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Negative Cosmological Energy Indicated by

Supernova Redshift-Luminosity Correlation

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Abstract

Milne's classical homogeneous-universe cosmology predicts a product of Hubble constant with luminosity distance that equals $z + z^2/2$, where z is redshift. Supernova-data's support of this unambiguous relation implies, throughout the universe, homogeneous *negative*-energy 'nonmatter' that joins positive-energy 'material clumps' to yield *zero* mean-energy density. (Matter-clump scales are small compared to that of Hubble; 'nonobjective' negative energy is unclumped.) Although negative energy balances positive *matter* (particle) energy to yield *vanishing* mean (Hubble-scale) *total*-energy density, the Milne universe is not 'empty'. Milne's age-arrow, in conjunction with matter's defining characteristic of *temporal-structural stability*, dictates matter-energy positivity.

Introduction

Milne's cosmology, [1] by implying zero mean total-energy density within the universe, was dismissed during the last century by all except its inventor. [2] But two recent developments, one experimental and one theoretical, have questioned the sanctity of energy positivity. (1) Data from supernovae at redshifts approaching $z = 1$ disagree with widely-shared theoretical expectations derived from positive-energy general relativity. [3] (2) A (heretofore unutilized) unitary Hilbert-space Lorentz- group representation, suited to quantum cosmology, associates gravity-generating energy with self-adjoint-operators whose continuous spectrum spans the *entire* real line--not only the positive half. [4] An associated natural quantum-cosmological *initial condition* for universe evolution specifies *zero* total-universe energy.

Although the S-matrix definition of 'particle'--a definition implying *temporal-structural stability*-- requires positive particle energy, not all the present universe's energy needs to reside in 'matter'. If we admit negative (nonmaterial—not structurally stable) energy in a quantum cosmology capable of generating a 'classical reality' where *all* energy both generates and responds to gravity, then Milne's classical (Hubble-scale) cosmology is vindicated. When Milne's cosmology is confronted with supernovae data, it passes the test.

Although his cosmology may be regarded as a special case of the Friedman-Robertson-Walker metric, [5] Milne did not arrive at his idea by that route; neither did the present author. For different reasons we *both* employed the Lorentz group as *foundation* for 'reality within spacetime'. Milne's cosmology--pure 'classical kinematics'--was Lorentz-group and spacetime motivated--with reference neither to quantum theory nor to gravity and energy. We, in contrast, have been motivated by the foregoing *quintet* of interdependent concepts to achieve cosmological satisfaction of Dirac-Feynman (quantum) principles through a previously-unutilized unitary Hilbert-space representation of the Lorentz group.

After achievement of definition for 'classical reality' in a gravity-encompassing single-universe quantum-cosmological theory [4] we have begun to contemplate experimental tests. Because the spacetime meaning to which quantum theory had led us relates to that of Milne, we are exploring the natural possibility that Milne's cosmology is a Hubble-scale classical approximation to *our* quantum theory of the universe—a theory, more general than his, which deals with *all* scales between Planck's and Hubble's.

Beyond assigning foundational status to the Lorentz group, our theory of spacetime reality recognizes *two* foundational *integers*, one 'large' and one 'huge', that allow *different approximations* to be 'physically viable', *separately*, for *different* limited-scale ranges. Each such approximation within its scale range is, for all practical physics purposes (FAPPP), 'reliable'. (Our large integer associates with the reciprocal of a 'GUT-scale fine structure constant' and our huge integer with the scale range spanned in the Standard Cosmological Model

by 'inflation'. [4]) Although the reliability of Milne (classical) Hubble-scale cosmology has yet to be deduced from our quantum cosmology, the supernovae data has provoked the present paper.

Milne Spacetime

Milne spacetime occupies the interior of a forward lightcone, with the 'age' of any spacetime point equal to its Minkowski distance from the lightcone vertex. Spacetime was seen by Milne as 'filled' with 3-dimensional (noncompact) hyperbolic (curved 3-space) manifolds, each with a *single* (positive) age. The *curvature* of a Milne 3-manifold equals the reciprocal of its age--independently of location within the manifold. Euclidean geometry is asymptotically approached in the limit as age approaches infinity. 'Milne relativity', distinct from either special or general relativity (and not only more general than his Hubble-scale classical cosmology but extendable to quantum cosmology), implies that any two universes related by a *global* Poincaré transformation are the *same* universe.

A Milne-Lorentz *boost* shifts spatial locations at a fixed age. To any spacetime location there associates a continuous (labeled by 3 Euler angles) set of rotationally-related 'local frames'. In any local frame the positive-timelike 4-vector displacement from the lightcone vertex of the location in question has components $(\tau, 0, 0, 0)$, where τ is the location's age.

Let the symbol β denote the dimensionless positive 'boost distance', along a hyperboloid geodesic, between two spacetime points of the same age. If $c = 1$ the 4-vector spacetime location of one of these points, in any of the (rotationally-related) local frames belonging to the *other* point, is $\tau \times (cosh\ \beta, \boldsymbol{n}\ sinh\ \beta)$, where $\boldsymbol{n}$ is a unit 3-vector whose pair of direction ('polar') coordinates refer (for 'origin') to the orientation of the *other* point's local frame. Spacetime points of *different* age but *parallel* location 4-vectors share the *same* 3-vector $\boldsymbol{\beta} \equiv \beta\boldsymbol{n}$. (They occupy the *same* location in 'boost space'.) Thus Milne spacetime is coordinated by $\tau, \boldsymbol{\beta}$ once some 'origin' within a 6-dimensional manifold—the product of a (compact) 3-sphere with a (noncompact) 3-hyperboloid--has been designated. [4]

