AltU: The Alternative Universe

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Abstract

The physics of the conventional description of the universe are founded on the equations of special and general relativity. In special relativity theory an observer perceives that moving clocks run slow, and that moving objects shrink in the direction of their motion. In general relativity theory clocks slow and space expands within gravitational fields, and in the empty regions of the universe space expands continuously while time remains stable. The equations that describe these phenomena work well, but they provide no insight into an underlying physical process or processes.

This paper postulates an alternative version of the universe, and a single physical process that underlies relativistic phenomena. This version of the universe has unchanging spatial distances, but a variable "speed limit" that determines the local speed of light and the local temporal rate. The combined gravitational fields of all the masses in the universe that affect a spatial location determine the local speed limit there.

Prior to the start of the modern universe there was only energy, in the form of massless particles. There was no mass and no gravitational fields, and the speed limit everywhere was effectively infinite. At the start time for the modern universe mass particles formed from the energy, and their gravitational fields have been growing, at the (gradually-slowing) speed of light ever since that event, some 14 billion years ago. As a result, the gravitational intensity everywhere has steadily increased and the speed limit has steadily decreased.

The alternative universe's occupants observe cosmic redshifts due to the gradually reducing speed of light, rather than due to spatial expansion. The redshifts that we predict for that universe closely match the results of astronomical observations, despite the fact that the alternative universe is spatially stable and contains no dark energy.

Where there are gradients in the gravitational intensity, the corresponding gradients in the speed limit underlie the gravitational accelerations of both masses and massless particles. Clocks, which work by counting cyclic motions involving masses, respect their local speed limit.

Unlike the conventional universe, in the alternative universe the speed limit never drops to zero. The alternative universe's black holes have no event horizons, and rather than being black they are just (very) red-shifted.

Notation, Symbols and Equations

Subscripts: We often embellish specific symbols with subscripts to attempt to clarify their meaning. There are three relevant identifiers: what, where, and from who's perspective. Some common subscripts are:

$\blacksquare_0$	Refers to the current universe.
$\blacksquare_c$ or $\blacksquare_{\_c}$	Refers to a "cosmic" observer's perspective: an observer unaffected by local gravitational fields. Note that AltU's observers are gender-less, and an observer is referred to as "it" where appropriate.
$\blacksquare_{loc}$	Refers to an observed location.
$\blacksquare_{obs}$	Refers to a local observer's perspective, an observer experiencing the temporal rate of the observed object's location. A local observer is assumed to be comoving with the cosmic observer.
$\blacksquare_i$, $\blacksquare_j$, $\blacksquare_{obj}$	Refers to a specific object.

Numeric notation: powers of ten are shown using the "e" notation, so 1.23×10^9 is shown as 1.23e9.

Vectors and matrices are identified by a bold font and an over-bar. The norm of a vector uses the same letter, without the bold font and over-bar. A unit vector is identified by a caret hat, e.g. $\hat{\boldsymbol{v}}_j$.

List of Symbols

a; $\overline{\boldsymbol{a}}$; $\overline{\boldsymbol{a}}_{j\_c}$	an acceleration; an acceleration vector; the acceleration vector of object *j* as observed by a cosmic observer.
$\overline{\boldsymbol{a}}_{\boldsymbol{c}} = \frac{d^2\overline{\boldsymbol{x}}_{\boldsymbol{s}}}{dt_c^2} = \frac{d^2\overline{\boldsymbol{x}}_{\boldsymbol{s}}}{dt_{loc}^2}\left(\frac{dt_{loc}}{dt_c}\right)^2 + \frac{d\overline{\boldsymbol{x}}_{\boldsymbol{s}}}{dt_{loc}}\frac{d^2t_{loc}}{dt_c^2}$	a local object's acceleration, seen by a cosmic observer.
c	the SI value of the speed of light, 2.99792458e8 m/s.
$c_c(t_c)$; c_{c0}	the cosmic observer's local speed of light; its current value.
c_{loc}	the speed of light at a specific location, expressed using its local time coordinate.
c_{loc_c}	the speed of light at a specific location, expressed using a cosmic observer's time coordinate.
c_{obs}	the speed of light at the observer's location.
c_{start}	the speed of light at the beginning (when $t_c = 0$).
ds	an incremental spacetime separation.
dt; dt_{obs}	a time increment experienced by an observer.
dt_{loc}	a time increment experienced by a local observer.
$d\tau$	a time increment experienced by an observed object.
$d\tau/dt_c$	an object's temporal rate (compared to the cosmic observer's rate).
dx_s	a spatial distance increment.

Notation, Symbols and Equations

G	the gravitational constant.
$H(t_c);\ H_0$	the Hubble coefficient; its current value.
$m;\, m_{nearby}$	a mass; a mass affecting a specific location.
r	a spatial distance or radius.
$r_h(t_c)$	the radius of the cosmic horizon.
$t_c;\, t_{c0}$	the time coordinate for a cosmic observer; its current value.
t_{loc}	the time coordinate for a local observer (typically in a gravitational field).
$\tau;\, d\tau/dt_c$	the time coordinate for a moving object (typically in a gravitational field); the "temporal rate" of the object.
U_{tot}	the total gravitational intensity (or potential) at a point ($U_{tot} = \frac{G}{c^2}\Sigma\frac{m}{r} = \frac{G}{c^2}\int\frac{\rho}{r}dv$).
U	the local intensity or potential: the difference between the total intensity at an observed point and the intensity at a cosmic observer's location.
$v;\, \bar{\boldsymbol{v}}$	a velocity; a velocity vector.
$\bar{\boldsymbol{v}}_{\boldsymbol{c}} \equiv \frac{d\bar{x}_s}{dt_c} = \frac{d\bar{x}_s}{dt_{loc}}\frac{dt_{loc}}{dt_c}$	a local object's spatial velocity, seen by a cosmic observer.
$\bar{\boldsymbol{v}}_{\boldsymbol{loc}} \equiv d\bar{\boldsymbol{x}}_{\boldsymbol{s}}/dt_{loc}$	an object's spatial velocity, seen by a local observer.
$\bar{\boldsymbol{v}} \equiv d\bar{\boldsymbol{x}}_{\boldsymbol{s}}/dt$	an object's spatial velocity, generically.
$\bar{\boldsymbol{x}}_{\boldsymbol{s}}$	an object's spatial coordinate vector.
z	the redshift of an observed light or radio wave.
$\bar{\boldsymbol{\nabla}}, \bar{\boldsymbol{\nabla}}_{\parallel}, \bar{\boldsymbol{\nabla}}_{\perp}$	the gradient operator Del, its component parallel to an object's velocity, its component perpendicular to an object's velocity.
γ	the Lorentz coefficient, $\sqrt{1 - v_{loc}^2/c_{loc}^2}$ or $\sqrt{1 - v_c^2/c_{loc\_c}^2}$. It can be calculated based on velocities observed from any inertial frame of reference.
$\bar{\boldsymbol{\eta}}$	The Minkowski metric matrix, $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$
θ	the angle in a polar coordinates system.
ρ	mass density.
ρ_{lt}	the long-term average mass density of the local universe.
φ	the conventional gravitational potential difference between an observed location and an observer. It reflects only the gravitational fields of masses that affect the observed location but not the observer. Typically, the observer is viewed as being in interstellar or intergalactic space and φ has a negative value.

Notation, Symbols and Equations

Within the paper the only equations that are numbered are those that are referenced elsewhere in the text.

Numbered Equations

Equation	**Section**	**No.**
$\frac{dt_{loc}}{dt_c} \cong \frac{c_{loc}}{c_c} \cong \frac{c_{loc\_c}}{c_{loc}} \cong 1 + \frac{\varphi}{c^2}$	4.1.1	(4.1)
$c_{loc\_c} = c_c \left(\frac{dt_{loc}}{dt_c}\right)^2$	4.1.1	(4.2)
$\frac{d\tau_{obj}}{dt_{loc}} = \frac{1}{\gamma} = \sqrt{1 - \frac{v_{loc}^2}{c_{loc}^2}}$	4.2	(4.3)
$U_j = -\varphi_j/c^2 = \frac{G}{c^2}\Sigma_{i\_nearby}\frac{m_i}{r_{ij}}$	4.3.1	(4.4)
$U_{tot\_j} = \frac{G}{c^2}\Sigma_{all}\frac{m_i}{r_{ij}} = \frac{G}{c^2}\int_{all}\frac{\rho}{r}dv$	4.3.1	(4.5)
$\frac{dt_{loc}}{dt_c} \cong 1 - U$	4.3.2	(4.6)
$\frac{c_{loc}}{c_c} = \frac{dt_{loc}}{dt_c} = e^{-U}$	4.3.2	(4.7a)
$\frac{c_c(t_c)}{c_{start}} = \frac{dt_c}{dt_{start}} = e^{-U_{tot}(t_c)}$	4.3.2	(4.7b)
$\mathrm{c_{loc\_c} = c_c e^{-2U}}$	4.4.1	(4.8)
$\frac{d\tau}{dt_c} = e^{-U}\sqrt{1 - \frac{v_{loc}^2}{c_{loc}^2}} = \sqrt{e^{-2U} - \frac{v_{obj\_c}^2}{c_c^2}e^{2U}} = \frac{e^{-U}}{\gamma}$	4.4.2	(4.9)
$\overline{\boldsymbol{v}}_{\boldsymbol{c}} \equiv \frac{d\overline{x}_s}{dt_c} = \frac{d\overline{x}_s}{dt_{loc}}\frac{dt_{loc}}{dt_c} = \overline{\boldsymbol{v}}_{\boldsymbol{loc}}\, e^{-U}$	4.4.3	(4.10)
$\overline{\boldsymbol{a}}_{\boldsymbol{c}} = \frac{\boldsymbol{d^2\overline{x}_s}}{\boldsymbol{dt_c^2}} = \frac{\boldsymbol{d^2\overline{x}_s}}{\boldsymbol{dt_{loc}^2}}\left(\frac{\boldsymbol{dt_{loc}}}{\boldsymbol{dt_c}}\right)^{\boldsymbol{2}} + \frac{\boldsymbol{d\overline{x}_s}}{\boldsymbol{dt_{loc}}}\frac{\boldsymbol{d^2t_{loc}}}{\boldsymbol{dt_c^2}} = \overline{\boldsymbol{a}}_{\boldsymbol{loc}}\, e^{-2U} - \overline{\boldsymbol{v}}_{\boldsymbol{loc}}\, e^{-U}\frac{\boldsymbol{dU}}{\boldsymbol{dt_c}}$	4.4.3	(4.11)
$c_c(t_c) = c_{start}e^{-U_{tot}(t_c)}$	5.1	(5.1)
$r_h(t_c) = \int_0^{t_c} c_c(t)\,dt$	5.1.4	(5.2)
$z = \frac{c_c(t_{emit})}{c_c(t_{obs})} - 1 = e^{U_{tot}(t_{obs}) - U_{tot}(t_{emit})} - 1$	5.1.5.2	(5.3)
$H(t_c) = -\frac{\dot{c}_c(t_c)}{c_c(t_c)} = \dot{U}_{tot}(t_c)$	5.1.5.2	(5.4)
$U_{tot}(t_c) = 4\pi\frac{G}{c^2}\rho\left[r_h(t_c)\int_0^{t_c} c_c(t)\,dt - \int_0^{t_c} r_h(t)\; c_c(t)\,dt\right]$	5.1.7	(5.5)
$H(t_c) = \frac{4\pi\, G}{c^2}\rho\, c_c(t_c)\, r_h(t_c)$	5.1.7	(5.6)
$\overline{\boldsymbol{a}}_{\boldsymbol{c}} = 2\left[c_{loc\_c}^2\overline{\boldsymbol{\nabla}}_{\perp}U - \left(c_{loc\_c}\overline{\nabla}_{\parallel}U + \frac{dU}{dt_c}\right)\overline{\boldsymbol{v}}_{\boldsymbol{c}}\right] \equiv 2\left[c_{loc\_c}^2\overline{\boldsymbol{\nabla}}_{\perp}U - \dot{U}\overline{\boldsymbol{v}}_{\boldsymbol{c}}\right]$ (for photons)		(6.1)

Notation, Symbols and Equations

$\overline{\boldsymbol{a}}_c = 2\left[c^2_{loc\_c}\overline{\boldsymbol{\nabla}}_\perp U + \mathrm{U}\frac{\dot{r}}{r}\overline{\boldsymbol{v}}_{\boldsymbol{c}}\right]$ (for photons) 6.3.1.3 (6.2)

$\mathrm{d\tau}^2 = e^{-2U}\mathrm{dt}^2_\mathrm{c} - e^{2U}\frac{\mathrm{dx}^2_\mathrm{s}}{c^2_c}$, i.e. $\mathrm{d\tau}^2 = \mathrm{dt}^2_\mathrm{loc} - \frac{\mathrm{dx}^2_\mathrm{s}}{c^2_\mathrm{loc}}$ 6.5.2 (6.3)

$\overline{\boldsymbol{a}}_{\boldsymbol{c}} = (c^2_c e^{-4U} + v^2_c)\overline{\boldsymbol{\nabla}}U + \left[-4(\overline{\boldsymbol{v}}_{\boldsymbol{c}} \cdot \overline{\boldsymbol{\nabla}}U) - \left(2 - \frac{v^2_c}{c^2_c e^{-4U}}\right)\left(H(\mathrm{t_c}) + \frac{dU}{dt_c}\right) - \frac{dU}{dt_c}\right]\overline{\boldsymbol{v}}_{\boldsymbol{c}}$ (6.4)

$\bar{\mathbf{a}}_\mathbf{c} = 2\mathrm{c}^2_{\mathrm{loc\_c}}\overline{\boldsymbol{\nabla}}\mathrm{U} - \left[4(\bar{\mathbf{v}}_\mathbf{c} \cdot \overline{\boldsymbol{\nabla}}\mathrm{U}) + 2\frac{\mathrm{dU}}{\mathrm{dt_c}}\right]\bar{\mathbf{v}}_\mathbf{c}$ (for photons) 6.5.3 (6.5)

$U_j = \frac{G}{c^2}\Sigma_i\frac{m_i}{r_{ij}} = \Sigma_{i\neq j}U_{j\_i} + U_{j\_self}$, where $U_{j\_self} = 1.20\frac{G}{c^2}\frac{m_j}{r_j}$ 6.5.4.1.1 (6.6)

$U_j = \frac{G}{c^2}\Sigma_{i\neq j}\frac{m_i e^{-U_i}}{r_{ij}} + U_{j\_self}$, where $U_{j\_self} = 1.20\frac{G}{c^2}\frac{m_j e^{-U_j}}{r_j}$ 6.5.4.2.1 (6.7)

$\frac{dU_{j\_i}}{dt_c} = -U_{j\_i}\left[\frac{\overline{\boldsymbol{v}}_{\boldsymbol{i\_c}} \cdot \overline{\boldsymbol{r}}_{\boldsymbol{ij}}}{r^2_{ij}} + \frac{dU_i}{dt_c}\right]$ 6.5.4.2.1 (6.8)

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1 Prelude: A Sample of What Lies Ahead

This is a lengthy and complex document- it touches on many areas of physics and cosmology, and presents a very unconventional interpretation of many observed phenomena. The reader will need to be both knowledgeable and persistent if they are to come to grips with it. This brief first section is intended to preview the kinds of concepts, and results, that are contained within the body of the document. It skips over the details like a spinning pebble skips over a pond, but hopefully it will be sufficient to give the reader a perspective, and motivation, to take on the rest of the document.

1.1 Time Dilation, Spatial Expansion, and the Speed of Light

1.1.1 Gravitational Time Dilation

General relativity theory predicts that the amount of temporal slowing within a gravitational field is $\frac{dt_{loc}}{dt_c} = \sqrt{1 + 2\varphi/\mathrm{c}^2} = \sqrt{1 - 2U}$, where dt_{loc} is a local time interval measured within a gravitational field, dt_c is the corresponding time interval measured by a 'cosmic' clock that is outside of the field, φ is the gravitational potential in the field (a negative value), and U is the (positive) potential term that is generally used in gravitational theory. The theory predicts that within a sufficiently intense gravitational field time actually halts. This occurs at the event horizon for a black hole, the locus where U equals 0.5.

However, the concept of event horizons around black holes has a fundamental problem. If light can't escape from a black hole then its gravitational field shouldn't be able to escape. That is the case because gravitational effects are transmitted at the speed of light. Mathemagical gravitational fields can of course get out of black holes and inform the rest of the universe about the black hole's location, mass, and spin, but real gravitational fields shouldn't be able to. But if black holes do have 'trapped' gravitational fields that would imply that the black holes at the centers of galaxies, and the collapsing binary black holes that have been observed by LIGO observatories, do not exist.

The same issue arises for a black hole's orbital partners: the event horizon should prevent their gravitational fields from reaching the mass at the center of the black hole and affecting its trajectory.

So the stopping of light at an event horizon is a problem[1], and it turns out that there is an analogous problem with the stopping of time. If relative clock speeds are controlled by the relative magnitudes of gravitational potentials, that would seem to imply that in some sense the absolute speed of a clock is determined by the absolute magnitude of its gravitational potential. Is there a meaningful definition of the absolute magnitude of the gravitational potential at a point?

We know that gravitational effects propagate at the speed of light, and that suggests that the total potential at a point is defined by all of the masses within its cosmological particle horizon (the distance that hypothetical particles traveling at the speed of light would have traveled over the age of the universe). A current estimate of the (comoving) distance to the cosmological horizon is about 47.0 Gly. The mean mass density (baryonic plus dark matter) of the universe (ρ) is estimated to be about 2.7e-30

[1] There are of course numerous online discussions of the problem, along with a variety of entirely unconvincing attempts to rationalize it.

g/cm[3]. These estimates define the current total potential as $U_{tot} = \frac{4\pi G\rho}{c^2}\int_0^{47.0\ Gly} r\ dr = 2.490$. That is far greater than the potential on Earth due to the Earth's gravity (6.96e-10), so we can visualize the Earth as being located on the floor of a deep gravitational ocean, within a very small local depression. An enormous gravitational field pervades the universe, and the gravitational potentials that we commonly deal with reflect parts-per-billion variations in that field. We already experience a high total potential, and the time-slowdown equation simply describes what happens to the local temporal rate when there is an incremental increase in the potential.

1.1.2 Time is Slowing

Interestingly, the total potential isn't a constant value, because the cosmological horizon isn't static- it is expanding at the speed of light. Based on that, we can calculate that U_{tot} is currently increasing at a rate of $\frac{4\pi G\rho}{c}(47.0\ \mathrm{Gly})$, or 1.06e-10 a^{-1}, a rate that is close to the value of the Hubble constant, ≈0.72e-10 a^{-1} (i.e. ≈70 km/s/Mpc).

If the total potential is increasing, then time should be slowing. In the distant past it must have progressed at a much faster rate than it does now, and in the future it will progress more slowly. Based on the above estimates of the mass density and the current horizon distance, in 4.51 billion years the horizon will have expanded to 51.5 Gly, the value of U_{tot} will have increased by 0.5, and accordingly time will freeze, with the universe caught in a temporal black hole.

1.1.3 A Temporal Black Hole?

Of course there is no such thing as a temporal black hole, and the prediction of time freezing is surely incorrect. But that prediction, along with the black hole event horizon issue, leads us to reconsider our assumptions, starting with the $\frac{dt_{loc}}{dt_c} = \sqrt{1-2U}$ equation for gravitational time dilation- it can't be right! It comes from the Schwarzschild metric equation, and it is backed up by a wide range of observational data, most notably by the fact that it is required in order to make the global GPS system work correctly. However, those observational data are based on really tiny variations in the total potential, small fractions of the Earth's 6.96e-10 contribution. All we can really deduce from the observational data is that locally $\frac{dt_{loc}}{dt_c} \cong 1 - U$. And that formulation immediately suggests a universe in which time never halts, and where the gravitational time dilation effect is described by a simple equation: $\frac{dt_{loc}}{dt_c} = e^{-U}$. With its exponential form this alternative equation for time dilation is stable over an arbitrarily-wide range of U values. Also, it has some intriguing implications.

1.1.4 Temporal Implications of the Alternative Time Dilation Formula

The first implication is, of course, that the universe's time is slowing, but it is never going to stop.

The second implication is that time doesn't stop at an event horizon around black holes, and there are no singularities at their centers. The local potential at the Schwarzschild radius around a highly compact mass still equals 0.5, but the time dilation factor there is just $e^{-0.5} = 0.607$. Electromagnetic radiation leaving the mass may be strongly red-shifted due to the gravitational redshift effect, but it does escape. So does the mass's gravitational field. We are left with objects that behave much like black holes, but that are in fact probably just more massive versions of neutron stars. They call to mind the "dark stars" that were postulated by John Michell in 1783.

So the postulated time dilation equation implies that not only is there no such thing as a temporal black hole, there is also no such thing as a conventional black hole. That's a shocking idea- could physicists really be totally wrong about black holes? Einstein thought so[2], though he didn't propose an alternative.

1.1.5 Additional Implications of the Alternative Time Dilation Formula

One of the striking attributes of the PPN metric equations[3] of relativity theory is that for weak gravitational fields their temporal terms equal $-c^2$ divided by their spatial terms. This symmetry between the terms can be seen as describing space expanding in a gravitational field by the same factor by which time slows there. Alternatively, it can be seen as describing the local speed of light as slowing by the same factor by which a clock slows.

Either way you interpret it, the symmetry implies that we might expect the same equation form to describe both the temporal rate and the effective local speed of light, so that $\frac{dt_{loc}}{dt_c} = \frac{c_{loc}}{c_c} = e^{-U}$, where c_{loc} is the locally-measured speed of light and c_c is the cosmically-measured speed. As it happens, this formulation correctly predicts the Shapiro time-delay effect. It also correctly describes the gravitational lensing of electromagnetic radiation, as it implies a spatially-varying vacuum refractive index that is equal to e^{2U}. That refractive index arises due to the temporal rate at a point being reduced, multiplied by e^{-U}, while the effective velocity of light there is multiplied by the same factor.

But what is really happening in gravitational fields: is space expanding, or is light slowing there? In a seminal paper by R. H. Dicke (Dicke, 1957) he postulated that in fact space does not expand in a gravitational field, and instead the speed of light is reduced. If true, that would have implications for the universe- it implies that as the total potential in the universe has increased over time space has not expanded, but instead the speed of light (and of clocks) has decreased. And a decreasing speed of light will cause visible redshifts when viewing electromagnetic radiation emitted at earlier times. Is that all possible: could astronomers and astrophysicists really have been wrong about the expanding universe, for almost a century?

1.1.6 The Cosmic Computational Model

Based on our postulated $\frac{c_{loc}}{c_c} = e^{-U}$ formula the governing equations for the cosmic redshifts were developed, and a computational model for the evolution of the gravitational potential in a non-expanding universe was constructed (see Chapter 5). The governing equations indicated that the Hubble coefficient is actually defined by and identical to the rate of change of the total intensity, U_{tot}. The computational model traces the history of the universe: the expansion of the cosmological horizon, the increase in the total potential, the slowing speed of light, and the redshifts that we observe today. The model starts at an arbitrary early time corresponding to a redshift of about one billion, with an

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[2] Einstein didn't much like conventional black holes. To quote Martin Rees, quoting in turn Freeman Dyson, "*Einstein was not only skeptical, he was actively hostile, to the idea of black holes. He thought the black hole solution was a blemish to be removed from the theory by a better mathematical formulation, not a consequence to be tested by observation.*".

[3] The terms in a metric tensor reflect the ratios between local coordinate distances and the same distances when viewed by a remote observer. The form of the embedded scale factors is discussed in section 6.5.1.

extremely high speed of light, a correspondingly high temperature (about 3e9 K), and a very high Hubble coefficient (*H*). The simulation is finished when the speed of light drops down to its current present-day value.

At that point the model's results have to pass a test: the calculated value of the Hubble coefficient has to match its observed current value H_0. The model adjusts its estimate of the mean mass density of the universe until the H_0 value is matched.

The model has only one input parameter, H_0. A simulation was carried out with H_0 equal to 70 km/s/Mpc, and the main results of that calculation were as follows:

1.1.6.1 The Age of the Universe

The computational model's calculated age of the universe is 13.92 Ga, somewhat greater than conventional estimates— a λCDM model using a flat universe, H_0=67.74 km/s/Mpc, and $\Omega_m = 0.3089$ gives 13.80 Ga.

1.1.6.2 The Cosmological Horizon and the Mean Mass Density of the Universe

The model predicted that the cosmological horizon is some 582 Gly away, much greater than the conventional estimate. The model's calculated value of U_{tot}, 20.82, is also significantly greater than the conventional estimate derived above.

The model's calculated mean mass density for the universe was found to be just 1.472e-31 g/cm^3, significantly lower than the astronomically-based estimates. That is problematic, but that particular result is determined by the universe's average mass density far beyond the locus of the cosmic microwave background (the 'surface of last scattering'). If the result is correct, it implies that the part of the universe that we can observe through telescopes represents a local region of above-average mass density. (It's also possible that dark matter doesn't exist, and that its apparent effects can be explained by a modified version of gravity. That would lower the estimate of the universe's mass density significantly, though it would still be somewhat higher than our calculated 1.472e-31 g/cm^3 value.).

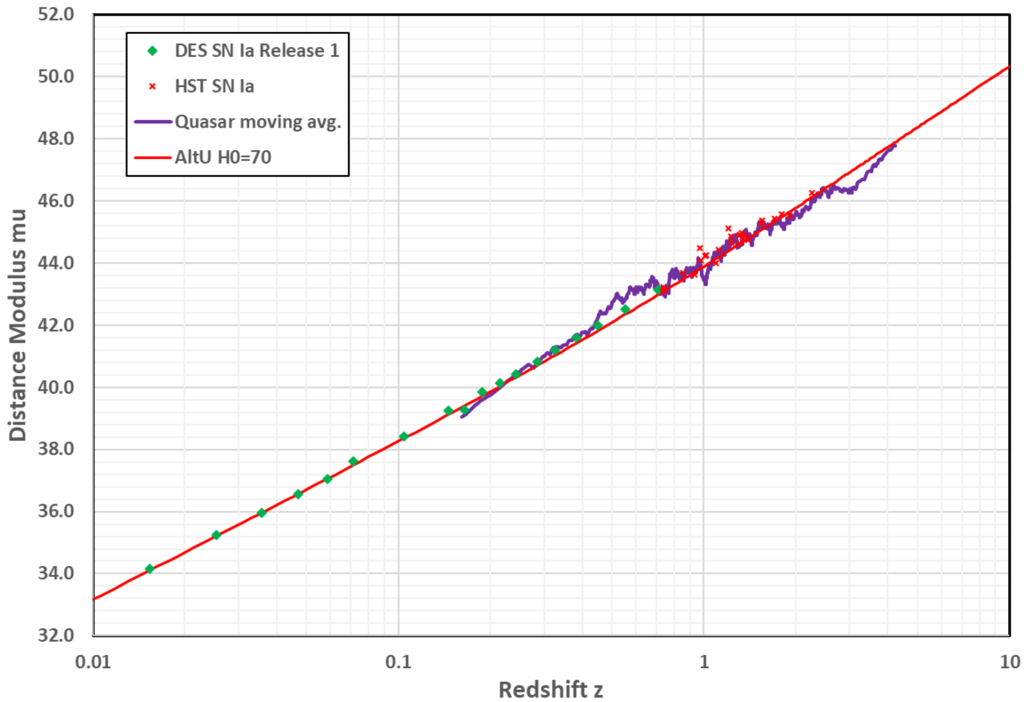
1.1.6.3 The Hubble Diagram Test

The following figure is a Hubble diagram that compares the calculated distance modulus values to the results of three sets of observational data at successively greater distances:

- The binned supernovae type Ia distance modulus results from Abbott et al (2019).
- The Hubble space telescope subset of the Pantheon supernovae dataset described in Scolnic et al (2018).
- The mean curve for the quasar dataset described in Risaliti & Lusso (2018). The purple quasar curve represents the moving average of a 51-quasar window.

The solid red line in the figure is our distance modulus prediction, based on the $\frac{c_{loc}}{c_c} = e^{-U}$ formula.

1. Prelude



Note that the observed data do not lie along a straight line on the chart, and that the primary basis for the inferred existence of dark energy in the conventional universe is the precise form of this curvature.

The predicted distance modulus curve has not been adjusted to match any data, other than via the H_0 value— this is simply what the variable light speed equation predicts.

1.2 Discussion

The proposed time dilation equation's exponential form resolves the anomalies associated with event horizons. It predicts black holes that do not have event horizons or central singularities, but do have gravitational fields.

The model, based on the simple variable light speed equation $\frac{c_{loc}}{c_c} = e^{-U}$, produces accurate estimates for the age of the universe and for the Hubble diagram. The model doesn't utilize the concepts of a Big Bang, or cosmic inflation, or spatial expansion, or dark energy. It is based on just three parameters: the current value of the Hubble coefficient, the gravitational constant *G*, and the standard value of the speed of light, *c*. Given its simplicity, it is highly unlikely that this close matching of observational data is a fluke, or a form of curve-fitting.

Note that the model requires a non-expanding universe- all of its calculations of gravitational effects are based on current distance measures. Its successful predictions of the age of the universe and the cosmic Hubble diagram imply that the universe is not expanding, and that space does not expand in gravitational fields.

The proposed formulas for the speeds of time and of light modify the basic post-Newtonian metric equation that is used in gravitational theory, but they don't significantly change any predicted gravitational results for weak to moderate gravitational fields.

It is possible to modify our computational model for the evolution of the universe to utilize the conventional Schwarzschild metric equation rather than the AltU metric, but when that is done the model's results are clearly invalid. The prediction for the age of the universe is significantly reduced, and the prediction for the Hubble diagram does not match the observational data.

1.3 A Note on Time in Conventional Cosmology Theory

The foundational metric equation for general relativity theory was the Schwarzschild metric, and it describes scale factors for both space and time: in general relativity theory a gravitational field expands space and slows time. However, in the conventional cosmological description of the universe space is expanding but time isn't slowing.

Why is there a discrepancy- why doesn't time slow in cosmology theory? The cosmological description of the universe is based on the FLRW metric equation, which was used in the late 1920's to explain the observed redshifts and to allow scientists to apply Einstein's field equation to the universe. There is no theory underlying the FLRW metric- it is simply a cartoon description of a universe that has a spatial scale factor that changes over time. The field equation provided the necessary theory, when it was used to predict the history of the scale factor- an approach that was pioneered by Alexander Friedmann in 1922. The arbitrary selection of the FLRW metric equation precluded the possibility of describing (or recognizing) a universe, such as AltU, where time slows as the universe ages.

2 A Revised Theory of Relativity and Cosmology?

Do we really need a revised theory of relativity and cosmology- isn't the current theory essentially completely proven? Isn't this the era of precision cosmology? Despite the respect it has earned, there are a significant number of challenges to conventional relativity theory— gaps, contradictions, unexplained phenomena, and awkward implications. For example: cosmic inflation, cosmic expansion, cosmic acceleration of expansion driven by dark energy, fine-tuning of the universe's stability, strange phenomena in and around black holes, the "vacuum catastrophe" (where the vacuum energy of quantum mechanics should have strong gravitational/cosmological effects), the absence of antimatter, the Hubble constant 'tension', and numerous other issues. Also, the conceptual foundations of the theory are surprisingly shaky, filled with incongruities and unjustified, unexplained assumptions. Appendix A presents the Author's perspective on some of the fundamental problems with general relativity theory, which were the motivators in the search for a deeper understanding of relativistic phenomena that is presented in this paper.

The paper starts from a somewhat unconventional perspective on special relativity, and uses that perspective as a basis to postulate a simple mechanism that underlies both gravity and the evolution of the universe. That mechanism implies a variable speed of light, with the speed varying both spatially and temporally. The result is a spatially stable universe that is very different from the current model— an alternative universe. For brevity, and a little humor, that universe is referred to herein as AltU. AltU has a lot in common with the conventional universe, but it differs from it in very fundamental ways. Effectively, AltU represents a different path than the one that physicists and astronomers chose to follow about a hundred years ago. In the balance of the paper we will start to explore it.

The paper focusses on relativistic phenomena, but there are a lot of similarities between relativistic and electromagnetic phenomena. Aspects of the following discussion may be relevant to the phenomena underlying electromagnetism.

The reader is presumed to be familiar with the basic concepts and equations of relativity theory. For readers who aren't sufficiently familiar I recommend Peter Collier's book, <u>A Most Incomprehensible Thing: Notes Towards a Very Gentle Introduction to the Mathematics of Relativity</u>, which is available on Amazon. Despite the title, it isn't light reading— but Collier is meticulous about explaining the conceptual and mathematical foundations of contemporary relativity theory.

This paper represents the author's personal speculations about the physical processes that underlie the dynamics of the universe. By and large it uses the authorial "we" to guide the reader through its logic, but occasionally it uses "I" to present the author's more subjective thoughts.

2.1 *<u>Is it Possible to Explain Relativity?</u>*

The theory of relativity has given us a deeper insight than Newton had into the processes underlying space, time, and gravity, but we still have no real understanding of those processes. Scientists, notably Einstein, have deduced fundamental principles that seem to apply universally, and based on those principles they have derived complex equations that work very well. However, the universe appears to be comprised of very small, very basic entities, and those entities have no concept of fundamental principles or complex equations. Each type of entity has its own attributes and behaviors, and what we consider to be fundamental principles simply reflect our observations of how those attributes and behaviors play out at a large scale. There is a spatial and temporal framework within which those entities cavort, but even that framework may only reflect the nature of the interactions between entities.

The early 20'th century saw the development of the foundations of relativity theory and quantum mechanics, the birth of mathematical physics, and the end of successful attempts to explain what the equations of physics describe. The world of physics, by and large, reluctantly abandoned the search for explanations and became resigned to a universe that operates on essentially arbitrary mathematical principles. Today, very few mainstream physicists continue the search for more intuitive explanations of the phenomena underlying relativity, quantum mechanics, or cosmology.

That presents an opportunity for naïfs such as the author to have a shot at it.

2.2 Framing the Relativity Problem

Before postulating explanations for them, we summarize below the primary phenomena that we seek to explain. Each of these will be discussed in more depth later in the paper.

2.2.1 Time-Related Phenomena

All temporal coordinates are based on the proper time measured by a clock, either a real or a hypothetical clock. There are many kinds of clocks, such as astronomical clocks, pendulum clocks, spring-and-mass clocks, and atomic clocks. They have little in common, other than that they count repeated dynamical cycles involving masses.

Note that in the following material we use the τ and t symbols almost interchangeably, preferring τ to describe the proper time of an observed object and t to describe the proper time of an observer's clock. We have a preferred 'cosmic' observer, in a generic location that is unaffected by the gravitational fields of any nearby masses. The cosmic observer uses an atomic clock that records cosmic time, t_c.

The key temporal behaviors that we need to explain are:

- Moving clocks, as observed by a static (inertial) observer, appear to run slower than the observer's clock. This is summarized in the Lorentz equation for a moving object: $d\tau_{obj} = dt_{obs}\sqrt{1 - v^2/c^2}$. Note that the observer is assumed to be at the same gravitational potential as the observed clock.
- An observer traveling with the moving clock perceives the opposite: the static observer's clock is seen to be running slower than the moving clock.
- Clocks in a location with a gravitational potential different from that of a comoving observer advance at a different rate than the observer's clock does. In general relativity theory, per the Schwarzchild metric, $\mathrm{d}\tau_{loc} = \mathrm{d}t_{obs}\sqrt{1 + 2\varphi/c^2}$, where φ is the local gravitational potential.
- When one member of a pair of entangled particles is observed, the other member's entangled attribute is instantaneously impacted. This "non-locality" challenges a fundamental postulate of relativity theory, that nothing can travel faster than the speed of light. Along the same lines, recent experimental results have demonstrated that quantum tunneling of particles is superluminal.

2.2.2 The Speed of Light

Local measurements of the speed of light (on Earth) have consistently resulted in the same value of c (to about one part in a billion), and the speed of light is generally assumed to be isotropic.

The speed of light has not been precisely measured in gravitational fields other than at the Earth's surface. Astronomical observations indicate that it is reduced, multiplied by a factor of $1 + 2\varphi/c^2$, in normal-strength gravitational fields.

2.2.3 Gravitational Phenomena

Gravitational fields slow clocks, and slow light waves.

Photons passing by the sun are deflected by twice the angle that Newtonian gravity predicts.

The gravitational effects of multiple masses can be characterized by a scalar gravitational field, the gravitational potential, where each mass's contribution is proportional to the amount of its mass and inversely proportional to its distance. Each mass's gravitational effects propagate spatially via its forward light cone, traveling at the speed of light- as proven by astronomical observations and gravitational waves.

Gravitational effects travel at the speed of light. But a close inspection of precise orbital equations for binary pulsar systems (see Will, 2018, Chapter 12; Poisson and Will, 2014) shows that the stars' gravitational acceleration vectors are not directed towards the locations of their partners when they emitted their gravitational 'messages'. Neither are they directed towards their linearly-extrapolated or even their quadratically-extrapolated locations based on the emission time. Instead, the acceleration vectors are directed a hair's breadth ahead of the instantaneous location of the partner's center of gravity. That hair's-breadth represents the very small net 'drag force' that eventually leads to orbital decay.

General relativity theory assumes that energy, as well as mass, originates gravity. That assumption is not consistent with the fact that the vacuum energy density, which is large, has no effect on the expansion of the universe.

2.2.4 Spatial and Distance-Related Phenomena

Regarding space, at a large scale the universe appears to be spatially flat. Its contents initially had a random pattern of density variation. Over time gravitational dynamics have altered the density variation patterns at smaller scales, creating foam-like structures, but at very large scales the original density variations have not yet altered significantly.

Special relativity theory implies that a moving ruler's length is diminished in the direction of its motion, multiplied by $\sqrt{1 - v^2/c^2}$, so that a moving observer using the ruler measures increased distances in the direction of its motion.

The spatial components of the metric equations used in general relativity theory are usually explained as being due to an increased amount of proper space in gravitational fields. However, they could also be explained by a ruler's length being reduced in a gravitational field and/or by a changed local speed of light. That effect might, or might not, be isotropic— the equations and observational data are murky.

The Schwarzschild metric appears to describe a strong radial anisotropy in the spatial scale, at least at large radii.

2.2.5 Relativistic Mass and Momentum

As a moving object's velocity increases it takes an increasingly large impulse to increment the object's momentum by a given amount. This is presented conceptually as being due to either an increase in the object's mass, or by redefining Newton's momentum (the product of mass and velocity) as the product of mass, velocity, and the Lorentz coefficient. It also raises the question as to whether relativistic mass has a gravitational effect.

2.2.6 Astronomical Observations

Astronomers have carefully observed a remarkable variety of systems, via a remarkable variety of modalities. This has resulted in a wealth of data that any proposed theory of relativity has to be consistent with.

2.2.7 Entities

We use the term "entity" loosely herein, to refer to both individual fundamental particles and also to aggregates of particles.

Most of the entities discussed by humans have no standing in the eyes of the universe— a flock of birds, or even a human body, are just arbitrary collections of smaller entities. However, the universe treats some quite complex entities as single things. Recent diffraction slit experiments have demonstrated diffraction and self-interference of very large molecules, as large as 2,000 atoms! (See link). Apparently the universe in some ways treats a molecule as a single entity. This suggests that the electric-force and nuclear-force bonds holding these molecules and their component parts together create something more tangible than just collections of individual particles reacting to field gradients, and raises the possibility that the bonds represent a form of quantum entanglement. And that raises the spooky possibility that gravitational forces are also communicated (instantaneously) via quantum entanglement, despite the much greater distances involved. We would like to think that, like politics, all physics is local… but perhaps it is not so.

