Reconciling Mach's Principle and General Relativity into a simple alternative Theory of Gravity

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Abstract

A theory of gravity reconciling Mach's Principle and General Relativity (GR) is proposed. Background gravitational potential from the Universe's matter distribution is c^2. This potential constitutes unit rest energy of matter and provides its unit rest mass, which is the essence behind $E = mc^2$. The background gravity creates a local sidereal inertial frame. A velocity increases gravitational potential through net blue-shift of Universe's background gravity, causing velocity time dilation, which is a form of gravitational time dilation. Time dilation does not become boundless in general, and the Lorentz factor applies to the motion of matter only under specific circumstances. Matter and energy follow different rules of motion, and matter may exceed the speed of light. The theory is consistent with existing relativity experiments, and is falsifiable based on experiments whose predictions differ from GR.

Keywords: Alternative theory of gravitation; General Relativity; Mach's Principle; time dilation; Universe gravitational potential

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1 Introduction

Unit rest energy of matter (c^2) is the gravitational potential of the Universe's homogeneous and isotropic matter distribution (background potential). This is the important concept which forms the basis of this paper.

Mass (amount of inertia) of matter is a gravitational phenomenon, and the Universe's background potential provides the *unit mass/energy* of a body at rest.

Universe's background gravity creates a local *sidereal rest frame* at every location, which we will call Universe Inertial Reference Frame (UIF). The *rest state* in UIF, far from massive bodies, corresponds to having no rotation or velocity with regard to distant Universal objects[1].

Empirical evidence shows that near massive bodies the UIF coincides and moves with the local Center of Gravity (CG). For example, velocities satisfying orbital equation ($v = \sqrt{GM/R}$) or used

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to compute time dilation (e.g. Hafele-Keating[2, 3], GPS Satellites[4]) need to be measured from sidereal CG frames in practice. This phenomenon, along with the Milky Way galaxy's gravitational potential at Earth being negligible compared to the Universe gravitational potential c^2, precludes detection of any preferred frame or mass anisotropy in Hughes-Drever[5, 6] type experiments.

A simple alternative theory of gravity is derived by reconciling Mach's Principle and General Relativity[7], showing that matter and energy/light follow different rules of motion, and that speed of matter can exceed speed of light. This does not affect GR predictions except in extreme cases, but demonstrates that practical interstellar exploration is possible. The theory is consistent with existing relativity experiments.

2 Meaning and usage of specific terms

In this paper, certain terms are used with a specific meaning:

- **Location:** The term 'location' signifies a *small body* and *its immediate surroundings*, at a uniform gravitational potential. Two locations need not be at mutual rest
- **Time dilation:** 'Time dilation' is the same as 'differential aging'. It stands for *invariant clock rate difference* between locations (experimentally measurable clock drift)
- **Gravitational potential:** We use the positive astronomical sign convention for gravitational potentials, such that it is a *positive* energy quantity per unit mass. A larger magnitude (e.g. closer to a large mass) indicates a *higher* or *increased* gravitational potential
- **Propagation Speed of light/energy:** Speed of light/energy from source
- **Total speed of light/energy:** Speed of light in UIF (*speed of source+propagation speed*)
- **Local:** What is 'local' depends on the accuracy of measurement desired for considering a location to have a uniform gravitational potential. Higher the measurement accuracy, smaller the volume of space that may be considered 'local'

3 Difference in derivation from current relativity theory

From Special Relativity[8], we know that *energy/mass* of matter increases with velocity, causing increased (relativistic) energy/mass and time dilation. A higher magnitude of gravitational potential being equivalent to an increased velocity (as shown in Einstein's derivation of GR), it also increases energy/mass, and causes time dilation.

The Universe has a large background gravitational potential at all locations from its matter distribution. Since energy/mass increases with gravitational potential, this background potential *must contribute* to the *rest* energy/mass of matter. Energy/mass of matter then is a gravitational phenomenon, and the Universe's background potential must constitute *unit rest energy* of matter, i.e. c^2.

In this paper, this is the starting point, and the derivations follow the reverse direction of current theory. Gravitational time dilation[9, 10] at a location is caused by additional gravitational potential from nearby massive bodies. A velocity causes gravitational potential increase through a net blue-shift of the Universe background gravity, causing velocity time dilation, which is another form of gravitational time dilation.

Deriving velocity time dilation without gravitational considerations (SR) requires 'length contraction' and 'relativity of simultaneity'. These concepts are not required, and should not be applied to judge the theory presented. Lengths of objects or distances between objects do not change with velocity or gravitational potential change. Each instant or period of time on a clock at any location corresponds to a specific unique instant or period of time on a 'coordinate clock'.

4 Understanding of time dilation and coordinate speed of light/energy

All motion is ultimately dependent on movement of energy at the lowest level. Speed of energy at a location determines the pace of local processes, from subatomic to observable events, and defines speed of local time or *proper time*. Clock-tick rate is one such local process, used in turn to measure the local speed of energy/light, making 'c' ($299,792,458m/s$) a local constant. (*Source independence* of light velocity is the other aspect of local constancy of c, and will be explained later).

'Time dilation' is a manifestation of the difference in *local* energy speeds between locations, caused by differential gravitational potential.

