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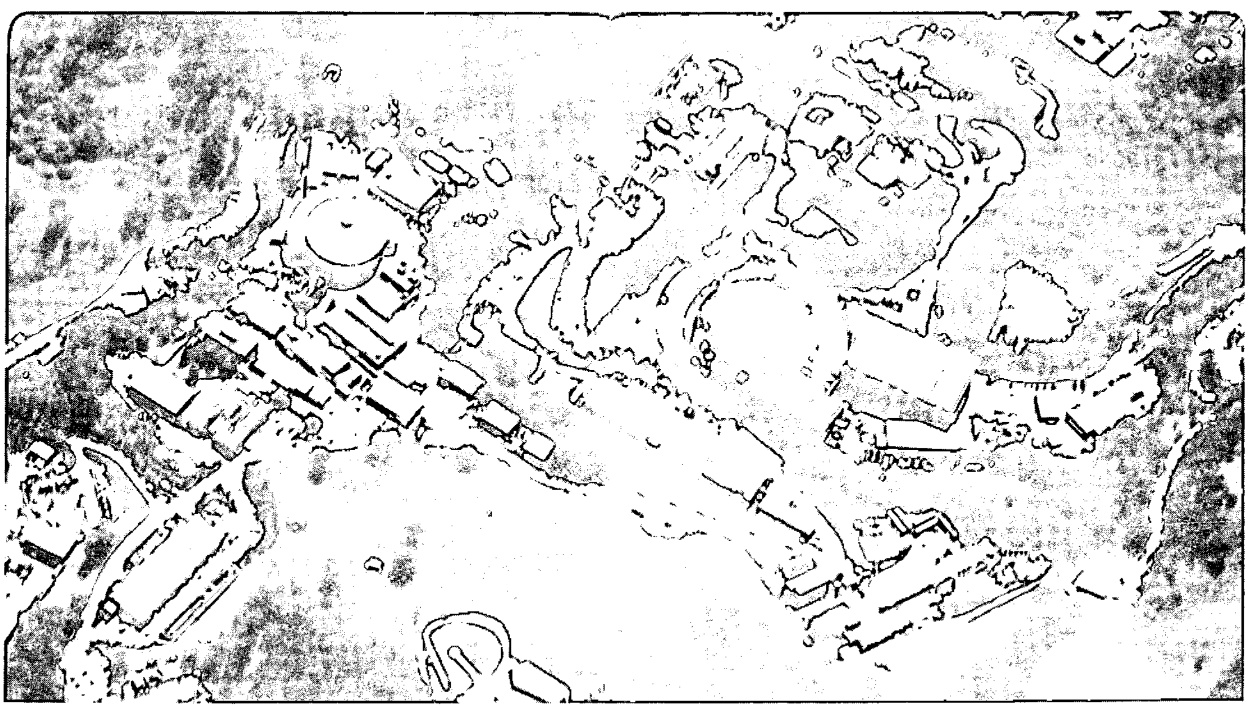

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Testing Single-Parameter Classical Standpoint Cosmology *

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Abstract

Experimental tests of homogeneous-universe classical standpoint cosmology are proposed after presentation of conceptual considerations that encourage this radical departure from the standard model. Among predictions of the new model are standpoint age equal to Hubble time, energy-density parameter $\Omega_0 = 2 - \sqrt{2} = .586$, and relations between redshift, Hubble-scale distribution of matter and galaxy luminosity and angular diameter. These latter relations coincide with those of the standard model for zero deceleration. With eye to further tests, geodesics of the non-Riemannian standpoint metric are explicitly given. Although a detailed thermodynamic "youthful-standpoint" approximation remains to be developed (for particle mean free path small on standpoint scale), standpoint temperature depending only on standpoint age is a natural concept, paralleling energy density and redshift that perpetuates thermal spectrum for cosmic background radiation. Prospects for primordial nucleosynthesis are promising.

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I. Introduction

Standpoint cosmology (Chew 1994, 1995), despite superficial phenomenological similarity to the "standard" cosmology of Friedmann-Robertson-Walker (see Weinberg 1972), differs profoundly in principle. Standpoint cosmology is closer in spirit to "kinematic cosmology" (Milne 1935), although a standpoint spacetime is *compact* with corresponding curvature. Essential to both kinematic cosmology and to standpoint cosmology is a concept of spacetime-localized "big bang" together with "age" measured therefrom. In the new model *age* belongs not to the entire universe as in the standard model but rather to a "standpoint" where "observer" is located.

Standard-model successes (greater than those of kinematic cosmology where there is no curvature) must eventually not only be matched but exceeded by the new model if the latter is to survive. The present paper, after reviewing conceptually-attractive novelties of standpoint cosmology, displays explicitly in standpoint-based coordinate systems the homogeneous-universe geodesics. Application thereof is then made (a) to the relation between standpoint age and Hubble time, (b) to mean energy density, (c) to relation between redshift and both luminosity distance and angular-size distance and (d) to Hubble-scale distribution of matter. Apart from the energy-density prediction $\Omega_0 = 2 - \sqrt{2}$, the foregoing relations coincide not only with those of kinematic cosmology but with those of the standard model for zero "deceleration".

A detailed thermodynamic approximation remains to be developed. It will nevertheless become plausible from what follows that, when particle mean free path is small on the (Hubble) scale of some standpoint, a standpoint temperature can be defined that depends only on standpoint age and that decreases as age advances. Age-temperature correlation dovetails with a photon redshift controlled entirely by ratios of standpoint ages. We shall be led to qualitative understanding of cosmic background-radiation and to optimism about nucleosynthesis within standpoint cosmology. The new model leaves undisturbed the theory of fluctuations, on length scales small compared to Hubble scale, that arise from weak Einstein gravity (Chew 1995).

II. Conceptual Novelties

The new model is economical; a *single* standpoint-associated parameter of length dimensionality, designated R, controls "radius of universe" (seen from standpoint) together with standpoint age ($c = 1$) and Hubble time. As is the case for Milne's cosmology, there is no scale parameter depending on universal time, no deceleration parameter, no cosmological constant. In tandem with the gravitational constant G, the parameter R determines mean energy density. Paucity of parameters places the new model in immediate jeopardy of experimental falsification.

As in Milne's cosmology, there is no meaning for universe beyond a horizon tied to big bang. All matter is causally connected- -sharing a spacetime-localized big-bang origin. Only optical opacity obstructs observation from any standpoint of the entire classical universe. Nevertheless there is a sense in which the universe is "infinite": departing from some standpoint in a fixed spatial direction, there is no limit to the different standpoints of same age to be encountered. In any standpoint coordinate system a huge quantity of matter concentrates near horizon. In Mach spirit one may think of such "maximally-distant" matter as responsible for the Minkowski metric tensor that holds sway (in homogeneous-universe approximation) near any standpoint in that standpoint's coordinate system (see Chew 1995).