2.3 What Would a Physical Explanation of Relativity Look Like?

One of the fundamental challenges of conventional relativity theory is that it is something like trying to understand the geometry of a house of mirrors, where you see everything through distorted reflections in mirrors. There are plenty of mirrors (i.e. coordinate frames) to choose from, but as far as you can tell none is "true" and undistorted. In the current theory of relativity we accept that constraint and we work with arbitrary mirrors, but it would be preferable if we could find an underlying undistorted geometry. That would put us in a better position to understand the processes that underlie our observations and equations. Fundamental coordinate systems for space and time are a foundational requirement for a physical explanation of relativity.

An explanation of relativity probably won't use the concept of spacetime. It seems clear that spacetime is just a mathematical convenience, and not a reality— spatial and temporal coordinates are essentially just accounting tools. It is also clear that conventional space and time coordinates are not absolute, but instead reflect the perspective of the observer, as exemplified in the Lorentz coordinate transformation.

2. A Revised Theory of Relativity and Cosmology?

If spatial distances are subjective, what controls their values for a given observer? If time is subjective, what controls its pace for a given entity— if I observe two entities, and their clock rates differ, what is the underlying cause of the difference? A physical explanation of relativity should address these questions.

The evidence seems to suggest that the effects of relativity are associated with interactions between entities and their local environments. If so, what are the relevant attributes of the local environment, and in what ways do they affect an entity? Mathematical physicists characterize those attributes in terms of “fields”, and one of our goals is therefore to replace the abstract concepts of fields by more concrete ones. At least at a high level we need to conceptualize the entities that populate the universe, and to describe their attributes, behaviors and interactions. The parameters and equations of mathematical physics should emerge from that conceptual model as valid descriptors, at a macroscopic scale, of the micro-scale dynamics of the entities.

The phenomena of special relativity, gravitation, and cosmology have three things in common: changed temporal rates, either spatial expansion or the shrinkage of objects, and a central role for the speed of light. Most likely the key to developing a deeper understanding of relativity will be to find a single mechanism that underlies all three.

Developing a physical explanation of relativity will make it easier for people to understand, and it may significantly change their perspective. It will probably lead to a unified basis for the equations that describe relativistic phenomena. But most of the predicted phenomena won’t change much- they are well established.

3 AltU's Conceptual Foundations

In this section we will discuss the conceptual foundation for AltU, starting with its basic spatial and temporal scales, then addressing special relativity effects and their underlying physical processes, and concluding with general relativity effects. This discussion is entirely conceptual, but it sets the stage for the quantitative equations that will be developed in the following sections.

3.1 <u>The Universe's Spatial and Temporal Scales</u>

We observe a universe where entities have three-dimensional spatial locations, and where the distances between the entities' locations can gradually change over time. There appear to be no absolute measures of spatial and temporal distances- we measure both distance types only by comparison. Our bases for the comparisons are "rulers" and "clocks", but we have no assurance that our rulers and clocks are unchanging. The sizes of physical objects, and the speeds of clocks, change in different environments.

Despite this underlying relativity of both spatial and temporal distances, cosmologists describe a universe that has unique scales for both time and distance, a universe wherein the distances between entities have increased over time, while time has progressed at an unchanging rate. The cosmologists hedge their bet a little bit- the distances between entities that are tied together by forces are assumed to be unchanging. The locally-unchanging distances apply at both micro- and macro-scales, though at the larger scales, for galaxies and galaxy clusters, the concept is increasingly ambiguous. At what distance does the expansion of the universe overcome the faint tug of gravity?

The cosmologists' choices for their spatial and temporal units are based on general relativity theory, and specifically on its assertion that the speed of light, *c*, is a universal constant. The concept of an expanding universe arose from the observation of cosmic redshifts, interpreted using that assertion about *c*. But despite our faith in the expanding universe, there is no evidence for a physical mechanism that underlies its spatial expansion- the expanding universe is a purely mathematical construct.

However, at large spatial scales there is unambiguous evidence of the stability of the relative distances between the universe's entities. We see this in the statistical analyses of the forms of the large-scale structure of the universe, and in the homogeneity of the cosmic microwave background. That evidence suggests a quite different spatial distance measure: a stable unit of distance based on the cosmic scale of the most distant observable entities.

If we have chosen the cosmic scale as the basis for our distance measurements, how do we explain the observed cosmic redshifts? We explain them not by space expanding, but rather than by the gradual infilling of the vacuum with virtual particles. Specifically, we think that the vacuum energy density has been growing over the history of the universe. We think that the increasing density of the virtual particles of the vacuum has reduced the speeds of massless particles, such as photons. In turn the speeds of those massless particles affect the speeds of particles that have mass. As a result, as the vacuum energy density has grown all speeds have dropped. The cause of the growing vacuum particle density is the increasing intensity of gravitational fields everywhere, as the gravitational fields from ever-more distant masses arrive. This effect is the same within an atomic nucleus and within intergalactic space.

The unchanging cosmic distance unit works well, but unfortunately there does not appear to be an analogous natural cosmic unit for time. The best we can do for a basic unit of time is a generic clock, one at a location that experiences the average vacuum energy density level. Its speed has varied in proportion to the speeds of particles that have mass, so like the speed of light the cosmic clock's speed has decreased over the history of the universe.

The gravitational intensity is greater in the vicinity of a mass, and so is the density of the virtual particles of the vacuum. When velocities and temporal rates are expressed using the cosmic distance unit and cosmic time, this locally-increased particle density is seen to cause reductions in the local speed of light and in the temporal rates of clocks within gravitational fields.

3.2 Special Relativity in AltU

The Lorentz transformation equations of special relativity theory are extraordinarily simple, but at the same time they are baffling. They describe relationships between the spatial and temporal coordinates of objects as seen by observers traveling at different speeds. From observer A's perspective, observer B's clock is slowed, and in the direction of A and B's relative velocity B's measured distances are increased compared to A's observations. Yet the inverse is true from B's perspective: A's clock is slowed, and A's measured distances are increased compared to B's observations. Thus neither the times nor the distances used in special relativity theory can be thought of as being absolute: they always reflect a specific observer's perspective.

The only credible explanation for this discrepancy is that something about an observer is physically changed as a function of its velocity- it isn't just mathematical magic. We need to identify what changes due to an object's velocity, and what causes those changes.

3.2.1 Tangherlini and Selleri's Concept

Special relativity theory is founded on the assumption of the constancy of the speed of light, *c*. The theory precludes the existence of an aether or a preferred spatial frame, as within an aether the observed speed of light should reflect the observer's velocity with respect to the aether.

However, measurements of the speed of light do not unequivocally prove that it is in fact a constant. Most such measurements are effectively round-trip speed measurements that can only reveal an average speed. One-way speed measurements require a clock at each end, and those clocks have to be synchronized— but the synchronization method that is chosen affects the result. Choose one way to synchronize and your test implies a constant speed of light, but choose a different synchronization technique and your test reveals motion through an aether.

Two of the fathers of special relativity theory, Hendrik Lorentz and Henri Poincaré, maintained a belief in the existence of the aether— there is a useful discussion in the Wikipedia article at link. Many years later, in 1958, Frank Tangherlini derived a transformation equation that was consistent with there being a preferred frame. The speed of light was isotropic in the preferred frame, but anisotropic in moving frames, yet the electromagnetic equations worked in all frames. Tangherlini's thesis and paper received little attention at the time (see Tangherlini, 2014 for an updated version). Tangherlini's original transformation equations have been given a number of different names, and rediscovered several times.

3. AltU's Conceptual Foundations

In 1977 Mansouri and Sexl showed that a number of variants of special relativity using different clock synchronization protocols can predict the same test results as special relativity theory. Tangherlini's transformation was among the variants that they considered. Somewhat later, Franco Selleri pursued those concepts (see Selleri, 1995 or Selleri, 1997). Selleri asserted that a unique "preferred" coordinate frame of absolute space and time, which incorporated slowing of moving clocks and contraction of moving rulers, was consistent with the empirical evidence from testing of special relativity theory. He argued that this also meant that the data that validate special relativity theory do not rule out the concept of a stationary aether.

Selleri's argument is basically simple:

- If there is a 'preferred frame', and
- If in the preferred frame the speed of light equals c, and is isotropic, and
- If in the preferred frame moving clocks slow by a factor of $\sqrt{1-v^2/c^2}$, and moving objects ('rulers') shrink (in the direction of motion) by the same factor,
- Then in any moving frame where spatial scales are determined by 'rulers' the two-way speed of light is c but the one-way speed is anisotropic, and
- The preferred frame's behavior and the Lorentz transformations are "completely equivalent for explaining the experimental evidence".

Selleri's publications appear to have aroused little interest, and no significant discussion or refutation of his ideas appears to exist. Selleri did not pursue the implications of his concept for general relativity theory, or its integration with cosmology. He did not contemplate the possibility that the two-way speed of light is not in fact a constant. He did not try to identify the preferred frame. But his approach offers us the promise of a valid starting point for an explanation of relativity.

Selleri's approach is simple, and intuitively satisfying. Unfortunately, it invalidates the equally simple special relativity concept of a universal speed of light, and it invalidates Einstein's method of defining simultaneity. With Selleri's approach the one-way speed of light on a moving platform such as the Earth is anisotropic, and varies depending on the angle between the light's path and the platform's path with respect to the preferred frame (which we assume is the cosmic frame).

3.2.1.1 The Cosmic Frame

If the universe does have a preferred frame, and if the universe is essentially homogeneous, then in that preferred frame the distance to the surface of last scattering of the cosmic microwave background (CMB) is the same in all directions: in the cosmic frame the CMB will have no dipole anisotropy. From the Earth we observe a Doppler shift in the CMB, and we deduce that in the cosmic frame the Earth is moving at some 370 km/s, or 0.00123 times the speed of light, in the direction of the Leo constellation.

3.2.1.2 Testing for Light Speed Anisotropy

Selleri's (also Tangherlini's) light speed prediction implies that on the Earth the speed of light is anisotropic, and therefore light of a given frequency has a significantly different wavelength depending on its direction. That seems unlikely— how could people have failed to notice such significant effects? There are some reasons why these effects might not be apparent. For one, the round-trip speed in any direction isn't affected, so round-trip timing tests don't reveal the anisotropy, and antennae behave normally and don't show a directional effect. More subtly, an antenna's physical dimensions change as a function of its orientation with respect to the cosmic velocity. Also, all wavelengths are affected equally, so spectra are not visibly affected.

Definitively measuring the one-way speed of light is theoretically impossible, as it requires a clock on each end of the test and those clocks have to be synchronized using an arbitrary synchronization protocol. However, it may be possible to test for an anisotropic light speed using two unsynchronized atomic clocks. Conceptually, start with a 100 m vacuum-filled tube, with a light sensor and an atomic clock at each end. Inject a pulse of light at one end, and record the difference between the times at which it passes each of the sensors. Because the clocks are not synchronized, that difference is an arbitrary value. Now wait a while, until the orientation of the tube has changed due to the Earth's rotation, and repeat the test. If the speed of light is anisotropic and the one-way light speed has changed then the difference between the two clock readings will have changed. Even though the unsynchronized clocks can't measure the (one-way) speed of light, they are very stable so they can measure changes in it. Selleri's equation predicts the amount of that change, as a function of the change in the angle between the tube's orientation and the direction towards Leo.

The nominal transit time for the test is 333.56 ns. Selleri predicts that this will be increased by 0.41 ns when the light pulse is traveling in the Leo direction, and decreased by o.41 ns when it is traveling in the opposite direction. A nanosecond is a very long time for a modern atomic clock, so a potential two-way travel time variation of up to 0.82 ns every twelve hours should be readily observable. Minor temperature changes would affect the length of the tube, but not by a significant amount. The tube's length changes as the Earth rotates, due to the changing angle between the tube's axis and the direction towards Leo, but by an insignificant amount (the change in the Lorentz parameter γ).

3.2.1.3 The Use of the Tangerlini/Selleri Theory in AltU

This approach provides an alternative to the conceptually unsatisfying logic of special relativity theory. It doesn't explain the phenomena of the preferred (cosmic) frame for the universe, or why moving clocks slow and moving objects shrink, but it does provide a solid platform for a more complete theory of relativity. We will use that platform as a foundation for our investigation.

In general, we will compare predictions based on AltU's gravitational equations to observational data as if Earth-based observations were actually made in the cosmic frame. In general, that approach is acceptable- the relative distances and durations within an observed gravitational system are not significantly affected by the Earth's cosmic velocity.

3.2.2 Real Shortening

The metric equations of general relativity are usually purported to describe both spatial and temporal distortions in the presence of gravitational fields: time slows and space expands. The equations of special relativity show very similar effects on metric equations, but the spatial effects clearly can't be caused by spatial distortions: different conceptual frames moving in different directions can't distort space. The only credible explanation was offered by Lorentz himself: that speeding objects (i.e. 'rulers') shorten.

These alternative explanations pose a challenge to the conventional interpretation of a spacetime metric as a reflection of spatial as well as temporal distortions. Lorentz's belief that all moving physical objects actually shorten in the direction of their motion, as interpreted with Selleri's assumption that the shortening really occurs in the preferred frame for the universe, is suggestive. Real shortening of moving objects, and shrinkage of objects within gravitational fields, appears to provide a more coherent explanation than the concept of spatial distortion.

Real shortening of objects might be explained by changes in the shapes of the electrical fields of moving charged particles, caused by interactions between the charged particles and the virtual and/or conventional particles that inhabit the vacuum. And as we will discuss later, analogous changes in the shapes of gravitational fields might arise from the same mechanism.

3.2.3 Real Time Dilation

Imagine an observer in the cosmic frame, watching two other observers that are moving with equal and opposite velocities. The cosmic observer perceives that the moving observers each have the same amount of time dilation. However, if either observer uses the Lorentz transformation to predict the temporal rate of the other moving observer it indicates that the other observer's temporal rate is slower. The transformation also indicates that the cosmic observer's temporal rate is slowed with respect to that of each of the moving observers.

In AltU we use the cosmic coordinate system for both space and time. In order for a moving observer to know the real temporal rate of another moving observer, they would first have to use the inverse Lorentz transformation to find their own true temporal rate in cosmic coordinates, and then use the forward Lorentz transformation to find the true temporal rate of the other moving observer. The true temporal rates of the moving observers depend on their cosmic velocities.

If one observer is moving at a small fraction of the speed of light, and the other is moving at a large fraction, none of this really matters. An observer on Earth, using the Lorentz transformation on an infalling muon, will calculate its temporal rate quite accurately.

3.3 AltU's Conceptual Model of General Relativity

In the preceding parts of this introductory chapter we have framed the relativity problem, described the expected form of a physically-based explanation of relativity, and postulated an explanation for the observed phenomena of special relativity. We initiated that discussion of special relativity by saying that *"… The only credible explanation for this discrepancy is that something about an observer is physically changed as a function of its velocity- it isn't just mathematical magic. We need to identify what changes due to an object's velocity, and what causes those changes*."

We will now consider the phenomena of general relativity, and our focus will be on gravitational fields. Gravitational fields are just mathematical abstractions, but they represent real local physical changes both to space (the vacuum) and to the objects (matter) that exist within that space. These changes arise due to the matter that is present in the universe, as a function of its quantity, distance, and velocity.

We will introduce the conceptual basis for AltU gravitational physics in this section. This will be a fairly quick tour, largely free of equations, to set the stage for Chapter 4 where the discussion will become quantitative.

AltU's conceptual model of gravitation is founded on the concept of a local speed limit, an attribute of the vacuum, which determines both the speed of light and the speeds of clocks. The speed limit is reduced within gravitational fields. In AltU the lengths of physical objects and the speeds of clocks vary both as a function of their velocities (i.e. special relativity) and as a function of their local speed limit (i.e. general relativity).

3.3.1 Space in AltU

The large-scale distribution of the contents of the AltU universe forms a 'cosmic frame' that defines an unchanging three-dimensional flat spatial coordinate system. **In this paper, distances are based on this cosmic frame and are measured in (current 2020 CE) light years**. The Earth is not stationary in the cosmic frame, but its velocity is a small fraction (about 0.00123) of the speed of light.

We evade the complexity of shrinking rulers by expressing all distances, and velocities, in terms of our fixed distance unit.

AltU's spatial vacuum incorporates vacuum energy, and the intensity of the vacuum energy determines the local speed limit- the speed at which massless particles move. The vacuum energy intensity at a point is determined by the combined gravitational fields of all the masses within the point's cosmological horizon (the ever-expanding limit of its past light cone).

3.3.2 Time in AltU, and the Speed Limit

Despite the predictions of relativity theory, there is evidence that an absolute simultaneity of events exists. The strongest evidence is the observed instantaneous effect of the collapse of quantum entanglement ("*spooky action at a distance*"). In principle, the absolute occurrence times of events in AltU can be sorted, and event A can precede, be simultaneous with, or follow event B. This is very different from the conventional description of the universe, where the Lorentz transformation appears to imply that there is no absolute sequence of event times. The existence of true simultaneity lets us conceive of an absolute time coordinate in AltU.

As a mental image of a real speed limit, think of photons or moving mass particles as taking frequent naps: their paths are unchanged, but during their naps they have a zero velocity. The speed limit in AltU works that way: time-consuming interactions with virtual particles of the vacuum ('gravitons') reduce the net velocity of particles. The interruptions of photon trajectories define the speed of light, and the interruptions of mass particles reduce the speed of clocks.

In this paper we will seldom refer to absolute time. Our preferred measure of time is "cosmic time" t_c, which is the time associated with a clock at a place that experiences the average gravitational intensity at any given time. When we say that the universe is about 14 billion years old, we are referring to cosmic time: it is the proper time of the universe. We will also sometimes refer to the time recorded by a specific observer, or to the local time measured by a clock at a specific location.

When we present equations involving time in AltU we always specify the observer whose clock is used. Most often it is the "cosmic observer", one observing gravitational phenomena from afar.

3.3.3 The Effect of Distant Masses

These concepts imply that the nature of the vacuum has been evolving over time, and that it varies spatially due to local gravitational fields. Any given point in the universe is experiencing the combined gravitational fields of all the masses within its cosmological horizon, and that horizon has been growing for some 14 billion years. This has caused the vacuum energy density to grow, and the speed limit to shrink. In AltU the gravitational fields of nearby masses are not just local phenomena, instead they are minor local variations in the gravitational field that pervades the universe.

Thus in AltU much of local physics is determined by the large-scale distribution of matter in the universe, via gravitational fields. This has echoes of Mach's principle, whereby the distant stars determine an absolute framework for rotation.

As the vacuum energy density grows a cosmic clock records a decreasing fraction of absolute time, so in terms of absolute time a cosmic second now is longer than a second was in the past.

In AltU we assume that prior to the 'start time' the universe's contents were pure energy (i.e. massless particles), and we assume that energy doesn't have a gravitational field. At the start time something changed and masses rapidly emerged ('baryogenesis'), with a statistically stationary density distribution and at a very high temperature, dominated by normal matter. Every particle of mass has its own gravitational field, and that field has expanded at the speed of light ever since that particle came into existence.

3.3.3.1 The Propagation of Gravitational Fields

Something other than mathematical magic must underlie the propagation of the gravitational field of a mass. Whatever that something is, it travels at the same speed as light. Unlike light it is unaffected by electromagnetic fields, and it passes freely through matter. It was not impeded by the baryon-photon plasma that preceded the time of recombination (when the cosmic microwave background photons were freed).

There are few obvious candidates for a particle of some sort that might carry out the propagation of gravity. Speculatively, gluons might do the job. Gluons are involved in the strong nuclear force, and serve to lash quarks together to form hadrons, the basic components of matter. Gluons have some quite strange properties (see Gluon - Wikipedia), and if they were to routinely leak out of hadrons and escape to the wider universe they might serve as the intermediaries that 'paint' gravitational fields into space.

Reserving the right to be corrected by actual observational data, in this document we will use the term gluons to represent the propagators of gravitational fields.

3.3.3.2 Gravitons and the Gravitational Intensity

We assume that the speed limit and the resulting local gravitational effects are mediated by virtual particles, and refer to those local particles as "gravitons". Most likely, our gravitons are in fact Higgs bosons. Higgs particles are not thought to have any role in gravitation, but in AltU they play the role of the enforcers of the speed limit. In AltU Higgs particles interact with all other particles, both massless particles and particles with mass, and the time consumed by those interactions reduces the velocities of the particles. In the conventional universe mass arises via Higgs particle interactions, but in AltU it arises by a quite different mechanism, one that involves gluons. This is discussed in section 6.3.2.

The graviton density is related to the vacuum energy density, and it has grown over time following the same general pattern by which the conventional universe expanded: explosively fast initially, and much more sedately at the present time. The graviton density at any given point is a function of a parameter that we refer to as 'the total gravitational intensity', U_{tot}, which is discussed in section 4.3.1. The total gravitational intensity is the negative of the total gravitational potential, divided by the constant c^2.

Currently in AltU the total gravitational intensity at any point reflects all of the masses within a radius of about 590 billion light years, as gravitational fields now extend about five times farther than the origin of the cosmic microwave background. As a result of the enormous volume that is involved the gravitational intensity is very uniform, with very small increases in the vicinity of large masses. At the Earth's surface, the intensity due to the rest of the (non solar-system) mass within Earth's past cosmological horizon is 3 billion times as great as the intensity due to the Earth!

The gluons and gravitons underlie Mach's principle, and the 'fog' of gravitons is the vacuum-filling aether that has long been sought. The mean graviton velocity is zero in the frame of the universe's matter, making it the preferred frame for Selleri's special relativity theory.

3.3.4 The Graviton Density, the Speed of Light, and the Speed of Time

Light waves travelling through glass are slowed slightly, as their photons interact with electrons within the glass. Each interaction consumes some time, and during an interaction the photon's advance is paused. In AltU, photons (and most other particles) interact in an analogous way with the gravitons, and as a result the graviton density controls the vacuum speed of light. The slowing occurs everywhere, but it is slightly more pronounced in the vicinity of large masses, due to the slightly increased graviton density there. Also, objects moving at significant velocities encounter more gravitons than stationary objects do, so they are slowed a bit more than stationary objects are. This slowing underlies the relativistic mass increases described by special relativity theory. We will expand on this below, in section 3.3.6.

The graviton density is proportional to $e^{2U_{tot}}$. The gradually increasing gravitational intensity over cosmic time represents an increasing graviton density which has slowed everything, so as time has passed temperatures have dropped along with the speed of light.

Quantum uncertainty may reflect the random spatial and temporal loci of graviton interactions.

By and large, clocks are comprised of moving particles of matter, so the slowing of matter particles due to graviton interactions results in slowed clocks. An electron's path within an atom is slowed, and this results in smaller atomic and molecular sizes— and shortened rulers. A moving ruler encounters more gravitons than a stationary ruler does, and those interactions cause an anisotropic shrinkage, shrinking the ruler along the direction of its motion. An object close to a significant mass encounters more gravitons than an object that is further away, so a clock that is close to a mass is slower than a clock further away.

3.3.5 A Varying Speed Limit: Implications for Values of Physical Constants

George Ellis (Ellis, 2008) discusses the implications of varying speed of light (VSL) cosmologies, and provides a check-list for the credibility of any such concept. One of the key items that Ellis points out is that the speed of light is integral to the equations of electromagnetism, as the speed of light in a vacuum can be expressed as a function of the electrical permittivity ε_0 and the magnetic permeability μ_0

of free space: $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$. Thus any valid VSL theory has to predict credible variations to the values of ε_0 and μ_0.

As an example of this, in 1957 Robert Dicke proposed a VSL theory of gravitation (Dicke, 1957). Dicke postulated that in the vicinity of a spherical mass $\varepsilon_0 = \mu_0 \cong 1 + \frac{2GM}{r}$, which leads to a speed of light equal to $\frac{1}{\sqrt{\varepsilon_0 \mu_0}} \cong c/\left(1 + \frac{2\mathrm{GM}}{\mathrm{r}}\right)$ (Dicke used units where *c*=1, so there is a hidden c^2 term following the '*r*' in his expressions). The foundational concepts of Dicke's theory are similar to those of AltU, and the reader of the present paper might find Dicke's paper illuminating.

Dicke went on to explore the implications for other physical constants. AltU's solution for the speed of light is quite different from Dicke's, but Dicke's conclusion that a changing speed of light would affect both lengths and atomic frequencies appears to be correct. Dicke found that atomic sizes would change in proportion to the square root of the speed of light, and that atomic clock frequencies would vary in the same proportion. The implication for AltU is that material objects have diminished in size over cosmic time, and cosmic time itself has slowed.

In regard to ε_0 and μ_0, the fine structure constant is known to have been very stable over billions of years (Uzan, 2003), and for this to be the case with a variable speed of light both ε_0 and μ_0 would have to vary inversely with the local speed of light, c_{loc}. The Coulomb constant, k_e, would have to vary directly with the local speed of light.

3.3.6 Velocities in AltU

AltU's distances are absolute, but the velocities that we discuss in this paper are based on those distances divided by times measured by clocks at specifically-identified locations— our velocity values are based on clock time, not absolute time. Also, the velocities that we refer to do not represent the values that would be measured using a local ruler, because we use absolute distances. Locally-measured velocities would be equal to our velocities multiplied by the local contraction factor. Thus where we predict a reduction in the local velocity of light a ruler-based measurement might report a constant value equal to c.

Masses are comprised of moving particles, and the motion of each particle is interrupted by its interactions with gravitons. Between interruptions a particle's motion follows a straight path and has a constant velocity in terms of absolute time. Interactions with gravitons simply delay a particle, but interactions with other particles can result in an exchange of momentum between the particles. The locations of the interactions are random, functions of the world-lines of the particles that interact.

A clock records the average amount of absolute time that its component particles accrue between their graviton interactions, which is known as its proper time.

A particle will slow down if it enters a region of increased graviton density, and speed up if it enters a more rarefied region. This behavior is distinct from the Newtonian acceleration due to the gradient of the gravitational intensity. As a thought experiment, place a moving clock inside a large hollow shell of mass, and slowly compress the shell. The graviton density within the sphere is homogeneous but slowly increasing, and both the velocity of the clock and its temporal rate will slowly decrease. An observer traveling with the clock would be unaware of the change.

3.3.6.1 Speeds

As in the conventional universe, in AltU nothing (except a collapsing entanglement) can travel faster than the speed of light, and at light speed proper time halts. This implies that photons (i.e. massless particles) spend all of absolute time engaged in graviton interactions. In principle a photon is a clock that records the passage of absolute time, with each graviton interaction corresponding to one tick.

Each successive interaction occurs further along the photon's path, and the photon takes zero time to jump from one interaction site to the next. If each interaction consumes the same amount of absolute time then the observed speed of light is proportional to the distance between graviton interactions, and thus inversely proportional to the gravitons' spatial density.

What defines a speed in AltU? Consider a timing experiment in a stationary laboratory involving a brief span of absolute time, a ruler, a clock, and a photon and an electron whose speeds are to be measured:

- Once it is launched the photon repeats a two-step process again and again: it spends some absolute time frozen in a graviton interaction and then it jumps instantaneously to its next interaction locus.
- The electron follows the same path as the photon, but more slowly. Its two-step process is to spend some time in a graviton interaction and then spend some time moving towards the target at a finite speed[4]. While it is moving its proper velocity is unchanging. Increasing that proper velocity has diminishing returns in terms of its observed velocity, because of its time dilation- its proper velocity would have to become infinite before it would match the speed of light. This is the process that underlies the mass increases described by relativity theory.
- The mass particles that comprise the clock or the ruler also repeat a two-step process: like the electron they each spend some time frozen in a graviton interaction and then spend some time in motion, pending the next graviton interaction. Even if the clock or ruler is stationary, its internal particles are always in motion. The more gravitons they encounter, the less distance they travel per unit of absolute time, the smaller the clock or ruler becomes, and the slower the clock's speed.

In general, graviton interactions slow clocks and shrink rulers in the same ratio, which is equal to the square root of the factor by which the speed of light changes. As a result local ruler-based measurements of the speed of light always yield c, even if the gravitational field strength, or the system's velocity, changes. However, an external observer outside of a local gravitational field observes the true reductions in clock speeds and ruler lengths within the field.

3.3.6.2 Relativistic Mass Increases

A force that is applied to a particle can only cause acceleration during time periods when the particle is not engaged in a graviton interaction. During those time periods the particle's absolute velocity changes as per Newton, in direct proportion to the force divided by the particle's rest mass.

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[4] This finite speed may only be apparent. Quantum experiments suggest that all motion is actually comprised of instantaneous microscopic jumps from one location to the next.

Consider a particle that has a different temporal rate than an observer, due to its relative velocity and/or gravitational intensity. If the observer perceives the particle's time dilation factor to be $\frac{d\tau_{obj}}{dt_{obs}}$, the observer will perceive its acceleration due to an applied force as being multiplied by $\frac{d\tau_{obj}}{dt_{obs}}$: its inertial mass appears to increase when its time dilation factor is less than one. We will derive the full equation for $\frac{d\tau_{obj}}{dt_{obs}}$ later, in 4.4.2.

3.3.7 The AltU Observers

As we develop the equations of relativity for AltU, we will repeatedly use a paradigm that involves three parties. We highlight below some concepts that will arise frequently in the rest of the paper:

1. A stationary cosmic observer, not affected by any local gravitational fields. The cosmic observer's (proper) time coordinate is t_c, and its current local speed of light is c_c. Note that c_c represents the average speed limit in the universe at any given time, but there are always local fluctuations due to inhomogeneities in the universe's mass distribution.
2. A stationary local observer that is within a local gravitational field. The local observer's (proper) time coordinate is t_{loc}, and its current local speed of light is c_{loc} (using the fixed distance unit). The cosmic observer sees the speed of light at the local observer's location to be c_{loc_c}.
3. A moving object at the same gravitational intensity as the local observer. The moving object's proper time coordinate is τ_{obj}. It perceives its velocity to be v_{obj}, the local observer perceives the object's speed to be $v_{obj\_loc} = v_{obj}\frac{d\tau_{obj}}{dt_{loc}}$, and the cosmic observer perceives the object's speed to be $v_{obj\_c} = v_{obj}\frac{d\tau_{obj}}{dt_c}$.

Recall that in AltU space is stable, so all our observers agree on distances and spatial coordinates. However each party experiences time at a different rate, and the speed of light varies with location and over time. Whenever we refer to a time coordinate or a velocity we will be careful to identify which party's time we are referring to. When we refer to an object's temporal rate, it is expressed as the ratio of the object's time to a cosmic observer's time during the same absolute time increment. Whenever we refer to the speed of light we will be careful to identify where and when that speed is observed, and in which observer's time coordinate its value is expressed.

4 AltU's Speed Limit

In this fourth part of the paper we will derive the equations for AltU's speed limit. They will be the foundations for the subsequent discussions of cosmology and gravity.

4.1 The Local Speed Limit c_{loc}

Many variable speed of light (VSL) theories have been proposed over the years, going all the way back to Einstein himself. There is a good summary discussion in the Wikipedia article at Variable speed of light - Wikipedia. A key difference between the AltU approach and most of the other variable speed of light theories is that in AltU it is not just the speed of light that varies; in AltU when the speed limit changes the temporal rate also changes.

In Dicke's (Dicke, 1957) proposed theory the atomic physics predicted that both the lengths of solids and atomic frequencies would vary in proportion to the square root of the speed of light. In such a case a reduction in the local speed of light would not be locally measurable using a clock and a ruler, though its effects would still be observable by a remote observer.

The speed of light measured in a local region which has a gravitationally-affected speed limit is referred to herein as $\mathrm{c_{loc}}$. The equation for $\mathrm{c_{loc}}$ will be derived later, but for the time being we will just use $\mathrm{c_{loc}}$ to refer in a generic way to a local speed of light. Note that $\mathrm{c_{loc}}$ is measured based on local time and the cosmic distance unit, not on a local meter-stick. The cosmic observer's measure of the speed of light in the observed location, using cosmic time and the cosmic distance unit, is $\mathrm{c_{loc\_c}}$.

4.1.1 The Shapiro Effect

Observations of the delay of light as it passes the Sun (the "Shapiro effect") indicate that the speed of light in the gravitational field in the Sun's vicinity is multiplied by a factor of $1+\frac{2\varphi}{c^2}$ (recall that φ is a small negative value). The speed of light in a gravitational field, observed by a cosmic observer, is thus $c_{loc\_c} \cong c_c\left(1+\frac{2\varphi}{c^2}\right)$. The $\frac{\varphi}{c^2}$ ratio is very small, so the observed $1+\frac{2\varphi}{c^2}$ factor is equivalent to the square of the observed time dilation factor in the vicinity of a mass, $\frac{d\tau}{dt_{loc}} \cong 1+\frac{\varphi}{c^2}$. A local observer, with their slowed temporal rate, would have observed $c_{loc} \cong c_{loc\_c}/\left(1+\frac{\varphi}{c^2}\right) \cong \mathrm{c_c}\left(1+\frac{\varphi}{c^2}\right)$.

Overall, the local temporal rate and the locally-measured speed of light (using the cosmic distance unit) are both reduced by the same factor:

$$\frac{dt_{loc}}{dt_c} \cong \frac{c_{loc}}{c_c} \cong \frac{c_{loc\_c}}{c_{loc}} \cong 1+\frac{\varphi}{c^2} \tag{4.1}$$

Note that in order for a local light speed measurement near to the Sun, based on a local ruler, to still equal c the ruler must have shortened by the same $1+\frac{\varphi}{c^2}$ factor by which local time was slowed. The local observer perceived that their light-speed measurement took less time, and covered more distance, than the distant observer thought- and both observers measured their own local light speed to be c. Thus, as predicted by Dicke, the local reduction factor for the temporal rate and the reduction factor for atomic sizes are each equal to the square root of the factor for the speed of light.

The cosmic observer perceives the speed of light at the local observer's location to be:

$$c_{loc\_c} \cong c_c \left(\frac{dt_{loc}}{dt_c}\right)^2 \tag{4.2}$$

The cosmic observer perceives that the gravitational intensity at the observed location has decreased the speed of light by the square of the time dilation ratio. This reduction is what the Shapiro effect describes. In AltU the refractive index of the space inside a gravitational field is $\frac{c_c}{c_{loc\_c}} = \left(\frac{dt_c}{dt_{loc}}\right)^2$, and it correctly predicts gravitational lensing.

In AltU the Shapiro effect's time delay of light has contributions from two processes:

1. Time is slowed near to the Sun, and
2. The speed of light there, measured using a local clock, is also reduced.

General relativity's explanation of the Shapiro effect also has contributions from two processes:

3. Time is slowed near to the Sun, and
4. The region contains more space than it would if the Sun wasn't there.

(More specifically, in general relativity theory space expands in the presence of a gravitational field, and in general it expands unequally in different directions, requiring a second-order tensor field to correctly describe the expansion. In general relativity practice (as opposed to theory) the expansion is usually treated as being isotropic.).

As will be discussed later, the difference between the explanations of the Shapiro effect— either a reduced speed of light or increased spatial distances— also plays out at a much grander scale: that of the universe as a whole. In many ways the resulting predictions made by the two approaches are similar, so we will need to look quite closely in order to find physical observations and tests that can discriminate between them.

4.2 The Local Effects of Time Dilation

Lorentz and Selleri both say that a moving object's temporal rate is defined by the Lorentz factor γ:

$$\frac{d\tau_{obj}}{dt_{loc}} = \frac{1}{\gamma} = \sqrt{1 - \frac{v_{loc}^2}{c^2}}$$

Where $d\tau_{obj}$ is a time span experienced by the moving object, dt_{loc} is the corresponding time span for a local observer, and $v_{loc} \equiv dx_s/dt_{loc}$ is the spatial velocity of the object based on the local observer's time coordinate.

In AltU this equation is presented as an explicit function of the local speed of light:

$$\frac{d\tau_{obj}}{dt_{loc}} = \frac{1}{\gamma} = \sqrt{1 - \frac{v_{loc}^2}{c_{loc}^2}} \tag{4.3}$$

Note that γ is unaffected by the choice of spatial and temporal units, provided the same units are used to measure v_{loc} and c_{loc}.

4.3 The General Equation for the Speed Limit

4.3.1 The Gravitational Intensity U

As mentioned above, nearby masses are observed to cause a reduction in the speed limit at a location, evidenced by a reduced local clock speed there— this is referred to as time dilation. The observed gravitational time dilation ratio near the Earth is a simple function of the sum of each of the nearby (rest) masses divided by its distance: $\frac{d\tau}{dt_c} \cong \frac{G}{c^2}\int \frac{\rho}{r} dv_{nearby} = 1 + \frac{\varphi}{c^2} = 1 - U$. Here ρ is the mass density, φ is the conventional gravitational potential, and U is the potential used in the parameterized post-Newtonian formalism (see Poisson and Will, 2014). For mass j in a set of masses:

$$U_j = -\varphi_j/c^2 = \frac{G}{c^2}\Sigma_{i\_nearby}\frac{m_i}{r_{ij}} \tag{4.4}$$

The Newtonian gravitational acceleration vector $\overline{\boldsymbol{g}} \equiv -\overline{\boldsymbol{\nabla}}\varphi = c^2\overline{\boldsymbol{\nabla}}U$. Note that c refers to the SI constant, not to the local speed of light c_{loc}.

In AltU we call the U parameter the "local contribution to the gravitational intensity". U represents a very small increment to a much larger parameter that we refer to herein as the **"**total gravitational intensity", represented by the U_{tot} symbol:

$$U_{tot\_j} = \frac{G}{c^2}\Sigma_{all}\frac{m_i}{r_{ij}} = \frac{G}{c^2}\int_{all}\frac{\rho}{r}dv \tag{4.5}$$

The value of U_{tot} at a point is the sum of all of the point's surrounding masses divided by their distances. The only restriction on "all" is that the contributing masses must lie within the cosmological horizon of the point.

Whenever the U variable is used, it refers to the difference between the total intensity at an observed point and the total intensity at the observer's space and time location. Conventionally, the observer's location is affected by all of the external gravitational fields that affect the system that is being considered, but it is not affected by the gravitational fields of the observed system. The shorthand version of this is that the observer is at the same potential as "the distant stars".

As we will discuss below, U_{tot} quantifies the physical attribute of space that underlies all relativistic phenomena in AltU. U_{tot} determines the cosmic speed of light, and it will dominate our discussion of cosmology in AltU. However, it is the local variations in U_{tot} that determine gravitational behavior, and those variations are reflected in the local contribution, U. Thus in our discussion of gravity in AltU, the U parameter will be central.

4.3.2 The Speed of Time, the Speed of Light, and the Gravitational Intensity

As mentioned above, for a stationary local clock which incremented by dt_{loc} while the cosmic observer's clock incremented by dt_c the observed time dilation relationship can be expressed as:

$$\frac{dt_{loc}}{dt_c} \cong 1 - U \tag{4.6}$$

Here U represents the increase in the gravitational intensity due to the local masses. U is typically a small number, much less than one— at the solar surface it is equal to 2.12e-6. U diminishes slowly with distance from a mass- at the Earth's surface the solar contribution has been reduced to 9.87e-9, but it still significantly exceeds the Earth's contribution of 6.96e-10.

General relativity theory extrapolates the very small observed time dilation factors to larger values of U using $\frac{dt_{loc}}{dt_c} = \sqrt{1-2U}$. For a single high-density central mass, this predicts that time stops[5] at its event horizon, the Schwarzschild radius, $r_s = \frac{2Gm}{c^2}$.

Equation (4.6) shows that a small increase in the local gravitational intensity slows local time. However, the local intensity is a very small component of the total intensity U_{tot}, and U_{tot} is steadily increasing due to expanding cosmological horizons- so that cosmological increase should also slow time. Based on current cosmological theory, the rate of increase of U_{tot} is[6] 1.06e-10 a^{-1}. If general relativity's equation is correct then time should halt when U_{tot} increases by 0.5. Based on the current rate of increase of U_{tot}, that prediction will come true in about 4.51 billion years. That seems unlikely to eventuate, which leads us to reconsider how the results of observed small-U variations should be extrapolated to larger U values.