Gravitational time dilation is caused by differential gravitational potential arising from relative proximity to a large body.

Velocity time dilation (SR time dilation) is caused by gravitational potential increase through a velocity-induced net blue-shift of Universe's background gravity.

At rest in UIF, far from all masses, gravitational potential is a minimum, and this defines a 'coordinate location'. Light here travels at 'coordinate speed', defining 'coordinate time'.

Proper time at different locations may vary, depending on their gravitational potentials, and corresponding local speeds of light/energy.

We will denote *coordinate speed* of light/energy as c_U, and *local speed* of light at non-coordinate locations as c_I. *Locally*, both would be measured as the constant 'c' ($299,792,458m/s$) as explained above.

Time dilation factor (γ) is the ratio between local energy speeds at two locations. Compared to a coordinate location, $\gamma = c_U/c_I$ is the time dilation factor at any other location. If coordinate time is denoted by t, and proper time by τ, then $d\tau/dt = c_I/c_U$.

5 Motivation behind this paper

Why do we need an alternative theory of gravity, since GR has been so successful in explaining and predicting numerous observational phenomena?

There are good reasons:

- Understanding of light speed as a *universal* speed limit needs refinement. Matter and energy follow different rules of motion, since matter does not undergo Shapiro delay[11, 12] (slowdown because of increased gravitational potential). Matter may exceed the speed of light, except in certain constrained motion. This does not affect GR predictions, except in the most extreme cases, but shows that practical interstellar exploration is possible
- Local constancy of light speed is a *postulate* in existing theory. Understanding the physical principles behind this postulate provides new insights
- A fundamental quantity like 'mass' does not have one consistent definition within GR. A simple and comprehensive definition of mass is developed in this paper
- Current formulation of GR creates a perception that physical laws of the Universe are so strange that we *cannot* use our intuition to understand them. This need not be so, as the more natural explanations of relativity phenomena in this paper will show. An intuitive understanding of relativity concepts will help develop this fundamental area of physics further
- A simpler theory of gravitation will facilitate development of a quantum theory of gravity

Apart from this, there are questions that do not have satisfactory resolution within GR, e.g.:

- The *singularity* at the center of a black hole defies any definition within GR
- Bailey et. al. experiment[13] (muon lifetime extension) may be considered as muons in orbital free fall under a central 'gravitational' acceleration towards the center of the muon ring. Lifetimes are compared between (a) stationary/slow muons in an inertial frame in Earth's weak gravitational potential, and (b) near-light-speed muons in a strongly accelerated frame (and therefore, by equivalence principle, in a massive 'gravitational' potential compared to Earth's). Why does no gravitational time dilation appear and why are the observations consistent only with velocity time dilation?

These questions will be answered by the theory in this paper, and we will obtain a much better understanding of how relativity applies to our Universe.

6 Gravitational potential of light/energy and matter

Light traveling transverse to a large body has *twice* the gravitational potential of stationary matter, since acceleration is double, as experimentally demonstrated by Eddington[14] and others[15, 16, 17, 18].

Gravitational energy flux (energy per unit time) received by a small body is proportional to the *square of the relative velocity* of the small body and the gravitational radiation (which travels at c_U) from the large body. Energy flux depends on two factors, (a) the gravitational energy conveyed by each quantum of gravity (i.e. graviton), and (b) the rate of gravitons received per unit time. For transverse motion at a velocity v, the factors would both be $\sqrt{{c_U}^2 + v^2}/c_U$ compared to rest, and the overall gravitational energy flux received would increase by a factor of $\left(1 + v^2/{c_U}^2\right)$. Similar considerations may be used to derive the change in energy flux for motion in other directions.

Gravitational acceleration is proportional to the gravitational energy flux. Relative velocity of transverse light with respect to the large body's gravity being $\sqrt{2}c_U$, the acceleration is double. This also doubles the gravitational potential.

The increased gravitational acceleration remains central, i.e. directed towards the CG of the large body, since locally the UIF coincides with this CG, and the gravitational acceleration has no component in any other direction.

We will shortly see that energy traveling in any direction in UIF also has double the gravitational potential of stationary matter. This includes all energy at a location, including that which directly drives the pace of local processes.

We will call this gravitational potential of energy as 'energy-potential' (denoted $\hat{\Phi}$), to distinguish from potential of matter (Φ). By earlier definition, Universe's energy-potential ($\hat{\Phi}_U$) at a location is:

$$\hat{\Phi}_U = \sum_{i=1}^{i=n} \frac{2GM_i}{R_i} = {c_U}^2 \tag{1}$$

where

$n =$ number of Universal bodies within the Hubble sphere[19] of the location considered
$G =$ Gravitational constant
$M_i =$ mass of the i^{th} body, adjusted for cosmological red-shift
$R_i =$ distance of the i^{th} body from the location considered

Rest energy of matter is the sum total of the 'energy-potential' of its constituent energy. This is the amount of energy that would be released if unit amount of matter were to be completely converted to energy.

The background gravitational potential of matter itself is $\Phi_U = \hat{\Phi}_U/2 = {c_U}^2/2$, when at rest in UIF.

