac{T_B}{c_B} \; and \; \frac{T_A}{T_B} = \frac{\Delta T_B}{\Delta T_A} \tag{1}$$

where

$T_A, T_B$ = rate of passage of time at A and B respectively
$c_A, c_B$= speed of energy at A and B respectively
$\Delta T_A, \Delta T_B$ = the same period of time as observed at A and B respectively

[Note: Local rate of passage of time is inversely proportional to the elapsed local time, so $\frac{T_A}{T_B} = \frac{\Delta T_B}{\Delta T_A}$]

No other physical meaning of time and time dilation is reasonable or possible. The reader should not proceed to read the rest of the paper without first intuitively understanding this explanation fully, which is summarized below at the risk of repetition:

- “Differential Aging”/“Time Dilation” between two locations is caused by a relative difference of energy speeds at the two locations (and therefore different comparative spacing of otherwise identical events).

- This time dilation (or energy speed ratio) between two locations is caused by difference of gravitational potential, with time/energy speed being inversely proportional to relative gravitational potentials.
- Such gravitational potential difference may arise because of differential proximity to a large mass (‘gravitational’ time dilation) or differential velocity in the Universe’s background gravitational potential (‘velocity’ time dilation), but the time dilation effects are physically indistinguishable.
- Time speed at a location is directly dependent on energy speed at that location, and hence energy speed (time-dependent displacement) is a local constant.

Whether we consider time to be something real, based on whose flow energy velocity is measured, or whether we consider time itself to be defined and measured based on a certain arbitrary unit distance of energy movement, is a difference of philosophical point of view only.

This explanation of energy speed and time speed equivalence ties in extremely well with the existing notion of gravitational time dilation. The conceptual difficulty in understanding time in this simple manner arises today from the counterintuitive concepts of ‘relativity of simultaneity’ and ‘length contraction’ from Special Relativity. Once we establish velocity time dilation also as a gravitational effect, in no way different from gravitational time dilation, these counterintuitive concepts and the corresponding philosophical difficulties disappear.

## IV. GRAVITATIONAL POTENTIAL OF THE UNIVERSE AND MASS

We start with the assumption that the Universe’s mass distribution may be considered homogeneous and isotropic at a large scale. This is a well accepted assumption in relativity and cosmology.

From existing Theory of General Relativity, we know that an increase in gravitational potential is equivalent to an increase in unit mass (and equivalently energy) of an object by the amount of the potential. This increased mass (compared to rest mass) may be referred to as ‘relativistic mass’, since we need not distinguish whether such potential increase is caused by large body proximity or by velocity.

The base Universe gravitational potential must then account for some or all of the ‘rest mass’ of any object (as postulated in Mach’s Principle). Our considerations in this section will show that it in fact defines the entire ‘rest mass’.

‘Amount of matter’ and ‘mass’ have to be clearly separated as concepts. Everything that exists, including light/energy and physical bodies, must be made up of something physical. We will call this as ‘material content’ to differentiate from the term ‘matter’ which describes an ‘aggregate of spatially constrained energy’ as described earlier. Amount of ‘material content’ of either energy or matter does not change because of any changes in gravitational potential, as it is an inherent property.

Mass is not an inherent property of either energy or matter, but a derived property that is obtained by interaction with gravity. In fact, unit mass is simply the gravitational potential, and the Universe gravitational potential accounts for the entire rest mass of any object.

Energy by itself is known to be massless, and therefore matter comprising energy alone should have been massless as well. Where does the rest mass of matter come from then?

Energy has some ‘material content’, however little. Its ‘mass’ depends on the UIF gravitational potential it obtains at its velocity of $c$.

Physical matter contains energy in spatially stable configuration where the vector sum of the velocities of its (constantly moving) constituent energy is zero, but the mass of such energy remains intact. The aggregate of the masses of its constituent energy gives matter its ‘rest mass’ or ‘base mass’.

The total energy/mass of an object is thus equal to its total gravitational potential from all other matter in the Universe, or as we will see later, all other matter whose potential reaches the object in question, given the expansion of the Universe. We will call this the ‘sphere of influence’ for the object.

The unit rest mass (mass per unit matter) of a body is a gravitational property, determined by the total gravitational potential it is in. Total rest mass is obtained by multiplying the ‘unit rest mass’ by the ‘amount of material content’ in the body.

## V. GRAVITATIONAL POTENTIAL OF ENERGY VS. MATTER

From our visualization of matter as a spatially stable configuration of moving energy, we need to draw a distinction here between the potential of light/energy and potential of matter. This distinction is important for our understanding of the concepts and deriving mathematical formulas in relativity.

The potential a small test body of matter obtains, when at rest, from a nearby large body of mass $M$ at a distance $R$ is given by the formula $GM/R$. The speed at which gravity reaches the body is $c_U$. Light/energy which itself travels at $c_U$ will **have a potential of $2GM/R$** when traveling in a transverse direction at a distance $R$ from the large body. This also applies to energy which is part of matter, even if the matter itself is at rest.

The reason for this is that light’s transverse velocity of $c_U$ results in a relative velocity of $\sqrt{2}c_U$ with respect to the gravitational energy from the large body. The gravitational potential (which is dependent on the gravitational acceleration) is proportional to the square of this relative velocity (this will be explained below). This makes the potential of light/energy 2 times that of matter at rest. We see evidence of this doubling of acceleration (which also doubles the potential) in the experiments on bending or deviation of star light by the Sun. As verified experimentally by Eddigton et. al.[15] and others[16,17,18,19], the deviation amount is double the Newtonian value, showing that acceleration is double.

While the energy which constitutes matter is part of the ‘rest energy/mass’ of matter, it does not play a direct role in the movement of matter as a whole, since on aggregate the energy velocities cancel out, leaving only the mass (which is the gravitational potential of the constituent energy). Therefore, for matter as a whole, the potential is $GM/R$, considering its ‘potential for movement’ under acceleration.

To elaborate this, consider a bit of matter at rest in UIF. It has no kinetic energy of its own. This is not true of its constituent energy, which keeps moving inside the atoms. However, while within the atom, this may be considered as potential energy, since there is no outside evidence of this energy while the atom remains whole. If the atoms are split up to release the constituent energy, this potential will become observable as kinetic energy based on its impact on other objects. This is the difference we have to keep in mind for our considerations.

If the overall matter were to be given a velocity, it will attain some kinetic energy as a whole, which then adds on to its total energy content.

When we look at time dilation, it is an effect of the slowdown of the internal energy of matter caused by increased gravitational potential, and that is why we need to use $2GM/R$ as the relevant potential.

We will also see that the formula for this potential of energy from the Universe gravitation is identical to transverse velocity near a large mass, providing the same $2GM/R$ formulation for light/energy potential in UIF as well, and not just for gravity coming from one direction.

All of this will be amply substantiated in the sections below when we derive the velocity time dilation formula.

In this paper, we will use different terms and notations for the potential of energy and matter, where that distinction is necessary. We will refer to the potential of light/energy as ‘energy-potential’ and use the notation $\hat{\phi}$, to distinguish from $\phi$, which is the potential of matter, which we will call ‘matter-potential’.

## VI. QUANTIFYING UNIVERSE GRAVITATIONAL POTENTIAL

We need to visualize how potential from the rest of the Universe affects a small body to understand how such potential will change because of proximity to large masses or velocity in UIF.

We do not know how large the Universe is. Nor does all the mass of the Universe necessarily contribute to gravitational potential at any particular location in an expanding Universe.

For a small body at any location in the Universe, the total potential is a sum of the potentials created by all the matter within a ‘sphere of influence’, which includes all matter whose gravitation reaches the body. This may or may not coincide with the Hubble[20] sphere, but the exact limit of this sphere is not important for our considerations. It is sufficient that there is a finite amount of matter within that sphere, uniformly expanding away, which creates a certain total potential at the location under consideration.

Gravitational potential contribution of farther away spherical layers of matter will be greater than closer to, up to a point. While gravitation from closer bodies would be the least red shifted, the amount of matter grows as a square of the distance $R$ (under assumptions of homogeneity and isotropy of the Universe). Therefore gravitational potential ($\sim 1/R$) would grow in proportion to $R$ with increasing distance, but will be tempered by increasingly larger red shifts. At the edge of the ‘sphere of influence’, the potential will be red-shifted out of existence, and gravitational potential of matter beyond that does not affect our small body.

We need to make one important assumption at this point. Whatever the red shift from a particular source of gravity, the gravitational energy that reaches the location of the small body under consideration from all Universal matter does so at $c_U$, which is the speed of energy in the base gravitational potential of the Universe far from massive bodies. Considering the large distances from bodies that have any appreciable away velocity, extinction[21] will ensure that all energy reaches the UIF rest position of all locations at a speed of $c_U$.

The total gravitational energy-potential contribution of a single body of mass $M$, at a distance $R$, moving away from the center of the 'sphere of influence' at a velocity $v$ may be represented as:

$$\hat{\phi}_M = 2\phi_M = \frac{2GM}{R} \times \left(\frac{c_U - v}{c_U}\right)^2 \tag{2}$$

where

$\hat{\phi}_M$ = gravitational energy-potential of body of mass $M$
$\phi_M$= Newtonian gravitational potential (matter-potential) of mass $M$, i.e. $GM/R$
G = Gravitational constant ($6.67384 \times 10^{-11}\ m^3 kg^{-1} s^{-2}$)

For time dilation considerations, the total gravitational potential of a body needs to be considered as the energy-potential, which is two times the Newtonian potential, as discussed in Section V.

The reduction factor $((c_U - v)/c_U)^2$ takes into account (a) the reduced gravitational energy conveyed by each quantum of gravity (i.e. gravitons) by the factor $(c_U - v)/c_U$, and (b) the reduced rate of gravitons reaching per unit time by an identical factor of $(c_U - v)/c_U$, compared to source being at rest. Thus, the overall gravitational energy from far away objects moving away from a location because of the expansion of the Universe is decreased by a factor of $((c_U - v)/c_U)^2$.

Now, considering all bodies within the 'sphere of influence', the total potential of the small body will be:

$$\hat{\phi}_U = \sum_{i=1}^{i=n} \frac{2GM_i}{R_i} \left(\frac{c_U - v_i}{c_U}\right)^2 \tag{3}$$

where

$\hat{\phi}_U$ = total gravitational potential at rest in UIF at the location
$n$ = number of bodies in the Universe that affect the gravitational potential at this location
$G$ = Gravitational constant ($6.67384 \times 10^{-11}\ m^3 kg^{-1} s^{-2}$)
$M_i$ = mass of the $i^{\text{th}}$ body
$v_i$ = radial velocity of the $i^{\text{th}}$ body because of expansion of the Universe
$R_i$ = distance of the $i^{\text{th}}$ body from the location under consideration

We may actually consider the distant masses to be adjusted by the red shift factor, and the gravity traveling from them to be reaching a location at $c_U$, with the below equation:

$$\hat{\phi}_U = \sum_{i=1}^{i=n} \frac{2GM'_i}{R_i} \tag{4}$$

where $M'_i$ = adjusted mass of the $i^{\text{th}}$ body = $M_i \left(\frac{c_U - v_i}{c_U}\right)^2$

Since this is all the energy a body of unit mass would have at this location, we may equate this to unit energy as per $E/m = c^2$:

$$\hat{\phi}_U = \sum_{i=1}^{i=n} \frac{2GM'_i}{R_i} = {c_U}^2 \tag{5}$$

The total **Universe gravitational energy-potential at any point**, far away from all masses, is then **exactly $\boldsymbol{{c_U}^2}$**.

This is also the minimum energy-potential possible for matter at any point in the Universe. The local speed of light/energy $c_U$ in this situation (UIF rest) is the same as the speed of the gravitational energy received, since in this situation all energy travels at the same speed in vacuum (i.e. velocity of external gravity and velocity of local energy are the same). We can state in this situation that $c_I = c_U$. Proximity to a large body or a velocity in any direction can only increase the potential, which will lead to a reduction of the local speed of light/energy, making $c_I < c_U$, as we will see in the next section.

The above is valid for unit amount of matter. For any arbitrary 'amount of matter' $m$ (in appropriate unit, like kg), the total energy of course would be:

$$Energy = m\hat{\phi}_U = m{c_U}^2 \tag{6}$$

One important point we must understand from this is that gravity is not a form of energy inherent to matter, created and emitted through conversion of some part of the matter itself.

**Gravity** is energy that **comes from other matter in the Universe, interacts with a body, and is retransmitted out** (and the same holds for all matter in the Universe). There must be equilibrium between the incoming and outgoing gravity for all bodies, as there is no change of mass of objects in a stable state. This could change very slowly over time as the Universe expands and distances become larger, but that does not affect our considerations.

## VII. CONSTANCY OF THE PRODUCT $\hat{\phi}{c_I}^2$

Consider a relatively sparse distribution of matter (as in a lightly packed body) in spherical symmetry with radius $r$ in a given volume of space. We call this body $X$. The gravitational energy-potential created by $X$ at a point $P$ at a certain distance $R$ can be computed using the gravitational energy-potential formula ($2GM/R$) using the total mass (say $M$) of $X$, and the distance $R$ from the center of gravity (CG) of the matter.

If we now compressed all this material and created a denser sphere (radius $r''$) without changing the CG, $X$'s total mass would have to increase, as each bit of matter within $X$ will get a higher potential (and therefore mass) from all the rest, through increased mass proximity. Therefore $X$'s gravitational energy-potential at the distant point $P$ will also increase. However, that would be a potential increase without any matter/energy being added to the gravity source $X$! Considering that no additional gravity is flowing into that volume of space, such an increase of gravitational potential would be equivalent of ‘creation’ of energy from nothing! This is, of course, impossible.

The situation is depicted in the figure (Fig. 2) below.

We come to the conclusion then that the potential at $P$ must remain the same before and after compaction of $X$. How would that happen?

We know from gravitational time dilation experiments that as the potential increases at a location, the local energy velocity is reduced (i.e. time slows down). Since, nothing else has changed, the above consideration implies that the mass/potential increase of $X$ must be exactly offset by reduction in energy velocity $c_I$ within $X$, implying an equivalent slowdown of rate of gravity flowing out per unit mass.

However, the local energy velocity $c_I$ does not explicitly appear in the potential formula $2GM/R$. Since $R$ is unchanged and $M$ has increased, the offsetting factor $c_I$ must be part of the Gravitational Constant $G$. This is discussed below.