Recall equation (4.1), which shows that $\frac{dt_{loc}}{dt_c} \cong \frac{c_{loc}}{c_c}$. This relationship is helpful, because we have quite precise measurements of the time dilation factor, and we don't have any direct measurements of the variation in the speed of light. Based on (4.1), equation (4.6) implies that $\frac{c_{loc}}{c_c} \cong 1 - U$, and thus $c_{loc} \cong (1-U)c_c$. Can we generalize this relationship to apply more universally?

We should view the inferred $c_{loc} \cong (1-U)c_c$ relationship as representing a derivative of the underlying relationship between the speed of light and U, measured at one particular value of U:

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[5] As discussed in Appendix A, this implies that things that travel at the speed of light freeze at the Schwarzschild radius. Since gravity propagates at the speed of light, it implies that a black hole's gravitational field is trapped within its event horizon. So black holes should have no gravitational fields, and they should be unaffected by external gravitational fields!

[6] See the prelude, and the discussion in Chapter 5, which contains the cosmic results for AltU. For AltU the current value of the total gravitational intensity in the universe, U_{tot}, is about 20.82, and its fractional rate of increase is the Hubble rate H, about 7.16e-11 a^{-1}. Thus in AltU $\dot{U}_{tot}$ =20.82(7.16e-11 a^{-1})=1.49e-9 a^{-1}

$$\frac{dc_{loc}(U)}{dU} \cong \frac{d(1-U)}{dU} c_c = -c_c$$

Although we effectively only know this derivative at one point on the $c_{loc} - U$ curve, it suggests a simple exponential form for the local speed limit: $c_{loc} = c_c\, e^{-U}$, or $\frac{c_{loc}}{c_c} = e^{-U}$. Applying equation (4.1) we get a fundamental local relationship:

$$\frac{c_{loc}}{c_c} = \frac{dt_{loc}}{dt_c} = e^{-U} \tag{4.7a}$$

This local equation can be seen as part of a more universal one. Imagine a cosmic observer located at the start time of the modern universe (when the total gravitational intensity is by definition equal to zero), contemplating a location where the gravitational intensity is equal to U_{tot}. If we define c_{start} as the speed of light that our observer measures (at the beginning of cosmic time), then:

$$\frac{c_{loc}}{c_{start}} = \frac{dt_{loc}}{dt_{start}} = e^{-U_{tot}}$$

Now replace the observed start-time location by that of another cosmic observer, one that is at a later time in the history of the universe, t_c when the cosmic light speed is $c_c(t_c)$. We can express the above relationship as:

$$\frac{c_c(t_c)}{c_{start}} = \frac{dt_c}{dt_{start}} = e^{-U_{tot}(t_c)} \tag{4.7b}$$

Equation (4.7b) describes how the cosmic speed of light, and the cosmic temporal rate, have evolved over the life of the universe. Both of these parameters have declined exponentially with the growth of the total gravitational intensity.

Equations (4.7 a and b) describe the speed limit everywhere in AltU. In Chapter 5 we will show that (4.7b) predicts the cosmic Hubble redshift diagram over a very wide range of U_{tot} values, and in Chapter 6 we will use gravitational tests to evaluate the effects of small local variations in U using (4.7a).

Note that because the local speed limit never drops to zero equation (4.7a) removes all of the bizarre behaviors currently associated with black holes- they just become very dense bodies, near to and within which time runs very slowly, which cause extreme red-shifts to any escaping electromagnetic rays. There is no sharp distinction between neutron stars and black holes. The gravitational fields of black holes propagate externally, and they are affected by external gravitational fields- though there may be some significant time lags involved.

4.3.3 AltU vs the Conventional Expanding Universe

Because the cosmological horizon never stops expanding $U_{tot}(t_c)$ continually increases, so equation (4.7b) implies that the speed limit has been decreasing ever since mass arose in the universe. Thus, in the early universe the fraction of the universe that a light ray would traverse in a single second was much greater than it is now. The same can be said of the conventional expanding universe, and it turns out that in many ways the dynamics of the two universes are comparable. AltU's distances are analogous to the conventional universe's comoving distances, and $e^{(U_{tot}(t_c)-U_{tot}(t_{c0}))}$ is analogous to the conventional universe's scale factor.

However, the distinction between the two concepts is real, and AltU is spatially static. There is quite strong astronomical evidence that the real universe is spatially static, evidence that has not been generally recognized. Chapter 5 discusses cosmology in AltU, and compares its predictions to observational evidence.

4.3.4 AltU and Quantum Entanglement

Equations (4.7) do not imply that the current speed of light is an absolute limit on interactions. If there are types of motion or interactions that are unaffected by the presence of gravitons, some modes of transmission of information between particles could occur at the same speed at which photons skip to their next graviton encounter. That appears to be infinite.

4.4 The Local Speed Limit and the Proper Time Equation

4.4.1 The Local Speed of Light

Equation (4.7a) shows that the local temporal rate $\frac{dt_{loc}}{dt_c}$, is equal to e^{-U}. This slowing of time is caused by the increase in the graviton density due to the gravitational fields of nearby masses[7]. This relationship lets us update equation (4.2) $\left(\mathrm{c}_{\mathrm{loc\_c}} = \mathrm{c}_{\mathrm{c}}\left(\frac{dt_{loc}}{dt_c}\right)^2\right)$ to define the local speed of light from the cosmic observer's perspective:

$$c_{loc\_c} = c_c e^{-2U} \tag{4.8}$$

Recall that c_{loc}, which equals $c_c e^{-U}$, is defined based on a local clock and our fixed cosmic distances. What would a local observer measure if they used a meter-stick instead? If we took a cosmic meter stick to the location in question, we would expect its length to shrink by a factor of e^{-U}. The local observer, measuring their speed of light, would therefore find it to equal c_c.

That means the local observer, using a local meter stick, will measure the same value as the cosmic observer. Since our 20'th century local observers measured the speed of light as c we conclude that the current value of the cosmic observer's speed of light, c_{c0}, is c.

In general in AltU, any observer that measures their local round-trip speed of light using a local clock and meter stick will measure c- the same result as in the conventional universe. It is only when we express distances using the cosmic scale that the speed of light decreases over time.

In some ways this is all just using different words to describe an expanding universe. In AltU rulers shrink and clocks and the speed of light slow over time, while in the conventional universe rulers and clocks and the speed of light are stable over time, but space expands. However, as we will see, AltU's stable universe predicts cosmic redshifts with no recourse to a concept of dark energy, AltU predicts

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[7] In equation (4.7a) our choice of the 'cosmic' observer with their associated cosmic speed limit c_c was arbitrary. The same equation form can be used to evaluate speed limit ratios for any two comoving points, by defining the integral to capture only the differences between the global $\int \frac{\rho}{r} dv$ integrals for the two points.

black holes that don't violate common sense, and AltU predicts galaxy sizes over time that match observations- which the conventional universe doesn't.

4.4.2 The Generalized Proper Time Equation in AltU

Recall the basic equation (4.3) for special relativistic time dilation: $\frac{d\tau}{dt_{loc}} = \frac{1}{\gamma} = \sqrt{1 - \frac{v_{loc}^2}{c_{loc}^2}}$. We can now convert this to use the cosmic observer's time t_c and their speed of light c_c, and incorporate the actual values of the speed limits, per equation (4.7a), to get the generalized version for a cosmic observer:

$$\frac{d\tau}{dt_c} = \frac{d\tau}{dt_{loc}}\frac{dt_{loc}}{dt_c} = e^{-U}\sqrt{1 - \frac{v_{loc}^2}{c_{loc}^2}} = \sqrt{e^{-2U} - \frac{v_{obj\_c}^2}{c_c^2}e^{2U}} = \frac{e^{-U}}{\gamma} \tag{4.9}$$

Equation (4.9) shows that e^{-U} is the cosmically-observed time dilation factor for a stationary observer or for an object moving at a low speed, with a $1/\gamma$ multiplier if it is moving at a significant speed. The equation is quite general, the only constraint is that the observer and the observed location have the same cosmic time. If their cosmic times are significantly different the equation has to be adjusted to compensate for the different cosmic speed limits at the two locations.

Recall that a time-dilated mass has an apparent increase in its inertial mass, as discussed in section 3.3.6.2, by a factor of $\frac{dt_c}{d\tau}$.

4.4.3 The Cosmic-Observer's Perspective

All observers in AltU use the same spatial coordinates, but their temporal coordinates differ. The basic equation for converting temporal coordinates is (4.7a): $\frac{dt_{loc}}{dt_c} = e^{-U}$.

A cosmic observer's view of a local velocity is described by the chain rule:

$$\boldsymbol{\bar{v}_c} \equiv \frac{d\boldsymbol{\bar{x}_s}}{dt_c} = \frac{d\boldsymbol{\bar{x}_s}}{dt_{loc}}\frac{dt_{loc}}{dt_c} = \boldsymbol{\bar{v}_{loc}}\, e^{-U} \tag{4.10}$$

A cosmic observer's view of a local acceleration uses the second-derivative chain rule:

$$\boldsymbol{\bar{a}_c} = \frac{d^2\boldsymbol{\bar{x}_s}}{dt_c^2} = \frac{d^2\boldsymbol{\bar{x}_s}}{dt_{loc}^2}\left(\frac{dt_{loc}}{dt_c}\right)^{\mathbf{2}} + \frac{d\boldsymbol{\bar{x}_s}}{dt_{loc}}\frac{d^2t_{loc}}{dt_c^2} = \boldsymbol{\bar{a}_{loc}}\, e^{-2U} - \boldsymbol{\bar{v}_{loc}}\, e^{-U}\frac{dU}{dt_c} \tag{4.11}$$

5 Cosmology in AltU

The conventional universe has a standard “concordance” cosmological model, built around the concepts of the Big Bang and the expanding universe. The model is detailed, precise, and quite complex. However, as discussed in Appendix A, its conceptual foundations are shaky.

For example, the conceptual basis for the expanding universe was Friedmann’s assumption that the universe could be treated as it was homogeneous, which enabled the application of Einstein’s field equation to it. Obviously the universe isn’t really homogeneous, so there must be some real physical mechanism by which discrete masses cause the expansion of the universe. For example, my coffee cup must currently be contributing to the expansion of the universe. Does it gush out space like a fountain? Or emit some invisible particles that at a distance erupt into spatial bubbles? The mathematical physicists don’t care about such mundane questions, but I would have hoped that over the last hundred years this most fundamental question would have challenged real-world physicists.

At a more pragmatic level, consider the following simple observation: “*Assuming the standard cosmological model as correct, the average size of galaxies with the same luminosity* (energy radiation rate*) is 6 times smaller at z=3.2 than at z=0”* (Lopez-Corredoira, 2010). That observation implies that modern galaxies are structurally very different from older ones— they must somehow have been evolving physically, either expanding at roughly the same rate as the expansion of the universe, or dimming. However, general relativity theory doesn’t predict any such expansion. So perhaps galaxies aren’t really expanding— perhaps many of the older galaxies are in fact quite similar to modern ones. Lopez-Corredoira found that a static universe, with effectively unchanging galaxy sizes, passed the angular size test that the standard model of the universe appears to fail.

There are a multitude of other criticisms of the standard model of cosmology, which are summarized in Lopez-Corredoira, 2017. At their heart, the criticisms portray the standard model as a continually-evolving construct that has repeatedly been made more elaborate in order to conform to new astronomical observations that it failed to predict. For example, dark energy didn’t exist prior to some new astronomical observations, in the 1990’s, that couldn’t be explained without it.

5.1 *The Evolution of the Cosmic Speed Limit c_c*

For a cosmic observer at time t_c, equation (4.7b) defines the cosmic speed of light:

$$c_c(t_c) = c_{start}e^{-U_{tot}(t_c)} \tag{5.1}$$

Here $U_{tot}(t_c)$ represents the mean gravitational intensity at time t_c, at a location far away from any localized mass concentrations. The evolution of U_{tot} is based on the average mass density of the universe, and on the expansion of gravitational fields since the start time.

The history of U_{tot} is central to cosmology in AltU, and in the following sections we will develop its equations and compare the resulting predictions to observed astronomical data. The $e^{-U_{tot}(t_c)}$ term in (5.1) is a sort of inverse version of the conventional universe’s scale factor, which increased explosively following the Big Bang.

5. Cosmology in AltU

5.1.1 The Main Cosmological Effects of the Decreasing Speed Limit

The gravitational intensity at an average point increases continuously over time, as the point's cosmological horizon expands and the effects of ever more distant masses are felt. This causes the cosmic speed limit to continuously decrease. The decreasing speed limit has a number of effects, and by and large they are the same as the effects of an expanding universe:

- Photon speeds and energies drop, and the universe cools down from its high initial temperature.
- Velocities of masses decrease (in the conventional universe it is the comoving velocities that decrease).
- Due to the reducing velocities particle collision rates drop, and the recombination and reionization processes occur.
- Observers see redshifts and time dilation in light emitted at earlier times.

The following sections derive the equations for the evolution of a spatially-static universe that starts as a very uniform, unbounded, hot, low-density mass-filled domain that does not yet contain a gravitational intensity field. (Energy is also present, in the form of radiation, but that does not affect the model's predictions). The speed limit at that early time (c_{start}) was very high. Since then the speed limit has steadily decreased, reaching a value of $c_c(t_0) \equiv c_{c0}$ at the current time, t_0.

5.1.2 Cosmic Time t_c

In the following, we will use the natural time coordinate introduced previously: the cumulative proper time at a point unaffected by any local mass concentrations, referred to as "cosmic time", t_c. We define the cosmic time to equal zero at our start time, a time very early in the history of the modern universe at which there was a very high temperature: 3e9K. This corresponds to a redshift z of about 1.1e9.

5.1.3 The Horizon Radius $r_h(t_c)$

Cosmic time zero is a time just after the universe's mass formed and gravitational fields started to grow. Launch a non-interacting massless particle at that start time, and as it flies track its progress in terms of the distance it has travelled:

$$r_h(t_c) = \int_0^{t_c} c_c(t)\,\mathrm{d}t \qquad (5.2)$$

Here r_h is the 'horizon radius' of the particle: the distance from its launch-point at cosmic time 0 to its position at time t_c. Note that the history of r_h represents a map showing how far things that travel at the speed of light have moved.

At any given location, at observation time t_{obs}, the observer will be within the gravitational fields of all masses located within a sphere of radius $r_h(t_{obs})$ centered at that point. Inversely, the launch-time for arriving gravitational news that has travelled distance r is $r_h^{-1}(r_h(t_{obs}) - r)$. Ignoring local variations, the gravitational intensity at a point is $\frac{2\pi\rho G}{c^2} r_h^2$, where ρ is the mean mass density within the point's cosmological horizon.

For any arbitrary redshift value *z* the Earth is currently receiving photons emitted by all of the luminous astronomical objects in a thin spherical shell that corresponds to that redshift. The distance to that shell is $r_h(t_0) - r_h(t_z)$, where t_z is the emission time for the photons.

5.1.4 Redshifts

5.1.4.1 Local Gravitational Redshifts

In a local gravitational field, and after correcting for any velocity-related effects, the observer at a higher elevation sees everything at a lower elevation moving in slow motion, and sees red shifts in the light emerging from the lower elevation. Observers at the lower elevation see this reversed: the higher clock is seen to advance more quickly, and they observe a blueshift in light emitted from the higher elevation. These clock differences are not just matters of perspective: an object at a lower elevation (or with a higher velocity) really does age more slowly.

In order to understand gravitational redshifts in AltU, consider a simplified case of an observer looking at light emitted from within a gravitational 'box' region. The speed limit at the observer's location is c_{obs}. The observer is measuring the redshift of a spectral line that normally has frequency *f* and wavelength c_{obs}/f.

The speed limit inside the box is c_{box}. A single wavelength of light with (local) frequency *f* is emitted within the region. When the light wave crosses the boundary to exit the region it takes $1/f$ amount of local time to exit. The corresponding amount of time for the wave to emerge into the outer region is greater, equal to $(1/f)(c_{obs}/c_{box})$, because the clock speed is faster there by a factor of (c_{obs}/c_{box}). The emerged wave in the outer region has a wavelength equal to$(1/f)\left(c_{obs}^2/c_{box}\right)$, and the light wave has a redshift of
$z = \frac{observed\ wavelength}{normal\ wavelength} - 1 = \frac{(1/f)\left(c_{obs}^2/c_{box}\right)}{c_{obs}/f} - 1 = \frac{c_{obs}}{c_{box}} - 1.$ Based on equation (4.7a),
$z = e^{U_{box}} - 1 \cong U_{box}$, where U_{box} is the gravitational intensity within the box.

5.1.4.2 Cosmic Redshifts and the Hubble Parameter

Observations of distant objects exhibit the same pattern as the local observations by the higher-elevation observer mentioned above: the expected wavelengths for specific spectral lines are multiplied by a factor of 1+*z*, where *z* is the redshift parameter, and observed objects appear to move in slow motion. As an example of that slow motion effect, the multi-week durations of the brightness curves of type Ia supernovae vary with the redshift— on average, the observed durations are increased by the same 1+*z* factor that applies to redshifts (Goldhaber et al, 2001; Blondin et al, 2008).

However, cosmic redshifts and cosmic time dilation are caused by a completely different mechanism than gravitational redshifts— cosmic redshifts arise due to the effects of the slowing speed limit while a light-wave is in transit. We can think of the cosmic effect this way: for the entire trip both the front-end of a wave and the back-end were slowing, but at any given point during the trip the front-end of the wave was always a little bit faster, so its trip took less cosmic time than the back-end's trip did. As a result the wave's period increased, which is observed as a redshift.

5. Cosmology in AltU

Suppose that an object is emitting photons in all directions. The photons that it emits at cosmic time t_{emit} will form an expanding sphere that at any observation time t_{obs} has a radius equal to $r_h(t_{obs})$-$r_h(t_{emit})$.

Based on the definition of the horizon radius r_h, a second photon, emitted dt_{emit} later than the first, has an initial horizon radius of $r_h(t_{emit} + dt_{emit}) = r_h(t_{emit}) + c_c(t_{emit})\, dt_{emit}$. It will arrive at the same observation point as the first photon at time $t_{obs} + dt_{obs}$, when it has travelled the same distance as the first photon did ($r_h(t_{obs})$-$r_h(t_{emit})$). We can equate the distance travelled by the second photon to the distance traveled by the first, and find the relationship between dt_{emit} and dt_{obs}:

$$[End\ r_h\ for\ 2'nd\ photon] - [Start\ r_h\ for\ 2'nd] = [End\ r_h\ for\ 1'st] - [Start\ r_h\ for\ 1'st]$$

$$[r_h(t_{obs}) + c_c(t_{obs})dt_{obs}] - [r_h(t_{emit}) + c_c(t_{emit})dt_{emit}] = r_h(t_{obs}) - r_h(t_{emit})$$

Simplifying, we get:

$$dt_{obs} = dt_{emit}\frac{c_c(t_{emit})}{c_c(t_{obs})}$$

The time between the photons that the observer experienced was increased by a factor of $\frac{c_c(t_{emit})}{c_c(t_{obs})}$ compared to what the sender experienced. Any observed history, from a single wavelength to the entire history of a supernova explosion, is stretched by the same factor. The redshift is thus:

$$z = \frac{c_c(t_{emit})}{c_c(t_{obs})} - 1 = e^{U_{tot}(t_{obs}) - U_{tot}(t_{emit})} - 1 \qquad (5.3)$$

Note that $z > 0$ because $c_c(t_{emit}) > c_c(t_{obs})$. Also, the distance between the two photons is unaffected: $c_c(t_{obs})dt_{obs} = c_c(t_{emit})dt_{emit}$, so the light's (cosmic) wavelength is unchanged while it is in transit.

Recall equation (4.7a): $\frac{c_{loc}}{c_c} = \frac{dt_{loc}}{dt_c} = e^{-U}$. Based on it, equation (5.3) tells us that for an earlier point in time the ratio of the speed of light then to the speed now equals the ratio of the temporal rate then to the temporal rate now, and both ratios equal $1 + z$.

The Hubble redshift equation is $z = \frac{HD}{c}$, where *H* is the Hubble parameter and *D* is the distance to an observed star. This original equation applies only for short distances, and a more precise definition of H is that at any given cosmic time t_c its value is $H(t_c) = \frac{dZ}{d(age)}$, where age is the time since photon emission. Using equation (5.3), we find that $H(t_c) = -\frac{\dot{c}_c(t_c)}{c_c(t_c)}$. Using equation (5.1) with that, we find $H(t_c) = \dot{U}_{tot}(t_c)$.

$$H(t_c) = -\frac{\dot{c}_c(t_c)}{c_c(t_c)} = \dot{U}_{tot}(t_c) \qquad (5.4)$$

Equation (5.4) is significant, as it equates the Hubble coefficient to the rate of change of the gravitational intensity. Measurements of the present value of the Hubble coefficient H_0 will provide a key boundary condition in our solution for the history of U_{tot}.

Note that because of the time stretching of the signal the observed photon flux rate is less than the emitted rate, by a factor of $\frac{c_c(t_{obs})}{c_c(t_{emit})}$. In terms of observed luminosity, the period increase and the flux decrease each multiply the emitted luminosity by $\frac{c_c(t_{obs})}{c_c(t_{emit})}$ or $\frac{1}{1+z}$, so the observed luminosity is reduced, multiplied by $\frac{1}{(1+z)^2}$.

Note that the redshifts reflect the differences between the gravitational fields of the masses that lie within the observer's cosmic horizon and the masses that lay within the observed object's cosmic horizon at the time the light was emitted. Effectively, the redshift is due to the mass within the region between the emission-time cosmological horizon and the observer's cosmological horizon. Thus the redshifts that we observe are completely dominated by the most distant parts of our past light cone, which lie far beyond the location of the cosmic microwave background. In a way, the Hubble coefficient is a telescope that is focused far beyond the domain of visible light.

5.1.5 The Mass Density of the Universe

In order to calculate the history of the speed limit, $c_c(t_c)$, we will need to specify the mean mass density of the universe, ρ. We assume that the mean mass density has not changed significantly since the start time.

There are numerous estimates of the mass density that are based on attempting to fit the conventional λCDM expanding universe model to astronomical data, but there are very few estimates based on direct observations. One recent estimate that was based on direct observations is Bahcall and Kuhlier (2013), who estimated an average density of 2.4e-30 g/cm^3 (based on H_0=70 km/s/Mpc). That value is similar to results found by λCDM model fits. For example, the Planck project by ESA (see Planck Collaboration, 2020) derived parameter values of H_0=67.36 km/s/Mpc (6.889e-11 a^{-1}), Ω_{baryon}=0.05249, and Ω_{cdm}=0.2628. The sum of those fractions of the critical density correspond to a density value of 2.688e-30 g/cm^3. As another example, a recent survey, Abdullah et al (2020), derived a best estimate for Ω_m of 0.318. This corresponds to a total mass density of 2.928e-30 g/cm^3 (based on H_0=70 km/s/Mpc).

5.1.6 Calculating the Total Potential U_{tot}

The gravitational intensity U_{tot} at a cosmic observer's location is defined by a volume integral over the region within the location's cosmological horizon: $U_{tot} = 4\pi \frac{G}{c^2} \rho \int_{\mathrm{r_{horizon}}}^{0} \frac{r^2}{r} (-\mathrm{d}r)$. The mass density term ρ represents the effectively constant mean mass density of the universe since the start time. That spatial integral is simplified by actually integrating over the cosmic time history, replacing the $-\mathrm{d}r$ term by $c_c(t)\,\mathrm{d}t$, and replacing r by $r_h(t_c) - r_h(t)$:

$$U_{tot}(t_c) = 4\pi \frac{G}{c^2} \rho \int_0^{t_c} \big(r_h(t_c) - r_h(t)\big) c_c(t)\, dt$$

The start-time contribution to the gravitational intensity came from the cosmic horizon at a distance $r_h(t_c)$ from the location, and subsequently-emitted contributions are from progressively smaller-radius components of that sphere.

We can split the integral into its two components:

$$U_{tot}(t_c) = 4\pi \frac{G}{c^2} \rho \left[r_h(t_c) \int_0^{t_c} c_c(t)\, dt - \int_0^{t_c} r_h(t)\, c_c(t)\, dt \right] \tag{5.5}$$

5.1.7 The Hubble Coefficient

Per equation (5.4), the Hubble coefficient is equal to $\dot{U}_{tot}$. Using (5.1) and (5.5) this can be expressed as:

$$H(t_c) = \frac{4\pi\, G}{c^2} \rho\, c_c(t_c)\, r_h(t_c) \tag{5.6}$$

Current estimates of the present-day value of the Hubble coefficient, H_0, range from about 67 km/s/Mpc to 75 km/s/Mpc. The AltU model requires the value of H_0 as an input, and we will use a value of 70 km/s/Mpc for the results that will be presented below.

5.2 The Computational Algorithm for the History of the Universe

Using an initial estimate of the mass density ρ we integrate (5.6) forward from time zero. At each timestep we extrapolate r_h based on the current values of c_c and H. Using this value we then advance each of the integrals in (5.5) over the step, and complete the step by calculating and saving the new values of c_c and H.

We specify the speed of light at the start time, c_{start}, as the value associated with a temperature of 3e9 K. The radiation temperature scales proportionally to the speed of light, and the current value of the temperature is 2.726K. At the start time the speed of light was therefore 3e9/2.726=1.1e9 times greater than it is now. The current value of U_{tot} is thus $ln(1.1\text{e}9\,) = 20.82$ (for comparison, the gravitational intensity at the Earth's surface, due to the Earth's mass, is 6.96e-10).

The simulation terminates when the calculated redshift drops to zero. If the input value for the mean mass density was correct we should then find that the calculated Hubble coefficient is equal to H_0. If that is not the case, we adjust the assumed value for the mass density of the universe and reiterate until the correct value of H_0 is calculated. A simple optimization algorithm carries this out.

During a simulation the model keeps track of a variety of metrics including the age of the universe, the horizon radius r_h, the speed limit c_c, the redshift factor z, the Hubble coefficient H, and the temperature of the background radiation.

5.3 Results of the Cosmological Model

A reference value of H_0=70 km/s/Mpc was used for the model. Except where specifically noted, all of the results presented below are for this reference case.

The mean density was found to be just 1.472e-31 g/cm^3, which is significantly lower than the astronomically-based estimates. A possible reason for this discrepancy is discussed in section 5.4.3.

Three primary measures were employed to test the cosmological model's verisimilitude: the calculated age of the universe, the Hubble diagram, and the angular size test for galaxies.

5.3.1 The Age of the Universe

The calculated age of AltU is 13.92 Ga, somewhat greater than conventional estimates— a λCDM model using H_0=67.74 km/s/Mpc and $\Omega_m = 0.3089$ got an age of 13.80 Ga.

The calculated age of AltU is approximately inversely proportional to the value of the Hubble constant H_0.

5.3.2 The Hubble Diagram (Redshift-Magnitude) Test

There are two primary bases for tests of cosmological models using astronomical data: tests based on the brightness (magnitudes) of distant sources, and tests based on the observed angular sizes of distant sources. Tests based on the brightness of distant sources use the fact that for a flat universe the observed luminous flux is a function of the current distance (aka the "comoving distance") from the source, while tests based on the angular sizes of distant sources use the fact that the observed angular size is a function of the distance from the source when the light was emitted (aka the "angular diameter distance"). Cosmological models predict these distances as a function of the light's redshift, which allows a model's predictions to be compared to observations.

The best-known current test is a Hubble diagram test based on the observed brightness of type Ia supernovae. All these supernovae have quite similar luminosities, and analysis of their observed light signatures allows quite precise prediction of individual luminosities. The standard form of the test compares normalized versions of the observed magnitudes to the predicted magnitudes for alternative cosmological theories. It was the failure of the conventional model of the universe to match these data that led to the 'discovery' of dark energy.

Figure (1) compares AltU's calculated distance modulus values to the results of three sets of observational data:

- The binned distance modulus results from Abbott et al (2019). These are part of the first data release from the Dark Energy Survey Supernova Program (DES-SN), and represent the most accurate and reliable SN Ia dataset to date. Note that the data points closest to z=0.1 represented relatively few observations and have higher uncertainty than the other data points.
- The Hubble space telescope subset of the Pantheon supernovae dataset described in Scolnic et al (2018). These represent individual high-redshift SN Ia observations, in a redshift range greater than the Abbott et al results.
- The mean curve for the quasar dataset described in Risaliti & Lusso (2019). The purple quasar curve represents the moving average of a 51-quasar window. The addition of these quasar data to the Hubble diagram is doubly valuable: it provides an independent check on the accuracy of the calculated SN-Ia distance modulus values, and also it significantly extends the range of redshift values.

The solid red line in the figure is AltU's distance modulus prediction, and the dashed red line shows the AltU distance to the source (plotted against the right-side axis).

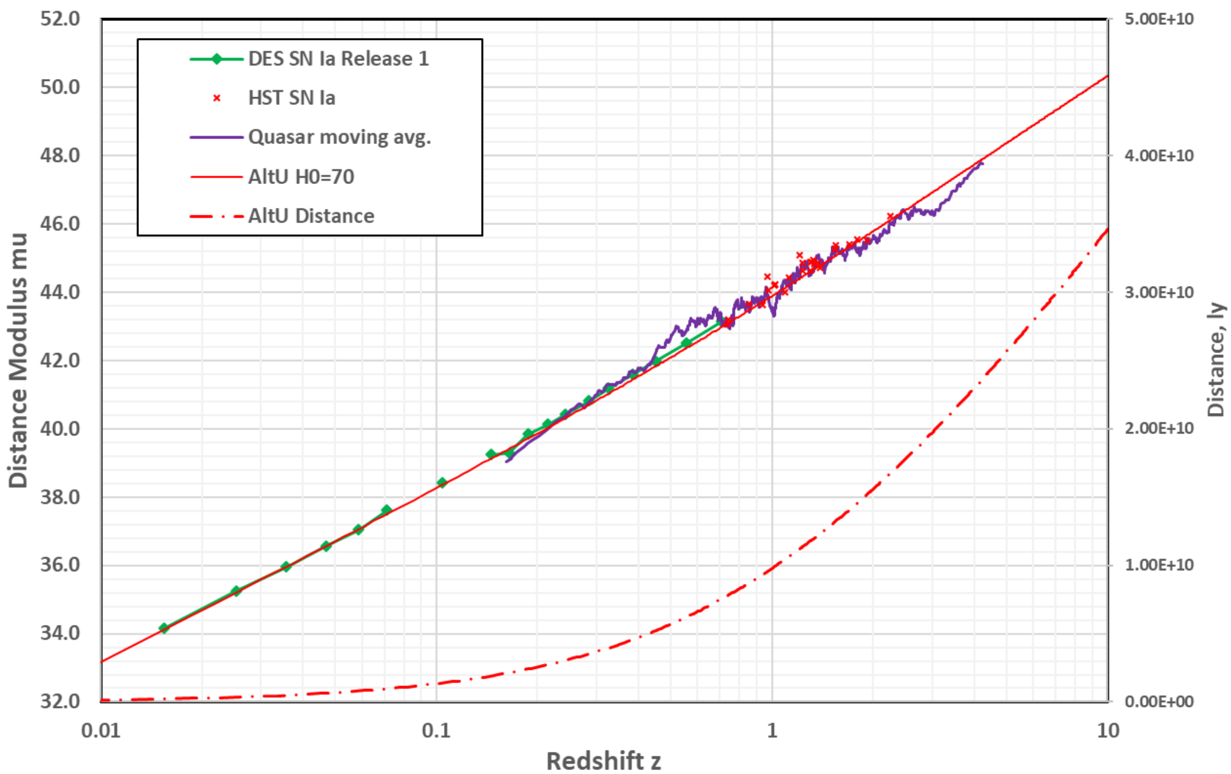

Figure 1. Hubble Diagram for AltU

The observed data do not lie along a straight line on the chart, and the basis for the inferred existence of dark energy in the conventional universe is the precise form of this curvature of the SNIa data.

Note that the AltU curve has not been adjusted to match the data, other than via the H_0 value— this is simply what the AltU equations predict. The curve is relatively insensitive to the selected H_0 value—a value of 73.6 km/s/Mpc lowers the curve by about one line-width, and a value of 67.4 km/s/Mpc raises it by about a half line width.

5.3.3 The Angular Size Test

As discussed above, in an expanding universe the telescopic images of distant objects are larger than they are in a static universe, because the distance at the time that the light was emitted was less than the distance when it is observed. Accordingly, the angular size that is observed for the expanding-universe object is larger by a factor of (1+z) than what is expected for a static universe. Angular size tests provide the most direct way to compare expanding-universe and static-universe cosmological theories.

Unfortunately, there is as yet no identified set of astronomical objects with sizes as uniform as the luminosities of the SN Ia supernova set. However, there is a large body of astronomical data for galaxies, and those data provide an interesting test. Figure (2) shows the calculated sizes for two sets of high-luminosity galaxies at multiple redshifts, based on their observed angular sizes. The figure compares the data as interpreted via the conventional model of the universe (black colors) to the data as interpreted via the AltU model (red colors). Each of the galaxy sets is subdivided into groups of similar redshift, and the mean sizes[8] of each of those groups are plotted in the figure:

- The solid dots are for the set of galaxies represented in Lopez-Corredoira (2010, Fig. 1).
- The open circles are for the galaxies shown in Shibuya et al (2015, Fig. 8).
- The red line represents a constant galaxy size to luminosity ratio.
- The black line represents an increasing galaxy size to luminosity ratio, proportional to the scale factor of a λCDM universe.

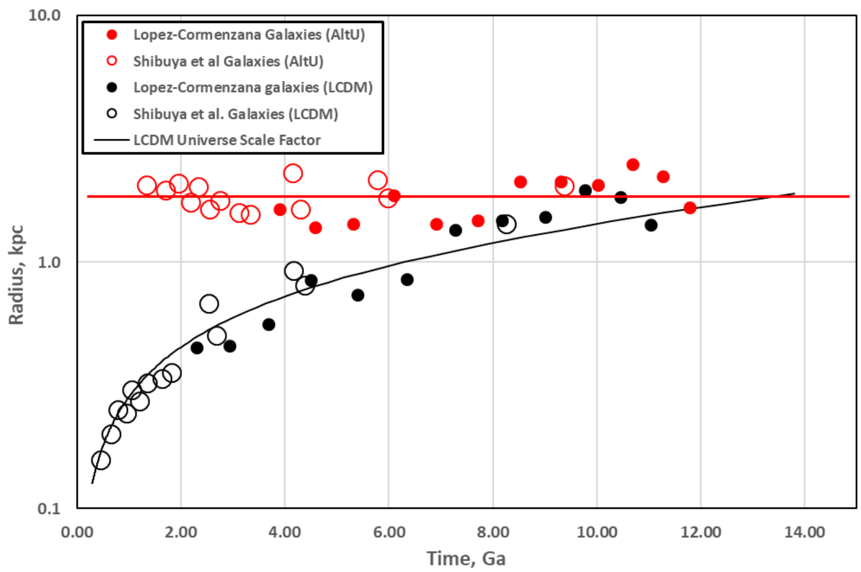

Figure 2 Angular Size Test Results

5.3.3.1 What The Curves Represent

Despite their appearance, the curves do not represent the evolutionary histories of the sizes of individual galaxies. High-luminosity galaxies are dynamic things, and a good mental image for one is of a radial conveyor belt pulling matter towards its center. Galaxies swoop through their clusters something like Roomba vacuum cleaners, gravitationally inhaling intergalactic gas. Within a galaxy, that gas is gradually pulled towards the galaxy's center by the conveyor belt (we discuss the physics of the conveyor belt in Appendix C, section 11.8). As the gas density increases stars ignite, and as they live out their lives they continue to be drawn towards the galactic center, where their carcasses accumulate.

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[8] The angles represent the median half-light effective radii of the galaxies. Each of the referenced datasets adjusted the observed radii to allow for the different luminosities of individual galaxies. In Figure 2 the Shibuya angles were multiplied by a factor of 0.42, as their galaxies are significantly larger than the Lopez-Corredoira set.

Shibuya's Figure 8 includes size estimates from a number of other researchers. The values vary, but the different investigators find essentially the same shape for the curve. The variation is probably due to the investigators selecting somewhat different ranges for the absolute magnitude of the galaxies that they studied.

The observed size of a high-luminosity galaxy reflects this dynamic process: the galaxy's visible size is defined by the region wherein star formation is occurring. That is what is represented by the curves of Figure 2.

Star-forming galaxies, which are the majority, have a continuous supply of primordial gas, sufficient to power numerous generations of stars. Estimates of the amounts of normal matter within galaxies suggest they have twice as much in the form of gas as in stars and dust. Additionally, galaxy clusters contain about nine times as much intergalactic gas as the normal matter inside their galaxies. So there is plenty of primordial gas in and around typical galaxies- it won't soon run out.

Active galaxies are capturing primordial intergalactic gas at roughly the same rate that the stars within them are burning it up. At the same rate that old stars dim out or explode, new ones are forming from the captured gas. This implies a process that reached an approximately steady state quite early in the history of the universe.

Due to their low gravitational power, small galaxies have a limited ability to sweep up intergalactic gas, and a limited ability to hold onto the gas they already have, which would explain the existence of a number of relatively small, old-style galaxies that have very low star formation rates.

5.3.3.2 Conventional λCDM Universe Interpretation of Figure 2

I find it very hard to conceptualize an explanation of Figure 2 for the conventional universe. The smaller observed radii of the older galaxies would seem to imply that their inflowing gas chose not to ignite until it had a much greater density than what is currently required. Yet the overall gas density in the universe was actually much greater than it is now- so in fact ignition would be expected at larger radii than in current galaxies.

Arguably the data in Figure 2 actually do represent the histories of representative galaxies, and they have experienced a gradual expansion as a result of energy and angular momentum added by mergers and near-misses, as described in Mo et al, 2010. And their in-flowing gas for some reason chooses to form stars at their expanding outer limits. And it is only a coincidence that the mergers and near-misses have caused two sets of star-forming galaxies, each with a quite different mean size, to grow at net rates that closely match the expansion of the universe.

5.3.3.3 AltU's Static Universe Interpretation of Figure 2

The AltU interpretation is much simpler: the figure shows that the size of high-luminosity galaxies has been quite stable over most of the 13.92 billion year life of the universe, a duration that represents multiple stellar lives. A galaxy of a given luminosity now is roughly the same size as a galaxy of the same luminosity was 12.8 billion years ago.

Star-forming galaxies are dynamic things, with old stars expiring and new stars being continuously created using cluster and intergalactic gas drawn in by the galaxy's gravity. In AltU the dynamics of this process have changed very little over the life of the universe.

5.3.3.4 Star Formation Rates

Shibuya et al also presented estimates of the rates of formation of new stars within their observed galaxies. These estimates were based on the projected areas of the galaxies, as equivalent new solar masses per square kiloparsec per year. Figure (3) presents those results in the context of a λCDM model in black, which show an almost two order of magnitude decline in the star formation rate over time. However, when the results are presented in terms of AltU's spatially static universe, they show a relatively stable picture:

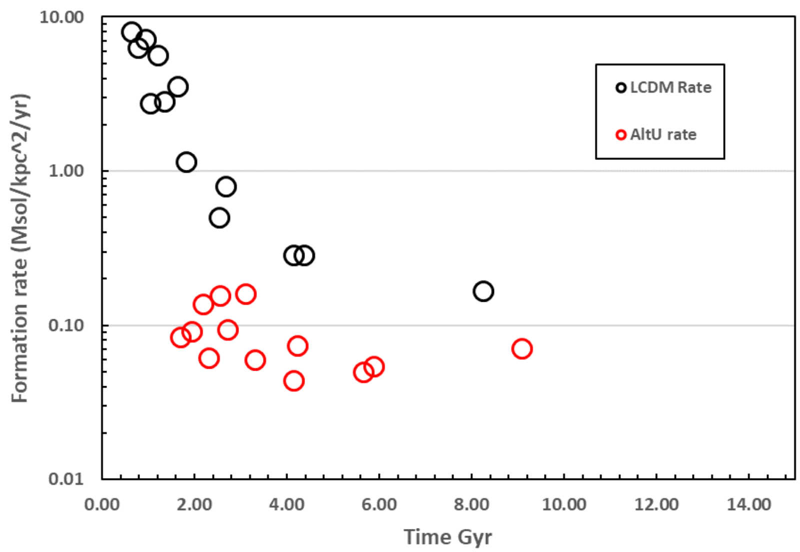

Figure 3 Star Formation Rates

The AltU results (in red) show similar star formation rates over much of the history, consistent with the concept of stable galaxies continuously sweeping up intergalactic primordial gas to fuel new star generations. Star formation rates were greater and somewhat more variable at early times, and may have become more uniform as time passed. There is no indication of any significant depletion of the gas over the last 10 billion years, though there are few data points at later times.