Gravitational energy-potential from a body of mass M, at distance R, is:

$$\hat{\Phi}_M = 2\Phi_M = \frac{2GM}{R} \tag{2}$$

We may use either energy-potentials ($\hat{\Phi}_U = {c_U}^2$, $\hat{\Phi}_M = 2GM/R$) or potentials ($\Phi_U = {c_U}^2/2$, $\Phi_M = GM/R$) for deriving time dilation equations, as long as they are used consistently. In this paper we adopt the energy-potential as the convention to be used.

7 Gravitational potential and mass

Unit rest energy of matter is ${c_U}^2$, as per $E = mc^2$ with m being unity.

If μ stands for *unit mass* of matter (at an arbitrary velocity and potential) and m_0 stands for the *amount of matter* in a body, then μm_0 represents total mass (m) of the body. The total energy of the body is $E = \mu m_0 {c_U}^2 = m{c_U}^2$.

At rest far from massive bodies $\mu = 1$, and mass is the same as rest mass. Amount of matter (m_0) and rest mass (μm_0) are numerically identical, and the energy equation becomes $E = m_0 {c_U}^2$.

Any increase in potential (through a velocity, or proximity to large body) raises the unit mass (μ), resulting in *relativistic* mass. This is simply an increase of unit energy (potential), which increases the *unit amount of inertia*, without any change in the amount of matter.

In terms of total energy-potential ($\hat{\Phi}_{Total}$) at a location, *unit mass* is:

$$\mu = \frac{\hat{\Phi}_{Total}}{\hat{\Phi}_U} = \frac{\hat{\Phi}_{Total}}{{c_U}^2} = \frac{(E/m_0)}{{c_U}^2} \tag{3}$$

8 Constancy of the product $\hat{\Phi}{c_I}^2$

Gravitational acceleration/potential from *a given amount of matter* at a distant point (X) remains the same, whether the matter is loosely or tightly packed.

In the latter case, $\hat{\Phi}$ within the matter is higher because of closer proximity of different parts. For acceleration/potential at X to remain constant, the energy flux at X must remain the same. Increase of unit mass ($\hat{\Phi}/{c_U}^2$) must then be exactly compensated for by reduction in gravity flux, which is proportional to ${c_I}^2$.

Of course, the gravitational energy will speed up as it leaves the body, and at X the speed of gravity will be c_U, with the gravitational radiation being slightly red-shifted as a result. This is analogous to red-shift of sunlight (gravitational red-shift) as predicted by Einstein and experimentally proven later[20, 21, 22, 23].

Therefore (*energy potential*) $\times$ (*local energy speed*)^2 or $\hat{\Phi} \times {c_I}^2$ is a constant.

At rest far from all masses (i.e., coordinate location) we have $\hat{\Phi} = \hat{\Phi}_U$ and $c_I = c_U$, so we derive an important relationship valid for all values of $\hat{\Phi}$ and corresponding c_I:

$$\hat{\Phi}{c_I}^2 = \hat{\Phi}_U {c_U}^2 \tag{4}$$

9 Effect of velocity on gravitational potential

A body at rest receives gravity from all directions at speed c_U, from matter within its Hubble sphere (Figure 1). Energy-potential is $\hat{\Phi}_U = {c_U}^2$ (and potential of matter itself is $\Phi_U = \hat{\Phi}_U/2 = {c_U}^2/2$).

A velocity v causes maximal blue-shift of gravitational energy in the direction of motion, and a maximal red-shift in the reverse direction. Intermediate values apply in other directions.

Gravitational acceleration and potential depend on the square of incident gravitational energy velocity. By symmetry, we compute the acceleration/potential change by integrating along the semicircle ABC.

Relative velocity of the body is $\sqrt{{c_U}^2 + v^2 + 2c_U v \cos\theta}$, where θ is the angle between direction of travel and gravity sources.

Gravitational energy-potential from an infinitesimal angle $d\theta$ is:

$$\hat{\Phi}_U \frac{{c_U}^2 + v^2 + 2c_U v \cos\theta}{{c_U}^2} \times \frac{d\theta}{\pi} \tag{5}$$

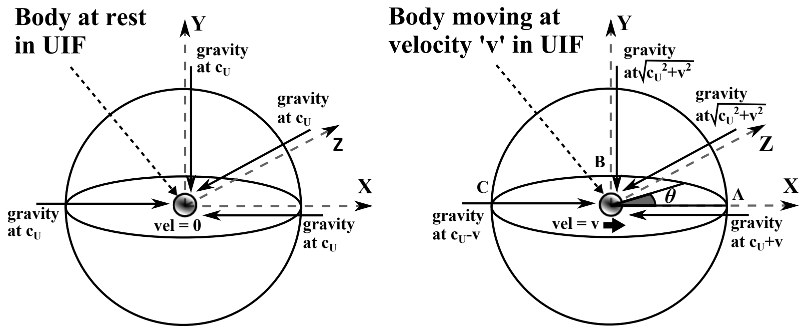

Figure 1: Universe background gravitational potential change with velocity.