Despite the prevailing physics paradigm of covariance within a *unique* unbounded spacetime, the new model attributes to *each* standpoint a *separate* compact spacetime endowed with a special set of coordinates. This coordinate system is suitable for describing experiments carried out in the neighborhood of that standpoint. On the scale of R (Hubble scale), "homogeneous universe" presents the same appearance from any standpoint when described by the coordinates belonging to that standpoint. Only a *portion* of one compact standpoint spacetime generally maps onto another such spacetime. It will nevertheless be shown that familiar Poincaré symmetry (of a *unique* spacetime) prevails (approximately) within neighborhoods that are small on Hubble scale.

The separate compact spacetimes are tied together by invariant metric combined with common origin of coordinate systems. The common origin is identified with "big bang". A "newly-born" standpoint originates in big bang and moves "outward" in *any* "old" standpoint coordinate system along a well-defined positive-timelike geodesic. Standpoint age is proportional to invariant "distance" from big bang. Each standpoint trajectory being labelable by "initial velocity" (near big bang), any standpoint is specified by age plus initial velocity. Because all standpoint spacetimes are Minkowskian near big-bang origin, "homogeneity of universe" corresponds unambiguously to a nonintegrable Lorentz-invariant distribution of initial standpoint velocities. Nonintegrability amounts to the previously-emphasized "infinite universe".

Standpoint-spacetime metrics are generally non-Riemannian, although they approach Minkowski form not only near big bang but, in homogeneous-universe approximation, also near standpoint. The metric is Riemannian for *radial* homogeneous-universe motion in any standpoint coordinate system and for general motion near standpoint if inhomogeneity is "weak" (see Chew 1995). In the latter case, Einstein theory of gravity applies in standpoint neighborhood (small on Hubble scale). Near "strong" inhomogeneities ("black holes"), the not-yet-understood non-Riemannian character of standpoint metric becomes important.

"Standpoint" represents separation between past and future - - i.e., the "present". Metric describing the past is different from that describing the future when Hubble-scale times are considered. Only for time displacements from the present short on Hubble scale is there (approximate) equivalence.

Many conventionally-tolerated displacements are disallowed in a compact standpoint spacetime. Consistency depends on additivity of *positive* timelike or lightlike displacements associable with matter motion. Asymmetry between past and future is dramatically manifested by an impassible future boundary - - called "abyss" (Chew 1994). Prediction of future based on present measurements - - i.e., measurements made near standpoint - - cannot extend beyond this boundary. The abyss limitation correlates with geodesics and may be regarded in the spirit of "Schwartzschild radius" accompanying a mass of order ρR^3, where ρ is energy density at standpoint.

The only region within a standpoint spacetime accessible to *measurement* is the neighborhood of the standpoint's backward light cone. The remainder of a standpoint spacetime facilitates *prediction* of results from (future) measurements to be carried out near older standpoints and *verification* of prediction based on (earlier) measurements made near younger standpoints. Essential to the integrity of standpoint cosmology's emphasis on measurement correlation is the "stability" of lightlike geodesics: a lightlike geodesic in one standpoint spacetime maps onto lightlike geodesic within any other (where mapping is possible). Classical-measurement correlation dovetails with *S-matrix* interpretation of *quantum* standpoint cosmology (Chew 1994).

Although the present paper will not discuss the quantum underpinning of standpoint cosmology, here *defining* the classical model by the metric of standpoint spacetime, this metric was uniquely inferred from symmetry properties of a more fundamental quantum model of expanding universe. Only for standpoints whose R greatly exceeds $R_{min} \sim 10$ cm (age large in nanoseconds) does 3-space in the quantum model achieve classical significance. Quantum-model meaning for "location" within a standpoint spacetime arises in conjunction with meaning for "particles". In a "dense" region of the universe - - where $R \ll R_{min}$ - - neither particles nor 3-space enjoy model meaning. According to the quantum model, "diluteness" is essential to classical significance for 3-space.

A semantic observation: although classical standpoint cosmology, with underpinning that lacks *a priori* spacetime, fails to accord with all aspects of general relativity, the model considered here may be described as "more relativistic" than the standard model. The latter, after all, is characterized by a universal time.

Milne's 1935 cosmology corresponds to standpoints of *infinite* age, which have past but no present and no future. It often turns out calculationally convenient to invoke infinite age where the metric is Minkowskian, but *physical* spacetime belongs to a *present* where the surrounding spacetime is curved.

III. Specially-Coordinated Standpoint Spacetimes

Because the spacetime belonging to a standpoint is compact, with boundary and well-defined "center", there is an accompanying natural system of coordinates. A standpoint locates at the center of its *own* spacetime where it is "at rest". In coordinate systems other than its own, a standpoint is displaced from center and generally is in motion. Any (compact) standpoint spacetime may be described as the intersection of interiors of forward and backward light cones whose vertices share the standpoint's spatial location while each vertex locates an interval R in time from the standpoint, one vertex in the standpoint's past and the other in its future. (The past vertex is identifiable with big bang.)

Using the boldface symbol $\mathbf{R}$ to designate a standpoint and the 4-symbol $\mathbf{x_R} = (t_{\mathbf{R}}, \vec{r}_{\mathbf{R}})$ for the special attached coordinates, restriction to the double-cone interior amounts to coordinates being constrained to the interval,

$$0 \leq t_{\mathbf{R}} \pm |\vec{r}_{\mathbf{R}}| \leq 2R. \qquad (III.1)$$

The $\mathbf{R}$ standpoint locates at $t_{\mathbf{R}} = R, \vec{r}_{\mathbf{R}} = 0$, i.e., at the double-cone center. (Big bang locates at $t_{\mathbf{R}} = 0, \vec{r}_{\mathbf{R}} = 0$). It will be seen in Section IV that standpoint-spacetime geodesics curve in conformity to (III.1) - - matter inside the double cone being unable to cross the boundary. This curvature constitutes a major departure from Milne's 1935 kinematic cosmology.