5.3.4 The Alcock-Paczynski test

The Alcock-Paczynski test is a variant of the angular size test. It effectively plots the sizes of the voids between objects of a given class, at different redshift values. Figure (4) plots the Alcock-Paczynski results[9] for the distances between members of several different classes of objects. Like the Hubble test result, the results are consistent with either the constant comoving distances and expanding galaxies of the conventional universe, or the constant absolute distances and stable galaxies of AltU.

[9] Data are taken from Lopez-Corredoira (2014) and Melia and Lopez-Corredoira (2017). The angular sizes of each group of points have been normalized so all three groups fall on the same curve.

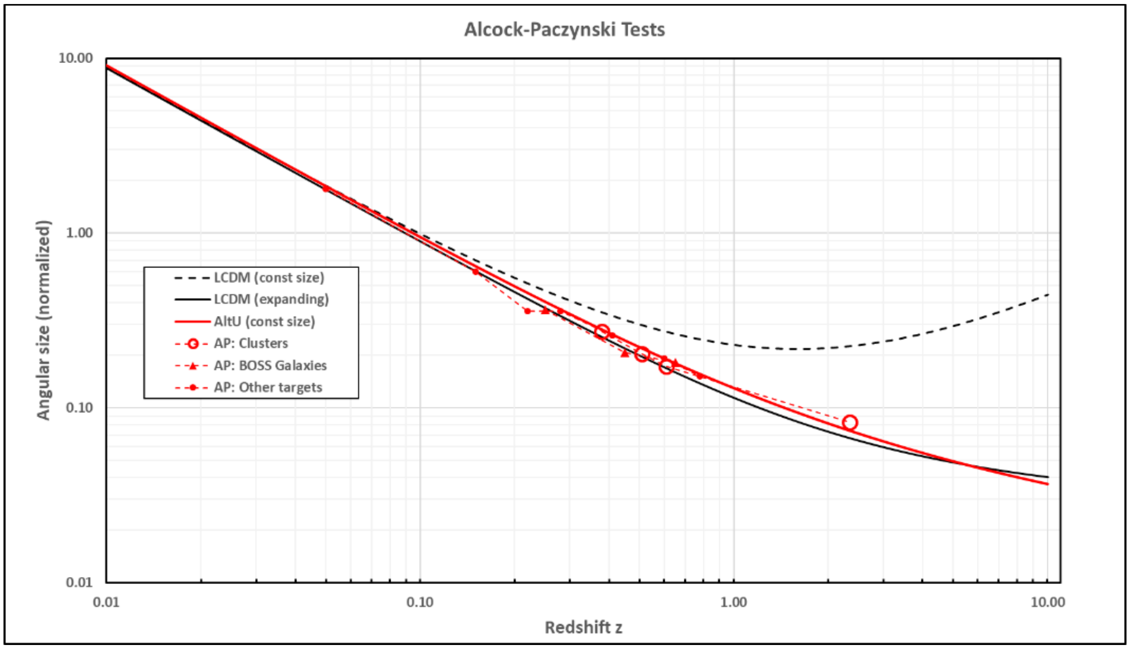

Figure 4 Alcock-Paczynski Test Results

5.3.5 The Surface Brightness Test

The surface brightness test examines the surface brightness of known-luminosity, known-size objects at different redshifts. In an expanding universe the increase in the angular size of an object, by a factor of (1+z), increases its angular area by $(1+z)^2$, and this reduces its surface brightness by a factor of $(1+z)^2$. In principle, this should make it an excellent test of whether the universe is actually expanding.

In order for a model's results to match observed surface brightness test data the model has to accurately match both the comoving and the angular diameter distances as a function of redshift. Thus the surface brightness test does not represent an independent validation of a model, but it can potentially support the validation results of separate Hubble diagram and angular size tests.

The challenge in applying the surface brightness test is to identify distant objects of a known physical size and luminosity. The best targets for the surface brightness test are galaxies, but it is difficult to confidently identify a distant galaxy's size, distance and luminosity in a model-independent way. As discussed in section 5.3.3, alternative cosmological theories posit alternative evolutionary behavior for the size of galaxies, and for their size/luminosity relationship.

Several authors have found that the surface brightness test supports their preferred cosmological model. A λCDM perspective is presented in Sandage and Lubin (2001). Lerner et al (2014) take a different approach, and conclude that the surface brightness test demonstrate a static universe. In the Author's opinion neither of these analyses is convincing, and the Hubble diagram and angular size test results offer a simpler and more direct test of the expanding universe hypothesis.

5.3.6 Other Comparisons to Observations

In general, AltU's initial evolution rate was significantly slower than that of the conventional universe.

1. A distant galaxy had a reported redshift of 3.58 (Crighton et al, 2016) which was calculated by a λCDM model as representing 1.63 billion years after the Big Bang. For that redshift the AltU benchmark gets 3.11 billion years after the start.
2. The oldest galaxy identified at the time of writing, GN-Z11, has a redshift of 11.1 (Oesch et al, 2016). According to the λCDM model this was 382 million years after the Big Bang. This result caused some consternation among the astronomers involved with the observation, as the galaxy appears remarkably mature for such an early age of the universe. The AltU benchmark gets 1.16 billion years after the start.

   Similarly, Laporte et al (2017) report finding significant amounts of dust in a galaxy at a redshift of 8.38, implying that significant numbers of supernovae had already occurred approximately 559 million years after the Big Bang. The AltU benchmark gets 1.51 billion years after the start for the same redshift value.

   Numerous other high-z observations have shown mature galaxies and/or quasars at redshifts that appear to be impossibly early based on the standard model of the universe, but which appear to be quite reasonable in AltU. See, for example, Melia (2018).
3. The cosmic microwave background (CMB) has a redshift of about **1,100** and based on the λCDM model the electron-proton recombination time is calculated to be about 440 thousand years after the Big Bang. The AltU benchmark got a much later time for that redshift: 13.2 million years after the Big Bang. (Also, in AltU recombination appears to occur at a somewhat lower temperature, with a correspondingly lower redshift).
4. The era of Big Bang nucleosynthesis has been successfully modeled by the λCDM approach (Steigman, 2007), and this result is very sensitive to the rate of expansion during the radiation-dominated era. The standard model predicts that nucleosynthesis occurred primarily between 1 and 100 seconds after the Big Bang, over a temperature range that was dropping from about 700 keV to about 90 keV.

   The AltU benchmark started at a temperature of 258 keV, and the model did not attempt to simulate the high-energy physics that were active at the time. It did not drop to a temperature of 90 keV until about 155 years had passed. This time range is many orders of magnitude longer than predicted by the standard model. However, the model's mass density at this time was the same as it is today, many orders of magnitude less than the density used in Big Bang nucleosynthesis models. Does the model's combination of longer time scales, faster light speed (by factors of billions), and lower density predict a nucleosynthesis process that is credible? That answer is not yet known.

5.3.7 Other Results of the Spatial Expansion Model

Figure (5) shows, for the AltU benchmark case, the evolution of the Hubble factor H, and the speed limit ratio c_c/c_0. Note the scale of the time axis: the most recent four billion years are all in the very last segment of the axis. On this chart the Hubble factor is almost indistinguishable from the inverse of the age of the universe, shown as t_inv.

Also, the speed limit ratio $c_c/c_0 \equiv 1 + z$ (per equation 3.3) at any given age is close to the current cosmic age (t_0) divided by the given age — which is shown as the dashed curve t0_tc on the chart.

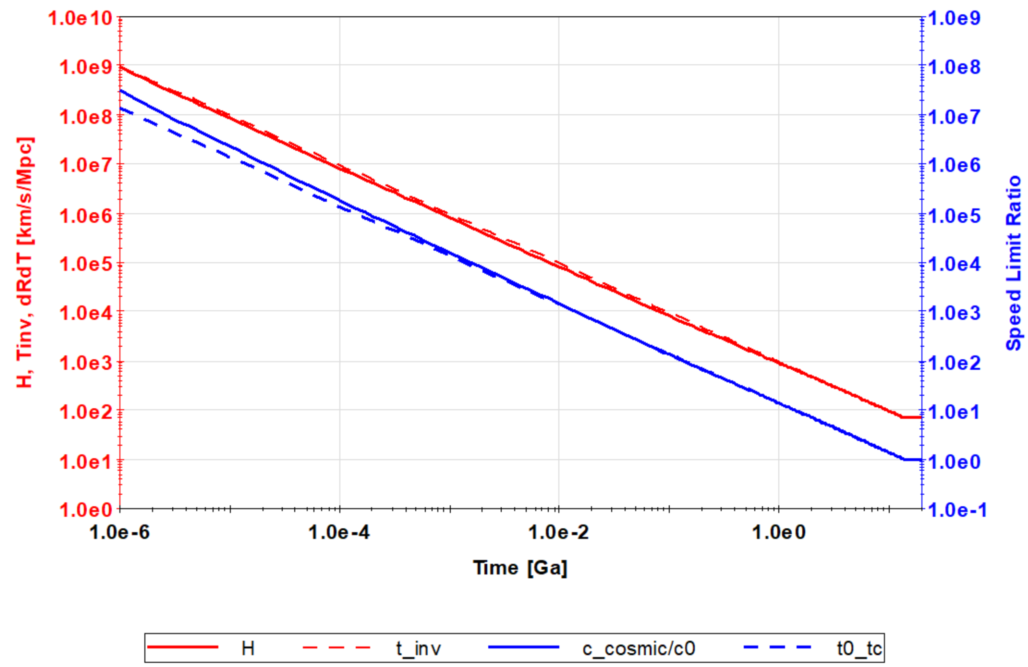

Figure 5 Time Histories of Spatial Parameters

5.3.8 <u>Distance Measures</u>

Suppose we are viewing a distant object, and the light waves we are viewing were emitted at a known time. How far away is that object? Figure (6) shows the actual AltU distance (red curve), the λCDM comoving distance (green), and the λCDM emission-time distance (dashed green). The right axis is used to display the redshift (dashed red). The λCDM results are plotted based on the redshift value, not on the emission-times.

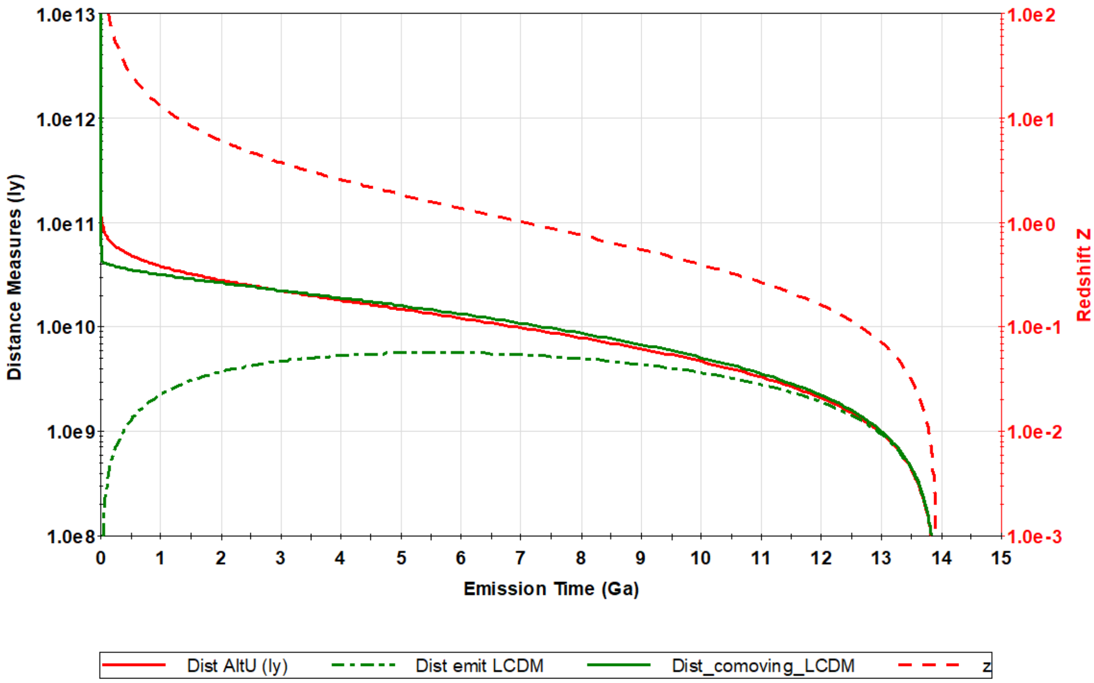

Figure 6 Comparison of Distance Measures

In general, for relatively low redshift values AltU's distance is very similar to the comoving distance of the conventional universe. At high redshift values AltU's distances are significantly greater than those of the conventional universe.

With a logarithmic time scale that shows early-time results better, Figure (7) presents AltU's distance and redshift over the full range of the simulation, along with the horizon radius r_h. The total distance to our cosmic horizon (i.e. time zero) is 5.82e11 light years, with most of the distance arising within the first few million years. That distance reflects the much greater speed of light at early times. The surface of last scattering for the CMB is at about 1.12e11 light years, about a fifth of the way to the horizon.

The plateau in the redshift curve reflects the specified mass density of the universe. A lower value of the density causes the main part of the redshift curve to extend farther back in time, and the plateau occurs at a higher redshift value. This is only of academic interest, as the underlying model is only considered to be valid for redshifts less than about 3e9.

5. Cosmology in AltU

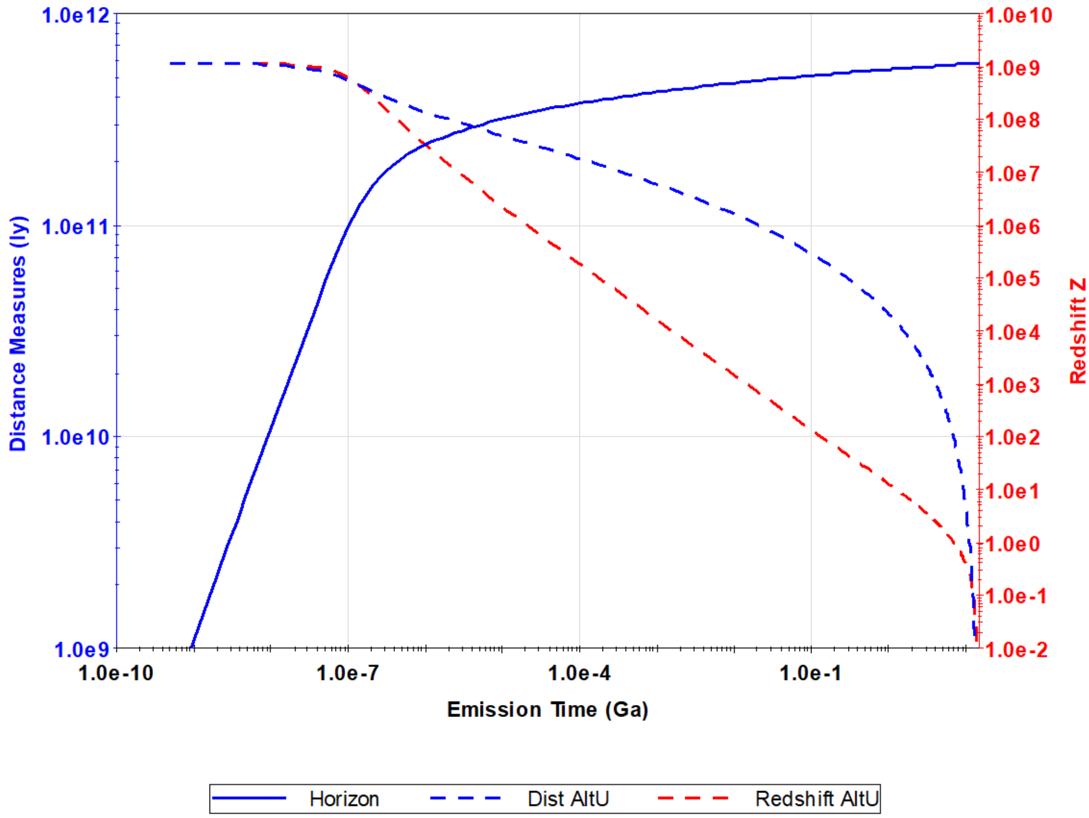

Figure 7 Growth of the Cosmic Horizon

The results shown in Figure (7) should be valid from the present time back to a time somewhere around 1.0e-7 Ga, when two early-time factors would have come into play:

1. At temperatures above about 3.0e9 K, i.e. a redshift in the order of 1.0e9, matter and antimatter particles cannot form.
2. As indicated by the horizon radius curve, at early times the model would have been driven by the mass within a significantly smaller cosmological horizon. Variations in the initial mass density field would have had relatively more effect, and the variability between different regions of the universe would have been increasingly significant.

5.4 Cosmology in AltU: Summary Discussion

5.4.1 What Initiated the Current Era of the Universe?

When we extrapolate what we know of the universe back to very early times we come to a place that is very hot, too hot for matter or antimatter particles to be stable. That place had no matter in it, and no gravity. However, it did contain a large amount of the precursors of matter and antimatter- Weyl fermions (I think). The speed limit in the region was extremely high— perhaps time as we know it didn't even exist.

If there was some spatial variability in the precursor population densities then regions might arise where the precursors of normal matter slightly exceeded the precursors of antimatter. The antimatter precursors and an equal number of normal-matter precursors in such a region could never stabilize and coexist, but the excess normal-matter precursors had the potential to create stable matter particles, and those stable particles would have expanding gravitational fields that would tend to cool the region.

Within a large region that had a slight excess, a much smaller local region with a greater excess of the normal-matter precursors might have precipitated stabilization. If enough normal-matter could survive long enough in the local region for its gravitational field to significantly reduce the local speed limit the local region would become stable. The gravitational fields from the matter in this stable pocket could then spread into and stabilize neighboring parts of the larger region, and the net normal matter would rapidly precipitate out of the entire larger region. The process would be similar to triggering flash-freezing of a super-cooled fluid. Any small pockets with a net amount of antimatter within the larger region of net normal matter would soon be annihilated.

As time passed the antimatter precursors and the equal number of normal-matter precursors within the large region would be significantly slowed, and they would eventually become the photons of the cosmic microwave background.

5.4.2 The Race Against Time

At very early times AltU's speed limit was extremely high, but as soon as mass existed gravitational fields spread extremely rapidly— and as a result the speed limit started to drop. Chapter 6 will derive AltU's gravitational equations, and will show that at early times gravitational acceleration rates were far higher than they are today.

For a local region of above-average baryonic mass density there was a race between gravitational collapse towards becoming a black hole, and the speed limit-slowing and gravitation-weakening effects of the mass in surrounding regions. How this race played out over time, for smaller and larger overdensity regions, has shaped the present-day AltU universe. Smaller overdensity regions would tend to collapse successfully, while progressively larger overdensity regions would consolidate more slowly, and also would have time to pick up stabilizing angular momentum from interactions with passing neighbors.

If matter is the universe's yin, then voids are its yang. As the dense regions collapsed, the voids grew and merged. The smallest voids formed first, and as time passed they expanded and merged. As the mean gravitational intensity grew that expansion process slowed, and by the time of recombination it had slowed to a crawl. The almost-frozen web of matter concentrations has a characteristic scale: voids smaller than the characteristic scale are slowly growing and merging, but at larger scales there has not been enough time for significant density changes to occur.

Lopez-Corredoira (2013, Figure 1) presents a chart of the self-correlation function for the cosmic microwave background, as shown below. It clearly shows the characteristic scale, which is about one degree. In AltU a one degree angle, at a redshift of 1100 and an age of the universe equal to 13.92 Ma, corresponds to a feature diameter of 1.89 Gly. At earlier times that characteristic scale of the universe's features would have been smaller, and by the present time it should be somewhat larger.

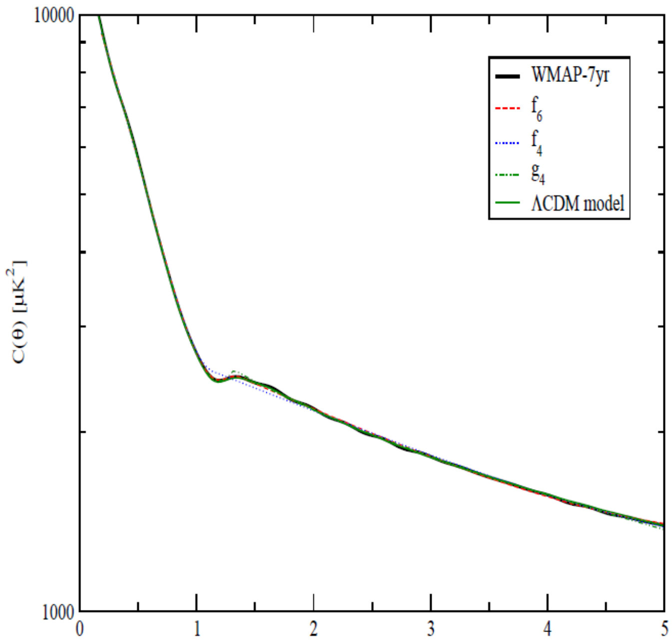

Figure 8. CMB Self-Correlation Function, from Lopez-Corredoira, 2013.

The figure's inner region shows a strongly hierarchical structure, while the outer region presumably shows the aboriginal statistical form of the density variations.

5.4.3 AltU's Low Average Mass Density

If the current estimates of the universe's mass density do accurately reflect the density in the outer parts of our cosmological horizon, then AltU's much lower density (only about 6% as much as the conventional value) must be explained.

The published density estimates for the universe are based on a local region with an outer boundary (at or below z~0.3, about 3.7 Gly) that is no more than 0.6% of the way to the horizon. However, the region that determines our observed redshifts is the part of our light cone that is closest to the horizon, about five times farther than the locus of the cosmic microwave background.

So perhaps the Earth and everything we can observe astronomically is located within an unusual local region— one with an above-average normal matter density compared to the mean density within our cosmological horizon. We might describe the region within our cosmic horizon as an island universe with a central peak that corresponds to our local region.

5.4.4 Early Times in AltU

The early-time thermal evolution (cooling rate) predicted by the model is much slower than the extremely high rate assumed by current theories of the expansion of the universe, but the model has much more proper time available for the cooling to occur. Also, because of its effectively infinite initial speed limit the model does not have to contend with the "flatness problem" that challenges the standard model of the universe. Accordingly, the slowing cosmic speed limit process is a candidate to explain all of the evolution of the normal-matter universe, not just post-inflationary growth.

The early-time results of the model present a challenge: they are very different from those of the standard model, and they are undoubtedly sensitive to the model's initial condition, which was not simulated. It is not yet known whether the significantly altered early-time physics implied by the model are consistent with the observed results of nucleosynthesis and with the cosmic microwave background. Evaluating the credibility of the model's results will require revisiting the standard models of these time periods, a significant effort.

We should be cautious about extrapolating the basic equation for AltU's speed limit (Equation (4.7b)) too far back into early times. Simple relationships are mathematically convenient, and the simple exponential relationship between the speed limit and the gravitational intensity can easily be extrapolated indefinitely. But there is no way to directly observe dynamical systems that have very low or very high values of the gravitational intensity, and as yet we have no real theory for the underlying physical processes that are at work.

5.4.5 Dark Matter

Dark matter appears to comprise some 85% of all the matter in the universe, and it is apparently about six times as common as ordinary matter. Despite its apparent invisibility and lack of a theoretical basis, the gravitational effects of dark matter appear to be a reality in AltU, just as they are in the conventional universe. It's presence ties everything together and explains numerous behaviors that would otherwise be mysterious: the evolution of the structure of the universe, the dynamics of galaxies and clusters, and gravitational lensing results.

Dark matter is the scaffolding of the universe, and it has taken its present web-like form as a result of gravitational amplification of aboriginal density variations. The gravitational clustering of dark matter proceeded during the early period when the hot gas-like photon-baryon plasma prevented normal matter from completely following suit. By the time of recombination, when the cosmic microwave background photons were freed, the large-scale form of the dark matter scaffolding had already taken shape and super-massive dark matter concentrations probably already existed. As the universe continued to cool the normal matter was drawn into the regions of dark matter concentration, where the increasing gas density seeded galaxies and their stars.

The physical form of dark matter remains a mystery, and it is most likely a non-interacting particle that has mass. Possibly concentrations of normal matter formed small black holes under the high gravitational accelerations of the early universe, and those small black holes have remained stable.

A less likely possibility is that dark matter is actually normal matter contained within massive black holes, and that the gravitational fields of massive black holes are quite different from those of smaller masses. We don't have a physical explanation for the inverse-distance relationship of the gravitational intensity, and conceivably the parameter responsible for the drop-off with distance is not in fact the spatial distance. Perhaps the field strength declines as a function of the cumulative number of graviton interactions, rather than as a function of distance. In that case a field-propagating particle exiting a massive black hole would already have traveled a substantial 'distance' before it emerged from the black hole. The gravitational intensity around a massive black hole could be affected by the 'depth' of the hole, so the effective gravitational distance from its center would equal that depth plus the radial distance. The resulting gravitational field intensity would decline quite slowly with respect to the spatial distance from the black hole, and the form of the field would approximate the forms deduced for the dark matter halos of galaxies.

5.4.6 The Cosmic Microwave Background

As mentioned above, the lack of spatial expansion in AltU means that the model's predicted physical size for the approximately one degree angular-sized cosmic microwave background features at the time of recombination is much greater than the size predicted by the standard model of the universe. In AltU the surface of last scattering of the cosmic microwave background (at a redshift of 1100) is about 108 Gly away. A 1° angular-sized object there would be 1.89 billion light years across— a size of the same order as galaxy superclusters, which are in the order of several hundred million to ten billion light years in size.

The most likely interpretation is that the CMB anisotropies reflect a random population of rarefied 'bubble' regions that are slowly growing as smaller structures are drawn by gravity towards the densified walls of the voids. Populations like this evolve naturally in simulations of large-scale structure formation at somewhat later times, as described in Springel et al, 2005. Starting from random distributions of massive particles, smaller gravitationally-bound structures form first, and then are gradually absorbed into ever-larger web-like structures. As a complementary part of the process void regions merge and become larger. In AltU the extreme gravitational accelerations at early-times would have initially hastened this process, and as the speed limit gradually slowed the collapse rates would also have slowed. Thus the CMBR anisotropies might represent a snapshot of this sort of densification process at a particular point in time. Its current state is described by very-large-scale astronomical surveys.

In AltU the density of the baryon-photon plasma within what are now the great cosmic voids would already have been significantly reduced by the time of recombination. Thus these regions would have become transparent earlier than the 'wall' regions did. The CMB that is viewed today would represent photons that emerged from behind the last 'wall' that became transparent in any given line of sight from the Earth.

The conventional explanation for the CMB features is that they represent shells of denser matter caused by pressure waves generated by expanding 'seeds' that were somehow scattered throughout the early universe. That is the origin of the term "baryon acoustic oscillations" (BAO) that is often used to describe the anisotropies. However, that conceptual model is incompatible with the concepts underlying the large-scale structure simulations described above. Also, there is no real theory or model that predicts the existence and nature of the "seeds"— the entire BAO concept appears to be questionable. The pressure and density distribution apparent in the CMB represents the balance between the gravitational forces drawing matter towards the dark matter framework and the resisting baryon/photon plasma pressure.

5.4.6.1 The Hubble Constant "Tension"

The cosmological community has recently been in somewhat of a furor, as two different approaches predict distinctly different values for the Hubble constant. One approach is based on a 'distance ladder', and it is valid in AltU provided no expanding-universe concepts have infected its results. The comoving distance ladder for the conventional universe is applicable to AltU.

However, the competing approach is based on the baryon acoustic oscillations concept, which appears (to me) to be entirely imaginary.

5.4.7 Implications for Cosmology

If the AltU approach is in fact valid, there are a number of significant implications for cosmology:

- Inflation and expansion never occurred. Space does not distort, shrink, or expand.
- The basic concepts of λCDM models and the Friedmann equations are not valid. Therefore:
    - The concepts of a critical density for the universe, and that there is a flatness problem, are invalid.
    - Dark energy does not exist. The results presented above successfully describe the 'expansion' of the universe with no recourse to dark energy.
- The form and the origin of the initial mass density distribution in the universe do not yet have a credible theoretical basis.

5.4.8 So Far, So Good…

The AltU cosmological model's results match a variety of measures remarkably well. It predicts the age of the universe and the evolution of the temperature of the universe's radiation. It accurately predicts the Hubble diagram for both supernovae and quasars, up to high redshift values. The angular size tests show that AltU's estimates of emission-time distances (angular diameter distances) for light from galaxies are good, and that the conventional model's expanding universe-based estimates are not so good. The ages of many early-universe benchmarks appear more reasonable in AltU than in the conventional universe.

AltU's cosmology is simple. It doesn't need a separate model of inflation, it doesn't need dark energy, and it doesn't need second-order tensors to describe complex spatial distortions. It doesn't predict some of the most jarring attributes of the standard model of the universe: a universe that emerged from a singularity, time and light waves stopping at black hole event horizons while gravity penetrates them freely, singularities and wormholes at the centers of black holes.

The AltU cosmological model has only one uncertain input parameter: the current value of the Hubble coefficient H_0, and its sensitivity to that coefficient is modest. It's foundational concepts are very simple, and its basic underlying equation (4.7b) is based on the observed relationship for gravitational time dilation here on Earth. Yet despite this simplicity it matches the age, history, and geometry of the universe— a remarkable coincidence, if it is not in fact the real thing. Its only apparent significant shortcoming is that its inferred value for the spatial mass density near to our cosmological horizon is significantly less than what is observed locally.

6 Gravity in AltU

The conventional theory of gravity is a remarkable achievement, and its results aren't going to be replaced by AltU's versions. Our goal is more modest than that- we seek to describe the same systems that conventional theory does, but from a different and more fundamental perspective. That is challenging enough!

Isaac Newton was the first person to describe gravity in mathematical terms, and his focus was on gravitational accelerations and the gravitational forces that they implied. That remained the paradigm for gravity for over two centuries, until Einstein's general relativity theory provided a much richer understanding. General relativity successfully predicted gravitational accelerations without using the concept of gravitational forces at all, as simply the responses of force-free bodies in a universe where space and time were subtly distorted in gravitational fields. General relativity theory also predicted the existence of black holes, and of gravitational waves- which over the last few years have been directly observed by LIGO observatories.

AltU is quite different from the conventional universe: it is spatially stable, and when you measure the speed of light using the cosmic distance unit that speed is reduced within gravitational fields, as is the speed of clocks. As we will discuss below, these changes to the local speed of light lead to gravitational accelerations that are very similar to those of the conventional universe. This paper isn't the first to discuss the concept that changes to the speeds of light and time, in a spatially-stable universe, can produce gravity's effects. R. H. Dicke's paper, "Gravitation without a Principle of Equivalence" (Dicke, 1957), explored the concept in some depth. Dicke in turn referred to work by H. A. Wilson, published in 1921.

This sixth chapter will first develop an explanation of what underlies gravity in AltU, and will then derive the equations for gravitational accelerations and test their predictions against observational data.

6.1 Gravity-Related Issues

In the Introduction we summarized the gravitational phenomena that we would seek explanations for:

- *Gravitational fields slow clocks, and slow light waves.*
- *Photons passing by the sun are deflected by twice the angle that Newtonian gravity predicts.*
- *The gravitational effects of multiple masses can be characterized by a scalar gravitational field, the gravitational potential, where each mass's contribution is proportional to the amount of its mass and inversely proportional to its distance. Each mass's gravitational effects propagate spatially via its forward light cone, traveling at the speed of light- as proven by astronomical observations and gravitational waves.*
- *Gravitational effects travel at the speed of light. But a close inspection of precise orbital equations for binary pulsar systems (see Will, 2018, Chapter 12; Poisson and Will, 2014) shows that the stars' gravitational acceleration vectors are not directed towards the locations of their partners when they emitted their gravitational 'messages'. Neither are they directed towards their linearly-extrapolated or even their quadratically-extrapolated locations based on the emission time. Instead, the acceleration vectors are directed a hair's breadth ahead of the*

instantaneous location of the partner's center of gravity. That hair's-breadth represents the very small net 'drag force' that eventually leads to orbital decay.

- *General relativity theory assumes that energy, as well as mass, originates gravity. That assumption is not consistent with the fact that the vacuum energy density, which is large, has no effect on the expansion of the universe.*

In the previous chapters we have touched on some of these issues. In the present chapter we will address them in more depth.

6.2 Gravitational Waves: an Introduction

To set the stage for our discussion of gravity in AltU we will start with a preliminary overview of the gravitational waves emitted by binary star systems. That's a fairly advanced topic, but it will illustrate some of the key issues in gravitational theory, and highlight some key differences between AltU and the conventional universe.

To focus the discussion, consider the Hulse-Taylor system, a binary pair of neutron stars where one of the stars is a pulsar. Discovered in 1974, this binary system is just 21,000 light years from the Earth. The pulsar has a mass equal to 1.44 solar masses, and its companion's mass is 1.39 solar masses. Based on the pulsar's observed time-varying signal astronomers have derived a remarkable amount of information about the system, and they found that its orbital period is decreasing at exactly the rate predicted by general relativity theory. That projected rate is based on the system's emission of energy and momentum via gravitational waves. Those waves are currently far too faint to be picked up by LIGO observatories, but in about three hundred million years as the final collapse of the binary system's orbits nears it will produce a very strong signal here.

The current gravitational effects of the binary pair here on Earth are minuscule. Because they are so far away the individual gravitational fields of the pair are indistinguishable, and the gravitational intensity due to the pair is just 2.1e-17. It adds a tiny contribution to the total gravitational intensity here on Earth. However, when the system eventually collapses its gravitational effects will become much more apparent here. The form of those effects will be quite different in AltU than it will be in the conventional universe.

6.2.1 Gravitational Effects of the Binary in the Conventional Universe

If we live in the conventional universe the binary's gravitational field currently has two effects on Earth: it slightly slows the passage of time here, and it causes a stretching of our local space in the binary-to-Earth direction. Per the Schwarzschild metric, the spatial strain in that direction is currently equal to 2.1e-17, and time here is slowed by the same fraction.

The conventional model of the universe offers us two quite distinct approaches to predicting how the gravitational effects of the binary will be experienced on Earth. One approach involves using special relativity theory to predict how the form of the Schwarzschild metrics of the stars will evolve here, and the other approach involves predicting the nature of the gravitational waves that the binary will produce. Some aspects of the predicted results of the two approaches, such as the period of the gravitational waves, are the same. However, other aspects are dramatically different.

6.2.1.1 Effects of Orbital Shrinkage on the Gravitational Fields

What will happen to the (Schwarzschild) gravitational fields of the pair as their orbits shrink and their orbital velocities increase significantly? Once the velocities enter the relativistic range special relativity effects will come into play. The two stars, and their gravitational fields, will start to shorten in the directions of their velocities. As is the case for the electric fields of rapidly-moving charges, the gravitational fields will weaken along their direction of motion, and strengthen in the perpendicular directions. At very high velocities you can visualize these oblate gravitational fields as approaching disk-shapes. Although they are distorted the fields will still modify the local metric on Earth as per the Schwarzschild metric: uniaxial spatial expansion plus an equivalent amount of temporal slowing.

This special-relativistic effect is already happening, but it is far too small to be detectable. That will change as the velocities become relativistic, and the unchanging gravitational field from the binary system that we currently experience will then start to vary.

The amount of variation experienced here on Earth will be greatest if the Earth lies close to the plane of the binary system's orbits, as that maximizes the velocity components of the binary stars towards or away from the Earth. A time lag is involved- the gravitational effects of the binary propagate at the speed of light. When the (time-lagged) velocities of the two stars were directed towards and away from the Earth their field strengths here on Earth will be at a minimum. When the velocities were perpendicular to the Earth's direction their field strengths here will be at a maximum. For each orbital period there will be two minima, and two maxima, as the gravitational 'disks' of the stars rotate.

If the Earth lies close to the orbital plane then due to the variations in the field strength the temporal rate here will vary cyclically, and space itself will experience a uniaxial cyclic strain in the direction of the binary system. As the orbital velocities increase the strains involved for both the temporal and the spatial variations will eventually be in the order of 2e-17. Earth's inhabitants won't be aware of the slowing of time unless they are closely monitoring a distant, stable frequency of some sort. However, in the unlikely event that the Earth still has LIGO observatories at that time the cyclic stretching of space will directly affect the distances between the mirrors suspended at the ends of their arms, and the observatories will report the observation of a very strong gravitational wave.

6.2.1.2 The Gravitational Waves Associated With Orbital Shrinkage

Awkwardly, the form of the metric variation that the special relativity approach described above predicts is almost entirely unlike that of the gravitational waves that current LIGO observatories are designed to monitor. The predicted frequencies are the same, and the strain amplitudes are similar. But the LIGO gravitational waves (see Will (2014) Section 5.3 or Will (2018) Chapter 11, for a summary, or Blanchet (2014) for more detail) are predicted to have a two-dimensional rather than a one-dimensional spatial strain field, with two distinct strain patterns involved, and those spatial strains are expressed most strongly along the axis of the binary's rotation and least strongly in the plane of the binary. Also, the LIGO-theorized waves have no temporal effect, they represent purely spatial strains.

We will leave the contradictions between the two alternative approaches for the adherents of the conventional version of the universe to explain.

6.2.2 Gravitational Effects of the Binary in AltU

If we live in AltU the binary's gravitational field currently has had three effects on the Earth: it has slightly slowed the passage of time here, it has slightly slowed the speed of light here, and it has slightly reduced the physical sizes of objects here. Per the AltU metric, both time and the local speed of light have been reduced by a fraction of 2.1e-17, and objects here have shrunk by the same factor. As a result of the shrinkage of objects, a local measurement of the speed of light based on a physical standard for length reports the same value of the speed of light with or without the presence of the binary system.

As the binary's orbits shrink and its velocities increase the shapes of their gravitational fields will evolve much as described in the preceding discussion. The specific equations for this are a bit complex, and they have been left for an Appendix (11.5.4). The result here on Earth will be growing cyclic variations in the gravitational intensity U.

In terms of the physical shrinkage of objects, under a rapidly-varying cyclic gravitational intensity the shrinkage and expansion of large objects can't keep up. A large object would experience a cyclically-varying stress but it would not have sufficient time to significantly change its size. However a small object's size could fluctuate at the same rate as the gravitational intensity.

In AltU the effects of the varying speed of light within a LIGO system would be significant. The changing temporal rate would also come into play, as the laser driving the LIGO system would be operating with time-varying relative frequencies during the gravitational fluctuations. Also, the laser would be small enough for its size to vary along with the gravitational field. How all of this would be reflected in a LIGO observatory's observations is unclear- the observatories are very complex.

6.2.3 Gravitational Waves: Summary

Our purpose in this introduction to gravitational waves is to highlight some of the more complex phenomena that are involved in gravitational systems, and to demonstrate that there is as yet no persuasive integrated model of gravitational processes. In the following sections we will follow a somewhat complicated path as we explore the issues around gravitation, try to develop an integrated conceptual model for it, and then derive the equations for gravitational accelerations in AltU.