Total gravitational energy-potential ($\hat{\Phi}_{U,v}$), integrating over θ from 0 to π, is:

$$\hat{\Phi}_{U,v} = \int_0^\pi \hat{\Phi}_U \frac{{c_U}^2 + v^2 + 2c_U v \cos\theta}{{c_U}^2} \times \frac{d\theta}{\pi} = \frac{\hat{\Phi}_U}{{c_U}^2}\left({c_U}^2 + v^2\right) = \hat{\Phi}_U\left(1 + \frac{v^2}{{c_U}^2}\right) \tag{6}$$

Since $\hat{\Phi}_U = {c_U}^2$, we may also write:

$$\hat{\Phi}_{U,v} = {c_U}^2\left(1 + \frac{v^2}{{c_U}^2}\right) = {c_U}^2 + v^2 = \hat{\Phi}_U + v^2 \tag{7}$$

Change in energy-potential of a body, because of a velocity v in UIF, is simply v^2, or a factor of $(1 + v^2/{c_U}^2)$.

Potential of matter becomes $\Phi_{U,v} = \hat{\Phi}_{U,v}/2 = {c_U}^2/2 + v^2/2$, where $v^2/2$ is the *specific kinetic energy*. Also, light which travels at $v = c_U$ must have *twice* the potential of stationary matter in UIF, as stated earlier.

A net free-fall acceleration also develops in the direction of motion (though negligible at low velocities). This may alleviate fuel needs for interstellar missions, and explain excessive energies of some cosmic muons[24, 25].

10 Velocity time dilation

We get the velocity time dilation factor (γ) from (4) and (7) as:

$$\hat{\Phi}_{U,v}{c_I}^2 = \hat{\Phi}_U {c_U}^2 \tag{8}$$

$$\therefore \gamma = \frac{c_U}{c_I} = \sqrt{\frac{\hat{\Phi}_{U,v}}{\hat{\Phi}_U}} = \sqrt{1 + \frac{v^2}{{c_U}^2}} \tag{9}$$

For small $v^2 \ll {c_U}^2$:

$$\gamma = \frac{c_U}{c_I} \cong \left(1 + \frac{v^2}{2{c_U}^2}\right) \tag{10}$$

Potential increase of a body, because of velocity v, reduces local energy speed by a factor of $\sqrt{1+v^2/c^2}$ ($\cong 1+v^2/2c^2$), causing *velocity time dilation.*

Equation (9) also shows that even if matter exceeds the speed of light, time dilation does not become infinite. This is the equation for velocity time dilation in general rectilinear motion in the Universe background gravity. In high velocity orbital motion, the potential created by the local acceleration becomes important, and the velocity time dilation metric becomes the Lorentz Factor, as will be shown later.

11 Gravitational time dilation

Energy-potential at a location from Universe matter distribution and a nearby massive body ((1) and (2)) is:

$$\hat{\Phi}_{U,M} = \hat{\Phi}_U + \hat{\Phi}_M = {c_U}^2 + \frac{2GM}{R} = {c_U}^2\left(1 + \frac{2GM}{R{c_U}^2}\right) = \hat{\Phi}_U\left(1 + \frac{2GM}{R{c_U}^2}\right) \tag{11}$$

Using $\hat{\Phi}{c_I}^2$ constancy:

$$\hat{\Phi}_{U,M}{c_I}^2 = \hat{\Phi}_U{c_U}^2 \tag{12}$$

Gravitational time dilation factor γ_g is:

$$\gamma_g = \frac{c_U}{c_I} = \sqrt{\frac{\hat{\Phi}_{U,M}}{\hat{\Phi}_U}} = \sqrt{1 + \frac{2GM}{R{c_U}^2}} \tag{13}$$

If $2GM/R \ll {c_U}^2$:

$$\gamma_g \cong \left(1 + \frac{GM}{R{c_U}^2}\right) \tag{14}$$

12 Total time dilation from gravity and velocity

From above, total energy-potential at a location from Universe background potential, velocity, and a nearby large body (ignoring any velocity-induced modification of the local large body's potential for simplicity) is:

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

Correspondingly time dilation factor is:

$$\gamma_{Total} = \frac{c_U}{c_I} = \sqrt{\frac{\hat{\Phi}_{Total}}{\hat{\Phi}_U}} = \sqrt{1 + \frac{2GM}{R{c_U}^2} + \frac{v^2}{{c_U}^2}} \tag{16}$$

For low gravity/velocity, we may approximate:

$$\gamma_{Total} \cong 1 + \frac{GM}{R{c_U}^2} + \frac{v^2}{2{c_U}^2} \tag{17}$$

This is same as Schwarzschild metric[26, 27] low velocity/gravity approximation, except velocity v in (16) and (17) may be in any direction, and not necessarily transverse to a spherical mass.

13 Effect of velocity on speed of light and matter

If c_I is *propagation speed* (speed from source) of light, and v is *speed of source*, total speed of light in UIF is:

$$c_{Total} = c_I + v \tag{18}$$

Velocity of a body of *matter* increases its background gravitational potential as explained earlier, but does not adversely affect speed of *the body itself*. Only *propagation speed* of free energy within the body slows down (causing velocity time dilation). For *light*, increased (blue-shifted) background gravitational potential because of a source velocity causes a *slowdown* of its propagation speed *in the direction of source velocity*. This is essentially Shapiro delay, and compensates for source velocity (Figure 2).