Portions of one standpoint spacetime map onto portions of others. Explicit mapping rules (in homogeneous-universe approximation) will be presented. Mappings are anchored by big bang - - the origin of one coordinate system mapping onto the origin of any other and, because all spacetimes are asymptotically Minkowskian in neighborhood of origin ($t_{\mathbf{R}} \ll R$), the (infinitesimal) positive timelike or lightlike 4-vectors $\mathbf{x_R}$ are there related to each other by Lorentz boosts. A convenient corollary is explicit elaboration of the symbol $\mathbf{R}$ into the 4-symbol $(R, \vec{\beta})$, with the 3-vector $\vec{\beta}$ interpretable as "initial rapidity" of standpoint. That is, in the coordinate system belonging to a zero-rapidity standpoint $\mathbf{R} = (R, \vec{0})$, some (other) "very young" standpoint located at $\mathbf{x_R}$ (with $t_{\mathbf{R}} \ll R$) has rapidity $\vec{\beta}$ such that

$$\tanh\left|\vec{\beta}\right| = \frac{|\vec{r}_{\mathbf{R}}|}{t_{\mathbf{R}}}, \quad \frac{\vec{\beta}}{\left|\vec{\beta}\right|} = \frac{\vec{r}_{\mathbf{R}}}{|\vec{r}_{\mathbf{R}}|}. \qquad (III.2)$$

We shall see that, as this standpoint of initial -rapidity $\vec{\beta}$ grows to an age of order R, its rapidity in the $(R, \vec{0})$ coordinate system diminishes so as to keep the moving standpoint within the compact $(R, \vec{0})$ spacetime. This deceleration, gravitationally interpreted, will in Section IV determine mean energy density in terms of R and G.

Mapping between $(R, \vec{\beta})$ and $(R', \vec{\beta}')$ coordinates is conveniently achievable by a 3-step process involving standpoints of *infinite* age:

$$(R, \vec{\beta}) \xrightarrow{A} (\infty, \vec{\beta}) \xrightarrow{B} (\infty, \vec{\beta}') \xrightarrow{C} (R', \vec{\beta}') \qquad (III.3)$$

Step B we shall see to be a simple Lorentz boost (with counterpart in kinematic cosmology). Steps A and C at fixed initial rapidity are also simple transformations but of a completely different type exposed in Section IV after standpoint-spacetime metric is introduced. Fixed-$\vec{\beta}$ mappings between coordinate systems of different ages are generally defined only for *portions* of the involved spacetimes.

IV. Geodesics

Compactness of standpoint spacetime, accompanied by non-Riemannian metric (Chew 1994), precludes applicability of numerous notions from general relativity. Surviving, nevertheless, is representation of gravity through matter motion along geodesics; gravitational mass continues to be indistinguishable from inertial mass. Classical metric is controlled by the symmetry of an underlying quantum dynamics whose description here is impractical. A convenient consideration is that *radial* homogeneous-universe motion in a standpoint spacetime is describable by a quadratic (Riemannian-like) form. For radial displacements with respect to **R** standpoint, an increment of "distance" turns out to be given by

$$ds^2 = \{(1 - t_{\mathbf{R}}/2R)^2 - (r_{\mathbf{R}}/2R)^2\}^{-1/2}(dt_{\mathbf{R}}^2 - dr_{\mathbf{R}}^2), \ r_{\mathbf{R}} \equiv |\vec{r}_{\mathbf{R}}|, \qquad (IV.1)$$

even though nonradial motion requires a *quartic* form. (Absence of subscript on ds^2 is remindful of distance invariance under change of standpoint.) The radial metric (IV.1) will generate the required mappings between standpoint spacetimes of same rapidity but different R. We shall not here need the quartic expression of more general metric.

Notice that the radial metric (IV.1) is singular along the backward-light-cone (future) spacetime boundary where $r_{\mathbf{R}}^2 = (2R - t_{\mathbf{R}})^2$. This singularity, present also in the general metric, prevents any geodesic from penetrating the future boundary - - which has been called "abyss" (Chew 1994). Notice further that in big-bang neighborhood (i.e., $t_{\mathbf{R}} \ll R$) or, equivalently, in the limit $R \to \infty$, the anticipated Minkowskian form is achieved. In standpoint neighborhood ($|t_{\mathbf{R}} - R| \ll R, r_{\mathbf{R}} \ll R$) the metric also is Minkowskian although here $ds^2 = 2(dt_{\mathbf{R}}^2 - dr_{\mathbf{R}}^2)$. The factor 2 will be found below to influence standpoint age.

The metric (IV.1) implies the radial equation of motion (geodesic differential equation)

$$\frac{d^2 r_{\mathbf{R}}}{dt_{\mathbf{R}}^2} = -\frac{1}{2}\left[1 - \left(\frac{dr_{\mathbf{R}}}{dt_{\mathbf{R}}}\right)^2\right] \frac{r_{\mathbf{R}} + (2R - t_{\mathbf{R}})\frac{dr_{\mathbf{R}}}{dt_{\mathbf{R}}}}{(2R - t_{\mathbf{R}})^2 - r_{\mathbf{R}}^2}, \qquad (IV.2)$$

for which explicit solutions will below be presented. Because radial motion with respect to one standpoint maps onto nonradial motion with respect to another standpoint of different spatial location (different initial rapidity), the mapping strategy (III.3) generates from solutions to (IV.2) the most general homogeneous-universe geodesics.

A Newtonian-gravitational interpretation of the linear approximation to (IV.2) in standpoint neighborhood, i.e., of the approximate equation of motion

$$\frac{d^2 r_{\mathbf{R}}}{dt_{\mathbf{R}}^2} \approx -\frac{1}{2}\left(\frac{r_{\mathbf{R}}}{R^2} + \frac{1}{R}\frac{dr_{\mathbf{R}}}{dt_{\mathbf{R}}}\right), \qquad (IV.3)$$

allows an inference of mean energy density in standpoint 3-space. At time $t_{\mathbf{R}} = R$, consider matter spatially displaced from **R**-spacetime center (i.e., from **R** standpoint) by a distance $r_{\mathbf{R}}$ that is small compared to R. Let this matter be at rest with respect to that standpoint - - displaced slightly from **R** - - which coincides in location with the matter. It may be deduced from formulas in Section VI that such "stationary" matter has radial velocity in the **R** system,

$$\frac{dr_{\mathbf{R}}}{dt_{\mathbf{R}}} = \frac{1}{\sqrt{2}}\frac{r_{\mathbf{R}}}{\mathbf{R}} + \text{order } \left(\frac{r_{\mathbf{R}}}{\mathbf{R}}\right)^2. \qquad (IV.4)$$

It then follows from (IV.3) that nonrelativistic matter acceleration in the **R** system, in the neighborhood of **R** standpoint, is

$$\frac{d^2 r_{\mathbf{R}}}{dt_{\mathbf{R}}^2} = -\frac{1}{2}\left(1 + \frac{1}{\sqrt{2}}\right)\frac{r_{\mathbf{R}}}{R^2} + \text{order } \left(\frac{r_{\mathbf{R}}^2}{R^3}\right). \qquad (IV.5)$$