6.3 Gravity and Particles

Gravitational fields are actually originated by the masses (and perhaps the energy) of particles, they are probably propagated by particles, and their observed effects are evidenced by particles. That puts particle physics at the heart of gravity, which poses a particular challenge to this author: I have a minimal understanding of particle physics. That led me to take a naïve approach to explore the role of particles in gravity. That approach is quite cartoon-like, but it appears to have produced some useful insights. I will summarize it in this section.

6. Gravity in AltU

6.3.1 Photon Trajectories in AltU

The foundational component of gravitational trajectories in AltU is the response of a massless particle, such as a photon, to the spatially-varying speed of light within a gravitational field. Can AltU's variable light speed explain the gravitational acceleration of light?

6.3.1.1 Photon Transverse Accelerations

Using the cosmic time coordinate, per equation (4.7a) the speed of light at a location with gravitational intensity U is equal to $c_{loc\_c} = c_c e^{-2U}$. The derivative of that value with respect to U is $-2c_c e^{-2U}$, so the spatial gradient of the speed of light is $-2c_c e^{-2U}\overline{\boldsymbol{\nabla}}U \equiv -2c_c e^{-2U}(\overline{\boldsymbol{\nabla}}_{\parallel}U + \overline{\boldsymbol{\nabla}}_{\perp}U)$. The gradient's component in the direction of an object's velocity is $-2c_c e^{-2U}\overline{\boldsymbol{\nabla}}_{\parallel}U$, and the gradient's component perpendicular to its velocity is $-2c_c e^{-2U}\overline{\boldsymbol{\nabla}}_{\perp}U$.

Think of the path of a photon as having a finite size, a tubular or helical pathway through space that has a small diameter, δ. We refer to the part that experiences the least gravitational intensity as the top of the pathway, and the part with the greatest gravitational intensity as the bottom. The instantaneous velocity of the photon is $c_c e^{-2U}$. The velocity difference between the top and bottom of the photon's path ($\delta \frac{d(c_c e^{-2U})}{dr} = -\delta 2c_c e^{-2U}\overline{\nabla}_{\perp}U$), divided by δ, defines a rotation rate that can be represented by a horizontal angular velocity vector of magnitude $2c_c e^{-2U}\overline{\nabla}_{\perp}U$. The cross product of that rotation rate with the photon's velocity defines its acceleration in the direction perpendicular to its velocity: $2c_c^2 e^{-4U}\overline{\boldsymbol{\nabla}}_{\perp}U$, or $2c_{loc\_c}^2\overline{\boldsymbol{\nabla}}_{\perp}U$.

6.3.1.2 Photon Longitudinal Accelerations

Based on equation (4.7a), a photon's speed changes at a rate of $-2c_{loc\_c}\dot{U}$. Here $\dot{U}$ is the rate of change of gravitational intensity experienced by the photon, defined as: $\dot{U} = c_{loc\_c}\overline{\nabla}_{\parallel}U + \frac{dU}{dt_c}$. For a single attracting mass, $\dot{U} = -U\frac{\dot{r}}{r}$. Thus a photon's acceleration component in the direction of its velocity is $-2\left(c_{loc\_c}\overline{\nabla}_{\parallel}U + \frac{dU}{dt_c}\right)\overline{\boldsymbol{v}}_{\boldsymbol{c}}$. We can express this more simply for a single attracting mass, as $2U\frac{\dot{r}}{r}\overline{\boldsymbol{v}}_{\boldsymbol{c}}$.

This longitudinal acceleration component is directed <u>away</u> from masses that lie along photon paths. A photon moving upward in a gravitational field speeds up, a descending photon slows down.

6.3.1.3 Photon Trajectories

We sum the transverse and longitudinal photon accelerations to get the acceleration of a photon (using cosmic time units):

$$\overline{\boldsymbol{a}}_{\boldsymbol{c}} = 2\left[c_{loc\_c}^2\overline{\boldsymbol{\nabla}}_{\perp}U - \left(c_{loc\_c}\overline{\nabla}_{\parallel}U + \frac{dU}{dt_c}\right)\overline{\boldsymbol{v}}_{\boldsymbol{c}}\right] \equiv 2\left[c_{loc\_c}^2\overline{\boldsymbol{\nabla}}_{\perp}U - \dot{U}\overline{\boldsymbol{v}}_{\boldsymbol{c}}\right] \tag{6.1}$$

For the case of a single attracting mass at distance r we get:

$$\overline{\boldsymbol{a}}_c = 2\left[c_{loc\_c}^2\overline{\boldsymbol{\nabla}}_{\perp}U + U\frac{\dot{r}}{r}\overline{\boldsymbol{v}}_{\boldsymbol{c}}\right] \tag{6.2}$$

These expressions correctly describe photon trajectories, including refraction (the first term) and the changing speed (the second term) in gravitational fields. They correctly predict gravitational lensing and Shapiro delays.

Note the conceptual approach that we took in this derivation: it was based on a massless particle moving within a region with a varying local speed of light. That approach is very different from the derivation of conventional metric-based geodesic equations, which we will return to in section 6.5.1.

Consider a photon in a circular orbit around a dense spherically symmetric mass. Its centripetal acceleration is $\frac{c_{loc\_c}^2}{r}$, and its gravitational acceleration is $2c_{loc\_c}^2\left(\frac{Gm}{c^2r^2}\right) \equiv 2c_{loc\_c}^2\|\overline{\boldsymbol{\nabla}}U\|$. If we equate these accelerations and solve for the radius it is $\frac{2Gm}{c^2}$, which is the Schwarzschild radius of the mass, and its gravitational intensity equals 0.5. In the conventional universe this corresponds to a place where time stops, but in AltU time there is merely dilated by a factor of $e^{-0.5} = 0.607$.

6.3.2 What is Mass?

All but two of the known fundamental particles (gluons and photons) have mass. What distinguishes particles that have mass from particles that have no mass? The underlying concepts feel a little vague, so we will try to craft a simple mental model of a mass. We will start with a model of a single particle that has mass, and then develop a model of a collection of such particles.

6.3.2.1 A Mental Model of a Small Mass

Contemplate a thought experiment: let's snag a couple of identical passing massless particles that carry momentum and tie them together with a short weightless string. What do we get?

We get a spinning doublet. If the particles were originally going in opposite directions our doublet will be stationary. When we created it our doublet's particles were orbiting a stationary central point, with common angular momentum vectors. Because the particles can't exceed the local speed of light, if we accelerated the doublet in the direction of its angular momentum vector the particles' momenta would have to gradually change from being purely angular to having increasing linear components. Their paths would become helical, like a DNA molecule. If the doublet actually reached the speed of light the particles would no longer need the string, they would just be massless particles on parallel paths.

It turns out that the doublet has a property that is a lot like inertial mass. In order to accelerate it we had to change the directions of the two component particles. Changing their directions meant changing their momenta, and that required a force. The doublet's acceleration rate was initially proportional to the applied force, but as the particles' velocity vectors swung towards the direction of the doublet's velocity vector the applied force became less effective in accelerating them. That is reminiscent of a relativistic mass increase.

What is the doublet's inertial mass? Define angle θ as the angle between the individual particle velocities and the velocity vector of the doublet. The doublet initially has $\theta = \pi/2$ and a zero velocity, and θ approaches zero as the doublet's velocity approaches the speed of light. The velocity of the doublet is $v_d = c_{loc}cos(\theta)$ and its acceleration is $a_d = \dot{v}_d = -c_{loc}sin(\theta)\dot{\theta}$, so during acceleration the rate of rotation of the particles' directions is $\dot{\theta} = -a_d/\big(c_{loc}sin(\theta)\big)$. If the momentum of each particle is $\overline{\boldsymbol{p}}$ then the magnitude of its rate of change is $-p\dot{\theta} = \frac{p/c_{loc}}{sin(\theta)} a_d = \frac{p/c_{loc}}{\sqrt{1-cos^2(\theta)}} a_d = \frac{p/c_{loc}}{\sqrt{1-v_d{}^2/c_{loc}^2}} a_d$. The rate of change of its momentum is by definition the force that is applied to the particle, so the dynamic mass of the particle is $\frac{p/c_{loc}}{\sqrt{1-v_d{}^2/c_{loc}^2}}$ and its rest mass is, unsurprisingly, p/c_{loc}. Somewhat surprisingly, our particle doublet is voluntarily respecting the Lorentz transformation[10].

So it appears that when we created our doublet we converted energy to mass- a crude version of a quark or a lepton. If we were to cut the string, that mass would be converted back to energy. This mental model suggests that mass is simply tethered momentum. The string represents the binding energy of our doublet: break it and the massless particles fly apart with their full energies

What would happen if we accelerated our doublet in a more arbitrary direction? Neither of its particles could exceed the local speed of light, so as its velocity increased its spin axis would have to start to align with its velocity, and it would have to precess.

If our doublet has mass, does it have a gravitational field? I think not, because our string won't do that job. However, I suspect that if instead of string we could have connected our particles using the strong force, mediated by gluon particles, then the doublet would have had gravity. I suspect that gluons leaking away from massless doublets are the communicators of gravitational fields, and that they stimulate the local populations of gravitons (Higgs bosons) in the quantum vacuum. The gluons leaking out of our doublet would lie within its plane of rotation, and the higher the doublet's velocity the more the gluons would be confined to the plane perpendicular to its velocity.

In AltU, accordingly, all particles that have mass are actually comprised of very fundamental particles that don't have mass- they just have momentum/energy. A mass particle's active gravitational effects are associated with the binding forces that connect its massless components (i.e. its gluons), while its inertial attributes are associated with the momenta of those embedded massless particles. The massless internal particles never stop moving at the local speed of light, even though the composite particles act as we expect masses to. But inside the composite particles their massless components are always tirelessly rotating at the local speed of light and leaking gluons into the wider universe. This is a simplistic cartoon, of course, but it is the conceptual basis for our understanding of how masses generate gravitational fields in AltU.

6.3.2.2 A Mental Model of a Larger Mass

In terms of a mental model of a larger mass, we view a larger mass as a collection of our doublets. When a larger mass is stationary the directions of its doublets' spins are random. Within a gravitational field a (momentarily) horizontally-moving massless particle would experience downwards acceleration.

[10] This assertion needs to be checked. In trying to understand how a single force could be delivered to the members of a doublet I found that they were slippery things to deal with. In the end I used an analogy to a frictionless wedge of angle 2θ being forced into a gap, and equating the work it did on the gap to the work its driving force did on it. For a real mass there would also be the issue of the potential effect of the decreasing angular rotation rate on the binding energy.

A vertically-moving particle would experience no acceleration. On average, it appears, a random doublet's net downward acceleration rate is half that of a horizontally-moving photon.

This means that our larger mass's gravitational acceleration due to a potential gradient is equal to $c_{loc\_c}^2 \overline{\boldsymbol{\nabla}} U$: basically, Newton's gravitational acceleration formula. The gravitational accelerations of masses thus arise due to refraction of the paths of their component massless particles!

What happens when we accelerate a collection of randomly-oriented doublets in a single direction? Because their constituent particle velocities can't exceed the local speed of light the doublets' rotational axes' orientations would have to rotate towards aligning with the overall velocity of the collection. I visualize this as something like wind socks rotating to face into the wind- a wind of gravitons, in this case. The individual gyroscopic moments due to these rotations would tend to average out.

So if we took a large mass and accelerated it, we would expect that as its velocity increased all of its internal doublet axes would start to align with the direction of its motion. The effect of that alignment within atomic nuclei would be for their leaking gluons to concentrate in planes perpendicular to the mass's motion. That would cause its gravitational field to be weaker along its axis of motion and stronger in the perpendicular direction, having an oblate rather than a spherical form.

The velocity-created alignment of its doublets would also affect how the mass responded to external gravitational fields. As it approached the speed of light its acceleration in response to an intensity gradient that was perpendicular to its velocity would be doubled, and apart from maintaining the local speed of light it would not accelerate at all in response to an intensity gradient that was parallel to its velocity.

In our earlier discussion of AltU's conceptual foundations, section 3.2, we asserted that the only credible explanation for the special-relativity discrepancies between different observers was that something about an observer is physically changed as a function of its velocity. The doublet-alignment process that we have just described represents that physical change. The acceleration that causes a changed velocity changes the alignments of the doublets within a mass, and those changes are retained until a subsequent acceleration modifies them again. That process is what underlies both the "twin paradox" of relativity theory and the changed shapes of moving masses and of their gravitational and electric fields.

6.3.2.3 The Longitudinal Shortening of High-Velocity Masses

At a much larger scale, an alignment effect would also have to happen to doublets comprised of orbiting electrons within atoms. If an atom is viewed as containing a collection of randomly orbiting electrons, as its velocity increased their increasingly aligned orbits would result in an anisotropic electrical field within the atom that would shorten the atom's length in the direction of the motion. That would be consistent with the Chapter 1 discussion of special relativity. Physical shortening of this form was a foundational assumption of the Tangherlini/Selleri variant of special relativity that AltU embraces.

For a mass with a net electrical charge, a similar thing presumably happens to its external electrical field, which becomes oblate. That particular effect is described by the Lorentz transformation as used in its original context, electromagnetic fields.

6.3.2.4 The Gravitational Fields of High-Velocity Masses

The equation for the oblate gravitational field of a high-velocity mass is derived in Appendix C, section 11.5.4. The effects are significant for high-speed orbital systems, as the resulting magnitude and direction of $\overline{\boldsymbol{\nabla}}U$ at a location vary with the location's orientation relative to the high-speed masses and their paths. For a high-speed binary pair of masses, each of their gravitational fields becomes disc-like. The effect at a distance is a disc-like overall gravitational field that sweeps over a distant observer twice for each revolution of the masses. In the conventional universe these variations in the gravitational intensity are described as being caused by gravitational waves.

The effect of the AltU gravitational waves is to cyclically modify a distant observer's local temporal rate and local speed of light. The proper lengths of small objects are also changed, in the same ratio ($e^{-\delta U}$). Due to the high-frequency nature of typical gravitational waves the lengths of large objects, such as LIGO observatory arms, would not change. Appendix C, section 11.6, discusses LIGO observations in AltU in more depth.

The oblate gravitational fields are also significant near to a single large mass that is rotating with a relativistic velocity at its equator.

6.3.2.5 Our Mental Models of Masses

The mental models of small and larger masses provide a useful conceptual explanation for the nature of masses and for their generation of and reaction to gravitational fields. However, the models are too simplistic to yield quantitative predictions. For that we will need to rely on general relativity's geodesic equation approach, which we will develop in section 6.5.

6.4 Is Gravity Propagated by Particles?

Two of the concepts that are generally accepted about gravity are that gravitational effects propagate at the speed of light, and that a mass's contributions to local metric equations vary in inverse proportion to its distance. AltU's cosmic redshift results strongly support these concepts.

The fact that gravitational effects propagate through a vacuum at the same speed as photons suggests that massless particles act as the propagation agents. However, that concept has some problems.

6.4.1 The Inverse Distance Problem

Particle fluxes from a source decrease with the square of the distance, and that doesn't appear to be consistent with the observed linear inverse-distance relationship for a mass's effects on time and on the speed of light.

6.4.2 The Doppler Problem

Particles might communicate gravitational effects directly to affected bodies, for example by transmitting or exchanging quanta of momentum between two masses. However, that would produce a Doppler effect which is not seen in nature. Consider an orbiting body, such as Mercury, that has an elliptical orbit. When it was approaching the Sun it would encounter the solar particles relatively more frequently, and would have an enhanced acceleration rate. When it was receding from the sun it would encounter the particles less frequently, and would have a reduced deceleration rate. Its orbit would be unstable, and it would soon be ejected from the solar system. Accordingly, a simple communication of gravitational forces via particles is ruled out.

6.4.3 The Aether Possibility

The Doppler problem might be overcome by a two-step process: gravity-propagating particles affect the aether as they pass through it, and the effects of gravity are mediated by the ensuing attributes of the aether- the gravitons that we have described. This concept still has a Doppler component- Mercury would find that the Sun's gravitational field was slightly stronger on the Aries side than on the opposite side- but Mercury's orbit would not necessarily be unstable.

The aether concept does not avoid the inverse distance problem.

These concepts for how gravity is propagated are vague and unsatisfying. We will return to the propagation issue at the end of this chapter.

6.5 Gravitational Trajectories

The key to the success of general relativity theory was that it went beyond Newtonian gravity and dynamics to identify, and quantify, a number of second-order gravitational effects. The first of these was the rate of advance of Mercury's perihelion, and the second was the deflection of light passing near to the sun. Later, other effects were incorporated: among them were the delay of light passing near to a mass, gravitomagnetic effects, and the perihelion advance and orbital decay rates for binary pulsars. All of these effects have been carefully measured by astronomers, and they constitute a strong set of tests for any theory of gravitation (Will, 2018). AltU's gravity is based on a very different conceptual model than that of general relativity, but it also has first-order and second-order effects.

In the Introduction we stated that we will use the cosmic frame as the basis for our calculations. In this section, we will develop the basic equations describing gravity in AltU, and test them by comparing their predictions to astronomical observations. Thus our approach largely ignores the fact that the Earth, the platform for almost all of our observational data, has a non-negligible velocity in the cosmic frame- some 0.00123 c. Effectively, we are assuming that a cosmically stationary observer would measure the same relative distances, velocities, and accelerations between the components of an observed system as an observer on the Earth does. Additionally, we are assuming that the relatively small cosmic velocity of an observed system has a minimal effect on the relative distances, velocities, and accelerations within it.

6.5.1 A Note Regarding Metric Equations

In linear algebra a metric space has a unique non-negative measure (the "metric") of the separation between any two points, and that measure is independent of the specific coordinate system that is used to describe the space. The separation is usually defined by an equation with the form $s^2 = \overline{\boldsymbol{X}}^{\boldsymbol{T}}\overline{\boldsymbol{M}}\overline{\boldsymbol{X}}$, where s is the separation, $\overline{\boldsymbol{X}}$ is the vector between two points, and $\overline{\boldsymbol{M}}$ is the metric matrix.

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In special relativity theory the Minkowski spacetime metric matrix $\overline{\boldsymbol{\eta}}$ is used, a diagonal matrix usually defined with a +1 temporal term and -1 spatial terms. The separations between spacetime points are directly proportional to the proper time interval ($\Delta\tau$) associated with a spacetime displacement $\overline{\boldsymbol{X}}$. Typically the separations are expressed as the product of the proper time interval with the constant *c*, but the separations can equally well be expressed as simply $\Delta\tau$, using a time unit. Conceptually, the separation is just the amount of proper time experienced by a clock that moves directly from one spacetime point to another. That is a very concrete, physical way of thinking of the separations, and it obviously reflects a unique ("invariant") value that is independent of any observer's coordinate system.

In general relativity theory local spacetime has a Minkowski metric. However, in the presence of a gravitational field an external observer's coordinate system sees the local coordinates as being distorted. The distortions can be described by a transformation matrix $\overline{\boldsymbol{T}}$, which converts the observer's coordinates to the local (proper) coordinates for a specific location. If we use $\overline{\boldsymbol{dX}_{\boldsymbol{obs}}}$ to represent a spacetime displacement in the observer's coordinates and $\overline{\boldsymbol{dX}_{\boldsymbol{loc}}}$ to represent the same displacement in the local Minkowski coordinates, then $\overline{\boldsymbol{dX}_{\boldsymbol{loc}}} = \overline{\boldsymbol{T}}\overline{\boldsymbol{dX}_{\boldsymbol{obs}}}$ and $ds^2 = \overline{\boldsymbol{dX}^{\boldsymbol{T}}_{\boldsymbol{obs}}}\overline{\boldsymbol{T}}^{\boldsymbol{T}}\ \overline{\boldsymbol{\eta}}\ \overline{\boldsymbol{T}}\overline{\boldsymbol{dX}_{\boldsymbol{obs}}}$. Thus the metric matrix based on the observer's coordinates is $[\overline{\boldsymbol{T}}^{\boldsymbol{T}}\ \overline{\boldsymbol{\eta}}\ \overline{\boldsymbol{T}}]$. Note that because the spacetime distortions vary continuously, the $\overline{\boldsymbol{dX}_{\boldsymbol{obs}}}$ vector has to be differential-sized.

As a result of the form of the general relativity metric matrix $\overline{\boldsymbol{T}}^{\boldsymbol{T}}\ \overline{\boldsymbol{\eta}}\ \overline{\boldsymbol{T}}$, it actually encodes two quite different types of information. The obvious information is the formula for the separation between the ends of a differential-sized spacetime interval. Not so obvious is the fact that the transformation matrix $\overline{\boldsymbol{T}}$ is implicit within the metric matrix.

The components of the transformation matrix $\overline{\boldsymbol{T}}$ represent $\frac{dx_{loc}}{dx_{obs}}$, and in most cases it is easy to select coordinate axis directions such that $\overline{\boldsymbol{T}}$ is diagonal. When that is done the diagonal terms represent the factors by which the local (proper) coordinates are stretched due to the presence of the gravitational field. For weak fields those stretch factors represent $1 + \epsilon_{coord}$, where ϵ_{coord} is the strain in that coordinate direction.

For a diagonal transformation matrix the metric matrix is also diagonal, and its terms simply represent the Minkowski metric terms multiplied by the squares of their stretch factors. The stretch factors are thus equal to the square roots of the absolute values of the metric matrix, and the strains are equal to those stretch factors minus one. The (small) h_{ij} terms used in linearized gravity theory are equal to twice the strains.

In an expanding universe, gravitational increases in spatial volumes are readily calculated by integrating the product of the three spatial stretch factors, minus 1, over a domain[11].

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[11] *I first did this calculation when I was exploring the basic principles of relativity theory, and I calculated the total amount of additional volume that one gram of matter has added to the universe, by integrating the incremental volume due to the one gram out to the cosmological horizon. I was intrigued by the result: it was close to the inverse of the estimated mass density of the universe. That was my first real step on the path that eventually led to AltU.*

6.5.2 AltU's Geodesic Trajectory Equation

Predicting trajectories in gravitational fields is typically based on predicting the instantaneous acceleration rates of objects that have known positions and velocities in the observer's coordinate system. In general relativity theory these predictions are described by what are known as geodesic trajectories: the trajectories that inertial, force-free particles follow in gravitational fields. There are a number of alternative derivations of the geodesic trajectory equation (see Geodesics in general relativity - Wikipedia), though none of them provides a particularly compelling explanation as to why they work.

The geodesic trajectory that an object follows is a function of the metric equations that describe spacetime at each point along the path. AltU's proper time-based metric equation for a vacuum is based on equation (4.7a), and is simply the local Minkowski metric expressed using the cosmic time coordinate and the cosmic speed of light:

$$d\tau^2 = e^{-2U} dt_c^2 \; - \; e^{2U} \frac{dx_s^2}{c_c^2}, \text{ or } d\tau^2 = dt_{loc}^2 \; - \; \frac{dx_s^2}{c_{loc}^2} \tag{6.3}$$

(It is conventional to multiply both sides of the line element of a metric equation by the constant c^2, but that has no effect on the resulting trajectory, and we omit it in our version of the metric).

Per the above discussion of metric equations, the temporal strain is $e^{-U} - 1$. There is no spatial strain in AltU, but the speed of light has a 'strain' that is identical to the temporal strain. For a weak gravitational field the strains equal $-U$: time and the speed of light are slowed equally.

For comparison, using our symbols the Schwarzschild metric[12] is: $\mathrm{d\tau^2 = (1 - 2U)dt_c^2 - \frac{1}{1-2U}\frac{dr^2}{c^2} - \frac{dx_\perp^2}{c^2}}$. The temporal strain is $(1 - 2\mathrm{U})^{1/2} - 1$, and the radial strain is $(1 - 2\mathrm{U})^{-1/2} - 1$. In a weak gravitational field those values are equivalent to AltU's values. However, AltU's spatial terms are isotropic while the Schwarzschild spatial strains are one-dimensional.

Our metric equation (6.3) leads to the following geodesic equation for the acceleration rate, using the cosmic time coordinate:

$$\overline{\boldsymbol{a}}_{\boldsymbol{c}} = (c_c^2 e^{-4U} + v_c^2)\overline{\boldsymbol{\nabla}}U - \left[4(\overline{\boldsymbol{v}}_{\boldsymbol{c}} \cdot \overline{\boldsymbol{\nabla}}U) + \left(2 - \frac{v_c^2}{c_c^2 e^{-4U}}\right)\left(-\frac{1}{c_c}\frac{dc_c}{dt_c} + \frac{dU}{dt_c}\right) + \frac{dU}{dt_c}\right]\overline{\boldsymbol{v}}_{\boldsymbol{c}}$$

Note that the $c_c^2 e^{-4U}$ term equals the square of the light speed at the location of interest, i.e. $c_{loc\_c}^2$. From equation (5.4) we know that $\frac{1}{c_c}\frac{dc_c}{dt_c} = -H(t_c)$, the negative of the Hubble coefficient, so we can express the above equation as:

[12] The radial r coordinate of the Schwarzschild metric is not the Cartesian radial distance. It is a non-linear function of the Cartesian radial coordinate, defined implicitly as representing a radial location where $2\pi\mathrm{r}$ equals the proper length of the circumference. The distinction between the two radial coordinates is usually ignored. The $dx_\perp$ term in the above equation represents a coordinate distance perpendicular to r, i.e. in a circumferential direction.

$$\overline{\boldsymbol{a}}_{\boldsymbol{c}} = (c_c^2 e^{-4U} + v_c^2)\overline{\boldsymbol{\nabla}}U - \left[4(\overline{\boldsymbol{v}}_{\boldsymbol{c}} \cdot \overline{\boldsymbol{\nabla}}U) + \left(2 - \frac{v_c^2}{c_c^2 e^{-4U}}\right)\left(H(t_c) + \frac{dU}{dt_c}\right) + \frac{dU}{dt_c}\right]\overline{\boldsymbol{v}}_{\boldsymbol{c}} \qquad (6.4)$$

Two components of the gravitational acceleration are apparent in equation (6.4): one parallel to the gradient of the gravitational intensity, and one parallel to an object's velocity (its velocity exposes it to changing gravitational intensity levels).

Equation (6.4) works well. Using the equation (5.1) definition of the local gravitational intensity U ($-\varphi/c^2$) it correctly predicts all basic gravitational phenomena, and it passes all of the basic tests for relativistic gravity, including the gravitational deflection and slowing of light and the precession rates of the planets. Ignoring the $H(t_c)$ term, it predicts stable orbits. (We will discuss the effects of the $H(t_c)$ term in Appendix C, section 11.8).

For example:

- AltU's prediction for the rate of advance of Mercury's perihelion matches astronomical observations and calculations: 42.994"/century.
- AltU's prediction for the deflection of a light ray passing close to the sun matches NASA's observations: 1.75126".
- AltU's prediction for the delay in the round trip of a radio wave transmitted from the Earth, passing close to the sun, and reflected back by Viking orbiters/landers on Mars matches NASA's observations: 247.3 μs.

However, equation (6.4) has limitations:

- It does not correctly predict the precession rates of binary pulsar systems (see Will, 2018, Chapter 12), underestimating them by about half.
- It does not predict the decay of orbits.
- Our formula for the gravitational intensity does not fully incorporate special relativity, and thus does not predict gravitoelectric and gravitomagnetic effects.
- It does not recognize that the universe has a preferred frame.

Our interpretation is that equation (6.4) represents a useful approximation. It's limitations partially arise from its simplistic representation of the gravitational intensity field of a mass, which is in reality subject to a variety of second-order effects. However, some of the limitations arise for a different reason: the geodesic metric-based approach does not fully capture gravitational dynamics. The PPN-based gravitational equation for a binary system, based on general relativity theory (see Poisson and Will, 2014 Equation 9.142) has a more complex basis. This equation, which successfully predicts the precession rates of binary pulsar systems, is not a simple geodesic based on a metric equation.

6.5.3 The Gravitational Acceleration of Light

For a photon $v_c = c_{loc\_c}$ and, ignoring the $H(t_c)$ term, the geodesic equation (6.4) simplifies to:

$$\overline{\boldsymbol{a}}_{\boldsymbol{c}} = 2c_{loc\_c}^2\overline{\boldsymbol{\nabla}}U - \left[4(\overline{\boldsymbol{v}}_{\boldsymbol{c}} \cdot \overline{\boldsymbol{\nabla}}U) + 2\frac{dU}{dt_c}\right]\overline{\boldsymbol{v}}_{\boldsymbol{c}} \qquad (6.5)$$

This geodesic trajectory equation for a photon is equivalent to the photon acceleration equation based on AltU's variable speed of light, equation (6.1). The varying speed of light approach and the metric-based solutions lead to the same result. That is a significant validation.

6.5.4 Second-Order Effects on a Mass's Gravitational Intensity

AltU's premise is that gravitational effects primarily arise from two factors, with a single underlying cause. The two factors are changes to the local speed of light, and changes to local clock speeds. The immediate underlying cause is the local gravitational intensity. The gravitational intensity reflects the local density of gravitons (Higgs particles, we think), virtual particles that populate the vacuum and directly determine the velocities of massless particles (such as photons). Because masses contain massless particles, the gravitons also cause changes to the velocities of masses.

However, there are nuances to gravitational trajectories that AltU's simple representation of the gravitational intensity does not reproduce. The conventional theory of gravitation is also metric-based, and with rare exceptions it has been unable to derive useful exact solutions of the metric. Its development has followed two more or less parallel evolutionary paths. One path is to try to patch together approximate local solutions for a metric equation, and the other path is to more or less abandon the use of a metric-based geodesic equation and instead focus on improved approximate solutions of Einstein's field equation and the trajectory equations. The latter path, in particular, has derived some spectacularly successful trajectory equations. However, neither of these paths is based on, or accompanied by, a conceptual model of the processes that underlie gravitational phenomena.

AltU's gravitational approach needs to develop further. The evolutionary path for the AltU concept should include identifying and describing subtleties in the gravitational intensity field and in its interactions with masses. Hopefully, the basic vacuum metric and geodesic equations won't need to be changed, and only the local form of the gravitational intensity experienced by an object will need to be modified.

This approach should lead to a more complex equation for the gravitational intensity, which is currently $U_j = \Sigma_i G m_i / c^2 r_i$. Second-order changes here will be reflected in U_j and $\overline{\boldsymbol{\nabla}} U_j$ and should lead to an improved ability to predict trajectories in high-intensity gravitational fields.

We discuss a number of possible second-order effects in Appendix C, section 11.5.

6.6 Gravity in AltU: Summary Discussion

6.6.1 The Scalar Gravitational Field

In AltU all of the local effects of gravity in a vacuum are defined by a single scalar field, the gravitational intensity. The metric equation in AltU really has only a single degree of freedom at a point, rather than the ten degrees of freedom associated with a conventional metric tensor. That's very convenient, but it isn't cast in stone. Possibly there are some velocity-related second-order effects on the gravitational field that require a more complicated metric tensor.

The scalar gravitational field defines the local speed of massless particles, and masses are comprised of tethered massless particles rotating in orbits at the speed of light. Gravitational accelerations of masses arise from the refraction of those particles caused by gradients in gravitational fields.

In addition to refraction-induced curvatures of their paths, massless particles also accelerate or decelerate along their pathways as they encounter variations in the local gravitational intensity. High-velocity masses also experience this effect, to a lesser extent.

6.6.2 What is Energy's Role in Gravitation?

The preceding discussion has only addressed the role of mass as a source of gravity, but in the conventional universe both mass and energy cause the spacetime curvature that drives gravity. There is ample evidence that mass can be converted to energy, and that energy can be converted to mass. However, there does not appear to be any evidence that 'pure' energy has gravitational effects. Quite the opposite, in fact: the cosmological constant problem, which is considered to be one of the major unsolved problems in physics, arises because the zero-point (vacuum) energy of empty space appears to have no gravitational effects. In AltU the presumption is that pure energy has no gravitational effect.

However, the bound energy of the massless particles that are locked within masses is the origin of their gravitational fields. In AltU the binding force that connects those massless particles is the source of gravitation. So that 'bound' form of energy does cause gravity.

Also, a proposed second-order gravitational effect (discussed in section 11.5.3) whereby a mass's gravitational strength is proportional to its temporal rate results in a mass at a higher elevation, with a greater potential energy and an increased temporal rate, having a stronger gravitational field. Its gravitational potential energy would be associated with the additional gravitational strength.

6.6.3 Black Holes are Very Different in AltU

Per equation (4.7a), around a single spherical mass the local speed limit $\mathrm{c_{loc}} = \mathrm{c_c} \mathrm{e}^{\frac{-\mathrm{GM}}{\mathrm{c^2 r}}} = \mathrm{c_c} \mathrm{e}^{-\mathrm{U}}$. The local temporal rate is $\mathrm{e}^{-\mathrm{U}}$. This means that in AltU black holes are much simpler than they are in the conventional universe. There is no central singularity, and there is no event horizon. They are simply massive, dense, dark red masses. Time moves very slowly within them, and their gravitational well is so deep that photons that escape have their energy essentially completely drained. Only long-wavelength radio waves should be able to escape from the inner regions. Quasars appear to fit this description nicely— sometimes we observe high-redshift photons that were emitted from their inner regions closer to the central mass, and sometimes we observe low-redshift photons that were emitted from the accretion disk farther away from the central mass.

Subsequent to the final nova when its fuel is exhausted, a star with a mass greater than 3-4 times the Sun is currently believed to collapse down below its Schwarzschild radius $\left(\frac{2\mathrm{GM}}{c^2}\right)$ and therefore to form a black hole, hidden within (and partially frozen at?) an event horizon. This does not occur In AltU because the temporal rate never drops to zero: instead the star's density increases until a new equilibrium is created. Something dense is created, but it is still connected to the rest of the universe and time still proceeds, albeit very slowly, within it.

As discussed in Appendix C (11.5.2), its own gravitational intensity causes a black hole to react somewhat sluggishly to gravitational fields, so very dense black holes would not be inclined to participate in binary inspirals.

Also, as discussed in Appendix C (11.5.3.2), a black hole's gravitational self-intensity weakens its internal gravitational accelerations, which results in lower densities for AltU's neutron stars and black holes.

We will continue to use the term "black hole" to refer to large-mass dense bodies in AltU, but in reality neutron stars and "black holes" are part of a single spectrum.

6.6.4 Implications for Einstein's Gravitational Theory

The successful test results for AltU's scalar gravitational field imply that the general relativity model of spacetime as a pseudo-Riemannian continuum may be unnecessarily complicated. The much simpler model of a universe where space does not distort, and only the speed limit changes, appears to be credible.

Also, there is a subtle but significant problem with general relativity's spatial expansion concept. As discussed in Appendix A, metric equations have to be functions of proper rather than coordinate distances— coordinate distances have no physical meaning. The AltU and PPN metrics are based on coordinate distances, and trying to convert either metric from a function of coordinate distances to a function of proper distances leads to a very messy, improbable-looking metric equation. The same is true of the Schwarzschild metric: it just doesn't work as a function of proper distances. However, in AltU space is unchanging, and coordinate distances are proper distances— so it is unsurprising to find physical properties (i.e. the gravitational intensity U) that are functions of those distances.

6.6.5 Cosmological Consequences of the Changing Acceleration Rate

From the cosmic observer's perspective, AltU's basic gravitational acceleration equation (6.2) for a static object is $\overline{\boldsymbol{a}}_{\boldsymbol{j\_c}} = c_c^2 \overline{\boldsymbol{\nabla}} U_j$: it is proportional to c_c^2. Over the duration of the cosmological model that was presented in Chapter 3, the speed of light dropped by a factor of 1.1e9, so since our start time gravitational acceleration rates have dropped by a factor of 1.21e18! Accordingly, in the very early universe the gravitational force was probably not negligible at very small scales. Fortunately for us, the mass density gradients were very low, and the gravitational acceleration rates dropped quickly. Still, in the early times there was a potential for rapid gravitational collapse of smaller baryonic masses into black holes, and the initial evolution of the dark matter scaffolding of the universe would have occurred very rapidly.

6.6.6 The Physics of Early Gravitational Fields

AltU's basic gravitational acceleration rate, from equation 6.4, is $\overline{\boldsymbol{a}}_{\boldsymbol{c}} = c_c^2 e^{-4U} \overline{\boldsymbol{\nabla}} U$. The cosmic light speed c_c continuously decreases, at the Hubble rate. The light speed that corresponds to a redshift of z is $(1+z)c_{c0}$, where c_{c0} is the present speed of light. The net effect is that the acceleration rate at the time corresponding to z was $(1+z)^2$ times what the current acceleration would be for the same local values of U and $\overline{\boldsymbol{\nabla}} U$. If we look back to the time corresponding to a redshift of 9, some 1.4 billion years after the start, when early stars would have been forming, gravitational accelerations would have been 100 times stronger than they are now.

However, physical objects would have been 10 times larger than they are now. If that size ratio also applies to orbital distances then orbital radii would have been 10 times greater, and radial gravitational accelerations for planets would have been the same as they are now. Orbital velocities would be 10 times greater, and orbital periods would be the same as they are now.

In fact, in AltU orbital radii do gradually shrink, at the Hubble rate. This is discussed in Appendix C, section 11.8.2. The net effect is that stable orbital systems experience unchanging acceleration rates and orbital periods, while their radii vary in proportion to $1 + z$.

The dimensions of solid masses would also vary in proportion to $1 + z$, and the stresses within a solid planet would be approximately the same as they are currently.

I'm not sure what the size and stresses would be for liquid or gaseous planets or stars- my first, and last, exposure to kinetic molecular theory was long ago. Hopefully the stresses would be equivalent to what they are currently, and the predicted behavior of the early stars would be similar to current stars.

6.6.7 Gravity: The Unsolved Time Delay Problem

It takes time for gravitational effects to propagate across space, but the masses in gravitational systems appear to react to the instantaneous locations of other masses. This was pointed out as long ago as 1825 by Laplace, who calculated that if gravitational accelerations were directed towards the prior locations of masses based on the travel time for light waves then the solar system would promptly become unstable.

Current relativity-based orbital models define the gravitational fields of masses based on instantaneous transmission. For example, gravitational fields are communicated instantaneously in NASA's extremely precise model of the solar system (Folkner et al (2014)), a model which predicts orbital locations over long time periods with centimeter-order accuracy.

6.6.7.1 A Binary Pulsar Example

Recent examples of this paradoxical result appear in the orbits of binary pulsar systems. For example, one of the binary pulsar systems that has been observed, and modeled very precisely using a higher-order Post-Newtonian approach, is known as PSR J0737 (see Kramer et al, 2006). Here is a summary of some of its key parameters:

- The binary consists of two pulsars, which have masses equal to 1.34 and 1.25 times that of the sun.
- They have a somewhat elliptical orbit, and are separated by about 9e5 km on average (about 1.3 times the sun's radius). At the speed of light it takes about 3.0 s for a gravitational effect to be communicated between the masses.
- The orbital period is 8,834 s (2.55 hr), orbital velocities are in the order of 315 km/s.
- The orbital period is slowly decreasing. On average, each orbit is about 11 ns shorter than the previous one, and the period is decreasing at a fractional rate of about 4.5e-9 a^{-1}.

- Based on the general relativity PPN equations[13], the orbital period decreases reflect a slight misalignment between the acceleration vectors of the two pulsars. Each of those vectors is directed towards a point just slightly ahead of the other pulsar's current location. The distance by which the vector leads the center of mass of the other pulsar is about 55 µm (the width of a human hair!), which corresponds to an angle of about 6.3e-14. For each mass the acceleration vector has a purely radial dominant component and a drag component[14] that is a 6.3e-14 fraction of the radial component. Although the drag components are absurdly small, they explain the observed data quite precisely. Even a slight variation in the drag components (i.e. in the acceleration direction) results in orbits that are inconsistent with the observed data[15].