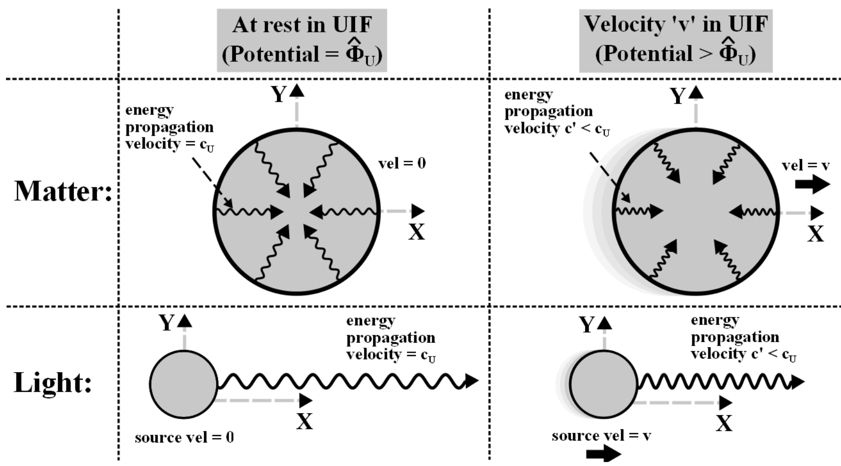

Figure 2: Effect of velocity on light and matter.

Light does not travel faster or slower than local c. Matter can be at rest, or move at any velocity, including faster than light under certain circumstances, as in Cherenkov effect[28].

Matter may travel faster than light even in vacuum, based on the same principles. The only reason we can apply relativistic velocity addition formula in Fizeau[29, 30] and similar experiments[31] is that the *principles involved are the same*. Density of a medium is equivalent to higher gravitational potential.

Particle accelerators (with force-carrier particles traveling at c from stationary source) or Alvager experiment[32], as will be explained below, cannot achieve $v \geq c$. A practical possibility is described later.

Light travels at c_U in UIF (at a coordinate location), and therefore already faces a higher background potential than it would have had at rest. To understand how a source velocity affects total speed of light in UIF, we must start from the 'base potential' ($\hat{\Phi}_{base}$) light would have had at rest.

If light, theoretically at rest, were to be given a velocity of V, potential would increase from $\hat{\Phi}_{base}$, causing a reduction of the *propagation speed* of the light. Using considerations of (6), the increased potential is (as a first approximation):

$$\hat{\Phi}_V = \hat{\Phi}_{base}\left(\frac{{c_U}^2 + V^2}{{c_U}^2}\right) = \hat{\Phi}_{base}\left(1 + \frac{V^2}{{c_U}^2}\right) \tag{19}$$

Since this increase is continuous over V, we break it into 'n' small steps, and take the limit as $(n \to \infty)$ to get an exact value:

$$\hat{\Phi}_V = \hat{\Phi}_{base}\lim_{n\to\infty}\left(1 + \frac{(V^2/{c_U}^2)}{n}\right)^n = \hat{\Phi}_{base}e^{\frac{V^2}{{c_U}^2}} \tag{20}$$

From this, we can compute how the velocity of light is affected by a source velocity which increases (or decreases) the Universe background gravitational potential for such light.

Light from a stationary star travels at c_U, and has a potential $\hat{\Phi}_U$. From (20):

$$\hat{\Phi}_U = \hat{\Phi}_{base}e^{\frac{{c_U}^2}{{c_U}^2}} \tag{21}$$

Light from a star traveling at v will have speed $c' = c_U + v$, as a first approximation. However, increased potential (denoted $\hat{\Phi}_{c'}$) will reduce the propagation speed c_I. From (20):

$$\hat{\Phi}_{c'} = \hat{\Phi}_{base}e^{\frac{(c_U+v)^2}{{c_U}^2}} \tag{22}$$

From (21) and (22), keeping $\hat{\Phi}{c_I}^2$constant:

$$\hat{\Phi}_{base}e^{\frac{(c_U+v)^2}{{c_U}^2}} \times {c_I}^2 = \hat{\Phi}_{base}e^{\frac{{c_U}^2}{{c_U}^2}} \times {c_U}^2 \tag{23}$$

Solving for c_I:

$$c_I = e^{-\left(\frac{v}{c_U}+\frac{v^2}{2{c_U}^2}\right)} \times c_U \tag{24}$$

Using $e^x = 1 + x + x^2/2! + x^3/3! \cdots$, ignoring orders above v^3/c^3 (since $v \ll c_U$):

$$c_I \cong c_U\left(1 - \frac{v}{c_U} - \frac{v^2}{2{c_U}^2} + \frac{v^2}{2{c_U}^2} + \frac{v^3}{2{c_U}^3} - \frac{v^3}{6{c_U}^3}\right) = c_U\left(1 + \frac{v^3}{3{c_U}^3}\right) - v \tag{25}$$

$$\therefore c_{Total} = c_I + v = c_U\left(1 + \frac{v^3}{3{c_U}^3}\right) \cong c_U for\ v \ll c_U \tag{26}$$

Change of total speed of light is *negligible* for small speed of source v. This is why light appears to be *source velocity independent* (i.e. $k \cong 0$ in $c' = c + kv$) in experiments like Michelson-Morley[33, 34, 35, 36] and Kennedy-Thorndike[37, 38].