In Newtonian terms the foregoing acceleration is attributable to a restoring gravitational force that resists displacement from the center of a spherically-symmetric mass distribution (whose radius is of order R.) If mass density at center is $\rho_{\mathbf{R}}$, the Newtonian gravitational potential at small $r_{\mathbf{R}}$ is

$$G\,\frac{\frac{4\pi}{3} r_{\mathbf{R}}^3 \rho_{\mathbf{R}}}{r_{\mathbf{R}}}, \qquad (IV.6)$$

corresponding to an acceleration (toward the center)

$$-G\,\frac{8\pi}{3} r_{\mathbf{R}} \rho_{\mathbf{R}}. \qquad (IV.7)$$

Equating (IV.7) with (IV.5) yields

$$\rho_{\mathbf{R}} = \frac{3}{16\pi}\left(1 + \frac{1}{\sqrt{2}}\right)\frac{1}{GR^2}. \qquad (IV.8)$$

Once R has below been related to Hubble time, it will be found that (IV.8) corresponds to the conventionally-defined density parameter (fraction of "critical" density in standard model),

$$\Omega_0 = 2 - \sqrt{2} = .586. \qquad (IV.9)$$

The foregoing prediction of Ω_0 is provisional, subject to systematic derivation of classical standpoint cosmology as a dilute-universe approximation to the more exact quantum model. Such a derivation would relate G to a "more-fundamental" small dimensionless parameter (Chew, 1994). In the interim, before a quantum-based theory of gravity becomes available, we are leaning on experimentally-supported (sub-Hubble-scale) features of classical Newton-Einstein theory (see Chew 1995) where G is regarded as a fundamental constant of nature.

The structure of (IV.1) exemplifies the general principle that the limit $R \to \infty$ for fixed $\mathbf{x_R}$ leads to Minkowskian metric. In this (Milne) limit the spacetime becomes *noncompact* and *unique* for all $\vec{\beta}$ - - corresponding to the forward light cone with big bang as vertex. Infinite-R coordinate systems, each labeled by a 3-vector rapidity, all describe the *same* spacetime. These systems are related to each other by Lorentz transformations, with $\mathbf{x}_{\infty,\vec{\beta}} = (t_{\infty,\vec{\beta}}, \vec{r}_{\infty,\vec{\beta}})$ behaving as a 4-vector. (Poincaré displacements are *not* allowed.) Infinite-R spacetime, while extremely useful as intermediary in the mapping strategy (III.3), is not a *physical* spacetime. "Usual physics" situates in the neighborhood of some finite-R standpoint and is to be described by the attached coordinate system. Section IX will explain how usual Poincaré symmetry (under displacements as well as Lorentz transformations) prevails *approximately* within standpoint neighborhoods small on the scale of R.

Invariance of the radial distance given by (IV.1) implies the fixed-rapidity mapping, $(R,\vec{\beta}) \to (\infty,\vec{\beta})$,

$$t_\infty \pm r_\infty = 4R\left\{1 - \sqrt{1 - \frac{t_\mathbf{R} \pm r_\mathbf{R}}{2R}}\right\}, \quad \frac{\vec{r}_\infty}{r_\infty} = \frac{\vec{r}_\mathbf{R}}{r_\mathbf{R}}, \qquad (IV.10)$$

with the inverse, $(\infty,\vec{\beta}) \to (R,\vec{\beta})$,

$$t_\mathbf{R} = t_\infty - \frac{t_\infty^2 + r_\infty^2}{8R}, \qquad (IV.11a)$$

$$\vec{r}_{\mathbf{R}} = \vec{r}_{\infty}(1 - \frac{t_{\infty}}{4R}). \qquad (IV.11b)$$

Here the rapidity index $\vec{\beta}$ has been suppressed. The interval $0 \leq t_{\mathbf{R}} \pm r_{\mathbf{R}} \leq 2R$ is mapped onto the interval $0 \leq t_{\infty} \pm r_{\infty} \leq 4R$ and vice versa. Straightline geodesics in infinite-R coordinates transform into curved geodesics in finite-R coordinates. (When these latter geodesics are radial, they satisfy the differential equation (IV. 2).) The most general geodesic may be written in infinite-age coordinates as the straight line

$$\vec{r}_{\infty} = \vec{a} + \vec{b}(t_{\infty} - c), \qquad (IV.12)$$

with $\vec{a}, \vec{b}, c$ a set of 7 constants constrained by $c \geq 0$, $|\vec{a}| \leq c$, $0 \leq \left|\vec{b}\right| \leq 1$. Here the 4-vector $\mathbf{x}_0 = (c, \vec{a})$ locates "source" of matter trajectory while the 3-vector $\vec{b}$ is matter velocity. The special geodesics followed by standpoints correspond to $\mathbf{x}_0 = 0$ with $\left|\vec{b}\right| = \tanh\left|\vec{\beta}\right|$ and $\vec{b}/\left|\vec{b}\right| = \vec{\beta}/\left|\vec{\beta}\right|$.

V. Standpoint Age

What time registers on a clock carried by an observer who starts clock close to big bang and moves along a standpoint trajectory? The clock adds up time increments $dt_{\mathbf{R}}$ in a succession of *different* coordinate systems as R increases, with the relation

$$dt_{\mathbf{R}} = \frac{1}{\sqrt{2}} ds \tag{V.1}$$

prevailing continuously along the trajectory. It follows that "standpoint age" is $\frac{1}{\sqrt{2}}$ times its invariant distance from big bang. Recognizing $\vec{r}_\infty$ to be zero everywhere along trajectory, distance from big bang is

$$s = \left(t_\infty^2 - r_\infty^2\right)^{1/2} = t_\infty. \tag{V.2}$$

From (IV.10) one calculates

$$t_\infty(t_{\mathbf{R}} = R,\ r_{\mathbf{R}} = 0) = 4R\ \left(1 - \frac{1}{\sqrt{2}}\right), \tag{V.3}$$

so standpoint age is

$$\begin{aligned} \tau_{\mathbf{R}} &= \frac{1}{\sqrt{2}}\, 4R\ \left(1 - \frac{1}{\sqrt{2}}\right), \\ &= \frac{R}{\frac{1}{\sqrt{2}} + \frac{1}{2}}. \end{aligned} \tag{V.4}$$

Phenomenologically, what we are calling "standpoint age" is the quantity commonly called "age of universe". The latter terminology, which fits the standard model, seems inappropriate here and we shall avoid it.

VI. Redshift and Hubble Parameter

The outcome of the following calculation of redshift is so simple that we state it immediately. The redshift factor commonly denoted $1+z$ is equal to the ratio of observer age to source age (or observer$-R$ to source$-R$). Equivalently, $1+z=e^{\Delta}$, where Δ is the magnitude of source-standpoint *initial* rapidity when observer-standpoint (initial) rapidity is zero. The simplicity of this relation raises expectation of a transparent derivation. Unhappily we are not presently in possession of such. The calculation to follow combines Doppler redshift due to source motion in observer system with "propagation redshift" due to gravity experienced by photons moving through observer-standpoint spacetime.