Apparently, at any given time each of the pulsars is experiencing a precisely-defined metric that was determined by the location and velocity of the other mass some 3.0 seconds previously, when that mass was located some 880 km short of its current position. The metric creates an acceleration vector that targets the future location of the other mass, 9e5 km away, with an eerily precise not-quite-correct value: the actual location plus an additional 55 µm in the pulsar's direction of motion. From our perspective, this requires a very precise transfer of information between two large, rapidly rotating, distant bodies. What possible type of infrastructure could support such an information transfer?

6.6.7.2 Retarded Potentials?

In electromagnetic theory a similar issue arises for the electrical field of a moving charge, as discussed in Purcell and Morin, (2013). At each point on a charge's path it is visualized as emitting a 'bubble' of electrical field. Each bubble's center follows the velocity vector of the charge at the instant the bubble was released, and each bubble expands at the speed of light. At a given place and time the electrical field due to the charge is defined by the particular bubble that is currently expanding through the location. Thus the observed field at a remote location extrapolates the predicted field based on the charge's earlier location and velocity.

It would be convenient if a similar concept would work for gravitational fields. However, simply extrapolating the velocity of one of our pulsars for 3.0 seconds leads to a predicted location that is some 1120 meters farther away from its binary partner and 0.9 meters short of the actual current location of the mass. Extrapolating quadratically improves the situation somewhat: the projected location is 0.52 meters further away from the partner and the same 0.9 meters short of its current location. Neither extrapolation approach predicts the actual target location for the metric-based acceleration vector with sufficient accuracy, i.e. to less than a hair's width. If we are going to successfully explain how gravity is

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[13] Equation (82) in Will, 2014, describes the incremental accelerations of a binary system's masses due to the radiation of orbital/gravitational energy. These accelerations are dominated by its 'drag' component parallel to each mass's velocity, though there is also a radial component. The underlying equations of gravitational radiation were developed much earlier (see Peters and Mathews (1963) and Peters (1964)).

[14] The drag component of the acceleration appears to vary with $(v/c)^5$ for this relatively low-velocity system.

[15] I tested this using a quite precise orbital trajectory integration model, the same one that is used for AltU's gravitational tests.

propagated we will have to look for a different concept. (This is probably also the case for electromagnetism).

An information transfer mechanism might arise from the velocity vectors or the density field of mediating particles that were emitted by the partner star as those particles pass by the affected pulsar. The combined gravitational fields of both members of a binary system would modify the trajectories of such particles, bending them somewhat. Perhaps as a result they tend to precisely align the velocities, or the gradient of the particle density, with the current location of the emitting pulsar. However, preliminary simulations based on this concept were not encouraging.

6.6.8 Gravity: a Propagation Solution?

In 1931 J. B. S. Haldane wrote that *"… the universe is not only queerer than we suppose, but queerer than we can suppose"*, and that quotation continues to resonate. Personally, I would prefer a complex universe built from simple components, and perhaps that is the case- but a simple explanation for the machinery of gravity is not apparent. I have experimented with numerous concepts, and the only one that might work has a distinctly Rube Goldberg flavor. For what it's worth, it is as follows:

As we have speculated, gravity is transmitted by particles emitted from masses, which we refer to as gluons. Each gluon is entangled with the mass particle that emitted it. The passage of gluons at a point injects the vacuum there with ephemeral activity- something like the trail of fire that a rocket leaves behind it. The amount of activity that each gluon injects is proportional to its <u>current</u> distance from its originating mass particle. *This implies that the gluon is entangled with its originating mass particle.* You might think of a gluon as something like a rubber band that is connected to its originator- its strength is proportional to its length. The total vacuum activity corresponds to AltU's gravitational intensity parameter, U_{tot}.

As we have discussed previously, in this concept the Higgs bosons of the vacuum are the local mediating particles for gravitational effects. The Higgs bosons interact with massless particles, and each interaction causes a time delay for a massless particle. Those delays are the source of relativistic effects of all types.

This is all absurdly complicated, but it does achieve a vacuum energy contribution from a mass that is inversely proportional to its distance rather than to the square of the distance, and it doesn't create a gravitational Doppler effect between one mass and another. The fact that the injected energy is ephemeral ensures that the vacuum's response to a transient gravitational wave is equally transient. It is the flux of the gravity-transmitting particles that determines the vacuum energy density.

The fact that emitted particles originate gravitational effects implies that a mass's gravitational strength is proportional to its temporal rate, and that is conceptually consistent with the conventional concept that energy is a source of gravity.

6.6.9 Gravity in AltU: Summary

Our exploration of gravity in AltU has been productive, but ultimately it fell short of the goal of deriving valid equations accurately describing all of the observed gravitational phenomena. In searching for the mechanism(s) underlying gravity it ruled out numerous possibilities, and it fleshed out a generally credible conceptual model based on the behaviors of particles. That conceptual model challenges conventional gravitational theory in some fundamental ways, in particular with respect to the distortion of spacetime, the nature of black holes, the form of gravitational radiation, and the mechanism by which gravitational fields are propagated. As a bonus, the model uncovered a conceptual basis for the mechanism that underlies special relativity.

If the concept that gravity is propagated via entangled gluons is correct then the entire universe within our cosmological horizon is literally touching each of us, and we are touching it.

7 AltU: Some Challenges, and Some Comments

The concept that masses cause a reduction to the speed limit in the space around them, and that this process underlies gravity and the history of the universe, appears to be novel. It will take time and effort to pursue and qualify the concept. However, the results presented above are encouraging— it is unlikely that such a simple concept would yield so many good predictions purely by chance.

7.1 Challenges

The AltU concept faces numerous challenges:

1. The Total Mass Density of the Universe. AltU's cosmological model requires a very low value for the total mass content of the more remote regions of our universe— something no more than about 1.47e-31 g/cm^3, much less than the 2.6e-30 g/cm^3 value inferred for our corner of the conventional universe.
2. AltU's Early Universe is Very Different. The AltU approach's predicted behavior of the early universe is very different from that of the standard model, and it will require a significant effort to evaluate its credibility. In particular, it will probably be necessary to simulate nucleosynthesis (and possibly baryogenesis) in AltU. New simulations of the evolution of the matter distribution in the universe will be required.
3. AltU's Gravitational Waves are Different From Einstein's. Gravitational waves, apparently created by the collapse and merging of pairs of orbiting black holes or neutron stars, have recently been observed in LIGO observatories (Abbott, B. P. et al., 2016). A model based on Einstein's physics is consistent with those observations, though there has been no direct observation of the originating systems that would validate their inferred properties.

   The AltU approach will also generate gravitational waves, and decaying orbits, and this is discussed at a conceptual level in Appendix C, section 11.6. However those gravitational waves have a different form from the waves predicted by Einstein. It is unclear whether they could have produced the observed LIGO results.
4. Lack of Integration with Quantum Mechanics. Can AltU be explained by quantum field theory? AltU is a much simpler target than general relativity was, but describing how gravitational fields are propagated, identifying 'gravitons', and establishing how they determine the speed limit, will be a (nice) challenge.
5. The Mechanism of Gravity's Propagation. As discussed in section 6.6.6, we have been unable to identify a fleshed-out conceptual model for the mechanism that underlies the propagation of gravitational effects.

Hopefully this paper will be sufficient to interest people to try to address some of these challenges, to see whether the AltU approach, or a modified version of it, is truly credible.

To keep these issues in perspective, despite a century of tweaking it the standard model still faces a number of challenges. Those challenges were the main motivators for the Author's search for an alternative. Appendix A discusses some of them.

7. Challenges and Comments

7.2 Testable Predictions

The AltU concept predicts a universe that differs significantly from the conventional universe in a number of ways. Some of these differences offer a possibility of direct tests:

1. The Aether, and the Anisotropic Speed of Light on the Earth. In the SI system the speed of light is a fundamental constant. Direct physically measurement of the one-way speed of light is problematic. However, as described in the Introduction (3.2.1.2) it does appear possible to measure the amount of anisotropy in the speed of light, which would be a strong test of one of AltU's fundamental concepts.
2. Gravitational Waves. In the conventional universe LIGO detectors should be quite sensitive to the orientations of their arms with respect to the plane of an observed gravitational wavefront. Sometimes they should pick up the full strain in the wave's metric, sometimes they should miss it entirely. To date, however, they all seem to observe quite similar strain levels— something that would occur in AltU. As the LIGO observations build up the inconsistencies should become more apparent, and AltU-type gravitational waves should be found to provide a better explanation.

   Also, conventional gravitational waves have their greatest amplitude close to the rotational axis of the binary, while AltU's waves have their greatest amplitude close to the orbital plane. If a post-inspiral telescopic observation of a collapse is ever achieved that should test the two approaches.

   Modified versions of existing gravitational wave detection systems may be able to prove or disprove the existence of temporal components in the gravitational waves, and the issue of isotropic vs. anisotropic 'spatial strains'.
3. Simulating Nucleosynthesis in AltU. Potentially an enhanced early-time version of AltU's cosmological model could incorporate a representation of the high-energy early-time physics. AltU's results would undoubtedly be somewhat different from those for the standard model of the universe, and might serve to increase or decrease its credibility.
4. Continued Strengthening of the Angular Size Cosmological Test. These test results are already very consistent with AltU's predictions, and stronger tests should serve to reinforce this finding, and to reduce the credibility of an expanding universe. Improved datasets, and increasing understanding of galactic interactions, should strengthen the test.

7.3 Some Personal Comments

Starting in 2016, at the age of 71 and with time on my hands, I developed the AltU approach presented herein over a period of several years, gradually evolving a theory that progressively moved further and further away from conventional general relativity and cosmology. Initially I considered an expanding universe model based on the anisotropic Schwarzschild metric's spatial strains and the concept of wave-like gravitons spreading gravitational fields. The results matched λCDM results for very early times, but they couldn't closely match the observed supernovae redshift pattern without invoking negative spatial curvature. However, an experiment using a spatially isotropic metric produced redshifts that fit very well.

A spatially isotropic metric isn't really compatible with Einstein's field equation, and it doesn't need a full second-order tensor to describe it. I was already deeply uncomfortable with the field equation, with the Schwarzschild solution, and with the Friedmann equations, as described in Appendix A. A spatially isotropic metric equation would need an underlying basis for gravity that was quite different. If all three spatial strains are the same, and given that the temporal strain is effectively equal to the inverse of the spatial strain, then a single scalar field defines everything gravitational. A search for a credible origin for whatever underlies that scalar field quickly suggested the speed of light as a candidate.

If gravity is based on a scalar field rather than a tensor field, and if the speed of light is involved, special relativity has to play a central role. Going back to look in more depth at special relativity and how it might underlie gravity led me to the concept of the varying speed limit, and to the resulting simple metric equation for gravity. That simple metric appears to work well, and it led directly to AltU's non-expanding universe, and the predictions for its cosmology.

In the end a remarkably simple conceptual model has been developed. It has only one parameter that has significant uncertainty, and though it needs testing and refinement, it does a remarkably good job of explaining much about the universe.

On the other hand, my attempts to discern the mechanisms underlying second-order gravitational effects have been fruitless. Some of the concepts may be valid, but I am clearly missing something significant- which is very frustrating.

When I first found myself doubting the foundations of conventional theory I had to laugh at my own temerity— I was absolutely unqualified academically to hold such opinions. However, over the last few years as the AltU concept has evolved I have developed great confidence in its basic validity— I think it's the real thing. Despite that confidence in the basic ideas, I'm sure that many of the more speculative parts of the paper will prove to be off base. We still have a lot more to discover about how the universe works!

My greatest frustration has been a complete inability to get a qualified physicist or astrophysicist to actually read and critically review the draft document. Since 2016 I have tried every approach that I could think of, with no success at all. I even sought comments from unqualified physicists, via various online fora, with no success. From time to time I submitted versions of this paper to journals, but it was inevitably rejected without being forwarded to reviewers. It has been baffling and frustrating— I think I could have got the paper to its current stage in a fraction of the time if I had someone to discuss my ideas with. On the positive side, my isolation led me to discover and enjoy learning a little bit about all sorts of fascinating phenomena and theoretical approaches.

If the AltU concept survives it will undoubtedly become more complex. In order to predict very early time behavior for the universe it will need a description of the spatial form of the initial variability of the universe's mass density. It may also turn out that there is some nonlinearity in the basic equation for the speed limit, which could be manifest at very early times or at very high values of the gravitational intensity (i.e. in black holes). Even so, AltU will probably be far simpler than our conventional λCDM universe, and it will be far more mundane: no inflation, no string theory, no expansion, no tensorial distortions of space, no time stopping at event horizons, no wormholes, no unsolvable nonlinear equations for gravity. At the same time, some of the familiar verities of the conventional universe will be lost: no more absolute conservation of energy or momentum.

Perhaps unsurprisingly, in many ways what is proposed here is not new— others have developed similar concepts. Following are some examples:

- In 1912 G. Nordström proposed a theory of gravitation that is very similar to AltU's, with the same scale factor ($e^{-\varphi/c_0^2}$), the principal difference being that Nordstrom applied the scale factor to masses rather than to the speed of light. This is discussed in the Wikipedia article "Alternatives to general relativity": link.
- Dicke (1957) postulated a static universe with a slowing speed of light, which he indicated would show redshifts for distant galaxies, along with providing conventional gravitation. He put quite a lot of flesh on those bones, but his initiative seems to have more or less petered out.
- As well as Dicke, over the years numerous other researchers have proposed VSL concepts. V. S. Troitskii (Troitskii, 1987[16]) investigated the concept in the latter part of the 20'th century, identifying other physical 'constants' that might have to vary along with c. A more recent concept was described by Albrecht and Magueijo (Albrecht and Magueijo, 1999).
- Watt and Misner (1999) proposed an approximate metric equation for what they titled 'scalar gravity'. Scalar gravity was presented as a good approximation to the "real thing" in numerical relativity computations, and they showed that it would match many standard tests closely. As it happens, scalar gravity's metric is identical to the AltU metric, equation (6.1).
- Urban et al (2011) suggested that a time-varying refractive index might arise due to interactions between photons and the virtual particles of the vacuum, with the index increasing in gravitational fields. They argued that this would result in gravitational effects equivalent to those predicted by general relativity theory. Following on from that work, Sarazin et al (2018) discussed the concept that gravitational fields cause changes to the speed of light and its refractive index, and explain gravity, and that a time-varying vacuum refractive index can explain the apparent expansion of space.

[16] Unfortunately, this paper has numerous typographic errors, and it also appears to be a very poor translation from a Russian-language original (*Dokl. Akad. Nauk* USSR **290).**

8 Acknowledgments

I would like to express my gratitude to Wikipedia, and all of the people who contribute so generously to its content. It is an astonishingly valuable resource to people like me, and as I worked on my ideas Wikipedia was a never-failing source of usually-accurate information. Also arXiv.org and ResearchGate.net frequently provided valuable access to published papers.

I hadn't got far into my musing on this stuff before I realized that I would need to learn a lot more about the theory of relativity. I found much of what I needed in Peter Collier's book A Most Incomprehensible Thing: Notes Towards a Very Gentle Introduction to the Mathematics of Relativity, which I found on Amazon. The book is a pleasure to read, and I returned to it again and again as I started to work on my ideas. It always delivered the information I needed.

Astronomer Martin Lopez-Corredoira's publications were very helpful to me as I tried to develop an adequate understanding of astronomically-based tests of cosmological theories. I was also encouraged, and amused, by his perspective on the group-think approach that dominates modern scientific research.

Lastly, I would like to acknowledge all the others who set out to explore, and then to challenge, established physics. The barriers are high, the process is intimidating, and there are a lot more dead-ends and closed doors than successful paths— but it's a worthy endeavor.

9 Appendix A: On The Foundations of Relativity and Cosmology

The theories of special and general relativity, and the gravitational and cosmological models that are based on them, have been very successful at describing reality. The theories have worked spectacularly well, and they are embedded within a wide range of conceptual models of astrophysical systems. Their successful predictions have served to validate the theories, and it is hard to imagine that they could be wrong. Could conventional relativity theory actually be incorrect?

Relativity theory is complex, and its foundations can be viewed as a hierarchy, with each level building on the one that preceded it:

1. The special theory of relativity.
2. The general theory of relativity's founding principle, that spacetime acts as a pseudo-Riemannian manifold: spacetime curvatures, described by metric equations, drive gravity. The corresponding geodesic equations describe inertial trajectories.
3. Einstein's field equation, which links the spacetime curvatures at a location to the presence and fluxes of mass, energy and momentum there.
4. The Friedmann (a.k.a. Robertson-Walker a.k.a. FLRW) cosmology equations, which describe the expanding universe.

The main AltU concept doesn't change the equations of special relativity, though it modifies the theory by proposing that gravitational fields reduce the speed of light and that the universe has a natural 'preferred' spatial coordinate frame. The AltU concept employs metric and geodesic equations but it completely ignores the field equation and the Friedmann equations. It is fundamentally incompatible with those equations: if it is valid, they are not.

The conceptual bases of conventional gravitation and cosmology are much more complex than their counterparts in AltU, and this appendix discusses and challenges some aspects of them. It also discusses the thought process that may have underlain the development of the field equation, and postulates how that thought process may have led to an inappropriate conclusion.

9.1 *Critique of the Field Equation*

A legitimate theory of gravitation should predict gravitational behavior, independently of Newtonian theory, and should do so better than Newtonian theory does. Ideally, it should also make significant, verifiable predictions about cosmological processes. Does the field equation, together with the Friedmann equations, pass these tests?

If you have accepted the first two items in the above list of foundations of relativity theory (the equations of special relativity and the use of metric-based geodesic equations), what else do you need in order to have a complete theory of gravity? A single key requirement comes to mind: ***a solution for how the metric equation at a spacetime point is affected by mass and/or energy in surrounding regions***. Our critique of the field equation is based on how effectively it provides a foundation for meeting that requirement.

The field equation is $G_{\mu\nu} \equiv R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = -\kappa T_{\mu\nu}$, where $G_{\mu\nu}$ is the Einstein tensor, $R_{\mu\nu}$ is the Ricci tensor, R is the Ricci scalar, and $g_{\mu\nu}$ is the metric tensor. The Ricci tensor and scalar are a function of the metric tensor and its derivatives. $T_{\mu\nu}$ is the energy-momentum tensor.

9.1.1 Issues with the Form of the Field Equation

There are a number of fundamental problems with the form of the field equation:

1. The Field Equation Does Not Explicitly Predict Gravitational Effects

The field equation does not explicitly predict how a metric equation changes due to the presence of mass and energy in surrounding regions. It doesn't even predict how a metric equation changes due to the presence of local mass and energy— it just provides a constraint on a metric equation's coefficients. It does this by defining a linear relationship between a function of those coefficients, the Einstein tensor, and the local energy-momentum tensor.

The Einstein tensor is a function of the local spacetime curvature as expressed in the Ricci tensor, and the Ricci tensor in turn is a function of the metric equation coefficients and their first and second derivatives with respect to space and time. Accordingly, the Einstein tensor only makes sense when those metric coefficients are continuous and twice-differentiable: they have to vary smoothly.

The energy-momentum tensor at a point is comprised of the fluxes of four-momentum there. The tensor can also be expressed using more mundane terms: the spatial density of mass/energy, the spatial fluxes of mass/energy, and the normal and shear stresses at the point. Similarly to the Einstein tensor, the energy-momentum tensor at a point only makes sense when those parameters vary smoothly. That creates a fundamental problem, which is discussed in more detail below, because in the real universe those parameters do not vary smoothly[17].

Thus, the field equation relates a function of the local metric coefficients and their derivatives to the local energy-momentum tensor. However, it doesn't actually define the metric coefficients and their derivatives. It's just a constraint equation. It is very much analogous to Poisson's equation, except that Poisson's equation incorporates the Newtonian gravitational potential while the field equation leaves the definition of the metric to the user. The field equation says nothing at all about the gravitational effects of non-local mass/energy.

So on its own the field equation doesn't really come close to meeting our key requirement: *a solution for how the metric equation at a spacetime point is affected by mass and/or energy in surrounding regions*. Accordingly, gravitational theorists have had to develop a variety of approaches to predict the metric equations for specific situations. Almost all of these approaches are presented as approximate solutions of the field equation, because finding exact solutions is rarely possible. Because there is no theoretical basis defining the gravitational effects of non-local mass/energy, these solutions typically have to rely on convergence towards Newtonian gravity at large distances, and on assumptions about basic principles and conserved quantities. There is a lot of art and science underlying these approximate solutions, but they are not our subject. The fundamental limitations of the field equation remain: it does not fully specify how the local metric

[17] However, the energy-momentum tensor for a finite heterogeneous region is a valid and useful construct for describing dynamics. This approach is central to successful models of orbiting systems.

equation changes due to the presence of mass and energy, and it does not provide a description of the gravitational effects of distant mass/energy.

2. The Smoothing Problem

The field equation equates a tensor that is only meaningful at a point (the Einstein tensor) to a tensor that is meaningless at a point (the energy-momentum tensor). That's problematic.

The energy-momentum tensor at a point is based on the point's mass/energy density, its mass/energy fluxes, and its stresses (normal and shear stresses). The problem is that when you attempt to find the values of those parameters at a point, unless the point is in a vacuum there are no stable limiting values at small scales. Without some form of averaging or smoothing of the energy-momentum tensor the resulting curvatures of the Einstein tensor would vary as dramatically as densities do, all the way down to the scale of fundamental particles. While it is trivial to do spatial or temporal smoothing in an arbitrary way, any particular method of smoothing or averaging of the curvatures or of the energy-momentum tensor would require some form of theoretical justification. The equivalent justification is easy to come by for Newtonian gravity, with its essential linearity, but it is not obvious that the field equation is legitimate when used with smoothed input variables. Absent a description of the gravitational effects of distant mass/energy, valid at both small and large scales, smoothing is problematic.

The smoothing problem is simply ignored in conventional relativity theory. The energy-momentum tensor is typically constructed for finite rather than infinitesimal volumes, and the flux of energy and momentum due to particles (e.g. 'dust', or sometimes even entire stars) is based on the sum of the individual particles' contributions. The scale of the volume that is used for a particular problem is left to the whim of the investigator. The resulting metric equation is typically assumed to in some way describe the finite volume as a whole.

3. The Covariance Problem

Gravitational physicists, starting with Karl Schwarzschild, routinely select a convenient coordinate system in which to solve the field equation for any given system. The justification for this is that the equation is "generally covariant"— it is supposedly valid in any coordinate system. For example, Schwarzschild selected a non-Cartesian, non-linear radial coordinate for his famous solution, and proceeded to show that the solution, using that coordinate, satisfied the vacuum field equation— its Ricci tensor was zero.

However, the Ricci tensor represents curvatures— it is a function of the second derivatives of the mapping from flat to curved spacetime. The Ricci tensor is not covariant under nonlinear transformations— an arbitrary nonlinear coordinate transformation will produce an arbitrary Ricci tensor. As an analogy, a curved rod would still experience internal stresses if it was described using a curvilinear coordinate system that made it appear to be straight. The same concept should apply for the spacetime continuum.

So, even if the field equation was meaningful and valid for Cartesian coordinates, the presumption that it would remain satisfied under arbitrary nonlinear coordinate transformations is not physically justifiable.

4. The Complexity Problem

The field equation implies that the universe has a really complex infrastructure: its second-order Ricci tensor requires ten independent variables to be somehow defined, for every point in the universe, as a function of every speck of mass or energy within the local cosmological horizon. It requires that space and time are not simply coordinates, but instead combine to represent a deformable entity, filling the universe. That entity deforms in response to local values of the energy-momentum tensor and propagates those distortions throughout its extent. Think of a giant block of rubber, subject to local pinchings or twistings whose effects attenuate at a distance. How does that entity work? What sort of quantum-mechanical machinery is involved? Needless to say, no one has a clue. Even AltU's simple scalar field, which is only a function of masses, is intimidating to figure out.

All of these problems with the field equation are reflected in the derivation of the Schwarzschild solution.

9.1.2 Issues with the Schwarzschild Solution

The Schwarzschild solution, published in 1916, is one of the few exact solutions of the field equation. It shows how a spherically-symmetric mass affects space and time in its vicinity. In particular, the mass somehow squeezes in extra space in the radial direction, while simultaneously slowing the passage of time, and these effects are more pronounced closer to the mass. The Schwarzschild solution accurately predicts most of the gravitational effects of a star or a planet, and its successful predictions are the basis for most of the presumed validations of the field equation. However, it has a number of issues:

1. The Schwarzschild solution is a vacuum solution of the field equation— it represents the external propagation of spacetime distortions that originate within spherical regions that have non-zero mass densities. However, because the field equation doesn't describe how gravitational effects propagate, the Schwarzschild solution's controlling boundary condition is matching Newtonian gravity at a large distance. That's pretty weak.

   In simple terms Schwarzschild found a metric equation, using a somewhat weird radial coordinate, that (a) has a Ricci scalar and tensor that are equal to zero (i.e. it's a vacuum solution of the field equation, if you believe that the field equation was intended to be used with somewhat weird coordinates), (b) is spherically symmetric, and (c) predicts gravitational attractions at a great distance that match Newton's. That's all— it really isn't based on the field equation in any meaningful way. In a way it's an intellectual sleight of hand, because it skips over the major deficiency in Einstein's theory: the lack of an explicit mechanism to propagate the predicted spacetime curvatures from the inner sphere of mass/energy into and throughout the surrounding vacuum. Einstein's equation doesn't even relate the gravitational effects surrounding the central sphere to the amount of mass within it— that also has to rely on Newton!

2. The Schwarzschild solution implies that a spherical mass causes a pattern of purely radial strain in the surrounding space— but that is impossible. The combined effects of all of the

components of a spherical mass can potentially create a zero-dimensional strain pattern due to isotropic spatial expansion, and they can potentially create a three-dimensional strain pattern, but they cannot create a one-dimensional pattern. In physical terms, a one-dimensional strain pattern is as credible as a planet with a square orbit[18].

3. The Schwarzschild solution is a simple function of the coordinate radius. However, coordinate distances have no physical meaning— in principle, only proper distances affect physical processes. The clockwork of the solar system has to run based on proper distances… but if the Schwarzschild solution is evaluated using proper radial distances rather than coordinate distances it gives incorrect results, and it can't easily be translated into a function of proper radial distances— it becomes extremely complex. It is very unlikely that a natural process would a) require an extremely complex equation to describe it, and b) magically take a very simple form in an arbitrary coordinate system. (According to the AltU theory proposed herein, the reality is that coordinate distances *are* proper distances, which is why they work so well.).

4. Also, the Schwarzschild solution only complies with the vacuum field equation when the Einstein tensor is calculated using the coordinate radius— which has no physical significance.

5. If gravitational effects propagate at the speed of light, how do they escape a black hole? As was mentioned previously, the field equation says nothing at all about the gravitational effects of non-local mass/energy. Schwarzschild simply wrote an equation that related the local metric to the presence of a distant mass, without addressing a physical process that might underlie that equation.

6. Lastly, there are the conceptual problems of time halting at the event horizon, and of the singularity at the center of a black hole. Physicists have learned to live with these concepts, but they are still *prima facie* difficult to accept.

9.1.3 Issues with the Validation of the Field Equation

It turns out to be remarkably hard to find any direct evidence supporting the field equation, other than for the diagonal term involving mass density. There is lots of evidence supporting the first two pillars of relativity, special relativity and the use of metric equations to determine trajectories. There is also a lot of evidence supporting the general validity of the Schwarzschild solution, at least at the scales involved in astronomical processes (it's predictions regarding what happens in and around black holes are fascinating, but not necessarily validated). But remember— the Schwarzschild solution is not based in any real way on the energy-momentum tensor, which is at the heart of the field equation. It is the

[18] Consider the strain pattern for a blob of space near to the Earth. Mentally subdivide the Earth into a number of small spheres, and for each sphere calculate the one-dimensional radial strain that it creates for the blob. Now combine those strains. They won't add up to a one-dimensional radial strain directed at the Earth's center, instead they will add up to a two-dimensional distortion of the blob, with both radial and circumferential strains.

Schwarzschild solution that has been proven accurate again and again, and not the full field equation! (And the Schwarzschild equation is a pretty good approximation of the AltU metric equation).

If you look for validation that a specific energy or momentum flux component other than T^{00} affected spacetime in the predicted way that validation is hard to find. Even validation of the effect of T^{00} is limited— T^{00} is based on local mass and energy densities, but validation of the energy component is hard to find— if you look for that validation the closest you come will be the nucleosynthesis predictions for the early universe. Those nucleosynthesis predictions are good, but they are based on the Friedmann equations— which aren't.

9.2 Critique of the Friedmann Equations

Putting aside the issues with the field equation, if you had a complete theory of gravity what else would you need in order to have a reasonably complete theory of cosmology? Two requirements come to mind:

1. ***A credible description of the universe at an early time***.
2. ***An explanation for and description of how it has evolved to its present state, with verifiable predictions***.

The Friedmann equations provide the foundation for conventional cosmology theory. Our critique of those equations is based on how effectively they support meeting the second of the above requirements— they don't address the first one.

9.2.1 Issues with the Conceptual Basis for the Friedmann Equations

Very early in the history of modern cosmology Alexander Friedmann pioneered a cosmological approach, introducing a shocking simplification: that at a large enough scale it is valid to represent the contents of the universe as a homogeneous perfect fluid, and to apply the Einstein field equation to that homogeneous universe. Obviously the stuff of the universe isn't a perfect fluid (otherwise you wouldn't be reading this), but if the field equation was going to tell us anything about the universe as a whole it was helpful to use this concept as a simplifying approximation of a complex reality. In a sense, Friedmann took the practice of ignoring the previously-discussed smoothing problem to the ultimate level.

The Friedmann equations are based on the field equation and an underlying metric equation, which was subsequently rebirthed as the Robertson-Walker (RW) metric: $ds^2 = c^2dt^2 - R^2(t)\left[\frac{dr^2}{1-kr^2} + r^2d\theta^2 + r^2sin^2\theta d\phi^2\right]$. Here R is the universe's scale factor, which currently equals 1, and k is a curvature parameter. For a flat universe $k = 0$.

The rebirth of that underlying metric equation was an *ad hoc* attempt to explain the observed redshifts of distant objects as arising from a homogeneous, expanding universe with an unchanging temporal rate— it is not based on the field equation, or Newton's gravitation, or anything else in general relativity theory. <u>There is no theoretical basis for the RW metric</u>— it's just an assumption.

Based on the homogeneous perfect fluid assumption and that assumed form for the metric, Friedmann used the field equation to show that the resulting cosmic pressure and density (and the effects of a potential cosmological constant representing dark energy) would affect the universe's scale factor in what is now the generally accepted expansion process— it's the basis for all modern cosmology. But, as we have described above, the field equation doesn't describe a physical process that would cause a localized quantity of matter (or energy) to reach out and affect the entire universe. There is no theoretical basis for Friedmann's averaging-out assumption.

Consider something tangible in your presence— perhaps the screen that you are reading this on. According to conventional theory, the mass of that screen is somehow contributing to the expansion of the universe. It's safe to say that the universe doesn't know or care what its average mass density is, so there must in fact be some sort of physical process by which that screen's mass reaches out and helps to drive expansion. Remarkably, in the hundred years since Friedmann's equations were published, no one seems to have ever proposed an explanation for that process. The reason for that absence is likely the fact that any possible explanation one can dream up to explain the process is patently nonsensical.

9.2.2 Other Theoretical Issues with the Friedmann Equations

The expansion of the universe appears to have no effect on some orbital systems, while it does for others, an anomaly for which there is no satisfactory explanation. Large-scale N-body simulations of the evolution of galactic clusters and the distribution of dark matter build in the expansion of the universe, and produce very credible-looking results. However, most models of individual galaxies or solar systems ignore the expansion, with the rationale that gravitationally-bound systems aren't affected by expansion. However, the N-body models successfully incorporate numerous gravitationally-bound subsystems.

Also, there is a duplication problem for the Friedmann equations. The AltU concept that the outer limit of a mass's surrounding metric perturbation grows at the speed of light, combined with the Schwarzschild metric solution of the field equation, implies an expanding universe. If you take a single gram of matter, created at the time of the Big Bang, you can easily calculate the amount of additional proper spatial volume that its Schwarzschild metric implies. The fractional increase in the radial proper distance at any given radius r is $\frac{2\mathrm{G(1g)}}{\mathrm{c^2 r}}$. Integrating the associated additional proper volume out to the conventional estimate of the current cosmic horizon, about 14 Gpc, gives a volume of: $\Delta V_{1\ gram} = 4\pi \int_0^{14\ Gpc} r^2 \frac{2\mathrm{G(1g)}}{\mathrm{c^2 r}}\,\mathrm{dr} = \frac{8\pi\mathrm{G(1g)}}{\mathrm{c^2}}\frac{(14Gpc)^2}{2} = 1.7\mathrm{e}30\ \mathrm{cm}^3$. That is a large volume for a single gram to generate (the estimated mass density of the universe corresponds to about 3.7e29 cm^3/g), and it should have arisen, and be continuing to expand the universe (and slow time), via a mechanism that is unrelated to the mechanism implicit in the Friedmann equations.

9.2.3 Issues With the Application of the Friedmann Equations

With the increasing power of observational astronomy there is growing evidence that the spatial expansion process predicted by the Friedmann equations is inconsistent with observational data. See the general review of issues with the standard cosmology in Lopez-Corredoira (2017).

There are a number of additional challenges to conventional cosmology:

1. The Friedmann equations only predict the observed flat and apparently slowly expanding universe for a very precise combination of mass and energy. This apparent cosmic coincidence

drove decades of efforts to estimate the amounts of normal matter, dark matter, and dark energy in the universe. But why would the universe be balanced on a knife-edge?

2. Then there is the "horizon" problem: how did the universe get to be so uniform? Addressing this problem led to the concept of inflation, whereby some unknown mechanism caused a very compact, uniform universe to rapidly expand. There is no real theoretical basis for inflation.
3. Also, based on the field equation and the RW metric, available data appear to strongly support the existence of dark energy, an inferred entity that is required in order to make the predictions of the cosmological equations match the observed patterns of redshifts. However, theoretical and experimental data fail to provide any significant evidence for dark energy's existence. Meanwhile dark energy is growing more complex, as theorists ascribe additional properties to it in order to try to continue to match observational data.
4. Then there is the question of the origin of the cosmic microwave background (CMB) anisotropies. The conventional explanation for the CMB features is that they represent shells of denser matter caused by pressure waves generated by expanding 'seeds' ("*pointlike initial overdensities*") that were somehow scattered throughout the early universe. Despite there being a large amount of literature discussing the CMB features, this Author has found no discussions about the nature or origin of these 'seeds', other than allusions to quantum fluctuations.
5. Lastly, analysis of the observed angular sizes of astronomical objects rules out the possibility that the universe is expanding. For details see Figures (2-3) and the discussion in Section 5.3.3.

9.3 Summary of the Issues

As discussed above, the foundations of conventional gravitational and cosmological theory are deeply flawed, and conceptually incoherent. These issues are generally either unrecognized or ignored by practitioners, awed by the apparent mysteries and convinced that those foundations are validated by the successful predictions of mathematical models based on them.

A convincing scientific theory is something like a footstool— it needs three legs to stand on. The first leg is a credible conceptual model of the subject system and its component objects and processes. The second leg is a mathematical model, based on the conceptual model, that successfully describes and predicts the behavior of the system. The final leg is the absence of an equally credible competing theory.

That first leg is absent from the standard models of general relativity and cosmology— they simply start with postulated equations, and there is nothing that really ties those equations together. Absent a conceptual model of the processes involved, the equations have little persuasive power, even if they do appear to describe the system well. Even worse, the equations are laden with gaps and incongruities— no coherent conceptual model could lead to them. Unavoidably, Frankenstein's monster comes to mind.

As for the third leg on the stool, the absence of an equally credible competing theory, that is the key reason for the current widespread acceptance of the standard model, despite its challenges. The development of a more credible competing theory, describing an alternative view of the universe, is the subject of this paper.

The preceding list of challenges to the field equation and the conventional conceptual model of the universe is lengthy. Perhaps it is not sufficient to persuade the reader that they are in fact wrong, but hopefully it will encourage him or her to seriously consider the possibility that the AltU concept might be right.

9.4 But… the Field Equation Works, Doesn't It?

When I first encountered the field equation, I took it at face value, as a constraining relationship for the metric at a point. Most of the time, when it was applied to a vacuum, it appeared to be used that way. That approach led to the Schwarzschild equation, which has the issues that are described above, but it wasn't fundamentally jarring. But the AltU metric doesn't satisfy the field equation, and neither does the PPN metric- and they work very well.

For non-vacuum solutions the field equation can be used for continuum-like systems, and when applied to the interior of a spherical homogeneous mass it yields the interior Schwarzschild metric. Like the exterior Schwarzschild metric this solution has conceptual challenges- for example it predicts an infinite pressure at a specific radius within a large mass. But it is a legitimate metric equation.

However, the main generator of praise for the field equation appears to be its applications to predict the dynamics of orbiting binary systems. It is used in the solutions which very precisely predict the orbital dynamics of binary pulsars, and which appear to predict the gravitational collapse process for binary systems up till very nearly the final merger. A description of the basis for these solutions can be found in Blanchet et al, (1995), and the results are summarized in chapter 12 of Will, (2017). I also discuss them in sections 6.2.1.2 and 11.7.3.

For me, the approach that is described is jarring. The approach uses the field equation, which is based on an energy-momentum tensor (a.k.a. the "matter stress-energy tensor") that somehow represents the entire binary system. That doesn't seem to make sense. Just like a metric equation, an energy-momentum tensor is only physically valid at a point in a smoothly-varying continuum. The best guess I can make is that the tensor is constructed based on the combined four-momenta of the two members of the binary system, but treating it as if it was uniformly distributed over an arbitrarily-sized spatial volume centered on the binary system. The solution goes on to calculate the total energy emission rate from the system (based on a mathematical analogy to a radio antenna), which it equates to gravitationally-radiated energy loss. Somehow, correct energy and angular momentum loss rates emerge from all this.

My suspicion is that the strange energy-momentum tensor, the corresponding metric equation, and the energy radiation via gravitational waves are all mathematical illusions with no physical reality. The equations and the solution process that are employed correctly predict the inspiral behavior simply because they capture the dynamics of the binary system. In reality the system loses energy because of a misalignment between the acceleration vectors of the masses rather than radiation of energy, and the gravitational waves that are observed are just the dynamically-changing gravitational fields of the masses.

9.5 A Theory of Evolution

Evolution can be a very effective process. It is the basis for life as we know it, and it is the basis for many of the remarkably powerful artificial intelligence systems that are currently being developed. It is also the basis for our science and technology— we modify and adapt prior knowledge in order to create better solutions, and "survival of the fittest" takes on a different meaning for science and technology.

In the world of technology "fitter" means more effective, so the primary drivers for technology development are political/military and financial. In the world of scientific research, "fitter" largely means leading to better professional and public reputations for the researchers and their institutions, with accompanying financial and social rewards. In the case of general relativity theory and its related cosmology aspects, thousands of dedicated and creative researchers have been pursuing that version of "fitter" for over a century. From that perspective, it is not surprising that an apparently very successful model has evolved— and it is appropriate to examine it closely.

9.6 What Might Have Gone Wrong?

Why does the field equation have the form that it does, relating a complex Ricci-based descriptor of spatio-temporal curvature to the equally-complex energy-momentum tensor? I'll try to put myself into Einstein's shoes and imagine his thought process as he was developing it.

He knows that a four-dimensional spacetime can be distorted in many different ways— the distortion is basically described by all of the second-derivatives of the relationships between the four basis vectors as they expand or shrink. Accordingly, he is looking for a distortion-causing physical correlate that has a structure that is as complex as that of spacetime. He knows that mass is the driver of Newtonian gravitation, but mass alone can't be the physical correlate that he needs— it's too simple, it doesn't behave in all of the necessary ways. However, he has previously discovered that mass and energy can be equated, and the combination of mass/energy and space/time can be expressed as a tensor, the energy-momentum tensor, which has a suitably rich form. It could be directly related to some measure of the distortion of spacetime, and that could be the basis for generating the spacetime distortions that cause gravity.