Orbital velocities of binary stars are typically $10 - 100 km/s$, giving $k \cong v^2/3{c_U}^2{\sim}10^{-7} - 10^{-10}$. This is consistent with de Sitter[39, 40] ($k < 0.002$) and Kenneth Brecher[41] ($k < 2 \times 10^{-9}$) experiments.

14 Acceleration and potential in orbital motion

A small body m is orbiting a massive body M at distance R with velocity v.

Considering m's relative velocity ($\sqrt{{c_U}^2 + v^2}$), M's acceleration on m is:

$$A_M = \frac{GM}{R^2}\left(1 + \frac{v^2}{{c_U}^2}\right) = \frac{v^2}{R} \tag{27}$$

Rest mass of m above accounts only for UIF energy-potential ($\hat{\Phi}_U$). Energy-potential of M (denoted $\hat{\Phi}_{M,v}$) is:

$$\hat{\Phi}_{M,v} = \hat{\Phi}_M\left(1 + \frac{v^2}{{c_U}^2}\right) = \frac{2GM}{R}\left(1 + \frac{v^2}{{c_U}^2}\right) \tag{28}$$

Including this, unit mass of m is higher by $\hat{\Phi}_{M,v}/{c_U}^2$, increasing *transverse momentum*. This will have to be counteracted by an *equal increase in central acceleration* (ΔA_M). Since $\hat{\Phi}_U = {c_U}^2$:

$$\Delta A_M = A_M \times \frac{(\hat{\Phi}_{M,v}/{c_U}^2)}{(\hat{\Phi}_U/{c_U}^2)} = A_M \frac{\hat{\Phi}_M}{{c_U}^2}\left(1 + \frac{v^2}{{c_U}^2}\right) \tag{29}$$

This incremental acceleration in turn creates further increase in potential, and therefore mass and transverse momentum. The relationship is recursive, and leads to the additional acceleration becoming (for $v^2 < {c_U}^2$):

$$\Delta A_M = A_M \frac{\hat{\Phi}_M}{{c_U}^2}\left(1 + \frac{v^2}{{c_U}^2}\left(1 + \frac{v^2}{{c_U}^2}(1 + \cdots)\right)\right) = A_M \frac{\hat{\Phi}_M}{{c_U}^2}\left(\frac{1}{1 - \frac{v^2}{{c_U}^2}}\right) \tag{30}$$

Energy-potential of m from M would be modified by the same factor:

$$\hat{\Phi}_{M,v} = \hat{\Phi}_M\left(\frac{1}{1 - \frac{v^2}{{c_U}^2}}\right) = \frac{2GM}{R}\left(\frac{1}{1 - \frac{v^2}{{c_U}^2}}\right) \tag{31}$$

Total energy-potential of m (adding UIF energy-potential $\hat{\Phi}_{U,v}$ from (7)):

$$\hat{\Phi}_{Total} = \hat{\Phi}_{U,v} + \hat{\Phi}_{M,v} = \hat{\Phi}_U + v^2 + \hat{\Phi}_M\left(\frac{1}{1 - \frac{v^2}{{c_U}^2}}\right) = \hat{\Phi}_U\left(1 + \frac{v^2}{{c_U}^2} + \frac{2GM}{R{c_U}^2}\left(\frac{1}{1 - \frac{v^2}{{c_U}^2}}\right)\right) \tag{32}$$

M's acceleration also needs to account for this additional UIF transverse momentum:

$$A_{M,v} = A_M\left(1 + \frac{v^2}{{c_U}^2}\right) \tag{33}$$

Therefore, total acceleration (A) is:

$$A = A_{M,v} + \Delta A_M = A_M\left(1 + \frac{v^2}{{c_U}^2} + \frac{\hat{\Phi}_M}{{c_U}^2}\left(\frac{1}{1 - \frac{v^2}{{c_U}^2}}\right)\right) \tag{34}$$

In terms of M's potential and m's orbital velocity, this is:

$$A = \frac{v^2}{R}\left(1 + \frac{v^2}{{c_U}^2} + \frac{2GM}{R{c_U}^2}\left(\frac{1}{1-\frac{v^2}{{c_U}^2}}\right)\right) \tag{35}$$

This gives us *energy-potential* (32) and *acceleration* ((34), (35)) for circular *orbit* under *central acceleration*.

By equivalence principle, this applies to both natural gravitational situations like GPS Satellites/black holes, and artificial situations like muons in the muon ring in Bailey et. al. experiment.

Anomalous precession of Mercury's perihelion is caused by the slightly increased acceleration ($\cong v^2/R \times (1 + 3GM/R{c_U}^2)$) for small v in (35).

We also see that although dense objects like black holes may form, there is no event horizon or singularity mandated.