From (IV.11) and (IV.12) with $\mathbf{x}_0=0$, it is straightforward to calculate in observer system the radial rapidity Δ_s of a source, located on the observer's backward light cone, that follows the trajectory of a standpoint whose *initial* rapidity magnitude was Δ. One finds

$$\Delta_s=\frac{1}{2}\ln\left(\frac{e^{3\Delta}}{e^{-\Delta}+2^{3/2}\sinh\Delta}\right). \qquad (VI.1)$$

It may be verified that there is deceleration - - i.e. $\Delta_s<\Delta$. (For small $\Delta, \Delta_s\approx(2-\sqrt{2})\Delta$.) The Doppler redshift factor is then

$$e^{\Delta_s}=\frac{e^{3/2\Delta}}{(e^{-\Delta}+2^{3/2}\sinh\Delta)^{1/2}}. \qquad (VI.2)$$

What about propagational redshift? Here we need to study geodesics along the observer's backward lightcone. From a computation described in the Appendix one finds a propagational redshift factor

$$\left(1+\frac{2r_s}{R}\right)^{1/4}, \qquad (VI.3)$$

where r_s is distance to source in observer system, the parameter R belonging to observer standpoint. The distance to source, from a calculation paralleling that leading to (VI.1), turns out to be

$$r_s=e^{-2\Delta}\sinh\Delta(\cosh\Delta+\sqrt{2}\sinh\Delta)\tau_R, \qquad (VI.4)$$

and, remembering (V.4), one then calculates from (VI.4) that

$$\left(1+\frac{2r_s}{R}\right)^{1/2}=e^{-\Delta}(e^{-\Delta}+2^{3/2}\sinh\Delta). \qquad (VI.5)$$

Thus the product of (VI.3) with (VI.2) is simply e^{Δ}.

That e^{Δ} gives the ratio of observer age to source age follows from the mapping of observer backward light cone onto a corresponding backward light cone in the infinite-age coordinate system that has spatial origin at observer. Along this infinite-age cone,

$$t_\infty + r_\infty = s^{observer}, \qquad (VI.6)$$

and remembering the general relation $s = (t_\infty^2 - r_\infty^2)^{1/2}$, together with the special relation $\tanh \Delta = r_\infty^{source}/t_\infty^{source}$, so

$$\begin{aligned} t_\infty^{source} &= s^{source} \cosh \Delta, \\ r_\infty^{source} &= s^{source} \sinh \Delta, \end{aligned} \qquad (VI.7)$$

it follows from (VI.6) that

$$e^{\Delta} s^{source} = s^{observer}. \qquad (VI.8)$$

Consider next the Hubble parameter, *phenomenologically* definable as

$$H_0 \equiv \lim_{r_s \to 0} \frac{z}{r_s}. \qquad (VI.9)$$

Because Formula (VI.4) exhibits a linear relation between r_s and Δ for small Δ,

$$\lim_{\Delta \to 0} \frac{r_s}{\Delta} = \tau_R, \qquad (VI.10)$$

while in the same limit $z/\Delta \to 1$, it follows that

$$H_0 = \tau_R^{-1}. \qquad (VI.11)$$

Before closing this section we remark that, according to (VI.4), the upper limit of r_s - - distance to source located on standpoint backward light cone - - is $R/2$, reached as $\Delta \to \infty$. In other words, $R/2$ is "radius of the **R** standpoint's universe." Such a statement, as emphasized above in Section II, can be misleading inasmuch as Section VIII will show that (apart from quantum limitation) an indefinitely-large amount of matter concentrates near standpoint horizon. Classically speaking, our universe is infinite.

VII. Luminosity Distance

In this section we shall compute luminosity distance (as defined by Weinberg 1972) and will find

$$d_L(z) = \tau_{\mathbf{R}}(z + z^2/2). \qquad (VII.1)$$

Although this result coincides with the standard-model formula for zero deceleration parameter, an independent derivation is required. There is no present understanding of the coincidence.

We are concerned with observer-system trajectories followed by photons emitted isotropically from the spatial origin of the source coordinate system. Let us designate by θ_s the angle of emission in source system with respect to the direction, $\vec{n} \equiv -\vec{\Delta}/\Delta$, that (in either system) connects source to observer. Our task is to compute, for extremely small θ_s, the photon impact parameter with respect to observer in observer system; this impact parameter will be equated with θ_s times "effective distance". After attention to redshift loss of photon energy and to extension of observer time interval during which some collection of photons is received, "luminosity distance" will emerge.

The direction $\vec{n}'$ of photon emission in the source coordinate system ($\cos\theta_s = \vec{n}' \cdot \vec{n}$) is also the direction of photon propagation in infinite-age rapidity-$\vec{\Delta}$ coordinates. In the latter system photon spacetime location is given by the 4-vector $\mathbf{x}_{\infty,\vec{\Delta}}$ which we abbreviate by $\mathbf{x}' = (t', \vec{r}\,')$. Introducing photon distance from big bang

$$s = (t'^2 - r'^2)^{1/2}, \qquad (VII.2)$$

it is convenient to represent photon trajectory as a 4-vector function of the invariant s, which at emission takes the value s^{source} and at observation equals $s^{observer}$. Under-$\vec{\Delta}$ boost the 4-vector $\mathbf{x}'$ transforms to the 4-vector $\mathbf{x} = \mathbf{x}_{\infty,\vec{0}} = (t, \vec{r})$ that locates photon in *zero-rapidity* infinite-age coordinates. Invariance of s means $s = (t^2 - r^2)^{1/2}$. When the photon is near observer, $t \approx s^{observer}$ and $\vec{r} \approx 0$; near observer it follows that

$$r' \approx s^{observer} \sinh\Delta. \qquad (VII.3)$$

Employing the symbol $\mathbf{R}$ for observer standpoint, with the coordinates $(t_{\mathbf{R}}, \vec{r}_{\mathbf{R}})$ *physically* locating the photon, we seek for photon near observer the component of $\vec{r}_{\mathbf{R}}$ *transverse* to $\vec{\Delta}$. Because at observer

$$t = s^{observer} = 4R\left(1 - \frac{1}{\sqrt{2}}\right), \qquad (VII.4)$$

Formula (IV.11) tells us that, near observer,

$$\vec{r}_{\mathbf{R}} \approx \frac{1}{\sqrt{2}}\vec{r}. \qquad (VII.5)$$

Using the subscript "tr" to denote transverse components of 3-vectors, it follows that the desired impact parameter is

$$r_{\mathbf{R},tr} \approx \frac{1}{\sqrt{2}}\, r_{tr}, \qquad (VII.6)$$

for $s = s^{observer}$. Because a Lorentz boost does not alter the transverse component of a 4-vector, we have

$$\vec{r}_{tr} = \vec{r}\,'_{tr}, \qquad (VII.7)$$

and consequently

$$r_{\mathbf{R},tr} \approx \frac{1}{\sqrt{2}}\, r'_{tr}. \qquad (VII.8)$$

Finally, because all trajectories are straight lines in infinite-age coordinates, it follows that $r'_{tr} \approx \theta_s r'$, and Formula (VII.3) together with (VII.8) leads to

$$r_{\mathbf{R},tr} \approx \theta_s \tau_{\mathbf{R}} \sinh\Delta. \qquad (VII.9)$$

For $\Delta \ll 1$ where, according to (VI.4), $\tau_{\mathbf{R}}\Delta$ approximates (observer-measured *or* source-measured) distance between source and observer, the result (VII.9) agrees with straightline photon propagation through a unique flat space; but for $\Delta \gtrsim 1$, (VII.9) becomes drastically non-Euclidean. (As $\Delta \to \infty, \tau_{\mathbf{R}} \sinh\Delta \to \infty$ whereas distance to source approaches $R/2$.)