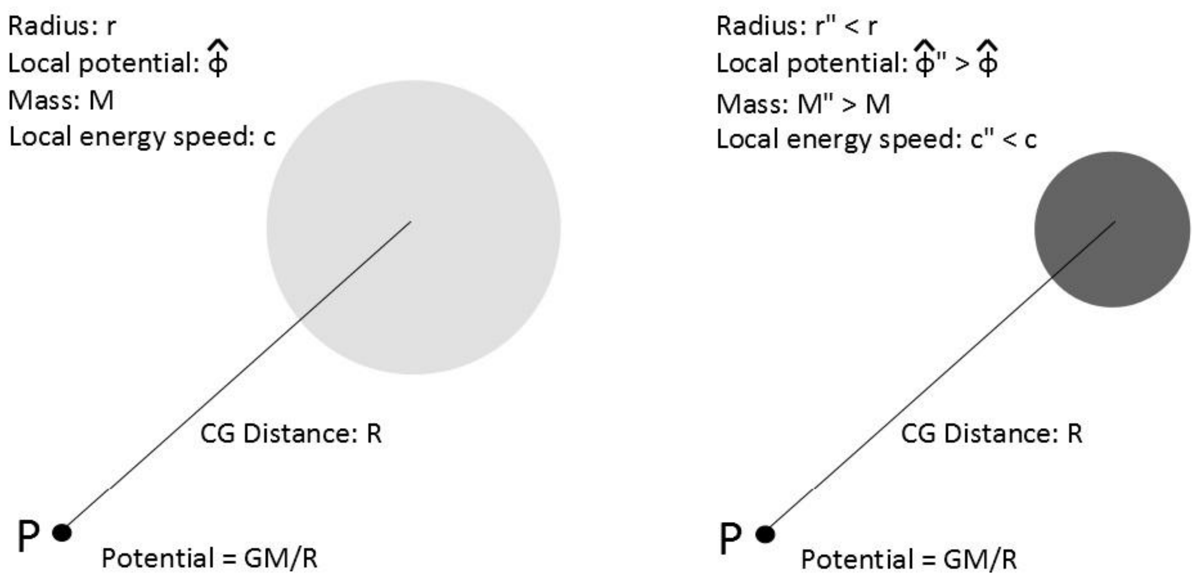


Fig **2:** When a sparse spherical body is compacted into a denser spherical body, the local gravitation potential of all contained matter and energy increases. This is equivalent to an increase in mass, but that cannot result in an increase in potential at a distance location P, as the total gravitational energy does not increase. The increase of mass is compensated by a reduction of energy speed or a red shift of all constituent energy (including gravitational energy) so that the potential at P remains the same.

We noted in the previous section that the potential at a location is affected not only by $M$ and $R$, but also the square of the velocity of gravitational energy ($c^2$). This is rarely explicitly called out as in most observational cases $c$ varies very little, and this factor remains hidden within the gravitational constant $G$ (and partly explains its curious units $m^3kg^{-1}s^{-2}$, which becomes $mkg^{-1}$ when we take out the $c^2$ explicitly).

We can define a reduced gravitational constant $\cancel{G}$ as:

$$\cancel{G} = \frac{G}{c^2} \tag{7}$$

Considering the original mass as $M$ and original energy velocity as $c$, we can write $X$'s original energy-potential $\hat{\phi}_P$ at point $P$ as:

$$\hat{\phi}_P = \frac{2\cancel{G}M}{R} c^2 \tag{8}$$

When the matter in $X$ is made more compact, the increased mass ($M$") and reduced energy velocity ($c$") must still give the same energy-potential ($\hat{\phi}_P$) at P:

$$\hat{\phi}_P = \frac{2\cancel{G}M"}{R} c"^2 \tag{9}$$

Equating the two RHS of Equations (8) and (9), we can derive that:

$$Mc^2 = M"c"^2 \tag{10}$$

Now, mass itself is nothing but the unit energy-potential density of the body, multiplied by the 'material amount'. Therefore we can also write this as:

$$\hat{\phi}c^2 = \hat{\phi}"c"^2 \tag{11}$$

where $\hat{\phi}$ is the original energy-potential within the gravity source $X$ (not at $P$), and $\hat{\phi}$" is the increased potential within the body after it is compacted.

We need to take careful note of the following to understand the implications of this clearly:

- It is the local energy-potential $\hat{\phi}$ within the body $X$ that increased because of the compaction. The energy-potential at $P$ ($\hat{\phi}_P$) from $X$'s gravity stayed the same as it must.
- The local energy velocity $c$ within the body was reduced on compaction (to $c$"). In effect, greater potential/energy density within the body reduces the speed of energy in such a way that the energy-potential at a distance $R$ outside the body would not change.
- The reduction of $c$ inside $X$ would translate into a slight red shift of gravity for an observer at point $P$, if one could measure gravity wavelength. This is similar to the slight red shift of Sunlight as observed from Earth, because of the slightly slower light velocity on Sun's surface because of its higher potential. The slightly increased mass $M$" will compensate for this reduction, such that the gravitational flux that reaches point $P$ would remain the same.

In effect, the increase of potential slows down energy in that volume of space such that the emission rate of gravitational energy per unit time remains the same as the absorption rate (which has not changed).

Noting that $c$ and $c''$ are the before and after values of internal speed of energy ($c_I$) within the body $X$, we can conclude by Equation (11) that the **product of (a) internal energy-potential (or unit mass) of a body and (b) square of the internal energy velocity is always a constant,** i.e.

$$\hat{\phi} {c_I}^2 = constant \tag{12}$$

We can also equate this to the energy-potential and velocity of free energy in UIF (where $c_I = c_U$) as:

$$\hat{\phi} {c_I}^2 = \hat{\phi}_U {c_U}^2 \tag{13}$$

This is a very important conclusion for understanding a lot of phenomena in relativity (like time dilation computations) and observations about the Universe's physical laws, as will be discussed in the below sections. Note that since this is an equation for potential per unit matter, it will remain valid even when the total amount of gravity absorbed/emitted per unit time changes, as would be the case when a body obtains higher velocity in UIF.

The other point to note is that $c_U$ is the value of $c_I$ only for light or free energy in UIF. Within matter, the potential is higher because of the high energy density within the matter itself, such that the energy velocity within matter would be somewhat lower than $c_U$. This is seen in refraction of light in transparent mediums. However, as long as we compare with the UIF energy state and equate $\hat{\phi} {c_I}^2 = \hat{\phi}_U {c_U}^2$, our considerations are not adversely affected.

This discussion also demonstrates that our earlier assumption about the homogeneous and isotropic distribution of matter in the Universe (as it affects a body's potential) is almost literally true. Whether the Universe has matter in large clumps (stars etc.) or is a uniform distribution of energy (as visualized by Einstein in his derivation of GR), the gravitational potential set up at a distant point in space will be the same. This would apply to everything including black holes.

## VIII. EFFECT OF PROXIMITY OF A LARGE BODY ON GRAVITATIONAL POTENTIAL

In this section, we consider what the energy-potential ($\hat{\phi}_M$) of a massive body of mass $M$ should be from the UIF point of view at a distance $R$ from the CG of the body.

### A. Potential of a nearby large body

As has been indicated earlier, the Newtonian matter-potential being $GM/R$, the energy-potential for relativistic purposes is twice that. We may state this potential $\hat{\phi}_M$ as:

$$\hat{\phi}_M = \frac{2GM}{R} \tag{14}$$

The base gravitational potential of the Universe has been established earlier as $\hat{\phi}_U = {c_U}^2$. The total potential including that of the proximal mass M (for a small test mass at distance R) would be given by:

$$\hat{\phi}_{Total} = \hat{\phi}_U + \hat{\phi}_M = {c_U}^2 + \frac{2GM}{R} = {c_U}^2\left(1 + \frac{2GM}{R{c_U}^2}\right) = \hat{\phi}_U\left(1 + \frac{2GM}{R{c_U}^2}\right) \tag{15}$$

There are several things to be noted from this derivation:

- The mass per unit matter (or relativistic mass of unit matter) is increased by the factor $\left(1 + \frac{2GM}{R{c_U}^2}\right)$
- Since $\hat{\phi}{c_I}^2$ of a body is constant, the reduced velocity of energy at this location, $c_I$, can be obtained from:

$$\hat{\phi}_{Total}{c_I}^2 = \hat{\phi}_U{c_U}^2 \tag{16}$$

$$\therefore c_U = c_I\sqrt{\frac{\hat{\phi}_{Total}}{\hat{\phi}_U}} = c_I\sqrt{1 + \frac{2GM}{R{c_U}^2}} \tag{17}$$

- We can derive the gravitational time dilation factor $\gamma$ from Equation (17), as used to compute the time dilation near a large mass (e.g. surface of Earth) compared to infinity (i.e. far from all large masses) as:

$$\gamma = \frac{c_U}{c_I} = \sqrt{1 + \frac{2GM}{R{c_U}^2}} \tag{18}$$

- If $\frac{2GM}{R} \ll {c_U}^2$ (which is practically true for all situations expect very near black holes) we may use the approximation:

$$\therefore c_U \cong c_I\left(1 + \frac{GM}{R{c_U}^2}\right) = c_I\left(1 + \frac{\phi_M}{{c_U}^2}\right) \tag{19}$$

  Equation (19) is analogous to the equation derived by Einstein in his 1911 paper ("On the Influence of Gravity on the Propagation of Light"):

$$c = c_0\left(1 + \frac{\phi}{c^2}\right) \tag{20}$$

[Note: We will use the notation $\gamma$ for both gravitational and velocity time dilation factor, as it is essentially the same thing.]

### B. Gravitational time dilation

The concept of **Gravitational Time Dilation** can be very intuitively understood based on the above discussion.

For two bodies $A$ and $B$ at distances $R_A$ and $R_B$ from a massive body ($M$), the relationship between their internal energy speeds $c_I$ (and therefore corresponding time rates/speeds $T$) can be found (using Equation (1) and Equation (19)) as:

$$c_U = c_{I:A}\left(1 + \frac{GM}{R_A {c_U}^2}\right) = c_{I:B}\left(1 + \frac{GM}{R_B {c_U}^2}\right) \tag{21}$$

$$\therefore \frac{c_{I:A}}{c_{I:B}} = \frac{1 + \frac{GM}{R_B {c_U}^2}}{1 + \frac{GM}{R_A {c_U}^2}} = \frac{T_A}{T_B} = \frac{\Delta T_B}{\Delta T_A} = \frac{\lambda_A \nu_A}{\lambda_B \nu_B} \cong 1 + \frac{GM}{R_B {c_U}^2} - \frac{GM}{R_A {c_U}^2} \; when \; \frac{GM}{R_A} \ll {c_U}^2 \tag{22}$$

where $\lambda, \nu$ stand for wavelength and frequency of light respectively

Gravitational time dilation is this ratio of local energy/time speeds (within matter and outside), or local clock tick rates, as applied in Hafele-Keating experiment and GPS clock time dilation computations. The velocity time dilation part of these observations/experiments will be covered shortly.

### C. Red-shift of Sunlight

The red-shift of Sunlight, or gravitational red shift, as predicted by Einstein in his 1911 paper ("On the Influence of Gravity on the Propagation of Light"), and experimentally proven later[22,23,24,25], is dependent on the relative value of local light speed $c_I$ at two locations – Sun surface and Earth surface. The light/energy speed at the Sun surface is slightly lower than that on Earth surface, because of the Sun's higher potential on its surface. Therefore, any light leaving atoms on the Sun's surface would be doing so at a slightly lower rate, or 'frequency' (according to Earth clocks, which have slightly shorter seconds compared to sun surface clocks).

When light leaves the Sun, it attains a slightly higher velocity during travel to Earth, as gravitational potential decreases. The wavelength gets stretched a bit because of this (as frequency cannot change as per Earth clocks). When it arrives on Earth, it is slightly red-shifted.

The amount of red-shift may be computed from Equation (22) putting $\nu_E = \nu_S$ (i.e. frequencies are measured as per Earth clocks). On the surface of the Sun, we have to consider only the potential of the Sun itself, as that of the Earth is negligible. On the surface of Earth, we have to consider the potentials of both the Sun and the Earth, as the Sun's is in fact significantly larger than Earth's own. Using the subscripts $S$ for Sun and $E$ for Earth, and denoting the Sun-Earth distance as $S_{S:E}$, we have:

$$\frac{c_{I:E}}{c_{I:S}} = \frac{\lambda_E \nu_E}{\lambda_S \nu_S} = \frac{\lambda_E}{\lambda_S} = \frac{1 + \frac{GM_S}{R_S {c_U}^2}}{1 + \frac{GM_S}{S_{S:E} {c_U}^2} + \frac{GM_E}{R_E {c_U}^2}}$$

Substituting known values for the variables, we see that $\left(\frac{GM_S}{S_{S:E} {c_U}^2} + \frac{GM_E}{R_E {c_U}^2}\right) \ll \frac{GM_S}{R_S {c_U}^2}$. Therefore we may approximate this as:

$$\frac{\lambda_E}{\lambda_S} = 1 + \frac{GM_S}{R_S {c_U}^2}$$

$$\therefore Red\ Shift = \frac{\lambda_{E-}\lambda_S}{\lambda_S} = \frac{GM_S}{R_S {c_U}^2} = 2 \times 10^{-6}$$

This is the same value as predicted by Einstein in his 1911 paper "On the Influence of Gravity on the Propagation of Light".

[On a historical note: In the same paper, light bending by the Sun was also predicted by Einstein, but the amount predicted was half the correct value. This is because Einstein explained both red shift and gravitational acceleration using $c$ order effects. While this is correct for red shift, gravitational acceleration is actually a $c^2$ order effect as we have seen. If the $c^2$ formulation had been used, the gravitational effect would have been computed based on $(1 + \phi/c^2)^2 \cong (1 + 2\phi/c^2)$, and the light deviation amount predicted would have been correct. This was later corrected in the formulation of GR, but by then gravity has been reformulated as a property of spacetime, and the explanation was based on spacetime curvature. It had become mathematically correct but less intuitively easy to understand].

## IX. EFFECT OF VELOCITY ON GRAVITATIONAL POTENTIAL

A velocity in the UIF creates a change in the gravitational potential experienced by a body because of the blue-shift of Universe gravitational energy caused by such a velocity.

### A. Potential increase from a velocity in UIF

When a body initially at rest in UIF begins to move in any direction at a velocity $v$, the overall Doppler Effect on the gravitational energy from other Universal matter is independent of direction, considering the symmetry of the gravitational field in all directions in the rest state. This is what gives velocity time dilation an appearance of being independent of direction of velocity.

We can consider the body to be at the center of the 'sphere of influence' of Universal matter symmetric in all directions. As mentioned earlier, the gravitational energy is received from all directions radially in equal quantities at uniform speed $c_U$.

We may depict this situation in the following diagram (Fig. 3):

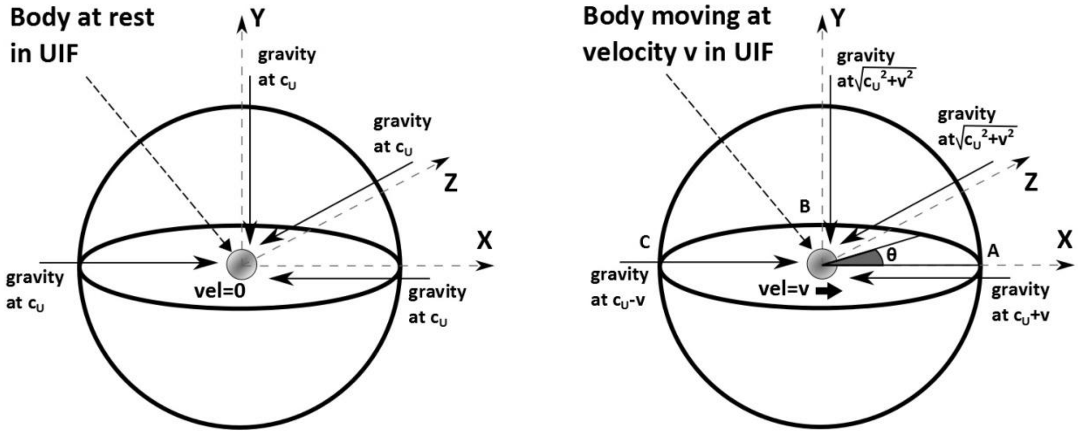


Fig **3:** A body at rest in the UIF receives gravitational energy at $c_U$ from all directions. When it travels with a velocity v in any direction (X-axis in the figure above), the gravity is blue shifted in the direction of motion and red shifted in the opposite direction, with intermediate values in other directions.