It's tricky though. Empty space obviously is distorted by gravity, but there is no mass or energy present in empty space to create that distortion. The gravitational distortion must be initiated in places where the energy-momentum tensor is non-zero, and it must somehow propagate to places where the tensor is zero. So the equation for initiating spacetime distortion can't fully prescribe the distortion at a point (or else empty space couldn't distort), but it has to constrain the local distortion in the presence of a non-zero energy-momentum tensor so that an appropriate overall distortion field will arise. What an intimidating challenge!

He explores the mathematics that can describe the kinds of distortions that must be involved, comes across the Ricci tensor and scalar, and eventually is able to combine these into the field equation: a legitimate tensor-based equation that constrains, but doesn't fully specify, the state of curvature at a point as a function of the energy/momentum there. He develops approximate solutions for the gravitational effects of astronomical bodies, and finds that they match previously-unexplained measurements of phenomena. He presents the theory in his 1916 paper, Schwarzschild comes along, so does Eddington, and the rest is history.

If he did go wrong, where did Einstein go wrong? Based on the imagined version of his thought process there was a subtle assumption involved: that complex spacetime distortions require an equally-complex driving function. And that led to developing an awfully complicated equation! However, we have learned, over recent years, that complex phenomena frequently arise from surprisingly simple underlying processes. That subtle assumption may have led Einstein, and all who have followed, down a completely wrong path.

10 Appendix B: Results of Gravitational Tests

The AltU approach results were compared to those of the Schwarzschild metric for some familiar scenarios: gravity on Earth's surface, the lunar orbit, the deflection of light by the Sun's gravity, and so on. Exact solutions for orbital forms based on the geodesic equation (6.2) are not readily apparent, so most of the tests discussed below were conducted using a numerical integration to solve for the trajectory of a particle (a small mass or a photon) with specified initial conditions. Because it is a numerical solution the results have finite precision, based on the timestep length and algorithm. The Schwarzschild solution's numerical predictions were calculated using the same code, but substituting its geodesic equation coefficients.

Most of the tests summarized below compare the AltU approach results directly to the Schwarzschild solution, which has been well validated in comparisons to observational data.

10.1 *Test: Gravity on Earth's Surface*

For a stationary object at Earth's surface, the acceleration was calculated in three different ways. The Earth's radius was taken as 6371 km, its mass M as 5.97237e24 kg. Geodesic equation results are expressed in terms of coordinate distance and time:

- Newton's equation: 9.818 065 732 166 m/s^2
- Schwarzschild geodesic equation: 9.818 065 732 166 m/s^2
- AltU geodesic equation ($e^{-2U}\bar{g}$): 9.818 065 718 499 m/s^2

All three approaches are identical to approximately nine significant figures at the Earth's surface, with the result of the AltU approach being slightly smaller than the Schwarzschild result, by a factor of 2.8e-9. This difference varies inversely with the radius, at ten times the Earth's radius the factor equals 2.8e-10.

10.2 *Test: Lunar Orbit*

For a circular orbit of 384,399 km radius, and Earth's mass equal to 5.97e24 kg, Newton's Law gives an orbital period of 27.460 289 657 days. Numerical integrations based on the Schwarzschild solution and on the AltU approach agreed with this value to eleven significant figures.

10.3 *Test: Deflection of Light Passing by the Sun*

For a photon just grazing the Sun's outer radius, the geodesic equations were integrated numerically to calculate the deflection angle.

The resulting deflections, expressed in seconds of arc, were:

- Schwarzschild theory ($4GM/c^2b$): 1.75126"
- Schwarzschild simulated: 1.75126"
- AltU approach simulated: 1.75126"

10.4 Test: Precession of Perihelion of Mercury

The solar contribution to the rate of precession of Mercury's orbit is estimated to be 43"/century (Will, 2018). Will reports the result of a general-relativity solution as being 42.98"/century, based on a general PPN equation of motion rather than explicitly on the PPN metric equation.

Numerical simulations of Mercury's orbit based on the Schwarzschild and AltU geodesics matched the orbit's parameters, and gave the following results for the precession rate:

- Schwarzschild, simulated: 43.000"/century
- AltU approach, simulated: 42.994"/century
- Will's PPN GR metric's geodesic, simulated: 42.994"/century

10.5 Test: Gravitational Redshifts

The ratio of the temporal scale factors at the emitting and receiving ends of a gravitational redshift experiment determines the ratio of the observed frequencies at the two ends. In some experiments this ratio is calculated directly, while in others it is calculated based on extrapolating the derivative of the scale factor from one end to the other.

The AltU approach has a time dilation factor of $e^{\frac{-GM}{c^2 r}}$, while the Schwarzschild metric's corresponding factor is $\sqrt{1 - 2Gm/c^2 r}$. If the same radius value is used for the two metrics then their scale factors, evaluated at the surface of the Earth, are identical to better than 16 significant figures.

The bottom line is that gravitational redshifts calculated using the AltU approach metric are functionally identical to redshifts calculated using the Schwarzschild metric. All redshift tests that have been applied to the Schwarzschild metric will have identical results with the AltU approach.

Will (2018) gives the Schwarzschild redshift formula as $z = \Delta\nu/\nu \cong \Delta U/c^2$, where z is the ratio of the frequency (ν) of a light beam at the observer's location to the frequency at the emitter and ΔU is the difference in the gravitational intensity at the two points.

For a hypothetical redshift measured between a point at the Earth's surface and a (stationary) point at a 10% greater radius, the predicted redshift values are:

- Schwarzschild theory, Will's approximation: 6.327 023 528e-11
- Schwarzschild theory, exact: 6.327 027 791e-11
- AltU theory: 6.327 027 791e-11

10.6 Coordinates and Parameters Used for the Tests

In order for the '*r*' coordinate in a metric equation to represent something physically meaningful it has to be evaluated based on measurements of observed invariant parameters, i.e. proper distances or times. Most observations of distances are based on light-wave travel times, and a metric equation is required in order to correctly convert these to coordinate distances. Thus, the underlying metric equation that is being tested has to be used as an integral part of a model of the entire solar system, and it is the parameters of that model that form the basis for evaluating the test results. This includes masses as well as orbital parameters.

The most precise and general current models of the solar system are not directly based on solving Einstein's field equation or on the Schwarzschild metric. Instead, they are based on the linearized theory of gravitation, and they use the isotropic PPN metric and the PPN equations of motion. For example, NASA maintains a sophisticated model of the solar system parameters and geometry, which is based on optimizing its match to a wide variety of observations, over a long period of time. See https://en.wikipedia.org/wiki/Jet_Propulsion_Laboratory_Development_Ephemeris for an overview of this, or Folkner et al (2014) for a recent summary report.

For solar system modeling the AltU metric equation is effectively identical to the PPN approach, and accordingly the AltU tests simply used the same parameters as described in Will's summaries of the different tests. It passed those tests with no difficulty.

However, the Schwarzschild metric, and its '*r*' radial coordinate, are slightly different. That difference is immaterial for most of the tests, but it was significant for the test of the gravitational delay of light waves. For that test it was necessary to quite precisely calculate the Schwarzschild radial coordinates for the Earth and Mars. This was done by adjusting the PPN coordinate '*r*' values, based on predicting the same orbital period in either coordinate system. The resulting Schwarzschild orbital radii for each planet are about 1.48 km greater than the PPN values. Once this correction was made the Schwarzschild metric correctly predicted the total round-trip times for the test.

10.7 Test: Time-Delay of Round-Trip Light Passing by the Sun

In 1964 I. I. Shapiro published a paper proposing a "fourth test of general relativity". This test would measure the amount by which a light wave (or radio wave) was delayed as it passed by a massive body. The seminal proof that general relativity (GR) passed that test, with precision, is described in Shapiro et al, (1977) and Reasenberg et al (1979). Those papers describe a sophisticated experiment based on the variation in the travel time for radio waves between the Earth and the Viking orbiters/landers on Mars, over a period in 1976 when Mars was almost directly opposite the Sun from the Earth.

We used an arbitrary approximate orbital radius for Mars. This is a tricky test, and for precise results careful attention has to be paid to the exact photon trajectories— they aren't straight lines.

The results for the round-trip time from the Earth are:

- Schwarzschild, theory: 2519.06 s
- AltU geodesic equation: 2519.06 s
- AltU trajectory equation: 2519.06 s
- PPN trajectory equation: 2519.06 s
- Observations (interpolated): 2519.06 s

In terms of the round-trip delay, the results are:

- Schwarzschild, theory: 227.6 us
- AltU geodesic equation: 247.3 us
- AltU trajectory equation: 247.3 us

- PPN trajectory equation: 247.3 us
- Observations (interpolated): 247.3 us

The Schwarzschild result difference is due to its use of a spatially anisotropic metric, while the PPN and AltU approaches are spatially isotropic.

11 Appendix C: Gravity in AltU: Additional Aspects

This appendix contains information and speculation about a number of additional aspects of AltU's gravity.

11.1 The Refractive Index of the Space Inside a Gravitational Field

From the perspective of a cosmic observer the light speed within the field equals the cosmic speed multiplied by $(dt_{loc}/dt_c)^2$, or e^{-2U}. Treating the current cosmic speed limit as the reference value for the refractive index, this defines the refractive index, $n = e^{2U}$, for each point in the field. For a distant but non-cosmic observer the relative speeds of light within the observed region would reflect the same refractive index.

As was mentioned previously, Dicke's proposed VSL theory of gravitation (Dicke, 1957) postulated that in the vicinity of a spherical mass $\varepsilon = \mu \cong 1 + \frac{2\mathrm{GM}}{\mathrm{c}^2\mathrm{r}}$, which led to a speed of light equal to $\frac{1}{\sqrt{\varepsilon\mu}} \cong c/\left(1 + \frac{2\mathrm{GM}}{\mathrm{c}^2\mathrm{r}}\right)$, and a refractive index of $\mathrm{n_{Dicke}} \cong 1 + \frac{2\mathrm{GM}}{\mathrm{c}^2\mathrm{r}}$. This is very similar to the AltU value.

11.2 Combining the Gravitational Fields of Individual Masses

Equation (4.7a) can be viewed from the perspective of a single gravitational mass. The presence of the mass results in a scalar field for the ratio of the speed of light at a 'local' position to the limit at an unaffected distant observer's location, where it equals the current cosmic speed of light c_c. That speed limit ratio is $\frac{c_{loc}}{c_c} = e^{-U_{loc}} = e^{\frac{-Gm}{c^2 r}}$. Thus each individual mass defines its own speed limit ratio field, and that field effectively travels with the mass.

The local speed of light at an arbitrary point is equal to c_c multiplied by the product of the speed limit ratios due to all of the nearby surrounding masses.

11.3 The Speed Limit Ratio Around a Spherical Mass

When Equation (4.7a) is integrated over the volume of a spherically-symmetric finite mass, the resulting speed limit reduction outside of the spherical mass is identical to that for a point mass:

$$\frac{\mathrm{c_{loc}}}{\mathrm{c_c}} = e^{-U} = \mathrm{e}^{\frac{-\mathrm{GM}}{\mathrm{c}^2\mathrm{r}}} = \mathrm{e}^{\frac{-\mathrm{r_S}}{2\mathrm{r}}} = \mathrm{e}^{\frac{\varphi}{c^2}} \cong 1 - \frac{\mathrm{Gm}}{c^2\mathrm{r}}$$

Where *r* is the radial distance to the center of the mass, and r_s is the Schwarzschild radius, $2\mathrm{Gm}/c^2$. The approximate result is appropriate when $\mathrm{r_s} \ll \mathrm{r}$. It is accurate to approximately 18 significant figures at the Earth's surface.

11.4 The Gravitational Intensity Inside a Spherical Mass

As is the case for Newtonian gravity, there are some useful tricks that help to calculate the intensity at points in and around an inhomogeneous spherically-symmetric mass:

- All of the mass at radii less than that of the point in question can be treated as being at the center of the sphere, resulting in the intensity: $\mathrm{U_{inner}} = \frac{\mathrm{G\,M_{inner}}}{\mathrm{c^2 r_{obs}}}$.
- All of the mass in the hollow sphere having radii greater than that of the point creates a constant-intensity field within that sphere. That intensity can easily be calculated from the perspective of the center of the sphere:
  $\mathrm{U_{outer}} = -\frac{4\pi\mathrm{G}}{\mathrm{c^2}}\int_{\mathrm{r_{obs}}}^{\mathrm{r_{outer}}} \rho(\mathrm{r})\,\mathrm{r\,dr}$, where ρ(*r*) is the mass density at radius *r*.
- The radial derivative of the intensity at the observation point is: $U' = -\frac{\mathrm{G\,M_{inner}}}{\mathrm{c^2 r_{obs}^2}} = -\frac{\mathrm{g_{Newton}}}{\mathrm{c^2}}$. It is unaffected by the mass at radii greater than the observation point.

11.4.1 The Gravitational Intensity Inside a Homogeneous Spherical Mass

Within a homogeneous spherical mass of radius r_{sp} the intensity is:

$$U(r) = \frac{GM}{c^2 r_{sp}} - \frac{G}{c^2}\int_{r_{sp}}^{r} \frac{4\pi r_{obs}^3}{3r^2}\,\rho\,dr_{obs} = \frac{G}{c^2}\left(\frac{M}{r_{sp}} - \frac{2\pi}{3}\left\{r^2 - r_{sp}^2\right\}\rho\right) = \cdots$$

$$\ldots = \frac{GM}{c^2 r_{sp}}\left(1 - \frac{r_{sp}}{M}\frac{2\pi}{3}\left\{r^2 - r_{sp}^2\right\}\rho\right) = \frac{GM}{c^2 r_{sp}}\left(1.5 - \frac{r^2}{2r_{sp}^2}\right) \qquad \text{(C.1)}$$

As an example of this, at the center of a homogeneous Earth the intensity would be 1.5 times the value at the surface, equal to 1.04e-9.

11.4.2 The Mean Value of the Intensity Within a Spherical Mass

The geodesic acceleration rate for a stationary particle, based on equation (6.2), is $c_{loc\_c}^2 \overline{\boldsymbol{\nabla}} U_j$. How should this be interpreted for a finite-sized object, where the intensity varies over the object's extent? In general, the acceleration force needs to be integrated over the extent of the object, and solid or fluid mechanics equations incorporated in order to determine the tidal deformations and the net acceleration of the object.

This can be simplified if the object is physically stable, as the density-weighted integral of the local acceleration values will define the acceleration of the object as a whole. For astronomical objects other than black holes or neutron stars the value of e^{-4U} is close to unity, and we can simplify a bit more, by using the density-weighted mean value of the gravitational intensity field within the object.

The contributions of distant masses to the mean intensity within a mass can be represented by the values of their intensities at the center of mass of the object. However, for the object's own intensity we have to explicitly carry out the integral in order to get its mean self-intensity:

$$\mathrm{U_{mean}} = \frac{4\pi}{\mathrm{M}}\int_0^{\mathrm{r_{sp}}} \mathrm{U(r)\rho(r)\,r^2\,dr} \qquad \text{(C.2)}$$

For a homogeneous sphere, and using $U = \frac{\mathrm{GM}}{c^2\mathrm{r_{sp}}}\left(1.5 - \frac{\mathrm{r^2}}{2\mathrm{r_{sp}^2}}\right)$ from equation (C1), this becomes:

$$\mathrm{U_{mean}} = \frac{4\pi\rho\mathrm{G}}{c^2}\int_0^{\mathrm{r_{sp}}}\left(1.5 - \frac{\mathrm{r^2}}{2\mathrm{r_{sp}^2}}\right)\mathrm{r^2\,dr} = \frac{2\pi\rho\mathrm{G}}{c^2}\left(\mathrm{r_{sp}^2} - \frac{\mathrm{r_{sp}^2}}{5}\right) = 1.2\mathrm{U_{sp}} \qquad \text{(C.3)}$$

So the mean intensity (or potential) in a homogeneous sphere equals 1.2 times the intensity (or potential) at its outer surface.

For an inhomogeneous mass the integral has to be carried out explicitly. As an example, using a realistic representation of the Earth's density variation results in a mean intensity that is 1.23 times the value at the Earth's surface. For a realistic representation of the Sun the result is a mean intensity that is 1.44 times the intensity at its surface, a greater multiplier because the sun's density is significantly greater near to its center.

11.5 Second-Order Effects on the Gravitational Intensity

The gravitational predictions for AltU's geodesic equation, discussed in Section 6, were generally very good, but the binary pulsar data revealed that the approach was oversimplified. In order to improve the approach it will be necessary to incorporate some second-order effects into the evaluation of the gravitational intensity at a point.

A variety of possible forms for such second-order effects come to mind:

- There might be a Doppler-like effect whereby an approaching mass's gravitational field (i.e. the local graviton density component due to the mass) is stronger than the field of a receding mass.
- Conventionally, a mass's own gravitational field is assumed to have no effect on its response to the gravitational fields of other masses. However, that field affects the local speed of light and the local temporal rate, so it should also affect the mass's response to external fields. This was discussed previously, in section 11.5.2.
- The temporal rate of an attracting mass might affect the strength of its field. The observed light emitted by a time-dilated source is dimmed, due to a reduced photon emission rate and to red-shifting. Similar effects might occur for gravitational fields.
- A moving mass's velocity affects the form of its gravitational field, which becomes oblate. The resulting gravitoelectromagnetic effects are analogous to electromagnetism.
- The gravitational information about a mass propagates along its forward light cone, so a delay might need to be incorporated into the metric equation. In this case a subtler formulation of the metric would be required, as the gradient of the potential won't automatically be directed towards the current location of an attracting mass. (However, there are no apparent effects of the delay, as discussed in section 6.6.7.).

The temporal rate of a mass affects its response to a gravitational field, in a generalization of the relativistic inertia increase of a moving mass, and an object's velocity also affects its response. However, both of these effects are fundamental components of the metric approach, and they are not obvious candidates for second-order effects.

A metric-based approach effectively decouples the relationship between an attracting mass and attracted objects, by inserting space itself as an intermediary. The approach assumes that the gravitational field is a real physical attribute of a spatial location. (In AltU's metric-based approach the field is an attribute of the vacuum energy, an attribute that is 'painted' onto the vacuum by the passage of particles emitted by masses.). But it is possible that this decoupling is not real- that instead gravitationally-affected objects directly interact with particles emitted by masses. That would be a completely different paradigm, however, and we will not pursue it.

Following are descriptions of some possible second-order gravitational effects.

11.5.1 There is no Doppler Effect

If particles act as the propagators of gravitational fields, the effective amount of mass i for a given spatial point j will be multiplied by a Doppler factor:

$$m_i \mathrel{*}= \frac{c_c e^{-2U_i} + (\overline{\boldsymbol{v}}_{\boldsymbol{i}} \cdot \hat{\mathbf{r}}_{\boldsymbol{ij}})}{c_c e^{-2U_i}}$$

Here $c_c e^{-2U_i}$ is the cosmically-observed speed of light at mass i (ignoring mass i's own gravity), and $\hat{\mathbf{r}}_{\mathbf{ij}}$ is the normalized vector from mass i to j.

Testing of this concept for Mercury's orbit or for a binary pulsar ruled it out: orbits rapidly collapsed.

11.5.2 The Inertial Effects of a Mass's Self-Intensity

Imagine a planet with a small void at its center, and a test mass floating in that void. Even though the planet's mass doesn't affect the gradient of the gravitational intensity within the void, it does increase the gravitational intensity there. For example, a clock placed within the void would run more slowly than it would if the planet was not present. Does that increase in the intensity affect the test mass's trajectory? If it does, then presumably a mass's self-intensity also affects the trajectory of the mass as a whole.

All formulations of gravitational trajectories indicate that the gravitational potential at a mass's location acts to reduce its acceleration in response to potential gradients. For our centrally-located test mass, within its void, its centripetal acceleration towards the barycenter of its solar system will therefore be reduced due to the self-potential of its enclosing planet.

The self-intensity effect implies that the gravitational self-intensity contribution of a large or dense mass acts to reduce the acceleration of each of the mass's individual component particles. Thus, the larger or denser a mass is, the less acceleration it will experience. For a homogeneous spherical mass m_j in AltU the effect adds a term to the equation (4.4) representation of the mass's gravitational intensity:

$$U_j = \frac{G}{c^2} \Sigma_i \frac{m_i}{r_{ij}} = \Sigma_{i \neq j} U_{j\_i} + U_{j\_self}\text{ , where } U_{j\_self} = 1.20 \frac{G}{c^2} \frac{m_j}{r_j} \qquad \text{(C.4)}$$

As discussed in section 11.4.2, the 1.20 multiplier is increased for inhomogeneous bodies that are denser at their cores; a multiplier of 1.23 is appropriate for an Earth-like planet, and a multiplier of 1.44 is appropriate for a sun-like star.

The inertial effect of the self-intensity multiplies mass j's accelerations by a factor of $e^{-4U_{j\_self}}$. This could significantly reduce the accelerations of masses associated with large, dense bodies such as neutron stars and black holes. It also implies a second-order gravitational effect for radially or spherically-symmetric systems due to the mass at a greater radius than an observed object. For example, in galactic dynamics the masses at a larger radius than a specific star increase its gravitational intensity and reduce its inward acceleration rate.

11.5.3 The Active Gravitational Effect of a Mass's Temporal Rate

Does the gravitational intensity at the location of object j, U_j, change if an attracting mass m_i has a significantly different local temporal rate? If this effect occurs it could be significant for orbital systems that have significant eccentricities. A large and/or dense mass i's temporal rate is dominated by its self-intensity, but it is also affected by its velocity and by the gravitational intensity at its location due to other nearby masses.

It is tempting to visualize a mass's gravitational field as being transmitted via particles that are emitted much like how a star emits photons: as a continuous flux. If this is the case then mass i's active gravitational mass is multiplied by its temporal rate, e^{-U_i}. A larger or denser or faster-moving or lower-elevation mass will have a relatively weaker gravitational field due to its reduced temporal rate. The elevation effect is consistent with the general relativity concept that treats energy (potential energy in this case) as a form of gravitational mass.

11.5.3.1 Calculating the Effect on a Mass's Gravitational Intensity

When calculating the gravitational intensity at a location, each of the contributing masses has to be multiplied by its temporal rate e^{-U_i}, so with the changes highlighted in yellow equation (C.4) becomes:

$$U_j = \frac{G}{c^2}\Sigma_{i\neq j}\frac{m_i e^{-U_i/\gamma_i}}{r_{ij}} + U_{j\_self}\text{, where } U_{j\_self} = 1.20\frac{G}{c^2}\frac{m_j e^{-U_j/\gamma_j}}{r_j} \qquad \text{(C.5)}$$

The self-intensity effect couples the solutions for the gravitational intensity for all of the masses in a system, and a simple iterative solution is the easiest way to solve for the intensities.

The geodesic equation also requires the rate of change of the intensity at a mass's location, $\frac{dU_j}{dt_c}$. If we assume that the rate of change of each mass's Lorentz coefficient is insignificant in this calculation, the rate of change of the intensity at j's location is:

$$\frac{dU_j}{dt_c} = -\frac{G}{c^2}\Sigma_{i\neq j}m_i\frac{e^{-U_i}}{\gamma_i}\left[\frac{1}{r_{ij}^2}\left(\bar{\boldsymbol{v}}_{\boldsymbol{i}}\cdot\frac{\bar{\boldsymbol{r}}_{\boldsymbol{ij}}}{r_{ij}}\right) + \frac{1}{r_{ij}}\frac{dU_i}{dt_c}\right] \qquad \text{(C.6)}$$

Where $\bar{\boldsymbol{r}}_{\boldsymbol{ij}}$ is the vector from mass i to mass j. This equation also couples the solutions for all of the masses, and a simple iterative solution is easiest.

Over long time periods the temporal rate effect also affects the geodesic equation, as it implies that the gravitational strengths of all masses evolves at the same rate as the cosmic temporal rate does: gravitational attractions decrease over time. The implications for orbital systems are presented later, in sections 6.6.6 and 11.8.2.

11.5.3.2 The Gravitational Field of a Black Hole

If a mass's gravitational strength is proportional to its temporal rate then its 'gravitational mass' is approximately equal to its rest mass multiplied by $e^{-U_{self}}$. Representative values of $e^{-U_{self}}$ are 0.999999999 for the Earth, 0.999997 for the sun, 0.76 for a neutron star, and approximately 0 for a billion solar-mass black hole that has the density of a neutron star. That super-massive black hole result appears to rule out the possibility that a mass's gravitational strength is proportional to its temporal rate.

However, for a large/dense mass the weakened gravitational strength due to its self-intensity implies a lower density, which in turn implies a reduced gravitational self-intensity. This will act as a sort of gravitational buoyancy, so that within a mass of any given size there will be a stable density pattern. Accordingly, in AltU the densities of neutron stars and 'black holes' is significantly less than is currently thought, and the self-intensity effect is limited.

11.5.3.3 Is the Temporal Rate Effect Consistent with AltU's Cosmology Model?

In AltU a distant, red-shifted mass's gravitational intensity was less than its current intensity is, by a factor of $ln(1+z)$. Its temporal rate was thus greater than it would be now, by a factor of $1+z$. If the strength of a mass's gravitational field is proportional to its temporal rate, then the distant mass's gravitational field was stronger by that $1+z$ factor than it would be today. However, the flux of its gravity-transmitting particles arriving at our location would be divided by $1+z$, just as its photon flux rate is. The two $1+z$ factors would cancel, so the net effect on us would be to experience the same gravitational intensity as if the mass was local, a simple inverse function of its distance. That simple inverse function of distance was the basis for the successful cosmological calculations presented in section 2 of this paper. So, the temporal rate effect is not inconsistent with our cosmological results.

11.5.4 The Gravitational Effect of a Mass's Velocity

In Section 3.2.2 we discussed how a mass's velocity affects its shape, and the shapes of its electrical and gravitational potential fields, effectively shortening them all by the Lorentz factor. Thus in a mass's frame, using its meter-stick, the fields are always spherical and described by the same equations. This is handled routinely in the theory of electromagnetism, and we can use the same frame-swapping approach to describe how velocities affect gravitational behavior in AltU.

We will seek the equation for the gravitational intensity and acceleration of object 'j' due to mass m_i. Mass m_i is located at $\bar{\boldsymbol{x}}_i$ and moving with velocity $\bar{\boldsymbol{v}}_i$, and object j is located at $\bar{\boldsymbol{x}}_j$ and moving with velocity $\bar{\boldsymbol{v}}_j$. We define θ as the angle between $\bar{\boldsymbol{v}}_i$ and $(\bar{\boldsymbol{x}}_j - \bar{\boldsymbol{x}}_i) \equiv \bar{\boldsymbol{r}}_{ij}$.

11.5.4.1 The GravitoElectric Field

Based on the Lorentz transformation Purcell and Morin (2013), section 5.6, derives an equation for the electric field of a moving charge. An analogous derivation for gravity leads to a modified equation for the gravitational intensity at a point due to a moving charge. Specifically, the effect of m_i's velocity is to multiply the gravitational intensity (and its gradient) at $\bar{\boldsymbol{x}}_j$ due to mass m_i by an orientation-specific factor (cf. Purcell and Morin eq. (5.15)):

$$U_{vj} = U_{j\_i}\left[\frac{1-\beta_i^2}{\left(1-\beta_i^2 sin^2\theta_{ij}\right)^{1.5}}\right] + U_{j\_self}, \text{ where } \beta_i = \frac{v_{i\_c}}{c_{i\_c}} \quad \text{(C.7)}$$

Objects lying close to mass i's path effectively 'see' a smaller mass, divided by γ_i^2. Objects perpendicular to its path see a larger mass, multiplied by γ_i. As β_i increases the gravitational field becomes increasingly oblate.

An observing object located in the plane of an orbiting mass experiences a delayed cyclically-varying gravitational intensity, at twice the orbital frequency. The delay is due to the transit time for the gravitational information. Peaks are associated with the times when the mass is at its closest and farthest distances from the observer, when $\theta_{\text{ij}} \cong \pm\pi/2$.

Recall that AltU's geodesic equation (6.4) has a term $\frac{dU}{dt_c}$, which describes the rate of change of the gravitational intensity at a mass's current location (not the rate of change of the intensity experienced by a moving mass). When the gravito-electric effect is incorporated into the intensity, that term becomes:

$$\frac{dU_{vj}}{dt_c} = \frac{dU_{j\_i}}{dt_c}\left[\frac{1-\beta_i^2}{\left(1-\beta_i^2 sin^2\theta_{ij}\right)^{1.5}}\right] + \left(U_{vj} - U_{j\_self}\right)\left[\frac{3\beta_i^2 sin\theta_{ij}\, cos\theta_{ij}}{\left(1-\beta_i^2 sin^2\theta_{ij}\right)}\right]\frac{d\theta_{ij}}{dt_c} \quad \text{(C.8)}$$

The $\frac{d\theta_{\text{ij}}}{dt_c}$ term reflects the attracting mass i's velocity and the curvature of its path; it equals the orbital rotation rate minus the rotation rate of mass i's velocity vector. The rotation rate of mass i's velocity vector is equal to its acceleration component perpendicular to its velocity divided by its velocity.

$$\frac{d\theta_{ij}}{dt_c} = \frac{\|\bar{\boldsymbol{r}}_{ij}\times(\boldsymbol{v}_j-\bar{\boldsymbol{v}}_i)\|}{r_{ij}^2} - \frac{\|\bar{\boldsymbol{v}}_i\times\boldsymbol{a}_i\|}{v_i^2} \quad \text{(C.9)}$$

The gradient of the intensity, $\bar{\boldsymbol{\nabla}}U_{vj}$, is also changed by the gravitoelectric effect:

$$\bar{\boldsymbol{\nabla}}U_{vj} = \bar{\boldsymbol{\nabla}}U_{j\_i}\left[\frac{1-\beta_i^2}{\left(1-\beta_i^2 sin^2\theta_{ij}\right)^{1.5}}\right] + \left(U_{vj} - U_{j\_self}\right)\left[\frac{3\beta_i^2 sin\theta_{ij}\, cos\theta_{ij}}{\left(1-\beta_i^2 sin^2\theta_{ij}\right)}\right]\bar{\boldsymbol{\nabla}}\theta_{ij} \quad \text{(C.10)}$$

Note that the U_{vj} term in the above expression does not incorporate mass's self-intensity.

The gradient of the angle from mass i's velocity vector towards mass j's location is:

$$\bar{\boldsymbol{\nabla}}\theta_{ij} = \frac{\bar{\boldsymbol{k}}\times\boldsymbol{r}_{ij}}{r_{ij}^2} \quad \text{(C.11)}$$

Where $\bar{\mathbf{k}}$ is a unit vector in the z-direction.

The gravito-electric effect may significantly affect orbital precession rates for fast-moving masses.

11.5.4.2 The GravitoMagnetic (GM) Field

The Lorentz transformation also implies that there is an additional component to the acceleration of an object j that is moving in a gravitational field. The magnitude of that component is equal to $\beta_j^2 = \frac{v_c^2}{c_c^2 e^{-4U_j}}$ times the basic gravitational acceleration $c_c^2 e^{-4U_j}\overline{\boldsymbol{\nabla}}U_j$, it lies in the same plane as the object's velocity and $\overline{\boldsymbol{\nabla}}U_j$, and it is directed so as to oppose $\overline{\boldsymbol{\nabla}}U_j$. For a circular orbit it acts in the centrifugal direction.

$$\overline{\boldsymbol{a}}_{\boldsymbol{GM\_c}} = (\overline{\boldsymbol{\nabla}}U \times \overline{\boldsymbol{v}}_{\boldsymbol{c}}) \times \overline{\boldsymbol{v}}_{\boldsymbol{c}} \tag{C.12}$$

(cf. Purcell and Morin eq. (5.29) and the accompanying discussion). Note that for an object in an elliptical orbit this centrifugal acceleration component is strongest at perigee, when the gradient and velocity are greatest, so over time it should tend to reduce the eccentricity.

(It isn't clear to me whether the gravitomagnetic effect is already implicit in the geodesic trajectory equation. The gravitoelectric effect certainly isn't incorporated.).

11.5.4.3 The Significance of the Special Relativity Effects

The basic concepts of gravitoelectromagnetism are well known, and they have been validated experimentally, but surprisingly its effects appear to have been studied only in the context of spinning masses. Our generic two-body system directly incorporates the effects. The gravitoelectromagnetic effects are minimal at solar system velocities, but are significant for binary pulsars and collapsing binary systems in general.

The velocity effect is significant for high-speed binary systems, and it is also significant for masses that rotate with high surface velocities. Neutron stars and smaller black holes rotate at such velocities, and as a result their local gravitational fields are strongest over their equators. It predicts the gravitational waves that are observed in LIGO observatories.

11.6 An Alternative Version of the Gravitational Intensity?

If gravity is communicated by particles (gluons, we have assumed) then something anomalous is occurring. The gluon flux from a point mass should decrease with the square of the distance, yet the basic descriptor of the gravitational intensity, U, decreases only linearly with distance.

One possible explanation for this would be that the potency of a gluon increases linearly with the distance from its origin. That appears to be an attribute of the strong force that is mediated by gluons, though it is thought to have a very limited range. An alternative to gluons of increasing potency could be a "gluon cluster" that adds a new member every so often.

If, one way or another, an emitted gluon's potency does increase linearly with distance, then equation (4.4) ($U_{tot\_j} = \frac{G}{c^2}\Sigma_i \frac{m_i}{r_{ij}} = \frac{G}{c^2}\int \frac{\rho}{r} dv$) for the total gravitational intensity has the appropriate form. However, the dependency on distance raises an epistemological question: how could a gluon "know" how far it has travelled? How could its spatial odometer work?

In AltU gluons (which are massless and travel at the speed of light) regularly encounter gravitons (Higgs particles). Could each of those encounters add an increment to a gluon's potency? That would imply a different measure than the cosmic distance, one based on the graviton density of a region.

The inverse of the graviton density at a point determines the distance between graviton interactions, and thus determines the local speed of light. Per equation (4.7), that implies that the local graviton density is directly proportional to $e^{2U_{tot}}$. Accordingly, the cumulative number of graviton interactions experienced by a gluon should be proportional to the integral over its path of $e^{2U_{tot}}$. That would revise the integral-based version of the equation (4.7) formula for U_{tot} to be:

$$U_{tot} = \frac{G}{c^2} \iiint \frac{\rho}{r^2} \left[\int_0^r e^{2\left(U_{tot}(s) - U_{tot}(t_0)\right)}\, ds\right] dv = \frac{G}{c^2} \iiint \frac{\rho}{r^2} \left[\int_0^r e^{2U_0(s)}\, ds\right] dv$$

Where $U_{tot}(s)$ is the intensity at a gluon's location when it was still distance s away from the observed location, and $U_{tot}(t_0)$ is the current total intensity. The use of the constant $U_{tot}(t_0)$ term in the equation reflects the fact that the constant G was measured at time t_0. Despite its reference to $U_{tot}(t_0)$ the equation is appropriate for any time period. This equation should apply at any time in the history of the universe.

Gravitational intensity variations within the solar system are minuscule, so the value of the integral of e^{2U_0} over a path here is effectively identical to the length of the path, i.e. r. Thus this postulated alternative version of U would have no locally-observable effect here and now.

When visualizing the consequences of this formulation, it may be helpful to note that the inner integral is proportional to the observed travel time for a photon. Thus in a very high-intensity local field, where light is significantly slowed, the gluon potencies will become substantially increased.

In a very low-intensity field, such as in the early universe, gluon potencies will be very low. However, temporal rates were very high at early times, and that probably caused increased gluon emission rates. That increase would halfway compensate for the reduced gluon potencies.

11.6.1 The Alternative Solution for the Total Potential

With the alternative formulation of the gravitational intensity the cosmology equation (5.5) becomes:

$$U_{tot}(t_c) = 4\pi \frac{G}{c^2} \rho \int_0^{t_c} \left[\int_{r_h(t)}^{r_h(t_c)} e^{2\left\{U_{tot}\left(r_h^{-1}(s)\right) - U_{tot}(t_0)\right\}}\, ds\right] c_c(t)\, dt$$

If this is integrated numerically, over a series of steps, it becomes a sum. Each step in that sum defines the contribution to $U_{tot}(\mathrm{t_c})$ of a spherical shell of matter. The first step's shell is adjacent to the cosmological horizon, the second step's shell is just within the first, and so on.

The inner integral, in the square brackets, represents summing a series of lengths, with one length corresponding to each of the outer integral's steps. For each outer step, $\frac{G}{c^2 r^2}$ times the total amount of mass associated with that outer step is multiplied by the sum of the inner-integral lengths between the outer shell and the target point where U_{tot} is being evaluated.

The Hubble parameter would be:

$$H(t_c) = \frac{4\pi\, G}{c^2}\rho\left[t_c c_c(t_c)e^2 + e^{2\{U_{tot}(t_c)-U_{tot}(t_0)\}}\right]$$

11.6.2 The Alternative *U* Value's Implications for Gravity

For a single point mass m at location $\overline{\boldsymbol{x}}_{\boldsymbol{m}}$, and an observation point $\overline{\boldsymbol{x}}_{\boldsymbol{obs}}$ at distance r, the local intensity at the observation point is defined by a line integral:

$$U(\overline{\boldsymbol{x}}_{\boldsymbol{obs}}) = \frac{Gm}{c^2r^2}\int_{\overline{\boldsymbol{x}}_{\boldsymbol{m}}}^{\overline{\boldsymbol{x}}_{\boldsymbol{obs}}} e^{2U_0(\overline{\mathbf{x}})}d\|\overline{\boldsymbol{x}}\|$$

The gradient of U (or of U_{tot}) at $\overline{\boldsymbol{x}}_{\boldsymbol{obs}}$ is:

$$\overline{\boldsymbol{\nabla}}U_{obs} = -\left(2\frac{U_{obs}}{r} - \frac{Gm}{c^2r^2}e^{2U_0(\overline{\boldsymbol{x}}_{\boldsymbol{obs}})}\right)\frac{\overline{\boldsymbol{r}}}{\|\overline{\boldsymbol{r}}\|}$$

These two equations are more difficult to evaluate than the original version of the gravitational potential, because the value of $U_0(\overline{\mathbf{x}})$ is implicit in its definition. Also, it is not appropriate to simply add the contributions to the intensity at a point due to all of its surrounding masses. The integral has to include the contributions of all significant masses to its $U_0(\overline{\mathbf{x}})$ term.

To begin to evaluate and use the equations, we will consider the case of a single spherically-symmetric finite mass, in the present era, and try to define the variation with distance of the gravitational intensity $U_0(r)$ that it creates. The key to our approach will be to find a solution where at a large radius U_0 equals zero, and we will define a "large radius" as one where the gradient becomes negligible. That radius will be quite different for a sun-sized mass than it is for a super-massive black hole's mass.

Our solution is iterative. Make an initial estimate of the U_0 value at the edge of the mass, $U_0(r_m)$, where $r_m = \sqrt[3]{\frac{3m}{4\pi\rho_m}}$ and ρ_m is the mean density within the mass. Then integrate $\overline{\boldsymbol{\nabla}}U$ out to a large radius. Subtract the calculated large-radius intensity value from the estimated U_0 value at the edge of the mass, and iterate until convergence.