Luminosity is source-generated energy received at observer per unit area per unit time. Impact parameter deals with photons per unit transverse area although not with energy per unit time. Momentarily deferring the latter, we recognize $\theta_s^2/4$ to be the *fraction* of photons isotropically emitted in source system that eventually arrive within the impact parameter (VII.9). Because the observer-system transverse area in question is $\pi\theta_s^2 d_e^2(\Delta)$, where

$$d_e(\Delta) \equiv \tau_{\mathbf{R}} \sinh\Delta, \qquad (VII.10)$$

the fraction of photons eventually arriving per unit area at observer is $[4\pi d_e^2(\Delta)]^{-1}$. Geometrically speaking, therefore, $d_e(\Delta)$ acts as "effective distance".

However, fraction of *energy* emitted per unit source time that is received *per unit observer time* is reduced by a factor $e^{-2\Delta}$ - - redshift reduction of photon energy being by a factor $e^{-\Delta}$, with a second factor $e^{-\Delta}$ arising from the ratio between source-time interval for emission of a number of photons and receiver-time interval for reception of these photons. Following Weinberg 1972, if instead of (VII.10) we define "luminosity distance" by

$$d_L(\Delta) \equiv \tau_{\mathbf{R}} e^{\Delta} \sinh \Delta, \qquad (VII.11)$$

then $[4\pi d_L^2(\Delta)]^{-1}$ gives "luminosity fraction" per unit area at observer. Remembering that $e^{\Delta} = 1 + z$, we may rewrite (VII.11) as

$$d_L = \tau_{\mathbf{R}}(z + \frac{1}{2}z^2), \qquad (VII.12)$$

finally achieving the result advertised above in (VII.1).

With *inversion* of source and observer, the calculation leading to (VII.9) yields the angle subtended at observer (in observer coordinates) by a source diameter (in source coordinates). The result is equivalent to "angular-diameter distance" (Kolb, Turner 1990)

$$\begin{aligned} d_A(\Delta) = \tau_{source} \sinh \Delta &= e^{-2\Delta} d_L(\Delta) \\ &= \tau_{\mathbf{R}} \frac{z(1 + z/2)}{(1 + z)^2}. \end{aligned} \qquad (VII.13)$$

Formula (VII.13) agrees with that given by the standard model with zero deceleration. Note that, according to (VII.13), the observed subtended angle approaches a *constant* $(2\frac{d_{source}}{\tau_{\mathbf{R}}})$ as $\Delta \to \infty$.

VIII. Matter Distribution

Because standpoint trajectories control Hubble-scale flow of matter, it is meaningful to speak of a "distribution of trajectories." Lorentz invariance of Hubble-scale distribution in infinite-age spacetime constitutes model definition of "homogeneous universe". From a selected standpoint to which zero initial rapidity is assigned, Lorentz invariance means *other* standpoints of initial rapidity $\vec{\Delta}$ are isotropically distributed and, in *magnitude* of initial rapidity, have a distribution proportional to

$$\sinh^2 \Delta d\Delta = \frac{z^2(1+\frac{z}{2})^2}{(1+z)^3} dz, \qquad (VIII.1)$$

once again in agreement with standard model (Kolb, Turner 1990) for zero deceleration. Normalized to (IV.8) at $\Delta = 0$, interpretation may be made of (VIII.1) as Hubble-scale "matter distribution". Close ($z \approx \Delta \ll 1$) to the selected standpoint where $\vec{r}_{\mathbf{R}} \approx \tau_{\mathbf{R}} \vec{\Delta}$, such a distribution is uniform in the usual sense of density independent of location, but as $\Delta \to \infty$ the density implied by (VIII.1) increases without limit. The distribution is nonintegrable, corresponding to an "infinite classical universe" as in Milne's kinematic cosmology.

Notice on the other hand that according to our luminosity distance (VII.11), sources with age-independent spectrum and brightness proportional to mass would mean an average luminosity of the sky distributed in Δ (or z) according to

$$e^{-2\Delta} d\Delta = \frac{dz}{(1+z)^3}. \qquad (VIII.2)$$

Most observed light thus would originate at $z \lesssim 1$. (The simple form (VIII.2), by virtue of ignoring variation of average intrinsic source brightness with age of source, is not to be regarded as a falsifiable model prediction).

The *quantum* lower limit on classical age, $\tau_{min} \sim 10^{-9} sec$, in principle keeps finite a standpoint's universe. On the standpoint backward light cone the age of matter is $e^{-\Delta}\tau_{\mathbf{R}}$, so the lower age limit places a corresponding upper limit on Δ (or z): $\Delta_{max} \sim \ln \tau_{\mathbf{R}}/\tau_{min} (z_{max} \sim \tau_{\mathbf{R}}/\tau_{min})$. In practice a far smaller bound to the visible universe is erected by observational impediments. A maximum observable redshift from our present standpoint is $z_{dec} \sim 1400$, corresponding to the "decoupling" temperature (see Peebles 1993 and Section X below) above which photon mean free path becomes small on standpoint scale. Nevertheless, over the "observable" interval $z < z_{dec}$ the standard model with deceleration-parameter $q_0 \sim 1/2$ predicts matter distribution in *redshift* increasing far less rapidly with z than that given by (VIII.1). Matter distribution provides potentially unambiguous model discrimination (Peebles 1993).