When the body moves at velocity $v$, the gravitational energy undergoes a Doppler shift in every direction. While there is a maximal blue-shift in the direction of motion, there is a maximal red-shift in the reverse direction. Intermediate values apply in other directions.

The gravitational acceleration is dependent on the square of the incident velocity and the mass (adjusted for red shift) of all Universal matter within the sphere of influence (as discussed in Section VII). We need to integrate over the entire sphere in all directions to see the overall change in gravitational potential. However, by reason of symmetry, we do not need to integrate along 3-dimensions, but can integrate along the semicircle ABC shown in the figure above, and obtain the same results.

The relative velocity of the body with respect to the uniform gravitational field in different directions will be given by $\sqrt{{c_U}^2 + v^2 + 2c_U v \cos\theta}$, where $\theta$ is the angle between direction of travel and uniformly surrounding gravity sources (i.e other matter within the sphere of influence).

The gravitational energy-potential from an infinitesimal angle $d\theta$ may be represented as:

$$\hat{\phi}_U \frac{{c_U}^2 + v^2 + 2c_U v \cos\theta}{{c_U}^2} . \frac{d\theta}{\pi} \tag{23}$$

We can obtain the total potential by integrating this value of θ from 0 to π (by reason of symmetry) as:

$$\hat{\phi}_{Total} = \int_0^{\pi} \hat{\phi}_U \frac{{c_U}^2 + v^2 + 2c_U v \cos\theta}{{c_U}^2} . \frac{d\theta}{\pi} \tag{24}$$

The integration gives us:

$$\hat{\phi}_{Total} = \frac{1}{\pi}\frac{\hat{\phi}_U}{{c_U}^2}\left[{c_U}^2\theta + v^2\theta - 2cv\sin\theta\right]_0^\pi = \frac{\hat{\phi}_U}{{c_U}^2}({c_U}^2 + v^2) = \hat{\phi}_U\left(1 + \frac{v^2}{{c_U}^2}\right) \tag{25}$$

Since $\hat{\phi}_U = {c_U}^2$, we can also write this in other useful forms:

$$\hat{\phi}_{Total} = {c_U}^2\left(1 + \frac{v^2}{{c_U}^2}\right) = {c_U}^2 + v^2 = \hat{\phi}_U + v^2 \tag{26}$$

For reference in later sections, we will use the notation $\hat{\phi}_{U,v}$ to denote this total potential in UIF when there is a velocity $v$:

$$\hat{\phi}_{U,v} = \hat{\phi}_U + v^2 = {c_U}^2 + v^2 \tag{27}$$

**This is a very important result.** It shows that the change in the base UIF gravitational energy-potential (${c_U}^2$) created by a small velocity $v$ in UIF is simply $v^2$, or equivalently a factor of $\left(1 + \frac{v^2}{{c_U}^2}\right)$. This simple relationship between an **UIF velocity** and **energy-potential** will help us establish that **velocity time dilation**:

- can be derived intuitively from purely gravitational considerations, without need for concepts like ‘length contraction’ or ‘relativity of simultaneity’.
- has the same root cause (gravitational potential difference) as gravitational time dilation.
- mathematical formulation applicability under different situations needs to be reexamined (i.e. the Lorentz factor applies only to orbital motion under transverse acceleration).
- does not restrict objects to a maximum possible velocity of $c$ in general, but only in cases where the Lorentz factor is applicable.

These will be the topics for discussion in the next few sections.

### B. Velocity time dilation

Since $\hat{\phi}{c_I}^2$ is a constant for a body, we get the time dilation factor ($\gamma$) from Equation (27) as:

$$\hat{\phi}_{U,v}{c_I}^2 = \hat{\phi}_U{c_U}^2 \tag{28}$$

$$\therefore \gamma = \frac{c_U}{c_I} = \sqrt{\frac{\hat{\phi}_{U,v}}{\hat{\phi}_U}} = \sqrt{\left(1 + \frac{v^2}{{c_U}^2}\right)} \tag{29}$$

For small velocities $v$ such that $v^2 \ll {c_U}^2$, we can approximate this as:

$$\gamma = \frac{c_U}{c_I} \cong \left(1 + \frac{v^2}{2{c_U}^2}\right) \tag{30}$$

### C. Maximum velocity of objects

This metric $\sqrt{(1 + v^2/{c_U}^2)}$ in Equation (29) for velocity time dilation is different from the currently used **Lorentz factor** $(1/\sqrt{1 - v^2/c^2})$, though both have the same low velocity approximation $(1 + v^2/2{c_U}^2)$.

For high velocities, the Lorentz factor dictates an absolute maximum possible velocity of $c$ for all motion. That is not the case with the above metric $(\sqrt{(1 + v^2/{c_U}^2)})$, which shows that while time dilation does increase with velocity, ***c* does not put an unconditional limit to the maximum possible velocity in space**.

Objects **can exceed the local value of *c* in UIF**, except for certain situations where the Lorentz factor is the appropriate metric. We will see shortly that the **Lorentz factor and a speed limit of *c* applies only to certain types of motion**, and when specific conditions are met, and **not for any velocity in UIF in general**.

Equation (29) provides the correct time dilation factor for unconstrained rectilinear motion in UIF.

## X. EFFECT OF GRAVITY ON LIGHT, AND THE INVARIANCE POSTULATE OF SR

As much as 'gravitational instantaneous action at a distance' is absurd, so is the concept of velocity of light being **completely** independent of the velocity of the source and of observers. Yet there are many experiments that appear to have validated this 'light speed invariance postulate' of Special Relativity to great accuracy.

In this section we will take a close look at how energy-potential affects the velocity of light in UIF. The equations derived will show us how speed of light changes with potential, and why the 'invariance postulate' appears to be experimentally vindicated. A much more intuitive understanding of this phenomenon will emerge.

### A. Potential of light/free energy

Light (or any energy) is not immune to the effects of change in gravitational potential, and slows down relatively when the potential increases. That, after all, is the physics behind time dilation, as is well established in existing GR theory for gravitational time dilation.

What is different for movement of light compared to movement of matter is that the UIF potential increase because of any source velocity will also result in a **light 'propagation velocity' slowdown in the direction of movement** of the source. Time dilation within matter does not affect the velocity of the overall matter, but time dilation of light does so affect, since **time dilation itself is nothing but a slowdown of energy speed (naturally in the direction of travel) in higher potential**. In other words, the potential itself determines the velocity of light, though not of matter. This is an essential difference between movement of matter and light that we must take into account, and at normal light velocities the invariance postulate will be mathematically seen to be very close to correct.

This difference in the behavior of matter and energy, in response to increased gravitational potential because of a velocity in UIF, is represented in the figure (Fig. 4) below. Recognizing this difference is the first step in understanding why the 'light speed invariance postulate' works.

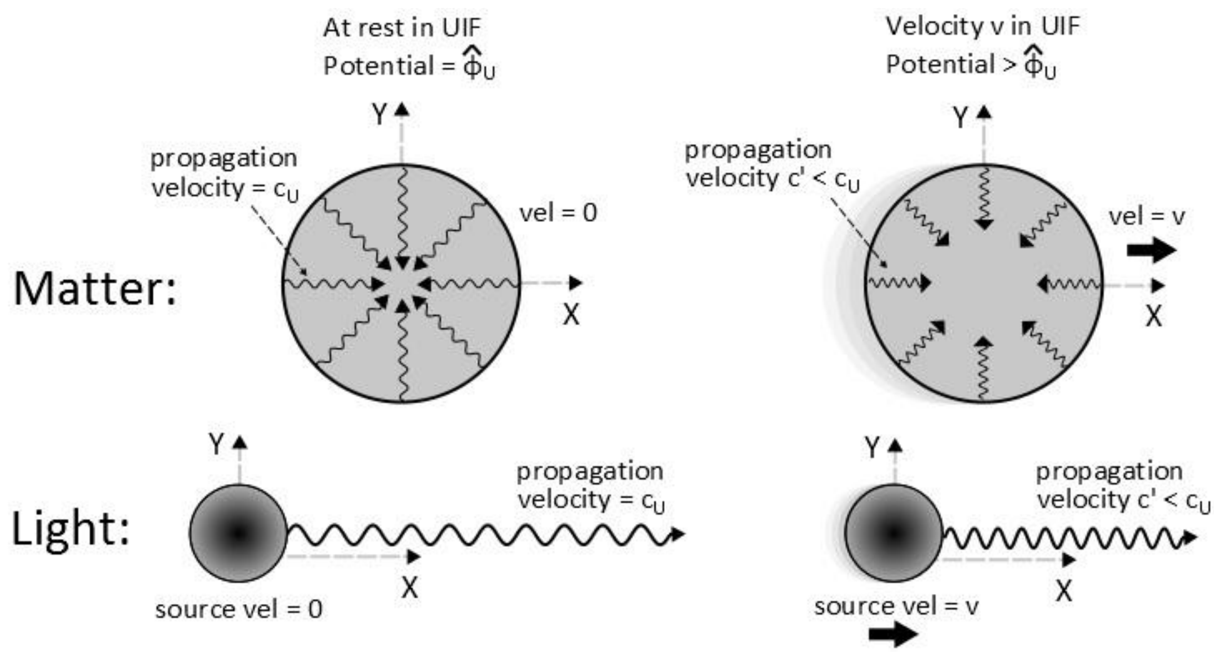


Fig **4:** Effect of changed potential on velocity of matter and light/ energy is different. When a body of matter moves at a velocity $v$ in UIF, energy propagation velocity within it is slowed down in all directions because of higher potential, but the velocity of the overall matter CG is not adversely affected by this, and remains $v$. When a source of light moves in the direction of emitted light at a velocity $v$, the slowdown of emitted light happens in the direction of motion, resulting in reduced propagation velocity $c' < c_U$ because of higher potential faced by the emitted light. If the source of light moves in the opposite direction, the propagation velocity increases because of reduced potential (compared to source at rest). The total velocity $v \pm c' \cong c_U$ when $v$ is small, which is 'why the light speed invariance postulate' is very close to correct for $v \ll c_U$.

We observe that light has a characteristic velocity in a given potential but matter does not. While velocity of light must slow down in a predictable way in higher potential, matter is not similarly affected (though energy comprising it is). This is why matter can be at rest or move slower than light at a given potential, while light must travel at the local $c$. On the other hand, if light is slowed down by a significantly higher energy density (as in a medium like water or glass), matter can travel faster than light, as seen in Cherenkov effect[26]. These will be discussed in greater detail once we develop the mathematical model in this section.

If it were possible for light (or photons) to remain stationary in the UIF, it would receive gravitational potential equally from all directions, just as matter does, at uniform $c_U$. This allows us to compute the base potential in such a situation as:

$$\phi_U = \sum_{i=1}^{i=n} \frac{GM'_i}{R_i} \tag{31}$$

using the same conventions as earlier.

Noting that light is not stationary but is constantly moving at $c_U$, we can compute the potential for such light using Equation (25) as:

$$\hat{\phi}_U = \sum_{i=1}^{i=n} \frac{GM'_i}{R_i} \times \left(1 + \frac{v^2}{{c_U}^2}\right) = \sum_{i=1}^{i=n} \frac{2GM'_i}{R_i} = 2\phi_U \;\; since\ for\ light\ v = c_U \tag{32}$$

### B. Relationship of potentials of light/energy and matter

Now that we have established this understanding of potential for light, we can extend this to matter at rest as well, since matter is essentially a spatially stable configuration of light/energy moving at $c_U$. **This is why matter at rest must have a total energy-potential $\hat{\boldsymbol{\phi}}_U = 2\boldsymbol{\phi}_U$, double the Newtonian value, as specified earlier.** This is a measure of the total potential of the all the energy contained in matter, which is what affects speed of internal energy and therefore time dilation. However, this potential does not play a direct role in the movement of the overall matter as a whole under some acceleration. It is not even in evidence unless we split up atoms and release the energy, except for its contribution to the 'mass' of the matter.

The potential of matter overall (when considered as just the mass at rest with all energy velocities canceling out) will still be only $\phi_U = \sum_{i=1}^{i=n} \frac{GM'_i}{R_i}$ in UIF, or simply $\phi = \frac{GM}{R}$ at a distance of R from a proximal massive body of mass M. This 'matter-potential' defines how the overall matter will move subject to the accelerations that set up this potential.

This gives us the basis for considering how the velocity of light emitted from a moving source will change compared to light emitted from a source at rest in UIF.

### C. Effect of source velocity on light velocity

#### *1. Light potential change because of source velocity*

When light is emitted from a stationary source, it will travel at $c_U$, and its potential is simply $\hat{\phi}_U$.

Now consider this scenario at a location where an observer is at rest in UIF, far from all massive bodies, observing a small light source moving away from the observer while emitting light in all directions, as shown in the figure (Fig. 5).

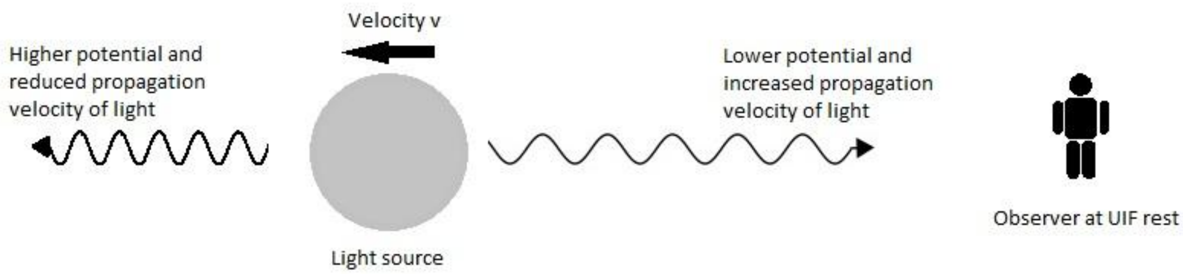


Fig **5:** As the light source moves away from the observer, light emitted towards the observer faces lower potential, and therefore its propagation velocity increases. At normal light speed in UIF (i.e. $c_U$), for a small velocity v, the negative speed of the light source is almost exactly compensated by the increase in propagation velocity, and the light speed appears unaffected to the observer at rest. This is the mechanism behind the 'invariance postulate'.

The light traveling towards the observer faces a **lower potential** than when the source was at rest. This is most important to understand. With the source at rest, the velocity of the emitted light towards the UIF rest position of the observer was already $c_U$. When the source is moving away, this light velocity **would tend to decrease** in UIF, thus **resulting in a lower potential** experienced by it. In effect, we are considering a $v$ reduced from $c_U$ in Equation (25).