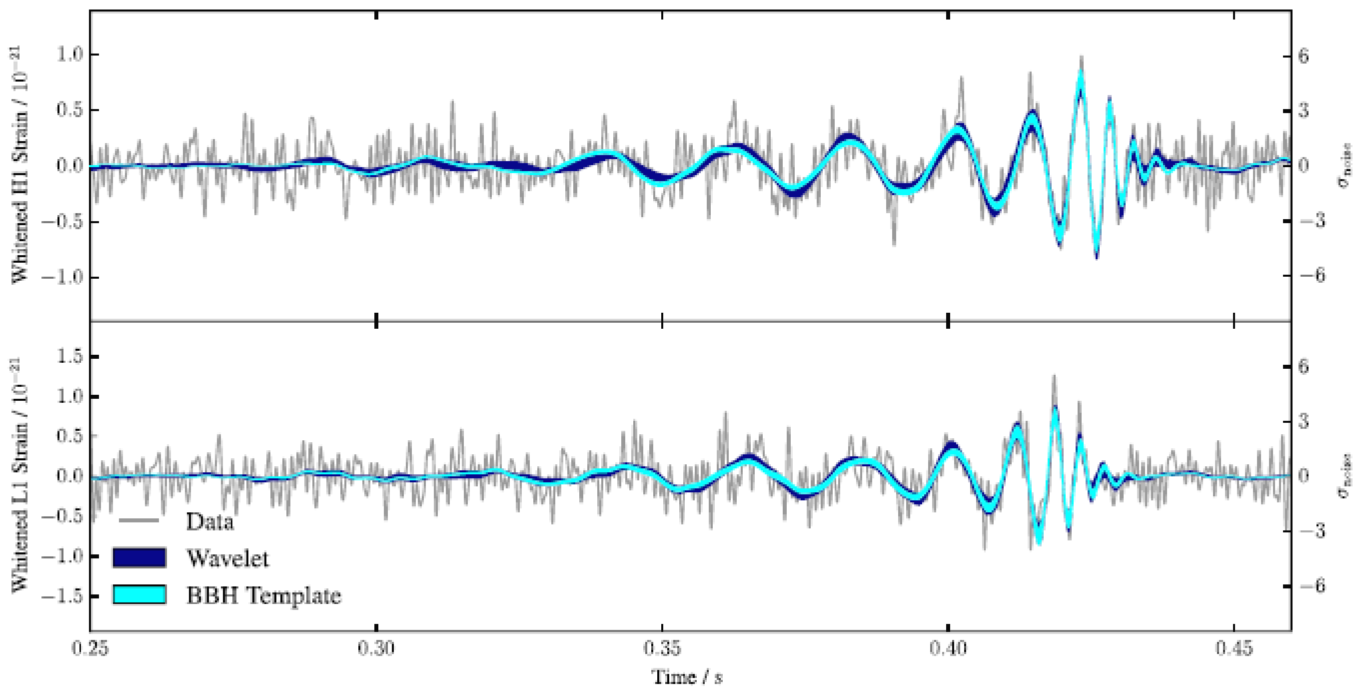
11.6.3 Status of the Alternative Intensity Formulation

I haven't pursued this alternative intensity concept very far. It is included here only as an interesting possibility.

11.7 Gravitational Waves

As an example of the special relativity velocity-driven effect, consider the LIGO GW150914 event.

On September 14, 2015 the first ever recording of a gravitational wave event happened at the two LIGO observatories that were active at that time (Abbott, B. P. et al., 2015). The observed strain values were compared to a library of possible waveforms that had previously been calculated, based on the Einstein gravitational energy radiation concept and numerical models of the strong-field gravitational effects. The best-fit result was for a binary pair of black holes, with a total mass 65 times that of the Sun, located 410 Mpc (1.34 billion light-years) away. The image below shows the recorded waveforms and the fitted model result:



The above figures (copied from Abbott, B. P. et al., 2015) indicate a frequency of some 125 Hz as the signal approaches its peak.

A simplified description of the conventional physics describing an inspiral and the resulting gravitational waves can be found in LIGO Scientific and VIRGO Collaborations (2016). There is also a nice video simulation of merging black holes in the Wikipedia discussion, at https://en.wikipedia.org/wiki/Gravitational_wave.[19] At the heart of the physical concepts is the idea that rotating masses radiate gravitational energy, resulting in a gradual decay of their orbits. The form of the gravitational waves was proposed by Einstein, and is consistent with general relativity theory, having a constant spacetime volume: one spatial dimension expands as a counterpart contracts. The waves are assumed to have no effect on proper time.

11.7.1 LIGO GW150914: The AltU Interpretation

The inferred parameters for LIGO GW150914 were a combined mass 65 times that of the Sun, located 410 Mpc away. If the masses were static, their combined gravitational intensity at the Earth's location would be $\frac{G \cdot 65M_{sun}}{c^2 \cdot 410\,Mpc}$, equal to 7.59e-21.

As the collapse approached, the frequency of the LIGO signal was in the order of 125 Hz. For these parameters, if the black holes were equal-sized a Newtonian analysis of the orbits (with a 62.5 Hz

[19] The video shows waves propagating outwards in the orbital plane, which is what is expected in AltU, but not what is expected in the conventional universe, where the greatest amplitude of the gravitational waves is along the axis of rotation. Per Stephen Fairhurst, Cardiff University, personal communication (2019).

frequency) indicates a separation of 382 km, with each mass having a velocity equal to 0.25c, so $\beta_i \cong 0.25$. Each of the black holes would have a Schwarzschild radius equal to 96 km (!).

Let's do a back-of-the-envelope estimate of AltU's predicted variation in the gravitational intensity observed on Earth (1.34 billion years later) due to this pair of black holes. Equation (C.5) indicates that due to the velocities of the masses the intensity experienced at the Earth is multiplied by $\left[\frac{1-\beta_i^2}{\left(1-\beta_i^2 sin^2\theta\right)^{1.5}}\right]$. At a moment when the Earth lay in the binary's plane of rotation and the masses' respective velocities (1.34 billion years previously) were directly towards and away from the Earth, then for the two masses $\theta = 0 \text{ and } \pi$, $sin\theta = 0$, and the multipliers are both equal to $1 - \beta_i^2$ or 0.9375. At a moment when the masses' velocities were perpendicular to Earth's direction, then $\theta = \frac{\pi}{2} \text{ and } \frac{3\pi}{2}$ and the multipliers are both equal to $\left(1-\beta_i^2\right)^{-0.5}$ or 1.01627. The Earth would therefore experience a cyclically-varying intensity at 125 Hz, varying between 7.113e-21 and 7.710e-21. The amplitude of this signal would be half the difference, about 3e-22. The temporal rate and local speed of light at a LIGO observatory on the Earth would vary cyclically by this factor of ±3e22.

The LIGO signal reproduced above has a frequency and amplitude that are very similar to this AltU result, and that is not an accident. In AltU gravitational waves are simply the gravitational fields of moving masses, delayed by their travel times at the speed of light. (This is the same travel-time delay effect that led to the successful prediction of cosmic redshifts which is described in Section 3.). Nothing magical is happening to the binary masses to cause them to "radiate energy". However, there are two special behaviors going on with respect to the masses:

- Due to the velocities involved, each mass particle's gravitational field is oblate rather than spherical.
- The masses' velocities are significant fractions of the speed of light. This somehow causes a misalignment of the two gravitational acceleration vectors, which leads to a decaying orbit.

The orientation of the Earth with respect to the binary's orbital plane is significant: if the Earth was located perpendicular to the binary's plane of rotation then it would experience no variation in its local gravitational intensity due to the binary.

The LIGO observatories are based on a concept of gravitational waves that cause oscillatory strains in proper space, which can be thought of as shrinkage in one direction accompanied by extension in a perpendicular direction. They observe the signal by measuring differential light-wave travel times in the multi-kilometer arms of the observatory. In AltU the change to the local metric is very different, and it has different effects. The temporal rate changes alter the absolute frequency of the lasers feeding a LIGO system, and the change in the speed of light alters the velocity and wavelength of its multiply-reflected light waves.

AltU also predicts that a material object's size varies in proportion to $e^{-\delta U}$- a real, isotropic strain. For slow variations in the intensity all objects will experience this effect, but if an object's size is significantly larger than the velocity of a pressure wave within it multiplied by the period of the δU variations the actual strains will be reduced. For example, the Earth as a whole would not respond measurably to the GW150914 waves: seismic wave velocities are in the order of 5 km/s, so a 100 ms period wave would have no effect on the Earth as a whole. A LIGO observatory's arms are in the order of 4 km long, so their lengths should be relatively unaffected by the observed waves.

It turns out that LIGO devices have surprisingly long memories, much longer than the periods of the observed waves. The reason for the long memories is that the devices recycle the reflected laser light waves many times, in order to build up the power within the system. On average, a photon travels about 4.2e7 m, which takes about 0.14 seconds[20], within the instrument. The recycling is a valuable technique that has no negative consequences if the wavelength of the light is constant, but in AltU the wavelength is changing, due to the varying speed of light caused by the gravitational wave. At higher values of the speed of light the laser, which has a constant frequency in terms of proper time, emits longer-wavelength light. Even though the change in the wavelength is very small, this means that during periods of a varying scale factor the LIGO cavities will contain a mixture of wavelengths, and their interference pattern will not display complete cancellation at the nodes. Without knowing details of the LIGO detectors one can only speculate whether the results of these effects would present similarly to the strain waves predicted by conventional relativity theory.

It is unclear how these changes would be reflected by a LIGO observatory's data processing system- they are complex (see Abbott et al, 2016-17). It will require careful analysis to identify whether a changing speed limit could have produced the observed signals.

11.7.2 Gravitational Waves: Possible Tests

There are several significant differences between the form of AltU's gravitational waves and the waves predicted by conventional theory. These differences offer the potential for proving or disproving one or the other approach.

11.7.2.1 AltU's Waves are Scalar, and Not Polarized

If the conventional model is correct, the observed strain level for an inspiral event will vary significantly based on the orientation of the LIGO instrument with respect to the plane of the originating binary system. The effects of this should be straightforward to observe, and definitive. The z-axis for the conventional wave's polarization plane is parallel to the rotational axis of the binary system. A LIGO instrument having the plane of its arms not perpendicular to the rotational axis will have an induced strain that is less than that of the wave, so different LIGO instruments should record different strain levels. This should show up as apparently random differences in the strain levels observed by different LIGO systems, and for any given event those differences should always be consistent with a single orbital plane orientation. So when multiple LIGO observatories, preferably three or more, record the same event the orientation of the orbital plane should be clear.

By comparison, if AltU is real, then all LIGO-type detectors on Earth will record similar strain levels for a given event, regardless of their orientation, though there may be systematic differences between them.

11.7.2.2 AltU's Waves are Strongest In-Plane, Einstein's are Strongest On-Axis

There is a second possible test: AltU predicts a stronger signal when the Earth lies closer to the orbital plane, while conventional theory predicts a stronger signal when the Earth lies closer to the axis of

[20] Brian O'Reilly, LIGO, personal communication (2017).

rotation. Thus if and when an actual binary pair has been imaged prior to its collapse, or if a post-collapse debris field indicates the prior orientation of the pair, the conventional and AltU approaches should be able to be contrasted.

As far as I can tell, neither the Earth's distance from the orbital plane nor the orientation of the LIGO arms with respect to the orbital angular momentum vector is routinely deduced from and integrated into analyses of gravitational wave observations. For example, the three-detector GW170814 binary inspiral reported in Abbott et al (2017a) shows almost-identical observed strain magnitudes for the three detectors (see Figure 1, bottom row). Note that in that paper's section V, SOURCE PROPERTIES, there is no mention of an inferred orientation for the originating binary system. This seems to imply that the antenna orientation and strain amplitude data were not actually used in the data analysis.

11.7.2.3 AltU Predicts Temporal Strains

Another key difference between the binary-system gravitational waves assumed by conventional theory and those of AltU, is that the latter involve temporal strains. It might be possible to test the two concepts, by looking for a temporal strain pattern associated with a gravitational wave. During a gravitational wave event the temporal strain at an observing instrument would vary cyclically. This would cause observations of a constant time-interval signal from a distant source to have varying time intervals.

One basic idea for such an experiment would be to continually transmit a stable high-frequency electromagnetic signal from the Earth to reflectors located some distance away. Normally, the frequency of the returned signals would be almost identical to that of the transmitted signal, with small Doppler shifts due to any gradual change of the distance involved. However, if the temporal strain at the transmitter changed between the time that a portion of the signal was transmitted and the time that portion's reflection returned, there would be an observable difference between the frequencies of the currently transmitted wave and the returning waves.

Another approach would be to continuously monitor the arrival times of pulses from one or more pulsars, using high-precision clocks. Temporal strains would cause changes to the intervals between pulses. However, these temporal strain approaches would require extremely high precision measurements of the timing of the signals, and they are probably not feasible.

11.7.3 The Conventional Theory of Gravitational Waves from Binary Systems

I'll try to summarize here some key aspects of conventional gravitational waves emitted by binary systems. There is a good overview of gravitational waves in general in Sathyaprakash and Schutz, 2009. Two seminal papers that underlie that overview are Peters and Mathews (1963) and Peters (1964). My description will be somewhat awkward, because I find the underlying theory to be conceptually incoherent, but I will do my best.

In AltU gravitational waves are just perturbations of the gravitational field of a system of masses that arise due to its internal motions, observed at a distance. But in the conventional universe gravitational waves represent radiated energy and angular momentum due to accelerating (i.e. orbiting) masses, and their energy and angular momentum content reflects the rate of loss of orbital energy and angular momentum from the originating system. The form of the waves is described by metric perturbation h_{ij}

terms that are proportional to the third time derivative of the second moments of the mass distribution of the originating binary system.

There are two distinct flavors of the waves, with different polarizations, and their radiated power distributions are different. In engineering terms each flavor represents a state of planar pure shear strain. The magnitudes of the strains vary inversely with the distance from the binary, and the angular distributions of the two polarizations are different. For a binary system the dominant part of the energy flux is directed along the rotational axis.

The underlying theory appears to be basically a recasting of the electromagnetic equations for antenna systems. It is based on a strange application of Einstein's field equation: a total energy-momentum tensor $T_{\mu v}$ for an entire binary system is substituted into the Einstein field equation, in place of the stress-energy tensor. (The stress-energy tensor is comprised of terms defining the density and flux of energy and momentum at a point). That substitution makes no sense, but it is used to derive apparently valid equations for the rate of loss of orbital energy and angular momentum. At that point the field equation is re-invoked in its correct form, and used to define possible forms for sinusoidal gravitational waves that have a zero Ricci tensor. The key part of the solution relates the power loss rate to the third time derivative of the second-moment tensor of the binary system, and that equation is based on one in Landau and Lifshitz (1975, and earlier editions).

Regardless of my quibbles, the resulting equations describe precisely how the orbits of binary systems decay. Time should tell whether LIGO observatories truly confirm their predictions for the resulting gravitational wave forms.

11.8 Modeling the Cosmic Effect— the Decreasing Universal Speed Limit

There is a widespread belief that gravitationally-bound systems somehow 'shrug off' the effects of spatial expansion, but there is no generally-accepted theoretical explanation for this. A good summary of the situation can be found in Carrera and Giulini (2010), where the authors state that: "*… the general problem of gaining a qualitative and quantitative understanding of how the cosmological dynamics influence local systems remains challenging, with only partial clues being so far provided by exact solutions to the field equations of General Relativity.*".

As one example of the problem referred to by Carrera and Giulini, there are very successful N-body simulations of the evolution of cosmic structure (see e.g. Bertschinger (1998)). The general approach used for these simulations uses a version of Newtonian gravity mapped onto an expanding universe, as initially set out in Peebles (1980). Those equations predict orbital systems that have stable orbital radii (i.e. their comoving radii shrink at the Hubble rate). However, simulated orbital systems have quite rapidly accelerating proper velocities— proper orbital velocities grow at three times the Hubble rate (!).

11.8.1 The Expansion of the Conventional Universe Isn't Apparent Locally

Precise determinations of solar system distances have only been available for a few decades, but that is enough time to determine that, if they are changing at all, solar system distances do not appear to be changing at the rate suggested by cosmic theory. As a mental benchmark for the magnitudes of potential changes in the conventional universe, if the mean Earth-Sun distance was increasing at the current Hubble expansion rate H_0 it would grow by some 10.7 m/a. In terms of time, the Hubble rate is equivalent to 7.16e-11 a^{-1} (each Earth year would be 2.26 ms longer than its predecessor).

The NASA solar system orbital model is based on the PPN dynamic equations, which do not incorporate any terms associated with cosmic effects. The resulting matches between the NASA model predictions and the observational data appear to rule out any local expansion or contraction. Here is a typical result for the Earth-Mars distance, taken from Folkner et al (2014), showing the difference between the orbital model and observations over a period of ten years:

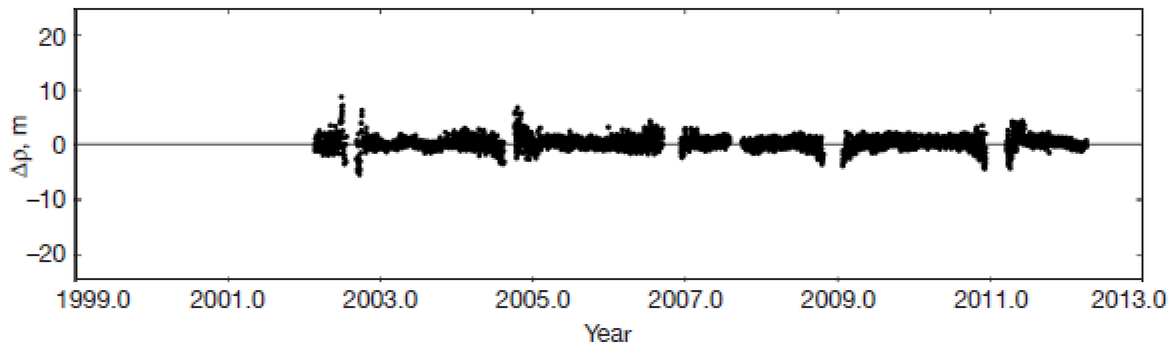


Figure 18. Residuals for range measurement to Mars Odyssey.

Similar closely-matching results are found for other planets, for the Moon, and for other time periods.

There is a little wiggle-room in the interpretation of these results. Accurate measurements of the distances to most solar system targets are extraordinarily difficult to make. The distance to the moon is relatively easy to measure, but the moon's distance is steadily increasing due to tidal effects, which cannot be predicted from first principles. The solar system models that are used are complex with a large number of input parameters, and most of those parameters are solved for by means of a best fit approach. So possibly there are modest changes in the orbits, and they have been obscured by slightly modified estimates of the parameters that are involved.

11.8.2 The Slowing Speed Limit and the AltU Approach

When solved ignoring the rate of change of the cosmic speed limit, AltU's geodesic equation (6.2) predicts unchanging orbital periods and distances, similar to the NASA model. When the slowing speed limit is included a photon that is not in a local gravitational field gradually slows at the Hubble rate: $\overline{\boldsymbol{a}}_{\boldsymbol{j\_c}} = -H\boldsymbol{v}_{\boldsymbol{j\_c}}$, and a non-relativistic mass slows at twice that rate.

AltU's geodesic trajectory equation (6.2) is:

$$\overline{\boldsymbol{a}}_{\boldsymbol{c}} = (c_c^2 e^{-4U} + v^2)\overline{\boldsymbol{\nabla}}U + \left[-4(\overline{\boldsymbol{v}}_{\boldsymbol{c}} \cdot \overline{\boldsymbol{\nabla}}U) - \left(2 - \frac{v^2}{c_c^2 e^{-4U}}\right)\left(H(t_c) + \frac{dU}{dt_c}\right) - \frac{dU}{dt_c}\right]\overline{\boldsymbol{v}}_{\boldsymbol{c}} \qquad (6.2)$$

The $-\left(2 - \frac{v^2}{c_c^2 e^{-4U}}\right) H(\mathrm{t_c})\, \overline{\boldsymbol{v}}_{\boldsymbol{c}}$ term acts as a drag force, which reduces orbital radii. When the solar system is evaluated (incorporating the second-order effect due to a mass's temporal rate), AltU's predicted orbital distances shrink at the Hubble rate. However, the speed of light is also decreasing at the Hubble rate. This implies that measured solar system distance based on radio wave transit times will be unchanging- which is what is observed. The AltU predictions are consistent with the observed astronomical data. Orbital systems shrink at the Hubble rate, the same rate at which material objects shrink.

The calculated orbital periods gradually increase very slightly, at about 1% of the Hubble rate, i.e. at 0.03 ms/a for the Earth, though this may be a numerical artefact. There are no observational data with sufficient precision to confirm or contradict this result.

The shrinking orbital radii should also apply to galaxies, which would appear to not be consistent with the angular size test results of Section 3.3.3. However, in AltU star-forming galaxies are continuously drawing in new gas and creating new stars, and it is primarily those new stars that we observe when we measure galaxy sizes. For a given galaxy size, the radial distance to the birthplace of new stars has changed little over the life of the universe.

11.9 Measuring Distances

11.9.1 Measuring Local Distances

The only real way to measure (as opposed to calculate) distances through space is to time the passage of photons between two points, as is done by a laser range finder. Thus direct measurements of distances in space are always affected by the speed limit ratio field.

We previously derived the equation for the refractive index of space: $\mathrm{n} = e^{2U}$. The total time for a photon's passage, as observed by a timing device, can be calculated by integrating the cosmic time over the length of the photon's trip and then multiplying by $e^{-U_{observer}}$ to account for the slowed proper time at the observer's location.

11.9.2 Measuring Distances to Remote Objects

In order to calculate distances, astronomical data have to be interpreted using a specific model of the universe. In the following notes we assume that the observer and the observed object are comoving—their relative velocity is negligible. There are two common ways to estimate the distances to an observed object: via its observed angular diameter, and via the observed flux of electromagnetic energy from the object. In the following the symbol 'd_{AltU}' refers to the AltU distance, and 'd_{com}' refers to the current comoving distance in the conventional universe. By and large, these distance measures are equivalent.

11.9.2.1 Measuring Distances in AltU

Distances to distant galaxies in AltU are constant, and can be calculated as follows:

- Angular Diameter Basis: The distance is equal to the physical diameter of the object at the time the light waves were emitted divided by its observed angular diameter: $d_{AltU} = \frac{object\ diameter}{angular\ diameter}$.
- Luminosity Basis: The observed flux is multiplied by $(1+z)^2$ to correct for the photon energy loss and arrival rate reduction due to the decreased speed limit. The corrected flux, multiplied

by $4\pi d_{AltU}^2$ equals the object's luminosity when the light waves were emitted, so $d_{AltU} = \sqrt{\frac{luminosity}{4\pi \cdot \text{flux} \cdot (1+z)^2}}$. This is identical to the comoving distance in the conventional universe. (In practice, the flux is also adjusted to compensate for other things that may have affected it: spatial opacity (typically dust or gas or electrons), and optical filter effects due to its changed wavelength.).

11.9.2.2 Measuring Distances in the Zero-Curvature Conventional Universe

In the conventional universe comoving distances increase with cosmic time, based on the universe's scale factor. The scale factor at the observer's current time is $(1 + z)$ times the scale factor when the light waves were emitted. Thus the comoving distance d_{com} is a function of time, but conventionally for a comoving distance the time is not mentioned and our current cosmic time is assumed.

For an observer at the current cosmic time, distances can be calculated as follows:

- The Angular Diameter Distance: This is equal to the physical diameter of the object at the time the light waves were emitted divided by its observed angular diameter: $d_{ang} = \frac{object\ diameter}{angular\ diameter}$. It equals the comoving distance at the time the light waves were emitted, i.e. the current comoving distance divided by $(1 + z)$.
- Luminosity Distance: The definition of the luminosity distance is $d_{lum} = \sqrt{\frac{luminosity}{4\pi \cdot \text{flux}}}$. This formula ignores the fact that the observed flux was attenuated due to the redshift, divided by $(1 + z)^2$. As a result the calculated luminosity distance exceeds the current comoving distance, which is defined by $d_{com} = \frac{d_{lum}}{(1+z)}$.

12 References

Abbott, B. P. et al., "Properties of the Binary Black Hole Merger GW150914". Physical Review Letters, PRL 116, 241102 (2016). https://arxiv.org/abs/1602.03840

Abbott, B. P. et al, "Calibration of the Advanced LIGO detectors for the discovery of the binary black-hole merger GW150914", 2017, https://arxiv.org/pdf/1602.03845.pdf.

Abbott, B. P. et al, "GW170814: A Three-Detector Observation of Gravitational Waves from a Binary Black Hole Coalescence", Phys. Rev. Lett. 119, 141101 –6 October 2017a.

Abbott, B. P. et al, "GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral", Phys. Rev. Lett. 119, 161101 –16 October 2017b.

Abbott, T. M. C. et al, "First Cosmology Results using Type Ia Supernovae from the Dark Energy Survey: Constraints on Cosmological Parameters", ApJL 872, L30, 2019. https://iopscience.iop.org/article/10.3847/2041-8213/ab04fa

Abdullah, M. H. et al, "COSMOLOGICAL CONSTRAINTS ON OMEGA$_m$ AND SIGMA$_8$ FROM CLUSTER ABUNDANCES USING THE GALWCAT19 OPTICAL-SPECTROSCOPIC SDSS CATALOG", ApJ 901 90, 2020. https://arxiv.org/pdf/2002.11907.pdf

Albrecht, A. and Magueijo, J, "Time varying speed of light as a solution to cosmological puzzles". Physics Review, D59, Article ID: 043516. http://dx.doi.org/10.1103/PhysRevD.59.043516 , 1999.

Bahcall, N. A. and A. Kulier, "Tracing mass and light in the Universe: where is the dark matter?", Mon. Not. R. Astron. Soc. Vol 439 Issue 3 pp 2505-2514 (2014). https://arxiv.org/pdf/1310.0022.pdf

Bertotti B.; Iess L.; Tortora P. "A test of general relativity using radio links with the Cassini spacecraft". Nature. 425 (6956): 374–376. 2003.

Bertschinger, E., "SIMULATIONS OF STRUCTURE FORMATION IN THE UNIVERSE", Annu. Rev. Astron. Astrophys. 1998. 36:599–654. https://ned.ipac.caltech.edu/level5/March03/Bertschinger/paper.pdf

Blanchet, L. et al., "Gravitational-Radiation Damping of Compact Binary Systems to Second Post-Newtonian Order", Phys.Rev.Lett.74:3515-3518,1995. arXiv:gr-qc/9501027v1 23 Jan 1995

Blanchet, L., "Gravitational Radiation from Post-Newtonian Sources and Inspiralling Compact Binaries", Living Rev. Relativity, 17, lrr-2014-2 (2014). 1310.1528.pdf (arxiv.org)

Blondin, S. et al, "TIME DILATION IN TYPE Ia SUPERNOVA SPECTRA AT HIGH REDSHIFT", Astrophys. J., 682, 2008. https://arxiv.org/pdf/0804.3595.pdf

Carrera, M. and D. Giulini, "Influence of global cosmological expansion on local dynamics and kinematics". Reviews of Modern Physics, volume 82, Jan-Mar 2010.

Carroll, Sean M., "Spacetime and Geometry", Pearson Education Inc., 2013.

References

Chou, C. W. et al, "Optical Clocks and Relativity", Science 329 (5999): 1030-1633, 2010. https://science.sciencemag.org/content/329/5999/1630.full

Collier, P. "A Most Incomprehensible Thing: Notes Towards a Very Gentle Introduction to the Mathematics of Relativity", Incomprehensible Books (Amazon), 2014.

Crighton, N.H.M. et al: "Possible Population III Remnants at Redshift 3.5". MNRAS 457, L44–L48 2016

Dicke, R. (1957). "Gravitation without a Principle of Equivalence". Reviews of Modern Physics. 29 (3):363‑376.

Einstein, A. "Über Gravitationswellen" ("On Gravitational Waves"), 1918. Translated to English: http://einsteinpapers.press.princeton.edu/vol7-trans/25 .

Einstein, A. and N. Rosen, "On Gravitational Waves", J. of the Franklin Institute, Vol. 223, No 1333-4, Jan. 1937.

Ellis, George F. R. (2007). "Note on Varying Speed of Light Cosmologies". General Relativity and Gravitation. 39 (4): 511‑520. https://arxiv.org/pdf/astro-ph/0703751v1.pdf

Everitt, C. W. F. et al. (2011). "Gravity Probe B: Final Results of a Space Experiment to Test General Relativity". Physical Review Letters. 106 (22): 221101. Bibcode:2011PhRvL.106v1101E.

Folkner, W. M. et al, "The Planetary and Lunar Ephemerides DE430 and DE431", IPN Progress Report 42-196. February 15, 2014. https://ipnpr.jpl.nasa.gov/progress_report/42-196/196C.pdf

Goobar, A. et al, "The cosmic transparency measured with Type Ia supernovae: implications for intergalactic dust", *Monthly Notices of the Royal Astronomical Society: Letters*, Volume 477, Issue 1, 11 June 2018, Pages L75–L79, https://arxiv.org/pdf/1803.08592.pdf

Goldhaber, G. et al. "Timescale Stretch Parameterization of Type 1a Supernova β-band Light Curves", The Astrophysical Journal, Volume 558, No.1. 2001. https://arxiv.org/abs/astro-ph/0104382

Hartle, J. B. "Gravity: an Introduction to Einstein's Relativity", PEL, 2013.

Kramer, M. et al, "Tests of General Relativity from Timing the Double Pulsar", SCIENCE Vol 314 6 October 2006. https://science.sciencemag.org/content/314/5796/97

Landau, L. and E. Lifshitz, "The Classical Theory of Fields", Pergamon Press, 1975.

Laporte, N. et al. "Dust in the Reionization Era: Alma Observations of a Z=8.38 Gravitationally-Lensed Galaxy", The Astrophysical Journal Letters, Volume 837, Number 2, 2017. https://arxiv.org/pdf/1703.02039.pdf

Lerner, E. et al, "UV surface brightness of galaxies from the local Universe to z ~ 5", International Journal of Modern Physics D Vol. 23, No. 6 (2014) 1450058. https://arxiv.org/abs/1405.0275

References

LIGO Scientific and VIRGO Collaborations, "The basic physics of the binary black hole merger GW150914", Ann. Phys. (Berlin) 529, No. 1–2, 1600209 (2017) / DOI 10.1002/andp.201600209, 2016 https://arxiv.org/abs/1608.01940.

Longo, M.J., "New Precision Tests of the Einstein Equivalence Principle from SN1987A", Phys. Rev. Lett, V60, Issue 3, Jan 1988 pp173-175. https://zenodo.org/record/1059079#.XsrC5kBFzoo

Lopez-Corredoira, M, "ANGULAR SIZE TEST ON THE EXPANSION OF THE UNIVERSE", Int. J. Mod. Phys. D 19, 2010, 245. https://arxiv.org/pdf/1002.0525.pdf

Lopez-Corredoira, M, "Peaks in the CMBR power spectrum. II. Physical interpretation for any cosmological scenario", Int. J. Mod. Phys. D, 22, 1350032, 2013. https://arxiv.org/pdf/1303.1375.pdf

Lopez-Corredoira, M, "Alcock-Paczynski Cosmological Test", The Astrophysical Journal, 781:96, 2014. http://iopscience.iop.org/article/10.1088/0004-637X/781/2/96/pdf

Lopez-Corredoira, M, "Tests and Problems of the Standard Model in Cosmology", Found Phys (2017) 47: 711. https://doi.org/10.1007/s10701-017-0073-8 https://arxiv.org/pdf/1701.08720.pdf

Mansouri, R. and R. Sexl, General Relat. Gravit. 8, 497, 515, 809 (1977). https://www.researchgate.net/publication/226579519_A_test_theory_of_special_relativity_I_Simultaneity_and_clock_synchronization

Melia, F. and A. S. H. Shevchuk, "The Rh=ct Universe", Mon. Not. R. Astron. Soc. Volume 419, Issue 3, 21 January 2012, Pages 2579–2586. https://doi.org/10.1111/j.1365-2966.2011.19906.x

Melia, F. and M. Lopez-Corredoira, "Alcock-Paczynski Test with Model-Independent BAO Data", Int. J. Mod. Phys D 26, 1750055 (2017). http://cdsads.u-strasbg.fr/abs/2017IJMPD..2650055M

Melia, F, "J1342+0928 Supports the Timeline in the Rh = ct Cosmology", Astronomy and Astrophysics, 2018, to be published. https://arxiv.org/pdf/1712.03306.pdf

Misner, Thorne and Wheeler (MTW), "Gravitation", Princeton University Press, 2017.

Mo, H. et al, "GALAXY FORMATION AND EVOLUTION", 842 pp text book, Cambridge University Press, 2010. https://www.astro.umd.edu/~richard/ASTRO620/MBW_Book_Galaxy.pdf

Mundy, C. J. et al, "A consistent measure of the merger histories of massive galaxies using close-pair statistics I: Major mergers at z < 3:5", Mon. Not. R. Astron. Soc, Volume 470, Issue 3, p.3507-3531. 2017. https://arxiv.org/abs/1705.07986

Newhall, X. X. et al, "A numerically integrated ephemeris of the Moon and planets spanning forty-four centuries", Astron. Astrophys. 125, 150-167, 1983.

Oesch, P. A. et al: "A Remarkably Luminous Galaxy at Z=11.1 Measured with Hubble Space Telescope Grism Spectroscopy", The Astrophysical Journal, Volume 819, Issue 2, article id. 129, https://arxiv.org/abs/1603.00461 [astro-ph.GA], 2016.

Peebles, P. J. E., “The Large-Scale Structure of the Universe”, Princeton University Press, 1980.

Persic, M. and P. Salucci, “The baryon content of the Universe”, Mon. Not. R. Astro. Soc, 258, 1992. https://arxiv.org/abs/astro-ph/0502178

Peters, P. C., “Gravitational Radiation and the Motion of Two Point Masses”, Physical Review, vol. 136, Issue 4B, pp. 1224-1232, Nov. 1964. http://gravity.psu.edu/numrel/jclub/jc/Peters_Mathews_PR_131_435_1963.pdf

Peters, P. C. and J. Mathews, “Gravitational Radiation from Point Masses in a Keplerian Orbit”, Physical Review, vol. 131, Issue 1, pp. 435-440, July 1963. http://gravity.psu.edu/numrel/jclub/jc/Peters_Mathews_PR_131_435_1963.pdf

Planck Collaboration, “Planck 2018 results I. Overview and the cosmological legacy of Planck”, EDP Sciences, 2020. https://www.aanda.org/articles/aa/pdf/2020/09/aa33880-18.pdf

Poisson, E. and C. M. Will, “Gravity: Newtonian, Post-Newtonian, Relativistic”. Cambridge University Press, 2014.

Purcell, E. M. and Morin, D. J., “Electricity and Magnetism”, Third Edition, Cambridge University Press, 2013.

Reasenberg, R. D. et al, “*VIKING* RELATIVITY EXPERIMENT: VERIFICATION OF SIGNAL RETARDATION BY SOLAR GRAVITY”, The Astrophysical Journal, 234:L219-L221, 1979 December 15.

Risaliti, G. & Lusso, ‘Cosmological constraints from the Hubble diagram of quasars at high redshifts’, *Nature Astron.* 3 (2019) 3, 272-277. https://arxiv.org/abs/1811.02590

Ross, D. K. and L. I. Schiff, “Analysis of the Proposed Planetary Radar Reflection Experiment”, Phys. Rev. 141, 1215. 1966.

Sanders, R. H., “The Dark Matter Problem”, Cambridge University Press, 2013.

Sandage, A. and Lubin, “The Tolman Surface Brightness Test for the Reality of the Expansion. I. Calibration of the Necessary Local Parameters”, Astron.J.121:2271-2288, 2001. https://arxiv.org/abs/astro-ph/0102213

Sarazin, X. et al. “Can the apparent expansion of the universe be attributed to an increasing vacuum refractive index?”, Eur. Phys. J. C (2018) 78:444. https://link.springer.com/content/pdf/10.1140/epjc/s10052-018-5932-8.

Sathyaprakash, B. S. and Schutz, B. F. “Physics, Astrophysics and Cosmology with Gravitational Waves”, Living Rev. Relativity, 12, (2009), 2 https://link.springer.com/article/10.12942/lrr-2009-2

Schramm, D. N. and R. W. Wagoner, “Element Production in the Early Universe”, Ann. Rev. Nucl. Sci. 1977. 27:37-74. See https://www.researchgate.net/publication/234152865_Element_Production_in_the_Early_Universe .

References

Scolnic, D. et al. "THE COMPLETE LIGHT-CURVE SAMPLE OF SPECTROSCOPICALLY CONFIRMED TYPE IA SUPERNOVAE FROM PAN-STARRS1 AND COSMOLOGICAL CONSTRAINTS FROM THE COMBINED PANTHEON SAMPLE", 2018. ApJ 859, Issue 2, article 101. https://arxiv.org/pdf/1710.00845.pdf

Selleri, F. "Space, Time and Their Transformations", Chinese J. of Systems Engineering and Electronics, Vol. 6, No. 4, 1995, pp. 25-44. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6074794

Selleri, F. "Remarks on the Transformations of Space and Time", APEIRON Vol 4 No. 4 Oct. 1997. http://www.naturalphilosophy.org/pdf/abstracts/abstracts_605.pdf

I. I. Shapiro, "FOURTH TEST OF GENERAL RELATIVITY", Physical Review Letters, Vol 13 No. 26, December 1964.

Shapiro, I. I. et al, "The Viking Relativity Experiment", J. Geophys. Res., 82, 4329, 1977.

Sheldon, E. et al, "CROSS-CORRELATION WEAK LENSING OF SDSS GALAXY CLUSTERS. III. MASS-TO-LIGHT RATIOS", The Astrophysical Journal, 703:2232-2248, October 2009). http://iopscience.iop.org/article/10.1088/0004-637X/703/2/2232/pdf

Shibuya, T. et al, "MORPHOLOGIES OF ∼190,000 GALAXIES AT z = 0–10 REVEALED WITH *HST* LEGACY DATA. I. SIZE EVOLUTION", The Astrophysical Journal Supplement Series, 219:15 (20pp), 2015 August. https://arxiv.org/pdf/1503.07481.pdf

Spergel, D. N. et al, "Wilkinson Microwave Anisotropy Probe (WMAP) Three Year Observations: Implications for Cosmology", ApJS, 170, 377, 2007. https://arxiv.org/pdf/astro-ph/0603449.pdf

Springel, V. et al, "Simulating the joint evolution of quasars, galaxies and their large-scale distribution", Nature 435 (2005) 629-636, https://arxiv.org/pdf/astro-ph/0504097.pdf

Steigman, G: "Primordial Nucleosynthesis in the Precision Cosmology Era", Annu, Rev. Nucl. Part. Sci. 2007. 57:463-91. https://arxiv.org/ftp/arxiv/papers/0712/0712.1100.pdf.

Tangherlini, F.R. (2014) "Galilean-Like Transformation Allowed by General Covariance and Consistent with Special Relativity". *Journal of Modern Physics*, **5**, 230-243. http://dx.doi.org/10.4236/jmp.2014.55033

Taylor, E. F., Wheeler, J. A., and Bertschinger, E. "Exploring Black Holes, Second Edition", 2018. http://www.eftaylor.com/exploringblackholes/

Troitskii, V. S., "Physical Constants and Evolution of the Universe", Astrophysics and Space Science 139 (1987) pp 389-411.

Urban, M. et al. "Does the speed of light depend upon the vacuum?" 2011. https://arxiv.org/abs/1106.3996.

Uzan, Jean-Philippe. "The fundamental constants and their variation: observational status and theoretical motivations". Rev. Mod. Phys.7 5:403, 2003. https://arxiv.org/pdf/hep-ph/0205340.pdf.

References

Watt, K. and Misner, C.W., "Relativistic Scalar Gravity: A Laboratory for Numerical Relativity https://arxiv.org/pdf/gr-qc/9910032.pdf (1999).

Weinberg, D. H. et al, "Observational Probes of Cosmic Acceleration", Phys. Rep., 530, 87. 2013. https://arxiv.org/pdf/1201.2434.pdf

Will, C. M.: "The confrontation between general relativity and experiment", http://www.livingreviews.org/lrr-2014-4, 2014.

Will, C. M.: "Theory and Experiment in Gravitational Physics", Second Edition. Cambridge University Press, Cambridge 2018.