IX. Poincaré Symmetry in Standpoint Neighborhood.

This brief section makes explicit the sense in which standpoint cosmology is compatible with "usual" classical physics inside any homogeneous-universe neighborhood that is small on Hubble scale. Consider two standpoint coordinate systems labeled by

$$(R, \vec{\beta}) \text{ and } (R', \vec{\beta}') \text{ with } |R - R'| \ll \frac{1}{2}(R + R') \text{ and } \left|\vec{\beta}\right| \ll 1, \left|\vec{\beta}'\right| \ll 1.$$

"Neighborhoods of standpoints", defined loosely by

$$\begin{aligned} |t - R| &\ll R, \quad |\vec{r}| \ll R, \\ |t' - R'| &\ll R', \; |\vec{r}\,'| \ll R', \end{aligned} \tag{IX.1}$$

then map onto each other even though the *full* spacetimes do *not* map. (For example, because the maximum possible invariant distances from big bang within these spacetimes are $4R$ and $4R'$, respectively, if $R' > R$ the portion of $\mathbf{R}'$ spacetime near abyss where $4R < s < 4R'$ does not map onto $\mathbf{R}$ spacetime.) Employing the strategy (III.3) we may ask for the relation between corresponding points $(t, \vec{r})$ and $(t', \vec{r}\,')$ within the neighborhood (IX.1). One finds

$$\begin{aligned} (t - R) \; - (t' - R') &\approx \tau' - \tau, \\ \vec{r} \; - \vec{r}\,' &\approx (\vec{\beta}' - \vec{\beta})\frac{\tau + \tau'}{2}, \end{aligned} \tag{IX.2}$$

up to corrections of order $(R{+}R')^{-1}$. Change of standpoint is thus equivalent to a familiar Poincaré displacement. Adding the consideration that, to the foregoing order, metric is Minkowskian within the neighborhood (IX.1) for both coordinate systems, one recognizes usual Poincaré covariance of a unique noncompact spacetime. For physics within this neighborhood any Poincaré transformation may be invoked such that errors due to finiteness of universe are tolerable.

X. Thermodynamic Approximation?

Because energy density varies inversely with square of age, near sufficiently young standpoints one expects particle mean free path (in time as well as in space) to become small on the scale of R, allowing a thermodynamic approximation to develop meaning. Isotropy of universe as viewed from a standpoint (using standpoint coordinates) makes natural an association with young standpoints of temperature and pressure, as well as energy density; expectation is that such quantities will be found in homogeneous-universe approximation to be dependent only on standpoint age. Accompanying energy density $\sim \frac{1}{GR^2}$, a temperature monotonically decreasing with standpoint age is anticipated. Not yet under control, however, is the thermodynamic role of gravity. Model geodesics imply unambiguous gravity and we have seen how attractive gravitational forces provide universe "confinement"- -defining a spatially-spherical spacetime "box" of radius $R/2$. But details of this "box" are unorthodox to a degree that momentarily is frustrating effort to formulate a consistent thermodynamic approximation.

Assuming thermodynamic equilibrium for sufficiently-small standpoint ages, with radiation decoupling as temperature at a certain age falls below atomic ionization energies, a thermal photon ("black-body") spectrum would survive to later ages with "photon temperature" decreasing inversely with age. The energies of all decoupled photons diminish by a common factor as age advances.

Nucleosynthesis must occur near standpoints whose temperature allows nuclear reactions but, in absence of thermodynamic gravity understanding, calculations have not yet been attempted. It is momentarily unknown what standpoint cosmology predicts for light-element abundances generated by primordial nucleosynthesis. Making a preliminary crude guess that, during thermodynamic equilibrium, energy density varies as T^4, the ratio $\sim 10^{22}$ is expected between age of photon decoupling and the minimum classically-meaningful age, τ_{min}. The latter accompanies a maximum classically-meaningful temperature near TeV scale. The MeV-scale temperatures needed for nucleosynthesis would occur near an age $\sim 10^{10}\tau_{min} \sim 10$ *sec.*

XI. Concluding Remarks

Not described here but presented in a separate paper (Chew 1995) is standpoint-cosmology prescription for "weak" gravity - - small departures from Minkowskian metric at standpoint, departures generated by matter-distribution *inhomogeneities* much less potent than black holes. For "weak" inhomogeneities characterized by length scales well below Hubble scale, the standpoint prescription concurs with Einstein theory. Only for inhomogeneity scale approaching Hubble might there be significant difference. Almost all previous work on gravity-induced fluctuations in matter density is sustained (see Peebles 1993).

For *any* matter distribution generating *large* metric deviation from Minkowskian form, the new model's non-Riemannian structure will generate unorthodox predictions. Up to present, however, exploration of these predictions has been confined to "homogeneous-universe" calculations of Hubble-scale metric curvature - - calculations reported in the present paper. Investigation of small-scale "strong" inhomogeneities ("black holes") remains for the future.

Prime candidate for early falsifier of standpoint cosmology is the predicted redshift dependence of luminosity distance (VII.1), but determination of matter distribution up to redshifts $\gtrsim .5$ could quickly eliminate the new model. Although ability of the new model to explain light-element abundances is not yet established, cosmic background radiation presents no qualitative challenge.

Motivation behind classical standpoint cosmology has been, not addition of curvature to Milne's 1935 kinematic cosmology, but rather representation of the symmetry of an underlying quantum model. That symmetry implies for each standpoint a quartically-metricized *compact* spacetime. The compactness in turn requires classical curvature: Out of quantum *symmetry* has flowed classical *dynamics.*

In homogeneous-universe approximation the quartic metric has yielded the geodesics described in the present paper, which for *infinite-age* standpoints reduce to those of Milne - - a limit where all standpoint spacetimes become isomorphic to each other, noncompact and Minkowskian. Although *physical* spacetime is curved, belonging to a *finite*-age standpoint, the following striking set of redshift-related phenomenological features from Milne's model have survived in standpoint cosmology:

(A) "Age of universe" equals a Hubble time defined by redshift.

(B) Luminosity distance and angular-diameter distance depend on redshift in the manner characterized standardly as "zero deceleration" (despite nonvanishing curvature of standpoint spacetime).

(C) The entire universe is in principle observable from any standpoint, with a nonintegrable distribution in redshift that is uniquely determined by Lorentz symmetry.

(D) Redshift factor equals ratio of observer age to source age (although total redshift combines Doppler and gravitational shifts).

Even if redshift-expressible predictions of standpoint cosmology all turn out indistinguishable from those of Milne's kinematic model, geometrical features differ. For example, at given age, the radius of a standpoint universe is larger than that of Milne by a factor $\frac{1}{2} + \frac{1}{\sqrt{2}}$, and the ratio of distance to Hubble-flow velocity is larger by a factor $1 + \frac{1}{\sqrt{2}}$. Despite observational impracticability of investigating the foregoing subtle differences, experimental determination of mean energy density is widely regarded feasible, and here Milne's model (unacceptably) seems to imply $\Omega_0 = 0$, while standpoint cosmology predicts $\Omega_0 = 2 - \sqrt{2}$.