The total velocity of light would always be given by:

$$\begin{aligned} &Total\ velocity\ of\ light \\ &\qquad = Velocity\ of\ Source \\ &\qquad + Velocity\ of\ Propagation\ of\ Light\ in\ a\ given\ potential \end{aligned} \tag{33}$$

The Velocity of Source in the above scenario is negative. Therefore the Velocity of Propagation of Light must **increase** because of the lower potential it now faces.

For the invariance postulate to hold, this means that the Velocity of Source must be almost exactly compensated by the increase of the Propagation Velocity, for the stationary observer to see the same Total Velocity in both cases of stationary and moving source. This is indeed the case when light is traveling at $c_U$ in UIF (which is the usual situation, when emitted from a stationary source), as our derivation below will show.

However, with increasingly larger negative Velocity of Source, the Total Velocity will ultimately start decreasing.

Thus, we will be able to determine a situation where the Velocity of Source does become exactly equal to the Velocity of Propagation of Light in the opposite direction, such that the Total Velocity of such light would be zero in UIF. This will happen at a negative Velocity of Source > $c_U$, since Velocity of Propagation will continue to increase from $c_U$ as lower and lower potentials are encountered. However, at Total Velocity zero in UIF, we have a situation for light which is analogous to matter being at rest in UIF. This is the 'base potential' of light in UIF (analogous to matter), from which we need to derive all relationships.

### *2. Determining the base potential of light*

One thing should be clarified here. Although photons may be momentarily at rest as seen in UIF rest frame, this does not constitute a rest frame for photons or light. In fact, light is propagating at a velocity faster than $c_U$ from the source, and is not in any way stationary in regard to the gravity coming from all directions (which is traveling at $c_U$ with regard to the light, or vice versa).

If the negative velocity of source were to increase further beyond this point, then the emitted light would in fact reverse direction, and start increasing with regard to local UIF rest frame, and the situation then would become analogous to matter, where potential would increase in either direction if there is a velocity change.

Let us call the potential faced by light in this UIF rest position as 'base potential', denoted by $\hat{\phi}_{base}$. The corresponding light propagation velocity will be denoted as $c_{base}$. The Velocity of Propagation of light in general will be denoted as $c_I$, as we denote the velocity of energy within matter, as they are essentially the same thing.

### *3. Light potential, source velocity and light velocity relationship*

We start our analysis from this **base potential situation** to derive the mathematical formula applicable. Let the velocity of the retreating source be reduced by a small velocity $V$. The emitted light thus gains a small velocity $V$ towards our observer, as a first approximation.

Using the equation derived for velocity time dilation (Equation (25)), we can compute the increased energy-potential as a first approximation as:

$$\hat{\phi}_V = \hat{\phi}_{base}\frac{({c_U}^2 + V^2)}{{c_U}^2} = \hat{\phi}_{base}\left(1 + \frac{V^2}{{c_U}^2}\right) \tag{34}$$

Note here that the $c_U$ here represents the velocity of external gravity, which remains $c_U$, no matter how the propagation velocity $c_I$ of light changes based on its source velocity and corresponding potential. The $c_I$ at the base situation had the value $c_{base}$, which must now decrease because of the higher potential encountered.

We now need to account for the **reduction of the 'propagation velocity' of light** from $c_{base}$, because of the slightly increased potential. To do that, we break this increase into 'n' very small steps such that the first approximation above may be considered valid, and account for the corresponding potential increase at each small step, using the 'compound interest' formula.

We may then rewrite the equation as:

$$\hat{\phi}_V = \hat{\phi}_{base}\left(1 + \frac{(V^2/{c_U}^2)}{n}\right)^n \tag{35}$$

Since this is a continuous increase, we make the number of steps n arbitrarily large, and in the limit get:

$$\hat{\phi}_V = \hat{\phi}_{base} \lim_{n\to\infty}\left(1 + \frac{(V^2/c_U{}^2)}{n}\right)^n = \hat{\phi}_{base} e^{\frac{V^2}{c_U{}^2}} \tag{36}$$

This is the base equation we need for understanding of potential of light and its effect on light velocity, as well as the 'invariance postulate'.

Potential of light increases as an exponential function of velocity, rather than linearly as is the case for matter. This is because the velocity of light in the direction of motion is itself affected by the change of potential. Using $\hat{\phi} c_I{}^2$ constancy, we are able to see that the total velocity of light will decrease as an inverse exponential function with source velocity. In the next sections on the de Sitter[27,28], Fizeau[29,30] and similar experiments[31], we will do this computation and see why the invariance postulate appears to be true in vacuum, whereas light dragging by a moving medium depends on the refractive index.

For now, it is important to note that velocity of light does not add on to velocity of the source simply as a scalar addition, as we would have expected from classical mechanics or emission theory. The inverse exponential function dictates that the total velocity of light in UIF will increase less and less with faster source velocity. At the speed of light in UIF, $c_U$, it turns out that the increase of total velocity is negligible (i.e. the decrease in propagation velocity exactly compensates for the increase in source velocity), as we will see in the de Sitter experiment discussion below. This is not a coincidence, but a necessary consequence of the velocity of light in the Universal gravitation potential, as the two are directly related.

When $V$ is $c_U$, the source of light is at rest in UIF. We then have the usual situation of light/energy traveling at $c_U$ in UIF frame, when emitted from a body at rest. Therefore we can derive from the above equation:

$$\hat{\phi}_U = \hat{\phi}_{base} e^{\frac{c_U{}^2}{c_U{}^2}} = e \times \hat{\phi}_{base} \tag{37}$$

From $\hat{\phi} c_I{}^2$ constant, we also get:

$$c_U{}^2 = \frac{\hat{\phi}_{base}}{\hat{\phi}_U} c_{base}{}^2 = \frac{c_{base}{}^2}{e} \tag{38}$$

These give us the relationship between energy-potential and propagation velocity at the 'base' and 'source at rest' situations in terms of a clock running at $c_U$.

### D. Explanations of relativity experiments

The understanding developed in the above section is of extraordinary importance. It provides an intuitive explanation of the invariance postulate without having to ascribe a magical property to light, viz. complete independence of light velocity from source and observer velocity. It also comprehensively and intuitively explains results of many important relativity experiments without the invariance postulate assumption. In this section we look at some of these experiments like **de Sitter** double star experiment, **Michelson-Morley**[32,33,34,35], **Alvager**[36] and **Fizeau** experiments in the light of the above discussions.

The de Sitter experiment, and subsequent repetitions by Kenneth Brecher[37], showed that we do not see apparitions/multiple-images of binary stars, as we would if the velocity of light were dependent on the velocity of the source stars. The conclusion reached is that the velocity of light must be independent of the source velocity.

The question is: **completely** independent, at all velocities of source? The Alvager experiment has been seen to answer this with an emphatic 'Yes'.

We need to look at each of these experiments in some detail in order to understand whether such conclusions are really cast in iron, or if more intuitive yet simple explanations exist that explain the observations just as well or better.

### 1. *The de Sitter double star experiment*

Let us consider the de Sitter experiment first. Two distant binary stars are revolving around their common CG at a velocity $v$ (assuming they are of reasonably similar mass). If the velocity of the source stars were added classically to the velocity of their emitted lights (constant $c$), the light emitted by one star when moving towards Earth, and light emitted by the same star when moving away from Earth, would ultimately overlap at some point in the journey to Earth. We would then see blurred or multiple images of the stars (de Sitter apparitions) instead of sharply differentiable stars. The experiments have instead established that the stars are seen as sharply differentiable objects, as would be seen if they were not moving relatively at all.

This observation is seen as a confirmation of the invariance postulate (zero effect of source velocity on emitted light velocity) against the ballistic/emission theory (velocity of the source gets added to $c$). To summarize the two points of view, the equation used is:

$$c^{'} = c + kv;\ where\ k = 0\ (for\ invariance)\ or\ 1\ (for\ ballistic/emission) \tag{39}$$

where $c^{'}$ = observed total velocity of light
$c$ = original velocity of light
$v$ = velocity of emitting source

Can we take the de Sitter experiment results as incontrovertible proof for the invariance postulate and against the ballistic/emission theory? Not necessarily. In fact, the actual explanation is in between the two, though the invariance postulate turns out to be much closer to the truth. For source velocity $v \ll c$, the invariance postulate is almost exactly true, but that changes somewhat with higher source velocities. Let us see why this must be so, based on the Equation (36) derived in the previous section.

*a. Velocity of light from the star moving towards Earth*

Light emitted by a stationary star would simply face a potential of [Equation (37)]:

$$\hat{\phi}_U = \hat{\phi}_{base} e^{\frac{c_U{}^2}{c_U{}^2}} \tag{40}$$

For light emitted from a star that is moving towards Earth at a velocity $v$, the total velocity of light would be $v_+ = c_U + v$, as a first approximation. However, the potential faced by such light, denoted $\hat{\phi}_{v+}$, will also have increased, and that will tend to reduce the propagation velocity of the light. Using Equation (36), we obtain this increased potential as:

$$\hat{\phi}_{v+} = \hat{\phi}_{base} e^{\frac{{v_+}^2}{{c_U}^2}} = \hat{\phi}_{base} e^{\frac{(c_U+v)^2}{{c_U}^2}} \tag{41}$$

From the above Equations (40) and (41), keeping $\hat{\phi}{c_I}^2$ constant, we can write:

$$\hat{\phi}_{base} e^{\frac{(c_U+v)^2}{{c_U}^2}} \times {c_{I+}}^2 = \hat{\phi}_{base} e^{\frac{{c_U}^2}{{c_U}^2}} \times {c_U}^2 \tag{42}$$

where $c_{I+}$ is the reduced propagation velocity of light from the star because of the higher potential.

Solving for $c_{I+}$ we have:

$${c_{I+}}^2 = e^{-\left(\frac{2vc_U+v^2}{{c_U}^2}\right)} \times {c_U}^2 \tag{43}$$

$$\therefore c_{I+} = e^{-\left(\frac{v}{c_U}+\frac{v^2}{2{c_U}^2}\right)} \times c_U \tag{44}$$

Expanding the exponential as a Taylor expansion as $e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} \dots$, the equation becomes:

$$c_{I+} = c_U \times e^{-\left(\frac{v}{c_U}+\frac{v^2}{2{c_U}^2}\right)} = c_U \left(1 - \left(\frac{v}{c_U} + \frac{v^2}{2{c_U}^2}\right) + \frac{\left(\frac{v}{c_U} + \frac{v^2}{2{c_U}^2}\right)^2}{2!} - \frac{\left(\frac{v}{c_U} + \frac{v^2}{2{c_U}^2}\right)^3}{3!} + \cdots\right) \tag{45}$$

Ignoring the small orders above $v^3/c^3$ (since $v \ll c_U$), we can approximate this as:

$$\therefore c_{I+} \cong c_U \left(1 - \frac{v}{c_U} - \frac{v^2}{2{c_U}^2} + \frac{v^2}{2{c_U}^2} + \frac{v^3}{2{c_U}^3} - \frac{v^3}{6{c_U}^3}\right) = c_U \left(1 + \frac{v^3}{3{c_U}^3}\right) - v \tag{46}$$

$$\therefore c_{Total+} = c_{I+} + v = c_U \left(1 + \frac{v^3}{3{c_U}^3}\right) \cong c_U \quad for\ v \ll c_U \tag{47}$$

In other words, the total light velocity increase from the star moving at velocity $v$, compared to if it were at rest, is negligible. The change is of the order of $v^3/{c_U}^3$, as opposed to the effects de Sitter was measuring for (order of $v/c$). This is why the invariance postulate (i.e. $k \cong 0$ in $c' = c + kv$) appears to be vindicated, and we do not see any 'de Sitter apparitions' or blurred images from distant binary stars.

The ballistic/emission theory is never close to correct, but at larger source velocities the total light velocity will be somewhere between the prediction of invariance postulate and emission theory (i.e. $0 < k < 1$ in $c' = c + kv$).

*b. Velocity of light from the star moving away from Earth*

For the other star in the binary, the one moving away from Earth, the equation will likewise be:

$$\phi_{base} e^{\frac{(c_U - v)^2}{c_U{}^2}} \times c_{I-}{}^2 = \phi_{base} e^{\frac{c_U{}^2}{c_U{}^2}} \times c_U{}^2 \tag{48}$$

where $c_{I-}$ is the increased propagation velocity of light from the star because of the lower potential its emitted light faces.

Solving for $c_{I-}$ in a similar manner as above, we derive:

$$c_{Total-} = c_{I-} - v = c_U \left(1 - \frac{v^3}{3c_U{}^3}\right) \cong c_U \quad for\ v \ll c_U \tag{49}$$

This again shows that the total velocity of light towards Earth, from the star moving away, is also practically the same as $c_U$, and we do not see any overtaking of one star's light by the other on the way to Earth.

Comparing to the equation $c' = c + kv$, we find that $k \sim v^2/3c_U{}^2$. Since orbital velocity $v$ for binaries is typically of the order of 10-100 km/s, $k$ is expected to be of the order of $10^{-7}$ to $10^{-10}$. This is consistent with the limits established by the Brecher experiment ($k < 2 \times 10^{-9}$), and well beyond the accuracy of the de Sitter experiment ($k < 0.002$). [Note: Extinction of visible light for the de Sitter experiment, and even partial extinction of X-rays for the Brecher experiment are not accounted for in the k-values reported for the experiments. If they were, the k-values would be even less stringent.]

In the above analysis we have ignored the slight reduction of the internal energy velocity of the stars themselves because of their own velocity. That would lead to a small correction of the initial velocity of the light emitted by the stars (somewhat similar to the Ives Stillwell experiment[38,39]). However, that change is negligible at small $v$, and is equally present during all observations. It does not affect our analysis of the de Sitter experiment.

### 2. Fizeau Experiment:

The experiment of Fizeau which established the formula for light dragging by moving water may also be explained by the effect of gravitational potential on light velocity.

In the experiment, when light was transmitted through water moving at $v$, the light was dragged to an extent as given by the below equation:

$$w_{+} = \frac{c}{n} + v\left(1 - \frac{1}{n^2}\right) \tag{50}$$

where

$w_{+}$ = velocity of light in water as observed from lab frame
$c$ = velocity of light in vacuum/air (essentially $c_U$)
$v$ = velocity of water in the same direction as light
$n$ = refractive index of water

In this case, the comparison is between the potential/energy density of stationary water and moving water. The light/energy that travels through water goes through a significantly higher potential/energy density than in vacuum. We may consider such light/energy traveling within the stationary water to be in the equivalent of a significantly increased UIF gravitational potential.

The refractive index of water, n, represents the change of light velocity with the increased potential in water:

$$n = \frac{c_U}{c_w} \tag{51}$$

where $c_w$ is the velocity of light in stationary water.