15 The Lorentz Factor

Time dilation factor ($\gamma = c_U/c_I$) in orbital motion can be found from $\hat{\Phi}{c_I}^2$ constancy and (32):

$$\hat{\Phi}_U {c_U}^2 = \hat{\Phi}_{Total}{c_I}^2 = \left(\hat{\Phi}_{U,v} + \hat{\Phi}_{M,v}\right){c_I}^2 = \hat{\Phi}_U\left(1 + \frac{v^2}{{c_U}^2} + \frac{\hat{\Phi}_M}{{c_U}^2}\left(\frac{1}{1-\frac{v^2}{{c_U}^2}}\right)\right){c_I}^2 \tag{36}$$

In *high velocity orbital motion* ($v \approx c_U$), as in Bailey experiment, we get $\hat{\Phi}_M \cong \hat{\Phi}_U$ (by (27) we have $GM/R = v^2/(1 + v^2/{c_U}^2)$, and since $v \approx c_U$, we get $\hat{\Phi}_M = 2GM/R \cong {c_U}^2 = \hat{\Phi}_U$).

As $1/\left(1 - v^2/{c_U}^2\right)$ becomes large, local energy-potential ($\hat{\Phi}_{M,v}$) overwhelms Universe energy-potential ($\hat{\Phi}_{U,v}$) in (36).

Therefore we may consider $\hat{\Phi}_{Total} \cong \hat{\Phi}_{M,v}$ in (36):

$$\hat{\Phi}_U {c_U}^2 \cong \hat{\Phi}_{M,v}{c_I}^2 = \frac{\hat{\Phi}_M}{(1 - v^2/{c_U}^2)}{c_I}^2 \cong \frac{\hat{\Phi}_U}{(1 - v^2/{c_U}^2)}{c_I}^2 \tag{37}$$

This gives us:

$$\gamma = \frac{c_U}{c_I} = \frac{1}{\sqrt{1 - v^2/{c_U}^2}} \tag{38}$$

This is the *Lorentz Factor*, applicable time dilation metric only for *very high velocity orbital motion*, when potential from local acceleration overwhelms Universe background potential.

This is why the Bailey experiment does not show any separate gravitational time dilation. Gravitational and velocity time dilations are one and the same in this case.

Lorentz factor is a multiplier of *local energy-potential* $\hat{\Phi}_M$. At low orbital velocities it contributes little, and velocity time dilation predominantly comes from blue-shift of Universe background gravity.

That the Lorentz Factor seems to apply at low velocities is an unfortunate coincidence of its approximation being the same as (10).

We also see why particle accelerators like the Large Hadron Collider (LHC) are able to accelerate particles to very high velocities and energies, though such particles never reach a speed of c.

The strong accelerations used along circular tracks produce extremely high energies (potentials) which slows down the 'clocks' of such particles significantly. Therefore the particles maintain such energies for considerable periods after being ejected from the accelerators, as the very slow movement of energy within them slow down the potential/energy loss process as well.

However, since the force-carrier particles that accelerate subatomic particles are themselves traveling at c from a stationary source (the accelerator magnets), they cannot push the speed of the accelerated particles to c or beyond.

16 Explanation of some important experiments

16.1 Fizeau experiment

The Fizeau experiment established the formula for partial light dragging by moving water. Light transmitted through water moving at velocity v is dragged as per below equation:

$$w_+ = \frac{c}{n} + v\left(1 - \frac{1}{n^2}\right) \tag{39}$$

where

$w_+ =$ speed of light in water as observed in lab frame
$c =$ speed of light in vacuum/air (i.e., c_U)
$v =$ velocity of water in the same direction as light
$n =$ refractive index of water

This is considered a proof of relativistic velocity addition formula from SR, but a more natural explanation is possible based on effect of gravitational potential increase on energy speed.

Light/energy traveling through water faces a much higher energy density than in vacuum. This is equivalent to a significantly increased UIF gravitational potential.

Refractive index of water is $n = c_U/c_w$ where c_w is the speed of light in stationary water. This is equivalent to the time dilation factor $\gamma = c_U/c_I$ where c_w is the local speed of energy c_I.

Since potential in water is higher than $\hat{\Phi}_U$, we compute the base potential of light in water (denoted $\hat{\Phi}_{base:w}$). Using same considerations as (20), with light speed of V, we get light potential ($\hat{\Phi}_{V:w}$):

$$\hat{\Phi}_{V:w} = \hat{\Phi}_{base:w} \lim_{n\to\infty}\left(1 + \frac{\left(V^2/{c_U}^2\right)}{n}\right)^n = \hat{\Phi}_{base:w} e^{\frac{V^2}{{c_U}^2}} \tag{40}$$

In stationary water, the potential is denoted $\hat{\Phi}_w$. Light speed V is c_w. Relationship between *base potential* and *potential in water at rest* is:

$$\hat{\Phi}_w = \hat{\Phi}_{base:w} e^{\frac{{c_w}^2}{{c_U}^2}} \tag{41}$$

In water moving at velocity v, potential faced by light increases in the direction of motion, resulting in a further reduced speed of light $c_{w'}$. Using $\hat{\Phi}{c_I}^2$ constancy, we derive:

$$\hat{\Phi}_{base:w} e^{\frac{{c_w}^2}{{c_U}^2}} \times {c_w}^2 = \hat{\Phi}_{base:w} e^{\frac{(c_w+v)^2}{{c_U}^2}} \times {c_{w'}}^2 \tag{42}$$

$$\therefore {c_{w'}}^2 e^{\frac{(c_w+v)^2}{{c_U}^2}} = {c_w}^2 e^{\frac{{c_w}^2}{{c_U}^2}} \tag{43}$$