The current competition, of course, is not with kinematic cosmology but with a "standard" cosmology based on Einstein's theory of gravitation. Because the latter was originally formulated without regard for quantum principles and without regard for meaninglessness of time "before big bang", its reliability at Hubble scale may be questioned. Phenomenologically-viable alternatives should not be ignored, especially if they entail fewer arbitrary parameters. A useful although not understood mnemonic is that, apart from energy density, all predictions listed here coincide with zero-deceleration standard-model predictions.

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Appendix. Gravitational Redshift Along Standpoint Light Cone.

Differentiating Formulas (IV.11a) and (IV.11b) and taking the quotient leads to the following expression for particle velocity as it varies along a *radial* standpoint-spacetime geodesic:

$$v_{\mathbf{R}} \equiv \frac{dr_{\mathbf{R}}}{dt_{\mathbf{R}}} = \frac{b(1-\frac{t_\infty}{4R}) - \frac{r_\infty}{4R}}{1-\frac{t_\infty}{4R} - b\frac{r_\infty}{4R}}. \qquad (A.1)$$

The constant b, limited to the interval $-1 \leq b \leq +1$, is the radial-motion special case of the 3-vector $\vec{b}$ appearing in the general geodesic (IV.12). Notice from (A.1) that in each of the two limits, $b \to \pm 1$, $v_{\mathbf{R}}$ approaches the same limit as b and that, for any allowed b, $|v_{\mathbf{R}}| \leq 1$. (It may also be verified that if $|b| < 1$ then, along the abyss boundary, where $t_\infty + r_\infty = 4R$, one *always* finds $v_R = -1$ - - i.e., *inward* matter motion *parallel* to boundary as required by confinement to compact standpoint spacetime.)

Light arriving at standpoint from a source located on standpoint backward light cone corresponds to the limiting case $v_{\mathbf{R}} = b = -1$. Our deduction of gravitational redshift will invoke the relation

$$v_{\mathbf{R}} = \frac{e^{\gamma_{\mathbf{R}}} - e^{-\gamma_{\mathbf{R}}}}{e^{\gamma_{\mathbf{R}}} + e^{-\gamma_{\mathbf{R}}}} \qquad (A.2)$$

between particle velocity $v_{\mathbf{R}}$ and particle *rapidity* $\gamma_{\mathbf{R}}$. Even in the limits $v_{\mathbf{R}} \to \pm 1$, where $\gamma_{\mathbf{R}} \to \pm\infty$, there is (finite) *rapidity variation* along the trajectory- - corresponding to energy shift. For zero-mass particles, energy varies in proportion to $e^{\delta|\gamma_{\mathbf{R}}|}$ where $\delta\,|\gamma_{\mathbf{R}}|$ means *change* in the absolute value of $\gamma_{\mathbf{R}}$. We may alter (A.1) to a rapidity-variation relation, applicable to incoming photons, by asymptotically expanding (A.2) for large negative rapidity,

$$\begin{aligned} v_{\mathbf{R}} &= -1 + 2e^{2\gamma_{\mathbf{R}}} + \text{ terms of order } e^{+4\gamma_{\mathbf{R}}} \\ -\gamma_{\mathbf{R}} &\gg 1 \end{aligned} \qquad (A.3)$$

and making a corresponding expansion of (A.1) around $b = -1$. Writing $b = -1 + \epsilon,\ \epsilon > 0$, one finds

$$v_{\mathbf{R}} = \frac{-1 + \epsilon\,\frac{4R - t_\infty}{4R-(t_\infty - r_\infty)}}{1 - \epsilon\,\frac{r_\infty}{4R-(t_\infty-r_\infty)}} \underset{\epsilon\ll 1}{=} -1 + \epsilon\frac{4R-(t_\infty+r_\infty)}{4R-(t_\infty - t_\infty)} + \text{terms of order } \epsilon^2. \quad (A.4)$$

By comparing (A.3) with (A.4), it may be inferred that

$$e^{2\gamma_{\mathbf{R}}} \approx \frac{\epsilon}{2} \frac{4R - (t_\infty + r_\infty)}{4R - (t_\infty - r_\infty)}, \qquad (A.5)$$

for $\epsilon \ll 1, -\gamma_{\mathbf{R}} \gg 1$. Because $\gamma_{\mathbf{R}}$ is negative, photon energy is thus proportional to

$$\left[\frac{4R - (t_\infty - r_\infty)}{4R - (t_\infty + r_\infty)}\right]^{1/2} = \left[\frac{2R - (t_{\mathbf{R}} - r_{\mathbf{R}})}{2R - (t_{\mathbf{R}} + r_{\mathbf{R}})}\right]^{1/4}, \qquad (A.6)$$

the right-hand form following if we remember from (IV.10) that

$$1 - \frac{t_\infty \pm r_\infty}{4R} = \left[1 - \frac{t_{\mathbf{R}} \pm r_{\mathbf{R}}}{2R}\right]^{1/2}. \qquad (A.7)$$

Along the standpoint backward light cone, $t_{\mathbf{R}} + r_{\mathbf{R}} = R$, while at standpoint $r_{\mathbf{R}} = 0$. It follows from (A.6) that the gravitational redshift factor for propagation between $r_{\mathbf{R}} = r_s$ and standpoint is

$$\left(1 + \frac{2r_s}{R}\right)^{1/4}. \qquad (A.8)$$

Of interest in principle (although not in practice) is gravitational redshift of light *emitted* from standpoint and proceeding along the standpoint's *forward* light cone where $t_{\mathbf{R}} - r_{\mathbf{R}} = R$. Repeating the foregoing calculation for the limit $v_{\mathbf{R}} \to +1, \gamma_{\mathbf{R}} \to +\infty$, one finds gravitational energy-reduction during propagation in **R** standpoint system by a factor

$$\left(1 - \frac{2r_s}{R}\right)^{1/4} \qquad (A.9)$$

for light reaching a distance r_s from standpoint. At abyss, where $r_s = R/2$, all **R**-system photon energies are thus reduced to zero. On the other hand, if one thinks of light *absorption* by matter at and moving with some *other* standpoint located on forward cone, the motion of that standpoint produces a Doppler shift so that the *net* redshift in the usual sense continues to be given by the ratio of standpoint ages.

References

Chew, G.F. 1994, *Lawrence Berkeley Laboratory preprint LBL-36314*, to be published in Foundations of Physics.

Chew, G.F. 1995, *Lawrence Berkeley Laboratory preprint LBL-36809*, submitted to the Astrophysical Journal.

Kolb, E.W. and Turner, M.S. 1990, *The Early Universe*, Addison-Wesley.

Milne, E.A. 1935, *Relativity, Gravitation and World Structure*, Oxford: Clarendon Press.

Peebles, P.J.E. 1993, *Principles of Physical Cosmology*, Princeton University Press.

Weinberg, S. 1972, *Gravitation and Cosmology*, Wiley, N.Y.