Since the potential within water is higher than $\hat{\phi}_U$, we have to compute the base potential in water (denoted $\hat{\phi}_{base:w}$). We can use the same considerations as in Equation (36) to derive the relationship between the base potential and the potential at a light velocity of $V$:

$$\hat{\phi}_{V:w} = \hat{\phi}_{base:w} \lim_{n\to\infty}\left(1 + \frac{(V^2/c_U{}^2)}{n}\right)^n = \hat{\phi}_{base:w} e^{\frac{V^2}{c_U{}^2}} \tag{52}$$

When the water is stationary, we denote the potential as $\hat{\phi}_w$ (stationary in UIF, but in higher potential within water). The light velocity $V$ in this situation is $c_w$. We can then write the relationship between base potential and UIF rest potential as:

$$\hat{\phi}_w = \hat{\phi}_{base:w} e^{\frac{c_w{}^2}{c_U{}^2}} \tag{53}$$

When the water is moving with a velocity$v$, the potential faced by light traveling through water in the direction of water motion will increase further, resulting in a further reduced velocity of light $c_{w'}$. Using $\hat{\phi} c_I{}^2$ constancy, we can derive the following relationship between the velocities of light in stationary and moving water:

$$\hat{\phi}_{base:w} e^{\frac{c_w{}^2}{c_U{}^2}} \times c_w{}^2 = \hat{\phi}_{base:w} e^{\frac{(c_w+v)^2}{c_U{}^2}} \times c_{w'}{}^2 \tag{54}$$

$$\therefore {c_{w'}}^2 e^{\frac{(c_W+v)^2}{c_U{}^2}} = {c_w}^2 e^{\frac{c_W{}^2}{c_U{}^2}} \tag{55}$$

Solving for $c_{w'}$, we get:

$$c_{w'} = c_w \sqrt{\frac{e^{\frac{c_W{}^2}{c_U{}^2}}}{e^{\frac{(c_W+v)^2}{c_U{}^2}}}} = c_w \sqrt{e^{\frac{-2c_W v - v^2}{c_U{}^2}}} = c_w e^{-\left(\frac{c_W v + v^2/2}{c_U{}^2}\right)} \tag{56}$$

Since $(c_w v + v^2/2)/{c_U}^2 \ll 1$, we can take the approximation $e^x = 1 + x$, and get:

$$w_+ = c_{w'} + v = c_w e^{-\left(\frac{c_W v + v^2/2}{c_U{}^2}\right)} + v \cong c_w \left(1 - \frac{v c_w}{{c_U}^2} - \frac{v^2}{2{c_U}^2}\right) + v \tag{57}$$

Substituting $c_w = c_U/n$, and ignoring the small $v^2/2{c_U}^2$ term, the total light velocity in moving water in the lab frame is given by:

$$w_+ = \frac{c_U}{n}\left(1 - \frac{v}{c_U n}\right) + v = \frac{c_U}{n} + v\left(1 - \frac{1}{n^2}\right) \tag{58}$$

This is the relationship observed in the Fizeau experiment. We derived in this section a very intuitive explanation of this formula, based on relationship between light velocity and energy-potential in a medium (water).

We can look at refraction as a Shapiro delay caused by the higher energy-potential within water (or any transparent medium denser than vacuum). This delay becomes greater (i.e. light moves even slower) in moving water because of further increased energy-potential.

Of course, this applies only to the wavelengths where a medium is ‘transparent’ and does not deflect or stop light itself (where other phenomena come into play).

### *3. Cherenkov effect:*

As we have seen above, the velocity of light is slowed in the direction of motion because of the increased potential, resulting in refraction in a transparent medium. Matter is not affected in the same way.

When matter travels in a higher potential, the energy within it is slowed down by the higher potential, but that does not adversely affect the velocity of its CG, which is the velocity of matter.

This allows subatomic matter to maintain its high velocity within a medium, while light must slow down to its characteristic velocity in the medium depending on refractive index (indicating higher potential).

Of course, the physical interaction of the subatomic particles with the medium would cause the subatomic particle to lose energy and slow down or stop over time. This dissipation of energy is seen a Cherenkov radiation. However, for a period of time, the subatomic particle (matter) can move faster than light. This would be true in vacuum as well. Moreover, there would be little slowdown of matter in vacuum of space, as it would not have much interactions with other matter as in a material medium.

### *4. Michelson-Morley experiment:*

For Michelson-Morley (and similar experiments like Kennedy-Thorndike[40,41]), which were testing for an order of $v/c$ change in light velocity (i.e. k ~ 1 in $c^{'} = c + kv$), it is clear from the explanation of the de Sitter experiment that such experiments would provide null results. A difference of the order of $k \sim v^2/c^2$ would have been nearly undetectable given the small Earth rotation velocity.

### *5. Alvager et. al. experiment:*

One experiment that is often taken as strong proof of the invariance postulate is the Alvager et. al. experiment, since it appears to prove that $c$ does not change even when emitted from a high-velocity source. This requires a closer examination in the light of the above discussion.

In the Alvager experiment, $\gamma$-rays produced by near-light-speed ($0.99975c$) protons striking a Beryllium target (with an intermediate stage of neutral $\pi$-mesons, or pions) do not show a velocity measurably higher than $c$ in a 'time of flight' measurement. The inference drawn is that the high velocity of the source does not affect the speed of light (the $\gamma$-rays), which still travels at the speed of light in the lab frame.

In terms of $c^{'} = c + kv$, the conclusion reached is that $k = (-3 \pm 13) \times 10^{-5}$.

However, the following points need to be noted:

- Given that the time dilation factor (Lorentz factor $\gamma$) has a value of nearly 45 at $0.99975c$, any energy within the protons are moving at $c_I = c_U/\gamma = 6.7 \times 10^6\ m/s$ only. Added to the proton velocity of $0.99975c$, the maximum possible velocity of the $\gamma$-rays would have been $3.064 \times 10^8\ m/s$ $(1.02c_U)$. This gives a corresponding k-value of $k = 2.2 \times 10^{-2}$, i.e. much less than 1. The $\gamma$-ray velocity would not have been that noticeably higher than $c_U$ anyway.
- The protons striking the beryllium target interact with much larger beryllium nuclei (themselves part of a much larger metal lattice) in a collision process to produce pions. The process of emitting the pions is preceded by the collision, so that the velocity of the protons at the instant of pion production is certainly reduced, even if slightly. Therefore we have no certainty that the source (proton) is moving at all in the original direction at $0.99975c$ at the point of pion production, such that a source velocity of $0.99975c$ may be reliably assumed.
- A presumption is made that high energy $\gamma$-rays traveling in the direction of proton path have that energy because of the incident protons' kinetic energy in that direction. Even if the invariance postulate keeps the velocity of the $\gamma$-rays same as light, the energy of the protons nonetheless must be reflected in increased energy of the $\gamma$-rays. This is necessary for the velocity of the protons to have had any bearing on the experiment at all. This is understandable. What has not been tested though is whether equally energetic $\gamma$-rays are being scattered in other directions (say

perpendicular to the movement of the protons). If found they would invalidate the entire experiment's basis, as the velocity/energy of the protons should have no bearing on $\gamma$-ray energy in a perpendicular direction. That energetic $\gamma$-rays are being scattered in directions other than directly in line with proton movement is a certainty, since Alvager et. al. themselves measure the velocity of these $\gamma$-rays at an angle of 6° to the proton direction. (It is also not clear whether this last fact is accounted for in the stated accuracy/error, but that is a minor point).

Without these, the experiment is at best inconclusive. The experiment would have to be repeated with energies and velocities of $\gamma$-rays in different directions (presumably with at least a semi-cylindrical Beryllium target) for any conclusion at all to be drawn.

## XI. TIME DILATION IN ORBITAL MOTIONS AND THE LORENTZ FACTOR

### A. Deriving the Lorentz Factor from orbital motion

It is important to characterize the current metric of velocity time dilation, Lorentz factor ($1/\sqrt{1-v^2/c^2}$). We need to understand its physical meaning and implications in a gravitational Universe, to see in what situations it is the valid metric. In this section we derive the Lorentz factor based on physical considerations to achieve this.

#### *1. Acceleration and energy-potential in orbit under transverse acceleration*

Consider a small body $m$ (of rest mass $m_0$) orbiting another massive body ($M$) at a distance $R$ with a velocity $v$. If the gravity of $M$ and velocity of $m$ had no impact on the unit mass of $m$, the Newtonian metric for gravitational acceleration $GM/R^2$ would be exact. Since mass of $m$ would remain the same as rest mass $m_0$, the acceleration would be $\left(\frac{GMm_0}{R^2}\right)/m_0 = \frac{GM}{R^2}$ . Thus, $Acc(A) = \frac{GM}{R^2} = \frac{v^2}{R}$ would be satisfied in circular orbit.

However, from GR theory we know that this equation is not exact. The anomalous perihelion precession of Mercury shows that the gravitational acceleration is slightly greater than computed classically from $GM/R^2$. Investigating the differences allows us to derive both the Schwarzschild metric and the Lorentz factor, and understand the conditions under which one or the other applies.

As a first step, we note that because of the orbital velocity of the small mass $m$, the gravitational acceleration will be multiplied by a factor of $(1+v^2/{c_U}^2)$, since the relative velocity of $m$ with respect to the gravity of $M$ is $\sqrt{{c_U}^2+v^2}$.

Therefore, the Newtonian gravitational equation needs to be modified as:

$$Base\ acceleration(A_M) = \frac{GM}{R^2}\left(1+\frac{v^2}{{c_U}^2}\right) = \frac{v^2}{R} \tag{59}$$

This means that for increasing $v$'s, slightly lesser gravitational acceleration will be required to maintain the orbit, since the relative velocity increase with respect to the source gravity will enhance the gravitational acceleration. For example, for light at $v = c$, we find that the total acceleration doubles. If $c$ had been the orbital velocity under consideration, this would have caused extra inward deviation from the orbit trajectory. Therefore, for $c$, the base acceleration $GM/R^2$ required for orbit would have to be half the centripetal acceleration $v^2/R$ (as can be computed from the above equation).

This base equation will hold for all velocities. The relativistic modifications discussed below will apply equally to both sides of this equation.

Note that this is an increase in magnitude only, and does not mean that this acceleration is towards the retarded position of the massive body $M$ because of the gravity propagation delay. In the local UIF frame, it is $m$ that is moving and $M$ that is at (nearly) rest. Thus $M$'s gravitational field may be considered a static field. The orbital acceleration is therefore always central (i.e. toward the instantaneous center of $M$), because there are no components of $M$'s gravitational acceleration in the direction of $m$'s velocity.

Now, in the above discussion, the rest mass accounts only for the UIF energy-potential $\hat{\phi}_U = {c_U}^2$, and does not consider the additional energy-potential of the local massive body $M$.

This base energy-potential is $\hat{\phi}_M = 2GM/R$. However, because of the orbital velocity $v$, the acceleration $A_M$ is slightly higher as shown in Equation (59). Therefore, we may write the actual energy-potential (denoted $\hat{\phi}_{M,v}$) as:

$$\hat{\phi}_{M,v} = \hat{\phi}_M \left(1 + \frac{v^2}{{c_U}^2}\right) = \frac{2GM}{R}\left(1 + \frac{v^2}{{c_U}^2}\right) \tag{60}$$

When we do take $\hat{\phi}_{M,v}$ into account in the unit mass of the small body $m$, the mass will have increased by $\hat{\phi}_{M,v}$. The **transverse momentum of $m$ will also have increased** accordingly. To counteract this, **an equal increase in the central acceleration is required** to maintain orbit equilibrium. The acceleration increase required would be:

$$\Delta A_M = A_M.\frac{\hat{\phi}_{M,v}}{\hat{\phi}_U} = A_M.\frac{\hat{\phi}_M}{{c_U}^2}\left(1 + \frac{v^2}{{c_U}^2}\right) \tag{61}$$

Now, this increase in the acceleration of $M$ would, in turn, create an increase in energy-potential by the same factor. That is equivalent to a further increase in mass and therefore transverse momentum of $m$. The relationship between the acceleration and transverse momentum becomes recursive, with increased transverse momentum at each step having to be matched by a corresponding central acceleration increase. This would ultimately lead to the additional acceleration becoming:

$$\Delta A_M = A_M.\frac{\hat{\phi}_M}{{c_U}^2}\left(1 + \frac{v^2}{{c_U}^2}\left(1 + \frac{v^2}{{c_U}^2}(1 + \cdots)\right)\right) = A_M.\frac{\hat{\phi}_M}{{c_U}^2}\left(\frac{1}{1 - v^2/{c_U}^2}\right)\ for\ v^2 < {c_U}^2 \tag{62}$$

Thus the total energy-potential of $m$ from $M$'s gravity (enhanced by $m$'s velocity) will be:

$$\hat{\phi}_{M,v} = \hat{\phi}_M \left(\frac{1}{1 - v^2/{c_U}^2}\right) \tag{63}$$

To get the total energy-potential of $m$, we add the modified UIF energy-potential $\hat{\phi}_{U,v}$ (Equation (27)) to the energy-potential from $M$:

$$\begin{aligned} \hat{\phi}_{Total} = \hat{\phi}_{U,v} + \hat{\phi}_{M,v} = \hat{\phi}_U + v^2 + \hat{\phi}_M \left(\frac{1}{1 - v^2/{c_U}^2}\right) \\ = \hat{\phi}_U \left(1 + \frac{v^2}{{c_U}^2} + \frac{2GM}{R{c_U}^2}\left(\frac{1}{1 - v^2/{c_U}^2}\right)\right) \end{aligned} \tag{64}$$

Since $M$'s acceleration also needs to take care of the slight additional transverse momentum from the UIF energy-potential, it will also have to increase by the same factor:

$$A_{M,v} = A_M \left(1 + \frac{v^2}{{c_U}^2}\right) \tag{65}$$

The total acceleration ($A$), taking into account all components would then have to be:

$$Acc(A) = A_{M,v} + \Delta A_M = A_M \left(1 + \frac{v^2}{{c_U}^2} + \frac{\hat{\phi}_M}{{c_U}^2}\left(\frac{1}{1 - v^2/{c_U}^2}\right)\right) \tag{66}$$

In terms of $M$'s gravitational potential and $m$'s orbital velocity, this may be stated as:

$$A = \frac{v^2}{R}\left(1 + \frac{v^2}{{c_U}^2} + \frac{2GM}{R{c_U}^2}\left(\frac{1}{1 - v^2/{c_U}^2}\right)\right) \tag{67}$$

We have now got the **complete equations for energy-potential** (Equation (64)) **and acceleration** (Equations (66), (67)) for a small body in a **circular orbit under a transverse central acceleration**. Note that this description applies to both natural gravitational situations like GPS Satellites around Earth, and artificial gravitational equivalent situations like muons in the muon ring in the **Bailey et. al. experiment**.

### *2. Time dilation in orbital motion, and the Lorentz factor*

For determining the time dilation factor $\gamma$, we can use $\hat{\phi}{c_I}^2$ constancy and Equation (64) to write:

$$\hat{\phi}_U {c_U}^2 = \hat{\phi}_{Total}{c_I}^2 = \hat{\phi}_U \left(1 + \frac{v^2}{{c_U}^2} + \frac{2GM}{R{c_U}^2}\left(\frac{1}{1 - v^2/{c_U}^2}\right)\right){c_I}^2 \tag{68}$$

At low velocities ($v \ll c_U$), $\hat{\phi}_M$ is little changed by $1/(1 - v^2/{c_U}^2)$, and we can approximate this as:

$$
{c_U}^2 = \left(1 + \frac{v^2}{{c_U}^2} + \frac{2GM}{R{c_U}^2}\right){c_I}^2 \tag{69}
$$

$$
\therefore \gamma = \frac{c_U}{c_I} = \sqrt{\left(1 + \frac{v^2}{{c_U}^2} + \frac{2GM}{R{c_U}^2}\right)} \cong 1 + \frac{v^2}{2{c_U}^2} + \frac{GM}{R{c_U}^2} \tag{70}
$$

This is the equation that is relevant for GPS time dilation and Hafele-Keating experiment calculations. Note that this approximation is exactly the same as that of the Schwarzschild metric $\gamma = 1/\sqrt{(1 - v^2/{c_U}^2 - 2GM/R{c_U}^2)}$ that is used from GR. This will be discussed in Section XII.