The 3-hyperboloid Lorentz-invariant (*dimensionful*) metric is

$$(ds)^2 = \tau^2\{ (d\beta)^2 + sinh^2\beta\ [(d\theta)^2 + sin^2\theta\ (d\varphi)^2]\}, \qquad (1)$$

where θ and φ are polar coordinates specifying the direction $\boldsymbol{n}$. The (4-spacetime) Minkowski metric is the sum of two *separately*-invariant terms: $(d\tau)^2 - (ds)^2$. Along any temporally-forward *lightlike* trajectory, $ds = d\tau$. Our theory supposes *Hubble-scale* light propagation to follow approximately such a 'Milne trajectory' (which ignores sub-Hubble-scale matter clumping—regarding matter as uniformly distributed).

For supernovae with redshifts of order 1 that share a common ('standard') energy release, the supposition that both supernova 'sources' and telescope 'sinks' are 'almost at rest' $(v/c \sim 10^{-3})$ in their respective local frames allows the straightforward computation in the

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following section of an unambiguous relation (no arbitrary parameter) between redshift and 'luminosity distance'.

Hubble-Scale Milne Relation between Redshift and Luminosity Distance

For boost-distance β between light source at age τ_{source} and light 'sink' at (later) age τ_{sink}, an immediate consequence of light propagation according to $ds = d\tau$ is

$$\tau_{sink} / \tau_{source} = e^{\beta}. \tag{2}$$

The ratio (2) *also* equals that between time *intervals* of energy emission and absorption in respective local frames.

The sink-source age ratio (2) further yields the ratio between emitted-photon (source frame) energy and absorbed-photon (sink frame) energy—i.e.,

$$e^{\beta} = 1 + z, \tag{3}$$

where z is the (standard) redshift parameter.

The definition of 'luminosity distance' [5] is

$$d_L \equiv (L/4\pi\ell)^{\frac{1}{2}}, \tag{4}$$

L denoting total energy emitted per unit time in source frame, while the symbol ℓ denotes a ratio

$$\ell \equiv P/A, \tag{5}$$

the symbol P representing power received (energy per unit sink time) by a mirror of area A whose surface is perpendicular to light-propagation direction. We now show that, for light propagating along Milne geodesics,

$$d_L = \tau_{sink}\, e^{\beta} \sinh \beta, \tag{6}$$

or, equivalently, $Hd_L = z + z^2/2$, once τ_{sink}^{-1} is identified with Hubble's 'constant' H and Formula (3) is employed to replace β by z.

Suppose the mirror to be circular, with radius b. The metric (1) then, by Formula (7) below, relates b to the tiny angle θ subtended in source frame by two geodesics that intersect at source, one geodesic passing through mirror center and the other contacting mirror perimeter:

$$b = \tau_{sink}\, \theta \sinh \beta. \tag{7}$$

The mirror is reached by a tiny *fraction*, equal to $(\theta/2)^2$, of the total number of emitted photons. It follows from (2) and (3) that

$$(\theta/2)^2 \, L = e^{2\beta} \, P. \tag{8}$$

Because the mirror (sink-frame) area A is πb^2, $P = \ell \pi b^2$. The central result (6)—the motivation for this paper--follows from Formulas (4), (5), (7) and (8).

Concluding Remarks

Elsewhere-detailed Feynman-path gravitational quantum dynamics proceeds through a retarded (second-rank symmetric Lorentz tensor) gravitational potential whose source is indefinite-sign energy located in the causally-accessible *past* of the path action. [4] (The source-energy-momentum current density is the gravitational potential's Dalembertian, divided by G.) An infinitesimal Lorentz-invariant gravitational line-integral action increment multiplies the gravitational potential by two *parallel* Lorentz 4-vectors--the infinitesimal spacetime-displacement along the path and the *path-transported* energy-momentum (*not* the energy-momentum of the potential's source—which is a component of 'classical reality').

Central to Milne spacetime is an 'age arrow' that accompanies redshift. Milne's arrow of global time permits *temporally-stable* clumping of positive-energy 'matter' but *not* of negative-energy 'nonmatter'. (Age arrow breaks Standard-Model CPT symmetry at scales huge compared to particle scale.) The sub-Hubble-scale distribution of positive and negative energy is, correspondingly, vastly different even though total universe energy vanishes. We conjecture homogeneity of negative-energy nonmatter at scales smaller than that of the entire universe. In early-universe evolution, sub-Hubble-scale density inhomogeneities are presumed to have been generated by gravity that clumped positive-energy ('stable') matter.

Absence of stable structure renders negative-energy nonmatter impossible to observe 'locally'. We have here associated negative-energy nonmatter within the universe to the hitherto-puzzling Hubble-scale correlation between supernova redshift and luminosity distance.

In a private communication to the author, J. Finkelstein has pointed out that Milne's (Hubble-scale) cosmology is formally equivalent to an 'empty', $\Omega_\Lambda = \Omega_M = 0$, FRW universe—with zero cosmological constant proportional to Ω_Λ and zero matter density proportional to Ω_M (in a general-relativistic sense that disregards negative energy).

Efforts to base quantum cosmology on radiation-field Fock-space operators have led others to associate 'cosmological constant' with Fock-space vacuum energy. The author's quantum cosmology, although including electromagnetic and gravitational radiation within its classical reality, [4] has *no* radiation-field operators and its Fock space *lacks* a 'vacuum state'.

Acknowledgement

References

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