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

$$c_{w'} = c_w \sqrt{\frac{e^{\frac{{c_w}^2}{{c_U}^2}}}{e^{\frac{(c_w+v)^2}{{c_U}^2}}}} = c_w \sqrt{e^{\frac{-2c_w v - v^2}{{c_U}^2}}} \cong c_w e^{-\left(\frac{c_w v + v^2/2}{{c_U}^2}\right)} \tag{44}$$

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

$$w_+ = c_{w'} + v = c_w e^{-\left(\frac{c_w v + v^2/2}{{c_U}^2}\right)} + v \cong c_w \left(1 - \frac{v c_w}{{c_U}^2} - \frac{v^2}{2{c_U}^2}\right) + v \tag{45}$$

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

$$w_+ = \frac{c_U}{n}\left(1 - \frac{v}{c_U n}\right) + v = \frac{c_U}{n} + v\left(1 - \frac{1}{n^2}\right) \tag{46}$$

This is the relationship established in the Fizeau experiment.

Refraction is a Shapiro delay caused by the higher potential within a medium, and the same principles of gravitational potential increase as applied in vacuum may be used to explain phenomena in denser mediums. Of course, this applies only to wavelengths where a medium is *transparent* and does not deflect or stop light itself.

16.2 Alvager et. al. experiment

The Alvager et al. experiment is taken as strong proof of the invariance postulate, since it appears that c is unaffected even when emitted from a high-velocity source. This requires a closer examination.

In the experiment, γ-rays produced by near-light-speed ($0.99975c$) protons striking a Beryllium target (with an intermediate stage of neutral π-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 γ-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 considered:

- With time dilation factor (γ) of nearly 45, energy within protons (and pions) is moving at $c_I = c_U/\gamma = 6.7 \times 10^6 m/s$ only. Added to proton velocity of $0.99975c$, maximum possible velocity of the γ-rays is $3.064 \times 10^8 m/s\,(1.02c_U)$. This gives $k = 2.2 \times 10^{-2}$, i.e. $\ll 1$. The γ-ray velocity would not have been that noticeably higher than c_U anyway.

- γ-rays are not produced *spontaneously* by protons in flight, but through a *collision process*. Source protons strike much larger beryllium nuclei in a metal lattice to produce pions. We have no certainty that the source protons are moving in the original direction at $0.99975c$ at the point of pion production.

- Velocity of the source protons should increase γ-ray energy in the direction of motion, for it to have any bearing on the experiment at all. If equally energetic γ-rays are being scattered in all directions (e.g. perpendicular to proton path), the entire experiment's basis is invalidated. This is not tested. γ-rays are certainly being scattered in different directions, since the experiment measures velocity of γ-rays at an angle of 6° to the proton path. (It is also not clear why the velocities are measured at this angle rather than along the proton path, and whether this angle deviation is accounted for in the experiment's reported accuracy and error).

This experiment, as a proof of *source velocity independence of light*, is at best inconclusive. It needs to be repeated with measurement of energies of γ-rays in different directions (with a semi-cylindrical Beryllium target), and somewhat lesser source velocity (say $0.9c$) such that the time dilation factor γ is not too high, for any reliable conclusions to be drawn.

17 Suggested experiments

17.1 Neutrinos generated at lower gravitational potentials

If simultaneous pulses of light and neutrinos are sent from lower to higher gravitational potential (e.g. High-Earth orbit to Low-Earth orbit), neutrinos should arrive earlier than light. Neutrinos generated at a location of higher c would exceed c (in vacuum) at the destination, as they would not undergo Shapiro delay. This is similar to CERN OPERA collaboration experiment[42], except neutrinos need to be generated at a lower potential and received at a higher potential.

Neutrinos from supernovas arrive at Earth earlier than light. Though current supernova theory has a different explanation for this, the observation is expected, as light experiences some Shapiro delay.

17.2 Intermediate velocity repetition of Bailey experiment

If the Bailey et. al. experiment is repeated at intermediate muon velocities ($v \sim 0.5 - 0.8c$), neither the Schwarzschild metric, nor the Lorentz factor would be adequate by themselves to predict the time dilation. Since the UIF potential would be comparable to the potential created by the local acceleration, we would need the full Equation (36) to compute the time dilation factor. There will be a $15\% - 19\%$ *difference* between this equation and the Lorentz factor in such situations.

If the muon lifetime extension is found to be as per (36) rather than the Lorentz factor, it will validate the modified equation and the underlying theory developed in this paper.

17.3 Spontaneous decay of high-velocity particles

If an unstable particle could be accelerated to a high velocity and then allowed to decay spontaneously (not via collision as in Alvager experiment), the forward velocity of any decay products (preferably particles rather than γ-rays/energy to eliminate any Shapiro delay) should exceed c. A slightly slower source velocity (say $v \sim 0.5 - 0.8c$) would be preferable to high velocities like $0.99975c$, as the reduction of internal energy speed (c_I) would not be that drastic, leading to a more easily measurable superluminal speed.

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