In situations where $v$ is close to $c_U$, as in the Bailey et. al. experiment, $\hat{\phi}_M$becomes nearly $\hat{\phi}_U$ (by Equation (59) we have $GM/R = v^2/(1 + v^2/{c_U}^2)$, and since $v \approx c_U$, we get $\hat{\phi}_M = \frac{2GM}{R} \approx {c_U}^2 = \hat{\phi}_U$). Therefore, $\hat{\phi}_{M,v}$ becomes much larger than $\hat{\phi}_{U,v}$ in Equation (64) as the $1/(1 - v^2/{c_U}^2)$ term becomes very large. In this high orbital velocity case, we can then consider the total potential of $m$ to be $\hat{\phi}_{M,v}$ itself in Equation (64).

From $\hat{\phi}{c_I}^2$ constancy and Equation (64), we get:

$$
\hat{\phi}_U {c_U}^2 \cong \hat{\phi}_{M,v}{c_I}^2 = \frac{\hat{\phi}_M}{(1 - v^2/{c_U}^2)}{c_I}^2 \cong \frac{\hat{\phi}_U}{(1 - v^2/{c_U}^2)}{c_I}^2 \tag{71}
$$

This gives us:

$$
\gamma = \frac{c_U}{c_I} = \frac{1}{\sqrt{1 - v^2/{c_U}^2}} \tag{72}
$$

This is the **Lorentz factor**, which is used to explain the time dilation of muons in the Bailey et. al. experiment.

### B. The meaning and applicability of the Lorentz Factor

The derivation in the above section section clearly shows us that the Lorentz factor is the appropriate metric for **time dilation** in **very high velocity** ($v \approx c_U$) orbital motion only.

For **low velocities**, Equation (70) is the appropriate formulation for computing **time dilation (both velocity and gravitational)**. Note that it is essentially the Schwarzschild metric approximation that is used to explain GPS satellite and Hafele-Keating time dilations.

The low velocity ($v \ll c_U$) approximation of the Lorentz factor is:

$$\therefore \gamma = \frac{c_U}{c_I} \cong \left(1 + \frac{v^2}{2{c_U}^2}\right) \tag{73}$$

Coincidentally, this is the same as the low velocity approximation of the correct metric for UIF velocity time dilation (Equation (30)). Since time dilation computations have always been done at very low velocity (e.g. GPS satellites and Hafele-Keating) or very high velocity (e.g. Bailey et. al.) situations, the Lorentz factor appears to have worked for all cases and is considered to be largely proven as the velocity time dilation factor for all velocities. Experiments on the lines of Bailey et. al. conducted at muon velocities of $0.5 - 0.8c$ will show this is not the case (there will be a $15\% - 19\%$ difference from the Lorentz factor), as time dilation contributions from neither UIF potential nor local potential can be ignored. Equation (68) would have to be used in such cases.

The important difference we need to recognize here is that the Lorentz factor is a multiplier of the local energy-potential $\hat{\phi}_M$, which for bodies like Earth or any star is very small compared to the UIF potential ($\hat{\phi}_U$). Thus, **at low orbital velocities** the Lorentz factor contributes little, and the velocity time dilation we see comes from a **body's velocity in the Universe gravitational potential**. At very **high orbital velocities**, the **increased local potential overshadows the UIF potential** and the **Lorentz factor** then provides the correct **time dilation ratio**.

This is why we see separate gravitational and velocity time dilation terms (from $\hat{\phi}_{U,v}$) in the cases like GPS satellites and Hafele-Keating, but only velocity time dilation (from $\hat{\phi}_{M,v}$) appears to be present in Bailey et. al. experiment. This will be explained in more detail in the next section.

For **unconstrained rectilinear motion** in the UIF, the **Lorentz factor does not appear** at all, as it is an artifact of transverse acceleration in orbital motion.

It is important to understand what the Lorentz factor physically implies, and does not imply, about velocity of light/energy. When $v$ approaches $c_U$ in orbital motion, both potential and acceleration increase boundlessly (Equations (64) - (67)). **If $\boldsymbol{v \geq c}$, a closed orbit is not possible** under a **transverse/central acceleration**. Conversely, a stable circular orbit must always have $\boldsymbol{v < c}$, no matter how large the potential.

The Lorentz factor **does not imply that a velocity of $\boldsymbol{v \geq c}$ is impossible** under non-orbital conditions.

### C. Explanation of the Bailey et. al. muon lifetime experiment

The Lorentz factor applies to potentials created by local accelerations themselves, irrespective of the UIF potential. The effects are significant only when the local potential is very large. Such potentials may be created artificially as in the case of the Bailey et. al. experiment, or naturally because of massive gravity close to very compact bodies like black holes.

In the Bailey experiment, muons at a velocity of $0.9994c$ were stored in a Muon Storage Ring at CERN for measuring their lifetimes. A black hole like transverse acceleration of nearly $10^{18}g$ (produced using strong electromagnets along the muon storage ring), kept the muons going in a circular orbit. The lifetime of the muons was found to be extended by a factor of $29.327$, very close to the value computed using the SR velocity time dilation metric (Lorentz factor) $1/\sqrt{1-v^2/c^2}$, compared to the average rest lifetime of about $2.2\ seconds$ found in unrelated and independent previous experiments.

The Bailey experiment set-up is exactly equivalent to orbital motion of planets around stars and satellites around planets. Both are orbital motion under transverse (central) accelerations. Therefore, one could expect the same metrics to apply to both.

The curious aspect of the Bailey experiment is that only velocity time dilation formula (Lorentz factor) seems exactly applicable, but no gravitational time dilation term appears (as opposed to the Schwarzschild metric for satellites). This is in spite of a black hole like transverse acceleration of nearly $10^{18}g$. Why does the SR formula alone apply in such a strongly accelerated frame?

From General Relativity we know that gravitational time dilation is co-present with the existence of an accelerated reference frame, and a very strongly accelerated frame was used. How is it that the potential created by such a large acceleration had no impact on time dilation?

Note the difference from other orbital motion observations and experiments (GPS satellites and Hafele Keating), where gravitational and velocity time dilations show up as additive quantities, based on the Schwarzschild metric (or actually the more correct equivalent metric in Equation (64)).

The reason is easy to understand from Equation (68) by substituting low and high $v$'s in the equation. This metric applies to all cases mentioned.

The very high velocity in Bailey experiment scales the **local central acceleration by $\boldsymbol{\gamma^2}$ and creates a massive potential**. This **local potential becomes dominant** and overshadows the UIF potential, **leaving only the Lorentz factor** in Equation (68). In this experiment, the 'velocity time dilation' is in fact one and the same thing as the 'gravitational time dilation' from the massive local potential created by the local acceleration.

This is very different from saying that the velocity by itself causes the time dilation, and accelerated frame plays no role at all, as concluded by Bailey et. al. in their paper. That explanation is contradictory to GR and the equivalence principle, when comparing muons lifetimes between non-accelerated and strongly accelerated frames.

The time dilation factor computed using the Lorentz factor was $29.33$. If the full Equation (68) had been used, the difference would have been by a factor of only 1 in 1000. Therefore, the Lorentz factor was the valid time dilation metric in this case.

Note that the time dilation factor of $29.327$ simply means that the significantly increased potential reduces energy velocity ($c_I$) inside the muons by a factor of $29.327$. The process of energy movement within muons that causes decay in $2.2\ \mu s$ at rest is slowed down by this factor, and the muons 'live' that much longer in consequence.

### D. Energy of relativistic particles

When particles such as beta rays are produced as a result of radioactivity or other atomic disintegration, they must then carry away the energy they have within the atom. Since particles like electrons are moving in orbits within atoms without leaving the spatial configuration of the atoms before atomic disintegration, they are also subject to massive accelerations. This implies that they carry large potentials within the atom (much like the muons in Bailey et. al. experiment), and leave with the same energies when released from atoms.

Thus, they would carry similar energies as computed by the Lorentz factor. Once they leave the atom, they would over time radiate and lose that energy. Initially, their internal 'time' would be extremely slow, and therefore they will retain their energies for considerable periods.

## XII. PUTTING GRAVITATIONAL AND VELOCITY TIME DILATION TOGETHER

We are now in a position to create the complete picture of the gravitational potential of objects under various conditions.

### A. Complete potential equation for orbit

For a small body orbiting a massive body, the total potential will have components of all of these: (a) gravitational potential of the Universe, (b) increase of this gravitational potential because of velocity in the UIF, and (c) gravitational potential of the local massive body, enhanced by the velocity. This is equivalent to Equation (64). The complete equation may be written as:

$$\hat{\phi}_{Total} = \hat{\phi}_U \left(1 + \frac{v^2}{{c_U}^2} + \frac{2GM}{R{c_U}^2}\left(\frac{1}{1 - v^2/{c_U}^2}\right)\right) \tag{74}$$

To compute the time dilation of the orbiting body, we need only apply the $\hat{\phi}{c_I}^2$ constancy along with the above equation to obtain $\gamma = c_U/c_I$ for any velocity. The usual cases of interest of very low and very high velocities are detailed in subsections C and D below.

### B. Unconstrained rectilinear motion in UIF

For unconstrained rectilinear motion in UIF (i.e. non-orbital motion), where a small body gets significant potential from a number ($n$) of large proximal bodies (possible having velocities in different directions), and has a velocity $v$ in UIF, the total potential equation for the small body would be:

$$\hat{\phi}_{Total} = \hat{\phi}_U \left(1 + \frac{v^2}{{c_U}^2} + \sum_{i=1}^{n} \frac{\hat{\phi}_{M_i}}{{c_U}^2}\left(\frac{{c_U}^2 + {v_i}^2 + 2c_U v_i \cos\theta_i}{{c_U}^2}\right)\right) \tag{75}$$

Here, $M_i$ is the mass of the $i^{\text{th}}$ proximal large body, $v_i$ is the velocity of the small body with respect to the $i^{\text{th}}$ large body, $\theta_i$ is the angle of approach between the small body and the $i^{\text{th}}$ large body, and $v$ is the velocity of the small body in UIF.

The Lorentz factor does not appear here as there is no constraint of an orbital trajectory under transverse central acceleration.

In the common case of one single proximal body which may be considered static, the equation simplifies to:

$$\hat{\phi}_{Total} = \hat{\phi}_U \left(1 + \frac{v^2}{{c_U}^2} + \frac{2GM}{R{c_U}^2}\left(\frac{{c_U}^2 + v^2 + 2c_U v \cos\theta}{{c_U}^2}\right)\right) \tag{76}$$

### C. Slow orbital velocity approximation

From Equation (68), at low velocities where $1/(1 - v^2/{c_U}^2)$ is negligible, as in the case of small velocities involved in satellite (e.g. GPS) or planetary revolution around stars, we may approximate the potential as:

$$\hat{\phi}_{Total} = \hat{\phi}_U \left(1 + \frac{\hat{\phi}_M}{{c_U}^2} + \frac{v^2}{{c_U}^2}\right) = \hat{\phi}_U \left(1 + \frac{2GM}{R{c_U}^2} + \frac{v^2}{{c_U}^2}\right) \tag{77}$$

Note that this is essentially identical to unconstrained rectilinear motion as in the previous section, when the velocity is exactly transverse to the large proximal mass.

In this case, the local body gravitational time dilation and UIF velocity time dilation effects are of comparable magnitudes and appear as separate effects. This is the same as the low velocity, low gravity approximation of the Schwarzschild metric, as it should be when $GM/R \ll c^2$ and $v^2 \ll c^2$, as proven in numerous experiments. However, this equation is in fact the exact metric and not an approximation, apart from ignoring the small $1/(1 - v^2/{c_U}^2)$ factor for such situations.

The time dilation factor of the small body (compared to UIF rest) will be given by Equation (77), using $\hat{\phi}{c_I}^2$ constant as:

$$\gamma = \frac{c_U}{c_I} = \sqrt{\frac{\hat{\phi}_{Total}}{\hat{\phi}_U}} = \sqrt{1 + \frac{2GM}{R{c_U}^2} + \frac{v^2}{{c_U}^2}} \tag{78}$$

This equation explains the time dilation results observed in the Hafele Keating experiment (between clocks in airplanes moving in opposite directions and clocks stationary on Earth) and time dilation between GPS satellite and Earth clocks. (For low gravity and velocity, the approximation of this metric is identical to the approximation of the Schwarzschild metric).

If the small body is in orbit around the local massive body (with velocity $v = \sqrt{GM/R}$), the potential of the small body (compared to UIF rest) will be given by:

$$\hat{\phi}_{Total} = \hat{\phi}_U \left(1 + \frac{2GM}{R{c_U}^2} + \frac{v^2}{{c_U}^2}\right) = \hat{\phi}_U \left(1 + \frac{3GM}{R{c_U}^2}\right) \; since \; v = \sqrt{\frac{GM}{R}} \tag{79}$$

The corresponding time dilation factor may be written as:

$$\gamma = \frac{c_U}{c_I} = \sqrt{\frac{\hat{\phi}_{Total}}{\hat{\phi}_U}} = \sqrt{1 + \frac{3GM}{R{c_U}^2}} \tag{80}$$

### D. High orbital velocity approximation ($v \sim c$)

Where $\left(\frac{1}{1 - v^2/{c_U}^2}\right)$ is the predominant factor in Equation (74), as in Bailey et. al. experiment or near black holes, the approximation will become:

$$\hat{\phi}_{Total} = \hat{\phi}_U \left(\frac{\hat{\phi}_M}{{c_U}^2}\left(\frac{1}{1 - v^2/{c_U}^2}\right)\right) = \hat{\phi}_M \left(\frac{1}{1 - v^2/{c_U}^2}\right) \; since \; \hat{\phi}_U = {c_U}^2 \tag{81}$$

In this case, the base UIF gravitational potential and UIF velocity time dilation effects are negligible, and gravitational time dilation and velocity time dilation are essentially the same thing, defined by the massive local potential.

In extreme high velocity cases like Bailey et. al. ($v \cong 0.9994c_U$), as explained for Equation (71), we would get:

$$\hat{\phi}_M \cong \hat{\phi}_U \tag{82}$$

The time dilation factor of the small body in this case will be the Lorentz factor (using $\hat{\phi}{c_I}^2$ constant):

$$\gamma = \frac{c_U}{c_I} = \sqrt{\frac{\hat{\phi}_{Total}}{\hat{\phi}_U}} \cong \sqrt{\frac{\hat{\phi}_{Total}}{\hat{\phi}_M}} = \frac{1}{\sqrt{1 - v^2/{c_U}^2}} \tag{83}$$

This is the domain of Special Relativity, where the Lorentz Factor alone is sufficient to explain the observed time dilations. For other situations, Equation (74) must be used, and that is the domain of General Relativity.

## XIII. EFFECT ON ACCELERATION

### A. Acceleration in orbital motion

As we have seen, in a stable orbit, the potential created by the local acceleration must be taken into account as part of the mass (and momentum) of an orbiting small body. From Equation (67), we have the complete orbital acceleration as:

$$A = \frac{v^2}{R}\left(1 + \frac{2GM}{R{c_U}^2}\left(\frac{1}{1 - v^2/{c_U}^2}\right) + \frac{v^2}{{c_U}^2}\right) \tag{84}$$

For orbital motion in gravitational acceleration in a low velocity situation, we may approximate this (using $v = \sqrt{GM/R}$) as:

$$A = \frac{v^2}{R}\left(1 + \frac{3GM}{R{c_U}^2}\right) \tag{85}$$

This shows us that in a planetary orbit the central gravitational acceleration is slightly greater than the classical Newtonian formulation.

The effect is usually very small for most planets in the solar system, since $R$ is large enough for the $3GM/R{c_U}^2$ factor to be negligible compared to 1. However, in the case of Mercury this factor is significant enough to show an anomaly (compared to classical computation) observable in the planet's orbital precession. The equation from GR (an approximation from the Schwarzschild metric) used to explain this phenomenon is the same as Equation (85) above.

For extremely high orbital velocities ($v \sim c_U$), since $2GM/R \approx {c_U}^2$ the acceleration becomes:

$$A = \frac{v^2}{R}\left(\frac{1}{1 - v^2/{c_U}^2}\right) = \gamma^2 \frac{v^2}{R} \tag{86}$$

**B. Acceleration in rectilinear transverse motion near a large mass**

For unconstrained (non-orbital) transverse motion near a large mass, we have from Equation (76):

$$A = \frac{GM}{R^2}\left(1 + \frac{v^2}{{c_U}^2} + \frac{\hat{\phi}_M}{{c_U}^2}\left(\frac{{c_U}^2 + v^2 + 2c_U v \cos\theta}{{c_U}^2}\right)\right) \tag{87}$$

$$\therefore A = \frac{GM}{R^2}\left(1 + \frac{v^2}{{c_U}^2} + \frac{2GM}{R{c_U}^2}\left(1 + \frac{v^2}{{c_U}^2}\right)\right) \; since\; \theta = \frac{\pi}{2} \tag{88}$$

This formula explains the doubled deviation/bending of light rays near the Sun, compared to Newtonian mechanics, as predicted by GR and proven in experiments by Eddington et. al. and others. Since the light is not in orbit around the Sun, we need to use Equation (76). Given that the transverse velocity of the light $v = c_U$, the total acceleration becomes:

$$A = \frac{GM}{R^2}\left(1 + \frac{{c_U}^2}{{c_U}^2} + \frac{2GM}{R{c_U}^2}\left(1 + \frac{{c_U}^2}{{c_U}^2}\right)\right) = \frac{GM}{R^2}\left(2 + \frac{4GM}{R{c_U}^2}\right) \cong \frac{2GM}{R^2} \ \left(since\,\frac{4GM}{R{c_U}^2} \ll 1\right) \tag{89}$$

Thus the acceleration and therefore deviation of light near the Sun will be double the Newtonian value.

## XIV. THE HIERARCHY OF GRAVITATION

Till now, we have considered gravitational and velocity time dilation in situations where a small body is close to a large mass, or has a velocity in the background of the Universe gravitational potential. We have also looked at a combination of the two situations in orbital and rectilinear motion.

We need to now consider the way celestial objects are organized in the Universe in hierarchies, and how we must apply the rules in such situations.

A simplified hierarchy of celestial bodies may be represented as follows (Fig. 6):

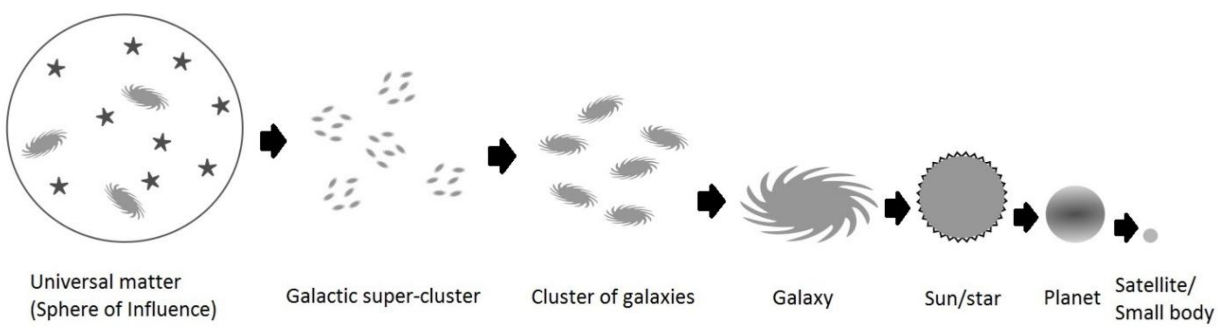


Fig **6:** Objects higher in the hierarchy determine the potential of objects lower down the order. Since gravitationally bound systems (objects at any two successive levels – e.g. planet and satellite) are subjected to the common potential of all higher order objects (e.g. Sun/star upwards), the relative time dilation between such objects depend solely on the local mass distribution and velocities from the CG within the system.

Let us consider the gravitational potential and corresponding time dilations at the level of Star/Sun → Planets → Satellites. A planet revolving around a star/Sun is subjected to the gravitational potential of the star/Sun, orbital velocity in UIF, and in addition the gravitational potentials of all objects up the hierarchy. We can ignore the small contributions of other planets in the stellar/Solar system for these considerations.

This goes up the order. We may consider the star/Sun to be similarly subjected to the gravitational potential of the galaxy, and so on. What is important to note is that at each level of hierarchy, a gravitationally bound system may be treated like a single body under the influence of gravitational potential (both proximity and velocity) of the next higher level, as long as the gravitationally bound system is of significantly smaller mass than the next higher level.

Being subject to common gravitational potential of all the higher level objects equally, a gravitational system consisting of a planet and its satellites would not show any difference in energy-potential and time dilation between the different components, except for mass differences and velocities **within the gravitational system itself**. For example, when computing time dilation for GPS satellites with Earth clocks, we do not have to consider the potential of the Sun (though nearly 15 times as strong as the Earth's own in the Earth-satellite system), nor the orbital velocity of the system around the Sun. Those apply equally to the satellites and Earth. This allows us to ignore such much larger but ubiquitous potentials for analysis of time dilation within a system. What difference we see is always based on the local velocity from the Center of Gravity (i.e. a local sidereal axis centered at the CG).

Clearly, a sidereal axis through the CG of the local gravitationally bound system then acts as the local inertial reference frame (UIF), and all velocities within the system must be considered from the CG for computing respective potentials/time dilations of different objects.

This amply verified in many experimental situations:

- This is how velocities in the Hafele-Keating experiment and GPS time dilation are computed.
- Velocities for artificial satellites that satisfy the Newtonian approximation of $GM/R^2 = v^2/R$ are computed from the orientation dictated by the local sidereal axis.

The above discussion gives us a simple way to compute time dilations, both for velocity and proximity, across hierarchies.

For example, we may compute velocity time dilation difference between the Earth and the Moon by simply taking their respective sidereal velocities from the CG of the system. This cannot be done currently using existing relativity theory for bodies of comparable but unequal mass, as it is not clear how the Schwarzschild metric or Lorentz factor may be applied to such situations.

Existing SR theory allows computation of differential aging caused by velocity only in cases where one of the bodies **is orders of magnitude massive compared to the other** (such that velocity from CG is practically the velocity of the small body). It may also trivially be applied to masses **of equal magnitude** like identical binary stars, where the difference is zero. In between lies the situations that cannot be analyzed in existing SR theory, and gives rise to confusion around apparent paradoxes like the twin paradox, where it is not clear which of the two situations above should apply.

This logic can be extended further for comparing time dilations between different levels of hierarchy, e.g. between artificial satellites of Earth and any satellites of Ganymede, Jupiter's moon. Computation of comparative gravitational time dilation due to proximity is obvious, by going up to the common level of hierarchy (Sun in this case) and computing the gravitational time dilations down the hierarchy. For Earth satellites, it will be a combination of the potential of the Sun and that of the Earth, while for satellites of Ganymede we would have to consider 3 levels of Sun, Jupiter and Ganymede.

What is interesting is that the velocity time dilation may be found exactly in the same way between two such objects, as we are able to identify and isolate the gravitational (proximity) time dilation at each level, and velocity time dilation compounds exactly in the same way as proximity time dilation, being basically gravitational in nature.

## XV. ROTATION AND REVOLUTION IN THE UIF

Without the external gravitational frame of reference (UIF), planetary bodies would not be able to revolve around one another. The Earth could not revolve around the Sun, for if the Sun did not have an externally imposed axis orientation, how could we talk about the Earth 'revolving around the Sun'? The only possible course of action for a Sun-Earth system in an otherwise empty Universe would be for them to be attracted by mutual gravity and ultimately merging together, because in such a scenario an orbital velocity is meaningless. Nor would there be any meaning to the Sun rotating around its axis.

Similarly, rotation and revolution of planets, stars and galaxies would not make sense without the gravitationally determined UIF.

Why should we bother about spatial orientation? We need to do so for an intuitive and simple understanding of motions like rotation and revolution in the larger background of the Universe, understanding the nature of time dilation in various situations, as well as phenomena such as the Sagnac effect[42,43].

The Sagnac effect is seen experimentally on Earth in ring interferometers, and requires corrections for it in the use of GPS system. Would it be seen in deep space in a ring interferometer, far away from all other matter?

The answer would have to be 'yes'. The effect is not local to Earth or to any particular planetary body. The motion of a ring interferometer has to be seen in regard to the local UIF sidereal axis, determined by the large potential of the Universe 'sphere of influence'.

Therefore, at any location in the Universe, there is a rest position as well as a rest orientation. Experiments and observations have shown us that this rest orientation is sidereal in nature.

## XVI. VELOCITIES HIGHER THAN LOCAL SPEED OF LIGHT

As we have seen, matter should be able to attain faster than light velocities. Why, then, do we not ordinarily see such phenomena, and how can it be achieved? This section discussed the reasons and the possibilities.

### A. Why we don't see faster than light velocities

Momentum conservation dictates that the velocity of separation of interacting objects cannot exceed the velocity of approach (i.e. coefficient of restitution is $\leq 1$).

Therefore, stationary sources of acceleration (like magnetic forces) cannot push a particle to a velocity of $c$, since the energy/momentum carrying particles themselves travel at $c$. This is true, no matter how powerful we make particle accelerators. Thus it would be impossible to accelerate particles in accelerators to velocities $\geq c$.

Given that most celestial objects move slowly in regard to our Earth position, and the Universe expansion is moving most such objects away from us, any matter or energy arriving from other celestial objects is unlikely to reach us at detectably higher velocities than $c$.

These factors hinder us from any realistic possibility of creating or even observing superluminal speeds ordinarily in nature.

### B. Achieving velocities higher than speed of light locally

**Cherenkov Radiation:** Note that Cherenkov radiation is not considered faster-than-light (FTL) travel, since the velocity of the subatomic particles is lower than that of $c$ in vacuum. This is an unwarranted conclusion.

Light (of a particular wavelength) travels at a characteristic velocity given a particular potential/energy density of a medium. No higher and no lower. As we have seen in the explanation of the Fizeau experiment, this potential can be equated to an increased UIF potential. What we call a 'medium' represents an increased potential, and even the Universe gravity provides one that determines the characteristic velocity of light in vacuum.

Therefore, if any particle can travel at higher than the speed of light in any medium, that is tantamount to FTL travel in that higher potential. This is achieved because matter and energy follow different rules of motion in increased potential, as explained in Section X earlier.

Can we actually achieve higher than local $c$ (in vacuum) velocities in some way? It is certainly difficult, but not impossible. Certain possible scenarios are discussed in the next section, where we will also consider other possible experimental results which, if proven, would support the concepts and formulae developed in this paper.

## XVII. POSSIBILITIES OF FTL EXPERIMENTS

### A. Intermediate velocity repetition of Bailey experiment

It may be possible to repeat experiments like Bailey et. al. at intermediate muon velocities ($\boldsymbol{v \sim 0.5 - 0.8c}$) where neither the Schwarzschild metric, nor the Lorentz factor are adequate by themselves, and we need the full Equation (74). There will be a $\mathbf{15\% - 19\%}$ **difference** between this equation and the **Lorentz factor** in such situations.

The difference between Equation (74) and the Lorentz factor at very low (say $v < 0.01c$) and very high velocities (say $v > 0.99c$) is negligible as explained earlier. This is the reason that the Lorentz factor appears to work accurately at both extremely low and extremely high velocities (and all previous experiments have been conducted in one situation or the other).

This experiment will not directly prove FTL velocities, but validate Equation (74). If the muon lifetime extension result is found to be as per Equation (74) rather than the Lorentz factor, it will lend support to the modified equation and the underlying theory developed in this paper as well.

### B. Spontaneous decay of high-velocity particles

One possibility would be to accelerate an unstable particle to near $c$ and then allow it to decay spontaneously (not via collision as in Alvager experiment), and measure the velocity of any forward moving decay products (preferably particles rather than $\gamma$-rays/energy, as that would eliminate any effect of the 'invariance postulate'). The velocity achieved would not be anywhere near $2c$, since the internal energy velocity of the unstable particle would by then be much less, but some velocity above $c$ should be achievable. The technical challenge may be in measuring such velocities by mapping specific source particles to their corresponding decay products.

### C. Neutrinos generated at lower gravitational potentials

Another option is to simultaneously send beams of electromagnetic radiation and neutrinos (assuming their velocity is consistent with light) from a lower to a higher gravitational potential location (e.g. from high Earth orbit to near Earth orbit, avoiding Earth's atmosphere), and measuring whether the neutrinos arrive earlier than light. Since the neutrinos would be generated at a location of higher $c$, they would exceed $c$ (even in vacuum) at the destination, as they would not undergo the Shapiro delay that light would. The concept is similar to the CERN[44] OPERA collaboration neutrino experiments done during 2011-12 except the neutrinos need to be generated at a lower gravitational potential and received at a higher gravitational potential.

## XVIII. OBSERVATIONS ON CELESTIAL PHENOMENA

### A. Black Holes and Singularities

As we can see from the formulation of gravitational time dilation in Equation (18), there is no singularity mandated, and no holes in the fabric of space-time. Extremely dense stellar objects can certainly form, with electron degenerate material, or even perhaps something closer to pure energy than matter. Such objects would demonstrate the properties of suspected black holes, without need for a singularity.

What is not possible is an 'event horizon'. As we see from the concepts discussed in this paper, complete stoppage of time at the event horizon is equivalent to a complete stoppage of energy, in which case even gravity could not have 'moved' outward from a black hole (leaving aside explanations like virtual particles which could apply equally well to light). Moreover, complete stoppage of energy requires infinite potential, which is also not possible. The fact that super-massive black holes appear to have an average mass density (within their Schwarzschild radius) less than that of water shows that there is refinement required to the current understanding.

According to interpretation of existing relativity theory, a free falling observer descending into a black hole would pass the event horizon (and not even notice it) in finite proper time by his clock, while an external observer will never see the free falling observer actually reach the event horizon. This also shows (based on our understanding of time and energy relationship) that the same energy must be considered completely stopped at the event horizon for the external observer, but moving for the in-falling observer, which is a physical impossibility.

The gravitational acceleration and potential of black holes are extremely large close to the center of gravity, and few things can escape such gravity. Light would be particularly affected, since the large potential near a black hole would reduce its velocity significantly because of Shapiro delay effect, and that would make it nearly impossible for light that gets close to a black hole to escape. This would make black holes appear 'black'.

Any light that has to escape from close to a black hole must in fact originate within the black hole, which obviously doesn't happen. Gravity escapes because it travels outward from the black hole, and is not similarly affected.

### B. UIF acceleration, and gravitational repulsion

When a body has a velocity in UIF, it will have a net acceleration in the direction of travel, as bodies in front would attract more strongly and bodies behind less strongly. This is a consequence of the same net blue shift of gravity that causes potential to increase for a moving body.

This acceleration is negligible at low velocities, but can be significant when a body is traveling fast.

At a velocity higher than $c$, there will be 'apparent' gravitational repulsion from bodies directly behind (since their gravitation would appear to come from the direction of travel). Higher velocity implies stronger acceleration. This increased 'push' from behind is insignificant from a single mass, but half the Universe is a different story.

On the whole, all gravitational sources within the gravitational 'sphere of influence' of a small body would always assist acceleration of the small body in the direction of motion, compared to when it is at rest in UIF. At large velocities, this may provide an excellent fuel-free source of acceleration for interstellar travel.

This UIF acceleration may also at least partially explain the unbelievably large energies observed of some cosmic muons[45,46]. At present there are no convincing explanations for the extraordinary level of energy seen in the highest energy cosmic rays. The UIF acceleration, which has never been considered till date, may well increase energies of fast particles significantly, given large distances and extended travel times.

## XIX.SIGNIFICANCE FOR INTERSTELLAR TRAVEL

The phenomena discussed in this paper have significant implications for interstellar travel. The main ones are:

- **Practical FTL travel:** First and foremost, travel through space at higher than speed of light is possible. Even for travel at very high speeds (many times $c$) and significant distances (hundreds of light years), the time dilation/differential aging will not be such that millions of years would pass in an astronaut's home planet after such a journey. It would be practical to do extensive interstellar travel and exploration, without the complications of having generations of human beings pass in travel. Getting up to the high speeds required may have engineering challenges of large accelerations and fuel needs, but it is not a scientific impossibility.
- **Sustained gravity assist:** Net UIF gravitational acceleration is always in the direction of travel. It gets stronger with increasing velocity, and can be significant at large velocities. This could alleviate some of the fuel needs. Interstellar missions can partly use the Universe's own store of energy as fuel. Moreover, this would be freefall acceleration, and even large values would not affect astronauts adversely. In fact, at high velocities, braking against the large acceleration may be a possible engineering problem. Perhaps interstellar matter or stellar radiation pressure of target stars could be used for that.

- **Time dilation advantages:** The time dilation that will happen provides multiple advantages because of the relative slow down of time in a spacecraft. Years or months on the home planets could be months or days respectively on a fast spacecraft. This means carrying less provisions even for long trips (food etc.), trips not being overly long for travelers, and perhaps someday even interstellar commerce in perishables!
- **Structural strength:** The higher mass that a spacecraft obtains can be large at high velocities and provide additional structural strength, and may be an advantage against space debris and cosmic radiation.

Engineering challenges of accelerating to high velocities, collisions with interstellar matter, etc. need to be surmounted still. However, there is no scientific barrier to practical and realistic interstellar travel.

## XX. CONCLUSIONS

Recognizing the role of the Universe's large gravitational potential, we are able to get a much more intuitive and simple understanding of the physics of relativity. We gain the following important insights:

### A. Physics behind time dilation

- The Universe's large gravitational potential plays an active role in defining mass and energy. It provides a local inertial frame for orientation and velocity of all objects. It is not an aether, as it interacts with matter and energy, and its parts are not rigidly fixed with respect to one another over time. Though not Universal in an absolute sense, this UIF frame defines the reference frame for any given locality in the Universe.
- Both gravitational and velocity time dilation have the same physical reason behind them, i.e., gravitational potential difference, which is the necessary physical asymmetry for differential aging/time dilation.
- Time dilation of both types can be computed based on the celestial hierarchy. For local computations, a sidereal axis through CG of the local system may be considered as UIF.

### B. Intuitive understanding of relativity

- Space and time dimensions can be separated if the effect of the Universe's gravitational potential is taken into account for velocity time dilation.
- Velocity of light/energy changes in a very well-defined manner with gravitational potential change. This leads to time dilation between locations. Lengths and distances are fixed.
- Velocity time dilation that leads to actual measurable clock differences is neither reciprocal between observers, nor dependent on their relative velocities. Such time dilation occurs because of asymmetry of physical conditions (gravitational potential difference), cause by differential velocity with regard to local UIF sidereal axis. Gravity defines the inertial frame for velocity measurement for time dilation, rotation and revolution.
- Local energy velocity and local speed of time are essentially one and the same thing.
- Counter-intuitive concepts like 'relativity of simultaneity' and 'length contraction' are not necessary for understanding or explaining relativity.

### C. Revised understanding of existing relativity concepts

- Speed of light is not the maximum velocity in the Universe, except for special trajectories.
- There is a Universal 'now' moment. Two initially synchronized clocks travelling at different velocities in UIF would not record a particular event as occurring at the same local clock reading

for both, but that is only because of different rates of passage of time in their localities. Given the velocities of both, either of them would be able to compute the clock reading of the other for such an event. Simultaneity of spatially separated events is an absolute fact, and any disagreement between moving observers is an apparent effect of the distance to events and limited speed of light as the information carrier.

This paper revisits some of the assumptions and concepts underlying the current Theory of Relativity, and presents an alternative and intuitive view of the physics behind it. This includes certain corrections to existing concepts, and simplification of the mathematics.

## REFERENCES


[1]Bailey, H., Borer, K., Combley F., Drumm H., Krienen F., Lange F., Picasso E., Ruden W. von, Farley F. J. M., Field J. H., Flegel W., and Hattersley P. M., "Measurements of relativistic time dilatation for positive and negative muons in a circular orbit," Nature **268** (5618), 301–305 (1977).

[2]Schwarzschild, K. "Über das Gravitationsfeld eines Massenpunktes nach der Einsteinschen Theorie (On the gravitational field of a point mass according to Einstein's theory)," Sitzungsberichte der Deutschen Akademie der Wissenschaften zu Berlin, Klasse fur Mathematik, Physik, und Technik pp 189 (1916).

[3]Schwarzschild, K. "Über das Gravitationsfeld einer Kugel aus inkompressibler Flussigkeit nach der Einsteinschen Theorie (On the gravitational field of a sphere of incompressible fluid according to Einstein's theory)," Sitzungsberichte der Deutschen Akademie der Wissenschaften zu Berlin, Klasse fur Mathematik, Physik, und Technik pp 424 (1916).

[4]Einstein, A., "Zur Elektrodynamik bewegter Körper (On the Electrodynamics of Moving Bodies)," Annalen der Physik **17**, 891 (1905).

[5]Hafele, J. C., and Keating, R. E., "Around-the-World Atomic Clocks: Predicted Relativistic Time Gains". Science **177**, 166-170 (1972).

[6]Einstein, A., *The Meaning of Relativity, 5th Ed.* (Princeton University Press, Princeton, 1955) p.109.

[7]Einstein, A. "Über den Einfluss der Schwercraft auf die Ausbreitung des Lichtes (On the Influence of Gravity on the Propagation of Light)," Annalen der Physik **35**, 898–908 (1911).

[8]Einstein, A., Translated by: Lawson, Robert w., *Relativity: The Special & The General Theory* (Methuen & co., London, 1920)

[9]Shapiro, Irwin I., "Fourth Test of General Relativity," Physical Review Letters **13** (26), 789–791 (1964).

[10]Shapiro, Irwin I., Pettengill, Gordon H., Ash, Michael E., Stone, Melvin L., Smith, William B., Ingalls, Richard P., and Brockelman, Richard A. "Fourth Test of General Relativity: Preliminary Results," Physical Review Letters **20** (22), 1265–1269 (1968).

[11]Ashby, N., "Relativity and The Global Positioning System," Physics Today **55** (5), 41-46 (2002).

[12]Einstein, A., "On the Generalized Theory of Gravitation," Scientific American **182** (4), 13-17 (1950).

[13] Einstein, A., "The Foundation of the General Theory of Relativity," Annalen der Physik **49** (7), 769–822 (1916).

[14]Rossi, B., Hall, D. B., "Variation of the Rate of Decay of Mesotrons with Momentum," Physical Review **59** (3), 223 (1941).

[15]Dyson, F. W., Eddington, A. S., and Davidson C., "A determination of the deflection of light by the Sun's gravitational field, from observations made at the total eclipse of 29 May 1919," Philosophical Transactions of the Royal Society A, London **220**, 291–333 (1920).

[16]Kennefick, D., "Testing relativity from the 1919 eclipse - a question of bias," Physics Today, **62** (3), 37–42 (2009).

[17]van Biesbroeck, G., "The relativity shift at the 1952 February 25 eclipse of the Sun," Astronomical Journal **58**, 87-88 (1953).

[18]Texas Mauritanian Eclipse Team, "Gravitational deflection of light: solar eclipse of 30 June 1973 I. Description of procedures and final results," Astronomical Journal **81** (6), 452-454 (1976).

[19]Jones B. F., "Gravitational deflection of light: solar eclipse of 30 June 1973 II. Plate reductions," Astronomical Journal **81** (6), 455-463 (1976).

[20]Hubble, E., "A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae," *Proceedings of the National Academy of Sciences of the United States of America* **15** (3), 168–173 (1929).

[21]Trumpler, R. J., "Preliminary results on the distances, dimensions and space distribution of open star clusters," Lick Observatory Bulletin **14** (420), 154–188, (1930).

[22]Adams, W. S., "The Relativity Displacement of the Spectral Lines in the Companion of Sirius," *Proceedings of the National Academy of Sciences of the United States of America* **11** (7), 382-387 (1925).

[23]Pound, R. V., and Rebka Jr., G. A., "Gravitational Red-Shift in Nuclear Resonance," Physical Review Letters **3**, 439–441 (1959).

[24]Pound, R. V., and Snider, J. L., "Effect of gravity on gamma radiation" Physical Review **140** (3B), 788–803 (1965).

[25]Pound, R. V., "Weighing Photons," Classical and Quantum Gravity **17** (12), 2303–2311 (2000).

[26]Cherenkov, Pavel A., "Visible emission of clean liquids by action of γ radiation," Doklady Akademii Nauk SSSR **2**, 451 (1934).

[27]De Sitter, W., "A proof of the constancy of the velocity of light," *Proceedings of the Royal Netherlands Academy of Arts and Sciences* **15** (2), 1297–1298 (1913).

[28]De Sitter, W., "On the constancy of the velocity of light," *Proceedings of the Royal Netherlands Academy of Arts and Sciences* **16** (1), 395–396 (1913).

[29]Fizeau, H., "Sur les hypothèses relatives à l'éther lumineux," Comptes Rendus **33**, 349–355 (1851). **English:** Fizeau, H., "The Hypotheses Relating to the Luminous Aether, and an Experiment which Appears to Demonstrate that the Motion of Bodies Alters the Velocity with which Light Propagates itself in their Interior," Philosophical Magazine **2**, 568–573 (1851).

[30]Fizeau, H., "Sur les hypothèses relatives à l'éther lumineux," Annales de chimie et de physique **57**, 385–404 (1859). **English:** Fizeau, H., "On the Effect of the Motion of a Body upon the Velocity with which it is traversed by Light," Philosophical Magazine **19**, 245–260 (1860).

[31]Michelson, A. A., and Morley, E. W., "Influence of Motion of the Medium on the Velocity of Light," American Journal of Science **31**, 377–386 (1886).

[32]Michelson, A. A., "The Relative Motion of the Earth and the Luminiferous Ether," American Journal of Science **22**, 120–129 (1881).

[33]Michelson, A. A., and Morley, E. W., "On the Relative Motion of the Earth and the Luminiferous Ether," American Journal of Science **34**, 333–345 (1887).

[34]Michelson, A. A., and Morley, E. W., "On a method of making the wave-length of sodium light the actual and practical standard of length," American Journal of Science **34**, 427–430 (1887).

[35]Michelson, A. A., and Morley, E. W., "On the feasibility of establishing a light-wave as the ultimate standard of length," American Journal of Science **38**, 181–186 (1889).

[36]Alväger, T., Farley, F. J. M., Kjellman, J., and Wallin, L., "Test of the second postulate of special relativity in the GeV region," Physics Letters **12** (3), 260–262 (1964).

[37] Brecher, K., "Is the Speed of Light Independent of the Velocity of the Source?," Physical Review Letters **39** (17), 1051-1054 (1977).

[38]Ives, H. E., and Stilwell, G. R., "An experimental study of the rate of a moving atomic clock," Journal of the Optical Society of America **28** (7), 215 (1938).

[39]Ives, H. E., and Stilwell, G. R., "An experimental study of the rate of a moving atomic clock II," Journal of the Optical Society of America **31** (5), 369 (1941).

[40]Kennedy, R. J., "A Refinement of the Michelson–Morley Experiment," *Proceedings of the National Academy of Sciences* **12** (11), 621–629. (1926).

[41]Kennedy, R. J., and Thorndike, E. M., “Experimental Establishment of the Relativity of Time,” Physical Review **42** (3), 400–418 (1932).

[42]Sagnac, G., “The demonstration of the luminiferous aether by an interferometer in uniform rotation,” Comptes Rendus **157**, 708–710 (1913).

[43]Sagnac, G., “On the proof of the reality of the luminiferous aether by the experiment with a rotating interferometer,” Comptes Rendus **157**, 1410–1413 (1913).

[44]ICARUS Collaboration, “Measurement of the neutrino velocity with the ICARUS detector at the CNGS beam,” Physics Letters B, **713** (1), 17-22 (2012).

[45]Linsley J., “Evidence for a Primary Cosmic-Ray Particle with Energy $10^{20}$ eV,” Physical Review Letters **10** (4), 146-148 (1963).

[46]Bird, D. J., Corbató, S. C., Dai, H. Y., Dawson, B. R., Elbert, J. W., Gaisser, T. K., Green, K. D., Huang, M. A., Kieda, D. B., Ko, S., Larsen, C. G., Loh, E. C., Luo, M., Salamon, M. H., Smith, D., Sokolsky, P., Sommers, P., Stanev, T., Tang, J. K. K., Thomas, S. B., and Tilav, S., “Evidence for correlated changes in the spectrum and composition of cosmic rays at extremely high energies,” Physical Review Letters **71** (21), 3401-3404 (1993).